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INDEX

- Accuracy of forecasting air trajectories; M. H. Freeman, 143
- Aerodynamic capture of particles; *review* by R. F. Jones, 181
- Airflow over broad mountain ranges—a study of five flights across the Welsh mountains; C. E. Wallington, 213, *corrigendum*, facing 330
- Applegate, T. H.; *retirement*, 212
- Applegate, T. H.; Year-to-year variations from meteorological averages, 203
- Approach to the problem of the forecasting of fog clearance; C. J. Kennington, 70
- Atlantic hurricanes (G. E. Dunn and B. I. Miller); *review* by S. E. Virgo, 58
- Auty, P.; photographic awards, 121
- Banner cloud on Brent Knoll; 211, *photographs between* 198, 199
- Barlow, E. W.; *obituary*, 61
- Bell, G.; *retirement*, facing 330
- Bigg, W. H.; *retirement*, 2, *photograph facing* 3
- Bird, L. G.; staff suggestions scheme award, 268
- Blower, B. J.; *obituary*, 362
- Booth, R. E.; Rainfall in England and Wales during the five months July to November, 1960, with special reference to southern England, 93
- Booth, R. E.; The generally mild winter of 1960–61 over England and Wales, with special reference to an exceptionally mild February, 209
- Briggs, J.; Severe clear-air turbulence near the British Isles, 245
- Briggs, J.; Widespread severe clear-air turbulence, 13 November 1958, 234
- Brown, P. R.; *obituary*, 363
- Brown, P. R.; Physical oceanography (A. Defant), *review*, 330
- Budd, C. J. G.; *retirement*, 61
- Bull, G. A.; Handbuch der Aerologie (ed. by W. Hesse), *review*, 325
- Bull, G. A.; Magyarorszácz Eghajlati Atlasza, *review*, 59
- Burns, F.; Dust haze in relation to pressure gradients, 223
- Cabin in a newly fitted-out weather ship, *photograph between* 138, 139
- Caton, P. G. F. and Hawson, C. L.; A synoptic method for the international comparison of geopotential observations, 336
- Cirrus development observed over Singapore and south Malaya; R. Frost, 348, *photograph facing* 348
- Collins, B. G.; A standing dew meter, 114, *photographs between* 116, 117
- Correlated fluctuations of wind direction and air temperature at Renfrew Airport on 12 October 1960; J. B. McGinnigle, 146
- Cottom, M. C.; staff suggestions scheme award, 364
- Crabtree, J.; Radioactive wastes, their treatment and disposal, *review*, 149
- Crossley, A. F.; Hail in relation to the risk of encounters in flight, 101
- Cumulus dynamics (ed. by C. E. Anderson); *review* by C. E. Wallington, 179
- Daking, C. W. G.; History of the United States Weather Bureau (D. R. Whitnah), *review*, 179
- Day, G. J.; Distribution of total solar radiation on a horizontal surface over the British Isles and adjacent areas, 269
- Dewar, D.; Routine computation of monthly upper air statistics using an electronic computer, 52
- Distribution of total solar radiation on a horizontal surface over the British Isles and adjacent areas; G. J. Day, 269
- Diurnal variation of visibility with light winds at Plymouth in winter; W. E. Saunders, 19
- Duration of surface wetness; J. M. Hearn, 174
- During the conversion stages in fitting out a weather ship; *photograph facing* 138
- Dust haze at Bahrain; J. Houseman, 50
- Dust haze in relation to pressure gradients; F. Burns, 223
- Duststorm at Aden; *photographs between* 88, 89
- Earth's problem climates (G. T. Trewartha); *review* by H. C. Shellard, 360
- Ebdon, R. A., and Veryard, R. G.; Fluctuations in tropical stratospheric winds, 125
- Estimation of averages of radiation and illumination; S. M. Taylor and L. P. Smith, 289
- Estimation of the dispersion of windborne material; F. Pasquill, 33
- Experiment in numerical forecasting (E. Knighting, G. A. Corby, F. H. Bushby and C. E. Wallington); *official publication*, 178
- Experiment in the verification of forecast charts (C. E. Wallington); *official publication*, 240
- Factors associated with the formation and persistence of anticyclones over Scandinavia in the winter half of the year (M. K. Miles); *official publication*, 240
- Fine day at sea; *photograph between* 138, 139
- Fluctuations in tropical stratospheric winds; R. G. Veryard and R. A. Ebdon, 125
- Fluctuations in stratospheric winds over Australia; R. G. Veryard, 295
- Forecasting in the Falkland Islands and Dependencies (S. D. Glassey); *official publication*, 239
- Fowler, W. J.; *retirement*, 30
- Frankcom, C. E. N.; "Weather Adviser", 24, *photographs between* 16, 17

- Frankcom, C. E. N.; World Meteorological Organization Commission for Maritime Meteorology—Third Session, 185, *photograph facing* 198
- Freeman, M. H.; Accuracy of forecasting air trajectories, 143
- Freeman, M. H.; Fronts investigated by the Meteorological Research Flight, 189, corrigenda, 362
- Frequencies of poor afternoon visibilities in England and Wales; L. P. Smith, 355
- Frontiers of the sea (Robert C. Cowen); *review* by F. E. Lumb, 121
- Fronts investigated by the Meteorological Research Flight; M. H. Freeman, 189, corrigenda, 362
- Frost, R.; Cirrus development observed over Singapore and south Malaya, 348, *photograph facing* 348
- Frost, R.; Pressure variation over Malaya and the resonance theory, *official publication*, 29
- Frost, R.; Short-period fluctuations of the semi-diurnal component of pressure in the tropics, 110
- General climatology (H. J. Critchfield); *review* by G. B. Tucker, 329
- Generally mild winter of 1960–61 over England and Wales with special reference to an exceptionally mild February; R. E. Booth, 209
- George, D. J.; Falkland Islands Dependencies—*photographs between* 48, 49
- George, D. J.; staff suggestions scheme award, 212
- Gingell, H.; *retirement*, 61
- Gold, E.; congratulations, 267
- Gordon, A. H.; Introduction to theoretical meteorology (S. L. Hess), *review*, 180
- Gordon, A. H.; Seasonally induced meridional flux of momentum in the atmosphere, 241
- Gordon, J. C.; A method of deriving 700 mb charts from 500 mb thickness patterns, 352
- Green, J. R.; staff suggestions scheme award, 364
- Grinstead, W. A.; awarded C.B.E., 61
- Hail in relation to the risk of encounters in flight; A. F. Crossley, 101
- Hamilton, R. A.; Weather forecasting for aeronautics (J. J. George), *review*, 59
- Handbook of meteorological instruments, Part II—Instruments for upper air observations; *official publication*, 362
- Handbuch der Aerologie (ed. by W. Hesse); *review* by G. A. Bull, 325
- Handbook of aviation meteorology; *official publication*, 28
- Harding, J.; Symposium on monsoons of the world, *review*, 261
- Harrison, D. N.; Radiosonde temperature readings and cloud amount, 319
- Hawson, C. L. and Caton, P. G. F.; A synoptic method for the international comparison of geopotential observations, 336
- Hearn, J. M.; The duration of surface wetness, 174
- High-altitude observations between the United Kingdom and Nairobi; M. J. Kerley, 3
- History of the United States Weather Bureau (D. R. Whitnah); *review* by C. W. G. Daking, 179
- Houseman, J.; Dust haze at Bahrain, 50
- Incidence of, and some rules for forecasting, temperature inversions over the north-east Atlantic (H. C. Shellard and R. F. M. Hay); *official publication*, 240
- Introduction to theoretical meteorology (S. L. Hess); *review* by A. H. Gordon, 180
- Iyer, H. M.; appointment to Gassiot Fellowship, 211, 364
- Jacobs, L.; Radiation recording in the Meteorological Office, 284
- “Jacob’s ladders” on the North Atlantic; *photograph between* 348, 349
- Jefferson, G. J.; Visibility in precipitation, 168
- Jones, R. F.; Aerodynamic capture of particles, *review*, 181
- Jones, T. W. V.; awarded I.S.O., 211
- Kennington, C. J.; An approach to the problem of the forecasting of fog clearance, 70
- Kerley, M. J.; High-altitude observations between the United Kingdom and Nairobi, 3
- Kirk, T. H.; “Pressure jumps” at Malta, 206
- Knighting, E.; Numerical forecasts made with two- and three-parameter models, 117
- Knighting, E.; Numerical weather analysis and prediction, 333
- Konieczny, J.; Rapid cloud development, 120, *photograph facing* 101
- Leaf, G. G. and Miles, M. K.; The occurrence and prediction of cold northerly-type spells over the British Isles in winter, 227
- Lewis, N.; *obituary*, 212
- Lloyd, D. C.; Meteorology and climatology for sixth forms (E. S. Gates), *review*, 296
- Lumb, F. E.; Frontiers of the sea (Robert C. Cowen), *review*, 121
- Lumb, F. E.; Relation between the terminal velocity and the dimensions of snowflakes, 344
- Lumb, F. E.; The problem of forecasting the downward penetration of snow, 310
- MacDonald, D. L.; staff suggestions scheme award, 212
- Magyarország Eghajlati Atlasza; *review* by G. A. Bull, 59

- Manley, G.; A preliminary note on early meteorological observations in the London region, 1680–1717, with estimates of the monthly mean temperatures, 1680–1706, 303
- McGinnigle, J. B.; Correlated fluctuations of wind direction and air temperature at Renfrew Airport on 12 October 1960, 146
- Meteorological Office awards to captains and navigators of civil aircraft, 267, *photographs between* 264, 265
- Meteorological Office Headquarters, Bracknell, 268
- Meteorology and climatology for sixth forms (E. S. Gates); *review* by D. C. Lloyd, 296
- Meteorology for glider pilots (C. E. Wallington), *review* by P. A. Wills, 265
- Method of deriving 700 mb. charts from 500 mb thickness patterns; J. C. Gordon, 352
- Miles, M. K. and Leaf, G. G.; The occurrence and prediction of cold northerly-type spells over the British Isles in winter, 227
- Moriarty, D.; *retirement*, 297
- Move of the Meteorological Office Library to the Meteorological Office Headquarters, Bracknell, 30
- National Survey of Atmospheric Pollution, 359, *photograph facing* 349
- New housing for the sensitive cup anemometer, Mark I; 89, *photograph facing* 69
- Numerical forecasting at Dunstable; *Meteorological Office discussion*, 78
- Numerical forecasts made with two- and three-parameter models; E. Knighting, 117
- Numerical weather analysis and prediction; E. Knighting, 333
- Occurrence and prediction of cold northerly-type spells over the British Isles in winter; M. K. Miles and G. G. Leaf, 227
- Pasquill, F.; The estimation of the dispersion of windborne material, 33
- Peters, S. P.; *retirement*, 1, *photograph facing* 2
- Physical oceanography (A. Defant); *review* by P. R. Brown, 330
- Powell, P.; staff suggestions scheme award, 364
- Preliminary note on early meteorological observations in the London region, 1680–1717, with estimates of the monthly mean temperatures, 1680–1706; G. Manley, 303
- “Pressure jumps” at Malta; T. H. Kirk, 206
- Pressure variation over Malaya and the resonance theory (R. Frost); *official publication*, 29
- Problem of forecasting the downward penetration of snow; F. E. Lumb, 310
- Radiation recording in the Meteorological Office; L. Jacobs, 284
- Radioactive wastes, their treatment and disposal; *review* by J. Crabtree, 149
- Radiosonde temperature readings and cloud amount; D. N. Harrison, 319
- Rainfall in England and Wales during the five months July to November 1960, with special reference to southern England; R. E. Booth, 93
- Rapid cloud development; J. Konieczny, 120, *photograph facing* 101
- Relation between the terminal velocity and the dimensions of snowflakes; F. E. Lumb, 344
- Report on the first season of the Bracknell Meteorological Office Cricket Club; 364
- Rigg, J. B.; Weathercraft (L. P. Smith), *review*, 361
- Rime on a stone wall at 2390 ft on Cross Fell, Cumberland, at 1400 hours, 18 March 1961; *photograph between* 348, 349
- Routine computation of monthly upper air statistics using an electronic computer; D. Dewar, 52
- Saunders, W. E.; Diurnal variation of visibility with light winds at Plymouth in winter, 19
- Scrase, F. J.; *retirement*, 302, *photograph facing* 303
- Sea-breezes along the Yorkshire coast in the summer of 1959; R. E. Stevenson, 153
- Seasonal variation of the sea surface temperature in coastal waters of the British Isles (F. E. Lumb); *official publication*, 239
- Seasonally induced meridional flux of momentum in the atmosphere; A. H. Gordon, 241
- Severe clear-air turbulence near the British Isles; J. Briggs, 245
- Shellard, H. C.; The earth’s problem climates, *review*, 360
- Short-period fluctuations of the semidiurnal component of pressure in the tropics; R. Frost, 110
- Smith, D. P.; A thunderstorm high over England, 74
- Smith, L. P.; Frequencies of poor afternoon visibilities in England and Wales, 355
- Smith, L. P.; Year-to-year variations in rainfall totals, 22
- Smith, L. P. and Taylor, S. M.; Estimation of averages of radiation and illumination, 289
- Sobey, Capt. H.; awarded M.B.E., 211
- Sports activities, 297, *facing* 330
- Stacey, F. D.; appointment to Gassiot Fellowship, 149
- Staff suggestions scheme awards; 61, 212, 268, 364
- Standing dew meter; B. G. Collins, 114, *photographs between* 116, 117
- Stevenson, R. E.; Sea-breezes along the Yorkshire coast in the summer of 1959, 153
- Sutcliffe, R. C.; awarded C.B., 211
- Sutton, Sir Graham; awarded honorary degree, 148
- Swain, F. B.; staff suggestions scheme award, 61
- Symposium on monsoons of the world; *review* by J. Harding, 261
- Synoptic method for the international comparison of geopotential observations; C. L. Hawson and P. G. F. Caton, 336
- Taylor, S. M. and Smith, L. P.; Estimation of averages of radiation and illumination, 289

- Third Session of the World Meteorological Organization Commission for Climatology; R. G. Veryard, 65, *photograph facing* 68
- Thunderstorm high over England; D. P. Smith, 74
- Training courses for co-operating observers; 26
- Troup, A. J.; Variations in 200-millibar flow in the tropics, 162
- Tucker, G. B.; General climatology (H. J. Critchfield), *review*, 329
- Two-hundred millibar mean winds on the route El Adem to Aden derived from aircraft reports; P. G. Wickham, 255
- Universal Decimal Classification; 26
- Upper winds over the world, Parts I and II; *official publication*, 29
- Upper winds over the world, Part III; *official publication*, 268
- Variations in 200-millibar flow in the tropics; A. J. Troup, 162
- Veryard, R. G.; Fluctuations in stratospheric winds over Australia, 295
- Veryard, R. G.; *retirement*, 301, *photograph facing* 302
- Veryard, R. G.; Third Session of the World Meteorological Organization Commission for Climatology, 65, *photograph facing* 68
- Veryard, R. G. and Ebdon, R. A.; Fluctuations in tropical stratospheric winds, 127
- Virgo, S. E.; Atlantic hurricanes (G. E. Dunn and B. I. Miller), *review*, 58
- Visibility in precipitation; G. J. Jefferson, 168
- Wallace, W.; staff suggestions scheme award, 364
- Wallington, C. E.; Airflow over broad mountain ranges—a study of five flights across the Welsh mountains, 213, corrigendum facing 330
- Wallington, C. E.; Cumulus dynamics (ed. by C. E. Anderson), *review*, 179
- “Weather Adviser”; C. E. N. Frankcom, 24, *photographs between* 16, 17
- Weather forecasting for aeronautics (J. J. George); *review* by R. A. Hamilton, 59
- “Weather Watcher” at sea; *photograph facing* 139
- Weathercraft (L. P. Smith); *review* by J. B. Rigg, 361
- White, R. S.; *obituary*, 212
- Wickham, P. G.; 200 mb mean winds on the route El Adem to Aden derived from aircraft reports, 255
- Widespread severe clear-air turbulence, 13 November 1958; J. Briggs, 234
- Wills, P. A.; Meteorology for glider pilots (C. E. Wallington); *review*, 265
- World Meteorological Organization Commission for Maritime Meteorology—Third Session; C. E. N. Frankcom, 185, *photograph facing* 198
- Year-to-year variations from meteorological averages; T. H. Applegate, 203
- Year-to-year variations in rainfall totals; L. P. Smith, 22

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S. P. PETERS, C.B.E., B.Sc.

Mr. S. P. Peters retired from the Meteorological Office on 31 October 1960 after more than 37 years' service.

His first connexion with official meteorology was in 1918 when he was on active service with the Meteorological Section of the Royal Engineers in Italy, but he did not join the Meteorological Office until 1923, after graduating with first class honours in physics, and working privately with Mr. C. J. P. Cave, a past President of the Royal Meteorological Society.

His initial posting was to Cranwell as Junior Professional Assistant. In 1925 he was promoted to Senior Professional Assistant and appointed to be the first Professional Assistant in the newly created Airships Services Division. For the next seven years he was based at Cardington, and apart from occasional interludes of forecasting for airship trial flights at Pulham and Howden, was occupied in the investigation of meteorological conditions along potential airship routes, and at planned bases within the Commonwealth. Following the disbandment of the Division after the disaster to airship R.101 Mr. Peters served for three years at Worthy Down, one of three R.A.F. stations at which night flying by bomber aircraft was then being developed.

In the summer of 1935 he was appointed instructor to the first training course for forecasters in the Meteorological Office, which was held at South Kensington. Owing to the Abyssinian crisis this course came to a premature and abrupt end after a few months and the six trainees (Assistants II) were posted for forecast duties. Mr. Peters was then transferred to Croydon to inaugurate a training course for new-entrant graduates, in which special attention was to be given to the synoptic meteorology of the North Atlantic, in anticipation of transatlantic civil flying.

In the spring of 1937 he was promoted Senior Technical Officer and posted to Foynes, where for the ensuing four years he was responsible for forecasting for the first, and subsequent, transatlantic commercial flights and for the training of staff for the newly established Irish Meteorological Service. Early in 1941 he was recalled to England for duty as Senior Meteorological Officer at the Overseas Air Movement Control Unit at Gloucester, and a few months later was transferred to Prestwick to establish a forecasting centre for aircraft delivery flights from Canada by R.A.F. Ferry Command and for return flights

of the ferry crews. In the late autumn of 1941 Mr. Peters was promoted Principal Technical Officer and appointed Head of the new North Atlantic Branch at Headquarters, with which was subsequently combined the Coastal Command Branch. In a reorganization shortly after the war he became Head of the newly constituted Civil Aviation Branch.

In March 1948 he was posted to the Central Forecasting Office at Dunstable with promotion to Senior Principal Scientific Officer, and shared supervisory forecasting duties with two colleagues for the next five years. In June 1953 he became Deputy Director (Forecasting) in the grade of Deputy Chief Scientific Officer and remained in this post, when it was later renamed "(Central Services)" until his retirement in July 1958 on grounds of age. Since his retirement Mr. Peters has occupied a Senior Scientific Officer post in the Techniques and Training Branch at Meteorological Office Headquarters.

Mr. Peters was a member of the Commission for Synoptic Weather Information of the International Meteorological Organization and, subsequently, of the Commission for Synoptic Meteorology of the World Meteorological Organization and also of Regional Commission VI (Europe). In these capacities he has represented the Meteorological Office at conferences in Paris, Salisbury (S. Rhodesia), Washington and Dubrovnik. Whilst Head of the Civil Aviation Branch he was a delegate at meetings of the International Civil Aviation Organization in Dublin and Paris in 1946. Mr. Peters was made a Companion of the Order of the British Empire in 1956.

His success as a pioneer over the years in a great many fields of an expanding meteorological service was due not only to his knowledge of meteorology and powers of organization but also to his personal interest in the well-being of his staff and his human understanding of their problems. All those who have experienced his friendliness and his constant readiness to give unstinting assistance in any difficulty, be it professional or personal, will wish Mr. Peters a long and happy retirement.

W. H. BIGG, O.B.E., B.Sc.

Mr. Bigg retired on 21 November 1960 after more than 40 years' service in the Meteorological Office.

His first appointment, in the grade of Technical Assistant, was in July 1920 and for the next six years he served at the R.A.F. Station, Biggin Hill. During this period Mr. Bigg studied in his spare time and passed the B.Sc. (General) degree of London University in 1924 and after a further two years he obtained an honours degree in physics in the examination for B.Sc. (Special). As a result of these academic successes Mr. Bigg was promoted to Professional Assistant, the forerunner of the Scientific Officer Grade, and took up forecasting duties first at Headquarters and later at the Royal Aircraft Establishment, Farnborough, followed in 1934 by a posting to the R.A.F. Station at Bircham Newton and in 1937 by a return to Headquarters. During this period he made a special study of ice formation in clouds and published the results as a *Professional Note* which achieved wide circulation among aviators and meteorologists.

During the inter-war years Mr. Bigg was an active member of the Reserve of Air Force Officers and on the outbreak of the Second World War he was



S. P. PETERS, C.B.E., B.SC.

To face p. 3]



W. H. BIGG, O.B.E., B.SC.

mobilized and, as a Squadron Leader, was appointed Senior Meteorological Officer to the Advanced Air Striking Force. His unit was the first meteorological section to arrive in France in September 1939. During the operations which led to the withdrawal of British Forces from France, Sqn. Ldr. Bigg received a mention in despatches. He then joined No. 1 (Bomber) Group, R.A.F. where he served with such distinction that he was appointed an Officer in the Military Division of the Order of the British Empire.

In 1943 plans were being developed for a more vigorous prosecution of the war in the Far Eastern Theatre and Sqn. Ldr. Bigg was promoted to Group Captain on appointment as Chief Meteorological Officer, Air Command, South-East Asia. This appointment carried enormous responsibilities both in planning and directing a wartime meteorological organization and in preparing the framework for a revived territorial organization in peace.

When the war ended Group Captain Bigg returned to Headquarters in London and in the 1948 re-organization he became an Assistant Director with responsibility for meteorological services required by Civil Aviation. In this post he has seen, and made important contributions to, the remarkable growth of airline operations with their splendid record of safety, regularity and punctuality.

During 40 years in meteorology, Mr. Bigg has not only seen an enormous number of changes and developments but has been actively associated with many of them. As a forecaster he was always in the first rank and enjoyed a high reputation among pilots. Meteorological organization, with its comprehensive array of technical procedures and regulations, owes much to him and many will acknowledge his wise counsel at international meetings. However, it is not enough merely to say that this has been a career full of performance. Hosts of people, service and civilian, of many nationalities, can testify to "Bertie" Bigg's capacity for friendship, to his wise and tolerant leadership, to his good humour and patience in protracted discussions. We wish him, with his wife and family, many years of happy retirement.

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HIGH-ALTITUDE OBSERVATIONS BETWEEN THE UNITED KINGDOM AND NAIROBI

By M. J. KERLEY

Introduction.—In June 1958 a Canberra aircraft, of the Meteorological Research Flight, was detached from Farnborough to Eastleigh Airport, Nairobi (latitude 1°S). It left Farnborough on 19 June 1958 and arrived at Nairobi on 21 June, having flown by way of Malta, Cyprus, Bahrain and Aden. Twelve flights were made from Eastleigh Airport between 22 June and 29 June. The aircraft left Nairobi on 2 July and, travelling over the same route, arrived back at Farnborough on 4 July.

The purpose of the detachment was to obtain measurements up to about 50,000 feet of temperature, humidity, wind and albedo and also cloud and clear-air turbulence information in low latitudes over Africa. Several of these quantities have not previously been measured. It is intended to combine them in later papers with other Meteorological Research Flight observations made in high latitudes but, in view of their general interest, the results obtained in this series of flights, and also during the transit flights, are presented below.

Instrumentation.—The instrumentation of this aircraft has been described in some detail elsewhere.¹ Briefly, temperature is measured by means of a flat-plate resistance thermometer and balanced bridge; humidity is observed with the manual Dobson-Brewer frost-point hygrometer; wind is obtained from the Doppler navigator; albedo in the wavelength range 0.3 to 3.0 μ , which covers all but the weak, extreme long-wave portion of the solar spectrum, is calculated from solarimeters mounted on the upper and lower fuselage; an accelerometer is switched on when turbulence is encountered; readings and cloud notes are taken by the observer approximately every five minutes and photographic recordings are obtained on automatic observers each minute of the flight.

Flight details.—In all 23 flights were made, 11 in transit and 12 at Nairobi and these are summarized in Table I below. Most of them were successful although there were some limitations due to failure of the wing-tip tanks to feed above 30,000 feet after leaving Malta, liquid nitrogen supplies for the frost-point hygrometer being available only at Nairobi, and partial failure of the canopy demisting equipment which sometimes made cloud observation at altitude difficult and cloud photography impossible. The Doppler navigator failed to operate over the smooth sea of the Persian Gulf on the return flight.

TABLE I—FLIGHT DETAILS

Date	Flight No.	Route	Time GMT	Flight Level ft $\times 10^{-3}$	Observations taken
16.6.58	1	Farnborough-Malta	0835-1115	38.0	Frost point, temp., albedo, winds
17.6.58	2	Malta-Cyprus	0555-0805	42.0	Temp., winds, albedo
17.6.58	3	Cyprus-Bahrain	1000-1320	33.5, 44.0	Temp., winds, albedo
18.6.58	4	Bahrain-Aden	0240-0550	31.5, 38.0	Temp., winds, albedo
18.6.58	5	Aden-Nairobi	0735-1005	32.0	Temp., winds, albedo
19.6.58	6	High-level ascent from Nairobi	0605-0745	climb to 50.0	Frost point, temp., winds, albedo
19.6.58	7	High-level ascent from Nairobi	0900-1045	climb to 50.0	Frost point, temp., winds, albedo
20.6.58	8	Nairobi-Aden	0550-0900	30.0, 46.0	Frost point, temp., winds, albedo
20.6.58	9	Aden-Nairobi	1020-1250	30.0, 46.0	Frost point, temp., winds, albedo
23.6.58	10	Nairobi-9°S-Nairobi	0635-1000	30.0, 46.0	Frost point, temp., winds, albedo
24.6.58	11	Nairobi-Aden	0540-0900	30.0, 38.0	Frost point, temp., winds, albedo
24.6.58	12	Aden-Nairobi	1025-1250	30.0, 38.0	Frost point, temp., winds, albedo
25.6.58	13	Nairobi-Aden	0540-0830	30.0, 46.0	Frost point, temp., winds, albedo
25.6.58	14	Aden-Nairobi	1135-1405	30.0, 34.0	Frost point, temp., winds, albedo
26.6.58	15	Nairobi-9°S-Nairobi	0530-0845	30.0, 38.0, 46.0	Frost point, temp., winds, albedo
27.6.58	16	Nairobi-Aden	0540-0840	30.0, 46.0	Frost point, temp., winds, albedo
27.6.58	17	Aden-Nairobi	1010-1245	30.0, 42.0	Frost point, temp., winds, albedo
27.6.58	18	Nairobi-Aden	0550-0825	30.0, 40.0	Frost point, temp., winds, albedo
27.6.58	19	Aden-Bahrain	1005-1320	30.0, 40.0, 48.0	Frost point, temp., wind, albedo
3.7.58	20	Bahrain-Habbaniya	0225-0350	22.5	Temp. only
3.7.58	21	Habbaniya-Cyprus	0655-0900	30.0, 38.0	Wind, temp., albedo
3.7.58	22	Cyprus-Malta	1050-1310	30.0	Temp., albedo
4.7.58	23	Malta-Farnborough	0830-1120	28.5, 36.5	Wind, temp., albedo

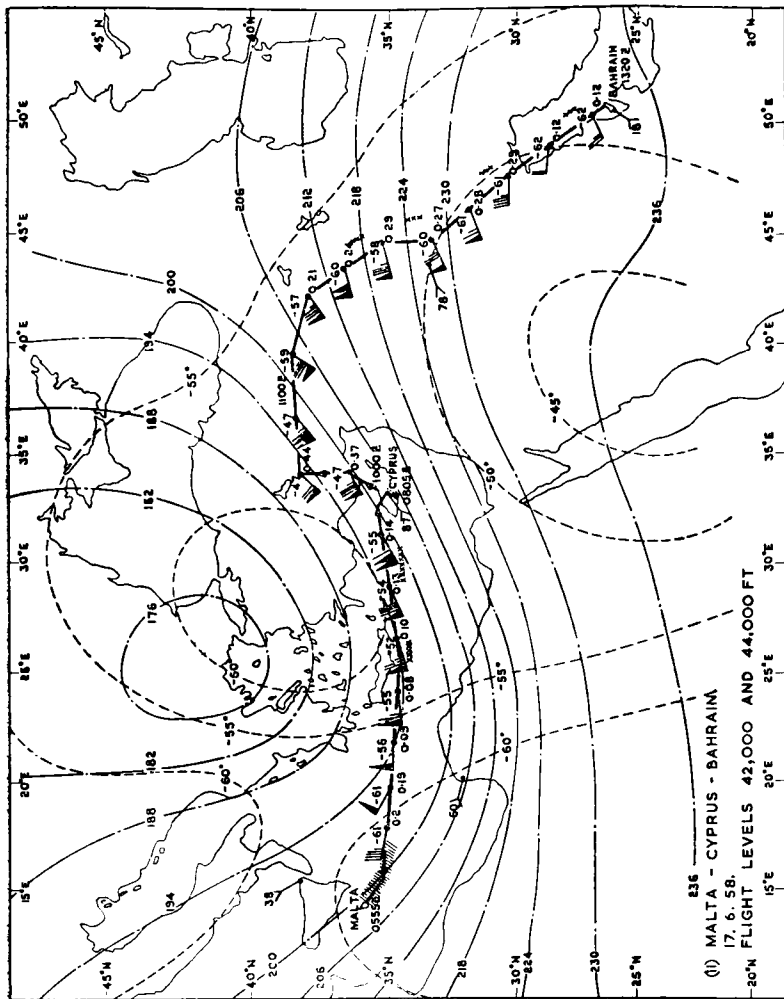
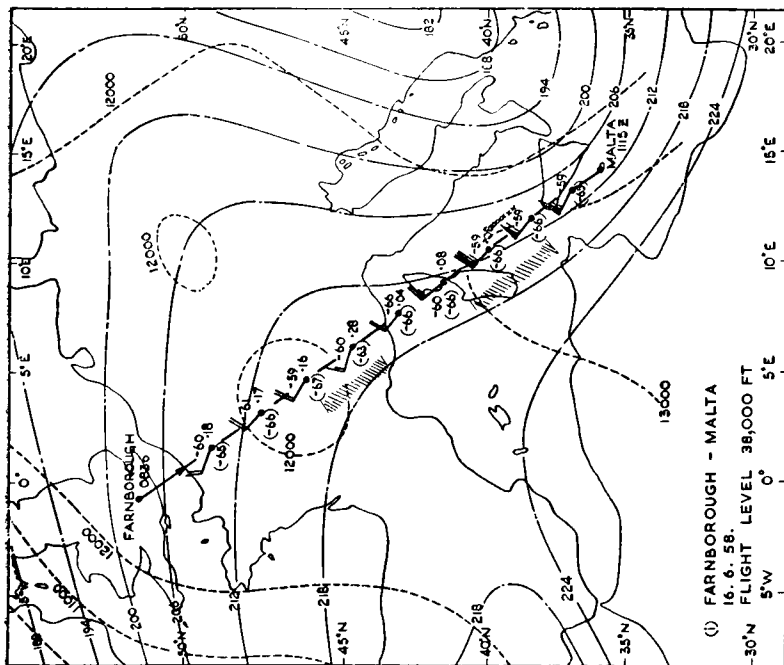
The measurements obtained can be divided broadly into the following groups:

(i) Measurements in transit flights.

(ii) Studies of upper air conditions above Nairobi and Aden by vertical soundings. One sounding was also made at Bahrain.

(iii) Horizontal flights between Nairobi and Aden and also to 9°S.

In all cases comparisons are made with available radio-sonde measurements and synoptic charts.



T - TEMPERATURE °C
 (FP) - FROST POINT °C
 D - WIND DIRECTION
 F - WIND SPEED, KT
 --- CONTOURS
 - - - ISOTHERMS OR TROPOPAUSE HEIGHTS
 // CIRRUS CLOUD
 *** TURBULENCE

FIGURE 1—OBSERVATIONS OBTAINED IN TRANSIT FLIGHTS, AND SELECTED SYNOPTIC DATA

(i) Farnborough-Malta; 200 mb contours and tropopause, 0001 GMT, 16 June 1958

(ii) Malta-Bahrain; 200 mb contours and isotherms, 0001 GMT, 17 June 1958

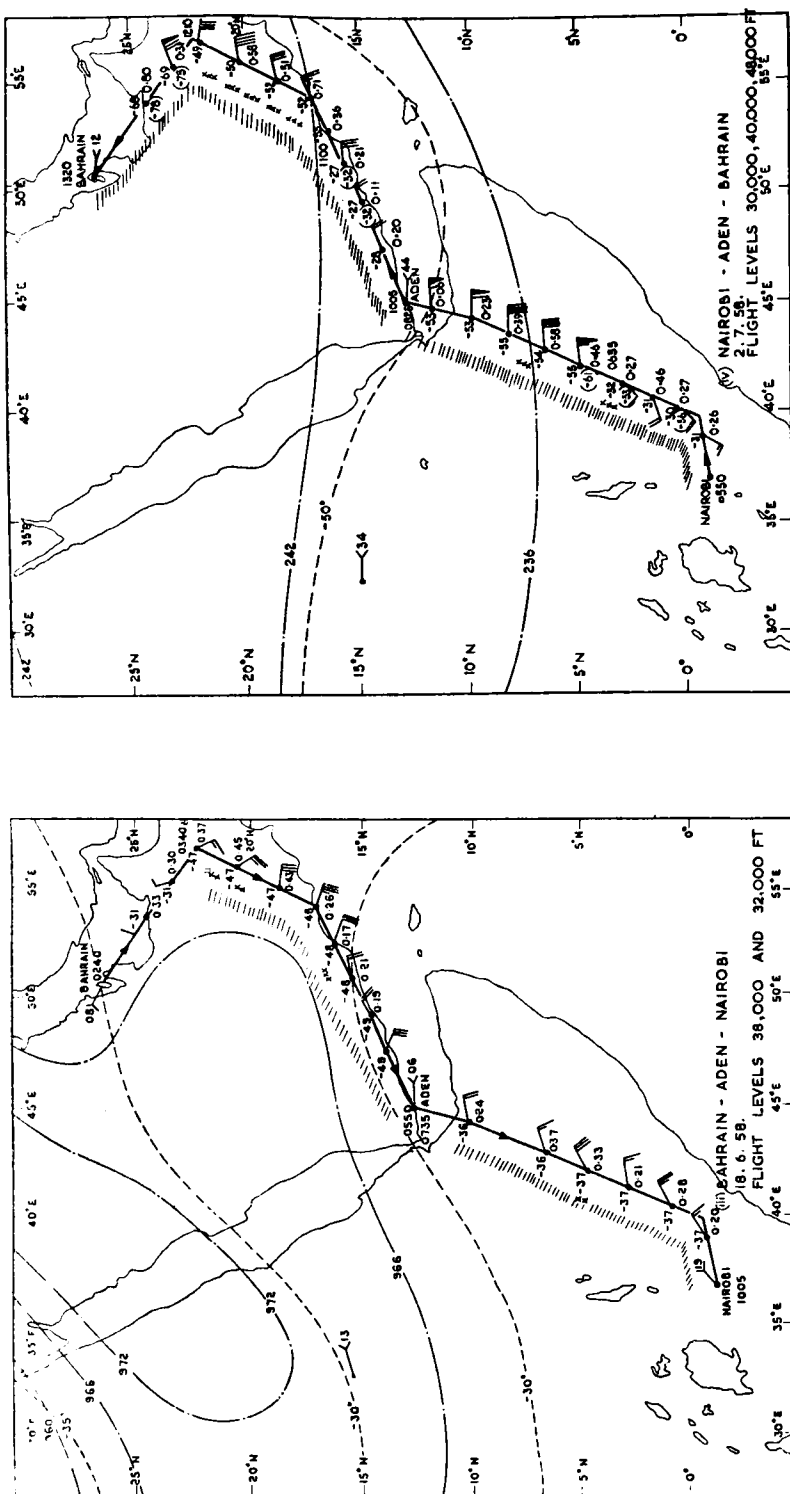


FIGURE I—OBSERVATIONS OBTAINED IN TRANSIT FLIGHTS, AND SELECTED
SYNOPTIC DATA (cont.)

- (iii) Bahrain-Nairobi; 300 mb contours and isotherms, 0001 GMT, 18 June 1958
- (iv) Nairobi-Bahrain; 200 mb contours and isotherms, 0001 GMT, 2 July 1958

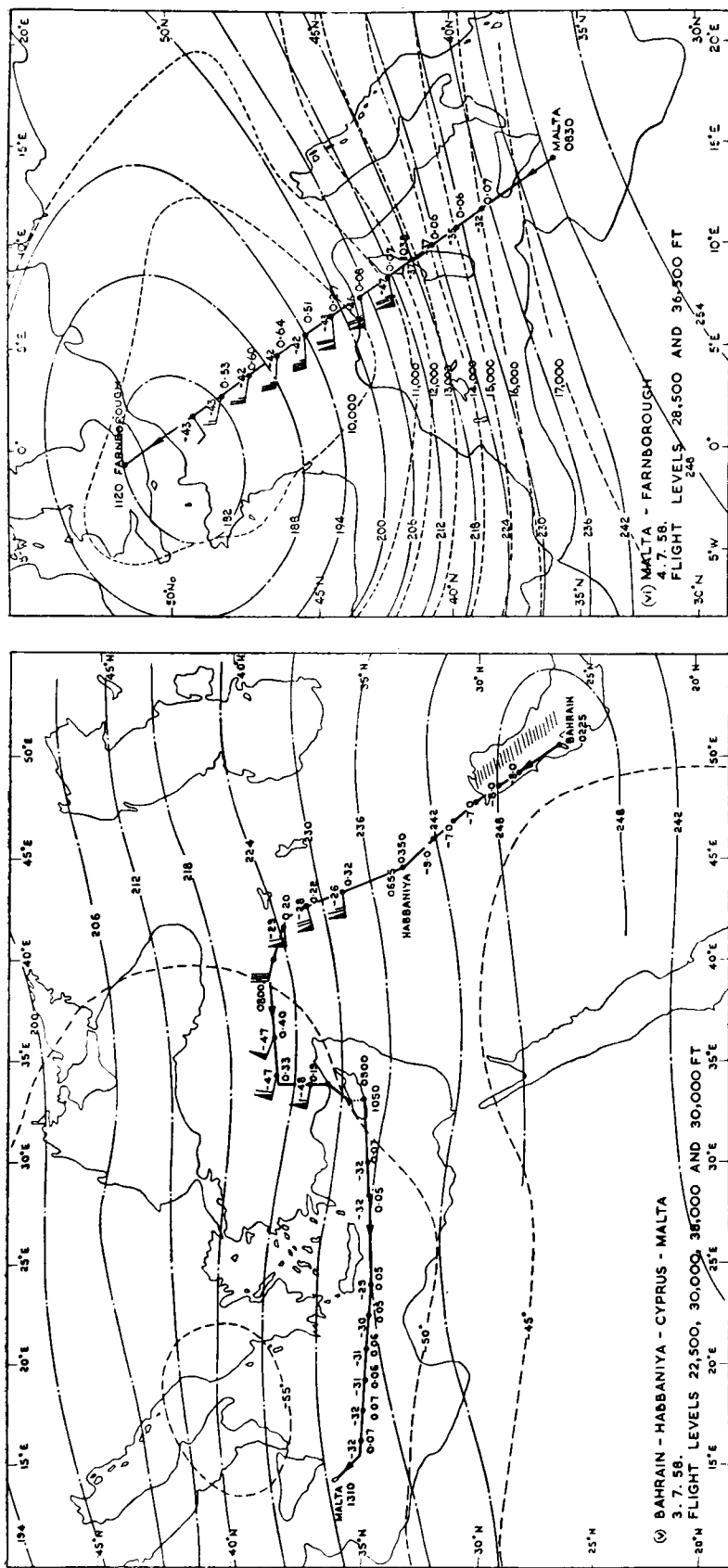


FIGURE 1—OBSERVATIONS OBTAINED IN TRANSIT FLIGHTS, AND SELECTED
SYNOPTIC DATA (cont.)

- (v) Bahrain-Malta; 200 mb contours and isotherms, 0001 GMT, 3 July 1958
- (vi) Malta-Farnborough; 200 mb contours and tropopause, 0001 GMT, 4 July 1958

Transit flights.—Details of the measurements made in the transit flights are shown in Figures 1 (i) to (vi). Short notes on each are given.

- (i) 16 June 1958, Farnborough–Malta, 0835–1115 GMT, 38,000 feet (11,500 metres).

Contours for 200 millibars at 0001 GMT are plotted at 60-metre intervals and approximate tropopause heights at 1000-metre intervals. The flight was therefore made just below a high cold tropopause, across a contour ridge in the north to a jet-stream entrance in the south.

The aircraft track did not differ much from the direction of the wind trajectories and the temperatures and frost points at this level showed little change throughout. High cloud was observed extending to about the flight level in the central and southern regions, that is, in the forward or central part of the ridge and near the right entrance of the jet stream. The only clear-air turbulence encountered was light and it was over the Mediterranean in the region of accelerating winds. The albedo varied rapidly with distance following the type of surface below, being in the region of 0.17 over France, 0.04–0.08 over the Mediterranean and 0.28 over the thickest cirrus clouds. There was very little other cloud except small cumulus over the Mediterranean islands and a haze top at 16,000 feet near Malta.

- (ii) 17 June 1958, Malta–Cyprus, 0555–0805 GMT, 42,000 feet (13,000 metres)
Cyprus–Bahrain 1000–1320 GMT, 33,500 feet (10,000 metres) and
44,000 feet (13,500 metres).

The contour chart shown is for 0001 GMT at 200 millibars and 200-millibar isotherms are also included. The lowest tropopause over the central Mediterranean was at about 12,000 metres and at Cyprus 13,500 metres so that the Malta–Cyprus leg was at first flown in the lower stratosphere and later just below the tropopause on the low-pressure side of the subtropical jet stream. The axis of this jet stream was probably at about 30,000 feet over the North African coast but higher to the east with strong winds from 400 to 150 millibars over a very considerable area. The wind direction was again almost along the flight path and the increase to over 100 knots as the aircraft approached the core of the jet stream near Cyprus is well illustrated. No frost-point measurements were made, but an increase in temperature was noted corresponding to the isotherms south of the trough centre. Slight to moderate clear-air turbulence was encountered both near the trough (and also probably crossing the tropopause) and in the region of strongest winds near Cyprus. The only high cloud observed was near Malta and there was small cumulus over the various islands. The albedo varied from 0.2 near Malta to 0.08 in clear conditions over the sea south of Crete.

The observations on the Cyprus–Bahrain leg are not homogeneous, a change of altitude from 33,500 to 44,000 feet being made at 1100 GMT over east Turkey. The temperature in the early part of this leg was almost constant and although the winds were very strong no clear-air turbulence was encountered. This region of the flight was on the cold side of the jet stream and no widespread high cloud was observed, although there were large cumuliform clouds with tops up to 30,000 feet below over Turkey. In this area the albedo was usually about 0.4 but locally as high as 0.6 over cloud centres. The remainder of the flight at 44,000 feet was in the equatorial troposphere near the exit region of the jet stream. Winds still reached over 100 knots and the temperature slowly decreased towards the south. Slight clear-air turbulence was found in the jet stream south of the maximum wind and there was also a region of intermittent

turbulence, sometimes moderate, at the north of the Persian Gulf. Over the whole of this leg the sky was clear apart from small amounts of cumulus in the extreme north. The albedo varied between 0.2 and 0.3 over the desert regions and was about 0.12 along the shores of the Persian Gulf. There was a haze top at 16,000 feet over Bahrain.

- (iii) 18 June 1958, Bahrain-Aden, 0240-0550 GMT, 31,500 feet (10,000 metres) and 38,000 feet (11,500 metres)

Aden-Nairobi, 0735-1005 GMT, 32,000 feet (10,000 metres).

The 300-millibar contour chart for 0001 GMT is shown together with the 300-millibar isotherms. It was generally found possible in this work to construct both 300- and 200-millibar charts reasonably to about 15°N but attempts to do this nearer the equator were unsatisfactory. All this leg was of course in the equatorial troposphere. The flight at 31,500 feet over the Persian Gulf showed only light winds, uniform temperature, no cloud and no turbulence. The albedo over land was rather high at 0.3 to 0.33 and there was a rather thick haze up to 16,000 feet.

From 0340 GMT onwards the flight level was 38,000 feet. The wind became rather strong easterly south of 20°N and it appears from other observations of this detachment that this easterly régime continued to well south of the equator. High cloud with its base about 38,000 feet became rather general in this easterly airstream. There was also occasional slight to moderate turbulence just below and in this cloud. The temperature became slightly lower to the south. Stratocumulus was also observed over the extreme south-eastern parts of Arabia where the albedo was between 0.4 and 0.5. Along the south coast of Arabia it was usually in the region of 0.2. The haze top at Aden was at 19,000 feet.

On the Aden-to-Nairobi section the temperature at 32,000 feet was relatively constant throughout and the winds although varying irregularly in speed were all light to moderate easterly. There was widespread high cloud with variable base mainly between 30,000 and 35,000 feet, and one patch of slight clear-air turbulence below the base of this cloud. Lower clouds, mainly stratocumulus and altocumulus, were observed over most of this area and the albedo varied irregularly between 0.2 and 0.4.

- (iv) 2 July 1958, Nairobi-Aden, 0550-0825 GMT, 30,000 feet (9,000 metres) and 40,000 feet (12,000 metres)

Aden-Bahrain, 1005-1320 GMT, 30,000 feet (9,000 metres), 40,000 feet (12,000 metres) and 48,000 feet (14,500 metres).

The 200-millibar contour chart and isotherms for 0001 GMT are shown, the gradients being very small. The leg from Nairobi to 0655 GMT was at 30,000 feet where the winds were light to moderate westerly. From there to Aden the flight level was at 40,000 feet where the winds were strong easterly. Occasional moderate clear-air turbulence was encountered during the climb from 30,000 to 40,000 feet which was in a region of strong vertical wind-shear; it was also found intermittently in the stronger easterly wind region at 40,000 feet. Temperatures at each level slowly increased to the north. Considerable high cloud apparently not connected with any cumulonimbus activity was observed all along this route; its base was probably around 40,000 feet in the south and there were small amounts around 35,000 feet with thin layers at 46,000 feet towards Aden. There was also almost complete coverage of stratocumulus

cloud below over the south of the route, decreasing to no low cloud in the north. The albedo varied considerably between 0.2 and 0.6 over land and cloud, and 0.06 over the sea. The haze top at Aden was at 18,000 feet.

The leg from Aden to 1100 GMT was flown at 30,000 feet where the winds were moderate easterly. Between 1100 GMT and 1210 GMT the flight level was 40,000 feet in stronger easterly winds and thereafter 48,000 feet where the wind was strong easterly over south-east Arabia and decreased steadily towards Bahrain. There was no clear-air turbulence at 30,000 or 48,000 feet but it was moderate intermittently all along the portion at 40,000 feet where the aircraft was mainly in the base of high cloud. Considerable amounts of this cloud were observed all along the route with its main base at 40,000 feet and occasional layers below. Over south-east Arabia the aircraft was still in the high cloud at 48,000 feet; near Bahrain there was no high cloud below the aircraft but a thin layer above with base 50,000 feet or more. There was no lower cloud over southern Arabia but to the south-east there was an eight-eighths layer of altocumulus, and towards Bahrain there was again no low or medium cloud. This cloud distribution is reflected in the albedo readings which are about 0.6 to 0.8 in the south-east and 0.1 to 0.2 in the south. On each horizontal leg the temperature steadily increased as the aircraft flew northwards.

(v) 3 July 1958, Bahrain-Habbaniya, 0225-0350 GMT, 22,500 feet (7,000 metres)

Habbaniya-Cyprus, 0655-0900 GMT, 30,000 feet (9,000 metres) and 38,000 feet (11,500 metres)

Cyprus-Malta, 1050-1310 GMT, 30,000 feet (9,000 metres).

The 200-millibar contour chart and isotherms for 0001 GMT show that, although this portion of the flight returned through a strong westerly wind zone, there was no well marked subtropical jet stream as was encountered on the outward flight. There were instrumental and aircraft faults on the Bahrain-Habbaniya leg and the observations were therefore very limited. High cloud occurred over the Persian Gulf but was not evident in the westerlies to the north. There was no low or medium cloud over this area but a thick dust haze extended to about 18,000 feet. Moderate clear-air turbulence between 13,000 and 19,000 feet was encountered on the climb out of Bahrain.

The flight from Bahrain till 0800 GMT was at 30,000 feet and from then onwards it was at 38,000 feet. At both of these levels moderate to strong westerly winds were measured but there was no clear-air turbulence. At 30,000 feet temperatures were somewhat lower to the north. There was no high cloud throughout, and the only low cloud was cumulus and stratocumulus over the mountains of Turkey. The albedo here was 0.3 to 0.4 compared to 0.2 to 0.3 over Iraq. The haze top over Cyprus was at 10,000 feet.

From Cyprus to Malta the flight was at 30,000 feet almost directly upwind. Temperature was almost constant throughout but it was not possible to measure the winds due to an instrument fault. No clear-air turbulence was found and the only cloud was small amounts of cumulus over Cyprus and Crete. The albedo remained low between 0.05 and 0.07 over the sea throughout. There was a fairly thick haze at Malta from about 16,000 to 5,000 feet.

(vi) 4 July 1958, Malta-Farnborough, 0830-1120 GMT, 28,500 feet (8,500 metres) and 36,500 feet (11,000 metres).

The 200-millibar contour chart and tropopause heights for 0001 GMT are shown. The aircraft was at 28,500 feet until 0935 GMT over Corsica and then

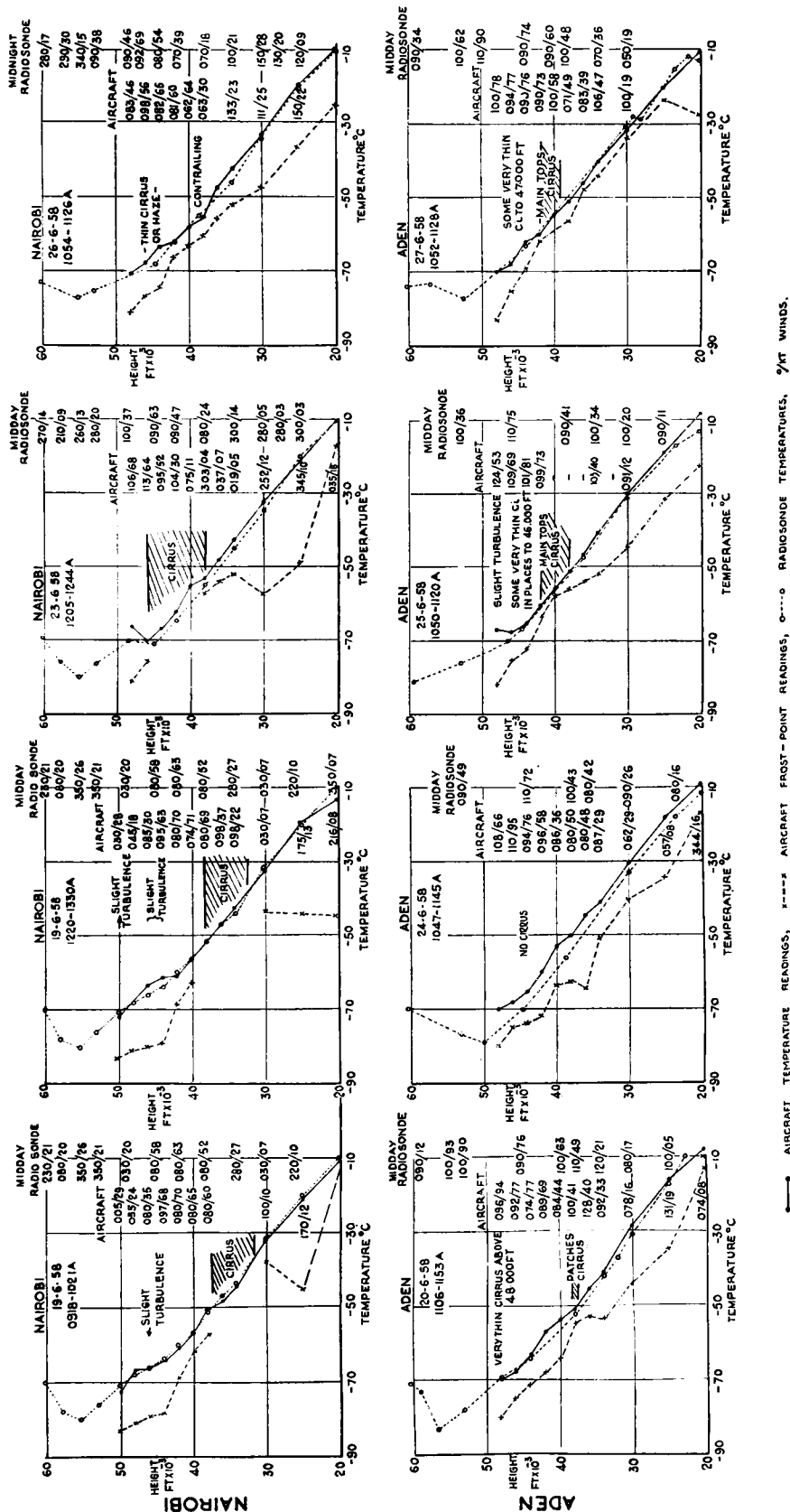


FIGURE 2—TEMPERATURE, FROST POINT AND WIND MEASUREMENTS IN VERTICAL SOUNDINGS OVER NAIROBI, ADEN AND BAHRAIN

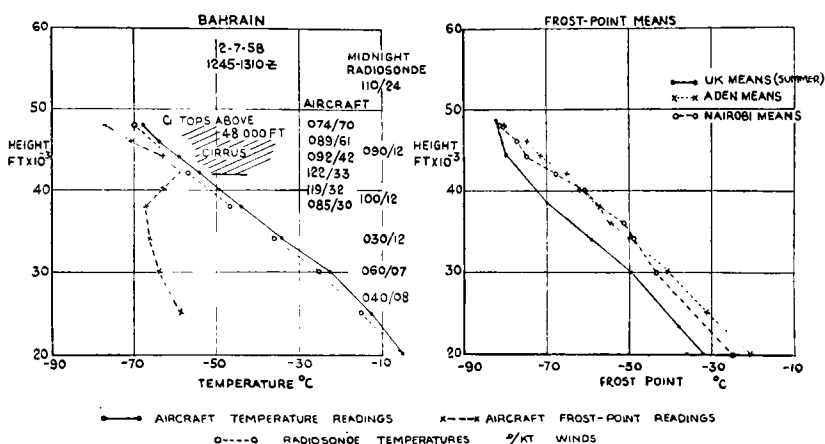


FIGURE 2—TEMPERATURE, FROST POINT AND WIND MEASUREMENTS IN VERTICAL SOUNDINGS OVER NAIROBI, ADEN AND BAHRAIN (*cont.*)

continued at 36,500 feet. During the early part of the flight which traversed the central area of a jet stream no wind observations were taken but during the latter portion the measured winds steadily decreased from about 75 knots to light and variable as the aircraft left the low-pressure side. Temperatures steadily increased during this section which was mainly in the lower stratosphere. No high cloud was observed throughout and no clear-air turbulence was encountered. There was patchy stratocumulus over the Mediterranean with small cumulus over the islands. Over France there was eight-eighths altocumulus and cumulus in the south with cumulonimbus in the north. These cloud observations are reflected in the albedo readings which varied from 0.06 over the Mediterranean to 0.64 over central France.

Vertical soundings at Nairobi, Aden and Bahrain.—Four ascents measuring temperature, wind and humidity to about 48,000 feet were made over Nairobi (1°S), four over Aden (12°N) and one over Bahrain (25°N). The results of these together with the nearest radio-sonde ascents are plotted on Figure 2. Also shown are the Nairobi and Aden means of frost points for these flights compared with summer means at Farnborough (50°N). The main results from these flights are as follows:

(i) The equatorial tropopause was between 55,000 and 57,000 feet so that all the aircraft measurements were in the troposphere. Although they were made up to several hours from the radio-sonde measurements, the two sets of temperature measurements were in good agreement. An interesting feature of many of the ascents was the decrease of the lapse rate in the upper troposphere suggesting the existence of a secondary tropopause at about 46,000 feet. There appeared to be little temperature variation from day to day at fixed levels.

(ii) Similarly the agreement between the winds measured by the aircraft and the radar-wind stations is reasonably good. At Nairobi during this period there were light mainly westerly winds up to about 30,000 feet with easterlies increasing above to a maximum value, usually between 60 and 100 knots, at about the level of the secondary tropopause mentioned above. At higher levels the easterlies decreased with height and were replaced by westerlies in the stratosphere. At Aden there were light westerlies in the lowest layers with easterlies observed at all levels above, the maximum again usually being 60 to

100 knots between 45,000 and 50,000 feet. It should be noted that there are, however, considerable day-to-day variations in the wind field in these regions and Figure 3 shows time cross-sections of wind at Nairobi and Aden, illustrating how the height range and speeds of the easterly wind belt in the middle and upper troposphere varied throughout this period.

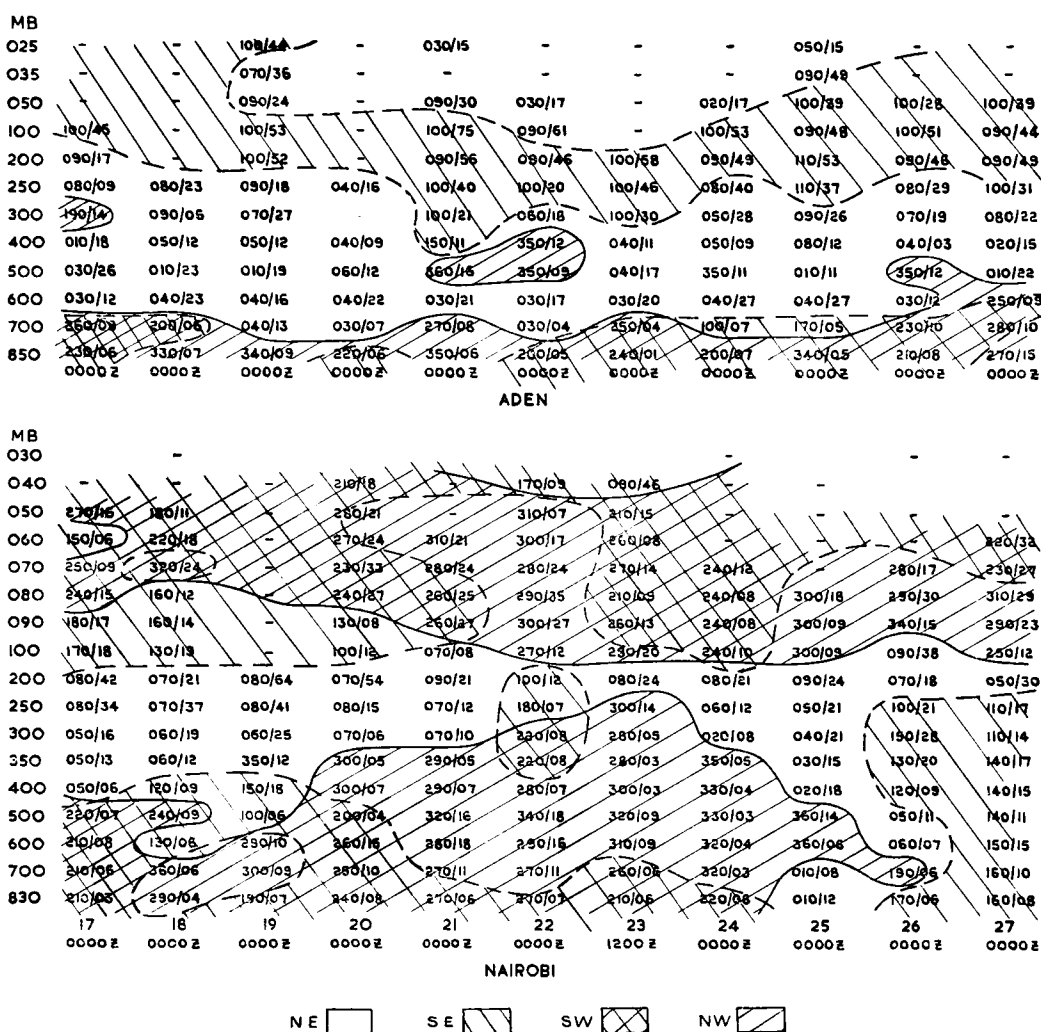


FIGURE 3—TIME CROSS-SECTION OF WIND AT NAIROBI AND ADEN, 17-27 JUNE 1958
Westerly wind areas are shaded.

(iii) The humidity measurements suggest that in the summer the mean frost points over Nairobi and Aden between 20,000 and 40,000 feet are roughly equal and about 12° - 15° C greater than over the United Kingdom. Above 40,000 feet, however, this difference decreases with height and at about 50,000 feet the frost point is approximately -80° C at all three locations. The single Bahrain measurement is considerably drier in the middle troposphere but rather moister at 50,000 feet.

Except at Bahrain, where the cirrus tops exceeded 48,000 feet, the aircraft nearly always succeeded in ascending above the main cirrus layer which usually had a base between 30,000 and 40,000 feet and tops in the region of the slackening of the lapse rate near 46,000 feet. Above 46,000 feet the atmosphere became

dry with frost points decreasing to about -80°C near 50,000 feet, a temperature approximating to the tropopause temperature at 55,000 to 57,000 feet. On one occasion (20 June 1958 at Aden), however, some very thin haze or cirrus cloud was seen well above the aircraft's ceiling and was suspected on other flights. There was considerable day-to-day variability in high cloud; and humidity in the middle troposphere often varied markedly from day to day.

A marked haze top associated with an inversion was usually observed at about 18,000 feet, particularly at Aden and in the northern parts of the flight; above this level visibility was very good.

(iv) Slight turbulence was encountered on three of these ascents all between 46,000 and 50,000 feet, that is, in the region of the strongest easterly winds, usually above the maximum. Some of the radar-wind measurements (for example, 20 June 1958 at Aden) indicate very strong vertical wind-shear above 50,000 feet and it seems that turbulence may be likely at times at these altitudes in this region.

Horizontal traverses from 9°S to Nairobi and Nairobi to Aden.—The principal information obtained from the horizontal traverses is summarized in Figures 4(a) and (b). Between Nairobi and Aden the flight plan was to ascend to 30,000 feet on track from Nairobi and then fly level for about half the distance, ascend to a higher altitude and then fly level making a slow descent over Aden. After refuelling the same procedure was applied in reverse on a return flight to Nairobi. For the flights to 9°S no landing was made at the southern end but readings were taken in the vertical between changes of flight level.

The flight of 20 June 1958 between Nairobi and Aden obtained data at 30,000 and 46,000 feet. At 30,000 feet the temperature and frost-point varied by only a few degrees over the 1100-mile track. Winds at this level were light southerly near Nairobi but somewhat stronger and easterly near Aden. Patches of turbulence were encountered near the base of the high cloud. (A useful subjective scale of turbulence is given in *Handbook of Weather Messages, Part II*.²) There was no cumulonimbus cloud over the route but high-cloud amounts were considerable though mainly in two layers, one just above 30,000 and a second more extensively between 40,000 and 45,000 feet. In the north there also appeared to be thin cloud well above 48,000 feet. At 46,000 feet the variability of the temperature and frost point was less than at the lower level. The winds were very strong easterly throughout, and considerable clear-air turbulence just above the cirrus tops was encountered during the southern half of the flight at this level.

Many of the main features of this flight were reproduced in the similar types of traverses made on 24, 25 and 27 June 1958 although it can be seen that there were significant differences in the cloud structures and minor changes in the wind field. At 30,000 feet, a level flown on each occasion, the temperatures varied little either from day to day or with latitude. The frost point was more variable as the base of the lowest high cloud was usually around this level. The wind was always moderate easterly at Aden but was more variable near Nairobi often with a southerly component. The steady increase of wind with height to strong easterly above about 40,000 feet is evident in each case although the details vary from day to day. At 38,000 feet on 24 June 1958, for instance, it was stronger at Nairobi than at Aden. The turbulence encountered was usually

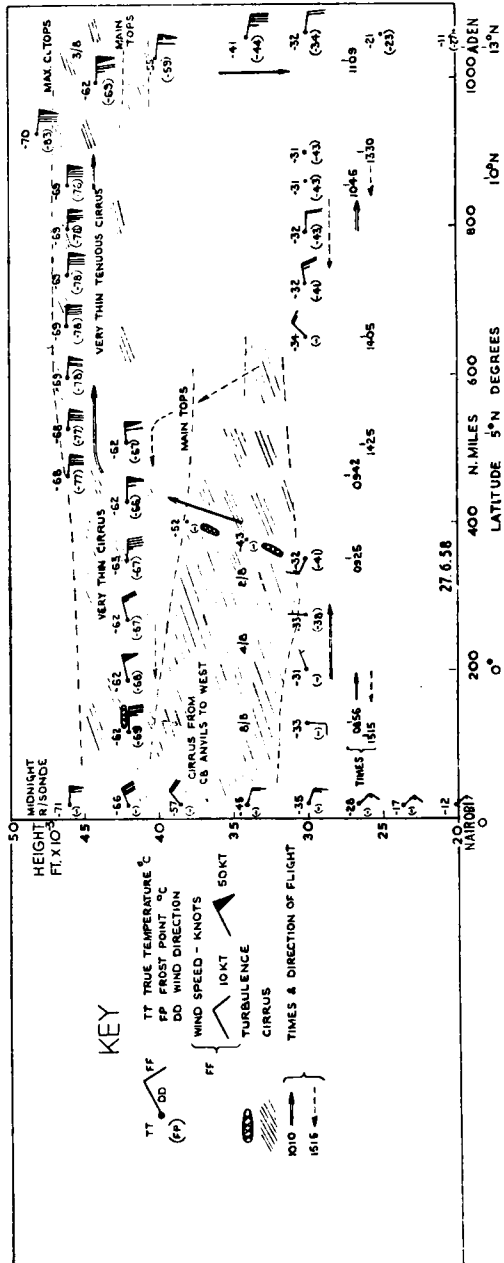
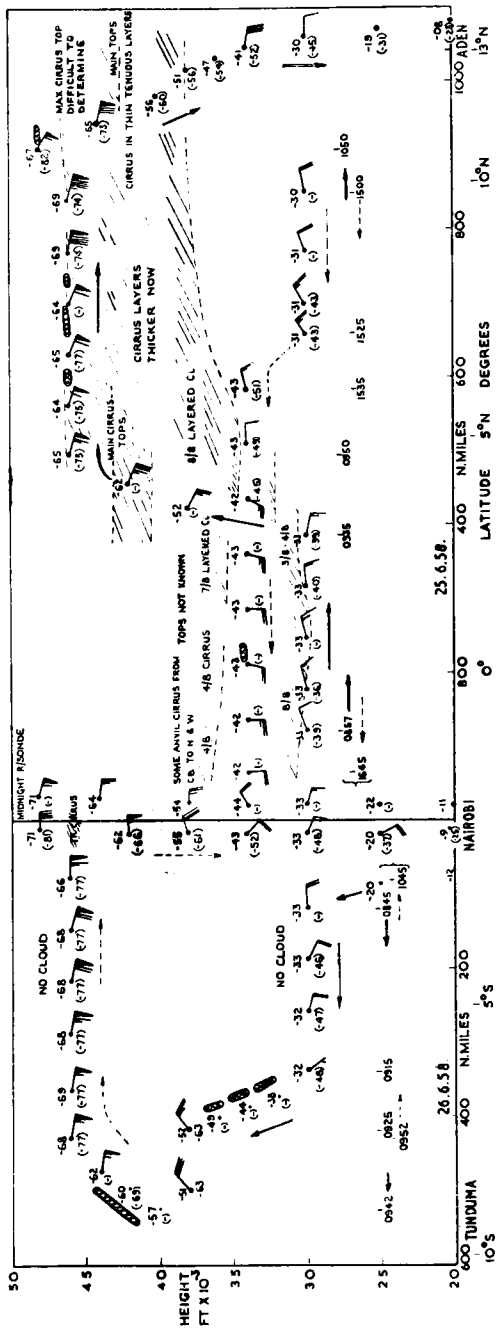


FIGURE 4(b)—FLIGHT CROSS-SECTIONS, ADEN-NAIROBI-9°S, 25, 26 AND 27 JUNE 1958



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“WEATHER ADVISER” AT SEA
(See p. 23)



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LADY SUTTON RENAMING "WEATHER ADVISER"
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MR. M. V. DUNPHY SHOWING A RADAR REFLECTOR TO LADY SUTTON
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associated with cirrus cloud in the lower flight levels and the region of strong winds at the higher levels. In the main it was much more frequent than would normally be expected at these levels in similar flights in temperate latitudes. The high-cloud systems shown were very extensive and on these other flights cumulonimbus clouds were observed and large areas of the high cloud, particularly at the lower levels and to the south, appeared to originate from the anvils of these clouds. The thinner, higher cirrus above 40,000 feet did not, however, appear to be associated with the cumulonimbus clouds.

The two flights to 9°S showed no large changes of wind and temperature fields from those measured at Nairobi. Winds at 30,000 feet were light easterly and increased to strong easterly towards 45,000 feet. It thus appears that over the period of these flights a steady strong belt of easterly winds existed in the middle and upper troposphere from at least 11°N to 9°S that is, over a distance of 1500 to 2000 miles. On the second flight (26 June 1958), when no high cloud was observed between 0° and 9°S, considerable clear-air turbulence was encountered in the ascent at 9°S from 30,000 to 46,000 feet—a region of considerable though not unusual vertical wind-shear. In contrast with this flight, that of 23 June 1958 was notable for a very extensive cirrus layer extending all over the flight region and between about 35,000 and 45,000 feet. This layer did not appear to be directly connected with any cumulonimbus activity.

The albedo observations are summarized in Figure 5.

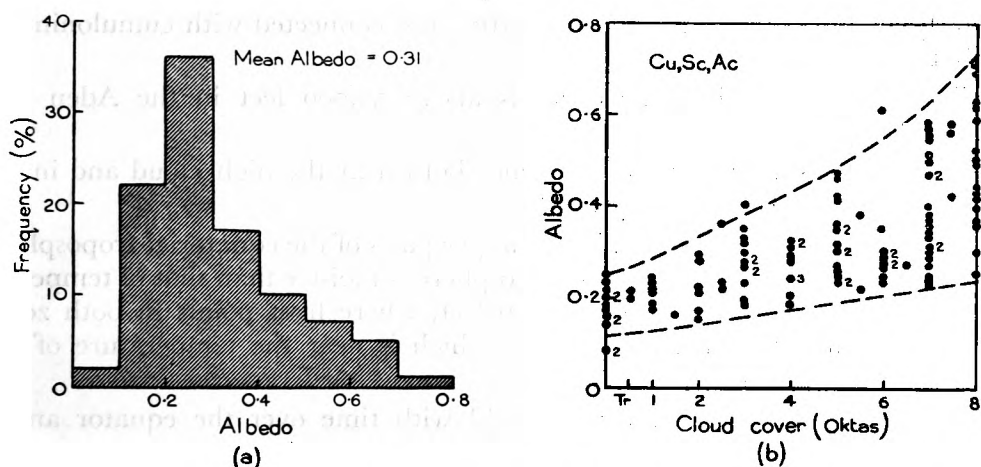


FIGURE 5—ALBEDO MEASUREMENTS, ADEN-NAIROBI-9°S

(a) This is a summary of all albedo observations obtained between Aden and 9°S presented as a frequency diagram.

(b) This is an attempt to correlate albedo with observed cloud amounts over the same route. Cloud amounts reported as n to $n+x$ oktas have been entered as $n+x/2$ oktas; a trace of cloud has been entered as $\frac{1}{2}$ okta.

All the observed cloud was reported as cumulus, stratocumulus or alto-cumulus and has been lumped together for the correlation of cloud cover with albedo. It is believed that most of the cloud reported as cumulus or stratocumulus was in fact in medium levels, particularly over high ground (for example, Kenya), since cloud appears to retain its low-level physical characteristics to a much greater height than in temperate latitudes. The spread of observations in Figure 5(b) is due to the dependence of cloud albedo on thickness as well as amount. One feature of interest was the occasional reports of

very thin (100–300 feet thick) stratocumulus in apparently stable and sometimes unbroken layers. These layers are responsible for values of albedo of less than 0.3 reported for cloud amounts of 6–8 oktas.

It was practically never possible to climb above the cirrus that frequently covered the equatorial skies, although the aircraft was often in cirrus. For this reason, the planetary albedo of the Aden–Nairobi–9°S strip is probably at least 50 per cent higher than the mean value of 0.31 observed. Values of albedo reported in cirrus have reached 0.75–0.8 (probably in anvil cirrus) but are generally in the range 0.3–0.5. It was noted that the ground ceased to be visible for albedos of about 0.4.

Use was made of the observed downward flux of solar radiation as a function of time during the flights to assist in the detection of very thin cirrus above the aircraft.

Summary and conclusion.—The principal interesting information obtained on this series of flights is summarized below. Clearly these conclusions cannot be regarded as general without considerably more data but they illustrate several features worthy of further study:

(i) The strength, relative constancy and large horizontal extent of the easterly wind belt in the upper troposphere between about 25°N and 10°S at least in this region in summer.

(ii) The large amounts and wide extents of high-cloud coverage in this easterly wind zone with a large proportion not connected with cumulonimbus activity.

(iii) The occasional tenuous clouds above 50,000 feet in the Aden and Bahrain areas.

(iv) The high frequency of turbulence both near the high cloud and in the region of the strongest easterly winds.

(v) The new humidity data in the upper parts of the equatorial troposphere which suggest that the equatorial troposphere is moister than that of temperate zones at all levels up to about 48,000 feet, where frost points in both zones converge to a value of about -80°C which is near the temperature of the equatorial tropopause.

(vi) The variability of the wind field with time over the equator and a possible relation of its maximum values to a stable region above 45,000 feet in the equatorial troposphere.

(vii) The variability of the measured albedo with surface and cloud conditions.

Acknowledgements.—The author wishes to make acknowledgements to the R.A.F. aircrew, Flt. Lt. S. J. Thomas and Sqn. Ldr. J. Canning who conducted the flights; the Director and staff of the East African Meteorological Service who supplied much of the African synoptic data presented and gave every help while the aircraft was at Nairobi; Dr. R. J. Murgatroyd, who also arranged the detachment, for constructive criticism; and Mr. M. Jackson for assisting in the reduction of data.

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DIURNAL VARIATION OF VISIBILITY WITH LIGHT WINDS AT PLYMOUTH IN WINTER

By W. E. SAUNDERS, B.Sc.

The effects of smoke on the diurnal variation of fog at airfields near large towns have received attention in a number of papers in recent years. It has been shown that heavy concentrations of smoke change the time of maximum fog frequency from the period around sunrise (which applies to rural sites) to some two hours later. Less attention has been given to visibility near the centres of large towns, mainly because the observing stations are mostly located at aerodromes on the outskirts. Visibility changes within the built-up areas are, however, of increasing importance to aviation, owing to the use of helicopters.

This note deals with winter visibilities at Plymouth (Mount Batten). An analysis of the cloud height and visibility at this station was undertaken by Walters in 1942.¹ This was based on pre-war data (for the five years 1933–37), and only on five observations per day. The variation of mist and fog with wind direction, and with the season of the year, was described. It was shown that while, in summer, most of the mist and fog reported is with south to south-south-west winds, in winter it occurs with more variable winds, mainly between north-west and north-east. The summer fogs are mainly sea fogs, brought in by moist winds from the Atlantic. These are air mass features, with little if any diurnal variation. The winter mists and fogs are partly due to radiation, but probably mainly due to the smoke of Plymouth. The present note deals with the diurnal variation of visibility during periods of light winds in the winter.

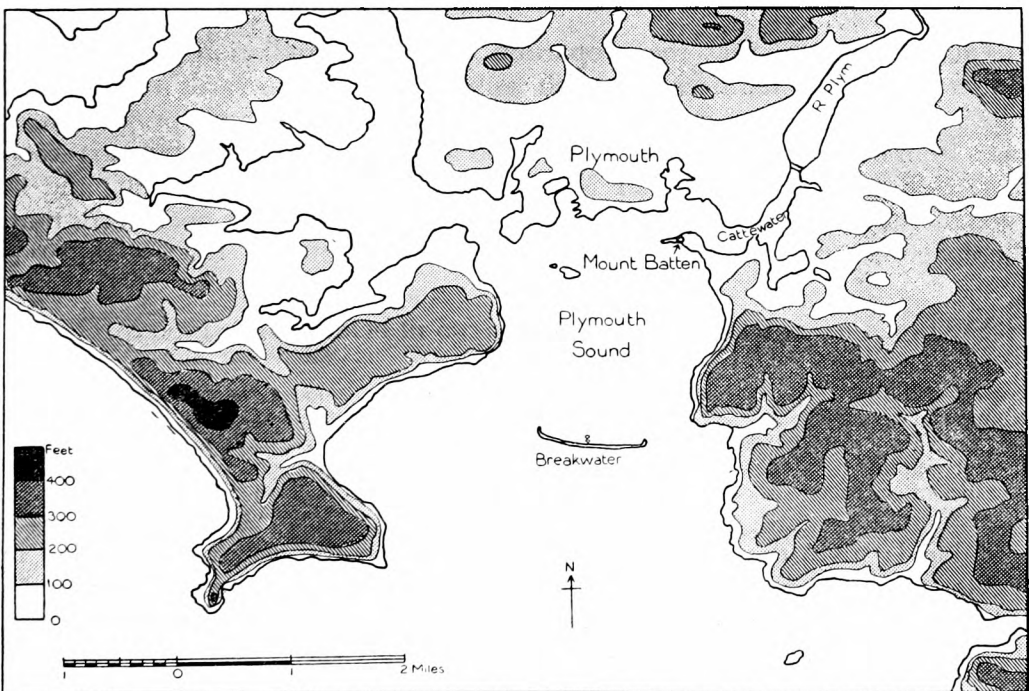


FIGURE 1—PLYMOUTH SOUND AND SURROUNDING AREA

The general topography of the area is shown in Figure 1. It may be added here that the visibility observations take in the lower parts of the city of Plymouth, and the Cattewater (a narrow strip of water separating Mount Batten

from Plymouth). The observations do not refer to Plymouth Airport, which is at Roborough, some four miles north of the city.

The analysis is confined to the winter months December, January and February, for the five years up to February 1960. Since the main interest is in daytime helicopter flights, and since smoke effects are seldom serious with winds over 10 knots, the investigation has been confined to days on which during the morning period, taken as 0600–1300 GMT, the wind speed did not exceed 10 knots. The period 1400–2100 GMT has been dealt with separately on a similar basis.

During the five winters there were 116 mornings on which the wind did not exceed 10 knots. The frequencies of various ranges of visibility are given in Table I.

TABLE I—VARIATION OF VISIBILITY DURING WINTER MORNINGS WITH LIGHT WIND AT MOUNT BATTEN

Visibility range		0600	0700	0800	Time, GMT		1100	1200	1300
					0900	1000			
					<i>number of occasions</i>				
Over 6 miles	...	17	15	6	4	2	6	10	19
2½–6 miles	...	45	43	29	12	16	18	33	42
3000–4200 yd	...	16	17	15	14	5	9	8	9
2000–2990 yd	...	21	16	19	19	23	19	20	15
1500–1990 yd	...	4	4	5	14	13	11	13	8
1000–1490 yd	...	3	10	26	28	33	28	14	11
500–990 yd	...	1	3	7	16	14	19	14	10
Below 500 yd	...	9	8	9	9	10	6	4	2

Table I suggests that the proportion of genuine radiation fogs is small—there were only ten occasions with visibility below 1000 yards at 0600 GMT. The important feature is the decrease in visibility in a large proportion of cases from over 2½ miles at 0600 and 0700 to below 2000 yards by 0900–1000 GMT. Not until after 1100 GMT is there much sign of improvement, and at 1300 GMT there are still more occasions with visibility less than 2000 yards than there were at 0600 GMT.

TABLE II—LOWEST VISIBILITY REPORTED IN PERIOD 0600–1300 GMT

Lowest visibility	...	over 6 miles	2½–6 miles	3000–4200 yd	2000–2990 yd
Number of occasions	...	—	6	9	16
Lowest visibility	...	1500–1990 yd	1000–1490 yd	500–990 yd	below 500 yd
Number of occasions	...	12	25	29	19

Table II gives the lowest visibility reported on the occasions included in Table I, and shows that visibility fell below 3000 yards at some time during the morning on 87 per cent, and below 1500 yards on 63 per cent of the days. Table III gives the time at which the worst visibility was reported.

TABLE III—TIME AT WHICH LOWEST VISIBILITY OCCURRED

Time, GMT, at which lowest visibility reported	...	0600	0700	0800	0900	1000	1100	1200	1300
Number of occasions	...	6	9	19	29	27	11	9	6

Table III shows that the worst visibility is often not reached until 0900–1000 GMT. Also, the lowest visibility during the morning period is as likely to be at 1200–1300 as it is at 0600–0700 GMT.

The afternoon and evening period, taken as 1400–2100 GMT, was similarly examined. There were 114 light wind occasions, and the visibility frequencies are given in Table IV.

TABLE IV—VARIATION OF VISIBILITY DURING WINTER AFTERNOONS AND EVENINGS WITH LIGHT WINDS AT MOUNT BATTEN

Visibility range		1400	1500	1600	Time, GMT		1900	2000	2100
					1700	1800			
		<i>number of occasions</i>							
Over 6 miles	...	25	20	14	3	1	1	1	4
2½–6 miles	...	48	47	41	20	14	14	17	16
3000–4200 yd	...	14	15	16	18	19	22	14	19
2000–2990 yd	...	11	17	23	40	50	45	48	43
1500–1990 yd	...	2	3	6	10	13	10	12	6
1000–1490 yd	...	7	6	7	16	9	13	13	17
500–990 yd	...	5	4	6	5	4	6	6	4
Below 500 yd	...	2	2	1	2	4	3	3	5

The main feature in Table IV is the visibility deterioration in the dusk period. The changes are less sharply pronounced than in the morning, and the most frequent deterioration is into the 2000–3000-yard range.

Tables V and VI give the lowest visibility reached in the afternoon and evening, and the time at which it was reached. The dusk period is seen to be the most likely time for deterioration.

TABLE V—LOWEST VISIBILITY REPORTED IN PERIOD 1400–2100 GMT

Lowest visibility	...	over 6 miles	2½–6 miles	3000–4200 yd	2000–2990 yd
Number of occasions	...	—	3	9	43
Lowest visibility	...	1500–1990 yd	1000–1490 yd	500–990 yd	below 500 yd
Number of occasions	...	10	29	10	10

TABLE VI—TIME AT WHICH LOWEST VISIBILITY OCCURRED

Time, GMT, at which lowest visibility reported	...	1400	1500	1600	1700	1800	1900	2000	2100
Number of occasions	...	5	10	7	26	22	13	9	22

It may be noted that the results presented do not give the full picture as to the number of days during the five winters on which visibility deteriorations occurred, since occasions on which the wind speed increased over 10 knots at any time were omitted in order to obtain a comparable series of observations. There were, for example, a number of additional mornings on which the visibility deteriorated along the lines suggested by Table I, but which were omitted because the wind speed later exceeded 10 knots. The wind speeds and corresponding visibilities for the morning of 29 December 1958 (Table VII) show how even a temporary lull in the wind during the critical smoke period produces a sharp visibility deterioration.

TABLE VII—WIND SPEED AND VISIBILITY, 29 DECEMBER 1958

Time, GMT	Wind speed, kt	Visibility
0600	11	10 miles
0700	3	10 miles
0800	2	2000 yards
0900	12	6 miles
1000	15	8 miles

It is also pointed out that the investigation was restricted to the midwinter months of December to February, but that similar deteriorations occur in November and March, and more exceptionally in October and April.

There can be no doubt that the visibility deteriorations are due to the smoke, partly domestic and partly industrial, from Plymouth and the growing dormitory areas, such as Plymstock. The morning deteriorations, in particular, are probably mainly due to smoke from industrial sites near the River Plym. When the pressure gradient over south-west England is light, and there has been a radiation night, there is a slow drift from the north-east of cold air from Dartmoor. This carries smoke from the Plym area to the Cattewater and the inshore part of Plymouth Sound where, having found its lowest level, it remains until there is some freshening of the wind. With the tendency for industrial development to increase in the area surrounding the Plym there seems little prospect of the winter visibility problem near Mount Batten improving.

REFERENCE

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551.577.3

YEAR-TO-YEAR VARIATIONS IN RAINFALL TOTALS

By L. P. SMITH, B.A.

Summary.—For practical purposes, the variations in rainfall can be conveniently represented by ten sample percentages of average. Such samples vary with the length of period considered, but the percentages are reasonably constant over England and Wales, both in high or low rainfall areas.

Introduction.—For irrigation planning it is necessary to find a method of representing the rainfall climate which gives not only the average value but also the expected variations about the average. The simplest way of doing this has been found to be the calculation of ten percentages which, when multiplied by the appropriate average, give ten sample rainfalls. These would give an estimate of the rainfall totals over ten years arranged in ascending, but not chronological order.

Suppose, for example, it was required to find the frequency and extent of irrigation need on a given farm. The optimum conditions might demand the maintenance of field capacity during May and June. The average rainfall and potential transpiration for the area are found. The ten sample percentages for a two-month period are then multiplied by the average rainfall to give ten sample totals which are assumed to represent the rainfall of the next decade. The transpiration is assumed to be constant, an assumption which is reasonable because variations from average are relatively small. By simple subtraction of the rainfall samples from the potential transpiration, not only is the frequency

of need (in years out of ten) found, but also a working estimate of the amount of extra water required. With these details the irrigation potential can be estimated in regard to both productivity and cost of installation, quite apart from the essential basic problem as to whether sufficient water is available to meet the irrigation need.

Previous work.—Several years ago such samples were calculated by examining the rainfall totals for 60 stations over the 25 years 1924–48. These stations were selected from five main areas, namely, Kent, the Vale of Evesham, Somerset, the Fen district and south Yorkshire. Only the summer months, April to September, were analysed and mean sample percentages were calculated for periods of 1, 2, 3, 4, 5, and 6 months. These samples were published in the Ministry of Agriculture's Technical Bulletin No. 4.¹

Present investigation.—Because the previous work was based on observations in a restricted area, over a short period of years and from stations with low rainfall averages, a new investigation was started using twelve well scattered stations with 50-year (1910–59) records. These are shown in Table I.

TABLE I—STATIONS UNDER REVIEW

Northern Area				Southern Area			
Station		1916-50 annual average		Station		1916-50 annual average	
		<i>in.</i>				<i>in.</i>	
Low Rainfall							
Newcastle	28	Oxford	...	...	26
Lincoln	24	Thetford (Norfolk)	...	...	25
Shrewsbury	26	Ashford (Kent)	...	...	29
High Rainfall							
Carlisle	32	Treherbert (Glam)	...	...	94
Haslingden (Lancs)	57	Kennick (Devon)	...	...	44
Leyburn (Yorks)	35	Ringwood (Hants)	...	...	33

Method of analysis.—For each station the six-month (April to September) rainfall total for each of the 50 years was expressed as a percentage of the 50-year mean. The required ten samples were then calculated by taking the mean of the five lowest percentages, the mean of the next lowest, and so on. The final figures were meaned over the twelve stations for each of the ten samples; similar means were also found for the six northern and six southern stations, and also for the six high rainfall and the six low rainfall stations.

This was repeated for 5, 4, 3, 2 and 1 month periods, using each possible combination of successive months during the summer period. The winter six-month samples (October to March) were also calculated.

Results.—The results for the twelve stations taken together were very similar to those previously published. The only difference worthy of comment was for the driest year in ten, when the previous work suggested a slightly lower percentage than the present investigation. The difference was hardly significant statistically and the published figures would not have occasioned any major errors.

Comparison between high and low rainfall areas showed little difference indeed, but there was a distinct tendency for the southern area stations to experience relatively drier years than those in the north. There is also a tendency, which is apparent in all areas, for lower rainfall totals during the later months in the summer period. (See Table II.)

TABLE II—LOWEST SAMPLE PERCENTAGE FOR A TWO-MONTH PERIOD

Months			Northern Area	Southern Area
			%	%
April and May ...	...	...	50	46
May and June ...	...	...	48½	44½
June and July ...	...	...	44	37
July and August ...	...	...	40½	35
August and September	...	...	36	35

The results may be summarized as in Table III. The full details have been circulated in Meteorological Office Agricultural Memorandum No. XXXI.²

TABLE III—SAMPLE PERCENTAGES OF RAINFALL AVERAGES

Northern Area											
Period	Lowest in 50 years	1	2	3	4	5	Samples 6 per cent	7	8	9	10
Summer											
6 months	53	62½	74½	83½	91	97	101½	107½	115	123½	144
5 months	51	61	73	81	89	96	103	108½	116	126½	146
4 months	49	58½	71	79½	87½	94½	102	108	116½	130	152½
3 months	44	53	67	77	86	94	102	110	119	133	159
2 months	30½	44	61½	72½	82	92	101	112½	123	139½	172
1 month	11	24½	47	62	75	87	99	113½	131½	155½	205
Winter											
6 months	58	65	76	83½	90½	95	101	108	115½	123	142½
Southern Area											
Period	Lowest in 50 years	1	2	3	4	5	Samples 6 per cent	7	8	9	10
Summer											
6 months	48	58½	72½	82½	90	96	103½	109½	116	127½	144
5 months	46	57½	71½	82	89	96	102½	109	117½	127½	147½
4 months	42½	54	69½	79	87	94½	102	110	120	131	153
3 months	38	49	66	76½	85	94	102	111½	121	135½	159½
2 months	27	39½	58	70½	81½	92½	103	113½	125½	142	174
1 month	9	20½	42½	59	73½	87	101	116½	134½	159	206½
Winter											
6 months	55	62½	75½	84	92	96½	101½	107½	115	124½	141

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1. Ministry of Agriculture and Fisheries; The calculation of irrigation need. *Ministr. Agric. and Fish. Tech. Bull.*, London, No. 4, 1954, Table 8.
2. SMITH, L. P.; Year-to-year variations in rainfall totals. *Met. Off. agric. Memor.*, London, No. XXXI, 1960 (unpublished, available in Met. Office Library).

“WEATHER ADVISER”

By C. E. N. FRANKCOM, O.B.E.

On 22 September, at the James Watt Dock in Greenock, the “Castle” class frigate *Amberley Castle*, having been converted to an ocean weather ship, was renamed *Weather Adviser* by Lady Sutton, wife of the Director-General of the Meteorological Office. The extensive work of converting her for her new duties had been carried out by the Blyth Dry Dock and Shipbuilding Co. Ltd. (Northumberland); a job which took about nine months to complete.

Lady Sutton was accompanied by her husband; the guests attending the ceremony included the Provost of Greenock, representatives of the shipyard, local authorities, and wives of various members of the ship’s company. Appropriately enough, it was a fine sunny day, so that the River Clyde looked at its best; *Weather Adviser*, with her newly painted yellow upper works and blue hull

and "dressed" with the flags of all those countries which operate weather ships in the North Atlantic, looked quite colourful. Her sister ship *Weather Reporter* and the veteran *Weather Observer*, the latter now withdrawn from active service and looking rather forlorn, were berthed astern of her. *Weather Adviser* ship's company were drawn up on the quay alongside the ship.

Before the actual renaming, Sir Graham Sutton gave an informal talk to the ship's company and guests in which he paid tribute to the good job that the ocean weather ships have done during their thirteen years of international duty in the North Atlantic. He emphasized the value of the surface and upper air observations made aboard these ships, not only for aviation but for general meteorological purposes and said how much he appreciated the way in which all concerned had continued to carry out this important work under the arduous conditions of North Atlantic weather. After inspecting the ship's company, Sir Graham and Lady Sutton accompanied by the Captain went aboard the ship where Lady Sutton cut a tape to release a canvas cover disclosing the ship's name, saying "I rename this ship *Weather Adviser*, may God bless her and all who sail aboard her". The visitors were then invited aboard the ship to inspect her and to take tea. The lay-out of *Weather Adviser* is very similar to that of *Weather Reporter*, but certain improvements have been introduced as a result of experience gained with *Reporter*. The arrangement of the accommodation has been improved by narrowing the alleyways and thereby giving somewhat larger cabins, and the meteorological office, radio receiving room, radar office and chart room have all been increased appreciably in size. The lay-out of the meteorological office is somewhat better than that aboard *Reporter*, and provision is made for the installation of "Cintel" equipment for automatic radio-sonde reception when that becomes available. The radio equipment of *Adviser* is of a commercial design and considerably more modern than that which was available for installing aboard *Reporter*. The naval type stabilized ten-centimetre radar equipment for radar-wind finding and for providing navigational "fixes" to aircraft in flight is similar to that carried in the other British weather ships, but is of more modern design. In order to achieve better results when the wind-finding balloon is abaft the ship during a radar-wind ascent, the fore-top mast has been removed. As in *Weather Reporter*, the lining and deck heads of all accommodation and offices are covered with plastic leather cloth bonded to asbestos panels, and the decks are covered with resin-bound tiles. All Officers and Petty Officers are berthed in single cabins; the ratings are berthed three in a cabin. Generally the accommodation is as good as one would find in any modern ship of a similar size, and the appearance of the furniture is particularly attractive.

In command of *Weather Adviser* is Commander H. Sobey, R.N.R., who joined *Weather Watcher* as Chief Officer in 1947 and was promoted to Command of *Weather Observer* in 1952. Unfortunately he fell sick shortly before the ceremony and Captain J. Clark, who would normally have been Chief Officer, assumed temporary command of the ship. Two other members of her ship's company have served in the weather ships since 1947; Mr. Lambert, the radio overseer and Mr. Gilbey, the boatswain, while two others have served in the ships since 1948. Mr. Dunphy, one of the meteorological officers, has the distinction of being the longest serving meteorologist in British ocean weather ships; he joined them in 1949 and has done 75 voyages. It was a coincidence that on the day of the renaming ceremony Mr. Dunphy received the news that he had been

awarded the L. G. Groves Second Memorial Award. Mr. Jones, the meteorological officer-in-charge aboard the ship has been in the weather ships since 1953.

Weather Adviser replaces *Weather Observer*, which was the first British weather ship to take up duty at a North Atlantic station in August 1947. *Weather Observer* did a consistently good job during her 103 voyages as a weather ship and fully maintained the reputation of the "Flower" class corvettes for sea-keeping qualities.

Two other "Castle" class frigates are being converted to ocean weather ships at Blyth, and are expected to be in service during 1961, in replacement of *Weather Recorder* and *Weather Watcher*.

NOTES AND NEWS

Universal Decimal Classification

551.5 *Meteorology*

In an earlier issue¹ were described the major changes, effective from 1 January 1957, from the classification in force since 1 January 1950. At its second session in November 1957 the former Commission for Bibliography and Publications of the World Meteorological Organization again agreed on a number of revisions of 551.5 which were later agreed by the Executive Committee and the International Federation for Documentation.

The complete revised classification was published as an appendix² to *WMO Technical Regulations* Volume 1, 2nd Edition, and was, at short notice, brought into use in the Meteorological Office Library for classifying books and papers received on and after 1 July 1960.

The major changes from the classification in force since 1 January 1957 are as follows:

551.501.7 *Upper air, methods of observation and computation*. Nine subdivisional numbers are allocated to cater for separate elements.

551.507.362.1 *Rockets* and 551.507.362.2 *Artificial satellites*. New numbers under 551.507.3 *Sounding vehicles for upper air, meteorological uses*.

551.508.86 *Sferics equipment*. New number added under 551.508.8 *Combined instruments*.

551.509.324 *Precipitation, rime, glazed frost* changed to *Cloud, precipitation, rime, glazed frost* under 551.509.3 *Bases and methods of forecasting*. Three appropriate subdivisional numbers are added.

551.509.33 *Forecasts for long period (week, month or season)*. Eight subdivisional numbers are allocated to cater for the varying forecasting methods such as correlation in space or time, analogue methods etc.

551.509.54 *Precipitation, glazed ice, rime*, changed to *Cloud, precipitation, rime, glazed frost* under 551.509.5 *Organization of forecasting services, use and checking of forecasts*. Three appropriate subdivisional numbers are added. See 551.509.324 above and remarks.

551.509.61, 551.509.612, 551.509.615, 551.509.617 are replacement numbers under 551.509.6 *Deliberate action on the weather* as distinct from 551.509.68 (new number) *Accidental action on the weather*.

551.510.535.2 and 551.510.535.4 are new numbers under 551.510.535 *Ionosphere*.

551.510.61, 551.510.62, 551.510.7, 551.510.71, 551.510.72, 551.510.721 are new or replacement numbers the first two of which cater for *Optical and radio refractive indices* and the remainder for *Atmospheric radioactivity and radioactive fall-out*.

551.515.4 *Thunderstorms* changed to *Convective precipitation systems, thunderstorms and showers*.

551.515.5 *Tropical atmospheric formations and disturbances other than tropical cyclones, hurricanes, typhoons*. New number with four appropriate subdivisional numbers.

551.515.9 *Damage caused by weather in general*. New number.

551.521.17 *Ultra-violet radiation* and 551.521.18 *Infra-red component of solar radiation*. Replacement numbers under 551.521.1 *Solar radiation in general* instead of under 551.521.6 *Radiation of specific wavelengths and corpuscular radiation* which number now becomes *Cosmic and corpuscular radiation*.

551.524.372 *Damage caused by frost*. New number.

551.524.7 *Upper air temperatures*. Ten subdivisional numbers are added to conform with the breakdown of surface air temperature.

551.574.1 *Physics, nuclei* becomes *Physics of condensation*. Four appropriate subdivisional numbers are added.

551.577.13 *Chemical properties* and 551.577.7 *Radioactivity of precipitation*. New numbers in *Precipitation* section.

551.578.46 *Snow cover* is given seven appropriate subdivisional numbers.

551.578.48 *Avalanches*. New number with four appropriate subdivisions.

551.590.3 *Effects of volcanic eruptions on weather and climate*. New number.

551.594.25 *Electricity of precipitation* becomes *Electricity of aerosols* with four appropriate subdivisions.

This note is published with the agreement of the British Standards Institution, copyright holders of the Universal Decimal Classification in the United Kingdom. The relevant BSI publications are quoted.^{3,4}

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1. London, Meteorological Office. Universal Decimal Classification 551.5 Meteorology. *Met. Mag., London*, **86**, 1957, p. 22.
2. Geneva, World Meteorological Organization. Technical Regulations, Volume 1—General, 2nd Ed., Appendix G., WMO—No. 49 Bd. 2/3, Geneva, 1959.
3. London, British Standards Institution. Universal Decimal Classification, English edition. British Standard 1000, 2, Part 3, Geology and geophysics (including meteorology), London, 1943.
4. London, British Standards Institution. Universal Decimal Classification, abridged English edition. British Standard 1000A, 2nd Ed. revised, London, 1957.
5. The Hague, International Federation for Documentation. Extensions and corrections to the UDC. The Hague, issued half-yearly.

Training courses for co-operating observers

Two courses for co-operating observers were held again this year at the Meteorological Office Training School, Stanmore. The first, intended primarily for agricultural meteorological station observers, was held from 3–7 October and the second, designed for climatological and health resort station observers, from 10–14 October 1960. The courses consisted of instructions in instrument maintenance, the taking and recording of weather observations, the completion of returns and, for the agricultural meteorological observers, talks on agricultural meteorology. In addition films and slides were shown and there were discussions on the applications of climatological data.

The agricultural meteorological station observers were taken on a visit to the Rothamstead Experimental Station by kind permission of the Director, and a visit to the London Weather Centre was arranged for the climatological station observers. Finally, both courses visited Harrow where they were able to see the British climatology branch, the punched-card installation, the instrument test rooms and wind tunnel, and where there were opportunities for discussing any problems at their particular stations.

In all, 42 observers attended the courses. They included agricultural students, foresters, school teachers, borough engineers and surveyors, etc., their ages ranging from 18 to 65. All were enthusiastic and the courses appeared to be much appreciated, particularly the periods devoted to practical work.

OFFICIAL PUBLICATIONS

The following publications have recently been issued:

Handbook of aviation meteorology.

The primary object of this handbook is to provide a work suitable for the use of pilots and navigators undergoing intermediate or advanced courses of instruction at flying training schools, whether military or civilian. Within these limits the subject is covered comprehensively, but an elementary knowledge of meteorology on the part of the reader will be an advantage. The presentation has been made reasonably simple and physical ideas explained as they arise; mathematical knowledge is not required beyond an ability to handle some simple formulae, but for the benefit of readers familiar with elementary calculus, proofs of most of the formulae used are collected together in an appendix.

It is, however, neither possible nor desirable to confine the scope of such a book to the precise needs of students attending a variety of courses and requiring to pass one or other of the several examinations open to them. Accordingly, with but very little widening of the scope, the book has a secondary object, that of the presentation of a general account of meteorology, including its theory and practice and its applications to aviation. It is hoped, therefore, that it will be found useful to any who are in one way or another concerned with the applications of meteorology to aviation and who require a non-mathematical account of the subject.

The book is divided into five parts which are more or less independent. Part I contains a somewhat detailed account of the physical principles of the subject, together with their immediate applications to aviation. Part II gives a brief description of the raw material of meteorology—the observations, how they are

made, distributed and charted. This leads on to a discussion of synoptic meteorology including examples of synoptic charts in Part III, with an outline of the principles of weather forecasting. Part IV describes the organization of the meteorological services for aviation; and finally Part V explains and describes very briefly the salient features of weather over the world and on the air routes.

The book, largely the work of Mr. A. F. Crossley of the Meteorological Office, was prepared as a successor to Dr. R. C. Sutcliffe's *Meteorology for aviators*.

GEOPHYSICAL MEMOIRS

No. 103—*Upper winds over the world; Parts I and II.*

This is a completely new edition of the earlier Memoir published in the same series and under the same title in 1950. A revised edition became both feasible and necessary because of the greatly extended geographical coverage of upper air data since the preparation of the earlier Memoir, which, moreover, has been out of print for several years.

The scope of the new edition is more comprehensive than that of any known similar publication. The information is presented mainly in the form of charts covering the whole world except for Antarctica. Average winds at six standard upper levels from 700 to 100 millibars (approximately 3,000 to 16,000 metres) are charted for the four mid-season months, January, April, July and October, the period covered being 1949–53. There are separate series of charts for contours of the standard constant-pressure surfaces and for the direct representation of the winds by average streamlines and isotachs. It is intended to show the variability of wind by charts of standard vector deviation, to be published separately as Part III.

Besides aiding studies of the general circulation of the atmosphere the Memoir provides information of practical use in aircraft design and air-route planning.

SCIENTIFIC PAPER

No. 4—*Pressure variation over Malaya and the resonance theory.* By R. Frost, B.A.

An analysis of the hourly observations from six Malayan stations near the equator shows the following features of the semi-diurnal variation of pressure:

- (i) The amplitude of the second harmonic is greater near the thermal than the geographical equator.
- (ii) The amplitude is greatest when the sun is overhead in March and September, and is greater in January when the sun is nearest to the earth than in July when the sun is farthest away from the earth.
- (iii) The mean monthly values of the amplitude show a close relationship with the monthly totals of solar radiation at the equator.
- (iv) The mean value of the phase angle of the second harmonic is in phase with the passage of the sun.
- (v) The time of maximum phase angle of the second harmonic expressed in local time occurs earlier on the west coast than on the east coast, but a difference in geographical pattern in the time of maximum phase angle occurs between the north-east and south-west monsoon seasons.

The above features are difficult, if not impossible, to reconcile with any resonance theory and an alternative theory is suggested.

METEOROLOGICAL OFFICE NEWS

Retirement.—The Director-General records his appreciation of the services of:

Mr. W. J. Fowler, Senior Experimental Officer, who retired on 10 November 1960. He joined the Office in September 1915 as a Boy Clerk at Falmouth Observatory, which was then administered by the Meteorological Office. From May 1918 to December 1919 he served in the Meteorological Section of the Royal Engineers. On demobilization he returned to Falmouth Observatory, but after a few months he was transferred to an aviation outstation. In 1921 he was posted to an outstation associated with services for the Army where he remained for some ten years. In 1931 he was again transferred to an aviation outstation and his subsequent career was spent at a number of such outstations, including several overseas in Iraq, Italy, Austria, Germany and the West Indies. From 1954 until his retirement he served at Upavon. Mr. Fowler has accepted a temporary appointment in the Meteorological Office.

Move of Meteorological Office Library to the Meteorological Office Headquarters, Bracknell

The Library will be occupied with the move of its material and certain pre- and post-removal matters during the overall period 6 March–21 April 1961. During this time the normal outside loans and advisory services will be suspended though certain limited facilities will be available, internally, on a personal reference basis for an interval after 6 March at Harrow and before 21 April at Bracknell.

The new address, effective from 11 April 1961, will be:

The Library,
Meteorological Office,
London Road,
Bracknell,
Berkshire.

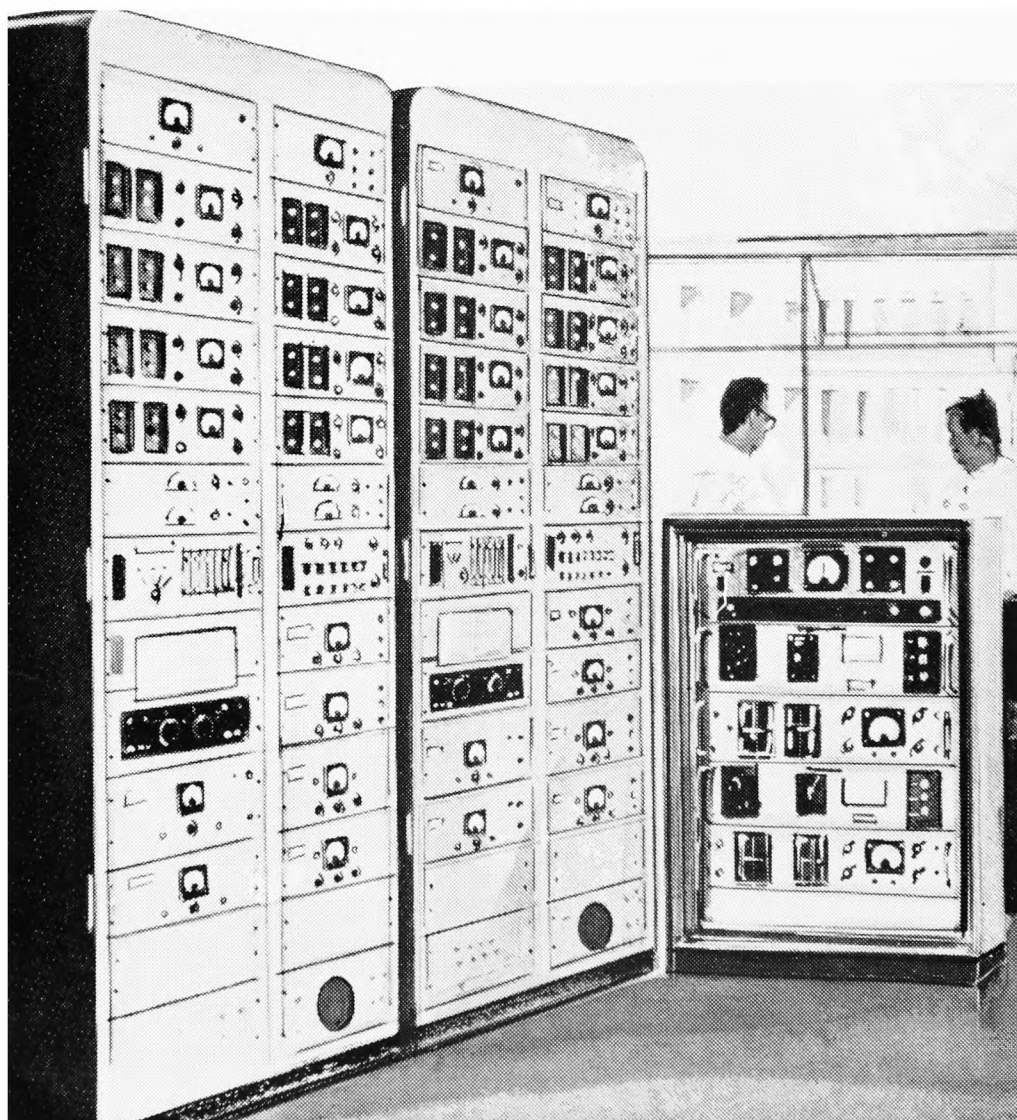
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METEOROLOGICAL OFFICE

THE METEOROLOGICAL MAGAZINE

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551 551.8

THE ESTIMATION OF THE DISPERSION OF WINDBORNE MATERIAL

By F. PASQUILL, D.Sc.

Introduction.—The theoretical estimation of the concentrations arising from sources of gaseous or finely divided particulate material has for long been based on treatments of atmospheric diffusion developed by Sir Graham Sutton, and subsequently expressed in the well known formulae for surface and elevated sources (see *Micrometeorology*, p. 290¹). These formulae are reliable for specifying the average distribution, over a few hundred metres downwind of a source operating for a few minutes on level unobstructed terrain, with a steady wind direction and neutral conditions of atmospheric stability. Extension to other circumstances has depended on empirical and often speculative adjustments of the diffusion parameters.

During the last few years, further investigations at the Chemical Defence Experimental Establishment, Porton, have shown that a fairly rational allowance can now be made for the effects of much of the wide variation in atmospheric turbulence which occurs in reality. This progress includes some extension to longer distances of travel. Although many aspects of the problem require further attention, these recent developments, supported also by experimental studies in the U.S.A., form a basis for a tentative system of estimating diffusion in a wide range of meteorological conditions and over distances up to about 100 kilometres.

The purpose of this article is to review the recent background of theoretical and experimental results, and to give details of the proposed system of calculating the distribution of concentration downwind of a source. These details are set out in two appendixes, the first giving complete instructions for carrying out the calculations, the second presenting an example.

The crosswind spread of a cloud from a continuous point source.—In the earlier treatments of diffusion from a continuous point source the main feature was the adoption of a conjectured form for the Lagrangian correlation coefficient in G. I. Taylor's (1921) statistical analysis of the dispersion of particles (see *Micrometeorology*, p. 284¹). Justification of the particular form was provided by using it to deduce a correct expression for the aerodynamic drag

of a surface. In effect this meant that a correct form for the eddy diffusivity determining the vertical transport of momentum had been specified. The remaining important steps were the assumptions of identity in the diffusivities for momentum and airborne material, and of analogy in the laws governing vertical and lateral diffusion from a source in the lower atmosphere.

Taylor's analysis assumes that the field of turbulence affecting the particles is homogeneous and steady, that is, that its statistical properties do not depend on position or time. It would be difficult, if not impossible, to find any example of atmospheric turbulence in which these conditions are strictly satisfied, and indeed it is known that near the ground the structure of turbulence changes systematically with height. However, subject to certain restrictions, it is not unreasonable to assume the existence of *quasi*-homogeneous, *quasi*-steady properties in the horizontal plane, and even in the vertical plane well away from the ground. The obvious restrictions are that the structure of the flow should not be systematically patterned by dynamical or thermal influences associated with surface topography, and that its properties should not change radically over the period of interest (hence, if there is a large diurnal variation, for example, attention should be confined to small fractions of a day at a time). For such quasi-homogeneous, quasi-steady conditions a simple and direct adaptation of Taylor's treatment has been developed by Hay and Pasquill².

The essential step in the new treatment is the adoption of a simple hypothesis regarding the Lagrangian variations of velocity (that is, those experienced by a single particle as it travels), which are difficult if not impossible to measure, and the variations which can be observed by using an instrument at a fixed position. In terms of the auto-correlation coefficient of eddy velocity the hypothesis is that this function has the same shape (with regard to time-lag) in the two cases, but that the Lagrangian coefficient takes β times as long as the "fixed-point" coefficient to decay to a given magnitude. It can be demonstrated analytically that identity in shape is not really critical, the important requirement being that the ratio (β) of the corresponding integrals of the whole correlograms should be known. Even then it follows directly from Taylor's original treatment that the magnitude of diffusion is insensitive to β at short range, and only depends on $\beta^{\frac{1}{2}}$ at long range.

In the simple form used in practice the crosswind spread of particles from their mean position is given by

$$\sigma_y/x \simeq [\sigma_\theta]_{\tau, x/\bar{u}\beta} \dots (1)$$

where σ_y is the standard deviation of the crosswind displacements of the particles at a distance x downwind, σ_θ is the standard deviation of wind direction, and \bar{u} is the mean wind speed. The subscripts are used to denote that this standard deviation is obtained by forming averages of the wind direction over moving intervals $x/\bar{u}\beta$, and using the values so obtained over a duration τ , equal to the duration of release of the material, or to the duration of sampling (or exposure to) the cloud, whichever is the shorter. When x/\bar{u} is greater than the duration of release (that is, when the plume is detached from the source), or than the duration of sampling of a continuous plume, the diffusion will be determined in a complex way by larger and larger eddies than those which contribute to the variation of wind direction over the time τ , and equation (1) will then underestimate σ_y .

From measurements of the crosswind spread of particles at a distance of 100 metres from a source of duration three minutes [$\tau = 3$ min in equation (1)], values of β were deduced which varied considerably but averaged about four. It was also shown that this value provided a satisfactory interpretation of diffusion data obtained earlier at Porton, and more recently in the U.S.A., for distances of travel up to about 1000 metres. Many more determinations of the effective value of β will be required to give a reasonably complete description, but for many practical purposes it would appear that a useful range of conditions is adequately represented by the foregoing value.

For ranges of travel much longer than 1000 metres the method is open to question on the grounds that as the plume spreads vertically its lateral spread will be affected by the systematic variation of wind direction with height above the ground. However, a limited examination (three cases) of the crosswind spread at a distance of about 75 kilometres showed that equation (1) did in fact give a reasonable approximation in terms of the surface wind. These cases were in daytime, with fairly vigorous mixing over a depth of about 1000 metres. The values of σ_y/x and σ_θ were as follows, the latter being determined from a Baxendall wind-direction recorder at the site of release:

σ_y/x	0.073	0.077	0.061
$[\sigma_\theta]_{\tau, x/4\bar{u}}$	0.084	0.066	0.068 radians.

Vertical diffusion at short range from a source at ground level.—A general treatment of vertical diffusion in the lowest layers of the atmosphere, based on laboratory laws relating wind profile and surface drag, has been given by Calder.³ The full exploitation of the treatment requires careful specification of the vertical profile of mean wind velocity characteristic of the surface. For practical purposes, however, changes in the small-scale roughness (for example, in grass length) have only a minor effect on diffusion. For example (see Calder's paper, p. 166³), a six-fold increase in the roughness parameter, corresponding to a doubling of the aerodynamic drag, produces only a 25 per cent increase in the *height* of cloud at 100 metres from a source (defined here as the height at which the concentration in the cloud is one-tenth of the ground-level value). So although the treatment has only been verified for grassland, the implication is that increases in roughness of a moderate order (for example, due to crops, small bushes and hedges) are unlikely to make a vast difference to the vertical diffusion. This suggests that for open country, but away from larger disturbances such as those caused by woods, buildings or sharp changes in contour, an acceptable working approximation is probably best represented by the long-grass case (see Calder's paper, p. 166³), for which the heights of cloud at 100 and 1000 metres downwind are respectively 10 and 70 metres.

It should be emphasized that these figures apply only to neutral conditions of stability, and cannot be directly extrapolated to longer ranges. The latter restriction arises from the assumption in the theoretical argument that the horizontal shearing stress is constant with height. In the present state of knowledge this can be assumed with confidence only over the first few tens of metres.

The method has been extended to non-neutral conditions by Deacon,⁴ using an empirical power-law form of wind profile which reduces to the required logarithmic form in the special case of neutral conditions. There is evidence for reasonable agreement with observations of diffusion in unstable conditions, though the accuracy required in measuring the wind profile is even greater

than in neutral conditions and there are other difficulties when the roughness elements are easily bent over or distorted by the wind. In stable conditions the method gives discrepant results, and Deacon⁵ has recently argued that this may be because of the flow not being aerodynamically rough at the very low wind speeds which then occur very close to the ground. More recently, treatments by Monin⁶ have attracted much attention from an analytical point of view, but have yet to be adapted for practical use.

At the present stage the most useful guide to the estimation of vertical spread in non-neutral conditions is provided by the *Prairie Grass* measurements in the U.S.A., which have been summarized in a convenient form by Cramer.⁷ These results show that *cloud height* at 100 metres downwind of the source ranged from about 4 metres in "extreme stability" to about 25 metres in "extreme instability", with $7\frac{1}{2}$ metres in neutral conditions. As the site was relatively smooth (roughness parameter $z_0 < 1$ cm) the latter figure compares satisfactorily with the value of $8\cdot 1$ calculated by Calder (*loc. cit.*) for a z_0 of $0\cdot 5$ centimetres. The magnitudes of vertical spread at greater distances (up to 800 metres) were inferred by Cramer from the measured variations (with distance) of peak concentration and cloud width. In unstable conditions they show an acceleration of the vertical spread with increasing distance. For example, in "extreme instability" the inferred cloud height at 800 metres downwind is about 1000 metres. Because of the indirect derivation (including the assumption of Gaussian shape in the vertical distribution) it is difficult to judge the precision of this latter value. However, such a rate of spread merely requires the incidence of sustained upcurrents with an inclination of about 45° , and there is little doubt that such upcurrents do occur with light winds and well developed convection.

The effect of an elevation of the source.—When material is released at an elevated position it may be expected that the effects of the variation of wind structure with height will initially be of secondary importance. As a first approximation, therefore, the vertical spread at short range may be derived on the assumption of quasi-homogeneous turbulence. In this case, on the same lines as those followed for lateral spread, the standard deviation of vertical spread (σ_z) at distance x is given by

$$\sigma_z/x \simeq [\sigma_\phi]_{\tau, T/\beta} \dots (2)$$

where σ_ϕ is the standard deviation of the wind inclination (in radians). The latter is obtained from data averaged over periods T/β ($T=x/\bar{u}$), and observed over a period τ equal to the duration of release (or of sampling) of the material. The application of equation (2) has recently been tested against experimental data obtained in the U.S.A.

Following custom, the plume from an elevated source is assumed to have Gaussian distributions of material both laterally and vertically, with standard deviations σ_y and σ_z . For simplicity, wind velocity is taken to be constant with height, and it is assumed that the effect of the ground can be represented by an *image* source (as in *Micrometeorology*, pp. 139 and 292¹). With the usual co-ordinate system (x alongwind, y crosswind, z vertical) the continuity condition leads to the following expression for the distribution of concentration χ (x, y, z) from a continuous source of strength Q at position ($0, 0, H$).

$$\chi(x, y, z) = \frac{Q \exp(-y^2/2\sigma_y^2)}{2\pi\sigma_y\sigma_z\bar{u}} \left[\exp\left\{-\frac{(z-H)^2}{2\sigma_z^2}\right\} + \exp\left\{-\frac{(z+H)^2}{2\sigma_z^2}\right\} \right]. \quad (3)$$

With the simplifying assumption that σ_y/σ_z is a constant independent of distance, differentiation of the above expression with respect to σ_z leads to the condition that $\chi(x, 0, 0)$ (that is, the concentration on the axis of the plume at ground level) is a maximum when

$$\sigma_z \sqrt{2} = H. \qquad \dots (4)$$

Similarly, if the integral of the crosswind distribution, that is $\int_{-\infty}^{+\infty} \chi(x, y, 0) dy$, is considered, the condition for this quantity to be a maximum is

$$\sigma_z = H. \qquad \dots (5)$$

Measurements have recently been made at the National Reactor Testing Establishment, Idaho Falls, U.S.A., of the ground-level distribution of a fluorescent tracer released at a height of about 50 metres. These provided *observed* estimates of the distance, $d(\text{max})$, at which the crosswind integrated concentration was a maximum. Records were also taken of the fluctuating inclination of the wind near the point of release, from which it was possible to evaluate σ_ϕ , for specified values of τ and $x/\bar{u}\beta$ as required by equation (2). Substituting the condition (5) in equation (2) gives

$$H = d(\text{max}) [\sigma_\phi]_{\tau, s} \qquad \dots (6)$$

with $s = d(\text{max})/\bar{u}\beta$, from which *calculated* estimates of $d(\text{max})$ were obtained (assuming $\beta = 4$), the *observed* estimates being used in assigning the appropriate averaging time for analysing the wind trace. The observed and calculated estimates from thirteen tests are listed in Table I.

TABLE I—OBSERVED AND CALCULATED ESTIMATES OF THE DISTANCE $d(\text{max})$ AT WHICH THE CROSSWIND INTEGRATED CONCENTRATION AT GROUND LEVEL IS A MAXIMUM

Data obtained at Idaho Falls, U.S.A., with a source at a height of 50 metres.

Test	Observed $d(\text{max})$	Calculated $d(\text{max})$ in metres
3	300	370
5	500	910
6	1000	850
7	600	487
8	500	445
9	600	830
11	400	305
12	600	805
13	600	790
14	400	540
15	300	370
16	700	765
17	400	304

The ratios of the calculated and observed values range from 0.76 to 1.82; apart from test 5 the range is 0.76 to 1.38; the overall average ratio is 1.14. These data suggest that useful estimates of $d(\text{max})$ may be made in a simple way from practicable measurements of wind fluctuations near the site of release.

Vertical diffusion at longer range.—The discussion of vertical diffusion has so far been restricted to distances of travel of about 1000 metres. For longer distances not only has there been no established treatment available, but until quite recently there were virtually no useful observational data. Consequently, estimates of diffusion at longer range have tended to be based on extrapolation

of the short-range data, a somewhat dubious procedure bearing in mind the primitive state of knowledge of turbulent and convective transport processes above the immediate surface layer.

In the last few years tracer studies of diffusion over distances of tens of miles have been undertaken at Porton and elsewhere. The work at Porton has been partly concerned with horizontal spread, but the main interest has been to obtain some reliable description of the extent of vertical diffusion. Earlier stages of this work at Porton were dependent on a limited effort in sampling from aircraft, and this proved incapable of providing more than a very rough indication of the vertical distribution of the tracer material.

More recently a technique has been developed for sampling the cloud from a crosswind line-source of tracer material, using units mounted on a barrage-balloon cable, and this has given valuable preliminary data on vertical distribution at a distance of about 50 miles from a source. These data include a demonstration of relatively uniform concentration (with height) in a convective régime, with a relative sharp fall-off near the base of the overhead inversion (at about 3500 feet in the case studied). It was also found that in the absence of convection, but without any marked stabilization near the surface, vertical diffusion could be very slow. Two separate experiments showed the cloud to be essentially confined to the first 2000 feet above ground, and in one of these the material was actually released at about 1000 feet. This slow vertical spread is all the more noteworthy when it is realized that extrapolation from short-range data would lead to a cloud height of 11,000 feet. On the other hand, it is at any rate qualitatively consistent with the small vertical gustiness measured at the same time in the first few thousand feet.

The latter measurements, with others made at intermediate distances, have been shown by Hay and Smith⁸ to be consistent with a new statistical treatment of the spread of a *cluster* of particles (as distinct from a continuous plume). This treatment enables approximate estimates of the spread to be made, given merely the total intensity of turbulence (in effect the σ_ϕ of equation (2) for large values of τ), though for more detailed analysis a knowledge of the energy spectrum of the turbulence is required.

A practical system for estimating the concentration or dosage pattern up to about 100 kilometres from a source (see Appendix I).—The method set out in detail in Appendix I is an attempt to combine in the most flexible manner the various ideas and observations which are now available. The basic assumption is that the crosswind and vertical distribution in a plume or cloud of windborne material can be represented by the Gaussian form, as adopted in equation (3). This equation implies that the wind direction is steady over the duration of release or of sampling. For general application, including highly variable wind direction, it is more convenient to use a lateral distribution on an arc centred on the source (instead of a crosswind line). Assuming this arc distribution to be Gaussian, equation (7) in Appendix I follows directly from the continuity condition.

Equation (7) gives the axial concentration from a ground-level source in terms of a lateral (angular) spread θ and a vertical spread h , which are defined by concentrations one-tenth of the axial or ground values respectively. Remembering that for a Gaussian distribution these dimensions are respectively 4.3 and 2.15 times the root-mean-square deviations from the axis or ground, it is

easily verified that equations (3) and (7) are identical when θ is small, and z and H are set equal to zero.

The advantages of equation (7) are firstly its simplicity, and secondly its use of plume dimensions θ and h which can be directly envisaged. There is accordingly less likelihood of unrealistic magnitudes of θ and h being adopted. When the necessary special data on wind fluctuation are available, θ should be calculated from equation (1). Likewise, it is recommended that h be calculated from equation (2), using data on the fluctuation of wind inclination well clear of the ground, except for short distances (say < 1 km) from a ground-level source. For use in the latter circumstances, and also generally when data on wind fluctuation are not available, estimates of h and θ in broad meteorological conditions are given in Figure 2 (Appendix I).

The estimates of h in Figure 2 have the following origins:

- (i) Neutral conditions (D) and distance < 1 km—experimental data consolidated by Calder's semi-theoretical treatment.
- (ii) Non-neutral conditions and distance < 1 km—experimental data obtained in *Project Prairie Grass* in the U.S.A. For extremely unstable conditions a round figure of 1000 metres is adopted for h at a distance of one kilometre.
- (iii) For neutral-moderately unstable conditions (D, C, B) and distance > 1 km—calculations from the available statistics on vertical gustiness,⁹ supported by some experimental data.
- (iv) Stable conditions (E and F) and distance > 1 km—these are essentially speculative extrapolations from the more reliable data.

The estimates of θ tabulated on Figure 2 are for a *short* release (a few minutes) and are based on recently acquired statistics of wind direction fluctuation.¹⁰ Those for $d=0.1$ kilometre are derived from equation (1), while those for $d=100$ kilometres are extremely tentative values based on a little experimental data, and on Hay and Smith's⁸ treatment of an expanding cluster.

Greater uncertainty in the data of Figure 2 is implied by the thinner and broken lines for h and the addition of brackets to the figures for θ . For longer releases no attempt is made to give statistical estimates of θ , and for use in the absence of detailed measurements of wind fluctuation a rough rule is given for deriving θ from a routine wind-direction trace (see Appendix I, para. 11).

It will be noted that in the extension to an elevated source no attempt is made to adjust the values of vertical spread, h , (though this would be automatically introduced to some extent if h were calculated from equation (2) using measurements of wind inclination near the height of the source). This use of common values of h , irrespective of the height H of the source, may introduce additional error at short distances (or more strictly while h is small, and less than H say). At the present stage, however, there is insufficient data on which to base any general correction of practical consequence. It should also be emphasized that the estimates of θ and h are appropriate to fairly level open country. In an urban area, or on an industrial site, there will be additional dynamical turbulence generated by the buildings, and this may be expected to increase the spread of the plume. No quantitative data are available, but *a priori* there would appear to be no reason to expect an important effect except at relatively short distances from the source, before the spread of the cloud becomes

large compared with the individual buildings. At these short distances buildings will also bring the further complication of *downdraught* and *downwash* effects, of the type described by Hawkins and Nonhebel,¹¹ both of which tend to bring effluent to ground level more quickly than in unobstructed flow.

The rest of the process of evaluating the distribution of concentration is dealt with in a self-contained fashion in Appendix I. It should be noted that no attempt is made to allow for deposition, decay or decomposition of the material.

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Appendix I

Instructions for the estimation of the distribution of concentration or dosage downwind of a source of windborne material

The Plume model and the formula for concentration or dosage from a ground-level source

1. Consider a ground-level source producing a plume with an idealized distribution as represented in Figure 1. Let the lateral spread θ ($=\angle AOB$) along an arc be defined by concentrations one-tenth of the peak or axial value. Similarly, let the vertical spread h be defined by a concentration one-tenth of the ground value. With the simplifying assumptions that the wind speed u is constant with height, that the material crosses the arc normally and that the crosswind and vertical distributions are of Gaussian form, the concentration distribution is completely determined by equating the rate at which material crosses the arc to the rate of release at the source.

2. For a rate of release of one “unit”/min the axial or peak concentration C_0 at ground level at distance d downwind is

$$C_0 = \frac{2 \cdot 8 \times 10^{-3}}{u d \theta h} \text{ “units”/m}^3, \quad \dots (7)$$

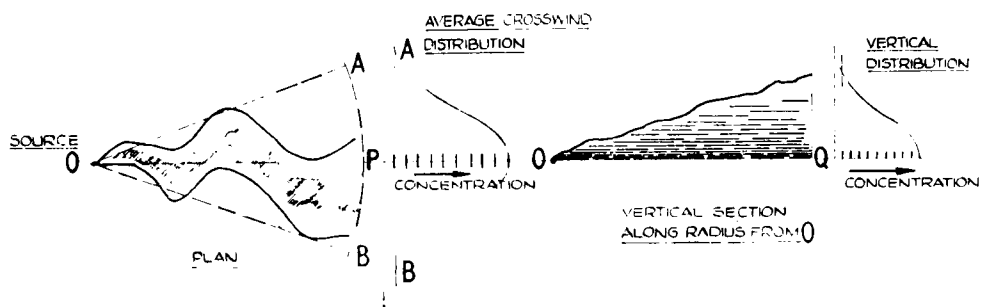


FIGURE 1—SCHEMATIC DIAGRAM OF A PLUME FROM A SOURCE AT GROUND LEVEL

with u in m/sec, d in km, θ in degrees and h in metres. This is also the *total dosage* in “units” min/m³ which would be experienced at the same position during the entire passage of the plume, when the *total* release is one unit. For any other rate of release, or total release, the values of C_0 should merely be increased in direct proportion.

3. The formula is valid in terms of concentration and rate of release provided the duration of release is sufficient for alongwind diffusion to be neglected, and in practice this may be taken to be the case when the duration of release is, say, equal to or greater than the time of travel from the source O to the point of interest P . Apart from a relatively short period near the beginning and the end, the concentration C_0 may then be regarded as obtaining (on average) for a period equal to the duration of release. On the other hand, when the release is terminated before the leading edge of the plume reaches the arc through P , the period of quasi-steady C_0 will be substantially less than the duration of release, and will be virtually nil when the duration of release is only a small fraction of the time of travel to P . In these cases, although equation (7) will give an over-estimate of the concentration experienced at P , it will still give the correct value of the *total dosage* for a *total* release of one unit.

4. On either side of P , and vertically above any point on arc AB , the concentration will fall off according to the (assumed) Gaussian form, and the complete downwind distribution may thus be determined from four parameters: the speed of the wind u (appropriately defined), the appropriate effective wind direction (fixing the position P), the vertical spread h and the lateral spread θ . The wind values need to be based on surface and upper air data, in a way which is explained later.

The estimation of the vertical spread h

5. The magnitude of h initially increases with distance d from the source, at a rate which depends on the amount of vertical mixing. If, as frequently happens, vertical transport is suppressed at some level in the atmosphere by an isothermal or inversion layer, the ultimate effect of this should be to transform the concentration profile into a uniform distribution between ground and inversion (or isothermal) base. Beyond this stage the effective value of h will be constant.

6. When data are available (either from current measurements or from

accumulated statistics) on the fluctuation of the wind inclination, values of h should be calculated from the appropriate form of equation (2), that is

$$h = 2150 d \sigma_\phi \text{ metres,} \qquad \dots (8)$$

where σ_ϕ is the standard deviation of the wind inclination ϕ (radians), obtained from averages of ϕ taken over periods equal to approximately one-quarter of the time of travel and observed for the duration of release or sampling. This procedure is recommended especially for an elevated source (for which condition corrections to equation (7) are made in para. 14), and also for a ground-level source once vertical spread has extended above the surface layer (10 metres or so in depth) in which wind shear is most pronounced.

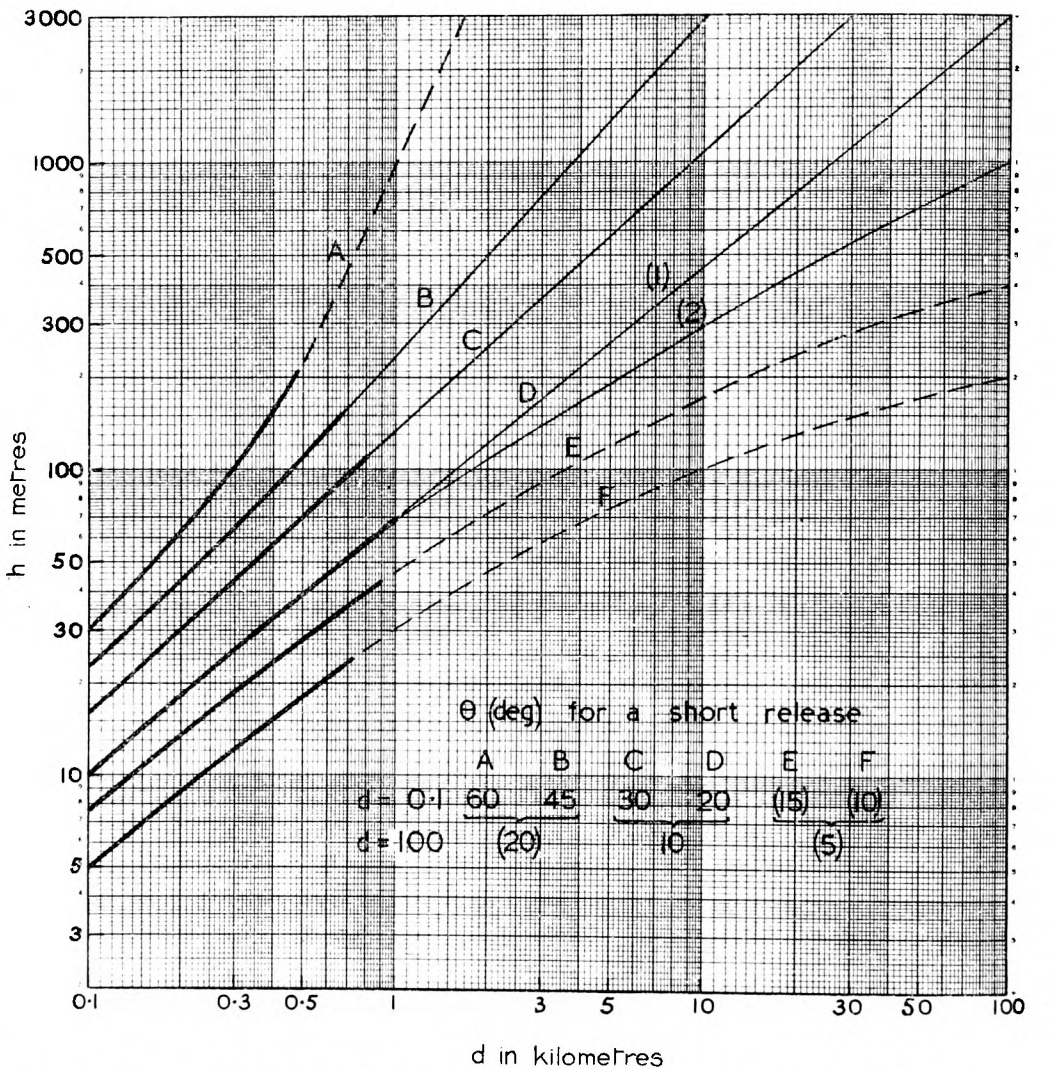


FIGURE 2—TENTATIVE ESTIMATES OF VERTICAL (h) AND LATERAL (θ) SPREAD

7. For use in the absence of wind fluctuation data, tentative estimates of vertical spread in open country are given in Figure 2 for six categories of stability (in the surface layer) which are specified qualitatively in terms of wind speed, insolation and state of sky. “Strong” insolation corresponds to sunny midday conditions in midsummer in England and “slight” insolation to

similar conditions in midwinter. Night refers to the period from one hour before sunset to one hour after dawn. The neutral category D should also be assumed, irrespective of wind speed, for overcast conditions during day or night, and for any sky conditions during the hour preceding or following night as defined above. The D(1) curve should be followed to the top of the dry adiabatic layer; thereafter, in sub-adiabatic conditions, D(2) or a curve parallel to D(2) should be followed.

TABLE II—KEY TO STABILITY CATEGORIES

Surface wind speed (at 10 m)	Insolation			Night	
	Strong	Moderate	Slight	Thinly overcast or ≥ 4/8 low cloud	≤ 3/8 cloud
<i>m/sec</i>					
< 2	A	A-B	B	—	—
2-3	A-B	B	C	E	F
3-5	B	B-C	C	D	E
5-6	C	C-D	D	D	D
> 6	C	D	D	D	D

For A-B take average of figures for A and B, etc.

8. In very light winds (< 2 m/sec) on a clear night, that is, conditions productive of sharp ground frost or heavy dew, the vertical spread may be even less than the values given for category F. However, because of lack of quantitative knowledge of this and because in practice the surface plume is unlikely to have any definable travel, no estimates are attempted for this case.

9. In unstable conditions the value of h estimated as in paragraph 6 or 7 should be used with increasing distance only until a magnitude h_1 is reached, equal to the estimated vertical limit of convection, at distance, say, d_1 . For approximate evaluation, at distances equal to or greater than about $2d_1$, a constant value of $2h_1$ should be used. In calculating C_0 from equation (7) this allows roughly for the assumed development of the vertical distribution, from the Gaussian form at d_1 to uniformity at $2d_1$. (Exact allowance for a uniform vertical distribution over depth h_1 actually requires $h = 1.71 h_1$ in equation(7).)

The estimation of the lateral spread

10. When suitable data are available on the fluctuation of wind direction, the lateral spread should be calculated from equation (1). The θ of equation (7) is equal to 4.3 times the σ_θ of equation (1), when consistent units are used, the numerical factor being appropriate to the assumption of Gaussian distribution.

11. When fine-structure data are not available, rough estimates of θ for a long release, in the region of one hour or more, may be made from a routine wind-direction trace as follows:

- $d = 0.1$ km, difference between extreme maximum and minimum of trace over period of release,
- $d = 100$ km, difference between maximum and minimum "15-minute averages" of wind direction.

For a short release (a few minutes) estimates are given on Figure 2 for the six stability categories.

The evaluation of the axial concentration

12. The axial concentration C_0 for unit source strength may be calculated forthwith from equation (7) by substituting the distance d , the estimated values of h and θ and the appropriate value of wind speed u . For most practical purposes it will be sufficient initially to do the calculation for four standard distances, 0.1, 1, 10, and 100 km. Moreover, since θ usually changes only slowly with distance, it will be adequate to take values at 0.1 and 100 km, and to interpolate for 1 and 10 km by assuming equal changes in θ in three intervals of distance. For the wind speed u the "surface" values should be used with $d=0.1$ and 1 km, but at the longer distances a mean value throughout the vertical extent of the plume is required. In practice, for vertical spread from a few hundred to say 1500 metres, a speed midway between the surface and geostrophic speeds should be a reasonable working approximation.

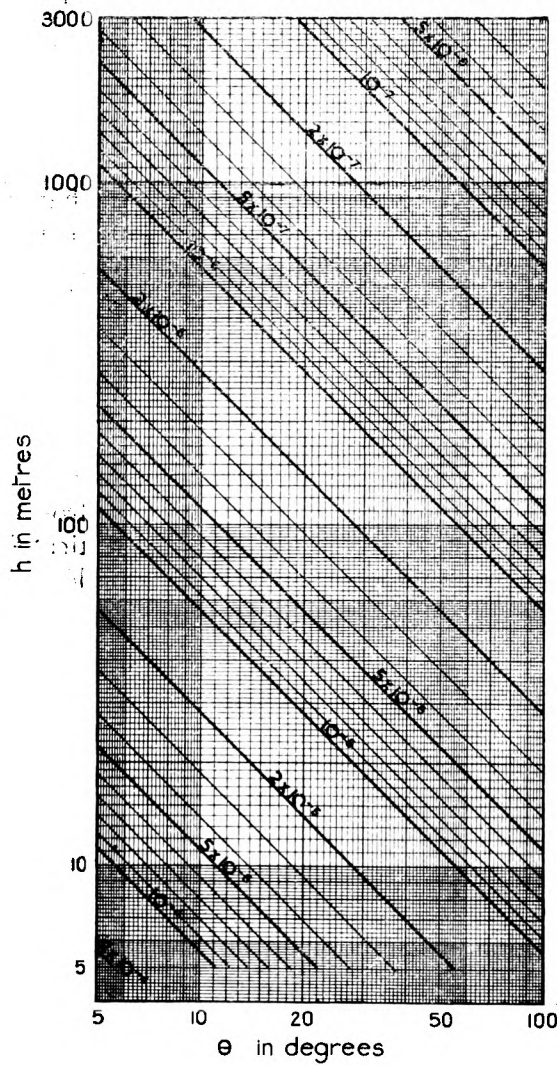


FIGURE 3—STANDARD VALUES OF AXIAL CONCENTRATION C_0 FOR $d=0.1$ KM AND $u=5$ M/SEC

For other values of d and u multiply by $0.1/d$ and $5/u$ (see equation (7)).

13. Rapid determination of C_0 may be carried out from Figure 3, which shows isopleths of C_0 for $d=0.1$ km and $u=5$ m/sec, for a practical range of h and θ . Corrections for distance and wind speed are easily made by multiplying the values from Figure 3 by $0.1/d$ and by $5/u$. The values for the four standard distances may then be plotted on log/log graph paper for subsequent interpolation (Figure 4 shows such a graph for the example set out in Appendix 2). If the distance $2d_1$ (see para. 9) falls between 1 and 10 km, the line joining the points at 10 and 100 km should be produced backwards to $2d_1$, and the interpolated point so formed should be joined to the point at 1 km. If $2d_1$ falls between 10 and 100 km, the line joining the points at 1 and 10 km should be produced forward to $2d_1$, and the interpolated point so formed joined to the point at 100 km. (in the example in Appendix 2, $2d_1$ is 11 km but the difference between this and 10 km is disregarded, and the points at the standard distances are joined directly.)

Allowance for elevation of source

14. If the source is elevated the concentration at ground level will be reduced at the shorter distances but will tend more closely to the ground-source values as distance is increased, that is, as the cloud spreads vertically the initial effect of placing the source above the ground is progressively lost. Correction factors F_1 as a function of h/H ,* where H is the height of the source, are given in the table below, and these should be used to multiply the previously derived values of C_0 . For this purpose it will be necessary to take values of h at shorter intervals and this of course can be done using Figure 2. The quickest procedure is to evaluate the distances corresponding to the given values of h/H , and to apply the factors F_1 to the corresponding values of C_0 on the graph of axial concentration (see Figure 4).

h/H	1/2	2/3	4/5	1	1 1/4	1 1/2	2	4	10
F_1	10^{-4}	5.6×10^{-3}	0.027	0.10	0.23	0.36	0.56	0.87	0.98

15. In the special conditions referred to in paragraph 8 it is possible that at the height of an elevated source the wind speed may be sufficient to give appreciable travel of the plume, though vertical spread would be negligible. This would mean that the development of vertical spread should be started not at the source, but at a downwind position corresponding to the wind speed and the estimated time for breakdown of the stable situation.

Plotting of the position and concentration of the plume (see Figure 5 for example)

16. In practice, interest will centre on the area covered by a concentration greater than some specified value. From the equivalent threshold value of concentration (that is, the actual threshold concentration divided by the source strength), the range of distance to be considered will be immediately evident. A drawing of the position and average distribution of the plume may then be prepared, as described below. If there is interest in the maximum distance of 100 km, then it will clearly not be practicable to construct the details within the 1 km distance, and for this a separate larger-scale drawing should be prepared.

* From equation (3), $F_1 = \exp(-H^2/2 \sigma_z^2) = \exp(-2.303H^2/h^2)$.

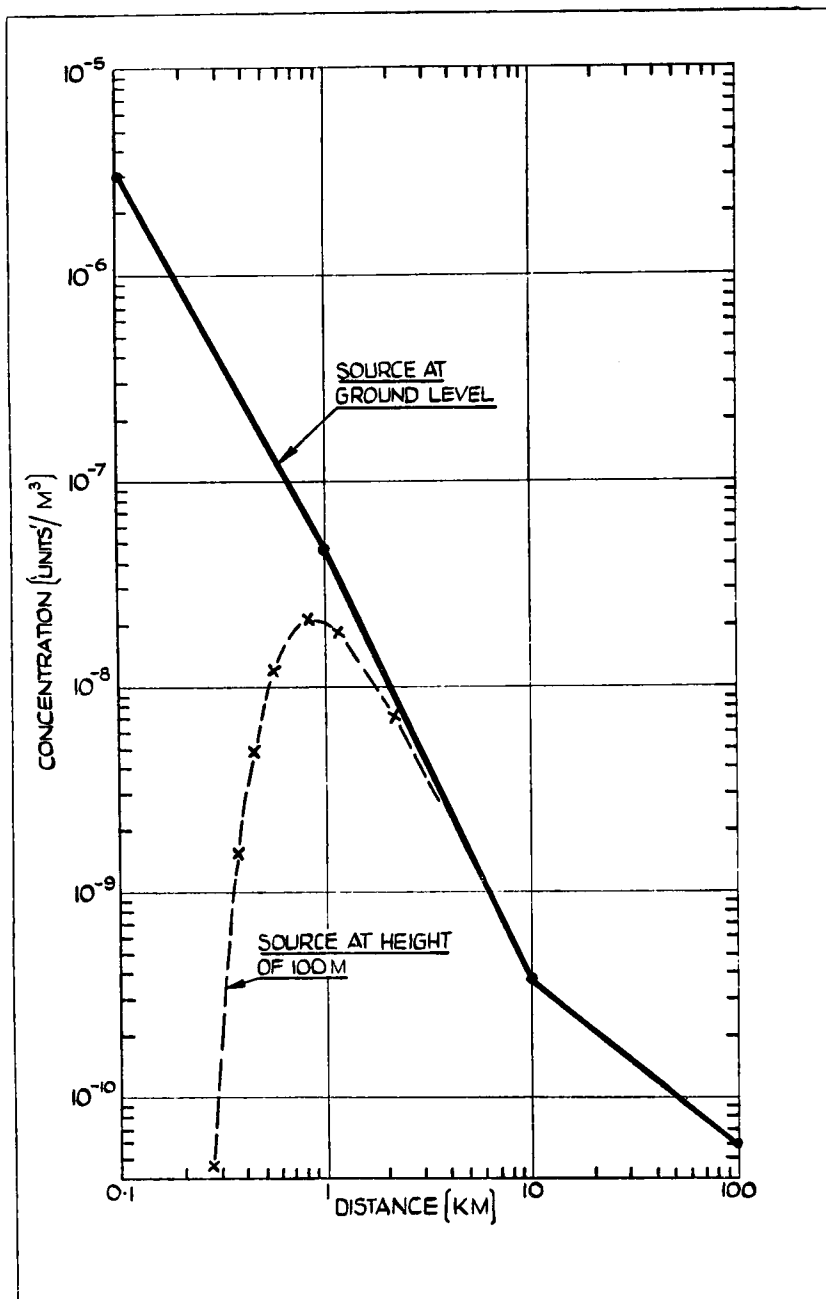


FIGURE 4—CONCENTRATION-DISTANCE DIAGRAM FOR THE EXAMPLE IN APPENDIX 2

17. The first step is to estimate the axial positions P at the various distances and these are given by effective mean wind directions as follows:

<i>d</i> in km	Effective wind direction
0·1-1	surface wind direction
10-100	average of the surface and geostrophic directions, backed by 10°

For a long release the basic estimates of wind direction should be made for the total period of release, and if direction changes with distance downwind appropriate allowance should be attempted from the synoptic data. Even in the case of a short release the important factor is the trajectory over some distance, and this will again be best given by an average wind direction corrected as necessary for variations downwind. Strictly speaking, the effective wind direction should be a mean through the vertical spread of the plume, weighted according to concentration. The rule given above for $d=10$ to 100 km is probably adequate for h of the order 1000 m, but for very much smaller or larger values increased weight should be given to the surface or upper winds.

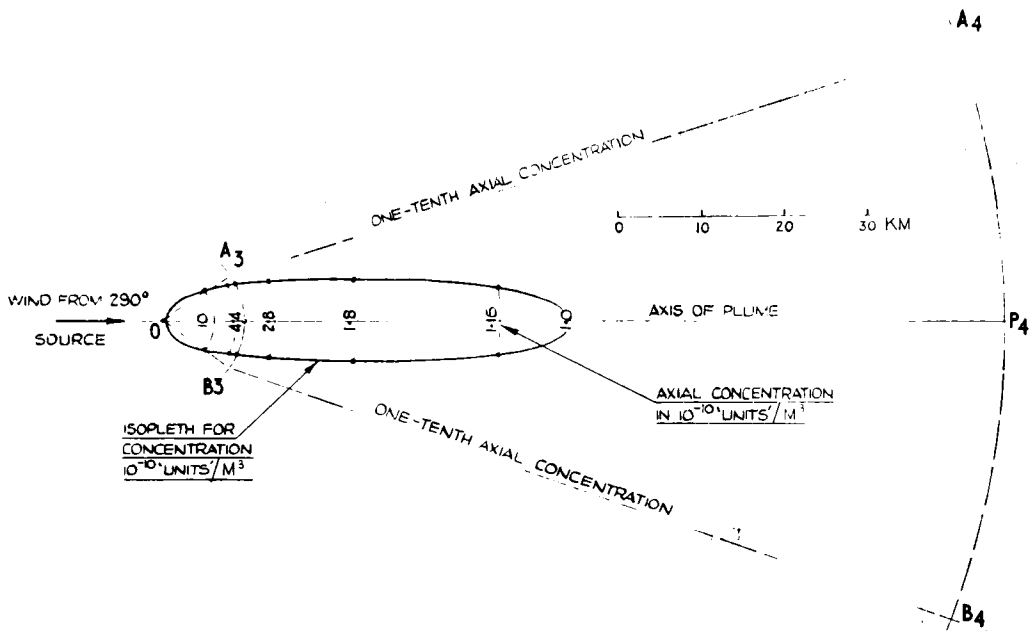


FIGURE 5—PLAN OF PLUME FOR THE EXAMPLE IN APPENDIX 2

18. Having marked the position O of the source, draw arcs at two or more standard radii (0·1, 1, 10 or 100 km). From O draw lines downwind, corresponding to the effective wind directions, to cut the appropriate arcs (at P₁ P₂ P₃ or P₄ respectively). The average plume axis is then given by joining OP₁ P₂ P₃ P₄ and values of concentration C_0 can be entered on this as required, using figures interpolated from the graph of C_0 against d . On each arc mark off points A₁ B₁ etc. symmetrically about P₁ etc., so that the angle A₁ OB₁ is equal to the estimated lateral spread θ . Then OA₁ A₂ A₃ A₄ and OB₁ B₂ B₃ B₄ are the "boundaries" of the plume, at which the concentration falls to 1/10 of the corresponding value on the axis OP₁ P₂ P₃ P₄.

19. For positions other than on the axis or "boundaries" concentrations may be interpolated by applying the following factors F_2 ,* which are the ratios of

* From equation (3), $F_2 = \exp(y^2/2\sigma_y^2) = \exp(2\cdot303(2\alpha)^2/\theta^2)$

the axial concentration to the off-axis concentration, for deviation α from the axis. These factors enable the isopleth of a given concentration to be drawn in quickly, as follows. If the given concentration is C' , read off the concentration-distance graph (Figure 4) the distances at which the *axial* concentration is $F_2 C'$, and plot $F_2 C'$ on the axis of the distribution (Figure 5). Points on the isopleth of C' are then obtained by marking off the corresponding deviations α from the axis.

Deviation α from axis (fraction of $\theta/2$)	0	$\frac{1}{4}$	$\frac{1}{2}$	$\frac{2}{3}$	$\frac{4}{5}$	1	$1\frac{1}{4}$	$1\frac{1}{2}$	2
$F_2 = \frac{\text{axial conc.}}{\text{off-axis conc.}}$	1.0	1.15	1.8	2.8	4.4	10	37	180	10^4

Allowance for type of wind direction variation

20. The above procedure is based on a Gaussian distribution of the fluctuating wind direction, and this can be assumed to apply sufficiently well as long as the *fluctuations* are large compared with any discernible systematic trend over the period of release. On the other hand, if there is a systematic veering or backing of the direction, over a range large compared with the width of the trace, then the factors in paragraph 19 will not apply. The procedure should be exactly as before up to the construction of the plume position, but then the concentration should be taken as uniform along any given arc, and equal to $0.58C_0$ ($\frac{1}{2}C_0$ will be adequate for most practical purposes), up to the cloud "boundaries" $OA_1 A_2 A_3 A_4$, and $OB_1 B_2 B_3 B_4$.

Rapid evaluation of the distance and magnitude of the maximum ground-level concentration from an elevated source

21. If interest or time is insufficient for carrying out the full procedure, an estimate may quickly be made of the distance d (max) along the axis, of the maximum ground-level concentration from an elevated source. Assuming that the lateral and vertical spread have the same variation with distance (that is, that $h/\theta d$ is independent of distance), $d(\text{max})$ is the distance at which h is approximately $3/2$ times the effective height H of the source. Having decided on the stability category, and given H , $d(\text{max})$ can thus be read directly from Figure 2.

22. The magnitude of this maximum concentration, that is $C_0(\text{max})$, for a release of one "unit"/min, is given by

$$C_0(\text{max}) \simeq \frac{2 \times 10^{-3}}{3 u d(\text{max}) \theta H} \text{ "units" / m}^3, \quad \dots (9)$$

with u , $d(\text{max})$ and θ in the practical units adopted in equation (7), and H (the height of source) correspondingly in metres.

Accuracy

23. It is emphasized that the present system can in general give only very approximate estimates of the magnitudes of the concentrations, especially when it is necessary to use the tentative statistical estimates of h and θ . In the more difficult cases of unstable and stable situations, it is obvious that errors in h of several fold could be involved at the longer distances of travel, and this should be kept in mind in applying the data to the assessment of hazards. On the other hand there will be relatively straightforward cases when the estimates of vertical spread may be expected to be correct within a factor of two, namely:



Photograph by D. J. George, F.I.D.S.

PLATE I—OROGRAPHIC CUMULUS ON BRABANT ISLAND, FALKLAND ISLANDS DEPENDENCIES, MARCH 1954

[To face p. 48]



Photograph by D. J. George, F.I.D.S.

PLATE II—SUMMER SEA FOG SPREADING IN THROUGH ENTRANCE TO HARBOUR AT
DECEPTION ISLAND, FALKLAND ISLANDS DEPENDENCIES, JANUARY 1954



Photograph by D. J. George, F.I.D.S.

PLATE III—DRIFTING AND BLOWING SNOW AT ADMIRALTY BAY, FALKLAND ISLANDS
DEPENDENCIES, MAY 1954



Photograph by D. J. George, F.I.D.S.

PLATE IV—HOLE IN STRATOCUMULUS, DECEPTION ISLAND, FALKLAND ISLANDS
DEPENDENCIES, WINTER 1953

The cloud was formed orographically by the ridges of Deception Island. The hole was apparently produced by the freezing of a water-droplet cloud, and fibrous trails of ice crystals can be seen below the hole. There were no aircraft in the vicinity.

- (i) all stabilities except extremes, for distances of travel of a few hundred metres, in open country,
- (ii) neutral to moderately unstable conditions, for distances of a few kilometres,
- (iii) unstable conditions in the first 1000 metres above ground, with a marked inversion thereafter, for distances of travel of 10 kilometres or more.

24. Uncertainties in the lateral spread of the plume are likely to be less important, except when the wind field is indefinite, in which case an even more important error will be that involved in prescribing the *position* of the plume. In such circumstances the best procedure would be to estimate the concentrations in the usual way, but then to allow for a wide range of possible directions of the plume, even to the extent of a full 360° in the most indefinite wind situations.

Appendix 2

Example of calculation of distribution of concentration from a point source of strength one "unit"/min

(Figures in parentheses are relevant paragraph numbers in Appendix 1.)

General data

Site	...	...	...	...	...	...	...	...	Southern England
Date	...	...	...	...	...	...	...	...	16 June 1959
Period	...	...	...	...	...	...	...	...	1000-1300 GMT
Effective height of release (<i>H</i>)	...	...	...	...	...	...	...	...	100 m
Surface wind	...	...	...	...	...	...	...	...	4 m/sec, 275°
Geostrophic wind	...	...	...	...	...	...	...	...	8 m/sec, 325°
Vertical extent of convection	...	...	...	...	...	...	...	...	1000 m
State of sky	...	...	...	...	...	...	...	...	1/8 Cu, 6/8 Sc, 6/8 Ci
Stability category (7)	...	...	...	...	...	...	...	...	B-C
Distance at which vertical spread (<i>h</i>), from Figure (2), equals vertical extent of convection	...	...	...	...	...	...	...	...	5.5 km

Calculation of C_0 , equation (7)

Distance <i>d</i>	...	...	...	0.1	1	10	100	km
Effective value of <i>h</i> (7)	...	...	...	20	170	2000	2000	m
Lateral spread θ (11)*	...	...	...	120	93	67	40	deg
Effective value of <i>u</i> (12)	...	...	...	4	4	6	6	m/sec
C_0	...	...	...	2.9×10^{-6}	4.4×10^{-8}	3.5×10^{-10}	5.8×10^{-11}	units/m ³

Allowance for elevation of source (14)

Assumed <i>h/H</i>	...	...	1/2	2/3	4/5	1.0	1 1/2	2.0	4.0
$F_1 = \exp(-2.303H^2/h^2)$	...	...	10^{-4}	5.6×10^{-3}	0.027	0.10	0.36	0.56	0.87
Distance at which corresponding values of <i>h</i> occur (Figure 2)	...	...	0.28	0.37	0.46	0.59	0.86	1.15	2.20
C_0	...	...	4600	2700	1800	1200	580	330	82
$F_1 C_0$	...	...	0.46	15	49	120	210	185	71
									10 ⁻¹⁰ units/m ³

Position of plume axis (18)

Distance	...	...	...	...	...	...	0.1	1	10	100	km
Effective wind direction (17)	...	...	...	...	...	...	275	275	290	290	deg

Rapid evaluation of *d* (max) and C_0 (max) (21, 22)

$$\begin{aligned}
 h \text{ at } d(\max) &= 3H/2 = 150 \text{ m} \\
 \therefore d(\max) \text{ (from Figure 2)} &= 0.85 \text{ km} \\
 C_0(\max) \text{ (from equation (9))} &= \frac{2 \times 10^{-3}}{3 \times 4 \times 0.85 \times 95 \times 100} \\
 &\simeq 2 \times 10^{-8} \text{ units/m}^3.
 \end{aligned}$$

* Obtained from routine wind-direction trace.

DUST HAZE AT BAHRAIN

By J. HOUSEMAN

Poor visibility, caused by blowing dust and dust in suspension, is frequent over the deserts of Iraq and northern Arabia, especially during the summer months. The prevailing winds over these deserts are north-westerly. Bahrain Islands, in the Persian Gulf, lying to the south-east of the deserts, are consequently to leeward and are also affected by the dust.

The increasing use of jet aircraft with their voracious appetites for fuel makes the forecasting of landing conditions more and more important. This is especially so for aircraft scheduled to land at Bahrain as, when dust is widespread over Iraq, Arabia and the Persian Gulf, the nearest unaffected airfield may be Damascus, over 800 miles away. An investigation into dust haze conditions was undertaken in the hope that it would be of value both to forecasters and to aircraft operators for long-term flight-planning purposes.

Reduction of visibility by dust at Bahrain Airport is partly influenced by the geographical position of the airfield and partly by local topography. The airfield is situated on the northern side of Muharraq Island, which lies north of Bahrain Island and some 25 to 30 miles east of the Arabian mainland.

With only very few exceptions, dust-raising winds are of the north-westerly type, known locally as "Shamal". Consequently dust affecting the airfield is nearly always brought from the Arabian coast, or from Iraq some 250 miles to the north-west. Locally lifted dust, unmixed with Arabian dust, while often raised over the main island to the south, only affects the airfield in squally conditions such as those connected with the passage of active fronts. It is infrequent over the airfield and is usually of short duration.

In general, winds of at least 25 knots are needed to lift local dust at the airfield and winds of over 40 knots are required to give severe reductions in visibility. On the other hand, dust which has been lifted over Iraq or Arabia and is held in suspension can reduce visibility for days at a time with only very light local winds. This type of dust haze is therefore more frequent than that caused by dust raised locally and can be considered the main subject of the investigation, though it has not been possible to differentiate between the two forms as they occasionally occur in conjunction.

Method.—The method used in the investigation is similar to that which has been used by a number of others in examining the frequency of fogs. The period investigated is from 1 January 1956 to 31 December 1958. The percentage frequencies of the occurrence of various visibilities for each hour of the day throughout the period have been evaluated and some of the results are illustrated graphically in Figures 1 and 2.

The three years show considerable variation in individual dust haze patterns and this variation obviously affects the results, but random sampling over ten other years indicates that the mean figures obtained are largely representative, provided only frequencies of 10 per cent and upwards are regarded as significant. The figures refer only to occasions when visibility was reduced solely by dust. Mist and fog are not included.

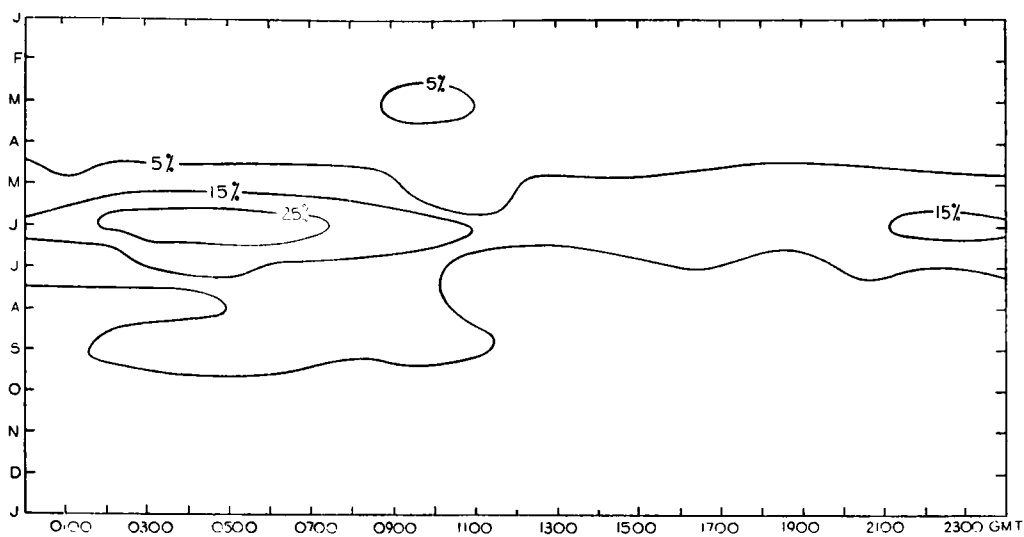


FIGURE 1—PERCENTAGE FREQUENCIES OF VISIBILITIES ≤ 3 N. MILES

Dust haze frequency and the climatological régime.—The main point of interest emerging from the figures is the way in which the dust frequency fits the climatological régime of the area. November to February is the rainy season and, although strong winds are then more frequent than in summer and the rainfall is slight, the moistening of the desert surface is still enough almost completely to prevent dust haze. In fact, in the period December to February dust was all caused by the passage of cold fronts accompanied by thunderstorms and squalls and was a mixture of locally raised dust and dust carried along by the fronts.

During March the surface soil begins to dry out and dust haze becomes more frequent, though the percentages are still low and the actual reduction in visibility is slight. Dust is partly brought from the mainland in suspension and is partly lifted locally by strong winds giving a small increase in frequency around midday when convection and gustiness are at their maximum.

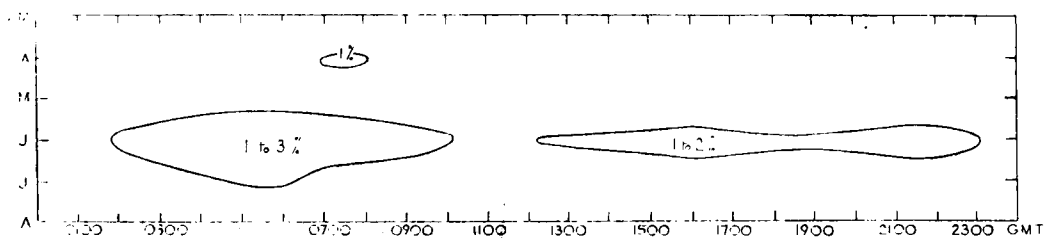


FIGURE 2—PERCENTAGE FREQUENCIES OF VISIBILITIES ≤ 1100 YARDS

From May, through June and July the dust is at its worst. This period, especially June and the beginning of July, is the time of the “forty-day Shamal”, an almost continuous north-west wind of varying strength, usually about 15 to 20 knots, associated with the monsoon low over India and Persia. It is noticeable that the highest frequency in these months occurs at 0400 GMT. This is caused by dust, picked up over Iraq during the afternoon and carried some 250 to 300 miles at 15 to 20 knots, reaching Bahrain in the early part of the following day.

This tendency for the highest frequencies to occur in the early morning continues through August to October, although August, which is usually a month of light winds, often south-easterly, shows a very much reduced total frequency. In September the winter régime of short periods of strong north-westerlies alternating with short periods of lighter winds begins again, but with the first rains over the northern desert in October the dust-raising properties of the stronger winds are much curtailed and a rapid reduction in dust frequency occurs. The more general rain of November settles almost all the dust other than that raised by the occasional front.

Occasions of very poor visibility.—Reduction of visibility below 2200 yards is most infrequent and reductions below 1100 yards are even more so. During the period examined reductions below 1100 yards occurred only in the six months March, April, May, June, July and December and only in the month of June did they last for more than two hours.

Average visibility.—Visibility in dust haze averages 3000 to 3500 yards. Once a slow improvement has brought visibility to three nautical miles, further improvement to six to ten nautical miles is usually rapid. During the winter months visibilities of 15 to 20 nautical miles are frequent.

Conclusions.—From October to February the chances of aircraft movements being hampered by dust haze at Bahrain are almost negligible. March and April remain clear for night operations and are only occasionally hazy by day. During May, June and July dust may affect the airfield at any time, the worst month being June and the worst period being around dawn with a tendency towards improvement in the late afternoon. August and September are again usually clear during the afternoon and night but are occasionally hazy in the mornings.

Even when dust is present average visibility is 3000 and 3500 yards. Reductions to below 1100 yards are only likely in June or during the passage of a squall.

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ROUTINE COMPUTATION OF MONTHLY UPPER AIR STATISTICS USING AN ELECTRONIC COMPUTER

By D. DEWAR, B.Sc.

Introduction.—In order to make full use of the results of the daily upper air soundings carried out for synoptic purposes at radio-sonde stations controlled by the Meteorological Office, it has been the policy of the Upper Air Section of the Climatological Division to have these data entered on suitable forms each month, and to use them for the production of monthly routine statistics giving values which are likely to be required at short notice for research, investigations, or the supply of information for aviation requirements.

In the early days of the Upper Air Section the computations were carried out by assistants with the aid of adding machines and tables only. Starting with data for 1948, much of the laborious arithmetic was eliminated by the use of punched cards and Hollerith machines but a lot of computing still had to be done by assistants using desk machines, and the checking of the computations and entries of final results on summary sheets required a considerable amount of assistants' time each month. A further step forward has now been made, after some months of development work, by the use of machine "programmes"

(coded instructions directing the operation of the computer) which enable nearly all the monthly routine computations to be done by the Ferranti Mercury computer installed in the Central Forecasting Office at Dunstable. A brief account of the procedure followed is given below.

Checking of data and conversion to tape procedure.—A rigorous checking system is used to try to ensure that errors in entries on the forms are eliminated before the forms are passed for the data to be punched on Hollerith cards and subsequently converted to the symbols on a reel of paper tape required for use in the computer. Errors which are not detected until the results of the machine processing are scrutinized entail an exorbitant waste of time in correcting the forms, Hollerith cards and data tapes.

All the data required for the upper wind statistics for one ascent are given on one Hollerith card. Four Hollerith cards are used to record values of temperature, heights of isobaric surfaces and humidity at standard pressure levels for one ascent, and for technical reasons it was decided that it would be best to record on the tape the data from the first Hollerith card (giving data for the lowest four pressure levels) for each day of the month, then data for the second Hollerith card (giving data for the next four pressure levels) for each day and so on. Before conversion to tape, the cards are “sequence checked” on a collator; though not infallible this check virtually ensures that all the cards in a pack are those for the required station, year, month, etc. A further check is provided by hand-punching at the beginning of each data tape a “preamble” giving the station number, year, month and hour to which the data relate; instructions in the programme provide for these particulars to be checked against those given at the beginning of each daily card and if there is disagreement the computer prints REJECT followed by information which indicates why the data were rejected. This checking procedure is considered worthwhile, although it adds to the operating time, as it also acts as a check on the correct functioning of the machines themselves.

Development of machine programmes

(a) *Wind programme.*—The development of the programmes was initiated by Mr. J. S. Sawyer, then Chief Forecasting Research Officer, who produced a demonstration “Autocode” programme for computing wind statistics using the daily wind components and also indicated the procedure to be followed to convert the data punched on Hollerith cards to a form, on tape, suitable for reading into the computer. Some modifications and additions have since been made to this programme to speed up the input of the data* and to provide for values for all hours combined to be given in addition to values for each hour of observation. Part of the print-out of results for Bahrain for October 1958 is shown in Table I. The programme provides for the output punch of the computer to give only essential indicative information and the required statistics; explanatory titles, numbering of columns, etc. have been added in italics in this illustration. In actual use, the results are filed in folders, one for each station, and a key to the data is provided inside each folder.

Values of the “all hours” mean components, etc. are computed by dividing totals for all hours by the total number of observations as this practice had been

* Mr. P. B. Sarson suggested this improvement and carried out the necessary amendments to the programme.

TABLE I—WINDS FOR BAHRAIN, OCTOBER 1958

	(a)	(b)	(c)	(d)						
	40427	58	10	12						
Level (mb)	(e)	(f)	(g)	(h)	(i)	(j)	(k)	(l)	(m)	(n)
850	2.5	-2.4	316	3.4	11.4	12.7	31	327	37	18
700	4.3	0.1	2	4.3	13.9	15.0	31	331	31	18
500	4.5	-15.3	286	15.9	21.1	18.7	31	277	51	15
400	5.0	-22.1	283	22.7	27.3	21.2	31	259	54	31
300	0.8	-29.3	272	29.3	34.4	25.2	31	283	69	15
200	-6.4	-33.3	259	33.9	39.0	27.5	31	247	67	10
150	-12.2	-32.9	250	35.1	38.5	27.5	29	247	86	30
100	-4.9	-13.5	250	14.4	18.1	16.0	27	277	40	14
(p)	1436	143	241	87	30					

Combined hours data

850	3.6	-0.5	352	3.6	12.2	13.1	45
700	3.8	0.1	1	3.8	14.6	15.9	45
500	4.7	-13.0	290	13.8	19.1	18.2	44
400	5.3	-19.7	285	20.3	24.6	20.7	43
300	0.1	-26.6	270	26.6	31.2	24.2	41
200	-7.5	-29.9	256	30.9	35.3	26.3	40
150	-12.6	-29.3	247	31.9	35.0	26.3	38
100	-6.6	-12.0	241	13.7	17.6	15.7	36

- (a) Station number
 (b) Last two figures of year
 (c) Month
 (d) Hour of observation
 (e) Mean N-S components
 (f) Mean E-W components
 (g) Vector mean wind direction
 (h) Vector mean wind speed
 (i) Scalar mean wind speed
 (j) Standard vector deviation
 (k) No. of observations
 (l) Direction of max. wind
 (m) Speed of max. wind
 (n) Date of max. wind
 (p) Data for max. wind at any level—height (decimetres), pressure, direction, speed, date
 Speeds are in knots; directions are in degrees from true north.

followed in earlier years; a change to the method advocated by the Climatological Commission of the World Meteorological Organization in its *Guide to climatological practices*, whereby an “all hours” mean value is taken as the mean of the values for the separate hours, will probably be made in January 1961, the end of the current five-year climatological period.

(b) *Programme for temperature etc.*—This programme is more involved than the wind programme as the data for one ascent are recorded on four Hollerith cards and three elements—temperature, heights of isobaric surfaces and humidity mixing ratios—are dealt with.

Table II shows the print-out, for all levels for one hour of observation and for both hours combined, of statistics of heights of isobaric surfaces and temperatures. Column numbers in italics and a key to the values have been added but otherwise the values are as printed out from the output tape by a teleprinter.

Statistics of temperature and height are first computed for the surface,* 900, 850 and 800-millibar levels, and are then printed out and also stored for use in the “both hours” computations. This part of the programme is then repeated three times to deal with the other twelve pressure levels, four at a time. The programme contains instructions which cause the machine to print out days for which data are missing for *all* the four levels being dealt with and to add in the number of these missing days to a count which it is instructed to make of consecutive days with missing data at *any* of the levels; if there are five or more consecutive missing observations, the machine prints an asterisk for

* The height of the 1000-millibar surface is given in place of the surface height.

each such occurrence beneath the appropriate pressure-level figures. The object of this procedure is to allow a user to judge from the number of observations and the number of asterisks how much reliance he can place on values for that pressure level. At 50 millibars in Table II, for example, there were eleven observations and these, if there was no gap of five days or more, could just be regarded as giving a satisfactory mean value. The asterisks, however, indicate that there were two such gaps. It was not considered practicable to provide for this indication of reliability to be given for the "both hours" values also.

The next part of the programme provides for the computation of similar values for both hours combined and for the differences between the 12 h and 00 h means of temperature and height to be printed. These differences, in addition to providing useful information, enable a quick rough check of the mean values to be carried out. Provision has also been made for a rough check of extreme values to be carried out by the computer; if the range of either the isobaric heights or temperatures exceeds five times the appropriate standard deviation a query is printed in the space beneath the figures giving the difference between the mean values.

TABLE II—TEMPERATURES AND HEIGHTS OF ISOBARIC SURFACES, FOR BAHRAIN, OCTOBER 1958

(a)	(b)	(c)	(d)				
40427	58	10	12				
(e)	(f)	(g)	(h)	(i)	(j)	(k)	
1000	2921	983	94	31.7	135	36	
	31	31	21.4	1.8	63	28	
900	31886	782	1029	25.2	1061	29	
	31	31	17.4	2.1	1003	21	
850	47339	668	1527	21.5	1555	25	
	31	31	15.4	2.2	1505	17	
800	63481	539	2048	17.4	2079	20	
	31	31	14.1	2.0	2029	13	
700	98236	278	3169	9.0	3210	11	
	31	31	13.8	1.4	3148	5	
600	137172	24	4425	0.8	4466	5	
	31	31	13.1	2.3	4402	-3	
500	181860	-242	5866	-7.8	5906	-4	
	31	31	19.3	1.9	5829	-12	
400	234445	-617	7563	-19.9	7606	-17	
	31	31	26.7	1.7	7509	-23	
300	298630	-1085	9633	-35.0	9700	-32	
	31	31	36.2	2.1	9560	-39	
250	337310	-1334	10881	-43.0	10960	-2	
	31	31	43.0	7.8	10790	-50	
200	382620	-1693	12343	-54.6	12430	-50	
	31	31	52.8	2.0	12230	-59	
150	424120	-1974	14137	-65.8	14220	-61	
	30	30	59.6	2.2	14030	-71	
MISSING	16	—	16				
MISSING	25	—	25				
100	479380	-2197	16530	-75.8	16610	-67	
	29	29	49.5	3.5	16450	-81	
80	499050	-2075	17823	-74.1	17890	-64	
	28	28	39.5	4.8	17720	-85	
60	410190	-1375	19533	-65.5	19620	-59	
	21	21	44.7	3.3	19460	-70	
50	227150	-675	20650	-61.4	20700	-56	
**	11	11	37.9	3.2	20580	-66	

TABLE II—TEMPERATURES AND HEIGHTS OF ISOBARIC SURFACES FOR BAHRAIN,
OCTOBER 1958 (*cont.*)

(a)	(b)	(c)	(d)						
40427	58	10	BOTH						
(e)	(f)		(g)	(h)	(i)	(j)	(k)	(l)	(m)
1000	5757 62		1836 62	93 22.2	29.6 2.8	135 56	36 24	3	4.2
900	63712 62		1583 62	1028 17.7	25.5 2.5	1062 999	29 20	2	-0.6
850	94658 62		1351 62	1527 15.6	21.8 2.3	1559 1503	25 17	1	-0.5
800	126988 62		1091 62	2048 14.3	17.6 2.2	2079 2027	21 12	-1	-0.4
700	196550 62		565 62	3170 13.7	9.1 1.5	3210 3148	12 5	-3	-0.3
600	274477 62		61 62	4427 13.2	1.0 2.4	4466 4402	6 -4	-4	-0.4
500	363911 62		-472 62	5870 20.2	-7.6 2.0	5912 5829	-4 -12	-6	-0.4
400	469110 62		-1231 62	7566 28.6	-19.9 1.8	7621 7509	-15 -24	-7	-0.1
300	597610 62		-2158 62	9639 39.5	-34.8 2.3	9720 9560	-31 -39	-11	-0.4
250	675000 62		-2691 62	10887 47.6	-43.4 5.8	10990 10790	-2 -50	-12	0.7
200	765760 62		-3369 62	12351 57.6	-54.3 2.1	12470 12220	-50 -59	-17	-0.5
150	863030 61		-3998 61	14148 64.9	-65.5 2.1	14270 14000	-61 -71	-21	-0.5
100	992620 60		-4549 60	16543 56.4	-75.8 3.2	16690 16430	-67 -81	-26	0.1
80	1052370 59		-4341 59	17836 50.9	-73.6 4.4	18000 17720	-63 -85	-26	-1.0
60	978090 50		-3202 50	19558 56.5	-64.2 3.9	19780 19460	-55 -70	-50	-2.5
50	703560 34		-2031 34	20682 69.2	-60.2 3.6	20940 20580	-53 -66	-63	-2.4

	<i>Upper line</i>	<i>Lower line</i>
(a) Station number	(f) Height total	No. of obs.
(b) Last two figures of year	(g) Temperature total	No. of obs.
(c) Month	(h) Mean height	S.D. of height
(d) Hour of observation	(i) Mean temperature	S.D. of temperature
(e) Pressure level*	(j) Max. height	Min. height
	(k) Max. temperature	Min. temperature

(l) Difference 12h-00h mean heights

(m) Difference 12h-00h-mean temperatures

Heights are in metres; temperatures are in °C.

* Height values are for 1000 mb, temperatures for surface.

The third part of the programme instructs the machine to compute daily values of humidity mixing ratio from the values of temperature and relative humidity (which were stored during input) and values of saturation vapour pressure which were read in as part of the programme instructions. Statistics are then computed, printed and stored for the first hour and a similar procedure followed for data for the second hour. Data for both hours combined are then computed and printed. Results for Bahrain for one hour and for both hours combined are shown in Table III. Explanatory headings have been added in italics but otherwise the Table is as printed out from the tape output.

The "both hours" mean values in this programme are obtained by taking the mean of the values for the separate hours.

TABLE III—HUMIDITY MIXING RATIOS FOR BAHRAIN, OCTOBER 1958

H.M.R. DATA

(a)	(b)	(c)	(d)			
40427	58	10	12			
(e)	(f)	(g)	(h)	(i)	(j)	
1000	490.8	31	15.83	22.7	8.4	
900	191.3	31	6.17	12.2	1.8	
850	144.6	31	4.66	6.8	1.6	
800	114.3	31	3.69	5.9	1.2	
700	79.7	31	2.57	4.2	0.7	
600	45.0	31	1.45	3.0	0.3	
500	20.9	31	0.67	1.5	0.1	
400	8.5	31	0.28	0.8	0.0	
300	2.7	31	0.09	0.3	0.0	
40427	58	10	BOTH			(k)
1000	1046.0	62	16.87	22.7	8.4	-2.08
900	393.6	62	6.35	12.2	1.8	-0.36
850	304.8	62	4.92	7.3	1.6	-0.50
800	238.3	62	3.84	8.1	1.2	-0.31
700	159.7	62	2.58	4.4	0.6	-0.01
600	91.2	62	1.47	3.1	0.3	-0.04
500	42.7	62	0.69	1.5	0.1	-0.03
400	17.5	62	0.28	0.8	0.0	-0.01
300	5.6	62	0.09	0.3	0.0	-0.01
(a) Station number	(f) Total					
(b) Last two figures of year	(g) No. of obs.					
(c) Month	(h) Mean					
(d) Hour of observation	(i) Max. value					
(e) Pressure level*	(j) Min. value					
	(k) Difference 12h-00h means					

Humidity mixing ratio values are in gm kg⁻¹.

* Values given against 1000 mb are actually surface values.

Computation, output and printing-out times

(a) *Wind programme.*—The initial reading-in of the programme instructions takes about one minute but this, of course, has only to be done once for all stations processed during a session. Reading in the data and computing statistics for one hour of observation takes about 23 seconds and punching out the results takes about 22 seconds. For a station making four ascents a day the total machine operating time is roughly $3\frac{1}{4}$ minutes. Subsequent printing out of the data from the output tape requires $9\frac{1}{2}$ minutes.

(b) *Programme for temperature etc.*—The initial reading-in of this programme takes just over two minutes. Reading in and computing data for heights and temperatures for one set of levels (for example, 700, 600, 500, 400 millibars) takes about 14 seconds and a further 17 seconds are required to punch out results. To compute and punch out all the humidity mixing ratio values takes a little over a minute. The total operating time for a station making two ascents a day is a little over $6\frac{1}{4}$ minutes, but printing out the data from the output tape requires about 25 minutes.

(c) *Total times.*—Using the above test times and making allowances both for the time required to insert tapes in the tape reader and for shorter processing times for stations not making the normal two temperature and four wind ascents a day, it is estimated that, with the present programmes, for the 24 or so stations to be dealt with each month, about four hours will be required to compute and punch out the data and about twelve hours to print out the values. It is hoped shortly to modify the programmes so as to be able to use

the line printer attached to the computer. This would greatly reduce the printing-out time and an output tape would then no longer be essential; if it is decided that this output tape could be dispensed with, it should be possible to reduce the total computing and printing-out time to something of the order of three hours.

It is not possible, for several reasons, to give a satisfactory answer to the obvious question, how much time does the new procedure save? Firstly, the work, to some extent, is still in the experimental stage and sufficient experience has not yet been gained to make a reliable estimate of times required for the ancillary processes—preparation of data tapes, scrutiny and, if necessary, correction of results necessitated by incorrect basic values or faulty printing. Secondly, the computer does far more than could be done by the assistant staff available. One interesting comparison can however be given. Some years ago similar wind statistics to those obtained from the computer were worked up by assistants from Hollerith tabulations, though only for “all hours combined”. The production of the required Hollerith tabulations took more time than is now required for the conversion of the cards to tape for use by the computer. The computation and checking of statistics worked from the Hollerith tabulations for the 20 or so stations then dealt with took a time equivalent to that of one assistant’s work for about 15 days. Using the computer, a reasonable time per station for computing and punching out results for “both hours combined” is about 130 seconds and for printing out results a little under two minutes is required, that is, about $1\frac{1}{2}$ hours for 24 stations.

The best answer probably is that the new procedure permits many more data to be computed using fewer staff for this side of the work and, what is perhaps more important still, it substitutes intelligent scrutiny by the assistants for the repetitive numerical drudgery they were formerly required to carry out.

REVIEWS

Atlantic hurricanes, by G. E. Dunn and B. I. Miller 9in. × 6in., pp. xx+326, illus., Interscience Publishers Inc., 250 Fifth Avenue, New York 1, 1960. Price: \$10.

This is a very good book. It is probably the most comprehensive book which has yet been written on hurricanes and covers every aspect of the subject (except mathematical theories). It should certainly be read by every forecaster in the area and by anyone contemplating research on the subject. There are eye-witness accounts from the ground and from the air, details of the life-history of hurricanes and a comprehensive summary of techniques for forecasting movement and development though, as the authors agree, there is still much room for research in this field. A chapter, which would be of particular interest to readers living in areas affected by hurricanes, concerns preparations to guard against damage.

The book is well printed, and the tables and diagrams are well placed in relation to the text. Most of the diagrams are clear, though the numerals in those on pages 176 and 177 are too small. A friend of the reviewer, not a professional meteorologist, describes it as “a most readable book” and adds “a word of praise must be given to the very useful Glossary of Meteorological Terms and the Indexes”.

S. E. VIRGO

Magyarország, Eghajlati Atlasza, Klimaatlas Von Ungarn (Climatological atlas of Hungary). 19 in. × 13 in., pp. 20+78, *illus.*, Akadémiai Kiadó-Budapest, 1960.

The atlas under review contains 130 charts most of which are on a scale of 1:1,250,000 and the rest on 1:2,500,000. The contents and descriptions are in German as well as Hungarian on a loose inset.

The volume opens with four maps of topography, soil types and vegetation. The climatic charts cover hours of sunshine, cloudiness, fog, actual (that is, unreduced) temperature, frost duration, dates of first and last frost, frequencies of "frost", "ice", "extreme heat" etc. days, vapour pressure, relative humidity at 1400, precipitation amounts and frequencies of days of precipitation of over one millimetre etc., evapotranspiration, amount of snowfall, duration of days of snow and snow lying, first and last dates of snow, wind roses and mean isobars, synoptic charts for six characteristic weather situations, temperature extremes shown by mean isotherms of the warmest and coldest winter and summer months, extremes of precipitation in similar form and phenology. Pillar diagrams of mean monthly rainfall at a number of stations are also given. The periods vary but are mostly for 1901 to 1950 and two of the extreme months are taken from before 1910. The charts for the various elements are not all given for the same portions of the year; the portions are changed to suit the natural variations of the elements. No element has twelve-monthly mean charts but means for mid-season months are given for many. The selection has been carefully made to give the best impression of the variations and extremes in minimum space.

The printing is very good. The areas between isopleths are coloured to harmonious schemes which vary with the element. This atlas is an excellent production and the reviewer's only criticism is that he would have liked to have seen German as well as Hungarian titles and legends on the maps themselves.

G. A. BULL

Weather forecasting for aeronautics, by J. J. George. 10½ in. × 6¾ in., pp. ix+673, *illus.*, Academic Press, New York and London, 1960. Price: £5 7s. 6d.

The title of this book gives a good idea of its contents except that the words "in the U.S.A." should have been added. The author, assisted by seven other contributors, is a meteorologist with Eastern Air Lines, and the book is almost wholly concerned with weather forecasting in relation to the operation of an airline in the United States of America.

In the first somewhat philosophical chapter the author stresses the economic value of weather forecasts. No forecast is certain; each forecast has a probability of success, and when considering the economic operations of an airline it is the probability of occurrence of a weather phenomenon which must be evaluated. The simple economics equation is that protective measures for an eventuality should be taken if the probability of its occurrence $P > C/L$ where C is the cost of taking preventative measures, and L is the loss which would result if these measures were not taken and the adverse eventuality materialized. Prediction diagrams are extensively used in the forecasting techniques described in the book and from these, in most cases, the probability of the meteorological eventuality can be estimated.

Eight chapters are concerned with the production of forecast charts. The chapter on the prediction of cyclogenesis (45 pages) is very thorough: the author describes methods of determining whether or not cyclogenesis will occur, and if it does whether it will take the form of deepening of the parent cyclone, or formation of a new cyclone, or of a centre jump. He then describes objective methods of determining the location of new cyclogenesis, its timing, the future intensity, the future track and the predicted speed. An even more extensive chapter (94 pages) is concerned with the movement, deepening and filling of cyclones, and objective methods are described for forecasting their development, speed, direction of movement and time of recurving.

These two are the most comprehensive chapters, but very useful and important are the following five chapters dealing with the movement of anticyclones in North America, the movement of cold lows at the 500-millibar level, the displacement of surface cold fronts, warm frontal analysis and movement, and the movement of tropical cyclones. A chapter entitled "the poor-man's numerical weather prediction system" completes the chapters concerned with the production of forecast charts.

The next four chapters are concerned with forecasting weather phenomena. There is a chapter on the prediction of very low ceilings and fogs, followed by one on pre-trough winter precipitation in which the author produces prediction diagrams for forecasting the amounts of precipitation. There then follows a chapter on the prediction of severe weather, thunderstorms, line squalls, turbulence, hail, tornadoes and aircraft icing—the latter is dismissed in a page as a phenomenon which can no longer be regarded as a hazard. Heavy snowstorms are discussed in a short chapter, wind and temperature forecasting at length, and there is a very lucid short chapter on the use of radar. The last hundred pages of the book are concerned with local forecast studies for airfields in the United States.

This is a first-class stimulating book. It is generously illustrated and it is so well written that the formidable task of reading 662 pages becomes at once a pleasure. What is wholly admirable about the book is its straightforwardness: it is what it professes to be, a handbook for forecasters, and while underlying theories are sometimes mentioned the emphasis is in describing forecasting methods. What is impressive is the variety of the forecasting methods; the parameters for the prediction diagrams are derived variously from surface, 850, 700 and 500-millibar charts, sometimes they are isotherm gradients, sometimes wavelengths or amplitudes; clearly the methods result from a great deal of trial and error, based on theory, and the charts and methods described are those which have been found by experience to give the best results.

The main value to the British forecaster of reading the book lies in its stimulus since probably none of the forecasting methods described as suitable for the United States can be used in the United Kingdom without modification. The book shows what can be done if a real effort is made. A great deal of operational research has been carried out in the United States of the kind that is necessary to bridge the gap between the theoretical work of the Rossbys, the Scherhags and the Sutcliffes, and the operational demands of the forecaster on the bench. This excellent book might be regarded as part of the dividends paid by that operational research.

R. A. HAMILTON

OBITUARY

Mr. Edward William Barlow, B.Sc.—It is with deep regret that we record the death of Mr. E. W. Barlow in his 74th year, on 9 January 1961, after a retirement of only two years. A short sketch of his career appeared in the *Meteorological Magazine* of January 1959.

Mr. Barlow's 39 years' service in the Meteorological Office, which he joined as a Senior Professional Assistant after service with the R.N.A.S. and R.A.F. in the First World War, was noteworthy in that he spent no fewer than 32 years in the Marine Division. Here he was primarily concerned with ocean currents and sea-ice, the preparation of the atlases on these subjects, based on observations sent in by British ships, and the corresponding text in the 73 volumes of the *Admiralty Pilots*, all of which he revised once, a number twice and a few three times, as fresh knowledge made a new edition possible.

He was responsible also for the selection of items from the meteorological logbooks of ships of the voluntary observing fleet for publication in our contemporary, *The Marine Observer*, and as an expert on various natural phenomena frequently contributed explanatory notes for them. His particular study was bio-luminescence, and on this subject he continued to advise the Marine Division after his retirement.

L.B.P.

HONOUR

The following award was announced in the New Year Honours List, 1961:

C.B.E.

W. A. Grinstead, Director of the West Indies Meteorological Service.

METEOROLOGICAL OFFICE NEWS

Retirements.—The Director-General records his appreciation of the services of:

Mr. C. J. G. Budd, Senior Experimental Officer, who retired on 28 December 1960. He joined the Office in June 1920 as a Technical Assistant at Croydon. In 1925 he was transferred to the Aviation Services Division at Headquarters where he remained for some nine years, except for a short spell at an aviation outstation in 1927. Since 1934 he served continuously at aviation outstations including a tour of duty at Malta. From 1948 until his retirement he served at Uxbridge.

Mr. H. Gingell, Senior Assistant (Scientific), who retired on 17 December 1960. He joined the Office in January 1936 as an Observer, Grade II. The greater part of his service has been spent at aviation outstations including a tour of duty in Iraq. He also served for short spells in the Instruments Division in 1945–6 and the British Climatology Division in 1954. In 1955 he was transferred to the London Forecasting Office where he remained until his retirement.

Staff suggestions scheme

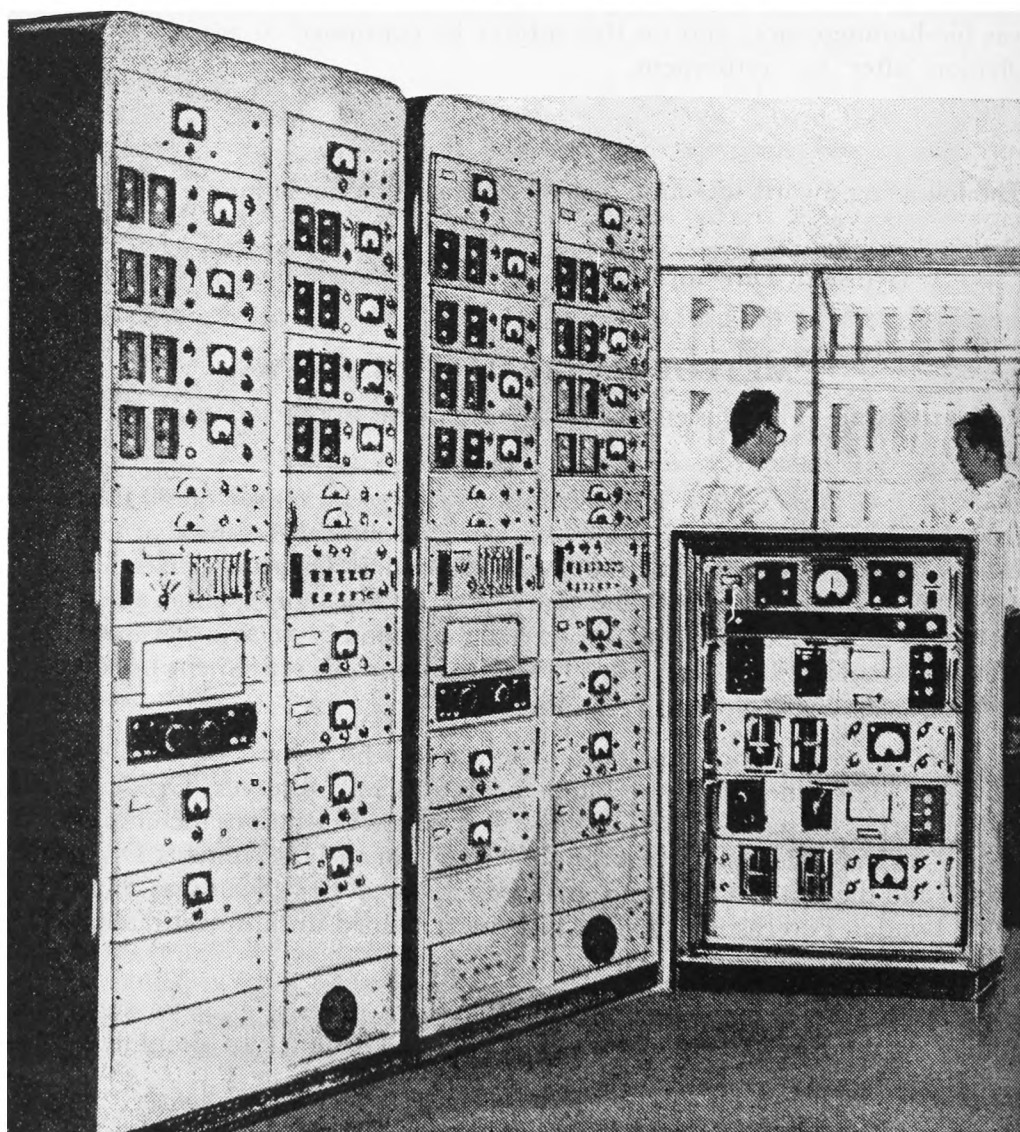
Mr. F. B. Swain, Experimental Officer, was awarded £25 for a suggestion leading to the introduction in the Meteorological Office of simplified topographical maps.

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METEOROLOGICAL OFFICE

THE METEOROLOGICAL MAGAZINE

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THIRD SESSION OF THE WORLD METEOROLOGICAL ORGANIZATION COMMISSION FOR CLIMATOLOGY

By R. G. VERYARD, B.Sc.

At the invitation of Her Majesty's Government, the Commission for Climatology of the World Meteorological Organization (WMO) held its Third Session since the formation of WMO at Church House, Westminster, from 1-15 December 1960. The Commission for Climatology was originally formed in 1929 in the days of the International Meteorological Organization but this was its first meeting in London. There were delegates from over thirty countries and from all five continents.

The session was opened by the Rt. Hon. The Viscount Hailsham, Q.C., Lord President of the Council and Minister for Science. In an encouraging and witty speech, Viscount Hailsham mentioned how gratifying it was that, in the field of climatology, scientists from all over the world had found a common meeting ground for discussion divorced from any political differences which might exist and he drew attention to the fact that climatology is a subject which could not be tackled successfully by an exclusively national programme but called for the closest international co-operation. In fact, throughout the session there was an excellent spirit of friendliness and without this the meeting could not have been so successful.

Following Viscount Hailsham, Sir Graham Sutton, C.B.E., F.R.S., Director-General of the Meteorological Office, Permanent Representative of the United Kingdom and a very active member of the Executive Committee of WMO, gave a welcoming address in which he remarked that, in the past, climatology had played the role of the Cinderella of meteorology but was at last coming into its own; he emphasized the importance of the dynamical approach to climatology.

After a short speech by Mr. O. M. Ashford, the representative of the Secretary-General of WMO, and the reading of best wishes sent to the meeting by telegram from the Secretary-General himself, the President of the Commission, Mr. R. G. Veryard, then gave the customary Presidential Address. His theme was "The new approach to climatology" and called for a critical appraisal of the functions, responsibilities and activities of the Commission for Climatology in view of the modern and developing three-dimensional and dynamical approach to the subject, the ever-increasing value of applied climatology and the economic importance of climatic fluctuations. The address has been published in full in the January 1961 issue of the *WMO Bulletin*.

With these formalities over, the Commission got down to business by setting up the necessary committees. Two working committees were established, one to deal mainly with organizational matters under the chairmanship of Mr. C. C. Boughner of the Canadian Meteorological Service and the other to deal mainly with technical matters under the chairmanship of Dr. H. E. Landsberg of the United States Weather Bureau. One could not have wished for two more able chairmen and the work of both committees was accomplished so efficiently that it was possible to clear their output at the plenary meetings a day ahead of schedule!

To describe in detail all the matters which were discussed during the session and the outcome of such discussion would require too much space, so only the more important items will be mentioned; fuller information will be obtainable in the "Abridged Final Report of the Third Session of the Commission for Climatology" to be published by WMO.

The item on which most time was spent was the "WMO Guide to Climatological Practices". This is one more of a series of handbooks which are being issued by WMO to provide advice and guidance to meteorological services, particularly those in newly developing countries. An introductory chapter and chapters on climatological organization, climatic elements and their observation, climatological data (collection, scrutiny, storage and supply), the use of statistics in climatology, data processing by machine methods, microclimatology, CLIMAT reports, and publication of climatic data had already been prepared and issued to members of the Commission. Other chapters, some of which had not been completed, on descriptive climatology, marine climatology, the climatology of the free atmosphere, and the application of climatological data were available in draft form. All chapters were thoroughly examined and of those already prepared two were held back from publication pending further revision—the chapters on the climatology of the free atmosphere and on applied climatology—but it was agreed that, for the time being, the material could be issued to meteorological services for information. Many amendments, affecting most chapters, were considered to be necessary and these were divided into two categories. Those in the first category, regarded as mainly editorial, would be taken care of by the Secretariat. The other amendments, requiring more time for study, would be referred to a new working group and the Commission decided to authorize the President to approve such proposals of the working group as he considered to be relatively straight-forward and non-controversial; otherwise amendments submitted by the working group would be circulated to members of the Commission for comment or referred for final decision to the next session. Thus it may be some time before a complete and generally acceptable version of the "Guide to Climatological Practices" becomes available. However, a good start has been made and a number of chapters should be "finalized" in the very near future. It may be of interest to mention that discussion on the Guide raised the question of the definition of climatology and its sub-branches. It is hardly necessary to say that complete agreement was *not* reached and would appear to be unattainable!

Much time was also spent on a review of "WMO Technical Regulations" which comprise the practices and procedures which all meteorological services are expected to follow. Particular attention was given to those regulations covering the climatological requirements of aviation. Several amendments were

agreed and the working group on the "Guide to Climatological Practices" was given the additional task of keeping under review those regulations relating to climatology. Of particular interest was the discussion on "normals". It was agreed that the best choice of period would depend on the purpose for which "normal" or reference values were needed and also on the element concerned and on geographical factors. It was realized, however, that for the use of CLIMAT reports and for climatic atlases a uniform period is required and that the combined effect of random errors and errors due to a systematic trend or change of exposure will often be minimized if a period length of 20–30 years is chosen. The outcome was that the Commission decided to recommend the use of the period 1931–60 as a reference period for CLIMAT purposes and to set up a working group to give guidance, as required, to meteorological services in regard to the most suitable periods for specified purposes and to study such aspects of the problem as the influence of periodic fluctuations on the most suitable length of the "normal" period and the need for different periods when dealing with specific climatic problems. An item under "Technical Regulations" on which agreement was *not* reached was the definition of "station level"! This was left to the working group to study.

Another item of general interest on which there was much discussion concerned CLIMAT and CLIMAT TEMP messages and CLIMAT data for ocean areas. A request from the Anti-Locust Research Centre, London, for additional CLIMAT stations in parts of Africa and Asia met with a very favourable response and countries concerned readily agreed to take the necessary measures to meet the request. A proposal that the 50- and 30-millibar levels be added to, and the 400-millibar level dropped from, the pressure surfaces for which data are given in CLIMAT TEMP reports was agreed, as was also a proposal to include two extra groups to give the mean surface pressure, temperature and dew-point at the time of release of the radio-sonde. These proposals were referred to the Commission for Synoptic Meteorology, who were also asked to study whether it would be possible to include in CLIMAT TEMP reports, for equatorial, antarctic and other remote stations, wind groups for the surface and standard pressure levels giving the monthly mean wind vector and the steadiness of the wind, the idea being to facilitate the drawing of the isobars on CLIMAT surface and upper air charts. In view of the difficulties in many countries in connexion with the computation of values for \overline{UU} (mean monthly relative humidity) in CLIMAT reports, the Commission recommended that the group be made optional and that the Regional Associations of WMO should be invited to consider "local" needs for \overline{UU} and to take steps to ensure that this need is satisfied. It was agreed that \overline{UU} should be retained in mailing CLIMAT reports to the Editor of *Monthly Climatic Data for the World*. In regard to the latter publication, appreciation was expressed of the fine efforts of the United States Weather Bureau in producing this very valuable summary of CLIMAT and CLIMAT TEMP data and arrangements were agreed for improving the verification of the data and for notifying in confirmatory messages the monthly rainfall amounts and the number of days on which mean values for each element are based.

Special attention was given to statistical requirements and methods in climatology and also to modern techniques for data processing, publication and storage. In regard to the former item, the Commission studied an excellent report by Dr. H. C. S. Thom, who had been the chairman of a working group on the subject. It was decided that the material was best suited for publication in a "WMO

Technical Note” and the working group was re-established with the job of expanding the draft to include worked examples—the Secretary-General to arrange for publication in due course. The Commission also decided to establish a working group on data processing by machine methods and endorsed a suggestion of the Regional Association for Europe that a seminar on machine methods be held in 1962. It was considered that whilst a complete international standardization of meteorological punch-card layout was not desirable, a partial standardization as regards the contents of the cards would have advantages for international exchange and a recommendation was passed indicating which elements should be contained in specified punch-cards.

The question of climatic atlases has now become a regular item on the agenda of the Commission for Climatology, but the original aim of facilitating the provision of a World Climatic Atlas still seems far from being achieved. However, progress although slow is being maintained. The publication, as an important step towards the production of world maps, of regional climatic maps according to WMO specifications was considered to be a matter of urgency. In this connexion, Prof. S. P. Jackson of the Witwatersrand University, who was present at the meeting and who is engaged on the preparation of climatic atlases for Africa, was able to give the Commission the benefit of his experience, and the Commission decided to request that the Regional Associations should make arrangements for regional maps to be prepared and published as soon as possible. To provide guidance on both technical and organizational aspects, for example, the selection and construction of base maps, the Commission decided to re-establish a working group on climatic atlases and urged that it should be given favoured treatment with respect to the financing of a meeting. It was also agreed that, particularly to meet aviation requirements and to facilitate studies of the general circulation, climatic atlases of the free atmosphere should be prepared on a world-wide scale: it was suggested that the Secretary-General should conduct an inquiry in order to collect information on existing or planned climatic maps of the free atmosphere.

On the subject of the optimum network of stations and the programme of observations required for climatological purposes there was, needless to say, considerable argument and it was generally felt that it would not be practicable to lay down criteria for all purposes. The Commission considered that there were two main problems to be dealt with under this item, namely (i) the world network needed for climatological studies on a global scale, that is, to facilitate studies of the general circulation and of climatic fluctuations, and (ii) the networks needed in the arid, tropical and polar zones for more detailed investigations, especially where lack of population, financial stringency or other reasons had prevented the establishment of an adequate number of surface and upper air stations. It was decided to set up a working group to study the problem and to make proposals for bridging the important gaps in the networks and for remedying deficiencies in the observational programmes. In this connexion, it might be mentioned that the Commission attempted to specify as far as possible the accuracy of measurements as required for climatological purposes!

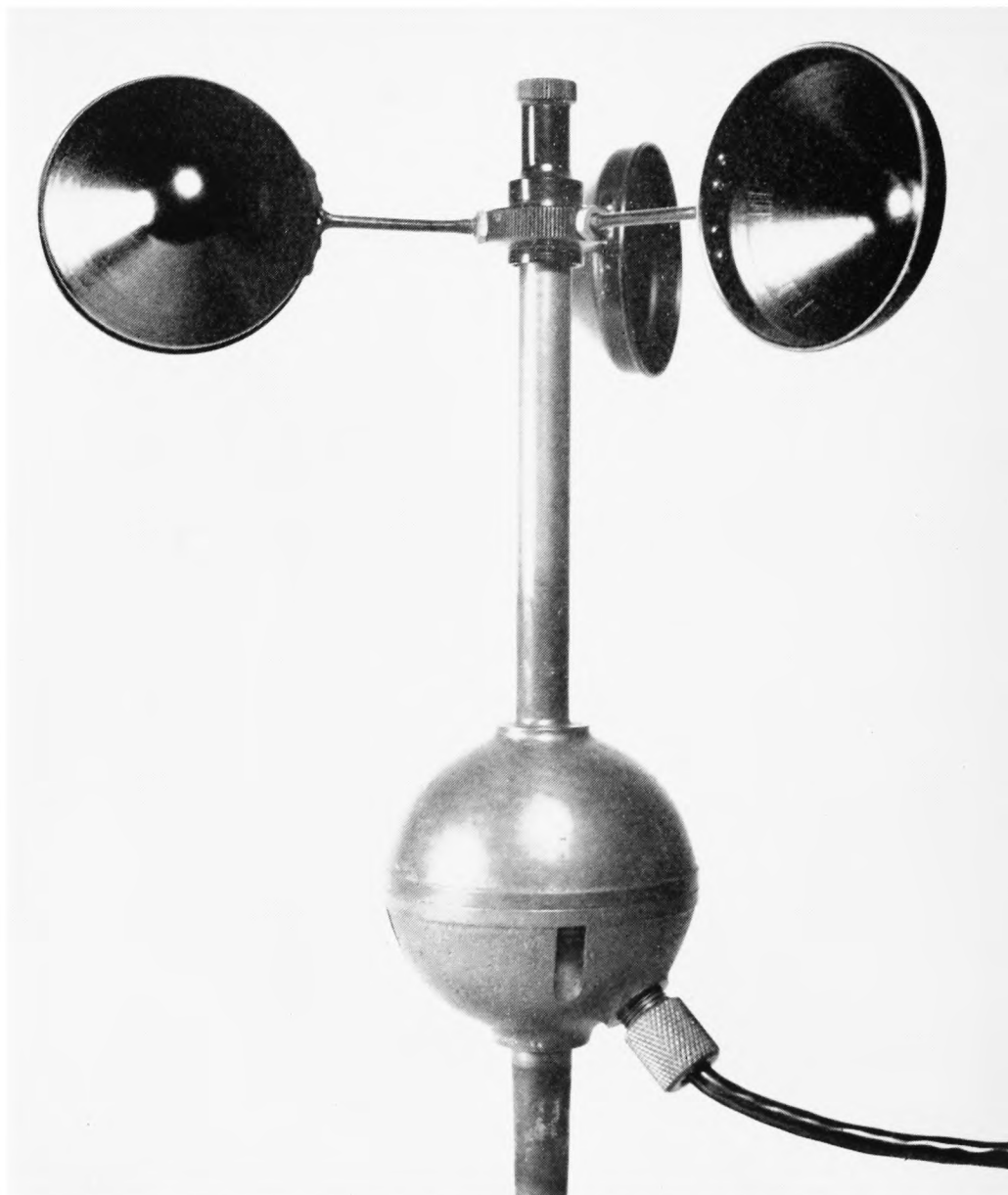
Finally, mention should be made of items involving collaboration with other international organizations. One such organization is the International Civil Aviation Organization, which was represented at the meeting by Mr. R. Berggren. Arising from a discussion of climatological requirements for aviation, it was recommended that studies of icing and turbulence (in particular, clear-air



LORD HAILSHAM OPENING THE THIRD SESSION OF THE WMO COMMISSION FOR CLIMATOLOGY

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To face p. 69]



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A NEW HOUSING FOR THE SENSITIVE CUP ANEMOMETER, MARK I
(see p. 89)

turbulence) along major air routes be undertaken by the countries most concerned. Then there is the International Society of Biometeorology and Bioclimatology, which was represented at the meeting by its Secretary, Dr. S. W. Tromp. Several delegates felt that, as far as meteorologists are concerned, the field of bioclimatology had been given too little attention, both at the national and the international level. It was decided to urge the members of WMO to send delegates to future bioclimatological congresses and to set up a working group to review the most important papers on human bioclimatology, to study the use of derived climatic elements in this field and the requirements for climatic classifications in dealing with problems in human bioclimatology, and to study ways and means by which meteorological services can contribute to the sound development of human bioclimatology in their respective countries. Quite a tall order! The Commission also dealt with certain requirements emanating from the Food and Agriculture Organization (represented at the meeting by Mr. S. J. Holt) and UNESCO and endorsed a resolution which was adopted by the Council of IUGG at Helsinki this year regarding the publication and exchange of meteorological data for research purposes. The Commission was particularly interested in the joint UNESCO/WMO symposium on Changes of Climate to be held in Rome in 1961 and recommended, among other things, that the Secretary-General should invite members of WMO to supply information about published and unpublished studies on changes of climate carried out in their countries so that such information could be made available in a suitable form before the symposium; it was suggested that the symposium should give attention to the possibility of using electronic computers for the analysis of long climatic series. The President of the Commission was authorized to establish a working group on climatic fluctuations at any time he might consider suitable.

During the session two afternoons were set aside for scientific discussions. One, on climatic fluctuations, was held in the conference building when papers were read by Mr. A. I. Johnson of the Climatological Research Division of the Meteorological Office and by Prof. Dr. H. Flohn of the Deutscher Wetterdienst, who made a special journey from Germany. The other was at the invitation of the Royal Meteorological Society, the latter having chosen for a special discussion meeting the subject of "Automatic methods of handling meteorological data". Social activities included a tour of their works at Harlow (including lunch and transport) arranged by Cossor Radar and Electronics Ltd., and a cocktail party at Lancaster House at the invitation of Her Majesty's Government.

That the meeting was a success was due not only to the fine co-operation of all the delegates but to the excellent work of the WMO Secretariat, Mr. O.M. Ashford, Mr. E. Hovmoller and Mr. P. Rogers, and to the Executive Secretary, Mr. C. W. G. Daking, and his staff. The facilities provided by the Church House authorities and by the Conference and Supply Department of the Foreign Office were excellent, the interpreters doing a particularly good job of work. In fact, the meeting ended with a flow of enthusiastic acknowledgements for all the help received, on which a meeting of such a kind is so dependent. Several members felt that, although WMO regulations permitted officers to serve for a second term, it was desirable that there should be a change at each session and the President decided not to stand for re-election. Mr. C. C. Boughner, the outgoing Vice-President, was elected *nem. con.* to succeed him and Dr. C. C. Wallen of Sweden was elected by a majority vote as the new Vice-President.

AN APPROACH TO THE PROBLEM OF THE FORECASTING OF FOG CLEARANCE

By C. J. KENNINGTON, M.A.

The time of clearance of radiation fog is never easy to forecast. While the number of factors involved is so large as to preclude any rigorous mathematical analysis of the problem, certain simplifications make the following analysis possible.

G. J. Jefferson has shown¹ how to draw a temperature-rise curve for a clear morning, and in a further article² has suggested a method of adjusting this curve to allow for fog. The present approach was suggested to me by J. R. Martin, and is based on unpublished work (1942) of the late D. J. Horrod. My thanks are due to J. R. Martin and Dr. K. H. Stewart for considerable help in the preparation of this paper.

The temperature which will be reached at any time on a clear morning may be calculated from a representative ascent on a tephigram using the proportionate heating amounts in Table I. This table, which is due to J. R. Martin, has been produced by assuming that the "Gold-square"³ maximum temperature will be reached by 1430 hours, taking proportionate parts of the insolation available, allowing for the sun's elevation, for each hour, and summing them progressively. It gives the insolation, in gm cal cm^{-2} , which will be received up to each hour in any month. These figures may be applied to the 1956 Meteorological Office tephigram by noting that on this form an area of 1 cm^2 represents an energy of $50 \text{ gm cal cm}^{-2}$.

TABLE I—TOTAL INSOLATION RECEIVED UP TO A GIVEN TIME
ON A CLEAR MORNING

GMT	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
					<i>gm cal cm⁻²</i>							
0500					2	4	2					
0600				3	9	14	10	3	1			
0700			3	11	19	24	20	15	8	1		
0800	1	4	10	22	33	40	33	26	17	8	2	2
0900	4	11	22	40	52	57	50	43	32	16	6	3
1000	10	20	35	57	73	81	71	62	45	26	11	7
1100	17	32	50	75	100	106	93	79	60	38	18	13
1200	25	46	67	95	120	128	116	101	77	51	25	19
1300	32	56	81	115	139	150	135	118	93	65	33	24
1400	38	66	90	134	164	171	157	138	104	73	38	29
1430	40	70	100	140	175	180	165	150	115	80	40	30

On the main part of the tephigram, F 2810A (1956), $1 \text{ cm}^2 = 50 \text{ gm cal cm}^{-2}$

On a foggy morning, part of the incoming solar energy is reflected from the fog top; the rest is used in heating the air and water in the fog bank, and in evaporating the water. E. W. Hewson⁴ has considered at length the theoretical aspects of reflection, absorption and transmission of a beam of solar energy passing through fog and cloud. He produced a table showing the effect of droplet size, water content, thickness and solar elevation on the distribution of the incident radiation. A simplification of this is shown (Table II) for droplet size $2 \times 10^{-3} \text{ cm}$ (considered representative of fog) and neglecting the slight effect of varying solar elevation. This shows that relatively little solar energy is absorbed, and that the percentage of energy reflected increases with depth and with water content. It is difficult to estimate the water content of a fog. If M_b and M_a are the saturation

TABLE II—PERCENTAGES OF INCIDENT SOLAR RADIATION REFLECTED, ABSORBED AND TRANSMITTED BY A BANK OF FOG COMPOSED OF WATER DROPLETS
RADIUS 2×10^{-3} CM

Depth of fog (m)	Water density (gm m^{-3})			Water density (gm m^{-3})			Water density (gm m^{-3})		
	0.1	1.0	5.0	0.1	1.0	5.0	0.1	1.0	5.0
	% reflected			% absorbed			% transmitted		
20	1.4	12.8	40.8	0.1	0.8	3.0	98.5	86.4	56.2
80	6.0	36.1	70.0	0.2	2.7	7.4	93.8	61.2	22.6
200	12.8	57.1	82.3	0.8	5.0	10.2	86.4	37.9	7.5

These average values neglect the small effect of varying solar elevation.

mixing ratios at the actual temperature and the temperature at which the fog formed, then $M_a - M_b$ gm kg^{-1} of water must have been condensed. This is an upper limit to the possible water content, but the actual content may be less because of loss by droplets falling to the ground. Common values of $M_a - M_b$ would be in the range 0.5 to 2.0 gm kg^{-1} . Experimental values are 0.2 to 1.0 gm m^{-3} (0.3 to 1.25 gm kg^{-1}) found in thick fogs by H. G. Houghton and W. H. Radford⁵, and 0.2 to 0.4 gm m^{-3} (0.3 to 0.5 gm kg^{-1}) found in advection fogs by D. Kuroiwa and S. Kinoshita⁶. At 1 gm m^{-3} (1.25 gm kg^{-1}) the reflection coefficient varies from 13 to 57 per cent with depth, while at 0.1 gm m^{-3} the range is 1 to 13 per cent. Gold allowed 20 per cent for reflection from the ground in evaluating his heating figures. The total reflection from fog lying on the ground cannot be less than this, and it is suggested that 40 and 60 per cent would be average reflection coefficients for fairly thin and thick fogs respectively. Gold in deducing his figures also deducted an allowance for normal evaporation ranging from 33 to 73 per cent of the final figures. This deduction is not relevant when considering insolation at the fog top; therefore, the available insolation for clearing the fog must be increased by this amount, as well as by the 20 per cent allowed for reflection. Table III shows the insolation available for dispersing a thick fog, after allowing for all these corrections; for a thin fog the figures should be increased by half.

TABLE III—TOTAL INSOLATION RECEIVED AT THE TOP OF A THICK FOG UP TO A GIVEN TIME, ALLOWING FOR 60 PER CENT REFLECTION

GMT	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
	gm cal cm^{-2}											
0500					2	4	2					
0600				3	8	12	9	3	1			
0700			3	9	17	21	19	13	7	1		
0800	1	3	8	19	29	35	31	22	14	6	2	1
0900	3	8	19	34	46	50	46	37	26	12	5	2
1000	8	15	29	49	64	71	66	53	37	20	9	5
1100	14	25	42	64	87	93	86	67	49	29	15	10
1200	20	35	56	81	106	112	98	86	63	38	21	14
1300	26	43	68	99	122	132	125	101	76	49	28	18
1400	30	51	76	115	144	150	146	118	85	55	32	22
1430	32	54	84	120	154	158	153	128	94	60	34	23

For a thin fog these values should be increased by half.

The amount of water evaporated during clearance of fog may be deduced by considering conditions at dawn and at the moment of clearance. If the dawn temperature is T_1 and that at clearance T_2 , and M_1 and M_2 are the corresponding saturation mixing ratios, then the amount of water vapour present at dawn is M_1 and that at clearance is M_2 . Therefore, $M_2 - M_1$ gm kg^{-1} of water must have been evaporated during clearance; part of this will have come from the

water droplets originally contained in the fog, and part from dew or other surface water. This is true both for the surface layer and for layers higher in the fog, where the additional water will have been transported upwards by mixing.

To forecast the time of clearance of fog, therefore, we must first forecast the clearance temperature. (One way of doing this is to take the surface temperature required to give a saturated adiabatic lapse rate to the top of the inversion.) The insolation required to raise dry air to this temperature can be found from the tephigram as outlined above. However, additional energy is required to warm and evaporate the liquid water content of the fog, so this insolation must be increased by the factor deduced below. The time by which this corrected insolation will have become available on a foggy morning may be read from Table III, and this is the forecast time of fog clearance.

To deduce the increase factor, we consider a layer of fog defined on the tephigram by two constant-pressure levels, and let T_α and T_β be the actual temperature at the height of this layer and the clearance temperature (in °F), and M_α and M_β the corresponding mixing ratios. C is the specific heat of air at constant pressure, and L the latent heat of evaporation of water.

Then to heat 1 kg of air from T_α to T_β requires

$$\frac{5}{9} (T_\beta - T_\alpha) 10^3 C \text{ calories;}$$

and to heat 1 gm of water from T_α to T_β and evaporate it requires

$$\frac{5}{9} (T_\beta - T_\alpha) + L \text{ calories.}$$

Now the amount of water to be heated and evaporated in clearing 1 kg of this fog (strictly 1 kg of saturated air with its suspended water droplets) at T_α is $M_\beta - M_\alpha$ gm. Therefore, to heat 1 kg of fog from T_α to T_β and evaporate its liquid water content requires

$$\frac{5}{9} (T_\beta - T_\alpha) 10^3 C + (M_\beta - M_\alpha) \left[\frac{5}{9} (T_\beta - T_\alpha) + L \right] \text{ calories.}$$

Therefore, the increase factor f of the energy required to clear the layer of fog compared with the energy required to heat an equivalent layer of dry air through the same temperature range is

$$\begin{aligned} f &= \frac{\frac{5}{9} (T_\beta - T_\alpha) 10^3 C + (M_\beta - M_\alpha) \left[\frac{5}{9} (T_\beta - T_\alpha) + L \right]}{\frac{5}{9} (T_\beta - T_\alpha) 10^3 C} \\ &= 1 + \frac{M_\beta - M_\alpha}{10^3 C} + \frac{9L}{5000C} \times \frac{M_\beta - M_\alpha}{T_\beta - T_\alpha}. \end{aligned}$$

Now in the range $T=28^\circ\text{F}$ to 60°F at 1000 millibars, M can be represented closely by the formula

$$M = \frac{(T-10)^2 + 541}{272},$$

where M is in gm kg⁻¹ and T in °F, and this varies only slowly with pressure. Now $C = 0.242$ and $L = 591$ at 50°F , and $M_\beta - M_\alpha$ in normal circumstances will not exceed 10, therefore $(M_\beta - M_\alpha)/10^3 C$ can be neglected, and

$$\begin{aligned} \frac{M_\beta - M_\alpha}{T_\beta - T_\alpha} &= \frac{(T_\beta - 10)^2 - (T_\alpha - 10)^2}{272 (T_\beta - T_\alpha)} \\ &= \frac{T_\alpha + T_\beta - 20}{272}. \end{aligned}$$

Therefore

$$\begin{aligned} f &= 1 + \frac{9}{5} \times \frac{591}{242} \times \frac{T_{\alpha} + T_{\beta} - 20}{272} \\ &= 1 + \frac{T_{\alpha} + T_{\beta} - 20}{61.7} \\ &\simeq \frac{T_{\alpha} + T_{\beta}}{60} + \frac{2}{3}. \end{aligned}$$

In order to apply this factor, it is strictly necessary to integrate it over the heating area on the tephigram, and the manner in which this is carried out depends on the assumed shape of the heating area. In practice, however, the possible forms of the integral all result in answers of the form

$$F = \int f ds = \frac{T_1 + T_2}{60} + \frac{2}{3} + \varepsilon,$$

where T_1 and T_2 are the actual surface temperature and the temperature at clearance, and ε is an expression in T_1 , T_2 and the fog depth, depending on the shape of the heating area, but of absolute value not exceeding 3×10^{-2} in ordinary circumstances. In comparison with the minor inaccuracies of the method, this can be neglected.

In practice, therefore, the factor by which the insolation required must be increased is

$$F = \frac{T_1 + T_2}{60} + \frac{2}{3}.$$

It is interesting to note that in practical cases the range of F is from about $1\frac{1}{2}$ to $2\frac{1}{2}$ (for low and high temperatures respectively).

The author has not been able to test the method exhaustively. However, the results of some preliminary tests on data from Kew kindly supplied by Dr. Stewart are given in Table IV.

TABLE IV—RESULTS OF TEST OF THE METHOD ON FIVE FOGS AT KEW

Date	Insolation required for dry air <i>gm cal cm⁻²</i>	F	Insolation required for clearance <i>gm cal cm⁻²</i>	Forecast clearance time GMT	Actual clearance time GMT
1956					
12 Oct.	16	2.25	36	1200	1145
13 Oct.	9	2.2	20	1000	1020
14 Oct.	7	2.2	15	0920	1000
15 Oct.	7	2.3	16	0930	0900
22 Nov.	18	1.8	32	1400	1500

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of movement of thunderstorms. Violent storms with hail were reported from White Waltham, Duxford and Stradishall.

The rapid development of these storms was undoubtedly partly due to diurnal heating. Nevertheless, the close association with the cold front is evidence of additional uplift; how this may have been created is problematical. Low-level south-east winds blowing from the depression towards the front may have been the cause. The 1200 GMT Crawley wind at 850 millibars did, in fact, show that winds over southern England were from the south-east. The cold front was, however, weak and did not extend far above a few thousand feet; it seems doubtful if this method could have caused the large-scale uplift which took place before diurnal heating was very far advanced. It appears more likely that a small mobile wave was induced on the front, perhaps by the formation of a trough extending out from the depression over France. The depression moved north-east during the day reaching Belgium by 1800 GMT and the storm centre followed a parallel course. Also, since the cold front was shallow, the air to the north of the front was similarly potentially unstable, and a minor perturbation on the cold front could have resulted in large-scale uplift.

Although there were few reporting stations on the path of the storm centre, the track is shown clearly by the hail reports collected by Ludlam², from whose paper the map of the distribution of maximum hailstone size (Figure 3) is mostly taken. The storm is seen to have had two surges of activity. The first lay over the Basingstoke–Maidenhead area and the second from north of the Chiltern Hills to Bury St. Edmunds. A large-scale chart of the situation at 1300 GMT (Figure 1) shows that a small high-pressure area had developed over the thunderstorm area. This was associated with the downdraught and resulting divergence of the cold air from the large concentration of storms. A pressure surge (Figure 2) marked the outward spread of this cold, diverging air, and this air had formed a pseudo-cold front against not only the warm air to the south of the original cold front but also against the cold air to the north of the front. This pressure surge was more marked than might appear from this chart, since it was offset almost immediately by a drop in pressure. All stations in the Cambridge area recorded a sharp pressure rise of about 4 millibars, with a rise at Oakington of 5.2 millibars. The passage of the pseudo-cold front, being the initial downdraught from the system, was also marked by a sharp temperature drop of 10–12°F, the onset of heavy precipitation and gusts of 30–40 knots. A further feature was the south-westerly wind which accompanied the pressure surge and with which the gusts were associated, as reported by Duxford in the 1300 GMT observation.

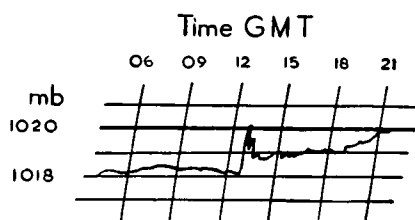


FIGURE 2—BAROGRAPH TRACE AT BASSINGBOURN, 9 JULY 1959

The records at Porton Down, Dunstable, Basingbourn and Mildenhall have been examined over the period of the storm. These four stations were situated

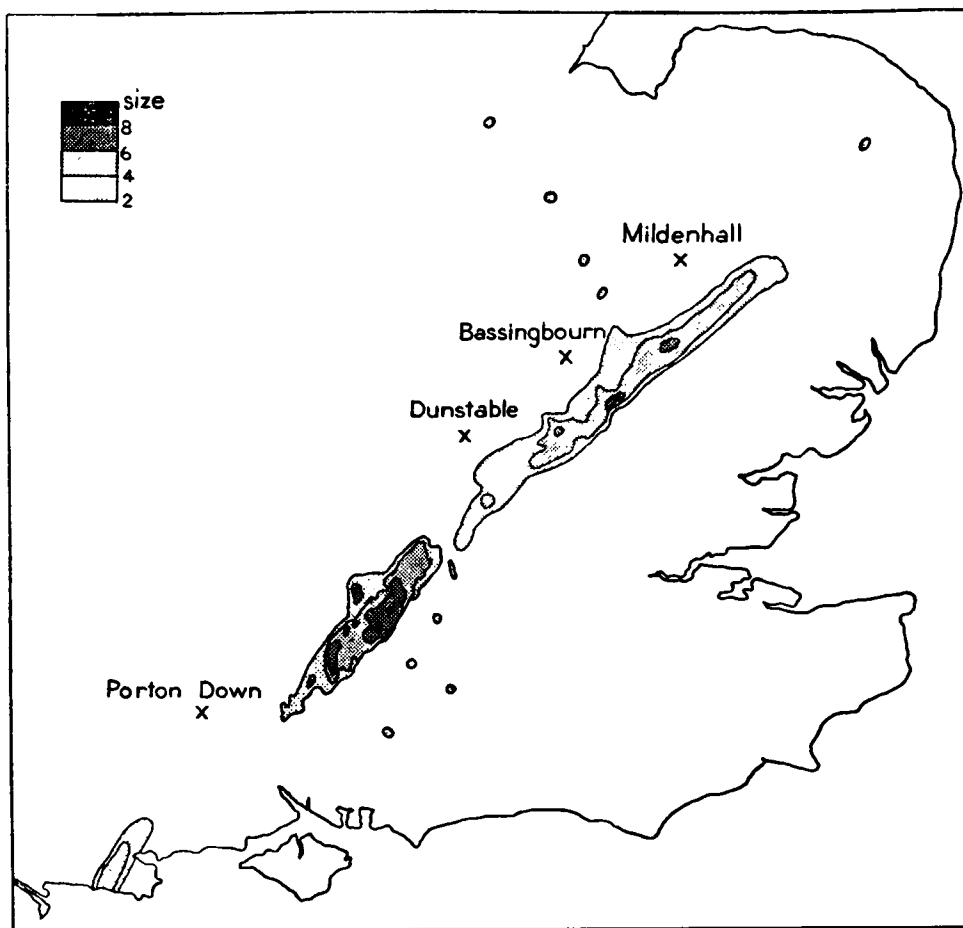


FIGURE 3—DISTRIBUTION OF MAXIMUM HAILSTONE SIZE, 9 JULY 1959

Isopleths are for stones of sizes 2, 4, 6 and 8 on the following scale: 2 = pea size; 4 = cherry size; 6 = walnut size; 8 = egg size. The small areas of hail shown to the north of Bassingbourn were probably from storms associated with the psuedo-cold front.

at about the same relative position to the track of the centre, being about 5–10 miles to the north. In relation to the two surges of activity, Porton Down was ahead of the first, Dunstable lay between the two, Bassingbourn was in the middle of the second and Mildenhall towards the end of the second. The barograph trace at Bassingbourn shows a sharp peak followed by a lesser rise and fall with a net gain of about two millibars (Figure 2). The traces at Mildenhall and Dunstable are similar except that the secondary peak is not so great; the peak at Dunstable is the lesser of the two, being half a millibar only, but at both stations a total rise of two millibars is recorded. At Porton Down the first peak was not experienced, and a simple rise of two millibars is shown. At the three stations with recording wind instruments (Porton Down, Dunstable and Mildenhall), the backing of the wind to south-west took place at the same relative time, being ahead of the secondary rise of pressure. Gusts associated with the south-west wind were 30–35 knots at Mildenhall and Bassingbourn (the latter by observation) and 16 knots at Dunstable. At Porton Down, however, the wind became almost calm. The fall of temperature and start of precipitation occurred with the secondary rise of pressure at all four stations, when the wind began veering to northerly again.

The general rise of pressure was due to the thunderstorm high cell passing over the stations. The sharp nature of the rise in pressure is typical of a front, so the pseudo-cold front had formed when the cell reached Porton Down. At this stage it appears to have had the characteristics of a normal, active cold front. At the other stations a pressure peak was recorded before the temperature drop or start of precipitation. An explanation for this peak would be a nose formed in the pseudo-cold front. As the system was in a more advanced and active state east of Wiltshire, the downdraught would be stronger and a nose more likely to be formed by surface friction. This ridge of cold and rapidly descending air recorded a higher pressure than the main downdraught which followed. The latter would be the secondary rise of pressure recorded at these stations, with the highest rise at Bassingbourn where the system was at the peak of the second surge of activity. Together with the isallobaric effect, which was considerable, the south-west wind was caused by the strong, initial downdraught in which the hail was contained; at White Waltham gusts of over 40 knots were observed. The temporary slackening of the wind speed at Porton Down would be due to the weakness of this initial downdraught, since the system was in its early stages, and the opposing isallobaric effect on the prevailing north-east wind.

The emergence of this pseudo-cold front increased the upslope motion over the whole system, since presumably the original motion still existed, but also both the warm and cold air masses on either side of the front were being lifted by the colder, descending air of the storms themselves, so that the system was partly providing its own triggering action. The area of strongest upslope motion would have been at the junction of the pseudo-cold front with the original cold front, since there three motions were combined; on the 1300 GMT chart violent thunderstorms were in that area.

The pseudo-cold front travelled through the Cambridge area at about 45 knots, and its position at 1300 GMT can be accurately determined in that area by reference to the time of the pressure surge at the various stations. Its position south of Stansted and west of Cardington is, however, rather doubtful in the absence of more detailed reports, and has been drawn to include the lower temperatures associated with the air of the downdraught (excepting the temperature at Stansted, which inexplicably dropped shortly after the 1300 GMT observation). Nevertheless, thunderstorms which occurred later over Essex and south-east England as well as at Gaydon and Cottesmore show that the pseudo-cold front was sufficiently well developed, especially against the warm air, to cause substantial lifting well away from the main thunderstorm area. Diurnal heating and orographic lifting are unlikely to have caused this secondary outbreak of thunderstorms, at least in the south, as both Southend and Shoeburyness, and later Kent coastal stations, were affected. An investigation by Ludlam² of radar reports on this occasion shows that at 1400 GMT storms and showers had spread outwards from the centre to the north and south on a line corresponding to the forward movement of the pseudo-cold front of Figure 1. There is also shown a small group of showers associated with the following wake depression.

The system was still active when it crossed the Norfolk coast at 1500 GMT, but the cessation of hail north of Bury St. Edmunds shows that the system was weakening. The storm probably died out over the North Sea, and SFERIC reports confirm this. During its passage, considerable damage was caused by hail on greenhouses near Wokingham, and a low-flying aircraft from Bassingbourn was similarly affected just south of the airfield.

It is interesting to note that a similar outbreak took place on the night of 10 July. A smaller pressure surge was recorded by the stations whose records are examined above, but it is probable that they were not as close to this second storm. At Kew the highest rainfall of the month was recorded on that night. Perhaps thunderstorm highs are not as uncommon in this country as is supposed.

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METEOROLOGICAL OFFICE DISCUSSION

Numerical forecasting at Dunstable

It is now two years since the high-speed electronic computer, Meteor,¹ was installed in the Napier Shaw Research Laboratory at Dunstable. Much of the machine's working-time has been used for numerical forecasting.

Opening the Monday Discussion on 17 October 1960, Mr. C. E. Wallington outlined forecasting experiments carried out at Dunstable since January 1959. After a brief introduction to numerical forecasting techniques,² he illustrated the basic features of the Sawyer-Bushby model,³ which was formulated and had been ready for use for some time. As soon as Meteor was installed, the staff of the Dynamical Research Branch put the model to a prolonged test.⁴ On almost every weekday from 12 January to May 1959, 24- and 30-hour forecasts were made from current midnight data. The initial data for each forecast comprised 500-millibar contour heights and 500-1000-millibar thicknesses for a network of 480 grid points covering an area extending from Nova Scotia to Russia and from Spitsbergen to North Africa. The distance between adjacent grid points ranged from about 130 to 170 nautical miles. The model included a statistically based effect of heating over the sea⁵ and the end product of the computations comprised forecast charts of the two basic fields—the 500-millibar contour and the thickness fields—and the difference between these two fields, namely the 1000-millibar pattern. The computed vertical motion at the 600-millibar level was also obtained.

In view of the necessary, but generally incorrect, assumption of no changes near the boundary of the computing area, hopes for satisfactory forecasts were limited to an inner "verification" area—a rectangular network of 192 grid points covering about the same area as the Central Forecasting Office (C.F.O.) routine prebariatrics, that is, the north-east Atlantic, Iceland and Europe.

The nature of the errors.—Broadly speaking, the 24-hour forecasts were encouraging. Some were very good, but to improve the general standard of forecasting we are more concerned with the faults of the technique. One of the principal faults stems from the boundary assumptions. Although most boundary effects in 24-hour forecasts are limited to peculiar distortions in the predicted contour and thickness patterns close to the boundaries, there are occasions when they do invade the verification area.

The assumption of no change at the boundary not only prevents systems from entering the computing area but also stops them getting out. Figure 1 shows a

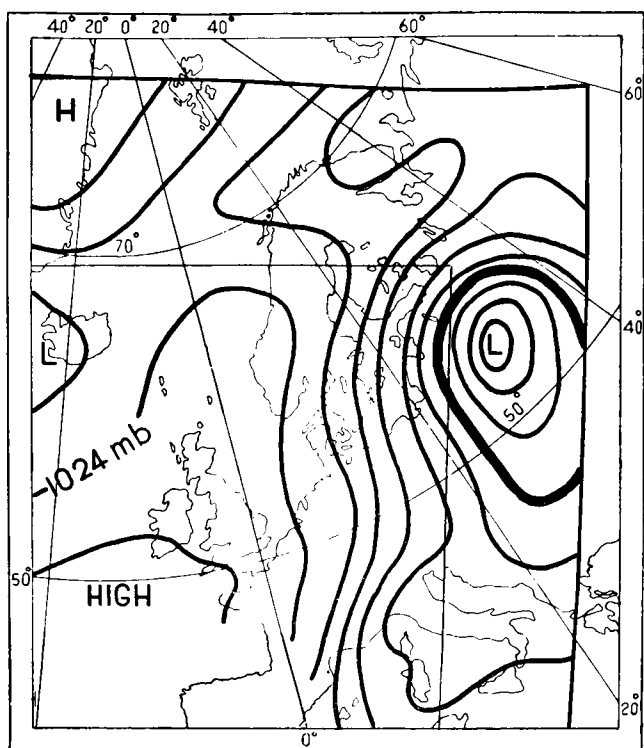


FIGURE 1 (a)—ACTUAL MEAN-SEA-LEVEL CHART FOR 0000 GMT,
20 APRIL 1959

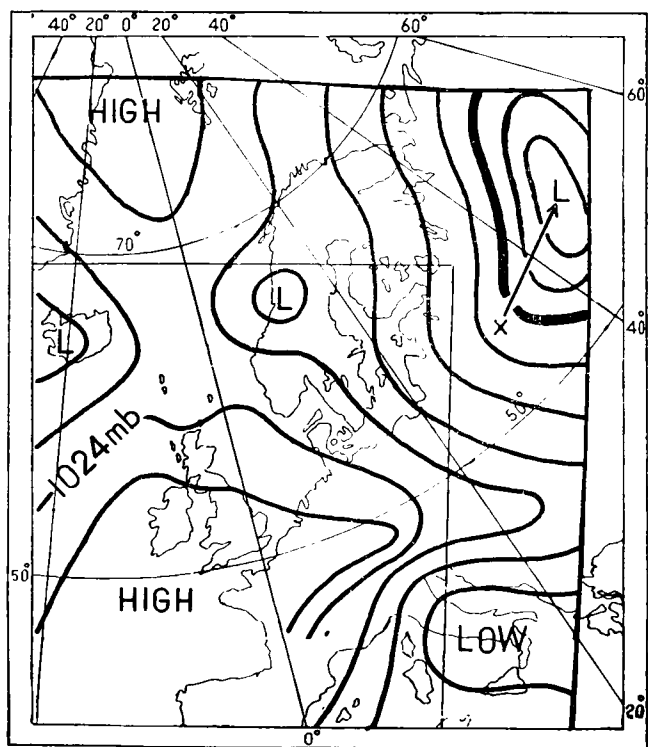


FIGURE 1 (b)—ACTUAL MEAN-SEA-LEVEL CHART FOR 0000 GMT,
21 APRIL 1959

The arrow shows the 24-hr track of the depression.

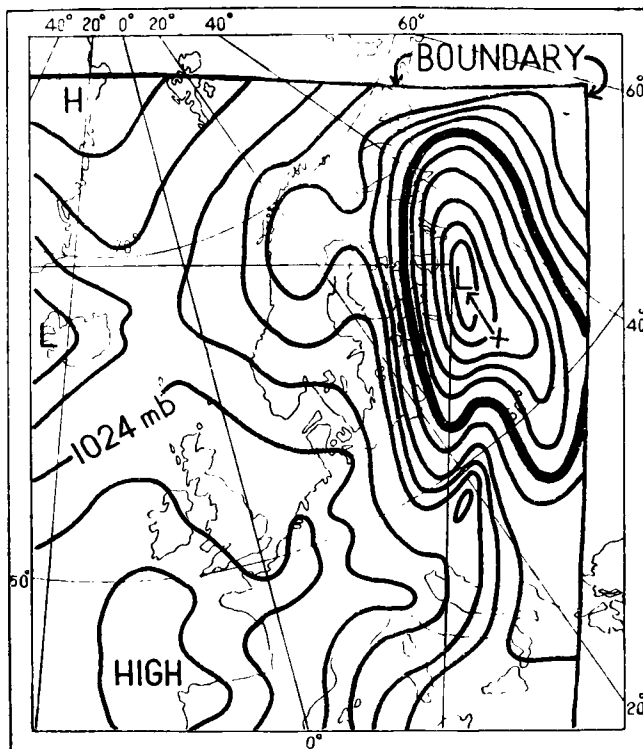
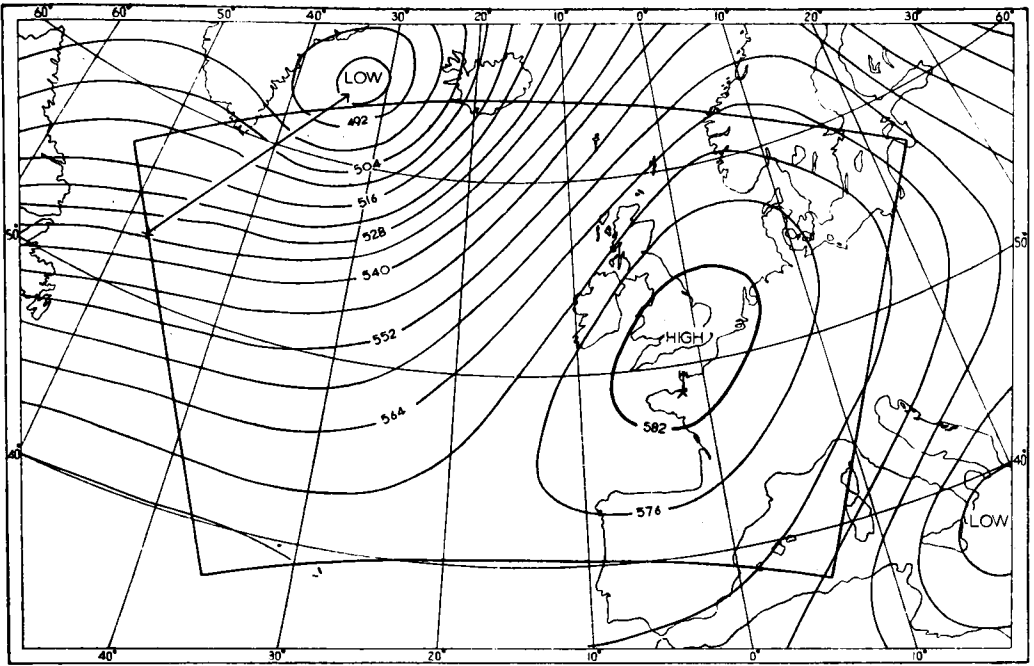


FIGURE 1(c)—24-HOUR NUMERICAL FORECAST OF MEAN-SEA-LEVEL CHART
FOR 0000 GMT, 21 APRIL 1959, USING THE TWO-LEVEL
SAWYER-BUSHBY MODEL

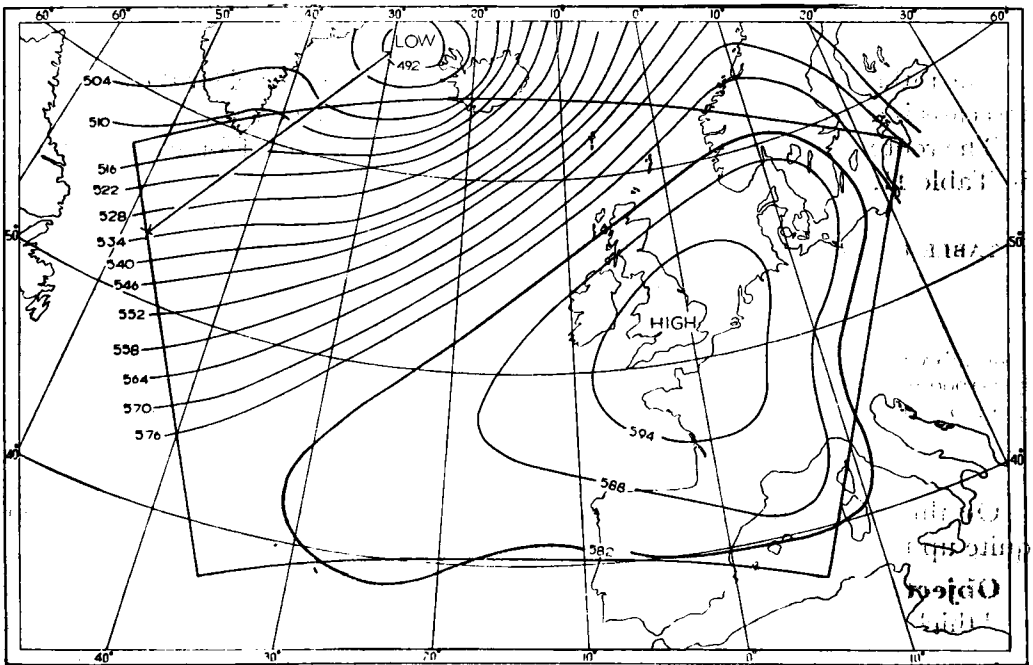
The arrow shows the 24-hr track of the depression.
The error in this forecast is explained in the text.

1000-millibar prediction in the north-east corner of the computing area, at the corner of the verification area. At the 500-millibar level the numerical forecast was almost, but not quite, correct. Inevitably the model failed to predict a slight change in orientation of the 500-millibar flow close to the eastern boundary. By itself this failure was not a major error, but the associated failure to advect warm air out across the eastern boundary was more noticeable and the 1000-millibar forecast, being the small difference between the almost correct 500-millibar contour heights and the excessive thickness values, included an excessively deep depression centred near the north-eastern corner of the verification area. In fact the depression had moved east-north-east and was filling up.

Another noticeable feature of the numerical forecasting errors during the four-month experiment was the presence of spurious anticyclogenesis, particularly in situations which included a broad flow from the south or west—like that shown in Figure 2. The anticyclone was incorrectly predicted to broaden and intensify, and this type of error is primarily due to using geostrophic instead of gradient winds in the relationship between contour heights and vorticities at the beginning and towards the end of each time step in the numerical prediction process. Notice on the forecast chart the excessively strong flow from the south-west, between the intense anticyclone and the depression whose movement was forecast fairly well. With such a strong flow it is not surprising that the thickness lines were advected too far. The tongue of warm air was predicted to move so quickly northwards that it entered the circulation of the 500-millibar depression



(a) Actual 500-millibar contours, in decametres, for 0000 GMT, 18 February 1959



(b) 24-hour numerical forecast of 500-millibar contours, in decametres, for 0000 GMT, 18 February 1959, using the Sawyer-Bushby model

Verification data: root mean square height error = 143 m;
root mean square vector wind error = 30 kt.

FIGURE 2—A CASE OF SPURIOUS ANTICYCLOGENESIS

and was swept around to the western side of this depression. Thus the 1000-millibar forecast showed an excessively deep depression almost underneath the 500-millibar low.

Verification indices.—The root mean square errors which are included in the diagrams already referred to, may be used as tentative guides to the overall quality of the forecast charts. These are not the only verification indices considered at Dunstable. While the test of the Sawyer-Bushby model was in progress another numerical experiment⁶ was being carried out to build up some experience of the usefulness of various indices such as correlation coefficients and coefficients of analogy. Their suitability as indicators of the success of a forecasting system was tested by comparing their values for a set of forecasts with the subjective assessments made by a panel of six forecasters. It was realized that no single index had been devised to describe all the relevant qualities of a forecast chart; however, out of all the indices tested, the root mean square contour height error came nearest to expressing numerically the consensus of opinion of the panel, and Table I shows values of this index for the complete set of forecasts made during the four-month experiment.

TABLE I—ROOT MEAN SQUARE HEIGHT ERRORS IN 24-HOUR FORECASTS

			Sawyer-Bushby two-parameter model <i>metres</i>	C.F.O. 24-hour forecasts <i>metres</i>	"Persistence forecasts" <i>metres</i>
1000 mb level	...	...	80	60	75
500-1000 mb thicknesses	...	...	56	58	77
500 mb level	...	...	89	75	99

There were 59 cases in the period.

The rather high value of 80 metres at the 1000-millibar level for the numerical forecasts is due mainly to the effects of spurious anticyclogenesis.

The root mean square vector wind errors for the same set of forecasts are listed in Table II.

TABLE II—ROOT MEAN SQUARE VECTOR WIND ERRORS IN 24-HOUR FORECASTS

			Sawyer-Bushby two-parameter model <i>knots</i>	C.F.O. 24-hour forecasts <i>knots</i>	"Persistence forecasts" <i>knots</i>
1000 mb winds	...	...	30	21	31
500-1000 mb thermal winds			29	24	32
500 mb winds	...	...	30	25	36

There were 59 cases in the period.

On this statistical root mean square rating the numerical forecasts were not quite up to the standard of the CFO forecasts.

Objective analysis.—Before a forecasting computation starts, contour heights and thicknesses must be obtained for all the grid points involved. This initial data can be obtained by reading the required values off the contour and the thickness charts, and punching a data tape for insertion into the machine. But this takes time. So, during the four-month experiments, an alternative system was developed. Briefly, the scheme was to feed ordinary communications tapes, containing routine data in the synoptic code, into Meteor's tape reader. The machine was then programmed to extract and store relevant radio-sonde data for a wide area. Then the contour heights and thicknesses were computed for each grid point by fitting

a quadratic formula (with some empirical modifications) approximately to the nearest radio-sonde heights and winds and to the results of the previous day's 24-hour forecast.

The testing and development of this objective analysis,⁷ as it is called, was more difficult than the actual forecasting problem, but considerable progress was made during the four-month experiment and, when a second four-month test of the Sawyer-Bushby model was made during the summer of 1959, the automatic extraction of data and the objective analysis were reasonably fast and accurate.

The use of stream functions.—An attempt to eliminate spurious anticyclogenesis can be made by transforming the initial contour fields into stream-function charts.⁸ In effect this transformation means adjusting gradients to take cyclostrophic forces into account. The numerical prediction process may be applied to the stream-function chart, and a forecast stream-function field may be converted back into an ordinary contour chart.

Certainly the injection of a stream function into the prediction procedure does reduce spurious anticyclogenesis, but there are difficulties in applying the technique. The computations required to turn contours into stream functions are sometimes lengthy, and it is occasionally difficult to steer these computations past inherent mathematical pitfalls. A further problem of more synoptic interest arises from the use of stream functions to represent thicknesses in the usual numerical prediction techniques. The difference between stream-function changes at two pressure levels is not a simple thickness change which can be equated easily to the thermodynamical equation for thickness changes. In effect, the appropriate stream-function equations usually include a slight approximation which weakens the synoptic link between the contour and the thickness fields. Therefore, at the 1000-millibar level it is not surprising to find small but queer distortions in the forecast pattern. The use of the stream-function technique leads to a reduction in the root mean square contour height errors at 1000 millibars, but the synoptically unreal distortions of the contours usually preclude any improvement in the root mean square vector wind errors.

The effect of topography.—The numerical model used in the prolonged tests at Dunstable neglects the effect of topography, but it has been difficult to isolate specific errors due to this omission. The suspected topographical errors so far investigated have been mixed in indeterminate proportions with boundary effects and spurious anticyclogenesis. However, there is statistical evidence that the numerical predictions of 24-hour changes are at their worst over the parts of Greenland and central Europe within the verification area. So attempts are being made to include the effects of topography into the prediction model. Basically, the method is to superimpose on the parabolic vertical motion profile another plausible vertical velocity distribution with a ground-level value determined from the geostrophic flow and the broad-scale slope of the ground.⁹

A three-parameter model.—Early in 1960 a three-parameter model¹⁰ was formulated for use with Meteor. The basic principles used to derive the Sawyer-Bushby model were applied to both the 1000–600 and the 600–200-millibar layers. In each layer the vertical motion profiles were parabolic with zero values at the 1000- and the 200-millibar levels and continuity at the 600-millibar level. The associated thermal wind assumption allows a change in thermal wind direction and speed per unit depth at the 600-millibar level. This three-parameter model was subjected to a four-month test early in 1960. The basic input and

output were similar to those for the two-parameter model with the addition of a 200-millibar contour field.

Figure 3 shows a 24-hour forecast derived with the three-parameter model. Examples of the computed vertical motion over four points on the chart illustrate the flexibility of the profiles imposed on the system.

Computed vertical motion and rainfall.—It is pertinent to inquire whether or not the computed vertical motion can be used to forecast rainfall. A rough and tentative answer to this question may be gleaned from contingency tables showing the relationship between observed rainfall and the sign of the computed vertical velocities. Table III shows the relationship between computed upward and downward motion and observed rainfall for four stations which are close to grid points of the computing network.

TABLE III—COMPUTED VERTICAL MOTION AND OBSERVED RAINFALL

Stations	Averages of computed vertical motion for 0000, 1200 and 2400 GMT using three-parameter model (1000–200 mb)	Observations at stations	
		Rain	No rain
		<i>percentage of cases</i>	
Scilly, Elmdon, Stornoway, Tynemouth	UP	29	19
	DOWN	22	30

55 cases in the period 29 February to 10 June 1960.

Although it is fully realized that broad-scale vertical motion is only one of several important factors in the production of rainfall, the rather inconclusive relationships illustrated by Table III were disappointing. Several other forms of rainfall and vertical motion comparisons were tested, but with no better results. However, the result for the three-level model was at least better than that obtained for the two-level system; so it appears that the increased flexibility of the three-level model is at least an important step in the right direction.

Root mean square errors for the three-level model.—Tables IV and V show the root mean square contour height and vector wind errors for a set of 20 forecasts made by the Sawyer–Bushby model, the three-level model and C.F.O.

TABLE IV—ROOT MEAN SQUARE HEIGHT ERRORS IN 24-HOUR FORECASTS

				Two-level model	Three-level model	C.F.O.
				<i>metres</i>	<i>metres</i>	<i>metres</i>
1000 mb...	...	...	...	94	72	71
500–1000 mb	...	...	...	68	58	67
500 mb ...	...	...	...	98	77	87
200–500 mb	...	...	...	62*	56	59
200 mb ...	...	...	...	114*	96	89

20 cases were used.

* Forecasts obtained by extrapolation upwards.

TABLE V—ROOT MEAN SQUARE VECTOR WIND ERRORS IN 24-HOUR FORECASTS

				Two-level model	Three-level model	C.F.O.
				<i>metres</i>	<i>metres</i>	<i>metres</i>
1000 mb...	...	...	...	37	25	26
500–1000 mb	...	...	...	41	30	27
500 mb ...	...	...	...	31	28	30
200–500 mb	...	...	...	29*	28	25
200 mb ...	...	...	...	44*	34	31

20 cases were used.

* Forecasts obtained by extrapolation upwards.

These tables illustrate the superiority of the three-level model.

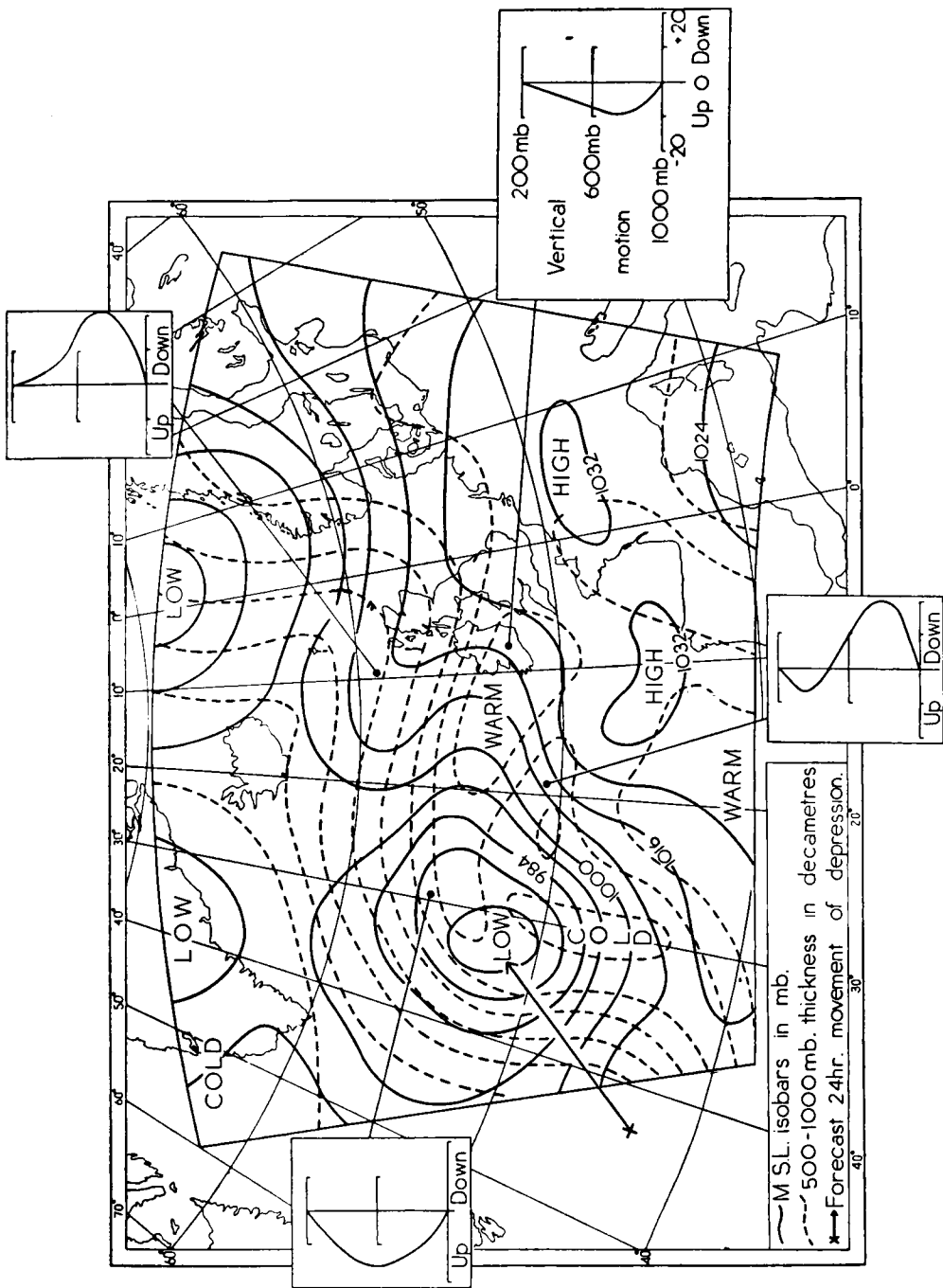


FIGURE 3—24-HOUR NUMERICAL FORECAST FOR 0000 GMT, 27 FEBRUARY 1959
USING THE THREE-LEVEL MODEL

The selected vertical motion profiles (applicable to the spots marked on the chart) are determined from the computed mean vertical speeds in the two layers 1000-600 and 600-200 millibars.

A hemispheric model.—The staff of the Dynamical Research Section (M.O.II) have started to explore the practicability of making forecasts on a hemispheric scale using Meteor. At present the principal problems arise more from computing rather than meteorological difficulties. Simple barotropic forecasts at the 500-millibar level have been made but they are not yet satisfactory. However, these computational problems are being resolved and at some later stage hemispheric forecasts using at least a two-level model will be attempted.

Movement of fronts.—Mr. Sawyer has already tested a computing procedure for advecting fronts with the geostrophic winds obtained in the numerical prediction process. The procedure appears to produce reasonably accurate results—provided, of course, that the numerical prediction of the contour fields is accurate.

Numerical forecasts of temperature and humidity fields have not yet been produced but the computing procedures for making the attempt are being developed.

The routine operational procedure.—The three-parameter model is considered useful enough to put into routine use as an aid to the C.F.O. forecasters. The routine procedure will start very soon. Each day the midnight synoptic data will be used to start off a three-parameter forecast for the 1000-, 500- and 200-millibar contour fields, the intervening thicknesses and the vertical motion. The forecasting process will stop at the six-hour time step, then a selection of the 0600 GMT synoptic data will be fed into the machine and the six-hour forecast will be corrected wherever data is available. Then the forecasting process will continue until forecast fields for 0600 GMT the next day are obtained. The aim is to have this forecast available by 0930 GMT each day. In judging the usefulness of each forecast the C.F.O. forecasters will have a number of charts, diagrams and statistics at their disposal to indicate the characteristics of the numerical forecasting errors.

In opening the discussion, the *Director-General* said that he looked forward to numerical forecasts being available to the Dunstable forecasters for criticism to root out the errors in the numerical systems. He was not too concerned at errors in particular forecasts, as long as they shed some light on the behaviour of the atmosphere.

After stressing that we should not allow premature empiricism to creep into our operational procedures, he welcomed the attempts to make hemispheric forecasts with the aid of Meteor. He noted that, with fairly simple assumptions concerning radiation, American workers had managed to construct numerical models which appeared to be consistent with features of the general circulation. It may be possible to extend the range of numerical prediction by putting specified rather than random disturbances into a general circulation model.

Mr. C. J. Boyden criticized statistical methods of judging forecasts and said that, at present there was no adequate substitute for the subjective assessment of forecasts based on experience in using them.

Mr. E. Knighting said that statistics were used as only a tentative numerical guide to the quality of the forecast.

Mr. N. E. Davis asked why the 200-millibar chart was chosen for numerical prediction, as the 200-millibar chart is a most difficult one to draw. The errors in radio-sonde heights are such that the chart cannot be drawn with any certainty. He suggested that ± 30 to 60 metres be added to all 200-millibar heights over the Atlantic and the numerical forecast based on these heights be compared

with that based on the original heights. If significant differences occurred then the conclusion would be that the 200-millibar chart was not suitable for numerical predictions.

Above 500 millibars, divergence increases to a maximum somewhere in the region of 300 or 250 millibars and then decreases again up to a level somewhere above 100 millibars, so that it would be preferable to use both the 300- and 100-millibar levels, though the 300-millibar level would be difficult to deal with, as it is the geostrophic motion in the vicinity of the jet stream that is the cause of development.

Mr. C. L. Hawson, referring to Mr. Davis's contribution, said there were indeed uncertainties in the 200-millibar analysis which are a handicap to any forecasting system. At C.F.O. some forecasters were now analysing the 100-millibar chart early, the 200-millibar chart being drawn in the light of the analysis at both 300 and 100 millibars. He believed the vertical velocity usually changed sign at some variable level above 300 millibars and after reaching another maximum, in summer at least, decreased to near zero at and above 100 millibars. He thought the 300-millibar surface more representative of the level of maximum divergence than the 200-millibar surface.

Mr. A. H. Gordon said that forecasters are particularly interested in the 1000-millibar chart and that he would therefore refer specifically to this level. Have comparisons of forecasts with actual charts been made on the basis of synoptic types, for example rapidly deepening depressions in their early stages, and polar or tropical lows? In fact, is all the dynamics included in the model equations as applied to these different systems? Then there are the large surges of pressure which are so difficult to forecast conventionally, yet which lead to changes of type, blocks, etc. Friction has not been mentioned in describing the model, but we all know that quite a few millibars can be gained or lost on account of friction.

With regard to spurious anticyclogenesis, could it be that the dynamics is there but that the spurious pattern is dynamically unstable so that the flow settles down and readjusts itself to the kind of pattern actually observed? Mr. Gordon also asked if there are any plans to extend the time scale to the 30-day CLIMAT period and to the infinite period of the general circulation.

Mr. M. K. Miles showed two cases of cutting-off which the two-level model failed to forecast. The first, made at 0000 GMT, 16 April 1959, showed that the trough was moved on too fast and contour heights at 500 millibars were not reduced sufficiently at the bottom of the trough or raised sufficiently in the narrowing neck over south-west England. Essentially the same errors were made in the forecast made at 0000 GMT, 10 September 1959.

In terms of cyclonic vorticity the actual charts differed from the forecast ones in having the maximum vorticity displaced towards the bottom of the trough with a region of very low values further north. One can suggest three main reasons for this difference:

- (i) The numerical forecast started with an analysis at 500 millibars which had too little vorticity in the rear of the trough (that is, in the north-westerly flow);
- (ii) the model was incorrectly advecting the existing vorticity; and
- (iii) the model was neither producing new vorticity at the bottom of the trough nor destroying vorticity further north along the axis.

If a forecast based on a 500-millibar analysis containing the maximum amount of positive vorticity behind the trough consistent with the observations still showed this difference, then the forecaster would know that he should not expect the two-level model to predict the cutting-off process.

Mr. H. B. Rowles maintained that identification of the positions of jet streams from upper air charts is important and wanted to know to what extent this is possible on charts produced by numerical prediction. Does smoothing result in the loss of these features? The concentration of considerable wind errors in the Mediterranean mentioned by *Mr. Wallington* may well be due to the inadequate prediction of northward displacements of the subtropical jet stream in that region.

Dr. R. C. Sutcliffe said that he would like to encourage the study of individual cases of special interest, especially where forecasts have gone wrong in a qualitative way. The cutting-off process and, allied with this, the blocking development, are not yet satisfactorily explained in dynamical terms and quantitative calculations using different physical assumptions would be of great interest. There is limited scientific interest in minimizing statistical averages by trying this or that variation in the procedures—this savours of a reversion to empiricism. It may be necessary if the objective is to develop quickly the best system for regular practical use, but it is equally important and much more interesting to gain a scientific understanding of different types of dynamical development.

With the changes of organization associated with the move of the Meteorological Office to its new headquarters at Bracknell, more research effort will be devoted to the dynamical problems of long-range forecasting and the general circulation.

Mr. J. S. Sawyer said that blocking and cutting-off are large-scale processes not easy to get into the area used. Improving the model gradually seems the most satisfactory way of making progress at present.

In closing the discussion, the *Director-General* amplified his remarks on the need to acquire a better understanding of the atmosphere before expressing his thanks to *Mr. Wallington* for opening the discussion and to the various contributors.

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DUSTSTORM AT ADEN, 0830 GMT, 1 OCTOBER 1958

To face p. 89]



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DUSTSTORM AT ADEN, 0830 GMT, 1 OCTOBER 1958

NOTES AND NEWS

A new housing for the sensitive cup anemometer, Mark I

The photograph facing page 69 shows a new housing for the electric contact type of the sensitive cup anemometer originally designed some twenty years ago by Professor P. A. Sheppard. The new housing has been designed by Dr. H. Charnock and Mr. F. E. Pierce of the National Institute of Oceanography to minimize the interference with the wind flow. By filling the instrument with carbon tetrachloride it can in its new form be used under water as a sensitive current indicator. For further details reference should be made to the article by Charnock and Pierce in the *Journal of Scientific Instruments*.¹

REFERENCE

1. CHARNOCK, H. and PIERCE, F. E.; New housing for the sensitive cup-contact anemometer Mk. I. *J. Sci. Instrum., London*, **36**, 1959, p. 329.

CORRIGENDA

Variation of surface wind velocity with height in hilly terrain

The following amendments should be made to Table III on page 290 of the November 1960 *Meteorological Magazine*:

Delete the figures in the columns headed "Sept. 1959" and "Nov. 1958–Oct. 1959" and the last two rows of the column for "Feb. 1959" and *substitute*:

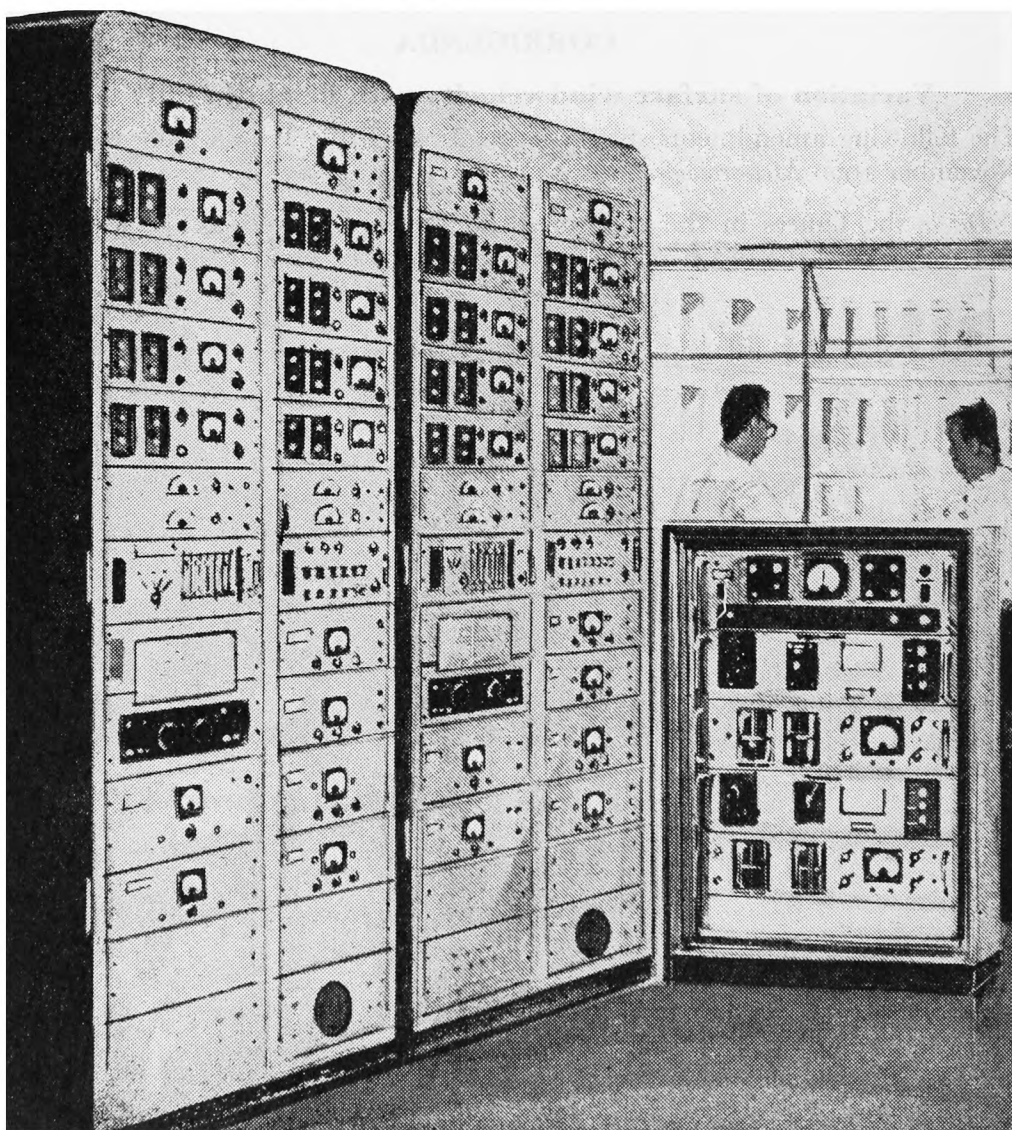
Sept. 1959 ...	—	4·03	4·72	4·80	4·43	3·98	4·01	4·06	3·37	3·88	3·66	4·10
Nov. 1958–Oct. 1959	—	3·69	3·51	3·39	3·42	3·56	3·20	3·20	2·89	2·84	2·71	3·19
Feb. 1959										3·72	4·66

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RAINFALL IN ENGLAND AND WALES DURING THE FIVE MONTHS JULY TO NOVEMBER, 1960, WITH SPECIAL REFERENCE TO SOUTHERN ENGLAND

By R. E. BOOTH

After the wettest winter in England and Wales since that of 1915 – 16, the spring and early summer of 1960 were comparatively warm and dry. The second half of the year however will long be remembered for its exceptional rainfall particularly in southern England during the five months July to November. In contrast rainfall in Scotland was below the average during three of these five months.

Taking England and Wales as a whole, the general rainfall of 26.9 inches over the five months July – November 1960 was more than in any similar five-month period in a series of rainfall estimates going back to 1727. These estimates are probably quite reliable from about the year 1820 but there is naturally less confidence in their reliability as the series extends backwards. In this series since 1727 the nearest approach to a total rainfall for the period July – November as large as that in 1960 was in the year 1852, when records were reasonably reliable and when 26.2 inches were recorded. Hence it seems likely that over England and Wales the period July – November 1960 was the wettest such period for nearly two and a half centuries.

Table I gives in ranking order the ten wettest July – November periods in England and Wales since 1727 and shows the year of occurrence, the total general rainfall in inches during the five-month period, the percentage of the 1916 – 50 annual average rainfall this represents and the percentage of the 1916 – 50 average rainfall during the period July – November. The 1916 – 50 average general rainfall over England and Wales for the period July – November is 17.1 inches and for the year 36.5 inches.

Only two years in the present century, 1903 and 1954, appear in these first ten, but if the table were extended to include the first 25, the following years would also appear: 1930 (12th, 60.2 per cent), 1927 (13th, 60.2 per cent), 1950 (17th, 59.1 per cent), 1946 (21st, 57.7 per cent), 1944 (22nd, 56.9 per cent) and 1924 (23rd, 56.6 per cent). The figures in brackets give the order in the 25-year table and the percentage of the annual average (1916 – 50) of rain which fell during the five-month period July – November of that year.

TABLE I—TEN WETTEST JULY – NOVEMBER PERIODS IN ENGLAND AND WALES
SINCE 1727

Year	Rainfall inches	Percentage of annual average per cent	Percentage of period average per cent
1960	26.9	73.7	157
1852	26.2	71.9	153
1841	24.3	66.5	142
1775	24.2	66.2	142
1768	24.0	65.9	141
1903	23.6	64.5	138
1875	23.5	64.3	137
1872	23.2	63.7	135
1799	23.2	63.7	135
1954	23.0	62.9	134

Table II gives for England and Wales and for nine districts of Great Britain the percentage of the 1916 – 50 average rainfall for each of the five months July – November 1960, and the number of days of measurable rain above or below the monthly average. The districts are those used in the *Monthly Weather Report* of the Meteorological Office and the values are based on five well distributed stations within each district. The Scottish districts are included to show that rainfall in Scotland was to a large extent below the average during the period being considered.

TABLE II—PERCENTAGE OF AVERAGE MONTHLY RAINFALL AND NUMBER OF
DAYS OF MEASURABLE RAIN ABOVE OR BELOW THE MONTHLY AVERAGE

District	July		August		September		October		November	
	per cent	no. of days	per cent	no. of days	per cent	no. of days	per cent	no. of days	per cent	no. of days
North Scotland	92	+ 1	133	+ 3	81	— 5	58	— 1	88	+ 1
East Scotland	106	+ 5	153	+ 7	74	0	198	+ 7	112	+ 4
North-east England	154	+ 7	113	+ 5	124	+ 1	268	+ 10	138	+ 6
East England	125	+ 7	164	+ 4	193	+ 2	234	+ 9	134	+ 7
Midlands	136	+ 6	123	+ 2	183	+ 1	203	+ 8	151	+ 8
South-east England	148	+ 7	169	+ 6	174	+ 3	230	+ 8	153	+ 10
West Scotland	114	+ 7	92	+ 2	78	— 2	56	+ 4	141	+ 5
North-west England and north Wales	136	+ 4	133	+ 3	109	+ 1	84	+ 2	184	+ 8
South-west England and south Wales	152	+ 10	155	+ 5	185	+ 2	213	+ 6	155	+ 9
England and Wales	142		139		150		199		153	

It will be noticed that southern and eastern England was the wettest part of the country nearly every month. In November the rainfall pattern was a little different from the other months with considerably above average rain in the north-west, but even so rainfall in southern England was more than half as much again as normal.

Figure 1 shows the percentage of the 1916 – 50 average rainfall in England and Wales during the five-month period July – November 1960. Southern England particularly stands out as having had rainfall greatly in excess of the average for the period. Two areas, one near Exeter and the other near the Sussex coast, received more than twice their average amount. Rainfall was more than 175 per cent of the average over the greater part of all but two (Cornwall and Kent) of the counties bordering the English Channel, over the Thames and Severn valleys, and locally in Cornwall, Kent, Lincolnshire,

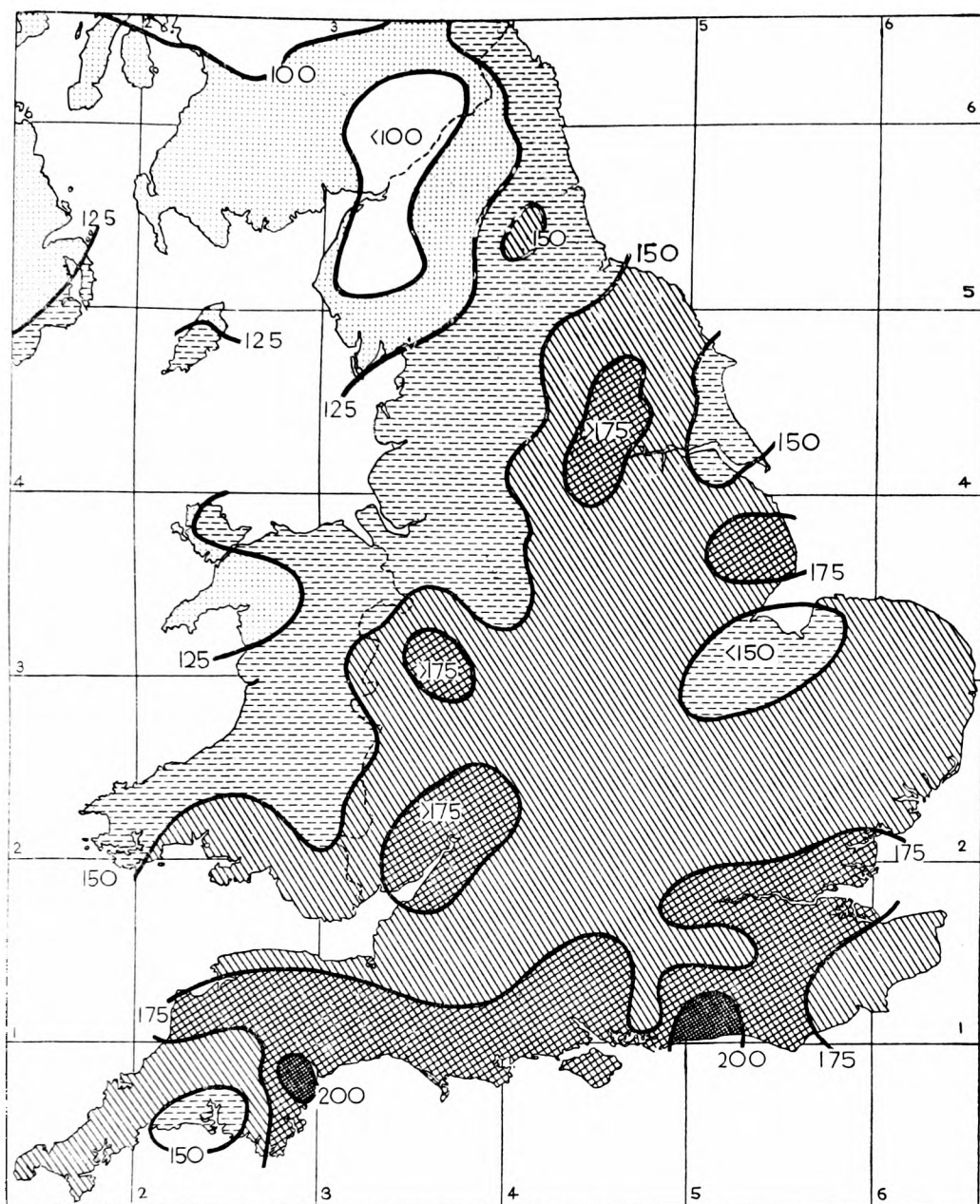


FIGURE 1—RAINFALL FOR JULY – NOVEMBER 1960 EXPRESSED AS A PERCENTAGE OF THE AVERAGE

Shropshire and Yorkshire. Severe floods occurred in all these areas. Only over a small area in the extreme north-west of England was rainfall below the average. A similar map was drawn showing the rainfall during the five-month period as a percentage of the 1916 – 50 average annual rainfall. This shows that rainfall in the five months was more than 90 per cent of the annual average south of Exeter, near the Sussex and Essex coasts and in parts of Lincolnshire. Worthing had almost as much rain during these five months (99 per cent) as falls on an average during the whole year.

Monthly percentage rainfall maps show large areas during each of the five

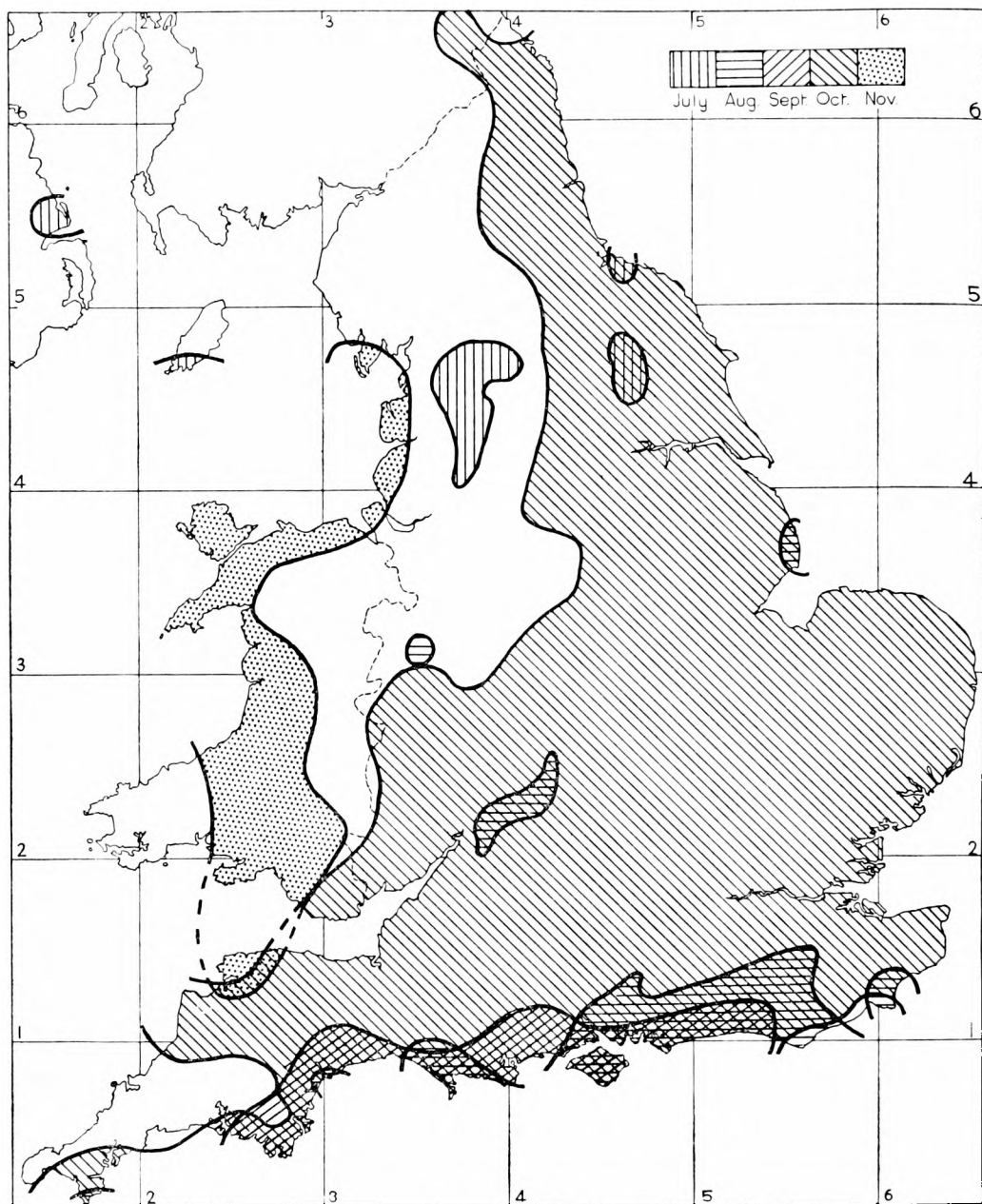


FIGURE 2—AREAS WITH MORE THAN 200 PER CENT OF THE AVERAGE RAINFALL,
DURING JULY – NOVEMBER 1960

months July – November where rainfall was more than twice the average. These areas for each of the five months have been superimposed one upon another in Figure 2. It will be seen that more than twice the average amount of rain fell during each of the three consecutive months August, September and October over an area near Exeter, southern Dorset, the southern part of Hampshire and Sussex extending from near Milford-on-Sea to Seaford, and over the Isle of Wight. More than twice the average also occurred during at least two of the five months in parts of Gloucestershire, Lincolnshire and Yorkshire. A striking feature of the map is the large part of the country which had more than twice the average rainfall during October.

Weather was persistently cyclonic in character from July to November and noteworthy heavy rainfall occurred in some part of England and Wales during each of the five months.

July.—Apart from the first few days July was dominated by cyclonic activity, a well developed frontal system or depression reaching the British Isles from the Atlantic every few days.

Weather was cool and wet generally with frequent thunderstorms. On the 6th heavy rain fell continuously from about 0300 GMT until 2359 GMT south of the forest of Bowland, Yorkshire (West Riding); over 5 inches was recorded in 24 hours at a number of places and there was considerable flooding in the area.

August.—An extensive low-pressure area over north-west Europe maintained light, predominantly northerly winds over the British Isles until the 19th, depressions from the Atlantic passing to the south of the country. During the next week winds became generally south-westerly under the influence of an intense Atlantic depression which gradually filled as it moved slowly south-east towards Cornwall. From the 25th until the end of the month a complex but shallow low-pressure area covered much of the country.

The cool, wet and thundery weather continued throughout August. During an unusually severe thunderstorm at Old Maldon, Surrey, on the 7th, about $3\frac{1}{4}$ inches of rain fell in 2 hours. From the 9th to the 11th there was heavy and persistent rain along part of the south coast, Brighton recording more than 5 inches of rain during this period, more than twice its normal rainfall for the whole month. On the 13th at Harlech, Merionethshire, one inch of rain fell in 15 minutes.

September.—The first week of September was changeable with frontal systems moving east across the country, but the second week was predominantly anticyclonic. Low-pressure systems lay over or near the British Isles during most of the third week but thereafter weather was again anticyclonic until the 26th, after which southern and central districts came under the influence of a complex depression centred off south-west England.

The outstanding feature of September's rainfall was the resulting disastrous series of floods in south-west England at the end of the month. The flooding was mainly due to four days of exceptionally heavy rain beginning on the 27th, some stations during this period recording as much as 5 inches. Figures 3 and 4 are based on a close network of rainfall stations and show the distribution of rainfall in the parts of southern England most affected by heavy rain on the 29th and 30th respectively. On the 29th nearly 4 inches of rain fell in the catchment-area of Dartmoor and over 2 inches in the Teignmouth and Exeter areas, while on the 30th 3 inches or more was recorded in 24 hours over Dartmoor, Exmoor and in the Exeter and Seaton areas.

October.—Apart from the week 10th - 17th when high pressure lay to the west or over the British Isles, a complex low-pressure system persisted for most of October off our south-west coasts and associated troughs and secondaries moved north-eastwards across the country.

Rainfall was three times the average in west Somerset, east Devon, Buckinghamshire, Lincolnshire and the East Riding of Yorkshire. More than four times the monthly average fell in the Exeter area. The sequence of days with exceptionally heavy rain in southern England which began during the last week of September continued until 8th October. Renewed flooding occurred in south-west England and later in eastern England. In thundery outbreaks

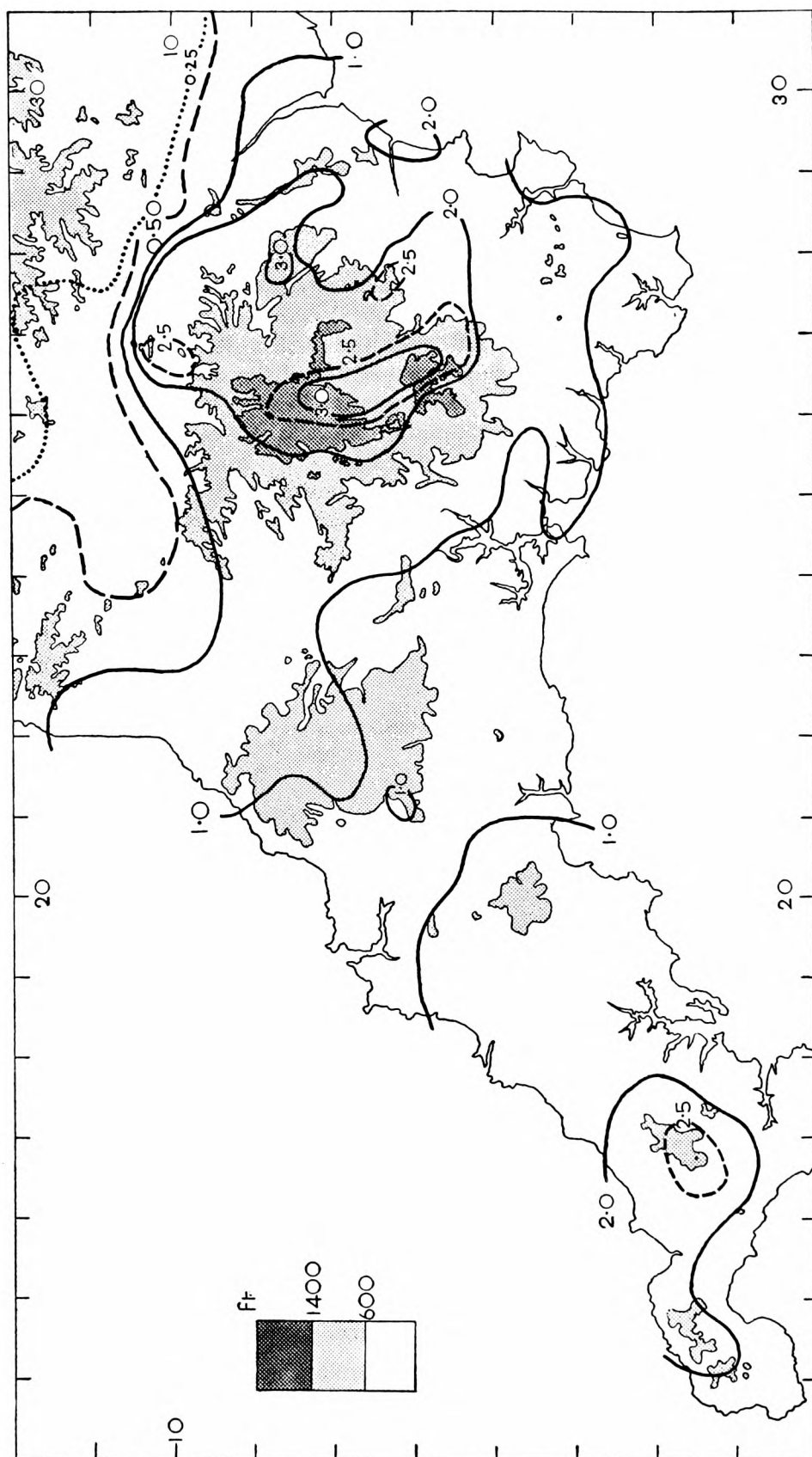
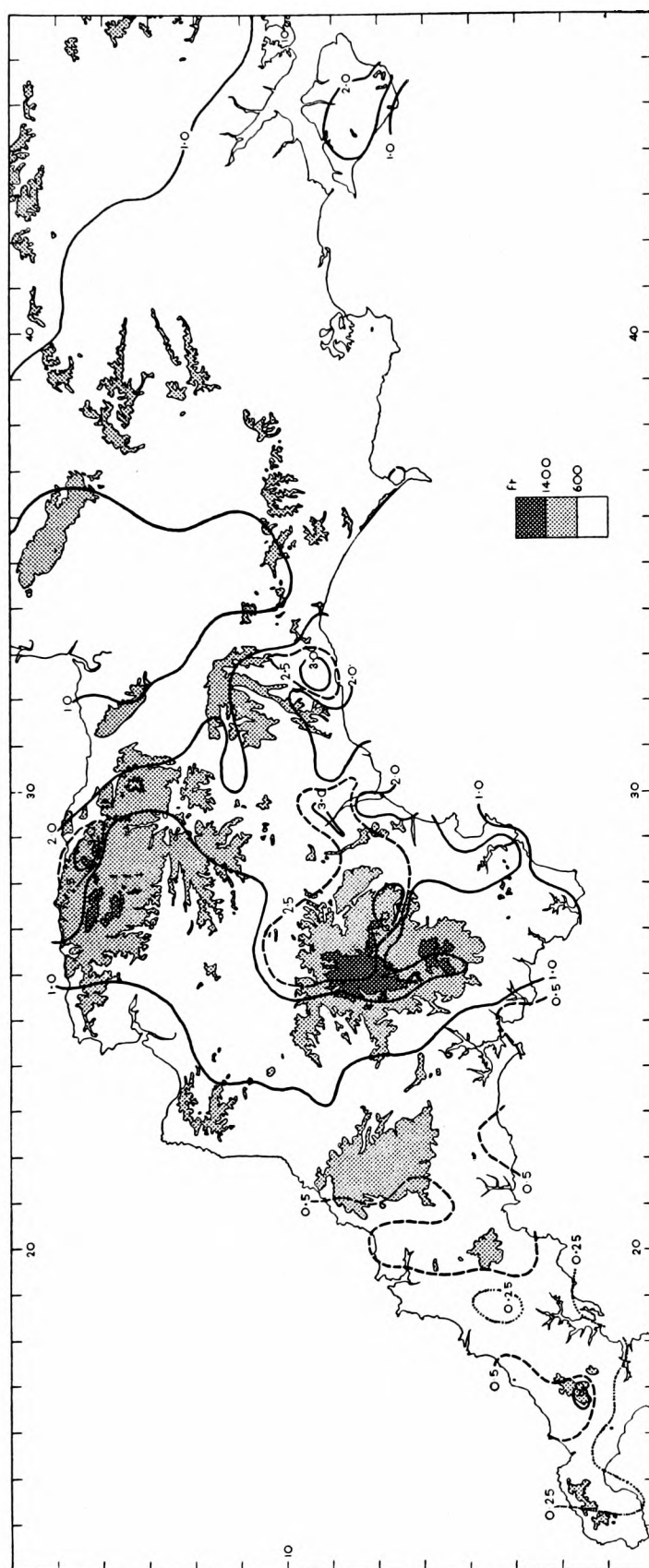


FIGURE 3—RAINFALL (INCHES) FOR THE 24 HOURS BEGINNING 0900 GMT,
29 SEPTEMBER 1960



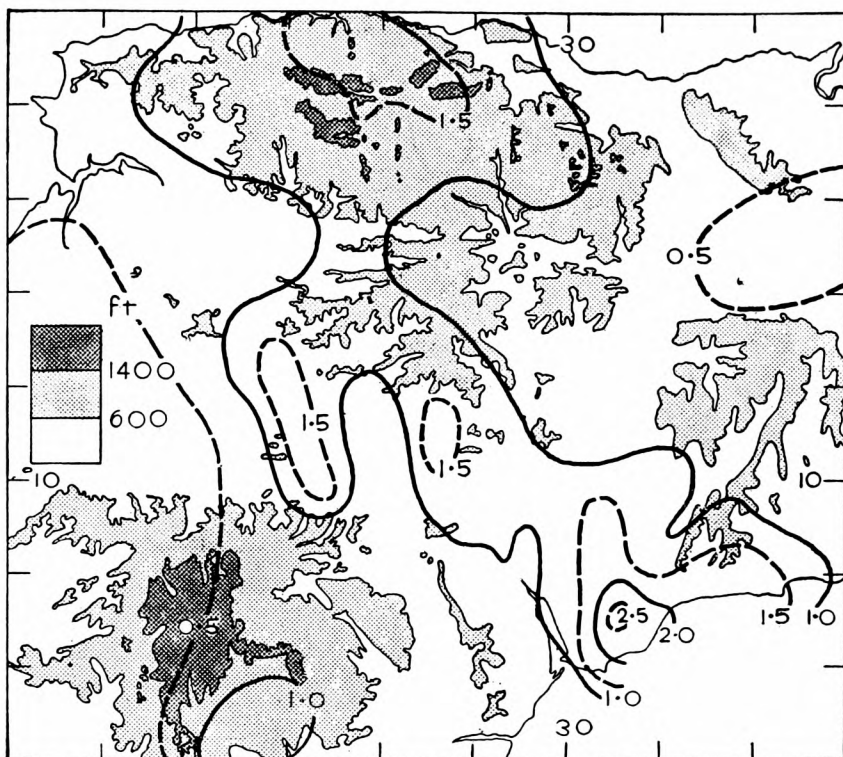


FIGURE 5—RAINFALL (INCHES) FOR THE 24 HOURS BEGINNING 0900 GMT, 6 OCTOBER 1960

during this period many places had more than 3 inches of rain in a few hours. Figures 5, 6 and 7 are maps of daily rainfall on the 6th, 8th and 26th respectively for parts of Devon and adjacent areas. Following the extremely heavy rain which fell over much of Devon on the 26th, rivers continued to rise and many in the county were at a higher level than recorded this century and in Exeter flooding was very serious.

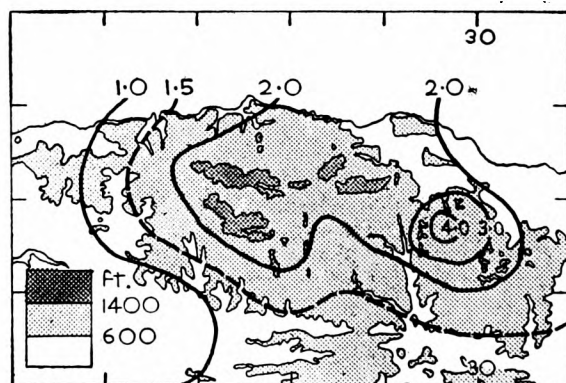


FIGURE 6—RAINFALL (INCHES) FOR THE 24 HOURS BEGINNING 0900 GMT, 8 OCTOBER 1960

November.—November weather also was mostly cyclonic in character with a well developed frontal system crossing the country every few days.

The month had a stormy end and beginning. Some of the heaviest rainfall

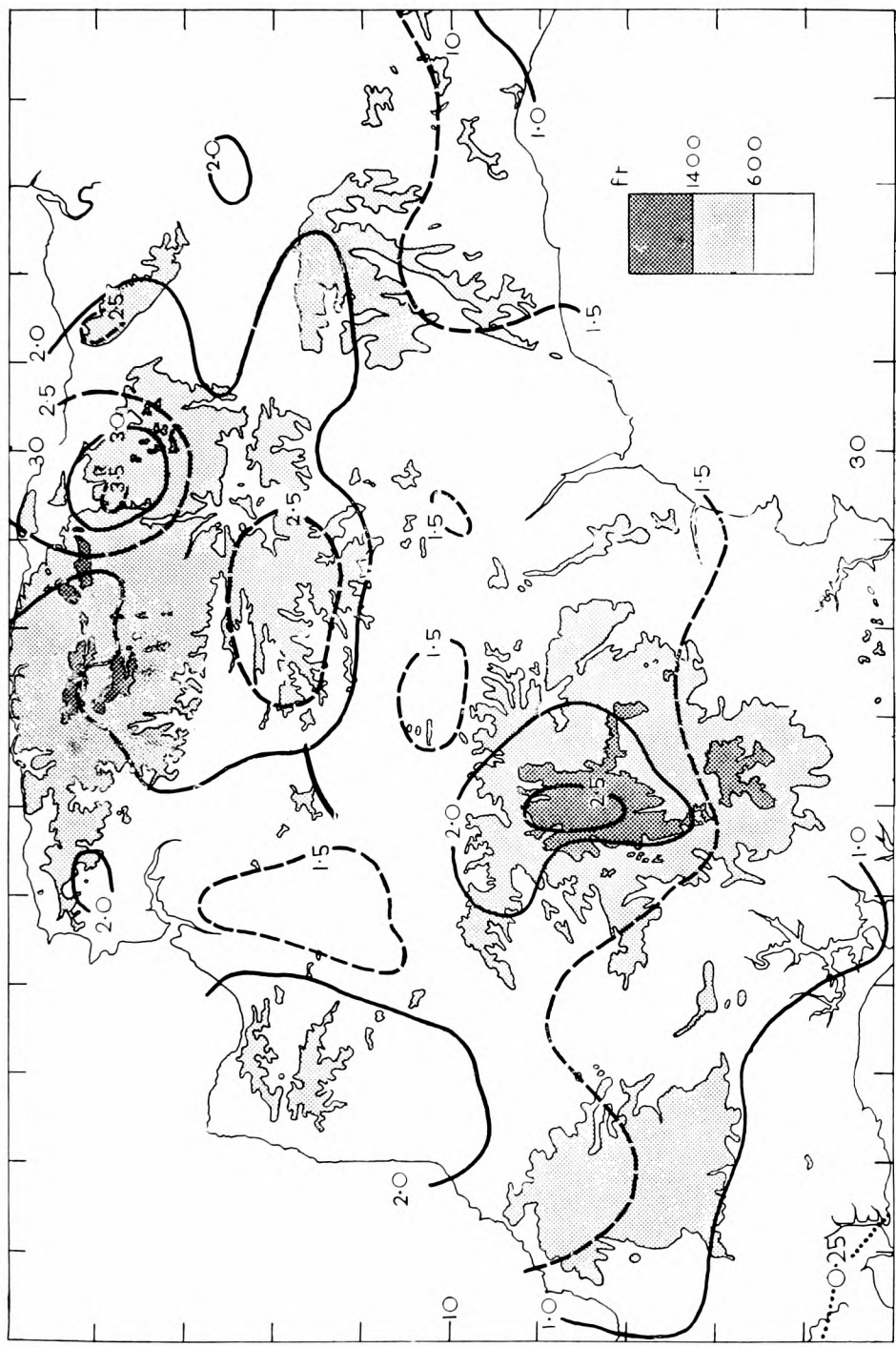


FIGURE 7—RAINFALL (INCHES) FOR THE 24 HOURS BEGINNING 0900 GMT,
26 OCTOBER 1960



Photograph by J. Konieczny

CLOUD DEVELOPMENT AT LITTLE RISSINGTON ON 11 JULY 1960
(see p. 120)

of the month occurred during the first three days, and it was particularly heavy in Wales and north-west England on the 1st. In Kent and Sussex on the 2nd there was extensive flooding, while on the 3rd 1·1 inches of rain were recorded in 35 minutes at Stanmore, Middlesex. Flooding occurred in many parts of the country during the month, but not on such a scale as in south Devon in October. In Devon the floods amounted to a disaster of the first magnitude. The greatest damage was near Exeter and in east Devon, but reports of flood damage were received from many areas of the country. About 2,000 houses were flooded, some being completely destroyed and others damaged beyond repair, and considerable damage was done to business premises, livestock and agricultural land. The floods are reported to have done more damage to Devon's railway system than occurred throughout the last war, and the dislocation to have been more serious than experienced at any time this century.

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HAIL IN RELATION TO THE RISK OF ENCOUNTERS IN FLIGHT

By A. F. CROSSLEY, M.A.

Introduction and summary.—The minimum size of hailstone likely to damage a supersonic aircraft needs to be determined in relation to existing or projected aircraft materials, and the chance of encountering hail larger than this minimum should be ascertained as far as possible. An article in *The MATS Flyer*¹ includes in a diagram cases of damage with hailstones as small as 0·05 inches (1 mm) diameter. This implies that practically any hail encountered is liable to damage existing aircraft with cruising speeds in the neighbourhood of 250 knots. If this speed is increased for supersonic aircraft by a factor of 4 to 8, the possible damage from hail, of whatever size, becomes evident. Strengthening the aircraft sufficiently to give protection from the impacts is likely to be practicable only for stones up to a certain rather small size, but there are considerable advantages if this size can be taken as at least 1·5 cm diameter. Stones larger than this would need to be avoided with the help of radar detection or otherwise, or by restricting flights to those areas, seasons or time of day in which large hail is not expected. For supersonic aircraft, the risk of encountering hail concerns the climb and descent stages in all latitudes and also flight up to about 55,000 ft in subtropical and equatorial latitudes; in higher latitudes, cruising flights above about 40,000 ft would almost always be within the stratosphere and so out of reach of hail on nearly all occasions.

Forms of hail.—Hail occurs in various forms which may be classified as follows²:

Hail. More or less spherical stones of ice, but sometimes of irregular shape, ranging in diameter from about 1 mm to 25 mm or more. The stones are usually composed of alternate layers of clear and opaque ice, but occasionally they consist entirely of clear ice.

Small hail. Semi-transparent round or conical grains of ice a few mm in diameter. Each pellet usually consists of a nucleus of soft hail (graupel) surrounded by a thin layer of clear ice which gives it a glazed appearance.

Ice pellets (American term sleet) are transparent, more or less globular grains

of ice up to about 5 mm in diameter. The interiors may be liquid and the ice shell may burst on striking a hard surface.

Soft hail, graupel or snow pellets. These are white, opaque, rounded or conical pellets of diameter up to about 6 mm. They consist of a central crystal covered with frozen cloud droplets (rime). They are easily compressible and apt to shatter on striking a hard surface.

The remainder of this note is concerned mainly with "hail" and "graupel" only.

Density of hail.—This can vary from about 0.1 to 0.9 gm cm⁻³ according to structure. Ordinary hail is often assumed to have a density of 0.7 to 0.9, the latter figure corresponding with clear ice; soft hail or graupel is often assumed to have a value of 0.3.

Size of hail.—*The size of hail observed at the ground* usually refers to the largest stones in any particular fall. Diameters up to about 5 inches (13 cm) have been reliably reported. Mason² quotes the following figures for the frequency distribution of the sizes of the largest hailstones observed in the Denver area, Colorado, during 1949 – 55.

TABLE 1—DISTRIBUTION OF HAILSTONE SIZES FOR THE DENVER AREA, COLORADO, 1949 – 55

	Diameter in.	No. of cases
Grain	< $\frac{1}{4}$	10
Currant	$\frac{1}{4}$	122
Pea	$\frac{1}{2}$	282
Grape	$\frac{3}{4}$	149
Walnut	1 – 1 $\frac{1}{4}$	38
Golf ball	1 $\frac{1}{4}$ – 2	26
Tennis ball	2 $\frac{1}{2}$ – 3	4

For India during the period 1833–97, Brooks³ gives the following figures for 509 reported falls, but adds that presumably many lesser storms escaped notice.

Diameter (inches)	0 – $\frac{1}{2}$	$\frac{1}{2}$ – 1	1 – 1 $\frac{1}{2}$	1 $\frac{1}{2}$ – 2	2 – 3	3 – 4	4 – 5	>5
Number	240	117	70	24	26	19	9	4

Cumulative frequencies from these data are shown in Figure 1.

Of 330 falls of hail spread over 12 days of storm and recorded⁴ within 100 miles of the Radar Research Station, East Hill, Bedfordshire, 298 had a maximum diameter less than about 1 cm, 27 between 1 and 2 cm, and five up to 4 cm.

Douglas and Hitschfeld⁵ describe 71 falls of hail on one day in central Alberta in which the stones were estimated to be of the size of a pea (6 mm) in 21 cases, grape (20 mm) in 42 cases, and walnut (30 mm) in eight cases.

There appear to be no data available concerning the size distribution of hail in any single fall.

The size of hail encountered in flight may be inferred from the damage sustained. Many case histories of damage to aircraft in the United States are listed by Souter and Emerson⁶; in 11 cases the maximum hail size was inferred from photographs of damage and ranged from about 1.3 to 1.8 inches diameter, but larger sizes have probably been encountered in flight, as mentioned below.

An analysis of the size of hailstones inferred from damage to United States aircraft is given in *The MATS Flyer*¹ in a diagram which is headed "103 cases 1954 to 1957", but only 96 are discernible. These are set out in Table II.

TABLE II—SIZE OF HAIL ENCOUNTERED IN FLIGHT (USAF)

Height	Diameter in inches $\pm \frac{1}{4}$								
thousands of feet	$< \frac{1}{4}$	$\frac{1}{4}$	$\frac{1}{2}$	$\frac{3}{4}$	1	$1\frac{1}{4}$	2	$2\frac{1}{2}$	3
	number of cases								
50 - 40			1						
40 - 30		5	5	1	2				
30 - 20	1	4	2	2	1				(1?)
20 - 10	8	3	3	4	1			1	
10 - 0	10	20	12	8				1	1
Total	19	32	23	15	4			1	1
	percentage								
Total	20	33	24	16	4			1	1

This table cannot be expected to give a fair representation of the distribution of hail encounters with height, since the aircraft flights are not uniformly distributed over the various height ranges, the actual distribution being unknown. The cumulative frequencies of hail size, taking all heights together, are shown in Figure 1, but it should be remembered that these observations take no account of the smallest, non-damaging hail; nevertheless 20 damaging cases of less than $\frac{1}{4}$ inch diameter are included. The differences between the three curves of Figure 1, although considerable, are not surprising in view of the different conditions to which they apply, and the difficulties of observation.

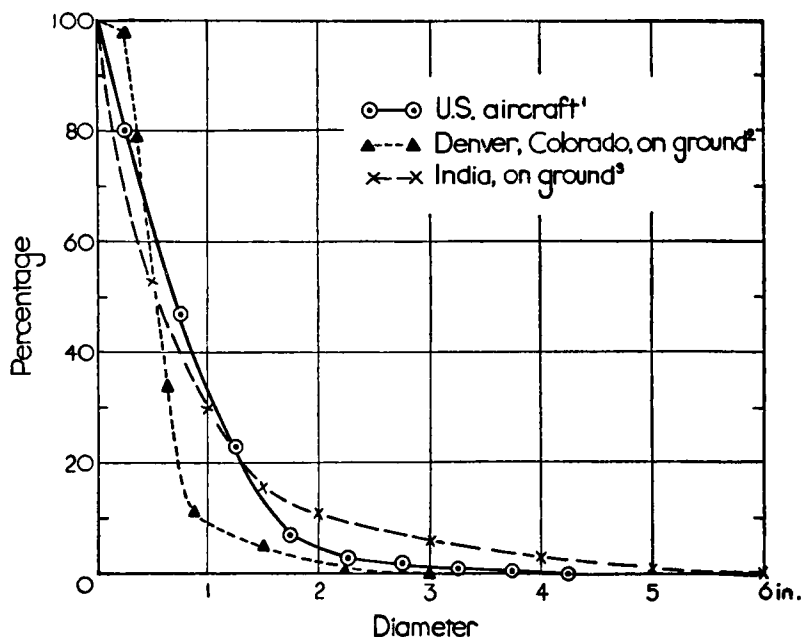


FIGURE 1—CUMULATIVE FREQUENCY OF LARGEST HAILSTONES

Upper limit of size of hail. In their work on the terminal velocity of hailstones, Bilham and Relf⁷ inferred on theoretical grounds an upper limit of about 5 inches diameter to the possible size of hailstones. This accords quite well with observations, only one case of substantially greater size having been reported, and that is of doubtful authenticity.

Duration of falls of hail.—An analysis⁴ of 251 falls of hail in the neighbourhood of East Hill, Bedfordshire, showed that the most frequent duration was 2 min, while almost 50 per cent of the falls were of 3 min or less. If five cases exceeding 30 min, which probably involved more than one storm cell, are excluded, the average of the remaining 246 cases is 5.6 min. The duration in

any case is affected by the movement of the storm; when this factor is eliminated, the average duration comes to about 7 min.

Mason² quotes an analysis by Beckwith of some 450 falls in the Denver area, Colorado; durations ranged from 10 sec to one extreme case of 45 min of continuous hail, the most frequent duration being 5 min.

Duration of hail encounters.—The duration of encounters in flight is given by Souter and Emerson⁶ for 30 cases. Reported durations ranged from 15 sec to 10 min, 78 per cent were of 2 min or less, and the average was 2 min. True air speed at the time of passing through the hail was reported in 21 cases; the range was from 160 – 360 mph with an average of 229 mph. The computed air distance through the hail ranged from 1 to 28 miles, with a mean of 7 miles; in two-thirds of the cases the distance was 5 miles or less. In seven penetrations of cumulonimbus cloud in Malaya which encountered hail, durations in precipitation ranged from 20 to 222 sec and air distances from 1 to 12 miles (Frost⁸). In five of these cases, rain or snow were reported as well as hail, and it is not clear whether the hail was continuous throughout each of the stated durations.

Observations of the ground pattern of falls of hail show that the width of the hail shaft when it strikes the ground is most frequently about 1 to 2 miles. Souter and Emerson⁶ quote a study by Lemons of 2105 damaging hailstorms in the United States; the widths (across wind) ranged from a few yards to 75 miles, while 50 per cent were within 1 to 3 miles. From this sort of evidence, one might imagine the hail core of a typical cumulonimbus cell in the mature stage to be of roughly circular section with a diameter of about 1 to 3 miles, but it seems that agglomerations of neighbouring cells can on occasions produce a more extensive area of hail. However, the inference from the pattern of hail at the ground of the pattern in the cloud may not be valid (see page 107).

The polar regions.—Hail at the surface is rare. What there is, is probably associated with frontal conditions, rather than with convection related to surface heating. Much of the hail is likely to be of quite small size or in the form of graupel. Observations from the north of Canada, slightly south of the arctic circle, indicate a frequency up to three days a year. Hail at higher levels is no doubt similarly rare, and it seems likely that there is no risk to present-day aircraft in these high latitudes. The risk to supersonic aircraft would need to be assessed in relation to hail size, and as a guess the maximum size here is put at about 1 cm diameter. At the same time, the polar regions in this connexion should be regarded as loosely defined.

Middle latitudes.—Hail is most common in the latitudes between the polar and equatorial regions. Distinction should be drawn between “large” hail and “small” hail, the latter including graupel and ice pellets. Large hail, which causes damage at the ground, is mainly confined to the interiors of the continents, and is said to be most frequent between latitudes 30° and 40° N. Small hail, on the other hand, appears to be more frequent over the oceans. Annual frequencies of hail do not appear to have been collated over the world as a whole; the average number of days with hail is around 5 – 10 in the continental areas mostly affected, with increases to 15 – 25 in some coastal regions which include the small varieties of hail in their records, and still larger values (again probably mostly of small hail) over parts of the oceans. The highest number so far noticed is 31 days per year at weather station J (52½° N, 20° W), and in the Falkland Islands, both averaged over a 10-year period.

Seasonal variation differs according to locality. Damaging hail over the continents occurs mainly in late spring and summer when surface heating and convection are most active, but there are exceptions; for example, places with Mediterranean-type climate get their hail in winter and spring. Hail over the north-east Atlantic is mainly a winter phenomenon. For example, the average number of days with hail in each month at weather station J over a 10-year period is as follows:

Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
6.4	5.8	2.6	4.0	1.3	0.2	0	0	0.5	1.5	3.2	5.4	30.9
<i>number of days</i>												

Hail is almost entirely absent from June to September, and is most frequent in January and February. In the Falkland Islands the seasonal variation is less marked.

Diurnal variation. According to Souter and Emerson⁶ "it is generally agreed that 50 per cent of all hailstorms occur between 1400 and 1800 local standard time and less than 10 per cent between midnight and noon". This remark probably refers to large hail in the United States of America, but is likely to be roughly applicable to other continental areas. From a graph given for the United States, it is deduced that 85 per cent of damaging hailstorms occur between 1300 and 2200 hours. On the other hand, "small" hail over coastal areas and oceans probably has no pronounced diurnal variation.

North Atlantic air routes. Routine observations received at London Airport from civil aircraft on North Atlantic routes in January and July, 1955 - 57, were analysed for the frequency of reports of hail. This element was included on three occasions in January and four in July out of a total of 16,346 meteorological observations. There was also a total of eleven reports of thunderstorms and it is possible that the aircraft may have encountered hail in some of these, since there is no provision for reporting both hail and thunderstorm simultaneously in the codes used (POMAR or AIREP). The hail reports by themselves indicate a frequency of occurrence of 1 in 2300 observations. The aircraft heights for all observations ranged from 6000 to 25,000 ft and on the occasions when hail was reported, from 8000 to 19,000 ft. There is no information in these reports on the size or type of hail encountered, or of any damage sustained.

Damage to BEA Viscounts. During the four years 1955 - 58, there were six occasions of damage by hail in 157,000 flights, or roughly 500,000 flying hours. These cases, together with one earlier one, are described by Harrower and Evans^{9, 10}. The incidents occurred near Lyons, Limoges, Basle, Zurich, Frankfurt, Hamburg, Barcelona, at dates from 5 May to 18 August. No information is available to the writer regarding encounters with hail which did not damage the aircraft.

Damage to BOAC aircraft. Argonauts and Constellations have suffered severe damage on average once in every 30,000 flying hours; Comet I's had one case of damage in 25,000 hours' flying, which occurred⁴ on climb from Rome between 2000 and 12,000 ft. A list of hail incidents to BOAC aircraft is given in the Appendix (page 109).

Hail size over the oceans. Reports of hail damage to aircraft in flight over the United States show a distribution in space which compares favourably with the distribution of large hail at the surface (Souter and Emerson⁶). The same publication states that no cases of significant damage to aircraft had been

reported over the North Atlantic and North Pacific Oceans adjacent to the United States. Similarly with BEA and BOAC aircraft, reports of damage appear to be confined to continental and coastal areas, no cases of damage over the open oceans having occurred, so far as is known. The absence of damage may in part be attributable to deliberate avoidance of the more intense convection clouds, but it seems unlikely that this is the whole explanation. Hence it appears that encounters with large hailstones are likely to be confined to land areas, and especially to those parts where large hail is most frequent at the surface.

Reports from North Atlantic routes discussed above, together with the information given in the appendix, show that hail is encountered over this ocean, but absence of reports of damage suggests that the hail is of small size. This is supported by the absence of hail at the surface at weather station J in summer, although it is encountered in flight in that season. It follows therefore that what hail there is in that area in summer, melts before reaching the surface. The 0°C isotherm in this area is then at about 10,000 ft (700 mb); if hail falling from this level melts before reaching the surface, its initial diameter cannot be greater than about 7 mm (0.3 inch) if it is composed of solid ice (specific gravity 0.9), or about 1 cm (0.4 inch) for graupel (specific gravity 0.3),¹¹ if indeed graupel can be as large as this. It is tentatively suggested that somewhat similar size limitations may apply also over the mid-latitude oceans in other seasons.

Equatorial regions.—*At the surface.* While the occurrence of hail in the equatorial regions is very infrequent particularly near coasts and at low levels generally where falls usually average less than one day per year, it has nevertheless been reported from many places and some quite large stones are on record. The following paragraph is based on some remarks quoted by Lemons¹² in respect of Porto Rico and the Virgin Islands which are perhaps relevant to most of the equatorial region:

Hail has occurred at San Juan only twice during a 40-year period. Favourable conditions for the formation of hail seldom occur over small tropical islands. Altogether some 30 cases of hail were reported in 10 years at stations in Porto Rico. Sixteen places reported one or more of these storms, but several of the interior stations above 500 or 1,000 feet reported from two to six each. Thus it is evident that either continentality, or elevation, or both favour somewhat greater frequency of hail. The increased frequency of thunderstorms in the interior and over the mountains in Porto Rico is much greater than that of hail, so that it is the upper air conditions more than surface conditions which limit hail frequency here.

Thus, while hail generally is rare at the surface through most of the equatorial region, it is relatively more frequent over land than over the sea, and the frequency tends to increase with both the extent of the land and its elevation.

In flight. Frost^a describes the results of a series of flights through cumulus and cumulonimbus clouds over Malaya and Sumatra. He says that hail "gave surprisingly little trouble"; it was encountered on 7 out of a total of 87 penetrations into cumulonimbus. Although the hail on one of these occasions was described as moderate to heavy, and on another as moderate, Frost makes no further mention of damage; presumably this was insignificant or at most slight, with the corollary that the hailstones encountered were not large. The true air speed was about 170 kt; aircraft heights ranged from 10,000 to 15,000

ft; temperature (outside cloud) ranged from $+10^{\circ}\text{C}$ to -4°C ; duration of precipitation (hail, rain or snow) from 20 to 222 sec, with a case of "moderate to heavy hail" lasting 60 sec.

The frequency of the encounters with hail in cumulonimbus reported by Frost (7 in 87 penetrations) is almost the same as that given by Byers and Braham¹³ and quoted by Frost for penetrations at similar heights (10,000 and 15,000 ft) in Florida and Ohio, totalling 52 in 684. There is no lack of intense convection in the equatorial region, and clouds build up at times to the neighbourhood of the tropopause at about 55,000 ft. The absence of large hail must presumably be accounted for in terms of the precipitation mechanism of the tropical clouds, which is known to differ on many occasions from that of extratropical clouds. Since any hail in the clouds must melt before reaching the ground at sea level, the maximum size of hail aloft can again be estimated from Mason's paper¹¹. The 0°C level here is at about 16,000 ft, and by extrapolation from Mason's results it is estimated that the diameter of the hailstones at that level cannot exceed about 1.5 cm (0.6 inches) for solid hail, or about 2.5 cm for graupel. This does not imply that hail or graupel of these sizes necessarily exist there.

Frost's report refers to a semi-oceanic area. The appendix contains two reports of slight damage in the tropics, one over Timor Island, and one on the route Karachi – Calcutta. There is a report (unpublished) of damage to a Britannia aircraft at 18,000 ft while on trials near Nairobi; the size of the stones was estimated from the damage as about 1 inch diameter. Another report¹⁴ mentions damage sustained by a Viking aircraft near Kisumu; the hail was estimated as 2 – 2½ inches diameter and the duration in hail was about 3 sec, but the height is not stated.

Relationship with thunderstorms.—There is no simple connexion between the frequency of falls of hail at the ground and the frequency of thunderstorms. Sometimes hail is reported more frequently than thunderstorms, sometimes it is the other way round. The relationship is complicated by the difficulty of ensuring that every fall of hail is observed, because of the possible melting of hail before it reaches the ground, and also because hail sometimes forms in convection clouds which do not develop into a thunderstorm. The restricted area and duration of hail in any one storm could explain why many flights through thunder clouds do not encounter hail. However, the meteorological conditions required for the formation of hail do not differ in kind from those required for thunderstorms, and any thunderstorm would be expected to provide at the least a possibility of hail. In a discussion by Wichmann¹⁵ of exploration of thunderstorms by sailplanes at a Rhône meeting in 1938, it is stated that hail was found in each storm *without exception*, and indeed up to the greatest heights reached by the gliders. The main updraught in the thundercloud as revealed by these flights was found to be concentrated in a narrow funnel whose diameter approximates to the turning circle of the gliders, that is, of order 100 metres; this funnel tapers slightly towards the top of the cloud and (as shown in a diagram) may be inclined to the vertical. Within the funnel the updraught is quite smooth, but at the edges very intense turbulence prevails which increases substantially with height. Hail occurs in the funnel and as it is carried upwards, so the stones continue to increase in size.

Presumably the greater spread of hail observed at the ground, after allowing for the drift of the cloud (see page 104) arises partly from the slope of the funnel,

and partly from hail carried out sideways from the top of the funnel before falling out through the cloud. Wichmann's work implies that the hail area in an active cell may be no more than a few hundred feet across, except temporarily due to fall-out when the updraught weakens and the cell begins to decay.

It hardly seems possible at present to estimate the frequency of hail encounters in flight from the frequency of thunderstorms. Apart from uncertainties regarding the area affected by hail and its duration, any one thunderstorm consists of a variable number of cells, new ones forming while older ones decay, and it is only while in the mature stage that a cell contains hail.

Practical measures against hail damage to aircraft.—Hail of small size is liable to be encountered in association with convection cloud in all localities. In most of the tropics, where convection cloud is very frequent, it appears (see pages 106 – 107) that hail is seldom greater than 1.5 cm diameter, while elsewhere the maximum size is likely to be less than this except over the continents. It is tentatively suggested that direct protection should be provided against hail up to at least 1.5 cm diameter and specific gravity 0.9, and that any larger stones should be avoided.

It would presumably be essential for supersonic aircraft to take avoiding action against large hail. Appropriate considerations include:

- (i) *Use of in-flight radar detection.* This has its difficulties arising from the high airspeeds envisaged, it being understood that avoiding action would need to be initiated at about 100 miles' distance. This method is likely to be useful only against isolated outbreaks of convection cloud. At present it is not practicable to recognize hail itself by means of airborne radar, but only the precipitation cores of cumulonimbus in which hail, if present, would be located. Hail is also known to occur, occasionally, outside the cloud in which it originates, so that it would be necessary to avoid the clouds by a few miles.
- (ii) *Use of pre-flight forecasts.* These forecasts will indicate in a general way whether intense convection would affect any stage of the route. If flight is to take place through an area in which convection is expected, consideration should be given to covering both the initial climb and the transition to supersonic flight by ground-based radar, since it is in these stages that avoiding action against convection cloud will be most difficult. The radar installation would be able to give the precise distribution of precipitating convection cloud immediately before take-off and also during flight. The cruising stage will mostly be above the levels attained by hail; any convection cloud affecting this stage would tend to be isolated and not difficult to avoid except possibly in the tropics. There is no means of forecasting hail itself, but only the convection clouds in which it might occur.
- (iii) *Use of flight planning to avoid the areas or times of day when large hail is most likely to occur.* In practice this would mean avoiding certain continental areas between about 1400 and 2200 hours local time in certain seasons, except where the areas concerned can be overflown at a height great enough to avoid the risk of encountering hail. As regards height, damage from hail has been sustained up to 45,000 ft (*The MATS Flyer*¹). The upper height limit of hail, of whatever size, is likely to coincide with the limit of convection cloud, that is about 35,000 to 45,000 ft in middle latitudes, increasing to 55,000 to 60,000 ft in the tropics. On present information it is not possible to indicate with confidence how the maximum size of hail

varies with height, although Table II gives some information. Also relevant is a discussion by Appleman and Lehr¹⁶ of hail encounters by aircraft of the United States Air Force; out of 109 cases at 25,000 to 44,000 ft, they find no evidence of any decrease with height in the chance of an encounter.

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Appendix

BOAC aircraft encounters with hail

From information supplied by Mr. E. Chambers, BOAC

Sector	Position	Altitude (thousands of feet)	Time GMT	Date	Intensity	Remarks
Atlantic routes						
Shannon - New York	51°N 36°W to 50°N 41°W	10.7	0350 - 0510	3. 5.57	light	Intermittent hail in thick As. No damage
London - New York	55° 10'N 34° 41'W	10	0110 - 0210	14. 6.57	moderate	—
Shannon - Gander	—	10 to 16	0500 - 1100	29. 1.57	moderate	Intermittent hail in Sc, embedded Cu
New York - London	overhead Sydney	11.5	0100	18.11.56	moderate	Layers and towering Cu
Prestwick - Gander	55° 20'N 07° 28'W	8	2210	25.10.56	light	—
London - Prestwick	Cheshire	6.5	1720	22. 8.56	heavy	Lightning strike
Prestwick - Gander	54° 40'N 25° 40'W	10	0125	22. 7.56	light	—
Shannon - Montreal	53° 30'N 52° 30'W	10	0536	July 1956	moderate	—
Gander - Bermuda	200 mi. SW Gander	18 to 15	2240	24. 7.56	light	Thick As, embedded Cu
Keflavik - Boston	59° 40'N 44° 10'W	11	0400	25. 4.56	light	Between layers
Moncton - London	overhead Stephenville	13 to 19	0330	6. 4.56	light	8/8 As, Ac, Cu
Gander - Montreal	Moncton	12.6 to 14.4	1115	25.12.55	light	—
European routes including Mediterranean						
London - Rome	Turin	19.5	1240	10. 7.57	moderate	8/8 Cs, embedded Cb tops 37,000 ft. Slight damage to radiators
Rome - Istanbul	abeam Amendola	15.5	1650	12. 6.57	heavy	Airframe effectively deiced by hail but no damage
Rome - London	Turin to Genoa	20.5 to 22.5	1200	19. 5.57	heavy	Flying through Cb. Hail approx. 1 in. in diameter
London - Beirut	—	15	—	16. 8.55	heavy	Line Cb tops 23,000 ft. across track. Aircraft lifted to 16,500 ft. Heavy turbulence. Considerable damage
London - Idris	—	16.0	Moonlight	7.11.57	heavy	Heavy Cu, all radiators damaged

BOAC aircraft encounters with hail (cont.)

Sector	Position	Altitude (thousands of feet)	Time GMT	Date	Intensity	Remarks
Rome - Istanbul	20 mi. WNW Araxos	13.6	0920	3.11.56	heavy	7/8 Cu, Cb from cold front. Damage to radiator intakes. Strong standing wave after front
Rome - London	Elba to abeam Pisa	19.5 to 22.5	0840	3. 9.56	heavy	8/8 Cb. Cowlings damaged and coolers deformed
Damascus - Frankfurt	Frankfurt	11 to 8	1140	15. 6.56	moderate	Slight damage on nose
London - Tripoli	40°N 08°E to 37°N 12°E	13.5 to 15.5	1900	23. 4.56	moderate	—
Cairo - Rome	100 mi. SE Caraffa	14.5	Night	27. 9.55	moderate	8/8 Ac, Cb. Slight damage to radiators
London - Beirut	15 mi. S of Athens	15	—	16. 8.55	heavy	8/8 Cb. Airframe skin damaged
Rome - London	46°N 03°E	14.5	1750	23. 6.53	light	7/8 Sc, towering Cu
Croydon - Madrid	Croydon to I.O.W.	2.2	0815	23. 1.45	light	—
Subtropical and tropical routes						
Beirut - Karachi	20 min. after take-off	10 to 16	2200	26. 4.55	moderate	8/8 Ac, Cu
Basra - Karachi	Jiwani	15.5	0630	2.12.56	light	Isolated Cb. Cb in general Ns layer
Baghdad - Beirut	Beirut	12.5	1645	19. 3.56	light	Sc and large Cu
Kano - Rome	22°N 10°E	13 to 19	2210 - 2310	13. 6.57	moderate	—
Calcutta - Bangkok	200 mi. SE Calcutta	16	—	5. 8.55	moderate	Monsoon cloud, lightning strike in vicinity of nose
Calcutta - Singapore	—	16	—	8. 6.55	—	Lightning strike on starboard side
Karachi - Calcutta	—	19.5	0945	21. 7.57	heavy	Superficial damage to propellers and wing tips
Darwin - Djakarta	Timor Is.	14.5	2017 - 2207	6. 3.57	moderate	Search radar unserviceable. In and out Cb, As. Starboard wing tip damaged. Lightning strike
Khartoum - Entebbe (returned Khartoum)	100/150 mi. S Khartoum	16	0415	27. 7.56	—	8/8 As, 6/8-8/8 Cb

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SHORT-PERIOD FLUCTUATIONS OF THE SEMIDIURNAL COMPONENT OF PRESSURE IN THE TROPICS

By R. FROST, B.A.

Most people who are interested in the problem of pressure oscillations of the earth's atmosphere have assumed either tacitly or openly that in the tropics a reasonably adequate determination of the dominant second harmonic of pressure can be made using hourly observations extending over a limited period of three or four years and that in the subtropics and temperate regions between five and ten years of hourly observations are required.

Out of curiosity, whilst investigating the general problem of pressure variations over Malaya¹, the present writer calculated the semidiurnal components of pressure at Changi (Singapore) for each month of each year for the decade 1948-57 in order to test this assumption. It was expected, in view of the flat and irregular distribution of pressure and the large and self-evident diurnal variations of pressure near the equator, that a few years would suffice to give a determination which, apart from slight refinements in the second decimal place, could be used with some confidence. Rather surprisingly, however, over the decade in question the mean amplitude of the second harmonic did not tend to a limit with increasing number of years but in fact after four years continued to increase almost linearly with the number of years taken to obtain the mean, which throws considerable doubt on the validity of harmonics determined from ten years' observations or less at stations outside the tropics. In view of this somewhat unexpected result it was thought that a brief review of the findings

TABLE I—YEARLY VARIATION OF AMPLITUDE (MILLIBARS) AND PHASE ANGLE
OF SECOND HARMONIC

	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
	a_2 A_2	a_2 A_2	a_2 A_2	a_2 A_2	a_2 A_2	a_2 A_2	a_2 A_2	a_2 A_2	a_2 A_2	a_2 A_2	a_2 A_2	a_2 A_2
1948	1.37 149.2	1.37 141.8	1.28 144.0	1.24 146.5	1.16 150.8	1.08 147.1	0.97 146.1	1.06 150.5	1.25 153.8	1.40 161.8	1.31 160.4	1.30 154.4
1949	1.32 150.1	1.26 142.8	1.30 142.5	1.19 150.1	1.06 144.0	1.00 146.4	0.97 146.5	0.97 149.6	1.05 144.6	1.20 156.6	1.25 155.8	1.24 157.7
1950	1.13 147.8	1.20 142.9	1.22 147.6	1.12 147.4	1.06 145.8	0.99 144.8	0.95 145.7	1.06 143.6	1.16 145.7	1.20 153.5	1.17 155.5	1.24 150.2
1951	1.13 151.0	0.98 145.6	1.29 145.9	1.12 143.8	1.07 148.0	0.96 147.9	0.94 141.0	0.96 141.5	1.14 144.9	1.22 154.0	1.09 152.8	1.03 148.5
1952	1.05 140.8	1.08 135.3	1.06 138.5	1.24 145.7	1.25 150.5	1.07 152.2	1.05 148.5	1.07 146.9	1.40 151.0	1.53 158.6	1.49 159.3	1.48 151.6
1953	1.33 154.6	1.45 144.9	1.50 145.6	1.58 146.0	1.42 152.4	1.25 150.5	1.21 148.5	1.24 148.7	1.32 152.3	1.45 158.9	1.48 156.2	1.50 158.4
1954	1.31 151.0	1.48 144.9	1.64 147.5	1.52 144.5	1.35 148.1	1.15 150.0	1.12 146.2	1.14 147.6	1.43 150.1	1.59 156.7	1.31 160.1	1.42 160.2
1955	1.39 152.8	1.41 144.0	1.59 145.0	1.54 148.8	1.38 150.8	1.24 152.5	1.27 146.4	1.34 145.2	1.40 151.0	1.64 156.0	1.44 159.8	1.45 153.1
1956	1.41 149.4	1.54 145.8	1.33 145.0	1.47 149.3	1.40 152.0	1.22 152.0	1.24 144.2	1.28 150.0	1.45 154.0	1.61 155.9	1.52 157.8	1.49 150.4
1957	1.45 146.1	1.31 150.8	1.62 146.5	1.61 149.3	1.48 146.4	1.24 153.5	1.15 152.2	1.30 148.9	1.40 152.5	1.62 160.1	1.59 157.8	1.50 152.5

TABLE II—VARIATION OF AMPLITUDE (MILLIBARS) AND PHASE ANGLE
OF SECOND HARMONIC OVER TWO FIVE-YEAR PERIODS

	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
	a_2 A_2	a_2 A_2	a_2 A_2	a_2 A_2	a_2 A_2	a_2 A_2	a_2 A_2	a_2 A_2	a_2 A_2	a_2 A_2	a_2 A_2	a_2 A_2
1948-52	1.20 147.8	1.18 141.7	1.23 143.7	1.20 146.7	1.12 147.8	1.02 147.7	0.98 145.6	1.02 146.4	1.20 148.0	1.31 156.8	1.26 156.8	1.26 152.5
1953-57	1.38 151.0	1.44 146.0	1.58 145.9	1.54 147.6	1.41 149.7	1.22 151.7	1.20 147.5	1.26 148.1	1.40 152.0	1.58 156.9	1.51 158.3	1.47 154.9

a_2 and A_2 are the amplitude and phase angle respectively of the second harmonic.

at Singapore would be of interest and possibly stimulate investigation at other stations in the tropics.

The variations in amplitude and phase of the second harmonic from month to month are exhibited in Table I for each year of the decade. Whilst as previously shown¹ the monthly means based on ten years' observations fall into a consistent pattern which bears a close relationship with the annual march of the sun, the monthly amplitudes calculated from the annual means show some rather surprising and non-random variations. These are shown even more clearly in Table III, which depicts the departures of the monthly amplitudes calculated from annual observations from those calculated from the decadal observations. From this table it can be seen that a marked discontinuity occurred between August and September 1952, the mean amplitudes before that date averaging approximately 0.12 millibar below the corresponding ten-year means and after that date averaging approximately 0.12 millibar above the corresponding ten-year means. No change of instruments or their location can be held responsible for this discontinuity.

TABLE III—MONTHLY DIFFERENCES IN MILLIBARS FOR EACH YEAR FROM THE MEAN MONTHLY AMPLITUDES FOR 1948–57 AT CHANGI (SINGAPORE)

	1948	1949	1950	1951	1952	1953	1954	1955	1956	1957
January ...	+0.08	+0.03	-0.16	-0.16	-0.24	+0.04	+0.02	+0.10	+0.12	+0.16
February ...	+0.06	-0.05	-0.11	-0.33	-0.23	+0.14	+0.17	+0.10	+0.23	0
March ...	-0.12	-0.10	-0.18	-0.11	-0.34	+0.10	+0.24	+0.19	+0.13	+0.22
April ...	-0.13	-0.18	-0.15	-0.25	-0.13	+0.21	+0.15	+0.17	+0.10	+0.24
May ...	-0.11	-0.21	-0.21	-0.20	-0.02	+0.15	+0.08	+0.11	+0.13	+0.21
June ...	-0.04	-0.12	-0.13	-0.16	-0.05	+0.13	+0.03	+0.12	+0.10	+0.12
July ...	-0.12...	-0.12	-0.14	-0.15	-0.04	+0.12	+0.03	+0.18	+0.15	+0.06
August ...	-0.08	-0.17	-0.08	-0.18	-0.07	+0.10	0	+0.20	+0.14	+0.16
September ...	-0.05	-0.25	-0.14	-0.16	+0.10	+0.02	+0.13	+0.10	+0.15	+0.10
October ...	-0.04	-0.24	-0.24	-0.22	+0.09	+0.01	+0.15	+0.20	+0.17	+0.18
November ...	-0.08	-0.14	-0.22	-0.30	+0.10	+0.09	+0.12	+0.05	+0.13	+0.20
December ...	-0.06	-0.12	-0.12	-0.33	+0.12	+0.14	+0.06	+0.09	+0.13	+0.14

The mean monthly amplitudes and phases calculated for the two lustra 1948–52 and 1953–57 respectively are given in Table II and show that the monthly amplitudes in the latter are almost consistently 20 per cent higher than those in the former. Since each amplitude is calculated from about 3600 observations whose standard deviation about the mean is of the order of 2 millibars, the standard deviation of each of these harmonics is approximately 0.05 millibar, so that it is very unlikely that the marked change in amplitudes can be attributable to chance. According to Simpson's empirical formula² the mean annual value of the amplitude at Singapore should be 1.25 millibars, whereas for the first lustrum the calculated amplitude is 1.17 millibars and for the second lustrum 1.40 millibars, whilst for the complete decade the calculated amplitude is 1.30 millibars. Now the mean annual value of the amplitude from six stations in Malaya (between 2° and 6° north of the equator) from each of which twelve to sixteen years of hourly observations were available, is 1.29 millibars, whilst the annual value of the amplitude at Djakarta (approximately 6° south of the equator) based on forty-nine years of hourly observations is 1.33 millibars¹. It would seem, therefore, that near the equator approximately ten years' observations are required to yield reasonably adequate values of the amplitudes of the second harmonic. Unlike the amplitudes, the monthly phase angles show little evidence of any systematic variation from year to year but values of the

phase angle determined for any month of the second lustrum are always higher than those of the first lustrum, the greatest difference being 4.3° or 8.6 minutes in February.

Consideration of the spatial and temporal variations in the long-period mean monthly amplitudes and phases of the second harmonic over Malaya and Singapore previously discussed¹, strongly supported the view that the second harmonic of pressure as well as the first was in some way or other connected with the solar heating, but certain features were difficult if not impossible to reconcile with the generally held resonance theory and, as an alternative hypothesis, it was suggested that the convective flux of heat in the layer from about one kilometre to the tropopause was the cause of the second harmonic. If this hypothesis is correct then it might be expected that the fluctuations in the amplitudes and in particular the marked discontinuity which occurred between August and September 1952 should be reflected in corresponding fluctuations in the temperatures of the upper troposphere over Singapore.

It is unfortunate that a consistent set of upper air temperatures is not available at Singapore for the decade under consideration but there is a striking parallelism between the fluctuations in these amplitudes and the fluctuations in the mean monthly temperatures over the same period at the 500-, 300- and 200-millibar levels at New Delhi which were discussed by Veryard and Ebdon³ (see Figure 1 of their paper). Table IV, taken in part from Table I of their paper, shows the yearly differences from the mean annual upper air temperature at New Delhi together with the yearly differences from the ten-year mean amplitude included for purposes of comparison.

TABLE IV—COMPARISON BETWEEN YEARLY DIFFERENCES IN $^\circ\text{F}$ FROM MEAN ANNUAL TEMPERATURES FOR 1948–57 AT NEW DELHI AND YEARLY DIFFERENCES IN MILLIBARS FROM MEAN ANNUAL AMPLITUDES OF SECOND HARMONIC AT SINGAPORE

mb	1948	1949	1950	1951	1952	1953	1954	1955	1956	1957
200 ...	... -4.3	-7.9	-5.0	-5.4	-1.8	+2.5	+5.0	+5.4	+3.6	+0.9
300 ...	... -3.2	-6.3	-4.3	-5.0	-1.3	+1.1	+4.0	+3.6	+3.0	+1.1
500 ...	... -2.3	-3.6	-3.4	-2.9	-1.8	+0.4	+1.3	+2.2	+2.0	+0.9
a_2 ...	... -0.6	-0.15	-0.17	-0.21	-0.07	+0.09	+0.09	+0.12	+0.13	+0.14

Whilst it is tempting to speculate on the possible cause of the apparent relationship between the changes of upper air temperature at New Delhi and the changes in the amplitude of the semidiurnal pressure wave at Singapore, the main purpose of this note is to draw attention to the remarkable variations in the amplitude of the second harmonic of the pressure variation at Singapore over the decade 1948–57, and it is considered that calculations of the amplitudes of the pressure waves at New Delhi and further data from Singapore are required before such speculation would be profitable.

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A STANDING DEW METER

By B. G. COLLINS

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Summary.—A portable, battery-operated dew meter is described which gives a direct reading of the total water deposit on a uniform short grass surface, such as a well cut lawn.

Introduction.—The presence of free water on a short grass surface, commonly regarded as “dew”, may be caused in one or more of three ways. Two of these involve condensation and Monteith¹ has proposed that they be distinguished by the names “distillation” (for upflux from the soil), and “dewfall” (for downflux from the atmosphere). The third is “guttation”, the exudation of water droplets by plant root pressure. This has been estimated by Angus² to account for 20-25 per cent of the total water in some circumstances. Any such moisture on the blades of grass will delay the rise of temperature and the onset of evaporation stress during the day and, if the total amount can be determined, useful information may be obtained without attempting to distinguish the source.

The standing dew meter here described, when placed on dewy grass, gives an immediate measurement of the total free water on the grass blades and may be used to sample rapidly a large area. It is easily portable and is independent of mains power supply.

Description.—The instrument, shown in general appearance in Plate I, has a sensing element the electrical capacity of which changes in the presence of more or less water. It is mounted in the bottom of a carrying case about 18 inches by 3 inches by 3 inches, which also contains a detecting circuit and indicator. The element consists of an interleaved grid of $\frac{1}{32}$ -inch brass strips let into a $\frac{1}{2}$ -inch ebonite base, and these form the two plates of a capacitor. Each plate was made of fifteen such strips with a separation of $\frac{1}{16}$ inch. The whole was set in Araldite casting resin type 123 B, the surface of which after hardening was milled to leave the brass elements flush with the Araldite. The surface was then given three coats of Estapol plastic coating type 7008. This provided a tough, transparent, insulating skin, some five thousandths of an inch thick, impervious to water and water vapour (Plate II).

When the element is placed on the grass any water present acts as a dielectric with specific inductive capacity different from that of air; hence the capacity increases with increasing amounts of dew. The variations in the capacity of the element, which is about 1,000 pico-farads, are detected by an electrical circuit using the repeated ballistic discharge method described by Jason³. In this circuit a vibrator operating at frequency n repeatedly charges the capacitor C to a potential E , and then discharges it through a current meter. The mean current I , indicated by the meter is given by $I=nCE$.

The arrangement used in the present instance is detailed in Figure 1. A standard commercial 12-volt vibrator (Oak type V6712) energized by two $4\frac{1}{2}$ -volt torch batteries connected in series has been found suitable, and it operates at about 100 cycles per second. Several months' use may be obtained from one pair of batteries as the daily period of operation is normally only a few minutes.

Six type 419E deaf aid cells provide the 180-volt source used for charging the capacitor. With the vibrator and sensing element used the value of the mean current drawn from these batteries with the greatest feasible amount of

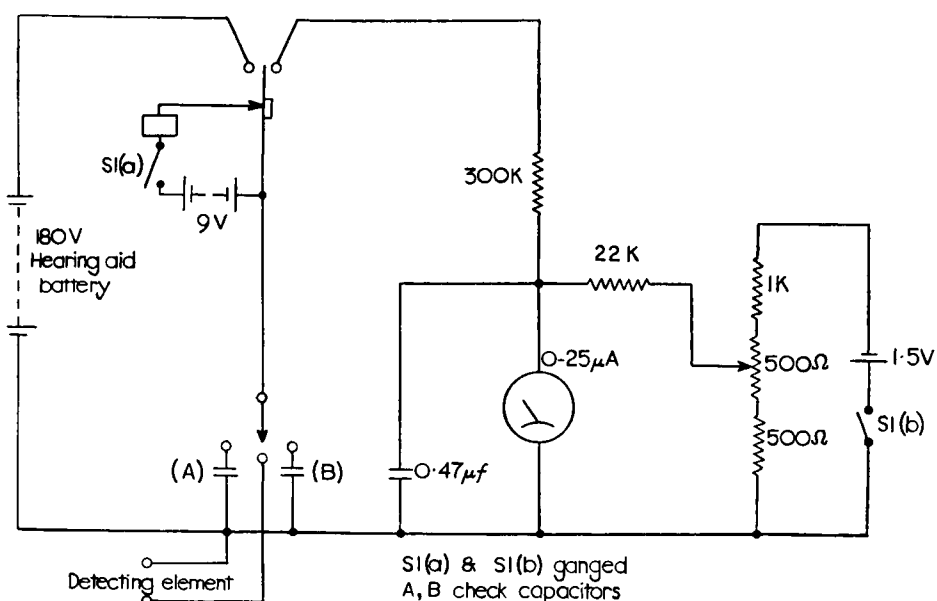


FIGURE 1—CIRCUIT DIAGRAM OF STANDING DEW METER

dew is only about 20 micro-amps, and their life is virtually shelf life. A backing-off voltage derived from a single 1.5-volt cell is used to obtain a zero reading on the meter when the element is dry. A 500-ohm potentiometer acting as a voltage divider in this circuit provides a zero setting control. Two fixed capacitors are included in the circuit to give check readings at two points on the scale and thus indicate any decline in battery condition, or zero drift in the measuring circuit.

Operation.—The standing dew meter has been used to obtain comparative readings of dew deposition on a standard grass surface. A strip of fairly fine grass was mown regularly to maintain the surface as nearly uniform as possible. The dew meter was pressed firmly on to the grass, the pressure was released and then the reading on the micro-ammeter taken. A mean of several such readings on different parts of the test area was taken, the sensing element being wiped dry between successive readings with an absorbent cloth. This eliminated any error due to moisture adhering to the surface of the element.

Calibration.—This was by comparison with readings obtained by absorption of dew with previously weighed filter papers. Although the accuracy of this method has been questioned by Monteith¹ there seems to be no more suitable alternative. The continuous weighing method described by Jennings and Monteith⁴ for example, provides an accurate record of the gain of moisture from the atmosphere (dewfall) but any moisture contributed by distillation or guttation would not be recorded although it would clearly affect the standing dew meter. It is also limited to a single, very small sampling area. The methods due to Duvdevani⁵ and Leick⁶ require the introduction of artificial dew catchers which is undesirable. It is felt that with the precautions described below the filter paper method provides a satisfactory calibration.

The procedure adopted was as follows: a plywood template was made, with five circular holes cut in it of diameter equal to that of the filter papers used, in this case Whatman No. 3 papers, 11 centimetres in diameter. The template was pegged on to the grass after dew deposition, and five previously weighed

filter papers used to mop up as much dew as possible from the five exposed areas of grass. These papers were then sealed into a previously weighed boiling tube. This was repeated, without moving the template, with two further sets of five filter papers, and the three boiling tubes with wet papers weighed. The mean amount of dew absorbed by each set of five papers was then expressed in millimetres of deposition. Plotting these amounts cumulatively gave a curve tending to an asymptote. Examples of such curves are shown in Figure 2. The asymptotic value was taken as the true amount of dew on the grass. From several such tests it was estimated that the total of the three measurements was close to 98 per cent of the asymptotic value.

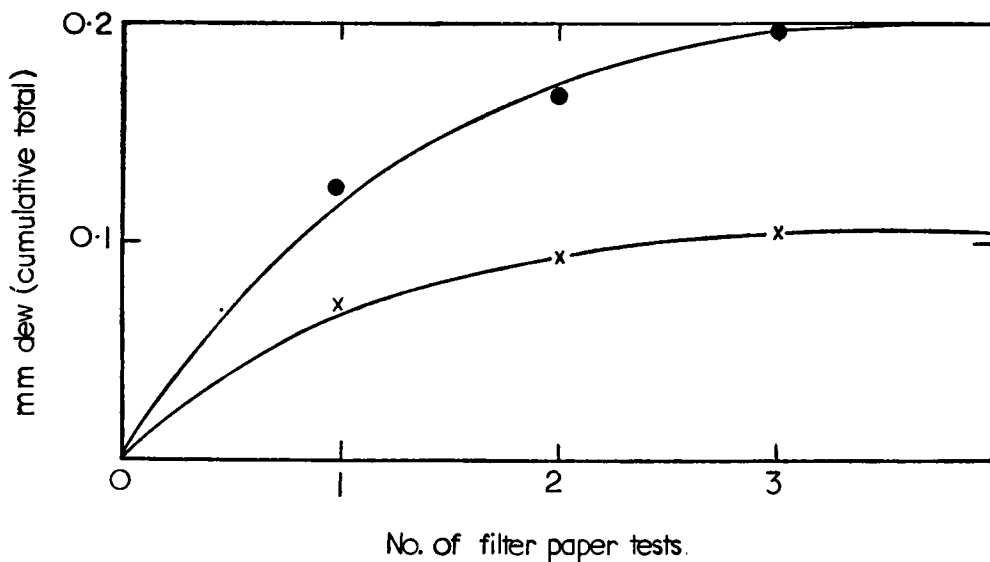


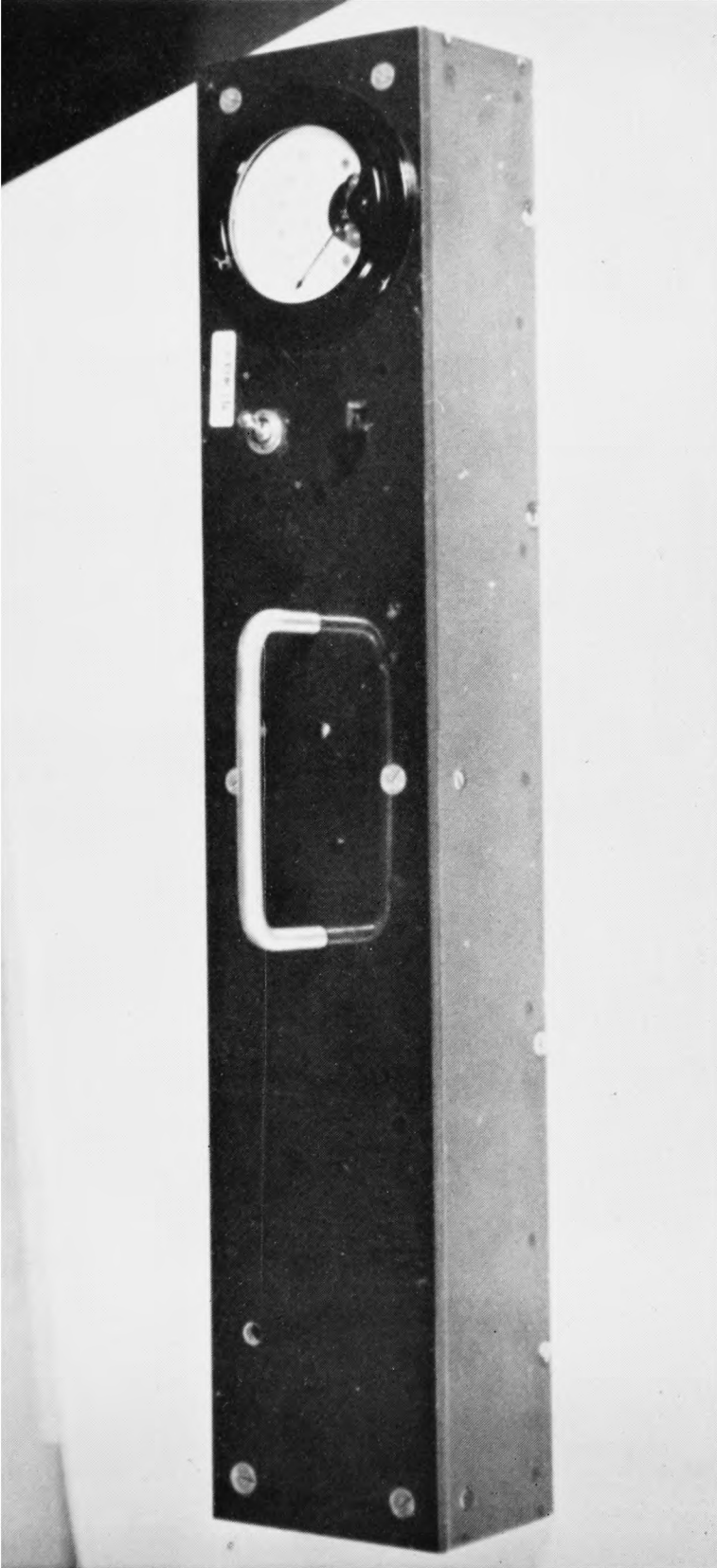
FIGURE 2—CUMULATIVE PLOT OF DEW ABSORBED BY FILTER PAPERS

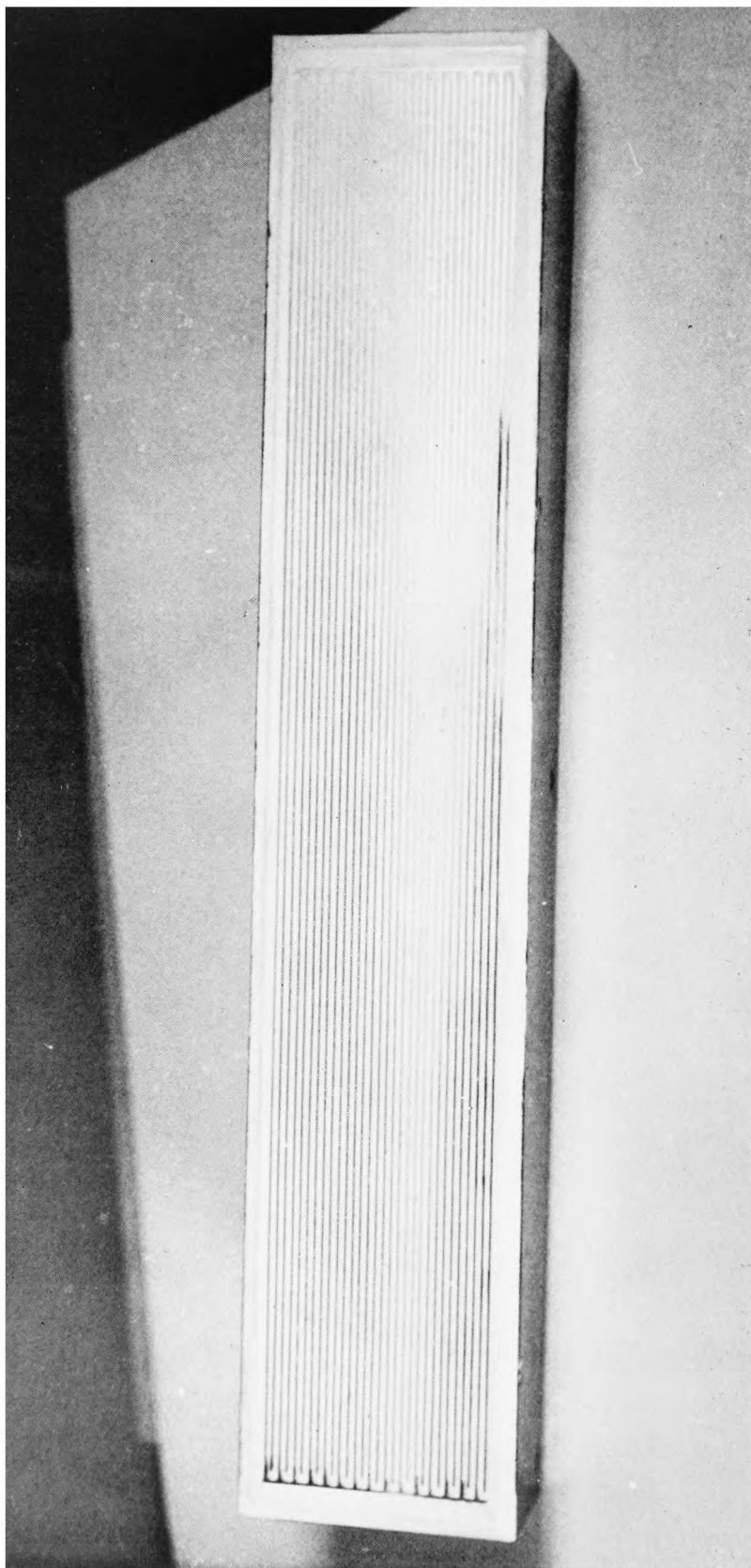
The dew meter calibration obtained by this method is logarithmic and is shown in Figure 3. The overall accuracy is within ± 10 per cent of the measured value. The maximum amount of dew measured was about 0.3 millimetre and this is consistent both with results obtained by other workers and with energy balance considerations. It is clear, however, that variations in the amount of moisture contained in the blades of grass themselves and in the first few millimetres of underlying soil would cause differences in calibration. These differences have been examined by taking “dry grass” readings after the dew had evaporated and it was found that the maximum variation attributable to this was ± 5 per cent of full scale deflection.

The calibration shown was taken in a regularly mown area of short grass and does not necessarily apply to other lengths or types of grass. Some tests were carried out on longer, coarser growth on which the filter paper technique was more difficult to apply, and the resultant points showed a much greater scatter than those obtained from the short grass. However, the mean values were not inconsistent with the calibration shown in Figure 3, although it is clear that neither the instrument itself nor the method of calibration is entirely suitable for use on rough grass especially as this normally also has an irregular underlying soil surface.

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PLATE I—GENERAL APPEARANCE OF STANDING DEW METER





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PLATE II—SURFACE OF DETECTOR ELEMENT

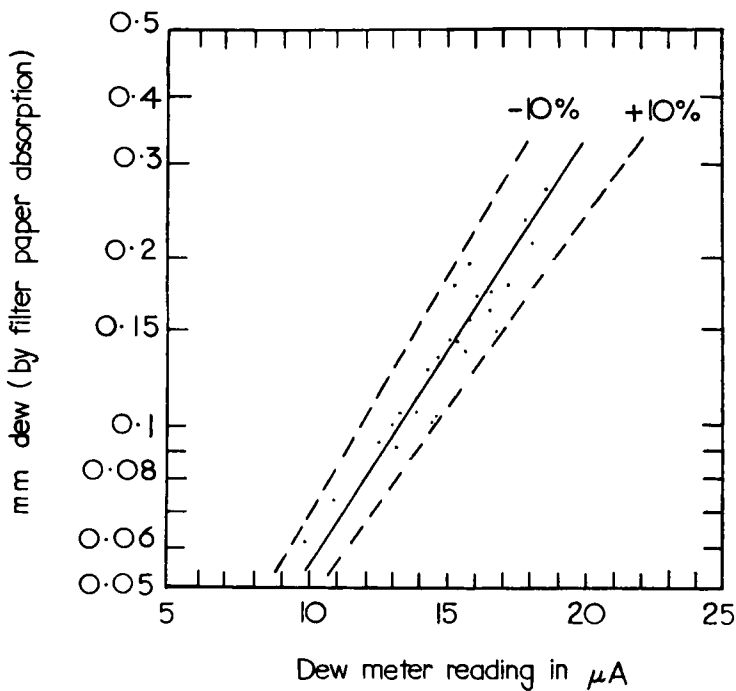


FIGURE 3—CALIBRATION OF STANDING DEW METER ON A SHORT GRASS SURFACE

Conclusions.—The standing dew meter described, which is simple and direct to operate, gives an estimate of the amount of dew (including guttation and distillation) on short grass with an accuracy of ± 10 per cent. In most cases, this will be sufficiently accurate for obtaining comparative records of the amount of dew forming each night on a well cut lawn, or similar surface.

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551. 509. 313: 551. 509. 5

NUMERICAL FORECASTS MADE WITH TWO- AND THREE-PARAMETER MODELS

By E. KNIGHTING, B.Sc.

Introduction.—The first prolonged experiments in numerical prediction of the pressure field carried out by the Meteorological Office were made in 1959 and have been reported at length in a *Scientific Paper*.¹ The experiments proceeded from the Sawyer-Bushby forecasting equations² and used both conventional and objective analyses to provide the initial data. The level of success of the 24-hour forecasts was similar to that of the conventionally produced forecasts, except that at 1000 and 500 millibars the root mean square contour height error was significantly larger for the numerical forecasts. A series of experiments using a stream function at the mid-tropospheric level to

compute the winds was carried out in 1959³ and it was shown that this modification significantly reduced the contour height errors. An extended test of both these models was started in the spring of 1960 and computations were carried out for 43 cases on a daily basis, excluding week-ends.

Models and data

- (i) The stream-function model chosen was that which assumed the wind field at 600 millibars to be given by a stream function obtained from the contour height field through the balance equation. The thermal wind field was derived from the thickness field by the ordinary geostrophic assumption and the system of equations closed by using the thickness equation derived from the first law of thermodynamics, allowance being made for the heating of relatively cold air over the sea³.
- (ii) The three-level model assumed geostrophic balance, with the wind shear and stability in the upper half of the troposphere differing from those in the lower half⁴.
- (iii) Forecasts were also made using the Sawyer – Bushby model as described in *Scientific Paper No. 5*¹.
- (iv) The initial data required to carry out the first and third experiments were the 1000- and 500-millibar contour heights at specified geographical points over an area covering most of the North Atlantic Ocean and Europe; objective analysis schemes were available for the computation of such data.

The three-level model required, additionally, data at 200 millibars; since an objective analysis scheme had not then been developed for this level and since the objective analysis schemes were undergoing revision to remove some faults in the region of deep depressions, the initial data was obtained from the conventionally analysed upper air charts, referring to 0001 GMT, of the Central Forecasting Office (C.F.O.), Dunstable. This method of obtaining the data is slow and would not be acceptable if the forecasts were to be made on an operational basis.

TABLE I—MEAN STATISTICS FOR 24-HOUR FORECASTS, FEBRUARY – MAY 1960

Model	1000 millibars				500 millibars				1000-500 millibars				200 millibars				500-200 millibars			
	a	b	c	d	a	b	c	d	a	b	c	d	a	b	c	d	a	b	c	d
	m	kt			m	kt			m	kt			m	kt			m	kt		
1. Stream-function	69	25	0.54	0.65	74	27	0.64	0.75	54	28	0.67	0.57	109	40	0.59	0.71	79	25	0.40	0.11
2. Three-level	{ 60 23 0.56 0.69				61 25 0.68 0.78				52 29 0.65 0.56				73 29 0.67 0.77				47 25 0.56 0.28			
	{ 55 21 0.56 0.69				57 24 0.69 0.79				49 27 0.65 0.58				69 28 0.67 0.78				45 25 0.54 0.28			
3. Sawyer-Bushby	71	26	0.51	0.65	65	28	0.64	0.76	52	29	0.67	0.56								
4. C.F.O.	{ 48 19 0.63 0.71				63 25 0.65 0.76				49 23 0.64 0.58				74 26 0.65 0.77				48 20 0.50 0.27			
	{ 45 18 0.61 0.72				61 23 0.65 0.76				47 22 0.63 0.60				71 25 0.63 0.77				47 20 0.49 0.28			
5. Persistence	{ 56 21				79 30				61 27				96 33				50 21			
	{ 53 20				76 29				59 26				91 32				48 21			

a: Root mean square contour height error.

b: Root mean square wind error.

c: Correlation coefficient between forecast and actual 24-hour contour height changes.

d: Stretch vector correlation coefficient.

The results for models 1 and 3 and the results given in the upper rows for models 2, 4 and 5 are for 43 cases. The results in the lower rows are for 55 cases, made up of 43 cases and another 12 cases.

Results.—Verification statistics were computed over an inner area of 16×12 points, as described by Knighting and others¹, for the numerical forecasts, the conventional C.F.O. forecasts and forecasts of persistence; they are summarized in Table I for the 43 cases. Table I also gives the statistical results for 55 cases, including the 43 cases already quoted, in order to indicate the stability of the statistics.

Before discussing the relative merits of the forecasts as indicated by the mean statistics of Table I it is interesting to compare them with the corresponding results for the Sawyer – Bushby model, C.F.O. and persistence forecasts obtained for a similar period in 1959. These results, given by Knighting and others¹, are reproduced in Table II.

TABLE II—MEAN STATISTICS FOR 24-HOUR FORECASTS, JANUARY – MAY 1959

Model	1000 millibars				500 millibars				1000-500 millibars			
	<i>a</i>	<i>b</i>	<i>c</i>	<i>d</i>	<i>a</i>	<i>b</i>	<i>c</i>	<i>d</i>	<i>a</i>	<i>b</i>	<i>c</i>	<i>d</i>
	<i>m</i>	<i>kt</i>			<i>m</i>	<i>kt</i>			<i>m</i>	<i>kt</i>		
Sawyer – Bushby	80	29	0.66	0.60	86	29	0.73	0.78	54	26	0.78	0.61
C.F.O.	63	24	0.67	0.61	79	27	0.69	0.75	64	26	0.68	0.58
Persistence	75	31		0.41	100	37		0.52	78	32		0.31

All the results are for 42 cases.

On comparing Table II with Table I it is clear that in 1960 there was more persistence of type, with the root mean square contour height and wind errors reduced and the correlation coefficients of persistence forecasts increased. In Table II it is also apparent that the 1000 – 500-millibar thickness is better forecast using the Sawyer – Bushby model than by C.F.O., and this result was repeated in the experiments carried out in the summer of 1959. In Table I the C.F.O. forecast of thickness was superior, a reversal of the former results and indicative that the conventional forecaster is relatively more successful in forecasting mean temperature changes in periods of lesser change than in periods of greater change. The differences in Tables I and II underline that forecasting systems can only be properly compared when tested over the same periods and that it is necessary to test over a large number of cases.

Returning to Table I, the figures relating to the 1000 – 500-millibar thickness forecasts are very similar for the three numerical models, because the thickness changes are dealt with in much the same way in all three. The root mean square wind errors are greater than those for the C.F.O. forecasts and also slightly greater than those for persistence. The root mean square contour height errors are similar to that of C.F.O. and less than those for persistence, while the correlation coefficients quoted are similar to those for C.F.O. and superior to those for persistence.

At the 1000- and 500-millibar levels the three-level model appears to be superior to the other two numerical models. At 500 millibars its forecasting success is equal to that of C.F.O.; at 1000 millibars its success is slightly inferior to that of persistence, which in turn is slightly inferior to that of the C.F.O. forecasts. The results of these tests at the lowest level should not be judged against persistence, because the period over which the forecasts were made was much more persistent in type than have been other periods tested in this country and elsewhere.

The Sawyer–Bushby and stream-function models, which deal with the motions of the 1000–500-millibar thickness field and at 500 millibars, imply changes in the contour fields above 500 millibars and hence are capable of

predicting the 500 – 200-millibar thicknesses and the 200-millibar contour heights. The forecasts were obtained by adding the implied forecast 24-hour changes to the initial fields. The three-level model deals directly with the changes in these upper fields. The statistics given in Table I show that using the three-level model leads to forecasts which are decidedly superior to those made using the two-level stream-function model. The results corresponding to the three-level model are directly comparable with those obtained from the C.F.O. forecasts, both being superior to those corresponding to persistence. Of the numerical models tested the three-level model is the most satisfactory and yields forecasts which are comparable with those produced by C.F.O. at all levels, except perhaps near the surface, where the C.F.O. forecasts appear to be a little better.

Conclusions.—The conclusions to be drawn from the data obtained are:

- (i) The three-level model gives superior forecasts to those obtained using either of the two-level models.
- (ii) The forecasts made using the three-level model are as successful as those made by C.F.O. except at the lowest levels, where they are slightly inferior.

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2. SAWYER, J. S. and BUSHBY, F. H.; A baroclinic model atmosphere suitable for numerical integration. *J. Met., Lancaster, Pa.*, **10**, 1953, p. 54.
3. KNIGHTING, E. and HINDS, M. K.; A report on some experiments in numerical prediction using a stream function. *Quart. J. R. met. Soc., London*, **86**, 1960, p. 504.
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NOTES AND NEWS

Rapid cloud development

An unusual and rapid cloud development was observed at Little Rissington, near Cheltenham, at about 1500 hours on 11 July 1960 and lasted for about eight to fourteen minutes. At this time, a deep depression was centred in the North Sea and an associated trough with heavy showers and thunderstorms affected the Cotswolds. A large cumulonimbus cloud was observed to approach the Rissington and Stow-on-the-Wold area and, while it was four to five miles to the west, its forward part protruded two to three miles sharply forwards. The base of the forward part was estimated at 4,000 to 5,000 feet and at the top was rapidly developing upwards to about 12,000 feet. The top of the main cumulonimbus cloud further west was estimated as over 20,000 feet.

At about 1500 hours the rapid vertical development in the protruding part of the cloud seemed to cease and heavy precipitation, absent before, commenced from the cloud but the precipitation did not reach the ground. Seconds later, cloud began to form in the precipitation and the cloud grew rapidly downwards. In a matter of four to five minutes the cloud base lowered from about 4,000 feet to about 200 feet above the high ground, with some fractostratus patches at tree-tops level. A photograph of the cloud structure faces p. 101.

The explanation would seem to be concerned with the breakdown of a development cell which started in the protruding part of the cloud. The interesting points are: the development cell being so far in advance of the main cloud structure and the very rapid formation and lowering of the cloud in the falling precipitation.

J. KONIECZNY

REVIEW

Frontiers of the sea, by Robert C. Cowen. 9 in. × 6 in., pp. 307, *illus.*, Messrs. Victor Gollancz Ltd., 14 Henrietta Street, Covent Garden, London, 1960. Price: 25s.

This book deals in a lively manner with many aspects of the science of oceanography—physical, chemical, biological, geological, and even political. The rapid developments in oceanographical research work during the last few years are adequately covered. There is little meteorology in the book, except in one chapter, “The Great Heat Engine”, and this is largely devoted to an account of theories of climatic change in which the oceans play a spectacular role, for example, the glacial theory of Ewing and Donn, which assigns a key role to the self-regulating variations in the efficacy of the exchange of water between the North Atlantic and the Arctic Oceans across the sill between Greenland and Norway.

The author emphasizes that our present knowledge and understanding of ocean currents is still only rudimentary. Quasi-synoptic measurements in the Gulf Stream show that it is by no means a continuous band of warm water but a complex branching system accompanied by eddies and interspersed with counter-currents. Oceanographers need something equivalent to the meteorologists’ synoptic charts if they are to gain a better understanding of the dynamics of the oceans. A start was made during the International Geophysical Year when 25 nations put 80 research ships to sea in co-ordinated survey work, and the Special Committee on Oceanographical Research (SCOR) has been appointed to promote further international co-operation in this field.

A striking example is given of the influence of climate on marine life: in the Sargasso Sea weedlike fishes and weedlike crabs exist and even one air-breathing inhabitant—the intrepid water-rider, which runs over the sea surface on six long hairy legs, using the Sargassum weed as a resting place. Climatologists of today will not be flattered by the implication on page 24 that they are statisticians who are content to extract an average picture from a mass of data. Perhaps it is some comfort to know that the author is here assessing the contribution of Maury to marine meteorology.

The book can be strongly recommended to anyone who is interested in the general science of the oceans.

F. E. LUMB

METEOROLOGICAL OFFICE NEWS

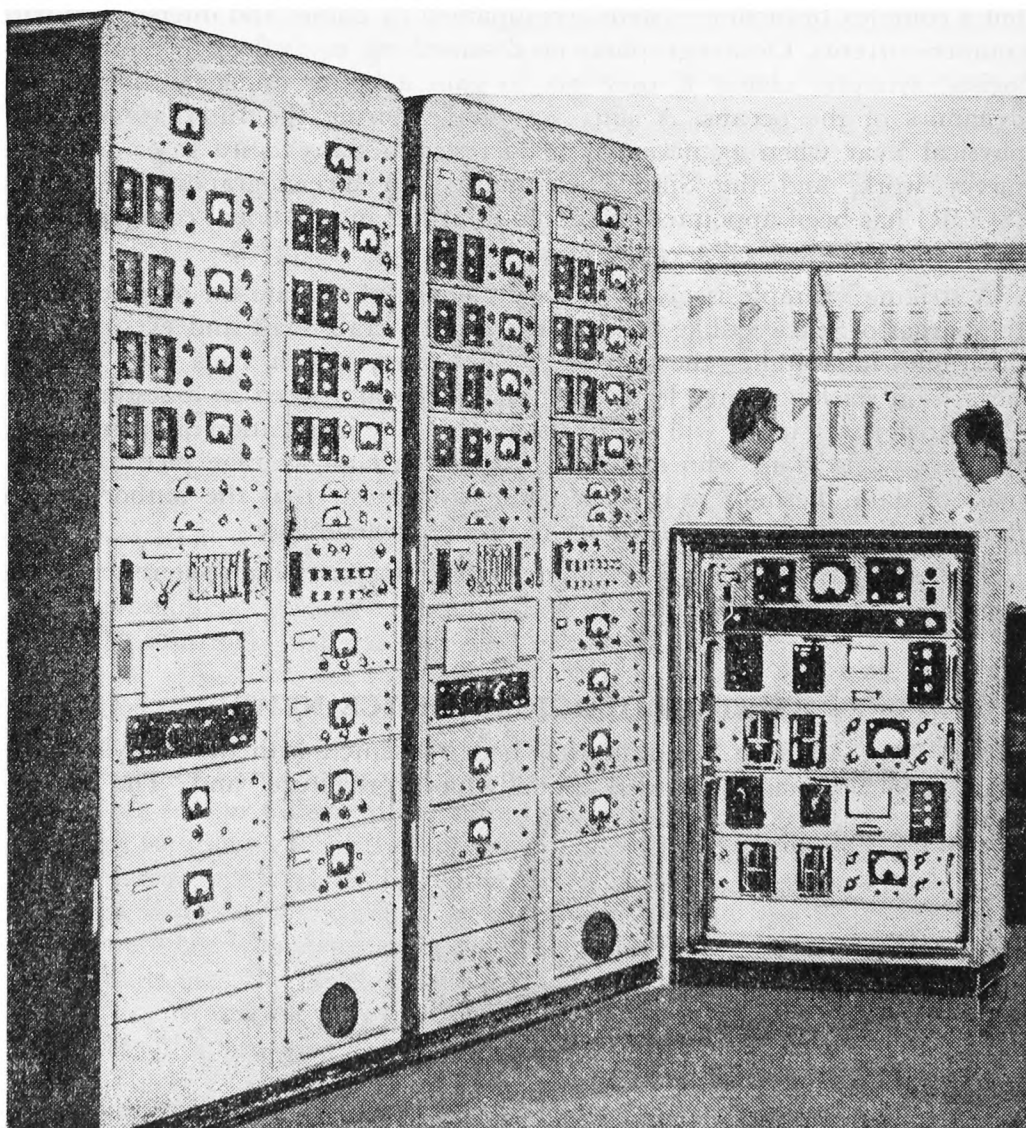
Mr. P. Auty, Assistant Scientific, has been presented with the Kenya Photographic Society’s cups, awarded annually for “Portraiture” and “The five best prints”.

Plessey

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Plessey is everywhere, you'll find . . . in the Middle and Far East for example, where minute by minute plotting and data transmission are the only key to effective warning of adverse weather conditions.



METEOROLOGICAL OFFICE

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FLUCTUATIONS IN TROPICAL STRATOSPHERIC WINDS

By R. G. VERYARD, B.Sc. and R. A. EBDON

Summary.—It has been found that there is a 23–29-month fluctuation in the zonal component of the stratospheric winds over the tropical regions from the equator to nearly 30°N. Insufficient observations are obtainable for upper air stations in southern tropical regions to indicate whether the fluctuation exists down to 30°S but such data as are available suggest that this may well be so. It appears that the fluctuation occurs almost simultaneously at the same level all round the tropics but there is a phase lag from higher to lower levels amounting to five to six months between the 25 mb and 60 mb levels. The range (twice amplitude) of the fluctuation increases with height but decreases polewards, for example, *as indicated by 12-monthly running means*, from approximately 30 knots at 60 mb and 70 knots at 30 mb at Christmas Island to approximately 10 knots at 60 mb and 15 knots at 30 mb at San Juan (Puerto Rico). Owing to the inadequacy and unreliability of the relevant temperature data it has not been possible to establish any link between the wind régime and the temperature pattern but the available observations for Canton Island suggest that a westerly régime is accompanied by warmer temperatures than an easterly régime. No firm evidence has been obtained that the fluctuation extends down into the troposphere.

Introduction.—In a recent letter to *Nature*¹ attention was drawn to a remarkable fluctuation with a period varying between 23 and 29 months in the zonal component of stratospheric winds recorded at equatorial upper air stations. It was mentioned that the fluctuation occurred almost simultaneously at the same level at each of the few stations for which adequate data were available but that there was a phase lag of several months between the occurrence of the fluctuation at lower levels compared with higher levels. It was also mentioned that results obtained up to that time indicated that the fluctuation also occurred at some distance, at least 10° of latitude, away from the equator. This paper gives a detailed account of the study and brings the findings up-to-date, findings which show that the fluctuation extends from the equator to nearly 30°N.

Equatorial stratospheric winds.—In an initial report² on the fluctuation of stratospheric winds at Christmas Island (02°00'N, 157°23'W) and Canton Island (02°46'S, 171°43'W), the impression was given that the fluctuation embraces a swing from a mainly westerly régime to a mainly easterly régime and also that the wind changes are apparent from daily observations and are not only revealed when long-period means are worked out. Subsequent work has shown that, whilst this is largely true for upper air stations close to the equator, the broad-scale fluctuation, that is over the tropical regions as a whole,

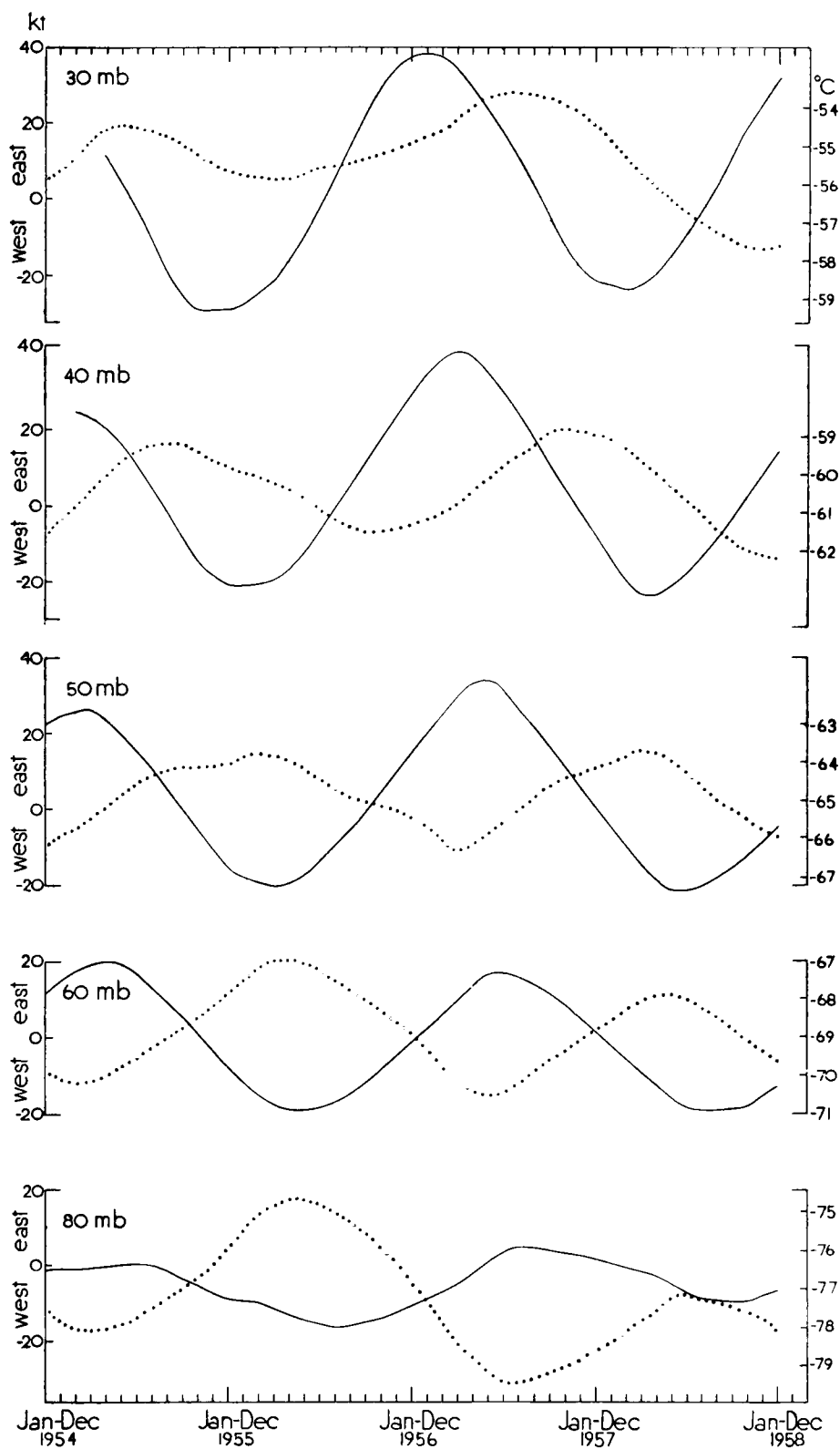


FIGURE I—TWELVE-MONTHLY RUNNING MEANS OF ZONAL WIND COMPONENT (CONTINUOUS CURVES) AND TEMPERATURE (DOTTED CURVES) AT CANTON ISLAND

really consists of an oscillation of the *zonal component* of the stratospheric winds, for example, between strong and weak easterlies as well as between westerlies and easterlies, and it may not be detected unless the annual variation is removed (for example by using 12-monthly running means).

It is not proposed to reproduce in this paper the figures (Nos. 1 and 2) in the initial report in which are plotted actual values of the mean monthly zonal and meridional components of wind at stratospheric levels at Christmas Island and Canton Island. However, to supplement the picture so given, the values for the period 1954-58 for Canton Island are given in Table I and curves of 12-monthly running means of the zonal component at the 30, 40, 50, 60 and 80 mb levels are shown in Figure 1 for Canton Island and in Figure 2 for

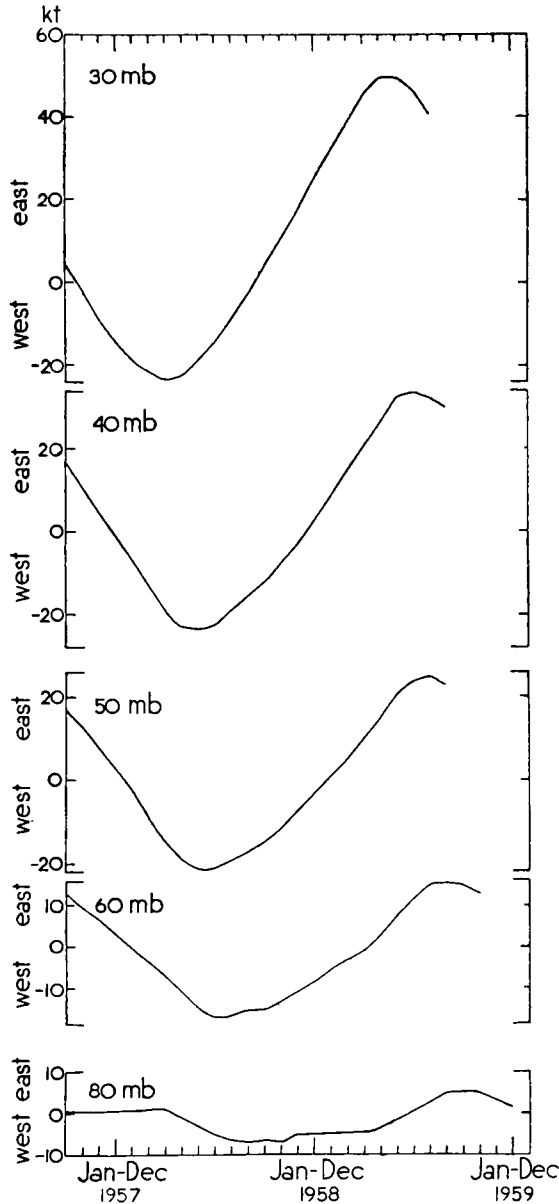


FIGURE 2—TWELVE-MONTHLY RUNNING MEANS OF ZONAL WIND COMPONENT AT CHRISTMAS ISLAND

TABLE I—MONTHLY MEANS (IN KNOTS) OF STRATOSPHERIC WIND COMPONENTS AT
CANTON ISLAND, 1954-58

	Zonal components					Meridional components				
	30mb	40mb	50mb	60mb	80mb	30mb	40mb	50mb	60mb	80mb
1954										
Jan.			-16.3	-17.7	-16.7			-0.2	+1.8	+1.5
Feb.			-4.7	-2.0	-0.2			-2.7	-0.8	+2.5
Mar.		+0.6	-12.8	-16.9	-8.2		-3.1	-7.2	-1.5	-2.3
Apr.		+6.7	-7.0	-14.2	-16.3		+3.1	+3.7	-0.8	-3.1
May	+46.3	+28.9	+24.8	-5.6	-19.2	-3.1	+1.0	-0.4	-2.1	0.0
June	+41.4	+37.3	+28.7	+9.7	-7.4	+4.3	+7.4	+1.4	-0.2	+1.4
July	+59.9	+47.6	+40.6	+20.9	+2.5	-1.5	-2.0	+1.5	+0.8	+1.2
Aug.	+50.9	+49.4	+44.1	+24.3	+14.2	+2.9	0.0	-0.8	+1.2	+0.8
Sept.	+36.8	+53.8	+44.4	+25.9	+17.9	-1.7	-0.8	+0.6	+2.2	-0.6
Oct.	+14.2	+55.8	+48.0	+29.1	+10.5	-1.2	-2.9	0.0	+4.1	-0.2
Nov.	-12.8	+27.0	+41.4	+34.2	+4.9	-3.3	-1.5	+1.7	+1.8	0.0
Dec.	-14.0	+10.7	+38.6	+31.5	-3.9	-1.5	0.0	+0.4	+2.9	-1.7
1955										
Jan.	-17.1	-14.2	+14.0	+24.3	-0.8	+1.5	-2.2	+1.4	-2.7	-0.6
Feb.	-22.4	-8.0	+5.1	+21.8	-10.1	+0.2	-1.0	+1.0	+0.4	-6.8
Mar.	-20.0	-10.1	-4.2	+14.4	+0.8	+2.5	+0.4	-1.2	-3.0	-2.9
Apr.	-26.3	-24.9	-21.1	-8.6	-13.4	-0.4	-0.2	-1.0	-0.7	-0.2
May	-37.3	-28.6	-23.1	-12.2	-11.1	+1.5	-1.2	-0.6	+0.4	-2.7
June	-36.4	-32.8	-29.9	-24.8	-6.6	+3.3	+1.0	+2.7	+0.9	-0.6
July	-36.0	-27.0	-18.3	-13.5	+0.4	0.0	+1.4	+0.2	+0.7	-1.2
Aug.	-62.6	-30.3	-22.2	-15.6	-4.3	+0.6	-1.0	+2.3	+0.7	-1.5
Sept.	-32.8	-24.5	-20.6	-19.6	-9.1	+2.7	+2.7	+2.5	+1.8	+0.2
Oct.	-30.5	-22.8	-19.6	-14.9	-7.2	-0.3	+2.0	+0.8	-1.3	-0.2
Nov.	-7.6	-13.0	-22.6	-31.1	-25.3	+3.3	-1.0	+1.0	0.0	-3.7
Dec.	-12.6	-11.7	-17.9	-18.5	-17.3	+2.0	+3.1	-1.8	-1.8	-2.3
1956										
Jan.	-2.2	-10.9	-13.7	-17.3	-8.1	-1.8	+0.9	-0.3	-2.1	-2.3
Feb.	+10.5	-6.6	-12.8	-16.4	-13.6	-1.5	-0.1	-1.0	-2.5	-3.6
Mar.	+19.3	-6.1	-18.2	-19.2	-20.7	-2.0	-3.7	-0.7	+0.1	-3.9
Apr.	+35.3	+8.2	-15.7	-22.1	-31.4	-2.3	-3.4	+1.1	+2.1	+0.4
May	+42.7	+27.9	+2.7	-21.6	-29.7	-1.4	-0.2	-1.3	+0.3	-0.6
June	+50.5	+36.2	+17.8	-13.8	-20.1	-0.3	+4.6	+1.4	-1.7	+0.1
July	+48.2	+41.9	+29.5	+4.6	-8.7	-0.6	-0.6	+0.6	+2.5	+1.0
Aug.	+51.7	+47.2	+33.7	+7.8	-0.4	+1.3	+0.9	+1.9	+0.9	+1.9
Sept.	+55.6	+48.0	+32.6	+13.4	+7.2	+0.6	+1.1	+1.6	+2.3	+1.0
Oct.	+65.5	+48.8	+39.1	+18.3	+0.2	0.0	0.0	+1.2	+1.7	-0.2
Nov.	+51.1	+53.5	+42.1	+20.1	-2.7	-0.8	-1.1	-0.3	-1.8	-3.3
Dec.	+24.2	+58.2	+42.8	+25.6	+5.0	-1.4	+0.5	0.0	-1.5	+2.5
1957										
Jan.	+1.1	+50.0	+44.7	+24.1	+8.0	-2.3	-1.2	-0.2	-1.7	-3.4
Feb.	+4.5	+44.5	+42.7	+30.6	+6.8	-5.4	0.0	+0.6	-0.9	+1.3
Mar.	-18.8	+24.4	+43.2	+26.9	+7.4	-1.6	-0.9	-1.0	0.0	+2.8
Apr.	-22.6	-5.4	+34.8	+23.4	+2.5	+0.1	-1.6	-0.8	-0.8	-2.1
May	-28.2	-22.9	+7.9	+19.9	+8.3	+0.1	+0.2	-2.6	-0.6	0.0
June	-26.4	-25.3	-18.2	-2.9	+10.5	0.0	+1.8	+1.2	+1.5	+0.9
July	-26.8	-27.7	-21.9	-9.5	+6.0	+2.2	+0.5	+0.1	-3.2	+0.4
Aug.	-30.5	-27.8	-25.2	-15.3	-2.2	+3.6	+0.1	+0.4	+0.2	-0.9
Sept.	-46.1	-27.5	-23.2	-12.7	-0.2	-1.3	-0.4	+2.0	+0.9	+2.9
Oct.	-30.3	-27.1	-23.1	-17.1	-6.3	+0.2	+1.7	-1.4	+0.2	+1.3
Nov.	-15.6	-25.6	-24.2	-23.1	-7.0	-0.9	-2.3	-1.5	-2.9	-1.3
Dec.	-10.7	-22.2	-23.1	-21.1	-9.1	-0.5	-0.5	+0.4	-0.5	-1.1
1958										
Jan.	-12.9	-22.1	-18.8	-13.9	-5.5	-0.4	+0.4	-0.2	+2.7	-1.2
Feb.	-12.3	-18.9	-15.7	-16.2	-4.9	-0.4	-2.0	-0.1	+1.8	-0.2
Mar.	-8.1	-18.7	-17.7	-10.4	-6.2	-1.2	-0.2	-0.6	-0.5	-1.1
Apr.	+9.1	-19.5	-21.3	-18.6	-7.4	+1.2	+1.9	+1.7	+1.1	+0.6
May	+38.0	+3.4	-24.6	-31.3	-24.4	-1.4	-0.5	-0.9	+0.3	+0.9
June	+43.0	+18.1	-19.0	-28.6	-17.0	+0.8	+1.9	+1.1	+0.1	-1.1
July	+43.6	+25.2	-7.2	-20.1	-7.3	-0.3	+0.3	-0.5	-0.5	+0.6
Aug.	+48.6	+30.0	-0.5	-14.6	-3.5	-1.3	-0.8	-2.6	+1.1	-1.5
Sept.	+51.5	+36.9	+4.7	-9.5	-5.4	0.0	+0.3	+0.3	+0.4	+1.0
Oct.	+59.5	+41.6	+13.9	-4.2	-8.1	+2.0	0.0	-1.5	+1.5	-1.1
Nov.	+61.8	+46.2	+23.1	+6.0	+4.4	0.0	+2.3	-1.8	-0.4	-0.4
Dec.	+61.5	+45.8	+26.9	+9.0	+3.8	-2.8	-2.3	+0.2	-0.9	+1.3

Note: Positive from north and east, negative from south and west.

Christmas Island. An extended curve for the 50 mb level at Canton Island, based on one hour of observation only, is given in Figure 15 which will be referred to later. Figures 3 and 4 respectively give similar curves for Nairobi ($01^{\circ}18'S$, $36^{\circ}45'E$) at the 60 and 80 mb levels and for Singapore ($01^{\circ}20'N$, $103^{\circ}53'E$) at 60,000 feet (about 65 mb). The data available for higher levels at Nairobi and Singapore were insufficient to enable reliable curves to be plotted; but for all the curves shown in Figures 1 to 4 at least 10 observations (and generally many more) were available for each month except for a few months in respect of the higher levels at Christmas Island. The general agreement between these curves will be seen at a glance but to illustrate the near simultaneity of the occurrence of the fluctuations at each of these stations, all of which are situated close to the equator, the curves for the 50 mb level at Christmas Island and Canton Island are superimposed in Figure 5 and the curves for the 60 mb level at Christmas Island, Canton Island and Nairobi plus the 60,000-foot (about 65 mb) level at Singapore are superimposed in Figure 6. In Figure 7 the curves for 80 mb at Christmas Island, Canton Island and Nairobi are also given together. It is unfortunate that the useful length of record and the number of observations available vary from station to station but the agreement of the curves in Figures 5-7 is most remarkable and significance tests are hardly necessary to support what seems to be a reasonable conclusion, namely, that a fluctuation varying between 23 months and 29 months in the zonal component of the stratospheric winds occurs almost concurrently at the same level all round the equator. Even short-period records, for example from the comparatively new upper air station at Gan ($00^{\circ}41'S$, $73^{\circ}10'E$) and from Guaquil ($02^{\circ}11'S$, $79^{\circ}52'W$) for which only some IGY data were available, confirmed the finding, as will be seen from Figure 8. This gives curves, for the 60 mb level, of the *actual* values of the monthly mean zonal wind components for these two stations and also for Canton Island, Nairobi and Christmas Island plus the 60,000-foot level at Singapore. The agreement of the curves for the last three stations during the peak in the easterlies in June 1959 is particularly noteworthy. Discontinuous or short-period data available for other stations near the equator, that is Entebbe ($00^{\circ}03'S$, $32^{\circ}27'E$), Ikeja ($06^{\circ}35'N$, $03^{\circ}20'E$), Recife ($08^{\circ}S$, $53'W$) and Truk Island ($07^{\circ}27'N$, $151^{\circ}50'E$) also support the finding. A curve for the 50 mb level at Truk Island is superimposed in Figure 5 on the corresponding curves for Christmas Island and Canton Island. It will be noted that the range of the fluctuation (*as indicated by 12-monthly running means*) is 20-25 knots less at Truk Island, the station most distant from the equator, than at the other two stations, that is, there is a decrease at the 50 mb level of about three knots per degree of latitude. This feature of the fluctuation will be referred to again in the next section. To test the correspondence between the mean monthly zonal components at one station and another, correlation coefficients were determined. The results were as follows:

- | | | |
|------|---|--|
| 0.97 | between 50 mb data for Christmas Island and Canton Island | |
| 0.94 | between 60 mb data for Christmas Island and Nairobi | |
| 0.76 | between 60 mb data for Christmas Island | } and 60,000 ft (65 mb) data
for Singapore with one-
month lag (see below) |
| 0.80 | between 60 mb data for Nairobi | |

In the initial report already referred to, it was pointed out that the data for Christmas Island indicated a phase lag between the occurrence of the fluctuation at a higher level and a lower level, and also a decrease in the amplitude of

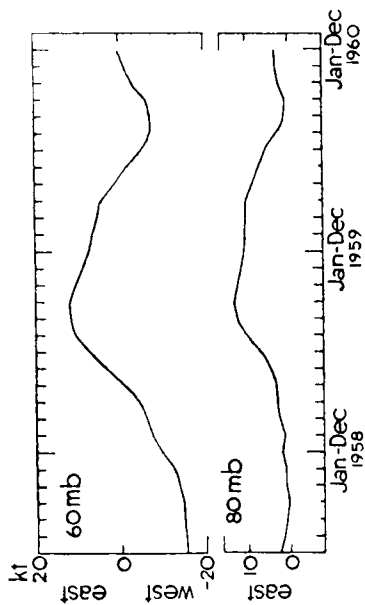


FIGURE 3—TWELVE-MONTHLY RUNNING MEANS OF ZONAL WIND COMPONENT AT
NAIROBI

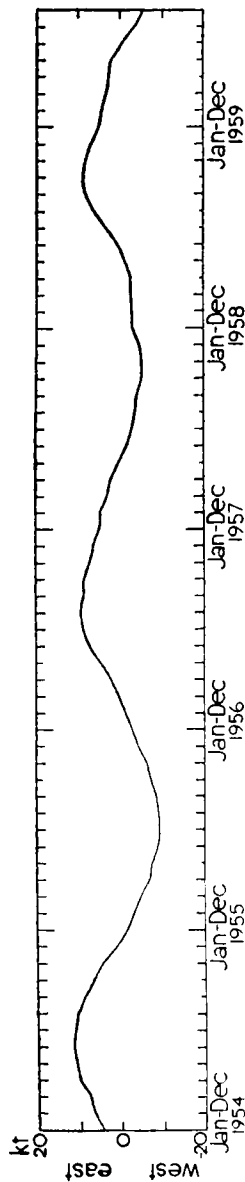


FIGURE 4—TWELVE-MONTHLY RUNNING MEANS OF ZONAL WIND COMPONENT AT
60,000 FT (ABOUT 65 MB) AT SINGAPORE

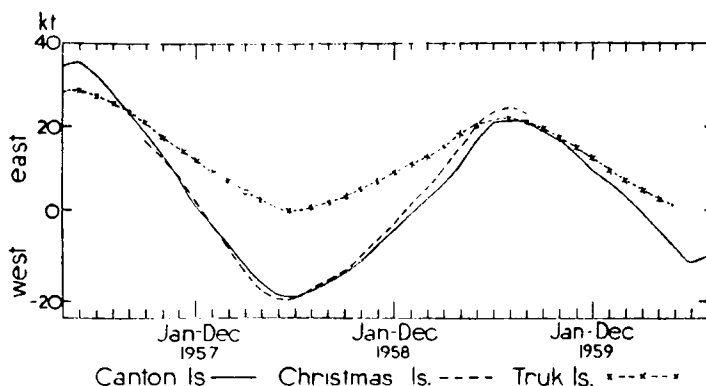


FIGURE 5—TWELVE-MONTHLY RUNNING MEANS OF ZONAL WIND COMPONENT AT 50 MB

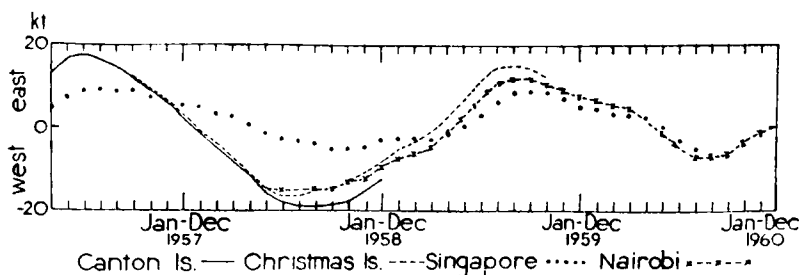


FIGURE 6—TWELVE-MONTHLY RUNNING MEANS OF ZONAL WIND COMPONENT AT 60 MB
For Singapore 60,000 ft was used.

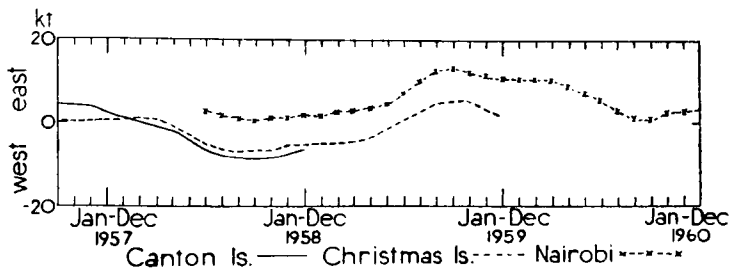


FIGURE 7—TWELVE-MONTHLY RUNNING MEANS OF ZONAL WIND COMPONENT AT 80 MB

the fluctuation from higher to lower levels. Both these features are revealed in Figures 1, 2 and 3 but it should be noted that the effect of using 12-monthly running means has been to reduce the amplitude in each case. In summary, the data for Canton Island and Christmas Island indicate that the average time-lag between peaks/troughs in the fluctuation at a higher level and at a lower level is about two months between 20 and 30 mb, one and a half months between 40 and 50 mb, and about one month between 50 and 60 mb, 60 and 70 mb, and 70 and 80 mb, which works out at about one month per kilometre change of height. The data for the 60 mb and 80 mb levels at Nairobi confirm this. Similarly, the range of the fluctuation (based on 12-monthly running means) decreases from about 70 knots at 30 mb to 60 knots at 40 mb, 45 knots at 50 mb, and 35 knots at 60 mb, which works out at a little less than 10 knots per

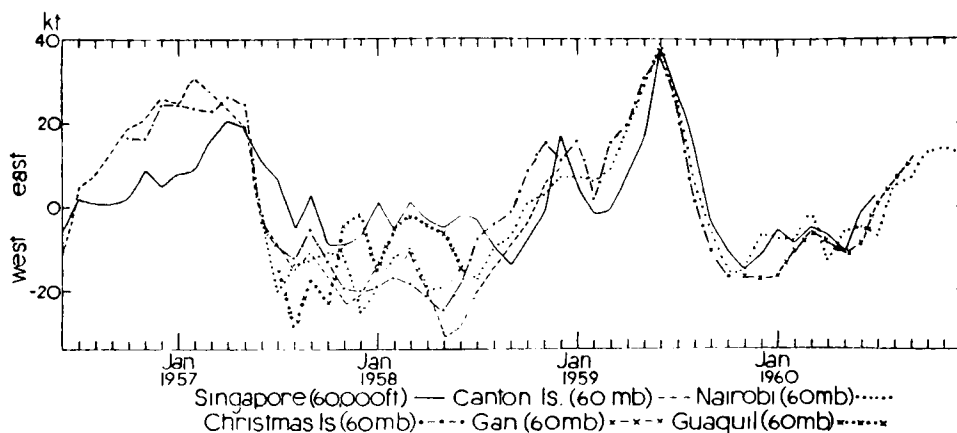


FIGURE 8—MONTHLY MEAN ZONAL WIND COMPONENTS

kilometre. The *actual* range, for example as indicated by individual monthly means for Canton Island (see values in Table I) decreases from 100 knots or more at 30 mb to about 90 knots at 40 mb, 75 knots at 50 mb and 65 knots at 60 mb. It will be noted from Figure 7 that whilst the phase and range of the fluctuation are about the same at 80 mb at Nairobi and Christmas Island there is a difference in the mean speed of about 8 knots (taking easterly winds as positive and westerly as negative), the mean wind at Nairobi being predominantly easterly whilst at Christmas Island there is an oscillation between westerly and easterly winds. To determine more precisely the dominant value of the period of the fluctuations, auto-correlation coefficients with lags of 1, 2, 3, 4 . . . n months were determined using the values of the 12-monthly running means for the 50 mb level at Canton Island. The results indicated a dominant period of 26 months with a lag correlation coefficient of 0.93.

Tropical stratospheric winds.—In the letter to *Nature*¹ it was mentioned that it was hoped to determine the extent to which the fluctuation extended north and south of the equator and in the initial report by Ebdon² it was indicated that the fluctuation had been found to exist at a few stations within the tropics. Actually, the data for some twenty stations have been examined but, in most cases, either the record was too short or the observations too few, especially for stations south of the equator, for it to be possible to make any reliable deductions. However, the data for a few stations were quite fruitful. Except for levels above 40 mb where the record was short, the observations available for San Juan, Puerto Rico ($18^{\circ}28'N$, $66^{\circ}07'W$), were particularly good and it was possible to “marry” data for height levels as used before 1956 with data for pressure levels used from 1956 onwards. Because of a marked annual variation in the upper winds at this station, it was essential to use 12-monthly running means and such values of the zonal component for the 20, 25, 30 and 40 mb/22 km, 50 mb/20 km,* 60 mb/20 km,* and 80 mb/18 km levels are given in Figure 9†. That a fluctuation similar to that found for equatorial stations occurred at San Juan, but with a smaller amplitude, is quite obvious. It will be noted that the range of the fluctuation, *as indicated by 12-monthly running means*, decreases from about 15 knots at the 30 mb level to

* 20 km is about half-way between the 50 and 60 mb levels.

† It should be noted that in Figures 9–14 the scale for windspeed is twice that used in other figures.

about 10 knots at the 60 mb level. There is also a phase lag from higher to lower levels but, owing to the flatness of the "peaks"/"troughs", it is not possible to determine this very precisely from the curves. However, from the individual values of the 12-monthly running means it is estimated that, on the average, there is a lag of two months from 30 mb to 40 mb, three months from 40 mb to 60 mb, and two months from 60 mb to 80 mb, which again works out at about one month per kilometre change of height. It will be seen from Figure 9 that the period of the fluctuation varies from about 22 months to 29 months; lag correlation (with a coefficient 0.93) indicated a dominant period of 23 months at the 50 mb level.

Although the data were not so plentiful as for San Juan sufficient observations were available in most months for curves of the 12-monthly running means of the zonal component to be drawn for the 60 mb level at Aden ($12^{\circ}49'N$, $45^{\circ}02'E$), Khartoum ($15^{\circ}36'N$, $32^{\circ}33'E$), Bahrain ($26^{\circ}16'N$, $50^{\circ}37'E$) and Malta ($35^{\circ}50'N$, $14^{\circ}27'E$). The curves for Aden, Khartoum and Bahrain are given in Figure 10 together with the corresponding curve for Nairobi so as to provide, approximately, a north-south picture. It will be seen that although the fluctuation appears to be present at Bahrain in 1954-57 it is not detectable in later years—but the data were rather inadequate, especially for the winter months. It will also be noted that at the other stations, although the fluctuation remains approximately in phase at the same level (60 mb), the farther away the station is from the equator the smaller the range of the fluctuation, that is about 28 knots at Nairobi, 20 knots at Aden and 11 knots at Khartoum. In fact, the greater is the distance from the equator the greater the decrease per degree of latitude—the average decrease being about one knot per one degree of latitude (see also the remarks on observations at Truk Island in the previous section). At Malta there was no sign of the fluctuation and this was also the case at Crawley ($51^{\circ}05'N$, $00^{\circ}13'W$) for both of which stations adequate data at 60 mb were available. As has already been noted, the range or amplitude of the fluctuation increases with height, and it might therefore have been possible to detect the fluctuation at higher levels at these more northern stations but, unfortunately, sufficient data were not available. Other stations for which curves of 12-monthly running means were drawn were Hilo ($19^{\circ}44'N$, $155^{\circ}04'W$), Jacksonville ($30^{\circ}20'N$, $81^{\circ}40'W$) and Washington ($38^{\circ}51'N$, $77^{\circ}02'W$). The curves for the 40, 50, 60 and 80 mb levels at Hilo are given in Figure 11, for the 30, 40 and 50 mb levels at Jacksonville in Figure 12 and for the 20, 25, 30, 40, 50, 60 and 80 mb levels at Washington in Figure 13. In both Figures 11 and 12 the curves for corresponding levels at San Juan are superimposed. It will be noted that the curves for Hilo agree fairly well with the corresponding curves for San Juan, both stations being in approximately the same latitude, but that there is no corresponding fluctuation in the case of Jacksonville (or in the case of Washington). In fact, all these curves reveal the same north-south relationship as is shown by Figure 10, that is a decrease in amplitude with distance from the equator and its disappearance north of about $30^{\circ}N$. It is interesting to note that the curves for the 20, 25 and 30 mb levels at Washington and for the 30, 40 and 50 mb levels at Jacksonville suggest a fluctuation with an anti-phase relationship to that of the fluctuation in the tropics but the records are much too short for this to be certain; neither were data from other middle- or high-latitude stations adequate to provide any check.

In Figure 14 the 60 mb curves for San Juan and Khartoum, within 5° latitude of each other, are superimposed. This appears to confirm the suggestion that the fluctuation may occur almost simultaneously around a latitude circle as has already been indicated by the curves for stations near the equator. Correlation of the data (12-monthly running means) for San Juan and Khartoum gives a coefficient of 0.69.

Before concluding this section, it should be mentioned that the findings described above were supported by short-period data available from Charleston ($32^{\circ}54'N$, $80^{\circ}02'W$) and Johnston Island ($16^{\circ}45'N$, $169^{\circ}32'W$). High-altitude observations made at tropical stations over Australia (Hopper, V. D.)³ suggest that the fluctuation may occur as far south as $20^{\circ}S$.

It will be noted with interest from Figures 1, 15, 4 and 9 that the three long-period records, that is for 50 mb at Canton Island, 60,000 feet for Singapore and 40, 50, 60 and 80 mb for San Juan (which demonstrate the existence of the fluctuation during the last nine to ten years) all show that in recent years the amplitude of the fluctuation has decreased. Maybe, like other alleged "periodicities" which have been discovered before, the fluctuation under discussion is only ephemeral and it will be interesting to see whether the fluctuation is maintained.

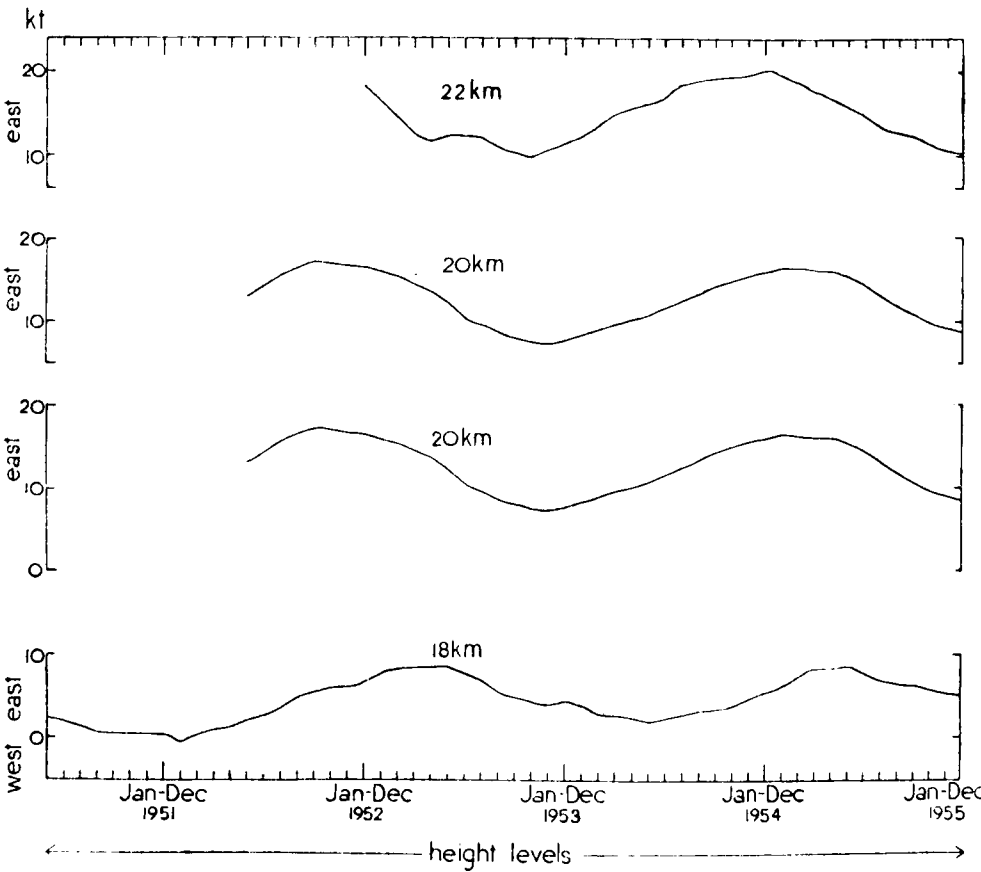
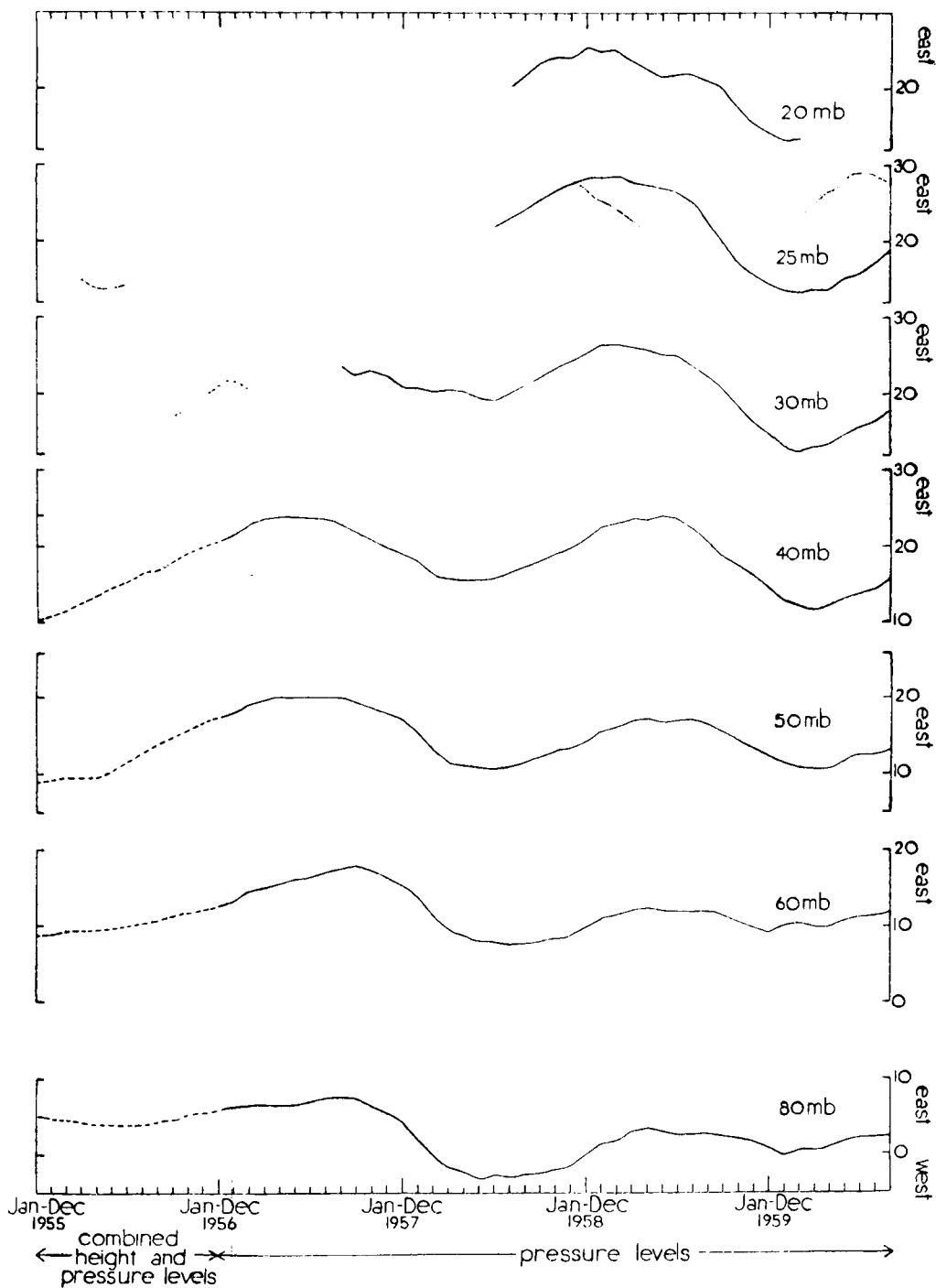


FIGURE 9—TWELVE-MONTHLY RUNNING MEANS



OF ZONAL WIND COMPONENT AT SAN JUAN

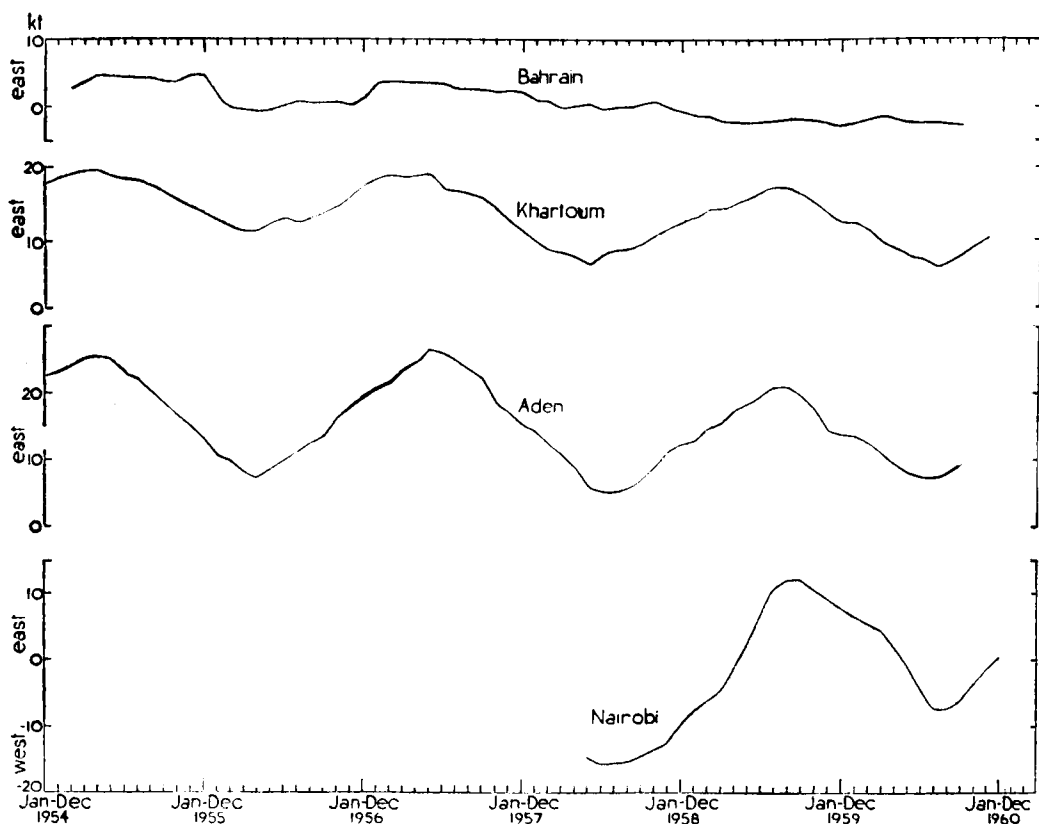


FIGURE 10—TWELVE-MONTHLY RUNNING MEANS OF ZONAL WIND COMPONENT AT 60 MB

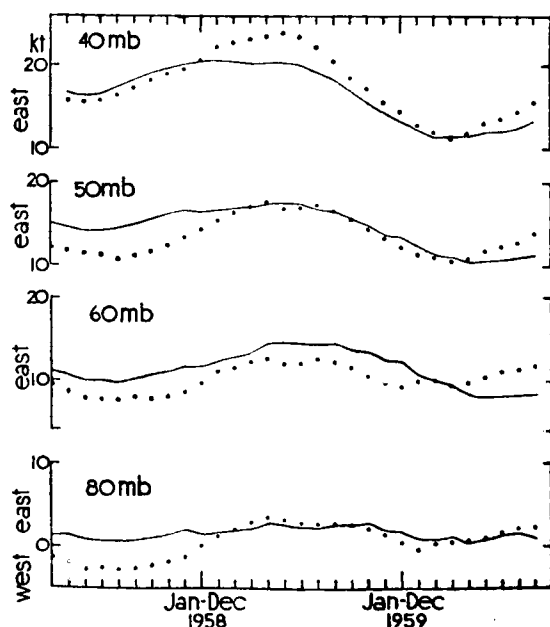


FIGURE 11—TWELVE-MONTHLY RUNNING MEANS OF ZONAL WIND COMPONENT AT HILO (CONTINUOUS CURVES) AND SAN JUAN (DOTTED CURVES)

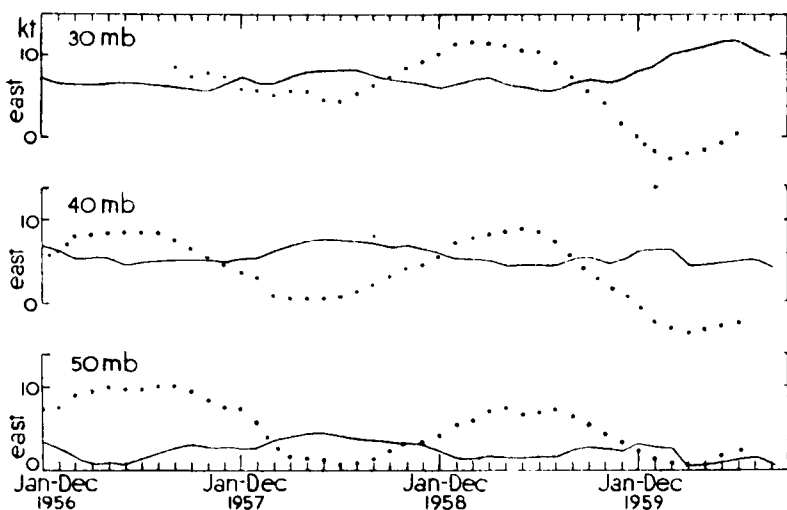


FIGURE 12—TWELVE-MONTHLY RUNNING MEANS OF ZONAL WIND COMPONENT AT JACKSONVILLE (CONTINUOUS CURVES) AND SAN JUAN
In superimposing the San Juan curves, 15 kt has been subtracted from the values at 30 and 40 mb and 10 kt from those at 50 mb.

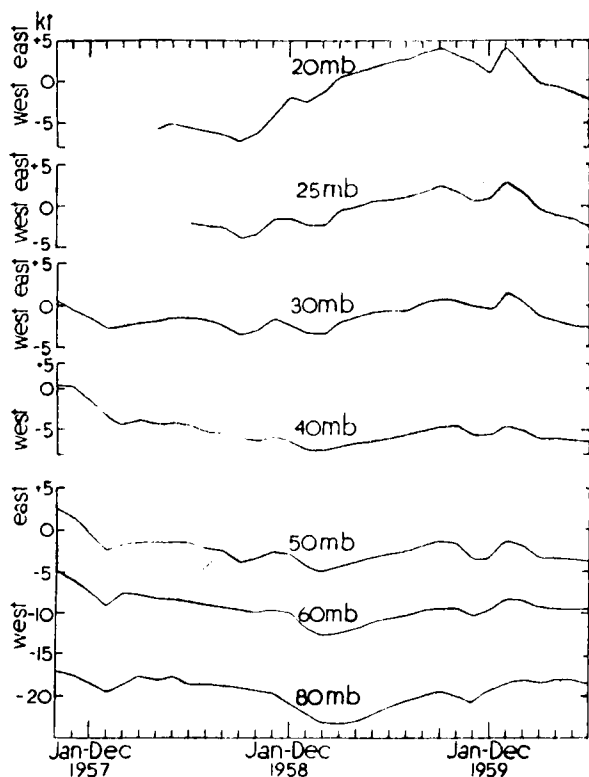


FIGURE 13—TWELVE-MONTHLY RUNNING MEANS OF ZONAL WIND COMPONENT AT WASHINGTON

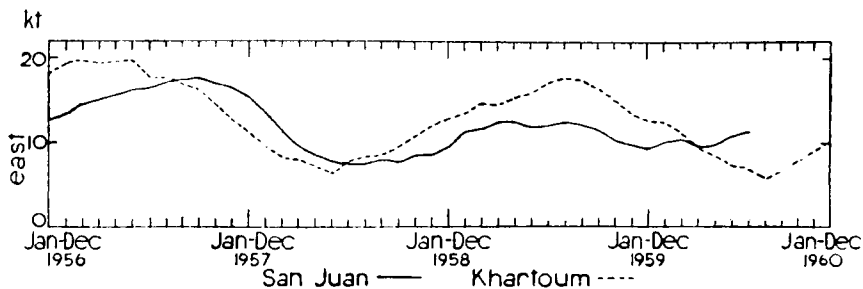


FIGURE 14—TWELVE-MONTHLY RUNNING MEANS OF ZONAL WIND COMPONENT AT 60 MB

Meridional component.—In view of the pronounced fluctuations which have been found in the zonal component of the stratospheric winds, it was obviously desirable to examine the meridional component also. But for no station did the relevant curves definitely reveal any similar fluctuation, although it should be mentioned that the meridional components were generally too small (especially at stations near the equator) to yield conclusive results. Auto-correlation of the values of the monthly mean meridional components for the various pressure levels at Canton Island and San Juan (both stations with good and fairly long records) did not reveal any marked fluctuation in the meridional component corresponding with that in the zonal component.

Temperature relationships.—In the initial report it was shown that, over the central Pacific, there is apparently very little difference in the temperature pattern at 50 mb whether the winds at that level are easterly or westerly. It was pointed out, however, that the curve of 12-monthly running means of 50 mb temperature at Canton Island indicated clearly a fluctuation with a periodicity of about 24–28 months. This curve is given in Figure 15 together with a similar curve for San Juan and, for reference, the 12-monthly running means of the 50 mb zonal wind components at Canton Island. It will be seen that there is a phase lag of one to two months between the Canton Island curves and that the San Juan curve shows no clear fluctuation (although there is, perhaps, a suggestion of a weak fluctuation in anti-phase with that at Canton Island). Examination of the temperature data available for Canton Island at other stratospheric levels, that is 80, 60, 40 and 30 mb, also revealed the existence of an approximately 26-month fluctuation at these levels—the range of the fluctuation, as indicated by 12-monthly running means, decreasing

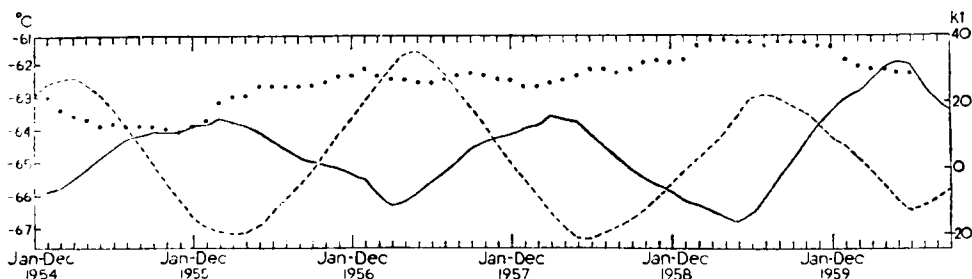
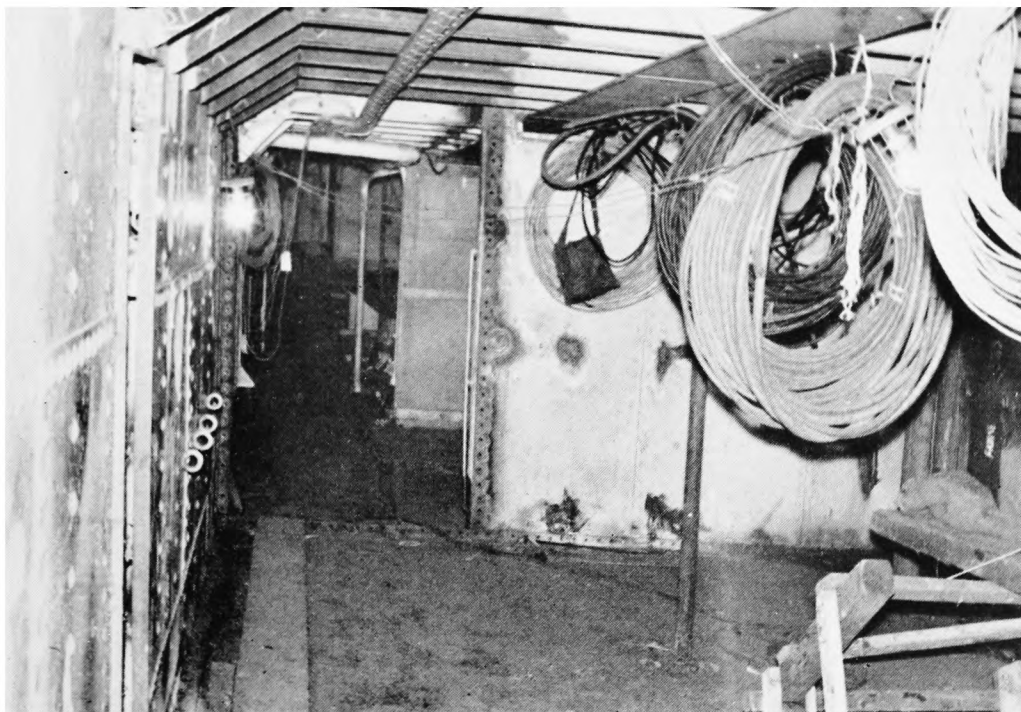


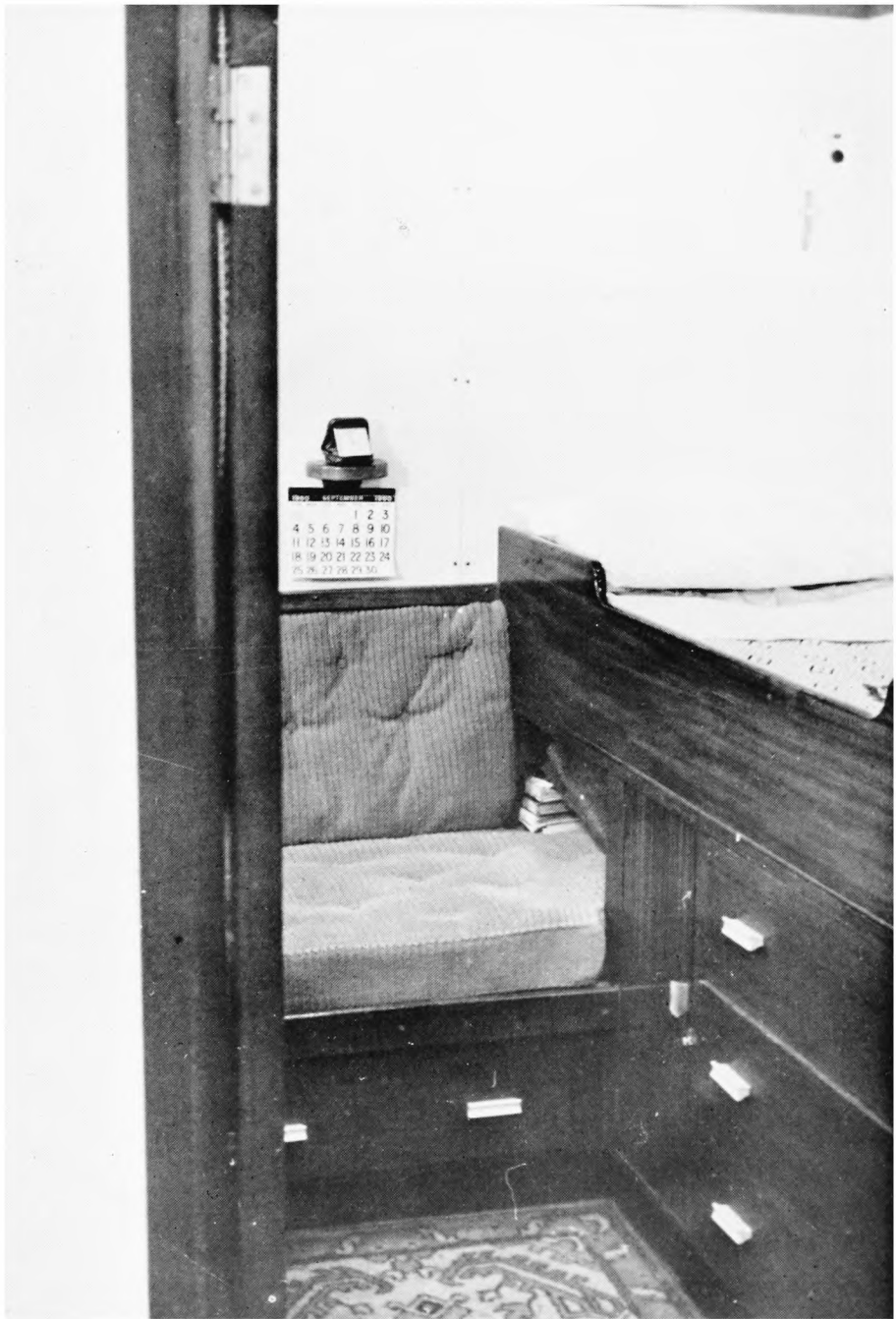
FIGURE 15—TWELVE-MONTHLY RUNNING MEANS OF 50 MB TEMPERATURE AT CANTON ISLAND (CONTINUOUS CURVES) AND SAN JUAN (DOTTED CURVES)

The 12-monthly running means of 50 mb zonal wind component at Canton Island (dashed curves) are also given.



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PLATE 1—DURING THE CONVERSION STAGES IN FITTING OUT A WEATHER SHIP



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PLATE II—A CABIN IN A NEWLY FITTED-OUT WEATHER SHIP



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PLATE III—A FINE DAY AT SEA



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PLATE IV—"WEATHER WATCHER" AT SEA

upwards from $3^{\circ}\text{--}4^{\circ}\text{C}$ at 80 mb to $1.5^{\circ}\text{--}2.5^{\circ}\text{C}$ at 30 mb and the lag between the temperature change and the wind change increasing upwards from one to two months at 80 mb to about seven months at 30 mb (see Figure 1).

As might be expected from this increasing lag with height between the temperature change and the wind change, the differences between the 12-monthly running means of the temperatures at the various levels, for example, between 30 and 80 mb as shown by the curve in Figure 16 reveal that the fluctuation is also to be found in the mean vertical temperature gradient.

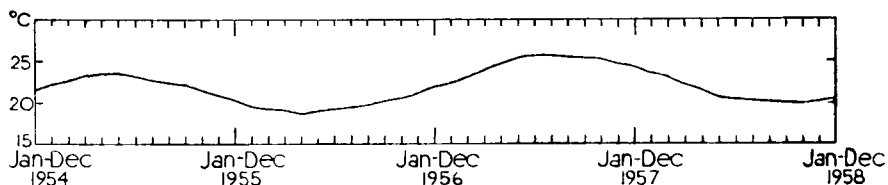


FIGURE 16—DIFFERENCES BETWEEN TWELVE-MONTHLY RUNNING MEANS OF TEMPERATURE AT 30 AND 80 MB AT CANTON ISLAND

In an attempt to amplify these results, 60 mb temperature data for Nairobi, Aden, Khartoum and Bahrain were examined and curves of 12-monthly running means covering the period July 1957 to December 1960 are given in Figure 17. It will be noted that for much of the relatively short period concerned there is a close agreement between the curves for Nairobi, Aden and Khartoum, but that there is little evidence for suggesting any fluctuation similar to that found in the 60 mb zonal wind component at these four stations. The number of 60 mb temperature observations at these stations was generally adequate except at Nairobi where ten of the monthly means had to be computed from less than ten observations.

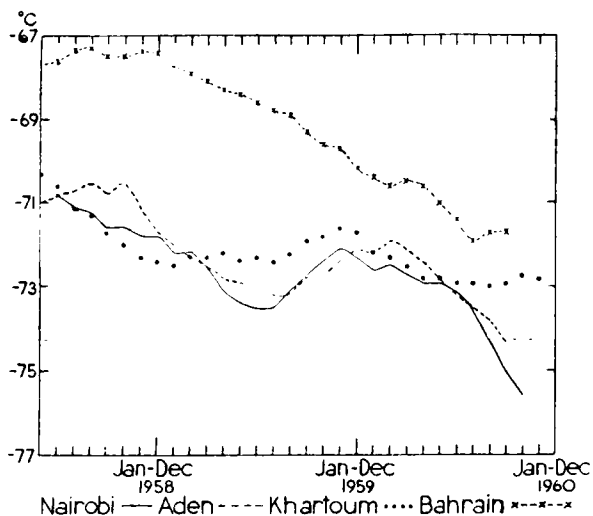


FIGURE 17—TWELVE-MONTHLY RUNNING MEANS OF 50 MB TEMPERATURE

It should be mentioned that there do not seem to be any other upper air stations near the equator with a stratospheric wind and temperature record comparable with that for Canton Island. Some rather doubtful temperature

data for Christmas Island did seem to support the finding for Canton Island but as the Nairobi data (which were scanty) did not, the question whether there is any general fluctuation of stratospheric temperature in equatorial regions linked with the fluctuation of the zonal winds cannot be answered at present.

Twelve-monthly running means of contour height at 50 mb and 60 mb were also examined for both equatorial and tropical stations but the results revealed no fluctuation with a periodicity of 23–29 months. Indeed, it seems that any attempt to find a relationship between the pronounced variations in the tropical stratospheric winds and the variation in the stratospheric temperature and contour heights cannot be effected until more accurate, more homogeneous and more plentiful data are available for a longer period.

Tropospheric aspects.—It was obviously desirable in view of the importance of possible stratospheric-tropospheric relationships, to ascertain whether any such fluctuation as had been found in the tropical stratospheric winds existed in the tropospheric winds; but, in confirmation of the earlier findings mentioned in the initial report by Ebdon,² no well defined parallelism was found. As an example, the curves for the 12-monthly running means of the zonal wind components at Canton Island for the 500 mb, 200 mb and 50 mb levels (mean tropopause about 90 mb) are given in Figure 18, and the 12-monthly running means of the zonal wind components at San Juan for the 500 mb/6 km, 300 mb/10 km, 200 mb/12 km and 100 mb/16 km levels (mean tropopause about 95 mb) are given in Figure 19. It will be noted that there is some correspondence between the tropospheric and stratospheric winds towards the end of the period (1957–59) at San Juan but this is not the case for the earlier parts of the curves. Moreover, in 1957–58 there appears to be a phase lag from lower to higher levels rather than from higher to lower levels as was found in the stratosphere. Actually the tropospheric curves which were drawn for Singapore and Christmas Island even suggested an anti-phase relationship. Such correspondence as there is may therefore be regarded as fortuitous. The negative results of the study of other tropospheric events (for example, precipitation and the “Southern Oscillation”) in relation to the fluctuation in the stratospheric winds have already been mentioned in the initial report by Ebdon and will not be reiterated in this paper. However, in spite of the fact that no linkage has been found, it is considered advisable to keep an open mind on the subject as the study of other parameters (for example, vertical motion) may show some connexion.

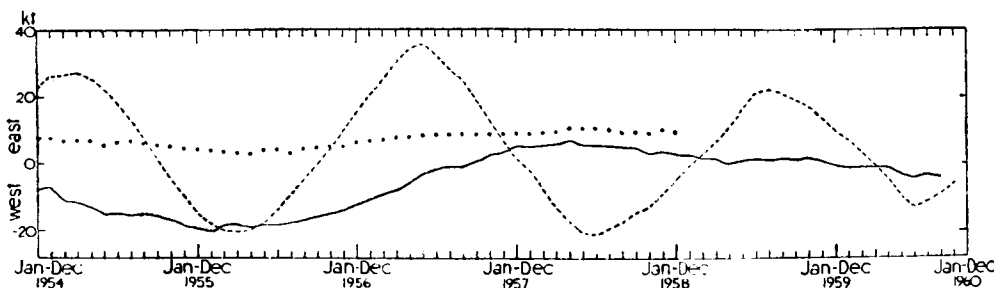


FIGURE 18—TWELVE-MONTHLY RUNNING MEANS OF ZONAL WIND COMPONENT AT CANTON ISLAND

50 mb: dashed curve; 200 mb: continuous curve; 500 mb: dotted curve

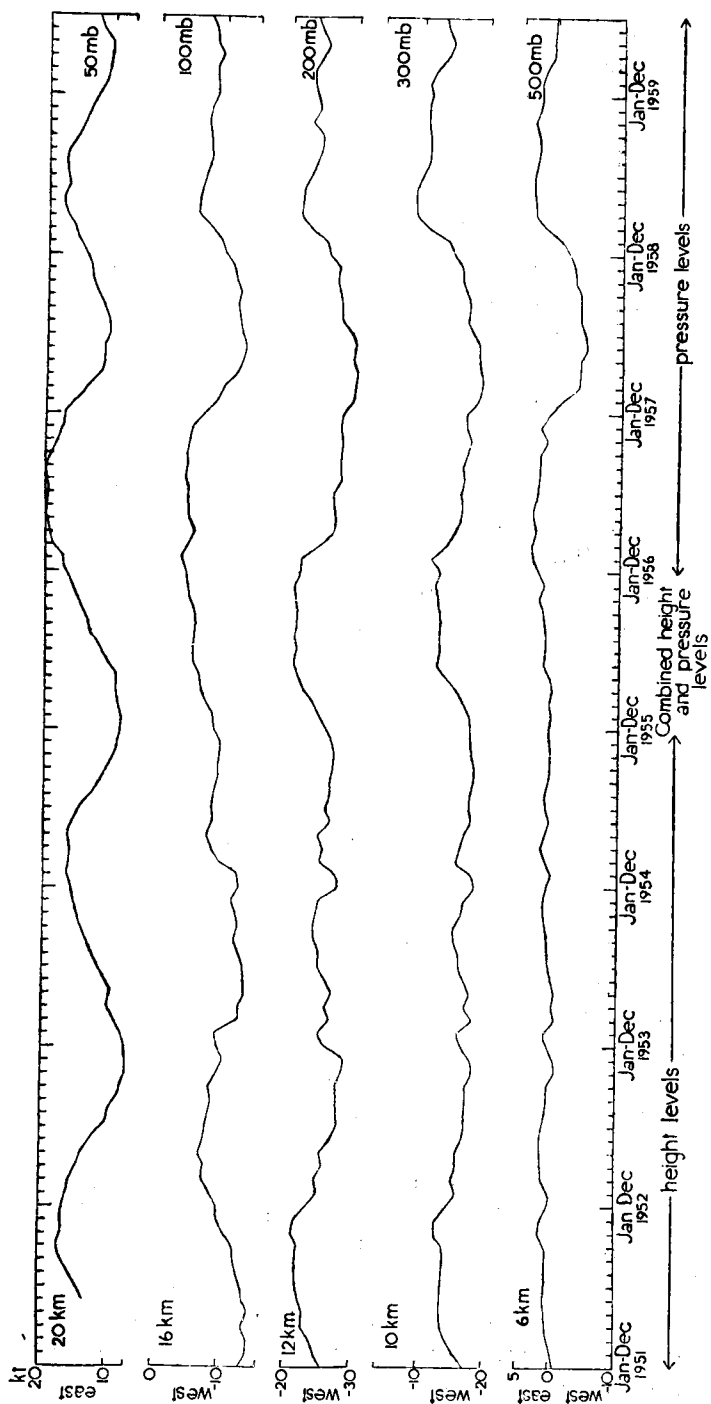


FIGURE 19—TWELVE-MONTHLY RUNNING MEANS OF ZONAL WIND COMPONENT AT
SAN JUAN

Discussion.—The existence of the fluctuation in the stratospheric winds over tropical regions with a period which varies from about 23 months to 29 months indicates that a mean monthly, seasonal or yearly wind obtained, as is usually done in climatology, by averaging over a period of years will be very misleading—especially to users of such data, for example, for studying radioactive fall-out. The finding also calls for a re-appraisal of the alleged existence of the “Berson” westerlies which are referred to in many publications as a narrow belt of westerly winds encircling the equator at about 20 kilometres (50–60 mb). That such a belt of stratospheric westerlies *could* extend right round the equator is suggested by the results given in this paper but it might be found at *any* level up to 10 mb (and possibly above)—and only for alternating periods of about 12–15 months. Actually, attempts were made, using IGY data, to find occasions when every upper air station near the equator (and there were several new stations operating during the IGY) reported westerly winds; but the observations were disappointingly scarce at stratospheric levels and the desired evidence could not be obtained.

The results which have been found also show that the idea, also to be found in many publications, that over the equator there are quasi-permanent easterlies, the so-called “Krakatoa” easterlies, above the 25-kilometre (about 25 mb) level needs to be revised. There is no doubt that the base of these winds must vary considerably. The Canton Island and Christmas Island data show that the westerly régime may for a time, certainly up to three months, prevail throughout a considerable part of the stratosphere—at least to above 25 mb. Thus it is possible that if the volcanic eruption of Krakatoa, from which the easterlies get their name, had occurred in August 1882 or 1884 instead of August 1883, writers on the subject might have coined the phrase “Krakatoa westerlies”!

As for the explanation of the remarkable fluctuation which has been reported in this paper, it is not even possible to make a reasonable guess. There is no well established oscillation of similar period, *based on physical or dynamical considerations*, with which the fluctuation could be associated. Berlage^{4,5} in an extensive study of over 50 alleged cycles of a year or more has argued that the so-called Southern Oscillation (a fluctuation, found by Sir Gilbert Walker in the pressure difference between the Malayan Archipelago and Easter Island) is a primary terrestrial period of $2\frac{1}{3}$ (2–3) years caused by mutual interactions of air and sea temperatures, the latter influenced by oceanic currents. As mentioned above, an attempt to find out whether there was any correlation between the zonal component of the tropical stratospheric winds and surface pressure proved unfruitful. Recent work in the U.S.S.R. (for example, Pokrovskaja⁶) has also suggested the existence of a two-year periodicity in certain elements, depression tracks, etc., but the details have not been studied. It is interesting to note that in a recent paper (Storebø⁷) on the exchange of air between stratosphere and troposphere, it is considered that about two years are required for the replacement of stratospheric air in the mean net circulation, suggested by tracer elements, by which air enters the stratosphere in the tropics, is transported polewards and leaves the stratosphere at higher latitudes. In any case, the finding presents a challenge to the theoretical meteorologists, and colleagues in the Climatological Research Division of the Meteorological Office are already studying the problem.

Acknowledgements.—Our thanks are due to the United States Weather Bureau and other meteorological services whose data have been used and to Dr. G. B. Tucker for his assistance in arranging for the correlation coefficients to be computed on "Meteor".

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ACCURACY OF FORECASTING AIR TRAJECTORIES

By M. H. FREEMAN, O.B.E., M.Sc.

Introduction.—In the normal course of his work a forecaster often wants to know what air mass will be over his station some hours hence. Usually examination of current charts and prebaratics will give him a good enough answer without any elaborate methods, but sometimes more precision will be needed, and forecast trajectories will have to be drawn. Studies into the accuracy of prebaratics have been made in the past and it was thought that these could usefully be supplemented by an investigation into the accuracy with which air trajectories could be forecast.

Outline of investigation.—Birmingham was selected as the station for which trajectories were to be drawn and it was assumed that the problem was to find out what air originating over the sea would subsequently reach Birmingham. It was further assumed that the trajectories of the air could be determined from geostrophic winds measured from surface charts. This, of course, is not strictly true since the streamlines do not, in general, coincide with the isobars. However, if geostrophic winds are used for both forecast and actual trajectories a reasonable comparison can be made.

In order to simulate operational conditions the forecasts were made using current charts in the Central Forecasting Office at Dunstable; normal forecasting methods were used to produce a series of forecast surface charts. Between 0730 and 0900 GMT prebaratics for 1800 GMT and 0600 GMT were prepared for the British Isles and a wide surrounding area. Using these charts and the 0800 GMT actual chart, more detailed forecast charts were made for the British Isles on a scale of 1:3 million for 1200, 1800, 0001 and 0600 GMT. Trajectories were drawn on these charts in six-hour steps. Geostrophic winds were measured from the 1200 GMT map to obtain the air movement for the period 0900 to 1500 GMT, and successive sections of the trajectories were obtained from the remaining charts. By trial and error a starting point over the sea was chosen so as to give a forecast trajectory which passed over Birmingham. The position of this starting point determined the air mass which was expected

to reach Birmingham. It was decided also to obtain some information on the way in which neighbouring trajectories spread out or converged, so four more trajectories were drawn starting over the sea at distances of 50 and 100 miles on either side of the central starting point. Information was also sought on the success of forecasting trajectories over distances greater than that from the coast to Birmingham, so the trajectories were drawn for the whole 24-hour period, 0900 GMT to 0900 GMT, even though this usually took them well past Birmingham.

After the event actual charts were used by another forecaster to obtain "true" trajectories of the air starting at the five selected points. For greater accuracy hourly charts and steps were used over the British Isles; if the trajectories continued over the sea three-hourly steps were used since ship reports were not available more frequently than every three hours.

Between November 1959 and August 1960 forecasts were made on 40 occasions at approximately weekly intervals. On a few of them the trajectories became lost in the centres of depressions, but wherever possible measurements were made of the end points of the forecast and actual trajectories after 6, 12, 18, and 24 hours.

Results.—On the average the distance of Birmingham from the selected starting points was 160 miles and over this distance the forecasts were usually fairly accurate. Nevertheless on two occasions, both with light winds, the trajectories had not reached Birmingham after 24 hours. For the remainder the perpendicular distance from Birmingham to the central trajectory was, on the average, 25 miles. The frequency of errors of various magnitudes is given in Table I.

TABLE I—FREQUENCY OF ERRORS

Distance by which central trajectory missed Birmingham ...							0-10	20-40	50-80 mi
No. of occasions ...	...	...	...	...	...	...	20	11	7

On five of the seven occasions when misses of 50 miles or more were recorded the mean wind speed was about 10 knots, and on the other two occasions 20 and 30 knots.

Over distances greater than that of Birmingham from the sea, the accuracy in forecasting trajectories fell off. A measure of the error of a trajectory is the distance between the forecast end point and the observed end point and this error was recorded for each trajectory after 6, 12, 18 and 24 hours. In general the greater the trajectory length, the greater was the error. The mean errors and frequency of errors of various sizes for different trajectory lengths are given in Table II.

TABLE II—ERRORS FOR VARIOUS TRAJECTORY LENGTHS

Trajectory length (mi)...		...	...	...	110-200	210-400	410-600	610-800
Mean error (mi)		...	...	...	65	95	120	165
		<i>per cent</i>						
Frequency of errors of	{ 50 mi or less		...	...	61	32	24	18
	{ 100 mi or less		...	...	85	70	56	33
	{ 200 mi or less		...	...	96	92	86	71
	{ 400 mi or less		...	...	99	100	98	95

The greater errors for the longer trajectories are largely due to the time factor; as the period increases the reliability of the forecast wind field decreases. This is demonstrated in Table III, which shows the mean error and the frequency of errors of various sizes for trajectory times of 6, 12, 18 and 24 hours.

TABLE III—ERRORS FOR VARIOUS TRAJECTORY TIMES

Period (hr)	...	...	...	...	6	12	18	24
Mean error (mi)	...	...	...	...	35	80	120	175
						<i>per cent</i>		
Frequency of errors of	{ 50 mi or less				88	41	20	13
	{ 100 mi or less				98	86	52	35
	{ 200 mi or less				100	96	91	67
	{ 400 mi or less					98	98	94

The errors are due partly to errors in forecasting wind speed and partly to errors in forecasting wind direction. The frequencies of errors of various sizes due to these causes are given in Table IV.

TABLE IV—ERRORS IN WIND SPEED AND WIND DIRECTION

Period (hr)	...	...	...	...	6	12	18	24
						<i>per cent</i>		
Speed errors of 5 kt or less	...	...	...	...	87	82	72	65
Speed errors of 10 kt or less	...	...	...	...	98	94	93	92
Direction errors of 10° or less	...	...	...	...	72	65	64	67
Direction errors of 30° or less	...	...	...	...	93	90	88	87

Good forecasts are more likely with some synoptic types than others. The most straightforward situation is a broad wind flow not changing markedly in direction. Twenty-three of the forty occasions could be classed in this category and sixteen of these were well or fairly well forecast. The larger errors on the others were mainly due to errors in forecasting the wind speed. As would be expected in these situations of a broad wind flow, errors in forecasting direction were generally small. The remaining situations included various synoptic types but were generally characterized by light winds, with ridges or highs predominating. In this group the proportion of good forecasts was smaller, and the larger errors were due mainly to wind direction being wrongly forecast.

The trajectories assumed interesting forms on a number of days. Convergence of the trajectories was marked on three occasions. The initial distance of 200 miles between the outside trajectories was reduced in the region of Birmingham to 70 miles on 8 December 1959, and to 100 miles on 26 January and 18 July 1960. The first was very well forecast but the others were not. On some days (for example, 30 December 1959 and 18 August 1960) the trajectories crossed one another. The crossing was well forecast on 30 December, and errors on both days were small. At the other extreme very divergent patterns sometimes occurred. On 15 March 1960 the initial 200-mile starting line had spread to 600 miles after 24 hours and this occurrence was quite well forecast. On two days, 14 December 1959 and 19 April 1960, air originating at either end of the starting line moved in almost diametrically opposite directions; these freakish occurrences were not correctly forecast. Another exceptional pattern occurred on 23 February 1960 when the trajectories started off in the general direction of Birmingham and then turned back on themselves. This was caused by the movement of a sharp ridge of high pressure and was fairly well forecast. There were rather similar situations on 30 May and 20 June 1960. On the whole most of the peculiar patterns occurred with light winds.

Acknowledgement.—The *post factum* drawing of the trajectories using actual charts was done by Messrs. A. R. Laird and P. F. Abbott.

CORRELATED FLUCTUATIONS OF WIND DIRECTION AND AIR TEMPERATURE AT RENFREW AIRPORT ON 12 OCTOBER, 1960

By J. B. MCGINNIGLE

On 12 October 1960, between midnight and 0600 GMT, correlated fluctuations of wind direction and air temperature were recorded at Renfrew Airport. Intermittent fluctuations of 30 to 50 degrees in wind direction corresponded with almost instantaneous changes of two to three Fahrenheit degrees in air temperature.

Observational data.—Figure 1 shows the records of the two above-mentioned elements imposed on a common time-axis. The upper part shows the mean wind direction in degrees true over the six-hour period and was constructed from the anemograph chart for the period. The lower part of Figure 1 shows the recorded air temperature over the period, and this was constructed by combining observed temperatures with the trace of the thermograph. The recorded wind speed was consistently in the range five to ten knots and showed no variation at the times of wind direction fluctuation. For this reason it has not been reproduced.

Observed dew-point temperatures did not vary appreciably during the period, remaining at $33^{\circ} - 34^{\circ} \text{ F}$ throughout, and the subsequent relative humidity range was 73 – 85 per cent. Visibility was good and one okta of cloud, base 5,000 feet, was the maximum observed amount between midnight and 0600 GMT.

The previous day's weather at Renfrew Airport had been typically convective, with broken cumulus cloud during the afternoon dispersing completely after sunset. The wind had been recording 10 – 15 knots from $320^{\circ} - 350^{\circ}$ during the afternoon, decreasing and backing to $5 - 10$ knots from $290^{\circ} - 310^{\circ}$ during the evening. After reaching a maximum of 54° F the temperature decreased steadily to reach 42° F by midnight.

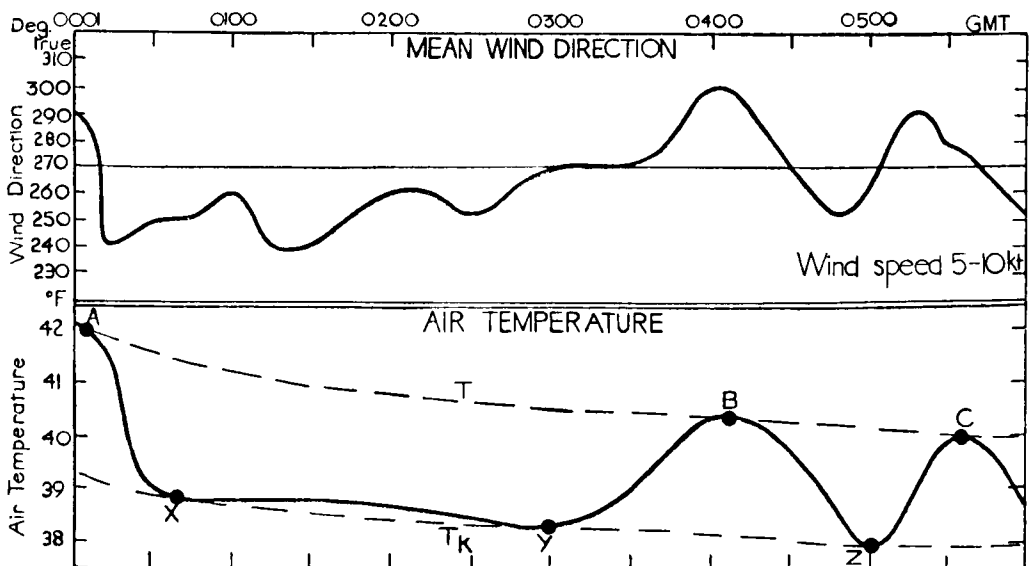


FIGURE 1—COMPARISON OF MEAN WIND DIRECTION AND AIR TEMPERATURE

Synoptic situation.—A simple synoptic situation existed over Scotland during the investigation period. A slow-moving depression over southern Sweden and an anticyclone over Iceland, ridging over the Atlantic, maintained an unchanging gradient for northerly winds of 25 – 35 knots over Scotland. The upper air ascents from Stornoway and Shanwell for midnight showed instability to 5,000 feet, with a surface temperature of 46° – 50° F, and an anticyclonic inversion above 5,000 feet. Between the top of the friction layer and 700 millibars there were no appreciable variations of wind speed and direction.

Topography.—Figure 2 shows the topography of the Clyde Valley and the position of Renfrew Airport between Paisley and Glasgow. From Renfrew Airport the ground slopes upwards gently to the north and south, but for the purpose of this investigation the significant features are situated in the north-west to south-west quadrant. The Clyde Estuary and the Valley lying along the line Dalry to Paisley are divided by the high ground of the Hill of Stake, which rises to 1,711 feet at a point approximately 14 miles west of Renfrew Airport. The slopes of this high ground are irregular and hold many stretches of water, the largest of which are reproduced in the sketch map. Thus there are two natural wind “channels” in this quadrant, and this “channelling” effect is often noticed in the wind observations at Renfrew Airport. This effect is an important feature in this investigation.

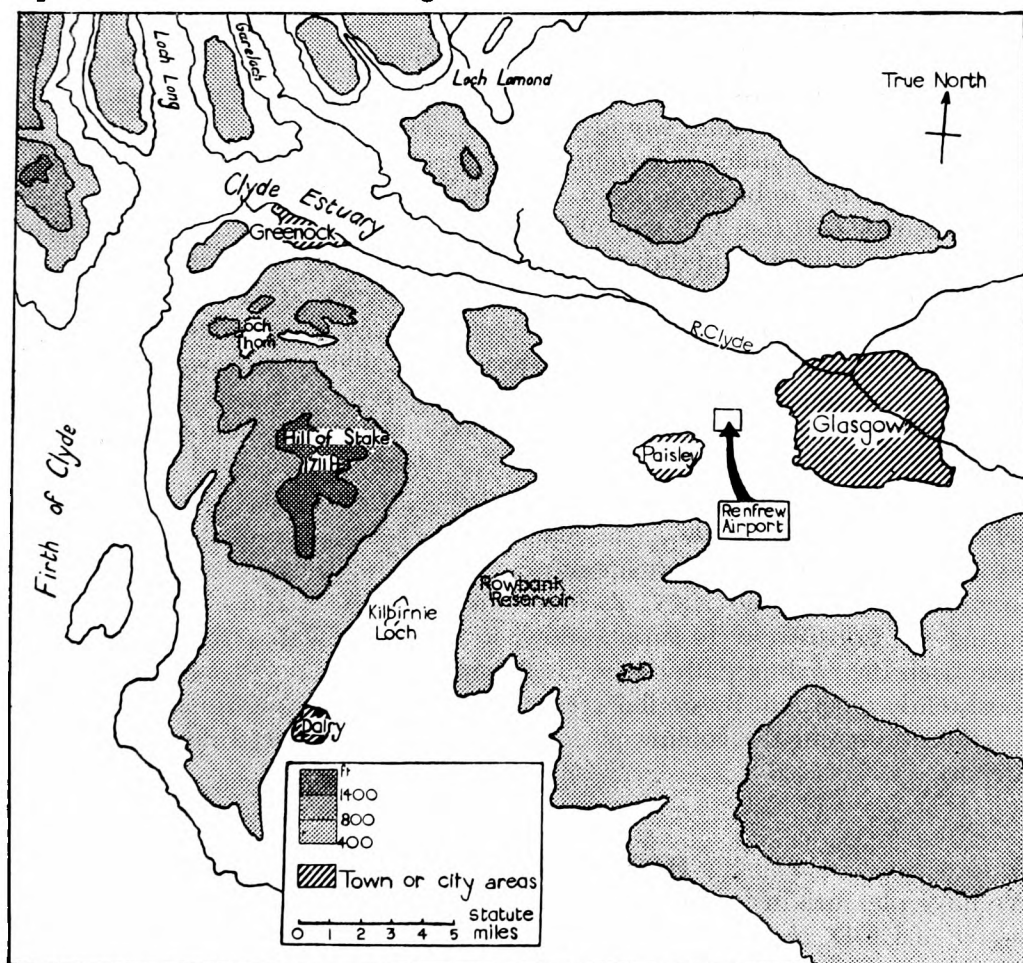


FIGURE 2—TOPOGRAPHY OF THE CLYDE VALLEY

Discussion.—The normal nocturnal wind direction recorded at Renfrew Airport in such a synoptic situation is $290^{\circ} - 310^{\circ}$ after flowing along the “channel” of the Clyde Estuary. From Figure 1 it will be noticed that between midnight and 0010 GMT, 0330 and 0430 GMT, and between 0505 and 0545 GMT, the wind flow was in this normal direction. At all other times in the period the wind direction was $240^{\circ} - 270^{\circ}$, a direction which had a component against the gradient. This contra-gradient flow was almost certainly induced by katabatic effects, a theory which is upheld by the associated falls in air temperature (with no change of dew-point temperature) which occurred at the times of the onset of this flow.

It is at this point that Figure 1 should be considered in two parts, firstly to explain the theory of a contra-gradient flow existing at Renfrew Airport, and then, on the basis of this, to discuss the fluctuations of both elements later in the night.

Midnight – 0300 GMT.—This part of Figure 1 shows a smooth slow fall of air temperature after an initial plunge of 3.2°F degrees, while an approximately similar configuration in the wind direction record shows that after backing to 240° at 0015 GMT, the wind remained in a direction having a contra-gradient component until 0300 GMT. Following the katabatic theory, early katabatic flow would start in the most sheltered area, which in this synoptic situation would be the south-eastern slopes of the Hill of Stake. On reaching the lower slopes this katabatic flow would be subjected to a westerly component from the gradient, thus producing a tendency for a generally westerly flow. Being cold and dense, the air mass would take the path of least resistance consistent with a westerly component, and would therefore flow along the valley from the Kilbirnie Loch to Paisley in a south-west – north-east direction, thus causing a $240^{\circ} - 260^{\circ}$ wind to be recorded at Renfrew Airport.

0300 – 0600 GMT.—This part of Figure 1 is seen to be subject to considerable fluctuations, both in wind direction and air temperature. Accepting the theory of the last paragraph, a generally decreasing air temperature would produce a general increase in katabatic flow, these taking place on other slopes in the vicinity. This complex flow, plus the effect of irregular terrain, would break up the smooth original katabatic flow which was responsible for the persistent west-south-westerly flow at Renfrew Airport, and thus at these times of interruption a normal surface wind of $290^{\circ} - 310^{\circ}$ would be recorded until the next “break through” of the katabatic induced flow occurred.

Cooling curves based on the air temperature record.—A study of the temperature record of Figure 1 shows that smooth curves can be drawn through the points annotated A, B, C and X, Y, Z. Since the points A, B and C were recorded during the north-westerly surface flow, it seems likely that this curve would have been the cooling path of the air flowing from the north-west had it been consistently recorded. By similar reasoning, the curve through points X, Y and Z would represent the cooling path of the katabatic induced flow at Renfrew Airport.

HONORARY DEGREE

We have pleasure in announcing that the University of Wales is to confer the degree of LL.D. (*honoris causa*) on the Director-General, Sir Graham Sutton, at a ceremony to be held in Cardiff on 21 July 1961.

REVIEW

Radioactive wastes, their treatment and disposal, General Editor, John C. Collins. 8½ in. × 5½ in., pp. xxi + 239, *illus.*, E. and F. N. Spon Ltd., 22 Henrietta Street, Strand, London, W.C.2, 1960. Price: £2 15s. *od.*

The problem of the disposal of radioactive wastes is an important aspect of the increasing use of radioactive materials for the production of power, in industry and in laboratories. It is essential that these wastes should be dealt with in such a way that no member of the public is in any danger from the radiations they emit. The publication of this book, which deals with practically all aspects of the problem, will be welcomed by all who are in any way connected with the disposal of such wastes.

Eight authors have contributed to the book, almost half of which is devoted to a brief account of the nature of radioactivity, its measurement and the biological effects of radiation. This half is far too condensed to be of any great value to anyone wishing to learn the fundamentals of radioactivity, but the rest of the book, dealing with the source of radioactive wastes, their treatment and disposal, gives a good account of the practical problems and the way in which they are overcome. A full bibliography is given with each chapter.

The chapter on the discharge of radioactive effluent into the atmosphere is the only one that concerns meteorologists as such, the problem being to determine the maximum amount of radioactive material, gas or vapour, that can safely be released into the atmosphere. In contrast with the other chapters in this part of the book, the discussion is almost entirely limited to theory. After a very brief discussion of the behaviour of the effluent plume under various temperature gradient conditions, the author shows how Sutton's equations can be used to estimate the distribution of effluent downwind from a ground-level source or a stack, and compares some experimental results with calculated values. No mention is made, however, of the effect of topography on the values of C_y and C_z . Topography could also be an important factor in its effect on local winds, especially under strong inversion conditions. The importance of sampling to check the levels of activity in the neighbourhood of the point of release is glossed over very quickly. Practical points such as these should undoubtedly have been included, bearing in mind the type of reader for whom the book is intended.

On the whole, the book should serve its purpose quite well, but it is rather expensive even by present-day standards.

J. CRABTREE

METEOROLOGICAL OFFICE NEWS

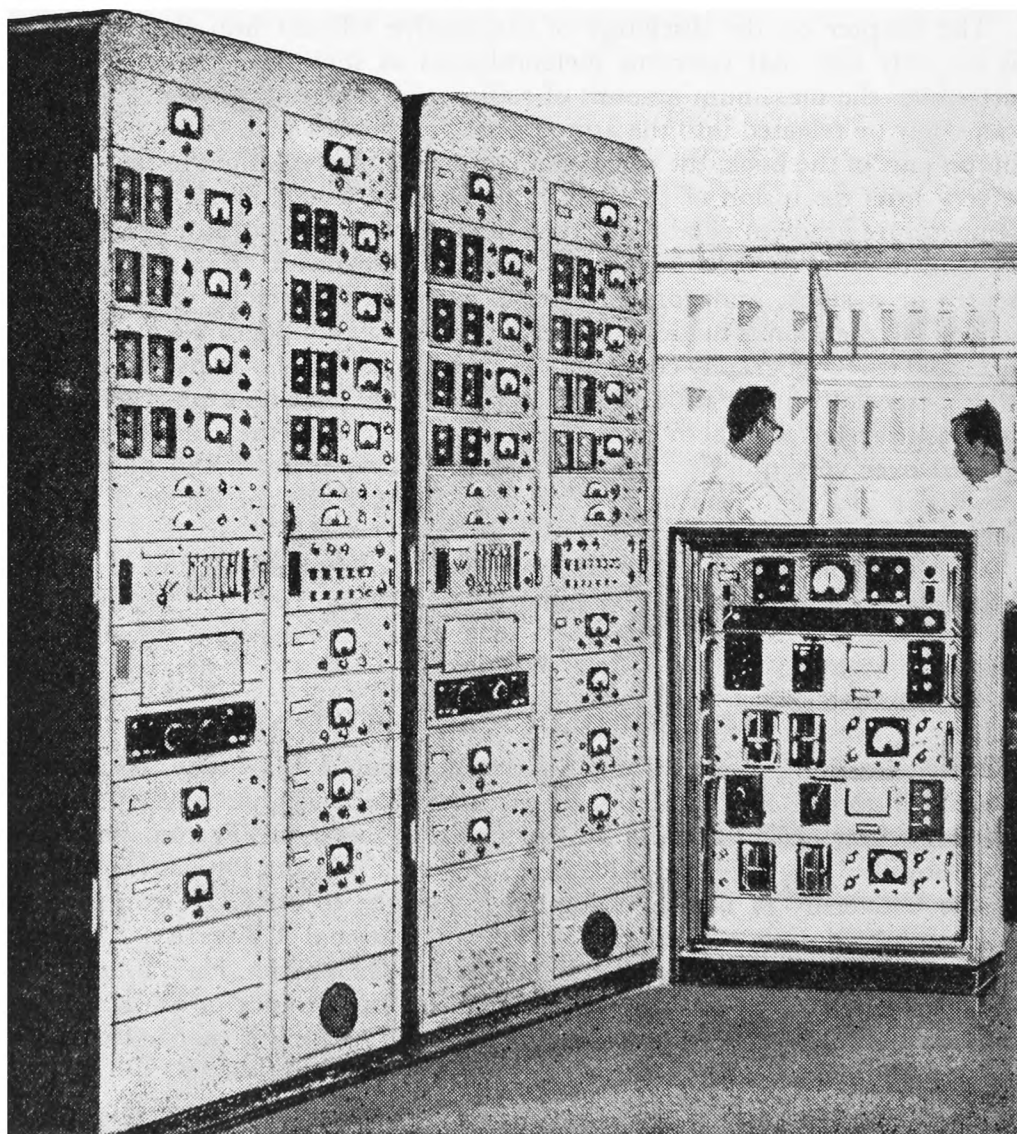
The first Gassiot Fellow will take up appointment in May 1961. He is Frank Donald Stacey, B.Sc., Ph.D., aged 31, a graduate of Queen Mary College, London. After presentation of an experimental thesis on "Ferromagnetism at high pressure", he accepted a Research Fellowship in the Physics Department at the University of British Columbia from 1953 to 1956. He comes to the Meteorological Office from the Australian National University, Canberra, where he was holding a Research Fellowship in Geophysics. He is interested in the mechanics of the Earth, rock-magnetism, the physics of ionization and fundamental and solid state ferromagnetism. Dr. Stacey is married with two young children.

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THE METEOROLOGICAL MAGAZINE

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SEA-BREEZES ALONG THE YORKSHIRE COAST IN THE SUMMER OF 1959

551-553-11

By R. E. STEVENSON

Allen Hancock Foundation, University of Southern California

The invigorating qualities of the climate along the Yorkshire coast have been discussed for generations. Modifying adjectives include rigorous, vigorous, bracing, stimulating, healthful; along with an occasional "bitter", or just plain "cold" from the lesser enthusiast. The inhabitants of this remarkably picturesque part of the English coast are generally quite proud of "their" climate. Indeed, many of them who trace their Yorkshire ancestry back for several generations boast that the health and longevity of the inhabitants are due to the extremes of temperature and wind.

Certainly the Yorkshireman is, for the most, a hardy, happy, healthy individual, who enjoys the sting of a "nor'easter" and the enveloping dampness of the spring "roke". As for myself, having lived for several enjoyable months among these wonderfully kind people, I am not necessarily convinced of the correlation between health, longevity, and the bracing "north-east breezes". Be that as it may, the coastal climate of Yorkshire is one of great interest to those concerned with relating climatic effects to water temperature distribution. It was for this purpose that I spent five months during the summer of 1959 investigating the nearshore oceanography and various meteorological parameters between Flamborough Head and Whitby.

The setting.—Adjacent to the coast and extending from Flamborough Head to north of Aberdeen, a turbulent tide stream results in an almost total mixing of the sea. Because of the configuration of the coast and the sea floor topography, the width of the mixed water varies from 7 to 10 nautical miles at Flamborough Head to 15 to 20 miles in the north. Throughout all of the year the water is nearly isothermal with depth (Dietrich¹). In the warmer months a distinct increase in the temperature gradient is developed seaward of the mixed area because of surface heating, but in the tide stream, heat is more evenly distributed throughout the water column. This results in the surface water nearshore being considerably cooler than that offshore. As a matter of side interest, bottom water temperatures are higher in the tidally mixed water than they are farther to sea.

Air flowing from the east, originating either over land or sea and passing over the cool nearshore water, is interestingly, and often dramatically, affected

in both temperature and moisture content. In order that information might be gained on the rate at which the air cools, it was desirable that temperature and humidity measurements should be made before and after the air passed over the area of cool water. Winds with a local origin were more useful than easterly gradient winds because of the greater ease in determining the entering characteristics of the air. Thus it was, during the summer, that I looked for and eagerly awaited days of land- and sea-breezes.

With the assistance of the Meteorological Office, a weather station was established on Flamborough Head. Records were obtained of the wind velocity and direction, temperature, and relative humidity. During the several days spent at sea to learn the distribution of water temperature, measurements were made every half hour of wind direction and velocity, and wet- and dry-bulb temperatures. From these data, a reasonably complete analysis of the winds is possible for the months of May to September, 1959.

The 1959 summer.—The summer of 1959 in Britain was the warmest and driest for several decades. In some parts of the British Isles, the increased evaporation and lack of rainfall resulted in serious water shortages. Yorkshire, too, experienced a summer far warmer and drier than normal. To exemplify the conditions, let us look at the mean air temperatures for August in several north-east towns.

At Durham, the mean temperature for August 1959 was 61.7°F . It is necessary to go back to the year 1947 before an August mean reached or exceeded this figure. At Scarborough, directly on the shore, the August mean in 1959 was 62.1°F ; a temperature that had not been exceeded since the year 1933. At Tynemouth the August mean temperature in 1959 was 60.9°F . This had been equalled in 1954, but had not previously risen to 60.9°F since 1933. In August, Hull had a mean temperature of 64.1°F . This had not been exceeded since the year 1947. So we see that not only inland, but along the coast, too, the temperatures in the summer of 1959 were considerably higher than they had been for a number of years.

It is interesting in this respect to look at the mean air temperatures for Flamborough Head. My hygrothermograph was so located as to record temperatures as near as possible to those of the air over the immediately adjacent sea. Whereas all towns along the Yorkshire coast and inland recorded mean temperatures higher than 60° in August, at Flamborough Head the mean was 59.3°F . This was 1.5°F lower than at Tynemouth and more than 5°F lower than the mean air temperature at York. The same was true throughout all of the summer months. Because the temperatures at Flamborough Head are representative of the air temperature over the nearby sea, the difference between the mean air temperature over water and that over the land is easily noted. This is true regardless of whether the location is taken near the shore, as at Scarborough, Tynemouth, or Spurn Head, or several tens of miles inland, as at York or Durham.

The general synoptic situation over the British Isles during the summer of 1959 was one of higher-than-normal pressure. Throughout all of the warm months, the Azores high pressure area extended well into northern Europe with pressure anomalies as high as $+8$ millibars. At the same time, the Icelandic low pressure trough exhibited negative pressure anomalies and was displaced somewhat to the west of its normal position. There was, therefore, a decrease in the westerly air transport, and fewer cyclonic passages. Rainfall and

cloudiness from frontal activity were minor over the Yorkshire coast. Rain fell at Flamborough Head on only four occasions from May to September. Three of the storms were the result of orographic clouds which had built up over the Pennines and moved across the coastal area.

As can be imagined the winds along the Yorkshire coast varied from the normal. Usually winds with westerly components dominate, with gradient winds from the north-east mainly in the late spring and early autumn months. Wind roses from Spurn Head and Tynemouth exemplify this condition (Figure 1). At Spurn Head, 20 per cent of the winds are from the west, 15 per cent from the south-west, and 17 per cent from the north-west. Less than 10 per cent blow from the east or south-east. North-east winds are present 8 per cent of the time. At Tynemouth, westerly winds are even more common. Here they occur nearly 40 per cent of the time: from the south-west, 20 per cent of the time; and from the north-west, 10 per cent of the time.

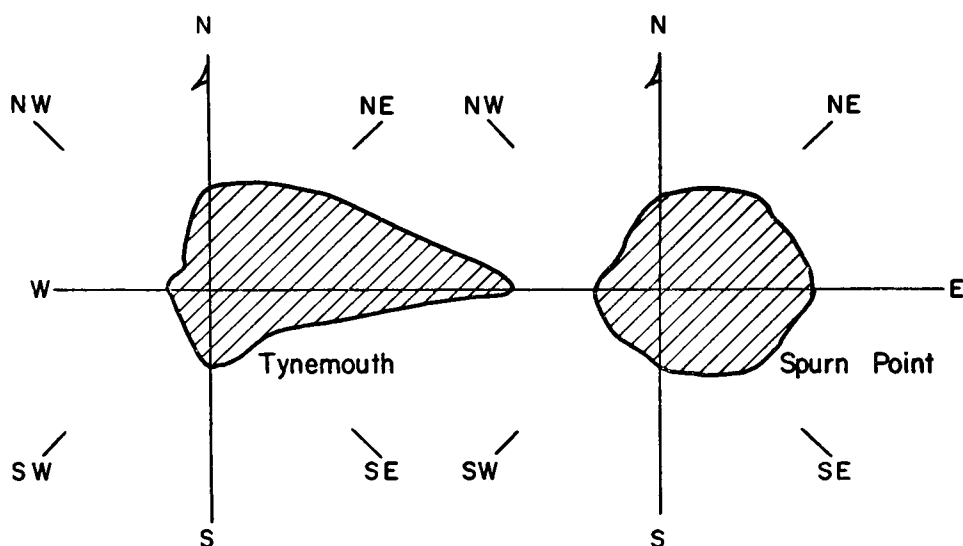


FIGURE 1—DIRECTION OF ANNUAL WIND AT 1300 GMT

At Flamborough Head during the summer of 1959, wind roses show a rather dramatic change from the average (Figure 2). In May more than 20 per cent of the winds came from the north-east with velocities generally higher than 15 knots. Winds were also common from the north, from the east and from the south. This is a distinct change from the normal wind system for the month of May. In June we again see a tendency for the winds to blow from the north. In this month, however, the dominant direction was north-west (25 per cent), but more than 10 per cent still came from the north.

In the month of July there was a definite change from the general northerly flow. Although more than 10 per cent of the winds came from the north-east, winds from the south-west and south blew 22 per cent and 21 per cent of the time, respectively. This change brought in warm southerly air.

In August, the air flow returned to a more normal pattern. Most of the winds were from the north-west, west or south-west, but still with a considerable percentage from north-north-west and north. Easterly winds were minor. In September another change occurred, as the dominant air flow was from the north-east.

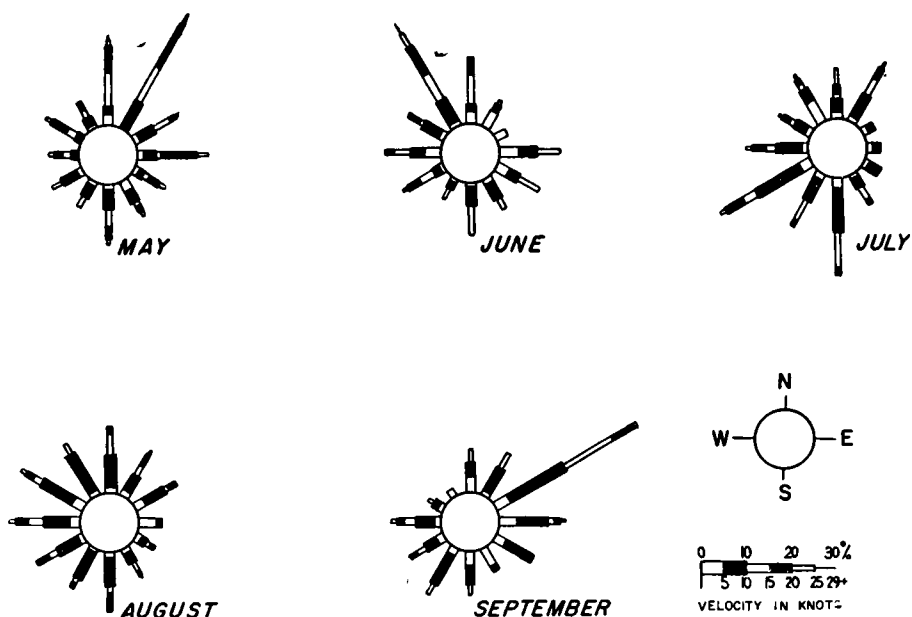


FIGURE 2—MONTHLY WIND ROSES FOR FLAMBOROUGH HEAD, 1959

The sea-breezes.—Local winds along sea coasts, and shores of other large bodies of water, have been studied by many workers and from many points of view. Balkema² discussed in considerable detail the sea-breeze phenomenon along the Dutch coast, and reviewed many theoretical papers as they related to his findings. Defant³ has given a good summary and a good bibliography. The effect of the winds on health has been noted by Bilham,⁴ and Stevenson⁵ has shown the effect on nearshore waters. These papers, although few in number and not necessarily chosen for their importance, indicate the range of study that has been involved. The interested reader may refer to the bibliography in Defant's report for more articles, both theoretical and empirical.

In many areas, where geographical conditions are similar, land- and sea-breezes are also similar in their occurrence and characteristics. However, frequently one notes that workers investigating more or less the same area have quite dissimilar views and/or results. Such situations are difficult to understand, even though the studies might have been carried out at considerable intervals of time. Despite the fact that north-western Europe has experienced a secular climatic change in the past few decades, it is not realistic to assume that such a variation would drastically effect a local condition. I must assume, therefore, that many of the differences indicated in land- and sea-breeze occurrences, longevity and frequency, must be a matter of definition.

To be sure that all understand which winds I included in the category of land- and sea-breezes, I give this explanation. If in any 24-hour period there occurred a definite diurnal change in wind direction, from land-sea-land, this wind system was considered as a "land-sea" breeze. Occasions when an easterly wind was blowing and the velocity increased during the time of maximum insolation were classed as a "sea-breeze tendency", but not as a sea-breeze. These latter conditions were quite common in May and September when north-east gradient winds blew for several days at a time. These cannot be called "sea-breezes" for the air moves with the general pressure gradient as the motive force, and not due to any local thermal displacement of air.

Those days from 1 May till the end of September when a diurnal wind shift occurred numbered thirteen in all. These, to me, are incredibly few occurrences along a coast which is renowned for its winds from the sea, and it seems especially surprising in view of the nature of the 1959 summer. During these months, a minor cloud-cover allowed maximum insolation, so that there were many days when strong convective currents occurred inland. Differences in air temperature over the land and sea along the Yorkshire coast were often of the magnitude of 15–30°F. Yet, on few of these days did a sea-breeze occur, and on no consecutive days during the five-month period was there a “land-sea” breeze sequence. I do not in this report attempt to explain this apparent anomaly, but rather to relate the synoptic conditions when a sea-breeze was active.

The synoptic situation during the occurrences of sea-breezes.—The days during which a diurnal reversal of winds resulted from local heating were most common in June and July. A land- and sea-breeze system was evident on two days in May, one day in August, and on five days each in June and July. Such a distribution of occurrences is in itself somewhat surprising, in view of the fact that higher temperatures were recorded on certain days in August and September than in the other months. The lack of the phenomenon in September and the few days in May, can be accounted for by the constancy of strong gradient winds. To some degree, therefore, the absence of dominant pressure gradients in June and July may explain the greater number of local winds.

As I have mentioned previously, the general synoptic situation over Britain during the summer was one of domination by the Azores high pressure system. Despite this, high pressures were not uniformly constant over the British Isles. Many minor variations in the synoptic pattern occurred, but we can note that certain conditions existed on each day when there was a sea-breeze. In every instance the isobars were oriented so as to extend in either a north-west to south-east, or a north to south direction along the coast, and they were widely spaced so as to present a negligible pressure gradient. Each day was mainly cloudless; the humidity was 70 per cent or less prior to the beginning of the sea-breeze; and the coast had been unaffected by gradient winds for 24 hours or more preceding the sea-breeze. In this last respect, it is of interest to note the common existence of an inversion layer overlying the nearshore water and the coast on all days of low wind velocity, regardless of the direction of air flow.

At this point I must say that the conditions just noted were not necessarily restricted to days when land- and sea-breezes occurred. Let us examine the synoptic situation from 14 June to 19 June to exemplify the varying patterns. Sea-breezes blew on the 14th, the 16th and the 19th.

On 14 June (Figure 3), an ellipsoidal high pressure area, centred more or less over Ireland, extended across England. A shallow pressure gradient existed over the central North Sea, but there was little or no gradient over the Yorkshire coast. A sea-breeze began to blow at about 1100 GMT, with a consequent drop of air temperature from 64°F to 54°F in two hours, and a concurrent rise in relative humidity from 60 to 94 per cent. The barometric pressure began to decrease at 1200 GMT from 1042 millibars and levelled off at about 0000 GMT at 1032 millibars.

The following day saw the low pressure system to the north move over the Baltic Sea with a north-west to south-east oriented cold front extending through the central North Sea and across Scotland. Again isobars were north to south

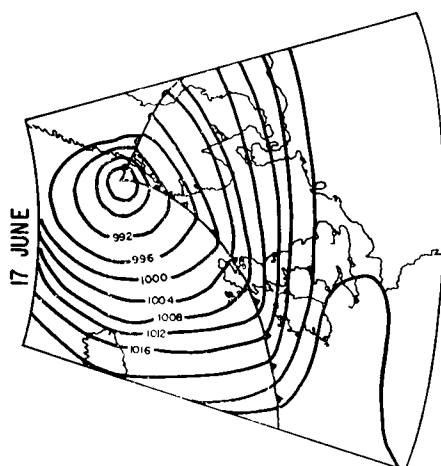
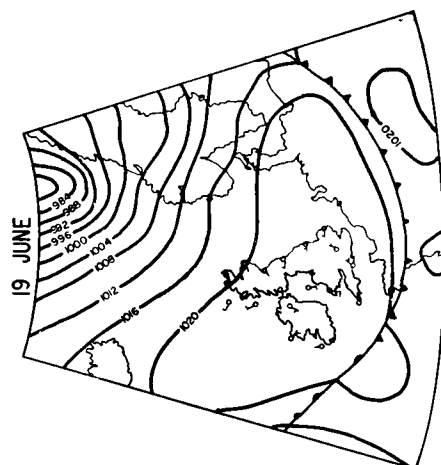
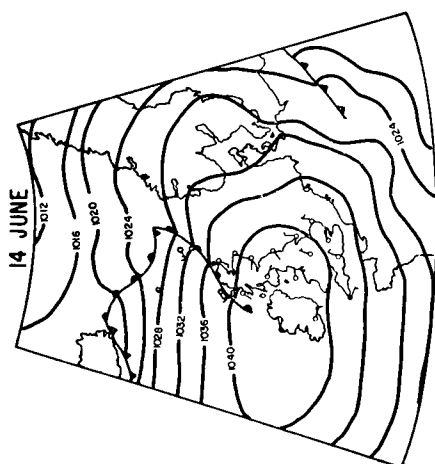
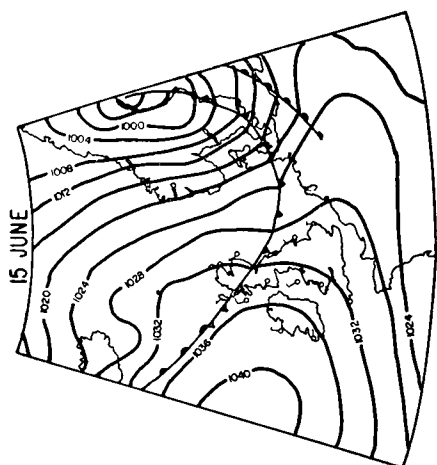
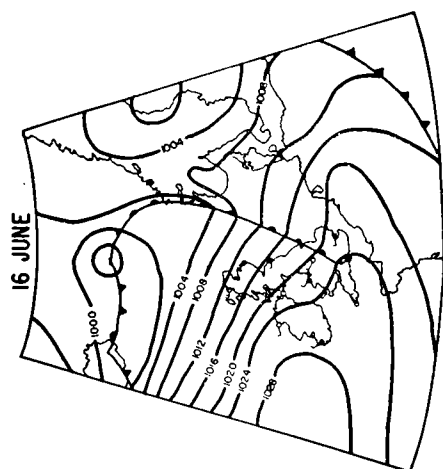


FIGURE 3—SYNOPTIC SITUATIONS
FOR 14-19 JUNE 1959

along the Yorkshire coast and rather widely spaced. North-west winds blew throughout the day. The barometric pressure continued to decrease and had reached 1026 millibars by midnight.

At midday, 16 June, a sea-breeze had been blowing for one hour and continued until about 1500 GMT. The air temperature dropped from 65°F to 58°F during this period, and the relative humidity rose from 55 to 80 per cent. The synoptic chart for this time shows a minor warm front crossing the coast. However, the barographic trace, although continuing to register a pressure decrease at Flamborough Head, gives no indication of a frontal passage. The rather rapid fall of pressure during this period is indicative of the approaching low pressure area north of Britain and the southerly course of the high pressure system south-west of Ireland.

By 1200 GMT on the 17th a strong pattern of westerly air flow, associated with the north-east to south-west oriented cold front, came over central and northern England. The air temperature rose to 72°F at Flamborough Head, and relative humidity dropped to 40 per cent. Each indicates the effects of the land mass on the air. The gradient flow easily dominated the winds on this day. On the 18th the frontal system continued to move south-eastwards and the following air flow, mainly from the north-west, brought low temperatures throughout the day. The pressure gradient was still strong and north-westerly winds occurred.

Pressures continued to rise irregularly on Friday, 19 June, and had reached 1023.5 millibars by 1000 GMT at which time a light breeze began from the sea. A high pressure system was centred over central England with ridges extending over north-east Europe and Iceland. This high pressure area continued to build during the following day, when the centre crossed the Yorkshire coast between 0900 and 1500 GMT. On this day, the 20th, however, no sea-breeze occurred.

Within this short period of six days in June there was a considerably varied series of cyclonic and anticyclonic activities affecting the Yorkshire coast. Yet, during these days there were the most closely spaced occurrences of land- and sea-breezes during the 1959 summer. They blew at times when one might have expected them to be precluded by the synoptic situation. Also there was a day (the 20th) when, with scattered clouds and no appreciable pressure gradient, the sea-breeze was absent. This latter condition, anomalous as it seems, was to occur with great frequency throughout the summer.

A high pressure sequence in July.—I believe at this time that the anomalous situation I have just mentioned deserves further elucidation. I have, then, chosen a period of 15 days in July when the pressure remained rather constant along the Yorkshire coast as a result of a continued series of high pressure areas. This was a period of maximum daytime temperatures above 60°F over the water (70°F on two days), and with night minima only once going below 54°F. Inland, some of the highest temperatures of the summer were recorded. A sequence of minor fronts occurred until the 18th, but from that day until the 25th a high pressure centre remained over England. Skies over the coastal area were mainly cloudless. Nevertheless, despite what seemed to be a condition when daily sea-breezes might blow, they occurred on only four days: the 14th, 19th, 21st and 24th. This last day nearly closed the activity for the summer, for it was not until 26 August that another sequence was to occur, and this, indeed, was the finale for the summer.

On 14 July the barometric pressure reached 1021 millibars at 0900 GMT. There were gradual falls and rises with a range of 5 millibars until the 19th,

followed by a steady rise to 1024 millibars on the 20th. Pressures remained about 1020 millibars until the 25th when a steady fall preceded a frontal crossing on the 27th. Pressure gradients accompanying the passages of the minor fronts were gentle and not so disposed as to result in even moderate winds (Figure 4, 21 July). Between the fronts, gradients were negligible (as on the 19th). Conditions were such that one might have expected a complementary sequence of sea-breeze. Such was not the case.



FIGURE 4—SYNOPTIC SITUATIONS FOR 14–24 JULY 1959

Of the sea-breezes that blew in July, that on the 19th was the only system that had any dramatic cooling effect, velocities greater than six knots, and a longevity of more than four hours. On this day the breeze began at about 1100 GMT, and continued to blow until 2000 GMT. Temperatures at the coast decreased by 4°F in a matter of minutes, and then continued their fall more gradually till 2000 GMT. The range was from 70° to 56°F at Flamborough Head and from 73.5° to 66°F some 10 miles inland. The breeze blew from the east-south-east, with a maximum velocity of 12 knots. At 1500 GMT it reached its greatest intrusion landward of 15 miles (Figure 5). At the boundary, a dramatic rise in temperature of some 5°F occurred in a distance of 200 yards where the easterly air flow met the general westerly flow from inland areas.

I shall not here go into further descriptions of the synoptic situations which might have been expected to result in sea-breezes, but there were many others,

particularly a fortnight in August when a breeze blew only on the 26th. The examples described are, I believe, adequate at this time to illustrate the rather interesting lack of such local winds in the summer of 1959.

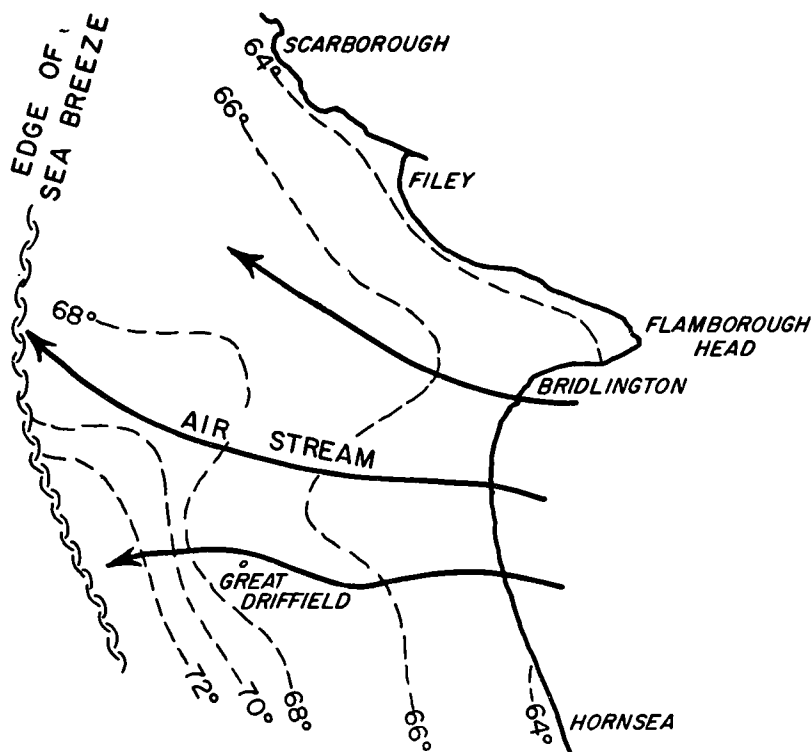


FIGURE 5—TEMPERATURE DISTRIBUTION FROM 1000–2100 GMT, 19 JULY 1959

Résumé.—It would be a presumption were I to conclude from the data gathered in 1959 that sea-breezes represent merely 8 per cent of the winds blowing over the Yorkshire coast in the summer months. Certainly there were several periods of consecutive days with north-easterly winds. On many such days the velocity of the wind rose appreciably (often to 20 knots) during the warmer hours. This must indeed be indicative of vertical air displacement inland allowing for augmentation of the easterly gradient flow. Again, there were many days, especially in August, when south-westerly or westerly winds blew night and day with a minor but distinct decrease in velocity beginning near midday. This, too, must be indicative of a sea-breeze tendency.

In this respect, I feel we must be definitive in those winds included in the category of land- and sea-breezes. An augmentation and/or retardation of velocity must not be compared, or confused, with the regularity of the diurnal reversals along tropical coasts; nor can they be analysed along with the less regular, but quite continuous, occurrence of the sea-breeze in the more temperate Mediterranean areas.

The summer of 1959 in England, one of the warmest and driest on record, would have been, it would seem, an ideal period for the maximum development of local coastal winds. A diurnal reversal, attributable to local heating and cooling, occurred on 13 days at Flamborough Head. (Two of these occasions might actually be suspected to be the result of passages of minor fronts. On one of these days, however, when two fronts were indicated on synoptic charts

as crossing the area, the depression of pressure by merely one millibar might cause one to suspect frontal existence.) Such a number seems to be low indeed, for an area which has been previously described as one where sea-breezes blow for "days on end". I must admit, therefore, that my feelings are more disposed towards the belief that gradient winds are far more important here than land- and sea-breezes.

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VARIATIONS IN 200-MILLIBAR FLOW IN THE TROPICS

By A. J. TROUP

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Introduction.—In a recent note Murray¹ drew attention to the unusually strong westerly winds over Aden at 200 millibars in January 1958, and pointed out that such large variations of monthly mean flow could be accounted for by displacements of a few degrees latitude in the mean position of the subtropical westerly or equatorial easterly jet streams, without regard to changes in their average intensity. Upper wind observations in the east Indian Ocean area suggested that abnormally strong westerlies or weaker easterlies prevailed in low latitudes during this month, and it was thought of interest to examine the data for other stations to see over how wide an area this was the case, since widespread variations in upper flow are probably connected with variations in the north-east and north-west monsoons. Since data were available for three stations in the one longitude (at and on either side of the equator) it was also of interest to see to what extent shifts of position or changes in intensity of the equatorial easterly maximum contributed to the variations of the flow as observed at one station.

Data sources.—The data used in this study have been taken from a number of sources. Daily data are provided in: *Daily Weather Report*, Overseas Supplement; Malayan Meteorological Service, *Pilot Balloon Data* and *Radar Wind Data*; New Zealand Meteorological Service, *Pacific Islands Bulletin*; and the microcards of the International Geophysical Year data published by the World Meteorological Organization. For some stations under Australian control, manuscript data were kindly provided by the Director of Meteorology, Commonwealth Bureau of Meteorology. Monthly and seasonal means have been computed from the above, or taken from the values given in: *Upper air data for stations maintained by the Meteorological Office*; United States Weather Bureau, *Monthly climatic data for the world* and *Climatic Data*, National Summary; and from publications by Clarkson², Phillpot³, Ramage⁴, Joint Task Force Seven⁵, and Crutcher⁶.

Distribution of anomalies in the 200-millibar zonal flow.—Only the zonal component of the flow will be considered here, since this is the relevant

quantity for consideration of the north – south displacements of the mean jet stream (although this component is also affected by other factors). The changes in meridional component would reflect to a greater extent east – west movements of the mean troughs and ridges, and also, if averaged over large areas, the changes in the mean meridional circulation; for an understanding of the dynamics of the process it would be necessary to consider this component as well.

In Figure 1 are shown mean zonal components at 200 millibars for January 1958 and their departures from the average value over several years for a number of stations in the East Asian and Pacific region. West components are positive, and departures are positive (westerly anomaly) when the west component is stronger, or the east component weaker, than average. Except for Christmas Island, Lae and Majuro, all averages are for five or more years' data.

It can be seen from Figure 1 that a marked westerly anomaly greater than 10 knots extends over East Asia and the east Indian Ocean to about 120° E and at least twenty degrees of latitude on each side of the equator. There is a marked easterly anomaly over the equatorial central Pacific. Strong upper westerlies also occurred over India (not shown); the mean zonal component over Madras (0001 GMT) was 40 knots. Rawin averages for India have not been published, but available cross-sections for winter^{7,8} suggest an average of 20 knots for the latitude of this station, 13° N. It thus appears that the westerlies were stronger or easterlies weaker than usual over almost a quadrant of the tropics. The anomaly at Aden is the largest one observed.

Since means are computed by calendar months, it could be that the anomaly for January 1958 is in a sense an accident; similar periods occurring partly in one month and partly in another would be averaged out or reduced. However it appears that the anomaly is an intensification of a general trend; seasonal (December – February) averages for the period December 1957 to February 1960 show similar behaviour to the averages for January 1958 when compared with averages for an earlier period centred around 1953. Values for several stations are set out in Table I.

TABLE I—DECEMBER – FEBRUARY AVERAGES OF THE 200 MB ZONAL COMPONENT AND DIFFERENCES FROM THESE FOR THE PERIOD DECEMBER 1957 – FEBRUARY 1960

Station	Period	Zonal component <i>knots</i>	Difference for Dec. 57 – Feb. 60	
			<i>knots</i>	
Nairobi	Dec. 1949 – Feb. 1954	–15.8	+10.6*	
Aden	Dec. 1948 – Feb. 1955	+20.0	+ 6.5	
Singapore	Dec. 1951 – Feb. 1955	–21.2	+ 6.3	
Koror	Dec. 1950 – Feb. 1957	–19.4	+ 2.2†	
Darwin	Dec. 1952 – Feb. 1957	– 5.1	+ 3.3	
Guam	Dec. 1949 – Feb. 1957	– 2.1	+ 1.8‡	
Wake Is.	Dec. 1949 – Feb. 1957	+26.8	+ 1.7	
Truk	Dec. 1951 – Feb. 1956	–11.2	– 0.9	
Canton Is.	Dec. 1949 – Feb. 1957	+ 8.4	– 9.2	
Johnston Is.	Jan. 1950 – Dec. 1956	+31.1	+ 3.3	
Hilo	Dec. 1950 – Feb. 1957	+43.3	+ 5.4 §	

Westerly zonal components are positive, easterlies negative.

*Dec. 1958 – Feb. 1960 only.

†Feb. 1959 not included.

‡Jan. 1959 not included.

§200 mb value for Feb. 1959 extrapolated from 250 mb value.

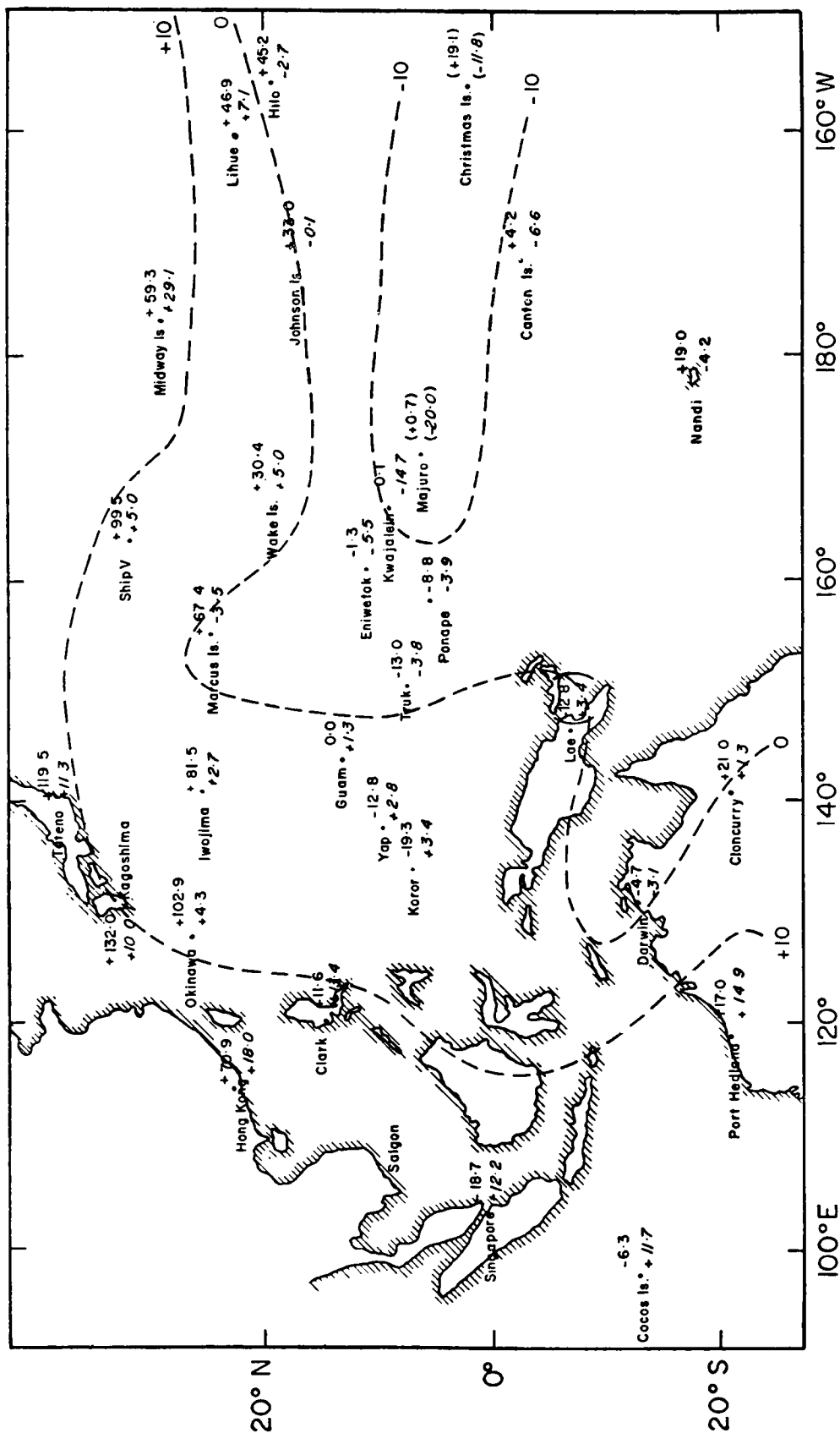


FIGURE 1—200 MB MEAN ZONAL WIND AND DEPARTURE FROM AVERAGE OVER EAST ASIA AND THE WEST PACIFIC, JANUARY 1958

Upper figures represent the 200 mb mean zonal wind in knots (westerlies positive) and the lower figures and isopleths the departures from average.

It can be seen that in particular the westerlies are stronger or easterlies weaker over the Indian Ocean region (Nairobi, Aden, Singapore) in the later period, while in the equatorial central Pacific (Canton Island) there is an opposite tendency. Where monthly averages are available the differences given in Table I are computed from monthly means; from these it appears that over the North Pacific the differences between earlier and later periods are most marked in December, but in the other regions any or all months can contribute. Some part of this effect at the higher-latitude stations is probably due to improvement in observing techniques, with fewer losses due to strong winds at high levels, particularly in connexion with the International Geophysical Year. However this would not apply at the lower-latitude stations where the upper winds are not as strong, nor where (as at Singapore) the effect is in the opposite sense to the direction of the strong mean winds.

Relative significance of speed changes and displacements in equatorial regions.—Climatologically, the strong upper easterlies over Asia during northern summer later weaken and move southwards, while the westerlies to the north increase, until in January – February the easterly maximum is located just south of the equator. The observations in January 1958 at 100° – 120° E indicate that in this region at least the anomaly is not due to southward displacement of the northern hemisphere westerly jet and a concomitant displacement of the equatorial easterlies, since one would then expect an easterly anomaly at Cocos Island. Nor is it due to the occurrence of the easterly jet at a higher level than usual, since the easterly at Singapore at 50,000 feet was weaker than at 40,000 feet. It rather appears that symmetry with respect to the equator tends to be preserved; the jet streams of both hemispheres were displaced equatorwards, with weakening of the intervening easterlies. This might imply as a synoptic process alternate north – south shifts of the easterly maximum combined with a general decrease in its strength; but inspection of the daily values shows that the variations can be in the same sense on both sides of the equator. In Figure 2 daily values (0001 GMT) of the 200-millibar zonal wind components are plotted for Saigon, Singapore and Cocos Island (in approximately the same longitude) from November 1957 to March 1958. The Aden values are also given for comparison. It will be seen that on several occasions major variations are in the same sense, at or about the same time. Note, for instance, the change at all three stations at the end of November and beginning of December, and the westerly flow at the beginning of January.

Quantitatively, this common variation may be expressed by correlation coefficients; these (together with their significance levels) are, for the period December 1957 to February 1958, Cocos Island – Singapore $+0.40$ (10 per cent), Singapore – Saigon $+0.64$ (1 per cent) and Saigon – Cocos Island $+0.29$ (above 10 per cent). The significance levels have been computed taking into account the values of auto-correlation coefficients for Singapore, which indicate that 90 days' observations correspond only to 18 independent ones. In view of the fact that the easterly maximum lies close to Singapore during this season, the existence of positive correlations at this station with stations both north and south of it indicates that overall changes of flow intensity at this time of year predominate over north – south shifts of the speed maximum. On some occasions the easterly stream is entirely disrupted, presumably by extended troughs⁹ reaching the equator in both hemispheres at or about the same

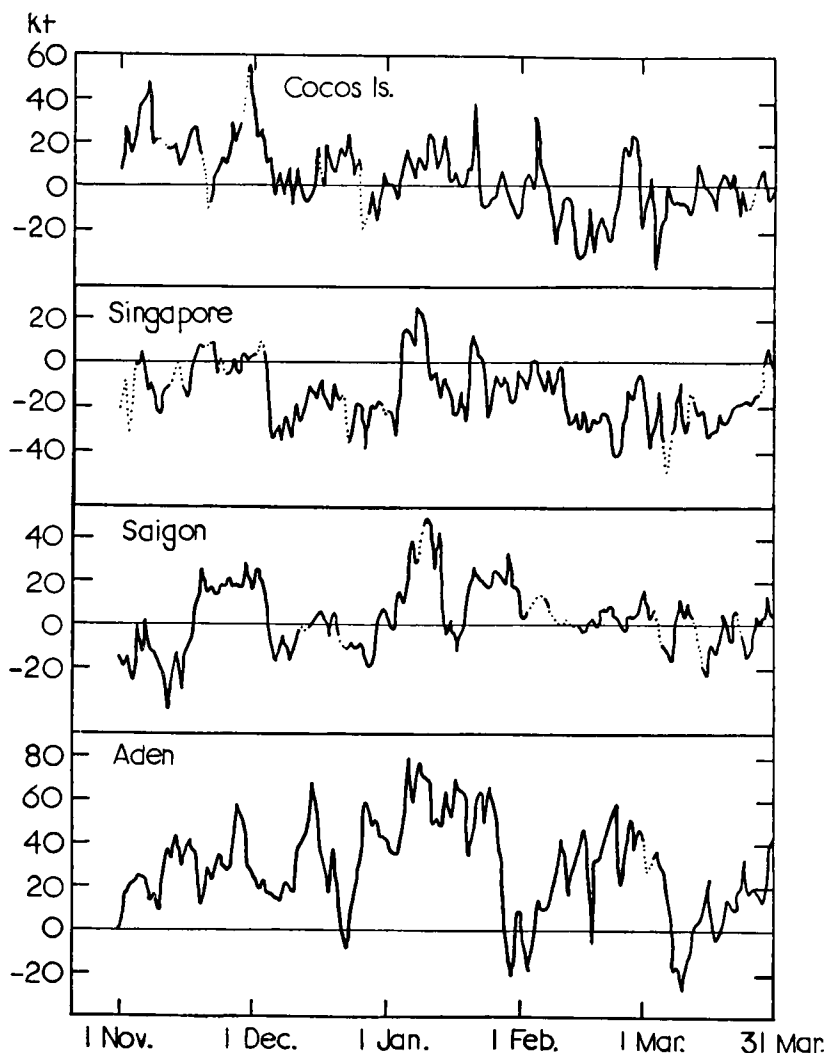


FIGURE 2—200 MB ZONAL COMPONENTS IN KNOTS, 0001 GMT, NOVEMBER 1957 – MARCH 1958

Westerly components are positive, easterlies negative. Dotted lines indicate interpolated values; for Cocos Island and Singapore they were interpolated from 1200 GMT observations when available.

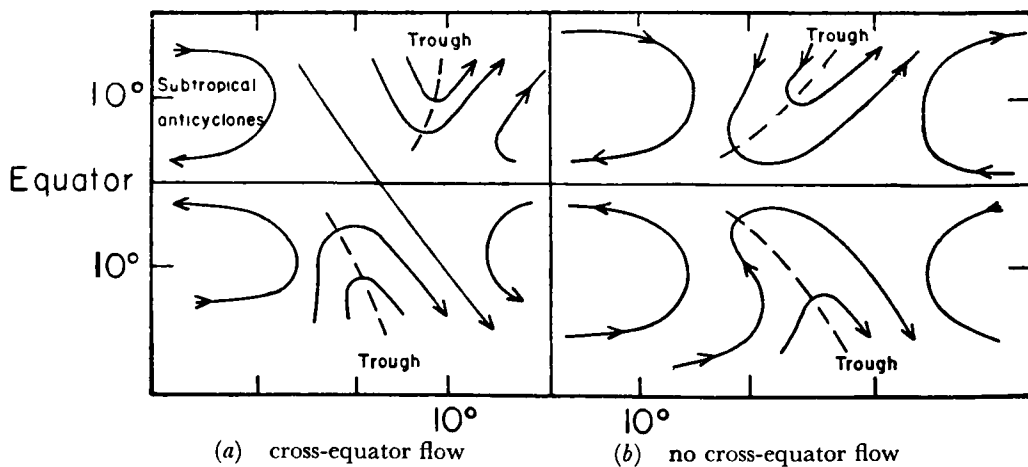


FIGURE 3—STREAMLINE PATTERNS WITH EQUATORIAL WESTERLY ANOMALY

longitude, as in the suggested streamlines given in Figures 3(a) (cross-equator flow) and 3(b) (no cross-equator flow). Such situations are common over the central Pacific at certain seasons, appearing even in the monthly means⁷; they are presumably much less common in the Asian region.

Similar correspondence in the fluctuations at Cocos Island and Singapore has been observed in other years, though not in all, and also an almost simultaneous formation and dissipation of westerlies in low latitudes extending to the equator in both hemispheres at this longitude. The correspondence extends to the monthly means if the seasonal trend is excluded; for example, the departures from the monthly means for December to February are given in Table II for Singapore and Cocos Island for the five years of common rawin observations. Departures of the same sign occur in nearly all months; if this is expressed as a correlation coefficient, the value is +0.81.

TABLE II—DEPARTURES FROM MONTHLY MEAN AT 40,000 FEET AT SINGAPORE AND COCOS ISLAND

Dec.	Singapore <i>kt</i>	Cocos Is. <i>kt</i>	Jan.	Singapore <i>kt</i>	Cocos Is. <i>kt</i>	Feb.	Singapore <i>kt</i>	Cocos Is. <i>kt</i>
1955	— 1.8	— 3.4	1956	— 7.9	—10.0	1956	— 6.5	— 7.8
1956	— 5.1	— 5.4	1957	+ 4.6	— 3.3	1957	— 0.7	— 3.6
1957	+ 1.5	+ 6.2	1958	+ 9.4	+11.6	1958	+ 3.3	+ 3.6
1958	+ 5.5	+ 7.4	1959	+ 0.4	+ 0.9	1959	+ 5.1	+11.5
1959	— 5.2	— 4.6	1960	— 6.5	+ 1.0	1960	— 1.3	— 3.2
Mean	—20.5	— 1.2		—15.9	— 6.2		—20.9	— 9.6

Conclusions.—The strong westerlies in January 1958 observed at Aden are part of an anomaly that extended over the Indian Ocean area, apparently being most marked in the west of the region. This was an intensification of a general tendency for the upper tropical easterlies to be weaker during the latter part of the decade 1950 – 60 than in the earlier part. In low latitudes, changes in intensity dominated shifts of the climatological jet streams in producing this result.

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VISIBILITY IN PRECIPITATION

By G. J. JEFFERSON, M.Sc.

Many forecasts of horizontal surface visibility contain phrases such as "reduced in precipitation to" or "falling in rain to", preceded and followed by forecast visibilities out of and in precipitation respectively. Such subjective estimates may vary widely as to how much visibility is reduced by precipitation of various kinds.

The reduction of visibility by precipitation depends on the size, number and nature of the elements of which it is composed and their uniformity over the area around the observer containing the visibility points. It also depends to some extent on the increase of humidity due to evaporation from the precipitation itself.

It is stated in the *Handbook of aviation meteorology*¹ that light rain has little effect, moderate rain usually gives a visibility of 2–6 miles, while heavy rain (as the term is used in temperate latitudes) reduces visibility below 1000 yards. In drizzle it varies from two miles to 500 yards and is commonly below 1000 yards in moderate snow and from 200 to below 50 yards in heavy snow.

In an appendix to a study of atmospheric opacity, Wright² calculates the reduction of visibility to be expected in moderate rain. He suggests that a reduction from code figure 8 (old International Code 12½–30 miles) to 6 (2½–6¼ miles) and from 6 to 5 (2200 yards—2½ miles) is to be expected.

Recent work in the U.S.S.R. indicates more precise relationships between visibility and precipitation. Poljakova³ derives the following formula connecting rainfall intensity and visibility:

$$S = 1.4 I^{-0.74},$$

where S is the visibility in kilometres and I the intensity of rainfall in millimetres per hour. This relation is based on 59 observations of the micro-structure of rain, 40 at Leningrad and 19 at Čakvi, near Batumi on the Black Sea. The coefficient of diminution of light and the intensity of rainfall were in each case calculated from the measured drop-size spectrum, using equations previously derived and described in an earlier paper. Visibility S in kilometres is taken as being related to α the coefficient of diminution of light per kilometre by the relation $\alpha = 3/S$. The observations gave a correlation coefficient of 0.95 between $\log \alpha$ and $\log I$. Using Poljakova's formula, the visibilities for the upper limits of slight rain (0.5 millimetres per hour) and moderate rain (4 millimetres per hour) are 12.6 and 2.7 nautical miles respectively.

In another paper, Poljakova and Tret'jakov⁴ describe experiments to ascertain the visibility to be expected in falling snow. Using cone-shaped collecting funnels of carefully computed shapes and dimensions, the rate of snowfall was measured and recorded and is expressed as an equivalent rate of rainfall in millimetres per hour. The transparency was measured by a light and a photo-electric cell over a base line of about 200 metres. Using 68 observations at Leningrad they derived for snow the formula

$$S = 0.94 I^{-0.91}$$

where S is again the visibility in kilometres and I is the intensity of snowfall equivalent to rainfall in millimetres per hour. The correlation coefficient between $\log \alpha$ and $\log I$ is in this case 0.91. An approximate form of the formula is the very simple relation

$$S \simeq \frac{1}{I}.$$

Assuming the depth of snow to be ten times the equivalent depth of rainfall, this formula gives visibilities of 0.95 nautical miles (1940 yards) and 0.14 nautical miles (286 yards) for the upper limits of slight snow (0.5 centimetres per hour) and moderate snow (4 centimetres per hour) respectively.

Richards⁵, being concerned to provide a method of forecasting the hourly rate of accumulation of snowfall from observed visibilities, has approached the subject from a different viewpoint. He used 193 cases at Malton Airport, Canada, from the months of December to March in the years 1941-52. Observed visibility is plotted against measured hourly snowfall accumulation. Although the scatter is rather wide, he has drawn a smooth curve based on average rates of accumulation computed for certain ranges of visibility. This curve is reproduced in Figure 1 together with a curve derived from the formula of Poljakova and Tret'jakov and it is evident that there is fairly good agreement between them. Richards' curve gives a slightly greater visibility for 0.5 centimetres of snow per hour than Poljakova and Tret'jakov, but his curve does not extend above the rate of fall of 1.6 centimetres per hour.

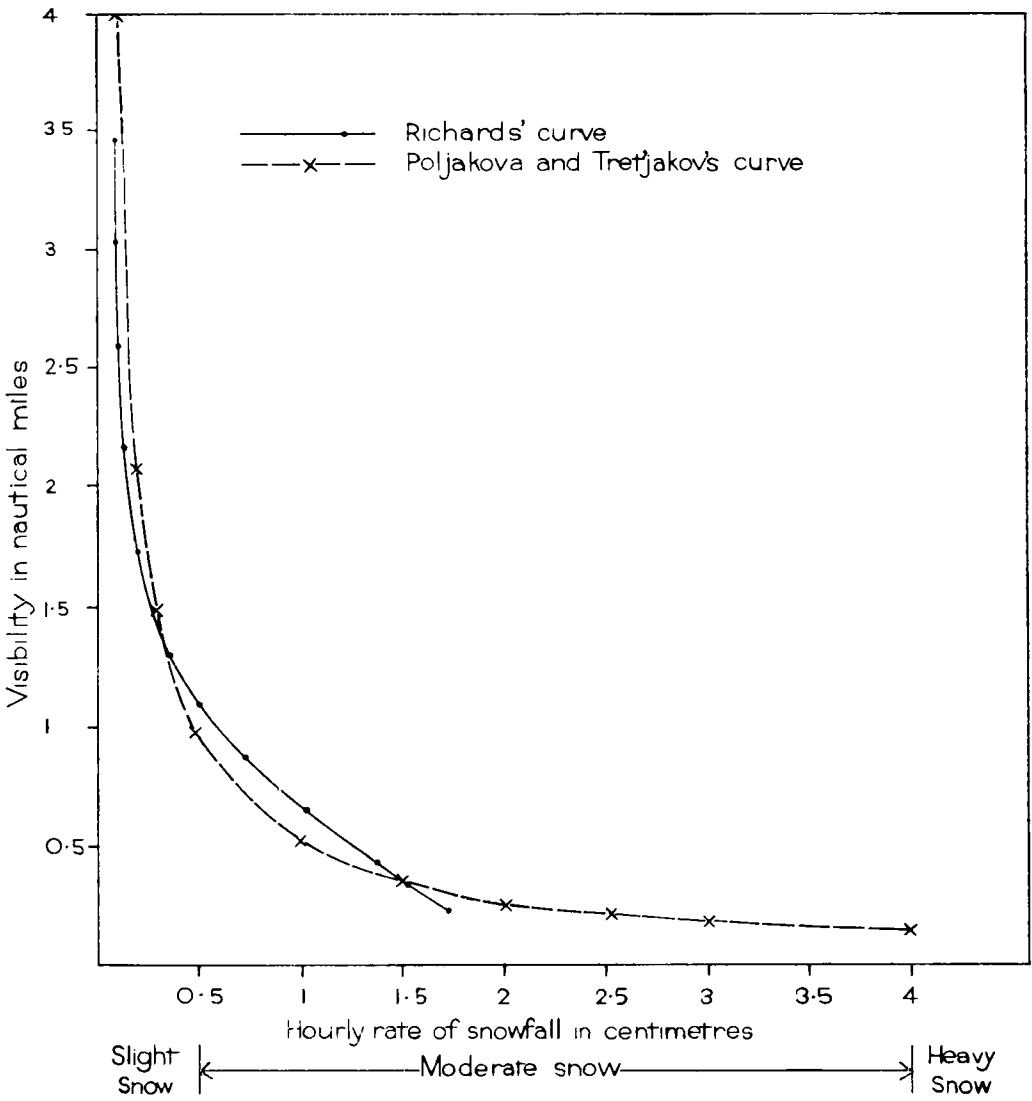


FIGURE 1—CURVES RELATING VISIBILITY AND RATE OF SNOWFALL

A short investigation of a different kind has been made into the relation between visibility and the different types of slight or moderate precipitation.

It is important to distinguish as far as possible between actual reduction of visibility by the falling elements of precipitation and any reduction by pre-existing fog, or fog (such as frontal fog) formed by the precipitation itself. The use of ocean weather station observations on the eastern North Atlantic has probably fulfilled these conditions as well as possible. Radiation and up-slope fogs and smoke pollution are eliminated whilst the data themselves show that other forms of fog are not common in precipitation. The use of ocean weather station data has also had the additional advantage that most of the required observations are available in punched card form.

The estimation of visibility at sea is handicapped by the absence of fixed objects which are used at a land station and visibility is reported in only one figure. Visibility is reported by ocean weather ships in the International Code figures 90–99⁶ in which the ranges of visibility expressed as the second code figure are those of the old International (before 1949) Code. American weather ships at ocean weather stations “A” and “C” reported in the American ship code until approximately 1954 and 1956 respectively. The change-over was gradual, as some American ships commenced to use the International 90–99 Code before others, and no precise date can be given. The observations have, however, been analysed so that the differences are small. The only limits derived from the American code which are significantly different are:

Code figure	American	International
91	0·1 n. miles	> 55 yds. < 0·1 n. miles
92	0·2 n. miles	0·1 n. miles

This, affecting poor visibility, makes little difference to the results here presented.

The stations considered in the investigation were ocean weather stations “A”, “C”, “J”, “I” and “M” and the observations used were for 1500 GMT for the first two and 1200 GMT for the others. This choice ensured that so far as possible all the observations were made in full daylight, although ocean weather station “M” lying just south of the Arctic Circle experiences almost total darkness for a short period centred on the winter solstice. The periods of observation used are shown in Table I.

TABLE I—PARTICULARS OF STATIONS FROM WHICH DATA WERE USED

<i>Ocean weather stations</i>	<i>Position</i>	<i>Period of observations used</i>	<i>Remarks</i>
“A”	62°N, 33°W	Jan. 1953–Dec. 1959	American ship’s visibility code used for some observations until December 1954.
“C”	52°45’N, 35°30’W	Jan. 1953–Dec. 1958	American ship’s visibility code used until about 1956–57. The change-over was gradual.
“J”	52°30’N, 20°W	Jan. 1953–Dec. 1959	Ocean weather stations “J” and “I” were at one time in slightly different positions.
“I”	59°N, 19°W	Jan. 1953–Dec. 1959	
“M”	66°N, 02°E	June 1948–Nov. 1958	
Manchester Airport		Jan.—July 1959	
		Jan. 1949–Dec. 1958	

Counts were made of the number of occasions of visibility in the ten ranges for all code figures of present weather from 00 to 49 together and for each

separate code figure from 50 to 99. An examination of the number of occurrences within each range of visibility showed that all stations experienced similar frequencies with each kind of precipitation and without precipitation. The data for all stations have, therefore, been combined to produce the histograms of Figure 2, showing percentage frequencies of occurrence for each type of precipitation for which there were at least ten observations. This eliminates precipitation reported as heavy, which is rare over the sea.

Whilst these histograms largely speak for themselves, there are certain interesting conclusions which may be drawn. Showers have less effect than precipitation of a more continuous type due to their smaller horizontal extent. Objects at a distance are more clearly visible by the observer in a shower which obscures only a portion of the distance between him and the object viewed than in continuous precipitation which obscures the whole distance even though the intensity at the place of observation is the same. Furthermore, since showers over the sea normally occur in cold air which is being warmed from beneath, their histograms show no poor visibility whereas the histogram for no precipitation includes cases of fog over the sea.

The effect of slight rain, slight snow showers and moderate rain showers is, in general, to reduce visibility by one code figure, the histograms in each case closely resembling those for no precipitation but displaced one step to the left. The effect of slight rain showers is even less, merely raising the percentage of code figure 97 above that of code figure 98. Moderate snow showers show a similar reduction of one code figure but can also cause poor visibility at times as shown by the appreciable percentages of code figures below 95. With slight drizzle and moderate rain the effect is to decrease the visibility by two code figures. This is in good agreement with the calculations by Wright². Slight showers of sleet show a fairly even distribution between code figures 96, 97 and 98, with an appreciable percentage of occasions of very good visibility. With moderate drizzle, the spread is much wider with a maximum frequency in code figures 95 and 96 but quite appreciable percentages of 97, 94 and 92.

It is interesting to note that the visibility given by Poljakova's formula for the upper limit of moderate rain (2.7 nautical miles) lies just within the lower end of the range of visibility on the histogram occurring most frequently in moderate rain. On the other hand, the visibility for the upper limit of slight rain (12.6 nautical miles) lies just above the range of visibility (code figure 97, 6-12 nautical miles) occurring most frequently on the histogram for slight rain. The upper limit for slight snow from Poljakova and Tret'jakov's formula (0.95 nautical miles) lies just below the lower limit of visibility code figure 95. As can be seen on the histogram only eight per cent of occurrences of slight snow showed a visibility below this.

For purposes of comparison with a typical station where smoke pollution is common, similar data for Manchester Airport are included (Figure 3). The effect of smoke is evident from a comparison of the histogram for conditions of no precipitation in Figure 3 with the corresponding histogram of Figure 2, code figure 96 being the most common as opposed to code figure 98 for the ocean weather stations.

A general comparison of the histograms of Figures 2 and 3 for each kind of precipitation suggests that the amount of reduction is about the same as that experienced at sea but when the visibility is already only moderate due to other causes such as smoke haze, no further reduction is to be expected.

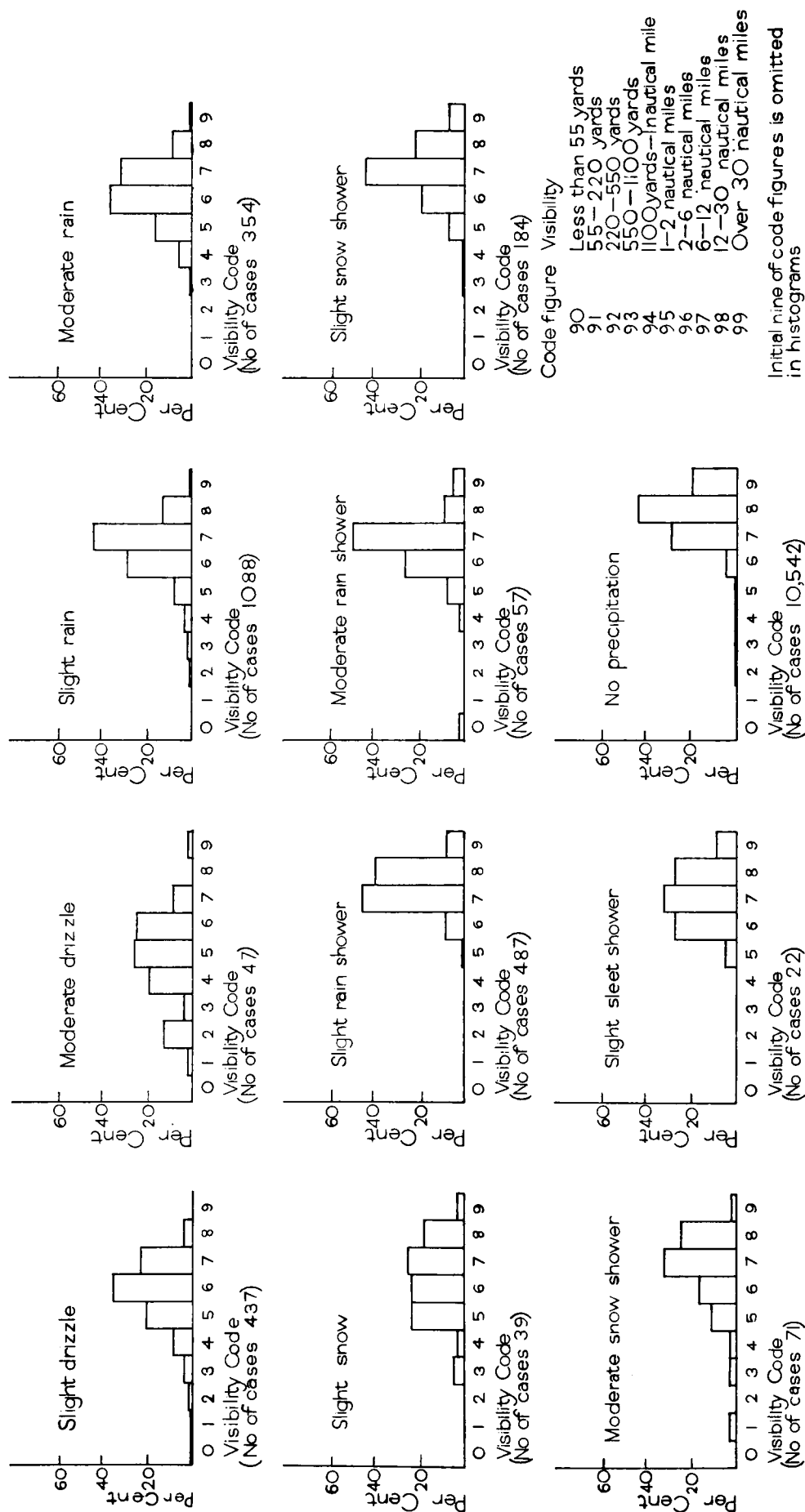
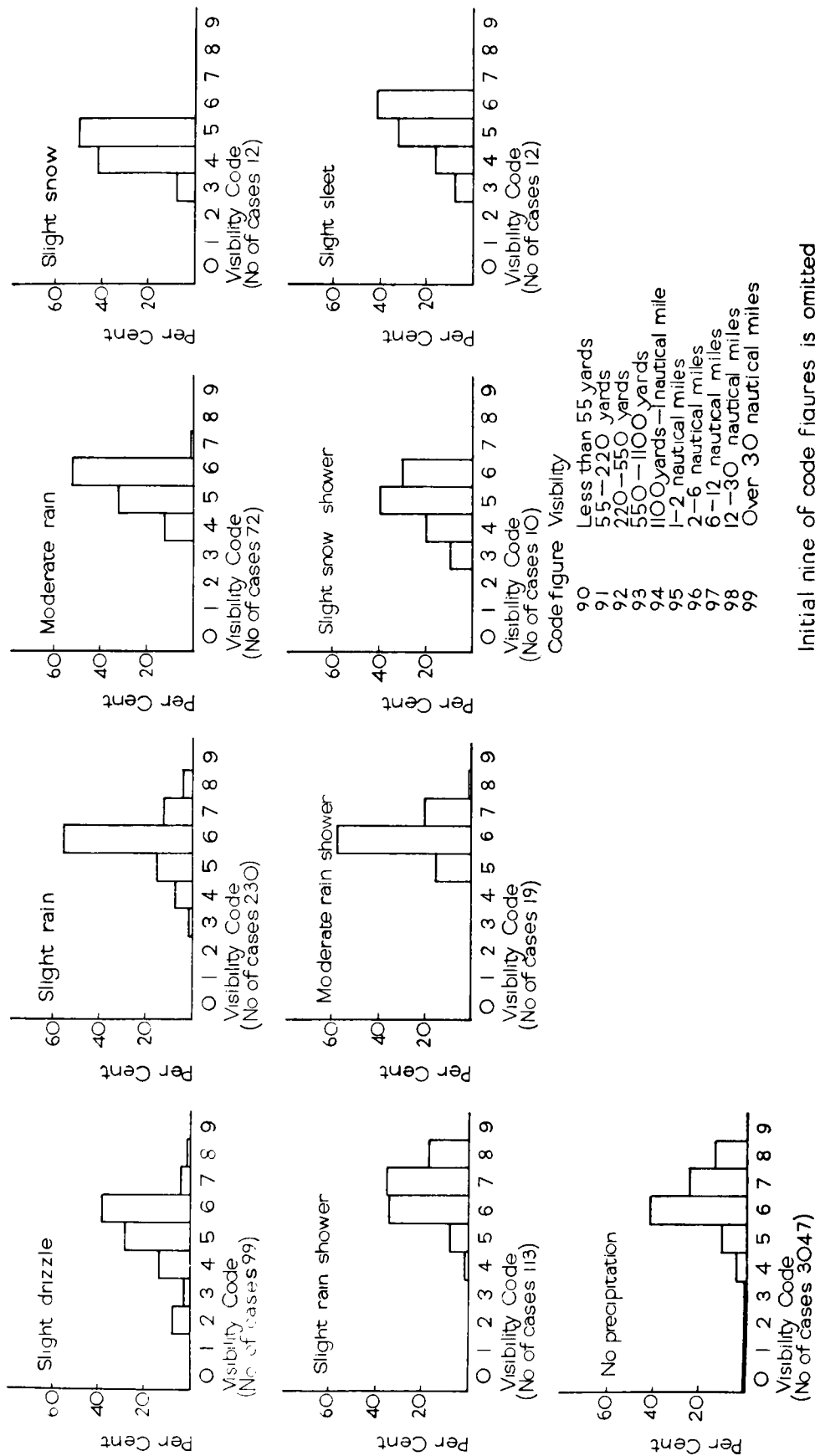


FIGURE 2--PERCENTAGE FREQUENCIES OF VISIBILITY DURING VARIOUS FORMS OF PRECIPITATION AT OCEAN WEATHER STATIONS "A", "C", "E", "J", "I", AND "M"



Initial nine of code figures is omitted in histograms

FIGURE 3—PERCENTAGE FREQUENCIES OF VISIBILITY DURING VARIOUS FORMS OF PRECIPITATION AT MANCHESTER AIRPORT

With slight rain showers, the percentage frequency of good visibilities is greater than with no precipitation. This is to be expected since showers are most commonly associated with cold air and often with moderate or strong north-westerly winds, while all wind directions and speeds are included in the "no precipitation" figures. The same tendency is evident with moderate rain showers, though in this case it is mainly confined to an absence of visibilities below 95. It is evident that with rain showers of moderate intensity, visibility is, on nearly 50 per cent of occasions, between two and six nautical miles and at almost all other times between one and two or between six and twelve nautical miles.

In general, it appears that no very great reductions of visibility are to be expected with slight or moderate precipitation and that really poor visibility is rare with most types. It is also worthy of note that with many types of precipitation, especially of the instability kind, visibility is often more than six miles and not infrequently over twelve miles.

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THE DURATION OF SURFACE WETNESS

By J. M. HEARN, B.Sc.

Introduction.—The weather has a pronounced effect on the incidence of plant disease. If weather data could be used to create a system of disease forecasting this would be of immense value to agriculture and horticulture. In the past, the process has been difficult, because there was insufficient knowledge of the significant elements. Methods are now being developed by meteorologists and pathologists which involve not only the use of new meteorological instruments but also the new use of standard meteorological observations. At the same time the experience so gained points the way to a new approach in the representation of humidity climate, which may prove useful not only in the problems of plant pathology but also in questions of barn hay-drying, grain storage and so on. This new approach was presented to the XVth International Horticultural Congress at Nice by Mr. L. P. Smith in 1958.¹ Research into apple scab and the weather is the subject of an article to be published in *Plant Pathology*² which reviews the progress made during the last ten years in which agricultural meteorologists have had a major role to play.

The surface wetness recorder.—The surface wetness recorder was produced as a result of close co-operation between plant pathologists at the Rothamsted Experimental Station and members of the Meteorological Office at Harrow.^{3, 4} The instrument is similar in nature to a dew-balance and it records the length of time that a polystyrene block retains surface moisture when exposed in the open air. A full deflexion on the instrument is approxi-

mately equivalent to a heavy dewfall or the minimum rainfall observed in a rain-gauge.

During the summer of 1957 one of these instruments was exposed in an orchard at Sudbury, Suffolk. The nearest meteorological station that records hourly humidity is Felixstowe, which lies on the coast some twenty miles distant to the east-south-east. The hours of surface wetness recorded at Sudbury were compared with the number of hours when the relative humidity at Felixstowe was 90 per cent or more. The results are given in Table I.

TABLE I—COMPARISON BETWEEN HOURS OF SURFACE WETNESS AT SUDBURY AND HOURS OF RELATIVE HUMIDITY \geq 90 PER CENT AT FELIXSTOWE

Date of ending of period of 10 days						10-day means of duration of	
						(a) surface wetness	(b) high humidity
						hours	hours
28 March	...	...	...	...	...	11·3	10·7
7 April	...	...	...	...	...	8·1	10·9
17 April	...	...	...	...	...	4·7	3·8
27 April	...	...	...	...	...	1·7	1·1
7 May	...	...	...	...	...	3·3	2·8
17 May	...	...	...	...	...	6·0	4·0
27 May	...	...	...	...	...	4·2	4·0
6 June	...	...	...	...	...	3·7	2·8
16 June	...	...	...	...	...	6·2	4·5
26 June	...	...	...	...	...	5·7	3·8
6 July	...	...	...	...	...	5·9	7·0
16 July	...	...	...	...	...	6·2	4·5
27 July	...	...	...	...	...	7·6	7·2

(Record for 18 July missing)

The correlation coefficient between these two sets of figures is 0·90. This is extremely high when one considers that one station is inland and the other coastal and that they are twenty miles apart. Furthermore, during the period under consideration there were several days when weather conditions differed in the two places. There were six days in all when coastal fog prevailed at Felixstowe and not at Sudbury (1–5 April and 5 July) and six other days when showers fell inland and not on the coast (10 April, 8, 12 and 26 June, 1 and 10 July). If these days are disregarded the coefficient becomes 0·97. The close

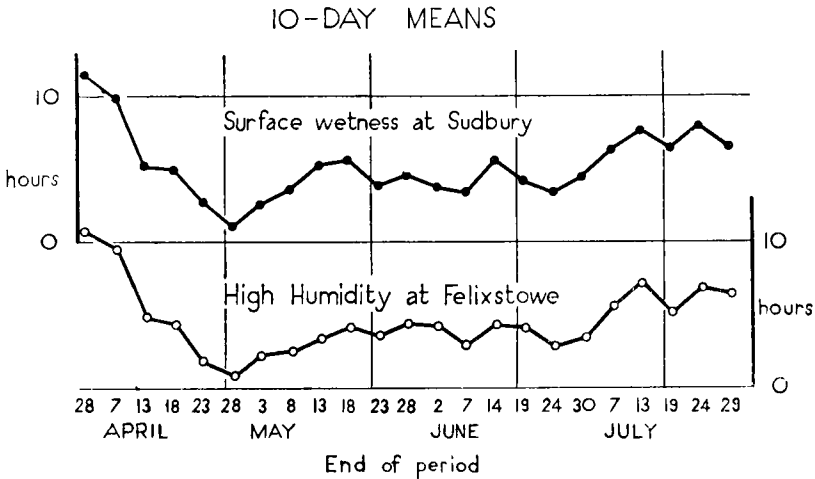


FIGURE 1—COMPARISON OF HIGH-HUMIDITY HOURS WITH SURFACE-WETNESS HOURS

similarity between the records is illustrated by the running 10-day means plotted in Figure 1.

The relationship between leaf wetness and relative humidity was also confirmed by observations taken by Mr. J. P. Jay of the Meteorological Office, Kehelland near Camborne. In a communication dated 22 October 1958 regarding the conditions in his own garden in Cornwall, he stated that "89-91 per cent (relative humidity) still seems to be the average drying point, the odd case not fully drying out until 85 per cent is reached. None dried out with relative humidity at 92 per cent or more".

Operational use.—The duration of surface wetness is of prime importance in the incidence of certain fungus diseases of crops. This is because the development and germination of spores and their infection of susceptible host tissues takes place only under specific conditions of temperature and wetness. These conditions vary with the disease but the criteria required for two of the most fully investigated diseases, namely potato blight and apple scab, are given by Beaumont periods and Mills periods respectively. In considering these it must be remembered that their criteria differ in that screen temperature and humidity records are used for the assessment of Beaumont periods whereas in isolating Mills periods macro-temperatures are used in conjunction with wetness recorded on a micro-scale, that is the surface of a leaf, if observations are taken visually, and the polystyrene block of a wetness recorder, if obtained instrumentally.

From 1956 onwards surface wetness recorders were used with considerable success to provide data from which the occurrence of Mills periods could be ascertained. But at the same time the use of humidity criteria for the definition of critical conditions was also being investigated.^{5, 6} Field work and observation showed that leaf surfaces tended to remain wet only if the relative humidity of the air, as measured under standard meteorological conditions, did not fall below 90 per cent. The validity of equating 90 per cent relative humidities with wetness was substantiated by the close similarity observed between the Sudbury surface wetness recorder and the Felixstowe humidity records and this idea was tested further when Mills periods, derived from surface wetness recorder data for the years 1956-59, were compared with periods which use 90 per cent relative humidity following rain as a threshold of wetness (now called Smith periods). A marked correlation was found to exist between these.

Examples for the year 1959 are given in Figure 2, which have been extracted

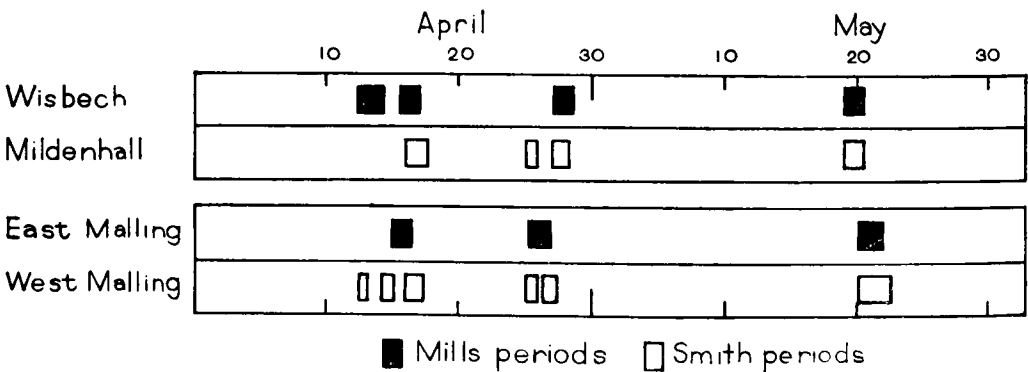


FIGURE 2—MILLS AND SMITH PERIODS, 1959

from charts showing the incidence of Mills periods at some fifteen stations using wetness recorders, and the Smith periods extracted from the hourly records of a similar number of synoptic stations in the same general area. Wisbech and Mildenhall are some thirty miles apart inland in East Anglia. East and West Malling are within a few miles of each other in Kent but the latter station is higher by nearly 200 feet.

Having established a relationship between high humidity and surface wetness it seemed clear that a network of stations reporting relative humidities of 90 per cent or more after the occurrence of rain or heavy drizzle could be used to provide substantiating evidence for the data already received from the surface wetness recorders. During 1960 this surmise was tested on an operational basis and found to be correct. Indeed the standard meteorological observations were, on the whole, the more reliable indicators of critical weather conditions. However, it is clear that the most satisfactory results come from the combination of data from both networks and that the information so gained can form a sound basis for the recognition of weather critical to the incidence of plant diseases and hence play a vital role in their prevention.

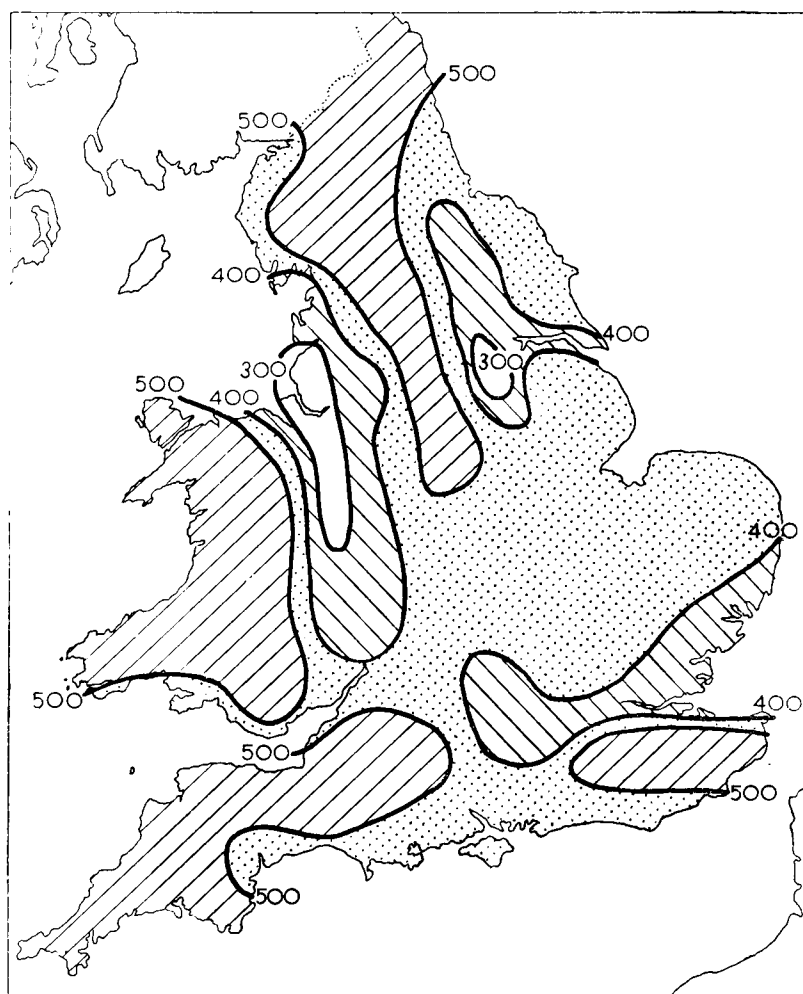


FIGURE 3—AVERAGE DURATION OF HIGH HUMIDITY (HOURS) DURING JUNE AND JULY (1950-54)

Climatological use.—Climatological maps showing the average duration of high humidities will obviously give a very good representation of the average duration of surface wetness. Figure 3 shows the average map for June and July. The areas with the least number of hours of high humidity are not those with the lowest average humidity or those with the lowest daytime humidities. The area with the least number of humid hours lies in the Wirral Peninsula and south-west Lancashire in the "shadow" of the Welsh mountains. A similar area exists behind the Pennines. Other factors which affect the parameter are

- (a) height above sea level,
- (b) nearness of the sea,
- (c) local topography and liability to frost or fog.

In confirmation of the existence of a non-humid area in north-west England, it is interesting to note that barn hay-drying has been unusually successful in the lowlands of Lancashire and Cheshire. It is also an area of relatively high potential transpiration.

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OFFICIAL PUBLICATION

The following publication has recently been issued:

SCIENTIFIC PAPER

No. 5—*An experiment in numerical forecasting*, by E. Knighting, B.Sc., G. A. Corby, B.Sc., F. H. Bushby, B.Sc., and C. E. Wallington, M.Sc.

A report is made on the first two numerical forecasting experiments carried out in the Meteorological Office. The theoretical and practical details are given and then the numerical forecasts are compared with the conventional forecasts made by the Central Forecasting Office (C.F.O.) using certain statistical measures of success. Some examples of the numerical forecasts are compared with their C.F.O. counterparts.

The results show that:

- (a) objectively analysed charts form a suitable basis for making numerical forecasts;
- (b) the statistical measures indicate that the numerical forecasts are of similar quality to the C.F.O. forecasts;
- (c) the errors in the numerical forecasts are mainly due to over-development of high-pressure systems and to the assumptions made regarding the changes at the boundary of the forecasting area.

REVIEWS

Cumulus dynamics (Proceedings of the first conference on cumulus convection). Edited by Charles E. Anderson. 9 $\frac{3}{4}$ in. \times 7 in., pp. ix+211, *illus.*, Pergamon Press Ltd., Headington Hill Hall, Oxford, 1960. Price: 70s.

In May 1959, 45 meteorologists met at Portsmouth, New Hampshire, U.S.A., to hold a week's conference on convection and cumulus cloud physics. *Cumulus dynamics* is a nicely produced report of the proceedings.

The 23 papers written into the book range from purely observational studies using laboratory models, photogrammetric methods and research aircraft to numerical studies tackled with the aid of high-speed computers. These papers include contributions by M. A. Estoque on the convective heat flux near the earth's surface, by L. Berkofsky on the inclusion of the latent heat of condensation in a numerical forecasting model, by T. Fujita on tornado development and by R. H. Douglas on hailstorms in Alberta. V. J. Schaeffer describes simple laboratory apparatus for the study of clouds and C. S. Downie broaches the interesting subject of cloud modification with carbon black.

It would be too lengthy to list all the papers and authors in the book, and indeed the papers themselves appear to be considerably condensed from the versions presented verbally at the conference itself. But this condensation is acceptable if the book is considered as a digest of the methods rather than the results of the research work described by the participants at the conference. As such the book is stimulating rather than profound. It is well produced with clear diagrams and attractive photographs, but the price seems to be rather high if it is intended to reach the student or young research worker in the field.

C.E.W.

A history of the United States Weather Bureau. By D. R. Whitnah. 9 $\frac{1}{4}$ in. \times 6 $\frac{1}{4}$ in., pp. xii+267, *illus.*, University of Illinois Press, Urbana, Illinois, U.S.A., 1961. Price: \$6.00.

It is not easy to review a book about the history of a government agency of a foreign country and one can only assume that domestic and national details have been reflected accurately. If this is so, then the author has not been as careful in his references to international meteorology and international events, such as World War II. Pages 203 and 210 contain some startling inaccuracies and naïve references to World War II and to the World Meteorological Organization. It is a shock to be told that that United Nations specialized agency is affiliated to UNESCO, a sister agency. Co-operation there is, of course, but certainly not affiliation.

One is left with the impression that the author at no time realized that meteorology provides an outstanding example of international collaboration on a big scale and this fact is most inadequately treated. It is true that before World War II, the new world considered that Europe exercised an unhealthy hegemony over international meteorological affairs, but this situation has changed radically since 1942. More attention could well have been paid to the contributions made by the United States Weather Bureau, notably by its Chief, Dr. F. W. Reichelderfer, which helped so much to create the truly international atmosphere which today exists in meteorological organizations such as WMO.

A reference is made to three-day forecasts for the North Atlantic begun in 1901 and to the benefits derived therefrom by European nations. The author says warnings were cabled to London and fog was forecast whenever possible!

No remark or amplification is made except a footnote to say that the period of validity of these forecasts had decreased to 36 hours in 1958—not altogether a surprise.

This reviewer cannot but conclude that the task of writing the history of a major State Meteorological Service ought not to be undertaken by a historian unless he has the help of advisers, both inside and outside that Service, who can and do ensure that all facets of the history can be and are carefully checked and edited. It would be difficult enough for a professional member of such a Service, but for a layman it is formidable indeed.

C.W.G.D.

Introduction to theoretical meteorology. By S. L. Hess. 9½ in. × 6 in., pp. xiv + 362, *illus.*, Constable and Company Ltd., 10 Orange St., London, W.C.2, 1961. Price: 60s.

It is often said, in an effort to attract recruits to a career in meteorology, that the atmosphere offers a wonderful natural laboratory for the young scientist who wishes to continue with his studies in physics. It is not so often said that the science of meteorology offers a vast and exciting field in which the budding mathematical physicist can employ his ingenuity. Almost every aspect of theoretical physics is brought to play in one form or another by the atmosphere, the whole extent of which is gradually being encompassed and digested by the meteorologist. The latter theme has not been developed as well as it might have been. Books on meteorology have tended either to fall in the popular class for the layman reader, and contain no mathematics at all, or in the specialist class for the advanced reader or experienced research worker in meteorology or one of its allied subjects, and contain mathematics which no one else can attempt to understand. There has been practically nothing to lead the way gently for the theoretically minded young scientists fresh from their undergraduate studies.

Professor Hess has gone a long way towards filling the gap in his *Introduction to theoretical meteorology*. He leads gently indeed and never tugs at the rein—yet at the end the initiate has followed every inch of the way and emerges with a sound and adequate basic background and, we hope, with an affection for the science which can store so many opportunities for theoretical exploration.

It is claimed that the book assumes no more than second-year mathematics and physics at the American University Level. This is probably about the standard of Advanced Level General Certificate of Education in this country. Actually certain methods included, as, for example, complex numbers and partial differential equations, go beyond the second or American sophomore year. To this Professor Hess says “. . . the reader need not comprehend their solutions, merely verifying by substitution that the alleged solution satisfies the governing equation”. This apology can perhaps well be applied to students in this country for whom Advanced Level represents the goal of academic attainment. But the undergraduate student would be studying more advanced mathematics concomitantly.

Professor Hess expresses the opinion that “. . . however aesthetically satisfying such methods as vector analysis may be to the accomplished theoretician, my teaching experience indicates that the majority of beginners are confused by unfamiliar mathematical language”—a well established but not always accepted truth.

The book contains the usual material in classical dynamical meteorology which will not be listed here. It concludes with a brief account of numerical prediction, followed by a concise chapter on the general circulation.

The book is beautifully produced; the paper and type are excellent. There are the usual few misprints in the mathematics which seem almost unavoidable in most books. The table of symbols on the cover is of great help. Finally the inclusion of problems is a very helpful asset. In Hess' words "... the student must learn to apply theory by solving challenging problems"—a principle that has not been used as thoroughly in teaching meteorology as it has in mathematics or physics.

A.H.G.

Aerodynamic capture of particles, edited by E. G. Richardson. 10 in. \times 6½ in., pp. 200, *illus.*, Pergamon Press, Oxford, 1960. Price: 50s.

This is another in the series of symposium reports in which these publishers specialize, being the proceedings of a symposium held at the British Coal Utilisation Research Association, Leatherhead, in January 1960. The proceedings are also reported in identical form in the *International Journal of Air Pollution*¹, and the papers are certainly more appropriate to a journal than to this more durable form of presentation.

The symposium performed the useful function of bringing together some of those in different fields of research to whom the mechanism and efficiency of capture of particles in a gas or liquid are of importance. In meteorology this interest is aroused by theoretical studies of the coalescence of droplets to form raindrops and by studies of the scavenging effect of raindrops in clearing the air of the particulate matter which is the most obvious constituent of atmospheric pollution. The use of water sprays to suppress dust in mines is the artificial analogue of this, while the dry deposition of particles is of interest in the design of filters, in the curing of fish by smokes, in coal mines and in the radioactive fall-out problem. The capture of water drops by moving surfaces has long been of interest in aircraft design because of its application to ice formation when the drops are supercooled, but new problems of erosion have arisen when the surface is moving at high speed. Collection efficiencies in all applications may be affected by electric charges on the particles or by the nature of their surface (for example wettable or non-wettable).

Papers on all these diverse interests were presented at the symposium and are reproduced in this book with a more-than-usually informative discussion of the theoretical papers. Some of the papers are brief surveys while others report results of original research. There is no really comprehensive and authoritative survey, however, such as would make the book of lasting value, but many will find something of interest to them here and there.

R. F. JONES

REFERENCE

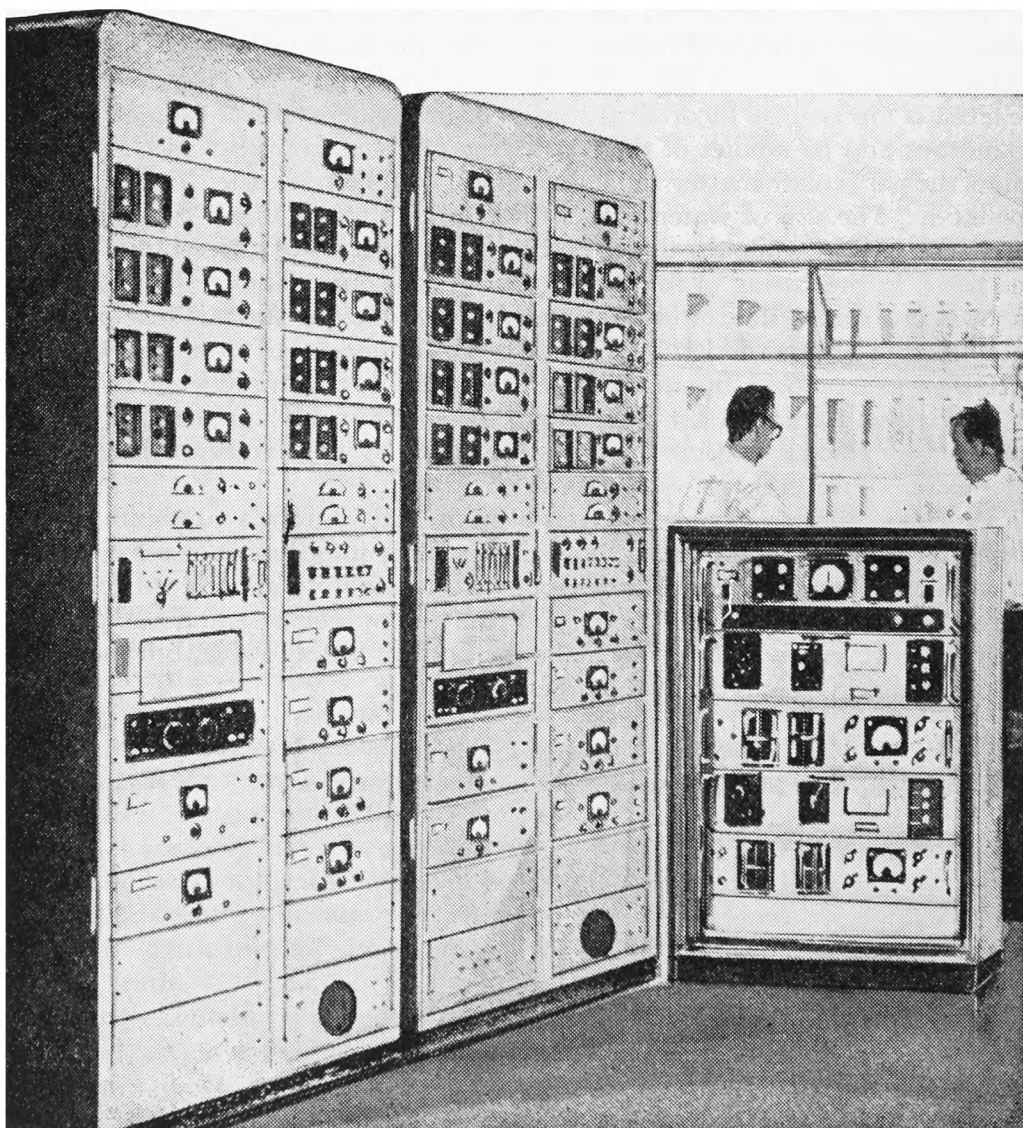
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METEOROLOGICAL OFFICE

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WORLD METEOROLOGICAL ORGANIZATION COMMISSION FOR MARITIME METEOROLOGY—THIRD SESSION

By C. E. N. FRANKCOM, O.B.E.

The Commission for Maritime Meteorology, which was established in 1907 and which met on thirteen occasions under the auspices of the International Meteorological Organization (IMO), held its third session as a technical commission of the World Meteorological Organization (WMO) at Utrecht in August 1960. Previous conferences of this Commission have been held in London (three times), Paris, Utrecht, Zürich, Copenhagen, Hamburg, De Bilt (twice), Warsaw, Berlin and Toronto under IMO; and in London and Hamburg under WMO.

It is pertinent to recall that IMO, although controlled by the directors of the meteorological services of the member states, did not enjoy full inter-governmental status, whereas WMO is a specialized agency of the United Nations and is thus an official inter-governmental organization.

Although Utrecht is situated about thirty miles from the sea, it is, like all towns in the Netherlands, linked with the sea by canals and as it is only about three miles from De Bilt, the Headquarters of the Netherlands Meteorological Service, which has always been very active in maritime meteorology, it was not inappropriate that the Conference should be held there. The session, which lasted a fortnight, took place in the magnificent Great Hall of the 14th century University of Utrecht—with its ancient tapestries and stained glass windows.

Representatives of thirty-one member states and observers from nine international organizations attended the session, which was presided over by Dr. Helge Thomsen of Denmark. Dr. Thomsen is an oceanographer with much sea experience and a meteorologist, and he has been a member of the Commission since 1938. Other members of the Commission were seamen or oceanographers and all of them have specialized in maritime meteorology in one way or another. Four Port Meteorological Officers—one from Israel, two from the Netherlands and one from South Africa—gave the Commission much practical advice.

One of the chief functions of this Commission is to endeavour to provide an adequate network of meteorological observations in all the oceans of the world—and a major problem which was discussed at the session was that of trying to improve the network in those oceanic areas where shipping is relatively sparse. The Commission had the aid of maps prepared by the WMO Secretariat showing the number of observations received from ships throughout the world on days picked at random during the International Geophysical Year. These maps clearly showed how deficient the network is in the southern hemisphere compared with the northern hemisphere. (A copy of one of these maps is shown in Figure 1.) The Conference recommended that in certain ocean areas much improvement could be effected if Port Meteorological Officers of countries bordering those areas were more active in recruiting auxiliary ships (that is, ships which are not supplied with official instruments, and which only make very simple observations when in “sparse” areas only,) and that certain countries could usefully be more active in disseminating rapidly all the reports they receive direct by radio from ships, for the benefit of neighbouring countries so that these reports could figure on all the weather maps in the areas. Evidence was produced which seemed to indicate that much of the alleged lack of ship reports in certain areas was not because ships failed to send radio weather messages, but that these were not all being disseminated. In other areas it was appreciated that there are no regular trade routes and hence no merchant ships, and the only way of improving the network there seems to be by the use of automatic floating weather stations or by establishing floating meteorological stations similar to the ocean weather stations in the North Atlantic and North Pacific. The Executive Committee had previously drawn up a draft project indicating the positions where floating meteorological stations could most conveniently be situated for meteorological purposes and the Commission had been instructed to study this project. The Conference set up a working group to study the problem, after the session, and to consider the possibility of chartering laid-up tankers as one way of solving this problem economically—the idea being that a tanker could remain a long time (up to twelve months if necessary) at sea and a relief crew could be put aboard by tender when required. Aboard such a vessel, upper air and surface observations could be made, as aboard a weather ship. The working group was also instructed to consider alternative plans, including the possibility of further observations aboard mobile ships (merchant ships) as has been done very successfully by the United States Weather Bureau aboard certain American merchant ships. The Commission considered that such observations, if carried out at all, could only be done by professional meteorologists aboard special types of ships (for example, bulk carriers) which spend considerably more time at sea than in harbour. Evidence was given concerning successful experiments carried out by the United States Weather Bureau with marine automatic weather stations, using a special mooring, in the Caribbean and South Atlantic, moored in depths of nearly 2000 fathoms.

The Commission recommended that action be taken by WMO on an international basis to secure more co-operation by fishing vessels of various nations in the provision of radio weather messages—bearing in mind the fact that fishing vessels tend to operate in areas where merchant shipping is relatively sparse—and to educate fishermen as to the importance of doing this and the value to themselves of regular and accurate weather information.

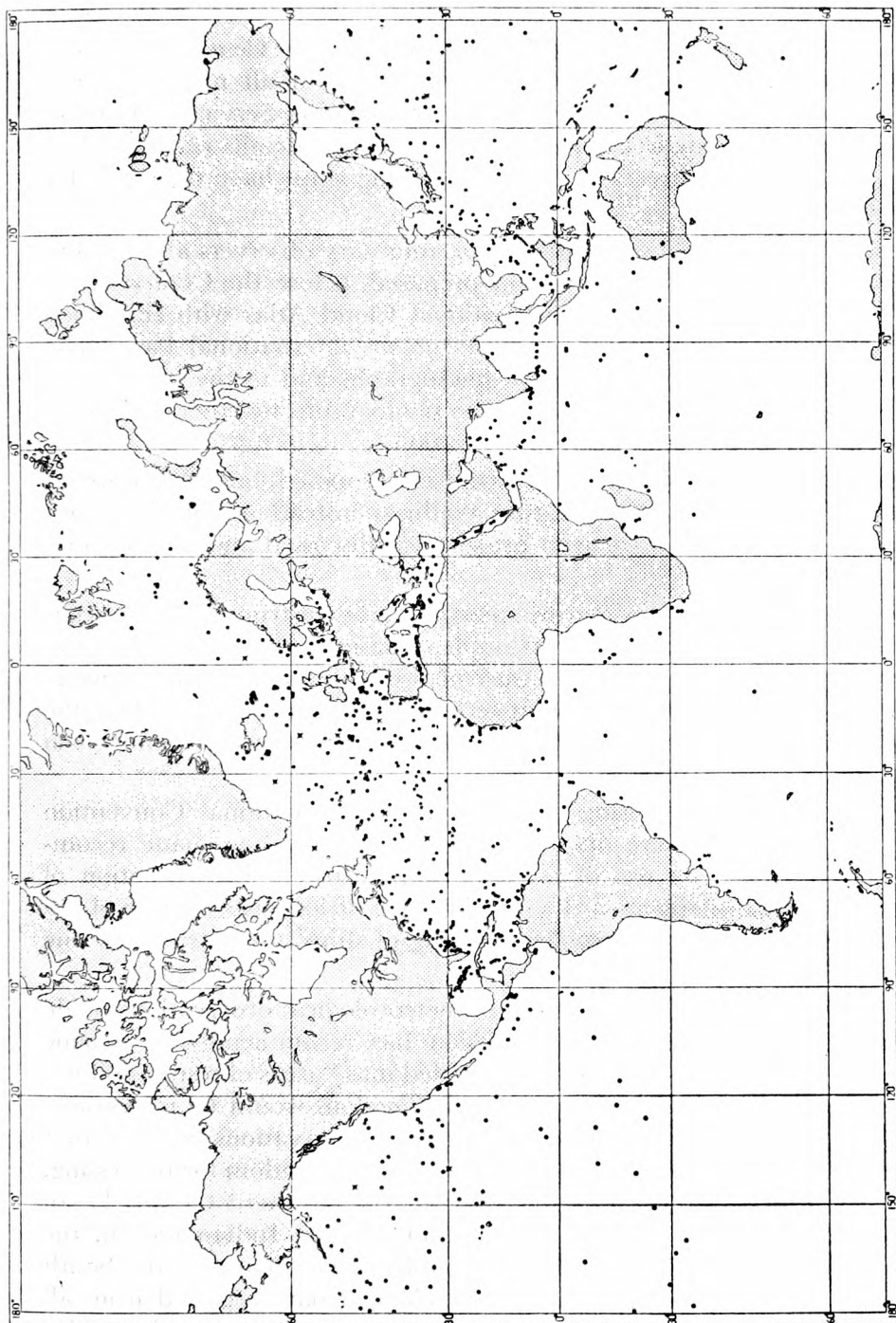


FIGURE 1—DISTRIBUTION OF SHIPS MAKING METEOROLOGICAL OBSERVATIONS AT 0600 GMT, 1 NOVEMBER 1957

Weather ships are marked with a cross.

Number of ships: Northern hemisphere 745

Southern hemisphere 106

World total 851

A recommendation was made with the object of obtaining the maximum number of meteorological observations from ships in the Indian Ocean during the international oceanographic expeditions in that Ocean (1960–64), which are being organized by the Special Committee of Oceanographic Research of the International Council for Scientific Unions, and of obtaining the maximum meteorological value from and of providing assistance to the ships of the expeditions themselves.

Resulting from a request from the Anti-locust Research Centre, the Commission recommended that voluntary observing ships of all nations should report direct by radio to the Desert Locust Information Service in London whenever locusts are sighted; the report would include details of the locusts seen and wind force and direction. British observing ships have done this for several years.

Cloud observations are always difficult for voluntary observers aboard ship and a working group of the Commission prepared, before the Conference, a selection of photographs from the International Cloud Atlas with simplified descriptions for issue to voluntary observers on an international basis. The Commission agreed with this selection of photographs and to the publication of an international cloud card embodying the photographs together with some guidance to observers on cloud height observation.

No drastic changes in the “ship” code form were proposed, but the possibility of recommending direct sea temperature readings instead of the difference between sea and air temperature as at present was discussed and is still under consideration.

Various problems relating to marine meteorological instruments and accuracy of observation aboard ship (for example, measurement of precipitation, sea temperature measurements and measurement of true wind by anemometer) were discussed as well as a suggestion that certain changes might be made in the wind speed equivalents of the Beaufort scale—all these questions are being given further consideration and study.

Meteorological questions arising from the 1960 International Convention for Safety of Life at Sea were discussed and the Commission made recommendations concerning the use of facsimile apparatus for the reception of weather maps and ice maps aboard ship, the issue of forecasts of state of sea and swell for shipping and the problem of icing of ships’ superstructures due to frozen spray.

In order to get the maximum value from meteorological observations made aboard ships of all nations, the Commission has recommended a scheme whereby the oceans of the world would be divided into “areas of responsibility” for climatological purposes. Thus, the United Kingdom would be responsible for most of the North Atlantic, and punch cards of observations made in that ocean by ships of all nations will be sent to the United Kingdom for processing. Similarly, South Africa would be responsible for the Southern Ocean, Japan and the U.S.A. for the Pacific, the Netherlands for the Indian Ocean, the U.S.S.R. for the Arctic and the Federal Republic of Germany for the South Atlantic. The general intention is that climatological data received from all ships in the various ocean areas, after being tabulated, will be sent to the WMO Secretariat for publication in the form of monthly climatological summaries. It has not been practical to publish oceanic summaries previously except in the

case of ocean weather stations, because data from the ships has never before been gathered together on an international basis. The Commission also made recommendations concerning the eventual preparation of a world climatological atlas of the oceans, for consideration by the Commission for Climatology, based upon data collected from all ships in the various ocean areas, the period selected being 1950 to 1979.

Another general subject discussed by the Commission was that of sea ice; recommendations were made about a unified code for reporting ice from aircraft, ships and shore stations, and for the publication of an international illustrated ice nomenclature.

During the Conference a series of lectures was held on the question of "methods of forecasting the state of sea on the basis of meteorological data", at which delegates from the Federal Republic of Germany, the Netherlands, the United States of America and the United Kingdom contributed. The U.S.A. and the Netherlands have used such forecasts during recent years in connexion with the weather routing of ships with which they claim to have secured quite a lot of success. A further technical discussion was held one evening, when the subjects included activities aboard U.S.S.R. oceanographical and weather ships in the Pacific and a description of a portable radio-sonde used aboard certain U.S.A. merchant ships.

Several working groups were set up by the Commission to discuss various problems during the three years that must elapse before the next Conference. At the conclusion of the session Mr. J. A. Montijn, Head of the Marine Department of the Netherlands Meteorological Institute, was elected President in place of Dr. Thomsen who wished to resign the Presidency. Mr. Montijn previously served as a Deck Officer in the Netherlands Merchant Navy.

Utrecht is an attractive old town and, although the delegates had to work hard to cover a formidable agenda, time was found for social activities and our Netherlands hosts were very hospitable. The activities included a trip round Rotterdam Docks in a motor launch and receptions by the Burgomasters of Rotterdam and of Utrecht.

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FRONTS INVESTIGATED BY THE METEOROLOGICAL RESEARCH FLIGHT

By M. H. FREEMAN, O.B.E., M.Sc.

Introduction.—Sawyer¹ has reported on the frontal observations made by the Meteorological Research Flight in 1950–52. Another series of flights was made during the period 1953–55 and forms the subject of the present article. On each sortie observations of temperature, frost point, cloud and precipitation were made at half-minute intervals on horizontal flights at about 500 and 600 millibars and at 500-foot intervals during climbs and descents. The track was chosen so as to be approximately perpendicular to the front being investigated, and the time so as to overlap the 1400 GMT upper air observations.

Method of analysis.—Vertical cross-sections along the line of flight were drawn using both the aircraft and radio-sonde observations. The diagrams for six of the more active fronts, three warm and three cold, are shown at Figures 1 to 6. In general there was fairly good agreement between the aircraft and

radio-sonde temperatures and it was possible to draw a frontal zone, as defined by the region of maximum temperature gradient, with reasonable confidence.

Figures 1(a) to 6(a) show the synoptic situation with surface fronts and isobars and the 500–1000-millibar thickness; the aircraft track is also marked. Two vertical cross-sections are presented for each front. On Figures 1(b) to 6(b) are drawn isotherms at 10°C intervals and isotachs showing the magnitude of the component of the upper winds perpendicular to the flight track, that is roughly parallel to the surface front. Figures 1(c) to 6(c) depict the cloud structure and precipitation as deduced from the aircraft observations and synoptic reports. Also on these diagrams are drawn isopleths of depression of dew/frost point. The vertical scale on the cross-sections is exaggerated 100 times.

Thermal structure of the frontal zone.—As in the previous series of flights investigated by Sawyer¹, these fronts showed a good deal of variety in their detailed thermal structure. The width of the frontal zone ranged from 25 to 180 miles. The greatest temperature gradient within the frontal zone was about 2°C in 10 miles and the least about 0.5°C in 10 miles; on one of the traverses the front appeared to be diffuse and it was not possible to define a temperature gradient. The horizontal profiles of temperature (and frost-point depression) for five of the six fronts have been published by Sawyer.² The slopes of the fronts also showed considerable variety, ranging from 1:30 to 1:140 for cold fronts and 1:110 to 1:200 for warm fronts.

Humidity in the vicinity of fronts.—One of the most striking things about these six frontal flights was the tongue of very dry air which was experienced near the frontal zone. Figures 1(c) to 5(c) all show a dry region (frost-point depression greater than 10°C) near the upper part of the frontal zone and orientated roughly along it. The dry air extended upwards from about 750 or 850 millibars and often reached nearly to the tropopause. The driest air was actually in the frontal zone and occurred at heights between 800 and 600 millibars. On 13 January 1955 (Figure 3(c)) a patch of very dry air with a frost-point depression of 25°C occurred at 8000 feet only 10 miles ahead of the frontal cloud and only 500 feet below the frontal cloud sheet above. Very large gradients of frost-point depression were not uncommon, an exceptionally large one being 13°C in 3 nautical miles as the aircraft approached the frontal cloud at 500 millibars on 13 January 1955. The greatest frost-point depression recorded was 45°C at 630 millibars on 16 September 1954. Potheary³ examined the front of 29 November 1954 and tracked the dry air back to a region where subsidence took place 24 to 36 hours previously. The humidity isopleths are such as would be expected from the descent of air along the upper frontal surface.

Frontal cloud structure.—The great diversity of cloud formations associated with fronts is well known and was amply exemplified by fronts investigated by the Meteorological Research Flight. Five of the six fronts illustrated in this article were well marked ones and the cloud sequences conformed moderately well with the “textbook” models. All three warm fronts were accompanied by cirrostratus, altostratus and nimbostratus, as was the slow-moving cold front of 11 January 1955 (Figures 1(c) to 4(c)). This latter was, in fact, the same front which was investigated on 13 January 1955 when it returned as a warm front. The cold front of 16 September 1954 (Figure 5(c)) was a good example of a “kata” front with descending air at the frontal surface and very

little frontal cloud. On all these fronts the bulk of the cloud was in the warm air, and the frontal zone was in clear air except in the lowest layers.

The warm fronts and slow-moving cold front all had cloud systems, the slope of which was about twice as steep as that of the frontal zone. This important fact was noted by Sawyer and Dinsdale¹ in 1955 and is well corroborated by these flights, though the level at which the cloud intersected the warm boundary of the frontal zone was generally lower than the 600 millibars suggested by Sawyer and Dinsdale. On the three warm fronts the forward edge of the precipitation was close to the position where the frontal cloud intersected the warm boundary of the frontal zone.

Wind régime.—On all six occasions a wind speed maximum occurred just below the tropopause in the warm air above the upper end of the frontal surface. The strength of the maximum component parallel to the surface front varied between about 60 and 150 knots. A commonly quoted feature of the frontal model is that the jet stream lies approximately above the intersection of the frontal zone with the 500-millibar level. This was roughly borne out by the six fronts considered, the relevant height being 550 millibars on the average with values ranging from 430 to 630 millibars on the individual fronts.

On the four fronts where a cirrus and cirrostratus sheet was present the edge of the cloud sheet appeared to be near the core of the jet stream and a little below it. Sawyer² on theoretical grounds deduced the presence of upward motion on the warm side of the jet stream core and downward motion on the cold side when the jet stream was intensifying or becoming more cyclonically curved. The presence of cloud on the warm side of the jet stream would be in agreement with Sawyer's thesis.

Notes on the individual fronts follow.

Warm front of 29 November 1954

(a) *Synoptic situation.* A depression had persisted to the south of Iceland for several days with a series of secondaries crossing the Atlantic to the south of the main centre. On 29 November 1954 a vigorous secondary depression approached Ireland from the south-west. At 1400 GMT the position was as shown in Figure 1(a) with the warm front lying across Cornwall and the Cherbourg Peninsula and moving north-east at about 35 knots. The flight was in the direction 050° from Farnborough and penetrated the frontal zone four times, on the ascent and descent and on horizontal sections at 19,000 and 14,000 feet.

(b) *Frontal structure.* The upper frontal zone was a fairly narrow one with temperature changes of 8°C in 65 nautical miles and 7°C in 80 miles at 19,000 and 14,000 feet respectively. Below 10,000 feet the frontal zone was more diffuse with some indication of a double structure; at 6000 feet the width of the zone was about 140 miles. The slope of the warm frontal surface was about 1:150. The front reached its maximum elevation over the Heligoland Bight and farther to the north-east it descended again as the upper cold front of an occlusion. On the horizontal flights some very large gradients of frost-point depression were recorded, 25°C in 14 miles at the edge of the frontal zone and 22°C in 15 miles near the top of a cumulonimbus cloud. The precipitation encountered was all in the form of rain and all occurred below 7000 feet; on the descent the aircraft entered the main cloud layer at 7800 feet and encountered rain at 7000 feet.

Warm front of 7 October 1955

(a) *Synoptic situation.* This example occurred during a period of unsettled westerly type of weather. On 7 October 1955 there was a complex low over the Atlantic with a wide warm sector. The passage of the warm front across England was slowed by a small wave which moved south-eastwards along the front. At 1400 GMT this wave was near Cornwall (see Figure 2(a)).

On this occasion two flights were made: (i) by Hastings at 13,000 and 18,000 feet on track 070° – 250° from Farnborough and (ii) by Canberra at 30,000 and 35,000 feet in direction 060° – 240° . The frontal zone was entered at 13,000 feet but all the other horizontal flights were made entirely in the warm air.

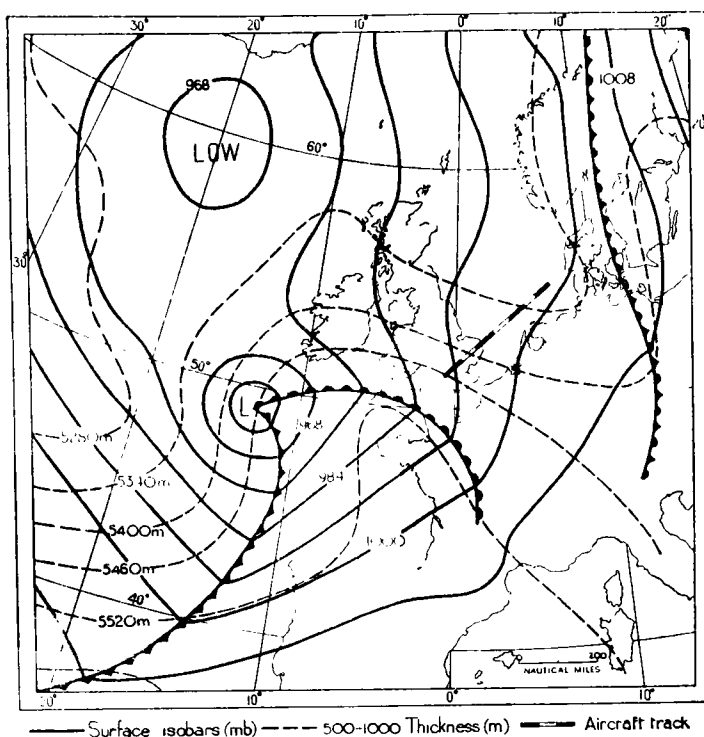
(b) *Frontal structure.* In the upper troposphere the frontal zone was about 50 nautical miles wide; below 15,000 feet the frontal zone was wider and a double structure was evident. This could also be detected on the surface charts, the dew-points rising in two stages, from the upper forties to about 55°F and then to 59° – 60°F . The frontal surface had a slope of about 1:110 and extended almost up to the tropopause (see Figure 2(b)).

The aircraft reports indicated that the cloud was in numerous layers rather than a solid mass, and the lower part of the frontal cloud (not penetrated by the aircraft) may have been more broken than indicated in Figure 2(c). Precipitation was not reported above 13,000 feet, but rain was found at this level, sometimes quite near the top of a cloud layer. The broken nature of the cloud system makes it difficult to assign a slope to it but on the whole the cloud has a greater slope than the frontal zone. Most of the frontal zone above 5000 feet was a region of dry air, a frost-point depression of 33°C being recorded by the aircraft at 13,000 feet.

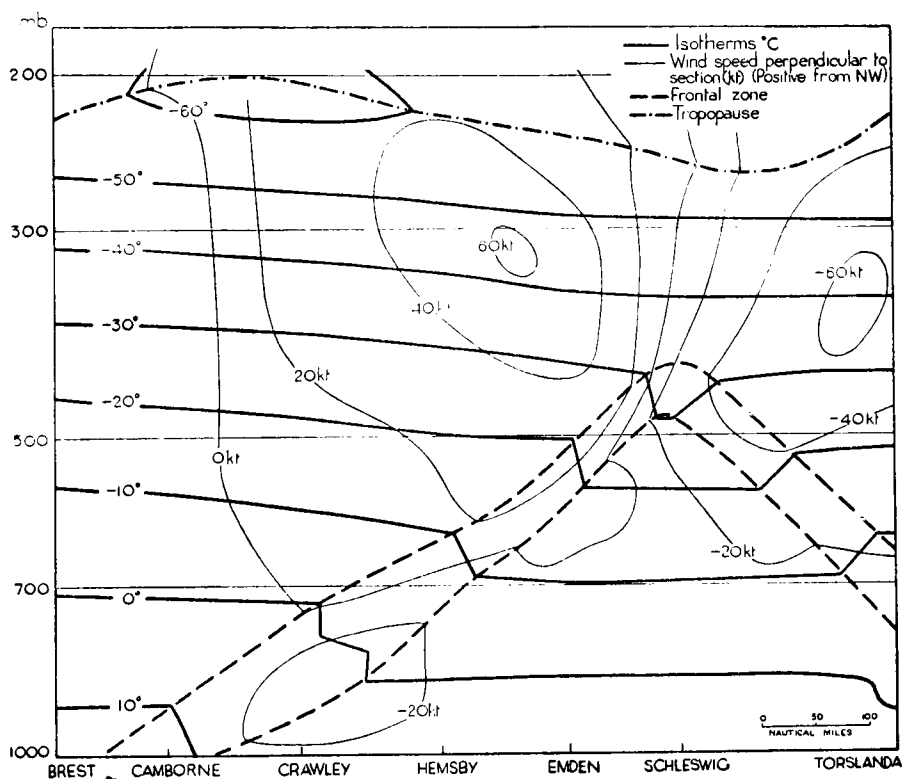
Warm front of 13 January 1955

(a) *Synoptic situation.* A depression over Scandinavia had brought a cold northerly airstream to all parts of the British Isles. Early on 13 January 1955 a depression broke away from the complex low in the central Atlantic and moved east in about latitude 50°N . An active warm front associated with this depression moved slowly north-north-east from the Bay of Biscay and at 1400 GMT on 13 January the position was as shown in Figure 3(a). Much of the flight, which took from 1150 to 1520 GMT, was made in the frontal zone (see Figure 3(c)).

(b) *Frontal structure.* The thermal structure showed a broad frontal zone with two fairly well marked regions of maximum temperature gradient. The upper frontal zone can probably be identified with an occlusion which amalgamated with the main cold front as it moved south across the British Isles three days previously, and remained in existence as a feature in the temperature field as the combined front moved back north-eastwards as a warm front. At 13,000 feet the temperature gradients measured were $5\frac{1}{2}^{\circ}\text{C}$ in 65 nautical miles and 2°C in 20 nautical miles in the two regions, while the total contrast between the two air masses at this level was about 14°C spread over a distance of about 300 nautical miles. The slope of the frontal surface was about 1:200. Precipitation reached the ground as snow at the forward edge of the precipitation belt, turning to rain after about 70 miles. The 500–1000-millibar thickness at the snow belt was between 5340 and 5390 metres, which are unusually high values to be associated with snow. Murray⁵ found that on only 0.4 per cent of occasions did snow occur with thickness values between 5370 and 5397 metres.

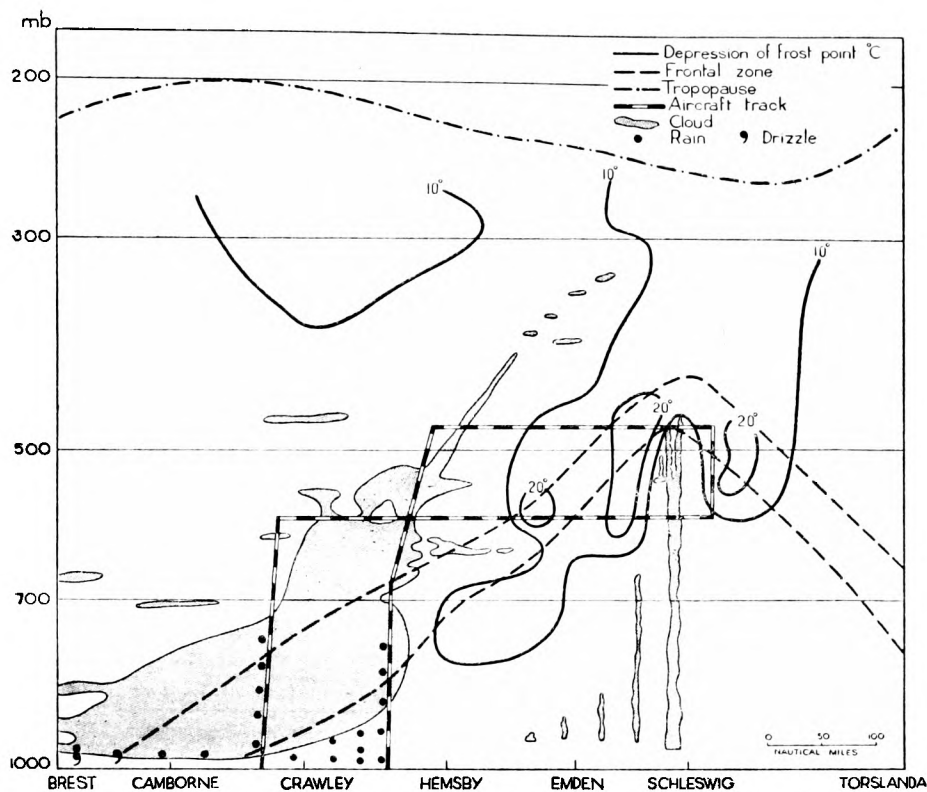


(a) Synoptic chart for 1400 GMT

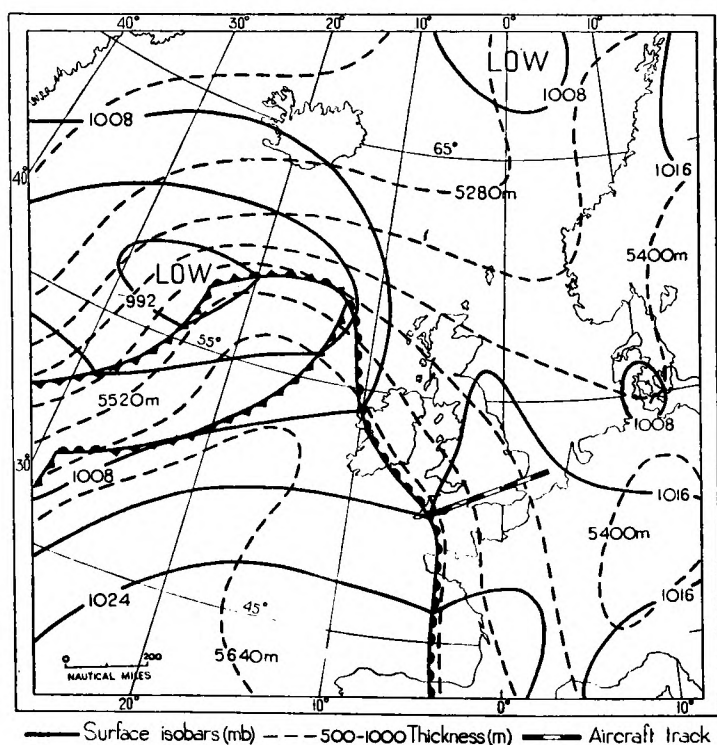


b) Vertical cross-section, Brest to Torslanda, showing isotherms and isotachs

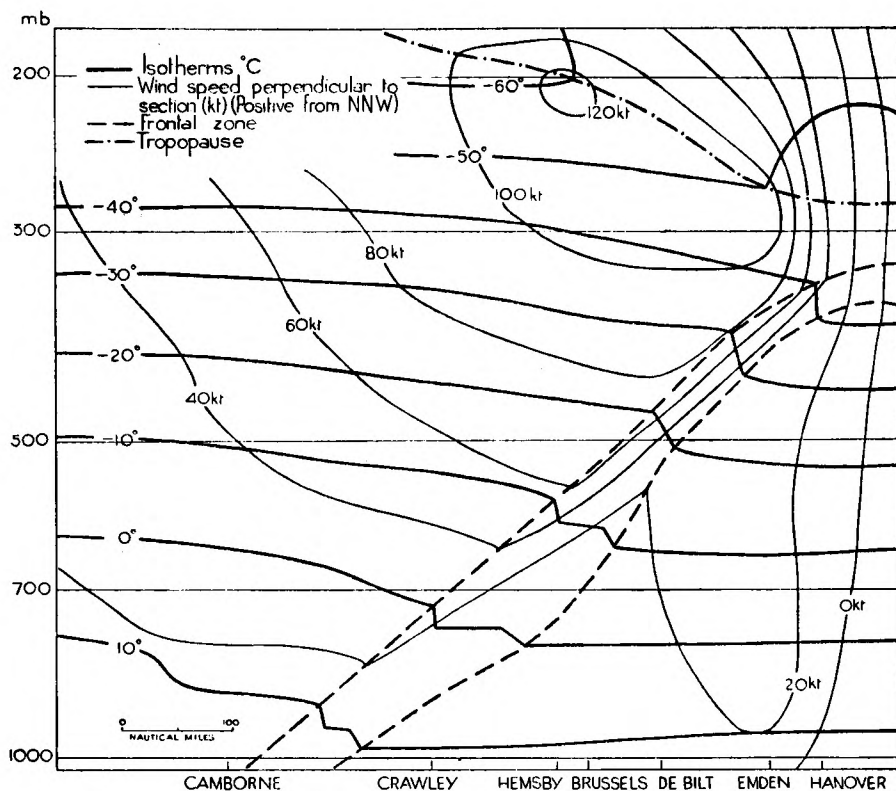
FIGURE 1—WARM FRONT OF 29 NOVEMBER 1954



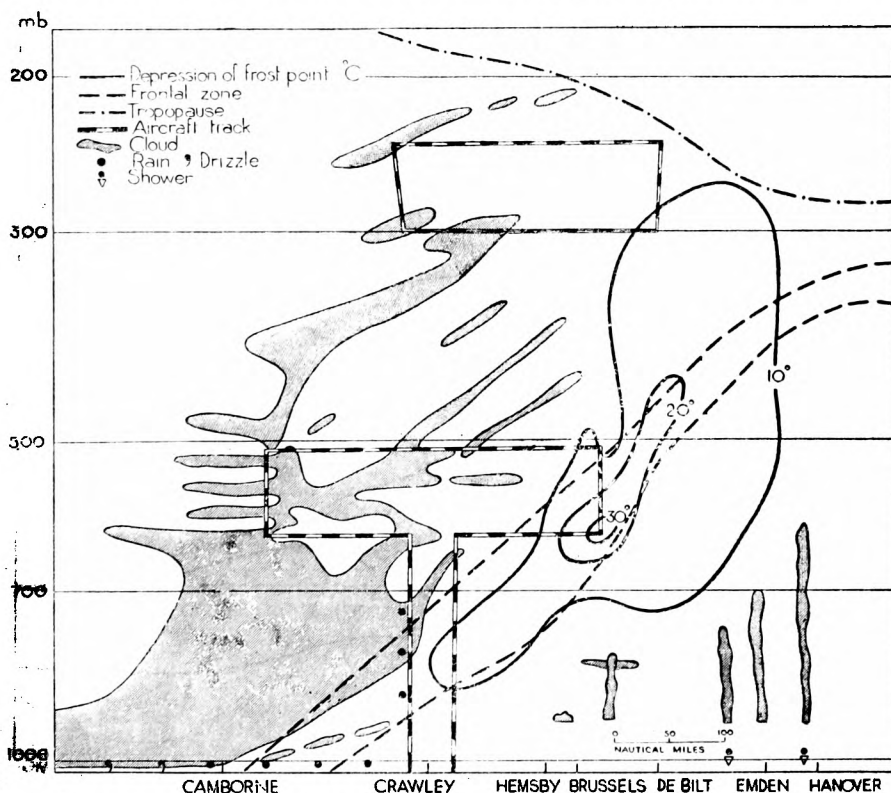
(c) Vertical cross-section showing humidity and cloud
 FIGURE 1—WARM FRONT OF 29 NOVEMBER 1954 (cont.)



(a) Synoptic chart for 1400 GMT
 FIGURE 2—WARM FRONT OF 7 OCTOBER 1955

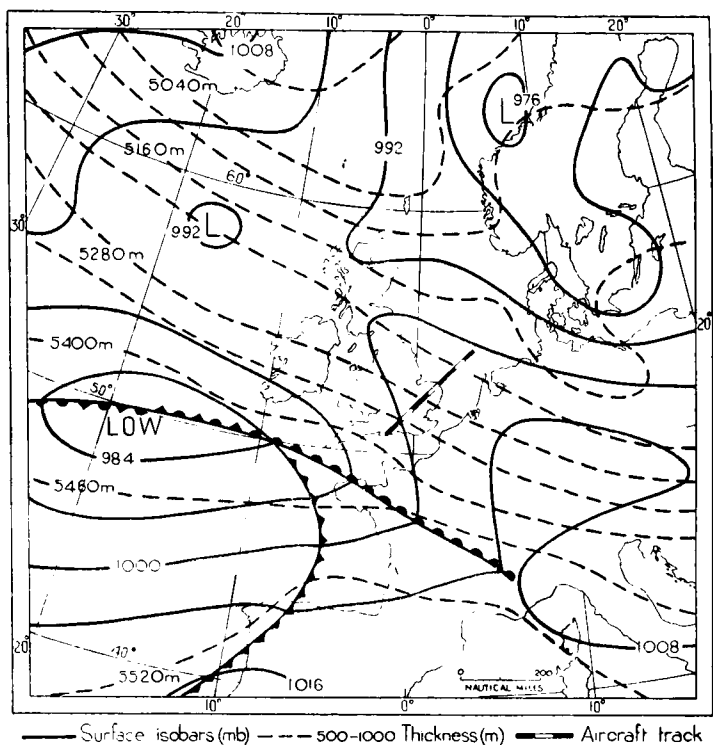


(b) Vertical cross-section, Camborne to Hanover, showing isotherms and isotachs

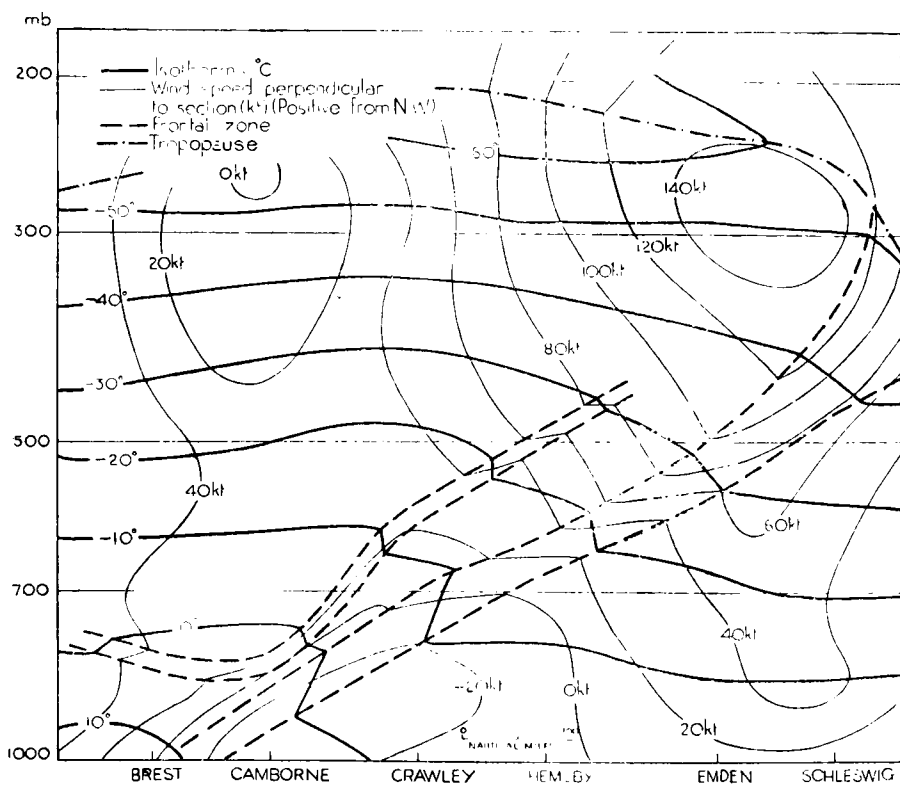


(c) Vertical cross-section showing humidity and cloud

FIGURE 2—WARM FRONT OF 7 OCTOBER 1955 (cont.)

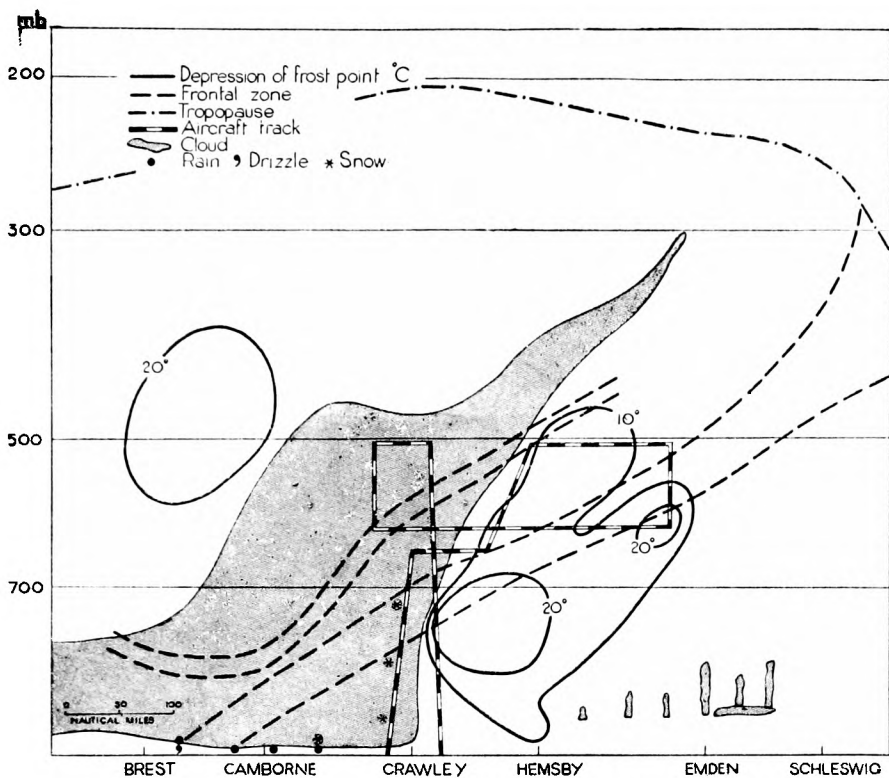


(a) Synoptic chart for 1400 GMT



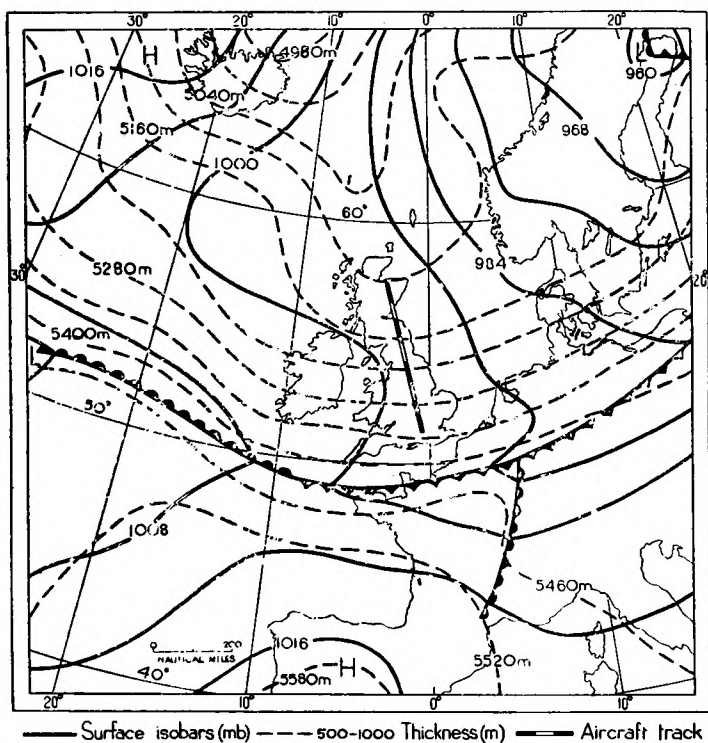
(b) Vertical cross-section, Brest to Schleswig, showing isotherms and isotachs

FIGURE 3—WARM FRONT OF 13 JANUARY 1955



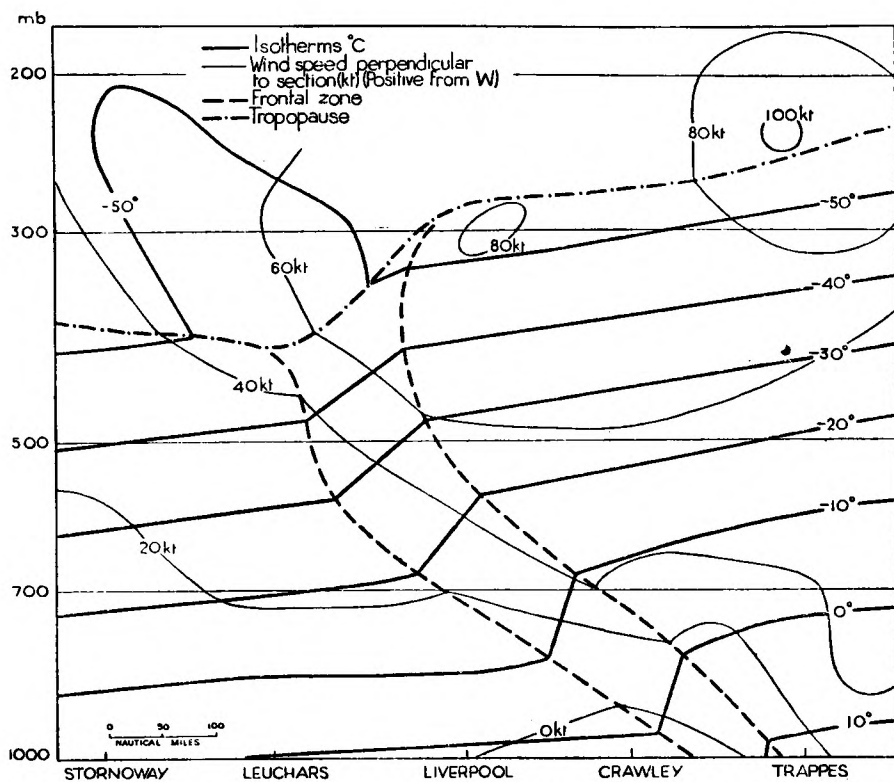
(c) Vertical cross-section showing humidity and cloud.

FIGURE 3—WARM FRONT OF 13 JANUARY 1955 (cont.)

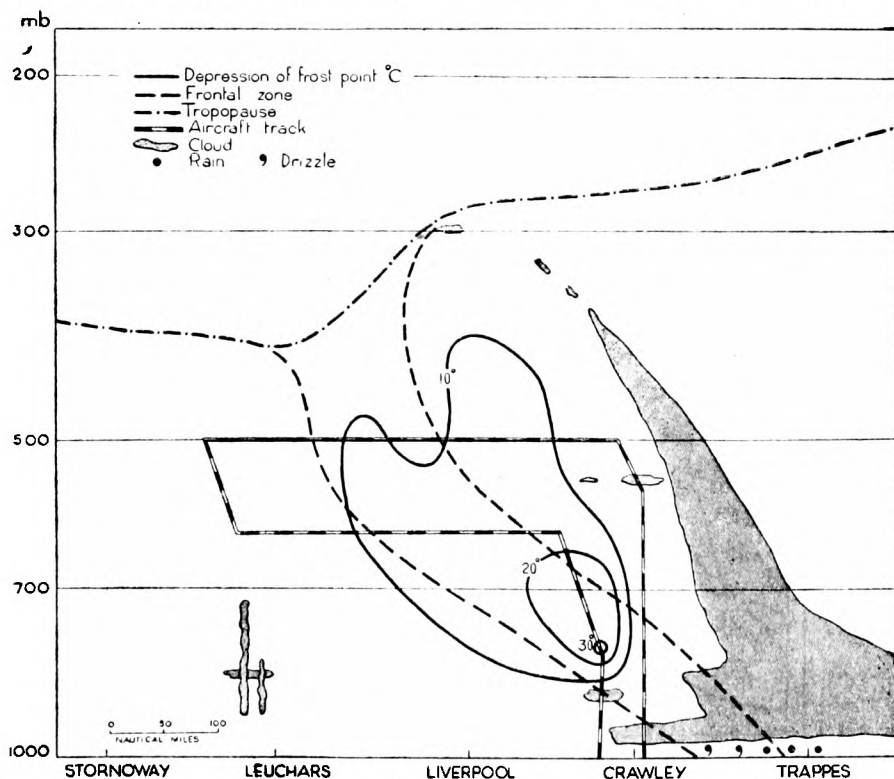


(a) Synoptic chart for 1400 GMT

FIGURE 4—COLD FRONT OF 11 JANUARY 1955



(b) Vertical cross-section, Stornoway to Trappes, showing isotherms and isotachs



(c) Vertical cross-section showing humidity and cloud

FIGURE 4—COLD FRONT OF 11 JANUARY 1955 (cont.)



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THIRD SESSION OF THE WORLD METEOROLOGICAL ORGANIZATION
COMMISSION FOR MARITIME METEOROLOGY

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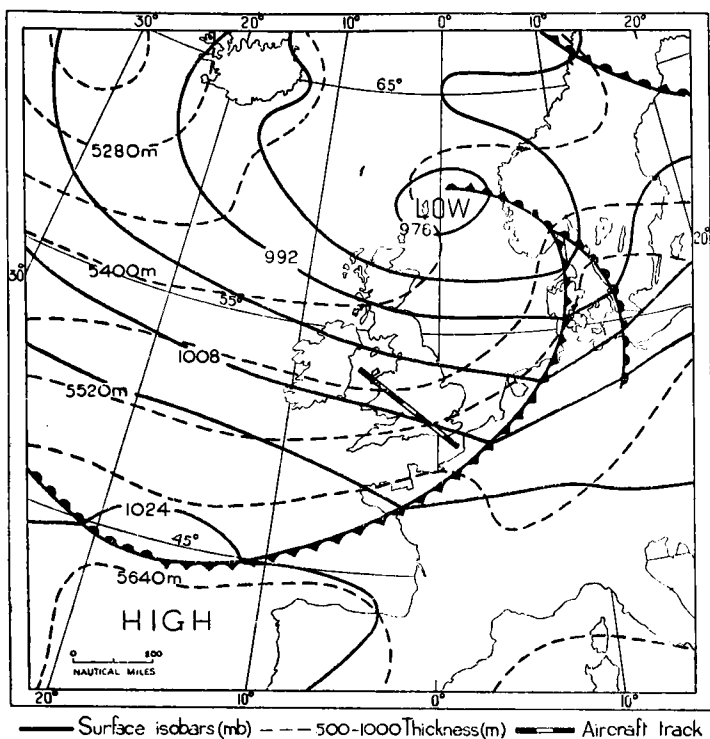
BANNER CLOUD ON BRENT KNOLL, 14 JULY 1960
(see p. 211)

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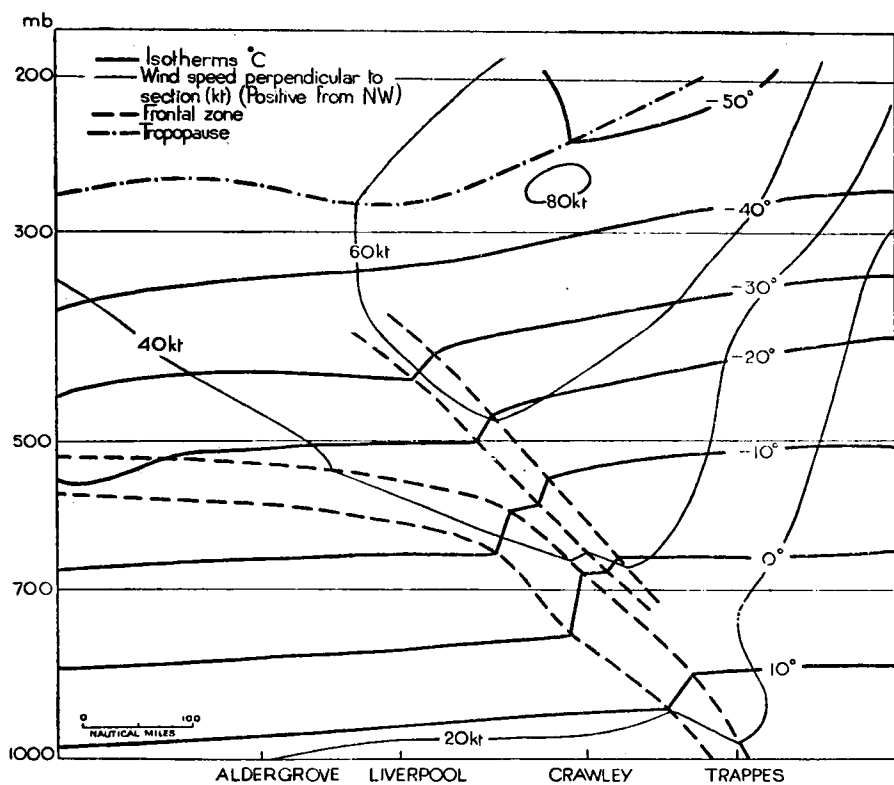


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BANNER CLOUD ON BRENT KNOLL, 14 JULY 1960
(see p. 211)

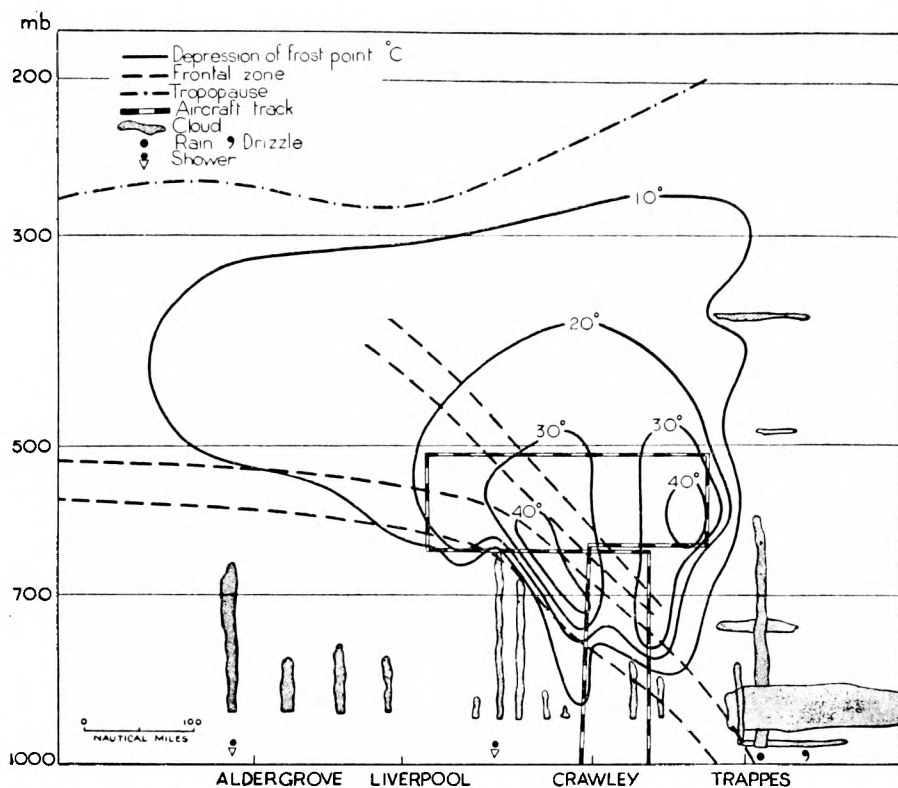


(a) Synoptic chart for 1400 GMT

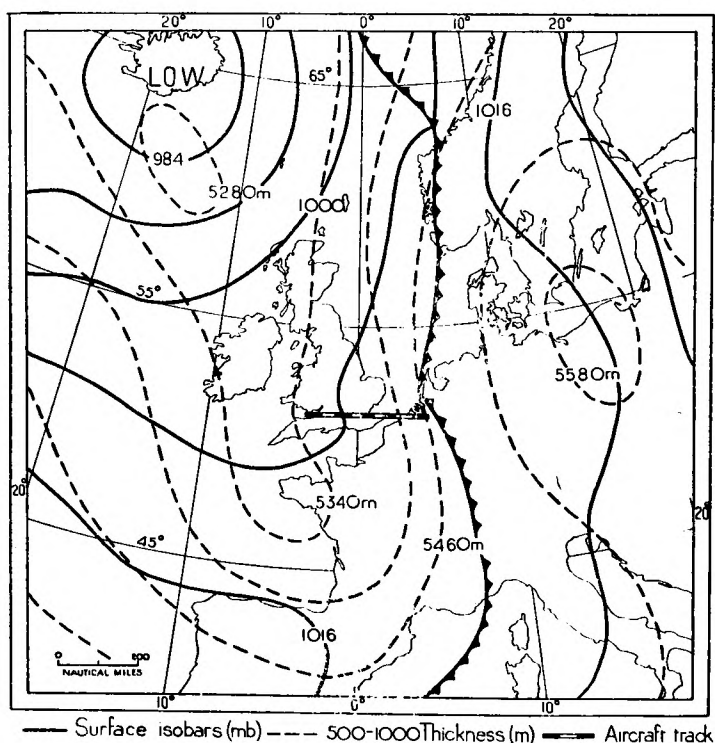


(b) Vertical cross-section, Aldergrove to Trappes, showing isotherms and isotachs

FIGURE 5—COLD FRONT OF 16 SEPTEMBER 1954

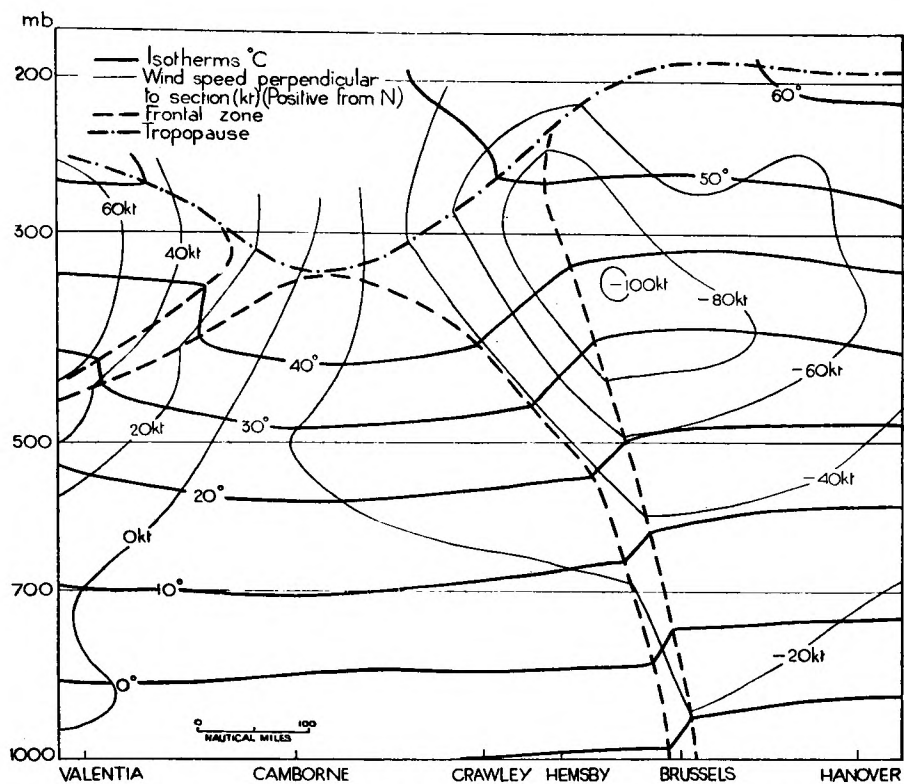


(c) Vertical cross-section showing humidity and cloud
 FIGURE 5—COLD FRONT OF 16 SEPTEMBER 1954 (cont.)

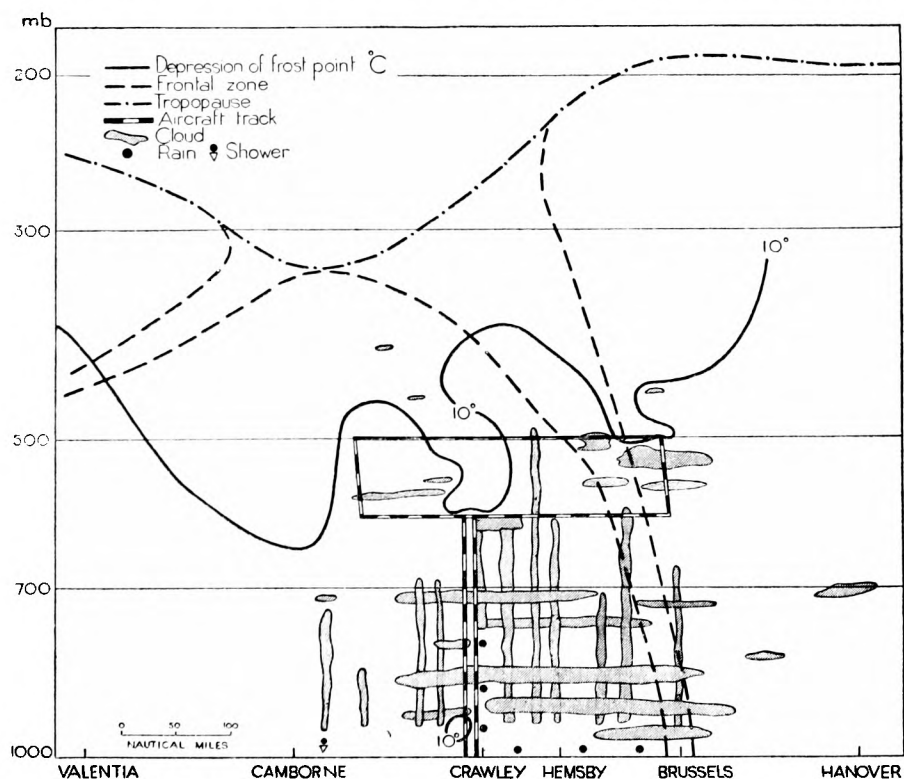


(a) Synoptic chart for 1400 GMT

FIGURE 6—COLD FRONT OF 20 OCTOBER 1953



(b) Vertical cross-section, Valentia to Hanover, showing isotherms and isotachs



(c) Vertical cross-section showing humidity and cloud.

FIGURE 6—COLD FRONT OF 20 OCTOBER 1953 (cont.)

Cold front of 11 January 1955

(a) *Synoptic situation.* A complex depression in mid-Atlantic had brought mild air to the southern half of the British Isles. A depression developed between Scotland and Norway and moved slowly north-east. A cold front associated with this depression moved slowly south across the British Isles and by 1400 GMT on 11 January 1955 lay along the north coast of France when it was moving south at about 12 knots (see Figure 4(a)). There was a surface temperature drop of some 10°F at the frontal passage and in many parts of England the post-frontal precipitation turned to sleet or snow. The flight was made on an approximately north-south track and intercepted the frontal zone on the horizontal sections at 620 and 500 millibars and on both the ascent and descent.

(b) *Frontal structure.* This was a good example of a slow-moving cold front with an extensive cloud sheet and broad precipitation belt behind the surface cold front. The horizontal flights at 18,000 and 13,000 feet showed a broad frontal zone about 180 nautical miles wide with a temperature drop across it of about 10°C . The slope of the front below 600 millibars was 1:140; above this level it was steeper, about 1:45. The driest air was at 6500 feet on the descent when a frost-point depression of 31°C was recorded.

Cold front on 16 September 1954

(a) *Synoptic situation.* During an unsettled westerly type of weather a depression moved east-north-east just to the north of Scotland. The associated cold front crossed the British Isles during the morning of 16 September 1954, moving south-east across England at 28 knots. By 1400 GMT the cold front had crossed the coasts of north France and the Low Countries and was in the position shown in Figure 5(a). The flight was made on a track of 310° – 130° through Farnborough and intersected the frontal zone on both the horizontal sections as well as on the climb and descent. It did not, however, reach the frontal cloud which lay over France.

(b) *Frontal structure.* This occasion provided a good example of a “kata” cold front with descending air at the frontal surface and very little frontal cloud. The passage of the surface front was accompanied by a rapid clearance of cloud.

The frontal zone was well marked on the flight at 12,500 feet with a temperature contrast of 9°C in 50 nautical miles. At 17,500 feet the temperature difference was only $4\frac{1}{2}^{\circ}\text{C}$ in about 35 miles. Below 12,000 feet the frontal surface was clearly defined and had a slope of about 1:110. Above 12,000 feet the original front was very weak and had a much smaller slope (about 1:400). The main temperature contrast aloft at the time of the flight lay above the old front and probably had a dynamical origin with very subsided air ahead and air which had subsided rather less forming the “cold” air.

The flight was notable for the extremely dry air encountered, a frost-point depression of 45°C being recorded in the warm air at 12,500 feet. Another very dry patch occurred at this level in the frontal zone. The whole of the flight was made in clear air, with cumulus cloud occurring in the cold air below the frontal zone. The position of the surface front was marked by a mass of cumulus and stratiform cloud with tops extending to about 14,000 feet.

Cold front of 28 October 1953

(a) *Synoptic situation.* A cold front associated with a depression near Iceland had moved east across the British Isles and become slow moving over the Low Countries and the North Sea. Minor waves moved north along the front and at

1400 GMT one of these was over Holland (see Figure 6(a)). An area of rain was affecting south-east England. The flight was made mainly in the cold air to the west of the front.

(b) *Frontal structure.* Although there was a large temperature contrast between the main air masses (about 11°C in 100 nautical miles in the upper troposphere), the frontal zone was somewhat diffuse. On the flight at 18,000 feet the main frontal zone was fairly well marked with a temperature change of $3\frac{1}{2}^{\circ}\text{C}$ in about 25 miles. At 14,000 feet, however, the temperature change was more gradual and no clear-cut frontal zone was observed. Below 500 millibars the slope of the frontal surface was large, 1:35. At greater heights the front was less steep.

The cloud observed was almost all in the cold air west of the front and consisted of multilayer cloud with cumulus cells embedded in it. Much of the cloud was below 10,000 feet but various broken layers were encountered at higher levels. There appeared to be little resemblance to the textbook cloud models for a cold front. Dry air was observed in the region of the front and in the cold air behind it, the maximum frost-point depression, 17°C , occurring in the warm air near the frontal zone at 500 millibars.

Conclusion.—The series of flights through fronts here described confirms Sawyer's findings in his report on the earlier series of flights made by the Meteorological Research Flight. The most striking fact is the presence of regions of dry air in and near the frontal zone.

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YEAR-TO-YEAR VARIATIONS FROM METEOROLOGICAL AVERAGES

By T. H. APPLGATE

In a previous article Smith¹ gave an explanation of a simple method of estimating the probable deviations from average monthly rainfall in a decade by means of ten sample percentages. This method has now been applied to averages of mean monthly air temperature, mean monthly 0900h dew-point temperature and mean monthly sunshine duration.

Data used.—For the temperature investigations twelve stations were used each of which had continuous records over the fifty years 1906-55. The stations were distributed as evenly as possible over England, six were on the coast and six inland. They were Durham, Manchester, Spurn Head, Bidston, Cromer, Coventry, Woburn, Bath, Plymouth, Newquay, Kew and Eastbourne. For the sunshine investigation it was not possible to find twelve well distributed stations with such a long record. Consequently six stations were selected with fifty-year records from 1901-50, namely Newton Rigg, Scarborough, Llandudno, Oxford, Rothamsted and Penzance.

Method.—For each station and each month, fifty-year averages were found. The deviations from average were then arranged in algebraic numerical order and the means of successive groups of five deviations were computed. This gave ten sample deviations for each month and each station; these samples for each month were then averaged over the twelve (or six) stations, or over sub-groups of northern, southern, inland or coastal stations as required.

Variations in mean monthly temperature.—Table I gives the sample deviations, month by month, taking the average samples of all twelve stations. The largest deviations from average are clearly to be expected in the winter months, especially in regard to the negative deviations in February. The monthly mean temperatures in May and June vary least from the long-term average.

TABLE I—MEAN DEVIATIONS FROM TEMPERATURE AVERAGE ($^{\circ}\text{F}$) IN A SAMPLE OF TEN YEARS

			1	2	3	4	5	6	7	8	9	10
January	...	...	-5.8	-2.8	-1.6	-0.8	-0.1	+0.6	+1.3	+2.0	+2.8	+4.5
February	...	...	-6.6	-3.1	-1.8	-0.9	-0.1	+0.8	+1.7	+2.4	+3.2	+4.4
March	...	...	-4.0	-2.7	-1.7	-1.1	-0.5	+0.3	+1.0	+1.7	+2.7	+4.3
April	...	...	-3.6	-2.2	-1.5	-0.8	-0.3	+0.1	+0.8	+1.4	+2.4	+3.7
May	...	...	-3.0	-1.9	-1.2	-0.7	-0.3	+0.3	+0.7	+1.2	+2.0	+2.9
June	...	...	-3.3	-1.8	-1.0	-0.5	-0.1	+0.3	+0.6	+1.0	+1.7	+3.0
July	...	...	-3.5	-2.2	-1.4	-0.8	-0.3	+0.2	+0.7	+1.4	+2.3	+3.7
August	...	...	-3.6	-2.0	-1.2	-0.7	-0.3	+0.2	+0.7	+1.2	+2.0	+3.8
September	...	...	-3.5	-2.0	-1.4	-0.7	-0.2	+0.3	+0.8	+1.3	+1.8	+3.6
October	...	...	-3.6	-2.0	-1.2	-0.7	-0.1	+0.3	+0.8	+1.1	+1.9	+3.7
November	...	...	-5.0	-2.5	-1.2	-0.5	-0.0	+0.5	+0.9	+1.6	+2.5	+3.7
December	...	...	-4.8	-3.0	-2.1	-1.2	-0.2	+0.7	+1.4	+2.0	+2.9	+4.3

Stations in the north tend to have larger variations than those in the south in spring and early summer; the reverse is true in early winter. There is little difference apparent in the other seasons of the year. As might be expected, inland stations always show a greater tendency to large variations from average, but the differences are not as great as might have been thought probable. These differences only become effectively apparent in the coldest or warmest years in ten, and these are summarized in Table II.

TABLE II—MEAN MONTHLY TEMPERATURE DEVIATIONS FROM AVERAGE ($^{\circ}\text{F}$)

		Coldest period in ten				Warmest period in ten			
Period		North	South	Coastal	Inland	North	South	Coastal	Inland
March–April	... ..	−4.0	−3.6	−3.7	−4.0	+4.2	+3.8	+3.8	+4.2
May–June	... ..	−3.3	−3.0	−2.9	−3.4	+3.2	+2.8	+2.7	+3.2
July–August	... ..	−3.7	−3.4	−3.4	−3.7	+3.6	+3.9	+3.4	+4.1
September–October	... ..	−3.6	−3.6	−3.4	−3.7	+3.6	+3.6	+3.5	+3.7
November–December	... ..	−4.7	−5.2	−4.6	−5.3	+3.8	+4.2	+3.7	+4.3
January–February	... ..	−6.1	−6.4	−5.8	−6.6	+4.5	+4.5	+4.2	+4.8

Variations in mean monthly ogooh dew-point temperatures.—Table III gives the sample deviations, in the same form as Table I, for the mean dew-points. As in mean monthly temperature, these deviations are greatest in winter and least in summer. It is worth noting that November can have an unusually large negative deviation. Clearly it is not uncommon for dew-points in that month to be on occasion considerably below average, more so than in either October or December.

There is little difference in the distribution pattern between north and south, or between coast and inland, in spring and autumn. In summer, the north is

more variable than the south; in winter this trend is decisively reversed. The difference between coastal and inland stations is not so marked. These differences are summarized in Table IV.

TABLE III—MEAN DEVIATIONS FROM DEW-POINT AVERAGE (°F) IN A SAMPLE OF TEN YEARS

			1	2	3	4	5	6	7	8	9	10
January	...	...	-5.7	-3.0	-1.8	-0.9	-0.1	+0.8	+1.4	+2.0	+2.7	+4.7
February	...	...	-6.1	-3.1	-1.9	-0.9	-0.1	+0.6	+1.4	+2.3	+3.2	+4.8
March	...	...	-4.3	-2.5	-1.8	-1.1	-0.5	+0.3	+1.1	+2.0	+2.9	+4.1
April	...	...	-4.2	-2.7	-1.6	-0.9	-0.2	+0.4	+1.0	+1.7	+2.5	+3.9
May	...	...	-3.9	-2.3	-1.5	-0.8	-0.2	+0.4	+1.1	+1.7	+2.3	+3.5
June	...	...	-3.3	-2.0	-1.3	-0.7	-0.2	+0.2	+0.7	+1.3	+1.9	+3.3
July	...	...	-3.1	-1.9	-1.2	-0.8	-0.2	+0.3	+0.8	+1.3	+1.9	+2.9
August	...	...	-3.2	-1.9	-1.2	-0.7	-0.2	+0.3	+1.7	+1.2	+1.8	+3.1
September	...	...	-3.9	-2.0	-1.3	-0.7	-0.3	+0.3	+0.9	+1.5	+2.1	+3.6
October	...	...	-4.5	-2.4	-1.4	-0.8	-0.3	+0.3	+0.9	+1.5	+2.6	+4.2
November	...	...	-5.8	-3.0	-1.3	-0.6	-0.0	+0.6	+1.1	+1.9	+2.9	+4.3
December	...	...	-5.1	-3.0	-2.2	-1.3	-0.3	+0.5	+1.2	+2.1	+3.1	+5.0

TABLE IV—MEAN MONTHLY DEW-POINTS (0900H) (DEVIATIONS FROM AVERAGE)

Period	Lowest period in ten				Highest period in ten			
	North	South	Coastal	Inland	North	South	Coastal	Inland
March–April
May–June
July–August
September–October
November–December
January–February

Variations in mean monthly sunshine.—Table V gives the usual sample deviations, expressed in terms of percentage of average. The variation is greatest in winter when the averages are small; the least variation is found in late spring and early summer. The coastal stations show less tendency to vary about the average than those inland; variation is usually greater in the north than in the south.

TABLE V—VARIATION IN MONTHLY SUNSHINE TOTALS (1901–50) (EXPRESSED AS PERCENTAGES OF AVERAGE)

			1	2	3	4	5	6	7	8	9	10
January	...	...	58	74½	82½	88½	93	100	109	118	128½	148
February	...	...	54	72	80½	89	95½	102½	109½	118	128½	150½
March	...	...	61½	74	82½	89	94½	100½	107	115½	125½	150
April	...	...	64½	75½	83½	89	95	100½	106	115	128	143
May	...	...	68	80	85	90	95½	101	105½	115	122	138
June	...	...	67½	81½	87	92	97	103	108	112½	119	132½
July	...	...	62½	75	82½	89	96½	102	108½	116	126½	141½
August	...	...	68	79½	85	90½	96	101½	107½	113	120½	138½
September	...	...	65	77½	83	89	95	101	108	116	124	141½
October	...	...	69	80	86	92	97	101½	106½	112½	120	135½
November	...	...	59	74	80½	87	93½	101½	109½	117½	128½	149
December	...	...	56	69½	77½	88	96	102½	109	118	129½	154
Mean	...	...	62½	76	83	89½	95½	101½	108	115½	125	143½

Extremes.—The extreme variations for each of the three elements amongst the sample stations are given in Table VI. These can in no sense be regarded as “records”, because of the smallness of the sample. For example, the highest August percentage of monthly sunshine is given as 201 per cent, which was recorded at Newton Rigg in 1947, the nearest approach to this by the other five

TABLE VI—EXTREMES IN FIFTY YEARS

			Deviation from mean monthly temperature (°F)		Deviation from mean monthly dew-point (°F)		Percentage of monthly sunshine	
			Highest	Lowest	Highest	Lowest	Highest	Lowest
January ...	...	...	+7.2	-10.9	+7.6	-11.4	206	19
February ...	...	...	+6.4	-12.1	+7.6	-11.2	197	22
March ...	...	...	+8.2	-5.3	+6.9	-9.5	202	36
April ...	...	...	+5.6	-5.8	+7.8	-6.2	164	49
May ...	...	...	+4.6	-5.7	+6.6	-7.3	158	37
June ...	...	...	+5.2	-5.0	+6.4	-5.8	158	55
July ...	...	...	+5.4	-5.4	+5.8	-5.4	168	41
August ...	...	...	+6.9	-5.5	+5.7	-5.1	201	36
September ...	...	...	+6.2	-5.3	+6.5	-5.7	160	46
October ...	...	...	+5.9	-5.9	+6.3	-7.3	162	57
November ...	...	...	+5.7	-7.5	+7.2	-8.9	178	38
December ...	...	...	+6.6	-7.8	+7.2	-8.3	189	34

sample stations was 156 per cent at Llandudno. There is no reason to suspect the Newton Rigg record but clearly other unexamined stations might produce similar extremes in other months. Furthermore it is by no means certain that all long-term temperature records in Britain are acceptably homogeneous, a condition which must be established before any precise deductions can be made.

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I. SMITH, L. P.; Year-to-year variations in rainfall totals. *Mct. Mag., London*, **90**, 1961, p. 22.

551.543.5: 551.553.5

“PRESSURE JUMPS” AT MALTA

By T. H. KIRK, B.Sc.

Atmospheric wave-motion is not uncommon at Malta. Some two-dozen examples a year of well defined regular waves on the anemograms can be found and on many more occasions some evidence of irregular wave-motion can be discerned. For the most part these oscillations are accompanied by only small regular fluctuations of pressure.

Lamb¹ has drawn attention to an unusual oscillation of the wind at Malta (Figure 1), of distinctive character, accompanied by a sharp rise of pressure. A

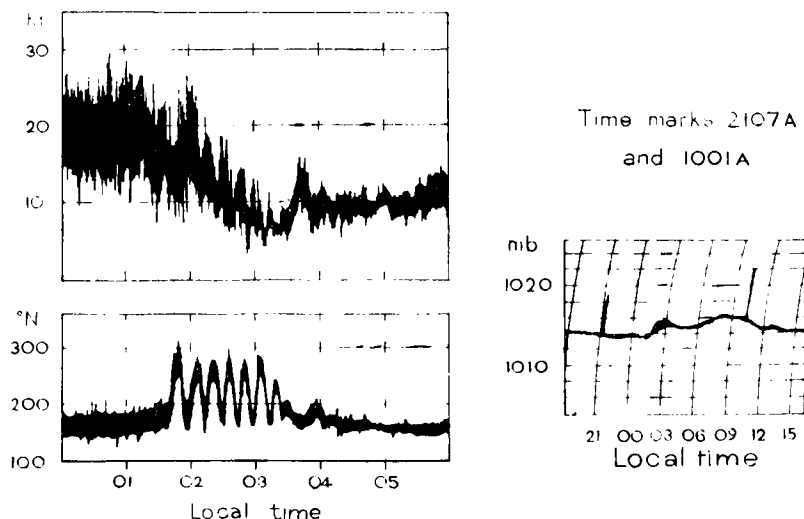


FIGURE 1—OSCILLATIONS OF WIND AND PRESSURE AT LUQA, MALTA,
16 OCTOBER 1953

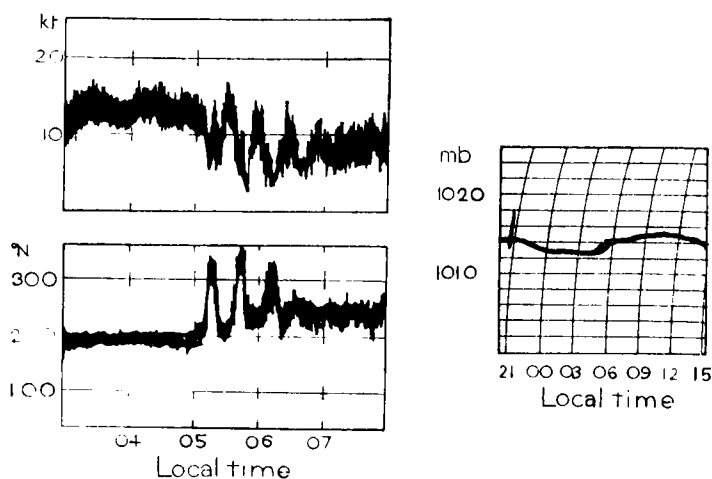


FIGURE 2—OSCILLATIONS OF WIND AND PRESSURE AT LUQA, MALTA, 9 AUGUST 1951

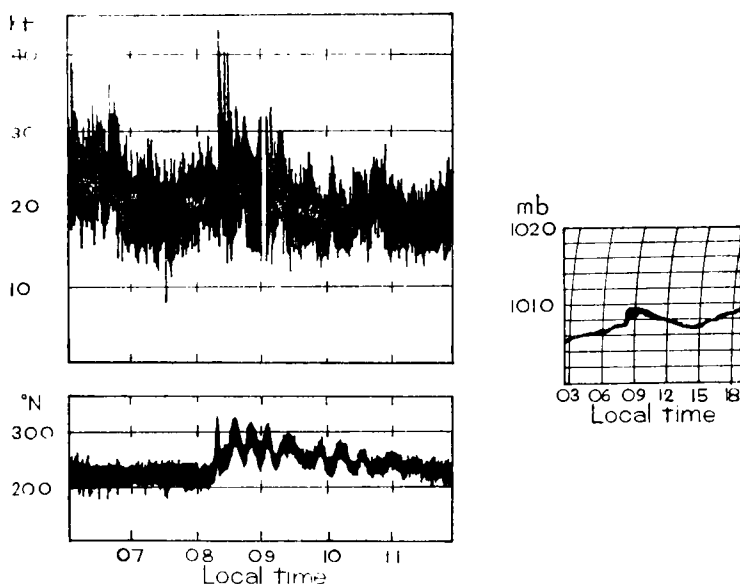


FIGURE 3—OSCILLATIONS OF WIND AND PRESSURE AT LUQA, MALTA, 30 MARCH 1952

detailed examination of wind and pressure records at Malta has led to the discovery of many more examples of the same type. Some are reproduced in Figures 2 to 5. There is evidence therefore for treating oscillations of the type illustrated as belonging to a separate class characterized by the sharp pressure rise at the time of onset of the oscillations. It is significant, too, that all the examples occurred in the presence of a temperature inversion.

It is now suggested that the major interest in this phenomenon is to be found precisely in this sharp abrupt change of pressure rather than in the wave motion, striking though this may appear at first sight. A cursory examination of the pressure changes suggests an identity with those discussed and illustrated by Tepper² and his term "pressure jump" may suitably be applied to them without necessarily accepting any particular theory of their formation or propagation.

Lamb attempted an explanation in terms of an old degenerate front and suggested that the wind oscillations corresponded to ripples on the degenerate

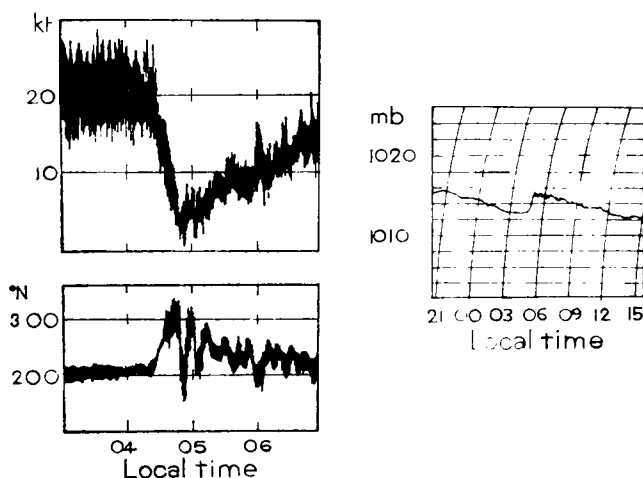


FIGURE 4—OSCILLATIONS OF WIND AND PRESSURE AT LUQA, MALTA,
19 SEPTEMBER 1952

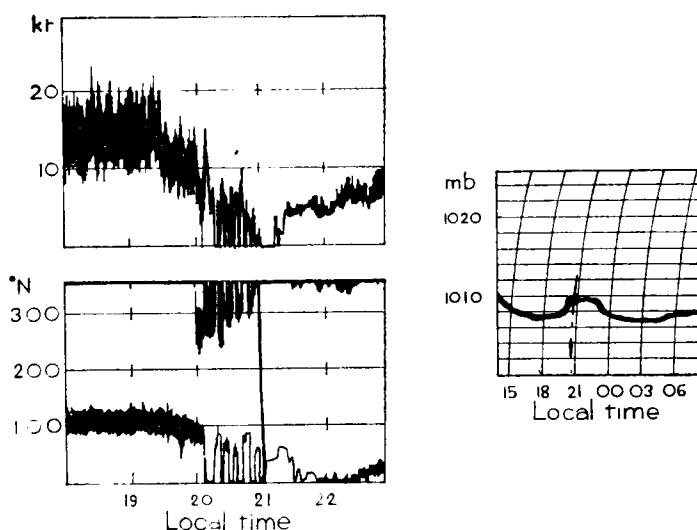


FIGURE 5—OSCILLATIONS OF WIND AND PRESSURE AT LUQA, MALTA, 4 JUNE 1951

front. The complete lack of true frontal characteristics apart from the pronounced pressure rise, which, incidentally, one would hardly expect at a “degenerate” front, suggests that an alternative explanation must exist. The probability of this is immeasurably increased by the discovery of many examples possessing the same distinctive characteristics.

We shall therefore propose that the pressure jump be considered as a discontinuity in its own right. Instead of the “degenerate front” we substitute the pressure-jump line. Perhaps it is more than a coincidence that in the example discussed by Lamb this line occurred ahead of a major cold front in much the same sort of situation for which Tepper propounded the pressure jump as a possible explanation of the “instability line”.

Synoptic experience, combined with a close examination of wind and pressure records at Malta, suggests that many of the discontinuities marked as fronts on the weather charts are not true fronts but rather pressure jumps or

instability lines. The realization of this may lead to greater consistency and insight in Mediterranean analysis.

Taking a broader view, the phenomenon of the pressure jump draws attention to the distinctive properties of flow under an inversion. It is the writer's opinion that a greater knowledge of these properties will do much to explain many peculiarities of weather in the Mediterranean where inversion conditions prevail for much of the year. It is hoped to assemble synoptic evidence for demonstrating the role of the pressure-jump line as a distinctive element in Mediterranean analysis.

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2. TEPPER, M.; A proposed mechanism of squall lines: The pressure jump line. *J. Met., Lancaster, Pa.*, **7**, No. 1, 1950, p. 21.

551.506.2(420,429)

THE GENERALLY MILD WINTER OF 1960-61 OVER ENGLAND AND WALES WITH SPECIAL REFERENCE TO AN EXCEPTIONALLY MILD FEBRUARY

By R. E. BOOTH

After an unusually wet summer and autumn in England and Wales, with more rainfall from July to November than during any corresponding period for at least two hundred years in parts of southern England, the winter of 1960-61 was generally wet and mild. Although there were some cold spells, particularly during January, it was a generally mild winter; February 1961 was exceptionally mild and ranks as one of the mildest Februaries over much of southern England since 1869.

The winter began with stormy cyclonic weather; rain was unusually heavy locally, particularly in parts of south Wales, where there was very severe flooding. During the first three days of December about seven inches of rain fell on the Brecon Beacons, some places having as much as four inches on the 3rd. At one time early in the month, floods were prevalent in forty counties.

The weather became more settled on the 4th with moderating winds allowing the floods to subside. From the 8th to the 17th a col between anticyclones centred over the Azores and over Russia lay over the country and weather was rather cold and foggy with some rain or wintry showers particularly in eastern England. Freshening northerly winds brought rain belts south-east across the country on the 18th and for the next four days disturbances moved down the North Sea on the eastern flank of an anticyclone centred in the North Atlantic; precipitation was heavier in the east than in the west of the country and often of a wintry character.

A period of about three weeks of mild unsettled weather began on 23 December as the Atlantic anticyclone moved south allowing a succession of depressions or troughs to pass over or near the British Isles. Most days were dull and wet, rain being particularly heavy in north Wales and north-west England on Christmas Day and again on 12 January.

An anticyclone moving eastwards from the Atlantic was centred over the British Isles on 14 January and during the next few days very high pressure built up over northern Europe forming a block to the eastward progress of troughs from the Atlantic. For much of the remainder of the month Britain was in a marginal area between cold dry air from Europe and mild moist air from the Atlantic. Any temporary weakening of the European high pressure centre resulted in the incursion of wet weather, mainly into western districts. Eastern districts on the other hand, particularly north-east England, experienced precipitation, often wintry in character, from the North Sea. It was because of these spells of easterly winds that the mean January temperature over England and Wales was below the average.

During the last few days of January and the first two weeks of February frequent disturbances moved eastwards across the British Isles on the northern flank of a high pressure belt extending from the Azores to central Europe. Weather over southern England became progressively milder with occasional rain; during the second week of February mean temperatures in south-east England and the Midlands were as much as 4°C above normal. By the 15th the centre of high pressure had moved to eastern Europe and for a week or more a dry and exceptionally mild south to south-east airstream covered the country. In the last week there was a change to a mild and unsettled westerly type of weather, the 27th being a particularly wet day as a small depression moved eastward along the English Channel.

Table I gives monthly and seasonal deviations from the 1921–50 average temperatures in degrees Celsius for six districts of England and Wales and for the country as a whole.

TABLE I—MONTHLY AND SEASONAL DEVIATION FROM AVERAGE TEMPERATURE

	Dec. 1960 °C	Jan. 1961 °C	Feb. 1961 °C	Winter season °C
North-east England	−0·5	−0·5	+2·2	+0·4
East England	−0·1	−0·3	+2·7	+0·8
Midlands	−0·4	−0·4	+2·9	+0·7
South-east England	−0·2	−0·0	+3·0	+0·9
North-west England and north Wales	−0·8	−0·5	+2·5	+0·4
South-west England and south Wales	−1·0	−0·4	+2·7	+0·4
England and Wales	−0·5	−0·3	+2·7	+0·6

It will be noted that mean temperatures were slightly below the average during December and January but that February was outstandingly mild in all districts, especially in south-east England. On 14 February it was exceptionally warm inland, afternoon temperatures rising to 15°C at many places and reaching 18°C in the London area, the highest mid-February temperature recorded in the area this century and some 11 degrees above the normal, although 19°C was recorded at Greenwich on the last day of February as recently as 1959. At Kew Observatory the mean February temperature was 8·3°C making it the warmest February since comparable records began in 1841.

NOTES AND NEWS

The photographs between pages 198–199 were taken on 14 July 1960 from the cockpit of a Canberra aircraft during the Farnborough morning reconnaissance. The hill is Brent Knoll, 457 feet high, some five miles south of Weston-super-Mare in Somerset. Each photograph is separated by roughly three seconds with the aircraft approaching from the south at an altitude of about 2000 feet. There was no other very low cloud in the area except for a trace of similar cloud on the hills about three miles to the north-east. Cloud details as observed during the flight as a whole were as follows: 8/8 Ac base 8000 feet tops 8800 feet over south-east England gradually becoming 6/8 westwards with patches of Sc base 6000 feet, layered to tops 7500 feet. 5/8 Cu near Bristol tops 8000 feet with decayed Cu tops to 15,000 feet. 518–6/8 Cu base 2000 tops 8000 feet, in Bristol channel with slight showers. Cumulus developing in “columns” over the south coast with estimated tops 7000 feet.

The synoptic situation at the time showed a depression of 994 millibars off north-west Scotland maintaining an unstable westerly airstream, with troughs over southern England.

The surface wind in the area of Brent Knoll was westerly, 10–15 knots. No temperatures were available in the near vicinity but Filton, some twenty miles to the north-east, reported a temperature of 59·0°F and a dew-point of 57·0°F (relative humidity, 94 per cent; condensation level, 680 feet above mean sea level). The difference in the height of the condensation level is probably explained by the close proximity of the sea to Brent Knoll and other factors involving location and orographic detail. The photographs were all taken within a minute of 0800 GMT.

HONOURS

The following awards were announced in the Birthday Honours List on 10 June 1961:

C.B.

Dr. R. C. Sutcliffe, O.B.E., F.R.S., Director of Research, Meteorological Office.

I.S.O.

Mr. T. W. V. Jones, B.Sc., Assistant Director Aviation Services, Meteorological Office.

M.B.E.

Capt. H. Sobey, R.D., Master, Ocean Weather Ship *Weather Adviser*.

METEOROLOGICAL OFFICE NEWS

The announcement of the first Gassiot Fellowship was made in the May 1961 *Meteorological Magazine*. The second Gassiot Fellow appointed by the Secretary of State for Air is Dr. H. M. Iyer. Dr. Iyer is currently working at the University of California and will take up his appointment in the Meteorological Office in the autumn, when he will work from Kew Observatory on the increasingly important subject of seismology.

Retirement.—The Director-General records his appreciation of the services of:

Mr. T. H. Applegate, Experimental Officer, who retired on 2 May 1961 after 42 years' service in the Office. He began as a Probationer at Kew Observatory and on appointment as a Technical Assistant he commenced a long period of service at aviation outstations. In 1936 he was transferred to the Marine Branch at Headquarters, but in the following year he was again posted to an aviation outstation. In 1953 he returned to Headquarters in the assistant directorate for climatological services and remained there until his retirement.

Staff suggestion scheme

Mr. D. J. George, Temporary Acting Senior Assistant (Scientific), was awarded £10 for his model for teaching pilot balloon theory at the Meteorological Office Training School.

Mr. D. L. MacDonald, Technical Grade III, was awarded £5 5s. od. for his suggestions about the design of GL. III maintenance log books.

OBITUARIES

It is with deep regret that we learn of the death on 27 April 1961 of Mr. N. Lewis, Technical Grade II, and Mr. R. S. White, Senior Assistant (Scientific). Both were killed as a result of a road accident while travelling on duty.

Mr. Norman Lewis joined the thunderstorm location unit at Dunstable from the Air Ministry in December 1942. At this time the location of thunderstorms by direction-finding on atmospheric waves was just developing. Norman Lewis believed that the system could be made reliable and accurate and for the next 19 years he enthusiastically worked towards this end. His enthusiasm and concern for the reputation of the Sferics organization spread to many of the staff who worked with him and also to many of the forecasters with whom he came into direct contact. He gave generously of his time and experience to research workers and meteorologists who sought the help and advice of the Meteorological Office in the field of Sferics, and he will be remembered and missed by many workers in this country and elsewhere. Outside his official duties he was a useful and willing helper to the organizers of many of the social activities connected with the office at Dunstable. His regular assistance at the children's Christmas party was only one of these. He is survived by a widow and two daughters to whom the sympathy of all who knew him is extended.

Mr. Ronald Sidney White joined the Office in October 1951 as an Assistant (Scientific). For the first two years he served at aviation outstations, but in 1953 he was transferred to thunderstorm location work and he continued in this work until his death. In the Sferics organization he found work which he enjoyed and which became one of his hobbies. His enthusiasm matched that of Mr. Lewis and the two were closely associated in most of the developments and special projects undertaken in recent years. He was most generous with his time off duty returning to help with any work on hand whether of an official nature or for the benefit of one or other of the office social activities. The sympathy of all who knew him is extended to his mother.

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AIRFLOW OVER BROAD MOUNTAIN RANGES—A STUDY OF FIVE FLIGHTS ACROSS THE WELSH MOUNTAINS

By C. E. WALLINGTON, M.Sc.

A number of theoretical studies of airflow over mountains involve assumptions and approximations which are difficult to test experimentally. Observational and numerical studies, such as that by Wallington and Portnall,¹ have concentrated on the lee-wave characteristics of the flow over flat ground downwind of long mountain ridges, but study of the flow pattern in the immediate neighbourhood of a ridge is beset with more theoretical and observational difficulties than those encountered in lee-wave investigations. However, a recent paper by Corby and Sawyer² makes certain deductions regarding the flow, and these deductions become particularly easy to interpret in the study of airflow across a broad mountain ridge. Furthermore, vertical motion on a scale somewhat broader than that of typical lee waves (of wavelengths between about 5 and 30 kilometres) is likely to be detectable through its effect on the temperature field. Therefore, it was decided to attempt a comparison of the computed airflow across a broad mountain range with the vertical motion deduced from temperature measurements made during reconnaissance flights through the flow.

The observational programme.—After paying due regard to operational limitations in the selection of a route for observations in flight, it was decided to make a series of flights across the Welsh Mountains between the points X and Y shown in Figure 1 with a flight pattern of the form illustrated in the Figure. The flights were made when, as far as could be foreseen, a moderate or strong flow from within 25 degrees of west was likely to blow across the Welsh Mountains with little or no change in the airstream wind and temperature structure during the period of the flight. A further aim was to ensure that the airstream was stably stratified at the levels of the traverses.

Deducing the streamlines.—The temperature and frost-point measurements made in flight were converted to true potential and wet-bulb potential temperatures before being plotted on the vertical cross-sections shown in Figures 2(a)–(e). Isopleths of potential temperature were drawn as straight lines between the appropriate vertical soundings. The vertical displacement of the air at each point on the traverses was then deduced on the assumption of conservation of potential temperature, and streamlines were constructed on the further assumption that within 1500 feet above and below the flight level any vertical variations

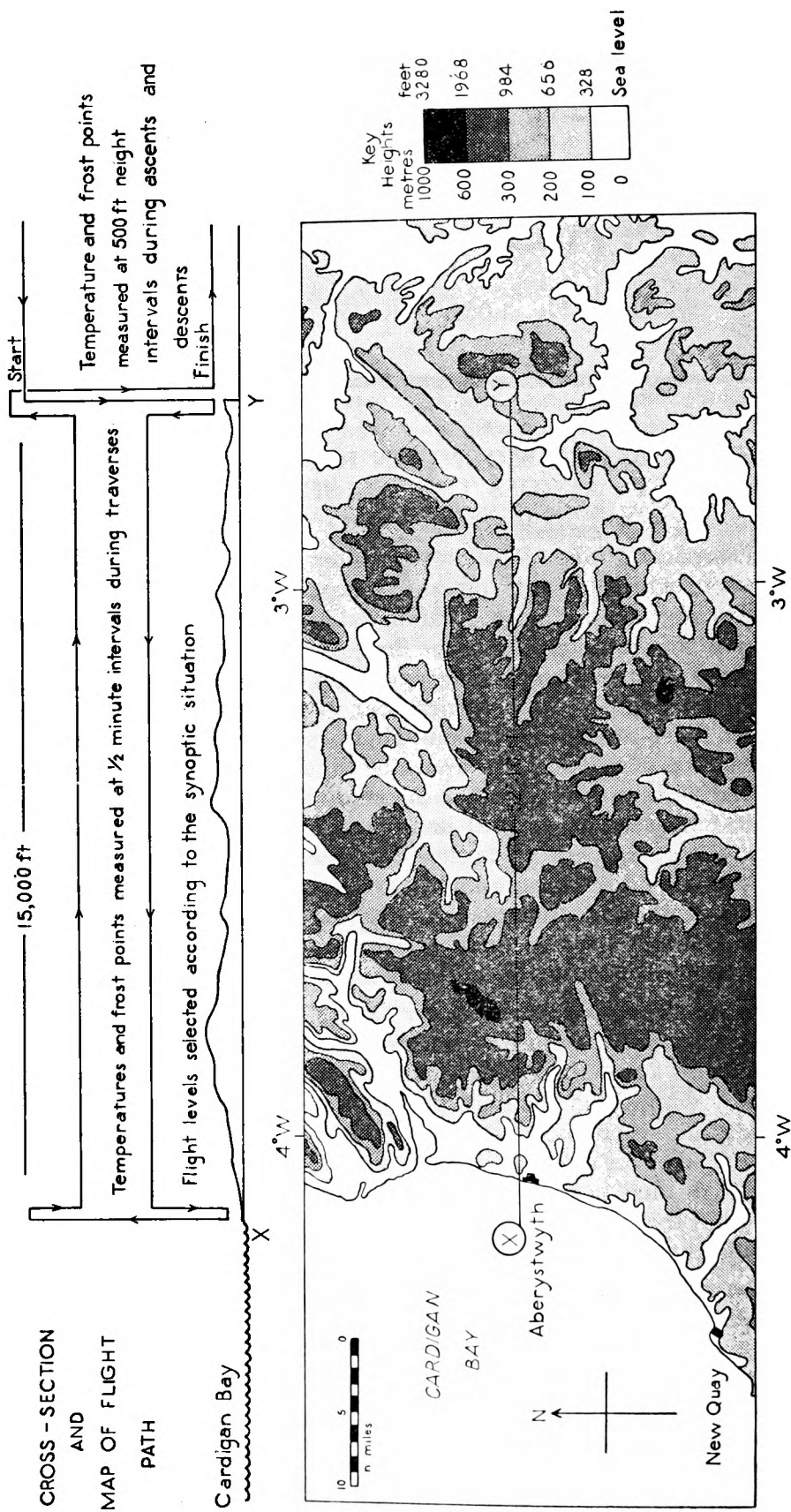


FIGURE I—CROSS-SECTION AND PLAN VIEW OF THE FLIGHTS MADE ACROSS THE WELSH MOUNTAINS

The flight path is indicated by the arrowed lines in the cross-section

in streamline displacement would be negligibly small. Wherever possible wet-bulb potential temperatures were used as a check on the potential temperature deductions; usually such a check could not be regarded as accurate since the vertical wet-bulb potential gradients were often weak, but the two sets of temperatures were found to be at least consistent.

Vertical motion (derived from the deduced streamlines and wind speeds obtained by interpolation from the surrounding routine radiosonde observations) appeared to be excessive in places; vertical motion of the air at speeds of about 300 feet per minute normally have noticeable effects on flight conditions, but many of the large vertical speeds deduced from the wind and temperature observations were not positively confirmed by pilots' remarks in the flight logs.

Probably the vertical temperature soundings made over the points X and Y were not truly representative of the initially undisturbed flow, but errors due to the operational difficulties in obtaining soundings farther upstream or downstream take the form of a slight raising, lowering or tilting of a whole streamline between the points X and Y; they do not produce errors in the main undulations in a deduced streamline, and it is reasonable to assume that the deduced flow pattern reveals the broad features of the air motion across the mountains.

Computing the streamlines.—A computing technique devised by Sawyer, and based on his theoretical treatment outlined in the Appendix to this article (page 221), was used to calculate streamline displacements over various mountain ridges of the type specified by equation (1), the airstream data for these calculations being obtained by interpolation between the routine midday radiosonde observations at Liverpool and Camborne. A high-ground profile similar to that of the real topography across the flight route was obtained by a synthesis of the various elementary ridges, and the corresponding two-dimensional flow pattern was determined. The real and synthetic high-ground profiles are illustrated in Figures 2(a)–(e).

The occasions investigated

(i) *28 November 1957.*—The lower of the deduced streamlines sketched in Figure 2(a) shows a slight rise just upstream of the principal mountain ridge followed by a general lowering over the main region of high ground. This lowering appears to be consistent with appreciable breaks in the low cloud which was more extensive at the beginning and end of the traverse. With the natural wavelength ($=2\pi/l$, where l is defined on page 222) structure depicted at the left of the figure it is not surprising that wave clouds were observed, and the indicated decrease of wind with height in such conditions is consistent with the turbulence encountered in flight. The upper deduced streamline shows only a slight lowering over the principal ridge and a somewhat larger fall towards the downstream end of the route. The computed streamlines for this occasion do not agree with the flight observations.

(ii) *5 March 1958.*—As shown in Figure 2(b) the shape of the lower deduced streamline is reasonably consistent with the observed cloud structure, but the absence of cloud despite the high humidity of the air sampled during the upper traverse suggests that the marked rise in the deduced upper-level streamline is excessive. The computed streamlines portray large-amplitude waves which are not confirmed by cloud observations or pilots' remarks; nor do they agree with the streamlines deduced from the observed temperatures. The fault is probably due to the assumption of approximately two-dimensional flow being substantially incorrect on this occasion.

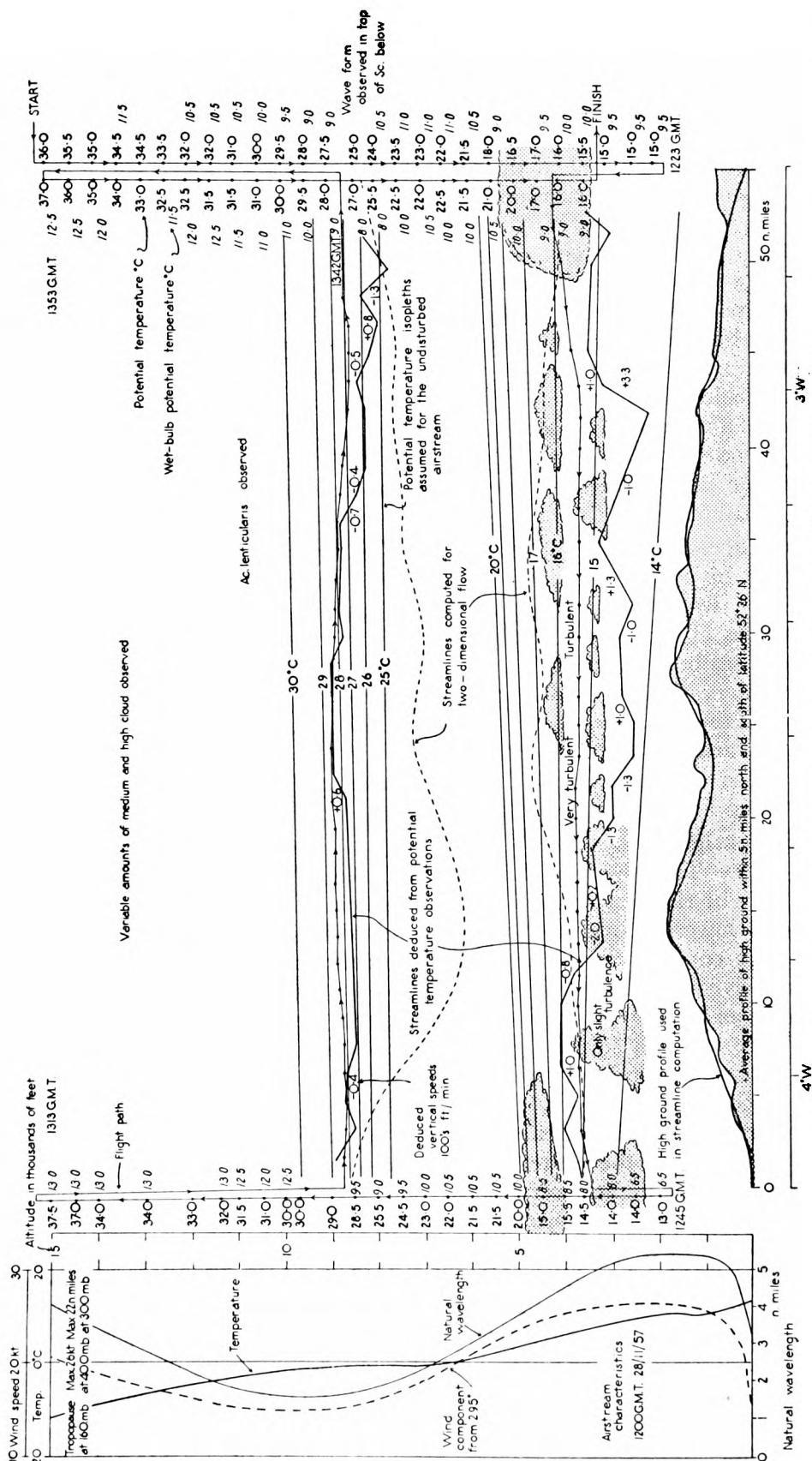


FIGURE 2 (a)—FLIGHT ACROSS THE WELSH MOUNTAINS, 28 NOVEMBER 1957

The arrowed lines with dots show the flight path, the dots being positions where temperatures and frost points were measured. The potential temperatures and wet-bulb potential temperatures in °C are denoted by large and small numbers respectively adjacent to the observing points on each ascent and descent. Selected potential temperature isopleths assumed for the undisturbed airstream are drawn as straight lines across the diagram.

Streamlines deduced from the potential temperature observations are shown as thick lines while thin broken lines show streamlines computed from the two-dimensional flow theory described in the text. Signed numbers adjacent to sections of the deduced streamlines denote vertical speeds (in hundreds of feet per minute) derived from the deduced streamlines and wind speeds obtained by interpolation from the surrounding radiosonde observations.

The high-ground profile used for the theoretical streamline computation was obtained as a synthesis of various symmetrical ridges of mathematically convenient shapes.

The temperature and wind profiles at the left were obtained by interpolation from the surrounding radiosonde observations while the "natural wavelength" denotes the parameter $2\pi/l$ (l is specified in the Appendix). On all of these five occasions the wind directions at the radiosonde stations used were almost constant with height through much of the troposphere.

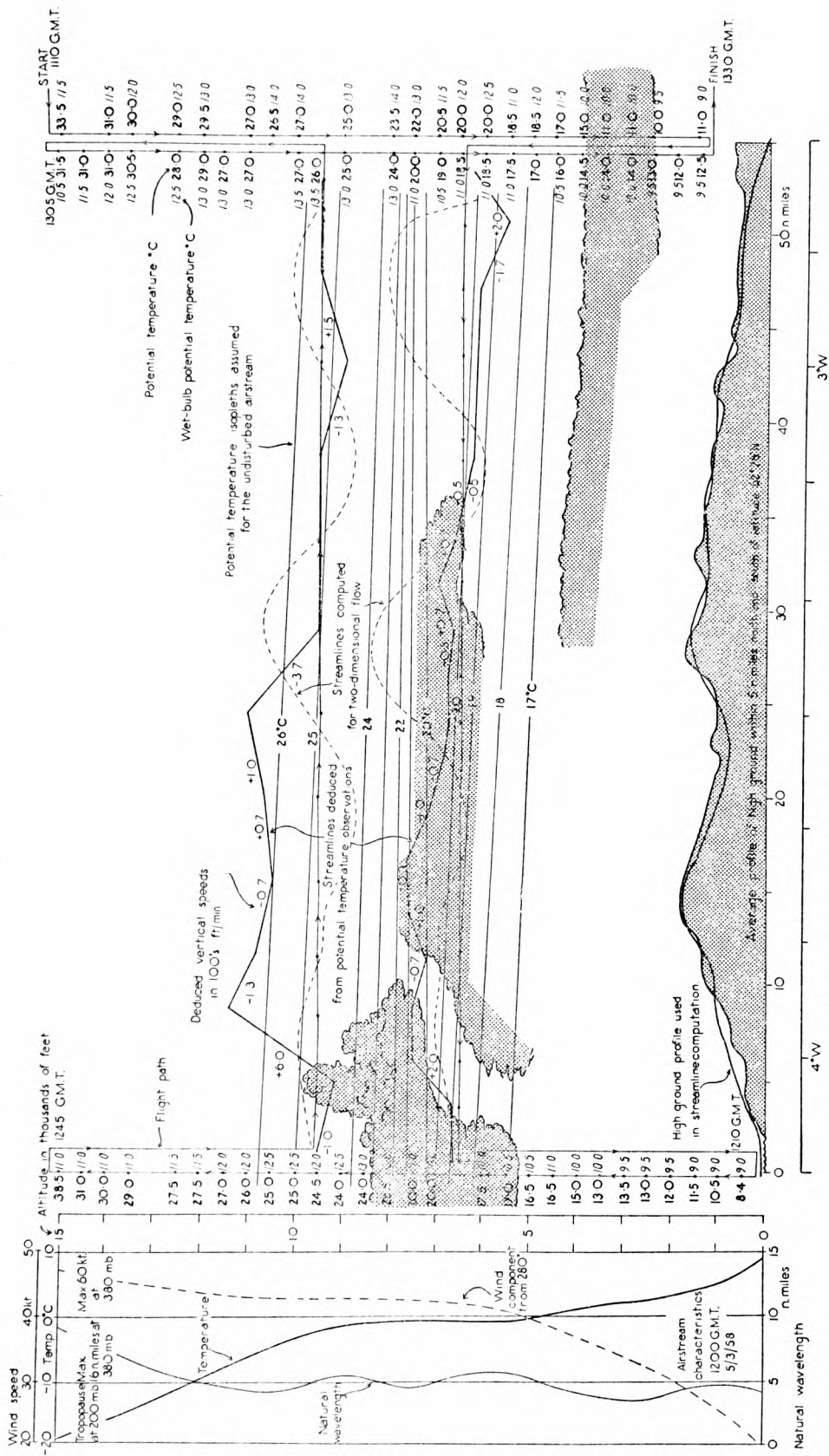


FIGURE 2(b)—FLIGHT ACROSS THE WELSH MOUNTAINS, 5 MARCH 1958

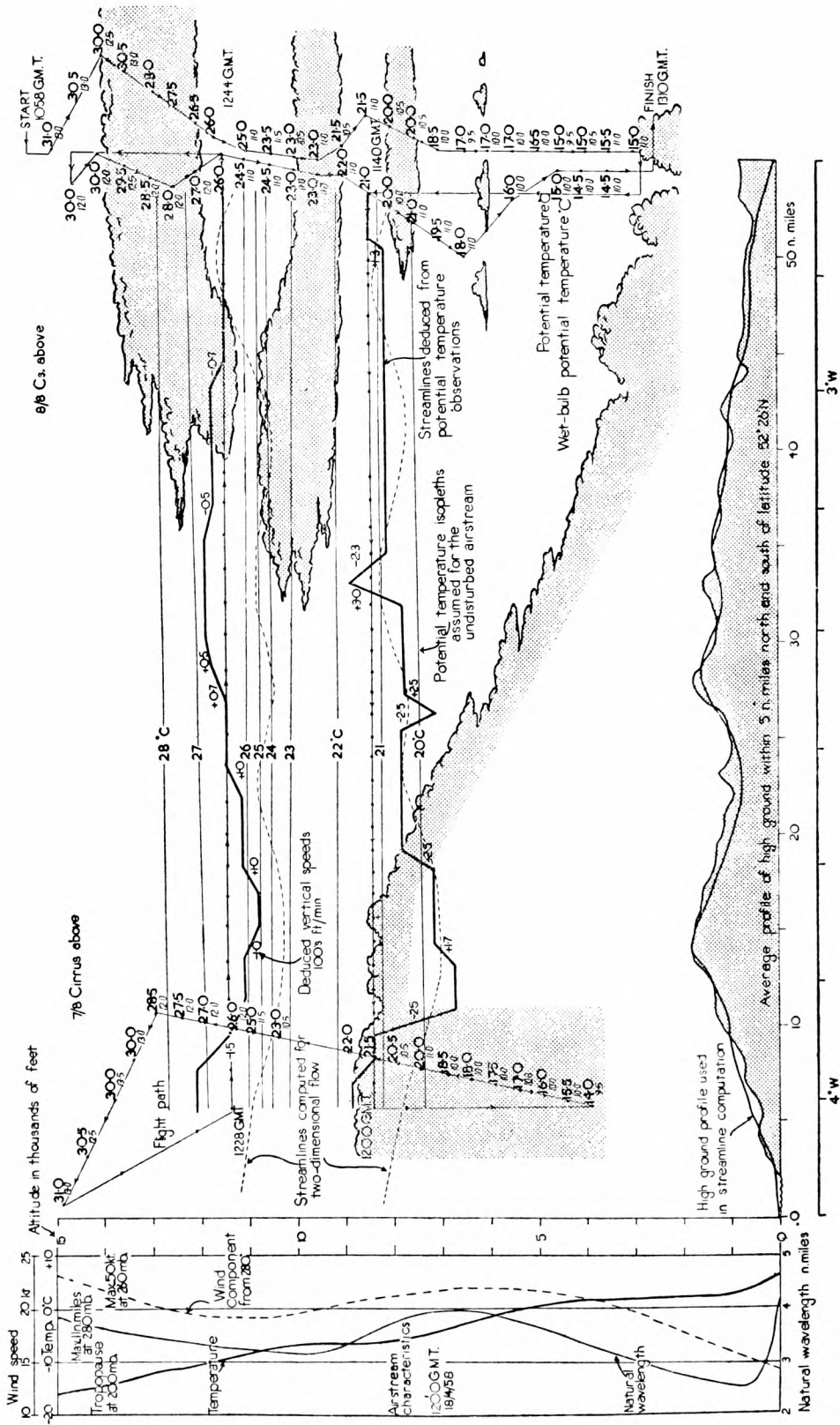


FIGURE 2(c)—FLIGHT ACROSS THE WELSH MOUNTAINS, 18 APRIL 1958

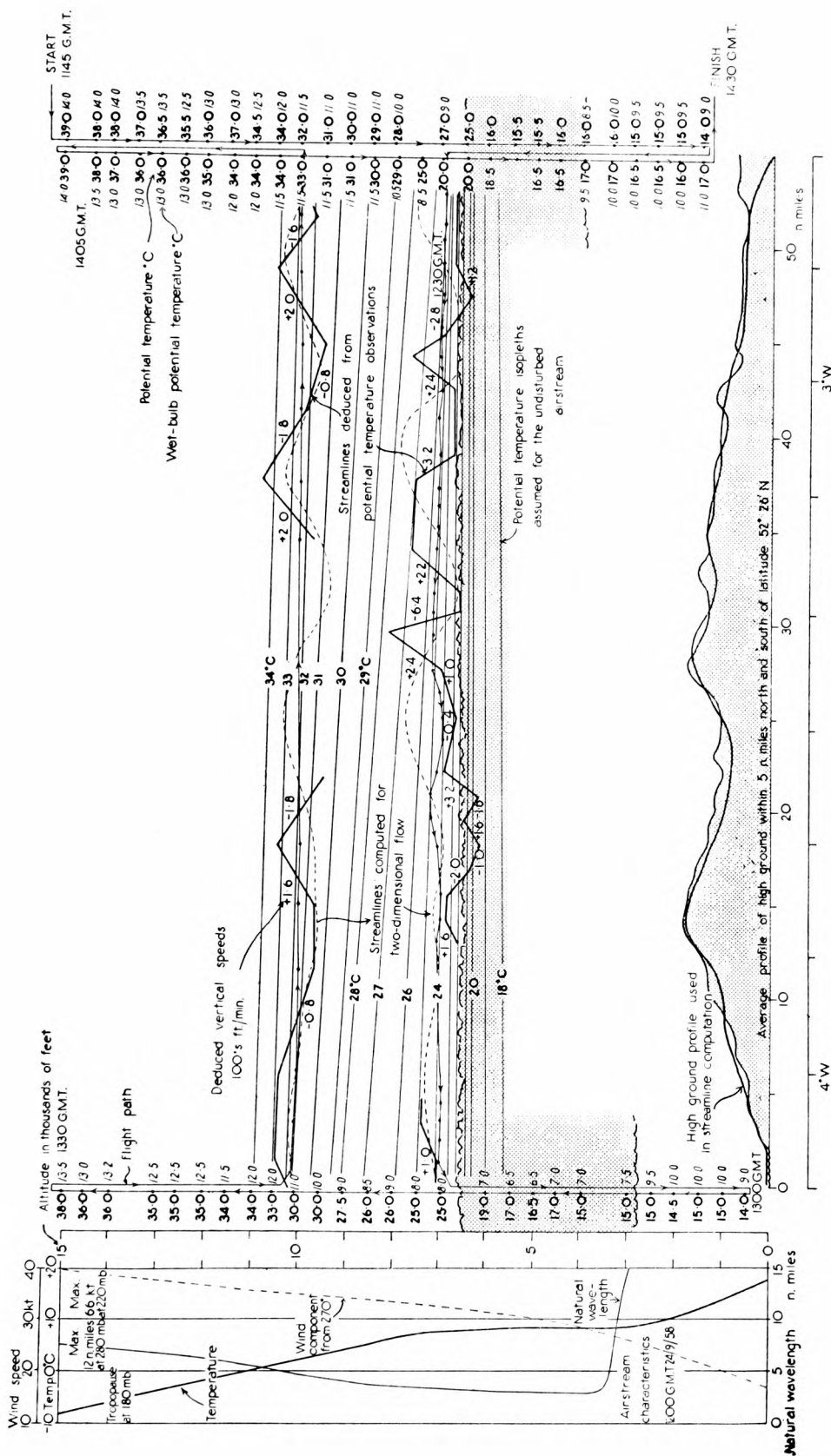


FIGURE 2(d)—FLIGHT ACROSS THE WELSH MOUNTAINS, 24 SEPTEMBER 1958

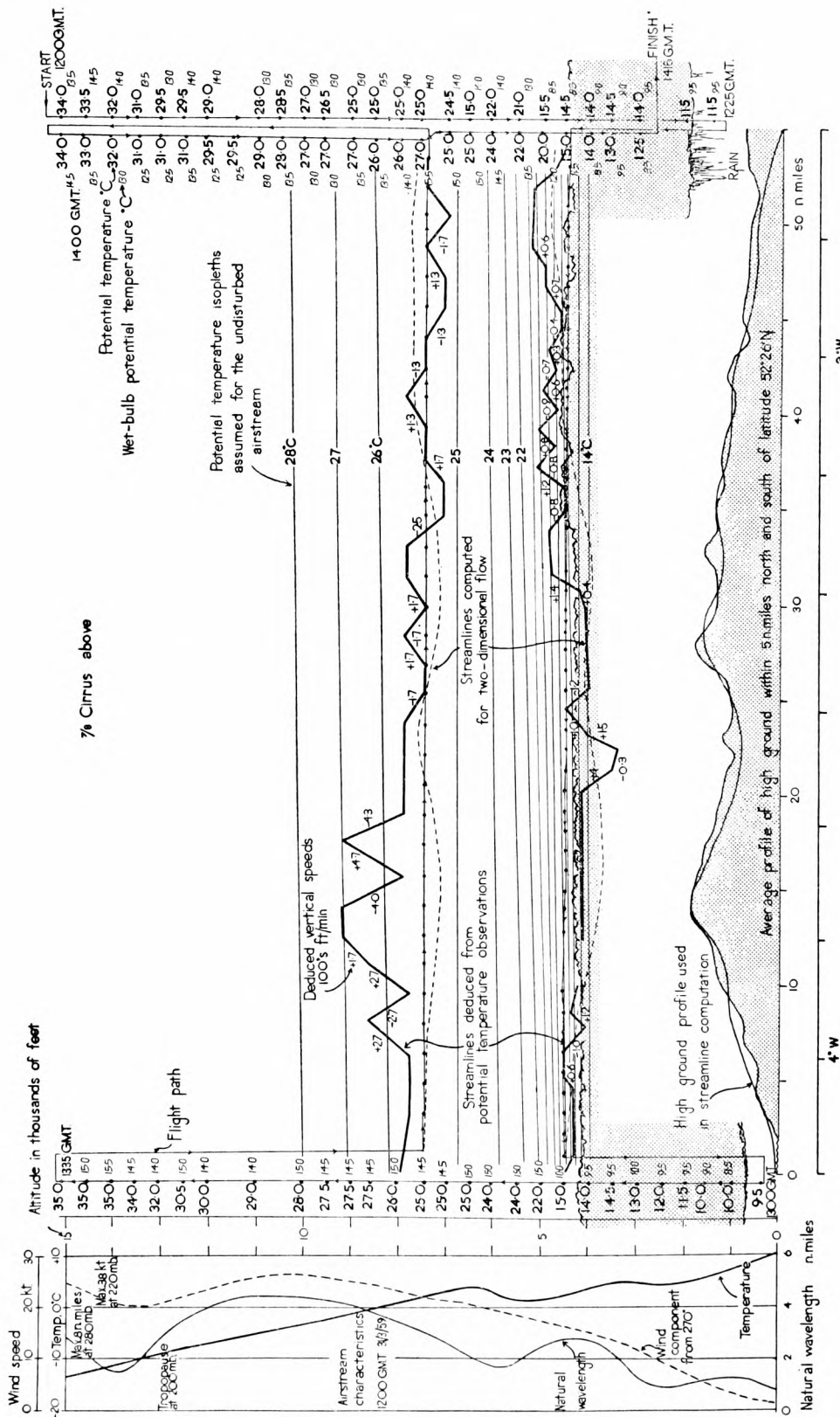


FIGURE 2(e)—FLIGHT ACROSS THE WELSH MOUNTAINS, 31 MARCH 1959

(iii) 18 April 1958.—On this occasion operational difficulties led to some distortion of the intended flight plan and truly vertical soundings over points X and Y were not obtained. But with the flight path as shown in Figure 2(c), it was still possible to deduce streamlines from the flight observations.

Allowing for the fact that the general level of a deduced streamline may be slightly incorrect, there is a broad but distinct similarity between the deduced and computed streamlines. Unfortunately the shape of these streamlines at low levels is not confirmed by the cloud structure but the apparent inconsistency is probably due to an advected thickening of the low cloud.

(iv) 24 September 1958.—Gaps in the deduced streamlines drawn in Figure 2(d) are due to temporary operational difficulties, but the observations are sufficient to reveal appreciable similarities between the deduced and computed streamlines.

(v) 31 March 1959.—Results on this occasion showed reasonable agreement between the deduced and computed streamlines, except for a section of the upper-level flow over the principal mountain ridge. As on a previous occasion the temperature observations suggested a marked rise while the computations produced a lowering of the streamline.

Conclusion.—This investigation is best regarded as a feasibility experiment to determine whether or not the operational method is practical or satisfactory, and although the results may provide material for discussion they must be viewed with considerable caution. There are several inconsistencies between the streamlines deduced from the potential temperatures and the cloud observations. Furthermore, the deduced vertical speeds appear to be excessive in places.

In view of these doubts the flight observations must not be regarded as a satisfactory check of the method of computing the flow over broad mountain ranges, but the calculated streamlines show such apparently excessive undulations that the theory of its application must also be open to considerable doubt.

Despite uncertainties in the details of the deduced streamlines, it is clear, however, that the air does not undergo a simple lifting as it crosses the hills; we find descent over the mountains on some occasions, and indeed theoretical study has called attention to mountain airflow characteristics of this nature, even though the details have not been accurately computed for regions immediately over the rugged terrain selected for this investigation.

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Appendix

The theoretical treatment

In order to make the theoretical problem tractable, it is convenient to treat the problem as two-dimensional in a vertical plane and to linearize the relevant equations, thus treating the problem as one of a disturbance in a uniform flow.

If the two-dimensional ridge is specified by the Fourier integral

$$\zeta_0 = \int_0^{\infty} F(k) \exp(ikx) dk, \quad \dots (1)$$

where ζ_0 denotes the height of the mountain ridge at a horizontal distance x from its crest, k is the wave number, and the sign $\stackrel{=}{=}$ means "equals the real part of", then the vertical displacement ζ_z of a streamline at any level z is given by

$$\zeta_z \stackrel{=}{=} \int_0^\infty \psi_k l^{ikx} F(k) dk, \quad \dots (2)$$

where ψ_k satisfies the equation

$$\frac{\partial^2 \psi_k}{\partial z^2} + (l^2 - k^2) \psi_k = 0 \quad \dots (3)$$

in which

$$l^2 = \frac{g}{u^2} \frac{1}{\theta} \frac{\partial \theta}{\partial z} - \frac{1}{u} \frac{\partial^2 u}{\partial z^2}, \quad \dots (4)$$

θ being the potential temperature, u the wind component across the ridge and g the acceleration due to gravity.

The solution of equation (3) requires the specification of suitable boundary conditions. The lower boundary condition is that the flow must follow the ground profile, but the choice of an appropriate condition to be applied to the upper limit of the integration has been the subject of controversy.

For the case in which l is independent of z , Corby and Sawyer have reasoned that the appropriate solution of equation (3) is

$$\psi_k = C \exp(i v z), \quad \dots (5)$$

where C is determined by the lower boundary condition and $v = \sqrt{l^2 - k^2}$, the positive value of the square root being taken if the flow is in the direction of increasing x .

For an individual Fourier component this solution corresponds to sinusoidal streamlines with the troughs and ridges inclined upstream. If the width of the mountain ridge is large compared with $1/l$, then the significant Fourier components have values of k which are small compared with l and the solution of equation (3) is practically independent of k .

The preceding treatment can be extended to an airstream in which l varies with height, by inserting a region with $l=a$ constant above a level which is chosen sufficiently high to leave the solution unaffected in the lower levels. The solution in this upper region of constant l is then known to have the form $\psi_k = C \exp(i v z)$ and the condition

$$\frac{\partial \psi_k}{\partial z} = i v \psi_k \quad \dots (6)$$

can be used as a boundary condition at any level in the region.

If the vertical distribution of wind speed and potential temperature are known, numerical integration can be used to obtain solutions of equation (3) subject to the upper boundary condition of equation (6) and the ground-level condition $\psi_k = F(k)$ for $z = 0$. For a broad mountain ridge v in equation (6) is independent of k and the solution has the same variation with height for all values of k . Thus it is possible to compute the pattern of streamlines for two-dimensional flow of any specified airstream over a broad mountain ridge.

DUST HAZE IN RELATION TO PRESSURE GRADIENTS

By F. BURNS

Introduction.—During the period November to April, north-easterly winds on the eastern side of the semi-permanent anticyclone over North Africa sometimes carry dust into northern Nigeria, and in the resulting haze, known as Harmattan haze, visibility can be reduced to 100 yards. Hamilton and Archbold¹ associate this dust haze with the post cold frontal conditions which prevail when cold air sweeps southwards behind Mediterranean depressions. They stress the role of strong convective activity in the cold air in lifting dust from the ground.

Forecasters at Kano have found the tracking of cold fronts over the desert to be exceedingly difficult, and of little practical use in forecasting haze. It is general practice to forecast haze for northern Nigeria after it has been reported at one of the few desert stations to the north-east—usually Faya-Largeau (international index number 64:753)—when the surface and low-level winds are from a favourable direction. The forecast then involves estimating its time of arrival in Nigeria and its intensity.

However, because of communication difficulties, vital observations from desert stations are sometimes missing or received corrupt at Kano, and it is consequently desirable to be able to link occasions of occurrence of dust with general synoptic developments. This note presents the results of an investigation into the relation between the presence of dust in the desert and the pressure gradient, which can usually be obtained with reasonable accuracy from synoptic charts.

Pressure gradients and dust at Faya-Largeau.—Dust at Faya-Largeau is often associated with a strong surface pressure gradient across the desert. Figure 1, the chart for 0600 GMT on 13 March 1958, shows a typical example of a favourable pressure pattern. To investigate this association quantitatively, pressure differences between stations Sebha (60:785) and Abechar (64:756) at 0600 GMT for each day of the period 1 December 1957 to 1 April 1958 were extracted and compared with the visibilities reported from Faya-Largeau at main and intermediate synoptic hours (0001, 0300, 0600, 0900, 1200, 1500, 1800 and 2100 GMT) for the same period. For a number of days, pressures were not available from Sebha, and for these days its pressure was estimated from surface pressure charts.

The visibility at Faya-Largeau will be taken to be characterized by the smallest of the visibilities for that day. On the vast majority of occasions this was given by the 0900 GMT observation. Two categories of haze will be considered: "dust haze" when the visibility is less than two kilometres, and "slight haze" when the visibility is between two and ten kilometres.

Table I shows the number of occurrences of haze with specified categories of visibility and pressure difference (Sebha minus Abechar).

It will be seen from this table that on all 22 occasions when dust haze occurred there was a relatively strong pressure gradient across the desert. The pressure difference, Sebha minus Abechar, was invariably greater than 10 millibars on these 22 occasions. On the other hand, there were 21 days when the pressure difference of over 10 millibars gave rise to only slight haze, and a further 22 days when no haze was reported.

TABLE I—OCCURRENCES OF VISIBILITY (IN KILOMETRES) FOR SPECIFIED PRESSURE DIFFERENCES

Pressure difference <i>mb</i>	Dust haze					Slight haze		>10.0
	≤0.1	0.2	0.3-0.4	0.5-0.9	1.0-1.9	2.0-5.0	6.0-10.0	
	<i>number of occurrences</i>							
20.0-18.0	3	2				1		
17.9-16.0	2	1				2	2	2
15.9-14.0		1	2	2	1	3	3	1
13.9-12.0		2				1	5	8
11.9-10.0		1	2	1	2	1	3	11
9.9- 5.0						4	10	36
4.9- 0.0						1	4	28
<0.0								3

If a period in which the pressure difference between Sehba and Abechar is at least 10 millibars on successive days is termed a spell, then the distribution of spell lengths is shown in Table II. Under (a) is shown in successive rows, for the various spell lengths, the number of occasions on which dust haze first appeared on the 1st, 2nd, 3rd and 4th day of the spell; similar information for the first occurrence of slight haze is given under (b).

TABLE II—DISTRIBUTION OF SPELL LENGTHS

		Spell length in days							
		1	2	3	4	5	6	7	8
		<i>number of occurrences</i>							
(a) First occurrence of dust haze	Total	5	5	4	2	2	2	0	1
	1st day	0	0	2	0	1	0	0	0
	2nd day		3	1	0	0	1	0	1
	3rd day			0	1	1	1	0	0
	4th day				1	0	0	0	0
(b) First occurrence of slight haze	1st day	1	1	2	1	1	0	0	0
	2nd day		3	2	1	0	2	0	1
	3rd day			0	0	1	0	0	0

It follows from Table II that if (assuming the absence of present weather reports from Faya-Largeau throughout the period) dust haze were forecast at Faya-Largeau on the second successive day on which a pressure difference of at least 10 millibars existed between Sehba and Abechar, the results in Table III would have been obtained.

TABLE III—FORECASTS OF DUST HAZE AT FAYA-LARGEAU ON SECOND SUCCESSIVE DAY OF PRESSURE DIFFERENCE

	No. of forecasts
Total	16 (15)
Correct both as regards occurrence and the day of occurrence of dust haze	6 (7)
When the occurrence of dust haze preceded the forecast	3 (3)
When the forecast time preceded the dust haze	4 (3)
When no dust haze was reported during the spell	3 (2)

If a pressure difference between Sehba and Abechar of at least 10.5 millibars is required (instead of 10 millibars) then the results for this set of data are slightly improved; the results are shown in brackets.

One use of this method was well illustrated on 22 March 1958. The differences on the 21st and 22nd (10.7 and 12.1 millibars) indicated a strong risk of dust haze at Faya-Largeau on the 22nd. On this day, however, wind and weather observations were not received at Kano from that station from 0001 GMT to

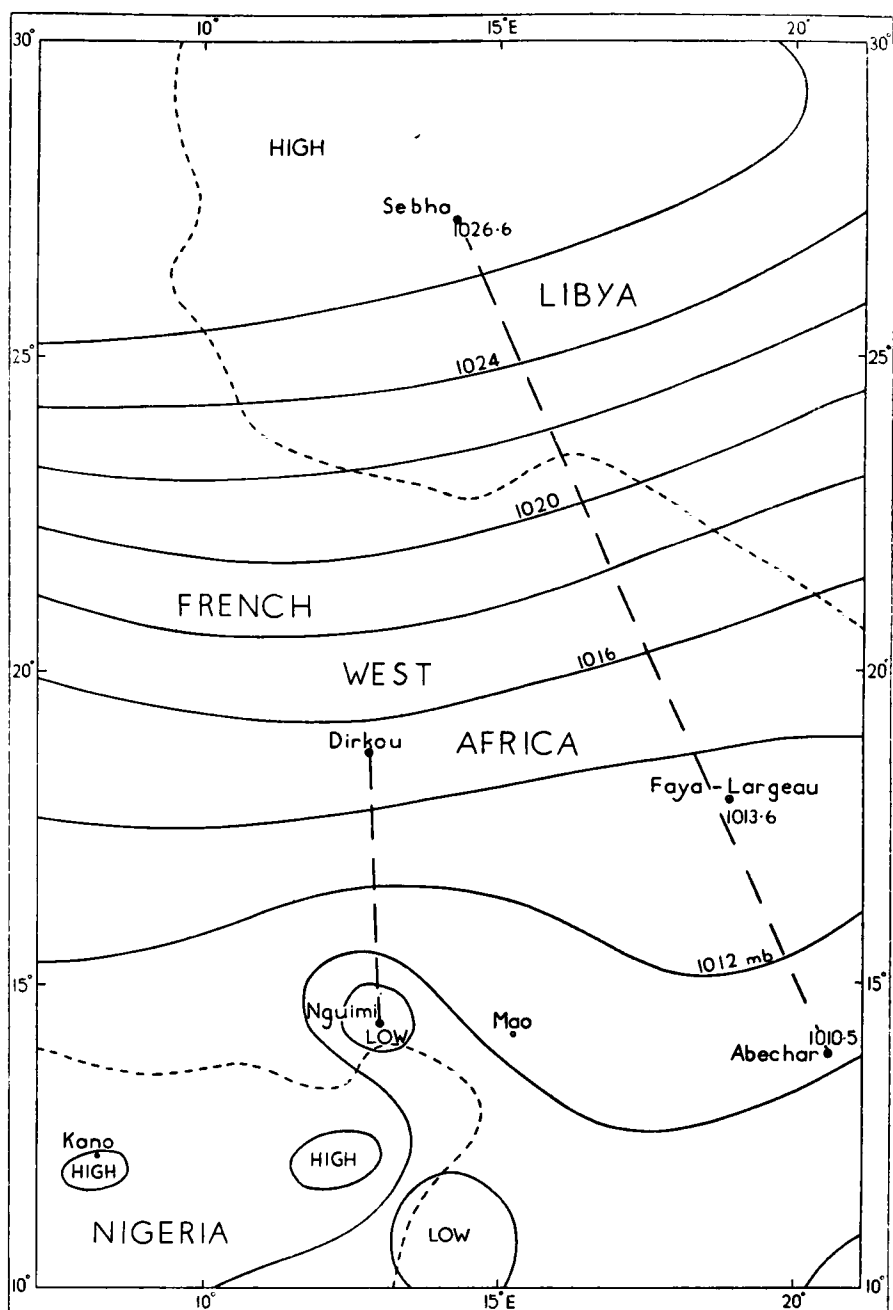


FIGURE 1—SURFACE SYNOPTIC CHART FOR 0600 GMT, 13 MARCH 1958

1200 GMT inclusive. The risk of dust haze at Kano on the morning of the 23rd was, however, put in forecasts on the strength of those differences. Dust haze affected Kano at 0500 GMT on the 23rd and dust haze at Faya-Largeau on the 22nd was later confirmed.

Persistence of haze at Faya-Largeau.—Table IV shows the distribution of visibilities at Faya-Largeau (a) on the first day of a spell (all spells included); (b) on the second day of a spell (spells of two days or more included); (c) on the third day of a spell (spells of three days or more included).

TABLE IV—DISTRIBUTION OF VISIBILITIES AT FAYA-LARGEAU

	Visibility in kilometres						
	0·1	0·2	0·3-0·4	0·5-0·9	1·0-1·9	2·0-5·0	6·0-10·0
	number of occasions						
(a)	0	1	1	1	0	0	2
(b)	0	3	2	1	1	3	4
(c)	3	1	1	1	1	2	2

Out of a total of 22 days when a pressure difference of at least 10 millibars existed and yet no haze was reported at Faya-Largeau, 18 were either the first or second day of a spell. It follows that, once haze has occurred, it is likely to persist as long as the pressure gradient remains high. Table I shows that when the pressure difference, Sebha minus Abechar, falls below 10 millibars visibility is likely to improve rapidly.

Arrival of haze in Nigeria.—If haze is reported or suspected in the Faya-Largeau area it will usually affect parts of north Nigeria within 24 hours. Dust haze reports at Faya-Largeau generally precede dust haze in Nigeria, though in Nigeria the dust haze is usually less intense, because of the effect on the dust of gravity, diverging winds aloft and convection. Similarly, slight haze at Faya-Largeau will generally result in slight haze in Nigeria. At the beginning and end of the dry season, however, the winds aloft over north Nigeria may be all southerly and keep the haze in the desert.

Dust haze in the Dirkou-Nguimi region.—Faya-Largeau is about 370 miles from the next station, Mao (64:701), in the direction of Kano, and about 850 miles from Kano itself. Haze often affects Kano within 24 hours of being reported in the Faya-Largeau area; and for this to be possible, dust must be rising in the vast area between Faya-Largeau, Mao and Dirkou (61:017).

On most occasions, dust haze at Kano has been preceded by dust haze at Faya-Largeau. Two instances in the season studied when this was not so were 13 and 17 March 1958, when only slight haze was reported at Faya-Largeau. Visibilities in north Nigeria were good on the 13th, but deteriorated on the 14th; they had improved again on the 17th but deteriorated on the 18th.

In an attempt to find a similar gradient criterion to the west of Faya-Largeau which might account for these unexpected deteriorations, extractions of 0600 GMT surface pressures were made for Dirkou and Nguimi (61:049). These stations were chosen because they lie more or less across the favourable pressure pattern as Figure 1 shows.

It was found that the pressure differences, Dirkou minus Nguimi, on the two dates above were abnormally high, 8·2 and 7·0 millibars respectively. The average value for this difference throughout the season investigated was 3·9 millibars. There were a few other occasions when this pressure difference was 7·0 millibars or more, but these were not enough to formulate a rule.

Conclusion.—It has been shown that in the absence of observations from desert stations, the occasions when dust haze is present can usually be inferred from the surface pressure pattern.

Acknowledgement.—The author is indebted to the Director, Meteorological Services, Nigeria, for permission to publish this article. It was initially published as a Technical Note of the British West African Meteorological Services.

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THE OCCURRENCE AND PREDICTION OF COLD NORTHERLY-TYPE SPELLS OVER THE BRITISH ISLES IN WINTER

By M. K. MILES, M.Sc., and G. G. LEAF, B.Sc.

Summary.—Cold spells of at least two days' duration over the British Isles with winds from the northern quadrant have been defined by reference to the thickness of the layer 1000–500 millibars over southern England. There were 34 such spells in the months November to March, inclusive, during the ten years 1950–59. Of these, 27 were preceded by the occurrence of a "southerly" flow of a certain minimum dimension located on average about 55° – 60° longitude upwind. This minimum size of the "southerly" flow appears to be the factor which ensures that the amplifying thermal trough associated with the cold spell remains open for at least 48 hours. The position of surface anticyclones and the location and direction of the flow downwind of the "southerly" have to be taken into account to enable a useful prediction of these cold spells to be made 24 to 48 hours before their onset.

Introduction.—Winter cold spells over the British Isles arise in three ways:

- (i) In areas of light winds associated with an almost stationary anticyclone.
- (ii) With persistent easterly winds, usually associated at some stage with an anticyclone over Scandinavia.
- (iii) With airstreams between north-east and north-west.

The first type is quite rare: it requires a special combination of anticyclone and absence of stratocumulus layer. Occurrences of the second type are estimated to average about two per year, and in November do not bring temperatures appreciably below the normal.

A cold spell defined by the occurrence of low thickness (1000–500 millibars) is more likely to be types (ii) and (iii) than type (i). Accordingly, for the purpose of this study a cold spell was said to have started when the 5280-metre (1000–500 millibar) thickness line moved southwards to reach 50° N within the longitude zone 10° W to 5° E. It was required to remain at or to the south of this latitude on two successive 1200 GMT (1500 GMT before 1957) thickness charts. (For November the 5340-metre line was used instead of that for 5280 metres.) A spell was said to have ended when the defining thickness line moved north of 50° N or out of the longitude zone. For the five months November to March, inclusive, of the ten years 1950–59, 34 spells occurred according to this definition. All cases where the defining thickness line moved into the British Isles from the east were excluded so that these 34 cases represent occurrences of type (iii).

A study of easterlies of at least four days' duration described by Miles¹ revealed 20 in the twelve years 1946–57*. Belasco² recorded 118 days of winds between north-east and south-east at Kew during the winter compared with 165 days of winds between north-west and north-east during the years 1931–45. Belasco² also states that spells of polar continental air (that is, easterlies) tend to be rather longer than spells with winds between north-west and north-east so that it may be concluded that cold spells from the northern quadrant are considerably more frequent than those from the eastern quadrant in winter.

Distribution and duration of the spells.—Table I shows the distribution by months and the durations of the northerly-type spells.

The frequency of occurrence by months may be a little affected by using the same thickness line (5280 metres) for December to March. The number in December and March may be somewhat less than it should have been had a more appropriate value, say 5310 metres, been used. The smaller number in November than in January and February probably represents a significant difference.

* Several of these easterly spells affected only southern England.

TABLE I—DISTRIBUTION AND DURATION OF NORTHERLY-TYPE COLD SPELLS OVER THE BRITISH ISLES, 1950-59, AND NORMAL THICKNESS AT 50°N, 00°W

		Duration in days					Normal thickness 1000-500 millibars at 50°N, 00°W in metres
	2-3	4-6	7-9	10 or more	Totals		
November	2	1	0	0	3		5420
December	1	1	2	0	4		5390
January	4	4	3	0	11		5370
February	4	3	1	1	9		5360
March	3	4	0	0	7		5390
Totals	14	13	6	1	34		

Temperature anomaly at Kew during the spells.—The departure of the maximum and minimum temperatures from the monthly means was worked out for Kew. It is common experience that even after an increase of thickness has occurred surface temperatures remain depressed for a further 12 to 24 hours during the winter months. Accordingly the maximum and minimum values for the day after the spell have been included in determining the mean temperature of the spell. In most cases it is clear from the data that the low temperatures do continue for a further day. This should clearly be kept in mind when considering the mean length of the spells.

TABLE II—MEAN TEMPERATURES AND ANOMALIES AT KEW DURING COLD SPELLS, 1950-59

	November		December		January		February		March	
	max.	min.	max.	min.	max.	min.	max.	min.	max.	min.
	°F		°F		°F		°F		°F	
Mean value	44.3	36.5	38.0	32.2	39.1	30.8	40.7	33.5	42.8	31.9
Mean anomaly	-4.9	-4.2	-6.5	-5.5	-5.0	-6.3	-4.5	-3.0	-7.6	-5.9

The mean values and anomalies for each month are given in Table II, and, for comparison, similar data based on Kew temperatures for the period 1931-45 determined by Belasco² for airstreams between north-west and north-east are given in Table III.

TABLE III—MEAN TEMPERATURES AND ANOMALIES AT KEW FOR AIRSTREAMS BETWEEN NORTH-WEST AND NORTH-EAST (AFTER BELASCO)

	November		December		January		February		March	
	max.	min.	max.	min.	max.	min.	max.	min.	max.	min.
	°F		°F		°F		°F		°F	
Mean value	45.2	36.7	40.7	32.7	38.2	30.7	41.0	32.2	46.5	34.2
Mean anomaly	-4.0	-4.0	-3.8	-5.8	-5.9	-6.4	-4.2	-4.3	-3.9	-3.6

The rather larger anomalies for December and March in Table II are possibly due to one or two less severe spells being eliminated by using the 5280-metre criterion. The small values for February are somewhat surprising. It may be that a thickness value a little less than 5280 metres is more appropriate to this month. The overall mean anomalies of the maximum and minimum temperatures are -5.6° and -5.1°F respectively.

Synoptic evolution associated with the spells.—The spells usually began with the surface airflow over the British Isles veering to a direction between north-west and north-east. This was often associated with the development of a surface anticyclone just west of Iceland as in Figure 1 or the development of a strong anticyclonic col between an anticyclone north of the Azores and one over Greenland. Associated with these developments there was either a deepening depression in the North Sea or marked trough development southwards into Europe.

Almost all of the spells were associated with a moderate or large amplitude contour ridge at 500 millibars over the East Atlantic. Just before the spell began this was most often between 30° and 40° W, moving to about 20° W by the second day of the spell.

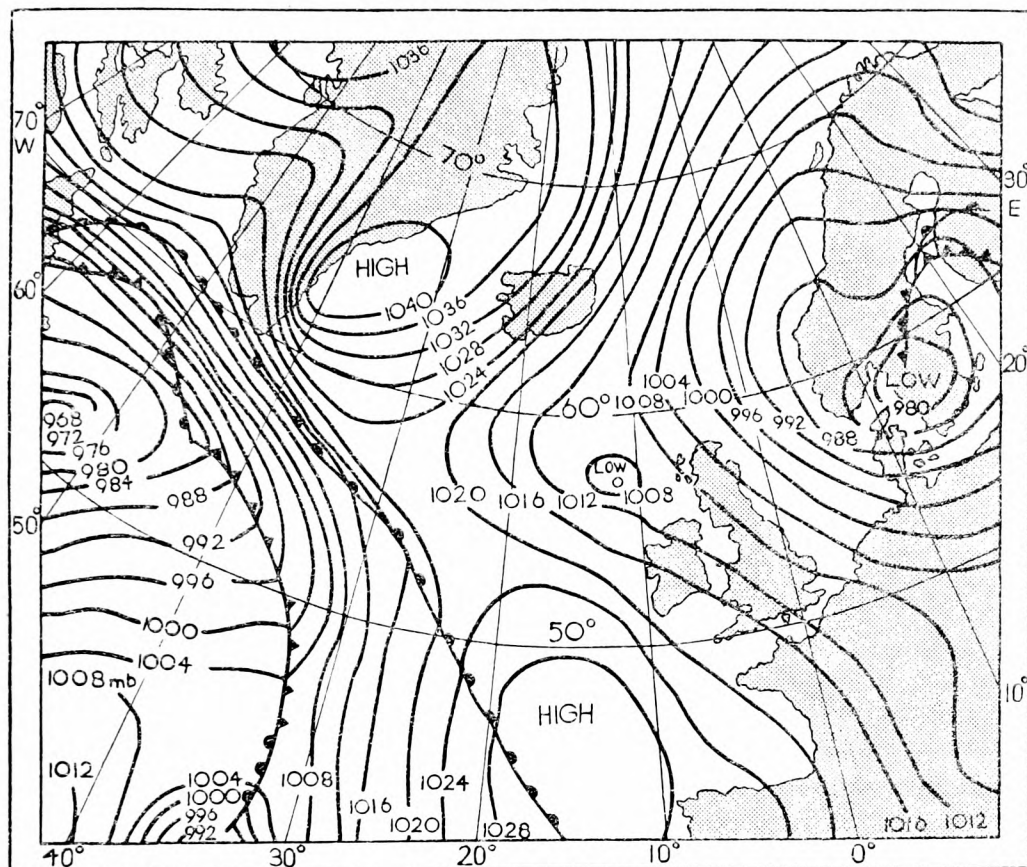


FIGURE 1—SURFACE CHART FOR 1200 GMT, 3 JANUARY 1959

Tropospheric flow patterns preceding the spells.—It seemed probable from earlier data on the growth of contour ridges given by Miles³ that the growth of these ridges would be preceded by the occurrence of predominantly southerly flow some 20° – 30° longitude farther west some 24 hours earlier. In fact 27* out of the 34 cold spells were preceded by a flow which had the following characteristics:

- (i) Mean direction was between 160° and 220° .
- (ii) The mean speed (measured over 400 nautical miles) was at least 40 knots.
- (iii) The length was at least 500 nautical miles and the width at least 400 nautical miles.
- (iv) The longitude of the centre of the flow was located between the limits 40° and 70° W (modal value about 55° W), and the latitude between 45° and 65° N.

With six of the remaining seven cold spells there was a marked contour confluence at 500 millibars over the Atlantic 24–48 hours before the onset of

*With two of the remaining seven cases there was a “southerly flow” but its length was about 100 nautical miles below the minimum value of 500 nautical miles.

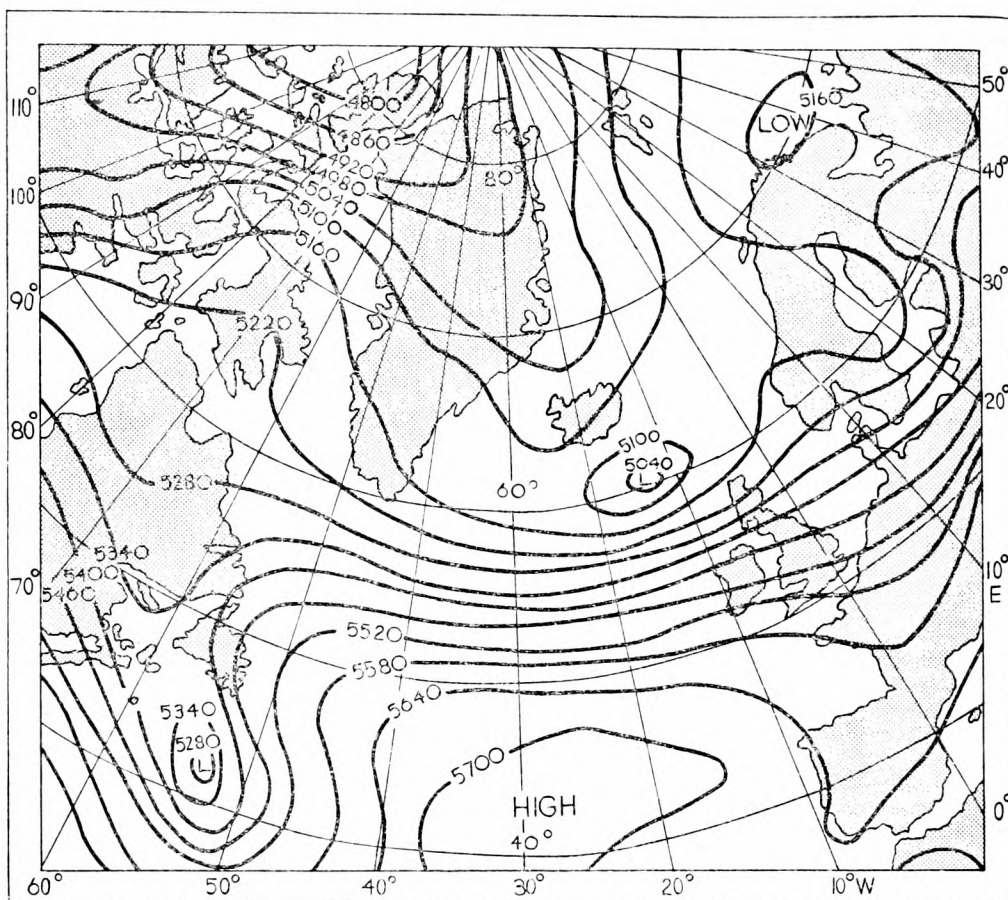


FIGURE 2—500-MILLIBAR CONTOURS FOR ABOUT 1200 GMT, 1 JANUARY 1959

the spell. The entrance to the maximum flow was usually located between longitudes 30° and 45° W, and north of 50° N. The usual evolution involved a substantial rise of contour height in the confluent region leading in about 24 hours to a ridge near or to the east of the initial position of the confluence. There was occasionally a “southerly” current to the west of the confluence and Figure 2 shows a development in which both features were present 48 hours before the onset of a cold spell, shown in Figure 3.

“Southerly” flow in the middle troposphere.—With trough extensions following inflexion points, as described by Miles³, the amplified trough frequently did not remain open for 48 hours, so that the condition for a cold spell as defined here was not satisfied. It is a reasonable assumption from the results described in the previous section that a certain minimum length and width of the “southerly” ensures the persistence of the cold outbreak.

Accordingly all southerly currents for the ten years 1950–59 satisfying the four criteria in the previous section were studied. There were, besides the 27 already mentioned, 102 others. Out of this total of 129 there were 17 per cent in which the model of ridge growth and trough extension failed entirely and 18 per cent in which the 5280-metre line of the extended thermal trough did not reach as far south as 50° N. Of the 83 per cent where there was some extension about 50 per cent were east of the British Isles and 15 per cent were to the west.

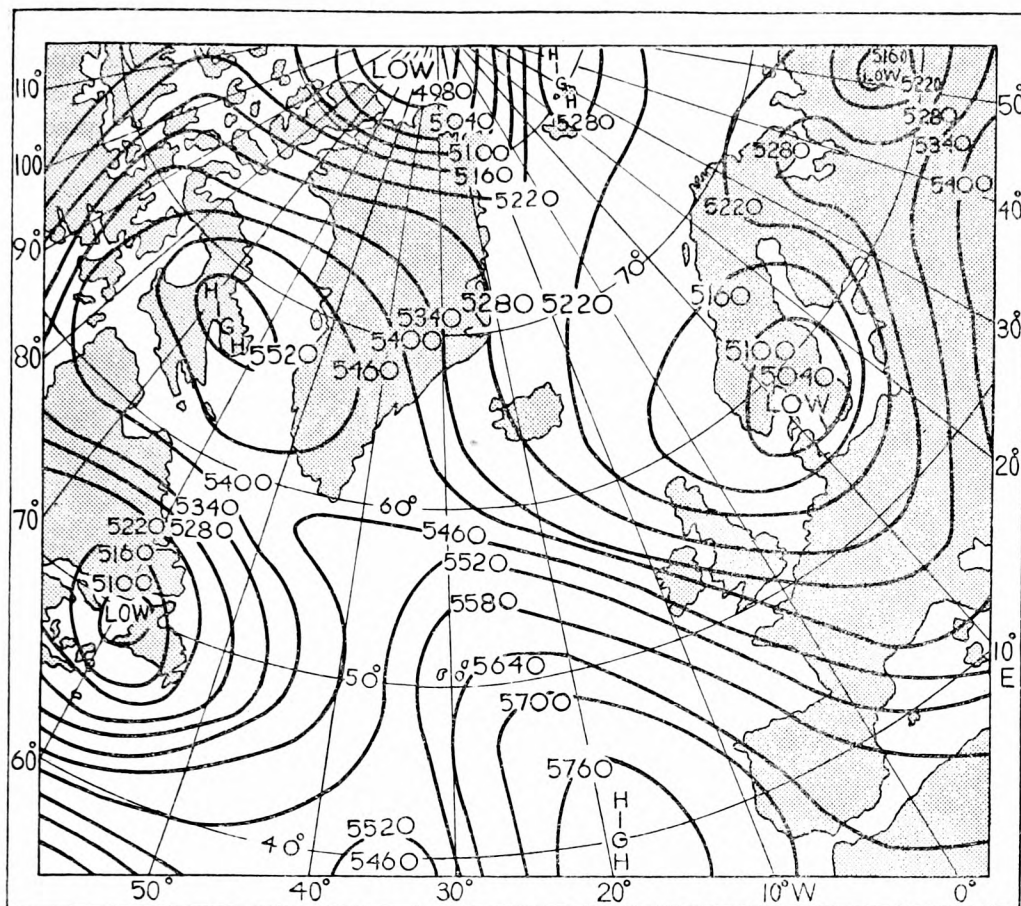


FIGURE 3—500-MILLIBAR CONTOURS FOR ABOUT 1200 GMT, 3 JANUARY 1959

The important question now to be considered concerns the factors which determine the longitude of the cold outbreak, but before doing this it may be useful to indicate three circumstances which were thought to be unfavourable to the working of the model.

They are:

- (i) A separation of 35° longitude or less between the two troughs immediately upwind of the southerly.
- (ii) A strong west-south-westerly flow to the south-south-west of the southerly.
- (iii) A comparable "southerly" flow within about 55° longitude downwind.

Factors determining the location of cold outbreaks following the occurrence of "southerly" flows

(a) *The location of surface anticyclones.*—An anticyclone centred in the hatched area shown on Figure 4 when the southerly first appears constitutes a favourable condition for a cold outbreak over the British Isles. Equally an anticyclone in the longitude zone 10°W to 20°E constitutes an unfavourable situation.

Since there was usually an anticyclone some 20° to 30° longitude downwind from the "southerly" flow another one in the zone 10°W to 20°E was often the eastern member of a pair. When the separation of the two cells was less than some 50° – 60° longitude the trough between them showed a marked tendency to weaken and move quickly across until it was some 10° – 20° longitude to the east of the second cell and then intensify. This almost invariably meant that the

cold outbreak was east of the British Isles. However, if the eastern member of the pair was at a lower latitude than the western member (the less common situation) the trough extension occurred either between the two centres or in the zone occupied by the eastern member which had by this time collapsed or moved southwards.

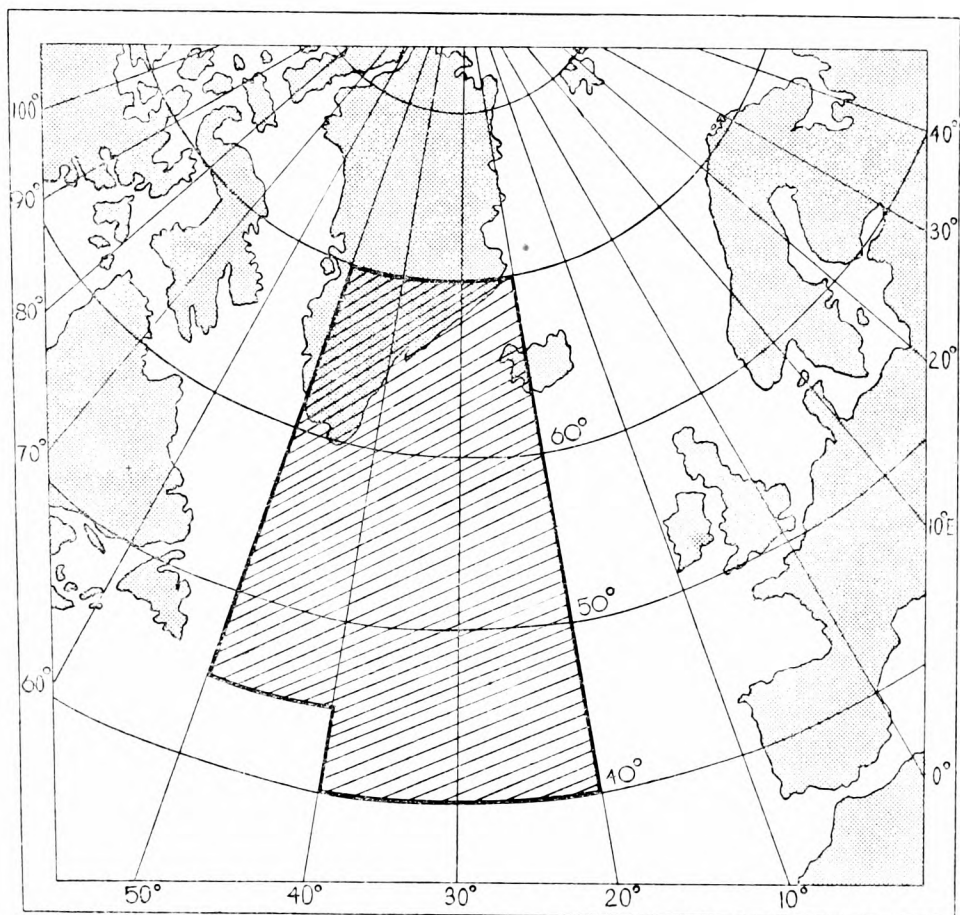


FIGURE 4—MOST FAVOURED AREA FOR ANTICYCLONES ASSOCIATED WITH COLD NORTHERLY SPELLS OVER THE BRITISH ISLES

(b) *Tropospheric flow downwind of the southerly.*—As mentioned earlier, the model associated with these spells involves the growth of a tropospheric ridge to the west of the British Isles. It was found that the direction and location of the tropospheric flow downwind of the ridge (or the incipient ridge) had to be taken into account to determine (i) whether there would be a strong cold outbreak and (ii) whether it would be over the British Isles or not.

The centres of the currents at 500 millibars were found to be mostly located between 20° and 40° longitude downwind of the southerly. Measurements of the directions of the flow at the centre at the time of the first appearance of the southerly showed that for the 29 occasions preceding cold spells over the British Isles this was only once less than 270°, and three days elapsed before the cold spell in this case.

Moreover, of thirteen cases when the direction of the flow was 310° or more and it was centred west of 35°W only one was followed by a cold spell over the

British Isles. For directions between 270° and 300° the flow should not be centred appreciably east of 30°W otherwise the cold outbreak is likely to be east of the British Isles.

The direction of the flow also appears to affect the length of the interval between the appearance of the southerly and the onset of the cold spell. Table IV shows the distribution of these intervals for a division of the directions into two classes (the two cases with southerlies about 400 nautical miles long have been included).

TABLE IV—INTERVAL BETWEEN APPEARANCE OF “SOUTHERLY” FLOW AND ONSET OF COLD SPELL OVER THE BRITISH ISLES IN RELATION TO FLOW DOWNWIND OF SOUTHERLY

	Interval in days				
	1	2	3	4	5
	number of cases				
Direction $< 310^{\circ}$	3	10	2	0	1
Direction $\geq 310^{\circ}$	9	4	0	0	0
All cases	12	14	2	0	1

This flow can be thought of as the one which veers during the growth of the ridge and advects cold air southwards, so that with an average rate of veering of about 30° per day, the two-day interval for initial directions of 300° or less is not surprising. Of course, the interval will also depend on the initial latitude of the cold source (that is, 1000–500-millibar thickness lines less than 5280 metres), but this effect has not been examined in this study.

The latitude of the centre of the flow appeared to have some effect on the longitude of the cold outbreak. The higher the latitude the farther eastwards was the outbreak, other factors being equal.

(c) *Optimum combination of these factors for cold spells.*—When a southerly has appeared in the defined area, a cold outbreak over the British Isles is most likely when the following four conditions are satisfied:

- (i) A surface anticyclone (1020 millibars or more) in the hatched area on Figure 4.
- (ii) No other anticyclone within 60° longitude to the east of this one unless it is at a lower latitude.
- (iii) The direction of the main flow at 500 millibars downwind of the southerly must be $\geq 270^{\circ}$.
- (iv) If the direction of this flow is greater than 310° then it must not be west of 35°W .

The result of applying these conditions to the 129 cases available is shown in Table V. This promises a fairly useful amount of success in distinguishing cold from not cold, though it might be unsatisfactory for some purposes to miss about 40 per cent of all the cold spells (that is, seven preceded by southerlies and seven which were not).

TABLE V—OCCURRENCE OF COLD SPELLS IN RELATION TO SPECIFIED CONDITIONS

		Cold over British Isles		Cold not over British Isles	
		number of cases			
Conditions satisfied for cold spell	...	20	11		
Conditions not satisfied	... ..	7	91		

Forecasting these cold spells.—These northerly-type spells account for more than a half of the severe winter weather over the British Isles and it may

be a matter of economic importance to provide a warning of their onset. The results given in this study appear likely to provide at least 24 hours' warning of the occurrence of just over a half of these spells. The likelihood of an indication not being followed by a severe spell would in practice probably be somewhat greater than 35 per cent.

In cases where the model shows no signs of working 24 hours after the appearance of a "southerly" and this still satisfies the conditions, it is possible that a fresh forecast using the current values of the variables might give more accurate results, especially when the anticyclone is outside the prescribed area on the first occasion and the flow downwind of the "southerly" is $<270^\circ$. This has not been done in this study: each "southerly" has been considered only on the day it first appeared east of 75°W .

In eighteen cases there were ridges of high pressure extending south from Greenland. These have been disregarded in the above analysis: in fact five of them preceded cold spells and thirteen did not. They appear not to play a decisive role, though synoptically they would seem to be important elements in this kind of evolution.

Conclusions.—A definition of cold spells in terms of the thickness (1000–500 millibars) over the British Isles fairly effectively covers those where the cold comes in from between north-west and north-east. Four-fifths of these spells followed the occurrence of a predominantly "southerly" flow at 500 millibars centred on average about 55° longitude west of the British Isles. Only a quarter of all "southerlies" of a certain strength and size between longitudes 40° and 75°W gave cold spells over the British Isles (the majority of the cold outbreaks were east of 5°E).

Anticyclones centred between longitudes 50° and 20°W were found to be a second requirement, but there should not be another anticyclone at the same or a higher latitude within 60° longitude to the east of it. A consideration of the direction and position of the main flow downwind of the "southerly" can give some indication of whether the cold outbreak is likely to be west or east of the British Isles, and of the interval before its onset.

The most favourable combination of these factors would have correctly indicated 60 per cent of all cold northerly-type spells over the ten years 1950–59 (inclusive). Sixty-five per cent of the indications of such spells over the British Isles would have been correct. The average interval between the indication and the onset of a cold spell was between 24 and 48 hours.

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WIDESPREAD SEVERE CLEAR-AIR TURBULENCE, 13 NOVEMBER 1958

By J. BRIGGS, B.A.

Introduction.—Unusually numerous and widespread reports of severe clear-air turbulence were received from aircraft flying over Great Britain on 13 November 1958. The turbulence was reported as occurring at various heights between

15,000 and 40,000 feet and affected a wide variety of types of aircraft. The exceptional severity of the turbulence was stressed in some reports, for example:

“turbulence comparable with cumulonimbus turbulence at low levels”

“extensive and severe; pilot never experienced such turbulence in 16 years’ flying”

“continuous and violent bumps; difficult to control aircraft and read instruments”.

The meteorological situation.—The surface synoptic charts showed a slowly intensifying ridge of high pressure across the country; Figure 1 gives the situation for 1200 GMT. A quasi-stationary front over the southern North Sea was weakening and a warm front approaching Ireland was beginning to slow up.

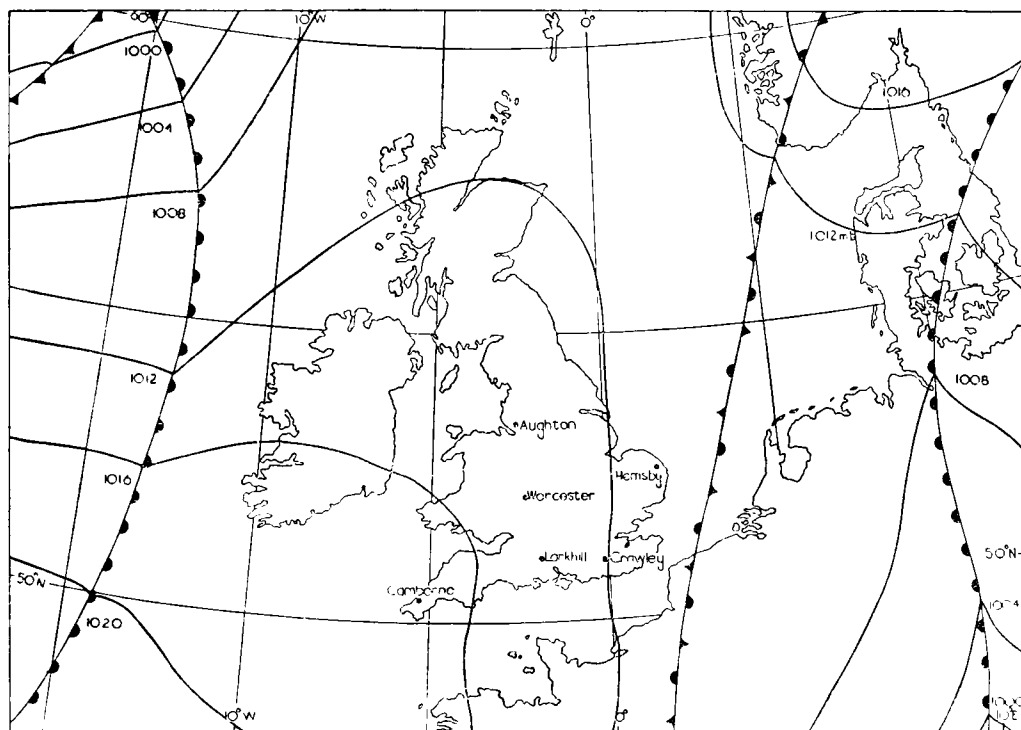


FIGURE 1—SURFACE CHART FOR 1200 GMT, 13 NOVEMBER 1958

At the upper levels strong northerly winds were affecting most of the country but there was a sharp moderation of wind over East Anglia with a quick reversal to southerly winds over the North Sea. Figure 2 shows the 300-millibar chart for 1200 GMT; a northerly jet stream extends from central southern England to north-west Scotland and a very sharp trough has its axis just off East Anglia. At the 700- and 500-millibar levels the trough was farther west and Hemsby was still reporting southerly winds at these heights. In the preceding 12 hours the trough had moved slowly eastwards and had become steadily sharper due to the combined effect of the warm air aloft, which was preceding the surface front over Ireland, and of continued warm air advection from the east over Germany.

Reported occurrences of severe clear-air turbulence are indicated on Figure 2; it will be seen that the majority were over eastern England between 1000 and 1500 GMT. The nearest time for which simultaneous soundings of wind and

temperature are available is 1100 GMT; Figure 3 is an east-west cross-section for that time. For a section centred at 52°N it is possible to use the ascents made at around 1100 GMT from Camborne, Liverpool, Larkhill, Crawley and Hemsby; an aircraft ascent made over Worcester at 0850 GMT is also shown on the cross-section. Wind components shown on the section are north to south components of the reported winds. Positions of the turbulence occurrences relevant to the section are indicated by crosses in Figure 3.

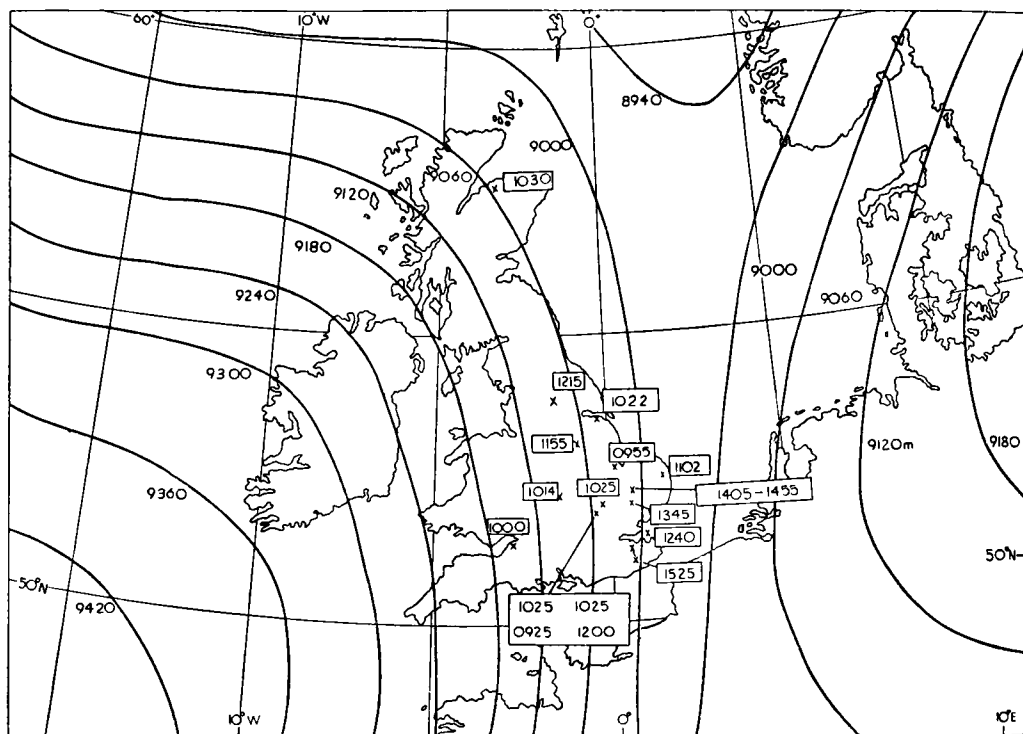


FIGURE 2—300-MILLIBAR CONTOURS FOR 1200 GMT, 13 NOVEMBER 1958

Crosses mark turbulence reports; times are in adjacent boxes.

The axis of the northerly jet stream is seen to lie just to the west of Crawley and just below the 300-millibar level at 1100 GMT. At Hemsby the southerly winds appear below about 320 millibars; extension of the cross-section to the east is limited by lack of data but there are indications that the southerly airstream itself approached “jet stream” magnitude. The most marked feature of the section is the exceptionally strong horizontal shear of wind between the two airstreams. Below the jet axis and on the low pressure side of the axis the shear is of the order of 2.5 knots per nautical mile; this probably exceeds any previously reported horizontal wind shear in the vicinity of the British Isles. A very strong vertical shear of wind is also shown and, in particular, the Crawley wind reports indicate a shear of the order of 14 knots per 1000 feet between 500 and 350 millibars.

Discussion.—Apart from not infrequent cases of bumpiness near the tropopause, Bannon¹ has found that clear-air turbulence is generally associated with pronounced horizontal wind shear and/or with small values of the Richardson number (R_i) which itself depends mainly on large vertical wind shear and small static stability. In general it is not possible to obtain reliable values of R_i as the

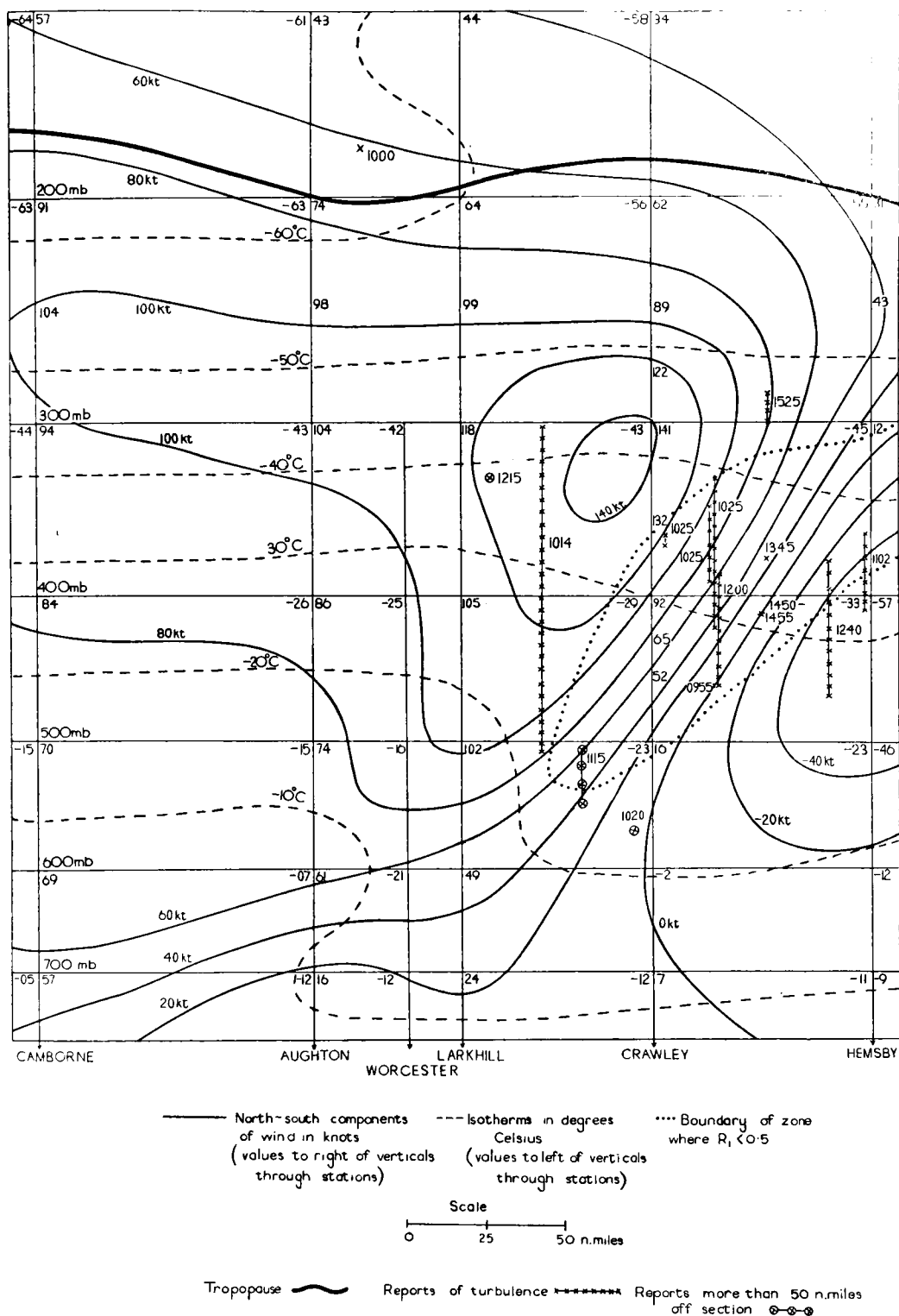


FIGURE 3—EAST-WEST CROSS-SECTION CENTRED AT 52°N FOR 1100 GMT, 13 NOVEMBER 1958

radio-sonde winds are really mean winds over depths of the order of 3000 feet and so vertical shears over shallow layers cannot be obtained. However, in this instance the wind shear, as shown by Hemsby and Crawley, is large over quite a deep layer and it is possible to obtain fairly accurate values of R_i . The variation of R_i with height at Crawley and Hemsby is presented in Table I. Also, using the cross-section, reasonable estimates can be made for the value of R_i in the zone of marked wind shear. On Figure 3 the approximate boundary of the zone within which R_i is 0.5 or less is indicated.

TABLE I—VARIATION OF THE RICHARDSON NUMBER (R_i) WITH HEIGHT, 1100 GMT, 13 NOVEMBER 1958

	Crawley	Hemsby		Crawley	Hemsby
Height <i>feet</i>		<i>R_i</i>	Height <i>feet</i>		<i>R_i</i>
17,000	7.1	—	25,000	0.45	0.39
18,000	0.50	8.4	26,000	2.0	0.40
19,000	0.25	9.5	27,000	2.0	0.40
20,000	0.26	9.6	28,000	2.1	0.40
21,000	0.89	9.7	29,000	2.1	0.41
22,000	0.18	9.7	30,000	0.70	4.4
23,000	0.13	2.3	31,000	0.71	—
24,000	0.45	0.39	32,000	0.71	—

Radar-wind soundings are available for 1700 GMT though no temperature values are obtained at that time. The 1700 GMT winds for Crawley and Hemsby are given in Table II. Both these ascents show that the zone of strong vertical wind shear has lowered; the strongest shear at Crawley is now between 4200 and 5400 metres and at Hemsby the shearing zone is from 5400 metres to about 9000 metres; these changes are consistent with a displacement of some 50 nautical miles eastward of the shearing zone of Figure 3.

TABLE II—WINDS AT 1700 GMT, 13 NOVEMBER 1958

Height <i>metres</i>	Crawley		Hemsby	
	<i>degrees</i>	<i>knots</i>	<i>degrees</i>	<i>knots</i>
900	010	14	350	11
1500	010	12	340	10
3000	070	02	140	03
4200	060	03	190	24
5400	010	64	230	18
7200	010	68	010	35
9000	360	93	360	72
10,500	010	86	360	55
12,000	350	70	350	49

The majority of the occurrences of clear-air turbulence lie inside the zone where R_i is less than 0.5; if due allowance is made for the displacement of this zone with time in line with the movement suggested by the 1700 GMT winds then only four reports lie outside the zone. These four reports are:

- (i) at 1000 GMT and 40,000 feet near Bristol,
- (ii) at 1215 GMT and 28,000 feet over Yorkshire,
- (iii) at 1014 GMT between 18,000 and 30,000 feet over the Midlands,
- (iv) at 1525 GMT and 30,000 feet over Kent.

Of these:

- Report (i) is in the vicinity of the tropopause,
- Report (ii) is more than 100 nautical miles to the north of the section and the section is not really applicable to this report.

Report (iii) extends from 18,000 to 30,000 feet and from the original report it is doubtful whether turbulence covered the whole of this range; turbulence in the lower part of the range lies near the zone $R_i < 0.5$ if suitable time adjustment is made. The upper part of this report is in a region of very strong horizontal anticyclonic shear; the cross-section suggests a shear in excess of the Coriolis parameter (about 0.4 knots per nautical mile). This excessive shear can be partly attributed to the breadth of the cross-section and may also be partly due to local wind fluctuations but it appears that the actual horizontal wind shear in the vicinity of the reported turbulence was at about the theoretical limit for dynamical stability.

Report (iv) lies in the zone of strong horizontal wind shear near the axis of the jet stream.

Conclusion.—The widespread turbulence of 13 November 1958 is seen to have been associated with an exceptionally strong wind shear both in the horizontal and the vertical. In accordance with previous findings (Bannon¹ and Jones²) the greatest number of the reports are on the low pressure side of a jet stream below the axis of the jet and there is considerable confirmation that low values of the Richardson number, probably R_i less than 0.5, are associated with the turbulence, although not all the occurrences of turbulence can be explained in this way.

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OFFICIAL PUBLICATIONS

The following publications have recently been issued:

SCIENTIFIC PAPERS

No. 6—*Seasonal variation of the sea surface temperature in coastal waters of the British Isles*. By F. E. Lumb, M.Sc.

Charts of sea surface temperature for summer and winter in coastal waters of the British Isles are examined, and it is shown that basic summer and winter isotherm patterns exist which are very stable. A physical explanation of these isotherm patterns is outlined, and the importance of tidal currents in determining the summer patterns is stressed. Examples of isotherm charts for five-day periods in January, April, June, September and November 1958 are given and used to demonstrate that maps of the sea surface temperature distribution at any time of the year round the coasts of the British Isles can readily be drawn with the aid of a few sea temperature readings backed by a knowledge of the basic summer and winter isotherm patterns. The interpretation of sea temperature readings from light-vessels is discussed in relation to the basic isotherm patterns.

No. 7—*Forecasting in the Falkland Islands and Dependencies*, by S. D. Glassey.

This paper is a study of weather forecasting in the South Atlantic sector of Antarctica, mainly that governed by the Falkland Islands Dependencies Survey, together with details of particular weather sequences and local effects in the area. It is intended to serve as a guide to students of Antarctic meteorology. Fundamental surface features are discussed and a short summary of available upper air information is made.

No. 8—*Factors associated with the formation and persistence of anticyclones over Scandinavia in the winter half of the year.* By M. K. Miles, M.Sc.

All surface anticyclones spending more than one day in the Scandinavian region during the twelve years 1946–57 (inclusive) have been studied synoptically. It was found that less than a fifth of the anticyclones appearing in the region persisted beyond three days. The rest usually moved east or south-east out of the region in this time. Nearly all of the strong anticyclones developed some 600 nautical miles to the east of a large-amplitude thermal ridge. Continued growth of this ridge for at least twenty-four hours after the anticyclone appeared in Scandinavia was usually required for persistence of the anticyclone. The persistent anticyclones were always accompanied by a fairly intense thermal trough in the west Atlantic, and the central pressure of any pre-existent warm anticyclone to the south or south-west of Scandinavia was usually less than 1030 millibars. The occurrence of east winds over Great Britain for a period of at least four days usually required a persistent anticyclone over Scandinavia, and this was especially so in January and February during the period studied.

No. 9—*An experiment in the verification of forecast charts.* By C. E. Wallington, M.Sc.

This experiment was carried out to build up experience of using various computed indices as indicators of the quality of forecast charts. It appears that the relatively simple root mean square errors are the most practical and useful of the indices considered. When discussing geostrophic wind errors it is important to specify the grid length over which the winds are computed; results of this experiment suggest that root mean square wind errors are approximately inversely proportional to the square root of the grid length.

No. 10—*Incidence of, and some rules for forecasting, temperature inversions over the north-east Atlantic.* By H. C. Shellard, B.Sc., and R. F. M. Hay, M.A.

Some statistical information is presented regarding the frequency, strength, height and persistence of temperature inversions and isothermal layers at the ocean weather stations I and J during one year. The relation between the occurrence of inversions, both frontal and non-frontal, and various synoptic features has been investigated and a number of significant relationships found. These are combined to give sets of rules which may be used for forecasting, from prognostic charts, the occurrence or absence of inversions over the ocean. Such forecasts are likely to be of interest mainly in relation to abnormal radio and radar propagation and, as this is most likely when a strong temperature inversion associated with a hydrolapse is present at low levels, special attention is paid to non-frontal inversions of 5°F or more with bases below the 750-millibar level. In this connexion it should be mentioned that the temperatures used were measured by radio-sonde and that the radio-sonde, due to its lag, tends to underestimate the strength of temperature inversions. Although the radio-sonde also measures humidity the humidity data have not been used in this paper because of their doubtful reliability.

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SEASONALLY INDUCED MERIDIONAL FLUX OF MOMENTUM IN THE ATMOSPHERE

By A. H. GORDON, M.Sc.

Introduction.—The atmospheric general circulation arises as a consequence of the conversion to kinetic energy of that fractional part of the sun's radiant heat energy which is received by the earth. The energy transformation takes place because of differential heating, which is mainly meridional, but also zonal locally, particularly in the northern hemisphere. In order to investigate changes in the general circulation of the order of a month in time and on a global scale it is useful to select a simple parameter which can be easily measured. Such a parameter is found in the mean zonal index of the geostrophic wind, calculated for standard pressure levels over ten-degree belts of latitude and integrated round the world.

The recent work of Heastie and Stephenson¹ provides the basic data from which mean zonal indices of the geostrophic wind can be computed. The data extend from the North Pole to 60°S and from 700 to 100 millibars inclusive.

The induced meridional velocities.—If contour gradients are averaged around parallels of latitude it may be assumed that the mean wind is geostrophic at all latitudes and heights. For the purpose of the calculations advanced in this work the geostrophic assumption is also extended to low latitudes where it is considered that the meridional contour gradients are sufficiently small to enable geostrophic balance to be established at mean velocities of reasonable magnitude. Since the mean zonal winds are computed for the intermediate latitudes (that is, 5°, 10°, 15°, etc.) the discontinuity of an infinite velocity at the equator itself does not arise.

The geostrophic departure equation for instantaneous motion in the customary notation where the horizontal component velocities u , v are orientated along the x , y axes, respectively, is

$$\begin{aligned}\frac{du}{dt} &= fv' \\ \frac{dv}{dt} &= -fu'\end{aligned}\quad \dots (1)$$

where u' , v' are the departure velocities.

If, initially, the geostrophic motion is assumed wholly zonal, any change in that motion will be described by the first relation of equations (1), where $v' = v$. Expansion of the acceleration term on the left-hand side for horizontal motion gives

$$\frac{du}{dt} = \frac{\partial u}{\partial t} + \frac{u}{\partial x} \frac{\partial u}{\partial x} + \frac{v}{\partial y} \frac{\partial u}{\partial y} \quad \dots (2)$$

If the right-hand sides of equations (1) and (2) are set equal to one another, it follows that

$$v = \frac{\frac{\partial u}{\partial t} + \frac{u}{\partial x} \frac{\partial u}{\partial x}}{f - \frac{\partial u}{\partial y}} \quad \dots (3)$$

Equation (3) refers to instantaneous motion; however, it is the mean motion that we wish to study, as given by the mean zonal wind index integrated around latitude circles. We will therefore denote the mean zonal motion by U , and the mean meridional motion by V . Equation (2) then becomes

$$\frac{dU}{dt} = \frac{\partial U}{\partial t} + \frac{U}{\partial x} \frac{\partial U}{\partial x} + \frac{V}{\partial y} \frac{\partial U}{\partial y} + \frac{\partial \overline{u'u'}}{\partial x} + \frac{\partial \overline{u'v'}}{\partial y} \quad \dots (4)$$

as derived by Lettau.² In equation (4) u' , v' are the turbulent velocities which are superimposed on the mean motion U , V to give the actual velocities u , v . The last two terms on the right-hand side of equation (4) are the eddy stress terms. Now if the integration is carried out around the globe along circles of latitude $\partial/\partial x = 0$ and the right-hand side of equation (4) becomes

$$\frac{\partial U}{\partial t} + \frac{V}{\partial y} \frac{\partial U}{\partial y} + \frac{\partial \overline{u'v'}}{\partial y}$$

Thus, from equation (3)

$$V = \frac{\frac{\partial U}{\partial t} + \frac{\partial \overline{u'v'}}{\partial y}}{f - \frac{\partial U}{\partial y}} \quad \dots (5)$$

The mean meridional velocity V may now be computed for specified pressure levels for the seasonally induced changes in the mean zonal wind as indicated by the term $\partial U/\partial t$. The latter term may be evaluated for the four seasonal periods January–April, April–July, July–October and October–January. The evaluation of all terms in equation (5) may be carried out in a straightforward way from the calculated mean geostrophic winds, except for the eddy stress term. An assessment of this term may be obtained from monthly charts of the eddy motion flux contained in the *Atlas of 300 mb. wind characteristics for the northern hemisphere*.³ It is found that the eddy term at 300 millibars is at least one order of magnitude less than $\partial U/\partial t$ when averaged around the globe. Although this evaluation of the eddy motion term has only been carried out at 300 millibars it may be assumed that the relative magnitude would not be greater at other pressure levels where the mean zonal motion is less.

Figure 1 (a)–(d) shows the patterns of meridional velocities induced by the changing heat balance caused by the changing seasons; positive values represent a southerly drift in the northern hemisphere and a northerly drift in the southern hemisphere—with this convention the ordinate of the system of coordinates is directed towards the pole for both hemispheres. The order of magnitude of the velocities is about one tenth of the magnitude of the values calculated by Tucker⁴ from actual wind observations. But the velocity patterns in Figure 1 (a)–(d) may be considered as being superimposed on the normal climatological meridional motion, and the latter may be looked upon as resulting from frictional stresses which prevent the establishment of geostrophic flow in the frictional layer. In a restricted, wholly frictionless atmosphere in which the differential heating was only meridional, the mean meridional velocities would be controlled solely by the seasonal changes in this heating and would be of the order of those in Figure 1 (a)–(d).

It is noted that the velocities are largest in the vicinity of the equator. Although this occurs because of the assumption that geostrophic flow exists there, the fact that the flow may not be exactly geostrophic does not invalidate the bases of the calculations in this region. Meridional velocities will be largest there whether the geostrophic assumption is made or not. If they are calculated directly from the accelerations arising from the existence of the relatively weak contour gradients the velocities will grow rapidly with increasing distance from the reference latitude. The geostrophic departure equation can give a useful guide to the induced meridional velocities at low latitudes using a range of latitude of 10° .

The pattern in Figure 1(a) illustrates the induced motion between January and April. The trend is for a northerly drift between 60°N and 40°S . Poleward of these latitudes the motion is southerly. Figure 1(b) shows the pattern from April to July; the northerly velocities have increased reaching a maximum of nearly 30 cm sec^{-1} within the 200–100-millibar layer. They have also extended into the Arctic. During the following six months the motion has reversed to mainly southerlies. The flow is mainly northerly in the Arctic between October and January.

The divergence.—The seasonally induced divergence patterns may be derived from values computed from the formula

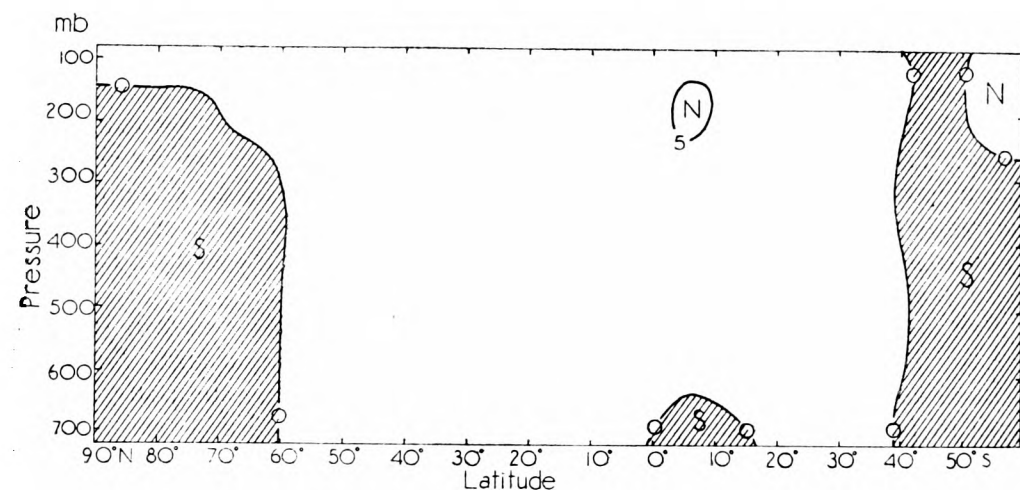
$$\text{div } V = \frac{\partial V}{R \partial \phi} - \frac{V}{R} \tan \phi, \quad \dots (6)$$

where R is the radius of the earth, ϕ the latitude and V is the mean meridional velocity calculated from equation (3). The patterns are shown in Figure 2 (a)–(d) for each of the four periods January–April, April–July, July–October and October–January.

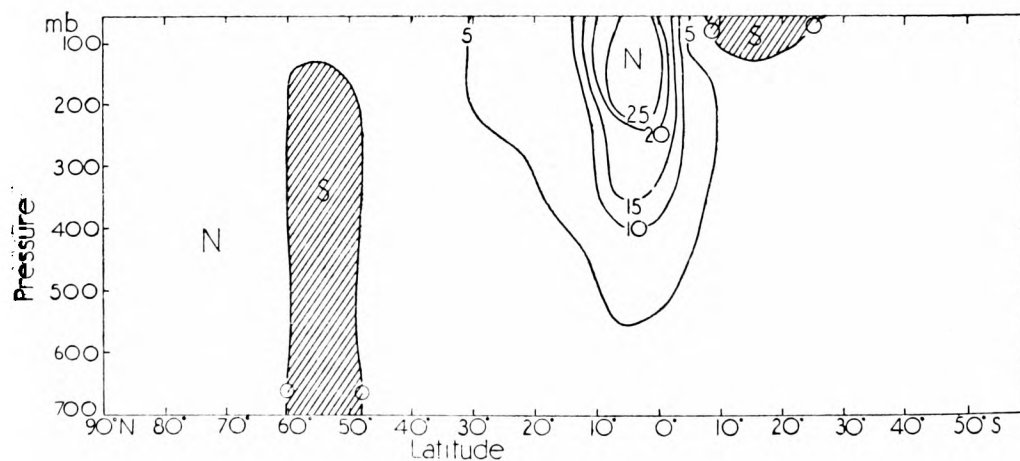
Figure 2(a), January–April, shows a large area of divergence between 70°N and 10°S . The Arctic north of 70°N is under the influence of convergence. In the southern hemisphere the region between 10° latitude and 45° latitude is subject to convergence also. The general pattern agrees well with the observed changes in the mean pressure distribution. For example, it is known^{5,6} that mean pressure rises in the region of the North Pole and falls in other belts of latitude in the northern hemisphere between January and April. The mass transfer from the northern to the southern hemisphere is accompanied by an increase in the intensity of the southern hemisphere subtropical anticyclone in these months.

Figure 2(b), April–July, shows that the divergence has extended well into the Arctic. This agrees with the fall in mean pressure observed in that area between spring and summer. An unexpected belt of convergence occurs at 60°N, a phenomenon which needs further investigation, as displacement of this belt may have effects on the northern hemisphere summers of the temperate latitudes. Elsewhere the general picture is similar to Figure 1(a). Maximum values appear near the equator. This is to be expected, since geostrophic control is small and induced meridional velocities are correspondingly large.

The patterns for the changes from summer to autumn and autumn to winter shown in Figure 2(c) and (d) are broadly the reverse of those occurring during the first half of the year. These, too, agree with the observed reversed mass transfer from the southern to the northern hemisphere, which is associated with the intensification of the northern hemisphere winter anticyclone.

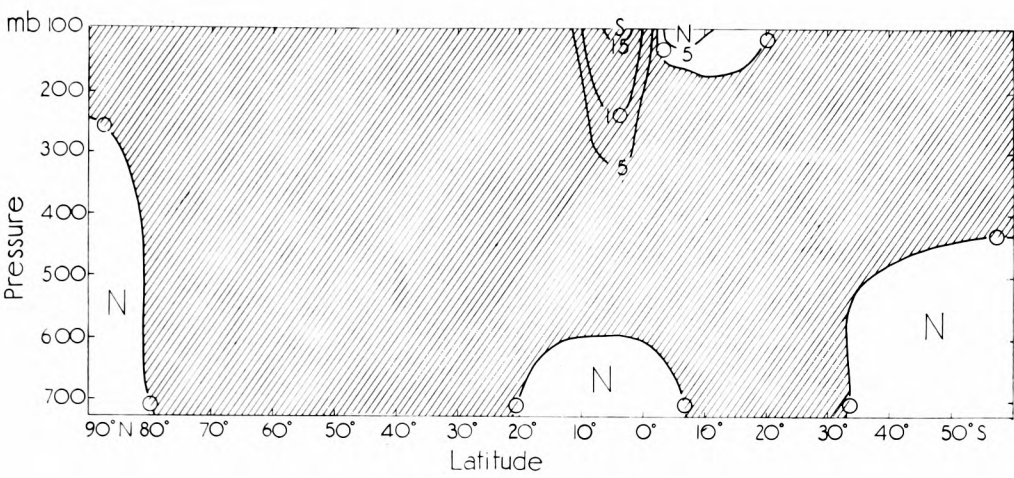


(a) JANUARY–APRIL

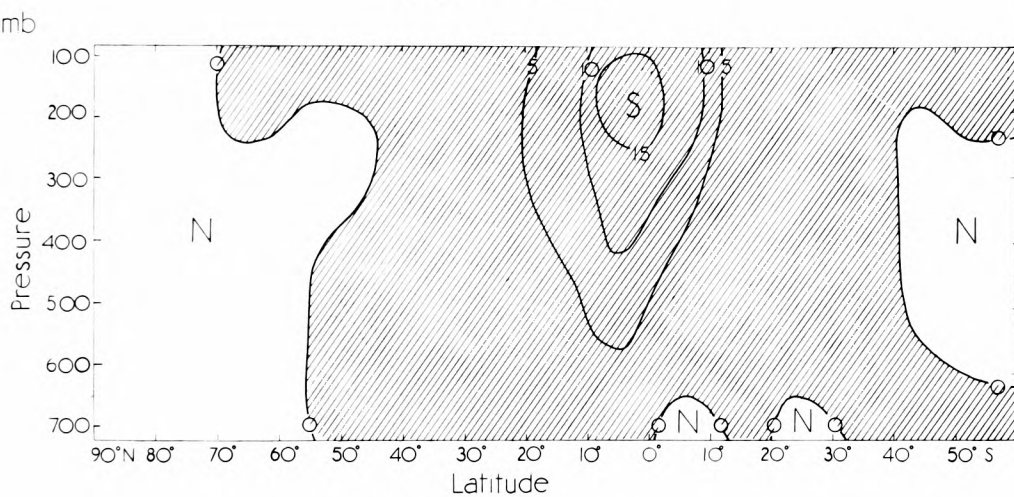


(b) APRIL–JULY

FIGURE 1—SEASONALLY INDUCED MERIDIONAL VELOCITIES (CM SEC⁻¹)
Southerlies are shaded.

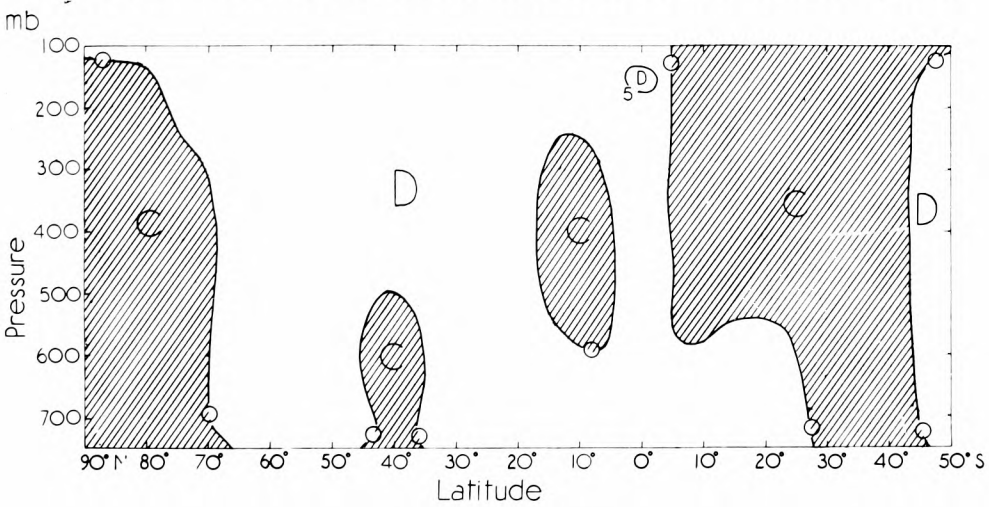


(c) JULY-OCTOBER



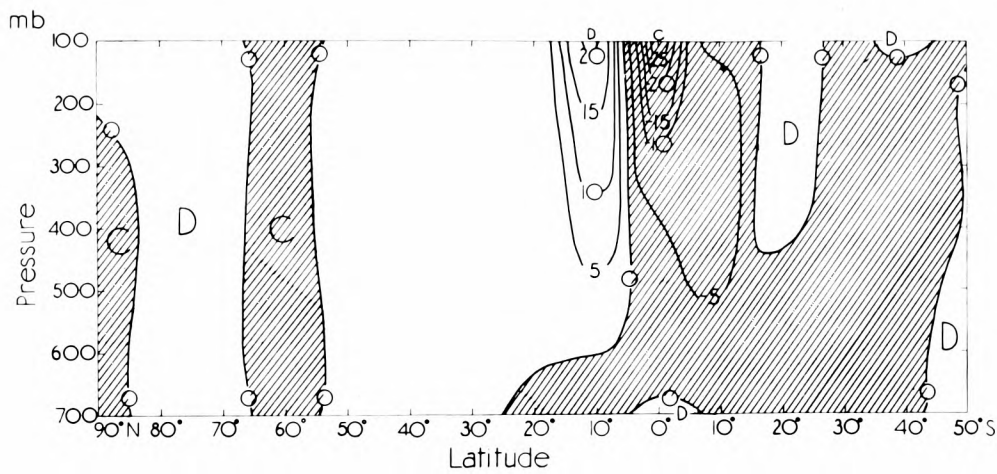
(d) OCTOBER-JANUARY

FIGURE 1—SEASONALLY INDUCED MERIDIONAL VELOCITIES (CM SEC⁻¹) *cont.*

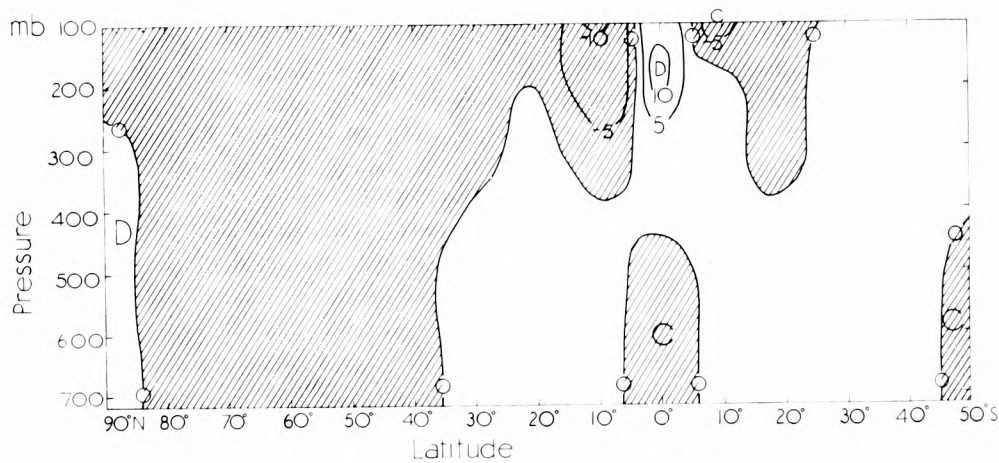


(a) JANUARY-APRIL

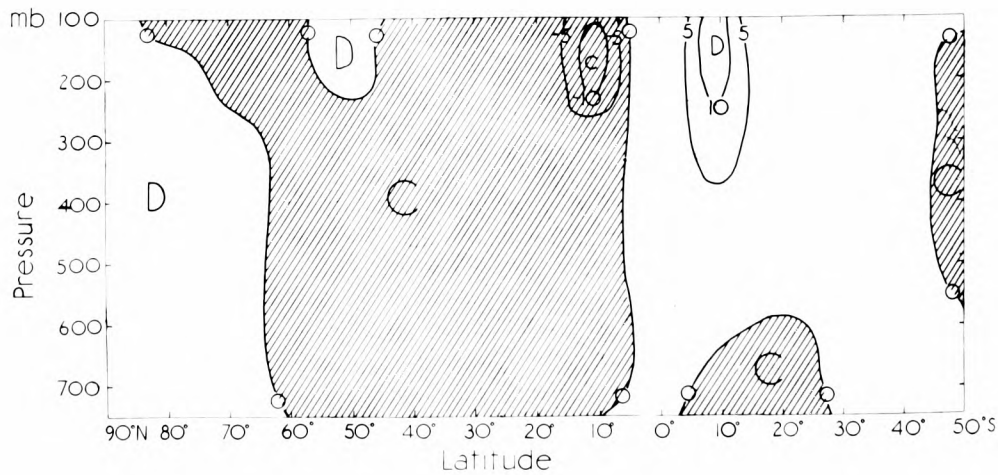
FIGURE 2—SEASONALLY INDUCED DIVERGENCE (10⁻⁸ SEC⁻¹)



(b) APRIL-JULY



(c) JULY-OCTOBER



(d) OCTOBER-JANUARY

FIGURE 2—SEASONALLY INDUCED DIVERGENCE (10^{-8} SEC^{-1}) *cont.*

Conclusion.—The changing meridional heating differential which accompanies the seasonal northward and southward march of the sun creates changes in the mean zonal index of geostrophic wind. These changes in the mean zonal wind induce a mean meridional circulation which is superimposed upon the frictionally driven actual meridional circulation. The seasonally induced meridional circulation gives rise to fields of convergence and divergence which are consistent with the known pattern of changes in the mean pressure and with the known mass transfers which take place throughout the year between the hemispheres.

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SEVERE CLEAR-AIR TURBULENCE NEAR THE BRITISH ISLES

By J. BRIGGS, B.A.

Introduction.—Previous analyses by Bannon^{1,2} and Jones³ have related the occurrence of severe clear-air turbulence to features shown on the upper air charts. Since these analyses a considerable number of reports of turbulence have been received and a further analysis seemed desirable. The reports, similar to those used in the previous papers, are mainly supplied by aircrew of the Royal Air Force or Royal Navy and the severity of the turbulence is generally a qualitative estimate; to obtain some uniformity of assessment, aircrew were asked to regard severe turbulence as corresponding to accelerations exceeding $\pm 0.5g$ and as characterized by difficulty in maintaining aircraft attitude or heading and with a marked tendency to be lifted from one's seat.

This paper examines 105 cases of severe clear-air turbulence at heights above 10,000 feet in the vicinity of the British Isles; the reports cover the period January 1958 to December 1960.

Relation of occurrences of clear-air turbulence to height and to the tropopause.—The distribution of the occurrences of turbulence in relation to the height above the ground and to the height of the tropopause, as estimated on the basis of the radio-sonde network are presented in Tables I and II.

The indicated peak frequency of turbulence at about 7500 metres (alternatively at about 3250 metres below the tropopause) and the secondary maximum near the tropopause are thought to be reliable although only very limited information is available regarding the different amount of flying time at different heights. Figures supplied by three service units have been used to

TABLE I—NUMBER OF OCCURRENCES OF SEVERE CLEAR-AIR TURBULENCE
IN SPECIFIED HEIGHT BANDS

Height band <i>metres</i>	No. of occurrences	Height band <i>metres</i>	No. of occurrences
<4000	1	9001-10,000	8
4001-5000	3	10,001-11,000	13
5001-6000	9	11,001-12,000	3
6001-7000	14	12,001-13,000	11
7001-8000	22	13,001-14,000	4
8001-9000	15	> 14,000	2

TABLE II—NUMBER OF OCCURRENCES OF SEVERE TURBULENCE FOR SPECIFIED
HEIGHT BANDS ABOVE OR BELOW THE TROPOPAUSE

Height above tropopause <i>metres</i>	No. of occurrences	Height below tropopause <i>metres</i>	No. of occurrences
4501-5500	1	501-1500	5
3501-4500	2	1501-2500	12
2501-3500	4	2501-3500	19
1501-2500	3	3501-4500	16
501-1500	7	4501-5500	8
Within 500 metres of tropopause	17	5501-6500	6
		6501-7500	4
		> 7500	1

obtain a rough estimate of the frequency of occurrence; the figures did not permit study of different height bands. With no allowance for variation with height the frequency of severe turbulence is one occurrence in 530 hours of flying between 15,000 and 45,000 feet.

The apparent decrease in incidence of turbulence with increasing penetration of the stratosphere is probably partly due to decreased flying time at the higher altitudes, but is thought to indicate a real decrease in frequency of turbulence. The highest report received, at 16,160 metres, was some 4000 metres above the tropopause though the nature of the report suggested that the "turbulence" may not have been entirely due to meteorological factors.

Relation of occurrence of severe turbulence to upper air features.—

Following Bannon^{1,2} and Jones³, each occurrence was related to features shown on the *Daily Aerological Record* though, where necessary, supplementary charts and cross-sections were drawn to assist the placing of the turbulence in regard to the features of the upper air charts. Table III presents a summary of these comparisons.

TABLE III—NUMBER OF OCCURRENCES OF SEVERE TURBULENCE ASSOCIATED
WITH SPECIFIED FEATURES OF UPPER AIR CHARTS

Upper air feature	No. of occurrences
Jet stream with axis not more than 100 nautical miles from occurrence ...	73
Upper trough or upper low	22
Near tropopause (but no associated jet stream)	2
Unclassified	8
Total	105

The unclassified cases showed no special features of wind or temperature shear and were mainly on the edges of upper anticyclones or ridges. Here a jet stream is regarded as a concentration of almost straight contours corresponding to a wind maximum of 80 knots or more and having a definite decrease in wind

speed on each side. The 73 cases associated with jet streams were further subdivided in regard to position relative to the jet axis and across the flow. Table IV presents the results of this subdivision.

TABLE IV—NUMBER OF OCCURRENCES OF TURBULENCE IN RELATION TO JET AXIS

	Position					No. of occurrences
Below jet axis and	{ on low pressure side	...	...	...	...	46
	{ on high pressure side	...	...	...	...	2
Above jet axis and	{ on low pressure side	...	...	...	...	10
	{ on high pressure side	...	...	...	...	15
					Total	73

Although estimates of the position of the jet axis based on the radiosonde network are necessarily somewhat subjective the errors should average out and the main features, presented in Table IV, are thought to be accurately shown. The almost complete absence of turbulence below the axis and on the high pressure side of the axis is the most outstanding feature; this confirms the previous analyses.

Estimates of the incidence of turbulence in regard to the position along the jet stream were not generally possible and reliable figures for this aspect cannot be given though there was some indication that the exit zone of the jet stream was the most favoured region for turbulence.

Relation of turbulence to vertical stability and horizontal wind shear.—For each report of turbulence an estimate was made, based on the radiosonde network, of temperature lapse rate, vertical wind shear and horizontal wind shear; the standard criterion of vertical stability, the Richardson number *Ri*, was then determined. Table V is a summary of the values obtained for *Ri* and for horizontal wind shear.

TABLE V—NUMBER OF OCCURRENCES OF SEVERE CLEAR-AIR TURBULENCE CORRESPONDING TO SPECIFIED VALUES OF *Ri* AND OF HORIZONTAL WIND SHEAR

Horizontal shear <i>hr</i> ⁻¹	Value of <i>Ri</i>				Total
	> 10	> 5 and ≤ 10	> 1 and ≤ 5 <i>number of occurrences</i>	≤ 1	
≤ 0.1	8	1	5	1	15
> 0.1 and ≤ 0.2	3	3	1	12	19
> 0.2 and ≤ 0.3	1	2	10	1	14
> 0.3 and ≤ 0.4	1	0	7	2	10
> 0.4 and ≤ 0.5	5	3	6	2	16
> 0.5	0	0	6	17	23
No estimate	2	2	3	1	8
Total	20	11	38	36	105

Interpolation between radiosonde values introduces a certain subjective element; also clear-air turbulence is generally limited to depths of the order of 1000–2000 feet and horizontal distances of 10–20 miles, whereas the radiosonde winds are spaced at distances of the order of 100 miles and are means over depths of 3000 feet or more. Large shears over a shallow depth and short horizontal distance are necessarily smoothed in the interpolation and in the radiosonde winds so that the estimated shears are likely to be underestimates of the real shears corresponding to turbulence. The value of *Ri* depends on the reciprocal of the square of the vertical shear so that an underestimate of vertical shear, particularly when the shear is relatively small, leads to an exaggerated overestimate of

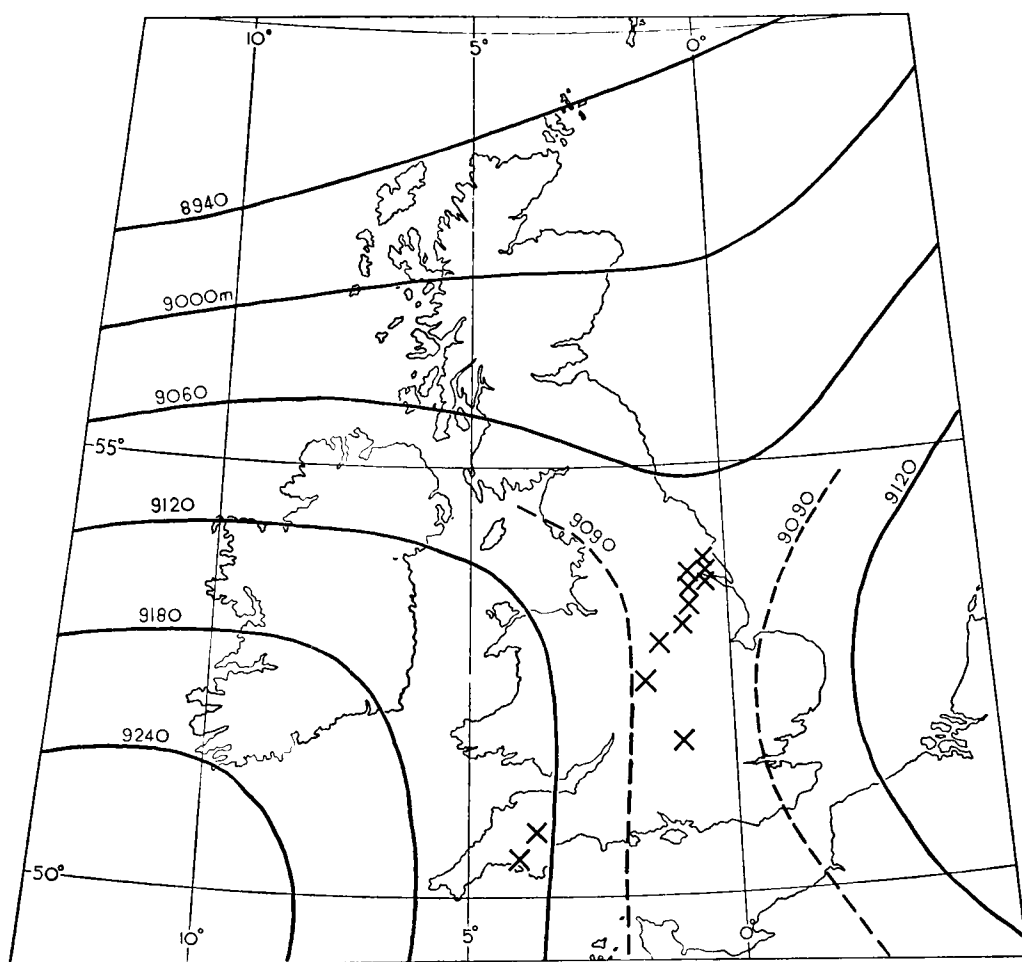


FIGURE 1—300 MB CHART FOR 1200 GMT, 30 APRIL 1959
Crosses mark positions of reports of severe clear-air turbulence.

Ri. The computed values of *Ri* must therefore be generally in excess of the real values obtaining in turbulent zones although the smaller values of *Ri*, corresponding to large shears, are likely to be quite close to the true values.

The separate effects of large horizontal shear and of large vertical shear are difficult to establish since Table V shows that, as can be expected from the frequency of association with jet streams, most occurrences had both these features. Considering the two factors separately it is seen that about 70 per cent of occurrences had values of *Ri* below 5 and that about 65 per cent had horizontal shears, of more than 0.2 hr^{-1} . These figures indicate the sort of success that estimates based on normal working charts might have in indicating turbulence but they do not provide reliable figures for the critical values of *Ri*, or of horizontal shear, associated with development of turbulence.

The occurrences of turbulence not associated with large horizontal shear nor with small values of *Ri* tended to be well into the stratosphere; thus of eleven occurrences with *Ri* exceeding 10 and horizontal shear not above 0.2 hr^{-1} six were more than 2000 metres above the tropopause, one more than 1000 metres above the tropopause, two near the tropopause and only two in the troposphere.

Notes on some individual cases

(a) *13 November 1958.* Very numerous and widespread reports of severe clear-air turbulence on this day have already been discussed.⁴ The occurrences were associated with an exceptionally strong wind-shear in both the vertical and horizontal.

(b) *30 April 1959.* Twelve reports of severe turbulence on this day are marked on Figure 1 which represents the 1200 GMT 300-millibar chart. The turbulence is seen to have been in the vicinity of a sharp upper trough lying north to south across England. The winds were mainly northerly west of the axis of the trough and southerly east of the axis, although the light east-west components indicate convergence on to the trough axis. Figure 2 is a cross-section of the trough again showing the positions of reported turbulence. Isopleths of the wind speed normal to the section show the considerable horizontal wind shear between 275 and 400 millibars in the region of the trough axis; the shear was of the order of 0.5 hr^{-1} for most of the reports of turbulence. The vertical shear was everywhere small except for the one report near 500 millibars and for the report at 250 millibars, that is, near the tropopause.

Of the twelve reports, seven reported the turbulence as corresponding to headings of 360 or 180 degrees and the other five reported turbulence on various headings. The aircraft were not engaged on special flights for the investigation of turbulence and it is to be expected that the relation of heading to turbulence occurrence would be mainly a matter of chance; therefore the large predominance of north and south headings in the reports suggests that the turbulence was most pronounced for these headings. This supports views put forward by Clodman⁵, who has previously found some evidence for the anisotropic nature of turbulence when a strong horizontal shear of wind appears to have been the predominating factor.

(c) *12 December 1958.* Eight reports of severe clear-air turbulence are marked on Figure 3 which represents the 300-millibar chart for 1200 GMT. Except for the isolated report near Leuchars the occurrences were in the exit zone of the west to west-south-west jet stream lying across the southern half of Great Britain. Figure 4 is a north-south section across the main zone of turbulence and shows the jet axis at about 32,000 feet between Worcester and Hemsby. The turbulence is seen to have been in two main zones, one in the vicinity of the tropopause and another in the region of strong vertical shear below the jet axis. The two regions of turbulence above and below the jet axis just to the south of Hemsby were reported by the same aircraft and so strengthen the suggestion that the vertical wind shear appears to have been the most important factor in causing the turbulence.

(d) *18 December 1958.* Figure 5 shows the 1200 GMT 300-millibar chart for this day and marks two reports of very severe clear-air turbulence observed at 1400 GMT. The radiosonde ascents suggest that warm air covered Ireland, Wales and south-west England and the warm front at 300 millibars is indicated on the Figure. The front marks a change from light west or west-south-west winds to moderately strong west-north-west winds; a real jet stream is not indicated but nevertheless Figure 6, which is a section through the area of turbulence at right-angles to the west-north-west flow, shows a distribution of wind velocity similar to that of a typical jet stream and with a wind maximum of about 80 knots. The frontal zone was clearly a region of large shear of wind, both in the vertical and the horizontal. Allowing for the difference in time between the

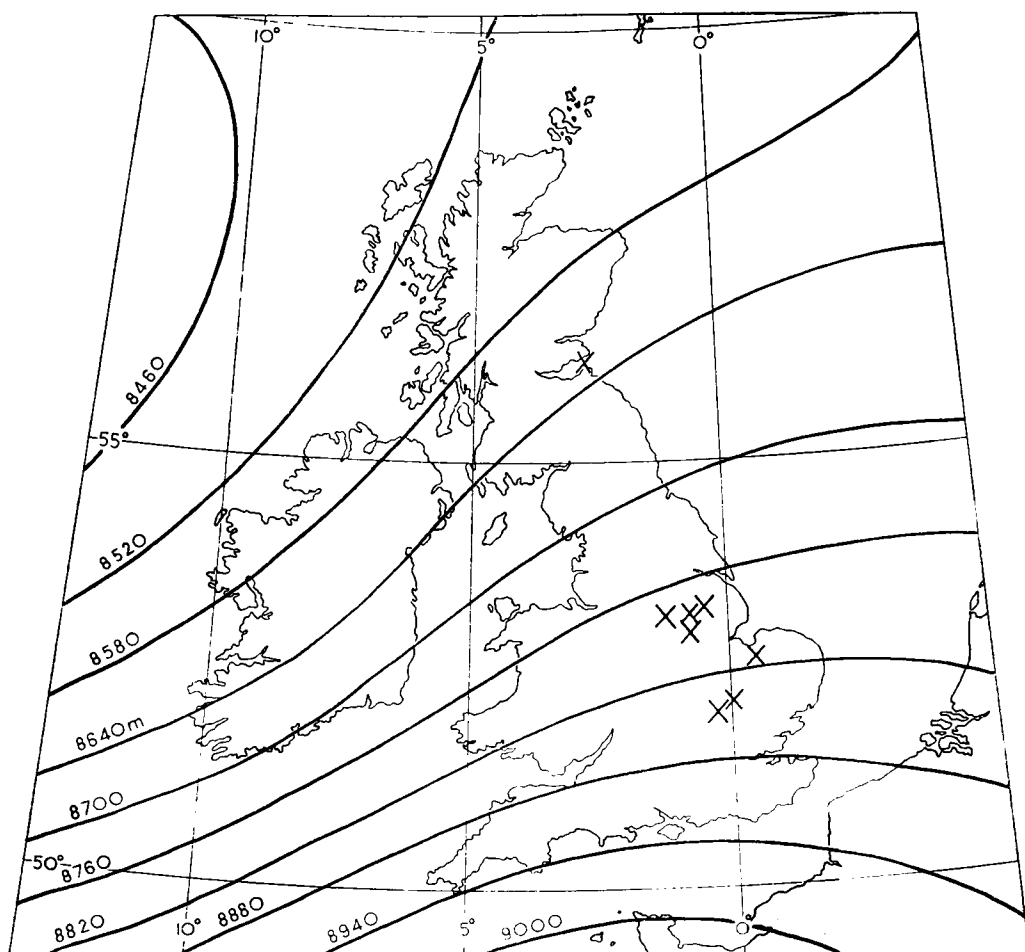


FIGURE 3—300 MB CHART FOR 1200 GMT, 12 DECEMBER 1958
Crosses mark positions of reports of severe clear-air turbulence.

section and the occurrence of turbulence it is apparent that the turbulence was almost coincident with the frontal transition zone.

Conclusions

(i) The present analysis confirms the previous findings of Bannon and Jones as regards association of severe turbulence with features of the upper air charts. The three main areas in which turbulence is found are:

- (a) the zone of strong shear of wind usually found below a jet stream and somewhat to the low pressure side of the stream,
- (b) the vicinity of a marked trough in the upper flow,
- (c) near the tropopause (usually also near a jet stream).

(ii) Small values of the Richardson number and/or large values of horizontal shear are associated with most occurrences of severe turbulence. As regards forecasting it appears that mean values of Ri of less than 5, or of horizontal shear exceeding 0.3 hr^{-1} , if based on accurate forecasts of wind and temperature and computed for networks corresponding to that of the radiosondes would cover more than 80 per cent of occurrences. In this connexion it must be emphasized

CRAWLEY LARKHILL WORCESTER HEMSBY AUGHTON LEUCHARS

- Isopleth of wind component normal to section
 ————— Tropopause
 Reports of severe turbulence
 X Isolated report
 X Range of turbulence
 X reported by one aircraft

FIGURE 4—CROSS-SECTION FOR 1200 GMT, 12 DECEMBER 1958

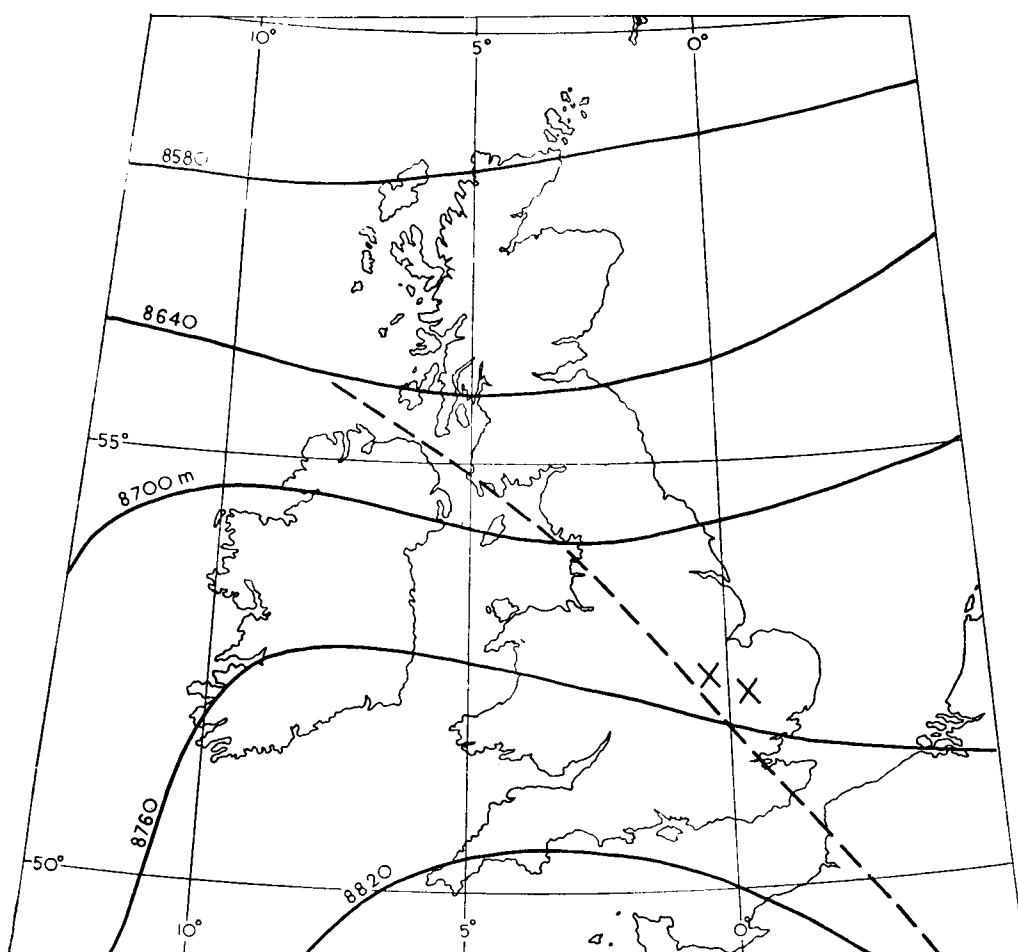


FIGURE 5—300 MB CHART FOR 1200 GMT, 18 DECEMBER 1958

Crosses mark positions of reports of severe clear-air turbulence. The dashed line indicates the front at 300 mb.

that the important shears need in fact exist for much smaller distances and height intervals so that any discontinuity, for example, associated with an otherwise insignificant front, may be important.

(iii) In the case of large horizontal shear associated with an upper trough the most pronounced turbulence may well be experienced in headings parallel to the axis of the trough.

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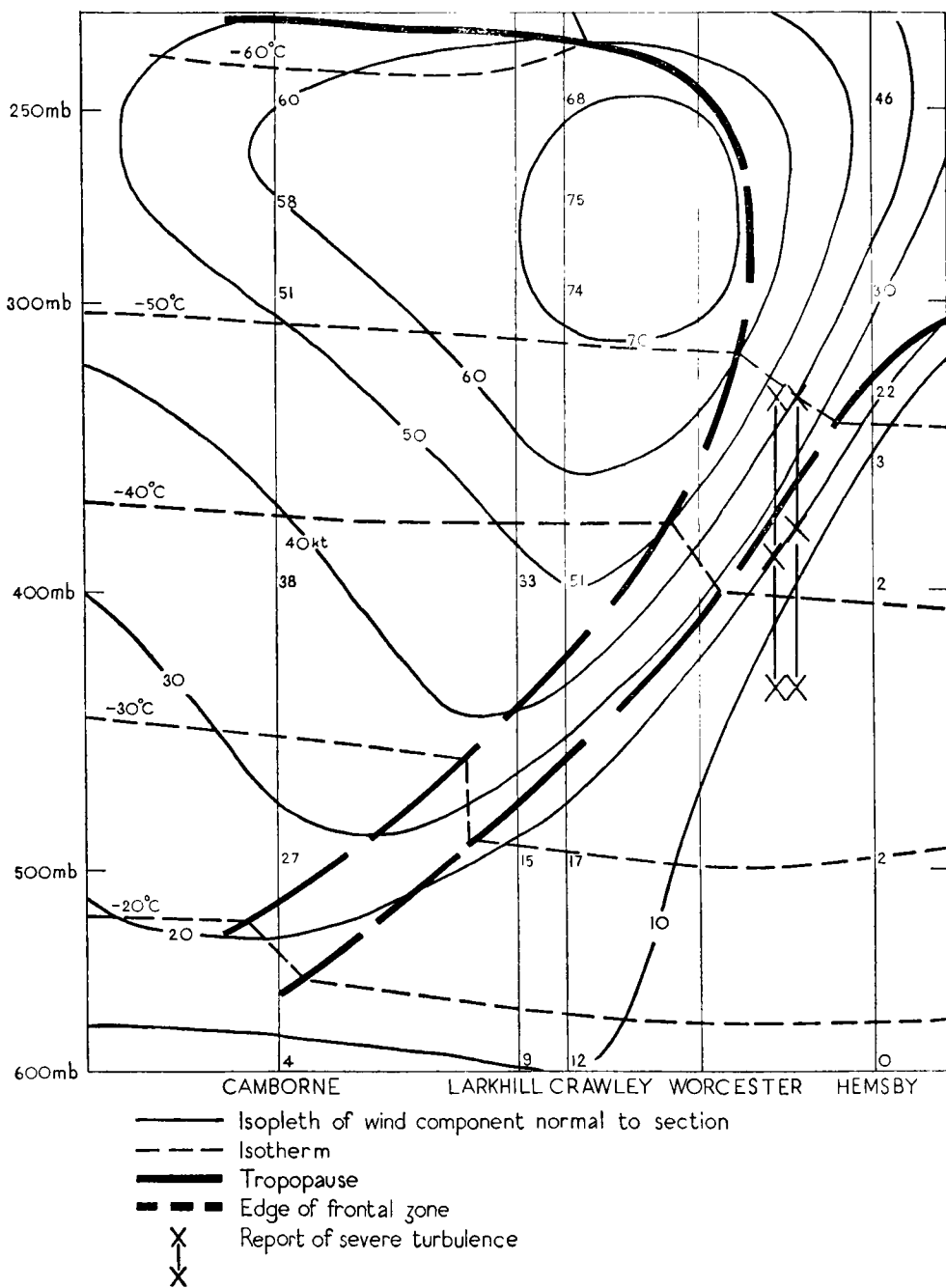


FIGURE 6—CROSS-SECTION FOR 1200 GMT, 18 DECEMBER 1958
 (see p. 49)

200 MB MEAN WINDS ON THE ROUTE EL ADEM TO ADEN DERIVED FROM AIRCRAFT REPORTS

By P. G. WICKHAM, M.A.

Introduction.—During the two-and-a-half-year period from May 1957 to November 1959, a quite considerable amount of data was accumulated relating to winds found by jet aircraft flying at levels around 40,000 feet on the route between El Adem and Aden.

These aircraft reports are not ideal data for producing mean winds. They are awkward to summarize owing to differences in the way the winds are found and presented, the varying flight levels of individual aircraft, and the discrepancies which occur between the winds reported by two or more aircraft flying over the same area at much the same height and time. In addition, over the short period considered, the total number of reports received during certain months was too small and the distribution in time of the reports during nearly every month was too irregular to allow a satisfactory statistical treatment. However, since the upper air information over Africa is so sparse, it is felt that this body of data is an independent and significant addition to our present knowledge of high-level winds in the area. While it is not possible to say how far the mean wind field may vary from year to year, the results given certainly reflect the regular seasonal rhythm which was apparent during the period.

Data.—The wind reports in this paper are taken from aircraft flying over any part of the route between El Adem and Aden, via 22°N, 25°E. A map of the route is shown in Figure 1.

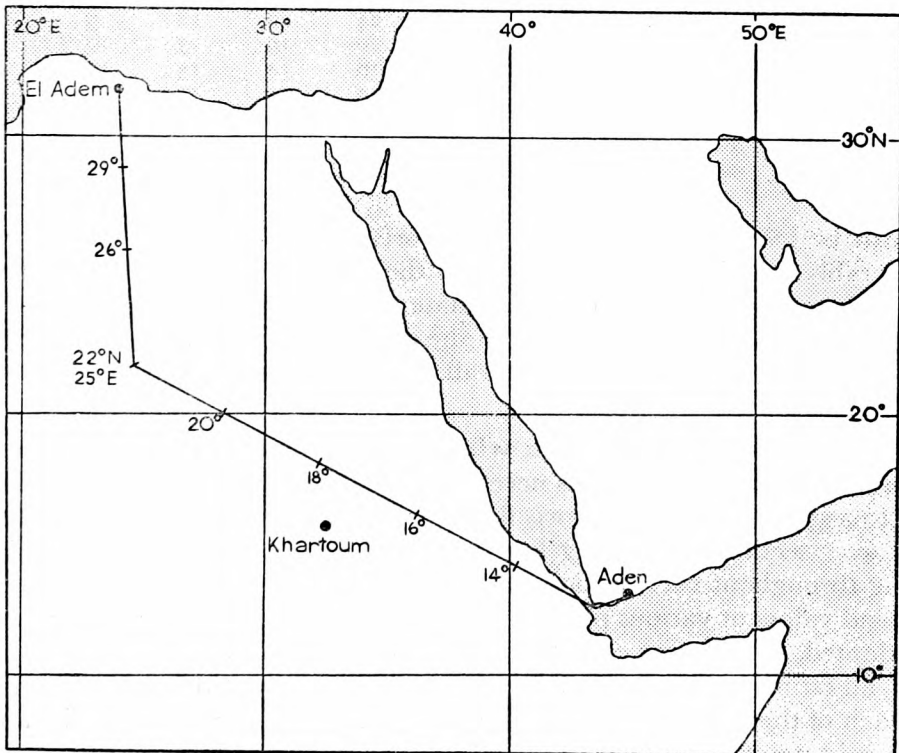


FIGURE 1—MAP OF ROUTE BETWEEN EL ADEM AND ADEN

For the purpose of analysing the reports, the route was divided into six sections. These are quite arbitrary sections and not of equal length, being chosen as convenient divisions of the route for forecasting purposes. The sections are from 29°N to 26°N; 26°N to 22°N; 22°N to 20°N; 20°N to 18°N; 18°N to 16°N and 16°N to 14°N. The mean winds presented refer approximately to the 200-millibar level and are computed from all reports received in the height band from 37,500 to 42,500 feet.

It should be pointed out that the quality of the wind reports found by different types of aircraft varies considerably. Some have to rely on visual and radio fixes in determining their position and in computing winds. This method, when used over the vast featureless expanses of north-east Africa may give some very unreliable results, or at best only give mean winds over rather long sections. Others, however, are equipped with Doppler wind-finding equipment which can give spot values of wind which are particularly valuable and reliable. The total number of flight reports used, either wholly or in part, was 278. Of these, about a third were from aircraft fitted with Doppler wind-finding equipment. Table I shows the number of aircraft reports on each section from which the monthly means have been computed.

TABLE I—NUMBER OF AIRCRAFT REPORTS AVAILABLE ON EACH SECTION

Month	Sections of route					
	29°N - 26°N	26°N - 22°N	22°N - 20°N	20°N - 18°N	18°N - 16°N	16°N - 14°N
	<i>number of reports</i>					
January
February
March
April
May
June
July
August
September
October
November
December

It can be seen that the number of reports available on each section varies considerably, and is regrettably small on the section nearest to Aden. The lack of reports on this section is an unfortunate result of the flight schedules during the period. Most of the flights were in the direction from Aden to El Adem and when flying in this direction the aircraft were almost always below the specified height band on this section.

Method of computing mean winds.—To summarize the aircraft reports and produce mean winds it was necessary to reduce the wind reports from each flight to a standard form. Reports from some aircraft were in the form of mean winds over sections of varying length, often with the altitude of the aircraft varying throughout each section. Other reports were in the form of a series of spot wind values at various positions. To deal with this, the following procedure was adopted, considering each flight in turn. First, on the basis of the reported winds, an estimate was made of the mean winds that would have been reported over each of the standard sections of the route, and of the height of the aircraft at the mid-point of each of these sections. This procedure is of course very subjective. Next, each of these estimated winds were resolved into components

(north and east). For each month, the components on each section were added and meaned. The mean components were combined to give a mean wind direction and speed, rounded off to the nearest five degrees and five knots. The final means for each month were computed from the reports received during that month throughout the two-and-a-half-year period.

In general, except on occasions when more than one report was received on any one day, all available reports have been used in this work. When two or more reports were received on the same day, the reports were combined to produce a mean wind for that day. Thus the monthly mean winds have been computed from not more than one wind report a day. Even so, since the distribution of reports throughout each month was usually very irregular, the computed means for any individual month often reflect a particular wind régime that was predominant during a small part of that month. This is unfortunate and it is hoped that by combining the computed means for a particular month over two or three years, a more representative monthly mean has been produced.

Monthly mean winds.—The monthly mean winds at 200 millibars on the route are given in Table II. The broad picture of the upper wind field shown by this Table is a fairly consistent one and is in agreement with what is already known. Briefly, two broad currents of air affect North Africa during the year. On Table II, isopleths of wind directions 250° and 110° have been superimposed to bring out more clearly these two currents, one westerly and the other easterly.

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
29°												
28°	270/90	260/105	275/95	280/85	285/65	245/30	150/10	180/10	255/25	245/55	270/80	265/80
27°												
26°												
25°												
24°	270/95	270/100	270/90	270/70	285/60	235/25	120/20	140/15	240/15	255/50	275/70	265/85
23°												
22°												
21°	270/90	260/85	265/75	275/65	275/45	200/10	105/40	115/25	160/15	245/10	275/65	265/70
20°												
19°	265/80	255/65	270/60	275/40	265/40	125/10	100/40	100/30	130/20	245/15	275/50	270/65
18°												
17°	260/60	265/45	265/45	285/30	245/35	140/15	090/45	100/40	105/25	170/10	285/45	275/45
16°												
15°	270/50	250/35	245/20	295/15	235/30	135/20	085/40	105/40	100/25	VAR/5	295/40	275/40
14°												

TABLE II—MONTHLY MEAN WINDS AT 200 MB ON ROUTE FROM EL ADEM TO ADEN
The hatched area, enclosed between isopleths of wind direction 110° and 250° , separates the main winter westerlies from the summer easterlies.

In wintertime, a westerly flow covers the whole route and, in latitudes north of 20°N , it very frequently reaches speeds in excess of 100 knots. In the spring, this westerly flow weakens and gives place to the easterly stream which moves north with the sun from the equator. In the summer, the easterlies are well established over the south of the route as far north as 22°N , but even in the height of summer do not extend quite as far north as the North African coast at 30°N . In the autumn the easterlies quickly recede south and the westerly stream becomes re-established. The westerlies prevail over El Adem for about nine months of the year and over Aden for about six months.

Subtropical westerly jet stream.—A number of features of the westerly jet streams which cover North Africa in wintertime were shown by the wind reports. October to May is the jet stream season.

Table II shows that during the months January to March even the mean wind speeds were about 100 knots on the two northernmost sections. During this period the subtropical jet stream is a permanent feature of the upper wind field. The aircraft winds reported during these months invariably showed a maximum wind greater than 70 knots on the northern sections and on four days out of five, westerly winds greater than 100 knots were reported at heights varying between 35,000 and 45,000 feet. The neighbouring months of December and April had not quite so large a proportion of high winds, but nevertheless winds of over 100 knots were reported on half the days of these months.

It was not possible on many occasions to determine the position of the core of maximum wind speed with any certainty. However, it appeared that the mean position of the jet core moved south across the North African coast in the late autumn. During the midwinter period, from January to March, the cores of the jet streams were definitely located from the aircraft reports at some latitude south of 29°N on more than half the total number of occasions for these months. Wind maxima over 100 knots have been reported as far south as $19\frac{1}{2}^{\circ}\text{N}$, with cores of lesser strength even farther south. In the spring the jet stream cores moved north again.

The highest speeds reported during the period by an individual aircraft was one of 260 degrees 178 knots, at 42,000 feet on 1 December 1957—this was a mean wind over the whole section from 22°N to 29°N . The highest “spot” value of wind speed was one of 260 degrees 165 knots, at 38,500 feet at $27\frac{1}{2}^{\circ}\text{N}$ on 26 March 1959.

On a number of occasions it was apparent that more than one core of maximum wind existed. These secondary maxima, which occurred to the south of the main wind maxima, were most common during the months from December to March. They were reported in latitudes ranging from 23°N to 14°N , usually in the region around 18°N , and the speeds exceeded 100 knots on occasions.

Zonal and meridional components of the mean flow.—Figure 2 shows isotachs of the zonal components of the mean monthly winds. This diagram shows essentially the same features as the resultant mean winds given in Table II but displays them more graphically. The high maximum speeds in the westerly components in February, the rapid change from westerlies to easterlies in June and back again in September, and the solid easterly stream over the whole route during July, are features which are clearly brought out.

The horizontal shear of the zonal components has been worked out, over intervals of two degrees of latitude, and the results are shown in Figure 3. With only small exceptions, the sense of the shear is anticyclonic over the whole route throughout the year. The actual values of the shears are mostly of the order of 0–20 knots per 120 nautical miles, with the westerly winds decreasing and the easterly winds increasing towards the south. The values of the shears in Figure 3, however, are given as percentages of the local value of the Coriolis parameter, f . It can be shown that if the wind shear in any region is anticyclonic and exceeds the value of f in that region, the resultant flow is dynamically unstable. This state of affairs may well exist from time to time in localized regions and may be very significant in explaining the formation of sudden developments in the wind

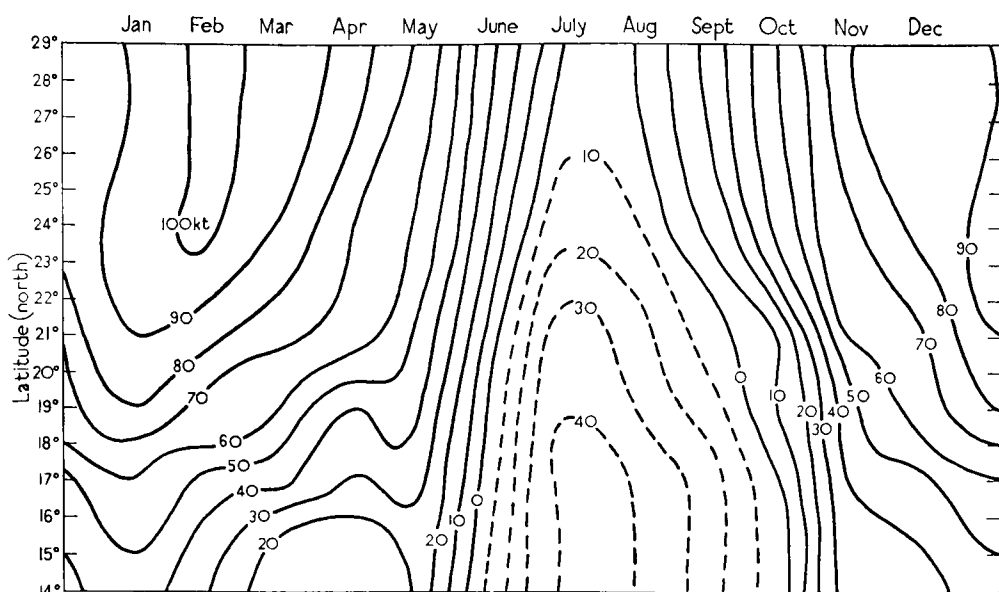


FIGURE 2—ZONAL COMPONENTS OF THE MONTHLY MEAN WINDS

Westerly and easterly components are continuous and broken lines respectively. Isotachs are drawn at 10 kt intervals.

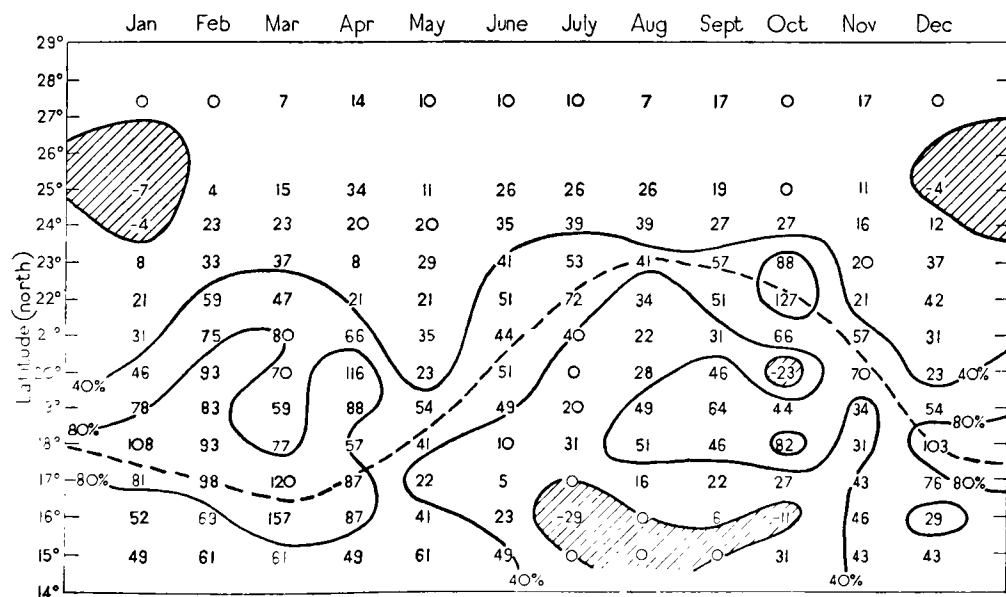


FIGURE 3—SHEAR OF ZONAL WIND COMPONENTS, EXPRESSED AS PERCENTAGES OF THE CORIOLIS PARAMETER f

Areas of cyclonic shear are shaded. Isopleths of 40 and 80 per cent of f are shown as full lines and the position of the maximum anticyclonic shear is marked by a dashed line.

and pressure fields. But it is scarcely to be supposed that the atmosphere would continue in such a state of dynamic instability in one region for periods of time long enough to register on charts of mean wind flow. Thus the very high individual values of the shear which appear in places on Figure 3 must be a consequence of the inadequate data on which the values are based. Indeed, with only very small adjustments in the values of the mean winds, all the shears could

easily be reduced to values less than f . For example, if in March the mean zonal component in the southernmost section had been only 5 knots greater and that in the next had been only 5 knots less than the values given here, the shear at 16°N would have been reduced from $1.57f$ to $0.98f$.

However, despite the obviously doubtful values and the erratic variations of the shear from one latitude to another, it seems clear that anticyclonic shears whose values approach that of f very closely, do exist in the mean for quite a long period of time, from December to April in the vicinity of 17° – 18°N . Further, by drawing isopleths on Figure 3, a zone where the shear (expressed as a percentage of f) is a maximum, is quite clearly discernible. This zone moves north during the spring and early summer to latitude 23°N in August–September and then moves south to reach about 16°N latitude in late winter. In winter the shears are frequently greater than $0.80f$ near this zone, but in summer at higher latitudes $0.60f$ is rarely exceeded. It would seem that this pattern of shears is an integral part of the wind field at this level, though its significance is not clear.

The meridional components of the flow are displayed in Figure 4. The features here are rather vague. During most of the year there is a south to north flow of air at this height over the whole route. This is in accord with the generally accepted picture of a thermally direct circulation pattern over low latitudes.

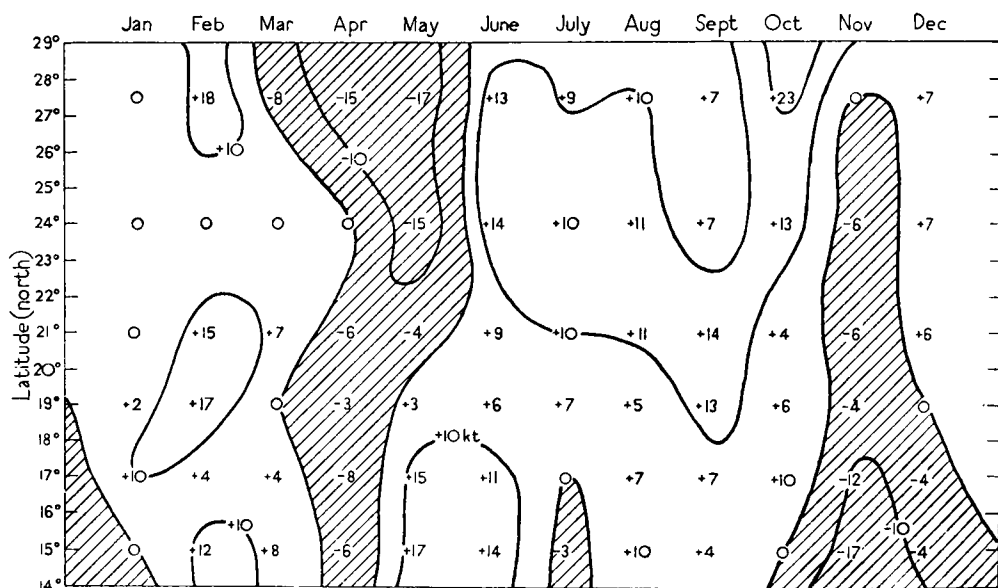


FIGURE 4—MERIDIONAL COMPONENTS OF THE MONTHLY MEAN WINDS

South–north components are marked positive and left unshaded; north–south components are negative and shaded. Isotachs are at 10 kt intervals.

Erratum—The value for January at 19°N should be $+7$.

Warm air rises in the equatorial trough and then moves polewards at high levels over the tropics before subsiding into the subtropical anticyclones. The circulation is completed at low levels by equatorward air flow in the trade winds from the subtropical highs to the equatorial trough once more. However, it seems that in April–May and again in November, the flow of air is from north to south at 200 millibars over this part of Africa. How regular or extensive these north-to-south flows may be is beyond the scope of the present data to determine. But it does serve to indicate that variations on the basic simple theme are very likely to occur in the pattern of the general circulation.

REVIEWS

Symposium on monsoons of the world. 9½ in. × 7 in., pp. x+270, *illus.*; Hind Union Press, New Delhi, India, 1960. Price: 19s.

The Second Session of the Commission for Synoptic Meteorology (CSM-II) was held in New Delhi during January–February 1958. This was conveniently followed by a symposium on “The monsoons of the world” under the joint auspices of the International Union of Geodesy and Geophysics and the World Meteorological Organization, ably backed by the Government of India through their Meteorological Department. The papers presented at the symposium and the discussions thereon have been published by the Government of India under the title “Monsoons of the world”; the publication is the subject of this review. The papers are presented in seven sections.

SECTION I, on the climatology of the monsoons, contains three papers, of which the first deals with the upper air climatology of India and neighbourhood in the monsoon seasons. It is largely factual, presenting the normal distribution of temperature and wind at six standard levels from 850 to 100 millibars for June and July representing the south-west monsoon season, November representing the north-east monsoon season and May, a transitional month. Temperatures have been derived from evening radiosonde ascents over a five-to-ten-year period up to the end of 1955; winds have been derived from pilot-balloon ascents up to the end of 1950 and from radio-wind ascents up to the end of 1956. Temperature features revealed by the charts include the influence of ground heating up to about three kilometres and a very warm area—attributed by the authors to heat liberated during condensation—at 100 millibars in July near the India–West Pakistan frontier. This latter feature does not appear on similar charts published elsewhere, emphasizing possible discrepancies in high-level temperatures determined by different radiosondes and the need for an accurate standard instrument. The charts illustrate the high-level easterly jet of the summer months and the subtropical westerly jet of winter.

The second paper in Section I, by H. O. Walker, describes the five weather zones experienced in Ghana and neighbouring areas as the monsoon moves north and south during the year. The difficulty of air mass analysis and frontal nomenclature in tropical regions is stressed. This subject produced lengthy and very lively discussion in committee during CSM-II, leading to a compromise solution with the adoption of descriptive terms for “intertropical discontinuity” and “subtropical discontinuity”.

Section I ends with a brief but informative paper by K. N. Rao of the Indian Meteorological Department. Analysing radiosonde data up to 1955 he demonstrates that convective instability up to 4 to 6 kilometres is a normal feature during the south-west monsoon in India.

SECTION II, containing twelve papers, covers monsoons and the general circulation of the atmosphere, and opens with a general review of the subject by K. R. Ramanathan. This is followed by a paper by H. Flöhn in which he examines critically the textbook conception of monsoon winds, which he summarizes as follows:

- (i) Monsoon winds are predominant air currents with a marked seasonal shift.
- (ii) Monsoon winds blowing from sea to land are moist, unstable and rainy; those in the opposite direction are dry, stable and rainless.

- (iii) The physical cause of monsoon winds is to be found in differential heating of land and sea, *i.e.* in the different response of the earth's surface to solar radiation.
- (iv) Tropical monsoons over the summer hemisphere are to be conceived as trade winds of the winter hemisphere crossing the equator and deflected by Coriolis forces.

Flöhn produces observational evidence and arguments leading to a deletion of (iv) above, and the replacement of (ii) and (iii) by the following:

- (ii) Winds with westerly/easterly directions and a component towards the pole/equator have, in general, a tendency for lifting/subsidence, instability/stability and raininess/dryness produced by Coriolis forces together with the spherical shape of the globe.
- (iii) The physical causes of monsoon winds are to be found (*a*) in the thermally controlled seasonal migration of the planetary pressure and wind belts in continental sections of the globe and (*b*) in the (seasonally changing) differential heating of land and sea.

In the third paper in Section II, Flöhn turns from global considerations to an account of recent investigations on the mechanism of the summer monsoon of southern and eastern Asia based on a wealth of climatological data. He touches on the persistence of westerly winds along the equator, the distribution of rainfall, the sources of moisture, and the correlation of the time of onset of the monsoon with extratropical features. Much of the paper deals with the important role played by the Tibetan Plateau as an elevated heat source and its influence on the build up of the equatorial easterly jet stream, the far-reaching switch of the planetary wind belts over southern and eastern Asia, and the "burst of the monsoon" over the Indian subcontinent.

A fourth paper, by S. L. Malurkar, is a discursive account of monsoons, particularly in the neighbourhood of India. Claims are made for the importance of shallow low pressure areas moving westwards near the equator in reinforcing the south-west monsoon by air from the south-east trades of the southern hemisphere; the role of air from the north-east trades of the North Pacific and of continental air from western Asia in the weather of the monsoon season is also discussed. Other topics discussed are certain rainfall régimes and the interaction of depressions on opposite sides of the equator.

P. Koteswaram also deals with the general circulation over the tropics during the summer monsoon, examining the equatorial easterly jet stream, and relating bursts of the south-west monsoon over India, and its fluctuations, as well as the formation of monsoon depressions, with perturbations in the upper easterly current. He emphasizes the importance of the Tibetan Plateau as a heat source and important features of his suggested schematic model of the vertical circulation in the Asian summer monsoon have been confirmed by recent work by Tucker on mean meridional air trajectories.

P. R. Pisharoty and G. C. Asnani contribute a paper on the flow pattern over India and neighbourhood at 500 millibars during the monsoon. The flow patterns fall broadly into two categories, one typical of normal monsoon conditions with well distributed rain over much of India, and the other typical of "breaks in the monsoon" when the rainfall over much of India, particularly the central parts, almost ceases and noteworthy rains occur along and near the eastern Himalayas.

Of the remaining papers in Section II one comes to the conclusion that the

monsoon does not exist over Madagascar, whilst the remaining five are merely abstracts of papers published elsewhere.

SECTION III deals with the dynamics of monsoons and opens with a review of the main studies in the field of monsoons in Europe and Asia by Soviet meteorologists. These studies are considered under three headings—climatological, synoptic and hydrodynamic. Generally speaking, the climatological school attributes monsoons to thermal non-uniformity of the earth's surface. On the other hand, the synoptic school does not regard this as the principal factor in the origin of monsoons. This school considers monsoons as a stage in a series of synoptic developments and that they cannot be considered as a problem divorced from that of the general circulation. Within recent years Khromav has completely abandoned the thermal non-uniformity idea on the origin of monsoons; he has also, in common with Flöhn, come to the conclusion that monsoons do not bring a certain type of weather. The hydrodynamical school associates monsoons closely with the general circulation, free convection, and heat sources and sinks. The review ends with problems still under investigation, as, for example, the exact nature of monsoons, their vertical formation, their weather characteristics, their association with the general circulation and the like.

The second paper in Section III is a survey of dynamical theories of monsoons by Pisharoty and Asnani, and contains a critical examination of theories by Jeffreys and Böhme. They conclude that the Indian monsoon cannot be regarded as a land- and sea-breeze on a continental and annual scale and lean towards the view that it is primarily due to the seasonal shifting of thermally produced planetary belts of pressure and winds due to differential heating of air over continents and oceans.

The final paper in Section III—"On the intertropical front and intertropical convergence zone over Africa and adjacent oceans" by K. H. Soliman—recalls the lively debate in committee during CSM-II between the frontal and non-frontal schools of tropical meteorology. Soliman, whilst recognizing the intertropical convergence zone between the high pressure belts over the tropical oceans, makes a strong plea for the recognition of an intertropical front and a subtropical front over large land masses such as Africa. He points out that whereas there is a narrow zone of low pressure where the trades meet over the ocean, we find over Africa and Asia in the northern hemisphere summer a wide belt of thermal lows. The associated air is extremely hot and dry. Soliman advocates the existence of an intertropical front between this hot, dry air and relatively moist and cool south-west monsoon air to the south; he also recognizes the existence of a subtropical front between the hot, dry air and cooler air on its northern flank. There was considerable support for Soliman's views at CSM-II and equally strong opposition from those who advocate that frontal characteristics cannot be attributed to these boundaries. CSM-II ended up with an international compromise solution—intertropical and subtropical "discontinuities".

SECTION IV deals with depressions and other perturbations in the monsoon, and opens with a case study of a monsoon depression in the Bay of Bengal by P. Koteswaram. The history of the depression is followed from its formation under the influence of a westward-moving high-level easterly wave, through its north-westward movement in keeping with the fields of warm and cold advection, to its recurvature around the high-level anticyclone over Tibet and

subsequent break-up over the Himalayas. Ananthakrishnan and Bhatia follow with a more general study of tracks of monsoon depressions to determine why a few depressions of the south-west monsoon recurve northwards towards Kashmir whilst the majority continue to move west-north-west to merge with the seasonal depression over north-west India. The paper maps the origin, place of recurvature, and dissipation of depressions by months for the period 1924–52. These maps indicate that depressions form over the sea in all months at the southern periphery of the anticyclonic cell at 10–12 kilometres and tend to follow the flow at this level. In keeping with this, depressions reaching the centre of the country during the south-west monsoon tend to curve north-west or north. However, a marked recurvature into Kashmir is rare, and is demonstrated to occur when there is a deep trough in the westerlies moving eastward from the north-west.

SECTION V deals with rain and cloud, mostly of the south-west monsoon. The opening papers deal with radar observations on rainfall and with an analysis of cloud heights and turbulence in the south-west monsoon as reported by Comet aircraft. These are followed by a study of rainfall in India during the south-west monsoon season by K. Parthasarathy. The south-west monsoon is responsible for 70 to 90 per cent of the annual rainfall over most of the country. The coefficient of variability of the monsoon rain for the country as a whole is only 10 per cent, but many parts of the country have a considerably higher variability. Rarely is a season of normal rainfall one of normal rainfall in all parts of the country, but one of excesses in some parts being compensated by deficiencies in others; neither is a wet year wet in all parts, nor a dry year dry in all parts. Few seasons occur without disastrous floods in one part or other of the country. Floods and droughts are characteristics of the south-west monsoon season. The role of monsoon depressions in producing flooding is described, as is also that of “breaks” in the monsoon producing excessive rainfalls in the lower Himalayas and a deficit of rain in the Gangetic plains and the central parts of the country. A claim is made for the important part played by the upper tropospheric anticyclone in controlling the regions of activity of the monsoon; westerly waves moving across the lower Himalayas play nearly as important a role as the easterly waves farther south in determining intensity and distribution of heavy rainfall.

Ramakrishnan and Gopinatha Rao deal with aspects of non-depressional rain during the south-west monsoon, including diurnal variations on the coast and inland, areas of maximum rainfall, duration and variability of rainfall. The section ends with a paper by K. N. Rao on the average amount of rainfall on a rainy day during the south-west and north-east monsoons.

SECTION VI deals with the variability of monsoons and opens with a paper by H. G. Bond on the drought of 1951–52 in northern Australia, resulting from a failure of the north-west monsoon and associated depressions. A good relationship is established between the pressure difference between Singapore and Darwin on the one hand, and southward movement of the intertropical convergence zone in the region of Australia and monsoonal and tropical storm activity over northern Australia on the other. The drought was associated with a series of stray and persistent anticyclones in the Australia–New Zealand region concurrently with a general pressure deficiency in the east Asia region.

Rao and Jagannathan, in a study of monsoon and annual rainfalls in India, failed to find any significant seasonal or annual trends for the country as a



By courtesy of B.O.A.C

CAPTAIN A. L. FRENCH OF B.E.A. (LEFT) AND CAPTAIN E. M. JONES, A.F.C.,
OF B.O.A.C. (RIGHT) WITH DR. A. C. BEST, O.B.E., D.SC.

(see p. 267)



By courtesy of B.E.A.

CAPTAIN A. L. FRENCH OF B.E.A. RECEIVING A BRIEF-CASE FROM
DR. A. C. BEST, O.B.E., D.SC.
(see p. 267)

whole; Moghe has found a periodicity approximating to seven days in the flow of the south-west monsoon over the west coast of India.

The volume ends with SECTION VII on extended and long-range forecasting of the monsoon, and opens with a paper on seasonal (monsoon) rainfall forecasting in India by Rao and Ramamoorthy. It is a tribute to Walker that the correlation method he introduced in 1907 is still the basis of the method used for issuing seasonal forecasts. Of the many factors investigated, South American pressure and Southern Rhodesian rainfall continue to be dominating factors in the seasonal forecasting formulae; however, there are increasing hopes that use can be made of the more recently available upper air data. The accuracy of these forecasts and their value to the national economy are held to justify their continued issue.

The final paper, by L. A. Ramdas, discusses the establishment, fluctuations and retreat of the south-west monsoon in India. Drought and flood years are defined and the characteristics of the rainfalls in thirty areas of the country for each of seventy-six monsoons are tabulated. An interesting relationship has been found between flood and drought years on the one hand, and pressure over south-east Australia on the other. Formulae for forecasting the date of onset and retreat of the monsoon are described briefly, indicating the lines of current research. Ramdas also draws attention to the importance of long-range forecasts of the frequency of depressions during the monsoon and also that of breaks in the monsoon.

The Asiatic monsoon is the best known of the monsoons. The oft-used saying that India's budget is a "monsoon gamble" reflects the importance of monsoon rainfall to the Indian economy. Food production and prosperity in India and some neighbouring countries are vitally dependent upon the monsoon, and it has been the subject of intensive study by meteorologists in India for many years; the work continues apace. Indian meteorologists, in common with their colleagues in many parts of the world, are faced with increasing demands for accurate long-range forecasts; the task is enormous, but the spur is great, for success would bring incalculable benefits to India.

Despite the major role of the Asiatic monsoon, and despite the setting of the symposium and the prominent part played by Indian meteorologists there, it is greatly to the credit of the Organizing Committee that more than a third of the papers discuss monsoons in general, or particular monsoons other than those over and near India. The result is a volume that forms a ready reference to general monsoon theories as well as containing a wealth of information on the all-important south-west monsoon of India. The editors deserve our thanks and congratulations.

J. HARDING

Meteorology for glider pilots, by C. E. Wallington. 8½ in. × 5½ in., pp. xii + 284, illus.; John Murray, 50 Albemarle Street, London, W.1, 1961. Price: 25s.

I have been gliding now for nearly thirty years, during which time my knowledge of the air has been acquired by a mixture of the "suck it and see" method, of endless conversations in bars and on the field, and a groundwork obtained by reading a few books on elementary meteorology.

Reading Mr. Wallington's book has in one stroke put all this information in the right order, has enabled me to cast out many misconceptions, and has

enormously added to my previous knowledge. In part this is a fair exchange, since I am sure that Mr. Wallington would be the first to acknowledge that much of what he now gives us has been obtained by analysing information obtained from glider pilots themselves by him and others like him. For whereas when I first started to glide, any unusual experience of a glider pilot would meet with incredulity from the meteorologists, for many years now the latter have been only too anxious to listen to any such events, and ingenious in producing theories to account for them. Much of this book is undoubtedly a crystallization of these decades of collaboration between people each in their own ways enthusiasts about the air.

Again and again throughout the book I came on explanations of things which I have experienced in flight, and there are few questions remaining to ask. The ultimate mystery about the air seems to me that we ever experience a calm day. The picture of a thermal as a kind of smoke-ring revolving about itself answers many problems, but the spectacle sometimes seen of a column of circling sailplanes at all altitudes from a few hundred feet to say 3000 feet underlines that these rings are often quite like the crude rising columns of my young days.

On page 209 I came on the exact diagram of the corrugated cardboard sheet of wave-cloud, flat on the underside and waved on top, amongst which I found myself flying over Sheffield during the 1954 World Championships. I am not sure, however, that I understand how in fact I climbed into and through this from a starting point some 1500–2000 feet below its flat base.

On page 230 I read that the upwind jump of a wave cloud is a rare phenomenon, seldom observed from the ground. From the banks of Lake Ohau in the Mackenzie Country of New Zealand I watched a stream of perfect lens clouds drifting downwind and each time the leading one drifted one wavelength a fresh one appeared like magic overhead. It was a conjuring trick of Nature, and I am glad it is not yet understood, though I expect Mr. Wallington or one of his colleagues will nail it down before long.

I long to understand and love the tephigram, but being a bear of very little brain find it hard to take in the conception of entropy. Telling me that I can think of it as the potential heat energy of the air doesn't quite get me there—I have an exasperating feeling that perhaps just one more sentence would open the door for me.

I have in store just one or two incidents yet to be cleared up—a belt of smooth rising air parallel to the Durham coast about 10 miles inland under a completely grey and featureless sky in May 1958, a sea-breeze effect of sorts around the north-easternmost bulge of England in July 1959 under a stormy grey sky, and so on.

But make no mistake about it, this book is a classic. It will go on being bought and read eagerly by glider pilots—and, I hope, by meteorologists—for years to come. So when Mr. Wallington comes to revise it, may I ask for two additions: an analysis of the dynamic upcurrents used by sea-birds such as the albatross in the lowest levels of the air, to indicate whether we could ever construct a sailplane to make use of them; and secondly some information on the vertical electrostatic potential gradient, to see if we can conceive an instrument enabling us to detect thermals from a distance, using radioactive probes on the wing-tips and possibly the nose and tail of our aircraft to measure any potential differential. For either of these developments would of course revolutionize our sport.

P. A. WILLS

NOTES AND NEWS

Meteorological Office awards to captains and navigators of civil aircraft

The Meteorological Office awards for 1961 to captains and navigators of civil aircraft for outstanding service in providing weather reports were presented by Dr. A. C. Best, Director of Services of the Meteorological Office, at a ceremony held by the Guild of Air Pilots and Air Navigators on 4 July 1961. In the unavoidable absence of the Master of the Guild, Dr. K. G. Bergin, the guests were welcomed by Sir Frederick Tymms, a former Master, who mentioned how conscious the Guild was of the value of the meteorological services provided to its members.

Dr. Best, in a brief speech before presenting the awards, reminded those present that the first of these ceremonies was held six years ago and they had now acquired the status of an annual event. The ceremonies had one characteristic which distinguished them from most meetings attended by professional meteorologists. Usually meteorologists were asking for something to improve the service—more frequent reports, reports from greater heights or reports of a different type—but, on these occasions, they were offering something as a token of their gratitude for the information they had received from members of the Guild. He emphasized that, despite the high quality of automatic instruments and continued efforts to improve them still further, the human intelligence was still the most effective instrument for reporting weather because automatic instruments lacked the flexibility and discretion of the human brain. Sometimes meteorological knowledge, obtained from instruments, at new and greater operational heights tended to lag a little behind that required for successful operation of aircraft but this lag could be and was being minimized by weather reports from aircraft.

Dr. Best then presented brief-cases to Captain E. M. Jones, A.F.C., of B.O.A.C. and Captain A. L. French of B.E.A.

Awards of suitably inscribed books will be sent to the following captains and navigators who provided the best series of reports (in-flight, post-flight, or on de-briefing):

Navigator R. Brown, B.O.A.C.	Captain D. Mason, B.E.A.
Navigator T. M. Clarke, B.O.A.C.	Navigator W. C. L. McKay, B.O.A.C.
Captain R. Hartley, B.E.A.	Captain K. D. G. Mitchell, B.E.A.
Navigator J. D. Hogg, B.O.A.C.	Navigator M. D. Richards, B.O.A.C.
Navigator G. G. Kingsmill, B.O.A.C.	Captain G. Thomas, B.U.A.
Navigator G. A. Kirkwood, B.O.A.C.	Captain B. J. Thwaites, B.E.A.
Captain C. N. Longdon, B.O.A.C.	Captain W. J. Wakelin, B.E.A.
Captain R. W. F. Wightman, B.O.A.C.	

The names of Captain W. J. Wakelin (who received a brief-case in 1958) and Navigating Officer M. D. Richards (who received a book in 1958) appear for the second time within three years.

CONGRATULATIONS

We offer our congratulations to Mr. Ernest Gold, C.B., D.S.O., F.R.S., on reaching his 80th birthday on 24 July 1961. Mr. Gold's retirement from the Meteorological Office after 41 years' service was announced in the November 1947 number of the *Meteorological Magazine*.

OFFICIAL PUBLICATION

The following publication has recently been issued:

GEOPHYSICAL MEMOIRS

No. 105—*Upper winds over the world, Part III. Standard vector deviation of wind up to the 100 mb level over the world.* By G. B Tucker, Ph.D.

Charts of standard vector deviation of wind have been prepared to accompany the contour height and streamline and isotach charts in Parts I and II of "Upper winds over the world" (*Geophysical Memoirs* No. 103). Over the standard five-year period 1949–53 a set of mean charts have been constructed at each of the standard pressure levels 700, 500, 300, 200, 150 and 100 millibars for the midseason months of January, April, July and October. The techniques used in compiling the charts are described. The method of constructing a wind rose from a given resultant wind speed and direction, and standard vector deviation has been reprinted from the earlier *Geophysical Memoirs* No. 85.

METEOROLOGICAL OFFICE NEWS

Meteorological Office Headquarters, Bracknell

It has been announced that the three components of the new Meteorological Office building at Bracknell will be known by names commemorating distinguished men of science. The central building will supersede the Napier Shaw Laboratory at Dunstable and will be known as the NAPIER SHAW BUILDING. The east wing housing the senior directing staff will be called the FITZROY WING and the west wing, largely devoted to instrumental laboratories of various kinds, will be known as the DINES WING.

Admiral Fitzroy was the first head of the Meteorological Office, being Superintendent of the Meteorological Department of the Board of Trade from 1855–65. Sir Napier Shaw was Director of the Meteorological Office 1900–18 and is particularly well known for his *Manual of Meteorology*. W. H. Dines was an exceptionally gifted designer of meteorological instruments; most of his work was performed in conjunction with the Office.

Staff suggestions scheme

Mr. L. G. Bird, Experimental Officer, was awarded £25 for a device for reducing loss of rain during the siphoning period of a Dines tilting-siphon rain recorder.

THE METEOROLOGICAL MAGAZINE

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551.521.11(261,41/42) : 551.521.12(261,41/42)

DISTRIBUTION OF TOTAL SOLAR RADIATION ON A HORIZONTAL SURFACE OVER THE BRITISH ISLES AND ADJACENT AREAS

By G. J. DAY, B.Sc.

Summary.—Total solar radiation data, available from stations in the British Isles and from British ocean weather ships, are examined and linear regression equations between monthly mean daily totals of total solar radiation on a horizontal surface and monthly mean daily durations of bright sunshine obtained where possible. It is found that the constants of the equations vary somewhat but apparently not systematically. Each set of constants is therefore used to derive total solar radiation data in the general area of a station at which radiation is recorded, duration of bright sunshine data being taken for stations of roughly comparable exposure. A distribution of total solar radiation is obtained, from direct and deduced data, and this is linked with a similar distribution recently obtained by Black¹ for the area 50°–60° N, 05°–30° E. The distribution is extended to the west by consideration of the data from the British ocean weather ships. The data are presented in the form of a series of monthly maps.

Introduction.—Interest exists in the areal distribution of solar radiation both from the aspect of the hemispherical heat balance and from the aspect of applied meteorology in the context of civil engineering and agriculture. In agricultural studies the use of solar radiation by crops and the associated uptake and loss of water is of particular significance.

At the present time solar radiation observing stations are few in number and even now the available records are of relatively short duration, being confined to the present century for the oldest stations, but to the last decade for most. In these circumstances it has been necessary in the past, and it is still, to use the very numerous long records of duration of bright sunshine (obtained with the Campbell–Stokes sunshine recorder and similar instruments) to infer total radiation data when no direct information is available. The intermediate step is usually taken of determining regression equations between total solar radiation and corresponding duration of bright sunshine data for stations where both are available. These regression equations are then used as interpolation formulae and the required data are deduced.

One of the earliest examples of such an approach was that of Angström² who obtained an equation of the form

$$Q = Q_A \left(a + b \frac{n}{N} \right),$$

where Q = total solar radiation

Q_A = total solar radiation received through a transparent atmosphere

n = duration of bright sunshine

N = maximum possible duration of sunshine

a, b are constants, taking the values $a=0.25$ and $b=0.75$ for Stockholm.

In recent years Penman³ has incorporated this approach in his well known work on evaporation and reports that, for Rothamsted, $a=0.18$ and $b=0.55$. Also Black^{4,5} has investigated total radiation data from 37 stations, principally in the northern hemisphere, with records lasting three years or longer. He has concluded that the constants a and b may be allotted the general values $a=0.23$ and $b=0.48$, and that there is no evidence for a systematic latitudinal variation of a and b though both may be grouped according to latitude ranges. On the basis of these latter figures Black has derived fairly coarse distributions of total solar radiation for the northern hemisphere.

In recent years the number of stations making solar radiation observations has increased greatly and the further development of international co-ordinating bodies has led to the adoption of a common pyrheliometric scale (the International Pyrheliometric Scale, 1957) and recognized standard techniques. It is worthy of comment that international co-operation in this field dates from early in the present century.

In Great Britain recording of total solar radiation on a horizontal surface started in 1913 at South Kensington where a continuously recording Calendar instrument operated until 1939; a similar record was made at Rothamsted between 1931 and 1940. Spot readings of the normal incidence radiation near noon on substantially clear days were made at the geophysical observatories at Kew and Eskdalemuir, after about 1911, with Angström compensation pyrheliometers.

Continuous recording of normal incidence radiation commenced at Kew Observatory in 1932 and the data has been analysed by Stagg⁶. Continuous recording of total solar radiation on a horizontal surface, however, was not recommenced until 1946, this time at Kew Observatory. In 1950 a small network of solar radiation recording stations was set up, though continuous recording was not general until 1952, but it was not until late in 1955 that arrangements were made for the regular calibration of equipment, the supervision of techniques and the reporting of data to a central organization. At about the same time, that is the middle of the last decade, several research groups outside the Meteorological Office and mainly working in agriculture commenced recording total solar radiation on a horizontal surface following the lead given by Rothamsted many years before.

At the present time there are 17 stations recording total solar radiation on a horizontal surface in the United Kingdom and one in Eire. Of these, six are operated by the Meteorological Office (which also makes radiation observations from ocean weather ships), one by Trinity House, one by the Electrical Research Association, one by the Building Research Station and the remainder by groups concerned in some way in agricultural or horticultural research. These stations are equipped variously with Moll-Gorczyński solarimeters or photocell detectors of a pattern developed by the National Institute for Agricultural Engineering⁷ and recording is by thread-recorder, potentiometric recorder, integrating motor or electrolytic integrator.

All these stations report their data on the International Pyrheliometric Scale and derive their standardization from one of three sources:

- (i) Kew Observatory,
- (ii) National Institute for Agricultural Engineering (N.I.A.E.),
- (iii) Physikalische Observatorium, Davos,

all three of which are linked by regular intercomparisons. The majority report their data, on a daily basis, on a common form to the Meteorological Office for registration on standard Hollerith cards and storage as part of the national library of meteorological records. Analysis of these data is undertaken as required.

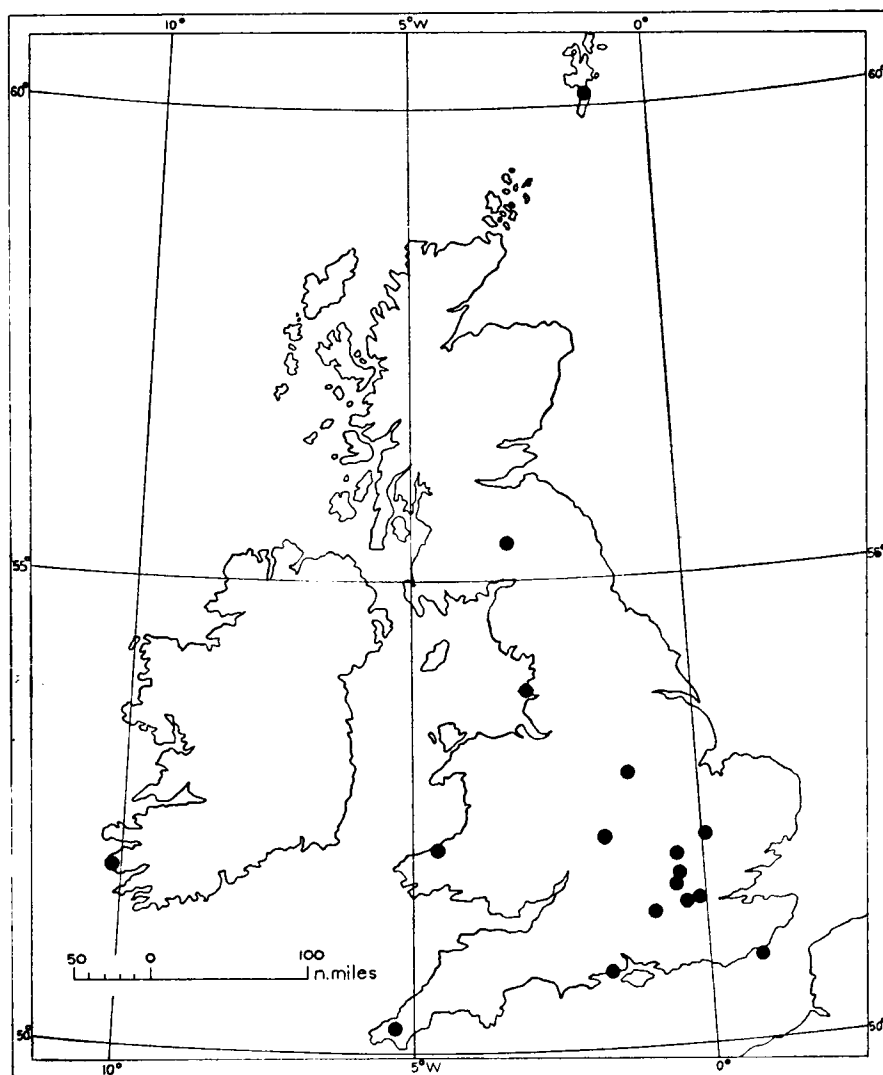


FIGURE 1—DISTRIBUTION OF STATIONS FROM WHICH DATA HAVE BEEN DRAWN

The data.—Data have been drawn from 17 land stations and 3 ocean weather stations having records lasting two years or longer. Table I lists these stations and some relevant information concerning them and Figure 1 shows their distribution.

TABLE I—DETAILS OF STATIONS USED

Station	Position	Responsible body	Period now available	Equipment	Source of standardization	Reports to Met. Office
Lerwick	60°08'N 01°11'W	Met. Office	1958-60	S. + T.R.	Kew	Yes
Eskdalemuir	55°19'N 03°12'W	Met. Office	1950-60	S. + T.R.	Kew	Yes
Fairfield	53°48'N 02°53'W	Min. of Agric. Fish and Food	1958-60	S. + E.I.	N.I.A.E.	Yes
Sutton Bonnington	52°50'N 01°15'W	School of Agric., Univ. of Leicester	1958-60	S. + E.I.	N.I.A.E.	Yes
Wellesbourne	52°12'N 01°36'W	National Vegetable Research Station	1956-60	S. + E.I.	N.I.A.E. and Kew	Yes, not in standard form
Cambridge	52°13'N 00°06'E	Met. Office	1956-59	S. + T.R.	Kew	Yes
Silsoe	52°00'N 00°28'W	N.I.A.E.	1956-60	S. + P.	Kew	Yes
Rothamsted	51°48'N 00°21'W	Lawes Agric. Trust	1955-59	S. + P.M.	Kew	Yes
Garston	51°42'N 00°23'W	D.S.I.R. Building Research Station	1957-60	S. + P.E.	Kew	Yes
Aberporth	52°08'N 04°34'W	Met. Office	1957-60	S. + T.R.	Kew	Yes
Air Ministry, Kingsway	51°30'N 00°07'W	Met. Office	1956-60	S. + T.R.	Kew	Yes
Kew Observatory	51°28'N 00°19'W	Met. Office	1952-59	S. + I.M.	Compares with Davos	Yes
Shinfield Green	51°25'N 00°57'W	Electrical Research Assoc.	1957-60	S.	N.I.A.E.	Yes
Rosewarne	50°13'N 05°18'W	Min. of Agric. Fish and Food	1958-60	Ph. + E.I.	N.I.A.E.	Yes
Efford	50°44'N 01°36'W	Min. of Agric. Fish and Food	1957-60	S. + E.I.	N.I.A.E.	Yes
Dungeness	50°55'N 00°58'E	Trinity House	1957-60	B.	Kew	Yes, not in standard form
Valentia Observatory	51°56'N 10°15'W	Met. Office	1958-60	S.	Davos	No
Ocean weather stations	$\left\{ \begin{array}{l} \text{A } 62^{\circ}60'N \\ \quad 33^{\circ}00'W \\ \text{I } 59^{\circ}00'N \\ \quad 19^{\circ}00'W \\ \text{J } 52^{\circ}30'N \\ \quad 20^{\circ}00'W \end{array} \right\}$	Met. Office	1958-60	S. + P.	Kew through Eskdalemuir	Yes

S. = Solarimeter
T.R. = Thread recorder
Ph. = Photometer

I.M. = Integrating motor + counter
E.I. = Electrolytic integrator
P. = Potentiometric recorder

P.M. = Potentiometric recorder + mechanical integrator
P.E. = Potentiometric recorder + electrical integrator circuit
B. = Bimetallic actinograph (M.O. Mk. III)

In addition to these data certain other stations record solar radiation but their data are either in an unsuitable form (for example, the School of Cosmic Physics, Dublin, which records radiation received by a spherical collector) or for a short period (for example, the Scottish Horticultural Research Institute, Invergowrie, and the Stockbridge House Experimental Horticulture Station). In the case of Dungeness, which is listed in Table I, a duration of bright sunshine record is not available, but data obtained directly have been used as a guide in drawing the distributions in the area.

In the case of those stations in Table I, the record used is often only a fraction of that available. In these cases a portion of the period has been discarded because of instrumental uncertainties, because the data are not easily accessible, or because a reliable duration of sunshine record has not been available for the whole period. The data remaining are, so far as can be ascertained, entirely reliable.

Following the precedent of Angström, Penman, Black and others a regression equation has been obtained for each of the stations listed, except for the ocean weather stations where a duration of bright sunshine record is not maintained. The regression equation takes the form stated above, that is

$$Q = Q_A \left(a + b \frac{n}{N} \right),$$

and the quantities used are monthly mean daily totals of bright sunshine n and of total solar radiation on a horizontal surface Q . In all cases n is derived from the Campbell-Stokes sunshine recorder. N is the length of day and Q_A that radiation which would be received on a horizontal surface at the station through a transparent atmosphere. The values of Q_A used are those listed by Angot.⁸ The results obtained are summarized in Table II.

Previous work has suggested that although the constants may be grouped according to latitude ranges there is no regular latitudinal variation. The present values appear to support this view. Of the values quoted in Table II those for Cambridge, Aberporth, Kingsway and Rosewarne call for comment. The view has been expressed (Penman) that these anomalous values arise from defects of instrumentation, tabulation or exposure and that they should be rejected, particularly as they produce local maxima in the deduced total solar radiation distributions. In the case of Aberporth, Cambridge and Kingsway these matters have been examined and there appears no cause to fault them save that the exposure at Kingsway is not entirely perfect. Rosewarne is regularly inspected by staff of the N.I.A.E. and there appears no reason for the station to be at fault any more than other stations supervised by the same institution. Further, Aberporth and Rosewarne, supervised independently by two different institutions and having differing types of equipment produce consistent data.

A further objection which might be raised is that in some cases (for example, Rosewarne) $a + b$ exceeds or approaches unity whence it would appear possible that $Q \geq Q_A$. However, the regressions have been obtained on the basis of monthly means of daily totals of the related data and $Q \geq Q_A$ would imply n/N approaching unity on a monthly basis. This is clearly highly improbable in the area to which the investigation is confined and it is not intended that the values obtained for the constants a and b should be regarded as generally applicable outside this area. The use of regression equations on a

TABLE II—REGRESSION EQUATION BETWEEN TOTAL SOLAR RADIATION AND DURATION OF BRIGHT SUNSHINE, $Q = Q_A \left(a + b \frac{n}{N} \right)$

Station	Number of months used	Period	Mean values of		Range of values of		Regression constants		Sum $a+b$	Correlation coefficient
			$\frac{Q}{Q_A}$	$\frac{n}{N}$	$\frac{Q}{Q_A}$	$\frac{n}{N}$	a	b		
Lerwick	43	1956-60	0.323	0.212	0.217 0.446	0.060 0.420	0.19	0.65	0.84	0.84
Eskdalemuir	100	1950-60	0.316	0.258	0.170 0.478	0.048 0.534	0.17	0.55	0.72	0.74
Fairfield	22	1958-60	0.313	0.317	0.145 0.457	0.127 0.518	0.11	0.63	0.74	0.63
Sutton Bonnington	25	1958-60	0.319	0.289	0.202 0.436	0.068 0.488	0.17	0.52	0.69	0.85
Wellesbourne	31	1951-60	0.276	0.280	0.179 0.425	0.089 0.521	0.12	0.57	0.69	0.87
Cambridge	32	1956-59	0.351	0.316	0.190 0.514	0.064 0.539	0.12	0.75	0.87	0.99
Silsoe	47	1956-60	0.346	0.325	0.203 0.545	0.078 0.591	0.15	0.59	0.74	0.86
Rothamsted	32	1955-59	0.344	0.312	0.203 0.501	0.050 0.579	0.16	0.60	0.76	0.78
Garston	40	1957-60	0.313	0.253	0.176 0.468	0.087 0.524	0.14	0.68	0.82	0.83
Aberporth	33	1957-60	0.400	0.320	0.227 0.563	0.145 0.580	0.15	0.77	0.92	0.81
Air Ministry, Kingsway	35	1956-60	0.304	0.277	0.135 0.551	0.028 0.581	0.10	0.75	0.85	0.87
Kew Observatory	96	1952-59	0.327	0.331	0.150 0.480	0.130 0.600	0.14	0.57	0.71	0.86
Shinfield Green	31	1957-60	0.270	0.315	0.096 0.457	0.116 0.598	0.08	0.61	0.69	0.86
Rosewarne	22	1958-60	0.411	0.349	0.224 0.631	0.127 0.623	0.08	0.96	1.04	0.95
Efford	45	1957-60	0.399	0.378	0.190 0.512	0.143 0.646	0.20	0.54	0.74	0.84
Valentia	60	1954-59	0.404	0.290	0.256 0.616	0.130 0.610	0.22	0.65	0.87	0.90

daily basis, when n/N may approach unity, has been investigated by Blackwell⁹ who has shown that (for Kew) it is not possible to obtain a simple linear equation. For this reason the extension of these data to periods significantly less than a month is specifically excluded from the present investigation.

For these reasons it has been decided to accept all the values listed in Table II as valid and they have been used in the deduction of distributions of total solar

radiation on a horizontal surface. Further, since the constants a and b vary widely from place to place a single set of mean values has not been used, but the regression equation for a particular radiation station applied to sunshine stations of approximately similar exposure in the vicinity. In this way solar radiation data have been deduced for 40 stations, reasonably uniformly distributed over the British Isles (though there are some notable areas of sparse coverage). Table III lists the sunshine stations used and the "parent" radiation station in each case.

TABLE III—STATIONS USED IN THE DEDUCTION OF SOLAR RADIATION DISTRIBUTIONS

"Parent" radiation station	Sunshine station	Position	"Parent" radiation station	Sunshine station	Position
Lerwick	Onich	56°43'N 05°13'W	Cambridge (cont.)	Cromer	52°56'N 01°17'E
	Stornoway	58°13'N 06°20'W		Felixstowe	51°57'N 01°20'E
	Kirkwall	58°59'N 02°57'W	Aberporth	Holyhead	53°19'N 04°37'W
	Nairn	57°36'N 03°52'W		Oxford	51°46'N 01°16'W
	Inverness	57°26'N 04°13'W	Rosewarne	Bude	50°50'N 04°33'W
	Oban	56°25'N 05°30'W		Penzance	50°07'N 05°32'W
	Craibstone	57°11'N 02°12'W		Jersey	49°11'N 02°06'W
Eskdalemuir	Keswick	54°36'N 03°09'W		Guernsey	49°27'N 02°23'W
	Newton Rigg	54°40'N 02°47'W	Efford (Lymington)	Brighton	50°49'N 00°50'W
Fairfield	Douglas	54°10'N 04°28'W		Bexhill	50°50'N 00°28'E
	Bidston	53°24'N 03°04'W		Totland Bay	50°41'N 01°33'W
	Morecambe	54°04'N 02°52'W		Ryde	50°44'N 01°10'W
Sutton Bonnington	Leamington Spa	52°18'N 01°30'W		Eastbourne	50°46'N 00°17'W
Wellesbourne	Birmingham	52°29'N 01°56'W		Weymouth	50°36'N 02°27'W
	Coventry	52°23'N 01°29'W		Sidmouth	50°41'N 03°14'W
	Malvern	52°08'N 02°18'W		Calshot	50°49'N 01°18'W
Cambridge	Norwich	52°37'N 01°17'E		Sandown	50°39'N 01°09'W
	Hunstanton	52°57'N 00°29'E		Ventnor	50°36'N 01°13'W
	Yarmouth	52°35'N 01°43'E		Worthing	50°49'N 00°22'W
				Bournemouth	50°43'N 01°53'W
				Hastings	50°51'N 00°34'E

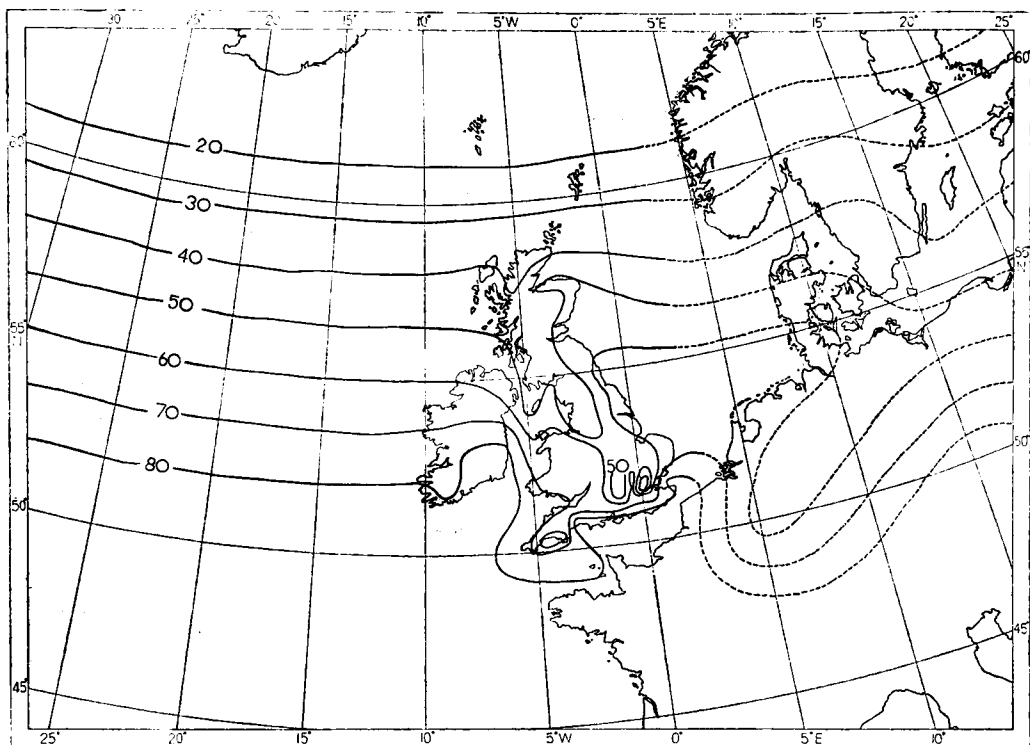


FIGURE 2—ISOPLETHS OF MEAN DAILY TOTAL OF TOTAL SOLAR RADIATION
(MW HR CM⁻² DAY⁻¹) FOR JANUARY

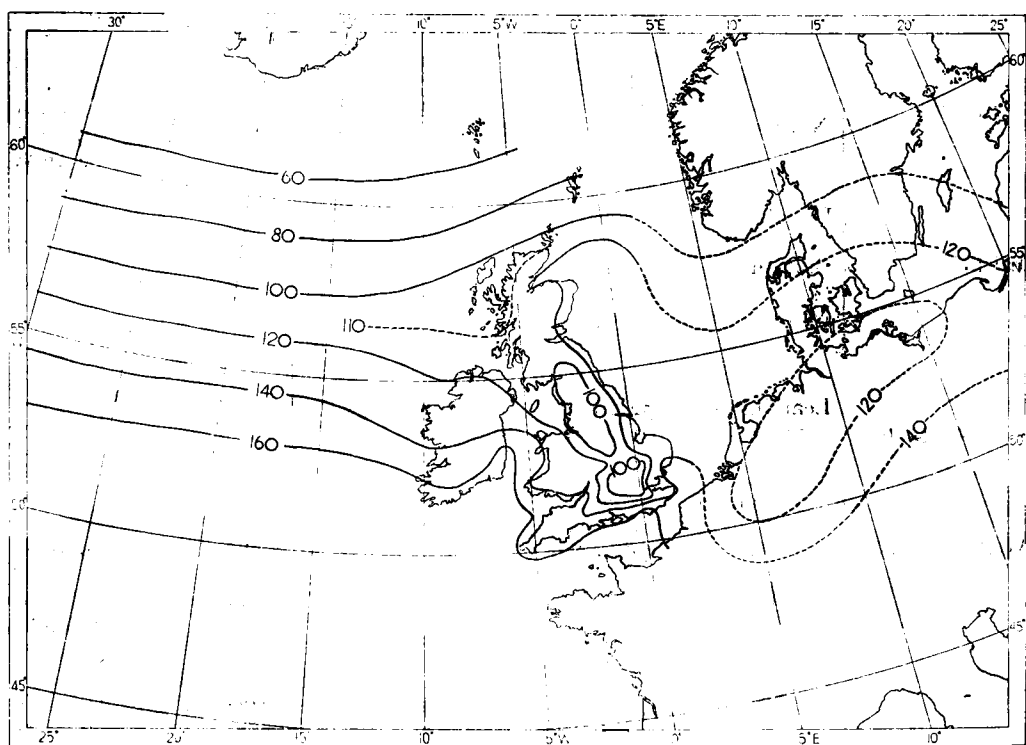


FIGURE 3—ISOPLETHS OF MEAN DAILY TOTAL OF TOTAL SOLAR RADIATION
(MW HR CM⁻² DAY⁻¹) FOR FEBRUARY

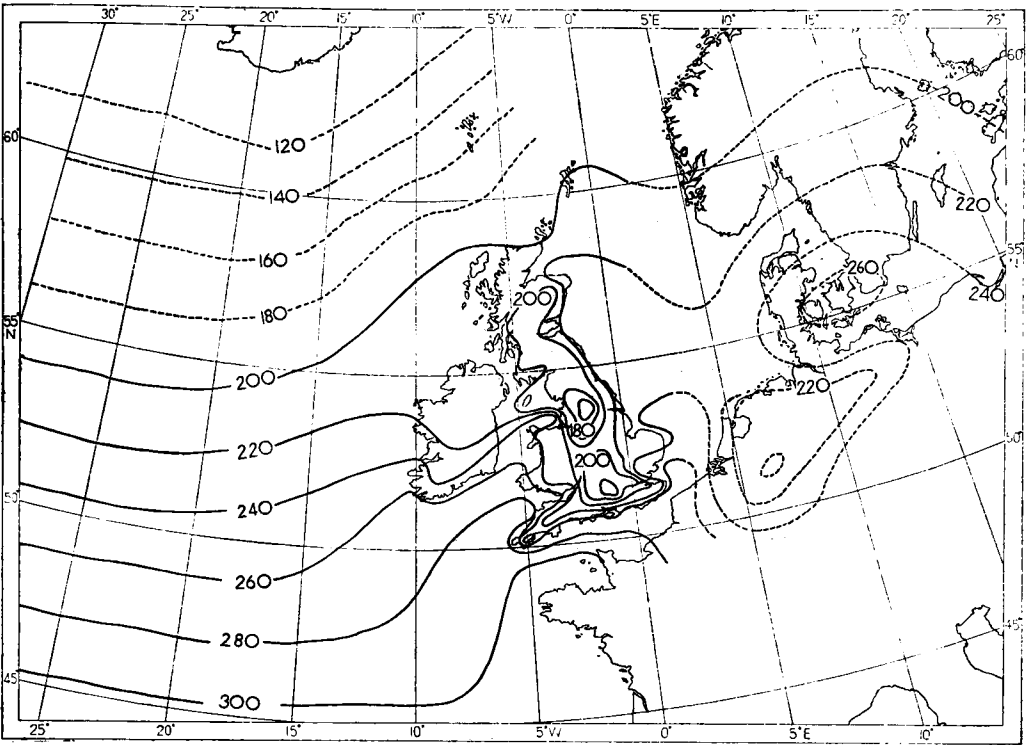


FIGURE 4—ISOPLETHS OF MEAN DAILY TOTAL OF TOTAL SOLAR RADIATION
($\text{MW HR CM}^{-2} \text{ DAY}^{-1}$) FOR MARCH

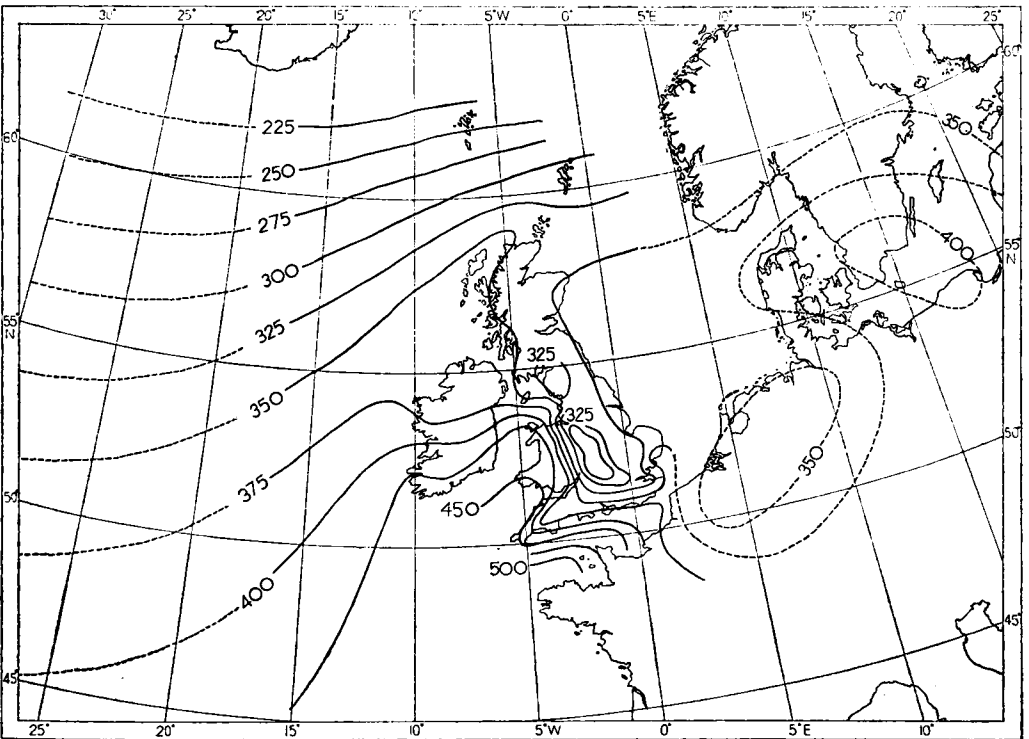


FIGURE 5—ISOPLETHS OF MEAN DAILY TOTAL OF TOTAL SOLAR RADIATION
($\text{MW HR CM}^{-2} \text{ DAY}^{-1}$) FOR APRIL

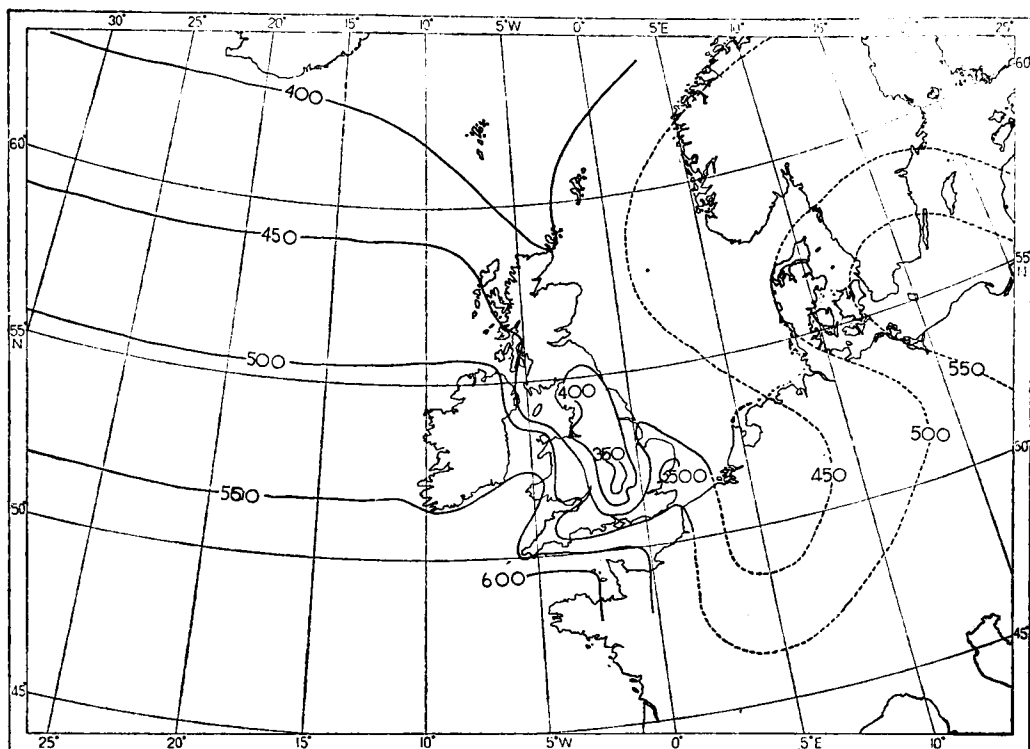


FIGURE 6—ISOPLETHS OF MEAN DAILY TOTAL OF TOTAL SOLAR RADIATION
($\text{MW HR CM}^{-2} \text{ DAY}^{-1}$) FOR MAY

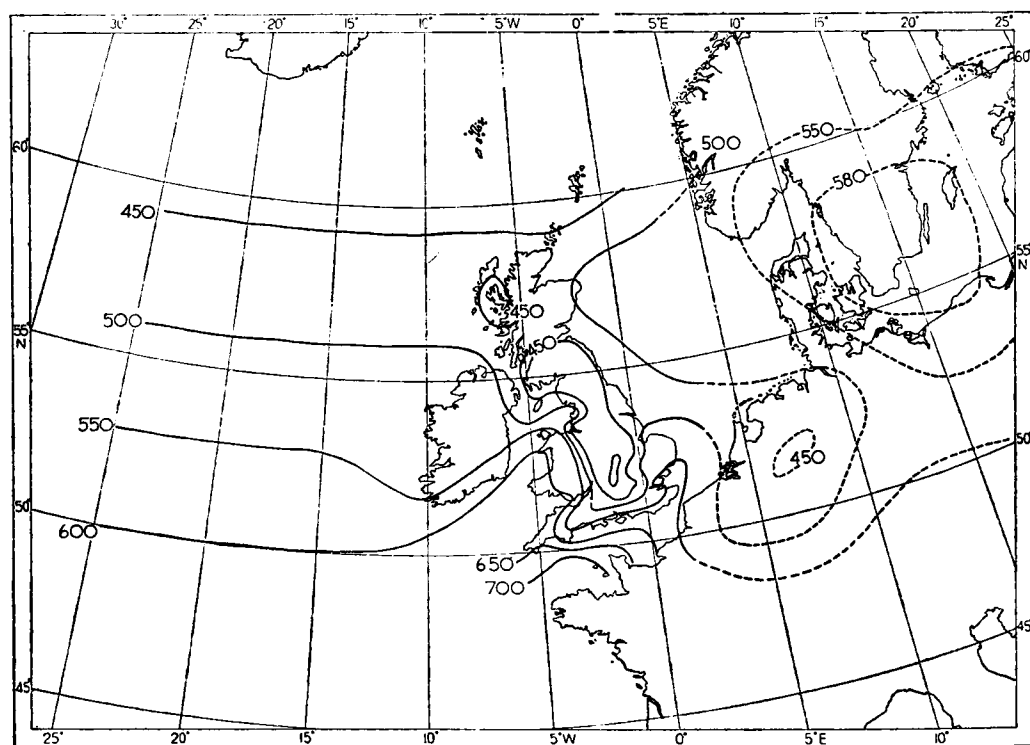


FIGURE 7—ISOPLETHS OF MEAN DAILY TOTAL OF TOTAL SOLAR RADIATION
($\text{MW HR CM}^{-2} \text{ DAY}^{-1}$) FOR JUNE

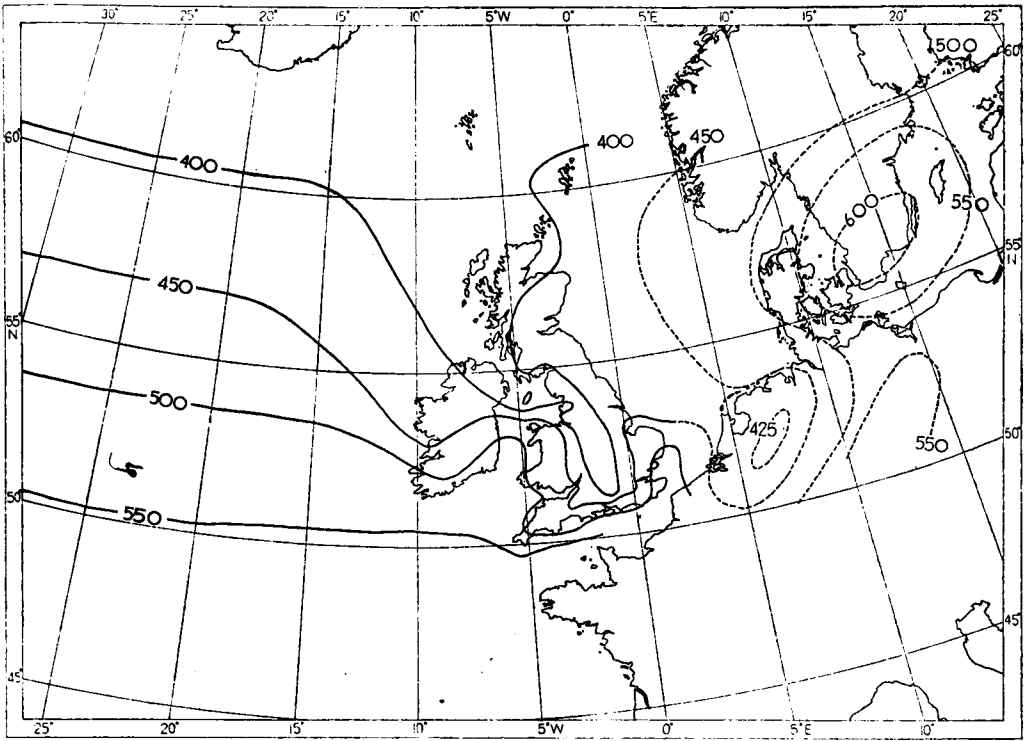


FIGURE 8—ISOPLETHS OF MEAN DAILY TOTAL OF TOTAL SOLAR RADIATION
($\text{MW HR CM}^{-2} \text{ DAY}^{-1}$) FOR JULY

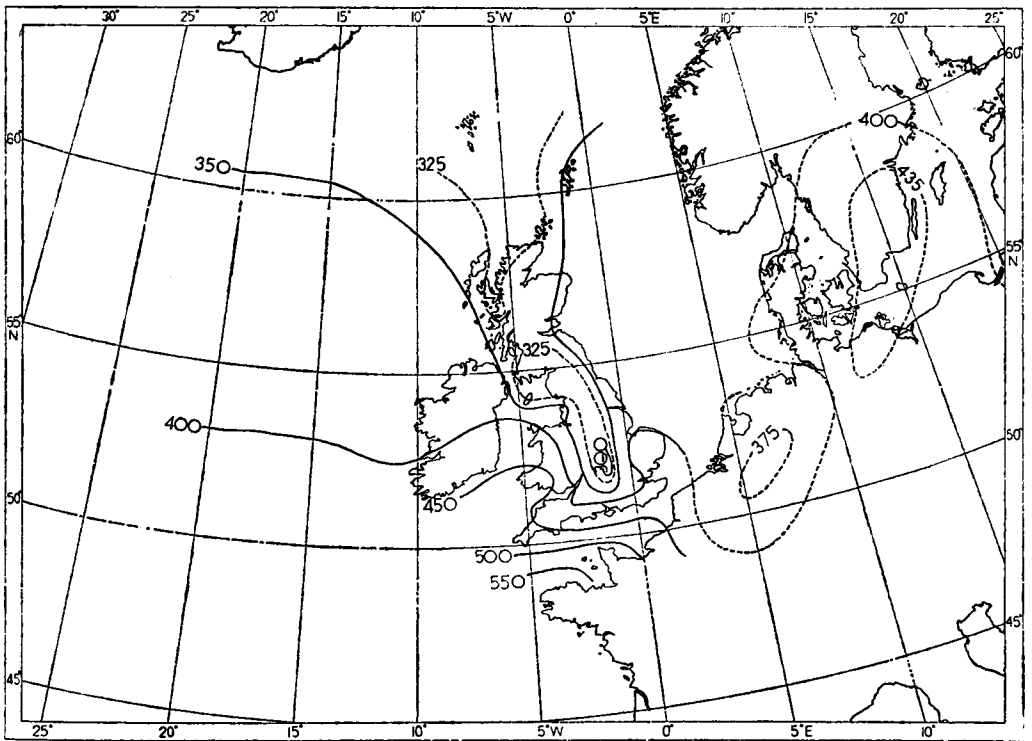


FIGURE 9—ISOPLETHS OF MEAN DAILY TOTAL OF TOTAL SOLAR RADIATION
($\text{MW HR CM}^{-2} \text{ DAY}^{-1}$) FOR AUGUST

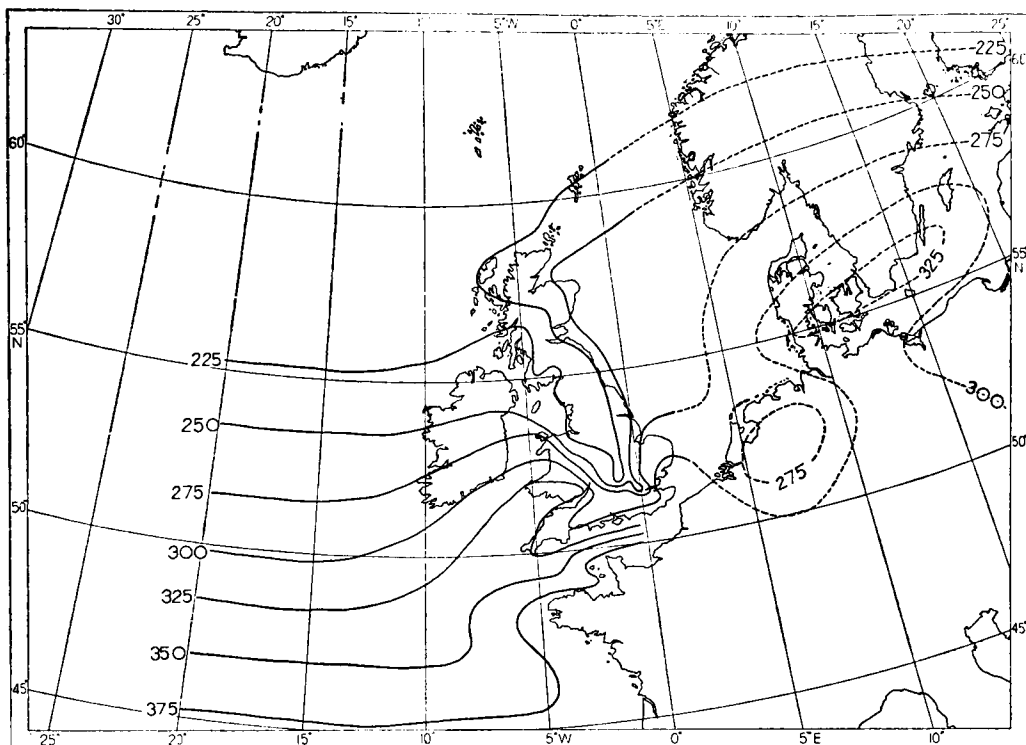


FIGURE 10—ISOPLETHS OF MEAN DAILY TOTAL OF TOTAL SOLAR RADIATION
(MW HR CM⁻² DAY⁻¹) FOR SEPTEMBER

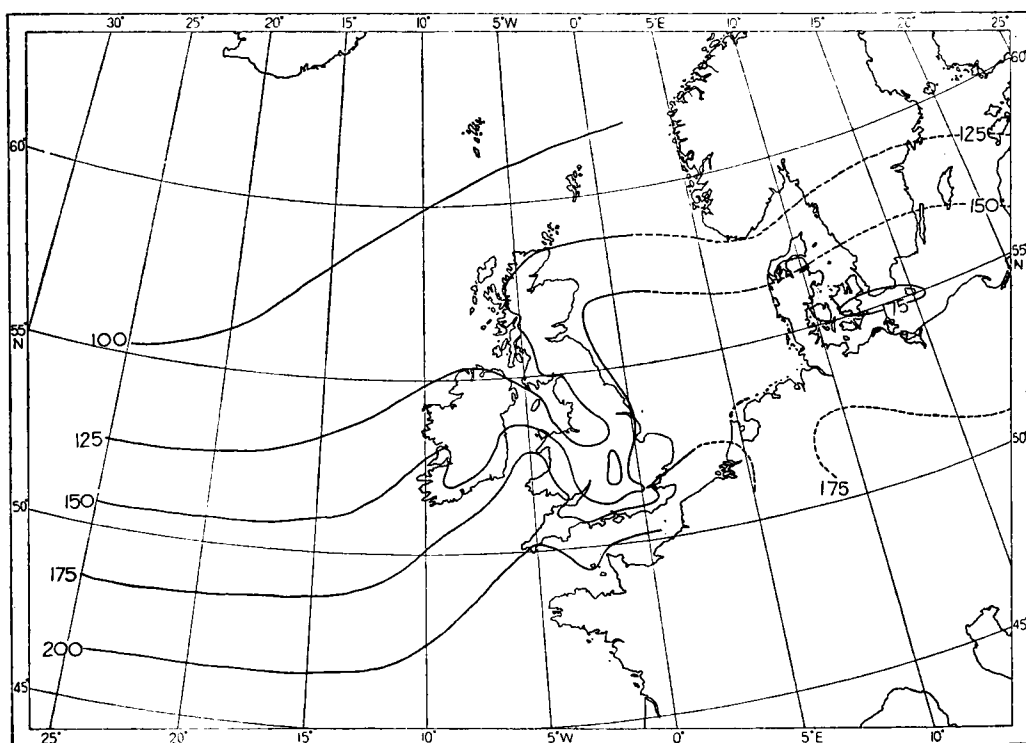


FIGURE 11—ISOPLETHS OF MEAN DAILY TOTAL OF TOTAL SOLAR RADIATION
(MW HR CM⁻² DAY⁻¹) FOR OCTOBER

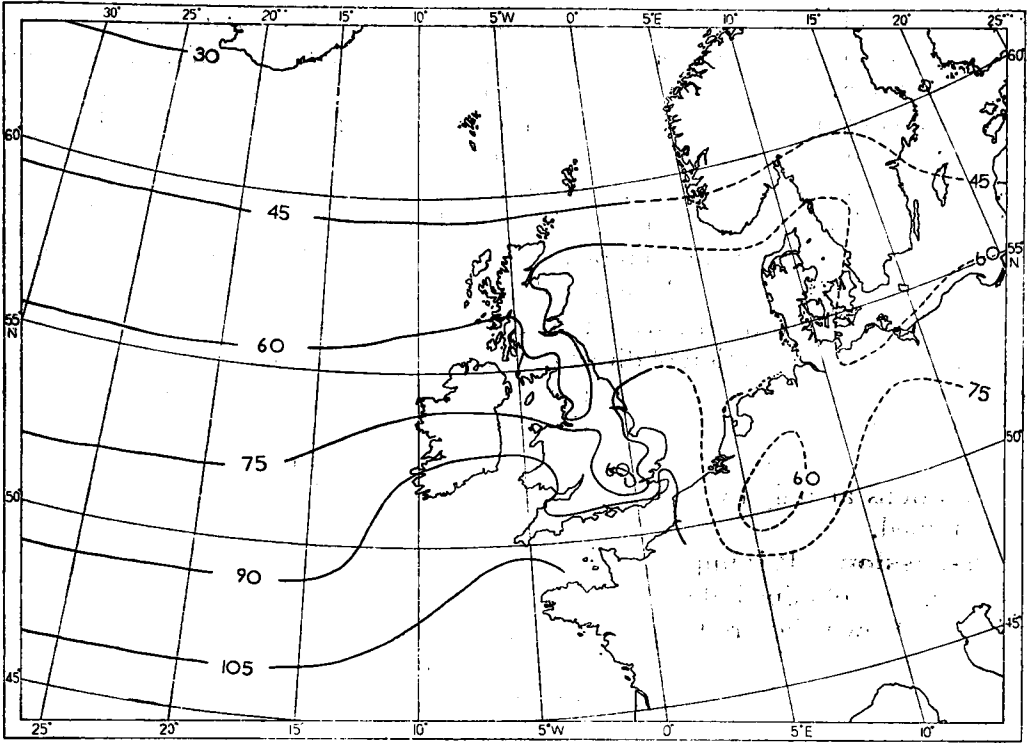


FIGURE 12—ISOPLETHS OF MEAN DAILY TOTAL OF TOTAL SOLAR RADIATION
($\text{MW HR CM}^{-2} \text{ DAY}^{-1}$) FOR NOVEMBER

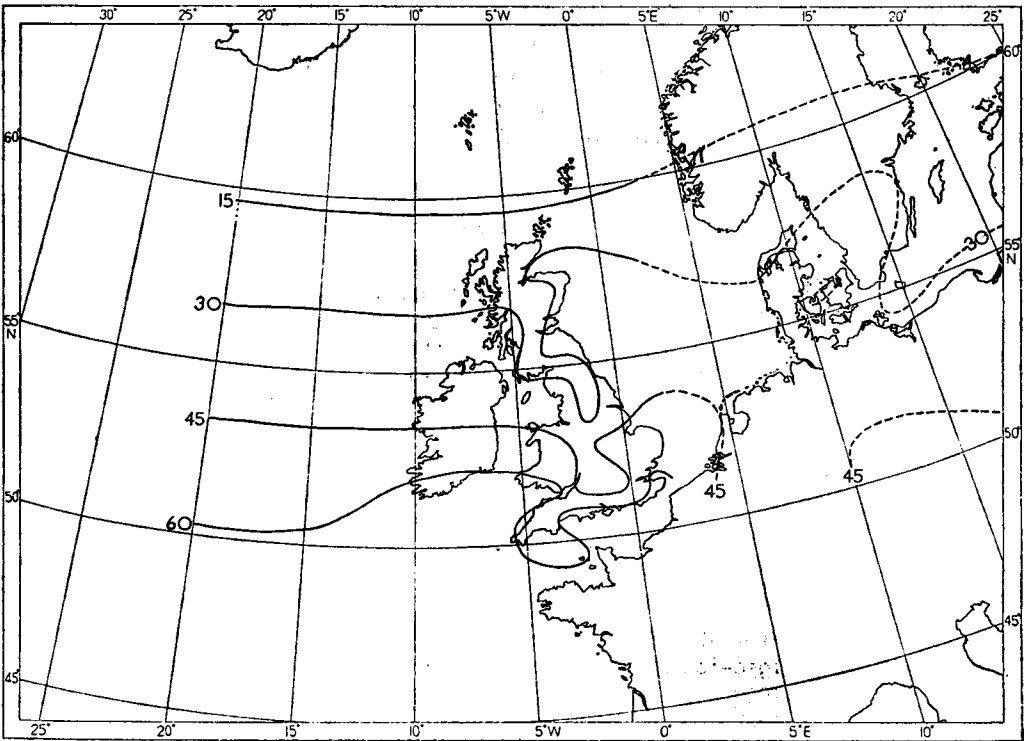


FIGURE 13—ISOPLETHS OF MEAN DAILY TOTAL OF TOTAL SOLAR RADIATION
($\text{MW HR CM}^{-2} \text{ DAY}^{-1}$) FOR DECEMBER

For each of these 40 stations the monthly mean daily totals of bright sunshine have been taken from *Averages of bright sunshine for Great Britain and Northern Ireland, 1921-1950*¹⁰ and the appropriate regression equation used to deduce a corresponding monthly mean daily total of total solar radiation on a horizontal surface. The direct data available from the 17 radiation stations listed in Table I have been normalized to the same period (1921-50) by use of the relative durations of bright sunshine, and the total of 57 values so obtained plotted as monthly distributions on a conical orthomorphic projection (standard latitudes 60° and 45°N). These distributions have been smoothly linked to the east with similar distributions obtained by Black for the region 50°-60°N and 05°-30°E by consideration of direct data from a number of radiation stations in north-eastern Europe. Similarly the distributions have been extended to the west by use of direct data from the British ocean weather ships, though this latter extension is much more tentative since it is based on a short period of observations at only two positions. Figures 2-13 are the monthly distributions so obtained.

Discussion.—It is important to consider what confidence may be placed in the diagrams obtained above. The questions arise:

(a) How valid are the extrapolations of short-period radiation data to the longer periods covered by the sunshine data?

(b) How valid is the application of a single regression equation obtained from a run of data to individual months, that is, is there a seasonal variation in the regression constants?

(c) How accurate are the estimates represented by the diagrams?

These questions may be considered in turn as follows:

Question (a).—We may take the data from the three stations having the longest run of data known to be reliable—Kew, Rothamsted and Eskdalemuir—and divide the data into minor runs, recalculating the regression equations and comparing the constants so obtained with those originally derived. The results are given in Table IV, whence it would appear that

TABLE IV

(i) *Kew*

Period			Value of constant	
			<i>a</i>	<i>b</i>
1952-59 ...	...	...	0·14	0·57
1952-55 ...	...	...	0·15	0·57
1956-59 ...	...	...	0·17	0·50

(ii) *Rothamsted*

Period		Value of constant		
		<i>a</i>	<i>b</i>	
1931-40 ...	...	0·18	0·55	<i>Note:</i> two periods correspond to differing instrumentation, hence earlier period not used in Table II.
1955-59 ...	...	0·16	0·60	

(iii) *Eskdalemuir*

Period			Value of constant	
			<i>a</i>	<i>b</i>
1950-60 ...	...	...	0·17	0·55
1950-55 ...	...	...	0·17	0·59
1956-60 ...	...	...	0·16	0·62

in the worst case (that is, of $n/N = 1$) the uncertainty at Kew is about $\pm 3\cdot5$ per cent, at Rothamsted about ± 2 per cent and at Eskdalemuir about ± 2 per cent.

Question (b).—Similarly, the data for Kew, Eskdalemuir and Lerwick may be subdivided into two-month groups and the regression equations recalculated, the constants then being examined for a seasonal variation. Table V lists the data obtained.

TABLE V—BIMONTHLY REGRESSION CONSTANTS

Station	Jan.–Feb.		Mar.–Apr.		May–June		July–Aug.		Sept.–Oct.		Nov.–Dec.	
	<i>a</i>	<i>b</i>	<i>a</i>	<i>b</i>	<i>a</i>	<i>b</i>	<i>a</i>	<i>b</i>	<i>a</i>	<i>b</i>	<i>a</i>	<i>b</i>
Kew ...	0.15	0.35	0.16	0.50	0.31	0.02	0.22	0.42	0.18	0.51	0.19	0.27
Eskdalemuir ...	0.13	0.69	0.22	0.42	0.16	0.60	0.20	0.57	0.17	0.59	0.15	0.52
Lerwick ...	0.17	0.61	0.14	0.75	0.23	0.54	0.20	0.67	0.33	0.04	0.19	0.62

a and *b* are constants in the regression equation $\frac{Q}{Q_A} = a + b \frac{n}{N}$

It will be seen that there is no consistent seasonal trend. This procedure may, however, be criticized in that the number of cases in each group is perhaps too small for a significant result to emerge. It is thought that, though no great use may be made of the values listed, some systematic pattern should have appeared had there been a seasonal variation.

Question (c).—It is instructive to examine records from the three stations Kew, Eskdalemuir and Lerwick once more. Examination of the individual monthly means shows that for a given value of n/N the observed value of Q/Q_A may vary by ± 20 per cent at Kew, ± 15 per cent at Eskdalemuir and ± 25 per cent at Lerwick and this is a measure of the possible error in the estimate for a single month. Obviously, however, for long-term prediction of an average condition the errors are much reduced, but these figures must still be borne in mind as an indication of the basic lack of precision of the method—there is no accurate substitute for actual measurement at a site, though in a particular case this is often impracticable, or not appropriate to the local problem.

The diagrams presented, then, provide an indication of the distribution of total solar radiation on a horizontal surface over the British Isles and adjacent areas, and of the changes in the distribution through the year. Estimates of total radiation based on these diagrams may, however, be in error by up to ± 25 per cent for an individual month and daily totals will differ greatly from these values.

Suggestions for further work.—As will have been noted, the distribution of radiation stations in the network is badly biased and the data at present available very restricted. An investigation similar to this one would appear to be desirable in a further five or ten years' time when more data are available. Consideration of an extension to the radiation network appears to be desirable at the present time.

Acknowledgements.—Acknowledgements are gratefully made to the authorities responsible for the stations named in Table I for permission to use the data gathered at their institutions, and are also due to several of my colleagues and to my wife for their assistance in the analysis of a large volume of data.

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551.501.42 : 551.508.2

RADIATION RECORDING IN THE METEOROLOGICAL OFFICE

By L. JACOBS, M.A., M.Sc.

Introduction.—This paper gives a short account of the types of radiation recording instruments in use in the Meteorological Office. These are solarimeters for measuring short-wave radiation, illumination recorders for measuring daylight, and radiometers responding to the vertical net flux of radiation (long- and short-wave) as well as the normal sunshine recorders. The instruments (and recording systems), described in turn below, are illustrated in Figure 1 and Plates I-IV (between pp. 284-285). Table I lists the home and overseas stations possessing radiation instruments and the dates recording began. The present automatic integration system being used at Kew is described and an outline is given of the digitization system being considered with tapes produced at each station being processed at a computer centre.

Short-wave radiation solarimeters

Normal incidence radiation.—Short-wave radiation in the band 0.3μ to 3μ is recorded by pyrhelimeters whose outputs are connected to recording galvanometers (Cambridge thread recorders); the direct normal incidence short-wave solar radiation has been recorded since July 1932 at Kew on a Moll-Gorczyński large surface thermopile (80 thermocouple junctions) on an equatorial mounting, driven originally by a pendulum and now by a spring clock. With slight changes of elevation each day to keep pace with changing solar declination, the heliostat ensures that the thermopile surface is kept normal to the direct radiation from the sun. A wire frame attached to a collar which fits on to the thermopile holder carries three metal diaphragms spaced outwards from the thermopile so that the angular aperture allows only radiation from the sun and a narrow annulus of sky to fall on the thermopile (see Plate I). The thermopile is protected by a glass cover.

Also at Kew are twin Moll-Gorczyński pyrhelimeters made exactly the same as the direct radiation one just described and in this case driven by an electric clock to keep them pointing into the sun's direct beam. These have filters on their apertures so as to restrict the band of solar radiation received. In the period September 1947 to November 1949 records are available separately for these two instruments and from 19 July 1956 they have been coupled so that the difference between the records of the two instruments is given thus recording short-wave radiation for a narrow band.



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PLATE I—SOLAR RADIATION EQUIPMENT AT KEW OBSERVATORY, 1953

(see p. 284)

- | | |
|-------------------------------------|-------------------------------------|
| A. Diffuse (sky) solarimeter | D. Total (sun and sky) solarimeters |
| B. Daylight illumination recorder | E. Gorczynski pyr heliometer |
| C. Twin pyr heliometer with filters | F. Sunshine recorder |



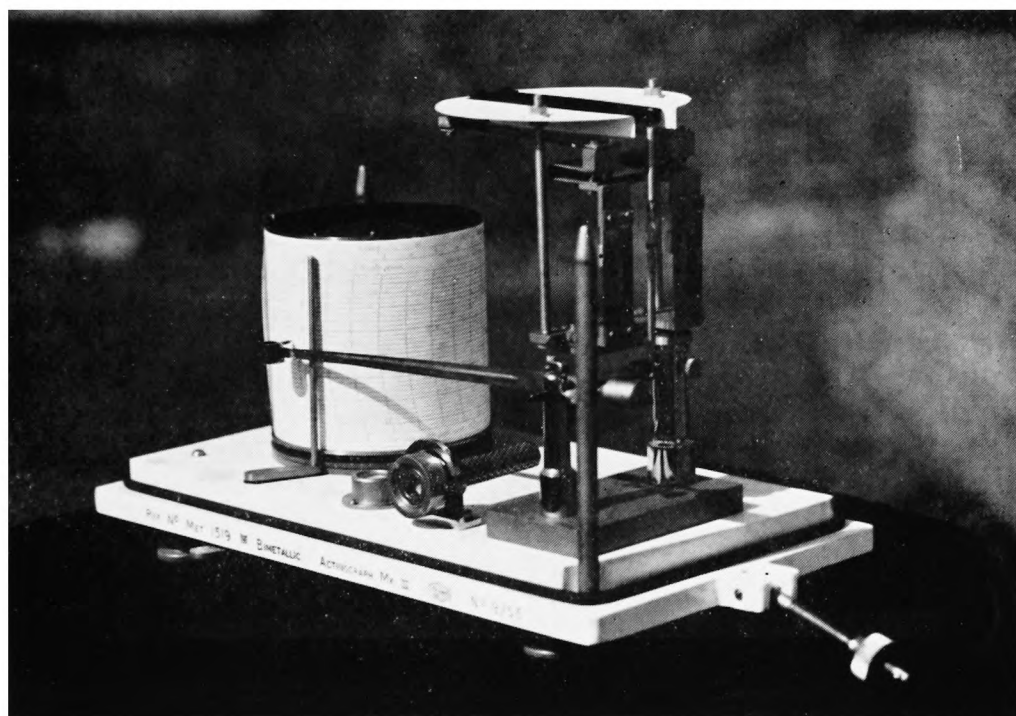
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PLATE II—TOP PLATFORM OF SOLAR RADIATION EQUIPMENT AT KEW OBSERVATORY,
1959

(see p. 285)

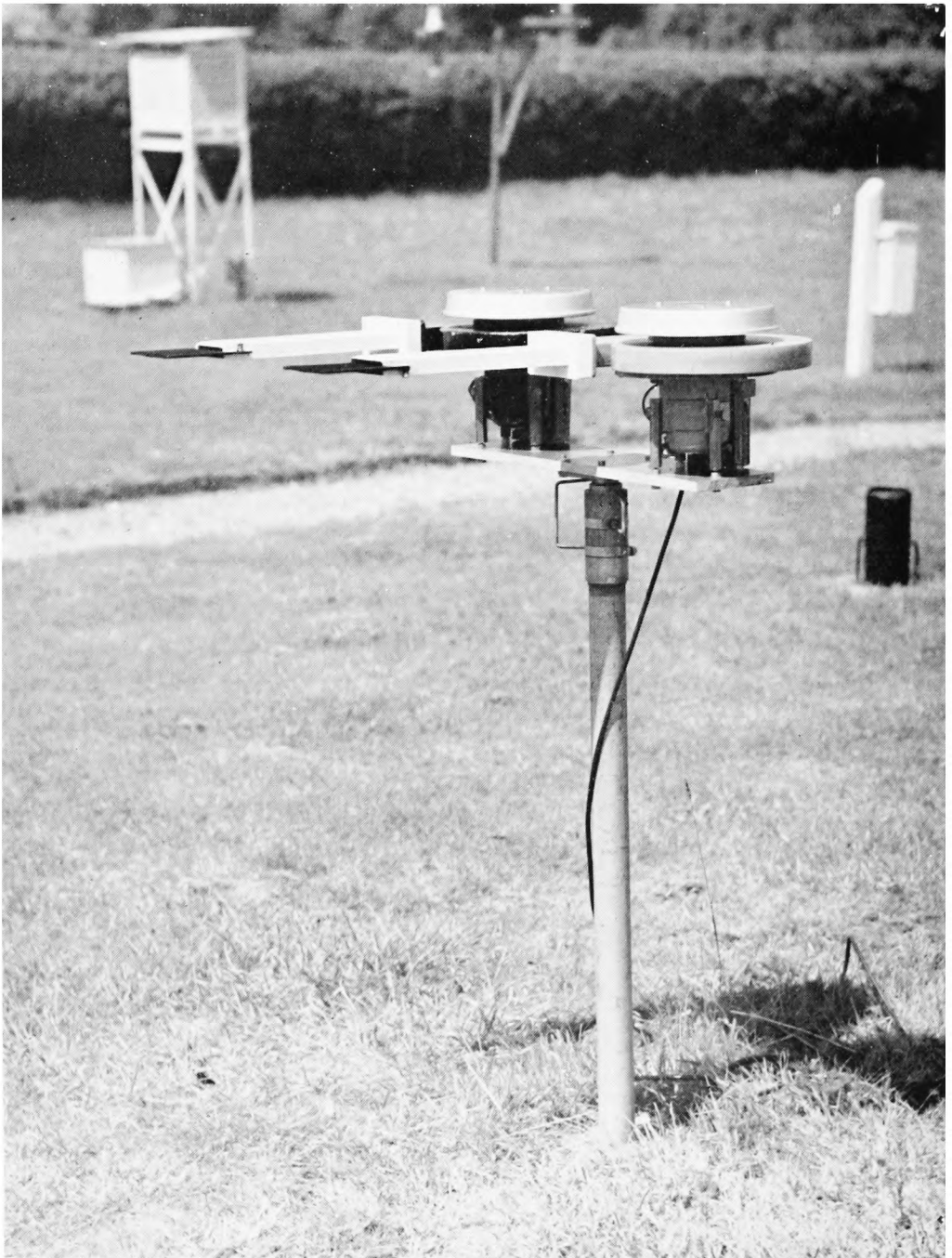
A. Daylight illumination recorder
B. Total (sun and sky) solarimeters

C. Diffuse (sky) solarimeter



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PLATE III—BIMETALLIC ACTINOGRAPH, MARK III
(see p. 286)



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PLATE IV—VENTILATED NET FLUX RADIOMETER
(see p. 287)

The records of the normal incidence solar radiation instrument were discussed by Stagg¹ for the period up to 1945. A further discussion of these results to 1949, together with the results obtained from the instruments with the filters, was given by Blackwell, Eldridge and Robinson.² Figure 2 of their paper shows the transmission properties of the filters used and the narrow band of wavelength (about 0.55μ to 0.65μ) covered by the difference of the filters. Kew is the only Meteorological Office station to have these normal incidence recorders.

TABLE I—METEOROLOGICAL OFFICE STATIONS POSSESSING RADIATION RECORDING INSTRUMENTS (EXCLUDING NORMAL SUNSHINE RECORDER), TOGETHER WITH DATE OF BEGINNING OF RECORDING

	Moll-Gorczynski pyrheliometer for normal incidence solar radiation July 1932	Moll-Gorczynski solarimeter for total radiation July 1946 Jan. 1952 Jan. 1952 Aug. 1956 Jan. 1953 Nov. 1956	Moll-Gorczynski solarimeter for diffuse radiation July 1946 Jan. 1952 Jan. 1952 Sept. 1956 Jan. 1953 Mar. 1957	Daylight illumination Jan. 1947 April 1958 April 1958 Feb. 1956	Net flux of radiation May 1953 Aug.-Sept. 1958 Oct. 1957 July 1957 June 1957 Mar. 1957 Mar. 1957
Kew					
Eskdalemuir					
Lerwick					
Cambridge					
Aberporth					
Victory House, London					
Four ocean weather ships		Jan.-Aug. 1958			
Malta		Oct. 1957	Oct. 1957		
Aden		July 1957	July 1957		
Stanley		June 1957	June 1957		
Argentine Islands*		Jan. 1956	Jan. 1956		
Halley Bay Antarctica*		Aug. 1956	Aug. 1956		

* The meteorological offices are controlled by the Falkland Islands Dependencies Survey but there is close liaison with the British Meteorological Office.

Notes: 1. A blank in the above table indicates that no instrument is held at the station

2. Stations with total radiation solarimeters have bimetallic actinographs as standby instruments (with the exception of the ocean weather ships).

Total and diffuse radiation on a horizontal surface.—The intensity of short-wave solar radiation (0.3μ to 3μ) on a horizontal surface is determined by Moll-Gorczynski solarimeters (obtained from Messrs. Kipp and Zonen). It is usual also to measure the diffuse radiation which is obtained by fitting a shade ring to the solarimeter in such a manner that the direct radiation from the sun is cut off. (The instruments used at Kew are shown in Plates I and II*.) The thermopiles have fourteen thermo-junctions covered by two hemispherical glass domes. The output from the two solarimeters is recorded by a multi-channel recording galvanometer (at land stations) or self-balancing potentiometer (on ocean weather ships). From the calibration factors of each instrument suitable resistances are included in the thermopile circuits so that under overcast skies the two traces will fall together. Recording with these instruments was started at Kew in January 1947 and the first five years of records have been discussed by Blackwell.³ These instruments are widely distributed—a list of radiation instruments maintained at the various Meteorological Office stations together with the dates of commencement of recording is given in Table I. It will be seen therein that much of the recording began with the International Geophysical Year but it is intended to continue the recording at the observatories as part of the normal routine and to do this also as far as possible at the other stations.

* Before the end of 1954 all the radiation instruments at Kew were on the balcony as shown in Plate I and corrections had to be made to the total and diffuse radiation results for obstruction by the observatory dome to the north and reflection by the dome. After this date instruments likely to be affected were removed to a new platform on top of the dome as shown in Plate II.

Short-wave radiation—bimetallic actinograph.—As a standby instrument for the total radiation solarimeter the bimetallic actinograph was developed at Kew from the Robitzsch-type actinograph.⁴ The detecting assembly consists of a central black strip and two outer strips shaded by white screens as shown in Plate III. The Mark III instrument as designed at Kew has been made commercially. The pen records on a chart are not normally analysed but are checked against the station solarimeters from time to time so that if the latter went wrong the bimetallic instrument could be used until a replacement solarimeter was obtained.

Daylight illumination recorder.—The daylight illumination recorder gives nearly the same response to the light as a standard eye, as specified by the International Commission on Illumination from the results of experiments of numerous observers. This specification states the relative sensitivity of the eye throughout the spectrum to a given quantity of monochromatic radiation. Although the sensitivity function varies with intensity at lower levels of illumination it is constant in the range adapted to conditions of high luminance (photopic vision).

The development of the illumination recorder at Kew has been discussed by Blackwell⁵ and Blackwell and Powell.⁶ Figure 2 of the first of these papers⁵ shows how close the “eye” and the selenium photocell combined with a specially constructed correcting filter, exposed below a diffusing surface of opal

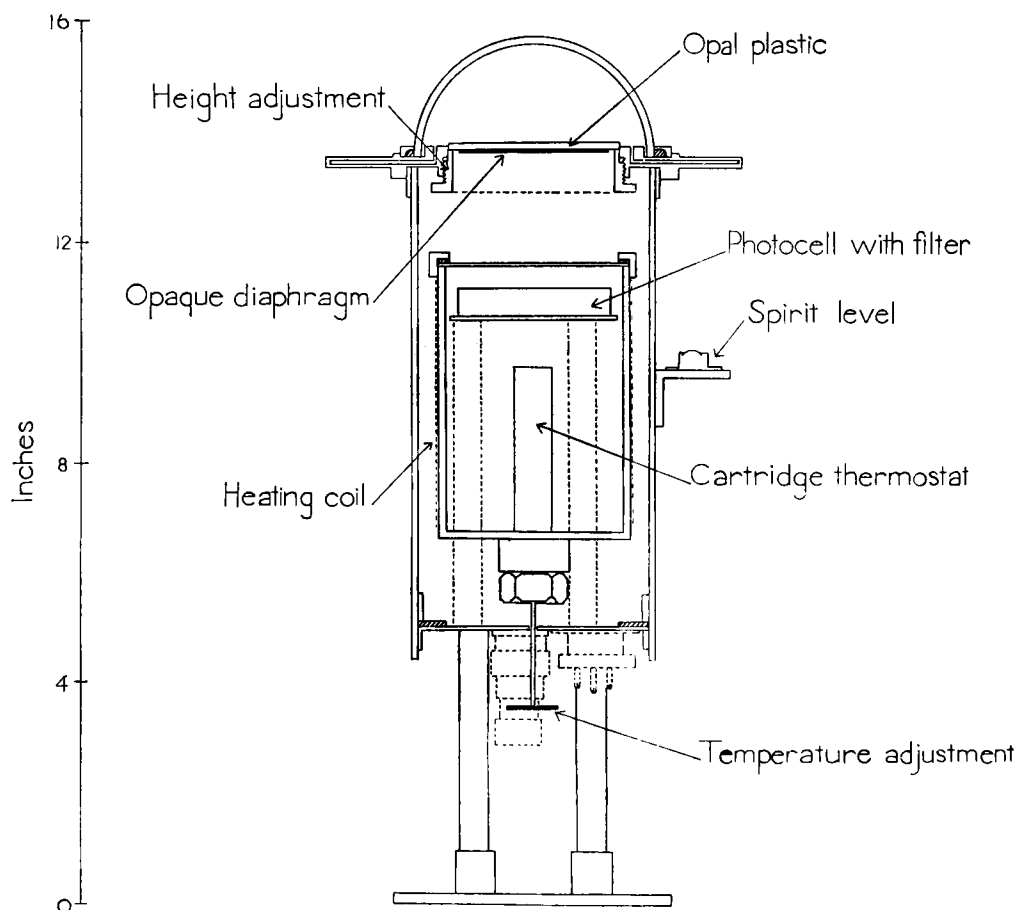


FIGURE 1—DAYLIGHT ILLUMINATION RECORDER, MARK III

plastic (see Figure 1), match in the given range 0.4μ to 0.7μ . The instrument is thermostatically controlled at 85°F to remove outside temperature effects. The current output against intensity of illumination curve for the type of photocell used depends on the load resistance. To obtain a nearly linear relation this resistance is best fixed at about 200 ohms. The output from the cell is led away to a recording galvanometer which is combined with a network of shunt and series resistors arranged in such a way as to allow three sensitivities (for different times of the year) while keeping the load resistance constant at 200 ohms.

Further development of the daylight illumination recorder is being considered at Kew including the study of photocells and filters with a longer life and the development of a recording photometer for the diffuse component of daylight.

Net flux of radiation (radiation balance).—To study the net flux of radiation, radiometers based on the design described by MacDowall⁷ (see Plate IV) are used. The sensitive element is a thermopile arranged to measure the temperature difference between the upper and lower surfaces of a flat plate about three inches square and an eighth of an inch thick. The plate, which is placed horizontally about three to four feet above a surface representative of the surrounding area, is painted black and is ventilated artificially by an electric blower to minimize the effect of wind changes. The black paint is an almost perfect absorber over a wide range of wavelength (at least 0.3μ to 40μ) and is reasonably weatherproof (though evaporative cooling causes the instrument to give false readings while the plate is actually wet from rain or snow). Land stations are generally supplied with two instruments, one for routine use and the other as a standard to judge whether the first has gone wrong. The element is robust enough to be washed to eliminate surface contamination by dust, salt or sand particles and can be repainted at the station. The output from these flux plates is recorded by a self-balancing potentiometer (on ocean weather ships) or, after amplification by a magnetic amplifier, on a pen recording milliammeter (at land stations).

On board ocean weather ships two radiometers are used one on each side of the ship surveying a half hemisphere, the two outputs being added before recording. Special mountings are necessary to ensure stability of position. Winds greater than Beaufort force 7 cause trouble through waves and spray and the instruments are then taken under cover.

Sunshine recorders.—Sunshine recorders used at stations are the normal Campbell-Stokes type and are merely mentioned here for completeness. The use of these records in considering the general radiation balance has been discussed by Blackwell, Eldridge and Robinson².

Recalibration of instruments.—Kew Observatory issues recalibrated radiation instruments about every year to all stations. Certain routine checks are made at the stations. The bimetallic actinograph is constantly checked against the total radiation solarimeter. For daylight illumination, stations can make a monthly test on a simple optical bench. The mutual check of the two net flux radiometers held at land stations has been mentioned above.

The standard of radiation at Kew is based on readings of Angström compensating pyrhelimeters which have unshielded black strips. The Moll-Gorczynski solarimeters used at Kew are calibrated against these Angström instruments (No. 24, 100A and 100B) by direct comparison on clear days. The

instruments used at outstations are calibrated by comparison with the Kew instruments, using natural radiation when possible and radiation from a 2000-watt lamp in bad weather. One of the Kew Angström instruments is calibrated against the primary standard at the Meteorological and Geophysical Institute, Stockholm, Sweden about every five years. The last calibration was made in 1959. The Office joins in international comparisons which are held at Davos in Switzerland—the last one was in August 1959. The results of these comparisons show that the Angström instrument keeps its calibration to within one per cent over a period of years.

The illumination recorders are calibrated at Kew by using filament lamps whose light output in standardized conditions has been measured at the National Physical Laboratory.

The response of the net flux radiometers to short- and long-wave radiation was carefully investigated by MacDowall⁷ and found to be identical. They are now calibrated (for short-wave radiation only) by comparison with the Angström pyrheliometers at Kew.

Accuracy of radiation measurements.—The general accuracy of radiation measurements including estimation of hourly totals from the recordings, as discussed in the various papers mentioned above, is within about ± 5 per cent, but may be worse in some normal incidence solarimeter records, under broken cloud conditions. It is hoped to eliminate the chart-measuring error by the automatic integration processes which are discussed below.

Publication of data.—The only routine publication of radiation data is in the *Monthly Weather Report* where mean, maximum and minimum daily totals are given for total radiation, diffuse radiation and illumination on a horizontal surface for Eskdalemuir, Kew, Kingsway, Lerwick, Aberporth and Cambridge. The unit for radiation is the standard mw hr cm^{-2} and illumination is given in kilolux-hours, but during and after the International Geophysical Year special World Meteorological Organization radiation forms were completed at all stations in cal cm^{-2} .

The Kew monthly totals of hourly values of normal incidence radiation (and sunshine) have been published in the relevant *Observatories' Year Books* up to 1956, following which all radiation (and meteorological) data no longer appear in the Year Books but are recorded on Hollerith punched cards. Special radiation forms to facilitate the use of Hollerith cards were introduced for routine use by stations from 1 January 1958 with the proviso that stations with records before that date are, as time permits, to complete the forms for earlier years. These forms list mean hourly values and daily totals.

Automatic integration—present system and future plans.—Blackwell⁸ described the system in use at Kew for automatic integration of solar radiation to eliminate the tedious procedure of obtaining hourly means by eye readings of the chart records. The method of integration adopted was to use a magnetic amplifier to drive a low inertia, permanent magnet d.c. integrating motor and a suitable counter. The original dials of the counter were read once daily but later (from March 1958) a time-marking system was utilized to operate an automatic camera to photograph all the dials (by then total, diffuse and normal incidence radiation, illumination and net flux of radiation were all recorded on separate dials) in order to give hourly totals of radiation. The negative is projected on a screen in a dark room for convenient reading. However, the photographic method of recording is not very convenient and a

system has been developed in which the recorded information is stored automatically on punch paper tape. The method adopted is to measure the output of each instrument by the self-balancing potentiometer once a minute; the reading of the potentiometer is then converted into a number (between 0 and 999) and the digits of this number punched on to the paper tape in the correct order by means of a standard tape punch. This tape will be sent to the Meteorological Office computer (Meteor) for processing. Complete chart records are also to be maintained. The first such automatic data processing equipment will shortly be installed at Kew Observatory and it is expected that such equipment will be used later at all other radiation stations.

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ESTIMATION OF AVERAGES OF RADIATION AND ILLUMINATION

By S. M. TAYLOR, B.Sc. and L. P. SMITH, B.A.

Data.—Records of daily values of radiation and illumination on a horizontal surface have been taken at Kew since 1947 in units of gram-calories* per square centimetre (*R*) and kilolux (*I*). Although they are not all of an equal standard of accuracy, 12 years of data are now available.

Initial analysis.—The data were divided into three 10-day periods per month. A simple regression against sunshine hours was computed for each of these 36 periods, that is 1–10, 11–20, 21–31 January and so on. Considering the possibility of unknown errors in the data and the other unconsidered meteorological factors involved the results were reasonably consistent, but slight irregularities in the terms were apparent. To obviate these, the coefficients were plotted on a time scale. A smooth curve was drawn and the monthly values read off at the appropriate points giving the results shown in Table I.

* [For purposes of comparison with other articles in this number 1 gram-calorie is equivalent to 1.16 milliwatt hours.—*Ed.*]

TABLE I

Month				Radiation	Illumination
January	...	...	...	$10.0 S + 37$	$11.6 S + 48$
February	...	...	...	$15.6 S + 61$	$18.4 S + 77$
March	...	...	...	$23.0 S + 101$	$25.6 S + 128$
April	...	...	...	$28.0 S + 140$	$24.0 S + 185$
May	...	...	...	$31.2 S + 178$	$30.2 S + 240$
June	...	...	...	$32.0 S + 212$	$40.8 S + 300$
July	...	...	...	$30.6 S + 200$	$40.2 S + 288$
August	...	...	...	$28.0 S + 164$	$37.2 S + 236$
September	...	...	...	$22.8 S + 126$	$30.4 S + 180$
October	...	...	...	$16.6 S + 83$	$20.0 S + 113$
November	...	...	...	$11.8 S + 46$	$13.2 S + 62$
December	...	...	...	$9.2 S + 30$	$9.6 S + 40$

S = mean sun hours

The effect of haze.—It is reasonable to assume that a considerable factor is the presence or absence of haze. Figures are available, from an earlier investigation, of the average number of days per month at about 60 stations when the afternoon visibility was (i) below 4400 yards and (ii) below $6\frac{1}{4}$ miles. It is tempting to use the sum of these two parameters as a “visibility factor” (V). If S is eliminated between the two sets of expressions in Table I, we obtain Table II for Kew:

TABLE II

Month				Value of R in terms of I	Mean visibility factor (V)
January	...	...	...	$0.86 I - 0.4$	43
February	...	...	...	$0.85 I - 0.3$	33
March	...	...	...	$0.90 I - 0.6$	30
April	...	...	...	$0.82 I - 0.4$	15
May	...	...	...	$0.80 I - 0.4$	11
June	...	...	...	$0.78 I - 0.7$	7
July	...	...	...	$0.76 I - 0.6$	6
August	...	...	...	$0.75 I - 0.4$	6
September	...	...	...	$0.75 I - 0.4$	9
October	...	...	...	$0.83 I - 0.6$	24
November	...	...	...	$0.90 I - 0.8$	39
December	...	...	...	$0.96 I - 0.9$	44

The correlation between the coefficient of I and the visibility factor is 0.9, which suggests that although the relationship between R and I is approximately constant, it does vary closely with the visibility in the afternoons. The mean value of the relationship is

$$R = 0.83 I - 0.5,$$

when R and I are in the units previously mentioned.

Further analysis.—The availability of a computer to perform multiple regression analysis enabled further analysis to be made to try to establish a relationship between R (and I) and sunshine, temperature, rainfall and visibility (V). Some close relationships were found but they were not consistent in form from month to month. In other words, the computer found a nearest straight line, but it did not find the nearest sensible straight line. For example, there were occasions when the coefficient of V was positive, implying that in a completely foggy month, illumination would be at a maximum. However closely such equations fitted the Kew data, they were manifestly useless for extrapolation elsewhere.

Final analysis.—Some subterfuge was inevitable. It was therefore decided to apply the expressions in Table I to each monthly mean and to find a relationship between the errors so obtained and the visibility factor (V). During some summer months when V was small, no improvement in fit was possible. To attempt to eliminate possible errors in R and V , the two years with the worst fit were discarded. In most cases these were the 1947 or 1948 readings. The results so obtained are given in Table III.

TABLE III

Month		Radiation	Mean percentage error in 10 "best" years
January	...	$10\cdot0 S - 0\cdot3 V + 50$	5\cdot6
February	...	$15\cdot6 S - 0\cdot9 V + 92$	6\cdot0
March	...	$23\cdot0 S - 1\cdot25 V + 136$	5\cdot1
April	...	$28\cdot0 S - 3\cdot0 V + 196$	6\cdot3
May	...	$31\cdot2 S - 5\cdot0 V + 240$	4\cdot9
June	...	$32\cdot0 S - 3\cdot7 V + 234$	6\cdot9
July	...	$30\cdot6 S + 200$	5\cdot1
August	...	$28\cdot0 S + 164$	5\cdot9
September	...	$22\cdot8 S - 0\cdot6 V + 136$	5\cdot0
October	...	$16\cdot6 S - 0\cdot35 V + 92$	7\cdot2
November	...	$11\cdot8 S - 0\cdot25 V + 55$	4\cdot6
December	...	$9\cdot2 S - 0\cdot35 V + 45$	5\cdot7
			Mean 5\cdot7

TABLE IV

Month		Illumination	Mean percentage error in 10 "best" years
January	...	$11\cdot6 S - 0\cdot75 V + 75$	6\cdot5
February	...	$18\cdot4 S - 0\cdot45 V + 86$	6\cdot3
March	...	$25\cdot6 S - 1\cdot2 V + 152$	3\cdot6
April	...	$34\cdot0 S - 4\cdot3 V + 258$	5\cdot8
May	...	$39\cdot2 S + 240$	4\cdot6
June	...	$40\cdot8 S - 5\cdot0 V + 320$	6\cdot4
July	...	$40\cdot2 S - 2\cdot35 V + 270$	4\cdot1
August	...	$37\cdot2 S - 3\cdot15 V + 257$	6\cdot4
September	...	$30\cdot4 S - 0\cdot3 V + 183$	5\cdot7
October	...	$20\cdot0 S - 0\cdot2 V + 110$	5\cdot0
November	...	$13\cdot2 S - 0\cdot8 V + 93$	5\cdot4
December	...	$9\cdot6 S - 0\cdot35 V + 54$	2\cdot8
			Mean 5\cdot2

Extrapolation.—The expressions in Tables III and IV can be used to estimate average values of radiation and illumination using standard normal data and the visibility data mentioned above, provided that the figures so obtained were corrected by a factor depending on the strength of the sun at various latitudes. The results are given in Tables V and VI (nearest five units). For areas other than in England and Wales, no visibility data were available, so for Scotland, Northern Ireland and the Channel Isles, the expressions of Table I were used in the same way. The results are given in Tables VII and VIII (nearest five units).

Degree of inaccuracy.—As the expressions of Table I were established for a hazy area, the estimates in Tables VII and VIII are probably too low, but if maps are plotted using data obtained by both types of formula, there is no very obvious discontinuity at the Scottish border, so that such inaccuracy may be small, especially in summer.

For year-to-year values these expressions can lead to errors at Kew up to 10 per cent, and on extrapolation this error must increase. For average values,

TABLE V—ESTIMATED AVERAGE DAILY RADIATION IN GRAM-CALORIES PER SQUARE

CENTIMETRE

England and Wales	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Acklington	45	100	185	295	370	405	360	295	220	125	60	35
Tynemouth	40	90	175	285	340	390	365	295	220	120	60	30
Catterick	45	95	170	280	330	385	365	290	220	120	60	35
Leeming	45	100	175	280	340	390	365	295	210	120	60	35
Harrogate	45	95	175	280	335	395	365	300	210	125	60	35
Driffield	45	95	180	290	365	385	365	305	225	130	60	35
Squires Gate	45	95	180	315	410	430	380	315	225	125	60	35
Southport	45	95	175	295	365	425	380	315	220	125	60	35
Liverpool (Speke) ...	50	95	180	295	355	410	390	310	215	125	60	40
Manchester	40	80	155	245	325	365	335	285	195	110	50	30
Church Fenton	45	90	160	255	345	370	365	300	215	120	60	35
Finningley	45	95	175	280	370	380	370	310	220	125	60	35
Spurn Head	50	100	185	290	355	400	390	315	210	130	65	40
Holyhead	55	115	200	325	410	440	380	320	230	135	70	45
Hawarden	50	100	180	290	350	415	370	305	220	125	60	40
Shawbury	55	105	185	300	370	420	370	305	225	130	65	45
Watnall	45	90	175	280	350	380	365	310	220	125	60	35
Cranwell	50	100	185	300	385	420	390	325	230	135	65	40
Wittering	55	100	190	305	380	405	380	320	235	140	70	40
Mildenhall	55	110	200	315	425	440	405	335	245	140	75	45
West Raynham	55	110	195	315	415	430	395	335	245	140	70	45
Yarmouth	50	105	195	285	350	410	405	335	240	140	70	45
Aberporth	60	120	205	335	415	430	385	310	235	140	75	55
St. Ann's Head	60	120	210	320	390	430	385	320	235	140	75	55
St. Athan	60	120	195	310	395	435	400	320	235	140	75	50
Ross-on-Wye	60	115	205	315	385	430	375	315	230	135	70	50
Defford	55	110	195	310	370	420	385	315	235	135	75	50
Birmingham	45	90	165	255	310	395	365	305	215	125	60	40
Honiley	50	100	175	295	355	405	375	310	225	135	65	40
Little Rissington ...	55	110	190	315	405	425	380	315	240	135	70	50
Cranfield	55	110	195	300	415	430	380	320	230	140	70	45
Dunstable	55	105	195	295	380	410	380	325	245	140	70	45
Felixstowe	60	115	210	320	415	455	415	345	250	145	75	50
Bristol... ..	60	115	205	330	400	445	400	320	245	140	75	50
Lyneham	60	115	200	325	400	430	390	320	245	135	75	50
Larkhill	65	120	210	340	415	445	395	335	250	145	80	50
Boscombe Down ...	60	115	200	325	400	440	395	330	245	140	75	50
Worthy Down	60	120	210	345	425	445	400	335	250	145	80	50
Abingdon	60	115	200	315	410	430	385	320	240	140	75	50
South Farnborough ...	60	115	205	315	395	450	405	340	245	145	75	50
Kew	50	95	180	280	375	435	395	330	235	135	65	40
Croydon	50	95	185	280	370	440	405	335	240	140	65	40
Greenwich	45	80	160	230	340	415	390	325	230	130	60	35
Biggin Hill	60	105	195	300	390	430	400	335	245	145	70	45
West Malling	60	110	200	310	410	445	410	340	255	150	75	45
Shoeburyness... ..	60	115	210	315	415	455	415	345	250	145	75	50
Scillies	70	135	230	360	415	445	400	350	255	160	90	65
St. Eval	65	130	225	355	410	450	400	340	250	155	85	60
Lizard	75	130	230	350	410	445	420	345	255	160	90	65
Falmouth	75	130	225	345	415	465	400	345	255	155	95	65
Hartland Point	65	130	225	345	420	455	400	330	245	150	85	60
Plymouth	70	125	225	340	415	450	395	355	255	155	85	60
Exeter	70	130	220	355	430	470	410	340	255	150	85	60
Portland Bill	70	130	220	335	420	455	425	355	260	155	90	60
Holton Heath	65	125	215	330	410	450	415	345	255	145	90	55
Calshot	65	125	220	335	415	460	420	355	255	155	90	55
Thorney Island	65	120	220	340	425	460	420	350	260	155	85	55
Tangmere	65	125	220	325	420	450	420	350	260	155	85	55
Dungeness	65	125	210	325	410	435	430	360	260	155	85	55
Lympne	60	120	220	325	420	460	425	355	255	150	80	55
Manston	60	115	210	330	420	435	425	365	255	150	80	50

TABLE VI—ESTIMATED AVERAGE DAILY ILLUMINATION IN KILOLUX

England and Wales	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Acklington	50	105	205	375	455	535	460	405	295	150	85	45
Tynemouth	50	100	200	355	455	510	460	390	295	150	80	40
Catterick	55	105	195	355	445	510	465	395	280	145	85	40
Leeming	60	105	200	355	450	515	470	400	285	145	85	45
Harrogate	55	105	200	350	455	520	460	395	280	150	80	45
Driffeld	60	105	200	365	460	505	470	415	300	160	85	45
Squires Gate	55	105	205	395	495	565	500	425	300	155	80	40
Southport	55	105	200	365	500	570	485	420	295	155	75	40
Liverpool (Speke)	65	110	200	370	475	545	475	415	290	155	85	50
Manchester	50	90	175	305	440	485	425	380	265	135	65	35
Church Fenton	55	100	185	315	450	490	450	400	290	150	80	40
Finningley	55	105	200	350	460	505	470	410	295	155	80	45
Spurn Head	60	110	210	360	475	530	485	410	285	160	90	50
Holyhead	75	120	225	410	515	575	490	435	310	165	105	55
Hawarden	65	110	205	360	475	545	475	415	290	155	85	50
Shawbury	70	110	215	375	475	555	480	415	300	155	95	50
Watnall	55	105	200	350	460	505	470	425	295	155	80	40
Cranwell	60	110	215	375	485	560	500	440	305	165	85	50
Wittering	65	110	215	385	490	535	490	440	315	170	90	50
Mildenhall	70	120	225	400	500	580	530	475	325	175	100	50
West Raynham	65	120	225	400	505	570	515	465	325	175	95	50
Yarmouth	65	115	220	350	500	555	510	435	320	170	90	55
Aberporth	85	125	230	425	480	565	505	435	315	170	110	60
St. Ann's Head	80	130	240	400	500	570	490	435	310	170	110	60
St. Athan	75	130	225	385	495	570	515	440	320	170	105	60
Ross-on-Wye	80	125	225	400	470	570	490	445	310	165	100	60
Defford	75	120	220	395	480	555	500	440	315	165	105	55
Birmingham	55	105	190	315	450	520	465	425	290	155	80	45
Honiley	65	110	200	370	475	535	480	425	300	165	90	50
Little Rissington	70	120	215	395	485	565	500	445	320	165	100	55
Cranfield	75	120	220	375	490	565	490	450	320	175	100	55
Dunstable	70	115	220	370	490	540	490	450	325	170	95	55
Felixstowe	75	125	240	405	520	600	540	480	335	180	100	60
Bristol... ..	75	125	230	415	490	585	520	450	325	170	100	60
Lyneham	80	125	225	415	485	570	510	450	330	165	105	60
Larkhill	80	130	235	420	490	590	515	470	335	175	110	60
Boscombe Down	80	125	225	410	490	580	515	465	330	170	105	60
Worthy Down	80	130	240	430	500	590	535	470	335	180	100	60
Abingdon	80	120	225	400	485	565	505	450	320	170	105	60
South Farnborough	75	125	235	400	495	590	525	470	330	180	105	60
Kew	60	110	205	350	485	575	510	460	315	165	85	50
Croydon	60	110	210	350	490	580	515	465	320	170	85	50
Greenwich	45	100	190	280	470	545	500	450	305	165	70	45
Biggin Hill	70	120	220	375	505	565	515	455	330	175	95	55
West Malling	75	125	225	390	510	585	530	465	340	180	100	55
Shoeburyness... ..	75	125	240	400	515	600	540	480	335	180	100	60
Scillies	100	140	255	435	525	585	515	480	340	195	130	75
St. Eval	90	135	255	430	505	595	520	465	340	185	125	70
Lizard	100	140	255	440	510	585	540	465	345	190	135	75
Falmouth	100	140	255	435	510	610	515	480	340	190	130	75
Hartland Point	90	135	250	435	500	600	520	460	335	180	125	70
Plymouth	90	135	255	430	505	595	510	490	340	190	120	70
Exeter	95	135	250	445	510	615	540	480	340	185	125	70
Portland Bill	95	135	250	425	520	600	550	495	350	190	130	70
Holton Heath	85	135	240	415	515	595	535	470	345	175	115	65
Calshot	85	135	250	420	525	605	545	490	340	190	115	65
Thorney Island	85	135	245	425	535	605	545	480	350	185	115	65
Tangmere	80	135	245	405	535	595	540	480	350	190	115	65
Dungeness	85	135	240	405	540	575	545	475	345	190	120	65
Lympne	75	130	250	410	525	620	550	490	340	185	105	60
Manston	75	130	240	415	540	590	550	500	345	185	110	60

TABLE VII—ESTIMATED AVERAGE DAILY RADIATION IN GRAM-CALORIES PER

		SQUARE CENTIMETRE											
Scotland		Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Stornoway	...	25	65	150	255	360	385	325	265	180	95	35	15
Fortrose	...	30	75	155	250	340	395	335	275	185	105	40	20
Inverness	...	30	75	155	245	335	390	330	275	185	100	40	20
Gordon Castle	...	30	75	155	245	345	390	335	280	190	105	40	20
Banff	...	30	75	155	250	345	395	340	280	190	105	40	20
Aberdeen	...	30	75	155	250	345	405	340	280	195	105	34	20
Arbroath	...	35	85	165	270	365	430	365	295	210	115	50	25
Oban	...	30	70	155	255	360	395	330	270	185	100	45	23
Perth	...	35	80	155	260	345	415	355	280	200	110	45	25
Dundee	...	35	80	160	255	340	405	345	280	200	110	50	25
Leuchars	...	35	85	165	270	360	425	360	290	210	115	50	25
Rothsay	...	35	75	155	260	360	410	345	280	195	105	50	25
Helensburgh	...	35	75	155	250	350	400	335	270	190	105	45	25
Renfrew	...	35	75	155	255	345	400	345	275	195	105	45	25
Stirling	...	35	75	155	250	330	395	330	270	195	105	45	25
Boghall	...	35	80	160	250	335	405	345	275	200	110	50	25
North Berwick	...	35	80	160	260	350	420	360	285	200	110	45	25
Kilmarnock	...	35	80	160	260	365	405	340	280	200	110	50	25
Turnberry	...	35	85	165	270	380	415	350	290	200	110	50	30
Dumfries	...	40	80	165	255	360	415	345	285	195	115	55	30
Eskdalemuir	...	35	80	155	245	340	390	335	270	190	110	50	30
Marchmont	...	35	75	160	250	345	405	345	280	195	105	50	25
Other areas													
Aldergrove	...	40	85	165	265	375	400	330	280	200	115	55	30
Douglas I. o. M.	...	45	90	180	290	395	440	375	315	220	125	60	35
Guernsey	...	65	115	220	330	415	490	445	380	270	155	80	50

TABLE VIII—ESTIMATED AVERAGE DAILY ILLUMINATION IN KILOLUX

Scotland		Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Stornoway ...	...	30	80	180	325	470	520	455	370	250	125	50	20
Fortrose ...	...	40	90	185	320	445	535	465	380	260	135	55	25
Inverness ...	...	40	90	185	310	435	525	460	380	260	135	55	25
Gordon Castle ...	...	40	90	185	315	445	530	465	385	260	135	55	25
Banff ...	...	40	90	185	320	450	535	470	390	265	135	50	25
Aberdeen ...	...	40	90	185	315	445	545	475	390	275	140	55	30
Arbroath ...	...	45	100	200	345	475	585	505	405	290	150	65	30
Oban ...	...	40	90	185	325	470	535	460	375	255	130	55	30
Perth ...	...	40	95	190	330	450	560	490	390	275	140	60	30
Dundee ...	...	45	100	190	325	440	545	480	390	275	145	60	30
Leuchars ...	...	45	100	200	340	465	575	500	400	290	150	65	30
Rothsay ...	...	45	95	190	330	470	550	475	390	275	135	60	30
Helensburgh ...	...	40	90	185	320	455	540	465	380	260	135	60	30
Renfrew ...	...	40	90	185	320	450	545	475	380	270	135	60	30
Stirling ...	...	40	95	190	320	430	535	460	375	270	140	60	30
Boghall ...	...	45	100	190	320	435	550	475	385	275	145	65	35
North Berwick ...	...	45	100	195	330	455	565	500	395	280	140	60	30
Kilmarnock ...	...	45	95	190	330	475	550	470	390	275	140	60	35
Turnberry ...	...	45	100	200	345	490	560	485	405	280	145	65	35
Dumfries ...	...	50	100	195	325	465	555	480	395	275	150	65	35
Eskdalemuir ...	...	45	100	190	315	445	530	460	375	260	145	65	35
Marchmont ...	...	45	95	190	320	445	550	480	390	275	140	60	35
Other areas													
Aldergrove ...	...	50	100	200	335	490	540	460	390	275	150	70	40
Douglas I. o. M. ...	...	55	105	215	370	510	595	520	435	305	165	75	45
Guernsey ...	...	80	140	265	415	535	655	615	520	370	200	100	65

the position is eased, owing to cancellation of yearly errors, and it is suggested that the absolute errors at any one station should be within the 10 per cent range. The relative errors are probably much less, and it is for this reason that these figures are now made available as they may be found to be useful in problems such as horticulture planning, siting of glasshouses etc. They should only be regarded as an interim guide until better information becomes available, in other words, as a first approximation.

FLUCTUATIONS IN STRATOSPHERIC WINDS OVER AUSTRALIA

By R. G. VERYARD, B.Sc.

In a recent article by Veryard and Ebdon¹ attention was drawn to a 23-29-month fluctuation which had been discovered in the zonal component of stratospheric winds over tropical regions. With the data then available it was possible to show that the fluctuation existed in the northern hemisphere to about 25° - 30° N, but lack of data precluded any firm conclusion regarding the distance to which the fluctuation existed south of the equator. Since the article was written some stratospheric wind data for Australian upper air stations have been received from the Commonwealth Bureau of Meteorology.

Examination of these data confirms that the fluctuation has occurred at Darwin ($12^{\circ}26'S$, $130^{\circ}52'E$) at least up to the end of 1958 and probably as far back as 1952. This is demonstrated in Figure 1 which gives a curve of the twelve-monthly running means of the zonal wind component at 60,000 feet (about 70 mb). From 1955 onwards observations were only occasionally missing for ten days or more in any month but for earlier years the data were less plentiful, particularly in the period September-December 1954, and the dashed part of the curve indicates that the values used are unreliable. For comparison, the curve for Aden ($12^{\circ}49'N$, $45^{\circ}02'E$) based on winds at the 50 mb level (about 68,000 feet) has been superimposed in Figure 1. It will be noted that the amplitude of the fluctuation at Aden is nearly twice that at Darwin but allowance must be made for the difference in the heights to which the curves refer in view of the finding, mentioned in the earlier article, that there is an increase of amplitude with height (at least up to 25 mb). It will also be seen that, up to about 1959, the curves are in phase except for a lag of a

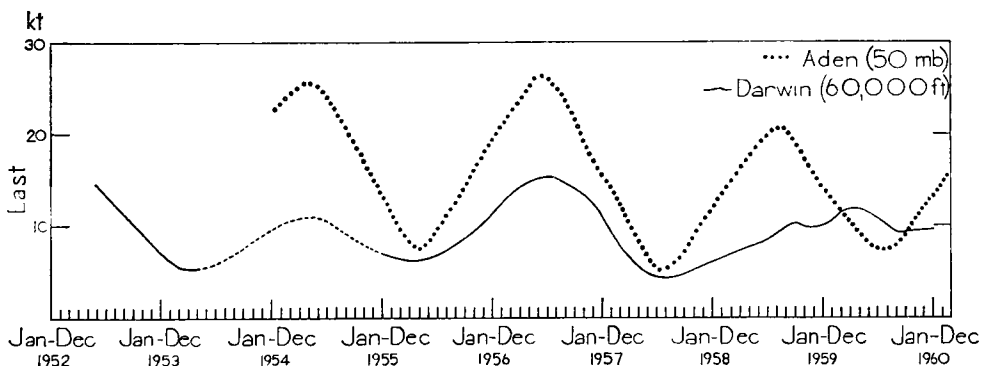


FIGURE 1—TWELVE-MONTHLY RUNNING MEANS OF ZONAL WIND COMPONENT AT DARWIN AND ADEN

month or so at Darwin which is again attributable to the height difference (as the fluctuation was found to have a phase lag from higher to lower levels). But from 1959 onwards, the correspondence disappears and it may be that the fluctuation has now "petered out" at Darwin—but perhaps only temporarily. As was pointed out in the earlier paper, the amplitude of the fluctuation appeared to be decreasing in recent years: in fact, it could not be detected at Bahrain ($26^{\circ}16'N$, $50^{\circ}37'E$) from 1958 onwards.

Data from other tropical stations in Australia were found to be inadequate

for the drawing of long-period curves as for Darwin and Aden, but the data available for Alice Springs ($23^{\circ}48'S$, $133^{\circ}53'E$) suggested that the fluctuation was present at that station from the end of 1956 to mid-1957 but absent from 1958 onwards. However, recent data indicate that the fluctuation after waxing and waning, is still being maintained at equatorial stations; but, in view of the finding that the fluctuation decreases in amplitude with distance from the equator (and perhaps the "meteorological equator"), it could be expected that a waning of the fluctuation would lead to its disappearing in higher latitudes.

A preliminary examination of data for Ascension Island ($07^{\circ}58'S$, $14^{\circ}24'W$) indicates the existence of the fluctuation at that station from September 1957 to March 1961; a full report will be given in a later article.

REFERENCE

I. VERYARD, R. G. and EBDON, R. A., Fluctuations in tropical stratospheric winds. *Met. Mag.*, London, **90**, 1961, p. 125.

REVIEW

Meteorology and climatology for sixth forms, by Ernest S. Gates. $9\frac{3}{4} \times 7\frac{1}{4}$ in., pp. 203, illus., George G. Harrap & Co. Ltd., 182 High Holborn, London W.C.1, 1961. Price: 13s 6d.

This book is intended "to convey the physics of meteorology to geographical students in a non-technical and non-scientific language and to stimulate their interest to go beyond the classroom and to carry out some practical studies in the subject". In these aims, except perhaps the last, it is highly successful. It is divided into two distinct sections. The first section, which forms the major part of the book and deals with general meteorology, seemed to the reviewer and to some sixth form pupils the more original and the more stimulating. The second section gives an outline treatment of world climatology in a more conventional manner.

The outstanding feature of the book is the number of excellent diagrams; at first sight many of these seem very large, but they gain thereby in clarity. Occasionally there is some over-simplification, for example, in Fig. 97 of the south-west monsoon; it also seems curious that for Fig. 105 Vancouver should have had to be chosen as an example of a west European climate. In only one case—Fig. 53 to explain the formation of rainbows—does a diagram seem definitely unhelpful. The tabulation employed is very good: the tables of cloud, fog, air mass and frontal characteristics given as appendixes to Part One are particularly commendable. An attractive selection of cloud photographs is also included.

The chapters on meteorology deal very fully with the phenomena described and they include clear explanations of a number of aspects, such as katabatic and anabatic winds and jet streams, which are not usually touched upon in a book of this standard. Some of the large amount of mathematics might seem unnecessary to many sixth form geographers: however it is probably a good thing that they should appreciate early that a good knowledge of mathematics is essential if they are to pursue a serious study of the subject. The treatment of air masses and of the upper atmosphere is very thorough; but it is a pity that only one type of condensation trail is considered. Also the conventional warm-front section in Fig. 66 might well have been modified to take into account the break in the tropopause at the jet-stream centre which is clearly shown in Fig. 72.

The first chapter in the book is perhaps the least successful. More might have

been included to encourage the student to use and even construct his own instruments, such as anemometer and rain-gauge. Also on p. 20 the "C." scale of temperature should be described as Celsius rather than Centigrade and mention of the Réamur scale is unnecessary.

In future editions, which it is to be hoped the demand will be sufficient to justify, mention might well be made in Chapter 12 of the possibility of the student's sketching his own weather maps from data such as that given in the shipping forecasts broadcast on 1500 metres.

At the publication price of 13/6 this book offers very good value for money. It should find a place in the school science library as well as in the geography library. Now that meteorology has been eliminated from the "A" level physics syllabus, it is unlikely to be bought as a textbook for sixth form scientists, although they would derive considerable benefit from its study. Many senior geography masters will want to purchase individual copies for their sixth form specialists: to meet "A" level geography requirements there is a wide selection of examination questions at the end of the book. Finally the book can also be recommended as a useful work of reference—and perhaps a welcome Christmas present—for the adult amateur of meteorology.

D. C. LLOYD

METEOROLOGICAL OFFICE NEWS

Retirement.—The Director-General records his appreciation of the services of:

Mr. D. Moriarty, Foreman of Stores, who retired on 22 August 1961. He started his career in the Meteorological Office in 1941 as a storekeeper at Kew Observatory, and on moving to the Instruments Branch at Harrow in 1946 he was promoted Leading Storeman. In 1952 he became Foreman of Stores and remained in the Instruments Branch until his retirement. Mr. Moriarty has accepted a temporary appointment as a Paperkeeper in the Air Ministry.

Sports activities.—The first Annual Sports Meeting organized by the Bracknell Social and Sports Committee was held on the evening of 17 August, in fine weather, at the Palmer Park Running Track, Reading. The various events, open to all members of the staff of the Meteorological Office, were well supported. Three new Meteorological Office records were established. They were:

Long Jump, Ladies. Distance 14 feet 8½ inches, Miss V. Lewis, M.O.3.

100 yards, Ladies. Time 12·2 seconds, Miss V. Lewis, M.O.3.

220 yards, Men. Time 24·2 seconds, Mr. J. Miller, M.O.13.

Four cups, donated by the Dunstable Social and Sports Club, were won by the following:

Tug of War	...	...	...	...	M.O.13/19
4 × 110 yards Men's Relay	...	...	...	...	M.O.3
4 × 110 yards Ladies' Relay	...	...	...	...	M.O.13/9
Division with most points	...	...	...	...	M.O.3

Four events (100 yards, 440 yards, one mile and Ladies' 100 yards) were Meteorological Office Championships for which medals were awarded.

The meeting was attended by Sir Graham and Lady Sutton, Dr. and Mrs. R. C. Sutcliffe, Dr. and Mrs. A. C. Best, and many of the Staff and their families now located in the Bracknell area, as well as visitors from London Airport, Harrow and other nearby offices. At the conclusion of a successful evening the prizes were presented to the winning competitors and teams by Lady Sutton.

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ATMOSPHERIC DIFFUSION

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F. Pasquill

of the Meteorological Office, Bracknell, Berks.

THIS BOOK DISCUSSES the physical problems which arise from the release of windborne materials into the atmosphere. Proceeding from a review of the analysis of turbulence and diffusion, Dr. Pasquill assembles a wealth of data derived from old and recent experiments and provides a study which as a survey of basic research, will interest the meteorologist, and as a guide to the assessment of dispersion, will meet the needs of other scientists concerned with air-pollution.

Dr. Pasquill approaches his subject by introducing a basic problem—the complex spreading effects of a plume of smoke issuing from a factory chimney into the atmosphere. In his examination and explanation of this problem, he emphasizes the statistical concepts of turbulence which have been developed in the field of fluid dynamics and aerodynamics.

The first four chapters are devoted to the essential background on the properties of the airflow, the theory of its diffusive action, and an evaluation of experiments and observations on diffusion. The remaining third of the book shows how this knowledge is used to estimate and describe systematically the distribution and concentration of various windborne materials under different conditions of weather and terrain.

Principal contents

1. Analysis of turbulence. 2. The statistics of atmospheric turbulence. 3. Theoretical treatment of diffusion. 4. Experimental studies of the basic features of atmospheric diffusion. 5. The estimation of diffusion from meteorological data. 6. The distribution of windborne material from real sources. — Bibliography. — Index.

6×9 in. 68 diagrams. 300 pages. 60s.

VAN NOSTRAND, 358 Kensington High Street, London, W.14

THE METEOROLOGICAL MAGAZINE

Vol. 90. No. 1,072, November 1961

R. G. VERYARD, B.Sc.

Mr. R. G. Veryard retired from his post as Deputy Director (Central Services) of the Meteorological Office in October 1959, and some details of his official career were given in the *Meteorological Magazine* for December of that year. Mr. Veryard subsequently accepted a temporary appointment as Senior Scientific Officer and served in the Climatological Research Branch until his final retirement in October 1961. His period of service with the Meteorological Office extended over more than 42 years, though from 1925 to 1936 he was seconded for duty with the Royal Air Force in India.

Mr. Veryard's service has been mainly on the operational side of the Office. He was one of the first to be appointed Senior Meteorological Officer at a Group Headquarters in the years of rapid Royal Air Force expansion just before the Second World War. His practical common sense and clear thinking will be remembered by many colleagues who took part in the daily telephone operational conference between the Central Forecasting Office and Group Headquarters during the early war years. For a time during the difficult period of pre-war expansion Mr. Veryard was an officer of the Meteorological Office Branch of the Institute of Professional Civil Servants.

Following his return from the Middle East in 1949, Mr. Veryard was employed on special work, mainly concerned with international matters, for the Director; during this period he compiled the first edition of "Meteorological Office Standing Orders". In 1953 he was appointed Assistant Director (Climatology) at Harrow, being in charge until 1957 of the branches now comprising the Assistant Directorates of Climatological Services and Research, the Meteorological Office Library and the Cartographical Pool. During this period Mr. Veryard was chairman of the very active and successful dramatic club of the Harrow office. He was promoted to the post of Deputy Director (Central Services) in 1958.

In January 1957 Mr. Veryard was elected President of the Commission for Climatology of the World Meteorological Organization and he was largely

responsible for the successful meeting of the Commission held in London in December 1960. His many friends and colleagues wish him a well earned, long and happy retirement.

F. J. SCRASE, O.B.E., M.A., Sc.D.

Dr. F. J. Scrase, O.B.E., who retired from his appointment as Assistant Director (Instrument Development) in August 1957 and returned to serve as Secretary of the Meteorological Research Committee finally left the service of the Meteorological Office on 15 August 1961.

His studies were interrupted by service in the First World War from 1915 to 1919 in the Special Brigade of the Royal Engineers and as an examiner in the Aeronautical Inspection Directorate. He was awarded the B.A. degree of Cambridge University in 1920 and joined the Office as a Junior Professional Assistant in August of that year. After a few months at Kew Observatory he was seconded to the War Office Establishment at Porton and returned in 1926 to Kew where he served for a further ten years. In 1937 he went, on promotion to the grade of Senior Technical Officer, to take charge of the Meteorological Office in Gibraltar and in 1939, with further promotion, he returned as Head of the Instruments Division. He retained this position, at a variety of locations, with a variety of titles, but with ever-growing responsibilities, until 1957. He was appointed an Officer of the Order of the British Empire in 1948.

Dr. Scrase is essentially a reserved man. He has a sometimes unconventional sense of fun and his anecdotes, particularly those concerning his days at Porton, are occasionally enlivened by a startlingly salty phrase. He is sometimes willing to comment, with candour, on attainments of others, but he rarely speaks of his own. For this reason many who have had contact with him in the later part of his career did not realize they were dealing with a scientist of more than usual ingenuity and originality. His work at Porton included one of the first investigations of the statistical properties of turbulence; the ideas were identical with those which, ten years later, in one of the first manifestations of the electronic revolution, led to the establishment of the modern treatment of turbulence. At Kew Dr. Scrase first worked in the field of seismology and in two papers published by the Royal Society pioneered the investigation of deep-focus earthquakes. He turned his attention to atmospheric electricity and with a series of ingenious devices made continuous recordings of all the important electrical properties of the lower atmosphere at Kew. In collaboration with Sir George Simpson he made the first electrical soundings in thunderstorms with instrumented free balloons. For this work he was awarded the Cambridge degree of Sc.D. in 1939. He found time whilst running the Instrument Development Division to make scientific studies of the results of high-level balloon soundings, and he was responsible for the heat-transfer analysis which established the radiation corrections of the Meteorological Office radiosonde. He was rewarded for this work by the grant of the L. G. Groves Memorial Prize for Meteorology in 1955. Even after retirement his scientific work did not cease, and he is now engaged on a fruitful study of the measurements of the space gradients of magnetic fields as recorded at Lerwick Observatory during the International Geophysical Year.

We can be sure that Dr. Scrase will enjoy his retirement, and not in idleness. We wish him a long one.



MR. R. G. VERYARD



DR. F. J. SCRASE, O.B.E.

**A PRELIMINARY NOTE ON EARLY METEOROLOGICAL
OBSERVATIONS IN THE LONDON REGION, 1680-1717,
WITH ESTIMATES OF THE MONTHLY MEAN
TEMPERATURES, 1680-1706**

By G. MANLEY, M.A., D.Sc.

Professor of Geography, Bedford College, University of London

In September 1663 Dr. Wilkins read a paper to the newly-founded Royal Society, in which he advocated the keeping of "a history of the weather" as a desirable objective. As a result Robert Hooke, who was then Curator of Experiments, was commissioned to devise a scheme for the maintenance of daily observations. This he presented at a meeting on 7 October. The "scheme" that he proposed, with its table of nine columns including readings of the barometer and thermometer, was printed in Sprat's *History of the Royal Society* (1667). It was brought to the attention of a number of the early Fellows, and readers who wish to refer to it can find an illustration in Sir Napier Shaw's *Manual of Meteorology* (vol. I, p. 161).

Hooke was later asked to produce "a thermometer that should serve as a standard"; this he did at a meeting on 11 January 1665. Dr. Louise D. Patterson has discussed the significance of this early Royal Society's thermometer and has deduced the approximate value of the degree on Hooke's scale (*Amer. J. Phys.*, **19**, 1951; *Isis*, **44**, 1953).

As a result of Hooke's work quite a number of his contemporaries began to keep daily records, and several of these seventeenth-century meteorological journals giving instrumental readings exist. Hooke's own daily readings from March 1672 to May 1673 can be seen in his MS diary at the Guildhall Museum. John Downes, physician to Christ's Hospital, provides daily readings from March 1680 to September 1694 (MS, Sloane Collection, British Museum). I am not without hope of being able to effect a link between Hooke's and Downes' observations.

The barometer and thermometer were the most common instruments in use and both were for long very imperfect. These early thermometers seem for the most part to have been sizeable, two feet or more in length, with a large spherical bulb using spirit. They were unreliable, for apart from the fact that the scale reading was liable to change with time, as the glass was not annealed, the spirit was not standardized and the bore of the tube might be irregular. It is evident that Locke and other users were quite conscious of some of these defects. But instruments were few and no doubt much valued. Hence it is understandable that it became common practice to hang the thermometer within a room adjacent to and perhaps mounted with the barometer, probably also beside a window, but not directly affected by sunshine. Moreover, many of the early observers were physicians interested in the relationship between the weather and disease, which no doubt led them to think that the state of the air within the rooms in which men spend much of their working time was significant. The range of the readings indicates that contemporary rooms were, to say the least, well aired and no doubt the wide chimneys helped. Winter morning temperatures were quite commonly below 40°F. Examination makes it clear that such indoor observations can be sufficiently consistent to provide a basis for estimates of the trend of mean temperature, but hitherto there has not been opportunity to link them with outdoor readings.

The first observer who consistently kept his thermometer out-of-doors was the Reverend William Derham, F.R.S., at his rectory at Upminster, 15 miles east of the city. We have ten years of his daily observations, almost complete, from 1697 to 1706. For eight of these years, beginning in 1699, he gives us thrice-daily readings of a thermometer on a north wall, at fixed hours. The time of the early morning observation varied from 5h to 8h in different months; the other readings were consistently taken at noon and at 21h. Derham's observations for 1697-99 were printed in the *Philosophical Transactions of the Royal Society*; and from 1700-06 he continued to send his beautifully-kept MS tabulations to the Royal Society.

Recently by good fortune I have found in the Bodleian Library three manuscript meteorological journals whose existence has apparently not hitherto been recognized. Two of these are in the Rawlinson Collection; by what appears to be an accident in printing, they are not readily to be found in the catalogue. The third is the original meteorological journal kept by John Locke at various places at intervals between 1666 and 1703 throughout his active life. Some parts of Locke's journal were published; for example, his daily observations for several months in 1692 were printed in a short paper in the *Philosophical Transactions* for 1703. But the original MS journal provides a continuation for a great part of each of the years 1693-1703, during the eight months or thereabouts when he was in residence at Oates, 20 miles north-north-east from the City, near Ongar in Essex. Barometer and thermometer were read daily; the thermometer was by Tompion, and Locke had the misfortune to break it in March 1701. It is interesting to note that he did not obtain a new one until September. In 1725 we likewise learn that Dr. Huxham at Plymouth had to wait for more than two months for a replacement to arrive from London.

The other newly-discovered MS journals are non-instrumental. The first (Rawlinson 662D) gives daily observations of weather from January 1669 to December 1700; with wind directions from May 1673 onward. No author is named; but I was struck by the resemblance of the wording to that used by Gadbury. Comparison of the handwriting with other MS known to be by him confirmed that this MS is in Gadbury's own hand and is very nearly identical with that which formed the basis of the printed journal, giving daily observations from November 1668 to December 1689, in Gadbury's *Nauticum Astrologicum* (1691; another edition, 1710). This last was discussed by E. L. Hawke (*Weather*, 3, 1948). The value of this manuscript lies in the fact that it provides eleven further years (1690-1700) of consistent daily observations for London.

The second MS (Rawlinson 1161D) is written up in a sizeable book, about $13 \times 9 \times 2$ in. On each left-hand page we find a variety of astronomical entries; on the right-hand, an entry of each day's weather, virtually complete from June 1699 to November 1717. There is a column giving "The air's weight" from which a table of pressures might possibly be compiled. Wind direction is also commonly mentioned. The journal ends rather suddenly; many of the later pages were unused.

There is absolutely no indication of the observer's name or of his exact place of residence. But there are many scattered entries reporting the weather at various places on the main roads leading from London; for example, Maidenhead, Dunstable, Barnet and Braintree are mentioned and sometimes London

itself. The weight of the evidence suggests that the observer resided in Middlesex, west of London, not very far from the Thames, and probably on or near a main road where he could pick up comments from passing travellers. But from 1705 to 1709 the journal is extremely hard to read as the ink has become absorbed and much blurred. The quality of the observations is quite good, testifying to an observer who was very fairly alert to the meteorological events of the day. I have taken out comparisons of entries relating to rain, snow and thunder against Gadbury, Derham and Locke. From these it appears that this anonymous observer was quite up to Derham's standard in regard to rain, and about equal to Gadbury. He was rather better than Derham in regard to his observations of the occurrence of snow. Over the years 1713-17 his entries can also be compared with those in Smith's well known Richmond journal; it is clear that he was much more alert, with about 25 per cent more rain days and nearly double the number of snow days. Smith is confirmed as a rather casual observer when we compare his entries with those in later journals, for example those kept by Jurin and Hooker.

The really valuable feature of this journal is that for the first time we have a complete run of daily observations through 1707 to 1713. This completes the series of links through which it now becomes possible to provide a meteorological comment on the weather in the London region for every day since November 1668.

Deductions with regard to the meteorology of the period 1680-1720.—

These several journals are now being collated and a preliminary summary can be given of the deductions that can be made from them, more especially in regard to the trend of mean temperatures and the frequency of occurrence of rain and snow. The intrinsic interest of this period, from the meteorological standpoint, is very great. There is widespread evidence that the last decade of the 17th century was marked by a predominance of cool unsettled weather over much of northern Europe. In England, the high price of corn was recorded in the phrase "King William's dear years"; in Scotland, the "seven ill years" were catastrophic; in Sweden, late springs and bad harvests were frequent; and in the Alps, Scandinavia and Iceland the glaciers advanced generally, until some time between 1715 and 1720.

With regard to temperature, in order to derive a series of estimates of monthly means, Derham's series of eight years of observations of an outdoor thermometer on a north-facing wall was carefully analysed. It is to be noted that there exists no direct method of overlapping these earlier records with the later London temperature observations which begin in November 1722. A very tenuous link exists through the early Dutch observations kept by Cruquius at Delft. These begin in January 1706 and run on to 1734; they have been reduced to present-day standards by Labrijn (*Meded. ned. met. Inst.*, 49, no. 102, 1945).

Derham read his thermometer at an early morning hour soon after sunrise. His later observations were at noon and 21h. The graduations of his thermometer were in tenths of an inch, and during these eight years the range, on his scale, lay from 58 to 182 at the observing hours, the freezing-point being 82. On twenty-two days however he gives an additional mid-afternoon reading. These were as we might expect days of unusual warmth for the season, and the highest reading he reports is 186. We have no exact knowledge of the value of

his degree, as we do not know an upper fiducial point. Hence we must deduce the probable equivalent by other means. Further, we are not fully informed with regard to details of the exposure.

From what we know of the range of temperature on a north wall in south-east England, for example from the properties of the old Kew screen, a beginning can be made by assuming that over eight years the highest temperature would approximate to 90°F . On such an assumption Derham's degree would equal 0.56°F . For example, the mean annual maximum over 30 years at Camden Square (1926–55) was 89.8°F . At Kew (1871–1921, *The book of normals*) in the old north-wall screen we have 85°F and at Cambridge (1876–1921) 87°F , the absolute extremes being respectively 94°F and 96°F . We can also refer to the published average hourly values of the shade temperature in each month for Kew, and also those for the old Glaisher stand at Greenwich. From these one can take out the mean difference to be expected in each month between shade temperatures observed at the hours used by Derham.

Analysis of the observations however, using the above approximate conversion, makes it clear that the mean daily range of temperature over the interval from early morning to noon, and from noon to 21h, was greater than that we now expect, not only in the north-wall screen at Kew, but even on the Glaisher stand at Greenwich. Moreover the consistent increase in the differences from January to July makes it evident that we are most probably dealing with a thermometer exposed, at noon, to reflected radiation, probably from an adjacent wall. Derham gives us no details, but his mean noon temperature in the summer months on this assumption comes out very similar to that observed on the old Greenwich Glaisher stand. The lowest fixed-hour reading in the early morning, 19°F , and the average lowest reading, 22°F , compare quite well with what one would expect on a fairly sheltered wall during a period of eight years over which there are no contemporary accounts of very excessive heat or cold. Upminster moreover is not so located as to be subject to unusually low winter minima. At Cambridge the average annual extreme minimum is given in the old *Book of normals* as 15°F , and at Kew (in the north-wall screen) as 20°F .

After a number of trials making various assumptions with regard to the behaviour of the thermometer, it seemed most reasonable to avoid using the noon observations and to take out a first approximation to the monthly means by using the early morning and 21h readings, and correcting them to a mean for the day, using the corrections that were found to be applicable to readings made at the stated hours on the Glaisher stand at Greenwich.

Over a period of ten years or so, an independent check on the overall mean temperature of the six colder months, November–April inclusive, can be derived from the average annual number of days with snow or sleet observed to fall (cf. Manley, *Quart. J.R. met. Soc.*, **84**, 1958). While the period of eight years, 1699–1706, is rather short, we can check the frequency of occurrence of days with snow from more than one source, and we find that the average annual total was appreciably higher than today and indeed is comparable with that of late Victorian times. Accordingly the mean temperature of the colder half of the year should be expected to be about 1°F lower than it is today.

In adopting a conversion factor for Derham's degree we have therefore two

criteria to satisfy. In the first place the amplitude of the range of temperature on Derham's thermometer is such that his instrument was clearly affected by reflected radiation. Hence one would expect that in the summer months his mean noon temperature, and likewise his absolute maxima, would be rather higher than the value initially assumed. Noon temperatures in summer actually average about 3°F higher than one would expect in relation to the morning and evening readings.

The second criterion is that the overall mean for the six winter months should be lower than it is today. These criteria are satisfied if we take the equivalent of Derham's highest reading in eight years to be 93°F so that the consequent value of his degree becomes 0.59°F. In turn, this implies a corresponding adjustment of the initial approximations to monthly means derived from the morning and evening observations. I find no clear-cut ratio between Derham's degree and others, save that Derham's degree appears to be approximately 5/6 of Hauksbee's degree. I also carried out some experimentation with the Fahrenheit equivalent of Derham's lowest summer daytime temperatures on cloudy days, comparing them with what we know of the extremes in the last 100 years, with satisfactory results. Lastly, the summer of 1706 was slightly warmer than the present-day normal in Holland, and on the above adjustment it likewise proved to be slightly above normal in Essex.

The observations before 1699.—Locke's indoor thermometer readings overlap those of Derham, and between 1692 and 1703 we can work out, by comparing months of the same name in different years, approximate means for most of the cooler months of the year. For the remaining summer months, when Locke was away, we can but make estimates. Here the Gadbury MS is useful; for example it is very noticeable how frequently during July and August 1695 he uses the adjective "cold" by comparison with the same months in other years. For the greater part of 1693 we can also compare Hunt's daily readings of a thermometer in London (given by Halley, *Phil. Trans.*, **18**, 1694).

In turn, Downes' indoor readings, March 1680–September 1694, overlap those of Locke. Unfortunately there is an interruption of the sequence of daily readings for two months of 1691, probably on account of a breakage as the later values are out of step. Hence, from 1680 to 1691 we have no overlap with the later Locke series at all, and there is evidence that Downes' thermometer changed its zero very considerably (by about 15°F) and not in a linear manner. Some indication of the rate of change during that period can be got by comparison with scattered observations by Locke during 1681–83.

The monthly means given below represent the best interpolation, based on a careful analysis together with the likelihood that no one monthly mean during those twelve years would lie seriously outside the extreme values observed in the London area since 1800. Moreover, the overall mean temperature of the six colder months falls into line with expectations based on Gadbury's observed frequency of days with snowfall, which over the twelve years averaged nearly half as much again as we should expect today. Gadbury's record is consistent in this respect and the good quality of his record is corroborated when comparison is made with the overlapping observations by Downes, and also by Ashmole at Lambeth.

The prolonged severe cold of the famous winter of 1683–84, with its brief spells of thaw, is very well supported by the contemporary accounts of the

remarkable duration of ice on the Thames. There seems little doubt that this winter (December–February), with a mean temperature of about $30\cdot3^{\circ}\text{F}$ in the London area, ranks as colder than any subsequent winter, for example 1740, 1814 or 1879. The exceptional mildness of the winter of 1686 is also well documented. The whole series of years shows a wide range of behaviour; for example there were three decidedly warm Mays and three exceptionally cold Septembers, two very warm Octobers and two very cold. The deductions appear to be well supported by contemporary descriptive notes of the seasons.

Summary

(a) *Precipitation*.—Given a careful observer, the average annual total of days with “precipitation observed to fall” is clearly in good general agreement with the present-day total of days with 0·01 inch or more measured. In Table I

TABLE I—AVERAGE NUMBER OF “DAYS WITH PRECIPITATION” AND “DAYS WITH SNOW OBSERVED TO FALL”

	No. of days with precipitation	No. of days with snow observed to fall
1921–1950	approx. 168 (0·01 in. or more)	12·5 (good, but not continuous observation)
1671–1680	155	17·2
1681–1690	167	18·2
1691–1700	179	25·5
1701–1710	(168)	(17·9)
1711–1720	(165)	(20·0)

I have summarized the averages by decades, from 1671 to 1720. For the years 1718–20 the estimates are derived by adjustment from the rather less “alert” record maintained by Smith at Richmond.

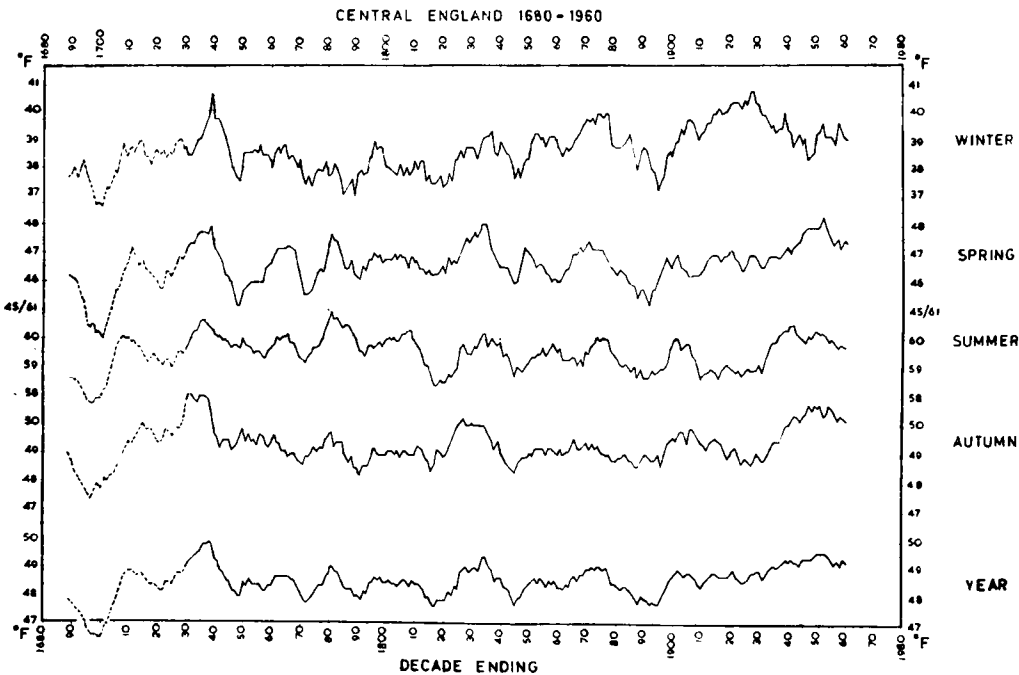


FIGURE 1—DECADAL RUNNING AVERAGES OF SEASONAL AND ANNUAL MEAN TEMPERATURES FOR CENTRAL ENGLAND, 1680–1960 (see p. 310)

It will be seen that the decade 1691–1700 was not only distinctly more unsettled than those before and after. The snow frequency was about twice that we should expect today. All the indications are that this decade was notably characterized by cold unsettled weather in spring and by cool and on the whole rainy summers. These deductions are in keeping with all contemporary descriptive reports, such as those in Evelyn's later diary. We may also note that in this decade there was a decided increase in the amount of ice in the northern Atlantic. According to Koch (*Medd. Grønland*, 130, 1945), during the summer of 1695 drift-ice was observed all around the coasts of Iceland.

In England, 1695 must rank as one of the coldest years ever known, comparable with 1879. An extremely snowy and very prolonged winter, during which the Thames was frozen over, was followed by a chilly spring and a very cool and wet July and August; the later autumn however was relatively mild.

TABLE II—ESTIMATES OF THE MEAN MONTHLY TEMPERATURE ($^{\circ}\text{F}$) IN THE LONDON REGION, 1680–1706

These estimates are primarily based on Derham's Upminster record, 1699–1706, partially overlapped by Locke's incomplete record, 1692–1703. Earlier years are less reliable, as there is no satisfactory overlap with the later records. Estimates for this period, and for Locke's missing months (in brackets) have taken into account the daily observations of wind and weather in other contemporary journals, and are given to whole degrees only (1699 onward to 0.5 $^{\circ}$).

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
1680	(41)	(39)	(43)	45	52	57	63	61	60	52	45	34	49.3
1681	34	36	40	48	53	59	61	63	59	54	45	38	49.2
1682	44	37	41	45	55	59	61	60	57	51	43	43	49.7
1683	39	37	43	51	55	63	62	58	57	45	41	33	48.7
1684	27	31	38	45	57	61	63	62	56	53	38	40	47.6
1685	34	39	42	49	56	60	59	60	55	54	46	44	49.8
1686	45	44	46	49	56	62	63	60	57	50	45	43	51.7
1687	39	41	41	45	54	57	62	61	53	53	44	43	49.4
1688	39	36	39	43	53	57	62	60	55	46	40	38	47.3
1689	34	41	42	48	53	56	62	61	57	48	42	41	48.7
1690	40	41	41	48	51	57	62	61	56	49	45	41	49.3
1691	35	35	42	45	52	58	61	62	54	(50)	(42)	39	47.9
1692	37	32	40	47	50	58	61	61	54	45	42	39	47.2
1693	38	42	38	45	50	60	61	61	55	51	44	38	48.6
1694	33	42	39	47	50	57	61	57	52	(47)	43	(37)	47.2
1695	31	33	39	43	50	(57)	58	(57)	(54)	50	(43)	40	46.2
1696	43	41	39	43	53	(57)	(62)	(62)	(55)	(50)	(43)	37	48.7
1697	35	34	43	46	55	57	(62)	(60)	(56)	(50)	(40)	37	47.8
1698	33	34	39	47	49	56	61	(61)	(57)	(50)	40	39	47.2
1699	38.5	39	40.5	45	51.5	60.5	65.5	61	58	50.5	42.5	39	49.3
1700	40	37.5	39.5	45	55.5	58.5	61	61	57.5	49.5	41.5	40	48.9
1701	38	37.5	38	41	53	59.5	67.5	63	60.5	47	44.5	39	49.0
1702	42	45	44	44.5	52.5	58	61	63	60	51.5	41	40.5	50.3
1703	36.5	40	43.5	49	55	59	63	63	52.5	47	46	42	49.7
1704	36.5	38.5	43	49	54	60	64	64.5	55.5	48.5	44.5	39	49.7
1705	37	39.5	41	47.5	53.5	56	62	65.5	55.5	49.5	40	40.5	49.0
1706	37.5	40.5	45	50	55.5	62	63	64	56.5	53.5	44	41	51.0
1681–90	37.5	38.3	41.3	47.3	54.3	59.3	61.7	60.6	56.2	50.3	42.8	40.4	49.1
1691–1700	36.3	37.0	39.9	45.3	51.5	57.8	61.3	60.4	55.2	49.3	42.1	38.5	47.9
1701–10	37.9	38.5	42.4	47.4	54.2	59.6	62.7	63.4	57.7	49.7	44.6	40.5	50.0

For the years 1707–10 approximations are based on Dutch monthly means, adjusted by reference to contemporary English accounts.

Probable values at Upminster today, based on *rural* stations around London:

1921–50	39.9	40.3	43.8	48.3	54.1	59.8	63.4	62.7	58.5	51.3	44.4	40.4	50.6
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(b) *Temperature*.—In Table II all statistics have been drawn up with reference to the New Style, or Gregorian, calendar months in order to assist

comparison with present-day conditions, and with contemporary events in France and other European countries in which the Gregorian calendar was already adopted. In Figure 1 I have used these averages to provide an extension of the series of ten-year running mean temperatures representative of the four seasons for "central England". This will serve to demonstrate the decided recession in the 1690's, followed by the well documented amelioration about 1730. It is hoped that the estimates of the monthly means here given will prove of service, at least as an indication of trend, until such time as further confirmation can be forthcoming. If my interpretation of the probabilities based on the frequency of snow is correct, the monthly means do not appear likely to err by more than 1°F. Primitive though these instrumental observations are, they appear at present to be the earliest series of any length in Europe, which renders the attempt to reduce them to modern standards the more alluring. Further work on these journals is in progress.

Acknowledgements.—I have to thank the Officers of the Royal Society, and the Librarian, for the privilege of working on the early manuscripts in their possession, the Bodleian Library at Oxford for the like privilege and Miss Elizabeth M. Shaw, M.Sc. for the compilation and drawing of the diagram.

551.509.324.1:551.578.4

THE PROBLEM OF FORECASTING THE DOWNWARD PENETRATION OF SNOW

By F. E. LUMB, M.Sc.

Summary.—During continuous moderate precipitation, if the lapse rate is close to the saturated adiabatic, snow can be expected to penetrate down to the level at which the wet-bulb temperature is 1.5°C, but is very unlikely to descend beyond the 3.5°C wet-bulb level. Even during heavy precipitation, snow will very rarely descend beyond the 4.5°C wet-bulb level. By means of a simple geometrical construction on the tephigram, the potential depth of penetration of snow for any known environment curve can be found.

Introduction.—A difficult problem which sometimes faces the forecaster in winter over the British Isles, when continuous moderate or heavy precipitation is expected, is to decide whether the precipitation will be in the form of rain or snow. A reliable forecasting rule is that if the 0°C wet-bulb level is less than 300 metres above the ground, continuous moderate precipitation will very probably be in the form of snow. In other words, snow can be expected to descend to the 1.5°C wet-bulb level if the wet-bulb lapse rate below the 0°C level is the saturated adiabatic (γ_s). There is, however, as yet no well established rule for forecasting the lowest level to which snow can be expected to descend during moderate or heavy precipitation. The unexpected snowfall over the Cotswolds on 1 November 1942 has been taken as evidence that it is possible for snow to descend as much as 1500 metres below the 0°C wet-bulb level, but this is based on the assumption that in the absence of surface fronts over southern England on that day, the 0°C level given by the Larkhill upper air sounding at 1100 GMT was applicable to the Cotswolds, only 80 kilometres to the north. However, a detailed examination of this snowfall by Lumb¹ has revealed that the above assumption was erroneous and it is most unlikely that snow penetrated downwards more than 600 metres below the true 0°C wet-bulb level.

Evidence is presented in this paper which shows that 600 metres can be taken as an upper limit to the depth of penetration of snow during precipitation whose equivalent rate of rainfall is light or moderate (that is, does not

exceed 4 millimetres per hour), provided the lapse rate is close to the saturated adiabatic (γ_s). In other words, a reliable forecasting rule is that during moderate precipitation snow will not descend below the 3.5°C level if the lapse rate below the 0°C level is γ_s . Also, it will be shown how a simple construction on a tephigram enables the lowest level of penetration of snow to be found, whatever the wet-bulb environment curve below the 0°C level may be, provided it is known accurately.

Lamb² has related the type of precipitation to 1000–500-millibar thickness, and Murray³ has assessed the probability of precipitation being in the form of snow when certain pairs of parameters (1000–500-millibar thickness and surface temperature, 0°C level and surface temperature) are known. Mineeva⁴ has made a similar study using the 1000–850-millibar thickness and the surface temperature. A knowledge of critical thickness values, in conjunction with 24-hour thickness charts, is useful in alerting the forecaster to the possibility of snow, but in order to make a more confident short-period prediction, it is necessary to consider the thermodynamical aspects of the problem, in particular the role of the falling snowflakes as a powerful cooling agent. Both cooling by evaporation and by melting are involved.

Cooling by evaporation.—It is a matter of common experience that cooling by evaporation during precipitation of moderate intensity can reduce the wet-bulb depression to a small fraction of its original value within an hour or two. The rate of cooling at any level decreases exponentially with time, and if the air below the 0°C level is dry there will be a rapid fall of temperature during the first hour. A column of air which has been subjected to at least two hours cooling by moderate precipitation will be saturated or very nearly so, and the temperature at any level will have been reduced practically to the wet-bulb temperature. An example of a snowfall which clearly demonstrates the importance of cooling by evaporation will be given later.

Cooling by melting.—Even when the 0°C wet-bulb level is several hundred metres above the ground, the possibility of snow reaching the ground cannot be ignored. Snowflakes of large mass can extend downwards several hundred metres below the 0°C level before being completely melted. The rate of cooling by melting is zero at the 0°C level and falls to zero at the level below which all snowflakes have completely melted. It is most rapid at some intermediate level within the melting layer so that in the lower part of this layer the lapse rate tends to increase, but the process of cooling by melting in the free atmosphere is strongly counteracted by convection, especially if the air is saturated. However, if a substantial amount of falling snow (in the form of partly melted snowflakes) reaches the ground, convection ceases, and the subsequent cooling of the whole column of air between the 0°C level and the ground by the melting of the falling snow can quickly reduce the temperature of the whole layer to 0°C , and precipitation then takes the form of snow at all levels down to the ground. This process was well illustrated by the Cotswolds snowfall of 1 November 1942, examined by Lumb¹, and by the New England snowfall of 13 April 1953, studied by Wexler, Reed and Honig⁵. In the former example, snow penetrated downwards 600 metres below the 0°C wet-bulb level and the precipitation changed from rain at a temperature of 2.8°C to snow at 0°C within a period of three hours. In the latter example, snow penetrated downwards between 700 and 750 metres below the 0°C wet-bulb level and precipitation changed from rain at a temperature of 4.4°C to snow at 0°C within a period of one hour.

Cooling by melting is most effective when prolonged precipitation is associated with light winds below the 0°C level, as in the case of the Cotswolds snowfall of 1 November 1942, or when the trajectory of the layers of air is such that they are subject to several hours' cooling in the precipitation belt, as occurred in the New England snowfall. It has little effect over the sea, and with onshore winds a coastal strip will escape the snowfall which may occur farther inland.

Depth of penetration of snow.—Experience shows that the fall of surface air temperature towards 0°C starts at about the time when the observed form of precipitation changes from rain to sleet.* It is therefore important to know the greatest depth (D) below the 0°C level in a saturated environment at which the form of precipitation can be readily recognized by an experienced observer as being in the form of sleet, since D is also the potential depth of penetration of snow.

D will depend on the temperature and humidity of the environment below the 0°C level, and on the intensity of the precipitation. For any given snowfall it can be shown theoretically (see Appendix, p. 316) that in a saturated environment

$$\int_{p_0}^{p_D} T_a \, d(\log p) = \text{constant}, \quad \dots (1)$$

where p_0 is the pressure at the 0°C level, p_D is the pressure at a depth D below the 0°C level and T_a is the temperature (in $^{\circ}\text{C}$) of the environment. The integral of equation (1) is proportional to the area on the tephigram contained between the environment curve, the 0°C isotherm and the p_D isobar. Equation (1) therefore means that this area is constant for any given snowfall, whatever the environment curve. An example of the application of equation (1) to a particular environment curve will be given later. If z is the vertical distance below the 0°C level, for a constant lapse rate γ equation (1) becomes

$$\gamma \int_0^D z \, dz = \text{constant}. \quad \dots (2)$$

D will also depend on the melted drop-size spectrum of the snowfall, since the greater the mass of a snowflake, the greater its melting depth. Gunn and Marshall⁶ have shown that in general the melted drop-size spectrum during snowfall broadens as the intensity of precipitation (I) increases. Consequently a positive correlation between z and I is to be expected.

Since over the land during continuous precipitation in maritime polar air, the lowest layers of the atmosphere are saturated or very nearly so, and the lapse rate is usually close to the saturated adiabatic (γ_s), it is of special importance to find an upper limit to the depth (D_s) of penetration of sleet (as an observable phenomenon) downwards in a saturated environment which has a lapse rate γ_s .

Over land, except in the rare circumstance that the start of an upper air sounding coincides with an observation of sleet, the lapse rate below the 0°C level is not known accurately. However, over the sea when sleet is reported, a

* Throughout this paper, the word "sleet" means "precipitation in the form of raindrops and melting snowflakes".

combination of heating from below by the relatively warm sea surface and cooling from above by thawing snowflakes, will ensure that the lapse rate is close to the dry adiabatic (γ_d) from the level of observation (about 10 metres above sea level) up to the cloud base, and close to γ_s in cloud.

If h_b is the height of the cloud base and h the height of the 0°C level, then assuming saturation at all levels, from equation (2) we have

$$\gamma_s \int_0^{h-h_b} z \, dz + \gamma_d \int_{h-h_b}^h z \, dz = \gamma_s \int_0^{D_s} z \, dz \quad \text{if } h > h_b \quad \dots (3)$$

and

$$\gamma_d \int_0^h z \, dz = \gamma_s \int_0^{D_s} z \, dz \quad \text{if } h < h_b. \quad \dots (4)$$

Integrating equation (3), we find

$$D_s^2 = (h-h_b)^2 + \alpha h_b(2h-h_b), \quad \dots (5)$$

$$\text{where } \alpha = \frac{\gamma_d}{\gamma_s}.$$

Also if T is the surface air temperature in degrees C,

$$h = h_b(1-\alpha) + h_s \quad \dots (6)$$

where
$$h_s = \frac{T}{\gamma_s}.$$

Eliminating h from equation (5) by means of equation (6), we get

$$D_s = (h_s^2 - \alpha(\alpha-1)h_b^2)^{\frac{1}{2}} \quad \text{if } h > h_b \quad \dots (7)$$

and from equation (4) we get

$$D_s = \frac{h_s}{\alpha^{\frac{1}{2}}} \quad \text{if } h < h_b. \quad \dots (8)$$

In practice the air below the cloud base is not saturated. Heat transfer theory shows that the contributions of conduction and condensation to the rate of melting are approximately equal. Hence by assuming a constant rate of decrease of the wet-bulb depression from the ship's observation level to zero at the cloud base, a correction (usually small) can be made to equation (7) or (8) to take account of the deviation from saturation. If T_w is the ship's wet-bulb temperature, and $T' = \frac{1}{2}(T + T_w)$, the modified form of equation (7) is

$$D_s = [(h_s')^2 - \alpha'(\alpha'-1)h_b^2]^{\frac{1}{2}} \quad \dots (9)$$

and the modified form of equation (8) is

$$D_s = \frac{h_s'}{(\alpha')^{\frac{1}{2}}} \quad \dots (10)$$

where
$$h_s' = \frac{T'}{\gamma_s} \quad \text{and} \quad \alpha' = \alpha \left(1 - \frac{T-T'}{h_b \gamma_d} \right).$$

If T , T_w and h_b are known, D_s can be calculated from equation (9) or (10) as appropriate. Hence, with the aid of these equations, observations of moderate or heavy sleet (present weather, $ww=69$) over the sea can be used to find the upper limit of D_s , that is, an upper limit to the potential depth of penetration of snow over the land during continuous moderate or heavy precipitation when the lapse rate below the 0°C level is the saturated adiabatic (γ_s).

Thirty-three occasions of $ww=69$ at the North Atlantic ocean weather stations have been found. As regards h_b , it is very difficult for an observer at sea to give an accurate estimate or measurement of the height of the cloud base during moderate or heavy precipitation. However, ignoring five cases of "sky obscured", the reported cloud base ranged from 400 to 3000 feet, the median value being 800 feet. Taking h_b to be 400 feet (122 metres) and 800 feet (244 metres) respectively, and using equations (9) or (10) as appropriate to calculate D_s , Table I is obtained.

TABLE I—VALUES OF D_s FOR ASSUMED CLOUD BASES
OF 122 AND 244 METRES

D_s metres	Assuming $h_b=122$ metres	Assuming $h_b=244$ metres
	number of occasions	
400	22	23
400–500	6	6
500–600	4	3
600–700	0	0
700–800	1*	1†

* $D_s=724$ m. † $D_s=708$ m.

It is significant that the one case when D_s exceeded 600 metres (station ALFA at 0900 GMT on 9 November 1956) was the only occasion when the cloud type was reported as being of convective origin, namely, cumulonimbus. Orographic influences being absent over the sea, it is unlikely that the intensity of precipitation would qualify for the description "heavy" except perhaps on 9 November 1956. Since for any given values of T and T_w , D_s increases as h_b decreases, Table I shows that D_s is very unlikely to exceed 600 metres during precipitation of moderate intensity. In other words, over land snow is very unlikely to descend below the 3.5°C wet-bulb level when the lapse rate below the 0°C level is the saturated adiabatic and the equivalent rate of rainfall is moderate.

It will be shown that this limit of 3.5°C was closely approached during two of the most striking examples of downward penetration of snow on record for the British Isles.

South Midlands snowfall of 28 December 1945.—A rapidly deepening depression moved quickly east-north-east over southern England during the day. The upper air sounding for Downham Market (Figure 1) at 0001 GMT is representative of the surface layers of the air through which snow subsequently penetrated down to the ground. Although the 0°C level was as high as 890 millibars and the temperature in the surface layers was above 5°C , nevertheless, over a belt of country to the north of the track of the centre of the depression, after several hours of rain and sleet, snow penetrated down to ground level and reached ground only 100 metres above sea level to the north of the Thames basin.

What is the explanation? The main contributory factor was undoubtedly the relative dryness of the air mass. Cooling by evaporation would quickly lower the temperature at almost all levels by 2° to 3°C . The rapid fall of pressure was

also a very important factor. Mean-sea-level pressure in the snow belt fell 15 millibars below that at Downham Market at 0001 GMT. This would result in the lowering of any given isobaric surface by about 120 metres, and reduce the wet-bulb temperature in the lowest layers by about 0.5°C . Under the combined influence of cooling by evaporation, adiabatic expansion, and convection, the environment curve below the 0°C level would be modified to the shape AB in Figure 1, that is, there would be a nearly constant lapse rate very close to γ_s .

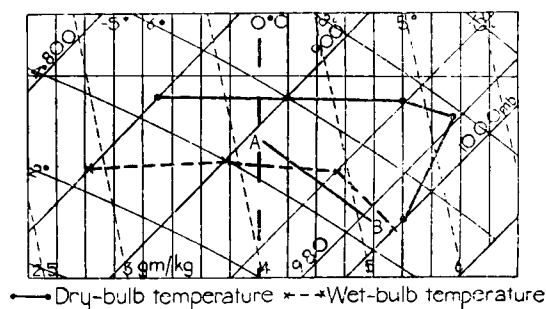


FIGURE 1—TEPHIGRAM FOR DOWNHAM MARKET, 0001 GMT, 28 DECEMBER 1945

In the snow belt, the snow penetrated down to the 980-millibar level, that is to the level where the temperature although originally as high as 6.5°C had fallen to 3.5°C under the combined influences of evaporation and adiabatic expansion. At North Weald, for example, at 0900 GMT, just before rain changed to snow, the dry-bulb and wet-bulb readings were both 38.0°F (3.3°C).

An examination of relevant rainfall records (for example, Bristol, Upper Heyford, Hampstead) shows that to the north of, but near to, the centre of the depression, the rate of rainfall was generally between 3 and 4 millimetres per hour, that is, near to the upper limit of moderate intensity.

Cotswolds snowfall of 1 November 1942.—Lumb¹ has given evidence to show that the environment curve below the 0°C level at Little Rissington on 1 November 1942, when sleet penetrated down to the ground, was as shown in Figure 2 (curve ABC). The air was saturated, and the lapse rate was very close to γ_s above 950 millibars but approximately isothermal below. By equation (1), if in Figure 2 the saturated adiabatic AB is produced to the level D , such that area BED = area $PQCE$, D is the level to which the snow would have reached if there had been a constant lapse rate γ_s . We see that the wet-bulb temperature

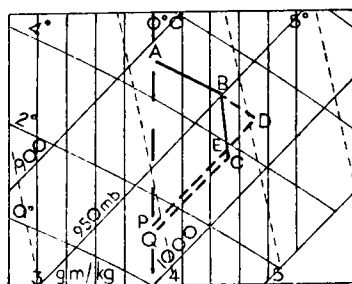


FIGURE 2—TEPHIGRAM (SATURATED AIR) FOR LITTLE RISSINGTON, 0740 GMT, 1 NOVEMBER 1942

This was deduced from the Larkhill sounding for 2000 GMT, 1 November 1942

at the level D on the saturated adiabatic is about 3.5°C . The rate of rainfall at the time when the form of precipitation changed from rain to sleet was between 3 and 4 millimetres per hour, that is near to the upper limit of the moderate range.

The construction on the tephigram shows that the presence of the isothermal layer enabled the snow to penetrate about 5 millibars lower than it would have done if there had been a constant lapse rate γ_s . The influence of the isothermal layer was therefore small, but probably crucial in permitting sleet (potentially snow) to reach the ground over the highest part of the Cotswolds.

Depth of penetration of snow during heavy precipitation.—Snowflakes of largest mass are found during the heavy precipitation associated with instability showers and polar air depressions, so that D_s will have its largest values during heavy instability precipitation. Sleet or snow showers in conjunction with ships' dry-bulb temperatures approaching 4.5°C are not uncommon over the north-east Atlantic during the winter, but are much less frequent when the air temperature exceeds 4.5°C , even sleet rarely being reported when the air temperature exceeds 5.5°C .

Twenty-seven cases of sleet or snow showers at ocean weather stations ALFA, INDIA and JULIETT have been found for which the ships' dry-bulb temperature was $\geq 40.0^{\circ}\text{F}$ (4.4°C). The reported cloud base for these occasions ranged from 1000 to 2000 feet. Accepting the reported cloud base to be a good estimate of the true cloud base, and using equation (9) or (10), as appropriate, Table II is obtained for D_s .

TABLE II—VALUES OF D_s USING REPORTED CLOUD BASES

D_s metres	number of occasions
600	12
600–700	8
700–800	2
800–900	2
900–1000	3

D_s exceeded 750 metres on only five occasions. Hence, even when there is heavy instability precipitation, the depth of penetration of snow is very unlikely to exceed 750 metres. This corresponds to the 4.5°C level when the lapse rate is γ_s .

This limit was very closely approached during the remarkable snowstorm over New England on 13 April 1953 when sleet, changing quickly to snow, reached the ground when the temperature was 40°F (4.4°C). Within one hour the form of precipitation had changed to snow and the temperature had fallen to 32°F (0°C). However, the rate of rainfall at the time when rain changed to sleet had on this occasion the unusually high value of 8 millimetres per hour. This snowfall was therefore an extreme example of downward penetration, and evidently contained many snowflakes of large mass which are characteristic of heavy instability snow showers.

APPENDIX

The melting of snowflakes in a saturated atmosphere

Mason⁷ has calculated the distance which hailstones have to fall in saturated air before completely melting, on the assumption that all melt water is retained and uniformly distributed around the ice. The basic equations governing the

transfer of heat between the air and the hailstone (assumed to be spherical) are:

$$-L_f 4 \pi a^2 \rho_i \frac{da}{dt} = 4 \pi a b K_w \frac{T_s}{b-a}$$

$$(\text{latent heat of melting}) = (\text{transfer through water})$$

$$= 4 \pi b K_a C (T_a - T_s) + L_v 4 \pi b D C [\rho_s(T_a) - \rho_s(T_s)] \dots (1)$$

$$= (\text{conduction through air}) + (\text{condensation on surface})$$

where

a	is the radius of the unmelted core
b	is the overall radius of the particle
T_s	is the surface temperature ($^{\circ}\text{C}$) of the hailstone
T_a	is the temperature ($^{\circ}\text{C}$) of the environment
L_f, L_v	are the latent heats of fusion and evaporation
K_w, K_a	are the thermal conductivities of water and air
D	is the diffusion coefficient of water vapour in air
ρ_i	is the density of the ice particle
C	is a ventilation coefficient (a function of the Reynolds number)
$\rho_s(T_a), \rho_s(T_s)$	are the saturation vapour densities appropriate to the temperatures T_a and T_s .

In contrast to hailstones, snowflakes are of low density, and as they melt the melt water will tend to percolate into the ice portion. It is therefore reasonable to assume that the surface of the snowflake consists of a mixture of ice and water whose temperature remains at 0°C , that is, for a melting snowflake $T_s = 0^{\circ}\text{C}$ and the term in equation (1) referring to transfer through water can be disregarded.

Equation (1) applies to a spherical particle, but snowflakes do not conform to any simple geometrical shapes. However, the term which represents the latent heat of melting can be brought into a more general form which does not assume any particular geometrical shape for the snowflake by writing it as $L_f m_o \frac{dF}{dt}$, where m_o is the mass of the snowflake at the 0°C level and F is the fraction of m_o which has melted at any time. Similarly, the terms for conduction and condensation can be generalized by substituting the symbol S for $4 \pi b C$, where S is a function of the size, shape and physical structure of the snowflake.

Equation (1) then becomes

$$L_f m_o \frac{dF}{dt} = S [K_a T_a + L_v D \{ \rho_s(T_a) - \rho_s(0) \}] \dots (2)$$

For the small range of temperature with which we are concerned (0° to 5°C), as a good approximation we can write $\rho_s(T_a) - \rho_s(0) = \beta T_a$ where β is a constant.

Hence equation (2) becomes

$$L_f m_o \frac{dF}{dt} = S (K_a + \beta L_v D) T_a \dots (3)$$

Putting $dt = dz/w$, where w is the speed of fall of the snowflake at any instant and z is measured downwards from the 0°C level, and writing

$$k = \frac{L_f}{K_a + \beta L_v D}$$

equation (3) becomes

$$k m_o \frac{w}{S} dF = T_a dz. \quad \dots (4)$$

Now for any given snowflake w and S are both determined at any time by the changing shape, size and physical structure of the snowflake as it gradually melts into a raindrop. Hence w and S at any time are determined by their values at the 0°C level (w_o , S_o) and by F . Since w_o is also determined by S_o , equation (4) can be written

$$k m_o \phi(S_o, F) dF = T_a dz. \quad \dots (5)$$

Integrating from the 0°C level to the level (d) of completion of melting,

$$k m_o \int_0^1 \phi(S_o, F) dF = \int_0^d T_a dz. \quad \dots (6)$$

For a given value of S at the 0°C level, that is S_o , ϕ is a continuous function of F only. Hence for any given snowflake

$$\int_0^d T_a dz = \text{const.} \quad \dots (7)$$

Since we are concerned only with a small range of temperature (5°C), equation (7) can be written

$$\int_{p_o}^{p_d} \frac{T_a}{p} d(\log p) = \text{const}, \quad \dots (8)$$

where p_o is the pressure at the 0°C level and p_d is the pressure at a depth d below the 0°C level.

The integral of equation (8) is proportional to the area on the tephigram contained between the environment curve, the 0°C isotherm and the p_d isobar. This area, A_d , is constant for any given snowflake, whatever the environment curve.

When considering a particular snowfall, we are concerned with a large number of snowflakes of different shape, size and physical structure, and the appearance of the precipitation at any pressure level p ($> p_o$) will be determined by A_p , the A -value at that level, since the degree of melting of each individual snowflake will be controlled by A_p . (If $A_p > A_d$, the snowflake will already be completely melted.) The lowest level (p_D) at which the form of precipitation would be reported as sleet will coincide with the level of complete melting of

those snowflakes whose A -value is A_D . Hence A_D is constant for any given snowfall, that is

$$\int_{p_0}^{p_D} \frac{p_D}{T_a} d(\log p) = \text{const.} \quad \dots (9)$$

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RADIOSONDE TEMPERATURE READINGS AND CLOUD AMOUNT

By D. N. HARRISON, O.B.E., D.Phil.

The work described in this note arose from questions discussed by the Commission for Instruments and Methods of Observation Working Group on the Comparison of Aerological Instruments. The results, though not conclusive, may be of interest as a pointer to further work.

In the first place, it was desired to investigate whether any relationship could be found between the radiation error of radiosonde temperature readings by day and the earth's albedo as measured by the total cloud amount. Such a relationship would be expected on theoretical grounds, for Scrase¹ finds that "a change of 0.1 in the albedo alters the errors by about 7 per cent" and therefore, since the albedo varies from about 0.1 for the earth or sea in the absence of cloud to 0.6 for continuous dense cloud, a variation over a range equal to roughly a third of the radiation correction ought to be shown by the published temperatures, even though these are corrected for radiation, since the corrections applied are independent of the albedo.

To test this, the values of the difference between the temperature at the midday ascent and the mean of the preceding and following midnight ascents at Crawley and Aughton were tabulated for the levels 200, 150, 100 and 70 millibars, together with the total cloud amount at a nearby surface reporting station (Gatwick, 8 kilometres north-north-east of Crawley, and Manchester, 48 kilometres east-south-east of Aughton*). The months January, February, June and July 1960 were taken. The temperatures were taken from the *Daily Aero-logical Record*; they have been corrected for radiation by the normal method.

* This is rather a large distance, but it was thought better to use Manchester than Squire's Gate, which is on the coast about 25 kilometres north of Aughton.

TABLE I—DISTRIBUTION OF DAY-NIGHT TEMPERATURE DIFFERENCES FOR JANUARY AND FEBRUARY 1960

Temperature difference °C	70 millibars						100 millibars						
	0	1	2	Cloud amount in oktas number of occurrences			3	4	5	6	7	8	Total
> +5						1							0
+5													0
+4½										1	2	1	4
+4								1		1		1	3
+3½												3	3
+3										1			1
+2½													
+2			1		2	1		1			1	1	4
+1½		1			1			1				3	6
+1					1	2							2
+½		1			1			1			3	9	14
0											3	7	13
		1			1	1		1	1	1	3	6	14
-½													
-1			1			1		1	1	1	1	5	9
-1½									3		2	1	8
-2								1		1	1	3	5
-2½						1					3	3	6
		1									1		1
-3													
-3½						2							1
-4													0
-4½											1		1
-5													0
< -5													0

Mean diff. °C	—	-0.1	+0.5	-3.0	+1.2	+1.0	+0.5	+0.6	+1.0	+0.6	0.0	+1.5	-0.1	+1.6	+2.6	+0.6	+0.5
No. of cases	0	4	2	2	5	4	4	12	24	57	0	7	7	7	21	43	95
Standard deviation										2.0		3	5				1.8
Radiation correction (Solar altitude 15°)										-2.8							-2.1

TABLE I—DISTRIBUTION OF DAY-NIGHT TEMPERATURE DIFFERENCES FOR JANUARY AND FEBRUARY 1960 *continued*

Temperature difference °C	150 millibars							200 millibars							Total									
	0	1	2	Cloud amount in oktas 3 4 5 number of occurrences				6	7	8	Total	0	1	2		Cloud amount in oktas 3 4 5 number of occurrences				6	7	8	Total	
> +5																								5
+5																								3
+4½																								1
+4																								2
+3½																								3
+3																								4
+2½																								8
+2																								7
+1½																								11
+1																								7
+½																								10
0																								9
-½																								10
-1																								9
-1½																								9
-2																								1
-2½																								5
-3																								1
-3½																								1
-4																								1
-4½																								2
-5																								0
< -5																								8

Mean diff. °C — -1.8 -1.3 +1.8 -0.4 +0.6 +2.0 +0.4 +0.3 -0.3 0.0 — +0.8 +1.5 -0.2 +2.6 +1.4 -0.5 +0.3 -0.2 +0.3

No. of cases 0 7 2 3 5 7 7 23 49 103 2.6 53 25 8 9 53 117

Standard deviation 2.6

Radiation correction (Solar altitude 15°) -1.5

TABLE II—DISTRIBUTION OF DAY-NIGHT TEMPERATURE DIFFERENCES FOR JUNE AND JULY 1960

Temperature difference °C	70 millibars						100 millibars						Total							
	Cloud amount in oktas number of occurrences						Cloud amount in oktas number of occurrences													
> +5	0	1	2	3	4	5	6	7	8	Total	0	1	2	3	4	5	6	7	8	Total
+5								1		1										0
+4½										0										0
+4								1		1						1				1
+3½							2		2	4							1	2		3
+3						1		2	1	4								2		2
+2½								1		1								1		1
+2								1		1										
+1½						2		4	2	8							1	1	6	4
+1						1	2	4		9			1	1		3	1	4	1	11
+½		1	2					3	1	8		1				5	1	4	1	13
0						3		4	2	9					1	1	1	9	1	10
		2				1		2	2	7		3	1	1		1	2	7	3	19
-½														1		2				
-1				1		1	2	3	1	8			1			2		2	2	7
-1½						1		3		4				1			2			5
-2				1	1				2	5						1	1			2
-2½					1			1		2								1		2
-3						1				1							2			2
-3½							1			2										0
-4										0										0
-4½										1										0
-5										0							1			1
< -5										1										0

Mean diff. °C	—	+0.3	+1.0	+0.3	-1.7	0.0	-0.1	+1.2	+1.1	+0.6	0.0	+0.3	+0.7	+0.5	-0.3	+1.2	-0.1	+1.1	+0.8	+0.8
No. of cases	0	3	2	4	2	13	10	30	13	77	1	4	2	4	2	16	14	39	16	98
Standard deviation										2.0										1.5
Radiation correction (Solar altitude 60°)										-4.4										-3.4

TABLE II—DISTRIBUTION OF DAY-NIGHT TEMPERATURE DIFFERENCES FOR JUNE AND JULY 1960 *continued*

Temperature difference °C	150 millibars						200 millibars						Total								
	0	1	2	Cloud amount in oktas number of occurrences			6	7	8	Total	0	1		2	Cloud amount in oktas number of occurrences			6	7	8	Total
> +5										0											
+5										2						1	1	2	3	6	
+4½										1								3	1	5	
+4										3						1		3	1	1	
+3½			1							2			1					3	3	4	
+3										4								1		1	
+2½			1			2				8					1	1	2	4	2	10	
+2					1	1				10						3	2	1	1	7	
+1½						2	1			9		1				1	1	3	2	9	
+1		1		2		2	2			13		2				2		4	1	9	
+½		2			4		2			22	1					1		1	3	6	
0	1					1	1			8				1	1	1	1	6		10	
-½																					
-1				1	2	1	2			14				3		2	1	1	1	8	
-1½										2		1				1	1	5		8	
-2						3	3			7						1	2	2	1	6	
-2½		1				1	1			8			1			1	1	1	1	4	
										3						2	3	1	3	9	
-3						1				1									4	4	
-3½							1			2								2		2	
-4										0								1		1	
-4½										0								1		1	
-5										0								2	1	3	
< -5										0								1		1	

Mean diff. °C	0.0	0.0	+3.0	-0.4	+0.2	+0.2	-0.4	+0.8	+1.2	+0.6	+0.5	+0.6	+0.7	0.0	+4.0	+0.8	+0.1	+0.6	+0.5	+0.6
No. of cases	1	4	2	5	3	17	15	48	24	119	1	4	2	5	3	17	15	48	25	120
Standard deviation										1.8										2.9
Radiation correction (Solar altitude 60°)										-2.5										-2.1

The results are given in Table I (January and February 1960) and Table II (June and July 1960), in the form of the frequency of occurrence of temperature differences in steps of $\frac{1}{2}^{\circ}\text{C}$, for cloud amounts from 0 to 8 oktas. The mean differences, standard deviations from the mean and approximate radiation corrections are also given. There is a mean difference of about $+\frac{1}{2}^{\circ}\text{C}$ at each level, but no correlation between temperature difference and cloud amount.

Although the cloud amount at a single fixed station is not a satisfactory measure of the albedo as seen by the sonde throughout its flight on all occasions, it seems probable that if a correlation between temperature and albedo existed it would be detected by this method. It is unlikely that the cloud amounts at the radiosonde stations themselves, had they been available, would have given a significantly different result. It can therefore at least be concluded that the total cloud amount does not provide a basis for improving the radiation corrections.

Secondly, for lower levels the question is, what error is introduced by applying the full radiation correction when the sonde is more or less in the shadow of cloud?

The differences between the temperature reading at midday and the mean of the preceding and following midnight soundings were tabulated for the eight stations in the United Kingdom for days in the months May–August 1960 when the neighbouring surface stations reported either (a) a total cloud amount of 0–3 oktas or (b) 6, 7 or 8 oktas of medium or high cloud and 0–4 oktas of low cloud. The results in the form of the mean and standard deviation, for each standard level from 850 to 200 millibars, are given in Table III. The standard radiation corrections for solar altitude 60° have been added for comparison. The stations used, and the relative positions of surface and upper air stations, are listed in Table IV.

TABLE III—MEAN TEMPERATURE DIFFERENCE (DAY-NIGHT) AND STANDARD DEVIATION ($^{\circ}\text{C}$)

			Pressure level (millibars)					
			850	700	500	400	300	200
			<i>degrees Celsius</i>					
(a)	{	Mean difference ...	−0.3	−0.4	−0.5	−0.7	−0.6	−0.1
		Standard deviation ...	1.2	1.3	1.6	1.7	2.2	2.6
(b)	{	Mean difference ...	−0.5	−0.3	0.0	+0.2	+0.3	−0.2
		Standard deviation ...	1.4	1.4	1.7	1.8	2.0	2.9
Radiation correction for solar altitude 60° ...			−0.8	−0.9	−1.2	−1.4	−1.6	−2.1

- (a) Total cloud amount 0–3 oktas; 130 cases.
 (b) Medium and high cloud 6–8 oktas, low cloud 0–4 oktas; 200 cases.

TABLE IV—STATIONS USED

Upper air station	Surface station	Position of surface station with respect to upper air station	
		distance (km)	direction
Lerwick	Lerwick	—	—
Stornoway	Stornoway	—	—
Shanwell	Leuchars	5	S
Aldergrove	Aldergrove	1	W
Aughton	Manchester	48	ESE
Hemsby	Gorleston	11	S
Crawley	Gatwick	8	NNE
Camborne	St. Mawgan	32	NE

Since the greater part of the radiation error is due to direct sunlight, it might be expected that when the sonde is in cloud shadow the application of the radiation correction would result in a temperature reading which is too low by nearly the amount of the correction, and that on the average the final error would be roughly proportional to the amount of cloud above the sonde, at least when the sun is near the zenith. For group (a) the mean cloud amount is about 2 oktas*, so that at 850 millibars a mean error of $-2/8 \times 0.8^\circ = -0.2^\circ\text{C}$ would be expected. For group (b) the mean amount of medium or high cloud is about 7 oktas, so that the expected error at 850 millibars is -0.7°C . (The presence of some low cloud would tend to make this figure more negative.) The mean day-night differences found are -0.3°C and -0.5°C , but these include the diurnal variation, which presumably tends to be larger on days of low than on days of high cloud amount; if so, the mean differences due to the effect under discussion are more negative than this and the distinction between groups (a) and (b) is obliterated. Thus the results give only qualitative support to the hypothesis, inasmuch as they indicate over-correction for radiation error. At higher levels, as the sonde passes through the cloud, a decrease of the effect would be expected; this is found in group (b), but the positive values here, the increasing negative values in group (a) and the change between 300 and 200 millibars in both cannot be explained in this way. Moreover, the values for 200 millibars in Table III are different from those in Table II. This may be due to sampling errors, as the mean values for 200 millibars are subject to a standard error of about 0.25°C .

As stated above, the temperature readings were taken from the *Daily Aerological Record*. A number of very large day-night differences occur, some of which at first sight suggest errors in the published figures. These have been examined as far as possible, and in many cases an outstandingly large value at one station is confirmed by a similar one at another; the general impression created is one of confidence in the data. No alterations were made, and no reading was excluded from the analysis merely because it looked improbable.

I am indebted to Mr. R. Brown for the computations on which this note is based.

REFERENCE

1. SCRASE, F. J.; Radiation and lag errors of the Meteorological Office radiosonde and the diurnal variation of upper-air temperature. *Quart. J. R. met. Soc., London*, **80**, 1954, p. 565.

REVIEWS

Handbuch der Aerologie, edited by W. Hesse. 9 in. \times 6½ in., pp. 897, *illus.*, Akademische Verlagsgesellschaft Geest & Portig K.-G., Leipzig, 1961. Price: 80 DM.

The author of the term "aerology" was W. Köppen who proposed it in 1906 at a meeting of the International Commission for Scientific Aeronautics in the following words: "The name aerology is recommended for the new branch of meteorology which has the study of the free atmosphere as its task and balloons and kites as its instruments". The term found ready acceptance as is shown by its use in a report presented to the International Meteorological Committee in 1907.

* It is noticeable that cloud amounts 1 and 3 oktas are much more frequent than 0 and 2.

In the years which have elapsed since Köppen made his proposal the scope of the study covered by the term has, on paper at least, increased as much as the apparatus at its disposal if we accept the present definition to be that printed in the opening lines of the book under review. They run: "Aerology, a subdivision of meteorology, is the science which conducts research into the physical and chemical states and processes in the atmosphere". The terms of reference of the World Meteorological Organization Commission for Aerology state that the Commission is responsible for questions relating to research in the physics and dynamics of the atmosphere, the scientific evaluation of technical meteorological procedure, the standardization and tabulation of physical functions and constants and the standardization of nomenclatures and classifications in physical and dynamical meteorology.

This Handbook might well be expected, on the basis of the recent definitions, to be a comprehensive textbook of physical and dynamical meteorology. In fact its scope is broadly that stated in Köppen's original definition.

The Handbook is divided into six parts entitled respectively Historical Development, Thermodynamics, Classical (i.e. roughly Köppen's) Methods of Measurement, New Methods of Measurement, Aerological Measurements, Applications of Aerological Measurements. The titles of the last two parts do not clearly describe their contents. In his preface the editor, W. Hesse, writes that he has striven to attain completeness especially in instrumental matters. Only in the chapters on the synoptic and climatological uses of aerological observation does he admit to having imposed space restrictions.

The first part written by W. Hesse himself is a most interesting outline of the development of instruments for observing in the upper air, from the flight of the first free balloon to be equipped with a barometer and thermometer to the rocketry of today, followed by a summary of arrangements for international co-operation in aerological work.

The second part, by Professor F. Möller and Dr. K. Bullrich, is a thorough account of atmospheric statics and thermodynamics, standard atmospheres, the representation of the state of the atmosphere on thermodynamic diagrams and the use of these diagrams in determining the degree of stability and height of condensation level. All types of aerological diagram are described with a natural emphasis on the Stüve diagram. Blank copies of the actual thermodynamic diagrams used in the weather services of the German Federal Republic and the German Democratic Republic are contained in a pocket in the back cover.

The third part consists of two chapters, the first by Dr. P. Dubois of Lindenberg Observatory on the technique of kite and tethered balloon ascents over land and the second by Dr. E. Huss of Friedrichshafen on similar ascents from water. The chapter on the land ascents is written in great detail with large figures of the construction of such fittings as cable coupling links and, apart from its historical interest, it should be of practical value in this still widely used method of obtaining instrumental recordings in the lowest kilometre. Particular interest in this chapter attaches to the methods developed at Lindenberg in 1937 to 1939 for holding a kite-balloon at a relatively "fixed point". These methods, no account of which has so far as the reviewer could ascertain previously been published, enabled a meteorograph to be held at a height of 530 metres with oscillations of only three metres. Interesting thermographs in stable and unstable air masses from such a meteorograph are reproduced. Huss

in the second chapter describes the methods employed in the well known ascents from Lake Constance directed for many years by W. Peppler.

The fourth part which is on newer methods of measurements contains five chapters respectively on the use of gliders by Professor W. Georgii, the use of powered aeroplanes by the late Professor H. Berg, radiosondes by Dr. J. Rink, the measurement of ozone by Dr. H. K. Paetzold and on rockets by Professor E. G. Schwidkowski (or in the international transliteration system E. G. Švidkovskij). The two writers on gliders and aeroplanes naturally deplore the tendency to abandon regular ascents by aircraft as the radiosonde network has been enlarged. Georgii's article describes the uses of gliders for observing several elements, notably atmospheric electricity, in which connexion the absence of electrification from exhaust gases gives gliders marked advantages. Georgii also describes in detail the observation of the air currents of orographic waves by both gliders and aeroplanes. The late Dr. Berg's chapter is very comprehensive on observations from aeroplanes ranging from the selection of the staff to practical details of instrumentation and hints on visual observations. Berg was in charge of German meteorological reconnaissance units during the Second World War and writes from an obviously deep experience of his subject. Rink's chapter on radiosondes is also very comprehensive. It opens with a history of the development of the radiosonde by Bureau and Idrac, Duckert, and Molčanov in the late 1920s and goes on to the general principles of operation with details of several types which appear to include all those now in use. Calibration and correction of errors, that for radiation relying largely on the work of Scrase, are well covered. Besides the conventional ones radiosondes for the detection of the presence of cloud, measurement of radiation and of cosmic radiation, and the electric potential gradient are described. The author is well aware of the deficiencies of the radiosondes now in use but does not give an example, such as can be found in the literature, on the "discontinuities" in upper air charts associated with different types of radiosonde. These "discontinuities" are briefly mentioned by Reuter in his chapter on synoptic aerology as being very disturbing at 300 millibars and above, but again no actual instance is given. Rink has a poor opinion of making comparisons between different types of radiosonde by suspending a number from one balloon and considers the only satisfactory way will be found to be comparison against a specially made standard test sonde which would use only electrical sensitive elements such as thermistors.

Paetzold's chapter on ozone is a small-scale treatise on the whole subject with emphasis, in conformity with the general trend of the Handbook, on methods of observation. The chapter on rocketry by the Russian Professor Schwidkowski is a broad summary without great detail of the measurement of meteorological elements in the high atmosphere from rockets and of the determination of air density from changes in satellite orbits. Both American and Soviet work are described. The possibility of the television of cloud systems from satellites is mentioned, but no statement that cloud photographs from a rocket or satellite have in fact been taken is made, though the article must have been written after the publication in the *Monthly Weather Review*, June 1955, of the cloud system of a Caribbean hurricane.

The fifth part consists of three chapters, one on methods of measuring upper winds by Professor Dr. H. G. Müller, one on turbulence and aircraft bumpiness by Professor H. Lettau and the third on the aerology of atmospheric electricity

by Professor H. Israël. Müller's chapter is comprehensive, ranging from the nephoscope through pilot balloons to the various radar methods in detail. As an example of the degree of detail there is a sectional drawing of an automatic valve for filling pilot balloons. The only thing the reviewer missed was an account of the magnitude of errors in wind-finding by the various methods, a matter on which several papers including some in German have been published. Lettau gives an excellent account of the meteorology of aircraft bumpiness based largely on recent American work such as the Jet Stream Project and the British work of Jones, Bannon, Chambers and Turner. Israël's chapter describes methods of making measurements of potential gradient, current, and conductivity in the free air and provides an outline of the results of observation which is particularly strong on the relation between meteorological and electrical turbulence.

The sixth part contains two chapters, the first on synoptic aerology by Professor H. Reuter and the second on aerological climatology by Professor H. Flohn. The synoptic aerology chapter is a survey of the computation, dynamics and forecasting of upper air flow patterns. The thermodynamic diagram aspect of synoptic aerology was covered in Part 2. Reuter opens with the construction of contour thickness and isotach charts, and the computation from them of wind and thermal wind with corresponding theory. There follows the construction and use of charts of isopleths of humidity mixing ratio on an isobaric surface. Next we have the representation of flow in zonal sections, the properties of jet streams, the mean variation of wind with height, the major flow patterns such as long waves and blocking highs. Finally there is the forecasting of upper flow starting with Petterssen's kinematic extrapolation method and going on to numerical prediction based on the vorticity equation by graphical and machine methods, and concluding with the regression methods due to Namias and Reuter himself. Reuter considers the regression methods a valuable and indeed at present necessary support to the dynamical ones. One misses in this otherwise wide cover any mention of the direct forecasting of upper winds by the regression equations deduced by Durst and his collaborators. Flohn's chapter on aerological climatology opens with sections on the practical handling for climatological purposes of the individual elements followed by critical summaries, arranged geographically, of the literature of upper air climatology. Finally there are sections on the climatology of special features such as inversions in the lower layers, the tropopause, and layers of maximum wind, in which there are steep gradients of the elements concerned, and on the computation of large-scale transport processes in the general circulation such as water vapour transport in monsoon regions and meridional transport.

The book ends with a collection of tables of means, frequencies, standard deviations and extremes of temperature, humidity and wind in the free air. The tropospheric temperature table is for 195 stations including Arctic ice-islands, ocean weather ships and the Antarctic International Geophysical Year stations some of which give observations for only a year. The other tables are for much fewer stations, the one giving the frequency distribution of relative humidity being only for Erlangen, Larkhill, Habbaniya, Aden and Stanley. Each chapter is followed by a bibliography. Those on radiosondes and aerological climatology, each of which has over 200 references, and those on the 19th century literature following the historical chapters will be found particularly useful. The book is on the whole very up to date, a reference even being made by Flohn

to *Geophysical Memoirs* No. 102 by Bannon and Steele on the average water vapour content of the air, published as recently as May 1960.

The text and bibliographies are in general very accurate and the few misspellings should not lead to confusion. The date of Seville Chapman's paper on thundercloud electrification in the bibliography on p. 697 should be 1953 not 1931. The figures are clear and photographs well reproduced. The only error noted was in Figure 23 illustrating the various types of stability and instability in which the two diagrams for latent and pseudo instability are incorrectly shaded.

What is the overall value of this immense work? The preface gives the reason for publishing it in the following words: "German meteorologists have played a great part in meteorological research, in the development of methods of aerological measurement, in the founding of aerological observatories and the establishment of aerological networks. No corresponding book exists in the German language. Therefore the editor and publisher hope that the book will fill a gap in meteorological literature". The work is hardly a handbook of tables and figures for reference and computing as, though it contains a number of such tables and figures, they are scattered and not brought together in the numbers or convenient manner of *Linkes Taschenbuch* or *Smithsonian Tables*.

Clearly this book should be in the library of every national meteorological service or university department of meteorology. The historical material forms a unique collection and the chapters on methods of observation from aircraft, on the use of kite-balloons, on radiosondes and on the climatological handling of upper air observations will be of much value to the specialists in these subjects. In the reviewer's opinion it would have been better to have firmly omitted all the material to be found in general textbooks, in particular the thermodynamics, in order to keep the price at a level which individual meteorologists concerned with upper air observations can afford.

The style of the German is direct and easily readable, the printing clear and the binding good.

G. A. BULL

General climatology, by Howard J. Critchfield. 9½ in. × 6 in., pp. xiii + 465, *illus.*, Prentice-Hall International Inc., London Branch, 34-36 Beech Street, London, E.C.1, 1960. Price: 50s.

It is always interesting to read the preface of a book in order to compare what the author says he has set out to do with what he has actually done in the contents. This is particularly revealing with regard to the class of reader and the level of knowledge at which the book is aimed. *General climatology* appears to be aimed at almost all conceivable types of potential reader: "businessmen, sportsmen, students of geography, earth sciences, biology and social studies". Although mathematics and physics are declared unnecessary for understanding the fundamentals of general climatology "the reader is urged to consult current journals for reports on the latest sensational breakthrough"! The text that follows is divided into three sections, one dealing with each of physical, regional and applied climatology.

At the outset one is astounded to read that climatology, although closely linked with meteorology, is a branch of geography. But soon after this come the

best three pages in the book which take the form of a short but excellent essay on the history of meteorology and climatology. The remainder of Part I deals with physical climatology and is reasonably comprehensive; but so many branches of atmospheric physics are treated as within the realm of physical climatology (including weather forecasting) that one wonders what is left for meteorology. Part of the section dealing with pressure and winds is most misleading; we are told, for example, that "it is the slight differences in pressure which motivate winds that transfer moisture and temperature quantities from one area to another" and "a pressure gradient is the immediate cause of all air movement; the direction of flow is from high pressure to low pressure". Herein lies the key to many geographers' misunderstanding of the dynamics of the atmosphere. The concept of motion under a *balance* of forces, and that only under very special circumstances does air flow directly from high to low pressure should have been made clear. This confusion extends to the "winds aloft" section where the treatment is muddled and at times incorrect. In the "extra-tropical cyclone" section it is amazing to find that a modern textbook, for whatever section of reader, can treat the frontal development sequence without a single reference to the upper wind pattern and the possible existence of a jet stream.

Part II deals with climatic classification, and here the author is obviously on more familiar ground; but the treatment has no particular merit and is merely a rehash punctuated with arid statistics, with little reference to the dynamics of climate, and no reference to modern ideas on dynamical climatology that have been developed over the past ten years.

The final part gives a comprehensive survey of the various fields of applied climatology, and here the treatment can be recommended to the non-specialist. However, it is a pity that the interesting climatological problems associated with the design and construction of dams are not mentioned; also, the urgency of the flood forecasting problem in hydrology could have been emphasized by including a typical hydrograph showing some examples of the rapid rise and fall of river levels.

Finally, therefore, the section on applied climatology is well done, but the book cannot be generally recommended because it contains some of the worst aspects of the geographers' approach to climatology.

G. B. TUCKER

Physical oceanography, by Albert Defant. Two volumes, 10 in. \times 7 in., Vol. I, xvi + 729, *illus.*; Vol. II, viii + 598, *illus.*; Pergamon Press Ltd., Headington Hill Hall Oxford, 1961. Price: £10 10s.

These volumes form an excellent up-to-date textbook on physical oceanography. Their publication was expensive and was made possible by a grant from the United States Office of Naval Research.

Although Professor Defant has spent much of his time on oceanographical research he is also noted for his work in the field of meteorology and on the interaction between the atmosphere and ocean. His name will be associated among others in the mind of some readers in this country with the "Meteor" expeditions, but many meteorologists will also be familiar with other aspects of his work.

The first part of Volume I describes the ocean and its physical and chemical properties and their distribution: it also includes a chapter on evaporation

from the sea surface and the water budget of the earth, and a chapter on sea ice. Dynamical oceanography is the subject of Part II of this volume: in reading it one is reminded time and again of the many similarities of the theories of the ocean and the atmosphere. The subject of Volume II is waves, tides and their related phenomena.

Many people will find Chapter I, Volume I, entitled "The Ocean" to be of general interest. The meteorologist will find in addition much of interest in the chapters on temperature, evaporation and the water budget and sea ice, as he will in much of Part II on dynamical oceanography. The marine meteorologist will find the sections of Volume II on waves applicable to his work, although they deal with this subject in great detail. Otherwise this volume will be chiefly of interest to oceanographers and tidal experts.

A few of the statements in the book may be open to criticism: for example, in Volume II, page 43, Defant states that in the North Atlantic the extreme wave heights are from 12–13 metres, and in exceptional circumstances higher waves occur through interference. In fact at ocean weather station I in the years 1949–53 over 0.1 per cent of all wave heights observed were over 43 feet, a percentage which is perhaps greater than that suggested by the word exceptional. That criticism of such finer points is possible may often be due to the fact that this work was translated from German into English before publication.

These volumes are naturally not intended primarily for meteorologists, few of whom will read the publication in full. It will probably for them, however, replace *The Oceans* by Sverdrup, Johnson and Fleming as a standard reference on physical oceanography.

Pergamon Press are to be congratulated on the first class production of these volumes which will provide a vast source of information for the oceanographer.

P. R. BROWN

CORRIGENDUM

Airflow over broad mountain ranges

In equation (2) on page 222 of the August 1961 *Meteorological Magazine*, for l read e .

METEOROLOGICAL OFFICE NEWS

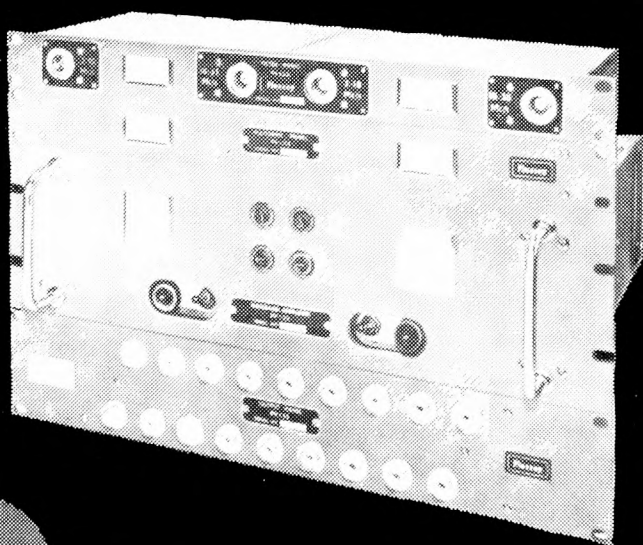
Retirement.—The Director-General records his appreciation of the services of:

Mr. G. Bell, Senior Scientific Assistant, who retired on 24 September 1961. He joined the Office in June 1934 as an Observer, Grade II, having previously served in the Royal Air Force from 1920 to 1932. The greater part of his service has been spent at aviation outstations, with periods at Headquarters from 1942 to 1945 and from 1947 to 1949. At the time of his retirement he was serving at the Manchester Weather Centre. Mr. Bell has accepted a temporary appointment in the Meteorological Office.

Sports activities.—The 33rd Air Ministry Annual Sports Meeting was held at the White City Stadium on 13 September 1961. The Meteorological Office retained the W. S. Jones Cup for the Division scoring the highest number of points at the Annual Sports. We also won the Ladies' Relay Cup and the Men's Relay Cup. Mr. C. W. Fairbrother won the High Jump Cup and Miss V. J. Lewis the Victrix Ludorum Cup, the 100 yards Cup, the High Jump Cup and the Long Jump Cup.

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NUMERICAL WEATHER ANALYSIS AND PREDICTION

By E. KNIGHTING, B.Sc.

Less than 20 years ago a meteorologist could write of the current papers in meteorology "In the course of this reading I have been introduced many times to the equations of motion on a rotating globe, the hydrostatic equation and the equation of continuity . . . But alas! the science of meteorology, in particular of dynamical meteorology, remains substantially where it was . . . The emphasis in recent years on the study of convergence and divergence to explain pressure variations has opened up splendid opportunities for mathematical juggling, but in its practical application has proved disappointing." (F. E. Lumb, *Weather*, 1, 1946, p. 244). This was not an isolated opinion; reviews of books and comments on papers written at that time show that it was indeed a prevalent view. Twenty years before, L. F. Richardson had made what was taken as a crucial test of the possibility of forecasting the pressure field by proceeding from the differential equations of motion of the atmosphere, integrating them approximately by finite difference methods, and he obtained a resulting pressure change which was an order of magnitude too great. The arithmetic involved, carried out necessarily by hand computer, was so great in volume that apparently no-one cared to repeat the experiment nor examine very carefully why the computation had led to incorrect results, and papers on dynamical meteorology continued to be divorced from synoptic meteorology as the hydrodynamics of a perfect fluid is divorced from that of a real fluid. This was largely owing to the difficulty of obtaining solutions of the non-linear differential equations and many papers dealt with linearized forms of the equations, essentially using perturbation methods. It would be quite wrong to suppose that these investigations were of little value, for perturbation theory is capable of indicating the way in which things are going to develop, even if unable to give correct quantitative answers.

During the past fifteen years the developments in dynamical meteorology have been rapid. Dr. Thompson's book* is the first published text in English that deals anything like adequately with these developments, which have led to

* *Numerical weather analysis and prediction*, by P. D. Thompson. 9½ in. × 6¼ in., pp. xiv + 170, illus., The Macmillan Company, New York, 1961. Price: \$6.50, 45s. 6d.

numerical weather prediction, and would be an important book in this respect alone, even if it did not have other qualities which will be noted later.

There were several contributing factors to the rapid development which started about 1946. First, there was new emphasis on the relevance of the scale of atmospheric motions and in particular on the size of the various terms in the equations describing synoptic scale motions. Second, there were the new upper air observations which had been made for military use during the Second World War and which, for the first time, gave an *adequate* picture of the three-dimensional structure of the atmosphere instead of the two-dimensional picture of the pressure field near the earth's surface. Fortunately these observations were continued and increased in number during the years following, owing to the large increase in civil aviation. Third, there was the development of high-speed electronic computers which made possible, in a few hours, computations which would have taken years with the aid of desk computers. This led to increased interest in the mathematics of computation. Dr. Thompson deals with these aspects of the possible emergence of a computational scheme for forecasting prebaratics in his first chapter.

The guiding principles in making numerical weather prediction are clear. One must set up the equations which govern the system, that is the dynamical, kinematical and thermodynamical equations. These will be very general and one must next inquire what distinguishes one kind of motion, say motions on a synoptic scale, from another, say sound waves. The differences are revealed by observations, in this case in the speed and amplitude of the wave motions and so on. The difficult next step is to discover what modification or constraint of the initial equations is necessary to admit one kind of motion and reject another kind. It is sometimes thought that such constraining is mathematical jugglery designed to make the mathematics tractable but this is not so; the principal function of such constraining is an economic one. If one had a large zoo full of different animals and one wished to investigate the habits of, say, sheep then one could either examine the habits of all animals and discard those of non-sheep or one could just pass all the animals through a sieve which separated sheep from non-sheep and examine the habits of the first class; needless to say the latter is the commonly accepted method. The constraining of the equations is just of this type. Finally the constrained equations must be solved and it is usually only possible to do this by finite difference methods. Dr. Thompson deals most effectively with these principles. Particularly to be commended are the chapters which deal with the possible types of wave motion in the atmosphere and the finite difference methods of solving linear wave equations. In the former he shows most clearly what physical processes give rise to sound, gravity and synoptic wave motions and how these physical processes are written as simple mathematical equations. Finite difference methods often appear abstruse to those not acquainted with the subject, largely because of the technical jargon—words such as “relaxation”, “sweep”, “Liebmann process” are used elliptically to embrace quite elementary ideas and processes. The author deals clearly with the use of finite difference methods from the simplest concepts in the chapter mentioned and also in a later chapter on solving the modified non-linear equations and can be followed by anyone whose mathematics rise to the calculus at sixth-form level.

The constrained, or filtered, equations which describe the way in which the large-scale atmospheric motions evolve are still too difficult to solve, even by

finite difference methods using an electronic computer and one must now construct an atmospheric "model" which reflects the rather more specific properties of the atmosphere as noted from observations, such as the static stability and the variation of wind speed with height. These new constraints are on a different footing from those described above, for they are mathematical simplifications designed to allow the equations to be solved without losing the essential physics of the problem. An example of such a simplification would be the assumption that the wind shear at any point is always in the same direction and varies linearly in the vertical. Almost any particular hodograph would contradict the assumption in detail but in the mean over a large number of cases the assumption is approximately true in the lower troposphere. By making such an assumption we replace the real atmosphere by a model atmosphere, which everywhere has this property, for the purpose of integrating the equations. Dr. Thompson discusses the effect of making such simplifying assumptions, showing very clearly the resulting equations and also how these equations are solved by using finite difference methods, firstly dealing with the equivalent barotropic model and later with more complicated models.

A little more than half the book deals with these basic ideas concerning numerical weather prediction and the practical problems of carrying out the computations. A later chapter caps this exposition by describing in fair detail the organization of the Joint Numerical Weather Prediction Unit, Washington, where numerical forecasts are computed on a routine basis for use by forecasters. This chapter will dispel any scepticism that may linger about the practical value of the application of the ideas that Dr. Thompson has been dealing with; one must hope that those who are concerned with the communication of meteorological information will realize that fresh problems in their field have already been raised by the possibility of using high-speed electronic devices.

The remaining chapters are a little more recondite. It is not sufficient that the method be possible, but also that understanding of the dynamical processes be clear, partly as an intellectual gain and partly because such clarity is suggestive of further lines of investigation which should improve both understanding and practical application. Perhaps the easiest problem to pose is "Why does the atmosphere organize motions on the synoptic scale?" and Dr. Thompson deals with the arguments concerning instability and energy transfer which are the first line of attack. He discusses also in a more sophisticated manner, the methods of filtering out the unwanted motions and, very briefly, the problems associated with a direct attack on the fundamental system of equations, and other problems which are of current concern.

In the preface the author writes that the book is designed to provide a text in numerical weather prediction for students of meteorology at graduate level and also for those with a general background of physics and mathematics, but no special knowledge of meteorology. He has certainly succeeded in the former aim and I expect that he has in the latter. The level of mathematics required to read the text looks formidable at a casual glance. I would like to emphasize that this is not so when the text is read. Nothing much more than some knowledge of vector and ordinary calculus is required and these are acquired at a lower level than graduate level. Moreover, this is a book about the *physics* of the atmosphere and the mathematics is a handmaiden. I wish that more meteorologists would recognize that the idea of numerical weather prediction

is essentially simple in concept, as easily understood as many of the other meteorological ideas that they accept as commonplace, and this text provides a proof of the assertion.

This is an important book in more ways than one. Clearly the first text to deal adequately with a quickly developing subject must be an important one. But, further than that, it replaces much of the dynamical writing to be found in the older texts, which has been repeated time and again, and in doing so has reached much nearer to the heart of the important problems. Those who have heard Dr. Thompson talk and have read his papers will be aware of his economy of thought and lucidity of expression; both are evident in this book. I commend it to every meteorologist whether he has mathematical training or not.

551.501.74 : 551.508.822 : 311.214

A SYNOPTIC METHOD FOR THE INTERNATIONAL COMPARISON OF GEOPOTENTIAL OBSERVATIONS

By C. L. HAWSON, B.A. and P. G. F. CATON, M.A., Ph.D.

Introduction.—The ever higher levels at which modern aircraft fly and the consequent demand for the analysis of higher and higher upper air charts have brought the question of the accuracy of upper air observations into increasing prominence. This paper describes a method of assessing both the systematic differences between the geopotential observations of the radiosondes of different countries and the random errors to which these observations are subject, using only routine observations and analyses on upper air charts.

Errors in the geopotential of isobaric surfaces determined from radiosonde observations tend to accumulate with height. Thus the higher the level of a synoptic chart, the greater are the inconsistencies between the observed winds and the contour gradients obtained from the geopotentials deduced from the pressure and temperature observations at the various stations. The inconsistencies arise mainly from errors or differences in the geopotential determinations which are partly systematic and partly random. Systematic errors are characteristic of the design of the radiosonde, although they may also result from differing operational techniques even with one type of instrument. Random errors are those which tend to be systematic from level to level on a particular individual sounding, but random in their incidence from sounding to sounding at a single station. Another form of random error also occurs in the temperature and pressure observations; this is random in its incidence from level to level on a particular sounding, but from the nature of the geopotential computation such errors tend to have very little effect on the geopotential calculated for isobaric surfaces and are not assessed by the method described below.

The problem presented by the reported 100 mb geopotential observations over and around Europe can be compared with that which would arise on a mean-sea-level surface pressure chart if each country provided only a few observations and used barometers set to national standards subject to diurnal change and differing between the highest and lowest by 25 mb or so. There would also be random errors having an even chance of being greater or less than anything from about 2 to 5 mb. Happily such a chaotic picture is purely

hypothetical for the mean-sea-level chart, and wind observations materially assist the analysis at the 100 mb level.

The method.—Over an area where, at a particular level, the acceleration of the air particles is very small the actual flow will be very nearly in geostrophic balance. In these circumstances the geostrophic relationship can be used with a high degree of accuracy to construct contour lines whose directions and gradients are in geostrophic balance with all the winds observed in the area. The facts that for the charts selected the large majority of the wind observations did readily fit into such contour patterns, and that these patterns were coherent, lent strong support to the premise that the vector errors in the observed winds were sufficiently small to enable adequate patterns of contours to be constructed. Very occasionally a wind observation was nevertheless encountered which did not accord with those from other stations or those from other levels at the same station. These were attributed to observational or transmission errors and rejected. The wider the contour spacing the smaller is the error in estimating the true differences between the geopotentials at particular stations, and a contour spacing corresponding to winds of the order 15 knots or less is suitable for comparisons over quite large distances. Wind fields of this order involving only very small accelerations of air particles in the flow occur quite frequently in summer over much of Europe and the North Atlantic at 100 mb, 50 mb and even higher levels. In this investigation several series of 100 mb charts were used and wind situations involving a rather wide variety of directions were included in the selection in order to minimize the effects of errors of technique on the mean values for the differences between stations.

Once suitable charts have been selected, and the contour patterns constructed from the wind observations, the contours only show relative geopotential over the area. It is necessary to relate the contour lines on each chart to some reference standard and number them accordingly. In this investigation the standard adopted was the mean of the values indicated for each set of contours by the eight radiosonde stations in the United Kingdom. These stations form a compact radiosonde and radarwind network controlled by a single authority, and by taking the mean value from eight observations much of the random error inherent in any single observation is materially reduced. This choice of standard is arbitrary and is not intended to attribute any particular quality to British ascents. Nevertheless it must be mentioned that examination of the time variation in the local geopotential over London derived from the charts using this standard, showed a slow smooth change and a diurnal 00h GMT to 12h GMT increase of less than $+0.5$ decametres. A difference of this order is consistent with the diurnal variation of wind at 100 mb found by Johnson¹, and it suggests that for practical purposes the chosen reference standard is the same at 12h GMT as at 00h GMT as well as being stable from chart to chart.

Comparison between the heights derived from the contour lines, constructed and numbered as described above, and the reported heights of the 100 mb surface at each station on each chart, then reveals inconsistencies. The difference, observed height minus the height indicated by the contours for a particular station on a particular chart, we have called the "Anomaly" (A) for that sounding. The "Anomalies" or A values were tabulated chart by chart for each station. The average values of A for each station at 00h and at 12h GMT were designated S_0 and S_{12} respectively and the standard deviations of A were called Q_0 and Q_{12} respectively. S_0 and S_{12} measure the systematic differences

from the chosen (United Kingdom) standard at 00h and 12h GMT whilst Q_0 and Q_{12} indicate the internal scatter (random error) of the reported heights at each station. When the tabulations indicated that two or more stations apparently were subject to similar anomalies, mean values S_0 and S_{12} were evaluated for the A values of the group and Q_0 and Q_{12} formed about the group means.

Trials of the method.—The method was first applied at 100 mb on 28 occasions for 00h GMT and for 32 occasions for 12h GMT, selected from the months April, May and June 1959 on the basis of the observed winds, that is wind fields involving only very small acceleration of air particles and low wind speeds. In a second investigation 20 occasions for 00h and 20 for 12h GMT were similarly chosen from May and June 1960. The area covered in the first work was broadly 40° to 60°N , 10°W to 25°E , but in the second study this was extended to 35° to 75°N , 10°W to 30°E and also to the Iceland–Greenland region. Because of the limitations imposed by the wind field considerations however, comparisons were not necessarily attempted over the whole area on each chart. A few analyses were also made covering eastern Canada and the north-east United States. Although in the extended regions it is still possible to intercompare stations hundreds of miles apart it is not practical to ensure that the zero relative to the United Kingdom is maintained. The 1959 and 1960 values of S_0 , S_{12} , Q_0 and Q_{12} , together with the number of comparisons made for the stations investigated are shown in Table I.

It will be seen that the majority of sondes indicate higher values of geopotential (higher temperatures) than the United Kingdom standard. In general the excess is greater at 12 h than at 00h GMT. The sondes used at West German, Canadian and American land stations, and at Vienna and Keflavik show the lowest standard deviations. For some stations, for example, the French group, Lisbon and the north-west German group, the 1959 and 1960

TABLE I—INTERCOMPARISON OF RADIOSONDES AT 100 MB, SUMMER SEASONS 1959 AND 1960

Group no.	Stations in group	1960						1959					
		00h GMT			12h GMT			00h GMT			12h GMT		
		N	S_0	Q_0	N	S_{12}	Q_{12}	N	S_0	Q_0	N	S_{12}	Q_{12}
1	Eight United Kingdom reference stations	151	0	$4\frac{1}{2}$	152	0	$4\frac{1}{2}$	209	0	4	243	0	4
1a	Valentia	19	0	4	19	0	5						
1b	U.K. ships on stations "A", "I" and "J"	39	0	$4\frac{1}{2}$	40	0	3						
1c	Gibraltar, Malta, *Tobruk, *Nicosia	74	0	5	75	— 2	$4\frac{1}{2}$	19	0	3	28	— 2	3
2	De Bilt	17	0	$5\frac{1}{2}$	19	+ 6	$5\frac{1}{2}$	26	+ 1	$5\frac{1}{2}$	29	+ 8	$5\frac{1}{2}$
2a	Dutch ships	19	0	6	20	+ 4	$7\frac{1}{2}$						
3	Uccle	18	+ 1	5	20	+ 13	$5\frac{1}{2}$	24	+ 1	4	30	+ 10	$4\frac{1}{2}$
4	Brest, Trappes, Nancy, Bordeaux, Lyons, *Nîmes, Ajaccio, *Algiers	104	+ 2	$6\frac{1}{2}$	144	+ 8	7	78	+ 5	5	137	+ 10	7
4a	French ships	20	+ 2	5	19	+ 8	5						
5	Payerne	18	+ 3	7	18	+ 4	8	14	+ 1	$4\frac{1}{2}$	18	0	6
6	Chateauroux, Zarazoga, *Kenitra, *Wheelus Field, *Athens	82	0	$3\frac{1}{2}$	78	+ 3	3	42	+ 2	3	38	+ 4	3
7	Madrid, Corunna, Palma	12	+ 3	$7\frac{1}{2}$	19	+ 9	7						
8	Lisbon	12	0	$7\frac{1}{2}$	12	+ 6	5	11	+ 10	$5\frac{1}{2}$	9	+ 22	$3\frac{1}{2}$
8a	Madeira	—	—	—	17 (+30)		6						

TABLE I—INTERCOMPARISON OF RADIOSONDES AT 100 MB, SUMMER SEASONS
1959 AND 1960—continued

Group no.	Stations in group	1960						1959					
		00h GMT			12h GMT			00h GMT			12h GMT		
		<i>N</i>	<i>S</i> ₀	<i>Q</i> ₀	<i>N</i>	<i>S</i> ₁₂	<i>Q</i> ₁₂	<i>N</i>	<i>S</i> ₀	<i>Q</i> ₀	<i>N</i>	<i>S</i> ₁₂	<i>Q</i> ₁₂
9	Milan, Udine	28	0	3½	29	0	4	54	0	4	64	+ 2	4½
9a	Rome	19	+ 2	4½	19	+ 8	5						
9b	Elmas	14	0	3	15	+ 2	6						
9c	Brindisi	19	- 3	5	19	- 1	5						
9d	Messina	17	- 5	5	18	- 3	5	6	+ 4	5	2	+ 22	—
10	Split, Zagreb	28	0	3½	—	—	—						
10a	Beograd	19	+ 6	3	17	+ 12	3½						
11	Budapest	8	+ 13	6	8	+ 24	5						
12	Bucharest	14	+ 12	5	8	+ 17	9	81	+ 6	2½	90	+ 8	2½
12a	Cluj	8	+ 3	6	—	—	—						
13	Sofia	13	+ 10	6½	13	+ 10	11½						
14	Thessaloniki	5	(- 3)	—	3	(- 4)	—						
15	Istanbul	11	(+ 1)	8½	6	(+ 10)	—	56	+ 5	2	61	+ 5	3
15a	Ankara	13	(- 4)	4½	18	(+ 3)	4						
16	Mersa Matruh	12	(- 5)	5½	13	(0)	6						
16a	Cairo	10	(- 1)	6	8	(+ 4)	4½						
17	Schleswig, Emden, Hannover, *Bonn	59	+ 4	2	65	+ 6	2½	67	+ 5	5	79	+ 10	5
17a	Stuttgart	20	+ 2	2½	19	+ 3	2½						
17b	Munich	20	+ 4	2	20	+ 4	2½						
18	Greifswald, Lindenberg, Wahnsdorf	55	+ 7	5	52	+ 11	5						
19	Prague, Poprad	26	+ 7	6	29	+ 13	6	21	+ 10	4½	29	+ 11	6½
20	Vienna	19	0	1½	20	+ 2	2½	28	+ 1	2½	30	+ 2	3½
21	Poznan, Wroclaw, Warsaw	8	+ 10	6	19	+ 35	7½	2	- 1	—	14	+ 25	5
22	Uzhgorod, Lvov, Brest, Kaliningrad, Kaunas, Riga, *Tallin	121	+ 7	7	125	+ 12	6	65	+ 9	5½	75	+ 13	8½
22a	Murmansk, Kandalaksha	33	+ 4	7	31	+ 7	6½	42	- 2	5	44	0	5
23	Sodankylä, Jokioinen	35	+ 1	5	33	+ 3	5						
24	*Östersund, Stockholm, Göteborg	54	- 1	4	53	+ 4	5½						
25	Copenhagen, Thorshavn	38	0	4½	39	+ 5	5						
26	Oslo, Sola	39	- 1	3½	38	+ 2	5	53	- 2	4½	63	+ 5	4½
26a	Bodö, Tromsø, Björnöya, Norwegian ship "M", Jan Mayen	93	+ 2	6	89	+ 7	5½	52	+ 2	5	54	+ 6	5½
26b	Isfjord (Spitsbergen)	17	(+ 4)	5	20	(+ 8)	5½	18	(+ 1)	3	16	(- 5)	3½
27	Nord	15	(- 1)	3	15	(+ 2)	2½						
27a	Danmarkshavn	14	(0)	2½	—	—	—						
27b	Kap Tobin	18	(- 5)	4	17	(+ 1)	3½						
27c	Angmagssalik	18	(+ 1)	3	20	(+ 4)	4	15	(+ 4)	5½	16	(- 0)	5
27d	Narsarsuaq	16	(- 7)	3	12	(- 5)	5½						
27e	Egedesminde	18	(+ 3)	4	15	(+ 4)	5½						
27f	Thule	18	(+ 1)	3½	16	(0)	5						
28	Keflavik	20	(- 1)	1½	19	(+ 1)	1½	45	(+ 4)	3	10	(+ 2)	—
29	American ships on stations "B", "C" and "D"	44	(+ 1)	3	45	(+ 4)	3						
30	Lajes	10	(0)	—	10	(+ 2)	—						
31	21 Canadian and Ameri- can stations east of 75°W	178	(0)	2	177	(+ 1)	2						

Units for *S* and *Q* are tens of geopotential metres; *S* values are positive when observations are higher (warmer) than reference; stations marked with an asterisk are not included in the group in the 1959 study; *N* is the number of comparisons from which the *S* and *Q* values are derived.

Note (i) It is probable that further grouping of stations should take place. For example, the sondes of groups 6, 28, 29, 30, 31 and possibly others are believed to be of one type. (ii) The values in brackets are considered less reliable than the average since, due to the isolation of the stations combined with substantial distance from the United Kingdom starting point, it was difficult to construct the streamlines without some reference to reported heights. As a further consequence the *Q* values probably underestimate the true standard deviations.

S values appear to differ significantly. In the case of Lisbon, the authors are confident from this evidence alone that some change of sonde or technique has occurred; (examination of the January 1961 charts suggests a further alteration to the Lisbon values as follows: $S_0 - 11$ decametres, $S_{12} - 7$ decametres). The changes in the French and German values may have arisen individually from small changes in technique or, in view of their similar magnitude, they indicate the possibility of a shift in the United Kingdom standards. An annual check on S values is obviously desirable and future changes in these values must be expected as radiosonde techniques advance. It may be mentioned that the Q values derived for the United Kingdom sonde are in good agreement with the instrumental standard deviation of 100 mb height found by Harrison through the evaluation of observations from pairs of sondes flown together (report as yet unpublished).

Estimation of the accuracy of the trial.—The probable error in the chosen contour height reference standard derived from the mean of eight stations is about ± 1 decametre (that is, $0.67 \times 4.5/\sqrt{8}$). With wind speeds of 10 knots (and accelerations involving geostrophic departures of less than 1 knot or 3°), a typical value, a systematic error of 10° in the direction of a contour corresponds to an error of $1\frac{1}{2}$ decametres in the estimated relative contour height 900 miles downstream; whilst a systematic speed error of 2 knots involves a comparable relative contour height error at the same distance cross-stream. Systematic errors in the construction of the contour lines on a single chart are considered likely to be of this order. Thus within the 1959 area of operation the estimated probable error of a single A determination was less than $2\frac{1}{2}$ decametres and the contribution of this error to the derived Q values was small in most cases. The standard error in the S value for a group of stations is $Q/\sqrt{(N-1)}$ where N is the number of comparisons; this error is less than $\frac{1}{2}$ decametre for several groups but, of course, is materially greater for those stations or groups for which only a few comparisons were possible.

The difference $S_{12}-S_0$, which is interpreted below, is subject to substantial uncertainty when, for single stations, the S values are estimated from 20 or fewer chart analyses. An improved estimate of $S_{12}-S_0$ is then often possible through comparison with the difference between three-monthly mean reported heights at 00h and 12h GMT (H_0 and H_{12}). These comparisons were made extensively for the May–July 1960 period, especially for stations in the Greenland, Iceland and Scandinavian areas. The difference $H_{12}-H_0$ for United Kingdom stations was $\leq + 0.5$ decametres, so that to a first approximation (see next paragraph) $H_{12}-H_0 = S_{12}-S_0$.

During consideration of these latter data and in particular of the mean heights at 00h, 06h, 12h and 18h GMT for Keflavik, Lajes, Stephenville, and Goose Bay, it became apparent that there was a real diurnal variation of 100 mb geopotential in addition to the instrumental variation ($S_{12}-S_0$) which alone it is desired to eliminate. Separation of the two components was difficult, but it appeared that the real diurnal variation had a range of about 3 decametres with a minimum soon after 06h *local time* and a maximum about 18h. These figures are broadly consistent with the diurnal variation of 100 mb wind, described by Johnson¹. Following Johnson's work it seems that the true difference in 100 mb mean height at 00h and 12h GMT over Europe (say longitude 10°W to 30°E) should be very small, but that over America (longitude 60°W to 120°W) the 00h GMT value should exceed that at 12h GMT.

This expectation was verified by comparing ooh and 12h GMT May to July mean 100 mb heights for two stations (Columbia and Trout Lake) at about 90°W, where solar elevations during the ooh GMT soundings are comparable to, or a little less than, those for the 12h GMT soundings.

Seasonal changes of S_0 and S_{12} .—The values of S_0 and S_{12} directly determined apply only to 100 mb observations in summer, when the solar elevation over Europe during the 12h GMT sounding is of the order of 60°. The problems arise of extending these values to other seasons and also of applying them to other levels.

To derive values for different seasons the authors attribute the difference $S_{12}-S_0$ for a particular station to the difference in solar radiation incident on the sonde at 12h and ooh GMT. Leaving aside those stations (broadly north of 65°N) at which the ooh GMT ascent in summer is wholly or partially in sunlight, it is assumed that S_0 remains constant in darkness and that the difference $S_{12}-S_0$ varies in accordance with seasonal changes of solar elevation. It is further assumed that to a first approximation the $S_{12}-S_0$ difference for all sondes varies with solar elevation in the same way as does the radiation correction of the United Kingdom sonde for which the radiation corrections as a function of pressure and solar elevation are readily available. These assumptions are not expected to be strictly true, but sufficiently so to have practical worth. Computations on these lines suggest that the $S_{12}-S_0$ difference appropriate to a solar elevation of 60° at 12h and darkness at ooh GMT should be varied with solar elevation as in Table II.

TABLE II—EFFECT OF VARIATION OF SOLAR ALTITUDE

Solar elevation at 12h (Darkness at ooh)	Fraction of $S_{12} - S_0$ for 60° solar elevation at 12h (Darkness at ooh)
—3° to 2°	one-quarter
3° to 20°	one-half
21° to 40°	three-quarters

The results for stations where the ooh GMT ascent is in sunlight may similarly be interpreted to give S values for ascents in darkness.

After consideration of Table II and the changes in solar elevation at ooh and 12h GMT throughout the year, and also bearing in mind the undesirability of frequent changes of correction at irregular dates, it was decided to divide the year into the following seasons:

Winter 16 October to 28 February.

Equinoctial 1 March to 15 April, and 1 September to 15 October.

Summer 16 April to 31 August.

The 100 mb S_0 and S_{12} corrections for each station for each of the above seasons were then derived on the lines indicated above. As examples a few values are shown in Table III.

Although in the winter season wind speeds are usually far too high to justify application of the technique described, a check on the deduction from the summer results is sometimes possible, for example (i) by comparison of the means of about 30 reported heights for, say, Kap Tobin and Jan Mayen (both 70°–71°N) in prevailing westerly winds and (ii) for single stations by the evaluation of monthly mean 100 mb heights at ooh and 12h GMT. A number of such checks was carried out and gave support to the values derived from the summer results.

TABLE III—EXAMPLES OF CORRECTIONS TO BE APPLIED TO OBSERVED 100 MB HEIGHTS TO REDUCE THEM TO THE UNITED KINGDOM STANDARDS

Group no.	Stations	Winter		Equinox		Summer	
		00h	12h	00h	12h	00h	12h
				<i>decimetres</i>			
3	Uccle	— 1	— 9	— 1	— 11	— 1	— 13
4	French stations	— 2	— 6	— 2	— 7	— 2	— 8
17	N.W. German stations	— 4	— 5	— 4	— 6	— 4	— 6
21	Polish stations	— 10	— 27	— 10	— 32	— 10	— 35
26	Oslo, Sola (60°N)	+ 1	— 1	+ 1	— 2	+ 1	— 2
26a	Norwegian ship "M" (66°N)	+ 1	— 3	+ 1	— 5	0	— 7
26a	Jan Mayen (71°N)	+ 1	— 2	+ 1	— 5	— 2	— 7
26a	Björnöya (75°N)	+ 1	— 1	+ 1	— 5	— 3	— 7
28	Keflavik (64°N)	0	— 1	0	— 2	0	— 3
30	Lajes (39°N)	0	— 2	0	— 3	0	— 3

Assessing the interstation differences at levels below 100 mb.—To assess the interstation differences at lower levels it is assumed that the 100 mb geopotential anomalies are caused by various simple kinds of instrumental error and the effects of these on calculated heights in an ICAO environment have been separately investigated. By this means it has been possible to evaluate the approximate percentage of the 100 mb anomaly which would be contained in the 700, 500, 300 and 200 mb geopotential determinations if the anomaly were solely due to any one of the simple instrumental errors postulated. These are shown in Table IV. The assumptions of error types are not exhaustive, in reality they will be more complex, the environment will have a second order effect and the height anomalies induced by pressure and temperature may be of opposite sign. Thus a wide variety of possible percentages at the lower levels can be appropriate to individual soundings.

TABLE IV—EFFECT OF INSTRUMENTAL ERRORS ON COMPUTED HEIGHTS IN AN ICAO ATMOSPHERE

Pressure <i>mb</i>	Nature of error				
	A	B	C <i>per cent</i>	D	E
700	15	3	7	13	2
500	30	11	16	30	15
300	52	33	34	68	56
200	70	57	52	100	100
100	100	100	100	100	100

Anomaly (expressed as percentage of 100 mb anomaly) assumed to be due solely to:

- Constant temperature error.
- Temperature error changing linearly with difference of temperature from ground level temperature.
- Temperature error varying with height in same way as temperature corrections due to radiation vary in British sonde at solar elevation 60°.
- Constant pressure error.
- Pressure error changing linearly with difference of pressure from ground level pressure.

Nevertheless the bigger the 100 mb anomaly the more likely are the contributions of the errors due to pressure, temperature and radiation to be all of the same sign, and the narrower the limits of the possible percentages of the 100 mb anomaly appropriate to lower levels. As a tentative practical expedient the authors suggest that the following percentages of the 100 mb anomaly be applied at analysis centres to lower levels: 500 mb 10 per cent, 300 mb 35 per cent and 200 mb 60 per cent (these percentages the authors believe are probably a little, say 5 to 10 per cent less, than the most likely mean values).

If, after application of the S value at 100 mb as a first approximation, it is clear that a random error is present on an individual sounding, the 100 mb anomaly to be used for the purpose of estimating lower-level corrections should be the difference between the reported height and the value estimated from the current 100 mb analysis, not just the appropriate S value.

The figures derived from the 1959 investigation were used experimentally in the analysis of upper air charts at the Central Forecasting Office, Dunstable, commencing in March 1960. They were found to have practical value and revised figures based on the 1960 study were introduced in January 1961. It may be mentioned that the advice in the final sentence of the last paragraph has led to a change in the order of analysis of the upper air charts. Instead of the 100 mb chart being drawn last, that is after the 700, 500, 300 and 200 mb charts, it is now common practice to analyse the 100 mb chart first, at least over Europe, and to use the observed height anomalies at 100 mb to estimate corrections to heights at lower levels. It is believed that the change has improved the standard of chart analysis at 500 mb and higher levels.

Additional comments.—The possibility has been considered that the winds used to construct the contour lines may, on average, have referred to a level above or below 100 mb (due to errors in the measurement of pressure) and may therefore have been systematically too light or too strong. On 28 occasions at 00h GMT the construction of contour lines was extended as far as Malta, where British radiosondes are used and the technical control is the same as in the United Kingdom. The systematic height anomaly at Malta for these occasions was zero, which indicated that any error arising from the above possibility was very small. The negative value of S_{12} at Malta (and Gibraltar) was thought to indicate over-correction for solar radiation by the British sonde in those latitudes at 12h GMT.

As already stated the application of the results of these studies in the form of corrections to observed geopotentials has been found to have substantial practical value in routine chart analysis. However, it is apparent that a regular reassessment of S values is necessary as radiosonde technique advances are made in different countries. It seems desirable not only that there should be an annual review, but also that all changes in equipment or technique should be notified internationally to the practising forecasters, as well as the instrumental specialists, to aid in the interpretation of the observations. It is clear that a substantial number of comparisons must be made before significant results are obtained for any one trial, and a technique utilizing routine soundings represents a substantial economy over any national or international study involving pairs of sondes flown together. The authors foresee extension of the methods outlined to the 50 mb surface and in particular that the differences in the height anomalies at 100 mb and 50 mb on an individual ascent may be utilized to assess temperature errors on that sounding.

Summary.—The methods described in this paper provide a cheap convenient means of estimating the systematic differences between the geopotential observations from the various kinds of radiosonde and also the standard deviation of the random errors of each model. The main technique is dependent on the existence, at high levels in the atmosphere, of large areas of light winds involving only low particulate accelerations in the air motion, where there is also a sufficiently dense network of upper wind observations. Such conditions occur quite frequently in summer in our latitudes at 100 mb. Methods are

suggested for extending the results of investigating these summer situations to other seasons and also for utilizing particular 100 mb synoptic analyses for estimating corrections (to a common standard) for geopotential values observed at lower isobaric surfaces on individual soundings. A summary of the results of trials based on the summers of 1959 and 1960 is presented.

Acknowledgments.—We wish to thank Mr. C. J. Boyden and our colleagues of the upper air section at Dunstable for their ready co-operation in this work.

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RELATION BETWEEN THE TERMINAL VELOCITY AND THE DIMENSIONS OF SNOWFLAKES

By F. E. LUMB, M.Sc.

Summary.—It is shown that the relationship between the terminal velocity (v) of snowflakes and their maximum dimension (l_{\max}) can be approximately represented by equations of the form $v = kl_{\max}^{\frac{1}{2}}$, where k is a constant for snowflakes of a particular type.

Introduction.—In deriving an expression for the terminal velocity of non-rimed and rimed snowflakes (assumed to be spherical) in terms of the radius, Magono¹ has assumed that a part of the air which collides with the snowflakes passes through them. On physical grounds, one would expect the percolation of air through falling rimed snowflakes to be small and it will be shown that a statistical analysis of the terminal velocities of snowflakes of various sizes confirms that any percolation of air through falling rimed snowflakes is probably very small. Even for non-rimed snowflakes, there is no justification for rejecting the hypothesis that they are impervious to the airflow, but the data for non-rimed snowflakes on which this conclusion is based are rather meagre.

Theory.—If snowflakes are in fact impervious to the airflow, a theoretical relationship between the terminal velocity and the size (for any given shape and structure) can be derived as follows:

Let V = volume of the snowflake

σ = density of the snowflake

ρ = density of the air

g = acceleration of gravity

C_D = drag coefficient (a function of the Reynolds number)

S = maximum horizontal cross-sectional area

v = terminal velocity.

In the terminal state, gravitational attraction balances the drag force. Hence

$$V(\sigma - \rho)g = C_D \frac{1}{2} \rho v^2 S. \quad \dots \dots (1)$$

For snowflakes which are three-dimensionally similar in shape, if l is a specified dimension, $S \propto l^2$. Hence for snowflakes of given shape equation (1) becomes:

$$V(\sigma - \rho) \propto C_D \rho v^2 l^2. \quad \dots \dots (2)$$

Magono² has measured the density of snowflakes, and given the mean

density of non-rimed snowflakes as 0.01 gm cm^{-3} , and of the rimed type as 0.02 gm cm^{-3} . Hence ρ which is of the order of 10^{-3} can be neglected in comparison with σ and equation (2) can be written:

$$d_e^3 \propto C_D \rho v^2 l^2 \quad \dots \dots \dots (3)$$

where d_e is the diameter of the equivalent raindrop.

Measurements by Langleben³ have revealed that to a close approximation

$$v \propto d_e^{\frac{1}{16}} \quad \dots \dots \dots (4)$$

for snowflakes of given structure.

Hence combining (3) and (4) we get

$$v \propto C_D^{\frac{1}{3}} \rho^{\frac{1}{3}} l^{\frac{2}{3}} \quad \dots \dots \dots (5)$$

for snowflakes of given shape and structure.

A test of the theory.—During a heavy snowfall on 9 December 1950, Magono¹ measured the terminal velocities of snowflakes of various sizes with a stop-watch over a period of four hours and estimated the maximum dimension (l_{\max}) by eye.

He classified them by shape as follows:

- (i) horizontal type — flat snowflakes whose shape approximates to that of a thin plate or disc
- (ii) vertical or inverted cone type } —irregular lumpy conglomerations of snow crystals

The maximum dimensions ranged from $\frac{1}{8}$ cm to 5 cm, and terminal velocities from 75 cm sec^{-1} to 250 cm sec^{-1} . Hence the Reynolds number Re varied from 10^2 to 10^4 .

As Re decreases from 10^4 to 10^2 , the proportional increase of C_D for circular and square plates, spheres, cylinders and cones of given semivertex angle is not more than 50 per cent*. Hence it is reasonable to assume that over this range of Re the variation of $C_D^{\frac{1}{3}}$ for snowflakes of given shape is not more than 6 per cent, and $C_D^{\frac{1}{3}}$ can be regarded as a constant without serious error. Also over a period of four hours, and at a fixed level of observation, $\rho^{\frac{1}{3}}$ is practically constant.

Hence equation (6) becomes:

$$v \propto l_{\max}^{\frac{1}{3}} \quad \dots \dots \dots (6)$$

Regression coefficients b of $\log v$ on $\log l_{\max}$ have been calculated using the data given by Magono for the following four categories of snowflakes:

- (a) non-rimed horizontal type
- (b) non-rimed vertical or inverted cone type
- (c) rimed horizontal type
- (d) rimed vertical or inverted cone type

The values of the regression coefficients and their standard errors are given in Table I.

TABLE I—REGRESSION COEFFICIENTS AND STANDARD ERRORS

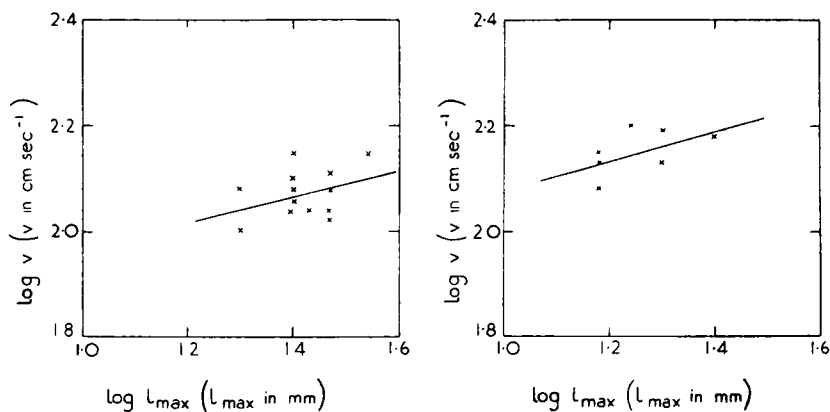
Type of snowflake	No. of observations	Range of l_{\max} in cm	b	Standard error of b
(a)	13†	2 to $3\frac{1}{2}$	0.242	0.205
(b)	7	$1\frac{1}{2}$ to $2\frac{1}{2}$	0.268	0.191
(c)	28	$\frac{1}{4}$ to $4\frac{1}{4}$	0.239	0.036
(d)	19	$\frac{1}{8}$ to $3\frac{1}{4}$	0.265	0.033

† Excluding one isolated observation for which $l_{\max} = \frac{1}{2}$ cm, $v = 90 \text{ cm sec}^{-1}$

* I am indebted to Mr. E. W. E. Rogers of the Aerodynamics Division, National Physical Laboratory, for this information.

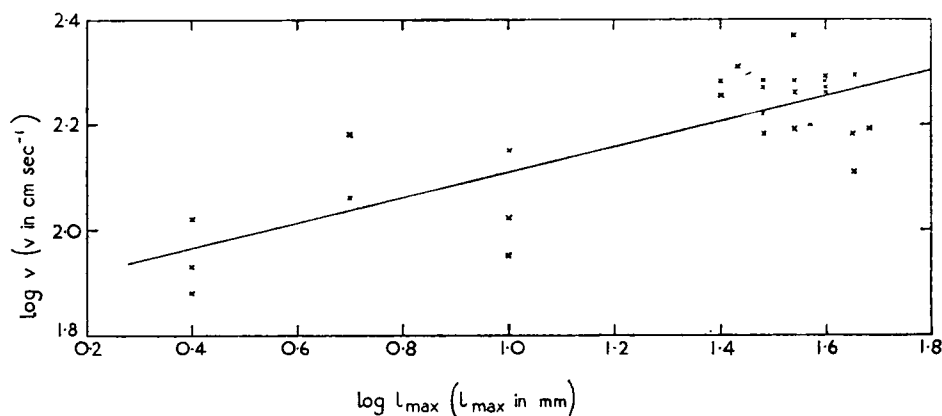
The corresponding regression lines of $\log v$ on $\log l_{\max}$ are shown in Figure 1.

Bearing in mind the visual estimation of l_{\max} and the crude classification by shape, the differences between the calculated values of b and the theoretical value of 0.25 are surprisingly small. Applying Student's t -test, the differences

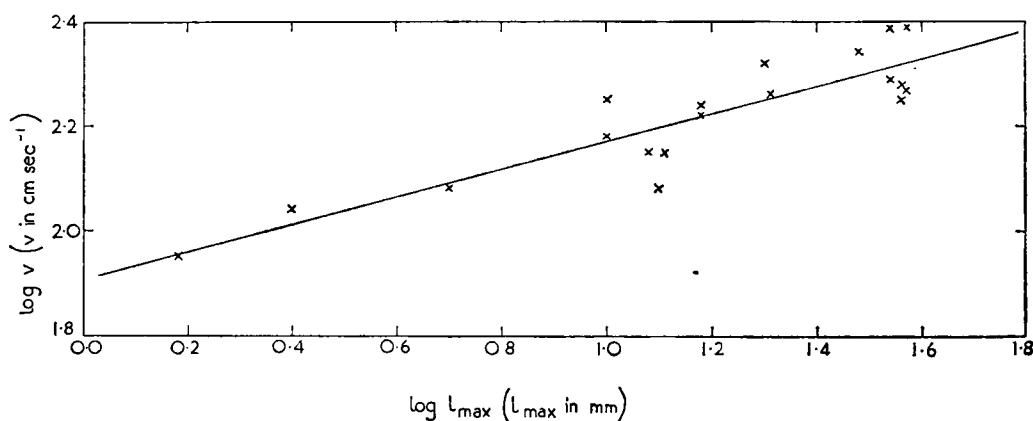


(a) Non-rimed horizontal type

(b) Non-rimed vertical or inverted cone type



(c) Rimed horizontal type



(d) Rimed vertical or inverted cone type

FIGURE 1—REGRESSION LINES OF $\log v$ ON $\log l_{\max}$ FOR FOUR TYPES OF SNOWFLAKE

Based on Magono's data for 9 December 1950

are found to be not significant for all four categories even at the 50 per cent level.

As is clear from Figure 1, the number and range of the measurements for the two rimed categories (c) and (d), are such as to justify the positive conclusion that rimed snowflakes are probably impervious to the airflow. The samples of measurements for the non-rimed categories (a) and (b) are much poorer than for the rimed categories (c) and (d); nevertheless, on the available evidence, there is no justification for rejecting the hypothesis that falling non-rimed snowflakes also are impervious to the airflow.

We therefore conclude that the relationship between v and l_{\max} for snowflakes of given shape and structure can be approximately represented by an equation of the form

$$v = k l_{\max}^{\frac{1}{4}} \quad \dots \dots (7)$$

Expressing v in cm sec^{-1} and l_{\max} in cm, the equation to the best fitting curve (using Magono's data) for each of the four types is obtained by substituting the values of k given in Table II.

TABLE II—VALUES OF k	
Type of snowflake	k
(a) non-rimed horizontal	93
(b) non-rimed vertical or inverted cone	123
(c) rimed horizontal	132
(d) rimed vertical or inverted cone	148

These curves are shown in Figure 2 for values of l_{\max} from $\frac{1}{4}$ cm to the largest value observed for each category.

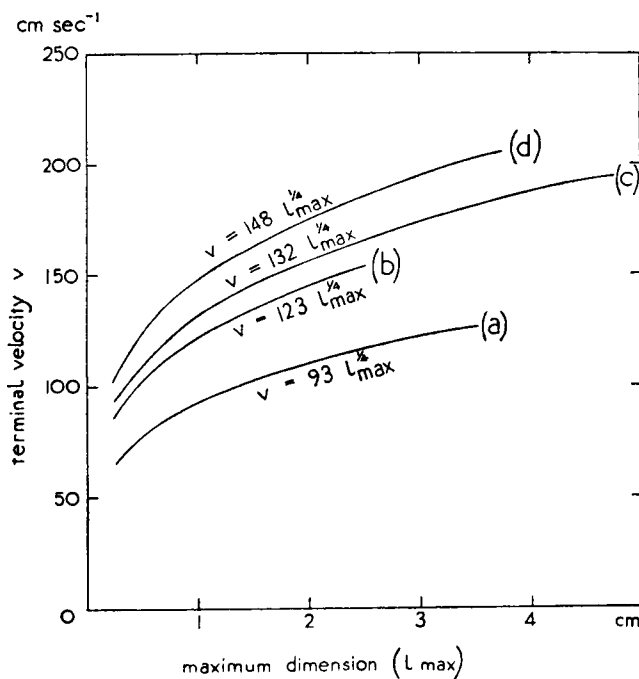


FIGURE 2—TERMINAL VELOCITY OF SNOWFLAKES IN RELATION TO TYPE AND SIZE

Based on Magono's data for 9 December 1950

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CIRRUS DEVELOPMENT OBSERVED OVER SINGAPORE AND SOUTH MALAYA

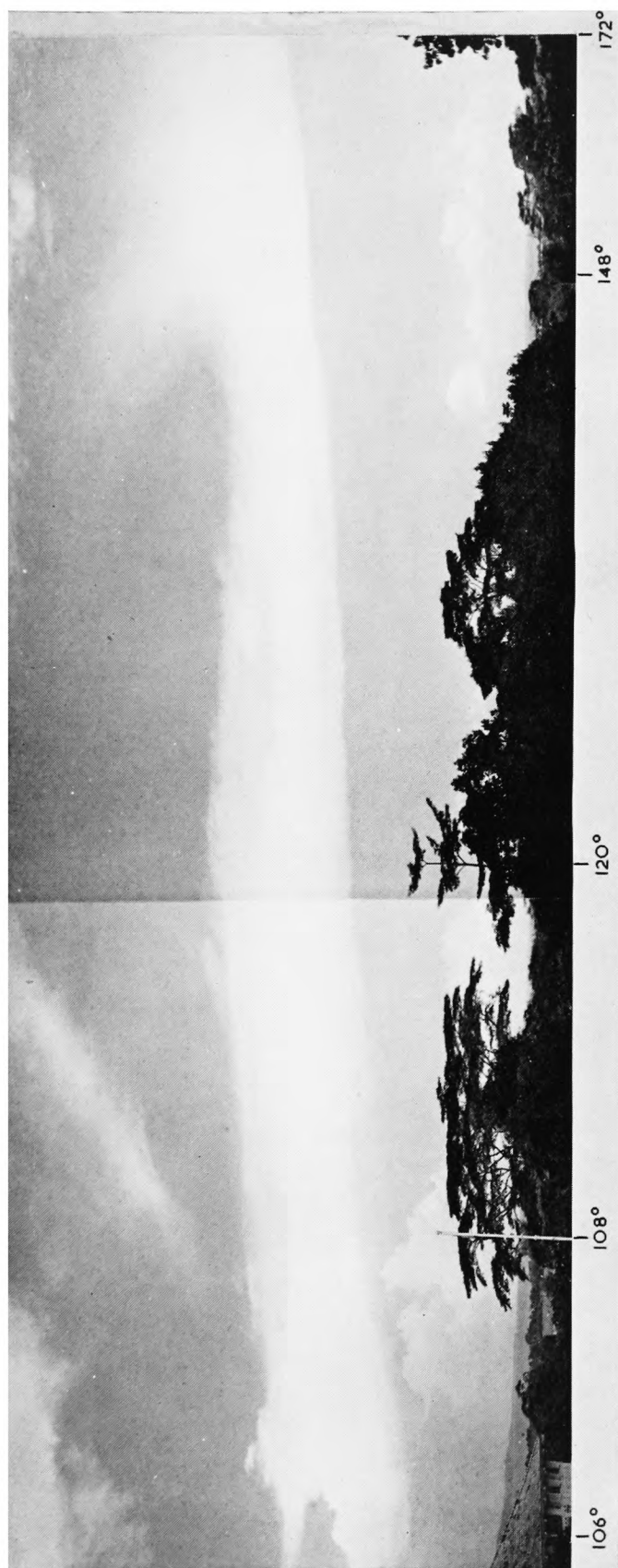
By R. FROST, B.A.

Introduction.—Layers of cirrus and cirrostratus cloud are frequently present over Singapore and Malaya, and Littlejohns¹ in an examination of pilots' reports of high cloud between 1954 and 1956 found that cirrus and cirrostratus, but not cirrocumulus, was found on about 90 per cent of all occasions in April, May, June and July. Much of this high cloud is probably explicable in terms of the southern shearline, where the air from the southern hemisphere converges with the belt of equatorial westerlies, which moves northwards with the sun and affects Singapore and Malaya during this period, but the example of cirrus development discussed here, and which has been noted on other occasions, suggests that a not inconsiderable number of occasions is due to false cirrus streaming for long distances downwind from the tops of cumulonimbus clouds which have penetrated into upper layers of very strong winds.

Observations.—The photograph facing p. 348 of a false cirrus canopy was taken by the photographic section at Royal Air Force, Changi at my request at 1500 local time on 19 June 1961. The cumulonimbus cloud seen on the extreme left of the photograph is over Bintan Island in Indonesia about 38 nautical miles east-south-east of Changi, which is on the eastern tip of Singapore Island. (The precise location of this storm and the other storms discussed in this note were obtained from the storm warning radar located at Changi.)

When first noticed at 1330 local time the developing cumulus cloud over Bintan Island was, as indicated by the fibrous appearance of its protuberances, in the process of transformation into a cumulonimbus cloud. Shortly afterwards the characteristic anvil cloud began to form but, owing to an obvious increase in wind speed from the east at high levels, the ice particles were sheared off by the wind to form an extensive canopy which by 1500 hours local time extended some 35 nautical miles downwind from its source. The leading edge of the canopy, unfortunately partially cut off in the photograph, shows the rapid increase of wind with height at the lower levels and also the veering and decreasing of the wind at greater heights. A similar but more extensive cloud canopy also developed from a series of cumulonimbus clouds over south Johore to the east-north-east of Singapore and this streamed downwind over Singapore Island. The southern edge of this cloud sheet is just apparent at the top left-hand corner of the photograph.

The upper winds at Paya Lebar at 0730 and 1830 local time are given in Table I and, as can be seen from this table, are moderate westerly from the surface up to about 20,000 feet falling off to light westerly or variable between 20,000 and 30,000 feet and becoming easterly 30 knots at 32,000 feet, while above this height the easterly winds increase up to 46,000 feet and then fall off



Crown copyright

FALSE CIRRUS CANOPY TO SOUTH-EAST OF SINGAPORE, 19 JUNE 1961
(see p. 348)

[To face p 348.



Photograph by A. Richardson

RIME ON A STONE WALL AT 2390 FT ON CROSS FELL, CUMBERLAND, AT 1400 HOURS
18 MARCH 1961



Photograph by R. M. Brass

"JACOB'S LADDERS" ON THE NORTH ATLANTIC



Crown copyright

TOWNS CO-OPERATING IN THE NATIONAL SURVEY OF ATMOSPHERIC POLLUTION
(see p. 359)

Each side panel lights up in turn, with the corresponding lights on the map, showing the positions of the conurbations (the six bright patches) and of the towns of population over 100,000, between 50,000 and 100,000, and of 10,000 to 50,000.

TABLE I—UPPER WINDS AT PAYA LEBAR, 19 JUNE 1961

Heights (feet)	Winds at 0730 local time	Winds at 1830 local time
1000	210/03	260/10
3000	270/15	280/16
5000	270/17	280/17
7000	280/23	280/20
10,000	250/15	270/25
12,000	230/14	260/17
14,000	280/05	270/14
19,000	290/09	230/07
25,000	020/03	170/05
32,000	090/30	100/31
36,000	090/36	070/26
41,000	060/43	050/37
46,000	080/58	090/43
50,000	130/32	130/34
54,000	270/05	030/16
62,000	280/12	060/04
63,000	290/13	
68,000		260/24

to light and variable at the tropopause at about 56,000 feet. In the stratosphere the winds become westerly. It is of interest to note that Mr. Sharp, the Senior Meteorological Officer at Changi, with the aid of a clinometer compass found that the angle at which the false cirrus sheared from the cumulonimbus was eight degrees which, with the cumulonimbus located at a distance of 38 nautical miles, gives the height at which the shear commenced as 32,350 feet, in extremely good agreement with the radar winds at Paya Lebar.

The upper air temperatures at Paya Lebar at 0730 local time, given in Table II, show that at 300 millibars (32,000 feet) the air temperature is -34°C and at 100 millibars (54,000 feet) the air temperature is -80°C , and it can be seen from these tables that the temperature at the level where the false cirrus sheared from the cumulonimbus cloud was -34°C . This is consistent with a conclusion by the present writer² who, in a discussion of cumulus and cumulonimbus cloud over Malaya, noted that the change-over from cumulus to cumulonimbus cloud occurred between 30,000 feet and 33,000 feet where the

TABLE II—UPPER AIR TEMPERATURES AT PAYA LEBAR ON 19 JUNE 1961 AT 0730 LOCAL TIME

Pressure levels (mb)	Temperatures ($^{\circ}\text{C}$)
Surface	24
1000	24
850	27
700	18
600	2
500	-1
400	-17
300	-34
200	-55
150	-70
100	-80

temperatures were between -30°C and -35°C with a standard deviation of about 2°C , and pointed out that this was in good agreement with the laboratory experiments of Findeisen and Schultz³ who, using an expansion chamber of two cubic metres, found with an expansion equivalent to a vertical speed of 5 m sec^{-1} that there was a very rapid increase in the number of ice crystals at -35°C .

At 1520 hours local time the pilot of a Meteor aircraft on return to Tengah

on the western side of Singapore Island came out of the canopy of false cirrus from the south Johore cumulonimbus about 30 nautical miles away at a true height of 28,500 feet.

It was observed that the cumulonimbus clouds over Bintan Island and south Johore had all dispersed soon after 1630 hours but the two canopies continued to move downwind and to spread laterally and by sunset, at about 1845 hours, appeared to have merged into one sheet of thin cirrostratus stretching at least 100 miles from their birthplaces. A lunar halo of 22° which was also observed at 2200 hours indicated the presence of ice crystals in the form of hexagonal plates and/or prisms with axes distributed at random in the thin cirrostratus sheet.

Discussion.—If for simplicity it is assumed that the ice crystals had fallen from an initial height of 31,500 feet one hour earlier this gives a falling rate of $\frac{1}{4}$ m sec⁻¹ for the crystals, which for an approximately spherical crystal corresponds to a radius of 50μ. In actual practice the shapes in which ice crystals are normally found in cirrostratus are not spheres but are hexagonal prisms or hexagonal plates according to photographs by Weickmann⁴ and also to the theoretical explanation of the 22° halo, but this value of 50μ appears to be of the right order of magnitude for spherical crystals equivalent in size to the actual crystals.

If the ice crystals move downwind in an environment which is not in general saturated with respect to ice they will commence to evaporate and it is of interest to estimate the “evaporation times” of such crystals. Following Jeffreys⁵ if we assume that the ice crystals are at rest relative to the air then the rate of evaporation of an ice crystal of mass *M* in an unsaturated atmosphere is given by

$$\frac{dM}{dt} = 4\pi CD(\rho_a - \rho_s) , \qquad (1)$$

where ρ_s is the vapour density at the surface of the crystal, ρ_a is the vapour density at a point remote from the crystal, *D* is the coefficient of diffusion of water vapour in air and *C* is the electrostatic capacity of the crystal. This equation may be used to evaluate the evaporation times of any ice crystals whose shapes approximate to those of conductors of known capacity.

For a sphere of radius *r*, *C* = *r* and *M* = $\frac{4}{3}\pi r^3\rho_i$ where ρ_i is the crystal density, so that equation (1) may be written

$$r \frac{dr}{dt} = \frac{D}{\rho_i} (\rho_a - \rho_s) \qquad (2)$$

If, therefore, *r* is the radius of the crystal at a time *t* and *r*₀ is the radius of the crystal initially

$$r^2 = r_0^2 - \frac{2tD}{\rho_i} (\rho_s - \rho_a) \qquad (3)$$

and it follows, therefore, that the half-life of a spherical crystal of radius *r*₀ is

$$t = \frac{3\rho_i r_0^2}{8D(\rho_s - \rho_a)}$$

so that the larger the ice crystal, and the higher the humidity of the environment, the less rapidly does it evaporate.

The capacity of an ellipsoidal conductor differs only slightly from that of a spherical conductor of the same volume and if the axes of the ellipsoid are

$2r(1 + \alpha)$, $2r(1 + \beta)$, $2r(1 + \gamma)$ where $(1 + \alpha)(1 + \beta)(1 + \gamma) = 1$, the capacity is approximately given by

$$C = r \left[1 + \frac{2}{15}(\alpha^2 + \beta^2 + \gamma^2) \right]. \quad \dots \dots (4)$$

Initially, therefore, an ice crystal which is ellipsoidal would commence to evaporate at a slightly faster rate than a spherical ice crystal of the same volume. In the case of an ellipsoidal crystal, however, the evaporation would be greatest at the ends of the major axis and least at the ends of the minor axis and would thus tend to promote spherical symmetry and thereby reduce the differential rate of evaporation so that the evaporation times of an ellipsoidal crystal should be of the same order as those of a spherical crystal.

The capacities of hexagonal plates and prisms are difficult to calculate but Mason⁶ found that to a first approximation hexagonal plates could be treated as oblate spheroids and hexagonal prisms as prolate spheroids. It can be seen from equation (4) that the capacities of an oblate spheroid and a prolate spheroid are approximately the same and if to get some idea of the shape effect we take $\alpha = \frac{1}{2}$, $\beta = 0$ and $\gamma = -\frac{1}{2}$ which corresponds to the case of an oblate spheroid in which the major axis is approximately double the minor axis, $C = 1.06r$ approximately.

It would thus appear that the theoretical evaporation times of a spherical ice crystal may be taken as representing to a first approximation the actual evaporation times of ice crystals of equal volume but of different shapes.

The only observation of frost points made in the tropics appear to be those made by Kerley⁷ between Aden and Nairobi in June 1958 and these suggest that between 20,000 feet and 40,000 feet there is little latitudinal variation in frost point in the tropics. If, therefore, we assume that the frost points over Singapore in June are the same as those at Aden and Nairobi, then the half-life of an ice crystal of 50μ radius at 300 millibars where the frost point is -43°C would be of the order of seven minutes whilst that at 200 millibars where the frost point is -63°C it would be about two hours. At 150 millibars where the frost point is -77°C the half-life would be about 11 hours and at 100 millibars where the frost point is about -85°C the half-life would be about three days.

On the basis of these calculations and assuming a settling rate of $\frac{1}{4} \text{ m sec}^{-1}$ it would appear that false cirrus cloud originally extending to near the tropopause would have a life of several hours and could during its life be carried several hundreds of miles from its point of origin.

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A METHOD OF DERIVING 700 MB CHARTS FROM 500 MB THICKNESS PATTERNS

By J. C. GORDON, M.A.

Introduction.—Prior to 5 November 1956 composite forecast upper air charts for 500 mb and 700 mb only were issued every six hours at London Airport though, on occasion, composite forecast charts at 200 mb were attempted for research purposes. After this date 300 mb fixed-time forecast charts were issued once daily for planning purposes to three recipients engaged in civil aviation. After 1 June 1957 the routine 500 mb and 700 mb forecast charts were issued with isotachs to all companies at London Airport. Before this date route winds and temperatures were given for each flight across the Atlantic. In addition a twice-daily issue of forecast 300 mb and 200 mb charts was begun. This has been extended so that forecast charts for 700 mb, 500 mb, 300 mb and 200 mb are now issued every six hours with the exception of the period midnight to 0600 GMT. No forecast 200 mb chart is issued for this period as there is a restriction on the departure of turbo-jet powered aircraft from London Airport between those times. The area covered by the forecast upper air charts is from 50°E to 110°W and from 75°N to 25°N. Tropopause and level-of-maximum-wind charts have become necessary and forecast tropopause charts are issued every twelve hours for an area similar to that above. All this brought a big increase in both the plotting and the drawing of upper level charts and some thought was given to finding a method of decreasing this work. The most hopeful line of attack lay in the 700 mb chart, as the number of aircraft flying below 14,000 feet had decreased considerably with the increasing number of turbo-prop and turbo-jet aircraft flying between Europe and North America.

The method.—A method was suggested in a paper by Treidl¹ dealing with thickness-temperature relationships over the North Atlantic. He found that the following numerical relationship held for 700–1000 mb thicknesses in the range 9200–9700 geopotential feet:

$$D_{700-1000} = D_{500-700} + 1000 \text{ gpft.}$$

By adding $D_{700-1000}$ to both sides this gave the relationship

$$\begin{aligned} 2 D_{700-1000} &= D_{700-1000} + D_{500-700} + 1000 \\ &= D_{500-1000} + 1000 \text{ gpft} \end{aligned}$$

and from this the following restricted equivalence table was formed:

$D_{700-1000}$	$D_{500-1000}$
9200 gpft	\equiv 17,400 gpft
9400 gpft	\equiv 17,800 gpft
9600 gpft	\equiv 18,200 gpft.

Because of the simplicity of the relationship it was decided to extend the equivalence table in both directions to cover all thicknesses on the 700–1000 mb thickness chart. The best fit was expected to be found in the region 9200–9700 geopotential feet, but it was hoped that a reasonable agreement would be found outside that range and within the range of the 700–1000 mb thicknesses existing over the North Atlantic routes.

To check the validity of the above relationship two methods were used. In the first the actual 500–1000 mb thickness pattern was used to derive an equivalent 700–1000 mb pattern and then a 700 mb chart was derived by using the actual 1000 mb chart. This 700 mb chart was then compared with the actual

700 mb chart. Such a comparison was carried on for a year and in all 128 pairs of charts were available for comparison. The centres of the highs and lows in nearly every case bore a close relationship to each other especially when strong gradients were present. The main method of comparing the charts was by measuring on both charts the equivalent headwind component on a great circle between Shannon and Gander as described by Harley².

The following is a synopsis of the results of these measurements:

Standard deviation of abbreviated method against actual charts = 3.3 kt

Distribution of errors

Errors (kt)	0	1	2	3	4	5	6	7	8
No. of cases	18	30	22	16	17	12	8	3	2
Mean error (kt)	2.6								

Errors greater than five knots were investigated. It was discovered that most of these large errors were associated with strong wind belts near the great circle route with a fairly rapid decrease in gradient to the north. There were also occasions when observations from ocean weather stations Juliett or Coco were not available at either level or available at 700 mb only. These could and did lead to inconsistent drawing of the 700 mb and 500 mb actual charts.

The second method of checking was by using the forecast charts. In a similar manner to that used in the first method a 700 mb forecast chart was derived from the forecast 500–1000 mb thickness pattern. Again this was compared visually with the forecast 700 mb chart derived by the normal method. Again the centres of highs and lows bore a close relationship to each other. The equivalent headwind components were measured on both charts, but in this method these components were not compared with each other. They were compared against the appropriate 700 mb actual chart. This actual chart was the one for a time three hours after the operative departure time from London Airport to which the forecast chart referred. Thus the forecast chart for a departure time of 0900 GMT was compared with the actual chart three hours later at 1200 GMT. Similarly the chart for a 2100 GMT departure was compared with the following actual midnight chart. These comparisons are acceptable as the forecast charts are composite and the time at 30°W, which is approximately halfway between Shannon and Gander, is three hours after departure time. In this way it was possible to compare the two methods of forecasting the 700 mb chart against one another.

At first the equivalent headwind components were measured only between Shannon and Gander but later they were extended to the routes between London and Keflavik and between Keflavik and Gander so as to encompass the area normally used for low-level flights over the North Atlantic. Tables I and III give the standard deviation of the two methods over the various routes, and the standard deviation seasonally over the route Shannon–Gander. Table II is the contingency table giving the errors of the abbreviated method against the

TABLE I—STANDARD DEVIATIONS

Route	Period	No. of cases	Standard deviation (kt)	
			Normal method	Abbreviated method
Shannon–Great Circle–Gander	21 June 1959–22 June 1960	112	6.4	5.7
London–Keflavik	2 Feb. 1960–22 June 1960	40	6.7	7.1
Keflavik–Gander	2 Feb. 1960–22 June 1960	40	10.0	10.1

TABLE II—CONTINGENCY TABLE FOR THE ROUTE SHANNON—GANDER

Errors of the abbreviated method plotted against those of the normal method of forecasting the 700 mb chart

Errors of normal method (knots)

[illegible]

TABLE III—SEASONAL STANDARD DEVIATIONS

Route : Shannon—Great Circle—Gander

	No. of cases	Standard deviation (kt)	
		Normal method	Abbreviated method
March–May	30	6·7	5·9
June–Aug.	37	4·9	4·7
Sept.–Nov.	20	7·2	6·7
Dec.–Feb.	25	7·1	5·9

normal method on the route Shannon–Gander. The seasonal differences were measured to see whether or not they would show a deterioration in the equivalence table of thicknesses, but such a deterioration is not obvious.

The large standard deviation in the equivalent headwinds between Keflavik and Gander is, in all probability, due mainly to the difficulty in forecasting the movement of surface lows in that area and only slightly to the forecast thickness pattern.

The results in themselves were surprising as it had been expected that the errors of the abbreviated method would at best be of the same order as those of the normal method. Even the distribution of errors as given in the contingency table shows a decrease in the larger errors. A possible reason for the decrease in the errors is that the greater number of lines in the 500–1000 mb thickness pattern leads to a greater discipline in their placing and to a subsequent improvement in the drawing of the associated 700 mb forecast chart. An investigation of the larger errors shows that they usually occurred on both forecast charts simultaneously and that the most probable reason for this was an error on the basic forecast surface chart.

Forecast 700 mb charts are now derived at London Airport by the abbreviated method described above and the area covered by the forecast charts has been extended with success to cover Europe and the Mediterranean as well as the North Atlantic routes. Because of the above results it is possible that some similar method could be used for forecasting the 300 mb chart and work to this end has been started at London Airport.

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551.591.36

FREQUENCIES OF POOR AFTERNOON VISIBILITIES IN ENGLAND AND WALES

By L. P. SMITH, B.A.

Introduction.—The light intensity is a factor of great importance in horticulture, especially where crops are raised under glass. Unfortunately it is only in recent years that accurate measurements of this factor have been attempted on a regular basis. It was therefore desirable to attempt an oblique approach to the subject by considering the extent of haze present in the atmosphere and the simplest way to do this was by analysing the visibilities in the afternoon, when water fogs were most likely to be absent.

Method.—This work was carried out some years ago by the Agricultural Branch at Harrow and the records of visibility contained in the *Monthly Weather Report* from 1923 to 1951 were used. Two difficulties were encountered. Firstly the time of the afternoon observation changed twice during this period. From 1923 to July 1944 it was at 1300h; from then until December 1944 it was at

1200h; from 1945 onwards it was at 1500h. These changes had perforce to be ignored. Secondly of the 61 stations which made such reports for periods longer than five years only 17 had complete records.

Two parameters were considered: (a) the number of occasions per month with afternoon visibilities less than 4400 yards (Code Figure 5 or less), and (b) similar occasions with visibilities less than $6\frac{1}{4}$ miles (Code Figure 6 or less) and a system of weighting had to be adopted. Of the 44 stations with incomplete records, 19 were weighted with respect to three neighbouring stations, the final answer being taken as the mean of the three weightings. Of the remainder, 16 were weighted with respect to two stations and nine with respect to one only. In this process it was clear that some stations had unreliable records, probably owing to the absence of suitable visibility points. The suspected results are enclosed in brackets in the accompanying tables.

Results.—The network of stations is shown in Figure 1. Such a network obviously leaves large gaps but the results were found to be generally consistent

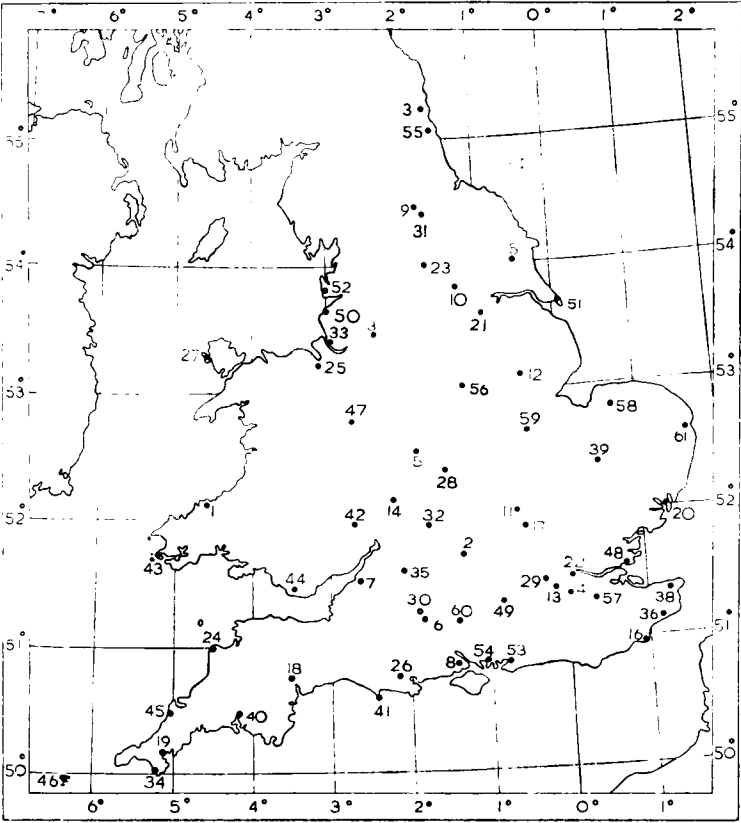


FIGURE 1—STATION MAP

Table I gives the place names represented by the numbers on this map.

in other areas. Table 1 shows the final results in a seasonal summary; winter was assumed to comprise December to February, spring March to May and so on.

About half the days of the year when the afternoon visibilities are below 4400 yards occur during the winter quarter, except in the south-west where the proportion is lower. As might be expected the summer fraction is very small, and about a quarter of the yearly total occurs in autumn. Inland in spring such days

TABLE I—AVERAGE DAYS PER SEASON, OVER PERIOD 1923–51, WITH AFTERNOON
VISIBILITIES (a) <4400 YARDS AND (b) <6¼ MILES

	Spring		Summer		Autumn		Winter		Year	
	(a)	(b)	(a)	(b)	(a)	(b)	(a)	(b)	(a)	(b)
	<i>number of days</i>									
1. Aberporth	3.0	13.0	2.5	10.3	1.9	12.4	3.7	19.2	11.1	54.9
2. Abingdon	3.5	22.0	1.3	12.1	7.9	27.6	15.2	37.2	27.9	98.8
3. Acklington	7.3	22.5	4.7	20.8	10.2	25.0	14.4	29.0	36.6	97.3
4. Biggin Hill	8.7	37.1	3.3	20.7	16.7	44.3	28.3	60.3	57.0	162.4
5. Birmingham	22.4	49.0	5.9	19.3	26.4	50.4	46.5	70.7	101.2	189.4
6. Boscombe Down	5.3	25.0	1.4	13.1	7.7	29.7	18.6	41.3	33.0	109.1
7. Bristol	6.4	23.5	1.4	11.2	13.9	34.6	21.7	52.4	43.4	121.7
8. Calshot	5.3	31.4	1.8	18.1	7.3	31.7	16.5	50.2	30.9	131.4
9. Catterick	11.5	32.1	5.6	23.9	17.4	34.9	27.6	45.4	62.1	136.3
10. Church Fenton	11.2	47.1	3.6	36.2	16.8	47.2	32.8	64.6	64.4	195.1
11. Cranfield	5.7	26.3	1.3	14.8	9.1	31.2	16.6	47.0	32.7	119.3
12. Cranwell	6.4	35.1	2.0	20.4	13.5	44.8	29.7	65.1	51.6	165.4
13. Croydon	15.1	48.3	2.7	17.6	22.2	53.0	41.2	82.2	81.2	201.1
14. Defford	4.7	31.8	1.6	16.2	6.4	27.6	19.2	42.5	31.9	118.1
15. Driffield	7.1	32.2	2.1	24.0	12.4	38.9	25.4	50.6	47.0	145.7
16. Dungeness	9.0	38.4	5.8	29.5	8.5	33.9	16.1	47.3	39.4	149.1
17. Dunstable	7.3	34.4	3.2	21.3	11.9	39.8	22.9	58.3	45.3	153.8
18. Exeter	3.1	13.9	1.2	7.1	3.8	15.3	6.8	19.0	14.9	55.3
19. Falmouth	5.9	20.3	1.8	13.5	2.7	16.0	3.2	21.4	13.6	71.2
20. Felixstowe	8.5	31.6	2.3	17.5	10.4	35.5	23.9	51.2	45.1	135.8
21. Finningley	9.3	35.1	2.8	34.9	14.0	49.6	31.4	66.0	57.5	185.6
22. Greenwich	19.3	69.4	1.1	22.6	33.1	72.7	64.8	90.3	118.3	255.0
23. Harrogate	(16.6)	32.8	(11.8)	25.0	(27.1)	37.7	(37.5)	50.2	(93.0)	145.7
24. Hartland Point	3.1	16.2	4.1	12.6	2.4	14.3	4.9	16.1	14.5	59.2
25. Hawarden	13.0	40.3	4.2	22.4	18.0	42.4	29.2	53.1	64.4	158.2
26. Holton Heath	7.3	26.7	3.4	15.4	9.6	30.4	16.9	41.8	37.2	114.3
27. Holyhead	6.3	27.5	4.7	18.7	4.9	19.9	8.2	29.8	24.1	95.9
28. Honiley	10.7	36.9	4.2	19.9	16.6	42.1	29.3	54.2	60.8	153.1
29. Kew	13.1	45.7	1.4	13.6	19.9	49.7	42.5	79.0	76.9	188.0
30. Larkhill	3.5	17.4	0.8	8.9	6.1	22.7	14.0	38.1	24.4	87.1
31. Leeming	9.4	30.8	4.5	22.5	12.8	32.4	22.2	39.6	48.9	125.3
32. Little Rissington	8.8	22.1	1.8	9.1	14.1	28.2	26.1	41.3	50.8	100.7
33. Liverpool	15.6	35.5	6.4	22.2	19.8	36.6	29.0	43.4	70.8	137.7
34. Lizard	7.7	20.8	8.0	17.1	6.6	17.0	7.2	20.6	29.5	75.5
35. Lyneham	5.1	23.1	1.1	9.1	7.6	27.0	14.2	43.8	28.0	103.0
36. Lympne	8.7	30.8	3.6	17.4	12.6	36.1	26.3	54.4	51.2	138.7
37. Manchester	14.5	45.1	4.9	29.4	22.1	53.8	37.5	69.8	79.0	198.1
38. Manston	8.7	33.7	2.3	21.1	11.7	35.7	22.5	53.7	45.2	144.2
39. Mildenhall	3.6	21.7	0.9	9.9	7.9	33.0	21.9	52.3	34.3	116.9
40. Plymouth	5.0	24.0	4.1	15.6	5.8	25.7	11.2	39.3	26.1	104.6
41. Portland Bill	4.9	24.9	3.0	16.8	3.5	19.5	4.9	24.5	16.3	85.7
42. Ross-on-Wye	6.2	24.7	2.0	12.4	11.3	28.9	15.6	37.9	35.1	103.9
43. St. Ann's Head	9.0	29.9	6.2	22.2	5.7	22.7	9.5	29.3	30.4	104.1
44. St. Athan	12.5	30.5	4.7	20.8	17.9	30.0	22.2	40.9	57.3	122.2
45. St. Eval	5.0	24.3	2.6	13.5	6.3	20.0	10.4	25.6	24.3	83.4
46. Scillies	6.4	27.2	6.4	19.4	6.3	23.0	6.0	25.6	25.1	95.2
47. Shawbury	8.4	31.7	1.9	17.4	11.1	31.9	20.9	41.4	42.3	122.4
48. Shoeburyness	6.4	29.5	1.6	17.3	10.5	35.2	21.6	53.2	40.1	135.2
49. South Farnborough	6.9	30.6	1.2	15.2	11.4	35.0	22.8	52.9	42.3	133.7
50. Southport	(22.5)	40.7	(9.2)	23.2	(33.6)	47.6	(45.6)	65.1	(110.9)	176.6
51. Spurn Head	11.3	43.2	5.5	36.1	11.6	47.4	24.6	60.2	53.0	186.9
52. Squire's Gate	11.1	25.9	4.0	18.1	19.3	46.5	41.6	61.4	76.0	151.9
53. Tangmere	6.4	36.2	1.9	20.9	9.3	33.4	20.0	56.4	37.6	146.9
54. Thorney Island	4.6	27.3	1.4	16.1	6.6	34.3	17.2	52.2	29.8	129.9
55. Tynemouth	8.5	38.9	5.1	32.5	14.1	46.5	28.0	62.0	55.7	179.9
56. Watnall	14.2	37.4	4.7	25.9	22.9	56.7	42.1	70.8	83.9	190.8
57. West Malling	12.8	27.2	4.3	14.7	15.2	32.7	30.6	56.0	62.9	130.6
58. West Raynham	4.2	26.3	1.2	15.0	7.7	41.3	18.9	50.6	32.0	133.2
59. Wittering	6.3	32.6	2.8	22.4	12.0	43.5	21.2	60.8	42.3	159.3
60. Worthy Down	4.1	18.8	2.5	10.2	8.6	26.6	16.3	39.3	31.5	94.9
61. Yarmouth	8.2	(57.0)	2.7	(43.3)	6.9	(53.9)	17.6	(66.4)	35.4	(220.6)

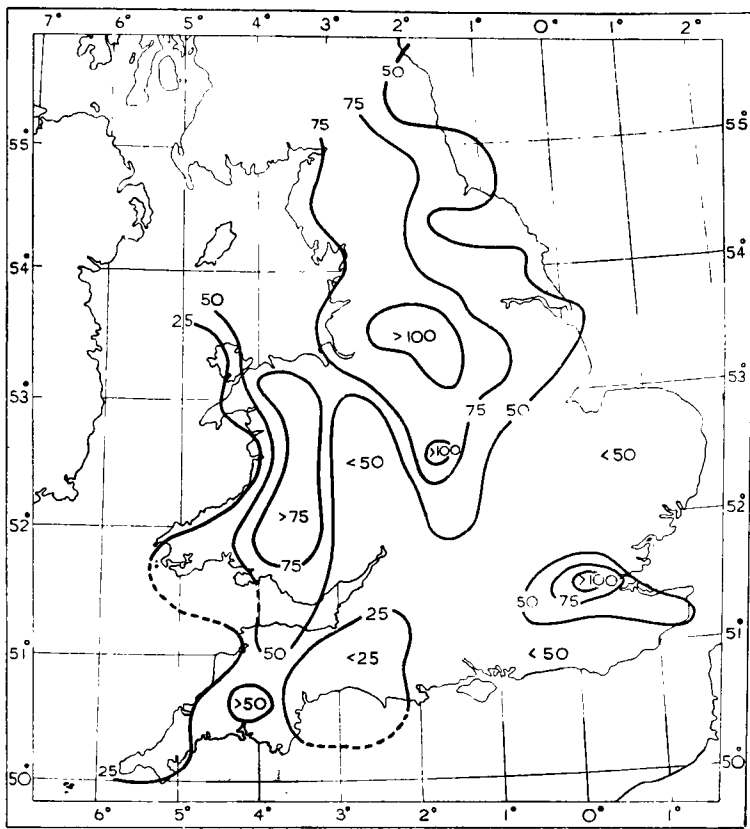


FIGURE 2—AVERAGE NUMBER OF DAYS PER YEAR WITH AFTERNOON VISIBILITIES
LESS THAN 4400 YARDS

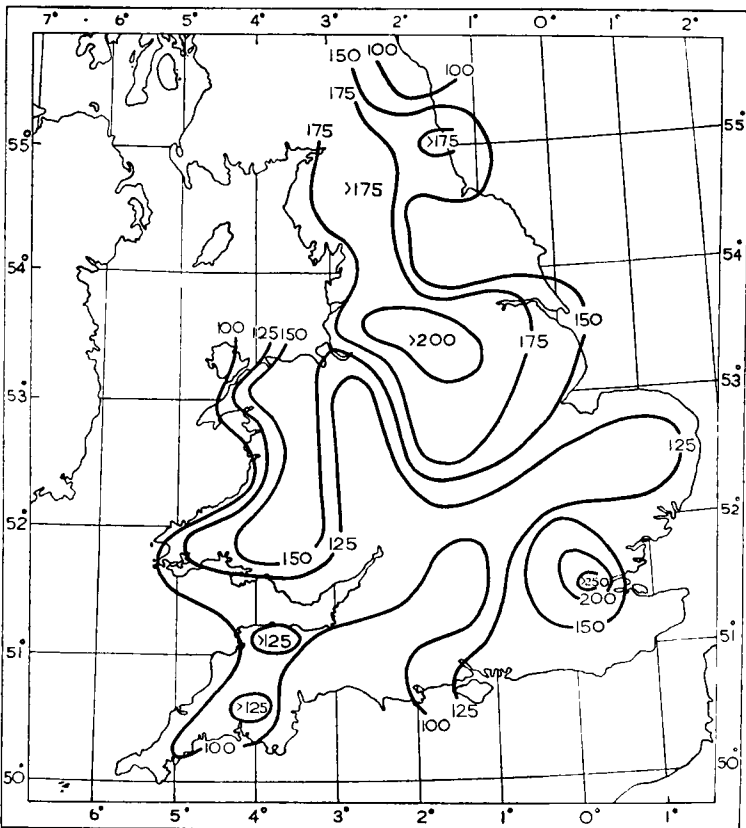


FIGURE 3—AVERAGE NUMBER OF DAYS PER YEAR WITH AFTERNOON VISIBILITIES
LESS THAN 6½ MILES

are relatively rare but on the coast, especially in the south-west, the proportion is higher, which suggests that such occasions are more likely to be due to the low cloud or sea fog rather than haze.

The yearly totals have been illustrated in two maps, Figures 2 and 3. The extrapolation of the isopleths over high ground called for a certain degree of imagination, but the general picture is reasonably satisfactory and bears a close resemblance to maps of coal consumption. The effect of the main industrial areas is obvious, and it is worthy of note that Kent seems to suffer London smoke more than Essex.

To obtain the clearest representation of the monthly distribution, the stations were grouped together as follows:

- (i) town (ii) country (iii) north-east coastal (Tynemouth to Yarmouth)
- (iv) south-east coastal (Felixstowe to Calshot) (v) south-west coastal (Portland Bill to Holyhead) (vi) north-west coastal (Hawarden to Squire's Gate).

TABLE II—MEAN MONTHLY DISTRIBUTION (PERCENTAGES OF ANNUAL TOTAL) OF POOR AFTERNOON VISIBILITIES

(a) *Afternoon visibilities < 4400 yards*

Type of Station	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
							<i>per cent</i>					
Town	18.2	12.1	9.9	4.2	3.7	1.7	1.6	2.0	3.0	8.2	16.2	19.2
Country	18.8	11.3	9.9	3.7	3.0	1.6	1.9	2.3	3.0	7.8	15.8	20.9
NE coastal	18.4	11.7	10.0	4.9	4.7	3.2	2.6	3.3	3.6	6.4	12.4	18.8
SE coastal	18.7	13.3	10.6	4.2	3.1	1.7	2.2	2.5	4.0	6.8	13.2	19.7
SW coastal	12.4	10.3	12.3	7.6	7.0	6.4	6.3	7.4	6.9	7.1	7.0	9.3
NW coastal	16.8	14.4	10.3	4.1	2.9	2.5	1.1	2.3	2.7	8.9	15.2	18.8

(b) *Afternoon visibilities < 6¼ miles*

Type of Station	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
							<i>per cent</i>					
Town	12.9	10.7	10.2	6.8	6.2	4.5	4.0	4.2	5.8	8.9	12.2	13.6
Country	13.5	10.0	10.2	6.3	6.0	4.5	4.3	4.8	5.7	8.8	12.1	13.8
NE coastal	12.1	9.3	9.3	6.6	6.5	5.7	6.5	6.6	6.7	8.1	10.7	11.9
SE coastal	13.3	10.7	10.1	6.6	6.5	4.7	4.6	4.9	5.8	7.6	11.5	13.7
SW coastal	11.3	9.8	12.0	7.8	7.6	6.7	6.3	6.4	6.5	8.5	8.0	9.1
NW coastal	12.6	10.2	10.2	5.7	6.0	4.4	3.7	5.0	6.1	9.6	12.4	14.1

With the exception of the south-west coastal stations, this distribution appears very uniform and, on allowing for the number of days per month, the values fit a fairly smooth curve. In the south-west coastal stations there appears a maximum frequency in March, the most likely time for sea fogs.

The results are given in Table II, and if allowance is made for the differing number of days per month, they fit a series of fairly smooth curves showing the annual variation. The March maximum on the south-west coasts is presumably a sea-fog effect, but it is impossible to eliminate this factor with the simple method of analysis used.

NOTES AND NEWS

National Survey of Atmospheric Pollution

Scope of Survey shown at Clean Air Exhibition, Brighton

Towns and cities taking part in the National Survey of Atmospheric Pollution were named for the first time by the DSIR's Warren Spring Laboratory at the Clean Air Conference and Exhibition in Brighton from 4-6 October 1961. Atmospheric pollution from various sources costs the country about £250,000,000 a year. The aim of the National Survey, which is organized by the Laboratory, is to provide more detailed information about the two major

sources of pollution—smoke (mainly from domestic chimneys) and sulphur dioxide (from industrial sources).

Measurements of air pollution have been made over a number of years by an increasing number of local authorities and other bodies. The usefulness of this information will now be increased by measurements taken in a number of additional towns, chosen on a valid statistical basis to give a representative picture of the distribution of pollution throughout the country. The National Survey is thus made up of measurements from the representative sample towns and from towns already taking daily readings. The main exhibit by the Warren Spring Laboratory at the Brighton Conference was a large map of Great Britain (facing p. 349), illuminated to show the towns which are co-operating with DSIR in the Survey.

Thirty-eight per cent of all the people in England and Wales live in the six conurbations of Greater London, south-east Lancashire, west Midlands, west Yorkshire, Merseyside and Tyneside. These conurbations are large groups of built-up areas and their special air pollution problems require detailed study. Measurements are being made in all six and also in all 30 of the towns outside the conurbations with a population of 100,000 and over, in which 13 per cent of the people of England and Wales live and work. It is planned to include all these towns in the representative section of the Survey.

A further eight per cent live in 32 towns outside the conurbations with a population of between 50,000 and 100,000. About half of these towns are already in the representative section of the Survey and the number will eventually be increased to 27.

A representative sample of about 30 towns is also being chosen from the 66 towns outside the conurbations with a population of between 10,000 and 50,000, which house a further 17 per cent of people in England and Wales. The remaining 24 per cent of the population live in towns of under 10,000 or in rural districts. Although small towns and villages are not shown on the air pollution map, about 70 authorities in this group are making measurements and, in addition, a representative sample of places of this size is now being selected by the Warren Spring Laboratory. Measurements already being made in Scotland and Northern Ireland form a fair representative sample of towns of different sizes in these areas.

REVIEWS

The earth's problem climates, by Glenn T. Trewartha. 10 in. × 7 in., pp. vi + 334, illus., University of Wisconsin Press, 430 Sterling Court, Madison 6, Wisconsin, 1961. Price: \$7.50.

In this major work Professor Trewartha has attempted a new approach to climatology which is to be highly commended. He has covered almost the whole earth and has attempted not only to list and describe the more important of its problem climates but also to suggest explanations for them in dynamical terms.

The book begins by considering the generalized world pattern of climatic distribution that should result from the operation of the planetary controls of solar energy distribution and general circulation as modified by the differential effects of oceans and continents. Climatic features of the actual continents which differ markedly from those which would be expected on a hypothetical continent are the *problem climates* which the author considers and attempts to explain, although his explanations are not claimed to be necessarily the final or correct ones.

Part I deals with "Latin America" and consists of five chapters, the first two of which have the same title—Pacific South America: Part II with "Australia—New Zealand and the Equatorial Pacific" in one chapter: Part III with "Africa" in four chapters: Part IV with "Southern and Eastern Asia" in three chapters: Part V with "Europe and the Mediterranean Borderlands" in three chapters, two of which have the same title—"Mediterranean Lands": and Part VI with "Anglo-America" in four chapters.

Although the book is aimed at a professional audience it is a pity that the author assumes that his readers are already familiar with the modified Köppen classification as outlined in his earlier book *An introduction to climate* and also with Thornthwaite's system. Both of these systems are employed in the book and it would not have added appreciably to its length if it had been made more self-contained in this respect. Neither does it help readers who are not too familiar with these alphabetic classifications that the coloured folding map showing the distribution of climatic types according to the first of these systems faces the wrong way for easy reference. Another minor irritation is the mixture of units that is employed. Most of the discussion concerns anomalies of temperature and of precipitation, but temperatures are sometimes given in °C, sometimes with the scale unstated, and sometimes in °F, while rainfall amounts are given sometimes in inches and sometimes in millimetres.

In the earlier chapters the author's declared aim of describing and attempting to explain problem climates is faithfully followed, but as the work proceeds Professor Trewartha tends to confine himself more to descriptive climatology.

The book is illustrated with a large number of useful and well drawn maps and diagrams and has at the end a lengthy list of explanatory notes and references. It is well produced and clearly printed on good quality paper.

H. C. SHELLARD

Weathercraft, by L. P. Smith. 8½ in. × 6 in., pp. 87, *illus.*, Blandford Press, 16 West Central Street, London W.C.1., 1960. Price: 9s. 6d

This book is a creditable and, on the whole, successful attempt to show the layman how a modest knowledge of meteorology can be turned to account in the garden. The author treats first of the weather "in general" and then "in particular", for example with particular reference to the forecasting of frost, climate under glass, soil temperatures, water need and the importance of aspect and site. Twenty-eight simple experiments are suggested. The photographs, pictures and graphs are clear and instructive. There are also some useful tables which relate rainfall at different seasons and in different parts of the United Kingdom to water need.

"Weathercraft" will be of particular interest to amateur and market gardeners and to those schools where agricultural science is taught as a special subject. The author has, however, tried to cast his net too widely and this has led to a sense of unbalance which destroys the unity of the book as a whole. The market gardener is unlikely to waste his time with experiment No. 8: "Select a few old weather sayings which you think likely to be true. Test them against the truth, either from past records or from current happenings." On the other hand there is a largely irrelevant, though interesting, chapter at the end of the book devoted to sailing small boats in squally weather. Although the author has obviously done all he can to cut down instrumentation to a minimum, nothing is said about the cost of essential instruments or where they may be bought: matters of primary importance to school-teachers.

Nevertheless this book can be positively recommended to those who are beginners in the study of agricultural meteorology. It is also to be hoped that Mr. Smith will be encouraged to write again for those who are interested in the practical study of meteorology at a humble level. Why not, in our largely urban and cancer-conscious community, "Air pollution without tears"?

J. B. RIGG

OFFICIAL PUBLICATION

Handbook of meteorological instruments, Part II—Instruments for upper air observations. The *Handbook of meteorological instruments* is a comprehensive survey of the technical equipment necessary for the operation of a modern meteorological service. It gives detailed information on the design, installation, operation and maintenance of the instruments used at the stations of the Meteorological Office, together with some information about other types of meteorological instruments to illustrate different principles. Part I, which deals with the instruments used for surface observations, was published in 1956. Part II, published recently, is concerned with the equipment used for observations in the upper air to heights of about 40 kilometres.

This second volume is a comprehensive guide to the upper air instruments that are now available and it forms a book of reference on the subject. It starts with a survey of the historical development of upper sounding. Six chapters are concerned with the application of radio and radar techniques to the measurement of the physical properties of the free atmosphere and there are chapters on instruments for meteorological observations from aircraft and on the methods of measurement in cloud physics. The volume, which is illustrated with 51 plates and 47 diagrams and is fully indexed, includes a glossary of technical terms and a bibliography.

CORRIGENDA

Fronts investigated by the Meteorological Research Flight

In the July 1961 *Meteorological Magazine* the key to wind speed in Figure 5(b), page 199, should read (Positive from SW) and the temperatures in Figure 6(b), page 201, should be negative.

OBITUARIES

Mr. B. J. Blower. It is with deep regret that we learn of the sudden death on 24 August 1961 of Mr. B. J. Blower, Experimental Officer, at the age of 56. "Bill" Blower was a much loved personality—a kindly and genial west countryman with a whimsical sense of humour. He joined the Office in August 1934 after service in the Royal Air Force and served at several stations at home and overseas. During the war he was commissioned as a Flying Officer in the Royal Air Force in which capacity he gave valuable service. In 1949 after a tour of duty at Malta he was posted to the Observations and Communications Branch at Dunstable where he remained until his death. As a member of the staff he was most conscientious and had a reputation for meticulous orderliness in his work, while as a colleague he gained the respect and affection of all who worked with him.

He leaves a widow, one daughter and two sons to whom we extend our deepest sympathy.

Mr. P. R. Brown. The death of Paul R. Brown on 30 September 1961 at his home in Wokingham near Bracknell at the early age of 45 came as a great shock to his family and to his friends and colleagues in the Meteorological Office.

He obtained a B.Sc. (Special) degree and A.R.C.S. in physics with subsidiary pure and applied mathematics, together with the D.I.C. and M.Sc. (London) in meteorology, before joining the Meteorological Office as a Technical Officer in October 1938. After undergoing a training course, he transferred to the Irish Meteorological Service in January 1939, where he was employed in forecasting duties at the original Shannon Airport flying-boat base at Foynes, County Limerick. Mr. Brown rejoined the Meteorological Office in November 1944, at Prestwick Airport, and was commissioned as Flight Lieutenant R.A.F.V.R. in April 1945. In March 1946 he was posted to the Far East where he served in Burma, Singapore and Japan. In 1946 he was promoted to Squadron Leader, and was released from the Royal Air Force on return to the United Kingdom in February 1948.

Owing to ill health it was not until October 1950 that Mr. Brown returned to the Meteorological Office and joined the Marine Division as a Scientific Officer. He was promoted Senior Scientific Officer in July 1954 and in November 1960, as a result of reorganization inside the Meteorological Office, was transferred to the Climatological Services Division.

During the first half of his ten years in the Marine Division, Mr. Brown was primarily engaged in marine climatology, for which he showed considerable liking and aptitude. His published work included papers on the meteorological aspect of cargo and ventilation; evaporation, humidity and condensation in enclosed spaces; climatic fluctuation in northern waters; humidity over the Atlantic; wave data for eastern North Atlantic and ice in the Newfoundland region. Further papers by him on climatic fluctuations over the oceans were read for him at the WMO/UNESCO Rome Symposium on Climatic Change a few days after his untimely death. He was responsible for the preparation of the atlas of monthly meteorological charts of the Greenland and Barents Seas. During the latter part of his stay in the Marine Division, he divided his time between climatology and the big task of building up the punched card installation, which was originally employed entirely for the work of the Marine Division, but which gradually extended its activities to the work of the whole Office. How well he did this job is shown in the efficiency of the large and comprehensive punched card installation at Bracknell which now forms part of the Support Services Division. While in the Marine Division, Mr. Brown was also responsible for providing meteorological evidence in connexion with marine inquiries held by the Ministry of Transport into shipping casualties.

Paul Brown was a sincere and friendly colleague who unfailingly gained the confidence of all those who worked with him. He leaves a widow and a young son.

C.E.N.F.

METEOROLOGICAL OFFICE NEWS

Gassiot Fellowships

Mention was made of the two Gassiot Fellowships in our May and July 1961 issues. The second Gassiot Fellow, Dr. H. M. Iyer, has now arrived in this country to take up his appointment. Dr. Iyer is of Indian nationality. He was

born in 1931 and educated in India and at London University, where he took his Ph.D. degree in 1959. He has been concerned with seismological studies for some time and has contributed extensively to the literature of the subject. Apart from theoretical and laboratory studies at Bracknell he will use Kew and Eskdalemuir Observatories as seismological field stations.

Report on the first season of the Bracknell Meteorological Office Cricket Club

The Bracknell Meteorological Office Cricket Club was formed in April 1961 under the chairmanship of Lt. Cdr. L. B. Philpott. The new Club is a merger of three former cricket clubs from Harrow, Dunstable and Victory House.

In spite of the fact that no home ground was available, "away" fixtures were arranged without great difficulty and there was enough cricket throughout the season to keep all members interested. Although a rather limited club membership made it difficult at times to field a strong side, the season was a reasonably successful one, as far as the results of the matches were concerned. However, with the prospect of a larger club membership next season and hopes that the club will then be able to run two teams, the outlook for the future seems even brighter.

Thanks are due to Lt. Cdr. L. B. Philpott and Mr. P. J. Cutting who were largely responsible for the formation of the club and the arrangement of fixtures. Overall results of the matches and the best batting and bowling averages are tabulated below.

		MATCHES					
		Played 14	Won 6	Drawn 0	Lost 8		
BATTING AVERAGES—FOUR COMPLETED INNINGS TO QUALIFY							
Batsman		No. of innings		Not out	Highest score	Runs	Average
R. Burns	9	2	47*	199	28.43
C. Hawson	6	1	51*	85	17.00
F. Reece	12	3	54*	153	17.00
P. Edwards	7	3	20	51	12.75
D. Clark	8	0	30	82	10.25

* Not out

BOWLING AVERAGES						
Bowler		Overs	Maidens	Runs	Wickets	Average
B. Butler	...	21.1	4	85	13	6.54
B. Morris	...	12.5	2	77	9	8.55
J. Nicholas	...	50	5	186	21	8.86
F. Reece	...	19	1	97	9	10.78
J. Cockburn	...	45	12	216	17	12.71
P. Edwards	...	55	9	198	15	13.20

Staff suggestions scheme

Mr. W. Wallace, Temporary Radio (Meteorological) Technician, was awarded £25 for his suggestion for a modification to "Mufax" chart recorders.

Mr. M. C. Cottom, Technical Grade III, was awarded £10 for his suggestion about the adjustment of "Mufax" recorders by means of a locally produced phasing pulse.

Mr. P. Powell, Senior Experimental Officer, was awarded £3 3s 0d for his suggestion about the provision of holders and refills in place of the present chinagraph pencils.

Mr. J. R. Green, Executive Officer, was awarded £1 1s 0d for his suggestion about the introduction of a standard form for claiming transfer grants.