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MR. J. DURWARD, C.M.G., M.A.

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## **JAMES DURWARD, C.M.G., M.A.**

Mr. Durward retired on January 31, 1956 after nearly 37 years' service in the Meteorological Office.

At the outbreak of the First World War he was at the University of Aberdeen. He enlisted in the Gordon Highlanders and was on active service in France. In June 1915 he was transferred to the newly formed Meteorological Section of the Royal Engineers in France, was commissioned in February 1917 and was promoted to the rank of Captain in March 1918.

On his return from France after the cessation of hostilities he was posted in charge of the meteorological office at West Lavington which catered for the needs of the artillery and sound-ranging units on Salisbury Plain. In April 1919 he was appointed Senior Professional Assistant, and a year later the meteorological office at West Lavington was transferred to the School of Artillery at Larkhill where he remained until July 1922, when he was promoted to the rank of Assistant Superintendent and transferred to the R.A.F. Flying Boat Station, Calshot, where lecturing in meteorology to the long Navigation Courses was an important commitment.

In December 1926 he was promoted to the rank of Superintendent and posted to Headquarters R.A.F. Middle East (Cairo), where he was responsible for the provision of meteorological services to the Royal Air Force and to civil aviation, particularly Imperial Airways (subsequently renamed British Overseas Airways Corporation). This was the beginning of a close association with civil aviation which continued throughout the greater part of his subsequent service in the Meteorological Office.

The main forecasting centre was at Heliopolis, a suburb of Cairo, and subsidiary offices were established at Ismailia, Abu Qir (near Alexandria), Ramle, (Palestine) and Amman (Transjordan). Forecasts for the Middle East area were broadcast twice daily and a collective broadcast of 0700 G.M.T. reports for the Mediterranean-Middle East area was inaugurated. Subsequently, towards the end of 1931, the Meteorological Office took over, from the Royal Air Force, responsibility for the provision of meteorological services in Iraq, and a main meteorological office was established at Hinaidi (near Baghdad) and subsidiary offices at Mosul and Shu'aiba under the overall control of Mr. Durward.

In November 1936, he was seconded to the Iraq Government for three years as Director of the recently formed Iraq Meteorological Service. His efforts in developing and organizing an efficient meteorological service and in training

Iraqi staff in meteorological duties were prodigious, and well merited the award of the Order of Rafidain bestowed on him by the Iraqi Government in March 1940.

On his return to the United Kingdom he was posted as Principal Technical Officer to be Head of one of the Branches of the Royal Air Force Division of the Meteorological Office in March 1940, and later as Head of the Overseas Branch, in November 1941. In the winter of 1943-44 he went by air to the South-East Asia Air Command making a detailed inspection of all important R.A.F. Staging Posts *en route*.

In April 1946 he was promoted to the post of Assistant Director (Civil Aviation) and in January 1948 he was promoted to the grade of Deputy Chief Scientific Officer to undertake the duties of Deputy Director in charge of the provision of meteorological services for the Army, the Royal Air Force, the Ministry of Civil Aviation and the Ministry of Supply.

Since the conclusion of the Second World War Mr. Durward has become increasingly well known in international meteorological circles, has frequently undertaken the chairmanship of some of the meteorological committees, and has taken a leading part in the formulation of meteorological procedures and practices, particularly those for aviation in the early days of the International Civil Aviation Organization. His world-wide interests in meteorology may be appreciated from the list of international meetings at which he has been a delegate. He was an adviser at meetings of the Synoptic Weather Information Commission of the International Meteorological Organization, and was the principal United Kingdom delegate at meetings of the Aeronautical Commission of the same organization both before and after it became the World Meteorological Organization. He was also a principle delegate at meetings of the International Civil Aviation Organization of the North Atlantic, South Pacific, Caribbean and South Atlantic Regions; of special Meteorological Division meetings; and of Joint Support meetings in respect of meteorological services in Greenland and Iceland and of the operation of ocean weather ships in the North Atlantic.

Mr. Durward was also concerned with meteorological services in liaison with the Colonial Office. Mention may be made of his visits to the West Indies in 1945 and to British West Africa in 1947 for the purposes of advising on the meteorological organization necessary to replace the war-time organization which had been developed as a Meteorological Office responsibility.

In recognition of his invaluable services, in June 1953, Mr. Durward was made a Companion of the Order of St. Michael and St. George, an honour which gave great gratification particularly to those members of the staff who have had the good fortune to serve under him.

Since his retirement from the post of Deputy Director (Services) on December 31, 1954, Mr. Durward has been Scientific Officer to the Director of the Meteorological Office, in which capacity his aid was invaluable before and during the Second Congress of the World Meteorological Organization held at Geneva from April 14 to May 13, 1955, and the Conference of Commonwealth Meteorologists held in the Air Ministry, Whitehall Gardens, during May 23-26, 1955.

A host of colleagues with happy recollections of his geniality, able guidance and willing assistance at all times wish Mr. Durward a long and very happy retirement.

# VARIATION WITH TIME OF WINDS AT 40,000 FT. AND 50,000 FT. OVER SINGAPORE

By L. S. CLARKSON, M.Sc.

**Introduction.**—The general significance of specified statistical parameters in relation to atmospheric circulation at high altitudes in the tropics and subtropics has been discussed by N. E. Davis<sup>1</sup>, while Durst<sup>2</sup> has investigated the variation of upper wind with time (and distance) in an analysis which deals mainly with the results of observations made over the British Isles, although some data for equatorial regions are included.

In view of Durst's conclusion, "Unless winds are available from accurate contour charts, the route wind for high-altitude flights is best obtained from actual winds by the use of regression equations, and in the tropics this is always so, since geostrophic winds have no real significance", it was considered worth while to make a comparative statistical investigation of the variation of high-altitude winds with time over Singapore.

**Analysis.**—The vector mean wind  $\mathbf{V}_R$  and the standard vector deviation  $\sigma$  at 40,000 ft. and 50,000 ft. over Singapore have been evaluated separately for each month from Army radar wind determinations considered by Hay<sup>3</sup>, and from the daily ascents at 0300 G.M.T. subsequently undertaken by the Malayan Meteorological Service.

Vector differences between the winds observed at 0300 and 1500 G.M.T. have been obtained from the daily observations covering November 1953 to December 1955, inclusive, and the standard vector variation in 12 hr.  $\sigma_{12}$ , calculated for each month. Similarly from consecutive daily observations at 0300 G.M.T. the standard vector variation in 24 hr.,  $\sigma_{24}$ , has also been computed.

Values have been calculated of the stretch vector correlation coefficient  $r_t$  between winds separated by a time interval of  $t$  hr. from the relation given by Durst<sup>2</sup>

$$r_t = 1 - \frac{1}{2} \left( \frac{\sigma_t}{\sigma} \right)^2$$

$\mathbf{V}_t$ , the statistically most probable wind to be expected  $t$  hr. after an observed wind  $\mathbf{V}$ , is given by the equation

$$\mathbf{V}_t = \mathbf{V}_R - r_t (\mathbf{V}_R - \mathbf{V}),$$

and this is readily solved graphically by a diagram given by R. F. Zobel in an unpublished memorandum, and reproduced here for convenience. In Fig. 1, OA is drawn to represent the appropriate value of  $\mathbf{V}_R$ , and OB the observed wind  $\mathbf{V}$ . Then OD represents the most probable wind  $\mathbf{V}_t$  when AD is made equal to  $r_t \times AB$ .

The standard vector error,  $\varepsilon_t$ , of wind estimates using the above regression equation is given by

$$\varepsilon_t = \sigma \sqrt{(1 - r_t^2)}.$$

The standard vector error involved in adopting the vector mean wind  $\mathbf{V}_R$  for the month as an estimate is given by  $\sigma$ , whilst that of using an observed wind as a forecast of the wind 12 or 24 hr. later is given by  $\sigma_{12}$  and  $\sigma_{24}$ , respectively.

Values of  $\mathbf{V}_R$ ,  $\sigma$ ,  $\sigma_{12}$ ,  $\sigma_{24}$ ,  $\varepsilon_{12}$ , and  $\varepsilon_{24}$ , with (in brackets) the numbers of observations or pairs of observations on which they are based, have been entered in Table I. Corresponding values for winds over Larkhill at 200 mb.

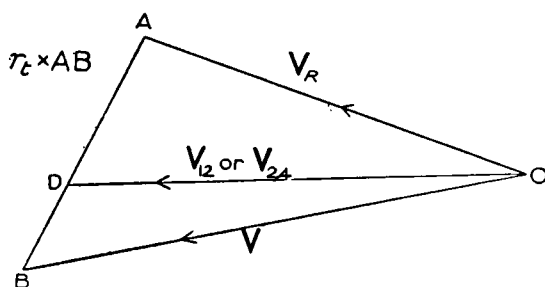


FIG. 1

taken or calculated from the data in Durst's<sup>2</sup> Table VII have been included for comparison.

**Discussion.**—The vector correlation coefficients of wind at 40,000 ft. with time for Larkhill and Singapore are comparable, although the 50,000-ft. winds separated by 12 hr. and 24 hr. are more highly correlated over Singapore. However, because of the lower variability, the standard vector variation in 12 hr. and 24 hr. is much smaller for Singapore than at corresponding heights for Larkhill. In consequence, the standard vector error involved in quoting the latest observed wind at 40,000 ft. or 50,000 ft. as an estimate of the wind to be expected 12 hr. or 24 hr. later over Singapore is roughly half the 33 kt. quoted by Durst<sup>2</sup> as the standard vector error of forecasts made at Dunstable of the wind 24 hr. ahead at 300 mb. over Larkhill in July 1951.

TABLE I—UPPER WIND STATISTICS OVER SINGAPORE AND LARKHILL

	Vector mean wind		Standard vector deviations			Standard vector errors		Stretch correlation coefficients	
	$V_R$		$\sigma$	$\sigma_{12}$	$\sigma_{24}$	$\epsilon_{12}$	$\epsilon_{24}$	$r_{12}$	$r_{24}$
	°	kt.	<i>knots</i>						
	<b>Winds at 50,000 ft. over Singapore</b>								
January ...	100	37	22 (64)	17 (45)	19 (44)	16	17	0.70	0.64
February ...	100	30	34 (75)	16 (53)	20 (50)	16	19	0.89	0.83
March ...	070	10	26 (85)	15 (59)	20 (54)	15	18	0.83	0.71
April ...	080	20	20 (78)	13 (59)	17 (58)	12	15	0.78	0.65
May ...	070	27.5	19 (78)	16 (59)	17 (54)	15	15	0.64	0.62
June ...	075	36	24 (75)	17 (53)	24 (54)	16	21	0.77	0.51
July ...	080	41	23 (76)	17 (59)	21 (56)	16	19	0.74	0.60
August ...	075	51	22 (64)	23 (49)	23 (43)	20	20	0.46	0.44
September	080	42	28 (65)	20 (45)	24 (39)	19	22	0.74	0.63
October ...	080	37	19 (77)	15 (52)	19 (52)	14	16	0.68	0.53
November	090	40	22 (97)	16 (75)	21 (74)	15	18	0.73	0.54
December	100	30	24 (70)	16 (53)	19 (46)	15	18	0.78	0.68
	<b>Winds at 40,000 ft. over Singapore</b>								
January ...	110	21	13 (65)	12 (47)	16 (45)	11	13	0.59	0.28
February ...	115	26	17 (78)	14 (55)	15 (54)	12	13	0.68	0.62
March ...	110	16.5	16 (85)	12 (59)	18 (54)	11	15	0.74	0.37
April ...	100	16	14 (79)	11 (60)	12 (58)	10	11	0.72	0.61
May ...	080	20.5	16 (81)	12 (60)	17 (56)	11	14	0.71	0.46
June ...	070	34	16 (81)	14 (55)	17 (56)	12	14	0.60	0.39
July ...	075	38	16 (84)	15 (62)	17 (60)	13	14	0.59	0.48
August ...	075	41	17 (77)	15 (56)	19 (51)	13	16	0.62	0.38
September	070	38	18 (71)	16 (52)	18 (49)	14	16	0.60	0.49
October ...	080	24	15 (81)	13 (57)	15 (57)	12	13	0.61	0.47
November	095	25	14 (96)	13 (75)	15 (72)	11	13	0.61	0.49
December	110	21	14 (78)	14 (55)	15 (50)	12	13	0.56	0.48
	<b>Winds at 200 mb. over Larkhill</b>								
March-May	290	21	35	29	34	26	30	0.66	0.53

From Durst's Fig. 4 the ratio  $\sigma_t/\sigma$  for  $t = 3$  hr. can be found to be approximately 0.36, so that with an annual standard vector deviation at 200 mb. equal to 42 kt., 15 kt. is obtained as the estimated standard vector variation of winds at 40,000 ft. in 3 hr. over Larkhill. Thus for Singapore, quoting the vector mean 40,000-ft. wind for the month as a forecast will achieve about the same accuracy as will taking an observation of the 200-mb. wind 3 hr. old as representative of current conditions over Larkhill. Furthermore, for Singapore we can do appreciably better than using the vector mean as a forecast by adopting instead the appropriate regression equation, in which case the standard vector errors of 12-hr. and 24-hr. wind forecasts are reduced to approximately 10–15 kt. at 40,000 ft. and 15–20 kt. at 50,000 ft.

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2. DURST, C. S.; Variation of wind with time and distance. *Geophys. Mem., London*, **12**, No. 93, 1954.
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### WEATHER OF 1955

By R. E. BOOTH

The year on the whole was dry and sunny, cold during the first half and warm and mild during the second. It was notable for the cold winter when particularly heavy snowfalls and low temperatures were experienced in Scotland, the brilliant warm summer when many stations in the north-west exceeded long-standing sunshine records for July, the lateness of the seasons, and the long periods of drought which reached serious proportions in some parts of the country.

Temperature was below the average in each of the first six months of the year apart from April, and particularly low during February in Scotland and Northern Ireland. From July to December each month except October was warmer than average, especially August in the Midlands and the west of England. During the first six months rainfall was above the average in England and Wales except during March and April, but in Scotland, however, below the average every month except May. During the latter half of the year rainfall was below the average except during September, October and December in Scotland. Throughout the year the dry weather was particularly outstanding in Scotland and north-east England. Sunshine was above the average except during January, June, November and December in England and Wales.

**Development of the synoptic situation.**—From January 1 to March 22, anticyclones either over the Continent or in the region of Greenland maintained cold wintry weather over the British Isles, with an inflow of a cold easterly air stream from the Continent alternating with an arctic or polar air stream from the north, except for a period of milder south-westerly winds from January 19 to February 8. A mild south-westerly air stream with rain at times predominated during the first and last weeks of April and at the beginning of May, but during April 10–24 an anticyclone was almost stationary over the British Isles, and weather was dry and sunny with a drought over the major part of the country. An influx of arctic air from near Greenland brought unusually cold weather during May 10–21; snow extended as far south as

Bournemouth on the 17th. Active depressions off the south-west seaboard gave generally unsettled but rather cold weather during June and the first few days of July. On July 6 a ridge from the Azores anticyclone developed north-eastwards over the British Isles, and, except for an unsettled period August 14-19, the whole of the remainder of July and most of August was brilliantly fine and warm with pressure high from the region of the Azores across the British Isles to Scandinavia. A persistent low-pressure system near Iceland maintained mild and unsettled weather during the first half of September, but there were finer periods during the latter part of the month. The first major depression of the autumn crossed southern Scotland on October 5 accompanied by widespread and sometimes heavy rain and gales. The second week of October was unusually mild, but an arctic air stream on the 15th brought snow showers to Scotland and isolated sleet showers as far south as the Midlands. A large low-pressure system near western Ireland gave mainly unsettled weather during the period November 2-11, but during the remainder of the month the weather was anticyclonic and mostly dry and cooler. A generally mild westerly air stream which persisted during the greater part of December was interrupted by the break through of arctic air which spread over the country on the 11th and 17th; on the 20th snow fell continuously for more than 16 hr. in east Yorkshire and lay up to 14 in. deep.

Figs. 1-6 are maps of mean monthly barometric pressure prepared by the Overseas Climatological Branch for three winter and three summer months of 1955. It will be seen that the mean isopleths for January show the predominance of south-easterly winds over the British Isles during that month; in February mainly north-easterly winds were experienced, whereas in March winds were probably more northerly. During the summer months the July and August maps show a ridge from the Azores anticyclone firmly established across the British Isles, but in September the ridges had receded southward to the Bay of Biscay and in general there was a south-westerly air stream across the country.

Apart from transitory ridges only one well established anticyclone remained over the British Isles during the first half of the year, that which persisted from April 10 to 24, but during the second half of the year there was a period of anticyclonic weather every month.

Eleven major periods with arctic or polar air may be identified throughout the year; dates of commencement of the cold influx were: January 11, February 9, March 28, May 10, June 7, September 13, October 15 and 26, November 20, December 11 and 17; the most severe was that during May. Arctic or polar air spread over the country every month except the predominantly anticyclonic months of April, July and August.

Absolute droughts occurred during the months of April, July, August, and November.

**Lateness of the seasons.**—Wintry weather did not begin in the British Isles until January 1, and continued with some intervening milder periods until the end of March. The backwardness of the season was maintained during April, for although there were many sunny days there were no spells of warm weather. Spring was unusually cool, and summer weather really began on July 6 when a brilliantly sunny day marked the beginning of a period of unusually warm, dry and sunny weather which lasted until about the end of

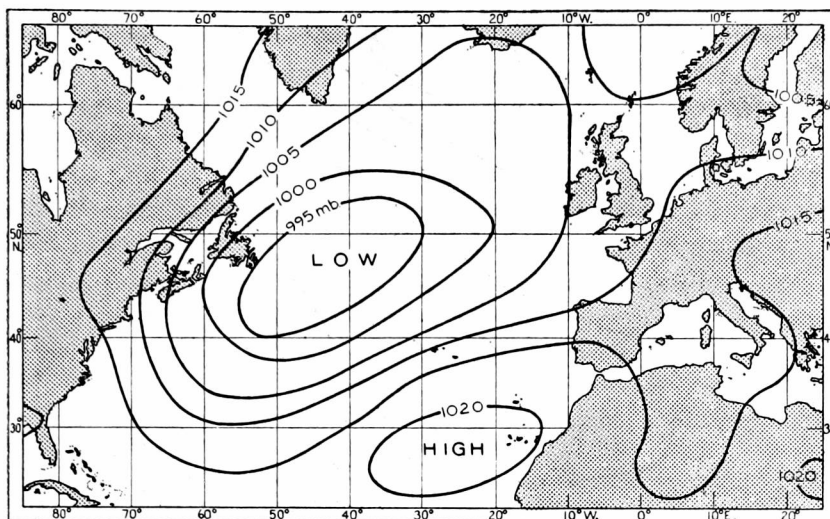


FIG. 1—MEAN BAROMETRIC PRESSURE AT SEA LEVEL, JANUARY 1955

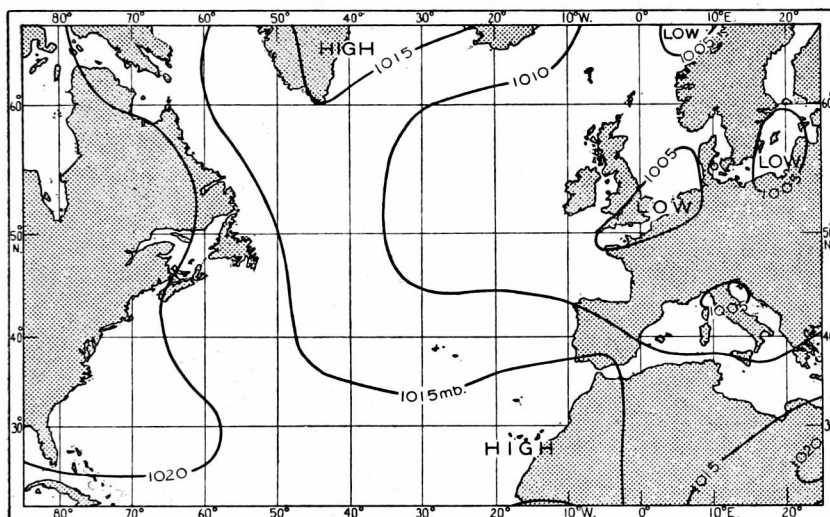


FIG. 2—MEAN BAROMETRIC PRESSURE AT SEA LEVEL, FEBRUARY 1955

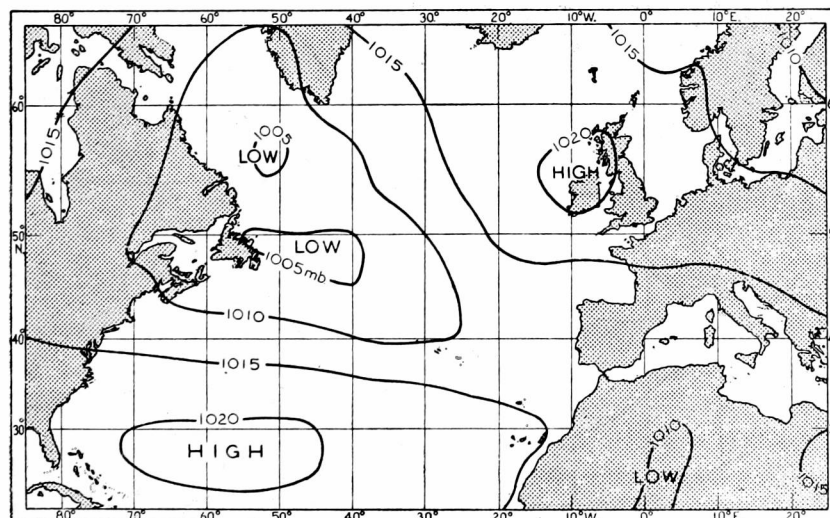


FIG. 3—MEAN BAROMETRIC PRESSURE AT SEA LEVEL, MARCH 1955



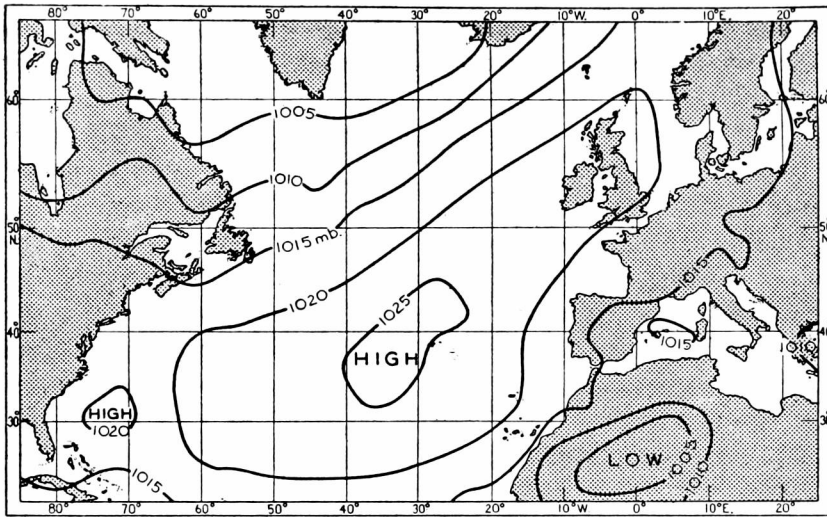


FIG. 4—MEAN BAROMETRIC PRESSURE AT SEA LEVEL, JULY 1955

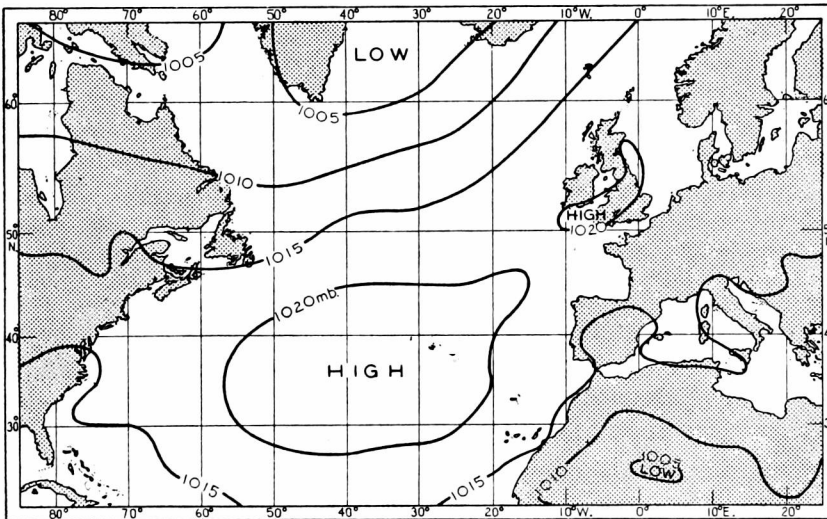


FIG. 5—MEAN BAROMETRIC PRESSURE AT SEA LEVEL, AUGUST 1955

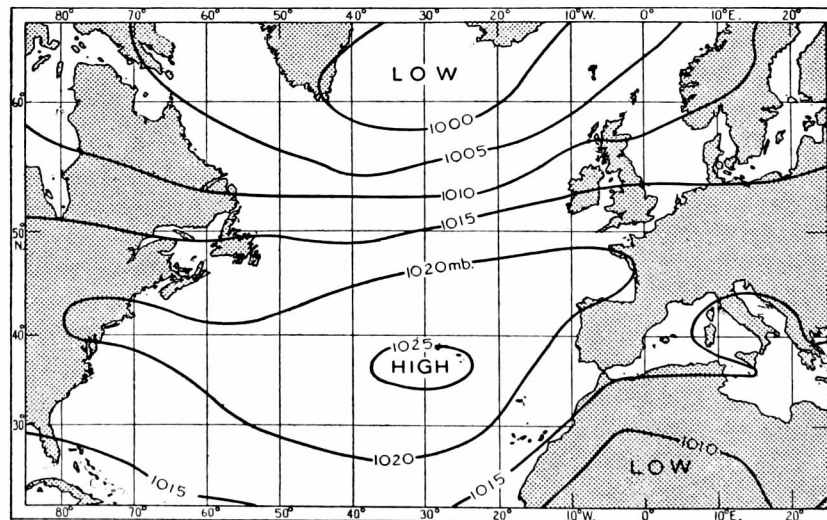


FIG. 6—MEAN BAROMETRIC PRESSURE AT SEA LEVEL, SEPTEMBER 1955

September. Late summer merged into autumn during October, the first month with temperature below the average since June, and apart from some wintry showers, mainly on high ground in the north but which extended as far south as the Chilterns and Exmoor on December 11, there was no real wintry weather until about December 20 in the north and none in the south-east.

**Highlights of the year.**—*Winter.*—During January and February snow lay to a depth of 18–24 in. over large areas of north and east Scotland, with drifts caused by high winds up to as much as 30 ft. deep. Many farms and villages were completely isolated for weeks and had to be supplied by air. This operation caused considerable interest in the press and elsewhere as it was the first time that organized relief had been carried out on such a large scale in the British Isles. Exceptionally low temperature was recorded in Scotland. During February temperature ranged from  $-13^{\circ}\text{F.}$  at Braemar on the 23rd to  $55^{\circ}\text{F.}$  at Lephinmore on the 1st; the minimum temperature was the lowest screen temperature recorded in the British Isles since 1895, and the range of  $68^{\circ}\text{F.}$  for the month has only been exceeded twice—in February 1897 and January 1871—during 100 yr. of Scottish records. There were some remarkably cold periods; at many places temperature was continuously below freezing during January 11–18 and fell below  $0^{\circ}\text{F.}$  during February 22–24; on these last three days temperature at Dyce fell to  $-7^{\circ}\text{F.}$ ,  $-5^{\circ}\text{F.}$  and  $-5^{\circ}\text{F.}$  respectively. Mean temperature was particularly low over a large part of north Scotland; for example, it was  $14^{\circ}\text{F.}$  lower than normal during the week beginning February 20. Among the places which had unusually cold days was Dalwhinnie where temperature did not rise above  $15^{\circ}\text{F.}$  on January 14 or above  $18^{\circ}\text{F.}$  on either February 20 or 22. Temperature in England and Wales was not so low, but there was an extremely cold period during January 15–20 when temperature frequently fell to  $15^{\circ}\text{F.}$ , and during the last week of February the mean temperature in the Midlands was  $11^{\circ}\text{F.}$  lower than the average. Very cold weather continued into March; Birmingham had its coldest March since 1916, and only in 1917 has March been colder at Kew since 1892.

The first week of January was exceptionally dull in eastern England, where most districts had 5 per cent. or less of their normal amount of sunshine. In contrast north and west Scotland had more than double the seasonal average of sunshine during February; Stornoway's total of 96 hr. was the best in February since 1881, whilst at several other stations it was the sunniest February for 40 yr.

A severe gale south-west of England on March 23 drove the Norwegian ship *Venus* (6,272 tons) on the rocks in Plymouth Sound and other shipping suffered considerable damage. At some places mean hourly wind exceeded 33 kt. for more than 12 consecutive hours; a gust of 73 kt. was recorded at Lizard and 82 kt. at Scilly.

*Spring.*—The most remarkable feature of the spring was the snow which spread from Scotland to the south coast of England on May 17; parts of Wiltshire and Dorset had the worst mid-May snowstorm in living memory with snow lying to a depth of 3 in. over a wide area. Unusually low maximum temperatures of  $40^{\circ}\text{F.}$  or below were recorded at several stations including Ross-on-Wye where  $40^{\circ}\text{F.}$  was the lowest maximum temperature recorded during May at that station since 1875, whilst at Aberystwyth the temperature only reached  $36^{\circ}\text{F.}$

Rainfall during May was also exceptional; many places had twice their monthly average and Hastings its wettest May since records began there in 1875.

Sunshine was above the average during April and May—Edinburgh had its sunniest May since 1901—but June, generally accounted one of the summer months, was remarkably dull and cold. Unusually low temperatures were experienced on the 9th when 24°F. and 22°F. were recorded in the screen at Glenlivet and Dalwhinnie respectively, the latter being the lowest temperature recorded anywhere in the British Isles in June for 100 yr.

*Summer.*—The summer, although it began late, was notably sunny, warm and dry. Temperature in England and Wales rose to 90°F. during both July and August; this was the first time for 22 yr., apart from 1947, that temperature had risen so high in both these months. In the south of England temperature rose daily to between 85° and 90°F. from August 20 to 25. In Scotland the mean August temperature, except for 1947, was the highest for any August since 1857; Elgin recorded 89°F. on the 25th and no higher temperature has been recorded in Scotland during August since 1876.

For Great Britain as a whole the two months taken together rank as the driest July and August since 1869, and also as the warmest and sunniest since 1911. There was a drought in many places from July 4 to August 8. Several places were completely rainless during the drought period including Camborne in Cornwall where there was no rain whatever from July 1 to August 2 and a total of only 0·36 in. for the two months. A second drought developed at many places from Sussex to Cornwall during the last three weeks of August; July to September was the driest of any similar period of three months for 85 yr. in England and Wales and also the driest, except for 1913, in Scotland over the same period.

There were several noteworthy thunderstorms, the one over Dorset on July 18 being the most outstanding; 11 in. of rain fell at Martinstown near Dorchester in 24 hr. This was by far the greatest fall ever recorded in the British Isles during the rainfall day; the second greatest occurred at Bruton, Somerset, during a storm in June 1917, when about 9·6 in. of rain were collected. A "very rare" fall was recorded, also on July 18, at Neath, Glamorgan-shire, when 3·32 in. of rain fell in 120 min. During heavy thunderstorms on August 13, 3·44 in. fell in 80 min. at Annaghanoon, County Down, and 3·50 in. in 120 min. at Sittingbourne, Kent.

Sunshine during the summer was outstanding, especially in the north-west, July being the sunniest month when many long-standing records were broken. During the second and last week of July sunshine was more than twice the average over Wales, north-west England, western Scotland and northern Ireland; it was 377 per cent. of the average in south-east England for the week commencing July 17. At Southport, July 1955 was the sunniest of any month since observations began in 1896, and many other stations had never recorded so much sunshine in July though in some cases observations covered a period of over 70 yr.

*Autumn.*—The relatively dry weather continued throughout the autumn in England and Wales, an unusual feature being the number of stations, chiefly in the southern half of England and in Wales, recording an absolute drought in November, a month which usually has few droughts<sup>1</sup>. It lasted in many places from the 11th or 12th to the 29th or 30th, and following such a dry summer

forced some authorities in north-east England to introduce water rationing. The autumn drought contrasts sharply with the heavy rainfall experienced in south-east England during the third week of October, which was over four times the weekly average. A four-day period of fog occurred in the Midlands during November; fog persisted day and night at Manchester from the 17th to the 20th inclusive.

1955 will undoubtedly be remembered in north Scotland for the severe winter and unusually heavy snow; in north-east England as well as in Scotland for its unusual dryness; in the north-west of the country for the exceptionally sunny July; and in Dorset for the phenomenally heavy thunderstorms on July 18.

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## AIR TEMPERATURES DURING SNOWFALL AT OCEAN WEATHER STATION I

By R. F. M. HAY, M.A.

The tragic loss of the two British trawlers *Lorella* and *Roderigo* during a storm off Iceland on January 26, 1955, is still a comparatively recent memory. At that time the two ships were on a fishing voyage a short distance north of North Cape, Iceland, when they encountered severe north-easterly gales, accompanied by low air temperatures, which lasted for several days. Spray from the heavy seas breaking over the vessels caused an accumulation of ice on their superstructures in such large quantities that both ships eventually capsized with the loss of all hands. A Public Inquiry into the losses of these trawlers was held recently, and, as a part of the meteorological evidence which was prepared, data were extracted in more detail than previously available regarding air temperatures at which snow and other forms of wintry precipitation fall over the open ocean. Data for ocean station I, the position of which for the purposes of this note can be regarded with sufficient accuracy as 59°00'N. 19°00'W. throughout the period considered, were used, and since the results have a general interest they are included in this note. When the work was undertaken, data for this ocean weather station were available on punch cards for the period between January 28, 1948 and May 26, 1954. The elements tabulated were the times of observation (in all cases synoptic hours), together with air and sea temperature, wind direction and force, and present weather.

On the punched cards three columns are allocated for describing present weather, in accordance with the code

1 = Snow	6 = Thunder
2 = Squalls	7 = Hail
3 = Rain	8 = Lightning
4 = Passing showers	9 = None of the above reported
5 = Drizzle	No observations = 000

The code thus makes it possible to distinguish between cases of snow, sleet, snow squalls and also of snow (or sleet) associated with hail.

In order to compare the results with those of a land station, comparable data were extracted for Shawbury (52°48'N., 2°41'W., height 249 ft. above M.S.L.) which, besides being a station for which such data were available, was also

considered to have a suitable land exposure. All occasions of snowfall at synoptic hours (0000, 0300, 0600, 0900, 1200, 1500, 1800 and 2100, G.M.T.) during the period November 1946–May 1955, i.e. nine seasons, were examined and the corresponding air temperatures tabulated. The results are given in Table I which gives the number of observations, the mean air temperature, and the upper and lower 10-percentile values of temperature in which snow, sleet and hail occurred at Shawbury. The same data are included for station I with the addition of mean values of sea temperature observed during the same periods. Some idea is given in Table II of the diurnal variation of the frequency of snowfall at Shawbury and station I.

TABLE I—COMPARISON OF TEMPERATURES AT WHICH SNOW, SLEET AND HAIL FELL AT SHAWBURY AND STATION I

	Shawbury				Station I					
	Air temperature			No. of observ- ations	Air temperature			Sea temper- ature Mean	No. of observ- ations	
	Mean	Upper 10 per- centile	Lower 10 per- centile		Mean	Upper 10 per- centile	Lower 10 per- centile			
	<i>degrees Fahrenheit</i>					<i>degrees Fahrenheit</i>				
Snow ...	31.1	33.8	27.1	272	36.0	40.0	32.5	47.2	124	
Sleet ...	35.1	37.1	33.3	94	39.3	44.5	36.0	47.7	31	
Snow squalls...	...	...	...	...	37.2	44.5	32.0	47.5	34	
Snow (or sleet) and hail ...	31.0	34.3	27.9	27	37.1	41.5	32.5	47.3	21	

TABLE II—DIURNAL VARIATION OF SNOW, SLEET, AND SNOW OR SLEET AND HAIL

	0000	0300	0600	0900	1200	1500	1800	2100
	<i>number of observations</i>							
	Shawbury							
Snow ... ..	29	33	33	46	39	36	31	25
Sleet ... ..	18	11	16	7	10	4	10	18
Snow (or sleet) and hail ... ..	1	3	1	5	6	3	4	4
All types of snowfall ... ..	48	47	50	58	55	43	45	47
	Station I							
All types of snowfall ... ..	33	21	14	23	31	32	26	30

The mean values of the air temperatures at which snow and sleet occur at the ocean weather station I (36.0° and 39.3°F.) are thus substantially higher than the corresponding values for Shawbury (31.1° and 35.1°F.). The main reason is undoubtedly the relative warmth of the sea on the occasions of snowfall at station I, which results in a steep lapse rate being formed in the lowest layers. Over the land in winter on the other hand it is not uncommon for snow to fall from an approaching front through an isothermal layer or even an inversion. A fairer comparison can be made between snowfalls at station I and at Shawbury in spring when cold air is often travelling over a heated land surface, although the physical circumstances are not entirely similar since a supply of cold air quickly cools a land surface although it makes little difference to the sea-surface temperature. The fact that the differences of air temperature (station I minus Shawbury) between the various months, given at the end of Table III, do indicate some decrease from winter to spring, suggests that this explanation is correct.

The Shawbury data referred to a period which is just over two years longer than the period used for station I and included the cold winters of 1946–47

and 1954-55. As a check the corresponding mean air-temperature data were extracted for Shawbury for the period November 1947 to May 1954. For this period the mean temperatures at which snow and sleet fell were 32.2° and 35.3°F. respectively, 1.1° and 0.2°F. higher than those found for the longer period used in the tables. The values in individual months for the shorter period showed very close agreement, except for snow in January when the value was 1.2° higher and in February when the value was 1.1°F. lower than the longer-period values. The conclusion that the temperatures at which snow (and also sleet) fall are substantially lower at Shawbury than at station I thus appears to be justified.

TABLE III—SURFACE TEMPERATURE ON OCCASIONS OF SNOW OR SLEET

Shawbury					Sleet				
	Snow			No. of occasions	Temperature			No. of occasions	
	Mean	Upper	Lower		Upper	Lower			
		10 per-centile	10 per-centile			10 per-centile	10 per-centile		
<i>degrees Fahrenheit</i>									
November ...	33.0	(33.7)	(32.2)	14	34.9	...	...	9	
December ...	32.2	33.9	30.2	32	35.1	(38.8)	(33.2)	19	
January ...	30.3	33.7	27.1	58	35.6	(38.4)	(33.4)	18	
February ...	32.2	33.8	26.1	111	35.1	37.1	33.6	20	
March ...	32.4	34.8	29.4	51	34.6	36.9	32.5	26	
April ...	34.9	...	...	6	...	...	...	0	
May... ..	...	...	...	0	40.5	...	...	2	

Station I						
	Snow		Sleet		Mean temperature differences	
	Mean temperature	No. of occasions	Mean temperature	No. of occasions	Station I minus Shawbury	Sleet
<i>°F.</i>						
October ...	42.0	2	(39.0)	1	...	...
November ...	(35.0)	1	...	0	(2.0)	...
December ...	35.6	15	37.8	6	3.4	2.7
January ...	34.8	24	42.4	5	4.5	6.8
February ...	35.4	35	37.7	6	3.2	2.6
March ...	36.8	19	38.1	8	4.4	3.5
April ...	36.7	23	(37.0)	1	1.8	...
May ...	37.8	5	42.4	4	...	1.9

The figures in brackets are estimates where there are insufficient observations to give a true percentile or a mean.

The higher humidity of the air in the lowest layers over the sea, as compared with the lowest layers of air over the land, can hardly be a reason for the occurrence of snowfall with higher temperatures over the sea than over the land; since the condensation which would occur on snowflakes falling through a very moist atmosphere would melt them more quickly than would otherwise be the case.

The figures for diurnal variation of frequency of snowfall show mainly the kind of variation which would be expected. Over land where the diurnal range of temperature is appreciable even in winter, snow or sleet is most frequent around 0900 G.M.T. At station I there is a maximum around

1500 G.M.T., presumably associated with the diurnal increase in the amount of cold-front rain in the afternoon first described by Goldie<sup>1</sup>. There is another equally pronounced maximum around midnight, which is possibly due to the passage of warm occlusions on occasions when the surface air temperature is lower than about 42°F. This would accord with the observation, also due to Goldie<sup>1</sup>, that the maximum frequency of rainfall of warm-front type occurs during the night hours at stations along the north-west seaboard of Great Britain. It is also a result to be expected from the development of instability in the layers below medium cloud level at night, due to cooling by radiation<sup>2</sup>.

The fact that snow and sleet occur at station I which is several hundreds of miles from the nearest land, at temperatures some 4–5°F. above those at which snow occurs most frequently at a typical land station in the British Isles is of some significance for the forecasting of visibility over the open sea at low temperatures. At temperatures below 40°F. (see Table I) precipitation at sea must occur more frequently in the form of snow than it does over land (other things being equal), and snow or sleet is more effective in reducing visibility than drizzle or rain. The frequent spells of poor visibility in sub-arctic and sub-antarctic waters associated with old occlusions on the poleward sides of stagnating depressions, must be prolonged to some extent from this cause in comparison with similar spells over land.

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## OPACITY OF THE ATMOSPHERE AFTER JULY 1953

By S. FRITZ

(United States Weather Bureau)

On the basis of measurements during total eclipses of the moon and visual evidence by other investigators, de Vaucouleurs<sup>1</sup> suggested that extensive pollution existed in widespread regions of the earth's atmosphere on July 26, 1953. He suggested that this might have been introduced into the atmosphere by the eruption of an Alaskan volcano on July 9, 1953. In order to investigate further the spread of the volcanic dust, de Vaucouleurs also suggested that a check be made of the pyrliometric data in widely separated areas.

Such a check of the pyrliometric data for stations in the United States has been made with the results shown in Fig. 1. The basic data are measurements of the direct solar beam. These measurements are made with Eppley normal-incidence pyrliometers at Lincoln, Nebraska, and Blue Hill in Milton, Massachusetts. The more precise Smithsonian silver-disk and modified Ångström normal-incidence pyrliometers are used at Table Mountain, California, and a silver-disk pyrliometer is used frequently to check the Eppley instrument at Blue Hill. The data shown in Fig. 1 are the percentage departures  $D$  of the average monthly radiation from the monthly normal; the "normal" was based on the 19-yr. period 1934–52, since the Blue Hill record began in 1934. The small numerals on each curve show the number of observations made during each month. The data for Blue Hill and Lincoln were taken from *Climatological Data*<sup>2</sup>, published by the Weather Bureau; for Table Mountain, the data were kindly supplied by Mr. L. B. Aldrich, Director of the Astrophysical Observatory of the Smithsonian Institution.

The instructions to the observers at the Weather Bureau stations, Lincoln and Blue Hill, are that observations should be taken at specified solar zenith distances  $Z$  only when there are no clouds obscuring the sun. This is sometimes a somewhat subjective matter and undoubtedly introduces some fluctuation into the data. At Blue Hill, a new observer reported for duty near the end of 1951, and has taken observations there since the beginning of 1952. He has chosen only the "clearest" skies, so that for  $Z = 70.7^\circ$  the "normal" appropriate to his observations is apparently about 11 per cent. higher than the normal for the period 1934-52.

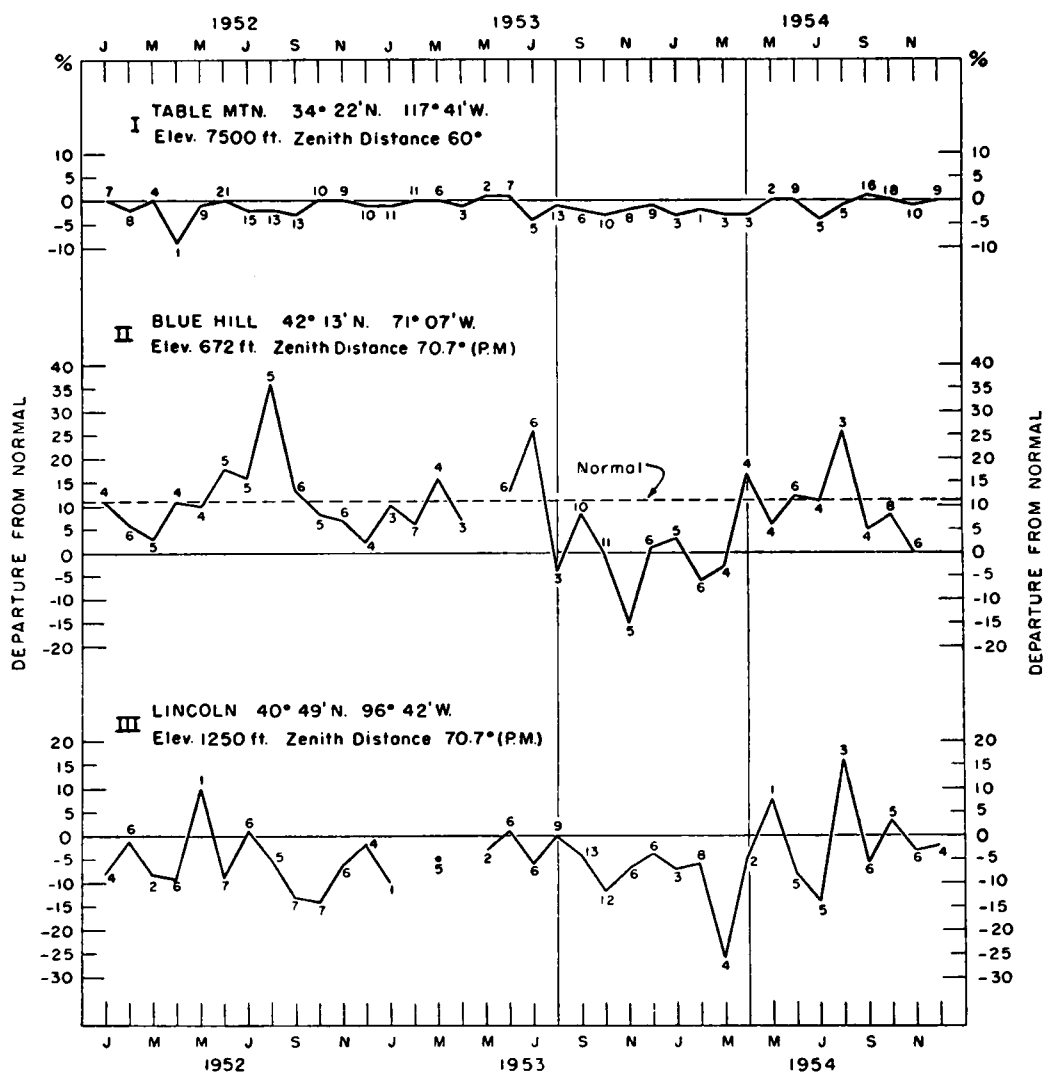


FIG. 1.—SOLAR RADIATION INTENSITY

In September 1953, all three stations showed  $D$  below normal and this situation prevailed until March 1954. My colleague, Mr. Enger, has found the measurements from each station for the period 1934-52 to be uncorrelated with those from either of the other two stations; moreover, he has found that during the six-month period, October 1953-March 1954, the average value of  $D$  was lower than the average  $D$  for any consecutive six-month period before August



1953 at each of the stations\*. For this to have occurred simultaneously at all three stations is a rare event indeed.

The cause of the decreased radiation is speculative, although the eruption of the volcano on July 9 in Alaska is suggestive. Moreover, the lunar-eclipse measurements suggested some effect in July over large parts of the earth; but from the data of Fig. 1, because of the large fluctuations, we cannot conclude that the atmosphere was unusually opaque in the United States during July 1953. It apparently was unusually opaque during the following October to March.

Study of pyrheliometric data is continuing here, and a more detailed report may be published later.

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## METEOROLOGICAL OFFICE DISCUSSION

### Meteorological aspects of solar radiation

The discussion, which was held at the Royal Society of Arts on Monday, January 16, 1956, was opened by Mr. G. J. Day.

Mr. Day suggested that the importance of the study of the interaction of solar radiation with the earth's atmosphere was evident from two widely divergent aspects—dependence of the atmospheric circulation on radiation and the influence of the local radiation climate on the pattern of everyday life. He mentioned that radiation data were important in civil, aeronautical and agricultural engineering.

The sun emits electro-magnetic waves of wave-lengths between about  $10^{-4}\mu$  and  $10^{10}\mu$  (10 Km.) of which meteorology has been concerned with the band between  $0.2\mu$  and  $50\mu$ .

The intensity of the solar beam at normal incidence on the outer limit of the atmosphere is about  $2.0 \text{ cal./cm.}^2/\text{min.}$  Of this about 40 per cent. is returned to space without change of wave-length, and the remainder is absorbed by the earth and atmosphere and eventually re-radiated to space with a changed spectral distribution.

The spectral distribution of solar radiation corresponds roughly to that from a black body at  $6,000-7,000^\circ\text{K.}$  for wave-lengths between  $0.45$  and  $25\mu$  and at  $4,000-5,000^\circ\text{K.}$  for wave-lengths between  $0.2$  and  $0.45\mu$ . For wave-lengths less than  $0.2\mu$  radiation from the solar corona is important, and lines corresponding to coronal temperatures of about  $10^6^\circ\text{K.}$  occur in the spectrum. The fairly sharp change in spectral character at about  $0.2\mu$  has recently been confirmed during a rocket ascent to 112 Km.

The flux of radiation in free space (the solar constant) has been estimated to be about  $1.94 \text{ cal./cm.}^2/\text{min.}$  by the Smithsonian Institution workers. As a result of rocket ascents over America and accurate ground-level spectro-bolometer studies of atmospheric attenuation, Johnson<sup>1</sup> has recently disputed this value and has suggested an amended one of  $2.00 \pm 0.04 \text{ cal./cm.}^2/\text{min.}$

The return of the unmodified radiation to space is achieved by scattering processes in the atmosphere and at the earth's surface. Atmospheric gas molecules give rise to Rayleigh scattering, but even in the cleanest atmosphere there is additional scattering which Fowle<sup>2</sup> correlated with water-vapour content. It has been shown, however, that the additional attenuation is probably particulate in origin, and Ångström suggested that it is due to scattering and absorption by natural and artificial nuclei; scattering by larger particles and by undetected cloud also contribute. Data gathered at Kew<sup>3</sup> suggest a total attenuation of about 10 per cent. of the incident radiation from these causes. It is not thought that scattering by volcanic dust and the smoke from forest fires can have any noticeable effect on surface temperatures over considerable areas, since although the direct radiation may be attenuated the diffuse radiation is enhanced and the total not greatly reduced.

Theoretical work by Hewson<sup>4</sup> shows the considerable effect of cloud on the local flux of radiation. This work is considered to be based on faulty assumptions, but yields a reasonably good result for the solar altitudes experienced in temperate and high latitudes. Hewson's predictions of the amount of reflection by clouds is partly confirmed by Aldrich<sup>5</sup> who obtained albedos of about 0.8 for stratocumulus clouds; these appeared to be independent of cloud thickness. Observations from Meteorological Research Flight aircraft, however, show considerable variation between 0.28 and 0.84 with no consistent variation with cloud thickness. Similar measure-

\*The average for the period April 1952–September 1952 was lower at Table Mountain, but this was influenced significantly by April 1952 which had only one observation. Also, in 1929, a six-month period with a lower average value occurred at Table Mountain.

ments in America by both Fritz<sup>6</sup> and Neiburger<sup>7</sup> support the Meteorological Research Flight result.

Reflection of solar radiation by the earth's surface is very variable. Land surfaces have albedos between 0.1 and 0.3 rising to 0.8 for new snow and about 0.5 for old. The albedos of sea surfaces are a function of the state of the surface and the solar altitude, and range from 0.03 for zenith sun over smooth sea to about 0.4 for low-altitude sun. The roughness of the surface produces a significant change only for low-altitude sun. Measurements from Meteorological Research Flight aircraft over the English Channel have given albedos between 0.06 and 0.07.

The total albedo of the earth is the sum of the separate contributions, and has been determined to be 0.39 for the visible spectrum by measurements of the intensity of the earthlight and sunlight reflected from the moon. By combining this figure with estimates of the other components, Fritz arrived at an average value of 0.05 for cloud. This value may be compared with that of 0.43 for the mean atmosphere in summer and 0.49 in winter obtained by Blackwell, Eldridge and Robinson<sup>8</sup> from the Kew radiation data. A completely overcast atmosphere at Kew had an average albedo of 0.56.

Mr. Day then considered the 60 per cent. of the incident radiation which is modified in spectral distribution by the earth and its atmosphere. Of this about 2 per cent. is absorbed in the stratosphere above 20 Km., 15 per cent. in the troposphere and the remainder by the earth's surface.

The low density of the high atmosphere results in large temperature changes consequent on small changes in radiative flux. This fact has led to recent suggestions that there is a connexion between radiation effects on the high atmosphere and surface synoptic features; Palmer<sup>8</sup> has suggested that there is a close association between tropical high-level cyclones and sudden ionospheric disturbances. Similar suggestions by Farthing<sup>9</sup> linked enhanced short-wave activity during sun-spot activity with increased precipitation and the passage of cold fronts, though his investigation was confined to the central Mid-West of the United States. It was suggested by Mr. Day that, although the physical mechanisms were obscure and the simplicity of the associations remarkable, it was nevertheless desirable that such suggestions be investigated thoroughly in view of the paucity of medium-range and long-range forecasting techniques.

Mr. Day now turned to the question of the absorption by atmospheric gases. It was noted that solar radiation was of negligible energy for wave-lengths greater than  $4\ \mu$  and that terrestrial radiation was of negligible energy for those less than  $4\ \mu$ ; it was thus possible to treat the streams of solar and terrestrial radiation quite separately with respect to absorption.

In the stratosphere absorption of the solar beam is controlled by the Hartley band of ozone whilst in the troposphere the main infra-red bands of water vapour are of the greatest importance. For terrestrial radiation water vapour is of the greatest importance in the troposphere, though the carbon-dioxide band at  $15\ \mu$  has some effect, but in the stratosphere water vapour, carbon dioxide and ozone are likely to be of comparable importance.

A knowledge of the interaction of the streams of solar and terrestrial radiation with the atmosphere and the earth, may be applied to the qualitative explanation of the temperature structure of the troposphere and stratosphere. The main regions of absorption of solar radiation are those due to oxygen above about 90 Km., to ozone in the layer 30–50 Km. and to the surface of the earth. At these points the atmosphere is heated leading to three main regions of relatively high temperature with minima between. Above the heated regions an approach to convective equilibrium may be expected and consequently the appropriate adiabatic lapse rate. The temperatures at the minima are probably controlled mainly by radiation processes.

About half the solar radiation reaching the earth is absorbed by the surface layers and produces local temperature changes. An equilibrium is established in which solar energy input is balanced by terrestrial radiation and various other losses. The equilibrium is much affected by the presence of cloud. Over the oceans the energy input is distributed by mixing processes through a considerable depth so that surface temperatures change little. About 30 per cent. of the incident radiation is used in evaporating water thereby producing the moisture for weather phenomena.

The amount of radiation falling on unit area of a horizontal surface at the outer limit of the earth's atmosphere varies with latitude and season. Additionally the amount of radiation reaching the earth's surface is affected by cloud amount and the distribution of atmospheric gases, particularly water vapour. It is found that incoming solar energy exceeds the outgoing terrestrial radiant energy only between the equator and a latitude of about  $30^\circ$ , there being an overall loss of energy from the earth-atmosphere system north of this latitude. Thus there is a transport of heat from the equator to the poles to maintain the long-term mean temperature distribution. This transport is achieved by the atmospheric circulation. Several workers have computed the mean poleward energy transport, the various estimates being given in Table I.

TABLE I—POLEWARD MEAN ENERGY TRANSPORT ACROSS LATITUDE  $40^\circ$ .

	$10^{27}$ erg/day		$10^{27}$ erg/day
Simpson, 1928 ...	3.4	Raethjen, 1950 ...	4.9
Simpson, 1929 ...	4.8	London, 1952 ...	2.4
Baur and Phillips, 1934	3.8	Houghton, 1954 ...	4.7

Robinson<sup>10</sup> has recently determined the energy budget of the atmosphere at Kew for one year and for summer and winter periods. He used the observations reported by Blackwell, Eldridge and Robinson<sup>3</sup> and measurements of conduction through the ground and estimates of evaporation for Kew by Roach. Only during the period May–July was there a net input of radiant energy into the earth-atmosphere system at Kew.

The presence of clouds has a profound effect on the energy balance, and Hewson has computed that absorption of solar radiation by clouds varies from 1 per cent. for very thin clouds to 7 per cent. for dense ones. Fritz<sup>6</sup> has reported aircraft measurements of up to 20 per cent. however, and measurements from Meteorological Research Flight aircraft of the radiation flux within strato-cumulus sheets suggest absorptions of about 12 per cent.

For terrestrial radiation all water clouds thicker than about 50 m. behave as black bodies. Little is known of the behaviour of ice-crystal clouds, but recent work by Houghton<sup>11</sup> suggests that tenuous cirrus cloud absorbs little more than would be expected from its constituent water vapour; measurements made from an aircraft of the Meteorological Research Flight showed that the emissivity of the earth for long-wave radiation was about 90–95 per cent. and that of dense water clouds always about 100 per cent.

Turning to a consideration of the instruments used for the measurement of solar radiation, Mr. Day described the two commonly used sub-standard instruments—the Ångström and the Smithsonian silver-disk pyrheliometers—and stated that the Meteorological Office relates its measurements to the Ångström scale, which differs from the Smithsonian scale by about 3 per cent. Continuous recording of solar radiation at Kew is achieved with Moll-Gorczynski thermopiles; one is mounted to receive sun-plus-sky radiation on a horizontal surface; another receives sky radiation alone; and three further thermopiles record the intensity of the direct solar beam—these latter are maintained normal to the solar beam by clockwork mechanisms.

The intensity of illumination is measured at Kew by a recorder in which a photo-cell corrected by filters to standard eye response receives the radiation from an opalescent diffusing screen.

Finally the ventilated flux plate radiometer was described. This instrument is used to measure the net flux of radiation in any direction by measuring with thermocouples the temperature gradient produced through a thin blackened plate exposed normal to the flux of radiation. The variable effects of natural convection are overcome by maintaining a constant blast of air over the plate.

Mr. Day concluded by mentioning some typical applications of radiation data to everyday life. These fall conveniently into the categories of agriculture and engineering, and include such diverse matters as the part played by solar radiation in plant growth and the heat balance of aircraft structures at great altitudes. In illustration of the application of radiation data the question of weathering of materials, particularly in the tropics, was discussed in some detail.

*Dr. Stagg* opened the general discussion by welcoming the visitors from outside organizations and inviting their participation.

*Mr. Petheridge* (Building Research Establishment) illustrated the application of radiation data to architectural problems by referring to the design of a school at Caithness. Estimates were made at Kew of the “luminous efficiency of daylight” for Caithness from total solar radiation data at Eskdalemuir and Lerwick. From this estimate daylight illumination at Caithness under typical conditions was computed, and window sizes chosen which gave an acceptable compromise between the need for natural illumination and that for adequate thermal insulation. He stressed the need for illumination data for places other than Kew.

*Mr. Hoare* (National Institute for Agricultural Engineering) cited the heating and ventilation of glass-houses as a problem in which radiation data were important. He discussed in particular the varying need for moisture of a plant under varying radiation conditions, and remarked that the plant was an integrator of radiant energy. Mr. Hoare concluded by emphasising the importance of radiation data in the discussion of biological experiments.

*Mr. Ward* mentioned his interest in the dispersal of radiation fog, and asked whether there was a simple and cheap instrument available for the measurement of radiation at outstations. He asked whether measurements of solar radiation had been made at ground level in fog, and whether there was any difference in the albedo of snow between total and diffuse radiation. Mr. Day replied that the cheapest instrument now available was the ventilated flux plate radiometer. There was some hope that a modified Bellani distillometer with a horizontal sensitive surface might prove acceptable for some purposes, and he referred Mr. Ward to Mr. Hoare’s group for further information. Measurements of radiation in fog had been made at Kew incidentally in the course of routine continuous recording but the data had not been extracted. Data were available only for the albedo of snow for total radiation.

*Mr. Hoare* sought to place the importance of solar radiant energy in perspective by remarking that far more energy is used by plants in fixing carbon than is used in producing electrical energy. About 2 per cent. of the incident energy is used by the plant.

*Mr. Spurr* (Central Electricity Authority) remarked on the considerable difference in the demand for electricity between clear and cloudy days, and requested that attention be paid to the forecasting of daylight illumination.

Mr. Ward asked whether there was a direct relation between daylight intensity and diffuse radiation. Mr. Day, in reply, said that a factor termed the "luminous efficiency of daylight" was used to relate the intensity of daylight to total solar radiation, and that this was well known for Kew for representative conditions; the factor varied from place to place. There was presumably a relation between diffuse daylight and diffuse solar radiation. Recording of diffuse daylight was not at present undertaken within the Meteorological Office, and therefore no definite answer could be given.

Mr. Page (Building Research Establishment) mentioned the need for tropical radiation data, and called attention to the differences between the luminous efficiencies measured in the United Kingdom, South Africa and the West Indies, and concluded with a plea for the organization of a working group on radiation for the United Kingdom.

Mr. Veryard queried the opener's statement that smoke and dust at great altitude did not greatly affect total radiation and thus temperature at the surface.

Dr. Robinson, in reply to Mr. Veryard, stated that volcanic dust would only cause a significant change in total solar radiation at the surface if it lay so thickly that multiple scattering processes became important. He added that the effect of smoke and dust in the London winter atmosphere was to increase depletion by scattering and absorption by 10 per cent. on average. In this connexion he asked for an explanation of the increase in crop yield of tomatoes following the change of location of a field station from the Lea Valley to the south coast. It would hardly be due to the increase of total radiation.

Mr. Gloyne observed that the increase in the tomato crop was probably a threshold effect due to the small extra amount of radiation in the early spring.

Mr. Hoare supported this statement and emphasized the importance of exceeding a threshold amount of radiation in plant growth.

Mr. Gloyne asked what changes in spectral distribution of solar energy were caused by dust. Mr. Day replied that sufficiently detailed filter measurements were not made in the Meteorological Office to answer the question, but agreed that it was one of some importance.

Mr. Sawyer sought information on the more explicitly meteorological aspects and asked what variations in solar radiation might be expected over periods of five to ten days. Dr. Robinson replied that it might be possible to integrate the solar radiation received over large areas for various periods, and referred in illustration to Danjon's lunar measurements which gave appreciable daily variations in the albedo of a whole hemisphere of the earth.

Dr. Stagg pointed out that Danjon's work gave no indication of changes in the spectral distribution, and remarked that it was believed that the ultra-violet component might be important.

Cmdr. Frankcom remarked that it was hoped to obtain solar radiation measurements at sea during the International Geophysical Year, and asked whether any such work had been done previously. Mr. Day said that he had no knowledge of earlier work; whilst agreeing that such measurements were very desirable, he stressed the attendant instrumental difficulties.

Mr. Petheridge observed that some measurements had been made over the sea by the Marine Biological Research Station.

Dr. Stagg asked whether instruments embodying distillation principles had been produced. Mr. Day, in reply, described the Bellani type of instrument, and said that the new type with a flat receiving surface showed considerable promise as a radiation integrator for use in field work.

Mr. Sawyer returned to the meteorological applications and said that he doubted the value of correlations between solar flares and similar phenomena and weather.

Mr. Hayward (Imperial College) mentioned his interest in the application of solar energy to house heating and similar matters, and stressed the need for a simple instrument of the calorimeter type for field measurements of the heat energy produced by solar radiation.

Mr. Gold drew attention to the tendency to over-emphasize the need for local measurements of solar radiation, and suggested that when data for a given solar elevation were known for clear-sky conditions it was merely necessary to know the local cloud amounts in order to give a reasonable estimate of average radiation conditions.

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## OFFICIAL PUBLICATIONS

The following publications have recently been issued:—

### GEOPHYSICAL MEMOIRS

*No. 97—Some features of jet streams as shown by aircraft observations.* By R. Murray, M.A.

The results of an analysis of aircraft observations of temperature, frost point, cloud and turbulence near jet streams are presented; brief mention is also made of reports of condensation trails. It is shown from frost-point observations that between about 500 mb. and 200 mb. there is on the average a horizontal gradient of humidity across the jet stream, with the moister air on the high-pressure side. At about the level of the jet stream the average relative humidity with respect to ice is about 50 per cent. at 250-300 nautical miles on the right of the axis, looking down wind, and decreases to about 10 per cent. at the same distance on the left, but individual jet streams show considerable variability. The average humidity distribution indicates the existence of a relatively dry patch of air below the jet-stream axis in the vicinity of the frontal zone at about 500 mb.

Layer cloud, both medium and high, is a feature of the high-pressure side of the jet stream, although amounts vary from case to case; such cloud is rare at distances greater than about 100 nautical miles from the jet-stream axis on the low-pressure side. Layer cloud does not appear to occur above the level of the jet-stream axis. The average distribution of layer cloud and humidity is discussed in relation to the surface fronts and a dynamical model is suggested. The broad features of the accepted thermal structure of the upper troposphere and lower stratosphere near jet streams are confirmed. The occurrence of clear-air turbulence near jet streams agrees with the results put forward by Bannon.

### PROFESSIONAL NOTES

*No. 117—Barometric changes and the efflux of gas in mines.* By C. S. Durst, B.A.

A relation is obtained connecting the variation of atmospheric pressure and the efflux of methane in a coal mine. In one particular mine experiments were undertaken with the aid of which the constants in the relation have been determined. Light is shed on the type of mine which is liable to suffer from efflux of methane owing to sharp pressure falls.

Experiments were undertaken in forecasting high emission of methane, and it was found that the forecasts from the Central Forecasting Office, Dunstable, are effective for this purpose on 65 per cent. of occasions.

*No. 118—Rainfall of depressions which pass eastward over or near the British Isles.* By J. S. Sawyer, M.A.

Depressions are classified according to the latitude in which they move eastward over or near the British Isles. Maps of the average rainfall and frequency of rain from depressions in each class have been constructed and are discussed. The rainfall amounts of individual depressions are examined in relation to the characteristics of the depression concerned, but no relations have been found which are close enough to be of much value in forecasting.

## METEOROLOGICAL RESEARCH COMMITTEE

The 20th meeting of the Instruments Sub-Committee was held on October 20, 1955, under the chairmanship of Dr. A. W. Brewer who has succeeded Prof. P. A. Sheppard. The development in the United Kingdom of a searchlight technique for the measurement of atmospheric density up to heights of 60 Km. has been under study for several years. Memoranda on this subject by Dr. J. S. Hey

and Mr. P. G. Smith of the Radar Research Establishment and by Dr. R. Frith and Mr. J. R. Bibby of the Meteorological Office were before the meeting. After discussion of these papers and other information the Sub-Committee noted the difficulties associated with the practical development of the pulsed-light technique to the routine operational stage, and recommended that effort should be concentrated on the modulated-beam method in order to institute an observational programme as soon as possible. Consideration of Mr. Almond's report<sup>1</sup> on the work done on an experimental pulsed-light cloud-base meter since 1950 led to the conclusion that further development would be justified if this type of equipment were required, but that prior attention should be given to work on the model of a modulated-beam searchlight in order that accurate and immediate information on cloud-base height can be provided for landings of aircraft. The Sub-Committee noted that the refrigerated-disc icing meter described by Mr. Day<sup>2</sup> would facilitate measurement of the higher ranges of liquid water content of cloud, and that it should be possible to use the instrument on routine meteorological reconnaissance flights. During the discussion of the two papers<sup>3,4</sup> relating to the measurement of upper wind by radar, comment was made that radar No. 3 Mk 7 is more mobile than radar GL III but the errors of the particular Mk 7 equipment used in the trials were greater than the errors of GL III radar; and that the state of the sea appears to have little effect on the mean vector difference between the radar measurements of wind made at the same time on two ocean weather ships near together. Information on a comparison of heights derived by means of a radar altimeter and a pressure altimeter installed in an aircraft was presented by Mr. Durbin. It was considered that this subject called for further investigation by the departments concerned.

The 36th meeting of the Synoptic and Dynamical Sub-Committee was held on October 25, 1955. Mr. Hay's paper<sup>5</sup> prompted suggestions on further investigation of factors which may influence the times of occurrence of daily maximum and minimum air temperature at sea. Some surprise was voiced at the high frequency of precipitation days (about 320 annually) at the ocean weather stations I and J. In presenting a paper<sup>6</sup> on the mean wind at 60 mb., Mr. Bannon referred to evidence of the occurrence of a narrow belt of westerly wind at 60 mb. at places near the equator. There was discussion on the jet-stream appearance of the 60-mb. contours over North America and South Greenland in winter. The hope was expressed that regular wind measurements at this level would be obtained in the Antarctic during the International Geophysical Year. The paper<sup>7</sup> by Mr. Hoyle gave rise to discussion on the mechanism of origin of the sub-tropical jet stream and to a tentative suggestion that the type of circulation model outlined in the paper may have interest in relation to atmospheres other than that of the earth. In the discussion on Mr. Harding's paper<sup>8</sup> it was suggested that it would be desirable to supplement the work described by making special aircraft flights extending southward from Wadi Halfa and also in the Aden region, and at a greater altitude.

The 34th meeting of the Physical Sub-Committee was held on November 2, 1955. The account<sup>9</sup> by Dr. Houghton and Dr. Brewer of the first results obtained with a new radiometer mounted in an aircraft was welcomed. Suggestions were made for further studies of the flux of long-wave radiation in the upper air, including the radiational effects of cloud. Most of the remaining time of the meeting was devoted to a discussion of cloud-seeding and experiments on a tificial production of rain. Arising from comments on aspects of this question

received from Dr. Bowen of Australia, it was agreed to examine the practicability of undertaking silver-iodide seeding experiments in a mountainous part of the United Kingdom. The lack of direct evidence that silver iodide released at ground level does reach the sub-freezing parts of cloud and that the nucleating properties of this agent are not adversely affected by the heat of the generating process or other factors was recognized. Mr. Jenkinson's paper<sup>10</sup> and the subsequent discussion confirmed the complexities in the design and assessment of results of rain-making experiments. In the discussion of a report by Dr. F. Pasquill support was given to the suggestions that the proposed further experiments on the diffusion of airborne particles should cover a variety of meteorological conditions and that a method of sampling in cloud should be sought.

#### ABSTRACTS

1. ALMOND, R.; An experimental pulsed-light cloud-base meter. *Met. Res. Pap., London*, No. 941, S.C. I/106, 1955.

Ultra-rapid light pulses produced by discharging a condenser across an air gap are beamed vertically by a paraboloid mirror, and the return from cloud droplets is focussed on to a rapid-response photocell, the resulting voltage pulse being amplified and displayed by a cathode-ray tube. The delay between emitted and received pulses gives the height. The details of the apparatus after trials are set out. The instrument is satisfactory over a range from about 600 to 15,000 ft. Specimen records are shown. Some suggestions for improvement are made. Appendices discuss some aspects of the theory and summarize the trial reports.

2. DAY, G. J.; A refrigerated disk icing meter. *Met. Res. Pap., London*, No. 916, S.C. 1/99, 1955.

An instrument for measuring liquid-water content of clouds, supercooled or not, is described. It consists of a hollow copper disk, cooled inside by liquid nitrogen, rotating twice a minute edge on to the local air stream. The thickness of ice on the edge is measured by a transducer. Theory, tests in the laboratory and in the air, and calibration are described.

3. ELSE, C. V.; Wind-finding trials of radar A.A. No. 3 Mk VII (Second series). *Met. Res. Pap., London*, No. 922, S.C. I/100, 1955.

Nine flights giving 500 sets of simultaneous readings of the A.A. No. 3 Mk 7 (GL VII) and the GL III at slant ranges up to 66,000 yd. are described and the results summarized. The GL VII can provide results comparable in accuracy with GL III up to at least 40,000 yd., and although complicated it is easier to operate (one observer instead of three) and service.

4. HARRISON, D. N.; Radar wind comparisons on the ocean weather ships (second series). *Met. Res. Pap., London*, No. 928, S.C. I/102, 1955.

Trials were made in 1953-54 to assess the improvement in radar wind accuracy since 1949 by comparing observations of pairs of ships. A small improvement was found.

5. HAY, R. F. M.; Five-year means of meteorological observations made at the ocean weather stations ITEM and INDIA, JIG and JULIETT, 1948-52. *Met. Res. Pap., London*, No. 923, S.C. II/192, 1955.

Monthly five-year averages at stations I (mean position 59°29'N. 19°29'W.) and J (53°06'N. 19°25'W.) are tabulated and discussed. Tables include mean wind velocity (with other windy stations for comparison showing that averages of 17·7 and 18·3 kt. were exceeded only by Adélie Land), wind frequencies by direction and force, pressure, air and sea temperature, days of phenomena, frequencies of visibility and low cloud height. Some values of diurnal variation are included.

6. BANNON, J. K. and JONES, R. A.; The mean wind at 60 mb. *Met. Res. Pap., London*, No. 925, S.C. II/194, 1955.

Vector resultant winds at 60 mb. (20 Km.) were constructed from the few wind observations available and from contour charts of 100-mb. level extrapolated to 60 mb., for January, April, July and October. Values of direction and speed are tabulated for 83 stations ranging from 61°N. to 52°S., plotted on Mercator charts and discussed.

7. HOYLE, H. D.; The subtropical jet stream of the eastern North Pacific in January and April 1952. *Met. Res. Pap., London*, No. 924, S.C. II/193, 1955.

A thorough analysis is made of the two jet streams in the North Pacific. Daily schematic charts, 60-15°N., 180-120°W., show the positions of jets (> 100kt.) at 300-400 mb. near the polar front and at 200 mb. 1,000 miles south. Vertical cross-sections in 160-150°W. show by isokinetics, isotherms and fronts 3 types of probable structure (strong W.-E. jet stream near Hawaii, weaker jet stream with N. component, and subtropical jet stream displaced northward). The 250-mb. or 300-mb. and 60-mb. isotherms, contours of various surfaces, and mean surface isobars are also plotted as monthly means and means for different types. The jets show pronounced shear and are associated with 3 tropopause levels, tropical (90 mb.), subtropical (200 mb.) and polar (300 mb.).

8. HARDING, J.; The profile of jet streams in the Middle East. *Met. Res. Pap., London*, No. 932, S.C. II/195, 1955.

Ground photographs from aircraft between Habbaniya and Bahrain, Port Said and Wadi Halfa and airspeed gave wind direction and speed. Eleven "windy runs" are discussed. "The strong westerly winds over the Middle East in winter, at heights approximating to those of maximum wind speeds, contain a belt of very strong winds which may be as wide as 200 nautical miles or more, and in which horizontal gradients of wind speed are small or negligible". Surface and 200-mb. or 300-mb. charts and wind profiles showing winds of 100–200 kt. are given for January 28 and February 6, 1953, January 16 and February 25, 1954 and March 5, 1955.

9. HOUGHTON, J. T. and BREWER, A. W.; Measurement of the flux of long-wave radiation in the upper air 1953–1954. *Met. Res. Pap., London*, No. 914, S.C. III/185, 1955.

Upward and downward flux of long-wave radiation at night were measured by radiometer in an aircraft at 3,000-ft. intervals up to 40,000 ft. Temperature and humidity were also measured. The downward flux below 30,000 ft. agreed with Elsasser's chart with a pressure correction and Yamamoto's chart for radiation from carbon dioxide multiplied by 1.2. The upward radiation was affected by cloud. Dense clouds had 100 per cent. emissivity, thin clouds down to 10 per cent. and ground 90–95 per cent. A clear atmosphere cooled by 1–2°C./day. Observations in the stratosphere were disappointing.

10. JENKINSON, A. F.; Some statistical aspects of a rain-making experiment. *Met. Res. Pap., London*, No. 931, S.C. III/190, 1955.

The problem is to test results of seeding with silver iodide on Salisbury Plain. The location of the plume and vertical and horizontal extent of effective seeding in cloudy frontal conditions are discussed. From rainfall statistics on 92 selected occasions in 1945–54 it is concluded that if the trials are made with five generators on a line of 20–25 miles on suitable occasions, a difference of 13 per cent. between rainfall of known seeded and control areas would be significant at the 1 per cent. level. If the seeded area is not known, a difference of 25–30 per cent. would be required.

## ROYAL METEOROLOGICAL SOCIETY

### Snow accumulation and ablation

A joint meeting of the Royal Meteorological Society with the British Glaciological Society was held on January 18, 1956. Dr. Sutcliffe, President of the Royal Meteorological Society, took the Chair, supported by Mr. Seligman, President of the British Glaciological Society. There was a discussion on snow accumulation and ablation.

Mr. R. A. Hamilton, who was Chief Scientist on the British North Greenland Expedition at Britannia Lake, opened the discussion with a brief geographical and meteorological description of Greenland. Britannia Lake, in the north-east corner separated from the coast by 20-mile wide glaciers, is rarely visited by disturbed weather and has one of the driest climates in the northern hemisphere. Net radiational loss of heat is usual and katabatic winds are easily formed over the fringes of the ice cap and flow down glaciers and fiords reaching gale force at times. It is, however, possible for a stagnant cold pool of air to form in a fiord with the katabatic wind flowing overhead.

Mr. H. Lister described, with the aid of a film and slides, some of the work done at Britannia Lake to help in the study of ablation—with particular reference to radiation, eddy convection and evaporation. Two stations, three miles apart with a difference of 150 m. in altitude, were established on Britannia Glacier, and a third station 230 miles to the west near the centre of the ice-sheet. During the ablation season temperature and humidity were recorded in screens at heights of 30 cm. and 300 cm., and checked by a whirling psychrometer; radiation was measured by a M. O. bimetallic radiation recorder; wind by cup counter anemometers and a 3-min. M. O. electrical impulse recorder connected to a cup contact anemometer; and ablation by means of stakes driven into holes drilled deep into the solid ice of the glacier. During special 48-hr. periods more detailed temperature and humidity measurements were made at heights of 2, 6, 10, 30, 100, 200, 300 and 400 cm. using an aspirated electrical apparatus developed by Pasquill, whilst wind was measured by sensitive cup anemometers at heights of 30, 100, 200 and 400 cm., and radiation, both total from above the horizontal and reflected from below, by a Moll thermopile (face downwards for the reflected radiation). Difficulty was experienced with the surface markers of an ablatograph which would persist in sinking into the snow; plaster-of-paris hemispherical bowls of 16.5 cm. diameter, made on the site, solved the difficulty. Many of the instrumental clocks developed troubles; the Meteorological Office clocks were best. The electrical impulse recorder Mk II was very successful.

Mr. Lister compared his results with those obtained by Deacon over short grass\* and found great difficulty in correlating the variations of the three elements: wind, temperature and vapour pressure. For coarse sastrugi snow his roughness parameter  $z_0$  was 1.1 cm. (very high for snow); as the snow melted and the glacier developed hummocks the value of  $z_0$  decreased to 0.5 cm.

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\* DEACON, E. L.; Vertical profiles of mean wind in the surface layers of the atmosphere. *Geophys. Mem., London*, 11, No. 91, 1953.



The ratio of wind speeds ( $u_{200}/u_{30}$ ) seemed constant and independent of the vertical temperature gradient which was almost always an inversion, even in summer, because of the permanent snow or ice surface. The temperature gradient in the very lowest layers was very marked—with sudden changes from inversion to lapse and back again; much more change occurred between the surface and 30 cm. height than between 30 cm. and 300 cm. and it was therefore useful to remember that with melting at the surface the conditions there would be 0°C. and 100 per cent. humidity. Further investigation of the lowest 100 cm. gave a value of  $z_0$  of 0.1 cm. over ice on Britannia Lake. Only by superimposing profiles of wind, temperature and vapour-pressure variation could he find as high a correlation coefficient between the mean gradients of wind speed and temperature as 0.52 (individual correlation coefficients between temperature and wind at different heights; 30 cm., 0.658; 100 cm., 0.589; 300 cm., 0.472). There was little correlation with vapour pressure. Mr. Lister attributed this loss of correlation to lack of turbulence at lower velocities and stronger inversions over ice surfaces.

Radiation measurements showed that a small increase of cloud (above the usual small amounts of north-east Greenland) would initially increase the radiation received—probably because of multiple reflection from clouds and snow or ice surface. Diurnal change of the elevation of the sun was more important than changes in the ice surface in albedo measurements during ablation. The incoming heat responsible for melting was: radiation 69 per cent., convection 28 per cent. and condensation 3 per cent.

Mr. Ward described some of the difficulties in the measurement of ablation directly on a glacier. The glacier is moving; the character of the snow (crystals or firm) changes with time and depth even without any net ablation; melt water can flow through the sub-surface or over the top of the glacier from higher levels; the loosely packed snow near the surface can provide a reservoir for water; and ice at different depths may melt and freeze several times in a season. To multiply the change in stake depth by a suitable density factor would not suffice when the change may have, and possibly has, been caused by settling due to melt water. Day-to-day ablation measurements were therefore difficult particularly in north-east Greenland where the snowfall is very small and ablation occurs in short intervals.

Among the questions that were asked at the meeting, Mr. Gloyne asked about the higher albedo at night and why the roughness parameter should decrease as hummocks developed on the surface. Mr. Lister said that the sun's elevation merely decreased at "night" and the greater proportion of red rays would be coincident with reflection. Mr. Ward said that when the sun was low the albedo was almost 1. The hummockiness observed after melting did not have as much resistance to the wind as surface roughness. Dr. Frith thought the increase in albedo with cloudiness might be due to a change in surface conditions. Mr. Lister said that surface melting continued through the "night" and surface changes of texture occurred principally during the first week of summer. Mr. Sawyer asked what was the effect on the wind of a rock surface (the film showed rocky country in parts). Mr. Lister said the lower station was  $\frac{1}{2}$  mile from the valley wall and the upper station  $\frac{3}{4}$  mile, but the wind was down glacier giving a fetch of 3 miles of a homogeneous snow or ice surface for flow at the anemometers.

Mr. Hamilton stressed the difficulties of instrumental work on expeditions, and mentioned that by observation of the refractive index of the air he had measured the vertical temperature gradient to an accuracy of  $1 \times 10^{-2}$ °C./m.

## LETTER TO THE EDITOR

### Variation between measurements of rainfall made with a grid of gauges.

In my paper on the measurement of rainfall with a grid of gauges, published in the November 1955 issue of the *Meteorological Magazine*, it was stated that the areas of the funnels of nine standard Meteorological Office rain-gauges were all in excess of the nominal value by between 0.8 and 1.3 per cent. It has been pointed out by the Meteorological Office that if this were so the diameters of these funnels would all have been outside the normal limits of error laid down by the Meteorological Office, which are that the maximum error in a mean diameter is 0.01 in., and that the maximum error in any individual diameter is 0.02 in.

The diameters of the funnels were subsequently measured, and it was found that with the exception of one, which had a maximum error in an individual diameter of 0.025 in., they were all within the specification. The reason for the discrepancy was that the original measurements were made with a specifically adapted planimeter to measure the areas directly, and a re-examination of the

method showed that it gave rise to a small but consistent over-estimation of the areas. Since the paper was concerned entirely with the differences between the amounts of rainfall collected by the gauges the conclusions given in the paper are not affected.

L. H. WATKINS

*Road Research Laboratory, Harmondsworth, February 16, 1956*

## NOTES AND NEWS

### Changes in B.B.C. weather forecasts

Changes in the times and contents of B.B.C. weather broadcasts will be introduced on Sunday, April 22, 1956. Essentially these consist of the transfer of all shipping information to the Light Programme and a consequent increase in the broadcasting time available for land-area forecasts on the Home Service. The primary reason for having the shipping bulletins in the Light Programme is that reception at sea has been found to be better on 1,500 m. than on the medium wave-band, so the longer wave-band only will be used.

The major obstacle to including in the Light Programme four shipping broadcasts a day at intervals of about 6 hr. arose from the nature of their contents. A weather bulletin intended primarily for a particular section of the community is not easily fitted into a programme for the general listener. However, 5-min. periods have been provided in the early morning and afternoon and at midnight, but only 2-min. periods in the early evening. Moreover, the times of two of the broadcasts will be different on Sundays because of the different pattern of the programmes. The schedule of broadcasts is as follows, in clock times, except for the broadcast at 0645 G.M.T.:

Week-days	Sundays
0645 - 0650 G.M.T.	0645 - 0650 G.M.T.
1340 - 1345 CLOCK TIME	1200 - 1205 CLOCK TIME
1758 - 1800 CLOCK TIME	1928 - 1930 CLOCK TIME
2400 - 0005 CLOCK TIME	2400 - 0005 CLOCK TIME

The 5-min. broadcasts will comprise a gale-warning summary, a general synopsis, forecasts for coastal sea areas for the next 24 hr. and a selection of the latest observations from a few coastal stations. The increase in broadcasting time will enable the wishes of the seaman to be met to the extent of providing a more detailed picture of the synoptic developments than is possible at present and no doubt this will appeal also to many amateur meteorologists on shore, while the broadcasting of actual reports will revive memories of AIRMET, although the number of stations included will not be comparable. Another innovation is to give the forecast areas in a fixed order, although a name may be followed only by a reference to another sea area with which it is bracketed later in the bulletin. This arrangement will help the listener at sea who often has to assimilate the forecast in difficult circumstances. The 2-min. broadcast in the evening will necessarily be confined to one item, namely the forecasts for the coastal sea areas, and these may at times have to deviate from the standard order.

In February of last year an informal meeting was held in De Bilt by representatives of the meteorological services which are directly concerned with the weather of the North Sea. One of their recommendations was that there should

be uniformity in the coastal sea areas used in different shipping forecasts. In consequence four new names appear in the B.B.C. broadcasts. The eastern parts of the present "Forties" and "Dogger" become "Viking" and "Fisher" respectively, and "Heligoland" is renamed "German Bight", while "Iceland" becomes "south-east Iceland" to avoid confusion with "North Iceland", an area introduced into the North Atlantic Weather Bulletin last November.

Times of weather broadcasts on the Home Service are unaltered but the broadcasts at 0655, 0755, 0855 (Sundays), 1255 and 1755 will be of 4-min. duration. This means that forecasters will be less handicapped by the need to compress their land-area forecasts within a number of words which has often proved inadequate during complex weather situations. No major changes are proposed in the general plan of these forecasts but it will be possible to adopt a somewhat freer style of presentation.

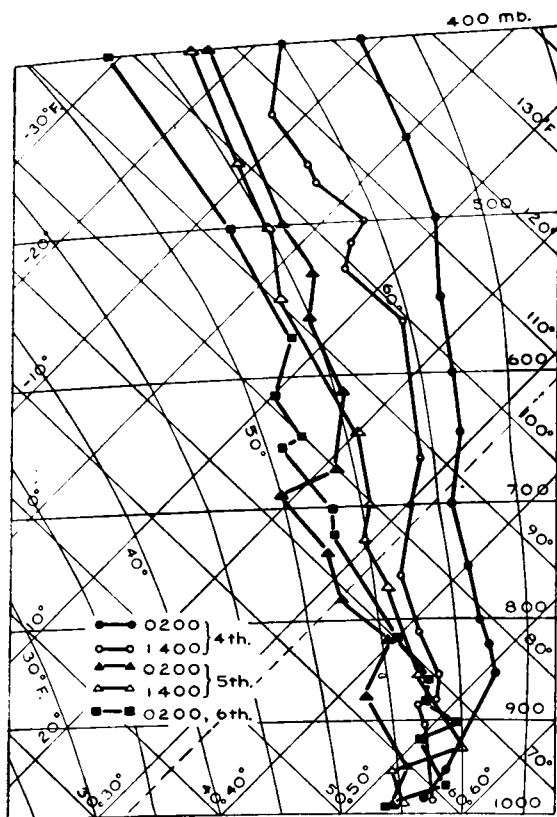
### **Exceptionally severe thunderstorm**

A very violent thunderstorm of almost tropical severity occurred in the Cambridge area on the night of November 5-6, 1955. The intensity of the storm was so great that people living in the locality were awakened and alarmed by the noise of the hail falling on the roofs of the houses and the exceptionally brilliant lightning and heavy thunder claps. In the village of Whittlesford (population 900) over a thousand panes of glass were broken, and at the R.A.F. Station, Duxford, over 500 panes were broken by the large hailstones.

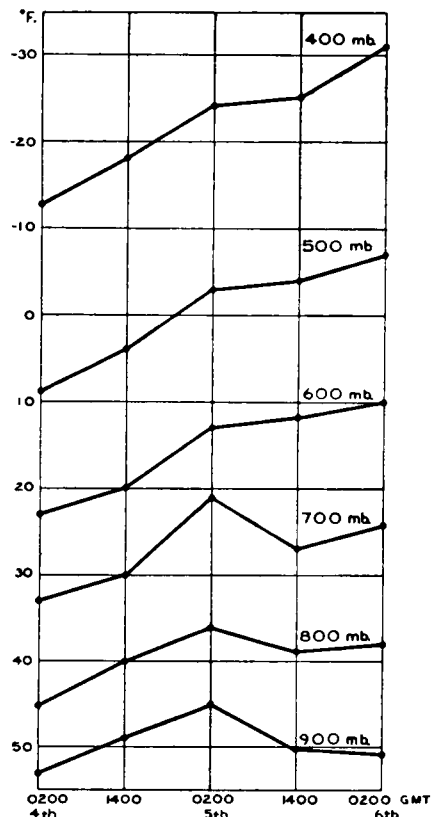
One extraordinary feature of the storm was the small amount of rain that fell compared with the amount of hailstones. These were generally of a round pellet formation of clear ice with a very small opaque core and averaged between 1 and  $1\frac{1}{2}$  in. diameter. A large number of the hailstones remained in the ice stage for quite a long time after the storm, one particular mass of them continued as ice for over 36 hr. despite the fact that they were lying at the foot of a south wall and the average screen temperature for the period was about 50°F.

During the 36 hr. preceding the storm a complex depression was almost stationary to the west of Ireland with a very moist south-westerly air stream crossing the country. A cold front, which cleared east and south-east England by midnight on the 4th, was followed by an unstable air mass with sferic activity reported as far south as Spain. By 1200 on the 5th the sferic activity had increased northwards and become intense between Scilly and Finisterre. A belt of rain and heavy showers extending from Liverpool to the Channel Islands, with a thunderstorm at Portland Bill reported at 2100 on the 5th, seemed to indicate that an upper cold front or trough was moving east over southern England, and this was supported by the fall of temperature at Crawley between 0200 on the 4th and 0200 on the 6th, as shown on the graphs in Fig. 1. This fall of temperature was more pronounced above 700 mb., and was probably the cause of the surprisingly heavy fall of hailstones of larger than usual diameter.

The small amount of evidence on the surface charts to indicate the upper front appears to be an interesting point, but no doubt the surface air and the air in the lower layers had been warmed in its travel over the sea whereas the air in the higher layers, above 700 mb. for instance, had been brought around the periphery of the depression from the northern side, and was more likely to retain its polar characteristics than the air in the lower layers.



Tephigrams



Time chart

FIG. 1—DECREASE OF UPPER AIR TEMPERATURE  
AT CRAWLEY, NOVEMBER 4-6, 1955

The size and speed of the falling hailstones left their mark on a number of caravans in the locality, the outer metal skin of the caravans being pock-marked very noticeably and sufficiently deep to show up on the photograph facing p. 128.

J. A. HICKS

[Thunderstorms were not confined to the Cambridge area; the whole of south-east England, east of a line from the Isle of Wight to Lincolnshire, experienced widespread thunderstorms during the 5th and 6th. In the Midlands they were scattered. They were particularly severe at Chorley Wood, Hertfordshire, where eight women in a home for elderly people had to leave their beds when the building caught fire after being struck by lightning. Considerable lightning damage was also reported from Fareham, Hampshire and from Iwade and Sittingbourne in north Kent.—Ed., *M.M.*]

### Beiträge zur Physik der freien Atmosphäre

All meteorologists will be pleased to learn that, thanks to the initiative of Prof. H. Koschmieder and Prof. W. Georgii, the *Beiträge zur Physik der freien Atmosphäre*, which was a leading meteorological periodical until it had to cease publication during the Second World War, is to appear again in the near future.

The journal will be published by the Akademische Verlagsgesellschaft M.B.H. at Frankfurt-am-Main, Germany, and the committee of editors consists of Prof. H. Flohn, Prof. W. Georgii, Prof. B. Haurwitz, Prof. H. Koschmieder and Prof. Dr. J. van Mieghem.

Papers will be welcomed on synoptic and dynamical meteorology, the meteorology of the high atmosphere, radiation and heat balance, turbulence and convection, the meteorology of gliding and soaring, the physics of condensation, clouds and precipitation, atmospheric electricity, radio meteorology, and the instruments and methods used for the exploration of the free atmosphere.

We extend our best wishes for the success of the *Beiträge* which will, we are sure, maintain the high standards established by the founders, R. Assmann and H. Hergesell.

## REVIEW

*On the mathematical expression of the annual variation of temperature.* By L. Mavridis. *Meteorologica* No. 3, 9½ in. × 6½ in., pp. 44, *Illus.*, University of Salonica, 1955. The annual variation of temperature has often been expressed by a harmonic form in which the temperature for the  $n$ th month is given by

$$T_n = a_0 + \sum_{j=1}^k (a_j \cos j\theta_n + b_j \sin j\theta_n)$$

where  $a_0$ ,  $a_j$ ,  $b_j$  are parameters characteristic of the station, and  $\theta_n$  is the mean value during the  $n$ th month of an angle  $\theta$  which increases from  $0^\circ$  to  $360^\circ$  during the year. The present author discusses another representation in which

$$\frac{1}{2} (T_n + T_{13-n}) = A + C \sin (L_n - V)$$

and

$$\frac{T_{13-n}}{T_n} = \frac{p}{1 - e \cos (L_n - w)}$$

Here  $L_n$ , the geocentric longitude of the sun, corresponds closely to  $\theta_n$  in the harmonic representation, while  $A$ ,  $C$ ,  $V$ ,  $p$ ,  $e$ ,  $w$  are six parameters to be determined for each station. Slight variations in  $L_n$  allow for the presence of leap years, and it is claimed that the parameters are more amenable to physical interpretation than those used in the harmonic representation.

Mr. Mavridis shows how to find the parameters by a method of least squares, and does so for monthly mean temperatures for Copenhagen, Vienna, Prague and Berlin. He finds the parameters for every decade of each record, or about 60 sets of values in all. He examines the residuals not accounted for by his mathematical form, and finds that these exceed the residuals left after fitting a three-term harmonic form (with seven parameters), but are less than those left after fitting a two-term harmonic form (with five parameters).

The demonstration though reasonable is not wholly convincing, because the four stations used are too closely grouped to furnish independent evidence, while the harmonic analyses are not carried out in quite the most accurate way. Nevertheless, the author has shown that the Xanthakis procedure gives reasonable results. The argument that the parameters are capable of easy physical interpretation is an attractive one, and the method deserves examination by any worker concerned with this branch of climatology.

J. M. CRADDOCK

## BOOK RECEIVED

*The I.B.G.: Retrospect and prospect.* By R. O. Buchanan. *Trans. Pap. Inst. Brit. Geogr.*, London, No. 20, 1954. 9¾ in. × 7¼ in., pp. 14, *Illus.*

## OBITUARIES

*Dr. A. W. Lee.*—We regret to report the death of Dr. Lee on February 10, 1956, in his 57th year.

His studies were interrupted by service with the R.E. Signals (Wireless Section) 1917–19, and he took the degrees of B.Sc. (Physics) in 1920 and of M.Sc. in 1922 at the Imperial College of Science. He was one of the first post-graduate students in the Meteorology Department of the College, working under Sir Napier Shaw. A paper on “The relation of the circulation in the upper air to a circumpolar vortex”, published in 1924, was one of the results of this work. He joined the staff of the Meteorological Office in 1923, and after a period at Calshot was transferred in 1924 to take charge of Lerwick Observatory, a post he occupied for five years. This was followed by a spell of 10 years at Kew Observatory. In the spring of 1939 he went to Eskdalemuir Observatory as Superintendent. The outbreak of war saw the end of his long connexion with observatories, and he served first as a forecaster at the Headquarters of Bomber Command, and then for five years as Senior Meteorological Officer at No. 12 Fighter Group R.A.F. Early in 1945 he was transferred to a Headquarters branch, but three years later he suffered a serious breakdown in health. He made a remarkable, though incomplete, recovery, and was not able again to face the strain of travel to central London. The last six years of his service were spent at Kew Observatory, but the journey to work became increasingly difficult for him and he retired in January 1954 at the age of 55.

Dr. Lee's duties at Kew Observatory were concerned mainly with seismology, and his stay was marked by the publication of a remarkable series of papers on this subject. He was acknowledged to be one of the world's leading authorities on microseisms. His work on the effects of geological structure, and his paper “On the direction of approach of microseismic waves” are still relevant to the problem of detection of meteorological disturbances by means of microseisms. He also made studies of individual earthquakes, and is the author of five *Geophysical Memoirs*. He was awarded the degree of D.Sc. of the University of London in 1935 for work on microseismic waves, and was a member of the British Association Committee on Seismological Investigations from 1933 to 1954.

He married whilst stationed at Lerwick and his wife, who survives him, shared in the life of the Observatory there and at Eskdalemuir. To her, and to his son and daughter—the former now in Australia—we extend our sympathy.

G. D. ROBINSON

*Sidney Andrew Hodson.*—It is with deep regret that we announce the death of Senior Aircraftman S. A. Hodson who was a passenger in the York aircraft which crashed at Malta on February 18, 1956. He joined the Office in September 1952 as a temporary Scientific Assistant and after a course at the Training School he was posted to an aviation station. He was called up for National Service in February 1954 and, shortly afterwards, he was posted to the Middle East. S.A.C. Hodson was returning to the United Kingdom for his release from National Service when the accident occurred.

## METEOROLOGICAL OFFICE NEWS

**Retirement.**—Mr. B. G. Brame, Senior Experimental Officer, relinquished his appointment as Senior Experimental Officer on December 1, 1955. He joined the Office in February 1911 as a Laboratory Boy in the Instruments Division

and at the time of his retirement he had completed 45 years' service. In 1915 he was transferred to Kew Observatory for about four months for training prior to his posting to Eskdalemuir Observatory. In 1921 he was transferred to the Climatology Division at Headquarters where he served in various sections dealing with different aspects of the work of the Division. In 1934 he returned to the Instruments Division to be in charge of the test room. In 1936, after a short spell at Kew Observatory, he was posted to the General Services Branch where he worked with Mr. E. Gold until 1939. From 1939 to 1946 he served in the Overseas and Royal Air Force Branches on administrative duties. For the past ten years he has held the post of Senior Experimental Officer in the Royal Air Force (Home Commands) Branch. He was also concerned with the compilation of Meteorological Office Standing Orders. For the last ten years Mr. Brame has been Honorary Treasurer of the Meteorological Office Social and Sports Committee. He was appointed a Member of the Order of the British Empire in the Birthday Honours List of 1944.

At a ceremony in the Conference Room in Victory House on March 2, 1956, Mr. T. W. V. Jones presented Mr. Brame with a cheque subscribed by his colleagues. In expressing his thanks Mr. Brame recounted some interesting and amusing recollections of the Office as it was over 40 years ago.

Mr. Brame has accepted a temporary appointment in the Meteorological Office.

**Sports activities.**—*Athletics.*—Messrs. Garrod, Bird, Stratton and Messem were members of the Air Ministry team which won the Civil Service Cross-Country Championship at Epsom on December 10, 1955.

*Yachting.*—Mr. L. S. Clarkson, Chief Meteorological Officer, Headquarters F.E.A.F. and Honorary Sailing Secretary of the Royal Air Force Changi Yacht Club won the International Snipe Class Race at the Royal Singapore Yacht Club Open Regatta on Saturday, January 8, 1956.

*Netball.*—Miss B. M. Edwards and Miss N. Edwards were selected to play for a Civil Service representative side against the Australian Ladies Netball team on February 29, 1956, at the Chiswick Sports Ground.

*Swimming.*—Mr. J. V. Evling was a member of the successful Ariel Club swimming team which won the Burton Cup for Civil Service medley relay teams at the Ironmonger Row Swimming Baths on February 29, 1956.

## WEATHER OF FEBRUARY 1956

The month will rank as a notably cold February in most parts of Europe, the mean temperature for the month being 12°C. below normal in Saxony, eastern Bavaria and Bohemia, with negative anomalies in all parts of the Continent mostly in excess of 5°C. The freezing-point isotherm ran through northern Spain and central Italy. Western Siberia, Mongolia and the Vladivostok province were also colder than usual. By contrast, mean temperature was above normal over the eastern half of North America (maximum anomaly +6°C. or more in the region of north Quebec—south Baffin Land) and over much of the Arctic (anomalies over Iceland and Greenland +3–4°C., Spitsbergen +7°C.). The mean temperature was generally 1–3°C., and locally 5°C. below normal in the Rocky Mountains region.

The pressure distribution was marked by vigorous depressions over the western Atlantic sending offshoots north and north-west towards Greenland and Labrador and south-east towards the Mediterranean (mean pressures 5–6 mb. below normal in 50°N. 50°W. and north Quebec, 8 mb. below normal in the Azores and 8–10 mb. below normal in Italy and the central Mediterranean). A great warm, southerly air stream was directed from mid Atlantic towards Spitsbergen and east of this anticyclones built up to attain at times exceptional extent and intensities over north Europe and Asia; 1074 mb. was observed at Salekhard, north-west Siberia on the 15th, a value only twice known to have been exceeded since 1872. The mean pressure for the month reached 1040 mb. near the Gulf of Ob and the maximum pressure anomaly was +22 mb. at the mouth of the Yenisei and +21 mb. at Thorshavn and in Lapland. Nevertheless there were frequent changes and movements within the region dominated by high pressure with several cold fronts

and occlusions crossing Scandinavia from the north-west during the month. There was also some appearance of a 7-day rhythm in a series of short-lived tongues of Atlantic mild air passing south-eastwards and southwards near or over the British Isles on the 5th, 12th, 19th and 26th.

Precipitation totals were below normal everywhere in western Europe, above normal (generally over 200 per cent.) all through the Mediterranean, and more slightly above normal in most places between 15° and 25°E.—i.e. east and north of the mountains—from Bear Island and northern Scandinavia to the Hungarian Plain. Precipitation was also well above normal in Iceland and east Greenland.

In the British Isles a very cold easterly air stream from the Continent dominated the weather for most of the month. The lowest temperature occurred during the first three days, but remained very low from the 9th to the 27th with considerable snow especially in the east of the country. A mild westerly air stream brought a rise of temperature of 15–20°F. and a rapid thaw on the 28th.

On the 1st, with pressure high over Scandinavia and low over southern Europe, very cold continental air which had arrived with easterly winds the previous day spread to the whole country. Temperature at Kew rose only to 24°F.—the lowest day maximum temperature recorded there since 1895—and maximum temperatures in the west were just as low: 24°F. at Ross-on-Wye and 22°F. at Bristol. Snow showers were frequent and snow lay to a depth of 2 in. at Sprowston and 7 in. at Hull. That night temperature fell to 9°F. at many places in East Anglia and to about 0°F. on the ground, and there were power cuts in the London area owing to the excessive demand for electrical heating. Renewed falls the next day brought reports of level snow lying a foot deep in parts of Kent and of 5-ft. snow drifts in the Midlands. Day temperatures remained below freezing until the 3rd, but the direct continental air supply by then was being gradually cut off as high pressure was slowly transferred from Scandinavia to southern England. With an anticyclone in the western English Channel on the 4th, a milder westerly air stream and rain spread to all areas. From the 5th to the 8th this anticyclone moved eastward and northward to cover much of the British Isles, but weather was generally dull with some slight occasional drizzle and patches of fog in many places. Very cold easterly winds returned again on the 9th as the British anticyclone became a ridge to a larger anticyclone which had formed over Scandinavia; temperatures fell generally below freezing point except in north-west Scotland and snow spread west and north to reach north Devon and south Scotland, but the chief falls were in eastern England. Along the Kent coast between Dungeness and Greatstones, Romney Marsh, cakes of ice formed as the sea came in on the rising tide and were piled up to a foot high on the beach. Pressure became highest to the south of Iceland on the 11th, and there was a temporary incursion of warmer maritime air over much of the country on the 12th and 16th; on the latter date 10 in. of snow fell in 24hr. at Scarborough and drifts 10–15 ft. deep were reported from parts of Yorkshire. Cornwall had its heaviest snowfall of the winter with 9–10 in. in the Newquay-Lizard area on the 19th and 20th as minor disturbances moved southward over western districts. East Kent was so badly affected by this time that the Kent County Council had to enlist military assistance to keep the roads clear. By the 21st the Icelandic anticyclone had joined with another over Russia restoring the very cold easterlies to the whole of Great Britain. During the next few days the high-pressure belt moved southward over the country, weather remaining very cold though dry in the south but becoming milder in the north with westerly winds spreading into Scotland. The milder air stream spread over the whole country on the 28th with widespread drizzle and rapidly rising temperature.

Precipitation was about half the average in most areas, but near the east coast there was an excess, particularly in Yorkshire. Sunshine was above the average over much of the country but well below in east-coast districts. Temperature was 7–10°F. below normal over most of England and Wales, and at some places in the Midlands and east mean temperature was below freezing point. Most farm work was at a standstill throughout the month. The severe frost, with only slight snow cover, apart from drifts, had a disastrous effect on most autumn-sown crops, but cereals and beans will probably recover. Fuel consumption for glasshouses was excessive. In the south-west the anemone crop was completely ruined, but daffodils were only retarded. As a result of plentiful fodder and mainly quiet conditions sheep and lambs are in reasonable condition.

The general character of the weather is shown by the following provisional figures:—

	AIR TEMPERATURE			RAINFALL		SUNSHINE
	Highest	Lowest	Difference from average daily mean	Percentage of average	No. of days difference from average	Percentage of average
	°F.	°F.	°F.	%		%
England and Wales ...	57	1	—8·0	44	—1	107
Scotland ...	55	—2	—3·2	70	—1	93
Northern Ireland ...	54	11	—4·6	52	—6	114



# RAINFALL OF FEBRUARY 1956

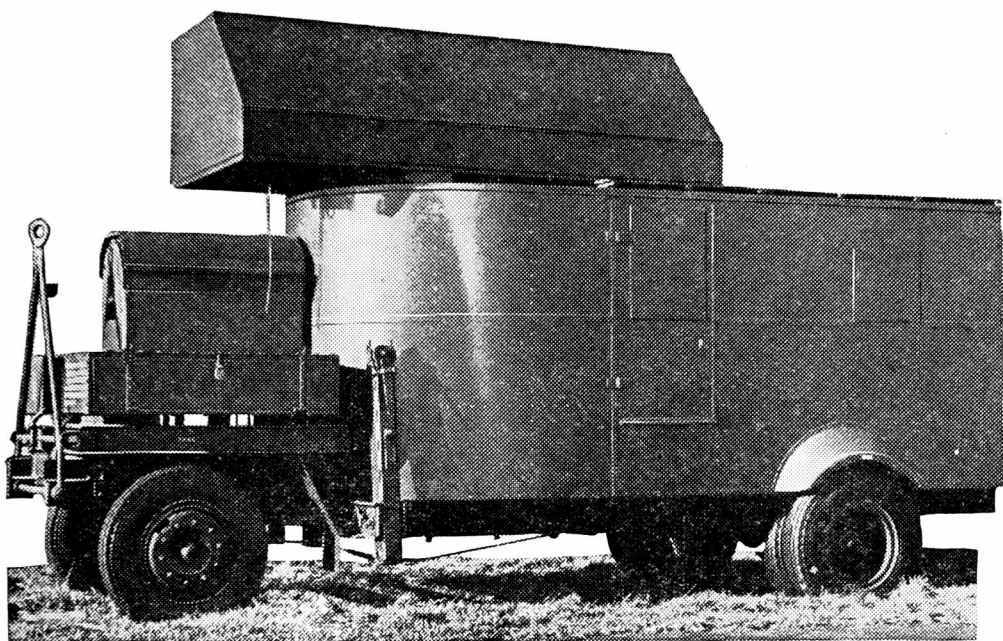
## Great Britain and Northern Ireland

County	Station	In.	Per cent. of Av.	County	Station	In.	Per cent. of Av.
<i>London</i>	Camden Square ...	0·30	18	<i>Glam.</i>	Cardiff, Penylan ...	0·32	11
<i>Kent</i>	Dover ...	2·51	131	<i>Pemb.</i>	Tenby ...	1·17	40
"	Edenbridge, Falconhurst	0·68	31	<i>Radnor</i>	Tyrmynydd ...	0·95	18
<i>Sussex</i>	Compton, Compton Ho.	0·26	10	<i>Mont.</i>	Lake Vyrnwy ...	0·90	20
"	Worthing, Beach Ho. Pk.	0·24	12	<i>Mer.</i>	Blaenau Festiniog ...	1·52	19
<i>Hants.</i>	St. Catherine's L'thouse	0·16	8	"	Aberdovey ...	0·70	23
"	Southampton (East Pk.)	0·10	4	<i>Carn.</i>	Llandudno ...	0·29	15
"	South Farnborough ...	0·23	12	<i>Angl.</i>	Llanerchymedd ...	0·86	34
<i>Herts.</i>	Harpenden, Rothamsted	0·60	31	<i>I. Man</i>	Douglas, Borough Cem.	0·91	29
<i>Bucks.</i>	Slough, Upton ...	0·18	11	<i>Wigtown</i>	Newton Stewart ...	1·03	27
<i>Oxford</i>	Oxford, Radcliffe ...	0·43	26	<i>Dumf.</i>	Dumfries, Crichton R.I.	0·66	20
<i>N'hants.</i>	Wellingboro' Swanspool	0·47	29	"	Eskdalemuir Obsy. ...	2·11	43
<i>Essex</i>	Southend, W. W. ...	0·41	30	<i>Roxb.</i>	Crailling ...	2·03	110
<i>Suffolk</i>	Felixstowe ...	1·26	100	<i>Peebles</i>	Stobo Castle ...	2·09	76
"	Lowestoft Sec. School ...	2·15	154	<i>Berwick</i>	Marchmont House ...	3·30	159
"	Bury St. Ed., Westley H.	0·87	58	<i>E. Loth.</i>	North Berwick Gas Wks.	1·86	119
<i>Norfolk</i>	Sandringham Ho. Gdns.	1·90	115	<i>Mid'l'n.</i>	Edinburgh, Blackf'd. H.	1·86	112
<i>Wilts.</i>	Aldbourn ...	0·43	19	<i>Lanark</i>	Hamilton W. W., T'nhill	1·35	47
<i>Dorset</i>	Creech Grange ...	0·21	7	<i>Ayr</i>	Prestwick ...	0·90	38
"	Beaminster, East St. ...	0·12	4	"	Glen Afton, Ayr San. ...	1·43	33
<i>Devon</i>	Teignmouth, Den Gdns.	0·17	6	<i>Renfrew</i>	Greenock, Prospect Hill	1·87	35
"	Ilfracombe ...	0·31	11	<i>Bute</i>	Rothsay, Arden Craig ...	1·38	35
"	Princetown ...	0·23	3	<i>Argyll</i>	Morven, Drimnin ...	3·32	63
<i>Cornwall</i>	Bude, School House ...	0·52	21	"	Poltalloch ...	2·68	62
"	Penzance ...	1·03	31	"	Inveraray Castle ...	3·22	47
"	St. Austell ...	0·96	25	"	Islay, Eallabus ...	1·72	41
"	Scilly, Tresco Abbey ...	1·22	44	"	Tiree ...	2·16	63
<i>Somerset</i>	Taunton ...	0·19	9	<i>Kinross</i>	Loch Leven Sluice ...	1·85	65
<i>Glos.</i>	Cirencester ...	0·28	12	<i>Fife</i>	Leuchars Airfield ...	1·13	65
<i>Salop</i>	Church Stretton ...	0·63	27	<i>Perth</i>	Loch Dhu ...	2·53	34
"	Shrewsbury, Monkmore	0·44	28	"	Crieff, Strathearn Hyd.	1·54	44
<i>Worcs.</i>	Malvern, Free Library ...	0·29	16	"	Pitlochry, Fincastle ...	1·87	64
<i>Warwick</i>	Birmingham, Edgbaston	0·52	28	<i>Angus</i>	Montrose, Sunnyside ...	1·64	89
<i>Leics.</i>	Thornton Reservoir ...	0·51	31	<i>Aberd.</i>	Braemar ...	2·27	80
<i>Lincs.</i>	Boston, Skirbeck ...	0·90	62	"	Dyce, Craibstone ...	1·78	78
"	Skegness, Marine Gdns.	1·56	102	"	New Deer School House	2·30	108
<i>Notts.</i>	Mansfield, Carr Bank ...	0·72	37	<i>Moray</i>	Gordon Castle ...	2·28	119
<i>Derby</i>	Buxton, Terrace Slopes	1·48	39	<i>Nairn</i>	Nairn, Achareidh ...	1·40	86
<i>Ches.</i>	Bidston Observatory ...	0·19	11	<i>Inverness</i>	Loch Ness, Garthbeg ...	3·19	92
"	Manchester, Ringway ...	0·59	41	"	L. Hourn, Kinlochourn	7·38	74
<i>Lancs.</i>	Stonyhurst College ...	0·98	29	"	Fort William, Teviot ...	4·28	57
"	Squires Gate ...	0·41	19	"	Skye, Broadford ...	4·43	69
<i>Yorks.</i>	Wakefield, Clarence Pk.	1·03	60	"	Skye, Duntuilum ...	2·94	64
"	Hull, Pearson Park ...	1·95	117	<i>R. &amp; C.</i>	Tain, Mayfield ...	1·79	78
"	Felixkirk, Mt. St. John ...	2·21	131	"	Inverbroom, Glackour ...	4·98	98
"	York Museum ...	1·50	99	"	Achnashellach ...	6·76	98
"	Scarborough ...	3·07	183	<i>Suth.</i>	Lochinver, Bank Ho. ...	3·22	80
"	Middlesbrough ...	1·80	138	<i>Caith.</i>	Wick Airfield ...	1·84	81
"	Baldersdale, Hury Res.	2·23	76	<i>Shetland</i>	Lerwick Observatory ...	1·32	42
<i>Nor'l'd.</i>	Newcastle, Leazes Pk. ...	2·50	163	<i>Ferm.</i>	Crom Castle ...	1·52	52
"	Bellingham, High Green	2·16	85	<i>Armagh</i>	Armagh Observatory ...	1·07	48
"	Lilburn Tower Gdns. ...	2·64	133	<i>Down</i>	Seaford ...	1·10	36
<i>Cumb.</i>	Geltsdale ...	1·64	63	<i>Antrim</i>	Aldergrove Airfield ...	1·19	49
"	Keswick, High Hill ...	0·78	16	"	Ballymena, Harryville ...	1·37	42
"	Ravenglass, The Grove	0·55	18	<i>L'derry</i>	Garvagh, Moneydig ...	1·48	47
<i>Mon.</i>	A'gavenny, Plás Derwen	0·35	10	"	Londonderry, Creggan	2·25	71
<i>Glam.</i>	Ystalyfera, Wern House	0·54	11	<i>Tyrone</i>	Omagh, Edenfel ...	2·20	74

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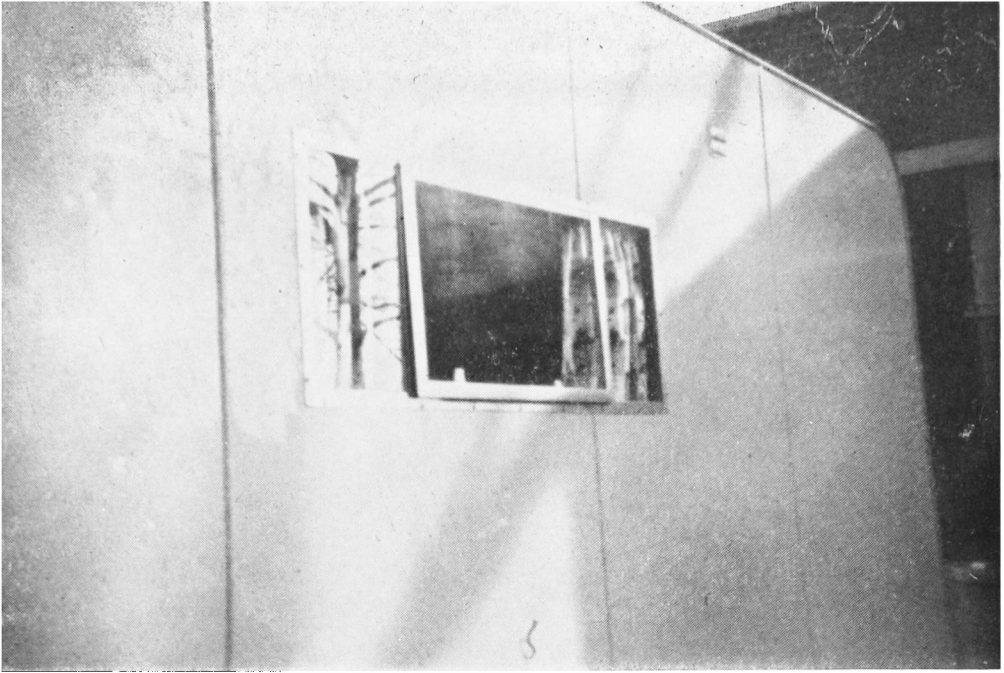
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