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EVIDENCE FOR A STRATOSPHERIC CIRCULATION IN VERTICAL MERIDIONAL PLANES BETWEEN POLAR AND EQUATORIAL REGIONS IN WINTER

By L. S. CLARKSON, M.Sc.

Introduction.—A series of cross-sections through the atmosphere has been published in recent years depicting the distribution with latitude and height along selected meridians of the seasonal means of radio-sonde observations of virtual temperature[1–5]. The mean tropopause shown on most of these cross-sections has been defined, for consistency with the spatial distribution of temperature, as lying at that height at which the mean temperature reaches a minimum in the vertical.

In this paper it is shown that a detailed examination, of the parts of the cross-sections which show seasonal mean temperatures and tropopause heights over equatorial regions, reveals phenomena which are most readily interpreted as being the result of a relatively greater subsidence occurring in the lower equatorial stratosphere in July–August than in January–February.

All available upper air observations from the southern-hemisphere polar regions have been considered, and, after a discussion of insolation errors, various explanations previously proposed to account for the relatively cold antarctic stratosphere observed in winter are examined. It is concluded that none of these is entirely acceptable separately, and that the phenomenon is at least partly to be attributed to relatively greater slow mass ascent occurring in the antarctic stratosphere in July–August than in the arctic stratosphere in January–February.

Further evidence for this conclusion is found from consideration of the published observations of the seasonal variation in the height of the polar tropopause and from a comparison of mean stratospheric temperatures over the poles and the equator.

Finally, the relative subsidence in the lower equatorial stratosphere and the relative ascent in the antarctic stratosphere, deduced earlier as simultaneously occurring in the southern-hemisphere winter season, are considered related in so far as they represent localized features of a general meridional circulation in the stratosphere between polar and equatorial regions in winter. Reference is made to additional and independent evidence for a circulation of this nature contained in publications by Brewer[6], Priestley[7] and Goldie[8].

Equatorial stratosphere and tropopause.—Fig. 1 is a reproduction of isotherms and tropopause heights from Hutchings's cross-sections. In latitude 15°S. at 20 Km. the mean temperature of the lower stratosphere is shown as

—60°C. in July–August and —78°C. in January–February. These figures are confirmed by reference to the tabulated means of radio-sonde temperatures at 20 Km. from Espiritu Santo (15°31′S., 167°13′E.) in July and Vila (17°44′S., 168°19′E.) in February[1]. Thus at 20 Km. the equatorial stratosphere is approximately 20°C. warmer in July–August than in January–February. A similar inference may be drawn from the cross-sections along the 80°W. meridian published by Hess[2]. It has been stated that the stratosphere over Batavia is coldest in January[9], and the Upper Air Climatology Branch of the Meterological Office reports that available evidence from Nairobi indicates an equatorial stratosphere slightly cooler in January than in July[10].

There is also a seasonal variation in the mean tropopause height over equatorial regions. In Fig. 2 the left-hand side depicts the seasonal change in the southern hemisphere along the 170°E. meridian as extracted from Hutchings's cross-sections[1], while the right-hand portion has been taken from Hess's northern-hemisphere cross-section[2] along the 80°W. meridian. These two independently obtained sets of results, when brought into juxtaposition, are seen to be in unison with each other in indicating that the tropopause over the equator is 2 Km. lower in July–August than in January–February. Also at both Nairobi and Aden the frequency of very high tropopauses is greater from December to February than from June to August[10].

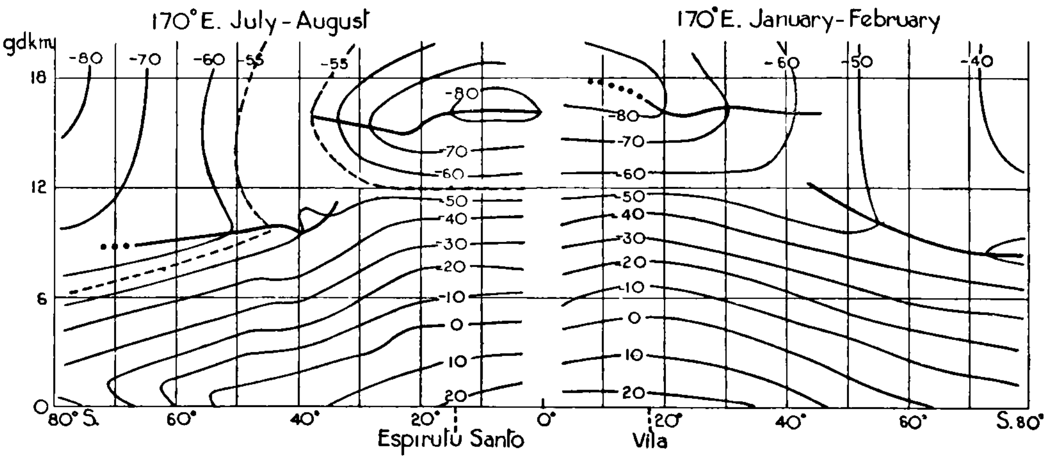

FIG. 1—CROSS-SECTION SHOWING ISOTHERMS (°C.) AND TROPOPAUSE HEIGHTS[1]

Thus the available radio-sonde observations combine to indicate a warmer stratosphere and a lower tropopause over the equator in July–August than in January–February. It is interesting to consider the most probable physical explanation of these facts.

It is generally accepted that at any level in the stratosphere the mean temperature is primarily determined by that equilibrium value at which the emission and absorption of radiation are equal[11]. Except at great heights of the order of 35–40 Km. the atmosphere is but slightly warmed by the direct absorption of short-wave incoming solar radiation. In fact, the lower stratosphere is warmed through the absorption of long-wave outgoing terrestrial radiation by those atmospheric constituents with absorption spectra in the appropriate part of the infra-red spectrum, namely carbon dioxide, water vapour, and ozone. Of these, Dobson[12] has emphasized the importance of ozone, present in low concentration, but possessing an intense absorption band in a region of the infra-red spectrum in which both carbon dioxide and water vapour are transparent.

In the lower equatorial stratosphere at, say, 20 Km. the absorption of long-wave radiation depends on the concentration at this level of water vapour, carbon dioxide, and, more particularly, ozone. Now the water vapour and carbon dioxide concentrations are unlikely to depend on whether the sun is overhead at Cancer or at Capricorn. With regard to ozone, spectroscopic measurements have shown that at the equator the total amount of this gas in a vertical column is seasonally fairly constant. However, such measurements have also shown that in the lower stratosphere the concentration of ozone increases with height[13] and with latitude[12]. Therefore any variation in mean meridional flow or in mean vertical motion from one solstice to the other will alter the mean seasonal

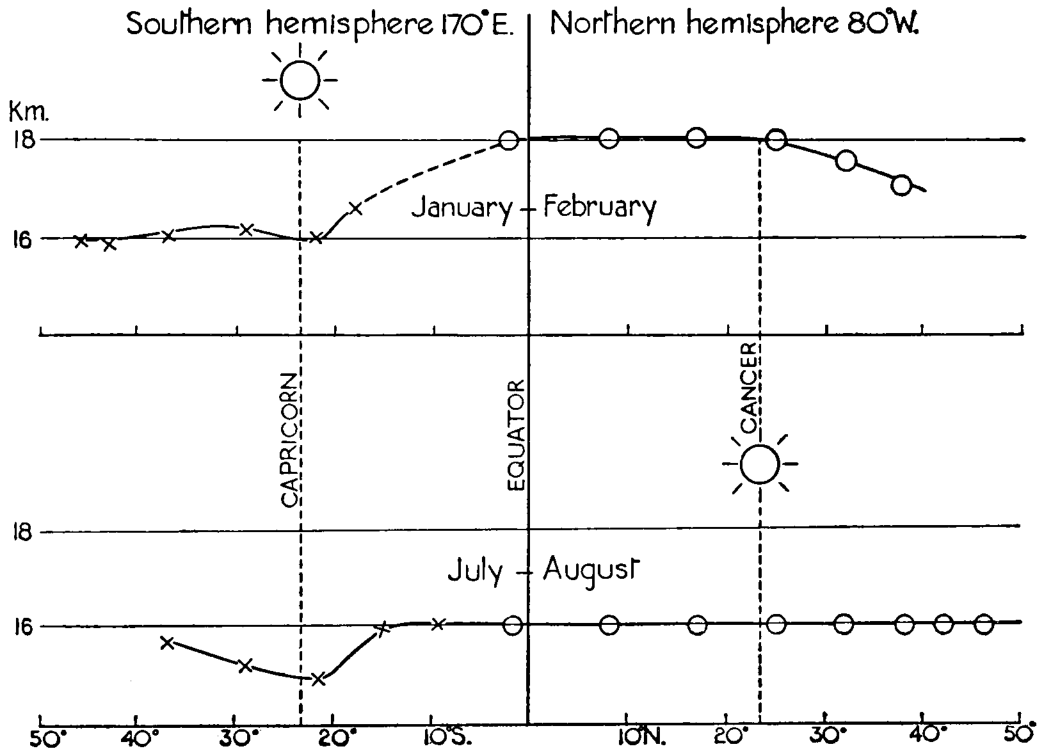

FIG. 2—SEASONAL VARIATION OF TROPICAL TROPOPAUSE HEIGHT

o — mean data from stations near the 80°W. meridian[2]
x — mean data from stations near the 170°E. meridian[1]

ozone concentration at this level. But the mean flow in the lower stratosphere over the equator is almost entirely zonal, so that any seasonal variation in the meridional component must be extremely small. There remains only the possibility of a seasonal variation in mean vertical motion affecting the ozone concentration, and hence the absorptive power of the atmosphere at 20 Km. over the equator.

The intensity of the stream of long-wave radiation reaching the stratosphere is dependent upon the temperature and water-vapour content of the air in the tropopause, and upon the temperature of the earth's surface beneath. These factors vary very little from one season to the other in equatorial regions[1-3].

The observed rise in mean temperature at 20 Km. from January–February to July–August, if entirely due to radiative effects, must therefore be caused by an increased absorptive power of the atmosphere at this level, which in turn can occur only through an increase in ozone concentration. And it has been shown above that such an ozone-concentration increase can most easily be explained by the downward component of the mean vertical motion being algebraically greater in July–August than in January–February; that is by relatively greater subsidence or lesser ascent in the southern-hemisphere winter season.

The thermodynamic effects of a seasonal variation in vertical motion such as that outlined would also contribute to an increase in the 20-Km. temperature from January–February to July–August, reinforcing the radiative increase, and further, would account qualitatively for the observed seasonal lowering of the equatorial tropopause inversion.

Polar stratosphere and tropopause.—Turning now to the antarctic, over 300 radio-sonde ascents obtained during the Byrd expeditions in summer seasons are available, together with the 18 *Schwabenland* ascents near latitude 68°S. in January and February 1939[5], and the data for summer and winter seasons of 1940–41 from Little America (78°34′S., 163°56′W.) on the Ross Ice Shelf, as quoted by Hutchings, Loewe and Radok, and Flohn.

Insolational errors.—Before considering these results, it is necessary to discuss the probable magnitude of errors introduced into the temperature means through insolation of the recording instruments, since in polar regions in summer the ascents necessarily cannot take place in darkness. In this connexion, Flohn[5] compared a series of ascents from the *Schwabenland* at about 69°S., approximately half of which took place with a solar elevation of 30°, and half with the sun only 4° above the horizon. From the comparison he found that a nomogram due to Väisälä[15], giving the insolational error of Finnish radio-sondes in terms of solar elevation and pressure below 200 mb., is also applicable to the Lange sonde flown from the *Schwabenland*, and that the errors in the uncorrected Little America summer ascents result in an apparent mean summer inversion in the stratosphere of 0·6–0·8°C./Km., whereas the inversion after correction for insolational heating is 0·3–0·4°C./Km. for the *Schwabenland* data, and also for Tromsø, Spitsbergen and Point Barrow in the arctic. It is understood that the Little America data agree with radio-sonde observations obtained more recently by the Anglo-Scandinavian Expedition to Maudheim. They are also consistent with the more extensive means available for lower southern-hemisphere latitudes, and so may be regarded as representative of mean conditions in south polar regions, except that the summer averages incorporate the insolational error to which reference has been made above.

Relatively cold antarctic stratosphere in winter.—In winter the antarctic stratosphere is markedly colder than at corresponding levels in the arctic. Little America, with a mean temperature at 14 Km. in winter of −78°C., is about 15°C. colder than Franz Joseph Land at the same height (Fig. 3), and 20°C. colder than Point Barrow and Arctic Bay[1].

It is interesting to consider those known differences in conditions between north and south polar regions which could contribute to the observed much colder winter stratosphere over the south pole.

Court[16] gives some attention to this point. Referring to the earlier views of Bjerknes and Simpson, he points out that the southern-hemisphere circulation is of a more truly zonal character than that in the northern hemisphere. This

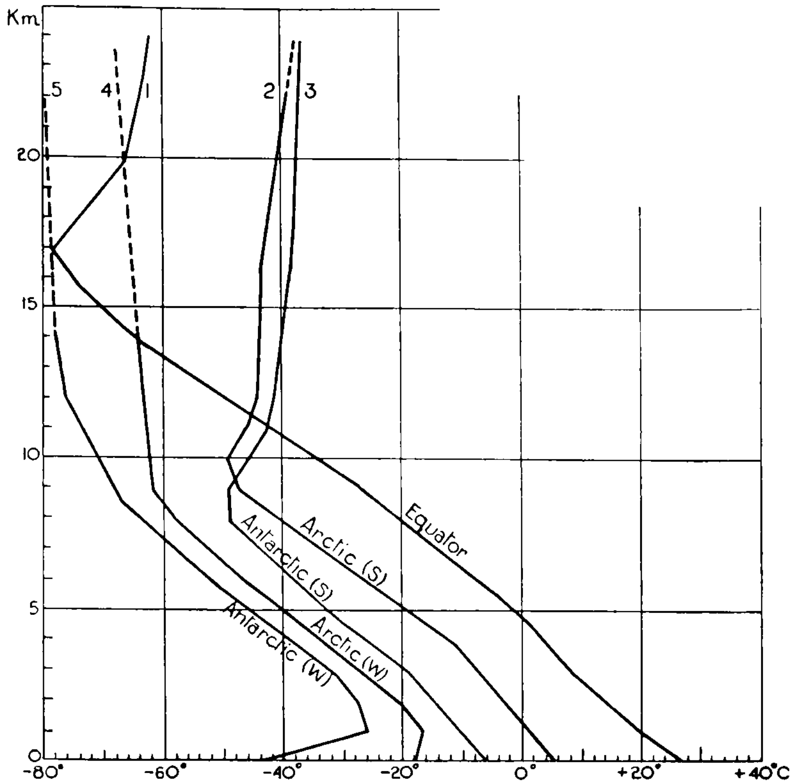

FIG. 3—MEAN TEMPERATURE-HEIGHT CURVES[5]

1 — Equator (annual mean)
2 — Spitsbergen 79°N. (summer)
3 — Little America 78°S. (summer)
4 — Franz Joseph Land 80°N. (winter)
5 — Little America 78°S. (winter)

view is accepted by Flohn[5], and indeed the close correspondence in latitudinal location of significant features shown in the published southern-hemisphere cross-sections along widely differing meridians is strong confirmatory evidence.

This being the case, it follows that the quasi-zonal mean circulation of the southern hemisphere permits of a lesser rate of meridional heat exchange between polar and subtropical latitudes than in the northern hemisphere. Hence it is to be expected that the atmosphere in the antarctic will be colder, and in the mid-latitude zones warmer, than in the northern hemisphere. But available data show that in summer the mean temperature of the southern-hemisphere troposphere up to 500 mb. is 7·5°C. lower in latitude 45° than in the northern hemisphere. This is clearly illustrated in Fig. 4 in which the mean thickness curves for the northern hemisphere, shown by the pecked lines, have been derived by Flohn from circumpolar charts of the 1000–500-mb. relative topography for summer and winter. These charts were plotted in 1943, but have been constantly amended, embracing all the existing aerological material, while the corresponding curves for the southern hemisphere have been drawn by the author from the *Schwabenland* data, together with results obtained by Loewe and Radok and by the fourth Byrd expedition as quoted in Tables 5, 21 and 19 respectively of Flohn's paper[5].

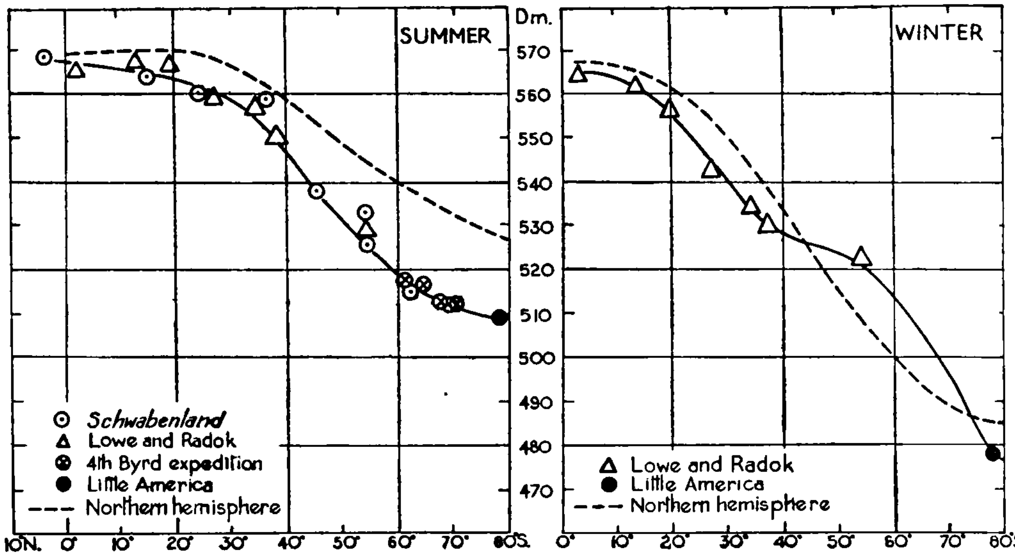

FIG. 4—1000–500-MB. THICKNESS TOPOGRAPHY

A thickness difference of 10 Dm. is equivalent to a mean temperature difference of the 1000–500-mb. layer of 5°C.

The discrepancy between the predictions based on a lesser southern-hemisphere mean meridional rate of heat transfer and actuality is (so far as the colder southern-hemisphere summer troposphere is concerned) usually explained in terms of the greater heat capacity of the more extensive southern-hemisphere oceanic area. But Loewe and Radok[3] point out that this explanation is not acceptable, since the heat stored in the oceans in summer would be returned to the atmosphere in winter, yet in winter, as may be seen from Fig. 4, mean tropospheric temperatures in both hemispheres in middle latitudes are much the same. Instead, Loewe and Radok consider that the colder southern-hemisphere summer troposphere is due to its greater mean cloudiness and consequently greater albedo.

The fact remains that the middle latitudes of the southern-hemisphere troposphere are colder in summer than corresponding zones in the northern hemisphere, and of about the same temperature in winter as the northern-hemisphere counterpart (Fig. 4). Even when current explanations are taken into account, this fact cannot be regarded as supporting the contention that there is a lesser meridional heat exchange in the southern-hemisphere general circulation.

Further, were the much colder winter antarctic stratosphere really due to a relatively isolated south polar circulation, then by the same argument, in summer, lesser lateral mixing with the colder stratospheric air of lower latitudes would, other things being equal, result in an appreciably warmer antarctic than arctic summer stratosphere, whereas in fact, when allowance is made for the Little America summer means being uncorrected for insolational error, Fig. 3 shows that there is very little observed temperature difference.

Court also points out that, in contrast to the arctic, the antarctic continent is a glaciated land mass, so that in north polar regions infra-red radiation from the relatively warm Arctic Ocean passing unabsorbed through the thin ice sheet may be the differential factor required to account for the markedly warmer winter arctic stratosphere. Flohn gives qualified support to this suggestion, which, however, cannot be regarded as completely acceptable until more is known about the infra-red absorption spectrum of ice.

Of course, the fact that the mean winter surface temperature at Little America in the antarctic is −44°C. compared with −18°C. at Franz Joseph Land and −24°C. at Point Barrow in the arctic inevitably means that the energy contained in the heat radiation leaving the antarctic surface is only about 70 per cent. of that originating from the surface in the arctic. But of the long-wave-length radiant energy reaching the respective stratospheres, that part distributed amongst wave-lengths capable of absorption by carbon dioxide and water vapour will be much more nearly equal, since this part of the terrestrial-radiation stream will have been absorbed and re-emitted by the carbon dioxide and water vapour in the respective tropospheres, where the mean temperatures are much less different than at the surface.

The basic question is thus primarily whether the difference in that undiluted fraction of the total radiation, originating at the surface, entering the stratosphere, and distributed amongst wave-lengths capable of absorption by ozone but not by carbon dioxide or water vapour, is sufficient by itself to account entirely for the 15–20°C. lower antarctic than arctic winter stratospheric temperature. In this connexion it is helpful to consider the significance of the very large seasonal range in antarctic stratospheric temperature compared with that at corresponding heights in the arctic. At 14 Km. at Little America the seasonal range is 39°C., whereas at Point Barrow and Arctic Bay the range is only 12–13°C. At the surface in the antarctic the range is again 39°C. and in the arctic 24°C. (Fig. 3). Thus, in the arctic the 14-Km. stratospheric seasonal temperature increase is approximately half that at the surface, whereas in the antarctic it is the same. These facts suggest that the seasonal variations in intensity of that fraction of the terrestrial radiation reaching the stratosphere, if sufficient to account for the arctic seasonal temperature range in the stratosphere, are, *inter alia*, insufficient to explain the proportionally much larger range in the antarctic stratosphere.

At this stage it is suggested that slow mass ascent in the antarctic stratosphere in winter, more pronounced than in the arctic, may be a fourth differential factor. Such a phenomenon would result in a relatively lower winter radiative-equilibrium temperature, since it would reduce the concentration of ozone at a given height in the lower stratosphere[17], and this radiatively produced temperature difference would be augmented by the additional cooling through adiabatic expansion of the air feeding the more pronounced ascent as it converges from higher latitudes into the polar winter high-level cyclone.

Polar tropopause.—Court[16] has discussed the winter ascents made at Little America in detail, emphasizing the observed lifting of the tropopause inversion in autumn, and its eventual complete disappearance towards the end of the winter. The increase in height of the antarctic tropopause from summer to winter is also remarked on by Loewe and Radok[3], and is well illustrated by the seasonal mean temperature-height curves in Fig. 3 taken from Flohn's paper. A similar though smaller effect has been detected in the arctic, at Abisko and at Mount Evans by Möller[18] and Ferguson[19].

These observations strongly suggest that mass ascent is taking place in the polar stratospheres in winter, for the thermodynamically produced temperature changes occasioned by ascent of a stratospheric air column must result in the base of the inversion therein being lifted, and eventually, in the inversion itself being converted into a temperature lapse[20]. This conversion is in accordance with observations, which show that, after correction for insolational error, a temperature inversion definitely characterizes the summer polar stratosphere over Tromsø, Point Barrow, Spitsbergen and the *Schwabenland*, whereas in winter a temperature lapse of 0·5–1·0°C./Km. is found at Franz Joseph Land and Little America (Fig. 3). This winter mass ascent will be relatively more pronounced in the antarctic, for here the tropopause is eventually completely destroyed[16], whereas in the arctic it is normally still detectable even at the end of the winter season.

Furthermore, the abnormally large seasonal range in antarctic stratospheric temperature, which we have maintained is not fully accountable in terms solely of the seasonal flux in outgoing terrestrial radiation, becomes understandable if augmented by a thermodynamical process involving a seasonal variation in mean vertical motion of the nature of that already outlined.

Mean stratospheric temperatures over poles and equator.—In Fig. 3 Flohn has carefully extrapolated the mean winter temperature-height curves for Little America and Franz Joseph Land above 14 Km., adopting for this a lapse rate of 0·5–1·0°C./Km., the same as that actually observed in mean winter observations to 17–20 Km. at Tromsø and Point Barrow. It may be seen that temperatures in the winter antarctic stratosphere are lower than at equivalent levels over the equator. Now Dobson[12] has noted that despite the lesser outgoing terrestrial radiation, the stratosphere is normally warmer in high latitudes than near the equator. This normal tendency is well illustrated by the mean summer cross-section in Fig. 1, and is explained by Dobson as being due to the observed fact that in the higher latitudes mean ozone amounts are much greater than near the equator, so that the thereby increased absorptive power of the high-latitude stratosphere over-compensates for the decreased intensity of the outgoing long-wave radiation stream, and results in the normally observed increase in mean stratospheric temperature from equator to pole. Only in the winter antarctic stratosphere, where temperatures are lower than at corresponding heights over the equator, is an exception found; and, unless the observed mean increase in ozone content with increasing latitude is suddenly reversed in winter in just these regions from whence spectroscopic measurements are either lacking or inaccurate* (namely, polewards of about latitude 70°), it must be assumed that the purely radiative control of mean winter antarctic stratospheric temperature is modified by thermodynamic cooling resulting from slow mass ascent in this region.

Inferred circulation in the stratosphere.—It is significant that the more pronounced polar ascent deduced as occurring in July–August (the antarctic winter) takes place in the same months as the more pronounced subsidence in the equatorial stratosphere. It seems likely that both are part of a general stratospheric circulation in vertical meridional planes between poles and equator, as indicated in diagramatic form in Fig. 5.

*At the Royal Meteorological Society discussion on the stratosphere, held in February 1951, Dobson stated that recent ozone measurements by means of spectroscopic analysis of starlight and moonlight at Tromsø show low ozone amounts in winter[21], but such observations are in his opinion not yet reliable, because of the low intensity of the light sources necessarily used.

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Photograph by the late Mr. M. C. Gillman

HEAVY CUMULUS DISPERSING TOWARDS SUNSET
(see p. 337)

Photograph by the late Mr. M. C. Gillman

HEAVY CUMULUS MERGING INTO A BANK OF CIRROSTRATUS
(see p. 337)

As a result of the thermodynamic and radiational effects of this circulation an otherwise apparently unrelated series of observations now falls into place as the natural consequence of one single mechanism.

Some slight evidence for the high-level quasi-horizontal part of this circulation is provided by Hoffmeister's determination[22] of winds at great heights from observations of meteor trails in the northern hemisphere. Goldie[23] has found that these winds show a mean meridional component from winter pole to equator.

The mean lower-level meridional air flow needed to complete that part of the stratospheric circulation for which evidence has been put forward in this paper has been inferred by Brewer[6], mainly from consideration of the vertical distribution of helium and water vapour in the lower stratosphere. It consists of a mean meridional drift of air from the subtropical upper troposphere polewards in the stratosphere, and then downwards into the temperate and polar troposphere, as indicated by the pecked arrows in Fig. 5. Further, Priestley[7] considers a mean poleward drift of this nature is necessary to preserve the balance in angular momentum across latitudes 30–35°.

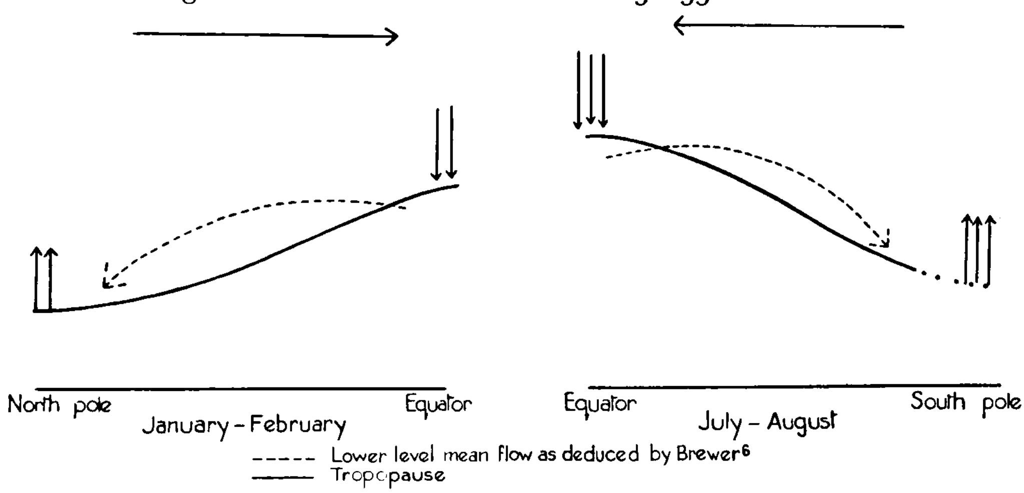

FIG. 5—STRATOSPHERIC CIRCULATION, WINTER SEASON

Goldie[8] has deduced, from density considerations, a world circulation in vertical meridional planes for both winter and summer seasons and covering a range of height from the surface to 45 Km., which is consistent with the requirements of the Bjerknes circulation theorem, and is independently supported by the results of humidity observations in the stratosphere over England. That part of Goldie's circulation relevant to the winter hemisphere between 12 and 28 Km. is similar to the one outlined in Fig. 5, and for which independent evidence has been advanced in this paper.

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METEOROLOGICAL EXAMINATIONS FOR CIVIL PILOTS AND NAVIGATORS

By A. F. CROSSLEY, M.A.

In the interests of safe flying, the licensing of the pilots and other members of the operating crew of aircraft is a means of ensuring that they are fully qualified, in respect of skill, knowledge, experience and medical fitness, to perform their several functions. Minimum standards of qualification have been agreed internationally through the International Civil Aviation Organization, and these standards, together with such additional requirements as are considered necessary in the conditions obtaining in the United Kingdom, have been embodied in the Air Navigation Order 1949, and in the Air Navigation (General) Regulations 1949, which prescribe the licences to be held by the members of the crews of aircraft registered in the United Kingdom.

Types and privileges of licences.—There are separate licences for the pilots of flying machines, gliders, airships and balloons, but in present conditions only the first of these categories is of sufficient meteorological interest to be considered in this note. A flying machine is defined as any power-driven heavier-than-air aircraft, and besides aeroplanes the term includes helicopters, gyroplanes and ornithopters or flapping-wing aircraft (although none of the last exist); each of these kinds of flying machine comprises land, sea and amphibian classes. Originally there were only two pilots' licences for flying machines, the Class " A " and the Class " B ", but with the introduction of the present regulations in April 1949, the Class " A " was replaced by the present Private Pilot's Licence, and the Class " B " by three different categories of

Professional Pilots' Licences, which are obtained after differing requirements have been met, and entitle the holders to correspondingly graduated privileges. Including the learner's or Student Pilot's Licence, there are five pilots' licences in all; these are listed below in ascending order of qualifications required, with an indication of the main privileges conferred by them. In addition there is a licence for navigators.

Student Pilot's Licence.—This is for a person who is still learning to fly, but who has already reached the stage of flying in sole charge of a flying machine. He does his flying only under the orders of a qualified instructor, and is not allowed to carry passengers.

Private Pilot's Licence.—This entitles the holder to fly "private" aircraft only, and excludes flying an aircraft for any remunerative purpose. Passengers may be carried.

The next three categories are known collectively as Professional Pilots' Licences, and are primarily for the pilots of flying machines which are being used for purposes of remuneration.

Commercial Pilot's Licence.—This entitles the holder to fly as pilot-in-charge of a public transport aircraft of authorized all-up weight not exceeding 12,500 lb. provided it is not engaged on a "scheduled" journey, i.e. part of a systematic service. The restriction on weight is relaxed when the pilot is flying other than public transport aircraft, or when flying as second pilot on a public transport aircraft, or when flying any aircraft on a non-scheduled journey.

Senior Commercial Pilot's Licence.—This entitles the holder to fly as pilot-in-charge of a public transport aircraft of authorized all-up weight up to 15,000 lb. with passengers, or up to 30,000 lb. if passengers are not carried. These restrictions are relaxed when the holder is flying as second pilot, or when he is in charge of other than public transport aircraft.

Airline Transport Pilot's Licence.—This entitles the holder to fly as pilot-in-charge of a public transport or other aircraft without restriction as to authorized weight, carriage of passengers or type of journey.

Flight Navigator's Licence.—This entitles the holder to fly as navigator on any flight for which the regulations require a qualified navigator to be carried. This requirement applies to flights by public transport aircraft extending 1,000 miles or more over water, or 1,500 miles or more over land. Frequently a Flight Navigator's Licence is held by the first or second pilot.

The licences either include or may be supplemented by various " ratings " defining more closely the activities which may be undertaken by the pilot. Thus all flying licences include an Aircraft Rating specifying the kinds of aircraft which the holder of the licence is entitled to fly in his capacity either as pilot-in-charge or as second pilot. To take another case, a private pilot may obtain a Night Rating empowering him to carry passengers at night, or a Towing Rating if he wishes to tow a glider, and so on. The only rating of any direct meteorological concern is the Instrument Rating which must be obtained before a pilot can fly in conditions which may necessitate instrument flying; it is supplementary to the Private and Commercial Pilots' Licences, involving a separate examination, but with the Senior Commercial and Airline Transport

Pilots' Licences the holding of this rating is compulsory, and it accordingly forms an integral part of these licences.

Instrument Rating.—The holding of this rating qualifies a pilot to fly in Control Areas and Zones under Instrument Flight Rules.

Technical examinations.—The flying licences and instrument rating described above are granted to applicants reaching the requisite standards of flying skill, flying experience, technical knowledge and medical fitness. The authority for granting a licence in this country is the Licensing Section of the Ministry of Civil Aviation. Flying tests are carried out in the main by staff of the M.C.A. Flying Unit at Stansted, Essex, while the technical examinations are conducted at M.C.A. Headquarters by the Training Branches with the assistance of some permanently attached Meteorological Office staff. The subjects for the senior licences include the following: astronomical navigation*, aviation law, form of the earth and aeronautical charts, flight navigation, flight operations†, instruments, meteorology, signals†, and aircraft technical knowledge†. The examinations take the form of written papers and oral tests, and are of a standard commensurate with the privileges conferred by the several licences. Examinations are normally held in London in alternate months for the Senior Commercial Pilots' and higher licences, and in every month for the other licences.

Examinations in meteorology.—Five different levels of examinations are conducted in meteorology. The lowest level is that for the Private Pilot's Licence (there is no technical examination for the Student Pilot's Licence), while at the highest level the standards for the Airline Transport Pilot's Licence and the Flight Navigator's Licence are identical, at least in British practice; further, the standard for the Instrument Rating, when taken as a separate examination, is intermediate between that for the Commercial and that for the Senior Commercial Pilots' Licences.

The examination in meteorology for the Private Pilot's Licence consists of a so-called " objective " or multiple-choice test; for each question, the candidate merely has to state which of three or four suggested answers is the correct one. Once a stock of questions and answers has been compiled, the setting and marking of the papers becomes a routine affair and is conducted by non-meteorological staff.

For the Commercial Pilot's Licence there is a written paper consisting of a number of short questions some of which relate to a synoptic chart, while for the senior licences there are both written and practical papers. The written papers include questions on physical meteorology and its application to aviation, on climatology, and on the meteorological organization and procedures for aviation. The practical examination comprises the plotting of observations from coded data on a partly prepared synoptic chart, the insertion of isobars and fronts (the analysed chart for the period 6 hours earlier being provided), the preparation of an elementary route forecast, and finally the answering of oral questions on the interpretation of the chart. Reference may be made to " Instructions for the preparation of weather maps " during the practical paper, but not when answering the oral questions.

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*Flight Navigators' Licence only. †Not required for Flight Navigators' Licence.

Two specimen theoretical papers are reproduced, one for the Commercial Pilot's Licence and the other for the Airline Transport Pilot's and Flight Navigator's Licences, which are of the same standard in meteorology. Both theoretical and practical papers for the Senior Commercial Pilot's Licence are similar in character to those for the Airline Transport Pilot's Licence although less detailed knowledge is required. Candidates for Instrument Rating take the same theoretical paper as for the Commercial Pilot's Licence, together with a practical paper as for the Senior Commercial Pilot's Licence. An indication of the relative standards in meteorology for the various licences is given by the total time allowed for the respective examinations, namely Commercial Pilot, 1 hr.; Instrument Rating, 2½ hr.; Senior Commercial Pilot, 4 hr.; Airline Transport Pilot and Flight Navigator, 5¼ hr.

To qualify in meteorology, as in most of the other subjects, a mark of 70 per cent. is required, although for the senior licences a mark not below 60 per cent. is accepted in not more than two subjects if the candidate nevertheless attains an average of 70 per cent. or more in the examination as a whole.

Training.—The Ministry of Civil Aviation is not responsible for the training of pilots and navigators, but only for ensuring as far as possible, by means of the examinations and flying tests, that the training in general reaches an adequate standard for the maintenance of safe flying. Training schools are maintained by the air transport corporations and by various other bodies, a list of which may be obtained if required from the Ministry. Close co-operation

(continued on p. 323)

COMMERCIAL PILOT'S LICENCE EXAMINATION

METEOROLOGY

Time allowed—1 hour

SECTION IV. METEOROLOGICAL ORGANIZATION

1. What are the arrangements for the Sub-area broadcasts of meteorological information in the United Kingdom?
2. What do you understand by the term POMAR? Say how and when it is used.
3. What is Regional QFF and what are its uses?
4. Say what action you would take, including information supplied by you, when requesting a flight forecast from a meteorological officer.
5. What cloud details are given in a message in the AERO code?

SECTION V. GENERAL METEOROLOGY

*1. Estimate the wind speed and direction at 2,000 ft. over SCILLY (49·9°N., 06·3°W.).

*2. What is the present weather (Code ww) reported at HONILEY (52·4°N., 01·7°W.)?

*3. What is the visibility in miles at PLYMOUTH (50·4°N., 04·1°W.)?

*4. Give three reasons for placing the cold front between VALLEY (53·3°N., 04·5°W.) and DUBLIN (53·4°N., 06·3°W.).

*5. Having left SILLOTH (54·9°N., 03·4°W.) at 0900 G.M.T. with altimeter set to QNH, what would be your altimeter error in feet on arrival at SHANNON (52·7°N., 08·9°W.) three hours later at the time of the chart? (assume 1 mb. = 30 ft.).

6. Describe, briefly, the diurnal variation in the wind between the surface and 1,500 ft.
7. Explain the formation of glazed ice on aircraft in flight.
8. How is advection fog formed? Give a typical meteorological situation that could give rise to advection fog.
9. What weather would you expect to experience during a passage of a " ridge of high pressure " across the British Isles?
10. Say what you can about the formation of stratocumulus cloud.

*Questions marked with an asterisk refer to a chart which is provided at the examination but is not reproduced here.

EXAMINATION FOR FLIGHT NAVIGATORS' AND AIRLINE TRANSPORT PILOTS' LICENCES

METEOROLOGY

PART II

Time allowed—3 hours Marks 250

INSTRUCTIONS

1. *Six Questions ONLY are to be attempted. Questions Nos. 1 and 2 are Compulsory.*
2. *Question No. 1 carries 50 marks, other questions carry 40 marks.*

Question No. 1 (Compulsory Question)

Write an account, from an aviator's point of view, of the climate of one of the following routes, giving special attention to seasonal variation:—

(*a*) ALGIERS (37°N., 3°E.)—KANO (12°N., 8°30′E.)—LAGOS(6°30′N., 30′E.)

(*b*) MARSEILLES (43°N., 5°E.)—MALTA (36°N., 14°30′E.)—CAIRO (30°N., 31°E.).

Question No. 2 (Compulsory Question)

Describe the arrangements in force whereby all meteorological offices in the United Kingdom have available to them full information as to weather reports, frontal structures and any other meteorological data necessary for the efficient functioning of the aviation forecasting service.

Question No. 3

Describe the weather normally associated with polar maritime air as it passes over the British Isles from north-west to south-east (*a*) in summer and (*b*) in winter.

What modifications would be expected if the air arrives over the British Isles from the south-west after being diverted over the Atlantic?

(Information on the geographical distribution of weather and the effects of diurnal variation should be included).

Question No. 4

Discuss the relationship between pressure gradient and wind showing how the gradient wind in a depression differs from that in an anticyclone.

Show also why, for a constant geostrophic wind, the spacing of the isobars differs with latitude and with temperature.

Question No. 5

Describe and account for the diurnal variation of radiation fog

(*a*) in winter

(*b*) in summer.

In the case of airfields located (i) in a valley and (ii) near a large town, explain the probable effects of such situations on the occurrence of fog.

Question No. 6

What do you understand by an " adiabatic change of temperature"? Under what natural circumstances can air be assumed to change temperature adiabatically?

If the adiabatic relationship between absolute temperature and pressure is:

$$\log T_1 - \log T_0 = 0{\cdot}288 (\log p_1 - \log p_0)$$

calculate the increase of temperature of a mass of air after descending from 500 mb. to 700 mb. if its initial temperature is -20°C.

Question No. 7

Write notes on two of the following:—

(*a*) Pressure-pattern flying.

(*b*) The effects of ocean currents on weather.

(*c*) Supercooled water.

Question No. 8

What do you understand by " convergence " at a front? ...

Explain the importance of convergence in relation to the rate of advance of

(*a*) warm fronts

(*b*) cold fronts.

Show, also, why no rain would be experienced during the passage of a front if the winds were strictly geostrophic.

is maintained between the Ministry of Civil Aviation and all interested parties in the aviation sphere on such matters as details of syllabi and the arrangements for examinations and flying texts.

The standard meteorological text-books in most frequent use by candidates are the " Meteorological handbook for pilots and navigators " for the lower licences, and Sutcliffe's " Meteorology for aviators " for the Senior Commercial Pilot's and higher licences. Both these books require to be supplemented by the " Air Pilot (United Kingdom)" Part II for information on meteorological organization and procedures; also for the Airline Transport Pilots' and Flight Navigators' Licences, a work such as Kendrew's " Climates of the continents " is required, even though this was not written for the purposes of aviation.

Publications.—Detailed information regarding the issue of licences for flying is contained in a series of pamphlets obtainable from His Majesty's Stationery Office; these are M.C.A.P. 40 " Flight navigator's licence ", M.C.A.P. 53 " Student pilot's and private pilot's licences ", M.C.A.P. 54 " Commercial pilot's licence ", M.C.A.P. 55 " Senior commercial and airline transport pilots' licences ", and M.C.A.P. 56 " The instrument rating ". For dates of examinations, amendments to the pamphlets and other matters, reference should be made to the current series of Information Circulars issued by the Ministry of Civil Aviation

ABRUPT SEASONAL CHANGES IN TROPOPAUSE LEVEL AND STRATOSPHERE TEMPERATURE AT HABBANIYA

By D. DEWAR, B.Sc.

An examination of radio-sonde ascents made at Habbaniya, Iraq (33°22'N., 43°34'E.) during 1948 showed that an abrupt change occurred in the tropopause pressure and temperature in June with another well marked change in October; during the summer months the tropopause was found to be at a considerably greater height than during the other months. Similar changes are shown by the data for 1949 and 1950, and it appears that during the summer months the upper air over Habbaniya follows a characteristically tropical régime with a high cold tropopause while during the remaining months a temperate régime prevails. The periods for which the tropical régime persisted during the different years were:—

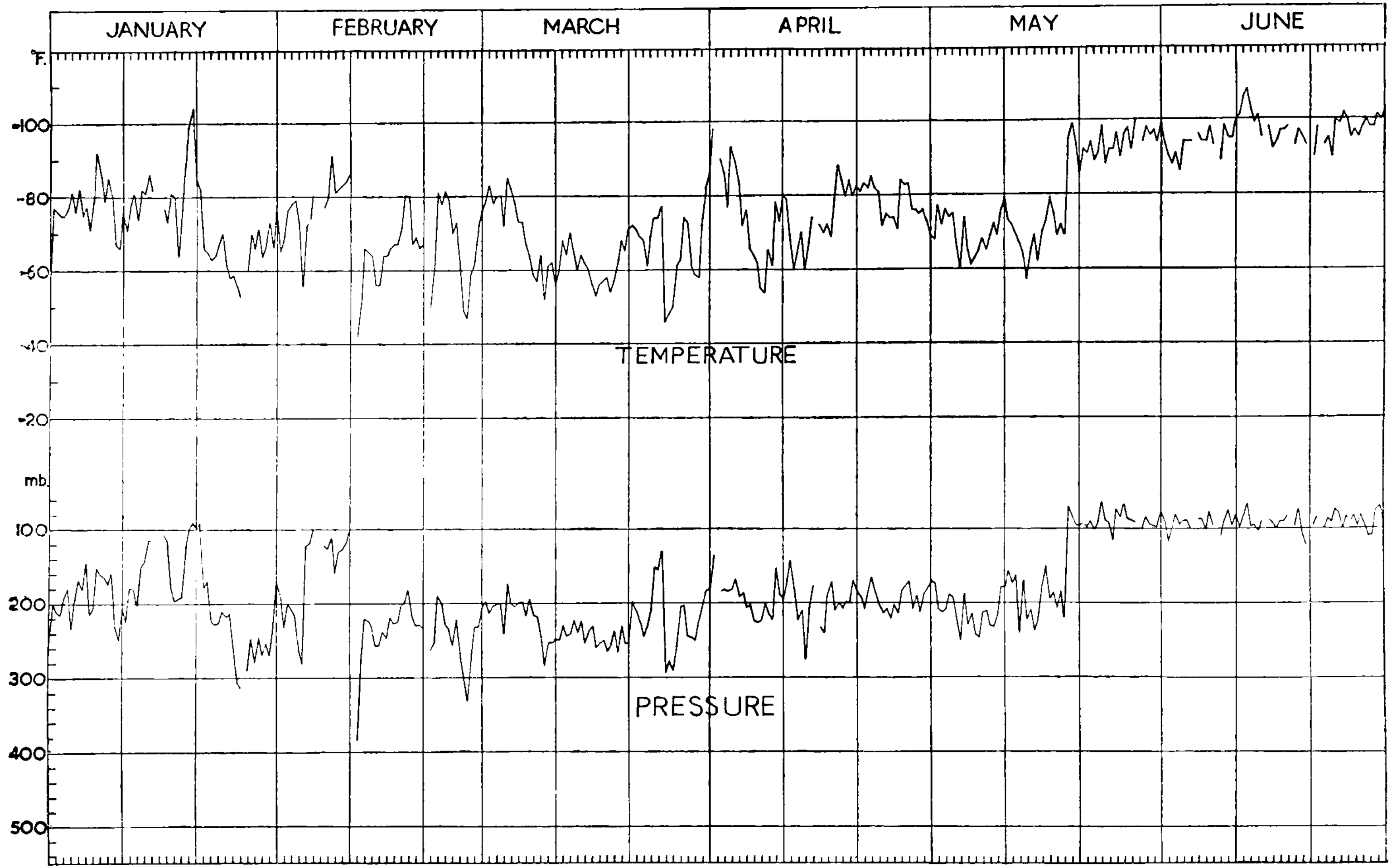
1948 June 9 to October 9

1949 May 11 to October 23

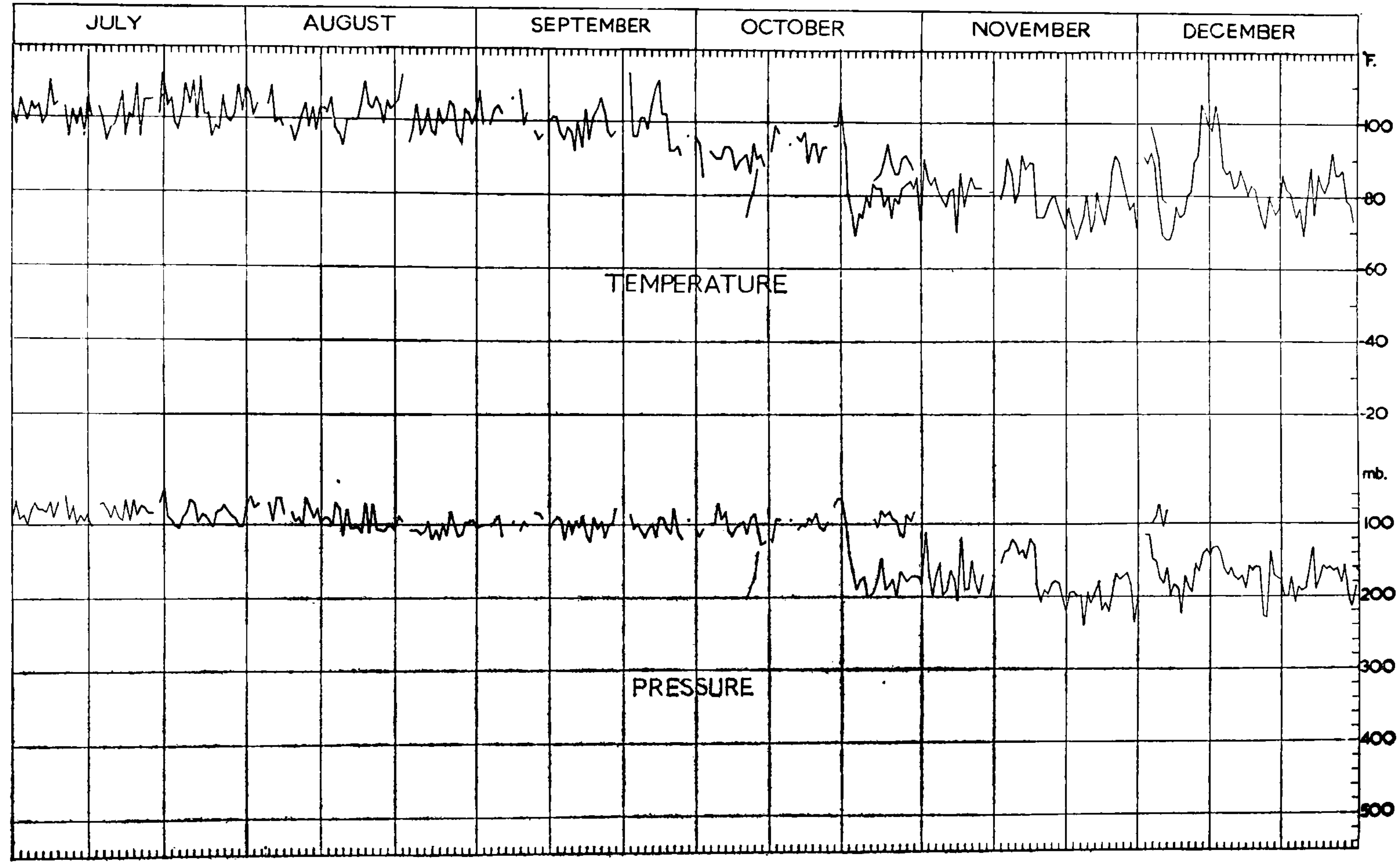
1950 May 19 to October 20

A graph of the daily values for 1950 is given on pp. 324 and 325. Ascents were made twice a day at approximately 0200 and 1400 G.M.T. but the tropopause was not always reached.

It will be noticed that two tropopauses are sometimes shown in October. From this month onwards stations were asked, when two tropopauses could be detected, to give data for both; before that date the ruling had been that for double tropopauses the data reported should refer to the first one reached. The graph suggests that double tropopauses often occur around the transition period, and probably throughout the winter half-year as has been found for stations in similar latitudes in Japan and Australia.



SEASONAL VARIATION OF THE TROPOPAUSE TEMPERATURE AND PRESSURE OVER HABBANIYA (33°22′N., 43°34′E.)
January–June 1950



SEASONAL VARIATION OF THE TROPOPAUSE TEMPERATURE AND PRESSURE OVER HABBANIYA (33°22′N. 43°34′E.)
July–December 1950

The correlation r between pressure and temperature at the tropopause and also the mean pressure $\overline{P}$ and temperature $\overline{T}$ and standard deviations σ_P, σ_T were computed for each régime using data for the three years, and the following values were obtained:—

	r	$\overline{P}$	σ_P	$\overline{T}$	σ_T
		mb.	mb.	°F.	°F.
Temperate régime	0·8	189·4	60·0	−74·2	12·4
Tropical régime	0·3	91·8	15·0	−99·7	6·3

They reveal a very interesting difference between the two régimes of upper air temperature; with temperate tropopauses there is a significant correlation between the pressure and the temperature at the tropopause and a considerable range of pressure and temperature values, while with tropical tropopauses there is a much smaller scatter of the values and no significant relation between temperature and pressure. Calculation of the standard errors confirms that these differences are without doubt significant.

GENERAL ASSEMBLY OF THE INTERNATIONAL UNION OF GEODESY AND GEOPHYSICS, BRUSSELS, 1951

By H. W. L. ABSALOM, B.Sc., D.I.C.

The International Union of Geodesy and Geophysics, comprising the International Associations of Geodesy, Seismology, Meteorology, Terrestrial Magnetism and Electricity, Physical Oceanography, Vulcanology and Hydrology, held its ninth general assembly from August 21 to September 1, 1951, in Brussels where the Union, along with other international scientific unions, was instituted in 1919. Some 950 delegates and guests from about 40 countries were present. The assembly, planned long in advance, covered a period two days longer than the assembly in Oslo in 1948. Certainly the period was one of sustained, usually concentrated, activity. Immediately preceding the assembly proper there were meetings in Brussels of the Joint Commission on Radio-Meteorology, of the International Union of Geodesy and Geophysics Commission on Radiation with the World Meteorological Organization Sub-Commission on Actinometry, and of the Joint Committee on the Physics of the Earth's Interior.

In the Free University, pleasantly located about two and a half miles from the centre of the city, provision was made for Union and Association offices and for most of the meetings. Here also, in the Cité Estudiantine, a number of delegates resided and many more availed themselves of restaurant facilities. The Belgian National Committee had arranged for firms from several countries to display geodetical and geophysical instruments in the Great Hall of the University.

The inaugural corporate gathering of the Union took place on the morning of August 21 in the Palais des Beaux-Arts in the city, when, in the presence of Queen Elisabeth of the Belgians, speeches of welcome were made by the President of the Royal Belgian Academy, the President of the Belgian National Committee for Geodesy and Geophysics, the Senior Alderman for Education, representing the Burgomaster of Brussels, and the Minister of Education. At the first plenary session which followed, the President, Dr. F. A. Vening-Meinesz, after reference to Union affairs discoursed on certain features of the conformation of the earth's crust. The General Secretary, Dr. J. M. Stagg, then summarized his report for 1948-50, drawing attention to the eight new member countries, the relations between the Union and other international organizations and the Union's financial indebtedness to U.N.E.S.C.O. to which it is affiliated through the International Council of Scientific Unions. After these collective preliminaries and participation of lunch in the imposing Salle de Marbre at the invitation of the Belgian National Committee, the seven individual Associations commenced their specialized yet wide-reaching activities. Their meetings that afternoon were held in rooms placed at their disposal in the nearby Palais des Académies.

The Associations, on a common basis in relation to the Union though differing among themselves in matters of internal structure and procedure, followed broadly the same type of programme during the assembly. Presentation and discussion of scientific papers occupied the greater part of the meeting time of all. Joint meetings were held by two or more Associations on subjects of common interest. Interspersed among these activities were others such as the hearing of reports from National Committees, the consideration of reports on international projects sponsored by Associations, consideration of representation on, or co-operation with, other international bodies, and the discussion of proposals and recommendations.

Association of Meteorology.—In his Presidential Address to the Association of Meteorology (I.A.M.) Prof. J. Bjerknes, in continuation of a contribution made by him at the Oslo meeting, referred to developments in our understanding of the general atmospheric circulation which have taken place since the presentation of Dr. H. Jeffreys's paper to the Association at Lisbon in 1933. He described recent work under his leadership in California on the transfer of angular momentum at levels up to the stratosphere in relation to the maintenance of the westerlies; work which would not have been possible without the regular upper air observations now available, nor practicable without the assistance of associate workers and computing machinery. The publication of this address will be welcomed by meteorologists.

The programme of the Association of Meteorology was noteworthy for prearranged symposia on main fields of research as follows, with names of chairmen:—cloud physics (Prof. T. Bergeron), radiation (Dr. A. Ångström), micrometeorology (Prof. O. G. Sutton), atmospheric ozone (Prof. G. M. B. Dobson), general circulation of the atmosphere and the oceans—jointly with the Association of Physical Oceanography (Prof. C.-G. Rossby and Prof. H. U. Sverdrup), and physics of the high atmosphere—jointly with the Association of Terrestrial Magnetism and Electricity (Prof. J. Kaplan). By the criterion of the countries of origin of the set contributions alone these symposia were satisfyingly international in character, with the British Commonwealth well represented. The number and length of set contributions at some sessions limited the time for general discusion; the symposia on cloud physics and general circulation each extended beyond the full day originally allotted. Regarded as a whole, these concerted discussions presented a comprehensive picture, with considerable detail, of the work which is in progress on the dynamical and physical processes in the atmosphere from the surface layer to great heights, and of advances achieved and foreshadowed by the application of the latest observational and theoretical techniques. There were joint discussions on evaporation at the surface of the earth and on microseisms with the Associations of Hydrology and Seismology, respectively. Concurrently with other meetings a day was devoted to the consideration of climatological and other topics.

During the meetings the Association of Meteorology learned from its Commission on Radiation of the work proceeding at Davos in the perfecting of instruments—in particular, a radiation-balance meter—and of the work at Uccle on filters. The Commission on Ozone, with headquarters at Oxford, reported that under its auspices the planned network of ozone stations in western Europe, including Iceland and the Azores, is nearly complete; and that ozone spectrophotometers are or will soon be in use in Afghanistan, India, Pakistan, New Zealand, the United States and Canada.

In an address on the subject of an international meteorological institute Prof. Rossby mentioned that an institute for advanced study and research is in process of formation in Stockholm and that it is hoped to secure staff from various countries. M. Viaut announced that a meteorological research centre will be established by the French Government in 1952 and that workers from other countries will be welcome.

An early evening visit to the Royal Belgian Meteorological Institute at Uccle Observatory enabled a numerous company to see the extensive radiation equipment in operation, the array of experimental rain-gauges and many other instruments, and the start of a radio-sonde ascent in which apparatus was carried to record the atmospheric electrical potential gradient. Those present will gratefully remember the hospitality dispensed alfresco by Dr. and Madame Lahaye and their helpers.

Association of Terrestrial Magnetism and Electricity.—A feature of the Association of Terrestrial Magnetism and Electricity is the activity maintained between assemblies by a number of Committees (fourteen at present) charged with the sponsorship of specific projects or general international co-ordination of various aspects of work with which the Association is concerned. Prof. S. Chapman's address as President ranged widely over the field covered by the Association: the development of the science and of international collaboration therein; the present scope, from the earth's core to the ionosphere, and the contacts with other branches of science; the increasing interest in the physics of the high atmosphere and the possibility of making specific provision for this within the Association; the main features of the work of Committees and suggestions concerning items to be considered during the assembly. The President referred to some recent developments. Observations of the daily variation of horizontal component of magnetic force made in low latitudes in America, Africa and India, at the instance of the Association, indicate the occurrence in the ionosphere (near the magnetic equator) in daylight hours of an intense eastward electric current—an electrojet—of small latitudinal breadth. The trend of the latest work on the earth's magnetism favours the view that the main field has its origin in electric currents in the earth's core, that changing eddies in the core give rise to subsidiary electric-current systems near the surface of the core and are responsible for anomalies in the earth's field and for its secular variation.

Turning from the main field of the earth there is now confirmation, from the auroral spectrum, of the theory long maintained that magnetic storms and auroræ are due to the ejection from the sun of some of its atmospheric gas. Records of the intensity of the earth's magnetic field obtained during recent rocket ascents in America have indicated the situation of the electric currents, due to solar wave radiation, which are responsible for the daily magnetic variation; further exploration by this means is highly desirable. Included among the subjects discussed at ensuing meetings were the development of magnetic airborne surveys in several countries, the physics of geomagnetic secular change, the variation with depth of the earth's magnetic field as shown by measurements in coal mines, the electrical conductivity of the earth's mantle or crust, the progress made in evaluating the lunar variation in the magnetic field and atmospheric pressure, an electrometer for atmospheric electrical measurements in conjunction with radio-sonde measurements and photo-electric registration in application to magnetographs. The valuable work of the Committee on Characterization of Magnetic Disturbance was noted. The three-hourly index (K) of the magnetic effects of solar-particle radiation and the more recently devised three-hourly planetary index find application not only in studies of solar-terrestrial relationships, but in practical matters of radio communication. While the Committee's proposal to replace the daily international magnetic character figure, used since 1906, by a similar but more objective index based on the three-hourly planetary index was not accepted for early introduction, further study on this point was recommended, and also on the possibility of devising measures of the magnetic effects of solar wave radiation and of the intensity of the equatorial ring current.

First-hand evidence of current development in Belgian provision for geophysical work was obtained during the Association's visit to the new geophysical centre situated at 700 ft. in open country near Dourbes, about 55 miles southward of Brussels and remote from sources of electrical interference, atmospheric pollution and night-sky glare. On the extensive site, installations, well spaced to avoid mutual interference and some in underground chambers, are to be made for measuring the magnetic field, earth currents, atmospheric electricity, ionospheric structure, the radio-electric field of distant radio stations, cosmic radiation, solar radiation, "sferics" and seismic movement. The magnetic section is about to operate. Early in the evening return drive to the city the company were entertained to a most welcome meal at Couvin.

Association of Hydrology and Association of Physical Oceanography.—Circumstances prevent the inclusion here of even a superficial general survey of items of meteorological interest in the proceedings of the Association of Hydrology (e.g. in the discussions of snow and ice areas and of surface water) or of the Association of Physical Oceanography. Reference is therefore limited to questions of modification of climate and of general circulation raised by the recession of the Ruwenzori glaciers at the 4,000–5,000-m. level in equatorial Africa; and to the studies in progress on deep ocean sediments as provided in the long cores obtained by the Swedish "Albatross" expedition —work which indicates the possibility of determining the major climatic changes of the last million years.

Association of Seismology.—The Presidential Address by Dr. R. Stoneley to the Association of Seismology was devoted to the International Seismological Summary which has been and is largely a British contribution in this field of international co-operation.

Final plenary session.—The strands were gathered together at the final plenary session of the Union in the Palais des Beaux-Arts on the last day. Main features of the activities of the Association were reported by the respective Presidents. Resolutions proposed by the Council of the Union and by Associations were adopted. The Union approved in principle, and made recommendations concerning, a proposal from the Joint Commission on the Ionosphere that arrangements should be put in hand for a third " international polar year " project in 1957–58. It approved and made suggestions regarding the scheme for " world days " in upper atmospheric research as proposed by the Joint Commission on High Altitude Research Stations. It recommended for trial the use of certain of the terms, but recorded reservation on other terms, contained in a memorandum on " Upper atmospheric nomenclature ", prepared by Prof. S. Chapman, which had been referred to the Union by the Joint Commission on the Ionosphere. It was agreed that further consultation should take place within the Union and with other interested bodies as to the best method of making adequate provision within an international organization for the subject of the physics of the high atmosphere; and that endeavour should be made to obtain funds from international sources to enable the non-magnetic ship *Research*, which was constructed by the British Admiralty before 1939, to be fitted out and brought into service so that much needed ocean magnetic survey may be undertaken. Another resolution stated that the Union would welcome resumption of U.S.S.R. contributions to the international scheme of magnetic indices, and invited the general co-operation of the U.S.S.R. in the work of the Union. Announcement was made that Prof. S. Chapman succeeds Prof. F. A. Vening-Meinesz as President, and that Dr. J. M. Stagg, after six years as General Secretary, has resigned and is succeeded by Colonel G. Laclavère. Other newly elected Presidents include—Dr. K. R. Ramanathan, Meteorology; Prof. J. Coulomb, Terrestrial Magnetism; Prof. J. Proudman, Oceanography. By invitation the next assembly, in 1954, will be held in Italy.

So ended the ninth general assembly of the International Union of Geodesy and Geophysics which, on current impressions and in retrospect, was highly successful, and not merely on grounds of size. Gatherings of this scope stimulate individual and international activity, provide a forum for public exposition and discussion, and also afford opportunities for the making and renewal of more intimate personal contacts—with exchange of views and information—between individuals. All this is true of the Brussels assembly. But this is not all. Those who were privileged to attend the assembly are deeply grateful for the warmth of welcome, the interest and the generous hospitality of the host country, made evident in so many ways. Queen Elisabeth graciously received the members of the Council and Executive Committee of the Union and their wives at the Palace of Laeken. On the opening day a reception was held in the Hôtel de Ville by the civic authority of Brussels, and on the last day but one the general company were entertained to dinner in the Palais des Beaux-Arts by the Belgian National Committee. A large body of delegates and guests were taken to Antwerp, conducted over places of interest according to choice, entertained to lunch and taken by steamship for an afternoon tour of the port. Other excursions were arranged to other cities and parts of Belgium according to the general and scientific inclination of delegates. In addition a special Committee watched over the interests of ladies and arranged a variety of visits. Finally, tribute is due to the Belgian National Committee and others for the admirable arrangements made to ensure the smooth working of the assembly.

BOOKS RECEIVED

Annual reports for 1937, 1938, 1939. Christchurch Magnetic Observatory. 6 in. $\times 9\frac{1}{2}$ in., pp. xiii+144, New Zealand Department of Scientific and Industrial Research, Wellington, *s.a.*

TURBULENCE AT HIGH ALTITUDE : A FURTHER METEOROLOGICAL ANALYSIS

By J. K. BANNON, B.A.

Introduction.—It has been shown[1] that the occurrence of turbulence in the upper troposphere and lower stratosphere of such a nature as to cause noticeable abnormal movement of an aircraft (bumps) is in many cases associated with small values of the meteorological parameter, the Richardson number. It also seems to be associated with abnormally large shear of wind in the horizontal, but neither of these two parameters appears to be necessarily associated with the occurrence of bumps.

In previous meteorological analyses of high-altitude turbulence[1,2,3] suitable observations of wind and temperature were seldom available at the same time and place as the occurrence of the bumps, so that interpolation in space and time was necessary to obtain appropriate values of the meteorological parameters. However, marked changes can occur in the upper air within a short distance and in a short time, and there is always the suspicion that interpolation in the meteorological variables may have invalidated some of the conclusions.

This note is a summary of an analysis[4] of a number of occasions of turbulence experienced between heights of 18,000 and 40,000 ft. on ascents by the Meteorological Research Flight during 1950 made primarily to observe humidity and temperature at high altitude. It was possible to make the flights within 10 miles of one or other of the upper air observing stations at Larkhill and Downham Market, and also within 20 min. of the time the observations of upper winds were made at those stations. Thus appropriate values of the meteorological variables were available for the analysis.

Cases of general shear in the vertical.—It has generally been assumed that the most important factor causing turbulence at high altitude is large wind shear in the vertical. For analysis the cases were therefore placed in one of two categories according as a general shear in the vertical was present or not.

Table I gives mean and median values of Richardson number and isentropic shear for the bumpy layers occurring in a general change of wind with height.

TABLE I—TURBULENCE IN A GENERAL SHEARING LAYER: RICHARDSON NUMBERS R_i AND ISENTROPIC SHEARS

	No. of layers	Depth	R_i below turbulent layer	R_i in turbulent layer	R_i above turbulent layer	Isentropic shear
		ft.				hr.$^{-1}$
Troposphere						
Mean	57	2,000	6·2	2·4	11·7	0·21
Median			3·3	1·6	4·6	0·18*
Stratosphere						
Mean	17	2,000	10·1	3·5	16·4	0·21
Median			3·8	2·2	9·1	0·17†

* 29 cases † 11 cases

The turbulence, assessed qualitatively, was classed as moderate in 11 cases and as slight in the remaining cases. It is seen that, notwithstanding certain errors which tend to increase its calculated value, the Richardson number, R_i, is usually small (order 1 to 3) in the turbulent layers, and that R_i is usually considerably greater above and below the turbulent layers. Horizontal shear is nearly always greater than isentropic shear, and thus it is seen from Table I that the isentropic shear associated with these occasions of turbulence was usually considerably greater than the normal, which for horizontal shear is about 0·08 hr.$^{-1}$ at these heights[1]. The isentropic shear is preferred to the horizontal shear as a parameter in turbulence analysis as lateral mixing, if existing, will tend to take place along isentropic surfaces[5].

Cases with no general shear in the vertical.—There was no general change of wind with height through the turbulent layer in approximately one quarter of the occurrences of bumps. In all these cases the turbulence was slight in intensity. In some of the cases the wind was fluctuating considerably with height about a general mean so that shears over depths of 1,400 ft. (the minimum depth over which shears could be measured) were quite large, though the shear over a depth of 3,000–4,000 ft. was small. Some cases occurred in broad wind maxima. As would be expected the Richardson numbers for these cases were mainly large, the mean of 19 cases in the troposphere being 9·2 and of 6 cases in the stratosphere, 28·5. The isentropic shears associated with these occasions of turbulence, for those cases where they could be estimated, were again usually considerably larger than normal, the mean of 11 cases in the troposphere being 0·19 hr.$^{-1}$.

Discussion.—In the cases occurring in a general change of wind with height the turbulence was presumably caused by the large shear in a manner resembling the way eddies are formed in the shearing layer near the earth's surface. The small values of Richardson number support this[6].

It is difficult to find a ready physical explanation of the turbulence which was not associated with vertical shear of wind. It is known that significant bumps can be caused only by vertical turbulent velocities, and perhaps it may be surmised that such turbulent velocities, in the absence of general shear in the vertical, can be caused by the degradation of considerably larger eddies rotating about almost vertical axes and perhaps several miles across, such as the eddies noted by Durst[7].

Other points which arose from the analysis were:—

(i) The turbulence did not appear to have affected either the temperature or the water-vapour distribution with height to any great extent.

(ii) Turbulence occurring in the stratosphere and in the absence of general wind change with height was usually associated with a low or trough in the circulation at about the 300-mb. level.

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Photograph by the late Mr. M. C. Gillman

FIG. 1—CUMULUS DURING THE LATE AFTERNOON NEAR DAR-ES-SALAAM
(see p. 337)

Photograph by the late Mr. M. C. Gillman

FIG. 2—GRADUAL DISPERSAL DURING THE EVENING OF CUMULUS CLOUD NEAR DAR-ES-SALAAM
(see p. 337)

Photograph by the late Mr. M. C. Gillman

FIG. 3—DISPERSAL OF CUMULUS CLOUD CAUSING FORMATION OF EXTENSIVE UPPER CLOUD (SHORTLY AFTER FIG. 2)

Reproduced by courtesy of J. B. Tuke

PHOTOGRAPH OF MOCK SUN TAKEN AT LYBSTER, CAITHNESS, MARCH 20, 1951

METEOROLOGY AT THE BRITISH ASSOCIATION

The annual meeting of the British Association was held this year in Edinburgh from August 8 to 15, under the presidency of H.R.H. The Duke of Edinburgh, K.G., F.R.S. As was appropriate to Festival Year the theme of the Presidential Address, and also of many of the addresses by section presidents, was a review of progress over the past 100 years.

In his presidential address to Section A (Mathematics and Physics) on August 9, Prof. Sir David Brunt, Secretary of the Royal Society, took as his title " A hundred years of meteorology, 1851–1951 " but covered more than two thousand years, tracing the development of meteorology from the time of Aristotle to the present day. He described the history of the Meteorological Office from its foundation in 1855 as a department of the Board of Trade, and referred to the excellent example to the politicians given by meteorologists in the field of international co-operation since 1872. Weather pays no attention to iron curtains, the wind blows through and mainly from west to east. Of progress since 1945 Sir David considered that real progress had been made in radiation and cloud physics, but was somewhat sceptical of the value of the contributions in the field of kinematics and depression structure. In one important aspect, however, we were a long way behind the rest of the world—the study of meteorology at the universities. There was only one full department of meteorology in the whole of the British Commonwealth—at Imperial College, London.

Following this address Mr. R. Wilson gave the results of some spectrophotometric observations made at the Royal Observatory, Edinburgh, during the " blue sun " of September 26, 1950, caused by smoke from Canadian forest fires[1]. Comparison of the observations with those obtained under normal conditions led to the conclusion that the phenomenon was caused by the scattering of the sun's light by transparent particles, uniform in size and concentration. The relation between the diameter d (expressed in microns) and the refractive index m was found to be $d(m-1)=0{\cdot}519$. The average concentration of the particles was about 70 $cm.^{-3}$, and Mr. Wilson considered them to be globules of oil formed from the distillation of the wood in the forest fires. In addition, the results indicated the presence of some totally absorbing particles which were probably carbon.

The session on August 9 concluded with a paper by Mr. J. Paton on auroræ and luminous night clouds, illustrated with many beautiful slides. Four stations in Scotland make simultaneous photographs of auroræ from which can be determined their height and position. Similar measurements were made on noctilucent clouds on the night of July 10–11, 1949, placing them over the Shetland Isles at a height of 89 Km. The clouds were a vivid blue and were drifting westwards at 50–80 m.p.h.

The session on August 10 was devoted to a number of papers on " Natural and artificial production of atmospheric precipitation ". The first part of the session was honoured by the presence of H.R.H. The Duke of Edinburgh.

Mr. B. J. Mason opened with a paper on " The fundamental physics of precipitation processes in the artificial production of rain ". In the case of precipitation from layer clouds he considered the Bergeron-Findeisen process to be dominant. For convection clouds, raindrop growth by coagulation of cloud droplets may occur, but the conditions required were: a high concentration of cloud water (about 5 gm./m.^{3}), up-currents of about 5 m./sec. and a cloud depth of several kilometres, such as occur in the tropics. In temperate regions he considered that ice crystals were probably required initially. He then discussed the various experiments which had been made in the artificial stimulation of precipitation using dry ice, silver iodide and small water droplets. He deprecated the tendency there has been to draw spectacular conclusions from a few observations, and made a plea for more careful observation and control of the experiments. The most promising technique is that of seeding the cloud near the base with small water droplets of the order of 100μ diameter. Effective seeding with dry ice or silver iodide is confined to a very narrow range of cloud-top temperatures before natural seeding is likely to occur. On the possibility of large-scale effects, Mr. Mason pointed out that the energy that could be released by seeding is trifling compared with that required to build up a large-scale atmospheric disturbance.

Mr. F. H. Ludlam followed with a description of the calculations[2] he has carried out on the growth of raindrops starting with exceptionally large nuclei of concentration " 1 per roomful " and diameter 20–30μ. These he regarded as being formed from sea spray and was therefore doubtful whether they would be operative in any other than a maritime climate. He was more optimistic than Mr. Mason (and others) on the economic value of cloud seeding.

Mr. I. C. Browne then spoke of the work he is doing at Cambridge using a vertically looking 3-cm.-wave-length radar. The variations of echo intensity with height in precipitation are measured. Bands similar to the upper bands of echo seen by Dr. Bowen in Australia[3] are also seen at Cambridge, but are differently interpreted as being due to curved precipitation streaks. Ice (evidenced by the bright band on melting) was found to be present in all thunderstorms examined, and in the centre of a storm the echo intensity occasionally increased very steeply with decreasing height in a region well below the freezing level. This increase is interpreted as evidence of a chain reaction of drops growing and breaking in this region. Positive electric fields observed simultaneously are in accordance with the breaking-drop theory for electrification of rain.

Mr. R. F. Jones followed with a description of the work being done at East Hill using radar on 10-cm. and 3-cm. wave-lengths. Observations are made of all types of precipitation in an area extending to about 140 miles radius of East Hill. Different types of weather situation lead to different radar responses, the most striking being the difference between layer and shower clouds[4]. Aircraft observations show that in the layer clouds the reflecting particles above the freezing level are usually large ice crystals, often in the presence of supercooled water droplets. In shower clouds water drops predominate even at considerable heights above the freezing level. This led to the suggestion of two different methods of producing rain; in layer clouds by the Bergeron process and in convection clouds by coalescence of water droplets.

The formal papers were concluded by a paper from Dr. A. W. Brewer, read by Mr. H. P. Palmer. The opinion in Oxford, while recognizing that rain is formed in the tropics by coalescence, is that all raindrops in this country originate as ice crystals. As evidence of this was cited the reliability of the forecasting rule that temperatures at the tops of cumulus clouds must fall below about $-10°$C. before showers will occur. The difficulty that ice-forming nuclei were very rare at −10°C. was overcome by assuming that crystals formed on these nuclei during the rapid growth of the ice, fractures of the crystals occurred, and several " splinters " were formed. A chain reaction of " splinter " formation then produced all the ice crystals necessary for rain formation. Such " splinters " from rapidly growing ice crystals have been observed at Oxford.

The discussion which concluded the session was opened by Sir David Brunt who reinforced Mr. Mason's plea for more closely observed experiments in cloud seeding and deprecated the extravagant claims which had been made on the prospects of controlling the weather. He did not think that more than very local efforts could be achieved in this country, a view which was supported by Dr. A. H. R. Goldie.

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LETTERS TO THE EDITOR

Deepening of frontal depressions

Mr. Sumner's description of the storm of October 24, 1945, in the British Isles[1] lends support to his theory that the presence of instability in the vertical may be an important factor in the development of severe frontal depressions. In further support of his proposal I would like to make a somewhat similar set of observations in connexion with the development of the enormous storm which occurred over the eastern United States during November 1950 and its counterpart which occurred in November 1913. In the early stages of the development of the 1950 storm, during the afternoon and evening of November 24, thunderstorms were observed at several stations in eastern North Carolina and Virginia. Similarly, in the November 1913 storm the instability of the air in the warm sector was clearly indicated by the torrential flood-producing rains which occurred in eastern North and South Carolina during the earliest stages of the development of that storm on November 8.

Synoptic charts, drawn and analysed at the time that the instability was in evidence for the storms of 1950 and 1913, will be found in articles by Smith[2] and Mook[3] respectively.

C. P. MOOK

U.S. Weather Bureau, Washington National Airport, Washington, D.C., August 30, 1951

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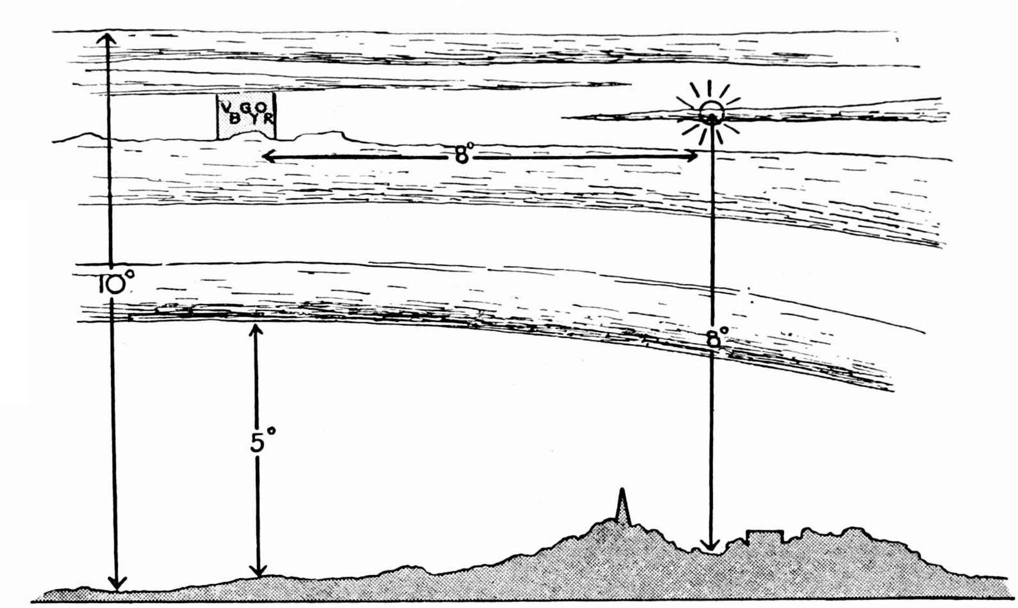
3. MOOK, C. P.; The famous storm of November, 1913. *Weatherwise, Philadelphia Pa.*, **2**, 1949, Figs. 1a and 1b, p. 126.

Rare optical phenomenon seen from Northolt

Whilst on observational duty at Northolt on August 5, 1951, I observed at 0528 G.M.T. an optical phenomenon (shown in the sketch below) as follows:—

A belt of high cloud stretched to the horizon in both directions, lying north-north-west to south-south-east and was apparently from 5° to 10° in altitude.



In one of several breaks was what appeared to be a section of a rainbow, at the same altitude as the sun and 8° to the left of it. The colouring was distinct and formed a complete spectrum, red being on the right; the apparent total width was about twice that of the sun, which was 8° above the horizon. The effect was that of a rainbow observed through a cloud break, although nothing was visible in the gaps either " above " or " below " the one in question. The phenomenon faded after about three minutes as the cloud formation slowly changed.

Conditions at the time were: surface wind calm, moderate to good visibility, but with ground fog patches on low ground to the north, trace of altocumulus at 16,000 ft., 3 oktas of cirrus, cirrocumulus and cirrostratus at about 22,000 ft.

JOHN G. SHIPCOTT

Northolt Airport, August 6, 1951

[It will be noted that the order of the colours of the phenomenon observed by Mr. Shipcott is that of a halo (refraction) and is the opposite to that of a corona (diffraction).

We are indebted to Mr. E. W. Barlow for the suggestion that the phenomenon was the rare halo of radius varying between 7°30′ and 10° or possibly a mock sun associated with that halo.

Besson[1] gives a list of six observations of this halo. The first report was by Van Buijsen[2] who observed it at Apeldoorn, Holland on April 6, 1892. A vivid description of its observation on May 11, 1915, in Florida is given by Andrus[3].

According to Humphreys[4] it requires the presence of pyramidal snow crystals which are rare.—Ed. *M.M.*]

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NOTES AND NEWS

Cumulus cloud development in east Africa

The photograph facing p. 316 was taken at sunset from a moving train in the area to the south-east of Lake Victoria. Heavy cumulus and cumulonimbus had developed over the land and the tops merged into a bank of really dense cirrus which thinned on its upper edge into a sheet of cirrostratus. During the night the lower portion of the convection cloud dissolved but there was much lightning in the residual upper portions.

The photograph facing p. 317 was taken shortly before sunset looking inland from Dar-es-Salaam. The cumulonimbus which developed in the late afternoon dissolved quite quickly during the evening without forming any appreciable residual cloud. This quick dispersion of well developed cloud is common during late May when weather conditions are beginning to reach the comparatively settled state of the SE. monsoon.

The photographs facing pp. 332 and 333 near Dar-es-Salaam were taken during the late afternoon (Fig. 1) and about two hours later (Figs. 2 and 3). The general cloud sequence is of maximum development inland during the afternoon and of gradual dissolution towards evening with the convection cloud giving rise to extensive upper cloud. The process is quite a slow one, as during April, when these photographs were taken, the weather over the area is definitely unsettled with considerable rainfall.

NEWS IN BRIEF

The L. G. Groves Memorial Prize for Meteorology has been awarded this year to Dr. R. C. Sutcliffe, O.B.E., Senior Principal Scientific Officer in the Meteorological Office, Dunstable, who has acquired a world-wide reputation by the many important papers he has published on the application of dynamical theory to weather forecasting. During the past year he has been the primary author of a paper which sets out the theoretical basis and the practical application of three-dimensional analysis to the forecasting of movement and development of pressure systems. This represents an important step in the science of forecasting. In addition to his personal contribution to the dynamical theory of forecasting, Dr. Sutcliffe, in his capacity as Assistant Director for Forecasting Research, has exercised a stimulating influence on many other important investigations which have been carried out by his team of research workers in the Napier Shaw Laboratory of the Meteorological Office.

Proxime accessit.—It was decided by the Selection Board that the name of Mr. A. C. Best, M.Sc., Principal Scientific Officer, Meteorological Office, Air Ministry, should be specially mentioned as researches carried out by him during the year were of outstanding merit.

The L. G. Groves Memorial Award for Meteorological Air Observers has been awarded this year to Flight Lieutenant D. Carlson, who has been employed continuously on meteorological air reconnaissance duties in Nos. 202 and 204 Squadrons for over three years. During this time he completed 61 sorties as a Meteorological Air Observer, involving 530 hours flying, often in difficult weather, and always showed great enthusiasm for his work. Flight Lieutenant Carlson has also carried out the duties of Squadron Meteorological Air Observer for two years. To his great credit a high level of efficiency has been achieved and maintained by the Observers in his Squadron. He has at all times set an excellent example on the ground and in the air, and his work and devotion to duty have been most praiseworthy.

METEOROLOGICAL OFFICE NEWS

A radio-sonde launched at Leuchars on September 4 was recovered, four days later, from the bed of the North Sea by the trawler *Drumaston* (Skipper, David Liston). The instrument was lying in about 45 fathoms, and was roughly 100 miles east of Leuchars. By a coincidence, the mate of the vessel, Mr. J. Angus, who actually found the radio-sonde, is a neighbour of Mr. B. V. Bishop of the Meteorological Office, Pitreavie, so that the instrument quickly found its way back to the Instruments Division, but, of course, after its immersion in sea water it was entirely useless.

In the annual sports of the Gloucester and District Civil Service Association a team representing the Meteorological Office, Air Traffic Control Centre, Gloucester, secured third place—a remarkable feat since the office was much the smallest Department competing, and had not previously succeeded in raising a team. Mr. E. B. Jefferies was second in the 440 yards, and a team was third in the 4×110 yards relay. Representatives of the Office also won first and third places in both the veterans' race and the egg-and-spoon race. A tug-of-war team also entered, but was defeated by Post Office Engineers.

WEATHER OF SEPTEMBER 1951

Mean pressure was between 1015 and 1020 mb. over western Europe, and between 1010 and 1015 mb. over most of Scandinavia and the British Isles. Mean pressure fell below 1010 mb. to the north and west of the British Isles, including the North Atlantic Ocean north of latitude 50°. Over North America mean pressure was generally between 1010 and 1020 mb.

Over the North Atlantic just west of the British Isles, mean pressure was 5–10 mb. below normal, and over the British Isles and south-west Europe it was 2–5 mb. below normal. Over Scandinavia mean pressure was a little above normal, the excess being between 1 and 3 mb.

Mean temperature was between 50° and 60°F. over the British Isles, increasing to 60–70°F. over Europe, 70–75°F. over the Mediterranean region and 80–90°F. over north Africa. Temperature was generally about 3–4°F. above normal in these areas.

In the British Isles the weather was rather warm generally. Broadly speaking it was dry in north and east Scotland, parts of northern England and locally in Northern Ireland, and wet elsewhere. Sunshine was below the average except in east Scotland, where there was an appreciable excess.

In the opening days a depression off north-west Scotland moved slowly east-north-east and filled, while small secondary depressions moved quickly east-north-east along the English Channel. Heavy rain and local thunderstorms occurred in the south of England on the 1st and at Guernsey again on the 2nd. On the 3rd and 4th a very deep depression moved rather quickly north-east from mid Atlantic and gales were recorded locally on our north-west coasts on the 4th. Meanwhile an associated trough moved north-east across the British Isles causing rain generally, which was considerable locally in the west. Associated with this depression a warm air stream from south of Bermuda crossed England and Wales, and temperature rose to 75°F. at a number of places in eastern England on the 4th and touched 79°F. at Gorleston and Mildenhall and 77°F. at Finningley and Spurn Head. Thereafter a weak trough moved very slowly south-east over England giving rain in east and south-east England and the Midlands. Rainfall was very variable; at Oxford a fall of 3·34 in. was registered during heavy thunderstorms on the night of the 6th–7th. Temperature continued high and reached 78°F. at Tangmere on the 6th. Between the 6th and the 9th an anticyclone moved north-east across Scotland to Scandinavia and a spell of mainly fair weather prevailed, though local thunderstorms occurred in the south-west on the 9th. A very unsettled spell ensued from the 11th to the 14th, when a deep almost stationary depression was situated to the south-west of Iceland. On the 11th and 12th a trough associated with this depression moved slowly east across the British Isles and rain fell in most parts but it was rather scattered in the south of England. On the 13th a vigorous secondary off south Ireland moved rapidly north-north-east and on the 15th another disturbance (originally a tropical hurricane) moved quickly north-east across England to the Baltic. During this spell rain occurred daily and was heavy locally at times (2·35 in. at Fort William and Thirlmere on the 14th) and thunderstorms were recorded in some places on the 12th and 13th. Strong winds, reaching gale force locally in the west, were recorded on the 13th. Subsequently an anticyclone off the west of Ireland moved south-east, later turning east-north-east across England to Germany, and a period of settled weather occurred apart from slight rain at times in the extreme west and north. The fair spell was broken on the 22nd when a depression to the south-west of the British Isles moved north and became almost stationary off the west of Scotland. Secondary disturbances swinging round the main centre caused rain generally, heavy locally at times (4·53 in. at Thirlmere on the 24th and 2·16 in. at Bradford and 2·14 in. at Dorchester on the 27th). On the 28th a ridge of high pressure moved east over the British Isles and on the 29th it became joined to an anticyclone centred near Leningrad; fair weather, apart from scattered showers, prevailed on the 28th and fair weather with morning fog persisted on the mainland of Great Britain until the end of the month.

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 ...	80	31	+1·6	141	+1	79
Scotland	73	28	+1·4	87	−2	103
Northern Ireland ...	71	36	+1·6	97	0	81

RAINFALL OF SEPTEMBER 1951

Great Britain and Northern Ireland

County	Station	In.	Per cent. of Av.	County	Station	In.	Per cent. of Av.
London	Camden Square ...	2·57	141	*Glam.*	Cardiff, Penylan ...	5·37	176
Kent	Folkestone, Cherry Gdn.	5·34	225	*Pemb.*	Tenby	3·89	123
„	Edenbridge, Falconhurst	3·88	171	*Card.*	Aberystwyth	..	..
Sussex	Compton, Compton Ho.	3·39	122	*Radnor*	Tyrmynydd	5·17	134
„	Worthing, Beach Ho. Pk.	3·46	162	*Mont.*	Lake Vyrnwy	6·14	170
Hants.	Ventnor, Cemetery ...	4·26	168	*Mer.*	Blaenau Festiniog ...	14·74	187
„	Bournemouth	3·25	139	*Carn.*	Llandudno	2·66	125
„	Sherborne St. John ...	3·61	176	*Angl.*	Llanerchymedd ...	5·83	198
Herts.	Royston, Therfield Rec.	2·20	117	*I. Man*	Douglas, Borough Cem.	5·27	161
Bucks.	Slough, Upton	3·15	179	*Wigtown*	Port William, Monreith	3·95	135
Oxford	Oxford, Radcliffe ...	4·92	288	*Dumf.*	Dumfries, Crichton R.I.	4·13	152
N'hants.	Wellingboro', Swanspool	1·27	71	„	Eskdalemuir Obsy. ...	6·90	186
Essex	Shoeburyness	4·29	257	*Roxb.*	Kelso, Floors	1·39	73
„	Dovercourt	2·93	164	*Peebles*	Stobo Castle	2·44	97
Suffolk	Lowestoft Sec. School ...	1·87	95	*Berwick*	Marchmont House ...	1·49	62
„	Bury St. Ed., Westley H.	3·42	172	*E. Loth.*	North Berwick Res. ...	·73	35
Norfolk	Sandringham Ho. Gdns.	2·63	127	*Midl'n.*	Edinburgh, Blackf'd. H.	·88	43
Wilts.	Aldbourne	3·83	192	*Lanark*	Hamilton W. W., T'nhill	2·99	112
Dorset	Creech Grange... ...	4·54	166	*Ayr*	Colmonell, Knockdolian	3·06	88
„	Beaminster, East St. ...	4·29	168	„	Glen Afton, Ayr San ...	6·16	158
Devon	Teignmouth, Den Gdns.	4·31	220	*Bute*	Rothesay, Ardencraig ...	4·51	111
„	Cullompton	4·00	178	*Argyll*	Morvern, Drimnin ...	6·27	111
„	Ilfracombe	2·85	106	„	Poltalloch	4·23	93
„	Okehampton, Uplands	4·53	140	„	Inveraray Castle ...	7·05	110
Cornwall	Bude, School House ...	2·53	102	„	Islay, Eallabus	3·89	93
„	Penzance, Morrab Gdns.	4·24	145	„	Tiree	3·77	102
„	St. Austell	4·76	149	*Kinross*	Loch Leven Sluice ...	2·26	88
„	Scilly, Tresco Abbey ...	3·18	124	*Fife*	Leuchars Airfield ...	1·40	73
Glos.	Cirencester	3·27	149	*Perth*	Loch Dhu	6·89	120
Salop	Church Stretton ...	2·54	120	„	Crieff, Strathearn Hyd.	3·05	107
„	Shrewsbury, Monksmore	1·98	121	„	Pitlochry, Fincastle ...	..	..
Worcs.	Malvern, Free Library	2·89	150	*Angus*	Montrose, Sunnyside ...	1·46	73
Warwick	Birmingham, Edgbaston	3·34	187	*Aberd.*	Braemar	1·82	73
Leics.	Thornton Reservoir ...	1·36	75	„	Dyce, Craibstone ...	1·25	52
Lincs.	Boston, Skirbeck ...	2·03	115	„	Fyvie Castle	·68	26
„	Skegness, Marine Gdns.	1·88	104	*Moray*	Gordon Castle	·66	26
Notts.	Mansfield, Carr Bank ...	1·72	94	*Nairn*	Nairn, Achareidh ...	·63	30
Derby	Buxton, Terrace Slopes	3·42	106	*Inverness*	Loch Ness, Garthbeg ...	1·76	57
Ches.	Bidston Observatory ...	2·29	95	„	Glenquoich	7·16	83
Lancs.	Manchester, Whit. Park	2·99	126	„	Fort William, Teviot ...	8·56	134
„	Stonyhurst College ...	3·18	83	„	Skye, Duntuilm ...	3·96	86
„	Squires Gate	3·05	113	*R. & C.*	Tain, Tarlogie House ...	·93	41
Yorks.	Wakefield, Clarence Pk.	2·39	149	„	Inverbroom, Glackour...	2·64	60
„	Hull, Pearson Park ...	1·07	62	„	Applecross Gardens ...	5·40	108
„	Felixkirk, Mt. St. John	2·66	146	„	Achnashellach	6·43	93
„	York Museum	1·77	109	„	Stornoway Airfield ...	2·27	61
„	Scarborough	·97	54	*Suth.*	Loch More, Achfary ...	..	..
„	Middlesbrough... ...	·84	51	*Caith.*	Wick Airfield	1·44	58
„	Baldersdale, Hury Res.	1·84	74	*Shetland*	Lerwick Observatory ...	2·58	86
Norl'd.	Newcastle, Leazes Pk....	·98	50	*Ferm.*	Crom Castle	2·94	105
„	Bellingham, High Green	2·13	89	*Armagh*	Armagh Observatory ...	1·89	77
„	Lilburn Tower Gdns. ...	·83	35	*Down*	Seaforde	3·21	117
Cumb.	Geltsdale	4·08	146	*Antrim*	Aldergrove Airfield ...	2·61	105
„	Keswick, High Hill ...	8·77	207	„	Ballymena, Harryville...	2·42	78
„	Ravenglass, The Grove	5·61	166	*L'derry*	Garvagh, Moneydig ...	2·75	93
Mon.	Abergavenny, Larchfield	4·58	196	„	Londonderry, Creggan	..	..
Glam.	Ystalyfera, Wern House	7·56	173	*Tyrone*	Omagh, Edenfel ...	3·27	107