M.O. 626 AIR MINISTRY

METEOROLOGICAL OFFICE

THE METEOROLOGICAL MAGAZINE

VOL. 86, No. 1,024, OCTOBER 1957

ATOMIC ENERGY AND THE METEOROLOGIST

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The development in recent years of processes involving the large scale use of atomic energy has led to a number of problems in which meteorological advice is of the greatest importance. The meteorologist is concerned in these problems because of the fact that when quantities of matter in the form of small particles are released into the atmosphere their subsequent history is largely governed by meteorological parameters. Contamination of the atmosphere by radio-active materials inevitably follows the use of atomic energy either in a weapon or in an industrial reactor, but more especially in the former. The meteorologist is therefore consulted about the transport of these particles by the wind, their diffusion and their ultimate removal from the atmosphere by gravity or by meteorological processes of which precipitation seems to be the most important. As is well known, radio-activity is extremely harmful, combining immediate dangers to bodily health with long term hazards to mankind. It is therefore essential that everything possible should be known about the meteorological factors that play so large a part in determining the future distribution of the radio-activity which is injected into the atmosphere as a result of modern scientific inventions. Thus, on the military side, the services of the meteorologist are indispensable in such questions as the choice of a site for a weapon test and in the timing of the explosions; in peaceful applications of atomic energy, the meteorologist will help in deciding the location of a nuclear reactor and the control procedures to be imposed for its safe operation.

The employment of atomic bombs towards the end of the last war brought home to people the potentialities of nuclear energy not only for waging war but also for industrial purposes. However, continuing tests of more and more powerful weapons and a growing awareness of the resulting atmospheric contamination combined to arouse in the minds of the public considerable anxiety as to the possible effects on the human race if limits were not set to the quantity of radio-activity that could be poured into the air. Not all radio-activity in the air is artificially produced and all the time there is present a background radiation from naturally occurring sources, examples of which are the components of cosmic rays and the small quantities of uranium and thorium present in rocks and soils throughout the world. The social problem is thus the extent by which the natural level of radiation can be increased without serious risk. It is a problem which so far has revealed itself to the public mainly in terms of weapon tests but it should not be overlooked that the next few decades will witness a tremendous growth in the applications of atomic energy to the industrial field. This development, if special precautions are not taken, could lead to the existence of local areas of high radio-active contamination in the vicinity of reactor plants. From the meteorological angle this would resemble the familiar question of the air pollution caused by traditional methods of fuel consumption but, in the case of pollution by radio-activity, the most stringent safeguards would be necessary. Smoke and sulphur gas emitted during the burning of coal and oil rarely retain their characteristics for more than a day or so and to some extent their destructive properties can be removed before release to the atmosphere takes place. On the other hand radio-active isotopes may remain dangerous for periods varying, in terms of half-lives, from fractions of a second to several centuries, and it is not practicable to hasten the decay of their radio-activity.

Governments have shared the misgivings of the public about increasing the amount of radio-activity in the atmosphere and in several countries have set up committees to make a detailed appraisal of the biological effects of nuclear and allied radiations and to estimate the long term dosages liable to be incurred by human beings through a continuation of projects involving atomic energy. In the United Kingdom the Medical Research Council at the request of the Prime Minister undertook the enquiry and produced a comprehensive report, which has been made available to the public[1]. In the United States the National Academy of Sciences examined the various problems through the agency of six committees dealing separately with genetics, pathology, meteorology, oceanography and fisheries, agriculture and with the disposal of radio-active waste products. A report summarizing the findings and recommendations of these committees has also been published[2]. Both the British and American reports contain directly or by implication a great deal of meteorology. It is clear that meteorological information and advice made important contributions during the course of the enquiries; and it seems equally clear that scientists in other fields—chemists, physicists, etc.—could in their turn help the meteorologist in the use of radio-activity to attack some of the problems of the atmosphere that still await solution.

Meteorology and nuclear weapons.—When an atomic bomb is exploded at or near the surface, the release of energy produces an intensely hot fireball which draws many tons of debris from the earth into the atomic cloud. The vaporized bomb materials are able to condense on the soil particles so that the resulting radio-active dust has a wide range in size, varying in diameter from fractions of a micron (10^{-4} cm.) to several hundred microns.

The ascent of an atomic cloud has been discussed by Sutton from the point of view of the convection processes that occur[3]. Immediately following the explosion the fireball, which is at a temperature several thousand degrees higher than that of the surrounding air, expands until equality between the internal and external pressures is achieved. Then because of its density deficiency, the fireball rises very rapidly, at the same time cooling by entrainment of colder air from the environment and by adiabatic expansion, until a level is reached where the buoyancy forces have fallen to zero. The height of this level depends mainly upon the energy of the bomb itself but also to some extent upon the temperature structure of the atmosphere in the vertical. In general the radio-active debris from a bomb in the kiloton range is confined to the troposphere while a megaton weapon is so powerful that a substantial fraction of the radio-activity reaches heights far into the stratosphere.

Once the ascent of the atomic cloud has come to an end, the future course of events can be considered in two classes—close-in fall-out which returns to the earth within about 20 hours of the explosion and long range fall-out by which is meant those particles which remain airborne for days, months or even years. The essential difference between these two types of fall-out is one of terminal velocity, the particles in the close-in category being large enough to acquire falling speeds that ensure their early removal from the atmosphere. The larger particles, like all the others, are radio-active and are transported by horizontal winds during their short period of descent. The location of a weapon test and its timing must therefore be chosen so that dangerous levels of contamination do not fall upon inhabited areas. The meteorological problem is thus reasonably clear cut but, since the upper winds may occasionally vary widely both in time and in space, not necessarily easy of solution. Kellog *et al.* have discussed the main features of the problem and have described a quantitative technique for deriving from the wind structure the probable distribution of radio-active material on the ground[4]. They point out that detailed and reliable forecasts of close-in fall-out must depend upon the existence of a close upper air network providing frequent wind observations to great heights around the area likely to be affected. Such elaborate facilities can be made available in advance of test explosions and an accurate forecast of the fall-out pattern could then be expected. In an emergency situation, however, the standard upper air network would probably be inadequate and the forecaster might have to confine himself to rather broad estimates of the sectors where ground contamination is most liable to occur.

The meteorology of close-in fall-out can be assessed in fairly precise terms because gravitational settling of the particles imposes a limit, less than a day, on the time during which the winds and other processes can exert control. By contrast long range fall-out presents a baffling problem to the meteorologist because the magnitude of the time element may be anything from a day to many years and also because some of the important features, wash-out by rain and diffusion, are not fully understood. The particles comprising long range fall-out are for the most part of diameter less than about 10 microns and have virtually no falling velocities. Vertical diffusion operates very slowly and a high percentage of these particles would remain airborne almost indefinitely if scavenging by precipitation did not occur. It would appear therefore that the long range fall-out which reaches the ground within a week or so of the explosion is deposited mainly as a result of the effect of precipitation upon particles in the lower levels of the troposphere. Particles which remain in the atmosphere for extensive periods are probably carried to very great heights in the first place and eventually diffuse downwards to the earth's surface or merely to levels where deposition can be completed more quickly through the agency of precipitation. All the time the particles are airborne they are of course carried by the winds appropriate to their heights and the large scale shearing motions always present in the atmosphere ensure that the particles, which originally formed a cloud of comparatively small size, are scattered to all longitudes and over a wide range of latitude.

With so many uncertainties, not least the time factor, the life history in the atmosphere of the particles forming long range fall-out is primarily a question of measurement and can only be regarded as a forecasting problem in the most general and qualitative way. Since shortly after the war observations of the rate of deposition of radio-active dust upon the earth's surface have been made at an increasing number of places, mostly in the northern hemisphere, and in addition several countries have carried out programmes for measuring the concentration of radio-activity at various heights in the atmosphere up to about 50,000 feet. If observations of this nature were made and exchanged over a sufficiently wide area, it would become feasible to make reasonable estimates of the total amount of radio-activity in the atmosphere and of its rate of deposition upon the earth and the oceans. Such information would be of the greatest interest and value to health physicists, biologists and many others.

Since 1948 the Royal Air Force Meteorological Reconnaissance Squadron which is based at Aldergrove in Northern Ireland has sampled the air for radio-active dust while engaged on routine weather observing duties. 'Bismuth' flights, as they are called, follow a triangular course over the Atlantic, the cruising level changing from 1,500 feet to 18,000 feet or vice versa at each corner of the triangle. The aircraft carries on its wing a cylindrical filter of high collective efficiency and a representative sample of the dust content of the lower troposphere is thereby obtained. At the end of each flight the filter with its collected dust is sent for analysis to the Atomic Energy Research Establishment on whose behalf the sampling programme is carried out.

The efforts of the Bismuth squadron have been supplemented from time to time with the aid of aircraft flying at much greater altitudes over the United Kingdom. It has thus been possible to measure the concentrations of radio-activity at various levels to about 48,000 feet in the neighbourhood of the British Isles which, situated far from test sites and therefore free from local effects, form a suitable observation area for the study of contamination on a global scale. These aircraft observations must therefore rank among the most important contributions to this problem and it is noteworthy that the results obtained have been used in the American[2] as well as in the British[1] report.

Stewart, Crooks and Fisher have analysed the data accumulated from the air sampling programmes and have reached important conclusions which have a direct bearing on the meteorological factors involved[5]. Of special interest is the observed difference over a long period between the concentration of radio-activity produced by a kiloton or atomic bomb and the concentrations produced by a megaton or hydrogen bomb. The cloud resulting from the explosion of an atomic weapon at the American test site in Nevada moves in the circulation of the troposphere and completes a circuit of the earth every four to seven weeks. At the end of the first circuit lateral diffusion is very largely complete and subsequent observations of radio-activity over the United Kingdom show a substantial decrease of concentration with time even when allowance is made for the normal processes of radio-active decay. By contrast the observations from the Bismuth flights following the hydrogen bomb tests in the Pacific in the spring of 1954, show only a very slight decrease with time of airborne activity but, when the correction for decay is applied, a gradual increase in atmospheric concentrations is revealed.

Stewart *et al.* attribute these differences in behaviour of the two types of cloud mainly to the very slow rate of vertical diffusion at the tropopause and above. The effect on the atomic bomb cloud is to inhibit upward diffusion from the troposphere and so the steadily diminishing concentrations observed after lateral diffusion has been completed may be interpreted as showing the rate of removal of radio-active dust by deposition upon the surface of the earth. Viewed in this way, the observations suggest that half the material in an atomic bomb cloud settles out of the atmosphere within about three weeks. On the other hand the cloud from a hydrogen bomb penetrates many thousands of feet into the stratosphere and the particles of dust size diffuse downwards steadily but very slowly. Concentrations in the lower atmosphere are therefore reinforced continuously by diffusion from above to an extent which may offset the losses by deposition.

Researches such as those described by Stewart *et al.* are clearly of great potential value to the science of meteorology and also suggest how much more could be learned if similar observing programmes were carried out in many different parts of the world as a concerted attack upon the problem of atmospheric diffusion.

Meteorology and reactor siting.—In the past industrialists have not always acknowledged the importance of meteorology when deciding upon a location for a factory and all too often the meteorologist has been consulted at a late stage to explain why the site chosen has proved to be a bad one. More recently, however, at those factories where the waste products released to the atmosphere contain obnoxious gases or particles, meteorological factors have been given close attention in measures taken to reduce the damage likely to be caused by the chimney effluents. The operation of a nuclear reactor presents similar problems, but as has been explained already, in a more vital way and there is no question but that local weather conditions must be taken into account in site selection. The problem is essentially one of safety, hence its importance. It is known that in routine operation a minimum amount of radio-active material will be discharged from the chimney of the reactor which must therefore be sited so as to ensure that human life, either directly or indirectly, is not exposed to harmful concentrations. Moreover, should a major accident occur at the reactor, there would be an almost instantaneous release of a large amount of radio-activity and for some distance down-wind lethal or dangerous concentrations would occur near ground level. Thus although every precaution is taken both in the construction and in the operation of a reactor and one can say that the possibility of a serious accident is remote, there must be general agreement about the wisdom of building reactors at distances well removed from densely populated areas.

The meteorological problem in relation to the operation of nuclear reactors again consists very largely of estimating the diffusive properties of the atmosphere. For routine operations we are concerned with concentrations from a continuous source of radio-activity and the chimney is regarded as approximating to an elevated point source; in considering the effects of a disaster the source is an instantaneous one and can also be regarded as a point source without over-simplifying the problem. Wind speed, wind direction and atmospheric stability, as indicated by the vertical distribution of temperature, are the most important parameters governing dispersion in the atmosphere and these are incorporated in Sutton's theory of diffusion by means of which quantitative estimates can be made of concentrations likely to occur in varying conditions of weather and for specified strengths of source[6]. The application of this theory to problems of airborne radio-activity is treated in considerable detail in a handbook compiled by the United States Atomic Energy Commission[7]. Both in this country and in the United States much attention has been given to the values to be used for the diffusion parameters, e.g. n and C_z, which appear in Sutton's equations. n is a dimensionless number which is related to the vertical gradient of the horizontal wind and varies in value from zero in very turbulent or high lapse conditions to unity when there is little or no turbulence as in the case of strong inversions. When the potential temperature is constant with height the appropriate value of n is 0·25. The parameter C_z is a generalized diffusion coefficient which serves to indicate the vertical spread of the plume or cloud and is therefore of special importance when considering ground level concentration from elevated sources. Observations of C_z in different areas and over a wide range of conditions have shown only a fair measure of agreement. Some portion of the discrepancies can be attributed to local terrain and this emphasizes the importance of accumulating data on the micrometeorology of an area which may be under consideration as a reactor site. In applying Sutton's equations in a specific locality it is therefore advisable to bear in mind that the theory was originally developed for diffusion over a level surface in a neutral atmosphere and that when these conditions do not hold some departure of observation from theory must be anticipated.

Precipitation is another weather factor of importance in the reactor problem as well as in the case of fall-out. It is well known that rain or a shower clears the air of dust and would presumably also be effective in cleansing the lower atmosphere of any radio-active matter that is present. It will be apparent therefore that the onset of precipitation could upset estimates of concentration based on ordinary diffusion theory and in a question of this importance it is essential that as much information as possible should be obtained about the precise influence of rainfall upon airborne particles.

Radio-activity in meteorological research.—Systematic observations have served to indicate the rate at which radio-active matter released during weapons trials mixes with the atmosphere and have also given prominence to the possibilities of using harmless radio-active substances as tracers for meteorological research. An important advantage of radio-activity is that the most minute quantities can be readily detected by modern sampling and analysing techniques. Thus, as Machta has pointed out, it may be practicable in the near future to study problems of the large scale circulation by plotting the progress through the atmosphere of a few grams of a suitable radio-active substance released at a selected time and place.

Geophysical research has a long history of the application of natural and artificial tracers, the use of drift bottles by oceanographers being one of the best known examples. The eruption at Krakatao hurled large quantities of dust into the high atmosphere and enabled meteorologists to study mixing and other processes there. In recent years constant-level balloons have been used to track individual air parcels for many days at a time. Important natural tracers are water vapour and ozone, the latter having space and seasonal variations that appear to be closely connected with circulations above and below the tropopause. In many experimental studies of local or small scale meteorological problems, tracers such as smoke have been indispensable accessories. Meteorologists now hope that the use of radio-active substances as tracers may produce more complete data in the case of some of the older types of field experiment and may also make possible trials of a kind never before considered feasible. Many ideas have been put forward such as the use of radio-active tritium in association with water to study the formation of dew and to investigate the hydrologic cycle generally; the use of a special tracer to observe air trajectories in jet streams; as a control in rain making trials; and for the purpose of measuring diffusion rates at various levels in the atmosphere. All such experiments must, however, be very carefully planned and the meteorologist will need full co-operation from specialist physicists and chemists. The properties required of a tracer—insoluble in water, not liable to be washed out of the atmosphere by rain, etc.—must be carefully defined. Large scale problems will call for the closest international co-ordination and may involve a lengthy period of preparation in order to perfect the arrangements. These precautions are essential because a large scale tracer experiment cannot be repeated using a further quantity of the same material as tracer until the original amount has decayed sufficiently, a process that may take several years.

International collaboration.—For several years the United Nations, through an Advisory Committee and through the specialized agencies, has played a leading part in promoting international collaboration both in arriving at the best assessment of the possible dangers from the uses of atomic energy and in exchanging information concerning the many aspects of the application of atomic energy to peaceful purposes. The World Meteorological Organization, which is one of the specialized agencies of the United Nations, has clearly an important part to play in these questions and at the Executive Committee Meeting in April, 1956 resolved to co-operate fully with other international organizations as well as to provide expert advice to its own Members. The Executive Committee appointed a panel to study the meteorological aspects of atomic energy with a view to ensuring that new techniques arising from this field of activity may be used to assist the science of meteorology in every possible way, including the development of new instruments. In its first report the panel has made several recommendations covering the dissemination of information to Members and the organization of research projects.

Collaboration among meteorologists in atomic energy matters will be greatly helped by some developments in connection with the International Geophysical Year. The programme of the I.G.Y. was recently extended to incorporate measurements of nuclear radiation in precipitation and in the air. It is hoped therefore that during the next year a good network of stations, with uniform methods of collecting and analysing rain water and air samples for radioactivity, will be established throughout the world. This initiative on the part of the I.G.Y. is especially to be welcomed because a vast network of observing stations will be required for the successful prosecution of tracer studies into the general circulation.

The international collaboration that is being actively encouraged in the meteorological aspects of atomic energy needs no underlining because meteorologists have long been accustomed to think internationally in the interests of their science. Another form of close collaboration which is developing is that between meteorologists and specialists in other sciences. Where atomic energy applications are concerned, it will not be sufficient for the meteorologist merely to consult the physicist or chemist or biologist and then to make his own way in his particular problems. The subject is indeed so complex that collaboration must take place at every stage of meteorological research in this field and it is not the meteorologist alone who will benefit. Physicists and chemists are finding that for many problems in radio-activity the atmosphere forms a convenient and accessible laboratory. But it has curious properties which the meteorologist can help to explain and perhaps circumvent.

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THE DIURNAL VARIATION OF SURFACE WIND AND PRESSURE AT BERMUDA

By P. C. BARTRUM, B.A.

Introduction—Bermuda is well situated for obtaining observational data free from the complications caused by orography and large land areas. Situated between latitudes 32° and 33°N. it lies for the greater part of the year on the edge of the Azores–Bermuda anticyclone, the prevailing wind being south-west. It is not, however, free from the disturbing effects of passing depressions and anticyclones, especially in the winter months when gales from a direction between north and west are common. It is also liable to be affected by hurricanes in the latter part of the hurricane season (late August to October), but during the years 1935 and 1936, with which we are concerned, hurricanes did not come close enough to cause much disturbance to Bermuda's weather. The relative freedom of Bermuda from such disturbing influences makes it particularly suitable for the investigation of the diurnal variation of wind and pressure.

The anemometer and its exposure.—The wind was measured by a Dines Pressure Tube Anemometer set up at Fort George, St. George's, Bermuda, latitude 32°23′N., longitude 64°41′W. The anemometer is situated on a parapet of Fort George and the height of the mast is 40 ft. Fort George itself is built into the summit of a hill about 170 ft. high above sea level, and the parapet is 182 ft. above sea level, so that the vane is 222 ft. above sea level. The hill slopes steeply in all directions except to the west, where the slope is gradual. The anemometer, therefore, has a good exposure in all directions, but owing to its position on a local prominence the winds recorded may be expected to be somewhat stronger than they would be over level ground at sea level.

Bermuda itself (at the time) had an area of about 19 square miles, being surrounded by sea for at least 600 miles in all directions. The majority of the land mass of Bermuda lies to the south-west of the anemometer.

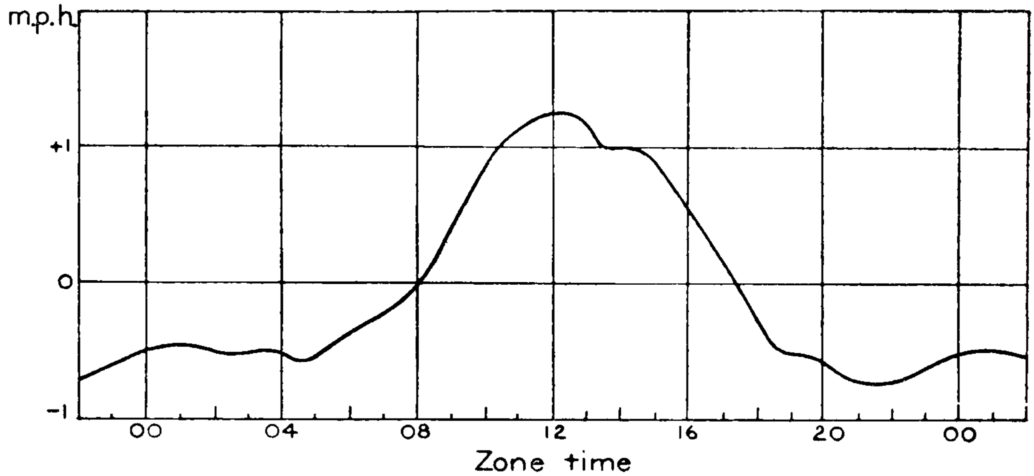

FIG. 1—DIURNAL VARIATION OF WIND SPEED AT ST. GEORGE'S, BERMUDA, 1935–36

Mean diurnal inequality for periods of an hour centred at each half hour.

Tabulation and analysis of wind data.—Mean wind speed and direction for hourly periods ending at the exact hour (zone time = G.M.T. − 4 hours) were read off the anemogram, speeds being estimated to the nearest mile per hour, and directions to the nearest of the 16 points of the compass (N, NNE, NE, etc.). These were tabulated by months for the two years 1935 and 1936. Vector components of wind from southerly and westerly directions were then calculated from the mean speed and direction over each hour. These were similarly tabulated by months. From these figures hourly diurnal inequalities of absolute speed, and the component velocities from west and south, were deduced for each month. The complete series of observations was used without any selection.

The monthly inequalities of each element were combined into three groups: Winter (Jan., Feb., Nov., Dec.), Equinoxes (March, April, Sept., Oct.) and Summer (May, June, July, August). Each of the resulting diurnal inequalities was therefore based upon about 240 readings. When these were plotted, random fluctuations of the order of 1/5 of the diurnal amplitude were in evidence. However, if all the data for the two years are combined together, the random fluctuations are reduced to reasonable proportions. The results are shown diagrammatically in Figs. 1 and 2.

Fig. 1 shows the diurnal variation of wind speed independent of direction. It is of the usual form with a maximum soon after 12 hr. due to the well known diurnal effect of temperature. The low value of wind speed between 13 and 14 hr. is apparently a real effect as it occurred in 15 of the 24 months (namely Jan., March, April, May, Aug., Sept., Oct., Nov. 1935 and Feb., April, May, June, Sept., Oct., Dec. 1936). This is perhaps a secondary temperature effect, due to the afternoon build-up of cloud.

The hourly diurnal inequalities, grouped into seasons, were also harmonically analysed and the first four harmonics deduced. As a check the diurnal inequalities based on the whole of the two years' data were also harmonically analysed. The harmonic components thus deduced were valid for mean values of the wind over an hour, centred at the half-hours. These were then corrected to give the harmonic components valid for instantaneous values commencing at 00 hours zone time. The method is given by Bilham[1].

The results are shown in Table I. In order to obtain local mean time from the zone time it is necessary to subtract 19 min. The phase angles are given with respect to zone time, so that to obtain phase angles valid for local mean time α_1 should be increased by 5°, α_2 by 9°, α_3 by 14°, and α_4 by 19°. In the case of the absolute wind speed the first harmonic has the largest amplitude, while in the case of the vector components the second harmonic preponderates. This is in accordance with what we should expect, the preponderance of the second harmonic in the wind components being connected with a similar preponderance in the diurnal variation of pressure.

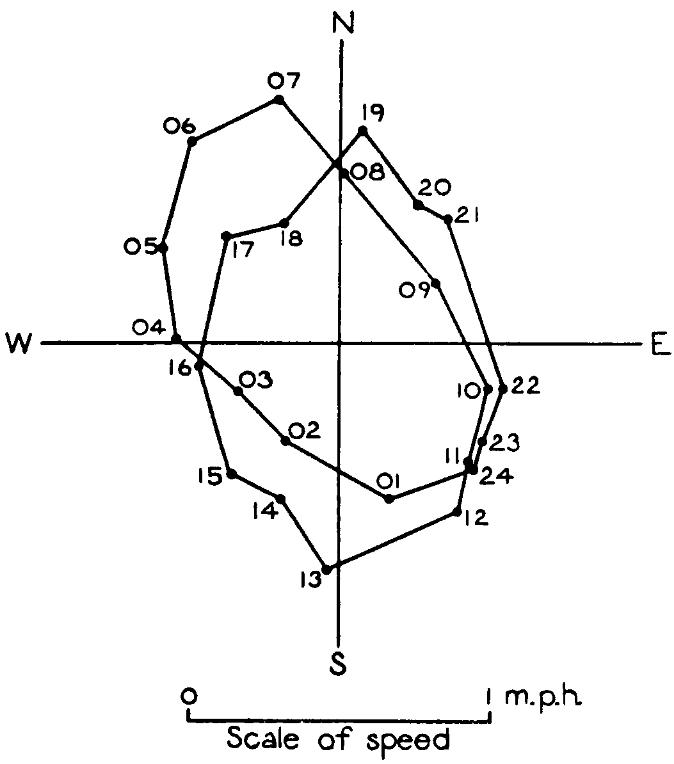

FIG. 2—DIURNAL VARIATION OF VECTOR WIND AT ST. GEORGE'S, BERMUDA, 1935–36
Mean diurnal inequality for periods of an hour, ending at the hour indicated (zone time). The wind is to be regarded as blowing *from* the appropriate point on the diagram *to* the origin.

The diurnal variation of pressure.—Owing to the interest in the relationship between the diurnal variation of the vector wind and the diurnal variation of pressure it was decided to analyse harmonically the latter for the same years, 1935 and 1936, at Fort George. The readings used were taken from a Short and Mason open scale aneroid barograph and adjusted to agree with the readings of the Kew Pattern mercury barometer, both at Fort George. Readings of the latter were made at 08, 14 and 20 hours, zone time. The results are given in Table II. The same adjustment must be made to the phase angles as in the case of the wind if values valid for local mean time are required.

TABLE I—HARMONIC ANALYSIS OF THE DIURNAL VARIATION OF SURFACE WIND AT ST. GEORGE'S, BERMUDA, 1935–1936

Absolute Speed (V)

	D_1	α_1	D_2	α_2	D_3	α_3	D_4	α_4	V_0
		°		°		°		°	
Winters ...	0·55	300	·22	055	·12	258	·07	090	18·4
Equinoxes ...	0·92	264	·35	055	·07	032	·09	225	15·6
Summers ...	1·33	250	·55	078	·10	050	·05	147	12·9
Years... ...	0·89	264	·37	066	·03	357	·04	162	15·6

Westerly Component (u)

	A_1	α_1	A_2	α_2	A_3	α_3	A_4	α_4	u_0
Winters ...	·34	002	·56	336	·22	183	·05	082	+2·9
Equinoxes ...	·17	284	·54	340	·01	157	·02	337	+0·1
Summers ...	·13	147	·45	320	·08	312	·08	280	+0·8
Years... ...	·09	342	·51	333	·06	200	·02	320	+1·3

Southerly Component (v)

	B_1	α_1	B_2	α_2	B_3	α_3	B_4	α_4	v_0
Winters ...	·33	013	·58	091	·03	234	·13	259	−0·4
Equinoxes ...	·33	140	·71	072	·07	203	·18	173	+1·4
Summers ...	·57	248	·62	075	·09	023	·08	329	+5·7
Years... ...	·09	240	·63	079	·01	276	·07	229	+2·2

The mean diurnal variations of wind are fitted to the forms:

$$V = V_0 + D_1\sin(\omega T + \alpha_1) + D_2\sin(2\omega T + \alpha_2) + \dots$$
$$u = u_0 + A_1\sin(\omega T + \alpha_1) + A_2\sin(2\omega T + \alpha_2) + \dots$$
$$v = v_0 + B_1\sin(\omega T + \alpha_1) + B_2\sin(2\omega T + \alpha_2) + \dots$$

where T = zone time of 60°W.
and ω = angular velocity of the earth's rotation.

Wind speed in m.p.h.

If these are compared with the values for 1933 and 1934 given by Bartrum[2], it will be seen that there is close agreement, especially in the second harmonic. Simpson's empirical formula for the second harmonic[3] gives, for Bermuda, $c_2 = 0{\cdot}95$ mb., $\alpha_2 = 144°$. The phase agrees closely with the observed value, but the predicted amplitude is somewhat larger than that observed.

The observed relationships between the second harmonics of pressure and of the wind components are shown in Table III. The significance level of the other wind harmonics is probably too small to warrant detailed consideration.

Relation between diurnal variation of wind and pressure.—It is well known that the second harmonic of the diurnal variation of pressure is such that the maxima and minima occur roughly at the same local time everywhere in the world (Simpson, 1918). This may be regarded as due to the passage round the world from east to west with the sun of two shallow anticyclones separated by two shallow cyclones, having their centres somewhere near the equator, and superimposed on the ordinary relatively static pressure distribution. For a station in the northern hemisphere the centres would pass to the south and the expected result would be a wind, superimposed on the ordinary wind, which should veer clockwise round the compass twice in 24 hours. This is exactly what is found in Bermuda (as in other places).

TABLE II—HARMONIC ANALYSIS OF THE DIURNAL VARIATION OF STATION LEVEL PRESSURE (MB.) AT ST. GEORGE'S, BERMUDA, 1935–1936

Height of barometer cistern above mean sea level 158 ft.

	C_1	α_1	C_2	α_2	C_3	α_3	C_4	α_4	p_0
Winters ...	·13	293°	·71	155°	·21	351°	·09	197°	1012·3
Equinoxes ...	·20	271	·67	145	·05	029	·02	083	1012·3
Summers ...	·19	274	·54	141	·11	152	·02	098	1012·7
Years... ...	·17	278	·64	147	·05	013	·03	172	1012·5

The mean diurnal pressure variations are fitted to the form:

$$p = p_0 + C_1\sin(\omega T + \alpha_1) + C_2\sin(2\omega T + \alpha_2) + \ldots$$

where T = zone time of 60°W.

and ω = angular velocity of the earth's rotation.

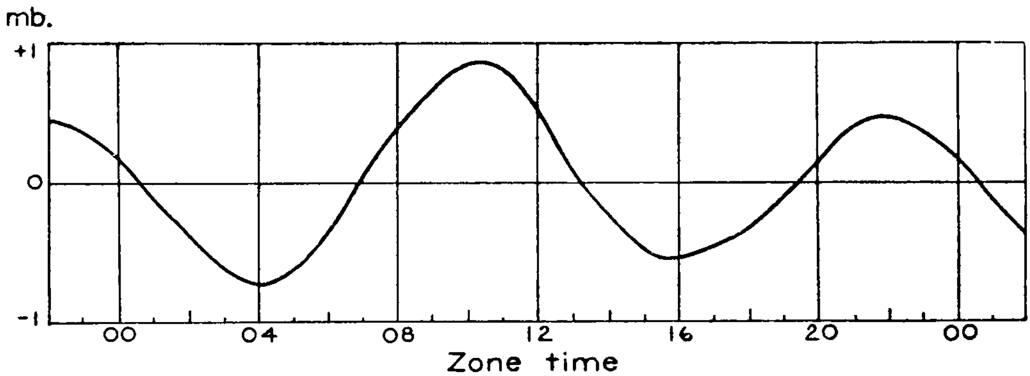

FIG. 3—DIURNAL VARIATION OF PRESSURE AT ST. GEORGE'S, BERMUDA, 1935–36

Mean diurnal inequality at each hour.

TABLE III—OBSERVED AND "IDEAL" VALUES OF PHASE DIFFERENCES AND RATIOS OF AMPLITUDE FOR THE SECOND HARMONICS

	Phase differences		Amplitude ratios		
	West–Pressure θ_2	South–Pressure ψ_2	West/South A_2/B_2	West/Pressure A_2/C_2 m.p.h./mb.	South/Pressure B_2/C_2 m.p.h./mb.
Winters	181°	296°	0·95	0·79	0·83
Equinoxes	195	287	0·77	0·81	1·32
Summers	179	294	0·74	0·84	1·13
Years	186	292	0·81	0·81	1·00
"Ideal"	180	270	1·07	0·95	0·89

Since the pressure systems are moving too rapidly we cannot make use of the geostrophic relation to estimate how the direction of the semi-diurnal wind should fit in with the maxima and minima of the semi-diurnal pressure wave. The problem was considered by Gold[4] who showed that if vertical motion and frictional forces are neglected, then for the semi-diurnal wave in the northern hemisphere the phase angle of the westerly component of wind should be 180° in advance of the pressure, and that of the southerly component should be 270° in advance of the pressure, i.e. the wind should be east at pressure maxima, west at pressure minima, and north or south when the pressure has its mean value in such a way that the wind vector rotates in a clockwise direction. Thus the wind should be in just the opposite direction to what we should deduce by a crude application of the geostrophic relation. Gold also deduced values for the amplitude ratios. These ideal relationships for the case of Bermuda are shown in the lowest row of Table III. It will be seen that there is general agreement, as can also be seen by comparing Figs. 2 and 3.

The formulae obtained by Gold gave waves of infinite amplitude at latitude 30°, and he therefore attempted to allow for frictional forces. He assumed a force proportional to the wind and in the opposite direction, a device having mathematical convenience but without satisfactory physical basis. The effect is to increase the phase differences θ_2 and ψ_2, and to decrease the amplitude ratios A_2/C_2 and B_2/C_2. When applied to the case of Bermuda these results did not give any marked improvement as regards agreement with observation.

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ESTIMATION OF THE FREQUENCY OF "RUNS OF DRY DAYS"

By E. N. LAWRENCE, B.Sc.

Part II

Persistence.—Throughout this study, the question of the effect of persistence occurs. In the geometric series it is assumed to be zero, i.e. no matter how long a spell lasts the chances of a further day remain constant. In the logarithmic series, a definite (positive) persistence is allowed for, but the persistence is forced into a special pattern. In the "Jenkinson-probability" series a "smoothed persistence", indicated by the value of σ_1/σ_2, is calculated for each site; a source of "error" here is probably the inherent assumption that one type of persistence exists throughout the range of lengths of run. In the "natural-persistence" series actual persistence values are introduced. It would appear that this achieves a greater accuracy than the other series when mean (area) values are assumed for the chances of a further day of the run. By considering totals of runs (spells) over a period or area, the "curves" of P_1, P_2, P_3, ... P_{15} against length of past run were constructed (see Fig. 7) for the months June, July, August and for the season, June to August inclusive, over the combined area of south-west, south-east and east England, showing the August and seasonal values for each of the three sub-areas, south-west, south-east and east England. These graphs suggest that, throughout the range of lengths of run, there are several "types" of persistence:

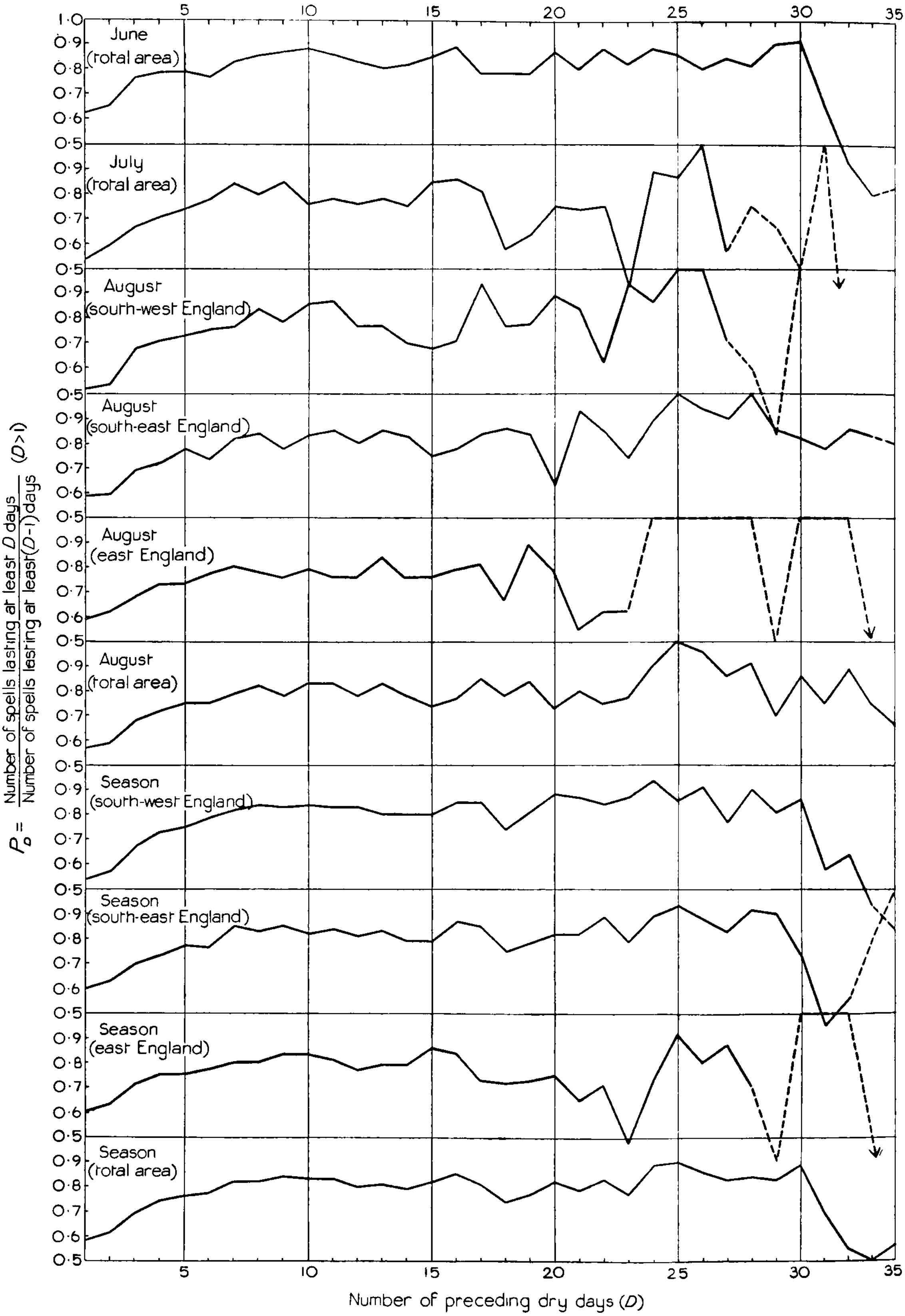

FIG. 7—VALUES OF P_D

(i) Up to run lengths of 8–10 days: positive persistence

(ii) From 8–10 days to 18–20 days: zero or slight negative or anti-persistence

(iii) From 18–20 days to about 25 days: zero or slight positive persistence

(iv) From about 25 days to about 30 days: slight negative or anti-persistence

(v) From about 30 days: negative or anti-persistence.

These properties may be illustrated also by graphs of length of run against cumulative frequency F plotted on a logarithmic scale, persistence and anti-persistence being revealed by the concavity or convexity, respectively, of the curve towards increasing F. It is interesting to note that Belasco[5] found that for anticyclonic days at Kew there was persistence in the range 3 to 20 days, and thereafter strong anti-persistence; this suggests that persistence of "dryness", under similar climatic conditions, would not become strongly negative until well after 20 days.

Similar data of runs of dry and wet days in Southern Rhodesia[6] were examined for runs of up to eight days and marked persistence was found up to about seven days. A range of the types of persistence present in an area may provide a useful measure in the study of climatic types. It is noteworthy that frequencies calculated from area values for the probabilities P_4 to P_{15} give remarkably good agreement with the observed cumulative series.

Conclusions.—The "natural-persistence" series with area probability values is the most convenient and accurate for calculating frequencies of runs of dry days. The logarithmic series also achieves a high degree of accuracy but is much less simple to compute. The geometric series does however provide reasonable estimates, though it is not quite so simple to compute as the "natural-persistence" series. The "Jenkinson-probability" series, which is specially suited to the frequencies of rarer runs, is not fully tested here for this quality.

The area probability values ("natural-persistence" method) are sufficiently different from month to month as to suggest that better frequencies could be calculated from a sliding scale of values, for each value of P_D, throughout the summer. These graphs would give, for each date and each area, the values of P_4 to P_{15} most appropriate to the calculation of frequencies of dry spells centred on that date.

The fact that area mean values of P_D give good approximations to run frequencies may be useful in deciding on "typical" sites or climatic regions for certain climatological variables or for comparing regions, in particular for the study of climatic types.

The value of persistence is not constant throughout the range of lengths of run. There is more than one "persistence régime", a fact which it may be necessary to consider in medium and long-range forecasting and allied problems.

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concluded

BRITISH OCEAN WEATHER SHIPS—10th ANNIVERSARY

By C. E. N. FRANKCOM

On 1st August 1947 *Weather Observer* sailed from London on her first voyage as an Ocean Weather Ship to Station "Juliett" in the North Atlantic (52°30′N., 20°W.)—thus being the first British Ocean Weather Ship to put to sea. On 5th August she took up duty for the first time at "Juliett" and sent her first radio weather message from that station to Dunstable and thereby inaugurated the United Kingdom's active participation in the North Atlantic Station Agreement, which had been signed in London in September 1946. (Her log-book shows that her first day on station was marked by westerly winds of force 4–5; air temperature being 65°F., dew-point 58°F. and sea temperature 67°F.)

Accordingly, August 1957 marks the tenth anniversary not only of *Weather Observer's* service as an Ocean Weather Ship, but also of British participation in this outstanding example of international co-operation.

Two of the other British Ocean Weather Ships complete ten years' service in the North Atlantic during 1957—*Weather Recorder* in October and *Weather Watcher* in November. *Weather Explorer* completes her tenth year of service in February 1958.

Weather Observer was primarily the "Flower" class Corvette *Marguerite*—a class of vessel which was made famous by Nicholas Monsarrat in his book *The Cruel Sea*. The other ships were previously named *Genista*, *Snowflake* and *Thyme* respectively.

Until January 1955 the four British ships, operating from their base at the Great Harbour in Greenock, confined their activities exclusively to Ocean Stations I and J. Subsequent to that date they have operated in rotation with French and Netherlands vessels at Ocean Stations A, I, J and K. (Norwegian vessels have also periodically done six monthly duty at Station A and have then returned to Station M which has been temporarily manned in the meantime by Netherlands ships.)

Considering the stormy conditions which so often prevail in the North Atlantic Ocean, these ten years have been strenuous not only for those who have served aboard the ships, but also for the vessels themselves. The meteorological statistics, published in the *Marine Observer*[1, 2, 3], aptly illustrate this point.

In addition to surface observations, upper air observations (radio-sonde and radar-wind) up to a height of about 50,000 ft. have regularly been carried out aboard the ships and the meteorologists, of whom there are seven in each ship, have

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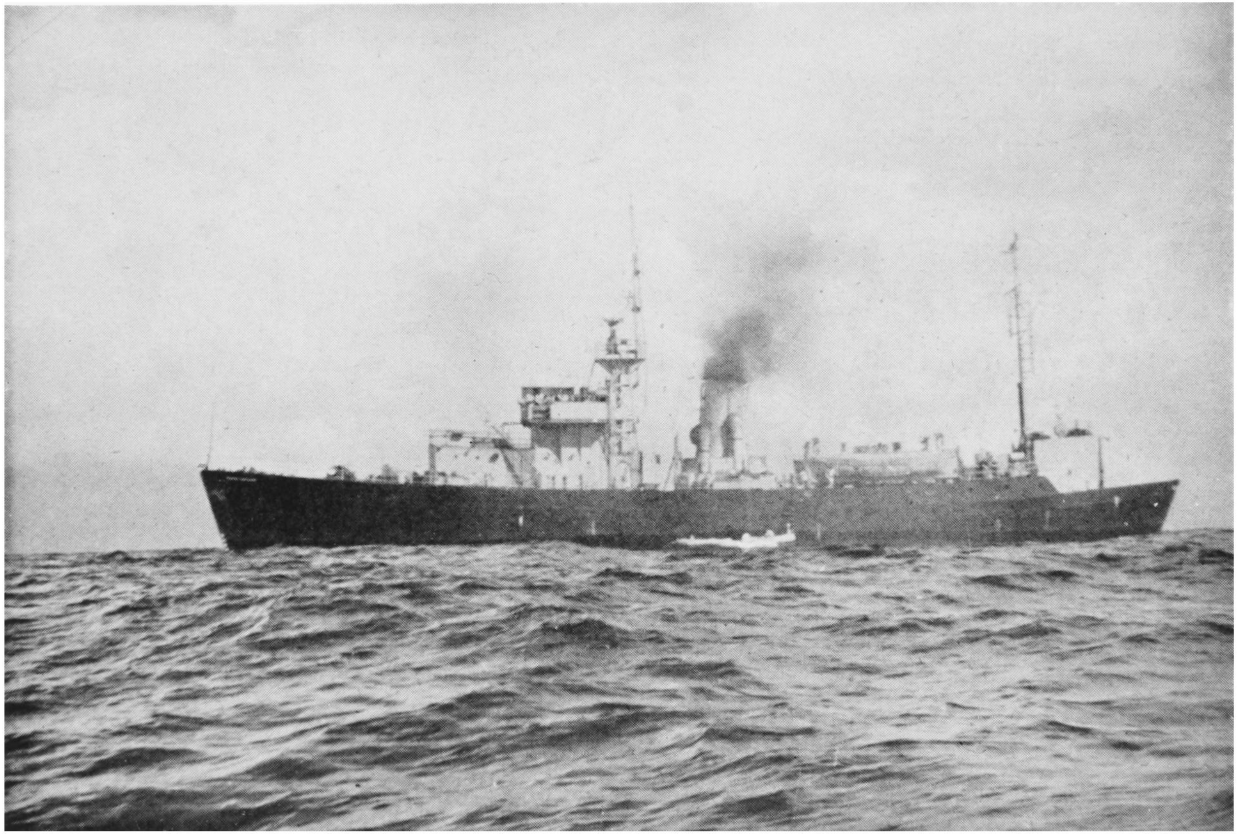
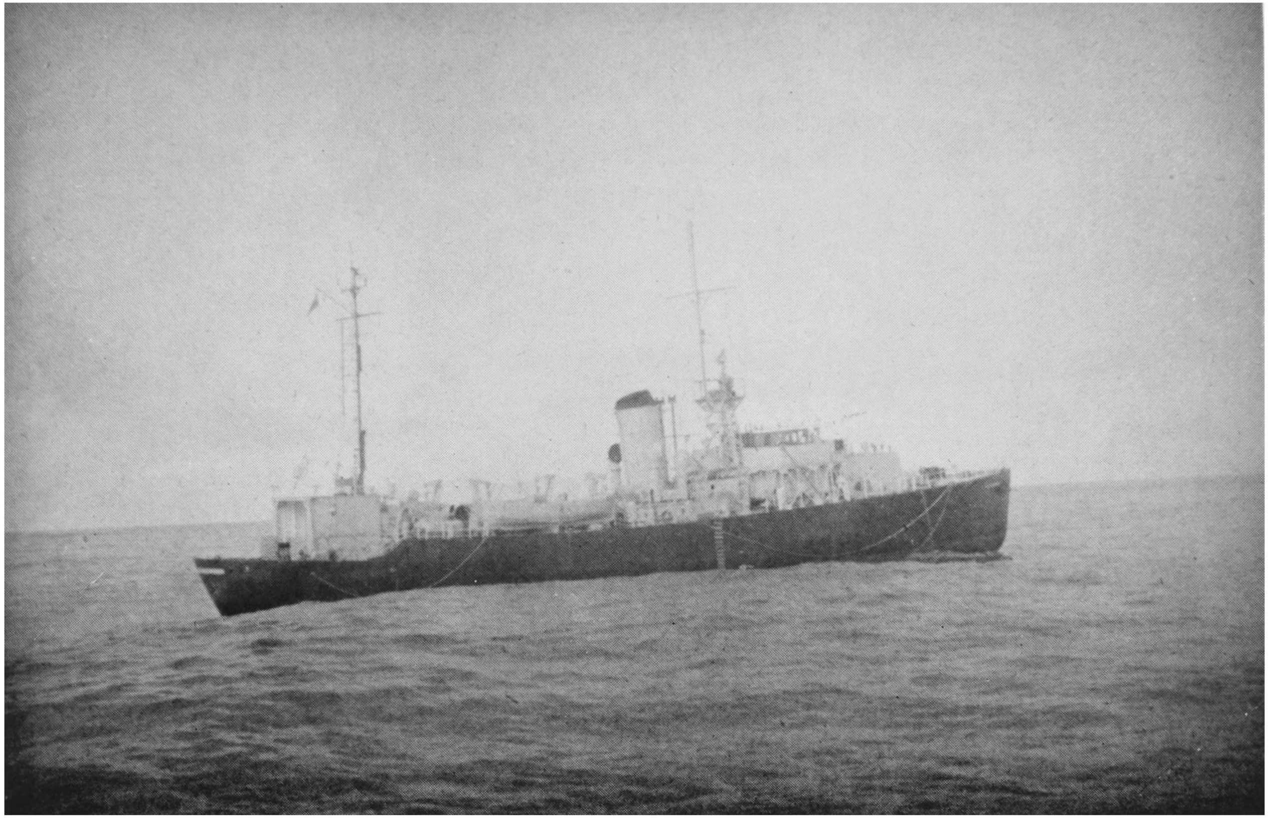
O.W.S. *WEATHER OBSERVER*



Photograph by D. Philips

O.W.S. *WEATHER EXPLORER*



Photograph by D. Philips

O.W.S. *WEATHER RECORDER*

Photograph by W. N. Burton

O.W.S. *WEATHER EXPLORER*
Meteorologists retrieving bathythermograph.

prided themselves upon the fact that it has been extremely rare for an upper air observation to be missed due to bad weather. Releasing the large balloon, with instruments attached ready for taking upper air observations, in a Beaufort force 11 wind aboard a small ship in mid-Atlantic is no easy task. When one considers that these meteorologists are not professional seamen one will realize what a fine job they have done.

For the upper wind observations aboard these ships a Naval-type radar has been used and the whole observations need constant visual attention and considerable skill on the part of the technicians operating the radar. This again is no easy job under heavy weather conditions. These technicians not only operate the radar but have maintained this apparatus as well as all the elaborate radio equipment aboard the ship in an admirable manner—often involving long hours of work in exposed and uncomfortable conditions.

Each individual aboard the ships—whether he be on Deck, in the Engine Room, in the Radio Office or in the Victualling Department—has played his part in the success with which the work of the British Ocean Weather Ships has been carried out during these ten years. One individual who certainly should not be forgotten is the cook aboard each of the ships, who has always managed to produce hot meals no matter how rough the weather has been.

Each of these ships carries a total crew of 53. The following are the names of those individuals who have served aboard the British Weather Ships throughout this ten year period:

Captain A. W. Ford	Master	Mr. A. J. Read	Chief Steward
Captain F. A. Elston	Master	Mr. A. M. Dunning	Chief Radio Technician
Captain H. Sobey	Master		
Mr. W. Oliver	Radio Overseer	Mr. R. H. Brass	Chief Radio Technician
Mr. T. Chadwick	Radio Overseer		
Mr. R. A. Gascoyne	Chief Steward	Mr. H. F. Clifton	Bos'n

The meteorologists normally serve a period of one year aboard a weather ship with the option of extending that period if they so wish. Mr. M. V. Dumphy has the distinction of having done the maximum number of voyages so far of any meteorologist i.e. 51 voyages (approximately six years). Mr. R. G. Findlay served for 45 voyages and Mr. W. N. Burton for 40 voyages. At the Base in Greenock Captain G. W. Steer, the Shore Captain, and Mr. F. W. Martin, Clerical Officer, have served throughout the ten years.

In addition to their meteorological duties, the Ocean Weather Ships provide navigational aids to aircraft in flight and air/sea rescue facilities and they also carry out certain oceanographical work on behalf of various authorities in the United Kingdom. All these activities add to the interest of life aboard the ships but they obviously involve much specialist work on the part of the individuals concerned. The Weather Ships have also provided a very convenient "platform" for special research and other activities to be carried out; e.g. these have included seismic experiments on behalf of Cambridge University; magnetic observations for the Admiralty; various experiments with new type inflatable life rafts and a considerable variety of meteorological experiments.

The existing ships were selected as most suitable for Ocean Weather Ships primarily on account of their excellent reputation for sea-worthiness as North Atlantic anti-submarine escort vessels during the war and also because they were surplus to naval requirements and were therefore acquired relatively cheaply. After all, this is an important consideration for the taxpayer. The ships have shown throughout these ten years what good sea boats they really are and they have fulfilled their task admirably. Their sea-worthiness and their eminent suitability for this work are largely related to their special design and their small size. They are, however, a little too small for the comfort of those who serve in them and, as the ships are now showing wear as a result of their strenuous ten years in the Atlantic, preceded by eight years even more strenuous war service, authority has now been obtained to replace one of these ships (*Weather Explorer*) by a "Castle" Class Frigate named *Oakham Castle* which has been transferred from the Admiralty to the Air Ministry for the purpose. *Oakham Castle* is now in the shipyard of Messrs. Lamont & Co. at Greenock for conversion to an Ocean Weather Ship. This is quite an extensive job and is expected to take about nine months. Steps are being taken with a view to replacing the other three ships after a little experience has been gained with *Oakham Castle.*

"Castle" Class Frigates are in fact the lineal successor to the "Flower" Class Corvettes. They are slightly larger (having a total length of 236 ft. compared with 205 ft.) and the accommodation aboard them will be considerably more roomy and comfortable than that aboard the existing ships.

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HELICOPTERS AND THE FORECASTER

By A. J. WILLIS

Helicopters are becoming increasingly numerous throughout the world and have a considerable operational future. Some forecasters may not, however, be quite as familiar with the operating characteristics of helicopters as with those of more conventional aircraft. The following notes have been compiled to help forecasters to give helicopter pilots the type of information most suited to their needs.

Wind.—*On the ground.*—When starting up or running down in gusty conditions the free-wheeling rotor blades are liable to "blade sailing". The blades are lifted violently upward when facing into wind and thrown downward as they face away from the wind. The vibrations thus set up in the rotor blades may so increase in amplitude as to cause the ends of the rotor blades to strike the rear of the fuselage with consequent damage. This effect may occur when surface winds exceed about 25 kt., and helicopter operators usually ask to be given a special warning when these conditions are expected. To reduce the risk of "blade sailing" some helicopters are fitted with "droop stops" which confine the vibrations to safe limits in winds up to about 40 kt.

During take-off.—Surface wind strength and direction may be of great importance when landing or taking-off in very restricted areas.

In flight.—Once the helicopter is airborne wind strength is important for two reasons:—

(i) With a cruising speed of only 60–80 kt. strong headwinds may make a point-to-point flight impracticable.

(ii) If for other reasons, e.g. low cloud, the helicopter has to be flown very close to the ground the turbulence associated with strong winds could be very dangerous.

Temperature.—Carburettor intake temperature is of extreme importance, especially on take-off, and over sun-heated concrete may be well in excess of nearby screen temperatures. Temperatures much above 80°F. may result in a drastic reduction of pay load.

Visibility.—*Forward visibility.*—Although the hovering capability of the helicopter is one of its most noted characteristics, flying at very low speeds greatly increases fuel consumption. Therefore visibility becomes of importance to the helicopter pilot if it causes him to reduce his speed to below 60 kt. for more than a limited period. In practice this means that for normal operation a forward visibility of not less than one mile is required although for short distances a visibility of much less than one mile may be accepted. It should be remembered that when surface visibility is reduced by smoke or haze beneath an inversion the haze may often be thicker near the inversion than at the surface. Thus the forward visibility for a helicopter pilot operating beneath the haze top at say 500–1,000 ft. may frequently be much less than that reported at the surface.

Air–ground visibility.—The oblique air–ground viewing angle of the average aircraft and of some helicopters makes visual contact with the ground more difficult to maintain than the surface observations would suggest. Some helicopters, however, allow a near-vertical air–ground viewing angle thus giving a much clearer view of the ground than would be afforded by a more oblique viewing angle.

Cloud.—Providing visual contact can be maintained with the ground, extremely low cloud bases represent in themselves no special problem but helicopter pilots generally try to avoid flying in cloud although limited flying in stable stratified cloud is practicable. Generally speaking there is no flying in very turbulent cloud and certainly no flying in cloud at temperatures below freezing point.

Precipitation.—Apart from freezing precipitation (see ICING), this represents only an indirect hazard to the helicopter pilot in that it may reduce visibility and so the safe cruising speed with a consequent rise in fuel consumption.

Icing.—This is the most serious of all the weather risks for the following reasons:—

(i) The helicopter has very high wing loading. For example the wing loading on a Sycamore helicopter is three times that on a Provost aircraft. Quite a small deposit of ice may therefore have a serious effect on the performance of the rotor.

(ii) Even a slight increase in weight on the rotor blades may cause an appreciable increase in the centrifugal reaction on the rotor head.

(iii) The rotor is very finely balanced and even slight irregularities of weight on the individual rotor blades will destroy the balance and set up severe vibration.

(iv) Ice accretion on the rotor head may interfere with blade control.

(v) As far as is known no British or American helicopter is at present fitted with de-icing devices although one Russian helicopter is reported to be fitted with a means of supplying de-icing fluid to the rotors.

Ground Ice Accretion.—It must be remembered that even on the ground ice formation can be a hazard to the helicopter operator. Ice forming on the blades while the helicopter rotor is turning may set up "ground resonance". This is a condition where vibrations due to the unbalanced rotor blades pass via the ground reaction to the undercarriage springing, where sympathetic vibrations may be set up of amplitude large enough to overturn the aircraft. Furthermore pieces of ice flying off rotor blades at speeds up to 400 kt. may also constitute a real danger to ground crew.

From the foregoing it is plain that even slight ice accretion is a grave danger to helicopters both in flight and while running-up on the ground. As helicopter pilots will normally avoid flying in cloud, the special hazards they may encounter are as under:—

(i) Freezing rain or drizzle.

(ii) Rime.

(iii) Wet snow at temperatures below freezing point. Dry snow is not a hazard.

Helicopter pilots expect these phenomena to be specially emphasized in briefing if they are expected.

Acknowledgement.—I wish to acknowledge the advice and co-operation in the preparation of these notes of Sqd.-Ldr. Dowling, Officer Commanding, Helicopter Squadron, Central Flying School.

WORLD METEOROLOGICAL ORGANIZATION

The meetings of the Aerological Commission and the Commission for Instruments and Methods of Observation, Paris, 1957

The second session of the Commissions for Aerology and for Instruments and Methods of Observation of the World Meteorological Organization took place in Paris, beginning on June 18 and ending on July 5 and 6 respectively. The meetings were held in the Hotel du Palais d'Orsay under the chairmanship of the Presidents, Prof. Dr. J. Van Mieghem (C.Ae.) and Mons. A. Perlat (C.I.M.O.). One of the Committees was a joint one; this dealt chiefly with upper air and radiation observations and instruments.

The functions of the Aerological Commission can be regarded broadly as falling into three groups.:

(*a*) to review developments in meteorological research and their international consequences,

(*b*) to provide the basis of international co-operation in regard to observations and other facilities required for meteorological research

and (*c*) to ensure that the technical procedures used internationally conform with current scientific knowledge.

All of these three aspects of the Commission's work were covered in the Paris session. The scientific aspects of meteorology which came under review included numerical forecasting, the artificial modification of cloud and rain, the jet stream, atmospherics, mountain waves, turbulent diffusion, aerological diagrams, ozone and atmospheric chemistry. It had been the practice to refer such subjects to small working groups which operate between sessions of C.Ae., and the reports of these groups were discussed in Paris. The groups were reconstituted to continue the study of these subjects, with the exception of the jet stream, on which a comprehensive report by the working group was submitted for publication by the W.M.O.

The second aspect of the Commission's work, the provision of the requirements for research, was prominent in the discussions of the final details of the organization of the International Geophysical Year, in the proposal to set up a network of stations for the chemical sampling of air and precipitation, and in the recommendation that the W.M.O. should assume responsibility for the network of ozone observations. Publication of aerological observations was also considered with a view to standardizing practices and the Commission expressed a desire for the continuance after the I.G.Y. of the centre set up by the W.M.O. to collect and publish I.G.Y. observations.

In regard to the third aspect of the responsibilities of the C.Ae., certain small changes in the definition of temperature scales were accepted to conform with the international practices in physics, but probably more interesting were the discussions regarding the jet stream and the tropopause. A definition of the "jet stream" has been recommended differing in detail from that recently adopted by the W.M.O. as a result of a postal ballot of Members. The definition of the tropopause in current use in the Meteorological Office was adopted by C.Ae., but a code was proposed for the further specification of the character of the tropopause and this, it is hoped, will go some way to overcoming the difficulties of classifying unconventional tropopause structures particularly in polar regions.

The terms of reference of C.I.M.O. cover the same ground as those of C.Ae., from the instrumental point of view. It is felt by some that the most valuable work that can be done by C.I.M.O. is that which appears in concrete form in the Technical Regulations or the Guide, and, as the President said in his report, the groundwork for this is done between sessions by the working groups, of which more than half the members in the present case were not serving on the Commission but were drawn from a wider sphere. C.I.M.O.–I appointed seven working groups, and one more was appointed by the President between the sessions. C.I.M.O.–II appointed eleven. Perhaps the most important new working group is that on Meteorological Instruments and Methods of Observation on Aerodromes, whose terms of reference include a study of possible ways of measuring "slant visibility".

The question of standardization of instruments was considered, but it was felt that the time was not ripe for any move in this direction. On the question of the standardization of accuracy of observations, a number of amendments to the Technical Regulations was recommended.

Various questions regarding the accuracy of radio-sonde and other upper air instruments were discussed by the two commissions jointly. Uncertainties regarding the accuracy and wide differences in the principles of operation of radio-sonde and upper wind equipment make the specification of generally acceptable standards a matter of difficulty. Little progress was made at the meetings towards the uniformity of the aerological network, but an attempt was made to present the results of the Payerne trials of 1956 in a form in which their usefulness could be tested on a synoptic scale. A working group on aerological measurements will continue the work of the former group on radio-sonde comparisons; although no further international trials on the Payerne scale are intended before the next session, it was felt desirable to keep the subject under review.

A report of the meetings would not be complete without a reference to the excellent entertainment provided by the hosts, the French Meteorological Service, for the enjoyment of the delegates between the meetings. These informal occasions gave many opportunities for the representatives of many different nations to get to know one another personally. Such contacts provided the opportunity for many exchanges of views which will no doubt be reflected in closer international co-operation on aerological and instrumental matters in the coming years.

The meetings also included a number of discussions of scientific papers and these occasions also provided opportunities for exchange of scientific knowledge of meteorology.

At the final session, Dr. R. C. Sutcliffe, Great Britain, was elected President of C.Ae. for the period until (and including) the next session. Dr. W. L. Godson, Canada, was elected Vice-President. The President and Vice-President of C.I.M.O., Mon. A. Perlat and Dr. L. M. Malet, were re-elected for a second term. In all the work of the Commissions, invaluable help was given by the representatives of the Secretariat, Dr. K. Langlo and Mr. O. M. Ashford.

NOTES AND NEWS

Meteorological Committee

The Secretary of State for Air announced in the House of Commons on June 29 that the Meteorological Committee of members nominated by other Departments, the Universities and Royal Society would be dissolved and be replaced by an advisory committee consisting of an independent chairman, two scientists and two laymen, all outside Government service. The chairman of the Meteorological Research Committee would serve *ex officio* as one of the two scientists and the other be appointed after consultation with the President of the Royal Society. He stated that Lord Hurcomb had accepted his invitation to become chairman. The function of the committee will be to keep under review the progress and efficiency of the meteorological services and the broad lines of current and future policy, the general scale of effort and expenditure devoted to the Meteorological Office, and the contacts between the Meteorological Office and those who use its services.

The membership of the Committee was completed in August as follows:

The Lord Hurcomb, G.C.B., K.B.E., (*Chairman*), Sir Austin Anderson, Sir David Brunt, F.R.S., Sir Charles Normand, C.I.E., Colonel N. V. Stopford Sackville, O.B.E., T.D.

In the course of his career as a Civil Servant Lord Hurcomb was Permanent Secretary of the Ministry of Transport and Director-General of the Ministry of War Transport. He is a member of the Nature Conservancy.

Sir Austin Anderson's interests are in shipping and insurance. He has been Chairman of the Orient Line since 1952.

Sir David Brunt and Sir Charles Normand need no introduction to readers of the *Meteorological Magazine*. Sir Charles is the present Chairman of the Meteorological Research Committee.

Colonel N. V. Stopford Sackville is Chairman of the Northamptonshire Agricultural Executive Committee and Liaison Officer of the Ministry of Agriculture and Fisheries for Northamptonshire and Leicestershire. He is a county Alderman and prominent landowner.

The Director-General of the Meteorological Office and a representative of the Permanent Under-Secretary, Air Ministry, will be in attendance at meetings of the Committee and the Secretary, Meteorological Office, will be its secretary.

Terminology in temperature forecasts for the British Isles

The terminology for temperature forecasts was changed on September 16, 1957, from the one given on pages 48 and 49 of *Your Weather Service* because the more extreme terms of the former table, e.g. very hot when temperature was expected to be more than 20°F. above normal, were little used.

The new definitions are as follows:

Departure from average °F.	Spring (mid-March to mid-May) Autumn (mid-Sept. to mid-Nov.)	Summer (mid-May to mid-Sept.)	Winter (mid-Nov. to mid-March)
+14	Very warm	Very hot	Exceptionally mild
+11 to +14		Hot	
+ 7 to +10	Warm	Very warm	Very mild
+ 3 to + 6	Rather warm	Warm	Mild
− 2 to + 2	Average	Average (or rather warm*)	Average (or rather mild*)
− 3 to − 6	Rather cold	Rather cool	Rather cold
− 7 to −10	Cold	Cool	Cold
−10	Very cold	Very cool or cold†	Very cold

* For the upper part of the range if desired.

† "Cold" for use when a marked fall in temperature is expected.

In addition to terms for temperature defined strictly as in the table, words such as "warm", "cold", "mild" will be used in forecasts in such phrases as "a cold easterly wind is spreading across the country".

The effects of wind and humidity on the human system will be taken into account by coupling the wind and temperature forecasts, when the forecaster considers it useful to do so, e.g. "rather cold with strong northerly winds", and by using the terms "close", "muggy" and "raw". These words are defined as follows:

Close: temperature average or above average for the time of year with high humidity, a cloudy or overcast sky and a calm or light wind; oppressive.

Muggy: warm damp air not necessarily oppressive.

Raw: cold damp air sometimes with fog.

In forecasting frost a special set of terms will be used, ground and air frost being treated differently.

Ground frost.—As the degree of severity of ground frost over a whole forecast region cannot be specified closely on account of topography and soil differences quantitative terms will not be employed in regional forecasts. In these the phraseology will be of the form "Ground frost will occur generally" or " Ground frost will occur in places". If it is thought that ground temperatures will fall to a low level, say below 20°F. in places the forecast will state that ground frost will occur and be severe in places.

In forecasts for one place, as distinct from an area, the forecaster may, when desirable, give the actual temperature likely to be reached in words such as "ground frost will occur with temperatures at the ground falling below 25°". The expression "sharp (ground) frost" will not be used.

Air frost.—The effects of frost at screen level are very dependent on the wind. This is reflected in the new terminology for air frost which runs:

	Corresponding screen temperature	
Term	Wind speed less than 10 knots °F.	Wind speed 10 knots or over °F.
Slight frost	32–27	32–31
Moderate frost	26–21	30–28
Severe frost	20–11	27–23
Very severe frost	below 11	below 23

To assist users to exercise their judgment on the likely effects to themselves the forecasts will make clear the connection between the severity of the frost and the wind speed by the use of such phrases as "Very low temperatures such as occurred last night are not expected tonight but with 30°–27° in many places and a continuing moderate or fresh northerly wind, moderate or severe air frost may again be widespread."

A lightning stroke on a hillside

On the afternoon of April 23, 1957, Mr. A. P. Clark of Black Hope Farm, Midlothian, was on the hillside about half a mile north-east of his farm-house when a lightning stroke hit the ground about 60 yards from him making a crater about 5 feet long by 18 inches wide and more than a foot deep. Several hundredweights of earth were displaced and some heavy lumps of turf were thrown a distance of 20 or 30 yards but these were probably helped by the steep down slope. Mr. Clark was fortunately down the slope from the strike so that his head was appreciably lower than the crater. He says that he experienced a feeling as though the pressure had risen and then a very definite wave of heat. Mr. Clark got in touch with Mr. Wrigley, late of the Royal Observatory, Edinburgh, who kindly ran the writer out to Blackhope.

On account of the rarity of appreciable mechanical effects when lightning runs to earth the following notes are offered.

The national grid reference of the hole is 36/327522.

The height above sea level is 1,150 feet but within a mile are 3 peaks of between 1,400 and 1,500 feet. A wire fence runs along the skyline (about 1,500 feet) of the hill to the east and Mr. Clark tells me that the posts have, on several occasions, suffered lightning damage. The crater was not even on the highest point of its immediate surroundings but was just above the place where a very steep upward gradient gave place to a more gentle slope.

Thunder was reported from a wide area in Scotland but rainfall measurements in the near vicinity were suprisingly small. Amounts for the 24 hours measured at 9 a.m. next morning were:

Station	Distance and bearing of thunder miles	Rainfall inches
Gladhouse	3·1 west-north-west	·02
Portmore	5·5 west-south-west	·10
Rosebery	3·7 north-west	Nil
Stow	8·1 south-east	·09
Gorebridge	5·6 north	·04
Ford	8·0 north-north-east	·05
Newbattle	8·0 north	·01

Mr. Clark noticed that a small burn draining one or two hundred acres to the west came down in spate but the bigger Blackhope water draining a few square miles to the south-west was not noticeably affected by the rain. There were many lightning flashes during the storm but no estimate of number could be made. Fuses were blown on the telephone circuit in the farm-house about half a mile away.

R. A. WATSON

LETTER TO THE EDITOR

Torrential rainfall

In Mr. D. C. Mason's note[1] on an occasion of torrential rainfall at Tengah, Singapore, when 4·4 in. fell in 99 min. he talks of a "solid sheet of water" and this would seem a reasonable description to anyone who has seen such very heavy rainfall. It is interesting, therefore, that the calculated proportion, by volume, of water to air in this storm is only 1:265,000. (An average terminal velocity for the raindrops of 5m./sec. has been used.) This, of course, is the average over the whole 99 min. and there would have been instantaneous proportions considerably greater, but even they would have been surprisingly small.

Mr. G. S. P. Heywood, late Director of the Hong Kong Royal Observatory, has pointed out that the highest rate of rainfall ever recorded—1·02 in. in 1 min. in California—yields a proportion of water to air of only 1: about 12,000.

E. T. BAKER

Northolt. August 10, 1957.

REFERENCE

1. MASON, D. C.; Torrential rainfall at Royal Air Force Station, Tengah. *Met. Mag., London*, **86**, 1957, p. 187.

[The liquid water mixing ratio corresponding to a proportion of water to air by volume of 1/12,000 is, at 1,000 mb. and 20°C. 70 gm./Kg. and for a proportion of 1/265,000 is 3·2 gm./Kg.

The saturation water vapour mixing ratio at 20°C. is 14·2 gm./Kg. The rate of rainfall would thus have had to be over four times that quoted by Mr. Mason for the amount of liquid water to equal the amount of water vapour in the air. Ed. *M.M.*]

REVIEW

Hurricanes. Their nature and history. 9th revised edition. By I. R. Tannehill. $8\frac{1}{2}$ in. $\times 5\frac{1}{2}$ in., pp. x+308, *Illus.*, University Press, Princeton: Oxford University Press, London, 1956. Price: 36*s.*

The United States hurricane warning service, with its convincing demonstration of lives saved, is one of the proudest achievements of applied meteorology. In recent years losses of life in inland parts of North America, which are seldom visited by hurricanes and where people do not so readily heed the warnings, have exceeded the deaths in the worse affected coastal states. Damage to property is hard to avoid. Consequently the effectiveness of the hurricane warning service may be gauged by the reduced number of human deaths per ten million dollars of property damage; in 1926–30 there were 161 fatalities per unit damage in the United States: this figure steadily declined to 4 deaths per unit damage in 1941–45 and 0·4 in 1949.

The American hurricane warning service was started during the Spanish–American war. President McKinley said he was more afraid of one West Indies hurricane than of the entire Spanish Navy. Already from 1875 or earlier, however, a similar warning service with purely humane motives had been organized by the Jesuit Fathers at Belem, Havana. War and peace also enter the story at Apia, Samoa, in 1889, where American and German warships were preparing for hostilities, when all were wrecked by a tropical cyclone and the would-be belligerents became friends, rescuing each other in many acts of heroism.

This book is the new edition of a standard work, first published in 1938, by the man who was head of the synoptic division of the United States Weather Bureau with responsibility for the hurricane warning service during the period when the death roll was so happily cut down. Most of the new matter in this edition appears to be contained in a thirty-six page appendix.

Sections dealing with the dimensions, maximum wind speeds, geographical and seasonal distributions, tracks and life history of the Caribbean and North Atlantic hurricanes, contain a wealth of information in easily readable form which will be invaluable to all whose livelihood is affected by tropical cyclones. The reviewer knows of no such convenient compendium of information on hurricanes for shipping and travel directorates, insurance agencies and others concerned. Further chapters deal with the tidal waves which sometimes accompany these storms, with the procedures of the warning service and with precautionary measures. There is also a chronological list of all the storms known since Columbus' time and notes in some detail of the worst storms from about 1750 to 1955.

Revision has, however, produced an unevenly balanced book: a mine of factual data, invaluable to layman and meteorologist alike, but relatively weak and out of date on the theoretical side. Meteorologists will be disappointed to find no reference to Bergeron's work, nor to the later writings of Riehl. Interpretation of the hurricane circulation and development is still presented largely in the words of those who wrote on the subject in the 1920's; opposing view-points are stated unnecessarily on some aspects. Pages 58–62 on the "height of the tropical cyclone" ought surely to have been entirely re-written in the light of modern knowledge of the upper air circulation from radio soundings and aircraft reconnaissance, though this criticism is partly met in the appendix. This is not the only instance in which statements in one part of the book are corrected elsewhere. The world map of cyclone tracks on p.4 might be taken to imply that the north American region is the worst in the world for tropical cyclones, whereas the discerning reader will discover on p.116 that these storms are more frequent as typhoons in the western Pacific and in the southern Indian Ocean. On p.141 the storm of February 12, 1493, near the Azores is quoted as the first recorded West Indian hurricane, but the reader's suspicions that this was an extratropical polar-front depression are finally given the verdict on p.239. The words "South Atlantic" on p.56, where "southern North Atlantic" is meant, may confuse the layman who is elsewhere informed, correctly, that tropical cyclones are unknown in the South Atlantic. These are, however, minor pitfalls which will not deceive the careful user who reads right through the book.

The reviewer has found some interest in the very appreciable change of hurricane frequency in the North Atlantic in recent years. The increased incidence since 1931 giving a 25-yr. average of 9 a year against 6 a year for the first 30 yr. of the century is noted in rather vague terms by Tannehill on p.110 and attributed by him largely to improved facilities for reporting; indeed he assumes, in a remark on p.143, that the frequency should have remained unaltered in each century since Columbus. The reviewer believes these conclusions to be false. Tropical storms in the Atlantic were more frequent in 1887–1896 with an average of 8·4 yearly, than in the later period to 1930. The long period of minimum frequency, 1897–1930, coincided with the minimum gradient of ocean surface temperature between the tropics and the Iceland region, a time of decreasing Arctic ice and relatively low temperature of the warmest parts of the Atlantic. This arrangement would discourage convection phenomena by reducing both instability and moisture content in the tropical zone.

There was another period of "remarkable scarcity" of tropical storms in the mid-nineteenth century between about 1843 and 1870, especially 1857–66; this too coincided with a minimum of Arctic ice, though nothing seems to be known about the temperature of the tropical Atlantic at that time.

The following table, based on Tannehill's data, shows the gradual increase of reported storms over the centuries; it also indicates superimposed variations which may deserve attention in connexion with climatic variation. Indeed some aspects of the over-all trend are probably real, notably the decrease from the 1500's to 1600–1650 and, perhaps, much of the increase from 1800 to the present day.

TABLE I—FREQUENCIES OF REPORTED ATLANTIC HURRICANES IN HALF CENTURIES AND VARIOUS SHORTER PERIODS

Period	Total number of tropical storms	Average yearly number
1501–1550	13	0·26
1551–1600	13	0·26
1601–1650	8	0·16
1651–1700	33	0·66
1701–1750	41	0·82
1750–1759	...	2·0
1751–1800	123	2·46
1780–1788	...	4·6
1789–1810	...	2·5
1801–1850	198	4·0
1811–1825	...	4·3
1826–1840	...	4·2
1841–1855	...	3·7
1851–1900	228	4·6
1856–1870	...	1·6
1871–1886	...	5·4
1887–1896	...	8·4
1897–1930	...	6·0
1901–1950	375	7·5
1931–1955	...	9·0

Bergeron has pointed out that tropical storms only form where the following three conditions are satisfied:

(i) very extensive areas of water with surface temperatures over 27°C. (which is nearly the maximum temperature at present found in the oceans),

(ii) sufficient depth of thermally unstable air, and

(iii) where the intertropical convergence zone is rather far displaced north or south of the equator.

It would seem inevitable from (i) and (ii) and, perhaps, from (iii) also, that the frequency of these storms must be very sensitive to climatic trends.

H. H. LAMB

OFFICIAL PUBLICATION

The following publication has recently been issued:

GEOPHYSICAL MEMOIRS

No. 99—*Tornadoes in England: May* 21, 1950. By H. H. Lamb, M.A.

Close examination of the trails of devastation left by the main tornado and two subsidiaries over south-eastern and eastern England on May 21, 1950 reveals a good deal of detail about their behaviour through many successive pulses of activity. Estimates of the magnitude of the greatest wind speeds, shear and suction effects (pressure reduction) are derived; the extreme winds probably exceeded, and perhaps considerably exceeded, 100 kt. at certain brief phases of the activity of the main tornado, but speeds of this order were only attained over a width of a few feet, sometimes only a foot or two.

These particular English tornadoes were clearly attributable to a complex of factors: they occurred, as is usual, in a severe thunderstorm, but the evidence shows that the instability cannot have attained the extreme values possible in England nor have extended through the greatest depth of the atmosphere ever occurring here. A low condensation level contributed to great potential instability in the lower layers, so that strong vertical currents could be formed near the ground in spite of only moderate to rather low afternoon temperatures. Close study of the terrain over which the tornadoes passed in relation to the main surface wind currents on May 21, 1950 suggests that a vital initial twisting impulse was supplied by a sudden local increase of the surface north-easterly wind immediately in front of the tornado cloud advancing south-south-west, just as it came clear of various obstacles such as various north-east : south-west ridges of hills with small cross valleys in which there was little or no wind. This was the setting where each of the main bursts of activity began.

Smaller obstacles on the ground, such as dense coppices and conglomerations of buildings, also obviously affected the behaviour of the tornado, causing it to lose energy, wander up to a couple of hundred yards aside of its track or break up, though they themselves sustained considerable damage.

Both frontal and topographical shears seem to have been present, though not in a very pronounced degree, and the frontal situation, which could be followed in some detail, proved interestingly fluid in a manner associated with intense convection and local modification of air masses by heavy rainfall.

A deduced pressure profile through these tornadoes is presented, and some more theoretical discussion shows how samples of the wide variety of velocity profiles occurring may be constructed.

METEOROLOGICAL OFFICE NEWS

Retirements.—*Dr. F. J. Scrase, O.B.E.*, Senior Principal Scientific Officer, retired on August 15, 1957. After service in the Special Brigade, Royal Engineers during the First World War he joined the Office in August 1920 as a Junior Professional Assistant at Kew Observatory. In 1921 he was posted to Porton, but he returned to Kew Observatory in 1926 and he remained there for 10 years. In 1937 after a short period at Croydon Airport he was posted to Gibraltar as Senior Meteorological Officer. On his return in 1939 he was appointed Head of the Instruments Branch and from 1948 until his retirement he was Assistant Director (Instrument Development). Dr. Scrase was appointed an Officer of the Order of the British Empire in the New Year Honours List of 1948 and he was awarded the L. G. Groves Memorial Prize for Meteorology in 1955.

At a ceremony at Harrow on August 15, the Director-General presented Dr. Scrase with a cheque subscribed by his colleagues.

Dr. Scrase has accepted a temporary appointment in the Meteorological Office.

Mr. H. W. Davis, Senior Experimental Officer, retired on August 16, 1957. He first worked at the Royal Observatory, Greenwich, and after service in the Royal Field Artillery in the First World War, he joined the Office in August 1919 as a Technical Assistant. Apart from short periods in 1937–38 in the Instruments Division and the Forecast Division at Headquarters, his 38 years' service has been spent at army and aviation outstations, including a tour of duty in the Middle East. From 1949 until his retirement he served at South Cerney.

Sports activities.—*Athletics.*—Senior Aircraftman C. W. Fairbrother who is at present serving in Western Germany was selected to represent Great Britain and Northern Ireland in the High Jump event in the Amateur Athletics

Association match against France at the White City on August 3 and 5. He was placed second, jumping the same height as the winner, 6ft. 3in. Earlier in the year in Western Germany he won his Group and Command high jump competitions establishing in the latter a record for the event with a jump of 6 ft. 2 in.

WEATHER OF AUGUST 1957

As in the previous month, August was marked by a fair degree of mobility, the depression track across the Atlantic being notably variable. Consequent upon the general variability, pressure anomalies were, on the whole, rather small. The Azores anticyclone was a little stronger than normal, whilst further north from Greenland to Spitsbergen, pressure anomalies were 2 to 3 mb. below normal. The general zonal flow across the Atlantic was thus stronger than normal. Perhaps as a result of this, depressions from the Atlantic penetrated well eastwards being frequently located over the North Sea–Denmark region where pressure was again 2 to 3 mb. below the normal for the month. Pressure was slightly above normal over a very wide area including most of Asia, The Pacific and North America, the greatest anomalies being over Canada where anticyclones had repeatedly moved in from Alaska. Pressures were low in the polar basin, however, as had been the case in the previous month.

Temperatures were below normal over much of France, Italy and Germany, being 2 to 3°C. below the August normal in Southern Germany. These regions were affected by frequent northerly winds from the North Sea. Temperatures were also below normal in Japan and Manchuria whilst positive temperature anomalies reaching +4°C. were reported in Cyprus and Northern Siberia.

Rainfall was above normal over most of Northern Europe and also in the west Mediterranean but was below normal in Southern France and Northern Italy and in Southern Spain, Morocco and Algeria. The rainfall distribution over North America was rather patchy but a region of above normal rainfall roughly along latitude 40°N. marked a region of frequent cyclonic activity.

Pressure was high over the British Isles at the beginning of the month and weather during the first few days was warm and sunny, with afternoon temperatures reaching 80°F. locally and with many places recording more than 13 hr. of sunshine daily. On the 4th, however, a shallow trough of low pressure, accompanied by outbreaks of rain, approached from the south-west and during the following two days thunderstorms developed fairly widely over the country. Many of the storms were severe and reports of storm damage and extensive floods were common, with rain in some places of very rare intensity. During a severe storm at Bwlchryllan, Cardiganshire on the 5th, Bank Holiday Monday, 3·43 in. of rain was recorded in 2 hr. while on the same day at Clifford, Herefordshire 4·11 in. fell in 90 min., the second heaviest fall on record for that period in the United Kingdom. The 8th to the 12th was a period of intense cyclonic activity over the British Isles with widespread thundery rain and frequent thunderstorms often accompanied by unusually heavy downpours of rain or hail. One such occurred at Llansadwrn, Anglesey, on the 10th when 5·38 in. of rain fell in 2 hr. Noteworthy falls occurred in and around London on the 12th and 13th, especially in the Kingston–Teddington area, where there was considerable flooding. The 12th was the wettest August day at Kew since records began nearly 100 years ago. Floods, owing to heavy rain, were also reported from many other parts of the country, notably from Bath, Salisbury and Oxford. In the north rainfall amounts were mostly small until on the 14th a deep depression moved east across Scotland bringing outbreaks of rain, heavy locally, to all districts of the British Isles and gales to exposed northern coasts. During the next few days depressions passed well to the north of Scotland and from the 16th to the 22nd weather was quieter and drier, and although rain or drizzle occurred at times, it was mostly slight, except in the north. On the 21st an anticyclone, moving in from the Atlantic, gave the sunniest day in the British Isles for nearly three weeks. A depression which developed off the west of Ireland on the 22nd heralded another period of stormy weather. This depression gave widespread and locally heavy rain on the 23rd, with strong winds and gales in exposed places, as it moved toward northern Scotland, and was noteworthy for its unusual depth for the time of year. Early on the 24th barometric pressure in the extreme north of Scotland fell to 976·8 mb. at both Sule Skerry and Cape Wrath, the lowest pressure ever recorded in the British Isles during August. By this time winds had reached gale force in all western and northern districts and the following day gales extended to the whole country and were severe in exposed places. As the depression moved slowly toward Scandinavia the north-westerly winds over the British Isles moderated gradually to give rather cool weather during the last week of the month, with showers which became progressively less frequent.

The month as a whole was rather cool and, except for the first week, there was a marked lack of warm days. In the second half of the month temperature rarely reached 70°F. Sunshine was below the average generally, although in southern England it was somewhat above the average for the period during the latter half of the month. Rainfall was the most outstanding feature of the month owing to its local intensity, but less than half the monthly average occurred over most of East Anglia and the East-Midland counties of England. The sunshine at the beginning of the month rapidly ripened grain and harvesting was well under way, particularly in southern England, until heavy rains and the gales of the 23rd and 24th caused widespread damage and put a stop to operations. Reports of damage by storms and flooding to stooks, standing crops, top fruit, hops and small buildings have been received from districts as far apart as Cardigan and Kent. Diseases such as potato blight and mildew on apples have become serious threats to yields in the wet humid weather, but some vegetable crops, such as runner beans and sugar beet, have responded well to the abundant rainfall.

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 ...	84	34	−0·7	121	+2	85
Scotland	80	30	−0·3	128	0	87
Northern Ireland ...	73	38	0·0	113	+1	87

RAINFALL OF AUGUST 1957
Great Britain and Northern Ireland

County	Station	In.	Per cent. of Av.	County	Station	In.	Per cent of Av.
London	Camden Square ...	2·64	119	*Glam.*	Cardiff, Penylan ...	3·39	80
Kent	Dover	2·41	104	*Pemb.*	Haverfordwest ...	2·48	59
,,	Edenbridge, Falconhurst	3·08	118	*Radnor*	Tyrmynydd	8·66	161
Sussex	Compton, Compton Ho.	3·59	116	*Mont.*	Lake Vyrnwy	8·18	153
,,	Worthing, Beach Ho. Pk.	1·97	87	*Mer.*	Blaenau Festiniog ...	11·39	102
Hants.	St. Catherine's L'thouse	1·98	103	,,	Aberdovey	4·81	108
,,	Southampton (East Pk.)	3·49	133	*Carn.*	Llandudno	5·62	199
,,	South Farnborough ...	1·46	66	*Angl.*	Llanerchymedd ...	4·53	125
Herts.	Harpenden, Rothamsted	2·14	84	*I. Man*	Douglas, Borough Cem.	3·02	79
Bucks.	Slough, Upton	2·00	92	*Wigtown*	Newton Stewart ...	3·37	81
Oxford	Oxford, Radcliffe ...	3·77	165	*Dumf.*	Dumfries, Crichton R.I.	3·69	91
N'hants.	Wellingboro' Swanspool	2·39	100	,,	Eskdalemuir Obsy. ...	6·63	129
Essex	Southend, W. W. ...	2·00	109	*Roxb.*	Crailing...	3·80	129
Suffolk	Felixstowe	1·41	81	*Peebles*	Stobo Castle	4·86	137
,,	Lowestoft Sec. School...	1·74	79	*Berwick*	Marchmont House ...	4·99	151
,,	Bury St. Ed., Westley H.	3·03	117	*E. Loth.*	North Berwick Gas Wks.	4·20	135
Norfolk	Sandringham Ho. Gdns.	2·59	96	*Midl'n.*	Edinburgh, Blackf'd. H.	2·90	90
Wilts.	Aldbourne	3·31	119	*Lanark*	Hamilton W. W., T'nhill	4·16	122
Dorset	Creech Grange... ...	3·39	119	*Ayr*	Prestwick	4·14	130
,,	Beaminster, East St. ...	3·91	125	,,	Glen Afton, Ayr San. ...	6·85	127
Devon	Teignmouth, Den Gdns.	2·10	93	*Renfrew*	Greenock, Prospect Hill	4·40	86
,,	Ilfracombe	4·57	127	*Bute*	Rothesay, Ardencraig ...	6·56	166
,,	Princetown	7·28	107	*Argyll*	Morven, Drimnin ...	5·73	109
Cornwall	Bude, School House ...	3·45	122	,,	Poltalloch	5·28	108
,,	Penzance	4·64	146	,,	Inveraray Castle ...	7·34	112
,,	St. Austell	4·45	123	,,	Islay, Eallabus	...	...
,,	Scilly, Tresco Abbey ...	2·76	100	,,	Tiree	3·69	88
Somerset	Taunton	2·09	88	*Kinross*	Loch Leven Sluice ...	5·40	141
Glos.	Cirencester	3·82	123	*Fife*	Leuchars Airfield ...	3·07	100
Salop	Church Stretton ...	8·00	240	*Perth*	Loch Dhu	5·99	89
,,	Shrewsbury, Monkmore	5·54	200	,,	Crieff, Strathearn Hyd.	4·40	105
Worcs.	Malvern, Free Library...	4·88	169	,,	Pitlochry, Fincastle ...	3·47	98
Warwick	Birmingham, Edgbaston	4·23	141	*Angus*	Montrose Hospital ...	4·00	143
Leics.	Thornton Reservoir ...	2·93	105	*Aberd.*	Braemar	4·52	133
Lincs.	Boston, Skirbeck ...	1·88	79	,,	Dyce, Craibstone ...	4·64	153
,,	Skegness, Marine Gdns.	2·56	105	,,	New Deer School House	4·33	146
Notts.	Mansfield, Carr Bank ...	3·83	137	*Moray*	Gordon Castle	4·99	157
Derby	Buxton, Terrace Slopes	6·95	159	*Nairn*	Nairn, Achareidh ...	4·55	187
Ches.	Bidston Observatory ...	2·99	97	*Inverness*	Loch Ness, Garthbeg ...	6·45	198
,,	Manchester, Ringway...	3·51	107	,,	Loch Hourn, Kinl'hourn	8·67	106
Lancs.	Stonyhurst College ...	6·66	132	,,	Fort William, Teviot ...	6·09	98
,,	Squires Gate	3·78	111	,,	Skye, Glenbrittle ...	...	...
Yorks.	Wakefield, Clarence Pk.	4·28	165	,,	Skye, Duntulm... ...	5·90	133
,,	Hull, Pearson Park ...	3·10	107	*R. & C.*	Tain, Mayfield... ...	4·17	154
,,	Felixkirk, Mt. St. John...	5·06	178	,,	Inverbroom, Glackour...	7·49	179
,,	York Museum	5·11	203	,,	Achnashellach	7·80	124
,,	Scarborough	2·56	92	*Suth.*	Lochinver, Bank Ho. ...	5·57	167
,,	Middlesbrough... ...	2·04	74	*Caith.*	Wick Airfield	5·13	187
,,	Baldersdale, Hury Res.	5·90	178	*Shetland*	Lerwick Observatory ...	3·17	105
Norl'd.	Newcastle, Leazes Pk....	3·29	117	*Ferm.*	Crom Castle	5·10	123
,,	Bellingham, High Green	3·71	105	*Armagh*	Armagh Observatory ...	5·56	154
,,	Lilburn Tower Gdns. ...	6·50	230	*Down*	Seaforde	4·83	129
Cumb.	Geltsdale	4·83	117	*Antrim*	Aldergrove Airfield ...	4·19	116
,,	Keswick, High Hill ...	7·53	144	,,	Ballymena, Harryville...	3·44	81
,,	Ravenglass, The Grove	3·62	79	*L'derry*	Garvagh, Moneydig ...	4·05	103
Mon.	A'gavenny, Plâs Derwen	3·38	102	,,	Londonderry, Creggan	3·88	84
Glam.	Ystalyfera, Wern House	7·25	117	*Tyrone*	Omagh, Edenfel ...	5·13	120

Printed in Great Britain under the authority of Her Majesty's Stationery Office
By Geo. Gibbons Ltd., Leicester

Wt-37. K16.