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EFFECTS OF URBANIZATION ON LONG-TERM CHANGES OF WINTER TEMPERATURE IN THE LONDON REGION

By E. N. LAWRENCE

Summary. Changes of temperature in central London during the period 1920–68 are compared with changes at other stations in south-east England. Mean values of the daily minimum and maximum temperature, for the winter season (December, January and February), are examined. The most marked change, attributed to urban effects, is a *decrease* in the mean daily *minimum* temperature in central London, relative to surrounding stations, of approximately 1·5 to 2 degF (1 degC), and an *increase* of approximately 1 degF (0·5 degC) in the corresponding mean *maximum* temperature, between the 1930s and about 1950. These temperature changes are considered to be the result of urban improvements and of the difference between urban and rural areas in their response to natural climatic change.

Introduction. Differences in the temperature régime between London and the surrounding country are described by Chandler.[1] Changes of temperature with time at Manchester Airport relative to other stations in the area have been attributed[2] to the effects of urbanization. In central London, such meteorological changes with time include an increase of sunshine duration relative to the suburbs and surrounding country (see for example, Chandler,[1] Monteith[3]). Also, Monteith[3] states that at Kingsway, in central London, the mean direct radiation (on a horizontal surface) per hour of sunshine increased from 21 mWh/cm^2 in 1957 to 27 mWh/cm^2 in 1963, consistent with the decrease in smoke in central London, following the Clean Air Act of 1956. The present note describes temporal changes in the difference between winter temperature in central London and that at surrounding rural stations during the period 1920–68. These changes can be attributed to changes in urbanization and to the difference between urban and rural areas in their response to natural climatic change. Urbanization is here defined to include all the artificial results of human habitation; winter is defined as December, January and February and is referred to by the year in which January occurs.

Data used. Monthly mean values of the daily maximum and minimum temperature were used for Kensington Palace (51° 30′N, 00° 10′W, 80 ft (24 m) above MSL: referred to as station K) in central London, and for the three relatively rural outlying stations of Porton, Wilts. (51° 07′N, 01° 42′W, 363 ft (111 m) above MSL: referred to as station P) approximately to the south-west of London, Woburn, Beds. (52° 01′N, 00° 35′W, 291 ft (89 m) above MSL: referred to as station W) approximately to the north-west of

London, and East Malling, Kent (51° 17′N, 00° 24′E, 122 ft (37 m) above MSL: referred to as station E) approximately to the east of London (see Figure 1). The dates of the periods of the data are given in the results section.

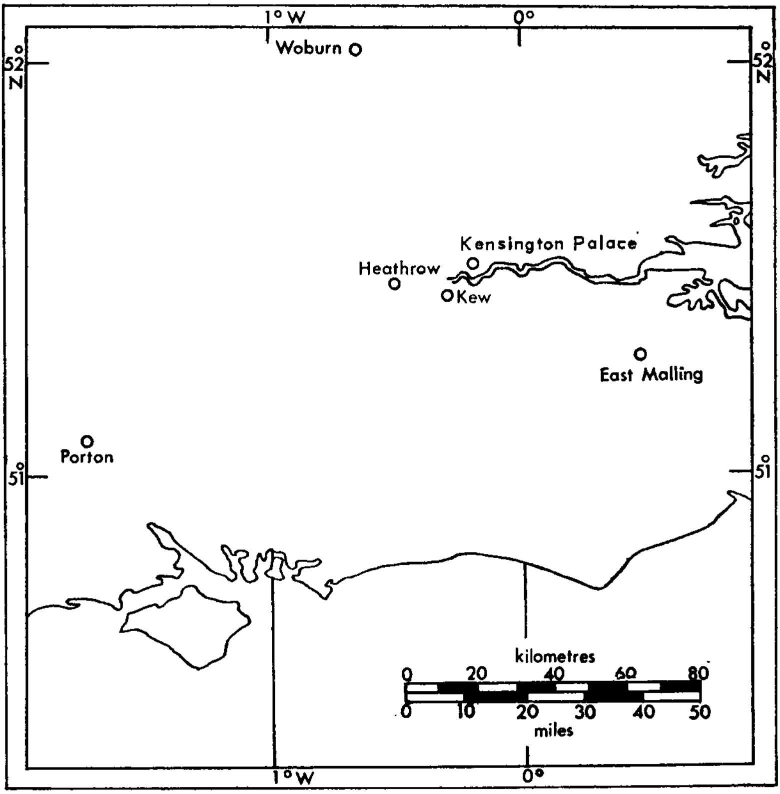

FIGURE 1—DIAGRAM SHOWING KENSINGTON PALACE (LONDON) IN RELATION TO SURROUNDING STATIONS

Winter mean values of sunshine duration and the run of wind refer to Kew Observatory (51° 28′N, 00° 19′W, 18 ft (5 m) above MSL) where the anemometer is 75 ft (23 m) above the ground with an effective height of approximately 50 ft (15 m).

Winter data (1951–68) for illumination refer to Kew Observatory and to the London Weather Centre in central London (in Kingsway and later in High Holborn).

Minor changes in the sites, chiefly at Woburn, are neglected in the present investigation.

Results. Graphs are shown for the months of December, January and February combined, for the following elements :

(i) Mean daily minimum temperature (Figures 2*(a)–(d)*), and mean daily maximum temperature (Figures 3*(a)–(d)*) for Kensington Palace (1921–68), Porton (1921–68), Woburn (1921–68) and East Malling (1926–68).

Smoothed curves of '10-year' running means are superimposed, plotted on the centre point of the period.

(ii) Difference between mean minimum temperature at Kensington Palace and that at surrounding rural stations, together with the corresponding difference in mean maximum temperature (Figure 4).

Kensington Palace minus Porton (K – P: Figure 4*(a)*),
Kensington Palace minus Woburn (K – W: Figure 4*(b)*) and
Kensington Palace minus East Malling (K – E: Figure 4*(c)*).

Smoothed curves of '10-year' running means are superimposed.

(iii) Mean values of the hourly run-of-wind (mean wind speed) (1921–68) for Kew Observatory with '10-year' running means (Figure 5).

(iv) Mean daily duration of sunshine (1921–68) for Kew Observatory with '10-year' running means (Figure 6).

Discussion. Smoothed minimum-temperature curves (Figures 2*(b)*, *(c)*, and *(d)*) for Porton, Woburn and East Malling show little long-term change, but that for Kensington Palace (Figure 2*(a)*) shows a distinct downward trend of approximately 2 degF (1 degC) during the period of data shown.

Smoothed maximum-temperature curves (Figures 3*(b)* and *(c)*) for the longer-period stations of Porton and Woburn show a slight tendency to a downward trend, whereas Kensington Palace (Figure 3*(a)*) shows a downward trend from about 1925 to about 1942, and then a rise to a peak about 1952, followed by another downward trend. The corresponding curve for East Malling (Figure 3*(d)*) is similar to the corresponding parts of the curves for Porton and Woburn.

Smoothed minimum-temperature-difference curves (Figures 4*(a)*, *(b)*, and *(c)*) show a downward trend from about 1930 to about 1950 and then level out.

Smoothed maximum-temperature-difference curves (Figures 4*(a)*, *(b)*, and *(c)* for K – P, K – W and K – E curves respectively) show a steady rise up to about 1950 (preceded by a fairly constant value up to about 1935–40 in the K – P and K – E curves) and then the K – P and K – W curves level out while the K – E curve shows a downward trend.

The main feature of the three pairs of temperature-difference graphs (Figures 4*(a)*, *(b)* and *(c)*) is their similarity, although the three stations are in different directions from London (see Figure 1). This result suggests that the trends shown are not due entirely to any changes from year to year in the natural distribution of wind directions.

There is another possible partly-natural cause of the trends in these temperature-difference graphs, namely, long-term trends in mean wind speed. For example, temperature differences could be increased as a result of lighter wind régimes, because light winds are often associated with maximum topographical effects on temperature. Thus, a steady decrease in mean wind speed could lead to a steady decrease in the dispersal of air pollution and so to increasing urban-rural differences in minimum temperature. However, it can be seen that the trend to *decreasing* minimum-temperature differences between about 1940 and 1950 is associated with a trend to decreasing mean

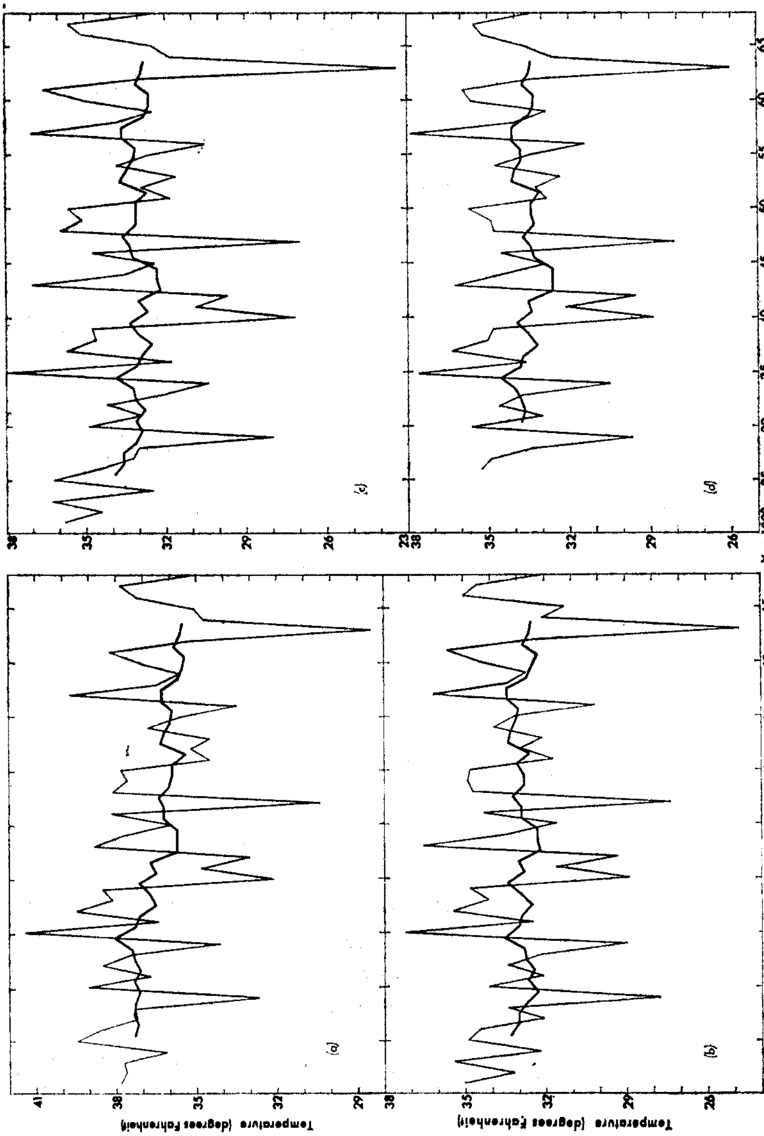

FIGURE 2—WINTER MEAN DAILY MINIMUM TEMPERATURE AND 10-YEAR RUNNING MEANS

(*a*) Kensington Palace (London), (*b*) Porton, Wilts., (*c*) Woburn, Beds., and (*d*) East Malling, Kent.

——— Mean daily minimum temperature ▬▬▬ 10-year running means

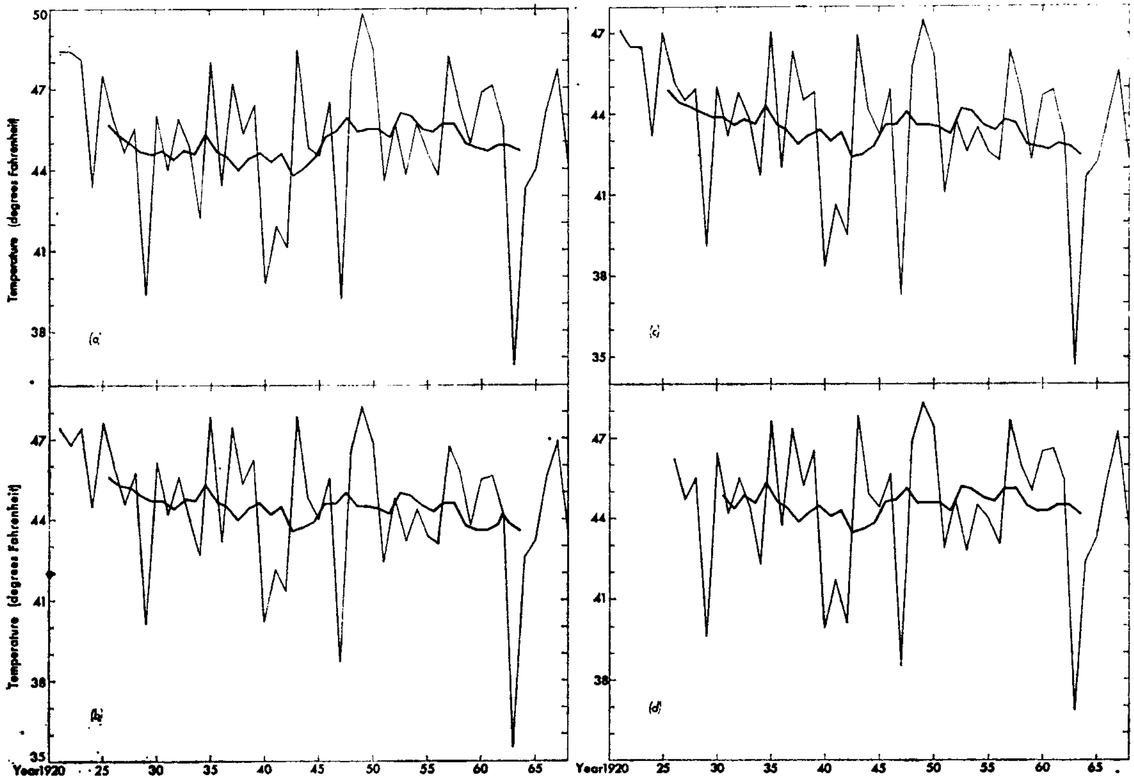

FIGURE 3—WINTER MEAN DAILY MAXIMUM TEMPERATURE AND 10-YEAR RUNNING MEANS

(*a*) Kensington Palace, (*b*) Porton, (*c*) Woburn and (*d*) East Malling.

——— Mean daily maximum temperature ——— 10-year running means

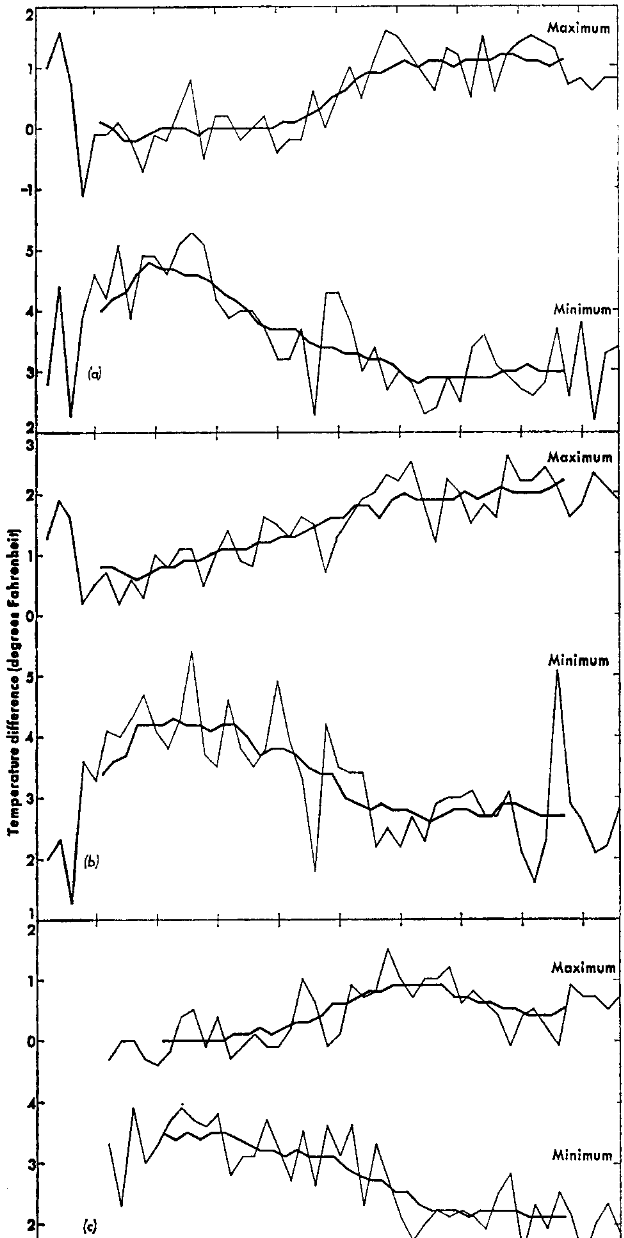

FIGURE 4—WINTER MEAN DAILY MINIMUM-TEMPERATURE DIFFERENCE AND MAXIMUM-TEMPERATURE DIFFERENCE BETWEEN KENSINGTON PALACE AND *(a)* PORTON, *(b)* WOBURN, AND *(c)* EAST MALLING, AND CORRESPONDING 10-YEAR RUNNING MEANS

(a) Kensington Palace *minus* Porton (1921–68)
(b) Kensington Palace *minus* Woburn (1921–68)
(c) Kensington Palace *minus* East Malling (1926–68).
——— Mean daily temperature difference ▬▬▬ 10-year running means

wind speed (at Kew; Figure 5); in general, trends in the temperature-difference curves cannot be explained as merely a result of trends in mean wind speed.

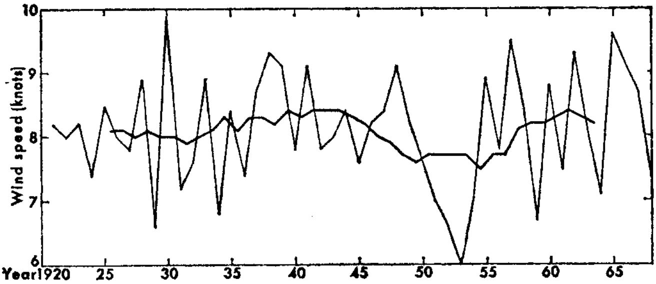

FIGURE 5—WINTER MEAN HOURLY WIND SPEED AT KEW OBSERVATORY AND 10-YEAR RUNNING MEANS

——— Mean hourly wind speed ━━━ 10-year running means

A further possible partly-natural cause of trends in temperature-difference curves is long-term trends in cloudiness. Like wind increases, an increase in cloudiness could reduce station differences and vice versa: for example, 'heat-islands' are less marked in strong winds and/or cloudy conditions. Conversely the relative increase, in Figures 4*(a)*, *(b)* and *(c)*, in London's maximum temperatures between 1935 and 1945 might be partly the result of a general (natural) decrease in cloudiness or increase in sunshine, but the trend in the duration of sunshine (Figure 6) does not support this explanation.

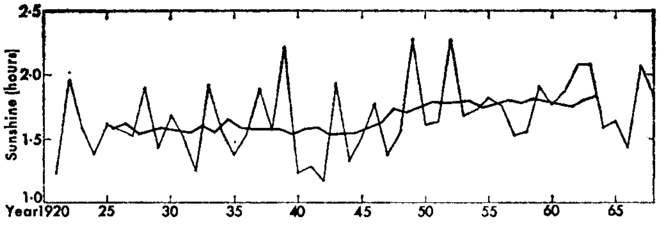

FIGURE 6—WINTER MEAN DAILY DURATION OF SUNSHINE AT KEW OBSERVATORY AND 10-YEAR RUNNING MEANS

——— Mean daily duration of sunshine ━━━ 10-year running means

However, there is an overall similarity between the sunshine trend (Figure 6) and the trends shown in the maximum-temperature-difference curves (Figures 4*(a)*, *(b)* and *(c)*). The correlation coefficients between sunshine and maximum-temperature-differences, for 10-year running mean values, are + 0·92 (K – P), + 0·84 (K – W), and + 0·68 (K – E). These rather high correlations may result from the fact that retention of solar radiation in urban areas, as compared with surrounding rural areas, is relatively greater when sunshine is greater.

The foregoing discussion shows that the main features of the temperature-difference graphs (Figures 4*(a)*, *(b)* and *(c)*), namely the relative increase in mean maximum temperatures and the relative decrease in mean minimum temperatures between the 1930s and about 1950, cannot be explained entirely by changes in wind, cloud or radiation. It is suggested that the results reflect the increasing use of cleaner and more efficient heating methods. After about 1950, changes in temperature differences seem to be less marked, in spite of the Clean Air Act of 1956, and the fact that during recent years, there seems to have been in central London, (i) some increase relative to surrounding rural areas, in the duration of winter sunshine,[1,3] (ii) an increase between 1957 and 1963 in the direct radiation per hour of sunshine,[3] and (iii) a relative increase of winter illumination, as a proportion of that at Kew, from 0·8 in the early 1950s to generally 0·9 to 1·0 in the 1960s, and (iv) a decrease of fog both in central London[4] between 1947 and 1962, and at London/Heathrow Airport[5] between 1946 and 1963.

The levelling-out of temperature-difference trends after 1950* could result from a number of possible causes, for example, (i) decreasing minimum temperatures in central London could lead to greater fuel consumption and artificial atmospheric heating and so check the earlier decrease in minimum-temperature difference, (ii) the greater amounts of sunshine could cause greater heat-retention and so likewise inhibit the previous decrease in minimum-temperature difference and (iii) increasing mean wind speed after the early 1950s might well have masked any increase of maximum-temperature difference resulting from urban improvements.

Conclusions. Climatological data from 1920 for the London region suggest that the most marked changes in London's winter temperatures, relative to its surroundings, occurred between the 1930s and about 1950, when in central London, mean maximum temperatures increased by approximately 1 degF (0·5 degC) and mean minimum temperatures decreased by approximately 1·5 to 2 degF(1 degC), relative to surrounding areas. The data suggest that these changes are the result of (i) urban changes, as for example, the improvement in heating methods, and (ii) the difference in effects between London and surrounding areas caused by natural changes of climate, as for example, natural changes in sunshine.

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* During the middle 1940s the trend in the 10-year running means of the difference between minimum temperature at Manchester Airport in winter and that at neighbouring stations was similar to the trend at London. In the 1950s the trend at London levelled out, but the trend at Manchester Airport showed a marked increase of about 1 degF (0·5 degC), which probably reflects the results of the more extensive local urban development around Manchester Airport during this period.

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CLEAR-AIR TURBULENCE OVER THE NORTH ATLANTIC; SOME NOTABLY TURBULENT PERIODS

By J. C. LENNIE

Summary. An examination was made of aircraft reports of clear-air turbulence. Notably turbulent periods occurred in two types of synoptic situations. In the first the turbulence was reported near a strong anticyclonically curved jet stream, and the association of this high-level feature with cyclonic deepening is shown in some cases. In the second situation the turbulence occurred in a large-amplitude ridge not far from the right exit of a jet stream. This high-level pattern belongs to a later stage of cyclonic development and is shown on most occasions to be associated with the point of occlusion.

Introduction. Although large numbers of aircraft cross the North Atlantic daily, there are seldom more than a few reports of turbulence. In 1967, for example, on more than 90 per cent of the 12-hour periods, 0000 to 1200 GMT and 1200 to 0000 GMT, not more than two turbulence reports per period were received at London/Heathrow Airport. A few periods, on the other hand, are notably turbulent. In 1967, on about 1 per cent of the 12-hour periods there were 10 or more reports of turbulence and it is these occasions, 9 in number, together with 2 equally turbulent occasions from early 1968 which are examined here. The numbers above refer to the area bounded by the latitudes 40°N and 60°N and the longitudes 10°W and 60°W, and to turbulence of intensity greater than light: the word turbulence is used in this sense throughout.

Frequent turbulence reports during a 12-hour period almost always indicate that the transatlantic aircraft have encountered, not widely scattered patches of turbulence, but one particularly turbulent area, the boundaries of which can be defined approximately from aircraft reports. This is so because the traffic pattern over the North Atlantic ensures that large numbers of east-bound aircraft are over the area concerned from 0000 to 0900 GMT daily, and large numbers of west-bound aircraft from 1200 to 2100 GMT daily. Present-day flight-planning procedures further ensure that in each instance most of the aircraft are concentrated on a few closely similar tracks. They almost all fly between 29 000 and 39 000 ft (9–12 km). The turbulence encountered at these flight levels is not necessarily associated with the zone of strong vertical wind shear under the jet stream in which clear-air turbulence is often found.

When the turbulence reports received during the notably turbulent periods were plotted on the most appropriate 300 mb chart (the 0000 GMT chart for east-bound aircraft, and the 1200 GMT chart for west-bound aircraft) the turbulent areas were found to be associated, broadly, with two types of contour patterns. These were (i) a broad, rather flat ridge with a strong contour gradient, and (ii) a jet stream orientated from between S and WSW debouching into a ridge of large amplitude and relatively light winds. The 300 mb chart, however, shows only the larger-scale features of the flow. The details of the wind field near the turbulent area can be shown more clearly by means of the winds reported by the aircraft. Since few of these are received simultaneously, it was necessary to illustrate the flow using winds measured at differing times. The period from which winds for this purpose were selected was made as short as possible consistent with adequate representation of the wind field and usually proved to be about two hours. At least one such chart of winds with contemporary reports of turbulence was plotted for 10 of the 11 turbulent periods.

Five notably turbulent periods associated with strong winds in broad 300 mb ridges. Five periods were associated with the type of 300 mb pattern illustrated in Figure 1. Similar situations are shown in more detail in Figures 2, 3 and 4. The detailed charts show, for each of the four periods for which it was possible to prepare them from winds reported by aircraft, that the turbulence was near a very strong, anticyclonically curved jet stream, and that although some turbulence was clearly on the cold side of the jet stream and some on the warm side, the bulk of it was close to the core. There was also a marked concentration of turbulence near the axis of the ridge, almost half of the total of 94 reports, as Table I shows, being within 5 degrees of longitude upwind and 5 degrees downwind of the ridge axis. Since the wind reports are usually at intervals of 10 degrees of longitude there is, of course, some doubt about the precise position of the axis.

TABLE I—DISTRIBUTION OF TURBULENCE AROUND THE AXES OF THE FOUR BROAD STRONG 300 mb RIDGES

Date	Degrees of longitude upwind				Ridge axis	Degrees of longitude downwind			
	16–20	11–15	6–10	1–5		1–5	6–10	11–15	16–20
21 Jan. 1967	1		5	1	2	8			
2 Mar. 1967				5	1	2	6		1
8 July 1967			10	4	5	5	1		
2 Dec. 1967		1	1	7	1	2	14	6	5
Total	1	1	16	17	9	17	21	6	6

The turbulence on 2 December 1967 is something of an exception, for then it occurred not only around the axis of the ridge, but was experienced all the way from the downwind trough to the axis (Figure 4).

The vertical relationship of the turbulence to the height of the jet-stream core is shown in Table II. As the jet streams were all very strong the shear of wind between flight levels was marked, so that the accuracy of the heights assigned to the jet cores is probably better than average.

TABLE II—DISTRIBUTION OF TURBULENCE AROUND THE LEVEL OF THE JET CORE

Date	Jet height*	Flight level*					
		290	310	330	350	370	390
21 Jan. 1967	330	0	1	10	5	1	0
2 Mar. 1967	350	0	2	2	11	0	0
8 July 1967	320	0	0	14	11	0	0
2 Dec. 1967	300	0	1	8	12	11	5

* Heights expressed in hundreds of feet.
Number of turbulence reports below jet-stream level = 5.
Number of turbulence reports at and above jet-stream level = 89.

The preponderance of turbulence at and above the level of the jet stream may be real or only apparent, and due to the large numbers of aircraft flying at 33 000 and 35 000 ft. Correction for this imbalance in the numbers of reports from different flight levels has been made by expressing the number of turbulence reports at each flight level as a fraction of the total number of aircraft reports at that level in the turbulent area. Table III shows that of the aircraft reports at and above the jet, the proportion which indicate turbulence was four times the corresponding proportion below the jet.

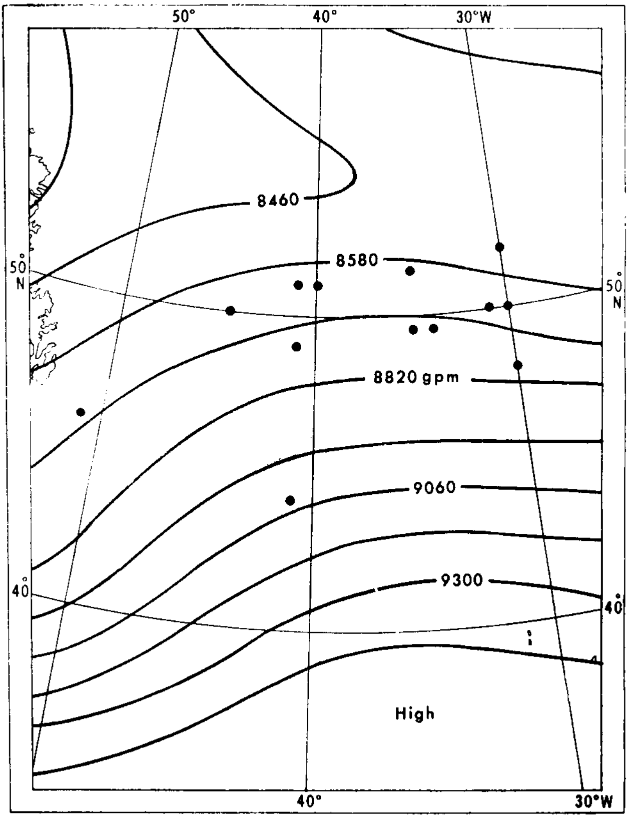

FIGURE 1—300 mb CHART, 0000 GMT, 21 JANUARY 1967
Dots show position of turbulence reported between 0100 and 0600 GMT.
Each dot may represent more than one report.

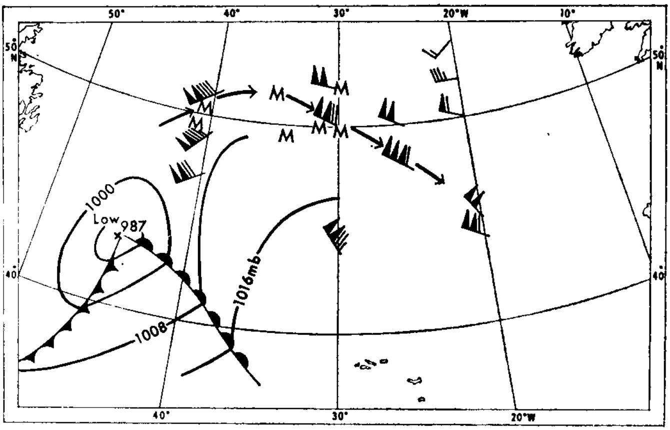

FIGURE 2—21 JANUARY 1967. AIRCRAFT-REPORTED WINDS AT ABOUT 33 000 ft (10 000 m), 0405 – 0525 GMT, TURBULENCE 0435 – 0530 GMT
M = light to moderate, moderate and moderate to severe turbulence. Surface analysis 0600 GMT.
Arrows show approximate position of the jet stream.

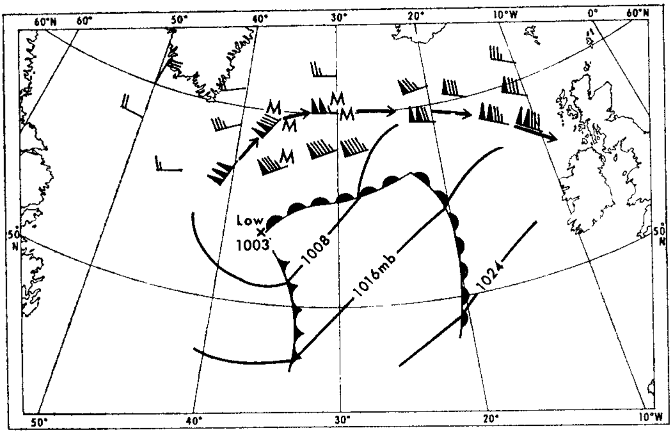

FIGURE 3—8 JULY 1967. AIRCRAFT-REPORTED WINDS AT ABOUT 35 000 ft (10 500 m), 1410 – 1535 GMT. TURBULENCE 1410 – 1540 GMT
M = light to moderate, moderate and moderate to severe turbulence. Surface analysis 1800 GMT. Arrows show approximate position of the jet stream.

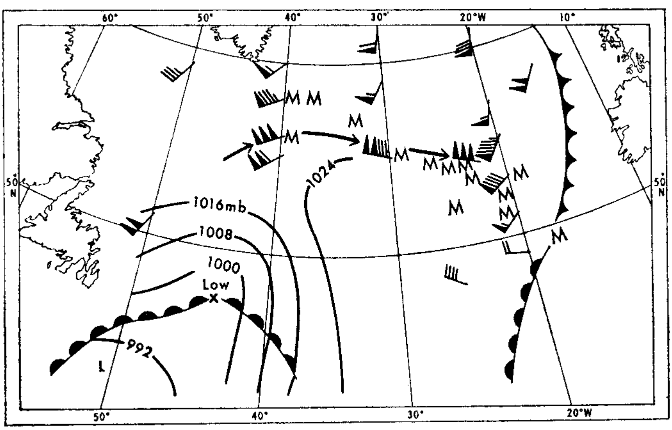

FIGURE 4—2 DECEMBER 1967. AIRCRAFT-REPORTED WINDS AT ABOUT 35 000 ft (10 500 m), 1335 – 1550 GMT. TURBULENCE 1405 – 1550 GMT
M = light to moderate, moderate and moderate to severe turbulence. Surface analysis 1800 GMT. Arrows show approximate position of the jet stream.

TABLE III—RATIOS OF TURBULENT TO TOTAL REPORTS IN RELATION TO THE LEVEL OF THE JET STREAM

Date	Below jet stream	At and above jet stream	Total
21 Jan. 1967	1/14	16/55	17/69
2 Mar. 1967	4/37	11/50	15/87
8 July 1967	0/12	25/61	25/73
2 Dec. 1967	0/7	37/134	37/141
Total	5/70	89/300	94/370
Per cent	7	30	—

So far it has been shown that on these four notably turbulent occasions the turbulence was near a very strong anticyclonically curved jet stream, that it tended to be concentrated round the axis of the ridge, and that much of it occurred at the level of the jet stream and above.

Binding,[1] when discussing turbulence in high-level ridges suggested that an increase in the speed or an increase in the anticyclonic curvature of the warm front jet stream, both of which may occur as a depression deepens, are factors tending towards an increase of turbulence. On the four occasions under discussion the jet streams were all of the warm front type, i.e. they were moving laterally towards colder air. So, in the light of Binding's suggestions, the surface features related to the jet streams were next examined. Table IV shows that on three of the four occasions the turbulent jet stream was associated with a deepening depression having a pronounced northward component of movement. On the fourth occasion the main feature was an old deep low with, on its eastern flank, a non-deepening secondary system moving rapidly NNE (Figure 4). In spite of the differences between the pressure pattern of the first three cases and that of the fourth, they have in common what appears to be an important factor, the capacity for driving warm air rapidly northwards.

TABLE IV—MAIN FEATURES OF THE SURFACE PRESSURE PATTERN ASSOCIATED WITH FOUR NOTABLY TURBULENT WARM FRONT JET STREAMS. *H* IS THE TIME OF THE SURFACE CHART NEAREST TO THE TURBULENCE

Date	Surface feature	Pressure at *H*-12	Pressure at *H*	12-hour pressure difference	Latitude at *H*-12	Latitude at *H*	12-hour movement north
			millibars			*degrees*	
21 Jan. 1967	Deepening warm sector low	1007	987	−20	39	43	+4
2 Mar. 1967	Deepening warm sector low	1003	982	−21	39	47½	+8½
8 July 1967	Deepening wave	1015	1003	−12	45½	53½	+8
2 Dec. 1967	Deep occluding low	979	975	−4	38½	39½	+1
	Secondary moving NNE*	998*	998	0*	44*	47½	+3½*

* Six-hour period only

Table IV provides support for the view that turbulence is particularly likely near the warm front jet stream during cyclogenesis, but in order to show the connection more clearly the situation leading up to the turbulent outbreak of 21 January 1967 has been examined in detail. Figure 5 shows schematically

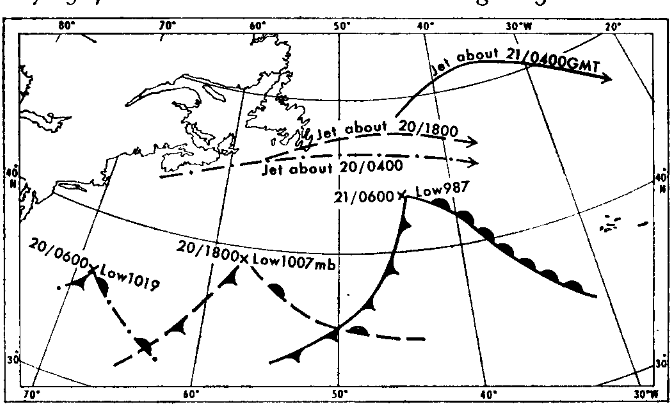

FIGURE 5—SITUATION LEADING UP TO THE TURBULENT OUTBREAK OF 21 JANUARY 1967

Positions of warm-sector depression at 12-hour intervals with the corresponding positions of the warm-front jet streams derived from aircraft reported winds.

the deepening depression with its frontal system at 12-hour intervals from 0600 GMT 20 January, and the positions of the warm front jet stream at about the same times obtained from aircraft reported winds. The details of the wind field in the vicinity of the jet stream about 0400 GMT on 20 January, when the depression was just beginning to deepen, are shown in Figure 6.

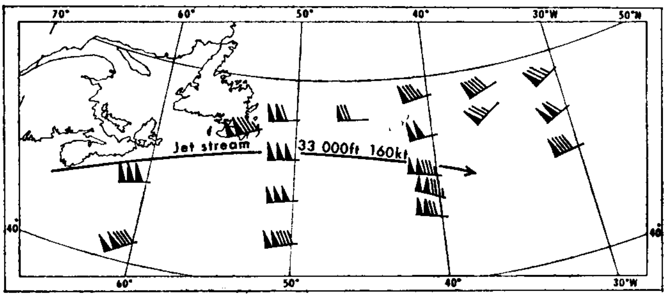

FIGURE 6—20 JANUARY 1967. AIRCRAFT-REPORTED WINDS AT ABOUT 33 000 ft (10 000 m) NEAR 0430 GMT WITH APPROXIMATE POSITION OF THE JET STREAM
The same jet stream about 24 hours later is shown in Figure 2.

About this time 60 reports were received from east-bound aircraft between 60°W and 40°W and within three degrees of latitude either side of the jet stream. No turbulence was reported. Twenty-four hours later, with the depression now deepened to 987 mb, the east-bound aircraft again encountered the jet stream. This time there were many reports of turbulence, mostly moderate, but occasionally severe. The changes which took place in the warm front jet stream during the 24 hours of cyclonic development can be seen by comparing Figure 2 with Figure 6. There is no apparent change in speed but there is a pronounced increase in the anticyclonic curvature of the jet stream.

Six notably turbulent periods associated with large-amplitude 300 mb ridges. The remaining six periods were associated with the type of 300 mb pattern illustrated in Figure 7. The relationship of the turbulent area to the wind field is shown in more detail for five of the six cases in Figures 8 – 12. The features of the wind field in the vicinity of the turbulent area which are common to all the illustrated examples are (i) the flow is anti-cyclonic and (ii) the wind speed decreases across the turbulent area in the direction of the flow.

Table V shows that more than half the turbulence occurred within five degrees of longitude upwind and five degrees downwind of the axis of the ridge and that there may be a tendency for more turbulence on the upwind than on the downwind side of the ridge.

TABLE V—DISTRIBUTION OF TURBULENCE AROUND THE AXES OF SIX LARGE-AMPLITUDE RIDGES

Date	Degrees of longitude upwind					Ridge axis	Degrees downwind	
	20	16–20	11–15	6–10	1–5		1–5	6–10
11 Apr. 1967				8	2	5	1	
8 Mar. 1967	1	5	1	3	3		1	
19 Dec. 1967	2	3	5	4	5		1	
23 Dec. 1967				1	11	4	5	11
8 Jan. 1968					2	4	8	5
27 Feb. 1968				6	24	9	3	
Total	3	8	6	22	47	22	19	16

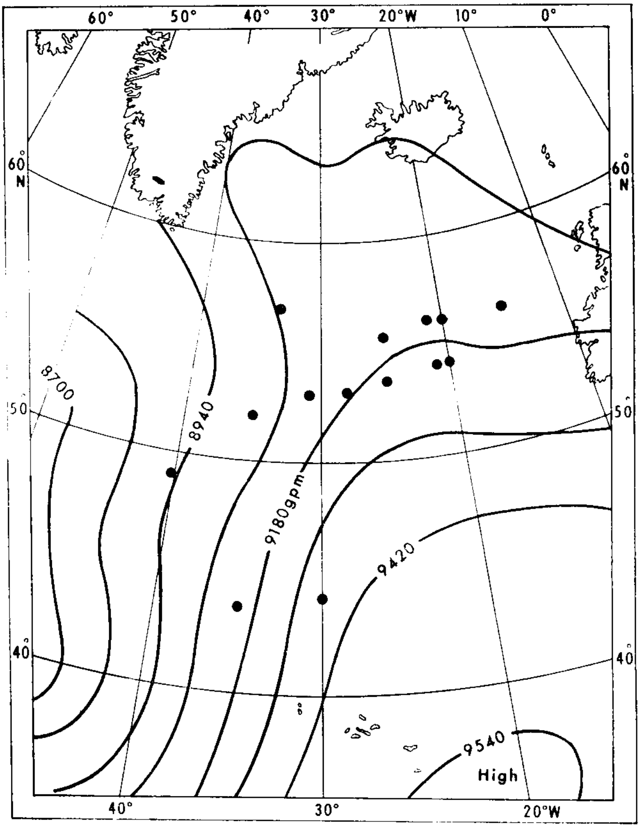

FIGURE 7—300 mb CHART, 0000 GMT, 19 DECEMBER 1967
Dots show position of turbulence reported between 0400 and 0800 GMT. A dot may indicate more than one report.

In this type of situation the winds in the turbulent area are too light for precise identification of the level of the jet-stream core, or the level of maximum wind in the ridge, but as far as can be judged, there was about the same proportion of turbulence reports below the jet-stream level as there was at and above it.

The 300 mb pattern common to all six periods is one often associated with a cold occlusion; and in five of the six cases the main feature of the synoptic situation was, in fact, a partially occluded low. Details are given in Table VI. In four cases (Figures 8, 9 and 10 illustrate three of them) the point of occlusion is either in or just upwind of the turbulent area. In the fifth case (Figure 11) the point of occlusion is some 300 nautical miles to the south of the turbulence, while in the sixth (Figure 12) the surface synoptic situation is quite different with the point of occlusion well to the north of the turbulence.

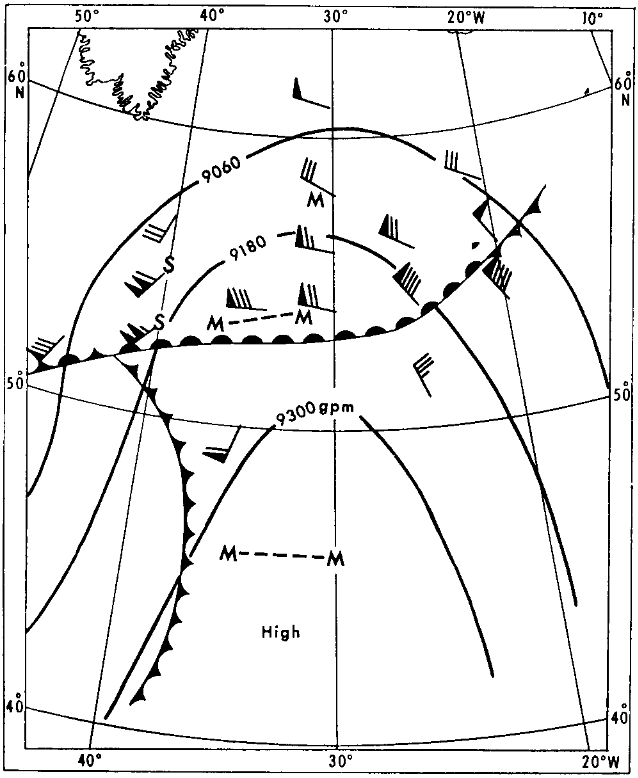

FIGURE 8—11 APRIL 1967. AIRCRAFT-REPORTED WINDS AT ABOUT 35 000 ft (10 500 m), 0505 – 0650 GMT. TURBULENCE 0515 – 0650 GMT

M = light to moderate and moderate, S = severe turbulence. – – – – indicates continuous turbulence. Surface analysis and interpolated 300 mb contours for 0600 GMT.

TABLE VI—MAIN FEATURE OF THE SURFACE PRESSURE PATTERN DURING SIX NOTABLY TURBULENT PERIODS ASSOCIATED WITH LARGE-AMPLITUDE RIDGES. *H* IS THE TIME OF THE SURFACE CHART NEAREST TO THE TURBULENCE

Date	Surface feature	Pressure at *H*-12	Pressure at *H*	12-hour pressure difference	Latitude at *H*-12	Latitude at *H*	12-hour movement north
			millibars			*degrees*	
11 Apr. 1967	Partially occluded low	987	983	−4	42	48½	+6½
8 Nov. 1967	Partially occluded low	998	988	−10	63½	66½	+3
19 Dec. 1967	Partially occluded low	991	993	+2	56½	57½	+1
23 Dec. 1967	Partially occluded low	967	959	−8	58	63½	+5½
8 Jan. 1968	Partially occluded low	970	963	−7	48	49½	+1½
27 Feb. 1968	Open warm sector low	976	980	+4	41	51½	+10½

Conclusions. During 11 of the most turbulent periods occurring over the North Atlantic in 1967 and early 1968 the turbulence, which was between

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Photograph by courtesy of The British Petroleum Company Ltd

PLATE I—ICE ACCUMULATION ON OIL TANKER

January 1968 in the Baltic. With several inches of ice on her foredeck and upperworks, the 16 000 deadweight ton BP tanker *British Vigilance* arrives at the town of Gavle, Sweden, 120 miles north of Stockholm. An ice-breaker had to clear a path into the port for the tanker before she could unload her cargo of gas oil, in a temperature of minus 4°F (36° below freezing point). The weather in the Baltic was unusually bitter during the winter of 1967–68.

PLATE II—THE NORTH WALL SCREEN AT KEW OBSERVATORY (WITH THE DOORS OPEN)

The photothermograph thermometer bulbs can be seen in the lower left (the wet bulb) and the lower right; the stems of these thermometers are bent twice at right angles, the horizontal portions passing through the wall of the building so that photographic recording can take place inside. In the centre are two control thermometers, one dry bulb and one wet bulb. On the left, outside the screen, is a reservoir of distilled water feeding both the wet bulbs. On the right, outside the screen, is an additional louvered screen to cut off solar radiation from the setting sun in summer (the main entrance of the Observatory cuts off radiation at sunrise). (See page 30).

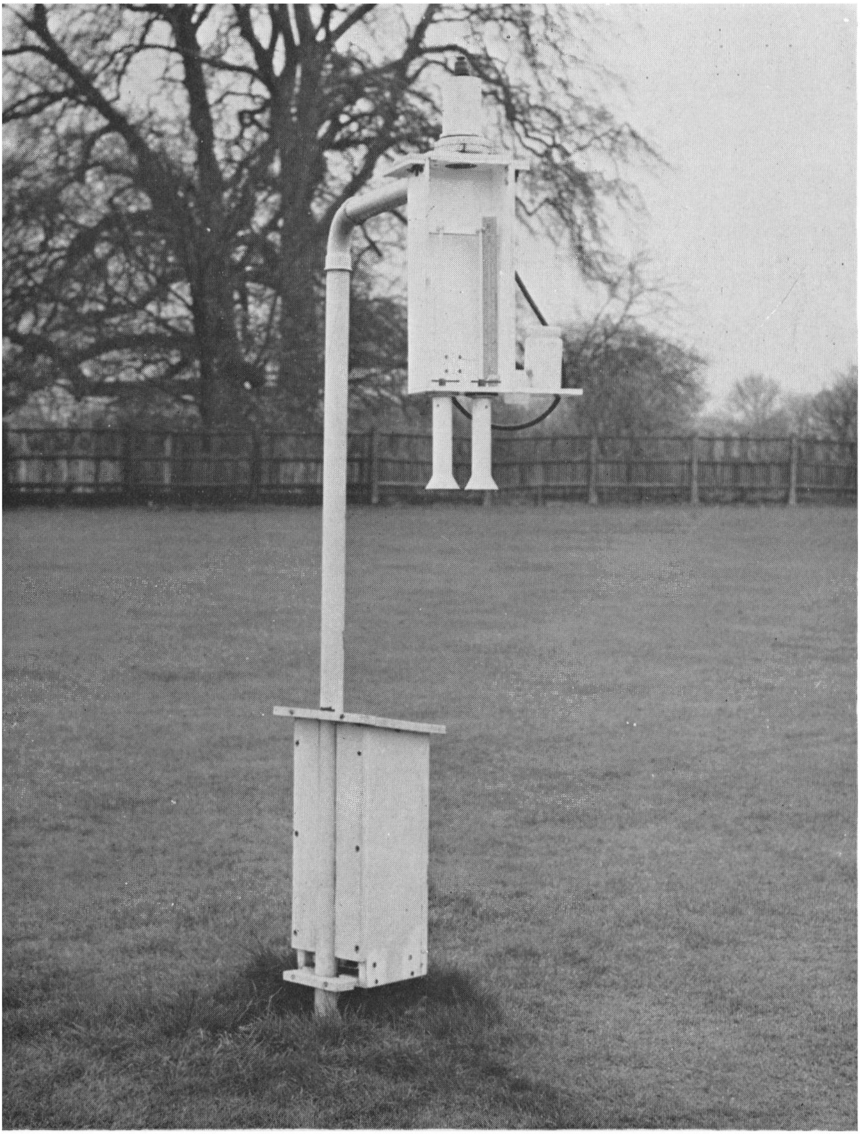

PLATE III—THE NEW ELECTRICAL RESISTANCE ASPIRATED PSYCHROMETER AT KEW OBSERVATORY

Air is drawn up through the double-walled radiation shields at the base of the instrument, and over the resistance thermometer elements. Sensitive open-scale mercury-in-glass thermometers (which can be seen through the clear perspex front — together with a foot-rule) are permanently mounted with their bulbs in cylindrical cavities in the centre of the resistance element; these enable frequent checks to be carried out on the resistance record.

The resistance elements are 1·25 metres above the ground level and the psychrometer is situated near the centre of the large lawn. The trees in the background are about 80 feet (27 metres) high and are some 190 feet (63 metres) distant. (See page 30).

To face page 17

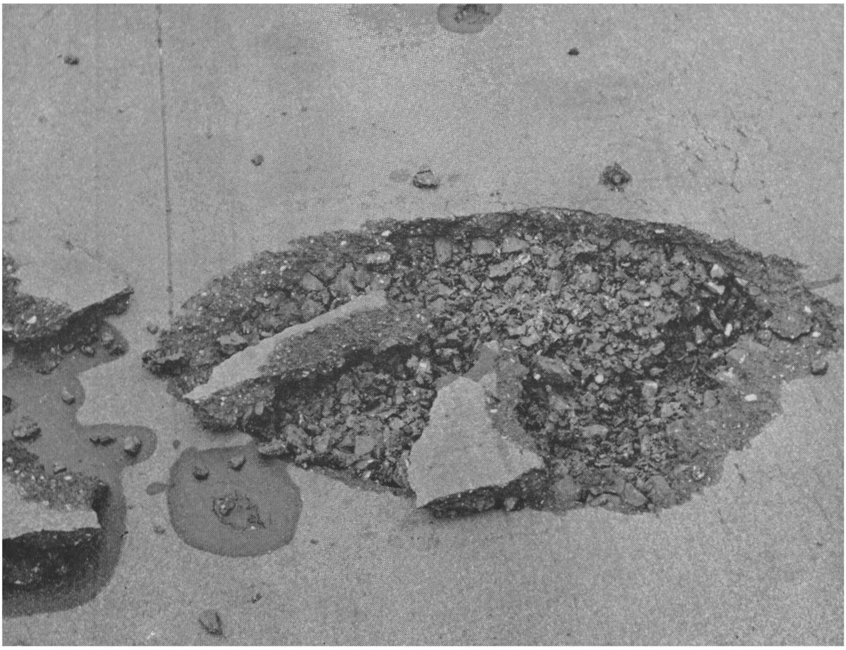

PLATE IV—LIGHTNING STRIKE AT RAF CHIVENOR, 2 JULY 1968 — A LARGE CRATER TORN IN THE RUNWAY SURFACE

PLATE V—DEBRIS FANNING OUT FROM THE CRATER FORMED BY THE LIGHTNING STRIKE AT CHIVENOR

See page 31.

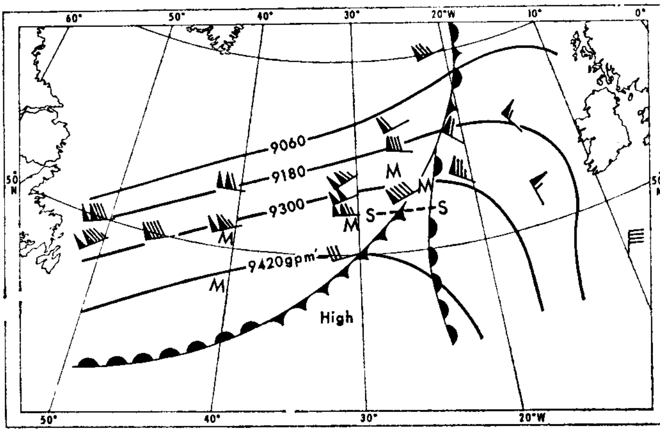

FIGURE 9—8 NOVEMBER 1967. AIRCRAFT-REPORTED WINDS AT ABOUT 35 000 ft (10 500 m), 0400 – 0555 GMT. TURBULENCE 0410 – 0550 GMT

M = light to moderate and moderate, S = severe turbulence. – – – – indicates continuous turbulence. Surface analysis and interpolated 300 mb contours for 0600 GMT.

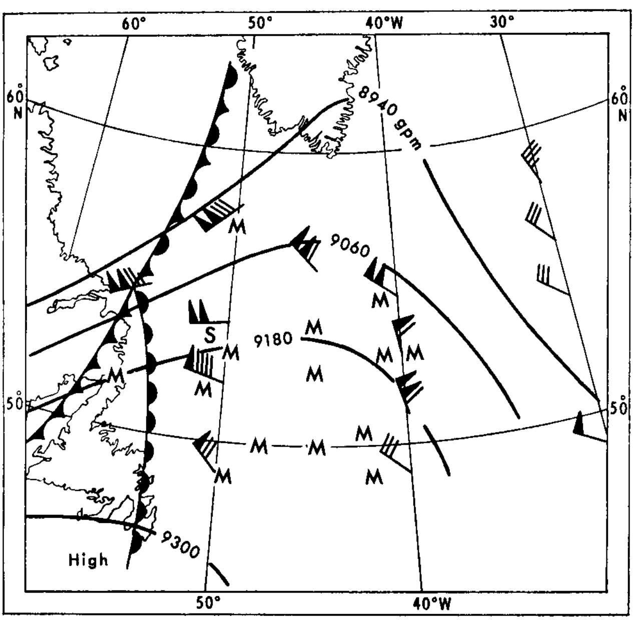

FIGURE 10—23 DECEMBER 1967. AIRCRAFT-REPORTED WINDS AT ABOUT 35 000 ft (10 500 m), 0400 – 0715 GMT. TURBULENCE 0405 – 0710 GMT

M = light to moderate and moderate, S = severe turbulence. Surface analysis and interpolated 300 mb contours for 0600 GMT.

29 000 and 39 000 ft, was all associated with anticyclonic curvature in the wind field. Two situations in which this type of high-level clear-air turbulence seems particularly likely can be recognized. The first is the broad ridge with strong winds which develops in the upper troposphere as a polar front depression deepens. Turbulence is then likely in the ridge near the warm front jet stream as it bends anticyclonically. The second situation arises as

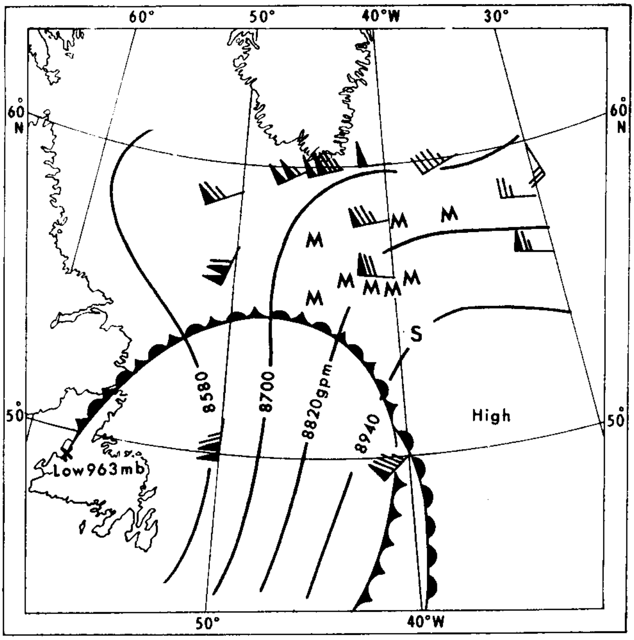

FIGURE 11—8 JANUARY 1968. AIRCRAFT-REPORTED WINDS AT ABOUT 35 000 ft (10 500 m), 1555 – 1755 GMT. TURBULENCE 1550 – 1745 GMT

M = moderate and moderate to severe, S = severe turbulence. Surface analysis and interpolated 300 mb contours for 1800 GMT.

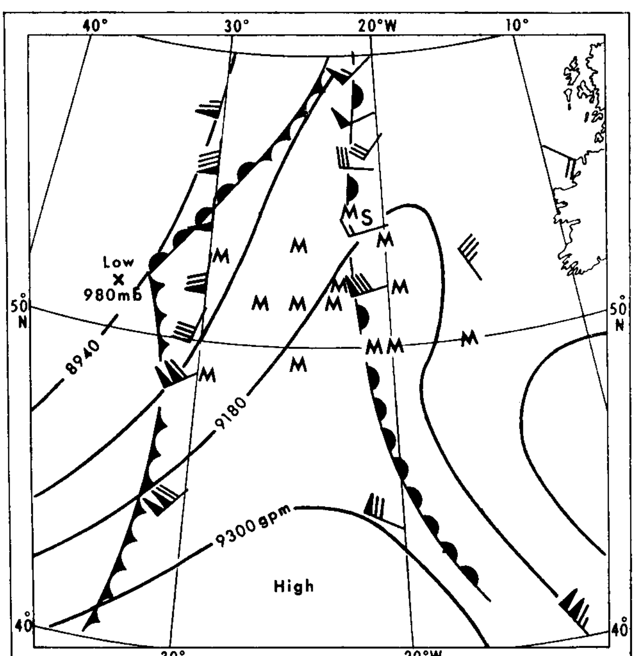

FIGURE 12—27 FEBRUARY 1968. AIRCRAFT-REPORTED WINDS AT ABOUT 35 000 ft (10 500 m), 0510 – 0800 GMT. TURBULENCE 0525 – 0755 GMT

M = light to moderate, moderate and moderate to severe, S = severe turbulence. Surface analysis and interpolated 300 mb contours for 0600 GMT.

the cyclonic development continues, and the amplitude of the upper ridge increases during occlusion. Turbulence may then occur in the ridge near the right exit of the cold front jet stream or, in terms of surface features, in the vicinity of the point of occlusion.

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1. BINDING, A. A.; Association of clear-air turbulence with 300 mb contour patterns. *Met. Mag., London*, **94**, 1965, p. 11.

551.509.322.7:311.214:629.13:681.3

THE COMPARISON OF SUBJECTIVE AND OBJECTIVE UPPER AIR FORECASTS FOR AVIATION (PART I)

By I. H. CHUTER, M.Sc.

Summary. Part I. Subjective forecasts of the 300 mb height field were compared with objective forecasts produced by means of a linear regression equation using the 1000, 500 and 200 mb forecast height fields. An objective method was used to compare the actual equivalent headwinds over a given route with those forecast. (Assessments were made on the 0000 GMT analyses charts and on the forecast charts valid for the same time — normally a 24-hour forecast.) The period covered was from August 1966–July 1967 giving about 360 forecasts, and these have been analysed in 3 sets of 120.

Headwinds were also converted into total flight times and assessments were made of timing errors in relation to the needs of airline operators. Root-mean-square errors in the objective forecasts of headwinds were lower than in subjective forecasts. An analysis of the total errors on each route showed that large errors were fewer in the objective forecasts than the subjective.

Part II of the paper will be published in the February issue and gives an analysis of errors in headwinds for individual 300 nautical mile zones on the air routes showing that the objective forecasting method was better than the subjective, and that forecast success does not depend on the geographical location of the zone. An analysis of the errors in estimated flight times shows that subjective methods increased the mean error.

Some of the possible sources of error in the data are discussed.

Introduction. Airline operators make extensive use of upper wind forecasts, especially over the North Atlantic where some choice of route is still possible.

The majority of Atlantic operations now take place between 30 000 and 40 000 ft (10 and 13 km), in the layer which frequently incorporates the jet stream, and the first purpose of flight planning is to select least-time tracks. Other factors such as clear-air turbulence and temperature are considered but for west-bound operations which are planned to avoid strong wind areas the emphasis is almost wholly on the forecast wind flow between 300 and 200 millibars.

Tests by Woodroffe[1] have shown that objective 300 mb forecasts by a regression technique were at least as reliable as subjective forecasts. Numerical forecasts for 300 mb have been produced, on the Meteorological Office COMET computer, by means of a linear regression equation using the 1000, 500 and 200 mb forecast height fields. Although results were available on an experimental basis in April 1966 they were not included in the routine output until September 1966.

Forecast verification. For the purpose of verifying the accuracy of forecasts it would seem to be most satisfactory to compare the actual time taken on a flight with the planned time derived from the forecast, but this was not attempted for several reasons. Firstly, the actual time may depend on non-meteorological factors, e.g. variations of flight level and route because of air traffic control instructions. Secondly, in the planning stage, allowance is made for initial climb and final descent and this requires some subjective interpolation. Also, the aircraft may experience temperatures that make it difficult or uneconomic to reach the planned flight level on certain stages of the route. Finally, forecasts are regarded as valid for departure over a period of six hours and no allowance is made for the flight durations.

An alternative and objective method was adopted based on the comparison of equivalent headwinds that an aircraft would experience on a specified route between London and New York at a constant level of 300 mb. Calculations were made for each of three routes, see Figure 1, known as the great circle, the polar curve and the rhumb line, which together cover a representative area of the North Atlantic.

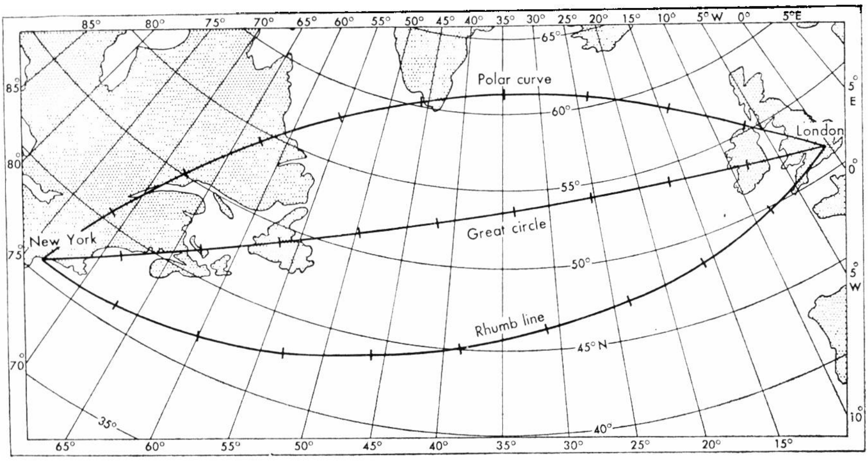


FIGURE 1—NORTH ATLANTIC AIRCRAFT ROUTES BETWEEN LONDON AND NEW YORK

Few actual flights are likely to follow any of these routes at precisely 300 mb (the average flight level for the majority of trans-atlantic jets being somewhat higher), and, strictly speaking, no fixed-time forecast is valid. Nevertheless the comparisons should indicate the relative accuracy of the forecast winds obtained by subjective and objective methods over an area which includes most of the London – New York flights.

Some characteristics of equivalent headwinds in relation to the vector properties of wind velocities, have been discussed earlier, by Howkins and Chuter.[2] The advantages in the use of headwinds include the property that they are scalar quantities, and the results bear a direct relationship to the principal object of the forecast, i.e. the accurate assessment of headwind for the calculation of pay-load and fuel requirements, and of flight time. The equivalent headwind E was obtained from the wind velocity using the relationship

$$E = V \cos \theta + \frac{V^2 \sin^2 \theta}{2 A}$$

where V is the wind speed
A is the aircraft speed
θ is the angle between the direction of the wind and that of the track.

The convention used resulted in a positive value for headwinds and a negative value for tailwinds. The flight time T is thus given by

$T = L/(A - E)$ where L is the track length.

Extraction of the data. Two sets of data were used for the error assessments.

(i) London/Heathrow Airport 300 mb analyses and forecasts.

(ii) COMET 300 mb forecasts produced by a linear regression from the standard levels of 1000, 500 and 200 mb.

London/Heathrow Airport. On each of the routine analysis and forecast charts the three routes were drawn, each route being divided into 10 equal zones. The wind speed and direction were estimated for each zone and applied to a perspex scale, constructed for an aircraft speed of 400 kt, to calculate the equivalent headwind for that zone, the results being rounded to the nearest 5 kt. With the analysis charts, weight was given to the wind observations both from upper air stations and from aircraft reports. With the forecast charts, the presentation is in the form of contours and isotachs and interpolation of the isopleths is necessary to obtain the zone winds.

Assessments were made on the 0000 GMT analysis charts and on the forecast charts valid for the same time. The normal forecast period was 24 hours from the initial chart time though, in practice, later information, i.e. aircraft reports and 0600 GMT wind observations, could influence the forecast.

It should be noted that the total equivalent headwind for a route is often quoted as the arithmetic mean of the values for equal length zones. Strictly the total headwind should be derived from the mean of the time spent in each zone, i.e. the harmonic mean of zone speed. In practice the difference is only small but it does depend on the variability of the individual zone values. In one case when the headwinds in two zones of the same track were 170 kt and 20 kt, a spread of 150 kt, the two methods gave an overall route headwind difference of 8 kt.

All the Heathrow values were punched on paper tape for processing by the computer and since the calculations could be readily performed, all route headwinds quoted are the true mean values for the route (as far as division into a finite number of zones will allow).

COMET. Information is presented as values for a rectangular array of 47 by 41 points. When these points are plotted on a chart drawn to a polar stereographic projection (as currently in use for synoptic work in the Meteorological Office), they form an array of squares with origin at the North Pole and sides parallel to the longitudes of 35°W and 55°E.

Since the grid squares are of equal size the actual side length on the surface of the earth varies with latitude from about 180 nautical miles near the pole to about 120 nautical miles at 30°N. Over the area crossed by the routes the square side length is about 160 nautical miles.

The 1000, 500 and 200 mb forecasts valid 24 hours from 0000 GMT were used as the basis for the regression, though some 0600 GMT surface information is included to amend the 1000 and 500 mb level final forecasts from COMET.

The *D*-values, i.e. the difference between the contour height of a given pressure level and the height of that level in the standard International Civil Aviation Organization atmosphere, were connected by the regression relation

$$D_{300} = a + bD_{1000} + cD_{500} + dD_{200}$$

where *a*, *b*, *c*, and *d* are coefficients and the subscripts refer to the pressure level.

The values of these coefficients were mean yearly values and no seasonal or latitudinal variation was introduced.

The three London–New York tracks were drawn on a chart of 1:15 million scale having an overprint of the grid squares. Coefficients were determined for each square crossed by the tracks. These denoted the position of the square on the grid, the length of track in that square and the angle between the track and the square side.

The mean geostrophic winds for 300 mb were calculated using the heights at the corners of each square crossed, and these were applied to the track coefficients to determine the equivalent headwinds (aircraft speed 400 kt) for each of the 10 zones, and for the total routes.

Period covered by the data. In the four months August–November 1966 the Heathrow forecasts were made from charts produced subjectively, but from December 1966 to July 1967 they were based on COMET forecasts with some subjective adjustment to isotachs. The data have therefore been analysed in three four-monthly sections,

(1) August–November 1966, (2) December 1966–March 1967 and (3) April–July 1967.

In addition to the objective chart of forecast 300 mb contours received by facsimile at Heathrow there is a presentation of mean geostrophic winds for each grid point printed on the North Atlantic chart area. Isotachs can readily be constructed from these values, and by tracing these and the contour pattern, the usual contour-isotach documentation can be produced from the COMET forecast.

In order to retain some subjective control the forecaster can amend the isotachs as thought necessary, e.g. by making allowances for non-geostrophic flow or adding jet-stream core-speeds.

From the beginning of December the Heathrow forecast headwind assessments were made from charts produced in this way although in the first period the Heathrow forecasts were made from charts produced subjectively. The effect on the headwind comparisons should be that the errors in Heathrow and COMET forecasts become similar. Any differences would be due to the method of assessment, or the result of human amendment, or a combination of both.

Error assessments. For the assessment of forecast errors it was necessary to have actual values for verification. Since the COMET 300 mb analyses are also obtained by regressions, and do not directly use the 300 mb observations, the headwinds from the Heathrow charts were taken as the best estimate of the true values.

The 24-hour forecasts of both COMET and Heathrow for each route were compared with the corresponding Heathrow actuals, the errors being defined as forecast value minus actual value. As a reference, the errors were also computed for the 24-hour persistence of the Heathrow actual.

When considering the comparison of headwind errors over long routes it is possible that large errors on one part may be compensated by large errors of the opposite sign on another part. Although the flight times are unaffected it may be embarrassing for an aircraft to be blown considerably off course on one section of the route and then experience a similar effect in the opposite sense further along the route. Meteorologically the effect might result from a serious error in the placing of a trough, ridge or centre.

To give a guide to the extent of such an effect an analysis was made of the errors on individual zones of each track.

Additionally, an attempt was made to simulate the use of the information made by the operators in least-time track selection, by converting the headwinds into total flight times.

It was assumed that the three routes were the only ones available and a least-time track was selected using the forecast values. The corresponding actual values were then examined to see the timing error involved and if the correct track had been chosen. The aircraft speed was again taken as 400 kt.

Three timing errors were assessed :

(i) The error on the chosen track — this indicates the difference between the flight time planned for the aircraft and the time actually taken.

This may be interpreted as the early or late arrival of the flight at its destination or may be related to the fuel to pay-load proportions.

(ii) Time difference in the actual flight times between the chosen track and the least-time track. This will be zero if the correct track was selected.

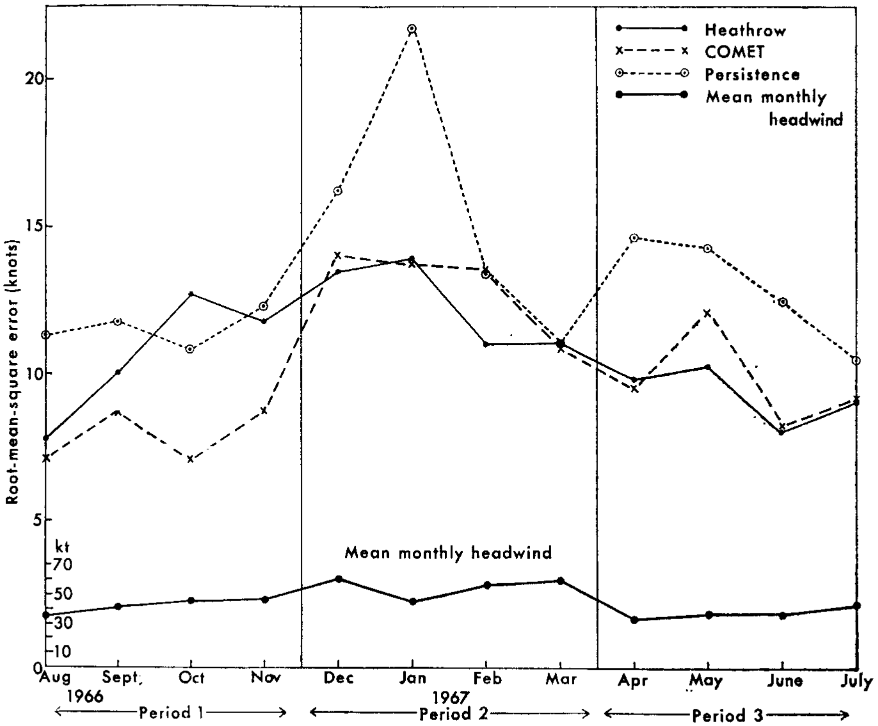
This time may be interpreted as the difference between the flight time experienced by the aircraft and that available had the forecast been perfect.

(iii) Time difference between the chosen track forecast, i.e. the planned flight time, and the least-time track actual. This will be equal to (i) if the correct track was chosen.

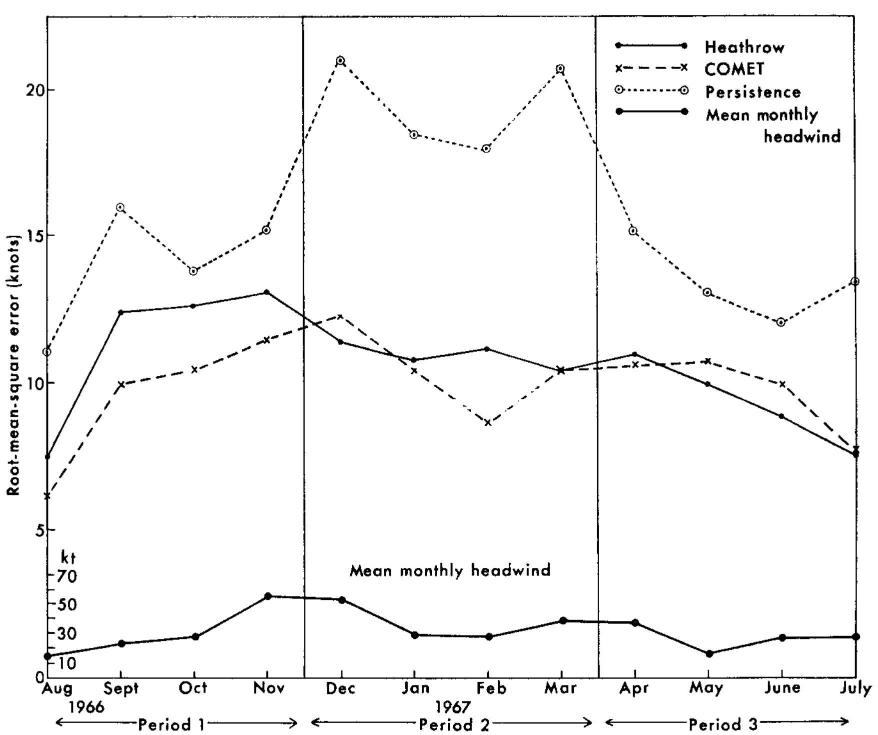
This value may be interpreted as the difference between the flight time planned for the aircraft and that available had the forecast been perfect. It can also be directly related to the economic loss resulting from errors in the forecast winds.

Results and discussion. *Headwind errors.* By definition a positive value indicates that the forecast headwinds are higher than the corresponding actuals. For west-bound flights this means that westerly winds were forecast as being too strong or easterly winds too light.

Root-mean-square errors. Figures 2*(a)* – *(c)* show the r.m.s. errors for the three routes for each month August 1966 – July 1967. For period (1), August – November, COMET values were consistently lower indicating the superiority over the purely subjective forecasts. The change of procedure coincided with the arrival of more unsettled winter conditions and the resultant rise in the

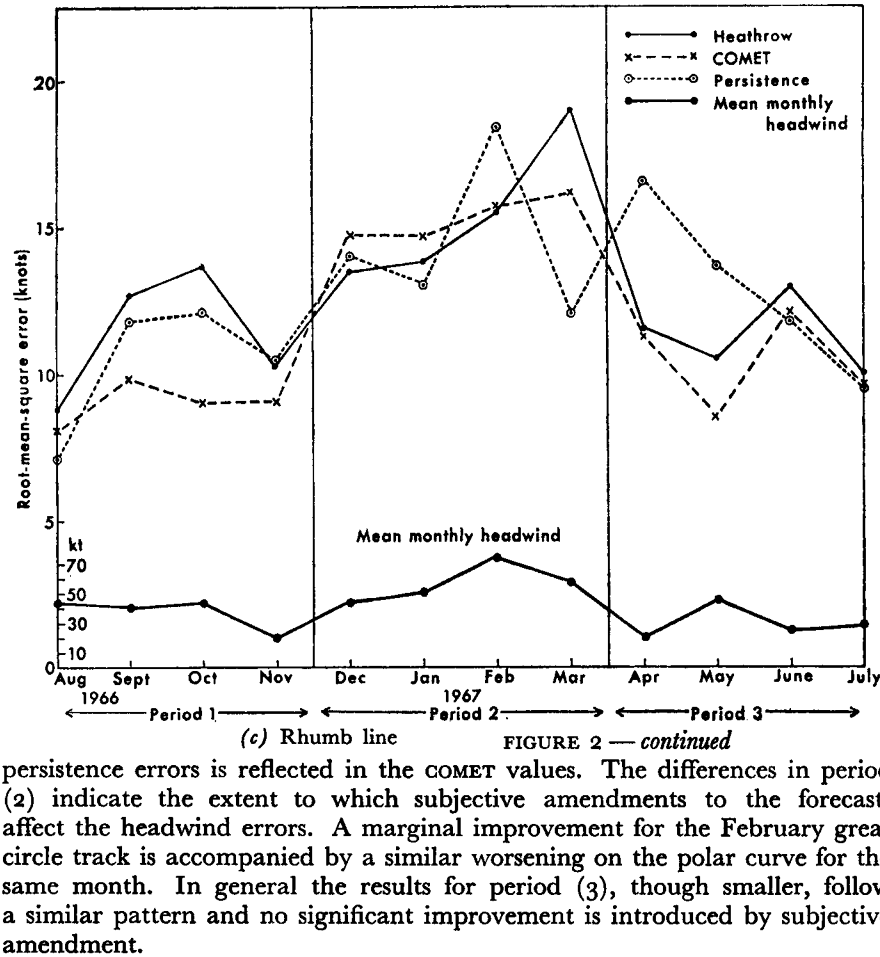


(a) Great circle



(b) Polar curve

FIGURE 2—ROOT-MEAN-SQUARE ERRORS FOR EACH ROUTE AND PERIOD



(*c*) Rhumb line FIGURE 2 — *continued*

persistence errors is reflected in the COMET values. The differences in period (2) indicate the extent to which subjective amendments to the forecasts affect the headwind errors. A marginal improvement for the February great circle track is accompanied by a similar worsening on the polar curve for the same month. In general the results for period (3), though smaller, follow a similar pattern and no significant improvement is introduced by subjective amendment.

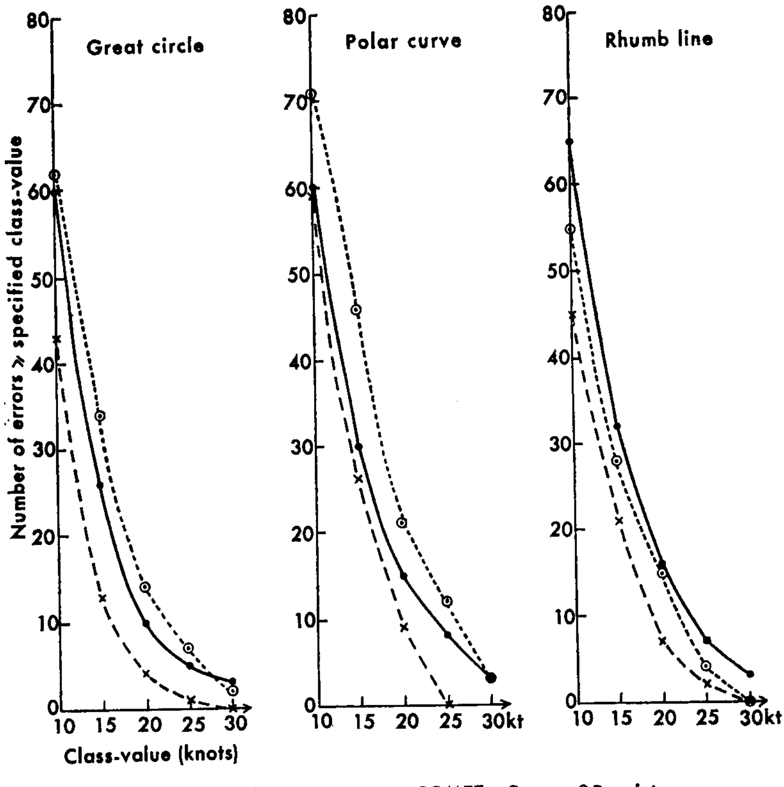
Whereas the errors for both forecasts for the great circle and polar curve generally improve on persistence this is not the case for the rhumb line. This is linked to the fact that the monthly mean error for the rhumb line forecasts, consistently has a positive value whilst that for persistence is, as expected, near zero, see Table I.

TABLE I—FOUR-MONTHLY HEADWIND MEAN ERRORS

	Period 1			Period 2			Period 3		
	Mean	S.D.	R.M.S.	Mean	S.D.	R.M.S.	Mean	S.D.	R.M.S.
Great circle									
Heathrow	+2·6	10·4	10·7	+2·3	12·3	12·5	+0·8	9·3	9·3
COMET	−0·2	8·0	8·0	−0·5	13·1	13·1	−2·7	9·7	10·1
Persistence	−0·2	11·5	11·5	+0·1	16·2	16·2	−0·4	13·1	13·1
Polar curve									
Heathrow	−1·6	11·5	11·6	−0·1	11·0	11·0	−1·2	9·4	9·5
COMET	−1·7	9·6	9·8	−2·7	10·2	10·6	−4·9	8·6	9·9
Persistence	−0·7	14·1	14·1	+0·1	19·6	19·6	+0·0	13·5	13·5
Rhumb line									
Heathrow	+4·3	10·7	11·5	+8·3	12·9	15·6	+5·3	10·0	11·3
COMET	+3·0	8·5	9·0	+9·5	12·1	15·4	+4·9	9·5	10·7
Persistence	+0·3	10·6	10·6	−0·0	14·5	14·5	−0·1	13·1	13·1

Period 1 August–November 1966, Period 2 December–March 1967, Period 3 April–July 1967.
S.D. = standard deviation, R.M.S. = root mean square.

Total route errors. A frequency analysis of route errors was made by sorting into 5-kt classes for each route, forecast and period. The number of errors greater than or equal to a specified class value (no account being taken of sign) was assessed and the results are shown in Figures 3*(a)* – *(c)*.

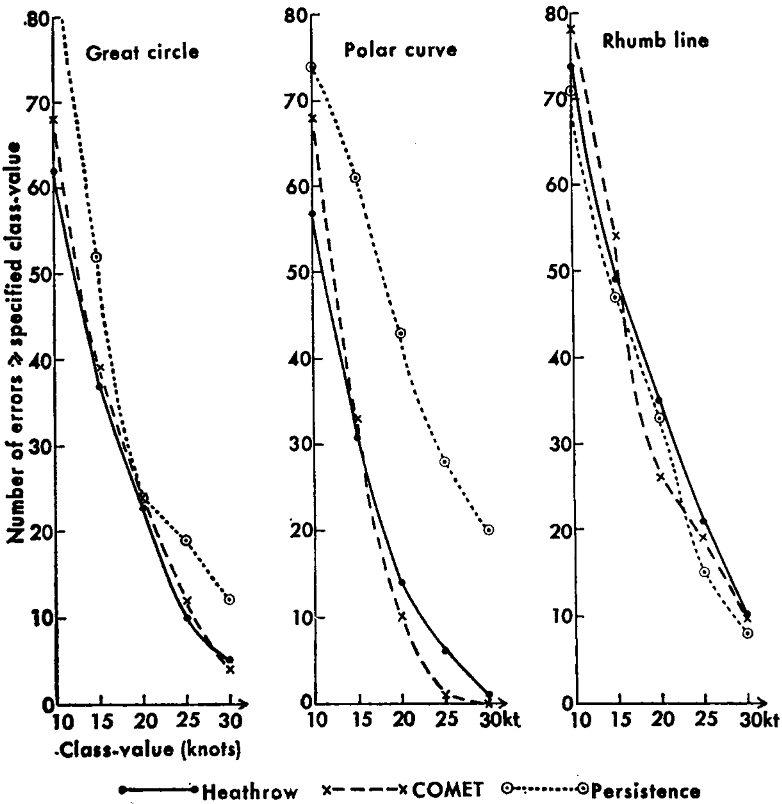


(a) August–November 1966

FIGURE 3—NUMBER OF ERRORS EQUAL TO OR GREATER THAN A SPECIFIED VALUE FOR THE WHOLE TRACK

For period (1) the superiority of COMET is again demonstrated by the fewer large errors. In periods (2) and (3) minor differences occur, but with about 120 cases considered in the construction of each line these cannot be regarded as significant. The anomaly for the rhumb line in producing little improvement over persistence is again apparent, especially in period (2).

One feature of the subjective amendment of the COMET forecasts is that 4-monthly mean errors, see Table I, for the great circle and polar curve are given a positive increment, whereas the already positive value for the rhumb line is scarcely affected. The reason for the positive increment is probably connected with the treatment of jet streams. These generally include a westerly component and so, when encountered, result in a positive headwind.



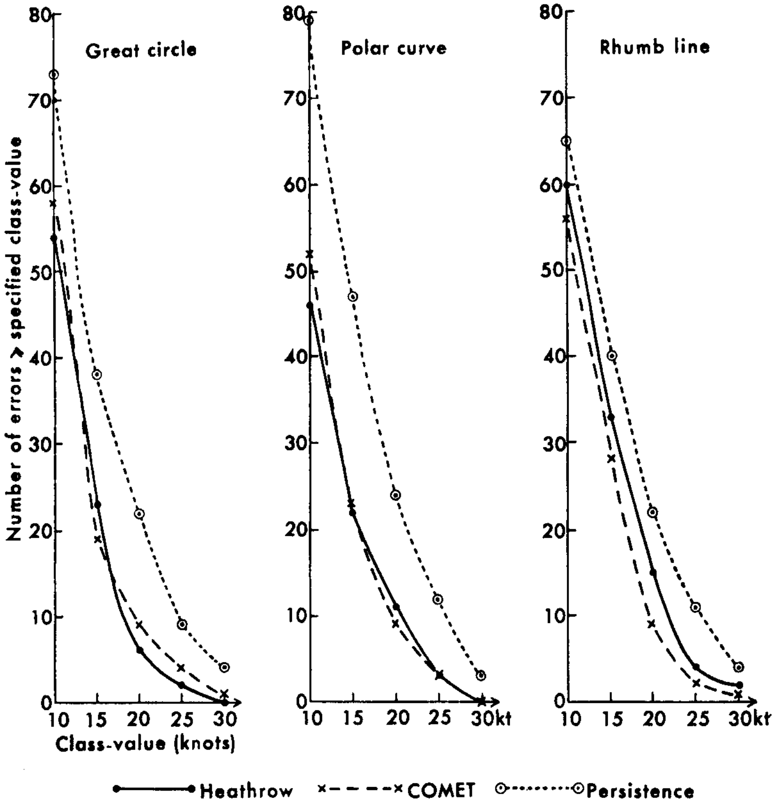
(b) December–March 1967 FIGURE 3—*continued*

They are also regions of high horizontal wind shear. If the jet core-speed of a COMET forecast is subjectively increased, a higher horizontal shear is usually implied and a larger headwind error results from a given placing error.

It is difficult to put forward a reason for the consistent positive bias which will apply selectively to the rhumb line, but in the case of the COMET forecast it may be a failure of the model in the particular geographical area through which the route passes. Since the effect is greatest in winter it may involve the sea heating term. It can be seen from Table I that in winter the subjective amendment reduces the positive bias slightly. Even the August–November purely subjective forecast has a mean positive error and the reason for this remains obscure.

An alternative suggestion that the COMET winds are geostrophic and thus will seriously over-estimate the winds in the bottom of troughs is only valid if it can be substantiated that this feature applies selectively to the rhumb line and occurs sufficiently frequently over a considerable length of the route.

Part II of this paper will be published in February.



(*c*) April–July 1967 FIGURE 3—*continued*

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REVIEWS

Kinetics of phase transitions of water in the atmosphere, by L. G. Kachurin and V. G. Morachevskii. 250 mm × 180 mm, pp. iv+124, *illus.* (translated from the Russian by the Israel Program for Scientific Translations, Jerusalem), Oldbourne Press, 1–5 Portpool Lane, London, E.C.1, 1967. Price: 56*s.*

I found this a rather disappointing book because although the authors promise to discuss a number of important topics, the treatment they actually give usually proves to be inadequate. One reason for this is that, as stated in the introduction, the book is based in its entirety on the authors' own results and therefore it inevitably presents a one-sided view of the subject.

The opening chapter discusses the basic physical principles of the kinetic theory of phase transitions, largely from a thermodynamic point of view. A number of fundamental equations are derived, but there is little attempt to evaluate the expressions to give the reader an accurate impression of the relative importance of the various terms under atmospheric conditions.

The second chapter is devoted to a discussion of the condensation of water vapour into the liquid phase. It is based on equations for the rate of growth of droplets in a supersaturated environment, but the authors explicitly state that they have neglected the effect of condensation on the temperature of growing droplets. It has been demonstrated repeatedly that this is by no means a negligible effect under atmospheric conditions, and therefore much of the discussion which follows must be suspect. The second half of this chapter is devoted to one of the authors' special interests, namely condensation 'torches' or 'plumes'.

The book continues with a discussion of the crystallization of supercooled water and concentrates on the rate of growth of the ice phase once it has been nucleated. I found the final section of this chapter which discusses electrical effects associated with freezing aerosols particularly disappointing. The authors have concentrated on the results of their own experiments and used them to make generalizations about electrification in real clouds, but they have given little attention to the extent to which their experimental conditions represent those in the atmosphere — a question which seems to me to be of crucial importance.

The closing chapter, which will probably be of greatest interest to Western cloud physicists, discusses the effect of introducing droplets containing surface active agents into homophase aerosols. The authors describe experiments which lead them to suggest that this may be an effective way of modifying the coalescence process in real clouds.

As is often the case with translations from Russian publications, the greatest value of this book to English language readers will no doubt be as an account of Russian work in this field and as a guide to the Russian literature.

J. T. BARTLETT

Measurement and estimation of evaporation and evapotranspiration, WMO Technical Note No. 83. 275 mm × 215 mm, pp. xiii+121, Secretariat of the World Meteorological Organization, Geneva, 1967. Price: Sw. F. 15.

This Technical Note is the report of a working group, set up in 1962 by the WMO Commission for Instruments and Methods of Observation, to review current methods of measurement and estimation of evaporation, and to make recommendations on an interim international reference evaporimeter. The working group comprised V. A. Uryvaev (U.S.S.R.), M. H. Omar (U.A.R.), T. J. Nordensen (U.S.A.) and G. E. Harbeck (U.S.A.), with M. Gangopadhyaya (India) as Chairman.

The Note begins with a detailed description of instruments used for measuring evaporation, i.e. atmometers, evaporimeters and lysimeters, followed by a discussion of their merits and demerits, and of the results of evaporimeter comparisons. The general requirements for siting and laying out an evaporation station are also given. A review of the methods of estimating the evaporation from open water, soil and vegetation, are given in the second half of the Note. The water budget, energy budget, eddy correlation and aerodynamic methods and the combination equations of Penman, McIlroy and Tanner, are described in detail, with particular emphasis on the basic assumptions. Other more empirical methods are mentioned briefly.

This Note provides a concise review of the methods of measuring and estimating evaporation. It is much more useful for those beginning research in this field than for those wanting to make reliable routine measurements of evaporation. The unsatisfactory state of our knowledge is reflected by the conclusions of the working group, which was able to give only very general recommendations, and added a strong word of caution on the use of evaporimeter measurements to estimate evaporation from vegetation. There is a comprehensive bibliography containing about 200 references, though none later than 1964. As a result more doubt is cast on the validity of the assumptions used in the Bowen ratio than there might have been if the results published by Swinbank and Dyer in 1967[1,2] had been available.

This WMO Technical Note, which gives a concise review of the methods available in 1964 for measuring and estimating evaporation, will be particularly useful for research workers entering this field.

J. B. STEWART

REFERENCES

1. SWINBANK, W. C. and DYER, A. J.; An experimental study in micro-meteorology. *Q. Jnl R. met. Soc., London*, **93**, 1967, p. 494.
2. DYER, A. J.; The turbulent transport of heat and water vapour in an unstable atmosphere. *Q. Jnl R. met. Soc., London*, **93**, 1967, p. 501.

NOTES AND NEWS

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Kew Observatory

The historic north wall screen photothermograph at Kew Observatory (see Plate II), was devised and installed in 1866 by Balfour Stewart, the Superintendent, and Robert Beckley, the Observatory mechanic. Since October 1867 it has been the standard instrument at Kew for deriving air temperature and humidity. In this instrument, the temperature of two mercury-in-glass thermometers, one acting as a dry bulb and one as a wet bulb, are recorded by the photography of the movement of air bubbles in the mercury columns; the thermometer bulbs are housed in a louvered screen fixed on the north wall of the Observatory at a height of about 3 metres (10 feet) above the level of the artificial mound on which the Observatory is built, and about 5 metres above the general level of the Observatory lawns.

It has now been decided that the use of this non-standard exposure should cease. The measurements available from 1 January 1969 will be those made with an electrical resistance aspirated psychrometer (see Plate III) in an open position on the main lawn, the bulbs being at the standard height of 1·25 metres.

There has been an overlap period of two years between the two systems of measurements and the data from this period are being examined by the Climatological Branch.

Lightning strike at RAF Chivenor, Devon

A very heavy storm passed over Chivenor airfield between 0000 and 0100 GMT on 2 July 1968. Lightning struck the ground and quite a large crater was formed.

During the hour, heavy rain fell, extremely strong winds were experienced and a brilliant display of lightning was seen by the observer — the whole area being illuminated at times. Considerable damage was caused to buildings and property in the area, the power supply was disrupted, and lightning started a fire at a local factory and several premises experienced minor flooding.

Lightning struck the ground at the north-west corner of Chivenor airfield on the disused runway, which is constructed of asphalt. The lightning struck with such force that a large crater was torn in the runway surface (see Plate IV).

The crater formed was roughly elliptical in shape, being 2 feet in length and 1½ feet wide. The depth of the crater at the centre was about 9 inches. Apart from one or two large chunks of asphalt lying in the crater it was a fairly clean-cut hole, with a few minor indentations in the runway surface surrounding the crater, see Plate V.

The crater was orientated almost north/south along its longest length and most of the considerable debris and rubble which was thrown up was deposited in a 20 degree arc fanning out from the crater, between 010 degrees and 030 degrees. Some of the debris was 50 yards from the crater.

M. H. LLOYD

Weather watch in the Arctic

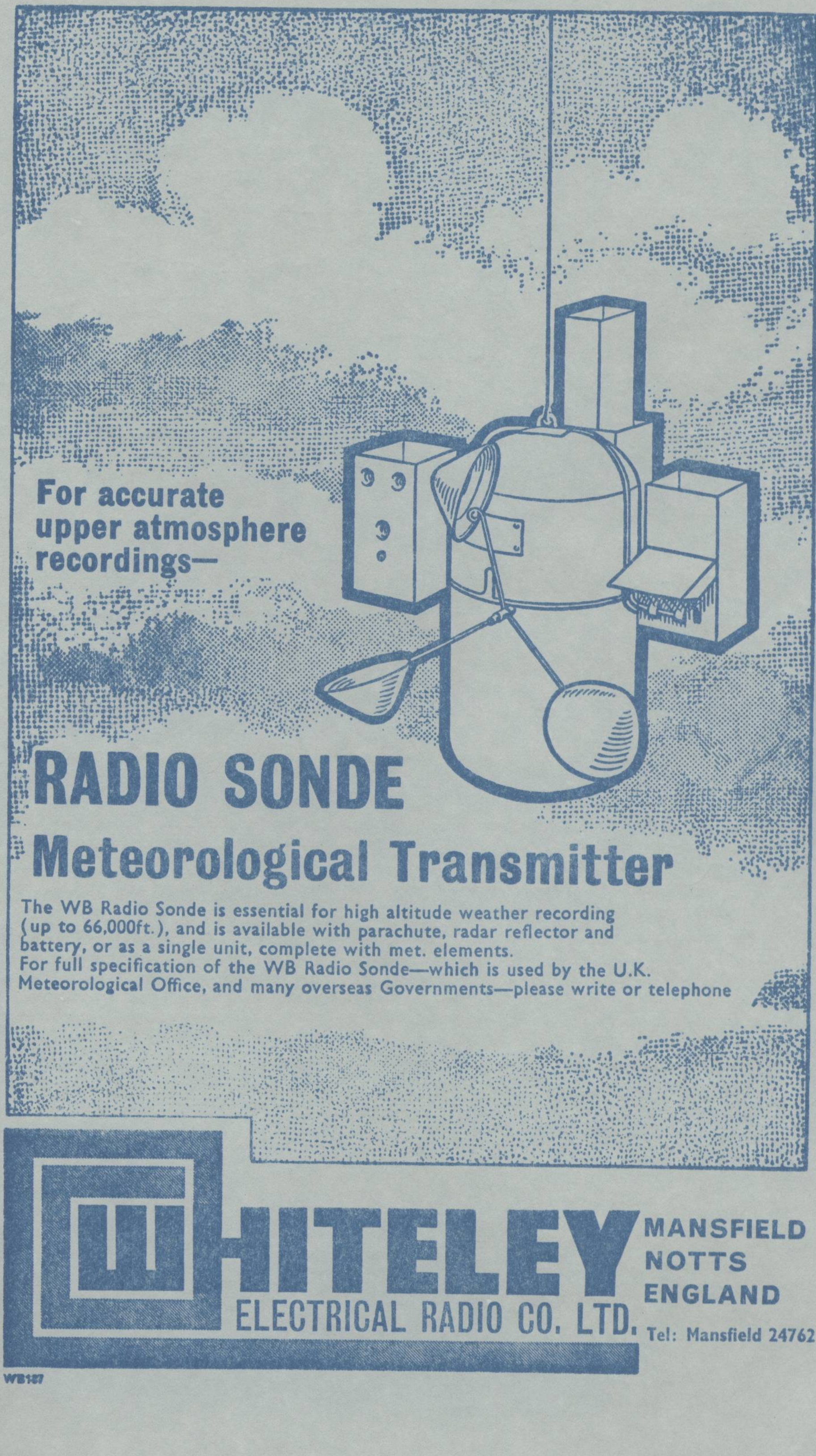
The trawler *Orsino,* chartered by the Board of Trade, sailed to Icelandic waters at the end of November 1968; it will remain there until 30 April 1969. The ship carries an experienced meteorologist, Mr D. P. Smith, who is responsible for the provision to the British fishing fleet operating near Iceland of weather forecasts and warnings, especially those relating to the deposition of ice on ships (see Plate I). The meteorologist will work in close association with the Central Forecasting Office at Bracknell. Mr D. P. Smith served for three years on trawlers during the Second World War.

OBITUARY

It is with regret that we have to record the death of Mr D. A. C. Poynton (S.A.) on 9 October 1968.

CORRIGENDUM

Meteorological Magazine, December 1968, p. 374, Figure 2. Figure caption should read: FIGURE 2—SURFACE CHART 1800 GMT, 9 JULY 1968.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