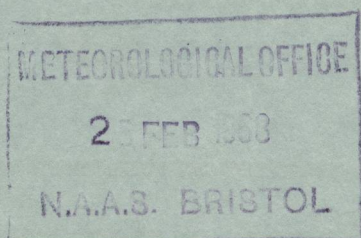


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METEOROLOGICAL OFFICE

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FEBRUARY 1968 No 1147 Vol 97

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# THE METEOROLOGICAL MAGAZINE

Vol. 97 No. 1147, February 1968

551.465.4:551.465.63(261)

## SEA TEMPERATURES AT OCEAN WEATHER STATION 'I'

By J. D. PERRY

**Summary.** The broad pattern of the thermal structure of the ocean is described briefly with some indication of the causes of the temperature distribution and its variation. Twice-daily bathythermograph observations made at ocean weather station (OWS) 'I' during the period February 1962 to January 1965 are analysed to determine whether it would be possible to forecast day-to-day variations in the vertical temperature structure in the North Atlantic Ocean.

A seasonal thermocline was found in each of the three years examined but its intensity and duration varied considerably from year to year while appreciable changes occurred within hours or even a few minutes. These changes are attributed partly to the effect of wind action at the sea surface but the effect is complicated by internal waves. In fact an isolated bathythermograph observation may give a completely misleading indication of the depth of the thermocline.

**Introduction.** An increasing amount of attention has been directed in recent years to the inter-relation between oceanography and meteorology. For many years sea temperatures near the surface have been determined by drawing up water in a bucket slung over the side of the ship, and temperatures at greater depths have been obtained by the reversing bottle method.<sup>1</sup> Early in 1962 however, bathythermograph observations<sup>1</sup> became part of the normal routine aboard British Ocean Weather Ships, giving continuous records of temperature twice a day vertically down to a depth of 450 feet.

The broad pattern of the thermal structure of the ocean has been known for a long time and, as records gradually became available over the period February 1962–January 1965, the author was given the task of examining the data to see whether the finer structure could be revealed and whether it would be possible to forecast the variations in vertical temperature structure in the top 450 feet of the Atlantic Ocean by relating these to the ever-changing atmospheric conditions. Somewhat similar work was being done in the Pacific by the Canadian Fisheries Research Board<sup>2</sup> but nothing comparable had been done in this country prior to 1960. The present article summarizes the full results<sup>3</sup> of the 1962–65 investigation of the temperature structure in the Atlantic.

First the broad pattern of the thermal structure of the top layer of the ocean is outlined for the benefit of the general reader. This is followed by a résumé of the results of the analysis of the bathythermograph (see Plates I & VI) from OWS 'I'. Finally the conclusions are summarized and some of the potentialities outlined.

**The broad thermal structure of the upper 500 feet of the ocean.** In areas unaffected by major current systems the normal vertical temperature distribution consists of an isothermal mixed layer overlying a layer in which

the temperature decreases rapidly with depth — the thermocline. The temperature and extent of these layers depend upon the distribution of the incoming heat energy by vertical mixing. Beneath these layers the temperature decreases slowly or may approach an isothermal distribution. In other words, warmer water lies over colder water with a transitional layer between.

Seasonal variations in the heat energy budget and the mixing processes produce a seasonal cycle of temperature changes in the ocean. At the end of winter the sea is isothermal to a depth of more than 500 feet as a result of winter storminess and convectional stirring. At this time there is a net loss of heat to the atmosphere and any heating of the sea by day is compensated by cooling at night. But as spring progresses, increased insolation results in a net gain of heat by the sea. In calm conditions this produces a distribution in which temperature decreases with depth but, if there is a wind, the resulting waves mix the waters of the surface layer to form a mixed layer overlying a weak thermocline. This mixing process is assisted by overnight cooling which sets up convection currents in the surface layer.

By early summer the accumulation of heat in the surface layer results in a marked thermocline at a depth of 100–200 feet. Up to this time the thermocline may be destroyed by a gale but later in the summer the vertical temperature-gradient is so large that even the strongest winds cannot provide the increased mechanical effort needed to overcome the density discontinuity and thus effect overturning. Once this stage is reached the thermocline must intensify rapidly, because the incoming heat is distributed within the layer above the seasonal thermocline. The mean depth of the mixed layer therefore decreases, while the water beneath the seasonal thermocline is protected from surface effects and, in the absence of advection, its temperature remains practically constant.

In the autumn the available solar energy decreases and a net loss of heat results, while the increased stirring and convectional mixing, besides cooling the mixed layer, also causes it to deepen and drives the seasonal thermocline downwards. This process continues into the winter until conditions approach those existing at the end of the previous winter. The seasonal cycle is then complete. Typical vertical temperature distributions for the north-east Atlantic are shown in Figure 1.

In spring or summer the mixed layer nearest the surface will frequently overlie a transient thermocline, while the seasonal thermocline continues to develop at some lower level through the progressive accumulation of heat energy. In the autumn and winter months transient thermoclines are infrequent and the mixed layer normally extends to the seasonal thermocline.

The model discussed here is over-simplified because the date of onset and the intensity of the seasonal thermocline vary from year to year, and the structure may also be complex, with two or even three marked thermoclines present on some occasions. As a result the depth of the mixed layer depends not only upon the prevailing meteorological and oceanographic conditions but also, to some extent, upon the interaction of these conditions earlier in the seasonal cycle.

This seasonal cycle is typical of temperate latitudes and is superimposed on the more pronounced oceanographic features such as the Gulf Stream. The eastern Atlantic is, however, relatively quiet — there are no currents comparable in intensity with the Gulf Stream — and it was therefore considered

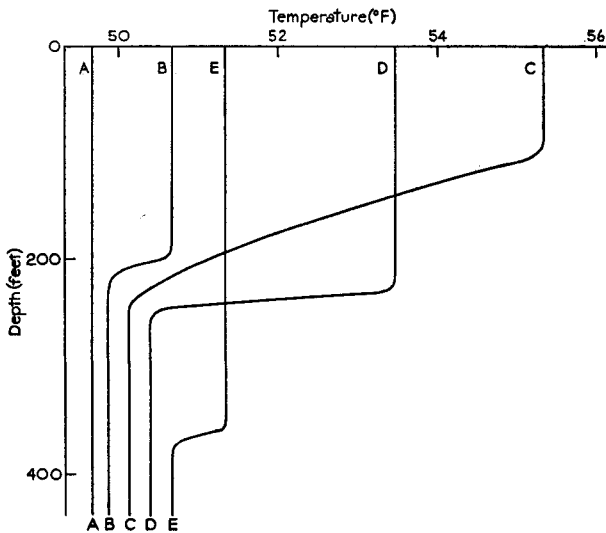


FIGURE 1—TYPICAL VERTICAL TEMPERATURE DISTRIBUTION IN THE NORTH-EAST ATLANTIC

A	End of winter	D	Autumn
B	Spring	E	Early winter
C	Summer		

sufficient to examine the seasonal effect at only two places, ocean weather stations 'I', 59°N 19°W and 'J', 52°30'N 20°W. It soon became evident that the seasonal changes at the two stations were broadly similar and therefore, because of the bulk of manipulation involved, it was decided to concentrate on OWS 'I'.

**Depth of mixed layer.** The mixed layer is defined for this analysis as the isothermal layer below the sea surface (the positive direction is vertically downwards). The depth of the mixed layer therefore, becomes zero when a vertical temperature gradient occurs directly at the sea surface. A gradient of 0.4 degF/100 feet was arbitrarily chosen to be significant, bearing in mind the thickness of the temperature/depth trace of a bathythermograph and the difficulty in reading the profile from a smoked-glass slide ; a gradient less than this value was therefore classified as isothermal.

Table I gives the averages and standard deviations of the depth of the mixed layer. For convenience the months February, March and April were classified as one group, as were November, December and January. The mixed layer depth is small in summer and large in winter, although the true winter values are undoubtedly greater than those shown in the table because the cases when the layer depth exceeded 450 feet have not been included in the calculations. The values for November, December and January in 1962-63 and 1964-65 are particularly small because of the occurrence of slight, but fairly frequent, positive temperature gradients at and near the sea surface. These gradients are a feature of the winter half-year, but the physical processes responsible for their formation are by no means clear.

**Correlation between depth of the mixed layer and wind speed.** When short periods of only a few days were examined, it was found that

TABLE I—AVERAGE DEPTHS OF THE MIXED LAYER AT OWS 'I' FROM FEBRUARY 1962 TO JANUARY 1965.

	Feb. Mar. Apr.	May	June	July	Aug.	Sept.	Oct.	Nov. Dec. Jan.
1962-63 Average depth of mixed layer (ft)	214	81	87	25	42	126	224	108
Standard deviation (ft)	121	62	62	34	47	59	71	147
Number of observations	39+74*	58	50	46	50	44	47+2*	82+84*
1963-64 Average depth of mixed layer (ft)	152	79	41	72	60	141	220	243
Standard deviation (ft)	135	101	51	71	50	91	145	147
Number of observations	67+88*	17+13*	57+1*	51	61	46	38+16*	27+103*
1964-65 Average depth of mixed layer (ft)	201	122	93	119	125	137	251	169
Standard deviation (ft)	111	123	62	60	64	57	78	166
Number of observations	48+126*	24+14*	42	58	57	55	47+1*	67+91*
1962-65 Average depth of mixed layer (ft)	183	91	71	76	77	136	233	152
Standard deviation (ft)	127	89	62	70	64	67	101	153
Number of observations	154+288*	99+27*	149+1*	155	168	145	132+19*	176+278*

\* Asterisked figures give the number of observations which showed no trace of a thermocline in the first 450 ft, and therefore could not be used in the statistics of depth of mixed layer.

during spring and summer there was evidence of a linear correlation between the depth of the mixed layer and mean wind speed. The effect of the wind on the sea is complex, depending upon the fetch of the wind, its duration and the depth of the water. Normally with winds of 30 knots or less the sea becomes fully developed within 24 hours, and so 24 hours was taken as a suitable time scale.

In order to show the correlation it was necessary to choose suitable periods of a few days containing a convenient range of wind speed. The results are shown in Figure 2 for three periods in May and early June 1962 (*a*), three later in June (*b*), and three in July and August (*c*). The line becomes less steep as the season goes on and this is consistent with Table I which shows that the seasonal minimum depth of the mixed layer in 1962 occurred in July.

The change in slope results from the increased thermal stability in the ocean as the seasonal thermocline develops. Mazeika<sup>4</sup> suggested that the difference in temperature between the surface and 450 feet,  $\Delta t$ , may be conveniently used to represent the thermal stability. This index was therefore adopted to combine data for the years 1962-65. During the months February to July, i.e. when  $\Delta t$  was increasing, the correlation between the layer depth and the mean wind speed was found to be statistically significant for  $\Delta t \geq 0.5$  degF. During the rest of the year, when  $\Delta t$  was decreasing, the correlation was only significant for values of  $\Delta t \geq 4.0$  degF. The results of this analysis confirm that mixing by waves produced by wind is largely responsible for variations in the mixed-layer depth during the development of the thermocline and that the seasonal decrease in the effect of wind on layer depth is a function of the thermal stability.

**Temperature of the mixed layer.** Since the temperature distribution in the mixed layer is isothermal, the temperature of the top few feet (commonly referred to as the sea surface temperature) is representative of the temperature of the mixed layer as a whole.

The annual range of sea surface temperature, normally of the order of 6 degF at OWS 'I', is made up of the seasonal trend and short-period fluctuations. The former is a rise of about 1 degF for every 15 days from May to August, followed by a similar fall in September and October. From November

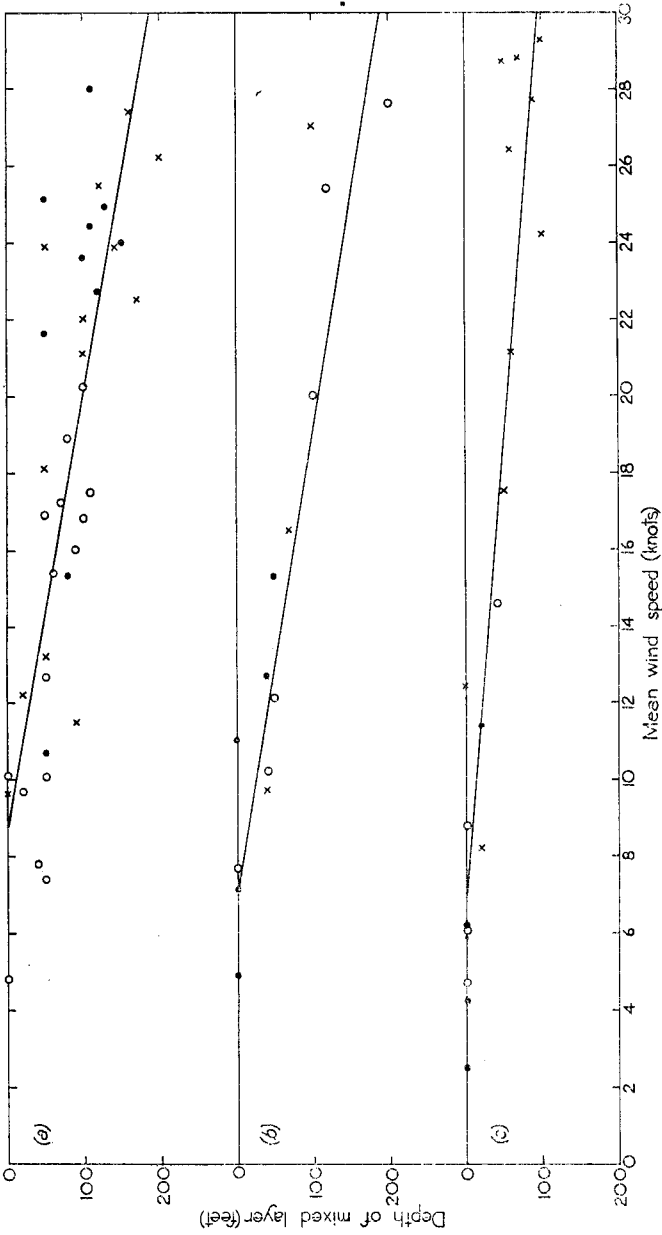


FIGURE 2—CORRELATION BETWEEN MEAN WIND SPEED AND DEPTH OF MIXED LAYER AT OWS 'I' DURING SELECTED PERIODS IN SPRING AND SUMMER 1962

(a) x = 2100 GMT, 11 May - 2200 GMT, 17th (b) x = 2200 GMT, 13 June - 1000 GMT, 15th (c) x = 2200 GMT, 18 July - 1000 GMT, 23rd  
o = 2100 GMT - 2000 GMT, 31st o = 1000 GMT - 2200 GMT, 25th o = 1000 GMT - 2300 GMT, 26th  
• = 2000 GMT - 1000 GMT, 6th • = 2200 GMT - 2000 GMT, 29th • = 1000 GMT - 1000 GMT, 3rd

Wind speed is mean over a period of 24 hours.

to April the change in the monthly mean temperature is normally less than 1 degF. The short-period fluctuations can, however, exceed 1 degF in less than a day and may even exceed it in an hour. There are considerable variations, even in the seasonal trend, from year to year as the anomalies in Table II show. The large summer and autumn anomalies in 1963 did not, apparently, relate to the sea temperature in the preceding winter or spring, and were probably the outcome of an unusual period of strong winds in the preceding May. The effect of the wind on the temperature of the mixed layer will be discussed more fully later. (p. 40)

TABLE II—SEA SURFACE TEMPERATURE ANOMALY AT OWS 'I' FROM FEBRUARY 1962 TO JANUARY 1965.

	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.
	degrees Fahrenheit											
1962-63	-1.6	-1.6	-0.4	+0.2	-0.9	-0.5	-0.7	-0.9	-0.4	-1.3	-0.7	-0.2
1963-64	+0.2	+0.7	0	-1.1	-1.4	-2.0	-2.2	-2.3	-2.0	-2.2	-1.1	0
1964-65	+1.1	+1.3	+0.5	-0.2	-0.2	-1.4	-1.4	-0.9	-0.2	+0.7	+0.2	+0.5

In order to investigate short-period variations, changes in the sea surface temperature in 12 hours, measured by the bucket method, were examined for the period May 1962 to April 1963, and the frequency distribution is shown in Figure 3. The standard deviation of 0.4 degF obtained for both summer and winter periods was similar to that found by Stubbs<sup>5</sup> for hourly observations at OWS 'J' in September 1962 but less than his value of 0.76 degF for 24-hour intervals. One third of the differences were  $\geq 0.5$  degF, and changes in excess of 1 degF were by no means rare at any time of year. These variations are in excess of the instrumental error in making a bucket reading,<sup>6</sup> and also well in excess of the diurnal variation which, according to Hay,<sup>7</sup> is about 0.2 degF in this region.

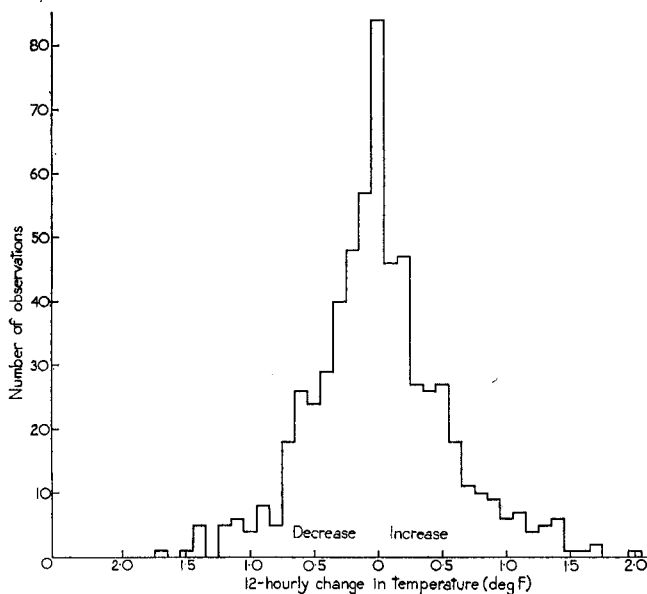


FIGURE 3—FREQUENCY DISTRIBUTION OF CHANGES OF 12-HOURLY SEA SURFACE TEMPERATURE (MEASURED BY BUCKET) AT OWS 'I', MAY 1962 - APRIL 1963



Confirmation of the variations in the bucket readings is given by the sea-temperature thermograph records from the weather ship. The thermometer which measures the sea temperature is situated at a depth of 13 feet and therefore represents the temperature of the mixed layer except on occasions when the mixed layer does not extend to 13 feet. These records also show that the variations found in the 12-hourly temperature readings can occur slowly within a period of a few hours or rapidly within a few minutes. The bathythermograph observations show that variations of temperature may occur even in a mixed layer of several hundred feet.

**The heat budget of the mixed layer.** The mean change in temperature for the 12-hour periods examined is about  $0.2 \text{ degF}$  throughout the year. In the summer this change would take place through about 100 feet and in the winter about 500 feet. The energies involved are therefore  $\pm 338$  and  $\pm 1690$  gramme calories/centimetre<sup>2</sup> ( $\text{g cal/cm}^2$ ) respectively. Although the values calculated are for half-day periods they are roughly comparable with those obtained for 24 hours by other investigations because the mean change of temperature in question is not necessarily maintained through two consecutive periods of 12 hours.

The summer figures compare with calculations by Hay<sup>8</sup> for OWS 'J'. He found that the highest value of the net flux of heat was  $235 \text{ g cal/cm}^2$  per day and maximum loss was  $396 \text{ g cal/cm}^2$  per day. Shellard<sup>9</sup> calculated that the heat input was  $189 \text{ g cal/cm}^2$  per day.

In the winter there is no possibility that  $1690 \text{ g cal/cm}^2$  per day, the energy required for an increase in temperature of  $0.2 \text{ degF}$ , can be supplied but the corresponding energy loss required for a similar decrease in temperature is approached by values calculated by Hay<sup>8</sup> and Craddock.<sup>10</sup> Hay found a maximum loss of  $803 \text{ g cal/cm}^2$  per day for OWS 'J' while Craddock calculated typical and extreme rates of gain of heat by Arctic air passing over a relatively warm sea on individual days as  $1128$  and  $1896 \text{ g cal/cm}^2$  per day respectively.

In view of the approximations involved, the estimates of the available incoming energy in summer might be considered to approach the value of  $338 \text{ g cal/cm}^2$  per day required for a mean temperature change of  $+0.2 \text{ degF}$  in summer, but there is no possibility that the required energy gain can be supplied at other times. On the other hand, the loss of energy to the atmosphere is possible in summer months and is largely accounted for in the winter months. It may therefore be concluded that the heat gain required for the mean increase of temperature of the mixed layer is mostly supplied from within, while the heat loss required for the mean decrease in temperature could conceivably be attributed to interaction with the atmosphere. If the changes in excess of the mean value are considered, especially with regard to the rapid changes in a few minutes shown by the sea temperature thermograph records, then neither the implied gains nor the losses can be explained in terms of the conventional heat-budget equations.

The short-period variations in temperature previously discussed suggest that the mixed layer has a horizontal temperature structure. The first possibility is that this patchiness is advected or that the ship making temperature observations is moving relative to the water mass. No attempt was made to relate wind direction, and hence surface water drift, to the temperature of the mixed layer however ; Hay<sup>8</sup> had found little evidence for such a relation.

Since the sea surface is, on average, warmer than the air throughout the year, it is considered that Bénard convectional cells are a more likely explanation for the patchiness and several authors have produced evidence that such processes do occur in the oceans. Cellular convection implies that heat is extracted only from a shallow surface layer and is replaced at intervals by convection. A considerable time and a large number of convectional overturnings are required before the whole of the mixed layer is appreciably affected. The heat energy, calculated from the change of temperature in the mixed layer over a short interval of time, is therefore representative of a small column within the mixed layer and will approach the values of Craddock and Hay only if the period of convection is long enough.

#### **Correlation between temperature of mixed layer and wind speed.**

Earlier it has been demonstrated that during the development of the thermocline, and to some extent during the early part of its decline, an increasing wind results in an increase in the depth of the mixed layer. Since there is normally a sharp decrease in temperature immediately below the mixed layer, such an increase would be expected to produce a fall in temperature within the mixed layer, particularly when the sea surface is losing heat to the atmosphere. The observations confirm that changes in temperature of the mixed layer may be produced, on occasions, by variations in the wind speed. Usually a fall of temperature occurs during periods of increased vertical mixing; a recovery of temperature follows as the wind decreases, provided that there is a net input of heat at the sea surface.

Figure 4 shows the variations in sea surface temperature, depth of mixed layer and wind speed for a 35-day period in July and August 1962. Initially the sea temperature rose from 52°F to 55°F in a period of 10 days with the mean wind speed averaging 10 knots and a mixed layer depth of 0–20 feet. This process was interrupted during the period 17–21 July when a freshening wind deepened the mixed layer and caused the temperature to fall some 2 degF. A reduction in wind speed during 21–24 July allowed a new thermocline to form at the surface, and the temperature rose sharply by some 3 degF. Later, two periods of strong winds were associated with increased layer depths and lower temperature minima, while the temperature continued its upward seasonal trend whenever the wind strength decreased.

**Other possible causes of variations in the temperature and depth of the mixed layer.** The effect of the wind on the mixed layer during the development of the seasonal thermocline has been shown. In the autumn and winter months, when the net heat flux is negative, both wind and convectional stirring erode the mixed layer.

There is no evidence of correlation between the mean wind speed and the depth of the mixed layer during this eroding process but a seasonal correlation between the temperature and the depth of the mixed layer in the autumn of each of the three years 1962–64 suggests that convection is of prime importance at that time of year.

For a regular series of bathythermograph observations (e.g. at intervals of an hour or less) the scatter about the mean depth of the mixed layer is made up of changes in the depth brought about by processes of interaction with the atmosphere (mixing by wind waves, convectional stirring, etc.) and oscillations due to internal waves (waves within the thermocline). Hence, if occasions

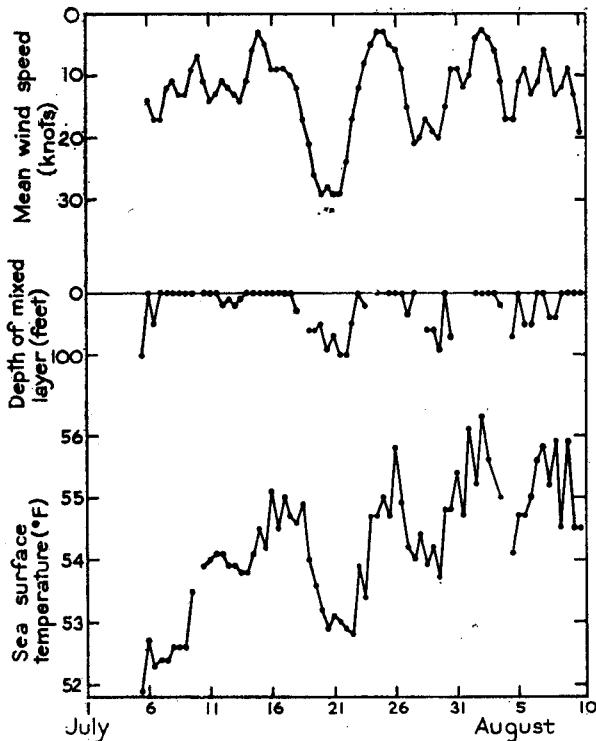


FIGURE 4—MEAN WIND SPEED, DEPTH OF MIXED LAYER AND SEA SURFACE TEMPERATURE AT OWS 'I' FOR A PERIOD IN JULY AND AUGUST 1962  
 Wind speed is meaned over a period of 12 hours.  
 Breaks in the isopleths occur where observations are missing.

are selected when the thermocline is relatively steady and the atmospheric conditions show little or no variation, the character of the internal waves may be determined. The data here are not amenable to such an analysis ; however, an examination of hourly observations of the temperature in the thermocline indicated that the scatter of observations for a linear regression between the mean wind speed and the mixed layer depth was consistent with fluctuations due to internal waves. An isolated bathythermograph observation therefore, may not give a true indication of the depth of the thermocline. The temperature of the mixed layer would be affected by internal waves only in very special circumstances.<sup>11,12</sup> Temperature and depth of the mixed layer can be stated, therefore, only in terms of mean values, with a tolerance to allow for internal waves which cannot at present be forecast.

Other causes of variation in the mixed layer are turbulent currents, the inter-action of two different water masses and the effects of convergence and divergence. The situation of OWS 'I' is such that it is not likely to be particularly influenced by turbulent currents, neither is there any evidence that changes in the water can be attributed to the interaction of two different water masses.

Convergent and divergent areas in the ocean are produced by the wind-induced surface-drift current. Generally, convergent areas are associated with

high atmospheric pressure and a deep thermocline, and divergent areas are associated with low pressure and a shallow thermocline. The bathythermograph observations for occasions of low pressure and high pressure were examined but failed to show any significant difference in the depth of the thermocline. It may well be that any relationship of depth with pressure is obscured by the scatter in the depth of the mixed layer brought about by internal waves.

**Conclusions.** Examination of bathythermograph data from OWS 'I' shows that the thermal structure of the ocean is rarely static. Not only does the seasonal thermocline vary in duration and intensity from year to year, but appreciable changes can occur within hours, or even in a few minutes. These changes are partly attributable to wind speed.

There is also a significant positive correlation between the 24-hour mean wind speed, and the depth of the mixed layer during the development of the thermocline and the early part of its decline. The dispersion of observations for this linear regression is consistent with the effect of internal wave motions, and the results suggest that the twice-daily bathythermograph observations do not adequately represent changes in actual water conditions which may be brought about by these waves, and that an isolated observation may be misleading.

Although the temperature and depth of the mixed layer respond to changes in mean wind speed, present knowledge of the short-period variations is insufficient for a simple model of these changes to be suggested. Temperature and depth of the mixed layer can be stated, therefore, only in terms of mean values with a tolerance to allow for internal waves which cannot at present be forecast.

**Some applications of an oceanographic analysis.** It has been shown that the depth of the thermocline (i.e. the mixed-layer depth) is complex and a single bathythermograph observation does not necessarily give a representative value. Further work is required on the intensity of the thermocline and the fluctuations of temperature at depth, about which little is known. Nevertheless it is possible to see that if sufficient observations were available spatially, synoptic charts of layer depth and thermocline intensity would be feasible, and the reader may well ask what purpose they would serve.

At a time when World Weather Watch is being established to collect data on a world basis, it is appropriate to look to the future when sufficient oceanographic data could be fed into the system to determine the energy exchange between atmosphere and ocean and to delineate the various sources and sinks. This would be of immense value to both meteorologists and oceanographers.

There would also be practical applications of these data; what promises to be one of the most interesting is the application to scientific fishing. Already several countries, notably Japan and Russia, make use of the limited data available and supplement these with spot observations made by their fishing fleets to improve their catches. The thermal structure is important since the thermocline marks a density boundary which traps the plankton necessary for fish life and plays an important part in seasonal and daily fish migrations. A knowledge of the thermal structure, therefore, enables one to forecast directly where the maximum concentration of fish will be found while local knowledge of the various fish migrations enables large catches to be made regularly.

Other applications in this field include commercial ship routing, the study of the dispersion of contaminants in the ocean, and inshore fish-farming.

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551.524.36(427):551.588.7

## CHANGES IN AIR TEMPERATURE AT MANCHESTER AIRPORT

By E. N. LAWRENCE

**Summary.** Changes of temperature at Manchester/Ringway Airport during the period 1942 - 1966 are compared with changes at other stations in the region. Annual and monthly mean values of the daily minimum, maximum and mean temperature and of the diurnal range of temperature are examined. The most marked change, attributed to increasing urbanization, is an increase in the mean daily minimum temperature at Ringway, relative to neighbouring stations, of about 2°F (1°C) in the annual mean, between 1946-48 and the early 1960's.

**Introduction.** The primary aim of this investigation is to examine the changes of temperature at Manchester/Ringway Airport in relation to urbanization and industrial development. Ringway is situated about 10 miles south of the centre of Manchester and is now almost absorbed by the Manchester conurbation where increased urbanization and industrial development, at least since World War II, could be expected to have an effect on the meteorological environment at Ringway. During the war years and for some time afterwards, there were restrictions on domestic fuel consumption and on urban development. From about 1960, some temperature effects at Ringway might be expected corresponding with the somewhat improved visibility which followed the establishment of smokeless zones in Manchester as a result of the Clean Air Act 1956.

There have been changes in the meteorological site at Ringway which complicate the investigation. On 15 March 1951, the meteorological station was moved a distance of 400 yards (366 metres) to the east and the height above MSL was thereby increased from 235 feet (72 m) to 248 feet (76 m).



Subsequently there was an increase in the number of nearby buildings. In June 1953 there was a further small move of 10 yd (9 m) to the north. Finally on 24 April 1961 there was a move of 100 yd (91 m) to the north-north-east to a site with a slightly lower altitude of 247 feet (75 m). Housing in the nearby areas gradually increased over the years.

The results of the present investigation, in general, do not indicate any marked temperature discontinuities which can be clearly associated with site changes at Ringway but any effects of such changes may have been concealed by other factors.

**Data used.** The present study concerns changes in annual mean and monthly mean values of the daily minimum, maximum and mean temperature and the diurnal range of temperature. Data are available for Ringway for the 25-year period 1942–66. Temperature changes at Ringway relative to other stations in the region were also examined. The stations selected were all those in the area with data for all or most of the period 1942–66, namely : Macclesfield (500 ft/152 m), Sheffield (429 ft/131 m), Buxton (1007 ft/307 m) and Northwich (65 ft/20 m). Data for Northwich are available only since 1947 and so this station, although probably the most suitable for comparison with Ringway, is omitted from some parts of the analysis. There is no evidence of any major change of site at these stations during the period 1942–66 except at Sheffield where the station was moved about 50 yd (46 m) to the south-south-west in October 1950. Annual mean daily maximum and minimum temperatures and site co-ordinates are given in Table I and a diagram of Ringway in relation to Manchester and its surroundings is shown in Figure 1.

TABLE I—ANNUAL MEAN DAILY MAXIMUM AND MINIMUM TEMPERATURES 1942–66

Station	Ringway		Macclesfield		Sheffield		Buxton		Northwich	
Latitude (N)	53°21'		53°16'		53°23'		53°15'		53°16'	
Longitude (W)	02°16'		02°08'		01°29'		01°55'		02°32'	
Height (ft)	247*		500		429		1007		65	
Year	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.
Degrees Fahrenheit										
1942	53·9	41·8	53·3	41·1	54·3	42·6	50·8	39·5		
43	55·9	43·2	55·4	42·9	50·3	44·2	52·6	40·8		
44	54·9	42·3	54·2	41·7	54·9	43·4	51·6	40·2		
45	56·6	43·5	55·7	43·3	56·8	45·0	53·5	41·4		
46	54·7	42·0	54·2	42·1	54·7	43·5	51·4	40·2		
47	55·5	42·1	54·9	42·5	55·0	43·3	51·9	39·7	57·0	43·8
48	56·0	42·6	55·7	43·0	55·8	43·9	52·6	40·6	57·5	44·8
49	57·5	43·4	57·0	43·5	57·1	44·5	53·9	41·1	59·2	45·3
50	54·8	41·9	54·5	41·9	54·7	43·0	51·4	39·6	56·7	43·7
51	54·4	42·2	53·6	41·6	54·2	42·7	50·9	39·7	56·2	43·7
52	53·9	42·0	53·0	41·6	54·2	42·9	50·5	39·8	56·1	43·5
53	56·2	43·4	55·3	42·8	56·2	44·3	52·9	41·2	57·8	44·2
54	54·0	42·6	53·0	41·8	53·9	42·9	50·4	39·9	55·9	43·8
55	55·5	41·9	54·2	41·4	54·9	42·8	51·5	39·3	56·9	43·3
56	54·1	41·8	52·8	41·0	53·7	42·5	50·3	39·3	55·3	43·1
57	56·1	43·8	55·0	43·0	55·8	44·2	52·1	41·1	57·3	44·7
58	54·7	43·2	53·7	42·5	54·7	43·3	51·0	40·4	55·6	44·0
59	58·3	44·5	56·8	43·8	57·7	44·7	53·8	41·1	59·0	45·2
60	55·7	43·8	54·5	42·7	55·5	43·9	51·6	40·6	56·7	44·3
61	55·6	43·9	54·9	42·8	56·0	44·0	51·8	40·8	56·9	44·3
62	52·9	41·9	52·5	40·7	53·3	41·5	49·4	38·8	54·7	42·4
63	53·0	41·7	52·3	40·4	53·1	41·2	49·8	38·7	54·4	42·4
64	54·5	43·4	53·8	41·9	54·9	42·7	50·9	40·1	56·1	43·8
65	53·9	42·5	53·2	41·3	53·9	42·2	50·2	39·6	55·4	42·9
66	54·4	43·8	53·6	42·3	54·1	43·2	50·5	40·6	55·9	44·4

\*235 ft before 15 March 1951, then 248 ft until 24 April 1961.

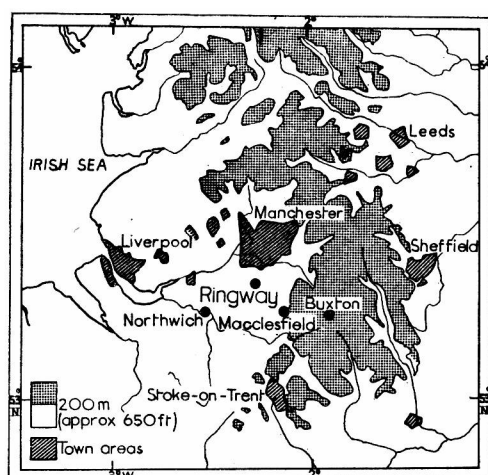


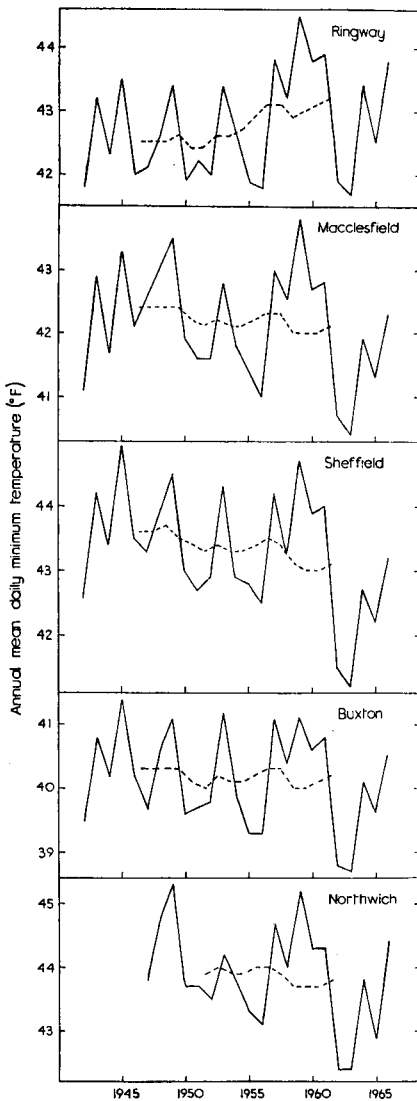
FIGURE 1—DIAGRAM SHOWING RINGWAY IN RELATION TO MANCHESTER AND ITS SURROUNDINGS

### Minimum temperature.

*Annual data.* Annual mean daily *minimum* temperatures at Ringway and other stations in the region are shown in Figure 2. As can be seen from the 10-year running-mean curves (pecked lines), there is an upward trend at Ringway but a slight downward trend elsewhere except at the high-level station of Buxton.

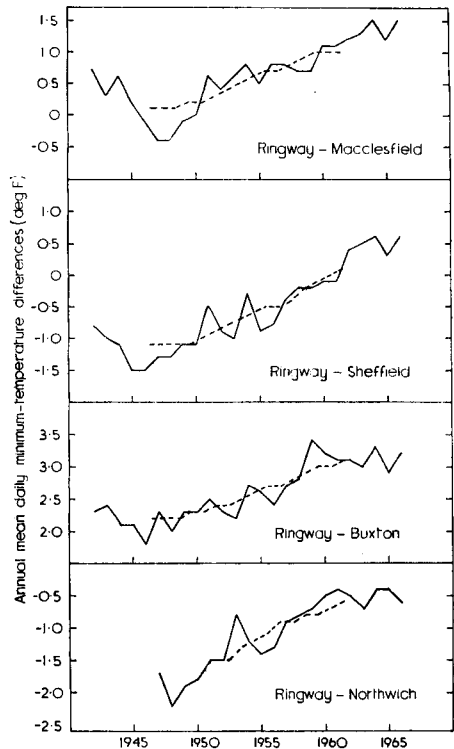
The anomaly in Ringway minimum temperature is further indicated by the curves of Figure 3 which show the differences in the annual mean daily minimum temperatures between Ringway and other stations in the region. These curves show that at Ringway during the post-war years, there was, relative to the other stations, a fairly steady increase of approximately 2 degF (1 degC) in the annual mean daily minimum temperature. This increase may be caused by the expanding Manchester conurbation with its industrial development and resulting smoke pollution, artificial heating, retention of heat by an abundance of concrete and masonry, etc.<sup>1</sup> Local effects at the airport, such as emissions from jet aircraft, may be a further contributory cause of the increase in minimum temperature at Ringway. All artificial influences will be referred to generally as those of urbanization. The tendency to decreasing difference in the minimum temperature (see Figure 3) during the war years may be related to war-time fuel restrictions; and the tendency of two of the curves for minimum-temperature difference (Ringway minus Northwich and Ringway minus Buxton) to level out around 1960–65 may well be a result of smoke control in the Manchester area.

The increasing mean daily minimum temperature at Ringway, relative to say, Northwich, between 1948 and 1960 could be caused by (i) an increasing input of air pollution and/or increasing artificial heating, etc. in the Manchester region, and/or (ii) a greater transfer of urbanization effects from central Manchester to Ringway as a result of (a) increasing frequency of light northerly winds, and/or (b) decreasing wind speeds, as suggested both by Parry's work<sup>2</sup> on air pollution and by the correlation coefficients between the relative increase of mean daily minimum temperature and the frequency of calms at



**FIGURE 2—ANNUAL MEAN DAILY MINIMUM TEMPERATURE AND 10-YEAR RUNNING MEANS AT RINGWAY, MACCLESFIELD, SHEFFIELD, BUXTON AND NORTHWICH**

--- 10-year running mean (plotted on centre point of period)



**FIGURE 3—ANNUAL MEAN DAILY MINIMUM-TEMPERATURE DIFFERENCES AND 10-YEAR RUNNING MEANS**

Ringway minus Macclesfield  
Ringway minus Sheffield  
Ringway minus Buxton  
Ringway minus Northwich

--- 10-year running mean (plotted on centre point of period)

Ringway, namely,  $+0.53$  (probability  $0.015$ ) for the winter half-year (October to March),  $+0.73$  (probability less than  $0.001$ ) for the summer half-year (April to September) and  $+0.72$  (probability less than  $0.001$ ) for the whole year.

Regarding the possible causes (ii) (a) and (b), it can be seen from Figure 4 that during the period 1948-60, there is no marked general tendency for decreasing wind speed or increasing frequency of calms or light northerlies, except possibly a slight increase of calms in summer. These results are consistent with the thesis that the relative increase of mean daily minimum temperature at Ringway is caused primarily by increasing urbanization of the Manchester-Ringway area.

Annual mean daily minimum temperatures for Ringway, Macclesfield, Buxton and Sheffield and annual mean minimum-temperature differences between Ringway and the other stations were examined also by variance ratio tests. The variance ratio here is the ratio of (1) the variance of the mean values over discrete five-year periods to (2) the variance of the annual values (total variance) minus the period-variance (group-variance) indicated by (1). The value of (2) is referred to as the residual variance. When there is a large trend in a series, the variance ratio is considerably greater than unity. Table II shows the variance ratios and the probabilities of being wrong in rejecting the null hypothesis that there is no significant difference in the period means. These results suggest that there is a significant change during the period of data, especially in minimum-temperature differences (for which the variance ratios are very much greater than unity).

TABLE II—ANALYSIS OF VARIANCE: ANNUAL MEANS (1942-66)

Stations	Minimum temp.*			Maximum temp.*			Diurnal range*			Mean temp.*		
	VR	DF	P	VR	DF	P	VR	DF	P	VR	DF	P
Ringway	3.71	4/20	≈0.03	3.25	4/20	≈0.03	6.64	4/20	≈0.003	2.79	4/20	≈0.05
Macclesfield	3.49	4/20	≈0.03	3.58	4/20	≈0.03	1.98	4/20	>0.1	3.70	4/20	≈0.03
Buxton	2.49	4/20	≈0.07	3.49	4/20	≈0.03	3.39	4/20	≈0.04	3.05	4/20	≈0.05
Sheffield	4.72	4/20	≈0.01	3.45	4/20	≈0.04	1.59†	20/4†	>0.1	2.57	4/20	≈0.07
Ringway minus Macclesfield	17.77	4/20	<0.001	8.22	4/20	<0.001	10.00	4/20	<0.001	13.05	4/20	<0.001
Ringway minus Buxton	20.74	4/20	<0.001	7.67	4/20	<0.001	8.58	4/20	<0.001	10.29	4/20	<0.001
Ringway minus Sheffield	38.02	4/20	<0.001	2.20	4/20	=0.1	16.59	4/20	<0.001	21.08	4/20	<0.001

VR = Variance ratio.

DF = Degrees of freedom:  $(G-1)/[(N-1) - (G-1)]$ , where  $G$  is the number of 5-year periods or groups and  $N$  is the total number of years.

P = Probability: chances of being wrong in rejecting the null-hypothesis, that there is no significant difference between the period means.

\* = All temperatures in degrees Fahrenheit.

† = In this case, the variance ratio refers to the residual variance (with  $N-G$  degrees of freedom) over the period or group variance (with  $G-1$  degrees of freedom).

Comparisons with minimum-temperature changes attributed to urbanization in other parts of the world are discussed along with maximum-temperature changes, in the next section.

*Monthly data.* The current investigation included also an examination of monthly mean values of the various temperature parameters already mentioned.

Graphs of individual monthly values of mean daily minimum-temperature difference (for example, Figure 5) show annual waves superimposed on the general trend shown by smoothed annual-value curves. These annual waves are much more regular for differences between Ringway and the nearby station of Northwich (illustrated in Figure 5) than for differences between Ringway and the more distant and climatologically more different (high-level) station of Buxton. To some extent, at least, the annual waves may be the natural result of topographical differences between two stations; but, if the minimum-temperature differences were caused by air pollution and

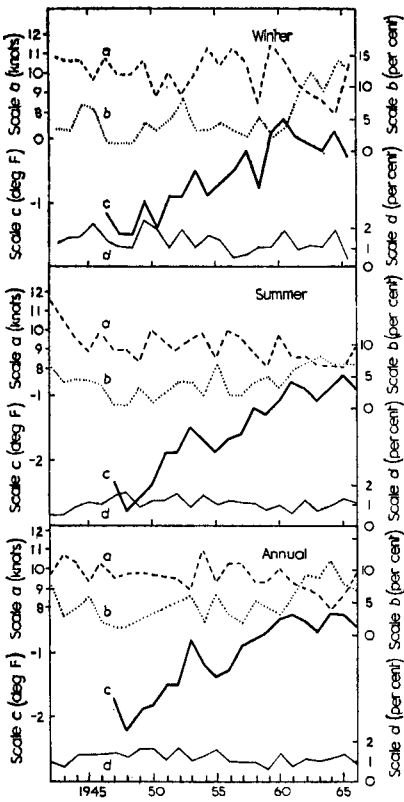


FIGURE 4—VARIATION OF WINTER HALF-YEAR, SUMMER HALF-YEAR AND ANNUAL VALUES OF (a) MEAN WIND SPEED (b) PERCENTAGE FREQUENCY OF CALMS AT RINGWAY, (c) MEAN MINIMUM-TEMPERATURE DIFFERENCE: RINGWAY MINUS NORTHWICH, (d) PERCENTAGE FREQUENCY OF WINDS FROM  $345^{\circ} - 015^{\circ}$ , 1-6 KT, AT RINGWAY

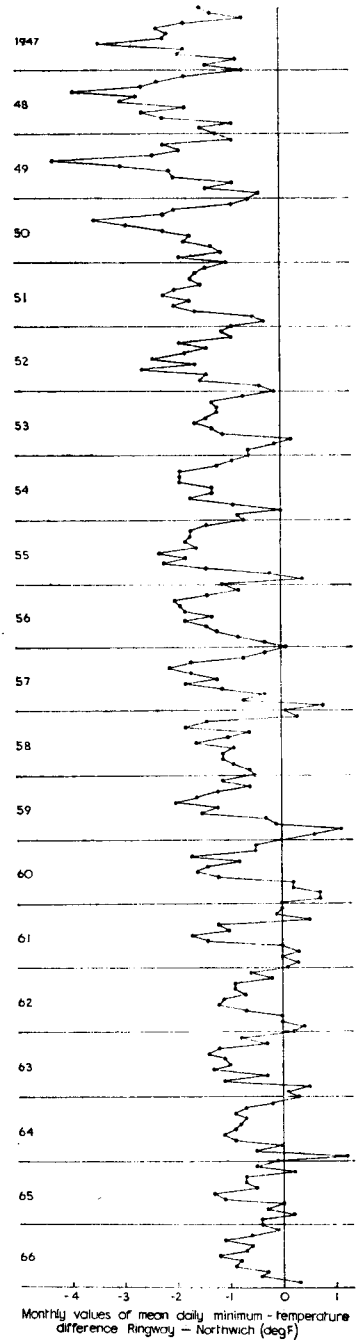


FIGURE 5—MONTHLY VALUES OF MEAN DAILY MINIMUM-TEMPERATURE DIFFERENCE, 1947-66  
Ringway minus Northwich





*Photograph by R. H. Brass.*

**PLATE I — BATHYTHERMOGRAPH**

Attaching the bathythermograph, a robust instrument which gives a record, scratched on a glass slide, of sea temperature changes with depth. *Weather Reporter*. See page 33.



PLATE II—MAJOR AND MRS K. J. GROVES WITH DR W. T. ROACH, WINNER OF THE  
MEMORIAL PRIZE FOR METEOROLOGY

(See page 62.)



PLATE III—MAJOR AND MRS K. J. GROVES WITH MR T. W. HARROLD, WINNER  
OF THE SECOND METEOROLOGICAL AWARD

(See page 62.)

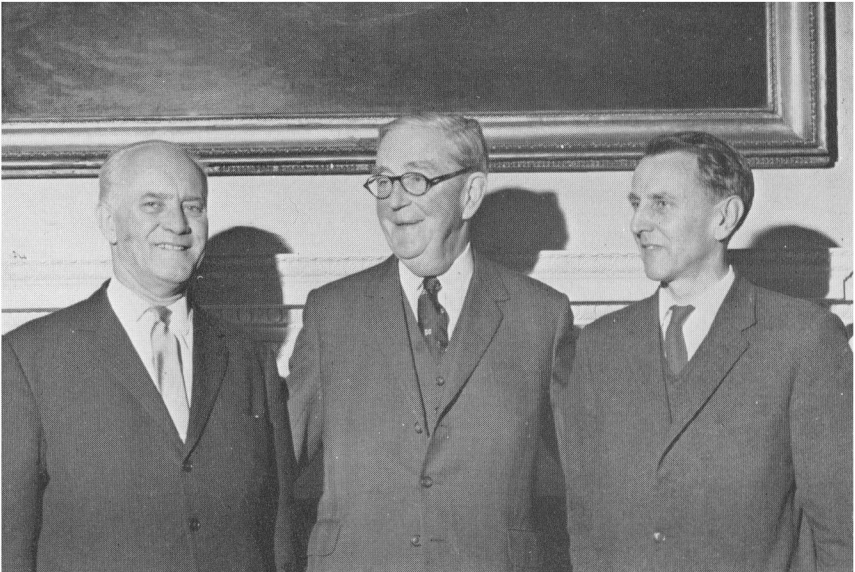
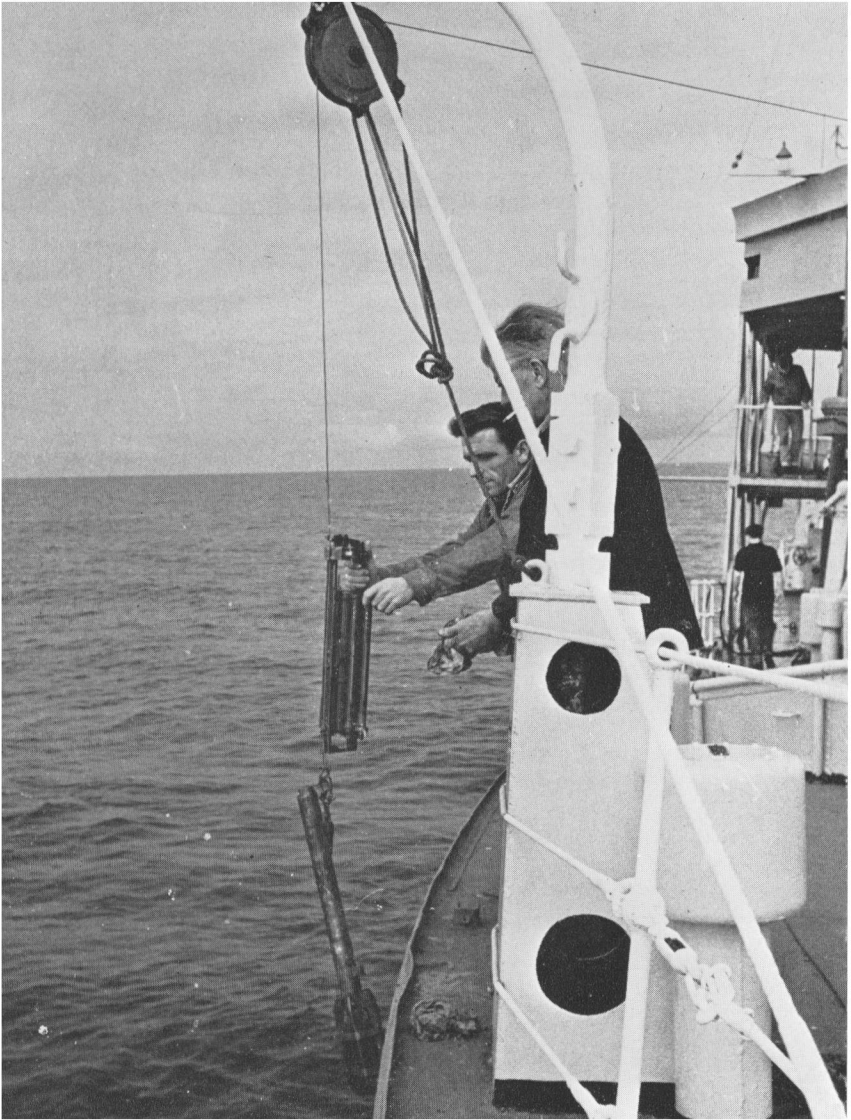


PLATE IV—MAJOR K. J. GROVES WITH TWO OF THE PRIZEWINNERS OF THE INAUGURAL YEAR, MR J. S. SAWYER (RIGHT) AND WING COMMANDER B. J. STANOJLOVIC (LEFT)  
(See page 62.)



PLATE V—AWARD WINNERS OF 1967 WITH MAJOR AND MRS K. J. GROVES AND AIR MARSHAL SIR PETER WYKEHAM

*Left to right* : Miss B. Dunning (on behalf of Mr A. M. Dunning), Senior Aircraftman T. Watson, Flight Sergeant J. Flint, Major K. J. Groves, Mrs K. J. Groves, Dr W. T. Roach, Mr T. W. Harrold, Air Marshal Sir Peter Wykeham. (See page 62.)



Photograph by R. H. Brass.

PLATE VI—BATHYTHERMOGRAPH

Removal, after a sounding, of the pair of 'reversing thermometers' (precision instruments read to a hundredth of a degree Celsius) which are used to check the recorded trace of the bathythermograph (suspended beneath). *Weather Reporter*. See page 33.

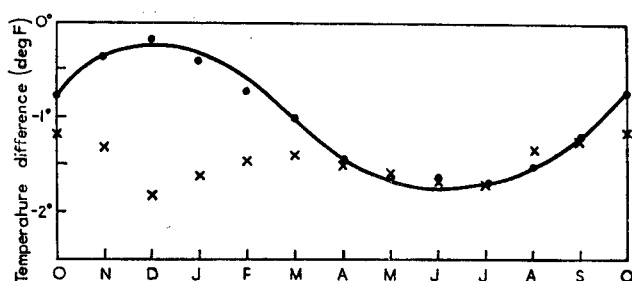


FIGURE 6—AVERAGE VALUE OF THE MONTHLY MEAN DAILY MINIMUM-TEMPERATURE DIFFERENCES AND MAXIMUM-TEMPERATURE DIFFERENCES, RINGWAY MINUS NORTHWICH, 1947-66

- Monthly mean daily minimum-temperature difference
- x Monthly mean daily maximum-temperature difference

artificial heating, the largest effects on minimum temperature would occur during the winter half-year and give a large departure from a nearly constant topographical difference, see the curve in Figure 6 which gives, for each month of the year, the *average* difference between the daily minimum temperatures at Ringway and those at Northwich during the post-war years.

Another interesting feature of Figure 5 is the decrease in amplitude of the annual wave from about 3 degF (1.5 degC) in the early post-war years to about 2 degF (1 degC) in recent years. A variance-ratio test on these annual amplitudes (calculated from the difference between the highest and lowest monthly values) gives a ratio of 4.34 with a probability of a little less than 0.03. This decrease in amplitude results from a more rapid increase of mean daily minimum temperature (at Ringway relative to Northwich) in summer than in winter, and could be caused, for example, by a relatively greater effect in summer of retention of heat by the increasing amounts of concrete and masonry, etc. near Ringway, or by the increasing summer frequency of calms (see Figure 4 (b)).

### Maximum temperature.

*Annual data.* Changes in annual mean daily *maximum* temperature are not so marked (see Table I). There is, however, an overall tendency for increasing station-differences of maximum temperature in the 1950's. Although the variance ratios for annual mean daily maximum temperature differences are rather smaller than those for annual mean daily minimum temperatures (Table II), they nevertheless appear to be significant.

Results generally for maximum and minimum temperatures agree with the results of analyses of continental data, given by Geiger,<sup>3</sup> which suggest that the effects of urbanization on maximum temperatures are distinctly less than the effects on minimum temperatures, for example a rise in minimum temperatures of 1-2 degC and a decrease in maximum temperatures of 0.5 degC. Further evidence of this phenomenon is given by Arakawa,<sup>4</sup> who found that in large developing cities, such as Tokyo and Osaka, 'the mean daily maximum temperature is almost invariable, whereas the mean daily minimum temperature tends to increase year after year with relatively large increasing rate.' For example, Arakawa gives the rates of increase in the mean daily minimum temperatures as 1.5 degC per century at Tokyo and 2.6 degC per century at



Osaka and he considers that the probable causes of the phenomenon are artificial generation of heat and atmospheric pollution. His figures, however, appear to include also any natural climatic change during the period 1876–1935 at Tokyo and 1883–1932 at Osaka.

Atmospheric pollution, artificial heating and retention of heat may each cause an increase of minimum temperature : but with regard to maximum temperature, while artificial heating and retention of heat may cause an increase, air pollution may cause a decrease. The combined effect of these and other urbanization factors appears to be an increase of minimum temperature while their combined effect on maximum temperature may seemingly be either positive or negative. For example, whereas for the continent, Geiger<sup>3</sup> gives a decrease in maximum temperature of 0.5 degC, the net result of London's urbanization on annual mean daily maximum temperature is (according to Chandler<sup>5</sup>) an excess of 1.6 degF (0.9 degC) in the temperature of central districts over that of the surrounding country ; the corresponding change in annual mean daily minimum temperature is +3.4 degF (1.9 degC).

*Monthly data.* The average annual wave of monthly mean daily temperature-differences is less regular for maximum temperatures than for minimum temperatures (see Figure 6).

In contrast with *minimum*-temperature difference curves of individual monthly values (Figure 5), the corresponding *maximum* temperature curves (not illustrated here) show less-regular annual waves. The curve for Ringway minus Buxton has more-regular annual waves than those for Ringway minus a close-by station such as Northwich. The peaks of the Ringway minus Buxton curve occur in *summer*, when urbanization effects may be at a minimum. These last two results suggest that the annual waves of the Ringway minus Buxton curve may result from topographical or natural climatic differences between Ringway and Buxton, and the masking of any urbanization differences.

**Diurnal range of temperature.** As minimum temperatures at Ringway tend to increase while maximum temperatures show no marked general trend, it would be expected that the diurnal range of temperature at Ringway would tend to decrease. Table II suggests that this trend is significant.

The same comments apply to changes in the diurnal range of temperature at Ringway *relative* to neighbouring stations.

**Mean temperature.** There is a marked trend of increasing minimum temperature at Ringway relative to neighbouring stations while maximum temperature shows no such marked general trend; so it would be expected that the mean temperature at Ringway relative to neighbouring stations would tend to increase. Table II suggests that this trend is significant.

There is no clear trend in *actual* mean temperatures at Ringway (see Tables I and II).

**General conclusions.** There is an increase in the annual mean daily minimum temperature at Ringway, relative to neighbouring stations, of about 2 degF (1 degC) between 1946–48 and the early 1960's. The annual increase appears to have been sufficient to reverse the slight downward trend exhibited by neighbouring stations. The evidence suggests that the increase in the mean daily minimum temperature at Ringway is caused by increased

urbanization and industrial development. Bearing in mind that the other stations used in the comparisons have also experienced some degree of urbanization, the absolute increase of minimum temperature at Ringway due to artificial causes may be somewhat greater than the values indicated. Changes in annual mean daily maximum temperatures are less marked.

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## RUNWAY VISUAL RANGE AT UNITED KINGDOM AIRPORTS

By D. P. SMITH

**Introduction.** In the United Kingdom the control, operating and reporting of runway visual range (RVR) is the responsibility of the Board of Trade (Civil Aviation Department), and the Meteorological Office provides scientific and technical advice and assistance. This note sets out the arrangements for RVR measurement in the U.K. and describes the various systems in use.

By definition, RVR is the maximum distance in the direction of take-off or landing, as the case may be, at which a runway, or the markers or lights delineating it, can be seen from a point 15 feet above its centre-line. Ideally, therefore, the position from which measurements of RVR should be made is at a point 15 feet above the centre-line of the runway in the touch-down zone. In practice, this is clearly not possible and the point from which RVR measurements are made must be situated off the runway. The measurements are made either by using a human observer to count lights or marker boards, as at present in the U.K., or by instrumental means.

**Human observer system.** The runway observing position (ROP) is as close to a point 110 metres from the centre-line and as near the touchdown zone (200–300 m from the threshold) as local circumstances permit. From this position, however, the observer will have a view of the runway lights which differs from that of a pilot at touch-down if the lights are of the beamed type of runway light, i.e. nearer lights will appear brighter to the pilot than to the observer and vice versa for more distant lights (considering those lights only on the side of the runway furthest from the observer) (see Figure 1).

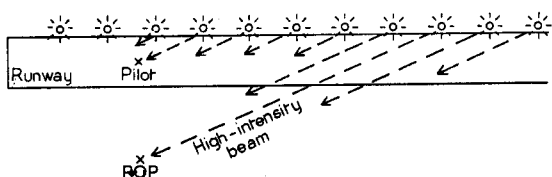


FIGURE 1 — POSITION OF PILOT AT TOUCHDOWN AND OF RUNWAY OBSERVER RELATIVE TO RUNWAY LIGHT

ROP = Runway observing position

It is necessary, therefore, to convert the light ranges as seen by the observer to those which would be seen by a pilot at touch-down. This is done by preparing a conversion table for each runway on which the number of lights counted by the observer is shown against the RVR. The process by which the conversion tables are prepared is known as the 'light calibration' and is designed to simulate operational conditions as closely as possible. It consists of taking comparison readings of the lights from both positions (ROP and pilot) with the Gold visibility meter. This instrument is held in the hand and can be made to introduce a variable degree of obscurity into the beam of any light towards which it is directed. The measured obscurity when the light is just visible is proportional to the intensity of the light. To the degree of obscurity measured by the meter is added a small correction for the prevailing visibility, which for a successful calibration should be better than 10 kilometres, and from this corrected value an equivalent daylight visibility (EDV), at which the light would just be visible from the ROP, is calculated for each light. This EDV is calculated so that the light intensities viewed from the ROP may be correlated with those viewed from the pilot's position. EDV values are then plotted against light distances, which in the case of values from the pilot's position are RVR readings, and a specimen graph is given in Figure 2. A line drawn vertically through positions on the ROP curve corresponding to each observed light will intersect the pilot curve, and the light distance value at that intersection will be the RVR for a count of lights up to and including that light through which the vertical line is drawn — the count having been made from the ROP. The example at Figure 2 shows a graph typical of a calibration on edge lights only and the effect of the high-intensity beam is evident from the shape of the curves, i.e. directed first towards the pilot position then towards the ROP. The RVR for the second light counted from the ROP would be 290 m and for the fifth light 480 m.

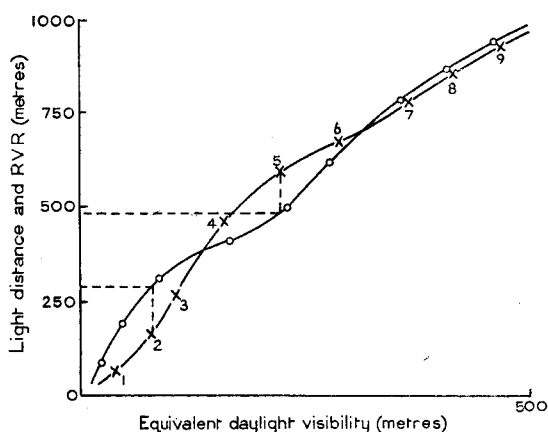


FIGURE 2 — SPECIMEN CALIBRATION GRAPH  
RVR = Runway visual range      o—o pilot; x—x observer

At most aerodromes the runway edge lights can be seen and counted individually by the observer at the ROP and so they are used as the RVR reference lights. On a few aerodromes all the edge lights cannot be seen clearly from the ROP and other lights have to be used as RVR references. These lights

may be installed specially for this purpose (as at London/Heathrow Airport as described below) or other suitable lights, such as omni-directional lights for runway delineation, may be used. Where high-intensity centre-line lights are available the RVR reported to the pilot is always based on them regardless of which lights are used as RVR reference lights; elsewhere RVR refers to the edge lights and in most of these cases the RVR reference lights and the runway edge lights are, in fact, the same lights. Marker boards are now very little used because the modern type of high-intensity runway lights installed at the majority of U.K. airports gives high visual ranges both by day and night. Boards are used where the runway lights are of low intensity or where the high-intensity lights are the narrow-beam type which cannot be wholly seen from the ROP. In these cases RVR by day is assessed by reference to marker boards, i.e. RVR reported is in fact meteorological visibility along the runway (known in U.S.A. as RVV). At a few outlying Scottish stations, e.g. Tiree, marker boards are placed at selected positions corresponding to aircraft RVR minima and assessment is made by the pilot of the aircraft when overflying the threshold.

It is important that the reference lights are clearly visible from the ROP. Where feasible the edge lights on the far side of the runway are counted in order to sample the air over the runway as closely as possible and for this reason, as well as to obtain a representative eye level, the ROP should be raised to at least 9 ft.

The Heathrow RVR system on the main runways required the installation of special reference lights because neither the centre-line nor the runway edge lights, being flush type lights, can be seen from the ROP. Flush runway edge lights are necessary at Heathrow because the runways are excessively wide and the lights have to be installed on the actual runway, some distance from the runway edge, to conform with international runway lighting recommendations. The centre-line high-intensity lights are at 100-ft intervals and similar lights are let into the row of edge lights on the near side to the observer for use as RVR reference lights. These RVR lights are at set intervals to give appropriate RVR distances and are directed in azimuth and elevation towards the observer so that they stand out from the other lights. Conversion tables are prepared, for each runway, which convert the reference light ranges to centre-line light ranges.

**RVR by instrumental methods.** The usual instrumental method of measuring RVR at present is to use a transmissometer to measure the transmissivity of the atmosphere and to compute RVR by choosing appropriate values for the sensitivity of the pilot's eyes (visual threshold), background brightness and intensity of the runway lights. The transmissometer consists essentially of a source of light (projector) beamed into a photo-electric cell (receiver) over a path of about 200 m. The receiver measures the luminous flux from the projector; from this the transmissivity of the atmosphere over the path between the projector and the receiver can be calculated. The U.K. does not, as yet, use instrumental methods for measuring RVR but transmissometer trials to this end are being made.

#### **RVR experiments.**

(i) *Variability of RVR along the runway.* During the winter of 1962/63 measurements of RVR at London/Gatwick Airport were supplemented by simul-

taneous measurements of RVR from ROPs appropriate to the centre and upwind end of the runway. Further measurements were taken during the winter of 1963/64 from the operational position and also from the centre position. It was evident from these experiments that along this particular runway (27/09) there were, at times, considerable variations in RVR and there were occasions when RVR reported from the centre position could be below aircraft minima when the operational RVR reported from the touchdown was above. In order to determine whether the variability at Gatwick was peculiar to that particular runway, it was decided to extend this experiment to three other aerodromes, i.e. Bournemouth/Hurn, Birmingham and Edinburgh/Turnhouse Airports. Centre observing positions were established at these three aerodromes and second observer trials began in the winter of 1965/66 and continued during the winter of 1966/67. Because of the low incidence of fog during these periods insufficient data have so far been collected to enable any definite conclusions to be reached.

(ii) *Difference of RVR off the centre-line.* An experiment was carried out at Bournemouth/Hurn to determine the difference of RVR, if any, which might be experienced by the pilot of an aircraft landing off the centre of the runway. This experiment was carried out in June 1964 when readings were taken on the runway lights from two positions, one on each side of, and 11 m from, the centre-line position from which the original calibration had been made. The curves obtained from the plotted light readings were then treated as pilot curves and compared with the original pilot curve. The variation between the three curves did not exceed 9 m up to about 900 m and above that distance the difference was not greater than 27 m. This experiment was carried out on broad-beamed high-intensity edge lights but has not been done for high-intensity centre lights where the difference might well be rather greater.

(iii) *Difference of RVR based on lights of different intensity.* In order to determine the difference, if any, which may exist between day and night assessments of RVR when the reference lights are considerably brighter or dimmer than the runway lights, e.g. when low-intensity lights are used as RVR references for high-intensity runway lights, and vice versa, an experiment was conducted at the Royal Aircraft Establishment, Bedford, in 1966. This experiment consisted of taking, from the centre-line only, Gold visibility meter readings on the edge runway lights, high and low intensity separately, both by day and by night. The ratios of the visual ranges of the two types of light were then compared, day and night. The results were inconclusive because the pronounced slope of the runway altered the height of the runway lights relative to the observer and this introduced a variation of apparent light intensity, different for each type of light, which unnecessarily complicated the experiment. Accordingly, the experiment was repeated later at Hurn and the conclusion drawn was that differences of RVR based on lights of different intensities by day and night could be substantial but factors such as runway slope and high-intensity light beaming introduced complications, the effects of which were difficult to assess.

**RVR and aerodrome lighting systems.** RVR in the U.K. is based on centre-line lighting where this is installed. This lighting consists of flush type high-intensity bi-directional lights at 100-ft intervals; the theoretical maximum output of the light at 3° elevation is about 10 000 candelas. This lighting is installed on the main runways at Heathrow, Liverpool, Glasgow, Newcastle/



Woolston and Edinburgh/Turnhouse. Most aerodromes other than Heathrow have elevated broad-beamed high-intensity edge lights and where centre-line lighting is not installed RVR is based on these edge lights. These lights are at 200-ft intervals and have a maximum output of 12 000 candelas at 3° elevation and 2° toe-in. The edge lights are single unit fittings which produce a beam in both directions simultaneously and incorporate an omni-directional element of about 2000 candelas. An observer, therefore, has no difficulty in seeing and counting this type of light regardless of distance and relative position.

RVR increments must be limited to the distance apart of the runway lights to which reference is made ; because of the conversion factor this increment can vary from between 20 m and 80 m but will average about 50 m. It is considered that with this system an average reporting increment of 30 m could be achieved simply by reducing the distance between runway edge lights or RVR reference lights ; the latter involves merely a redeployment of the actual reference lights but the former requires respacing of the edge lights from 200 ft to approximately 100 ft. RVR reporting would then be possible without difficulty up to at least 700 m. Beyond 700 m merging of individual lights would create a problem (counting of runway lights at 200-ft spacing from present ROPs becomes exacting at about 1100 m) but reporting at these lesser intervals is probably not worth-while beyond this limit.

**General remarks and comments.** The human observer RVR system has been operating in the U.K. for at least 10 years. During this period there have been a number of modifications, e.g. the calibration procedure has been changed to simulate operational conditions more closely, and the system has been extended to a large number of aerodromes. At present 57 runways on 28 aerodromes are calibrated and have been issued with conversion tables for RVR. Routine calibrations are carried out to ensure that the conversion tables are still valid and comparison experiments will be made to ensure that the conversion tables produced from a calibration under experimental conditions are valid for actual observations made in fog conditions. Also, the variations in calibration curves obtained from calibrations made simultaneously by different observers have, so far, been small. The calibration procedure itself is solely to establish the relative brightness of the lights when viewed from the two positions and visual acuity is not considered a significant factor. Nevertheless, it is recommended that observers should have at least average eyesight ; this, in itself, is a safety factor because the pilot should have at least as good if not better eyesight (though factors such as windscreen obscurity, speed of approach or difference in visual threshold due to different approach lighting are not accounted for).

Runway visual range in the U.K. has been a developing facility and current procedures and methods are constantly under review to ensure that a RVR system, simple in operation and accurate in results, is available at those aerodromes where it is required. The present and proposed range of instrumental experiments are expected to produce an alternative method for RVR and may well lead to extended reporting methods.

**Acknowledgement.** The substance of this article has also been contributed to the Commonwealth Air Transport Council and was published in the December 1967 issue of *CATC Electronics News*.

551.507.321.4:551.508.953:551.558.1

# A NOTE ON THERMALS OBSERVED BETWEEN 300 AND 900 METRES ALTITUDE AT CARDINGTON, BEDFORDSHIRE

By G. W. PALTRIDGE  
Radio and Space Research Station, Slough

One aspect of the research on tropospheric radio-wave scatter carried out by the Radio and Space Research Station (RSRS) has involved soundings with a microwave refractometer at heights up to 3 kilometres using a tethered balloon. In a two-week exercise in May 1967 at Cardington, Bedfordshire, the spaced-cavity refractometer developed at RSRS (Lane,<sup>1</sup> Fowler *et alii*<sup>2</sup>) was flown in conjunction with a platinum-resistance thermometer and an anemometer, in order to study the positions of regions of large variance in refractivity and of small scale-size variance in relation to temperature inversions and wind shear.

This note reports some remarkable results from three soundings on 18 May. The first ascent was made between 1000 and 1130 GMT, when the cloud base (8/8 cumulus) was at 900 m. The second was made between 1330 and 1500 GMT, at which time the cumulus had dispersed entirely. The third was made between 1600 and 1700 GMT when 7/8 cumulus had returned and a ground wind of 5 to 10 knots had replaced the almost calm conditions of the previous flights. A section of the recordings from the second ascent is presented in Figure 1.

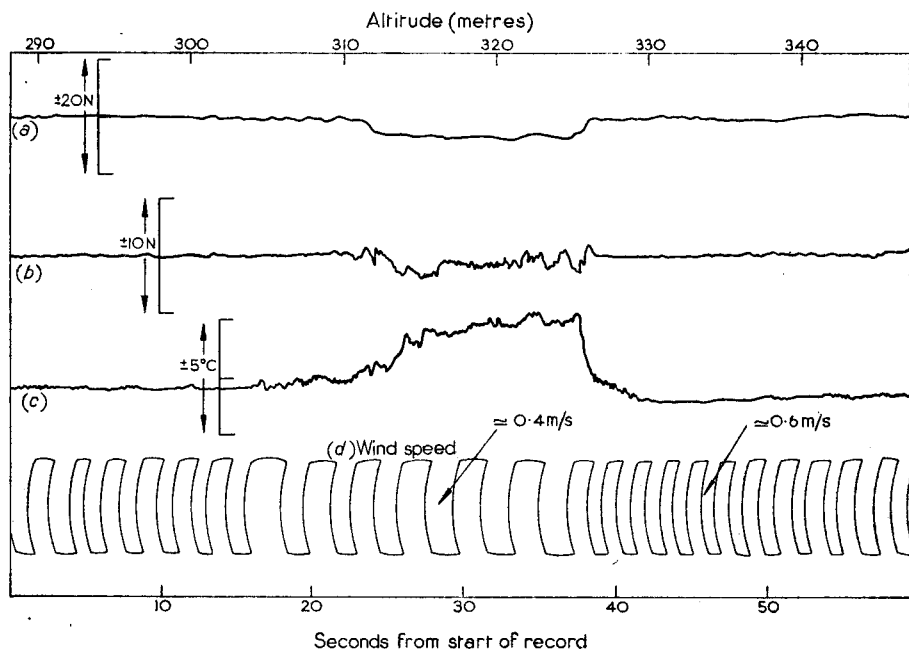


FIGURE 1—MULTICHANNEL RECORDING FROM THE SECOND ASCENT

Traces are (a) change in total refractive index, (b) differential refractive index, (c) change in temperature and (d) wind speed. The wind speed  $V$  (m/s) is given by the formula  $V = 0.2 + (0.048 \times x)$  where  $x$  is the speed of oscillation of the trace in cycles per second.

The recorded variables are labelled on the figure. It shows (a) the change in total refractive index  $n$  (in units of  $N = (n-1) \times 10^6$ ) as measured by an open-closed cavity arrangement and recorded by a slow time-constant pen,

(b) the fine-scale fluctuations in refractive index as measured by a differential technique with two open cavities 1 metre apart vertically, (c) the change in the temperature and (d) the wind speed, represented here by the speed of oscillation of the trace. Both (b) and (c) were recorded by a pen of 40 c/s response time. The variables are measured as a function of time and, therefore, of altitude, since the rate of ascent was uniform. The section illustrated is that obtained between 290 and 340 m.

It can be seen that the instrument passed through, or was passed by, a sharply defined region where the temperature, relative to the surrounding air, was extraordinarily high — some 6 degC above the ambient temperature for that height. The phenomenon was seen at several points between 300 and 900 m (970 to 900 mb) in this second flight (both on ascent and descent) and, with lower temperature variations, over the same height interval in the first flight. However, these variations had disappeared by the third ascent late in the afternoon. The reality of the magnitude of temperature increase is supported by the record of total refractive index, see Figure 1 (a), which changed by the amount which could be expected for a 6 degC temperature change ( $\approx 8.0$  *N*-units), assuming negligible change in humidity.

The situation is almost certainly a classic example of a rising 'thermal'. Thermals are well known to meteorologists and are much discussed in the relevant literature, for example by Scorer.<sup>3</sup> They are parcels or bubbles of hot air rising from a source of local heating at the ground, and are characterized, among other things, by the difference between the wind velocity in the bubble itself and the wind velocity in the ambient air. This last is an important factor in the transference of atmospheric momentum from upper to lower levels. The extraordinary aspect of this particular example is the magnitude of the temperature differential. Previous workers (Grant,<sup>4</sup> Warner and Telford,<sup>5</sup> and others) refer to temperature differentials of perhaps 1 or 2 degC.

The explanation probably lies in the fact that the soundings were made some 200 m downwind of the two large balloon sheds which were originally the R100 and R101 airship hangars. It is quite feasible that local heating of 6 degC above ambient could be caused by their black-painted iron roofs. During the second ascent the ambient temperature lapse rate was very nearly adiabatic, so that the temperature differential of a thermal would not change greatly during its ascent. (Figure 2 shows the temperature and dew-point

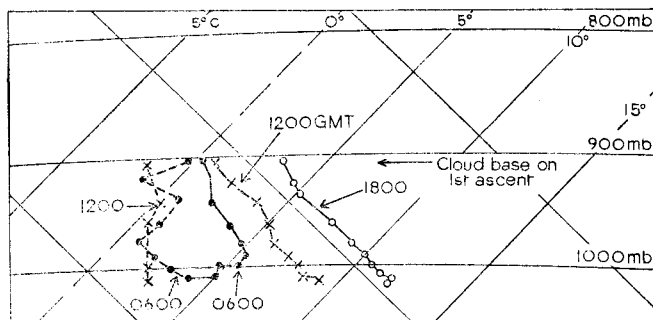


FIGURE 2—UPPER AIR ASCENTS OBTAINED FROM METEOROLOGICAL OFFICE TETHERED-BALLOON SOUNDINGS (BALTHUM) AT 0600, 1200 AND 1800 GMT ON 18 MAY 1967

—— Temperature      --- Dew-point

profiles obtained from the three meteorological soundings, with a tethered balloon, taken on the same day some 300 m further downwind.) From Figure 2 again, the early-morning temperature lapse was such that the 2 degC temperature differential of the thermals actually observed at 600 m during the first ascent would require a ground source temperature 4 degC above the ambient temperature. The estimated height of the early-morning cloud base on the basis of this 4 degC is consistent with that actually observed.

Finally it is interesting to note from the differential refractive index curve in Figure 1 that the fine-scale variance in refractive index is greater within the thermal than outside it. It is to be expected, in fact, that a fast-rising bubble of air should have small-scale turbulence associated with it, particularly on its outer edges where entrainment would be taking place; and it is conceivable that this turbulence would be associated with a large variance of the small-scale refractive index fluctuations. However, in some of the examples observed on this day there was no such evidence of small-scale fluctuations within the thermal.

**Acknowledgements.** The work described was carried out at the Radio and Space Research Station of the Science Research Council and is published with the permission of the Director. The author acknowledges the help and advice received from Mr Lane of RSRS and Mr Tyldesley of the Meteorological Office, Cardington. The assistance of Messrs Champion and McKinley of RSRS is appreciated.

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551-501-45:551-552

## ESTIMATION OF MONTHLY MEAN WIND SPEEDS

By G. LUPTON

**Introduction.** The object of this investigation was to ascertain whether monthly mean wind speeds could be estimated from frequency distributions of the wind speeds at four fixed hours, namely 0300, 0900, 1500 and 2100 GMT, for the five ranges 34 knots or more, 22-33, 11-21, 1-10 knots and calm, as published in Table IV of the *Monthly Weather Report*.<sup>\*</sup> Monthly mean wind speeds are important climatological parameters and have been used, for example, in estimating evaporation amounts, wind chill indices, etc.

**Method.** The data used were the frequency distributions for the specified hours for certain stations having anemographs with effective heights of approximately 33 feet (10 metres), thus requiring no corrections to be applied to their readings. For each of these stations an accurate monthly mean speed calculated from its tabulated hourly mean speeds is published in Table II of the *Monthly Weather Report*.

<sup>\*</sup> London, Meteorological Office. *Monthly Weather Report*.

If the true mean wind speed for one month at a station is  $V$  knots (based on hourly values, then

$$V \approx \left\{ \sum_{i=1}^{i=5} u_i f_i \right\} / 4n \quad \dots (1)$$

where  $f_1, f_2, f_3, f_4$  and  $f_5$  are the total frequencies (i.e. the sum of the frequencies for 0300, 0900, 1500 and 2100 GMT in each speed range,

$u_1, u_2, u_3, u_4$  and  $u_5$  are representative mean speeds for each range, and  $n$  is the number of days in the month.

By trial and error, mean speeds  $u_1, u_2, u_3, u_4$  and  $u_5$  were found for each station-month such that the monthly mean speed, calculated by using equation (1) was equal to  $V$  for that station-month. Initially speeds of 36, 27, 15.5, 6.5 and 0 knots were used as first approximations to  $u_1 \dots u_5$  respectively.

**Results.** Values of  $u$  were calculated for each month of 1963 for Turnhouse, Elmdon, Heathrow, Ringway and Rhoose and the averages of all these individual monthly means were then computed to give the required most representative values of  $u_1, u_2, u_3, u_4$  and  $u_5$  which were found to be 35.7, 26.9, 15.3, 6.3 and 0 knots respectively.

**Test of results.** Using data for Lerwick, Kirkwall, Benbecula, Prestwick, Carlisle, Stansted, Gatwick, Speke and South Farnborough, the following results were obtained :

60 per cent of the estimated speeds lay within 3 per cent of the true mean,  
76 per cent of the estimated speeds lay within 5 per cent of the true mean,  
92 per cent of the estimated speeds lay within 10 per cent of the true mean.

The results shown in Table I were obtained if station-months were subdivided into three categories :

- (i) 'Windy' months — months in which  $(f_1 + f_2 + f_3)$  exceeds  $(f_4 + f_5)$ .
- (ii) 'Normal' months — months in which  $(f_4 + f_5)$  exceeds  $(f_1 + f_2 + f_3)$  but is not greater than twice that quantity.
- (iii) 'Quiet' months — months in which  $(f_4 + f_5)$  exceeds  $2(f_1 + f_2 + f_3)$ .

TABLE I—PERCENTAGE OF TEST RESULTS LYING WITHIN VARIOUS RANGES OF DEPARTURES FROM THE TRUE MEAN

Approximate range per cent of true mean	'Windy' months	'Normal' months per cent	'Quiet' months
Within 3	81	62	41
Within 5	94	79	61
Within 10	100	98	80

**Conclusion.** Reasonably satisfactory estimates of monthly mean wind speeds may be obtained from the monthly frequency distributions of speeds at 0300, 0900, 1500 and 2100 GMT, as given in Table IV of the *Monthly Weather Report*, by using equation (1) and the following representative mean speeds for the 5 speed ranges in that table:

Range	Mean speed	Range	Mean speed
	<i>knots</i>		<i>knots</i>
34 or more	35.7	1 - 10	6.3
22 - 33	26.9	Calm	0
11 - 21	15.3		

This result can be applied to any station for which data are included in Table IV of the *Monthly Weather Report*, not only to anemograph stations, as used in this paper. For anemograph stations it will generally be more accurate to use the mean speed based on hourly values given in Table II of the *Monthly Weather Report*, corrected where necessary to the standard height of 33 feet above the ground. The accuracy of an estimated monthly mean speed obtained by this method is greatest in a windy month.

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## THE INTERNATIONAL SYMPOSIUM ON FLOODS AND THEIR COMPUTATION, 15-22 AUGUST 1967, LENINGRAD

By F. SINGLETON

Almost every country in the world is currently experiencing an increasing demand for water and power. In some areas, of course, the two are synonymous. In order to use water, however, it is usually necessary to control it and this often implies the construction of dams to form reservoirs. Since large volumes of water may be thus impounded it is essential that risk of failure of dams be removed as far as is humanly possible when loss of life would result, or reduced as far as economic conditions dictate (or allow) otherwise. It is, therefore, appropriate that the 10-year programme of hydrological research currently being undertaken in an atmosphere of international co-operation [the International Hydrological Decade (IHD), sponsored by the United Nations Educational, Scientific and Cultural Organization (UNESCO) in collaboration with the World Meteorological Organization (WMO), the Food and Agriculture Organization (FAO), the International Atomic Energy Agency (IAEA), the International Association of Scientific Hydrology (IASH), and other international agencies] should include a symposium specifically to consider the problems posed by floods. One country which has within its boundaries an extremely wide range of flood problems is the U.S.S.R., so the acceptance of its offer to act as host country for the symposium was particularly apt.

The 102 papers presented in the symposium were divided into three main parts :

- (i) General problems, theory of formation and methods of computation of rainfall floods.
- (ii) Theory of formation and methods of computation of snow-melt floods.
- (iii) The effects of basic characteristics in flood hydrograph components.

Hydrology, like meteorology and medicine, is an inexact science : an incomplete set of data, sometimes of doubtful accuracy, is presented, from which firstly a diagnosis and thereafter a prognosis has to be produced. In hydrology, as in meteorology, two main forms of prognosis are required, one for planning or design and one for operational use. In both instances the prognosis often has to be produced, in order to be useful, before there is time or opportunity to study the situation in such detail as to ensure a high degree of accuracy. This is a situation analogous to meteorological operational forecasting, when the best possible answer has to be produced using the available data. The majority of papers at the symposium were explicitly concerned with planning and design rather than with operational requirements although the latter were by no means overlooked.

Since hydrological and hydrometeorological data are necessarily incomplete and the processes leading from rainfall or snowfall to run-off are so complicated as to render imprecision an inherent feature of flood problems, it is inevitable that many methods of flood computation for design purposes should involve the methods of extreme value statistics. Similarly, 'black box' techniques are used for forecasting as well as design purposes. (In this context 'black box' techniques imply the derivation of relationships between observed inputs and outputs so as to be able to predict the latter from given values of the former without necessarily being concerned with the precise processes leading from one to the other. A meteorological analogy would be the objective forecasting of visibility, for example.) Several papers were presented which were devoted wholly or partly to extreme value methods for single elements, for combined temporal series or for spatial-temporal series. The end product of the papers in most cases was the derivation, from relatively small amounts of data, of flood flows of low probability of excess. Other papers, which dealt with 'black box' methods, produced statistical or derived functional relationships between flood-producing phenomena and floods.

Papers concerned with more direct 'physical' approaches to the problems of understanding flood processes were in two main categories, theoretical and observational. The former derived models of snow-melt, rainfall and run-off and from them calculated possible values of flood flows. The latter studied observed flows and attempted to show the effects on them of catchment characteristics, one object here being eventually the calculation or estimation of the effects of natural or artificial changes in land. There are some areas in the world where deforestation has taken place since the design and construction of dams, and it is now thought that, with consequent reduced evaporation, floods occur more frequently than was allowed for at the design stage. As there are obvious dangers in the invalidation of design criteria in this manner, either some control of catchment use is necessary or allowance for such effects must be made in the original calculations. (The converse may also occur of course, and it may well be that afforestation either due to natural seeding or intentional planting can lead to reservoir yields falling below expectation.)

When there is a list of 102 papers by acknowledged experts from which to choose, the selection of any one paper for special mention must be somewhat arbitrary. The paper by V. A. Uryvaev and G. M. Loukashenko on aerial photogrammetric methods of estimating flood discharges, however, was noteworthy for its originality and its direct application to real problems.

The main value of the symposium must be the collation and subsequent publication by UNESCO of the papers and discussions thereon. In this way a substantial body of current thought on flood hydrology, as well as a masterly scientific summary of the whole symposium by Professor Sokolov of the U.S.S.R., will be available in three languages.

The symposium was organized by UNESCO in co-operation with WMO and the U.S.S.R. committee for the IHD with the support of IASH. There were about 350 participants of whom 200 were from the U.S.S.R., the remainder being from 36 other countries. Although the organization obviously posed immense problems, even for a host country with the resources of the U.S.S.R., the manner in which difficulties were overcome was most impressive. Before the conference, for example, English and French papers had to be translated into Russian and vice versa. The papers had to be printed in three languages

together with a separate list of abstracts. A veritable army of interpreters, many of them teachers on vacation, had to be assembled and the conference itself was conducted using simultaneous translation by UNESCO and U.S.S.R. interpreters. All the interpreters coped extremely well with unfamiliar terminology and technical jargon.

The conference was held in the Palace of Education, Leningrad. This building (the scene of Rasputin's assassination) was one of the many dwellings of the former aristocracy which have been put to everyday public or private use yet still retain much of their former decorative splendour.

During the conference, participants had ample opportunity to see much of Leningrad both with guides on conducted tours and individually. The main impressions received were of fine looking buildings, wide streets, graceful gold-plated spires and the realization that, although the people have little wish to remember the Czarist rule as such, the Russians are nevertheless very proud of their cultural heritage as evidenced in architecture and art. One particularly interesting aspect is the manner in which old buildings destroyed or badly damaged in the last war, have been rebuilt or restored to their former glory. The most poignant moment was the visit to the cemetery to see the mass graves of those who died during the siege of Leningrad by Hitler's armies.

The social programme of visits and excursions included the Experimental Laboratory of the State Hydrological Institute. This appeared to have a similar programme of work to that undertaken at the United Kingdom Hydraulics Research Station. The most interesting project here was an attempt to model river-bed processes involving erosion and the transport of sediment. After the conference some participants were able to visit the Valdaj Hydrological Research Laboratory to see the latest developments in Russian water budget experimental research.

The symposium, in the final analysis, enabled hydrologists, hydrometeorologists and engineers of many countries and persuasions to discuss, both openly at formal sessions and in private, a general topic of great interest and importance, the magnitude of which could be measured by the number of papers that the organizing committee considered worthy of both publication and oral presentation.

## **AWARDS**

### **L. G. Groves Memorial Prizes and Awards**

The presentation of the L. G. Groves Memorial Prizes and Awards for 1967 were made by Major K. J. Groves on the 24 November 1967 at the Ministry of Defence, Whitehall. The presentation was presided over by Air Marshal Sir Peter Wykeham. As this was the 21st anniversary of the awards, it was pleasant to welcome back two of the prizewinners of the inaugural year, Mr J. S. Sawyer, M.A., F.R.S., Director of Research, Meteorological Office, and Wing Commander B. J. Stanojlovic, O.B.E., RAF, (Retired).

The Memorial Prize for Aircraft Safety was awarded jointly to Flight Sergeant J. Flint of the School of Combat Survival and Rescue, and to Senior Aircraftman T. Watson, a safety equipment worker, Royal Air Force Geilenkirchen. Flight Sergeant Flint designed and produced a rig, to be mounted on the aft of a suitable marine craft, from which aircrew members



could be given realistic training in the final stages of para-entry into water and subsequent para-dragging. Since its introduction to the School of Combat Survival and Rescue, many hundreds of aircrew have been trained on the equipment. Without the experience gained, the final phase of an otherwise successful abandonment could become hazardous, confusing and possibly fatal.

Senior Aircraftman Watson, a safety equipment worker of RAF Geilenkirchen, observed that on practice dinghy drills and during servicing, the drogue lines often became entangled in such a way as to prevent full and free inflation of the dinghy. He proposed a simple Velcro closure to retain the drogue and lines until inflation is almost complete, at which stage the pressure will force open the stowage and fling both drogue and lines well clear. In this way there is no risk of entanglement or rupture of the dinghy.

The Memorial Prize for Meteorology was presented to W. T. Roach, Ph.D., D.I.C., a Principal Scientific Officer at the Meteorological Office, in recognition of his important scientific contribution to the study of atmospheric structure particularly as it effects the operation and safety of aircraft and as exemplified in a recently published analysis of structure of the tops of severe storm clouds based on photographs from U-2 aircraft. Dr Roach's studies have been directed at the very practical problem of determining the likelihood of encountering conditions hazardous to aircraft, and he has displayed much ingenuity in collecting relevant data from a wide variety of sources and in directing the flights by the Meteorological Research Flight to seek out turbulent areas. Dr Roach's results are of especial importance for planning the operation of supersonic aircraft.

Mr A. M. Dunning, Electronics Officer, Ocean Weather Ships, received the Meteorological Observer's Award with the following citation: 'During 20 years service in Weather Ships in the North Atlantic — 5 years as Radio/Radar Technician and 10 years as Electronics Officer — Mr Dunning has performed his duties with outstanding zeal, ability and good humour. He has been responsible for the maintenance of all the electronic equipment in the ship, including radio transmitters and receivers and Meteorological equipment, and for the maintenance and operation of the radar used for upper wind observations. This radar is hand-operated and its maintenance and operation — which depends much upon the skill and ability of the Electronics Officer — is often a strenuous and uncomfortable job in North Atlantic weather. Mr Dunning has, thus, throughout his service made a major contribution to the Meteorological work of his ship.'

The Second Meteorological Award was awarded to Mr T. W. Harrold, B.Sc., D.I.C., Senior Scientific Officer, Meteorological Office. The citation says: 'Mr T. W. Harrold has made several significant contributions to the Science of Meteorology during the year, mainly with particular application to the measurement of rainfall and the determination of the air motion in the vicinity of fronts. He has also contributed to the study of the structure of severe thunderstorms with particular relevance to the safety of aircraft in their vicinity. In all his work Mr Harrold has shown a remarkable ability to co-ordinate advanced techniques so as to lead to results of practical importance in Meteorology and its applications.'

### NOTES AND NEWS

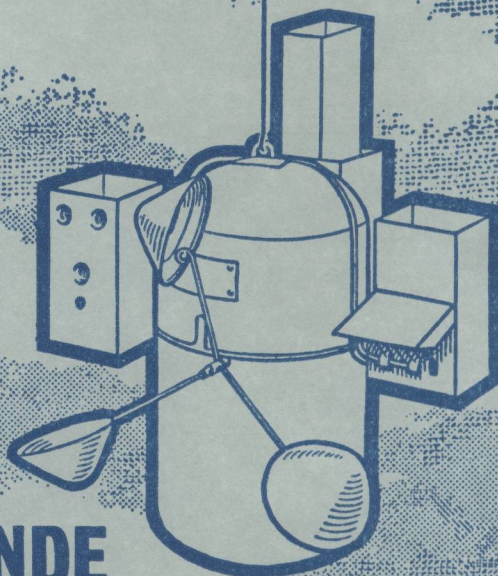
#### **WMO Symposium on Urban Climates and Building Climatology**

A Symposium on Urban Climates and Building Climatology, organized by the World Meteorological Organization, will be held in Brussels from 16 to 25 October 1968. Further details may be obtained from Dr T. J. Chandler, Department of Geography, University College, London.

### OBITUARY

*Mr R. Corless, C.B.E., M.A.* We note with regret the death of Richard Corless on 11 December 1967 after 20 years retirement. He was amongst the first of the highly qualified scientific officers introduced into the Office by the late Sir Napier Shaw and when he first held the rank of Assistant Director in 1939 there were only two Assistant Directors directly under the Director of the Meteorological Office. He served in two world wars in high administrative posts and eventually retired in 1947. Details of his career and an appreciation of his services are recorded in the *Meteorological Magazines* for January 1939 and May 1947.

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NOTICES

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Printed in England by The Bourne Press, Bournemouth, Hants.

and published by

HER MAJESTY'S STATIONERY OFFICE

3s. 6d. monthly

Annual subscription £2 7s. including postage

Dd. 133110 K16 1/68

S.O. Code No. 40-43-68-2