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A study of a katabatic wind at Brüggen on 27 February 1975

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Summary

An investigation was carried out into the circumstances associated with a good example of a katabatic wind recorded at Brüggen. It is suggested that the apparent rapid decay of the katabatic wind after 2000 GMT was due to the anemometer head becoming submerged in a suddenly deepening pool of more stagnant colder air and that katabatic winds continued to flow at higher levels above the station. It is also suggested that buoyancy waves occurred associated with fluctuations in the height of the stable interface between the air in the top of the cold stable layer and the lower part of the warmer katabatic flow.

1. Introduction

Brüggen (station 10 401) is situated at 51°12′N, 06°08′E and 76 m above mean sea level (m.s.l.) on a small ridge (Fig. 1). Southwards, the ground first falls to about 40 m across the valley of the Rur then rises gently to 200 m at Aachen, a distance of 50 km, and then more steeply to over 610 m in the Eifel range of hills, a further distance of 20 km. Katabatic winds are not uncommon at Brüggen although in general wind speeds do not exceed 4 m s^{-1}. However, almost invariably these winds prevent fog formation, even when the air temperature falls below the normally forecast fog-point or, on occasions when fog is present, they may clear the fog.

2. Synoptic situation

At 1200 GMT on 27 February 1975 an anticyclone of 1037 mb was centred near Dresden with a ridge extending to the southern North Sea (Fig. 2). A very light pressure gradient associated with south-easterly winds existed over most of Germany and the Benelux countries. The air mass was dry with a relative humidity of 41 % at Brüggen at 1200 GMT and as will be seen from the following table and Fig. 3, the air at 610 m over Uccle (near Brussels) and Essen at 1200 GMT was even drier.

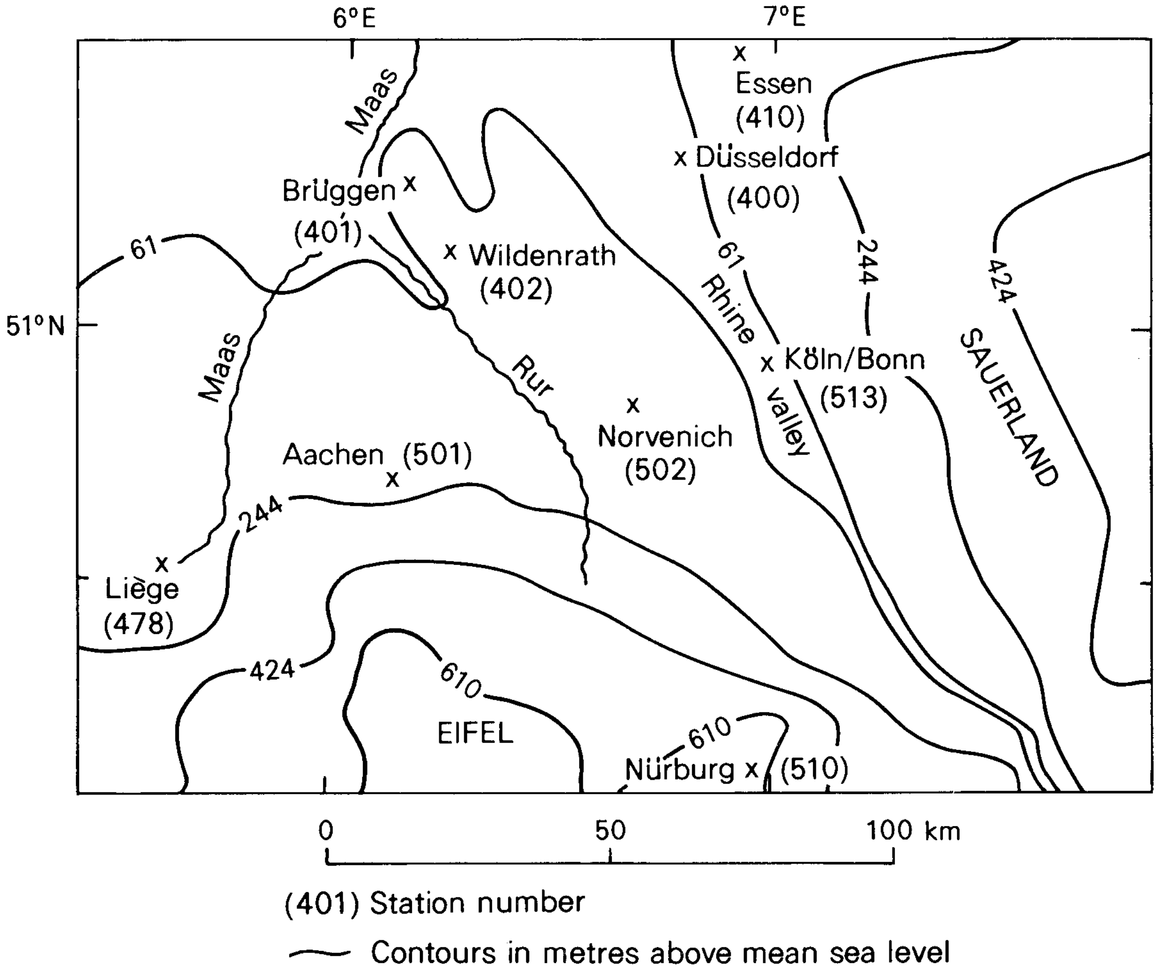

Figure 1. Location of Brüggen showing high ground and principal reporting stations in the area.

Temperature and humidity measurements

(a) *On the surface at Brüggen*

Time GMT	12	15	18	21	(Sunset 1713)
Air temperature (°C)	8·9	10·8	6·2	4·3	
Dew-point (°C)	−3·8	−4·1	−4·6	−4·3	
Relative humidity (per cent)	41	35	46	53	

(b) *By radiosonde at* 610 *m* (*approximately* 960 *mb*)

	Essen	Uccle
Time GMT	12	12
Air temperature (°C)	4·0	4·0
Dew-point (°C)	−18·0	−13·0
Relative humidity (per cent)	18	28

At 1800 GMT winds obtained by radiosonde from Essen and Uccle were 160–170°, 2–5 m s^{-1} at heights to 900 mb (about 1060 m).

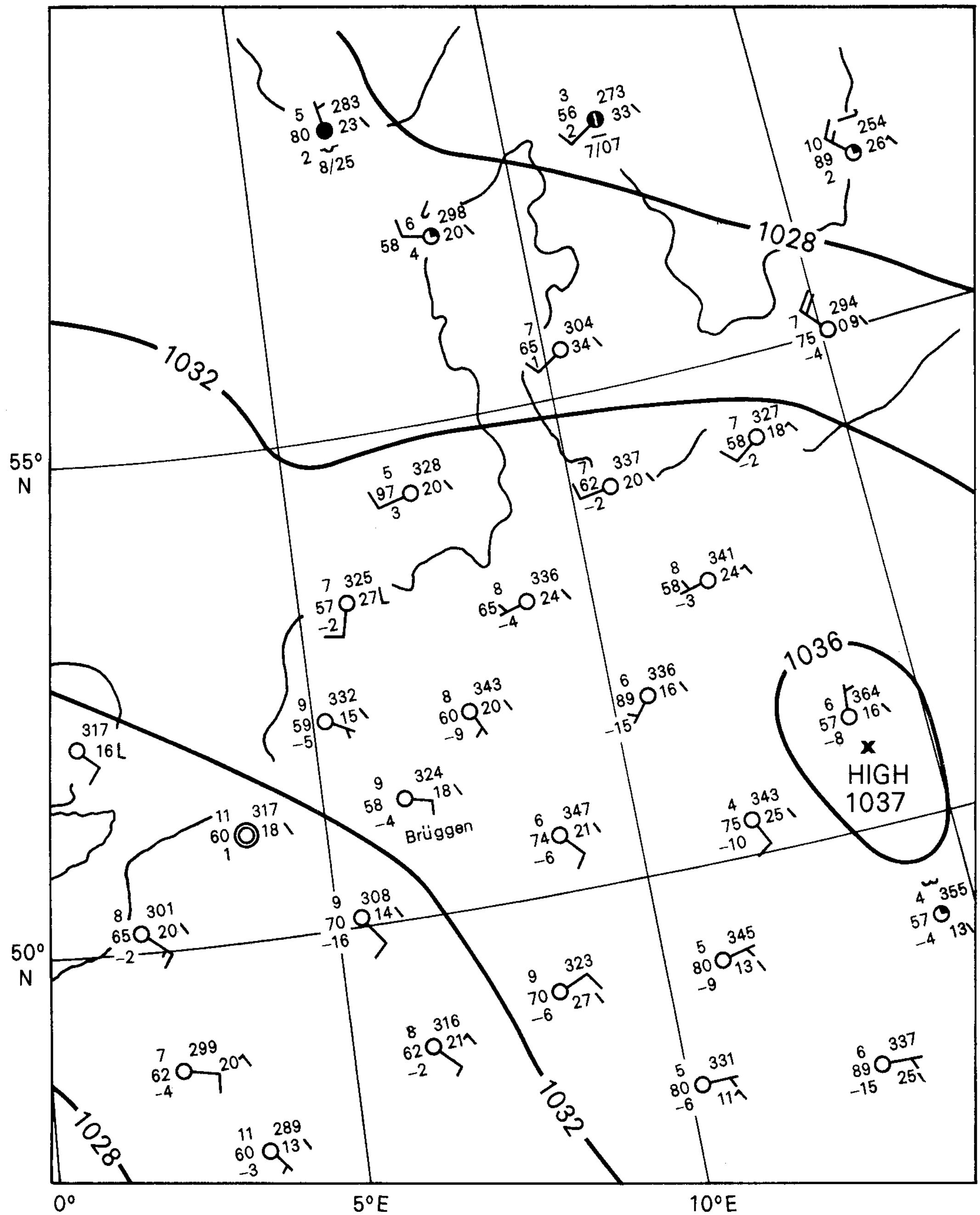

Figure 2. Synoptic situation on 27 February 1975 at 1200 GMT.

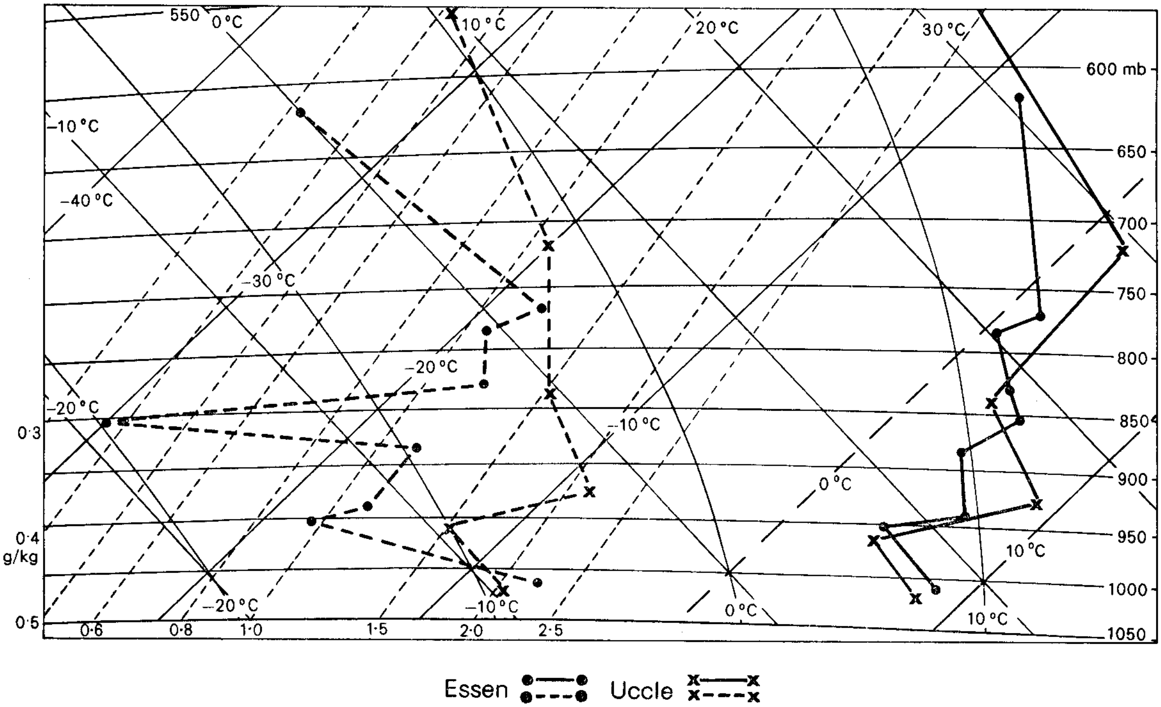

Figure 3. Radiosonde ascents for 1200 GMT on 27 February 1975.

3. Observations at Brüggen

(a) *Development of the katabatic wind*

Throughout the day and into the evening, skies were clear over north-west Germany and the Benelux countries. The mean surface wind at Brüggen during the afternoon was 110°, 10 kn (5 m s^{-1}), but from 1600 GMT the wind decreased in speed, became less turbulent and backed to become 100°, 5 kn by 1730 GMT (Fig. 4). Thereafter the wind started to veer and increased in both speed and gustiness, with a maximum veer to 180° being reached at about 1920 GMT when the mean speed had increased to 10 kn. By 1950 GMT the mean speed had reached 14 kn, with a gust to 20 kn, but from 1950 to 2010 GMT the wind rapidly backed and decreased to 060°, 5 kn and the traces narrowed. Tabulated values in Fig. 4 are mean wind directions and speeds (degrees true and knots) and a maximum gust (knots) in the hour indicated. Time marks on extensions of Fig. 4 indicate that the chart time is in accord within a minute of the times at which the marks were recorded.

For the rest of the night until 0400 GMT the surface wind speed varied between 2 and 7 kn, but four notable peaks occurred—at 2230, 0005, 0235 and 0335 GMT. The wind direction changed frequently. In particular there were periodic fluctuations between north-east and south-east with a period of about 15 minutes between 2015 and 2115 GMT and further periodic fluctuations of smaller amplitude and a slightly longer period between 2130 and 2230 GMT, all associated with wind speeds of about 5 kn (see Fig. 4). Other, less pronounced, periodic variations continued through the night associated with lower speeds. On three of the occasions of speed increases already noted, the wind direction reverted to southerly, associated with the strong katabatic.

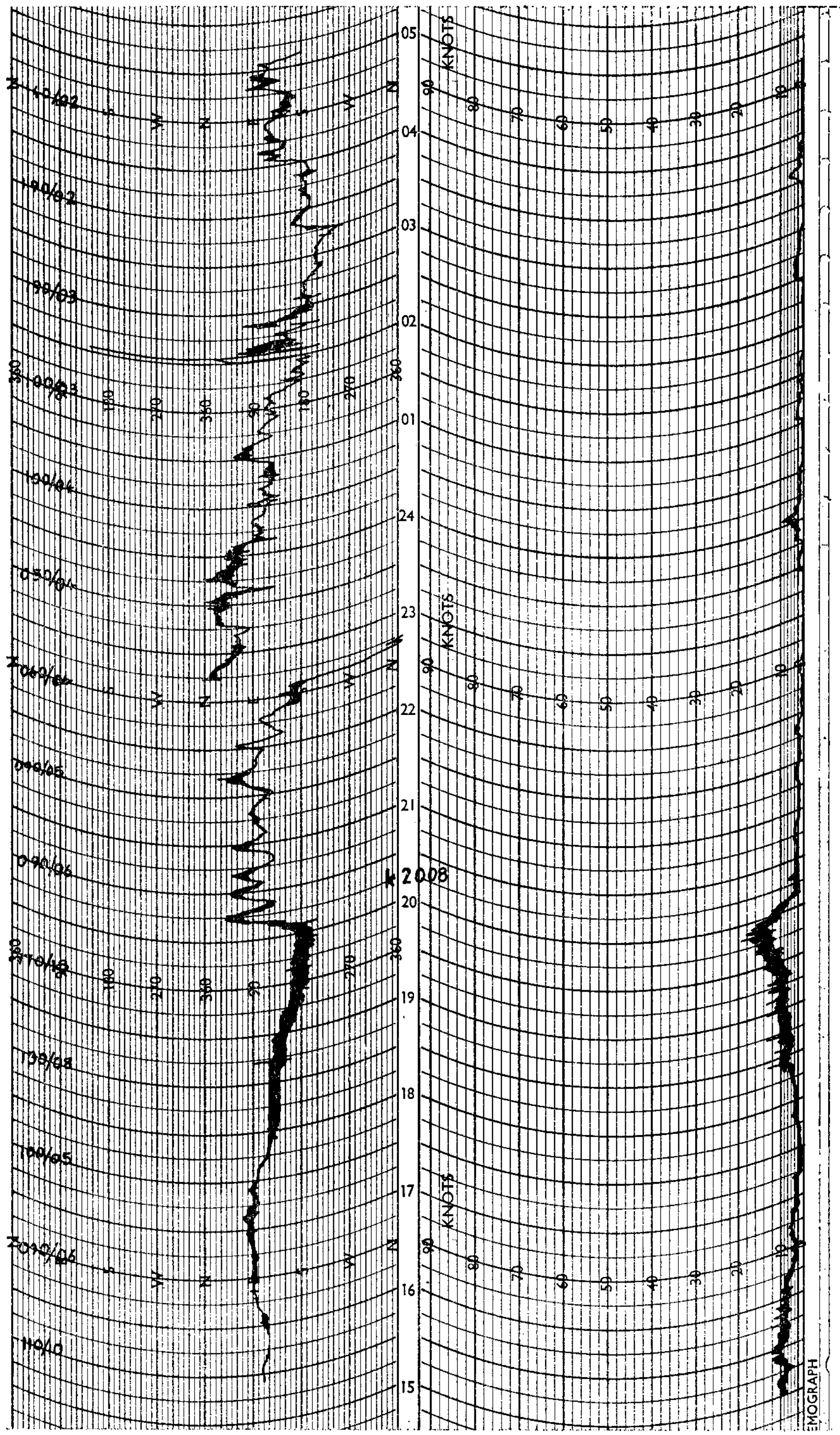

Figure 4. Anemogram from Brüggen, 27–28 February 1975.

(b) *Variation in surface temperature, humidity and pressure*

From a reading of 10·8 °C at 1500 GMT, the temperature fell rapidly to 5 °C at about 1800 GMT, but between 1800 and 2000 GMT, whilst the katabatic wind was being recorded, it exhibited two apparently periodic fluctuations between 5 °C and 6·5 °C with periods close to one hour (Fig. 5(a)). The sharp fall of temperature was resumed from about 2000 to 2200 GMT, but although there was a slow overall fall of temperature during the night, periodic fluctuations occurred with rises and falls of temperature of 1 to 2 °C, with a period of about one hour until 0300 GMT but with longer periods after this time. Similar changes but of opposite signs were recorded on the hygrogram (Fig. 5(b)).

By superimposing corresponding maxima and minima on the hygrogram and thermogram for different parts of the night it is evident from the detailed shapes of the traces that the two traces are in antiphase throughout the night. However, this superimposition also indicates that the relative apparent times of the two records changed from a difference of the order of 30 to 35 minutes at the start of the night—in reasonable agreement with the evidence from the time marks—to a difference of about 15 to 20 minutes late in the night. Apparently the relative timings of the two records changed by something of the order of 15 minutes during the course of the night. It is likely that this change was due not so much to clock rates of the recording drums, but to non-coincidence of the pen arcs with the curved time lines on the charts. If this is so it implies that the time of the autographic record is (at least sometimes) a function of the variable under record—as well as the clock rate. This incompatibility of timing between thermogram and hygrogram made it impracticable to relate time on these records with sufficient precision, relative to the phases of the anemogram pulsations, to be sure of the phase relationship between the oscillations of wind and of temperature and humidity.

The barogram trace (Fig. 6) shows that pressure mostly fell slowly and unsteadily throughout the 27th and 28th without any particularly unusual features. Nevertheless there was a temporary increase in the rate of fall followed by a check to little change at about 1930 barogram time, which, according to the time mark at 1150 on the 27th, corresponds to about 2000 clock time. However, again there is uncertainty in the timing. According to the time marks the barogram time is about 20 minutes slow on the 26th, 30 minutes slow on the 27th and 30 minutes fast on the 28th.

4. Observations in the surrounding area

(a) *The observed synoptic temperature field*

Synoptic observations of the temperature distributions at screen level, together with associated winds and dew-points within 200 km of Brüggen at 2100 GMT on 27 February and 0300 GMT on 28 February are shown in Figs 7(a) and 7(b) respectively. Areas of relatively high temperature in the foothills of the Eifel and Sauerland are apparent on both charts. In flowing down the slopes the dry air would be subject to adiabatic warming at a rate approaching the dry adiabatic lapse rate (i.e. about 5 °C/500 m). The extent of this warming would depend on the height change experienced by the air along its track. If this were the only factor the air temperature would increase northward on the charts as the air flow from the hilltops passed over lower and lower ground. The fact that the screen temperature decreased northward from the foothills at these times indicates that a more complex process was taking place, such that away from the foot of the steeper slopes radiative cooling was more than making up for lower station levels—as far as screen-level temperature was concerned.

(b) *Surface wind, temperature and pressure characteristics at other stations in the local area*

Copies of the anemograms, thermograms and barograms were obtained from a number of stations in the vicinity of Brüggen—i.e. Wildenrath (89 m above m.s.l.), Nörvenich (135 m above m.s.l), Düsseldorf

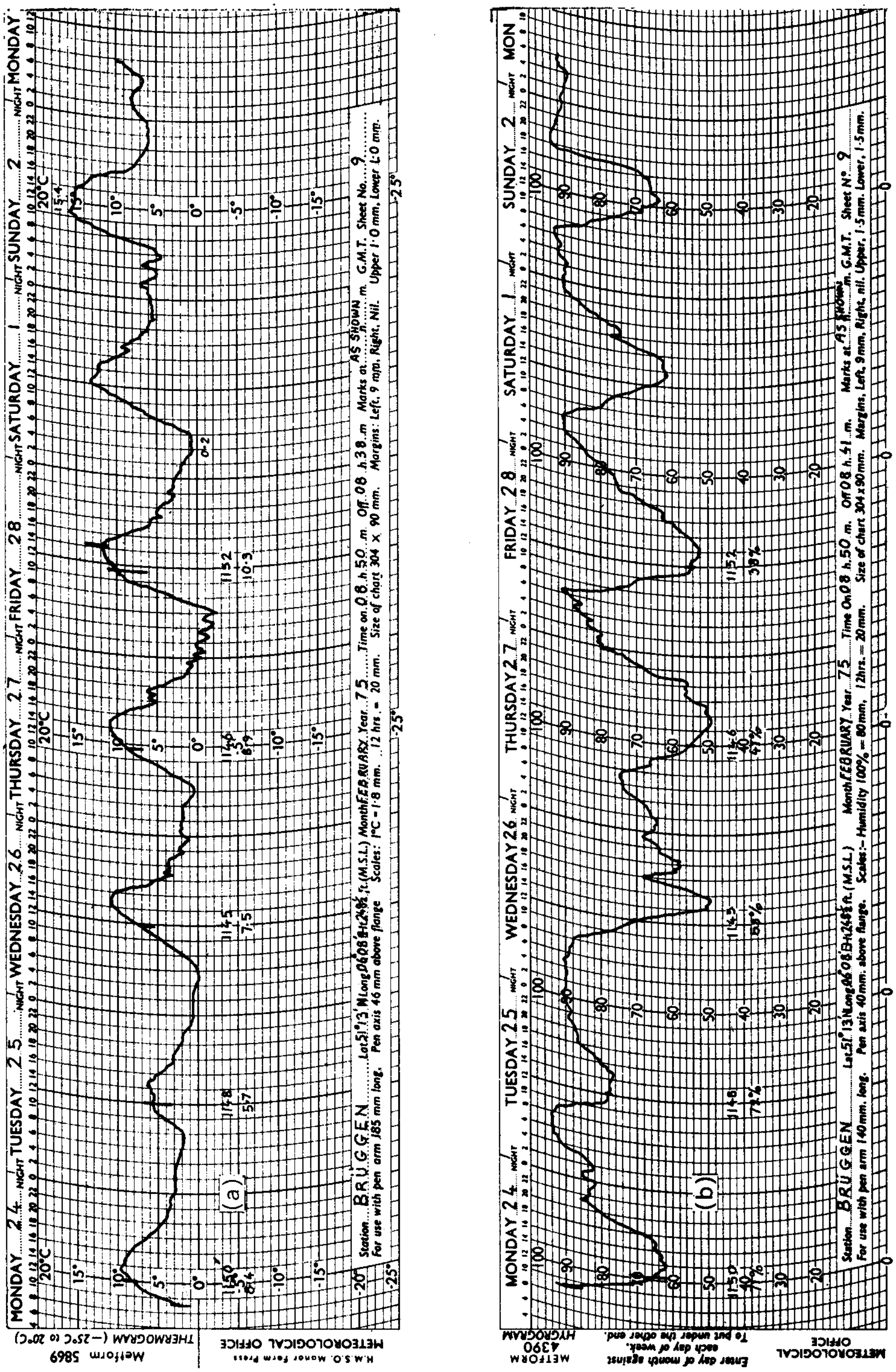

Figure 5. Thermogram (a) and Hygrogram (b) from Brüggen, 24 February–2 March 1975.

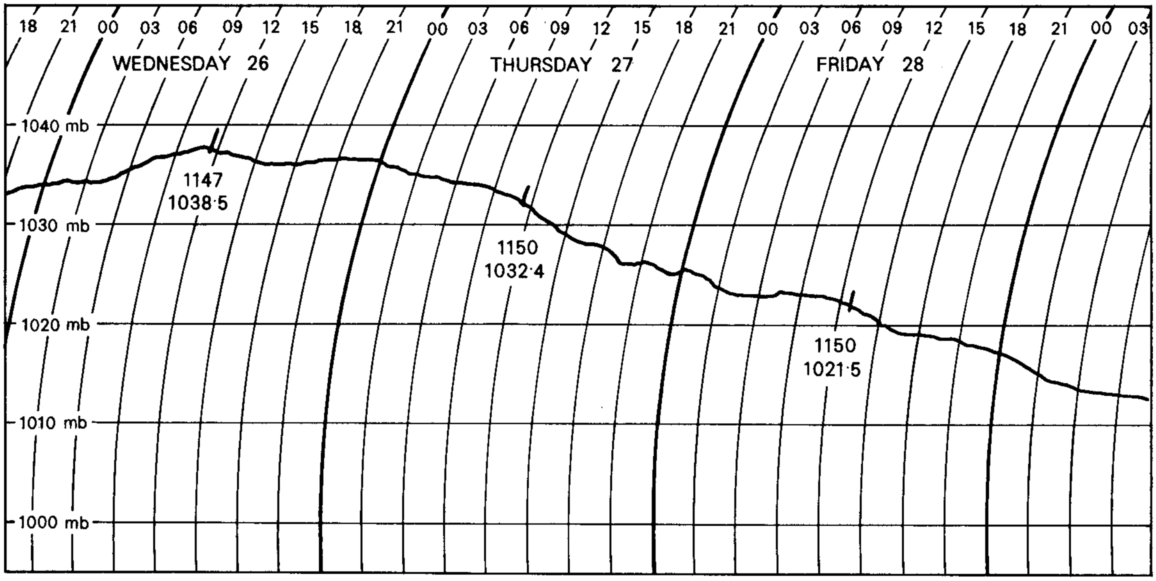

Figure 6. Copy of barograph trace from Brüggen, 26–28 February 1975.

(44 m above m.s.l.), Köln/Bonn (92 m above m.s.l.), Aachen (205 m above m.s.l.) and Essen (161 m above m.s.l.). In general, katabatic winds were in evidence at all these stations and the thermograms at most sites displayed features comparable with, but less well-marked than, those recorded at Brüggen.

At Wildenrath—less than 20 km to the south-south-east of Brüggen—the anemometer continued to record a southerly until 2055 GMT (i.e. one hour later than at Brüggen), then backed to easterly with direction oscillations from north-east to south-east of periods of about 12 to 20 minutes.

At Nörvenich—50 km to the south-east of Brüggen—the anemometer recorded a temporary backing from south-east to north-east at about 2020 GMT, but a southerly continued until after 2200 GMT before backing to an easterly and there is evidence of fluctuations of temperature at about 2020 GMT.

At Aachen—60 km to the south of Brüggen—the anemometer recorded a north-easterly wind from 1500 to after 1800 GMT, and thereafter the direction indicated wandered between north-east and south with signs of sticking until after 2000 GMT, but then resumed normally fluctuating recording at slightly west of south until after 0300 GMT.

The barograms showed small-scale features similar to those recorded at Brüggen.

5. Discussion

(a) *Conditions suitable for the katabatic wind to develop*

From the midday radiosonde ascents at Uccle and Essen, it would be expected that the temperature in the free air at 610 m above m.s.l. to the north of the Eifel range during the afternoon would have been 4 °C (Fig. 3). Over the high ground at about the same level above the sea, typified by Nürburg, 629 m above m.s.l. and some 120 km south-south-east of Brüggen, the 1500 GMT surface temperature was 7 °C, i.e. some 3 °C higher. By 1800 GMT the temperature at Nürburg had fallen to 3 °C. On the basis of the usual rates of temperatures change in clear weather it is suggested that it fell in the following manner:

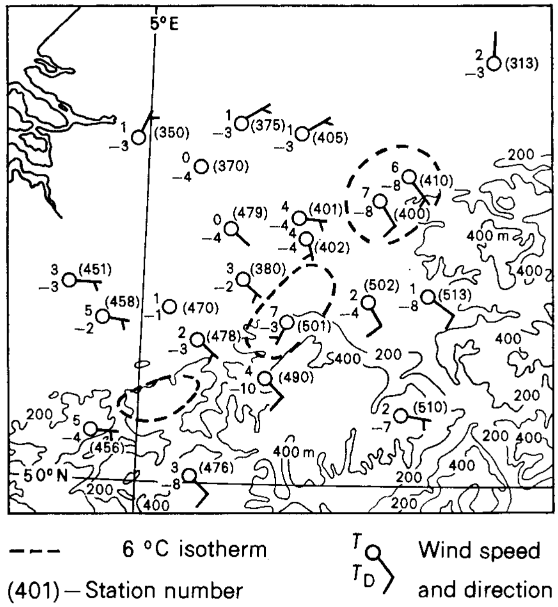

Figure 7(a). Surface chart for 2100 GMT on 27 February 1975.

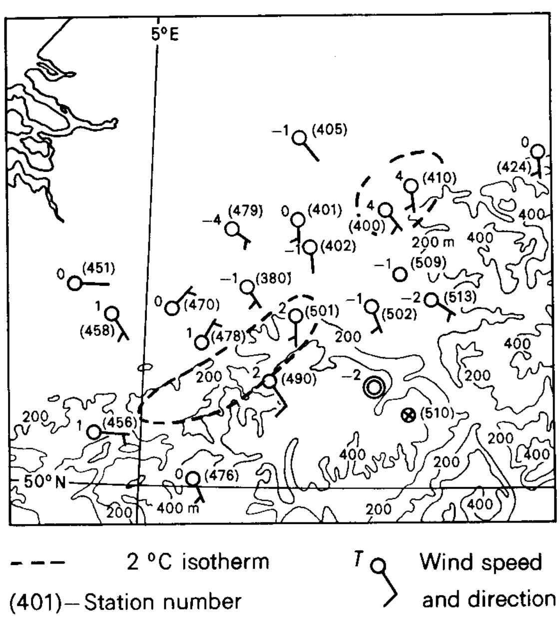

Figure 7(b). Surface chart for 0300 GMT on 28 February 1975.

Surface temperature at Nürburg

Time GMT	15	16	17	18	19
Air temperature (°C)	7·0	6·5E	5·5E	3·0	2·0E

E = Estimated

The decrease in speed and associated backing and reduced gustiness of the wind recorded between 1600 and 1730 GMT at Brüggen is likely to be due to the decrease in insolation (sunset 1713 GMT) and consequential reduction in the downward flux of eddy momentum from the wind in the free atmosphere.

Around 1730 GMT the surface temperature over the higher ground had fallen to equal the value of 4 °C, which existed at the same height above m.s.l. in the free air to the north. Thereafter, as the temperature over the slopes of the hills fell further, the surface air became denser than that at the same level relative to m.s.l. above the low ground and began to sink. With this process taking place all along the slopes of the Eifel range, from levels at about 610 m to the lower level around 180 m, a southerly katabatic wind was produced. This wind reinforced the light south-easterly flow that existed due to the pressure gradient so that the strength of the surface wind increased up to values recorded at Brüggen. It is probable that the katabatic wind occurred in the form of several streams down the hillsides, the one affecting Brüggen perhaps being steered northward along the Brüggen ridge.

At Brüggen after the peak katabatic wind at 1950 GMT the surface wind fell light with the periodic fluctuations in wind direction and temperature already noted.

(b) *Possible explanation for the observed surface wind and temperature variations at Brüggen*

As demonstrated by Fig. 4 the katabatic wind at Brüggen was turbulent, which would increase the depth of the atmosphere otherwise involved and modify both the temperature and the wind profiles in the vertical. The change of temperature with height in this dry turbulent current would tend to approach the dry adiabatic lapse rate and the associated rate of change of mean wind with height would be relatively small although some of the differences between turbulent elements could be quite high. The apparent rapid decay of the strong katabatic flow around 2000 GMT with subsequent wind changes and the nocturnal temperature changes are of particular interest. The following suggests tentative explanations of the observations.

The nocturnal radiative process gave rise not only to the katabatic wind but also to ground-based layers of more stagnant air, characterized by increase of temperature with height, which grew in depth above local ground levels as the night progressed. Initially these ground-based stable layers would form as isolated puddles over local depressions and low relatively level ground but as their tops grew upwards these puddles would progressively amalgamate into larger and larger pools effectively forming deepening sinks above which wind in the free air would continue to flow. At the interface zone between the top of the stagnant pools and the free atmosphere there would be a marked shear of wind. Where the wind above the stagnant stable layer had been augmented by katabatic effects, involving air parcels travelling downwards through substantial heights, the air in the katabatic current would have been subjected to adiabatic warming along its trajectory (as well as radiational cooling) and the rate of increase of temperature with height in the stable layer would probably be enhanced through the interface zone. This combination would give rise to travelling buoyancy waves which would effectively vary the local height of the interface as they passed by. If the wind shear with height became too strong to be supported by the thermal stability, turbulence would develop and redistribute the profiles to reduce the wind shear—effectively deepening the interface, extracting wind energy from the free atmosphere, and feeding into the sinks, so that the pools grew further in depth. In particular, katabatic winds would flow on top of and mix into the tops of pools growing above lower level ground, in the way rain-streams on uneven pavements flow to form puddles and—with the aid of indicators such as traces of oil—can be seen to stream for a time in the upper parts of the puddles they feed. There is also the possibility that hydraulic jumps could form at the foot of the steeper hills and propagate along the stable layer and interface as suggested by Clarke (1972) in his explanation of the morning glory of the Gulf of Carpentaria, following Ball (1956) in his theory of strong katabatic winds in the neighbourhood of Antarctic coasts. It is noteworthy that Ball, describing these winds, states: 'During the period of the lull strong winds may be both audible and visible higher up the slopes and sometimes a strong air stream, rendered visible by drift snow, is seen overriding the calmer air beneath'.

The Brunt–Väisälä period of the stable layer and interface would be of the order of a few minutes or even much less, but that of the turbulent katabatic layer would be much longer, of the order of half an hour at least, and probably substantially longer, depending on how little the lapse of potential temperature in the turbulent katabatic layer departed from zero. Thus buoyancy waves with periods in the range from a few minutes to an hour or so would tend to be trapped and travel long distances in the interface and stable layer, and be associated with periodic changes in the local height of the interface above the ground. These height changes would be in addition to the more general increase of height of the interface with time from sunset.

Within this general hypothesis—which involves the anemometer head at Brüggen becoming submerged in a more stagnant layer about 2000 GMT, whilst a wind probably still katabatically enhanced continued to blow in some rather higher layer—there are three possibilities to consider, which we call (A), (B) and (C). In (A) the stagnant stable layer grew over the local ground so that the local interface grew above the level of the thermograph and hygrograph screen soon after sunset—some hours before it grew above the anemometer head. In (B) the stagnant stable layer grew over lower ground gradually spreading to engulf the screen and anemometer head at nearly the same time—rising locally at Brüggen much more rapidly than in the first. In (C) the depth of the stagnant stable layer of (B) also increased almost discontinuously when a hydraulic jump passed over the area.

On (A) during the period 1700–2000 GMT at Brüggen—whilst the anemometer was recording the developing katabatic wind but the screen was in the stagnant stable layer below the level of the interface—passage of some of the buoyancy waves on the interface should appear as cyclic variations of temperature and coincident and antiphase oscillations of relative humidity. Indeed the two oscillations shown on these instruments during the period 1800 to 2000 GMT with periods close to one hour could be evidence of such waves. There are no clearly defined associated wave features on the anemogram. (Up to this time it is postulated that the anemometer head remained above the level of the interface.) Associated changes in surface pressure are likely to be too small to be reliably detected on an ordinary barogram and it cannot be claimed that particular small changes are associated with particular waves (no microbarograph records are available). However, on this first possibility the apparent decay of the katabatic wind recorded at about 2000 GMT would be mainly a record of the shear of wind across the interface—a vector change of the order 15 kn (7 m s^{-1}) over a very small height interval presumably of only a few metres. Considering the Richardson number

$$(Ri) = \frac{g}{\theta} \cdot \frac{\partial\theta/\partial z}{(\partial v/\partial z)^2} \qquad (1)$$

(where θ is the potential temperature,
g is the acceleration due to gravity,
v is the horizontal wind vector, and
z is the vertical co-ordinate)

the flow will be unstable, resulting in a redistribution and a reduction of the vertical shear of wind if (Ri) is less than, say, $\frac{1}{4}$. Putting $g = 10$ m s^{-2}, $\theta = 280$ K and expressing equation (1) in finite difference form this becomes

$$\frac{\Delta\theta\Delta z}{(\Delta v)^2} = 7. \qquad \text{(2)}$$

Thus if $\Delta v = 7$ m s^{-1} and $\Delta z = 2$ m then to avoid instability $\Delta\theta$ is required to be of the order of 175 K which is quite impossible and decisively disproves (A).

Alternatively, setting an order of magnitude of 5 K for $\Delta\theta$, then for $\Delta v = 7$ m s^{-1}, Δz needs to be 70 m to avoid instability. This accords more reasonably with (B) and especially (C), that the stagnant stable layer grew first over lower ground and the change of wind at Brüggen at about 2000 GMT was associated with much more rapid change of height of the interface above Brüggen than in (A)—so that the screen as well as the anemometer was not submerged in the stable layer until nearly 2000 GMT.

The temperature (and humidity) changes from 1600 to 2000 GMT are then interpreted as an ordinary diurnal fall (a rise for humidity) —checked by the developing katabatic air stream (which was itself warmed adiabatically during the descent and deeper than the more stable surface air)—with the diurnal fall resumed after the screen became submerged. The periodic changes recorded between 1800 and 2000 GMT are then interpreted as mesoscale advective features associated with the veering of the wind from south-east to south as the katabatic wind developed. The temperature and humidity variations between 1800 and 2000 GMT are thus considered to be due to different physical mechanisms to those recorded later in the night.

The check in the fall of pressure at about 1930 barogram time (probably about 2000 clock time) might be evidence in support of the hydraulic-jump concept.

After 2000 GMT, when the top of the stable layer was above the anemometer head at Brüggen, passage of buoyancy waves along the interface and within the stable layer showed up as vector variations in the wind recorded by the anemometer (especially as wind direction variations) as the height of the interface and its associated shears of wind oscillated relative to and above the anemometer head. The periods of these oscillations, as recorded on the anemograph, started at about 12 minutes over the first two cycles, increased to about 21 minutes over the next four cycles and there is evidence that quasi-periodic changes continued throughout the night—many of them with periods of about 15 minutes. The periods of the oscillations on the thermogram and hygrogram which also continued throughout the night were much longer, ranging from about 1 to $1\frac{1}{2}$ hours—the longer periods occurring in the latter part of the night. Since the screen is much closer to the ground than the anemometer head it is likely to be affected by only some of the oscillations of the height of the interface which affected the anemometer.

The vector wind changes recorded at the surface in the first few cycles after 2000 GMT are of the order of 3 m s^{-1}. It is a matter of speculation what shear this represents in the vertical. If the associated potential temperature change (which is likely to be larger than any associated temperature change at the screen level) is 2 K equation (2) implies that the lower limit for Δz is 30 m; if $\Delta\theta$ is 5 K then the lower limit for Δz is 13 m.

If this explanation is broadly correct it is to be expected that when oscillations of wind and temperature are due to the passage of the same wave they will be related in phase such that veered winds are associated with temperature maxima and with relative humidity minima. The evidence in this respect is inconclusive; there appears to be both support and contradiction, but as already stated it proved impracticable to relate the time on the thermogram and hygrogram with sufficient precision relative to the phases of the anemogram pulsations.

Evidence in support of the contention that a wind enhanced by katabatic effects continued to blow over Brüggen after it had ceased at anemometer level is provided by the anemograms already mentioned for Wildenrath, Nörvenich and Aachen which continued to record katabatic winds long after the katabatic wind had apparently ceased at Brüggen. Presumably it took longer for the interface to grow above anemometer heights at these stations. It is conceivable that the katabatic wind above Brüggen decreased considerably after 2000 GMT and that the buoyancy waves travelling over Brüggen were generated by the interaction of katabatic winds elsewhere nearer the hills and a pre-existing stable layer as suggested by Christie *et al.* (1978) for their microbarograph waves of elevation. However, whatever the source of the buoyancy waves and whether or not the wind in the free air above Brüggen continued to be enhanced by katabatic effects the Brüggen anemograph indicates that substantial wind shear in the vertical continued to exist above anemometer height throughout the night.

6. Conclusions

The outstanding example of a katabatic wind recorded at Brüggen on 27 February 1975 was stronger than usual and apparently decayed at about 2000 GMT. Subsequent fluctuations of wind, particularly in direction, were recorded through the night, mainly with periods of the order of 15 minutes. Fluctuations of temperature and relative humidity, in antiphase, in the screen were recorded from about 1800 GMT through the night with periods mainly of the order of one hour.

The recorded changes are consistent with (a) the development of a layer of katabatic wind, (b) the development of a more stagnant stable ground-based layer, whose interface with a windier layer grew upwards starting above lower ground to pass suddenly above both the thermometer screen (2 m above ground level) and above the anemometer head (10 m above ground level) at about 2000 GMT, (c) the passage of trapped buoyancy waves along this interface and within the stable layer, and (d) the existence of strong shear of wind with height above Brüggen long after 2000 GMT. This suggests that an organized low-level wind shear, perhaps hazardous to aircraft, could be encountered at the bottom as well as at the top of a katabatic air stream at night—even after the local anemometer had ceased to record the katabatic flow.

Acknowledgements

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A comparative study of classifications of monthly mean sea surface temperature anomalies in the North Atlantic Ocean

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Summary

On the basis of mean monthly sea surface temperature data received in 1977 from the Meteorological Office at Bracknell, a classification of anomalies has been made for the North Atlantic Ocean. This is compared with the classification made by Ratcliffe (1971). In a good number of cases there is general agreement between the results of the classifications, but in many cases there are important differences.

Introduction

Nowadays it is generally assumed that ocean surface temperature anomalies on a large scale form one of the most important factors which might cause long-term weather anomalies. For this reason—in the search for methods to improve long-term weather forecasts—there was at the Royal Netherlands Meteorological Institute a few years ago a need of a climatology of North Atlantic sea surface temperatures (SST). In a preliminary study monthly SST anomalies have been calculated for each 1° × 1° square of this ocean for the period from January 1949 to December 1972. This was done using a magnetic tape, received from the Meteorological Office at Bracknell, containing mean monthly SST data for this period as well as monthly normals derived from U.S. Naval Oceanographic Office (1967). These data have also been used by Ratcliffe (1971). The number of observations is very variable both in space and in time. There are too many gaps to give a representative picture of the whole ocean for a certain month. The best coverage was found for about the same area as that used by Ratcliffe for his classification of SST anomalies (Fig. 1).

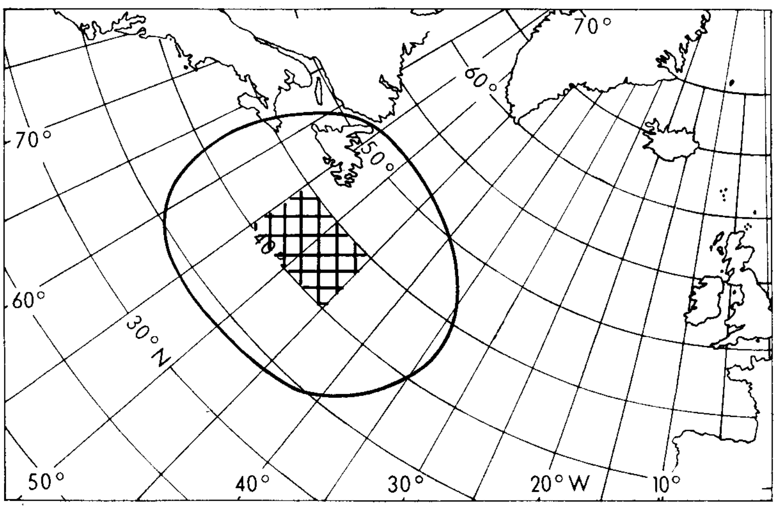


Figure 1. Area of ocean warmer or colder than usual for main classificaton types WP5 (warm case) and CP5 (cold case). Displacements east and west of the main anomaly centres by up to 10° are defined as WPE or WPW for the warm cases and CPE or CPW for the cold cases.

Because of the poor data coverage the original plan to make a classification for the whole North Atlantic Ocean was abandoned. Instead of this only the easy exercise of classifying the available material was performed, using the criteria and types described by Ratcliffe (1971).

The classification

In Tables I, II and III the present classification is compared with the Ratcliffe classification. The details of the classification are repeated here briefly.

The main classification concerns the sign of the anomaly of sea surface temperature in the area between 35°–50°N and 40°–60°W, particular importance being given to the sign of the anomaly from 40°–45°N and 45°–55°W (see cross-hatching in Fig. 1). If there is a well-defined warm or cold pool—anomaly exceeding 1 °C—covering much of this area the classification is WP5 for a warm pool centred near 50°W, WPE for a warm pool displaced up to 10° eastwards (i.e. centred between 40° and 50°W), WPW for a warm pool displaced up to 10° westwards (i.e. centred between 50° and 60°W) and there are three similar categories for cold pools, i.e. CP5, CPE and CPW. In the E and W cases particularly, the warm and cold pools may extend beyond the eastern or western boundaries respectively of the area as defined.

In addition to the six main types other classifications are possible. These are:

(a) *EZ or enhanced zonality.* In this class the ocean is colder than usual in the north-west Atlantic and warmer than usual in the southern and eastern part of the North Atlantic (Fig. 2).

(b) *DZ or decreased zonality.* In this class the ocean is warmer than usual in the north-west Atlantic and colder than usual in the southern and eastern part of the North Atlantic.

(c) *MWW or meridional warm west.* In this case the ocean is warmer than usual in the west (west of about 30°W) and colder than usual east of 30°W.

(d) *MCW or meridional cold west.* In this class the ocean is colder than usual in the west (west of about 30°W) and warmer than usual east of 30°W.

The comparison

It would take too much space to give the whole comparison for each individual month, so the following has been done. For both warm and cold pools there are three possibilities: WPW, WP5 and WPE for warm pools, and CPW, CP5 and CPE for cold pools. Combinations of these types can occur. In order to make an objective comparison between both classifications the classes have been extended in the following way:

WWW — WPW, WP5 and WPE.
WW . — WPW and WP5; no anomaly in the eastern part of the considered area.
W . . — WPW only.
W . C — WPW and CPE.
. . . — No anomaly, no type.
. W . — WP5 only.
etc.

This comparison can be found in Table I. In the 288 possible cases there was exact agreement 75 times (26·1 %); in 105 cases (36·5 %) there was a difference in one of the three positions; in 88 cases (30·5 %) there was a difference in two positions; while in 20 cases (6·9 %) all three positions were different.

Of the 89 months which were not classified in the sense of WP or CP in the original classification 59 could be classified with the help of the new data, while of the 62 months which could not be classified with the new data, 32 were classified in the original classification.

Table I. *Comparison of the present classification with the original classification by Ratcliffe over the period* 1949–72. *The numbers represent numbers of months*

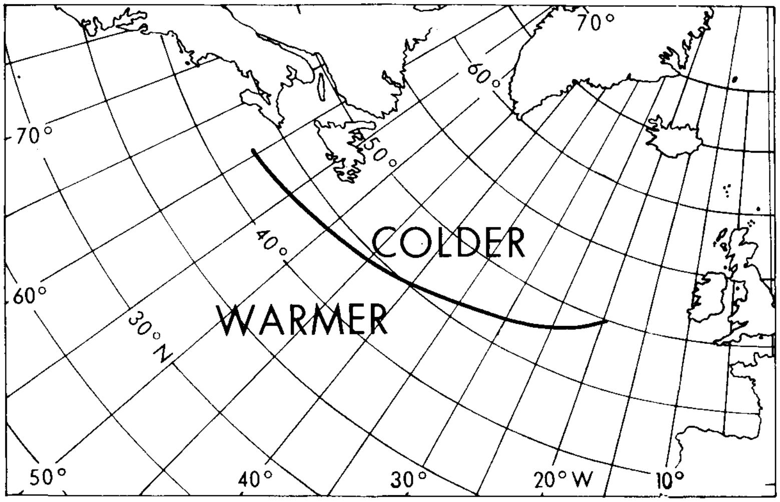
	Present classification																								
Ratcliffe	WWW	WW.	W..	W.W	.W.	.WW	..W	WWC	W.C	.WC	WC.	CCC	CC.	C..	C.C	.C.	.CC	..C	C.W	CWC	CW.	CWW	.CW	...	Total
WWW	1	—	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	2
WW.	5	—	2	5	—	—	—	—	2	—	—	—	—	—	—	—	—	1	—	—	—	—	—	3	18
W..	2	1	8	3	—	2	3	1	1	—	—	—	—	1	—	—	—	2	1	—	—	—	—	4	29
W.W	—	—	—	—	—	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1
.W.	7	—	4	1	3	1	1	—	1	1	—	1	1	2	—	—	1	6	—	—	—	1	—	9	40
.WW	4	1	—	—	—	1	3	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	5	14
..W	2	—	—	—	—	—	6	—	—	—	—	—	—	—	—	—	—	—	2	—	—	—	—	1	11
W.C	—	—	—	—	—	—	1	—	1	—	—	—	—	—	—	—	1	—	—	—	—	—	—	—	3
.WC	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	—	—	—	—	—	—	1
WC.	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	—	—	—	—	—	—	—	1
CCC	—	—	—	—	—	—	—	—	—	—	—	1	—	—	—	—	—	—	—	—	—	—	—	1	2
CC.	—	—	—	—	—	—	—	—	—	—	—	2	2	4	—	—	1	1	—	—	—	—	—	—	10
C..	—	—	—	—	—	—	—	—	—	—	—	1	—	5	1	1	—	1	3	—	—	1	—	1	14
.C.	—	—	—	—	—	—	—	—	—	—	—	2	—	1	—	1	1	3	—	—	—	—	1	2	11
.CC	—	—	—	—	—	—	—	—	—	—	—	2	—	—	—	1	—	—	—	—	—	—	—	—	3
..C	—	—	—	—	—	—	—	—	—	—	—	8	—	—	1	—	2	16	—	—	—	—	—	4	31
C.W	1	—	—	—	—	—	1	—	—	—	—	—	—	2	—	—	—	—	—	—	—	—	—	—	4
CWC	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	—	—	—	—	—	—	—	—	—	1
CW.	—	—	—	—	—	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	2	3
...	2	—	1	4	3	1	11	—	4	—	—	8	—	8	—	2	1	10	3	1	—	—	—	30	89
Total	24	2	15	14	6	5	28	1	9	1	—	25	3	23	3	5	8	41		1	—	2	1	62	288

Table II. *Comparison of both classifications with a reduced number of classes*

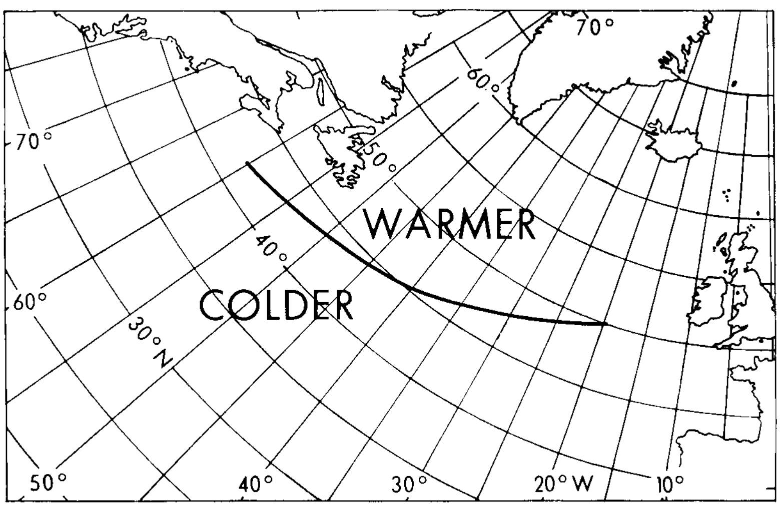
	Present classification				
Ratcliffe	WP	MC	CP	NC	Total
WP	68	10	15	22	115
MC	4	1	6	2	13
CP	—	5	58	8	71
NC	22	8	29	30	89
Total	94	24	108	62	288

Table III. *Comparison for the types DZ and EZ*

	Present classification			
Ratcliffe	EZ	DZ	NC	Total
EZ	26	1	12	39
DZ	1	17	34	52
NC	29	13	155	197
Total	56	31	201	288



(a) Enhanced zonality EZ.



(b) Decreased zonality DZ.

Figure 2. Area of ocean warmer or colder than usual for EZ and DZ classification.

'Not classified' means that there was no clear anomaly existing over a larger area (within 35°–50°N, 40°–60°W); it is not excluded that these cases can be classified as DZ or EZ.

For some months several classifications are possible. Of the 32 times that DZ occurred in the period 1949–72 it was accompanied in 16 cases by CP and in 3 cases by WP. Of the 56 times that EZ occurred in this period it was accompanied in 15 cases by CP and in 18 cases by WP. This confirms Ratcliffe's conclusion that DZ often occurs together with CP and less often with WP. However, his conclusions that EZ occurs more often together with WP than with CP is not confirmed.

Some researchers (Ratcliffe and Murray 1970, Oerlemans 1975) use a rougher classification by taking WWW, WW ., W . ., W.W, .W., . .W and .WW together to form one class WP (Warm Pool) and by taking CCC, CC., C.., C.C, .C., .CC and ..C together to form one class CP (Cold Pool). This has also been done in Table II. In class MC (Mixed Classification) those cases are taken together in which, for example, in the western part of the area considered there is a positive anomaly and in the eastern part a negative anomaly or the other way round. NC means Not Classified.

Of the 115 cases in which the Ratcliffe classification was WP there is agreement in only 68 cases. For CP the agreement is better, namely in 58 of the 71 cases. Finally, in Table III a comparison is given for the types EZ and DZ. Here, too, the agreement is not very good.

Persistence

The mean duration of the cold patterns was found to be 3·3 months and that of the warm patterns was 2·8 months. According to the Ratcliffe classification these numbers are respectively 1·7 and 2·9 months for the period 1949–72. So we also find a substantial difference here.

Conclusion

An attempt has been made to reproduce the Ratcliffe classification for the period 1949–72 using a tape with mean monthly SST data received from the Meteorological Office and using his criteria (objectively applied). Nevertheless, there are many differences in the results. This does indicate at least some ambiguity and one must be very careful in correlating certain atmospheric phenomena with certain categorized sea surface temperature anomaly patterns.

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551.574.41 (423)

Unusual road surface condensation

By B. A. Davey

(Meteorological Office, Royal Air Force Lyneham)

Summary

During the afternoon of 10 December 1980 the formation of a large quantity of moisture on road surfaces was witnessed at Lyneham. This note sets out to explain this phenomenon.

Introduction

By 1600 GMT on 10 December 1980 the duty observer at Lyneham had become concerned because the concrete and tarmac road surfaces in the vicinity of the observing office had become wet, although no precipitation had been observed. A thorough inspection of rain-gauges and all exposed metal and glass objects was made, but no evidence of precipitation could be found, nor could condensation be found elsewhere. The grass was also found to be dry.

By late evening so much moisture had formed that it began to collect in small pools, as though there had been a recent moderate shower.

Reports of what seemed to be the same phenomenon having occurred were received from towns and villages near Lyneham, namely: Wootton Bassett at 1500 GMT, Purton at 1900 GMT and Devizes at 1800 GMT (see Fig. 1). (The author had noticed moisture forming as early as 1415 GMT in the vicinity of Lyneham.)

Weather

On the day in question the south of England was under the influence of a cloudy south-westerly airstream (see Fig. 2). The wind between 1200 and 2200 GMT was a steady 210°, 7 m s^{-1}, with gusts to 13 m s^{-1}. Very small amounts of precipitation were recorded around the periphery of the area under discussion, but the Upavon rainfall radar confirmed that it was unlikely that any precipitation occurred in the vicinity of Lyneham. (The last recorded precipitation was on 5 December 1980.)

Although the airstream could be classified as tropical maritime it was not exceptionally moist, the humidity rising slowly throughout the day from a minimum of 76% at 0800 GMT to a maximum of 91% at 2100 GMT.

During the previous fortnight air temperatures at Lyneham had been well below average and ground frosts occurred on every night but one. The absolute minimum temperatures for this period occurred during the morning of 8 December when the air temperature fell to −5 °C and the concrete minimum (as measured by the standard alcohol-in-glass thermometer) fell to −7·5 °C. Subsequently the temperatures rose slowly as the mild south-westerly airstream became established.

Discussion

In addition to routine hourly observations of air temperatures at Lyneham an hourly record is also maintained of temperatures on and slightly below the surface of a 91 × 91 × 10 cm concrete slab. The concrete temperatures are measured by electrical resistance thermometers exposed both on, and 5 mm below, the surface of the concrete slab.

A study of graphs constructed from all the observations (see Fig. 3) reveals some interesting fluctuations in all the temperatures.

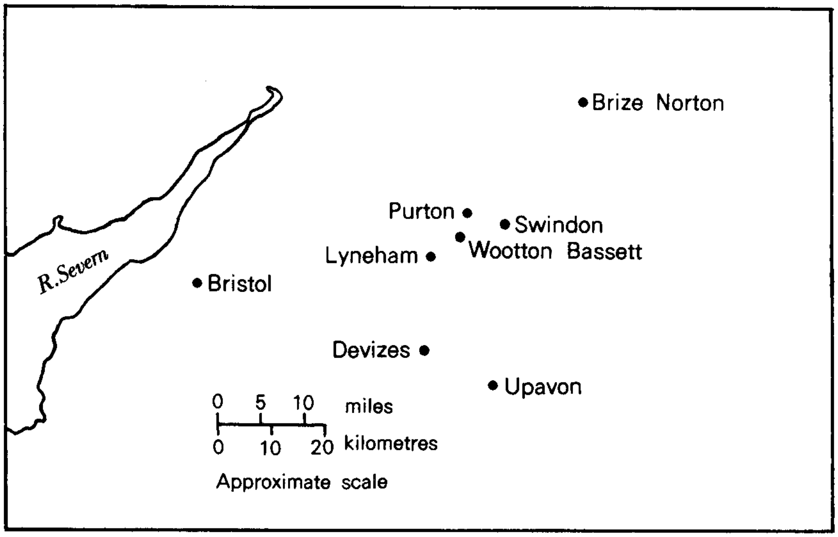

Figure 1. Showing Lyneham and surrounding area.

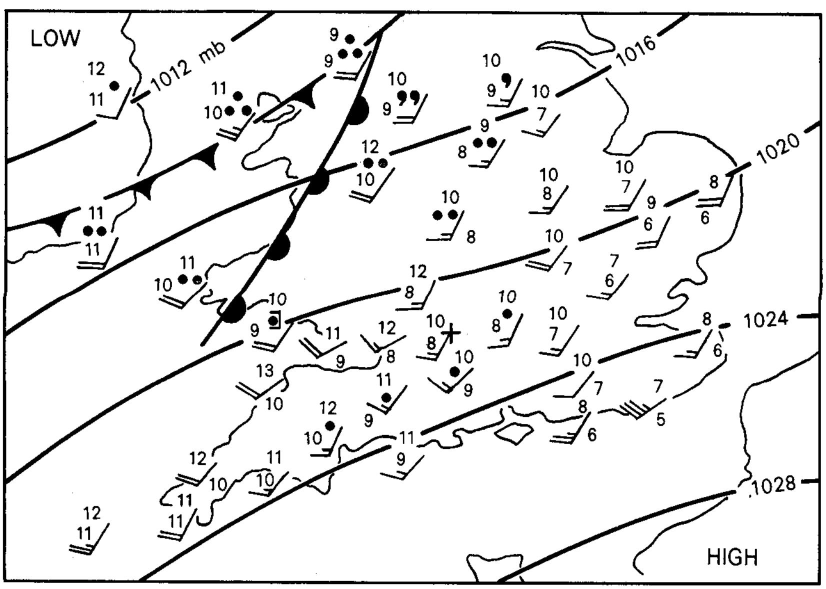

Figure 2. Synoptic situation at 1500 GMT on 10 December 1980. (Cross indicates Lyneham.)

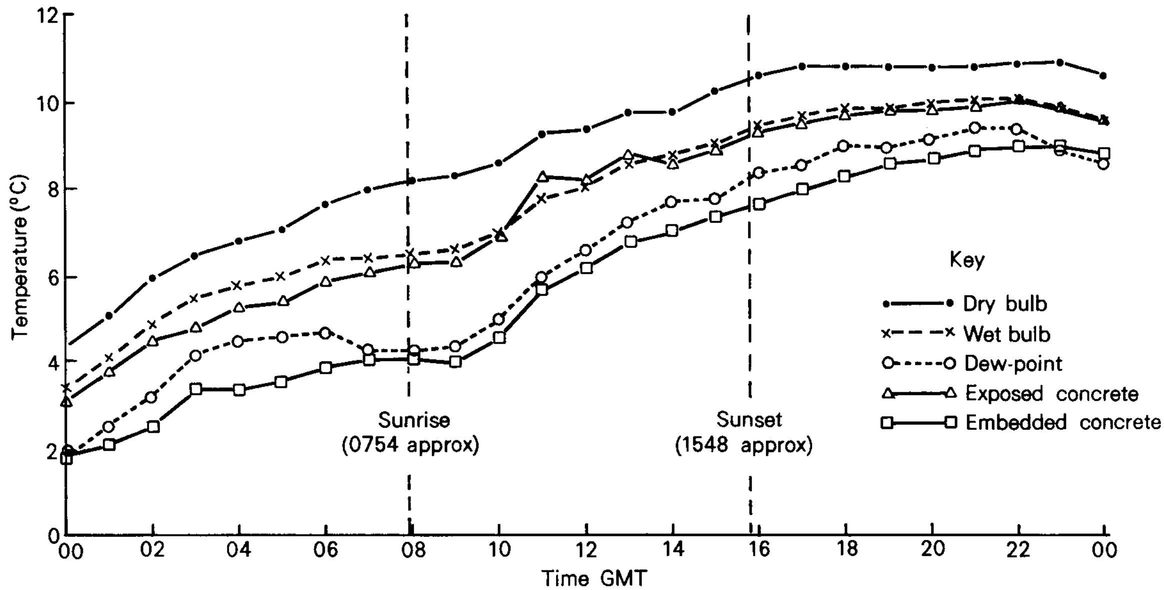

Figure 3. Hourly readings of the various temperatures at Lyneham on 10 December 1980.

As would be expected from the changing synoptic situation both the dry- and wet-bulb screen temperatures show a steady increase throughout the day, although a reduction in the rate of increase of the wet-bulb temperature between 0600 and 0900 GMT indicates the passage of a patch of relatively drier air. Moister air returned soon afterwards.

From 0600 GMT the graphs of temperatures recorded by the two concrete thermometers closely follow the shape of the wet-bulb temperature curve. The relatively large increase in temperature registered by the exposed concrete thermometer between 1000 and 1100 GMT can be attributed to low cloud cover temporarily dispersing and allowing a small amount of heating to reach the surface despite an almost total cover of medium-level cloud.

The subsequent fall of temperature on the concrete surface between 1300 and 1400 GMT coincides with the author first noticing a dampness on the road surface and is believed to have been the result of moisture forming on the electrical resistance thermometer and causing it to act as a wet-bulb thermometer, particularly as it was exposed to wind.

At the same time the temperature difference, ΔT_c, between the dew-point of the air and the temperature 5 mm below the concrete surface increased from a consistent 0·3–0·4 °C to 0·6–0·7 °C. This increase in ΔT_c seems to have come about solely through a reduction in the rate of increase of the temperature of the concrete slab. No explanation can be offered as to why this should have occurred but there is little doubt that the effect was not an isolated one. It is important to note that the true temperature of the skin of the concrete in contact with the air is given neither by the exposed thermometer lying on the surface (it responds partly at least to air temperature) nor by that embedded at 5 mm. With the flux of heat being downward in this case the true skin temperature would be a little above that at a depth of 5 mm, but it must have been below the dew-point temperature of the air during the period of condensation.

The apparent lack of condensation earlier in the day, between 0300 and 0600 GMT when ΔT_c exceeded 1 °C, is difficult to explain but the answer may be related to the humidity of the air. At this time the relative humidity, measured at screen level, did not exceed 85% (see Table I) and it is suggested that had any condensation occurred it would have quickly evaporated. After 1300 GMT the relative humidity increased to 85–88% and, although only slightly greater than the earlier measurements, it was sufficient to restrict any evaporation.

Table I. *Hourly humidities at Lyneham for* 10 *December* 1980

Time GMT	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Relative humidity (%)	83	84	83	84	85	84	81	77	76	76	78	80	83	84	87	85	86	86	88	88	90	91	90	87	88

Conclusion

It has long been appreciated that the advection of mild moist air over a cold surface results in condensation. What makes this event so noteworthy is the large amount of moisture deposited even though concrete and tarmac road surface temperatures could only have been very slightly below the dew-point temperature of the air.

In view of the large amount of condensation it is interesting to speculate whether or not this mechanism can contribute to increased streamflow in much the same way that fog drip does (Gardiner 1977, Gurnell 1976).

Some practical forecasting rules related to conditions leading to icy roads have suggested that condensation occurs when there is a 'sudden' change from cold to milder weather. The event described here occurred long after the onset of the milder weather.

Acknowledgements

I should like to thank Mr B. J. Booth, Senior Meteorological Officer, Lyneham for his help and encouragement in formulating this article, and Mr R. P. Gosnell, the observer on the afternoon and evening of 10 December 1980.

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Gurnell, Angela M. 1976 A note on the contribution of fog drip to streamflow. *Weather*, **31**, 121–126.

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Letter to the Editor

Origins of the Meteorological Office

The recent article by Mr R. P. W. Lewis on the beginnings of the Meteorological Office[1] contained much that was of interest, and it seems worth while to extend the story backwards for a few more years.

Although the origins of the Office undoubtedly followed directly from the 1853 Brussels conference convened by Lieutenant Maury, U.S.N., the conference itself arose out of a British initiative taken by Major-General Sir John Burgoyne, R.E., the Master-General of Fortifications. In 1851 Burgoyne had been responsible for the origination of a scheme for making meteorological observations at foreign and colonial stations of the Royal Engineers[2] and, with the intention of extending this network still further, he sought assistance from the American government.[3] The proposals were referred to Maury (then head of the US National Observatory in Washington), who welcomed the idea in principle but suggested that the scope be broadened to include other nations, proposing in turn that an international conference be called to consider the possibilities of co-operation between the leading maritime powers. Burgoyne demurred, thinking that an international conference would present too many difficulties and that the United Kingdom and the United States of America as 'the greatest maritime powers' should proceed alone since 'they would intercommunicate in the same language and, it is believed, have the same weights and measures'. In the face of Burgoyne's reaction, Maury now pursued the idea of an international conference on his own, his efforts eventually resulting in the 1853 meeting in Brussels referred to above. Ten nations attended, Britain being represented by Captain F. W. Beechey, R.N., head of the Marine Department of the Board of Trade, and Captain Henry James, R.E., the officer in direct charge of the scheme of meteorological observations organized at Burgoyne's direction.[4]

It is interesting to note that Lord Wrottesley, who figured prominently in the subsequent moves towards the actual founding of the Office,[5] was himself a close associate of Burgoyne, and that his third son, the Hon. George Wrottesley, an officer in the Royal Engineers, married Burgoyne's daughter in 1854 and became his A.D.C. a year later.[6] This close personal relationship was again in evidence when Burgoyne was recalled to Britain during the war in the Crimea, following an almighty row with the French. Wrottesley objected to the manner in which the recall was announced in Parliament as possibly casting a slur upon Burgoyne's reputation and he induced Lord Lansdowne, the Government leader in the Lords, to deliver a 'very eloquent eulogium'[7] on Burgoyne in the House.[8] Captain James eventually rose to become head of the Ordnance Survey, an interesting sideline being that James Glaisher,[9] then in his early twenties, had worked with him earlier on the survey of Ireland during 1829–30.[10]

To go back just one step further, Burgoyne's work for meteorology appears to have been prompted by William Reid, another Royal Engineers officer, who had served under Burgoyne during Wellington's Peninsular Campaign and also at New Orleans.[11] Reid became interested in the circulatory theory of storms when confronted with hurricane damage in the West Indies during the early 1830s and he worked on the problem of storms[12] in close collaboration with the American, W. C. Redfield.[13] The study of what we would now call synoptic meteorology was attempting to take its first systematic, if faltering, steps at this time, another pioneer in the field being Captain Francis Beaufort, R.N., the Hydrographer of the Navy, who attempted to set up a system of marine observations in the 1830s, but failed owing to lack of funds.[14]

Finally, the choice of FitzRoy as head of the new department probably followed from initiatives taken during his term as Tory M.P. for Durham in the 1840s. FitzRoy's persistence in seeking to promote legislation on the subject of safety at sea resulted in the setting up of a Parliamentary Select Committee to study the subject in 1843.[15] FitzRoy was both appointed to the Committee as a member and called as first witness.[16] The final report of the Committee included proposals for a number of important reforms, but it also generated considerable opposition from shipowning interests faced with the prospect of expense in raising safety standards on their ships.[17] Unfortunately, at this stage FitzRoy was appointed Governor of New Zealand and the proposals lapsed,[18] although many of them were later included in the Merchant Shipping Act of 1854.[19]

The evidence that was given to the Committee by FitzRoy was to take on a quite different significance several years later when, in 1861, he was to go well outside his original brief as head of the Meteorological Department and set up the world's first comprehensive storm warning and weather forecast[20] service for shipping, using the recently developed facility of the electric telegraph. The repercussions for FitzRoy himself were tragic, but the traditions of service to the community by the meteorologists had been well and truly laid.

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Notes and references

1. Lewis, R. P. W.; The founding of the Meteorological Office, 1854–55. *Meteorol Mag*, **110**, 1981, 221–227.
2. Details of the organization are contained in: James, Captain Henry, R.E., F.R.S.; Instructions for taking meteorological observations at the principal foreign stations of the Royal Engineers. London, John Weale, 1851.
3. The whole of the correspondence dealing with Burgoyne's original proposal and the reasons behind Maury's subsequent actions is contained in: *P.P.* (*Parliamentary Papers*), 1852–3, LX, 443.
4. Abstract of copy of Report of Conference held at Brussels respecting meteorological observations. *P.P.*, 1854, XLII, 443.
5. Op. cit., note 1.
6. Wrottesley, Hon. George; A history of the family of Wrottesley of Wrottesley Co. Stafford. Exeter, William Pollard, 1903, pp. 382–383.
7. Ibid., pp. 379–380.
8. *Hansard*, 3rd series, 136, 1737–1738.
9. James Glaisher, F.R.S., was the secretary and inspiration of the British (later Royal) Meteorological Society from the time of its formation in 1850 until 1873 (apart from the years 1867–68, when he was President). A brief account of his career is given in: Hunt, J. L.; James Glaisher, F.R.S. (1809–1903). *Weather*, **33**, 1978, 242–249.
10. Hollis, Henry Park; Dictionary of national biography, supplement 1901–11 (entry on James Glaisher). Oxford University Press (reprinted 1966).
11. There are many references to Reid in: Wrottesley, Hon. George; Life and correspondence of Field Marshal Sir John Burgoyne, Bart (2 vols). London, Richard Bentley, 1873.
12. His principal work on the subject was: Reid, Lt.-Col. W., C.B.; An attempt to develop the Law of Storms. London, John Weale, 1838.
13. Redfield was amongst the first to propose a circulatory theory of storms, publishing an article on the subject in the *American Journal of Science and Art*, **20**, 1831. There are apparently three folio volumes of the correspondence between Reid and Redfield held in the library at Yale University.
14. Beaufort does not appear to have left a record of these activities, but they are mentioned in a number of sources, for example: Prouty, Roger; The transformation of the Board of Trade 1830–1855. London, William Heinemann, 1957, p. 52.
15. Parliamentary Select Committee on Shipwrecks. The first report of the Committee was ordered by the House of Commons to be printed on 10 August 1843.
16. Minutes of the proceedings are given in: *P.P.*, 1843, IX. The record of FitzRoy's evidence notes his opinion *inter alia* that '. . . neglect of the use of the barometer has led to the loss of many ships: from a want of attention to the barometer they have either closed the land (if at sea), or have put to sea . . . at improper times and in consequence of such want of precaution the ships have been lost, owing to bad weather coming on suddenly . . . While alluding to the use of the barometer, I may remark, that if barometers were put . . . at the principal stations round the coast . . . they might be the means not only of preventing ships going to sea just before bad weather was coming on, but of preventing the great losses of life which take place every year on our coasts . . .'

17. The story of the hesitating progress towards reform of the Merchant Shipping regulations during the second quarter of the nineteenth century is recorded in: Op. cit., note 14, pp. 34–51.
18. FitzRoy's stay in New Zealand was brief, turbulent and unhappy. In contrast to his fundamentalist views on religion, his attitude towards race relations was, in practice, very advanced for his day, although based on the belief that all men are of one blood, having originated in the biblical lands and spread across the world. In consequence, FitzRoy was not disposed automatically to support the settlers against the native Maoris. There is also little doubt that the aristocratic FitzRoy adopted an arrogant attitude in dealing with the relatively rough-hewn colonists.
19. Merchant Shipping Act, 1854, *P.P.*, 1854, IV.
20. FitzRoy issued his first storm warnings on 6 February 1861. The first organized system of forecasts and storm warnings was instituted by Christoph Buys Ballot in Holland during May 1860, but the organization was on a smaller scale than the slightly later British system.

Notes and news

25 years ago

The following extract is taken from the *Meteorological Magazine*, January 1957, **86**, 25.

Royal Society International Geophysical Year Expedition to Antarctica

Since early January 1956 the advance party of the British International Geophysical Year Expedition has been established at a site a mile and a half inland on the ice shelf in Coats Land on the eastern side of the Weddell Sea. The base is known as the Royal Society Base, Halley Bay. The revised co-ordinates are 75° 31′S, 26° 36′W. The main party of the International Geophysical Year Expedition and that of the Trans-Antarctic Expedition sailed from London on November 15, 1956 in the M.S. *Magga Dan* (2,000 tons). The Trans-Antarctic Expedition base is at Shackleton, 77° 57′S, 37° 16′W, about 250 miles south-westward of Halley Bay.

The Expedition's main party of 20 under the leadership of Col. R. A. Smart, R.A.M.C., includes 11 scientific members who will be responsible for the observational programme of the aurora, geomagnetism, glaciology, the ionosphere, meteorology, radio-astronomy and seismology until the end of 1958. The component for work in meteorology, geomagnetism, glaciology and seismology consists of the following members of the Meteorological Office, Messrs. J. MacDowall, A. Blackie, J. M. C. Burton, D. T. Tribble and D. G. Ward; all of whom, along with several other of their Office colleagues, volunteered for this enterprise more than a year ago. They will be joined, for 1957, by another colleague, Mr P. H. Jeffries, who has been with the Trans-Antarctic Expedition advance party at Shackleton throughout 1956. Having accomplished their indispensable mission during 1956 of establishing the base at Halley Bay, instituting preliminary scientific observations and carrying out other essential pioneer work, the advance party, which includes Mr D. W. S. Limbert of the Meteorological Office, will return to the United Kingdom early in 1957.

An immediate preoccupation of the new arrivals at Halley Bay will be to erect, on the ice shelf, the instrument and observation huts (including those for the geomagnetic instruments and for filling radiosonde balloons) and additional aerial arrays, and to install equipment with minimum delay so that everything shall be fully operational well before the beginning of the International Geophysical Year, July 1, 1957.

Our best wishes for complete success go to the whole party at Halley Bay, and to the several other similar parties in the far South, in their endeavours to achieve significant contributions to the general International Geophysical Year programme for Antarctica.

50 years ago

The following extract is taken from the *Meteorological Magazine*, January 1932, **66**, 287–288.

Fog, Friday, December 18th

The following may be of some interest. Morning, thick fog and hoar frost. Fair and sunny midday. Wind light—NE. Afternoon and evening, blinding fog, which made the eyes run with water, and smelling strongly of soot. My brother and I, after pedal-cycling through fog during the evening, returned home with complexions and clothes the colour of nigger minstrels. Traffic was chaotic. Next morning trees, vegetation, telegraph wires and clothes lines were an inch thick with dirty black frost. Cabbages, &c., were filthy and had to receive many ablutions.

The evening fog drifted from north-west and visibility was at times less than three feet.

F. CLAUDE BANKS

Market Gardens, Horndon-on-the-Hill, Essex. *December* 28*th*, 1931.

*** Although such unpleasant occasions of thick smoke-laden fog continued to occur until the 1950s—the case of 5–8 December 1952 was notorious—the passing of the Clean Air Act in 1956 has by now made them things of the past.

Reviews

Red sky at night shepherd's delight? Weather lore of the English countryside, by Paul J. Marriott. 155 mm × 245 mm, pp. viii + 376, *illus.* Sheba Books, Oxford, 1981. Price £9.90.

This is a book of collected weather lore with a difference. Mr Marriott, as a professional meteorologist, has not only collected nearly 1900 adages classified by reference to months of the year, movable feasts, birds, animals, reptiles and insects, wild flowers and plants, and a host of other topics, but has subjected nearly all of them to careful observation and testing and published his results. Each adage is given a star rating—one to six—and many have attached the results of a two-year trial in the form (number of times total) and percentage. The book is charmingly illustrated with Victorian and earlier sketches of birds, trees and flower motifs. A good bibliography is given and a list of the data sources used for some of the assessments and ratings. Adages are included for their oddity and quaintness as much as for any conceivable value; for example, 'A dead kingfisher hung up by the legs even inside a house is said to turn its beak to windward'—a foolish but interesting saying, as the author remarks. The more sensible and useful sayings are explained by reference to scientific meteorology where possible.

The text would have benefited from more careful checking and editing which might have removed many examples of spelling mistakes and clumsy and ungrammatical English. Occasionally the reader is baffled. Commenting on 'If rats are more restless than usual, rain is at hand', the author says, 'Although rats are experts of conditioning, the "more restless" habit is really old hat'; I do not know what this means.

The 'thunder planet' (page 215), a term which puzzles the author, presumably means Jupiter, the Roman god of storms and thunder corresponding to Thor and Zeus.

R. P. W. Lewis

Earth, space and time: an introduction to earth science, by John Gabriel Navarra. 185 mm × 235 mm, pp. viii + 438, *illus.* John Wiley & Sons, New York, Chichester, Brisbane, Toronto, 1980. Price £12.65.

This book is yet another in the rapidly increasing number on all aspects of earth science, including sections on geology and continental drift, oceanography, the biosphere, the atmosphere, and the evolution of the universe and solar system. The meteorologist naturally turns to the section on the atmosphere, composed of three chapters entitled respectively 'The atmospheric envelope', 'Circulation within the atmosphere', and 'Weather analysis and forecasting'; he will rapidly conclude that if the author's knowledge of the other topics dealt with in the book is as deficient as it is of meteorology it is a bad book indeed. Howlers abound, for example:

'. . . English farmers . . . have seen their growing season decline by two weeks since 1950. The shortened growing season in England has meant an overall loss in grain production of possibly 100,000 tons per year.' (page 263).

'Examination of the troposphere reveals that temperatures decrease at a rate of 3·5°F for every 1000 feet of height (6·4°C per kilometer). This phenomenon is known as the **normal adiabatic lapse rate.** It is the average normal decrease in the temperature of air with height in the troposphere.' (Page 271).

Mr Navarra is weak on Latin too: 'The solar radiation that reaches the Earth and is involved in heating its surface and atmosphere is often referred to as **insolation.** The term is an abbreviation for incoming solar radiation.' (Page 280).

In discussing the general circulation of the atmosphere (pages 304–305), he contrasts ideas of large-scale convection and heat transfer with those of conservation of momentum as though they were in some way mutually exclusive and not complementary.

On page 308 is a map of Africa and Arabia showing 'Sahel Areas' over Arabia and 'The Sudan' over Niger.

The codes and symbols shown on pages 330–331 are in many respects long out of date internationally, and probably so even in local US contexts; cloud-cover in tenths and winds in Beaufort force are two examples.

There are, however, no howlers in the account given of computer-modelling and numerical analysis and prediction in the chapter on 'Weather analysis and forecasting'. The reason is simple: these topics are not mentioned. After all, it is only a quarter-century since such methods were first used operationally.

The book is of course beautifully produced by Wiley, with excellent photographs and diagrams that are always clear even if incorrect.

R. P. W. Lewis

Dr J. Glasspoole, I.S.O.

Dr John Glasspoole, who died on 11 October 1981, was the last surviving member of the old British Rainfall Organization which had been founded by J. A. Symons, F.R.S., in the last century and was taken over by the Meteorological Office in 1919. (The *Meteorological Magazine* is of course the official continuation of *Symons's Monthly Meteorological Magazine*, the organ of the Organization.) Dr Glasspoole joined the British Rainfall Organization in 1916 when it was a small independent body under the control of Dr Hugh Robert Mill and Mr Carle Salter. For several years the Organization remained as a separate unit of the Office, but was then absorbed by the general British Climatology Division; Dr Glasspoole's responsibilities became correspondingly diversified though his chief concern continued to be the study of rainfall. During his career—he retired as a Principal Scientific Officer on 31 December 1957—he was regarded as the outstanding British expert on rainfall and meteorological hydrology. His interest in rainfall continued until the end of his life, and during the past year letters from him have appeared in the correspondence columns both of the *Meteorological Magazine* and of *Weather*.

Dr Glasspoole had been, in his younger days, a lawn tennis player of considerable ability; in later life he took up the game of bowls at which he also became an expert.

Obituary

We regret to record the death on 5 August 1981 of Mr D. S. Lillingstone, Assistant Scientific Officer, who was stationed at Coltishall. Mr Lillingstone joined the Office in 1964, and had spent almost all his career at Coltishall.

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NOTICES

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The accuracy of London Weather Centre forecasts of temperature for the gas industry

By R. M. Morris

(Meteorological Office, Bracknell)

Summary

Routine forecasts of temperature are prepared several times daily by forecasters at London Weather Centre for British Gas. Verification of the accuracy of these forecasts shows them to be, on average, better than persistence. Mean errors are generally less than 2 °C and there is a tendency to underforecast night minima in autumn and winter and to overforecast day maxima in spring and summer. The May–June period appears to be a particularly difficult season for forecasting beyond 24 hours ahead.

1. Introduction

British Gas has a contract with the Meteorological Office for the provision of weather forecasts several times daily for a number of places around the United Kingdom. The most important element in the forecast is temperature because gas demand by industrial and domestic consumers is most sensitive to variations in temperature. The format and times of issue of the forecasts (called MET GAS forecasts) are essentially the same at all the issuing meteorological offices and this paper evaluates the accuracy of the temperature forecasts prepared by London Weather Centre (LWC).

The temperature forecasts prepared by LWC are for LWC itself in two-hour steps for periods ranging from up to 24 to 36 hours ahead. The forecasts are updated every four hours as routine but amendments may be issued at shorter intervals if significant changes are envisaged as a result of fresh ideas or information. In general a change of at least 2 °C to a forecast temperature necessitates an amendment or special advisory message.

The regions which receive the LWC forecasts are Eastern Gas, North Thames Gas and Southeast Gas. The most important forecast is the 1530 h issue (day 1) which covers the period up to 0500 h (day 3), i.e. approximately a 36-hour forecast. This particular forecast is used to assess gas demand for the 24-hour period commencing 0600 h (day 2) and the regions have to place their orders for gas with British Gas (central London) by 1630 h on day 1. British Gas, in turn, then order their gas from the offshore companies before 1800 h on the same day. (The symbol h indicates clock time.)

Gas demand is split between domestic and industrial consumers with the balance varying from region to region. Domestic demand has two peaks, 0700–1000 h and 1700–2300 h, and British Gas estimates that a change of 1 °C during these times can affect demand by some 2–3%. Exactly how these estimates are quantified is not known because it is certain that wind, both speed and direction, sunshine and rain also have some effect on demand except where the gas supply is entirely thermostatically controlled.

Although Gas regions attach great value to the temperature forecasts they also give a significant weighting to persistence. This is partly because there is a tendency for demand by the consumer to lag behind changes in the weather. For this reason orders for gas always take into account yesterday's and today's temperatures as well as the forecast for tomorrow. Public holidays create other problems in anticipating demand and there can be a good deal of subjectivity in predicting the demand for gas more than a few hours ahead.

Under most circumstances the Gas Controllers are grateful for any information or advice that the forecaster can give; for example, temperatures may vary across the region and LWC may not be representative in certain situations. It is important that when there is doubt in the forecast this should be communicated to the Controllers who can take precautionary action.

Because of the importance of temperature forecasts to the gas industry and the need to quantify the usefulness of the forecasts, a verification procedure is carried out at London Weather Centre, chiefly on the 1530 h daily issue. Additional verification data have been acquired from North Thames Gas which usefully supplements the LWC studies. Three years' data are considered in this report—1978–80.

2. Forecasting the temperature

Methods of predicting surface temperature are well documented in the *Handbook of weather forecasting,* Chapter 14 (Meteorological Office 1975) and also in the *Forecasters' reference book* (Meteorological Office 1970). Essentially, the prediction process takes place in three stages. Firstly the low-level air mass changes must be correctly predicted, including the moisture content; secondly the amount of medium and upper cloud must be evaluated, including the presence of precipitation; and thirdly the surface wind field must be adequately forecast.

Outstation forecasters in the Meteorological Office receive a good deal of direct assistance from the output of the operational 10-level numerical model as well as the surface prognoses and the General Synoptic Reviews issued by the Central Forecasting Office at Bracknell. For most of the period of this study the direct assistance consisted of analyses and forecasts of airflow at several levels in the troposphere. The 1000–500 mb total thickness fields were used to assess air mass changes and characteristics.

Since August 1980 direct numerical support to outstations has been extended to include 850 mb wet-bulb potential temperature and 700 mb relative humidity fields. The former are used to identify air mass changes and, by making use of Belasco's work (1952) on air masses, it is possible to relate the 850 mb data to surface temperatures. The 700 mb data are used to assess the likelihood of cloud and precipitation. As LWC also receives computer forecasts of surface wind (Morris 1981) to assist with forecasting for the offshore industry, these wind fields may be used in temperature prediction.

The period during which the extra computer guidance has been available is too short to assess separately as part of this particular study but the effects on the accuracy of temperature forecasts will be an interesting study in two years' time.

3. Verification of temperature forecasts

(a) *1530 h issue*

The 1978–80 period was divided into two-month seasons, January–February, March–April etc., i.e. for each season there were six complete calendar months. For each of the (approximately) 180 forecast temperature sequences in each season four quantities were noted or calculated:

(1) forecast temperature at each step, i.e. 1700, 1900, 2100 h, etc.,

(2) actual temperature at each step,

(3) modulus error of the forecast at each step, and

(4) modulus error of a persistence forecast at each step.

The persistence forecast was based upon the last recorded temperature for the appropriate time, e.g. for 1700 h on day 1 the forecast would be actual temperature at 1700 h on day −1, etc.

Values for each time-step were meaned over the four-month period.

The only purpose in comparing (1) and (2) is to see if any systematic errors show up in temperature prediction for inner London.

Table I demonstrates the mean systematic bias in the forecasts throughout the 36-hour period for each of the six 'seasons'. Most of the bias is negative, i.e. underforecasting of the LWC temperature, peaking at almost 2 °C at the end of the forecast period in the winter. On the other hand there is a clear tendency to overforecast the maximum temperatures on day 2 during the early and high summer. However, inspection of the figures for the forecast period as a whole and also the more important sections of the period shows clearly that the most significant bias is negative between September and the following February. The underforecasting at night is presumably due to the heat island effect which prevents inner London from cooling as much as it would otherwise do but for the high density of large buildings. The overforecasting of maximum day temperatures during the summer is more puzzling but it may be due to greater mixing of air on the LWC roof than otherwise allowed for, particularly as winds rarely fall below 5 knots.

Table II contains mean modulus forecast errors for the odd-numbered hours of the period and also an indication of performance compared with persistence forecasts. Mean forecast errors are below 2 °C except at the end of the period in the two winter seasons. Over the period as a whole and in most of the important sections the improvement over persistence is at least ½ °C. It is gratifying to see the relatively large improvements for the period 1700–2300 h on day 2.

Table III depicts year-to-year trends in mean modulus errors for the whole forecast period and comparisons with persistence. The errors are remarkably consistent from year to year although there is some suggestion that 1979 was the most difficult year.

Summing up, there appear to be two broad patterns of forecast error. Between September and February the largest errors occur in the prediction of night minimum temperature in the early hours of day 3 and there is evidence of a significant systematic component to these errors. Between March and August the largest errors occur in the prediction of the day 2 maximum of temperature and there is some (though less than in the winter period) evidence of a systematic component here too.

Counteracting the systematic error. An exercise has been carried out on all of the 1530 h forecasts prepared in 1980. The forecasts for the periods 0700–1000 h and 1700–2300 h (day 2) were amended by an amount equal and opposite to the systematic error in Table I. The effect upon the accuracy of the forecasts is shown in Table IV. There are some improvements in most seasons although amounts are not generally large.

(b) *'Average' temperature*

North Thames Gas Board (NTGB) calculate an 'average' temperature based upon the 24 hours commencing 0600 h on day 2. The actual temperatures, at two-hourly intervals throughout the period, are meaned to yield the 'average' temperature. Forecast values are meaned similarly and daily errors are calculated from sets of these two figures.

Table I. *Mean values* (3 *years*) *of mean* (*seasonal*) *forecast minus mean* (*seasonal*) *actual temperature* (°C) *at London Weather Centre for the period* 1978–80 *inclusive.*

Season	Day 1 (17	19	21	23)	Day 2 (01	03	05	07	09	11	13	15	17	19	21	23)	Day 3 (01	03	05)	Mean of whole period	Mean 07 (day 2)–05 (day 3)	Mean 07–10 day 2	Mean 17–23 day 2
Jan.–Feb.	−0·2	−0·2	−0·5	−0·8	−0·8	−1·0	−1·2	−1·1	−0·8	−0·6	−0·2	−0·4	−0·6	−0·8	−1·1	−1·4	−1·6	−1·7	−1·9	−0·9	−1·0	−0·9	−1·0
Mar.–Apr.	−0·2	−0·2	−0·2	−0·4	−0·7	−0·7	−0·7	−0·4	−0·4	0·0	0.2	0.3	0·0	0·0	0·0	−0·4	−0·7	−0·8	−0·8	−0·3	−0·3	−0·4	−0·1
May–June	0.2	0.1	0.1	−0·1	−0·2	−0·5	−0·7	−0·1	−0·1	0.3	0.9	0.9	0.5	0.2	0.2	−0·2	−0·6	−0·8	−1·0	0·0	0·0	−0·1	0·2
July–Aug.	0.3	0.2	0.1	−0·2	−0·5	−0·6	−0·8	−0·2	−0·2	−0·4	0.5	0.6	0.8	0.3	0.3	−0·3	−0·8	−1·2	−1·2	−0·2	−0·1	−0·2	0·3
Sept.–Oct	0.3	0.4	0.7	−0·4	−0·6	−0·8	−0·9	−0·8	−0·6	−0·5	−0·2	0.2	0.0	0.2	−0·7	−0·5	−0·9	−1·3	−1·5	−0·4	−0·6	−0·7	−0·3
Nov.–Dec.	0·0	−0·1	−0·4	−0·7	−0·9	−1·1	−1·3	−0·8	−0·8	−0·8	−0·1	0·0	0·0	−0·4	−0·7	−1·0	−1·3	−1·2	−1·3	−0·7	−0·7	−0·8	−0·5

Table II. *Mean modulus errors in forecast temperatures* (°C) *and associated improvement over corresponding persistence forecast temperatures for the period* 1978–80 *inclusive.*

		Day 1 (17	19	21	23)	Day 2 (01	03	05	07	09	11	13	15	17	19	21	23)	Day 3 (01	03	05)	Mean of whole period	Mean 07 (day 2)–05 (day 3)	Mean 07–10 day 2	Mean 17–23 day 2
Jan.–Feb.	A	0·6	0·8	1·0	1·2	1·3	1·4	1·5	1·5	1·6	1·4	1·5	1·5	1·5	1·6	1·8	1·9	2·0	2·0	2·4	1·5	1·7	1·5	1·7
	B	1·2	0·8	0·8	0·6	0·5	0·4	0·5	0·6	0·4	0·3	0·5	0·9	0·8	0·7	0·7	0·4	0·3	0·3	0·2	0·6	0·5	0·5	0·7
Mar.–Apr.	A	0·6	0·8	1·0	1·0	1·1	1·2	1·2	1·4	1·4	1·6	1·8	1·9	1·9	1·5	1·7	1·5	1·5	1·6	1·6	1·4	1·6	1·4	1·7
	B	1·7	1·2	1·0	1·0	0·6	0·6	0·7	0·5	0·3	0·3	0·3	0·4	0·9	1·2	1·0	1·1	1·0	0·7	0·6	0·8	0·7	0·4	1·1
May–June	A	0·7	1·1	1·2	1·2	1·1	1·2	1·2	1·1	1·2	1·7	1·9	2·1	1·9	1·9	1·7	1·5	1·6	1·5	1·6	1·4	1·6	1·1	1·7
	B	1·5	1·0	0·8	0·5	0·5	0·4	0·3	0·3	0·2	0·3	0·6	0·6	1·3	1·1	0·8	0·7	0·7	0·8	0·4	0·7	0·8	0·3	1·0
July–Aug.	A	1·0	1·0	1·1	1·0	1·1	1·0	1·1	1·0	1·1	1·4	1·7	1·8	1·9	1·7	1·4	1·3	1·3	1·4	1·5	1·3	1·5	1·1	1·6
	B	1·4	0·9	0·6	0·3	0·3	0·3	0·3	0·4	0·3	0·2	0·3	0·5	1·2	1·0	0·7	0·6	0·4	0·2	0·2	0·5	0·5	0·3	0·9
Sept.–Oct.	A	0·7	0·7	0·9	1·0	1·2	1·2	1·3	1·3	1·3	1·4	1·4	1·5	1·5	1·4	1·4	1·5	1·6	1·8	1·9	1·3	1·5	1·3	1·5
	B	1·0	0·7	0·6	0·5	0·4	0·5	0·7	0·8	0·5	0·3	0·1	0·2	0·8	0·6	0·6	0·6	0·5	0·5	0·6	0·5	0·5	0·7	0·7
Nov.–Dec.	A	0·6	0·7	1·0	1·3	1·4	1·5	1·5	1·5	1·5	1·5	1·3	1·4	1·4	1·6	1·7	1·9	2·0	2·2	2·4	1·5	1·7	1·5	1·7
	B	1·4	1·3	1·1	0·7	0·7	0·6	0·7	0·7	0·8	0·7	1·0	0·7	1·1	1·1	1·0	0·5	0·4	0·2	0·3	0·7	0·7	0·7	0·9

A—Mean forecast error
B—Mean improvement over persistence forecasts

Table III. *Trend in mean modulus forecast and persistence errors* (°C) *over the three years* 1978–80.

Season		1978	1979	1980
January–February	F	1·4	1·5	1·5
	P	2·0	2·2	2·0
March–April	F	1·3	1·6	1·3
	P	2·2	2·4	2·0
May–June	F	1·6	1·5	1·4
	P	2·2	2·2	2·0
July–August	F	1·3	1·3	1·3
	P	1·6	1·9	2·0
September–October	F	1·3	1·4	1·2
	P	1·9	1·9	1·8
November–December	F	1·4	1·5	1·5
	P	2·1	2·3	2·4

F—Forecast error
P—Persistence error

Table IV. *Mean modulus forecast temperature errors* (°C) *for* 1980. *Modified forecasts include effects of countering systematic errors* (1978–80).

	07–10 h		17–23 h	
Season	Original	Modified	Original	Modified
January–February	1·5	1·3	1·8	1·5
March–April	1·3	1·1	1·6	1·5
May–June	0·9	0·8	1·9	1·9
July–August	1·1	1·1	1·5	1·3
September–October	1·1	1·1	1·4	1·3
November–December	1·6	1·3	1·5	1·4

Daily errors in forecasts of 'average' temperature have been supplied by NTGB to LWC for the period April 1978 to December 1980. Five forecast issues are considered: 1530 h on day 1, 0001 h, 0800 h and 1530 h on day 2, and 0001 h on day 3. The forecast 'average' temperature calculated using the 0800 h day 2 issue, 1530 h day 2 etc., onwards, included an increasing number of actual temperatures. Thus the 1530 h day 2 forecast included some 10 hours of actual temperature and only 14 hours of forecast temperature, whilst the 0001 h day 3 'forecast' included some 18 hours of actual temperature and only 6 hours of forecast temperature.

Table V contains the mean modulus errors in forecast average temperature for each forecast issue, averaged over each two-month season.

Mean errors are well below 2 °C in all seasons but the May–June period is highlighted as a difficult forecasting season. The first three forecast issues in Table V may be regarded as genuine forecasts whereas the last two forecasts contain an increasingly large element of observed temperatures.

Table VI reveals on how many occasions the 'forecast average temperature' errors reached 3 °C or more in each of the three years.

There appears to be a distinct reduction in the number of large errors between the 1530 h and 0001 h issues. The most important new factor to cause a revision of the temperature forecasts during that period must be the availability of forecast wind, humidity and temperature fields based upon 1200 GMT analysed data.

Table V. *Mean modulus errors in average temperature forecasts* 1978–80 (°C).

Time of issue	Jan.–Feb.	Mar.–Apr.	May–June	July–Aug.	Sept.–Oct.	Nov.–Dec.
1530 h day 1	1·6	1·3	1·5	1·0	1·1	1·4
0001 h day 2	1·2	1·1	1·3	1·0	1·0	1·2
0800 h day 2	0·8	0·7	1·0	0·8	0·7	0·8
1530 h day 2	0·5	0·5	0·5	0·4	0·5	0·6
0001 h day 3	0·2	0·2	0·1	0·1	0·2	0·1

Table VI. *Number of occasions when forecast average temperature errors were greater than or equal to* 3 °C *in the period* 1978–80.

	Jan.–Feb.			Mar.–Apr.			May–June			July–Aug.			Sept.–Oct.			Nov.–Dec.		
Time of issue	78	79	80	78	79	80	78	79	80	78	79	80	78	79	80	78	79	80
1530 h day 1	—	8	9	—	6	2	10	4	4	0	2	1	3	5	2	8	4	5
0001 h day 2	—	3	2	—	3	2	5	3	2	3	1	0	0	4	0	6	2	4
0800 h day 2	—	0	1	—	1	0	1	2	0	3	0	0	0	1	0	0	0	1
1530 h day 2	—	0	0	—	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0001 h day 3	—	0	0	—	0	0	0	0	0	0	0	0	0	0	0	0	0	0

A study of the major errors (i.e. ⩾3 °C) in forecast average temperature revealed that most could be ascribed to three factors:

(1) Errors in timing and general speed of transition from one air mass to another. In these cases a measure of uncertainty in the forecast would usually be commented on to the Gas Controller.

(2) Systematic errors peculiar to London as demonstrated in Table I.

(3) Errors in the predicted rate of cooling or warming between the maximum and minimum, or minimum and maximum, temperature despite often quite accurate predictions of the extremes. It appears that the rate of change of temperature often approximates to a straight line rather than to a curve, which leads to inaccuracies in several forecast temperatures during these periods of normal temperature changes.

(c) *Conclusions*

(1) Temperature forecasts for inner London issued at 1530 h for up to 36 hours ahead are, on average, demonstrably better than persistence. Mean forecast errors are generally less than 2 °C. Part of the

forecast error appears to be systematic with underforecasting of night minima in autumn and winter and overforecasting of day maxima in spring and summer.

(2) The May–June period appears to be a particularly difficult season for prediction of temperature for periods of 24 hours and longer ahead.

(3) There is a substantial reduction in the number of large errors ($\geqslant 3$ °C) between the 1530 h (day 1) and 0001 h (day 2) forecast issues in most seasons. However, at what stage after 1530 h this improvement becomes significant is not known. Further research is required to establish this important point.

(4) It is also necessary to establish the impact of weather variables other than temperature upon gas demand.

Acknowledgements

Most of the numerical calculations in this report have been carried out by forecasters at London Weather Centre and their co-operation is gratefully acknowledged. The co-operation of British Gas, and North Thames Gas in particular, is also gratefully acknowledged.

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Weather and the spoon-gassing of rabbits

by C. P. Roe

(Meteorological Office, MAFF*, Reading)

and I. G. McKillop

(MAFF, Worplesden Laboratory)

Summary

One of the main methods of rabbit control is 'spoon-gassing', involving the transfer of a cyanogenetic powder by spoon to the rabbit burrow which is then sealed. The period of transfer to the burrow is hazardous to the operator in wet or windy conditions (MAFF 1978b). The paper briefly reviews the problems caused by a large rabbit population and assesses the time available for the gassing operation to be carried out safely.

1. Introduction

The European rabbit (*Oryctolagus cuniculus*) was introduced into England during the eleventh or twelfth century and for many years was highly valued as a source of fresh meat and fur by lords of the manor, and poaching by villagers was severely punished. Farmers, however, became increasingly aware that its destructiveness to crops of all kinds far outweighed the value of its carcass and by the mid-nineteenth century the rabbit was recognized as the most destructive vertebrate pest of agriculture (MAFF 1978a).

The virus disease myxomatosis first spread to Britain from France in 1953 and over the next two years it killed 99% of the rabbit population. Less virulent strains of the myxoma virus have since predominated and during the past 15 to 20 years the rabbit population has increased (Ross 1972).

Mature rabbits (weighing up to 2 kg) may eat up to 0·5 kg of green food over an 8-hour nocturnal grazing period (forests and orchards are also at risk through 'ring barking' and the eating of seedlings). Close inspection of retarded cereal crops and grassland in spring will often reveal that rabbit-grazing is to blame. Plate I shows clearly the contrast between a 'protected' control area of winter cereals in an early stage of growth and the rest of the rabbit-grazed field. Rabbits prefer to live where there is harbourage, e.g. woodland, scrub and rough areas, in close proximity to neighbouring pasture, cereals, etc. (MAFF 1978a). A suitable harbourage is seen in the background in Plate I.

2. Control

Control programs are planned for the November to March period when herbage has died back (allowing large infestations to be located easily) and before young litters are produced. Although trapping, shooting, ferreting, netting, snaring, fencing and dazzling are used on a small scale (producing saleable carcasses!), gassing is considered the most humane and efficient control measure (MAFF 1978a). The method involves driving underground as many rabbits lying out as possible and injecting a sufficient quantity of fumigant (in the form of powdered cyanide compounds) into the warren. In contact with moist air the powder evolves a poisonous gas from which death is rapid. Several methods of administering the powder are currently in use:

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* Ministry of Agriculture, Fisheries and Food.

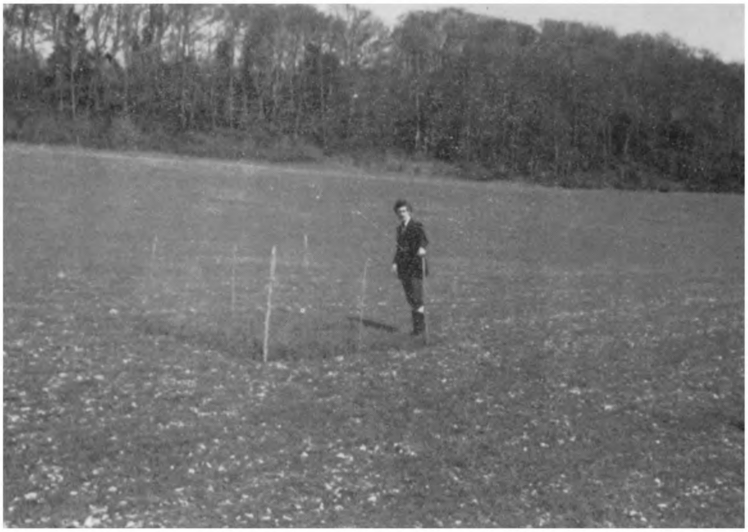

Plate I. Showing the contrast between a 'protected' control area of winter cereals in an early stage of growth and the rest of the rabbit-grazed field.

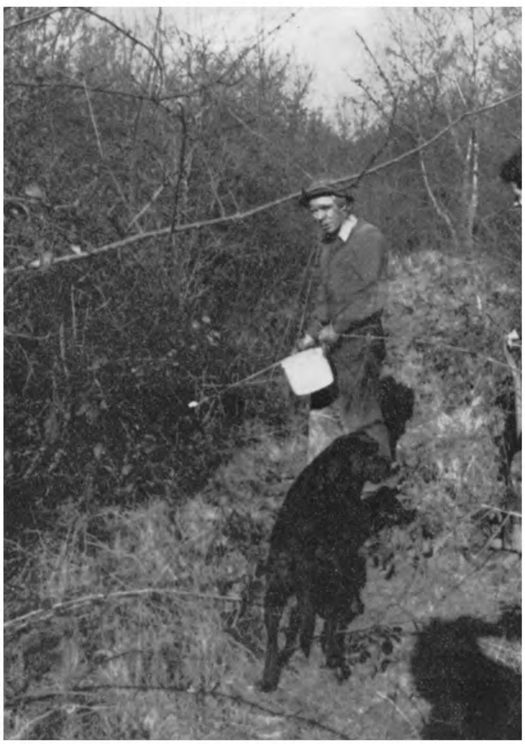

Plate II. Spoon-gassing of rabbits. The operator spoons the poison into the burrow entrance.

(a) Power gassing—whereby the powder is blown into the burrow system by a powered fan. A method suitable for large, well-populated warrens with many holes.

(b) Hand-operated pumps—for smaller warrens.

A moderate airflow is necessary in both (a) and (b) to ensure an even distribution of gas throughout the burrow system; both methods are 'labour intensive', requiring two or three people.

(c) Spoon-gassing—particularly suited to small infestations. It is widely used amongst farmers and professional operators. A small quantity of powder is spooned into the burrow entrance (Plate II) which is then sealed. The concentration of poisonous gas builds up and kills rabbits which attempt to dig out of the burrow.

3. Assessment of the time available for spoon-gassing

Limitations imposed by the weather will vary according to the field situation; control carried out in open fields and exposed hedgerows is likely to be more weather sensitive than similar work being carried out within a woodland.

The Worplesdon Laboratory is currently assessing the effectiveness of spoon-gassing in three study areas represented by the meteorological sites at Honington, Cardington and Boscombe Down, the selection being limited to those stations with at least eight years of hourly observations. Analysis was restricted to the daylight hours over the control period October to April in studies (3.1 to 3.4) relating to the surroundings in which the gassing was to be carried out.

3.1 *The potential number of (daylight) working hours in an area of open ground*

This study gives the maximum possible number of hours available to an operator concentrating solely on spoon-gassing and who is prepared to work every hour if the weather conditions are suitable.

Work would not proceed during wet or windy weather, where wet weather is defined to be any hour when rain has fallen or when snow is lying on the ground. Elementary studies in outdoor conditions indicated that wind speeds of about 10 kn at 0·5 m (the working level) could blow powder from the spoon. To allow for an adequate safety margin (and taking into account work on relationships between mean wind speed and gusts reported by Hardman *et al.* (1973)) mean wind speeds less than or equal to 8 and 12 kn at 10 m (roughly 5 and 7 kn at 0·5 m) were taken as 'ideal' and 'practical' working conditions respectively. The 8 kn limit would permit an operator to use heaped spoonfuls with little risk from inhalation while the 12 kn limit represented a 'practical' limit for the seasoned operator, prepared perhaps to shelter the heaped spoon with his body.

The criteria for a potential gassing hour were taken to be:

(a) no precipitation,

(b) no snow or melting snow lying (state of ground code 5–9 inclusive), and

(c) mean hourly wind speed at 10 m $\leqslant 8$ or $\leqslant 12$ kn.

An hourly frequency program was run for daylight hours during the months October to April for Boscombe Down (1969–78), Honington (1969–78) and Cardington (1971–78) to extract the hours when these criteria were satisfied. Hourly reports of 'state of ground' were not available (the total error introduced by omitting this criterion anyway are estimated at only 3% at Boscombe Down; however, since most snow fell during a few months in 1969–71 and in 1978, larger errors for these months may occur). Approximately one-third of hours limited by state of ground were also limited by virtue of the wind and precipitation criteria. It was finally decided to allow for hours intermediate to the synoptic hours (00, 03 . . . . 21) by assuming that state of ground unsuitable on two consecutive hours was also unsuitable during intermediate hours and that unsuitable ground conditions at only one synoptic hour were unsuitable for one hour either side of that hour.

Day length was calculated from times of sunrise and sunset; hourly observations occurring just before sunrise or just after sunset were included in the analysis.

The potential time available at each station is shown in Figs 1, 2 and 3.

3.2 *The number of half-day periods suitable for gassing along a woodland periphery available to an operator who uses local weather forecasts*

The majority of operators contemplating spoon-gassing are unlikely to start work unless they are confident of several hours of good 'gassing-weather'. This study concerns those operators who contact their local forecasting office each day to find out whether or not the weather will be conducive to work for part or all of that day. The method supposes that three consecutive hours with 'appropriate' gassing criteria satisfied during the morning or afternoon would enable the operator to get out and do the job and that each occasion would have been correctly forecast. The hour 1200–1300 GMT has been designated a lunch break and is not included.

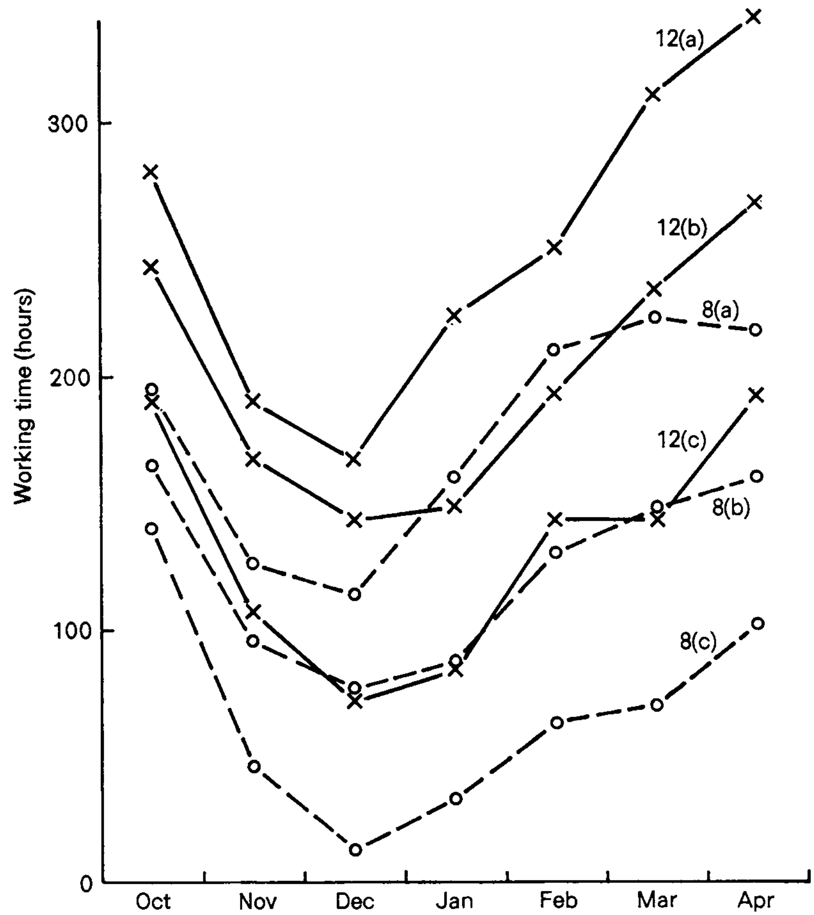

Figure 1. Potential number of daylight hours during the month when spoon-gassing in an area of open ground was possible at Cardington, 1971–78. 8 and 12 denote critical wind speeds; (a), (b) and (c) denote maximum, mean and minimum working times.

Wind is less restrictive than in case 3.1 and the wind criterion was modified to allow for shelter by the hedgerow such that a critical wind speed of 16 kn at 10 m (approximately 10 kn at 0·5 m) represents acceptable working conditions; a 20 kn wind at 10 m (approximately 12 kn at 0·5 m) is perhaps more appropriate to the operator willing to accept some degree of risk in order to get the job finished.

A half work-day is defined as three consecutive hours during the morning or afternoon with:

(a) no precipitation,

(b) no snow or melting snow lying on the ground (the assumptions used in study 3.1 for intermediate hours still hold), and

(c) mean hourly wind speed at 10 m ⩽16 or ⩽20 kn.

Hourly data for Cardington were extracted (daylight hours) for 1971–78 to determine the number of half-day periods suitable for gassing and these are presented in Fig. 4.

An intensive gassing program at a particular site would often last for only a couple of weeks, so each month was sub-divided into two to enable the most favourable two-week period for gassing to be established within the limited sample of years studied. As the data were analysed manually the average day lengths (rounded up to the nearest hour) for each month were used (see Table I).

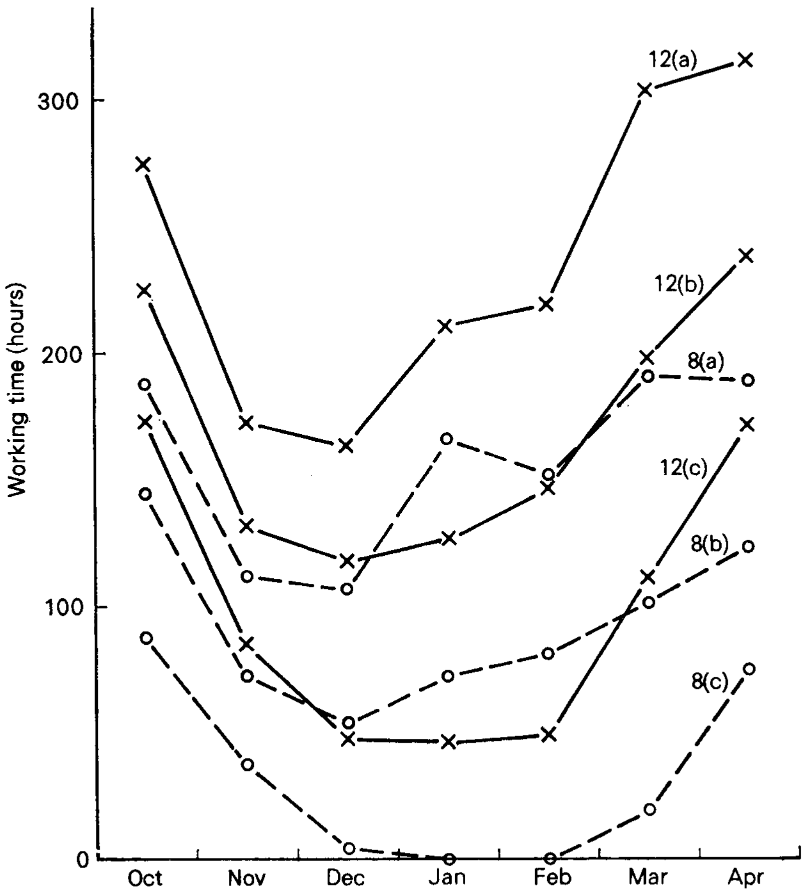

Figure 2. Potential number of daylight hours during the month when spoon-gassing in an area of open ground was possible at Honington, October 1969–December 1978. 8 and 12 denote critical wind speeds; (a), (b) and (c) denote maximum, mean and minimum working times.

Table I. *Average day lengths and the total number of daylight hours each month at Cardington.*

	GMT	Total daylight hours
October	0700–1700	310
November	0800–1600	240
December	0900–1600	217
January	0900–1600	217
February	0800–1700	252
March	0700–1800	341
April	0600–1900	390

3.3 *The number of half-day periods when a start to spoon-gassing along a woodland periphery might be made by an operator who does not use local weather forecasts*

This study relates to those operators who tend to take little more than a passing interest in weather forecasts and plan their work based on their own subjective decision on whether to work or not, depending on the weather situation first thing in the morning and straight after lunch.

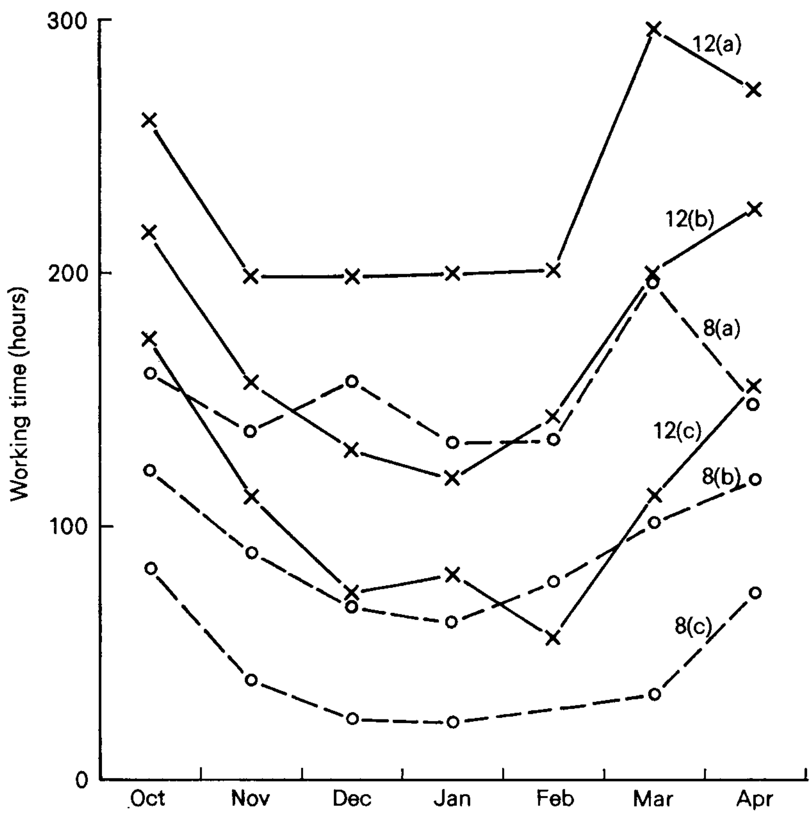

Figure 3. Potential number of daylight hours during the month when spoon-gassing in an area of open ground was possible at Boscombe Down, 1969–78. 8 and 12 denote critical wind speeds; (a), (b) and (c) denote maximum, mean and minimum working times.

Hourly data for 0800 GMT (0900 GMT in December and January) and 1300 GMT were extracted for Cardington; acceptable conditions for a start to work at either of these hours were taken to be defined by the criteria of case 3.2. The results are given in Fig. 5.

3.4 *The potential number of (daylight) working hours within a dense woodland*

Large rabbit infestations may be found in dense harbourage, where the tree canopy may significantly reduce the free wind flow and afford some shelter from precipitation.

Hours suitable for spoon-gassing are suggested to be those with:

(a) precipitation ⩽1 mm,

(b) mean 10 m wind speed ⩽30 kn, and

(c) no state-of-ground limitation.

An hourly frequency program employing these criteria was run for the daylight hours (calculated from times of sunrise and sunset) during October to April for Cardington, 1971–78 and the results are shown in Fig. 6.

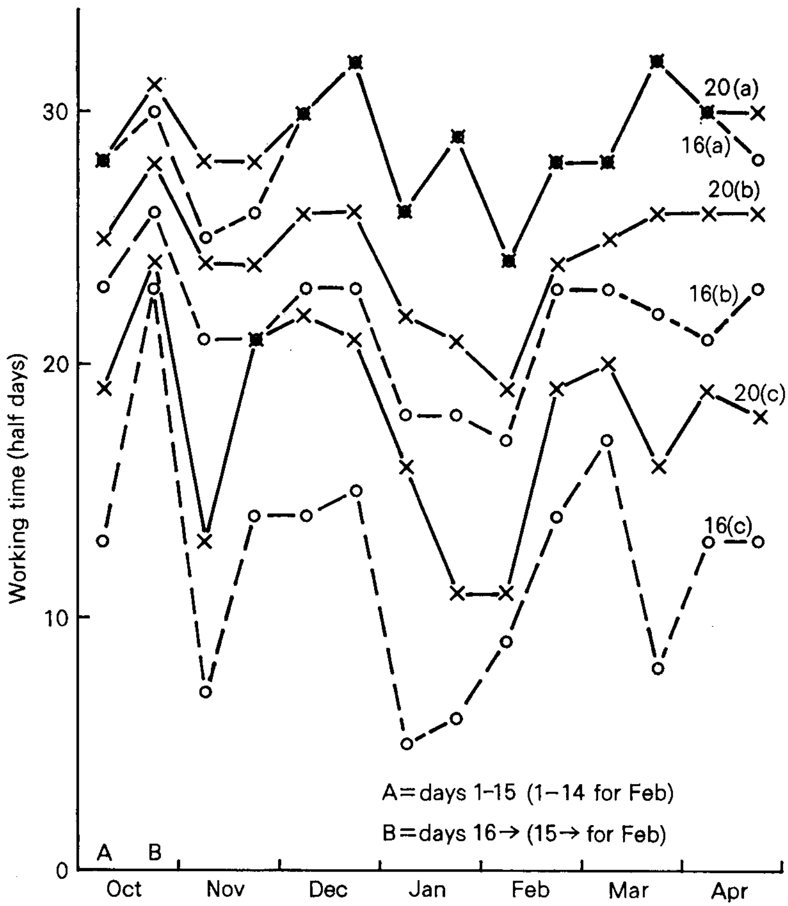

Figure 4. Number of half work-days (during daylight hours) when spoon-gassing was possible along a woodland periphery at Cardington, 1971–78, for the operator who obtains local weather forecasts. 16 and 20 denote critical wind speeds; (a), (b) and (c) denote maximum, mean and minimum working times.

4. Discussion

Over relatively open ground, Cardington has potentially the most time available for gassing owing possibly to the more frequent rainfall at Boscombe Down and comparatively more severe winters at Honington (with many days of snow cover). Ideal conditions (10 m wind $\leqslant$8 kn) prevailed for approximately 40–50% of the daylight hours at Cardington depending upon the month, while at Honington only 30% of the time was suitable for work. Under less stringent criteria (wind $\leqslant$12 kn) 50–80% of the time was suitable for gassing. October and April are consistently the best months with relatively high mean values and a small range while December and January are less reliable. These figures were derived for well-exposed sites and may vary appreciably from site to site depending upon the influence of local topography on wind and rainfall regimes. It is of course a theoretical consideration and the time available to the operator who is not prepared to work every hour possible is probably much less.

Along a woodland periphery regularly over 20 half-days (mornings or afternoons) per fortnight provided good gassing weather (mean value) indicating that the weather is unlikely to be a problem. The second half of October, all December and mid-February to mid-March seem to be the most favourable periods while the first two weeks in November and January to mid-February are less so.

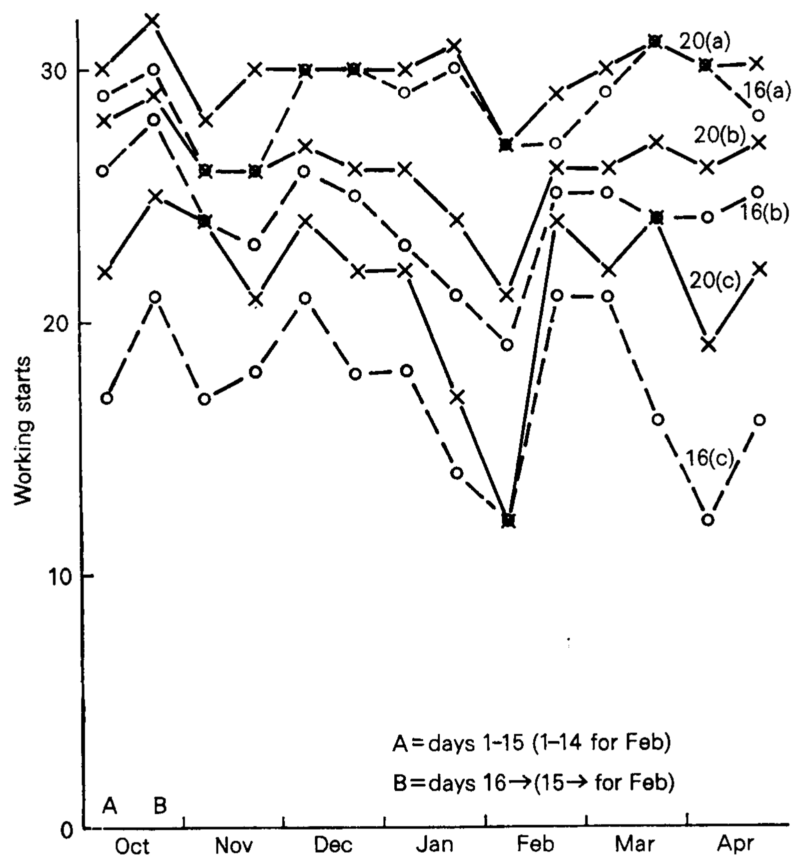

Figure 5. Number of work starts (during daylight hours) for spoon-gassing along a woodland periphery at Cardington, 1971–78, by the operator who does not use local weather forecasts. 16 and 20 denote critical wind speeds; (a), (b) and (c) denote maximum, mean and minimum working hours.

Comparison of Figs 4 and 5 might suggest superficially that the operator who takes meteorological advice achieves less work than the operator who relies simply upon his own assessment of whether conditions are suitable for a start to work. In the latter case, however, many of the work periods have to be abandoned fairly soon because of deteriorating weather so that in fact the operator achieves fewer uninterrupted work periods than shown in Fig. 4. In January, for example, approximately 1 in 5 of the starts to work at Cardington had to be abandoned on average, with as many as three-quarters being false starts in one particular year. One must suspect also that the operator is at greater risk during these circumstances owing to some inclination to continue with the job in hand regardless of the weather.

The potential time available within a dense woodland is over 90% of the maximum possible in all months at Cardington, assuming that the tree canopy greatly reduces the effects of the weather. This figure will alter slightly from place to place, coniferous trees affording more protection from strong winds and falling precipitation than deciduous trees during the winter months (although an intricate network of leafless branches offers some shelter).

5. Conclusions

Although taken over a short period (8–9 years) the results clearly indicate that gassing carried out within, or bordering, a woodland, where most control programs will be based, is unlikely to be greatly restricted except, perhaps, in severe winters such as 1968–69 and 1978–79.

One would suggest that the findings of this study could be applied to inland areas of south-east, central southern and eastern England where wind and rainfall regimes are likely to be similar to the

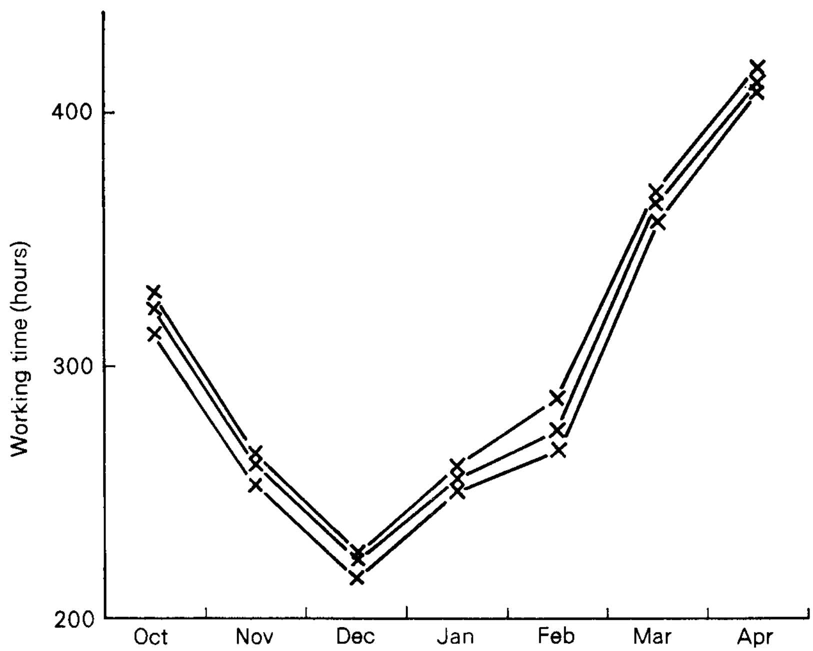

Figure 6. Potential number of daylight hours during the month when spoon-gassing in an area of woodland was possible at Cardington, 1971–78. Critical wind speed is 30 kn; maximum, mean and minimum working times are shown.

sites considered here. In most other parts of the country rabbit control using this technique could be more limited by the weather.

(It is emphasized that this work only considered the effects of the weather on the time available to carry out spoon-gassing and makes no attempt to comment on the effectiveness of spoon-gassing as a control technique once the powder has been placed in the burrows.)

Acknowledgements

We should like to thank Mr P. Butt, Agricultural Development and Advisory Service (ADAS), Oxford, and Mr P. E. Sayers, ADAS, Reading, for providing much of the background information. Thanks also go to Dr J. Starr and Mrs S. Morris from this office for their many useful contributions and to the computing division of the Agricultural Meteorology Section (Met O 8a), Bracknell, for providing the computer analyses. We are indebted to ICI Chemicals Ltd for providing a sample of the base compound of the gassing powder (magnesium sulphate).

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BBC Television weather forecasts—audience research results

By R. D. Hunt

(Meteorological Office, Bracknell)

Summary

Early in 1981, the BBC Broadcasting Research Section carried out a survey of audience reaction to the BBC 1 weather forecasts. The results, some of which are summarized in this note, reveal the importance of the television forecasts to the viewers and the high regard in which the service is held by those taking part in the survey.

The BBC has recently published the results of a study carried out by the BBC Broadcasting Research Section on audience reaction to the weather forecasts broadcast on BBC 1. The results, which are based on a sample of 945 members of the Viewing Panel, provide a very favourable comment on the service provided by the Meteorological Office to BBC Television. The main findings of the survey are summarized below.

Of those asked, 92% thought that weather forecasts are at least quite an important service for BBC Television to provide; most thought that they are very important. When asked to mark their overall attitude to them on a five-point scale ranging from 'very well worth hearing' (A) to 'not worth hearing at all' (E), 42% of the sample gave an A marking compared to a negligible 1% who responded with an E. The general level of satisfaction is even better demonstrated by the 80% who gave an A or B mark, compared to the 3% whose response was D or E.

The viewers, 90% of whom watched the forecasts out of general interest as opposed to professional interest (4%), were asked to state the importance of various types of weather information to them; the response is given in full in Table I. Note that the list includes 'road conditions' which, of course, are not part of the weather information as such and are only explicitly mentioned in the forecasts if ice is expected to form on roads. Nevertheless, the replies under that heading demonstrate that some of the most important users of forecasts are those intending to travel by road. Noting the importance of frost forecasts, one can perhaps deduce that gardeners are another important group. It is of interest to see that far more people want to know whether they will feel warm or cold than want to know the forecast temperature.

Table I. *Relative importance of types of weather information to members of the Viewing Panel.*

Information	Very important %	Quite important %	Not very important %	Not at all important %
Frost or not	41	35	18	6
Road conditions	39	36	17	8
Wet or dry	33	46	16	5
Foggy or clear	30	39	23	8
Feeling warm or cold	24	48	23	5
Actual temperature	14	36	40	10
Wind strength	14	31	40	15
Humidity	7	24	44	25

The popularity of the weatherman (or, more accurately, weather person) was revealed by the fact that 70% of the sample preferred seeing a weatherman with a chart, compared to only 9% who preferred a brief script being read by a BBC announcer over the display of a caption chart. Of the 70% who preferred the person in vision over half wanted to see a weatherman after both main news bulletins every day of the week—at the time of the survey there was only one live weather broadcast on Saturday and Sunday evenings. In fact, since these results were published, a weatherman slot has been installed in the peak viewing period after the late Saturday evening news on BBC 1.

Other questions in the research paper concerned technical aspects of the weather forecast. Generally speaking, there was a reasonable degree of understanding of the weather charts claimed by the sample, with about half of those questioned 'completely understanding isobars and fronts'. A further third claimed a partial understanding of isobars and fronts, leaving only a small number who were left completely nonplussed by the Atlantic chart; a stubborn 2% saw no reason to understand in any case.

As would have been expected, the large majority of the audience found the satellite pictures displayed at least sometimes helpful with only 18% finding them confusing or unnecessary. Bearing in mind the rather poor quality of the pictures sometimes shown this result is encouraging. The standard of pictures should improve in the months to come, with a new facsimile machine to be installed in the weatherman's office at the BBC Television Centre, and with Meteosat 2 working satisfactorily.

Table II gives the response to a question which is of particular interest to the Meteorological Office at present. Since the end of 1979, when BBC Midlands began taking a service of live forecasts once daily using staff from the Nottingham Weather Centre, many BBC regions have expressed an interest in a more detailed regional forecast than the brief script most of them were receiving from their nearest forecast office; in many cases they have considered a similar live weatherman slot, usually in the regional 'opt-out' time at 1800 on BBC 1. BBC South and BBC West have already taken such a service (as indeed have ATV). Clearly the vast majority of those questioned in the survey wanted to see a mixture of regional and national forecasts. The system of providing detailed regional forecasts by a Meteorological Office forecaster following the national weatherman's presentation after the Early Evening News on BBC 1 seems to be the most satisfactory way of meeting this demand.

Table II. '*Would you like to see only a national forecast, only a forecast for your own region, or a mixture of both?*'

National forecast only	13%
Regional forecast only	9%
Mixture of both	78%

One question related to a topic which has been under discussion for many years, within both the Office and the BBC, is of particular interest. Of those asked, 73% thought that the forecasts were of the right length; 22% would prefer them to be longer. No specific mention was made in the question to the fact that the various routine forecasts are of different lengths, ranging from 45 seconds in the early evening to about 3 minutes in some lunch-time forecasts. Nevertheless, generally speaking the sample was obviously not unhappy with the amount of time given to weather forecasts. On the other hand, in answer to the question 'Do you think that the right amount of time is spent on past weather and future weather?', 9% wanted more past weather and 42% wanted more future weather. It is not clear whether these 51% wanted the extra information within the current time limits.

Two other topics raised in the questionnaire are worthy of mention. Firstly, 79% of the sample realized that the weathermen were members of the Meteorological Office staff, 19% thought that they were BBC staff, while an undiscerning 2% thought that they were fully fledged actors.

The other interesting topic concerns the long-running Centigrade/Fahrenheit issue. Thirty-one per cent indicated that it made no difference to them whether temperature was given in degrees Centigrade or degrees Fahrenheit. Fahrenheit was preferred by 49%, while only 20% preferred Centigrade. This continuing preference for the Fahrenheit scale almost certainly reflects a resistance to changing from well-known units, particularly in an area which impinges on the lives of most people for only a few seconds each day. But perhaps credit can be given to the public for appreciating that the Fahrenheit scale is better suited to the range of temperatures usually quoted in a UK weather forecast than is the Centigrade scale. The weatherman frequently refers to 'temperatures in the seventies' rather than 'temperatures between 21 and 26 degrees Centigrade'. Certainly the former phrase trips off the tongue better than the latter.

Perhaps the most fitting summary of the survey is provided by reproducing the answers to the question 'On the whole, do you think the television weathermen do a good job?' Eighty per cent of the sample said 'Yes, most of the time', 15% said 'Yes, some of the time' and 5% said 'No, none of the time'. Clearly the viewing public are very satisfied with the BBC weather forecasts. To quote from the survey report: '[The viewers] considered the forecasts a very important service for television to provide and their content and presentation were held in high regard'.

Acknowledgement

The British Broadcasting Corporation has kindly given us permission to publish this note, which is based on a BBC Broadcasting Research paper entitled 'Weather forecasts on BBC Television'.

Review

The precipitation of Pakistan, by Bilquis Azmat Gauhar. 230 mm × 150 mm, pp. 153, *illus.* Asian Publishing Company, London, 1980. £9.95.

This is a monograph on the rainfall of a relatively small part of the Indian subcontinent, and as such will not have wide appeal to climatologists, most of whom would be more interested in a general account of rainfall for the whole subcontinent.

The work is divided into seven chapters. The first is concerned with topographical influences. Chapters 2 to 5 describe the general climatic conditions and seasonal changes at the surface and in the upper air over southern Asia during the traditional seasons: winter, pre-monsoon, monsoon and post-monsoon. Many diagrams are brought together from well-known sources and these will be familiar to most readers. During the winter, western disturbances bring light to moderate rainfall to Pakistan and, even in the pre-monsoon period of April and May, they give some thundery showers and occasional very cold bursts. The author gives one synoptic example of a cold burst in April, but none of a western disturbance during winter.

Most of the rainfall in Pakistan is brought by monsoon depressions from the Bay of Bengal, and the author discusses these in relation to weak and active monsoon conditions but gives no synoptic examples. And surely a table of annual amounts of monsoon rainfall for Pakistan as a whole for the past 100 years might have been provided.

Chapter 5 discusses the post-monsoon season, with its lack of rainfall. Chapter 6 discusses the statistics of variability of annual rainfall and of rainfall probability maps prepared by the author. Chapter 7 describes the author's subdivision of Pakistan into rainfall zones.

Although the book gathers together useful information from many sources, it cannot be recommended as a source of new information or ideas.

A. F. Jenkinson

Notes and news

In memoriam

A wreath was laid by Mr P. G. Rackliff, of the Defence Services Branch of the Meteorological Office, at the Commonwealth Air Forces Memorial, Runnymede, on 8 November 1981, in memory of the crews of 517 and 518 Long-range Meteorological Reconnaissance Squadrons who lost their lives on operations during the period 1943–45.

The wreath was obtained through donations given by former Air Observers of 517 and 518 Squadrons, now working at Bracknell and Heathrow. It is intended to make this a regular feature of the annual Remembrance Service.

Obituary

We regret to record the death on 2 October 1981 of Mr R. Stansfield, Senior Scientific Officer, Upavon. Mr Stansfield joined the Office in 1947 as an Assistant and was promoted to Assistant Experimental Officer in 1950. He served at a number of outstations in the United Kingdom and also had tours of duty in Ocean Weather Ships, and at Cyprus and Gan.

He was promoted to Senior Experimental Officer in 1971 and, after working in that grade at Manby and Little Rissington, was posted to Upavon in 1976. During the last few years he was Senior Meteorological Officer of the forecasting team at Southern Sector, Bristol, which is part of the UK Monitoring Organization.

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NOTICES

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Retirement of Dr N. E. Rider

Dr Norman Rider, Deputy Director (Observational Services), retired from the Meteorological Office on 8 January 1982 after a career of almost 35 years in the Office during which time he carried out a wide variety of jobs on both the Services and Research sides of the Office.

Dr Rider studied for his first degree at University College, Exeter (as it was then) and graduated with high honours in Special Physics in 1943. He spent the remaining war years in the Royal Navy and was demobilized in 1947 when he joined the Office as a Scientific Officer. His initial posting was to the Instrument Branch, then at Harrow, where his main job was concerned with equipping the four original Ocean Weather Ships.

Towards the end of 1947 Dr Rider was posted to Kew Observatory where, under the guidance of Dr G. D. Robinson, he worked on radiation and boundary-layer problems. His research was concerned with turbulent exchange processes near the surface and this led to a posting in late 1949 to the School of Agriculture at Cambridge. Here he carried out many experiments relating to evaporation from various crop surfaces and published several important scientific papers on this subject. In 1958 he was awarded a three-year fellowship by the Australian Commonwealth Scientific and Industrial Research Organization. Whilst in Australia he continued his boundary-layer studies, extending them to consider the effect of advection on boundary-layer exchange processes. The excellence of this research led to him being awarded a London University D.Sc. in 1962.

Dr Rider was posted to the Instrument Development Branch of the Office on his return from Australia in 1961. He was promoted to Senior Principal Scientific Officer in 1967 when he became the Assistant Director in charge of that Branch until 1970. He then was detached to Geneva where he became a consultant to the Secretary-General of WMO for two years. Whilst in Geneva he undertook, with others, the planning of the GARP Atlantic Tropical Experiment (GATE). This was subsequently one of the most successful international meteorological field experiments that have taken place, and this was in no small way due to the expertise of the planning staff.

When Dr Rider returned to the Office in 1972 he became Assistant Director in charge of the High Atmosphere Branch. During the four years that he held that post he was especially involved in the planning of special observing systems for the tropics exploiting geostationary satellites. In 1976 he was promoted to Deputy Chief Scientific Officer and became the Deputy Director responsible for observational services and climatology until his retirement in January 1982.

During his long career in the Office Dr Rider acquired both an expertise in experimental meteorology and in organizational matters. His sound common-sense approach to problems was of great value, both nationally and internationally. Within the Office he was a valued member of the Directorate and for the last three years an exceptionally loyal and efficient deputy to the Director of Services. He has been a member of the North Atlantic Ocean Station (NAOS) Board for several years and was Vice-President for the last three years. Indeed, it is a remarkable coincidence that Dr Rider's first job within the Office was to equip our first four weather ships and almost his last was to visit the OWS *Admiral FitzRoy* as she was preparing to sail on the last voyage made by one of our own weather ships.

We wish him and Mrs Rider a very long and happy retirement.

F. H. Bushby

551.509.314:551.509.323

Forecasting daily maximum surface temperature from 1000–850 millibar thickness lines and cloud cover

By N. S. Callen and P. Prescott

(Faculty of Mathematical Studies
Southampton University)

Summary

A regression equation to predict daily maximum surface temperature throughout the year is developed in terms of the expected 1000–850 millibar thickness. The model has a simple form and allows for variable cloud cover and seasonal effects. In addition an interaction component is included which adjusts for different effects of cloud cover at different times of the year. Three years of daily weather records at Crawley and Gatwick Airport are used to estimate the parameters in the model and an additional year of data is used to assess the model's performance.

1. Introduction

Forecasting surface temperature accurately for up to 24 hours ahead, and approximately for a further two or three days, is evidently important for many types of industry, particularly the gas and electricity industries as discussed by Parrey (1972). Several methods of predicting maximum or minimum surface temperatures are available. Gold's (1933) method for maximum temperature uses the depth of the layer which is changed from an isothermal to a dry adiabatic by solar heating on clear days. Johnston (1958) modified this method and it was discussed further by Inglis (1970). Boyden (1958) described a procedure to predict daily mean surface temperature from the 1000–500 millibar (mb) thickness lines and, later, Boyden (1962) extended these ideas to the prediction of maximum temperatures. Inglis (1970) discussed methods based on the tephigram and compared forecasts of maximum temperature using these methods with forecasts based on the 1000–850 mb thickness. He concluded by saying that the direct, and possibly the best, way to establish a relationship between thickness and maximum temperature would be by means of a regression equation, possibly determined separately for each month except that the midsummer months could be grouped together.

Forecasts of minimum temperatures may be obtained using McKenzie's (1944) method or from a regression equation applicable to the whole year developed by Craddock and Pritchard (1951). Tinney and Menmuir (1968) discussed the results of forecasting in two separate seasons defined as summer, April to September, and winter, October to March. Regression models for these two seasons were compared with the yearly regression equation of Craddock and Pritchard and with McKenzie's method by Gordon, Perry and Virgo (1969). It was clear from their comparisons that the results for the different methods are similar, 'provided sufficient trouble is taken to establish a reliable basis', for the tabulations and equations involved.

Here we consider the relationship between the daily maximum temperature and the 1000–850 mb thickness, using regression analysis to build a model including adjustments due to the extent of cloud cover and seasonal effects. The objective is a simple equation, applicable to the whole year, based on easily obtained variables which may be used to provide accurate forecasts for one or more days ahead.

2. Variables used in the analysis

In order to predict the surface maximum temperature from other easily assessed meteorological variables, it is necessary to know what is happening at the surface and in the air above. Data were therefore required from an upper-air station and a surface station in close proximity. Crawley and Gatwick Airport were chosen for this study with several variables being measured at each station.

Although variables such as 900 millibar wind speed, surface pressure and surface wind speed were analysed as part of the investigation, only those appearing in the final model are described in detail below.

The dependent variable is the maximum day temperature T at Gatwick Airport between 0900 GMT and 2100 GMT. Observations were available for 1096 days during the three-year period 1968 to 1970.

Boyden (1958 and 1962) used the 1000–500 mb thickness as the main predictor variable in his investigations but Inglis (1970) considered the 1000–850 mb thickness so that the results were more directly comparable with those obtained using Gold's method. Since Hawson (unpublished) also suggested use of the 1000–850 mb thickness and it is likely that the relationship with surface temperature will be better for shallow layers near the surface than for deeper ones, this variable was obtained from records at Crawley for the same three-year period.

An important factor in determining the maximum temperature reached during the day is likely to be the state of the sky. Boyden (1962) used the number of hours of sunshine expected during the day to provide an adjustment to the predicted value of the maximum temperature. This is, however, a difficult variable to forecast with any certainty and it was considered that a broad classification of cloud cover could provide a useful, yet simply determined, variable. Lumb (1964) produced a cloud classification which was felt to be too complicated for the present study, therefore a simplification was introduced to give a four-point scale 0–3 for cloud cover, C as defined in Table I.

Table I. *Cloud cover classification (C) for period dawn to 1200 GMT* (C_L = *low-level cloud*, C_M = *medium-level cloud and* C_H = *high-level cloud*).

	Cloud cover classification C
Forecast state of sky throughout the period:	
(a) Predominantly clear: $C_L + C_M \leqslant 3/8$ with or without variable C_H cover	0
(b) Variable $C_L + C_M$, with or without precipitation, or $C_H \geqslant 6/8$	1
(c) Predominantly overcast: $C_L + C_M > 6/8$	2
(d) Predominantly overcast with precipitation (not including odd spots of drizzle)	3
Forecast of fog:	
(a) Only around dawn, clearing to $C_L + C_M \leqslant 3/8$	0
(b) Persisting for any length of time after dawn, clearing to $C_L + C_M \leqslant 3/8$ or fog clearing to variable cloud cover	1
(c) Clearing to $C_L + C_M \geqslant 6/8$	2
(d) Throughout the period	3

3. The prediction model

The data were initially analysed using stepwise regression within months to see if different combinations of variables would provide the best models at different times of the year. However, it was evident from these separate analyses that a strong relationship existed between maximum temperature and 1000–850 mb thickness, h, at all times of the year, with the cloud cover variable being more important during the summer months as was to be expected. This suggested that monthly models of a consistent form, each involving only the two variables thickness and cloud cover, could prove to be reasonably accurate prediction equations.

Consequently a regression analysis was used to fit the equation

$$T = \beta_0 + \beta_1 h + \beta_2 C \quad \ldots \quad (1)$$

to the data for each month in turn.

The models obtained appeared to fit the data reasonably well.

An examination of the residuals for each model suggested that maximum temperature was also highly time-dependent within the months of March to May (spring) and September to November (autumn). This can be clearly seen in Table II which shows the number of large positive and negative residuals during the first and last ten days of these months.

Table II. *Number of residuals (above one standard deviation from mean) observed during (a) the first and (b) the last ten days of each of the spring and autumn months.*

	Spring			Autumn		
	Mar.	Apr.	May	Sept.	Oct.	Nov.
(a) Positive	3	3	3	11	8	10
Negative	12	5	5	1	2	1
(b) Positive	8	5	7	2	2	0
Negative	1	2	0	2	9	9

In view of this evident time-dependence and also the basic similarity of the monthly models it was conjectured that a single model involving the two variables thickness and cloud cover, together with an adjustment for the time of year, could prove to be reasonably accurate for prediction throughout the whole year.

To assess the seasonal variation in maximum temperature the mean daily maximum temperatures for each month at Gatwick during the years 1959 to 1970 were computed and plotted against time. It appeared that this underlying seasonal variation could be adequately described by a single sinusoid and that a single harmonic introduced into the equation would be sufficient to allow for the seasonal variation in maximum temperature.

The equation

$$T = \beta_0 + \beta_1 h + \beta_2 C + \beta_3 \cos(2\pi t/365) + \beta_4 \sin(2\pi t/365) \quad \ldots \quad (2)$$

was fitted to the data using a regression analysis. In this equation t is the day number starting with $t = 1$ for the first of January. The least-squares estimates of the parameters in this model were obtained to give the prediction equation

$$T = -196.59 + 0.159h - 0.89C - 3.215\cos(2\pi t/365) - 0.206\sin(2\pi t/365) - \quad \ldots \quad (3)$$

which had a residual root-mean-square error (RMSE) of 1.51 °C and accounted for 95 per cent of the total variation in the observed maximum temperature over the three years' data. This RMSE compares well with those obtained for the monthly analyses and is smaller than most of the RMSE values in Inglis's (1970) comparison of different prediction methods using only clear summer days at Aughton from 1966 to 1969.

Although this model appeared to be quite a reasonable fit to the data, an examination of the residuals suggested that account should be taken of the interaction between cloud cover and the time of the year. It was evident from the data, and logically reasonable from a practical viewpoint, that the effect of cloud cover on maximum temperature was greater in the summer months than in the winter. To account for this interaction, a cross-product term involving cloud cover classification, C, and day of the year, t, was introduced into the model by adding $\beta_5\, C \times D$, where $D = \cos\{2\pi(t+10)/365\}$, to equation (2). This form was chosen for D so that the minimum and maximum values of D occur at $t = 172.5$ and 355, that is on 21/22 June and 21 December, the summer and winter solstices respectively. This will imply that the cloud cover will be most effective at the summer solstice and least effective at the winter solstice.

With this interaction term included in the model the regression analysis gave the prediction equation

$$T = -192.65 + 0.156h - 0.888C - 3.807\cos(2\pi t/365) - \\ -0.179\sin(2\pi t/365) + 0.320C\cos\{2\pi(t+10)/365\} \quad \ldots \quad (4)$$

which accounted for just over 95 per cent of the variation in maximum temperature and had a RMSE of 1.49 °C.

Although the extra sum of squares accounted for by the inclusion of the interaction term is not large, it was decided to retain this term in the equation since it represents a logical feature of the meteorological situation and does not over-complicate the model.

In order to use the model in equation (4) to predict maximum temperature it is necessary to estimate the expected 1000–850 mb thickness and to have an assessment of the cloud cover on a particular day of the year. Thus the model may be used for any number of days ahead provided that estimates of thickness and cloud cover are available. This feature makes the model more attractive than others involving lagged temperature that could be developed and probably would be just as accurate.

Substitution of the three values, h, C and t for any particular day into equation (4) is simple enough, but it is even easier to consider the model as if it consisted of two components, a prediction due to the thickness variable and a seasonal adjustment depending on the amount of cloud cover.

The first component, given by

$$T(\text{unadjusted}) = -192.65 + 0.156h, \quad \ldots \quad (5)$$

is tabulated in Table III. The adjustments necessary to allow for the seasonal effect and amount of cloud cover may be read from Fig. 1. The appropriate adjustment is obtained by entering Fig. 1 with the date and reading the temperature scale according to the particular cloud classification curve.

For example, an estimated thickness of 1325 gpm yields a value for T(unadjusted) of 14.0 °C. The adjustment to add to this value corresponding to a cloud classification 2 on 11 December is −4.7 °C. Therefore an estimate of the maximum temperature in this case would be 9.3 °C.

4. Assessment of the performance of the model

The least-squares estimates of the regression coefficients were based on data measured during 1968–1970. The performance of the model was assessed by comparing the predictions obtained with the observed maximum temperatures during 1978. Data were available for 355 days during that year. The

Table III. *Unadjusted maximum temperature (°C) in terms of 1000–850 mb thickness measured in geopotential metres (gpm).*

Thickness *gpm*	0	1	2	3	4	5	6	7	8	9
1240	0.8	0.9	1.1	1.3	1.4	1.6	1.7	1.9	2.0	2.2
1250	2.3	2.5	2.7	2.8	3.0	3.1	3.3	3.4	3.6	3.8
1260	3.9	4.1	4.2	4.4	4.5	4.7	4.8	5.0	5.2	5.3
1270	5.5	5.6	5.8	5.9	6.1	6.2	6.4	6.6	6.7	6.9
1280	7.0	7.2	7.3	7.5	7.7	7.8	8.0	8.1	8.3	8.4
1290	8.6	8.7	8.9	9.1	9.2	9.4	9.5	9.7	9.8	10.0
1300	10.1	10.3	10.5	10.6	10.8	10.9	11.1	11.2	11.4	11.6
1310	11.7	11.9	12.0	12.2	12.3	12.5	12.6	12.8	13.0	13.1
1320	13.3	13.4	13.6	13.7	13.9	14.0	14.2	14.4	14.5	14.7
1330	14.8	15.0	15.1	15.3	15.5	15.6	15.8	15.9	16.1	16.2
1340	16.4	16.5	16.7	16.9	17.0	17.2	17.3	17.5	17.6	17.8
1350	17.9	18.1	18.3	18.4	18.6	18.7	18.9	19.0	19.2	19.4
1360	19.5	19.7	19.8	20.0	20.1	20.3	20.4	20.6	20.8	20.9
1370	21.1	21.2	21.4	21.5	21.7	21.8	22.0	22.2	22.3	22.5
1380	22.6	22.8	22.9	23.1	23.3	23.4	23.6	23.7	23.9	24.0
1390	24.2	24.3	24.5	24.7	24.8	25.0	25.1	25.3	25.4	25.6
1400	25.7	25.9	26.1	26.2	26.4	26.5	26.7	26.8	27.0	27.2
1410	27.3	27.5	27.6	27.8	27.9	28.1	28.2	28.4	28.6	28.7
1420	28.9	29.0	29.2	29.3	29.5	29.6	29.8	30.0	30.1	30.3

predictions of maximum temperature were derived from actual observations, not predicted values, of thickness and cloud cover. It was realised that this would favourably bias the assessment, since the model has been developed as a forecasting tool, but predicted values, especially for cloud cover, could not be easily assessed from past records. However, the use of actual observations should confirm whether or not the model is highly dependent on the 1968–1970 data.

The predicted maximum day temperatures using equation (4) are shown as the dashed lines in Figs 2(a) and 2(b), superimposed on the observed maximum temperatures. The residual root-mean-square error for these predictions is 1.51 °C which is only slightly larger than that for the three years' data on which the model was developed.

The fit to this independent set of data is very good and suggests that the estimates of the parameters in the model are not highly dependent on the particular data set used to determine them and that the model is generally applicable.

The fluctuations in daily maximum temperature about the underlying seasonal trend are quite large, as may be seen in Figs 2(a) and 2(b) but the adjustments for cloud cover and thickness in the model seem to be able to follow these fluctuations quite well. Meteorological reasons for the larger errors in forecast values were not easily determinable. Those errors which occurred with a particular synoptic situation did not seem to recur in similar situations. Furthermore, an analysis of the residuals against various meterological elements was also inconclusive.

5. Concluding remarks

The prediction model described by equation (3) was developed using stepwise multiple regression analysis applied to various models involving not only the thickness variable and cloud cover classification, but several other variables which were found to contribute insignificantly to the regression sum of squares once the more important variables had been entered into the equation.

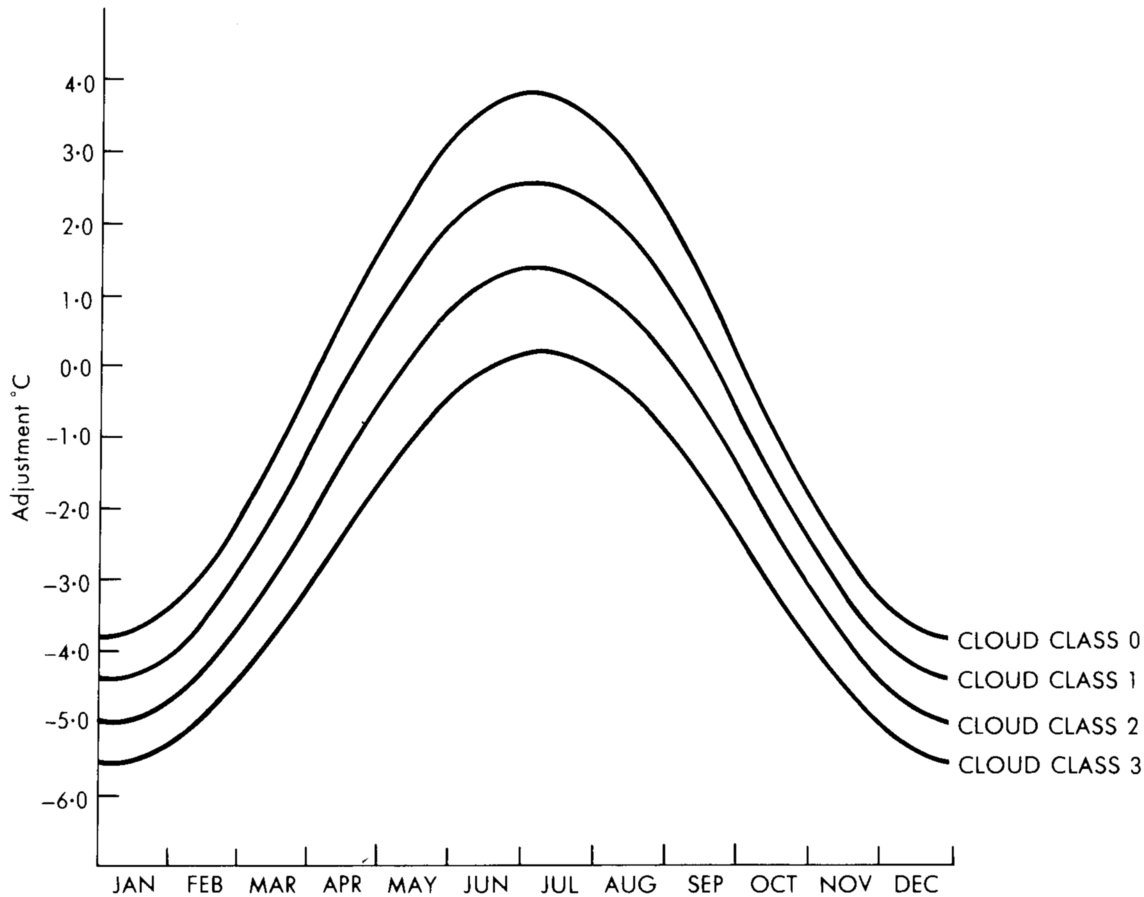

Figure 1. Adjustments to be made to figures in Table III to allow for cloud classification and seasonal effect.

Interactions other than the cloud-time interaction were also examined and found to add little to the analysis.

The resulting equation is reasonably simple to apply and has been found to be quite accurate when used to forecast recent maximum temperatures. Although there is no real evidence to suggest that the model is more, or less, accurate than other methods as a predictor of maximum temperature, the form of the model does allow it to be used throughout the year without any restriction on cloud cover.

Acknowledgement

This work is based on a degree project undertaken by N. S. Callen while employed by the Meteorological Office.

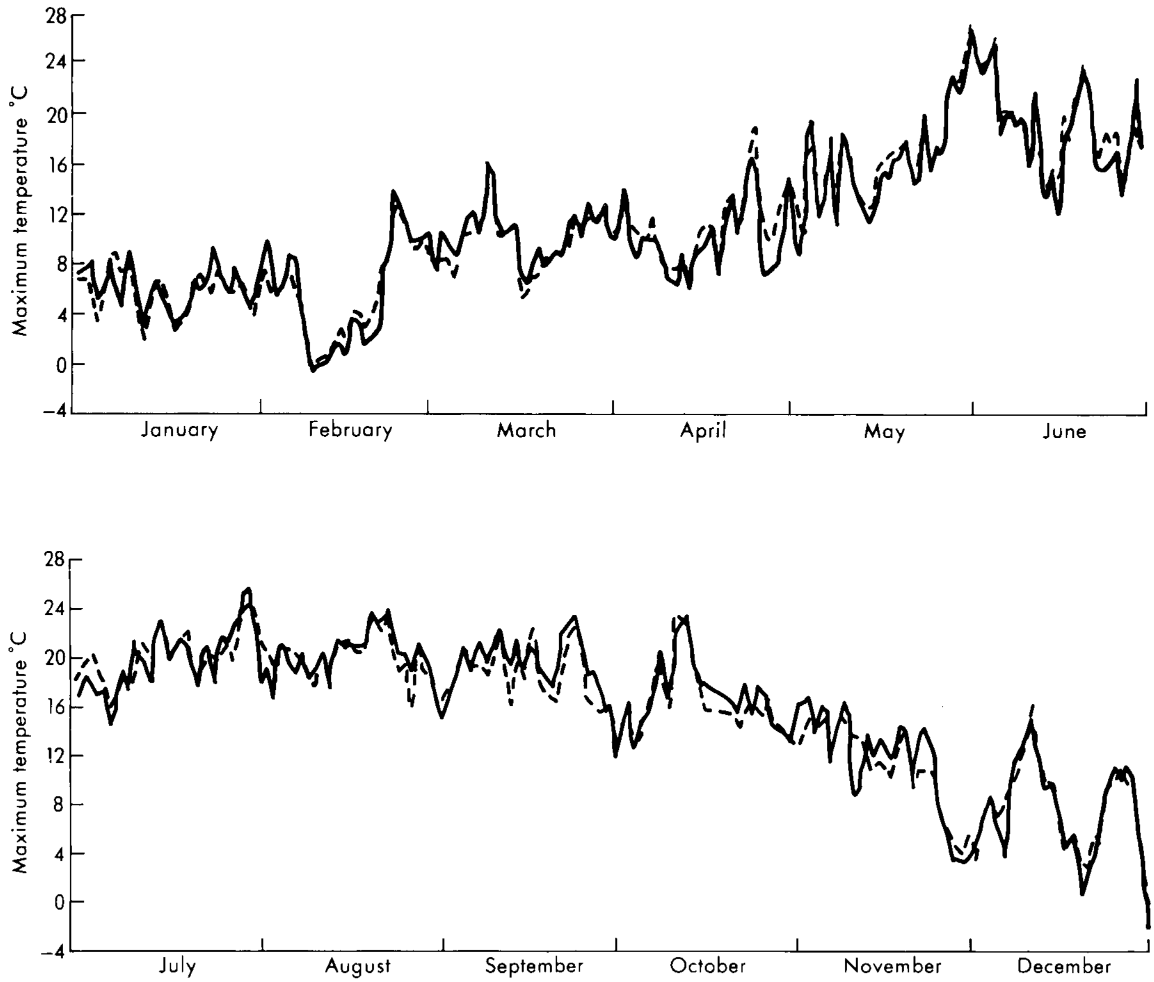

Figure 2. Plots of observed maximum day temperature (full lines) and predicted maximum day temperature (dashed lines) for (a) January to June and (b) July to December.

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Where will the heavy rain occur? — A study of the heavy rain in Northamptonshire on 26 July 1980

By P. F. Waterfall

(Nottingham Weather Centre)

Summary

Methods of forecasting heavy rain are examined in relation to the occurrence of unexpectedly heavy falls in Northamptonshire in an attempt to identify those most useful in locating heavy rainfall.

Introduction

On 26 July 1980 heavy rain occurred on a slow-moving cold front over the Midlands, although little rain was apparent on the synoptic charts. The front was positioned between Benson and Birmingham in the west, and Nottingham, Wittering and Bedford in the east. A report the following day from a farmer near Northampton of '4 inches of rain yesterday' seemed hard to credit.

Synoptic situation

At 0001 GMT a depression was situated just south of Ireland and a cold front extended from north-west Scotland to the Isle of Man thence across Wales to central southern England (Fig. 1).

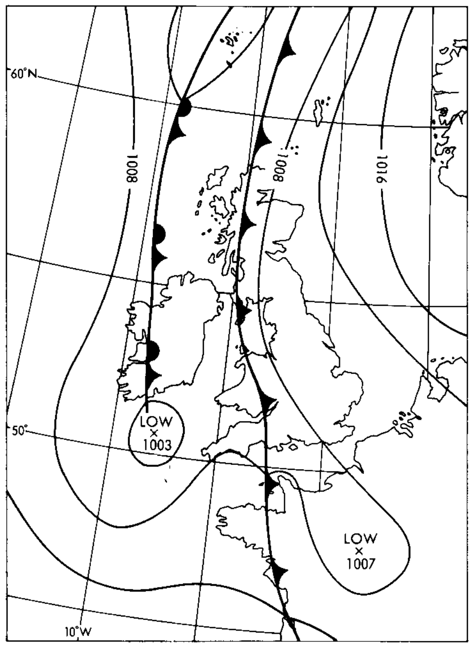

Figure 1. Synoptic situation at 0001 GMT on 26 July 1980.

The 850 mb wet-bulb potential temperature (θ_w) chart for 0001 GMT (Fig. 2) reveals the broad frontal zone lying over England and western France with a tongue of very high values, in the warm air ahead of the front, extending from central France across eastern England. Aloft, the 300 mb contour chart for 0600 GMT (Fig. 3) shows England to be situated between a ridge over Scandinavia and a trough over Biscay, with a jet stream to the north. This is a typical development situation.

Although plenty of thunderstorms were reported, most rainfall was shown as 'intermittent slight' on the synoptic charts and the hourly rainfall amounts showed nothing exceptional.

The cold front was forecast to move slowly north-east across the Midlands during the next 24 hours and outbreaks of rain, heavy and thundery at times, were expected during the day. By 0300 GMT the cold front had advanced to lie from Liverpool to Southampton. Outbreaks of slight rain were being reported at Nottingham Weather Centre and London/Heathrow Airport, all stations to the east being dry.

During the day a small depression moved across south-east England and into the southern North Sea, the cold front becoming slow-moving across the country, roughly along the line of the M1 motorway. The rain finally cleared from the east Midlands between 2200 and 2300 GMT.

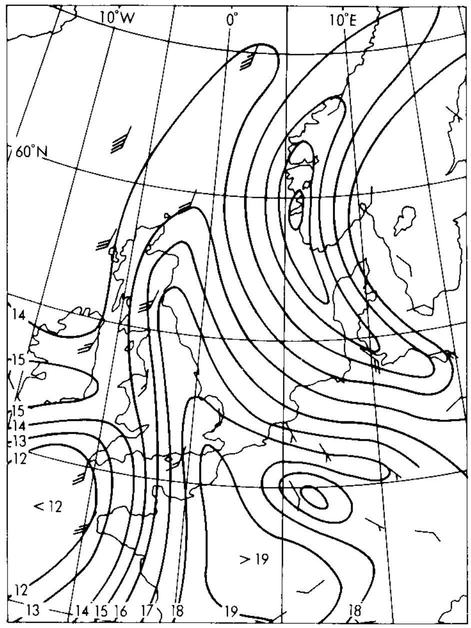

Figure 2. Winds and wet-bulb potential temperature (°C) for 850 mb at 0001 GMT on 26 July 1980.

The rainfall

The period of most intense rainfall occurred between 0500 and 1100 GMT and since this overlaps the two rainfall days (0900–0900 GMT), the 48-hour period was taken as a whole. There was no significant rain before or after that associated with the cold front under review (the occlusion over Ireland became insignificant). From 0001 to 2400 GMT on 26 July the total rainfall as reported by Meteorological Office stations in the Midlands was:

Nottingham Weather Centre	17.2 mm
Birmingham Airport	3.9 mm
Gloucester	1.2 mm
Brize Norton	9.8 mm
Benson	21.3 mm
Bedford	18.1 mm
Wittering	2.6 mm

The maximum reported hourly fall early in the day of 6.4 mm occurred at Brize Norton between 0400 and 0500 GMT. Thus the synoptic reports did not suggest any very heavy falls prior to the events in Northamptonshire.

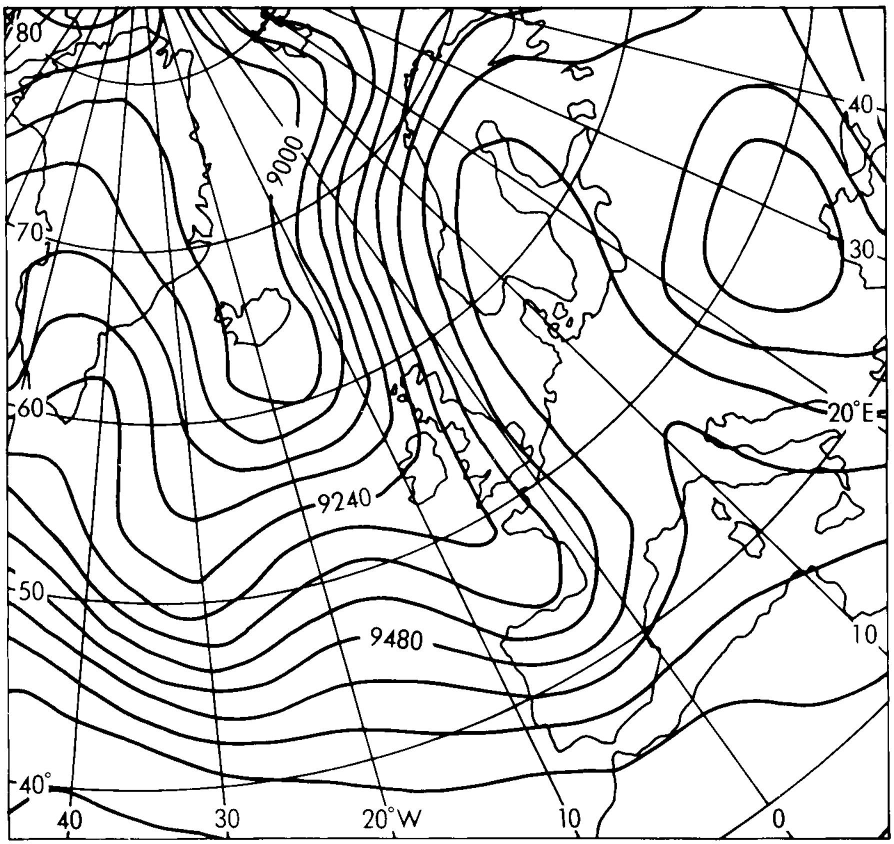

Figure 3. Central Forecasting Office 300 mb analysis for 0600 GMT, 26 July 1980. Values in geopotential metres.

The heaviest rainfall discovered in the area was the 100.4 mm (3.95 in) already mentioned — caught by Mr Turney at Brixworth. He measures his rainfall by collecting the rain in a glass jar under a 5-inch funnel. Normally readings are taken at 0600 local time but on this day the rainfall was so intense that Mr Turney was fearful his jar would overflow and measured the contents several times during the day. He must have lost some rainfall while so doing, and thus the actual fall would have been slightly greater. Between 0500 and 0930 GMT he collected 68.6 mm (2.7 in) of rain, and there was a further 19.1 mm (0.75 in) in the following hour. The amount is confirmed by the 100.1 mm recorded by the Anglian Water Authority gauge at Pitsford Reservoir which is about 3 km south of Brixworth, and the 93.4 mm (3.7 in) at Hollowell which is about 6 km west of Brixworth. A map showing the 2-day total falls surrounding the Northampton area between 0900 GMT on 25 July and 0900 GMT on 27 July 1980 is shown at Fig. 4. Rainfall records at Brixworth have been kept by the Turney family since 1915 and this was the biggest daily rainfall that they had ever measured. July 1980 also turned out to be the wettest month that they had ever recorded on their farm.

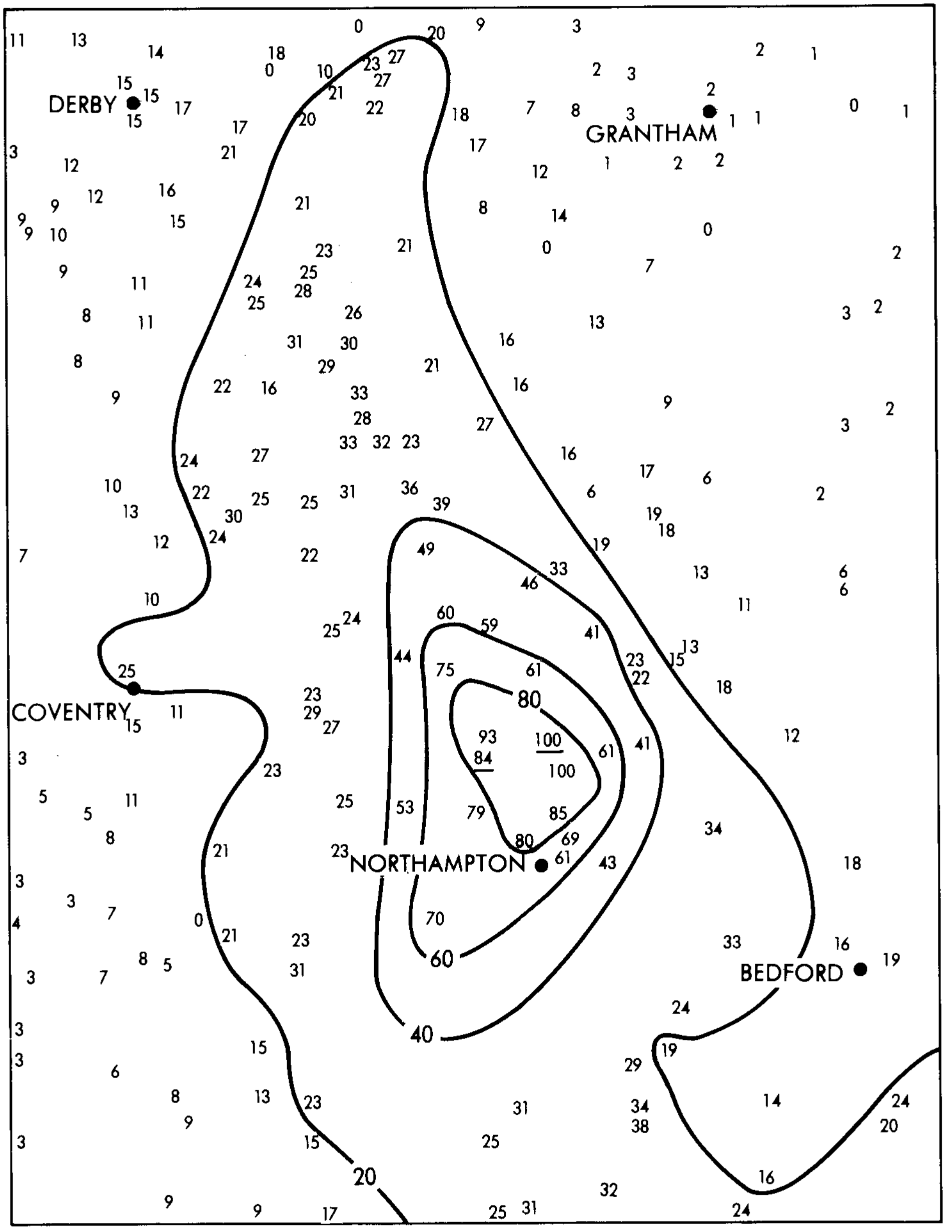

Figure 4. Total rainfall (mm) from 0900 GMT, 25 July to 0900 GMT, 27 July 1980. (The reports from Brixworth Farm and Ravensthorpe Reservoir are underlined.)

The most intense rainfall occurred quite early in the storm, 13 mm in 5 minutes being measured by recording rain-gauges belonging to the Anglian Water Authority at Stimpson Avenue, Northampton, between 0540 and 0545 GMT, and at Ravensthorpe Reservoir, which is about 7 km west of Brixworth, between 0530 and 0535 GMT. Rainfall amounts for each 5-minute period between 0500 and 1400 GMT at Ravensthorpe are shown in Fig. 5.

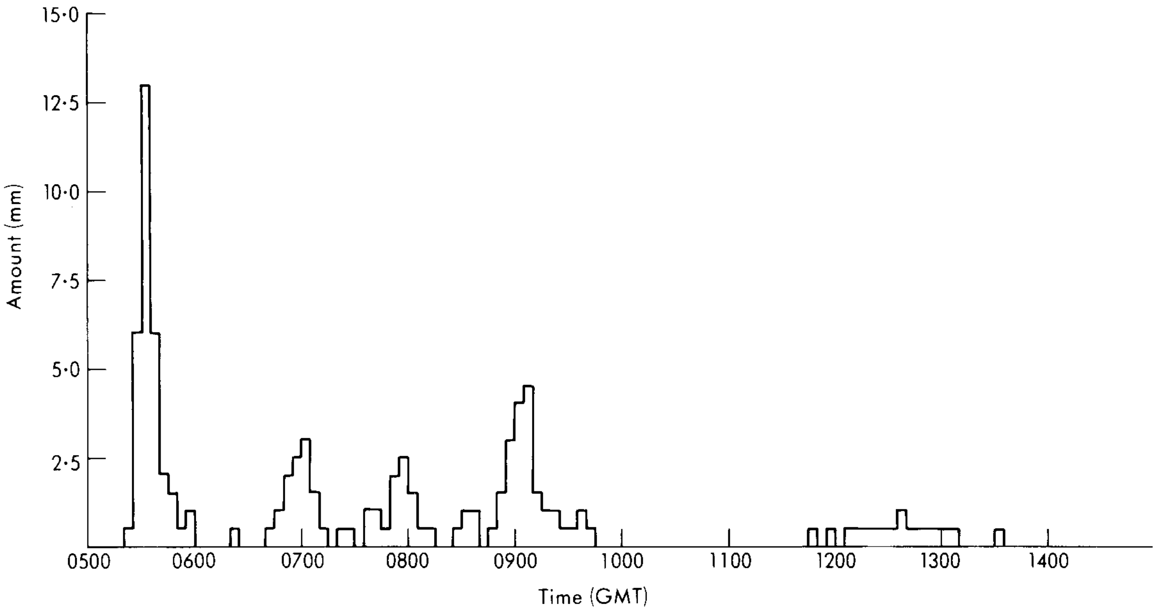

Figure 5. Rainfall amounts for each 5-minute period for Ravensthorpe Reservoir from 0500 to 1400 GMT on 26 July 1980. (Total rainfall 83.5 mm.)

Although the amounts of rain decreased later in the day and away from the Northampton area, data from other recording rain-gauges kindly supplied by the Severn–Trent, Anglian and Thames Water Authorities show a similar pattern with a short heavy burst followed by a period of mainly light rain.

The rainfall caused severe flooding in Northampton and some of the surrounding villages, and produced the highest summer flows ever recorded on the River Nene. A detailed report of the hydrological aspects of this rainfall was produced by the Welland and Nene River Division of the Anglian Water Authority (1980) and contains details of the calculated return periods for these events, some of which are in excess of 100 years; these correspond well with the readings taken at the farm.

Forecasting techniques

The *Handbook of weather forecasting* (Meteorological Office 1975), Chapter 19, section 19.7, lists those aspects to be considered when forecasting rain and many were relevant here.

Local rules for forecasting heavy rainfalls in the Trent River area in use at Nottingham Weather Centre require a depression or wave-tip over southern England, the warm air dew-point to be 4 °C or more above normal (i.e. 16 °C or higher in July) and minimum pressure at Nottingham Weather Centre to be less than 1005 mb during the rainfall day. The synoptic situation and dew-point criteria both apply to this case.

Amongst their conclusions, Ogden and Gray (1971), writing on heavy falls of rain at London Weather Centre, also draw attention to the passage of a surface low across the area, a significant association with active cold fronts, and the contribution of convective instability in the warm air. All three of these apply in this case. (The 0001 GMT radiosonde ascent for Crawley is shown at Fig. 6.)

The *Handbook of weather forecasting*, Chapter 19, suggests that for the occurrence of 'severe local storms', as described by Browning and Ludlam (1962), we require:

(i) A supply of warm moist air at low levels, i.e. high values of surface wet-bulb potential temperature (θ_w), typically about 20 °C, but the possibility of severe storms should be considered if θ_w exceeds 17 °C.

(ii) Great depth of instability.

(iii) Great buoyancy, indicated by a large excess of θ_w over the saturation wet-bulb potential temperature (θ_s) in the middle and upper troposphere.

(iv) Vertical wind shear, typically a veer with height throughout the convective layer. The convective layer is the entire troposphere for 'severe local storms', and shear between the ground and the 500 mb level is usually in the range 30–60 knots. Shear of the order of 30 knots in the lowest 150 mb (intense warm advection) is particularly favourable for storm formation.

(v) Trigger action, namely daytime surface heating, low-level convergence, or orographic uplift.

The 0001 GMT Crawley radiosonde ascent (Fig. 6) gives a value of θ_w between 17 and 18 °C, and there are potentially unstable layers from about 6000 to 24 000 ft. The average value of θ_s in these layers is between 17 and 18°C, very similar to the surface θ_w, but an inversion extends from the surface to 1000 ft and θ_w at this level is 20 °C. This ascent is fairly typical of a situation where heavy thundery rain could occur when the instability is released by convergence.

The upper-air soundings available on this day are not particularly helpful in assessing the wind shear, the nearest (Crawley) being about 140 km south-south-east of the heavy rain area. Analysis of the 0001, 0600 and 1200 GMT variations at Crawley, Hemsby and Aughton suggests that the criteria of a veer with height and a change of 30–60 kn in the wind speed between the ground and the 500 mb level could have been met in Northamptonshire, where surface winds were light and mainly north-easterly to the north of the small secondary depression between 0300 and 0600 GMT. The convergence associated with the formation of the small surface depression could provide the trigger action.

Grant (1980) draws attention to the work of Miller (1972) and Crisp (1979) in America on severe weather forecasting, and the parameters that they use suggest lines along which further investigations into synoptic techniques could proceed. However, the general lack of data west of the British Isles would inhibit some of their methods. Their ideas relating to the intersection of significant lines (frontal, convergence, moisture, etc.) seem likely to be most relevant, and accordingly a number of mesoscale analyses have been done by the Special Investigations Branch and the author to see if they would have been effective in this case. The 0600 GMT synoptic chart (Fig. 7) shows the situation shortly after the time of maximum rainfall. A mesoscale anticyclone is moving south-eastwards ahead of the advancing cold front, blocking and retarding it. This slowing down is producing local prolongation of the thundery rainfall associated with the front. The anticyclone is combining with the north-eastward movement of the small secondary low to produce the maximum low-level convergence in the warm air just ahead of the front. It is noteworthy that this is in the Northampton area.

No really significant contributions from moisture patterns were found in this case.

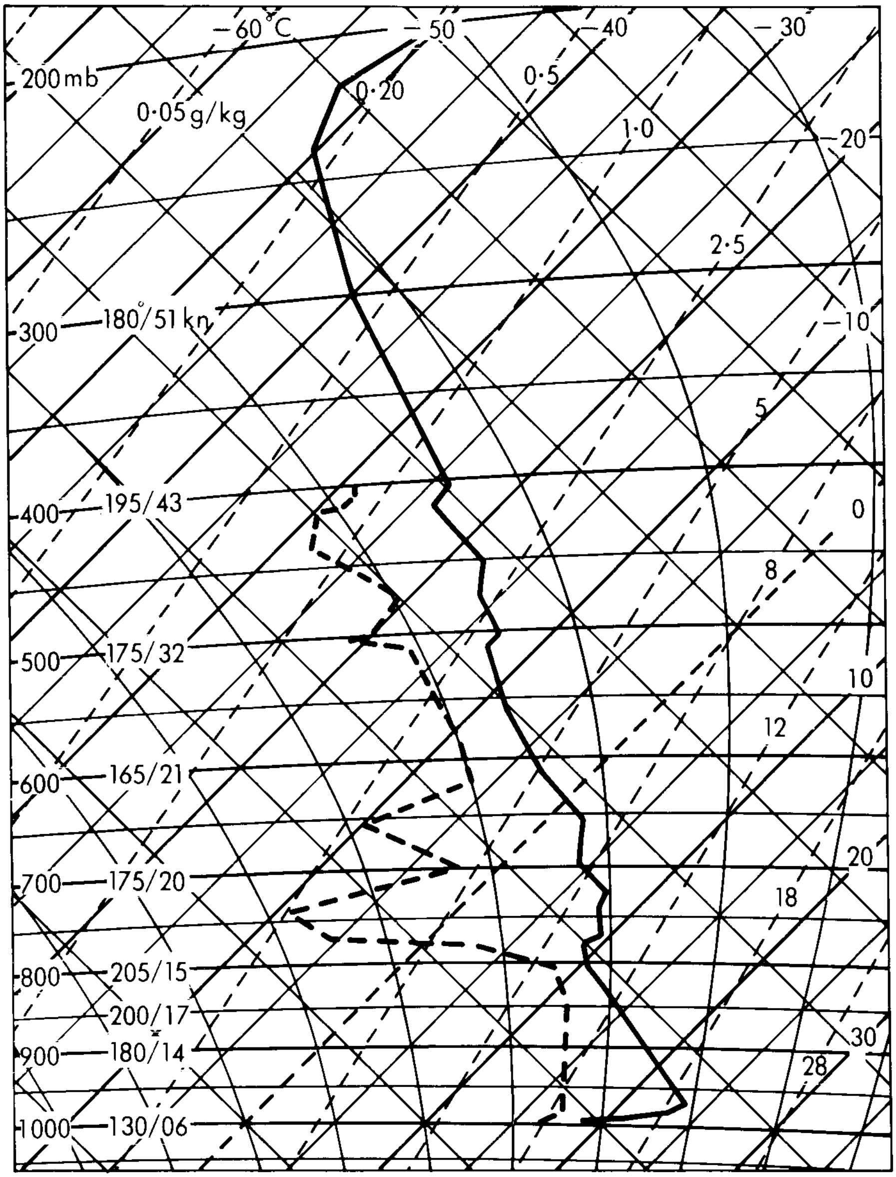

Figure 6. Tephigram for Crawley, 0001 GMT on 26 July 1980.

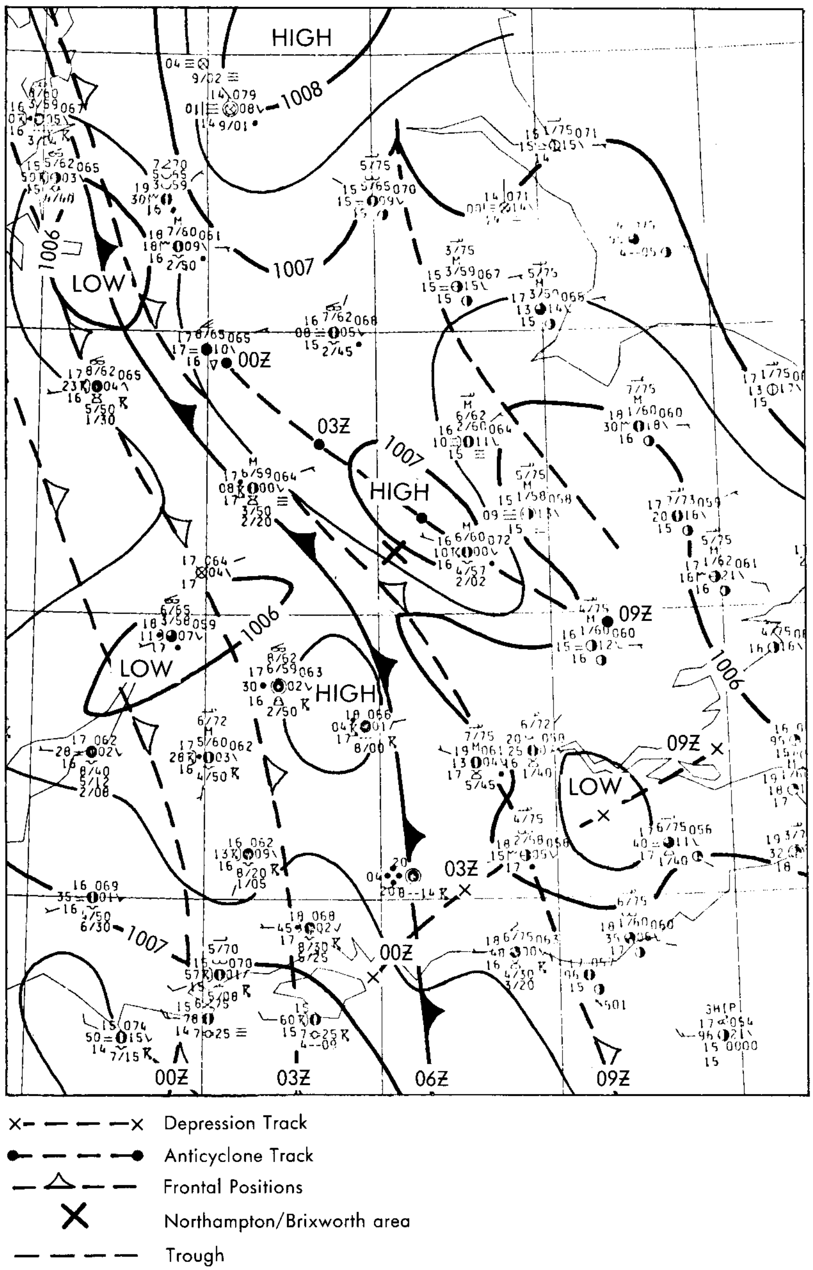

Figure 7. Surface analysis for 0600 GMT, 26 July 1980.

Conclusions

The forecasting techniques described earlier enabled the duty forecaster to provide a correct forecast of 'heavy rainfall in places' on that day, but none of it would have enabled the synoptic forecaster to provide specific and successful forecasts of the events in Northamptonshire, and the non-events elsewhere, although the Trent area heavy-rainfall rules, the mesoscale analyses and the criteria for the formation of severe local storms give some clues to why it occurred. However, it is suggested that the rules in use for the Trent area need to include a mention of the significance of areas just ahead of an active cold front. The need for careful analyses of synoptic data in these situations is also apparent.

It would seem likely from the reports by Browning (1980) and Browning *et al.* (1980) that the Areal Rainfall Radar systems now being introduced will be much more successful than synoptic techniques in dealing with occurrences of heavy rainfall, particularly where they are localized, although a major drawback is that they can only come into operation when the heavy rain commences. Radar data provided by the Meteorological Office Radar Research Laboratory at Malvern for 26 July 1980 show an area of heavy rain moving north-eastwards into Northamptonshire between 0430 and 0600 GMT, with maximum rainfall rates in the Northampton–Brixworth area between 0530 and 0600 GMT in excess of 120 mm/h. The radar picture for 0600 GMT (Fig. 8) shows the area of maximum rainfall just clearing the Northampton area.

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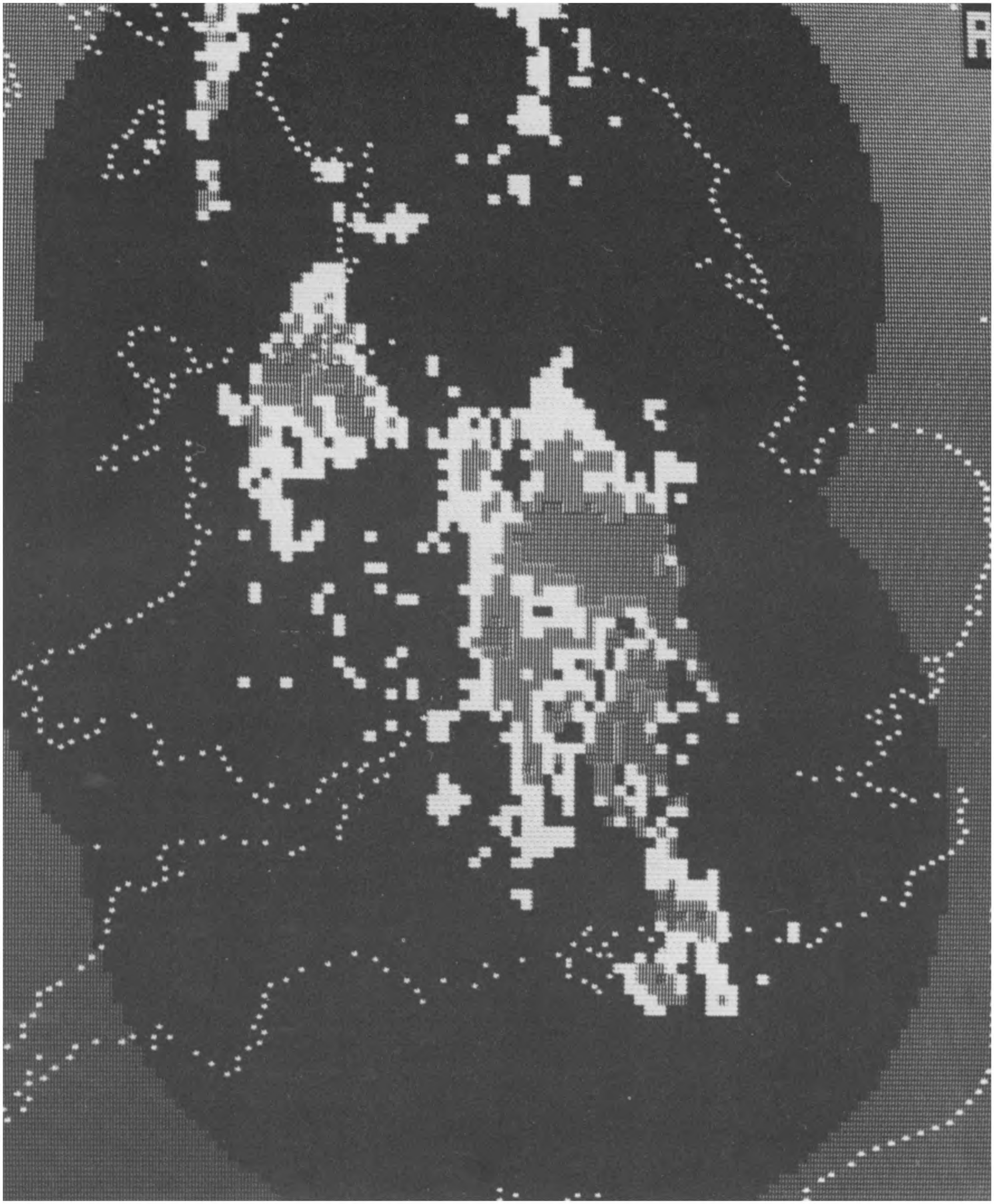

Figure 8. Rainfall radar display, 26 July 1980 at 0600 GMT. (Black represents 0 mm h^{-1}, white < 2 mm h^{-1}, light hatching < 8 mm h^{-1} and dark hatching ⩾ 8 mm h^{-1}.)

Notes and News

100 years ago

The following extract is taken from *Symons's Monthly Meteorological Magazine*, March 1882, **17**, 26.

DENSE FOG AND BLACK RAIN IN THE ISLE OF MAN.

To the Editor of the Meteorological Magazine.

SIR,—A few notes on the fog of Tuesday, February 7th, may be interesting to some of your readers. In the morning the fog gradually crept up from the sea. About noon it became very dense, assuming a yellow tint which gradually deepened into a greenish black, and from 2 to 2.30 p.m., we were enveloped in almost absolute darkness. During this remarkable half hour, a heavy shower of rain and hail fell yielding ·12 in., which on being examined proved to be quite black and to be loaded with minute particles of carbon, which, even after standing for 48 hours, did not fall to the bottom. These black particles were no doubt wafted to us from the "black country" in England and were retained in the atmosphere by the abnormally high barometric pressure which has prevailed so long (*i.e.* the atmosphere was heavy enough to retain these particles which would under ordinary conditions have fallen to the ground). At 2.30 the darkness began to decrease and the fog gradually departed in a northerly direction. From the reports of various correspondents in different parts of the Island I have been able to trace its course—at Port Erin and Castletown there was nothing but a mist; at St. John's and Kirk Michael it was dull and a few drops of rain fell, but there was no fog, while the mountains were enveloped in it; so it was confined to the eastern side of the mountains. At Ramsey there was dense fog with soft hail and rain about 3 p.m., when the gas had to be lit in the shops. Two huge black columns of cloud passed over Andreas and Bride between 3.15 and 4 p.m., and it rained briskly at the same time, but the fog was not very dense. All the "oldest inhabitants" I have "interviewed" combine in saying that they never witnessed such a phenomenon before in the Isle of Man, and this must be my excuse for writing at such length.

Yours truly,

Cronkbourne, Isle of Man, Feb. 23, 1882. A. W. MOORE.

Obituary

We regret to record the death on 28 November 1981 of Mr J. G. Moore, Principal Scientific Officer, deputy to the Assistant Director (Central Forecasting). John Moore, a graduate of London University, joined the Office in 1951 and after his initial training was posted to the Upper Air Climatology Branch at Harrow where, during the next three years, he collaborated with Miss Austin and Mrs Goldie in the preparation of Geophysical Memoir No. 103, Upper Air Temperature over the World. On promotion to Senior Scientific Officer in 1956 he moved to the Central Forecasting Office at Dunstable to begin his long association with operational forecasting work. In 1960 he joined the Dynamical Research Branch for a period, but in 1962 returned to the bench, this time at London (Heathrow) Airport. In 1966 he was promoted to Principal Scientific Officer and rejoined the Central Forecasting Office (now at Bracknell) where, apart from two years in the Special Investigations Branch, he remained for the rest of his life, becoming one of the most experienced Senior Forecasters in the Office; latterly, he was engaged in Branch administration and planning. In 1959 John Moore married one of his colleagues, Elizabeth Walsh, who herself had worked at Harrow and Dunstable.

John Moore had an excellent and well-trained bass-baritone voice which he used to give pleasure to a large number of people; he performed at Office concerts and with amateur operatic societies, and was also a member of various small vocal groups who went round east Berkshire entertaining the residents of old people's homes and other institutions. He was an active churchman, and was a churchwarden and member of the parochial church council of All Saints, Ascot.

John Moore was much liked by all who knew him, was hard-working and had a merry sense of humour; he will be much missed by all his friends and colleagues.

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NOTICES

It is requested that all books for review and communications for the Editor be addressed to the Director-General, Meteorological Office, London Road, Bracknell, Berkshire RG12 2SZ and marked 'For Meteorological Magazine'.

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Automated temperature forecasting, an application of Model Output Statistics to the Meteorological Office numerical weather prediction model

By P. E. Francis, A. P. Day and G. P. Davis
(Meteorological Office, Bracknell)

Summary

The method of Model Output Statistics is explained together with the technique for developing forecasting equations by regression analysis. Data from the Meteorological Office numerical weather prediction model and climatological archives are used to develop equations to forecast temperature extremes up to 5 days ahead and temperature at fixed hours for a 36 hour period. When applied to independent data, for the winter half of the year, these equations yield forecasts of temperature values with acceptable accuracy. Such comparisons as can be made with subjective forecasts indicate that the Model Output Statistics results are comparable with or better than the subjective forecasts, at least in terms of root-mean-square error and bias.

1. Introduction

'Model Output Statistics' (MOS) is a numerical technique for forecasting those meteorological variables that are not explicitly represented in a numerical weather prediction (NWP) model. The basis of the technique lies in identifying consistent relationships between forecast values of those variables that are explicitly represented, for example, temperatures, humidities and winds at fixed pressure levels and discrete grid points, and observed values of physically related variables such as surface temperature, cloud height and amount, and visibility. The required relationship is usually determined by means of a statistical analysis using a multivariate linear regression model.

An alternative system, the perfect prognosis method, establishes similar empirical relationships between observed atmospheric variables and the 'weather' feature of interest, and then in the forecast mode uses the forecast numerical fields as predictors in place of the observed variables. The strength of the perfect prognosis (PP) method is that it is independent of the NWP model used to obtain the forecast predictor variables and only the final forecast 'weather' values are model dependent. In contrast, the MOS method is model dependent; the established empirical relationships tending to compensate for persistent bias in model forecasts, for example phase errors in synoptic scale waves. This gives an advantage in terms of the accuracy of results for MOS at the expense of the need to re-examine the relationships used when significant changes are made to the NWP model. Any improvements in numerical weather forecasting will bring the performances of the MOS and PP methods closer together, since, given greater accuracy in the forecast fields, the major weakness in both MOS and PP systems will always be the inherent errors of a statistically based relationship between local and synoptic weather patterns, whether actual or forecast.

A considerable amount of work on MOS has been carried out by American research groups, using the technique to forecast a wide variety of weather variables, with mixed success. The work of most interest in the present context is contained in a series of papers (Klein and Hammons 1975; Hammons, Dallavalle and Klein 1976; Carter, Dallavalle, Forst and Klein 1979) in which an operational system for the automated forecast of surface temperatures is developed and assessed. The success of that system has provided much of the impetus for carrying out the limited trial described in this paper.

As a preliminary to presenting the results of the trial we consider it important to outline briefly the principles and methods adopted in constructing the statistical model on which the results are based. The package of computer programs for the statistical analysis was taken from BMDP-79 developed at the Health Sciences Computing Facility, University of California, Los Angeles.

2. The Statistical model

An examination of the many published papers that discuss MOS applications reveals an uncritical reliance on the use of multiple regression techniques to produce predictive equations that express as much as possible of the variance of the predictand. The question of the stability of such equations when applied to independent data is not explored in any depth, and little attempt is made to justify the inclusion of physically unrelated variables as predictors. The statistical techniques described in these papers are interesting in themselves but it is doubtful if they constitute a sound enough basis on which to build a prediction model. A more reasoned approach to the question of selection of predictors is certainly worth considering.

The solution adopted here is two-fold in structure. First, only those observations of weather variables and those products of the NWP model which can be seen as being related to the predictand in a physical sense are presented to the regression screening process as possible predictors. The second step is to curtail the regression screening process in a manner which takes into account the meteorological implications of the predictors selected by the statistical technique. These restrictions ensure that there is an underlying physical coherence in the prediction system, a coherence that is strengthened by the inclusion of physical processes in the NWP model. The resulting predictive equation should then apply to independent data in a more stable manner, and perhaps also carry over to a different NWP model. Note that it is difficult to determine the relative statistical significance of predictors that are sometimes closely correlated with one another.

Stage one of the selection process effectively limits the number of possible predictors, to the degree that a selection process called 'all possible subsets' regression can be employed in preference to the more usual 'stepwise' regression procedure. 'All possible subsets' regression presents the results of combining the offered predictors into groups of increasing size, allowing those combinations that express the higher amounts of variance of the predictand to be examined. 'Stepwise' regression follows a path of including or dropping predictors, starting with the predictor that singly expresses most variance. The experience of the authors is that the more comprehensive choice offered by 'all possible subsets' allows more powerful combinations of predictors to be found, especially when more than two or three predictors are to be included in the group. Which combination to use as the predictive equation is determined by insistence on a physically meaningful role for every component of the equation, the inclusion of extra variables being stopped at the point beyond which no physical significance can be attributed to the new predictor. When a choice of equations is available, i.e. several meaningful combinations with the same number of components in each, the combination expressing the highest amount of the variance of the predictand is chosen.

Two applications of MOS methods are reported in this paper, both of which use equations constructed following the rules given above. The test of these rules is whether or not they yield stable and consistent predictive equations, judged by their performance on independent data.

3. Data

The Meteorological Office numerical weather prediction model is a grid-point model with ten levels which is routinely operated in two versions. The fine-mesh version has a grid spacing of 100 km in mid latitudes and covers a rectangular area over the North Atlantic and western Europe. The coarse-mesh version covers the Northern Hemisphere down to 20° N and has an equivalent grid spacing of 300 km. Both versions of the model are run twice a day, at midnight and midday GMT. Output from the models is in the form of analysed and forecast values of a number of meteorological variables at each grid point and every pressure level from 1000 to 100 mb. These grid-point values are routinely stored on magnetic tapes for a limited period. After eighteen months the cyclic usage of these tapes causes the data to be lost by over-writing. A more extensive archive of data for MOS purposes was initiated by extracting data, for a limited area round the United Kingdom, starting from the then current eighteen months of forecast archive which extended back to October 1978. Thus there are now nearly three years of data in the MOS archive.

In order to investigate MOS applications at the location of observing stations, the model grid-point values are then interpolated to the position of the relevant station. Thus there are also in existence a number of 'single station' forecast data sets that contain the interpolated model variables. During the period of the MOS archive there have not been any major changes in the Meterological Office NWP model, hence the data in the archive are reasonably consistent.

In addition to forecast data, the most recent observed data are used in the regression model. The climatological archives of the Meteorological Office contain quality controlled archives of the necessary observations. Data from these archives and the 'single station' MOS archives are submitted together to the regression screening process.

4. Development of a model for temperature forecasting

When making a forecast of temperature, the subjective forecaster has to take into account the thermal structure and the moisture content of the air masses expected to be influencing the weather in his area during the forecast period. Cloud cover at medium and low levels also has to be forecast, as well as wind speed and direction. These variables greatly influence the radiative heat balance which controls surface temperatures, especially during hours of darkness. As far as possible, any objective forecasting model such as MOS must be designed to include representations of these processes.

Two applications of MOS are considered in this paper, the forecasting of daily temperature extremes and the forecasting of temperature at fixed hours. Both applications should be governed by the above guidelines, and consequently the forecasting models should be similar in content. The possible predictors that are physically sensible are shown in Table I, but not all these could be presented to the regression program at once and a careful reduction was necessary. Preliminary work indicated a broad division of the forecasting problem into two categories, viz day-time and night-time hours. During daylight hours, i.e. for maximum temperature and, say, 09–18 GMT, the preferred combination of predictors was usually taken from forecast temperature values at 1000 mb and relative humidity values at 700 mb. During night-time hours, forecast 1000–850 mb thickness values, 950 mb relative humidity, and 1000 mb wind speeds were preferred for minimum temperatures and fixed-hour values. This broad grouping of predictors enabled the reduction in numbers of possible predictors required. Relevant observations from Day 0 were also included as shown in Table I.

Table I. *Variables available for selection by the regression programs*

Numerical weather prediction model variables	Day 0 station observations	MOS predictions
1000 mb temperature	minimum temperature	Day 1 minimum
1000–850 mb thickness	06 GMT temperature	Day 1 maximum
950 mb relative humidity	12 GMT temperature	
850 mb relative humidity	14 GMT temperature	
700 mb relative humidity	12 GMT dew-point	
1000 mb wind speed	14 GMT dew-point	
1000 mb *u* wind component (relative to model grid)	12 GMT low-cloud amount	
	14 GMT total cloud amount	
1000 mb *v* wind component (relative to model grid)		

The predictive equations for temperature extremes were developed using data from the coarse-mesh grid, since extended period forecasts were to be made. Data from the fine-mesh NWP model were used to develop the forecast equations for temperatures at fixed hours. In both cases data were taken from the midday forecast run, and from two 6-month winter seasons, i.e. October to March in 1978/79 and 1979/80. The independent data for testing purposes were the corresponding period of 1981/81. At the time of writing (July/August 1981) only two summer seasons are available; preliminary tests have shown this is not really a sufficiently wide data base to give reliable results. Eventually 3-month seasons may be employed but a sufficient number of cases would have to be aggregated first. The relative advantages of shorter seasons on which to have data are shown in Hammons, Dallavalle and Klein (1976).

5. Forecasting maximum and minimum temperatures

(a) *Preamble*

Four stations were chosen in an investigation of the usefulness of MOS techniques in forecasting maximum and minimum temperatures. The stations are in different climatic areas of the United Kingdom and were expected to pose different problems during the investigation. The stations are Exeter in the south west, Dyce near Aberdeen in north-east Scotland, Waddington near Lincoln in central east England, and Heathrow Airport near London. Following the technique described earlier a set of variables considered to be physically relevant was offered to the regression analysis program, with maximum temperature (09 to 21 GMT, tomorrow) or minimum temperature (21 GMT tonight for 12 hours) as the dependent variable (the predictand). Once the equations for Day 1 were finalized the process was repeated for Day 2 with the addition of the forecast maximum and minimum values for Day 1 as extra predictors. The combinations of variables chosen for the four stations are shown in Table II.

(b) *Evaluation of prediction equations*

There are a number of features common to the equations for the four stations. At all the stations the equation for Day 1 maximum temperature includes the 14 GMT station temperature observation, this being probably the latest temperature observation available. These equations also include two forecast 1000 mb temperatures with assessment times of 12 and 18 GMT on Day 1. The fourth variable in these

Table II. *Variables used in the selected prediction equations for* (a) *maximum temperature and* (b) *minimum temperature*

(a)

Model variable used in forecast	Forecast period in hours: T + 24 (T + 48)	T + 30	(T + 72)
1000 mb forecast temperature	H_1 W_1 D_1 E_1 H_2 W_2 D_2 E_2	H_1 W_1 D_1 E_1	
1000–850 mb forecast thickness			H_2 W_2 D_2 E_2
1000 mb forecast *u* wind component (relative to model grid)	D_1	E_1	
700 mb forecast RH	H_1	W_1	

For Day 1 predictions all stations also use the observed 14 GMT temperature on Day 0 at their site. For Day 2 predictions all stations also use the Day 1 predicted maximum temperature.

(b)

Model variable used in forecast	Forecast period in hours: (T + 30)	T + 12 (T+ 36)	T + 18 (T + 42)	(T + 48)
1000–850 mb forecast thickness		D_1	H_1 W_1 E_1 H_2 W_2 E_2	D_2
950 mb forecast RH	H_2 W_2 E_2	W_1 D_2	H_1 D_1 E_1	
1000 mb forecast wind speed		H_1 W_1 E_1 H_2 W_2 E_2	D_1 D_2	
1000 mb forecast *u* wind component (relative to model grid)	D_2	D_1		
1000 mb forecast *v* wind component (relative to model grid)		D_1 D_2		

H_1, W_1 and D_1 also use the observed 12 GMT temperature and E_1 the observed 14 GMT dew-point on Day 0 at their site. H_1, W_1 and E_1 also use their observed total cloud amount at 14 GMT on Day 0. All stations also use the predicted Day 1 maximum for predicting the Day 2 minimum.

H = Heathrow, D = Dyce, E = Exeter, W = Waddington

Subscript 1 denotes Day 1 predictions and subscript 2 denotes Day 2 predictions (bracketed forecast periods).

equations for Day 1 maximum temperature varies from station to station. At Heathrow and Waddington a forecast value of 700 mb relative humidity (RH) is chosen, although for different assessment times, which value, along with a negative coefficient, serves to act as a cloud indicator. At Dyce and Exeter the particular arrangement of topography necessitates the inclusion of a forecast component of wind, again at different assessment times. Equations with more than four variables show little improvement in forecast results. The forecast equation for the Day 2 maximum temperature at all stations uses a thickness value valid T + 72h (there being no 1000 mb temperature for or beyond T + 48h), where T is 12 GMT on Day 0. The forecast maximum temperature for Day 1 is also included as a term in the equations for Day 2, taking the place of the 14 GMT temperature value in the equations for Day 1.

The equations for minimum temperature forecasts show Dyce to be anomalous compared with the other three stations. In addition to an observed temperature on Day 0, a forecast surface resultant wind speed, i.e. at 1000 mb, relative humidity at 950 mb and a 1000–850 mb thickness, common to all stations, the equation for Dyce includes both forecast components of surface wind in place of the observed total cloud amount at 14 GMT on Day 0. These wind components are not difficult to justify on physical grounds, bearing in mind the effect of wind coming off the North Sea or over the Scottish mountains. Similar equations are obtained for minimum temperatures on Day 2, except that the forecast maximum temperature for Day 1 replaces the Day 0 temperature observation and the Day 0 cloud amount is no longer a significant predictor.

The equations obtained from the regression analysis were used to forecast maximum and minimum temperatures in a third, independent, season; October 1980 to March 1981. The errors of the forecasts are summarized in Table III, where the corresponding statistics for both climatological and persistence forecasts are also included. The results of the MOS forecasts are significantly better than those using persistence or climatology but what is really needed is a comparison with subjective forecasts issued at roughly the same time, i.e. 1630 GMT.

Table III. *Root-mean-square errors in forecasts of* (a) *maximum temperature and* (b) *minimum temperature for the period from October 1980 to March 1981*

Station	Standard deviation in observed maxima	Root-mean-square errors in the forecasts				
		Day 1		Day 2		
		MOS	Persistence	MOS	Persistence	Climatology
		degrees Celsius				
(a)						
Dyce	3.7	1.9	3.1	2.4	4.1	3.5
Exeter	3.5	1.5	2.4	1.9	3.1	3.1
Heathrow	3.9	1.7	2.7	2.1	3.5	3.2
Waddington	4.0	1.6	2.9	2.1	3.8	3.5
Combined	3.8	1.7	2.8	2.1	3.6	3.3
(b)						
Dyce	3.3	1.7	3.4	2.3	4.0	3.1
Exeter	4.5	1.9	4.0	2.5	5.3	4.6
Heathrow	4.6	1.8	3.7	2.3	5.0	4.4
Waddington	3.9	1.6	3.2	2.2	4.3	3.7
Combined	4.1	1.8	3.6	2.3	4.7	4.0

Forecasts of 'tomorrow's' maximum temperature may be compared by means of a coarse score evaluated by several meteorological outstations in order to judge the accuracy of radio forecasts issued by London Weather Centre at 1755 clock time. This is not a particularly sensitive score, since errors are categorized and marked in 2 °C bands, though it allows a rough comparison to be made when the MOS forecast errors are marked in the same way. At Heathrow and Waddington MOS and subjective forecasts both score around 87% of possible marks, at Exeter MOS results (91%) are 8% better than subjective, while at Dyce the subjective results are clearly better (90% compared to 84%). This poor result at Dyce is also immediately apparent from the figures in Table IIIa where the root-mean-square (r.m.s.) error values for maximum temperature forecasts at Dyce are higher than for the other stations in spite of a relatively low variance in observed maxima. These results are probably due to a higher day-to-day variation of maximum temperature at Dyce in the 1980/81 winter season, confirmed by the higher persistence errors.

Other easily obtainable forecasts are those issued by London Weather Centre in the mid afternoon, giving the overnight minimum temperature for Heathrow. The r.m.s. error of these forecasts is 2.0 °C, slightly higher than the result of the MOS forecasts, 1.8 °C. Mean errors are comparable, both forecasts having a negative bias, i.e. forecasting too cold on average, in this particular period. Root-mean-square errors of less than 2 °C are also obtained using the MOS method for all of tomorrow's maximum temperature forecasts (Table IIIa) and the overnight minimum temperature forecasts (Table IIIb). Beyond 24 hours it is apparent that in winter it is easier to forecast maximum temperatures; the overall r.m.s. error (combining all four stations) for the day after tomorrow's maximum forecast being 2.1 °C compared to the value of 2.3 °C for tomorrow night's minimum temperature r.m.s. forecast error.

(c) *Extended period forecasts*

Finally in this section on forecasting extreme temperatures it is tempting to explore the possibilities of forecasting for several days ahead, using forecast information from the octagon. Fig. 1(a) shows the r.m.s. error values, aggregated for all 4 stations, of equations that forecast temperature extremes up to 5 days ahead, for the period October 1980 to March 1981. These equations follow the style of those for the Day 2 extremes, i.e. they incorporate the forecast maximum for the previous day as a predictor for both maximum and minimum temperature of the current day. The number of variables used in the equations reduces as the forecast period increases, until in some cases only the previous day's maximum is used in the equation. Another noticeable feature of the equations is that relatively later forecast temperatures and thicknesses are used as the forecast period increases. Thus equations for Day 4 temperature extremes already contain forecast data valid for Day 5. This is undoubtedly a result of phase errors known to occur in the numerical model. The r.m.s. error values associated with climatological forecasts are also shown in Fig. 1(a), and by Day 5 the overall MOS values of r.m.s. error are still better than those of climatology. Fig. 1(b) illustrates the change in mean errors of the maximum and minimum forecasts up to Day 5, again for the period October 1980 to March 1981. These are comparable with the mean errors of climatological forecasts (−0.3 °C for maxima and −0.5 °C for minima).

The medium-range forecaster in the Central Forecasting Office (CFO), Bracknell, makes a daily forecast of maximum and minimum temperatures for Heathrow, but using information based on the midnight NWP model run. A comparison of forecast errors for Heathrow temperature extremes is possible if the CFO forecasts are given an extra 12 hours 'lead time' in order to allow for the later data available to a MOS forecast based on 12 GMT NWP products. Fig. 2 contains r.m.s. error and mean error information for temperature extreme forecasts by both MOS and subjective methods up to 120 hours ahead. In Fig. 2(a), again using independent data from October 1980 to March 1981, it can be seen

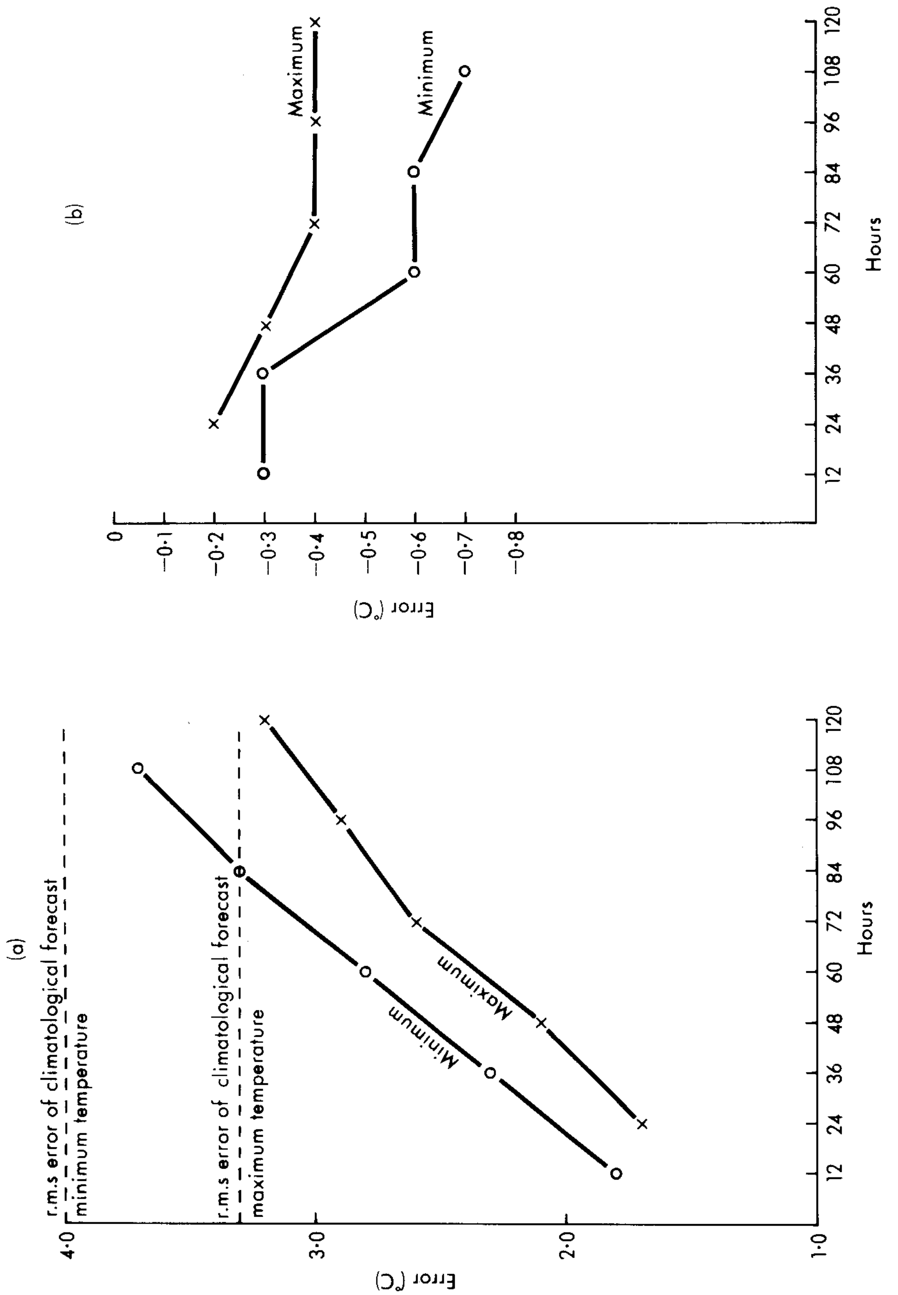

Figure 1. Maximum and minimum temperature forecasts for all stations, October 1980–March 1981. (a) Root-mean-square error values and (b) mean error values.

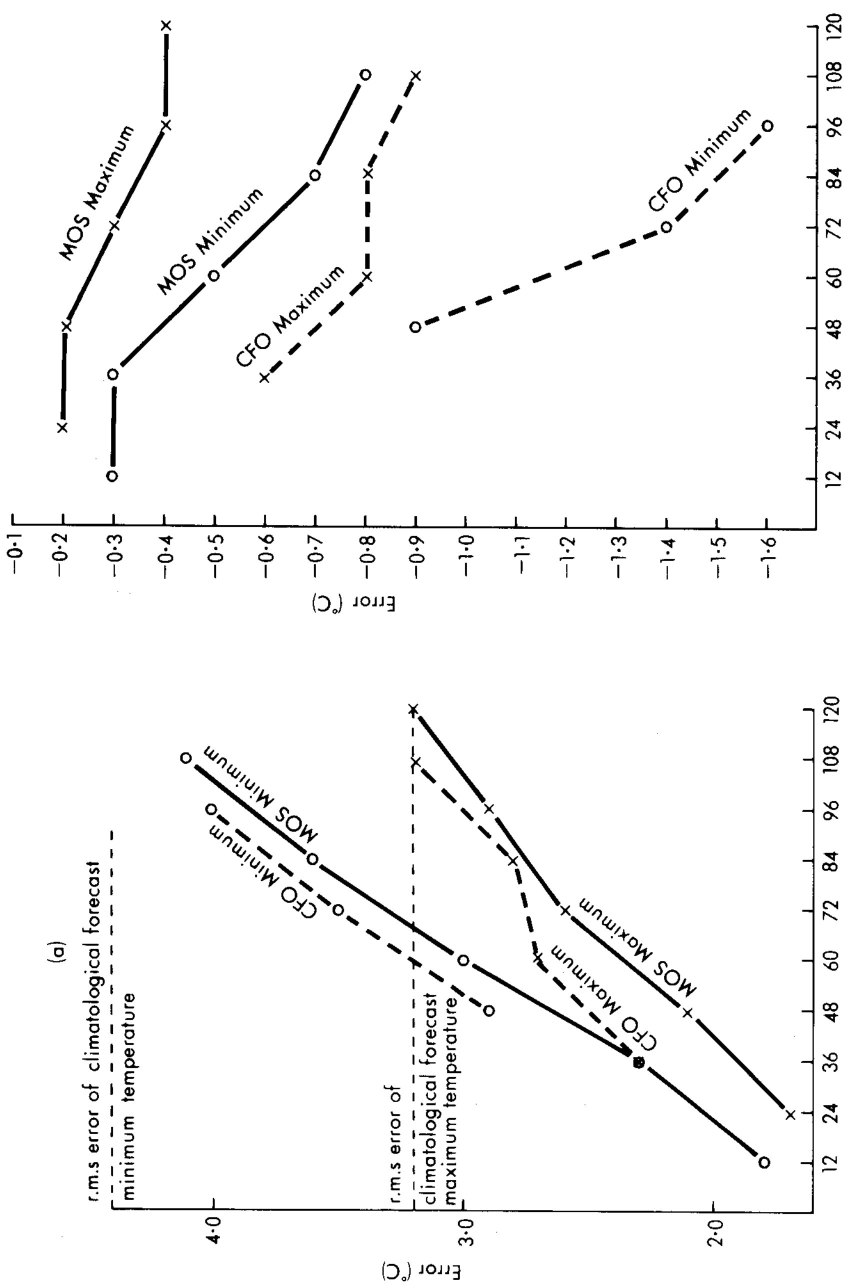

Figure 2. Maximum and minimum temperature forecasts by MOS and CFO for Heathrow, October 1980–March 1981. (a) Root-mean-square error values and (b) mean error values.

that the r.m.s. error values for MOS forecasts are slightly, but consistently, better than those obtained by subjective methods. Curiously, the results for forecast maxima are more separated at the beginning of the period rather than at the end. It is when the values of mean errors are examined, Fig. 2(b), that one strength of the MOS method is revealed. The subjective forecasts in CFO have an increasing cold bias over the period, especially the minimum forecasts, an effect that is much less marked in the MOS results. A comparison of the standard deviation of errors for the two groups of forecasts shows similar values for the minimum forecasts throughout and for the maximum forecasts beyond Day 2. Climatological forecasts for Heathrow over the same six-month period have mean errors of −0.2 °C for maximum and −0.8 °C for minimum.

6. Forecasting temperatures at fixed hours

(a) *Preamble*

London Weather Centre (LWC), in common with some other public service offices, issues temperature forecasts for periods of from 24 to 36 hours ahead with values at two hour intervals through the period. These forecasts are used by regional Gas Boards to estimate the demand for gas.

The main forecast is that issued at 1530 hours clock time which covers the 36 hour period from 1700 on Day 0 to 0500 on Day 2. This forecast is based on numerical products from the 00 GMT run, modified in the light of an up-to-date surface analysis.

A trial was initiated to determine whether MOS forecasts could produce values of temperature at fixed hours as good as subjective forecasts for the same period. The LWC 'Met Gas' forecast at around 1530 is ideally suitable for a comparison with MOS products based on the 12 GMT run on the NWP models. LWC assess their forecasts against temperature observations taken at LWC, these being representative of the inner city area with a marked 'heat island' effect. It was decided that in addition to producing forecast temperatures at fixed hours for checking at LWC, the opportunity would be taken to produce similar forecasts for checking at Heathrow, where a larger variance is exhibited in the diurnal temperature curve. This station was taken as being more representative of the London suburbs, but an additional reason for extending the trial to Heathrow will be discussed in the section on rationalization.

LWC provided information containing the Met Gas forecasts issued from October 1980 to March 1981. MOS equations for these 'winter' months were then developed for both LWC and Heathrow using actual data from climatological archives and forecast data from both fine-mesh and coarse-mesh NWP models run on 12 GMT data. The coarse-mesh model data were used to extend the forecast period beyond the latest assessment time of data from the fine-mesh model, i.e. 00 GMT on Day 2. A separate equation was derived for temperature at each of the synoptic hours from 18 GMT on Day 0 to 06 GMT on Day 2. The variables offered as predictors were again those listed in Table I.

(b) *Evaluation of prediction equations*

Table IV shows the variables that were chosen for each of the forecast equations for the two stations and illustrates the similarity between the choice of predictors for each station. Most of the forecast equations use the starting temperature at 14 GMT on Day 0, with the exception of those for times near that of minimum temperature when the midday temperature value is sometimes preferred. The other observed parameter sometimes selected is the cloud amount at 14 GMT on Day 0, an obvious indicator of radiation receipt and thus of temperature change. This predictor is used in equations for times up to midnight. The choice of predictors from the NWP model forecast fields varies from night to day; the preference is for 1000–850 mb thickness values at night but 1000 mb temperature values during the day (cf. variables for maximum and minimum temperature forecasts in Table II). This effect may be a result of the

Table IV. *Variables used in the prediction equations for temperatures at fixed hours (GMT)*

		Day 0 18	 21	Day 1 00	 03	 06	 09	 12	 15	 18	 21	Day 2 00	 03	 06
Day 0 station observations:	12 GMT temperature				H	H							L	L
	14 GMT temperature	L H	L H	L H	L	L	L H	L H	L H	L H	L H	L H	H	
	14 GMT total cloud amount	L H	L H	H										
NWP model variables:	1000–850 mb forecast thickness	L H	L H	L H	L (2) H (2)	L H					H	L H	L H	L H (2)
	1000 mb forecast temperature						L (2) H	L (3) H (2)	L (2) H (2)	L (3) H (2)	L (2) H	L	L	L
	1000 mb forecast wind speed		L H	L H	L H	L H	L H	H			H	H	L H	L H
	700 mb RH							L H	L H	L	L			
	950 mb RH	H	L H	L H	L H	L H	L H				H	L H	L H	L H

L = London Weather Centre, H = Heathrow.

Figures in brackets indicate the number of time levels at which forecast values of that variable are used in the equation.

method used in the NWP model to calculate 1000 mb temperatures from the basic height fields. During the night both the 950 mb RH and 1000 mb wind speed are used. The choice of 950 mb RH can be seen as an approximation to two variables used by forecasters, namely the representative dew-point of the air mass and the average amount of low cloud or fog overnight. The 1000 mb wind speed corresponds to the use by the forecaster of the forecast strength of surface or gradient wind. During the morning hours the importance of the wind speed–relative humidity combination decreases and eventually the forecast 700 mb RH alone is selected, presumably again as an indicator for cloud amount. The respective roles of the relative humidity terms are more apparent when the signs of the coefficients for each term are examined. The 950 mb terms have positive coefficients, high humidities giving higher night-time temperatures (lower radiation loss); the coefficients of the 700 mb RH terms are negative, high values leading to lower daytime temperatures (lower radiation receipt). Similar combinations of predictors are found in the equations for maximum and minimum values.

The variables chosen from the NWP model are usually measured within six hours of validity time, except for the second night when some predictors are valid for 12 or 18 GMT on Day 1. The explanation for this timing anomaly is probably that, without a midday observed temperature for use as a base value, i.e. as for Day 0, some degrees of reliance is put on a notional maximum forecast temperature, i.e. using NWP model values for assessment at 12 or 18 GMT. As an alternative approach, the forecast MOS temperature values for Day 1 at 12 and 15 GMT were offered to the regression model as predictors (cf. the process for maxima and minima beyond Day 1) but they were not selected. The percentage of variance expressed by the equations for the dependent samples ranged from 95% at 18 GMT on Day 0 for both stations to 77% (Heathrow) and 84% (LWC) at the end of the forecast period.

The chosen prediction equations were tested by using as an independent sample the data for October 1980 to March 1981. The performance of the MOS equations can then be directly evaluated against that of the subjective temperature forecasts for LWC, kindly made available by the Principal Meteorological Officer. The r.m.s. errors (Fig. 3) for the MOS forecasts of LWC temperatures are about 0.5 °C lower than those of the subjective forecasts for most of Day 1. By the end of the forecast period this difference has increased to almost 1 °C, e.g. compare 2.5 °C with 1.6 °C at 03 GMT. Indeed, MOS forecasts for 36 hours ahead have similar errors to the subjective forecasts for only 12 hours ahead. The number of large errors (⩾ 3 °C) is correspondingly lower throughout the period for the MOS forecasts (Fig. 4), the number being less than a third of those for the subjective forecasts during the second night, e.g. 44 against 12 at 03 GMT. The r.m.s. errors for the MOS estimates at Heathrow are higher than those for LWC as would be expected with the increased variance in the temperature data, the value at 06 GMT on Day 2 being 2.4 °C. The mean errors (Fig. 5) for both sets of MOS forecasts show a small negative bias, i.e. are too cold, whereas the subjective forecasts for LWC show a very marked diurnal variation in bias together with an increasing negative trend. This feature of small bias strongly reinforces the value of MOS forecasts.

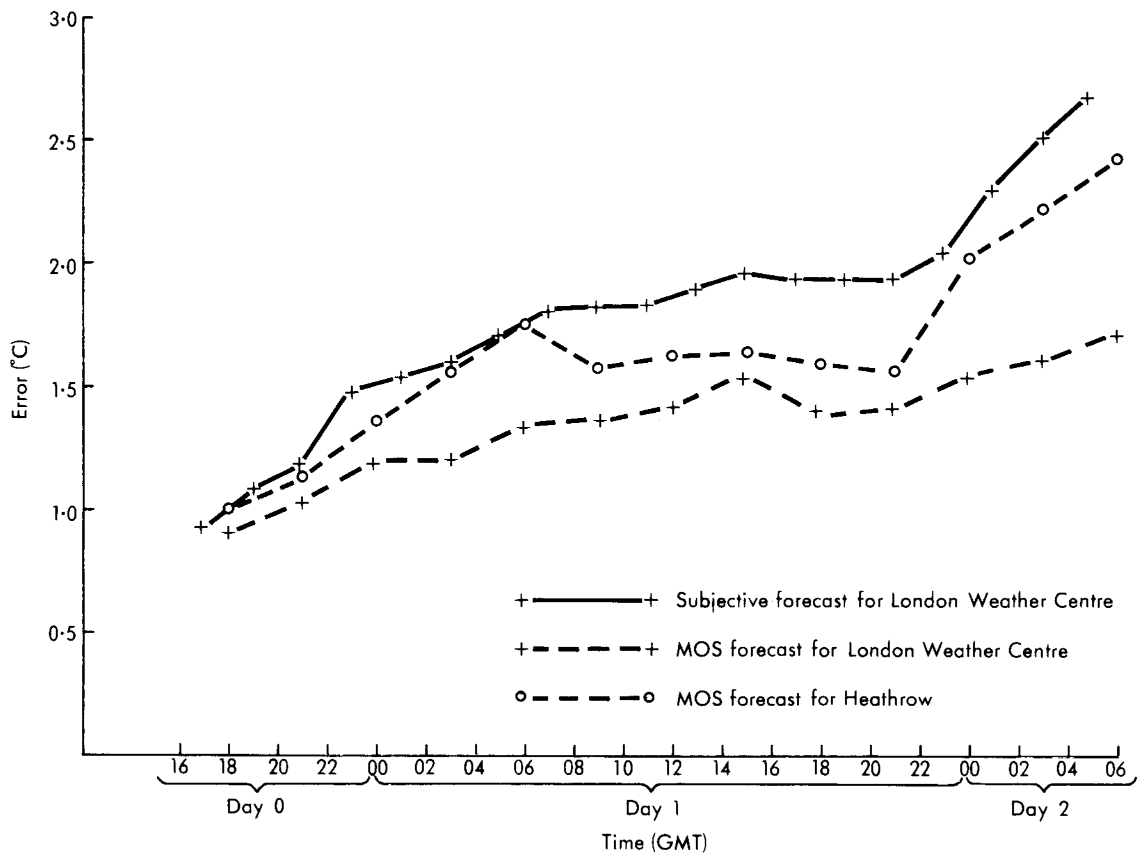

Figure 3. Root-mean-square errors of forecast temperatures for fixed hours, October 1980–March 1981.

(c) *Rationalization of extreme and fixed-hour forecasts*

The separate forecasting of temperatures at fixed hours from that of the extreme values can of course lead to inconsistent forecasts (Carter *et al* 1979), hence a small investigation has been conducted to see whether deriving maxima and minima from the forecasts at fixed hours would entail any loss in accuracy. The dependent data for Heathrow were processed as outlined above to give forecasts at fixed hours. The relevant maximum and minimum values of these forecasts in the appropriate period were then abstracted and compared with observed values. Regression equations for a linear model gave results which indicated a simple mean error correction as the best model to adopt, hence the formulae below were applied to independent data.

$$\text{Maximum (09–21 GMT)} = 1.03 \times \text{maximum of fixed-hour forecasts} + 0.5\ ^\circ\text{C}$$
$$\text{Minimum (21–09 GMT)} = 1.01 \times \text{minimum of fixed-hour forecasts} - 0.8\ ^\circ\text{C}$$

The forecast maxima and minima employing this technique had r.m.s. error values of 1.6 and 1.7 °C respectively, with mean errors of —0.1 and —0.2 °C. A comparison with the results of section 5(b) is not completely valid since data from the coarse-mesh NWP model were used to derive those results. A

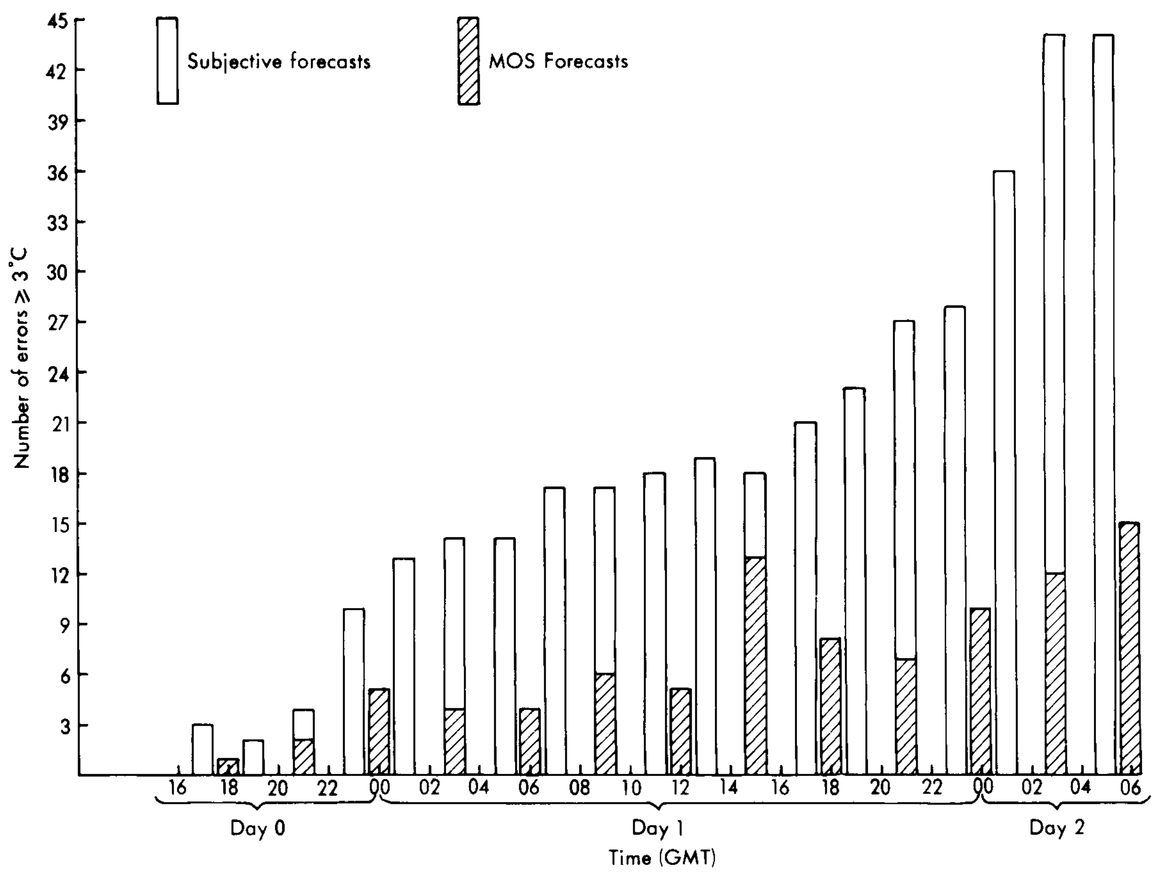

Figure 4. Number of forecast errors ≥ 3 °C, October 1980–March 1981.

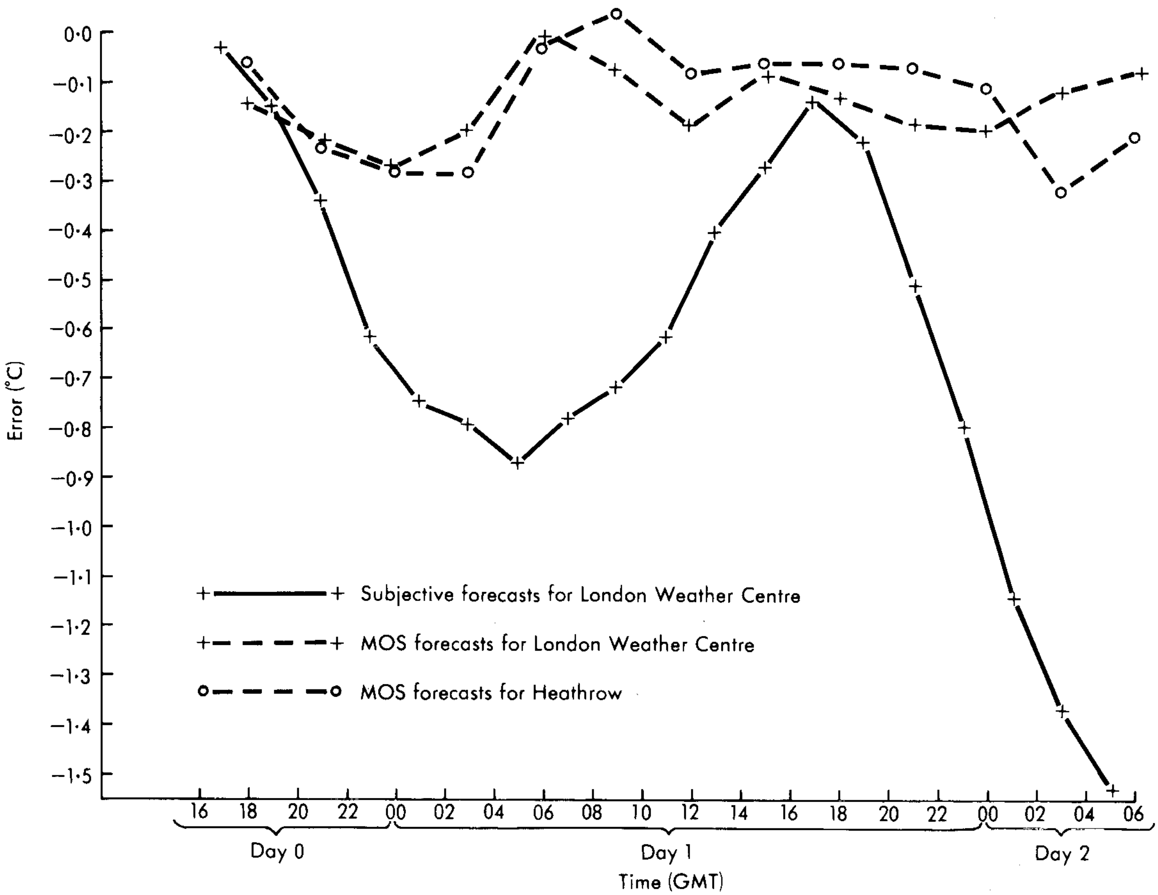

Figure 5. Mean errors (forecast minus actual) of forecast temperatures for fixed hours, October 1980–March 1981.

similar MOS analysis, using fine-mesh NWP model products to yield extreme temperature forecasts directly, produced similar r.m.s. error values, i.e. 1.6 and 1.7 °C. Thus for areas where fixed-hour temperature forecasts are given it would be consistent, and no less accurate, to derive maxima and minima forecasts via this less direct route. An interesting side issue is the higher accuracy of minima forecasts using fine-mesh NWP model data, presumably a result of better forecast fields.

7. Summary and conclusion

It has been demonstrated in this account that forecasts of temperature values for up to five days ahead, during the winter half of the year, can be made with acceptable accuracy using MOS techniques. As the forecast period increases the accuracy of the predicted maximum and minimum temperature values approaches that of a climatological forecast.

Such comparisons with subjective forecasts as can be made indicate that the MOS forecasts are as good as, or better than, the subjective forecasts, at least in terms of r.m.s. error and bias. This is particularly so for the comparisons of forecasts of temperature at fixed hours. A cautionary note is sounded by the relatively higher errors in the MOS forecasts of extreme temperature at Dyce, which suggest that local effects there have a large influence on temperature variation. A possible method of improving MOS forecasts, by accounting for some local effects, is by stratifying the development and test data (e.g. Woodcock 1980). With the limited data available at present a valid test of this approach is difficult to carry out, but a trial experiment based on a stratification by wind direction does appear to show promising results.

The best way forward at present is probably to use MOS forecasts as a guide to the forecaster, rather than as a finished article, in order to ensure the optimum forecast. Such guidance could be produced in the form of a chart of the British Isles with forecast and climatological temperature data for about 20 evenly distributed stations. It is also very desirable to continue the tests on further independent data and to extend the work to cover the summer six months.

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A consideration of the effect of 500 mb cyclonicity on the success of some thunderstorm forecasting techniques

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Summary

Forecasts of thunderstorms were made using as predictors only differences of wet-bulb potential temperature at 500 and 850 mb, and the criterion of cyclonic/non-cyclonic flow at 500 mb. The results were compared with established techniques and these techniques were then tested to see whether they were more successful when they also took into account the curvature of the 500 mb flow.

Introduction

Forecasts of thunderstorms are not only needed by the general public, but also some assessment of the likelihood of lighting is required for specialized jobs such as work by the Central Electricity Generating Board on cables and overhead transmission lines, storage of inflammable materials and gases, and many varied pastimes such as hot-air ballooning, hang-gliding and pigeon racing.

The present techniques used in the Meteorological Office, based upon work by Boyden (1963), Rackliff (1962) and Jefferson (1963), are indices which relate the degree of instability at an upper-air station to various vertical temperature differences with some allowance made for moisture content, but none specifically consider the curvature of the flow.

Inspection of days when thunderstorms were reported at Manchester Airport in 1967, a year selected at random, showed that on almost all the occasions the thunderstorms were associated with cyclonic curved flow at 500 mb, usually ahead of an upper trough or low advancing from the west or south-west. On all these thunder days it was also noted that the wet-bulb potential temperature at 500 mb (θ_{w500}) minus that at 850 mb (θ_{w850}) was less than +3 K. This difference decreases with instability, in contrast to other indices.

Bradbury (1977) has already suggested the use of values of 'potential stability' (the difference between θ_{w500} and θ_{w850}) in combination with surface and upper-air charts to forecast thunderstorms. It was decided to investigate the association of thunderstorms with the curvature of the upper flow, together with the criterion θ_{w500} minus θ_{w850} less than +3 K, and to compare the results with established techniques.

Preliminary study

The study was extended to the summer months (April to September) for the years 1968, 1969 and 1970. The area chosen covered most of Wales and north-west England from 52° to 55° N and from 2° to 5° W. Sferics (atmospherics) data for that period were obtained and, allowing a gap of two days between events to suppress the effect of persistence, a total of 59 'thunder days' emerged. A 'thunder day' was defined as one on which sferics were reported in the area between midnight and midnight. An equal number of non-events was selected by allocating numbers to dates, months and years and selection was made using random numbers. Again, two days were allowed between each non-event. It should be remembered that because cathode-ray direction finding (CRDF) stations operate only for part of each hour, it is possible that, on occasions, thunderstorms may occur without being detected by the CRDF network.

For each of the 'thunder' and 'no thunder' days the following data were extracted from the *Daily Aerological Record:*

(1) A brief description of the 500 mb contour pattern over and near the British Isles at 1200 GMT — noting those days when an upper trough or low was in the area 45° to 60° N and between 0° and 20° W.

(2) The type of flow over this area at 500 mb, designated A, C or N, where

A = Anticyclonic flow,
C = Cyclonic flow, and
N = Neutral flow (indeterminate or 'straight' contours).

(3) The prevailing wind direction over the area 52° to 55° N and 2° to 5° W at 700 mb — this being the 'mid-level' wind of the layer being considered for the present investigation.

(4) The sounding upwind of the area was noted and the following data extracted:

(a) 850 mb temperature, dew-point and wet-bulb potential temperature,
(b) 500 mb temperature, dew-point and wet-bulb potential temperature,
(c) 1000 mb and 700 mb geopotentials, and
(d) 700 mb temperature and dew-point depression.

For each day, the Boyden and Jefferson indices were calculated for the upwind station at both midnight and midday. A 'yes' forecast for thunderstorms was made if either of these was above the relevant threshold limits, and the forecast was correct if sferics were reported in the area during the 24 hours from midnight to midnight.

For a 'yes' forecast of thunderstorms using the present technique the following criteria had to be satisfied:

(a) a 500 mb trough or low in the area 45° to 60°N and 0° to 20°W,
(b) cyclonic curved flow at 500 mb, and
(c) θ_{w500} minus θ_{w850} less than + 3 K at the upwind station.

There are many different formulae from which skill scores are derived to evaluate the success of yes/no categorical forecasts. Johnson (1957) made a comprehensive review of various formulae and concluded that there is no single score which is suitable for all purposes. Some markedly weight 'prefigurance', the probability that an occurrence will be predicted, while others emphasize 'postagreement', the probability that a prediction will be fulfilled. The present study was intended to devise a general technique to give the best results when forecasting both 'thunder' and 'non-thunder' days and therefore Yule's index (Meteorological Office 1975) was used to determine the skill scores as this does not give undue weight to either prefigurance or postagreement.

Given a contingency table of the form:

Observed	Forecast Yes	Forecast No	Totals
Yes	a	b	$(a + b)$
No	c	d	$(c + d)$
Totals	$(a + c)$	$(b + d)$	$a + b + c + d$

Yule's index is

$$(ad - bc)/\{(a+b)(b+d)(a+c)(c+d)\}^{1/2}.$$

It varies from —1 for totally wrong forecasts to +1 for perfect forecasts. By adding 1 to the index, dividing the sum by 2 and multiplying by 100, a value emerges which measures what for convenience is called the 'equivalent percentage success', i.e. the success which would be achieved if there were equal numbers of 'yes' and 'no' events actually encountered in the trial.

Table I shows the results obtained from the trial period 1968–70, giving the percentage of correct 'yes' and 'no' forecasts out of the total of 118 occasions, the Yule's index and the equivalent percentage success for each method, associated with suggested critical values of the indices, e.g. Boyden $\geqslant$ 94.

Table I. *Results of preliminary study, related Yule's index, percentage of correct forecasts and equivalent percentage success for each method.*

	Yule's index	Equivalent percentage success	Percentage of correct yes/no forecasts
Pickup	0.528	76.4	76
Jefferson ($\geqslant$ 28)	0.467	73.4	73
Boyden ($\geqslant$94)	0.472	73.6	72
Boyden ($\geqslant$95)	0.435	71.8	69

Using past data it was difficult to determine exactly the nature of the 500 mb flow from only one North Atlantic chart each day, so the next step was to produce forecasts in 'real time' and a comprehensive study was made for the period from April to September 1980.

The 1980 study

From April to September 1980, charts for 850, 700 and 500 mb were plotted every 6 hours, giving a more detailed analysis over the area, and these were used in conjunction with the $T+18$ h forecast charts for these levels to determine the curvature of the flow during the forecast period. On occasions when the flow upwind lay between two radiosonde stations, the data from both were used and, in conditions of light winds, the data from the nearest station, Aughton, were used.

Values of the Boyden, Jefferson and Rackliff indices were calculated for both midnight and 1200 GMT. A forecast of thunderstorms based on the midnight GMT data and the 1800 GMT forecast charts was considered correct if sferics were reported in the area between midnight and midnight GMT, and on the 1200 GMT actual and 0600 GMT forecast charts if they occurred between 1200 GMT and 1200 GMT the next day. For each technique at least two different threshold values were used. A total of 366 forecasts was made.

For the present technique the criteria were reduced to only two:

(a) Cyclonic curved flow at 500 mb over the area at some time during the forecast period, and
(b) θ_{w500} minus θ_{w850} less than +3 K.

Table II shows the results obtained and the related Yule's index for each method. The results varied from an equivalent percentage success of 72 for the present technique down to 60 for Rackliff (≥30).

When the Boyden, Jefferson and Rackliff results were modified so that thunderstorms were forecast only when the flow was cyclonic during the period, there was an improvement in the Yule's index varying from 0.05 for Rackliff (≥30) to 0.11 for Boyden (≥95). The equivalent percentage success improved by 3–6; Boyden (≥94) improved to 70, only 2 below the success of the present technique. The results are shown in Table III.

Saunders (1967) has suggested that 'there can be circumstances in which the method to be preferred may not be the one with the highest skill score'. It is a matter of individual choice whether a system which produces a higher percentage success in forecasting 'yes' events is preferred to another which produces more correct 'no' forecasts.

If it is considered more important that the actual occurrence of thunderstorms be forecast with the least number of 'false alarms', an index should be used which weights prefigurance. Peirce's index (Meteorological Office 1975) has this virtue and these values were also calculated, producing similar results to those for Yule's index with an equivalent percentage success for the present technique of 76 down to 65 for the Rackliff (≥ 30) results in Table III.

Discussion of the various techniques

Boyden

The Boyden index is given by the formula:

$$I = Z - T - 200,$$

where Z = 1000–700 mb thickness in decageopotential metres, and
T = 700 mb temperature in degrees Celsius.

Table II. *Results obtained and related Yule's index for each forecasting method.*

V = Yule's index. EPS = Equivalent percentage success.

Pickup

Observed	Forecast Yes	Forecast No	Total
Yes	45	19	64
No	54	248	302
Total	99	267	366

$V = 0.448$ $EPS = 72.4$

Boyden (⩾94)

Observed	Forecast Yes	Forecast No	Total
Yes	51	13	64
No	112	190	302
Total	163	203	366

$V = 0.326$ $EPS = 66.3$

Boyden (⩾95)

Observed	Forecast Yes	Forecast No	Total
Yes	30	34	64
No	61	241	302
Total	91	275	366

$V = 0.234$ $EPS = 61.7$

Rackliff ⩾ 29)

Observed	Forecast Yes	Forecast No	Total
Yes	46	18	64
No	134	168	302
Total	180	186	366

$V = 0.209$ $EPS = 60.4$

Rackliff (⩾ 30)

Observed	Forecast Yes	Forecast No	Total
Yes	37	27	64
No	99	203	302
Total	136	230	366

$V = 0.197$ $EPS = 59.8$

Jefferson (⩾ 26)

Observed	Forecast Yes	Forecast No	Total
Yes	35	29	64
No	72	230	302
Total	107	259	366

$V = 0.258$ $EPS = 62.9$

Jefferson (⩾ 27)

Observed	Forecast Yes	Forecast No	Total
Yes	30	34	64
No	55	247	302
Total	85	281	366

$V = 0.258$ $EPS = 62.9$

Jefferson (⩾ 28)

Observed	Forecast Yes	Forecast No	Total
Yes	25	39	64
No	34	268	302
Total	59	307	366

$V = 0.287$ $EPS = 64.4$

Table III. *Results obtained and related Yule's index for each forecasting method associated with cyclonic flow only.*

V = Yule's Index. EPS = Equivalent percentage success.

Boyden (⩾94)

Observed	Forecast Yes	Forecast No	Total
Yes	46	18	64
No	67	235	302
Total	113	253	366

$V = 0.409$ $EPS = 70.4$

Boyden (⩾95)

Observed	Forecast Yes	Forecast No	Total
Yes	28	36	64
No	31	271	302
Total	59	307	366

$V = 0.346$ $EPS = 67.3$

Rackliff (⩾29)

Observed	Forecast Yes	Forecast No	Total
Yes	42	22	64
No	88	214	302
Total	130	236	366

$V = 0.290$ $EPS = 64.5$

Rackliff (⩾30)

Observed	Forecast Yes	Forecast No	Total
Yes	34	30	64
No	71	231	302
Total	105	261	366

$V = 0.249$ $EPS = 62.4$

Jefferson (⩾26)

Observed	Forecast Yes	Forecast No	Total
Yes	35	29	64
No	48	254	302
Total	83	283	366

$V = 0.352$ $EPS = 67.6$

Jefferson (⩾27)

Observed	Forecast Yes	Forecast No	Total
Yes	30	34	64
No	38	264	302
Total	68	298	366

$V = 0.335$ $EPS = 66.7$

Jefferson (⩾28)

Observed	Forecast Yes	Forecast No	Total
Yes	25	39	64
No	23	279	302
Total	48	318	366

$V = 0.354$ $EPS = 67.7$

Most thunderstorms are associated with cloud depths greater than 10000 feet, with tops well above 700 mb. Boyden considered only the layer from 1000 mb to 700 mb. When changes are taking place above the 700 mb level, e.g. warm advection or subsidence, no change will take place in the Boyden index.

On 16 June 1980 a thundery trough had moved across the British Isles with a weak ridge moving into Ireland. Warm advection was taking place and, although the midday ascents from Aughton and

Valentia showed the Jefferson index falling from a value of 31 down to 10 and the Rackliff index from 33 to 24, the Boyden index at both stations was the same at 94.

In Table II, Boyden ($I \geqslant 94$) correctly forecast 51 out of the 64 thunder occasions but there were, in fact, a total of 163 'yes' forecasts, i.e. only a third of these forecasts were correct. The number of incorrect 'yes' forecasts was reduced by 40% — from 112 to 67 — when only occasions with cyclonic flow were considered for a 'yes' forecast. When the Boyden criterion was $I \geqslant 95$, the number of correct forecasts (both 'yes' and 'no') increased from 271 to 299 out of the total of 366, but again the proportion of 'yes' forecasts which were correctly forecast was low — being approximately 50%.

Rackliff

The Rackliff index is given by the formula:

$$I = \theta_{w900} - T_{500},$$

where θ_{w900} = 900 mb wet-bulb potential temperature, and
T_{500} = 500 mb dry-bulb temperature.

This technique was the least successful, having only 214 ($I \geqslant 29$) and 240 ($I \geqslant 30$) correct forecasts in Table II, and this increased to only 256 and 265 respectively in Table III. The proportion of correct 'yes' forecasts was only between 25% and 32%.

Jefferson

The Jefferson (1966) index is given by the formula:

$$I = 1.6\theta_{w850} - T_{500} - \tfrac{1}{2}\, T_{d700} - 8,$$

where θ_{w850} = 850 mb wet-bulb potential temperature,
T_{500} = 500 mb dry-bulb temperature, and
T_{d700} = 700 mb dew-point depression.

Although this technique was generally more successful than that of either Boyden or Rackliff, having 304 correct 'yes' and 'no' forecasts in Table III for a critical value of $I \geqslant 28$, the proportion of 'yes' forecasts was low and 39 events were not forecast.

Yule's index was also calculated for either side of the suggested critical values, associated with cyclonic flow. With $I \geqslant 25$ the index fell to 0.286 and to 0.228 using $I \geqslant 29$. In Table III the results were similar for the three criteria considered, and the slight decrease at the mid-point ($I \geqslant 27$) is probably not significant.

Frith (1948) has found that variations of dew-point (frost-point) of as much as 15 K occur over distances of only a few miles, and it is therefore misleading to assume that one ascent is totally representative of an air mass. Values of the Jefferson index could vary by 7 or 8 over short distances. This most probably accounts for the low number of correct 'yes' forecasts.

Present technique

During the 1980 survey this method correctly forecast 293 out of the 366 occasions. Forty-five of the 64 days when thunderstorms were observed were actually forecast out of a total of 99 'yes' forecasts which were made.

When it was decided to forecast thunderstorms only on occasions with cyclonic flow at 500 mb, this was intended to go some way towards highlighting areas of ascending air. Of course, cyclonically curved flow or areas of cyclonic vorticity are not always associated with ascent of air and, ideally, charts showing the advection of cyclonic vorticity and partial or total thickness advection are required (e.g. Morris 1971, 1972). This may account for some of the occasions when sferics were not reported on days when thunderstorms were forecast.

Forecast charts of $\theta_{w500} - \theta_{w850}$ are available, and charts showing these values for 5 June 1980, when thunderstorms were widespread over the British Isles, are shown in Figs 1, 2 and 3, together with the actual 500 mb chart for 1200 GMT on the 5th (Fig. 4).

An area of $\theta_{w500} - \theta_{w850}$ around 0 K moved east across the British Isles ahead of an upper trough, and in the area 52° to 55° N, 2° to 5° W alone there was a total of 414 'flashes' recorded by the CRDF network between midnight and midnight GMT with a maximum in any hour of 62 between 1600 and 1700 GMT. These, of course, were recorded in two 10-minute periods, 1550–1600 GMT and 1620–1630 GMT.

Rainfall totals for the north-west of England for the period from 0900 GMT on the 5th to 0900 GMT on the 6th showed that parts of the Manchester area recorded almost 2 inches of rain. During the afternoon of the 5th, 1.69 inches of rain was reported in one hour at Eccleshall in Staffordshire, with hailstones observed up to 20 mm in diameter.

Conclusion

None of the 64 occasions (midnight to midnight GMT or 1200 to 1200 GMT) when thunderstorms were reported during the period from April to September 1980, were associated with marked anticyclonic flow although 5 were classified as 'neutral' and 2 as 'slightly anticyclonic'.

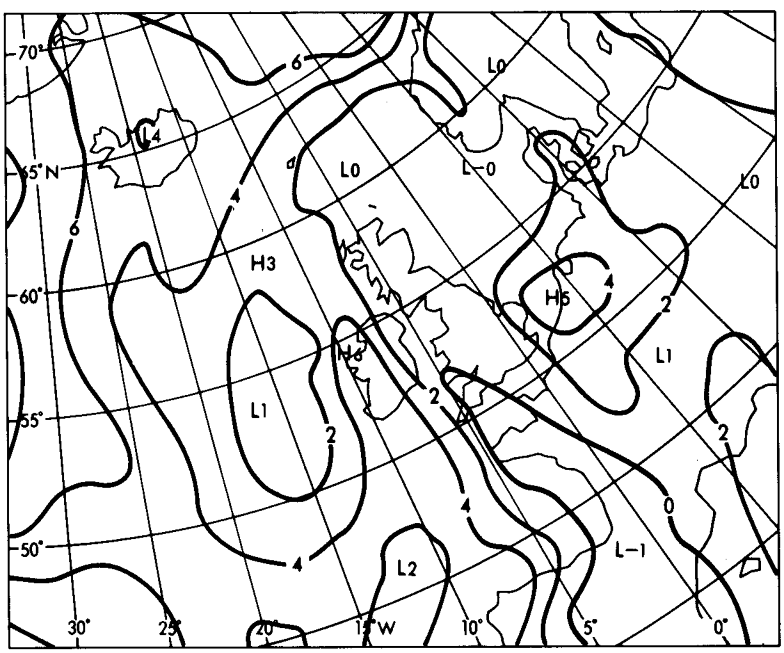

Figure 1. Wet-bulb potential temperature difference (500–850 mb) 6-hour forecast for 0600 GMT, 5 June 1980.

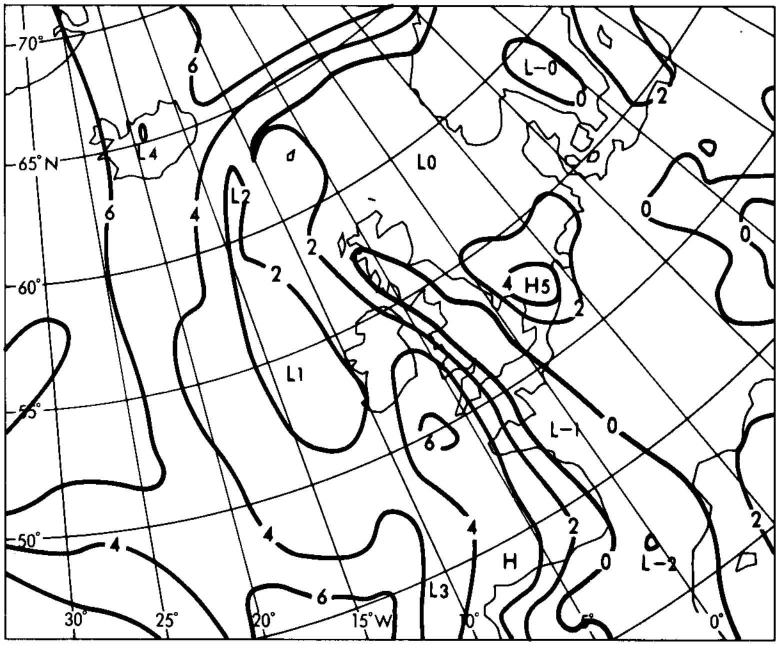

Figure 2. Wet-bulb potential temperature difference (500–850 mb) 12-hour forecast for 1200 GMT, 5 June 1980.

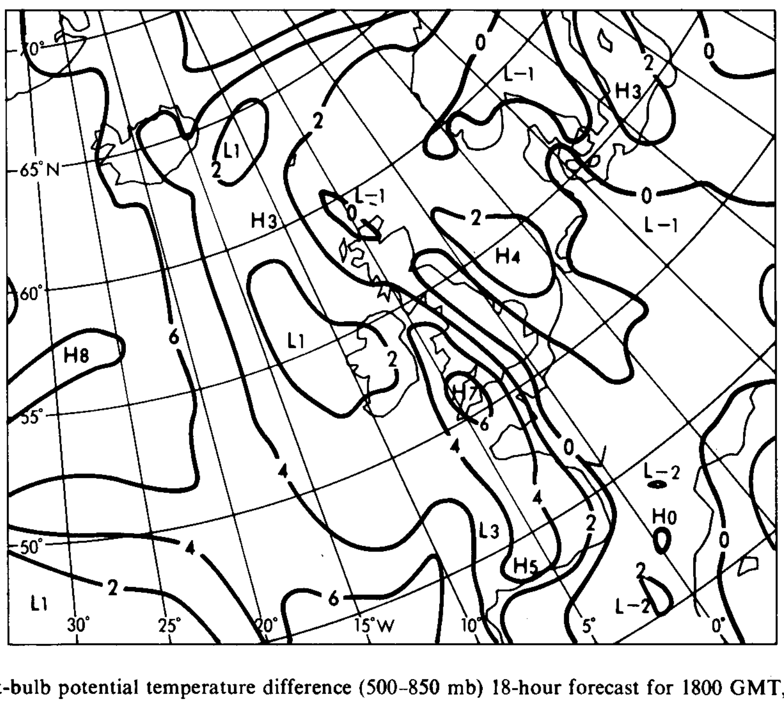

Figure 3. Wet-bulb potential temperature difference (500–850 mb) 18-hour forecast for 1800 GMT, 5 June 1980.

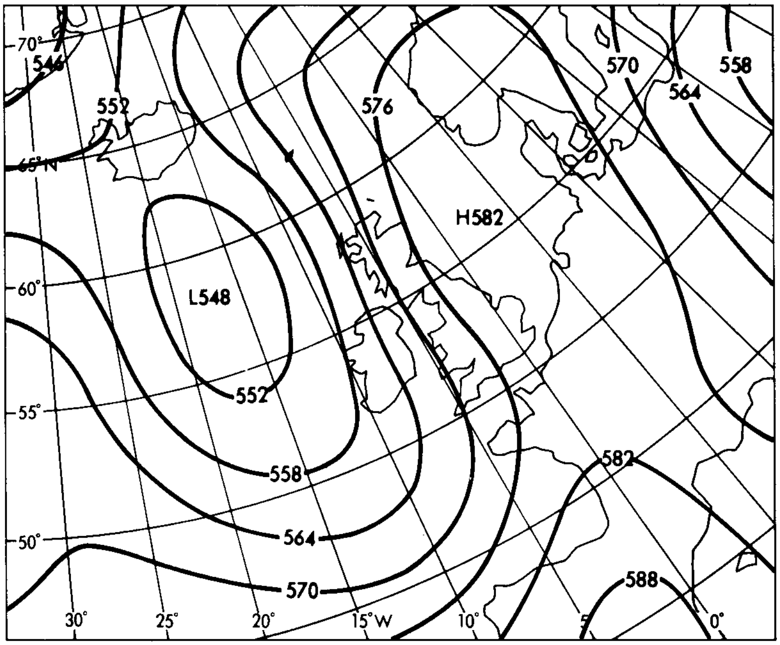

Figure 4. Central Forecasting Office 500 mb analysis for 1200 GMT, 5 June 1980. Values in geopotential metres.

Improvements have been made when using the Boyden, Jefferson and Rackliff indices if thunderstorms are forecast only when the values are above the critical limit, together with marked cyclonic flow. Large dew-point depressions in middle levels do not preclude the possibility of thunderstorms if the air mass is potentially unstable.

The present technique, using differences in wet-bulb potential temperature between 500 mb and 850 mb associated with cyclonic flow, showed the highest equivalent percentage success during the 1980 survey. As values of $\theta_{w500} - \theta_{w850}$ decreases to or below 0 K the intensity of thunderstorms increases, provided they are not associated with anticyclonic flow. Computer charts of forecast vertical motion in mid-troposphere and of wet-bulb potential temperature differences could be used to highlight the most likely areas for thunderstorm activity.

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551.5(09):551.501.9

Auxiliary Reporting Station Gorleston

By C. S. Broomfield

(Meteorological Office, Bracknell)

The closure of Auxiliary Reporting Station Gorleston (03497) in October 1981 brought to an end 114 years of synoptic reports from the district.

Synoptic reports from Yarmouth started in 1867 and were made by Mr T. Robinson, a telegraphic clerk. The reports, with those of five other stations, were sent daily to M. Le Verrier for publication in the daily bulletin of the Observatoire Impérial, Paris. In return M. Le Verrier supplied the Meteorological Committee with daily reports from six continental stations. The observations were also included in the Daily Weather Chart when it was first issued in 1872.

On the death of the observer in 1872 the commitment was taken over by the Secretary of the Sailors' Home, Yarmouth. An anemometer was erected a few feet above the roof of the Home and figured prominently on picture postcards of the era. (See Fig. 1) In 1873 the reports and those of two other stations were supplied to the Swedish Meteorological Service in exchange for reports from four Swedish stations.

In 1907 HM Coastguard assumed responsibility for the reports. A Dines pressure-tube anemograph was installed on the Brush Pier, Gorleston, in 1908 to test the exposure of the Robinson anemometer on the Sailors' Home. The Dines anemograph was 42 feet above the pier and not surprisingly showed much stronger winds than those from the Robinson just above roof level.

During World War I the station was taken over by the Royal Navy but with the posting of the Chief Petty Officer observer the routine was transferred to the War Signals Station, Gorleston, in 1915. The Town Council made available a site for an instrument enclosure in a public garden which was near to the Signals Station.

After the War the coastguards resumed observations. Replanning of the public garden in 1924 led to the instrument site being moved about 400 yards from the Coastguard Station. (See Fig. 2)

During an air raid on 24 June 1941, six bombs fell within 15–35 yards of the anemograph. For six days the coastguards had to pass within 30 yards of an unexploded bomb while making the observation. A fragment of metal or shrapnel was found buried in one of the copper tubes of the anemograph and caused the instrument to under-record by 8 mph.

Figure 1. Telegraphic Reporting Station Yarmouth. Anemometer on top of Sailors' Home, 1896.

Figure 2. Auxiliary Reporting Station Gorleston. Instrument enclosure, with vandal-deterrent fence, at climatological site in public park.

War-time HM Coastguard duties eventually meant it was no longer possible to make frequent visits to the enclosure, and a screen was erected on the roof of the coastguards' lookout. Visits to the public garden site were then restricted to 0900 and 2100 GMT only. Naval ratings assisted with the observing program during and immediately after World War II.

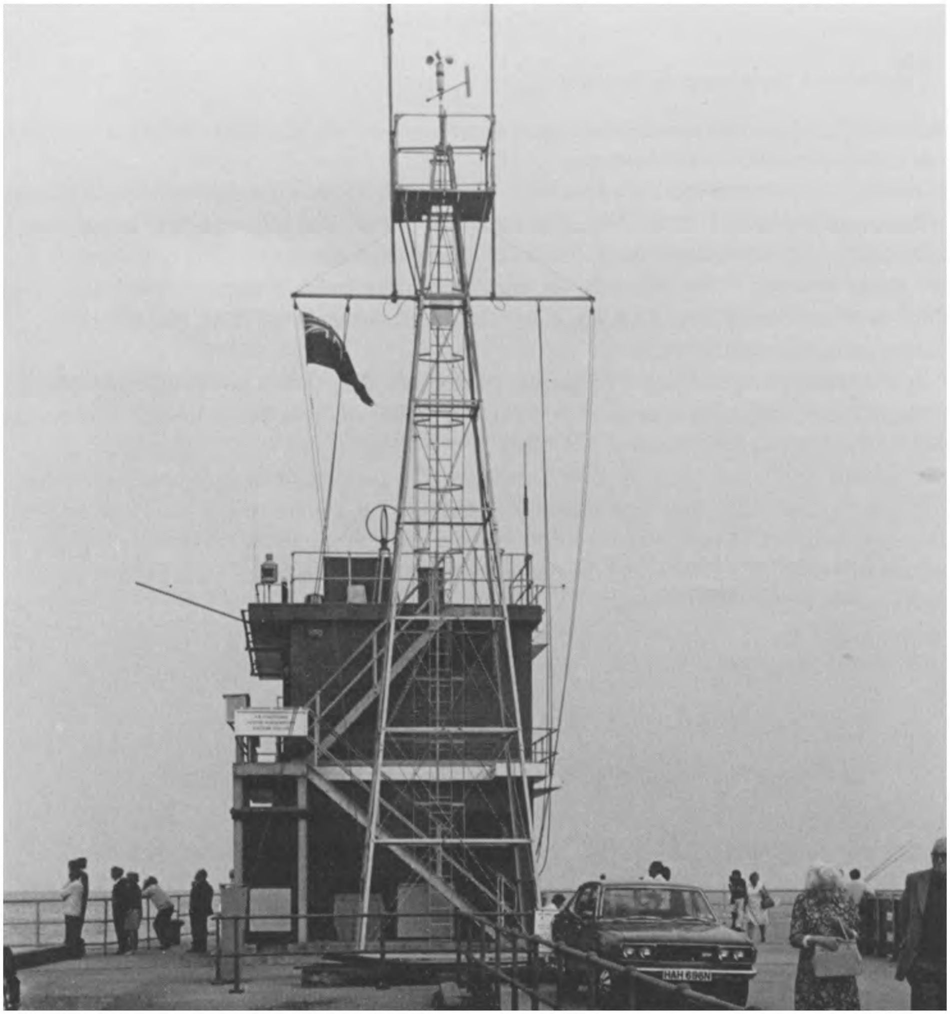

Figure 3. Auxiliary Reporting Station Gorleston. Anemometer and balcony screen at synoptic reports site on South Pier, 1976.

The pressure-tube anemograph was wrecked by a lorry in 1958 and was replaced by an electrical anemograph (Fig. 3) the following year.

In 1981 HM Coastguard moved most of their staff to a seven-storey office block at Havenbridge House, Great Yarmouth. The new location formed the nerve centre of a communications network which covered the coastline from Berwick-upon-Tweed to Orford Ness. Advanced equipment was available for gathering and displaying information on marine activities for the whole coastline and for 40 miles out to sea. The site, alas, was unsuitable for weather observing, and further reductions in the manning of the lookout meant observations coming to an end in October 1981. For a while, at least, anemograph records will continue as will 0900 GMT climatological readings from the site in the public garden.

Synoptic observations from the upper-air station at Hemsby (03496), which started in June 1978, now fill the gap which would otherwise be created by the closure of Gorleston.

Notes and news

Opening of Athalassa Rawinsonde Station

On 17 October 1981 in brilliant sunshine at a site just south of Nicosia, the first formal launch took place from a smart, well-planned, new station.

The first rawinsonde ascents from Cyprus were made from Nicosia during the Second World War and the station continued to launch until 1969. The equipment was then moved to Paramali, near Episkopi, on the south coast and ascents continued until 1976. From then until early 1981 Graw-sonde ascents only were made each evening from Akrotiri. Hence there has been a gap of over four years in the measurement of upper winds over Cyprus, other than by pilot balloon, and in obtaining values of the other variables at the standard times.

In 1978, as the result of a joint initiative by the Meteorological Office and the Cyprus Meteorological Service, a project to re-establish a rawinsonde station in Cyprus was put in hand under the auspices of the Voluntary Co-operation Program of WMO.

The Government of Cyprus has provided the site, the fine modern buildings, services, furniture, ancillary equipment and staff. The Government of the United Kingdom has provided specialist advice and training, major items of equipment and a two-year supply of consumables. The smooth progress of the project is one of the many fruits of the close relationship which has always existed between the two meteorological services.

Mr K. Philaniotis, Head of the Cyprus Meteorological Service, made brief introductory remarks, thanking everyone concerned for their individual contributions, and introduced Sir John Mason. The Director-General spoke of the enormous advances made in the science of weather forecasting, stressing, to a large and mainly professional audience, that no amount of modelling skill and computing power could succeed without high-quality data of the sort now available at Athalassa.

Dr Andreas Papasolomontas, Director-General of the Ministry of Agriculture and Natural Resources, a well-known plant pathologist, made the address of thanks and formally inaugurated the station.

After the ceremony the Minister of Agriculture and Natural Resources (Mr N. K. Pattichis), who had been unable to attend the ceremony owing to a Cabinet Meeting, entertained a party, including Sir John Mason, the Minister of Telecommunications and Building, the UK High Commissioner and Dr Papasolomontas, to lunch.

Honours

The award of the Imperial Service Medal to Mr E. J. Perrow, Radio Operator, was announced on 17 December 1981.

In the New Years Honours List for 1982 it was announced that Mrs J. M. Cowlard, (Higher Scientific Officer), Information Officer in the National Meteorological Library, had been appointed a Member of the Order of the British Empire.

THE METEOROLOGICAL MAGAZINE

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NOTICES

It is requested that all books for review and communications for the Editor be addressed to the Director-General, Meteorological Office, London Road, Bracknell, Berkshire RG12 2SZ and marked 'For Meteorological Magazine'.

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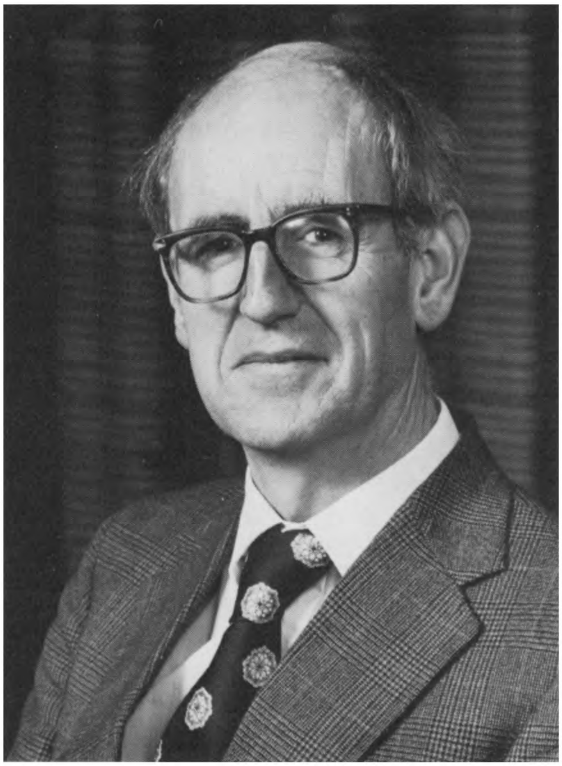


Dr K. H. Stewart

Retirement of Dr K. H. Stewart

When Dr K. H. Stewart retired as Director of Research on 29 March 1982 the Meteorological Office lost one of its most able scientists of the post-war generation and one who had contributed greatly to its research in physical meteorology for more than 30 years.

Educated at Ottershaw College, Chertsey, and Trinity College, Cambridge, Ken Stewart graduated in 1943, received his MA in 1946, and obtained a PhD in 1949 for research on the behaviour of ferro-magnetic materials. Indeed he wrote a monograph on Ferro-magnetic Domains while still a research student. This was published by Cambridge University Press in 1951 and was very well received.

After leaving the Cavendish Laboratory he joined the Meteorological Office in 1949 and, after a period of forecasting training, was posted to Victory House to study problems of horizontal and slant visibility under Dr A. C. Best. In 1954 he went to Kew Observatory as a research scientist under Dr G. D. Robinson. During the next seven years or so he carried out a series of investigations on visibility and on the constitution, formation and dissipation of radiation fog. These included a notable design study, followed by some experimental trials, on the feasibility of dissipating fog by spraying it with hygroscopic particles.

It was during this period that, despite his quiet and retiring nature, his abilities as an experimental physicist came to the fore and were clearly recognized by his seniors. He was promoted to Principal Scientific Officer in 1957, at the then very early age of 35, and remained at Kew until he joined the newly-formed High Atmosphere branch at Bracknell in 1961. It was here, during the next 13 years, that he was to do his most important scientific work for which he received the L. G. Groves Memorial Prize in 1964 and achieved promotion to Senior Principal Scientific Officer (Special Merit) in 1965. Stewart's group was the first in the Office to develop highly sophisticated instruments for both rockets and satellites and to introduce the advanced techniques necessary to build these in house. He was personally concerned with measurements of the concentrations of ozone and molecular oxygen in the stratosphere from both the Ariel II and III satellites and measurements of solar ultra-violet radiation and ozone with Skylark rockets fired from Woomera. He also contributed to the design of the Meteorological Office version of the pressure-modulated radiometer that is at present obtaining excellent measurements of stratospheric temperature on board the US Tiros-N series of satellites.

Although up to this stage of his career Ken Stewart had been regarded as a back-room research scientist, it became evident that he had the leadership qualities required of a successful manager and so, in 1974, he was promoted to the post of Deputy Director (Physical Research) and then, in 1976, he followed Mr J. S. Sawyer as Director of Research with the rank of Under Secretary. In these roles Dr Stewart has played a very important and influential role in guiding a large and broad research program. A man of few words, his authority derives from a first-class scientific mind, excellent judgement and the ability to spot any weakness in a scientific argument. He has also played a very important role in the development of the European geostationary satellite (Meteosat) especially as Chairman of the Scientific and Technical Advisory Group where his efforts have been greatly appreciated, not least by his European colleagues.

I shall miss his wise and courteous counsel and I am sure that all his colleagues would wish to join with me in wishing Ken and Hilary Stewart a long, fruitful and happy retirement.

B. J. MASON

551.5(09): 551.509.21:06

The Daily Weather Report and associated publications: 1860–1980

By R.P.W. Lewis
(Meteorological Office, Bracknell)

Summary

A brief historical account is given of the *Daily Weather Report, Daily Aerological Record*, and *Overseas Supplement* to the *Daily Weather Report* published by the Meteorological Office between 1860 and 1980.

Photographs of typical examples are included.

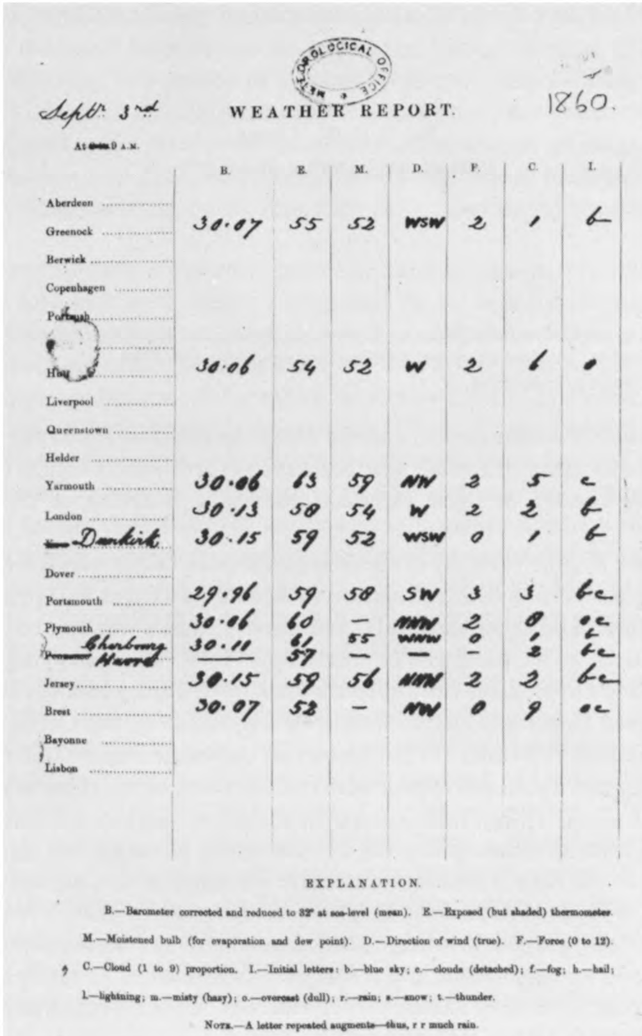
With the demise of the *Daily Weather Report* and the *Daily Aerological Record* at the end of 1980, more than 120 years of daily publication of British weather data by the Meteorological Office came to an end. This article sketches the history of these publications and a selection of them are shown in the illustrations.

The first *Daily Weather Report (DWR)* of the Meteorological Office was issued free to the Press on 3 September 1860 and consisted of a brief tabulation of data handwritten on a printed form. Gradually, the tabulations became fuller and more elaborate, and remarks and a weather outlook were added, but duplicate copies continued to be handwritten until July 1868 when copying by lithography was introduced. In 1871 the Meteorological Committee were shown copies of daily charts produced in the United States, and decided that daily charts should be produced by the Office too; the first *Report* containing charts appeared on 11 March 1872. These more elaborate *Reports* were, like the earlier ones, reproduced by lithography and about 200 copies were run off, some of which were sold to the public. The minutes of the Meteorological Committee record negotiations with the Revd C. H. Griffith who declined to take out an annual subscription for £5 (including postage) but agreed when the Office brought the price down to £2.10s.* Forecasts were first included in the *Report* on 1 January 1881.

When the Office moved from Westminster to South Kensington in 1910, it was discovered that the new site was too far from lithographic printing establishments for speedy reproduction of the *Report* to be carried out under the old arrangements, and it was therefore decided to set up a press actually within the Office; this press started work on 1 January 1911 and was run by Wyman and Sons under contract from His Majesty's Stationery Office (HMSO).

In 1919, after the First World War, the Meteorological Office expanded considerably and was placed administratively under the Air Ministry, largely because of the greatly increased amount of work on the new task of forecasting for aviation; the Forecasting Office was in consequence transferred to an Air Ministry building in Kingsway. From January 1920 the *Reports* were printed at the Kingsway building on a press run directly by HMSO, an arrangement which was to continue during the period at Dunstable (from 1940 to 1961) and then at Bracknell.

*For comparison, the annual subscription in 1980 (1st class post) was £86.55.



Sept^r 3^rd WEATHER REPORT. 1860.

At 9 A.M.

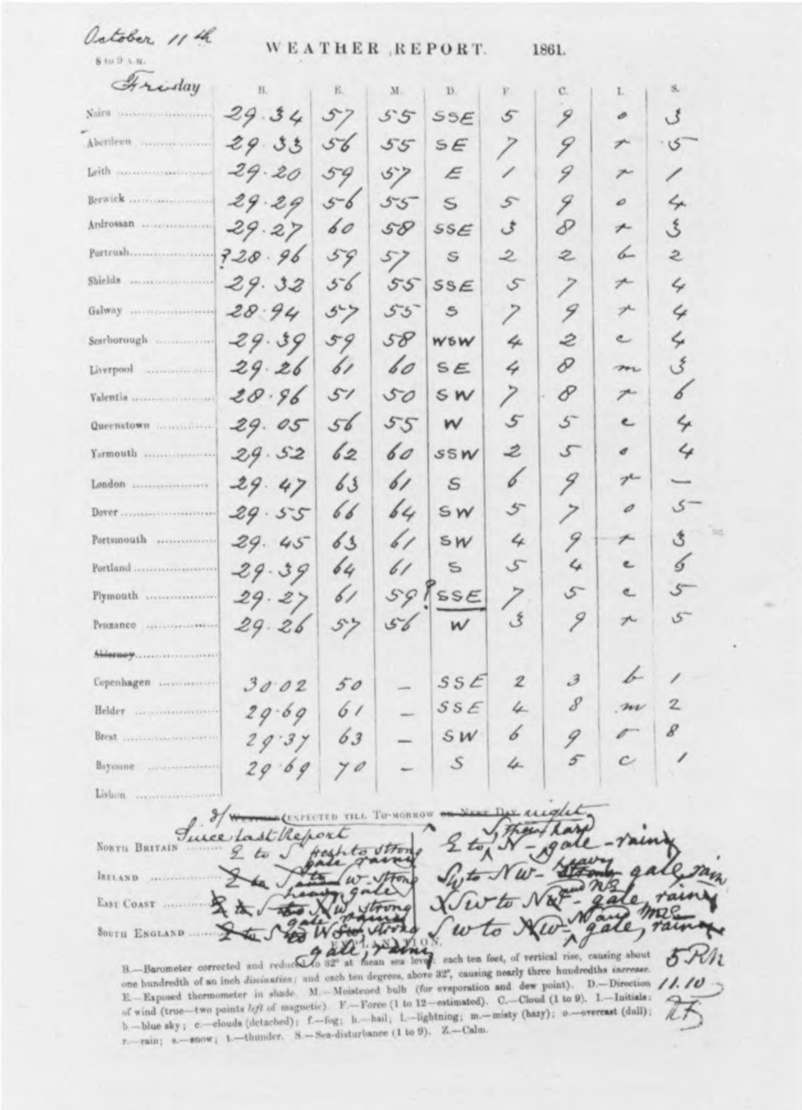
	B.	E.	M.	D.	F.	C.	I.
Aberdeen							
Greenock	30·07	55	52	WSW	2	1	b
Berwick							
Copenhagen							
Portrush							
Hull	30·06	54	52	W	2	6	o
Liverpool							
Queenstown							
Helder							
Yarmouth	30·06	63	59	NW	2	5	c
London	30·13	58	54	W	2	2	b
~~[illegible]~~ Dunkirk	30·15	59	52	WSW	0	1	b
Dover							
Portsmouth	29·96	59	58	SW	3	3	bc
Plymouth	30·06	60	—	NNW	2	8	oc
~~Penzance~~ Cherbourg	30·11	61	55	WNW	0	1	t
Havre		57	—	—	—	2	bc
Jersey	30·15	59	56	NNW	2	2	bc
Brest	30·07	58	—	NW	0	9	oc
Bayonne							
Lisbon							

EXPLANATION.

B.—Barometer corrected and reduced to 32° at sea-level (mean). E.—Exposed (but shaded) thermometer. M.—Moistened bulb (for evaporation and dew point). D.—Direction of wind (true). F.—Force (0 to 12). C.—Cloud (1 to 9) proportion. I.—Initial letters: b.—blue sky; c.—clouds (detached); f.—fog; h.—hail; l.—lightning; m.—misty (hazy); o.—overcast (dull); r.—rain; s.—snow; t.—thunder.

NOTE.—A letter repeated augments—thus, r r much rain.

Figure 1. First *Daily Weather Report (DWR)*, issued to the Press on 3 September 1860.


October 11th
8 to 9 A.M.
Friday

WEATHER REPORT. 1861.

	B.	E.	M.	D.	F.	C.	I.	S.
Nairn	29.34	57	55	SSE	5	9	o	3
Aberdeen	29.33	56	55	SE	7	9	r	5
Leith	29.20	59	57	E	1	9	r	1
Berwick	29.29	56	55	S	5	9	o	4
Ardrossan	29.27	60	58	SSE	3	8	r	3
Portrush	?28.96	59	57	S	2	2	b	2
Shields	29.32	56	55	SSE	5	7	r	4
Galway	28.94	57	55	S	7	9	r	4
Scarborough	29.39	59	58	WSW	4	2	c	4
Liverpool	29.26	61	60	SE	4	8	m	3
Valentia	28.96	51	50	SW	7	8	r	6
Queenstown	29.05	56	55	W	5	5	c	4
Yarmouth	29.52	62	60	SSW	2	5	o	4
London	29.47	63	61	S	6	9	r	—
Dover	29.55	66	64	SW	5	7	o	5
Portsmouth	29.45	63	61	SW	4	9	r	3
Portland	29.39	64	61	S	5	4	c	6
Plymouth	29.27	61	59?	SSE	7	5	c	5
Penzance	29.26	57	56	W	3	9	r	5
~~Alderney~~								
Copenhagen	30.02	50	—	SSE	2	3	b	1
Helder	29.69	61	—	SSE	4	8	m	2
Brest	29.37	63	—	SW	6	9	o	8
Bayonne	29.69	70	—	S	4	5	c	1
Lisbon								

3/ ~~Weather~~ (EXPECTED TILL TO-MORROW ~~or Next Day~~ night

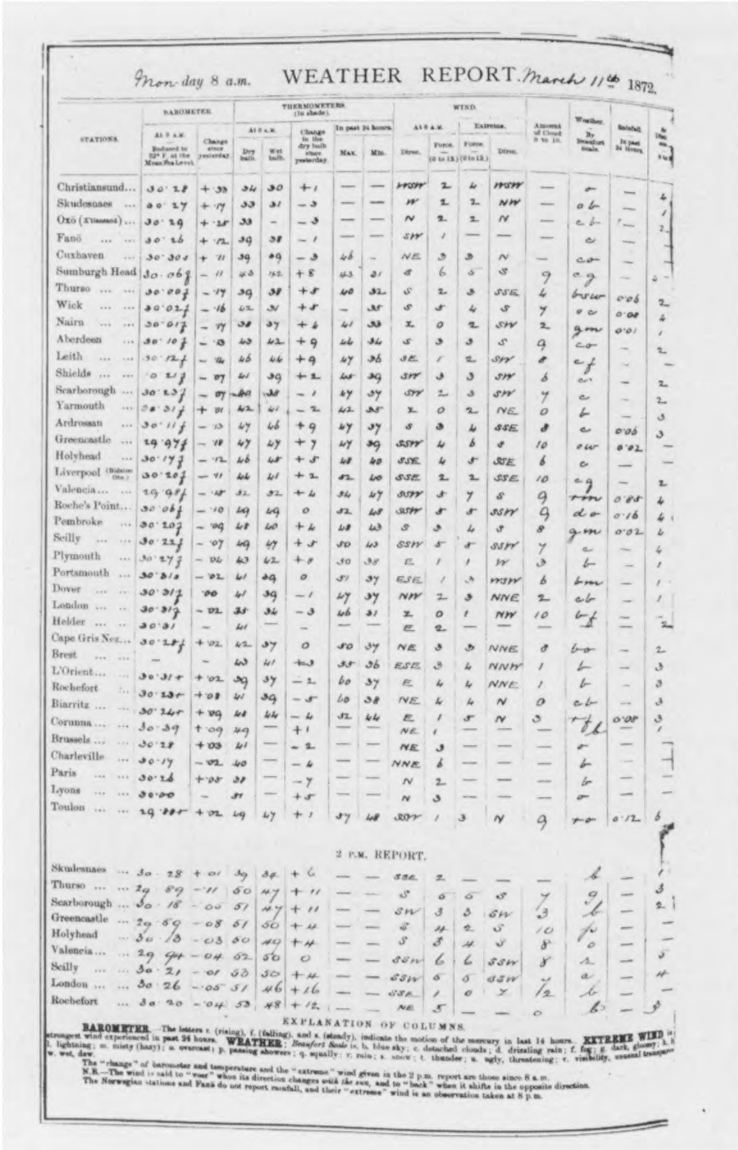
	Since last Report	
NORTH BRITAIN	E to S fresh to strong gale rain	E to S then hard N — gale — rain
IRELAND	~~E to~~ S ~~to~~ W — strong heavy gale	SW to NW — heavy ~~strong~~ gale, rain
EAST COAST	~~E to~~ S ~~to~~ NW strong gale rain	SW to NW and NE — gale, rain
SOUTH ENGLAND	~~E to~~ S ~~to~~ W strong gale, rain	SW to NW — N and NE gale, rain

EXPLANATION.

B.—Barometer corrected and reduced to 32° at mean sea level; each ten feet, of vertical rise, causing about one hundredth of an inch *diminution;* and each ten degrees, above 32°, causing nearly three hundredths *increase*. E.—Exposed thermometer in shade. M.—Moistened bulb (for evaporation and dew point). D.—Direction of wind (true—two points *left* of magnetic). F.—Force (1 to 12—estimated). C.—Cloud (1 to 9). I.—Initials: b.—blue sky; c.—clouds (detached); f.—fog; h.—hail; l.—lightning; m.—misty (hazy); o.—overcast (dull); r.—rain; s.—snow; t.—thunder. S.—Sea-disturbance (1 to 9). Z.—Calm.

5 PM
11.10
RF

Figure 2. Early *DWR* initialled by Admiral FitzRoy (bottom right).



Monday 8 a.m. WEATHER REPORT. March 11th 1872.

STATIONS.	BAROMETER: At 8 A.M. Reduced to 32° F. at the Mean Sea Level.	BAROMETER: Change since yesterday.	THERMOMETERS (in shade): At 8 A.M. Dry bulb.	At 8 A.M. Wet bulb.	Change in the dry bulb since yesterday.	In past 24 hours Max.	In past 24 hours Min.	WIND: At 8 A.M. Direc.	At 8 A.M. Force. (0 to 12.)	Extreme. Force. (0 to 12.)	Extreme. Direc.	Amount of Cloud 0 to 10.	Weather. By Beaufort Scale.	Rainfall. In past 24 Hours.	
Christiansund...	30·28	+·33	34	30	+1	—	—	WSW	2	4	WSW	—	o	—	4
Skudesnaes ...	30·27	+·17	33	31	−3	—	—	W	2	2	NW	—	ob	—	1
Oxö (Christiansand) ...	30·29	+·25	33	-	−3	—	—	N	2	2	N	—	cb	—	2
Fanö	30·26	+·12	39	38	−1	—	—	SW	1	—	—	—	c	—	
Cuxhaven ...	30·30s	+·11	39	49	−3	46	-	NE	3	3	N	—	co	—	
Sumburgh Head	30·06f	−·11	43	42	+8	43	31	S	6	5	S	9	cg	—	
Thurso	30·00f	−·17	39	38	+5	40	32	S	2	3	SSE	4	bcw	0·06	2
Wick	30·02f	−·16	42	31	+5	—	35	S	5	4	S	7	oc	0·08	4
Nairn	30·01f	−·17	38	37	+6	41	33	Z	0	2	SW	2	gm	0·01	1
Aberdeen ...	30·10f	−·13	43	42	+9	44	34	S	3	3	S	9	co	—	2
Leith	30·12f	−·14	46	44	+9	47	36	SE	1	2	SW	8	cf	—	—
Shields	30·21f	−·07	41	39	+2	45	39	SW	3	3	SW	6	c	—	2
Scarborough ...	30·23f	−·07	40	38	−1	47	37	SW	2	3	SW	7	c	—	2
Yarmouth ...	30·31f	+·01	42	41	−2	42	35	Z	0	2	NE	0	b	—	3
Ardrossan ...	30·11f	−·13	47	46	+9	47	37	S	3	4	SSE	8	c	0·06	3
Greencastle ...	29·97f	−·18	47	47	+7	47	39	SSW	4	6	S	10	ow	0·02	—
Holyhead ...	30·17f	−·12	46	45	+5	48	40	SSE	4	5	SSE	6	c	—	—
Liverpool (Bidston Obs.)	30·20f	−·11	44	41	+2	52	40	SSE	2	2	SSE	10	cg	—	2
Valencia... ...	29·98f	−·15	52	52	+4	54	47	SSW	5	7	S	9	rm	0·85	4
Roche's Point...	30·06f	−·10	49	49	0	52	48	SSW	5	5	SSW	9	do	0·16	4
Pembroke ...	30·20f	−·09	48	40	+4	48	43	S	3	4	S	8	gm	0·02	6
Scilly	30·22f	−·07	49	47	+5	50	43	SSW	5	5	SSW	7	c	—	4
Plymouth ...	30·27f	−·04	43	42	+8	50	38	E	1	1	W	3	b	—	1
Portsmouth ...	30·31s	−·02	41	39	0	51	37	ESE	1	3	WSW	6	bm	—	1
Dover	30·31f	·00	41	39	−1	47	37	NW	2	3	NNE	2	cb	—	1
London	30·31f	−·02	35	34	−3	46	31	Z	0	1	NW	10	bf	—	—
Helder	30·31	—	41	—	—	—	—	E	2	—	—	—	—	—	2
Cape Gris Nez...	30·28f	+·02	42	37	0	50	37	NE	3	3	NNE	8	bo	—	2
Brest	—	—	43	41	+3	55	36	ESE	3	4	NNW	1	b	—	3
L'Orient... ...	30·31r	+·02	39	37	−2	60	37	E	4	4	NNE	1	b	—	3
Rochefort ...	30·23r	+·08	41	39	−5	60	38	NE	4	4	N	0	cb	—	3
Biarritz	30·24r	+·09	48	44	−4	52	44	E	1	5	N	3	rfb	0·08	3
Corunna	30·39	+·09	49	—	+1	—	—	NE	1	—	—	—	—	—	1
Brussels	30·28	+·03	41	—	−2	—	—	NE	3	—	—	—	o	—	
Charleville ...	30·17	−·02	40	—	−4	—	—	NNE	6	—	—	—	b	—	
Paris	30·26	+·05	38	—	−7	—	—	N	2	—	—	—	b	—	—
Lyons	30·00	—	31	—	+5	—	—	N	3	—	—	—	o	—	—
Toulon	29·88r	+·02	49	47	+1	57	48	SSW	1	3	N	9	ro	0·12	6

2 P.M. REPORT.

STATIONS.	Barometer	Change	Dry bulb	Wet bulb	Change	Max.	Min.	Direc.	Force	Extreme Force	Extreme Direc.	Cloud	Weather	Rainfall	
Skudesnaes ...	30·28	+·01	39	34	+6	—	—	SSE	2	—	—	—	b	—	1
Thurso	29·89	−·11	50	47	+11	—	—	S	5	5	S	7	g	—	3
Scarborough ...	30·18	−·00	51	47	+11	—	—	SW	3	3	SW	3	b	—	2
Greencastle ...	29·69	−·08	51	50	+4	—	—	S	4	2	S	10	p	—	—
Holyhead ...	30·13	−·03	50	49	+4	—	—	S	3	4	S	8	o	—	—
Valencia... ...	29·94	−·04	52	50	0	—	—	SSW	6	6	SSW	8	r	—	5
Scilly	30·21	−·01	53	50	+4	—	—	SSW	5	5	SSW	7	a	—	4
London	30·26	−·05	51	46	+16	—	—	SSE	1	0	Z	1/2	b	—	—
Rochefort ...	30·20	−·04	53	48	+12	—	—	NE	5	—	—	0	b	—	3

EXPLANATION OF COLUMNS.

BAROMETER.—The letters r. (rising), f. (falling), and s. (steady), indicate the motion of the mercury in last 14 hours. **EXTREME WIND** is strongest wind experienced in past 24 hours. **WEATHER**: *Beaufort Scale* is, b. blue sky; c. detached clouds; d. drizzling rain; f. fog; g. dark, gloomy; h. h; l. lightning; m. misty (hazy); o. overcast; p. passing showers; q. squally; r. rain; s. snow; t. thunder; u. ugly, threatening; v. visibility, unusual transpa; w. wet, dew.

The "change" of barometer and temperature and the "extreme" wind given in the 2 p.m. report are those since 8 a.m.

N.B.—The wind is said to "veer" when its direction changes *with the sun*, and to "back" when it shifts in the opposite direction.

The Norwegian stations and Fanö do not report rainfall, and their "extreme" wind is an observation taken at 8 p.m.

Figure 3. First *DWR* containing charts, 11 March 1872.

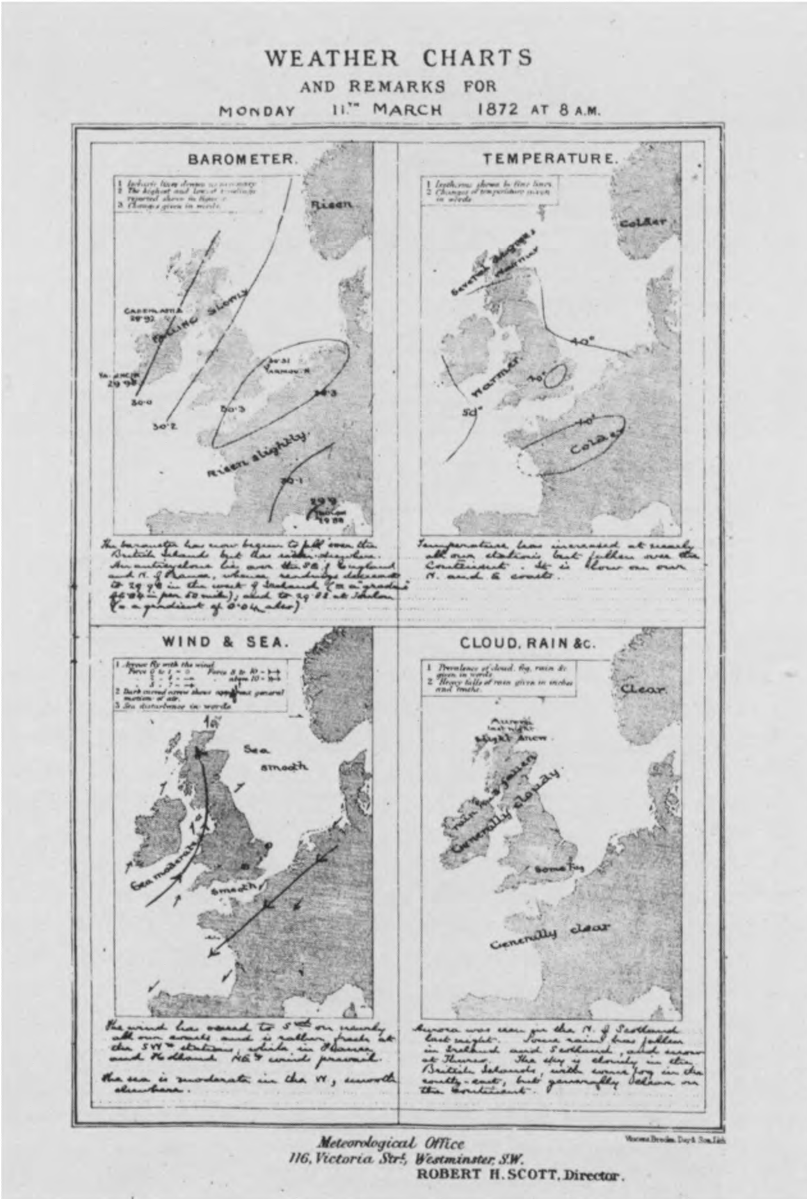
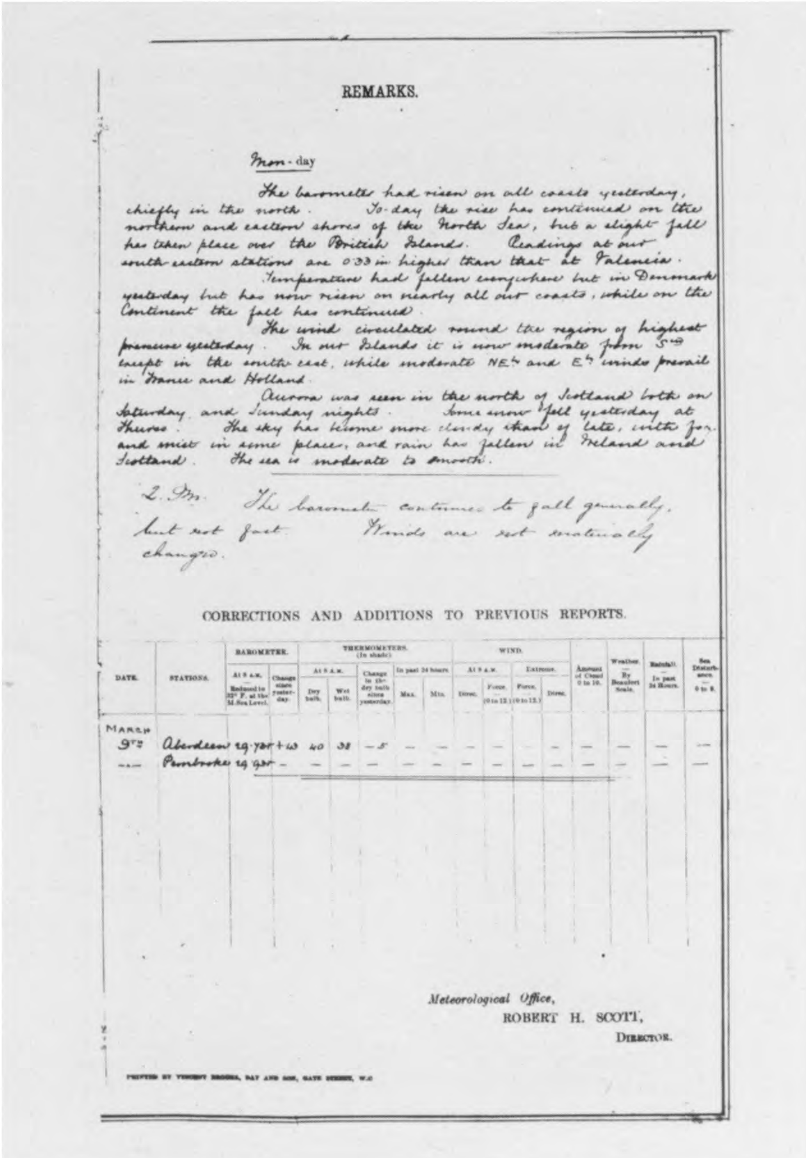


Figure 3 - *continued.*



REMARKS.

Mon-day

The barometer had risen on all coasts yesterday, chiefly in the north. To-day the rise has continued on the northern and eastern shores of the North Sea, but a slight fall has taken place over the British Islands. Readings at our south-eastern stations are 0·33 in higher than that at Valencia.

Temperature had fallen everywhere but in Denmark yesterday but has now risen on nearly all our coasts, while on the Continent the fall has continued.

The wind circulated round the region of highest pressure yesterday. In our Islands it is now moderate from S^ly except in the south-east, while moderate NE^ly and E^ly winds prevail in France and Holland.

Aurora was seen in the north of Scotland both on Saturday and Sunday nights. Some snow fell yesterday at Thurso. The sky has become more cloudy than of late, with fog and mist in some places, and rain has fallen in Ireland and Scotland. The sea is moderate to smooth.

2. P.M. The barometer continues to fall generally, but not fast. Winds are not materially changed.

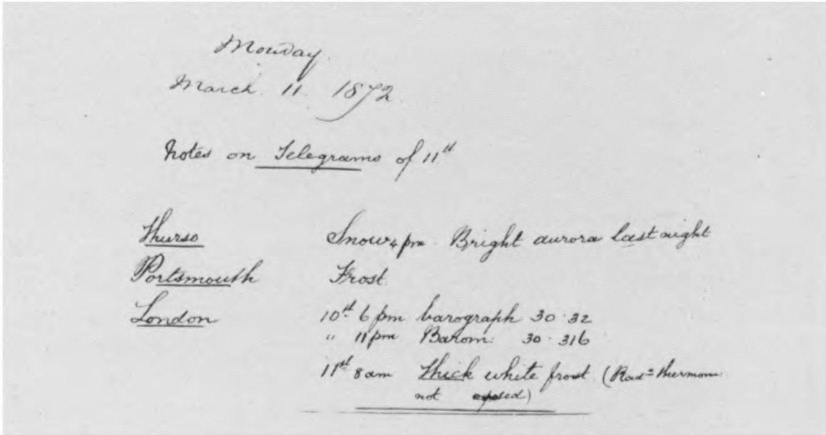
CORRECTIONS AND ADDITIONS TO PREVIOUS REPORTS.

DATE.	STATIONS.	BAROMETER. At 8 a.m. — Reduced to 32° F. at the M. Sea Level.	BAROMETER. Change since yesterday.	THERMOMETERS (In shade). At 8 a.m. Dry bulb.	THERMOMETERS. At 8 a.m. Wet bulb.	THERMOMETERS. Change in the dry bulb since yesterday.	THERMOMETERS. In past 24 hours. Max.	THERMOMETERS. In past 24 hours. Min.	WIND. At 8 a.m. Direc.	WIND. At 8 a.m. Force. (0 to 12.)	WIND. Extreme. Force. (0 to 12.)	WIND. Extreme. Direc.	Amount of Cloud 0 to 10.	Weather. — By Beaufort Scale.	Rainfall. — In past 24 Hours.	Sea Disturbance. — 0 to 9.
MARCH 9TH	Aberdeen	29·725	+·03	40	38	−5	—	—	—	—	—	—	—	—	—	—
—	Pembroke	29·935	—	—	—	—	—	—	—	—	—	—	—	—	—	—

Meteorological Office,
ROBERT H. SCOTT,
DIRECTOR.

PRINTED BY VINCENT BROOKS, DAY AND SON, GATE STREET, W.C.

Figure 3 – *continued.*


Monday
March 11 1872

Notes on Telegrams of 11th

Thurso	Snow 4 pm Bright aurora last night
Portsmouth	Frost
London	10th 6 pm barograph 30·32
	" 11 pm Barom: 30·316
	11th 8 am thick white frost (Rad: thermom. not exposed)

Figure 3 - *continued.*

The *Daily Weather Report* had, from the earliest days, continually enlarged its coverage of weather information from both home and overseas. After the end of the War the amount of extra information had become so large that the *Report* was split into three parts: British, International, and Upper Air; the first issues in the new style were made on 1 April 1919. The British Section contained surface charts for 07 GMT only (as well, of course, as tabulated data), but the International Section contained charts drawn at six-hourly intervals, two covering the British Isles only, and two covering Europe and the eastern Atlantic. On 1 March 1930, the British Section underwent a major modification with the introduction of a new chart covering most of the northern hemisphere; plotted observations were not, however, synchronous, but varied over a wide range from e.g. 07 GMT in western Europe to 19 GMT of the previous day at 180° E. (A fully synchronous northern hemisphere chart seems not to have been achieved until 1949.) During the 1939–45 War, all these publications, though printed regularly, were classified as Secret; they were declassified soon after the War ended. The International Section ceased publication on 31 December 1949, and on 1 January 1950 the Upper Air Section was renamed the *Daily Aerological Record (DAR)*; as compensation for the loss of the old International Section the British Section introduced charts drawn at six-hourly intervals. On 1 January 1951 publication began of an *Overseas Supplement* to the *Daily Weather Report* which contained data for Meteorological Office stations overseas; this *Overseas Supplement* continued to be printed until 31 December 1972. The inclusion of upper-air charts in the *DAR* ended on 31 December 1975, which thereafter contained tabulated data only.

Forecasts 'for Great Britain and Northern Ireland until noon tomorrow' together with an outlook for the following 24 hours continued to be included in the *DWR* until 31 December 1966 but from then on were dropped, the chance of a *DWR* reaching any subscriber on the day of issue having long since become effectively zero.

With the issues of the *Daily Weather Report* and *Daily Aerological Record* for 31 December 1980, and of the *Monthly Summary* for December 1980, the work of the local HMSO Press at the Meteorological Office, Bracknell ceased.

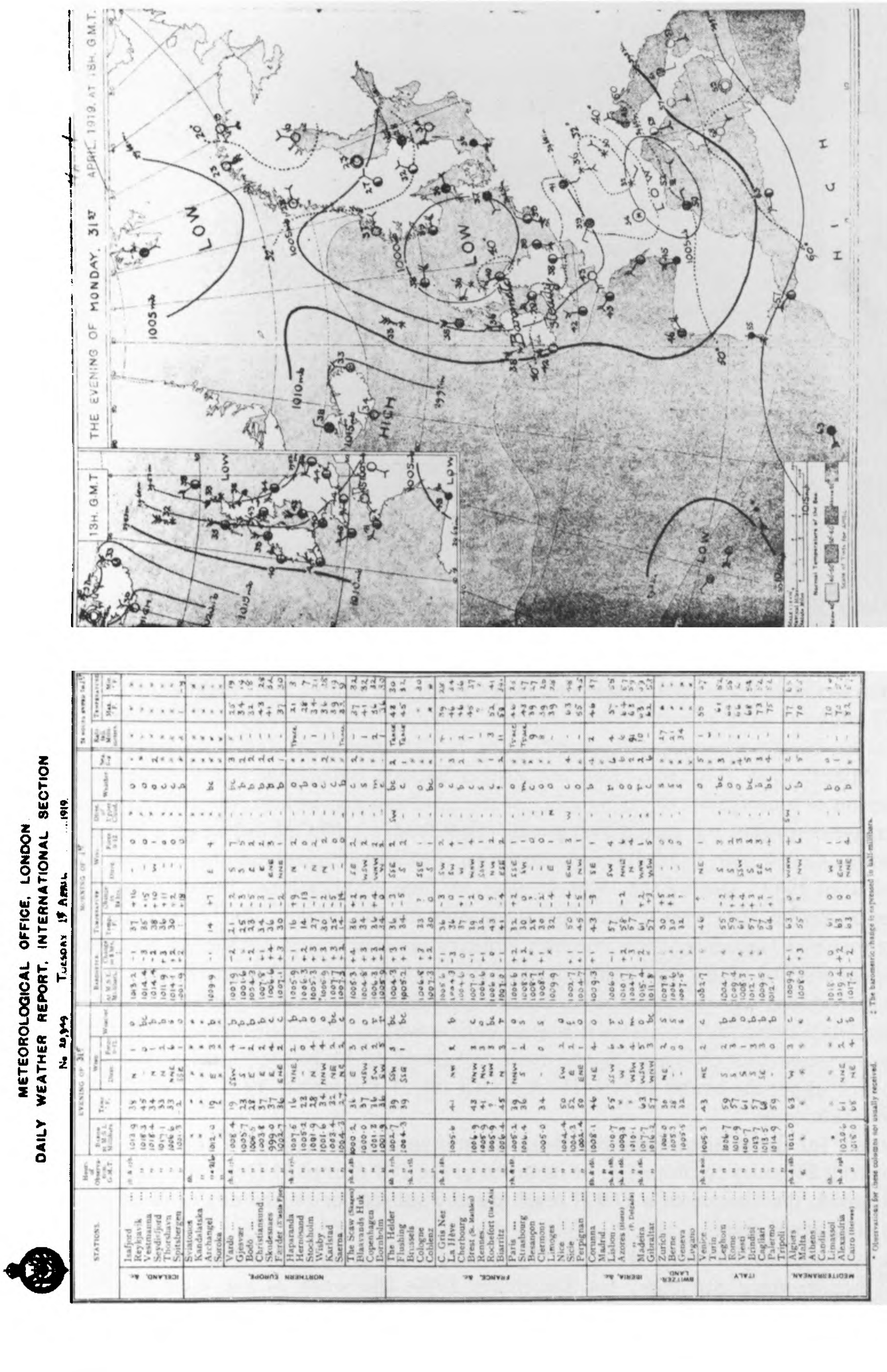
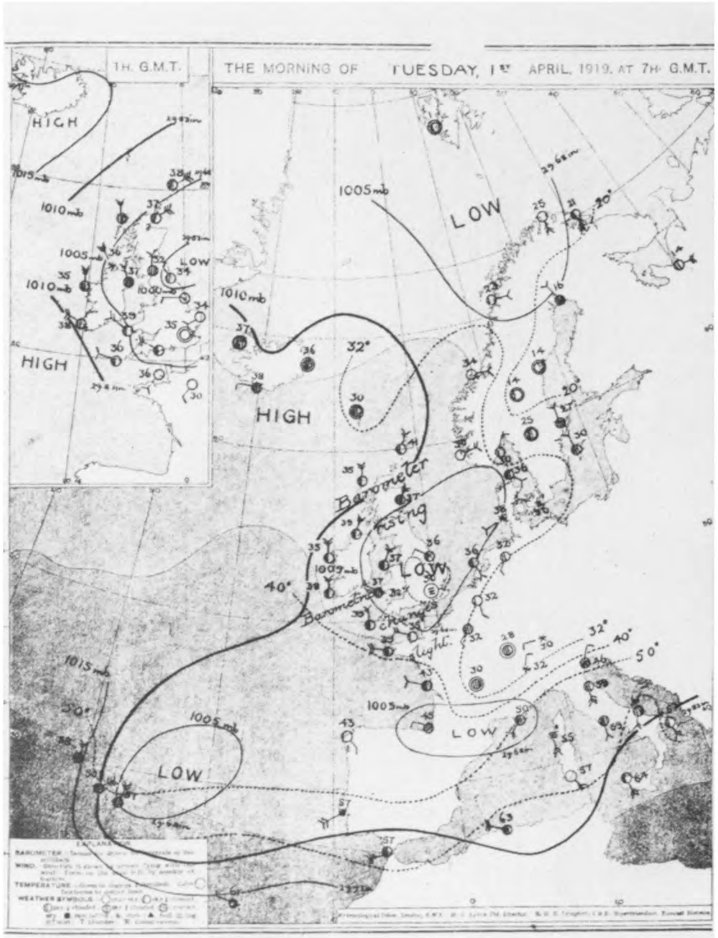


Figure 4. First issue of *DWR* split into three parts – International, British and Upper Air – 1 April 1919.



DAILY WEATHER REPORT OF THE METEOROLOGICAL OFFICE, INTERNATIONAL SECTION, 1919. No. 91... { TUESDAY 1st April

WIRELESS REPORTS FROM THE ATLANTIC.

Hour.	Ship.	Lat. °	Long. °	Barom. m.b.	Temp. °F	Wind.		Weather.	Hour.	Ship.	Lat. °	Long. °	Barom. m.b.	Temp. °F	Wind.		Weather.
						Direc.	Force.								Direc.	Force.	

NOTES ON THE WEATHER OF THE 24 HOURS ENDED 7H TO-DAY.

A large shallow depression over the North Sea with secondaries over England was still the dominating feature of the weather of North-Western Europe on Tuesday. An area of high pressure was centred over the Faröe and pressure was moderately high in the region of the Azores.

Over the western parts of the British Isles the main wind current was Nly. or NEly. and moderate temperatures prevailed. To the south of the depression, over North France and Rhineland generally a light SWly. current prevailed, and very low temperatures - many below freezing point - were recorded on the morning map. Over most of England, as over Scandinavia, light variable winds were prevalent and the weather continued cold, with variable sky.

Slight snow or sleet showers were experienced locally in Ireland and North Wales and on the Danish coast, and there was much mist and frost over the country generally. Fog was reported in Surrey and Essex.

TERMS OF SUBSCRIPTION.—The report is sent by post to any address in the United Kingdom upon payment of the following subscriptions :—
7s. 6d. per quarter for all three parts ; 6s. 6d. per quarter for any two parts ; 5s. per quarter for one part.
Single copies of any of the reports can be obtained at the Meteorological Office, S.W. 7, price 1d. each.

Figure 4 – *continued.*

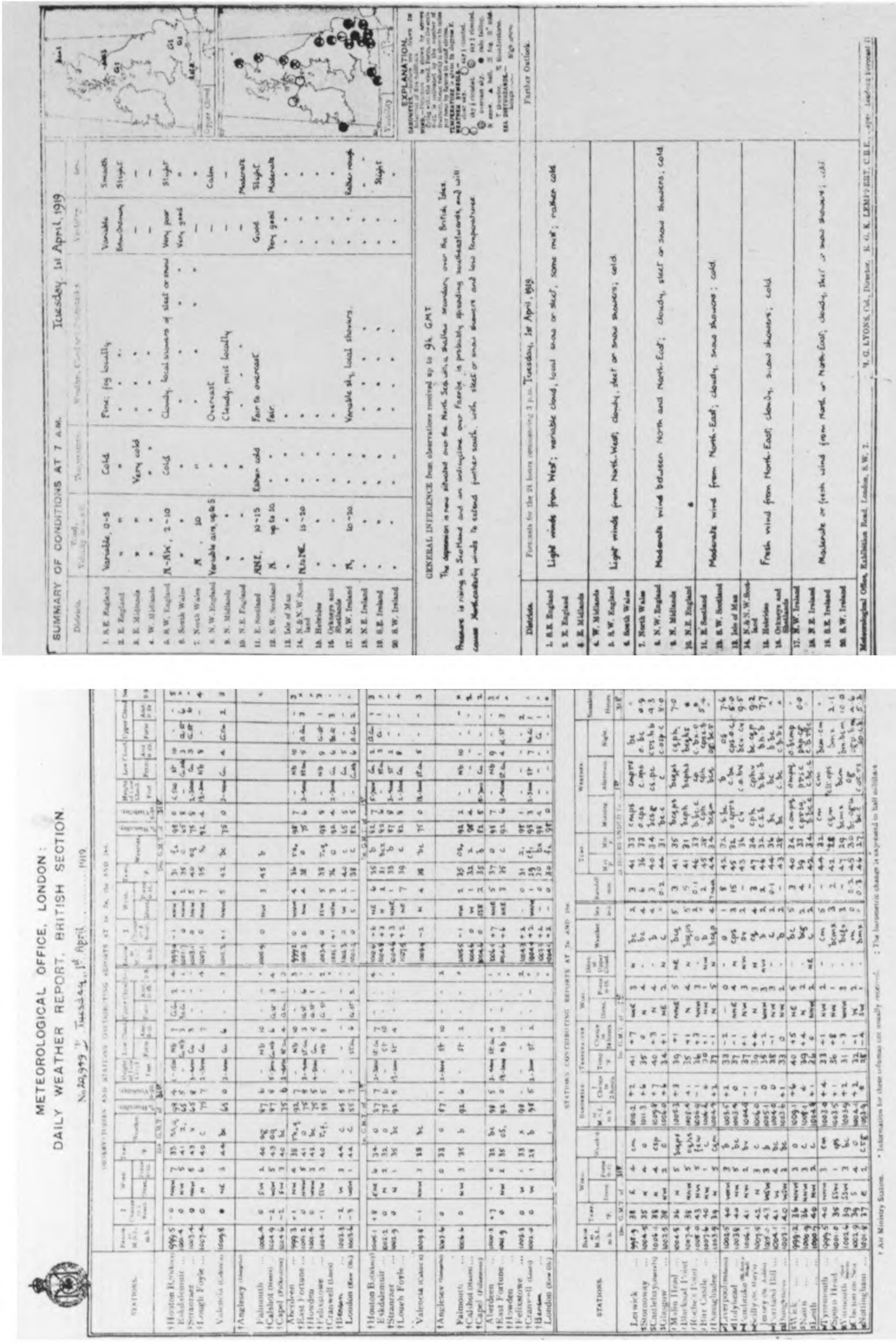


Figure 4 – *continued.*

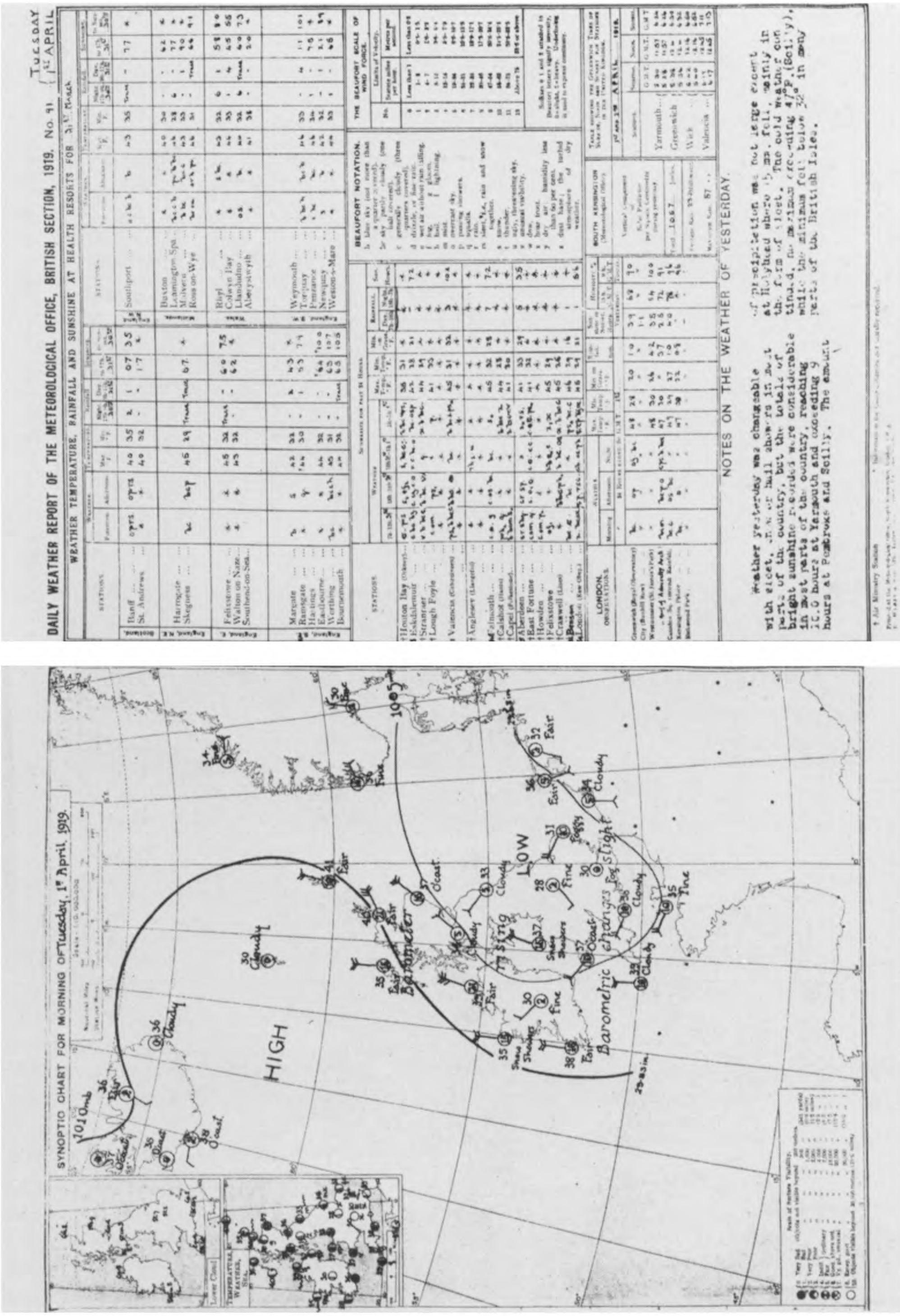


Figure 4 – *continued.*

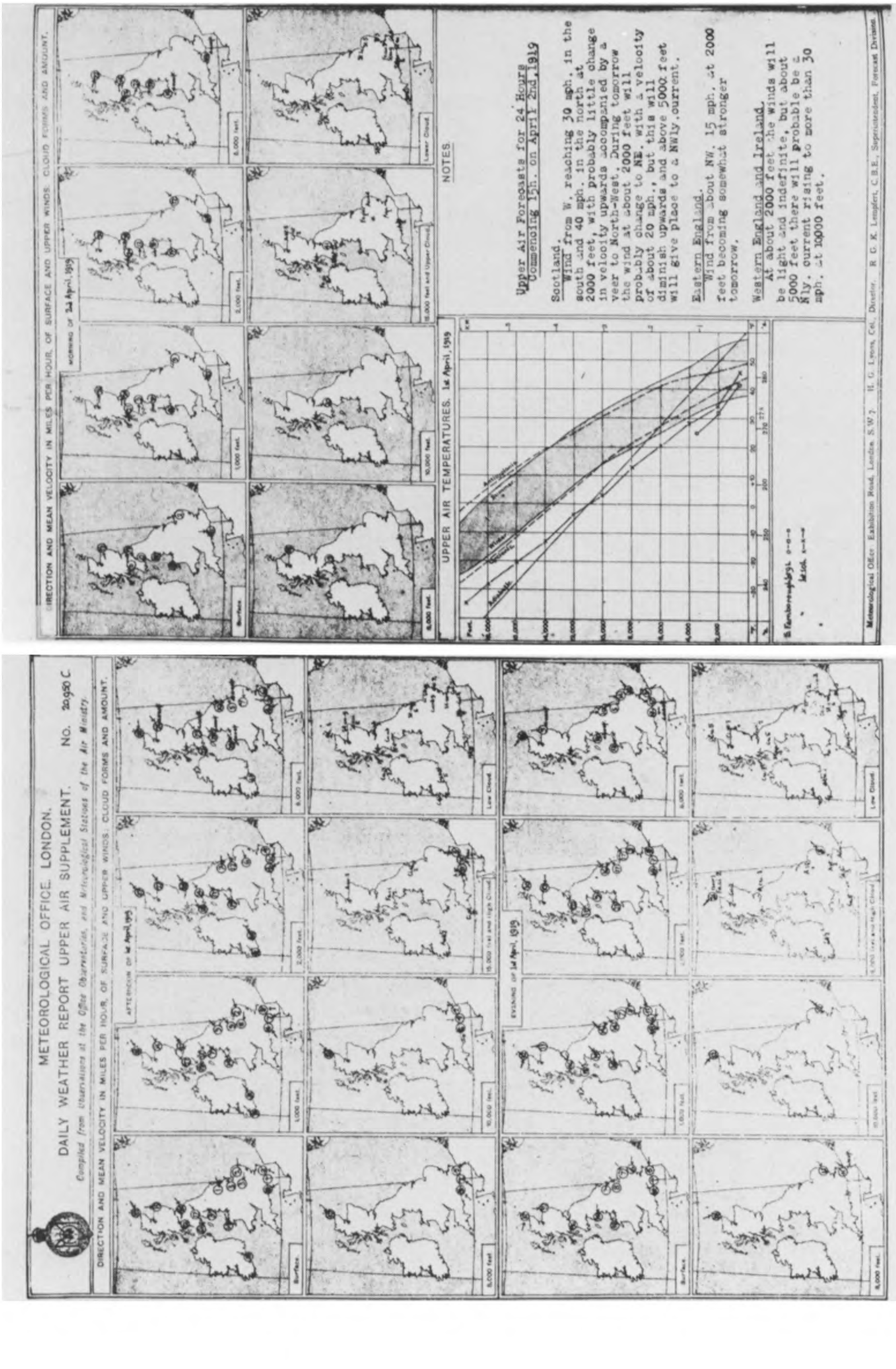


Figure 4 – *continued.*

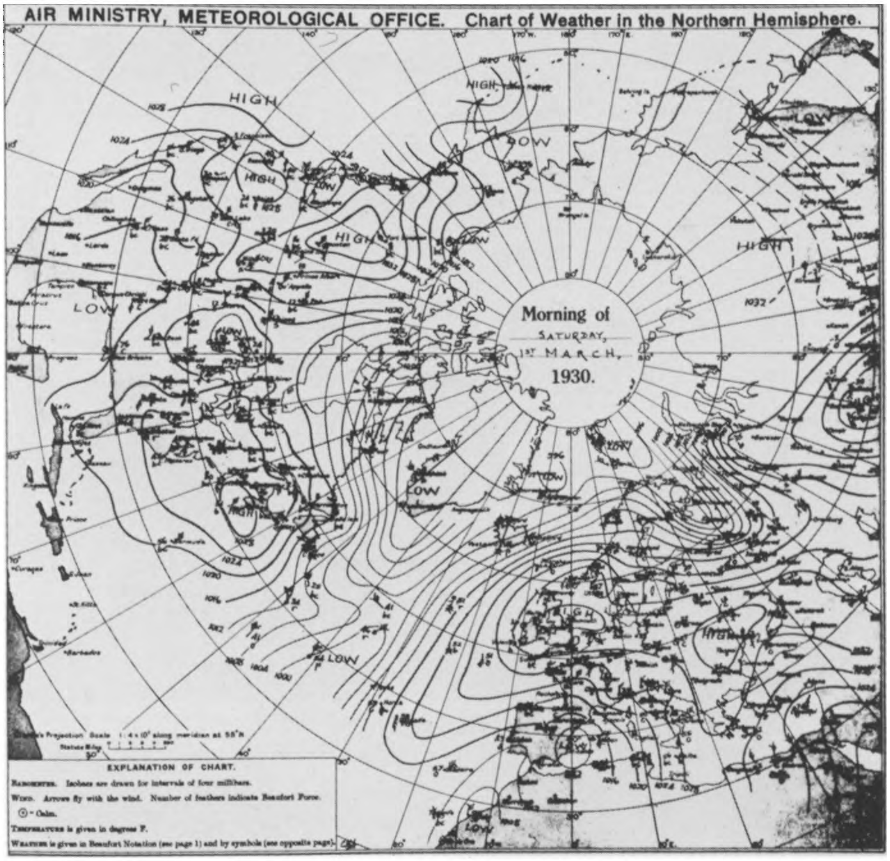


Figure 5. First *DWR* containing chart of northern hemisphere, 1 March 1930.

The circulation of the *DWR* and its sister publications was not large, never, it seems, having exceeded three figures. It is difficult to find evidence of the numbers issued in the past, but occasional pieces of information do occur in the Minutes of the Meteorological Committee. For example:

in November 1907, about 580 *DWR*s were posted each day;
the plan for 1910–11 envisaged a printing of 650–700;
in May 1915, 650 copies were 'received' and 539 'issued', a remark being inserted in the Minutes that the 'issue [was] restricted on account of War conditions';
in 1919 it was proposed that in 1920 the numbers produced of the British, International, and Upper Air sections should be 800, 300, and 800 respectively.

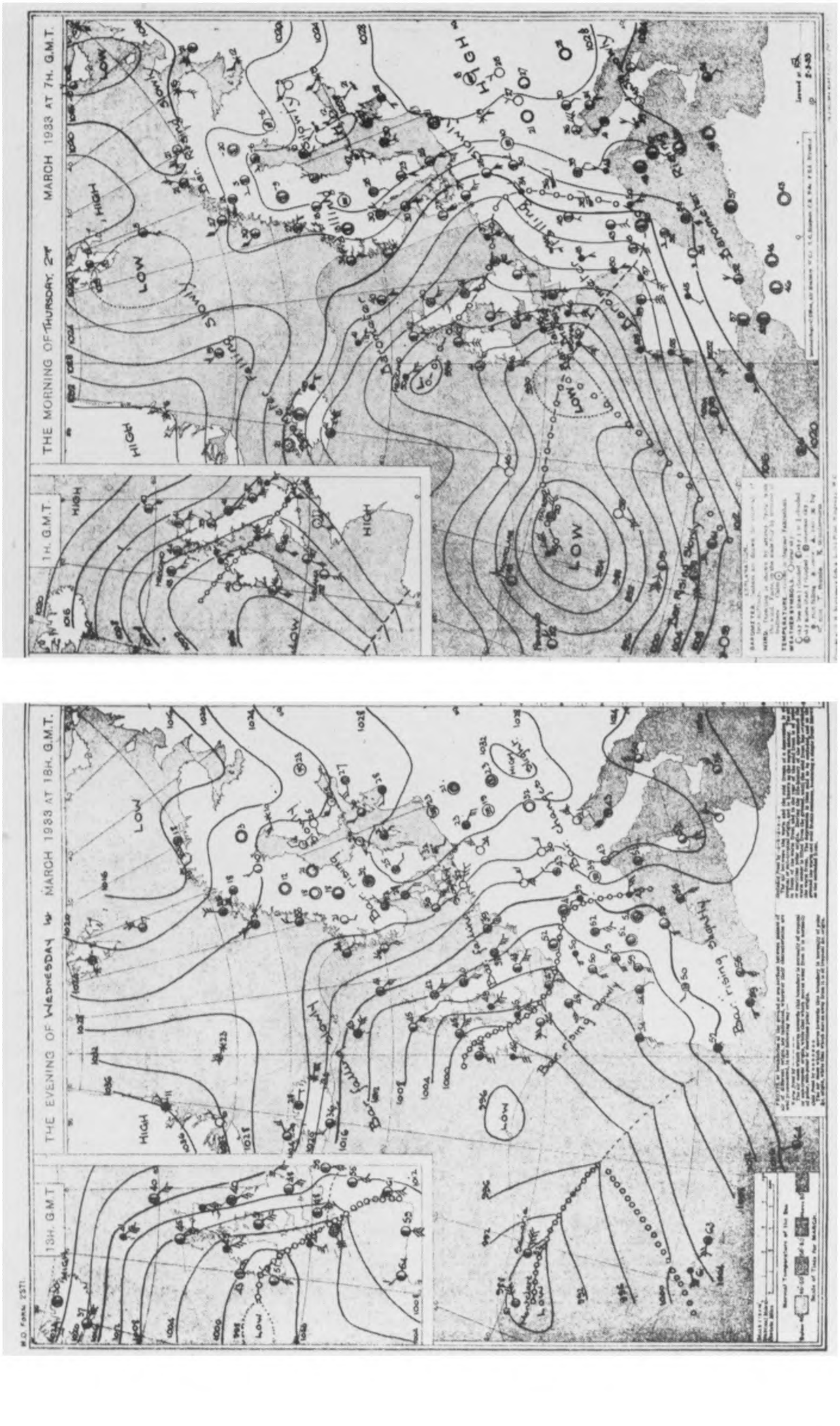


Figure 6. Charts from International Section of *DWR* for 1 March 1933. This was the first time that fronts appeared on the charts.

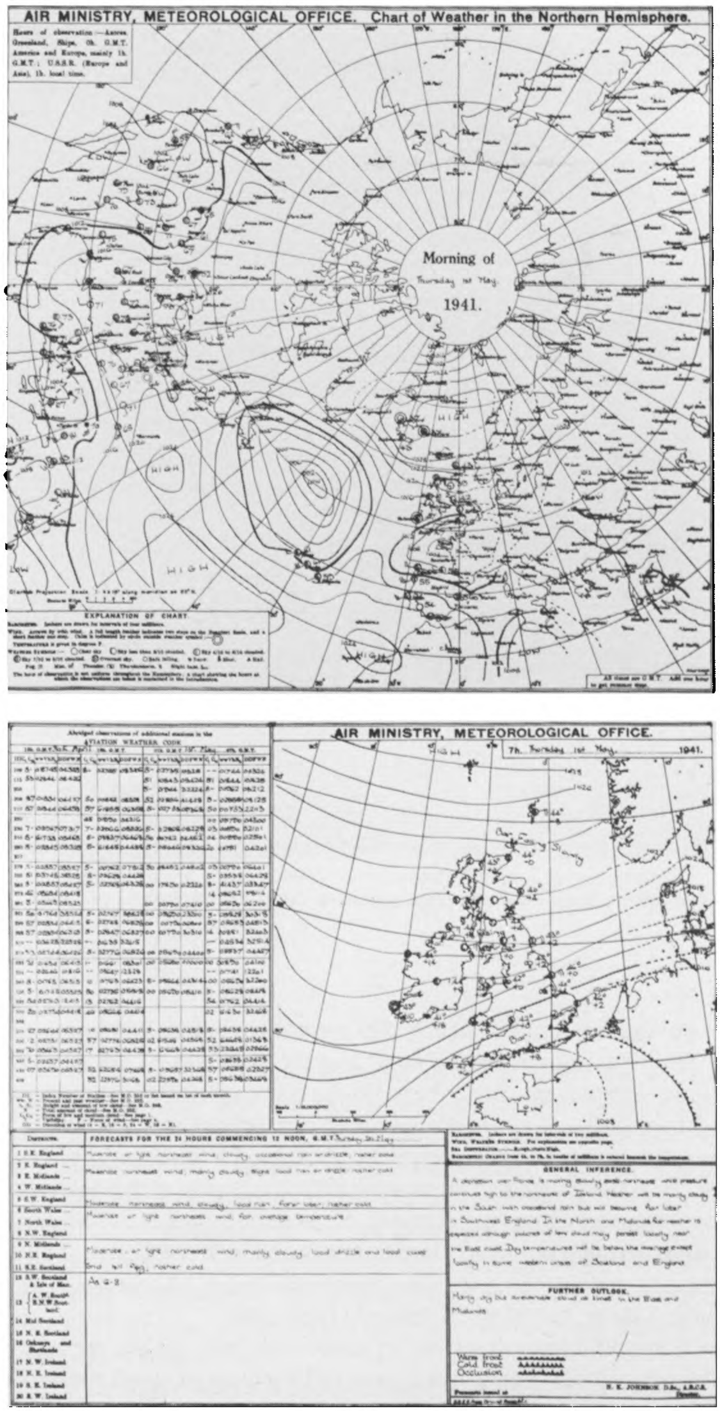


Figure 7. Charts from British Section of *DWR* for 1 May 1941, showing first appearance of fronts on British Isles charts.

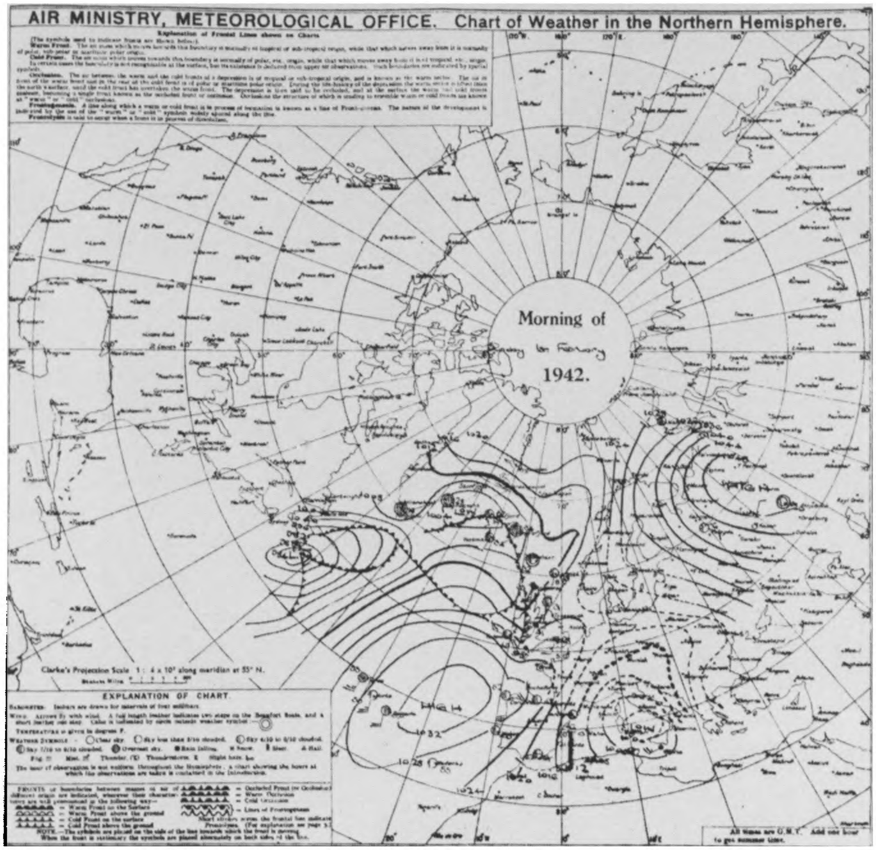
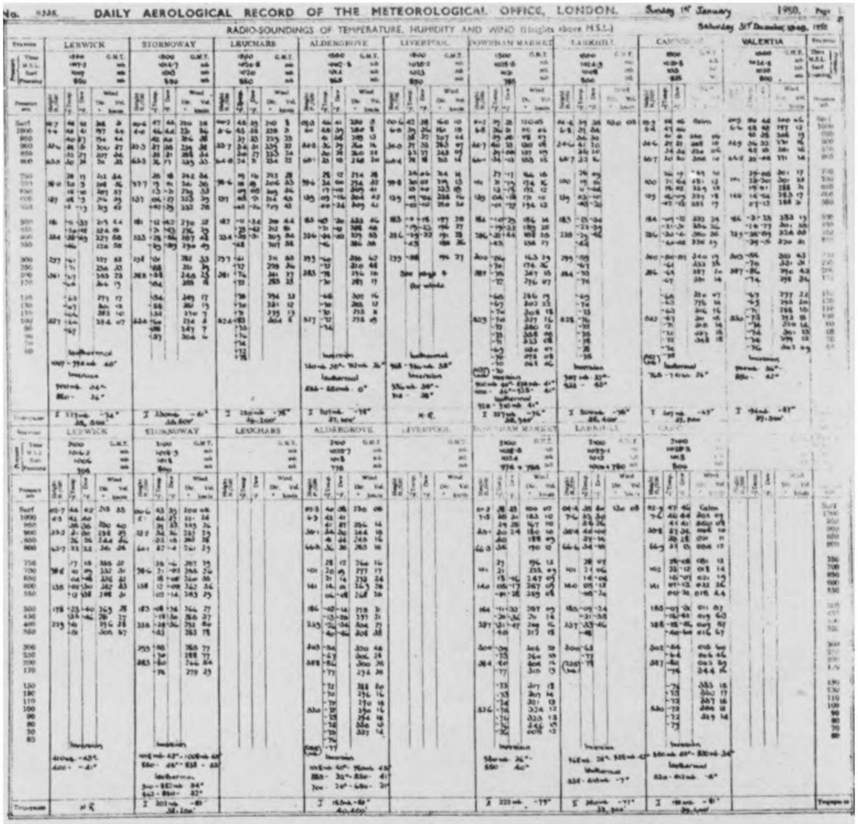


Figure 8. First northern hemisphere chart on which front appeared, from British Section of *DWR*, 1 February 1942.

In 1980, just before publication ceased, nearly 500 were distributed, 266 going to paying customers and 223 being issued free. Paying customers were largely made up of educational institutions and libraries; there were hardly any private subscribers. Of the free issue, 99 were used by the Meteorological Office, 5 went to the Royal Navy, 5 to lighthouses and coastguard stations, 26 to other Government departments and major museums, 5 to the copyright libraries, 15 to schools, colleges and universities (mainly those of an official nature such as Dartmouth and Sandhurst, or schools of navigation, or those associated with a meteorological observing station), 57 to foreign countries on exchange agreements, and 11 to miscellaneous addressees who had close connections with the Office. The *DAR* had about 51 paying customers — mainly universities and other centres of higher education — and about 120 copies were issued free, including those for Meteorological Office use.

It has, of course, been impossible to describe, let alone illustrate, all the minor changes of style and content that have occurred over 120 years, but a very full account of these variations was prepared in 1961 by E. Cayhill, and a typescript copy is kept in the National Meteorological Library at Bracknell where it may be consulted.


DAILY AEROLOGICAL RECORD OF THE METEOROLOGICAL OFFICE, LONDON.

RADIO-SOUNDINGS OF TEMPERATURE, HUMIDITY AND WIND ([illegible] above M.S.L.)

LERWICK, STORNOWAY, LEUCHARS, ALDERGROVE, LIVERPOOL, DOWNHAM MARKET, LARKHILL, CAMBORNE, VALENTIA

Figure 9. First issue of ***Daily Aerological Record***, 1 January 1950.

One topic does, however, warrant some detailed mention, and that is the introduction of the representation of frontal analysis into the published charts. For some peculiar reason, which is unknown to me, fronts were used in the charts of the International Section more than eight years before they appeared in the British Section. The issue of the former dated 1 March 1933 bore a legend referring to fronts and introducing the symbolism ----- for a warm front, ooooo for a cold front, and -o-o-o- for an occlusion; fronts appeared for the first time on the 18 GMT chart for 1 March 1933 printed on the issue dated 2 March. (Modern symbolism was introduced on 1 January 1937, possibly as one result of an extended visit paid to the Meteorological Office by Professor J. Bjerknes from December 1935 to May 1936 when he instructed the senior forecasting staff of the Office in the latest methods of the Norwegian school.)

In the British Section, though isobars in troughs were kinked more and more sharply from the mid 1930s onwards, fronts themselves were not represented until 1 May 1941, and then only on the small British Isles chart; they did not appear on the northern hemisphere chart until 1 February 1942.

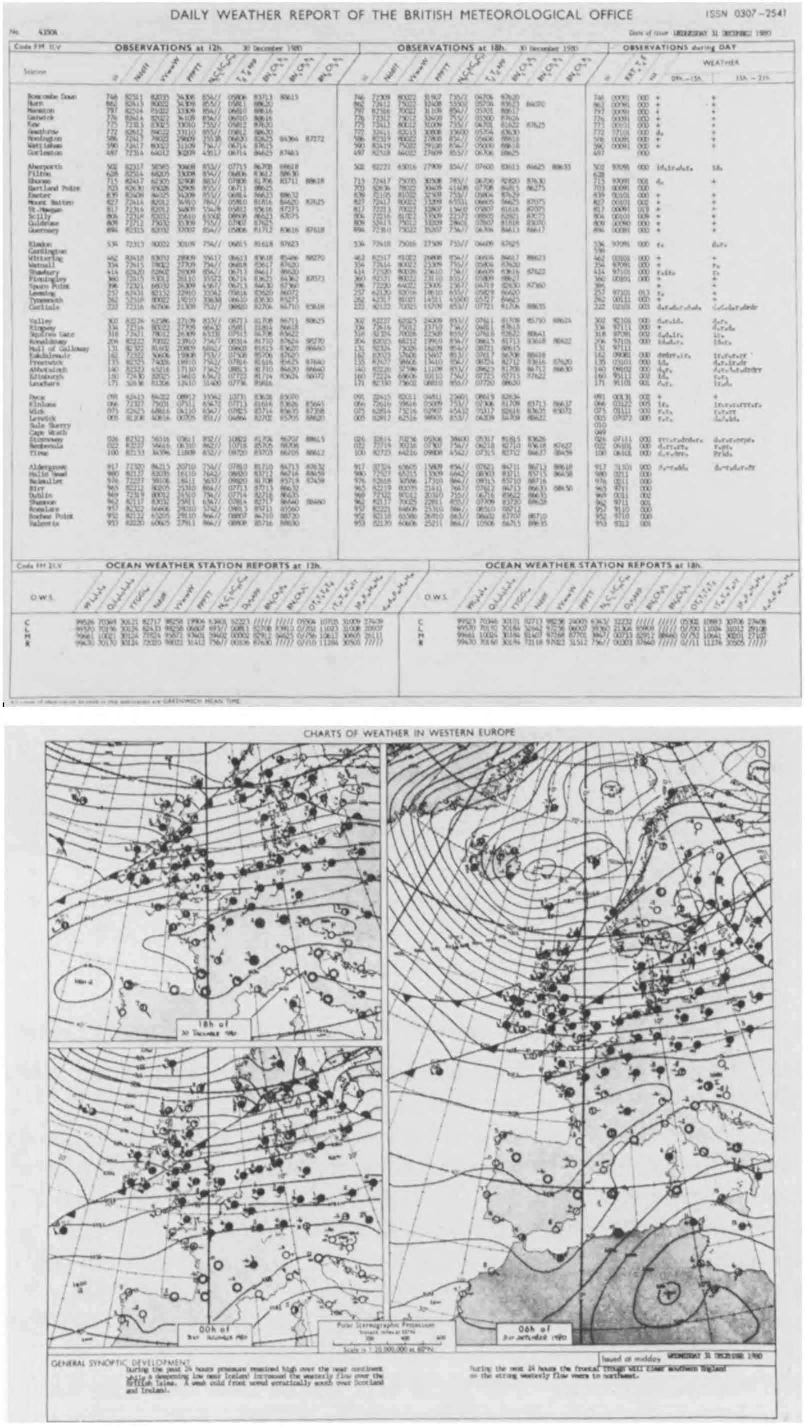
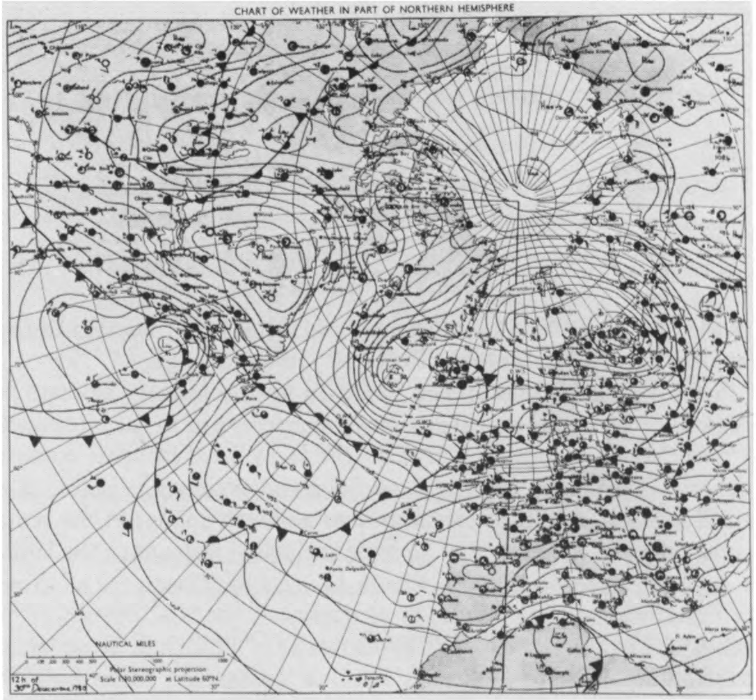


Figure 10. Last issue of *DWR*, 31 December 1980.



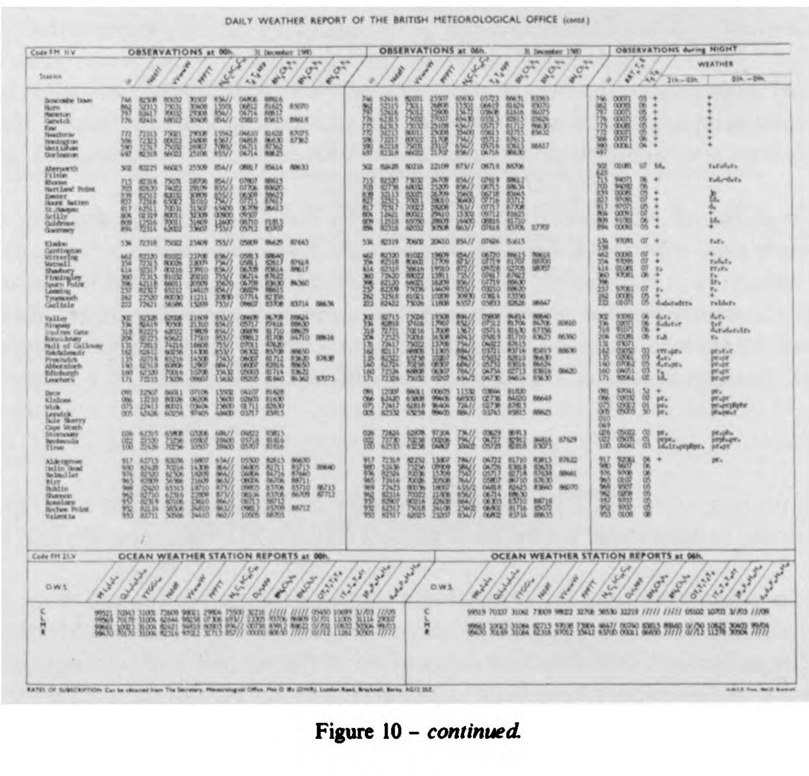


Figure 10 – *continued.*

551.593.653

Noctilucent clouds over western Europe during 1981

By D.H. McIntosh and Mary Hallissey
(Department of Meteorology, University of Edinburgh)

Table I summarizes the observations of noctilucent cloud (NLC) over western Europe during 1981, as reported to the Department of Meteorology, University of Edinburgh.

The times given in the second column of the Table do not necessarily indicate the duration of the display, though appearance and disappearance times are referred to in the Notes where known. In the third column brief notes of the displays enlarge on the facts listed in other columns — NLC forms discernible, tropospheric cloud conditions, photographs and sketches available. Co-ordinates of the observing stations and selected details of elevation and azimuth appear in the remaining columns.

Routine hourly observations were made at 13 meteorological stations in the United Kingdom, 3 in Sweden and when darkness permitted at Reykjavik in Iceland. Observers at these stations provide information of sky conditions during all hours of darkness; the significance of 'negative' nights is obviously great when trying to assess the overall appearances of NLC. It is, however, always remarkable and much appreciated that in many instances NLC is recognized when quite large amounts of tropospheric cloud — in fact, up to seven oktas — are present.

The usually accepted peak occurrence periods — the last two weeks of June and the first two weeks of July — were very cloudy in 1981. During this period few instances occurred where observing conditions permitted with any degree of confidence the statement 'no NLC' to be made. According to the film taken at Edinburgh (automatic exposures at 15-minute intervals throughout) the nights 15/16, 16/17 and 27/28 June were clear; several hourly observing stations were sufficiently clear to back up these negative observations.

Positive observations of NLC were received from 13 hourly observing stations, 3 other United Kingdom meteorological stations, 3 Swedish stations, the Icelandic station, a Swiss observatory, and from voluntary observers in Edinburgh, Milngavie, Newton Stewart, Stevenston, Fiane (Norway) and Turku (Finland). On occasions, the observation points were well scattered. Many of the observations were accompanied by sketches, and the list at the end of the report summarizes the many photographs taken. Details of these are available if required. Positive reports occurred on 41 nights. This number compares with 32 in 1980 and 43 in 1979.

The most outstanding and widely reported displays occurred on 6/7, 21/22, 22/23, 28/29 June, 8/9 and 9/10 July.

A selection of photographs and a graphic compilation of the data received over the years 1970-81 were on display at the International Union of Geodesy and Geophysics conference held in Edinburgh in August 1981.

The help and co-operation of the many observers who were fortunate enough to see NLC and of the many more who watched in vain are gratefully acknowledged. A grant from the Meteorological Office makes possible the collection, collation and publication of the written and photographic data. All the data published here and elsewhere have been incorporated by Dr Fast of the University of Tomsk into his catalogue of NLC data.

Table I. *Displays of noctilucent clouds over western Europe during 1981*

Date — night of		Times UT	Notes	Station position*		Time UT	Max. elev.	Limiting azimuths
							degrees	
1981								
19/20	May	2300	Possible NLC seen from neighbouring stations [Kirkwall & Wick] in breaks in tropospheric cloud.	59°N	03°W	2300		
		0100		58.5°N	03°W	0100		
26/27		2300	Possible faint NLC visible from SW Scotland.	55°N	04.5°W	2300		
6/7	June	2245–0300	Widespread display of NLC, first visible in south at Boulmer, and last seen from Tiree. The delicate formation of bands and denser patches against a veil background show up well in sketches from Kinloss and Edinburgh, and in photographs from Edinburgh and Joppa. Maximum elevation to 24° at Kinloss, to 10° at Boulmer and at Tiree. Medium to bright.	57.5°N	03.5°W	0040	24	310 005
				57°N	02°W	2400		
						0100	–	060
				56.5°N	03°W	2400	15	020–030
						0100	14	330–030
				56.5°N	07°W	2400	8	320–360
						0100	10	
				56°N	03°W	2310	15	017 025
						2330	11	- –035
						0015	11	346–011
				55.5°N	01.5°W	2245	7½	350–020
						2340	10	350–020
						0040	10	340–030
						0145	10	010 040
				55°N	01.5°W	0025	4	340–010
						0050	5	350–020
8/9		2400,0100	Possible NLC seen Kinloss, Peterhead and Aldergrove — no details	57.5°N	03.5°W	2400		
				54.5°N	06°W	2400		
						0100		
9/10		2200	Silvery-blue streaks of NLC visible Boulmer above stratocumulus	55.5°N	01.5°W	2200	20	280–040
17/18		0100	NLC seen Kinloss and Tiree in breaks in tropospheric cloud. Extent of display hidden.	57.5°N	03.5°W	0300	–	330,025
		0240–0305		56.5°N	07°W	0100	15	340–360
20/21		2200,2400	Possible small areas of NLC — reported from three stations.	56.5°N	07°W	0100	–	315
				55.5°N	03°W	0100	–	020
		0015,0100		55°N	04.5°W	2215	–	–
						0015	–	–
21/22		0030–0305	Skies sufficiently clear at several stations 2200–2400 to claim 'no NLC'. NLC first seen 0030 in NE England and visible Church Fenton until 0305. Sketch from Kinloss shows bright and very bright patches against veil background, bright bands and fine ripples. Similar detail noted at Newcastle and Boulmer. Visible Church Fenton as veil or silvery streaks on N horizon.	57.5°N	03.5°W	0100	21	320–065
				55.5°N	01.5°W	0030	19	350–030
						0200	19	340–010
				55°N	01.5°W	0050	7	360–050
						0120	12	360–050
						0150	15	360 040
				54.5°N	01.5°W	0100	5	340–020
						0200	5	340–020
				54°N	01°W	0100	–	360
						0300	–	–
22/23		2220–0030	This rather spectacular display reported earliest from Milngavie where a series of photographs was taken. Intensely bright NLC with typical ice blue at higher elevation, yellowing towards horizon. Well defined bands and herring-bone formation reported from Milngavie and Leuchars, also whirls and billow much in evidence from Leuchars, and noted on Edinburgh film. Display visible through breaks in thick tropospheric cloud at Boulmer. Overcast conditions hampered viewing display to its conclusion.	56.5°N	03°W	2300	30	330–030
						2400	20	340 360
				56°N	03°W	0001	15	360
				56°N	04.5°W	2220	42	360
						0025	40	360
				55.5°N	01.5°W	2400	12	330
23/24		2345	Bright silvery bands of NLC seen from Livingston.	56°N	03°W	2345	45	360
25/26		2400,0100	Tiree reported 'no NLC' at 2300 - almost cloudless sky - and again at 0200–0400. At 2400 and 0100 small band of NLC visible there; at 0100 at Ronaldsway faint wisps of NLC visible above low cumulus.	56.5°N	07°W	2400	15	360–020
						0100	15	360–020
				54°N	04.5°W	0100	15	340–020
26/27		2345–0100	Faint NLC thought to be discernible on film at Edinburgh, low N horizon.	56°N	03°W	0100	3	360
28/29		2400–0245	Several stations able to state 'no NLC' before midnight. By 0030 at Leuchars extensive display of NLC with veil, bands, billows and whirl formation, the bands running N-S direction. The NLC spread in south-easterly direction, fading from the north. Detailed sketches from Leuchars and Church Fenton, photographs Edinburgh.	57°N	02°W	0100	–	–
				56.5°N	03°W	0030	28	320–070
						0120	36	320–085
						0220	30	090 175
				56°N	03°W	0100	25	360
				55.5°N	01.5°W	2400	22	340 030
						0100	20	360–365
						0200	30	340–020
				55.5°N	05°W	2400	5	340
				55°N	01.5°W	0045	8	340–020
						0115	12	340 020
				54.5°N	06°W	0100	12	020 050
						0200		357,090
				54°N	04.5°W	0100	10	350 030
						0200	25	340 090
				54°N	01°W	0110	8	350–055
						0205	46	350–095

*To nearest 0.5 degree.

Date — night of		Times UT	Notes	Station position*		Time UT	Max. elev.	Limiting azimuths
							degrees	
1/2	July	2400	Short-lived appearance of NLC bands in NE seen Dyce ['no NLC' in previous and following hourly observations], and showing as veil on Edinburgh film.	57°N	02°W	2400	10	045
				56°N	03°W	0015	5	360
3/4		0045-0200	Sketch from Kinloss depicts NLC bands N-S orientation. From Boulmer and on film from Edinburgh NLC seen in breaks in tropospheric cloud.	57.5°N	03.5°W	0100	35	360
							24	040
				56°N	03°W	0030	15	360
				55.5°N	01.5°W	0100	8	340
						0200	15	360
4/5		2030-0115	Faint NLC discernible for short period low N on film from Edinburgh. Observation from Basel Observatory started 2030 GMT and reported a strip of light yellow colour.	56°N	03°W	0030	10	360
				47.5°N	07.5°E	2030	5	315-360
6/7		0110	NLC bands visible at Leuchars between tropospheric cloud. Sky obscured at times of previous and later observations.	56.5°N	03°W	0110	-	
7/8		2330-0200	NLC visible over the period on film from Edinburgh, and for one observation from Dyce at 0130.	57°N	02°W	0130	-	
				56°N	03°W	0130	10	360
8/9		2130-0200	In spite of sky brightness at 60°N Mr Parviainen, Turku, was able to photograph his first display of the season, which almost filled N sky with typical wave formations, drifting N-S, and additionally a curved band originating near sun's position below horizon curving to 50° elevation. Slightly south of his position at Jönköping and Visby, display recorded over 3 hours, with varying brightness. All forms of NLC noted. Curved bands recorded at Benbecula at later time, and at Tiree very bright billows seen against veil background.	60°N	22°E	2200	60	360
						2210	90+	360
						2300	90+	360
				58°N	14°E	2130	30	300-030
						2200	30	330-015
						2230	20	330-010
						2345	20	320-010
						0015	20	310-350
				57.5°N	18.5°E	2120	45	330 020
						2220	30	340-030
						2250	20	340-040
						2345	20	290-060
						0020	15	290-040
				57.5°N	07.5°W	2355	20	010-050
						0100	-	360-045
				56.5°N	07°W	0200	40+	360
9/10		2145-2245 2400-0100 0145-0215	Faint display of NLC seen Turku forms mainly rising E and N, drifting NE-SW (photographs). From Tiree 2 faint bands seen against very faint veil. Photographs from Edinburgh showed bands against brighter veil, above low tropospheric clouds.	60°N	22°E	2145	20	090
						2200	10	360
							40	090
						2245	15	360
							10	045
							10	090
							90+	225
				56.5°N	07°W	2400	10	360
						0100	10	360
				56°N	03°W	0200	30	360
				55°N	04.5°W	0040	7	320 040
11/12		2400	From Tiree NLC bands and 'patch' visible above tropospheric cloud [to 5°].	56.5°N	07°W	2400	20	330-350
12/13		2215-0200+	NLC visible over this period on film from Edinburgh, finely structured and herring-bone formation developing on earlier veil. In later stages only veil visible in breaks in tropospheric cloud. At Benbecula faint streak of NLC visible after clearance of tropospheric cloud.	57.5°N	07.5°W	0200	17	010
				56°N	03°W	2400	10	360
						0130	20	360
13/14		0130,0230 0205-0235	Bright and banded veil seen on Edinburgh film, and later at Leuchars after clearance of tropospheric cloud. Patch and billows seen W. London	56.5°N	03°W	0230	20	360-030
				56°N	03°W	0130	15	360
				51.5°N	0.5°W	0205	7	030
14/15		2150-2315 0100	Hazy, faint NLC first visible W and zenith at Turku, quickly filling N and W sky to 120° elevation. Further bands forming to W and E, fading S of zenith. Small patches of NLC visible Boulmer at later time.	60°N	22°E	2200	120	180
						2230	50	270
						2250	90	90
				55.5°N	01.5°W	0100	15	040
16/17		2140-0130	Series of NLC bands rising NE and NW, varying brightness, seen Turku [photographs], drifting S and fading. Later bands irregular in shape, remaining bright until tropospheric cloud covered sky. From film at Edinburgh display seen to be extensive with bright herring-bone formation, but largerly obscured.	60°N	22°E	2200	30	045
						2210	40	360
							40	045
						2220	20	340
							40	360
							40	010
				56°N	03°W	2245	-	360
17/18		2150-0020	Bright banded veil visible Visby for some hours, becoming less bright later.	57.5°N	18.5°E	2150	30	350 040
						2250	30	350 040
						2350	40	010 060
						0020	45	030 090
18/19		2145-2245	Medium-bright NLC visible Turku in breaks of tropospheric cloud [photographs].	60°N	22°E	2145	40	360 045
						2245	15	360 045
23/24		2300	Possible sighting of NLC at Kinloss in tropospheric cloud breaks.	57.5°N	03.5°W	2300	-	360

Date — night of		Times UT	Notes	Station position*		Time UT	Max. elev. (degrees)	Limiting azimuths (degrees)
24/25		2050–2120 2300–0100	Medium brightness NLC bands visible at Visby, fading within an hour. NLC also visible Lerwick and Dyce.	60°N 57.5°N 57°N	01°W 18.5°E 02°W	2300 0100 2050 2120 2300	– – 30 30 –	340–045 340–045 010–040 010–040 045
26/27		0130	Faint showing of NLC on film from Edinburgh.	56°N	03°W	0130	–	360
29/30		2240–0030 0200	Bright billow formation NLC visible at Sundsvall for 2 hours. NLC visible later on film from Edinburgh.	62.5°N 56°N	17.5°E 03°W	2240 0030 0200	30 30 15	340–020 340–020 045
30/31		2340–0050 0325–0340	Bright, becoming medium bright, veil and whirl formation visible Jönköping around midnight. The possible sighting at the later time from Kinloss was described as bright red lenticular cloud visible in gaps in stratocumulus.	58°N 57.5°N	14°E 03.5°W	2340 0020 0050 0330	20 20 30 8	320–340 310–330 310–360 044
1/2	Aug.	2130	Possible sighting of NLC from Newton Stewart.	55°N	04.5°W	2130	–	–
4/5		2100	NLC visible at high elevation at Fiane.	59°N	09°E	2100	90	–
6/7		0200	Multiple NLC bands visible Reykjavik NNE. 5/8 tropospheric cloud obscured earlier and later observations.	64°N	22°W	0200		020
9/10		2200,2300	Faintly visible patch of NLC visible Turku. At Benbecula NLC very bright but seen between breaks in tropospheric cloud, fading later to very faint veil.	60°N 57.5°N	22°E 07.5°W	2200 2200 2300	35 – –	045 360 360
10/11		2340–2400	Bright bands of NLC visible Turku, N–S orientation, height increasing slightly during observation — N edge hidden by stratospheric cloud.	60°N	22°E	2340	8	360
11/12		2123 0120–0305	Report of possible NLC bands from RAF Mount Batten is thought to be unlikely, as solar depression angle greater than usually acceptable. Earlier report from Fiane of NLC veil to high elevation in westerly direction when SDA approx. 6°.	59°N 50.5°N	09°E 04°W	2123 0120	 –	–
14/15		2400	Bright bands of NLC visible Reykjavik.	64°N	22°W	2400		360–030
22/23		2100	Possible sighting of NLC bands from Wick [aurora visible later].	58.5°N	03°W	2100		340–020
10/11	Sept.	2045	NLC veil visible Fiane in breaks in tropospheric cloud.	59°N	09°E	2045	–	

Photographs

6/7	June	2335–0115	D. Gavine, Edinburgh
		2315	Edinburgh Met. Dept
22/23		2250–2330	D.A.R. Simmons, Milngavie
		2330–0030	Edinburgh Met. Dept
26/27		2345–0100	Edinburgh Met. Dept
28/29		0001–0200	Edinburgh Met. Dept
1/2	July	2330–0100	Edinburgh Met. Dept
3/4		0030	Edinburgh Met. Dept
4/5		0001–0115	Edinburgh Met. Dept
7/8		2330–0200	Edinburgh Met. Dept
8/9		2150–2300	Mr Parviainen, Turku
9/10		2145–2245	Mr Parviainen, Turku
		0145–0215	Edinburgh Met. Dept
12/13		2215–0200	Edinburgh Met. Dept
13/14		0130	Edinburgh Met. Dept
16/17		2140–2240	Mr Parviainen, Turku
		2230–0130	Edinburgh Met. Dept
18/19		2145–2245	Mr Parviainen, Turku
26/27		0130	Edinburgh Met. Dept

Note

The corresponding survey for the 1982 NLC season will be the last to be made under current arrangements. The report for 1982, with a summary for the whole period of the survey (1964–82), will appear in an edition of *The Meteorological Magazine* in 1983.

The authors will be glad to receive suggestions as to how a survey, perhaps of a less detailed kind than previously, may be continued for the 1983 season and beyond.

551.507.362.2

Meteorological satellites: a current survey

Prepared by the Satellite Meteorology Branch

(Meteorological Office, Bracknell)

Summary

An account is given of all operational and research satellites, current and planned, that yield (or are intended to yield) data of meteorological interest. The type of data produced and their availability are described.

1. Introduction

The purpose of this paper is to provide a list of all satellites with a meteorological role, to indicate their purpose, and to discuss the availability of data. The list is presented in three sections: current operational meteorological satellites; current or recent research satellites; and future programs and satellites. More detailed information on the first two of these categories can be found in a World Meteorological Organization publication (WMO 1975). Satellites, such as LANDSAT, which are intended primarily to provide very high resolution pictures for study of the earth's surface have not been included, though their data can sometimes be useful in meteorological research. Satellites observing planets other than Earth have been excluded.

Meteorological satellites can be classified according to their orbit. Firstly those in low (about 1000 km) circular orbits inclined steeply to the earth's equatorial plane are known as polar-orbiting satellites. By suitable selection of height and inclination, the orbit plane can be arranged to precess about the earth's axis once per year so that the satellite always crosses the equator at the same local time. Such 'sun-synchronous' orbits can be used to provide global coverage of observations twice per day (once in daylight, once at night). To obtain more frequent observations at low- and mid-latitudes it is necessary to have more than one satellite. Secondly there are 'geo-synchronous' (often termed geostationary) satellites. These are in circular orbits at a height of about 36000 km over the equator and have an orbital period of 24 hours. Thus these satellites keep pace with the rotation of the earth. In this orbit a large part of the earth is continuously visible to the satellite and the frequency of images is limited only by the instrumentation (in most cases, a complete disc image is produced every 30 minutes). This frequency of images allows air motions to be deduced from the displacement of clouds and the diurnal cycles in cloud development to be studied. To achieve complete coverage up to mid-latitudes, five satellites are required spaced around the equator. Polar regions* cannot be seen from this orbit. Research satellites may be in different orbits, chosen to match the requirements of their experiments.

The satellites to be described in this paper are listed in Table 1.

2. Current operational satellites

2.1 Polar-orbiting satellites

During the 1960's the USA launched 22 research or operational satellites into low earth orbit. Their second operational generation was known as ITOS and ran to six members. The last of these, called NOAA-5, was turned off in March 1979. A list of all these satellites can be found in *Satellite Activities of NOAA 1980.* (It is US practice to call the first satellite of a series by the name of the series. Subsequent

*beyond about latitude 70°

Table I. *Recent, current and proposed satellites and programs*

Current operational satellites:
Polar-orbiting satellites TIROS-N*† (NOAA), DMSP, Meteor-2
Geostationary satellites GOES†, Meteosat*†, GMS (HIMAWARI)

Current and recent research satellites:
NIMBUS*†, Meteor, HCMM (AEM-A), SEASAT†, GEOS-3, ATS, SAGE (AEM-B)†, SME, plus others

Future programs and satellites:
Polar-orbiting operational satellites TIROS-N*†, DMSP, Meteor-2
Geostationary operational satellites GOES†, Meteosat*†, GMS, INSAT, GOMS
Semi-operational satellites for oceanography and meteorology MOS, NOSS, ERS-1*†
Research satellites ERBS†, EXOS-C, UARS*†, Shuttle/Spacelab
Geostationary communications satellites with special relevance to meteorology SIRIO-2*†, INMARSAT*

*Denotes satellites to which the UK contributes (or is likely to contribute) directly in money or by providing instruments.
†Denotes satellites to whose data the Meteorological Office has direct or privileged access.

Notes.
Names (with alternative names in brackets) usually apply to several more or less identical satellites in a series, each with its own number.
INMARSAT is not strictly a satellite; see text.

spacecraft bear the name of the organisation e.g. NOAA (National Oceanic and Atmospheric Administration) — and a serial number, which carries over from one series to the next and is given only if the satellite comes into use. Before launch each follow-on satellite in a series is identified by a letter, which runs in sequence from A.)

The current series of US civil satellites is known as TIROS-N. There are two active satellites: NOAA-6 (launched June 1979) and NOAA-7 (June 1981). They are in sun-synchronous orbits, at heights of about 850 km, with northbound equator crossing times of 1930 and 1430 'apparent' solar time respectively. Their payloads provide visible and infra-red cloud pictures (in 4 spectral channels on NOAA-6 and 5 on NOAA-7), temperature and humidity sounding (by infra-red and microwave techniques) and a means of locating and receiving messages from meteorological sensors on sea, land or in the air. All data are broadcast in real time and some are tape recorded for processing in the USA. Routine NOAA products include atmospheric temperature profiles and sea surface temperatures. The Meteorological Office is providing one of the instruments (the Stratospheric Sounding Unit (SSU)) for these satellites.

The US Air Force operates DMSP (Defense Meteorological Satellite Program) satellites. They normally have two satellites operating in sun-synchronous orbits also at a height of about 850 km. The satellites provide visible and infra-red cloud pictures and incorporate a facility for night-time visible imagery by moonlight. Other sensors include an infra-red temperature sounder. Data transmissions from these satellites are in cipher.

The USSR also operates a series, known as Meteor-2. They provide visible and infra-red cloud pictures; low resolution versions are broadcast. Some members of the series carry a simple infra-red temperature sounder.

2.2 Geostationary satellites

The USA operates satellites producing visible and infra-red cloud pictures, which are disseminated (by the satellite after ground processing) in digital and analogue form, and providing a data collection service. Winds are derived from the motion of clouds seen in sequences of pictures taken at 30 min intervals. The pictures are produced by satellites located over the equator at about 75°W and 135°W. Spacecraft in these positions are often referred to as GOES-East (or GOES-E) and GOES-West, whilst a third 'station' at about 107°W, used for some of the dissemination services, is called GOES-Central. GOES stands for Geostationary Operational Environmental Satellite. Each satellite is also given a serial number in accordance with the scheme mentioned in the previous section. The two latest, GOES-4 and GOES-5, carry an experimental high resolution temperature and humidity sounding facility (known as VAS) which also produces the operational imagery.

The European geostationary satellite Meteosat-2 was launched in June 1981 and is located over the Greenwich meridian. It provides similar imagery and dissemination services to GOES and in addition produces pictures showing the distribution of water vapour in the upper troposphere. It is essentially a replacement for Meteosat-1 (launched in November 1977) but since its on-board data collection and relay facility is faulty, Meteosat-1 (now at 10°E) is still being used for this service. Regular distribution of quantitative products such as winds, sea surface temperatures and cloud analyses has been delayed by installation of new computers at the ground processing centre, but it is expected to begin in the spring of 1982.

Japan is operating GMS-2 (Geostationary Meteorological Satellite, sometimes called HIMAWARI), again providing similar services to GOES. Products include nephanalyses, sea surface temperatures and cloud analyses as well as winds. GMS-2 at 140°E was launched in August 1981 as a replacement for GMS-1 (launched July 1977). GMS-1 remains available as a spare or back-up spacecraft.

International collaboration between operators, through meetings of the group for Co-ordination of Geostationary Meteorological Satellites (CGMS), has resulted in compatibility between data-collection systems and to a lesser extent in the dissemination services. However, there are significant differences in performance of the image systems: GOES provides the highest resolution (1 km) visible images, whilst Meteosat has the highest spatial resolution (4.5 km) in the infra-red and a third spectral channel.

3. Current and recent research satellites

NIMBUS. This has been the principal US NASA (National Aeronautics and Space Administration) series of polar-orbiting research satellites, extending from NIMBUS-1 (launched in 1964, the first earth-stabilized satellite and night-time cloud pictures) to NIMBUS-7 (October 1978) which concluded the series. These satellites are also referred to by corresponding letters (e.g. G for 7). Each satellite has carried a different and successively more complex payload. NIMBUS-7 carried eight instruments, for studying: sea surface roughness, precipitation, soil moisture, snow and ice cover; sea surface colour; clouds and surface temperature; radiation balance; ozone; stratospheric aerosol; temperature and minor constituents from 15 to 100 km. The Department of Atmospheric Physics, of Oxford University, provided a limb-sounding radiometer for minor constituents and has flown extremely successful temperature sounding radiometers on earlier NIMBUS spacecraft. WMO Publication No. 411 (WMO 1975) lists the last three payloads and indicates which instruments are still working. Data recovery is now very limited from NIMBUS-6.

METEOR. Several USSR Meteor satellites (e.g. -25, -28, -29, -30) have been devoted to research, carrying various infra-red and microwave radiometers for studies of clouds and the earth's surface.

HCMM. (Heat Capacity Mapping Mission). This NASA satellite, launched into sun-synchronous orbit in 1978, was the first Applications Explorer Mission and so was sometimes called AEM-A. It provided visible and infra-red images, with 0.5 km resolution, at times when surface temperature was near its maximum and minimum. These are being used to test methods for deducing soil moisture data and for snow mapping. Operations terminated at the end of September 1980.

SEASAT. A NASA satellite, launched June 1978, which operated for only 3 months (also referred to as SEASAT-A and as Ocean Dynamics Satellite). It carried microwave sensors (altimeter, scatterometer, synthetic aperture radar, passive radiometer) to provide information on surface winds, wave heights, wave spectra, sea surface topography (currents have been located) and ice. A simple radiometer provided cloud pictures. All data were transmitted in real time. The low-power and data-rate sensors were used continuously and their data are being processed in the USA. The life of SEASAT overlapped the JASIN (Joint Air-Sea Interaction) experiment and the RAE Oakhanger facilities were used to receive the relevant data.

GEOS-3. (Geodynamics Experimental Ocean Satellite). This NASA satellite carried an earlier version of the SEASAT altimeter and demonstrated the feasibility of deriving significant wave heights.

ATS. (Applications Technology Satellite). Three satellites in this US NASA series have carried meteorological sensors. ATS-1 and ATS-3 were the first geostationary satellites to carry cloud cameras. They were launched in 1966 and 1967 respectively. From 1969 their visible pictures and telecommunications relay facilities were used in a semi-operational role and winds were derived (from cloud motions). Their cameras were used for six and eight years respectively. ATS-6, launched in 1974, was a 3-axis stabilised geostationary spacecraft primarily for telecommunications research. It also carried an infra-red and visible-imaging radiometer.

SAGE. (Stratospheric Aerosol and Gas Experiment). This is a NASA satellite, also known as AEM-B, launched in February 1979 to measure profiles of aerosol attenuation, ozone and nitrogen-dioxide in the stratosphere.

SME. (Solar Mesosphere Explorer). This is another NASA satellite. It was launched into sun-synchronous orbit in October 1981 to measure minor constituents (e.g. ozone, nitrogen dioxide, water-vapour) and temperature in the upper-stratosphere and mesosphere. The experiments are all from within the USA and principally from the University of Colorado.

Other experimental satellites and manned spacecraft (e.g. Skylab) have been used to provide observations relevant to meteorology. Two of special interest were the joint US/UK Ariel-2 satellite, which in 1964 carried Office experiments to study ozone and dust, and the French EOLE, which, with its fleet of super-pressure balloons, provided important information on winds in the lower stratosphere.

4. Future programs and satellites

4.1 Polar-orbiting operational satellites

TIROS-N. There are firm plans to carry the TIROS-N program into the 1990s. Starting with NOAA-8, a somewhat larger spacecraft, ATN (Advanced TIROS-N), will be used that can carry additional payload and provide more power. Instruments to measure radiation fluxes (see ERBS below) and ozone will be included from about 1984, and an improved microwave sounding instrument may be flown around 1990. The latter would provide better height and spatial resolution for temperature and humidity sounding under cloudy conditions. It would also make temperature measurements up to 50 km, taking over the role of measuring temperatures in the upper part of this height range from the Meteorological Office's Stratospheric Sounding Unit.

DMSP. No information is available but it is believed that this US Air Force series will also continue through the 1980's.

METEOR-2. No information is available on long-term plans but new satellites are being launched periodically to maintain the service.

4.2 Geostationary operational satellites

GOES. The US geostationary system with satellites at 75° W and 135° W is expected to continue for a long time to come — certainly well into the 1990's. A third satellite will probably be operated near 100° W for much of the time, to provide image dissemination services. Construction or procurement of a further four spacecraft for the program is already in hand.

METEOSAT. There is at present no guarantee of any successor to Meteosat-2 which it is hoped will operate to around 1984. Over the past year or two there have been discussions of ESA (European Space Agency) proposals for an operational program, EUMETSAT, which (if adopted in full) would provide observations at 0°W for a 10-year period using five satellites. Although many European nations have indicated their interest in such a program, no firm commitments have yet been made.

GMS. It is understood that a third spacecraft in the series is being, or has been, built and may be launched as GMS-3 in 1984.

INSAT-1. This Indian satellite system will provide telecommunications and broadcast television services as well as carrying a visible and infra-red radiometer for imagery. The satellites are being made by a US company and are 3-axis stabilised. A meteorological data processing centre is being established in New Delhi. Image dissemination and data collection services will be provided as part of the telecommunications service. INSAT-IA is expected to be launched in 1982 and will be positioned at 74°E. INSAT-IB will probably be launched quite soon afterwards, as an in-orbit spare.

GOMS. (Geostationary Operational Meteorological Satellite). This satellite, originally promised by the USSR for FGGE (First GARP Global Experiment), has not yet been launched. It is understood, however, that the USSR plans to launch two or three geostationary meteorological satellites over the next few years.

4.3 Semi-operational satellites for oceanography and meteorology

MOS. (Marine Observation Satellite). This is a Japanese semi-operational satellite to monitor atmospheric water content, sea surface temperature and colour, and sea-ice, using microwave radiometers and infra-red and visible imagery at medium and high spatial resolution. MOS-1 should be launched into sun-synchronous polar orbit in early 1985, with MOS-2 in 1986.

NOSS. (National Oceanic Satellite System). Work on this program, which was being jointly funded in the USA by NASA, NOAA and the Department of Defense, has now been stopped. Launch had been provisionally set for 1985.

ERS-1. (Earth Remote Sensing). The Members of ESA are expected to agree early in 1982 to the Definition Phase of this ocean monitoring satellite to be launched about 1987. The instrument payload will include a combined wind/wave scatterometer and synthetic aperture radar, and a radar altimeter. A final decision on development of the satellite will be taken in mid-1983.

4.4 Research satellites

ERBS. (Earth Radiation Budget Satellite). This is a US NASA experimental satellite primarily for the measurement of incoming and outgoing short- and long-wave radiation. The orbit plane will precess, providing observations at differing solar times which will complement those from similar sensors on TIROS-N series spacecraft (at fixed solar time). University College London (UCL) will be participating in data analysis and interpretation. ERBS will also carry SAGE-II, a NASA experiment for measuring vertical profiles of aerosol and ozone in the stratosphere by occultation techniques. It is planned to launch ERBS in May 1984.

EXOS-C. An experimental Japanese mission to study minor constituents in the stratosphere, mesosphere and lower thermosphere. Payload is expected to include airglow, ultra-violet back-scatter, solar occultation, and infra-red limb-sounding sensors. It is proposed to be launched around 1984 into an elliptical 65° orbit.

UARS. (Upper Atmosphere Research Satellite). Comprehensive investigation of composition, dynamics and energetics of stratosphere, mesosphere and lower thermosphere. NASA experimental spacecraft in polar-orbit. Payload not yet decided but is likely to include from Oxford an advanced infra-red limb-sounder for minor constituents and an interferometric limb scanner for winds, in which UCL are involved. The Office is participating in the planning and expects to be involved through analysis of the various observations and by modelling. This satellite is expected to be launched around 1988. The NASA HALOE (Halogen Occultation Experiment) experiment for measuring vertical profiles of minor constituents (e.g. HCl, CF_2Cl_2) in the stratosphere, previously included in the ERBS payload, is now likely to be flown on UARS instead. The Meteorological Office is represented on the science team of HALOE.

Shuttle/Spacelab. This facility will be used to fly a number of short period experiments of meteorological interest. Experiments already proposed include: microwave and cooled infra-red limb-sounding radiometers to measure profiles of minor constituents (e.g. freons) in the upper atmosphere; interferometers for measuring winds; lidar systems for measuring aerosols, and cloud-top height, winds and surface pressure; and instruments to monitor in-coming solar radiation. Unfortunately, after the First Spacelab Payload (FSLP), there is no definite provision for European experimenters. The share of flight costs on subsequent missions will be a major constraint.

4.5 Geostationary communications satellites with special relevance to meteorology

SIRIO-2. This experimental ESA satellite will carry a system known as MDD (Meteorological Data Dissemination) to demonstrate the use of telecommunications via a geostationary satellite for collecting and distributing meteorological messages between national and regional centres. Launch is planned for Spring 1982 with a 2-year operating life. The experiments will mainly involve centres in Africa.

INMARSAT. This is actually not a satellite but an international organisation concerned with the exploitation of communication satellites to increase the efficiency of maritime communications. Initially, INMARSAT is using satellites operating in the experimental MARISAT scheme but they will be superseded in 1982 by purpose-built systems carried on the INTELSAT V satellites together with the MARECS-A and MARECS-B communication satellites. In meteorology the system is likely to be used extensively for 2-way transmission of data between ships (including platforms and rigs) and shore stations, i.e. for sending observations to collecting centres for insertion on the GTS (Global Telecommunication System), and for transmitting forecasts, warnings, routeing advice, etc. to vessels at sea.

5. Availability of data

For instruments which produce only modest amounts of data it is usual for the data to be recorded on the spacecraft and replayed to a central ground station provided by the spacecraft operator. In these cases the operator acquires all the data and may use them and archive them, either in raw or condensed form. Image data may be stored only as photographs. For polar-orbiting satellites data from several successive orbits may be merged and presented, for instance, in a polar stereographic projection.

Image data from geostationary spacecraft are voluminous. Each Meteosat image comprises 30 million 8-bit numbers providing a potential of 1.5×10^9 numbers per day. This is one reason why products, such as winds, are produced centrally for distribution by normal channels. Archives of these data by the operator are generally selective (e.g. 8 images/day), particularly in digital form. Retention may not be permanent. Proposals have been made for a condensed format, suitable for climate and radiation studies, which could be generated from the images and held permanently. Users may also create their own specialized partial archive based on disseminated data.

Most high spatial resolution sensors on polar-orbiting satellites transmit their data immediately. Data are recovered only for those areas which are within range of a suitable reception facility. (However, up to 10 minutes of high resolution image data can be recorded during each orbit for the TIROS-N series.) Data of this type are not generally held by the satellite operator and archive policy depends on the local reception station. An example of this in the UK is the Dundee University service for the 1 km visible and infra-red pictures produced by the current TIROS-N series spacecraft financed by NERC (Natural

Environment Research Council). It is often necessary to refer back to the satellite operator (or experimenter) for supplementary information.

The Meteorological Office has facilities for direct reception (through the RAE Lasham station) and immediate distribution (by landline) of satellite pictures. All the 4 km resolution pictures from the current spacecraft of the TIROS-N series (covering most of the North Atlantic and Europe from North Africa to the Arctic) are received four times each day. Limited areas (UK and North Sea) taken from the high resolution 1 km imagery are also distributed.

The facilities can also handle selected Meteosat data and image data for North America and the Pacific relayed via GOES-East. The Meteorological Office receives, within a few hours, via its normal telecommunications channels, temperature profiles for the northern hemisphere extracted by NOAA from sounding instruments on the TIROS-N spacecraft and winds for the belt 50°N to 50°S derived from the images of various geostationary spacecraft by the appropriate operators. Meteorological messages obtained through the various satellite data collection systems are received in the same manner.

Archived data from current and many past US operational satellites (including DMSP) can be obtained from NOAA's Environmental Data and Information Service (EDIS). They issue Satellite Data User Bulletins, which describe their stocks. Data from the Meteorological Office's SSU are also archived at Bracknell and are available to external users in various forms (see Pick and Brownscombe 1981). Meteosat data and products can be obtained from ESA at Darmstadt; GMS data and products from the Meteorological Satellite Centre in Japan.

Archived data from these satellites are available without restriction, usually at the marginal cost of reproduction. Charges may be higher for commercial and foreign users. Products (winds, temperatures) are generally archived by Meteorological Services alongside the other global meteorological observations which they receive.

Data from research satellites conventionally belong to the experimenter, who has a responsibility to publish his results. In recent years there has been increased emphasis on the formation of Experiment Teams, to include those who want to use the data as well as those providing the instruments. Privileged access to data is given to members of such Teams and special arrangements are made for exchange of data between Teams. Data are subsequently released to other workers, either informally through the principal scientist or formally by announcements of opportunity for data use. These arrangements have generally improved the accessibility of data from research satellites.

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TIROS-N/GOES	National Environmental Satellite Service. Catalog of products, 3rd edition, D. C. Dismachek, A. L. Booth and J. A. Leese, NOAA, *Tech Memo*, NESS 109, (1980)

100 years ago*

DAILY ATLANTIC WEATHER MAPS.

Almost, if not quite, all our readers must be aware how long and earnestly we have pleaded for the preparation and publication of Daily Maps of Atlantic Weather.

There are, however, two statements respecting the subject, the reproduction of which is needed to complete the narrative. Both are by Mr. Symons, one, the concluding paragraph of a letter published in *The Times* of Oct. 28th, 1881, is as follows:-

As regards the study of Atlantic weather, no one desires its development more than I do. For years I have urged that we ought to have daily weather charts for the Atlantic, and the only reason that we have them not is that they would cost a few thousands per annum. This is, of course, work which lies wholly within the domain of the Government establishment, the Meteorological Office, and their accounts show that they could only establish such a system either at the cost of suppressing some of their existing observatories, or on receiving an increased vote. I think personally that Parliament could do few wiser things than to appropriate, say for five years, £4,000 per annum for that purpose. Being entirely unconnected with the Meteorological Office, and not a member of its council, this proposal may perhaps be appropriately made by

Your obedient servant,

October 27th, 1881. G.J. SYMONS, F.R.S.

Symons's Monthly Meteorological Magazine*, **17, 1882

The other reference is a portion of the Presidential Address to the Meteorological Society:-

I must, however, pass to a different class of subject, that of deductions as distinguished from that of instruments. First in that list I place Daily Maps of Atlantic Weather on a scale of not less than 1 inch to 300 miles. The compilation of such charts is essentially national or international work, and falls wholly within the domain of the Government office. Years ago Captain Toynbee showed us what could be done. I have long pleaded for their regular issue, and shall continue to do so, because, irrespective of their utility as contributions to Physical Geography and to Navigation, they are, I believe, the best helps towards increased accuracy in weather forecasting. I am glad to plead this cause in the very words of the Meteorological Council, for when they published Captain Toynbee's charts they said –

"The Meteorological Council have authorised the present publication as a remainder of the work of their predecessors. It cannot be doubted that more work of the same nature as that here submitted would throw light on the atmospherical conditions which influence and determine the weather in the West of Europe."

Moreover, in thus writing, the Meteorological Council only repeated what Le Verrier had urged a dozen years previously, viz., on January 29th 1864, when, speaking of the charts in the *Bulletin International*, and pleading for Meteorological Records from the Atlantic, he said –

"Unfortunately our charts embrace only Europe, which is not sufficient. They contain nothing of what is occurring on the surface of the ocean, and this is the more to be regretted since most of the storms which attack us seem to take their rise in those parts."

These being our views, it will readily be understood that it was with extreme pleasure that we saw in *The Times* the memorandum which we reprint verbatim at the end of this note.

We have, however to call attention to one decision of the Office, for which no reason is given, and which, at present, appears to us a mistake. Our readers are aware of the system of eight-hourly synchronous observations introduced by the Signal Office of the United States. By this system observations are made at hundreds of stations all over the globe at the same instant of absolute time, viz., at 7 a.m., 3 p.m., and 11 p.m., Washington mean time, which is approximately synchronous with noon, 8 p.m., and 3 a.m. (of the following day) Greenwich mean time.

This system was expressly designed to facilitate and perfect the class of investigation which the Meteorological Office is now going to push forward.

On the other hand the log-books issued by the office are arranged for observations *not* synchronous, but made at fixed hours of local time, so that the observation to be made for log-book purposes at 8 a.m., local time would, off the West of Ireland, be made at 9 a.m. Greenwich time; and the corresponding 8 a.m. entry at Bermuda would be made at about 5 a.m. Greenwich time.

The memorandum asks for observations at 8 a.m., and at noon, local time; the first of these will range between 3 and 8 a.m., Washington time, and the second between 7 a.m. and noon, Washington time. The first may therefore be anything between four hours before, and one hour after the 7 a.m. Washington synchronous observations; and the second may be anything between identical with the 7 a.m. Washington Synchronous observations, and five hours after them.

Although it is possible that the total number of observations collected may be greater by adopting the system selected by the Meteorological Office, we think that the advantage so gained will be far outweighed by the difficulties introduced by the abandonment of the synchronous principle.

We presume that it is intended that the charts shall represent the weather at noon Greenwich time, which, as we have said, may be taken as the equivalent of the 7 a.m. Washington synchronous observation, but curiously enough the memorandum ignores the synchronous observations, and does not say for what hour the charts are to be constructed.

We, however, believe the above surmise to be correct, and that the intention is to correct the 8 a.m. and noon (local time) readings to what it is believed they would have been at the hour adopted for the charts. Although we have implicit faith in the care with which this will be done under Captain Toynbee's supervision, we adhere to the opinion previously expressed, that the ignoring of the synchronous system is a mistake. Of course it will be urged that an observation to be made daily at a different time (because of the change of the ship's position), would be less easily obtained that two at fixed hours. But it would be very easy to prepare a printed table showing the time for each degree of longitude, and the fewer the corrections applied to observations the better.

DAILY WEATHER CHARTS FOR THE NORTH ATLANTIC OCEAN.

The Following statement has been issued by the Meteorological Office:-

"The Meteorological Council propose to undertake the preparation of daily weather charts of the North Atlantic Ocean for the 13 months beginning on August 1 in the present year, and ending on August 31, 1883.

"It is well known that the changes of weather which we experience are in general caused by atmospheric disturbances which travel more or less rapidly, and undergo more or less modification during their progress. By far the larger number of the disturbances which visit the British Islands arrive on our shores from the Atlantic Ocean, and our earliest information as to any impending change is consequently derived from telegraphic reports from the Atlantic coasts, especially from the British stations at Stornoway, Mullaghmore, and Valentia, and occasionally from the continental observatories at Rochfort and Corunna. But of the origin and previous history of these systems we have no sufficient knowledge, except in a few isolated cases.

"The Meteorological Council believe that any systematic information which can be obtained as to the origin, development, and laws of motion of the atmospheric disturbances which occur over the Atlantic Ocean would promote the science of meteorology, and be of immediate practical utility. Such information could not fail to be a benefit to seamen traversing the Atlantic Ocean, and would tend directly to the improvement of the forecasts and storm warnings issued to the British coasts, by rendering the interpretation of the first indications of approaching changes observed at the western meteorological stations more easy and certain.

"The importance of a systematic study of the weather of the North Atlantic Ocean has long been recognized, and series of daily synoptic charts, more or less resembling those now in contemplation, have been prepared at various times, not only by the Meteorological Office, but also by the Association Scientifique de France under the guidance of Le Verrier; by Captain Hoffmeyer, of the Danish Meteorological Institute; by the Deutsche Seewarte, at Hamburg; and (as a part of a wider plan) by the Chief Signal Officer of the United States. But none of these charts, however valuable in other respects, supply adequate materials for a satisfactory discussion of Atlantic weather, chiefly on account of the small number of the observations upon which they are founded as compared with the magnitude of the area over which they are spread.

"Evidence of the interest attaching to the connection between English and Atlantic weather is afforded by the efforts which have been made during the last few years by the proprietors of the *New York Herald* to transmit to England from America telegraphic predictions of approaching disturbances which (it is presumed) are founded on the reports of vessels arriving in America from the Atlantic Ocean. Reports such as these from a large number of vessels would be of great value; but the predictions taken by themselves cannot be utilised in a scientific investigation of weather.

"The Meteorological Council gratefully acknowledge the large measure of invaluable help which they have hitherto received from seamen and the shipping interest generally. But as the object now proposed can only be achieved by the voluntary co-operation of an increased number of observers, they feel justified in making a special appeal for assistance to the owners, captains, and officers of ships, and especially to the great companies whose steamers ply between this country and America. In a science which, like meteorology, is still in its infancy, every advance is attended with great difficulties, and the Council are well aware that it would be easy to be too sanguine as to the importance of the results to be obtained by the inquiry which they are about to undertake. But having regard to the loss of life and property occasioned by storms on our coasts, they feel confident that their proposal will commend itself to the public generally, and will insure the active co-operation of those classes of the community for whose benefit it is primarily intended.

"It is proposed to ask for observations of the barometer, of open air and sea surface temperatures, wind (direction and force) and weather at 8 a.m. and noon each day, with the position of the ship at noon.

"Forms for recording the observations will be supplied by the Meteorological Office, 116, Victoria Street, London, S.W., on application to the Marine Superintendent."

Award

Dr R. Hide, F.R.S., Head of the Geophysical Fluid Dynamics Laboratory, has been awarded the Holweck Medal and Prize of the French and British Physical Societies. The Medal and Prize are awarded in odd-dated years to a French physicist and in even-dated years to a British physicist. The award was instituted in 1945 as a memorial to Fernand Holweck, Director of the Curie Laboratory of the Radium Institute in Paris, who was tortured and killed by the Gestapo during the last war. It is given for distinguished work in experimental physics, or in theoretical physics if closely related to experimental work. Dr Hide is the first scientist to receive the award for work in geophysics.

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NOTICES

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Meteorological services for Defence

By I. J. W. Pothecary
(Assistant Director (Defence Services), Meteorological Office, Bracknell)

Summary

Meteorological services for Defence form the largest single area of activity within the Meteorological Office and currently absorb about 25% of the total staff of the Office at 60 Defence locations outside Bracknell. The cost of services for Defence represents about 36% of the gross cost or 52% of the net cost of the Office as a whole. Apart from providing support day-by-day for Defence the Meteorological Office is concerned with maintaining a cost-effective response to Defence needs. In particular, the needs of the Royal Air Force, which remains the largest single user of Meteorological Office services, have been thoroughly reviewed in close consultation with the Air Staff to ensure that reduced manpower resources are used to the best effect. In providing meteorological services for Defence there is an essential need for an understanding of the military requirements but, if that support is to be fully effective, it is equally essential that there is a corresponding awareness on the part of military commanders of the effect of weather on military operations.

Introduction

The first recorded use of meteorological knowledge in the defence of a nation was in 480 BC when the Athenian admiral Themistocles timed his engagement of a large invading force of Persian ships under Xerxes to coincide with the onset of the afternoon sea-breeze between the island of Salamis and the mainland coast at Piraeus. The Persian fleet of 1200 large and unwieldy ships was preoccupied with keeping off the lee shore in rough water with little sea-room and was destroyed by the small but highly manoeuvrable Athenian fleet of only 380 ships, forcing Xerxes to abandon his plans for extending the Persian empire westwards over the Mediterranean.

Thereafter history frequently records the unplanned and random effect of weather on the outcome of war, but the occasions when a knowledge of the weather was used in central military planning were rare, although a notable exception was the work of the Meteorological Section of the Royal Engineers in France during the First World War. There were many occasions in the Second World War when military actions were successfully based on meteorological advice, but the one occasion when the outcome of the war could be said to have been decisively determined came in June 1944 with the commitment of the Allied Forces to the invasion of Europe. The invasion was launched on a forecast of the essential short spell of quiet weather in the English Channel. The weather of June 1944 was unusually disturbed but the required spell of quiet weather was accurately forecast at a time when the German High Command had relaxed its vigilance on advice that the weather would be against the launching of the invasion.

Following the end of the Second World War the trained manpower providing meteorological services for the Armed Forces was largely dispersed. The requirements of the Royal Air Force and the Army for meteorological services were once again met from within the civilian resources of the Meteorological Office, although the needs of the Royal Navy continued to be met from within Navy resources, as before the war, by the Naval Weather Service (now the Directorate of Naval Oceanography and Meteorology).

The need to co-ordinate afresh the activities of the Meteorological Office in support of Defence was recognised in 1966 when meteorological services for the Royal Air Force, the Army and the Procurement Executive and the national response to the meteorological needs of NATO were concentrated into one Services Directorate Branch under the title of Defence Services. The concentration within one Branch of almost the entire organizational effort of the Meteorological Office for Defence showed that the response to Defence needs represented the largest single group of activities within the Meteorological Office. Defence has since remained the largest single user of Meteorological Office services, requiring the direct involvement of a quarter of the total staff at Defence locations in the United Kingdom, Germany and the Mediterranean, and absorbing rather more than 50% of the net cost of the Meteorological Office.

The scale and diversity of meteorological services for Defence is summarized in Table I. By the end of the financial year 1981/82 a total of 687 staff was employed in direct support of Defence in 60 Defence Services Branch outstation meteorological offices located with the Royal Air Force (51), the Army (4) and the Procurement Executive (5); 49 of the offices are at outstations in the United Kingdom, 7 in Germany and 4 in the Mediterranean. The headquarters of the Defence Services Branch is located in the Meteorological Office Headquarters at Bracknell with 12 staff.

Table I. *Summary of Defence Services offices and staff complements — 1 April 1982*

	UK		Germany		Mediterranean		Total	
	Offices	Staff	Offices	Staff	Offices	Staff	Offices	Staff
Defence Services Branch HQ	1	12					1	12
C Met O HQSTC	1	4					1	4
C Met O HQ RAF Germany			1	7			1	7
Principal Forecasting Office	1	59					1	59
Main Meteorological Offices	5	125			2	43	7	168
Subsidiary Forecasting Offices:								
RAF stations	28	262	4	50			32	312
RAF units at PE establishments	3	22					3	22
Army Aviation stations	2	11	1	8			3	19
HQ 1(BR)Corps			1	(1)[a]			1	(1)
PE Army trials establishments	4	41					4	41
NATO Allied Meteorological Office:								
UK staff at AMO Maastricht			(1)[b]	3			(1)	3
Observing offices:								
RAF stations	4	19			1	5	5	24
PE/Army trials establishments	1	1					1	1
Radiosonde units:								
RAF stations					1	15	1	15
PE/Army trials establishments	(4	– –)[c]					(4	)
Total serving RAF	42	491	5	60	4	63	51	614
Total serving Defence	50	556	7	68	4	63	61	687

Notes:

a. Post held by S Met O Detmold.

b. Office outside Meteorological Office but staff remain on the Meteorological Office complement.

c. Function integrated with subsidiary forecasting offices at PE establishments.

Meteorology in military operations

A decisive factor in modern warfare is the speed and flexibility with which air power can be deployed to its full effect, to the extent that the primary aim of strategy is to achieve supremacy in the air and the primary tactical objective is air superiority. Rather than making weather redundant as a factor in the effective use of air power, increasing sophistication in aircraft design and in the technology of weapons systems is having the effect of lowering the minimum weather conditions in which air power can be effectively used. Success in air operations is more likely to go to the air commander who has the training, experience and meteorological advice which he can apply in assessing the effects of weather on operations under his control, allowing aircraft and weapons systems to be used right down to the minimum weather limits.

The area of interest to the Royal Air Force as a component of the Second Allied Tactical Air Force in the North Atlantic Treaty Organization (NATO) defence of western Europe extends from the North Sea through the Low Countries and the northern half of West Germany eastwards across the north European plain. The climatology of the region falls conveniently into three areas bounded by the longer northward-flowing rivers: between the Rhine and the Weser, the Weser and the Oder, and the Oder and the Vistula. Apart from the ridges of high ground extending northwards on either side of the Weser from the Harz mountains, the area has a low relief mostly below 150 metres. The meteorological data for most airfields in the three areas can therefore be regarded as representative of conditions over wider areas surrounding each airfield.

The analysis in Fig. 1, based on published data from airfields representative of each area, shows the average percentage frequency by months of cloud base below 300 feet and/or horizontal visibility less than 1 nautical mile, taking all hours of observation together.

The assessment of the level at which weather becomes a significant factor in military operations is a matter for military decision but the analysis in Fig. 1 shows that if a cloud base below 300 feet and/or a horizontal visibility less than 1 nautical mile restrict air operations, then the chance of failure in the effective use of air power at low level owing to poor weather, taking the day as a whole, will lie between 15 and 20% during November–February in the area between the Rhine and the Weser, and in the same range in December between the Weser and the Oder. Between the Oder and the Vistula the incidence of poor weather likely to inhibit low-level operations is less than 10% through the year. Between the Rhine and the Oder the incidence of poor weather falls below 10% from April to September, although between the Weser and the Oder the incidence falls to less than 10% in March, a month earlier.

The diurnal variation of conditions during winter when the cloud base is less than 300 feet and/or visibility is less than 1 nautical mile shows that there is little significant difference between the average incidence of the conditions during the hours of darkness and the hours of daylight. Assuming that close air support is not possible during the hours of darkness, the time during which close air support can be exercised effectively during the four winter months from November to February is limited to about 7 hours per day between the Rhine and the Weser, 7½ hours per day between the Weser and the Oder, and 8 hours per day between the Oder and the Vistula.

The percentage frequency of occasions when the cloud base will be above 1000 feet and the horizontal visibility better than 3 nautical miles, when the weather is likely to have little or no effect on low-level operations, is shown in Fig. 2. Between the Rhine and the Weser such favourable conditions will apply for over 50% of the time from March to October but only between 40 and 50% of the time from November to February. East of the Weser the incidence of such conditions is higher, averaging over 70% from March to October and between 55 and 70% from November to February.

Success or failure in a military operation may depend on exploiting the marginal differences that could tip the balance decisively one way or the other. The commander who assumes that the effects of

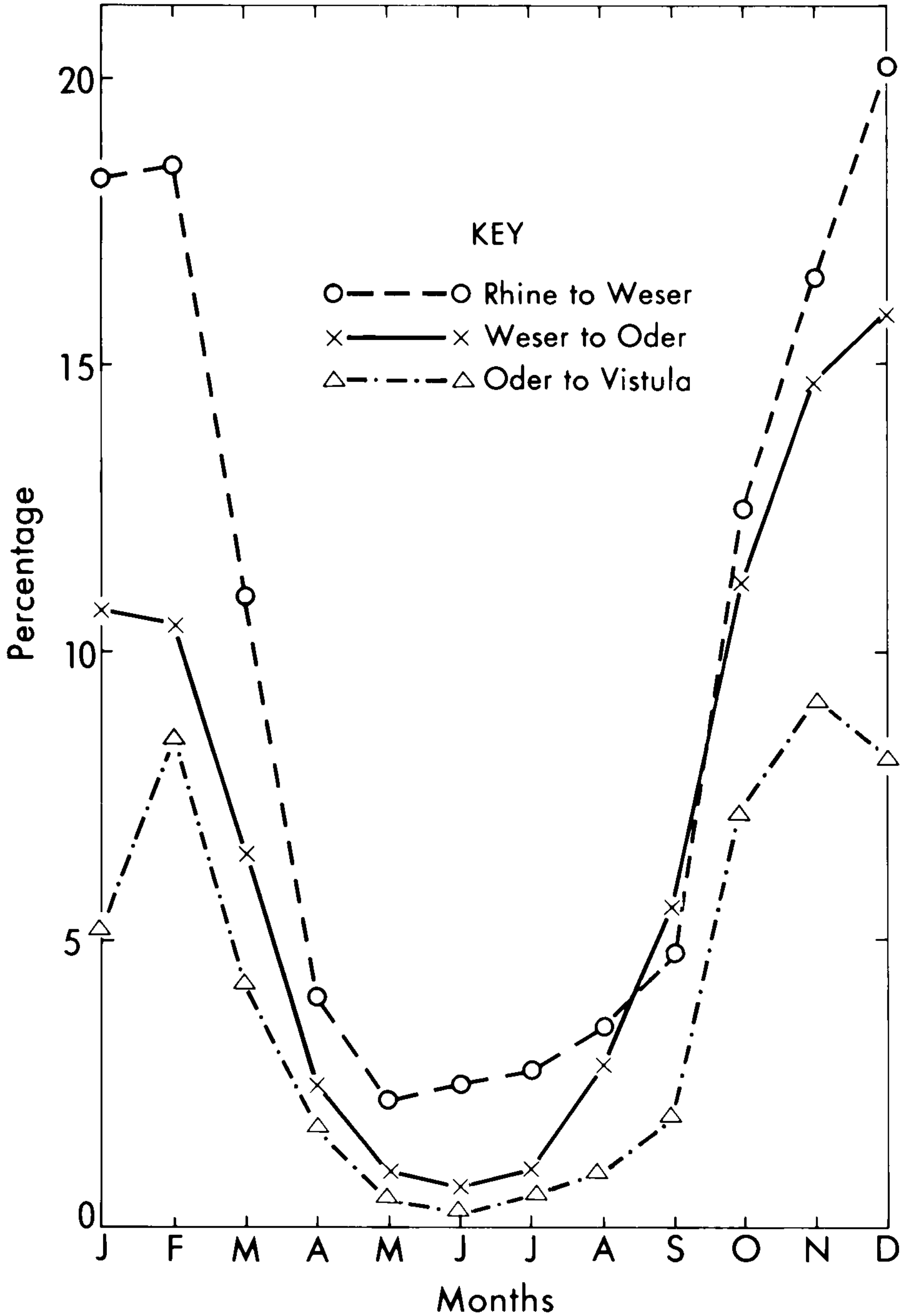

Figure 1. North European plain: monthly average percentage frequency (all hours) of cloud base less than 300 feet and/or visibility less than 1 nautical mile.

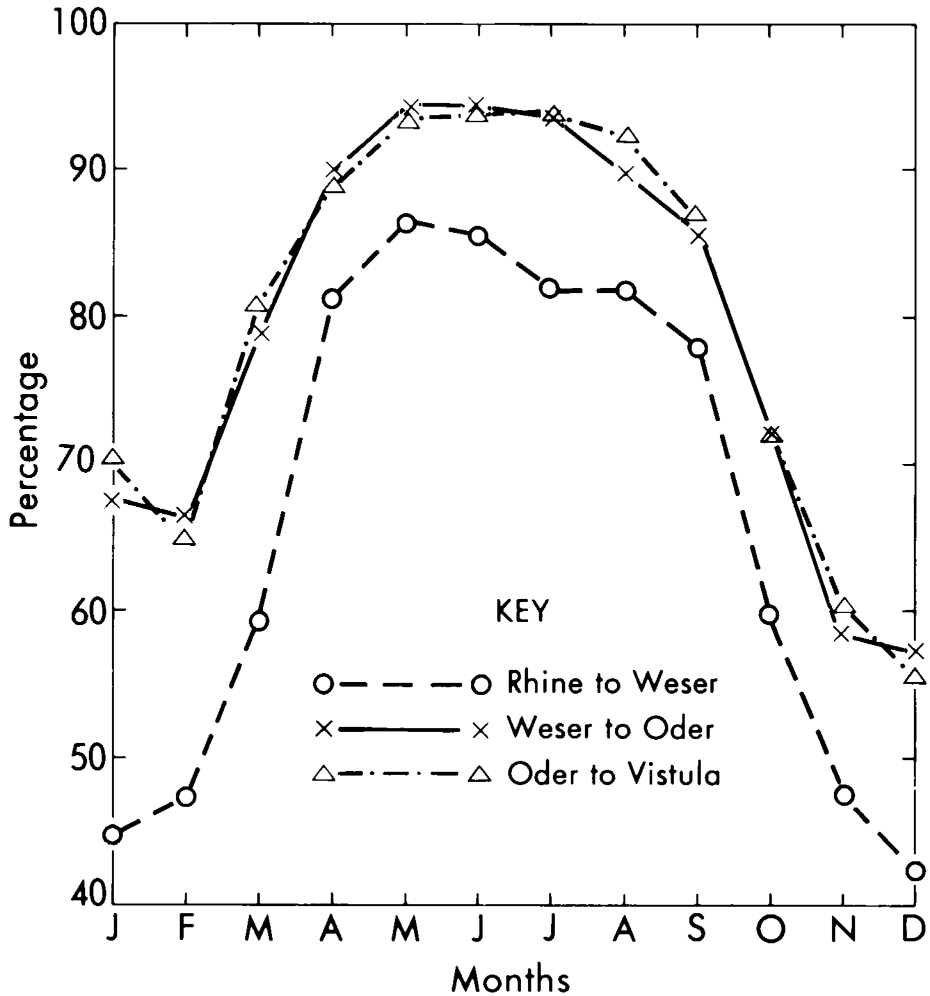

Figure 2. North European plain: monthly average percentage frequency (all hours) of cloud base higher than 1000 feet and visibility more than 3 nautical miles.

weather on his operations are the luck of the draw may fail to recognize an opportunity to load the balance in his favour. The commander who is sensitive to the effects of weather on his own and on the opposing forces will be in a position to exploit adverse weather rather than suffer it. The effective use of air power is likely to remain sensitive to weather in western and central Europe because of the high incidence of weather that is sufficiently adverse to affect operations, particularly in winter, even with increasingly sophisticated aircraft. The role of meteorologists in the defence of western Europe is to provide commanders with the advice and services that will allow the opportunities for marginal advantages to be recognized and exploited. For that to be effectively done there is a need for an understanding of the effects of weather on the exercise of air power at all levels of command, and a need for meteorological support to be given with an understanding of the relevance of weather to military operations.

The Meteorological Office response to Defence needs

(a) *Organization of meteorological services for the Royal Air Force.* The close historical relationship between the Meteorological Office and the Royal Air Force goes back to 1918 when the Royal Air Force was formed from the Royal Flying Corps and at the same time the Meteorological Office was brought under the control of the new Air Ministry. The close relationship remains and is reflected in the staff of 614, out of the total of 687 in the Defence Services Branch, who were employed on 1 April 1982 in 51 meteorological offices in direct support of the Royal Air Force, mostly at operational airfields and at Group and Command Headquarters.

After the Second World War the organization of meteorological services for the Royal Air Force continued to reflect the wartime chain of command down to the operational squadrons in the maintenance of Main Meteorological Offices (MMOs) at the various Group Headquarters. By 1965 the meteorological office at Headquarters Bomber Command at High Wycombe had begun to provide centralized advice directly to a number of airfield meteorological offices and had been designated as a Principal Forecasting Office (PFO), although some services to the airfield meteorological offices continued to be provided from the MMOs. By 1968, with the amalgamation of Bomber, Fighter and Coastal Commands into a new Strike Command, the PFO was working directly to the requirements of most of the meteorological offices at the operational airfields. Meteorological offices at some of the training airfields also received direct technical support from the PFO. With the incorporation of Air Support Command into Strike Command in 1972 there was a further extension of the direct technical parentage exercised by the PFO. The growing trend towards centralization in meteorological services for the Royal Air Force was a direct reflection of the command and control of the operational squadrons exercised from Headquarters Strike Command (HQSTC).

Under a long-standing arrangement between the Meteorological Office and the Royal Air Force, meteorological offices serving Royal Air Force needs, with the exception of the PFO, operate as multifunctional offices. Services for the general public are available from meteorological offices at Royal Air Force stations to the limits set by the staff complements established for the Royal Air Force need alone, and subject always to the priority of the Royal Air Force work. Similar services are also available from the MMOs at Group Headquarters.

In 1977 a requirement for meteorological services was prepared by the Air Staff and endorsed by the Vice-Chief of the Air Staff. The statement of requirement made it possible for the Meteorological Office to develop long-term plans for support for the Royal Air Force on authoritative forward-looking assumptions which took full account of the introduction of a new generation of aircraft into the Royal Air Force. The statement emphasized the importance of meteorological support to the efficient conduct of day-to-day flying training and to the effectiveness of air operations. Particular importance was attached to the forecasting of weather at low level for short periods ahead. The Air Staff also emphasized the importance of the direct relationship between forecasters and aircrew at the airfield level, recognizing that the requirement for details of the physical behaviour of the atmosphere in terms of cloud base, visibility, low-level turbulence and precipitation over a period only up to about six hours ahead is not susceptible to centralized automated methods of analysis and forecasting but is likely to remain, for the foreseeable future, as an area where subjective skills and expertise and local knowledge have a real contribution to make. It was also recognized that there is a need for forecasters in direct contact with operations staffs and aircrew to have a clear understanding of the operational roles for which they are providing meteorological support.

For a number of years the trend towards the centralization of meteorological support had made the outstation forecaster seem less important. The concentration of computer facilities and experienced forecasters in centralized offices was appropriate to the support of aviation conducted at medium and high levels and requiring forecasts well beyond six hours ahead. The Air Staff requirement, however, foresaw the introduction of new aircraft into the Royal Air Force inventory which would change the emphasis towards low-level high-speed operations, generating an increasing demand for forecasts of the physical behaviour of the lowest levels of the atmosphere for only short periods ahead. Support for medium- and high-level operations would still be required but would no longer generate the main demand from the Royal Air Force for meteorological support.

The only effective way in which the Royal Air Force needs can be met, as confirmed by the Air Staff, is to maintain the forecaster in direct contact with operations staff and aircrew and to provide him with the support he requires to deploy his professional skills. It would run counter to the stated Royal Air Force requirement if he were to be required to act solely as an agent for a centralized organization rather than as a professional adviser in his own right.

The statement of requirement for meteorological services for the Royal Air Force was timely. The steady trend towards the direct parentage of airfield meteorological offices from the PFO had resulted in the development of a centralized organization but the stage had not been reached when the work of the airfield forecaster could be adequately performed from the centre. Now that the requirement for retaining the forecaster in direct contact with the operators has been clearly established, the centralized organization can be developed as a system which will allow the forecaster to react faster, more effectively, and directly to operational demands.

Traditional methods of providing meteorological data to the forecaster by analogue facsimile and slow-speed teleprinter limit the speed and the effectiveness of the response to the operational needs of the Royal Air Force. A computer system has been introduced into the PFO at HQSTC which is designed to support the airfield forecaster in his main task of short-period forecasting for low-level operations. It is planned to install remote computer terminals in airfield meteorological offices, allowing the centralized system supporting the needs of the Royal Air Force to function as a demand system on the initiative of the airfield forecaster rather than as a broadcast system with a content determined at the centre. The system will be tested in pilot projects at RAF Lyneham and RAF Honington during 1982/83 and, if the pilot projects are successful, it is planned to extend the system to the meteorological offices at all Royal Air Force operational airfields over the following two or three years. It should also be possible to process radar and satellite data in the central computer in the PFO at HQSTC into a format which can be called up on the airfield computer terminals at the initiative of the forecaster. The introduction of a computer system in support of services to the Royal Air Force should result in a significant improvement in the standard of service. The ability to provide centrally a constantly updated data bank on which the airfield forecaster can draw as required will provide better technical support than is possible with the present system of fixed-time broadcasts with unavoidable delays in making available the latest data.

Flight-planning for many civil airline operations is a centralized computer-based function which leaves few decisions to be made by the aircraft captain as the result of a personal weather briefing. In military aviation, operations staff and aircrew retain some responsibility for decision-making in the detailed conduct of assigned tasks. Weather information imparted at a personal briefing using the latest available data is always relevant to mission planning and sometimes decisive. A comparison of the trends in the number of personal briefings year by year from 1974 to 1981 illustrates this significant difference between civil and military aviation in the use of meteorological support (Fig. 3). The total number of personal briefings for civil aviation shows a slight decrease over the eight-year period while personal briefings for military aviation show a marked upward trend over the same period. Further evidence of the increasing use of meteorology in military aviation is shown by the trend in the average annual number of personal briefings for each squadron in service. In 1974 there were 3232 personal

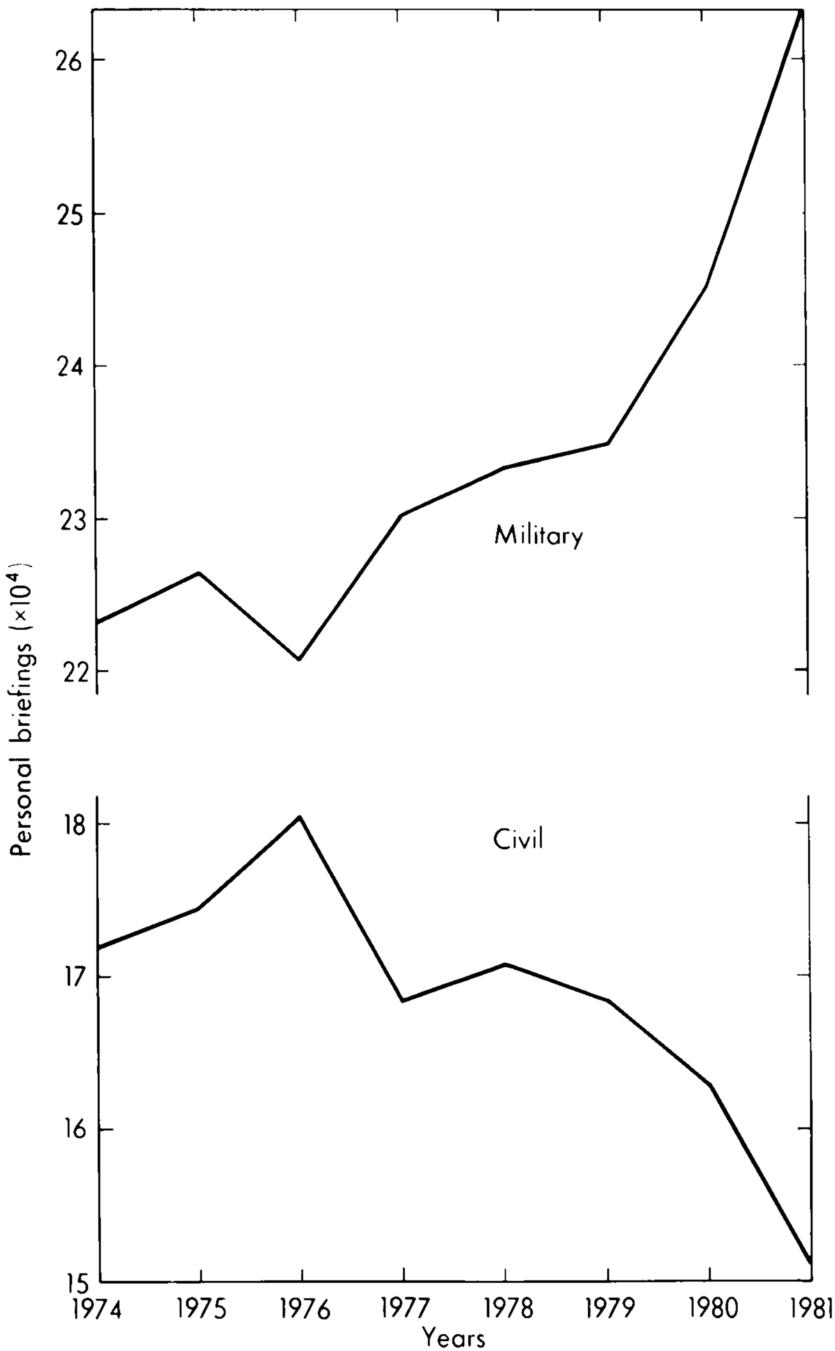

Figure 3. Personal briefings for civil and military aviation.

briefings per squadron but by 1981 the number of briefings had increased to 4461, an increase of 38%. The upward trend in the annual number of personal briefings confirms the 1977 Royal Air Force requirement for the maintenance of direct contact between forecasters, operations staff, and aircrew and reflects an increased commitment to weather-sensitive low-level operations and an increased sensitivity to the importance of weather in mission planning.

A measure of the productivity of Meteorological Office staff in response to the needs of military aviation is provided by relating the number of written forecasts and personal briefings for military aviation to the number of forecasters in the Defence Services Branch. In 1974, with 317 forecasters meeting the needs of military aviation, the average number of written forecasts issued by each forecaster was 2907. By 1 April 1982 the number of forecasters had fallen to 236 but the average number of written forecasts issued by each forecaster had increased to 3779, that is by 23%. The average number of personal briefings given by each forecaster in 1974 was 704, but by 1982 the average number had increased to 1115 or by 58%.

A significant feature of the role of the civilian Meteorological Office forecasters at operational airfields is that they function as an integral part of the operations staffs and are fully involved in national and NATO exercises, working in protective clothing and respirators in the Combat Operations Centres as and when required and often at short notice. The Meteorological Office is also responsible for the manning of the Mobile Meteorological Units of the Royal Air Force Tactical Communications Wing, operating with other assigned Royal Air Force squadrons as part of the Mobile Force of the NATO Allied Command in Europe. The Units are manned by a small complement of forecasters and observers, all of whom hold Class CC commissions in the Royal Air Force and operate in the field in uniform. The cadre of staff concerned are all volunteers and receive training in basic military skills.

(b) *Organization of meteorological services for the Army.* The Army Air Corps is faced with problems similar to the Royal Air Force in operating helicopters and light aircraft, and a close association has developed over the past decade with the Directorate of the Army Air Corps. The scale of effort is very much less than for the Royal Air Force, with only 19 staff employed in three meteorological offices at the Army Air Corps airfields at Netheravon and Middle Wallop and at Detmold in Germany. The services which are provided relate mainly to flight safety in the operation of helicopters and light aircraft, often at very low levels, although there is an increasing awareness on the part of the Army Air Corps of the relevance of meteorological advice to the effective conduct of Army Air Corps support in land-force operations. A routine part of the service to the Army Air Corps is the provision of forecast data related to the natural illumination of ground targets at night resulting from a combination of moonlight and cloud cover. The organization of services for the Army Air Corps is similar to the organization of services for the Royal Air Force. As there are only two meteorological offices serving the Army Air Corps in the United Kingdom and only one in Germany, the offices are integrated into the organization designed to meet Royal Air Force requirements although they react to the needs of the Army.

The wider interest of the Army in environmental support services is not well defined, partly because of a lesser sensitivity of Army operations to weather and partly because the effect of weather on land-force operations is not as natural a part of the training of the field officer as it is in the training of aircrew. Useful experience in the importance of weather in land operations was, however, gained by the Army in the major British Army of the Rhine exercise CRUSADER 80 held in the 1 (BR) Corps area in September 1980. The Senior Meteorological Officer (S Met O) in the meteorological office at Detmold also holds the post of S Met O at the Headquarters of 1(BR) Corps. He was fully involved in CRUSADER 80 at the field headquarters of the Corps and was able to demonstrate the capability of the Meteorological Office in providing meteorological inputs to land-force command and control decisions.

By making use of the central resources of the Office he was also able to provide advice to the Commander which proved useful in decisions related to minimizing the damage to farmland caused by tracked vehicles.

(c) *Organization of meteorological services for the Procurement Executive.* Meteorological advice for the artillery ranges and the research and development establishments of the Procurement Executive (PE) is considered by the users as essential to the effective conduct of trials, in terms both of acquiring data for subsequent trials analyses and for range safety. A total of 42 staff in five meteorological offices is deployed in direct support of the Procurement Executive on the ranges at Aberporth, Eskmeals, Larkhill, Pendine and Shoeburyness. A full radiosonde capability is maintained at each of the ranges, with the exception of Pendine, and is used to provide upper-air data in support of specific trials. The Mk 3 radiosonde system has been specially modified at all four locations to provide detailed upper-air data in near-real time and computer-tape records for use in trials analyses. The meteorological office at Shoeburyness provides services for the Atomic Weapons Research Establishment explosives testing ground at Foulness. The meteorological office at Larkhill, as well as providing services for the Royal School of Artillery, provides services for the Chemical Defence Establishment at Porton and the Royal Aircraft Establishment range on Salisbury Plain.

An important part of the service provided from the meteorological offices on the Procurement Executive ranges is the forecasting of noise propagation which allows explosives and ordnance trials to be conducted with the minimum of inconvenience to the general public. Much of the development work associated with improving the forecasting of noise propagation is carried out at the meteorological office at the Royal School of Artillery in close co-operation with the range authorities. A method for producing noise-propagation forecasts using numerical techniques was developed in the Meteorological Office in 1978 and has since been tested and improved at Larkhill, using the small desk-top computer which forms part of the Mk 3 radiosonde system adapted for use on the ranges. The accuracy of forecasts of noise propagation has been considerably enhanced, giving over-pressure forecasts which verify to within 5 decibels. The application of the technique to acoustic forecasting for artillery trials at Larkhill has minimized periods when firing is restricted because of the likelihood of blast damage. Taped programs have been compiled for use in the other range offices equipped with the Mk 3 radiosonde system.

(d) *Meteorological support for the Home Office.* The Home Office United Kingdom Warning and Monitoring Organization (UKWMO) exists to provide warnings of air attack and to monitor and predict nuclear fallout for both national and NATO civilian and military purposes. Although no Meteorological Office staff are permanently employed in direct support of the Home Office UKWMO, there is a cadre of 15 volunteer staff who man the meteorological cells in the five UKWMO Sector Controls when required. The volunteer staff are normally fully employed elsewhere in the Meteorological Office as forecasters. Their function in the Sector Controls is to provide the meteorological data essential to the calculation of fallout trajectories. The data are obtained through links with the Central Forecasting Office (CFO) at Bracknell and there are also direct links with the eight radiosonde stations in the United Kingdom.

(e) *Meteorological support for the Royal Navy.* Meteorological services for the Royal Navy are provided by the Directorate of Naval Oceanography and Meteorology (DNOM). The Meteorological Office is responsible for making available to DNOM observational data which are not available from Naval sources and also provides, for guidance, analyses and forecasts prepared by CFO at Bracknell. Very close co-operation is maintained between the Defence Services Branch and DNOM, both at the working level between the PFO at High Wycombe and the Fleet Weather and Oceanographic Centre at

Northwood and between the Defence Services Branch headquarters and the headquarters of DNOM in Whitehall. A Naval Liaison Officer on the staff of DNOM is located at the Defence Services Branch headquarters in Bracknell. The close co-operation ensures that meteorological support from both the Meteorological Office and the Royal Navy is co-ordinated nationally and within NATO across the whole range of Defence requirements.

(f) *Meteorological Office NATO responsibilities and relations with other national military meteorological services.* National representation for the United Kingdom in the NATO Military Committee Meteorological Group and other NATO agencies concerned with meteorology is provided by staff from the headquarters of the Defence Services and the Telecommunication Branches, supported and advised in Naval matters by staff from DNOM.

National support from the United Kingdom for the small meteorological organization in Europe under direct NATO control is provided through the allocation of a forecaster and two assistants from the Meteorological Office to the Allied Meteorological Office (AMO) at Maastricht in Holland. A Principal Scientific Officer fills the uniformed post, with a Class CC commission in the rank of Group Captain, of Chief Meteorological Officer (C Met O) to the NATO Supreme Allied Commander in Europe at the Supreme Headquarters Allied Powers in Europe (SHAPE) at Mons in Belgium.

An important aspect of the international work of the Defence Services Branch is the maintenance of a close working relationship, outside the NATO agencies, with the Air Weather Service of the United States Air Force and the German Military Geophysical Office. The Meteorological Office presence in Germany in support of the Royal Air Force and the Air Weather Service presence in the United Kingdom in support of the United States Air Force result in areas of common concern to all three national meteorological organizations serving military needs. NATO Military Committee policy for meteorological support is based on the various national facilities which can be made available in a time of tension, crisis or war, and increasing use is being made of the meteorological resources of the host nations in support of national and NATO activities. The United Kingdom, through the meteorological Office representatives in the various NATO bodies, is taking the initiative in improving the NATO-wide co-ordination of national meteorological resources for military purposes. Closer co-operation with the United States Air Weather Service and the German Military Geophysical Office is developing from that initiative.

(g) *Contingency planning.* Most of the meteorological services for Defence are provided through the 60 meteorological offices located with the Royal Air Force, the Army and the Procurement Executive users, but there is a range of activities related to Defence, other than the management of the Defence Services Branch, which is organized by the small headquarters unit of 12 staff located in the Meteorological Office Headquarters at Bracknell. Contingency planning for emergencies both within the Meteorological Office and, in co-operation with all three Services, for the wider requirements for meteorological support in a national emergency is an important feature of the work in the headquarters of the Defence Services branch, working closely with the Directorate of Naval Oceanography and Meteorology. Particular attention is also paid to emergency plans for providing meteorological advice from the nearest MMO, including computed fallout trajectories, to the various nuclear establishments in the event of the accidental release of nuclear material either from a fixed location or in transit.

Support from the central resources of the Meteorological Office

The extensive central resources of the Meteorological Office at Bracknell provide major support for the meteorological offices meeting Defence needs. The central planning teams responsible for the development of computer-based systems are directly concerned with the extension of automated support to the Defence Services outstation forecasters; the communications needs of the Defence Services organization, in particular the development of automated communication systems, are integrated into Meteorological Office communication planning as a whole and the considerable research capability of the Meteorological Office takes account of Defence needs for meteorological research, previously through the Defence representatives in the Meteorological Research Committee and now through the representation of Service interests in the expanded Meteorological Committee.

With the introduction of a new cost-accounting system in 1978 it became possible to present financial information in detail and to analyse the allocation of expenditure over the whole range of Meteorological Office activities, including the provision of central meteorological support and advice for Defence. The cost-accounting analysis for 1980/81 showed that more than 50% of the net cost of the Meteorological Office was allocated to activities directly concerned with Defence. The value of providing services for Defence from within one organization meeting almost all the meteorological needs of the nation is demonstrated by the channelling to Defence of over 50% of the net expenditure of the Meteorological Office through only 25% of the total staff. The situation is unique amongst meteorological services meeting military needs and explains why the Meteorological Office is able to maintain the highest standards in its service to Defence, through the capability for drawing on central support such as numerical forecasting, computer-based systems and communications developments and Defence-related research. There is an additional advantage to the manning of Defence Services Branch posts in that the 25% of the total Meteorological Office staff who are required to work in the military environment can be selected from the total complement.

The Meteorological Office, apart from providing the meteorological support required day-by-day for Defence activities, is concerned with developing the organization which meets those needs so that it will remain relevant into the foreseeable future. An important aspect of that task is the maintenance of an understanding of the military needs for environmental support in the Meteorological Office response to the needs for Defence. If meteorological support for Defence activities is to be fully effective it is equally essential that there is a corresponding awareness on the part of military commanders of the effect of weather on military operations.

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Low-level flow through the Strait of Gibraltar

By A. A. Bendall

(Meteorological Office, Royal Air Force Gibraltar)

Summary

On 25 August 1981 an unusual and fortunate set of circumstances allowed the NOAA-6 satellite to give a picture of the winds through the Strait of Gibraltar thereby enabling the wind flow to be related to the surface pressure pattern.

1. Introduction

Although the flow of air into and out of the Mediterranean Basin is largely in response to synoptic scale developments, the low-level winds are more or less controlled by the topography, especially when they are constrained to move horizontally by the presence of an inversion below the level of the adjacent high ground. Of course, the movement of the air will approach the geostrophic balance wherever and whenever possible, but owing to orographic influences the isobaric pattern is often forced to undergo some large local changes and the associated winds such as the Mistral and the Bora are well known features of the Mediterranean weather patterns.

2. Topographical aspects near Gibraltar

In the area surrounding the Strait of Gibraltar—a natural gorge and the main gap into the Mediterranean in the west—the local pressure changes usually take the form of a centre of high pressure upwind of the Strait and a downwind area of low pressure. This leads to the air being accelerated down the pressure gradient, through the Strait, with the wind direction normal to the isobars. In westerly situations, that is when the general low-level flow has a component from the west, this effect is usually not well pronounced as the air can escape southwards.

When the air is trying to get out of the Mediterranean it is trapped in the Alboran Basin and the easterly wind—the Levanter—which develops often accelerates from comparatively light airs in the Basin to near gale force at the other end of the Strait. Such winds produce some dangerous seas, especially when they are blowing against the tide and current, and the observational network is such that they would go largely unnoticed in the absence of ship reports. Even with ship reports it is not easy to build up a comprehensive picture of the wind field, and the descriptions that emerge are more of a mosaic of isolated reports made over periods of time.

3. Interpretation of the satellite pictures

Normally satellite pictures are not of any great assistance in this respect; however, on 25 August 1981 the NOAA-6 satellite provided a graphic illustration of not only the flow through the Strait but also the shape and extent of the Levanter well out towards the Atlantic.

During 24 and 25 August an anticyclone moved slowly into the area of the British Isles with a subsequent pressure rise over the western Mediterranean. Some of the surface air forced out of the latter area of high pressure was pushed westwards into the Alboran Basin, and as the sea was essentially cooler than the surface air over the anticyclone a low-level inversion formed, the height of which was about 1200 feet in the Gibraltar area. Consequently, most of this westerly flowing air below the inversion level had to be forced through the Strait. Fig. 1 shows how the pressure pattern had changed from a weak anticyclonic flow over the western end of the Mediterranean and the surrounding land masses to accommodate the effects of the topography. Normally, and particularly during the summer months, this sort of situation also produces stratus cloud, below the inversion, obscuring the sea surface from satellite scanners. Fortunately, on the 25th, not only was the air too dry for the formation of any cloud, but the position of the sun was such that sun glint would occur off reflecting surfaces, such as a smooth sea, in the Gibraltar area on pictures transmitted by the morning pass of the satellite. Fig. 2 is a satellite photograph in visible light from the NOAA-6 satellite showing Spain and part of north-west Africa. The two land masses are comparatively dark with the sea between them a much lighter shade. This is in marked contrast to that from the Atlantic where sun glint could not occur. On the right hand side, the easterly winds were strong enough to disturb the sea surface which shows as grey; further in towards the Strait they had slowed to the point where they were not strong enough to form sizeable ripples and the image is quite bright. Through the Strait and out towards the Atlantic there is a plume where the picture is nearly as dark as that from the land indicating quite clearly that the air is suddenly accelerated into a wind strong enough to destroy completely the smooth surface of the sea. The plume continues for some 100 km as a well defined, slightly widening, belt of strong winds.

Fig. 3 is the corresponding infra-red image, and it should be noted that here the sun glint has disappeared and the surface of the sea shows up as uniformly dark thereby confirming the interpretation of the visual image given above.

4. The surface pressure fields

At Gibraltar, the strength and direction of the surface wind are monitored by plotting the algebraic difference between the pressure at Alicante, on the east coast of Spain, and that reported at Casablanca, in Morocco. The direction of the wind—east or west—is given by the sign of the difference and an empirical relationship based on the magnitude is used to give the strength. Of course, such a relationship has to be used with circumspection as there are some situations that automatically preclude it as either a forecasting or an analytical tool, particularly when large isallobaric components are involved. Fortunately these situations tend to be the exception rather than the rule and for much of the year the pressure difference between stations referred to above can be used to calculate the wind, not only at Gibraltar, but in the Strait, where observations are few and far between. Indeed, it is the only way in which the winds may be forecast or estimated since there is no practical way of calculating them when the forces are markedly unbalanced.

On 25 August this pressure difference had risen to about 5 or 6 mb which can be translated into an easterly wind of about Force 4 at Gibraltar and Force 6 or thereabouts at the western end of the Strait. Although the satellite imagery cannot be used to give the strength and direction of the surface wind, it does illustrate quite clearly the pattern of the winds in the Gibraltar area when they occur with the sort of pressure field shown in Fig. 1. Since this sort of pressure distribution is quite common at any time of the year when air is trying to get out of the Mediterranean, the pictorial evidence of the winds provided by the satellite is quite valuable.

It is interesting to note that although the geostrophic force has little effect on the winds in the Strait, inasmuch as it is probably counteracted by minor changes, it is probably responsible, together with the pressure gradient force downwind of the Strait, for the maintenance of the winds generated in the Strait as a discrete area of strong winds well out towards the Atlantic until they are finally destroyed by frictional forces and a certain amount of lateral mixing with air of much lower momentum.

5. Conclusion

The fact that the wind can blow in a direction normal to the isobars for long periods of time is not as widely appreciated as it might be, especially in the small-ship community. This illustration, apart from showing the value of satellite imagery, may help with the understanding and interpretation of weather charts received by radio facsimile in the areas of the Mediterranean where the low-level flow is strongly influenced by the topography.

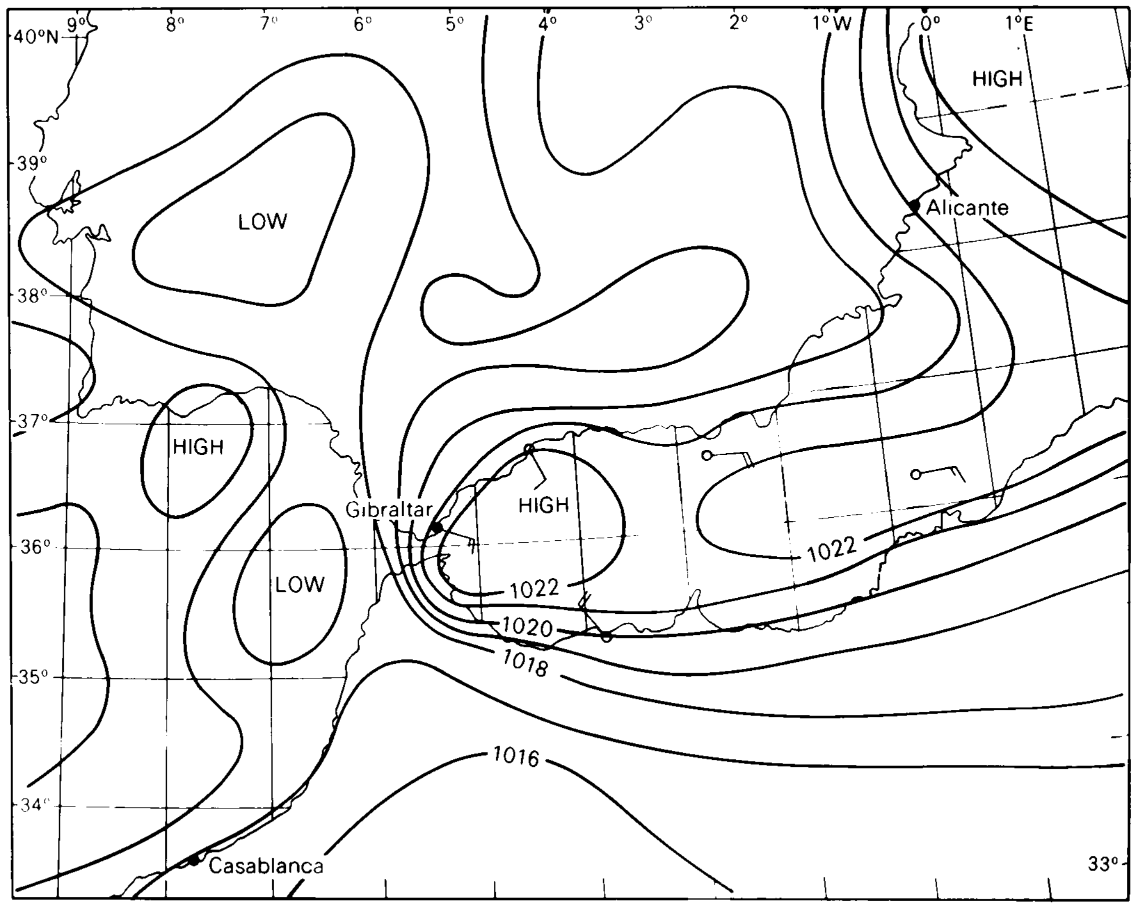
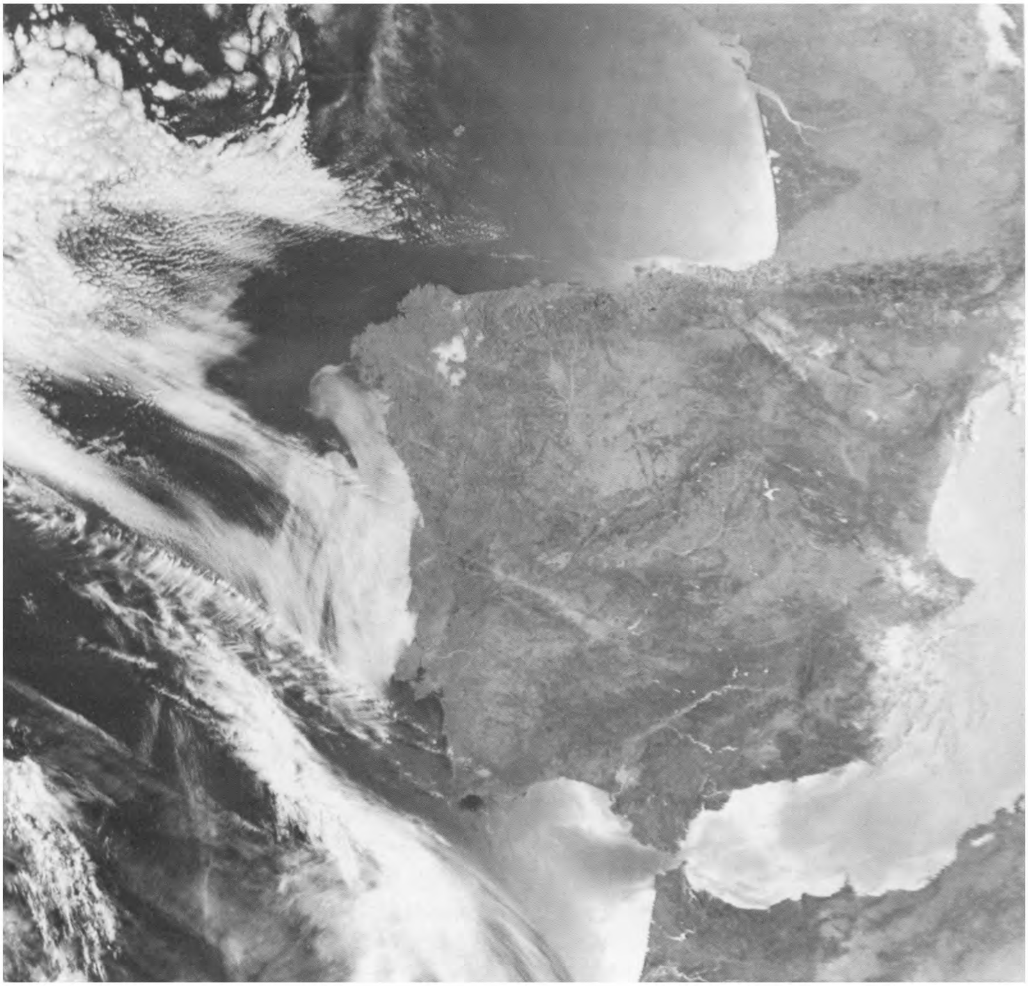
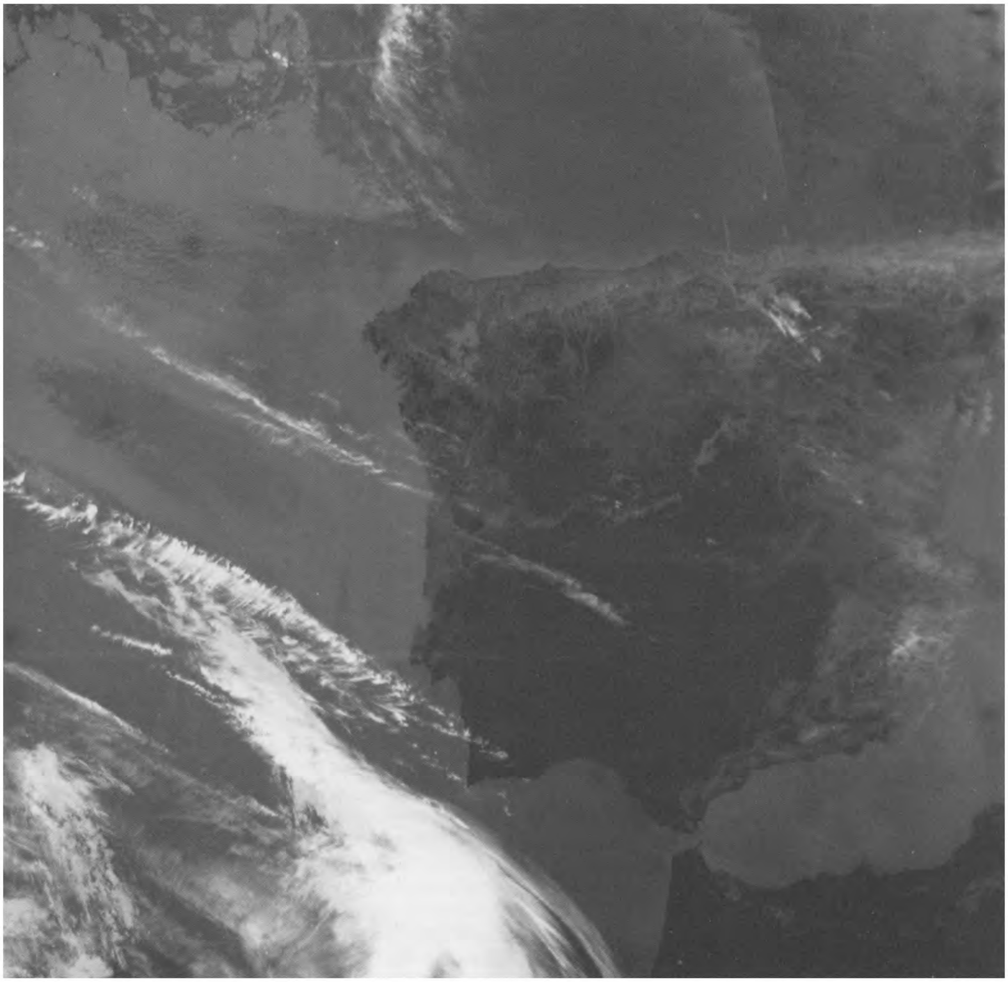


Figure 1. Mean-sea-level pressure pattern at 12 GMT on 25 August 1981.



Photograph by courtesy of Dundee University

Figure 2. Visual image received from NOAA-6 at 0858 GMT, 25 August 1981.



Photograph by courtesy of Dundee University.

Figure 3. Infra-red image from NOAA-6 for the same time as the visual image shown as Figure 2.

100 years ago

The following extract is taken from *Symons's Monthly Meteorological Magazine*, June 1882, **17**, 65.

GALE OF APRIL 29TH, AND SEA SPRAY IN LONDON.

We remember reading, but, until Mr. Ramsay's *Scientific Roll* comes to the rescue, we cannot tell where, that in one great gale all the windows in Leeds which faced W, were covered with a thin film of sea salt. From Leeds to the sea is, in that direction, about 54 miles, and between the two runs the Pennine range of hills with an average height of quite 1500 feet.

On April 29th, 1882, a very violent gale swept over the South of England—at some stations a stronger gale than on either October 13th or November 26th, 1881—and it proved seriously injurious to the young foliage of many trees, notably horse chestnuts. The precise *cause* of this injury is disputed, and as we think the matter worthy of attention, we reprint *in extenso*, or in abstract, all the notices that we have received or seen respecting it. Some persons hold that the damage was solely mechanical, and was due to the bruising of tender foliage by the violent wind, others contend, and bring evidence in support of their contention, that it was largely due to the atmosphere being charged with salt. We regret being unable to contribute anything worthy of consideration as scientific evidence to the question; for although we noticed that our windows were more obscured than usual, even after a dirty London rain, and that they looked slightly milky or frosty, it did not occur to us to examine them before they were cleaned.

We proceed with the notices upon the subject, taking them as nearly as possible in chronological order.

SATURDAY'S GALE

To the Editor of the Standard.

SIR—May I draw your attention to the unusual fact that the wind during the gale on Saturday last was, to the distance of at least thirty miles inland from the South Coast, largely impregnated with sea-salt? The effect of this on the vegetation is very marked. The foliage of this part of the country, which two days ago was dressed in its freshest Spring garb, is now, after some twelve hours of wind, reduced in many cases to a state as black, shrivelled, and scorched as it was before bright and beautiful.

Few people, I imagine, will, at first sight, suspect the true cause of this blighted state of the blossoms and foliage, some no doubt ascribing it to the extreme boisterousness of the wind, which, by knocking the leaves one against the other, beat them to their shrivelled black condition, whilst others will put it down to the peculiar sharpness of the wind. But the actual cause is easily ascertained by applying the tongue to the surface of a large broad leaf which has been plucked from some tree or shrub that has stood in the face of the wind. On some of the leaves which I examined the salt was actually visible, showing how heavily the air must have been laden with it. I had no instrument for determining the extreme velocity of the wind on Saturday, but it must, judging from the effects, have exceeded anything of the kind in this part of the country for the last seven years; probably the pressure per square foot was not far short of forty-five pounds.

I am not aware how far the wind has been known to carry the sea-brine—probably to a distance greatly exceeding thirty miles. What eventual effect this highly salinous top-dressing will produce on the fruit trees of this country remains to be seen, very probably it will manifest itself in a reduction of the crop by one-half.

I am, Sir, your obedient servant,

E.L.D.S.

Tonbridge, May 1st.

To the Editor of the Standard.

SIR—Saturday's gale produced a similar effect on the trees in the Old Deer Park, in which this Observatory is situated, to that observed by your correspondent at Tonbridge, shrivelling up and blackening the leaves not only of the horse chestnuts, but also of the oaks and elms.

Seeing his letter in this morning's paper, I have examined some of the leaves. These not only give strong evidence of the presence of salt, when water in which they have been soaked is treated with silver nitrate, but on examining their surfaces, crystals may easily be seen, which, when viewed microscopically, are readily identified as salt, by their well-known cubical form.

As this observatory is over fifty miles from the sea, in the direction of south-south-east, in which the wind was blowing during the gale, the evidence of transport of salt to such a distance is interesting.

As to the velocity of the wind in the storm, although our greatest hourly run here was fifty miles, yet I timed several gusts between three and four p.m., when for two or three seconds the rate was from seventy to eighty miles per hour.

The meteorological observations at this observatory have now been made for about forty years, and I do not recollect ever seeing an entry of such an occurrence as that of last Saturday.

I remain, Sir, your obedient servant,

G. M. WHIPPLE, Superintendent.

Kew Observatory, Richmond, Surrey, May 2nd.

To the Editor of the Standard.

SIR—Your correspondent "E.L.D.S." says that he is not aware how far the wind has been known to carry the sea-brine. I can inform him that it has been credited with conveying it a much greater distance than thirty miles. I remember a storm which occurred on a Sunday, about twenty years ago, when I was residing at Burton-on-Trent (from which place the sea at its nearest point must be about ninety miles distant), on which occasion the *savants* of the neighbourhood declared that they discovered the presence of sea-spray in the air. For the accuracy of their researches I cannot vouch, but I can attest the fact that throughout that memorable afternoon a seagull was circling over the waters of the Trent, which were lashed by the wind into the miniature resemblance of a storm-tossed ocean.

I am, Sir, your obedient servant,

J.R.

London, May 2nd

To the Editor of The Times.

SIR—The gale of Saturday last has entirely changed the appearance of the country in these parts, and has besides effected considerable damage on the fruit trees, especially in exposed situations.

The leaves of the elms and oaks on the south-west sides of the trees might convey the impression that they had been scorched by fire, while the more tender foliage of the lime, maple, and poplar appear to be well-nigh destroyed, and several weeks must elapse before the injuries received can be repaired by fresh growth; though it may be doubted whether these trees will wholly recover throughout the summer, as the young shoots are in many instances entirely destroyed. Pears have suffered much, as far as the leaf is concerned, although the fruit itself, which is now mostly set, does not appear to be greatly injured; still, as every one who has any acquaintance with gardening is aware, fruit cannot grow on trees that are denuded of leaves. The plum trees, though perhaps to a less degree, are a good deal cut about, while the leaves of the apple are blackened and the blossoms crippled. Black-currants are also sufferers, whole branches being torn off from bushes growing in open places, and the remainder appearing as though frosted.

I have never recorded so severe a gale from the south-west during the month of April, nor does the recollection of a similar one occur to the memory of that proverbial individual, "the oldest inhabitant". At this season of the year, if gales take place, they blow almost without exception from the east, or north-east, but this year these winds have been confined to the first ten days in April.

With this fact in view, and considering at the same time the unusual force of wind just experienced from south-west, I have little doubt that this will be the prevalent wind for some weeks to come and, though forecasting for any length of time beforehand is always dangerous, that the early summer, at least, will be more or less wet.

I am, Sir, your obedient servant,

WILLIAM R. C. ADAMSON.

The Rectory, Ashtead, Surrey, May 2nd

To the Editor of the Standard.

SIR—That the interesting observation of "E.L.D.S." that a deposit containing salt was left after last Saturday's (April 29th) gale was correct, I have been at some pains to verify.

Today, by washing a third-storey window, in an exposed situation, with distilled water and a piece of cotton wool (previously tested as to absence of chlorides, and not held in my fingers), I obtained a solution which markedly contains chlorides (with nitrate of silver test) and its evaporated residue crystals of salt. Its taste is decidedly saline.

Yesterday (2nd) I failed to obtain satisfactory proof by testing damaged foliage, for some showed its presence decidedly, whilst on others it was absent, the reason probably being that a later rain had removed it. I was, therefore, unable, without extensive experiments, to say for certain whether the foliage in itself did or did not contain salt.

As to the destructive effect of this salt on the foliage, I cannot but disagree with "E.L.D.S." until I have made further experiments, for frequently only the side of the damaged tree exposed to the blast is the injured side. Surely the other side must have had salt on its young and tender leaves, for they are not yet developed enough to screen one side completely from the other. Then again, each leaf has frequently only its outer edge damaged. Also I have noticed here and there a tender stem blackened in only one spot, where it has bent or been struck. I should imagine that had the destruction been due to salt in the air it would have been more universal, and not confined to those parts exposed in the teeth of the blast. Surely, battering of the leaves and branches can explain it. If due to salt, perhaps those living near the sea can say whether saline air only destroys young foliage.

I am, Sir, your obedient servant,

A.C.H.

Tonbridge, May 3rd.

BUSHEY PARK.—Probably nowhere near London was such destruction caused by Saturday's gale as in the magnificent avenue of chestnut trees in Bushey Park, which the public are informed by the usual notices are "now in full bloom". From Teddington at one end, to Hampton at the other, the scene may be described as one of wreckage. Many large trees were uprooted, while some hundreds of others have suffered severely.

SIR,—The gale of April 29th has here, as elsewhere, done much harm; no one seems to recollect such a gale at this time of the year. It was much worse, in its effect, than that of the 25th, lasting longer, too, though with less rain. The oak trees are blackened, as if by frost; in the less exposed situations, however, one side of the trees remain green. Birches, which last week were in full leaf, now look as bare as in winter. Pear trees have suffered severely, the fresh young leaves being black and scorched. The white cherry-blossom has been suddenly turned brown; in some gardens the currant bushes and young peas are much cut up, and I have seen even rhubarb all bruised and spoilt. The hop-bines in places are so injured as to be useless for tying up, and poles will have to wait for fresh shoots to be properly furnished. So that, altogether, we have a sad interruption to the prospects of a fruitful season.—Yours truly,

J. ELLIS MACE.

Tenterden, May 3rd, 1882

The terrible wind and rain storm of the 29th ult. is worthy of, and will doubtless meet with, notice in your columns. I do not remember ever seeing such devastation wrought amongst vegetation. In this district of Mid-Surrey no great damage has been done, and not many trees were blown down, but the aspect of vegetation on the side from which the storm came is forlorn in the extreme. The chestnut trees have suffered especially; so blackened and withered are the leaves and flowers on the storm side in all unsheltered places that it seems doubtful whether they can ever revive through the summer. The contrast between the storm-beaten and other side of trees is most remarkable. Even the bushes of currant and gooseberry bear considerable traces of damage, the very weeds and nettles by the wayside are blackened. Some of the daily papers have spoken of severe frost coming after the storm. I observed nothing of the kind here; my lowest reading at the time being 35° and 36°, and I am inclined to attribute all to the strange bitterness of the gale, and the cutting blast of hail during one portion of it.—A.C., *Journal of Horticulture, May 11th*, 1882.

ROYAL HORTICULTURAL SOCIETY.—SCIENTIFIC COMMITTEE—May 23rd, 1882.

Sir J. D. Hooker, F.R.S., in the chair.

Foliage injured by Salt in the late Gale.—Dr. Church described experiments he had made at Cirencester during the last fifteen years to ascertain the amount of salt brought by autumnal gales, especially from S.W. He found from 5 to 7 grs. per gallon, while the ordinary amount was only 0.5 grs. The average winter amount was but little more than that of summer. He noticed that in Oakley Park one side of the trees was severely injured, and that if no rain followed for a few days after the gale, the salt sparkled on the trees even at a distance of 35 miles from the British Channel. The salt abstracted the moisture from the cells and formed a condensed solution, so that the leaf became completely dried up and perished.

Mr. McLachlan added that salt had been observed on windows at Lewisham and at Croydon and elsewhere.

Sir J. D. Hooker remarked that Dalton first noticed it at the beginning of this century. With regard to beeches withstanding the gale better than oaks, as mentioned at the last meeting, it was stated that they were unhurt at Kew and Valewood, Haslemere; but at Cirencester, in Dorsetshire, and in Cornwall, they suffered severely.

Mr. Blackmore exhibited foliage of pears, &c., from Teddington; some were quite unhurt; of other trees growing adjacent to them the leaves were severely cut. Vines and peaches showed similar differences. He suggested that it could not be salt in this case.

The opinion generally entertained was, that such discrimination was due to the trees being relatively hardy and less hardy kinds.

SIR, My house here stands on a hill-side exposed to the S.W. I look across a valley, and on the opposite horizon see Leith Hill Tower, 5 miles distant, from which the sea is visible. Of course we felt the full violence of the gale last Saturday (29th); a torrent of rain fell and streamed down my windows for hours together. The next day (Sunday) was very dry and sunny, and I was surprised at 9 a.m. to find my window panes covered with what looked like a finely-crystallized deposit. Examining this with a lens, I detected regularly formed crystals, and on wiping them up with my finger, and tasting them, I found them to be *salt*. I did not chemically analyse it, but its taste was that of common table salt.

The gale was from the S.W., and the nearest sea-coast in that direction, in a direct line, is about 35 miles off.

When I read in the *Times* of Thursday the week's weather report from Kew, I was astonished to find that salt had been found *there* on the leaves, so many miles further from the sea than Dorking.—Yours faithfully,

JAMES DIXON.

Harrow Lands, Dorking, May 5th, 1882.

SIR,—We are thirty miles, at least, from the sea, but on the previous Saturday, our windows were thickly coated with salt, and our foliage is ruined for the year, mainly, I think, by the force of the wind, certainly *not* by insects, though they now abound.—Sincerely yours,

E. S. ROWCLIFFE.

Hall Place, Cranleigh, Guildford, 5th June, 1882.

Our readers have now before them all the evidence which we have been able to collect. We shall be glad to see the subject further discussed.

⁂ This great gale was referred to by the Revd T. A. Preston in his "Report on the Phenological Observations for the Year 1882" (*Q J Meteorol Soc*, **9**, pp 47-60 (1883)) made to the Meteorological Society. In the discussion of the Report which took place on 20 Dec. 1882 Mr. Edward Mawley (later to become President) commented as follows:

On the 29th of April, however, there occurred a gale, which as regarded the wholesale destruction of leaves and blossoms of trees, and indeed of all vegetation exposed to its direct influence, was in his experience unprecedented. For some time afterwards the windward side of those trees, the foliage of which was sufficiently advanced to be affected, appeared as if blackened by fire, whilst the sheltered side was unscathed. Later on all this was changed, so that only the usual dull green leaves of mid-summer were to be seen on the north side, while the south or injured side bore the fresh green foliage of spring. In many cases these new leaves were slow in appearing, owing to the severe shock the trees had themselves sustained through their untimely defoliation; and the effect of this was to leave them greatly open to the attacks of blight, caterpillars, and other insect pests. Only a few weeks ago a third result of this gale was apparent, for while the injured trees, and particularly oaks, had scarcely a leaf left upon them, those few which had escaped the storm continued in such active growth, owing to the cool summer and wet autumn, as to retain nearly the whole of their foliage, the dead leaves clinging to the still unripened wood. It would be, as remarked in one of the horticultural papers at the time, interesting in years to come to trace in felled timber the influence of this storm upon the thickness of the layer or layers of wood which had been formed during the current year. Mr. Mawlay was pleased to find that Mr. Preston in no way attributed the damage to trees either to the deposit of salt spray upon their young foliage, or to the action of frost, but had happily described the leaves as simply "beaten to death" by the wind. It had been popularly supposed that the salt which fell during this gale occasioned much of the mischief, and even so keen an observer of nature as the Poet Laureate appeared to have held this opinion, for in his new drama of "The Promise of May" he spoke of a "salt wind" which "burnt the blossoming trees." Whereas the long-continued violence of the wind was in itself sufficient to account for all the damage done to the tender young leaves. At Addiscombe a velocity of thirty-six miles an hour was on this occasion maintained for six consecutive hours, and at Kew some of the individual gusts were stated to have attained a rate of between seventy and eighty miles an hour. In fact, Mr. Eaton had noticed that much injury had been done to the foliage of several chestnut and pear trees in Croydon before any salt had been deposited, and some time before the storm had reached its height. In another part of Mr. Preston's report an instance had been given of even the comparatively tough leafage of autumn having been killed by the violence of the wind during the severe storm of October 1881.

However, Brazell in *A Century of London Weather* (HMSO, 1968, p. 75) says that 'It is probable that the sea salt carried inland by the wind was mainly responsible for the damage.'

Notes and news

Heaviest daily rainfall in Scotland

Recent correspondence with Mr G. Reynolds of the North of Scotland Hydro-Electric Board has drawn to our attention the fact that the daily rainfall total for the 24 hours commencing 9 a.m. on 17 January 1974 at Sloy Main Adit, amounting to 238.4 mm, broke the previous daily total officially recorded for any site in Scotland. The location of the Sloy rain-gauge, by grid reference, is NN (27) 293104 and at 204 metres above sea level.

The previous record was apparently held by Loch Quoich, Kinlochquoich, when 208.3 mm was recorded for the rainfall-day of 11 October 1916. The now third-highest total in Scotland seems to be the 199.1 mm at Dalness (Glen Etive), on 17 December 1966.

The highest daily fall in the United Kingdom remains the 279.4 mm at Martinstown on 18 July 1955, whilst the highest fall on record in Wales is 211.1 mm on 11 November 1929 at Rhondda, Lluest Wen, and on record in Northern Ireland is the 152.4 mm at Coleraine, The Cutts, on 15 December 1928.

Correspondence

Comment on 'Computation of vapour pressure, dew-point, and relative humidity from dry-and wet-bulb temperatures'

Sargent (1980) discussed a number of equations for evaluating saturation vapour pressure and compared their results with those given by the Goff-Gratch formula.

The well-known 'Tetens' expression (e.g. Lowe 1977, Murray 1967, Stackpole 1967) was not included although it is particularly suitable for use in small programmable calculators. It gives results acceptable for most meteorological purposes and is readily solved to give an expression for calculating dew-point temperature from vapour pressure.

As given by Stackpole,

$$e_s = 6.11 \times 10^{7.5/(T+273.3)}$$

where e is the saturation vapour pressure over water in millibars (mb) and T is temperature (°C).

From this is obtained

$$T_d = \{237.3 \log(e/6.11)\}/\{7.5 - \log(e/6.11)\},$$

where T_d is the dew-point temperature corresponding to a vapour pressure e.

Slightly better agreement with results from the accepted standard formulae is obtained by using more figures for the constant 6.11. (6.107 if the formula recommended by the World Meteorological Organization (WMO) (1979) is taken as the standard; 6.1078 if, following Sargent, the Goff-Gratch formula is taken as the standard.)

The differences in saturation vapour pressure calculated with this formula and that given by WMO, are less than 0.02 mb between −50 °C and +50 °C (Table I). If the Goff-Gratch values are used as reference, or if the more exact values for the constant are used, the differences are still smaller.

In calculating dew-point the deviations are smaller than 0.05 °C from about −15 °C to +60 °C.

Table I. *Saturation vapour pressure calculated from WMO and Tetens formulae.*

Temperature *degrees Celsius*	Saturation vapour pressure *millibars*		
	WMO (*W*)	Tetens (*T*)	*W*−*T*
−50	0.064	0.061	0.003
−20	1.254	1.247	0.007
0	6.107	6.110	0.003
10	12.271	12.283	0.012
20	23.371	23.389	0.018
30	42.427	42.442	0.015
50	123.390	123.395	0.005

A routine for calculating the saturation vapour pressures, relative humidity, and dew-point from wet- and dry-bulb temperatures, using these formulae, requires only 59 program steps in a Hewlett-Packard 97 programmable calculator.

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J. D. Coulter & S. K. Sharma

Fiji Meteorological Service

The author replies:

Coulter and Sharma quote (or rather misquote!) the 'Tetens' formula for evaluating saturation vapour pressures and imply that it should have been included in my original paper. The same could be claimed for other formulae (e.g. Tabata, Bogel, Rasmussen, etc.) but it was never suggested that the paper was exhaustive and only a selection of formulae and procedures was included.

The Tetens formula is quite useful and in order that intending users should not be misled it is appropriate that it be quoted correctly, viz:

$$e_s = 6.11 \times 10^{(7.5\,T)/(T+237.3)}.$$

Although the differences are small enough to be ignored for most practical meteorological purposes, I found the values given by the WMO recommended formula to be as in Table I. The differences are shown as relative differences which give a better idea of the accuracy of the evaluations.

Table I. *Saturation vapour pressure calculated from WMO, Goff-Gratch and Tetens formulae.*

Temperature *degrees Celsius*	Saturation vapour pressure *millibars*			Relative difference *millibars*	
	WMO (W)	Goff-Gratch (G)	Tetens (T)	$W-T$	$G-T$
-50	0.064	0.064	0.061	0.046	0.044
-40	0.189	0.189	0.184	0.027	0.026
-30	0.509	0.509	0.502	0.014	0.014
-20	1.255	1.255	1.247	0.007	0.006
-10	2.865	2.864	2.858	0.002	0.002
0	6.111	6.111	6.110	0.000	0.000
10	12.279	12.279	12.283	0.000	0.000
20	23.385	23.384	23.389	0.000	0.000
30	42.452	42.450	42.442	0.000	0.000
40	73.813	73.811	73.774	0.001	0.001
50	123.451	123.449	123.395	0.000	0.000

G. P. Sargent

Meteorological Office,
Bracknell.

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The development of the Meteorological Office new operational forecasting system

By A. Gilchrist
(Deputy Director (Dynamical Research), Meteorological Office, Bracknell)
and P. W. White
(Assistant Director (Forecasting Research), Meteorological Office, Bracknell)

Summary

During the ten years since the 10-level model was brought into use for operational weather forecasting there have been considerable advances in automatic and remote sensing techniques as well as in theoretical aspects of numerical weather prediction. With the acquisition of a CYBER 205 computer, the Meteorological Office is now able to update and improve its data analysis and forecasting methods to take advantage of new sources of observational data and to increase the accuracy and scope of the services it provides to customers. An outline is given of the background to new developments in the subject followed by a description of the main features of the forecast system that will replace the present operational 10-level model in the latter part of 1982.

Introduction

It is perhaps surprising that weather forecasting, an apparently inexact skill, was one of the first practical applications of computers. Indeed, the principles underlying their use for such purposes were established during the First World War, and published shortly after it by L. F. Richardson (1922), a remarkable British mathematician who spent several years working in the Meteorological Office.

Richardson's essential contribution was to set down weather forecasting as a problem in classical physics and to indicate how the resulting equations could be solved by numerical techniques. At that time the conventional method of weather forecasting was based on experience and history. Depressions and anticyclones were followed and their movements extrapolated or predicted on the basis of historical precedents, but this was done without a clear conception of what caused the motion or, indeed, why depressions and anticyclones formed in the first place. Richardson's proposal was to change these inexact, qualitative methods for quantitative techniques based on the established laws of physics. The mathematical problem was formidable. The atmosphere was to be represented by the values of variables (i.e. temperature, pressure, wind, humidity) on a three-dimensional mesh of points with a horizontal separation of 400 km and a vertical separation of about 200 mb. The equations of motion, thermodynamics and conservation of matter could then be written in a form that enabled the changes taking place at a particular mesh point to be calculated from the values at surrounding mesh points. The changes could be added to the initial values to find the expected state of the atmosphere a short time later. The calculations then had to be repeated so that the 'forecast' could be stepped forward towards the time for which it was required. The calculations when carried out by hand were so laborious that Richardson was employed for many hours in evaluating a 6-hour forecast for a single point on the earth's surface. The pressure change he calculated (145 mb in 6 hours) was completely unrealistic, and his failure seemed to put paid to attempts to make weather forecasting more quantitative.

Richardson's work on weather forecasting was carried out at least a quarter of a century before electronic computers were developed. When they were, the possibility of using them in weather prediction was recognized by the distinguished American mathematician J. von Neumann. He collected together a group of talented young scientists to work on the problem and so exploit the potential for more accurate weather forecasts which seemed to be opening up. Some of those involved, for example Professors J. G. Charney and J. Smagorinsky, were to be among the most outstanding and influential dynamical meteorologists of our day. From these beginnings stemmed developments which, over the last three decades, have revolutionized the science and practice of weather forecasting.

Within the United Kingdom similar but independent research on the quantitative description of atmospheric changes was going on, the outstanding names being those of Dr E. T. Eady who worked within the Meteorological Office during the Second World War but, after it, left to become a member of the distinguished group of meteorologists who constituted the Meteorological Department at Imperial College, London, and Dr R. C. Sutcliffe whose paper in the *Quarterly Journal of the Royal Meteorological Society* in 1947 was the mainspring of developments in dynamical meteorology within the Office for more than a decade. The first models which were used in the Office for research into forecasting by computer methods owed their derivation directly to Sutcliffe's work.

An important element in the researches of that time, which was crucial to the practical application of computers in forecasting, was the elucidation of the main reason why Richardson's initial attempt at forecasting produced such a poor result. Essentially it was that the meteorological observations on which his forecast was based were used in a 'raw' form. In general, measurements made in the atmosphere are influenced by the effects of motion due to meteorological phenomena of many different scales, for example by the motion created by individual clouds or by narrow frontal systems as well as by the depressions and anticyclones, the larger features which the forecasters were hoping to deal with. The motions associated with the features Richardson was hoping to forecast were being seriously contaminated by those caused by much smaller, short-lived features which could not be represented by grid points 400 km apart. This led to the concept of adjusting the initial analyses so that they represented only that part of the wind and temperature field associated with the large systems, and of 'filtering' the equations which formed the atmospheric model to ensure that they did not give rise to unrealistic small-scale motions. When these new ideas were incorporated into the models, the difficulties experienced by Richardson were removed.

The first model used by the Meteorological Office to produce numerical forecasts operationally was a 'filtered' model which had three levels in the vertical where the calculations were carried out and where results were available to the forecasters, and a horizontal mesh with nodes positioned about 300 km apart. The event which enabled this model to be used in providing information directly to the forecaster quickly enough to influence the forecasts issued to the public, was the replacement of the first Office computer, a Ferranti Mercury, by the faster English Electric Leo KDF9. This operational system provided the guidance for Meteorological Office forecasts for seven years, a period during which the products came to be recognized and regarded as the most important information available for forecasting the weather for 24 hours to 36 hours over the British Isles.

However, even before the system became operational, research was indicating rather clearly that the use of filtered equations to suppress extraneous motions sometimes prevented the models from indicating atmospheric developments realistically. The constraints imposed by the filtering could be harmful, and furthermore they were shown to be not strictly necessary. It was discovered that filtering could be replaced by much less restrictive methods and, in effect, one could return to techniques much closer to those introduced by Richardson, provided care was taken to ensure that the initial conditions were still tailored to eliminate certain types of motion not of meteorological interest. If the initial data for a forecast were of the right kind, then, with reasonable care in the numerical techniques, the representations of atmospheric motion remained realistic when the equations were integrated forward in time to obtain a forecast. The new models which then became possible were termed 'primitive equation' as opposed to 'filt ed' models and their power was rapidly demonstrated when they were applied to forecasting real conditions. In particular, they could forecast not only the wind field but the rainfall and cloudiness, features which presented enormous difficulties to the earlier models. Furthermore, since they were more general, they had the potential to represent smaller-scale aspects of the meteorological situation, for example frontal systems which are of such significance in the rainfall of this country.

In the Meteorological Office, research aimed at exploiting 'primitive equation' models, particularly to investigate the processes occurring within fronts, was initiated in the early 1960s by J. S. Sawyer. It led to the development by F. H. Bushby of a new model with 10 levels in the vertical and a horizontal mesh length of 100 km (Bushby and Timpson 1967). The first situation on which it was tested was 1 December 1961, when a shallow trough some 500 km west of Ireland developed rapidly to become an active depression and deposited large amounts of rain on southern England as it ran quickly eastwards. The conventional forecast on this occasion was not particularly successful, but the new model predicted the deepening of the depression, its eastward movement and the rainfall very well. The promise of this model was such that when the opportunity arose in 1972, through the replacement of the KDF9 computer by an IBM 360/195, to improve the Meteorological Office numerical weather forecasting system a version of it was chosen as the basis for future operational guidance. Since that time the basic operational system has been essentially unchanged, though of course minor changes have been made from time to time as investigations indicated them to be desirable. At the present time, the 10-level model with a 300 km horizontal mesh length covering most of the northern hemisphere is used twice a day to provide the forecasts for aviation and the basis for forecasts to the general public. In addition, a 'fine-mesh' version of the model covering Europe and the Atlantic is used very soon after the standard observations are received, to provide preliminary guidance and to give more detailed forecasts for the British Isles, including estimates of precipitation. One of the most significant improvements that has been achieved by using this model is that it has been possible to extend the period over which numerical predictions provide guidance from about 48 hours at most with the 3-level filtered model to more than twice this length of time. The model now provides forecasts to six days regularly, and the results are useful on most occasions. It is as a result of the improved ranges to which numerical predictions can now be pushed that the European Centre for Medium Range Weather Forecasting was established with the aim of extending the period to ten days at least. In the future, therefore, the Meteorological Office will be concentrating on the early part of the range, about one to four days, leaving the later period to be dealt with by the Centre.

Despite the success of the 10-level model, the desirability of changes on a more fundamental scale than have been undertaken in the last decade has become clear. Twenty years since its initial conception and nine years since its introduction into operational use, the model continues to provide forecasts comparable with any produced elsewhere. Indeed, if account is taken of the relatively small amount of computer time it consumes and of the rapidity with which observations are processed and used to provide guidance to weather forecasters, the system as a whole is probably the most effective in the world. Nevertheless, improvements are now desirable, particularly to take account of two new factors. First, forecasts are required for larger areas of the globe and to greater heights in the atmosphere; and second, changes in the meteorological observing network call for different methods of analysis, involving the use of the model itself to derive the best starting point for a numerical forecast. In addition, some aspects of the model need to be redesigned to derive maximum benefit from recent developments in representing atmospheric processes. In the following sections the research on the design of aspects of the new model and the changes in the observing network and analysis techniques are discussed. In the final section the operational system now being developed is described and an example of its performance presented.

Research leading to the design of the next operational model

The atmosphere contains motions on all possible scales. Eddies form downstream of stones, blades of grass, telegraph wires and trees; winds swirl around buildings, sometimes forming intense gusts or vortices; the shimmering seen on hot summer days is caused by hot pockets of air rising from heated surfaces; individual clouds range from the very small to thunderstorms which may be 10 km across and occupy the whole depth of the troposphere. Beyond these systems come the fronts associated with the travelling depressions and anticyclones of middle latitudes which are largely responsible for the variable weather experienced in the British Isles.

The effect of small-scale motions (which are not represented on the model's mesh of points) on the larger-scales (which are) is a very important factor in the improvement of weather forecasts and has been the subject of much research.

In its early stages, numerical forecasting concentrated on the dynamics of the largest scales; the mesh sizes used aimed to deal with features on a scale of 2000 km and upwards adequately, as this included the most commonly observed cyclones and the long waves which tend to control their movement. They were treated almost independently of smaller-scale motions, though it was recognized that on many occasions the latter's influence in modifying the main systems could be significant. This is particularly obvious on some summer days when thunderstorms originating over northern France and moving northwards can transform the large-scale situation; or in winter-time when cold Arctic airstreams reaching Britain from the north are warmed and modified as a result of small-scale heating from the surface by travelling over relatively warm seas. On a slightly longer time-scale, it is necessary to include the effects of small-scale motions in maintaining the vigour of the larger systems because it is generally through them that the energy of the atmosphere is destroyed and replenished. Friction at the earth's surface caused by roughness such as waves on the sea surface, trees and buildings destroys energy at a rate which, it is estimated, would bring the atmosphere to rest in about 10–14 days if it were maintained. That energy has to be replaced by energy created largely as a result of differential heating, and therefore, for consistency, if the terms representing the slowing down of the large-scale motions by friction are to be included (as they must be to forecast, for example, the decaying stage of a depression's life-cycle), then so must also the differential heating between the tropics and higher latitudes, between land and sea, and between cloudy and cloud-free areas. Most of the heat rises from the earth's surface in small-scale turbulence and is then carried through the depth of the troposphere in cumulus clouds. These effects clearly should be represented in numerical forecasting models.

It is of course out of the question to create a general-purpose model capable of representing all the important atmospheric motions at the same time. Two fairly obvious things can be done. Firstly the mesh spacing can be reduced so that a larger span of motions can be described adequately in explicit terms. Thus the spacing in the first numerical models was commonly 400–500 km, and this has been reduced progressively to 250 km or less, with even finer mesh models over restricted areas to try to capture the detail required. However, as the mesh is made finer, the computing time for a forecast increases; if only the horizontal distance between nodes is halved, the time is increased by a factor of eight, and clearly therefore there is a limit to how far it is profitable to go in this direction. Secondly, one can parametrize (i.e. represent statistically) the effects of the smaller-scale motions in terms of the average values which the model can be assumed to represent; for example, the energy extracted from the wind over a given surface by turbulence can be estimated in terms of the average wind speed over the area. Fortunately, investigations of turbulent motions in the atmosphere have indicated that the more important small-scale phenomena are controlled by the structure of the atmosphere on larger scales together with the character of the underlying surface of the earth, and observations of clouds have shown that they can often be related to the buoyancy characteristics of the airstream in which they occur.

Research aimed at providing adequate parametrizations of the effects of small-scale motions has been a major preoccupation of meteorological research since at least the mid-1960s. It remains an area in which understanding is partial and patchy and from which therefore we can expect research to continue to improve numerical forecasting in the future.

Broadly speaking, the parametrization problem can be split into three:

(1) the interaction between the atmosphere and the earth's surface;
(2) the transfer of heat, water and momentum vertically through the depth of the atmosphere, mainly as a result of buoyancy effects; and
(3) the interaction between the atmosphere and radiation, including the effects of clouds on both short- and long-wave radiation.

The interaction between the atmosphere and the earth depends on the characteristics of the surface—its temperature, roughness and wetness, for example—and also on the lowest atmospheric layers, particularly the wind strength, and whether they are stably or unstably stratified. As the boundary layer, in which the effects on the atmosphere due to the proximity of the earth are appreciable, is usually around 1000 m deep ($\approx$ 100 mb near sea level) and the present operational model has levels 100 mb apart, it is clearly not possible in the model to represent the detailed variation of atmospheric properties close to the ground. The scheme now used to calculate the effects of interaction between the earth and atmosphere has been tailored to these constraints. It was devised by A. J. Gadd and J. F. Keers (1970). Over the oceans, which do not respond significantly to the diurnal variation of solar radiation, a number of simplifications are possible, and therefore the problems to be dealt with are best illustrated by considering the situation over a land surface. The surface temperature responds to the receipt of solar radiation, and there are resultant changes in heating rates, frictional drag, evaporation and cloudiness in the boundary layer. The fractional transmission of solar radiation through the atmosphere depends primarily on the cloud that is present, and in order to find its value an estimate of cloudiness is required. It is deduced from the relative humidity values at grid points. Gadd and Keers then estimate the surface radiation loss using published observations relevant to the cloudiness conditions indicated by the model. The net surface radiation resulting from these calculations is partitioned into heat stored in the ground and sensible and latent heat exchanges with the air, taking account of the wetness of the surface as indicated by climatological data. These exchanges are used in determining the resultant atmospheric changes. It is to be noted that, in this process, surface temperature is not determined explicitly, nor does the stability of the lower atmosphere influence the calculation. For these reasons, among others, the method is limited in its accuracy, and not only the facilities available but the basic understanding have now advanced to the point where it is possible to implement procedures which are capable of calculating the exchanges in a more adequate way.

The new model will have a better resolution in the boundary layer so that stability can be taken into account in the calculation, and surface temperature will be found explicitly, enabling the atmospheric structure near the ground to be inferred more precisely. These changes are desirable on scientific grounds, as they will permit a more realistic simulation of the atmosphere by the model, but they are required in a more direct sense to provide the more detailed information about conditions in the boundary layer that are needed to meet many wide-ranging demands for forecasts. The methods to be implemented in the new model are possible because of a large amount of observational and theoretical research carried out at a number of centres over the globe, but depend particularly on parametrization studies in the Dynamical Climatology Branch. The interaction of the atmosphere with the underlying surface is crucial to an understanding of the physical basis of climate, and investigations concerned primarily with setting up climate models have clarified a number of aspects which have direct relevance also to forecast models.

The surface temperature, and conditions in the atmosphere immediately above, control numerous meteorological processes of direct interest to the forecaster. The accumulation and melting of snow, the rate of cooling at night, frost and the formation and dissipation of fog are obvious examples. As already pointed out, such processes eventually influence the behaviour of the atmosphere on large space-scales and there should therefore be an improvement in the general standard of the forecasts from these measures. The use of the new boundary-layer and surface-exchange parametrization will enable more realistic assumptions to be made about other aspects of the boundary layer. The intensity of the low-level turbulence can be expressed in terms of the low-level wind shear and stability, the infra-red radiative loss will be determined with its appropriate temperature and humidity dependence, and snow predicted by the model will be accumulated or melted according to the calculated values of the surface temperature. Evaporation from the earth's surface will be dependent on the surface wetness, determined from the forecast accumulation of rain reaching the surface, with allowance for percolation into the soil. These parametrizations have already been tested in general circulation models where the validity of the schemes can be assessed from the realism of the climatological simulations. Empirical constants which necessarily appear when particular processes are simplified in a fairly gross way can be chosen to give optimum results on the basis of the calculated climatological distributions of relevant parameters.

Turning to levels above the boundary layer, in which vertical transfer of heat, water vapour and momentum is effected mainly by motions on the scale of individual clouds, a different kind of parametrization is required. Surface heating during the day sets off convection currents which carry the heat up through the atmosphere. The depth of the layer through which it is carried grows as the warm air gradually penetrates and mixes with more stable air at higher levels. In some atmospheric conditions the latent heat released when water vapour condenses to form cumulus clouds capping the convective currents is sufficient to increase their buoyancy to such an extent that the currents accelerate upwards to form rain-shower clouds rising to heights comparable with the depth of the troposphere.

The earliest attempts to represent convective processes in numerical models were based on an examination of the vertical profiles of temperature within the model for buoyant instability and readjusting the atmospheric heat distribution to a neutral or stable configuration. A scheme of this kind was used for some time in the 10-level model. However, the procedure takes little or no account of the actual structure of convective motion as observed. For example, it makes no attempt to represent the direct transfer of heat from the surface to high levels on occasions of vigorous convection. It is not possible to build into it an adequate representation of the vertical transfers of heat, water vapour and momentum nor of the formation of convective clouds and rainfall. Other more elaborate conceptual models have been devised and they permit more realistic representations of such processes.

The current operational model makes use of a parametrization scheme which rests on the supposition that deep convective clouds are initiated and sustained by an input of moisture at low levels concentrated by convergence of the large-scale surface wind field (Hayes 1977). Although such a mechanism is important for some forms of convection (for example within frontal zones), it does not appear to account satisfactorily for other types of deep convection. For example, during the summer months, instability at mid-tropospheric levels is responsible for initiating the growths of cumulonimbus clouds over northern France. They then move northwards across England and Wales, sometimes producing intense hail and thunder, and are maintained for several hours by moisture drawn in at low level by ascent within the storms themselves rather than by large-scale convergence. An alternative scheme for representing deep convection in models was developed by W. H. Lyne and P. R. Rowntree (1976), working in the Meteorological Office Tropical Group in connection with the GARP Atlantic Tropical Experiment (GATE). One of the main aims of GATE (see the *Meteorological Office Annual Report 1978* for an account of the Meteorological Office's participation in the Experiment, pages 78–85, but especially page 83) was to provide research scientists working in this area with high-quality observations to test the adequacy of proposed parametrizations. In the parametrizations developed in the Office the column of air above each ground-surface grid point is examined for convective instability by determining whether air with a small amount of excess buoyancy relative to its surroundings would remain buoyant if it rose from one level to the next, thus simulating the observed tendency for convection to be initiated by warm bubbles or plumes of air. In this stability assessment, due account is taken of mixing between the rising parcel of air and the surrounding atmosphere and also of the latent heat released as water vapour condenses into liquid water during cloud formation. The liquid water is assumed to fall to the ground as convective rainfall, though allowance is made for some evaporation of the raindrops to take place at intermediate unsaturated levels before they reach the earth's surface. The heating of the large-scale environmental air within which the convective plumes are forming is assumed to arise mainly from subsidence which compensates for the upward mass transfer of the rising buoyant air parcels. Extensive tests of this scheme in tropical forecasts, made and verified using GATE data, showed that it gave appreciably more accurate indications of the amounts and distributions of convective rainfall than simpler methods.

The third area requiring parametrization is the effect of radiation and cloud. Spatially varying radiative exchanges create horizontal and vertical temperature gradients, and air motions are then generated which redistribute the heat. Potential energy lost through the lowering of the centre of gravity of the atmosphere reappears as the kinetic energy of air motion. Such effects are fundamental to the atmospheric circulation both on planetary and local scales. Changes in the average temperature of the atmosphere as a whole have a less immediate impact on the weather.

Two kinds of radiation need to be considered, namely short-wave radiation reaching the earth from the sun and long-wave heat radiation emitted by the surface and the atmosphere.

Apart from the absorption of ultra-violet radiation by ozone in the stratosphere, atmospheric gases are largely transparent to solar radiation, and the main factor determining the amount reaching the earth's surface is cloudiness. Clouds are generally highly reflective to short-wave radiation and therefore they can reduce the heat input to the earth-atmosphere system very substantially. The main difficulty which arises in introducing this effect realistically into numerical models is that clouds are extremely variable in space and time, and in many circumstances there is no clear relation between the amount of cloud and the large-scale variables. Thus, many extensive cloud sheets which reflect a large proportion of the incoming radiative energy are much thinner than the vertical separation of levels in a model, and in a region of mixed cloudy and clear conditions there may be many individual clouds of varying depth and opacity within a single grid area. In these circumstances the 'best' parametrization cannot be derived directly from observations as it will depend on the structure of the model: for example, on the horizontal and vertical grid-spacing, on the parametrizations of other quantities and on the finite difference approximations used in dealing with water vapour. Methods which have been tested and shown to give reasonable results in other Meteorological Office models enable the amount and the depth of cloud to be related not only to the relative humidity, the obvious parameter, but to the vertical velocity and the vertical gradients of temperature and humidity. Such methods are being tested in the new model, but it seems clear that the best parametrization will only be decided after a period of operational testing.

The interaction of infra-red radiation with clouds is also important; they trap radiation leaving the earth's surface, and the radiative cooling from cloud tops can lead to the intensification of convective motion within the clouds. The passage of infra-red radiation through the clear atmosphere is also a fairly complex process involving the radiatively active gases, viz. water vapour, carbon dioxide and ozone. While the most significant aspects of infra-red radiative interchanges are, broadly, understood and computer programs are available to calculate them accurately, the particular techniques which work best and are most efficient depend upon the characteristics of the numerical forecasting model and on the specific purposes for which it is used. As with solar radiation and the selection of methods to derive cloudiness, the most appropriate techniques will be selected from the wide range of possibilities available as a result of the experience gained during operational trials.

The meteorological observing network

In the 1950s and 1960s when numerical weather forecasting was being developed into a robust dependable technique, giving predictions of large-scale features of the atmosphere at first comparable with, but later superior to, those of skilled forecasters, the network of observations on which the predictions depended was well-established and fairly static. Surface conditions were recorded at many stations on land, and from numerous merchant ships usually plying the main routes across the Atlantic and the Pacific. Observations of upper-air conditions were made at a much smaller number of special upper-air stations which released balloons carrying the necessary instruments twice a day at 00 and 12 GMT, and sometimes at the intermediate hours 06 and 18 GMT.

For many purposes the network of surface observations was probably adequate over most of the northern hemisphere although, not infrequently, small depressions over the oceans escaped detection, and in tropical regions the network was not established on a secure başis. The problem of the oceanic areas could be serious for countries like Britain lying at the ocean boundary; indeed, some of the worst forecast errors were associated with depressions about which detailed information was lacking at a sufficiently early stage of their development. Nevertheless, the surface situation was very much better than that concerning upper-air observations.

For numerical models the conditions in the upper air are crucial. They calculate how the atmosphere will change, not by following the history of the motions but by interpreting the atmospheric situation at a particular instant, and therefore they require the three-dimensional structure of the atmosphere to be defined accurately if the forecasts are to be correct. Over most of the land surface in the northern hemisphere the upper-air network was quite good but there were large gaps with no observations, and over the oceans the handful of weather ships could not provide all the detail that was desirable.

In analysing the upper-air conditions with such a relatively scattered set of observed values it was essential to make the maximum possible use of the information available, including theoretical relationships, forecasts from an earlier time, and climatological values as well as the observations themselves. In addition, the methods used sought to make optimum use of the known characteristics of the network. Thus the geographical positions of the observing stations were known and they did not vary from day to day; the observations were made synchronously and therefore it was not necessary to deal with off-time values; although radiosondes differed from one country to another, they were measuring essentially the same variables in a similar way and such variations in accuracy and response characteristics as existed could be allowed for straightforwardly; instrumented balloon soundings almost always measured pressure, temperature and humidity (from which, given the surface pressure, the altitude can be deduced), and most of them tracked the balloons carrying the instruments to measure the upper winds, so that winds could almost always be associated with pressures at the same location. The analysis system that derived initial conditions for numerical models was therefore geared to deal with a fixed network of stations, providing data that were generally reliable and accurate. Additionally, because the forecast area was almost entirely confined to extratropical latitudes, the geostrophic relation could be used rather freely to convert wind information into information concerning the gradient of upper-level pressure and vice versa. (Where the geostrophic relation holds, winds can be inferred with acceptable accuracy from pressure charts; for example, the low-pressure systems or depressions which affect the British Isles have winds blowing around them in an anticlockwise direction. However, in the tropics the relationship is no longer strong and fields of wind and pressure need not be closely connected.) Though the mathematical problem of analysis was difficult because the maximum amount of information had to be extracted, and there was little redundancy in the system to check the results, it could nevertheless be specified in considerable detail and satisfactory methods for solving the problems were developed fairly quickly.

Over the last two decades the observing network has been changing in significant ways. At an early stage in the development of satellites it was realized that they were ideal platforms for meteorological observations as all parts of the earth could be looked at, in large areas simultaneously. It was conceivable that they could provide the extra information from the oceans and from the tropics that was needed to achieve a more adequate monitoring of the atmosphere. There was also the possibility that satellites could replace parts of the conventional network. Essentially, however, the only measurements relevant to the atmosphere that can be made from satellites are of the intensity of the radiation reaching them from a part of the earth's disc. If the measurements are in the visible, then a picture of clouds and the earth's surface can be built up; if in the infra-red then it is possible to deduce information about the temperature of the emitting body, and by taking a variety of wavelengths it is possible to estimate temperatures and (as water vapour is one of the important radiating constituents) humidities through the depth of the atmosphere. When geostationary satellites were put into orbit, work started on trying to deduce winds by tracking suitable cloud elements between pictures taken a short period apart. Research on these aspects of using satellites to obtain winds and temperatures has now been going on actively for over a decade, and some of the latest satellites provide reasonable estimates of temperatures and winds in favourable conditions. What is important from the point of view of analysis, however, is that the estimates are no longer easily compatible with conventional measurements. Thus the temperatures are average values over substantial volumes of the atmosphere rather than discrete values at a point, and their accuracy depends a great deal on how much cloud the volume contains. For measurements of winds from geostationary satellites the main difficulty is in attributing them to specific levels. The level has to be decided from radiation measurements from which it is possible to make estimates of the cloud-top temperatures, and therefore of the approximate height of the cloud in the troposphere. Other technological developments, coupled with the increase in the cost in relative terms of the conventional methods of observing the atmosphere, have led to other changes. Mainly these have been towards automation which enables observations to be made without the need for human skill or human intervention. It is now possible to measure winds accurately in aircraft flying commercial routes without the aircrew having to be involved. They can then be transmitted via a geostationary satellite into the meteorological telecommunication system. Such observations are potentially extremely valuable for analysing atmospheric conditions since they provide accurate measurements at well-defined heights. They do, however, present problems of consistency, because in using them to best advantage it is necessary to try to recreate the pressure and temperature fields at levels below the aircraft winds so that the structure throughout the entire depth is reasonable and leads naturally to the observed winds. Other technological developments have made possible automatic observations of quantities which are already observed and where the gain is mainly in the increased numbers that are, or can be made, available. For example, surface pressure can be measured on unmanned drifting buoys and transferred to the telecommunication network by satellites; more complicated automatic systems have been devised for a wider range of measurements.

The analysis method

From the point of view of analysing the atmosphere these new types of observations have complicated the problem enormously. The observations are no longer synchronous, no longer reasonably uniform in type and accuracy, no longer complete at a particular horizontal location. The new conceptual and mathematical problems are formidable and we cannot be sure at this stage that we know how best to deal with all aspects. This is particularly true because the system and methods of interpreting the observations are still changing. We can, however, create an analysis program which gives better results than we have had before and which is sufficiently flexible to cope with changes in the network which will arise in the future. The question of optimizing the results from the method is a longer-term project when the new operational system is working to reasonable satisfaction.

The analysis problem for numerical weather forecasting is that of representing the three-dimensional structure of the large-scale features in the atmosphere as accurately as possible consistent with the meteorological observations at a particular instant, and of presenting the information to the forecasting model in a form that will allow the best simulation of future developments to be produced. As discussed in the introduction, this implies the creation of a set of internally consistent values which describe only the meteorological features and in which extraneous motions are absent or very small. Ideally, the set should be complete and include realistic vertical motions. However, a particular difficulty concerns the vertical motion at the initial time. It is closely related to the divergent component of the wind, which itself constitutes less than 10 per cent of the wind analysed as being representative of the large-scale features. Atmospheric developments, other than those brought about by simple translation, depend on vertical motion which is the means whereby stored potential energy is converted into kinetic energy and motion. Thus the intensification of depressions requires the ascent of relatively warm air with compensating descent of relatively cold air elsewhere. If the distributions of vertical velocities or of temperature are significantly in error the intensification will be predicted incorrectly. Neither the present observational system nor any likely to exist in the foreseeable future provide the information required to diagnose the vertical motion field associated with large-scale systems directly.

The procedure adopted in the present operational model is to analyse the mass (or, equivalently, pressure) distribution in the atmosphere as accurately as possible. Wind observations are used in this process since in extratropical latitudes they are related to the pressure gradient. The wind velocities over the whole area of the forecast are then deduced theoretically from the mass field by a method which automatically eliminates non-meteorological motions. This procedure, known as initialization, ensures that wildly unrealistic developments do not occur in the subsequent forecasts. However, the winds deduced at an observation point may not be precisely the same as those measured and the vertical motions are unlikely to be those required to give the true atmospheric developments in the initial stages of the forecast. Fortunately it is found that the numerical model is generally able to develop more realistic and consistent vertical velocities, so that the developments judged by changes over 12–24 hours are usually correct. The analysis method which has been developed to replace the present operational system is intended to overcome some of these shortcomings. It does so mainly through two significant changes: (1) it deals with observations of different types on the same footing, so that the geopotential will no longer be the prime variable for analysis, and (2) the concept of analysing the observations for a specific instant independently of the numerical model is abandoned in favour of an analysis period within a normal forward run of the model when the observations are allowed to influence and change the model state. Whereas in the present system the vertical velocity is set to zero at the beginning of the analysis and estimated anew from the analysed field of geopotential, in the new system it will be retained and modified like other variables as a result of the gradual assimilation of new information. Such a system is better adapted to circumstances in which many observations apply to times between the main meteorological observing times and are heterogeneous as regards reliability and accuracy. Also it seems to hold out promise for improving the forecast of developments in the first few hours, and could therefore have applications in finer-mesh models designed for short-period forecasting.

Analysis and data-assimilation schemes have been developed over a number of years in the Forecasting Research and the Dynamical Climatology Branches. Techniques developed for analysing tropical data during GATE have been particularly useful. More recently the process of assimilating data into a numerical model has been tested during the Special Observing Periods of the First GARP Global Experiment (FGGE), a world-wide intensive observational program carried out during 1979 to obtain accurate data concerning the entire global atmosphere. In the scheme which has been tested, separate analyses for winds, temperatures and surface pressures are produced. The analysis procedure, known as 'optimum interpolation', uses the observations to calculate corrections to a preliminary estimate of the values of the physical quantities obtained from a forecast from a previous time. The corrections are expressed as weighted averages of the departures of the observed values from this preliminary estimate, the weights themselves being selected so that the statistically expected errors in the analysis are minimized. This assumption enables the weights to be calculated in terms of the expected error distributions of the preliminary estimate, the probable error bounds of each observational technique and, where appropriate, correlations of the error at each observation with those of its neighbours. The procedure takes due account of the differing accuracies of various observing systems (for example, winds inferred from following the movement of clouds viewed from geostationary satellites are likely to be less accurate than those found by tracking balloons with radar).

Two quality-control checks are made to test the validity of the data. Each observation is first checked against the value of the preliminary estimate. It is regarded as possibly erroneous if it departs by more than a pre-set amount, though greater tolerances are allowed for observations made by using techniques assessed as likely to have larger errors. Secondly, a more stringent test is applied by comparing the observed values with values analysed, using all observations except the one being tested.

The corrections calculated by this method are assimilated directly into the forecast model by a method of repeated insertion over a short period of time preceding the observation time. At each time-stage the differences between the forecast and the observed values are multiplied by weights calculated in the way just described to provide values of the adjustments required at each grid point. However, to avoid sudden alterations to the forecast values, only a small fraction of the changes are added into the model as the forecast advances time-step by time-step towards the observation time. This is done because sudden local changes are found to generate spurious non-meteorological motions which rapidly disperse the effect of the alterations implied by the observations. In this way the model is steadily adjusted towards the observed state of the atmosphere and a natural balance is set up between the winds and other physical variables which correctly reflects the evolution in time of the weather systems. Realistic vertical velocity patterns are set up and the subsequent forecast continues on a realistic course. When this system was tested during FGGE it was found to give particularly accurate wind analyses, an aspect which in the current operational analysis and initialization procedure is often unsatisfactory. An example showing the detail that can be achieved by the assimilation technique is illustrated in Fig. 1 which portrays the analysed winds at 300 mb over the Indian Ocean on an occasion during the summer months of FGGE.

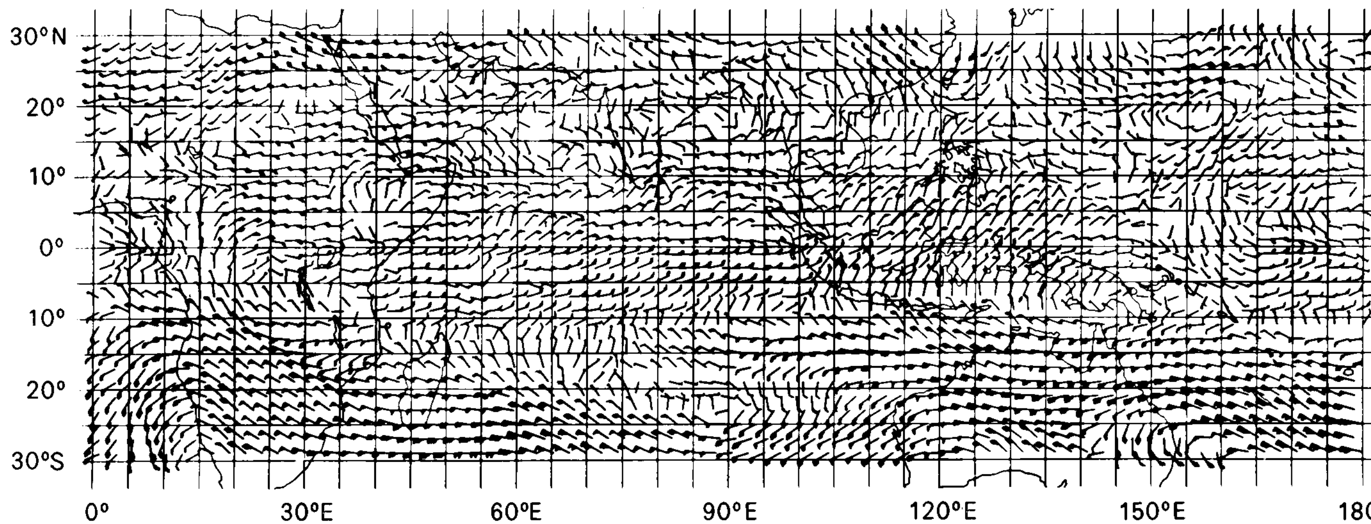

Figure 1. Wind analysis using the FGGE data-assimilation scheme at 300 mb for 12 GMT on 16 June 1979 in an equatorial zone east of the Greenwich meridian to 180° between latitudes 30°S and 30°N.

The next operational model

An operational forecasting system must be geared to strict deadlines determined by the needs of forecast offices. Advice has to be available quickly after the making of the observations, and the best possible advice is required for the main forecasts sent out in the early morning and in the late afternoon. To meet this requirement an acceptable schedule has evolved over the 15 years or so during which numerical forecasts have been used operationally in the Central Forecasting Office. It is based on two forecasting models, the first of which covers a limited geographical region and is run as soon as the observations from Europe and the Atlantic have been received; by this time some American observations are usually also available. Preliminary advice based on this model is presented to the forecaster within 3½ hours of the observing time. Before this, the whole sequence of operations to produce a forecast has to be gone through: this involves receiving, sorting and checking the observations; using them in an analysis scheme, with human intervention as necessary, to produce a representation of the three-dimensional state of the atmosphere at the time of the observations; adjusting the initial state to suit the forecasting model, and to be free of non-meteorological motions; integrating the forecast model for the required length of time; and, finally, obtaining the output quantities in their required formats, which involves drawing charts and the interpretation of model data to determine quantities which are not treated explicitly. It is a tight schedule, which can only be achieved consistently by ensuring that the computer programs and the personnel involved work efficiently with close attention to the deadlines and the alternative routes to be followed should any link in the chain of operations fail. A similar schedule is followed for the large-area model when observations from further afield have been received. In this case results are presented to the forecasters 4½ hours after the observing time.

With the new operational model and analysis schemes, the schedule, again based on two models, will be maintained essentially unaltered. However, the great power of the new CYBER 205 computer will enable many features to be introduced that have been identified by research over the past few years as contributing to improved forecasts; some of these have been described in previous sections.

As now, the large-area model will use a coarser mesh than the limited-area model, and the distinction between the two will remain, namely that the limited-area model aims to provide relatively short-range forecasts over the British Isles while the large-scale model produces forecasts up to several days ahead for a wider area and is used directly for aviation route forecasts. The new area for the large-area model will be the part of the globe north of 30°S, thus placing the southern boundary in a relatively quiet zone from a meteorological point of view. It has been demonstrated in the past that a boundary at or near the equator distorts the active circulation associated with the Intertropical Convergence Zone and the south-east Asian monsoon, and the errors soon spread to higher latitudes. The new area is sufficiently large to cover the major shipping and aircraft routes in the world, and will enable the increasing number of requests for forecasts for longer routes to be met. The limited area will be defined by lines of latitude and longitude (at present it is a rectangle on a polar stereographic map) and this will permit the eastern part of America to be included and its observations used in defining the initial state. It is hoped that this will lead to improved forecasts of the generation of depressions over the western Atlantic; they often move and deepen very quickly and soon affect weather conditions over much of the Atlantic.

The horizontal grid lengths of the two models will be made as small as is compatible with the forecasting schedules and the speed of the computer, since there is ample evidence that a smaller grid length will give more accurate forecasts. It is hoped that the large-area model will have a mesh length of about 150 km; for the limited-area model half or a third of this value is aimed for. The finer resolution will improve a number of features of the forecasts. Areas of rainfall will be more clearly defined, and amounts on average will be nearer those observed (average values now tend to be less than observed, for reasons that are broadly understood); jet streams and frontal systems will be delineated in greater detail; rates of deepening of depressions will, in general, be more accurate. In the vertical, the number of levels will be increased from 10 to 15, with greater concentrations in the boundary layer and near the usual jet-stream levels. As described above, the concentration in the boundary layer will enable the structure of the layer and surface exchanges to be represented more adequately and this should lead to improved forecasts at the earth's surface. Better definition at upper-tropospheric levels should lead to improvements in aircraft wind forecasts, and particularly in the probability of clear-air turbulence, as well as in more general forecasts up to several days ahead.

The models will use a terrain-following vertical co-ordinate rather than pressure as now. This will allow the effects of orography to be calculated more accurately and will dispense with the special mathematical conditions which, in the past, have had to be invoked whenever mountains were intersected by a pressure surface on which values of variables used by the model were specified. Better forecasts of orographic rainfall, and of conditions in mountainous regions generally, will be possible. The numerical technique used for solving the equations will be essentially the same as in the current operational model since it has been shown to be the most efficient (in terms of computer usage) that has yet been devised.

Tests of a version of the new model have already been carried out for several occasions. However, because of limitations in the computing time available before the new computer was delivered, the experimental version had a lower resolution and a smaller forecast area than are to be used in practice. Also, it has not yet been possible to test fully the combined system including the new data-assimilation technique to provide the initial data analyses. However, despite these limitations, it has become clear that the quality of the forecasts from the new model is distinctly better than from those currently available, particularly for three days or more ahead.

An example of a test forecast is illustrated in Figs 2–5. The initial data were for 12 GMT on 16 June 1980. During the subsequent three days the depression near Iceland moved away and became less active while the pair of small depressions near Newfoundland moved across the Atlantic and combined into a single intense depression which, by 12 GMT on 19 June, was situated north of Scotland (Figs 2 and 3). North-westerly surface winds of 40–45 knots were reported from several merchant ships sailing north of Ireland at this time. The three-day forecasts from the new model (Fig. 4) indicated this deep depression only slightly displaced from the observed position. Although the central pressure was slightly too shallow, the model correctly forecast strong north-westerly winds in about the right areas. The forecast produced by the current operational model (Fig. 5) moved the depression too far north to a position west of Iceland with a central pressure some 17 mb too high. As a result, the wind forecasts off the coasts of Scotland and Ireland were too weak. In general, it has been noted that the present operational model often forecasts insufficiently strong pressure gradients. The new model appears to offer the prospect of overcoming this defect.

The development of the Meteorological Office operational weather prediction system has been an evolutionary process over many years. In the early stages of numerical weather forecasting research the main problems were those of a mathematical nature. However, it is clear that the design and maintenance of a forecasting system with as wide a range of applications as is proposed for the new system depends heavily on a broadly based research program covering many different facets of meteorology. It is expected that the new operational weather forecasting system will produce more accurate forecasts than is at present possible and will extend the ability of the Meteorological Office to provide the service required by its customers, while the flexibility of its design will allow future improvements and modifications to be made to suit changing needs.

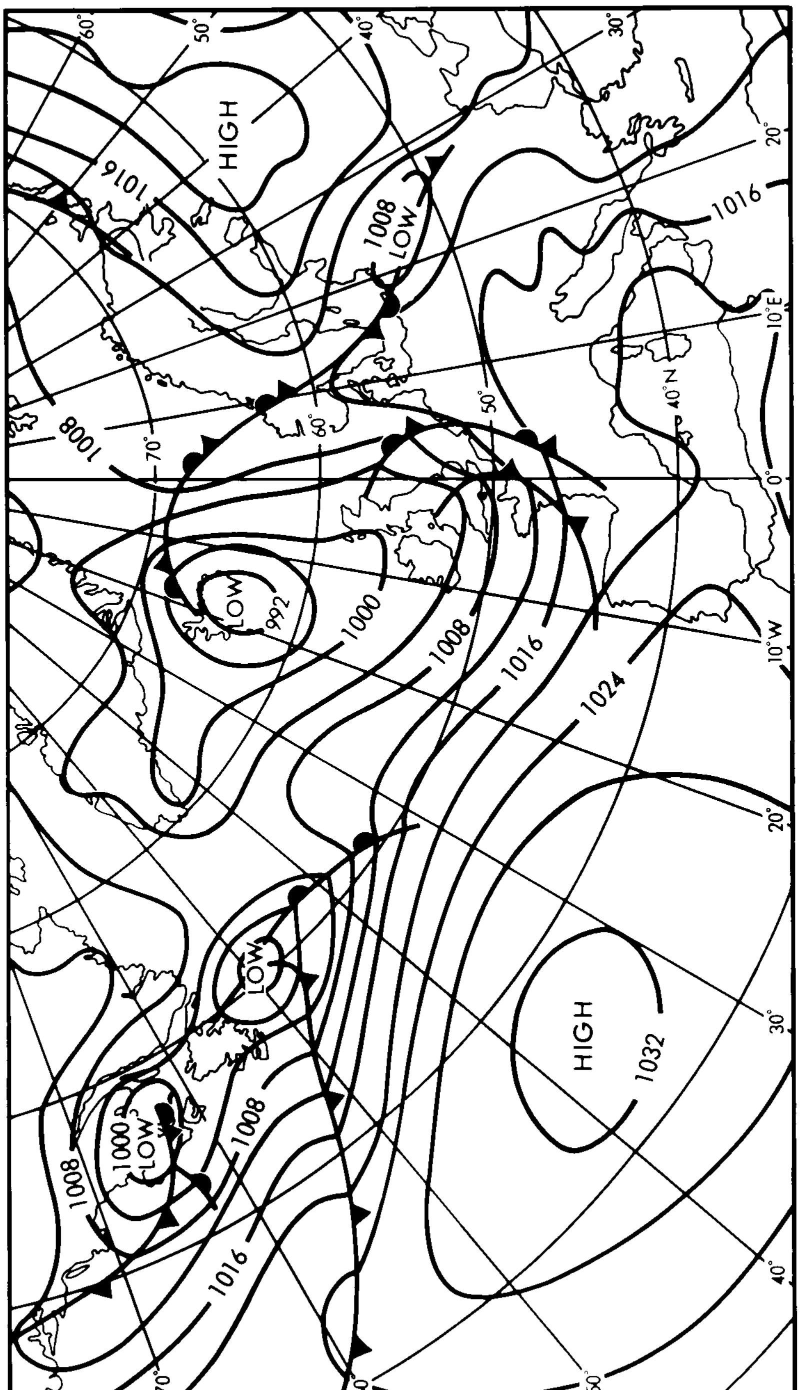

Figure 2. Synoptic chart for 12 GMT on **16 June 1980**, as analysed by hand at the Central Forecasting Office, Bracknell.

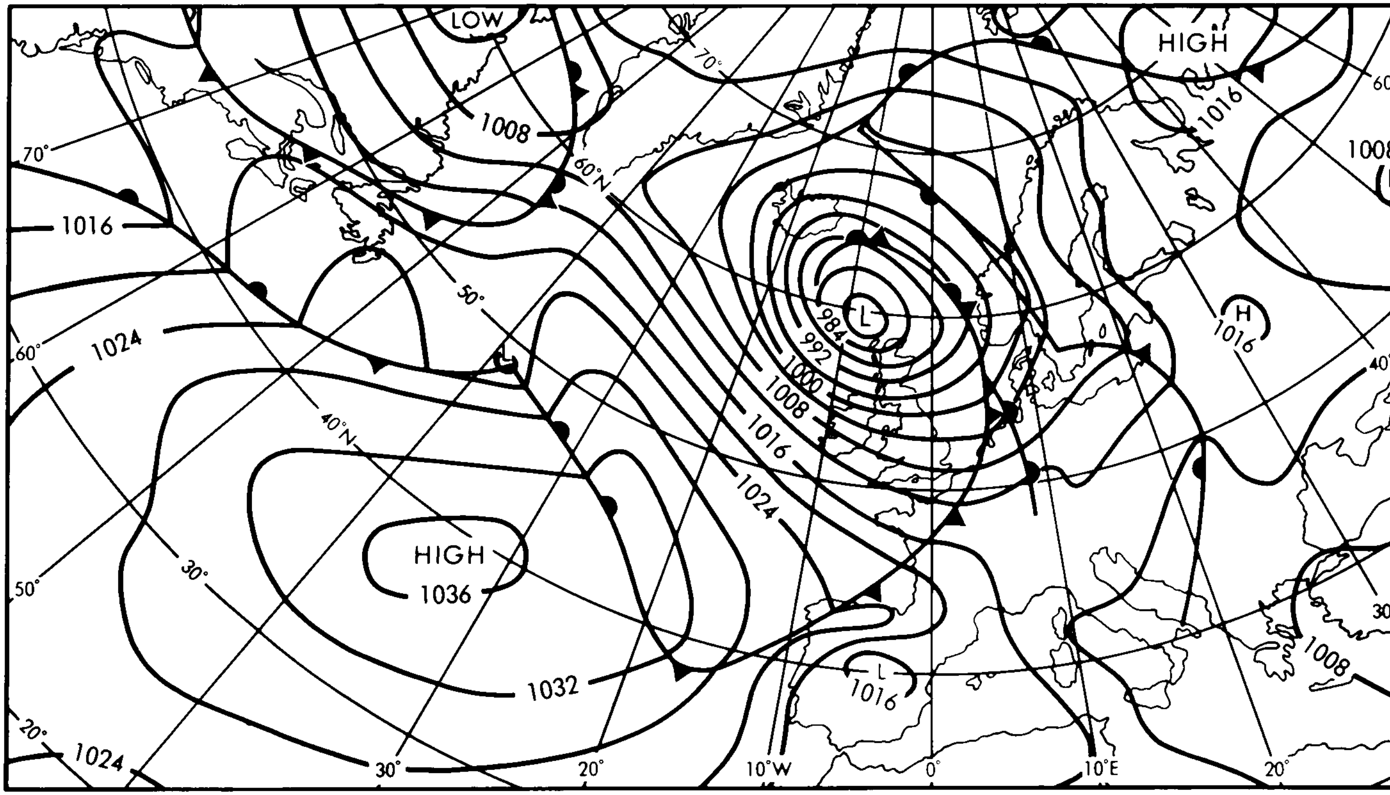

Figure 3. Synoptic chart for 12 GMT on 19 June 1980, as analysed by hand at the Central Forecasting Office, Bracknell.

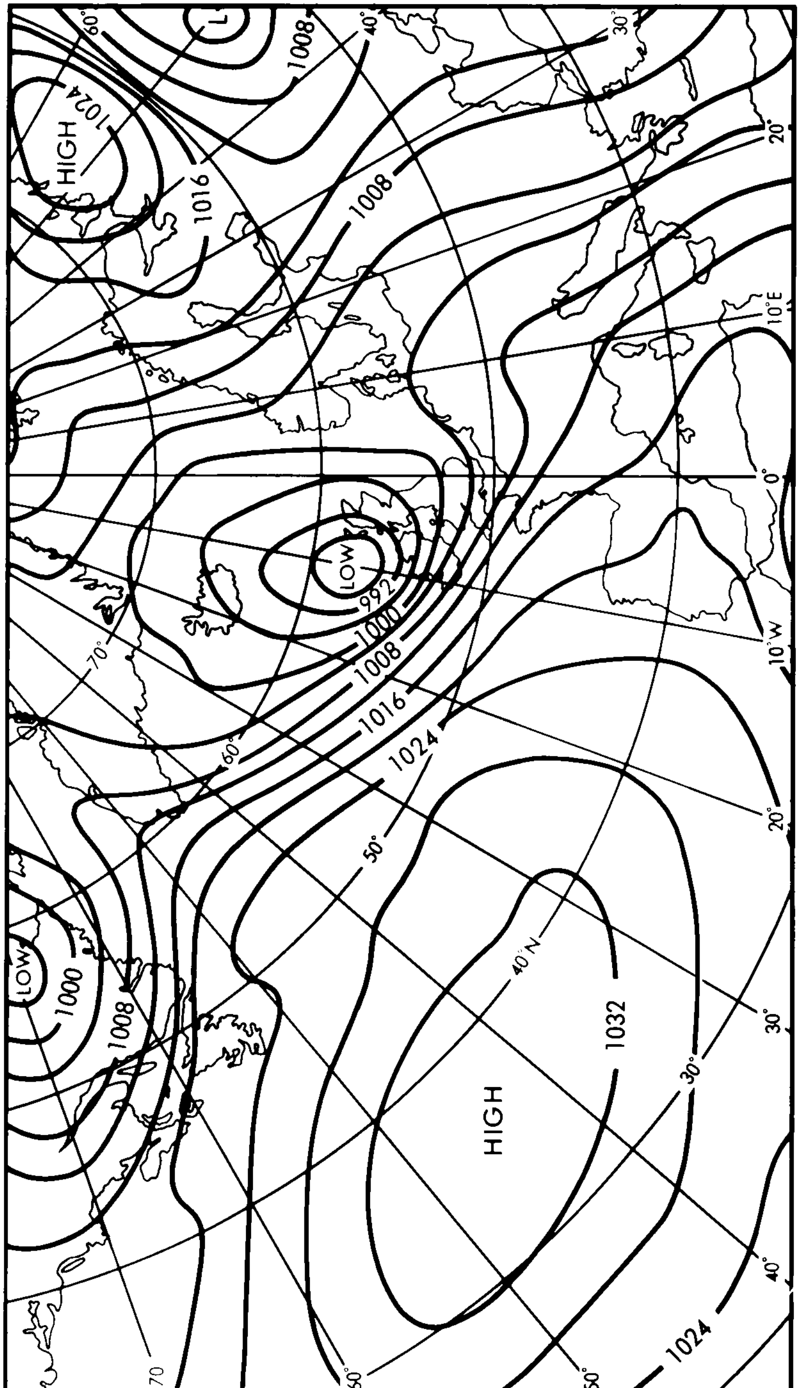

Figure 4. Surface pressure forecast for 72 hours after the data time (12 GMT on 16 June 1980) as produced by the new model.

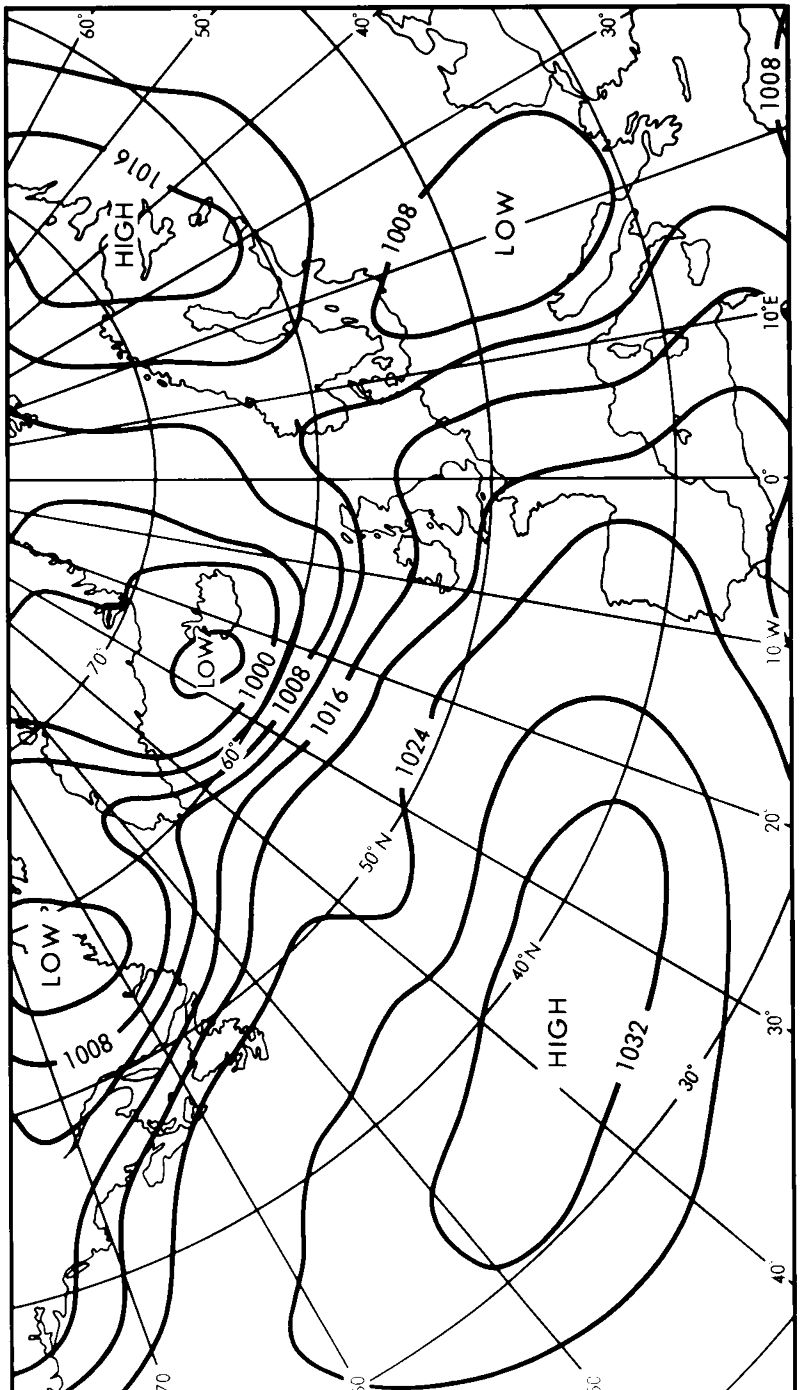

Figure 5. Surface pressure forecast for **72 hours after the data time (12 GMT on 16 June 1980) as produced by the current operational model.**

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The July lower troposphere over the Middle East

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Summary

Maps of July vector mean winds for six levels from 900 to 500 mb, also July mean wet-bulb potential temperatures and relative humidities at 850, 700 and 500 mb, have been prepared for the area 10–40°N, 30–75°E. In this paper the 850 mb winds and a vertical cross-section are depicted, and features of the flow such as the 'shamal' and the 'wind of 120 days' are discussed.

Great improvements have been made over the past decade in the network of upper-air stations in several countries in south-west Asia, notably Saudi Arabia, Iran and Afghanistan. In the years up to and during the Second World War, and for some time afterwards, the Meteorological Office maintained a network of pilot-balloon stations in this area in support of the Royal Air Force and the Army. Palestine, Iraq, the Persian Gulf and southern Arabia all had their stations, while Cyprus, Egypt and the Sudan to the west, and Pakistan and India to the east supported a relatively dense network. Eventually radiosonde stations were set up, those in the Arabian area being Habbaniya near Baghdad (1949-58), Bahrain (1956-70) and Aden (1956-66), also Masirah in Oman (1967-76).

Though several stations have now closed, the network of stations with data available is remarkably close for a desert area, only the Rub' al Khali in south-eastern Arabia and the Nafud desert of northern Arabia being devoid of data. This suggested the possibility of detailed climatological maps of the upper air in the Middle East, using the data in the Meteorological Office's Technical Archives and Archive of Machinable Data, also summaries published by the individual countries. For many stations monthly data are available, but the number of stations where manual averaging of daily values was necessary meant that detailed coverage could only be attempted for one month. July was chosen as being the standard summer month, and one when the Asian south-west monsoon is fully developed. In winter the flow over Arabia is stronger and mainly westerly, showing less interesting features. The levels 900, 850, 800, 700, 600 and 500 mb were analysed. Above the 500 mb level, pilot-balloon data were unreliable, and the flow was less affected by orography (except near the Himalayas).

The horizontal vector mean winds were evaluated and analysed using major streamlines and isotachs at $2\,m\,s^{-1}$ intervals. A simplified version of the 850 mb map is shown in Fig. 1. A vertical cross-section (Fig. 2) along 240°–060° through the northern Persian Gulf shows the mean wind component from 330° from 900 to 500 mb. For radiosonde stations, mean temperatures, dew-points, relative humidities and wet-bulb potential temperatures were charted at 850, 700 and 500 mb.

The main findings of the analysis are as follows:

(1) The shape of the 'shamal' north-westerlies over Iraq, Kuwait and the western Persian Gulf is seen to be a result of deflection of the airflow by the Zagros mountains of Iran. The core of the stream slopes westwards with height and is still evident in the mid-troposphere near Riyadh. At 600 mb there is a definite, though weak, south-easterly flow along the length of the Zagros mountains. Here the wet-bulb potential temperature is 20 °C compared with 18 °C in the 'shamal'.

(2) There is a marked northerly flow in western Afghanistan. Upper winds from Herat help to define this stream, with maximum mean wind 050° 12 m s^{-1} at 800 mb flowing through a gap in the mountain ranges. This mean wind appears to be anomalously veered from the general flow, possibly because of some orographic influence. This is the upper wind which must cause the 'wind of 120 days' in the Seistan depression. The flow is similar to the 'shamal' though on a rather smaller scale.

(3) Over southern Arabia, pilot-balloon winds and July 1980 radiosonde data for cloudy Salalah have been examined. Above the moist air at stratus and stratocumulus levels they show a strong inversion at about 850 mb and frequent north-north-westerly winds at about 600 mb, much further backed than the north-easterlies usually analysed. This is evidence for a summer mid-tropospheric mean trough over south-eastern Arabia.

(4) A considerable area of south-westerly flow is present at 700 and 600 mb over north-western Saudi Arabia and eastern Egypt.

(5) The low-level moist south-westerlies of the southern Sudan and the persistent north-westerlies in the southern Red Sea gradually change to north-easterlies at higher levels. More detail than usual is seen, but little new insight is gained into the exact three-dimensional boundary between the dry and moist air masses. The dry north-westerlies are bounded in the south by the strong winds of the south-west monsoon (Findlater 1971).

The detailed maps of vector mean winds at six levels and humidities at three levels, together with tables of the winds and steadiness (vector mean speed as a percentage of scalar mean wind) at each station, are given in Special Investigations Memorandum No. 111 (Grant 1982).

References

Findlater, J. 1971 Mean monthly airflow at low levels over the western Indian Ocean. *Geophys Mem, Meteorol Off*, No. 115.

Grant, K. 1982 Vector mean winds and humidities in the lower troposphere over Arabia and environs in July. Special Investigations Memorandum, *Meteorol Off*, No. 111, to be published.

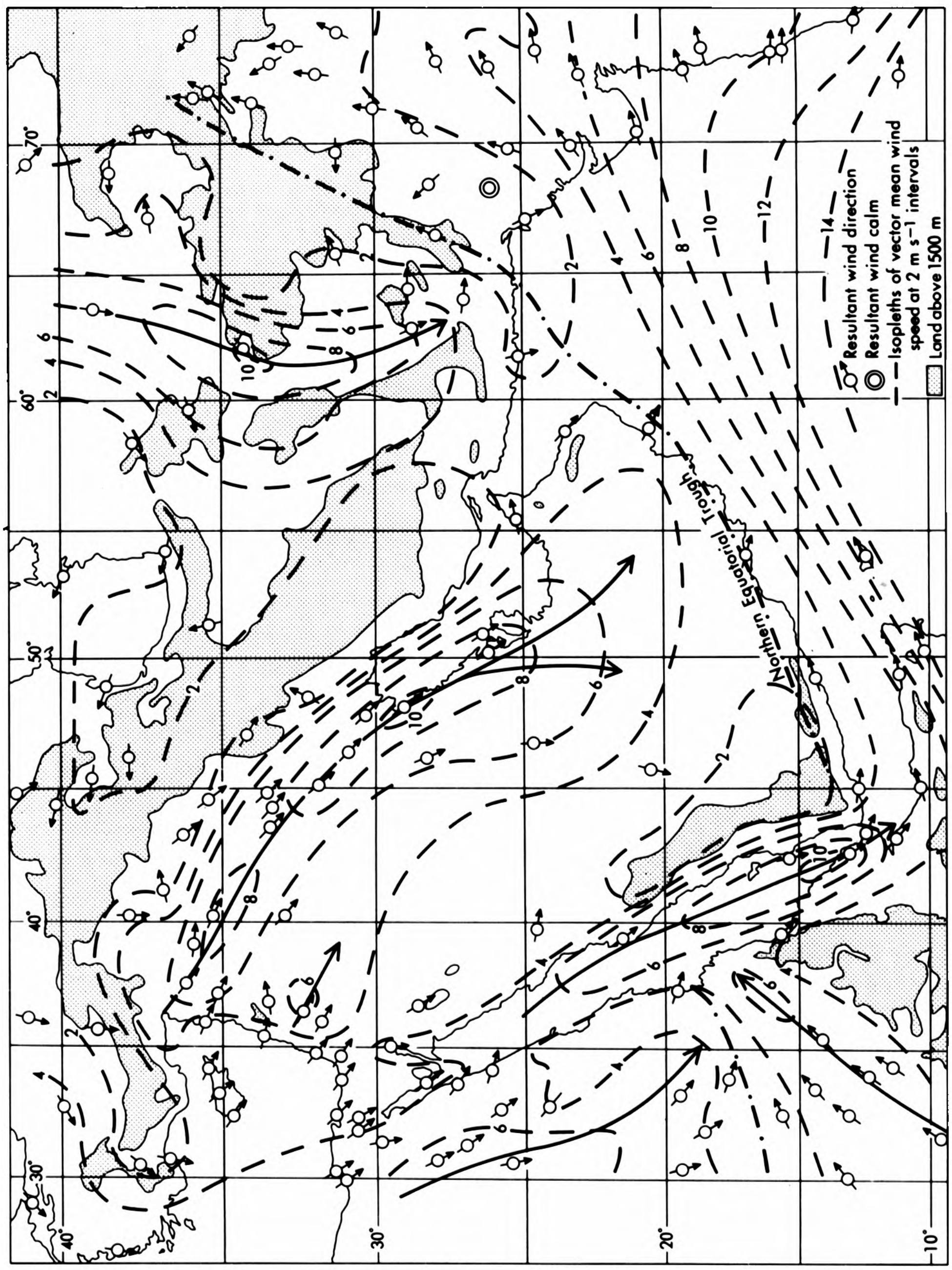

Figure 1. July mean monthly airflow at 850 mb.

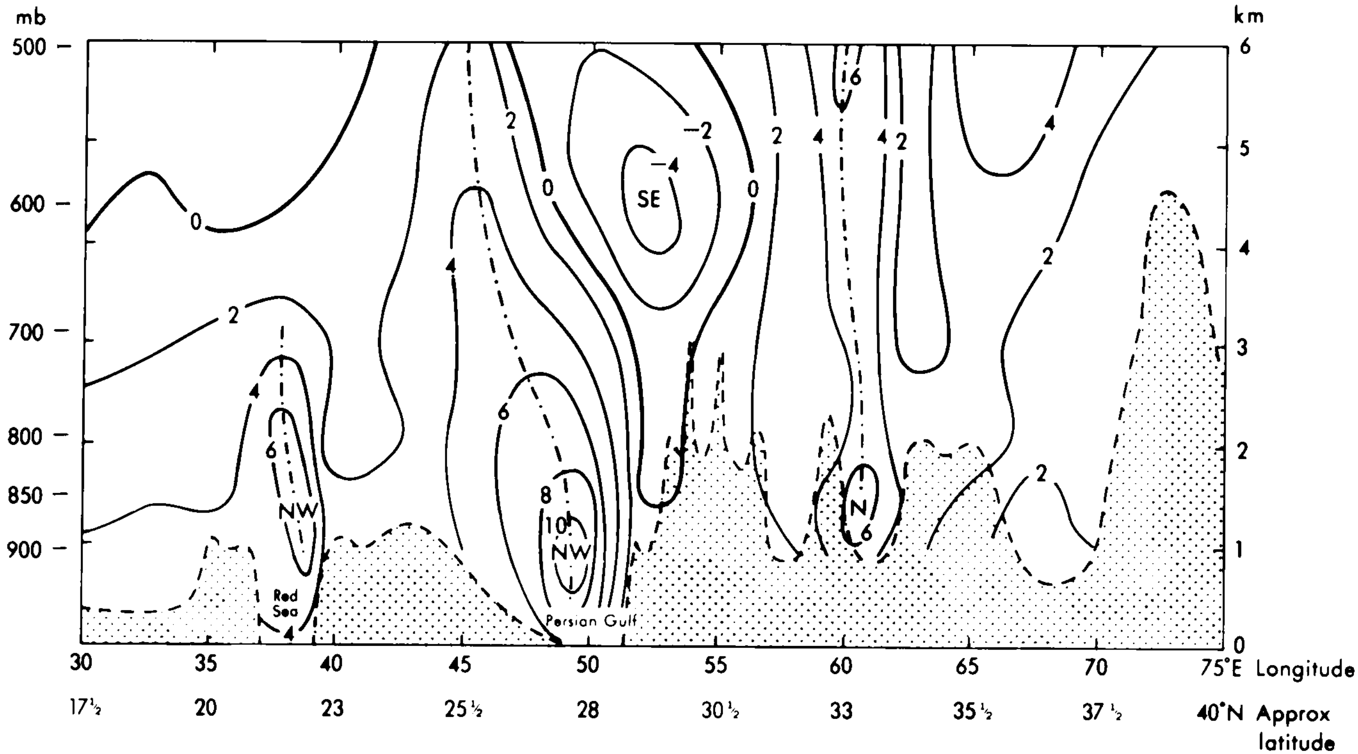

Figure 2. 240 – 060° cross-section through the northern Persian Gulf showing mean July wind component from 330° (m s^{-1}). The land surface is shown schematically.

551.574.42

The curious case of the horizontal icicles

By S. D. Burt

(Meteorological Office, Bracknell)

The two photographs here reproduced (Figs 1 and 2) illustrate a fairly unusual meteorological phenomenon: horizontal icicles. They were taken from the first floor of the Meteorological Office Headquarters building at about 1115 GMT on Friday 8 January 1982. Along with many other parts of England and Wales, Bracknell had suffered from a night and morning of fine, powdery snow (falling at a temperature of between −2 and −3 °C), whipped by a fresh to strong easterly wind into huge drifts. Upon

Figure 1. Horizontal and vertical icicle in close proximity.

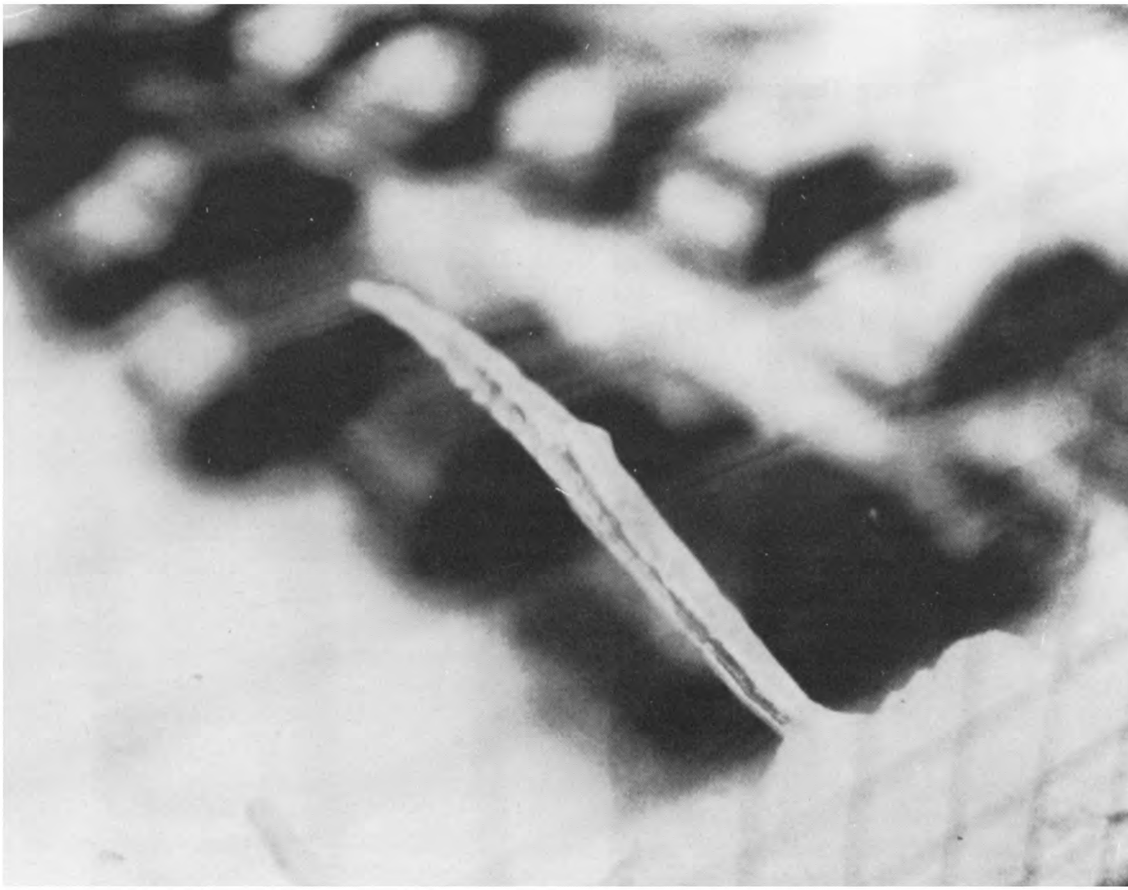

Figure 2. Close-up of horizontal icicle shown in Fig. 1.

contact with the relatively warm surface of the (single-glazed) windows of the building the snow melted briefly into pools of liquid water which then froze rapidly in the harsh ambient conditions into a series of impressive icicles. Most of these were vertical, or nearly so, but in a surprising number of places, on the north and east side of the building, the eddying of the wind obviously favoured sufficiently stable 'updraughts' to permit the anomalous horizontal growth. The icicle shown in Fig. 1, and close-up through the window upon whose sill it had formed in Fig. 2, was 11–12 cm long, the largest of a good many horizontal icicles observed that morning, and is all the more remarkable for existing within a short distance of 'normal' icicles also visible in Fig. 1.

Acknowledgements

I am grateful to Mr F. Singleton and his staff in the Climatological Services Branch for drawing my attention to the icicle that morning.

551.501.9

Synoptic reports from the Isles of Scilly

By C. S. Broomfield

(Meteorological Office, Bracknell)

The closure of the auxiliary reporting station Scilly/St Mary's (03804) on 1 January 1982 brought to an end a series of synoptic reports covering 111 years.

A telegraphic reporting station was established on St Mary's on 1 January 1871. Mr W. Thomas, a signalman, was the observer and he reported twice a day. The reports were included in the Daily Weather Chart which was first issued in 1872. A third daily observation was added to the program in 1878. During the early years there were numerous breaks in the cable to the mainland; some of these were not repaired for several months.

A small Robinson anemograph was installed about 1881. The pillar on which the anemograph was placed rocked in gales so that the pendulum struck the wall of the case and stopped the clock. Wooden stays were fitted (see Fig 1) and a portion of the iron case filed away to give clearance. The observer asked for a shelter to attend to the anemograph in gales and rain but this was refused as it was thought it would seriously affect the air flow.

The station's data were included in the Monthly Weather Report from 1884. Mr Thomas died in 1890 and Mr A. Hicks, a Lloyds signalman, was appointed observer. In that year arrangements were made for the 8 am and 2 pm observations to be displayed, together with those of 5 other coastal stations, on a board outside the Office at 63 Victoria Street, London.

The Revd W. C. Ley, who inspected the station regularly, commented after his visits in 1890 and 1891 that Mr Hicks was probably the only person on St Mary's who could undertake the work so well.

Mr R. H. Curtis visited the station in 1895 and found the Robinson anemograph working well. He took it entirely to pieces, cleaned and reassembled it, and erected a Dines pressure tube anemograph by the side of the Robinson (see Fig 1). The Dines vane was on a stayed mast 32 feet 6 inches (10 m) above ground.

In 1898 the site of the thermometer screen and anemometers, which was at Garrison Hill, was taken over by the War Office, and the Meteorological Council was charged five shillings (25p) per year site rental. The instruments were resited in 1901. (See Fig. 2.)

Following the retirement of Mr Hicks in 1910 the observing routine was taken over by the coastguards at Lloyds Signal Station.

In 1926 the station moved to Telegraph. A Dines pressure tube anemograph was erected on top of the coastguard lookout tower, access to which was by a number of vertical iron ladders inside the brick tower. The vane was 20 metres above ground. Overlap readings continued at Garrison Hill. The equipment at Garrison Hill was eventually dismantled by the Meteorological Office, with the help of a local man at one shilling (5p) per hour, and the site given up in 1931.

The first inspection during World War II was made in March 1942, by which time hourly reports were being made and cloud-base balloon equipment had been supplied. A new Dines mast which was installed in 1943 caused so many leaks in the roof that it was impossible to use the instrument in wet weather. Lightning struck the building in 1947 throwing the duty coastguard off his chair; a lightning conductor was immediately requested for the Dines mast.

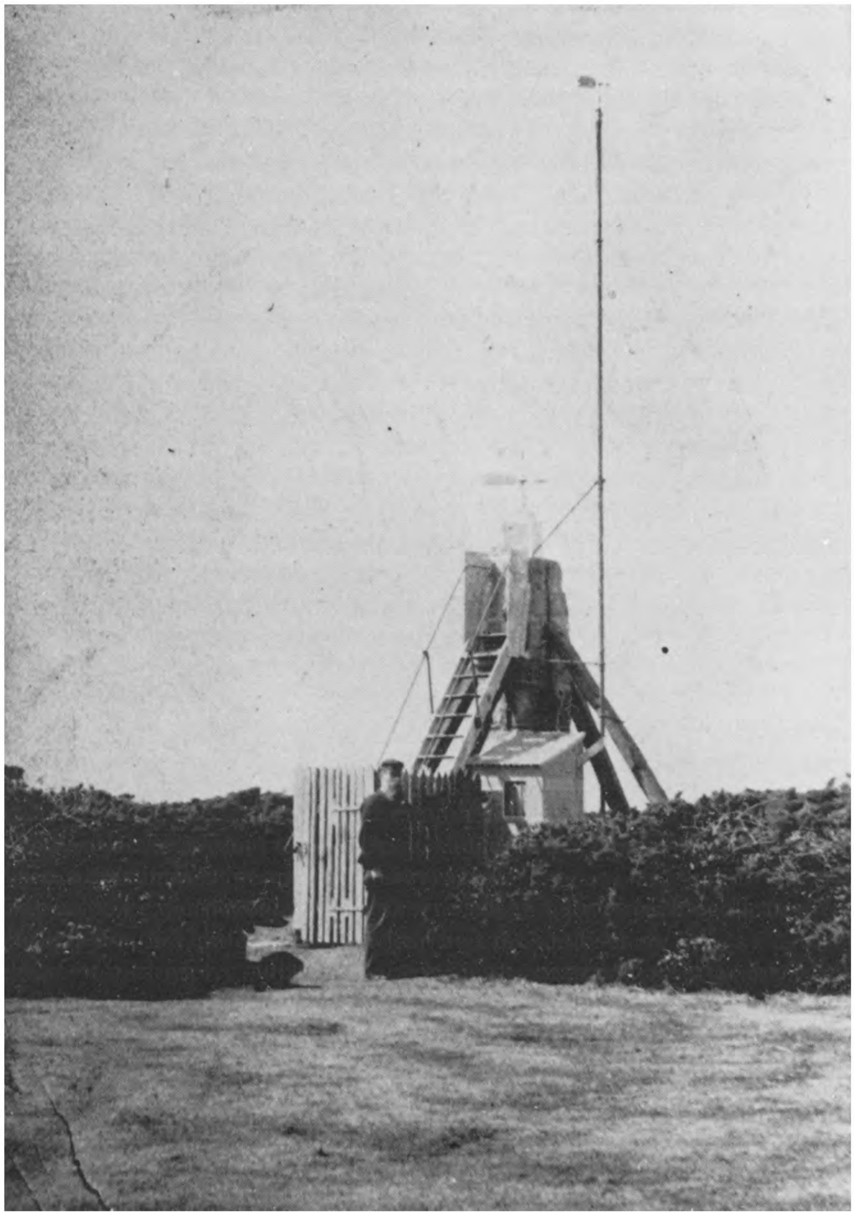

Figure 1. Early site at Garrison Hill.

A cloud searchlight was installed in 1957; siting difficulties restricted the base line to only 399 feet—probably the shortest in the country. The site was used until the station closed.

Temperatures were added to each hourly report from 1958. The coastguards were unable to leave the look-out to visit the screen every hour, so a small screen with dry- and wet-bulb thermometers was fixed to the parapet of the tower (see Fig. 3). This was used at other than main and intermediate synoptic hours.

In January 1962 flying debris damaged the wind vane in gusts of up to 90 miles per hour, in the gales of January 1969 the alidade was torn from its mounting, and the parapet screen and thermometers were smashed when gales blew the screen from its mounting in February 1972.

In September 1976 the parapet thermometers were replaced by electrical resistance sensors in the enclosure screen. The observers had previously noted differences on occasion of over 2 °C between the readings from the parapet screen and the screen in the enclosure.

With the installation of remote surveillance equipment, monitored at HM Coastguard centre at Falmouth, there was no longer a need for continuous manual watch at St Mary's and from 1 January 1982 the station was manned only during an emergency or in a special situation. The opportunity to obtain regular weather observations was therefore lost.

With the kind permission of Trinity House the Keepers at Round Island Lighthouse (03802 49°59′N 6° 19′W) (Fig. 4), at short notice, afforded their co-operation by supplying eight reports a day. The Meteorological Office has initiated the installation of an automatic weather station on St Mary's. Abbreviated reports from the Air Traffic Controller at St Mary's Airport (03801) are also broadcast when available.

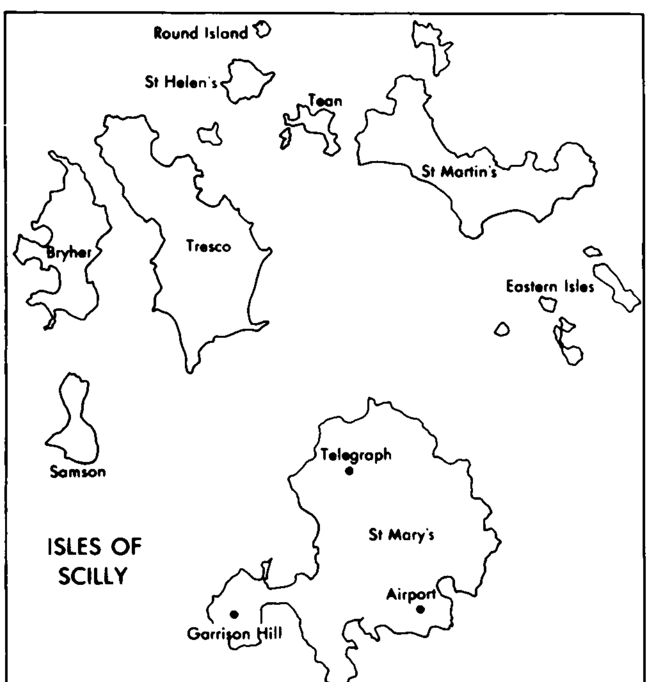

Figure 2. Map showing location of places mentioned in the text.

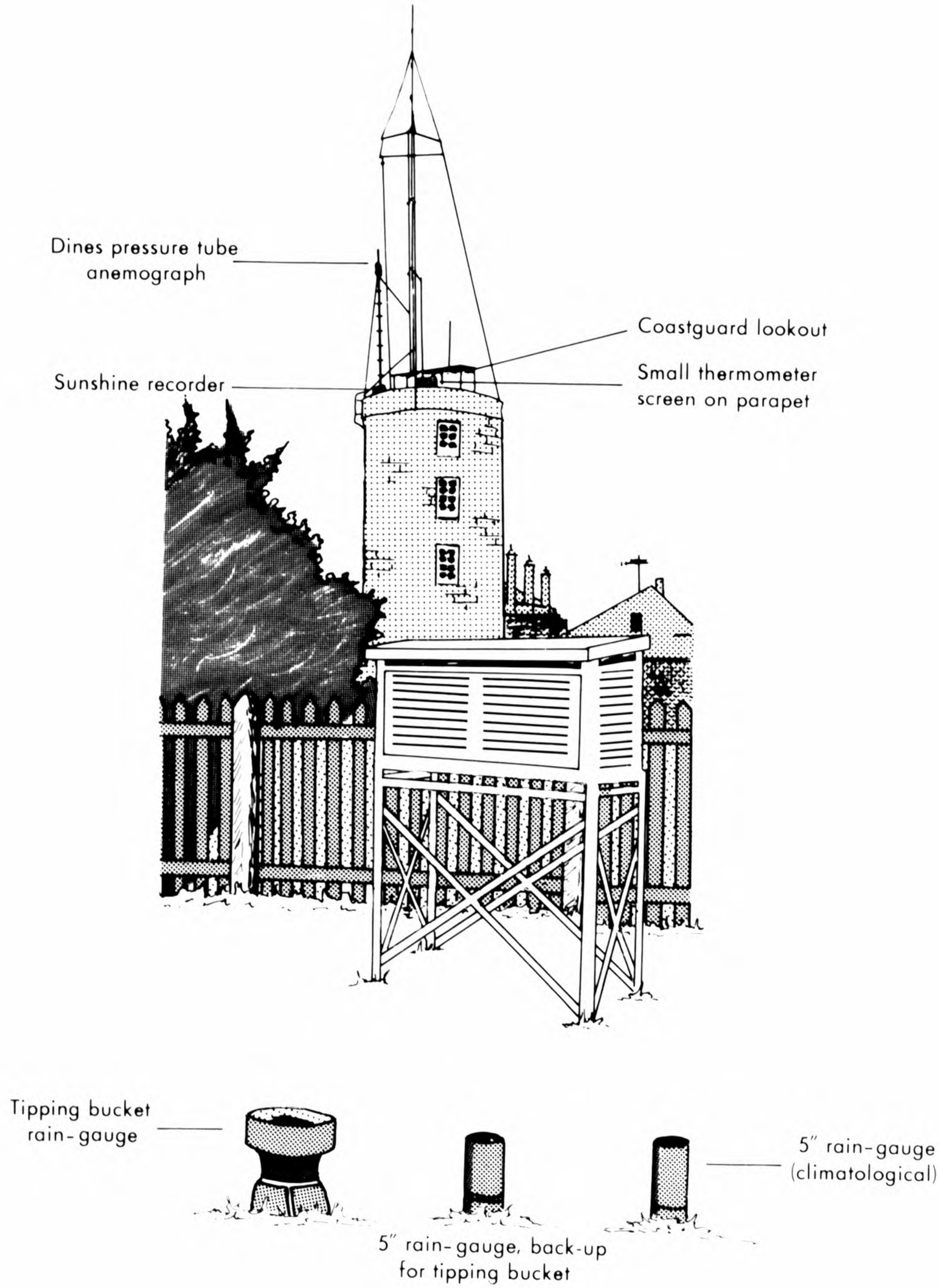

Figure 3. Pen and ink sketch of site at Telegraph.

Figure 4. Round Island Lighthouse from the north-east.

Addendum

After the above article was submitted Scilly/St Mary's was reopened temporarily by the Directorate of Naval Oceanography and Meteorology on 20 March 1982.

100 years ago

The following extract is taken from *Symons's Monthly Meteorological Magazine*, July 1882, 17, 81.

RESUMPTION OF THE BEN NEVIS METEOROLOGICAL OBSERVATIONS, 1882.

By Clement L. Wragge, F.R.G.S., F.M.S.

Under the auspices of the Scottish Meteorological Society.

May 25th.—Arrived at Fort William from Edinburgh.

May 26th.—Engaged making arrangements for workmen, &c. In evening erected Stevenson's thermometer screen, at Achintore, in the same field as last year, by the Loch beach, and about 28 ft above the sea.

Subsequently hung the low level barometer, a fine Board of Trade by Adie, London, its greatest error being but 0.003 in., and compared with it the mercurial barometer that is to be used at a new fixed and fully equipped station I had arranged with the Scottish Meteorological Society to establish at the Lake (1840 ft.)

May 27th.—Started off four men and a mason betimes for the Lake. I followed, accompanied by Mr. Livingston of Public Schools, Fort William, and Mr. J. B. Simpson of Edinburgh University. Away nine hours, and engaged with the men building a cairn for the barometer near the water's edge, 1,840 ft. above sea. Had great trouble in getting the stone, collected granite from the quagmire adjacent and the water's side, where it lies and "crops up" in some quantity. Had to battle with pitiless hail squalls and heavy weather in the afternoon; men could not make rapid progress, and cairn not completed, by some 4 ft. However, fixed the box to contain the barometer inside.

May 28th.—Sunday's rest—engaged, however, examining instruments, and fixing those at Achintore, Fort William.

May 29th.—A heavy day's work. Men left Fort William at 7 a.m., returning about 9 p.m. Two men and mason engaged at the Lake, I superintending. The barometer cairn there finished, and the Stevenson's thermometer screen fixed. These are situated by the edge of the tarn, at the N.E. end. Twelve men and joiner engaged on summit of Ben Nevis, I superintending there in afternoon. Snow covered the entire plateau of the summit to a depth of from 3 to 5 ft. Engaged "digging out" the barometer cairn, which was surrounded by snow 3 ft. 6 in. deep, thermometer cage and hut, and in excavating an area, 18 ft. in diameter, where another thermometer screen was fixed (some ten paces E. from the other). This is to contain a self-recording hygrometer, acting by clockwork, to record the temperature of the air, and that of evaporation at 9 p.m. on the Ben. Messrs. Negretti and Zambra are the makers of this invaluable apparatus, and have most kindly placed it at my disposal, for use on Ben Nevis. The snow walls of this area averaged 3½ ft. high, and presented a most singular appearance. It will be remembered that the barometer was securely built-up last October in its cairn. Great labour was expended to-day, before the north side of the cairn was reopened; the stones were so hard frozen that a crowbar had to be used to remove them. To my delight, I found the instrument in excellent order—nothing the worse for its winter's "rest." Snow had deeply accumulated inside thermometer cage. The reading of the minimum thermometer that has been on the Ben all winter was 11·0, and this occurred since January, when Mr. Livingston, of the Public Schools, Fort William, made an ascent.

May 30th.—Engaged at Achintore Observatory on sundry matters—sowing grass-seed around thermometer box, and placing post for new solar radiation thermometer.

May 31st.—A most important day. Fixed all the instruments for the commencement of my work on the morrow. Up at 5 a.m.: examined the thermometers, to ascertain their index errors; then packed up those for the new "Lake" station and Ben Nevis. Set out at 8 a.m., I carrying barometer for the Lake, accompanied by Mr. Mackenzie, of the Inland Revenue, Fort William, and Mr. J. B. Simpson, Edinburgh University, carrying the thermometers. The Lake Observatory, fully equipped by 3 p.m., and barometer safely hanging in its cairn; then set out for the Ben. By 8.15 p.m. all instruments were fixed in position on the summit of Ben Nevis, including Negretti and Zambra's clockwork hygrometer, and a new tarpaulin was placed over the hut. Arrived at Achintore, Fort William, about 11 p.m.; afterwards re-fixed instruments at the sea level station, and being satisfied that all was correct got to bed about 1 a.m., very tired. Up again by 5 a.m., June 1st, and commenced work, taking observations on the outward and homeward journeys, and five sets of readings on Ben Nevis.

The work this year is much heavier than that of last season, and the following is the plan that has hitherto been, is being, and will be, adhered to till the end of the season:—Outward to Ben Nevis (fixed stations), observations at Achintore, Fort William, are taken at 5 a.m.; on the Peat Moss, about 30 ft. above sea, and two miles N.N.E. from Fort William at 5.30; at "The Boulder," about 840 ft. above sea, 6.15 a.m.; at the new fully-equipped observatory at "The Lake," 1,840 ft., at 7 a.m. (Here are barometer, and dry and wet bulbs, maximum and minimum thermometers in cairn and Stevenson's screen respectively; rain gauge; tubes for earth temperature and ozone tests); at Brown's Well, about 2,200 ft., at 7.30; at the Red Burn Crossing, about 2,700 ft., at 7.55 to 8 a.m.; and at Buchan's Well, about 3,575 ft., at 8.30. On the summit of Ben Nevis, 4,406 ft., the observations are taken at 9, 9.30, 10, 10.30, and 11 a.m.; and consist of atmospheric pressure, by mercurial standard and aneroid barometers, temperature and extremes of ditto, hygrometrical conditions, ozone, rainfall, solar and terrestrial radiation, wind, force, cloud, amount of ditto, movements of the various strata, hydrometeors, &c., and temperature of "Wragge's Well," about 25 ft. from summit: Negretti & Zambra's clockwork hygrometer, registers at 9 p.m.

From June 15th ozone observations are taken half-hourly, and three more rain gauges will be examined at 9 a.m. at different points, from the centre of the plateau to the precipice, to ascertain if, and to what extent, the rainfall varies with different winds. Dr. Angus Smith, F.R.S., of Manchester, has kindly undertaken to supply apparatus for the measurement of the actinism of the sun's rays and of daylight. Browning's Rainband spectroscope is also used.

Homewards from Ben Nevis, the observations are at Buchan's Well at 11.30, at the Red Burn Crossing at noon, at Brown's Well at 0.30, at "The Lake" at 1, at "The Boulder" at 1.45, on the Peat Moss at 2.30, and at Fort William at 3 p.m.

At all intermediate stations a "travelling" hygrometer is used (dry and wet bulbs), and the observations consist of pressure by aneroid, temperature of air (of Lake), wells, and burns, moisture, wind, force, cloud and amount, &c.

Simultaneous observations are taken in direct connection with the foregoing at the low-level observatory at Achintore, Fort William, about 28 ft. above sea, and the hours of observation there are 5 a.m., 5.30, 6.15, 7, 7.30, 8, 8.30, 9, 9.30, 10, 10.30, 11, 11.30, and noon, also 0.30 p.m., 1, 1.45, 2.30, 3, and at 6 and 9 p.m., and the elements of observation are precisely the same. Lest reading half-hourly at the low-level station should, by the heat of the observer's person, cause vitiation of readings of the self-registering thermometers, these instruments have been placed at 30 ft. distant from the hygrometer and other thermometer screen, in a new special screen. I am fortunate in having an able assistant, whom I have myself trained, and who relieves me when occasion requires in the ascent of Ben Nevis, and who takes the low-level observations. Mr. J. B. Simpson has also assisted, and my best thanks are due to him. I have also other assistants in training, so that any emergency may be met. The work is very heavy, but well under control, and punctuality and method will carry it through. The weather during the last few days on the Ben has been bitterly cold, and much new snow has fallen. The barometer cairn and thermometer cages on the 15th instant, were entirely frozen up, and great difficulty was experienced in opening them. A supply of fuel is very necessary, for one's hands get so dead with the cold that writing and handling keys, instruments, &c., are difficult matters—hence the necessity for an observatory house. Temperature has been between 23° and 30°, with biting N.E. winds, and maximum below 32° Fah.

One of the greatest difficulties I have to contend with is the getting the horse (on which I ride to and from the Lake) over the ruts and swamps. The latter are so very treacherous and deep, that the poor animal has a trying time of it. By keeping the work well in hand, I can keep time punctually at the intermediate stations, and so secure the simultaneous, or nearly simultaneous, observations, that I trust will be of the greatest value. The hardest climb is from Buchan's Well to the summit in the half-hour. Earth temperature will be added to the observations on July 1st, and systematic observations of the rainband by Browning's spectroscope will be by then an important feature in the work. CLEMENT L. WRAGGE. *Fort William, N.B., June 16th*, 1882.

P.S. The great value of the intermediate observations is, that they enable disturbances in the varied stratum of atmosphere between Ben Nevis and Fort William to be localised and examined in discussion. We hope largely to increase the value of forecasts.

SUBSEQUENT NOTE. *July 1st*, 1882.

Stevenson's screens, somewhat smaller than the usual size, are now fixed at all intermediate stations (from July 1st) between Fort William and Ben Nevis (at the Lake the large "Stevenson" is used), and in these are exposed neat and small "sling" thermometers with small bulbs fitted as "dry" and "wet." The labour of swinging is thus done away with, punctuality ensured, and accuracy also. The entire observing system goes like clockwork.

There are now 4 rain gauges, 15 paces apart on the plateau of the summit of Ben Nevis, read daily 9 a.m.—*viz.*, A in centre of plateau, D on edge of great precipice, and B and C intermediate. There is a gauge at the Lake 1840 ft. (also on Peat Moss at base of mountain) read weekly; and gauge at Achintore, Fort William, read 9 a.m. 9 p.m.

CLEMENT L. WRAGGE.

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No. 1320 July 1982 Vol. 111

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551.583.1

Large-scale interannual variability of climate

By D. E. Parker

(Meteorological Office, Bracknell)

Summary

Climate is discussed in terms of research into its interannual variability on large spatial scales. Some of the statistical properties of this variability are presented. Several examples of hemispheric-scale fluctuations are used to elucidate the physical mechanisms at work.

1. Introduction

Variability is an essential feature of climate. To regard the normal alone as an adequate expression of climate would be a serious error; it is better to regard current climate as the entire ensemble of recently observed atmospheric conditions. The possibility that the climate itself changes on time-scales of decades or longer will be discussed in other papers: the present paper is mainly concerned with atmospheric variations on time-scales of one to five years. Such variations may be regarded as expressions of the existing climate, rather than as changes of climate: there is, of course, no real dividing line between interannual fluctuations and climatic change.

Most of the research into large-scale interannual variability in the atmosphere has, until recently, been of an empirical nature, not only because of the need to establish the facts before setting up hypotheses and models, but also because of the difficulty in formulating relatively simple working hypotheses which not only fit the facts but also represent realistically the complex physics and dynamics of the atmosphere and ocean. A further limitation has been the impossibility of integrating complex numerical models through simulations of many years. This account will begin empirically by illustrating the magnitude of interannual variability, the statistical distributions to which it appears to conform, and the degree of regularity of the variability in time and space; but then an attempt will be made to examine the underlying causes of interannual variations, in the context of the tropical stratospheric quasi-biennial oscillation and of the large-scale tropical fluctuations known as the Southern Oscillation.

2. Illustrations of interannual variability

Variability of climate in terms of temperature and rainfall is a natural consequence of variability of the atmospheric circulation, which will therefore be the main subject of this section.

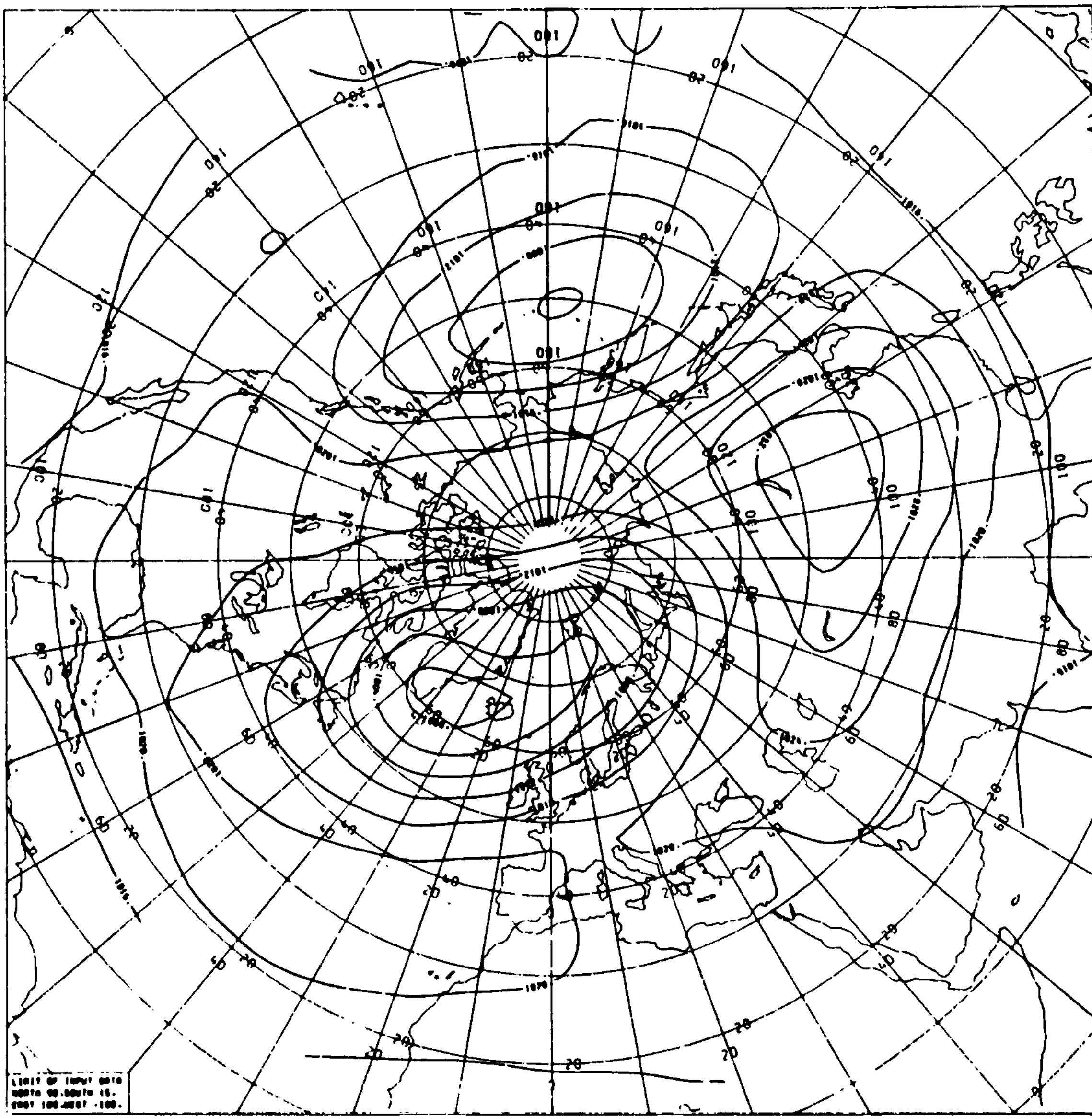

Figure 1(a). Normals of monthly mean pressure (mb) at mean sea level (MSL) for January. Data for 1900–80.

(a) *The magnitude of climatic variability*

The magnitude of the variability inherent in the atmospheric circulation is illustrated by Figs 1(a) and 1(b) which show the normal January mean-sea-level pressure pattern and the standard deviation of individual January averages. It is clear, from a comparison of the normal pressure gradients with the standard deviations, that the variability is sufficient occasionally to reverse major features, such as the mid-latitude westerlies in the Atlantic, for whole months. The maxima of variability are near the

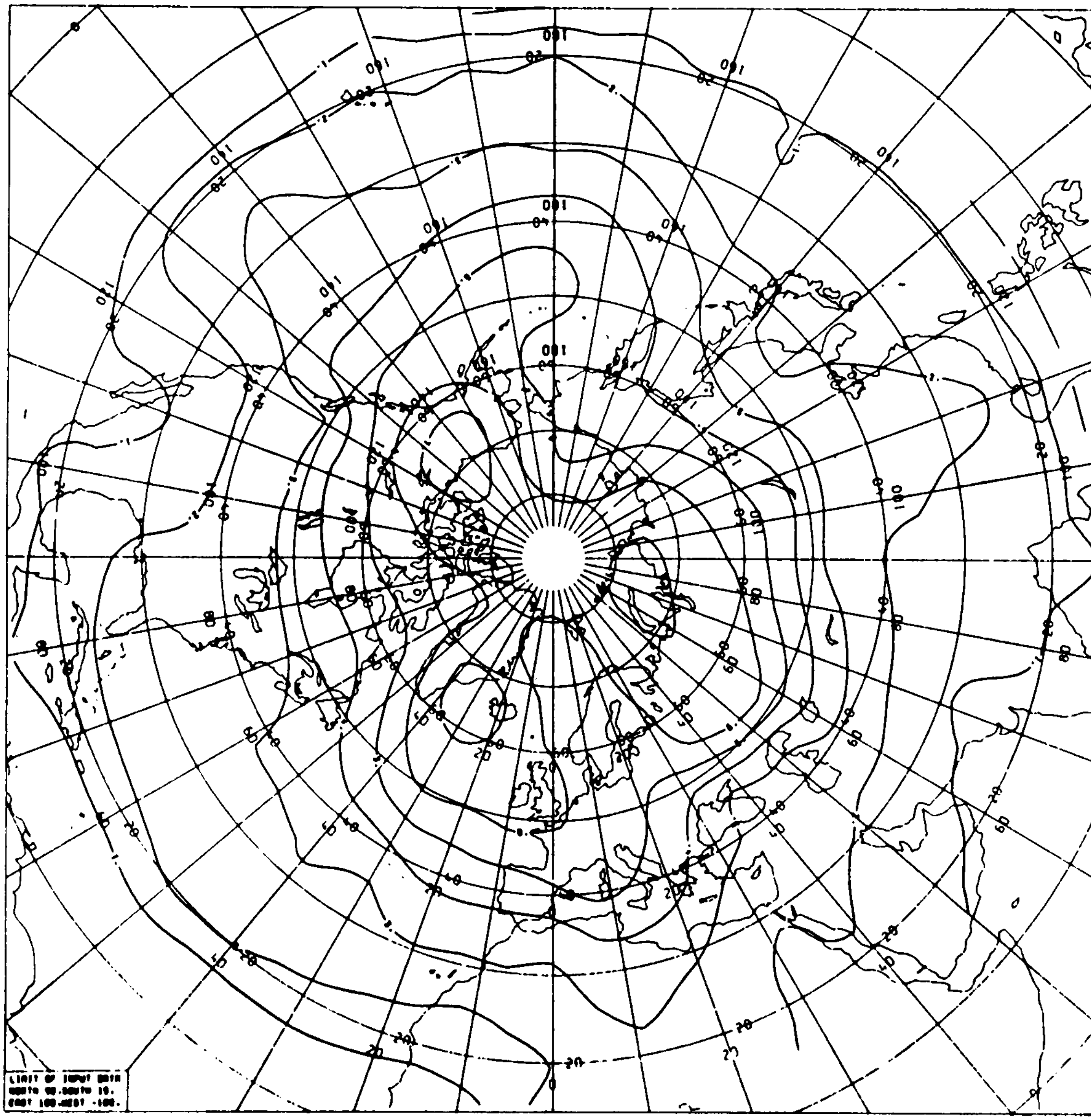

Figure 1(b). Standard deviations of monthly mean pressure at MSL (mb) for January. Data for 1900 80.

subpolar lows and have been found to be related not only to statistical scatter in the depths of individual depressions, but also to variability on time-scales of weeks, associated with the occurrence of major interruptions of the mid-latitude westerlies, i.e. blocking. The magnitude of the interannual variability of circulation is exemplified by the fact that the northern hemisphere atmospheric annual mean angular momentum varies by up to 25% (Rosen *et al.* 1976).

Circulation variability entails variability in cloud cover, resulting in variability in the earth's long-wave radiation budget as documented by Heddinghaus and Krueger (1981). The effects of circulation variability on local temperature and rainfall are a complex function of the earth's geography and will not be discussed here.

An important component of climatic variability is in the sea surface temperature. Figs 2(a) and 2(b) show the February normal of sea surface temperature and the standard deviation of individual February averages. In this case the variability is generally insufficient to reverse the north–south temperature gradient. However, the variability of sea surface temperature in some low-latitude regions, such as the tropical east Atlantic (Rowntree 1976) and the equatorial east Pacific (Bjerknes 1966, 1969), appears to be physically linked to the atmospheric variability, both locally and far afield. The equatorial east Pacific is discussed below in the context of the Southern Oscillation. The importance of the mid-latitude North Pacific has also been stressed (e.g. Namias 1978).

Attempts to simulate atmospheric variability with three-dimensional dynamical models have hitherto been thwarted by the computational difficulty and expense of including an ocean which interacts realistically with the atmosphere. However, in contrast to the above-mentioned results on sea surface temperature, Manabe and Hahn (1981) found that omission of interannual sea surface temperature variability from their general circulation model resulted in an underestimation of atmospheric variability only in the tropics, where the oceanic aspects of the Southern Oscillation could not be represented.

(b) *The statistical distribution of climate*

The possibility that uninterrupted westerly flow, and blocked flow, mentioned above, are two alternative equilibrium states for the mid-latitude atmosphere (cf. Charney and DeVore 1979), is suggested by the discovery that some measures of the circulation show skewness or even bimodality in their frequency distribution. The example in Fig. 3, Azores minus Iceland mean-sea-level pressure for winter months, is skew and slightly bimodal. The bimodality was found to be greater in periods when blocking was more frequent, e.g. 1940–81. The skewness is reflected in the statistical distribution of winter temperatures in central England, which are strongly controlled by the Atlantic flow. The Azores minus Iceland mean-sea-level pressure distribution for the other seasons is more nearly Gaussian.

The monthly averaging process applied to daily winter European temperatures also fails to produce a Gaussian frequency distribution of these temperatures because of the extreme coldness of easterly flows. By way of contrast, Parthasarathy and Mooley (1978) found that Indian summer monsoon rainfall conformed to a Gaussian distribution. Individual daily rainfall values are unlikely to approximate to a Gaussian distribution because a large frequency of dry days (zero rainfall) is likely to be superimposed on a J-shaped distribution for days with rain; but the daily Indian values must have satisfied the conditions in which the central-limit theorem applies, so that averaging produced a more Gaussian result.

(c) *Quasi-periodicity*

The best-known example of an almost periodic interannual variation is the quasi-biennial oscillation of wind direction and speed and temperature in the lower stratosphere in the tropics. The monthly mean 30 mb winds over Canton Island (Pacific) up to 1967, then over Gan (Indian Ocean), are shown in Fig. 4. It is possible to form such a composite series from two widely separated stations only because the quasi-biennial oscillation occurs on a global scale in the tropics with very little time-lag between different longitudes. The period of the oscillation is not constant; it varies from less than two years to about three years, and averages two years and three months. Periods near either two or three years tend to be favoured, and there are favoured seasons for changeover of the wind direction (Parker 1976). There is

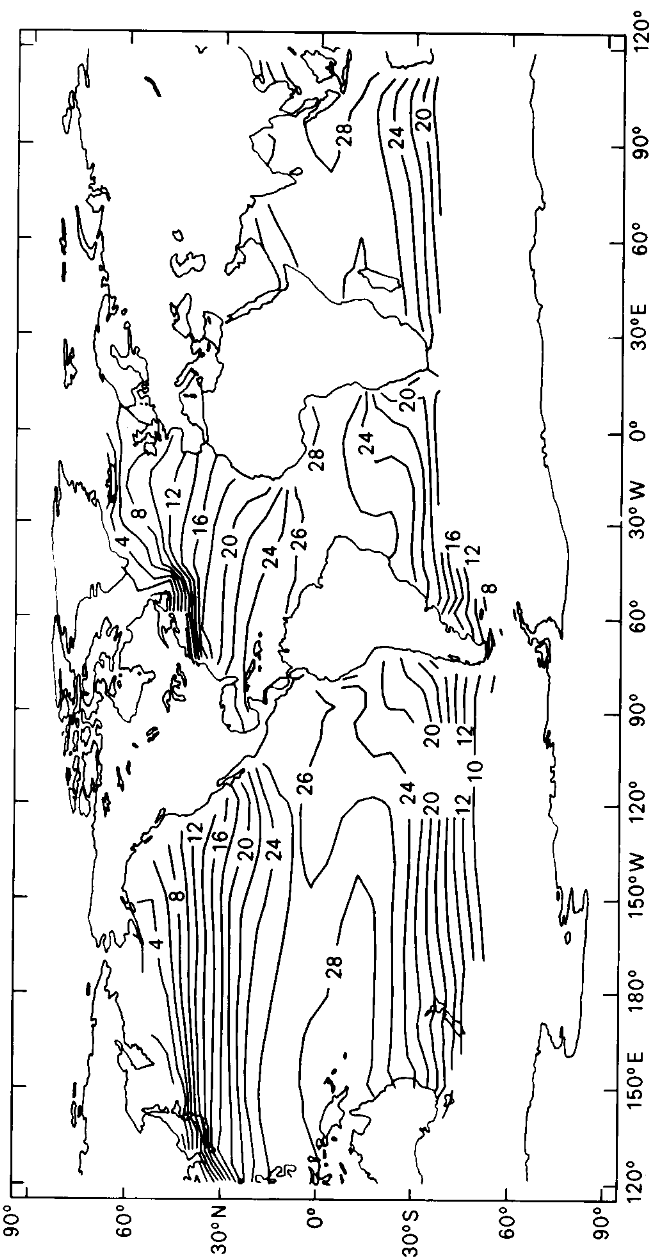

Figure 2(a). Normals of sea surface temperature (°C) for February. Data for: 1900–60, Atlantic area; 1931–60, other areas.

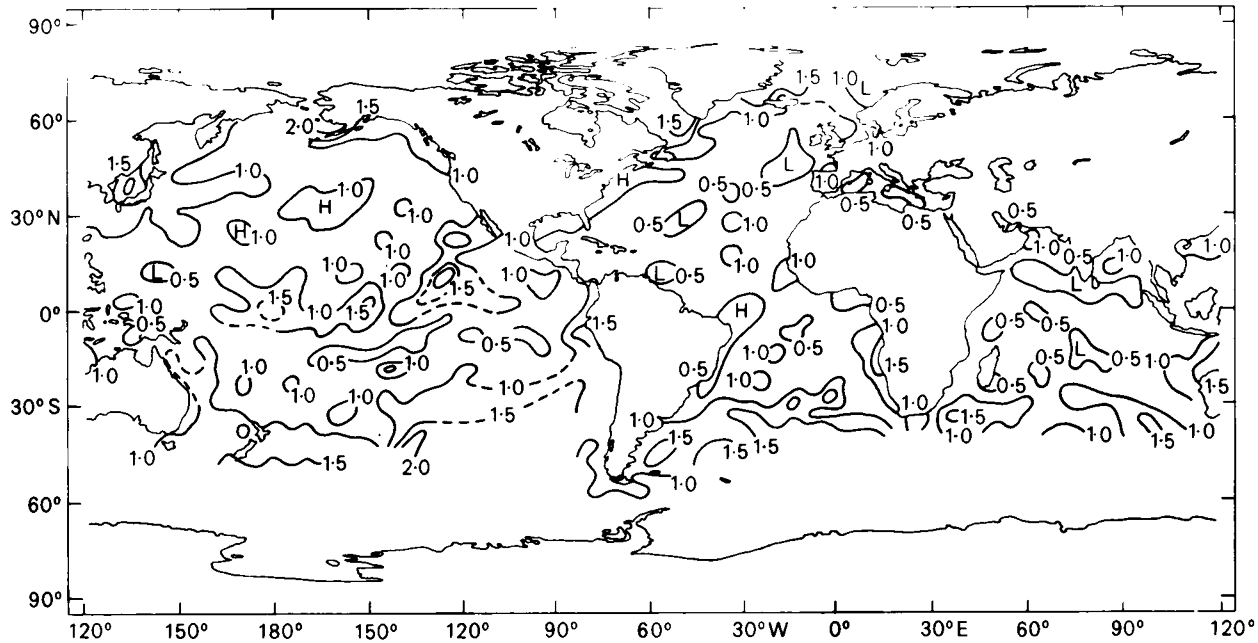

Figure 2(b). Standard deviations of sea surface temperature (°C) about monthly normals for February. Data for: 1900–60 Atlantic area, 1931–60 other areas.

also downwards phase propagation with, for example, changes in the 50 mb wind vector lagging by several months behind changes in the 30 mb wind vector.

The discovery of the tropical stratospheric quasi-biennial oscillation has been followed by very widespread reports of quasi-biennial behaviour in local tropospheric climate and circulation parameters. Parthasarathy and Mooley (1978) found a quasi-biennial oscillation in Indian monsoon rainfall, but this was not strong and regular enough to be used for annual forecasting. Ebdon (1975) documented differences in the mean northern hemisphere mid-latitude surface pressure and 500 mb geopotential patterns and in zonal winds aloft, according to the phase of the tropical quasi-biennial oscillation. Fig. 5 illustrates the mean-sea-level pressure anomalies for Julys with a westerly tropical quasi-biennial wind mode. The anticyclonic anomaly near the British Isles was found to be statistically significant at about the 5% level. In addition, not only Ebdon (1975) but also Angell and Korshover (1977) observed that the circumpolar upper-tropospheric vortex was smaller during the westerly phase of the tropical quasi-biennial oscillation, particularly in winter (Fig. 6), with an associated increase of tropospheric temperature of several tenths of a degree Celsius in mid-latitudes. Consequent effects on, for example, summer temperature and sunshine in the United Kingdom, were noted by Ebdon. Furthermore, Holton and Tan (1980) have demonstrated that there is a 50 mb and 1000 mb quasi-biennial oscillation in the geopotential and temperature of the northern polar regions. The two levels are

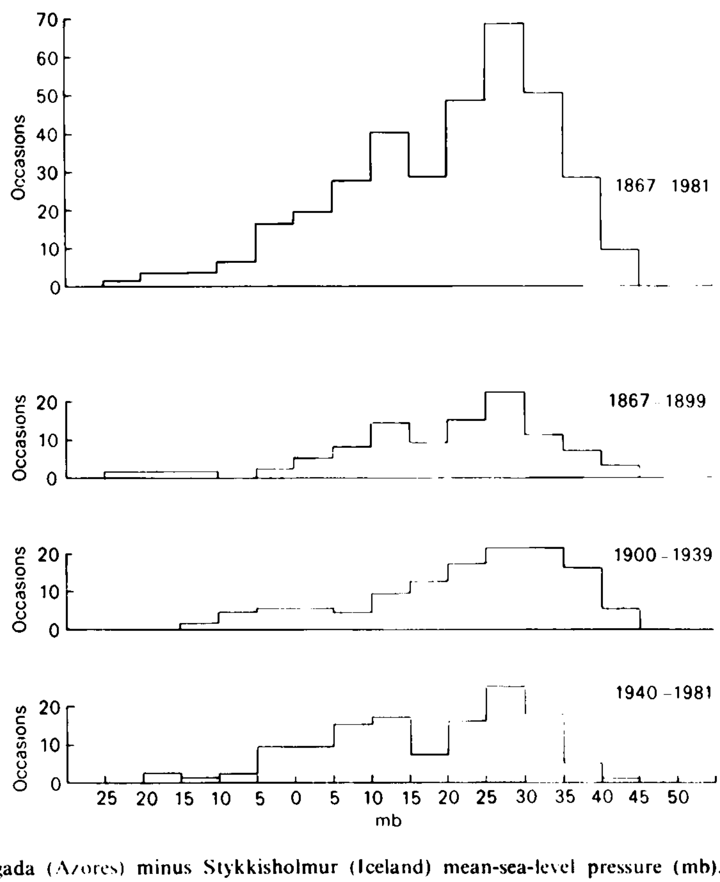

Figure 3. Ponta Delgada (Azores) minus Stykkisholmur (Iceland) mean-sea-level pressure (mb), winter months (up to December 1981).

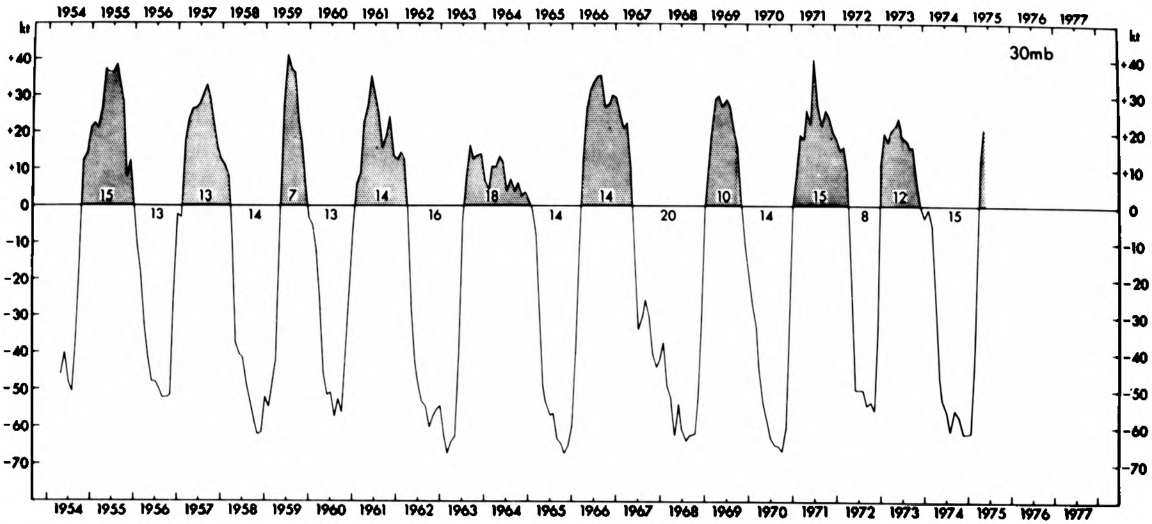

Figure 4. 30 mb monthly mean zonal wind components at Canton Island (Pacific) to 1967, then at Gan (Indian Ocean). After Ebdon (1975). Components towards the east are positive and stippled. Figures along the zero line indicate the duration, in months, of westerlies or of easterlies.

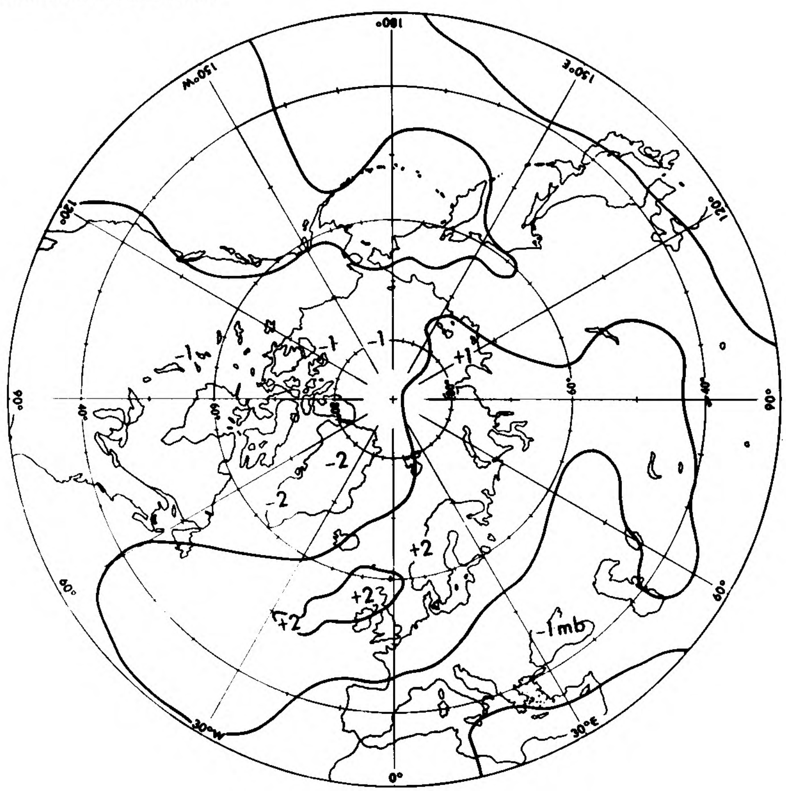

Figure 5. MSL pressure anomaly from 1951–70. July average. Mean of eight Julys with quasi-biennial oscillation at 30 mb. (After Ebdon 1975.)

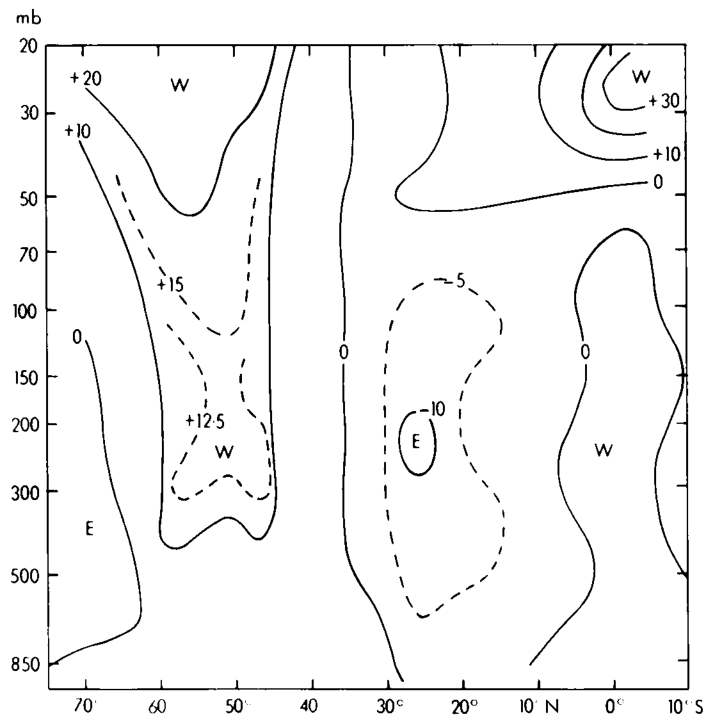

Figure 6. Vertical cross-section at 80° W showing differences between zonal wind component during westerly and easterly phases of the quasi-biennial oscillation at 30 mb in January. (After Ebdon 1975.) Speeds in m s^{-1}.

in phase but the effect is weaker at 1000 mb. It must be emphasized that these observations of quasi-biennial oscillations outside the tropical stratosphere have only been associated statistically with the tropical stratospheric quasi-biennial oscillation at this stage. Physical associations have not been established.

(d) *Teleconnections*

Interannual variations in the atmosphere are sometimes coherent on very large scales. In fact, events at locations in differing regions of the globe have often been found to be statistically connected in the sense that opposite effects tend to occur at distant places (the effects are negatively correlated). An important example of such a 'teleconnection' is the Southern Oscillation, documented by Walker and Bliss (1932) as an inverse but non-periodic pressure variation on interannual time-scales between the east Pacific Ocean and the east Indian Ocean at low latitudes. The major northern hemisphere long-distance relationships are summarized for winter in Fig. 7, from Wallace and Gutzler (1981), in which negative correlations are indicated between locations at opposite ends of the arrows. The variations are not periodic. Of particular interest are the North Atlantic oscillation, which is an inverse variation of the pressure in the Azores anticyclone and the Iceland low, a similar effect in the western North Pacific, and a negative correlation between pressure in the Aleutian low and over the northern Rockies, forming a link in a chain of events tenuously connecting the tropical Pacific with the Atlantic. The fluctuations in the Iceland low result in inverse variations ('seesaw') in winter temperature in Greenland and northern Europe (Van Loon and Rogers 1978). The pattern of teleconnections over the east Pacific and America

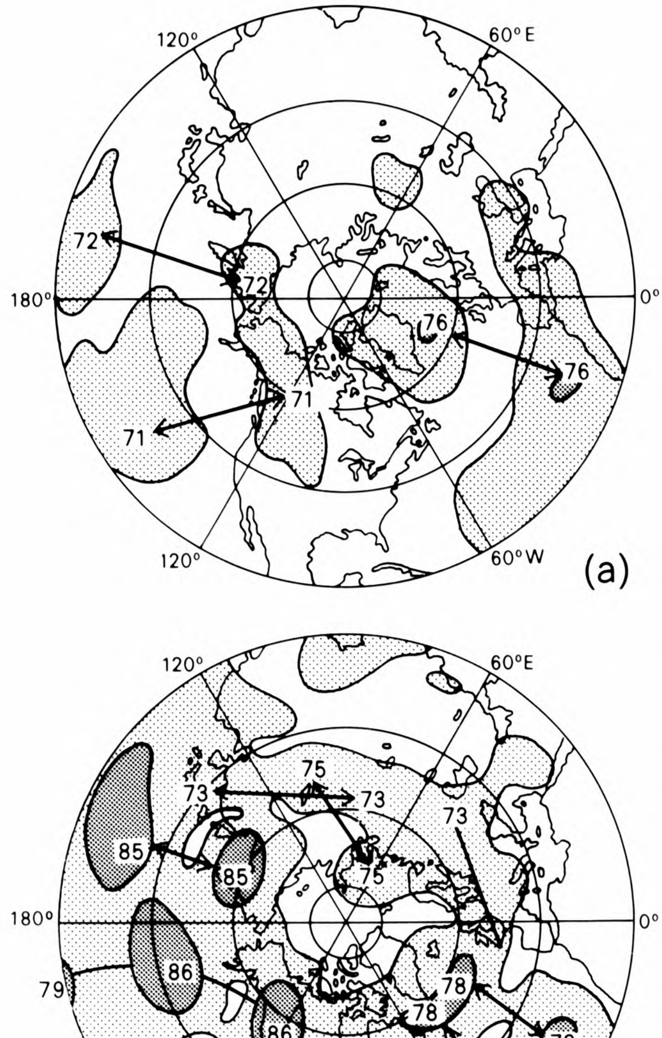

Figure 7. Strongest negative correlation p_i with any point, plotted at the base grid point for (a) sea level pressure and (b) 500 mb geopotential. Based on 45 winter months (Decembers, Januarys and Februarys) for 1962–63 to 1976–77. (After Wallace and Gutzler 1981.) Negative signs have been omitted and correlation coefficients multiplied by 100.
Regions where $p_i < 60$ are unshaded, where $60 \leq p_i < 75$ stippled lightly, where $75 \leq p_i$ stippled heavily.
Arrows connect centres of strongest teleconnection.

in Fig. 7(b) is reminiscent of the wave-trains resulting from subtropical thermal and orographic forcing in the five-layer baroclinic model of Hoskins and Karoly (1981), whose results may also throw light on the relationships between the Southern Oscillation and interannual variability in mid-latitudes, discussed in the next section.

3. Hypotheses for interannual variability

There are at least three classes of explanation of atmospheric interannual variability: interactions within the atmosphere, whereby short-period fluctuations create and maintain longer-term equilibria; thermal interactions with the oceans and cryosphere (ice and snow); and external forcings. The last group of theories will not be discussed here: it includes the influence of variations in solar constant, which has, however, hitherto been very difficult to measure to the required accuracy, and the influence of volcanic dust. In the present paper, internal atmospheric interactions will be discussed in the context of the tropical stratospheric quasi-biennial oscillation and atmosphere–ocean interactions will be illustrated by an examination of the Southern Oscillation.

(a) *Interactions within the atmosphere: the quasi-biennial oscillation*

Holton and Lindzen (1972) have formed a hypothesis that the downward-propagating quasi-biennial oscillation in the tropical lower stratosphere is driven by vertical convergence of the momentum flux of radiatively dissipating, vertically propagating, short-period (5–15 days) waves excited in the upper troposphere. The radiative dissipation results from reduction of the amplitude of the temperature cycle of the wave by Newtonian cooling.

Imagine an atmosphere initially at rest until waves of a type which propagate westerly momentum upwards are excited near the tropopause, as a result of e.g. geographically irregular tropospheric heating. Equatorial 'Kelvin waves' have the appropriate properties, propagating eastwards as well as upwards. The waves will propagate upwards with weak attenuation up to near 30 km (10 mb) where, because the radiative dissipation increases with height, their amplitude will decrease rapidly with height, leading to a rapid reduction with height in the upward westerly momentum flux associated with the waves, and hence to a westerly acceleration of the mean flow. As a result there will be a reduction of the eastward phase speed relative to the mean flow. If the acceleration of the mean flow is slow compared with the accelerations involved in the wave motions, linear approximations will apply and it can be assumed that the vertical phase speed of the waves will be reduced in proportion to the horizontal phase speed. The reduced vertical phase speed will allow more time for Newtonian cooling to reduce the wave amplitude; in other words there will be increased radiative dissipation of the waves where they encounter the westerly flow, i.e. in the shear zone beneath the strongest westerly flow. The resulting decrease of wave amplitude with height will lead to convergence of the wave momentum flux at these lower levels. The momentum will no longer be available for the upper levels, where the acceleration will therefore decrease. However, the increased acceleration at the lower levels will lower the shear zone, further lowering the level at which most of the momentum flux converges. Eventually a westerly shear zone will descend to near the tropopause where a balance will be established between convergence of wave momentum and vertical diffusion of momentum into the troposphere.

Now imagine that waves which propagate easterly momentum upwards are also excited near the tropopause; such waves are also observed in the tropics. These waves will be able to propagate through the westerly shear zone but, as a result of radiative dissipation at higher levels, their easterly momentum flux will converge there, so that, in a manner similar to that described above, a downward-propagating easterly shear zone will follow the westerly shear zone. Eddy diffusion will permit the easterly shear zone to propagate to the tropopause without leaving a shallow layer of westerlies.

Holton and Lindzen illustrated their hypothesis with a one-dimensional analytical model, which also included an imposed climatological mid-stratospheric tropical semiannual oscillation of zonal wind. Their results are presented in Fig. 8. The downward propagation and periodicity (27 months) are similar to what on average is observed, but the periodicity could have been varied by altering the radiative dissipation rates, or by changing the wave amplitudes at the lower boundary. However, their values for these parameters were all compatible with observations, lending credibility to their theory. The semiannual oscillation may be responsible for the synchronous nature of the quasi-biennial oscillation throughout the tropics because, by affecting wave phase speeds and thus momentum convergence in the 30–40 km layer, it could limit the possible times of onset of new shear zones. However, the semiannual oscillation is not essential to Holton and Lindzen's theory and they did not regard it as determining the time-scale of the quasi-biennial oscillation.

Plumb (1977) has suggested modifications to Holton and Lindzen's theory. In particular, because the wave amplitude and therefore the momentum convergence at a given level are controlled by the mean flow at lower levels, he found the vertical variation of radiative cooling to be unnecessary. Also, Plumb found that the destruction of the lowest zone was a result of eddy diffusion of momentum from the zone of reverse winds immediately above, rather than eddy diffusion into the troposphere.

The mechanisms by which the tropical lower stratospheric quasi-biennial oscillation affects the rest of the atmosphere are still uncertain. It is possible that the associated temperature changes near the tropical tropopause may affect the strength of the convection, and thereby influence the Hadley cell and subsequently the rest of the circulation (Folland, private communication).

(b) *Atmosphere–ocean interactions: the Southern Oscillation*

The Southern Oscillation has already been referred to as an inverse variation of pressure between the Indian and Pacific Oceans in the tropics. Fig. 9 shows the global scale of the phenomenon and Fig. 10(c), in which a positive index denotes above-normal pressure over the tropical south-east Pacific, shows that the fluctuations are irregular in time but occur on time-scales of the order of several years. However, Figs 10(a), (b) and (d) also show the involvement of winds, sea surface temperatures and rainfall in the equatorial Pacific. When pressure is higher than normal over the tropical south-east Pacific there is enhanced easterly flow along the equator in mid-Pacific, accompanied by reduced sea surface temperatures and reduced rainfall. There is also an enhanced westerly return flow aloft (Julian and Chervin 1978) completing a direct circulation in an equatorial plane, known as a 'Walker cell'. According to Bjerknes (1966), the reduced sea surface temperatures are a result, not mainly of westward advection of water from the cold Humboldt Current, but largely of enhanced upwelling of water as a result of the wind-induced Ekman drift: persistent easterlies result in poleward motion of surface water in geostrophic equilibrium, and the consequent equatorial divergence can be balanced only by equatorial upwelling. The rainfall in the equatorial mid-Pacific is reduced, partly because of suppression of local convection over the cooler ocean, and partly because of subsidence associated with the large-scale vertical circulation (Bjerknes 1969). At the opposite stage of the Southern Oscillation cycle pressure is lower than normal over the tropical south-east Pacific, with reduced mid-Pacific equatorial easterlies, increased mid-Pacific rainfall and increased eastern and mid-Pacific sea surface temperatures. Horel and Wallace (1981) have also shown that the entire tropical troposphere is warmer at this stage of the Southern Oscillation. It is thus an important phenomenon on a global scale.

Bjerknes (1969) considered either stage of the Southern Oscillation to be self-amplifying. For example, an increase in the pressure difference is associated with an increase in the easterlies, leading to a reduction of the sea surface temperatures in the central and eastern equatorial Pacific and hence to an increase of east–west temperature contrast, so that the Walker direct cell is strengthened, giving a further

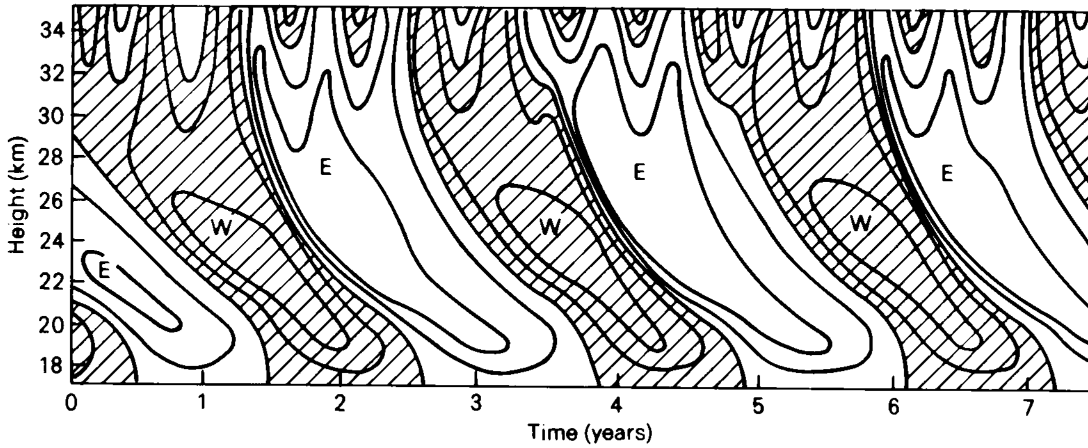

Figure 8. Time-height cross-section of mean zonal wind. After the model of Holton and Lindzen (1972). Isopleths are drawn at 10 m s⁻¹ intervals.
Regions of westerly flow are shaded.

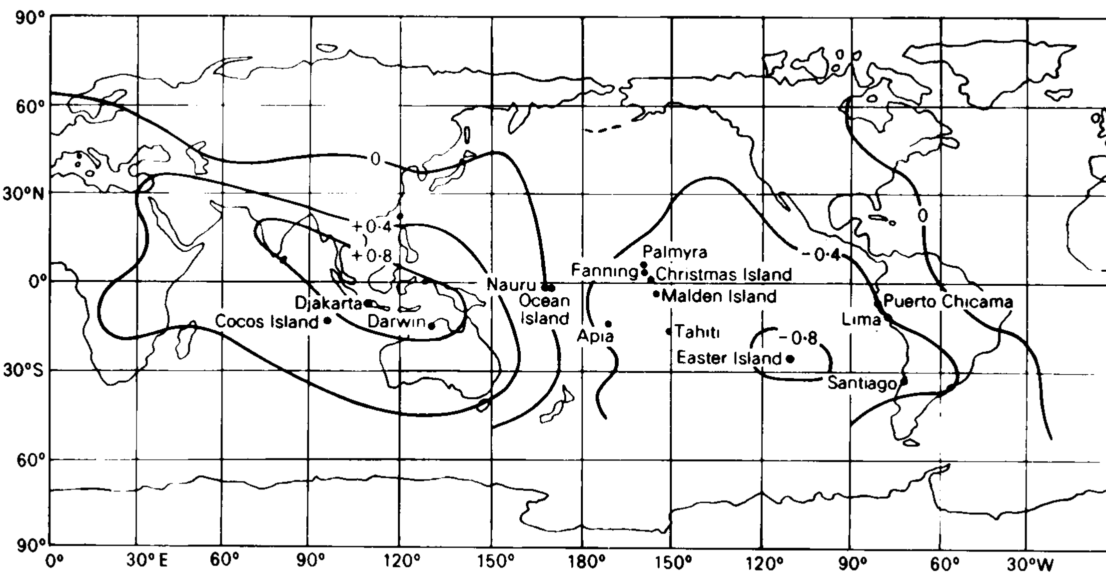

Figure 9. Schematic map (after Berlage 1966) showing isopleths of correlation of monthly mean station pressure with that of Djakarta, Indonesia.

increase in pressure difference and stronger winds, and so on. But in his 1969 paper Bjerknes was unable to specify the means of turnabout between opposite stages of the Southern Oscillation. In his 1966 paper, however, he had proposed the well-known hypothesis that an anomalously warm ocean surface would provide extra energy to the north–south (Hadley) circulation at that longitude. It would follow (Julian and Chervin 1978) that not only the subtropical westerly jet but also the low-latitude, low-level easterlies would increase, the equatorial ocean would cool, and so the Southern Oscillation would change to its opposite phase. However, the cool ocean would now be a reduced energy source for the

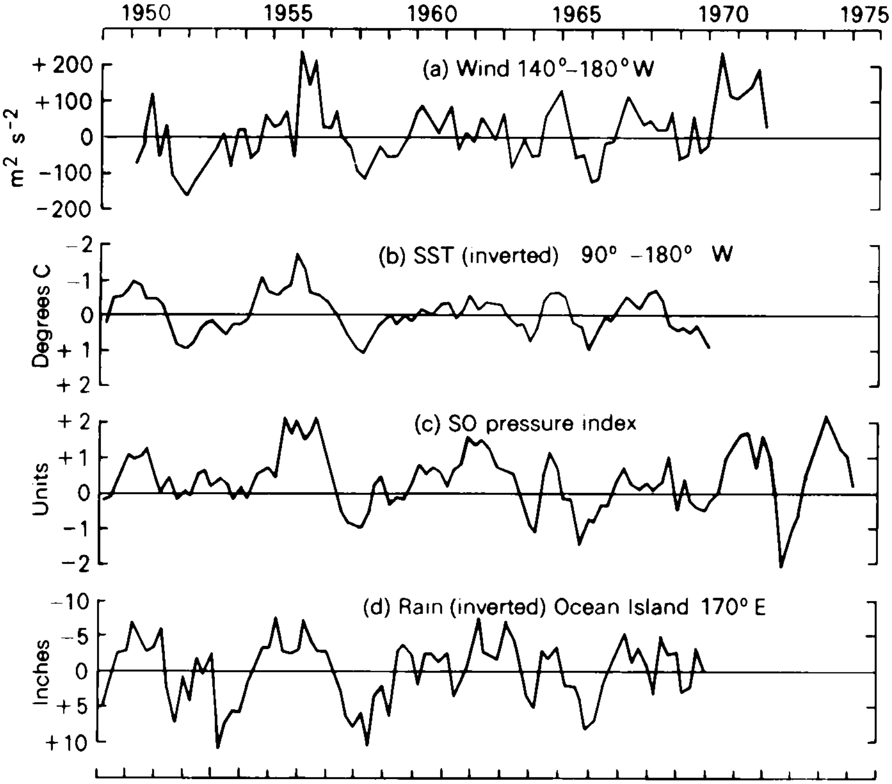

Figure 10. Parameters of the Southern Oscillation (after Wright 1977).
(a) Zonal component of wind stress, 4°N–4°S, 140°W–180°W, seasonal anomalies relative to 1950–69 mean (after Wyrtki 1975).
(b) Sea surface temperatures, 10°N–10°S, 90°W–180°W, seasonal anomalies relative to 1949–69 means.
(c) Southern Oscillation seasonal pressure index.
(d) Rainfall at Ocean Island, 0°52′S, 169°35′E, mean monthly anomalies for each season relative to 1950–69 mean.
Ticks along the top and bottom margins denote northern autumn of the year immediately preceding.

Hadley circulation, which would weaken, giving reduced low-latitude easterlies and a warming of the equatorial ocean, so that the Southern Oscillation would have come full circle.

If the above chain of reasoning were correct there would be a lag, on the time-scale of atmospheric circulation changes, i.e. days or weeks, between the time of warmest ocean and the time of strongest easterlies. Fig. 10 does not support this; the strongest equatorial easterlies appear to occur towards the end of periods with cold ocean. Wyrtki (1975) therefore proposed a different hypothesis to explain the changeover of the Southern Oscillation from positive index (strong winds, cold ocean) to negative (warm ocean). On the basis of sea-level observations from coastal and island stations, he suggested that the increased easterlies in the cold-ocean phase can strengthen the South Equatorial Current and thereby maintain an anomalous slope of sea level, upwards towards the west. But within a few months of a weakening (for an unspecified reason) of the winds, the accumulated warm water will move east from the west Pacific and the thermocline will be lowered, so that the remaining winds will be unable to cause upwelling of cold water, even though there is some evidence that upwelling is at least as intense at this stage (Anderson 1981). Thus the warm-ocean phase will be established. The warming occurs only during northern winter and Wyrtki also showed that the same phenomenon occurs in a less intense form during every northern winter. He did not attempt to explain the mechanism of reversion to the cold-ocean phase of the Southern Oscillation. Neither does Wyrtki's hypothesis appear to explain the fact (Horel and Wallace 1981) that the equatorial central Pacific warms several months later than the Peruvian coastal waters. Barnett's (1977) statistical study lends support to Wyrtki's hypothesis so far as the eastern equatorial Pacific is concerned, and then favours westward advection of less-cool water and reduced wind-induced equatorial upwelling, as reasons for the later mid-Pacific warmth.

Despite the inadequacy of Bjerknes's hypothesis in explaining the turnabouts of the Southern Oscillation it has been shown, in agreement with his hypothesis, that the annual mean strength of the northern hemisphere subtropical jet stream in the longitude range of interest increases as the eastern equatorial Pacific warms (Julian and Chervin 1978). In addition (Van Loon and Rogers 1981) the characteristics of the winter northern hemisphere mid-latitude circulation are changed, with increased heat transport in the quasi-stationary eddies, lower mean temperature between 30°N and 60°N, and heat transport by transient eddies reduced north of 45°N but increased south of 45°N. Similar adjustments of the mid-latitude long waves appear in the steady-state linearized primitive-equation model of Hoskins and Karoly (1981) when a subtropical forcing (heat source) is introduced. These and other theoretical results also indicate that strong teleconnections to mid-latitudes are possible only when the upper tropospheric westerlies extend over the low-latitude heat source. For the northern hemisphere mid-Pacific this condition is fulfilled only in the winter half-year and the observational evidence indeed suggests that the strong teleconnections with mid-latitudes occur only in winter.

4. Conclusion

Future investigation of large-scale interannual variability of climate requires observational and modelling studies of atmospheric and oceanic aspects. Modelling studies may in some cases be in simple forms for testing specific hypotheses, as in the quoted work on the quasi-biennial oscillation, but many phenomena appear to require fully fledged models for adequate representation. In the particular case of the Southern Oscillation, an interactive ocean–atmosphere model would be of considerable value in investigating what has turned out to be a highly complex and intriguing phenomenon.

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The forecasting of state of sea

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(Meteorological Office, Bracknell)

Summary

The requirement for, and history of, state-of-sea forecasting in the Meteorological Office are briefly described, together with a summary of the present operational forecasting system. The various forms of output from the system are discussed and some examples are given of the applications to which they are put. The results of some verification exercises are also examined.

1. Introduction

A firm need for a state-of-sea forecasting service has been established over the last 10 years, principally because of the growing offshore industry in the North Sea, but also as a result of economic pressures on shipping lines and an increasing general requirement for greater safety margins in all aspects of marine activity.

The Meteorological Office is currently satisfying the need for such state-of-sea forecasts because of a unique coincidence of necessary skills, information and facilities. The wind fields that are forecast by the numerical weather prediction models provide the necessary forcing functions that enable a state-of-sea forecast to be made for a wide area and a long forecast period. The wide experience of numerical modelling of physical systems that is found in the Office has been fruitfully turned to designing an operational state-of-sea forecasting model which incorporates the known physical processes which govern the behaviour of the sea surface. The combination of powerful computing resources and a centralized telecommunication system provides an environment where the necessary complex mathematical modelling can be efficiently carried out and the required products and information quickly distributed to the users.

Before the advent of powerful computer technology the accepted means of state-of-sea forecasting was by way of empirical wave-growth curves, deducing the wave height in terms of wind speed, duration and fetch. The numerical model in use by the Office incorporates in more stringent formulations the essential physical principles which underlie such empirical techniques. Details of the physical basis of the current models are to be found in the Appendix; it is sufficient here to summarize the basic processes which are modelled. Recent theoretical and experimental work by oceanographers in many countries has greatly increased the degree of knowledge of the processes involved in wind-wave generation and dissipation. The model in use incorporates such processes as wave growth, interaction and dissipation, the advection of swell energy and, in the higher-resolution version, such depth-dependent processes as refraction and bottom friction.

2. The operational system

The current operational state-of-sea forecasting services are based on the products of two numerical models which are run on the IBM 360/195 computer following the twice-daily integrations of the atmospheric prediction models. Like the atmospheric models the state-of-sea models consist of a coarse-mesh and a fine-mesh version, using winds from the appropriate atmospheric model. The coarse-mesh version covers the North Atlantic and North Pacific Oceans down to 18°N with an approximate grid resolution of 300 km in mid-latitudes (Fig. 1). The fine-mesh model has a more limited area, the continental shelf and north-eastern Atlantic, with a resolution of 50 km (Fig. 2). The winds for this model are interpolated from data on the fine-mesh atmospheric model grid. The coarse-mesh model is run for a forecast period of 48 hours and provides boundary values for the fine-mesh model; i.e. swell forming in the Atlantic is passed into the continental shelf model and advected onward. The shelf model runs for a 36-hour forecast period.

Output from the models is usually in chart format, showing significant wave-height contours for either swell or total seas (Figs 3 and 4). Information is also available on wave periods. Some products are in the form of grid-point data, either assembled into WMO grid code for many points for onward transmission or listed in tabular form as a printout (Fig. 5).

Before running each forecast a 12-hour 'hindcast' is performed. This is essentially a repeat of the first 12 hours of the previous integration but this time using wind fields that are updated either with observations or with analysed products from the atmospheric models. This process ensures that the starting point of each state-of-sea forecast is the best possible description within the limits of the numerical simulation technique. These hindcast fields are kept in an archive, currently containing three years of acceptable data. At present no wave observations go into the models as data during the hindcast run.

The use of observed wave data, whether as visual estimates or measured values, is confined to the area of validation. Some detailed figures are given in Table 1. A data set of forecast values for a greatly reduced number of grid points is retained during operational runs, so that at the end of each month a validation exercise can be carried out. Included in Table 1 are the corresponding errors of the forecast

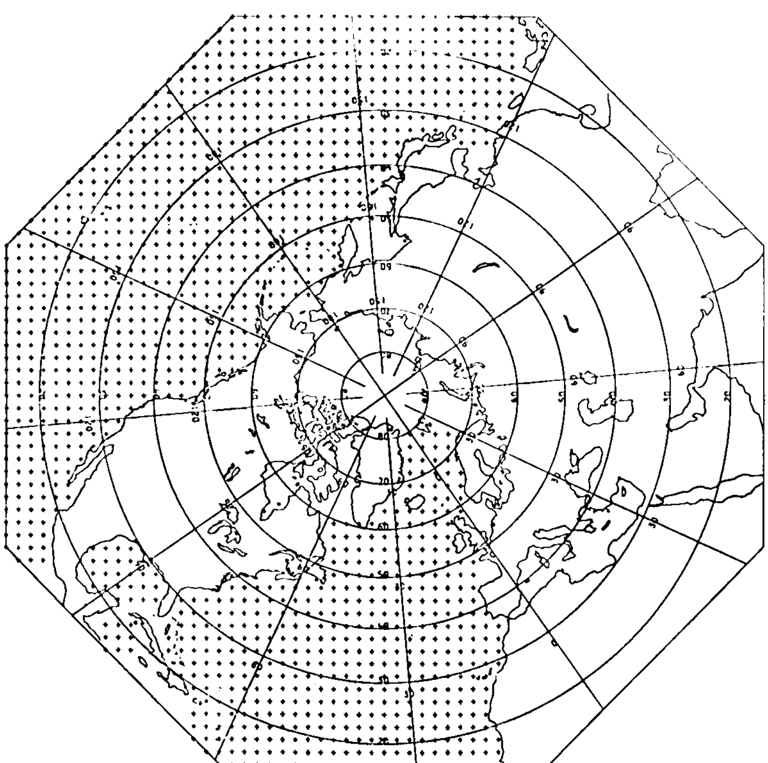

Figure 1. Grid points of the coarse-mesh wave area.

wind field at the same locations. Not surprisingly there is a good correlation between higher forecast wind errors and higher errors in forecast significant wave height. The scatter in the relationship is due to the differing proportions of 'local wind sea' and 'advected swell' components of the total significant wave height at different locations. The lowest root-mean-square errors of wave height for given wind errors are found at Penzoil, at the southern end of the North Sea, where incoming swell is a minor constituent. The worst errors are found at Ocean Weather Station 'L' where incoming Atlantic swell is very important and perhaps not simulated well enough by the coarse-mesh model which provides the boundary values.

3. Applications

The different resolutions of the two models, together with the depth-dependent effects found only in the fine-mesh versions, reflect the potential uses for the model products. The use of the coarse-mesh products is confined to shipping activities, hence a chart format is the most suitable output medium. A forecaster in the Central Forecasting Office (CFO) has the responsibility of preparing 24-hour and 48-hour forecast charts of total significant wave height for the North Atlantic. These charts are produced by modifying the products of the coarse-mesh wave model in the light of the expected differences in wind-field evolution from the forecast values given by the coarse-mesh numerical weather prediction model,

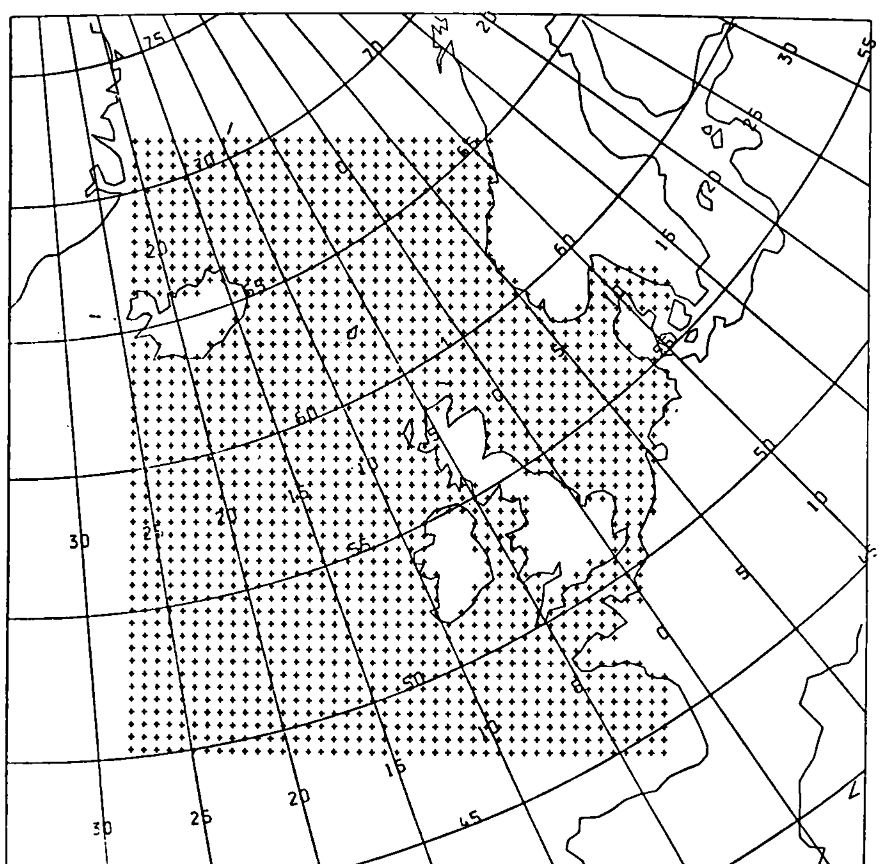

Figure 2. Grid points of the fine-mesh wave area.

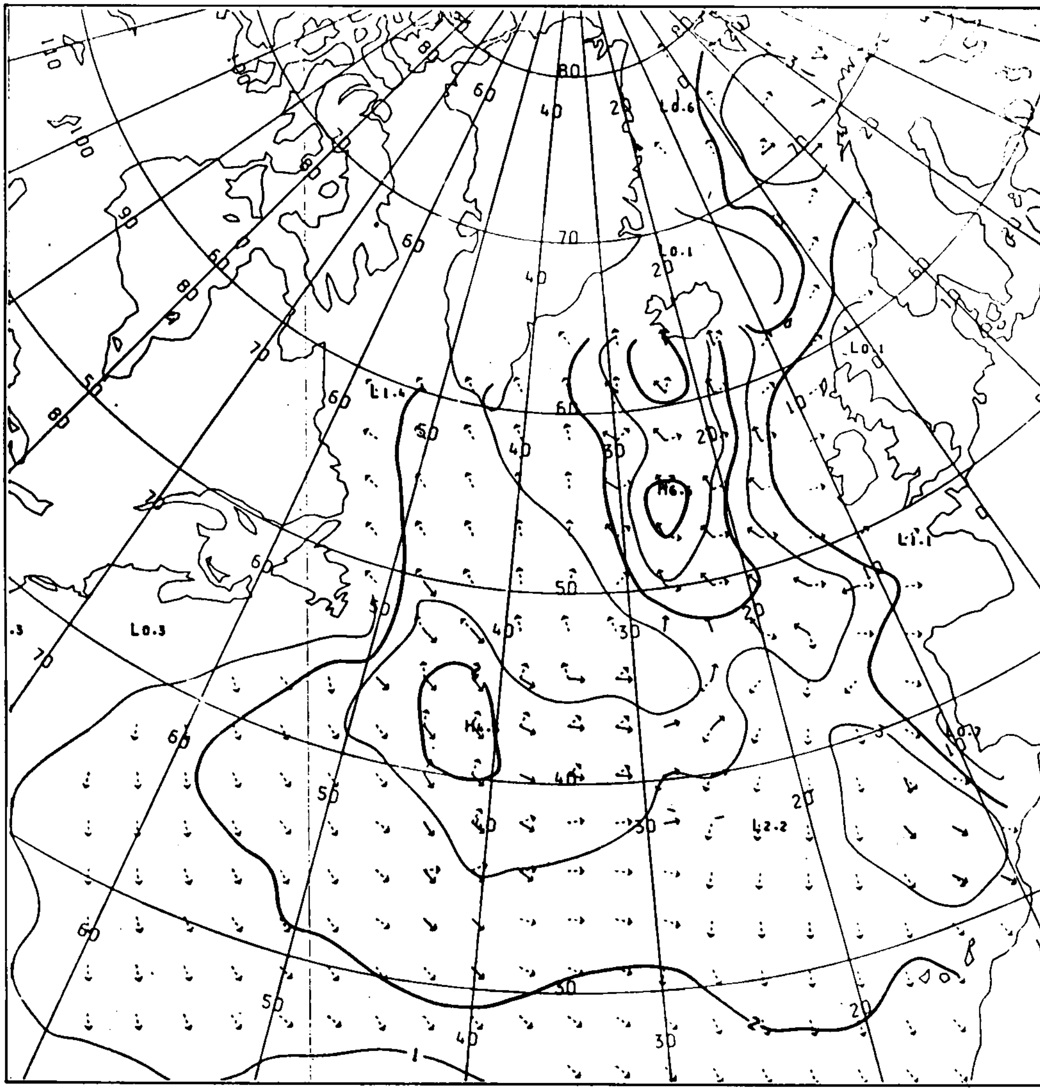

Figure 3. Example of output from state-of-sea model in chart format. Sea and swell contours for 12 GMT on 4 November 1980. Arrows indicate wind direction. Dotted arrows indicate swell direction.

using the forecaster's experience of the relationship between broad-scale wind fields and the associated wave developments in the model. The final product is hand drawn and then broadcast by means of radio facsimile. The Ship Routeing Service also uses the amended North Atlantic chart and, following discussions with CFO forecasting staff, makes use of forecast wave products for the North Pacific. Occasionally, special runs of a Mediterranean sea wave forecast model are made when the Ship Routeing Service requires such information. The cost of running these models forms an element of the fees charged for the complete routeing service. For conventional vessels the object of the service is to select the best route for the ship to follow in order to reach her destination in the shortest possible time, with the most economical fuel consumption, commensurate with least damage to ship and cargo. Wave

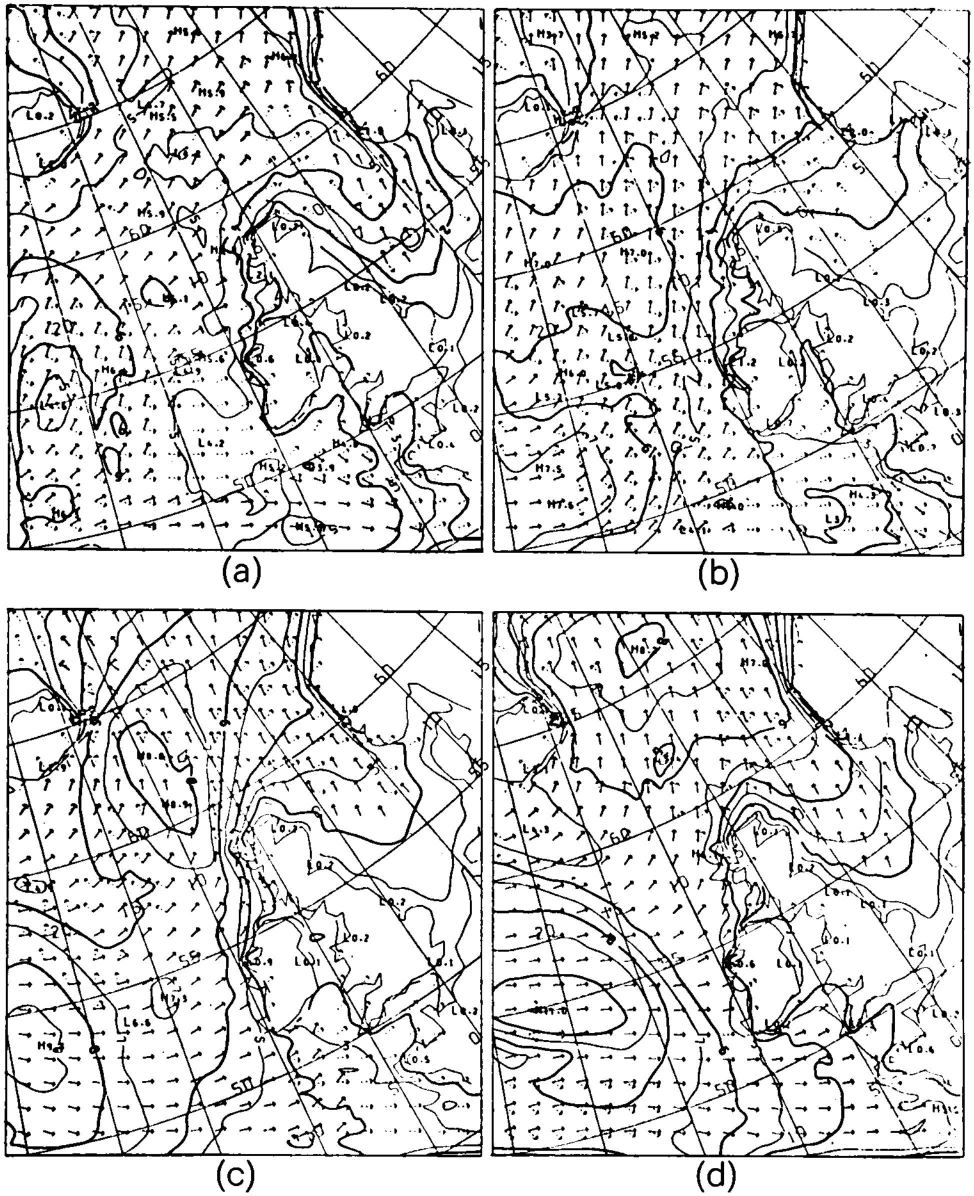

Figure 4. Example of output from state-of-sea model in chart format, showing sea and swell contours, wind direction (arrows) and swell direction (dotted arrows).
(a) Starting point of forecast at 00 GMT on 7 March 1982.
(b) 12-hour forecast.
(c) 24-hour forecast.
(d) 36-hour forecast.

FOR TRANSMISSION TO SOUTH WEST WATER AUTHORITY VIA MET.O.5 PAGE 1

INITIAL DATA TIME 12Z 7/ 2/82

LOCATION 50.3N 3.6W

HOURS AFTER DATA TIME	WIND SPEED KTS	WIND DIRECTION DEG(FROM)	TOTAL WAVES HEIGHT M	TOTAL WAVES PERIOD SECS	WIND SEA HEIGHT M	WIND SEA PERIOD SECS	SWELL HEIGHT M	SWELL PERIOD SECS	SWELL DIRECTION DEG(FROM)
0.0	6.8	205.	1.7	6.6	0.3	0.1	1.6	7.1	233.
3.0	12.2	227.	1.6	6.6	0.6	3.6	1.5	7.9	235.
6.0	17.9	236.	1.6	6.2	0.9	3.9	1.3	8.8	236.
9.0	20.6	254.	1.5	6.2	0.9	4.1	1.2	8.4	231.
12.0	24.0	262.	1.4	6.2	0.8	3.9	1.2	8.1	231.
15.0	20.7	264.	1.4	6.2	0.8	4.0	1.2	8.0	232.
18.0	18.5	277.	1.4	6.2	0.6	3.7	1.2	7.4	230.
21.0	13.2	239.	1.4	6.5	0.4	3.1	1.4	7.1	231.
24.0	19.9	223.	1.6	6.3	0.8	4.0	1.3	8.1	231.
27.0	26.6	227.	2.0	6.2	1.6	4.8	1.2	9.0	224.
30.0	26.0	224.	2.5	6.3	2.3	5.5	0.9	10.0	220.
33.0	27.6	228.	2.8	6.5	2.5	5.8	1.2	9.9	218.
36.0	26.7	221.	3.1	6.7	2.6	6.2	1.7	9.8	215.

LOCATION 49.8N 4.8W

HOURS AFTER DATA TIME	WIND SPEED KTS	WIND DIRECTION DEG(FROM)	TOTAL WAVES HEIGHT M	TOTAL WAVES PERIOD SECS	WIND SEA HEIGHT M	WIND SEA PERIOD SECS	SWELL HEIGHT M	SWELL PERIOD SECS	SWELL DIRECTION DEG(FROM)
0.0	8.8	222.	3.1	8.2	0.5	2.8	3.1	8.7	260.
3.0	14.2	244.	3.0	8.1	0.7	3.6	2.9	8.9	261.
6.0	17.8	243.	2.9	7.4	1.8	5.6	2.2	10.7	266.
9.0	20.3	256.	2.8	7.0	1.7	5.0	2.2	10.1	263.
12.0	24.1	261.	2.8	6.8	2.2	5.6	1.8	10.8	264.
15.0	21.4	261.	2.8	6.8	2.6	6.6	1.2	11.8	269.
18.0	19.3	272.	2.7	6.7	2.2	6.0	1.6	10.4	259.
21.0	15.4	242.	2.7	6.9	1.7	4.8	2.1	9.2	256.
24.0	20.8	226.	2.7	7.0	2.5	6.5	1.1	11.9	265.
27.0	25.6	227.	3.0	6.6	2.6	6.2	1.5	10.5	253.
30.0	25.6	222.	3.3	6.8	3.2	6.9	1.1	11.9	262.
33.0	26.6	223.	3.6	6.9	3.4	7.1	1.1	12.0	257.
36.0	26.6	221.	3.9	7.2	3.9	8.0	0.5	13.7	269.

Figure 5. Example of output from state-of-sea model in tabular form.

conditions as well as wind are an important consideration in such an exercise since average speed over the route as well as stability is a function of state of sea. Non-conventional requests, such as for tows, may have more restrictive state-of-sea limitations and advice can be given on weather and state-of-sea 'windows' during which movements are possible.

Products of the fine-mesh continental shelf model are used for a wider variety of purposes. The forecast products are used extensively by staff at London Weather Centre where the greater part of the forecasting service for the offshore gas and oil industries takes place. Both charts (Fig. 4) and grid-point digital data go to London Weather Centre where, by a judicious synthesis of up-to-date analyses, numerical forecasts and empirical techniques, forecasts of state of sea are derived for transmission to users. Some basic forecast data are also sent direct to staff at Aberdeen, Kirkwall and Lerwick. The staple product for the offshore industry is significant wave height but some operations, such as the placings of large modules, are also sensitive to particular wave periods. The formulation of the forecast models enables primary energy-containing periods in the frequency spectrum to be identified, thus allowing forecasters to give an informed opinion of whether such sensitive operations should be planned during the forecast period. The expansion of forecasting services to the offshore industry is, however, hampered by difficulties in telecommunication, a restraint which at present severely affects forecasters

Table I. *Forecast errors of fine-mesh wind speed and significant wave height.*

Station	Forecast time (hours)	Wind speed ($m\ s^{-1}$) N	Mean	RMS	Wave height (m) N	Mean	RMS
OWS 'M' 64.8°N, 3.2°E	+12	1234	−2.0	3.8	1228	0	1.1
	+24	1233	2.3	4.2	1227	0	1.2
	+36	1230	−2.5	4.7	1224	−0.1	1.3
OWS 'L' 57.1°N, 19.7°W	+12	1229	1.0	3.8	1218	0	1.4
	+24	1228	1.3	4.2	1216	−0.1	1.5
	+36	1225	−1.5	4.7	1212	0.2	1.5
Penzoil 53.2°N, 3.2°E	+12	1091	0	2.7	1022	0	0.5
	+24	1088	0.1	2.9	1022	0	0.6
	+36	1086	0	3.3	1020	0	0.6
Statfjord 61.2°N, 1.8°E	+12	1051	0.1	2.7	880	−0.2	0.8
	+24	1052	0.1	3.6	879	−0.2	1.0
	+36	1049	−0.2	3.9	877	0.2	1.1
Data Buoy I 48.7°N, 9.0°W	+12	1045	0.2	2.9	988	0.1	0.9
	+24	1043	0.1	3.1	985	0.1	1.0
	+36	1044	−0.2	3.4	985	0	1.0

Data from June 1980 to February 1982.
N = Number of occasions. RMS = Root mean square.

deployed offshore at the sites of operations. A tailored service in terms of wave height, period and direction could be supplied, given adequate communications. Other users of forecast state-of-sea data from the fine-mesh model are those water authorities with responsibility for some aspects of coastal defence. At present four such authorities receive forecast state-of-sea information, once or twice a day, for locations along their coastline. The data are usually in a tabular form (Fig. 5) giving forecast information at 3-hour intervals. This service was initiated following the Portland flooding of February 1979 and usually runs from September to April. A comparison between hindcast wave heights and measured data in Lyme Bay is given in Fig. 6. The correlation is quite acceptable, bearing in mind that the hindcast model data are available only at 12-hour intervals, i.e. that absent maxima are not necessarily unpredicted, and also that the wave rider buoy concerned was only 100 m or so from the beach. The model purports to represent open-sea situations.

The archive of hindcast states, or diagnoses, has been used quite extensively in a variety of ways. The major application has been as an aid to the Wave Energy Steering Committee of the Energy Technology Support Unit. The archive has been interrogated to give an additional estimate of the long-term average wave energy resource, both off the Hebrides and in the western approaches. The agreement between short-period averages given by the model and by wave rider buoy measurements was extremely close. Other applications of the diagnostic archive have been also mainly climatological in nature, principally for the Hydraulics Research Station, but there have been interesting oddities like the ecology of East Yorkshire beaches and the estimated state of sea in which a ship was abandoned by its crew!

The models have also been used in less conventional ways in order to meet commercial research and development requirements. Both Marex Ltd and the United Kingdom Offshore Operators Association have placed contracts with the Office for the state-of-sea models to be run under specified wind-field conditions. Such special projects have earned £28 000 since 1980. The income from routine services is

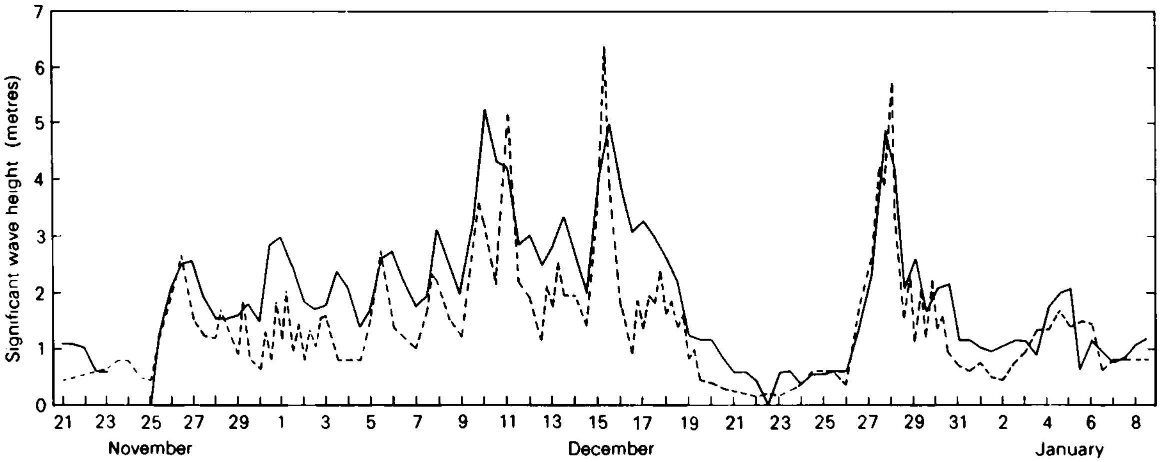

Figure 6. Comparison between hindcast wave heights and measured data in Lyme Bay (50.5°N, 2.6°W) for the period from 00 GMT on 21 November 1979 to 12 GMT on 8 January 1980.
——— Hindcast data. - - - Measured data.

harder to quantify since both the London Weather Centre and the Ship Routeing Service charge a fee which incorporates all aspects of costs for services rendered. All that can be said is that the level of business for both organizations is constantly rising and that the availability of forecast state-of-sea data is a significant added feature in promotional exercises. Directly raised charges, i.e. for services to water authorities, the Energy Technology Supply Unit, the Hydraulics Research Station etc., stand now (1981–82) at £10 000 a year.

4. Future development

The acquisition of the CYBER 205 computer provides the opportunity for the state-of-sea forecasting service to be re-examined and assessed with respect to known requirements and possible expansion. The models themselves can be improved, both by means of better forecast wind fields (products of the new numerical weather prediction models), higher resolution in space, spectral frequency and direction, together with the incorporation of improvements to the simulation of some of the physical processes represented in the models.

The increased processing power of the CYBER will allow the resolution improvements referred to above, but it will also make possible an expansion of geographical coverage. This increase in area covered by the models will overcome existing deficiencies as well as lending extra promotional weight to the Ship Routeing Service. Specifically, a tropical ocean model will provide trade-wind swell input to the northern ocean areas, a feature notably lacking in the current models.

Wider coverage introduces the problematic question of validation of forecasts against reliable data. To cover this need the Office is maintaining an interest in state-of-sea measurement by means of high-frequency radar from land stations and by remote sensing from satellites. Such measurements also lead to estimates of wind speed and direction over the sea surface, another very promising source of information in areas of sparse data.

Appendix: Brief description of wave model

The basis of the operational state-of-sea forecast models is a statistical representation of the wave field, rather than an array of discrete values representing individual waves. The spectrum as represented is a function of the variance distribution of the surface elevation; hence such features as significant wave height and a representative wave period can be arrived at by means of the ratio of the appropriate moments of the spectrum at a point.

The point representation is made up of 12 directions (i.e. at 30° intervals) and 11 spectral frequencies ranging from 0.05 to 0.308 Hz (i.e. from 20 to 3.25 seconds period). Thus a sum of very short to very long waves can be assembled for each direction totalling 132 values for each grid point. The models function by considering the evolution of each spectral component through the forecast period, an evolution controlled by physical processes which have varying degrees of effect depending on the specified frequency and direction.

The rate of change of the magnitude of each component during a model time-step can be split into the contribution of individual processes:

(a) *Propagation.* Energy is moved from one part of the wave field to another. In deep water this process occurs without change of direction or speed. Speed of advection is inversely proportional to the frequency of the component.

(b) *Refraction.* As water shallows, the direction and speed of propagation change, following Snell's law. An important effect in the fine-mesh model.

(c) *Growth and decay.* In response to wind forcing, wave initiation and growth take place. Initial wave growth is linear but this stage is rapidly succeeded by an exponential growth stage up to a limit dependent on local wind speed. As waves become too steep they break, resulting in an energy loss; this process is also modelled. Initial growth, and decay through 'white capping', are essentially higher-frequency effects.

(d) *Non-linear interaction.* An internal redistribution of energy between neighbouring frequency components. Observations show that wave energy tends to migrate to lower frequencies than those which are fed in by the wind; i.e. waves become longer.

(e) *Bottom friction.* Owing to the roughness of the sea bed, long-wave components begin to lose energy. Again this is an important effect in the fine-mesh model.

The net result of these processes in physical reality is to shape the spectrum into a form that has been extensively reported in scientific literature. The operational model is to a large degree forced into that representative spectral shape, thus preserving the correct orders of magnitude for the individual physical processes being modelled.

Note: 'Significant wave height' is the mean height of the highest third of the observed waves.

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The Meteorological Office Ship Routeing Service

By Captain G.V. Mackie

(Deputy Marine Superintendent, Meteorological Office)

Summary

The Meteorological Office Ship Routeing Service employs a team of Master Mariners who work closely with forecasters at the Central Forecasting Office, Bracknell. Ships' performance curves are used in conjunction with forecasts of state of sea to estimate optimum routes satisfying various criteria, e.g. least time, minimum damage, maximum fuel saving, etc. Various complicating factors are briefly described as are the financial benefits to be obtained.

1. Introduction

Up to the nineteenth century ships crossing the oceans of the world could only make use of the fund of well-known climatic principles built up by their predecesors. It was not until 1852 that Lieutenant Maury of the US Navy painstakingly collected observations from ships' deck logs in order to compile a volume of recommendations of routes for vessels crossing the Atlantic.

The practice of determining the route for a ship (routeing) from a shore-based centre only became cost-effective in the post-World War II era following the introduction of efficient means of telecommunication and the use of high speed computers to predict the development and movement of weather systems. The first shore-based ship routeing centre was formed in the USA in the 1950s and this was followed by various European state meteorological services during the 1960s. The Royal Netherlands Meteorological Institute introduced a service in 1961 and the Meteorological Office, Bracknell began its service in 1968.

Although the term 'weather routeing' is sometimes used, 'ship routeing' is a more correct phrase since, although the weather is the main factor, the principles of navigation, seamanship, naval architecture, oceanography and marine engineering are also considered in selecting a particular route for a particular ship.

It might be suggested that the Master of a ship would be the best person to choose the route that his ship will follow. He can, of course, obtain climatological data, radio weather bulletins and facsimile charts, but he is a busy man and the information he can get is necessarily limited. At a meteorological centre such as Bracknell, on the other hand, the Ship Routeing Service employs a team of three Master Mariners who devote their whole time to selecting and monitoring the most advantageous and cost-effective routes for those ships which use the Service to follow. This team works alongside the Central Forecasting Office (CFO) forecasters and is provided with an up-to-date flow of analysis and forecast charts, ice information, warnings, bulletins and satellite pictures.

2. The ship routeing method

The first requirement in providing a ship routeing service for any particular ship is to determine the ship's response to the various wave fields it may meet. This is done by extracting data from the ship's deck log-book in order to construct a performance curve (Fig. 1). Next the 24-hour and 48-hour forecasts charts of total significant wave heights covering the route are obtained from the CFO forecasting staff. (See the companion paper, 'The forecasting of state of sea', page 209, for further details of the way these charts are produced.)

The forecast wave height and direction fields are then used, in conjuction with the ship's performance curve, to determine how far the vessel will travel in a 12-hour period over a number of possible courses and the end points of each of the 12-hourly tracks are joined to form a 'time-front'. From selected points

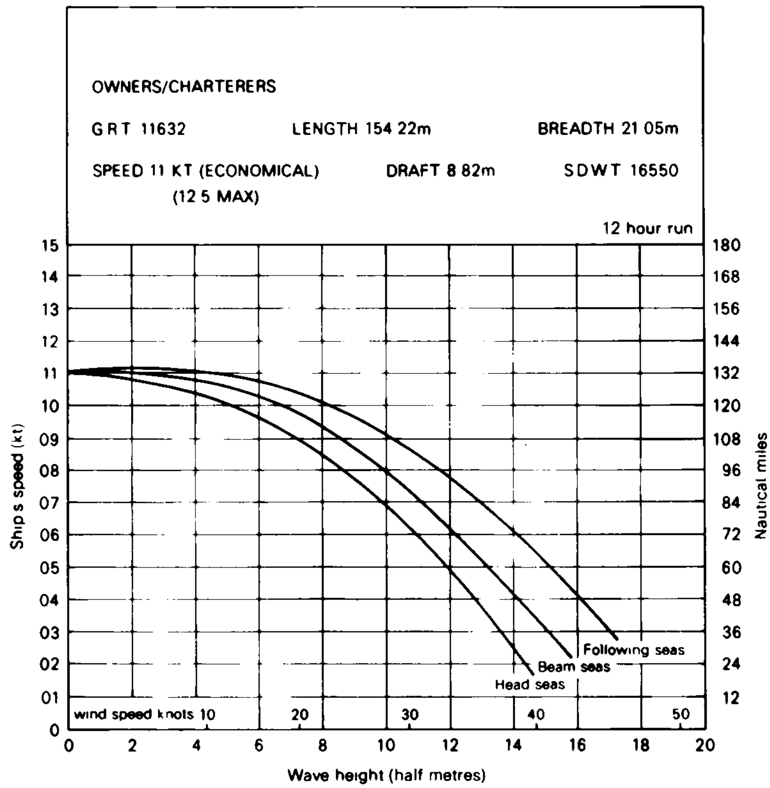

Figure 1. Example of a performance curve graph.

on this time-front the process is then repeated in successive 12-hour steps and this allows a least-time track to be calculated for that part of the route (Fig. 2). In the absence of other external factors this would normally be the course that the vessel would be advised to follow. However, at this stage, subjective consideration must be given to other parameters. The ship router has to consider a number of points, such as:

(a) Is the course navigationally feasible?

(b) Does the state of loading make the heading inadvisable?

(c) Would the time thus gained be lost through adverse currents?

(d) Would the course proposed take the vessel into an area of fog or ice?

Eventually an optimum route is selected and a message is transmitted to the Master advising him to follow the selected route. This message will also include a forecast of wind force and sea direction and height along the route.

During the course of a ship's passage this route is continued daily and the ship's progress is monitored regularly by plotting its position on successive 6-hourly weather charts. The ship maintains contact with Bracknell either by a plain-language message over telex channels or, in the case of Voluntary Observing Fleet vessels, via its 6-hourly coded weather reports.

The first part of the routeing procedure is often modified when, at the start or end of a voyage, the vessel has to pass through restricted waters such as the North Sea, the Caribbean or the Gulf of St

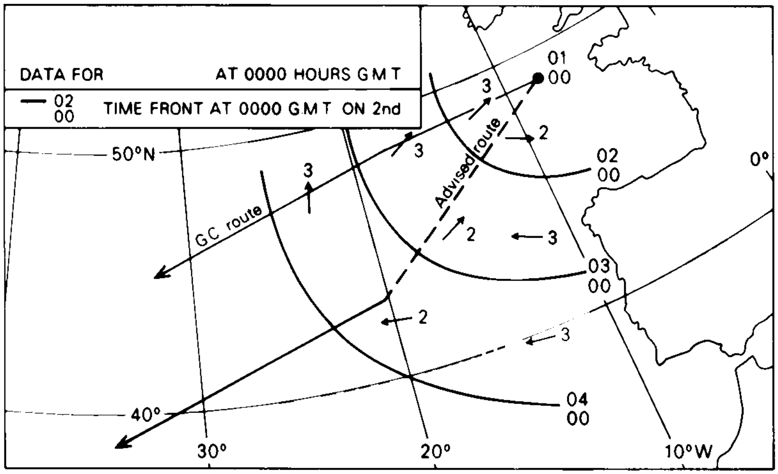

Figure 2. Calculation of least-time track; alternate time-fronts omitted for clarity.

Lawrence, Canada. In these cases the important advice will concern whether the ship should proceed through one channel rather than another. For example, in one particular case a ship was due to leave Middlesbrough bound for St John's, Newfoundland loaded with steel plates. The Master was concerned about her stability and consequently it was essential that she avoided heavy weather, particularly on the beam. The wave forecasts for the period 48 hours after sailing (Fig. 3) showed heavy north-westerly seas off north-west Scotland, so the Master was advised to sail the longer route southwards from Middlesbrough and down the English Channel.

It should be noted that it is always up to the Master of the ship to decide whether to take the advice offered or whether to take an alternative route. In most cases, at the end of the passage the Ship Routeing Section plots a chart showing the forecast passage times and weather on the advised route and compares this with the calculated times and actual weather on comparison alternative routes. This chart is sent to the shipping company to allow it to assess the value of the service for itself. Fig. 4 shows such a chart, in which it is clear that a time saving of almost two days was made by following the advised southern route.

3. The aims of the Ship Routeing Service

The main aim of each routeing service will vary according to the type of ship and the requirements of the operating company. Discussions take place at an early stage between a member of the Ship Routeing Section and the company to define the problems which may arise. The following particular points are likely to be considered:

(a) *Routeing for least time on passage.* When ship routeing began the main aim was to reduce the time on passage regardless of other considerations. Nowadays, however, least-time routeings are mainly confined to oil tankers, which do not suffer cargo damage and are less susceptible to hull damage than other ships. For these ships fuel saving is the prime requirement from the Ship Routeing Service. On the basis of time saved one tanker company has calculated that during one winter of ship routeing in the Pacific an average saving of 30 hours and a total saving in fuel costs of £24 758 was achieved for a cost of £1475 on routeing fees. In the North Atlantic the same company calculated the total saving in fuel costs during the same winter to be £13 118 net.

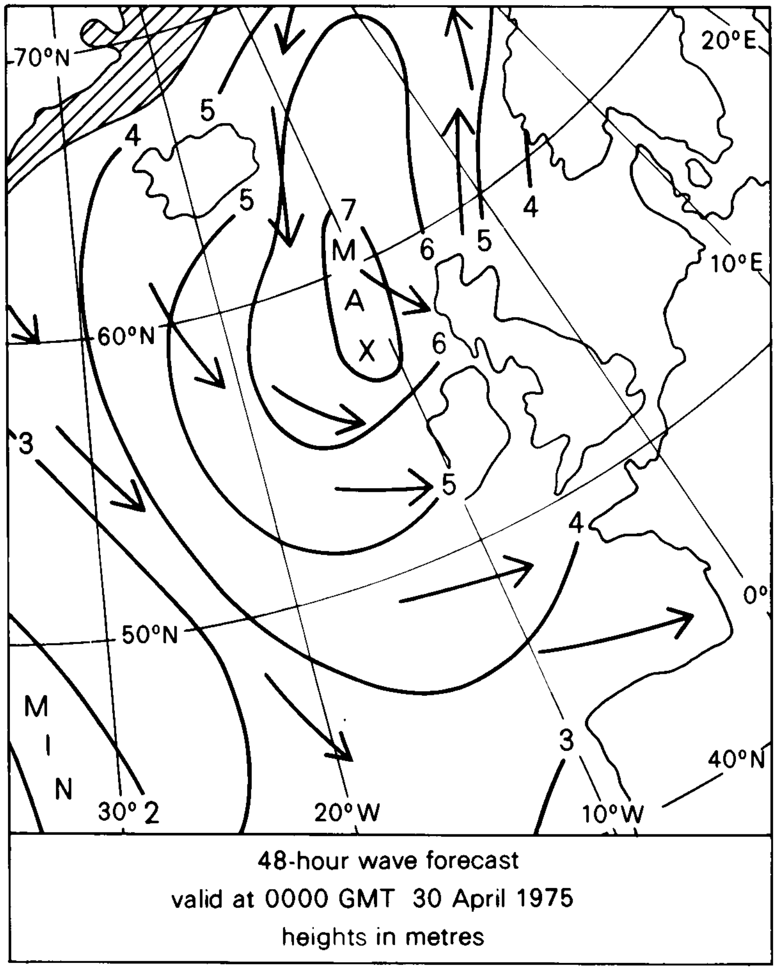

Figure 3. Example of a wave forecast.

(b) *Routeing for minimum-time passage with minimum damage to hull and cargo.* In many cases the shipping company will be concerned to reduce its damage bills and the use of the Ship Routeing Service can be most effective in doing this. For example, one London company carrying paper products from Newfoundland to the United Kingdom, and employing ships liable to hull damage from pounding when in ballast, found that damage bills fell from £30000 per ship per year to negligible amounts by using the Ship Routeing Service. The roueting charge per ship per year was about £300.

(c) *Routeing for least damage.* This is requested when the vessel is carrying a particularly sensitive cargo, such as livestock on deck.

(d) *Routeing for constant speed.* Some ship charters call for the maintenance of a certain speed over a certain time, with a financial penalty for failure. Routeing advice is adjusted to achieve this.

(e) *Routeing for fuel saving.* More recently, with escalating fuel costs, the most significant advantage of ship routeing has been in fuel saving, although this has always been a direct spin-off from least-time

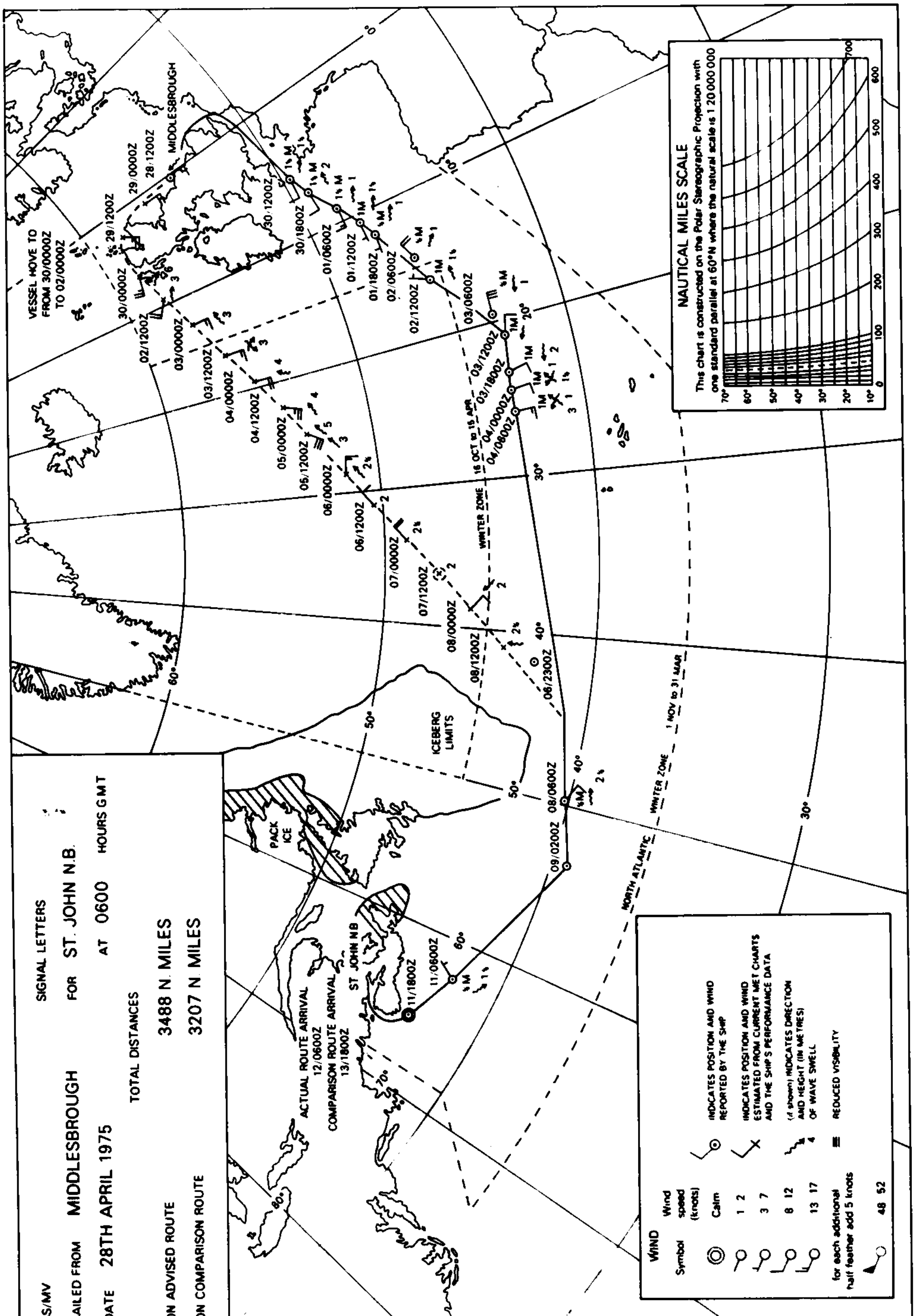

Figure 4. Example of a ship routeing chart.

or least-damage routes. The present charge for ship routeing is equivalent to about two tons of fuel for an Atlantic crossing and three tons on the Pacific, so significant savings can be made on fuel bills (as mentioned at (a) above), even in those cases where service speed has been reduced as part of the fuel economy program. It has been shown that a reduction of about 8% in fuel consumption can be achieved if the ship's engines can be run at constant power. This can be gained only if the ship is routed away from the worst of the weather. Fig. 5 is a schematic diagram showing the effects of weather on vessel operating profits.

(f) *Routeing for tows.* During the last few years the standard routeing service given by the team at Bracknell has been modified in order to give advice on the movement of oil rig and other tows, particularly in those cases where there are limiting weather factors. The standard routeing service is given only on trans-oceanic crossings, usually when eastward moving depressions are avoided by alterations of course to north or south. Where tows are concerned the ship router uses his navigational skills in conjunction with up-to-the-minute meteorological data to advise the tow operators when to sail and when and where to shelter. Recent work has included advice on the movement by barge of a steel jacket from Sardinia to Cherbourg, the towage of the Port of London Authority crane *Mammoth* from Tilbury to Greece, and the movement under tow of the Thames Barrier gates from their construction yard on Tees-side to London, at the specific request of the Chief Marine Superintendent, Cunard, who is nautical adviser for this aspect of the Thames Barrier project. More recently this type of routeing service has been requested by the insurance companies themselves as a condition for their insurance.

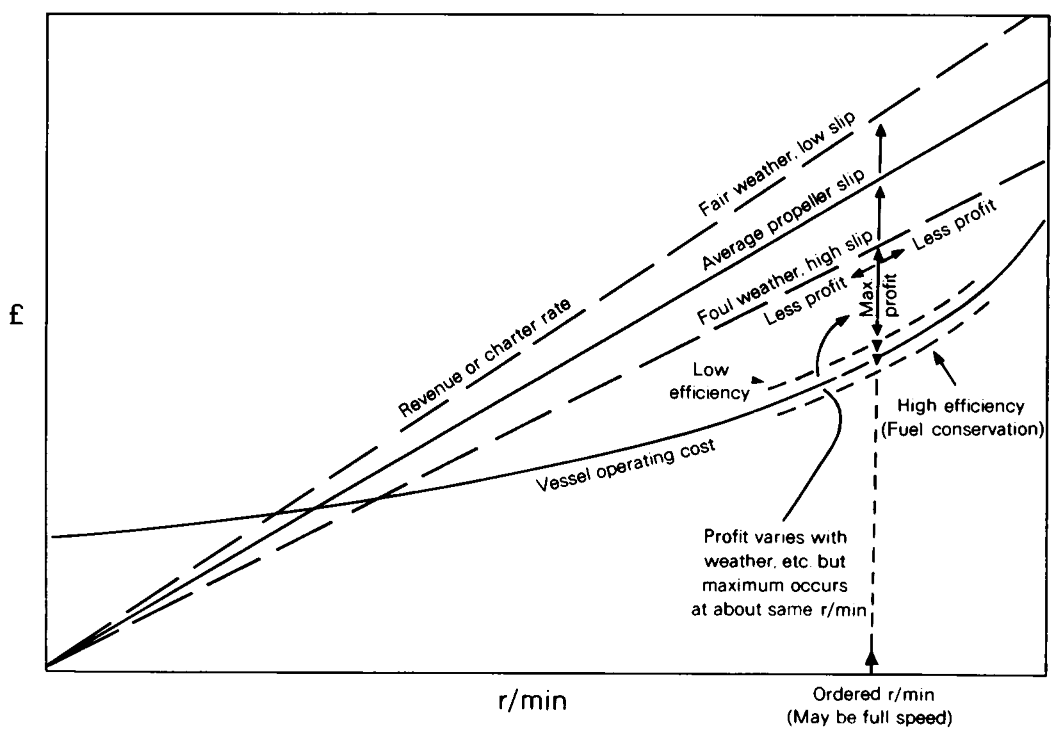

Figure 5. Schematic diagram showing effects of weather on vessel operating profits.

4. Financial aspects of the Ship Routeing Service

The Ship Routeing Service offers the shipping companies a dedicated professional service in which the close contact between the ship's Master and the shore-based centre allows the optimum routes to be selected. This expert selection of route can achieve appreciable savings in time on passage and a significant reduction in the damage to ships or cargo. Reductions in fuel consumption and in time off charter can also be obtained.

For example, the table below was obtained from one of the major UK shipping companies, which operated a very large fleet of UK flag and chartered vessels. This illustrates that substantial savings can be made in fuel usage and therefore in costs.

	Time saved (lost)	Equivalent fuel saving (loss)	
Pacific westbound	77.5 hours	£24758	Net, i.e. cost of routeing has been deducted from the full calculated bunker savings.
Pacific eastbound	(8) hours	£(2156)	
South Indian Ocean	36 hours	£5802	
Atlantic westbound	148 hours	£10053	
Atlantic eastbound	40 hours	£3060	

The value of ship routeing advice to the customer depends in the first place on the existence of adverse weather conditions and secondly on whether such conditions can be avoided. The potential economic benefits, such as the saving on fuel costs and heavy weather damage, can be realized only if conditions along the shortest route are adverse and there is a choice of a more favourable (and navigationally feasible) route.

In the 14 years since the Meteorological Office began the Ship Routeing Service, they have provided routeing advice to 3700 ships, tows, etc. and thereby earned a total of about £552000. The current fees for the Service are £150 for North Atlantic crossings and £225 for passages on other oceans. The Meteorological Office Ship Routeing Service, having the full back-up of forecast information for the entire northern hemisphere from the computer model, and access via the Global Telecommunication System to observations in both the northern and southern hemisphere is able to provide a full global ship routeing advisory service.

Annual receipts from the Service have been increasing steadily over the past three years owing to vigorous marketing and the recognized excellence of the product. They cover in full the staff costs of those directly involved in the Service, plus a significant contribution towards overheads.

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100 mb temperature forecasts for Concorde

By N. J. Atkins

(Meteorological Office, Bracknell)

Summary

Continuity charts of 100 mb temperatures are often used as a forecasting tool but can only give a first assessment. Forecast charts from the operational 10-level numerical model also have certain deficiencies though improvements are expected with a new operational model to be introduced this year. A further method is described for obtaining a 100 mb temperature forecast to meet the needs of stratospheric flights by Concorde aircraft.

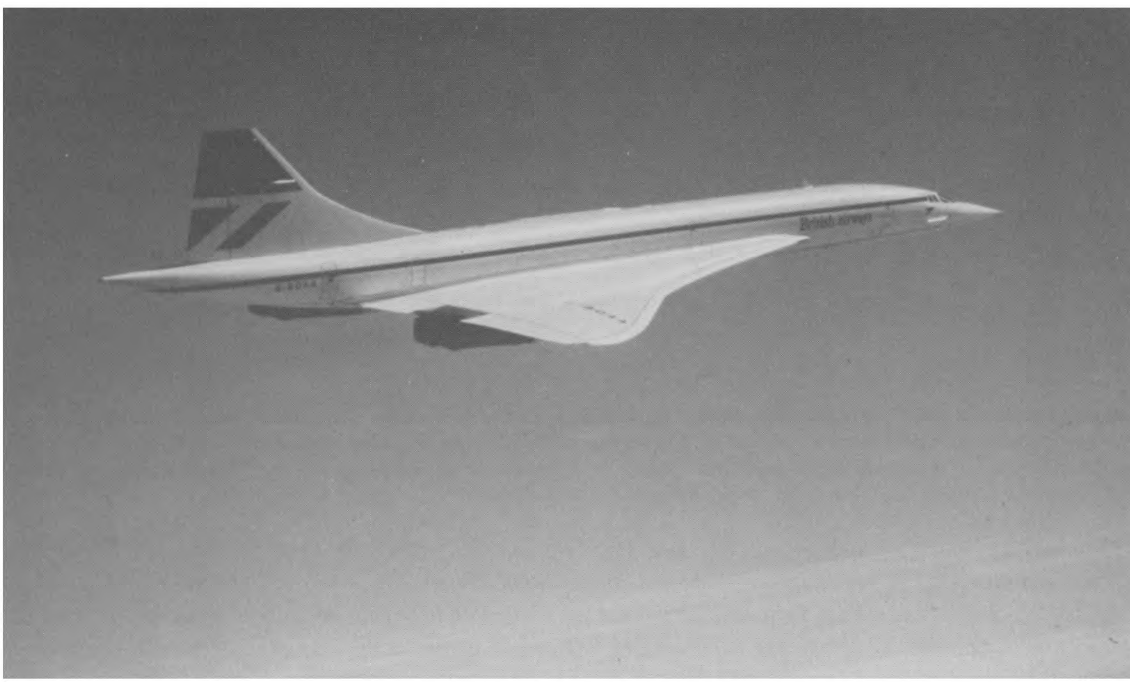
1. Introduction

In 1975 Concorde (see Fig. 1) began scheduled transatlantic flights at heights of up to 60000 feet and for a time flights were also made to Bahrain. From the outset a regular service for Concorde was provided by the Central Forecasting Office (CFO) at Bracknell where some other North Atlantic and European flight forecast charts are also prepared as a routine for aircraft at flight levels lower than those of Concorde. The aviation forecaster at CFO was provided with additional computer output to meet the Concorde forecast requirement but it was soon realized that the 100 mb temperature forecasts from the 10-level model were unable to meet the accuracy required by the operators of Concorde, namely British Airways and Air France.

Straightforward temperature continuity charts often give reasonable results, but are not usually reliable in areas of synoptic development. The method described here uses the 300 mb pattern and usually the results agree with, or improve on, the continuity forecast. The method cannot be applied to flow along straight contours, but in that case the continuity forecast is usually good.

2. Requirements of British and French airlines

The two main meteorological aspects which affect the performance of jet aircraft are wind and temperature, efficiency increasing with a decrease of ambient temperature. At the flight level of most jets the effect of wind is generally more significant but for Concorde, flying at above 50000 feet, the temperature is equally important. For a typical supersonic Atlantic crossing between London and New York the effect of a 1 °C increase in temperature throughout is to increase fuel consumption by about 100 kg. If the ambient temperature is above —51.5 °C the effect is even greater, each 1 °C change making a difference of 350 kg of fuel. This is because the aircraft surface temperature at the normal standard cruise Mach number becomes limiting at —51.5 °C owing to friction, and therefore as the ambient temperature rises above this value, a corresponding reduction in aircraft speed has to be made with a consequent loss of efficiency and increase in fuel consumption.



A British Airways photograph

Figure 1. Concorde in flight.

An example of a 100 mb flight forecast chart is given in Fig. 2 which broadly follows the recommendations contained in the final report of the fifth session of the Commission for Aeronautical Meteorology.* The isotherms are shown by continuous lines and are given in °C as departures from the International Standard Atmosphere (ISA), which at 100 mb is —56.5 °C, at 5 °C intervals. Isotachs are shown by dashed lines at 20 kn intervals (together with areas of MINimum winds) and streamlines of wind direction are shown by arrows. Forecast temperatures at 150 mb (also given as departures from ISA) are supplied in table form for every 10 degrees of longitude along the fixed flight route. Both the route and the table can be seen in Fig. 2. Forecast charts are issued twice daily, at 04 and 11 GMT for validity times of 12 and 00 GMT respectively.

*Fifth session of the Commission for Aeronautical Meteorology. WMO No. 322 (1971).

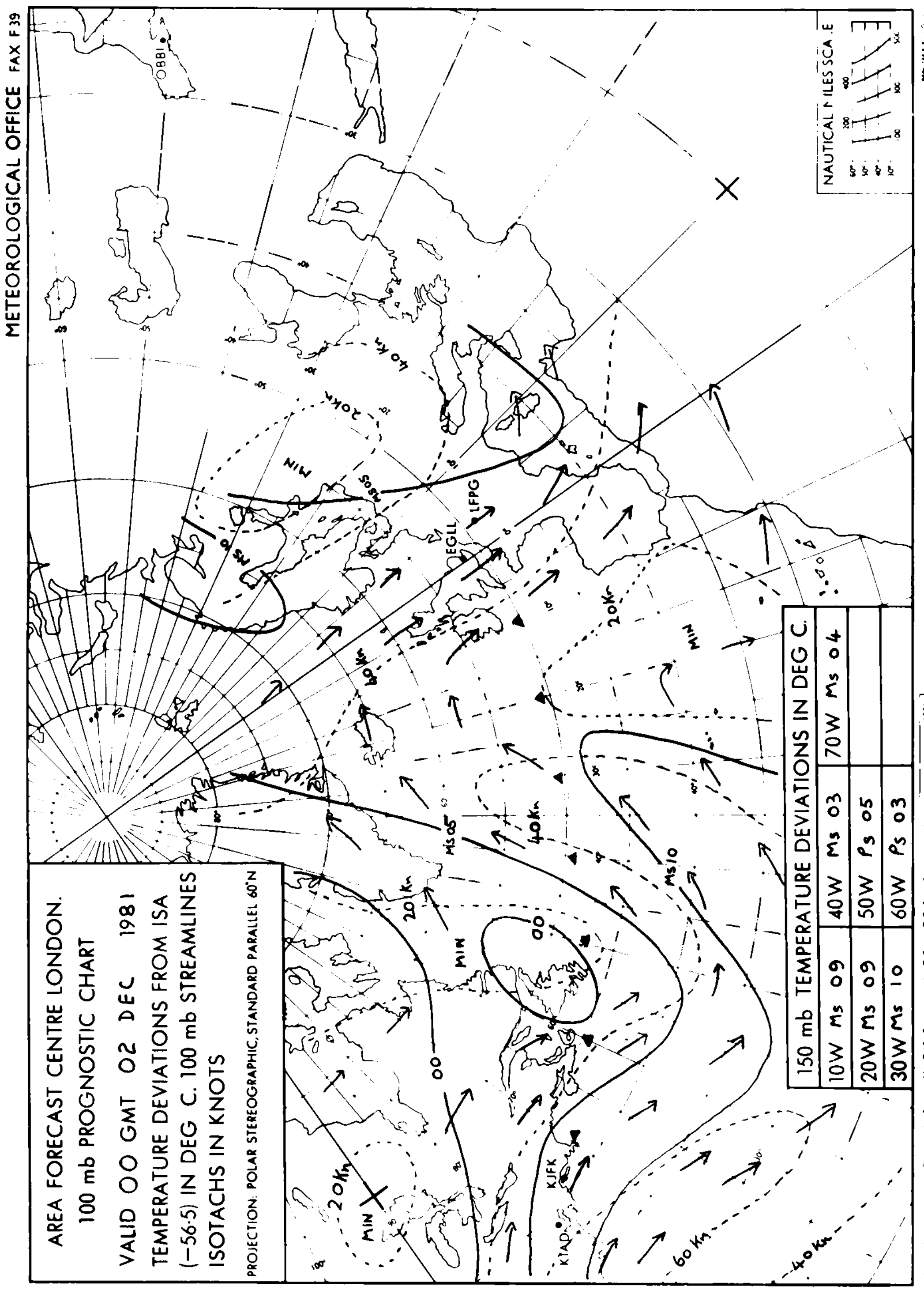


Figure 2. An example of a flight forecast chart for Concorde. (The normal route across the Atlantic has been added, shown by the symbol ▲.) Positive and negative values are indicated by PS and MS respectively.

3. Concorde reports

Reports of wind speed and direction, temperature, flight level and time, are received regularly from Concorde aircraft (both British and French) and are extremely useful for chart analysis considering the sparsity of observations over the Atlantic. It is not intended in this article to dwell on the accuracy of aircraft thermometry but during the first year of scheduled flights, temperature comparisons between reports from Concorde and those from radiosonde stations (Valentia, Camborne and Ocean Weather Ships) suggested that Concorde temperature reports were slightly too high, and that the error may differ between eastbound and westbound flights. In practice, 2 or 3 °C are normally subtracted from the Concorde reported temperature when the 100 mb temperature field is analysed.

4. Computer output

A T+24-hour forecast using data for 00 GMT is available to the forecaster in CFO for the forecast to be issued at 11 GMT; the forecast for issue at 04 GMT, however, is based on a T+24-hour computer forecast using data for 12 GMT the previous day. The computer forecast of isotachs and of wind streamlines are of acceptable standard. This is not so for the 100 mb temperature forecast from the current UK numerical model although the forecast does act as a useful guide to the general pattern of isotherms. The errors arise from the fact that 100 mb is the top level in the current model (note that this will not apply to the new model to be implemented this year). One noticeable feature is that even the analysis is consistently too warm in upper troughs and too cold in upper ridges. An example of this error in an upper trough is seen in Fig. 3 where the geopotential contours have been omitted for the sake of clarity.

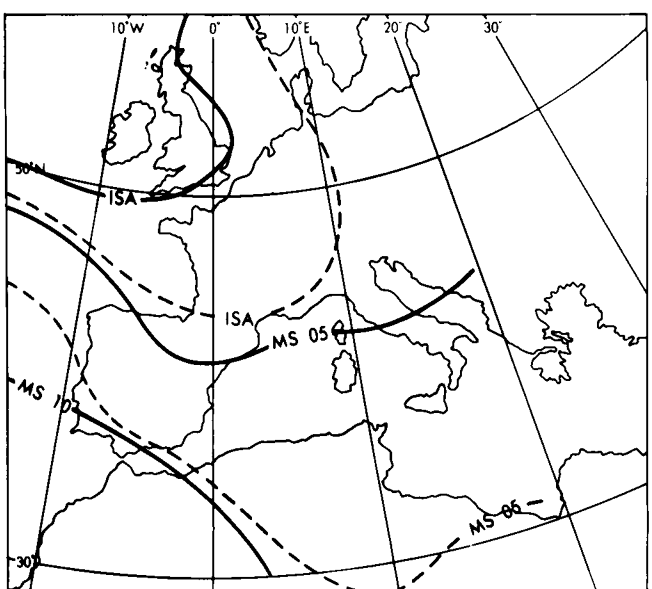


Figure 3. A comparison at 100 mb between the computer analysis (dashed lines) and the analysis of radiosonde temperatures (full lines). Isotherms are given in degrees Celsius as a departure from ISA.

5. A method for obtaining a 100 mb temperature forecast

A first assessment by the forecaster is made using a 12-hourly continuity chart and drawing isotherms as departures from ISA at 5°C intervals; automatically plotted 100 mb charts in conjunction with the computer 100 mb geopotential forecast chart are also used to provide a preliminary consistency check.

The continuity forecast may be unreliable in areas of synoptic development. An example is given in Fig. 4 which shows little continuity between three 12-hour intervals. However, a reasonable forecast can often be obtained by superimposing the 100 mb isotherms (as departures from ISA) on the 300 mb height contours for the same data time (Fig. 5) and then sketching the isotherms on a computer forecast of the 300 mb height contours while maintaining the same relative positions. Points normally used are just ahead of, at the base of, and just to the rear of troughs; ridges can be dealt with in the same way. Difficulty aries when the upper flow pattern is straight or nearly straight but this means that there is no development taking place and continuity alone will probably suffice. The final assessment is made by comparing the continuity forecast with this second method, tending towards the latter in development areas.

Fig. 6 shows the positions of the 100 mb isotherms relative to the 300 mb geopotential contours after a period of 12 hours from the time of Fig. 5. In this example, the upper trough sharpened as it moved east from Spain to Italy. It can be seen that the −61.5°C isotherm (i.e. −5°C departure from ISA) stays between the 924 and 936 decageopotential metre contours at the base of the trough although moving northwards; the −66.5°C isotherm (i.e. −10°C departure from ISA) remains close to the 948 decageopotential metre contour. It should be remembered that even though there are plenty of observations the isotherms cannot be accurately placed in the analysis because of observation errors.

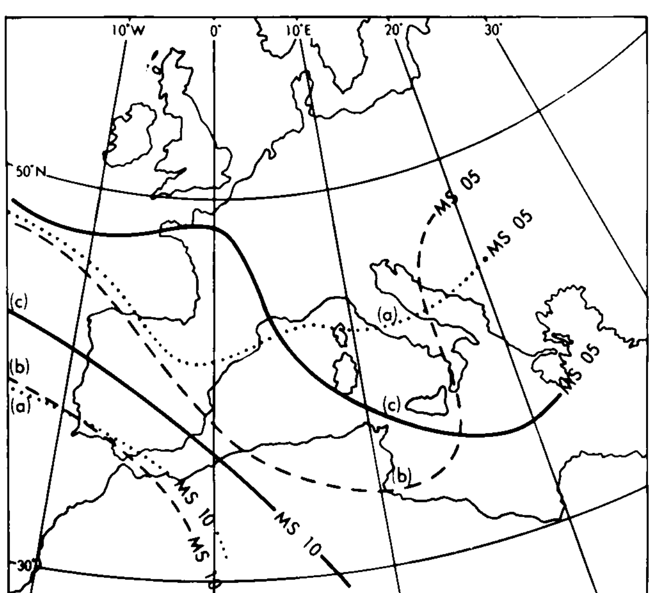


Figure 4. 12-hourly 100 mb isotherms in degrees Celsius as a departure from ISA for (a) 12 GMT 12 December 1981, (b) 00 GMT 13 December 1981 and (c) 12 GMT 13 December 1981.

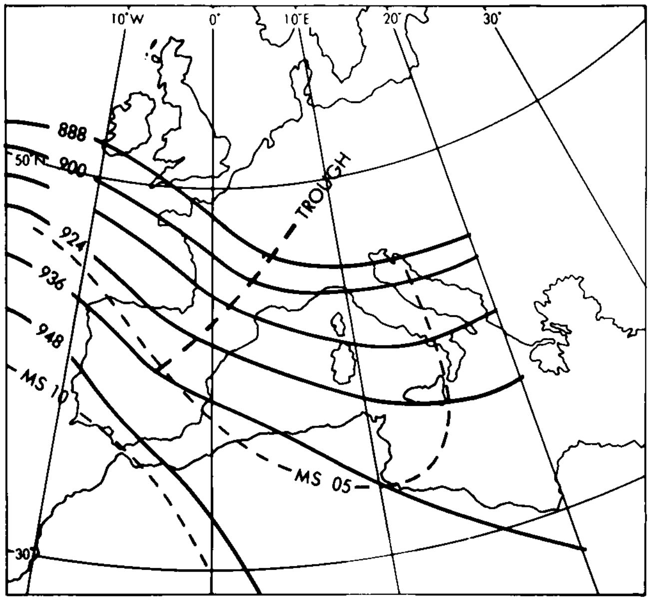


Figure 5. 300 mb contour chart for 00 GMT 13 December 1981. Values in decageopotential metres. Relative positions of the 100 mb isotherms, in degrees Celsius as a departure from ISA, are also shown.

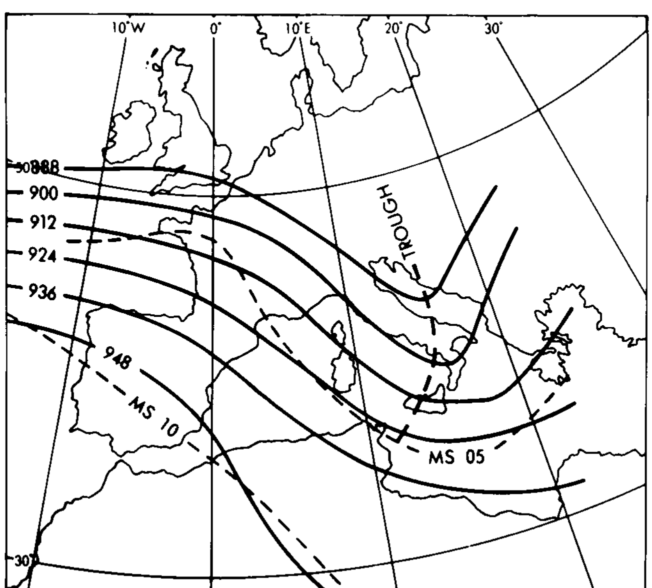


Figure 6. A similar chart to Fig. 5, 12 GMT 13 December 1981.

Although not illustrated, the 300 mb computer forecast for 12 GMT 13 December 1981 agreed reasonably well with Fig. 6 but the trough over Italy was not quite sharp enough and the 924 and 936 decageopotential metre contours were about 2 degrees of latitude further south. Fig. 7 shows the forecast prepared by the method of this section and its improvement over a continuity forecast. Experience has shown that this method considerably reduces the errors that would have been made with a simple continuity forecast.

Note that no useful guidance can be obtained by using the 100 mb geopotential contours in place of the 300 mb contours since the upper flow is considerably smoothed out when temperature changes of only 5° C or so are being dealt with.

6. Completion of the Concorde flight forecast chart (Fig. 2)

The computer handling of the 150 mb temperature is better than that of the 100 mb since the former can be derived directly from the model fields, reducing the error mentioned in section 4. The computer forecast is therefore compared with a 12-hourly continuity chart, and between the two of them a reasonable forecast can be obtained. Streamlines and isotachs are drawn directly from the computer product but with some modification in the light of up-to-date aircraft reports.

7. Concluding remarks

(a) Scheduled times of issue are not ideal. It can be seen from sections 2 and 4 that the forecast for 12 GMT issued at 04 GMT uses a computer 24-hour forecast based on data for 12 GMT the previous day, i.e. with only 8 hours of the forecast period left.

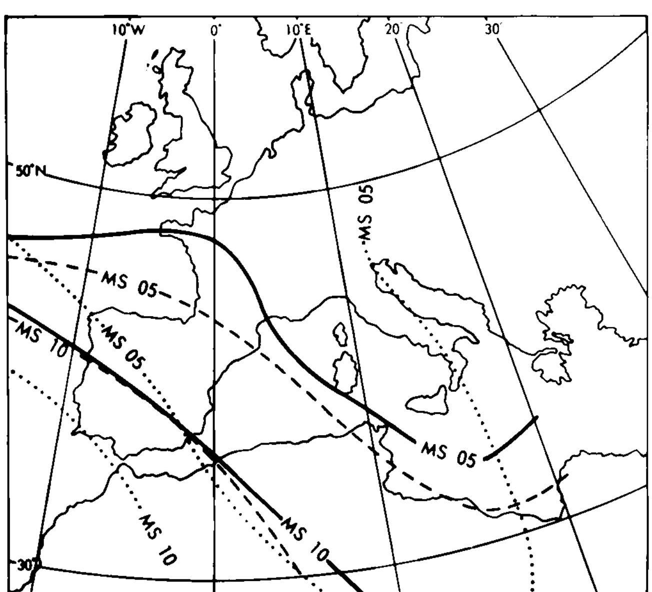


Figure 7. A comparison between the analysis of the 100 mb isotherms (full lines) with the forecasts obtained by continuity (dotted lines) and with the 300 mb contour method (dashed lines) described in section 5. 12 GMT 13 December 1981. Isotherms are given in degrees Celsius as a departure from ISA.

(b) The 10-level model at present in use at Bracknell is to be replaced by a 15-level model extending up to near 20 mb and the quality of the 100 mb temperature fields are expected to improve.

(c) Reports from Concorde over the Atlantic should be a useful source of information for the new 15-level model, provided a detailed check is made of the thermometry to determine corrections to be applied.

(d) A certain amount of continuity is used when analysing the 100 mb temperature chart where observations are sparse, but the analyst is advised to watch carefully any development at 300 mb.

(e) Temperature forecasts at 100 mb can be improved by determining the relationship between the analysed 300 mb geopotential contours and the 100 mb temperatures and extending this using the computer 300 mb contour forecast.

Acknowledgements

I thank British Airways for providing the photograph of 'Concorde in flight' (Fig. 1) and in particular Mr T. C. R. Guest, Manager, Navigation Services, for the information relating to fuel consumption.

551.553.6(41-4)

An index of windiness for the United Kingdom

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Summary

An index has been formulated which gives an objective measure of the relative windiness of past months, seasons and years for three regions covering the United Kingdom. The index is based on the standardized anomalies of monthly mean speeds at a number of stations. Daily grid-point surface pressure data have been used to estimate the value of this index for all months from January 1881 to December 1980.

1. Introduction

The increasing degree of interest shown in the potential of wind power as an alternative energy source has led to the Meteorological Office receiving a number of enquiries regarding wind speed frequency distributions at different sites. Although the Meteorological Office holds records of hourly mean speeds in machinable form for over 200 stations in the United Kingdom (UK), many of these records are of less than 15 years' duration and are not homogeneous in time owing to site, exposure or instrument changes. As a result, it is often difficult to analyse the spatial variation of wind speed distributions over the UK.

The Investigations Group of the Climatological Services Branch is addressing this problem by developing stochastic models of time series of hourly mean speeds for various locations in the UK. These models are based on the comparatively short periods for which machinable data exist and it is therefore necessary to know just how representative are the periods from which the models are being derived.

For this reason, and indeed for other applications, there is a need to be able to assess objectively the windiness of a particular period, be it a month, season or year. It appears that no such indicator or index exists for the UK. This is probably because:

(a) Any study of wind speeds at different stations is complicated by the fact that speeds can vary substantially over short distances in the vertical and in the horizontal, particularly at the heights at which speeds for climatological purposes are recorded. The exposure of anemometers in the UK varies from station to station and, although an effective height of 10 m is the recommended standard, many stations have their instruments positioned at other heights; they may be on the tops of buildings, for example.

(b) At any one station there may have been changes in the type of anemograph or changes of site or both. Many stations observing during the 1950s and 1960s replaced a pressure-tube anemograph by a Mk 2 (and subsequently a Mk 4) cup generator anemograph. Work by the present author indicates that Mk 2 and Mk 4 cup generator speeds are on average about 1–2 kn higher than pressure-tube values (Smith 1981). It is also possible that readings from the Mk 5 cup generator, recently installed at several UK stations, are not consistent with those from the Mk 2 and Mk 4. Site changes can also occur quite frequently (for reasons such as the construction of buildings close to the anemometer) and speeds from one site are often not consistent with speeds from another.

Despite these problems, work has been undertaken to devise an index of windiness using stations that appeared to provide reasonably long-period homogeneous records of wind speeds. Indices were determined initially on a monthly basis and then means of successive monthly indices were taken to construct seasonal and annual values. In the second part of this paper a procedure for estimating index values based on surface pressure gradients is described and results given. Estimates have been produced for months from January 1881 onwards, well before anemograph observations become available.

Possible applications of the index are:

(a) to gauge the long-term year-to-year variability of wind speed,

(b) to determine the representiveness of speeds in a specific period relative to speeds from a longer period,

(c) to act as a quality control of mean wind speeds at individual stations, and

(d) to study climatic change.

2. Index values based on anemograph data

2.1 *Stations and data*

A total of 17 stations having data considered to be reasonably homogeneous for the period 1965–79 were selected for the analysis. Their locations are shown in Fig. 1; the regions delineated are discussed later. The distribution of the stations across the country is seen to be fairly uniform. (Unfortunately, there are no suitable stations available to fill the 'gaps'.) With the exception of Benbecula, Leeming and Honington each of these stations has hourly mean speeds recorded each hour of the day for the period 1965–79 with:

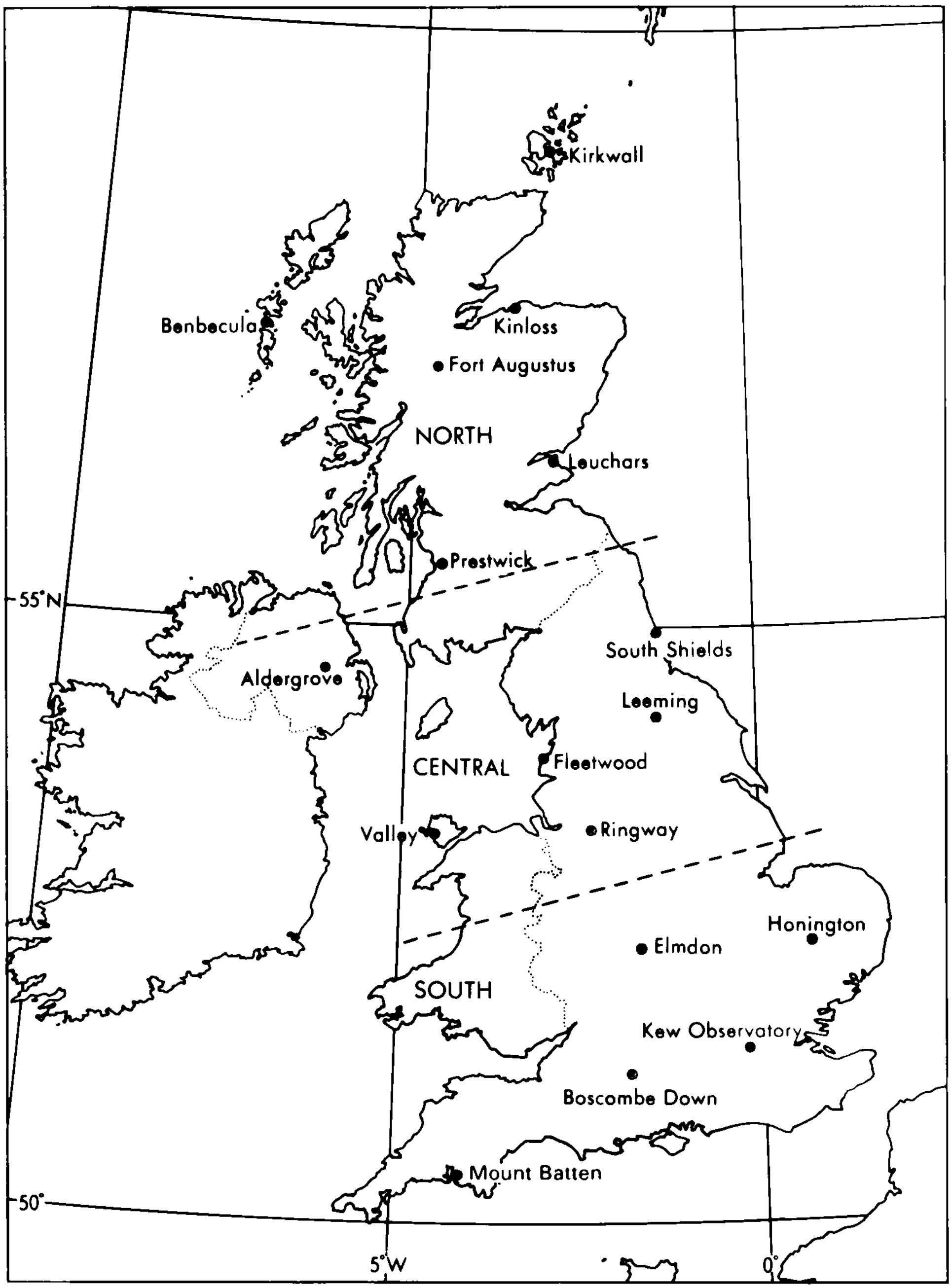

Figure 1. Location of the stations and regions used for the derivation of the values of the index.

(a) no more than 170 missing observations in any month,
(b) no recorded change of instrument from a pressure-tube to a cup generator anemograph, and
(c) no recorded site change.

At Benbecula there was a site and instrument change on 1 April 1965. For Leeming and Honington data are available only from December 1965 and October 1969 respectively.

Monthly mean speeds were determined for all stations for each month from January 1965 to December 1979. Missing values for Leeming were estimated from Ringway data. For Honington, data from Mildenhall (only 25 km from Honington) were used to derive estimates for the period 1965–1968, with Elmdon speeds used for estimating values for January – September 1969.

2.2 *Formulation of index*

An index of windiness based solely on the absolute magnitude of the wind speed at different stations would be unsatisfactory because its value would depend greatly on the locations and sites of the stations chosen. The index is therefore based on the standardized anomaly of each month's speed relative to a long period monthly average.

The average and standard deviation of the monthly means from 1965 to 1979 were calculated for each of the 17 stations and for each month of the year. The difference between the mean speed for an individual month and the long period average for that month was then determined and expressed as a proportion of the standard deviation. So, for each station, a series of monthly standardized anomalies, y_i, were obtained, given by

$$y_i = \frac{x_i - \bar{x}}{\sigma} \quad \ldots \quad (1)$$

where x_i is the mean for month i, and $\bar{x}$ and σ the 1965–79 average and standard deviation of the individual means for the month in question.

The distributions of y_i have zero mean but are somewhat positively skewed because positive anomalies of monthly mean speeds tend to be larger in absolute value than negative anomalies.

The values of y_i for each station are shown for January 1974, a windy month, and for August 1976, a month with below-average speeds, in Figs 2(a) and 2(b) respectively.

It was observed, quite frequently, that the standardized anomalies varied considerably across the country in a consistent fashion (although not in Figs 2(a) and 2(b)). It therefore seemed appropriate, for the purpose of formulating a windiness index, to divide the UK into regions. In general the spatial correlation of wind speed is greater in an east–west direction than in a north–south direction, owing to the predominantly zonal movement of synoptic features at mid-latitudes. A north–south division of regions was therefore chosen and the regions are shown in Fig. 1. The south region contains five stations and the others, six stations each.

The final step in deriving the index I was, for each region and for each month, to take the arithmetic mean of the y_i values over the stations within the region. This averaging reduces the effects of any inconsistent values in a region, such as the rather low values for Fleetwood and South Shields observed in Fig. 2(a), and should produce a quantity which is more representative of the region as a whole than could be obtained from any single station.

Winter (October to March), summer (April to September) and annual (January to December) indices were also obtained for each region by averaging the monthly indices over the appropriate months, then

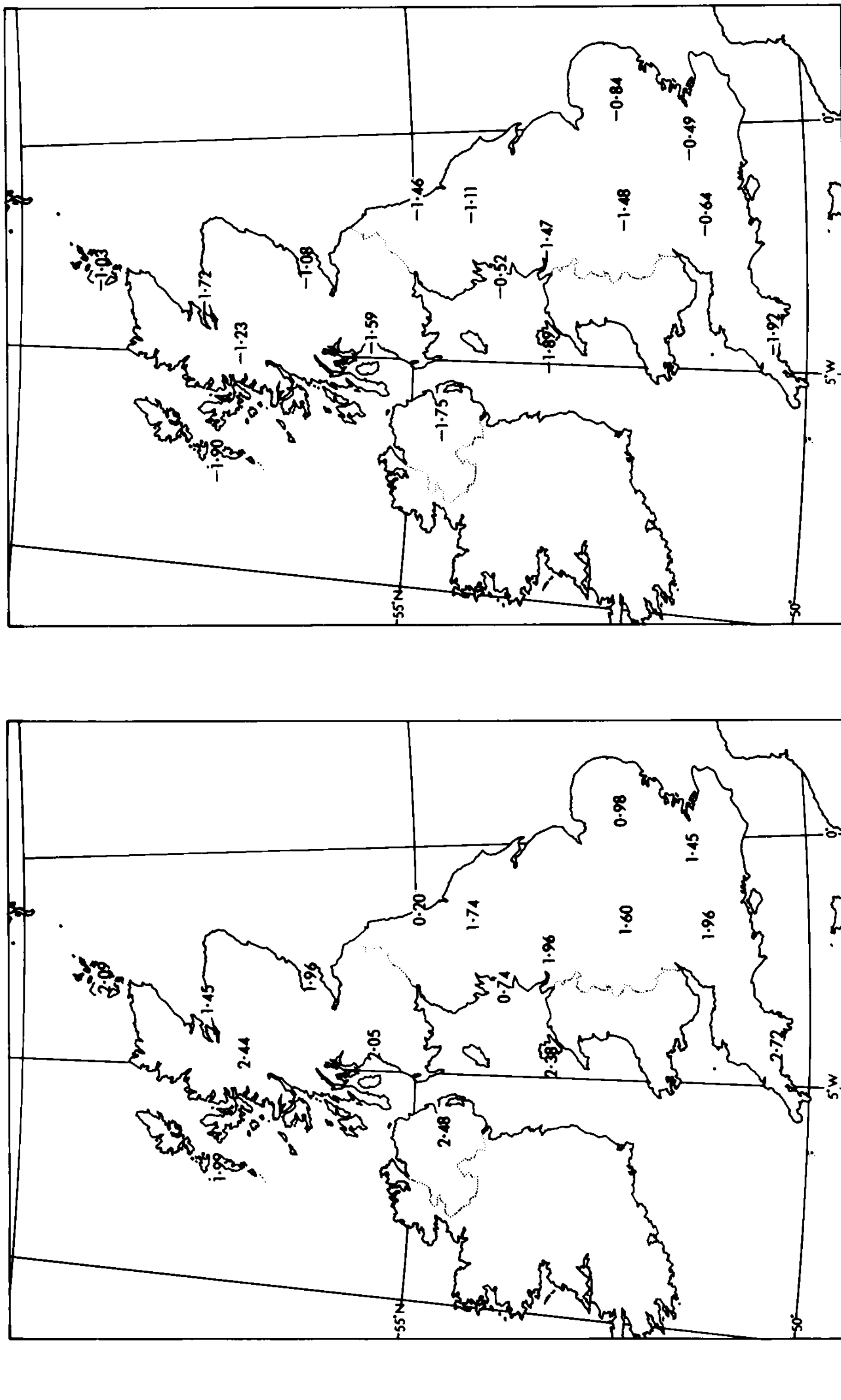

Figure 2. 'Standardized anomalies' of monthly mean wind speeds (see text) for (a) January 1974 and (b) August 1976.

expressing each value as a proportion of the standard deviation of the derived averages for the season (or year) over the period 1965–79*.

Note that it is possible to derive estimates of the absolute monthly mean speeds, say, for a particular site from the corresponding regional monthly indices if the 1965–79 means and standard deviations for the site are known or can be estimated.

2.3 *Results*

In what follows, I_n, I_c and I_s will denote the indices for the north, central and south regions respectively, I the collective term for these indices and 'quiet' will be used as an antonym of 'windy'.

I_s is plotted for January and July as the full line in Fig. 3. (The 'estimated' values also shown in this and the next two figures are explained in the next section.) For January, a noticeable feature is the run of windy months between 1974–76. The graph for July indicates that, for the south, Julys between 1968 and 1973 inclusive were quiet except for 1970.

I_n, I_c and I_s are shown for winter, again as the full lines, in Fig. 4. Values are plotted against the year in which January–March fell. Taking the three regions together, the windiest winter was 1966–67 and the quietest, 1976–77.

Annual indices are plotted in Fig. 5. The year 1967 was the windiest with 1971 and 1976 the quietest.

3. Estimated index values based on surface pressure gradients

3.1 *Preliminaries*

It was not feasible to produce index values based on anemograph data for years prior to 1965 because the number of stations with homogeneous data extending from before 1965 to at least 1979 decreases rapidly as one goes back in time. The possibility of using daily surface pressure values (which are available from 1 December 1880 onwards) to derive wind speeds and hence indices was therefore explored.

The Synoptic Climatology Branch of the Meteorological Office have produced time series of daily southerly and westerly 'flow indices' for various grid points around the British Isles, obtained from surface pressure gradients at midnight or midday. From these indices the wind speed W_j at the jth grid point can easily be determined. Details of the procedure are given in the Appendix. W_j is equivalent to geostrophic speed at 55° N 5° W and approximately geostrophic speed at other grid points. Speeds from six grid points (see Fig 6) were used to estimate I_n, I_c and I_s.

Monthly means of W_j were produced for these grid points from January 1881 to December 1980 by averaging the daily values. Unfortunately the data are not homogeneous because the grid-point surface pressures have been obtained from different sources based on different analysis schemes—the sources are listed in Benwell (1976). Jenkinson and Collison (1977) suggest adjustment factors to homogenize high daily values of W_j. They advocate adding 9% to observations in the periods 1899–1939 and 1949–59 and 25% to values in 1960–65. A comparison of annual means of W_j against annual values of I_s for 1965–80 and a time series plot of annual W_j indicated that the addition of 25% for 1960–65 speeds is probably too high for the present application. A correction of +20% was therefore used instead, with +9% still applied to the two earlier periods. These adjustments are rather speculative in view of the lack of supporting data, especially for the earlier years, but they are considered to be the best available.

*Index values have now been calculated for each month, season and year for 1980.

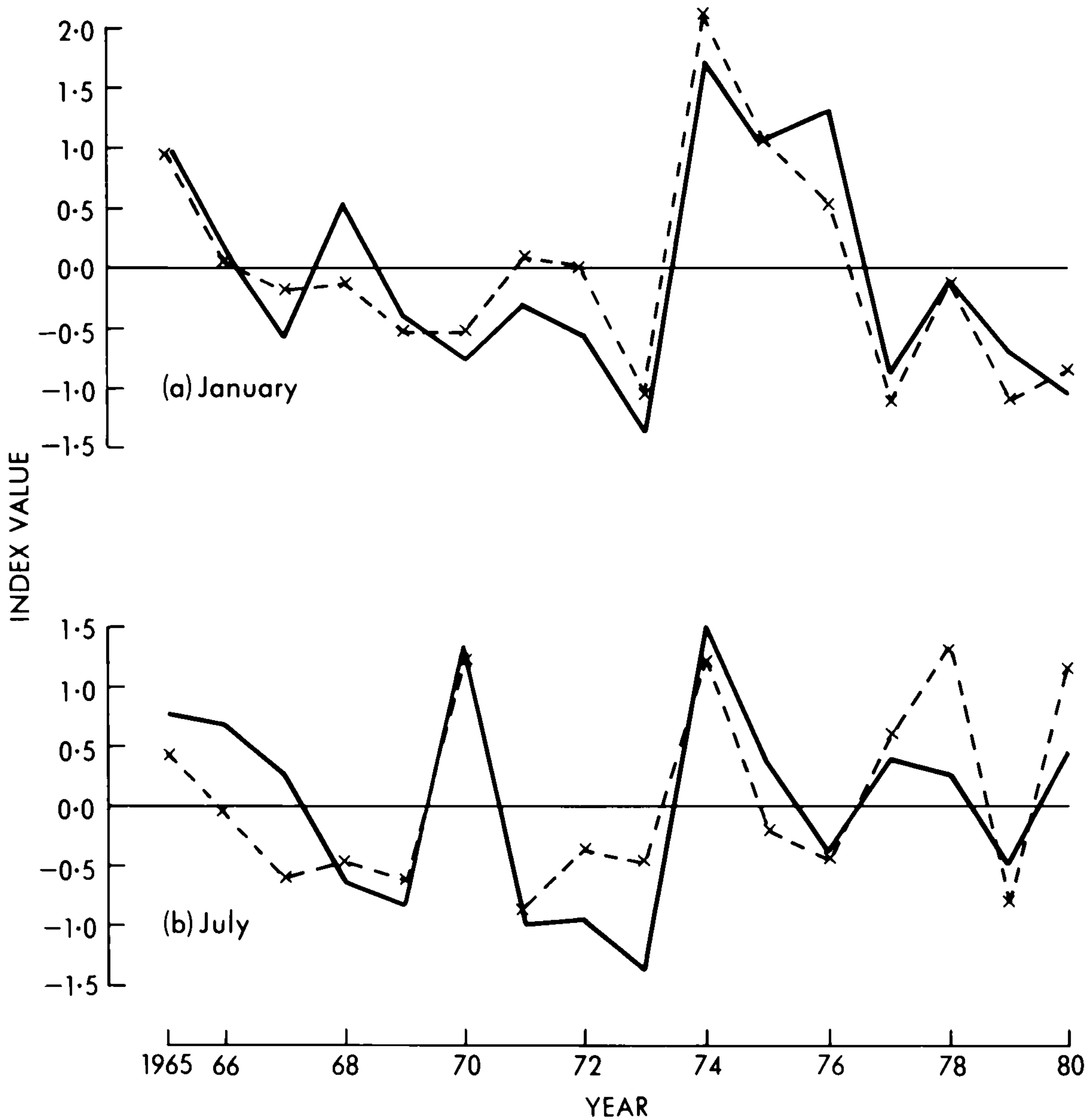

Figure 3. Actual (full lines) and estimated (dashed lines) values of the index of windiness for January and July, south region.

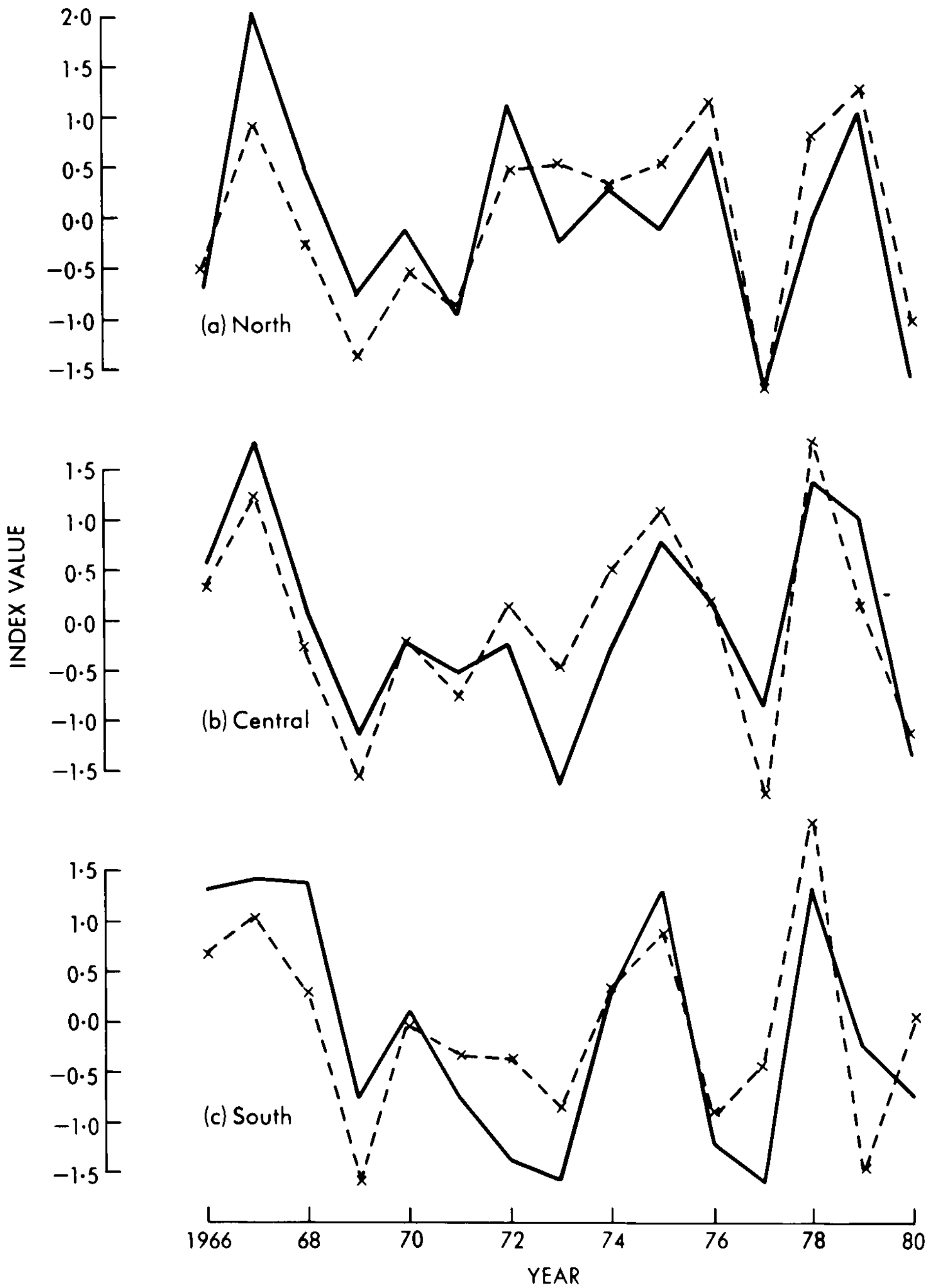

Figure 4. Actual (full lines) and estimated (dashed lines) values of the index of windiness for winter (Oct. Mar.), all three regions.

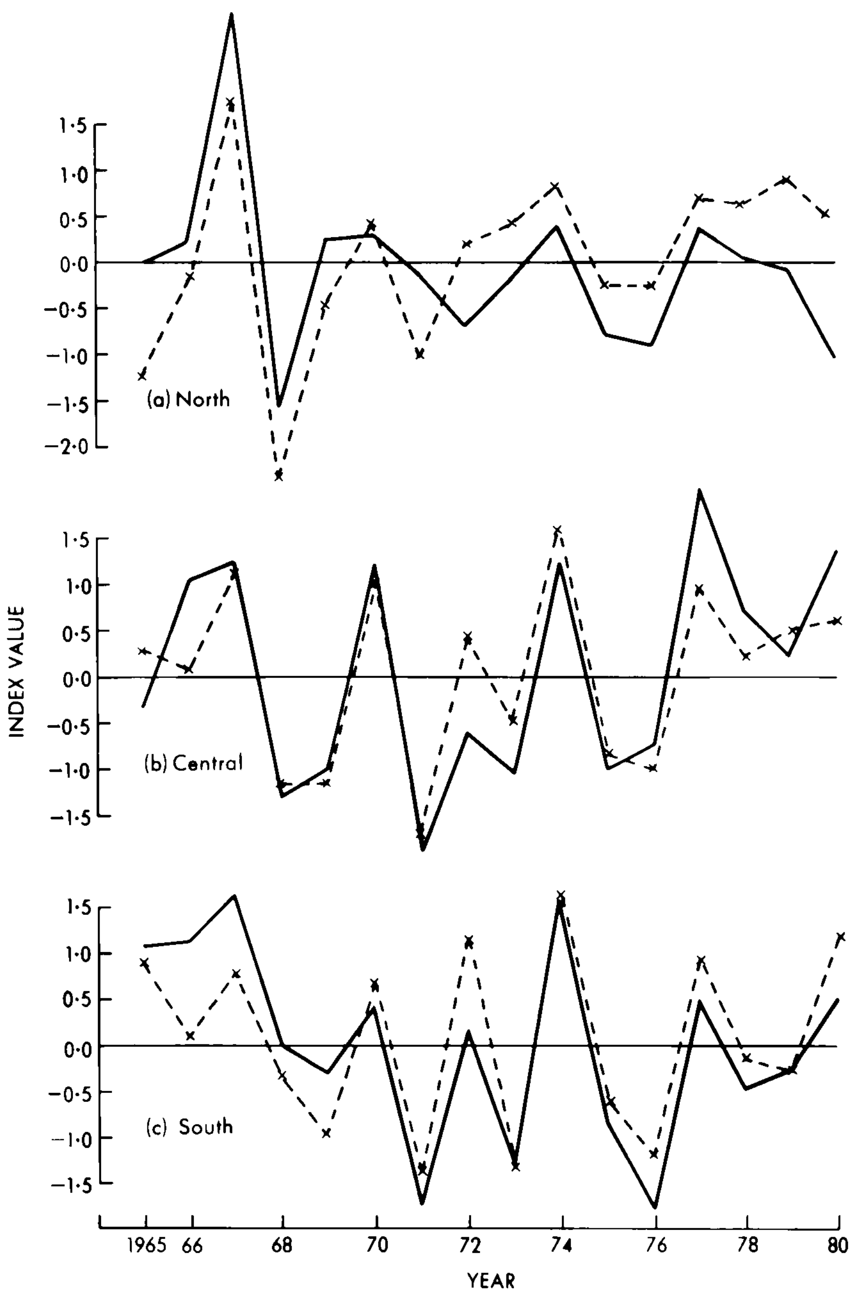

Figure 5. Actual (full lines) and estimated (dashed lines) values of the index of windiness for the year, all three regions.

Means and standard deviations of adjusted monthly W_j were calculated for each month of the year and over the same period for which I had been determined, namely 1965–79. Monthly standardized anomalies (S_j) were then produced using the form of equation (1) for each grid point from 1881 onwards.

3.2 *Estimation procedure*

It was next required to estimate I_n, I_c and I_s using the six grid point S_j as predictors. To obtain the regression equations the stepwise regression computer program BMDP2R, available in the BMDP statistical package (University of California 1979), was run on 192 monthly values—January 1965 to December 1980 inclusive—of I_n, I_s and I_c separately with corresponding grid point S_j.

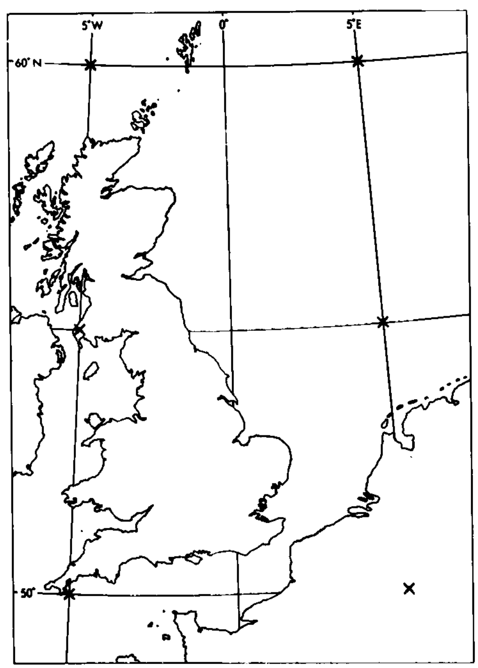

Figure 6. Location (X) of grid points used for the estimation of the values of the index.

The resulting regression equations are presented in Table I. The BMDP 'all possible subsets regression' program (BMDP9R) was applied to subsets of the sample of 192 cases to study the mathematical stability of the equations. Results were found to be satisfactory.

The standard error of the residuals and the squared multiple correlation coefficient are also shown in Table I. The magnitude of the latter, representing the fraction of the variance of I explained by the regression, indicates that the estimates are reasonable approximations to I_n, I_c and I_s.

The variance of the estimated indices (which will be denoted by $\hat{I}_n$, $\hat{I}_c$ and $\hat{I}_s$) was observed to be about 15% less than the variance of the actuals. This arises from the smoothing inherent in the regression equations. $\hat{I}_n$, $\hat{I}_c$ and $\hat{I}_s$ were therefore multiplied by appropriate factors to restore the original variances.

Table I. *Regression equations for estimates of monthly indices*

Region	Equation	Standard error of residuals	Squared multiple correlation coefficient
North	$\hat{I}_n = 0.25S_2 + 0.63S_3 - 0.13S_6$	0.39	0.77
Central	$\hat{I}_c = -0.11S_1 + 0.69S_3 + 0.18S_6$	0.39	0.76
South	$\hat{I}_s = 0.41S_5 + 0.34S_6$	0.48	0.69

S_j represent monthly standardized speeds at grid point j where
$j = 1$ corresponds to 60°N 5°W
$j = 2$ corresponds to 60°N 5°E
$j = 3$ corresponds to 55°N 5°W
$j = 5$ corresponds to 50°N 5°W
$j = 6$ corresponds to 50°N 5°E

Finally seasonal and annual estimates were determined from the monthly values by averaging and standardizing, as carried out for the actual indices.

3.3 *Comparison between estimated and actual index values*

Fig. 3 displays I_s and $\hat{I}_s$ for January and July between 1965 and 1980. The standard error of the estimates is greater for July and in general there is a slight tendency for errors to be larger for the summer months compared to winter months. Also the correlation between monthly indices for different regions is in general lowest in the summer months. These findings probably arise from the fact that in summer, winds are lighter and pressure systems less intense leading to a weaker relationship between pressure gradients and surface wind speeds and a higher spatial variation. The plots visually confirm that $\hat{I}_s$ is a reasonable indicator of I_s.

Winter and annual values of the actual and estimated indices are shown for all three regions in Figs 4 and 5. Again the year-to-year variation in the actual values is well reflected by the movement of the estimated indices. There does appear to be a bias in the estimates, particularly those for the north, in that the estimates tend to be lower, relative to the actuals, before 1972 than in subsequent years. This may arise from a change in the analysis of surface pressures around 1972.

4. Results

The estimated index values need to be treated with some caution, not only because they are estimates and are therefore subject to error but also because it is probable that the effects of the inhomogeneities present in the surface pressure data have not been completely removed by the adjustments made to W_j. However the estimates should provide a useful guide to the relative windiness of a month, season or year.

Annual means of the estimated indices are plotted for the different regions in Fig. 7 together with the seven year running mean calculated using 1/64, 6/64, 15/64, 20/64, 15/64, 6/64, 1/64, as 'binomial' weights. The windiest periods are the 1920s and 1950–64. The quietest periods are 1930–47 for the north and central regions and the late 1960s onwards for all regions. The last-named is of particular interest, of course, because most of the available anemograph data relate to this period. The values for a number of years show large variations between regions e.g. 1882, 1898, 1965 and 1973.

Table II gives the windiest and quietest months, seasons and years for each region over the period 1881–1980 based on estimated values throughout. The only month to be the windiest in all regions is February 1903; note also that the following month, March 1903, is the windiest March for two regions. Examination of daily weather summaries for February and March 1903 indicated that during these months a succession of vigorous depressions passed over or close to the British Isles. The distribution of windiest months through the 100 years is fairly even. For the quietest averages, June 1895 and December 1890 are extreme months for all three regions. Study of weather summaries revealed that the weather at these times was dominated by high-pressure systems. The most recent years have given several low extremes, a feature which is particularly noticeable on the seasonal and annual time scale.

Finally, to present the indices for all months together in a convenient form the monthly values for each region have been averaged and are shown in Table III. Again estimated values have been used throughout. Occasions when the range of values I_n, I_c and I_s exceed 1.5 are marked with an asterisk; for these months the variation in windiness across the UK is thus relatively large. The windiest month (relative, of course, to the 1965–79 mean for that month) is seen to be February 1903 and the quietest months are the Novembers of 1942, 1945 and 1958. One interesting feature of the values is the small number of Augusts with below average speeds between 1881 and 1930.

Table II. *Windiest and quietest monthly, seasonal and annual averages for the period 1881–1980*

	North		Central		South	
	Windiest	Quietest	Windiest	Quietest	Windiest	Quietest
Jan.	1916	1881	1916	1881	1937	1953
Feb.	1903	1942	1903	1917	1903	1891
Mar.	1967	1929	1903	1929	1903	1946
Apr.	1949	1974	1947	1974	1947	1956
May	1956	1977	1964	1940	1972	1978
June	1923	1895	1923	1895	1882	1895
July	1928	1968	1954	1955	1954	1901
Aug.	1940	1947	1891	1937	1891	1937
Sept.	1950	1894	1950	1972	1954	1971
Oct.	1934	1914	1934	1937	1891	1978
Nov.	1888	1882	1888	1942	1881	1934
Dec.	1974	1890	1974	1890	1929	1890
Winter (Oct.–Mar.)	1881–82	1976–77	1902–03	1887–88	1902–03	1952–53
Summer (Apr.–Sept.)	1919	1968	1923	1971	1882	1976
Annual	1923	1968	1923	1971	1882	1971

5. Future calculation of index values

Already since 1980 Kew Observatory has closed and the Mk 4 anemometer at Elmdon has been replaced by a Mk 5 and moved to a different site. Inevitably there will be further closures, changes of site or changes of instrument at other stations used in the calculation of the windiness indices, reducing the usefulness of anemograph data for the estimation of windiness for periods after 1980. Barometer readings from individual stations could be used instead but owing to non-availability of data it is not possible at present to derive windiness indices extending very far back in time using such values. The daily grid-point surface pressures may therefore be the most satisfactory indicators of windiness for future climatological studies on a large scale. This is with the proviso that any inhomogeneities in time introduced into the surface pressure data by alterations to the Meteorological Office numerical analysis scheme (from which surface pressure values are currently obtained) are insignificant or can be allowed for.

Table III. *Monthly indices averaged over the three regions for the period 1881–1980*

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1881	−1.5	−0.4	0.0	0.4	0.1	1.3	0.5	1.3	−0.9	0.7	2.6	−0.4
1882	−0.1*	0.8*	0.6	0.3	0.1	1.8*	1.2*	2.0*	−0.6	−0.3*	−0.4*	−1.0
1883	0.8	2.1	0.4	0.0	0.5	−1.1	0.4	0.8	0.2	0.8	0.6	−0.2
1884	1.0	2.3	0.1	−0.9	0.8	−0.8*	−0.2	0.0	0.4	0.8	−0.9	0.4
1885	0.1	1.2	−0.4	−0.1	0.6	0.1	−0.4	0.4	0.7	0.6	−0.6	−0.3
1886	0.2	−1.2	0.3	0.5	−0.2	0.3	1.0	0.8	0.3	0.1	−0.6	−0.3
1887	0.0	0.5	−1.1	−0.3	0.2	−0.8	0.6	0.6	−0.2*	−0.1	−1.1	−0.3
1888	−0.7	−0.8	−0.4	0.4	1.2	0.1	0.2	1.2	−1.2	−0.2	2.7	−0.5
1889	−0.7*	1.6	−0.6	0.3	−0.7	−1.4	−0.3*	1.6	−0.2	−0.4	−1.0*	−0.2
1890	1.5	−0.6	0.3	0.0	0.3	1.2	1.2	0.9	0.4	0.1	−0.1	−1.7
1891	−0.3	−0.8*	0.3	−0.8	0.2	0.9*	0.3	2.7	1.3	1.6*	−1.3	0.6
1892	0.4	0.6	−1.0	−0.8	0.1	0.1	0.2	0.8	0.8	−0.4	−0.5	−1.0
1893	−0.7	0.8	−0.4	−1.3	−0.3	−1.2	0.0	1.3	0.2	−0.3	−0.1	0.7
1894	1.3	2.7*	0.3	−0.5	0.5	0.1	−0.2*	1.1	−1.5	−1.2*	0.8	0.4
1895	−0.8	−0.4	−0.3	0.1	−0.4	−2.1	0.2	0.8	−0.6	−0.4	0.6	0.4
1896	−0.8	−0.2*	0.5	0.0*	−0.8	−0.5*	0.4	0.9	1.0	0.2	−1.5	−0.4
1897	−0.4	0.2	0.9*	0.5	1.4	0.0	0.2	1.7*	0.4	−0.4	−1.1	0.5
1898	−0.6*	2.2*	−0.5	0.1	0.4	0.3	0.0	1.5	−0.3	0.0	−0.7	1.0
1899	0.0*	0.3	−0.8	0.4	−0.6	−1.7	−0.2	0.3	0.8	−0.1	0.9	−1.2
1900	0.3	−0.7	−0.9	−0.3	0.9	0.1	−0.3	0.0	−0.2	−0.3	1.2	0.8
1901	1.0	−1.7	0.3	0.5	−0.5	1.2*	−1.1*	0.8	0.8	−0.1	−1.2	0.3
1902	0.1	−0.2	−0.2	0.0	0.9	0.8	−0.1	−0.4	0.0	−0.5	0.6	0.6
1903	1.0	3.5	2.0	0.3	0.3	0.4	0.0	1.8	1.3	0.3*	−0.3	−0.7
1904	0.9	0.2	−0.4	1.8	0.6	1.7	−0.2	0.6	0.0	−0.5	−1.0	−0.8
1905	1.0*	1.1	0.5	0.2	−0.2	−0.1	−0.8*	0.3	0.6	−0.3	−1.1	0.3*
1906	1.4	1.0	0.7	−0.3	0.7	−0.5	0.1	0.5	−1.0	−0.3	0.1	0.1
1907	0.2	1.1*	0.4	0.2	0.6	2.1	−0.4	1.3	−0.9	−0.7	−1.9	0.2
1908	0.5	1.7	−0.3	−0.2	0.4	0.1	−0.4	0.9	0.6	0.1	0.2	0.0
1909	0.5*	0.0	−0.7	0.2	0.5	−0.4	1.3	0.6*	−1.1	1.3	−1.3	−0.5
1910	0.8	2.3	−0.1	0.0	0.3	0.6	0.5*	−0.1*	−0.9	0.0	−0.9*	0.5
1911	−0.3*	1.4	−0.1	0.7	−0.1	1.0	0.2	0.8	−0.2	−0.2*	1.3	0.8*
1912	−0.5	0.3	0.6*	0.2	−0.7	0.6	0.0	0.6*	0.4	0.5	0.0	1.1
1913	0.9	0.5	1.5	1.1	0.9	0.8	−0.4	−0.7	−0.5	−0.4	1.7	−0.1
1914	0.0	1.6	0.6*	0.9	0.0	−0.3*	0.2	0.2	0.5	−1.7	0.5	0.4
1915	−0.2	1.1	−1.0	0.5	−0.5	−1.5	0.0	−0.5	−0.6	−1.0	−0.5	−0.8*
1916	1.9*	1.8	−0.2	0.5	−0.8	1.6	−1.1	0.2	0.2	1.3	0.9	−1.3
1917	−0.7	−1.7	−0.1	−0.4	−0.2	−0.1	−0.6	1.2*	0.4*	1.1	0.3*	−0.7
1918	−0.1	2.7*	−0.8	−1.1	−0.7	0.6	0.2*	0.8*	0.8	0.8	−0.5	0.1
1919	−0.4	−1.2	−0.8	0.6	0.5	2.4*	−0.1	1.3*	0.8	−0.4	−0.3	1.1
1920	1.3	2.0*	0.6	0.0	0.8*	0.6*	0.7	0.1	−0.3	−0.2	0.5	−0.7
1921	0.8	−0.7	1.6	−0.1	0.0	0.4	−0.2	0.6	−0.4	−0.9	−0.1	1.1
1922	0.9	1.4	−0.3	−0.8	0.8	0.2*	1.0	0.6	−0.4	−0.5*	−0.7	0.1
1923	0.5*	1.9	−1.0	0.3	0.6	2.8*	0.5	2.0	0.7	1.7	−0.3	0.3
1924	0.2	0.1	−1.1	−0.5	0.0	−0.4	0.5	1.3	0.9	−0.5	−0.8	1.0
1925	0.7	1.4	−0.5	0.3	0.6	0.8*	−0.3	0.6	0.8	0.1	−1.5	−0.1
1926	0.3	1.2	0.3	0.0	0.2	−0.5	0.1	1.6	−0.5	−1.0*	−0.1*	−0.8
1927	0.7	−0.3	0.1*	0.9	−0.3	0.7	−0.1	1.1	0.1	−0.5*	0.4	−0.1
1928	1.6	2.6	−0.2	0.4	0.1	1.3	0.7*	0.4	−0.4	0.8	1.6	−0.5
1929	−1.3	0.2	−1.4	−0.6	−0.1	1.1	−0.2	0.8	0.3*	0.5	2.1	1.9*
1930	0.8	−1.4	−1.0	0.3	−0.3	0.0	0.1	1.4*	−0.4	1.4	0.2	−0.8

Note. Months where the range of values for the three regions exceeds 1.5 are marked with an asterisk.

Table III.—*continued*

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1931	−0.6	1.1	−0.4	0.3	0.3	−0.4	0.7*	0.7	−0.9	−0.1	0.6	−0.1
1932	1.1	−0.6	−0.9	1.2	0.2	−1.3	0.5	−0.8	−0.1	0.0*	0.3	0.6
1933	0.0	0.8	0.4	−0.4	−0.7	0.0	0.2	0.9*	−1.5	0.3	−1.8	−1.3
1934	1.2	0.0*	−0.2	0.5	0.7	−0.8	−0.4	1.2	1.5	1.8	−2.1*	0.2
1935	−0.5	1.9	−0.5	−0.4*	−0.5	0.7	0.3	−0.5	0.9*	1.6	0.8	−1.0
1936	−0.7	−0.3	−0.8	−0.1	0.1	−1.2	0.7*	0.0	−1.0	0.8	−1.0	1.0
1937	2.1	1.3	−0.7	−0.3	−0.9	0.4*	−0.5	−1.5	0.2	−1.7	−2.1	−1.3
1938	1.0	1.1	0.5*	−0.3	−0.1	2.2	0.0	−0.3	−0.5	1.5	1.8	0.3
1939	−0.3	1.9	0.2	0.2	−0.5	1.0	1.0*	−0.6	−0.7	0.0	1.8	−1.2
1940	−1.3	−0.6	−0.1	−0.1	−1.4	−1.0	−0.3*	1.7*	0.8	0.0	0.4	−0.4
1941	−1.1	0.5	−0.9	−0.1	−0.3	−0.6*	−0.6	1.8*	−0.8	0.0	0.1	−0.3
1942	−0.4	−1.9	−0.6	0.8*	0.4	−1.0	0.9	1.4	0.3	0.2	−2.5	0.6
1943	0.2	1.9*	−0.4	1.4*	0.4	0.8*	0.2	1.1	0.5*	0.5	−0.3	−1.1
1944	0.8	0.2	−1.1	−0.1	0.3	1.0	−0.4	−0.2	0.0	−0.2	0.0	−0.2
1945	−0.9	1.9	−0.1	−0.1	0.2	1.6	0.2	−0.3	0.1	−1.0*	−2.5	−0.2
1946	0.7	1.1	−0.9	−0.2*	0.3	1.2	0.7	0.2	1.2	−1.0	0.0*	−0.6
1947	0.3	0.1	−0.6	2.3	0.0	0.7	−0.3	−1.3	−0.1	−0.9	−0.1	−1.0
1948	−0.2*	0.7	−0.1	0.0	−0.8	0.9*	0.9	0.5	1.1	0.3	−0.5	0.4
1949	1.0*	2.2*	−0.5	1.9*	−0.2	−1.0	−0.6	0.5	−0.6	0.7	0.5	0.7
1950	−0.1	1.6	−0.2	1.1	0.0	0.0	0.5	1.9	2.2	0.5	0.0*	−0.9
1951	−0.2	0.3	−0.5	0.9	0.3*	−0.4	−0.4	1.9	0.8	−0.2	1.1	0.9
1952	0.6	−0.2*	0.3	0.2	−0.1	0.6*	0.3	0.2	0.7	1.0	−1.7	−0.1
1953	−1.1*	0.4	−0.7	−0.5	0.0	−0.5	1.0*	1.2	0.7	−0.3	1.2*	−0.7
1954	0.3	0.1	−0.1	0.0	0.8	1.0	1.9	0.7	1.7	0.6	0.7	1.3
1955	−0.7	−0.5	−0.9	0.2	0.9	0.9*	−1.2	−0.4	0.9*	−0.5	−1.2	0.3
1956	−0.5	−1.1	1.0	−1.5	1.2*	1.5	0.5	0.2*	0.2	0.4	1.0*	0.8
1957	1.4	0.1	0.1	−0.1	0.1	−1.0	0.1	1.1	1.0	0.5*	−1.0	0.1
1958	0.3	0.6	0.0	0.3	−0.3	−1.0	−0.3	0.9	0.5	0.3	−2.5	0.8
1959	−0.7	1.2*	0.0	0.4	−0.4	1.8	−0.2	0.4	−1.2	1.1	−0.1	0.6*
1960	−0.7	0.2	0.3	1.3	0.2	0.5	0.6*	−0.3	−0.3	−0.9	0.5*	−0.6
1961	−0.1	2.0	0.5*	−1.1	0.3	0.9*	0.4	2.3	0.5	1.2	−0.8	−1.0
1962	1.1	2.8*	−1.1	0.1*	0.5	1.9	−0.2	1.7	0.1	−0.1	−1.8	0.2
1963	−0.8	−0.4	0.6	0.1	1.3	0.5	−0.1	0.1*	0.5	1.5	−0.7*	−0.4
1964	−0.2*	1.1	−0.3	0.5	1.5	0.8*	1.1	0.4	0.1	−0.7	0.2	−0.1
1965	0.4	−0.4	−0.8	0.2	0.3	0.8	−0.3	1.0	−0.4	−0.1	−0.3	−0.1*
1966	−0.3	0.7	0.3	0.4*	0.6	−0.3	0.3	−0.2	−0.6	−1.3	−0.3	0.7
1967	−0.3	1.6	1.8	0.5	0.8	−0.1*	0.0	−0.3	−0.2	1.7	−0.9	−0.3
1968	−0.1	−1.1	0.6	−0.4	−0.7	−0.4	−0.9	0.0	0.1	−0.4	−0.4	−0.7
1969	−0.6	−0.5	−0.8	0.3	−0.7	−0.5	0.3*	0.5	−0.5	0.0	−0.2	−0.7
1970	−0.5	0.8*	−0.1	0.6	0.4*	−0.3	1.4	−0.3	0.6	0.7	−0.2	−0.7
1971	−0.4	−0.2	−0.8	−1.2	−0.7	−0.1	−0.9	−0.1	−1.2	0.3	0.1	0.0*
1972	0.1	0.0	−0.2	0.7*	1.1	1.7	−0.7	0.3	−1.4	−0.3	0.0	0.9
1973	−0.8	0.4*	−0.7	0.5	0.6	−0.1*	−0.5	−0.1	−0.6	−1.2	0.4	0.1
1974	2.0	0.5	−0.9	−1.8	0.5	0.4	1.0	0.5	1.1	0.2	−0.2	1.9
1975	1.2	−0.5	−0.8	0.3	−0.2	−0.1	−0.3	−1.1	0.6	−0.2	−0.4	−0.4*
1976	1.1	0.3	0.1	−0.3	0.3	−0.7	−0.4	−1.3	0.0	0.0	−0.9	−1.3
1977	−0.7	−0.5	0.5	1.2	−0.9	−0.4	0.2	−0.5	0.9	1.2	2.1	0.1
1978	−0.1	−0.8	0.8*	−0.8	−1.4	0.6	0.9	0.4	1.0	−0.6*	0.7*	0.0
1979	−1.0	−0.3*	1.2	−0.2	−0.1	−0.6	−0.1	1.0	0.6*	0.0	0.4	0.4
1980	−1.2	−0.8	−0.3	−0.3	−0.3	0.7*	0.7	0.9	0.7	0.9	0.6*	0.9

Note. Months where the range of values for the three regions exceeds 1.5 are marked with an asterisk.

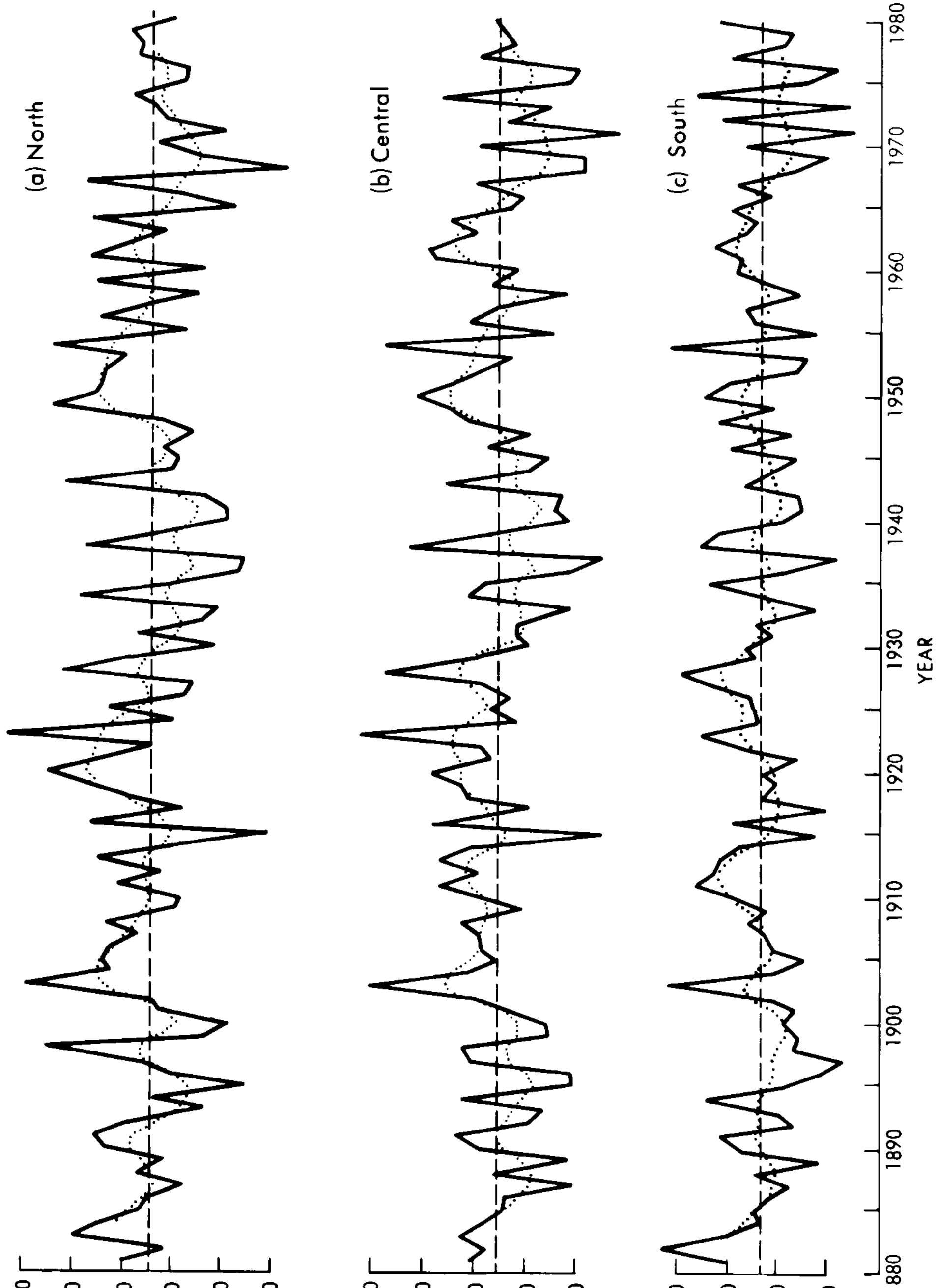

Figure 7. Annual means of the estimated values of the index of windiness (full lines), seven-year weighted running means (dotted lines) and 1881–1980 mean (dashed lines), all three regions.

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Appendix

Derivation of daily wind speed from surface pressures

Let A, B, C, . . . denote the surface pressures (mb) at midnight or midday which are available for the grid points as indicated:

Latitude	Longitude		
	10°W	0°	10°E
65°N	A	B	C
60°N	D	E	F
55°N	G	H	I
50°N	J	K	L
45°N	M	N	O

Then, for example, to determine the daily speed at 55°N 5°W:

Westerly flow F_w along 55°N is given by

$$F_w = \tfrac{1}{2}(J + K) - \tfrac{1}{2}(D + E).$$

Southerly flow F_s along 5°W is given by

$$F_s = 1.74 \;\{\tfrac{1}{4}(E + 2H + K) - \tfrac{1}{4}(D + 2G + J)\}$$

Resultant daily speed at 55°N 5°W = $(F_w{}^2 + F_s{}^2)^{\frac{1}{2}} \times 1.2$ kn.

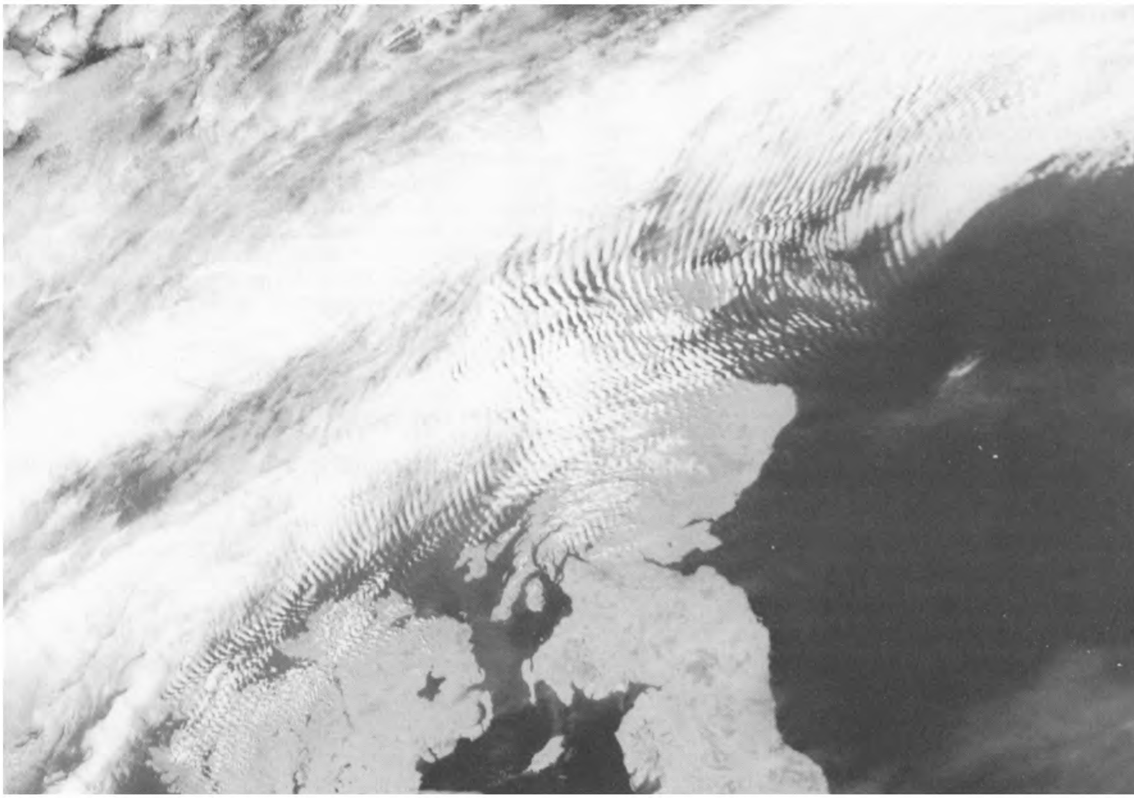
Similar expressions hold for the speed at the other five grid points shown in Fig. 6.

Notes and news

Cloud patterns observed by satellite on 26 March 1982

At 1435 GMT on 26 March 1982 the polar orbiting satellite NOAA-7 showed a remarkable series of regularly spaced cloud undulations running from north-west Ireland across north Scotland and out over the North Sea (Figs 1 and 2). The synoptic situation is shown in Fig. 3; there was little change of wind direction with height and the upper-air charts largely reproduce the pattern of the sea-level flow. Ascents for Stornoway and Lerwick are shown in Fig. 4. The wavelength of the undulations as measured from the photographs is about 10 km, and an estimate by Caswell's method* of the expected wavelength of standing waves yields a figure of 11 km.

* *Meteorol Mag*, **95**, 68 80, 1966



Photograph by courtesy of Dundee University.

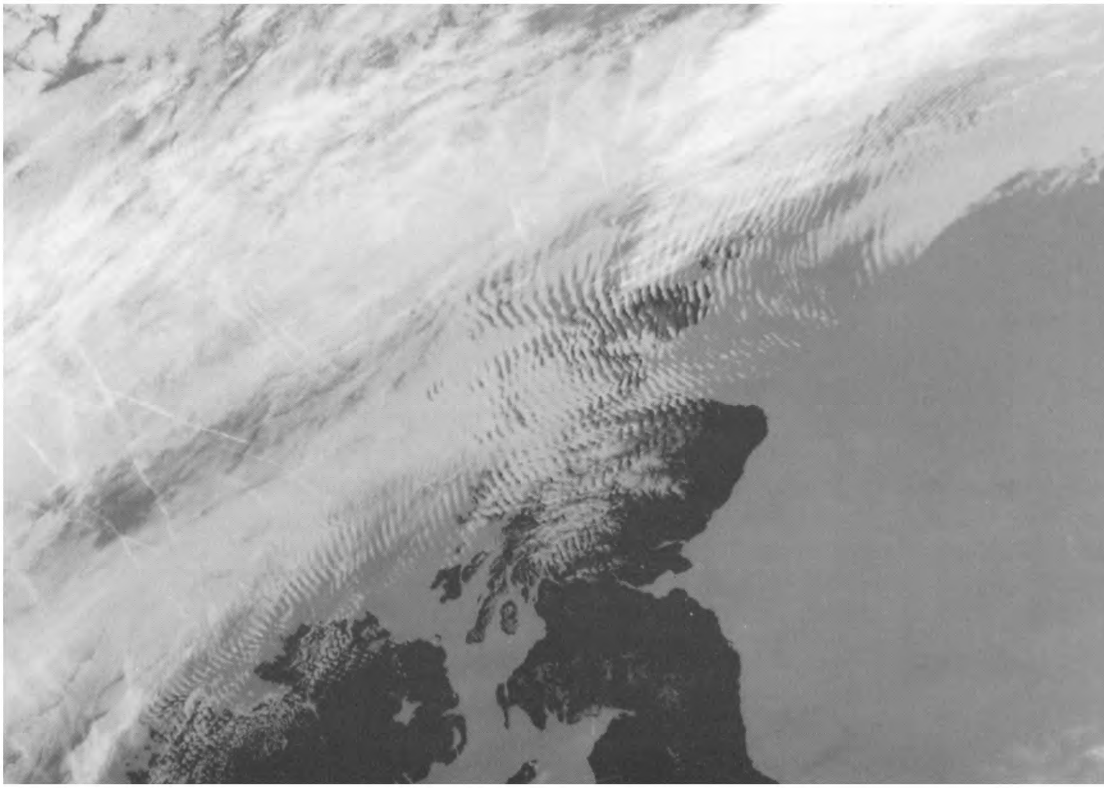
Figure 1. Visual image received from NOAA-7 at 1435, 26 March 1982.

It is, of course, impossible to tell from Figs 1 and 2 whether the undulations are moving or stationary. Telephone enquiries to the Senior Meteorological Officer at RAF Kinloss revealed that no special observations were recorded in the Moray Firth area that afternoon, but apparently wave and billow clouds are so common in that part of Scotland that nothing is normally entered in the 'Remarks' column of the register about them.

Note also the condensation trails, shown as shadows on the cloud in Fig. 1, and directly in Fig. 2.

25 years ago

The Meteorological Magazine for September 1957 contained an obituary written by Mr Ernest Gold of R. G. K. Lempfert who had the distinction of being the first man with high scientific qualifications ever to be appointed to the staff of the Meteorological Office. (The Directors—more recently Directors-General—have of course all been distinguished scientists from the days of Admiral FitzRoy onwards, and all except one have been Fellows of the Royal Society.) Mr Gold quotes Sir Napier Shaw's words that until 1902 'one of the peculiarities of the Meteorological Office as a scientific establishment was that none of the members of the staff had had any preliminary scientific training'. Lempfert had graduated



Photograph by courtesy of Dundee University.

Figure 2. Infra-red image from NOAA-7 for the same time as the visual image shown as Figure 1.

with high honours in Physics at Cambridge and for a time worked in the Cavendish Laboratory under J. J. Thompson. His appointment and those a few years later of Gold himself and Corless were amply justified by results as regards both their own scientific work and their influence on policy and administration; this was the beginning of the process whereby the Office grew into the renowned scientific institution that it is today. The papers by Lempfert and Corless on air trajectories and trough lines, for example, led up to the work of the Norwegian school during the first World War and introduced the word 'front' as a technical term for the first time.

The same issue also contained four photographs by D. W. S. Limbert, taken the previous year at Halley Bay in the Antarctic while he was a member of the Royal Society Expedition of the International Geophysical Year; they include one illustrating the midnight sun.

50 years ago

The Meteorological Magazine for September 1932 contained a good deal of information about the heat wave of the previous month which had been the warmest August over much of England since 1911; the nights were particularly warm, Lympne recording a minimum of 73 °F on the 20th. There were

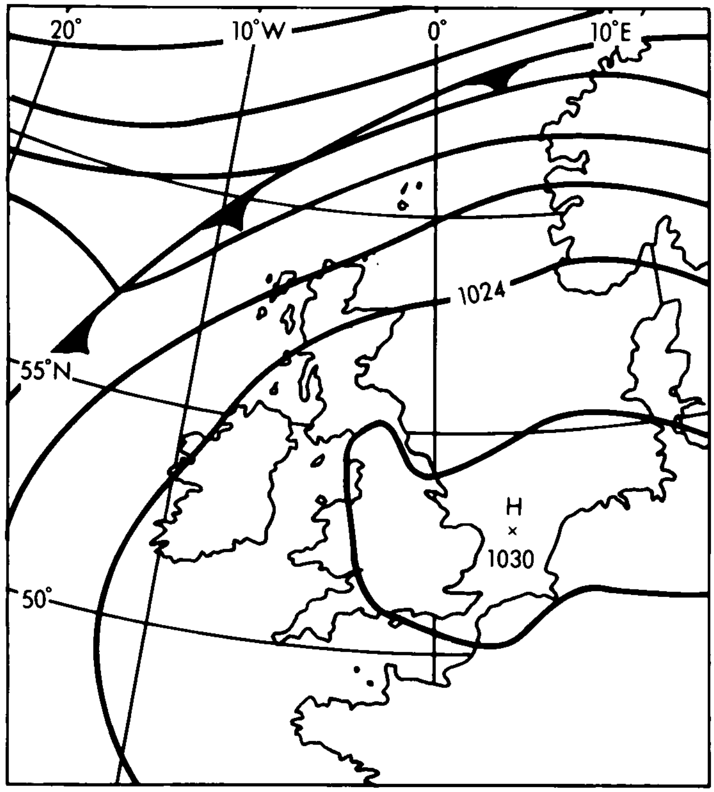


Figure 3. Synoptic situation at 12 GMT on 26 March 1982.

several heavy thunderstorms, and the effect of one of these was described graphically in the same issue by Mr E. L. Hawke, the well-known writer on meteorological matters who was Superintendent of the weather station of the Hampstead Scientific Society at the time, and was an Honorary Secretary of the Royal Meteorological Society from 1935 to 1949. Mr Hawke lived in Rickmansworth, and his account includes the following passage:

For the second time within three weeks, the Rickmansworth and Chorley Wood district of Hertfordshire was visited by a thunderstorm of unusual severity early on Friday, August 12th. The storm approached rapidly from south-south-west over an easterly surface wind, breaking, it is believed, after only a single preliminary thunderclap. Increasingly heavy rain began at 4h. 55m. G.M.T., and from 5h. until 5h. 30m. the fall maintained a persistence of intensity unparalleled in the writer's twenty-seven years' experience of meteorological observing in England and abroad.

After about 5h. 2m. the deluge was accompanied by nearly continuous hail. The stones were spheroidal, and appeared to average 0.5in. in diameter, but were in some instances amalgamated into masses approximately the size of a golf ball. To save the radiation thermometers from destruction, a journey that will not readily be forgotten was made to the instrument enclosure at 5h. 5m. The assault of ice and water can only be described as terrific. At 5h. 30m. the hail ceased abruptly, and there was a progressive slackening of the rain. By 5h. 40m., when the gauge was examined, the fall was over, except for 0.01in. The measurement for the 45 minutes from 4h. 55m. to 5h. 40m. was 2.24in. an amount that may well have been short of the true figure by reason of the hailstones rebounding from the funnel of the gauge. Both before 5h. and after 5h. 30m. the rain was not of outstanding violence, and it is estimated that of the measured total of 2.25in. yielded by the storm, nearly, if not quite, 2in. must have fallen within the half-hour.

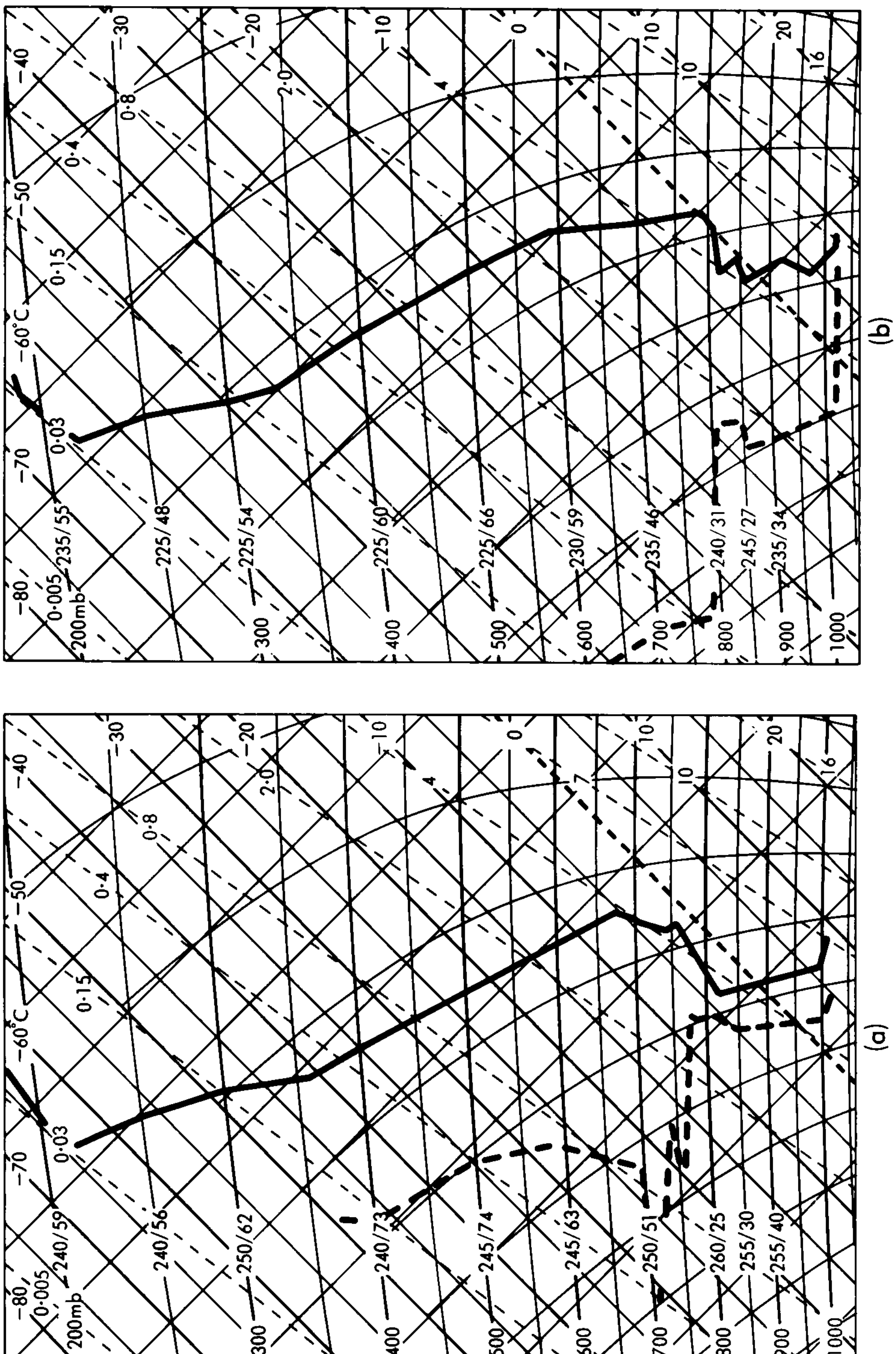


Figure 4. Tephigrams for (a) Lerwick and (b) Stornoway, 12 GMT on 26 March 1982.

Mr C. K. M. Douglas

Mr C. K. M. Douglas, O.B.E., A.F.C., B.A. died on 19 February 1982 in his 89th year. By the time of his retirement* from the Meteorological Office in 1954 he had become an almost legendary figure among forecasters. He was certainly the greatest weather forecaster of his generation in the United Kingdom, and quite possibly of all time. No one else has combined his sound grasp of mathematical and physical theory with such immense synoptic experience; his memory of individual occasions was extraordinary and all forecasters who worked with him could give examples. During the Second World War he was a Senior Forecaster in the Forecast Division at Dunstable where as one of the 'back-room boys' he was a regular and respected participant in the daily operational forecasting conferences by telephone. His assessment of the weather situation and its probable developments played a large part in the preparation of the forecasts for the D-day operation in 1944, as has been described by the late J. M. Stagg (1971);† his contribution was acknowledged by General Eisenhower in a personal letter of thanks.

He began his independent meteorological investigations before he joined the Office by his pioneering work on the upper air and air-borne cloud photography while he was a pilot in the Royal Flying Corps. He published a large number of scientific papers and articles, both alone and in collaboration with other scientists; the Brunt–Douglas equation still finds a place in the textbooks.

A nervous affliction produced certain idiosyncrasies of behaviour which were at first a little alarming to new acquaintances, but these were soon forgotten. He was not interested in administrative matters which he would leave to others while he concentrated on what he regarded as his real work. After his retirement he moved to Beer in Devon, where from 1956 to 1973 he became a rainfall observer and made daily readings which were forwarded to the Office and published in *British Rainfall*. He was awarded both the Buchan Prize and the Hugh Robert Mill Memorial Medal and Prize of the Royal Meteorological Society.

Obituary

We regret to record the death on 7 March 1982, under particularly tragic circumstances, of Mr R. S. Hewer, Assistant Scientific Officer, at Birmingham Airport; he was working in the remote observing office, preparing for the 2100 GMT observation, when an intruder entered the building and for no apparent reason shot him at his desk.

Ray Hewer joined the office in 1949 and served at a number of RAF stations, including some old names such as Swinderby, Aston Down, Lichfield, Morton Hall and South Cerney as well as at Shawbury, Pershore and in Germany, before moving to Civil Aviation in 1961 at Liverpool. He went to Birmingham the next year, 1962, and apart from a short break between 1966 and 1969 remained there for the rest of his life.

He will be remembered most for his rather quiet, dry sense of humour and the meticulous way he carried out his work. He was one of the old school who believed that the greatest help that he could give to weather forecasting was to ensure that his observations were made with care and accuracy. His records in the *Daily Registers* at Birmingham are a testimony to the high standard he set.

Outside the office, he was very much a family man. He did not have a car but he took great pleasure in planning holiday routes by train and bus so that his wife and daughter gained the maximum benefit from their holidays all over the Continent.

Ray Hewer was a willing and co-operative colleague and will be missed much by all who worked with him; he was a stalwart of the office at Birmingham and died doing what he enjoyed most about his work—observing the weather.

*See *Meteorol Mag*, **83**, 1954, 225–226. †Stagg, J.M., 1971, Forecast for Overlord. London, Ian Allan.

THE METEOROLOGICAL MAGAZINE

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NOTICES

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Line squall and minor tornadoes at Holyhead, 23 November 1981

By A. K. Kemp and S. J. Morris

(Meteorological Office, Royal Air Force, Valley)

Summary

On 23 November 1981 an active line squall which was associated with tornado development swept eastwards across England and Wales. The *Journal of Meteorology, Trowbridge** gives references to '70 known tornadoes' on this day. This article relates to tornadoes reported at Holyhead.

Introduction

Severe gales or storms occur on west Anglesey on several days each year. At Valley the strongest gust of the year averages 70 knots and yet even with winds of this speed little damage is normally reported, apart from the occasional television aerial blown down. The citizens of Holyhead, therefore, were a little surprised when on the morning of 23 November a storm struck without warning causing serious damage to a school and many houses in the town.

An investigation into the meteorological situation showed conditions were favourable for severe squalls at Holyhead.

The synoptic situation

The 00 GMT chart for 23 November (Fig. 1) shows a deep complex depression of 986 mb near the Faeroes and an associated cold front, with a minor wave, over western Scotland. Most of the British Isles was under the influence of a strong west-south-westerly flow in the warm sector.The warm air was potentially unstable and scattered outbreaks of heavy rain from unstable medium cloud were reported. Thunder was heard at Cork at 0300 GMT and lightning was seen at Valley between 0500 and 0530 GMT. Upper-air charts suggested a minor trough embedded in the general south-westerly upper flow over the British Isles and probably this trough provided the mechanism for the release of the instability. During the morning of the 23rd the depression engaged very cold air from the Iceland area

J Meteorol, Trowbridge*, **6, 344, ibid. **7**, 29–30 and 60.

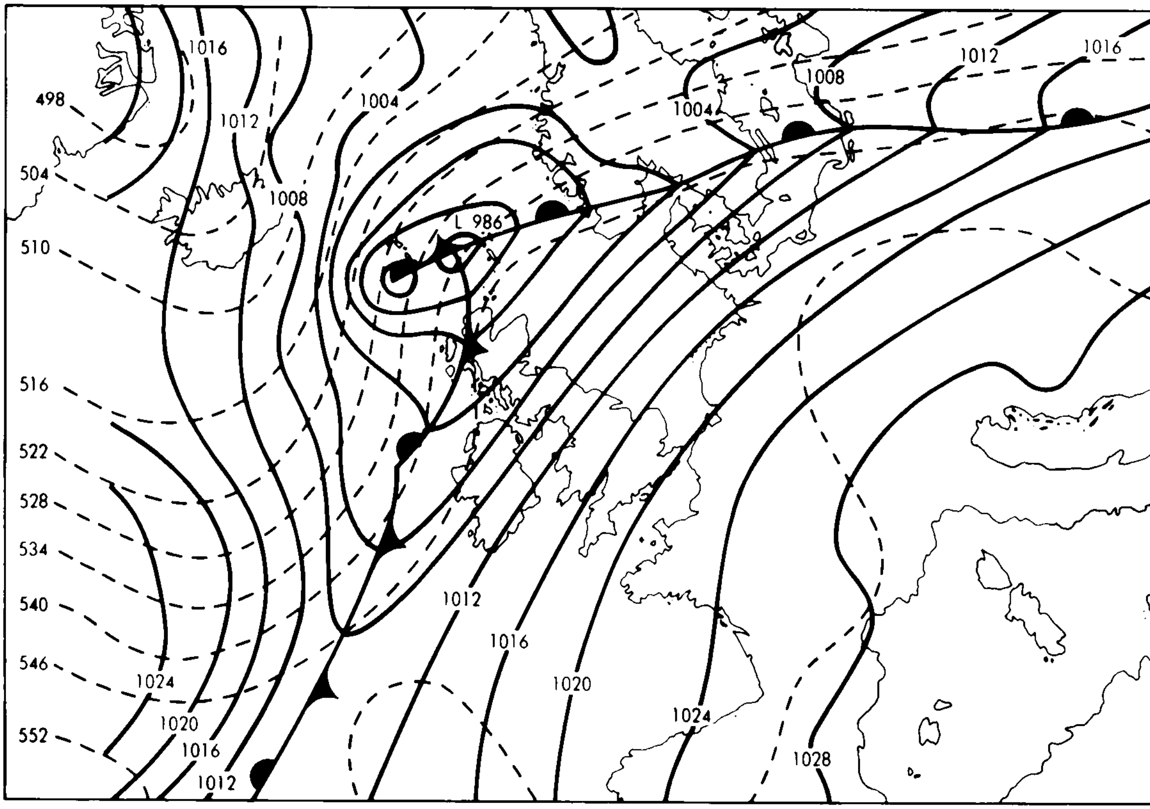


Figure 1. Surface and 1000–500 mb thickness analysis for 00 GMT 23 November 1981. Pressure (full lines) in millibars. Thickness (dashed lines) in decageopotential metres.

and deepened to 968 mb whilst at the same time the cold front accelerated south-eastwards. At 10 GMT (see Fig. 2) a small cyclonic centre had developed on the front just to the west of Anglesey and large pressure falls were occuring over north-west Wales. These pressure falls were produced on the forward side of an intense thermal trough which showed marked extension as it moved east across the British Isles. The tephigrams for Long Kesh 12 GMT and Aberporth 06 GMT (see Fig. 3) give a good indication of the very marked change of air mass associated with the cold front and also Aberporth shows the latent and potential instability in the warm air.

The squall as observed at Valley and Holyhead

At the meteorological office at Valley, situated about 10 km south-east of Holyhead, the cold front was timed to cross the station between 1000 and 1100 GMT. The large pressure falls ahead of the accelerating active cold front prompted the duty forecaster to issue a warning of a squall at the passage of the front with gusts likely to exceed 50 knots. Heavy rain commenced at 0900 GMT with the front crossing the station at 1035 GMT when the wind veered from south-south-west to north-north-west and gusted to 57 knots. The autographic records from Valley (Fig. 4) show the classic features of the passage

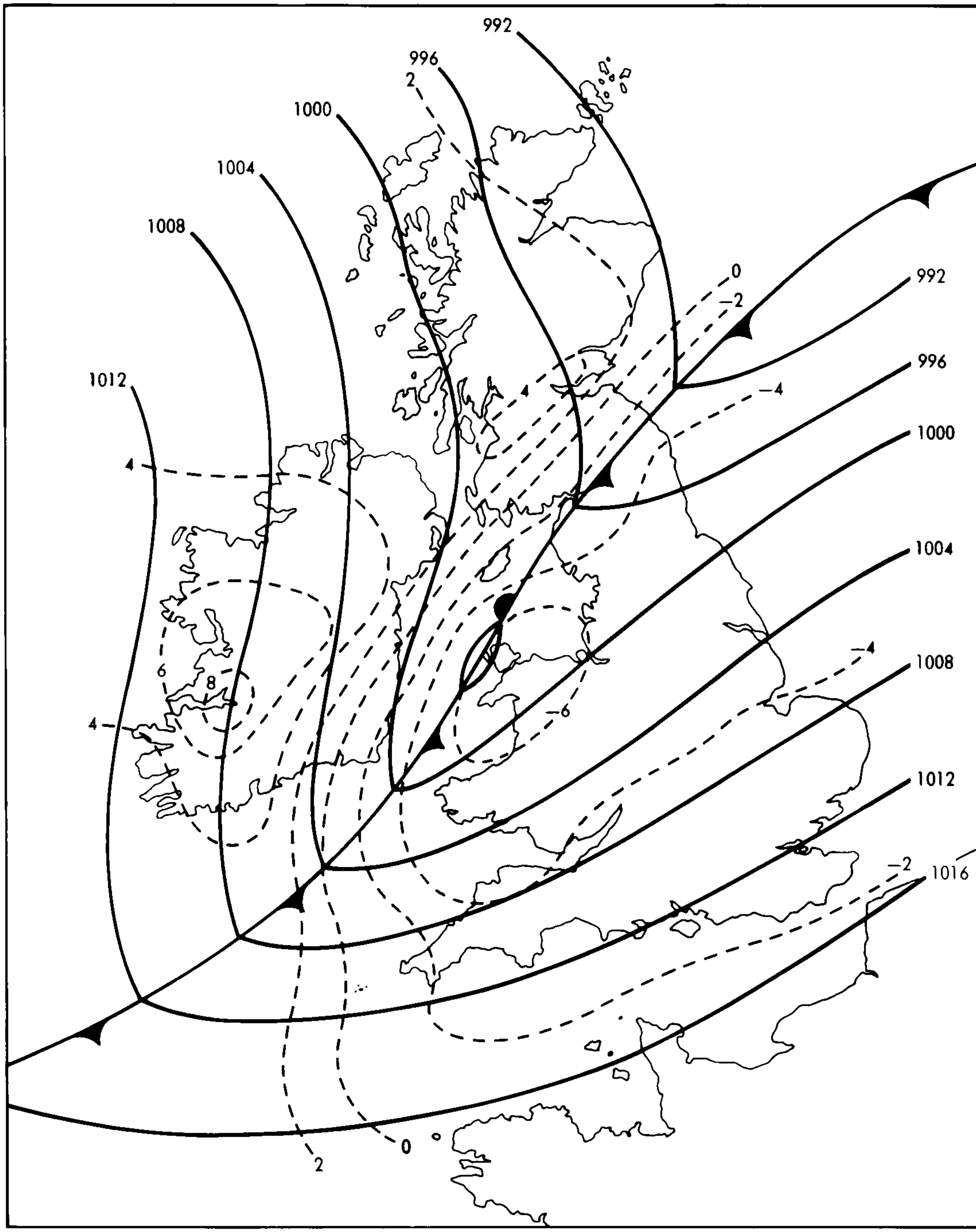
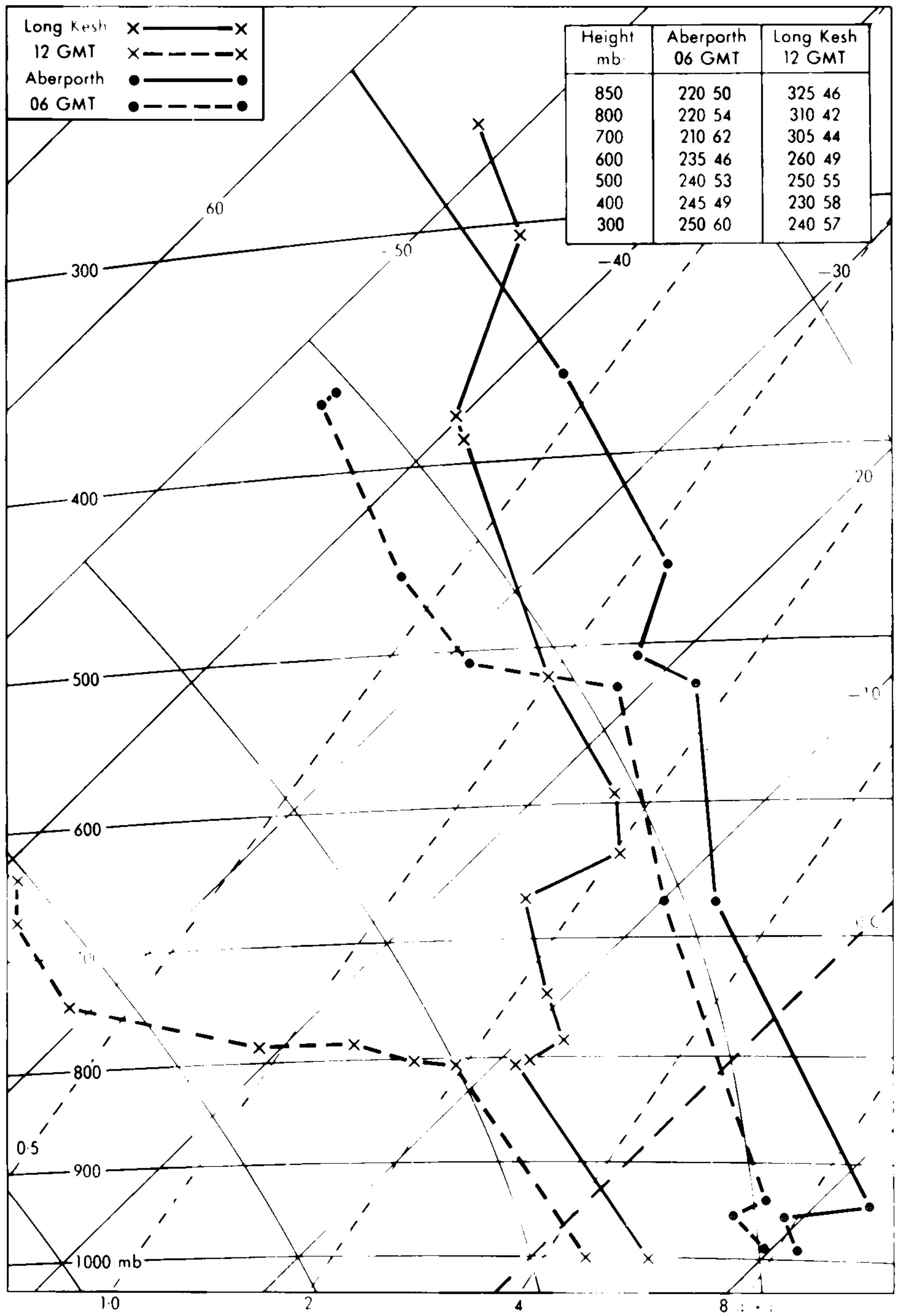


Figure 2. Surface analysis for 10 GMT 23 November 1981. (Isallobars in millibars for the period 07–10 GMT are shown as dashed lines.)



Height mb	Aberporth 06 GMT	Long Kesh 12 GMT
850	220 50	325 46
800	220 54	310 42
700	210 62	305 44
600	235 46	260 49
500	240 53	250 55
400	245 49	230 58
300	250 60	240 57

Figure 3. Tephigrams for Long Kesh 12 GMT and Aberporth 06 GMT, 23 November 1981.

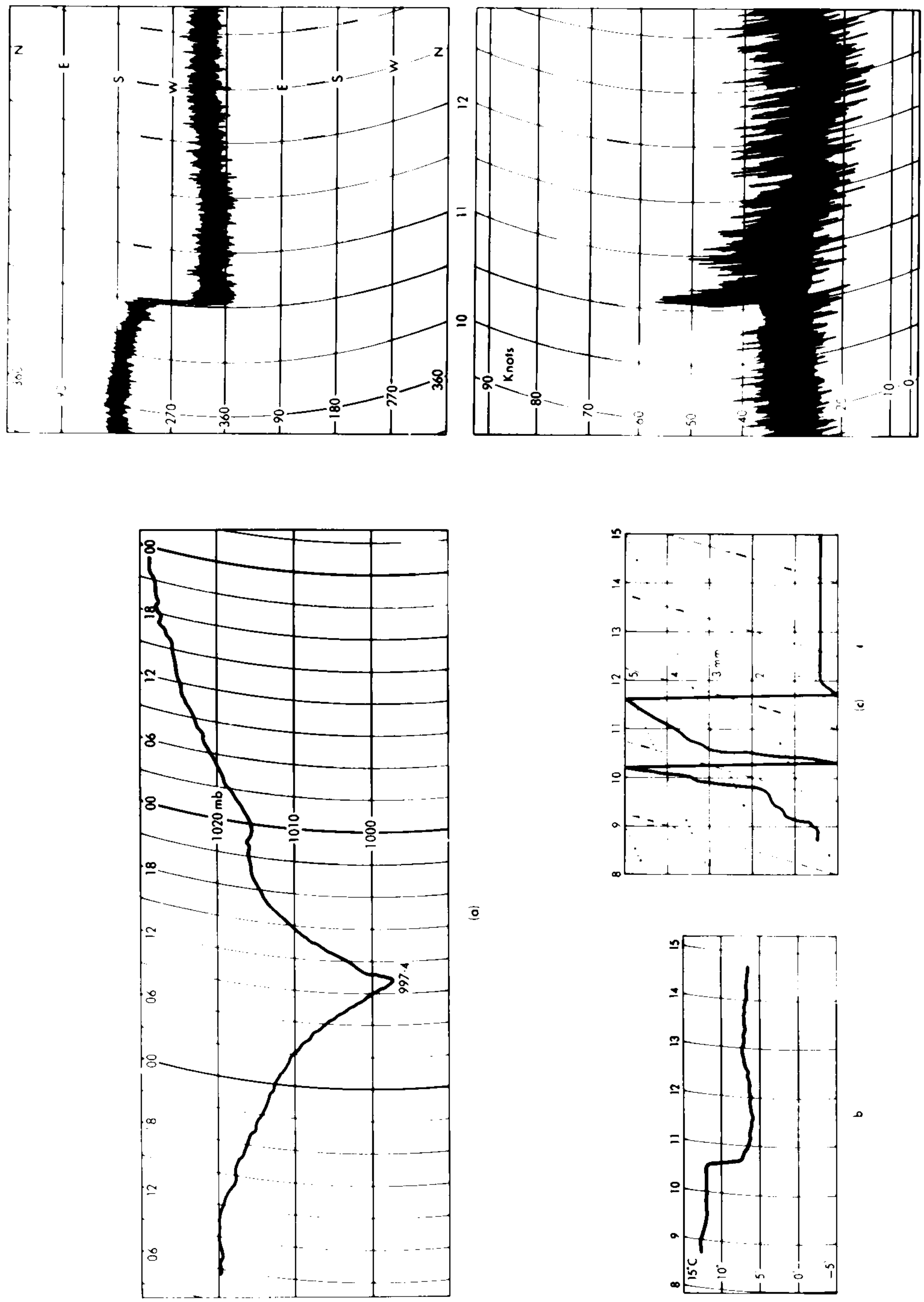


Figure 4. Diagramatic representation of autographic records for Valley, 23 November 1981. (a) barogram, (b) thermogram, (c) rain recorder chart, and (d) anemogram.

of an active cold front very well. During the worst of the storm driving rain made it impossible to recognize any particular cloud features and because of the bad weather no Valley-based aircraft were flying, so no cloud information was available from this source either. However, a radar report from Manchester Weather Centre at 1105 GMT reported a solid line of cloud 3 n. mile wide extending from Colwyn Bay to Kendal with the top of the rain echoes at 17000 feet.

Shortly after the passage of the squall at Valley several telephone calls from members of the public in Holyhead made it clear that a very severe squall had struck the town. The squall was described by several people as a whirlwind sweeping across Holyhead from the west. Sergeant Whelan at 1113 Marine Craft Unit, Holyhead observed the squall and supplied a written statement and sketch (see Appendix). From his description it appears that two short-lived tornadoes may have formed over Holyhead.

Damage in the area

The storm made the headlines in the local Press and on Welsh Television. From these reports and with the help of the local Fire Station personnel we were able to locate where the damage had occurred (Fig. 5). The most serious damage took place along a line about three-quarters of a kilometre long

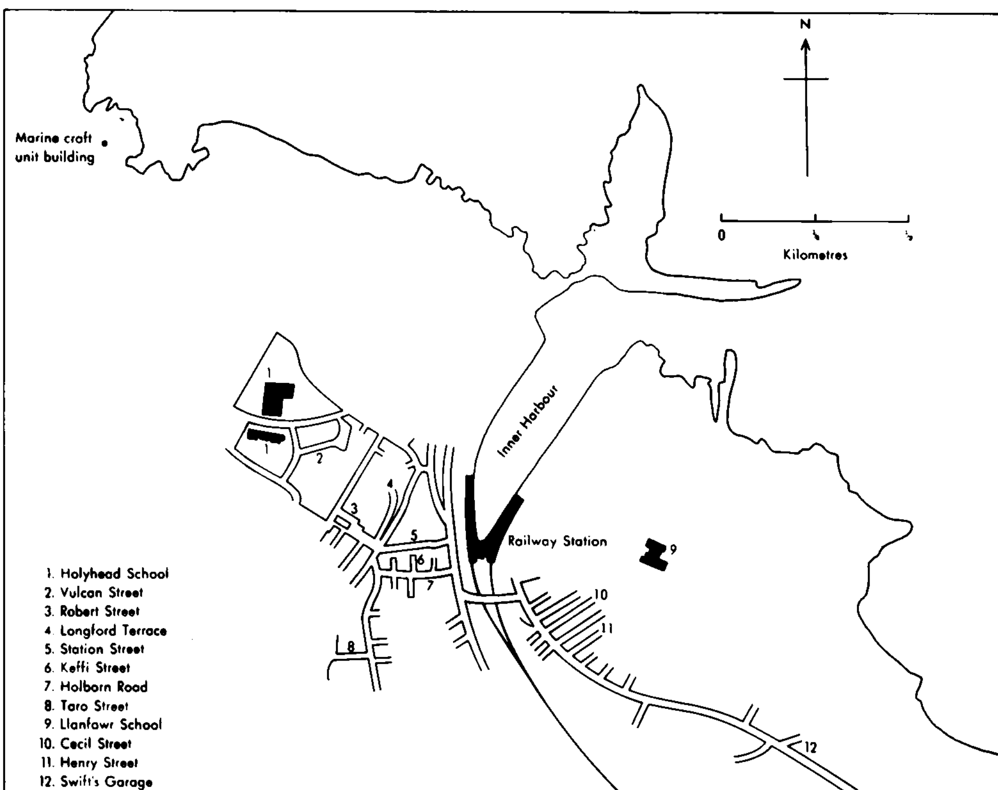


Figure 5. Locations of reported tornado damage.

between Holyhead School and Holborn Road. Further damage occurred about half a kilometre to the east-south-east, near Swift's garage. At Holyhead School (Fig. 6) a large section of the roof of an old school building was removed, hurling joists, bricks and slates all over the school yard and damaging nearby buildings. Had the storm occurred five minutes later, children would have been in the yard for their morning break. A tall modern science block at the school was also damaged and rendered unsafe for use that day. In the town the most serious damage occurred in Station Street with eight houses damaged, mainly roofs and windows. One quotation from a local newspaper about the damage in Station Street is of meteorological significance— 'The suction of the whirlwind had blown windows outwards'. Other Press reports described damage in the Penrhosfeilw area, to the south-west of Holyhead. Here, a farmer's van was 'tossed in the air' and a heavy coal bunker lid was 'whirled round the house, landing at the front door broken in half'.

Discussion and conclusions

The damage in the Holyhead area indicated that wind speeds had occurred in excess of anything normally reached in winter storms in this area. Visual evidence of a dark rotating cloud reaching the ground and the instance where windows were blown outwards, strongly suggests that minor tornadoes

Figure 6. Tornado damage at a Holyhead school.

affected the area. Certainly many of the necessary meteorological conditions for tornado development were present—a potentially unstable warm air mass, a supply of moist air at low levels, the presence of a small cyclonic centre with falling pressure and resulting low-level convergence. The main trigger action was of course the active cold front. A cold-front squall is normally caused by frictional retardation of the surface air and the formation of an overhanging nose of cold air. This nose of cold air will at times plunge to the surface giving strong downdraughts and severe gusts. The advance of the front may thus take place in a very unsteady manner and its activity may vary greatly with time and locality. Surface relief may also affect the movement and activity on a front and this was probably a very important factor in the case under consideration. The western side of Holyhead town is situated on the lower slopes of Holyhead Mountain which rises to a height of 220 metres. The western side of the high ground drops steeply to the sea (see Fig. 7), ending in a line of formidable cliffs about 100 m high. As the cold front and small depression moved east across Holyhead Island the low-level wind flow would become very complex. The resulting complex interaction of very different air masses in an area of strong horizontal wind shear and strong cyclonic vorticity almost certainly led to the development of the tornadoes.

Acknowledgement

The authors wish to thank the *North Wales Chronicle* for supplying the photograph for Fig. 6.

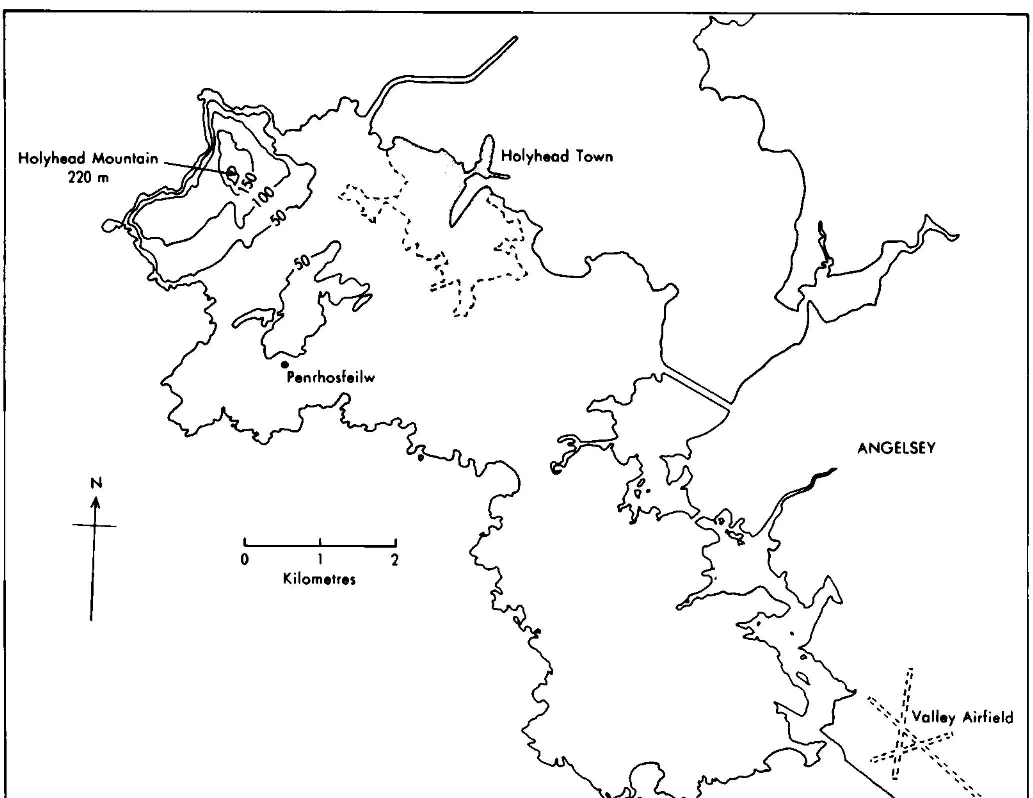


Figure 7. Map of Holy Island. Contours in metres.

Appendix

Eye-witness account of the squall supplied by Sgt Whelan of 1113 Marine Craft Unit, Holyhead:

Time. Approximately 1040 a.m.

A large, very dark, cloud of approximately ½ mile in a north-south direction and 1 mile in an east-west direction in extent, was passing over the seaward side of town and harbour. The wind was southerly F7-8 with fine precipitation. Within 5-10 minutes the wind veered through west to north-west, increasing in strength to whole gale F10 occasionally F11 in gusts.

I glanced towards Holyhead town and noted that the large black cloud was developing a hooked tail at the western end (similar to enlarged hooked cirrus). The tail started to extend and a mushroom top started to form under the cloud. Within approximately half a minute the tail of the now formed whirlwind appeared to extend down to ground level beyond the sea-front houses (see Fig. A1).

The whirlwind was dark in colour as if filled by water vapour visible in suspension mixed with cloud.

This first whirlwind had a duration of approximately 15-20 seconds, collapsing from ground level up after covering a distance of ¼ mile, travelling east.

A second larger whirlwind formed about 10 seconds later (see Fig. A1) moving east and collapsed after 10 seconds. This was later followed by heavy rain and gusts of wind to F11.

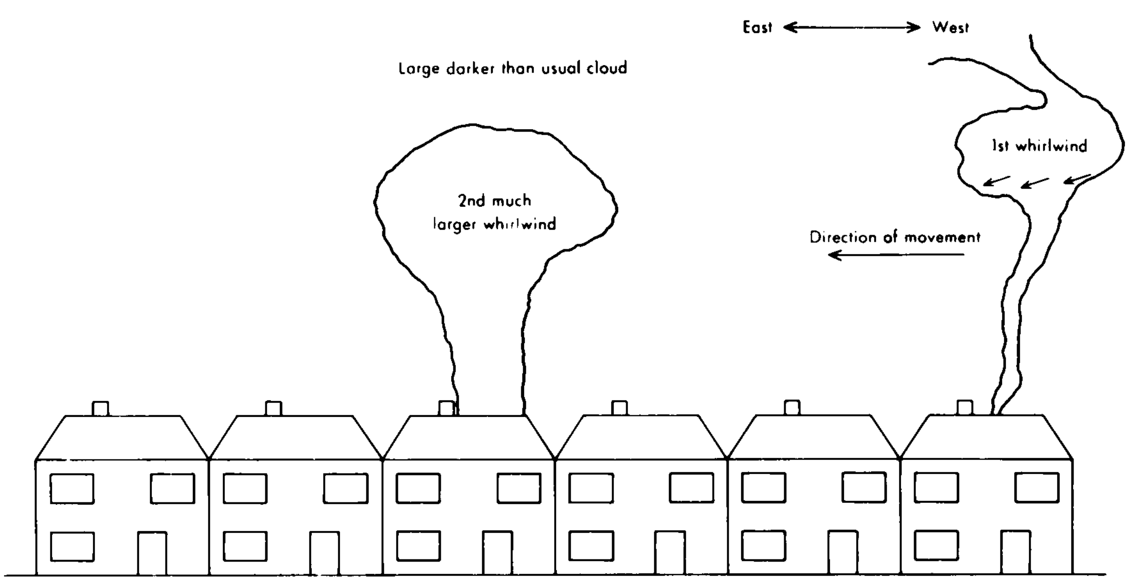


Figure A1. Picture of the squall. (Drawn from a sketch supplied by an eye-witness, Sgt Whelan of 1113 Marine Craft Unit, Holyhead.)

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ALPEX: The Alpine Experiment

This account is based on a WMO Press release issued shortly before ALPEX was due to begin; the use of the future tense in many sentences of this release has been retained.

Where: *Outer experiment area:* Europe; eastern Atlantic; North Africa.
Inner experiment area: countries surrounding the Alps; Mediterranean Sea.

When: *Special Observing Period:* 1 March to 30 April 1982.
General Observing Period: 1 September 1981 to 30 September 1982.

Who: 19 European nations and the USA.
Project direction and co-ordination by:
WMO (World Meteorological Organization)
ICSU (International Council of Scientific Unions)
IOC (Intergovernmental Oceanographic Commission)

Why: To observe and understand the influence of mountains on the global, regional and local weather.
To improve the capability of predicting weather developments induced by mountains, specifically by the Alps, including:
(a) floods and storm surges caused by the so-called 'Genoa cyclones'
(b) severe downslope winds, such as mistral, foehn and bora.
To simulate mountain effects properly in computer models of the atmosphere and ocean.
To aid, through improved weather prediction, the economy and well-being of countries in mountainous areas in other parts of the world.

How: Co-ordinated international effort composed of numerous national contributions including:
over land: 22 additional upper-air sounding stations supplementing the World Weather Watch, a network of microbarographic stations, radars, etc.,
over sea: 11 ships and many buoys, fixed platforms and tide gauges,
in the air: 17 aircraft, including some highly instrumented long- and medium-range planes, and
in space: the European geostationary satellite 'Meteosat 2' and the utilization of polar-orbiting satellites.

ALPEX and the Global Atmospheric Research Program

The Alpine Experiment is part of the 'Global Atmospheric Research Program' (GARP), a program supported by virtually all countries of the world. GARP focuses on major scientific problems which are holding up the progress of atmospheric sciences and of weather forecasting because they cannot be solved without pooling the resources of many countries.

ALPEX is the last in a series of large international research projects conducted under GARP. It addresses the critical problem of airflow over and round mountain complexes and its effects on the global, regional and local weather.

Among the possible sites for this experiment the Alps were selected, in spite of their modest size (compared with mountain ranges such as the Andes, Rocky Mountains or Tibetan Mountains). The reasons for selecting the Alps are that they produce most of the severe weather phenomena encountered in other mountain areas of the world, that they have already a long record of meteorological observations, and that the weather effects of the Alps are of vital importance to the European countries surrounding them.

What ALPEX will do

Mountain complexes even of moderate size are known to influence the atmosphere on practically all scales. On the largest scale, the planetary scale, the airflow over the northern hemisphere can switch to an alternative state under the influence of mountain ranges affecting the weather world-wide.

On the next smallest scale, the cyclonic scale, mountains often cause powerful disturbances on their down-stream side, the so-called lee cyclones (Fig. 1) which are usually associated with severe weather, floods and, over the sea, with storm surges. No mountain range in the world produces more of these depressions than the Alps. These are the 'Genoa cyclones' responsible for many of the disasters which have ravaged the alpine valleys and Italy. The events in Florence and Venice are reminders of these cyclones which present a notorious forecasting problem for the countries surrounding the Alps. ALPEX will try to clarify the processes leading to their development.

On the next smallest scale, mountains cause a host of local weather phenomena which may lead to entirely different weather characteristics on opposite sides of the mountains or between the plains and the mountain tops (Fig. 2). Best known are the 'mountain waves' (see Fig. 3) and the severe downslope winds which carry different names in different parts of the world (e.g. the 'chinook' of the Rocky Mountains, the 'foehn' and 'mistral' of the Alps and the 'bora' of the Yugoslavian coastal mountains). Duration and intensity of these winds on the ground—they can reach over 200 km/h in some parts of the world—are among the most difficult forecasting problems. Their mechanism is not fully understood. ALPEX will systematically explore these phenomena. For this purpose a vertical stack of aircraft will make co-ordinated traverses over the St. Gotthard and Brenner Passes (Fig. 4) directly above lines of highly accurate ground pressure stations ('microbarographs'). The same will be done above the Dalmation coast.

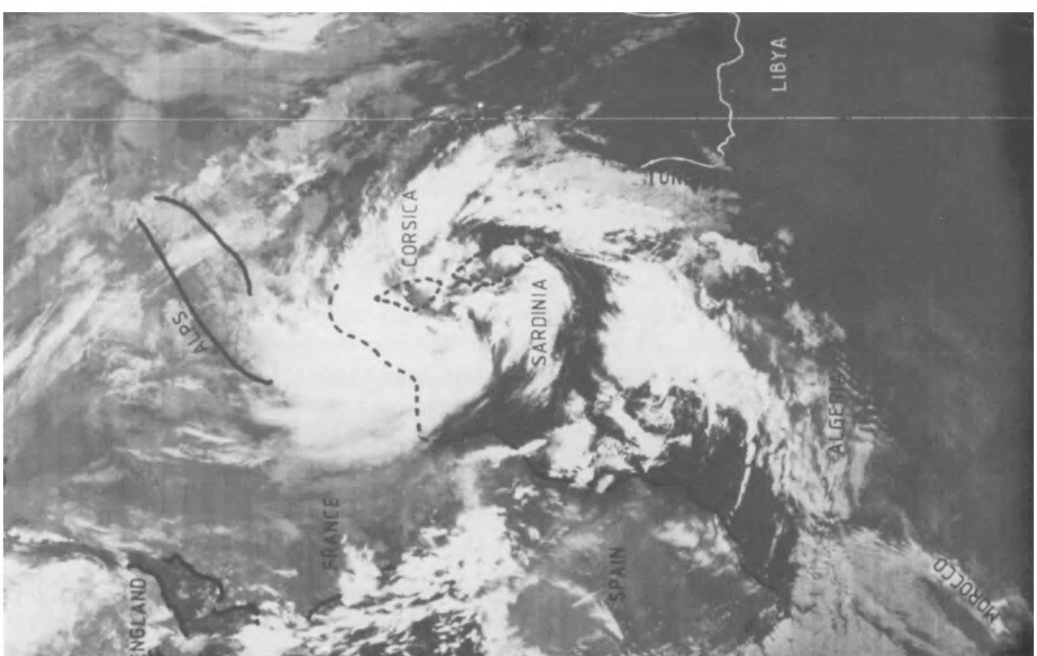
There is a special difficulty in simulating steep mountain ranges such as the Alps properly in mathematical forecasting models as they are used today in all major weather services. The detailed observations to be achieved by ALPEX will serve to diagnose the errors of these models and to verify their predictions.

In the western Mediterranean and the Adriatic Seas an oceanographic program, called MEDALPEX (for Mediterranean ALPEX), is being implemented. It focuses on the effects of 'wind forcing' on the western Mediterranean and Adriatic Seas, specifically on ocean currents, eddies, storm surges and dynamical factors governing the plankton distribution. Numerous ships, buoys, fixed platforms and tide gauges will be used for these investigations (see Table I).

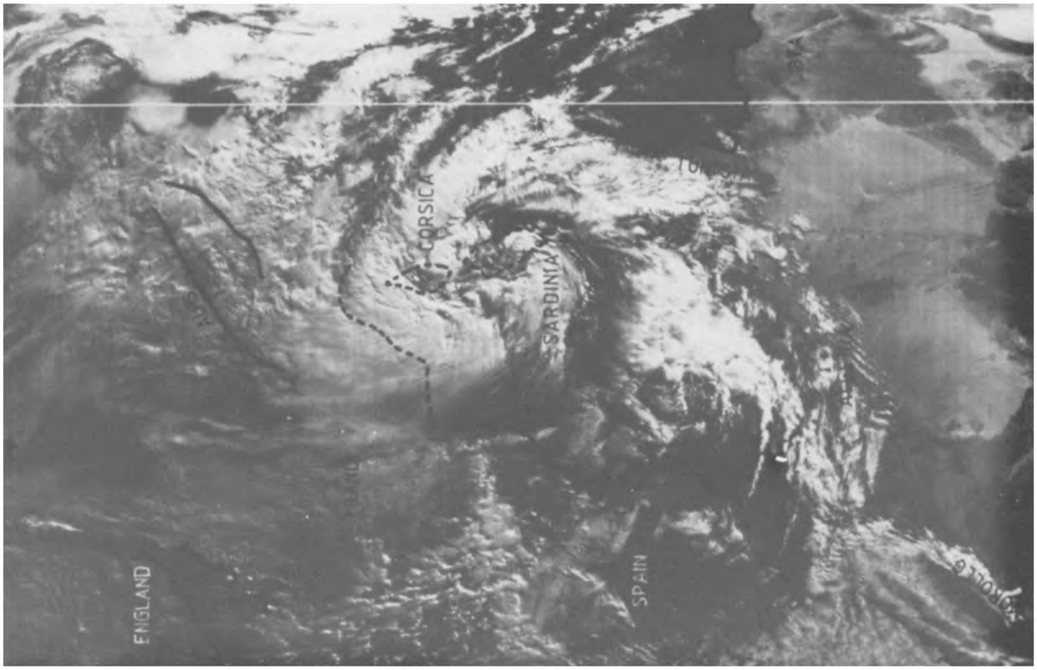
These are examples of the many scientific investigations planned for ALPEX according to an internationally agreed research plan. In addition, the participating countries will conduct a great number of national programs.

Observational systems and experiment areas

Numerous special observing systems are required to conduct this experiment. Table I lists the major systems to be used in ALPEX. Never before has such a comprehensive array of observing platforms been installed in Europe. They have been contributed by the participating nations. These observing systems complement each other and form jointly a 'composite observing system'.



(a) Visual image



(b) Infra-red image

Figure 1. The development of a cyclone in the lee of the Alps as seen from space. The centre of the cyclone is near Corsica.

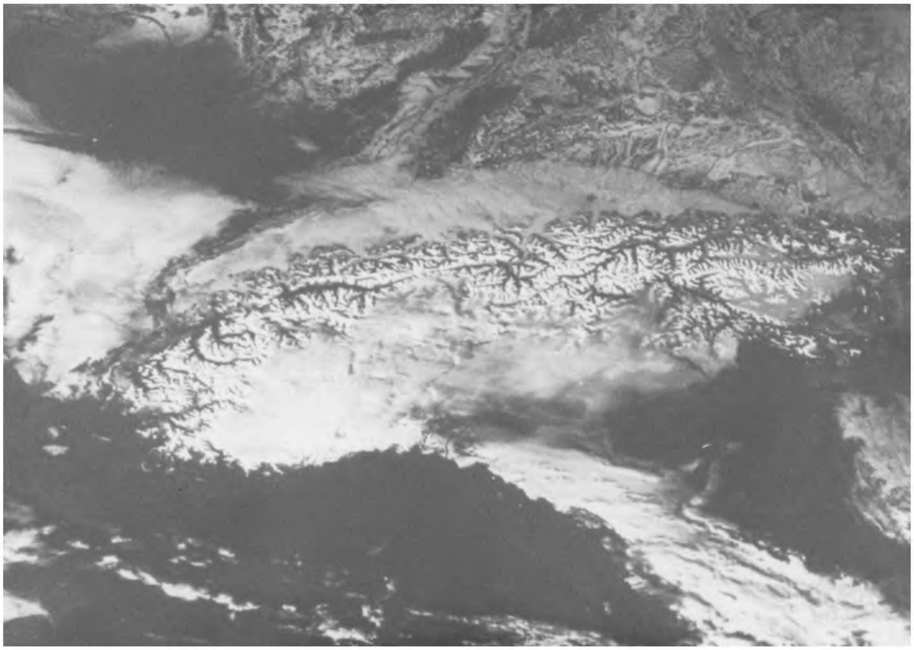


Figure 2. The Alps on a fair weather day in winter as seen from space (NOAA-6 visual image). The snow covered mountains are surrounded by fog and cloud fields covering the plains and valleys.

Figure 3. Wave clouds at about 10 km altitude formed by the Sierra Nevada mountains (California).

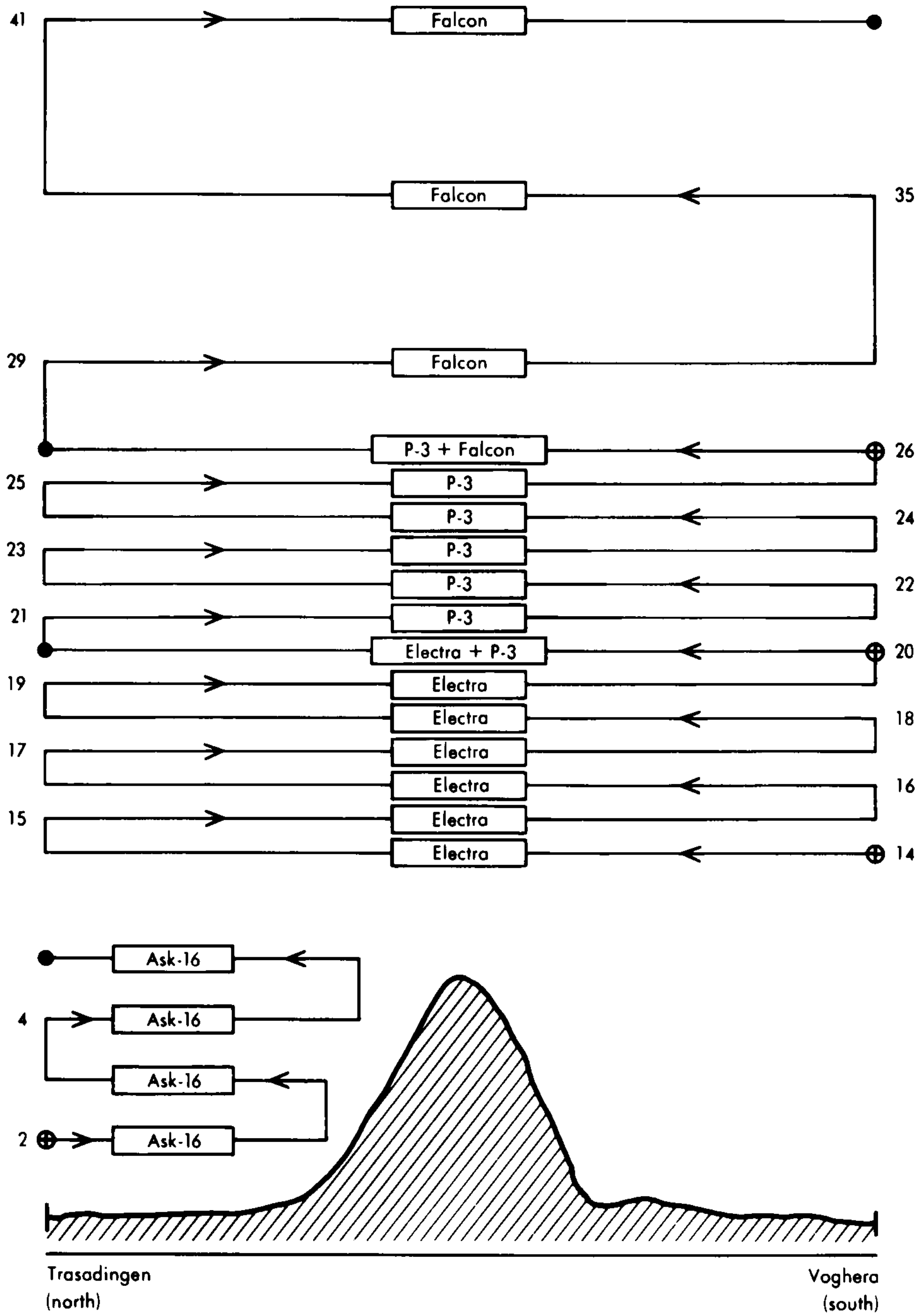


Figure 4. Proposed flight traverses over the Alps during foehn situations. The aircraft (a Falcon jet, a P-3, an Electra turboprop and 3 ASK-16 motorgliders) fly back and forth in a co-ordinated vertical stack.

Table I. *National contributions to the ALPEX special observing systems*

Nation	Aircraft	Ships	New upper-air sounding stations	Microbaro-graph stations	Radars available to ALPEX	Ocean buoys and fixed platforms
Austria			3	4	1	
Belgium		1				1
Czechoslovakia	1[a]					
France	2[a]	2	3		6	20
Federal Republic of Germany	8[b]		4	10	1	
Greece			1			
Hungary					2	
Italy	2[a]	3	4	9	3	4
Poland	2[a]					
Romania					6	
Spain		1				2
Switzerland			4	27	3	
USA	2[c]				2	
USSR		3[d]				
Yugoslavia		1	3	12		1
Total	17	11	22	62	24	28

In addition: the European geostationary satellite Meteosat 2, the USA polar-orbiting satellite TIROS-N together with 35 tide gauges, balloon systems, acoustic sounders, lidars, etc.

Notes: a. Short-range aircraft.
b. Includes 1 medium-range aircraft and 4 motor gliders.
c. Long-range aircraft.
d. Plus 3 weather ships.

Most of the observing systems will be installed in the 'inner experiment area' surrounding the Alps. This area is part of a larger 'outer experiment area' which describes the general airflow in which the mountain induced disturbances are embedded, (see Figs 5 and 6).

The participants

Table II gives a list of countries and international agencies participating in ALPEX and in MEDALPEX, its oceanographic component. About 20 nations have pooled their technical, scientific and monetary resources to make this project possible.*

Field operations

The nerve centre of ALPEX will be the Operations Centre near Geneva Cointrin airport. From here all international operations will be directed. Telecommunications exist between this centre and the nine national operations subcentres, the oceanographic fleet, the various forecasting and satellite centres and the secondary operations centre at the Marco Polo airport in Venice. A stream of up-to-date scientific and operational information will arrive at the Geneva centre and allow the assembled international group of scientists to decide on the daily operations plans. Three of the most modern

*The Meteorological Office took part in the early planning stages of ALPEX but, because of other commitments, was unable to take part in the experiment itself.

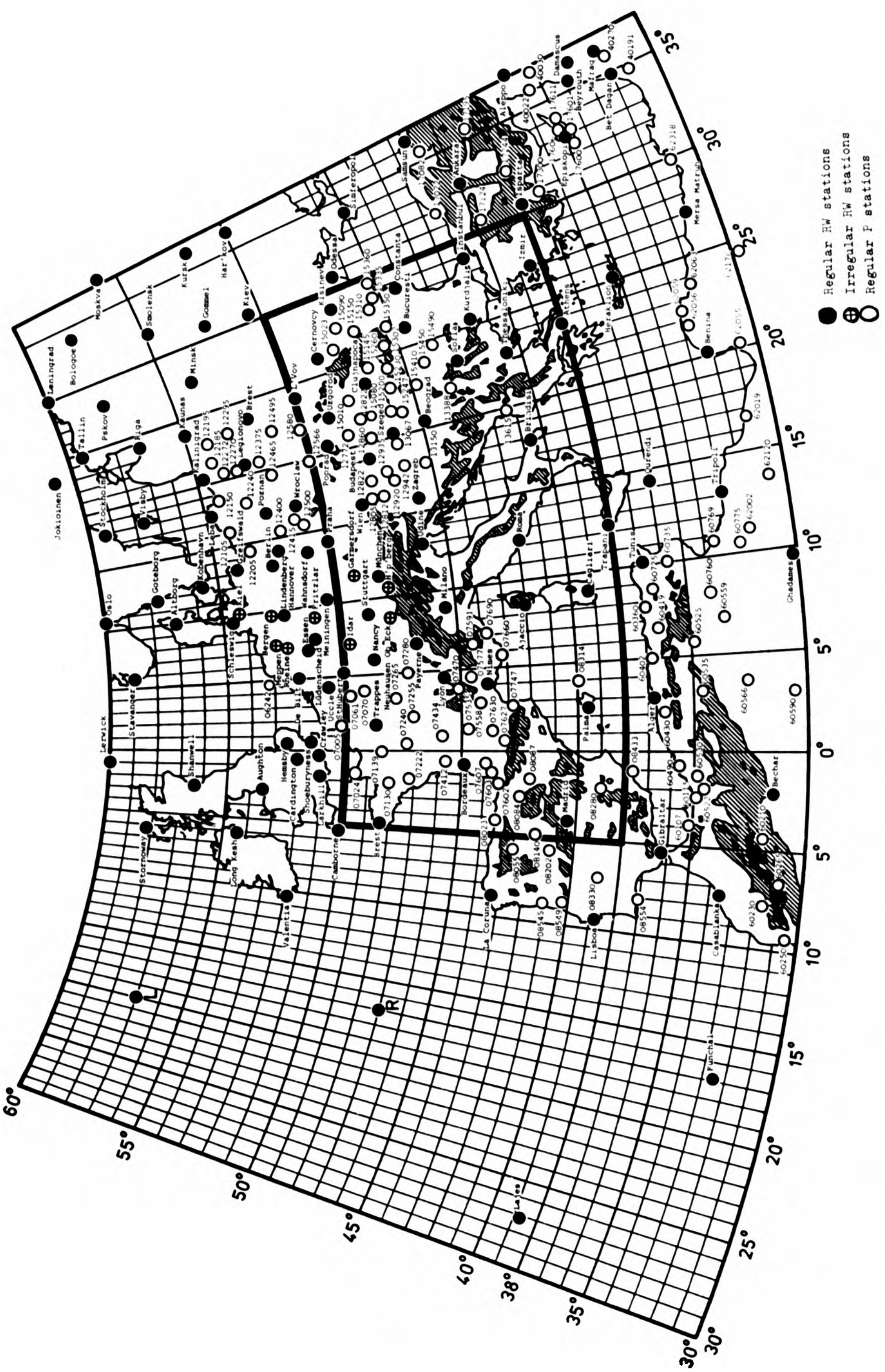


Figure 5. Outer and inner experiment area of ALPEX.

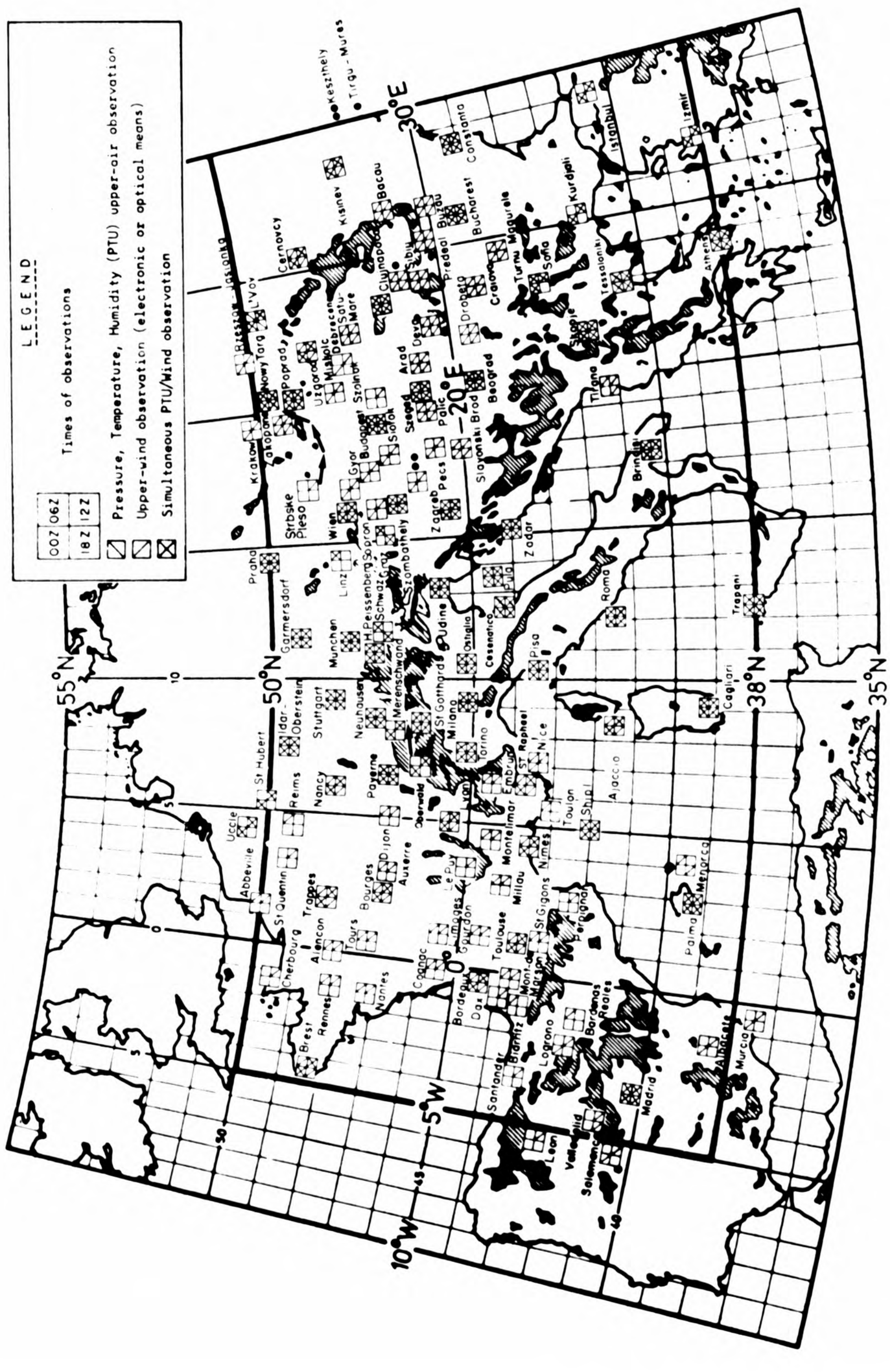


Figure 6. Upper-air sounding stations operating in the inner experiment area of ALPEX during March and April 1982.

Table II. *Countries and international agencies participating in ALPEX and in MEDALPEX, its oceanographic component.*

ALPEX:	Austria	Greece	Spain
	Belgium	Hungary	Switzerland
	Czechoslovakia	Italy	USA
	France	Poland	USSR
	Federal Republic of Germany	Romania	Yugoslavia
	Canada, Israel, Portugal and Turkey are also contributing.		
	European Space Agency (ESA)		
	European Centre for Medium Range Weather Forecasts (ECMWF)		
MEDALPEX:	Belgium	Monaco	USSR
	France	Spain	Yugoslavia
	Italy		

research aircraft in the world will fly out of Geneva across and around the Alps, over central Europe, the Atlantic and the Mediterranean Sea, according to the given atmospheric conditions. The Operations Centre in Geneva will house over 100 scientists, technicians and supporting personnel.

Data management

An enormous amount of data will evolve from ALPEX. These will be processed by national and special data centres and subsequently assembled and validated by the 'International ALPEX Data Centre' in Reading, UK. From this centre the final ALPEX data set will go to the World Data Centres in Moscow and Ashville, USA for distribution—in late 1983—to all interested scientific users. The World Meteorological Organization, the International Council of Scientific Unions and the Intergovernmental Oceanographic Commission will be responsible for following up this data flow and its scientific evaluation. The final scientific results of ALPEX may be expected around 1985.

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ALPEX completed

Based on a WMO Press release dated 10 May 1982

The work of the ALPEX Operations Centre in Geneva and its subcentres within Europe was completed on 30 April 1982. This brought to an end the two month Special Observing Period of the Alpine Experiment organized under the auspices of the World Meteorological Organization.

During the months of March and April 1982, excellent data have been collected by the research aircraft (see Fig. 1) in Geneva, as well as by the numerous observing networks installed by the participating countries around the Alps in Europe and by the research ships (see Fig. 2) operating in the Mediterranean Sea.

Figure 1. One of the highly instrumented long-range research aircraft participating in ALPEX. (USA Lockheed 'Electra'.)

Figure 2. One of the USSR research ships participating in ALPEX.

Favourable weather conditions made it possible thoroughly to investigate the formation of cyclones over the Mediterranean Sea caused by the Alps. Two to three events were expected but six occurred. The analysis of the collected data should bring improvements in the very difficult forecasting of these complex disturbances. Also mountain induced winds, such as the mistral in southern France and the bora over the Adriatic Sea, were explored. Weather conditions were not favourable for the study of the foehn which is normally connected with southerly winds; however, the so-called 'north-foehn' was studied both over the Alps and the Pyrenees. Finally, the deformation of fronts passing over and round the Alps was measured.

One of the most striking features observed by the ALPEX aircraft was the degree to which cold air masses in the atmospheric boundary layer flow round rather than over the Alps. Adjustments of computer models to this reality should bring improvements in weather forecasting, especially for several days ahead. Other scientific results will have to await the processing and finalization of the complete data set.

The aircraft in Geneva flew over 330 flight hours or 94% of those available to ALPEX. The scientific success rate of most of these flights is estimated at near 80%. Eleven ships operated in the Mediterranean, collecting surface and upper-air data and oceanographic parameters. Numerous upper-air stations, radar and special observing systems were operated successfully by the 19 participating countries.

The ALPEX Operations Centre at Geneva, installed in the vicinity of Cointrin airport, functioned smoothly under Swiss direction and housed a total of 170 participants. The co-operation of the air traffic control centres in Europe during the research flights was outstanding.

ALPEX brought together an unusual group of scientists from many countries, all interested in the airflow over and round mountains. This resulted in a lively exchange of ideas. Nearly 40 seminars were given by the visiting scientists.

It will take another 18 months until all data have been processed and finalized. There is little doubt that this unique data set will have an impact on weather forecasting and on the understanding of atmospheric flows over mountains in many parts of the world.

ALPEX is the last of the major international research projects conducted under GARP and jointly organized by WMO and ICSU. Its scientific results will bring to an end a 12-year effort to explore the weather of the globe, and with it the largest scientific undertaking ever conducted by the nations of the world.

551.508.23

Sunshine cards—then and now

By Désirée M. Allen

(Meteorological Office, Bracknell)

During the last century meteorological instruments have undergone many changes and have been redesigned to improve efficiency of record and measurement. The sunshine recorder is no exception to this period of change. The current Mk 3C recorder is a far cry from the earliest type, which was a wooden bowl with a glass sphere in its centre.

The sunshine card, however, has changed very little in the last 67 years. Recently, a small bundle of sunshine cards for January 1915 from the climatological station at Raunds (Northants) was sent to the Meteorological Office at Bracknell to be archived. Except for the use of roman numerals, the face of the card has changed little in those 67 years, as shown in Fig. 1.

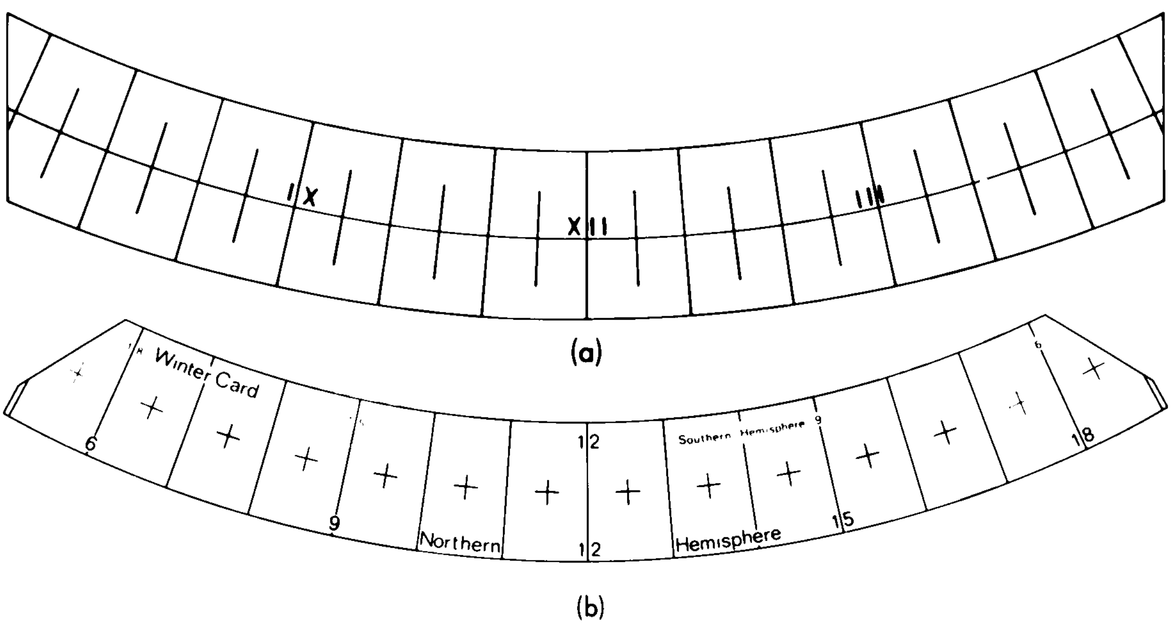

Figure 1. (a) Sunshine card used by Raunds (Northants) during January 1915 and (b) a present-day winter card.

Those seem to have been days of strict economy (probably due to World War I) in that the card remained in the recorder until there was sunshine to be recorded. All measurements of cards were verified. This bundle was accompanied by M.O.Form 424, as shown in Fig. 2. It is interesting to note that the verification shown here was by E. Gold* who in 1940 became Deputy Director of the Meteorological Office.

*See *Meteorol Mag* **76**, 241, ibid. **105**, 133.

M.O. Form 424.

METEOROLOGICAL OFFICE, S.W.

18th March, 1915.

Result of Examination of Sunshine Cards.

from RAUNDS *for* January 1915.

Day.	Measurements.		Notes.
	M.O.	Observer.	
2	3·0	2·8	
8	2·4	2·4	
15	1·3	1·3	
18	4·5	4·5	
31	2·7	2·5	
	13·7	13·5	

Figure 2. Result of examination of sunshine cards from Raunds (Northants) for January 1915.

Review

Climatic variations and variability: facts and theories, edited by A. Berger. 160 mm × 240 mm, pp. xxvi + 795, *illus.* D. Reidel Publishing Company, Dordrecht, Boston, London, 1981. Price Dfl. 175.00, US $87.50.

This book is the proceedings of the First Course of the International School of Meteorology at Erice and is a massive tome of nearly 800 pages containing the text of 41 lectures and 3 papers reviewing the lectures. The lectures are grouped in six parts whose titles indicate the scope of the Course: 'Mathematical and Physical Basis of Climate', 'Mathematical Techniques in Climate Reconstruction and Data Banks', 'Facts: Reconstruction of Past Climates' (the use of the world 'facts' is perhaps a little tendentious, in the pre-instumental period at least), 'Theories of Climatic Variations and their Modelling', 'Man's Impact on Climate', and 'Climate Impacts on Man'. The 'summary-reviews' are called 'Techniques for reconstructing past climates', 'Climate modelling', and 'Man's impact on Climate'. The lectures include most of the leading workers in the field from America and Europe. A detailed critical review of a book such as this is impossible in a short notice; suffice it to say that it must be an essential reference for all meteorologists interested in the subject.

Regrettably, but perhaps not surprisingly, the word 'anthropogenic' is used unnecessarily in the anomalous sense of 'man-made' or 'human' with wearisome frequency in Parts V and VI.

R.P.W. Lewis

Notes and news

An Edwardian dedication

Some happy serendipity in the deeper recesses of the National Meteorological Library has brought to light a sizeable book by William Digby, published in 1902 by Hutchinson, entitled *Natural Law in Terrestrial Phenomena.* It opens with the following sonorous dedication:

TO

The Astronomers Meteorologists and Geologists
of the United Kingdom

WHOSE SINGULAR AND UNEQUALLED DEVOTION AND ZEAL
IN THE
STUDY OF NATURAL PHENOMENA
PRODUCE GREAT RESULTS AND WIN ADMIRATION FROM
ALL WHO BECOME ACQUAINTED WITH THEIR PAINSTAKING,
CONTINUOUS, AND OFTEN VOLUNTARY, OBSERVATIONS
AND RECORDS WHICH CONSTITUTE
A MONUMENT OF UNWEARIED INDUSTRY
THE ATTEMPT (HEREIN RECORDED) TO GET BEHIND
VARIOUS OUTWARD MANIFESTATIONS OF
TERRESTRIAL PHENOMENA
(AN ATTEMPT CONCEIVED AND CARRIED OUT IN A
REVERENT AND SCIENTIFIC SPIRIT) AND THE
BODY OF EVIDENCE AND EXAMPLES
OF HITHERTO UNRECOGNISED CO-ORDINATION OF NATURAL
FORCES IN THE CAUSATION OF PHENOMENA ARE
SUBMITTED FOR CONSIDERATION AND EXAMINATION
AND RESPECTFULLY DEDICATED,
IN THE HOPE THAT IT MAY BE RECOGNISED AND
AGREED THAT ONE MORE OF NATURE'S SECRETS
HAS BEEN WRESTED FROM THE UNKNOWN

It is unlikely, though it may be regretted by some of our readers, that this style will be followed in future official publications of the Meteorological Office.

Enquiries on the weather, then and——

It seems that the type of enquiry received by meteorological organizations has not changed all that much in over one hundred years, as is shown by this extract from the 1869 volume (Number II, new series) of the *Journal of the Scottish Meteorological Society*.

CASES OF INQUIRY FOR INFORMATION AT THE OFFICE OF THIS SOCIETY, ON MATTERS AFFECTING IMPORTANT INTERESTS.

By ALEXANDER BUCHAN, *Meteorological Secretary*.

1. A corn merchant inquired whether, on a particular day in the autumn of 186—, rain had fallen in a certain district of Scotland. He had purchased a quantity of potatoes from a farmer, who, by agreement, carted them two or three miles to a railway station, where they were weighed immediately on arrival. On being delivered in Edinburgh, they were weighed by the merchant, and the weight was found to be considerably less than that alleged by the farmer as ascertained at the railway station. The merchant maintained that the greater weight stated by the farmer was owing to a heavy rain which fell while the potatoes were being carted to the station, and that they were weighed in a wet condition, but that when weighed by him they were dry. On this account he refused to pay the full amount charged. The farmer, on the other hand, maintained that no rain fell on that day; and he insisted on payment according to his weight. The case went into Court. The Society had several stations in the district where the potatoes had grown and had been carted. On consulting the returns from these stations, the Secretary, on being consulted, found such entries as 'a rainy day' marked on the day in question, a considerable quantity of rain also marked as having fallen, a low barometer, and wet weather, as reported at stations at a greater distance. He considered, therefore, that there was no reasonable doubt that rain had fallen on the potatoes on the way to the station. Extracts were given from the schedules detailing the state of the weather on this day.

2. A house-agent wished to be informed if it had rained in a particular town on a certain day in the summer of 186—. One of the tenants of the houses for which he was agent, stated that it had rained heavily on that day, in consequence of which rain had entered by the roof, and damaged the ceiling of a room. The tenant insisted that the agent bear the cost of the damage. This the agent refused to do, on the ground that he had not been informed in time of the damage done to the roof, in which case he would have had the roof repaired before the rain fell. The point was this: The tenant alleged that he had written the agent, acquainting him with the state of the roof, two days before the ceiling was damaged, and that as the repairs were not executed till after the ceiling was damaged, he would not be held responsible for it. The agent left on a tour through Scotland before the tenant's letter was delivered, and a day or two elapsed before he received it in the country. It so happened that in that part of the country where he was the weather was very fine, and no rain whatever fell on the day the ceiling was stated to have been damaged. It was surmised that the damage had been done before the letter was written by the tenant; and this could evidently be shown to be the case, if no rain fell at the place on the day the damage was said to have taken place. The Society had a station in the town, and for the day in question the observer had entered in the column of remarks in the schedule, that 'several heavy showers had fallen in the course of the day.' From this information, the lawsuit which had been proposed was given up.

3. A dealer in perishable goods forwarded a large quantity to a distant town, one day in spring 186—, by rail. These goods the company was bound to deliver to the consignees without delay, unless prevented by some occurrence which could not have been foreseen or provided against. The goods were not delivered till two days after date, when, on the boxes being opened, the goods were found to be unfit for sale. The dealer claimed damages, which were refused, the company saying that so heavy a fall of snow

had taken place just before the goods arrived, that the streets were impassable for their vans, that two days elapsed before they were cleared, and that immediately on the streets being cleared, the goods were delivered. As no snow had fallen in the town from which the goods had been sent, the consigner doubted the excuse made by the railway company. He proposed to prosecute the case, but before doing so, called at the office to ascertain the facts as to the weather. It was plainly shown, from the records in the office, that the statements made by the company were correct. The proposed lawsuit was accordingly given up.

4. Some time since an engineer applied for a statement of all the heavy daily rainfalls that had taken place in one of the large towns of Scotland during several years. An important drainage scheme was proposed at the time, and he had ascertained what sizes of drains were required to carry away all the water which fell during certain days of heavy rain,—the amount that fell on each occasion having been measured with the rain-gauge. The object was to determine the size of the drains which would be required to carry away all the rain, except in those cases of very heavy rainfalls, which, as they occur but seldom, do not require, in a case of this sort, to be provided against.

5. A considerable number of applications have been made for an account of the average annual rainfall in particular districts, with reference to the water supply of towns. From the number of years for which observations have been made at the stations, viz. thirteen, and for rain, a longer period at some places, trustworthy annual averages are now available, together with the amounts for the smallest annual rainfall of any two consecutive years.

6. A lawsuit was instituted by the proprietors of a bleachfield against a company that made coke in the immediate neighbourhood. Damages were claimed for the damage done by the smoke of the coke-works when it was carried by the wind over the bleachfield. The point was to settled the amount of damages, which plainly would to a great extent be determined by the number of days during the time the wind had blown from that direction which brought the smoke to the bleachfield. Extracts showing this were given from the schedules of a station a few miles distant. The observer proved his observations, and I was examined as a skilled witness, for my opinion how far the observations at the Society's station might be held as showing the direction of the wind at the bleachfield and cokeworks.

7. Some years ago a severe railway accident occurred through some trucks being blown off a siding, and thence down an incline, up which a passenger train was proceeding at the time. In the collision which followed, some lives were lost, and severe injuries were sustained. In an action of damages against the railway company, it was pled, on behalf of the company, that a great storm of wind was raging at the time—a storm so unprecedentedly great, that the company could not be held responsible for the trucks being driven down the incline, and for the events which followed. The schedules from the Society's stations were examined, from which it appeared that a storm of wind of considerable violence had passed over this part of Scotland at the time, but not so great as several storms which had previously occurred; that it was such a storm as might be expected to occur once or twice, or oftener, every winter. On this account the company were held responsible, for not having made provision to secure the trucks in such a manner as to resist being driven from their position by the force of the wind.

8. Application was made for the probable force of the wind at a railway station, on a night during which some trucks had been moved from a siding. The point in dispute was, whether the trucks had been set in motion by some malicious person, or by the wind.

9. Observations showing the particular character of the weather on a day in November 186—, were asked for. A gentleman of weak mind and in infirm health was boarded with some friends, who had been directed by the medical attendant on no account to allow him to walk out in wet or cold weather, such weather being, from the nature of his complaint, almost certain to prove fatal. On that day he had been allowed to go out. Shortly after he took ill, and died, and the friends with whom he resided at the time thereby succeeded to considerable property. A lawsuit was instituted by some others of the relatives,

who stated that the day on which the gentleman had gone out was wet and cold, and that he had been allowed to go out in this weather for the purpose of bringing on illness. An examination of the returns from two of the Society's stations in the immediate neighbourhood, together with others at a greater distance, showed that on that day the barometer was moderately high and steady, the temperature a little above the average, the wind very light, the sky clear or nearly so, and no rain; in other words, that the weather was indicative of a fine November day.

10. A gentleman, whose health had broken down from too close application to study, and who had been advised by his medical attendant to leave this country for Australia or New Zealand, called to make inquiries regarding his passage out, and the general characteristics of the climates of the parts of Australia and New Zealand where he might ultimately settle. It was most desirable that he should have the benefit of the long voyage round the Cape of Good Hope, and it was judged necessary that he should leave the British Isles as soon as possible, so as to avoid the east winds of spring. The voyage round the Cape could be taken, provided that the temperature there in June (the winter season) would not be too low, otherwise the overland route would be taken. From an examination of the mean and extreme temperatures in the south of Africa at this time of the year, and comparing them roughly with our own climate, it was decided that his health would stand the weather likely to be met with in rounding the Cape. A general idea was given of the climates of the parts of Australia and New Zealand he thought of going to, particularly with respect to their temperature and humidity. Many similar inquiries regarding the colonies and other foreign countries have been made.

11. Very many inquiries have been made asking advice regarding winter, spring, summer, or permanent residences. These inquires are made mostly by invalids, and by persons who have returned to this country, and intend settling somewhere in Great Britain. Guided mainly by the facts stated, and the opinions given, property has been leased or purchased, and houses built.

Much is now known regarding the capabilities of our British climate in different parts of the island; but the knowledge is far from being so generally diffused as it might be. It still sometimes happens, for example, that an invalid is sent from a place in the east of Scotland to one of the inland counties in the south of England, for the benefit of the milder winter climate which is supposed to prevail there. Since the climates of these two parts of Great Britain are at this season, as regards temperature, practically the same, no advantage is gained from a residence in this part of the south of England.

Award

We note with pleasure that the International Meteorological Organization Prize for outstanding work in meteorology or operational hydrology and international co-operation has been awarded by the WMO Executive Committee to Dr W. J. Gibbs, OBE, former Director of the Australian Bureau of Meteorology.

Dr Gibbs was born in 1916 and graduated with a BSc degree from the University of Sydney in 1938. He joined the Australian Bureau of Meteorology in 1939. During the Second World War he served as a weather forecaster in the Royal Australian Air Force. In 1943 he took an MSc degree at the University of Sydney and in 1952 an MS degree at the Massachusetts Institute of Technology. From 1948 he occupied a full-time research position in the Bureau of Meteorology and was promoted to Assistant Director (Research) in 1958. Dr Gibbs became Director of Meteorology in 1962, a post which he occupied until his retirement in 1978.

Dr Gibbs became widely known in the meteorological community both for his activities at national level and for his valuable and prominent role in international meteorological affairs for more than 30 years.

Dr Gibbs's meteorological research activities continued throughout his career. In all, he published some 75 scientific papers and participated in many scientific conferences. He is a member of many scientific institutions and was awarded in 1965 an honorary Doctorate of Science by the University of Melbourne. In 1968 he was awarded the title of Officer of the Order of the British Empire.

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NOTICES

It is requested that all books for review and communications for the Editor be addressed to the Director-General, Meteorological Office, London Road, Bracknell, Berkshire RG12 2SZ and marked 'For Meteorological Magazine'.

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An analysis of sudden, large falls in temperature at Lyneham during periods of weak advection

By B. J. Booth

(Meteorological Office, Royal Air Force Lyneham)

Summary

Following an unexpected and large fall in temperature at Lyneham in light winds during the early hours of 30 January 1981, the records were examined to find similar previous events. This paper describes the results of that search and identifies the situations when the phenomenon is most likely to occur.

Introduction

Sudden, large falls ($\geqslant 3.5\,^{\circ}$C) in temperature are phenomena usually associated with large-scale air-mass change but, while this is generally true, a study of the records for Lyneham in Wiltshire suggests that other causes must also be considered because, of 15 such events since 1954, 5 occurred during, or immediately following, periods of weak advection.

Lyneham (maximum elevation 156 m above mean sea level (m.s.l.)) is situated on a dome-shaped limestone outcrop with steep descents in the north-western semicircle from the airfield perimeter to the floor of the Avon valley 90 m below. The north-facing slope, Lyneham Banks, is especially severe with a mean gradient of about 1:8 along its 3.5 km length (Fig. 1). The slope in the eastern quadrant is much less

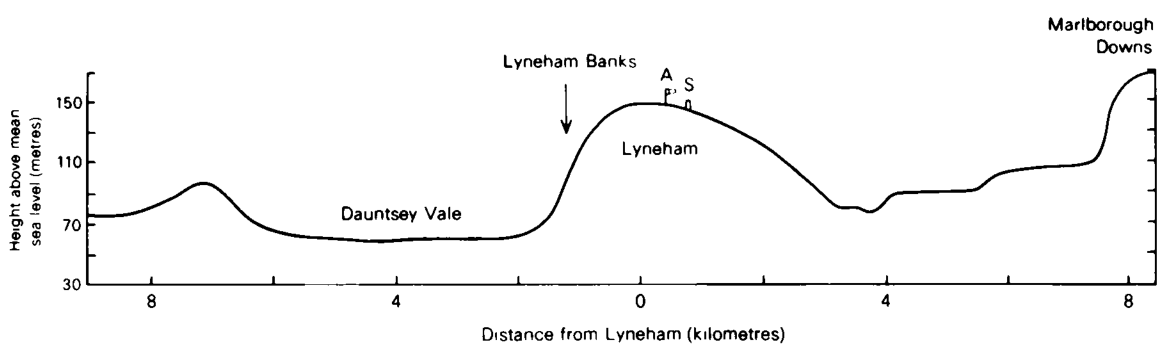


Figure 1. Topographical cross-section through Lyneham along 330°–150°. A and S are present sites of anemometer and instrument enclosure respectively.

marked and continues for some 6–8 km before reaching the scarp of the Marlborough Downs. The low ground immediately north of Lyneham, Dauntsey Vale, is a natural depression, bounded in the north-east by a watershed extending north-west from Wootton Bassett, and in the north-west by the southern slopes of the Cotswolds (Fig. 2).

The major waterway in the locality is the River Avon, but there are several minor streams, and mist or fog is often observed near these long before visibility decreases on the airfield.

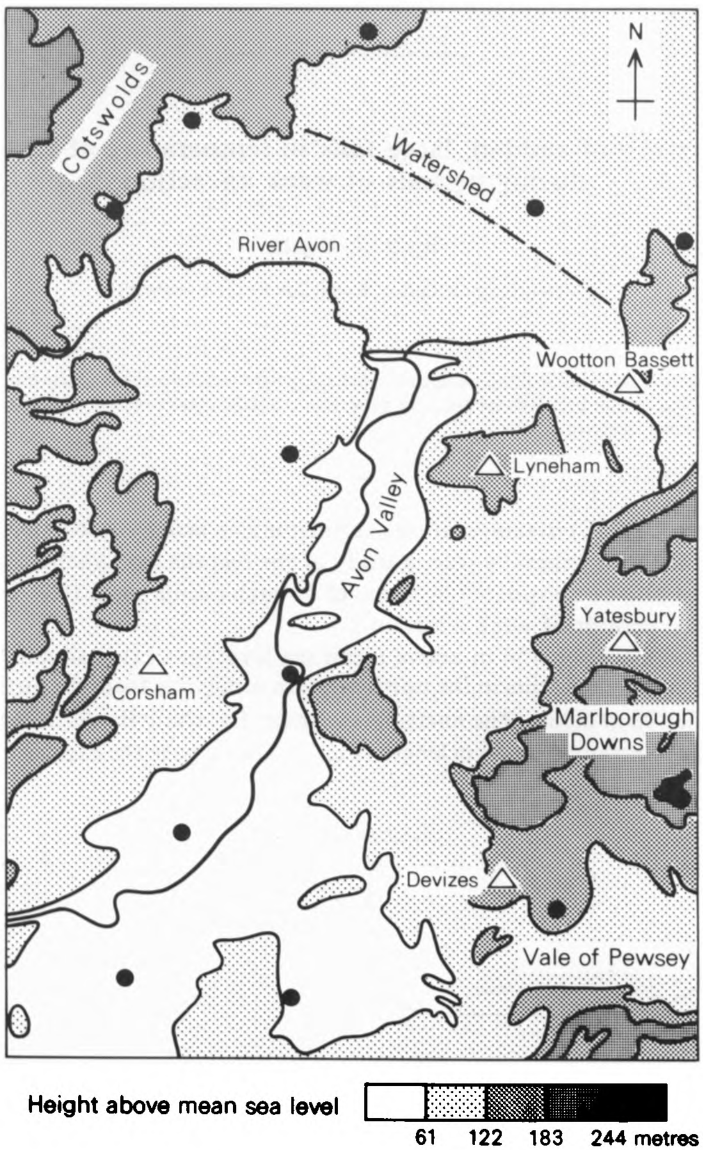


Figure 2. Locations of places referred to in the text (△) and observation sites (●).

Since 1961 the observing office has been located in the Air Traffic Control (ATC) building and is surrounded by open grassland, but previously observations were made from the site of the old ATC building near the airfield complex some 500 m to the north-east. Both sites are within 1000 m of the north and south-west facing slopes bounding the airfield (Fig. 3).

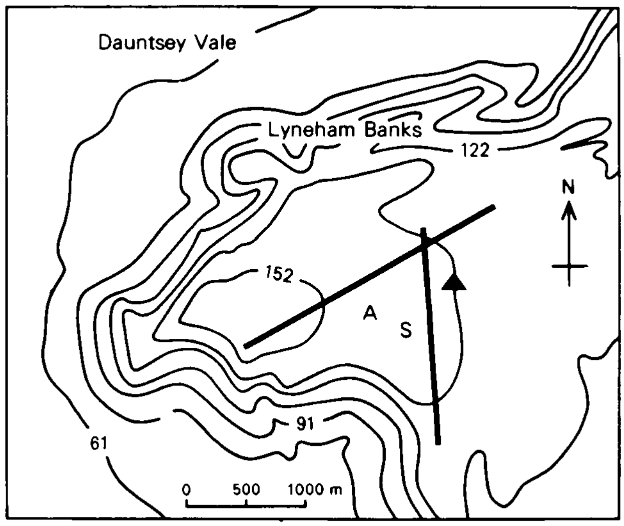


Figure 3. Topography in the immediate vicinity of Lyneham. Heights are in metres above mean sea level and contours are at 15-metre intervals. A and S are present locations of anemometer and instrument enclosure, and ▲ is the site of the instrument enclosure before 1961.

Before 1959 the anemometer was positioned 15 m above ground level on the roof of the old ATC building, where it was sheltered by hangars from winds in the eastern quadrant. During May 1959 it was repositioned on a lattice tower 13 m above ground level, 300 m north-west of the present observing office. An anemograph was not installed until 1976, so until this date only hourly wind values read directly from anemometer dials are on record, and it must be recognized that in very light winds these do not reflect all variations of direction.

In the following descriptions of the five events the absolute values of temperature changes must necessarily be approximate owing to the limitations of the thermograph. The temperature traces in Fig. 4 have been adjusted with respect to time and, where appropriate, transferred from a Fahrenheit to a Celsius scale. (Any errors created by this action are considered insignificant in the context of this paper.) All references to wind and temperature relate to surface conditions at Lyneham unless otherwise specified.

No significant low or medium cloud was observed between 18 GMT and 06 GMT the following day in any instance.

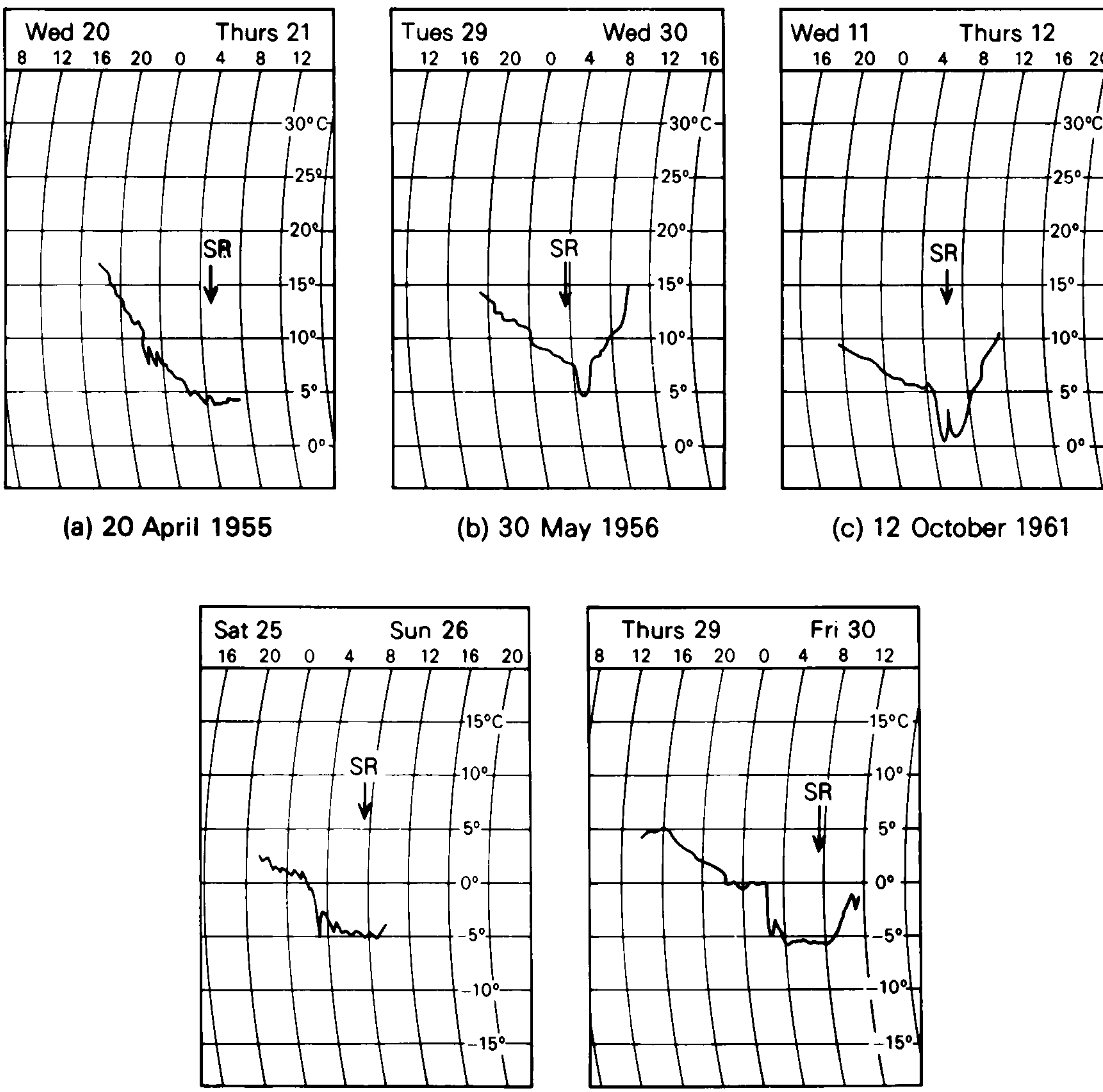
20 April 1955

At 18 GMT Lyneham was in a weak north-westerly geostrophic flow on the south-west flank of a shallow depression over the north Midlands. The flow subsequently veered to just east of north and strengthened slightly as the depression moved south-eastwards to be centred near London at midnight.

During the evening the temperature behaved much as would have been expected, falling steadily until just after 22 GMT when there was a sudden fall of over 3.5 °C (Fig. 4(a)).

Despite the north-westerly geostrophic flow the surface wind during the early part of the cooling period was very light and generally from the south or south-west but, coincidental with the temperature fall, it shifted to the north and increased to about 3 m s^{-1} (Table I(a)). Thereafter the wind remained in this quarter for the remainder of the night.

Visibility remained good during the whole period.



(a) 20 April 1955 (b) 30 May 1956 (c) 12 October 1961

(d) 26 November 1961 (e) 30 January 1981

Figure 4. Copies of Lyneham thermographs during five sudden and large drops in temperature (SR = sunrise).

Table I. *Lyneham observations during each of the five events (sky visible on each occasion and no significant cloud).*

(a) *20 April 1955*

Time GMT	20	21	22	23	00
Wind (°/m s⁻¹)	180/0.5	210/0.5	240/1.0	350/2.5	350/3.0
Temperature (°C)	13.5	12.6	11.9	8.6	7.8
Visibility (km)	24	16	16	16	13

(b) *30 May 1956*

Time GMT	02	03	04	05	06
Wind (°/m s⁻¹)	220/4.5	220/4.0	360/1.5	Calm	Calm
Temperature (°C)	9.1	8.4	6.5	5.3	8.9
Visibility (m)	1300	11000	100	700	200

(c) *12 October 1961*

Time GMT	02	03	04	05	06
Wind (°/m s⁻¹)	200/1.0	230/1.0	230/1.0	Calm	Calm
Temperature (°C)	7.2	7.0	6.9	2.4	3.0
Visibility (m)	4000	4000	4000	300	1700

(d) *26 November 1961*

Time GMT	01	02	03	04	05
Wind (°/m s⁻¹)	200/1.0	200/1.0	210/1.0	050/1.0	340/1.0
Temperature (°C)	2.3	1.7	−4.2	−2.9	−3.8
Visibility (m)	700	200	100	100	80

(e) *30 January 1981*

Time GMT	00	01	02	03	04
Wind (°/m s⁻¹)	080/1.0	130/1.0	140/1.0	150/1.0	340/1.0
Temperature (°C)	0.3	1.2	0.9	−4.2	−3.8
Visibility (m)	200	1000	5000	600	200

30 May 1956

The weather over southern England was dominated during the early hours of 30 May by an anticyclone, which at 06 GMT was centred just south-west of Lyneham.

Although the wind had been north-easterly 2.5 m s^{-1} earlier in the night, between 01 and 03 GMT a 3–4 m s^{-1} south-westerly developed which, considering the almost total lack of pressure gradient, is more than a little surprising.

Subsequent to the 03 GMT observation fog was observed 'forming quickly to the north' and by 04 GMT visibility had decreased to 100 m, although the sky was still clearly visible, and the wind had become northerly 1.5 m s^{-1} (Table 1(b)). At the same time the thermograph recorded a rapid fall in temperature of over 3.5 °C (Fig. 4(b)).

12 October 1961

At 06 GMT an anticyclone was centred just north-east of Lyneham, having moved north during the previous six hours as an intensifying feature.

On this occasion mist developed on the airfield during the previous evening and shallow fog was observed to the south-east at 02 GMT. Although there was little change in the temperature during the next two hours (Table 1(c)) there was a sudden fall of over 4.5 °C shortly after 04 GMT (Fig. 4(c)) and visibility fell from 4000 m to 300 m. Before this the wind had been south-westerly 1 m s^{-1} but subsequently fell calm.

An amplifying note in the *Daily Register* at 07 GMT indicates that the fog was shallow but more than 2 m deep and, although visibility improved to 11 km during the hour, a further note records fog persisting in the valley to the south-east.

26 November 1961

The main synoptic feature during this event was a weak ridge of high pressure extending east–west across southern England at 00 GMT. Individual high cells could be identified within this ridge, one being just north of Lyneham.

Fog developed on the airfield when the temperature fell to 2 °C shortly before the 23 GMT observation on the 25th. Subsequently there were only minor temperature fluctuations until just before 03 GMT when the temperature plummeted to –4.2 °C (Fig. 4(d)).

Before this the wind was a steady 200°/1 m s^{-1} but by 04 GMT it had become 050°, subsequently backing to 340° by 05 GMT (Table I(d)).

30 January 1981

The previous descriptions are necessarily brief owing to the lack of complementary data and suitable instrumentation. The following account of the event on 30 January 1981 contains references to observations elsewhere in the locality and it must be noted that some of the temperatures were recorded with non-standard instruments in overexposed locations. Special reference is made to data from Corsham (93 m above m.s.l.) in the Avon valley, Devizes (137 m above m.s.l.) at the western end of the Vale of Pewsey (but near the foot of steep slopes similar to Lyneham Banks) and Yatesbury (168 m above m.s.l.) on the Marlborough Downs.

Temperatures at Corsham and Yatesbury are recorded in Stevenson screens, but the Devizes thermometer, a Six's, is *underexposed,* being close to the junction of a hedge and north-east side of a house, and covered with a brown wicker waste-paper basket.

The southerly airstream which existed over southern counties at 03 GMT (Fig. 5) had developed some time previously and was maintained by a ridge of high pressure extending north-west from an anticyclone over central Europe. Upper-wind soundings made at Larkhill (33 km south of Lyneham) before and after the event, showed 0.5 – 2.5 m s^{-1} south-easterlies at the surface veering with height to become 2.5 – 5.0 m s^{-1} south-south-westerlies at 900 m above m.s.l.

Extensive low cloud and poor visibility affected much of England on the morning of the 29th but conditions improved considerably during the afternoon as cloudless air moved north from France. This clearance reached Lyneham soon after 15 GMT and before long the temperature began to fall steadily. At 22 GMT a sudden fall of 1 °C (to 1 °C) coincided with a brief shift of wind from 120° to 010° and fog was observed on the airfield. Following a slow veer of wind to 130° the fog dispersed at 0030 GMT as the temperature rose to 1.2°C. At 0218 GMT the wind unexpectedly backed to 330–360°, contragradient, (Fig. 6) and as the temperature plummeted to –4° C (Fig. 4(e)) the visibility fell to 100 m. Thereafter the temperature remained below this value until after dawn, apart from a brief recovery at 03 GMT.

Comment has already been made on the anomalous strength of the wind before the event on 30 May 1956 and, curiously enough, although it was not shown by the hourly observations, the wind also increased on this occasion, to 2.5 m s^{-1} for 20 to 25 minutes at 01 GMT (Fig. 6).

Despite visibility falling at times to 100 m, the vertical depth of the fog was never very great, the fog top probably being 15–20 m above the airfield (or 105 m above the valley floor). This is consistent with the 06 GMT Larkhill ascent (Fig. 7) which shows high humidity being confined to a shallow surface layer.

Dense fog formed at Corsham between 2100 and 2130 GMT at a temperature of 0.6 °C (Lyneham temperature at this time was 2.2 °C), but despite the fog the temperature continued to fall steadily before reaching a minimum of –2.7 °C at 09 GMT (Fig. 8), over six hours after the temperature fell to –4 °C at Lyneham. Minimum temperatures recorded elsewhere in the Avon valley were generally between –2 °C

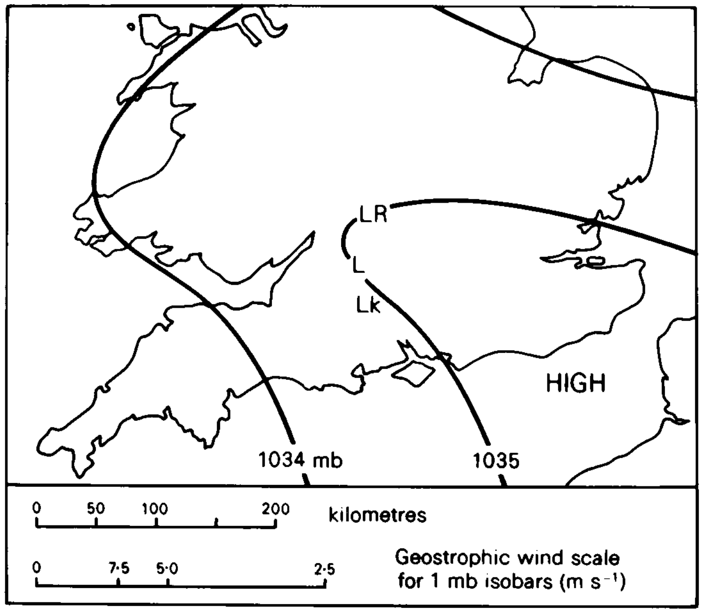


Figure 5. Synoptic situation at 03 GMT on 30 January 1981. (L = Lyneham, Lk = Larkhill and LR = Little Rissington.)

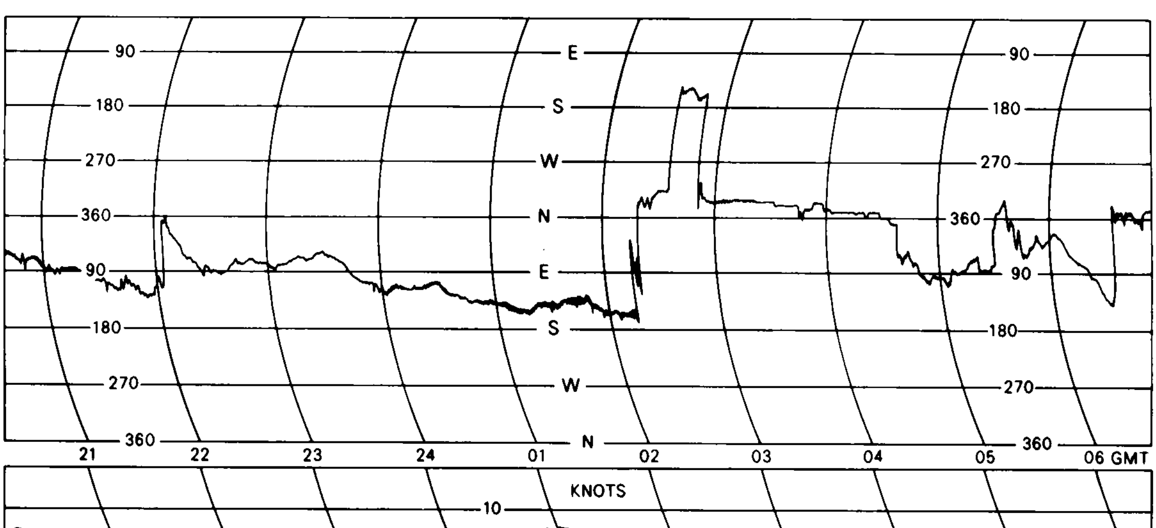


Figure 6. Copy of Lyneham anemogram for 29–30 January 1981.

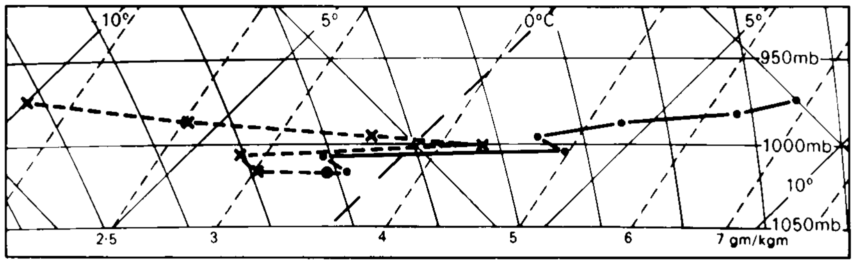


Figure 7. Larkhill radiosonde data for 06 GMT on 30 January 1981.

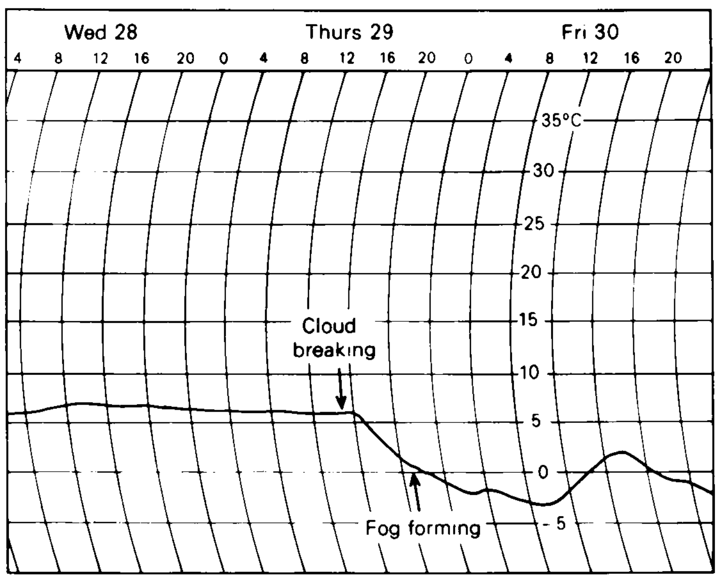


Figure 8. Copy of Corsham temperature trace for 29–30 January 1981.

and −3°C (Fig. 9), but the −6°C at Devizes and the −4°C of the fog which engulfed Lyneham are indicative of pockets of colder air at the foot of steep slopes.

It has been estimated from average clear-sky cooling curves for January-February (unpublished data held at Lyneham) that the minimum temperature at Lyneham would have been about -0.5°C if the airfield had not been affected by fog. This is considerably higher than the minimum of -3.7°C recorded at Yatesbury despite the site being 12 m higher than Lyneham, but the discrepancy can be readily accounted for by the different drainage characteristics of the two sites, since Yatesbury lies in a depression whereas Lyneham is on a dome-shaped outcrop.

Discussion

With the exception of 20 April 1955 each of the events occurred on anticyclonic radiation nights and (with the further exception of 26 November 1961) coincided with fog spilling on to the airfield from the adjacent Avon valley, the fog being restricted to a shallow depth by a marked, but shallow, inversion.

Considered in isolation it would be difficult to explain the temperature fall on 26 November 1961,

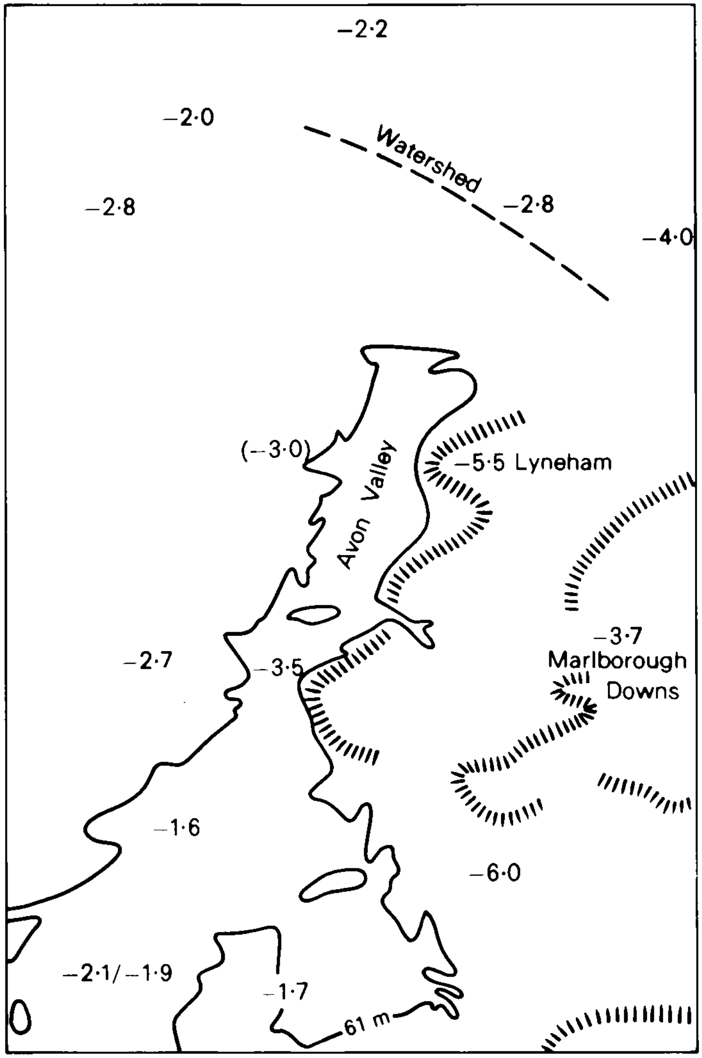


Figure 9. Minimum temperatures (°C) recorded in the vicinity of Lyneham on the night of 29–30 January 1981. ((−3.0) is an actual temperature read at 0730 GMT.)

since fog had developed *in situ* on the airfield some four hours before the event. However, in view of the remarkable similarities between this and the event of 30 January 1981, it would seem that this event was brought about in the same manner as were the other three, the difference being that the arrival of the valley fog (and hence the cold air) was masked by the existing fog.

In both cases the wind had a light southerly component before the temperature fall and a light northerly component after it; the events occurred at almost identical times; the temperature falls exceeded 5° C and were immediately followed by temporary recoveries (Figs 4(d) and 4(e)) and, finally, the lowest temperatures recorded during the events were between −4 °C and −4.5 °C.

When fog forms in the Avon valley on radiation nights Lyneham often remains fog-free until after dawn when conditions deteriorate as fog is lifted out of the valley by insolation or wind. Occasionally, however, subsequent radiative cooling from the fog top results in the fog deepening sufficiently to spill on to the airfield before dawn, with the associated temperature changes reflecting the different rates of cooling between the hill and valley locations. These temperature changes are usually relatively small, but larger ones do occur, and the very large falls described here are notable examples of the phenomenon. None the less, although such sudden changes in temperature are rare they are by no means unique to Lyneham, similar events having been noted at Little Rissington (229 m above m.s.l. and 100 m above adjacent valleys) by Konieczny (1957).

The events of 26 November 1961 and 30 January 1981 are especially noteworthy in that the cold valley air somehow acquired sufficient southward momentum, as it spilled on to the airfield, to overcome the existing gradient-induced surface flow.

The event of 20 April 1955 differs from the others in that it occurred when there was no fog. In this case radiation conditions during the early evening were ideal for a lake of cold air to collect in Dauntsey Vale. In the absence of any fog this would have deepened only slowly and would not have affected the airfield had it not been advected southwards by the strengthening northerly wind.

Conclusion

These sudden temperature falls occurred on radiation nights and were caused either by fog-free cold air being advected from the adjacent low ground by an increase in wind, or by fog developing in the same area and deepening sufficiently to suddenly engulf the airfield.

In both situations the suddenness of the temperature change is probably due to the close proximity of the airfield to the source of cold air (the instrument enclosure is 1000 m from the scarp at the airfield boundary), and the lack of mixing as the cold air crossed the intervening ground.

Although Lyneham forecasters have long been aware that nocturnal temperatures in the Avon valley are significantly lower than those experienced on the airfield, no attempt has ever been made to quantify the differences. Remembering therefore that this analysis relates essentially to foggy situations, it would not be unrealistic to expect minimum temperatures in the Avon valley on radiation nights to be generally 3°C or 4°C, or locally as much as 6°C, cooler than at Lyneham. (Harrison (1967) has observed comparable temperature variations over similar terrain in Kent.) Moreover, the greater part of this temperature differential develops during the early part of the cooling period and can occur at any season.

The events described are particularly instructive examples of the inadvisability of assuming a single station's observations to be representative of an area—especially on radiation nights.

Acknowledgements

A great many people, both within the Meteorological Office and elsewhere, have contributed to this discussion. In particular I would acknowledge the assistance given by Mr. R. Gosnell for his search of Lyneham's records to identify previous instances of the phenomenon, Mr. Mortimore of Corsham, Mr. Colman of Devizes and Mr. Partridge of Yatesbury.

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551.5:06:551.509.1:551.515.9:656.1

The influence of snow, fog and heavy rain on the demand for road transport information at Glasgow Weather Centre

By K. Smith

(Department of Geography, University of Strathclyde)

Summary

The number of enquiries received by Glasgow Weather Centre depends both on the current weather and the needs of the enquirer; average hourly totals are shown to vary systematically through the day and daily totals to vary through the week with a peak on Fridays. Rapid increases in the enquiry rate are produced by snow, fog and heavy rain in decreasing order of importance; snow can cause a rise in enquiry rate of over 600% in a three-hour period.

Introduction

Certain weather hazards disrupt road transport and lower road safety standards. In particular, snow and ice cause slippery roads whilst fog reduces visibility. Such hazards can occur in combination and affect both road surface conditions and visibility, as in the case of freezing fog or falling precipitation.

Since road transport appears to be affected immediately by bad weather, it is reasonable to suppose that this weather sensitivity will be reflected in the demand for meteorological information by road users. It is equally reasonable to suppose that routine weather forecasts will not always be able to meet the immediate need for the local information and the consumer will turn to the nearest Weather Centre for advice, as shown by Smith (1981). However, the previous study failed to indicate the high day-to-day variability of road transport enquiries and their dependence on adverse driving conditions. These factors are important because the concentration of such enquiries on days of poor winter weather is mainly responsible for the peak demands imposed on the Weather Centres. Therefore, the aim of the present paper is to examine how the demand for meteorological information by road users is influenced by snow, fog and heavy rainfall.

Road transport enquiries at Glasgow Weather Centre

Glasgow is the third busiest Weather Centre in Britain and, over the past two decades, the annual total of 'spontaneous' road transport enquiries (i.e. enquiries that have not been pre-arranged) has risen from less than 1500 to a maximum of nearly 25000 in 1978. These figures represent about 20% of total Weather Centre enquiries. Well over 90% of all these spontaneous enquiries are made by telephone and normally two forecasters answer such queries during the approximate hours of daylight between 06 and 18 GMT. The forecasters log each enquiry according to a standard system, including road transport, to produce hourly categorized totals for the 12 'daylight' hours plus a grand total for the full 24-hour day. Four public telephone lines were employed until a decision to limit the availability of this service reduced the number to two on 13 April 1979 with a further reduction to one line only on 9 February 1981. Thus, public access to this type of information has been limited, especially during periods of peak demand, and the annual enquiry total has dropped each year since 1978.

The concentration of demand by road users during spells of bad weather is very evident. Seasonally, well over 95% of road transport enquiries occur in the seven months from October to April inclusive and the only two months which have ever generated an aggregate of more than 15000 enquiries were the particularly wintry months of January 1978 and January 1979 when transport enquiries were dominant.

The highest ever individual daily total for road transport enquiries was 980 recorded on 29 December 1978, when snow fell throughout the day giving an accumulation of 6 cm in the city by 18 GMT. Peak daily transport enquiries fell to 578 in the 1979–80 winter and to 276 in 1980–81.

In view of the marked seasonal demand for weather information from road users, the remainder of this paper analyses daily and hourly road transport enquiries during the October–April winters for the years 1978–79, 1979–80 and 1980–81. These data reveal that, in addition to the seasonal pattern, community factors operate to produce a cycle of demand on smaller time-scales. Fig. 1 illustrates the mean daily totals of road transport enquiries received through the week during the study period. It is evident that the major demand occurs on Fridays, when the daily incidence is almost double the demand at the beginning of the week. This pattern implies that the information is used largely in the planning of, and participation in, leisure activities. The change in demand through the day is even more regular, although the individual hourly totals vary considerably according to month (Table I). In all cases demand rises quickly in the early morning to reach a peak between 09–10 GMT as consumers assess the prospects for travel during the day. Thereafter, there is a gradual decline in enquiries, only temporarily arrested by a small secondary peak in mid-afternoon (15–16 GMT) before a rapid recession in late afternoon. A comparison of the 12-hour totals with the 24-hour totals shows that rather more than 80% of all road transport enquiries are confined to the 'daylight' half of the day. Table I also details the marked mid-winter increase in the enquiry rate at all hours with the peak morning period in January generating more than 10 road transport enquiries per hour during an average day. On a few occasions during snowfall, and with all four telephone lines open, it has been possible for the Weather Centre to service 120 road transport enquiries per hour at the morning peak period.

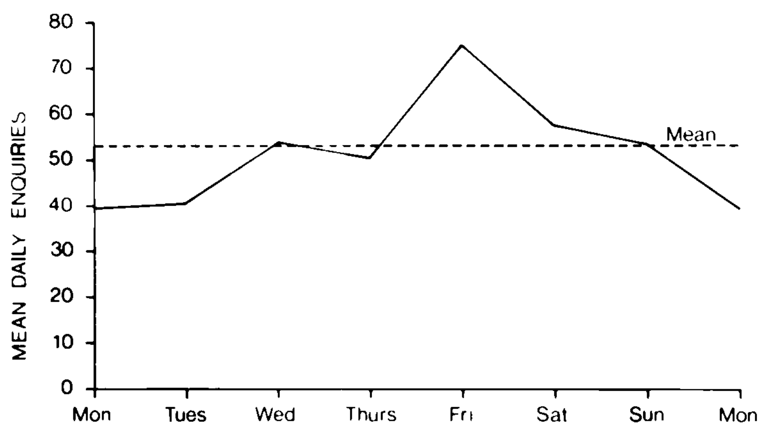

Figure 1. The weekly cycle of mean daily road transport enquiries at Glasgow Weather Centre.

It is apparent that these road transport enquiries are influenced not only by bad weather but also by consumer requirements which must be considered in any analysis. Similarly, an acceptable methodology must take account of the reduced availability of public telephone access to the Weather Centre over the period concerned.

Table I. *Mean number of hourly and daily road transport enquiries during the* 1978–79 *to* 1980–81 *winter periods at Glasgow Weather Centre.*

Month	Average number of enquiries per hour 6–7	7–8	8–9	9–10	10–11	11–12	12–13	13–14	14–15	15–16	16–17	17–18	12-hour total	24-hour total	Percentage of daily enquiries 06–18 GMT
Oct.	0.13	0.26	0.55	0.94	0.77	0.42	0.39	0.35	0.19	0.26	0.16	0.23	4.65	5.80	80
Nov.	0.83	1.33	2.10	2.83	2.80	2.67	2.30	2.10	2.10	1.97	1.93	1.70	24.66	29.78	83
Dec.	1.29	2.10	5.13	7.06	5.77	5.03	4.58	4.45	4.68	5.19	4.55	4.29	54.12	69.65	78
Jan.	1.74	3.13	6.84	13.90	13.35	12.48	9.74	9.81	9.26	9.58	7.81	6.23	103.87	119.63	87
Feb.	1.21	1.64	4.00	8.89	7.71	6.36	5.61	4.79	4.11	4.32	3.93	3.07	55.64	64.15	87
Mar.	1.58	2.97	5.23	9.26	8.06	7.16	5.71	5.00	5.13	5.32	3.39	2.61	61.42	70.94	87
Apr.	0.33	0.40	0.83	1.30	1.13	0.83	0.63	0.53	0.47	0.30	0.33	0.20	7.28	8.42	86
Mean	1.02	1.69	3.53	6.31	5.66	4.99	4.14	3.86	3.71	3.85	3.16	2.62	44.53	52.62	84

Methodology and interpretation of results

Hourly totals of road transport enquiries for the three winters were abstracted from the Weather Centre log sheets and combined to give 12-hour and 24-hour daily totals for each seven-month season. Meteorological data were obtained from Glasgow (Abbotsinch) airport which lies some 10 km to the west of the city centre. As such, the airport is well within the region served by the Weather Centre and is reasonably representative of the outer suburban ring which supplies many commuters to the city. From the available observations, the following periods and severities of weather hazards were defined:

Snowfall

(1) 3 hours with ≥ 0.5 cm fall (06–18 GMT)
(2) 12 hours with ≥ 0.5 cm fall (06–18 GMT)
(3) Days with sleet or snow falling (00–24 GMT).

Fog

(1) Dense—hours with visibility < 100 m (06–18 GMT)
(2) Thick—hours with visibility 100–200 m (06–18 GMT)
(3) Days with visibility < 200 m (00–24 GMT).

Heavy rainfall

(1) Hours with ≥ 4 mm fall (06–18 GMT)
(2) Days with ≥ 20 mm fall (00–24 GMT).

The analytical method adopted was the 'matched-pair' approach used by Bertness (1980). This method firstly involved preparing a list of all the periods which met a criterion for a weather hazard as defined above. Then the hour, 3-hour period or day exactly one week later than each defined hazard period was checked to see if it conformed to the same, or any of the other, hazard criteria. If it did not, it was selected for the sample. If it did so (i.e. if the attempted matched period reached any of the hazard thresholds indicated) or if it fell on a holiday period, it was rejected. In this case, the period exactly one week before the hazard period was selected, provided that it was a non-hazard period and had not previously been matched to any other hazard day. If neither of the potential non-hazard periods was acceptable, both they and the initial hazard period were withdrawn from the sample. This procedure was undertaken sequentially for snow, fog and heavy rain. Using the paired lists, the numbers of road transport enquiries were then compared, using the t-test, to determine the effect of the particular weather hazard.

The advantages of the matched-pair approach are that, despite the inevitable exclusion of many periods through the cross-checking procedure, it can produce statistically significant results with relatively small samples. Equally important is the fact that the study area serves as its own control for factors such as road conditions or traffic volumes which may affect a road user's perception of transport problems. By matching periods exactly seven days apart, the method eliminates any complications arising from regular hourly or day-of-the-week variations or any problems caused by the planned reduction in telephone access to the Weather Centre.

On the other hand, certain assumptions underlie the methodology:

(1) *Temporal and spatial sampling.* It is assumed that transport enquiries represent a direct reaction to the onset of bad weather, i.e. that no consumers are wanting long-term forecast advice or any road transport information unrelated to the prevailing weather conditions in the local area. There is also an assumption that meteorological observations at one site are representative of the weather over the entire area.

(2) *Identification of weather hazards.* The threshold values selected are entirely arbitrary, although it is believed that they contribute substantially to reduced visibility and low road friction. It has not been possible to exclude adverse weather completely from the 'non-hazard' periods which may have low temperatures or high winds, for example. Similarly, the effect of multiple hazards cannot be explored even though it is likely that, for example, there will be more enquiries during periods of freezing fog than will occur with equivalent visibilities at higher temperatures.

(3) *Accuracy of enquiry totals.* Complete accuracy cannot be expected from the enquiry data, especially during periods of peak demand when the forecasters may be too busy to log every call and potential consumers may find all the telephone lines engaged. These people will either do without the weather information they were seeking or turn to other sources, e.g. the Automatic Telephone Weather Service. Such circumstances will lead to an underestimation of the effects of adverse weather on demand. It is also possible that, largely as a result of imprecise information provided by the consumer, there may be errors in the classification of road transport enquiries relative to other calls, although it is believed that individual categories are correct to within ± 5% (Allardice, private communication).

Results

The detailed results are presented in Table II. It can be seen that all weather hazard periods produced at least a two-fold increase in enquiries. Since measured snowfall data were not available on an hourly basis, it is impossible to compare the three selected hazards over periods of less than 24 hours. However, if the enquiry totals associated with measurable snowfall can be assumed to distribute evenly over the constituent individual hourly periods, then it would appear that such heavy snow produces an average of at least 25 road transport enquiries per hour compared to 12 for dense fog and 3 for intense rain. It should be stressed that these enquiry rates refer to the hours between 06 and 18 GMT when most road use takes place. The same pattern is evident over the full day. Taking the mean of three separate winter totals for snowfall days, it may be deduced that a day with either sleet or snow falling, however slight the

Table II. *Number of road transport enquiries during selected weather hazard and matched non-hazard winter periods at Glasgow Weather Centre. (All periods less than 24 hours in length lie between 06 and 18 GMT.)*

Weather hazard period	Mean number of enquiries during hazard period	Mean number of enquiries during matched non-hazard period	Ratio	N (number of pairs)	Significance*
Snowfall					
$\geqslant$ 0.5 cm per 3 h totals	77.32	12.16	6.36	19	HS
$\geqslant$ 0.5 cm per 12 h totals	335.50	59.83	5.61	12	HS
Days with sleet/snow falling (24 h totals)					
winter 1978–79	210.61	57.51	3.66	41	HS
winter 1979–80	104.50	22.58	4.63	26	DS
winter 1980–81	90.13	19.76	4.56	38	HS
Fog					
Visibility < 100 m per 1 h totals	12.52	4.07	3.08	27	DS
Visibility 100–200 m per 1 h totals	5.55	2.14	2.59	22	NS
Days with visibility < 200 m (24 h totals)	78.93	32.93	2.40	14	PS
Heavy Rainfall					
$\geqslant$ 4 mm per 1 h totals	3.00	0.50	6.00	10	NS
Days with $\geqslant$ 20 mm (24 h totals)	29.55	13.00	2.27	11	NS

*NS (not significant) indicates significance at 0.10 level
PS (probably significant) indicates significance at 0.05 level
DS (definitely significant) indicates significance at 0.01 level
HS (highly significant) indicates significance at 0.001 level

amount and irrespective of when it falls, produces some 130 transport enquiries compared to approximately 80 for days with thick fog and 30 for days with heavy rainfall. The marked decline in mean snowfall day enquiries from over 200 in 1978–79 to less than 90 in 1980–81 may be largely explained by the reduced telephone access to the Weather Centre.

This overall rank order of hazard influence is confirmed by the statistical testing. All the snowfall results emerge as statistically significant, mostly at the highest level, depite the expectation that the 24-hour results might be less significant than the 3-hour results if the enquiry reaction is assumed to be immediate. The fog hazard seems to operate at a rather lower level of statistical significance, although there is a clear difference between the definitely significant hourly result for dense fog (visibility < 100 m) compared with the unsignificant result for thick fog (visibility 100–200 m). Apart from the fact that driving conditions improve considerably with horizontal visibilities beyond 100 m to prompt fewer enquiries, it is likely that some of the fog observations will be confined to the vicinity of the airport which lies close to the valley of the Black Cart Water and its confluence with the river Clyde. There is no evidence that rain falling at the intensities defined in this paper has any statistically significant effect on road transport enquiries. This result is difficult to account for with certainty. It is possible that the thresholds adopted are too low for rainfall to present a hazard to road users but it is also possible that the relatively high frequency of rainfall in the Glasgow area may have led to some behavioural adaptations by local drivers who have learned to live with the hazard without needing to seek weather advice.

Conclusion

Any weather sensitivity shown by road transport enquiries does not necessarily imply an equal sensitivity of road transport use since no direct knowledge is available concerning the weather information consumer, the reason for his enquiry and the use, if any, which is subsequently made of the information. Despite this limitation, two major conclusions emerge. Firstly, it has been demonstrated that the demand for weather-related road transport information is influenced on a regular basis by community factors which control the weekly and diurnal rhythm of enquiries. Over a longer time-scale, the effect of decisions to reduce the availability of this service to the public can also be seen. Secondly, and more important from the viewpoint of this paper, distinctive concentrations of enquiries have been found to occur, on timescales from the season down to hourly intervals, in association with atmospheric conditions. Bad weather is highly effective in creating short-term demand peaks. Snowfall has the greatest effect and is capable of increasing demand around six-fold during the working day to produce an enquiry rate well in excess of 100 per hour. This effect appears to be approximately double that associated with fog. There is some evidence for a rise in enquiries linked to heavy rainfall but no statistical significance can be attached to the results.

Acknowledgement

The author wishes to thank Mr J. G. Allardice, Senior Meteorological Officer at Glasgow Weather Centre, for supplying the enquiry data and most of the meteorological information used in this paper. Mr Allardice also made valuable suggestions concerning the interpretation of these data, although the responsibility for the opinions and conclusions expressed remains with the author.

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Retirement of Mr D. R. Grant

Mr D. R. Grant, B.Sc., Assistant Director (Observational Requirements and Practices) retired from the Meteorological Office on 20 September 1982 after a career of 34 years covering a wide range of meteorological activities in both the Research and Services sides of the Office.

Donald Grant was born in 1922 in Newport, Fife, and was educated at the Royal High School, Edinburgh and Edinburgh University. He joined the Office as a Scientific Officer in August 1948 and, following the usual Scientific Officer Course and short detachment (to Pitreavie) for forecasting experience, he spent the next three years at the Meteorological Research Flight developing an ultra-rapid response thermometer (URT) for use on aircraft in the study of the small scale variability of temperature in the atmosphere.

From 1951 to 1959 he continued his interest in instrumentation in the Upper Air Instruments Development Branch (then called M.O. 17) and in 1952 he was promoted to Senior Scientific Officer. Although his report on the ill-fated radar sonde project resulted in its abandonment, the work put into the meteorological sensors was not wasted, and with some modifications these sensors are still in use in the Mk 3 Radiosonde today.

After a short spell as a forecaster at Heathrow from 1959–61, Mr Grant returned to the Meteorological Research Flight in 1961 on promotion to Principal Scientific Officer. There he took up his interest in convection again using the URT and radio refractometer installed on the MRF aircraft, and produced a number of papers on the topic. He was also involved at that time in looking at some of the problems involved in measuring air temperature from supersonic aircraft.

Five years later, in 1966, he was posted to the Middle East as Chief Meteorological Officer in Aden. One of his first major tasks there was to organize the move of meteorological services to Bahrain following the evacuation of Aden by British forces. This was only a short spell abroad, however, and in 1967 he was back in the United Kingdom as Principal Meteorological Officer of the Meteorological Research Unit, Cambridge. During his stay in Cambridge he produced further research papers on a study of methods of measuring evaporation from crops (such as barley) in a joint project with the Cambridge University Departments of Agriculture and Botany and the Plant Breeding Institute.

After five years at Cambridge, he moved back to Scotland as Superintendent of the Office at Edinburgh, a job which allowed him to make full use of his wide background knowledge. There he was very successful in opening up new contacts with the Scottish meteorological community and broadening the scope of the work there.

It was no surprise when in 1975 he was promoted again to become Assistant Director in charge of the Special Investigations Branch of the Office, where he was able to make full use of his varied background. His thoroughness and attention to detail proved of great use in this post, and have continued to stand him in good stead in his final post (since 1977) as Assistant Director of the Branch responsible for Observational Requirements and Practices. There, as Chairman of the Working Group on the UK Observational Network, he has had a considerable influence on the development of the Meteorological Office's new observing system. He was also Chairman of the Working Group on the Introduction of the New Common Surface Codes, and it was largely due to him that this significant change was brought about so smoothly on 1 January 1982.

Mr Grant has been a Fellow of the Royal Meteorological Society since 1948; he has published papers in the *Quarterly Journal of the Royal Meteorological Society*, the *Journal of Scientific Instruments*, the *Meteorological Magazine*, the *Journal of Agricultural Science*, *Agricultural Meteorology*, and the *Journal of Soil Science*. He has been active and well known in the international meteorological community, in particular during his five years as the United Kingdom representative on the WMO Commission for Basic Systems (CBS) Working Group on the Global Observing System. He has also been a United Kingdom delegate to meetings of the WMO Commission for Basic Systems and a number of WMO Study Groups.

Donald Grant married in April 1961 and has three children. In his retirement he will continue his close association with meteorology, since he will take up a new appointment as Executive Secretary of the Royal Meteorological Society. We therefore expect to continue to see quite a lot of both him and his wife Jill. We wish them a long and happy time in this new way of life, and hope that they will continue to enjoy good health and contentment.

D. N. Axford

Notes and news

Sir Napier Shaw and the Meteorological Office in 1900

Our September issue (Notes and news—25 years ago) contained a reference to the obituary of R. G. K. Lempfert—the first member of the Office to be appointed holding professional scientific qualifications – and quoted some comments by Sir Napier Shaw who was responsible for having the appointment made.

A letter written by Sir Napier on his retirement in 1920 and published in our issue for December of that year sheds interesting light on the difficulties he faced on taking charge of the Office in 1900. It is addressed to the Chairman of the Meteorological Committee, Major-General Sir Frederick Sykes, Controller-General of Civil Aviation:

10, Moreton Gardens,
Old Brompton Road, S.W.5,
16 November 1920.

DEAR GENERAL SYKES,

PLEASE convey to the Members of the Meteorological Committee my warm acknowledgment of their kindness in sending by you so cordial an appreciation of my services to the Meteorological Office.

I have indeed been fortunate. In the early days of my work as Secretary I was rather disconcerted by Sir Francis Galton. He had retired after giving a large part of his life to the control and also the practical management of the Office, and of the Kew Observatory at Richmond. He had been also largely responsible for advising the Government upon meteorological affairs from 1860 onwards. When I went to see him about some office business he inquired very dubiously whether I really thought that anything could be made of it, and gave me to understand that he had little or no hope.

The situation was indeed difficult because the acknowledged ground of appeal for public funds for the Office was not the collection and ordering of trustworthy facts about the weather of all parts of the world for economic and scientific purposes, as it should be, but simply and solely forecasting the weather of to-morrow. And making predictions for publication from the beginning, is, and always will be, rather abhorrent to the mind of a person of scientific habit like Galton's unless it can be conducted by a strict process of calculation like the predictions of the Nautical Almanack. The objection is fundamental.

Galton had been instrumental in developing at the Office from 1867 to 1876 the chief properties of the travelling cyclone and anticyclone, the latter of which he had named; and in 1878 it appeared as though the process of understanding the weather would be the simple continuity of what had been already achieved. His disappointment at finding that nothing further came out of the study of cyclones and anticyclones protracted over twenty years was perhaps a legitimate cause for his pessimism. It was, I think, shared in 1899 by a Committee of the Royal Society appointed to consider what the Office was doing.

I found that the comparative stagnation in which the science was thus bogged arose with the formation of meteorology as a new science, partly geographical and partly physical, with the weather map as its basis of experience as distinguished from the individual observation. It was thus distinguished from the older meteorology, which had been entirely physical. Curiously the stagnation was compatible with the direction of the Office by the strongest body of scientific men that has ever directed anything. But the Office itself was simply clerical in its training, and it had no experimental observatories of its own.

I managed gradually to introduce a staff with scientific training, partly paid and partly voluntary, to take charge of various activities. They could look at the work from an extraneous point of view, and later on, not without some tears, I unified the control of the observational establishments of the Office.

So it happened that when General Seely wanted meteorological assistance at the beginning of the R.F.C. we could indicate the lines on which it could be given; and when the war broke out we had the type of organisation already in operation which could be developed simply by multiplication to meet the requirements of the case.

I am satisfied that the stagnation which overcame Galton is no longer to be feared. We have begun to see the way through, and that not by any facilities of a new era, but simply by following out methods which Galton himself had thought of and even commenced but had no trained staff to carry out.

I certainly shall like to give reasons at greater length for not accepting Galton's pessimism as a guiding principle in the administration of the Office, and I think I can do so by the development of the School of Meteorology to which you allude so kindly; and I can still look upon the development of the science as some contribution to public service.

That I shall still have to rely upon the support and assistance of the Meteorological Committee in making that endeavour successful is only a pleasure for me, as the relations between myself and the Committee have always been in the past.

It was my experience of the old Meteorological Council that the capacity of distinguished men of science for understanding a difficult situation was only equalled by their capacity for misunderstanding a simple one when they were so inclined. It has been my good fortune always to have difficult situations for the Committee to deal with, and they have always been at their best. I need hardly assure them of my grateful thanks.

Let me also thank you for your personal note. The essential difficulty of the organisation of the Office is the proper adjustment of the scientific staff in relation to administration. At the time of its development it was necessary for the administration to be largely in the personal charge of the Director. That arrangement was not, of course, intended to be permanent, but the war broke out while we were still unfledged. Consequently, in transferring to the Air Ministry I had not only to think of what had been, but also of what might have been and would have been in the natural course of events. The difficulty of working a scientific establishment as part of a public office is that the customary duty of a public office is to exercise control, whereas the primary duty of a scientific establishment is experimental initiative, which to any controlling authority must have something of rash speculation about it.

I sincerely trust that the framework of the organisation which the Committee of 1905–20 gave to the Office will be found serviceable to the Air Ministry, and through them to the many folk for whom meteorological work has an interest of one sort or another.

With best wishes for its continued success,

Believe me,

Yours sincerely,

(Signed) NAPIER SHAW.

Major-General Sir Frederick Sykes, G.B.E., K.C.B., Air Ministry.

Meteorological Magazine—increase in price

As from January 1983 the price of an issue of the *Meteorological Magazine* will be £2.00 and the annual subscription will be £26.50 including postage.

Review

Deposition of atmospheric pollutants. Proceedings of a Colloquium held at Oberursel/Taunus, West Germany, 9–11 November 1981, edited by H.-W. Georgii and J. Pankrath. 165 mm × 240 mm, pp. ix + 217, *illus.* D. Reidel Publishing Company, Dordrecht, Boston, London, 1982. Price Dfl. 85.00, US $37.00.

These proceedings contain the texts of 20 lectures in addition to the introduction by J. Pankrath. The great majority of these papers, like that of the participants, came from the Federal Republic of Germany, and are divided into three sections covering respectively dry deposition, wet deposition, and deposition on plants and vegetation. To quote Professor Georgii's words in the preface:

> The problem of 'acid precipitation' has been recognized with growing concern in many industrialized countries. The incorporation of pollutants into cloud and rain elements and their transfer to the ground by 'wet deposition' are dominant

mechanisms leading to a self-cleansing of the troposphere but, on the other hand, to hazards to the soil, vegetation and forests. The influence of orographic and meteorological parameters and of the regional distribution of precipitation on the deposition of pollutants are insufficiently known factors.

During previous years, several projects and analyses have been initiated to improve our knowledge on the dry and wet deposition of pollutants and on the mechanisms of transport of gaseous and particulate components from the atmosphere to the ground. Research activities have been supported in different fields and it appeared not only useful but necessary to bring the different research groups together to endorse the communication and co-operation between scientists in the related fields. A symposium was arranged in Oberursel/Taunus in November 1981 to discuss the results of the experimental and theoretical work in the field of deposition and to gain a better understanding of each other's methods, experience and observations.

The papers presented in this symposium will be necessary reading for all workers in this important field.

R. P. W. Lewis

Award

We note with pleasure that Mrs G. W. S. Simpson, of Eddleston Auxiliary Reporting Station, has been awarded the British Empire Medal in the Queen's Birthday Honours List.

Mrs Grace Simpson began reporting in 1944 together with her husband, who was the station-master at Eddleston in Peeblesshire until the line closed in 1962.

The observations were initially required in connection with BEA flights between Turnhouse and Northolt. Balloons were often used to measure the height of low cloud.

Throughout the 38 years observations have been sent hourly between 8 a.m. and 5 p.m. on weekdays and between 8 a.m. and 12 p.m. on Saturdays. Mrs Simpson has continued this program single-handed since the death of her husband in 1976.

Mr S. Morris Bower

It is with regret that the Office records the death on 3 August 1982 of Mr S. Morris Bower of Auxiliary Reporting Station, Huddersfield/Oakes.

Samuel Morris Bower of the Thunderstorm Census Organization had been an enthusiastic meteorologist all his life and had reported as an auxiliary observer for the Meteorological Office since July 1935.

He joined the staff of the Meteorological Office in 1939 and saw service at a number of war-time stations including Falmouth, Sheffield and Topcliffe. In 1944 he returned to Huddersfield/Oakes from where, with his wife, he continued a full program of co-operation with the Meteorological Office. Mrs Bower died on 20 December 1981.

The station at Huddersfield/Oakes continues to operate under the direction of Miss M. K. Redman.

Obituary

We regret to record the death on 24 March 1982 of Mr N. Annis, Senior Scientific Officer, who was stationed at Lossiemouth. Norman Annis joined the Office as a Scientific Assistant in 1947 and was promoted to the forecasting grade of Assistant Experimental Officer the following year. His career was spent in forecasting at various outstations including Prestwick, Abbotsinch, and Glasgow Weather Centre, and he also served for three and a half years at Brüggen; he was promoted to Senior Scientific Officer in 1979. Norman Annis was a quiet and unassuming man, considerate to his colleagues and well liked by all he came in contact with, including his 'customers' in the RAF.

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NOTICES

It is requested that all books for review and communications for the Editor be addressed to the Director-General, Meteorological Office, London Road, Bracknell, Berkshire RG12 2SZ and marked 'For Meteorological Magazine'.

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Recent developments in the quality control of climatological data

By E. A. Spackman*
(Meteorological Office, Bracknell)

and F. Singleton
(Assistant Director (Climatological Services), Meteorological Office, Bracknell)

Summary

This paper describes, in brief, recent work within the Climatological Services Branch of the Meteorological Office in the use of multivariate statistical methods for the study of climatological data with particular reference to areal quality control. A fuller description of the investigation and methods used will be found in Spackman (1979, 1980).

Introduction

Climatological data archived by the Meteorological Office represent a resource of ever increasing value. Enquiries for which these data are used can relate to such major items as large construction projects, planning projects, and the assessment of alternative energy sources. At the other end of the financial scale, but still of considerable importance to the enquirer, are such matters as detailed weather on specific occasions and advice on the best areas for retirement or holidays. In order to use climatological data with confidence quality control is necessary, particularly because of the large number of enquiries which relate to legal cases for which certified or witness statements are required. Much information is also supplied for insurance claims which can, of course, be followed by litigation and, here also, statements of actual weather must be capable of withstanding legal scrutiny and questions.

Historical

Quality control has always been undertaken by the Meteorological Office for climatological data and, for many years, this was by 'hand and eye' methods making good use of the experience and expertise of individuals. Growth in the numbers of climatological stations and the turnover of staff made it necessary

* Now at Meteorological Unit, ADAS, Cambridge.

to introduce a degree of objectivity into quality control work and Bryant (1979a) described briefly the objective methods employed at that time. Basically, queries to climatological data are raised objectively but decisions upon what values should be archived following such queries are made subjectively. Computer archives contain the corrected data with flags set to show when a correction has been made while the 'paper archives' contain the original reports with amendments made in a contrasting coloured ink.

In this paper changes are described in the system used for areal quality control. Techniques for checking the internal consistency of reports from climatological stations, sequential checking, climatological extreme checks and so on remain more or less unchanged. Data entry is still by manual keying of data from manuscript returns for the 480 or so climatological stations which report once, or occasionally twice, per day. In WMO terminology these are known as Ordinary Climatological Stations. Official Meteorological Office stations and some auxiliary synoptic stations are now archived by accessing the synoptic data bank thus obviating the need for the keying of data from these stations. In total, there are about 140 of these stations of which about 60 report hourly. Most of these latter are Principal Climatological Stations in WMO terminology.

This paper concentrates on the quality control of temperature data, that is maximum temperatures, minimum temperatures, 0900 GMT temperatures, 0900 GMT wet-bulb temperatures and grass minimum temperatures. Quality control of anemograph data has been described by Bryant (1979b); soil temperatures, because of their conservative nature, are checked largely by means of sequential methods.

In 1975 a group was established within the Climatological Services Branch with the following general terms of reference:

(a) To study the factors which influence the several elements which make up the climate of a particular locality.

(b) To assess quantitatively, using appropriate statistical methods, the representativeness of an observing station and to specify the network of stations required to estimate the climate of a particular locality within specified limits in any part of the United Kingdom.

(c) To define a map of the United Kingdom showing climatological districts each having a relatively homogeneous or readily definable climate.

(d) To study statistical methods for the analysis of climatological data and for the presentation of information to users in the most effective way.

Factor analysis

In order to begin to study the variation of climate across the United Kingdom in an objective manner it was decided to concentrate on each climatological variable separately and to develop a technique which could be used reasonably easily for them all. Most of the initial investigational work was undertaken for daily minimum temperature because, from a climatological point of view, this is one of the more complex elements with values at individual stations being greatly influenced by local topography.

The decision to use multivariate statistical methods was made in order to gain familiarity in their use in this particular field. The relevant programs are now readily available in many statistical packages. Those used being the Biomedical Computer Programs (BMDP) described in Dixon (1975).

Factor analysis is a technique which aims at reproducing the correlation or covariance matrix of a set of variables measured on many cases from the knowledge of a small number of factors. Thus, a formidable volume of data may be reduced to manageable proportions. The factors identify modes of variation in the data and, it is hoped, may also point to the underlying physical causes. The particular form of factor analysis used was Principal Component Analysis (PCA) followed by orthogonal rotation on the first few components. The aim of PCA is to attempt to assess the structure of variables within a particular set, independently of any relationship they may have to variables outside the set. PCA of a set of m original variables X_i produces m new variables called principal components denoted by c_i where $c_i = b_{i1}X_1 + b_{i2}X_2 + \ldots + b_{im}X_m$. The coefficients b_i are chosen subject to the conditions:

(a) Successive components have the largest possible variance.
(b) All pairs of components are uncorrelated.
(c) The sum of the squares of the coefficients involved in any one component equals unity (normalization).

The values of b_i are found by computing the eigenvectors of the covariance or correlation matrix, and the proportion of variance accounted for by each component is derived from the eigenvalues. It is possible to consider just a few of the components and perform a rotation on them by relaxing one or more of the above conditions to obtain what usually is termed a simpler structure. An orthogonal rotation which maximizes the variance of loadings within columns of the factor loading matrix is often used and referred to as a 'varimax' rotation. Within each factor this normally produces only large or small loadings—a structure that usually simplifies interpretation of the components. The final result may be expressed by

$$X_{ij} = a_{i1}f_{1j} + a_{i2}f_{2j} + \ldots + a_{ip}f_{pj} + r_{ij} \qquad (1)$$

where $f_{1j}, f_{2j}, \ldots f_{pj}$ are factor scores at each station j, $a_{i1}, a_{i2} \ldots a_{ip}$ are factor loadings for each factor, r_{ij} are error or residual terms accounting for the unexplained variance and X_{ij} are the original variables for day i for station j.

Data used

Daily values of minimum temperature, nominally measured at 0900 GMT, for 1973 to 1977 were used in the analysis. Most stations provided observations for each day and those with fewer than 99% of possible observations either had data missing for sequential periods, for reasons such as malfunctioning of instruments, or were stations which commenced or ceased operation within the period. Missing values were estimated by taking the mean of all values in the county for the day and adjusting this mean by the annual average difference between station value and county value. Estimates were only made for stations where there were at least 330 observations in the year. After the estimation of missing values there were about 670 stations each year with a complete set of daily values.

In order to reduce the effects of serial correlation and to provide a set of data for which the dependence between the variables had been minimized it was decided to use values at 3-day intervals. The actual values used in the analysis were anomalies of the temperature at each station with respect to the mean temperature over all stations on each day.

Results of the factor analysis

The decision on how many components were retained for the varimax rotation was based upon the variance explained by each component. Fig. 1 shows, for 1977, the variance accounted for by each component prior to rotation and it can be seen that the first few components account for most of the variances. Beyond component 20 the amount of variance accounted for decreases approximately as the logarithm of the variance. It was decided to rotate 15 components; this explained nearly 85% of the variance. The distribution of variance within each component is comparable each year—as shown by the values given in Table 1.

In order to study the factors in detail use was made of a single-variable analysis package developed in the Central Forecasting Branch for the analysis of scalar variables. At each grid point on a 10-kilometre grid a weighted average of each factor was obtained in a similar fashion to the operational analysis of geopotential fields; isopleths of values at the grid points were then drawn using a microfilm plotter. It was noted that several of the factors were highly correlated with altitude. From a study of the patterns produced the following conclusions were drawn:

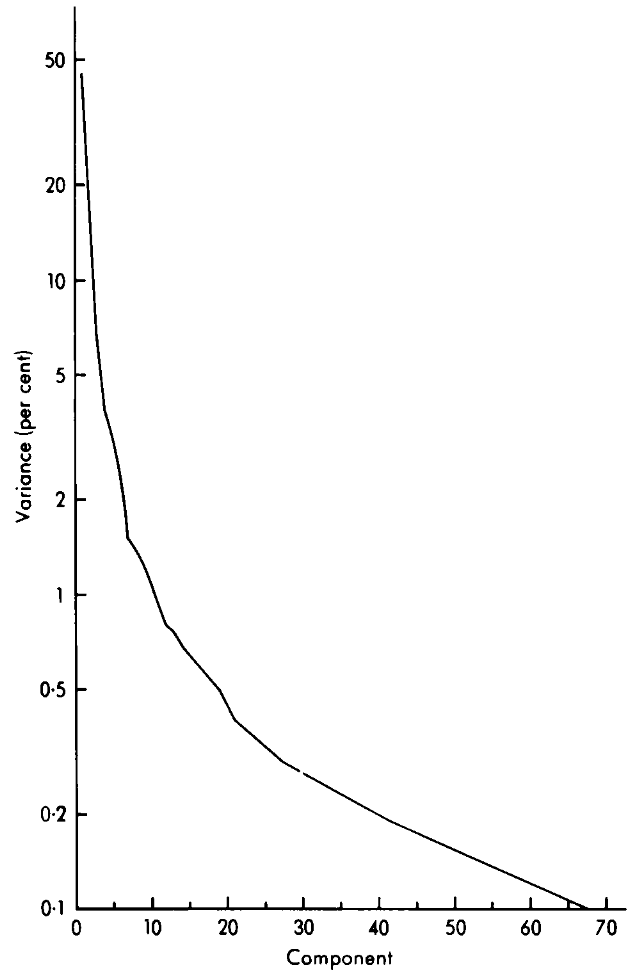

Figure 1. Variance explained by each component expressed as a percentage of the total variance for one year (1977).

Factor 1 represents an altitude variation superimposed upon a latitude variation—this is basically a 'latitude' factor.

Factor 2 shows a contrast, particularly over England and Wales, between inland and coastal regions. This is a contrast which is particularly marked on radiation nights under clear skies and anticyclonic conditions. Factor 2 may therefore be interpreted as a 'radiation' factor.

Table I. *Variance accounted for by first 15 components of Principal Component Analysis for daily minimum temperatures for 1973 to 1977. Values are given as (° C)² with cumulative percentages in brackets.*

Component	Year 1973	1974	1975	1976	1977
1	260.9(39.0)	247.9(45.6)	261.3(38.7)	234.6(38.5)	264.8(45.0)
2	132.2(58.8)	74.3(59.3)	111.3(55.2)	94.2(54.0)	87.6(59.8)
3	36.5(64.2)	28.6(64.6)	47.8(62.3)	35.1(59.8)	39.1(66.5)
4	31.3(68.9)	20.1(68.3)	29.8(66.7)	33.7(65.3)	23.1(70.4)
5	19.4(71.8)	15.4(71.1)	22.9(70.1)	22.6(69.0)	17.8(73.4)
6	15.2(74.1)	13.6(73.6)	20.4(73.2)	19.1(72.1)	13.2(75.7)
7	11.0(75.7)	10.1(75.4)	13.4(75.2)	16.2(74.8)	8.8(77.2)
8	9.1(77.1)	7.4(76.8)	10.5(76.7)	10.9(76.6)	8.5(78.6)
9	8.6(78.4)	6.8(78.1)	9.3(78.1)	8.4(78.0)	7.7(79.9)
10	7.3(79.5)	6.2(79.2)	8.2(79.3)	7.4(79.2)	6.0(81.0)
11	6.1(80.4)	5.7(80.2)	6.5(80.3)	6.2(80.2)	5.4(81.9)
12	5.5(81.2)	4.7(81.1)	6.3(81.2)	5.7(81.1)	4.9(82.7)
13	4.5(81.9)	4.2(81.9)	5.7(82.1)	5.4(82.0)	4.7(83.5)
14	4.4(82.5)	3.6(82.5)	5.4(82.9)	4.5(82.8)	4.0(84.2)
15	3.9(83.1)	3.5(83.2)	4.6(83.5)	4.1(83.4)	3.8(84.8)

Factor 3 is, broadly speaking, a contrast between the north of England, in particular the Irish Sea coast on the one hand and north Scotland and southern England on the other. This is apparently an 'Irish Sea' factor.

Factor 4 is an altitude variation superimposed on a west-south-west to east-north-east contrast—a 'longitude' factor.

Special features can be identified in many of the other factors, for example factor 6 shows the contrast across the Pennines, factor 7 is a coastal/inland contrast for north Scotland, while factor 9 is specific to East Anglia. Factor 10 shows a contrast between (i) the Scottish Lowlands and the coastal regions of the Moray Firth and Firth of Forth and (ii) the rest of the northern parts of the United Kingdom. Factor 12 is an east to west contrast over Scotland, and factors 13 and 15 seem to explain some of the individual responses of stations particularly over England and Wales.

There is no particular reason why any factor or factors should provide a physical explanation of the way in which minimum temperature varies from place to place. The factors are, simply, just one way of describing the variations of minimum temperature. Nevertheless, the relationships noted do support intuitive ideas and previous studies of the climate of the United Kingdom in which latitude, distance from coast, altitude and specific affects of topography have been found to be important. The comments made above regarding some of the factors were substantiated by evaluating the mean-sea-level pressure pattern for days when the various factors had high loadings – that is high values of the 'a' terms in equation (1). Factor 1 had high loadings with westerly flows, typical of average conditions, while factor 2 had high loadings under anticyclonic conditions. Factor 3 was important with a strongish north-westerly airflow and factor 4 with northerlies or southerlies. The relative importance of the other factors depended upon the position of the anticyclone or ridge conditions affecting particular parts of the United Kingdom.

Application of the factor analysis to quality control

The distribution of the residuals from equation (1) may be studied both with respect to day and to station in order to determine how well the factor model (equation (1)) fits the observed data on given days or at particular stations. The residuals include error contributions from at least the following sources:

The inadequacy of the factor model in representing the peculiarity of a station site or the temperature variation on a given day.
Instrumental errors.
Observer errors.
Data processing errors.

Since the model accounts for a large proportion of the variance of the data it is worthwhile studying the residuals to identify stations with large values. Factors were obtained for 1973 to 1977 for both minimum and maximum temperatures and then data from all days of 1974 were used in a regression of minimum temperatures and maximum temperatures against these factors using the BMDP6M multivariate linear regression program. In order to use as many stations as possible the estimated values of missing data were used in the regression, but residuals from these values were not used in compiling statistics for each station. The standard deviation of the residuals ranged from 0.5 °C to 1.9 °C with a mean over all 627 stations of 0.97 °C for minimum temperatures. For maximum temperatures the standard deviation of the residuals ranged from 0.4 °C to 1.6 °C with a mean value of 0.79 °C over 598 stations.

A preliminary investigation of the general distribution of the standard deviations of residuals suggests that:

Residuals in the north of the United Kingdom tend to be larger than the south (this may, of course, merely reflect the differences in station density).

Known frost hollows usually have large residuals (greater than 1.1 °C).

Meteorological Office stations tend to have small residuals.

Stations with records over a long period tend also to have small residuals.

Values of the mean residual are generally small (i.e. less than 0.3 °C) although larger values have been found at some stations with incomplete records over the 5 years, and for some relatively isolated places such as the Isles of Scilly and stations in Orkney and Shetland.

Some stations which habitually have large residuals provide very severe problems during the quality control process. In some cases the reason is, simply, that the amount of missing data has rendered the derivation of the factors difficult. In other cases it may be that the station is unrepresentative; urban roof sites, such as London Weather Centre and Cheltenham, and frost hollows typically have large residuals.

By means of objective analysis of patterns of individual factors stations can be detected that do not fit the general pattern in one factor or another. These stations can be expected to be unrepresentative under the conditions when the factor or factors are important. Large values of residuals on a daily basis might indicate poor observing practices.

In order to detect suspect data on a day-to-day basis the residuals are studied after fitting the factors to the appropriate data by linear regression. The residuals, r_{ij} of equation (1), are given by

$$r_{ij} = (\text{observed value})_{ij} - (\text{estimated value})_{ij}$$

and an observation is defined as suspect if

$$S = \left| \frac{r_{ij} - \bar{r}_{ij}}{\sigma(r_{ij})} \right| \geqslant 3.25$$

where S is the 'standardized deviation', $\bar{r}_{ij}$ is the mean residual and $\sigma(r_{ij})$ is the standard deviation of the residuals. For this test a mean and standard deviation are computed for the climatological area of the United Kingdom where the station lies. These areas consist of

Orkney, Shetland and Caithness
Isle of Man
Channel Islands
The 10 climatological districts (excluding stations in the above areas) shown in Fig. 2.

Appropriate sets of factors have been obtained for maximum temperatures, minimum temperatures, 0900 GMT dry-bulb temperatures, 0900 GMT wet-bulb temperatures, grass minimum temperatures and sunshine. Using the value of the standarized deviation as an indicator of suspect data the following observations can be made:

Where the standardized deviation is less than 3.5 then data are *usually* acceptable.

Where the standardized deviation is greater than 4.5 the observations will *usually* be in error.

Most unacceptable observations are detected by taking the limits of the standardized deviation at 3.25 although up to 50% of the suspect data may, in fact, be subsequently deemed acceptable.

It should not be assumed that data are necessarily wrong (or right) simply by use of the standardized deviation. Definitive identification of data which are erroneous, and only those data which are erroneous, is impossible.

The technique seems to work fairly well for temperatures but rather less well for sunshine; for sunshine it seems that small-scale variations are sometimes poorly fitted by the model resulting in several nearby stations with similar values all being queried. A 'hand and eye' technique involving the visual scrutiny of a computer-plotted chart of daily values is used in conjunction with the objective method.

Problems in fitting data (for all parameters) were greater in some districts than in others. For example, difficulties were encountered in coastal parts of East Anglia, outlying islands, and sparse data areas in mountainous terrain.

In certain extreme conditions, such as during December 1981 and January 1982, some correct data resulted in standardized deviations which, in normal circumstances, would have indicated a high probability that the data were incorrect.

Presentation of information on suspect data

An example of the output from the computer to the quality control staff is shown in Fig. 3. Suspect values are shown with a ≠ sign and are plotted with nearby values in their approximate relative geographical positions. All the data are also tabulated with their DCNN (the climatological station number—District, County, NN), first four characters of station name, and altitude (metres). For the suspect observation the printout contains the following:

DCNN	
First eight characters in the name	Residual
Date (left blank if for a monthly mean)	Probable reason for error
Suspect element	Estimated value
Observed value	Standardized deviation.

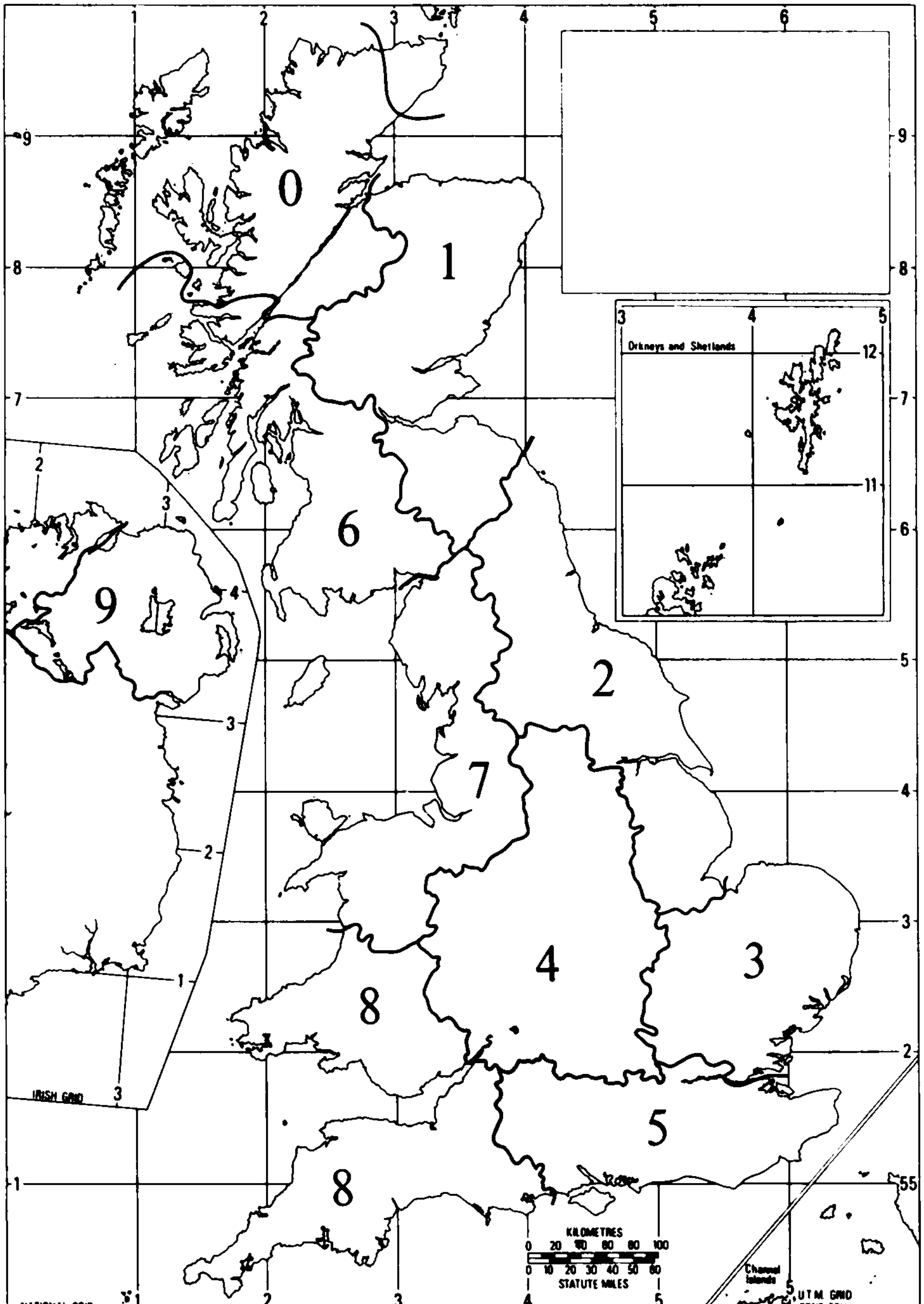

Figure 2. Areas for which means and standard deviations of residuals were computed.

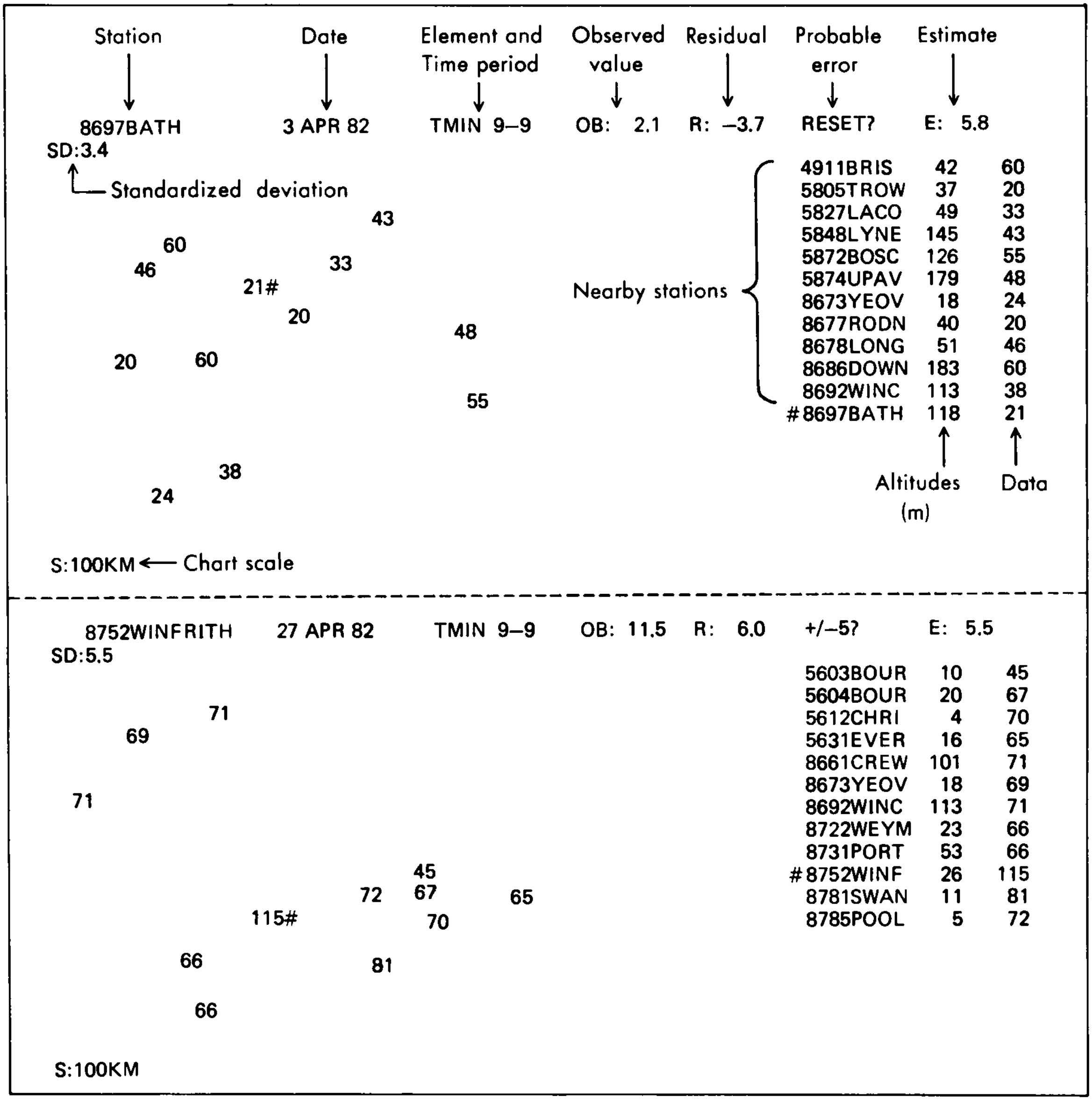

Figure 3. Examples of error printout for Bath (DCNN 8697) for 3 April 1982 and Winfrith (8752) for 27 April 1982. Standardized deviations of 3.4 and 5.5 indicate that observed values are 3.4 and 5.5 standard deviations from the estimate. The former is clearly a doubtful report and the latter almost certainly incorrect. Chart width normally corresponds to 100 km but can vary in areas where data are sparse.

ESTIMATE on the printout for the suspect value is obtained using the factor for the station in question and the factor loadings appropriate to the particular element and day. In other words it is an objective 'best guess'.

Reasons for error can be suggested as follows:

INDEX when a suspected value of a minimum temperature is about 7 °C below the computer estimate. This corresponds to the length of the index within the alcohol of the thermometer and it is a fairly common mistake for an observer to read the wrong end of the index.

SIGN when an apparently erroneous reading would be corrected by a change of sign.

RESET when a suspected value of maximum or minimum temperature is within 0.5 °C of the value read on the previous day. The implication is that the observer may have forgotten to reset the instrument.

+/-5 or +/-10 when a suspected temperature could be rectified by the addition or subtraction of 5 °C or 10 °C respectively.

The two examples in Fig. 3 show sample printout for minimum temperature at Bath on 3 April and Winfrith on 27 April 1982.

For the Bath report, inspection of nearby observations shows that Trowbridge (DCNN 5805) had a similar minimum temperature which was not queried. Bath is at a height of 118 m compared to Boscombe Down (DCNN 5872) at 126 m and Lyneham (DCNN 5848) at 145 m. It might be that on a night with radiation cooling the lower-level stations would be colder than those higher up and that Bath is indeed in error. However, inspection of hourly observations at Boscombe Down and Lyneham shows that cloud amounts were very variable that night. Boscombe Down reports show a decrease from 7/8 stratus to 2/8 between 0300 and 0500 GMT while Lyneham had 7/8 throughout. On balance it was decided that while the Bath report was suspect there was not enough evidence for us to be sufficiently sure to propose an alternative value.

The report for Winfrith on 27 April is rather more clear-cut in that inspection of nearby observations confirms that 11.5 °C was anomalous and that a 5 °C error was probably made by the observer. A value of 6.5 °C was taken by the quality control staff as being the most likely value and this appears both in the computer archive and as an amendment to the manuscript return. Although still 1 °C different from the objective estimate, it is well within the expected range of possible values for the station on the night in question.

These two examples quoted clearly demonstrate that, even with a fairly sophisticated technique for detecting possible errors, the decision to accept or reject an observation must still be subjective. Even when it is accepted that a report is incorrect the assessment of the possible correct value is still a subjective one.

Further uses of factor analysis

One of the original aims of the investigation team which undertook this work was the definition of climatologically homogeneous areas. This work will be discussed in a future paper together with the use of factor analysis to determine climatological station network density requirements. Another application of factor analysis in studying climatological data is its use in indicating inhomogeneities in station records. In a test (Done 1980) the factor analysis technique was applied to monthly minimum temperatures for 125 climatological stations. Studies of the series of residuals showed some striking discontinuities which could, on many occasions, be correlated with changes of site, change of site characteristics or changes of instrument. It might be possible to use the same techniques to detect the effects of changing land use. For example, a gradual rather than a sudden change in the character of the residual might indicate urban development near the observing station or an increase in shelter due to tree growth.

Conclusions

The use of factor analysis has been shown to be a powerful tool in the handling of large amounts of climatological data and the first application of the work has been to improve objectivity in the detection of possible errors in climatological data. In common with all quality control techniques the final decision as to what data are correct or incorrect must be a subjective one as must be the estimates of the likely correct values. The technique also has potential in evaluating the homogeneity or otherwise of long-term climatological records and, as such, is of value in selecting those stations which can be used for determining secular changes in climate.

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Winds estimated by the Voluntary Observing Fleet compared with instrumental measurements at fixed positions

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Summary

Measured wind speeds at fourteen offshore locations are compared with visual estimates made by the deck officers of merchant ships adjacent to the sites. The methods of measurement and estimation of the speeds are discussed together with their climatological reliability. Extreme values derived from the distributions of estimated wind speeds are compared to determine whether extreme values from visual estimates can be used with confidence when reliable wind speeds from instruments are not available.

1. Introduction

Observations of wind conditions over the ocean and seas come from two main sources, fixed position observing stations and merchant shipping.

Observers located at fixed position observing stations, for example Ocean Weather Stations (OWS) and light-vessels (LV), make wind measurements using anemometers, whilst the deck officers of merchant ships, which form the Voluntary Observing Fleet (VOF), estimate the wind speed from the state of sea at regular intervals during a voyage. Consequently, the fixed stations produce a set of regular observations for each position whereas the merchant ships provide a set of observations which are randomly distributed, along trade routes, in space and time.

Since there are few fixed measuring stations, and these are widely distributed, any analyses of winds over the oceans must depend largely upon observations from the VOF.

Measured observations have usually been considered more accurate than the visual estimates, and results derived from regular data at a fixed location rather better than those from estimates. Several studies have been made that attempt to relate these two types of observation and determine the relative accuracy of the VOF data, for examples see Quayle (1980) or Kaufeld (1981).

The purpose of this study was to look more closely at several different types of measured observation and at the VOF data in surrounding areas to establish, in general terms, the confidence that can be placed in the VOF data when no suitable measured data are available.

For the VOF estimates 18 years of data were available for this project, 1961-1978 inclusive. Periods covered by the measured data are shown in Table I. Where possible the same period of VOF data was used, for example OWS 'I' and 'J' and their corresponding VOF data covered 1962-1975, OWS 'M' 1962-1978 and the LV 1961-1978. For the other stations where only a short period of measured data was available it was decided to use all the available VOF estimates because using only those from the corresponding periods reduced the number of estimates considerably. For example, for Brent and DB 1 only one year of measurements was available for direct comparison with VOF estimates.

2. Estimated wind data

Wind speeds are estimated by the deck officers of merchant ships of many nationalities using essentially the same method. The observer estimates wind speed from the state of sea or sometimes, particularly at night, from the way the ship is handling. The Beaufort scale of wind force is used which is related to standard descriptions of state of sea. Each Beaufort force has speed limits, in knots (see

Appendix Table IA), assigned to it according to the scale adopted by the World Meteorological Organization in 1946. The observer then estimates, within those limits, a wind speed to the nearest knot.

Because of the use of these discrete groups the wind speed values recorded tend to cluster around the middle value of each Beaufort force range and, consequently, the data can only really be used in the Beaufort force classes. The scale used by the VOF is now considered incorrect and alternative limits have been devised for each scale number (see Appendix Table IA). This scale is commonly called the 'scientific' Beaufort scale by certain Branches of the Meteorological Office and should correct the speeds in those classes previously overestimated.

The averaging time or representative time for these observations is not really known but in this study it has been taken as equivalent to an hour owing to the relatively slow response of the sea to changes in wind speed. These estimated winds may be taken as hourly mean values of wind speed that are observed every six hours by the majority of VOF ships.

The data used were derived from ships' logbooks and should be complete. This was necessary because many ships do not transmit radio messages at night and so data from telecommunication sources are usually incomplete.

3. Instrumental data sources

A set of 14 stations was used, comprising four OWS, four LV, three stations manned by ships sponsored by the United Kingdom Offshore Operators Association (UKOOA), one island station, one oil rig and one data buoy. Locations are as shown in Fig. 1.

All these stations were equipped with anemometers, but observing practice varied from site to site. The methods used are presented in more detail below and a list of these stations with dates and total number of observations is given in Table I together with the corresponding dates and number of observations for VOF data.

(a) *Measured wind observations from ocean weather ships*

Ocean weather ships carry at least one anemometer in a well-exposed position. British weather ships carry two anemometers on a yard-arm, one on each side of the main mast, at a height of 20 m above sea level with dials on the bridge registering instantaneous wind speeds.

Table I. *Availability of measured wind data and periods for which estimated data were used in the analysis*

Station	Measured wind speeds Period	Measured wind speeds No. of observations	Estimated wind speeds Period	Estimated wind speeds No. of observations
OWS 'I'	1962–75	113 072	1962–75	2 355
OWS 'J'	1962–75	112 317	1962–75	3 356
OWS 'L'	1975–79	28 957	1962–78	2 975
OWS 'M'	1962–78	126 335	1961–78	666
Seven Stones LV	1961–78	13 100	1961–78	12 410
Shambles LV	1961–78	9 988	1961–78	12 797
Mersey Bar LV	1961–78	8 192	1961–78	1 608
Varne LV	1961–78	46 194	1961–78	9 932
Stevenson (10 minute)	1973–76	2 005	1961–78	5 702
FitzRoy	1973–76	2 379	1961–78	3 088
Boyle	1974–77	3 643	1961–78	6 315
Stevenson (hourly)	1973–76	21 010	1961–78	5 702
DB 1	1978–79	5 888	1961–78	13 338
Brent B	1978–79	4 950	1961–78	9 178
South Uist	1961–78	29 266	1961–78	1 743

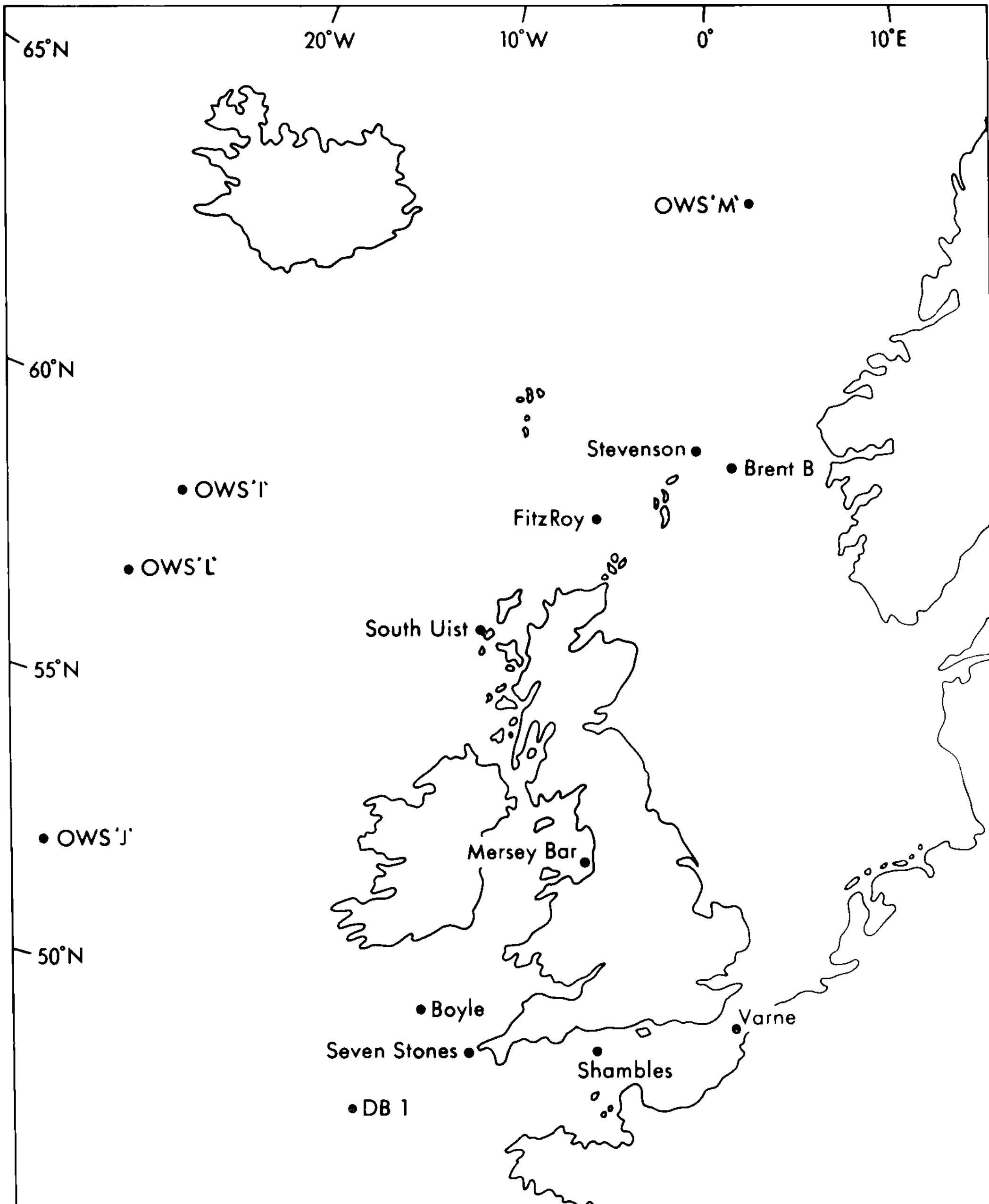

Figure 1. Positions of fixed stations used in the analysis.

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The observer is instructed to take an average, by eye, of the dial readings over a period of 10–15 seconds at the time of observation. However, the precise method of making the observations is not clear. The *Marine observer's handbook*, which refers to British weather ships, makes the statement that 'even here estimates are made regularly of wind force and direction from the appearance of the sea as a check on the instruments'. Informal discussion with the weather ship observers suggests that the visual element may make a large contribution to the observation in some cases. Consequently, how many of the observations are averages over 10–15 seconds and how many are instrument assisted estimates with longer effective averaging times is unknown.

There are also uncertainties regarding the siting of the anemometers on ships of different nationalities and in the non-linear response of anemometers in wind speeds of less than 10 knots; in practice, Meteorological Office anemometers require a gust of approximately 2–4 knots to overcome instrument inertia before they begin to register wind speeds. The wind speeds are not corrected for the ship's pitch and roll, and also it is not known whether or not the ship was steaming when the observation was made: this can make a considerable difference to the pitch and roll of the ship, which in turn affects the wind speed recorded by the anemometer because the ship's motion is amplified by the height of the instrument above sea level.

(b) *Measured wind speeds from light-vessels*

Observers on LV are not professional meteorologists but are instructed on how to use hand-held anemometers to make the observation from a well-exposed part of the ship, and to take an average reading, by eye, of the wind speed over a 10-minute period.

It is difficult to achieve reasonable accuracy with a hand-held anemometer and the actual exposure of the anemometer is unknown, as is the actual length of time over which the wind speed is averaged. It is likely that the observer would find some difficulty in making an accurate estimate of the 10-minute mean speed and, therefore, that data from the LV are more representative of 1-minute mean wind speeds.

(c) *Measured wind speeds from UKOOA sponsored ships*

The data for the three UKOOA stations were taken from the meteorological logbooks. For Stevenson there is also a data set of quality controlled hourly mean wind speeds.

The data from the meteorological logbooks consist of measured values, but the source of measurement and averaging time is uncertain. It is likely that most of the data are from readings of anemometer dials, as on the OWS, but since chart recorders were available some readings may have been taken from these.

Unfortunately, the data sets cover short periods, about 3 years each, and have many gaps when no observations were made.

(d) *Other stations*

South Uist. The data for this position were taken from Benbecula, a land station equipped with an anemograph to record wind speeds. The data were provided by a manual analysis of the average wind speed over a 10-minute observing period in each hour. These data were included because wave data from a buoy moored off South Uist were to be used in a wave climate synthesis project currently in progress as a joint National Maritime Institute/Meteorological Office venture.

DB 1. DB 1 is a data buoy recording meteorological and wave data automatically. It has two anemometers, one mounted at 8.7 m above sea level and the other at 6 m above sea level. These provide instrumentally calculated 10-minute mean wind speeds every hour. This location should provide better 10-minute mean wind speeds than any other site because there is no doubt about averaging time or exposure. Unfortunately, the record is so short that it is of little use in the estimation of extreme conditions over long return periods.

Brent B. (Oil rig owned by Shell) The anemometer on this rig is mounted on top of the drilling derrick at a height of 108 m above sea level in the best position available. The observations were made every three hours, readings being taken from a digital display and entered in the meteorological logbook from which the data set used here was compiled. These winds, therefore, must be considered 'spot winds' or 3-second gusts.

4. Reliability of measured data for climatological purposes

Reliability of data is a difficult quality to quantify because the properties that define it vary with the purpose for which the data are required. For example, data sources that are considered useful for synoptic purposes may not be acceptable for climatological investigations.

It is particularly important in climatology to be aware of the limitations of the data. Thus, it is necessary to be aware not only of the accuracy of each individual measurement, but also of the long term consistency of the method of measurement so that there are no discontinuities in the data which could affect any result derived from them. Such discontinuities can be due to changes in instrument type and method of observation, or changes in coding practice.

The prime requirement for climatological data is that they should cover as long a period as possible; three years of data is not really long enough for a data set to be considered representative of climatological conditions, but, often, the quality of the data themselves can be taken into account to increase confidence in the climatological reliability of the data set. This was the case with the data set of quality-controlled hourly mean wind speeds from the Stevenson site. The hourly means were derived from continuous recordings of wind speed from digital or analogue recorders and were fairly complete, 80% of the possible total number of observations being present. This compares favourably with an average of 75% for the OWS 'I' and 'J', although these data sets cover a period of 17 years.

The LV data sets cover a period of 18 years but, as mentioned above, the climatological reliability of each individual measurement is in question. The LV provide very useful observations on the synoptic scale since they can be considered in the light of the current situation. However, the accumulation of the doubtful measurements produces data sets of questionable climatological reliability.

It is unfortunate that there are only 18 months of data available from DB 1. In time these data should prove to be useful for climatological purposes, although the record will still be short. The method of measurement is known exactly and the only variable is the calibration of the instrument; this can be checked and the data adjusted accordingly.

5. Analysis of data

The descriptions of observing methods and other factors given above indicate quite clearly the difficulties involved in comparing measured and estimated values of wind speed. It has to be assumed that deck officers on ships of the VOF estimate winds in a similar fashion and this is supported by the similarity in the distributions produced for each site (Fig. 2). However, the measured distributions are all very different in shape. This is not only because of the different geographical locations but also the differences in anemometer height, the method of determining wind speed and the different averaging times used. Ideally, corrections would be applied to produce a consistent set of data, but this is not practicable owing to the uncertainty surrounding the observing practice.

Because of these inconsistencies it was not possible to make any direct comparisons between all the wind speed distributions. It was necessary to decide which of the measured distributions should be considered reliable and to compare these with the corresponding estimated distributions. The data were required to cover a long period with few gaps, and with a known method of observation that was thought to be used consistently to make corrections possible.

Within these constraints the OWS were considered 'reliable' although with some reservations concerning the short period for OWS 'L'. The hourly data set from the Stevenson station was also considered 'reliable' since the data had been studied and quality controlled.

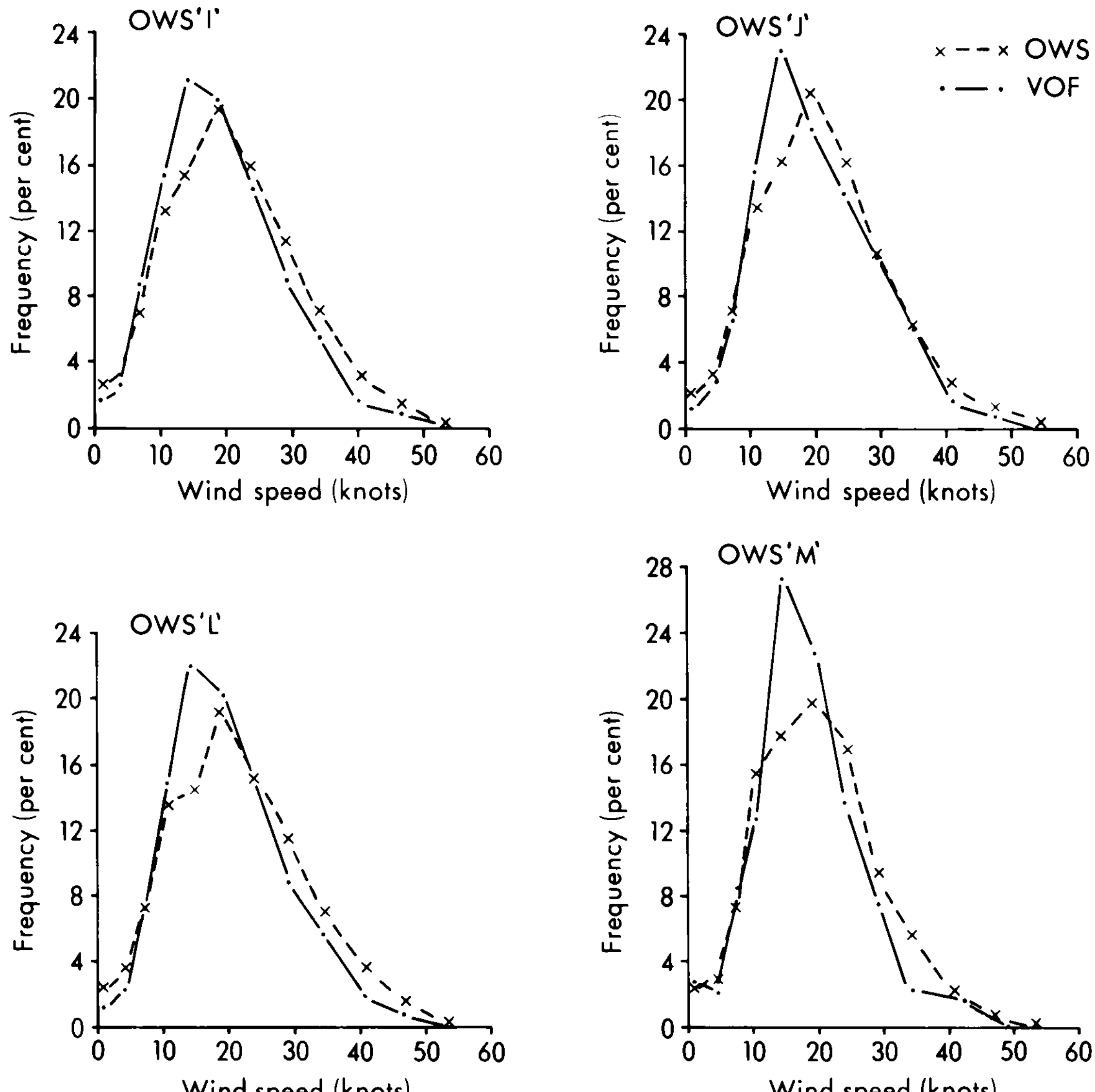

Figure 2(a). Wind-speed frequency distributions for OWS compared with those for co-located VOF ships within 2° × 2° squares centred on the OWS.

(a) *Simultaneous data and calibration of estimates*

For each site the instrumental wind speeds were compared with VOF estimated wind speeds made at the same time. These estimates were taken from 2° × 2° 'square' area around the instrumental source. Comparisons were not made when the wind directions differed by more than 45° unless one of the winds was a calm.

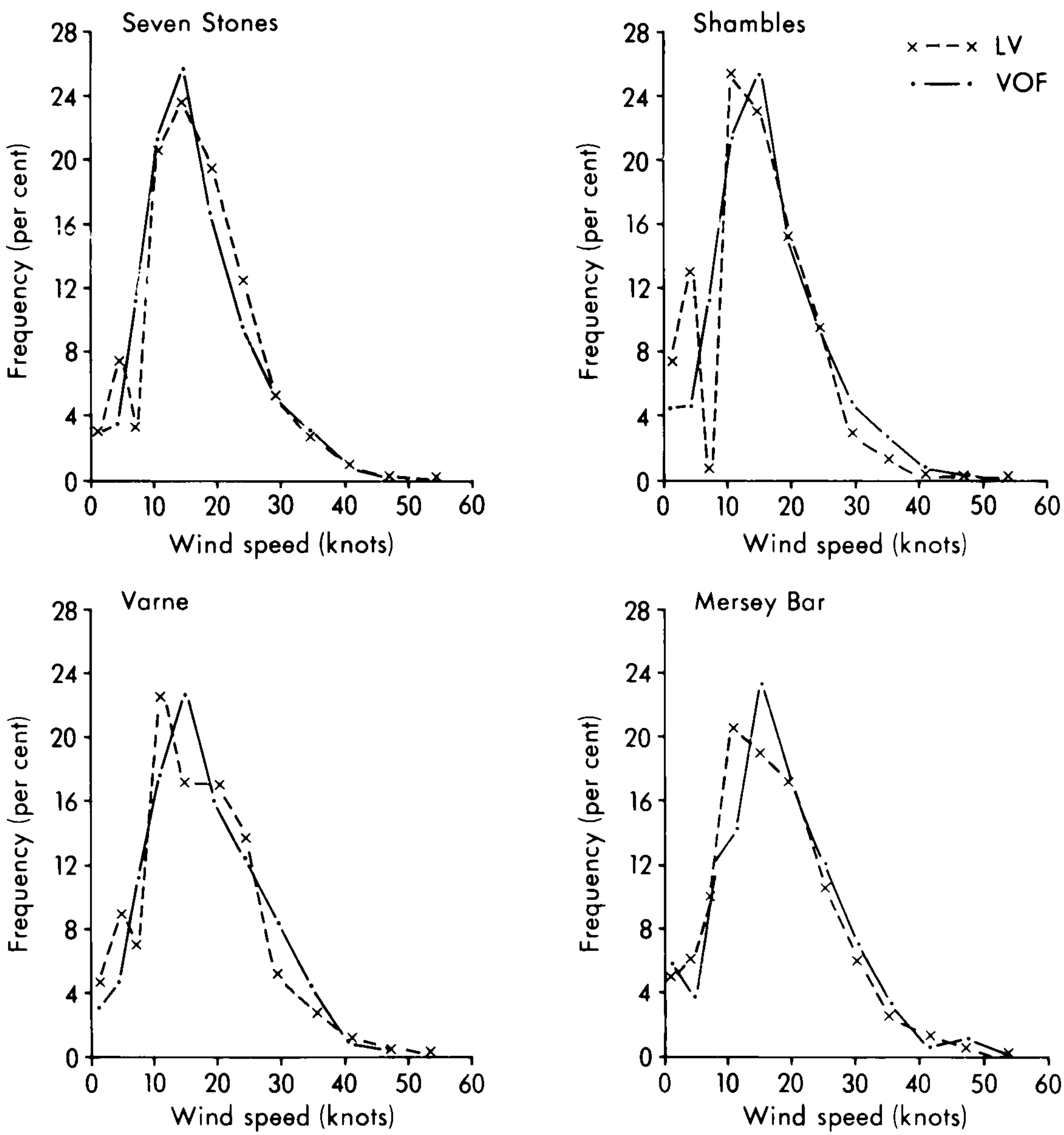

Figure 2(b) Wind-speed frequency distributions for light-vessels compared with those for co-located VOF ships.

Unfortunately, this process reduced the number of observations from the data sets and only four stations were considered to have enough data for comparison purposes.

For initial comparison the measured wind speeds were grouped according to the scientific Beaufort scale and the means and standard deviations of those estimated winds corresponding to the measured groups were calculated. The results are shown in Fig. 3 for OWS 'I' and 'J' and LV Seven Stones and Varne. The mid-point of each Beaufort force class for the measured data is plotted against the mean of the estimates with one standard deviation of the estimated wind speeds shown.

The data fit a straight line fairly well but there is a large scatter in the estimated data. The visual observations appear to be underestimated but this effect could well be due to the different averaging

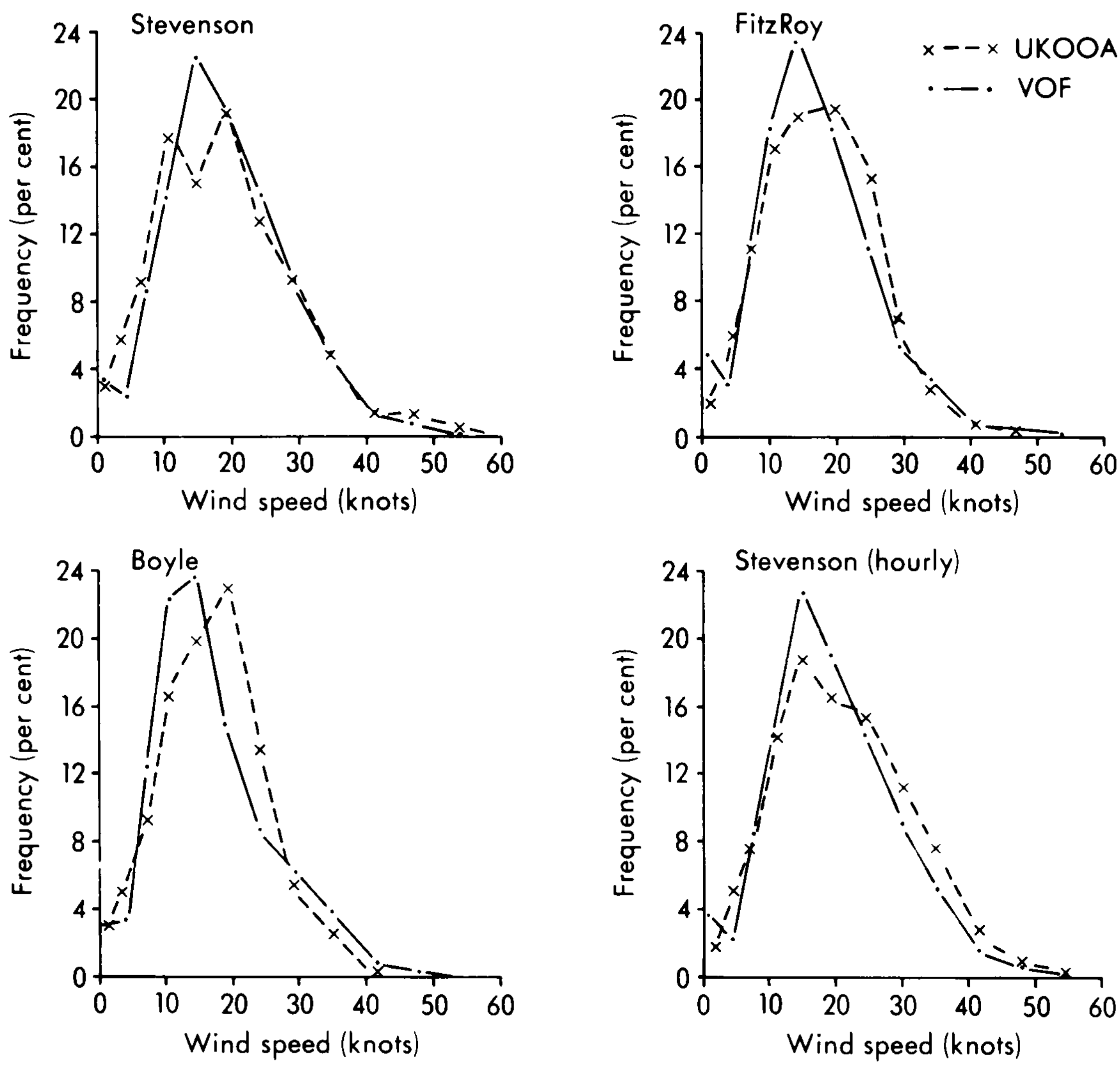

Figure 2(c). Wind-speed frequency distributions for UKOOA ships compared with those for co-located VOF ships.

times used for each type of instrumental observation. The use of very short averaging times, as on the OWS (10–15 seconds), is likely to cause the observer to bias the estimation of the average wind speed towards the higher speeds registered by gusts. In such small samples of data produced here by the selection of simultaneous data this bias is likely to dominate the results. Over a long period of time and with a large number of observations the mean wind speed should be independent of the averaging time (except where this is very short) although the scatter about the mean will be greater for the short averaging times.

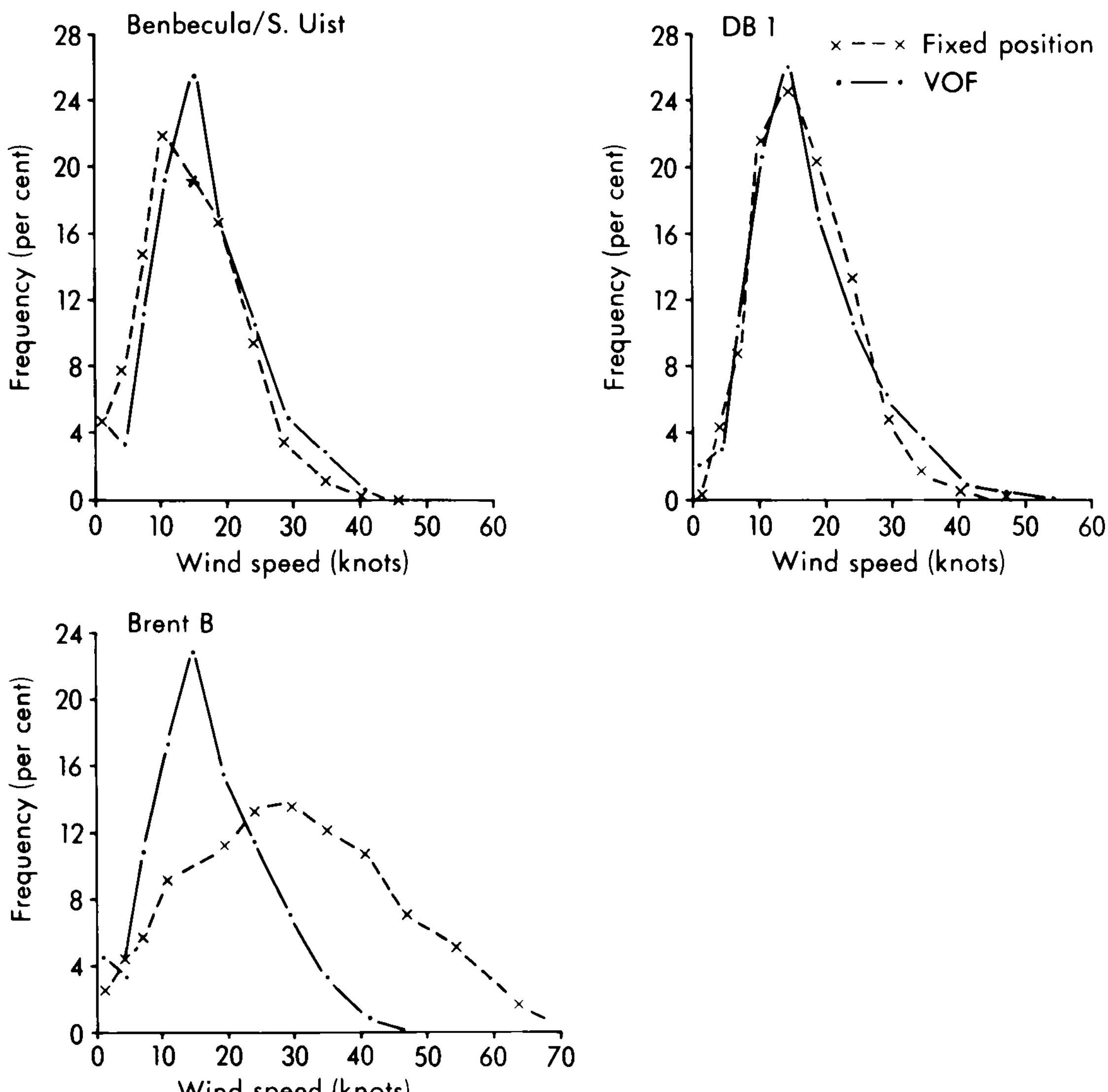

Figure 2(d). Wind-speed frequency distributions for South Uist (Benbecula), Brent and DB 1 compared with those for co-located VOF ships.

The calibration of the estimated wind speeds from the comparison described above simply produces a single correction for each Beaufort force. The scientific Beaufort scale was developed to produce such a correction and although some doubt has been expressed about its accuracy it is still generally held to be good (Kaufeld 1981).

An alternative method could be to correct each estimated speed individually. This would produce calibrated wind speeds equivalent to those of a different averaging time and the calibration would vary according to the type of instrumental data used. Such an attempt at calibration was made for OWS 'I' and 'J' from measured wind speeds and the corresponding estimates.

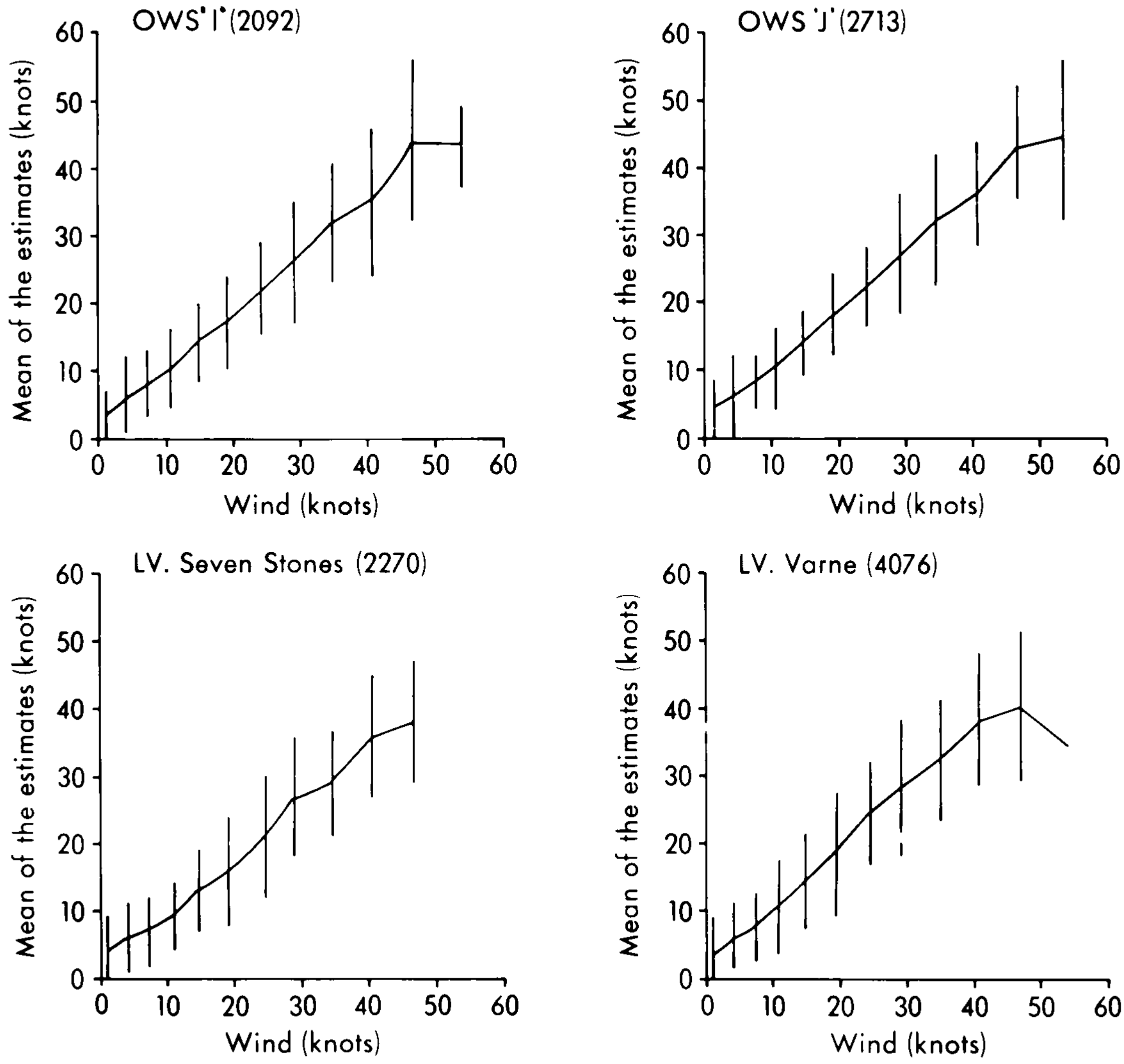

Figure 3. Mean of estimated data and standard deviation plotted against measured data using contemporaneous information. (Numbers of observations used are indicated.)

For each value of wind speed V (V = 1,2,3 . . . knots) a calibrated speed was derived by taking the mean of all measured winds corresponding to estimates of V. The resulting wind speed distributions were rather distorted. It is likely that this was due to the method of estimation of wind speeds in Beaufort forces; this produces clusters of wind speed estimates around a mid-point value for each force.

In all the following analyses the complete data sets were used, not simultaneous data. This was because the process of producing data sets of simultaneous data takes only a sample of the original data. The VOF data is already only a small sample of the possible population of observations in the area and this sample should be compared with the best estimate of the whole population that is available.

The measured distributions are the best estimates available for the whole population even when the data set covers only a relatively short period. For those sites where the measured data cover approximately the same period as the estimated data sets, and the data are considered climatologically reliable, the comparisons should produce reliable results. It must be remembered, however, that the measured distributions are still only samples of the whole population and, though they are much better estimates of the whole population than are the VOF samples, they are still subject to possible sampling errors.

(b) *The effect of normalization of the VOF data*

There is a high density of observations during the summer of each year, possibly because there are more ships at sea during the summer than the winter. Consequently, there may be biasing of the VOF data towards the less severe summer conditions.

An attempt was made to reduce any such bias by defining a mean monthly observation count. The effect of setting such a count was that each observation for a month with M observations (where M>30) was reduced by a factor of $30/M$. Months with M<30 were not adjusted, all observations being used without the scaling.

This normalization, or weighting, of the data should reduce the effect of the larger number of observations available in the summer months without altering the distribution of wind speeds observed during those months.

Although this weighting action did produce some differences in the distributions it was very slight in all cases and could not be said to be significant.

(c) *Extreme-value analysis*

The estimation of extreme value is important for design and planning purposes. It is, therefore, of interest to compare the extremes derived from both the measured and estimated wind speeds.

Extreme values are estimated by fitting a distribution to the available data and extrapolating the tail of the distribution to the value having a cumulative probability of exceedance corresponding to the return period required. This gives the value expected to be exceeded, on average, once in N years, where N is the return period.

There are many distributions that can be used to predict extreme values. Several require the identification of annual maxima. This means that a long period (several years) of regularly observed data is necessary. Since the VOF data are randomly distributed in space and time such methods cannot be used because the maxima cannot be identified. The method used here to predict extremes from both measured and estimated data is to fit a 3-parameter Weibull distribution to the data.

The form of the distribution function (Weibull 1951) is

$$1 - P(V) = \exp\left\{-\left(\frac{V - V_o}{B}\right)^A\right\}$$

where $1 - P(V)$ is the probability of exceedance and A, B and V_o are the three parameters to be determined. This expression can be rearranged to give a straight line of the form

$$\ln[-\ln\{1 - P(V)\}] = A\ln(V - V_o) - A\ln B.$$

The data were fitted by computer program to this straight line by finding the best correlation between $\ln[-\ln\{1 - P(V)\}]$ and $\ln(V - V_o)$ for various values of V_o. The other two parameters, A and B, were given by the line of best fit with the optimum value of V_o The once in N-year value was then estimated by assuming that the number of observations that could be expected in N years was n. The corresponding probability of exceedance was $1/n$ and could be used in the expression

$$V_N = \exp\left(\frac{\ln\{-\ln(1/n)\} + A\ln B}{A}\right) + V_o$$

where V_N is the once in N-year extreme.

Because of the various averaging times (see Table II) it was necessary to convert the extreme values deduced for each station to extreme values appropriate to averaging times of one hour. This conversion, necessary for comparison purposes, was effected by means of figures derived by the Meteorological Office and given in Table III. Similar figures can be found in the Department of Energy Offshore Installation Guidance Notes (1977).

Table II. *Effective averaging times for the various sources of data*

3 seconds	15 seconds	1 minute	10 minutes	1 hour
Brent B	OWS	LV	UKOOA DB 1 Benbecula	VOF Stevenson

Table III. *1 in 50-year extreme winds at 10 m and 100 m above sea level for various averaging times expressed as ratios of the 1 in 50-year hourly 10 m wind*

Height	Averaging time				
metres	10 minutes	1 minute	15 seconds	5 seconds	3 seconds
10	1.05	1.17	1.27	1.34	1.37
100	1.39	1.54	1.56	1.61	1.63

6. Results

The results of the extreme-value analysis are shown in Table IV for the 50-year return period. Both normalized and unnormalized VOF data were used. The normalized distributions tended to produce higher extremes, but for five stations there was no difference. Of the other ten stations, seven were increased by 1 kn, two by 2 kn and one, Varne, decreased by 2 kn because of normalization and an abnormal frequency distribution; the only wind of Beaufort force 11 occurred in a month of more than 30 observations so that its contribution to the normalized distribution was insignificant in the extreme-value analysis.

The large difference between extremes derived from the instrumental data from Brent B and the corresponding VOF data may be due to the height of the anemometer on the rig (108 m) and, also, to variations in observing practice. The extreme has been corrected to an equivalent hourly mean wind speed at 10 m but the original data were uncorrected.

Table IV. *Comparisons of 1 in 50-year extreme winds derived from measured and estimated data*

Station	50-year extreme wind speeds derived from: Measured data	Estimated data: Not normalized	Estimated data: Normalized	Differences between extremes derived using measured and estimated data: Not normalized	Normalized
			knots		
OWS 'I'	65	66	67	1	-2
OWS 'J'	65	61	62	+4	+3
OWS 'L'	67	64	65	+3	+2
OWS 'M'	59	53	54	+6	+5
Seven Stones LV	66	58	59	+8	+7
Shambles LV	66	61	62	+5	+4
Varne LV	64	61	59	+3	+5
Mersey Bar LV	69	66	66	+3	+3
Stevenson (10 minute)	84	62	62	+18	+18
FitzRoy	57	59	60	-2	-3
Boyle	56	59	59	-3	-3
Stevenson (hourly)	69	62	62	+7	+7
DB 1	55	62	62	-7	-7
Brent B	78	62	64	+16	+14
South Uist	58	59	61	-1	-3

The very high extreme wind speed of the Stevenson 10-minute data may be due to sampling errors. There were only 23% of the possible total number of observations in the data set and three values above 60 kn contributed a comparatively large percentage to the distribution.

The differences between the extremes for 50 years from instrumental and estimated data are also shown. In 11 cases out of 15, the differences at the 50-year return period between extremes derived from instrumental data and from the estimated data were either reduced or remained the same when the estimated data were normalized.

Considering climatological reliability, as discussed above, and the number of observations in each sample it can be concluded that reliable data samples exist for OWS 'I', 'J', 'L' and the Stevenson hourly data. OWS 'M' is not included because of the low number of VOF estimates. This conclusion does not mean that the samples of data considered reliable are necessarily true representations of the climate in that area, only that it seems reasonable to assume so. It is quite possible that the data samples from other stations are good representations of the conditions despite reservations about their climatological reliability.

The difference between the 50-year return period extremes derived from the measured data and the normalized distribution of VOF estimates from the area surrounding the 'reliable' stations OWS 'I', 'J', 'L' and Stevenson (hourly) are respectively, -2, +3, +2 and +7 kn (Table IV). If it is borne in mind that the extremes are derived from wind speeds in Beaufort force classes (average range 5 kn) the extremes can only be considered accurate to within ±5 kn at best, and more likely ±7 kn, since the range of the Beaufort force classes increases with increasing wind speed. Consequently, the estimates of the 50-year extremes derived from each source are quite close. In fact only two stations have differences of more than ±7 kn, so that most of the 50-year extremes estimated from the VOF distributions are correct within the range of accuracy of the extremes derived from the measured distribution. Of the remaining five, three are stations with short periods of measured data, FitzRoy, Boyle and DB 1. One, South Uist, has measured observations from a land station (Benbecula) which would be expected to underestimate the wind speeds compared with open sea values. The remaining station is OWS 'I' with an overestimation from the VOF distribution of 2 kn. There is no obvious explanation for this difference though it is most likely due to the sampling in one of the data sets concerned. For the OWS 'I' measured data, annual maximum wind speeds were extracted and fitted to the Gumbel (or Fisher–Tippett Type I) distribution to give estimates of extreme values. Extreme wind speeds were also estimated in this way for OWS 'J'. Since 'I' and 'J' are in similar climatic locations it should be possible to determine whether, or not, the results from OWS 'I' are reasonable by comparing the extremes from each OWS derived using each method of extreme value estimation.

Table V shows some of the resulting extremes from both methods of analysis and Fig. 4 shows plots of extreme wind speed against the return period. The estimated extremes from the Gumbel analysis are similar for both OWS 'I' and 'J' as are those estimated using the Weibull distribution. It would seem that the results for OWS 'I' can be considered reasonable and that it is the VOF distribution of estimated wind speeds which is unrepresentative of the climatic conditions in the area. The extreme values for the 50-year return period for OWS 'I' and 'J' wind speeds here are very similar. This is a coincidence and it should not be assumed that similar results are given for the 50-year return period for every location. There is no very obvious anomaly in the VOF distribution, but there is a small percentage of observations of wind speeds greater than 60 kn (0.04%). These observations are not necessarily incorrect but have not been matched by lower observations in the rest of the distribution. Therefore, the whole distribution becomes unrepresentative owing to a quirk of sampling.

The two stations with very large differences between estimated 50-year extremes can be discounted for reasons explained above. Most of the sites have underestimates of the 50-year extreme derived from the

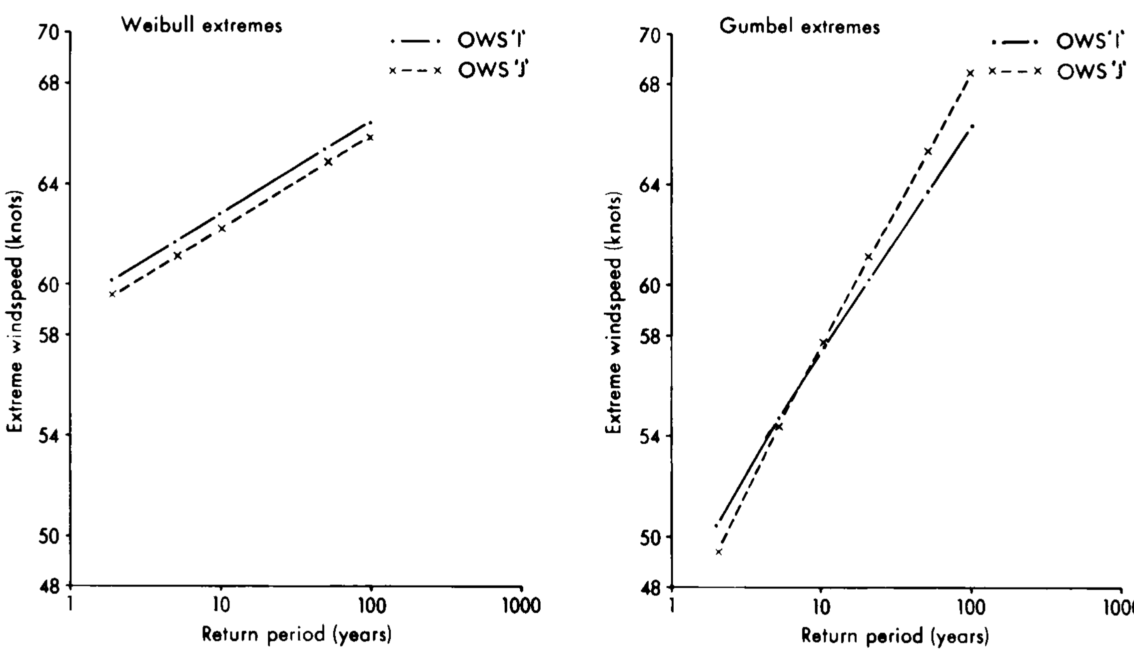

Figure 4. Extreme values of wind speeds for OWS 'I' and OWS 'J' derived from Weibull and Gumbel distributions.

VOF distribution compared with the corresponding extremes from the measured distribution. The average value of this underestimation is 5 kn. It does not seem unreasonable to assume that, in most cases, if 5 kn is added to the extremes estimated from the VOF distribution the resulting extreme value will be a better estimate. Obviously this will not be always true and, although sensible assumptions can be made regarding the apparent reliability of the data samples, there is no rule which will say whether or not any sample is a good representation of the conditions in the area over which it is taken.

If one considers the average differences between the extremes derived from the VOF estimates and the measured observations a similar conclusion can be drawn for extremes for the other return periods. That is, the average difference for the stations is about 5 kn, so a 5kn addition to the VOF estimate in general would improve the estimated extreme. It must be emphasized that this correction is an average result and will not necessarily improve the result in every individual case.

Table V. *Extreme wind speeds for OWS 'I' and 'J' derived using Weibull and Gumbel (or Fisher-Tippett Type I) distributions*

	OWS 'I'		OWS 'J'	
Return period	Weibull extremes	Gumbel extremes	Weibull extremes	Gumbel extremes
years		*knots*		
10	63	57	62	58
50	65	64	64	65
100	66	66	66	68

7. Conclusions

The distributions of estimated wind speed observations are different from those derived from wind speeds taken from instrumental sources. These differences are most likely due to the different observing techniques used.

This study suggests that a distribution should not be considered reliable simply because it has been taken from instrumental sources. It may not be any better than a distribution of estimated observations. The quality of measurements must be taken into account and the length of time over which the data set exists is also important.

It seems that where there is no absolutely reliable set of instrumental data the VOF data in that area can be used with confidence and it is likely that if an addition of one Beaufort class is made to the 50-year return period extreme (and similarly to all other return period extremes) the result will be somewhat improved.

8. Acknowledgements

This work is part of a wave climate synthesis project carried out in collaboration with the National Maritime Institute with the support of the Maritime Technology Committee.

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Appendix

Table IA. *Comparison between the limits of wind speed for the Beaufort scale numbers with those for the 'scientific' Beaufort scale*

Beaufort scale Equivalent speed at 10 m above ground Limit *knots*	Force	'Scientific' Beaufort scale Equivalent speeds at 20 m above sea surface Limit *knots*
<1	0	0-2
1-3	1	3-5
4-6	2	6-8
7-10	3	9-12
11-16	4	13-16
17-21	5	17-21
22-27	6	22-26
28-33	7	27-31
34-40	8	32-37
41-47	9	38-43
48-55	10	44-50
56-63	11	51-57
≥64	12	≥58

50 years ago

The following extract is taken from the *Meteorological Magazine*, December 1932, **67**, 249.

The British Polar Expedition to Fort Rae

During the first International Polar Year in 1882-3 a combined British and Canadian expedition under Captain Dawson occupied Fort Rae on the shore of the Great Slave Lake in 63°N. In spite of its comparatively low latitude, this station was of great importance, especially for observations of terrestrial magnetism and aurora, because it lies very near the zone of maximum frequency of aurora which surrounds the magnetic pole. When the second International Polar Year was planned for 1932-3, one of the important aims was the determination of the change of the magnetic elements during the interval of fifty years, and for this purpose it was necessary to occupy as many as possible of the earlier stations. The re-occupation of Fort Rae fell to the British share, while other stations in the extensive sub-polar regions of North America were the objectives of Canada and the United States.

The British Expedition consists of a party of six, Mr. J. M. Stagg* (leader), Mr. W. R. Morgans, Mr. P. A. Sheppard, Mr. A. Stephenson, Mr. W. A. Grinsted and Mr. J. L. Kennedy. Although the Polar Year did not officially start until August 1st, the party left England in May in order to have as long a time as possible for the construction of special huts, the erection of the instruments and generally to get the station into working order. They reached the settlement on June 19th, at the beginning of the short northern summer, accompanied by about 600 cases of instruments and food, all of which had been specially packed because of the cost and difficulty of transport. Mr. Stagg writes: "Our recollection of

* Later Director of Services, Meteorological Office.

the bustle of the early days at Rae is full of packing cases, curious Indian onlookers and swarms of hard-sucking mosquitoes, which, taking advantage of our occupation along other lines, had ample opportunity to feast on the fresh English blood they seem to relish so much.

"The first big jobs were the preparing of huts for instrumental gear. By earlier arrangements with the Hudson Bay Company and the Royal Canadian Mounted Police, of which there is a detachment here, we were spared the trouble of erecting dwelling-house and sleeping quarters. But other disused Indian shacks had to be converted and reconditioned. One, to house the photographically recording magnetic instruments, was made non-magnetic, light-proof and heat-insulated by building a double-walled chamber with wood-wool from our packing cases in the interspace and then fitted with a double door and piled up with turf and muskeg outside. Another old log hut was dismantled and transplanted from one end of the settlement to the other for manufacturing hydrogen in and filling our pilot and meteorograph balloons, while a third to house the engine generator and storage battery for the continuous lighting of the photographic recording instruments was largely reconditioned. A special completely non-magnetic hut for the absolute magnetic observations was built. Fortunately we found, ready made, a substantial log hut we could use for the main meteorological observatory and office.

"By the beginning of July many of the meteorological instruments were erected and observations begun, but it was nearer the beginning of August before the magnetograph chamber was satisfactorily complete and all the three independent sets of magnetic recorders properly settled down. By August 1st every instrument was functioning, and the complete routine of observations every three hours throughout the day was instituted. Already, in July, aurora had been noticed on every evening. Rae must be near, if not actually inside, the zone of maximum auroral frequency.

"From our early days here, the Indians have been amused spectators of our activities. The balloons we send off daily specially interest them. They feel sure that the unusually long rainless period we had in August had some connexion with the ultimate purpose and fate of the balloons in the high atmosphere, and attribute to us a specialised form of super medicine-man technique. A thunderstorm with lightning flash to ground near the settlement, nearer than they cared to recollect they had ever seen one before, confirmed them in this belief."

The new station is not actually on the site of that of 1882-3, but some 20 miles further up the lake in one of the largest Indian settlements in northern Canada. The old site was overgrown by bush, but the little island on which Captain Dawson erected his anemometer is still known by the natives as "White Man's Island." The old station has not been entirely abandoned, however, as the programme includes parallel magnetic observations at the old and new Forts to determine the secular change in the magnetic elements since the first Polar Year. Mr. Stagg adds: "We are taking advantage of the visits there to use the station as the other end of a base-line connecting the two Forts for simultaneous photography of aurora for height determinations."

Obituary

We regret to record the death on 30 May 1982 of Mr R. Hill, Higher Scientific Officer, who was stationed at Nottingham Weather Centre. Russell Hill joined the Office in 1946 as a Scientific Assistant and worked at a number of forecasting outstations including Bawtry, Finningley, London/Heathrow Airport and Shawbury. He was promoted to Higher Scientific Officer while at Shawbury in 1971, and the following year was posted to the office at Royal Air Force Watnall (which later became Nottingham Weather Centre).

Mr Hill had a dry sense of humour; he was a keen gardener and enjoyed foreign travel.

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