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VISIT TO THE METEOROLOGICAL OFFICE BY H.R.H. THE DUKE OF EDINBURGH

On the afternoon of 16 February 1973, the Meteorological Office was honoured by a visit from His Royal Highness the Duke of Edinburgh, K.G., K.T., O.M., F.R.S., who came to see something of the operational work in the new Richardson Wing of the Headquarters building.

His Royal Highness was greeted on arrival at the entrance of the FitzRoy Wing by Dr B. J. Mason, the Director-General, and Mr Ian Gilmour, M.P., Minister of State for Defence. His Royal Highness then proceeded to the Director-General's office where he was introduced to Mr J. M. Wilson, Permanent Under Secretary (Administration) in the Ministry of Defence, Mr P. J. Meade, Director of Services, Mr J. S. Sawyer, Director of Research, and Mr H. E. Davies, Secretary of the Meteorological Office, and he was then invited to sign the Visitors' Book.

After a brief talk by the Director-General on the work of the Office, His Royal Highness was escorted round the Richardson Wing. In the Central Forecasting Office he showed a deep and detailed interest in the techniques used for producing the daily forecast and, in particular, the way in which the computer products are used. He was shown an impressive selection of satellite photographs, the development of several heavy showers on the radar display, and ships being routed across both the Atlantic and Pacific Oceans. In the Telecommunication Centre, His Royal Highness showed considerable interest in the methods by which meteorological data are collected and disseminated both by the teleprinter network and the facsimile system and was shown the computer-controlled message-switching system, linking Bracknell with Washington, Paris and Offenbach, that had become operational only a few days before. In the Computing Laboratory he saw part of an operational forecasting suite being run on the IBM 360/195 computer and was particularly interested in the automatic production of charts on the high-speed line-printer and cathode-ray-tube plotter.

His Royal Highness then returned to the Director-General's office where he took tea with the guests and senior members of the staff and initiated a very lively discussion with Dr Mason and Mr Sawyer on the possible influences of man-made activities on weather and climate. He appeared thoroughly to enjoy his visit which lasted for about two hours, showed a real interest in and understanding of what he saw, and spoke to several members of the staff during his tour.

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MONTHLY MEAN WIND PATTERNS AT 40 000 FEET OVER AUSTRALIA

By T. R. HEALY

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Summary. Processing of the most comprehensive set of data yet available for the Australian region led to the compilation of new monthly mean vector-wind charts for 40 000 feet. Inspection of the charts gives rise to the inference of a preferred location or quasi-permanent trough in the upper-tropospheric westerlies centred about 150°E over eastern Australia. A complementary mean ridge was found to be present over central Australia at about 125°E. The amplitude of the mean trough–ridge system was between 4° and 8° of latitude.

Introduction. Preliminary upper-tropospheric monthly mean wind statistics for the Australian region were derived by Phillpot,[1] Gabites and Porter,[2] and Phillpot and Reid[3] in the early 1950s. Later, in response to the demand for upper-wind information upon the introduction of high-flying jet aircraft, Phillpot,[4] using data collected to 1956, analysed the wind fields at all levels to 60 000 ft.* Unfortunately the resulting charts were constructed from data which were inhomogeneous both in time and in method of observation and were thus considered 'provisional'. Accordingly, for this study it was decided to construct new vector mean wind charts in order to take advantage of both the increased data network and the enlarged time span of homogeneous observations. These charts are expected to show with greater precision the monthly patterns of vector mean wind flow and the behaviour of the maximum westerlies and Australian subtropical jet stream (STJ) as depicted by monthly mean upper-wind flow. Because upper winds over Australia are measured at fixed altitudes, the level chosen for analysis was 40 000 ft, this being the closest to 200 mb and the recognized level of the upper-tropospheric maximum westerlies.[5]

Data network. Most of the stations selected supposedly possessed an unbroken set of records for the 12-year period 1956–67, although some stations had been in continuous operation for only the 6-year period 1962–67. Unfortunately the method of wind finding varied at a number of stations during these periods because of the introduction of new wind-finding radars.

Distribution of the upper-wind stations used in this study is illustrated in Figure 1. Distribution shows a bias of concentration in the eastern zone (east of 145°E) which possesses 26 of the 53 stations. The central zone (125°–145°E) contains 16 stations while the western zone contains only 11 stations. Oceanic stations are few, and this study suffers — as have all to date — from the acute lack of observations over the Indian and Antarctic Oceans. Nevertheless, the upper-wind network used here is the densest of any study so far attempted for this region (cf. Phillpot:[4] 21 stations). Of the 53 upper-wind stations used (including the 5 New Zealand stations and Nandi, Fiji) 31 were pilot-balloon theodolite stations in 1956. Throughout the period under consideration the number of stations using visual methods of upper-wind recording steadily decreased until in December 1967 only 14 remained, whereas the number of radar-wind stations increased from 16 in 1956 to 39 by 1968.

* 1000 ft ≈ 300 m.

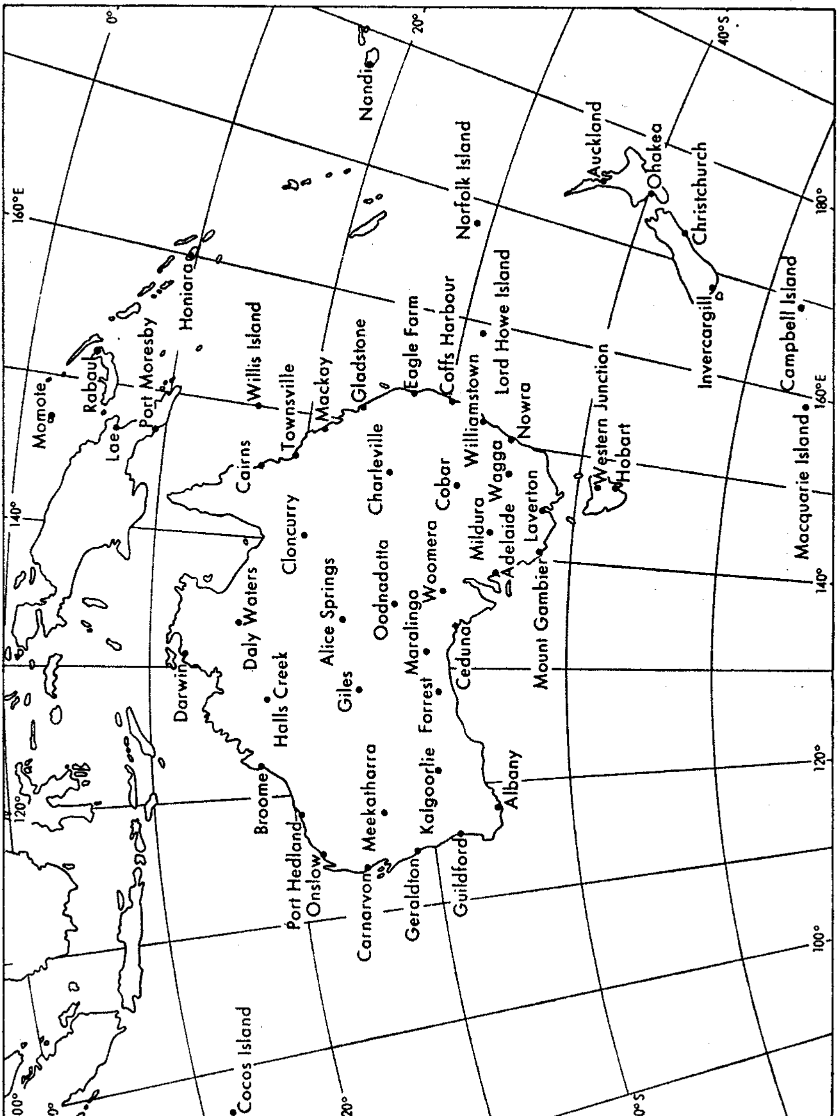


FIGURE 1—DISTRIBUTION OF UPPER-WIND STATIONS IN THE AUSTRALIAN REGION

Data source. All upper-wind observations made by the Commonwealth Bureau of Meteorology are stored on punch-cards.[6] Wind observations at fixed heights for each station are extracted from the original wind sounding. Direction and magnitude are recorded in units of 10 degrees and knots respectively. These data, for the years 1956–67, were obtained from the Bureau of Meteorology in the form of card images on magnetic tape.

Problems in the analysis. A number of problems arose in the analysis of the raw data supplied by the Bureau of Meteorology. These principally related to the checking and homogeneity of the data, and they were solved as follows:

(a) Checking of the raw data for embedded blanks, incorrect punching and illegal characters was carried out within the Bureau of Meteorology. However there is no safeguard against mistakes in the original wind observations. The complete set of original observations were not checked in detail although random checks of two flights per month per station are made, prior to punching, in the Weather Statistics section of the Bureau of Meteorology. A number of checks for correct data were incorporated in the program (e.g. correct card, times of flight, etc.) but no curve-fitting or smoothing of individual upper-wind soundings was included.

(b) Although it was originally proposed to utilize a homogeneous set of records complete for 12 years for 56 upper-wind stations, this proved impracticable. A number of stations were converted from pilot-balloon to radar methods of measurement during that period, and truly reliable wind records thus date from that event. Frequently pilot-balloon observations reaching 40 000 ft were too few per month to consider for inclusion in computation of the statistics. Thus the aim of obtaining a long period of homogeneous upper-wind records was to a certain extent frustrated.

(c) Although some stations (e.g. Laverton) undertake four flights per day, for standardization and to reduce serial correlation only the 23-GMT observations have been utilized for this study.

(d) The problem of the influence of diurnal variation in wind flow, which can be detected in the vector means up to levels of about 10 000 ft,[4] is not considered significant at 40 000 ft and was disregarded in this study.

(e) The final charts are not completely objective in that a certain amount of smoothing of the isotachs was necessary to allow for disparate values of adjacent stations, arising as a function of the wind-measuring device.

(f) Sources of errors in upper-wind observations, and assessment of the reliability of Australian data, are discussed in detail by Spillane.[7]

New Zealand stations and Fiji. Statistics for the New Zealand stations (Campbell Island, Invercargill, Christchurch, Ohakea and Auckland) and Nandi, Fiji, were extracted directly from de Lisle.[8] All statistics for these stations were based on 10–12 years of observations made by wind-finding radar. Although normally four flights per day are made, the statistics presented are also computed from the 00-GMT observations only, in order to decrease serial correlation. Otherwise, treatment of the data is the same as that outlined by Maher and McRae.[9]

Construction of the charts. The monthly vector mean wind and standard vector deviation were calculated for each station on the CDC 3200 and Burroughs B 5500 computers at the Monash University Computer Centre. Unless the number of observations at 40 000 ft for each station exceeded 10, that month was excluded from the computation. The vector mean winds and standard vector deviations for most of the stations have been plotted on the 12 charts constituting Figure 2 and the remainder are presented in Table I. Although the original aim was to base these upper-wind statistics on 6–12 years of continuous records this was not always possible. Choice of stations was restricted to those at which at least 3 years of observations contributed to the computations, as suggested by Phillpot.[4]

On the charts isotachs have been drawn. As with Phillpot's charts[4] some smoothing was inevitable so that the mean flow patterns resulting are somewhat subjective. For this reason, the analysis has been confined to the areas with a relatively high density of upper-wind stations. Little attempt has been made to interpolate over the data-sparse regions.

On most charts it was possible to locate an isotach maximum (of jet-stream strength) for the months April–November. The axis of the upper-tropospheric mean maximum westerlies is also indicated.

TABLE I—VECTOR MEAN WINDS AND STANDARD VECTOR DEVIATIONS AT 40 000 FEET OVER THE AUSTRALIAN REGION: STATION DATA OMITTED FROM THE CHARTS OF FIGURE 2 BECAUSE OF SPACE LIMITATIONS

	Port Hedland		Onslow		Meeka-tharra		Maralinga		Ceduna		Woomera	
	Wind *deg kt*	σ *kt*	Wind *deg kt*	σ *kt*	Wind *deg kt*	σ *kt*	Wind *deg kt*	σ *kt*	Wind *deg kt*	σ *kt*	Wind *deg kt*	σ *kt*
January					264/34	30					244/33	36
February					266/33	32	251/37	33			247/37	34
March							254/41	39	252/34	40		
April	269/45	31					262/57	40			259/51	39
May			254/53	41			264/56	43			262/61	49
June							262/74	47			262/80	50
July			268/57	32			268/87	44			264/95	47
August							259/95	46			259/95	44
September							260/76	42			263/75	42
October					269/73	42	262/73	40			260/69	43
November							267/53	38				
December							257/46	34			258/46	36

	Mildura		Laverton		Mount Gambier		Coffs Harbour		Townsville		Mackay	
	Wind *deg kt*	σ *kt*	Wind *deg kt*	σ *kt*	Wind *deg kt*	σ *kt*	Wind *deg kt*	σ *kt*	Wind *deg kt*	σ *kt*	Wind *deg kt*	σ *kt*
January	249/37	39	262/39	44			262/35	39			272/30	31
February	253/36	39	258/39	43			269/37	46	272/17	28		
March	253/45	41	259/39	42			266/40	40			272/35	31
April	252/34	37	264/36	37			272/50	38			278/55	29
May	260/47	45	262/42	40			266/56	42			272/71	40
June	264/59	43	263/43	38			270/76	56	272/55	37		
July	262/80	43	264/53	39					272/51	30		
August	262/74	45	262/51	37					269/50	32		
September	262/65	44	264/49	39			263/79	42	272/48	33		
October	264/53	41	265/46	38					271/49	30		
November	258/49	36			264/53	40	261/48	41	268/47	31		
December	257/40	40	264/40	41			264/46	37	268/39	28		

σ = Standard vector deviation.

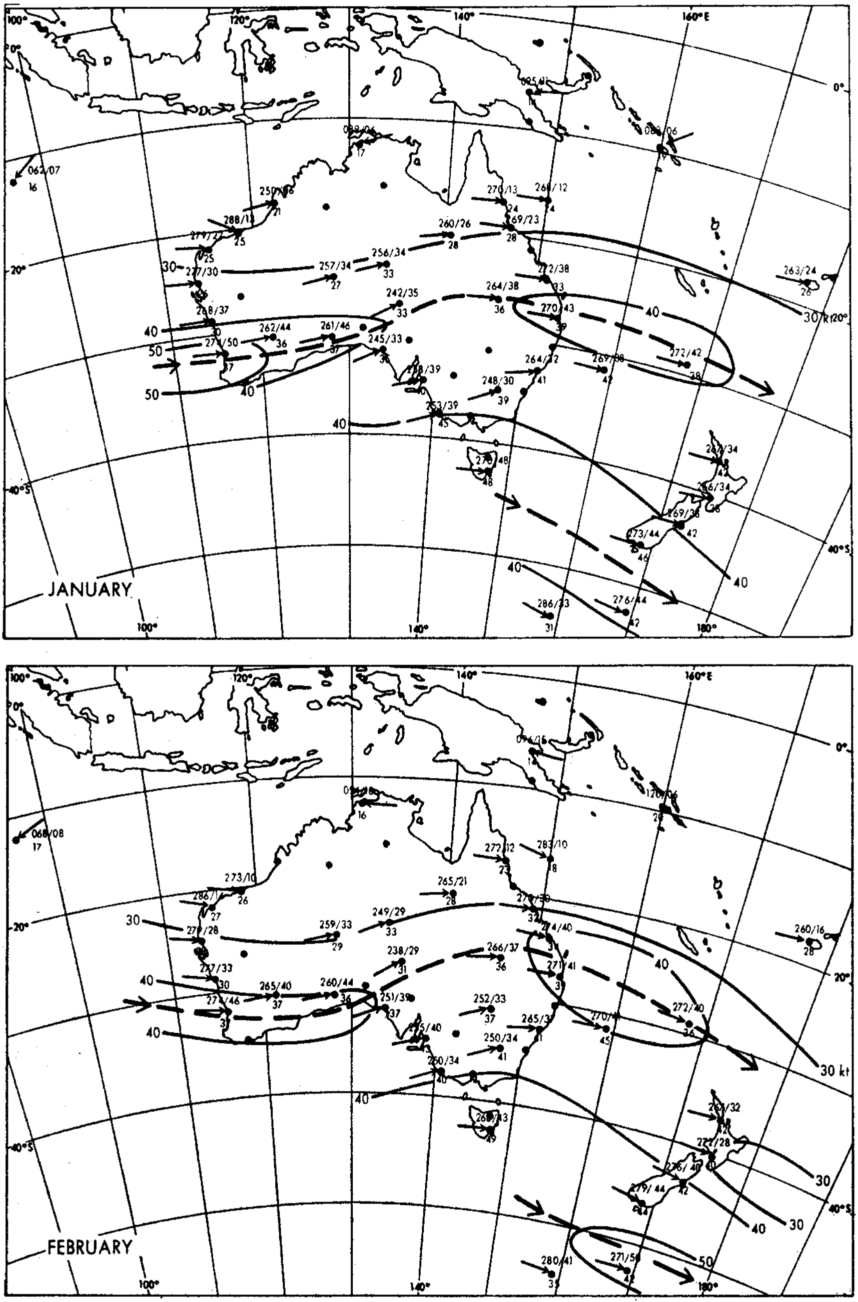
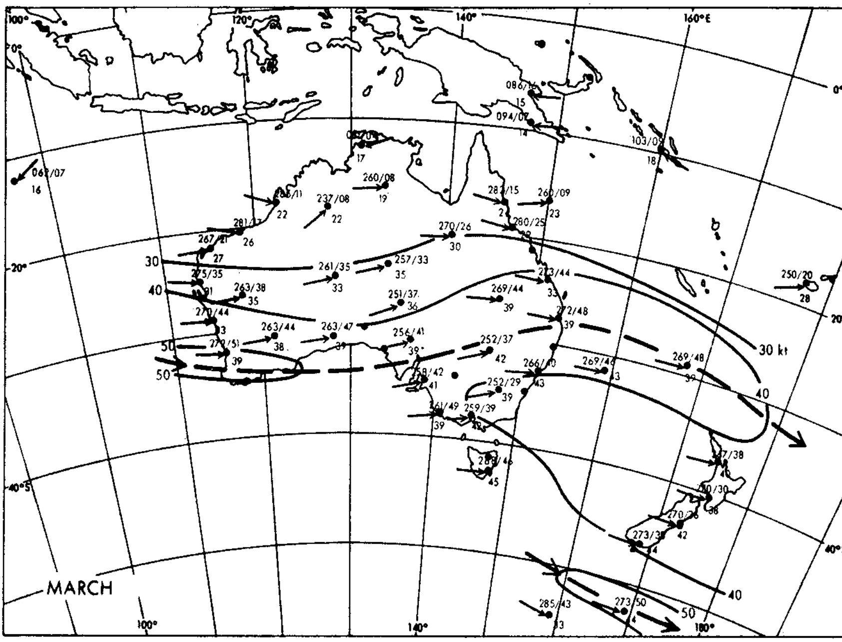


FIGURE 2—MONTHLY VECTOR MEAN WINDS AT 40 000 FEET IN THE AUSTRALIAN REGION

— → Mean maximum wind axis ——— Isotachs at 10-kt intervals

Directions are given in degrees and speeds in knots above the station circles; standard vector deviations are given in knots below them.

See Table I for data omitted from the charts because of space limitations.



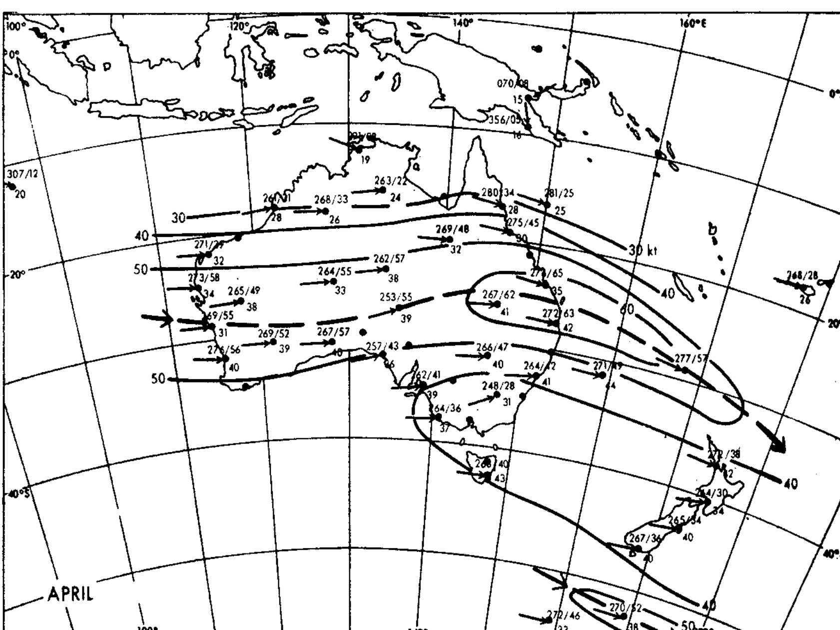


FIGURE 2—*continued*

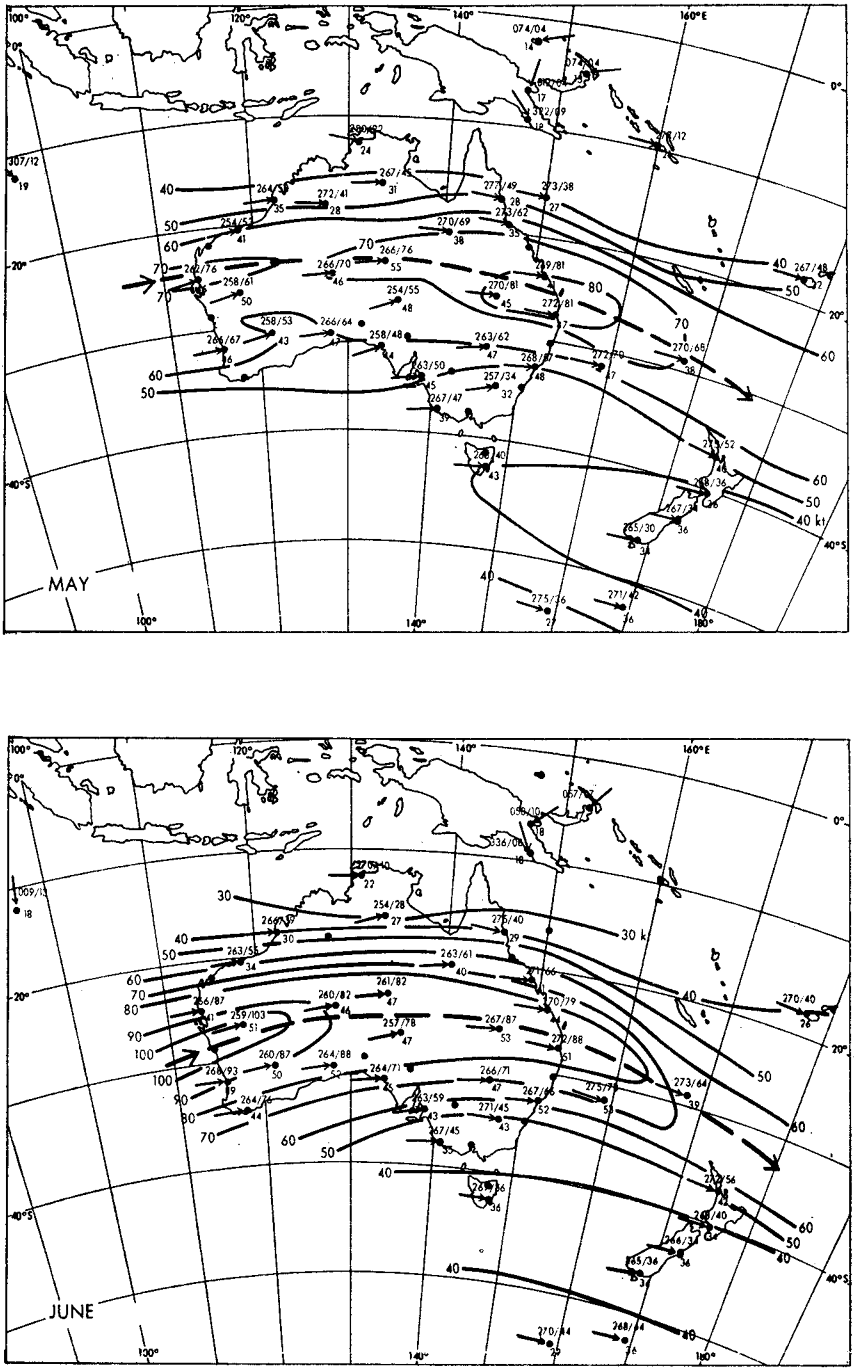
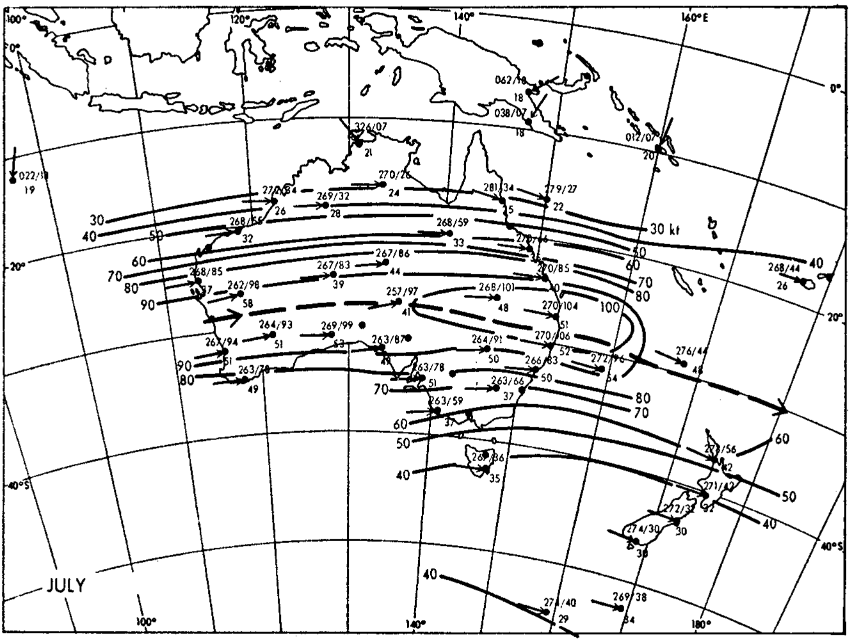


FIGURE 2—*continued*



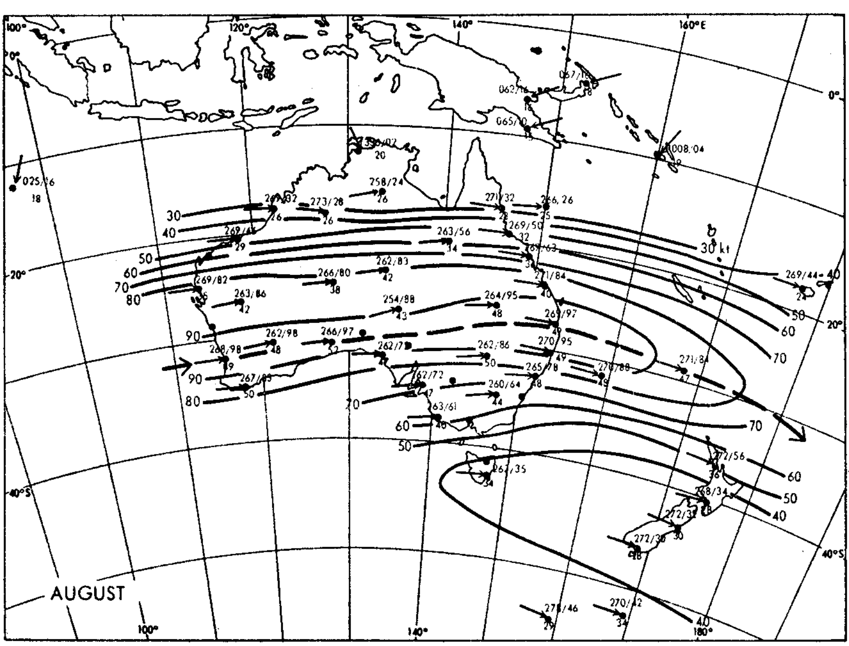
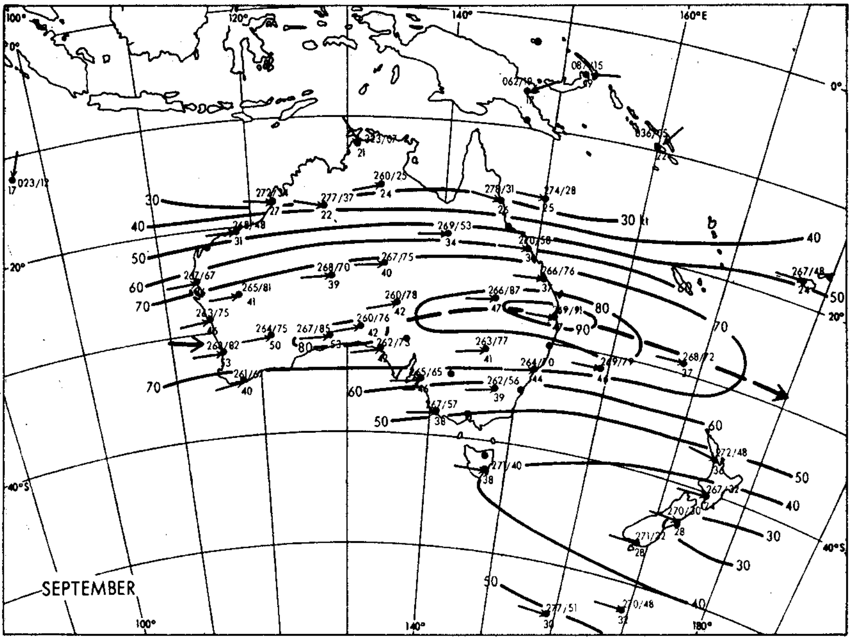


FIGURE 2—*continued*



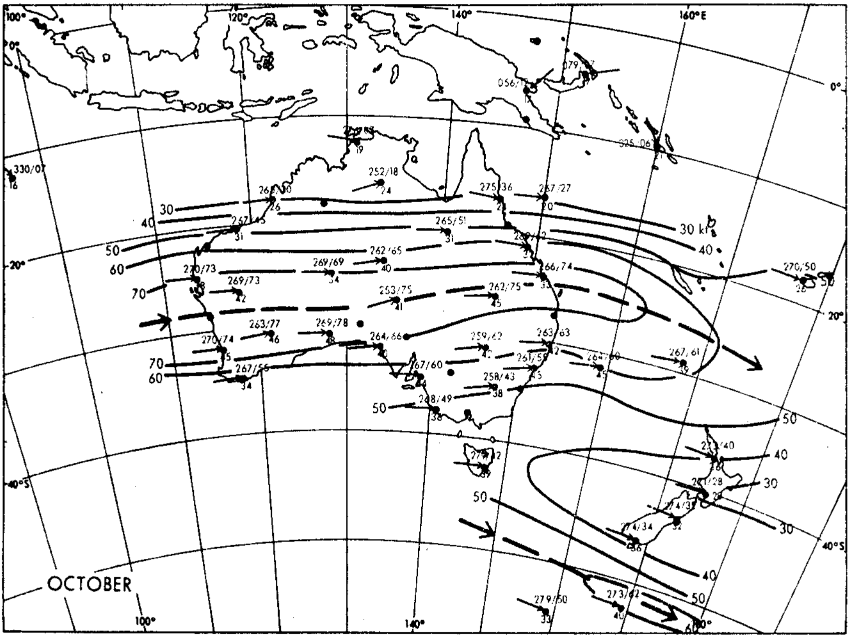
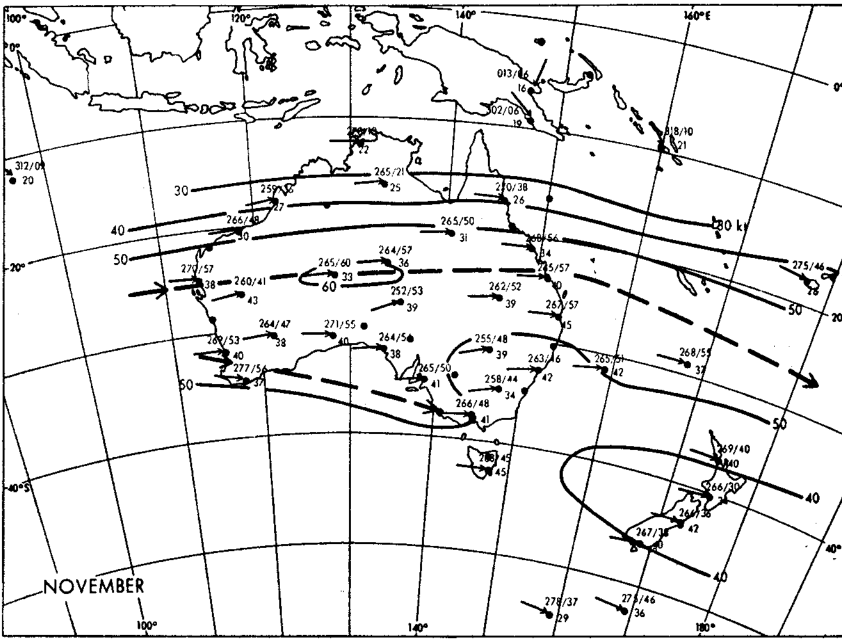


FIGURE 2—*continued*



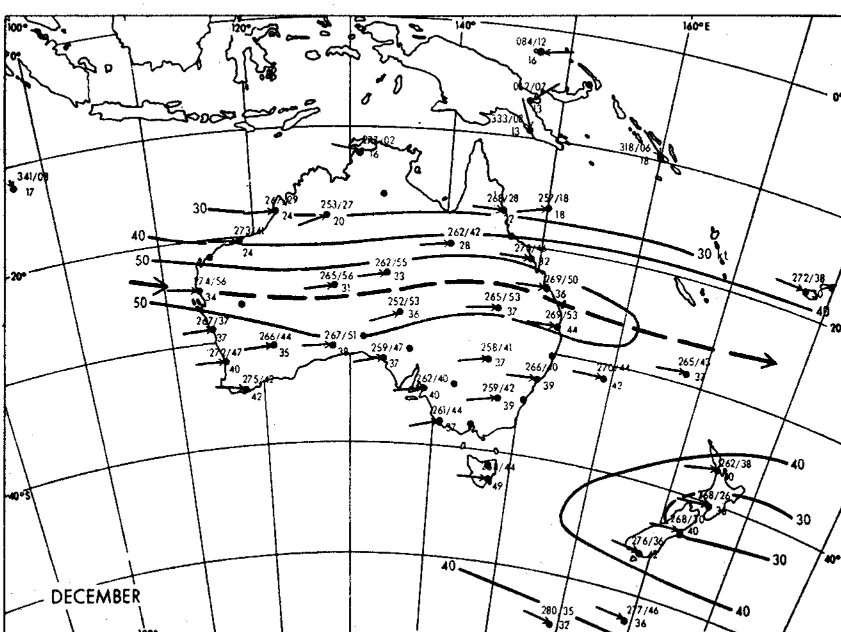


FIGURE 2—*continued*

Monthly mean flow patterns at 40 000 ft. A number of general points arise from the monthly mean flow patterns illustrated in Figure 2. Discussion is limited to those areas covered by the data network.

(a) In contrast to the mean charts presented by Phillpot,[4] much greater deviations from mean zonal flow are evident in the present charts. Phillpot shows that from March to November the mean flow is directly zonal. In contrast, of the charts constructed for this study only three months exhibit mean flow which is directly zonal (i.e. within 2–3 degrees of latitude over 100 degrees of longitude).

(b) Isotach maxima are generally lower than those calculated by Phillpot[4] for the autumn, winter and spring months, but are about the same as his values for the summer months. For example the highest isotach value shown here (100 kt*) occurs over eastern Australia in July whereas Phillpot shows a zone of 110 kt traversing the continent during that month.

(c) Mean jet-stream speeds (>60 kt) are evident from April to November (cf. Phillpot: April to December).

(d) Wind flow at 40 000 ft is well above the frictional influence of the earth's surface.[10,11] Hence it can be assumed that the wind flow at 40 000 ft will follow the 200-mb geopotential contours and that the isotachs will roughly define a mean contour trough or ridge. This assumption is implicit in the following discussion.

Strongest mean wind and direct zonal flow are exhibited in July. An isotach maximum of 100 kt is located between 140°–160°E and 25°–30°S. However, the extraordinarily light wind computed for Norfolk Island probably reflects either the unreliability of the Metox radiotheodolite for measuring strong winds at 40 000 ft or, alternatively, mistakes in the data. A minimum with mean speeds of less than 40 kt is located over the South Island of New Zealand and apparently extends across to Tasmania. This minimum coincides with the area marked by Lamb[12] as an area of blocking anticyclones. It is also shown by Karelsky[13] as an area of maximum anticyclonicity. Grant[14] and Radok and Grant[15] indicate that the region of wind minimum may extend south of the Australian continent at about 40°S. This minimum appears to be evident only in the Australian region of the hemisphere.[16] North of the minimum there is an incipient weak mean trough with an axis located between 150° and 160°E.

August shows a similar pattern. The eastern mean trough centered at 150°E becomes evident with an amplitude of 4–5 degrees of latitude. Mean maximum wind speed over Australia is between 95 and 100 kt (cf. Phillpot:[4] 110 kt). September and October are similar with mean maximum wind decreasing to about 75 kt over the continent in the latter month. The minimum extending over southern New Zealand and the south Tasman Sea remains, although a distinct current from 280° appears over Macquarie Island with a constancy of 77 per cent.

By November only a small area of mean wind exceeding 60 kt remains over the continent. In December a mean ridge appears over the central and western parts of the continent and the amplitude of the eastern mean trough increases. Mean maximum vector-wind speed over Australia is about 55 kt.

* 1 kt ≈ 0·5 m/s

In January, February and March the mean wind trough–ridge system over the continent attains its greatest amplitude (8 degrees of latitude) although the mean wind speeds associated are low — less than 50 kt. During February–April a mean west-north-westerly stream exceeding 50 kt is located in the vicinity of Macquarie and Campbell Islands. By April a mean maximum, reaching jet-stream speeds (>60 kt), appears in the eastern trough at the eastern coastline. This increases to 80 kt in May, and flow becomes nearly zonal again in June with a maximum of 100 kt located over Western Australia. A minimum zone extends longitudinally between 40° and 50°S although its cell-like character is lost.

The information presented here indicates that the mean trough found by Lamb[12] centred at 120°E at 500 mb does not seem to extend to 200 mb. On the other hand the evidence supports the existence of an eastern mean trough as suggested by Muffatti.[17]

In summary, the major features of upper-tropospheric monthly mean subtropical jet (STJ) flow seem to be :

(a) Mean STJ speeds greater than 60 kt prevail over the continent from April to November.

(b) A mean trough, with axis near 150°E over eastern Australia, is clearly discerned from October to April but is also incipiently developed from May to September (Figure 2).

(c) A complementary mean ridge, centred about 125°E, is evident in the summer months from December to March.

(d) A cell of minimum wind speed appears situated over southern New Zealand and the south Tasman Sea as far west as Tasmania. The minimum seems to be bounded to the south by a westerly stream over Macquarie Island.

Discussion: implications for the mean circulation. The mean west to west-north-westerly stream over Macquarie Island may bear little relation to the STJ. Instead this stream may be explained by the presence of a mid- to high-latitude jet, possibly the southern polar-front jet, troughing slightly to the west of Macquarie Island. Alternatively this stream may indicate a preferred region of STJ diffluence which, presumably, would be located either near the south-western tip of the continent or in the zone of the mean ridge south of the continent. The origin remains problematical[18] and, indeed, both interpretations may commonly feature on the synoptic 200-mb daily analysis charts prepared by the Bureau of Meteorology. The need for further research on the detailed structure of the jet streams over the southern oceans is obvious.

The existence of the mean STJ trough located in the vicinity of 150°E over the east coast of Australia was recently firmly established by Weinert[19] and indirectly by Campbell.[20] Mean troughs over the eastern sectors of continents are well-known phenomena.[21,22] Their origins are complex but are believed to be related to orographic[23] or thermodynamic influences[24] or perhaps to instability of the zonal baroclinic current.[25,26] Although an orographic influence may be applicable to the North American situation, there is no barrier in Australia comparable to the Rockies.

Thermal influences superimposed on the basic zonal current seem the most appropriate for the Australian situation. In summer the zonal current is

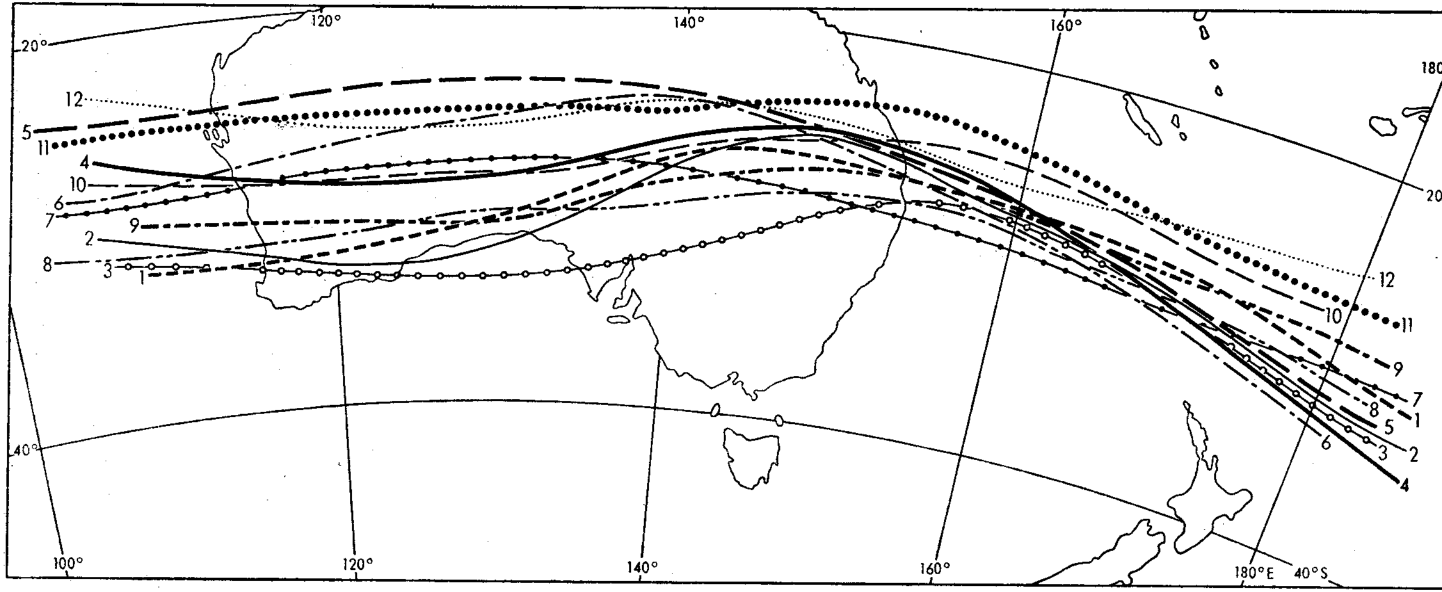


FIGURE 3—MONTHLY MEAN TRACKS OF THE AUSTRALIAN UPPER-TROPOSPHERIC MAXIMUM WESTERLIES

1 = January, 2 = February, 3 = March, 4 = April, 5 = May, 6 = June, 7 = July, 8 = August, 9 = September, 10 = October, 11 = November, 12 = December.

much less intense and the continent acts as a secondary heat source. Pressures higher than the latitudinal average tend to build up in the upper troposphere over the continental heat source. Over the surface layers of the heat 'low' a tendency for mean cyclonic circulation would be expected with a tendency for anticyclonic circulation in the upper troposphere. On either side of the heat source anticyclonic circulation should be maintained at lower levels with cyclonic flow aloft. Since the intensity of the zonal current increases with height, the resulting pattern at upper levels should have a wave-like structure with upper troughs over areas of lower temperatures at the surface and upper ridges over areas where the air is heated from below.

The above model seems fitting for the Australian continent in all seasons except winter when flow is strong and closely zonal. In winter the continent is cooler than the oceans,[27-29] and a mean trough may be expected over the continent. However, the land–sea thermal contrast is relatively less and hence the features of the wave pattern at upper levels do not change essentially from winter to summer (Figure 3).

Conclusion. Although it was hoped to compile new charts of vector mean wind for 40 000 ft, based on 12 years of complete and homogeneous records, this was not found to be practicable. Only 35 stations consistently gave reliable monthly statistics (cf. Phillpot:[4] 21 stations). Notwithstanding this the mean winds at 40 000 ft computed in this study are based on the most homogeneous data and densest data network to date. Unfortunately construction of the mean isotach contours remains subjective and includes a certain amount of smoothing.

Despite these deficiencies, the mean charts do indicate a degree of 'pattern' of the Australian upper-tropospheric maximum westerlies. This is evident both as seasonal (climatological) variation and as deviation from direct zonal flow (Figure 3). The mean trough and ridge features determined are of only small amplitude however, which possibly suggests that Rossby-type perturbations evident on 200-mb synoptic charts tend to have a preference for certain locations, or alternatively they may reflect large-scale thermal influences.

Acknowledgements. The author is grateful to the Director, Commonwealth Bureau of Meteorology, for making available the upper-air data, and to Mr J. C. Langford (Southern Hemisphere Analysis Centre) and Mr A. Muffatti (Extended Range Forecasting), both of the Commonwealth Bureau of Meteorology, Melbourne, for critical discussion of an earlier draft of this paper. Financial assistance was provided by Monash Univeristy.

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RADIATION FOG AND STRATUS FORMATION AND FOG CLEARANCE IN TERMS OF GEOSTROPHIC WIND — SOME APPLICATIONS OF WIND MEASUREMENTS ON A HIGH MAST

By W. E. SAUNDERS

Summary. Wind data from the Belmont mast are used to show the upper limits of geostrophic wind speed above which radiation fog and low stratus are unlikely at Manby. Within the range of wind speed favourable for fog the geostrophic wind direction is shown to be of great importance. With regard to fog clearance due to insolation, it is shown that the stronger geostrophic wind speeds increase the chance of a lifted-fog phase before final clearance and that most commonly this is preceded by vertically thick fog (reported as 'sky obscured').

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Photograph by courtesy of the Bracknell News

PLATE II—HIS ROYAL HIGHNESS SIGNING THE VISITORS' BOOK

PLATE I—HIS ROYAL HIGHNESS THE DUKE OF EDINBURGH IS GREETED BY THE DIRECTOR-GENERAL, DR B. J. MASON, AND THE MINISTER OF STATE FOR DEFENCE, MR IAN GILMOUR, ON ARRIVAL AT THE METEOROLOGICAL OFFICE HEADQUARTERS ON 16 FEBRUARY 1973

PLATE III—HIS ROYAL HIGHNESS DISCUSSES THE FORECAST FOR THE NEXT DAY WITH THE SENIOR FORECASTER (MR R. M. MORRIS — BACK TO CAMERA)

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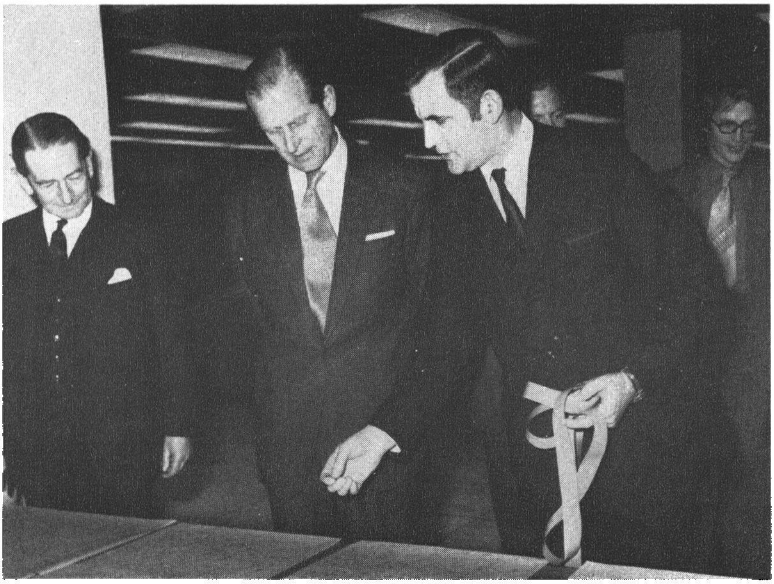

PLATE VII—THE 360/195 COMPUTER LABORATORY: HIS ROYAL HIGHNESS INSPECTING PLOTTED AND LINE-DRAWN CHARTS PRODUCED ON THE CALCOMP 1670 COMPUTER OUTPUT ON MICROFILM PLOTTER

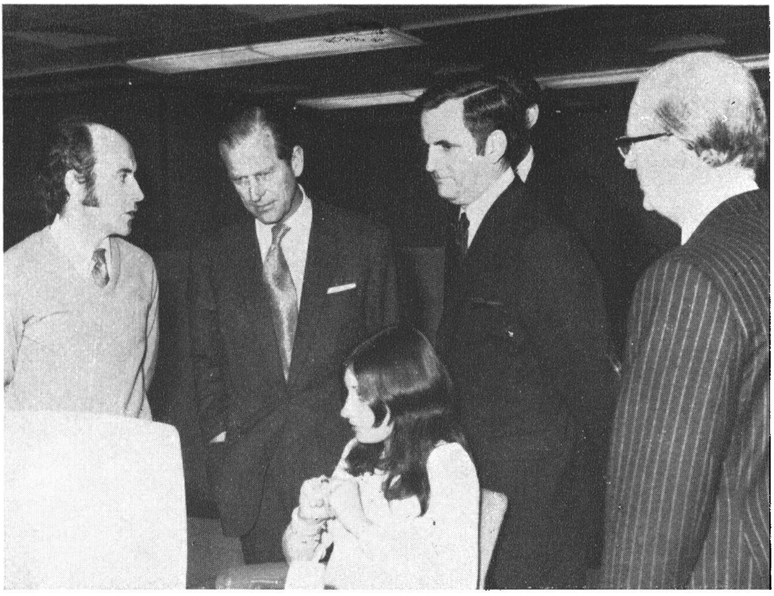

PLATE VIII—THE 360/195 COMPUTER LABORATORY: HIS ROYAL HIGHNESS AT THE TAPE/DISK CATHODE-RAY-TUBE CONSOLE WHERE MESSAGES CONCERNING MAGNETIC TAPE AND DISK REQUIREMENTS ARE DISPLAYED

Fog and stratus formation. It is common experience that during a radiation night wind speed above some limit prevents radiation fog formation but may permit the formation of stratus cloud with base a few hundred feet above ground. Above some higher limiting speed this form of low stratus also becomes unlikely. Little attempt appears to have been made to define these limits, either theoretically or experimentally. This note describes an attempt to derive these wind speed limits on the basis of actual observations.

Since September 1970 the forecast office at Manby, Lincolnshire, has been connected through a display panel (console) to a Munro Recorder, belonging to the Central Electricity Generating Board, at the Belmont mast of the Independent Broadcasting Authority. This is located 11 miles ($\approx$18 km) west of Manby, as shown in Figure 1. The site is 400 ft ($\approx$120 m) above m.s.l. An anemometer at 1275 ft ($\approx$390 m) above ground level has a clear exposure above the top of the mast.

C. A. S. Lowndes has made comparisons between the Munro Recorder readings and those taken at the Manby console. The comparisons showed that, for the 1275-ft wind speed, the mean difference (console minus Munro) was −1 kt, with standard deviation 1 kt. For wind direction, taken in units of 10 degrees, the mean difference was −0·4, standard deviation 0·6. Comparisons have also been made, by Manby forecasters, between the console readings of the 1275-ft wind speed and the geostrophic wind speed measured from the hourly synoptic charts. These have shown that the mean difference (geostrophic wind minus console wind) is generally about 1–3 kt.

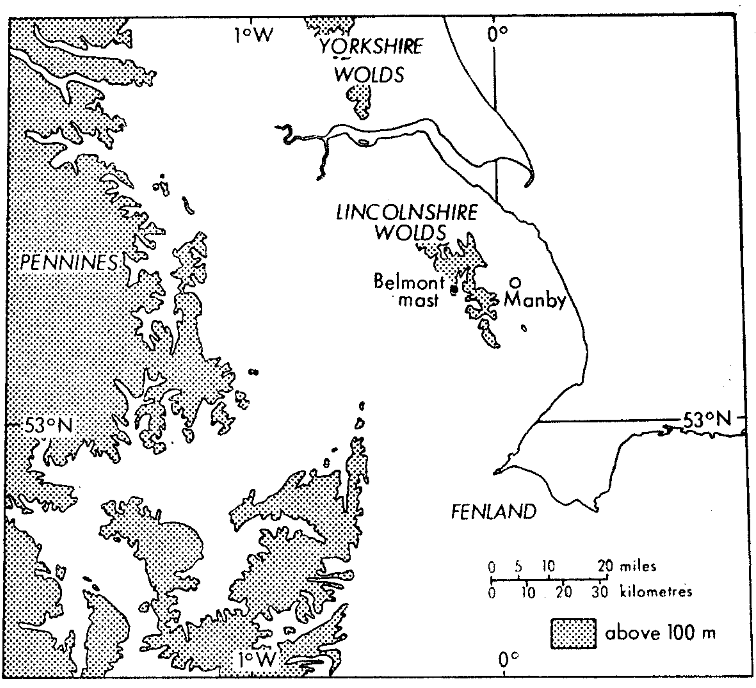

FIGURE 1—MAP ILLUSTRATING THE POSITION OF THE BELMONT MAST IN RELATION TO MANBY

It follows that the Belmont 1275-ft wind readings taken from the Manby console can be used with reasonable confidence as representative of the geostrophic wind. This is probably more true during a radiation night than in the day-time, because of the reduced depth of the friction layer at night. One advantage of having the Belmont winds available is that they are ready to hand on occasions when it is difficult to draw isobars accurately on that part of the chart which covers the Lincolnshire coast (e.g. when the geostrophic direction is nearly parallel with the coastline, coupled with the usual shortage of pressure readings over the North Sea). Another advantage is that the scrutiny of these wind readings taken at frequent intervals gives an indication of trends toward change in the geostrophic wind, perhaps before this is recognized from changes in the barometric tendency. This can be of great assistance in fog or stratus forecasting.

In the work described in this note, Belmont 1275-ft winds read from the Manby console were used. The wind speeds as read were corrected to accord with a calibration carried out by the Central Electricity Research Laboratory for the period up to 12 October 1971.

Manby observations for all radiation nights when Belmont data were available in the period from September 1970 to April 1972 were examined. The Belmont 1275-ft readings at the time of fog formation were extracted for occasions when radiation fog formed — visibility less than 1100 yd ($\approx$1000 m). Similarly, if low stratus cloud formed instead of fog the winds at the time of stratus formation were found. When neither fog nor stratus formed, the time of maximum relative humidity in the screen was noted and the wind at this time was extracted. The investigation was confined to radiation nights, and occasions of fog or stratus advection from the North Sea were omitted.

The results of this investigation are shown in Figure 2. When fog or stratus formed, the appropriate symbol has been entered against the geostrophic wind direction and speed at the time of formation. When there was no fog or stratus the small circular symbol has been entered against the geostrophic wind direction and speed at the time of maximum relative humidity. The height of the base of stratus and the value of the maximum relative humidity are shown for each occasion.

Examination of Figure 2 leads to the following conclusions :

(a) The upper limit of geostrophic wind speed for radiation fog formation is about 21 kt, but within the range 18–21 kt there is an increasing probability of stratus cloud forming at a few hundred feet instead of fog forming at the surface.

(b) There is no reliable lower geostrophic wind speed limit for fog.

(c) Geostrophic wind speed at the time of fog formation does not provide any guidance on whether or not the sky will become obscured during fog.

(d) Stratus at a few hundred feet is liable to form with geostrophic wind speeds mainly within the range 18–29 kt. At wind speeds above 29 kt there is generally a sharp fall in the screen-level maximum relative humidity reached, but note that in this sample all occasions of wind speed above 29 kt lie in the sector 210°–340°: a zone associated with lee effects. However, even within the wind speed limits which favour stratus formation this cloud forms on only a small proportion of the occasions.

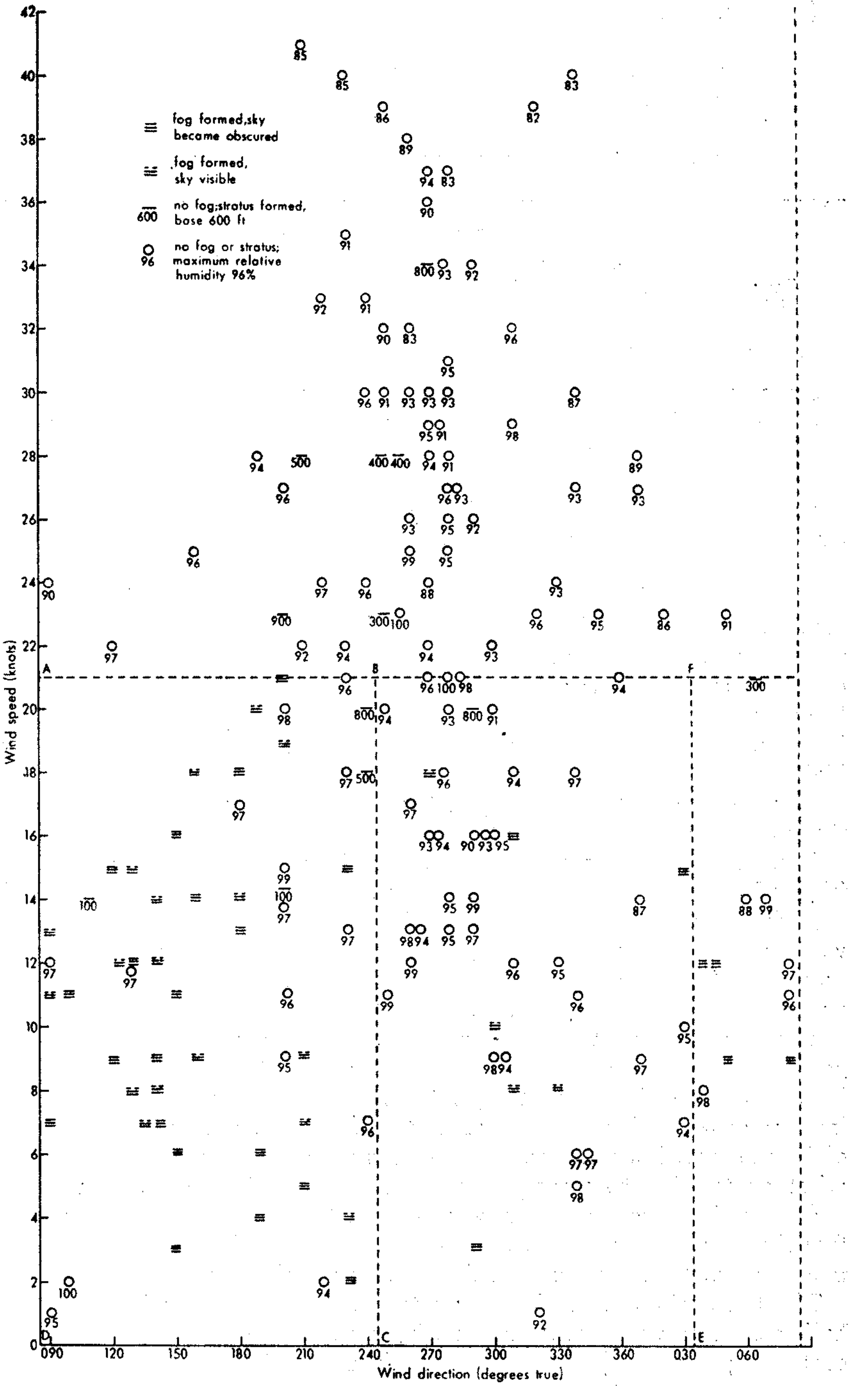

FIGURE 2—THE INCIDENCE OF FOG OR LOW STRATUS ON RADIATION NIGHTS AT MANBY IN TERMS OF WINDS ON A MAST 1275 FEET ABOVE THE GROUND AT BELMONT

(e) Geostrophic wind direction is clearly of importance. Scrutiny of Figure 2 suggests that below the critical wind speed limit of 21 kt the diagram may be divided into three zones, where AD, BC and EF have been placed to accord with changes in the fog or stratus frequencies. The differences between these zones are tabulated in Table I. The boundary BC is clearly of considerable significance.

TABLE I—FREQUENCIES OF FOG AND STRATUS WITH GEOSTROPHIC WINDS FROM SELECTED DIRECTIONS

Zone	No. of occasions	No. of occasions with : fog	stratus	Percentage of occasions with : fog and/or stratus
ABCD	56	37	4	73·2
BFEC	45	7	1	17·8
FADE	10	4	1	50·0

Some comments on the distribution of fog occasions follow :

Zone ABCD (*directions 085°–245°, through 180°*). The incidence of fog reaches a maximum with wind direction 140°–170°. The sample is small, but if confirmed over a longer period it implies that fog always forms on radiation nights when the geostrophic wind is in this sector. It is the situation in which air has moved from the Wash and the fen areas of south-east Lincolnshire towards Manby.

Examination of the 15 occasions when no fog or stratus formed showed that 12 were within the summer half-year, a season when the fog-point is sometimes not reached owing to the short length of night. On all 3 winter occasions saturation was not reached and the minimum temperature was below freezing, in the range −1 to −4°C, i.e. the fog-point was well below freezing. It follows that in the winter half-year the fog probability is very high indeed on a radiation night when the geostrophic wind falls within ABCD.

Zone BFEC (*directions 245°–035°, through 360°*). The outstanding feature is the low incidence of fog and/or stratus compared with that of zone ABCD.

In a large proportion of the occasions with no fog, the Manby surface wind followed a definite pattern, with the speed increasing towards the end of the night from some lower value to within the range 6–12 kt, and with the direction varying between 240° and 280°. The increased wind speeds referred to were around 50–80 per cent of the Belmont 1275-ft speeds at the same time. It was also found that as the geostrophic wind direction veers through north this nocturnal surface westerly wind at Manby still occurs, and does so until the geostrophic wind direction reaches at least 030°. This supports the placing of boundary EF on Figure 2 at 035°. There seems no doubt that the nocturnal increase of wind often prevents saturation being reached and is a main cause of the relatively low incidence of fog in this zone. It is possible that a katabatic effect is intensified by a component of geostrophic wind in the same direction.

Another factor which may have some effect in reducing the fog incidence is that the air will in its recent history have crossed high ground, i.e. the Welsh mountains or the Pennines, and then the Lincolnshire or the Yorkshire Wolds.

The 8 occasions when fog or stratus formed were all within the winter half-year. One was unusual for Manby, smoke fog (relative humidity 90 per cent at fog formation) forming in mid afternoon. On this occasion saturation was not reached until the temperature had fallen to −0·2°C. The Belmont 1275-ft wind speed was only 3 kt. On the other occasions the fog-point was always above 2·5°C, and the Belmont wind speed was 8 kt or above. Of the occasions with no fog or stratus, 19 were in winter, and on 7 of these the minimum temperature was above 2·5°C.

The main conclusions reached tentatively from this rather small sample, and subject to amendment as more occasions are recorded, are :

In summer : fog and stratus are unlikely.

In winter : the overall chance of fog and/or stratus is about 1 in 3, but is higher than this if the fog-point is above 2°C. If the fog-point is below 2°C the fog probability appears to be very low unless the geostrophic wind is unusually light (it is possible that with very light geostrophic winds the differences between the zones become negligible because of the general stagnation of the air mass; but the number of occasions is as yet insufficient to show whether this is true and to indicate the value of the lower limit).

Zone FADE (*directions 035°–085°*). Fog or stratus forms on half of the occasions. There were no significant seasonal variations. Probably the tendency for air with high fog-point to move in off the North Sea is in some cases offset by the advection of relatively warm air in this sector.

Fog and stratus clearance. In the clearance of radiation fog through insolation and turbulence there is frequently a lifted-fog phase before final clearance. To investigate the relation of this to geostrophic wind speed the Belmont 1275-ft winds were extracted for the times of Manby fog clearance. The only item observed as routine which gives some indication of the vertical depth of fog is the state of the sky, i.e. whether or not it is reported as obscured. The author has shown previously,* from Cardington data, that a report of 'sky obscured' probably corresponds to a fog depth of 300 ft or more.

In Figure 3 symbols have been entered showing the geostrophic wind at the time of Manby fog clearance, whether or not the sky was obscured before clearance and whether or not there was a lifted-fog phase, and the cloud base when the latter occurred. Occasions when small amounts of lifted fog, 1/8–3/8, were reported temporarily during the clearance were disregarded.

From Figure 3 it can be seen that :

(a) The likelihood of a lifted-fog phase increases as the geostrophic wind speed increases, as shown in Table II.

(b) A lifted-fog phase is nearly always preceded by a 'sky obscured' fog. However, a 'sky obscured' fog is not necessarily an indication that there will be a lifted-fog phase, especially if the geostrophic wind does not exceed 10 kt.

(c) The geostrophic wind speed gives no guidance on the likely cloud base when there is a lifted-fog phase.

TABLE II—RELATIONSHIP BETWEEN THE INCIDENCE OF A LIFTED-FOG PHASE AND THE GEOSTROPHIC WIND SPEED

Geostrophic wind speed	Fog clearance	
	With lifted fog	Without lifted fog
kt	*No. of occasions*	
0–10	2	17
over 10	16	9

* SAUNDERS, W. E.; Daytime fog clearance at Exeter Airport. *Met Mag, London*, **89**, 1960, pp. 261–263.

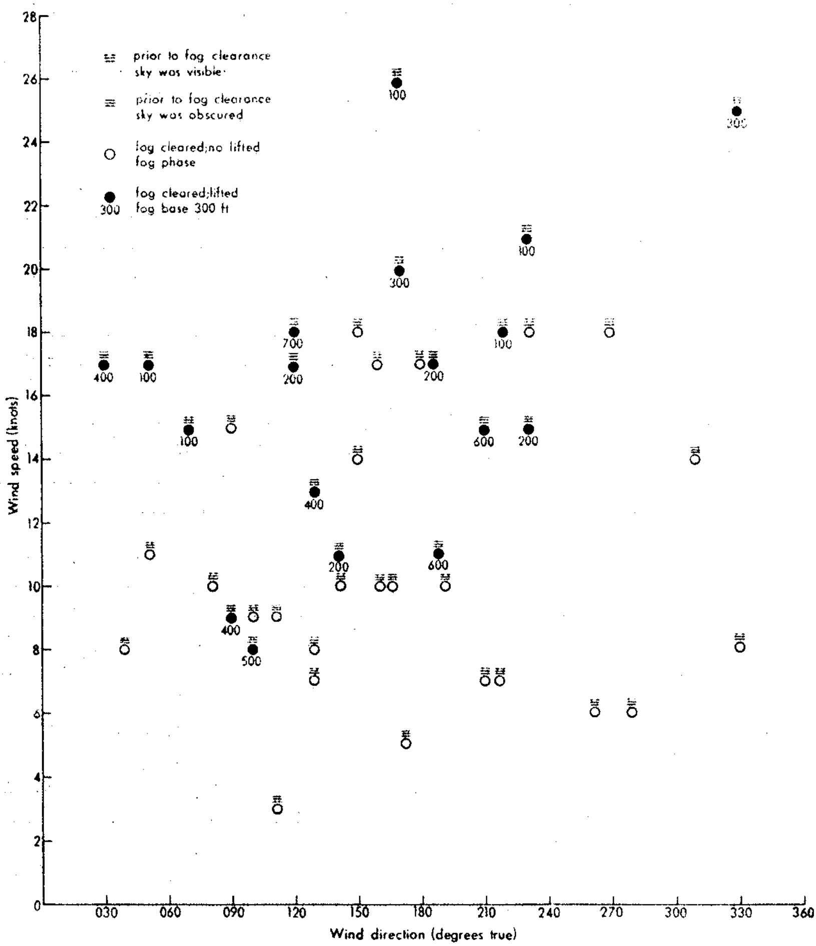

FIGURE 3—RADIATION FOG CLEARANCE AT MANBY IN TERMS OF WINDS ON A MAST 1275 FEET ABOVE THE GROUND AT BELMONT

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AN INVESTIGATION INTO A RELATIONSHIP BETWEEN UPPER-AIR RELATIVE HUMIDITY AND CLOUD COVER

By J. N. RICKETTS

Summary. An investigation was conducted to establish what relationships exist between cloud cover and relative humidity. It was instigated primarily to find a method of determining cloud cover from relative-humidity forecasts made by means of the 10-level model, in connection with the absorption of radiation by cloud and for forecasting cloud distributions. Relative humidity and total cloud cover were first compared, each being estimated over grid-square areas. A roughly linear association was apparent from this. Then the two variables for the individual stations concerned were compared so as to obtain more-definite relationships which took account of cloud at different levels. Two linear relationships, one each for low and medium cloud, were obtained.

Introduction. The filtering effect of the atmosphere upon radiation is increased by the presence of cloud. Radiation is absorbed or reflected by cloud according to its type and thickness, and there are great differences between the effects of low, medium and high cloud. Low cloud types exhibit the greatest variation in effect upon radiation, ranging from the high degree of absorption by thick stratocumulus to the high reflectivity of large cumulus. Medium and high clouds reduce the amount of radiation reaching and leaving the earth in proportion to their amount and thickness. An important factor in cloud formation is the relative humidity of the air, and this variable can be forecast numerically.

Designed in the context of the 10-level numerical model, the present work was intended to improve on the relationships given by Gadd and Keers.[1] They had compared 12-hour forecasts of relative humidity at the grid points of the 48 × 32-point rectangular (fine mesh) areas with the observed cloud distribution taken from synoptic charts. Earlier work by Smagorinsky[2] was based on comparisons between observed relative humidities and cloud-cover values. Gadd and Keers's relationships were similar to Smagorinsky's for medium and high cloud but rather different for low cloud. Both papers defined low cloud as having its base in the 1000–800-mb range but they defined the ranges for medium and high cloud slightly differently.

Initially, in the present investigation, smoothed values of relative humidity and total cloud cover over grid-square areas were compared, but there could be no attempt to discriminate between cloud levels on this basis. Total cloud cover and the highest relative humidity values over 100-mb layers (1000–900 mb, 900–800 mb, etc.) were compared, over grid squares, on the assumption that the predominant cloud would be in the moistest layer.

In a further analysis, low, medium and high cloud were compared separately with relative humidity in the three ranges 1000–800 mb, 800–500 mb and 500–300 mb respectively. Relative humidities were averaged vertically for 100-mb layers from 1000 to 300 mb. The amount of cloud in each of the three ranges was compared:

(a) with the highest average relative humidity of the 100-mb layers in the range (type A comparison), and

(b) with the mean relative humidity over the entire range (type B comparison).

Such an analysis could not be made over grid squares, so reported cloud amount was compared with observations of relative humidity taken at approximately the same time and place. The relationship between cloud type and mean relative humidities was briefly considered but a lack of time prevented a detailed investigation.

Collection of data. Periods of about a fortnight which were considered representative of each of the four seasons were chosen for the investigation. These were: 16–31 January, 16–30 April, 16–31 July, and 16–31 October 1969.

Relative humidity and cloud data for radiosonde stations in the United Kingdom only were used — Lerwick, Stornoway, Shanwell, Long Kesh, Aughton, Hemsby, Crawley and Camborne, with the addition of the supplementary stations: Aberporth, Shoeburyness, Larkhill and Eskmeals. Mean relative humidities over 100-mb layers were assessed by eye from Väisälä diagrams, which were obtained from each of the above stations.

The amount of data which could be used was limited because radiosonde observations, in general, are taken only at noon and midnight. However, since comparisons were being made with surface observations for standard times, care had to be taken to check the time of ascent. There were occasional late starts, and the supplementary stations often made soundings at other times. Only ascents made within two hours either side of 00 GMT or 12 GMT were considered.

Grid-square analysis. This need be mentioned only briefly since the final results came from the later work. Estimates of relative humidity and the corresponding cloud cover were made over the 100-km grid squares of the 10-level model which lay over land in the U.K. The estimates were divided into ranges of relative humidity and cloud cover, so any association found between them by this method would be fairly rough. An approximately linear relationship was found which varied inconsistently with time of year. There did appear, however, to be a consistent variation with time of day, although this was later found to be not significant. The approximate relationship did show that clear skies can be associated with much higher relative humidities and that the change from clear to cloudy conditions occurs in a narrower range of relative humidity values than either Smagorinsky or Gadd and Keers had indicated.

Direct analysis. So far, no discrimination between low, medium and high cloud had been attempted, but it was clearly necessary. As was mentioned in the Introduction, this could only be done in terms of individual stations and in the first instance three were used : Crawley, Shanwell and Long Kesh. Cloud reports were extracted from *Daily Weather Reports* for nearby surface stations: Gatwick, Leuchars and Aldergrove respectively. The upper-air stations were chosen for their position and because the nearby surface stations are airfields, from which good cloud reports might be expected. Each of the type A and type B comparisons, as defined in the Introduction, was subdivided to consider low and medium cloud separately (Table I). No useful comparisons could be made for high cloud since the data were inadequate.

It is obvious from Tables I (a) and (b) that occurrences of extensive cloud (7–8 oktas) become proportionately greater with increasing relative humidity, and the form of the distribution in Table I (a) and (b) does indicate an approximately linear relationship.

Unfortunately, the medium cloud distributions (Table I (c) and (d)) are unavoidably biased. Values of medium cloud amount are rarely reported when low cloud cover is greater than 6 oktas, and when low cloud is even moderately extensive they are more in the form of estimates. Tables I (c) and (d) show a disproportionate number of reports of small amounts of medium cloud and very few reports of moderate amounts. Clearly, more data are necessary before the regression lines corresponding to the distributions can be properly defined.

Humidity data from the radiosonde stations at Lerwick, Stornoway, Shanwell, Long Kesh, Hemsby, Aberporth and Crawley were assembled with cloud reports from the nearby surface stations, Gorleston being taken as the surface station for Hemsby. Reports of medium cloud were used only when there were 3 oktas or less of low cloud, except when medium cloud amount was greater than 6 oktas. The data were not grouped and scatter diagrams were compiled. Figures 1 and 2 for 16–31 July 1969 are typical of the diagrams for low cloud. Figures 3 and 4 give the complete distributions for medium cloud. It is evident from these diagrams that the type A analyses are more compact than the type B.

TABLE I—RESULTS OF COMPARISONS OF RELATIVE HUMIDITY AND CLOUD COVER FOR CRAWLEY, SHANWELL AND LONG KESH

(a) Low cloud — type A analysis

Cloud cover	Relative humidity (per cent)								
	< 20	20–29	30–39	40–49	50–59	60–69	70–79	80–89	≥90
oktas	*number of occasions*								
7, 8						4	31	103	22
5, 6							24	30	3
3, 4					1	4	24	16	1
≤2					8	28	62	15	2

(b) Low cloud — type B analysis

Cloud cover	Relative humidity (per cent)								
	< 20	20–29	30–39	40–49	50–59	60–69	70–79	80–89	≥90
oktas	*number of occasions*								
7, 8				1	1	15	52	73	9
5, 6					2	10	31	19	2
3, 4					2	10	27	9	1
≤2			1	6	26	32	40	9	1

(c) Medium cloud — type A analysis

Cloud cover	Relative humidity (per cent)								
	< 20	20–29	30–39	40–49	50–59	60–69	70–79	80–89	≥90
oktas	*number of occasions*								
7, 8					2	5	15	10	1
5, 6			2	4		2	5	3	
3, 4					2	2	2		1
≤2	13	12	20	26	31	27	21	2	1

(d) Medium cloud — type B analysis

Cloud cover	Relative humidity (per cent)								
	< 20	20–29	30–39	40–49	50–59	60–69	70–79	80–89	≥90
oktas	*number of occasions*								
7, 8			2	1	3	11	15	3	
5, 6		3	1	3	2	1	5		
3, 4			1		3	1	1	1	
≤2	17	29	34	36	26	10	5		

Of the statistics presented in Table II, only the humidity variances of the low cloud type A and B analyses were significantly different at the 5 per cent level. This provided statistical support for considering the type A analyses to be less scattered than those of type B. The bias in the medium cloud distributions made any statistical examination of them of little value. Figures 3 and 4 show that a disproportionately large number of observations of humidity were associated with zero cloud cover, and this gave regression lines for medium cloud which predicted less than 8 oktas cloud cover at 100 per cent relative humidity, which is obviously physically unreasonable.

In order to reduce this weighting effect, the type A distributions of low and medium cloud were analysed using means of cloud cover calculated over 10 per cent ranges of relative humidity. It was immediately noticeable

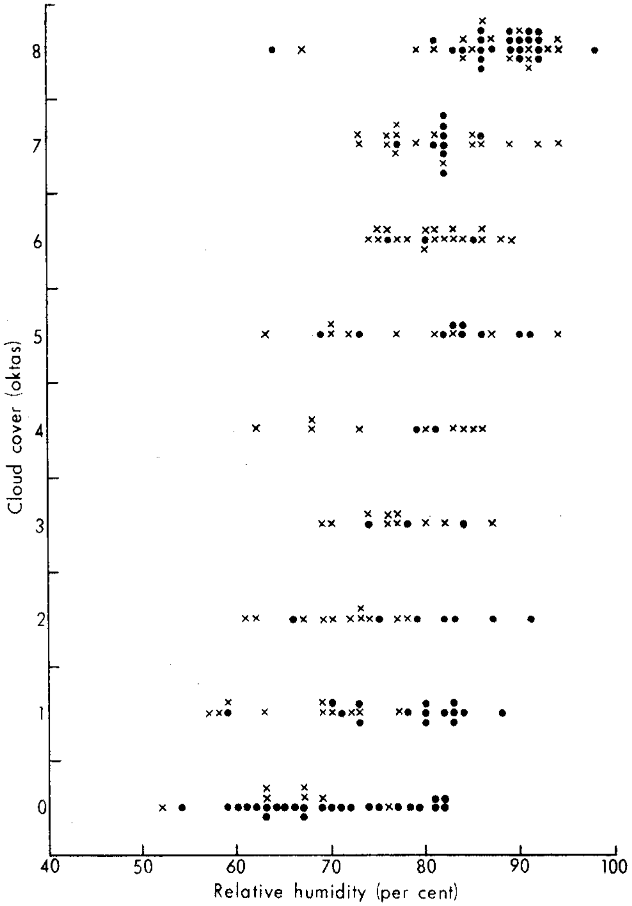

FIGURE 1—DISTRIBUTION OF LOW CLOUD (TYPE A ANALYSIS) AT 00 AND 12 GMT: SUMMER, 1969

● Night-time observation × Day-time observation

TABLE II—CORRELATION COEFFICIENTS AND VARIANCES FOR THE TYPE A AND B ANALYSES OF LOW AND MEDIUM CLOUD

	Type of analysis	No. of observations	Correlation coefficient	Variance of cloud cover	Variance of humidity
Low cloud	A	788	0·57	6·10	45.83
Low cloud	B	788	0·54	6·45	76·39
Medium cloud	A	293	0·59	6·66	253·44
Medium cloud	B	293	0·63	6·15	224·70
Medium cloud but ignoring points below 50 per cent relative humidity	A	192	0·59	7·24	76·74
Medium cloud but ignoring points below 50 per cent relative humidity	B	128	0·60	7·08	59·29

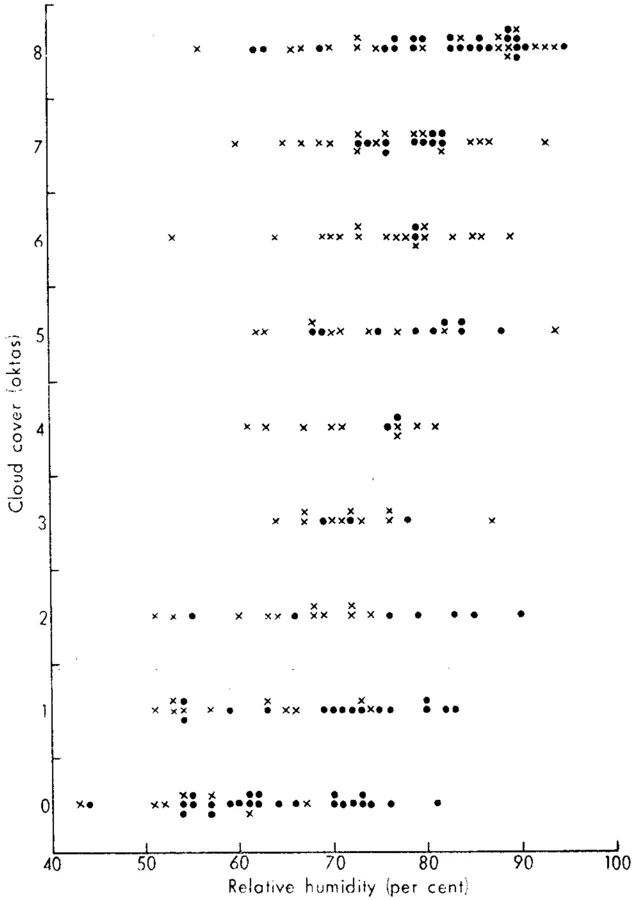

FIGURE 2—DISTRIBUTION OF LOW CLOUD (TYPE B ANALYSIS) AT 00 AND 12 GMT: SUMMER, 1969

● Night-time observation × Day-time observation

from the curves shown in Figure 5 that points below 50 per cent relative humidity are distributed differently from those above 50 per cent, particularly for medium cloud. Since, on the average, relative humidity values up to 50 per cent are associated with less than 2 oktas cloud amount, which would have little effect on radiation, this part of the distribution can be ignored. The regression lines for low and medium cloud were re-calculated on this basis and are also shown in Figure 5.

Application of results. With the exception of Crawley and Larkhill, the U.K. radiosonde stations are situated on or near coasts. Lerwick, in particular, is representative of a purely maritime station whereas airstreams affecting other stations could be either maritime or continental in character.

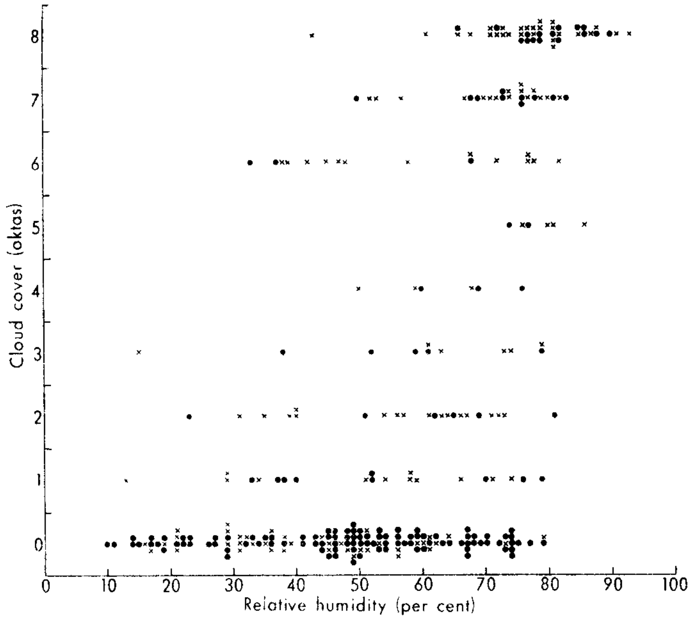

FIGURE 3—DISTRIBUTION OF MEDIUM CLOUD (TYPE A ANALYSIS) AT 00 AND 12 GMT: ALL SEASONS, 1969

● Night-time observation × Day-time observation

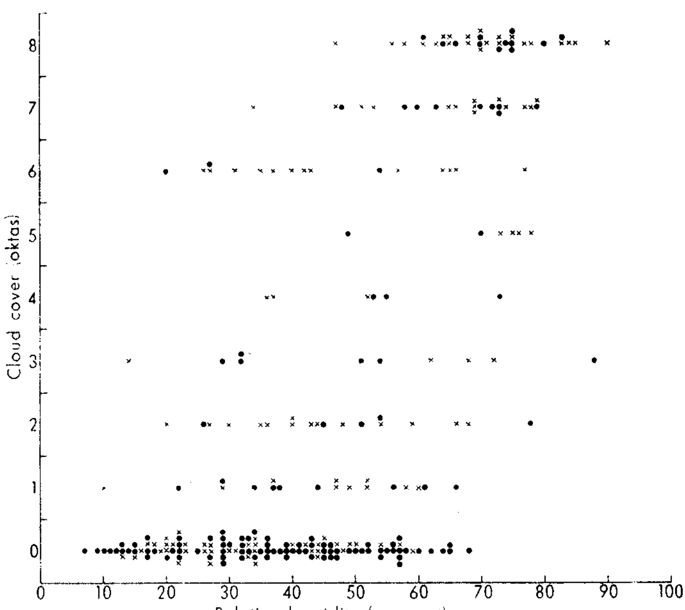

FIGURE 4—DISTRIBUTION OF MEDIUM CLOUD (TYPE B ANALYSIS) AT 00 AND 12 GMT: ALL SEASONS, 1969

● Night-time observation × Day-time observation

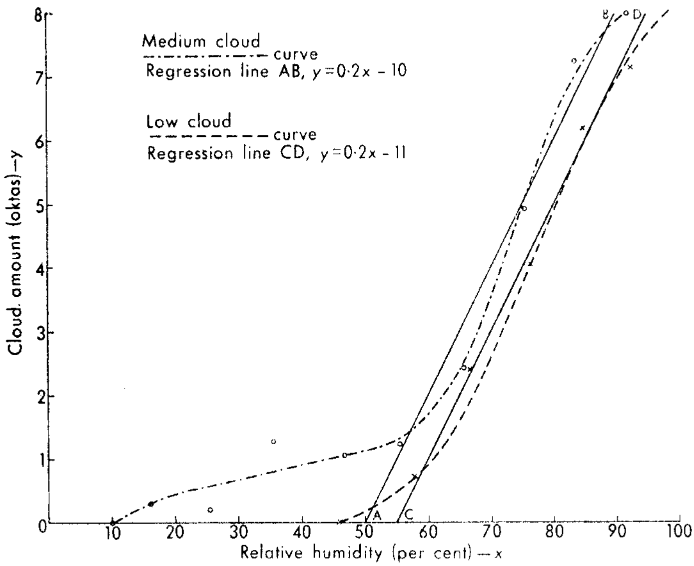

FIGURE 5—DISTRIBUTION OF LOW AND MEDIUM CLOUD (TYPE A ANALYSES) BASED ON MEANS OVER 10 PER CENT RANGES OF RELATIVE HUMIDITY

Included are the regression lines calculated after all points with relative humidity below 50 per cent were ignored.

However, there was no evidence to suggest any significant difference in distribution between one station and another. Also, the results for an area with much convective activity, such as the tropics, may be expected to be different from those for the U.K., where stratiform clouds tend to predominate. Any such difference should have been apparent between the distributions for each season, summer being a more convective time of year than winter. But seasonal differences were inconsistent, showing that there was no single predominant factor.

Conclusions. During the course of this work it became evident that any relationship between relative humidity and cloud cover would be rather indefinite. Even if humidity is assumed to be the only factor in cloud formation, no account was taken of cloud thickness, and type was defined only by the terms low, medium and high.

The relationship between medium cloud cover and relative humidity is approximately linear; that for low cloud is more definitely linear. Therefore, it is reasonable to estimate low and medium cloud cover from forecasts of the highest average relative humidity of the 100-mb layers in the two ranges 1000–800 and 800–500 mb.

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2. SMAGORINSKY, J.; On the dynamical prediction of large-scale condensation by numerical methods. *Geophys Monogr, Washington*. 1960, No. 5, pp. 71–78.

REVIEW

Review of forecast verification techniques, WMO Technical Note No. 120, by E. M. Dobryshman. 275 mm × 213 mm, pp. x + 51, Secretariat of the World Meteorological Organization, Geneva, Switzerland, 1972. Price: Sw. Fr. 10.

The meteorologist may well think that his task is completed when a forecast has been issued, perhaps pausing to pat himself on the back when it turns out to be substantially correct or to consider the possible causes of failure if things go wrong. But there is a need for a more systematic assessment of many types of forecast in order to show, for example, whether the forecasts are providing useful guidance or whether a change in forecasting techniques brings about any improvement in accuracy, and most meteorological services carry out some kind of evaluation of at least some types of forecast. The aim of Professor Dobryshman's report is to make a systematic classification of the methods of forecast verification in use in various countries and to lay down guide-lines for future work in this field.

The review starts off with an excellent brief outline of the problem, with examples of the difficulties encountered. The second chapter gives an account of the types of verification methods in use, with a summary of their common and their desirable features. In just a few places in this chapter there are mistakes which are, however, readily spotted, while here and there the text is a little obscure. The third chapter, entitled 'Consideration of various types of forecast and possible methods of verification', is the one to which the reader will look for guidance on establishing a scheme for the verification of a particular type of forecast. The treatment is, however, rather disappointing, mainly because it does not really get down to fundamentals but also because there are one or two places where it is misleading. There are two, usually distinct, aspects to the assessment of a set of forecasts, viz :

(a) to check the accuracy of the forecasts themselves, i.e. verification or empirical evaluation; and

(b) to assess their usefulness to the customer; this is not strictly verification but may be termed 'operational evaluation'.

Although the author does talk about the two types of assessment he does not draw a sufficient distinction between them, and the reader is left with the impression that for certain types of forecast only the first aspect matters while for others only the second is important. A good deal could usefully be said about the purposes for which forecasts are assessed or evaluated, but this area still needs further exploration.

Two less general but still important points in this chapter require comment. Equation (5) on page 16 forms an index to indicate the 'degree of success' of a set of forecasts by averaging three quantities which are calculated in very different ways, and it is difficult to see how variations of the index can be related to the properties of the forecasts. The second point arises in the discussion of 'alternative' (black/white or yes/no) forecasts: the author suggests an index, Q, which appears to be new, but a few lines of simple algebra suffice to show that it is in fact identical with that put forward in 1884 by Peirce and criticized on the grounds that it unduly weights prefigurance (the ability of a set of forecasts to predict successfully the occurrence of a given state, regardless of the number of forecasts of that state which are not fulfilled).

A short chapter on 'Conclusions and recommendations' comes next, followed by two appendices giving detailed verification schemes for short-range weather forecasts and long-range forecasts. The schemes appear to be based on the needs and established practice of the author's home country and may not be as useful elsewhere. It would have been better to lay down the fundamental principles more thoroughly in Chapter III and leave the individual services or units to work out the details.

J. CRABTREE

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LETTER TO THE EDITOR

SI units in the Meteorological Office

Mr Lumb,* in his article discussing the use of the International System of Units within the Meteorological Office states that 'A major problem arises with series of data over a long period of years including readings in different units . . . but with computer help there is little difficulty in using (the new unit) as the common unit. There may be other reasons for treating the series as two separate parts . . .'.

The purpose of this letter is to point out that in practice difficulties can arise when the original readings have been recorded to the nearest integer on the old scale and integers on that scale do not fall uniformly into unit bands of the new scale. It is then possible for uniform steps on the new scale to correspond to non-uniform steps on the effective scale of the converted data, with effects on the apparent frequency distribution. When a frequency analysis is carried out on such data alone the effect is usually obvious, but where the analysis is of mixed old and new data, the effect is sometimes less easy to see and can give rise to erroneous deductions.

As an example, temperature data originally recorded in degrees Fahrenheit rounded to the nearest degree for climatological purposes, on being converted to Celsius are distributed in such a way that two integral degree-Fahrenheit numbers fall into each unit degree-Celsius interval for four successive degrees Celsius, but only one such number falls into every fifth unit degree-Celsius interval. In consequence although intervals of 1 degC are apparently uniform in width, in fact every fifth interval is only half the width of the intervening four in terms of the effective unit of the data sample under analysis, and for such intervals a frequency count only about half that expected appears in the apparent analysis.

For analysis of mixed data originally recorded partly in degrees Fahrenheit and partly in degrees Celsius the depression of every fifth apparent frequency depends upon the relative numbers of old and new data encountered in the class and is not necessarily uniform.

* LUMB, F. E.; SI units in the Meteorological Office. *Met Mag, London*, **101**, 1972, pp. 366–368.

The problem is not of course confined to temperature. One way to overcome the difficulties is to carry out analyses in parts, using the units in which the data were originally recorded for each part and then expressing the results for each part in the new units.

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Berkshire

C. L. HAWSON

OBITUARIES

It is with regret that we record the death on 6 January 1973, of Mr D. Girdwood, Higher Scientific Officer, Aberdeen Airport, and the death on 20 January 1973, of Mr D. R. Hoskin, Higher Scientific Officer, Met O 12.

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