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THE CLIMATOLOGY OF NOCTILUCENT CLOUDS ACCORDING TO OBSERVATIONS MADE FROM NORTH AMERICA DURING 1964–66

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Summary. The organization of a large network of noctilucent cloud observing stations in North America is described, and the observations made by these stations during 1964–66 are analysed. The results show that: (i) 95 per cent of the sightings were made within the solar depression angle range of 5·4° – 14·7°, (ii) the number of displays per year was fairly constant at 53±4, (iii) the earliest and latest displays occurred on 1 April and 8 September respectively, (iv) the seasonal frequency of occurrence of the clouds is latitude-dependent with the peak of activity occurring progressively later at higher latitudes, but at all latitudes the peak of activity occurs well after the summer solstice, (v) 92 per cent of the displays occurred during the months of June, July and August, (vi) 82 per cent of the displays occurred after the summer solstice, (vii) no noctilucent clouds were seen in the winter, (viii) displays occurring after the solstice were generally brighter and more extensive than those occurring before the solstice, (ix) the clouds were usually first seen before midnight but were brightest and most extensive after midnight, (x) noctilucent clouds were observed from latitudes as low as 45·5°N, (xi) the clouds occasionally extended over areas of millions of square kilometres and were seen on the same night, but not at the same time, by many observers in North America, Europe, and the U.S.S.R., (xii) these clouds are generally quite persistent and last for periods up to and greater than 5 hours, but individual parts often form and decay within a few tens of minutes.

Introduction. Noctilucent clouds (NLC) are formed at an altitude of about 82 km and are observed predominantly during summer months from latitudes polewards of 45°. Because these clouds are so tenuous, they cannot be seen during the day and are only observable during twilight when the sun is well below the horizon.

The first recorded observation of NLC, recognizing that it was an unusual phenomenon, was made by Backhouse[1] at Kissingen, Germany, on 8 June 1885. Many other observations of them were made from western Europe and the U.S.S.R. about that time and in subsequent years, but it was not until 1933 that they were detected from North America (Vestine[2]). Reported sightings of these clouds from North America remained scarce until 1962 when a systematic observing programme was begun at the Geophysical Institute in College, Alaska (Fogle[3]). With the co-operation of the U.S. Weather Bureau and the Meteorological Service of Canada, this observing

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programme was greatly expanded during 1962–64 to include approximately 100 stations in Alaska and Canada (Figure 1). Several of the meteorological stations in Greenland and Iceland and the crews of some of the commercial aircraft flying in high latitudes during twilight also participated in this programme. A considerable increase in NLC reports resulted from the systematic watch kept by this network of stations during the International Years of the Quiet Sun (IQSY), 1964 and 1965, and the post-IQSY year of 1966. This paper is a study of these observations.

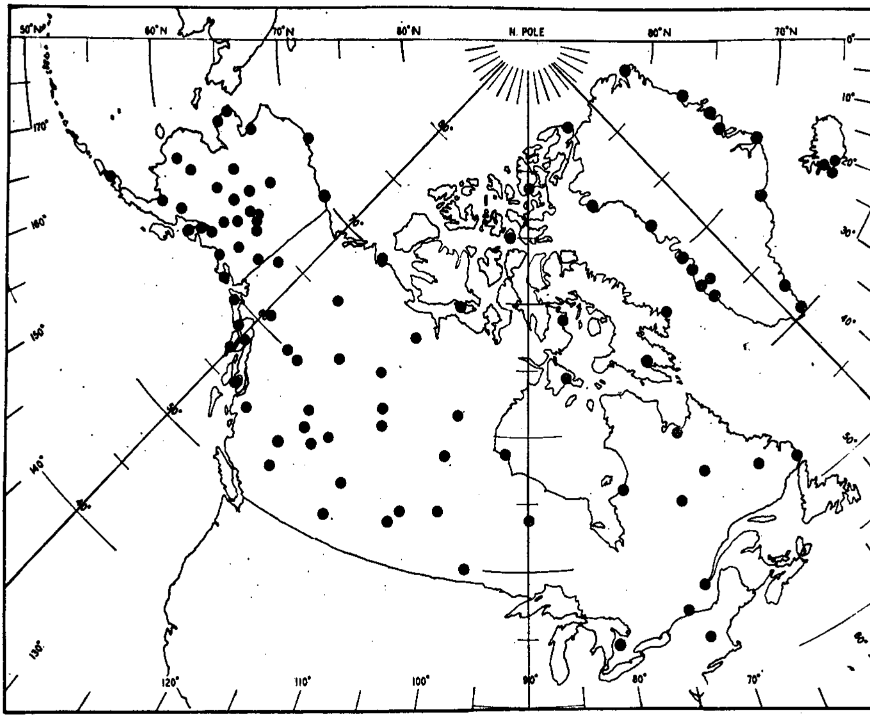

FIGURE 1—NETWORK OF NOCTILUCENT CLOUD OBSERVING STATIONS IN ALASKA, CANADA, GREENLAND AND ICELAND

The observations. During the period March to October, personnel at the network stations made hourly observations for NLC during the twilight periods when these clouds could be seen if present. These observations were carried out according to procedures set forth in the observation manual (Fogle and Gotaas[4]) sent to all stations. When NLC were sighted at a station, additional observations at 15-minute intervals were generally made. A daily log of the observations, containing such information as the presence or absence of NLC and the degree of tropospheric cloud cover, was kept at each station. When NLC were sighted, information on the angular extent, direction, brightness and forms of the display also were recorded. These records were sent to the data centre at the Geophysical Institute in College, Alaska, where they were transcribed to punch cards for computer analysis. In order to eliminate erroneous, unlikely, or uncertain reports of NLC, a validity test was formulated and applied to all observations (Fogle[5]). According to this test, reports were rejected if: (i) the date, time, and place of observation were not specified and no details of the observed clouds were given, (ii) rapid changes in the angular extent of the display and/or colours and forms characteristic of the aurora were reported, (iii) the sun was either above the horizon or more than 16° below the horizon at the time that NLC were reported, (iv) the sun was between 0° and 6° below the horizon for the entire period that a station reported NLC on a particular night and other nearby stations were clear and did not report NLC.

A summary of the results of the reliable NLC observations reported from North America during the years 1964–66 is given in Tables I and II (see Fogle[5] for a comprehensive review and listing of these observations). During this three-year period, (i) 160 displays (or nights of NLC) were reported, (ii) the number of NLC displays per year remained fairly constant at 53 ± 4, (iii) most (79 per cent) of the displays were first seen before midnight by at least one station, (iv) the number of station nights per display (i.e. the number of stations reporting each display) varied from 1 to 25, and the average number of stations reporting each display was about 5, (v) the total number of NLC station nights averaged 260 ± 30 per year and totalled 775 for the three years, (vi) 22 per cent of the NLC station nights were reported only during the evening, 44 per cent only during the morning, and 34 per cent during both evening and morning; 56 per cent of them were first seen before midnight, (vii) the earliest and latest displays observed were on 1 April and 8 September respectively, (viii) the peak of NLC activity occurred around 20 July during each of the three years, (ix) the lowest and highest latitudes of NLC reports were 45·5°N and 71·3°N respectively, (x) the average length of time that NLC were observed at each station was 1·6 hours, and the longest period of time that NLC were continuously observed at one station was 5 hours.

TABLE I—SUMMARY OF NORTH AMERICAN NLC DATA FOR 1964–66

	Year			Sum	Average
	1964	1965	1966		
No. of observing stations	90	105	97	—	97
No. of displays (N_{NLC})	57	50	53	160	53
N_{NLC} first seen before midnight	44	40	41	125	42
Average no. of stations reporting each display	4·5	5·8	4·4	—	4·9
No. of NLC station nights (N_{SN})	254	290	231	775	258
N_{SN} first seen before midnight	132	159	131	422	141
Earliest display	26 Apr.	1 Apr.	5 May	—	—
Latest display	30 Aug.	30 Aug.	8 Sept.	—	—
Peak of activity	20 July	15 July	20 July	—	20 July
Lowest latitude sighting	45·5°N	49·6°N	48·0°N	—	—
Highest latitude sighting	71·3°N	67·2°N	71·3°N	—	—
Average observed duration of NLC	1·5 h	1·8 h	1·6 h	—	1·6 h
Maximum observed duration of NLC	4·0 h	5·0 h	4·5 h		
Zurich sunspot no.	10·2	15·1	47·0		

TABLE II—DATES ON WHICH NLC HAVE BEEN REPORTED BY ONE OR MORE STATIONS IN NORTH AMERICA DURING THE PERIOD 1964–66

Day of month	Apr.	May	June	July	Aug.	Sept.
1	65			64, 65, 66	64, 65, 66	
2			64	66	64, 65, 66	
3			65	65	64, 65, 66	
4				64, 65, 66	65, 66	
5		66	64	64, 65, 66	64, 66	
6				64, 65, 66	64, 65, 66	
7				64, 65, 66	64, 65, 66	
8				64, 65, 66	64	66
9		64	64	66	64, 66	
10			64	64, 65	66	
11		64	64	64, 65, 66	64, 65, 66	
12			64, 65	64, 65, 66	66	
13			65	64, 65	64	
14				65, 66		
15			64, 65	64, 65, 66	65	
16			65, 66	64, 65, 66	66	
17		64		64, 65	66	
18				65, 66	66	
19			65, 66	65, 66		
20			64, 65, 66	64, 65, 66	64	
21			64	64, 65, 66		
22			66	64		
23			64, 66	64, 65, 66		
24			64, 65	64, 66	66	
25			65, 66	64, 65, 66		
26	64		65, 66	64, 65, 66	66	
27		66	66	64, 65, 66		
28	64	65	64, 66	64, 65 ,66		
29			64, 65	64, 65, 66	64	
30	64	66	64, 65, 66	64	64, 65	
31				65, 66		
Totals	4	7	35	75	38	1

Climatological distributions. The distributions of NLC with solar depression angle, season, year, latitude, and longitude, and their duration and spatial extent are discussed in this section.

Dependence of NLC sightings on solar depression angle. Geometrical considerations of NLC scattering (Fogle and Haurwitz[6]) and observational results show that these clouds are generally observable during twilight when the solar depression angle (SDA) is between 6° and 16°. Exceptionally bright NLC are sometimes seen during civil twilight but it is difficult to distinguish them from cirrus at such times.

To examine the dependence of NLC sightings on SDA, the North American NLC reports for 1964–66 were grouped according to the SDA at the reported time of observation. The number of reports, N_R, for each degree of SDA (the intervals* used were 6° – 7°, 7° – 8°, etc.) were determined and these results were smoothed (using the Bartels smoothing function — see Vestine[2])

* Note. The convention used in allocating intervals was to begin the intervals at the even number, e.g. SDA 6° to 7° includes those values in the range 6·0° to 6·99°. The same applies to the longitude ranges (e.g. 60°W to 90°W includes those values in the range 60·0°W to 89·99°W) and the latitude ranges (e.g. 50°N to 55°N includes those values in the range 50·0°N to 54·99°N).

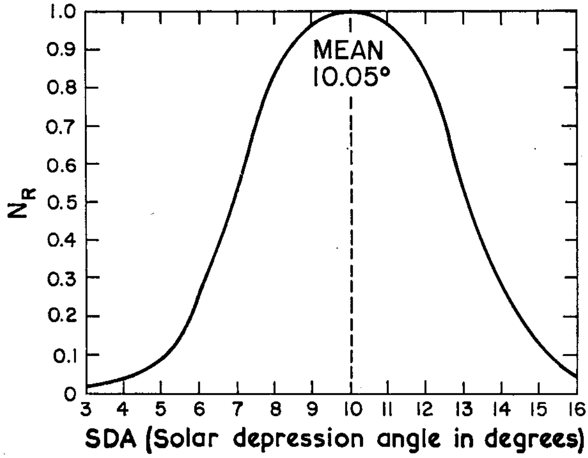

FIGURE 2 — VARIATION OF NLC REPORTS, N_R, WITH SOLAR DEPRESSION ANGLE, SDA

N_R is smoothed and normalized.

and normalized. The resulting distribution of N_R with SDA (Figure 2) shows that the optimum condition for observing NLC occurs at SDA $\simeq 10°$. The standard deviation from the mean is $\sigma = 2{\cdot}34°$, so 67 per cent of the observations were made when the SDA was between 7·7° and 12·4° and 95 per cent when it was between 5·4° and 14·7°.

Year-to-year variation. During the three years 1964–66, neither the number of NLC displays per year nor the number of NLC station nights per year changed appreciably ; both remained fairly constant at 53 ± 4 and 260 ± 30 respectively. In view of the question about a possible correlation of NLC activity with sunspot activity, it is interesting to note that despite an increase of the annual mean (Zurich) sunspot number from 10·2 in 1964 to 47·0 in 1966, there was no corresponding systematic change in NLC activity. While this result is suggestive, it is not conclusive, and a longer series of systematic observations from the same network of stations will be required to settle the question of whether systematic annual variations in NLC activity do exist.

Seasonal variation. To examine the apparent variation of the frequency of occurrence of NLC with season, all the reports for 1964–66, independent of latitude and longitude, were grouped into 10-day intervals (1–10 June, 11–20 June, etc.). The values of the number of NLC per 10-day interval were then smoothed and normalized. The results (Table III, Figure 3) show that while NLC occurred as early as 1 April and as late as 28 September, the peak of NLC activity each year occurred about 20 July, a month after the summer solstice. A comparison of the North American data with data from Europe and the U.S.S.R. shows that during the month of July NLC are seen nearly every night in some parts of the northern hemisphere.

Displays occurring before the summer solstice were found to be generally weaker and less extensive than those occurring afterward. As yet, no satisfactory explanation has been advanced to account for this asymmetry of NLC activity with respect to the summer solstice. No well-documented

TABLE III—SEASONAL FREQUENCY OF NLC OCCURRENCE

Interval		N_{NLC} per ten-day interval 1964	1965	1966	Total 1964–66
Apr.	I	0	1	0	1
	II	0	0	0	0
	III	3	0	0	3
May	I	1	0	1	2
	II	2	0	0	2
	III*	0*	0·91*	1·82*	2·73
June	I	4	1	0	5
	II	4	6	3	13
	III	6	5	7	18
July	I	7	8	8	23
	II	7	10	8	24
	III*	9·09*	8·18*	8·18*	25·45
Aug.	I	6	6	9	21
	II	3	2	5	10
	III*	1·82*	0·91*	0	2·73
Sept.	I	0	0	1	1
	II	0	0	0	0
	III	0	0	0	0

*The results for these intervals were reduced by 10/11 to account for the extra day.

sightings of NLC were reported during the six winter months of October–March, despite a careful watch being kept for them by experienced observers; this suggests that NLC do not occur in the winter.

Dependence of seasonal variation on latitude. From a study of a long series of NLC observations from Edinburgh, Scotland, Paton[7] found that the southernmost boundary of these clouds recedes polewards in late summer. If such a poleward recession does occur, then the seasonal frequency of

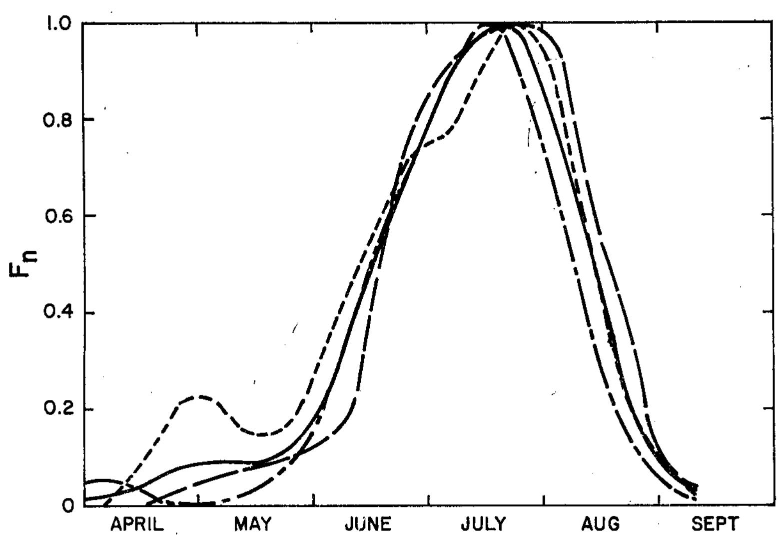

FIGURE 3—FREQUENCY OF OBSERVED NLC OCCURRENCE FOR ALL DATA, INDEPENDENT OF LATITUDE, AS A FUNCTION OF SEASON

F_n is the smoothed and normalized number of reported NLC displays per 10-day interval.
------ 1964, ·—·——· 1965, — — — 1966, ——— Mean.

occurrence of these clouds should be latitude-dependent, with the peak of activity occurring progressively later at higher latitudes.

To examine this possibility, the seasonal frequency of NLC occurrence was determined for each of 10 North American stations in the 50° – 61°N latitude range. The results (Table IV, Figures 4, 5) indicate that the seasonal frequency of NLC occurrence is latitude-dependent with the peak of activity occurring about five days later for each degree one proceeds polewards. This suggests that the clouds recede polewards after the solstice at the rate of about 0·22° per day.

TABLE IV—SEASONAL VARIATION OF NLC ACTIVITY AT DIFFERENT LATITUDES

Station	Latitude	Number of displays 1964–66	Earliest report	Latest report	Peak of activity
Saskatoon	52·2	16	21 June	26 July	3 July
Edmonton	53·3	23	3 June	11 Aug.	28 June
Prince George	53·9	13	13 June	25 July	25 June
Grande Prairie	55·2	28	3 June	31 July	10 July
Peace River	56·2	24	13 June	31 July	14 July
Beatton River	57·4	21	20 June	3 Aug.	10 July
Fort Chimo	58·1	16	9 May	2 Aug.	26 July
Fort Nelson	58·8	54	27 May	13 Aug.	16 July
Watson Lake	60·1	42	23 June	15 Aug.	25 July
White Horse	60·7	19	30 June	13 Aug.	1 Aug.

Diurnal variation. Occasionally, NLC occur in the same location on successive nights, but whether they are continuous during the intervening daytime (when the sky background is too bright for them to be seen) cannot be established from the kinds of observations now available. There is also a question as to whether these clouds are still present when they are in the earth's shadow and no longer illuminated by the sun, but optical radar observations of NLC may soon answer this question.

Because of these limitations, a study of the diurnal variation of NLC activity must be restricted to a comparison of their activity during evening and morning twilights when they can be seen. An examination of the North American data for 1964–66 (Table I, see also Fogle[5]) shows that most (79 per cent) of the displays were first observed before midnight by at least one station and, for those displays that were present during both evening and morning twilight, more stations reported seeing the clouds after than before midnight. These results suggest that, while NLC generally first appear during evening twilight, they are brighter and more extensive during morning twilight.

Latitude variation. To examine the variation of the frequency of observed occurrence of NLC as a function of the latitude of observation, the number of station nights of NLC per 5° latitude interval (45°N – 50°N, 50°N – 55°N, etc.) was determined for each of the three years, 1964–66, separately and for the average. The results (smoothed and normalized) given in Figure 6 show that NLC are most frequently seen from stations in the latitude range 50° – 65°N and that the optimum observing latitude is around 58°N. The lowest and highest latitude reports were from 45·5°N and 71·3°N respectively. The decrease in NLC sightings at latitudes polewards of 58° is due at least in part to the fact that as one proceeds polewards of 60°, there are increasingly longer periods, centred about the summer solstice, when the sky background

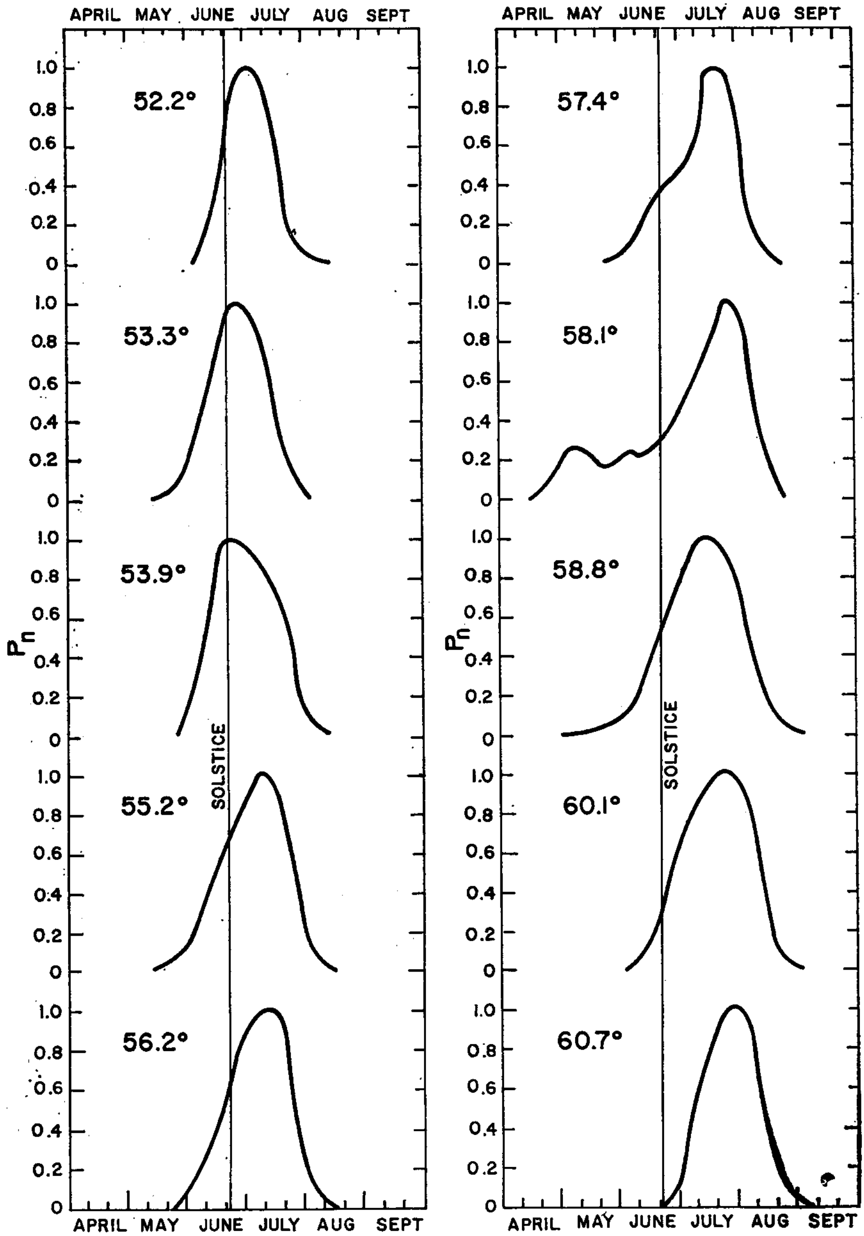

FIGURE 4—FREQUENCY OF OBSERVED NLC OCCURRENCE AS A FUNCTION OF SEASON FOR DIFFERENT LATITUDES

P is the smoothed and normalized percentage of clear nights that NLC were reported per 10–day interval. The latitudes for each portion of the diagram are given in °N.

is too bright for NLC to be observed, if present. The decrease in NLC sightings with decreasing latitude below 58°N seems, however, to be a real effect because in these latitudes there are periods during each day of the year when NLC could be seen if they were present.

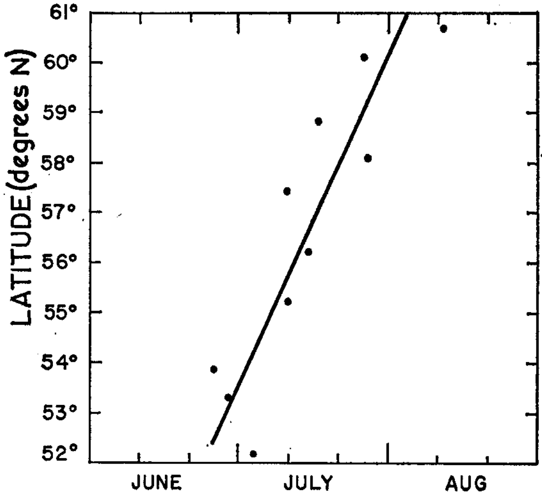

FIGURE 5—LATITUDE DEPENDENCE OF THE PEAK OF NLC ACTIVITY

No reliable observations of naturally occurring NLC from latitudes below 45° were reported from North America, although systematic observations were made by experienced observers at Hanover, New Hampshire (43°N), and Boston, Massachusetts (42·2°N). It is possible for an observer to see NLC

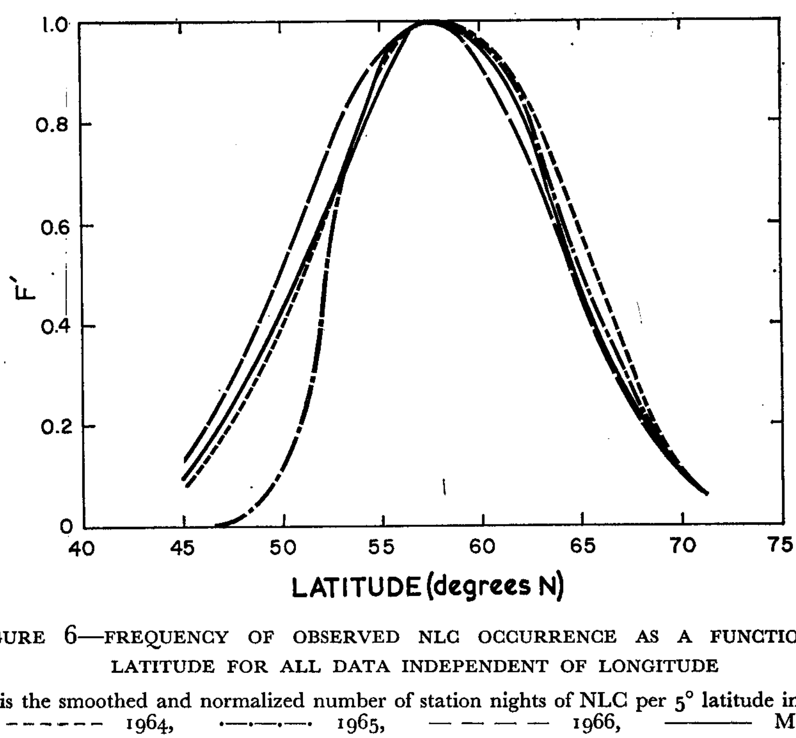

FIGURE 6—FREQUENCY OF OBSERVED NLC OCCURRENCE AS A FUNCTION OF LATITUDE FOR ALL DATA INDEPENDENT OF LONGITUDE

F′ is the smoothed and normalized number of station nights of NLC per 5° latitude interval.
- - - - - - 1964, •—•—•— 1965, — — — — 1966, ———— Mean

as far as 9° north of his location. Therefore the fact that no reliable reports of these clouds have been made from latitudes below 45°N suggests that they are confined to latitudes above 54°N. The highest latitude at which NLC form is uncertain because of the unsuitable viewing conditions in latitudes polewards of 60°N during mid summer when the clouds are most frequent. The few high-latitude sightings that have been reported do show, however, that the clouds extend up to around 80° latitude. The apparent latitude of maximum NLC activity has been shown to be at around 65° (Fogle and Haurwitz[6]).

The above results are similar to those obtained by Sharanov[8] for the U.S.S.R. data; the lowest and highest latitudes from which NLC were reported there were 45°N and 71·5°N, and the latitude of maximum reports was between 55°N and 60°N. The similarity in these results suggests that the NLC zone is symmetric with respect to the geographic instead of the geomagnetic pole.

Longitude variation. The possibility of a longitudinal variation of NLC activity was raised by Sharanov[8] whose analysis of the U.S.S.R. data for the years 1958–59 showed an east to west increase in NLC activity.

Fogle and Haurwitz[6] performed a similar analysis on the North American NLC data from 1964 and 1965 and obtained different results. They divided the region 51°N – 61°N, 55°W – 175°W into three longitude-sectors (55°W – 95°W, 95°W – 135°W, 135°W – 175°W) and found, on determining the number of displays seen from each section, that NLC were most frequently reported from the middle sector, centred at 125°W, which in addition to having the most stations also had the best weather.

The distribution, with longitude, of NLC reports from North America has been re-examined using an additional year's (1966) data and smaller longitude-sectors. In this analysis, the observing stations in the 51°N – 61°N zone were grouped into sectors of 30° longitude (60°W – 90°W, 90°W – 120°W, 120°W – 150°W, 150°W – 180°W). The number of nights that NLC were reported and the number of nights when they could not have been seen from each sector were determined along with the percentage of station nights that were clear. The number of NLC displays reported from each sector was then adjusted upwards to account, at least partly, for the nights when most of the stations in each sector were within viewing range of the sector in question. The results (Table V), as before, show that the apparent NLC activity is generally highest in the longitude zones having the best weather and the most stations and do not support the view that there is a variation of NLC activity with longitude. There may however, be such an effect, particularly at those longitudes — approximately 0°W and 140°W — where the maximum auroral zone crosses the latitude of apparent maximum NLC occurrence

TABLE V—LONGITUDE DISTRIBUTION OF NLC DISPLAYS

Sector	1	2	3	4
Longitude	60°–90°W	90°–120°W	120°–150°W	150°–180°W
No. of stations in sector	6	20	16	8
No. of station night reports	2227	6945	6334	2614
Percentage of station nights clear	40%	62%	44%	20%
No. of NLC displays	33	83	87	14
Adjustment for cloudiness	27	0	6	35
Adjusted no. of NLC	60	83	93	49

(Fogle and Haurwitz[6]). If a low mesopause temperature of around 135 degrees Kelvin is needed for NLC formation (as suggested by the evidence now available), and if during years of high sunspot activity the mesopause in the auroral zone frequently experiences considerable heating, it might be expected that fewer NLC would form near 0° and 135°W longitudes than elsewhere. Such an effect, if it occurred, would however be difficult to detect from the existing data.

Duration. Since NLC are only visible during twilight, it is not possible to determine whether they exist during the day when the sky background is too bright or at night when the mesopause is not sunlit. Because of these limitations, a determination of their maximum duration cannot be made except in those few cases when they form and decay during the twilight period.

An examination of the North American NLC data for 1964–65 shows that although the clouds are usually quite persistent and have an average duration of about 1·6 hours, individual parts of the clouds, particularly the billow structure, sometimes form and decay within a few tens of minutes. Weak displays of limited spatial extent are also occasionally short-lived and last for less than an hour.

On several occasions, bright NLC displays were continuously observed at one or more of the North American stations during the entire twilight observing period and durations of 4 – 5 hours were recorded. The appearance and disappearance of these displays, which were already well formed when first sighted, seemed to be controlled by the brightness of the sky background rather than their formation and decay at those times. This would suggest that the clouds can exist during the day and, if this is true, maximum durations of the order of days is not unlikely.

Spatial extent. The extent of sky at the 82-km level visible from the ground is a circular region of about 1000 km in radius and 3 million square kilometres in area, but only a part of this can be illuminated by sunlight against a dark sky background at any one time.

Sometimes the entire boundary of an NLC display can be seen from one station and its area can be estimated; this may be only a few thousand square kilometres (as in the case of the 16 June 1966 display). More often, however, the displays are too extensive for the entire boundary to be seen from one station and the areas covered by them are much larger — of the order ten thousand square kilometres to hundreds of thousands of square kilometres. Occasionally, NLC displays are very extensive and cover areas in excess of a million square kilometres (e.g. the displays of 29 June 1964; 5, 11, 16, 24 July 1964; 2 August 1964; 17, 26 July 1965; 1 August 1965; and 29 June 1966). All of the widespread displays were found to occur after the summer solstice.

The 2 August 1964 display was observed by 13 stations in Alaska and Canada and by the pilots of two BOAC aircraft off the south coast of Iceland. This display, if continuous, extended in longitude from 25°W to 150°W. Since, on that date, NLC can be simultaneously observed only within a sector of about 120° longitude (Fogle and Haurwitz[6]) it cannot be said with certainty that this display was continuous over the range of longitudes from which it was observed. It is possible that NLC might at times be circumpolar and have an area of about 10^8 square kilometres but this, if true, would be difficult to establish from the kind of observations now available.

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A RECENT CHANGE IN VISIBILITY CHARACTERISTICS AT FINNINGLEY

By G. A. CORFIELD and W. G. NEWTON

Finningley aerodrome is situated to the east of the densely populated industrial areas of the West Riding of Yorkshire (Figure 1) so that winds from directions between south-west and north-west bring smoke pollution which causes a reduction in visibility.

In 1956 the Clean Air Act came into force and since then many towns and cities have introduced progressively increasing programmes of smoke control, which have been becoming effective from about 1960 onwards. The figures in brackets on Figure 1 show the approximate percentage of domestic buildings brought under smoke control by the end of 1965. Ratcliffe[1] showed that visibility at Finningley (in 1953) was better on Sundays than on Fridays owing to the cessation of industrial smoke at weekends, and Wiggett[2] showed that at London/Heathrow Airport the frequency of fogs in the visibility range of 440–1100 yd has decreased in recent years (1946–62) and suggested that this decrease is due in part to the reduction of smoke pollution from London. Atkins[3] showed that at Manchester the incidence in the winter half-year (October to March) of hourly visibilities of less than 2200 yd in calms has fallen from 71 per cent of the number of calms in 1955–59 to 61 per cent in 1960–64 and implied that the change is due to the introduction of smokeless zones.

The Clean Air Act having been in force for over ten years, it was decided to do a statistical analysis of visibilities in relation to wind direction at Finningley (i.e. ignoring calms) to see if there were any trends similar to

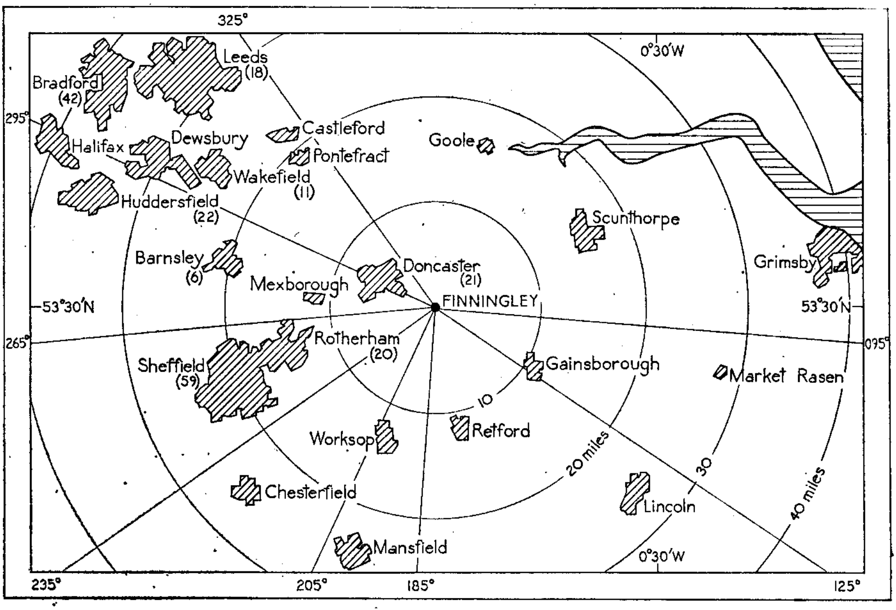


FIGURE 1—DISPOSITION OF FINNINGLEY SMOKE SOURCES
The numbers in brackets show the approximate percentage of domestic buildings brought under smoke control by the end of 1965.

those found by Atkins at Manchester and if these trends could be linked with the decrease of smoke production in areas around Finningley. It is considered that the results of the investigation show that there is a marked change taking place and, particularly with winds in the sector 235° – 265° bringing smoke pollution from Sheffield and Rotherham, a marked improvement of visibility is shown during the period 1958–65. It seems reasonable to link this change with the great efforts made towards complete smoke control by Sheffield.

For the analysis about 40 000 hourly observations of visibility, wind speed and direction were classified, covering the years 1958–65, omitting calms. Occasions when precipitation was occurring were excluded from the count. For comparison the years were divided into two four-year periods, 1958–61 and 1962–65.

Wind directions were grouped into sectors to include smoke-pollution sources within 40 miles (35 n. miles) of Finningley (Figure 1).

(i) Sector 295° – 325°. The smoke-pollution sources are a very complex group including Doncaster, Wakefield, Pontefract, Castleford, Dewsbury, Halifax, Bradford and Leeds.

(ii) Sector 265° – 295°. The smoke-pollution sources are Doncaster, Barnsley, Mexborough, Huddersfield and Halifax.

(iii) Sector 235° – 265°. The smoke-pollution source is the Sheffield/Rotherham area.

(iv) Sector 205° – 235°. The smoke-pollution sources are Chesterfield and scattered mining villages.

(v) Sector 185° – 205°. Winds in this sector bring smoke from the market towns of Worksop and Mansfield.

(vi) Sector 095° – 125°. This additional sector was chosen so that the effluent from smaller towns, such as Gainsborough and Market Rasen, would be sampled.

The results are set out in Table I which shows the percentage distribution of visibility in six ranges and six sectors for the two periods 1958–61 and 1962–65. Two sectors, 235° – 265° and 265° – 295°, show marked improvements in visibility, which can probably be linked directly to smoke control. In the sector 205° – 235° there is a smaller improvement and, as might be expected, little change in the 185° – 205° sector. In the 295° – 325° sector there is a marked improvement in visibility ⩽3000 yd (Table I, ranges *(a)* and *(b)*), which is offset by an increase in the number of occasions in the range >3000 yd to 2½ n. miles (range *(c)*) and not, as in other sectors, by improvements of visibility above 6 n. miles (ranges *(e)* and *(f)*). (Figure 1 shows how very complex the urban areas are within this sector.) Most local authorities have plans for extending smoke-control zones so that we can expect some further improvement of visibility with winds in this sector.

TABLE I—PERCENTAGE OF WIND DIRECTION OCCURRENCES WITH VISIBILITY OF VARIOUS RANGES AT FINNINGLEY FOR PERIODS 1958–61 AND 1962–65

(*a*) ⩽1100 yd (*b*) >1100 yd to ⩽3000 yd (*c*) >3000 yd to ⩽2½ n. miles (*d*) >2½ to ⩽6 n. miles (*e*) >6 to ⩽10 n. miles (*f*) >10 n. miles
Metric values : (*a*) ⩽1000 m (*b*) >1000 to ⩽2800 m (*c*) >2800 m to ⩽5 km (*d*) >5 km to ⩽12 km (*e*) >12 km to ⩽20 km (*f*) >20 km

Period	Sector *degrees*	(*a*)	(*b*)	(*c*)	(*d*)	(*e*)	(*f*)	Number of occasions
1958–61	185–205	5·0	18·5	8·1	37·8	22·2	8·3	1785
62–65		3·2	13·5	9·8	39·6	25·2	8·7	1694
58–61	205–235	1·3	9·9	7·8	35·9	30·1	15·1	2707
62–65		1·3	5·1	4·9	35·8	37·3	15·6	2785
58–61	235–265	1·4	11·7	7·1	36·8	29·0	14·1	2266
62–65		0·4	4·9	5·5	29·6	34·6	25·0	2755
58–61	265–295	2·7	14·6	9·3	36·5	27·5	9·5	3758
62–65		1·6	10·1	8·4	32·5	32·2	15·2	4164
58–61	295–325	7·3	19·2	8·9	32·5	22·6	9·6	2135
62–65		4·4	14·7	17·0	32·5	21·5	9·9	2294
58–61	095–125	8·8	14·4	8·3	31·2	22·7	14·5	1617
62–65		8·4	15·7	12·9	32·6	16·2	14·3	1353

The sector 095° – 125° was expected to show little change but in fact there was some worsening of visibility with an increase in the percentage occurrences in the range ⩽2½ n. miles and decreases above 6 n. miles. It is thought that this is due to the steady growth of urban dwellings around the smaller towns within the sector, extensive near Gainsborough and not all subject to the Clean Air Act. It should be noted that with winds in this sector a large proportion of visibilities below 1100 yd and 3000 yd occur, but that little change has taken place in these ranges. The increase of haziness in this sector is probably consistent with the growth of built-up areas without smoke control.

It may well be that changes of distribution of winds according to speed or from season to season might contribute to the production of changes in the distribution of visibility. As visibility has improved most radically in the sector 235° – 265°, it was decided to examine these figures in greater detail. In Table II, for the sector 235° – 265°, are shown the changes in percentage occurrences of three ranges of visibility for five overlapping four-year periods. These show a steady increase in visibilities above 10 n. miles and a small decrease in visibilities ⩽1100 yd. Table III (i) to (v) shows the seasonal and annual distribution of visibilities for the two four-year periods for three ranges of wind speed: below 6 knots, 7–16 knots and 17 knots or over. The trend is to better visibility almost throughout the range, showing decreases of the percentage occurrences of visibility ⩽2½ n. miles and increases of the percentage occurrences of visibility above 6 n. miles in most cases.

TABLE II—PERCENTAGE OCCURRENCE OF VISIBILITY AT FINNINGLEY IN THREE RANGES FOR FIVE OVERLAPPING PERIODS OF FOUR YEARS WITH WIND DIRECTIONS IN THE SECTOR 235°–265°

Period	⩽1100 yd	>3000 yd to ⩽2½ n. miles	>10 n. miles
1958–61	1·5	7	14
1959–62	0·9	7	16
1960–63	0·4	7	17
1961–64	0·3	7	22
1962–65	0·4	7	25

A critical examination of Table III (i) to (v) brings out the following points :

(1) In spring a marked improvement is evident for wind speeds of 1–6 kt in the visibility range ⩽3000 yd. Improvements are evident at both the higher and lower ends of the visibility range for wind speeds of 7–16 kt and, although the number of occasions of wind speed in excess of 17 kt for the period 1962–65 is double that for the period 1958–61, the improvement, especially in the frequency of visibilities greater than 10 n. miles, is more than doubled for the later periods.

(2) As might well be expected, the improvements for all speeds are least in summer, but small as they are, they are significant for wind speeds above 7 kt and are likely to be the result of improved industrial practice, e.g. the

TABLE III—SEASONAL AND ANNUAL PERCENTAGES OF WIND SPEED OCCURRENCES IN THE SECTOR 235°–265° AT FINNINGLEY WITH VISIBILITIES IN SIX RANGES FOR PERIODS 1958–61 AND 1962–65

(*a*) ⩽1100 yd (*b*) >1100 yd to ⩽3000 yd (*c*) >3000 yd to ⩽2½ n. miles (*d*) >2½ to ⩽6 n. miles (*e*) >6 to ⩽10 n. miles (*f*) >10 n. miles

(i) *Spring*

Wind speed (*knots*)	Period	Visibility (*a*)	(*b*)	(*c*)	(*d*)	(*e*)	(*f*)	Number of occasions
		per cent						
1–6	1958–61	6·9	36·1	15·3	29·2	12·5	0·0	72
	1962–65	0·0	14·1	21·9	53·1	7·8	3·1	64
7–16	1958–61	0·0	5·9	9·4	53·5	26·9	4·3	256
	1962–65	0·0	1·6	4·8	33·6	45·2	14·8	310
⩾17	1958–61	0·0	0·9	0·9	28·3	46·8	23·1	113
	1962–65	0·0	0·0	0·0	7·9	35·8	56·3	229
All speeds	1958–61	1·1	9·5	8·2	43·1	29·7	8·4	441
	1962–65	0·0	2·3	4·8	35·9	37·6	29·4	603

TABLE III—SEASONAL AND ANNUAL PERCENTAGES OF WIND SPEED OCCURRENCES IN THE SECTOR 235°–265° AT FINNINGLEY WITH VISIBILITIES IN SIX RANGES FOR PERIODS 1958–61 AND 1962–65 (*continued*)

(ii) *Summer*

Wind speed (*knots*)	Period	Visibility (*a*)	(*b*)	(*c*)	(*d*)	(*e*)	(*f*)	Number of occasions
		per cent						
1–6	1958–61	0·0	8·9	10·8	51·6	24·9	3·8	157
	1962–65	0·0	10·2	11·1	46·3	28·7	3·7	108
7–16	1958–61	0·0	2·8	2·4	27·1	41·5	26·2	465
	1962–65	0·0	0·2	0·8	24·7	44·2	30·1	608
≥17	1958–61	0·0	0·0	0·0	9·9	37·6	52·5	202
	1962–65	0·0	0·0	0·0	2·8	21·6	75·6	218
All speeds	1958–61	0·0	3·3	3·4	27·6	37·4	28·3	824
	1962–65	0·0	1·3	1·8	22·1	37·2	37·6	934

(iii) *Autumn*

Wind speed (*knots*)	Period	Visibility (*a*)	(*b*)	(*c*)	(*d*)	(*e*)	(*f*)	Number of occasions
1–6	1958–61	4·0	43·6	11·9	32·6	5·9	2·0	101
	1962–65	6·0	23·0	19·0	42·0	8·0	2·0	100
7–16	1958–61	0·0	14·7	5·2	53·9	23·2	3·0	232
	1962–65	0·0	7·6	5·5	35·9	39·7	11·3	435
≥17	1958–61	0·0	0·0	0·0	7·1	48·2	44·7	56
	1962–65	0·0	0·0	0·6	10·9	55·8	32·7	165
All speeds	1958–61	1·1	20·1	6·2	41·6	22·3	8·7	389
	1962–65	0·9	8·0	6·3	30·9	39·0	15·0	700

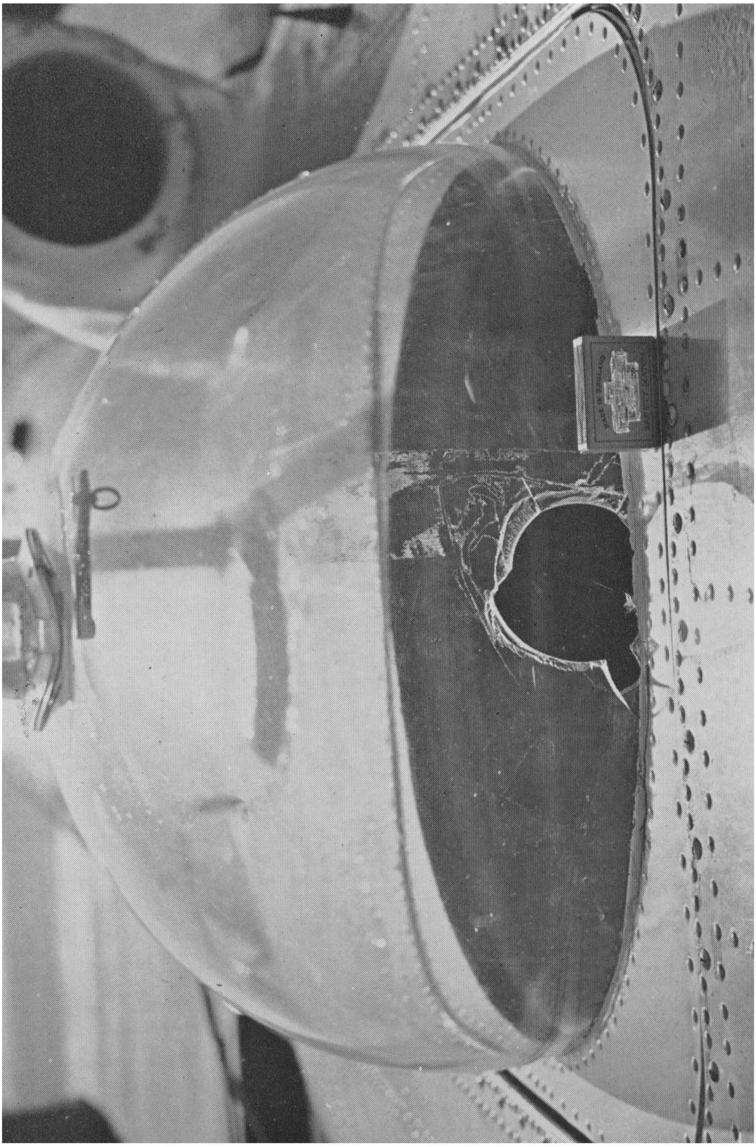
(iv) *Winter*

Wind speed (*knots*)	Period	Visibility (*a*)	(*b*)	(*c*)	(*d*)	(*e*)	(*f*)	Number of occasions
1–6	1958–61	15·2	35·8	12·0	32·6	4·4	0·0	92
	1962–65	3·4	49·1	10·2	35·6	1·7	0·0	59
7–16	1958–61	2·7	22·2	10·5	43·0	20·8	0·8	370
	1962–65	0·0	10·0	12·4	51·2	21·6	4·8	250
≥17	1958–61	0·0	1·6	1·6	54·8	37·2	4·8	126
	1962–65	0·0	0·0	0·8	31·5	40·2	27·5	127
All speeds	1958–61	4·1	19·9	8·8	43·9	21·8	1·5	588
	1962–65	0·5	12·4	8·7	43·3	24·3	10·8	436

(v) *Annual*

Wind speed (*knots*)	Period	Visibility (*a*)	(*b*)	(*c*)	(*d*)	(*e*)	(*f*)	Number of occasions
1–6	1958–61	5·5	27·7	12·1	39·1	13·7	1·9	422
	1962–65	2·4	21·7	15·4	44·4	13·6	2·4	331
7–16	1958–61	0·8	10·9	6·5	41·3	29·7	10·8	1323
	1962–65	0·0	4·0	4·7	33·6	39·7	18·1	1603
≥17	1958–61	0·0	0·6	0·6	25·1	40·9	32·8	497
	1962–65	0·0	0·0	0·3	11·1	36·8	51·8	739
All speeds	1958–61	1·5	16·2	6·2	37·3	24·7	14·0	2242
	1962–65	0·3	5·1	4·8	28·7	35·7	25·5	2673

use of higher chimneys, etc. If the sector 235° – 265° is extended about 50 n. miles south-westwards it is found to include Stoke-on-Trent, a city where in recent years the fuel used in the firing processes of the pottery industry has been changed from coal to gas or electricity. It is true too that almost all the big industries in the sectors under consideration are finding ways to reduce smoke, often by conversion to gas or oil burning.



PLATES I – IV—HAIL DAMAGE TO BEVERLEY AIRCRAFT XM 111 AT COLD FRONT OVER THE RED SEA (0920 GMT, 6 OCTOBER 1967)

PLATE I—HOLE IN ASTRODOME

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PLATE II—DAMAGE TO NOSE SECTION

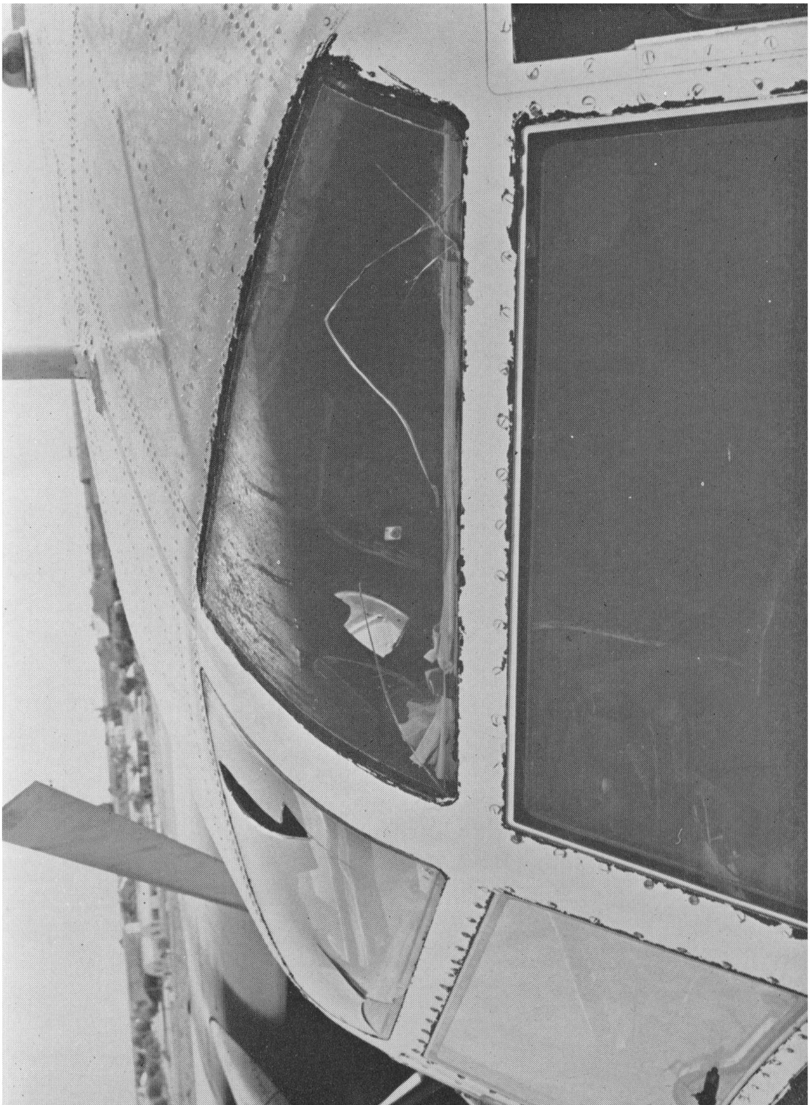

PLATE III—DAMAGE TO UPPER WINDSCREENS

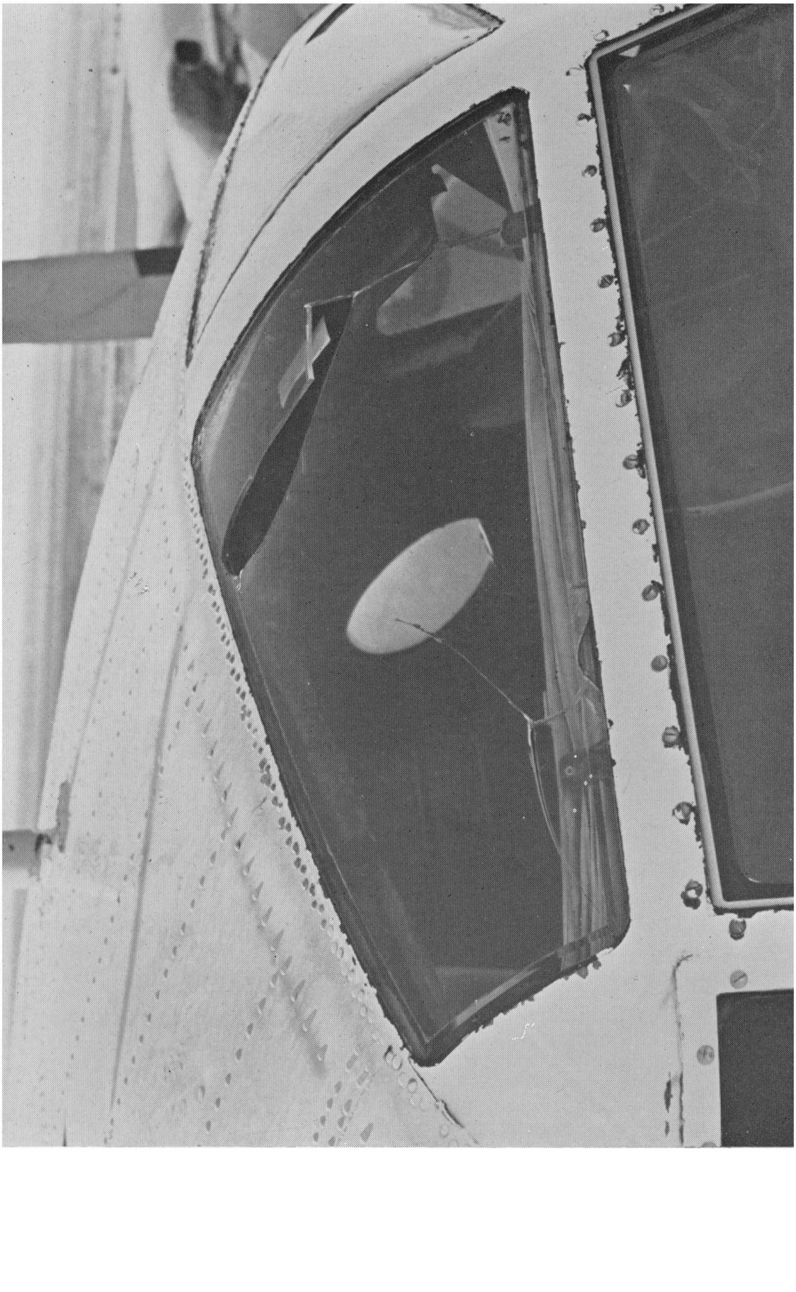

PLATE IV—HOLE IN UPPER WINDSCREEN

(3) Autumn shows a similar tendency to spring, in that the trend is for better visibility, especially for wind speeds in the 7–16 kt range, and in winter for speeds in the range 1–6 kt a marked improvement is shown in the incidence of fog, while for the higher wind speeds a marked improvement is demonstrated in both the lower and higher range of visibility.

(4) Taken on an annual basis (Table III (v)) significant improvements are evident for each range of wind speed and for all speeds, and these improvements far outweigh any significant difference in distribution of wind speed in the two four-year periods.

Conclusions. The period to which statistics of visibility refer needs to be clearly stated because the distribution of visibility is changing as a result of a change in human habits. In particular, where very large urban areas have ever-growing smoke-controlled zones, the visibility with winds from these zones has shown quite marked improvements in recent years. At Finningley, with winds in the 235° – 265° sector the recent improvement in visibility occurs at all wind speeds and is statistically significant for all speed ranges. It is suggested that this implies a need for revised visibility statistics, for most places affected by urban smoke pollution, for the period after 1960.

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681.3

A GENERAL-PURPOSE COMPUTER-PROGRAMME FOR STATISTICAL WORK

By M. H. FREEMAN, O.B.E., M.Sc.

The capacity of a computer to carry out computations at fantastic speeds can only be harnessed when a suitable set of instructions, or programme, has been written in a form which can be correctly interpreted by the computer. Since the computer will do exactly what it is told to do, however silly, great care is needed in writing a programme so that precisely the desired result is obtained. For large tasks that will be performed many times, such as the daily production of numerical forecasts, skilled programmers are needed to produce efficient programmes in the machine code used by the computer. A scientist wanting a simpler one-off job done may not want to spend the time it would take him to become a competent programmer, and for this reason a number of less-complicated programming languages have been developed, such as ALGOL and FORTRAN. These have the considerable advantage that programmes written in them can be run on almost any computer. The programmer does not have to concern himself with the way his data are stored in the computer, but for some applications ALGOL is more complicated than necessary, and so a simpler system, METO, was developed in the long-range forecasting branch of the Meteorological Office by Craddock and Freeman[1] to carry out a large variety of mainly statistical computations.

Full details of METO are given in 'The Users' Manual for the METO Computer Language', copies of which are held in the Meteorological Office Library, Bracknell. A short description of the system is given below, taking as an example the instructions needed to provide the figures of Table I associated with the article[2] on 'Visibility statistics for London/Heathrow Airport' on page 214.

TABLE I—EXAMPLE OF A COMPUTER-PRODUCED TABLE OF FREQUENCIES

JANUARY
// 1957 //

	0	1	2	3	4	5	6	7	8	9	10	11	12
25	0	0	0	0	0	0	0	0	0	0	0	0	0
50	0	0	0	0	0	0	0	0	0	0	0	0	0
100	0	0	0	0	1	1	1	1	0	0	0	0	0
200	1	0	1	1	1	0	0	0	0	0	0	0	0
400	0	1	1	1	0	1	1	1	2	0	0	0	0
1000	0	0	0	0	0	0	0	0	0	1	0	0	0
2000	0	0	0	0	0	0	0	0	0	0	2	2	1
4000	1	0	0	0	0	0	1	1	2	4	5	2	3
10000	14	14	10	9	8	11	9	9	8	14	11	13	11
20000	13	11	14	15	16	15	15	16	18	11	13	13	15
	2	5	5	5	5	3	4	3	1	1	0	1	1
	31	31	31	31	31	31	31	31	31	31	31	31	31

continued

	13	14	15	16	17	18	19	20	21	22	23	
25	0	0	0	0	0	0	0	0	0	0	0	0
50	0	0	0	0	0	0	0	0	0	0	0	0
100	0	0	0	0	0	0	0	0	0	1	0	5
200	0	0	0	0	0	0	0	0	0	0	1	5
400	0	0	0	0	0	0	0	0	0	0	0	8
1000	0	0	0	0	0	0	0	0	1	0	0	2
2000	0	0	1	1	1	1	1	2	1	0	0	13
4000	3	1	0	1	5	5	5	5	4	2	0	50
10000	12	17	16	17	19	19	18	15	17	16	18	325
20000	14	11	12	12	6	6	6	9	8	11	11	291
	2	2	2	0	0	0	1	0	0	1	1	45
	31	31	31	31	31	31	31	31	31	31	31	744

The METO language contains over 200 general orders. For example order 91 has the effect of subtracting one block of data from another block and storing the answers; this could be used to obtain a field of thickness values from fields of 1000 mb and 500 mb heights. Before the computer can carry out such an order it needs to know where the blocks of data and answers are stored in the machine and how many items there are in each block, and these must be specified by the user. In general, each order requires a certain number of parameters to make it specific, and this number varies from order to order.

The user has to decide on the sequence of orders to be obeyed and write them into a control message. After being punched on paper tape this message is read into the computer by the master METO programme, which then gives instructions to carry out each order in turn. The data are stored in the high-speed memory of the computer in a set of some 8000 main store addresses (*Mads*) numbered from 0 upwards. The control message consists of a list or directory of the orders required (stored in directory addresses or *Dads*) and a list of the necessary parameters (stored in parameter addresses or *Pads*). The directory consists of number pairs, the first being the order and the second being, usually, the address *(Pad)* of the first of the relevant parameters, which then follow in sequence. Table II shows a sample control message as written. The *Dad* and *Pad* numbers and the notes, which have been printed in italics, would not be punched. The control tape would consist of all the pairs of directory numbers first, and then, as shown by the dashed route on Table II, all the parameters in sequence. Arrows are necessary indicators to allow the master tape to recognize the various sections of the control tape.

The orders in Table II will have the effect of extracting the hourly visibilities for January 1957 from the magnetic tape containing Heathrow data, and of printing a table showing the frequency with which the visibility lay in certain ranges at each hour of the day. The full investigation into Heathrow visibility, naturally, needed a more complicated control message. The simple version in Table II does, however, illustrate several important details of the METO system and the orders will be discussed in turn.

Order 2; 5820; reads the title 'January', which is punched on the control tape following the parameters, and stores it in *Mad* 5820 onwards. No other parameter is needed for this simple order. Later in the control message (at *Dad* 28) 3; 5820; appears, and this prints the title on the line printer.

Order 101; 0; reads into the machine the ten values of visibility that form the boundaries of the visibility ranges we are interested in and which have been punched on the control tape after the title 'January'. The order needs four parameters which are stored in *Pad* 0 onwards to *Pad* 3, the address immediately preceding the first *Pad* in the next order. These parameters form a typical set and can be referred to as *Mad, Skip, Nib, Nob* — a set that is used in many of the orders.

Mad is the main store address of the first item of the first block of data. *Skip* is the difference between the first addresses of successive blocks. These must be equally spaced but can be separated, consecutive, overlapping or coincident and negative *Skips* are permitted. *Skip* has proved a very versatile feature of the system and several different uses of it are noted below. *Nib* is the number of items in a block and *Nob* is the number of blocks. In this particular example *Nob* is 1 and so the value allotted to *Skip* is immaterial; the ten boundary values will be stored in *Mad* 5880 onwards.

Seven of the instructions used in Table II, namely 101, 71, 83, 238, 237, 62 and 90, have *Mad Skip Nib Nob* as their first four parameters. They enable operations to be carried out on blocks of data rather than on individual numbers (there is a special set of orders for dealing with single numbers).

Order 33; 4; (using parameters in *Pad* 4 to *Pad* 7) generates an arithmetic progression of 24 items, starting with 0 and increasing by increments of 1, and stores them in *Mad* 6669 onwards, where they will be used for printing out the hours 0 to 23 as column headings.

Order 71; 8; transfers items from Mad_x $Skip_x$ *Nib Nob* to new positions specified by the next two parameters, Mad_y $Skip_y$ (*Nib* and *Nob* are necessarily the same and need not be repeated). In this example we are moving 10 consecutive blocks of 1 (the visibility boundaries) and putting them down in *Mad* 6694 and subsequent addresses spaced at intervals of 26. Here they will form the labels for rows when the frequency tables are printed.

TABLE II—METO CONTROL MESSAGE FOR PRODUCING LONDON/HEATHROW AIRPORT VISIBILITY STATISTICS

Dad	Order	*Pad*	Parameters	*Notes*
	→			
0	2; 5820;		→	*Read title 'January'.*
2	101; 0;	*0*	5880; 10; 10; 1;	*Read visibility boundaries.*
4	33; 4;	*4*	6669; 24; 0; 1;	*Form hours 0 to 23 for column headings.*
6	71; 8;	*8*	5880; 1; 1; 10; 6694; 26;	*Move boundary values to row headings.*
8	71; 14;	*14*	6669; 0; 24; 31; 5900; 24;	*Form table of hours.*
10	49; 20;	*20*	3; 1;	*Claim magnetic tape.*
→*12*	56; 22;	*22*	1; 0; 776; 2;	*Read one day data from tape.*
14	83; 26;	*26*	9; 32; 1; 24; 800; 1;	*Store 24 visibilities.*
16	45; 32;	*32*	2; 25; 1; 30; 24;	*Increase 2 parameters.*
18	1030; −6;			*Go back 6 and repeat loop 30 more times.*
20	238; 37;	*37*	800; 744; 744; 1; 11; 5880;	*Classify visibilities.*
22	237; 43;	*43*	800; 5100; 744; 2; 11; 24; 1820;	*Form contingency table.*
24	247; 50;	*50*	1820; 11; 24;	*Add row and column totals.*
26	71; 53;	*53*	1820; 25; 25; 12; 6695; 26;	*Transfer to table for printing.*
28	3; 5820;			*Print 'January'.*
30	15; 1957;			*Print '1957'.*
32	16; 26;			*Set 26 columns.*
34	62; 59;	*59*	6668; 338; 338; 1; 4; 0;	*Print table.*
36	90; 65;	*65*	1820; 25; 25; 10; 1845; 25; 1845; 25;	*Form cumulative totals.*
			→ →	
38	71; 53;			*Transfer for printing.*
40	62; 59;			*Print cumulative total.*
42	0; 0;			*End.*
			↑ JANUARY ↑→→	*Title of month.*
			→ 25; 50; 100; 200; 400; 1000;	
			2000; 4000; 10000; 20000; →→	*Ten ranges of visibility.*
			↑ +MAH772BH311264B ↑ →→	*Identification of magnetic tape holding observational data.*

Note. The *Dad* and *Pad* numbers and the *Notes*, which have been printed in italics, would not be punched. The control tape would consist of all the pairs of directory numbers first and then, as shown by the dashed route, all the parameters in sequence. Arrows are necessary indicators to allow the master tape to recognize the various sections of the control tape.

The next order 71; 14; moves the hours 0–23 and puts them down 31 times in *Mad* 5900 onwards to form a table of hours which will be needed by a later order (237). In this example *Skip* was zero.

Order 49; 20; claims a magnetic tape having +MAH772BH311264B as identifier (these characters are punched at the end of the control message) and allots to it the serial number 1. The programme can cope with up to three magnetic-tape readers at any one time. The next order 56; 22; reads one block of data from tape 1, and stores the items of data separately in *Mad* 0 onwards. There are 776 items in the block (a whole day's hourly observations) and the day we want, 1 January 1957, happens to be stored in block 2.

Order 83; 26; using similar parameters to 71; picks up 24 visibilities from *Mad* 9, *Mad* 9+32, etc., converts them from binary integers, as they were stored, to floating-point numbers for processing and places them in *Mad* 800 to 823.

We now require to store the 24 visibilities from the next day, and so on. If we had to laboriously write out the full instructions again for each day, programming would be impossibly tedious; all programming systems make extensive use of loops to overcome this problem. Before we again obey orders (56; 22;) and (83; 26;) the block number, 2, in *Pad* 25 must be increased by 1 and the storage address *Mad* 800 in *Pad* 30 must be increased by 24. The next order 45; 32; does just this, the first parameter, in *Pad* 32, specifying the number of parameters to be increased. The loop is completed by 1030; –6; which instructs the computer to go back 6 *Dads* (to *Dad* 12 in fact) 30 more times. After each cycle the order in *Dad* 18 (initially 1030) is automatically reduced by one. When the value 1000 is reached the computer does not go back again, but proceeds to the next instruction.

The next three orders are the ones that do the statistical work. Instruction 238 classifies the 744 (24 × 31) visibilities as 0 to 10 according to the boundary values stored in *Mad* 5880. Instruction 237 forms a contingency table using the classified visibilities in *Mad* 800 onwards and the hour table we previously put in *Mad* 5900 onwards (a *Skip* of 5100). Instruction 237 requires 7 parameters, the last of which (1820) specifies where the answers will be stored. The next instruction 247 adds the row and column totals to the contingency table.

The next order 71; 53; moves the answers to the spaces in the printing table. Then 3; 5820; prints the title 'January', and 15; 1957; (needing no parameters) prints 1957. The order 16; 26; sets the printing routine to print in 26 columns, and 62; 59; prints one block of 338 items from *Mad* 6668 onwards with four figures before the decimal point and none after.

Instruction 90 uses parameters Mad_x $Skip_x$ *Nib Nob* Mad_y $Skip_y$ Mad_z $Skip_z$, adds the x data to the y data and stores the answers in the z position. The reader may like to satisfy himself that the values given in *Pad* 65 onwards will have the effect of producing cumulative totals, so that successive lines of the table will show all occasions less than 25 m, less than 50 m, less than 100 m, etc. The final orders for printing the cumulative table use parameters which have already been specified and which do not, therefore, have to be repeated.

The foregoing description gives a good idea of the way in which the METO language is used. Altogether the system has nearly 50 instructions to deal with various aspects of 'housekeeping' and a dozen or so each for input, output and magnetic tape operations. The algebraic functions on blocks of data are covered by about 70 instructions, and there are over 30 instructions that act on single numbers. Some of the most powerful of the instructions are included in a set of two dozen statistical and matrix orders.

In a sizable block of meteorological data there is often a possibility of an observation being missing. The METO language takes account of this and replaces any missing value by -2^{23}. At every subsequent operation the computer checks whether the observation is missing and, if it is, takes some appropriate action, usually storing the answer as 'missing observation', and printing it as 'M'. If some impossible mathematical operation is attempted, such as taking the square root of a negative quantity, the machine does not stop, but puts 'missing observation' in the answer and carries on.

Some errors in writing a control message, such as trying to use a negative *Nib* or *Nob*, will be detected by the programme, which will print a short warning message. In this case WN (wrong *Nib*) will be printed, followed by the *Dad* of the order concerned, and the offending parameter will be replaced by 1 and the computation will continue. The results will not be those intended but will probably provide the user with information which will help him to correct his control message. Other blunders are such that it would be nonsensical for the computer to continue and after printing the warning message the computation will be closed down. Facilities exist for the computer operator to return control to a specially written section of the control message and so allow emergency action chosen by the user to be taken.

The METO system has proved to be one which is simple to use and, although mistakes are possible, the facilities provided make it highly likely that success will be obtained on a second run. Experience has shown that about 80 per cent of all control messages are made up from 30 frequently used orders. These are soon memorized and reference has to be made to the manual for only a few of the less-common orders on each occasion.

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551.575.36:551.591.36(421)

VISIBILITY STATISTICS FOR LONDON/HEATHROW AIRPORT

By M. H. FREEMAN, O.B.E., M.Sc.

Introduction. Hourly observations for London/Heathrow Airport for the 18 years 1949–67 have been stored on magnetic tape, and the KDF9 computer (COMET) at Bracknell has been used to extract some statistics of visibility for this period. The programme for carrying out the computations was written in the METO computer language, an easily used system admirably suited to this type of work, which is described in an article[1] on page 209.

Change in visibility characteristics over a long period. Wiggett,[2] using three-hourly data for the 17 years 1946–63, showed that the frequency of fog had decreased during the period and suggested that the improvement in visibility was due to a reduction in smoke pollution. The present investigation confirms this trend, which appears to have become accentuated in recent years. Opportunity was taken of extracting frequencies of visibilities above 1000 m as well as in the fog range. Table I shows the frequencies, for specified ranges of visibility, for each 12-month period from July 1949–June 1950 to July 1966–June 1967.

TABLE I—NUMBER OF HOURLY OBSERVATIONS WITH VISIBILITY AT LONDON/HEATHROW AIRPORT IN CERTAIN RANGES IN 12-MONTHLY PERIODS FROM JULY TO JUNE 1949–67

Year July–June	Visibilities Under 25m	25m to 49m	50m to 99m	100m to 199m	200m to 399m	400m to 999m	1000m to 1999m	2000m to 3999m	4000m to 9999m	10km to 20km	Over 20km
1949–50	15	69	43	99	99	298	675	1194	2460	2429	1379
50–51	7	37	27	43	45	232	422	1344	2468	2424	1711
51–52	16	69	31	41	69	255	564	1161	2752	2291	1511
52–53	53	80	84	82	136	335	622	1161	2607	2309	1291
53–54	1	55	79	72	74	276	571	1105	2647	2328	1552
54–55	8	13	54	42	34	189	460	936	2591	2583	1850
1955–56	27	56	48	40	56	170	504	1079	2773	2651	1356
56–57	7	36	63	72	64	227	442	791	2681	2766	1611
57–58	3	41	42	48	46	189	476	915	2657	2463	1880
58–59	24	97	95	121	99	269	718	1004	2380	2326	1627
59–60	11	71	39	43	41	139	397	1001	2943	2443	1632
60–61	3	20	25	53	52	139	463	978	2643	2640	1744
1961–62	7	31	42	43	46	199	462	802	2390	2734	2004
62–63	25	61	61	42	48	209	585	1206	2709	2231	1583
63–64	6	40	49	50	86	199	460	1322	2767	2130	1651
64–65	1	17	32	53	40	145	302	1111	2493	2666	1900
65–66	0	15	27	44	53	138	358	1081	2240	2691	2113
66–67	1	17	25	29	30	64	243	840	2199	2842	2470

The figures vary a lot from over the years. The foggiest winter (1952–53) had nearly 5 times as much fog as the least foggy winter (1966–67). Wiggett used 5-year running means to smooth the data and the same procedure has been used in Figures 1 and 2. Figure 1 shows the 5-year means (starting with July 1949–June 1954) of visibilities in the ranges: less than 200 m, 200 m – 999 m and 1000 m – 1999 m, corresponding to thick fog, fog and mist. Wiggett had noted that up till 1958–63 there had been little change in the mean frequency of thick fog, but there has been a notable drop during the succeeding 4 years. In the range 200 m – 999 m the most rapid improvement took place in the early years of the period; and the reduction in the frequency of mist was at a maximum during the last 5 years.

Because the frequency of poor visibility has decreased, at some range of better visibility the frequency must have increased during the period 1949–67. Figure 2 shows the mean frequencies, over 5-year periods, of visibility below 2 km and above 20 km, and it will be seen that the loss of occasions of visibility less than 2 km is largely compensated by an increase of visibilities better than 20 km. The changes in 5-year frequencies of visibilities in the range 2 km–20 km were small.

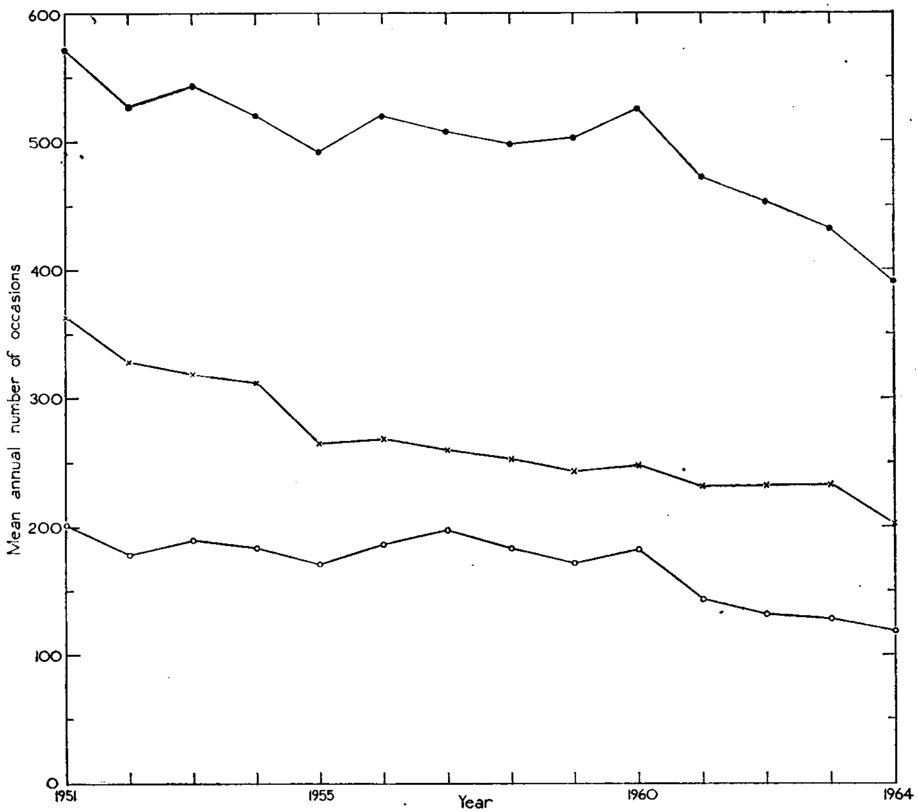

FIGURE 1—ANNUAL FREQUENCY OF THICK FOG, FOG AND MIST AT LONDON/HEATHROW AIRPORT (RUNNING 5-YEAR MEANS PLOTTED ON CENTRE POINT OF PERIOD).

o———o Thick fog (visibility less than 200 m).
x———x Fog (visibility 200 m – 999 m).
·———· Mist (visibility 1000 m – 1999 m).

The improvement in visibility with the years is most marked in the winter. This can be seen from Table II which shows the percentage frequency of fog (visibility less than 1000 m) month by month for the two periods 1949–56 and 1957–66.

TABLE II—PERCENTAGE FREQUENCY OF FOG AT LONDON/HEATHROW AIRPORT

Month	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
1949–56	11·7	8·6	7·6	0·8	1·1	0·5	0·3	1·2	2·8	11·2	11·8	13·3	5·9
1957–66	9.5	5·8	3·3	1·3	0·5	0·3	0·1	0·4	2·9	7·6	8·3	12·0	4·3

Diurnal and monthly variation of fog. Davis[3] used hourly observations for a 4-year period (1946–50) to study the diurnal and monthly variation of fog at Heathrow. Tables III and IV give up-to-date percentage frequencies of fog (visibility below 1000 m) and thick fog (visibility below 200 m) respectively for the 10 years 1957–66.

TABLE III—DIURNAL VARIATION OF FOG AT LONDON/HEATHROW AIRPORT 1957–66

Percentage frequency of visibility below 1000 m.

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	All hours
January	11	10	11	11	11	10	9	9	10	10	10	11	9	8	7	7	6	7	7	8	11	13	11	10	10
February	8	7	6	7	8	7	7	7	10	7	6	5	3	3	3	3	3	3	3	4	6	7	8	9	6
March	3	3	4	6	6	5	6	8	7	5	4	2	2	1	1	1	1	1	2	2	2	2	1	3	3
April	0*	1	3	2	2	4	4	5	3	2	0*	0*	1	1	0*	0*	0	0	0	0	0	0*	1	0	1
May	0	0	0*	1	3	2	2	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0*
June	0	0	0	1	1	1	2	1	0*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0*
July	0	0	0	0	0	0*	1	0*	0*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0*
August	0*	0*	0*	1	1	2	1	1	1	1	0	0	0	0	0*	0	0	0	0	0	0	0	0	0	0*
September	2	2	4	6	6	7	10	10	10	5	2	1	1	0	0	0	0	0	0*	0	0	0*	1	1	3
October	11	12	13	13	15	14	15	16	14	12	7	5	3	1	1	0*	0*	1	2	3	5	4	5	8	8
November	11	13	12	11	12	12	11	11	12	10	7	6	4	4	3	3	4	3	4	4	8	11	12	12	8
December	14	17	15	13	11	10	11	10	13	14	13	13	11	9	8	8	9	8	10	11	12	14	17	16	12

* = less than 0.5 per cent

TABLE IV—DIURNAL VARIATION OF THICK FOG AT LONDON/HEATHROW AIRPORT 1957–66

Percentage frequency of visibility below 200 m.

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	All hours
January	5	5	5	5	7	6	5	4	5	4	3	3	2	1	1	1	1	1	1	2	2	2	4	4	3
February	1	2	2	3	4	4	5	4	3	3	1	1	1	0*	0*	0	0	0*	0*	1	1	1	2	1	2
March	1	1	2	2	2	2	2	3	3	1	1	1	0	0	0	0	0	0	0	0	0*	0*	1	1	1
April	0*	0	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0*
May	0	0	0	0*	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0*
June	0	0	0	0	1	1	1	0*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0*
July	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
August	0	0	0	0*	0*	1	0*	0*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0*
September	0	1	1	2	2	4	4	6	3	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1
October	4	5	7	7	8	9	8	8	9	5	3	2	1	0*	0*	0	0	0*	0*	1	1	2	2	3	4
November	4	6	6	6	7	7	6	6	5	4	3	2	1	1	1	1	1	1	1	2	3	4	4	3	4
December	8	7	8	6	5	5	5	6	5	5	5	5	5	3	4	4	4	5	6	6	6	5	5	7	5

* = less than 0.5 per cent

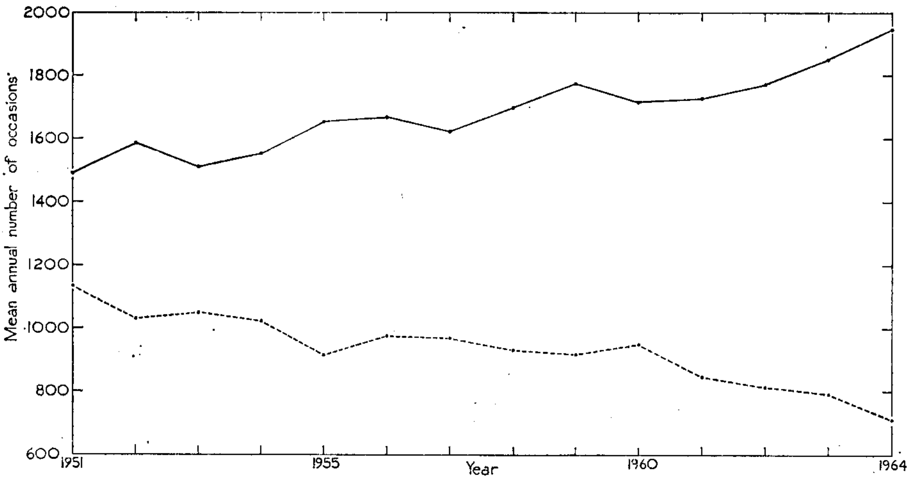

FIGURE 2—ANNUAL FREQUENCY OF VISIBILITIES LESS THAN 2 KM AND GREATER THAN 20 KM AT LONDON/HEATHROW AIRPORT (RUNNING 5-YEAR MEANS PLOTTED ON CENTRE POINT OF PERIOD)

•————• Visibility greater than 20 km.

•— — — —• Visibility less than 2 km.

The main features of the distribution of fog through the year, as noted by Davis, may also be seen in Tables III and IV. The rapid increase in frequency in autumn and decrease in spring are still evident. A number of Davis's points of detail are, however, different. The higher frequency of fog soon after sunrise is a feature of all the winter months and not merely February and March. The foggiest month is December rather than November as found by Davis. The peak frequency soon after dawn in October is still noteworthy, but it has dropped from about 27 per cent in 1946–50 to 17 per cent in 1957–66. This is typical of the generally improved visibilities in recent years.

There is little doubt that the effects of the Clean Air Act (1956) on the reduction of smoke pollution in the London area are, to a large extent, responsible for the progressive decrease of poor visibility at Heathrow. Brazell[4] found a considerable increase from 1958–61 in the number of premises and dwellings covered by smoke control in the Heathrow area.

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REVIEWS

An introduction to fluid dynamics, by G. K. Batchelor. 23·5 cm × 16 cm, pp. xviii + 615, *illus.*, Cambridge University Press, Bentley House, 200 Euston Road, London, N.W.1, 1967. Price: 75*s*.

Hydrodynamics is a study which has ever-widening applications, as experimental work on all scales — from dealing with large-scale atmospheric motions to the behaviour of small drops — is carried out and reported in a number of journals of international repute. Quite specialist texts exist dealing with isolated parts of the subject such as wind waves on the ocean surface and the stability of problems of particular flows. The steady increase of knowledge has called for a textbook which will present the basic facts in the light of modern theories and link together the specialized work but, despite the large number of books which have appeared in the last 20 years, the most famous textbook on hydrodynamics is still probably that of Lamb, first published in 1879 and brought up to date in a series of editions, the last of which appeared in 1932. That the book is still on sale — more than can be said of some of its more recent competitors — is a tribute to the care and foresight which Lamb showed in selecting his material for presentation. Now we have another 'big' Cambridge book on fluid dynamics by the Professor of Applied Mathematics, making a new selection of material both to present to the student and to act as a reference source for the applied mathematician.

Professor Batchelor's book falls into three parts of approximately equal length. The first part deals with the general properties of fluids and their expression in mathematical terms; here the foundations are laid more solidly than in any other text that I know, and research workers as well as students will be grateful to have an authoritative treatment of some of the difficulties and obscurities that can arise. The author has not not hesitated to delve deeply and a minor criticism is that since he proposes to deal almost exclusively with thermodynamically inactive fluids he does not pursue the thermodynamic properties as far as he might.

The second part deals with viscous flow and so is generally concerned with flow near boundaries where diffusion processes and the degradation of energy are important. The simplified equations are set up and solved for quite a number of physically interesting problems, some dating back half a century and some only a few years. Flow at large Reynolds numbers is dealt with, leading to problems in boundary layer theory, flow near an obstacle, and wakes. The results obtained in the text are magnificently illustrated by photographs revealing the details of the fluid motions as observed in laboratory work.

The last third of the book deals with fluid motions in the bulk of the fluid away from boundaries, where the effects of the boundary layers can usually be neglected, as, for example, the classical irrotational flows past a body and the motions well away from its immediate position. It includes a treatment of motions in which the vorticity is of paramount importance, as it is in many atmospheric problems. Again the results are illustrated with beautiful photographs.

The whole book is written in the clearest style, with full concise explanations of the assumptions that are made in setting down a physical problem in mathematical terms, and there is little doubt that the text will remain in great demand for a long time as being authoritative on those parts of hydrodynamics which the author has selected for treatment. Although the text deals almost exclusively with incompressible fluids there is much of immediate interest to meteorologists; to cite only a few examples: Ekman spiral, boundary layer problems, flow of rotating fluids and the effect of viscosity on the motion of small particles. The meteorologist, and others, will regret the omission of wave motions and further development of the theory of compressible fluids in which the heat exchanges are of great importance. However, Professor Batchelor has provisionally promised a further volume dealing with these topics, as well as others of extreme interest to geophysicists and we can only hope that he has already begun. The promised volume, along with that under review, would surely prove a classic pair assured of a long life.

One of the most remarkable aspects of the book is its price, which represents splendid value for money, for the layout of the mathematics and the printing have in no way been sacrificed to economy. For a book of this size there are singularly few immediately apparent misprints, though fortunately for our comfort the gas constant for dry air is $2{\cdot}87 \times 10^6$ cm^2/s^2 degC and not as given on p. 43 ! Both the author and the Cambridge University Press are to be congratulated on their combined effort.

E. KNIGHTING

'Deserts', the problem of water in arid lands, by Martin Simons. $8\frac{1}{2}$in × 9in, pp. 96, *illus.*, Oxford University Press, London, 1967. Price: 16*s*, (Paperback 11*s*. 6*d*.).

This publication is one of 'the changing world' series of the Oxford University Press, and the author's avowed intention is to discuss what might be done to conquer the world's deserts as a contribution to the solution of problems arising from growing populations.

Opening with an account of the distribution, properties and climate of deserts the author then studies the lessons to be learnt from the plant and animal life surviving in them. These lessons are interesting if hardly essential to the main theme — the possible sources of water for exploitation of deserts. The use of ground water is examined first, and the dangers of over-extraction are exemplified by an account of the bitter lessons learnt in Arizona's Santa Cruz Valley and California's Santa Clara Valley. The section concludes that the amount of potable water under deserts is limited and that full and controlled exploitation would still leave major parts of deserts unchanged. The use of exotic rivers* is illustrated in particular by accounts of the Nile and Aswan High Dam, the Indus and its dams, and the Jordan River. The associated problems — political, evaporation losses from reservoirs, waterlogging, salination, and silting — are well brought out, and here again the conclusions are disheartening; deserts will remain almost untouched even when desert rivers are fully exploited.

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*Exotic rivers — rivers which rise outside the desert regions but which flow into and across them.

Discussion of the large-scale diversions of water from extra-desert sources introduces a somewhat happier note although the conclusion is that many deserts will still remain as problems when diversion has been fully exploited. There are interesting accounts of the Californian Water Transfer Scheme and the southward diversion of water from north-flowing rivers in the U.S.S.R. The next section deals with water from the sea, and several types of desalination plant are described. Here the happier note on diversions is maintained. The author then considers the possiblity of increasing rainfall by cloud seeding and rightly concludes that herein lies no solution to the problem of the true desert. A final speculation on changing the climate is understandably and mercifully brief.

In a look at the future the author puts his money on desalination of sea water, with power from nuclear energy. The parallel is drawn with the sun and evaporation from the oceans. Attention is called, yet again, to the vast sums of money involved in the projects discussed in this book. Economic and sometimes political factors must be considered. Although the emphasis throughout the book is on irrigation of fields to grow crops, there is growing realization of the advantages of the desert city and the need for water for growing industries and populations. In America in particular, increasing use is being made of deserts for holidays and weekends, and with modern facilities the desert is becoming the ideal place for living. To an increasing degree the capital and running costs of development of water resources are being recovered from industry and not merely from agriculture. In earlier civilizations the desert city was all important. New desert cities may well appear in modern times.

The book is extremely readable and should give the non-specialist reader a clear picture of the problems posed by deserts — problems that are the vital concern of all who live in arid and semi-arid regions and which have repercussions throughout all countries. The text is profusely illustrated with excellent figures and adequate photographs.

J. HARDING

NOTES AND NEWS

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International Conference on Aeronautical Meteorology

Among the items discussed at the World Meteorological Organization's Scientific and Technical Conference which concluded recently in London were : the need for meteorological radar in forecasting hail, lightning and associated turbulence; meteorological satellite information for aircraft; and computers for the rapid production of forecasts for supersonic transport aircraft (SST).

The Conference — three consecutive symposia — lasted from 18 to 29 March, and considered the most significant problems facing the aeronautical meteorologist today.

The following were among the conclusions reached: there is an urgent need, by designers of aircraft and of aircraft systems, for further observations and analyses of the wind structure in the vicinity of airports; weather radar is, at present, the most effective and practical method of giving warning of, and making short-period forecasts of, convective activity and the associated dangerous phenomena of turbulence, hail and lightning in the neighbourhood of aerodromes; there is also need for some re-evaluation of present practices of measuring wind, gustiness, Runway Visual Range, and the height of cloud base.

In the extratropical latitudes, the introduction of numerical weather prediction in routine operations is significantly improving the forecasts of upper winds and temperatures; however, in the tropical areas the further development of forecasting techniques is handicapped to some extent by the inadequate data network and the doubtful quality of some upper air observations.

The very important aviation problem of clear-air turbulence, despite some progress, requires much co-ordinated research before there can be adequate forecast techniques and/or satisfactory remote airborne detection systems — this applies particularly to the occurrence of turbulence at the levels at which SST aircraft will operate.

Computer-produced forecasts which are ideally suited for use in airline flight planning will be widely available within the near future.

For SST aircraft, in the transonic and supersonic flight stages, temperature will play an important role, especially in the transonic phase; turbulence, both in clear air and in cloud, as well as hydrometeors, pose problems in both these stages. The greatest economic disadvantage will be noticed when strong head-winds are combined with temperatures which are considerably higher than standard.

In support of SST operations, research is needed on the height of convective cloud tops in the tropics, especially through analysis of satellite meteorological data; high-speed communications will be required for the collection, and rapid distribution of meteorological information for SST operations. In this respect, subjective reports of turbulence and other significant weather conditions encountered during transition or during cruise should be transmitted from air to ground with a minimum of delay after the event, to permit their timely use in the meteorological support of subsequent flights.

The Conference was attended by 225 experts from about 50 countries, and by representatives of organizations interested in aviation activities.

Hail damage to aircraft

The photographs, Plates I – IV, show hail damage sustained by Beverley aircraft XM 111 at a cold front over the Red Sea on 6 October 1967. At 0920 GMT (position 22°05′N, 38°12′E) hail was encountered at 10 000 ft (temperature +9°C, True Air Speed 156 kt). Flight Lieutenant Collins, the navigator, reported that there was very severe turbulence for 10–15 seconds and that the aircraft was holed by hailstones the size of tennis balls.

Retirement of Mr C. J. Boyden

Charles James Boyden, B.A., retired from the Meteorological Office at the end of April 1968 after 38 years service. Entering as a Junior Professional Assistant at Edinburgh he reached the grade of Senior Principal Scientific Officer in 1954 and held four assistant director posts from that time till his retirement.

After his initiation in Edinburgh he served at several outstations and headquarters before beginning his long association with the staff training work of the Office with his posting, in late 1936, to Croydon as instructor to the newly formed forecasters-training course. With but one break of less than a year early in the war this association lasted till 1947. The years 1947 to 1952 were by way of being an aviation interlude, with service in the Azores and at Prestwick. In the late 1952 he resumed his wider contact with the staff on appointment as Head of Met.O.10 (Personnel Branch). After seven years as Assistant Director in charge of Central Forecasting and three years in charge of Synoptic Research he renewed his association with staff training when, in 1964, he was appointed Assistant Director in charge of Publications and Training.

Jim Boyden's long association with forecasting and staff training taught him the value of practical tools for use in forecasting. This is reflected in his published papers, and I would draw attention to a selection of these. His first papers appeared during his earliest association with forecaster training and included one on the prediction of night minimum temperatures. He was to return to the theme of surface temperatures 20 years later. In 1958 appeared his paper on the forecasting of daily mean surface temperature from 1000–500 mb thickness lines, and a similar approach for forecasting maximum surface temperature appeared in 1962. The jet stream featured in three papers that appeared during his service in synoptic research. The first dealt with the relationship between the jet-stream profile and the thermal field, the second with the development of the jet stream and cut-off circulations, and the third with jet streams in relation to fronts and the flow at low levels. About the same time there were papers on the relationships between sea-level isobars and the wind speed at 900 metres, a comparison of snow predictors, a simple instability index for use as a synoptic parameter, and on subsidence in the middle and lower troposphere. The Encyclopaedic Dictionary of Physics contains articles by him on air masses and fronts and the weather map.

Jim Boyden can justly look back with pride on a career that contributed in no mean fashion to the meteorological advancement of a large proportion of those who have served in the Meteorological Office within the last 30 years. We wish him and his wife many years of happiness to come.

J. HARDING

551.508.824

Automatic weather stations for Australia

Australia is about to enter the era of automatic weather stations. Within the next five years it plans to have 11 such stations operating in an arc covering the northern coastline of the continent.

This arc of stations, stretching from North-West Cape, Western Australia, to north-east of Brisbane, Queensland, will provide early warnings of the tropical cyclones which form in the India Ocean and Coral Sea and roar and rage down the north-west and north-east coasts, causing widespread havoc and destruction and sometimes loss of life.

Two automatic weather stations have been operating in tropical areas for several years. Prompted by their success, the Australian Commonwealth Bureau of Meteorology has embarked on a plan to install a further 9 stations in areas where little or no information is at present available.

Because of its size, its relatively small population and vast uninhabited areas, Australia has not the resources of finance or manpower to establish manned observing stations on remote off-shore islands or along its northern seaboard. Automatic weather stations are therefore the answer.

With the current development of vast mineral deposits in Western Australia, the Northern Territory and Queensland, and the construction of harbours and wharf facilities for bulk carriers, early warnings of cyclones will be vital, especially for the safety of the work-force and the protection of installations. The additional information obtained by automatic weather stations will also be valuable for the nation's general weather service.

The first of the new stations is at present under construction on Cape Wessel Island, off the northern tip of Arnhem Land, Northern Territory, and is expected to be operational by the end of May. When operating, it will take measurements of air pressure, temperature, humidity, rainfall, and wind speed and direction — the basic elements of weather — and radio this information at predetermined times each day to the bureau's regional office in Darwin.

There the information will be used in the preparation of charts of the current and predicted weather for the region and in the compilation of forecasts and warnings. The information will also be fed into the bureau's communications network and passed to the central analysis office in Melbourne for use in the preparation of master charts for the whole of the Australian region.

From Cape Wessel Island the installation team will then move to Frederick Reef, in the Coral Sea, to erect the second of the automatic weather stations. This should be operational in October. Automatic stations will be established on Browse Island and Rowley Shoals, off the north-west coast of Western Australia, and on Marion Island in the Coral Sea, this year.

Other stations being planned are for Scott Reef, off north-west Western Australia, and Lihou Island and Flinders Reef, in the Coral Sea. These stations are not expected to be operational before 1970.

In addition, planning will begin in 1969 for stations at Mitchell Point and Pearce Point, Northern Territory, and at locations yet to be selected in desert regions and southern Tasmania. These stations will have no cyclone warning role, but will augment the bureau's network of observing stations which extends from Cocos Island, in the Indian Ocean, to Norfolk Island, in the Pacific, from Manus Island, near the equator, to the Antarctic continent.

E. SAUNDERS

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CONTENTS

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