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Geophysical Memoirs No. 112
(SECOND NUMBER, VOLUME XV)

AVERAGE TEMPERATURES, CONTOUR HEIGHTS AND WINDS AT 50 MILLIBARS OVER THE NORTHERN HEMISPHERE

BY

R.A. EBDON

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AVERAGE TEMPERATURES, CONTOUR HEIGHTS AND WINDS AT 50 MILLIBARS OVER THE NORTHERN HEMISPHERE

INTRODUCTION

Geophysical Memoirs Nos. 101,[1*] *103*[2] and *105*[3] included charts of average temperature, contour height and wind, and the variability of wind and temperature at the standard pressure levels (700, 500, 300, 200, 150 and 100 mb) for the months of January, April, July and October for most of the world. The need for information at higher levels has increased over the years since the publication of the earlier Memoirs and the aim of this Memoir is to present maps and diagrams describing average temperatures, contour heights and winds, and the variability of each, at the 50-mb level (approximately 20.5 km or 68 000 ft) over the northern hemisphere, in a form acceptable to those planning aircraft operations in the lower stratosphere as well as to the theoretical meteorologist. The physical implications contained in the material presented are not discussed except in so far as they materially affect the practical interpretation of the charts.

The Memoir is divided into three parts. Part I deals with average temperatures, Part II with average contour heights and Part III with average winds. The basic charts, i.e. those showing the average values and their variability for all the months considered, are published together as Plates 1–35 (for ease of reference) whilst additional charts and diagrams are included in the relevant part of the text.

THE DATA

The charts are based upon observations made chiefly within the five-year period 1957-61 by radiosonde and radar wind-finding equipment. All available ascents, irrespective of hours of observation, were used in the computation of the averages and standard deviations. As the period included the International Geophysical Year (IGY) and the subsequent period of the International Geophysical Co-operation (IGC), data from two radiosonde ascents per day were available for many areas from July 1957 to October 1959 but for the remainder of the period published data for only one ascent per day were readily available for many countries. Apart from the IGY/IGC microcards[†] the main source of the daily values was the *Daily Series, Part II Data Tabulations*[4] but, in addition, the publications of individual countries were used where these provided data at both hours of ascent.

The individual values of contour height, temperature and wind were punched on to paper tape for some 400-450 stations[ø] (about 200 stations in February and March when the charts were restricted to the area north of 45°N) and the results were obtained by means of the Meteorological Office electronic computer. The machine programme provided individual monthly means but the averages and standard deviations were computed from all ascents during the period and no weighting factor was applied to a year with a small number of observations.

Over some parts of the hemisphere the data coverage at the 50-mb level was adequate for analyses of winds, contour heights and temperatures, with homogeneous observations covering a large area, for example much of North America. For many stations, however, the data, covering only one or two years, were few and in the final analysis of the charts a good deal of subjectivity was inevitable. Regard was paid to the total number of ascents reaching 50 mb and to the number

* The index numbers refer to the bibliography on page 59.

† Geneva, World Meteorological Organization. Catalogue of IGY/IGC meteorological data. WMO/OMM, No. 135, IGY/AGI.4, 1962.

ø In this Memoir the spelling of station names follows the recommendations of the World Meteorological Organization.

of years for which data were available but, as might be expected when dealing with such heterogeneous data, there were sometimes significant differences between averages based on comparable numbers of observations at neighbouring stations. In general, in areas where ascents did not regularly reach 50 mb there were more (in some cases, for example China, many more) temperatures recorded than either winds or contour heights. This is because use was made of the additional levels reported near 50 mb. Any readings in the range 55–45 mb were extracted but no attempt was made to interpolate or extrapolate to obtain the height of the 50-mb surface.

The frequency with which radiosonde and radar wind ascents reach the 50-mb level is determined not only by the quality of the equipment and instruments used but also by the winds and temperatures prevailing at the time of the ascent. As a consequence more ascents reach this level in conditions of lighter winds and warmer temperatures than is the case when winds are strong and the lower stratosphere is relatively cold.

At tropical stations using the Meteorological Office radiosonde Mark 2B, temperature data for 1962-64 or 1961-64 were used because it was found that the earlier data gave spuriously low average temperatures and large standard deviations which, it was established, were very largely due to instrumental errors.

Corrections to the average temperatures and contour heights, to make allowance for the different types of radiosonde instruments, were evaluated using values given by Hawson.[5] In general over the northern hemisphere (except Africa) little account was taken of these corrections because they suggested relatively small changes in the average temperatures during all months. The most significant changes were in the average contour heights for July and so, in the analysis of the July charts, the revised contour heights were often used.

PART I – AVERAGE TEMPERATURES AT 50 MILLIBARS AND THEIR VARIABILITY

§1 – GENERAL

The charts of the distribution of average temperature at 50 mb cover the northern hemisphere for the months of January, April, July and October (Plates 1, 3, 4 and 5) but charts from the pole to 45°N for February and March (Plates 2A and 2B) are included in order to assist in the understanding and interpretation of events leading up to the 'final warming' and the usually rapid breakdown of the winter régime in higher latitudes. South of 45°N interpolation between the January and April charts is considered adequate for most practical purposes. Corresponding charts of standard deviation of temperature at 50 mb for the same months, together with frequency distributions for a selection of stations, are contained in Plates 6-10.

In a later section of the text which describes some features of the 'final warming', reference is made to the very different thermal régimes that dominate the high-latitude stratosphere during the winter season and the often bimodal character of the temperature distribution. This type of distribution makes useful interpretation of the average temperature and standard deviation extremely difficult and can sometimes give rise to misleading deductions. The charts should, therefore, be used with considerable caution in areas where non-normal temperature distributions prevail, and in order to assist the user in this matter two things have been done:

(i) The frequency distributions of 50 mb temperatures for a selection of stations in different latitudes are given in Figure 6.

(ii) Additional histograms for January, February, March and April are provided alongside Plates 6-8.

Superimposed on these histograms are the theoretical normal distributions obtained by numerical integration of the expression

$$(1/\sigma)\ (2\pi)^{-1/2}\ \exp(-(T - \bar{T})^2/2\sigma^2)$$

where $\bar{T}$ is the average temperature and σ is the standard deviation. Ordinates at intervals of 0.5 degC were used for the integration. The observed and theoretical frequency-distributions provide information for latitude bands from 80°N to 45°N in the North American and Atlantic/European sectors. Over Asia the data coverage at 50 mb is poor, but histograms for a few selected stations are included.

The selection of histograms included with the charts of standard deviation of temperature (Plates 6-8) together with those in Figure 6 will, in most cases, enable the user to determine for himself those areas in which the temperatures do not conform to the normal distribution.

§2 – DISCUSSION OF THE CHARTS

On the January chart (Plate 1) there is a cold region, centred over the northern half of Greenland/North Pole/Kara Sea/Jan Mayen, in which temperatures are probably colder than −68°C and may be colder than −70°C (perhaps several degrees colder) at the centre. It should be mentioned that over the Arctic from about 60°W through the Greenwich Meridian to beyond 180° the few reporting stations provided very little data. The charts for February and March (Plates 2A and 2B) show that this cold area shown on Plate 1 moves south-east and that monthly average temperatures within it increase to −66°C in February and −58°C in March, by which month the cold centre is situated over north Scandinavia. These three months display patterns that show the winter régime to be present with intensity decreasing from January to March. During this period of the year other climatological features are:

(i) the warm area in the region of Kamchatka where average temperatures are about −45°C, and

(ii) the warm belt around the hemisphere, centred near latitude 45°–55°N in January, which is displaced northwards as the winter progresses.

South of the temperature maximum in middle latitudes there is a decrease of temperature to −68°C to −70°C towards the Equator.

By April (Plate 3) the cold area has disappeared and the pattern resembles the less complicated summer régime typified by the chart for July (Plate 4), when the main feature is a warm area near the North Pole. Within this warm area the average temperatures are a little above −40°C and there is a gradual decrease to values of −62°C to −66°C near the Equator.

Plate 5 shows that by October considerable cooling has taken place over high latitudes and, to a lesser extent, over middle latitudes and the chart exhibits all the features (although they are much less intense) seen on the January chart, which may be regarded as typical of winter. For example the warm area near the pole in summer has given way to a cold area, and a warm area over the Bering Sea has become well established. There is also evidence of the winter stratospheric warm belt around the hemisphere as a whole but the average latitude of this warm belt is several degrees north of the January position.

The average latitude of the warm belt in January, February, March and October can be seen in Figure 1. This diagram shows clearly the large annual variation of average temperatures in high latitudes and the much smaller variation in other latitudes. These variations are shown in

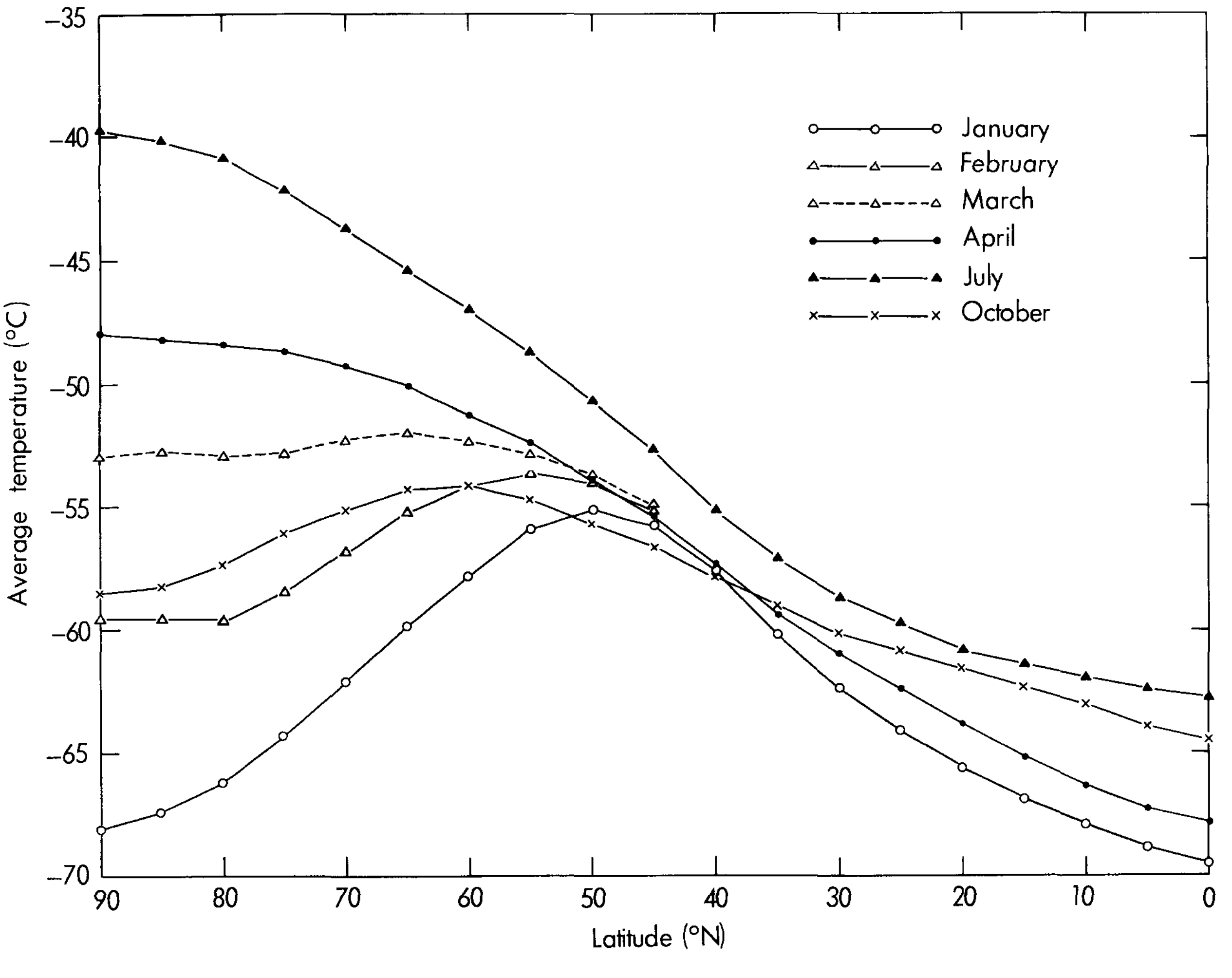


FIGURE 1. TEMPERATURES AT 50 MILLIBARS AVERAGED AROUND LATITUDE CIRCLES

more detail on the charts depicting the changes of temperature between particular months (Figures 2–5).

Figure 2 shows that in an area near the North Pole and north Greenland there is a rise of over 20 degC between January and April. Most of this warming in fact takes place in the period January to March and is dealt with in more detail later in the text under the heading 'The final warming'. It can be seen in Figure 3 that average summer temperatures off north-east Greenland are as much as 30 degC warmer than those of winter whilst in the region of Kamchatka and north Japan, i.e. in the vicinity of the warmest area on the January chart (Plate 1), there is a cooling from winter to summer of about 5 degC.

Figures 4 and 5 show that in high latitudes the October average temperatures are about mid-way between the summer maxima and the winter minima. It is apparent from Figure 5 that the Aleutian/Kamchatka warm area intensifies considerably between October and January with a maximum warming of 6 degC in that region but with little change in average temperature there between July and October. The increase in temperature in middle latitudes over the eastern North Atlantic and over southern Europe and Russia between October and January is due to the southward displacement of the stratospheric warm belt in those sectors.

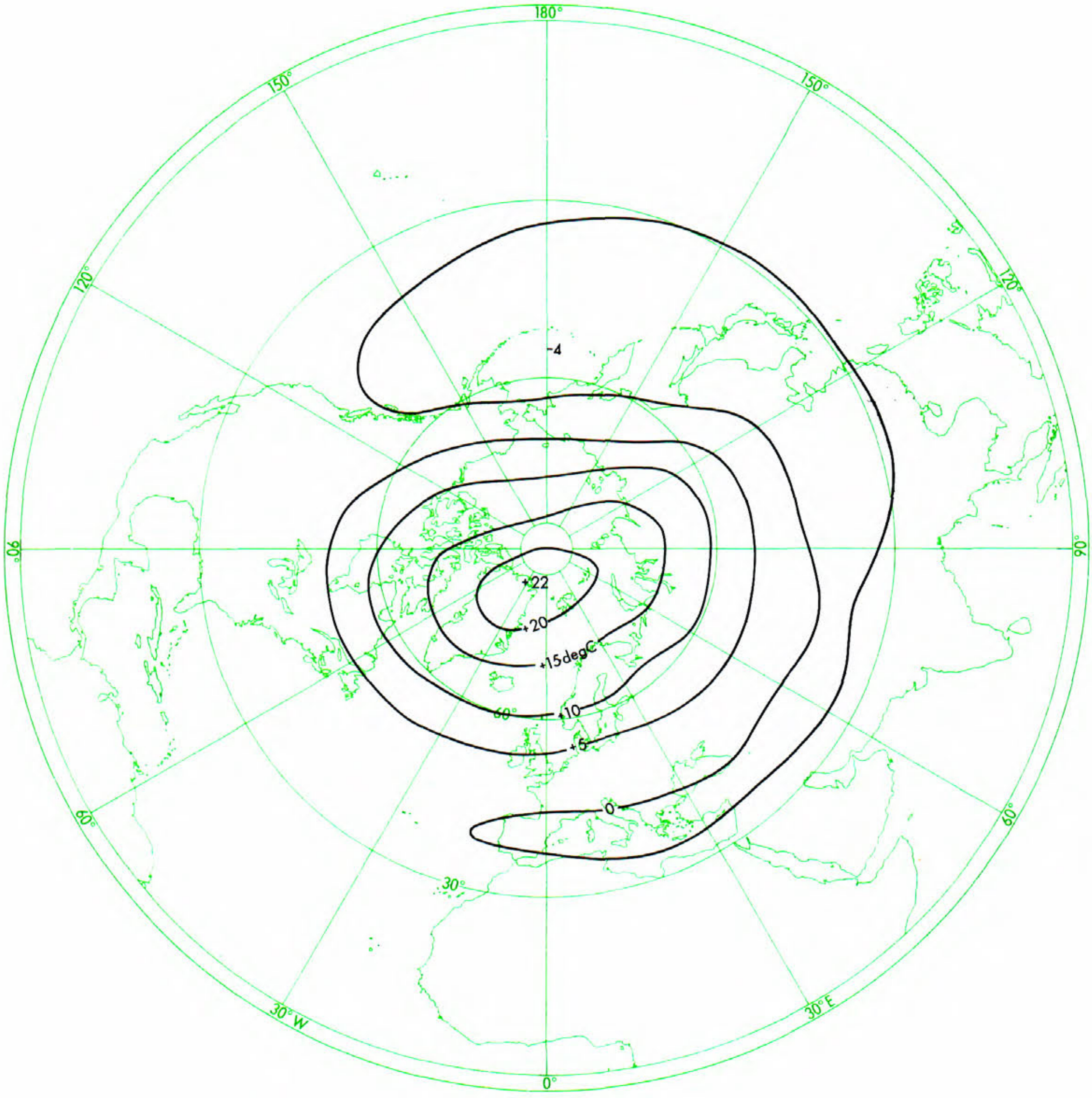


FIGURE 2. CHANGE OF AVERAGE TEMPERATURES AT 50 MILLIBARS, FROM JANUARY TO APRIL, 1957-61

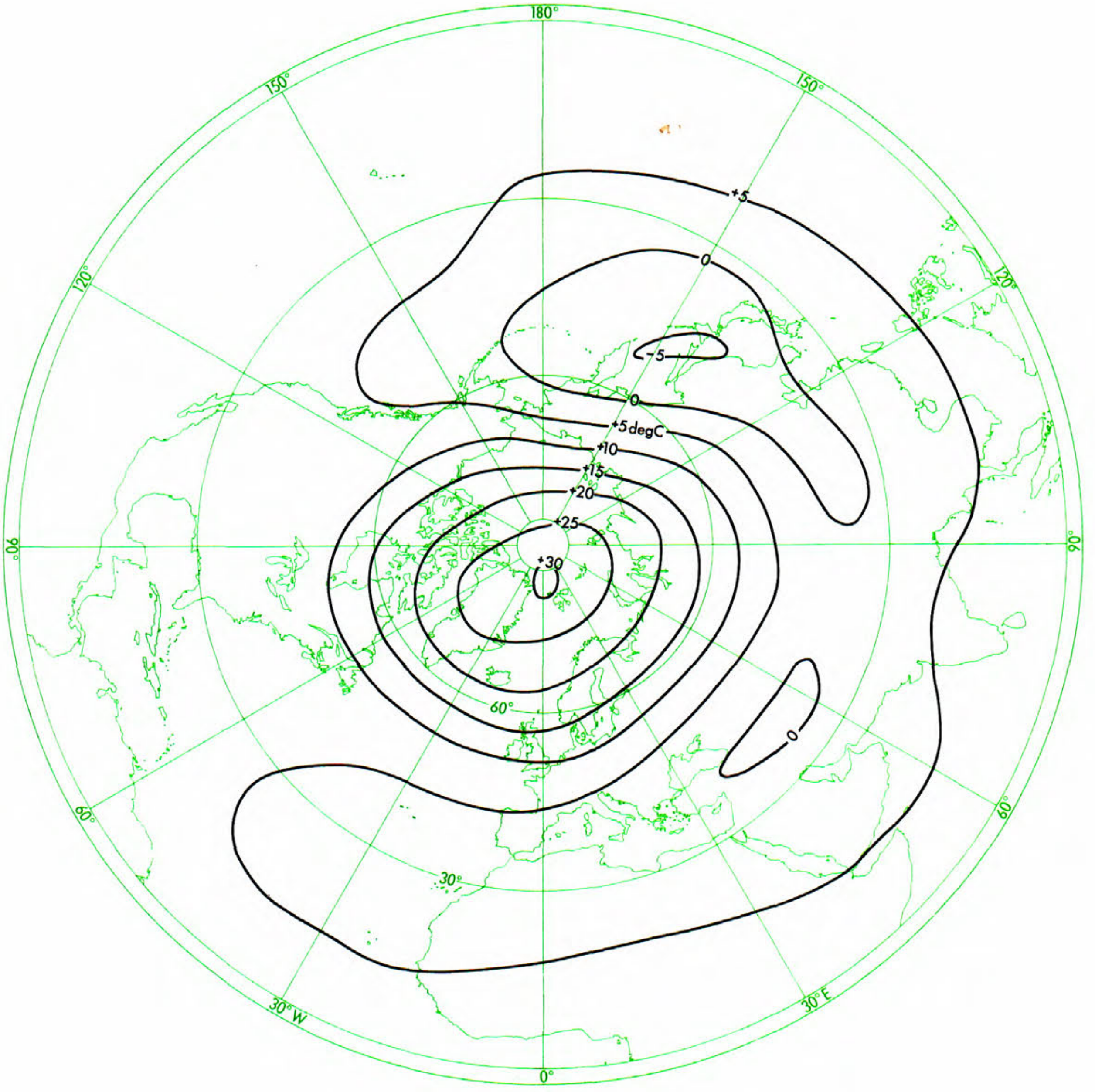


FIGURE 3. CHANGE OF AVERAGE TEMPERATURES AT 50 MILLIBARS, FROM JANUARY TO JULY, 1957-61

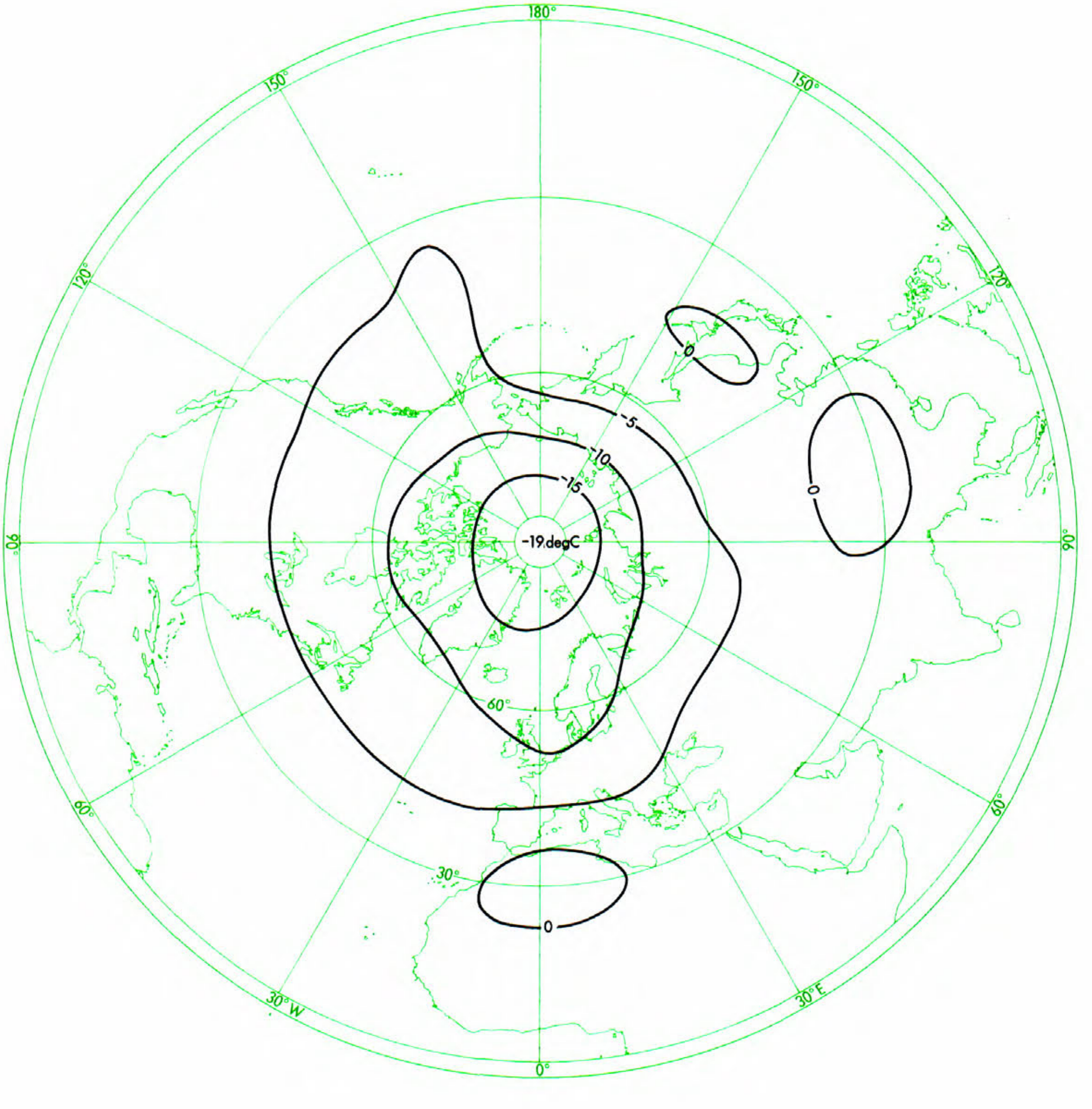


FIGURE 4. CHANGE OF AVERAGE TEMPERATURES AT 50 MILLIBARS, FROM JULY TO OCTOBER, 1957-61

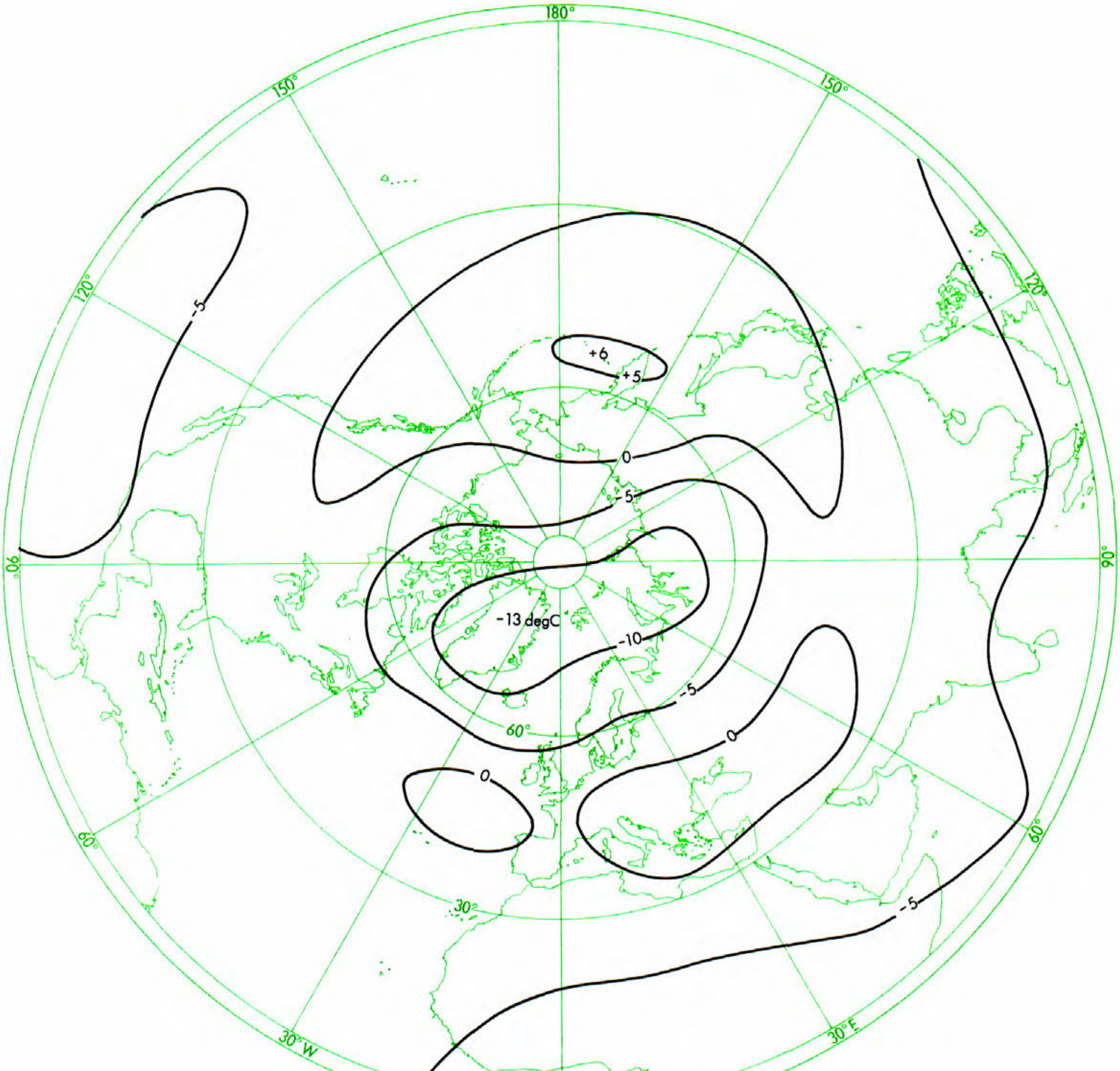


FIGURE 5. CHANGE OF AVERAGE TEMPERATURES AT 50 MILLIBARS, FROM OCTOBER TO JANUARY, 1957-61

In low latitudes there is a relatively small, but noticeable, annual variation, with the maximum values occurring in July and the minimum in January. The charts and Figure 1 indicate that between January and April there is a general but small warming, with a more significant rise between April and July. After July there is a general cooling which is more marked between October and January. In addition to this annual variation, in these low-latitude areas there is also a fluctuation in the monthly mean temperatures, which is associated with the approximately 26-month fluctuation in the zonal wind components. The fluctuation in the temperatures is such that at 50 mb higher temperatures are recorded in a westerly régime than in an easterly régime but the two oscillations are not exactly in phase. The range of this temperature oscillation amounts to about 2 degC.

The charts of standard deviation of temperature at 50 mb, together with frequency distributions for selected stations, are shown in Plates 6-10. The chart for February (Plate 7A) shows that in high latitudes this is the month when variability is at a maximum, with an area off north-east Canada in which the standard deviation exceeds 14 degC (14.8 degC at Alert based on 223 observations in five years). In March (Plate 7B) the variability in high latitudes is less but, as in January (Plate 6), there is an area over north-east Canada and north-west Greenland where values exceed 10 degC. The April chart (Plate 8) shows the high-latitude lower-stratospheric temperature régime to be much less variable, with values of 5 degC over the pole. In July (Plate 9) the standard deviation in high latitudes is less than in April; in October (Plate 10) over a large part of the hemisphere the values are approximately 2.5–3.5 degC and the variability is comparable with that in July.

On all the charts there is a suggestion of higher values in low latitudes over Africa, India, south-east Asia and China. As was mentioned earlier, data for 1962-64 (or in some cases 1961-64) were used from tropical stations where the Meteorological Office radiosonde Mark 2B was in use. These more recent data gave lower standard deviations (to which the isopleths have been drawn) but it is apparent that in areas where the temperature is increasing rapidly with height the standard deviation of temperature is very sensitive to errors in the pressure element. It seems very probable, therefore, that in spite of a modification made to the pressure element in recent years part of the variability is still attributable to instrumental errors, which can only increase the observed standard deviation. The paucity of data in these particular low-latitude areas makes reliable analysis difficult and it seems likely that a knowledge of the true standard deviation of lower-stratospheric temperatures there must wait until more plentiful and more reliable data are available. However, the charts show that over the remainder of the low-latitude band of the hemisphere the standard deviation is generally 2–3 degC with little or no annual variation.

The frequency distributions of 50-mb temperatures for a selection of stations in different latitudes are given in Figure 6 and the relevant statistics are presented in Table I. These histograms, and those for high-latitude stations which accompany the standard deviation charts (Plates 6–8), confirm the findings of McClain[6,7] that in winter the frequency distributions of lower-stratospheric temperatures in some high latitudes are distinctly bimodal. From the histograms for Alert and Eureka especially it can be seen, as McClain has pointed out, that in winter the arithmetic average is very nearly a least-likely estimate of the temperature and also that the standard deviation becomes difficult to interpret. The histograms for Adak, situated within the Aleutian stratospheric warm area, illustrate that the cold régime never establishes itself there during the winter months. At Crawley, at a comparable latitude on the other side of the hemisphere, it is evident that much wider fluctuations of temperature occur. The lower-latitude stations all show a unimodal temperature distribution in January, and the histograms for April, July and October show that the lower-stratospheric temperature distribution is nearly normal over the hemisphere generally.

TABLE I – AVERAGE 50-MILLIBAR TEMPERATURES AND STANDARD DEVIATIONS FOR THE STATIONS FOR WHICH HISTOGRAMS ARE GIVEN IN FIGURE 6

	Alert 82° 30′N, 62° 20′W				Eureka 80° 00′N, 85° 56′W				Bødo 67° 16′N, 14° 24′E			
	$\overline{T}$ degrees Celsius	σ	N	Years	$\overline{T}$ degrees Celsius	σ	N	Years	$\overline{T}$ degrees Celsius	σ	N	Years
Jan.	–69.2	9.7	182	1957–61	–65.7	10.4	198	1957–61	–68.0	7.6	80	1958–61
Feb.	–58.5	14.8	223	1957–61	–58.3	13.1	240	1957–61	–63.7	7.1	89	1958–61
Mar.	–53.5	10.3	269	1957–61	–51.8	10.6	264	1957–61	–58.1	5.8	129	1958–61
Apr.	–47.9	5.1	270	1957–61	–47.5	5.4	253	1957–61	–53.8	5.6	127	1958–61
July	–40.4	1.0	290	1957–61	–40.6	1.0	289	1957–61	–45.6	2.2	203	1957–61
Oct.	–58.7	3.3	261	1957–61	–57.2	3.2	274	1957–61	–57.9	3.4	124	1957–61

	Keflavík 63° 58′N, 22° 36′W				Adak 51° 53′N, 176° 39′W				Crawley 51° 05′N, 00° 13′W			
	$\overline{T}$ degrees Celsius	σ	N	Years	$\overline{T}$ degrees Celsius	σ	N	Years	$\overline{T}$ degrees Celsius	σ	N	Years
Jan.	–66.2	7.6	250	1957–61	–47.4	3.0	243	1957–61	–60.6	5.8	184	1957–61
Feb.	–56.9	8.8	254	1957–61	–50.3	3.3	222	1957–61	–59.9	5.6	163	1957–61
Mar.	–55.2	5.9	224	1957–60	–50.1	3.2	220	1957–61	–57.8	3.5	184	1957–61
Apr.	–53.2	3.2	276	1957–61	–51.7	2.8	230	1957–61	–57.0	3.0	177	1957–61
July	–44.2	1.3	287	1957–61	–49.2	2.0	186	1957–61	–50.1	2.4	190	1957–61
Oct.	–56.9	3.8	271	1957–61	–52.8	3.0	254	1957–61	–59.1	2.8	165	1957–61

	Portland 43° 39′N, 70° 19′W				Sapporo 43° 03′N, 141° 20′E				Clark 15° 10′N, 120° 34′E			
	$\overline{T}$ degrees Celsius	σ	N	Years	$\overline{T}$ degrees Celsius	σ	N	Years	$\overline{T}$ degrees Celsius	σ	N	Years
Jan.	–58.1	4.3	224	1957–61	–48.2	3.8	246	1957–61	–64.5	4.4	232	1958–61
Apr.	–55.1	2.8	255	1957–61	–52.3	3.3	199	1957–61	–65.3	2.8	207	1958–61
July	–51.6	1.7	262	1957–61	–53.6	2.1	256	1957–61	–60.9	2.1	252	1957–61
Oct.	–56.6	2.7	249	1957–61	–53.3	2.7	264	1957–61	–61.8	2.2	279	1957–61

	Taguac 13° 33′N, 144° 50′E				Aden 12° 49′N, 45° 02′E				Balboa 08° 56′N, 79° 34′W			
	$\overline{T}$ degrees Celsius	σ	N	Years	$\overline{T}$ degrees Celsius	σ	N	Years	$\overline{T}$ degrees Celsius	σ	N	Years
Jan.	–65.4	2.8	272	1957–61	–68.2	3.8	98	1962–64	–65.9	2.7	228	1957–61
Apr.	–65.2	2.4	281	1957–61	–66.8	3.1	92	1962–64	–65.1	2.7	246	1957–61
July	–60.5	2.1	276	1957–61	–64.2	4.0	83	1961–64	–60.8	2.8	233	1957–61
Oct.	–61.4	2.4	248	1957–61	–66.5	4.2	126	1961–64	–62.3	2.4	204	1957–61

$\overline{T}$ is the average temperature,
σ is the standard deviation and
N is the number of observations

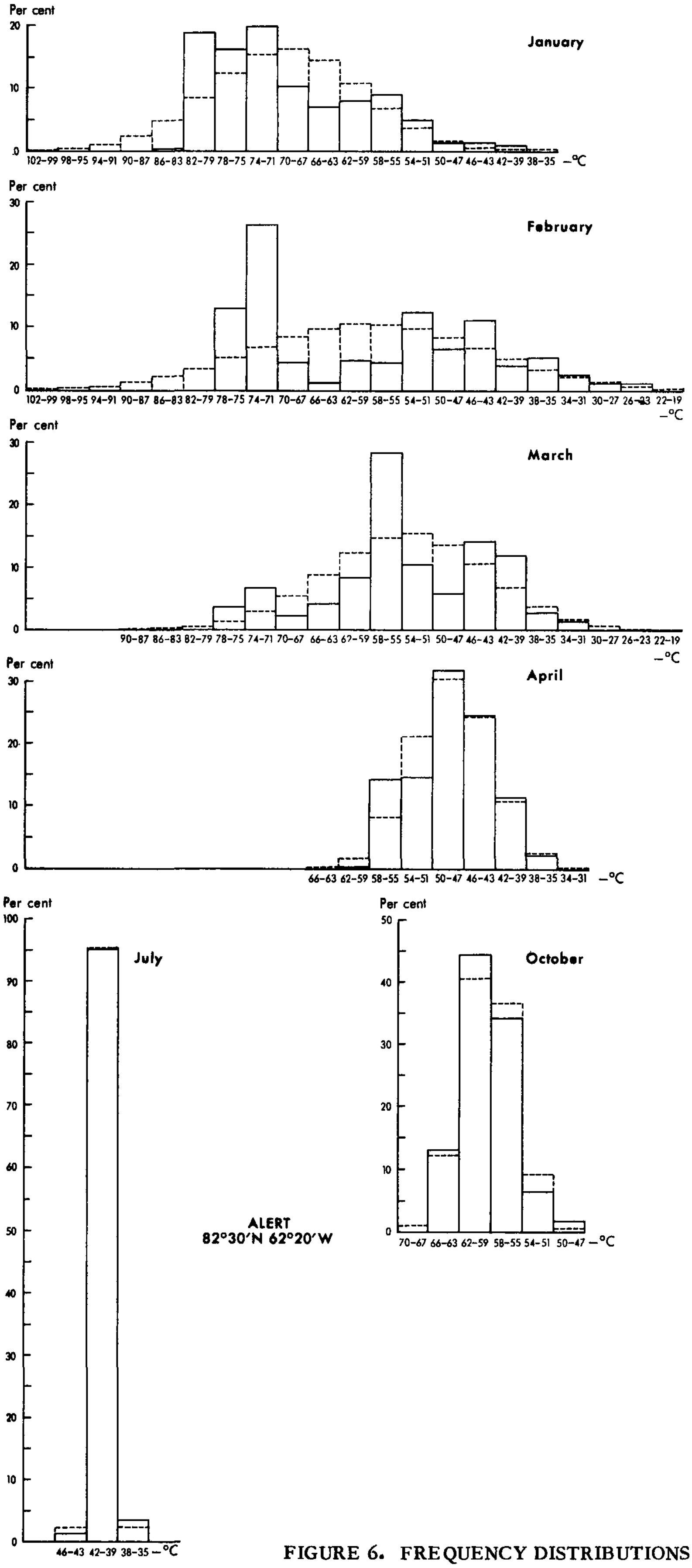


FIGURE 6. FREQUENCY DISTRIBUTIONS OF TEMPERATURE AT 50 MILLIBARS

——— Observed distribution
- - - - - Theoretical distribution
See Table I for relevant statistics

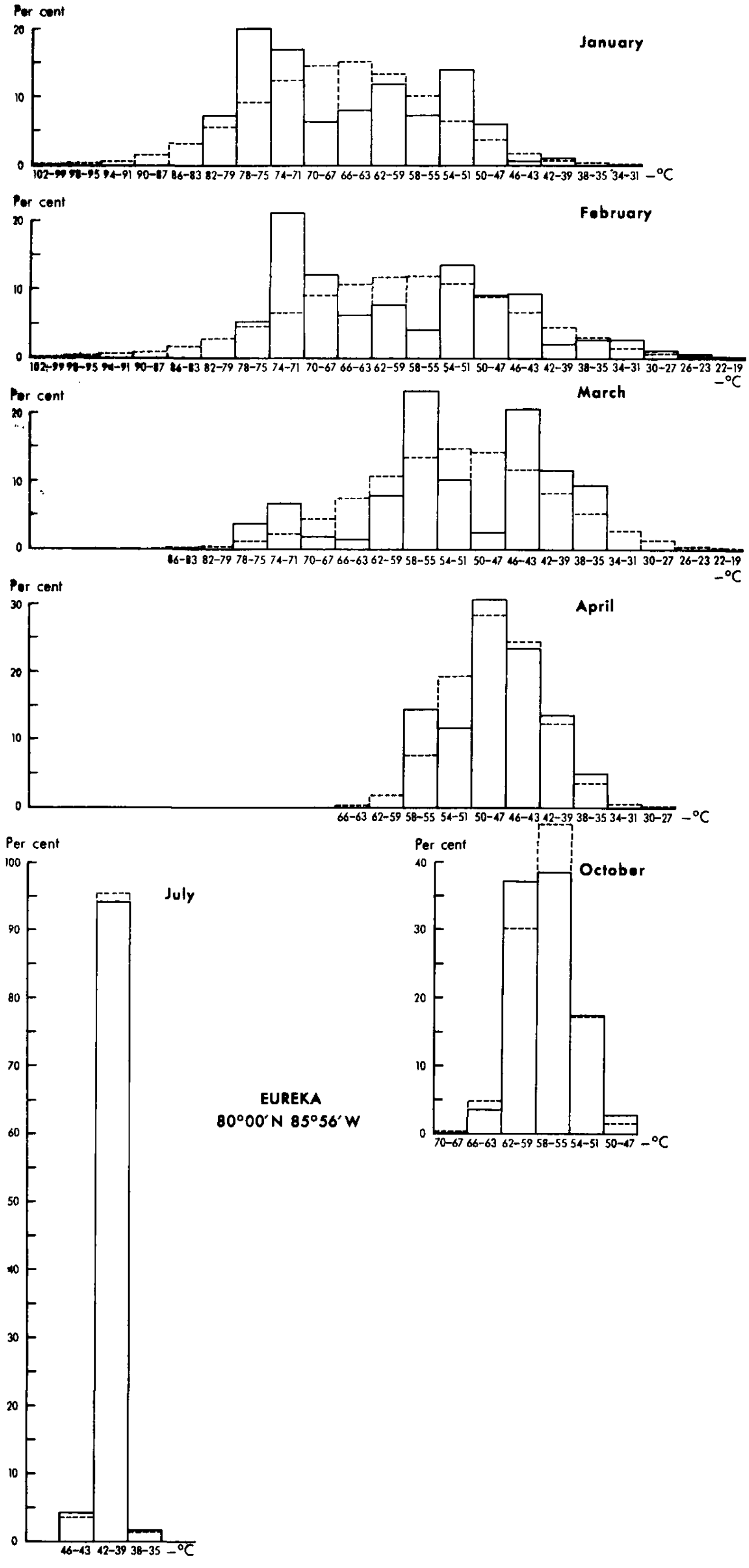


FIGURE 6. FREQUENCY DISTRIBUTIONS OF TEMPERATURE AT 50 MILLIBARS *(contd)*

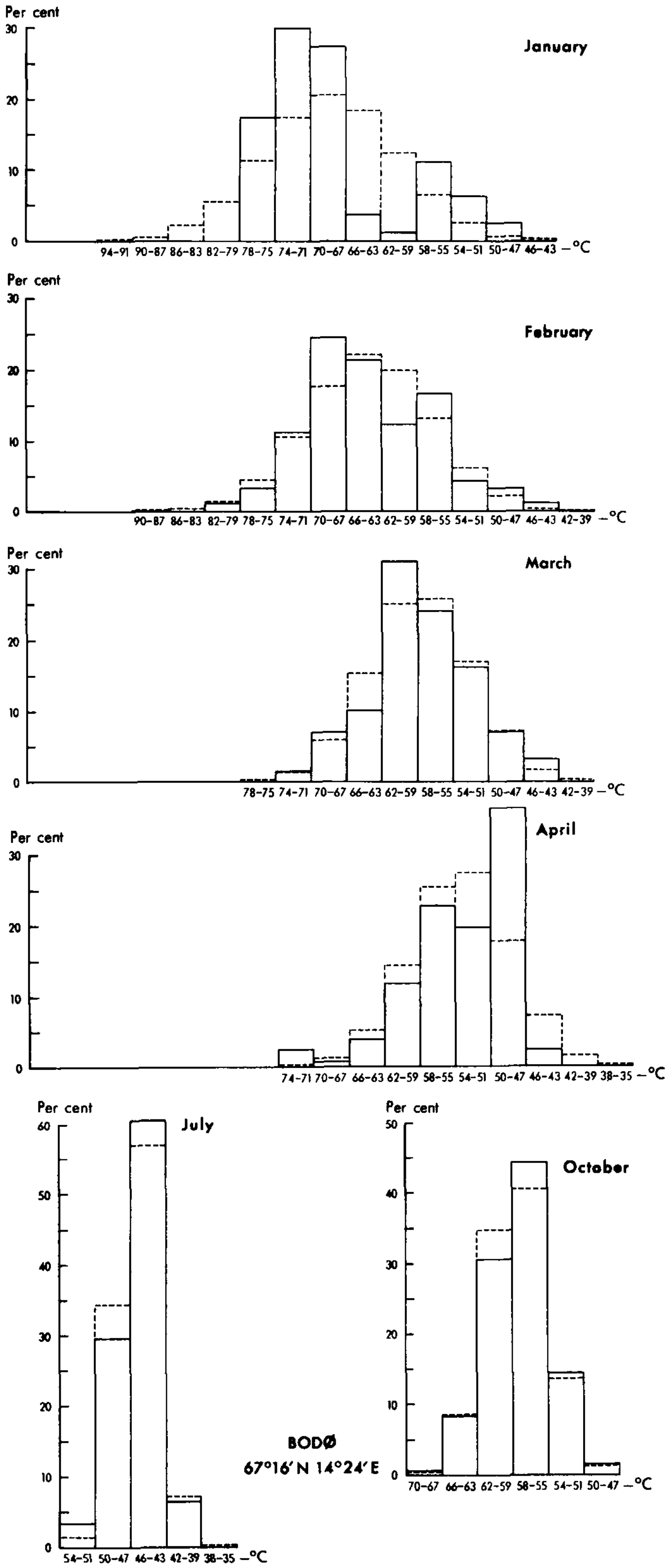


FIGURE 6. FREQUENCY DISTRIBUTIONS OF TEMPERATURE AT 50 MILLIBARS *(contd)*

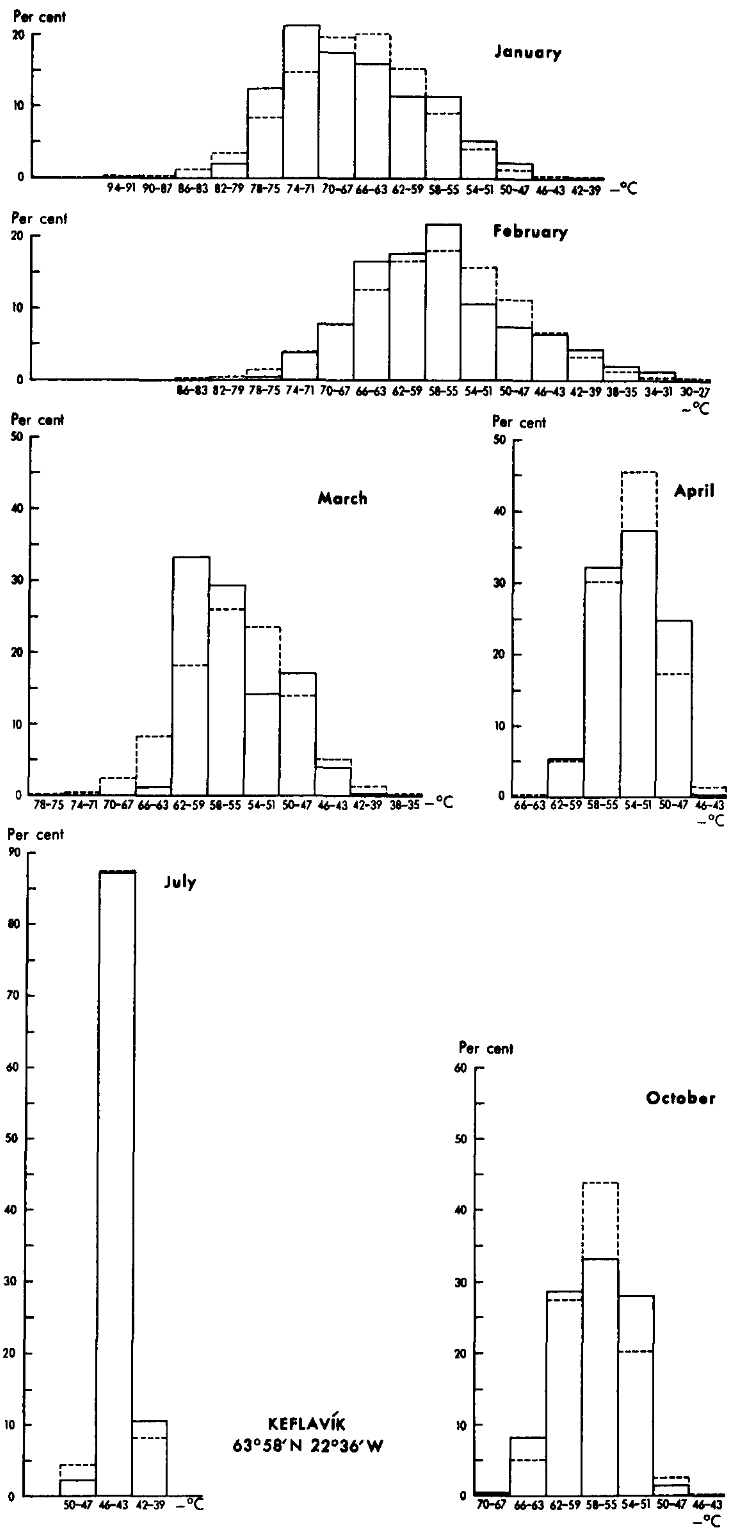


FIGURE 6. FREQUENCY DISTRIBUTIONS OF TEMPERATURE AT 50 MILLIBARS *(contd)*

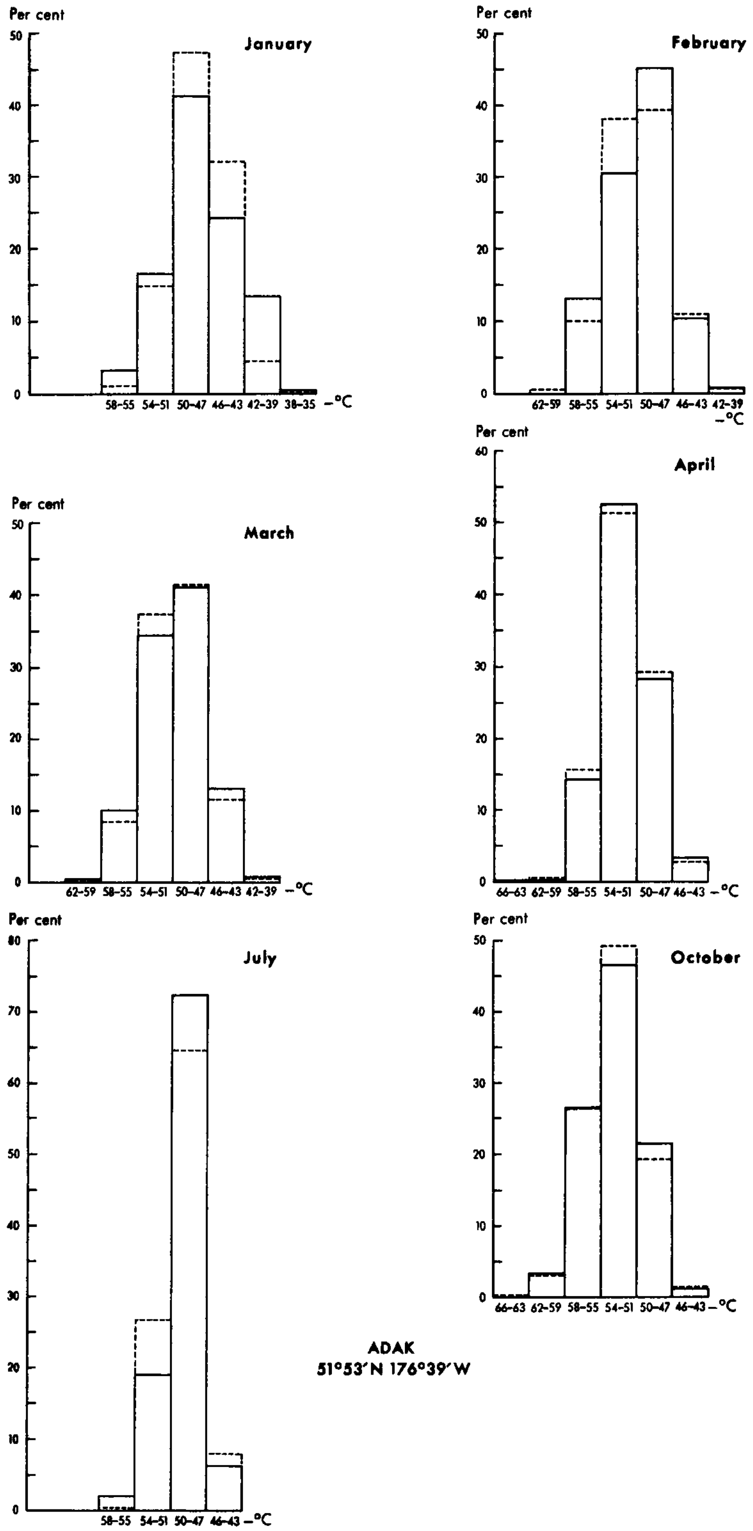


FIGURE 6. FREQUENCY DISTRIBUTIONS OF TEMPERATURE AT 50 MILLIBARS *(contd)*

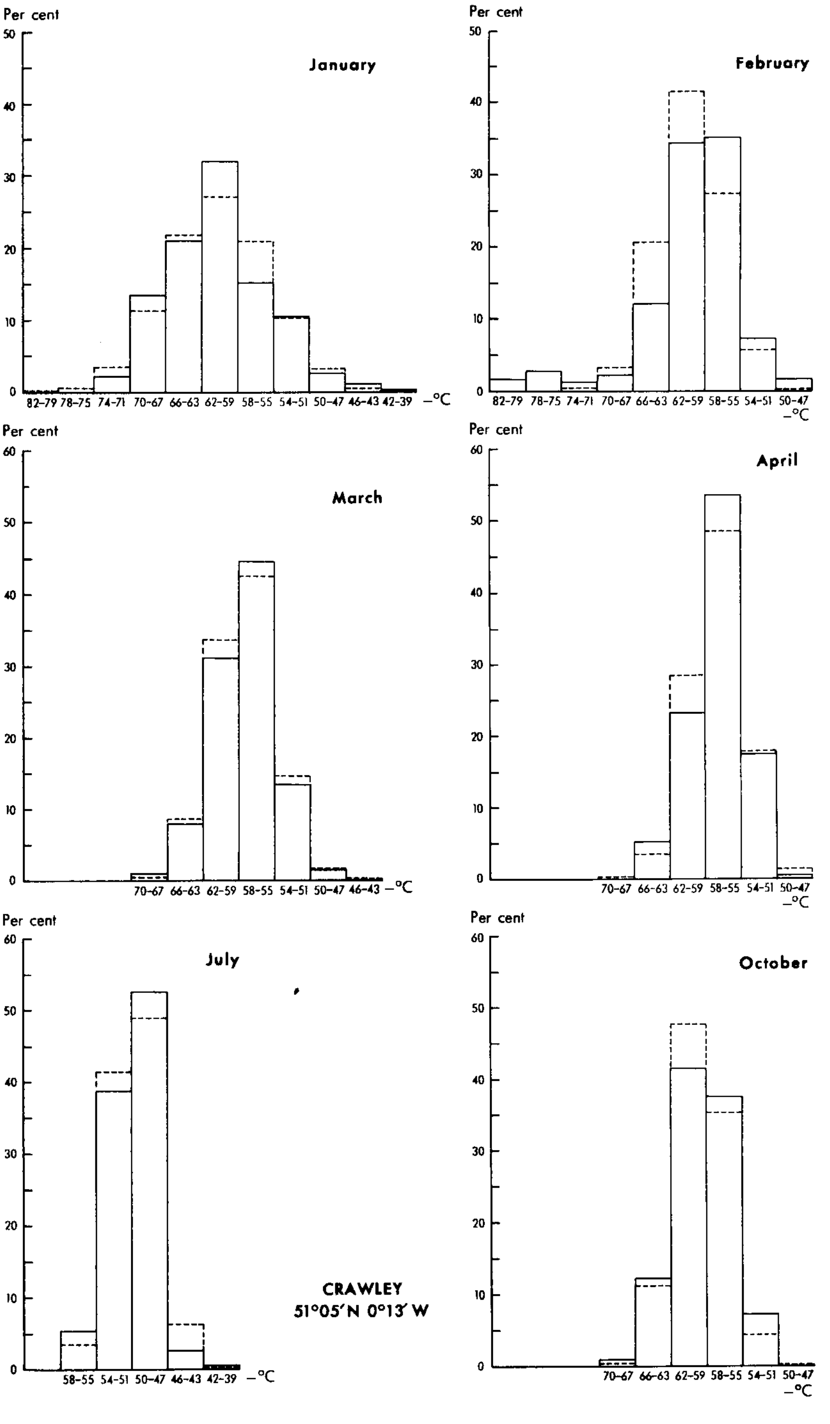


FIGURE 6. FREQUENCY DISTRIBUTIONS OF TEMPERATURE AT 50 MILLIBARS *(contd)*

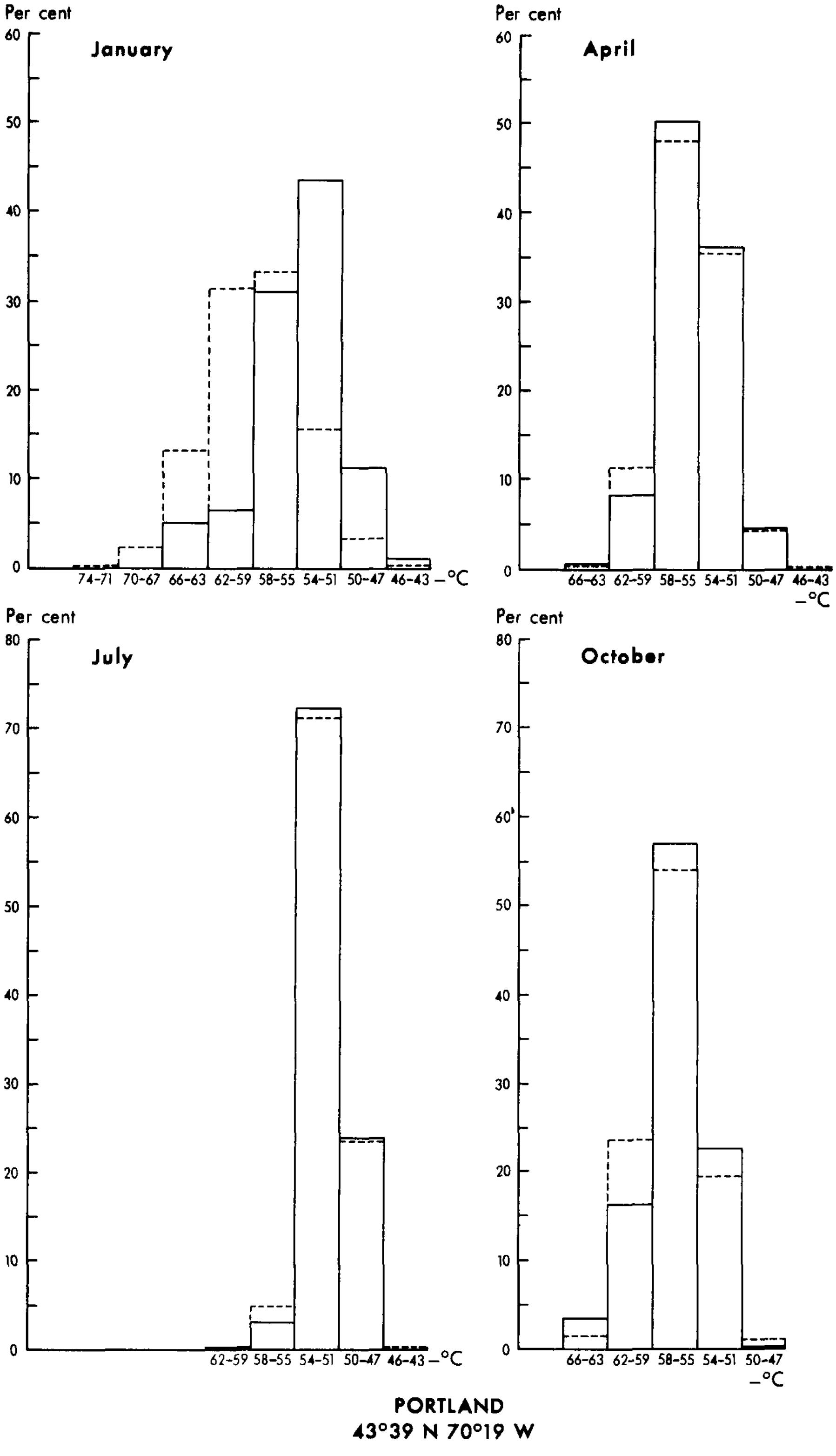


FIGURE 6. FREQUENCY DISTRIBUTIONS OF TEMPERATURE AT 50 MILLIBARS *(contd)*

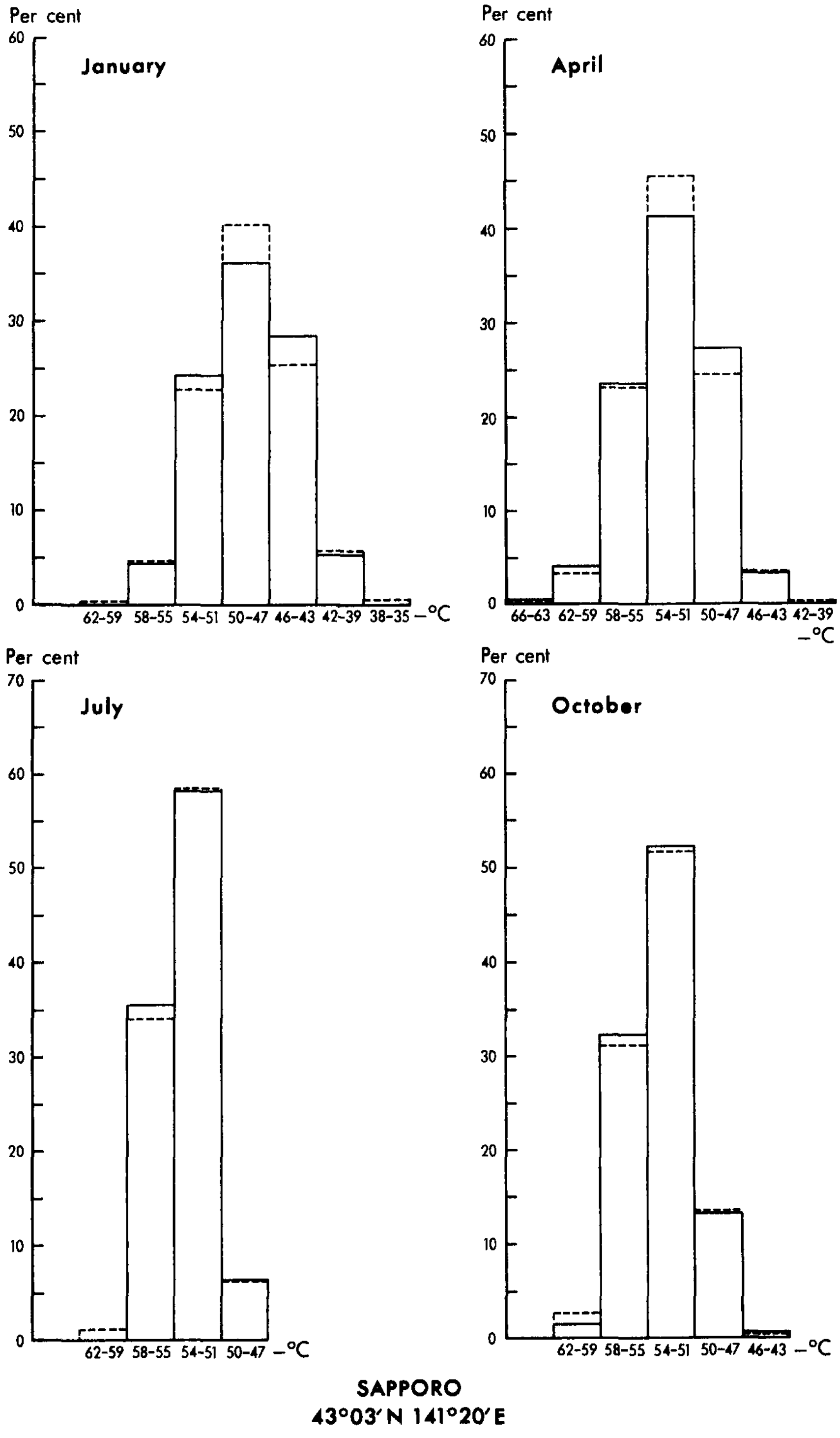
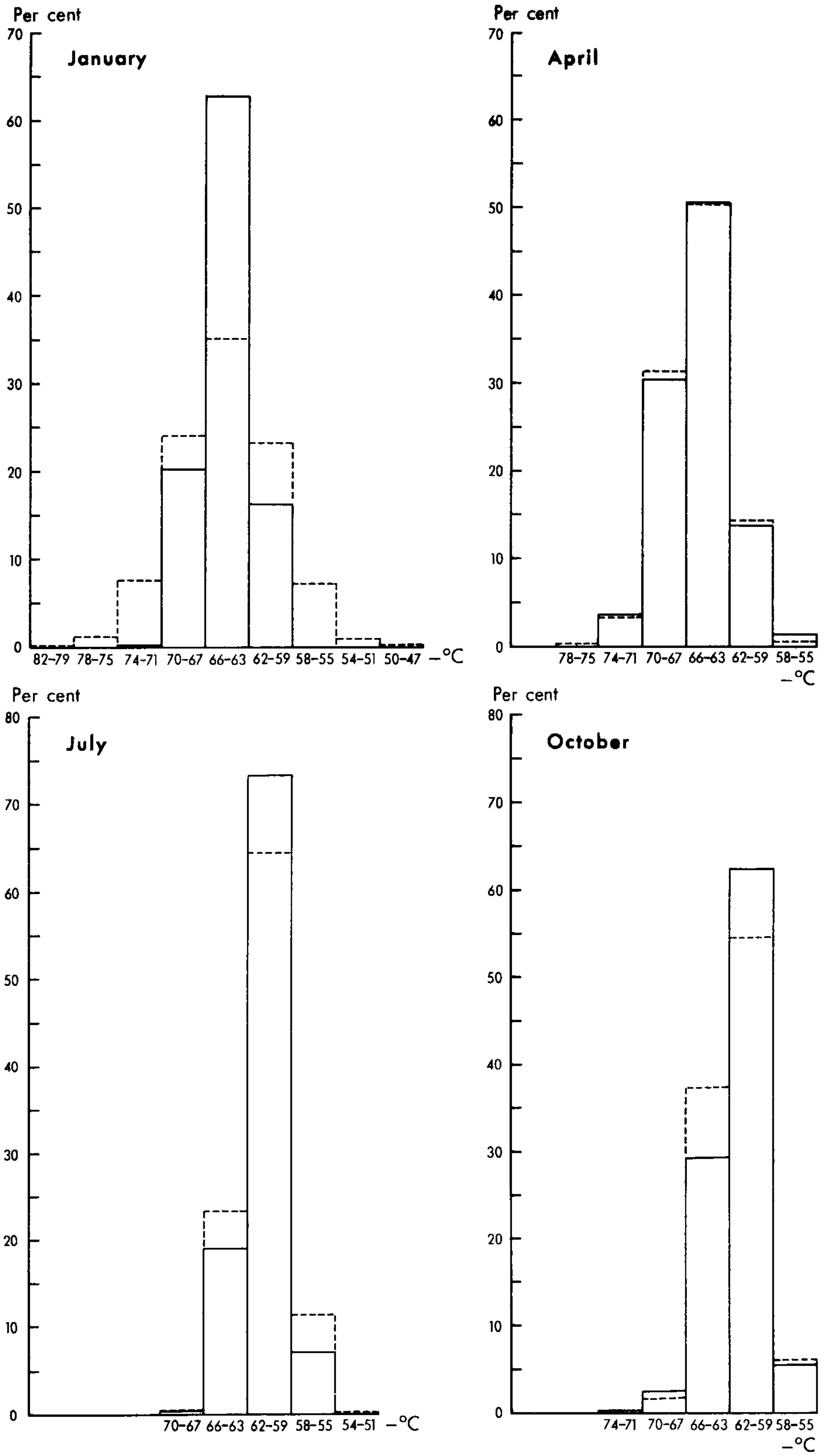


FIGURE 6. FREQUENCY DISTRIBUTIONS OF TEMPERATURE AT 50 MILLIBARS *(contd)*



CLARK
15°10′N 120°34′E

FIGURE 6. FREQUENCY DISTRIBUTIONS OF TEMPERATURE AT 50 MILLIBARS *(contd)*

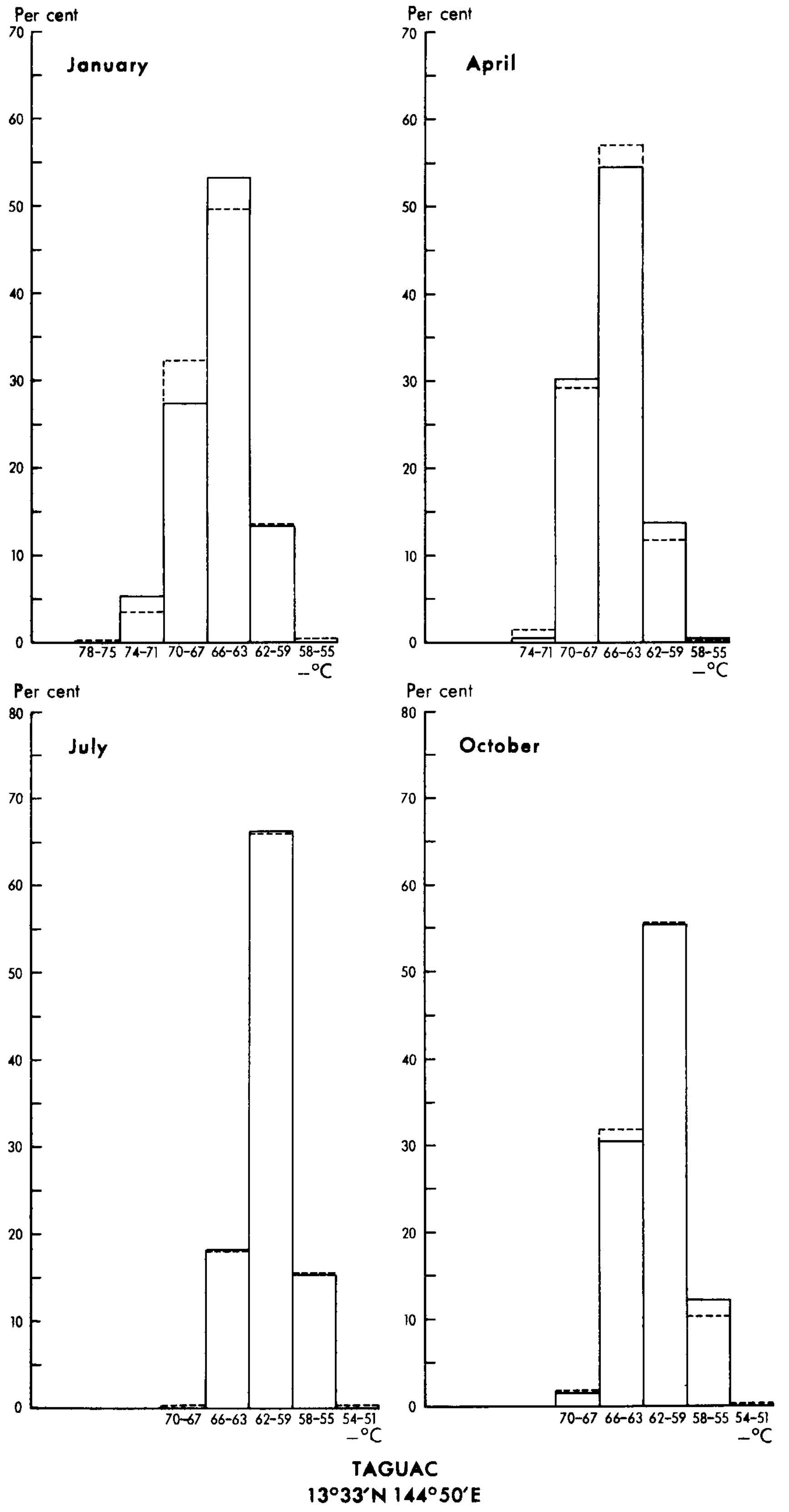


FIGURE 6. FREQUENCY DISTRIBUTIONS OF TEMPERATURE AT 50 MILLIBARS *(contd)*

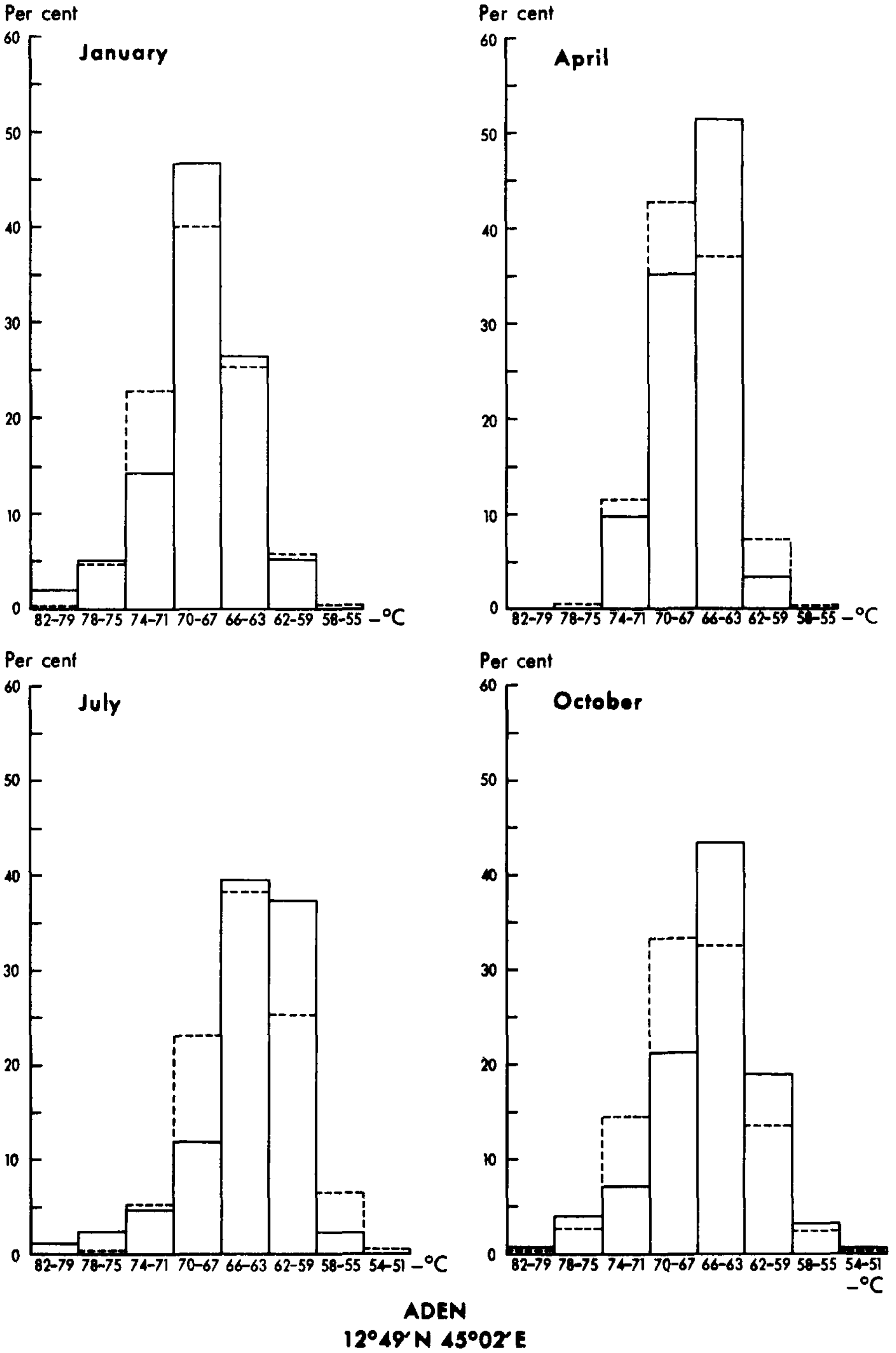


FIGURE 6. FREQUENCY DISTRIBUTIONS OF TEMPERATURE AT 50 MILLIBARS *(contd)*

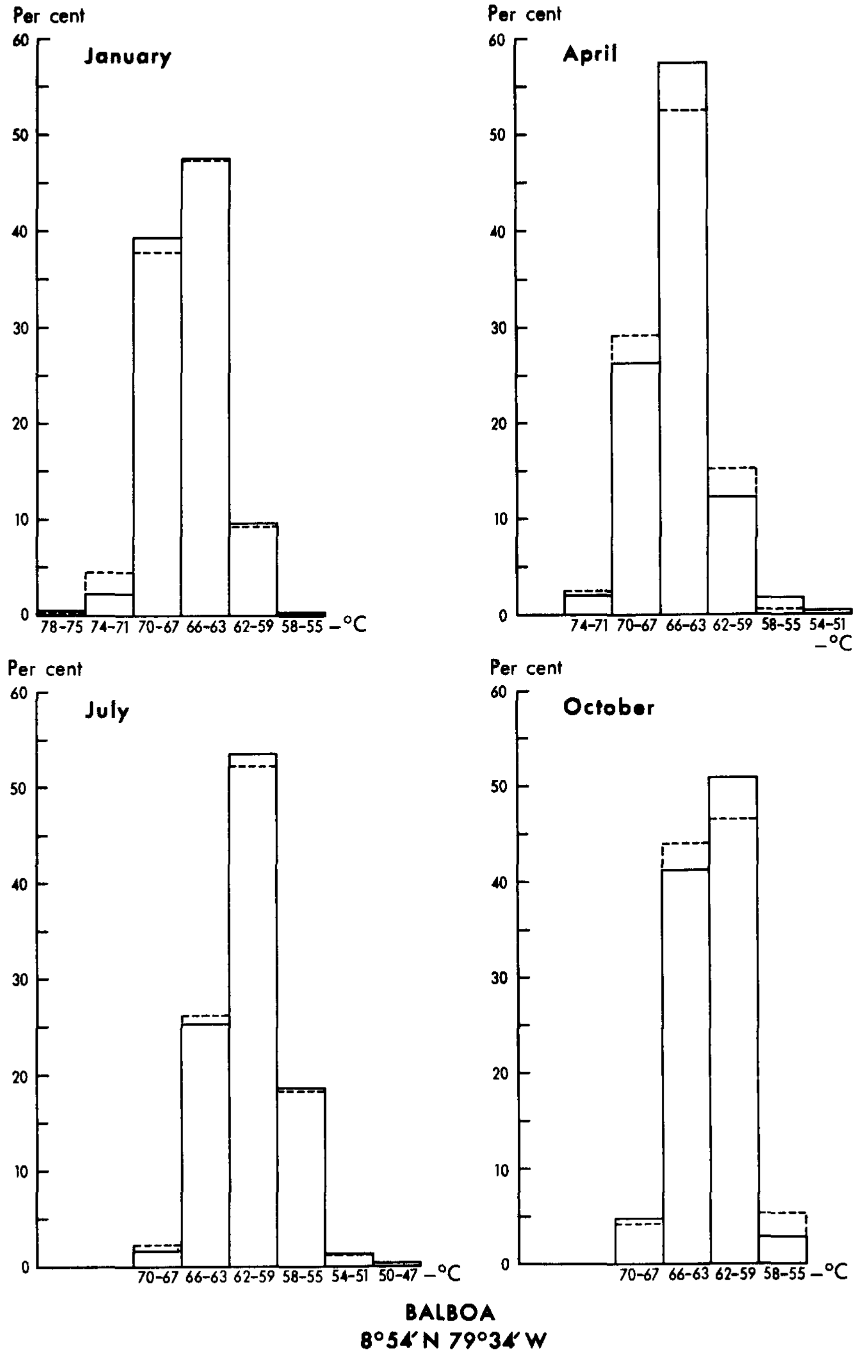


FIGURE 6. FREQUENCY DISTRIBUTIONS OF TEMPERATURE AT 50 MILLIBARS *(contd)*

§3 – THE FINAL WARMING

Reference has already been made to the warming of the lower stratosphere in high latitudes when the polar vortex, which is a typical feature of the winter charts, collapses at dates varying between approximately late January and April. The collapse of the vortex is accompanied by large temperature-oscillations with, at some stage, a sudden and rapid warming (often of about 30 degC) which can be described as the 'final warming', and the temperature curves for Alert in Figure 7 illustrate the considerable year-to-year differences in the time of this final warming. In both 1958 and 1962 temperatures at 50 mb were about –80°C in January but in 1958 the warming started near the end of the month and by 1 February a temperature of –30°C was recorded. This was followed by a more gradual cooling to about –47°C by the end of April. In 1962 there were brief periods in early February and mid-March when the temperature rose above –60°C but the final warming, after which temperatures remained above –60°C, did not occur until early April. Figure 7 shows that in spite of the very large differences between the two years, 1958 and 1962, during the late winter and spring, these differences cease to be apparent in July and the curves illustrate the small variation from one July to another.

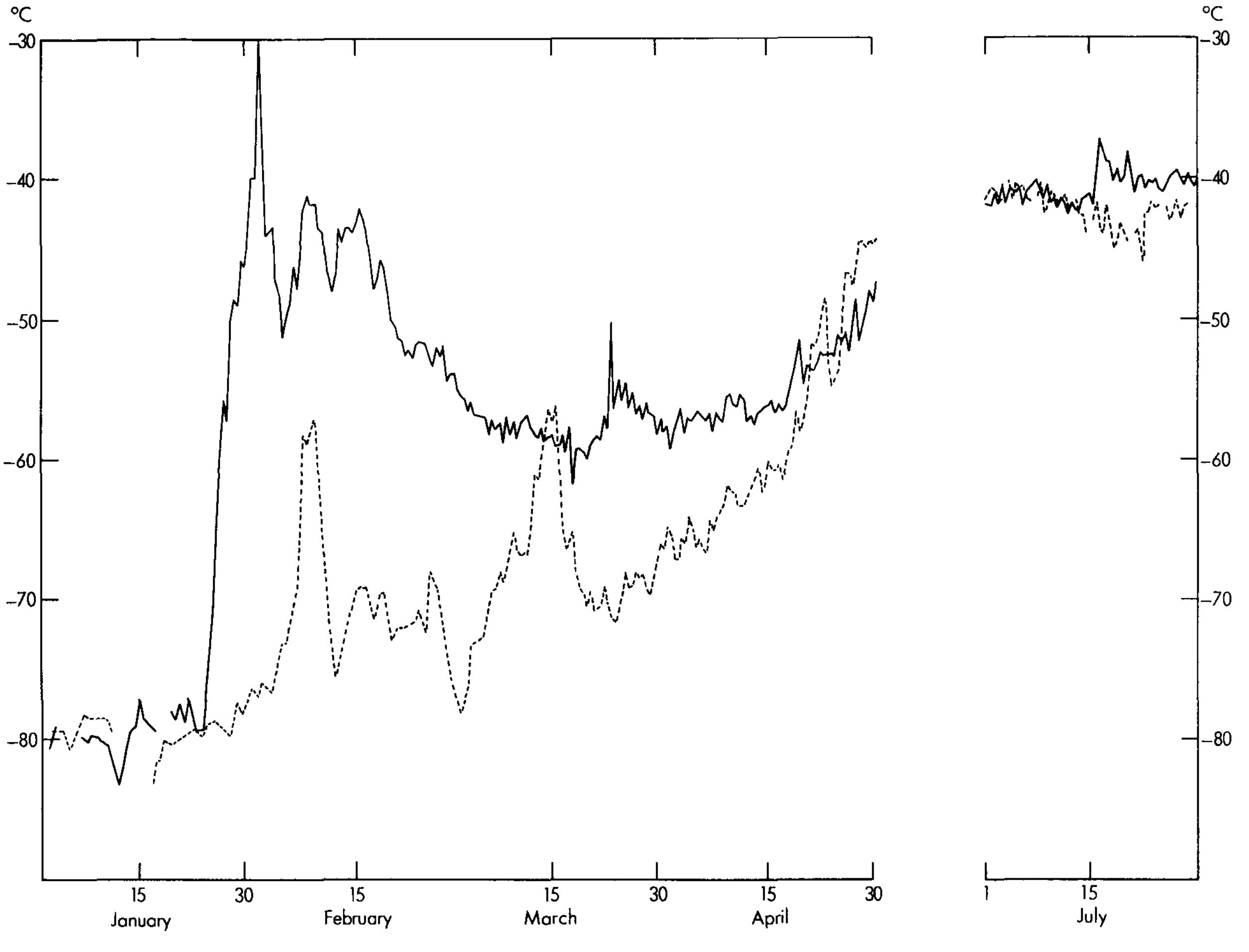


FIGURE 7. TEMPERATURES AT 50 MILLIBARS AT ALERT FOR JANUARY TO APRIL AND FOR JULY, 1958 AND 1962

——— 1958 -------- 1962

It must be remembered that the actual patterns associated with the final warming and the breakdown of the vortex can, and do, differ considerably from year to year (Hare,[8] Wilson and Godson[9]). As a result of these large differences in the wind, contour height and temperature fields between one year and another in high latitudes it must be emphasized that:

(i) the averages over a five-year period are not representative of a single year and it may require many more years data before a representative long-term average is established, and

(ii) the standard deviations contain a large element of year-to-year variation – the deviations from the monthly mean in a single month are substantially smaller in some areas than in others.

After the final warming there is a rapid change from isotherm patterns typical of winter to those more representative of summer.

McClain[7] divided the high-latitude zone into three sectors, each with a different thermal régime in winter and, using data up to the 100-mb level, he showed that relatively low temperatures prevailed in the Scandinavian and west Russian sector whilst in the Alaskan and east Russian sector relatively high temperatures predominated. The remaining sector, covering east Canada and north Greenland, experienced both types of régime but the colder one was the more frequent of the two. Consequently during the winter season parts of the Arctic stratosphere are, in fact, dominated by two very different thermal régimes, as is indicated by the distinctly bimodal character of the relevant histograms in Figure 6. An examination of the data for Alert and Eureka for the period 1955-62 for January and April, and for the period 1957-62 for February and March, shows the following estimated percentages of 'cold' and 'warm' days in those months (Table II).

TABLE.II – ESTIMATED PERCENTAGES OF 'COLD' AND 'WARM' DAYS AT 50 MILLIBARS

	January		February		March		April	
	Warm	Cold	Warm	Cold	Warm	Cold	Warm	Cold
	per cent							
Alert	25	75	41	59	70	30	97	3
Eureka	30	70	50	50	77	23	99	1

Warmer than –64°C was taken as 'warm'

A detailed analysis of the data from these same two stations for the eight years 1955-62 is given in Table III and this shows that the monthly mean temperature for January varied between –50°C and –79°C with individual ascents recording extreme values of –40°C and –83°C. In February the monthly mean varied from –41°C to –74°C with extreme values of –22°C and –78°C. Although the variability becomes much less by April there are still considerable differences in the individual monthly mean values, e.g. from –42°C in 1960 to –58°C in 1962. In July the monthly mean temperatures vary little, with individual ascents recording extreme values of –35°C and –46°C. It is of interest to note that the data show that over north-east Canada, during this eight-year period, both the highest and the lowest temperatures were recorded during winter months. The highest temperature recorded (–22°C) occurred in February 1957 and the lowest (–83°C) occurred in January 1958 and January 1962.

As has been mentioned, the type of distribution experienced at these stations in winter and spring as well as presenting problems regarding average monthly or seasonal temperatures also makes interpretation of the standard deviation of all the observations difficult. Although the average standard deviation proves to be about 14 degC in February it is in fact about 4 degC in a month when either the cold (as in 1959) or the warm (as in 1958) régimes persist. In his more detailed work on the climatology of the Arctic stratosphere in January, McClain[6] split the distribution at the antimodal class and found that the standard deviation with respect to the warm mode was 4.3 degC while with respect to the cold mode it was 4.2 degC.

TABLE III – 50-MILLIBAR TEMPERATURES AT EUREKA (80° 00′N, 85° 56′W) AND ALERT (82° 30′N, 62° 20′W); MONTHLY MEANS AND EXTREMES

YEAR		JANUARY N	T_m	T_{max}	T_{min}	σ	FEBRUARY N	T_m	T_{max}	T_{min}	σ
			degrees Celsius					degrees Celsius			
1955	Eureka	30	−50	−44	−70		17	−56	–	–	
	Alert	28	−50	−43	−70		14	−57	–	–	
1956	Eureka	0	−75				5	−70	−64	−78	
	Alert	0	−75				0				
1957	Eureka	2	−73	−71	−74		41	−41	−22	−71	11.0
	Alert	9	−76	−73	−79		44	−41	−23	−71	9.9
1958	Eureka	47	−69	−40	−82	12.2	54	−48	−35	−54	3.8
	Alert	41	−70	−40	−83	13.9	55	−47	−30	−54	4.6
1959	Eureka	44	−74	−64	−80	5.0	46	−71	−62	−78	4.0
	Alert	47	−77	−68	−80	3.0	34	−74	−68	−78	2.0
1960	Eureka	44	−59	−48	−75	7.8	50	−62	−52	−74	7.5
	Alert	49	−64	−53	−76	7.8	53	−65	−53	−75	8.1
1961	Eureka	61	−61	−50	−74	7.7	49	−68	−56	−76	4.9
	Alert	45	−66	−57	−74	5.7	37	−72	−63	−77	2.8
1962	Eureka	58	−78	−74	−82		56	−65	−46	−74	
	Alert	24	−79	−76	−83		34	−70	−57	−77	
1957-61	Eureka	198	−65.7	−40	−82	10.4	240	−58.3	−22	−78	13.1
	Alert	182	−69.2	−40	−83	9.7	223	−58.5	−23	−78	14.8

YEAR		MARCH N	T_m	T_{max}	T_{min}	σ	APRIL N	T_m	T_{max}	T_{min}	σ
1955	Eureka	25	−60	–	–		3	−53	–	–	
	Alert	17	−62	–	–		14	−55	−49	−61	
1956	Eureka	11	−52	−42	−67		20	−45	−41	−47	
	Alert	25	−56	−46	−69		22	−45	−41	−48	
1957	Eureka	30	−55	−52	−59	2.0	27	−52	−46	−56	2.9
	Alert	49	−55	−51	−60	2.4	48	−51	−47	−58	2.5
1958	Eureka	60	−57	−53	−60	1.9	58	−54	−48	−58	2.8
	Alert	59	−57	−50	−62	1.7	56	−55	−47	−59	2.9
1959	Eureka	60	−43	−35	−64	5.6	54	−44	−38	−46	2.7
	Alert	57	−46	−37	−71	7.7	53	−43	−39	−45	1.8
1960	Eureka	49	−66	−44	−75	9.5	58	−42	−37	−52	4.2
	Alert	45	−69	−48	−77	7.3	58	−43	−36	−51	3.6
1961	Eureka	61	−42	−34	−54	3.8	56	−48	−45	−50	1.1
	Alert	56	−43	−31	−60	5.6	55	−48	−46	−51	1.0
1962	Eureka	62	−65	−54	−77		60	−57	−43	−66	
	Alert	51	−68	−56	−78		54	−58	−44	−67	
1957-61	Eureka	260	−51.8	−34	−75	10.6	253	−47	−37	−58	5.4
	Alert	266	−53.5	−31	−77	10.3	270	−48	−36	−59	5.1

YEAR		JULY N	T_m	T_{max}	T_{min}	σ
1955	Eureka	39	−42	−41	−43	
	Alert	49	−41	−39	−43	
1956	Eureka	50	−40	−35	−43	
	Alert	49	−41.	−38	−44	
1957	Eureka	57	−41	−39	−43	0.9
	Alert	61	−41	−38	−43	1.0
1958	Eureka	56	−41	−39	−43	1.1
	Alert	62	−41	−37	−43	1.1
1959	Eureka	57	−40	−38	−42	0.8
	Alert	58	−40	−38	−42	0.8
1960	Eureka	60	−41	−38	−44	1.0
	Alert	58	−41	−39	−42	0.8
1961	Eureka	60	−41	−38	−44	0.9
	Alert	51	−40	−38	−43	1.1
1962	Eureka	61	−42	−40	−46	
	Alert	54	−42	−40	−46	.
1957-61	Eureka	289	−41	−38	−44	1.0
	Alert	290	−40	−37	−43	1.0

NOTES

N = Number of observations
T_m = Monthly mean temperature (°C)
T_{max} and T_{min} = highest and lowest recorded temperatures
σ = Standard deviation (degC)

For February and March 1955 monthly means were taken from Climatological Summaries for the Joint Arctic Weather Stations, Toronto. Temperatures at 100 mb – 60 mb were used to estimate the monthly mean for January 1956 and to confirm the values given for January 1957.

PART II – AVERAGE CONTOUR HEIGHTS AT 50 MILLIBARS AND THEIR VARIABILITY

The average contour charts for the 50-mb level are reproduced in Plates 11-15. As with the average temperatures the charts cover the northern hemisphere for the months of January, April, July and October but only from the pole to 45°N for February and March. The corresponding charts of standard deviation of contour height at 50 mb for the same months are contained in Plates 16-20.

§4 – DISCUSSION OF THE CHARTS

The average chart for January (Plate 11) shows the lower-stratospheric circumpolar vortex to be well established in the vicinity of the Kara Sea, with two main troughs in the contour pattern – one over eastern Canada and the other over Siberia. On the February chart (Plate 12A) there is a small eastward displacement of the vortex but it is still centred near Novaya Zemlya and, although there is still a strong westerly circulation around most of the hemisphere north of 45°N, average contour heights within the vortex are a little higher than on the January chart. The troughs over eastern Canada and Siberia continue to be prominent features and in February there is evidence of another mean trough near 30°E over southern Russia.

In March (Plate 12B) although the vortex has drifted a little farther from the pole it is still centred in the region of Novaya Zemlya but is much less intense than on the February chart. The strength of the circulation around the vortex is considerably weaker, with gradients in many areas only half as strong as those in February. (Average heights in the vortex rise by about 200 m from January to February and by about 400 m from February to March.) The three-trough pattern on the February chart is also evident in March but the troughs are weaker features.

On the April chart (Plate 13) there is a weak vortex centred over the north of central Siberia with average heights in that area some 300 m higher than in March. Over the northern part of Siberia the pattern is similar to that on the March chart but elsewhere around the hemisphere, north of about 45°N, the circulation is very much weaker. The small low across Hudson Bay in the average contour pattern is supported by the average winds for stations in that area but it may be representative only of the years examined. In low latitudes the centre of high 50-mb contour heights is at approximately latitude 25°N in April (i.e. some 10° to 15° north of the January position) with the main centre situated over north India.

On the July chart (Plate 14) the weak cyclonic vortex in high latitudes in April has been replaced by a region of high contour heights with maximum values of 21.1 km near the pole and there is a very weak circulation pattern over most of the hemisphere north of about 40°N. The lowest average heights (less than 20.7 km) in July occur near the Equator and the July chart shows the disappearance of the high centre over India and south-east Asia which is a feature of the January and April charts.

On the average contour chart for October (Plate 15) there is a radical change from the summer pattern and it has many of the features which are characteristic of the lower-stratospheric winter circulation. The circumpolar vortex is well established near the pole where the lowest average heights are less than 20.1 km (i.e. about 1 km lower than in July but still 0.7 km higher than the average January values). The region of highest average heights is at approximately 30°–35°N around the whole hemisphere, having been in high latitudes in July and nearer the Equator in January.

The charts of standard deviation of contour height at 50 mb are shown in Plates 16–20. In high latitudes the values for January and February (Plates 16 and 17A) are very similar, with an area over north-east Canada and north-west Greenland within which maximum values exceed

500 m. This area almost coincides with the area of maximum variability of temperature at 50 mb in those months. From this maximum area, near the pole, the standard deviation decreases towards lower latitudes to a value of about 100 m near to, or south of, 45°N.

In March (Plate 17B) the highest values (in excess of 300 m) again occur over the Arctic and there is a decrease to 100 m over middle latitudes By April (Plate 18) the maximum (an area within which values in excess of 200 m occur) is situated over the Russian Arctic and Siberia whilst in low latitudes the area of low (i.e. mainly 50-100 m) standard deviation is more extensive than in January, extending northwards to near 55°N over North America and probably to near 30°-35°N over Asia.

The July chart (Plate 19) shows a further reduction in the variability of the contour heights. The highest values – limited areas in excess of 150 m – occur between 60° and 65°N over Russia and Siberia but over much of the hemisphere the standard deviation is less than 100 m with considerable areas in which it is less than 50 m. The chart for October (Plate 20) is very similar to that for April with maximum values in excess of 200 m over the Arctic and Siberia and minimum values of 50-100 m in lower latitudes.

PART III – AVERAGE WINDS AT 50 MILLIBARS AND THEIR VARIABILITY

§5 – GENERAL

Wind data were extracted and processed for nearly all available stations in the northern hemisphere and the streamline/isotach charts (Plates 21-25) were constructed from the average winds. Charts of average zonal and meridional components and their standard deviations are shown in Plates 26-30 and 31-35 respectively.

The charts have been analysed to the Equator but, because of the approximately 26-month fluctuation in the zonal component of equatorial and tropical stratospheric winds, it is essential to exercise considerable caution when using the values obtained in low latitudes. A section dealing with some aspects of this phenomenon is included later in the text but it is quite apparent that, wherever the approximately 26-month fluctuation in the zonal component is the dominant feature, the wind distribution is neither homogeneous nor circular[10] about the long-period average wind for a particular month. Non-circularity of the wind distribution, although most marked in lower latitudes, is not confined to these areas. During recent years doubts have often been expressed about the validity of the assumption that the winds are, in fact, circularly distributed – especially in some areas of the world – and several workers have shown that there is a marked tendency for the distribution to be elliptical* rather than circular. [11, 12, 13]

§6 – DISCUSSION OF THE CHARTS

The predominant feature of the January chart (Plate 21) is the mainly westerly flow that covers most of the hemisphere as far south as about 20° to 30°N. These westerly winds reach a maximum in the polar night jet, with average wind speeds exceeding 50 kt in a narrow belt from south-west of Iceland to west of Norway and also from European Russia across Asia to west of Japan. Although observations over the Arctic Ocean were few it seems probable that there may also be average wind speeds which are close to 50 kt in an area off the Canadian Arctic islands.

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*A distribution in a series of vector quantities (e.g. winds) such that, when the individual vectors are drawn on a polar diagram, the lines of equal frequency of the vector end points are ellipses centred on the end point of the vector mean wind of the series.

It should be remembered that the centre of the polar night jet is well above 50 mb – probably nearer 10 mb (30 km) – and that it merges with the mesospheric westerly current which has a maximum near 60 km over middle latitudes. To the south of the polar night jet there is a gradual decrease to average speeds of less than 10 kt in low latitudes. The difficulties of trying to arrive at a reliable average wind near to and above the 50-mb level in low latitudes are apparent from papers dealing with the stratospheric wind fluctuation.[14, 15, 16] It is now well known that in low latitudes there is a fluctuation in the zonal component of stratospheric winds which has a period varying between approximately 22 and 33 months and which amounts to a complete reversal of the wind direction. This phenomenon will be considered in more detail later in the text.

The predominantly westerly flow over most of the hemisphere in high and middle latitudes continues into February (Plate 22A). The westerly maximum (a small area within which average speeds exceed 60 kt) occurs over the north of Scandinavia, and over the Eurasian area the axis of the polar night jet is displaced a few degrees of latitude north of its January position. In spite of the apparent increase in the maximum average speeds the area enclosed by the 50-kt isotach is much smaller than in January. There appear to be two secondary maxima in which average speeds exceed 40 kt – one over the Arctic from east Siberia to off north Canada and another in a small area over north-east Canada. The chart for March (Plate 22B) shows the average wind direction to be still westerly over middle and high latitudes and although the maxima still occur in areas similar to those in January and February the average speeds are lower.

The chart for April (Plate 23) shows a marked change in middle and high latitudes with a further decrease to about 20 kt in the area of maximum average wind speeds situated over the area from west Russia – north China – Japan. Over much of the Pacific, North America and the North Atlantic the average wind speeds are less than 10 kt (in many places less than 5 kt) and are still predominantly westerly: nearer to the equator the latitude at which average easterlies can be determined in April is several degrees north of that on the January chart.

By July (Plate 24) there is a mainly easterly flow over practically all the hemisphere. In high and middle latitudes average wind speeds are everywhere less than 10 kt and sometimes less than 5 kt. The easterly flow increases to a maximum near latitude 20°N with average speeds exceeding 40 kt in a belt from south Arabia, across India to the South China Sea. South of this maximum the average winds decrease and the chart shows, for this particular five-year period, an average wind direction of easterly extending to close to the Equator. The average speeds appear to decrease to about 15-25 kt between about 5°N and 10°N; however, in the vicinity of the Equator the average wind for July, 1957-61, may well have been a light westerly. At Nairobi (01° 18′S) it was 314° 6 kt and at Canton Island (02° 46′S) it was also a very light westerly.

As has been mentioned, by July there is a light easterly flow over middle and high latitudes. A more detailed analysis of the 50-mb data for Leuchars/Shanwell* for the period 1957-64 was made, to examine both the time of onset of the change-over to the light easterly flow typical of the middle and high latitude stratosphere in summer and also the time of the autumn reversal to a winter westerly. The pentad average values in Figure 8 show that the average time of change-over to light easterlies is late April but the reversal can occur at widely different times. For instance, in 1959 it took place very early – about mid March – and in 1958 the final change did not take place until mid May. Veryard[17] has shown that within the period 1957-61 the preferred time of *major* warming at 50 mb over the British Isles was at the end of January, but his diagram also shows a distinct warming just before the average date of the change-over to the easterly

*With effect from the 1800 GMT sounding on 16 September 1959 the radiosonde station at Leuchars (56° 23′N, 02° 53′W) was moved to Shanwell (56° 26′N, 02° 52′W).

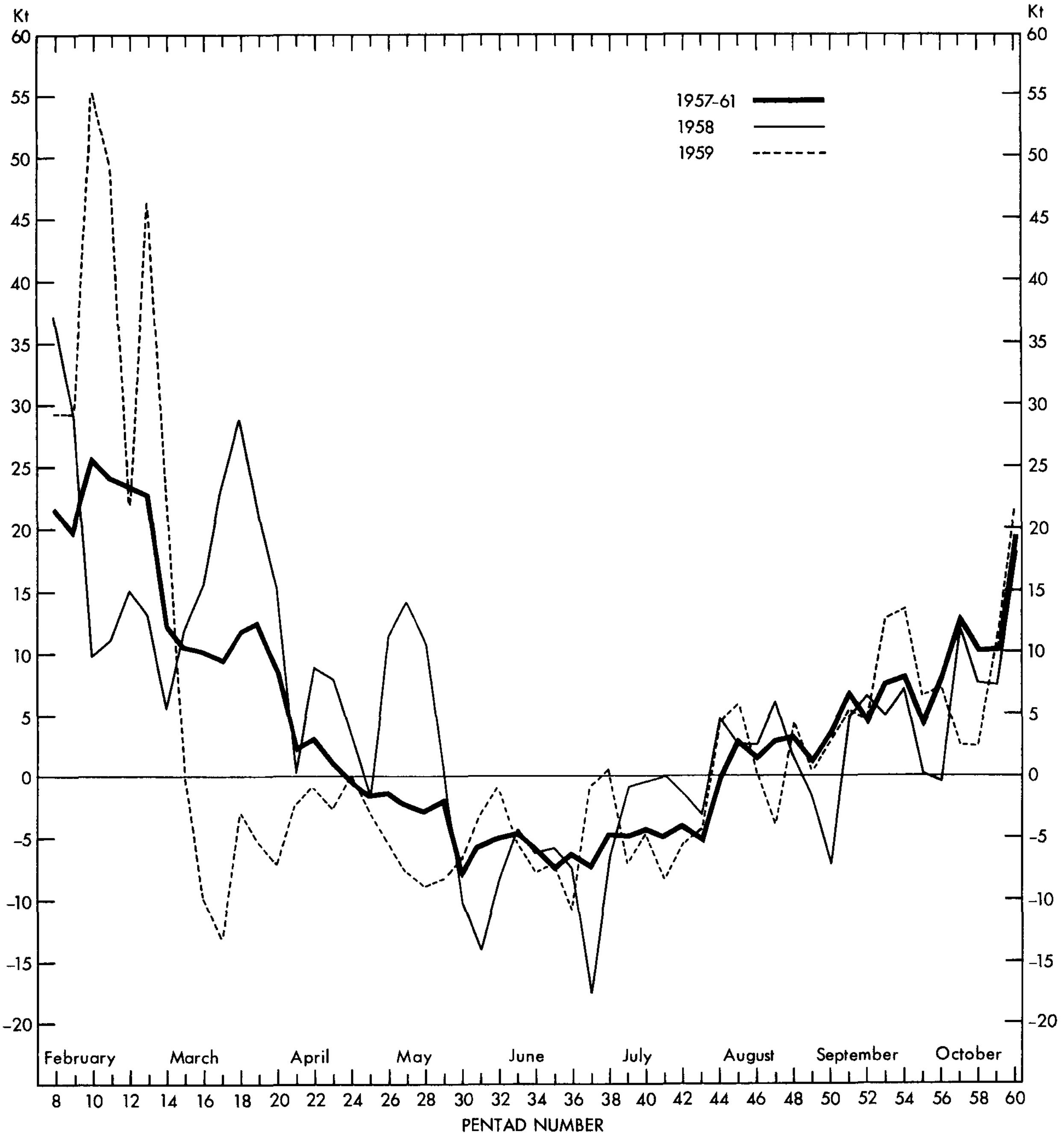


FIGURE 8. FIVE-DAY AVERAGE ZONAL WIND COMPONENTS AT 50 MILLIBARS AT LEUCHARS/SHANWELL

——— 1957-61 —.—.—.—. 1958 — — — — — 1959

Components towards the east are positive

régime of summer. 'The reversal of stratospheric winds over North America during 1957, 1958 and 1959' has been fully described in a paper with that title by Belmont.[18] His work shows that during those three years the time of the reversal over North America varied from the first half of May in 1959 to the first half of June in 1958. However, he points out that in 1959 the reversal had an unusually early start as, by the first half of March, easterlies already extended from 25°N to 65°N.

The average wind chart for October (Plate 25) shows a westerly flow to be well established over the hemisphere north of about 35°N. The breakdown of the summer stratospheric easterlies and the onset of the westerlies over middle and high latitudes is a much more regular feature than the reversal earlier in the year. The end of the summer wind régime at 50 mb shows far less inter-annual variability than the end of the winter régime and this appears to be true around the hemisphere as a whole.[18, 19] The Leuchars/Shanwell data in Figure 8 show that during the period 1957-64 the average time of change to westerlies was early August and individual years vary relatively little from this. Belmont,[18] in his work on the autumn reversal over North America found that the westerlies first appear to propagate upward in the stratosphere in August near 55°N and that by mid September all the stratospheric region above 20 km, north of 55°N, has changed from easterly to westerly. In October the average westerlies are light in high latitudes and appear to reach a maximum of about 30 kt near latitude 45°N across China, whilst in low latitudes the average wind is easterly. These low latitude easterlies appear to exceed 10 kt in a zone around the hemisphere situated near 15° to 20°N over the Pacific and near 10°N over Africa. South of this easterly maximum the analysis suggests a light easterly flow during this five-year period but, as in July, it is likely that near the equator the average wind is a very light westerly.

The charts of average zonal and meridional components of winds and their standard deviations are shown in Plates 26-30 and 31-35 respectively. As one of the main practical uses envisaged for these charts is the estimation of standard deviations of the components so that theoretical distribution ellipses may be constructed for any position on the charts, the following remarks are confined to drawing attention only to the principal features in the variability of the components.

In January (Plate 26) the standard deviation of the zonal wind component over high and some middle latitudes is generally greater than 20 kt, with a small area over western Russia where the maximum exceeds 30 kt. Around the hemisphere, in a band centred near 25°N, the standard deviations are at a minimum of between 10 and 15 kt but in lower latitudes they increase again to a maximum of 30 kt over the Pacific. However, in these low-latitude areas the increase is due to the existence of the 26-month fluctuation which will be referred to later. The chart for February (Plate 27A) shows maximum values in excess of 30 kt off north-west Canada but the area enclosed by the 20-kt isopleth is rather smaller than in January.

The March chart (Plate 27B) indicates that a considerable area north of 45°N within which values exceed 20 kt still exists, but over much of North America there is a significant northward extension of the area covered by values of less than 20 kt. By April (Plate 28) there is a marked decrease in the standard deviation over middle and high latitudes, with the region of greater than 20 kt confined to the latitude band 40°-50°N over central and east Asia. Values of near to or less than 10 kt cover a large part of North America, the North Atlantic and those parts of Africa and Asia situated near 25°N. Towards the Equator, values appear to increase again to greater than 20 kt but the spurious nature of the standard deviation in these low-latitude areas has already been mentioned.

In July (Plate 29) the values are less than 10 kt over a large part of the hemisphere. The maximum values (greater than 15 kt) appear to occur between 30° and 45°N across China but because of lack of data this isopleth cannot be regarded as a very reliable feature of the chart. The October chart (Plate 30) shows that values are generally between 10 and 15 kt over most middle and high latitude areas. There appears to be a zone of minimum values (5-10 kt) centred near 30°N (the axis lies south of this latitude over the Pacific and north of it over Western Europe and the eastern North Atlantic) and in both July and October there is again the apparent but unrepresentative increase towards lower latitudes.

The standard deviation of the meridional component in January (Plate 31), like that of the zonal component, is generally greater than 20 kt over high and some middle latitudes. The maximum (greater than 30 kt) occurs over Greenland and Iceland with a decrease towards low latitudes to 5-10 kt in sub-tropical and tropical regions. Over middle and high latitudes the standard deviation of the meridional component in February (Plate 32A) is very similar to that for January – the main difference is in the area over western Russia and eastern Europe within which values exceed 30 kt. By March (Plate 32B) the area in which the standard deviation exceeds 20 kt is much smaller than in the preceding months, and by April (Plate 33) the maximum values are 15-20 kt in an area over north-east Canada and north Greenland and also over Russia. Over much of the hemisphere the standard deviation is in the range 5-10 kt in both April and July (Plate 34). In the latter month values in excess of 10 kt are confined to parts of western Russia. In October (Plate 35) values exceed 15 kt in some middle and high latitude areas but fall to mainly 5-10 kt in lower latitudes.

§7 – ELLIPTICAL DISTRIBUTION OF THE WINDS

During the course of this work the wind distributions for 25 stations were examined in some detail. The average wind was subtracted from the individual winds, and the distribution of these departures from average were tested for both circularity and ellipticity by means of the chi-square test. The stations used were chosen partly because adequate data were available and partly because they could be taken as typical of different climatological régimes.

The 30, 60 and 90 per cent probability circles were obtained by using radii appropriate to the normal circular distribution, i.e. 0.59, 0.96 and 1.52 times the standard vector deviation. Corresponding ellipses were constructed with the appropriate axis (usually the major one) along the east-west axis, and the lengths of the major and minor axes were determined by using the standard deviations of the zonal and meridional components multiplied by the relevant values R from Table IV.

TABLE IV – PERCENTAGE FREQUENCY OF END POINTS OF INDIVIDUAL VECTOR WINDS WHICH OCCUR WITHIN ELLIPSES OF GIVEN SEMI-AXES CENTRED ON THE END POINT OF THE VECTOR WIND

Percentage frequency	10	20	30	40	50	60	70	80	90	95	99
R	0.46	0.67	0.84	1.01	1.18	1.36	1.55	1.79	2.15	2.45	3.03

(The lengths of the semi-axes are $\sigma_u \times R$ and $\sigma_v \times R$)

The winds were sorted into four direction-ranges, each representing a quarter of the area of the ellipse or the circle. For the circle the four boundaries were 045°, 135°, 225° and 315°, and for the ellipse:

$$270° \text{ or } 090° \pm \tan^{-1} \frac{\text{semi minor axis}}{\text{semi major axis}}, \text{ i.e. in most cases } \pm \tan^{-1} \frac{\sigma_v}{\sigma_u}$$

where σ_u and σ_v are the standard deviations of the zonal and meridional components respectively. The quadrants were selected in this way because the strongest wind speeds often occur in the east-west direction. This method of sorting into direction ranges therefore makes the chi-square test particularly strict but it was considered preferable to that of using quadrants bounded by the major and minor axes. Had that been done the stronger winds within a few degrees of 270° or 090° would have been allocated to separate quadrants.

Whilst the exact number of degrees of freedom in these circumstances is somewhat uncertain, clearly it will be fractionally less for the ellipse because if the chi-square test is applied to all 12 'boxes' together there is one fewer constraint. (The 12 boxes are made up of the four quadrants in the 0-30, >30-60 and >60-90 per cent ranges.) In both the circularity and ellipticity tests the chi-square value for the 5 per cent significance level with three degrees of freedom has been used as the critical value, and occasions in excess of this (i.e. greater than 7.81, indicating significant *non*-ellipticity or *non*-circularity) are summarized in Table V. (The results for these 25 stations are listed in greater detail in Appendix I.)

In January only 24 stations were used because one station had too few observations to allow application of the chi-square test and so the totals in the last two columns of Table V represent the number of occasions out of 99 tests when the chi-square value exceeded 7.81. Of the 25 stations used, 16 were situated north of 35°N.

Clearly these results are highly significant: they indicate that the distribution is almost certainly not circular and that it is better described as elliptic. An inspection of the distribution for all 25 stations for the four months reveals that between the >60-90 per cent boundaries there were 71 occasions of non-circularity compared with 29 occasions of non-ellipticity. It is evident from Table V (and from Figures 9 and 10) that south of 35°N the circular distribution cannot possibly be regarded as an adequate description of the observed distribution because no less than 86 and 92 per cent of the tests at the >30-60 and >60-90 per cent bands respectively indicated significant non-circularity. (In April and October the figure was 100 per cent for the >60-90 per cent range.) North of 35°N the distribution proved to be significantly non-circular on 57 and 60 per cent of occasions over the corresponding ranges. However, it should be noted that although the ellipse provides a much better estimate of the observed distribution it is by no means a complete description and in all cases the number of occasions when the distributions proved to be non-elliptical far exceeded 5 per cent of the totals.

A second set of chi-square tests was carried out in a similar manner to that outlined above, using the same values of σ_u and σ_v, but with the major axis of the ellipse taken along the average wind direction. In nearly all cases the number of occasions of significant non-ellipticity proved to be slightly greater than when the major axis was assumed to lie east-west or (occasionally) north-south.

The angle of rotation of the true major axis of the ellipse, i.e. the angle between the assumed major axis (usually the east-west axis) and the true major axis, was also calculated for each set of data. The results for the 25 stations used in the chi-square tests indicated that had the true major axis been used in those cases where the angle of rotation was greater than 20° then, for both the >60-90 per cent and >30-60 per cent bands of the distribution, there would have been some small reduction in the number of occasions significantly non-elliptical at the 5 per cent level. (The angle of rotation for each of the 25 stations is given in Appendix I.)

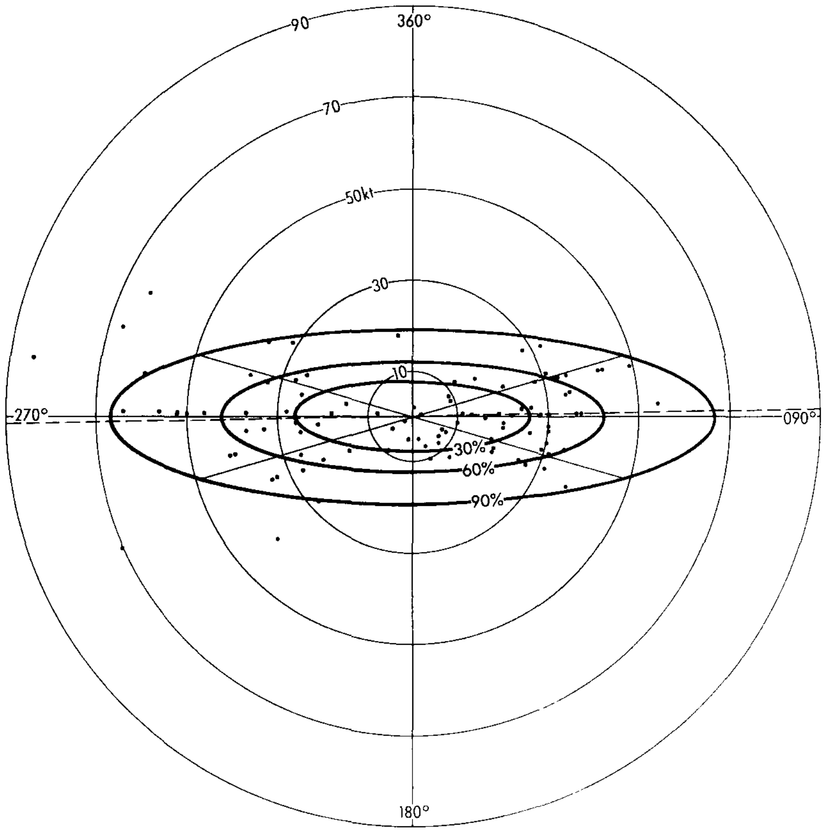
In order to illustrate and clarify some of the points made concerning the nature of the wind distribution, scatter diagrams for a selection of stations are given in Figures 9-15. The plotted points represent departures of the individual winds from the vector mean wind V_R and (where practicable) the 30, 60 and 90 per cent distribution ellipses are shown. These ellipses were constructed in the manner described earlier, with the major axis along the east-west (or north-south) axis of the diagram.

When interpreting the results in Table V and when using the scatter diagrams in Figures 9-15 it should be borne in mind that many users of climatological wind statistics are usually more concerned with the distribution of large departures from average (i.e. the >60-90 per cent part of the distribution) than with the distribution of winds that are near average (i.e. the 0-30 per cent part). In this connection it should be noticed that in July (Plate 24), over much of the hemisphere except lower latitudes, wind speeds are very light. Also, the relevant scatter-diagrams show the individual winds to be often so close to the average wind that even very small variations in speed or direction result in large changes in the chi-square value. Similar remarks apply to the 0-30 per cent range for other months at some stations.

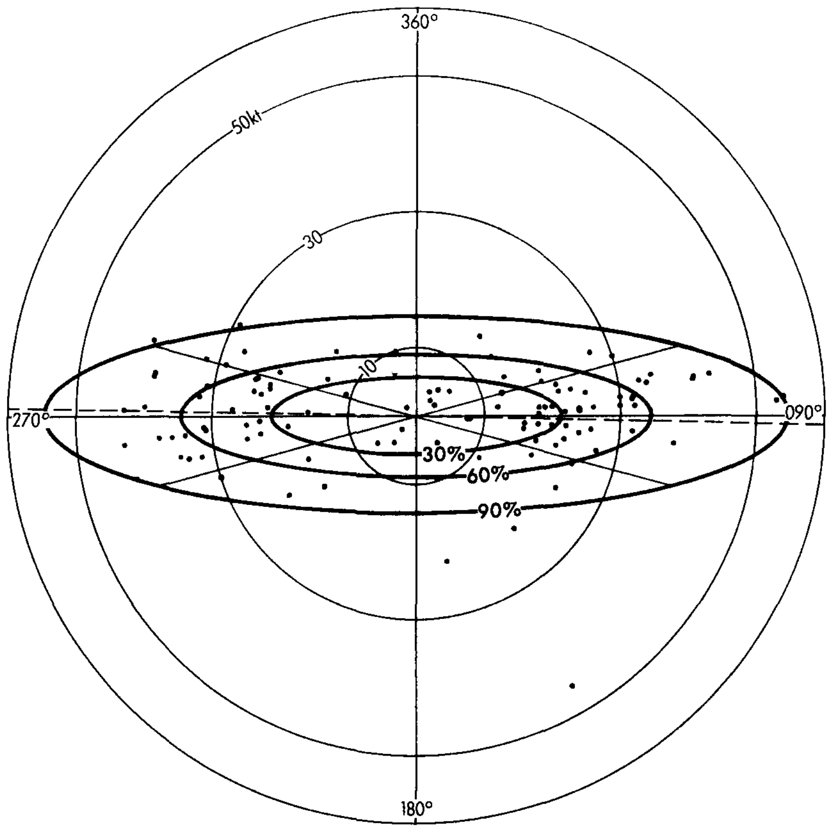
TABLE V – NUMBER OF OCCASIONS WITH CHI-SQUARE VALUE GREATER THAN 7.81
(i.e. 5 PER CENT LEVEL WITH 3 DEGREES OF FREEDOM)

Probability bands	JANUARY						APRIL						JULY						OCTOBER						TOTALS – FOUR MONTHS					
	Number of stations						Number of stations						Number of stations						Number of stations						Number of stations					
	North of 35°N		South of 35°N		Total		North of 35°N		South of 35°N		Total		North of 35°N		South of 35°N		Total		North of 35°N		South of 35°N		Total		North of 35°N		South of 35°N		Total	
	15		9		24		16		9		25		16		9		25		16		9		25		16		9		25	
	a	*b*	*a*	*b*	*a*	*b*	*a*	*b*	*a*	*b*	*a*	*b*	*a*	*b*	*a*	*b*	*a*	*b*	*a*	*b*	*a*	*b*	*a*	*b*	*a*	*b*	*a*	*b*	*a*	*b*
0–30%	6	5	5	2	11	7	7	8	5	3	12	11	9	9	5	3	14	12	7	6	4	5	11	11	29	28	19	13	48	41
>30–60%	12	10	8	4	20	14	10	5	8	4	18	9	5	3	7	2	12	5	9	8	8	3	17	11	36	26	31	13	67	39
>60–90%	10	3	8	2	18	5	10	5	9	4	19	9	7	5	7	3	14	8	11	5	9	2	20	7	38	18	33	11	71	29

Col.(*a*) – circularity test   Col.(*b*) – ellipticity test



(a)

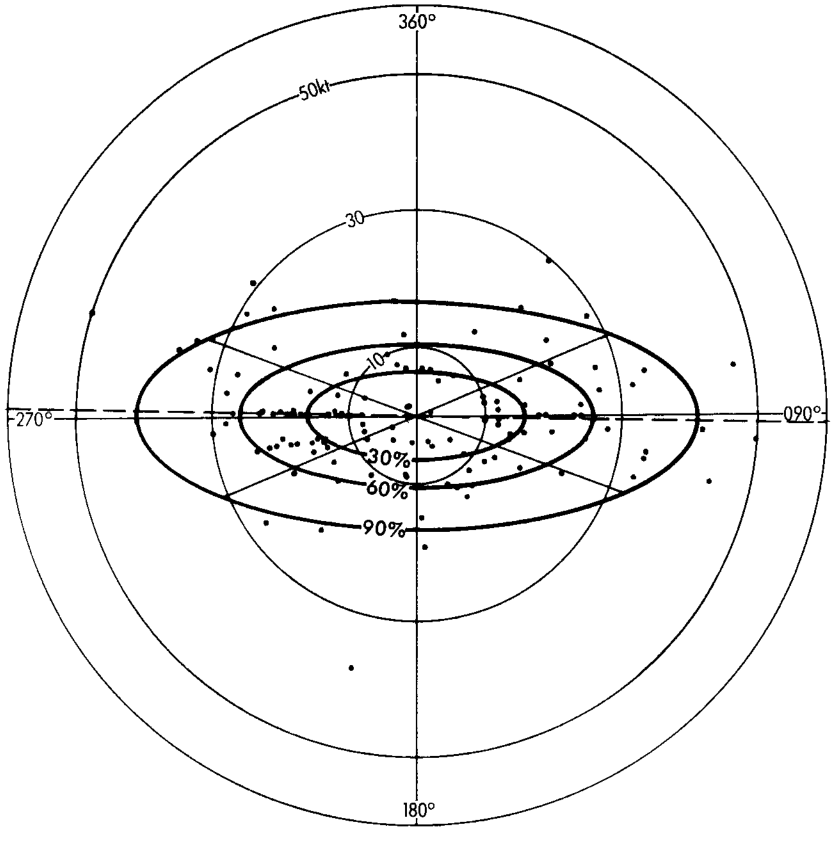


(b)

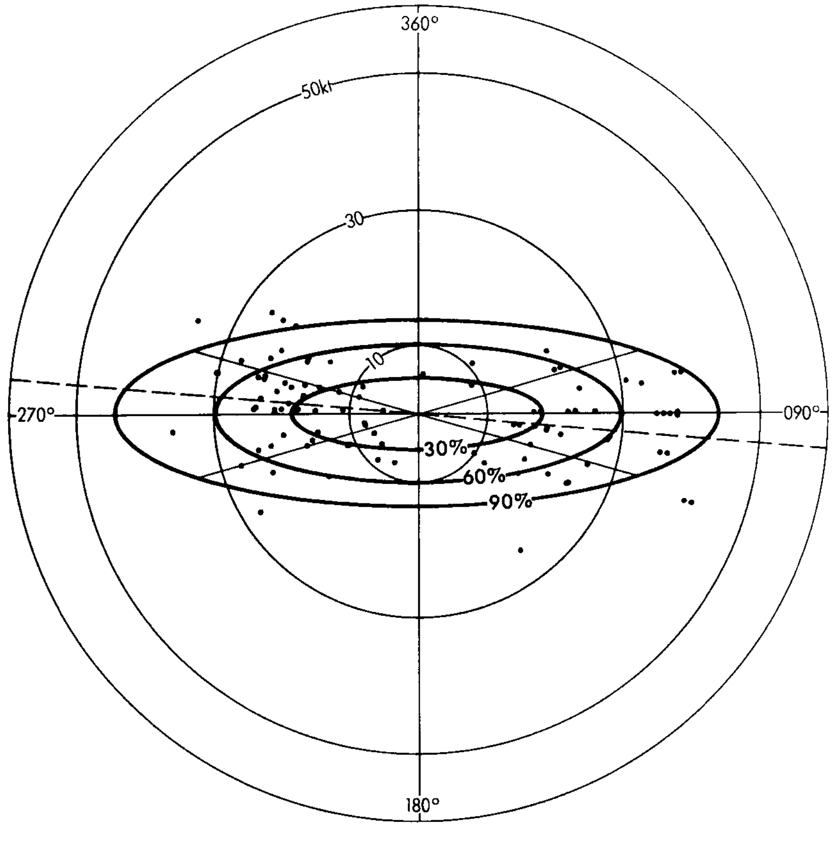
FIGURE 9. DISTRIBUTION OF DEPARTURES FROM THE AVERAGE 50-MILLIBAR WIND, CANTON ISLAND (2°46′S, 171°43′W), 1957-61

	(a) JANUARY	*(b) APRIL*	*(c) JULY*	*(d) OCTOBER*
Vector mean wind V_R	093° 14 kt	096° 12 kt	269° 66 kt	263° 3 kt

– – – – – – True major axis of ellipse (see Appendix I for relevant statistics)

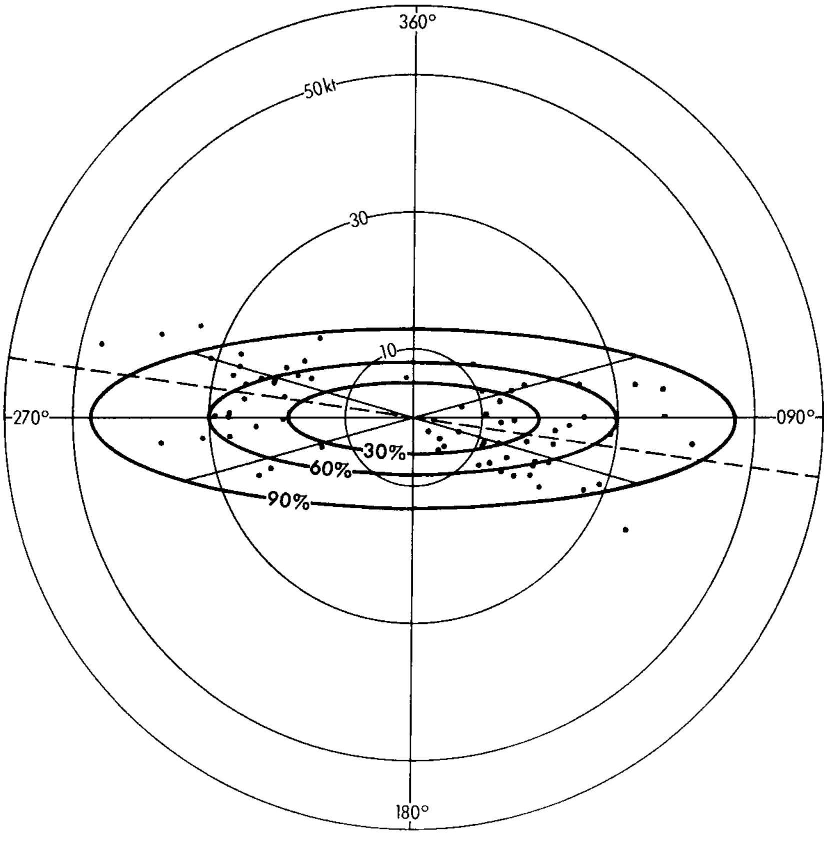


(c)

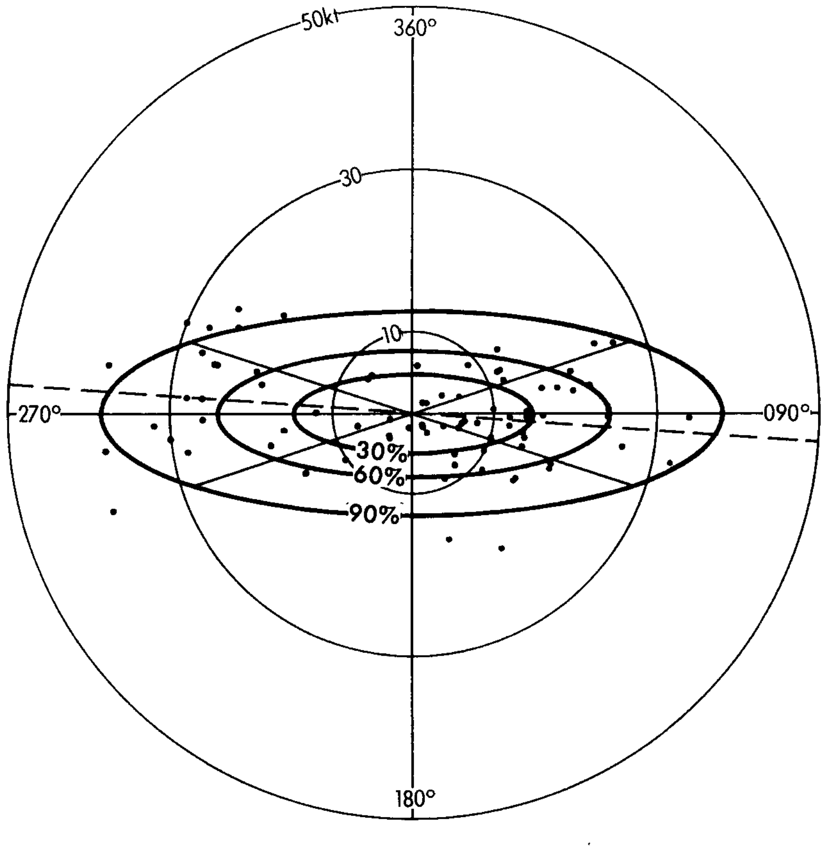


(d)

FIGURE 9. *(contd)*



(a)

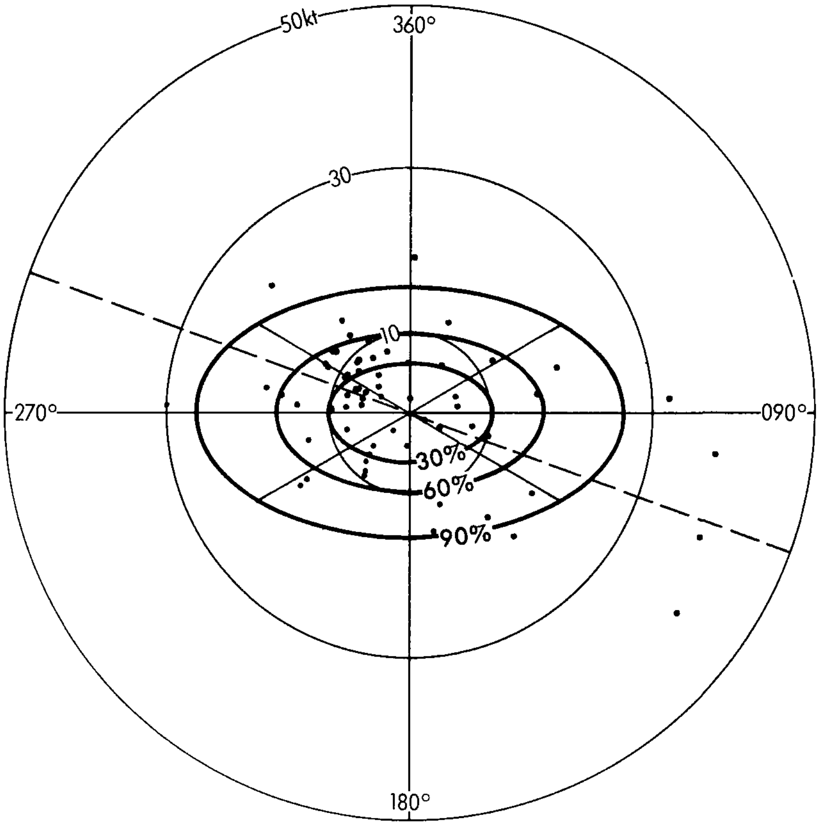


(b)

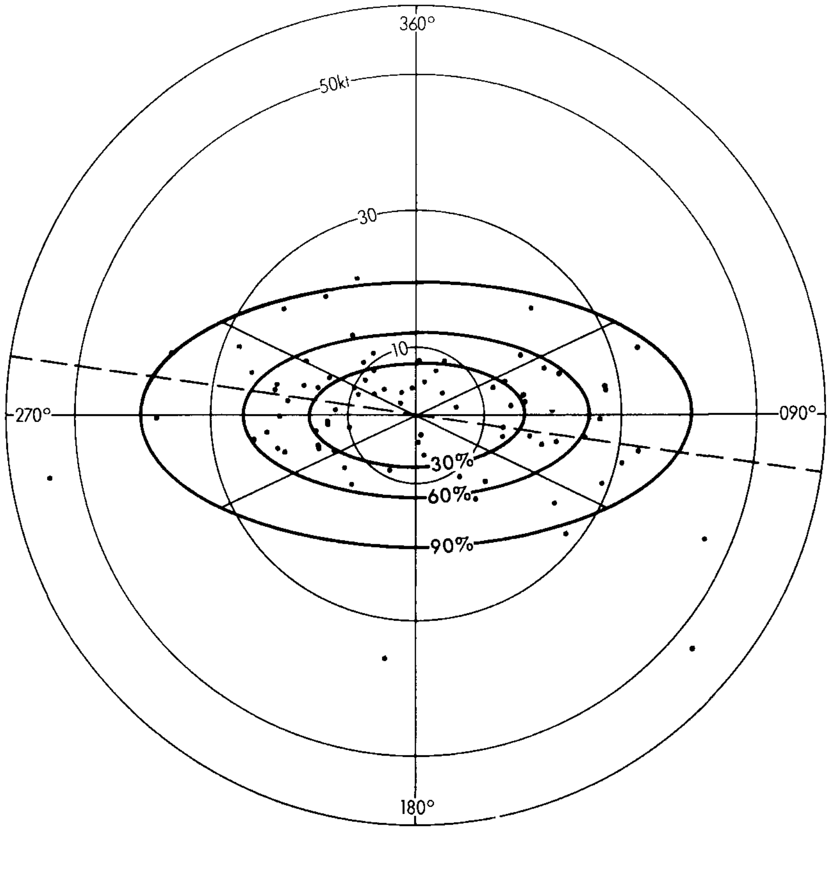
FIGURE 10. DISTRIBUTION OF DEPARTURES FROM THE AVERAGE 50-MILLIBAR WIND, YAP (9° 31′N, 138° 08′E), 1957-61

	(a) JANUARY	*(b) APRIL*	*(c) JULY*	*(d) OCTOBER*
Vector mean wind V_R	093° 9 kt	089° 16 kt	092° 28 kt	101° 11 kt

– – – – – – True major axis of ellipse (see Appendix I for relevant statistics)

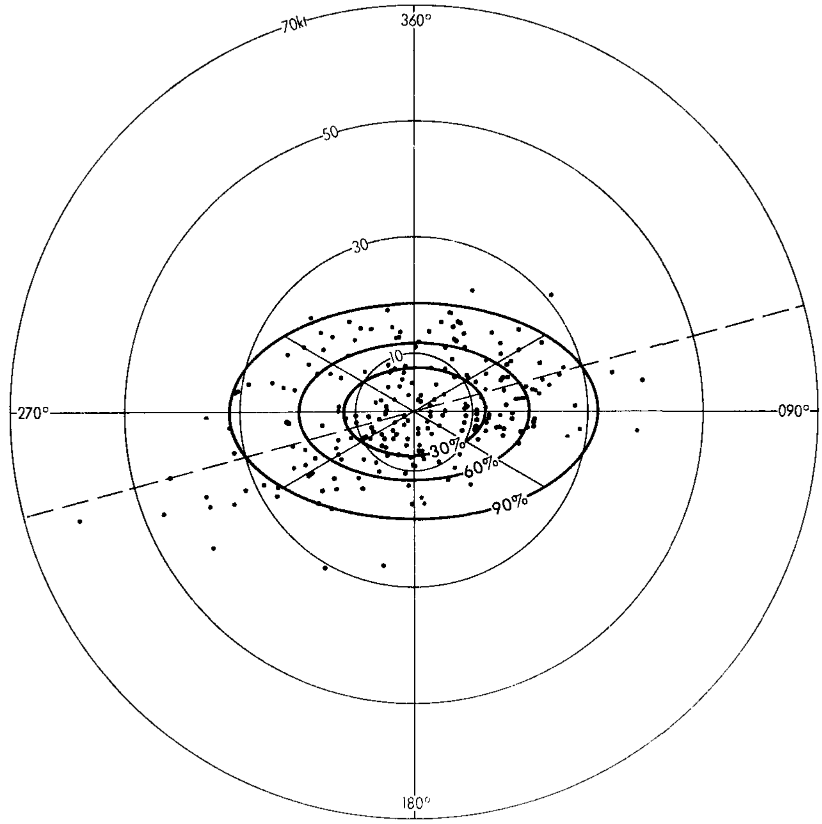


(c)

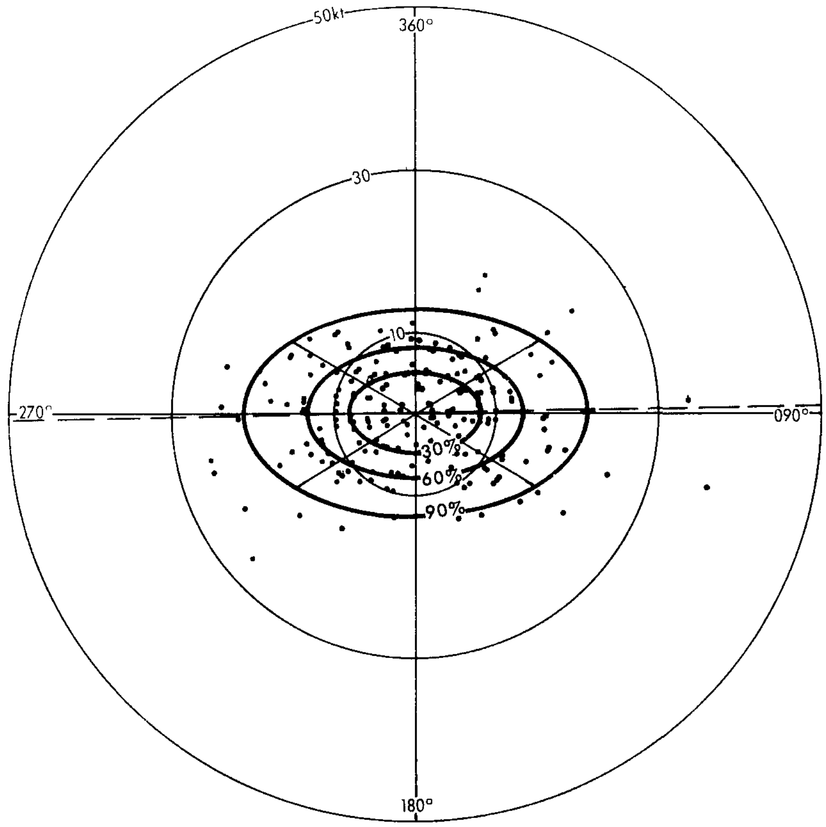


(d)

FIGURE 10. *(contd)*



(a)

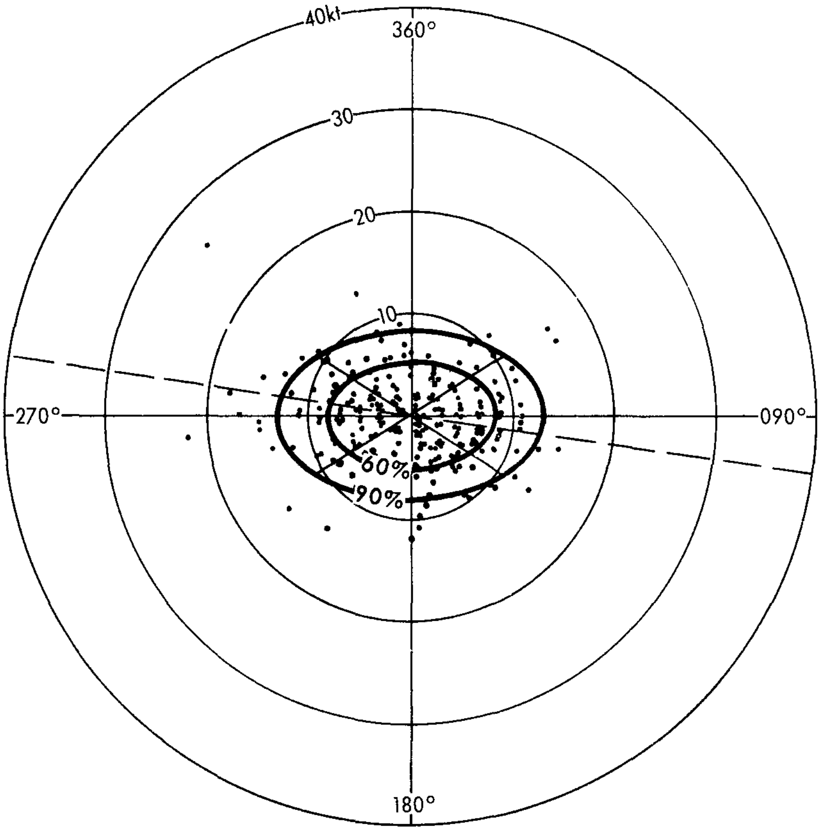


(b)

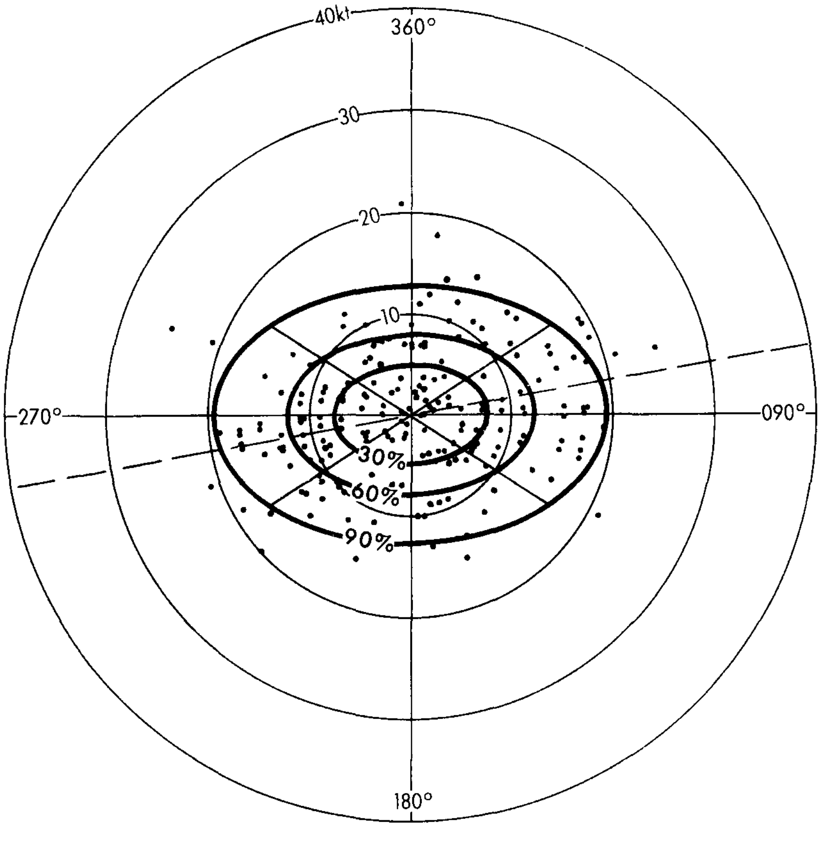
FIGURE 11. DISTRIBUTION OF DEPARTURES FROM THE AVERAGE 50-MILLIBAR WIND, SHREVEPORT (32° 28′N, 93° 49′W), 1957-61

	(a) JANUARY	(b) APRIL	(c) JULY	(d) OCTOBER
Vector mean wind V_R	275° 19 kt	260° 6 kt	087° 23′kt	277° 3 kt

– – – – – – True major axis of ellipse (see Appendix I for relevant statistics)

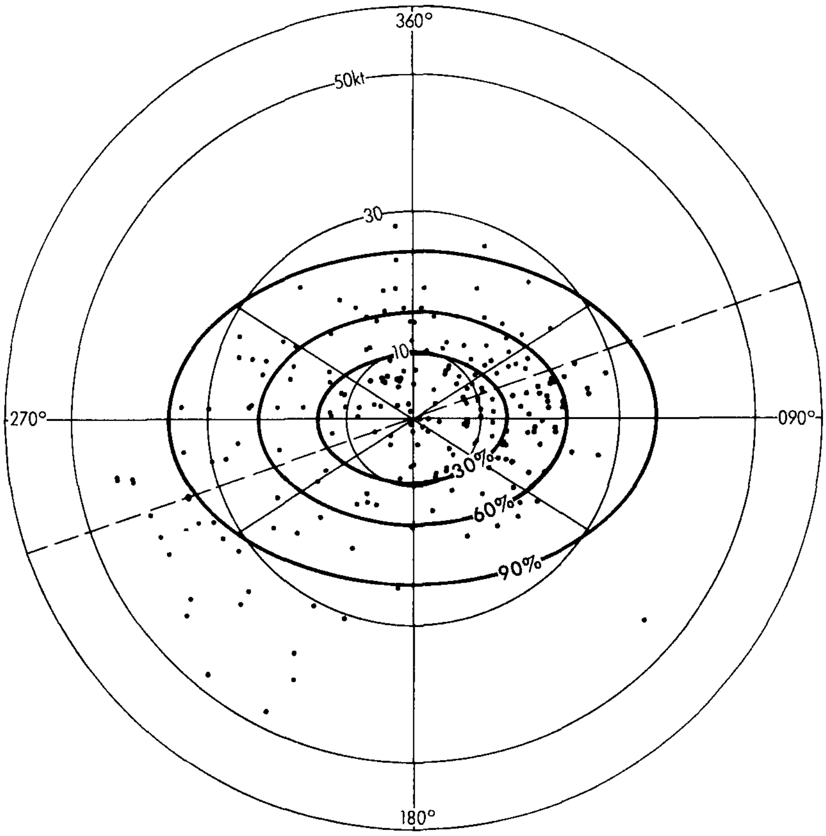


(c)

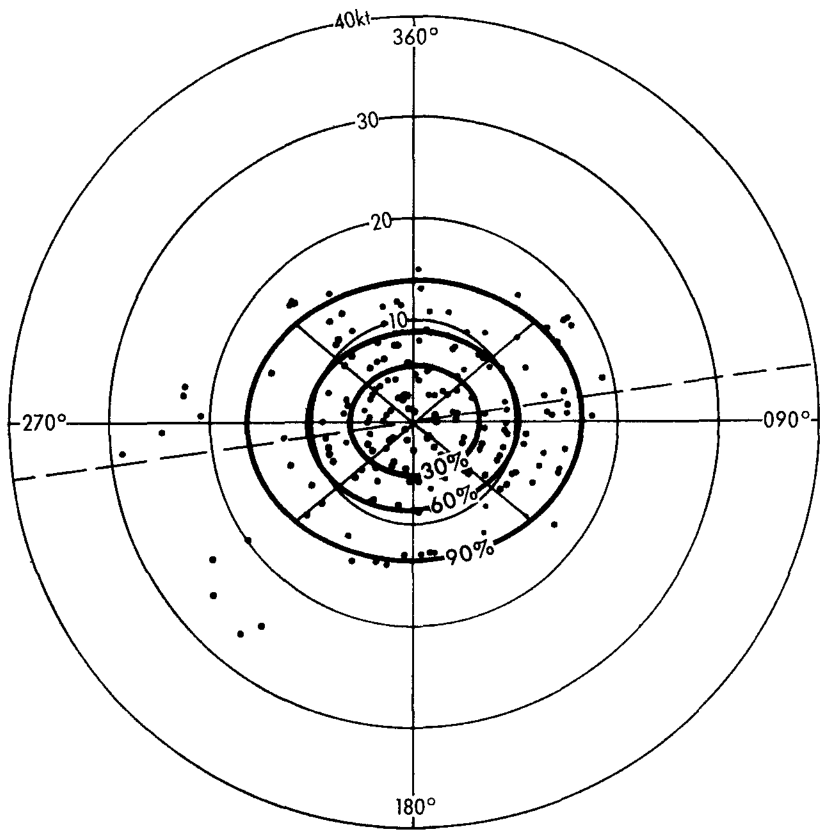


(d)

FIGURE 11. *(contd)*



(a)

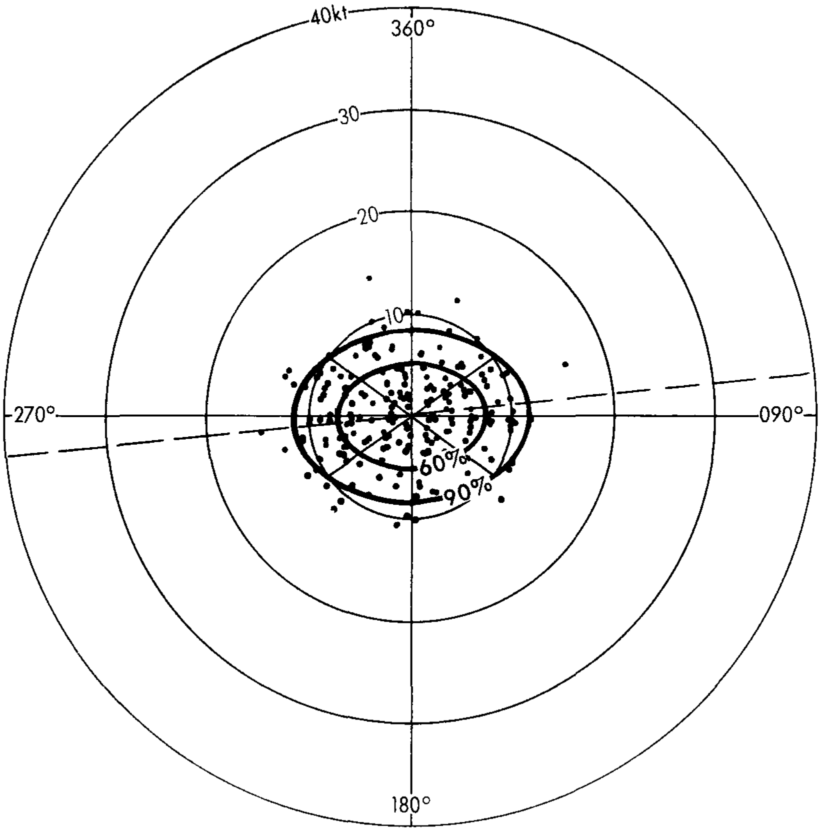


(b)

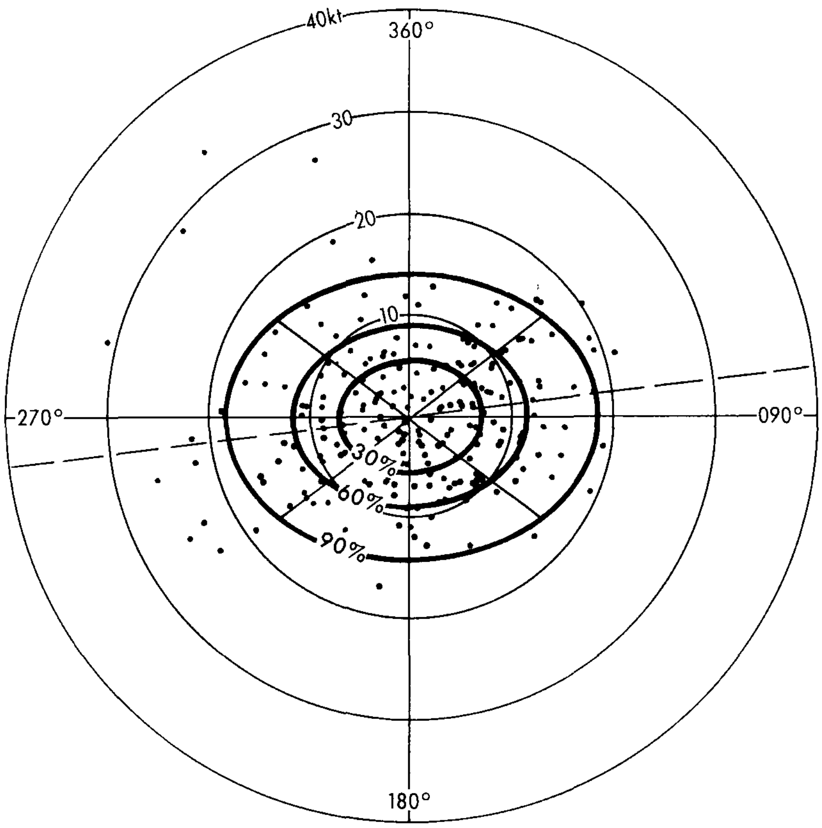
FIGURE 12. DISTRIBUTION OF DEPARTURES FROM THE AVERAGE 50-MILLIBAR WIND, LAJES (38° 45′N, 27° 05′W), 1957-61

	(a) JANUARY	(b) APRIL	(c) JULY	(d) OCTOBER
Vector mean wind V_R	264° 16 kt	291° 3 kt	088° 16 kt	300° 5 kt

------ True major axis of ellipse (see Appendix I for relevant statistics)

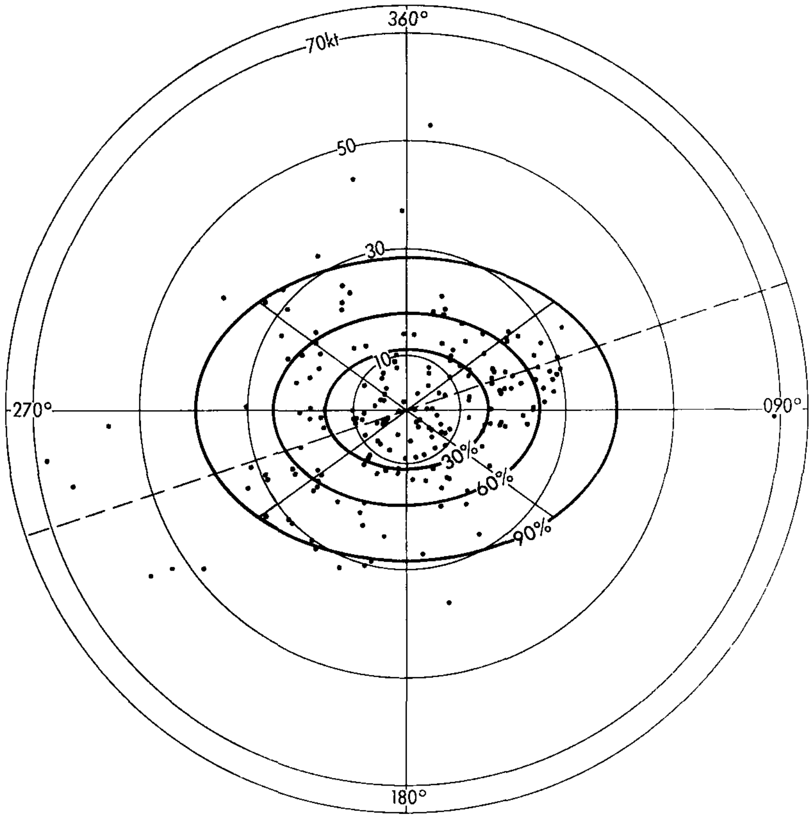


(c)

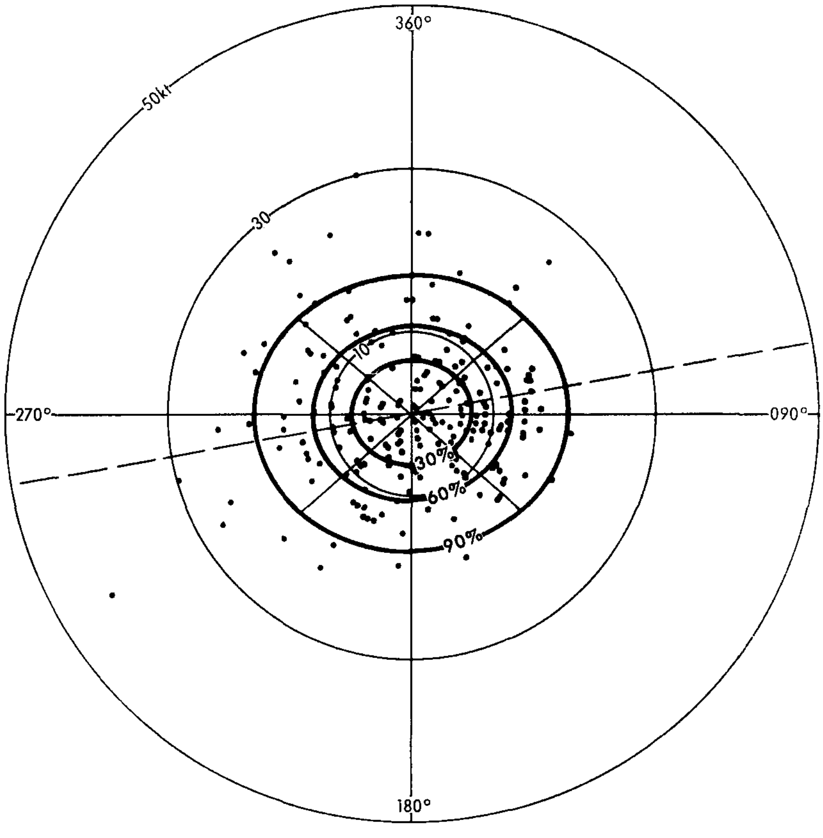


(d)

FIGURE 12. *(contd)*



(a)



(b)

FIGURE 13. DISTRIBUTION OF DEPARTURES FROM THE AVERAGE 50-MILLIBAR WIND, PORTLAND (43° 39′N, 70° 19′W) 1957-61

	(a) JANUARY	(b) APRIL	(c) JULY	(d) OCTOBER
Vector mean wind V_R	265° 36 kt	272° 10 kt	085° 7 kt	269° 14 kt

– – – – – – True major axis of ellipse (see Appendix I for relevant statistics)

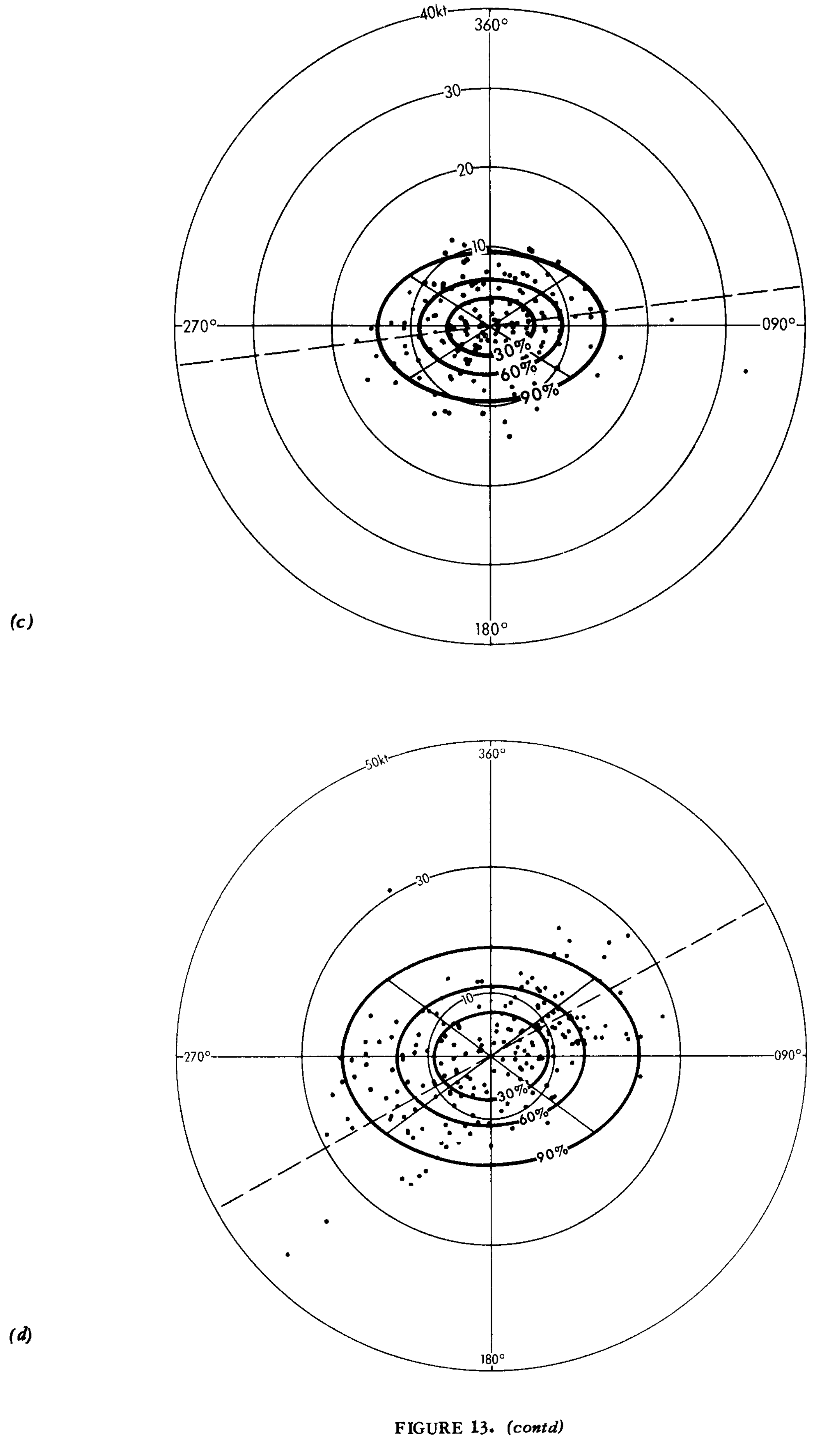
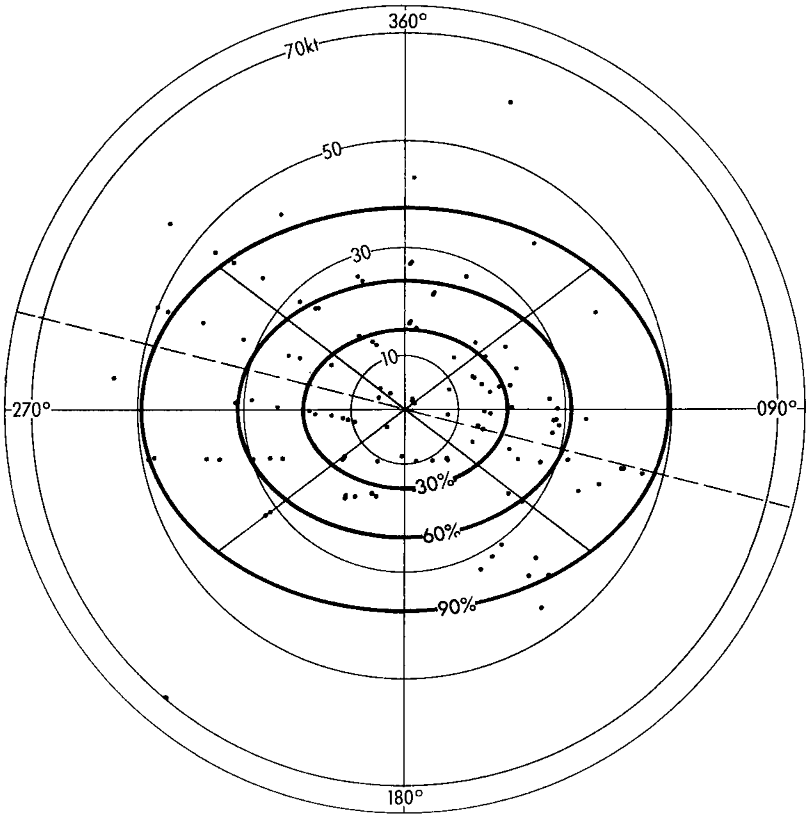
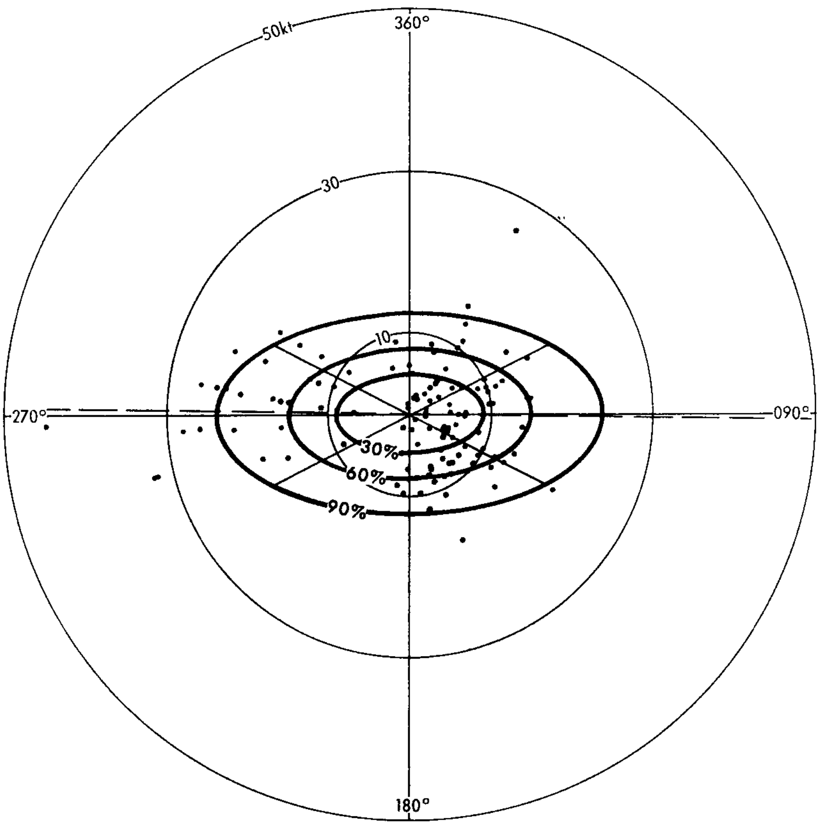


FIGURE 13. *(contd)*



(a)

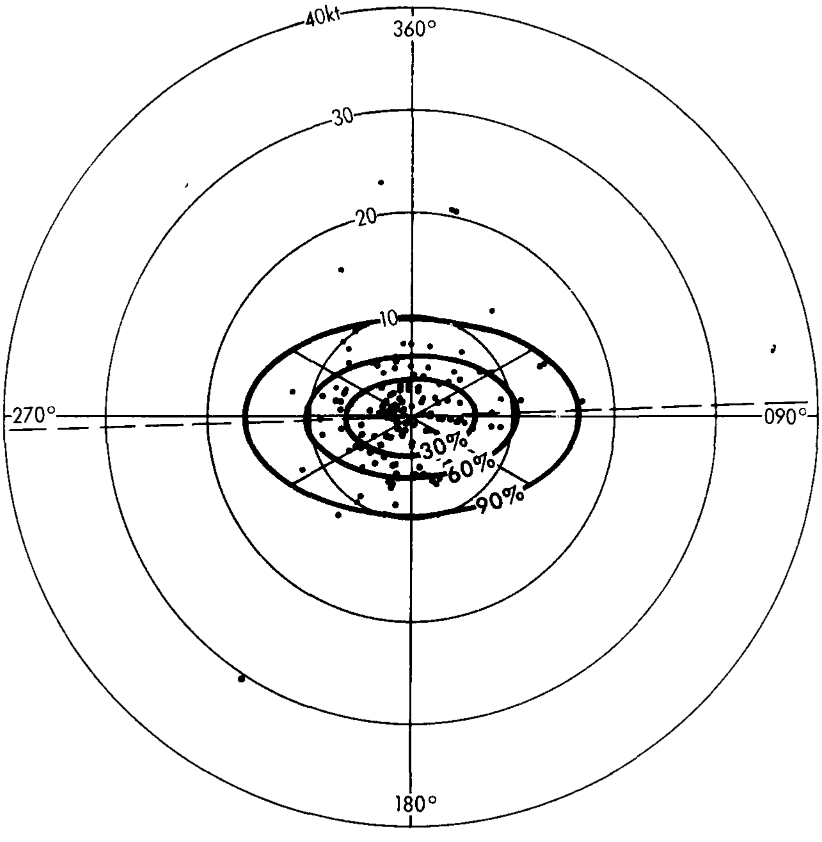


(b)

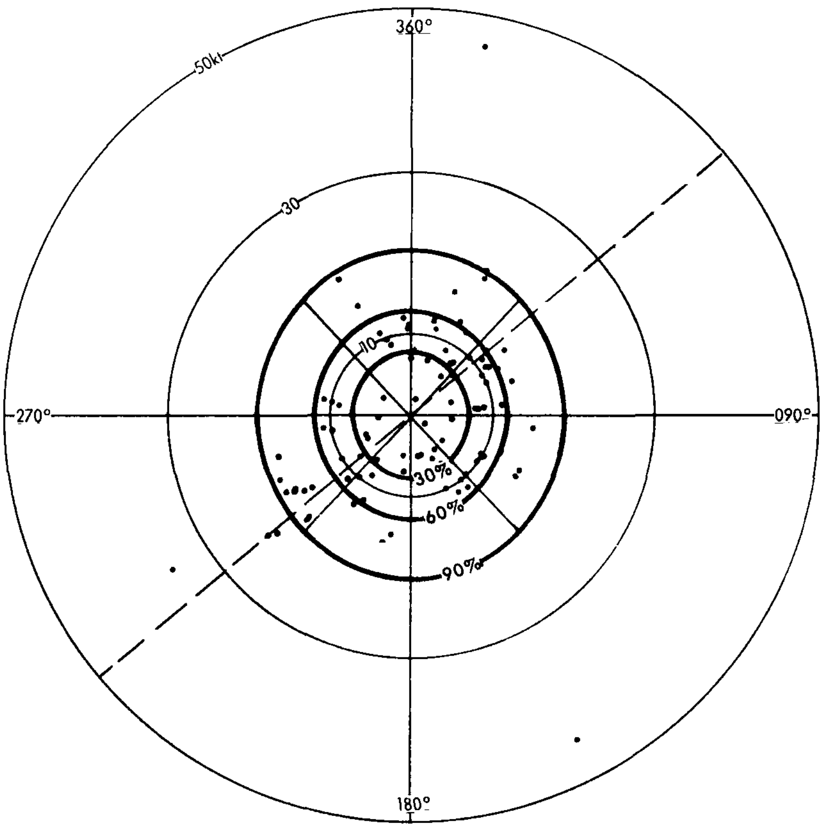
FIGURE 14. DISTRIBUTION OF DEPARTURES FROM THE AVERAGE 50-MILLIBAR WIND, SCHLESWIG (54° 32′N, 9° 33′E) 1957-61

	(a) JANUARY	*(b) APRIL*	*(c) JULY*	*(d) OCTOBER*
Vector mean wind V_R	287° 32 kt	292° 5 kt	102° 7 kt	300° 10 kt

– – – – – – True major axis of ellipse (see Appendix I for relevant statistics)

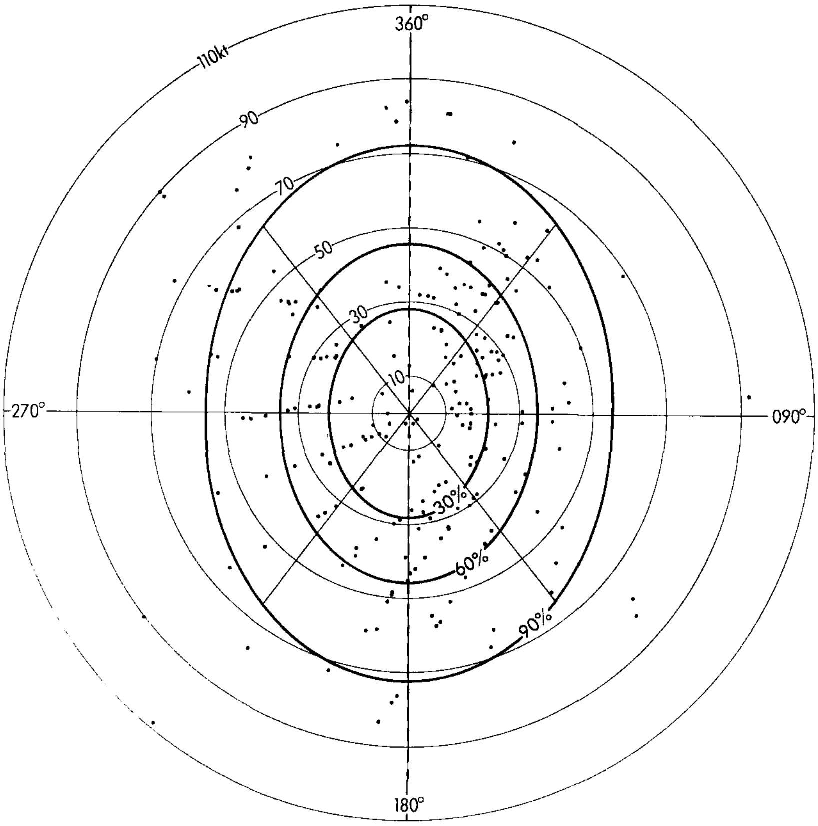


(c)

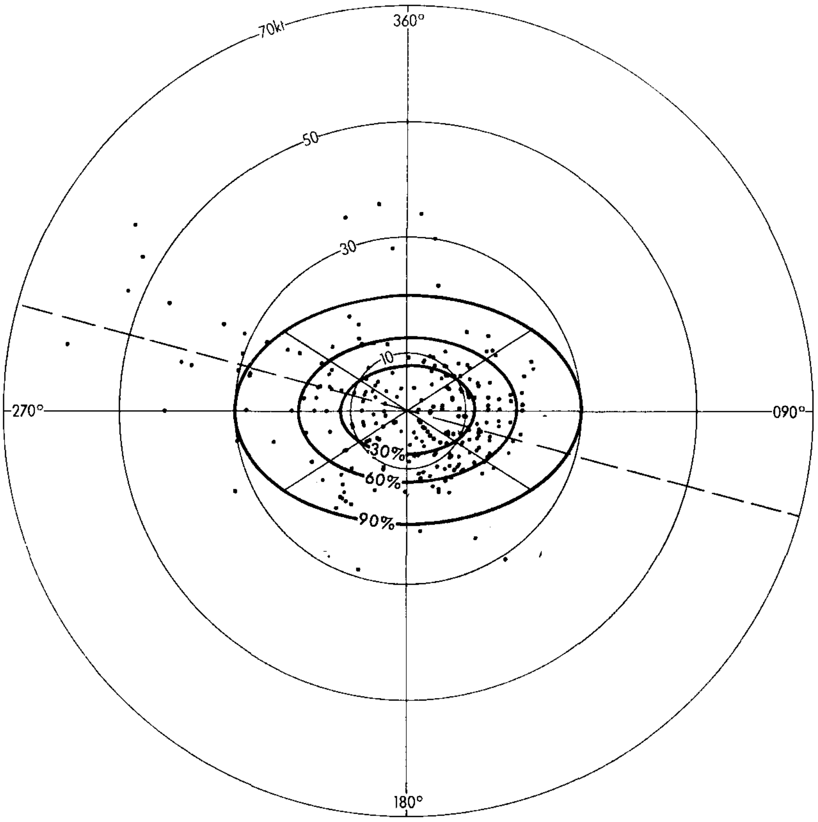


(d)

FIGURE 14. *(contd)*



(a)

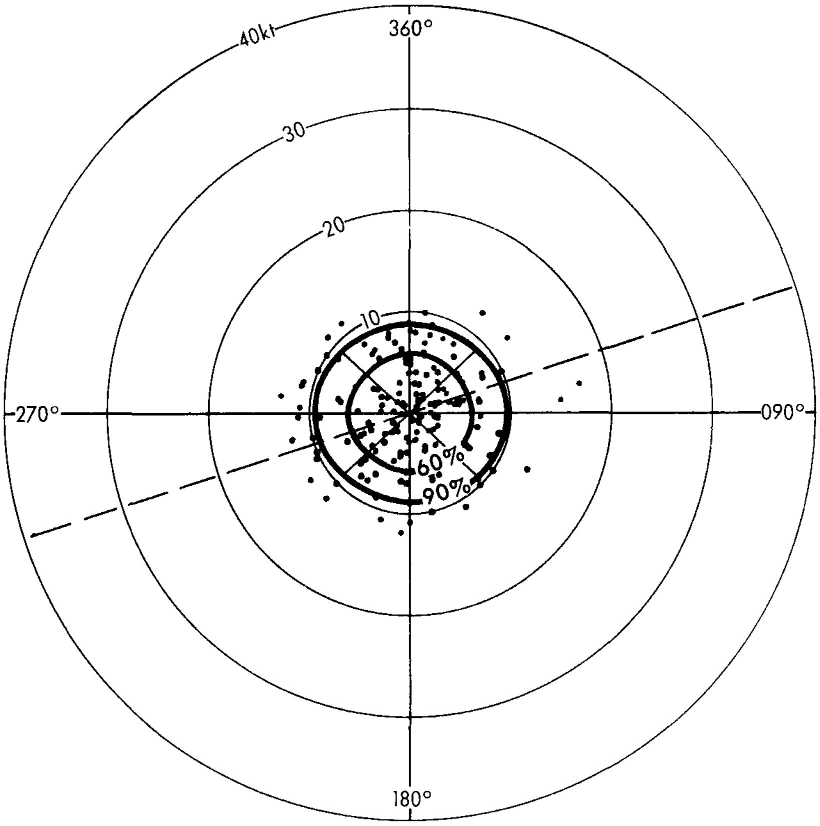


(b)

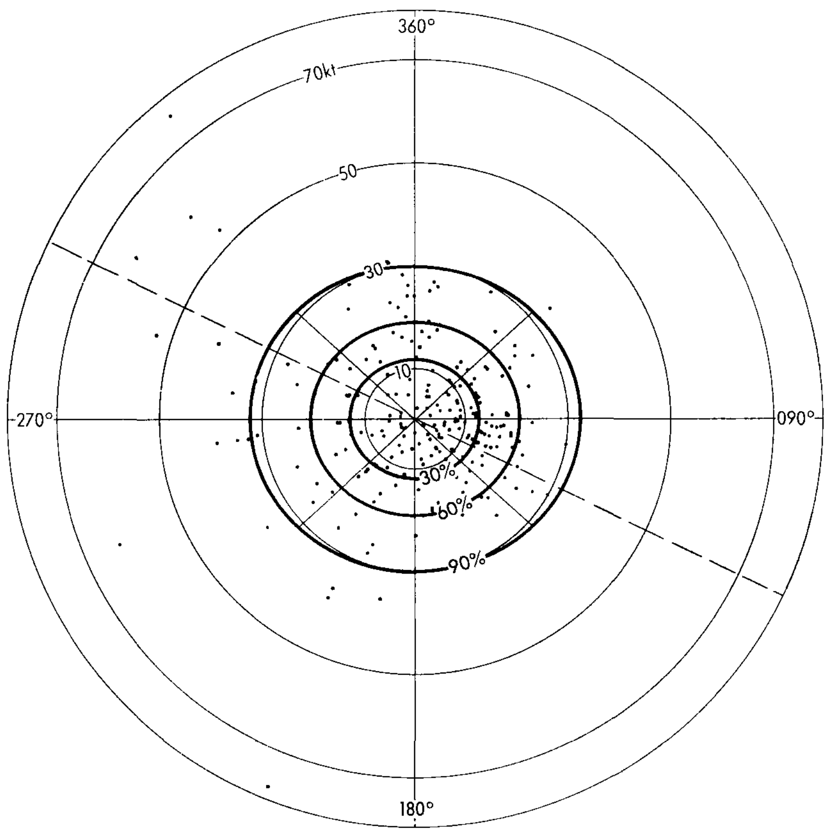
FIGURE 15. DISTRIBUTION OF DEPARTURES FROM THE AVERAGE 50-MILLIBAR WIND, KEFLAVIK (63° 58′N, 22° 36′W), 1957-61

	(a) JANUARY	(b) APRIL	(c) JULY	(d) OCTOBER
Vector mean wind V_R	253° 52 kt	270° 8 kt	098° 7 kt	255° 17 kt

– – – – – – True major axis of ellipse (see Appendix I for relevant statistics)



(c)



(d)

FIGURE 15. *(contd)*

The extent to which these factors affect the chi-square values for the elliptical distribution tests was examined in more detail. In Table VI the results for the 25 stations used in the tests are arranged in three latitude-bands as follows: 3 stations south of 15°N; 11 stations between 15°N and 45°N and 11 stations north of 45°N. Occasions when the chi-square value indicated significant non-circularity together with non-ellipticity, and various other possible significant and non-significant combinations, are also listed. The three low-latitude stations are considered together as being representative of the area in which the 26-month fluctuation in the zonal wind component is the dominant feature. Table VI shows that the distributions in the >60-90 per cent range (the larger departures from average) were significantly non-elliptical on 17 occasions out of 43 between 15°N and 45°N and on 11 occasions out of 44 at stations north of 45°N. These occasions were examined to ascertain the reasons for the significant non-ellipticity. Of the 17 occasions it was found that 8 were associated with average wind speeds of less than 10 knots and that on 3 other occasions the values of the standard deviations of the meridional and zonal components were small. As has been mentioned, and as the scatter diagrams indicate, when these conditions prevail even small changes in the individual wind observations can lead to large changes in the chi-square values. On 2 of the remaining occasions the angle of rotation of the true major axis of the ellipse was large: had the true major axis been used instead of the east-west axis then the chi-square values would almost certainly have been reduced. This leaves 4 occasions of significant non-ellipticity but on 1 of these the value of chi-square was only marginally above 7.81. Of the 11 occasions when the distributions were significantly non-elliptical at stations north of 45°N the average wind speed was less than 10 kt on 6 occasions and on 3 of the remaining 5 occasions the angle of rotation of the true major axis of the ellipse was greater than 20°.

TABLE VI – SUMMARY OF SIGNIFICANT AND NON-SIGNIFICANT COMBINATIONS OF CHI-SQUARE VALUES FOR CIRCULARITY AND ELLIPTICITY TESTS

Chi-square value		South of 15°N (3 stations)			15°N-45°N (11 stations)			North of 45°N (11 stations)		
Circular distribution	Elliptical distribution	*0-30%	>30-60%	>60-90%	*0-30%	>30-60%	>60-90%	*0-30%	>30-60%	>60-90%
>7.81	>7.81	1	6	0	18	10	15	19	18	11
>7.81	<7.81	4	5	10	3	21	21	3	7	14
<7.81	>7.81	1	0	0	0	2	2	2	3	0
<7.81	<7.81	6	1	2	22	10	5	20	16	19

Occasions with chi-square value greater than 7.81 indicate significant non-circularity or non-ellipticity

*Probability bands

In using these values it should also be borne in mind that the original data can be published in various ways. For some stations data are only available with wind directions reported to the nearest ten degrees and this affects the chi-square values – more particularly when winds are light or the variability is small.

The foregoing remarks make it clear that in dealing with lower-stratospheric winds it can be very misleading to use the derived statistics in any way which assumes the wind distribution to be normal and circular; on most occasions such use will tend to overestimate the stronger meridional components and underestimate the stronger zonal components. The distribution is certainly more adequately described by a series of confocal ellipses constructed in the way already described. These ellipses do not provide a perfect representation of the distribution but they are, in many areas, more adequate than circles especially when large departures from the average wind are being considered. If detailed statistics for an individual station were required then it would be advisable, and perhaps desirable, to compute the angle of rotation of the major axis of the ellipse and to use the standard deviations of the components relative to the new axes in determining the lengths of the major and minor axes when constructing the theoretical ellipses. However, use of this method on a hemispheric scale would complicate the presentation of the statistics to an extent that the results do not appear to justify.

For the 25 stations used in the chi-square tests the angle of rotation of the true major axis was determined for each of the mid-season months, i.e. 100 cases. (These are listed in Appendix I.) Detailed examination of these results shows that on 52 occasions the angle of rotation was actually 10° or less and on 77 occasions it was 20° or less. Of the 23 occasions when it was greater than 20° the average wind speed was 10 kt or less on 11 occasions. Of these 23 occasions 8 were significantly non-elliptical (and also non-circular) at the >60-90 per cent range but 4 of the significantly non-elliptical cases were associated with average wind speeds of 10 kt or less. Consequently if our main concern is with the stronger winds and larger departures from average, as suggested earlier, then the ellipses constructed with their axes along the east-west and north-south directions will usually provide an adequate description of the observed distribution but the method will be less satisfactory for light winds and smaller departures from average.

In order to construct the theoretical frequency ellipses in the manner described earlier in the text it is necessary to know the three parameters: V_R the vector mean wind, σ_u the standard deviation of the zonal wind component and σ_v the standard deviation of the meridional wind component. From the charts in Plates 21-35 these parameters can be estimated for any point in the northern hemisphere.

To provide an illustration of the method, the actual statistics for Shreveport for April (see Appendix I) have been used in Figure 16 but the parameters could, of course, have been estimated from the relevant charts. The dots represent the end points of the individual wind vectors and the 30, 60 and 90 per cent probability ellipses were constructed in the way already described. In this example the total number of observations was 257, and so outside the 90 per cent distribution ellipse we should expect approximately 26 observations with between 6 and 7 located in each quadrant. In fact there were 24, distributed as shown in the diagram: this distribution gave a chi-square value of 1.7. If the observed distribution conformed to the statistical distribution described, then each of the 12 boxes inside the 90 per cent distribution ellipse should contain 19 of the wind vectors. The numbers actually observed are entered for comparison and the relevant chi-square values appear in Appendix I. The low values of the chi-square indicate that in this case the wind distribution is well represented by an ellipse. However, the observed winds falling outside the 90 per cent distribution *circle* were as follows: from >315° to 045°, 1; from >045° to 135°, 10; from >135° to 225°, 0; and from >225° to 315°, 11. This distribution gave a chi-square value of 16.1, denoting significant non-circularity and, as the values given in Appendix I show, this distribution was also significantly non-circular at both the >30-60 per cent and >60-90 per cent ranges.

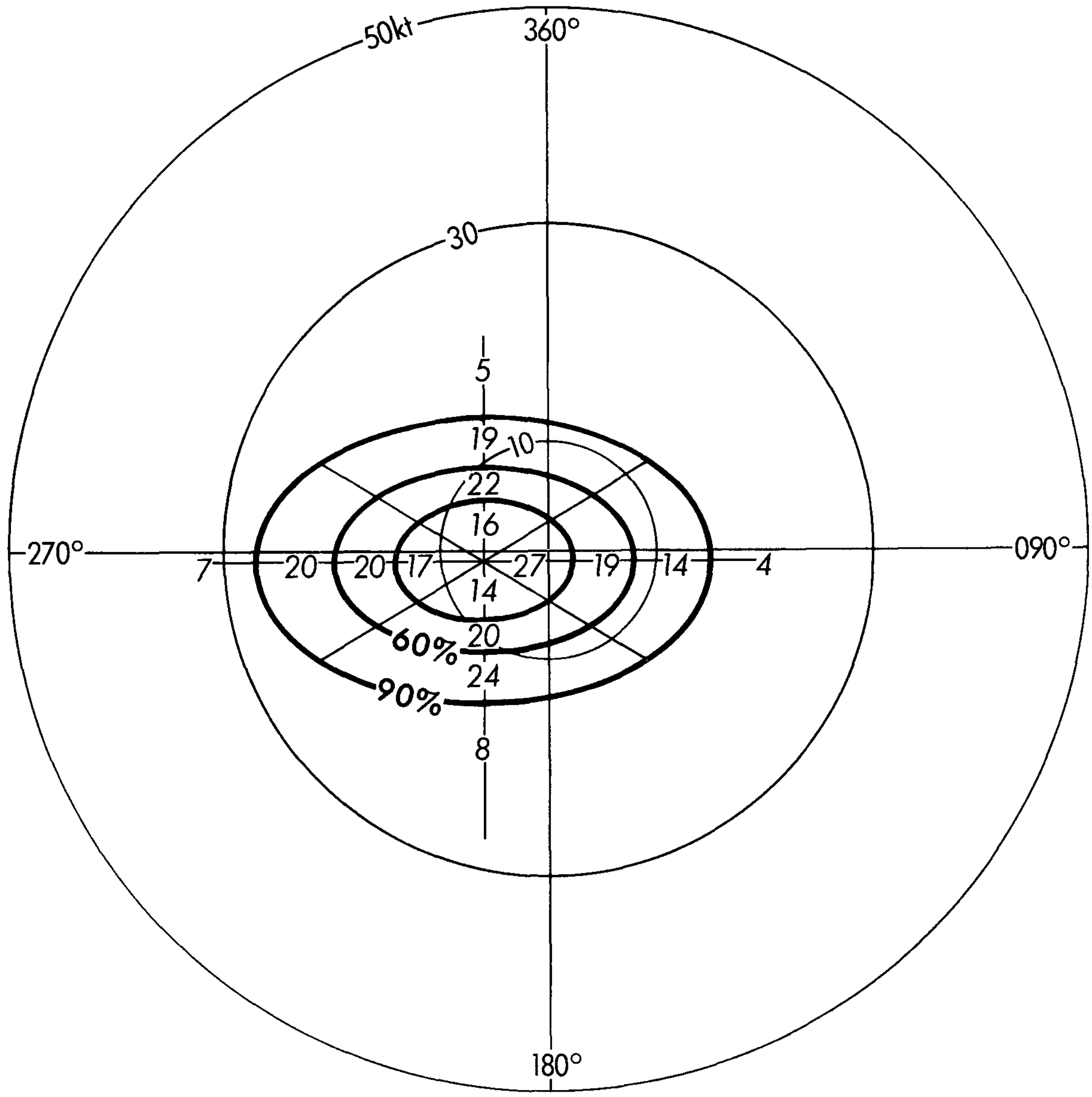


FIGURE 16. DISTRIBUTION OF 50-MILLIBAR WINDS FOR SHREVEPORT (32° 28′N, 93° 49′W), APRIL 1957-61
(See Appendix I for relevant statistics.)

§8 – THE TROPICAL STRATOSPHERIC WIND FLUCTUATION

Earlier in the text, reference has been made to the so-called 26-month fluctuation in zonal wind components, illustration by the observations from Canton Island (02° 46′S, 171°43′W) and Gan (00° 42′S, 73° 10′E) in Figure 17. This curve shows that the generally accepted climatological methods are not suitable for the analysis of tropical and equatorial stratospheric wind data and that the five-year average for any particular month (or a monthly average based on data for any other number of years) may well be a very misleading statistic. During the years since attention was first drawn to this phenomenon much has been written about it. As nearly all the papers so far published have been of a descriptive nature the general characteristics of low-latitude stratospheric winds are known in some detail.[15, 16] The purpose of this section is to describe the fluctuation only insofar as it materially affects the interpretation of the average 50-mb charts published in this Memoir.

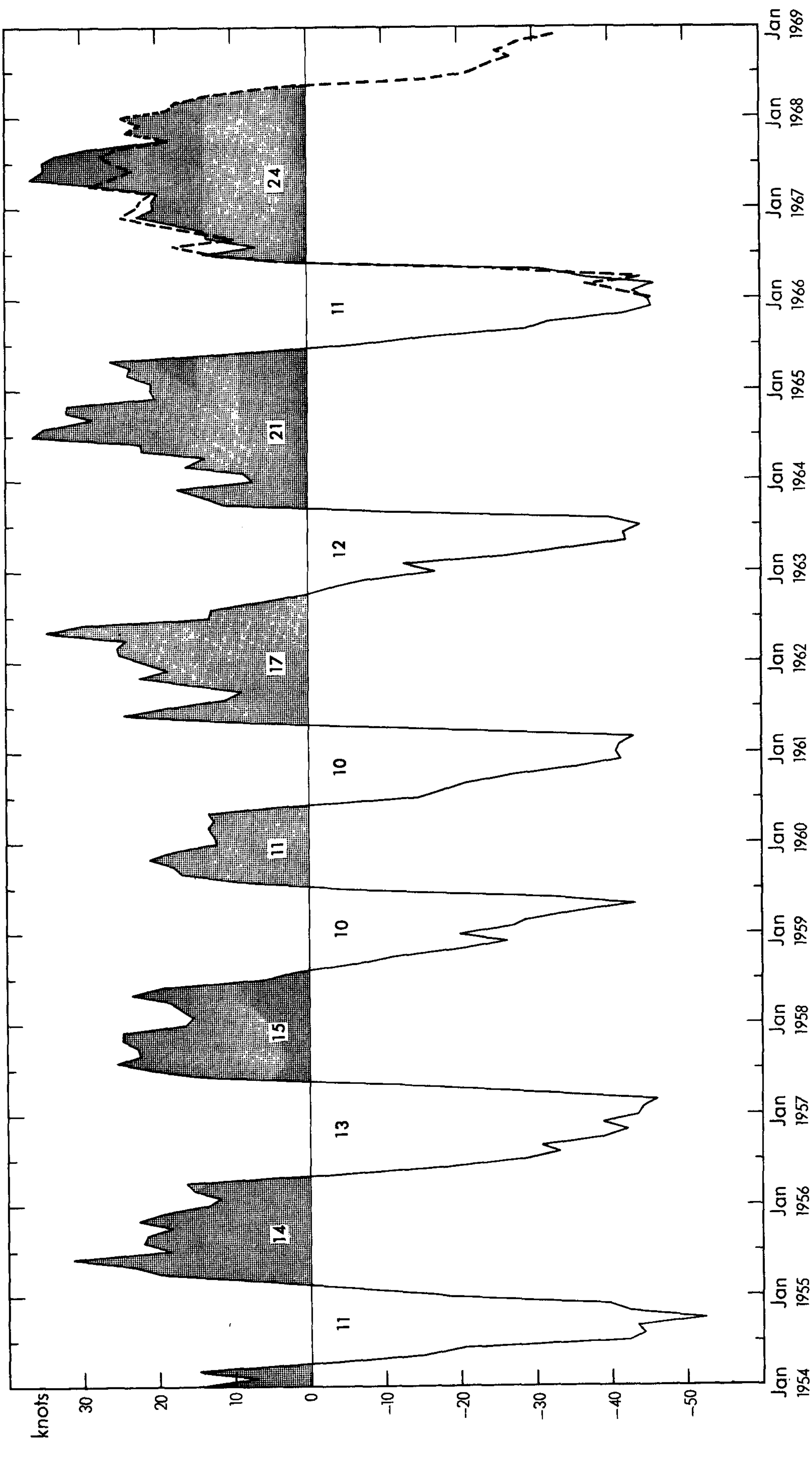


FIGURE 17. MONTHLY MEAN ZONAL WIND COMPONENTS AT 50 MILLIBARS FOR CANTON ISLAND FROM JANUARY 1954 TO AUGUST 1967 AND FOR GAN FROM JANUARY 1966 ONWARDS

——— Canton Island - - - - - - Gan

Components towards the east (shaded) are positive. The duration, in months, of each régime is given near the zero line

For practical purposes the main facts concerning the fluctuation in the zonal component are:

(i) The period of the fluctuation, although often referred to as 26 months, has actually varied from about 22 to 35 months over the years since 1954. Figure 17 shows that once a predominantly easterly régime is established it is likely to persist for about 10 to 13 months whereas the westerly régime tends to be much more variable in length and may persist for periods ranging from 11 months to 24 months.

(ii) As far as can be judged the fluctuation is symmetrical (or nearly so) about the Equator, where the range is at a maximum. The poleward decrease is such that at 25°-30° from the Equator the fluctuation is only just detectable.

(iii) The range (as indicated by monthly means) is such that, close to the Equator, it increases steadily with height from about 60 kt at 60 mb (19.5 km) to about 90 kt at 30 mb (24 km). The range probably reaches a peak value in the region of 25-30 mb with little change thereafter up to 10 mb but owing to limitations of the available data the average values at the higher levels are not so well established. However, rocket soundings have shown that the fluctuation exists at heights of 40-50 km.[20]

(iv) The change from easterly to westerly (or vice versa) starts at the higher stratospheric levels and gradually descends. This change in wind direction usually takes about 12 months to descend from 10 mb to 60 mb and about 6 months to descend from 25 mb to 60 mb. This implies a rate of descent of about 1 km per month.

(v) The easterly winds are appreciably stronger than the westerly winds. When a particular régime is established the wind directions are very near to zonal and the meridional components are usually very small except during the months when the change-over from one régime to another occurs.

(vi) The fluctuation appears to encircle the globe and to be in phase all round a latitude circle.

Table VII shows that at Canton Island, near the Equator, the lower-stratospheric monthly mean winds show little or no regular annual variation and the approximately 26-month fluctuation is the dominant feature. Away from the Equator, at Aden (12° 49′N, 45° 02′E) in the tropics, although the 26-month fluctuation is still present, there is, during the period 1954-64, a very marked annual variation from strong easterly in summer to weaker easterly in the winters of odd years and to westerly in the winters of even years. It is clear from the Canton Island values that considerable year-to-year variations occur in the monthly means in each of the four mid-season months. The Aden values also show this year-to-year variation but to a lesser degree. At Canton Island the 10-year (1954-63) average zonal component for each of the months proves to be a light easterly but within this period the 5-year averages vary from light easterly or light westerly on the one hand to 12-15 kt easterly on the other, depending on the choice of period.

The difficulties of arriving at reliable and meaningful average winds and of describing the variability of the winds in low latitudes are apparent, and to use an 'average' wind of light easterly is clearly very misleading when, within either an easterly or westerly régime, the wind speed is much stronger and the variability much less. In low latitudes, monthly average winds based on data covering a period of years usually bear little or no relation to the values experienced in any one year and, as a consequence, a new method of describing the climatology of the equatorial stratosphere is required.

Earlier in the text it was shown that at these levels the theoretical elliptical distribution gave a much better portrayal of the observed wind distribution than did the normal circular distribution. However, in areas where the 26-month fluctuation predominates this method can be improved upon because we know that once a particular régime is established it is likely to persist for several months.

TABLE VII – MONTHLY MEAN ZONAL WIND COMPONENTS AT CANTON ISLAND (02° 46′S, 171° 43′W) AND ADEN (12° 49′N, 45° 02′E)

	CANTON ISLAND				ADEN			
	Jan.	Apr.	July	Oct.	Jan.	Apr.	July	Oct.
	knots				*knots*			
1954	+15.7	−0.8	−42.2	−52.5	+6.8	−8.3	−46.1	−30.6
55	(−18.0)	+19.8	+18.3	+18.1	−17.9	−12.0	−37.7	(−8.1)
56	+13.2	+16.5	−28.3	−38.9	(+8.6)	−1.2	−51.5	(−45.0)
57	−43.6	−30.5	+20.9	+22.6	−6.1	−13.0	−37.2	−1.1
58	+16.3	+18.4	+5.5	−11.6	+6.7	+8.1	−36.7	−24.5
59	−19.9	−35.7	−4.8	+17.8	−1.5	−10.9	−47.3	−0.8
60	+12.0	+12.4	−14.7	−27.0	+4.3	+5.2	−45.6	−18.4
61	−40.8	−19.9	+19.1	+15.7	(−9.8)	−15.3	(−32.3)	+2.0
62	+22.0	+24.0	+13.1	−0.1	+8.3	+10.3	−32.8	(−18.8)
63	−17.0	−33.9	−44.0	+10.9	−15.7	−22.0	−53.3	−3.9
64	+7.2	+13.5	+36.5	+31.9	+21.5	+14.5	−24.5	−6.4

Wind components towards the east are positive, values of the components are given in knots, and bracketed values indicate that the monthly mean was based on less than 10 observations.

The Canton Island data are for the 50-mb level but those for Aden are for the 60-mb level from January 1954 to April 1961 and for the 50-mb level from July 1961 onwards.

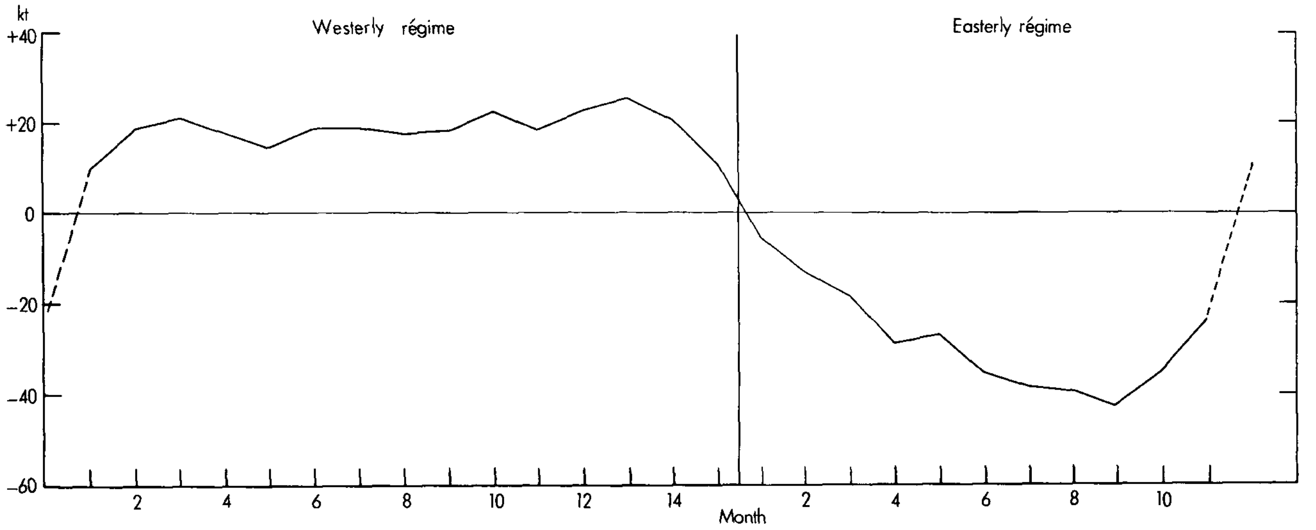
In an attempt to resolve some of the difficulties of presenting the climatological facts of the 26-month fluctuation a more detailed study of the Canton Island 50-mb data for the period April 1954-June 1965 was carried out. This period of 135 months covered exactly five full periods of the oscillation but, although this suggests an average length of 27 months, it can be seen from Figure 17 that during those years the period varied quite considerably. The easterly régime only varied from 10 months to 13 months but the westerly régime varied from a minimum of 11 months to a maximum of 24 months. Before the westerly régime which lasted from October 1963 to June 1965 there was a volcanic eruption at Mount Agung, Bali (08° S, 115° E), in March 1963, and it has been suggested[21] that the solar radiation absorbed by the volcanic dust thrown into the lower stratosphere may have played a part in causing this particular prolonged period of westerlies.

April 1954, May 1956, September 1958, July 1960 and October 1962 values were taken from the Canton Island data to provide average values for the first month of the easterly régime. Other relevant months were used for the 2nd, 3rd ... up to the 11th month of the easterly régime; as there were only two occasions when the easterly lasted for 12 months and only one when it lasted for 13 months these were not included. The months within the five westerly régimes were treated similarly and they provided statistics based on five occasions for months 1 to 11; four occasions for months 12 to 14 and three occasions for month 15. For months 16 to 21 the number of relevant occasions fell to two or one and so these were not included.

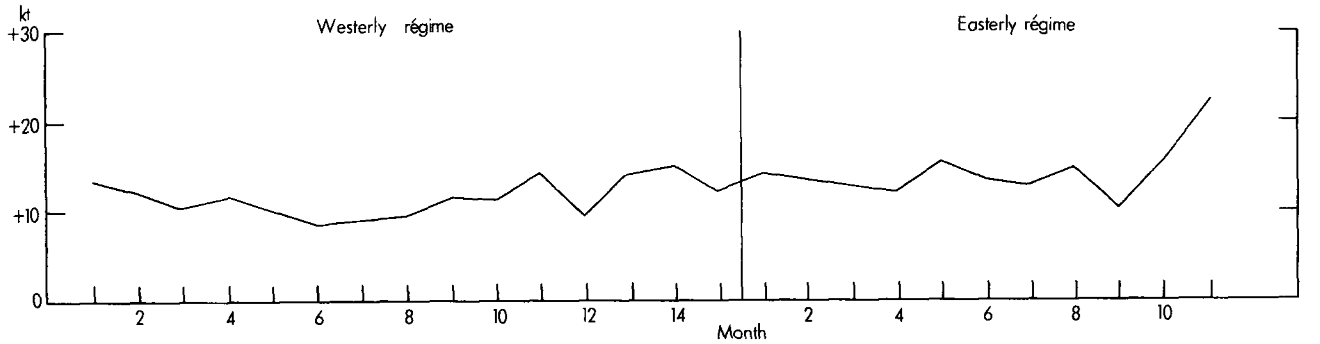
The data selected in this way were processed to provide average zonal and meridional components and their standard deviations for each set of months. The averages were obtained by taking all the individual observations together, and the standard deviations describe the variability about this average. In all cases the average meridional component was small (usually within the range ± 1 kt) and so this is not reproduced with the other statistics shown in Figure 18(a), (b) and (c). In addition chi-square values for each set of data were obtained in the manner described earlier in the text and these are shown at Figure 19(a), (b) and (c). These diagrams, based on a detailed analysis of the 26-month fluctuation confirm the more general results for low-latitude stations. At the >60-90 per cent range of the distribution, in 20 of the 26 months the distribution proved to be significantly non-circular but only four were significantly non-elliptical. (Figure 19(a) shows that in only two of these, i.e. the first and eighth easterly months, was the chi-square value noticeably above the 5 per cent significance level of 7.81). In the >30-60 per cent range there were 16 occasions of significant non-circularity compared with only eight occasions of non-ellipticity but in the 0-30 per cent range (the smaller departures from average) the elliptical distribution shows no improvement over the circular distribution.

With the information given in Figure 18(a), (b) and (c) the theoretical distribution ellipses can be constructed for a month at any given stage of the fluctuation although, because of the very variable length of the westerly régime, it is not possible to provide statistics to cover all eventualities – particularly occasions when the westerlies persist for a longer period than usual. However, for some users this might be an unnecessary refinement and it may be quite adequate to be able to portray and describe the distributions during either an easterly or a westerly régime. In order to do this the relevant statistics were obtained for 70 'westerly' months and 47 'easterly' months. If the monthly mean zonal wind component was less than 10 knots at the beginning or end of a régime the data were ignored but if it fell below 10 knots within an established westerly or easterly régime then the data were included. The theoretical elliptical distributions and the statistics obtained in this way are reproduced in Figures 20(a) and (b).

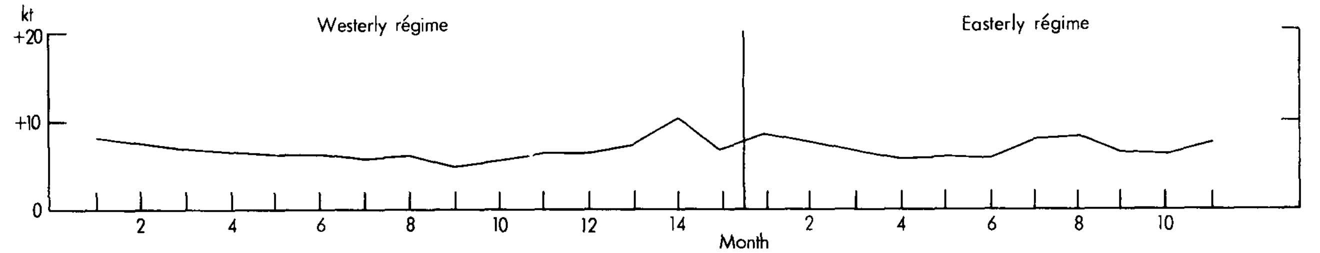
Any attempt to describe the climatology of the lower stratosphere, in regions where the approximately 26-month fluctuation is the dominant feature, is complicated by the very variable length of period (22-35 months) during the years since reliable data became available in 1954. It is possible, therefore, that very many more years of data will be needed before the climatology of the lower-latitude stratosphere can be adequately described. However, until such time, it is suggested that if there is a need to provide statistics for these areas then an acceptable solution is to add to the curve of monthly mean zonal wind components in Figure 17 as more data become available and to extrapolate from this for periods of up to a few months ahead. (As radar wind ascents at Canton Island ceased in September 1967 the curve in Figure 17 has been extended up to December 1968 by using the monthly mean zonal wind components for Gan (00° 41°S, 73° 10 'E) with an overlap between the two stations from January 1966 to September 1967. Although Gan is in the Indian Ocean and Canton Island is in the Pacific Ocean the curve may, for practical purposes, be taken as representative of equatorial regions generally, as the fluctuation is very nearly in phase all round a latitude circle.) When the part of the fluctuation that is relevant to the period of interest has been obtained the values given in Figures 18(a), (b) and (c) may be used to construct the theoretical distribution ellipses. Alternatively, Figures 20(a) and (b) provide a somewhat cruder estimate of the distribution to be expected within an established easterly or westerly régime.



(a) Average zonal wind components $\bar{u}$



(b) Standard deviation of zonal wind components σ_u



(c) Standard deviation of meridional wind components σ_v

FIGURE 18. CANTON ISLAND (2° 46′S, 171° 43′W) 50-MILLIBAR AVERAGE ZONAL WIND COMPONENTS *(u)* AND STANDARD DEVIATIONS OF ZONAL (σ_u) AND MERIDIONAL (σ_v) COMPONENTS BASED ON FIVE FULL CYCLES OF THE 26-MONTH OSCILLATION FROM APRIL 1954 TO JUNE 1965

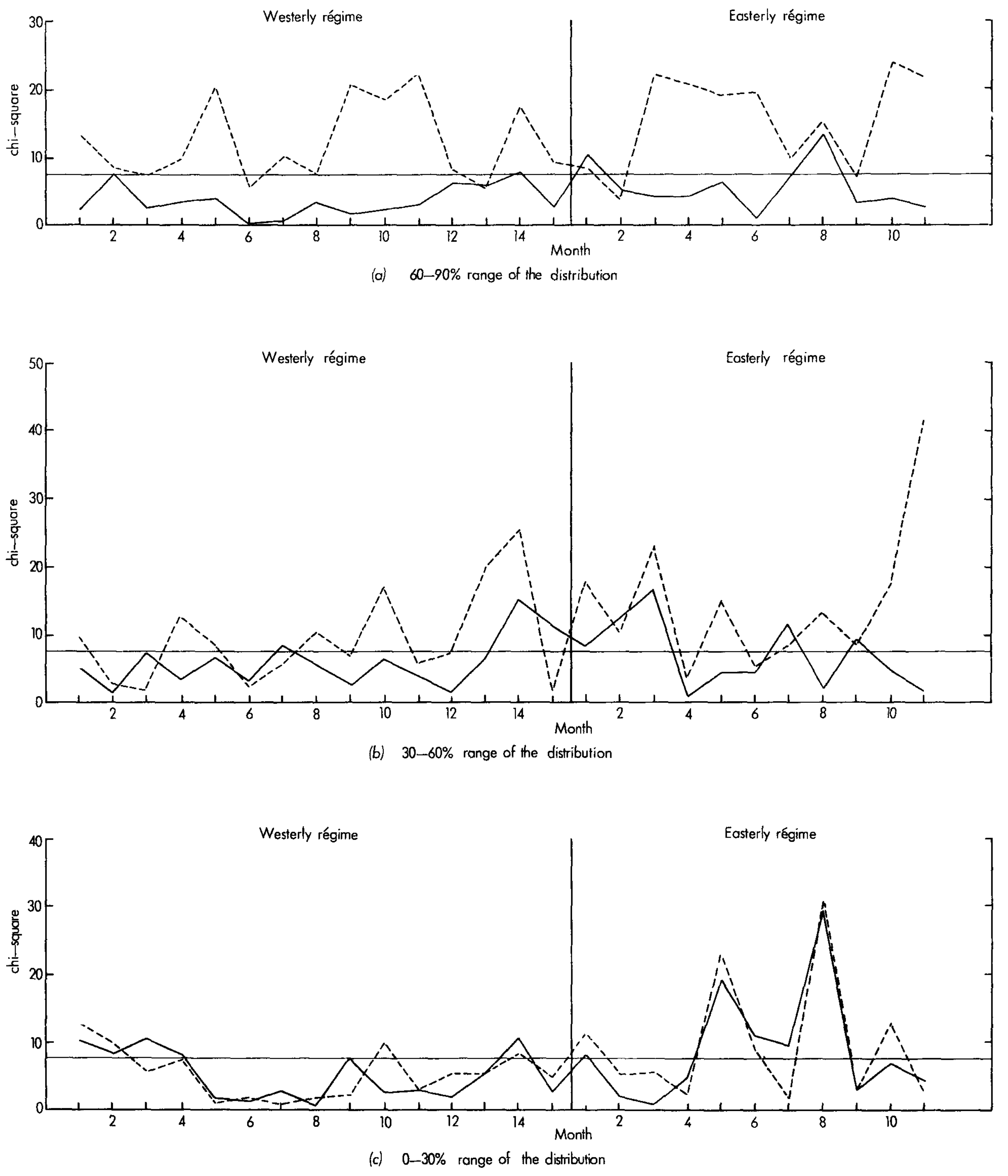


FIGURE 19. CHI-SQUARE VALUES FOR ELLIPTICITY TEST AND CIRCULARITY TEST FOR CANTON ISLAND 50-MILLIBAR WINDS, BASED ON FIVE FULL CYCLES OF THE 26-MONTH OSCILLATION FROM APRIL 1954 TO JUNE 1965

———— Ellipticity test - - - - - - - - - - Circularity test

The horizontal lines at 7.81 represent the 5 per cent significance level

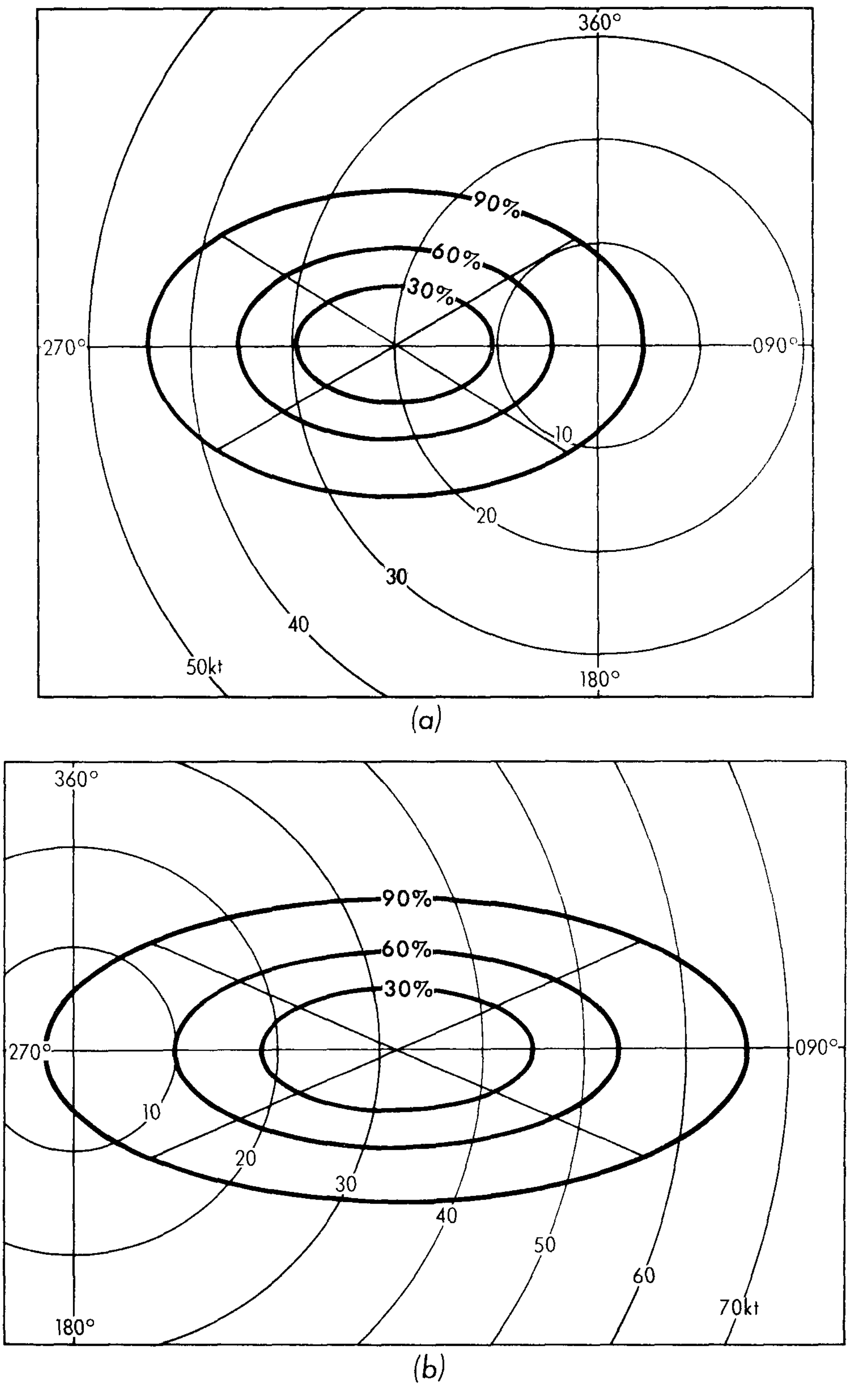


FIGURE 20. THEORETICAL DISTRIBUTION OF 50-MILLIBAR WINDS IN LOW LATITUDES BASED ON (a) 70 MONTHS OF WESTERLY RÉGIME AND (b) 47 MONTHS OF EASTERLY RÉGIME AT CANTON ISLAND

(a) Vector mean wind (V_R) = 271° 20 kt, standard deviation of zonal component (σ_u) = 11.4 kt, standard deviation of meridional component (σ_v) = 6.9 kt, number of observations (N) = 1651

(b) Vector mean wind (V_R) = 090° 32 kt, σ_u = 16.1 kt, σ_v = 7.0 kt, N = 1030

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APPENDIX I – STATISTICS FOR THE 25 STATIONS USED IN THE CHI-SQUARE TESTS

Station	Position	Month	Vector mean wind V_R		Standard deviation of wind components: Zonal σ_u	Meridional σ_v	Number of observations N	Chi-square values for Circularity test: *0-30%	>30-60%	>60-90%	Ellipticity test: *0-30%	>30-60%	>60-90%	Angle of rotation**
			deg	*kt*	*kt*	*kt*								*deg*
Canton Island	02°46′S,171°43′W	Jan.	093	14	31.0	8.9	107	12.71	47.08	25.94	4.88	11.78	1.13	1
		Apr.	096	12	25.4	6.7	116	6.34	54.34	38.20	6.89	29.83	7.81	-1
		July	269	6	19.2	7.7	134	2.93	17.93	26.00	4.20	8 46	7.77	-1
		Oct.	263	3	21.9	6.3	101	12.23	54.65	33.10	7.99	26.87	5.88	-5
Yap	09°31′N,138°08′E	Jan.	093	9	22.0	6.1	72	27.82	28.42	32.08	7.71	5.93	4.79	-8
		Apr.	089	16	17.8	5.8	84	8.88	34.21	24.95	6.53	4.18	4.76	-4
		July	092	28	12.3	7.1	66	8.47	9.52	5.86	5.60	4.49	7.07	-20
		Oct.	101	11	18.8	9.0	83	4.30	16.27	16.74	4.71	11.75	4.96	-8
Aden	12°49′N,45°02′E	Jan.	267	2	12.7	7.3	90	0.26	17.44	19.00	1.89	19.96	4.04	7
		Apr.	109	4	16.5	5.7	68	1.73	20.71	16.56	3.69	5.81	3.77	3
		July	089	39	9.5	7.4	67	6.14	3.41	2.41	7.50	5.01	3.04	-1
		Oct.	096	6	14.4	5.1	84	6.98	32.62	11.49	8.56	7.23	2.15	-4
Lihue	21°59′N,159°21′W	Jan.	093	3	11.1	6.5	157	1.49	11.98	15.29	6.23	8.58	4.31	-2
		Apr.	095	5	8.8	5.9	214	7.75	8.10	8.11	5.25	0.33	1.15	5
		July	094	36	7.0	6.0	272	3.19	12.48	11.13	1.40	6.13	6.43	-25
		Oct.	093	15	7.2	4.9	267	1.68	8.47	14.07	3.48	4.09	3.06	3
Central Airfield Iwo Jima	24°47′N,141°20′E	Jan.	261	20	22.7	8.7	181	36.42	18.09	33.24	11.65	5.68	4.96	11
		Apr.	189	2	14.7	6.2	183	15.73	42.38	26.54	5.85	10.50	19.05	11
		July	088	36	7.8	6.1	280	33.33	13.10	23.71	29.52	7.33	19.86	3
		Oct.	095	15	11.4	8.9	214	36.80	15.32	24.01	50.18	2.21	15.07	-29
Kindley Field	32°22′N,64°41′W	Jan.	273	28	24.4	11.4	230	48.39	49.09	23.29	44.94	5.55	11.20	0
		Apr.	286	7	15.4	8.7	250	51.91	40.07	25.45	25.48	11.64	27.75	8
		July	091	23	7.5	5.9	287	53.70	9.66	32.19	52.96	4.81	33.42	-12
		Oct.	085	2	8.9	6.5	259	16.23	13.73	16.12	10.32	6.93	3.82	9

*Probability bands.
**The angle between the true major axis of the ellipse and the east-west (or occasionally north-south) axis. A negative sign represents rotation in the clockwise direction.

APPENDIX I *(contd)*

Station	Position	Month	Vector mean wind		Standard deviation of wind components		Number of observations	Chi-square values for						Angle of rotation**
					Zonal	Meridional		Circularity test			Ellipticity test			
			V_R		σ_u	σ_v	N	*0-30%	>30-60%	>60-90%	*0-30%	>30-60%	>60-90%	
			deg	*kt*	*kt*	*kt*								*deg*
Shreveport	32°28′N,93°49′W	Jan.	275	19	14.9	8.7	260	8.56	6.92	24.26	3.64	8.77	3.13	15
		Apr.	260	6	9.9	5.9	257	0.68	18.36	14.84	5.36	0.44	2.63	1
		July	087	23	6.2	3.9	291	14.35	4.52	22.35	7.28	0.80	7.02	-8
		Oct.	277	3	9.1	5.8	220	1.03	4.18	12.18	4.18	5.03	1.15	10
Wheelus Field	32°54′N,13°17′E	Jan.	269	17	17.3	12.9	261	7.55	11.08	5.03	5.13	4.16	8.05	16
		Apr.	250	9	16.3	9.3	275	91.36	10.26	33.98	46.88	5.68	22.48	16
		July	093	23	7.5	6.4	277	1.67	8.73	7.95	3.56	8.29	5.88	5
		Oct.	231	9	17.1	11.9	237	28.56	8.64	31.79	30.12	9.92	22.39	22
Kenitra	34°18′N,06°36′W	Jan.	291	12	14.3	10.6	243	4.68	9.34	17.37	5.36	7.75	7.34	5
		Apr.	274	9	12.6	8.3	239	19.01	5.27	28.33	8.77	12.26	11.64	5
		July	094	19	8.7	6.8	261	38.04	9.87	14.24	33.07	5.43	11.19	8
		Oct.	268	9	11.1	7.1	263	1.67	10.11	21.10	1.97	6.72	7.26	4
Nicosia	35°09′N,33°17′E	Jan.	259	18	14.9	8.8	59	–	–	–	–	–	–	8
		Apr.	252	8	8.9	7.6	91	4.02	3.14	4.52	2.46	1.48	2.07	18
		July	095	19	8.0	5.9	124	4.60	3.26	5.54	2.88	1.59	1.37	12
		Oct.	265	12	8.9	7.2	137	4.71	4.05	11.02	3.21	0.33	1.63	31
Wajima	37°23′N,136°54′E	Jan.	265	50	24.0	12.1	197	1.98	13.14	31.75	4.82	4.87	1.35	-8
		Apr.	263	24	18.4	10.8	199	8.79	21.90	16.13	10.42	4.16	2.69	9
		July	083	18	12.0	6.9	239	71.36	23.09	40.75	62.53	5.83	31.08	5
		Oct.	253	18	14.0	9.4	233	35.95	8.87	20.57	43.07	3.46	7 32	17
Lajes	38°45′N,27°05′W	Jan.	264	16	16.7	11.3	252	28.25	28.19	19.88	19.05	45.38	12.36	19
		Apr.	291	3	7.8	6.4	248	17.60	3.96	11.93	13.82	5.27	11.19	8
		July	088	16	5.5	3.9	301	0.85	8.22	11.53	3.62	0.63	2.17	6
		Oct.	300	5	8.6	6.5	267	0.35	3.47	10.86	0.54	2.02	4.47	7

*Probability bands.
**The angle between the true major axis of the ellipse and the east-west (or occasionally north-south) axis. A negative sign represents rotation in the clockwise direction.

APPENDIX I *(contd)*

Station	Position	Month	Vector mean wind V_R		Standard deviation of wind components: Zonal σ_u	Meridional σ_v	Number of observations N	Chi-square values for Circularity test: *0-30%	>30-60%	>60-90%	Ellipticity test: *0-30%	>30-60%	>60-90%	Angle of rotation**
			deg	*kt*	*kt*	*kt*								*deg*
Portland	43°39′N,70°19′W	Jan.	265	36	18.4	13.1	195	5.35	11.80	11.65	1.63	13.78	2.38	18
		Apr.	272	10	9.1	7.9	239	5.93	3.35	5.01	3.70	5.52	1.93	10
		July	085	7	6.8	4.3	255	9.82	21.28	5.48	14.92	3.51	6.24	7
		Oct.	269	14	11.0	8.1	244	2.10	21.57	13.24	1.00	20.02	4.04	29
Salem	44°55′N,123°01′W	Jan.	326	13	16.9	11.4	225	26.03	18.12	26.74	19.14	13.50	18.77	-14
		Apr.	272	5	8.9	7.8	246	4.92	22.76	7.17	6.47	16.21	8.27	19
		July	092	9	4.8	3.8	272	5.82	4.87	4.79	4.13	5.16	5.49	21
		Oct.	283	10	8.4	8.1	257	2.01	3.33	9.78	2.53	5.55	9.34	41
Wakkanai	45°25′N,141°41′E	Jan.	250	38	21.3	14.0	164	3.70	7.02	20.39	4.68	5.23	2.27	5
		Apr.	246	16	12.7	9.8	140	7.71	2.38	8.48	3.52	3.90	7.52	11
		July	077	12	6.6	5.2	226	1.53	0.42	11.50	0.80	5.89	7.30	-3
		Oct.	252	28	15.3	10.4	221	8.47	8.95	13.14	5.64	15.03	9.08	9
Milano/Linate	45°26′N,09°17′E	Jan.	274	29	26.9	20.5	120	9.56	20.89	8.33	9.00	12.00	9.78	29
		Apr.	265	7	8.9	10.1	74	33.01	3.55	3.91	38.41	3.53	6.11	12
		July	096	6	12.4	9.1	136	36.11	7.02	13.82	46.66	5.82	11.45	3
		Oct.	274	9	10.1	8.9	157	39.09	5.27	14.22	36.08	4.37	12.64	35
Crawley	51°05′N,00°13′W	Jan.	286	31	22.6	15.1	161	6.75	24.74	13.16	2.08	17.36	1.87	10
		Apr.	327	5	8.9	7.2	195	2.76	12.35	9.32	2.04	7.68	7.41	-22
		July	110	5	4.9	5.0	195	3.35	2.26	4.76	2.94	2.52	4.23	36
		Oct.	283	10	10.0	9.2	197	0.75	6.56	1.44	1.29	4.94	0.22	38
Adak	51°53′N,176°39′W	Jan.	194	13	16.2	11.5	184	23.98	17.08	10.71	21.24	5.85	5.82	12
		Apr.	227	5	12.5	11.1	163	10.79	6.07	5.72	8.69	4.15	4.18	9
		July	087	12	8.9	12.2	154	59.25	1.70	18.69	64.44	5.53	20.08	22
		Oct.	259	13	14.0	10.9	162	8.54	12.30	11.66	9.43	6.53	5.74	-12

*Probability bands.

**The angle between the true major axis of the ellipse and the east-west (or occasionally north-south) axis. A negative sign represents rotation in the clockwise direction.

APPENDIX I *(contd)*

Station	Position	Month	Vector mean wind V_R		Standard deviation of wind components: Zonal σ_u	Meridional σ_v	Number of observations N	Chi-square values for Circularity test *0-30%	>30-60%	>60-90%	Chi-square values for Ellipticity test *0-30%	>30-60%	>60-90%	Angle of rotation**
			deg	*kt*	*kt*	*kt*								*deg*
Goose	53°19′N,60°25′W	Jan.	257	48	30.0	25.7	208	3.48	16.48	10.86	6.89	29.40	4.16	31
		Apr.	242	6	10.4	7.4	263	12.89	16.25	9.15	3.22	7.24	1.26	-7
		July	096	4	5.6	5.5	234	10.91	10.91	1.46	12.15	9.77	1.46	-37
		Oct.	268	19	13.7	10.6	256	3.46	7.39	8.37	2.58	9.24	4.58	27
Schleswig	54°32′N,09°33′E	Jan.	287	32	23.0	17.5	123	2.45	5.05	4.18	2.96	5.62	0.71	-14
		Apr.	292	5	11.1	5.8	129	37.30	11.34	13.96	20.23	5.38	3.40	-1
		July	102	7	7.7	4.4	175	5.40	7.76	5.66	7.38	9.89	5.66	2
		Oct.	300	10	8.8	9.5	101	4.52	27.14	4.29	5.03	24.80	5.57	40
Churchill	58°45′N,94°04′W	Jan.	317	41	27.0	24.7	130	8.69	5.41	5.26	7.87	7.92	3.67	5
		Apr.	319	5	11.2	9.5	169	3.26	12.14	25.66	4.18	5.14	25.11	23
		July	046	6	5.1	4.2	153	7.23	22.78	4.07	4.62	16.01	3.87	-7
		Oct.	290	21	14.5	11.7	179	15.56	31.24	16.16	16.95	13.75	13.64	10
Keflavík	63°58′N,22°36′W	Jan.	253	52	25.8	33.7	238	7.51	10.11	7.61	6.52	9.12	6.91	0
		Apr.	270	8	14.0	9.2	272	6.85	55.57	22.74	13.33	12.80	16.29	-15
		July	098	7	4.4	4.2	278	29.55	3.91	12.00	29.36	5.29	8.86	18
		Oct.	255	17	15.1	13.9	257	20.94	19.56	6.47	23.89	14.20	6.16	-26
Kotzebue	66°52′N,162°38′W	Jan.	251	24	19.9	17.0	136	8.05	12.52	5.78	7.68	11.03	5.15	1
		Apr.	182	3	9.4	8.9	176	1.21	9.06	4.39	1.21	10.01	4.39	-7
		July	094	7	7.1	5.0	209	24.67	4.73	9.77	22.05	4.27	7.75	14
		Oct.	253	28	11.2	12.1	184	5.82	10.84	5.07	6.50	11.03	4.79	-11
Barter Island	70°08′N,143°38′W	Jan.	292	47	25.0	22.7	232	3.24	14.42	9.28	3.82	6.44	5.89	-28
		Apr.	297	4	9.6	8.5	246	7.33	10.14	11.34	10.82	8.60	7.75	-3
		July	088	4	5.2	5.1	252	21.82	5.04	5.25	19.98	4.83	5.44	37
		Oct.	265	27	12.7	12.1	245	11.79	7.87	4.45	10.26	9.09	3.55	39

*Probability bands.
**The angle between the true major axis of the ellipse and the east-west (or occasionally north-south) axis. A negative sign represents rotation in the clockwise direction.

APPENDIX I (*contd*)

Station	Position	Month	Vector mean wind		Standard deviation of wind components		Number of observations	Chi-square values for						Angle of rotation**
					Zonal	Meridional		Circularity test			Ellipticity test			
			V_R		σ_u	σ_v	N	*0-30%	>30-60%	>60-90%	*0-30%	>30-60%	>60-90%	
			deg	*kt*	*kt*	*kt*								*deg*
Thule	76°31′N,68°50′W	Jan.	339	22	21.5	27.3	123	4.42	8.59	5.64	5.45	8.87	4.61	-16
		Apr.	301	4	11.4	16.3	257	32.52	13.31	26.70	33.68	26.00	23.65	20
		July	095	6	4.1	4.2	281	9.34	1.72	4.29	10.42	0.46	4.94	7
		Oct.	267	15	14.0	16.0	224	3.22	1.66	8.14	3.83	0.13	8.56	31

*Probability bands.
**The angle between the true major axis of the ellipse and the east-west (or occasionally north-south) axis. A negative sign represents rotation in the clockwise direction.

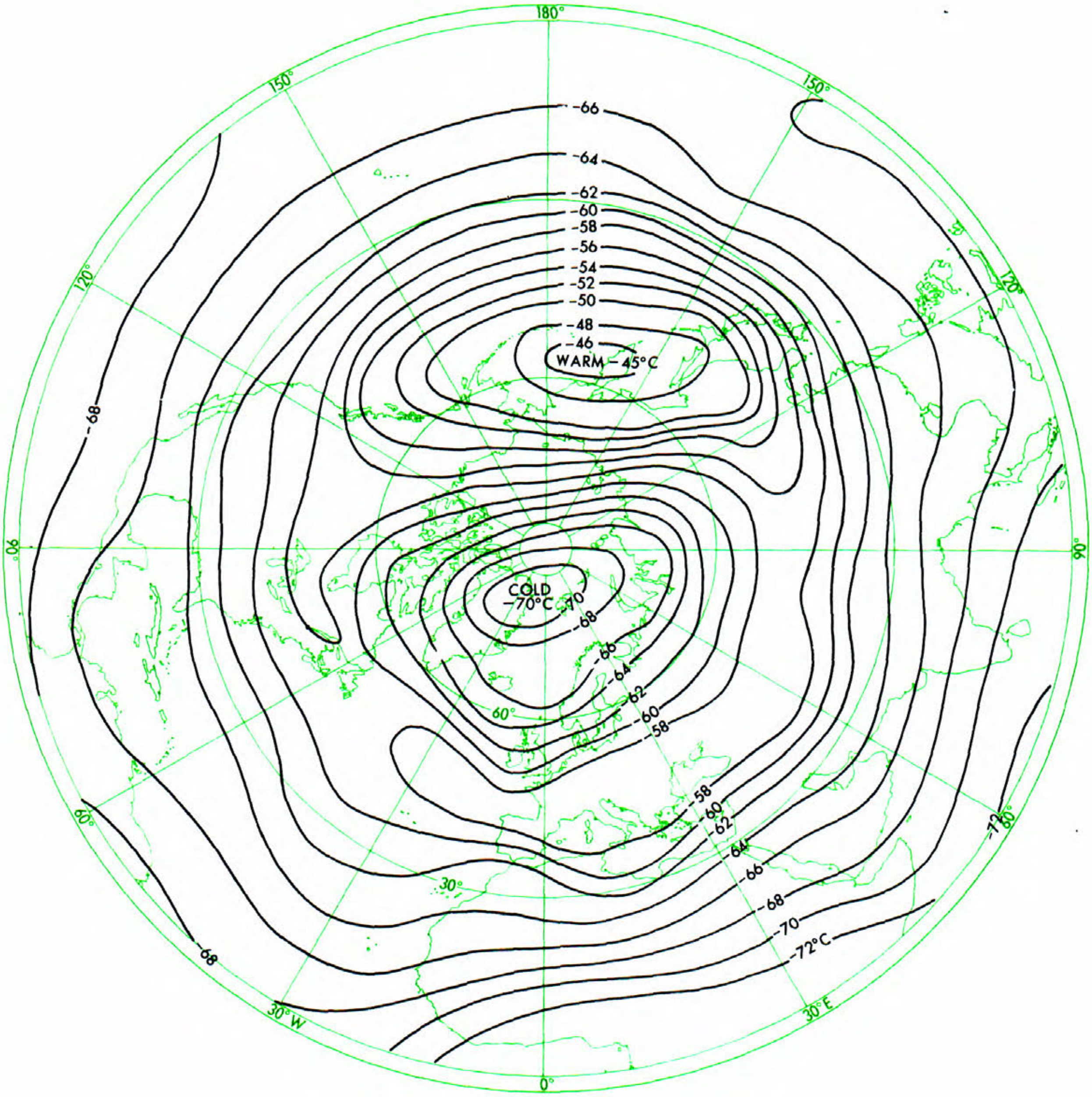
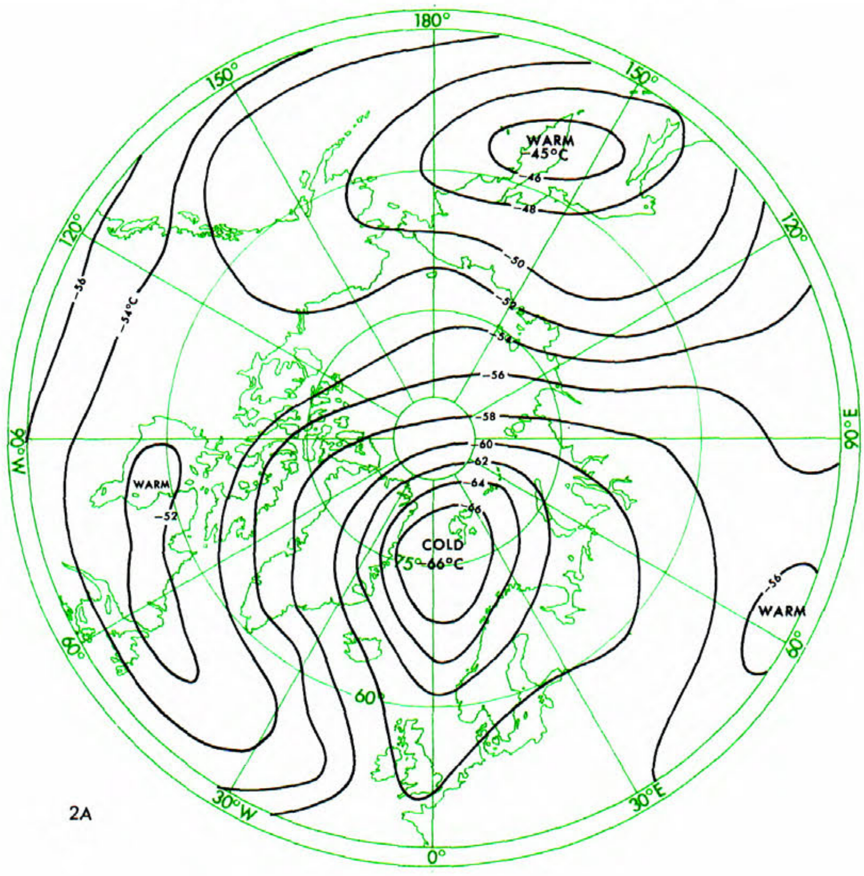
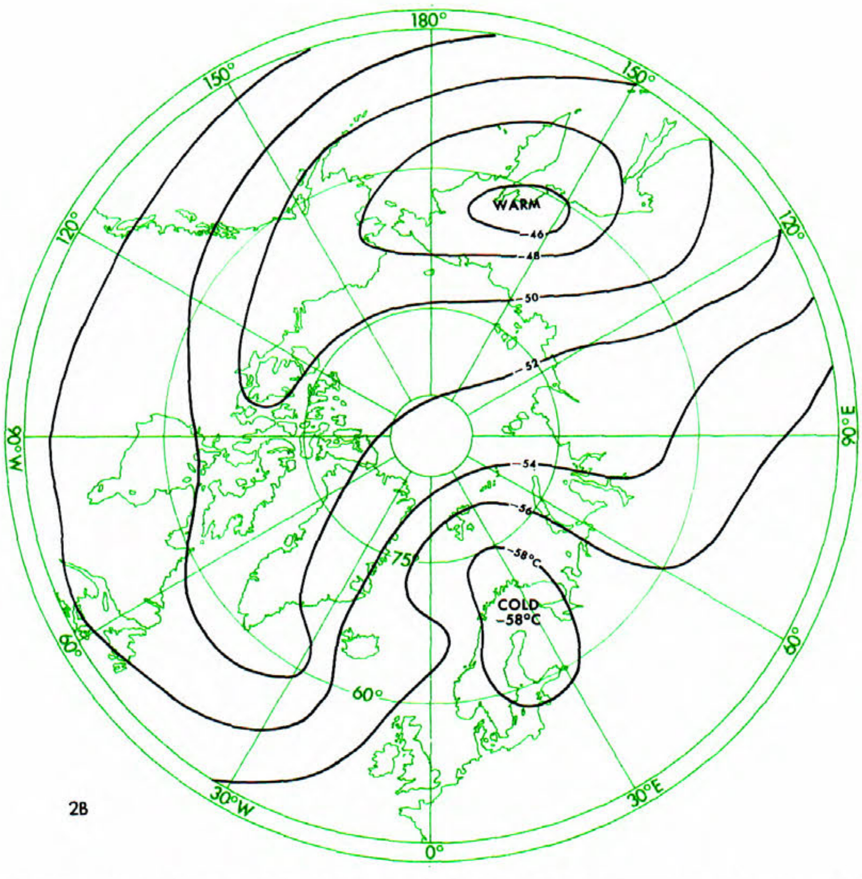


PLATE 1. AVERAGE TEMPERATURES AT 50 MILLIBARS OVER THE NORTHERN HEMISPHERE IN JANUARY, 1957-61
Temperatures are in degrees Celsius



2A



2B

PLATES 2A AND 2B. AVERAGE TEMPERATURES AT 50 MILLIBARS OVER THE NORTHERN HEMISPHERE (NORTH OF LATITUDE 45° N) IN FEBRUARY (2A) AND MARCH (2B), 1957-61

Temperatures are in degrees Celsius

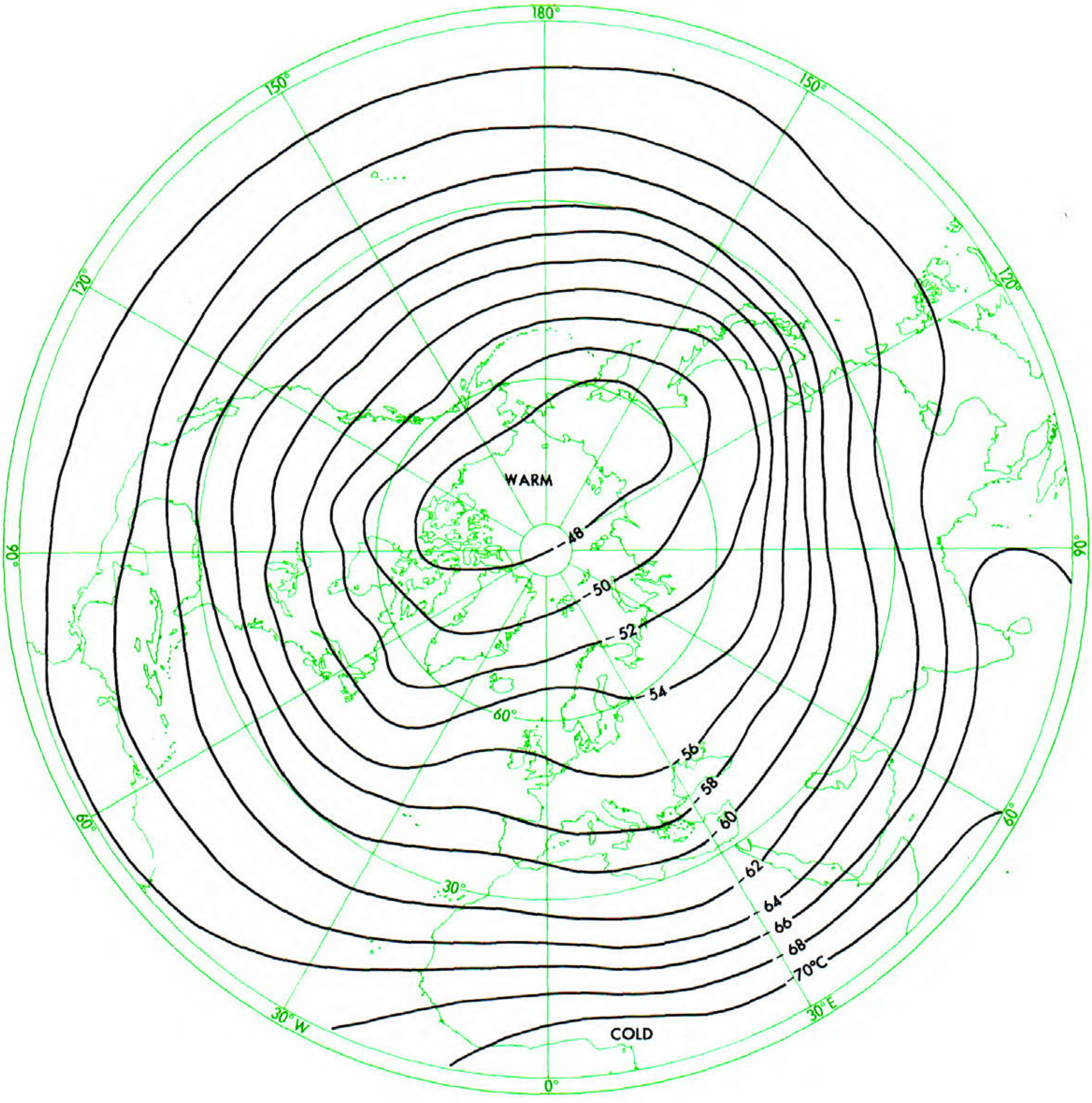


PLATE 3. AVERAGE TEMPERATURES AT 50 MILLIBARS OVER THE NORTHERN HEMISPHERE IN APRIL, 1957-61

Temperatures are in degrees Celsius

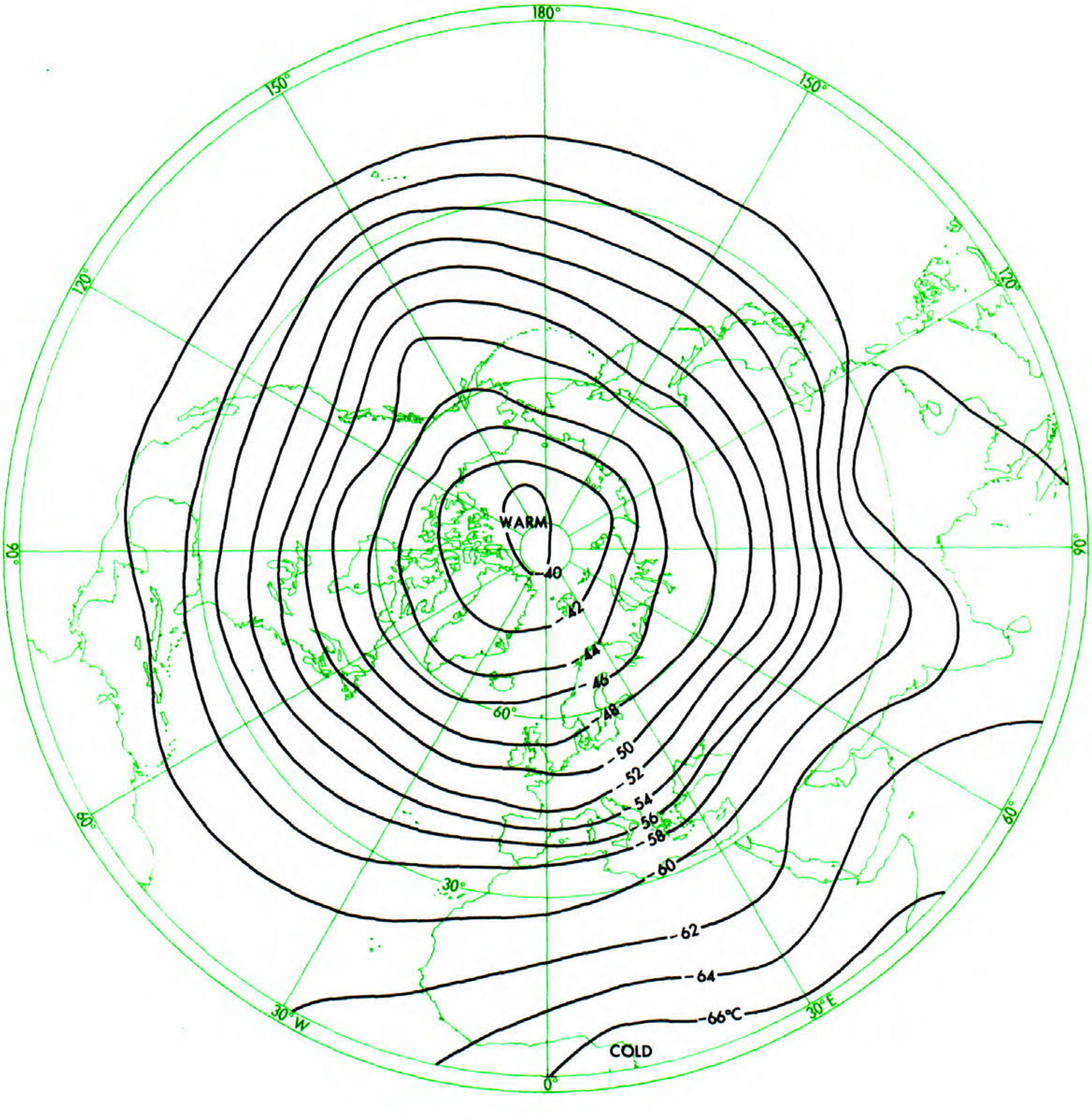


PLATE 4. AVERAGE TEMPERATURES AT 50 MILLIBARS OVER THE NORTHERN HEMISPHERE IN JULY, 1957-61
Temperatures are in degrees Celsius

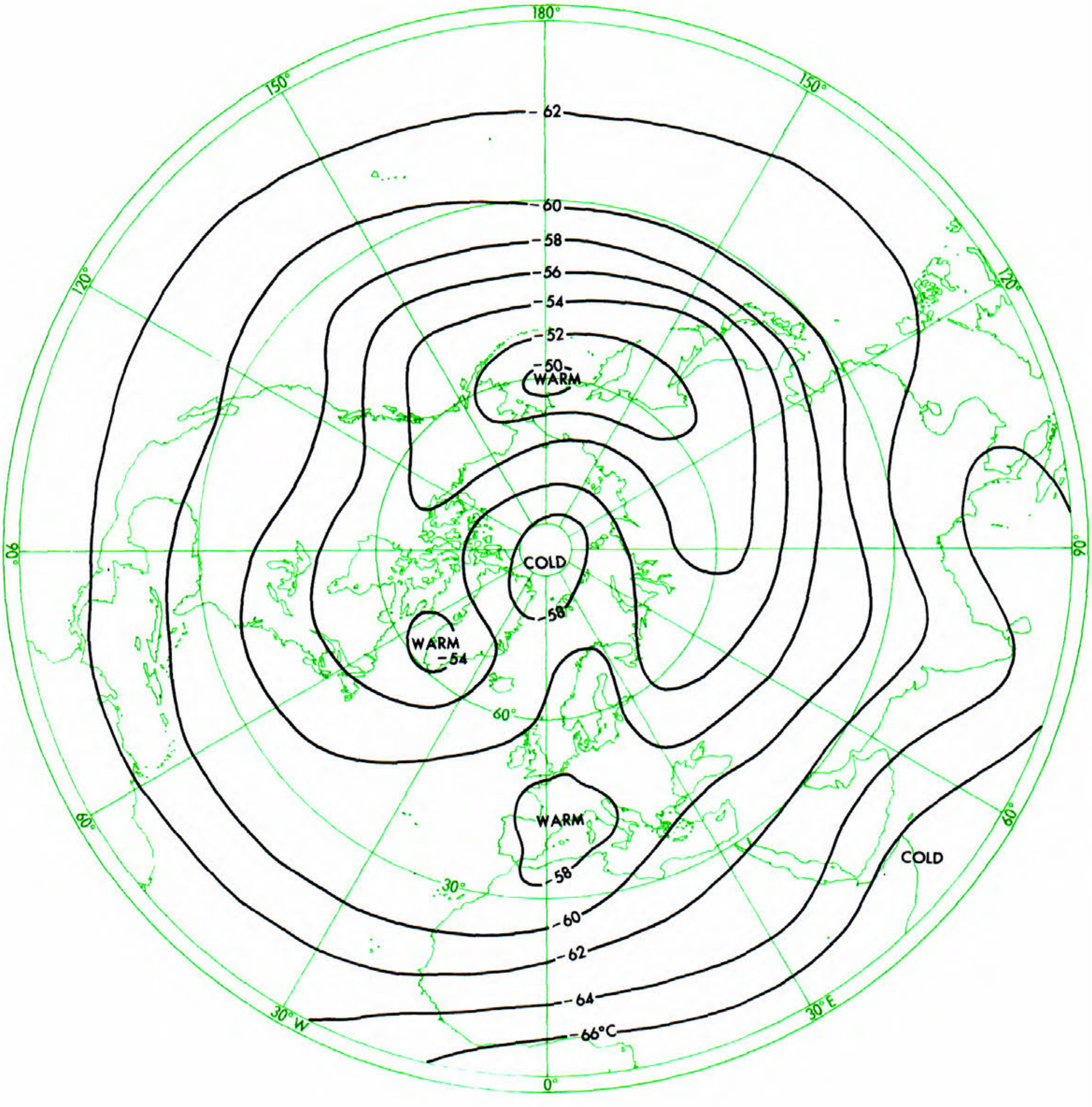


PLATE 5. AVERAGE TEMPERATURES AT 50 MILLIBARS OVER THE NORTHERN HEMISPHERE IN OCTOBER, 1957-61

Temperatures are in degrees Celsius

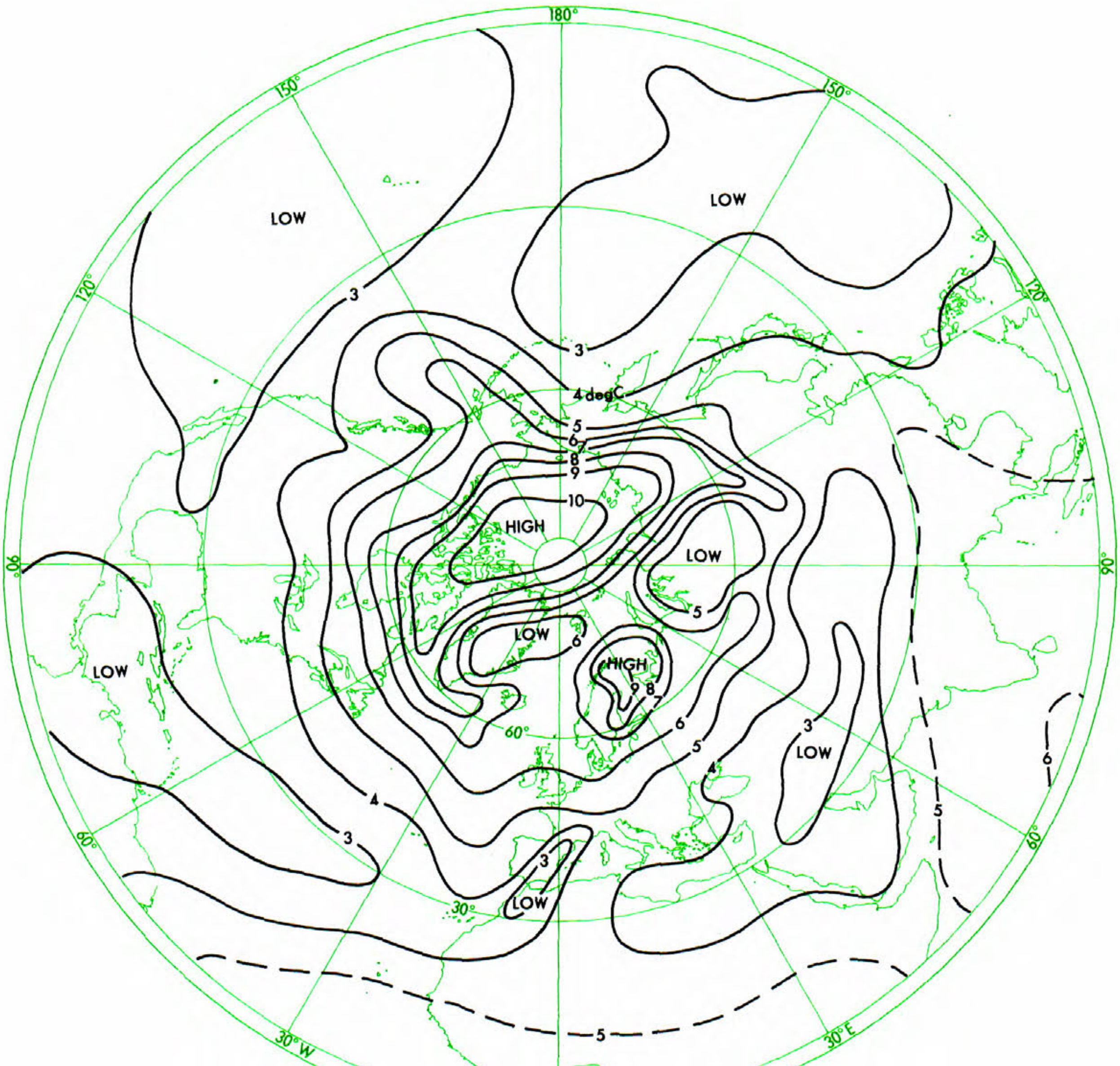


PLATE 6(i). STANDARD DEVIATION OF TEMPERATURES AT 50 MILLIBARS OVER THE NORTHERN HEMISPHERE IN JANUARY, 1957-61

Temperatures are in degrees Celsius

- - - - - indicates tentative analysis in low latitudes (see page 9)

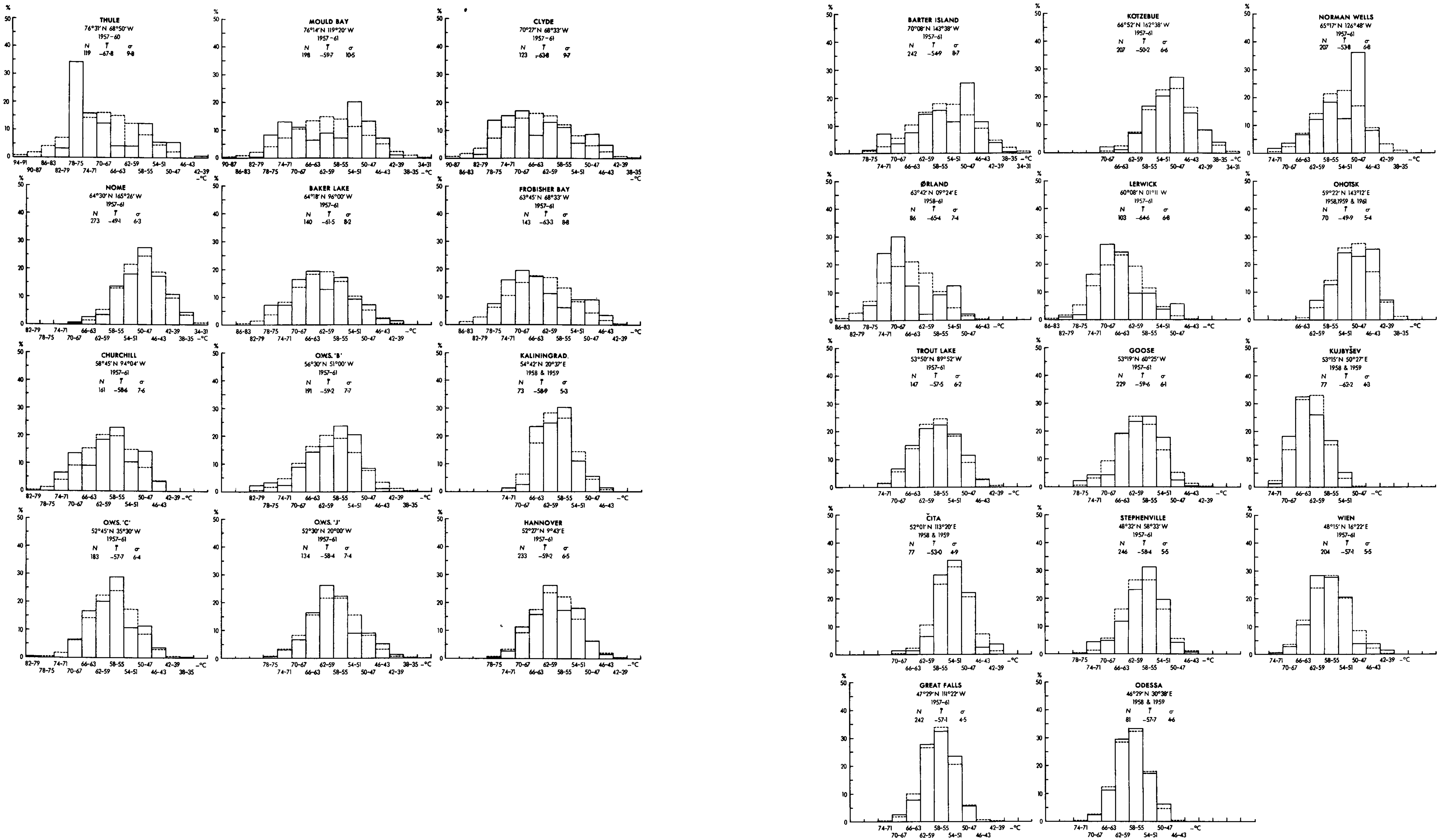


PLATE 6(ii) FREQUENCY DISTRIBUTIONS OF TEMPERATURE AT 50 MILLIBARS FOR SELECTED STATIONS IN JANUARY, 1957-61

——— Observed distribution   – – – – – Theoretical distribution

N = number of occasions. $\overline{T}$ = average temperature, σ = standard deviation, in degrees Celsius

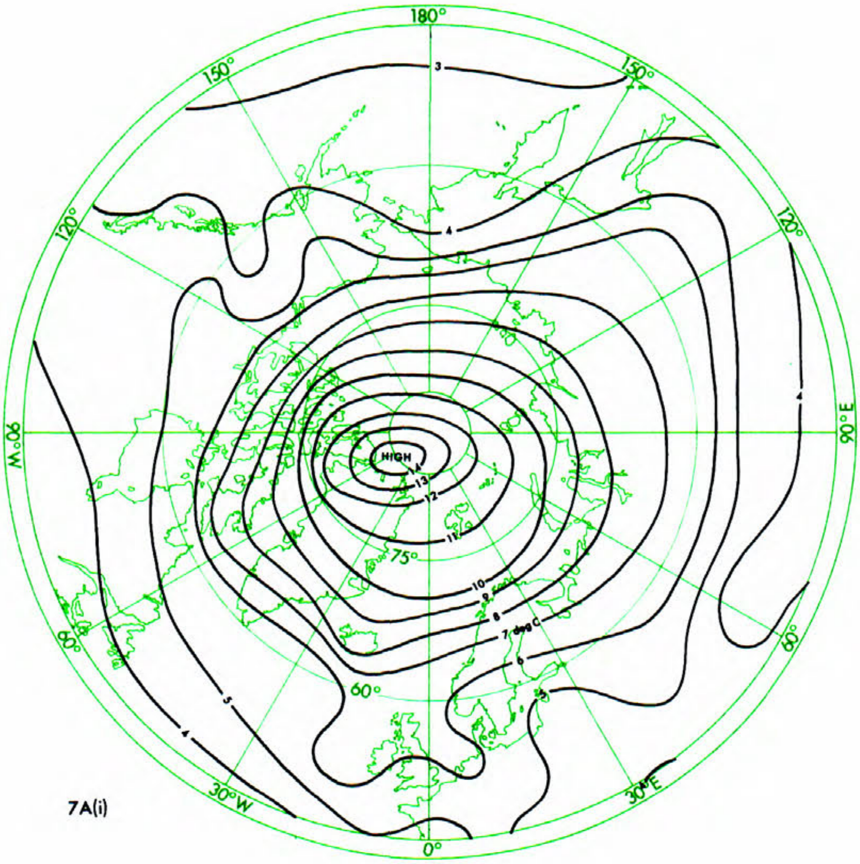


PLATE 7A(i). STANDARD DEVIATION OF TEMPERATURES AT 50 MILLIBARS OVER THE NORTHERN HEMISPHERE (NORTH OF LATITUDE 45° N) IN FEBRUARY, 1957-61
Temperatures are in degrees Celsius

GEOPHYSICAL MEMOIRS No.112

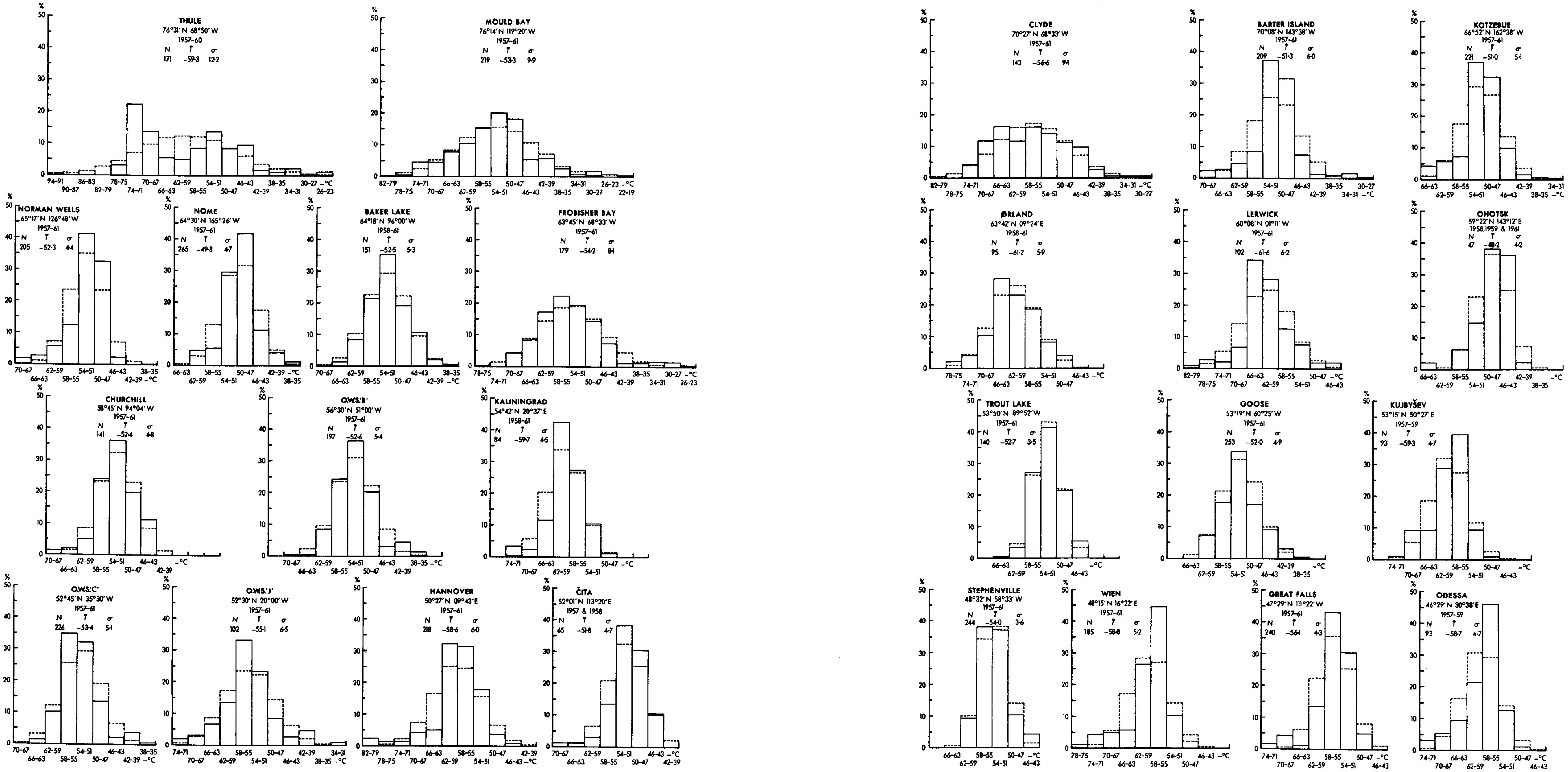


PLATE 7A(ii). FREQUENCY DISTRIBUTIONS OF TEMPERATURE AT 50 MILLIBARS FOR SELECTED STATIONS IN FEBRUARY, 1957-61

——— Observed distribution ----- Theoretical distribution

N = number of occasions. $\overline{T}$ = average temperature, σ = standard deviation, in degrees Celsius

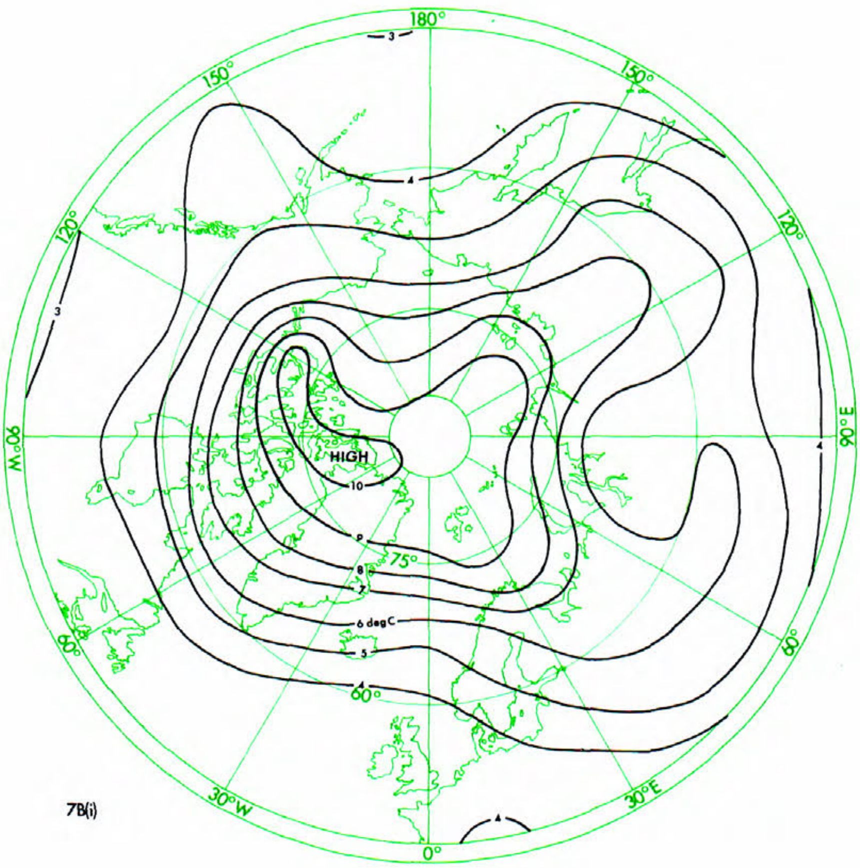
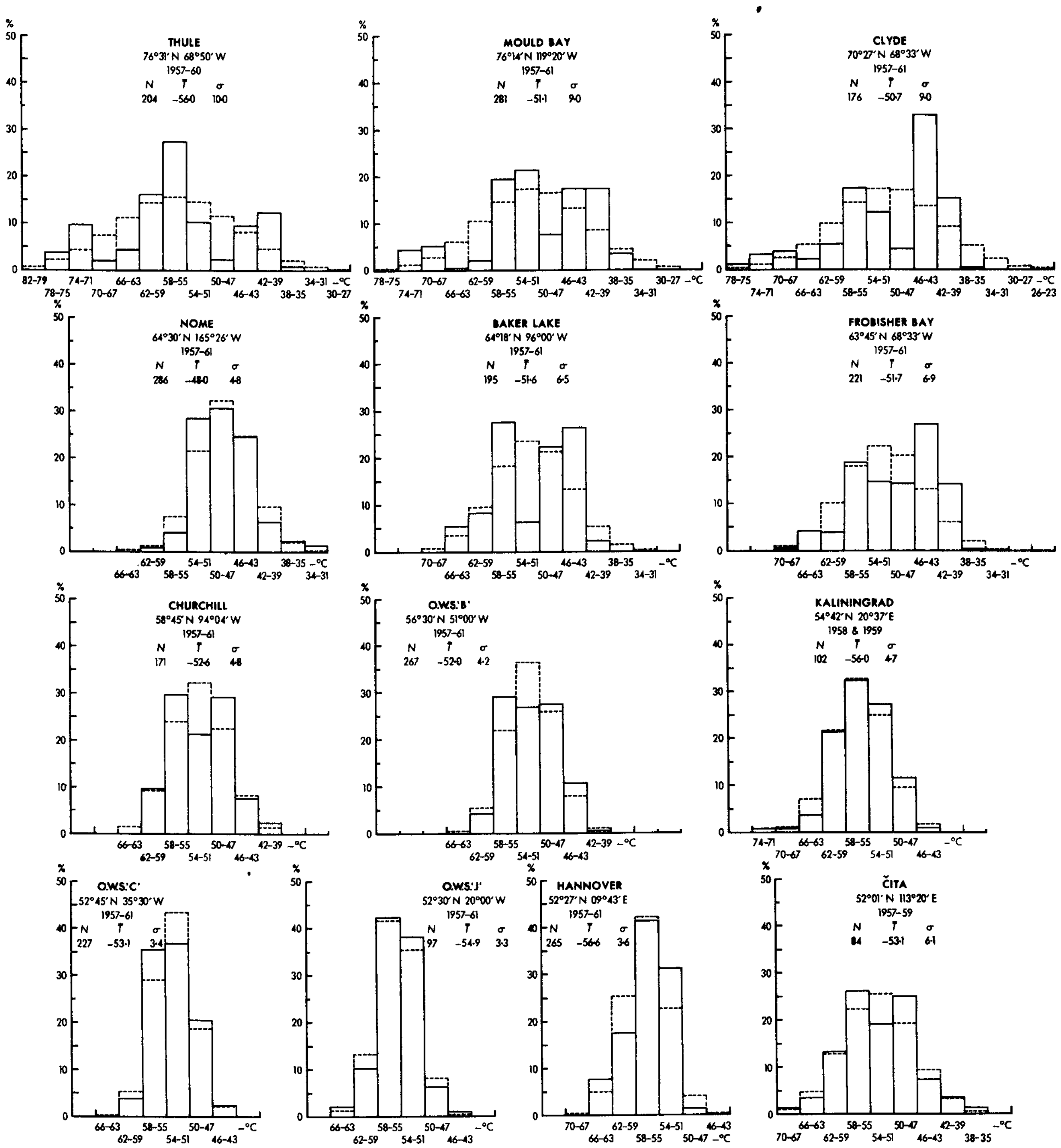


PLATE 7B(i). STANDARD DEVIATION OF TEMPERATURES AT 50 MILLIBARS OVER THE NORTHERN HEMISPHERE (NORTH OF LATITUDE 45° N) IN MARCH, 1957-61

Temperatures are in degrees Celsius



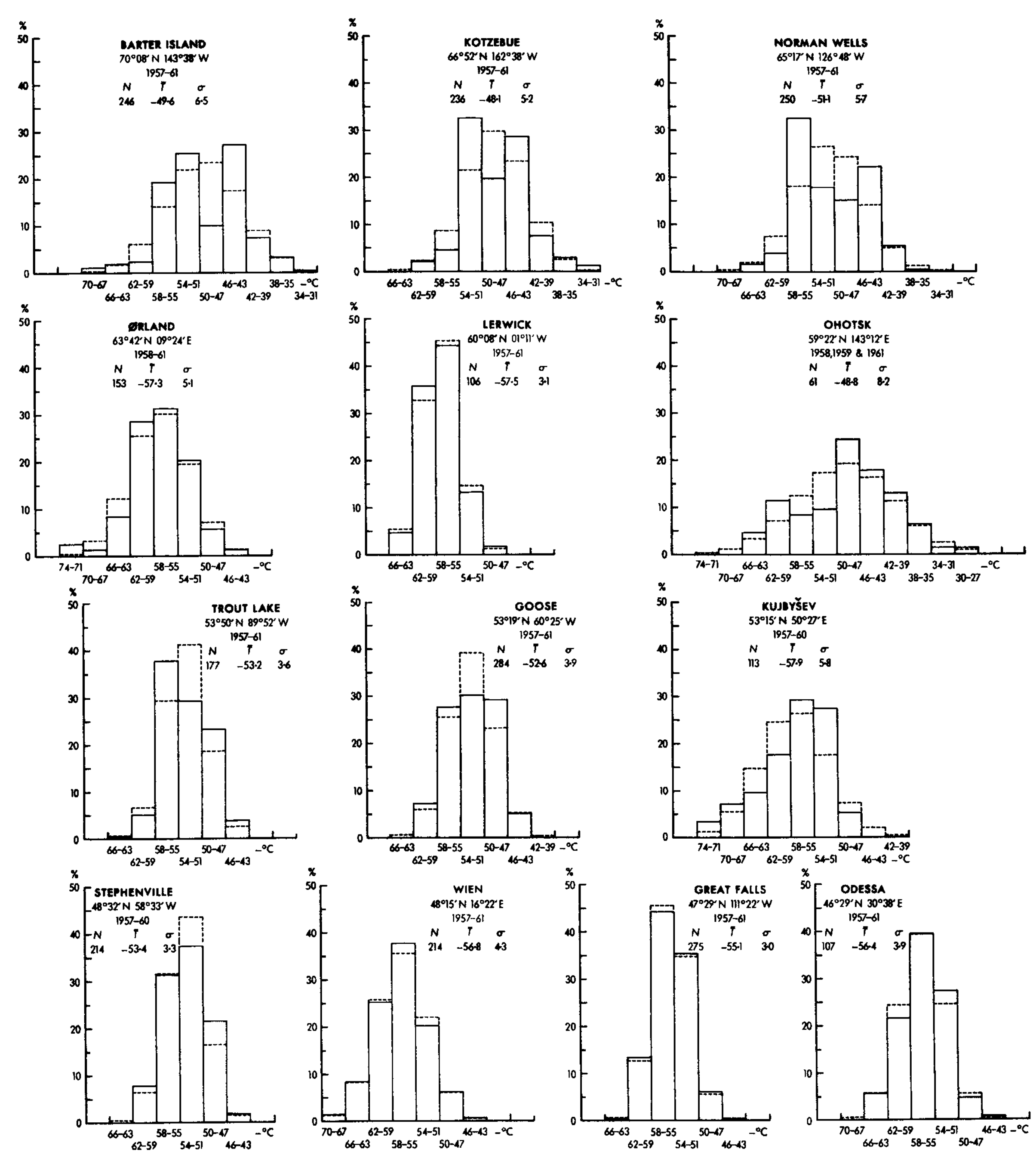


PLATE 7B(ii). FREQUENCY DISTRIBUTIONS OF TEMPERATURE AT 50 MILLIBARS FOR SELECTED STATIONS IN MARCH, 1957-61

——— Observed distribution - - - - - Theoretical distribution

N = number of occasions. $\overline{T}$ = average temperature, σ = standard deviation, in degrees Celsius

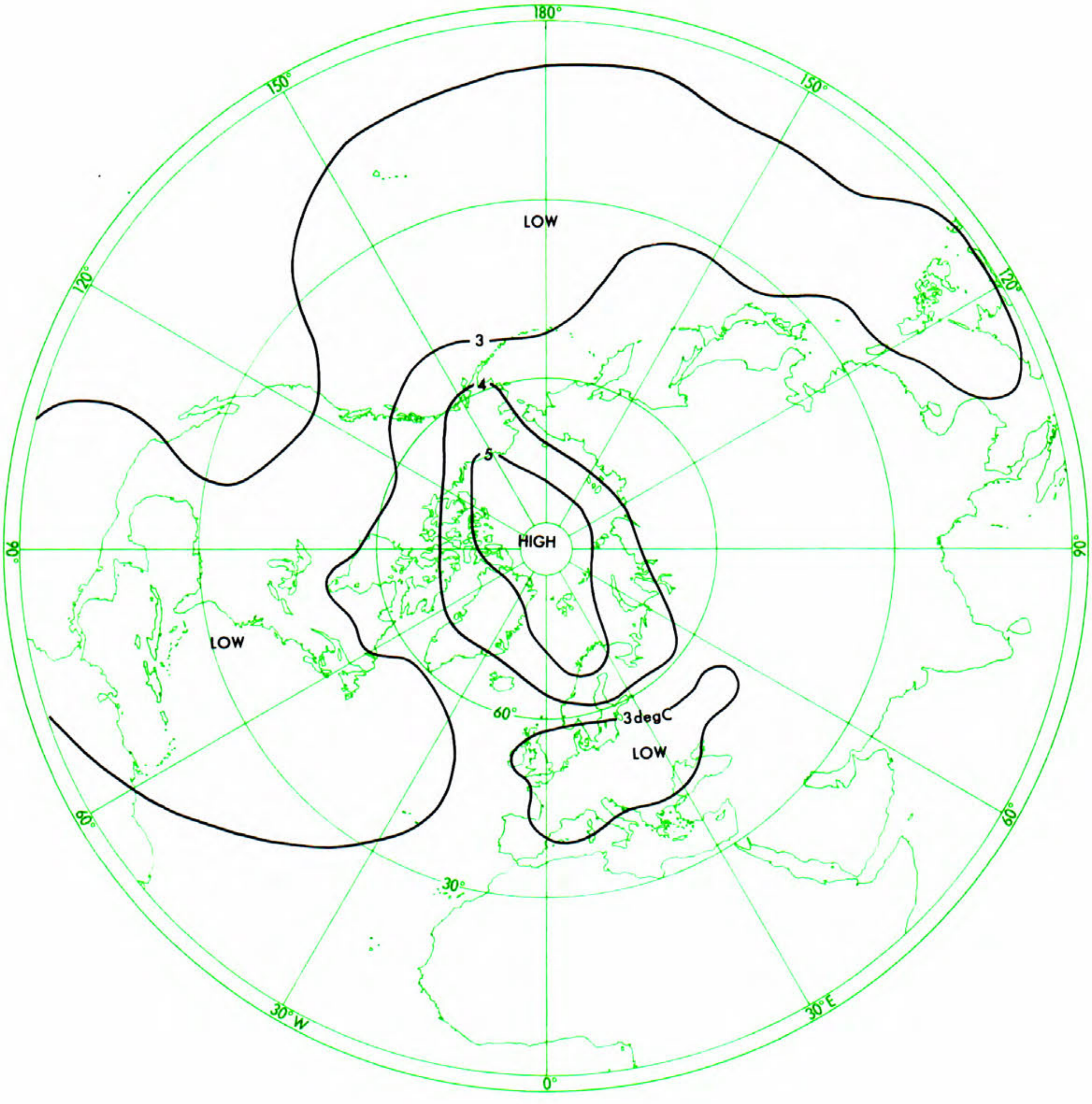
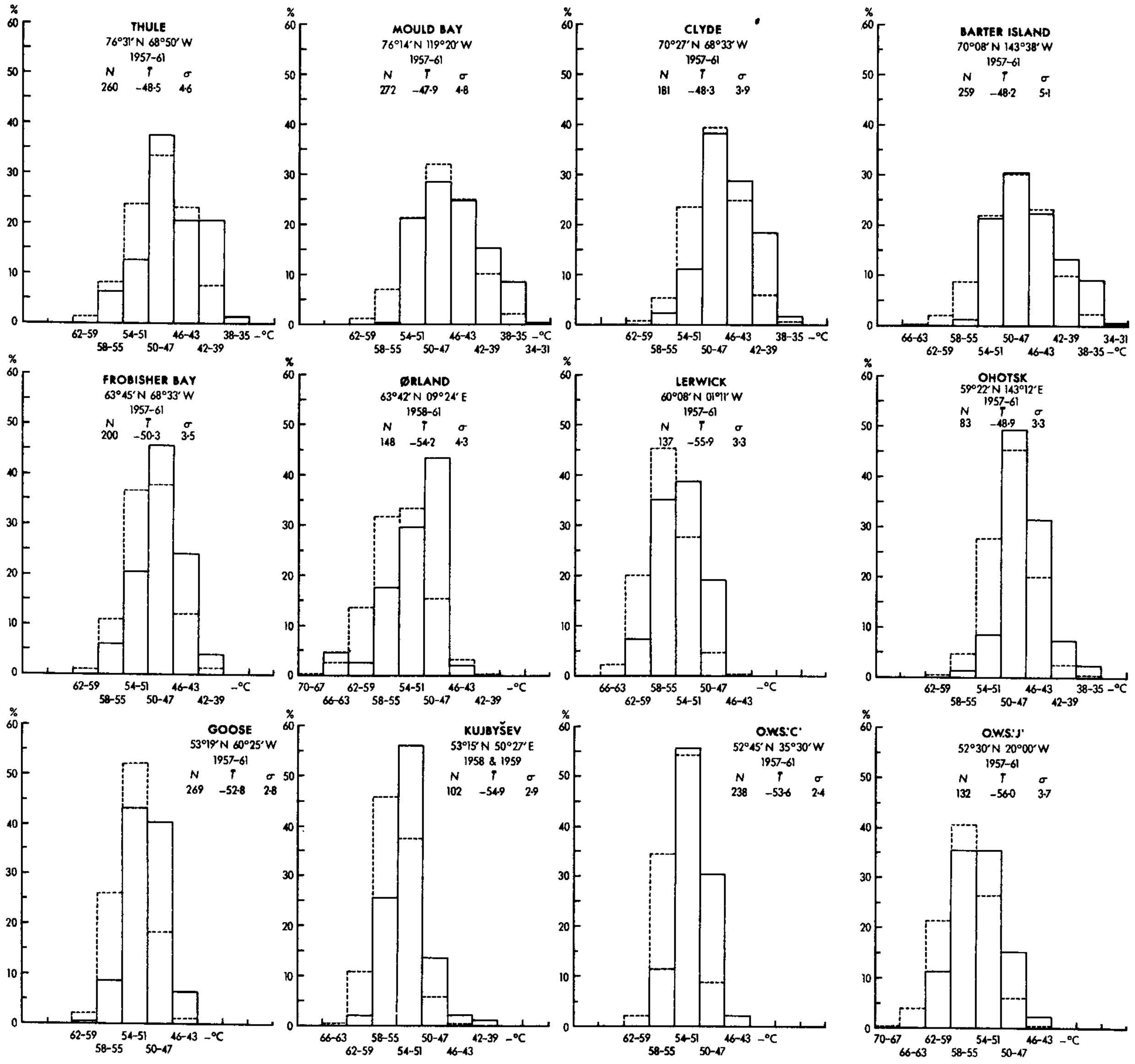


PLATE 8(i). STANDARD DEVIATION OF TEMPERATURES AT 50 MILLIBARS OVER THE NORTHERN HEMISPHERE IN APRIL, 1957-61
Temperatures are in degrees Celsius

GEOPHYSICAL MEMOIRS No.112



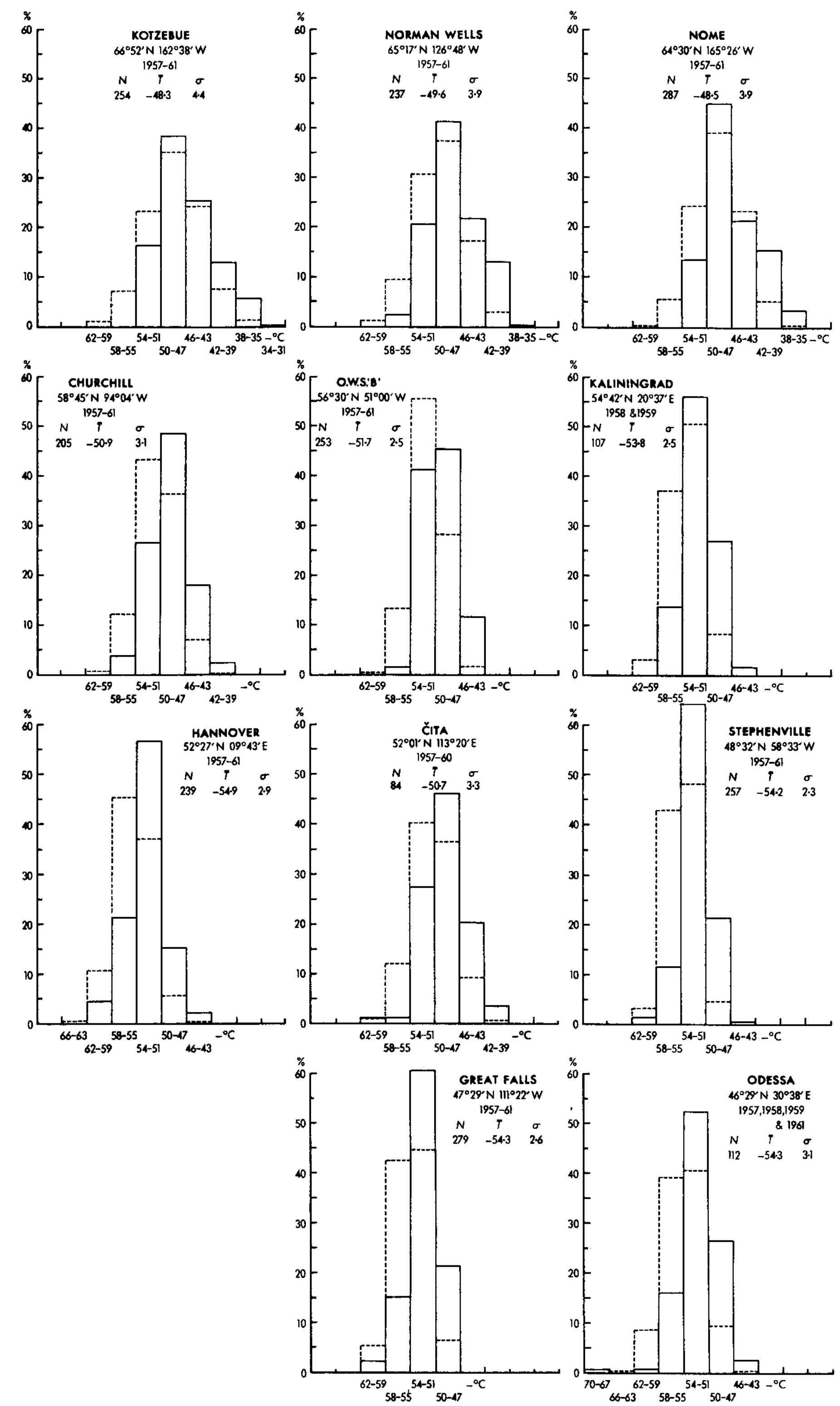


PLATE 8(ii). FREQUENCY DISTRIBUTIONS OF TEMPERATURE AT 50 MILLIBARS FOR SELECTED STATIONS IN APRIL, 1957-61

——— Observed distribution - - - - - Theoretical distribution

N = number of occasions. $\overline{T}$ = average temperature, σ = standard deviation in degrees Celsius

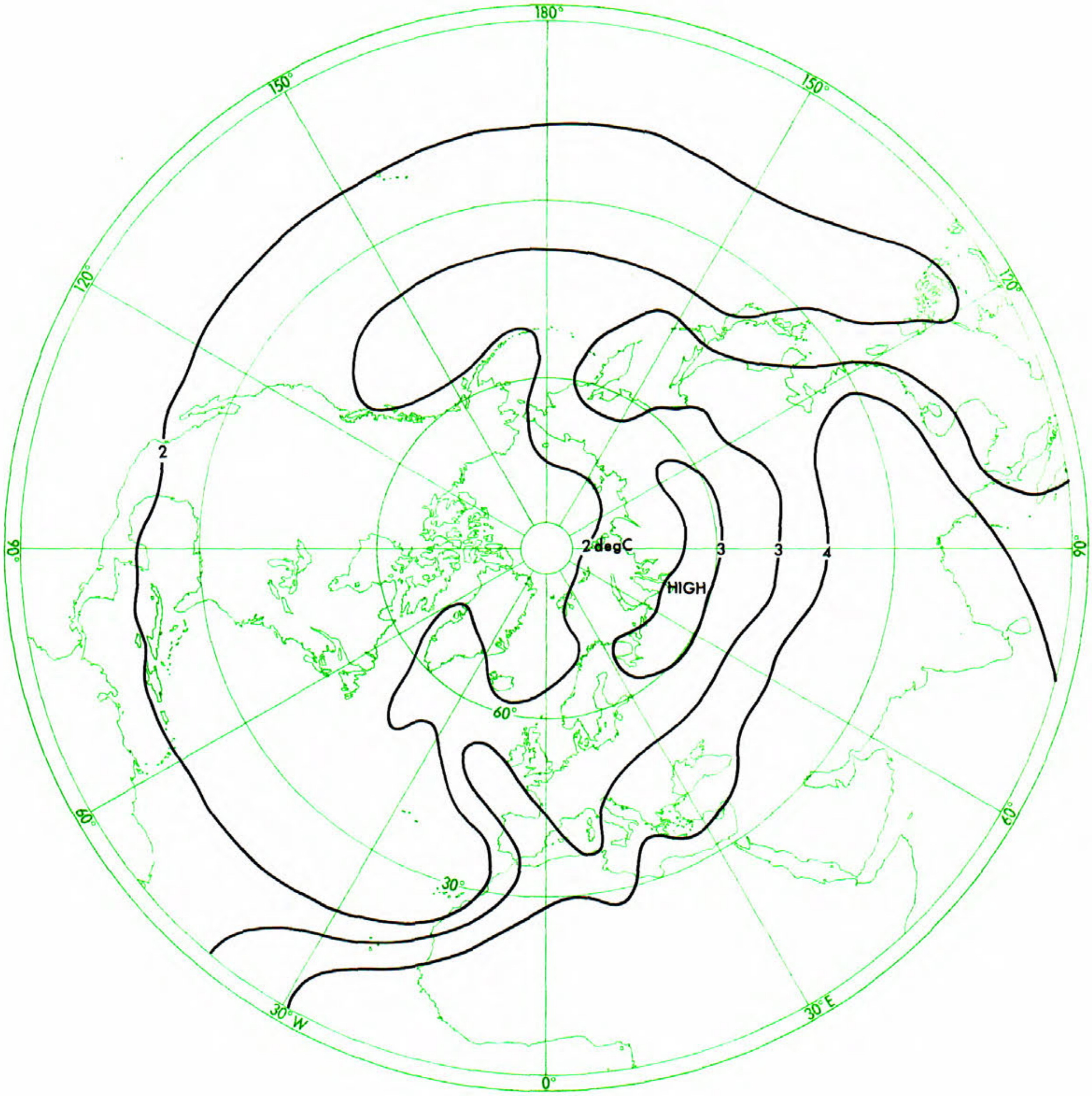


PLATE 9. STANDARD DEVIATION OF TEMPERATURES AT 50 MILLIBARS OVER THE NORTHERN HEMISPHERE IN JULY, 1957-61
Temperatures are in degrees Celsius

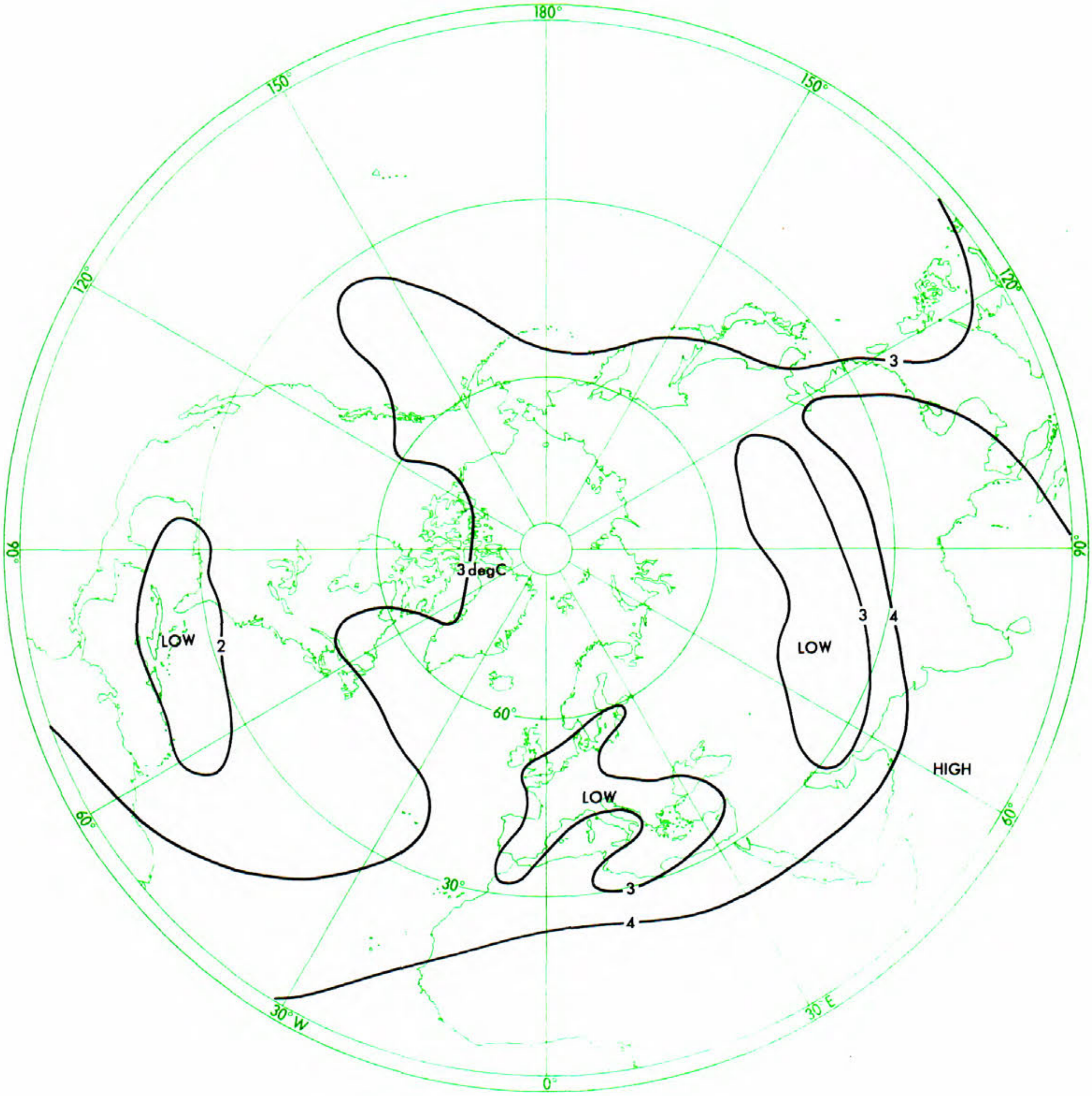


PLATE 10. STANDARD DEVIATION OF TEMPERATURES AT 50 MILLIBARS OVER THE NORTHERN HEMISPHERE IN OCTOBER, 1957-61
Temperatures are in degrees Celsius

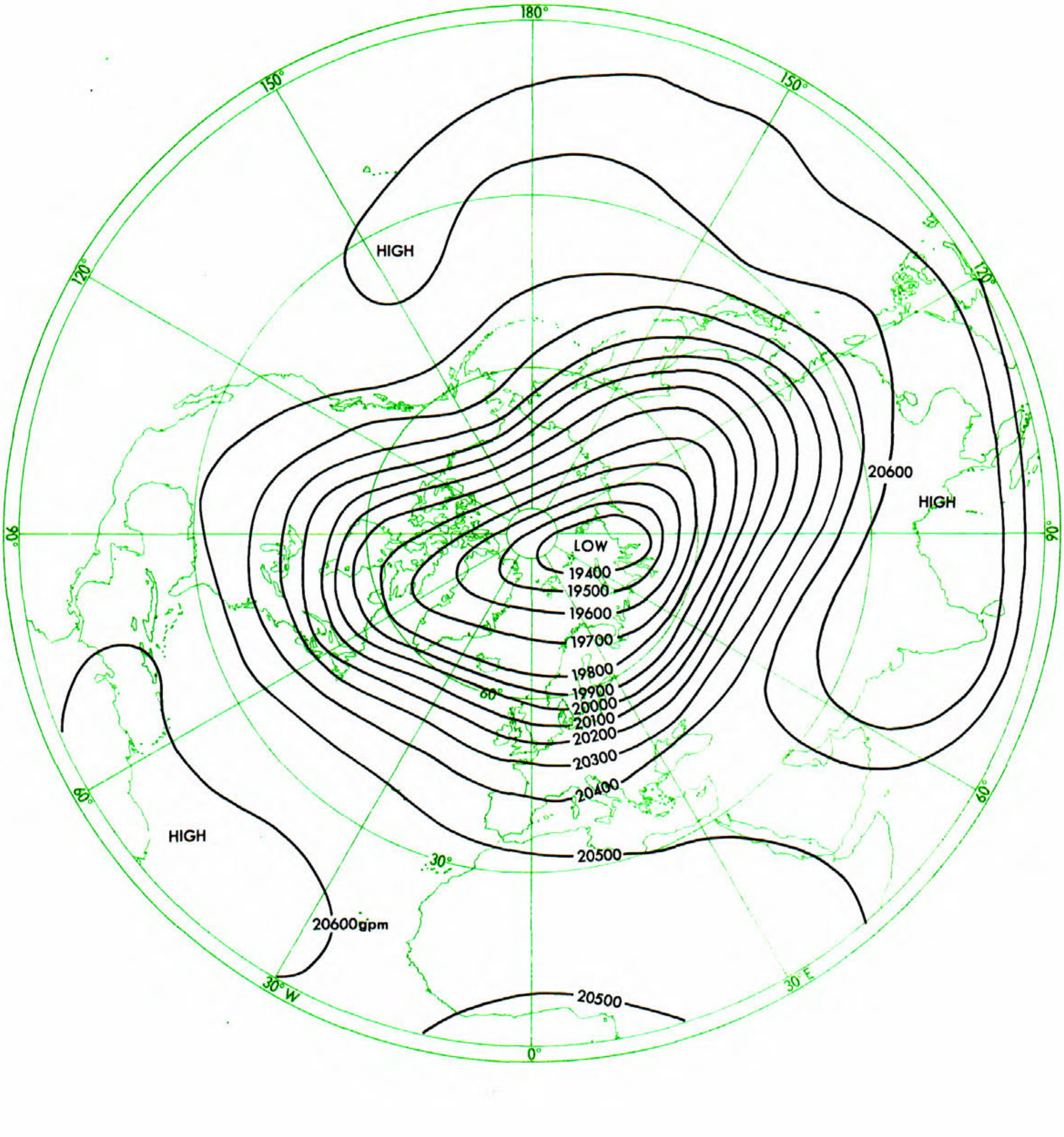
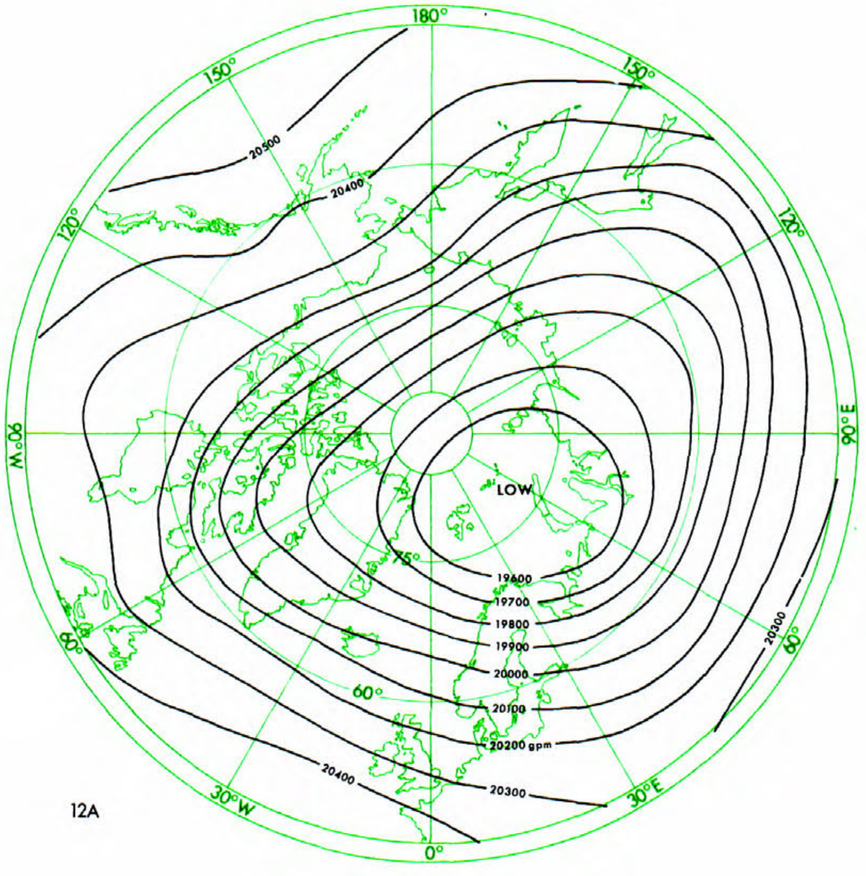
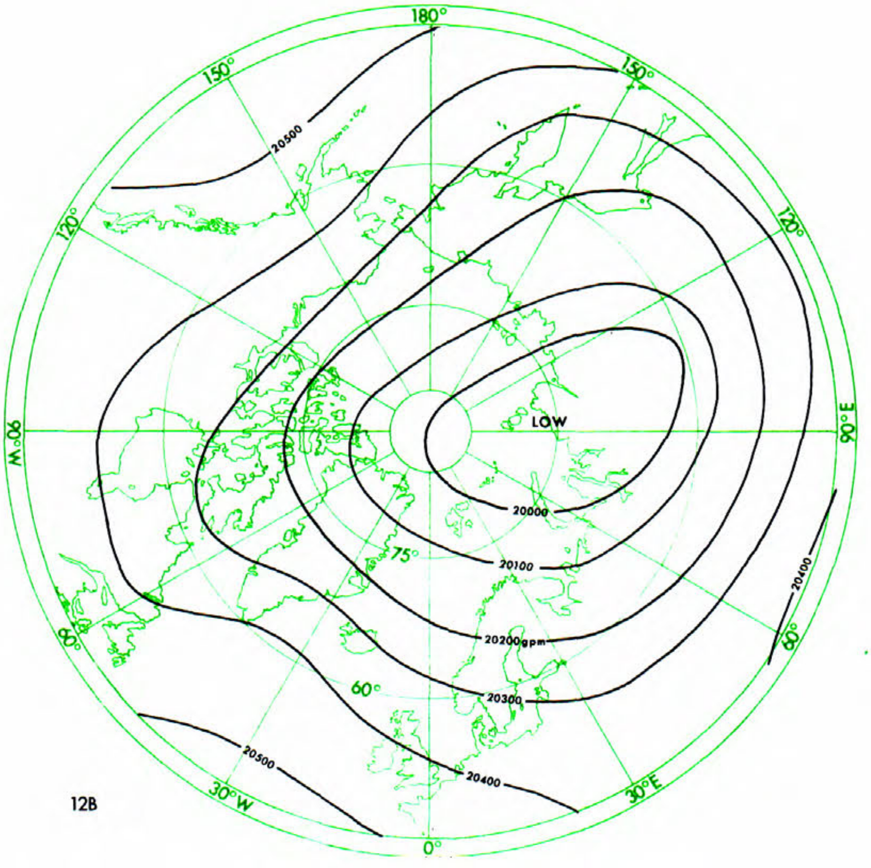


PLATE 11. AVERAGE CONTOUR HEIGHTS AT 50 MILLIBARS OVER THE NORTHERN HEMISPHERE IN JANUARY, 1957-61
Heights are in geopotential metres





PLATES 12A AND 12B. AVERAGE CONTOUR HEIGHTS AT 50 MILLIBARS OVER THE NORTHERN HEMISPHERE (NORTH OF LATITUDE 45° N) IN FEBRUARY (12A) AND MARCH (12B), 1957-61

Heights are in geopotential metres

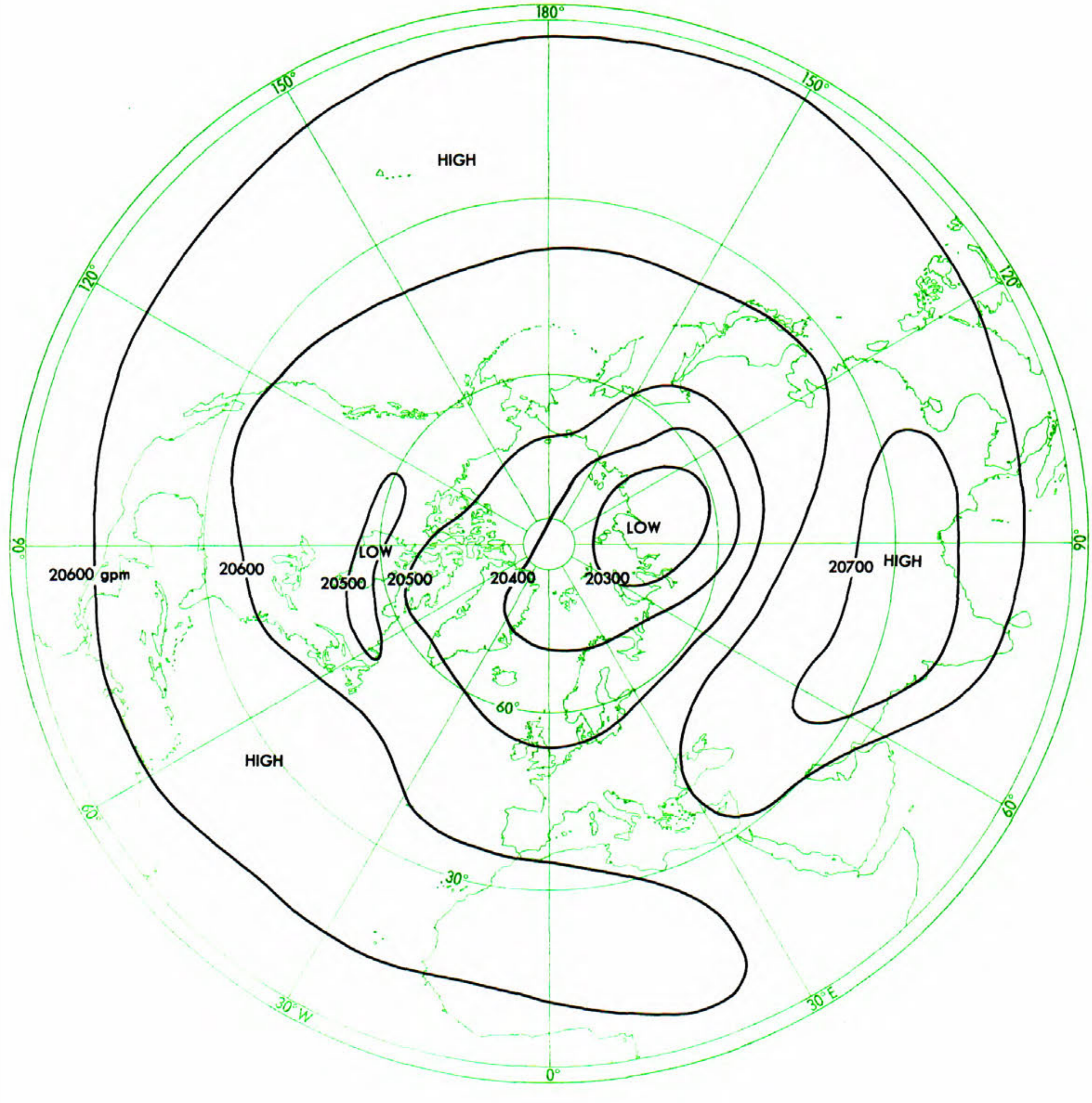


PLATE 13. AVERAGE CONTOUR HEIGHTS AT 50 MILLIBARS OVER THE NORTHERN HEMISPHERE IN APRIL, 1957-61

Heights are in geopotential metres

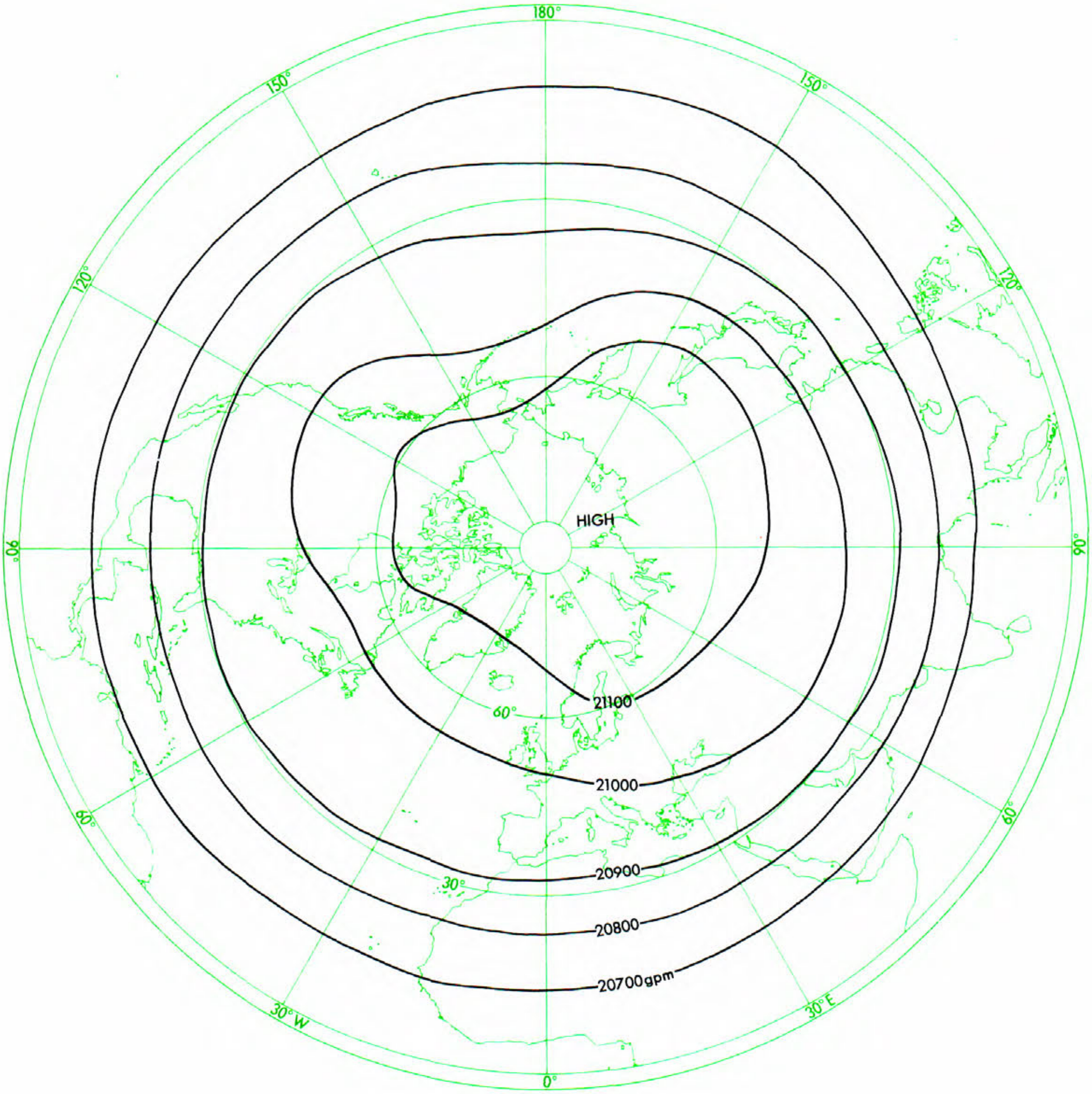


PLATE 14. AVERAGE CONTOUR HEIGHTS AT 50 MILLIBARS OVER THE NORTHERN HEMISPHERE IN JULY, 1957-61
Heights are in geopotential metres

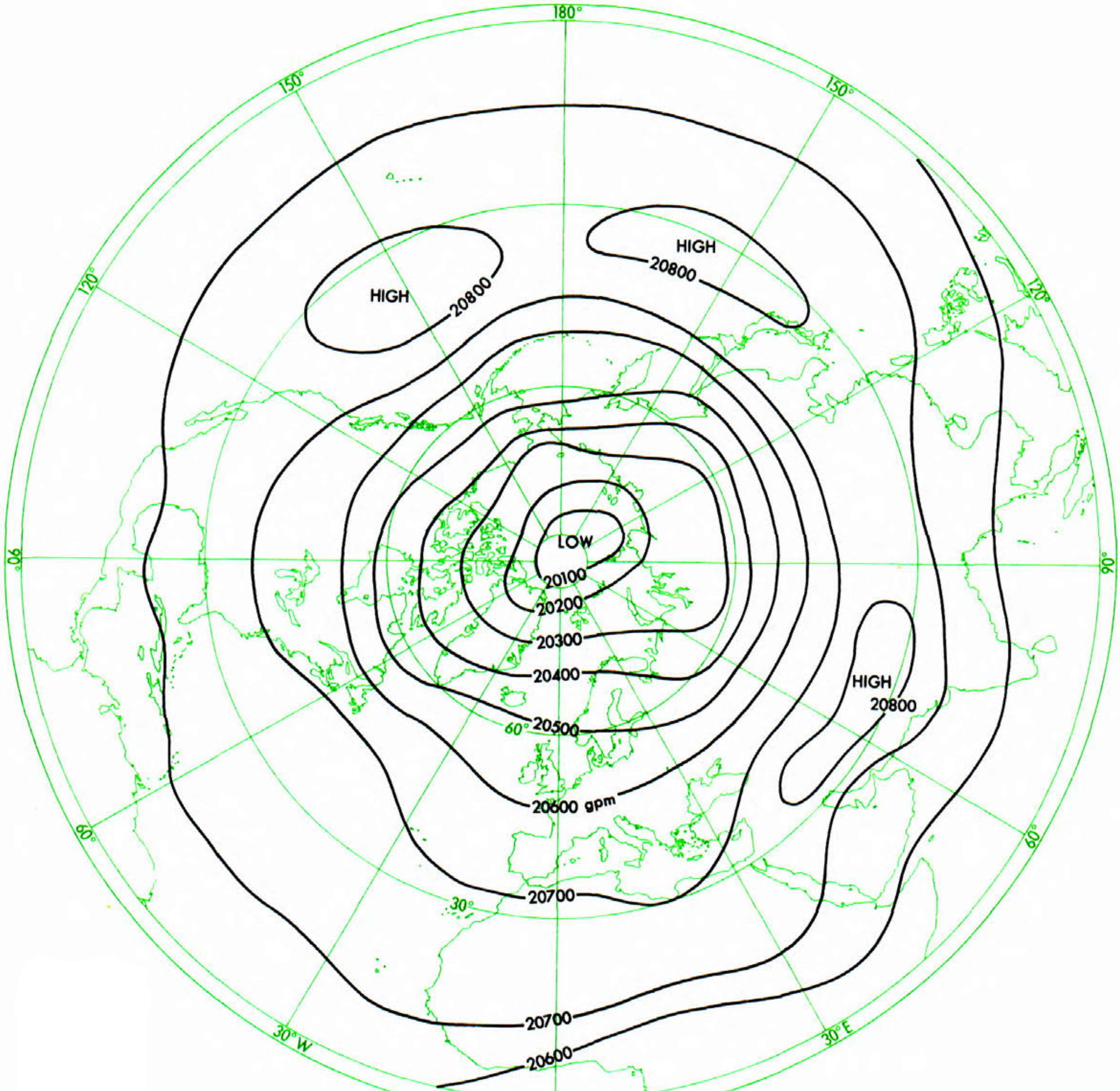


PLATE 15. AVERAGE CONTOUR HEIGHTS AT 50 MILLIBARS OVER THE NORTHERN HEMISPHERE IN OCTOBER, 1957-61

Heights are in geopotential metres

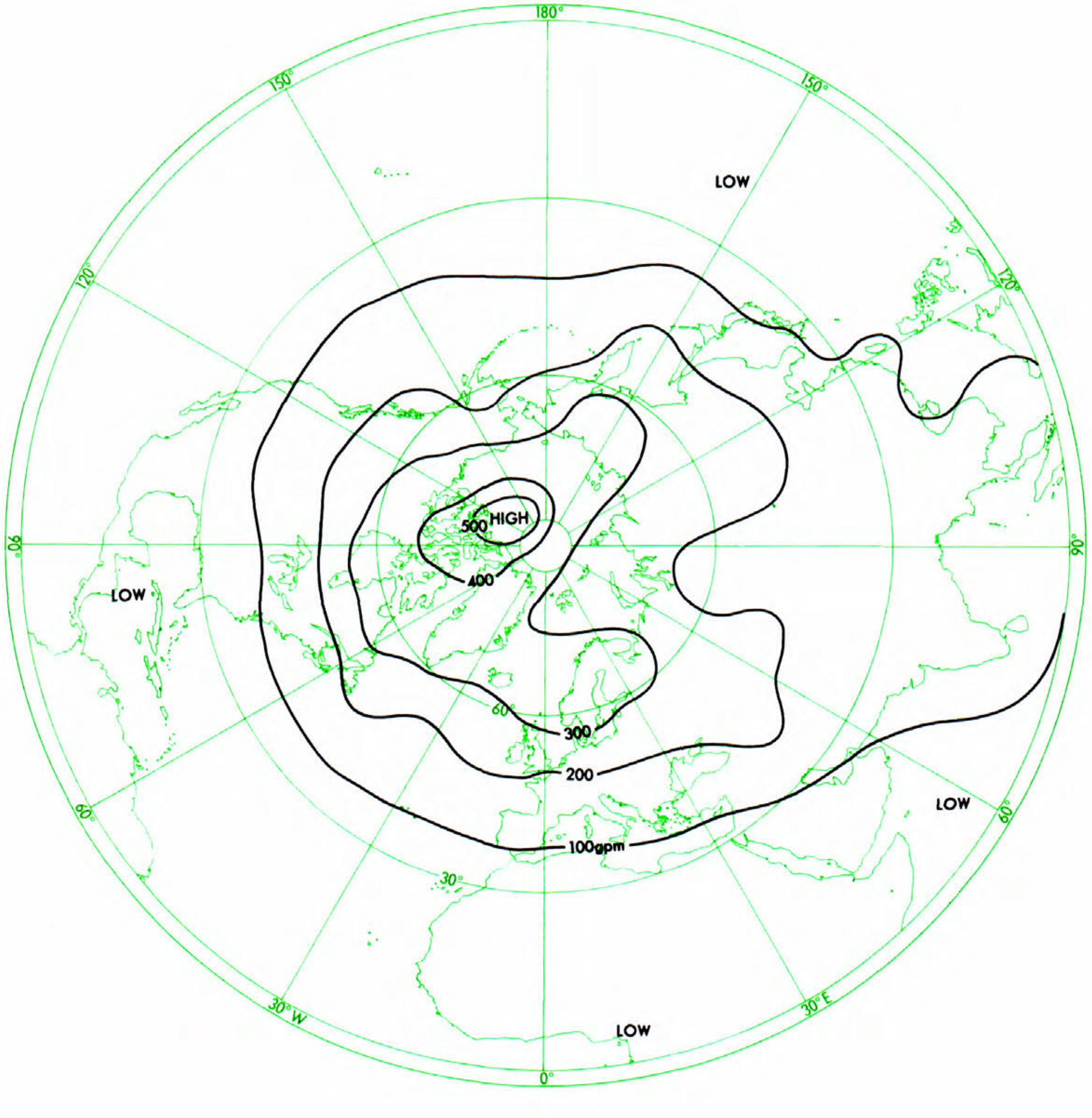
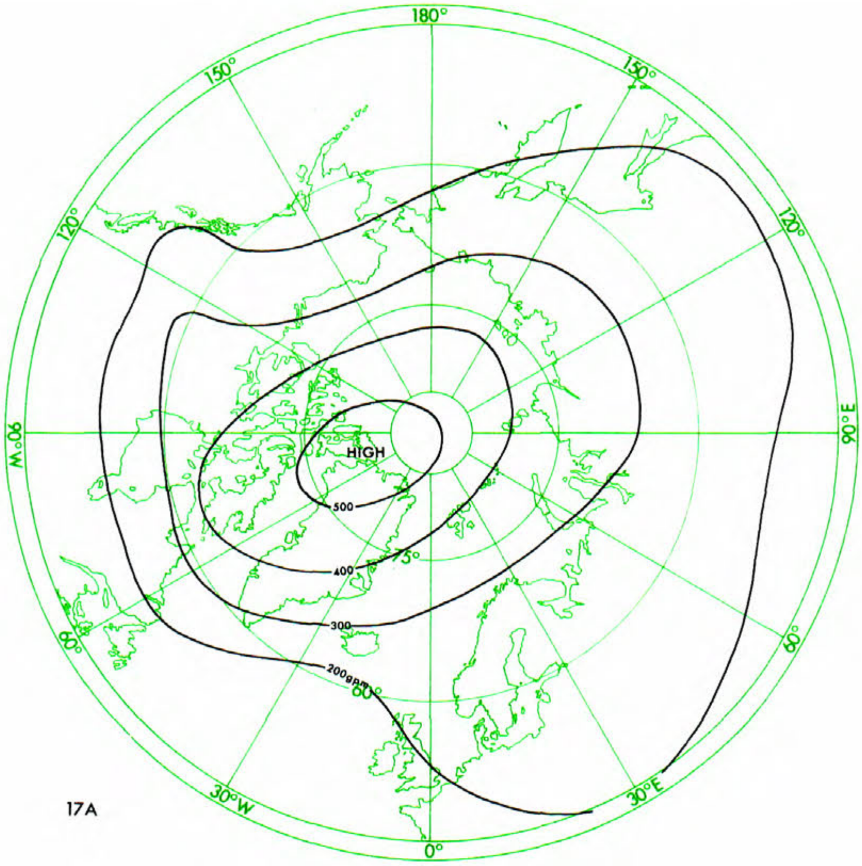
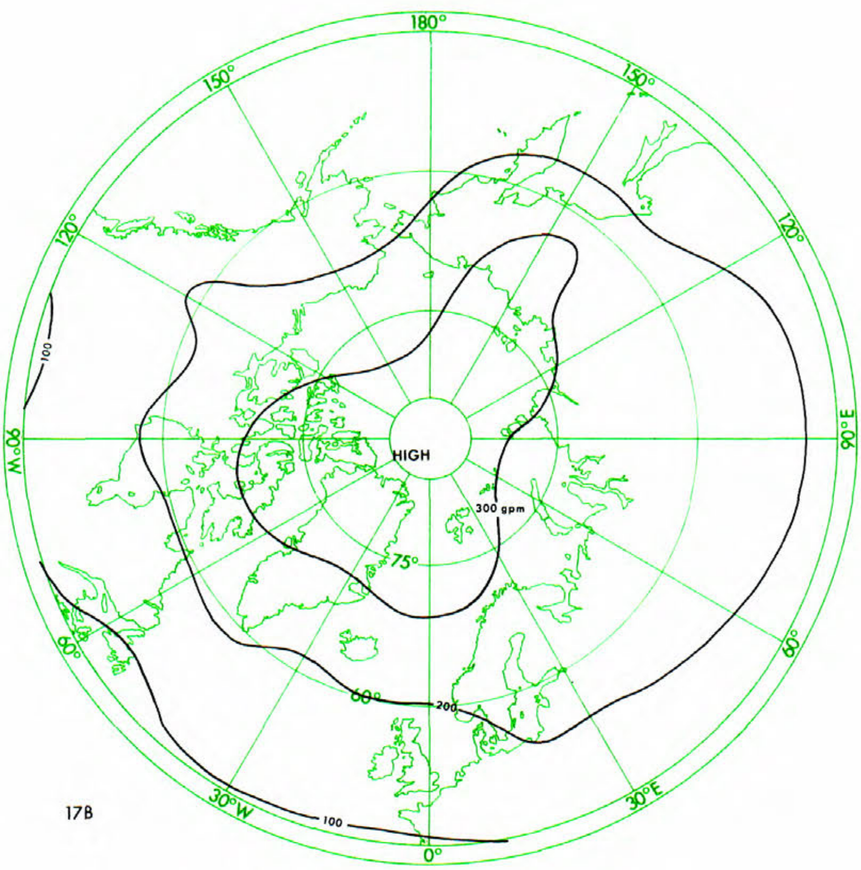


PLATE 16. STANDARD DEVIATION OF CONTOUR HEIGHTS AT 50 MILLIBARS OVER THE NORTHERN HEMISPHERE IN JANUARY, 1957-61
Heights are in geopotential metres



17A



17B

PLATES 17A AND 17B. STANDARD DEVIATION OF CONTOUR HEIGHTS AT 50 MILLIBARS OVER THE NORTHERN HEMISPHERE (NORTH OF LATITUDE 45° N) IN FEBRUARY (17A) AND MARCH (17B), 1957-61

Heights are in geopotential metres

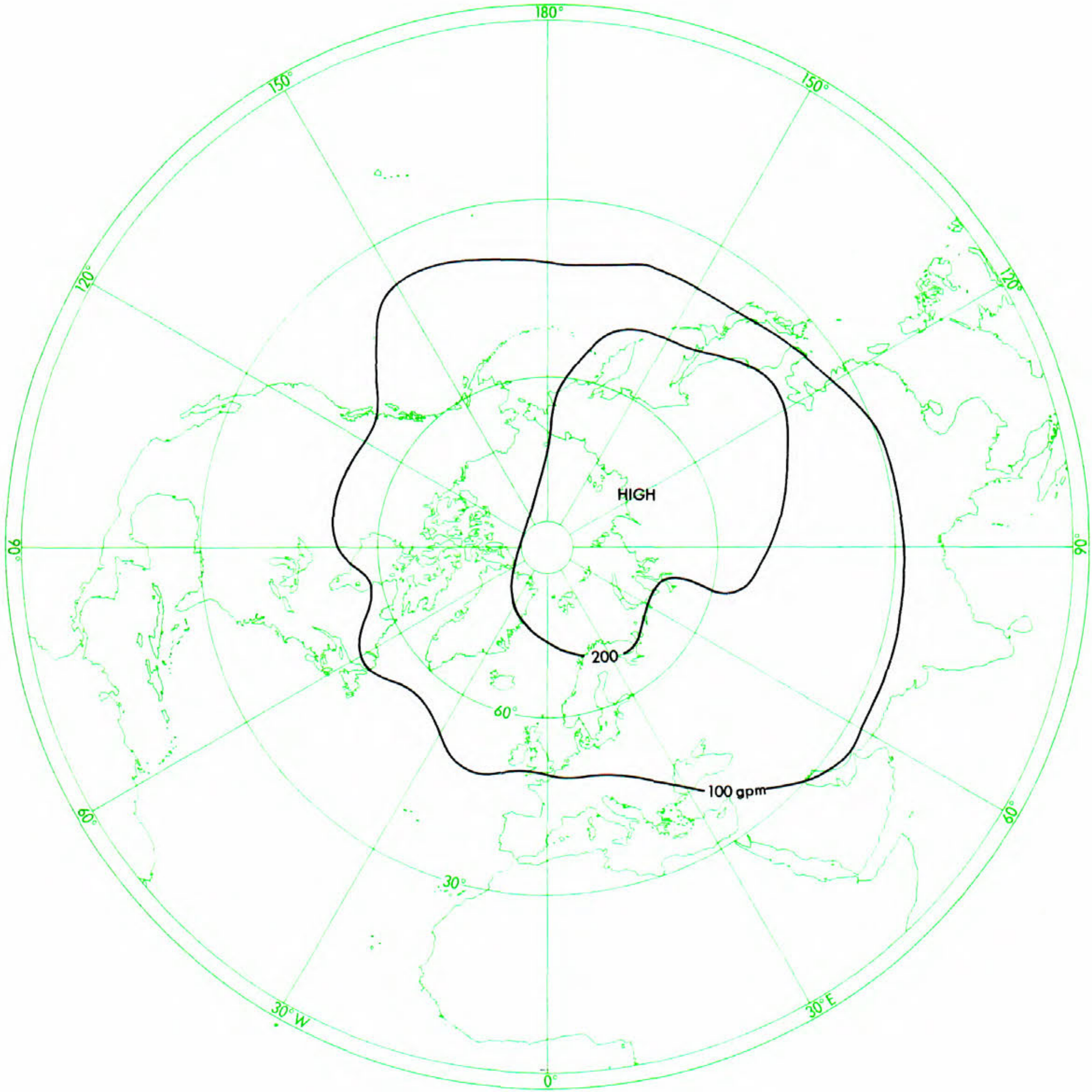


PLATE 18. STANDARD DEVIATION OF CONTOUR HEIGHTS AT 50 MILLIBARS OVER THE NORTHERN HEMISPHERE IN APRIL, 1957-61
Heights are in geopotential metres

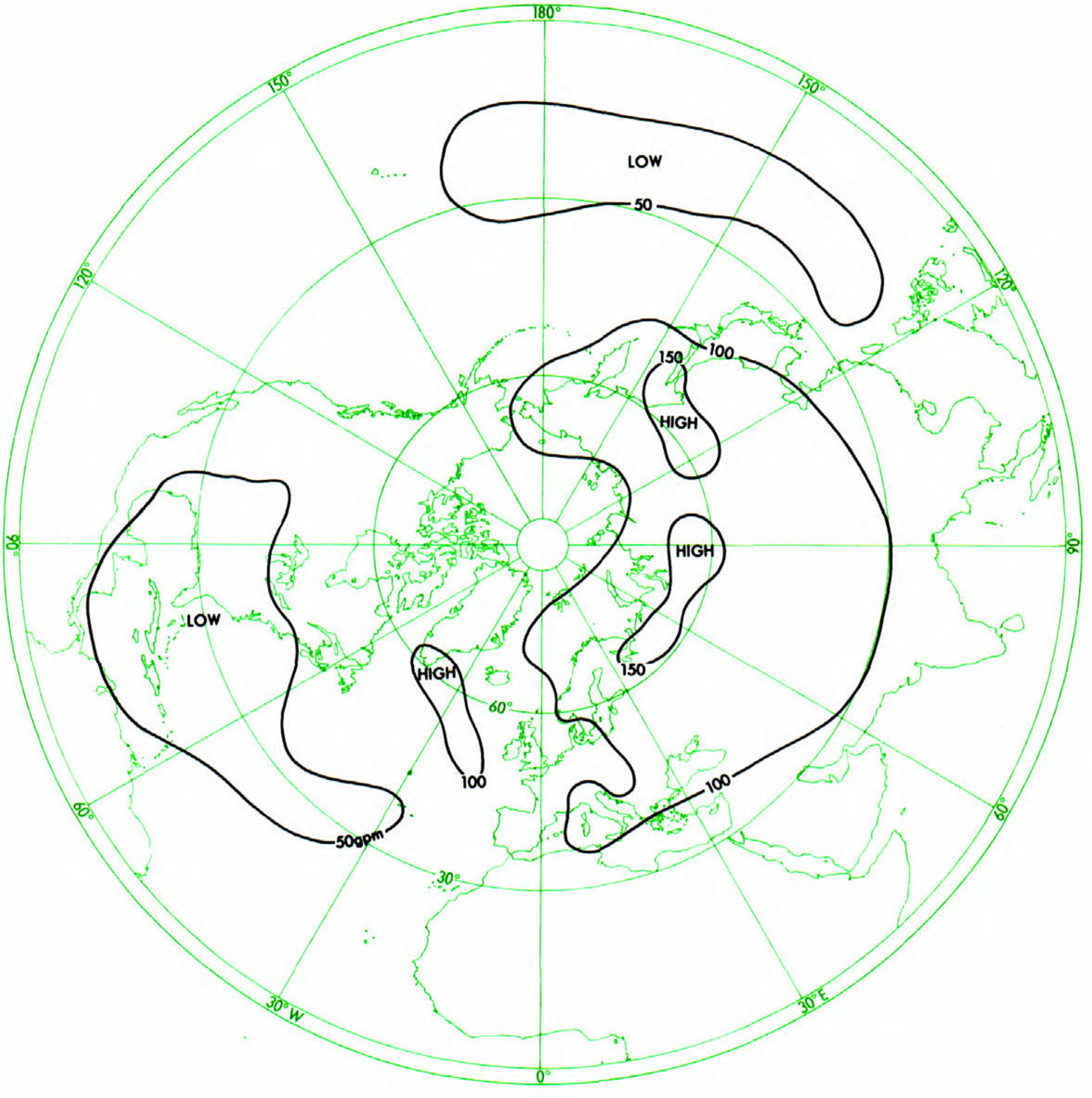


PLATE 19. STANDARD DEVIATION OF CONTOUR HEIGHTS AT 50 MILLIBARS OVER THE NORTHERN HEMISPHERE IN JULY, 1957-61

Heights are in geopotential metres

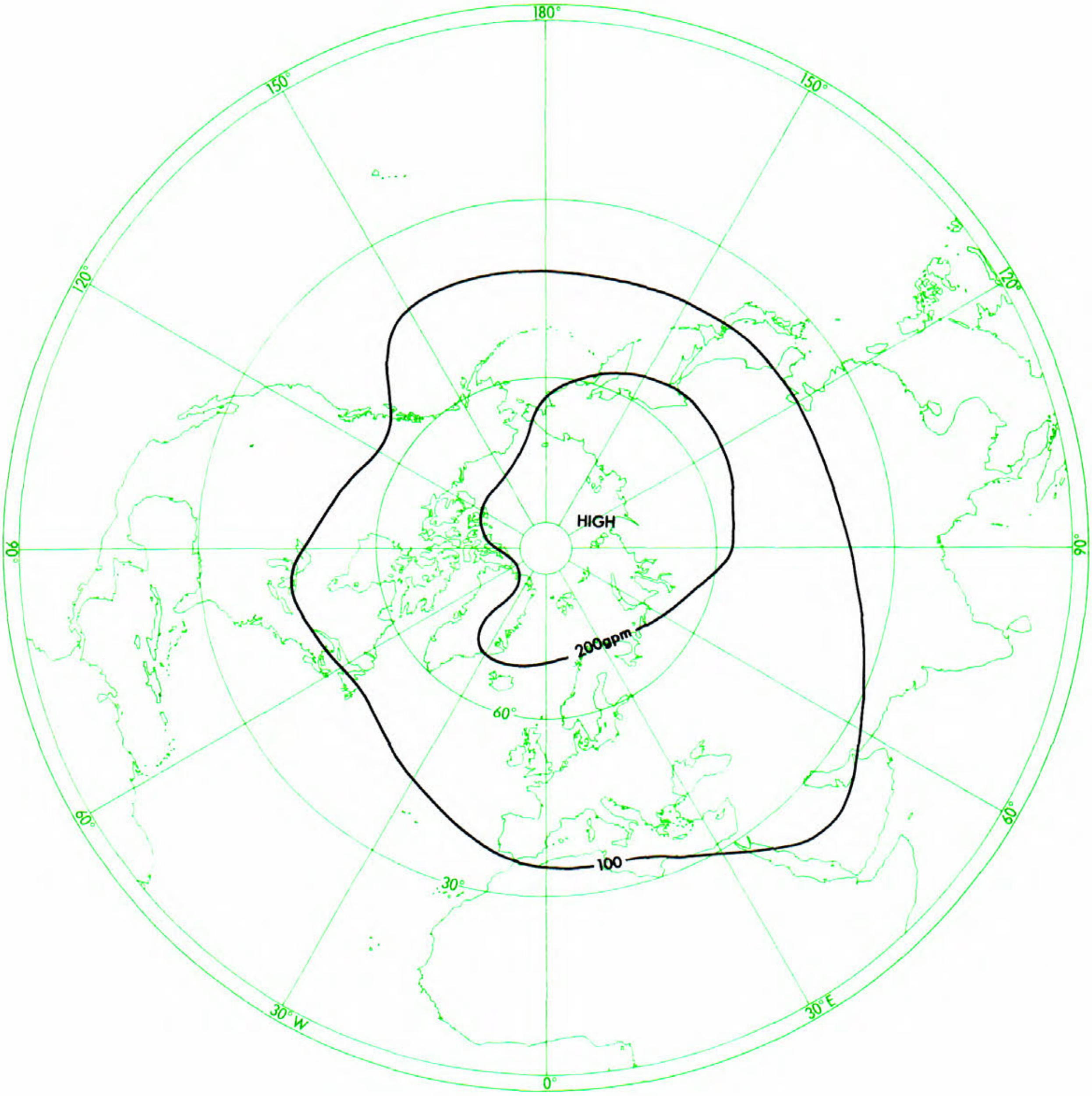


PLATE 20. STANDARD DEVIATION OF CONTOUR HEIGHTS AT 50 MILLIBARS OVER THE NORTHERN HEMISPHERE IN OCTOBER, 1957-61
Heights are in geopotential metres

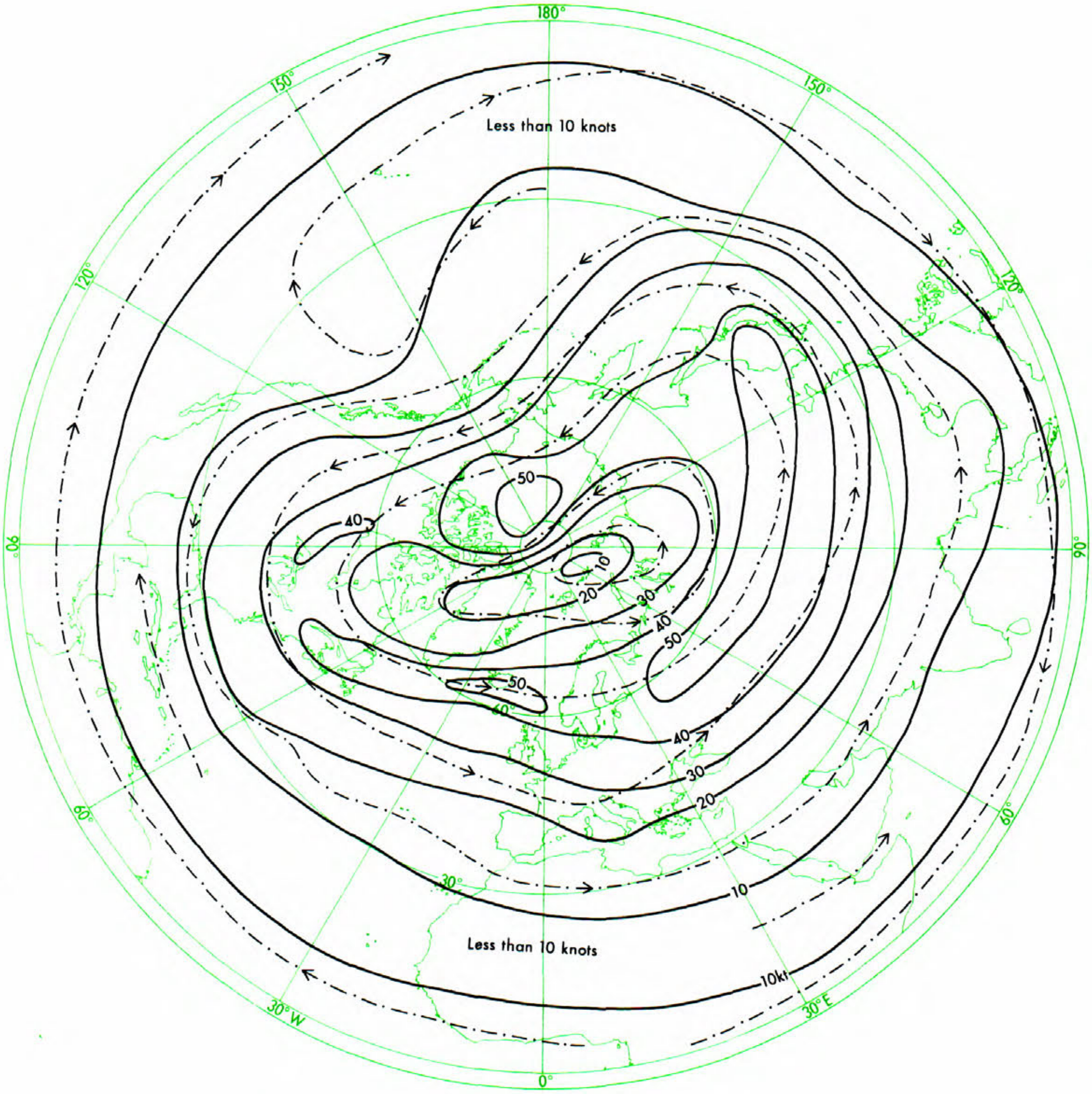
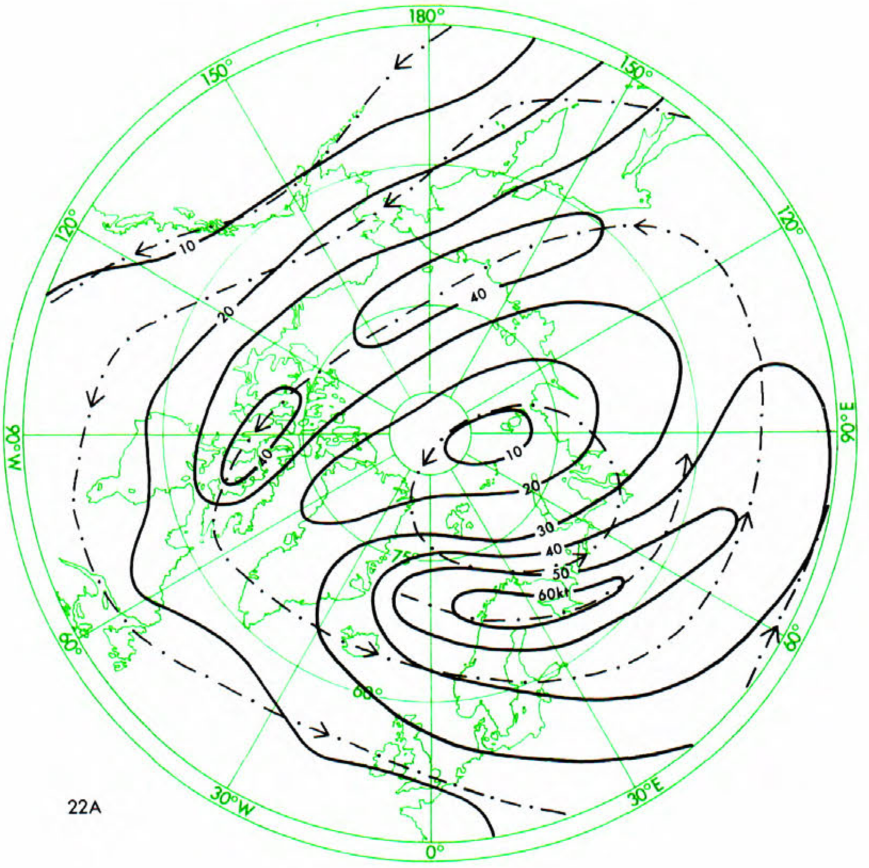
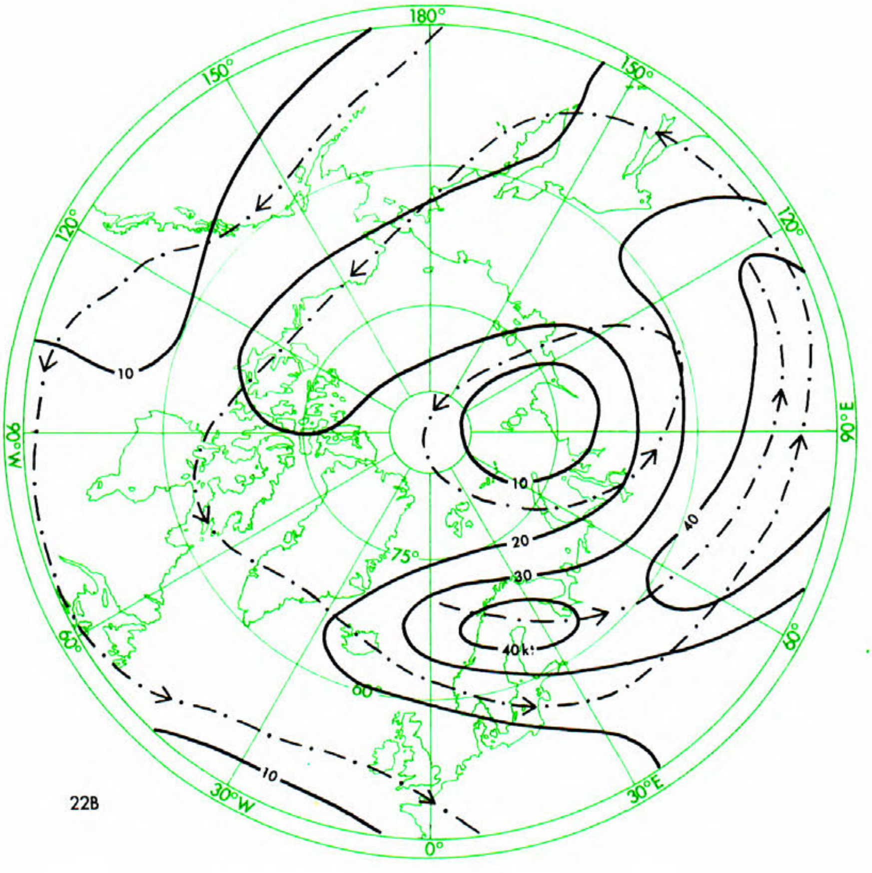


PLATE 21. AVERAGE WINDS AT 50 MILLIBARS OVER THE NORTHERN HEMISPHERE IN JANUARY, 1957-61
——— Isotachs (knots) —·→·—·→·— Streamlines



22A



22B

PLATES 22A AND 22B. AVERAGE WINDS AT 50 MILLIBARS OVER THE NORTHERN HEMISPHERE (NORTH OF LATITUDE 45° N) IN FEBRUARY (22A) AND MARCH (22B), 1957-61

——— Isotachs (knots) —·→·—·→— Streamlines

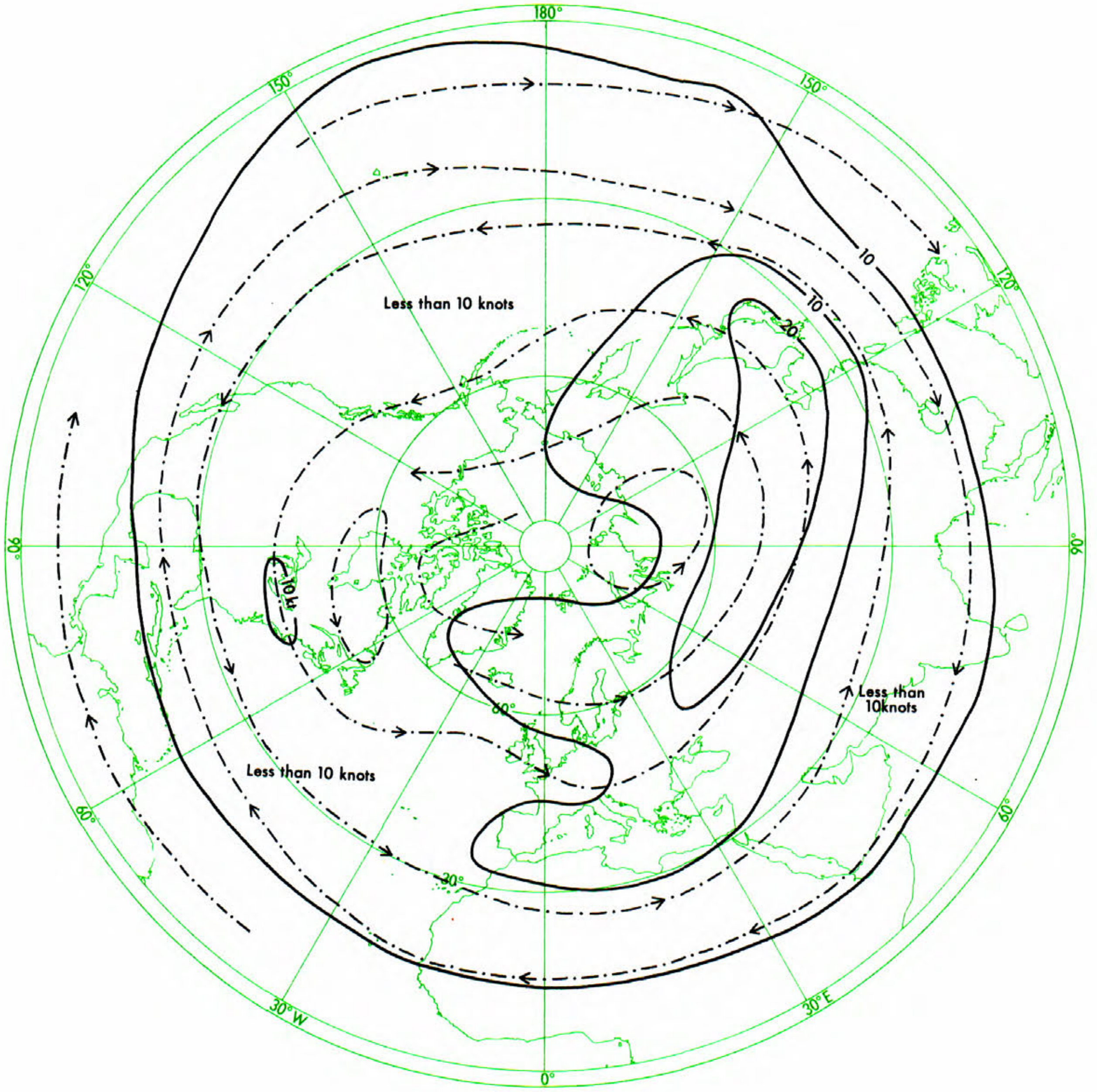


PLATE 23. AVERAGE WINDS AT 50 MILLIBARS OVER THE NORTHERN HEMISPHERE IN APRIL, 1957-61
——— Isotachs (knots) —·→·—·→·— Streamlines

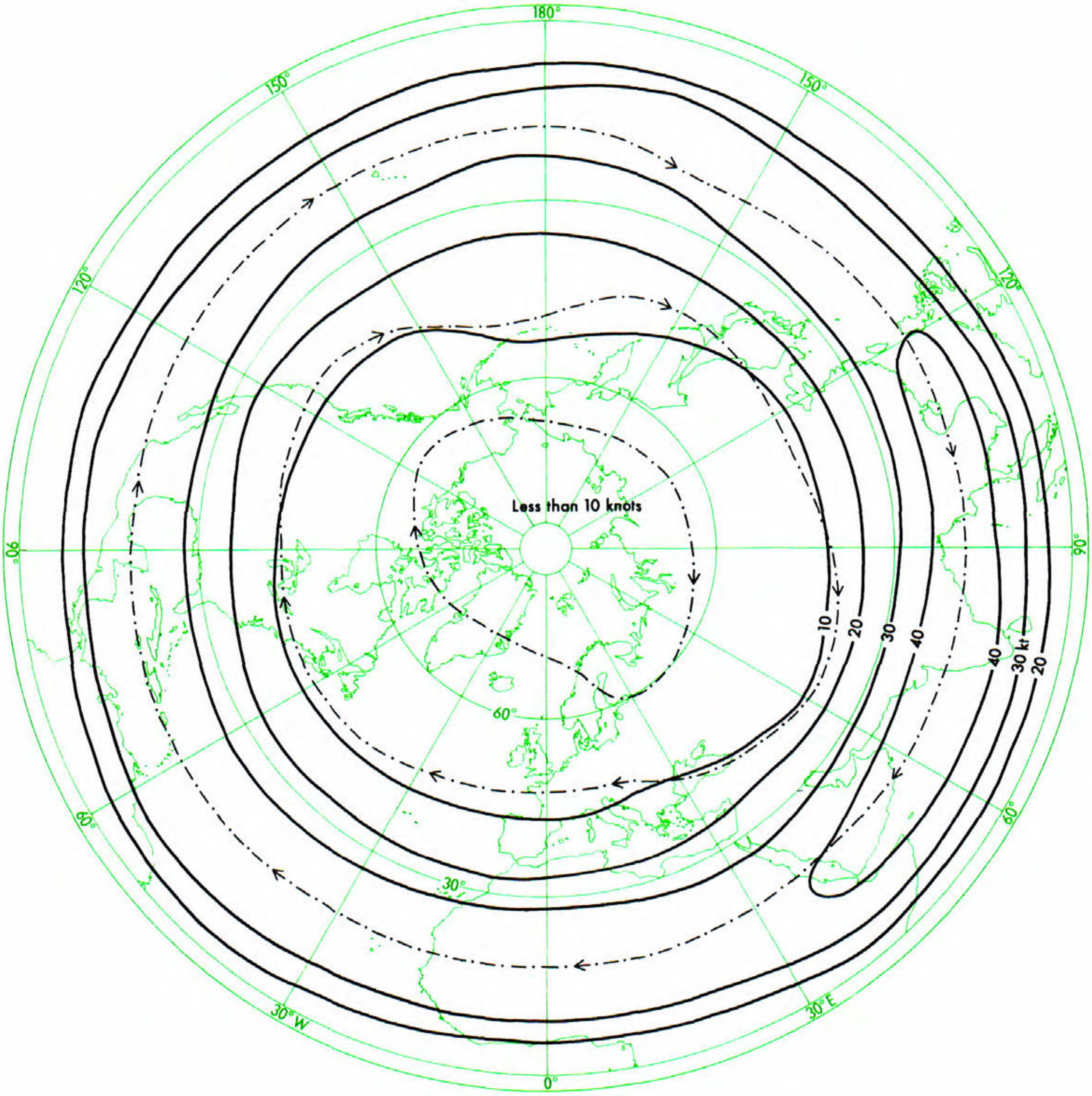


PLATE 24. AVERAGE WINDS AT 50 MILLIBARS OVER THE NORTHERN HEMISPHERE IN JULY, 1957-61
——— Isotachs (knots) —·→·—·→·— Streamlines

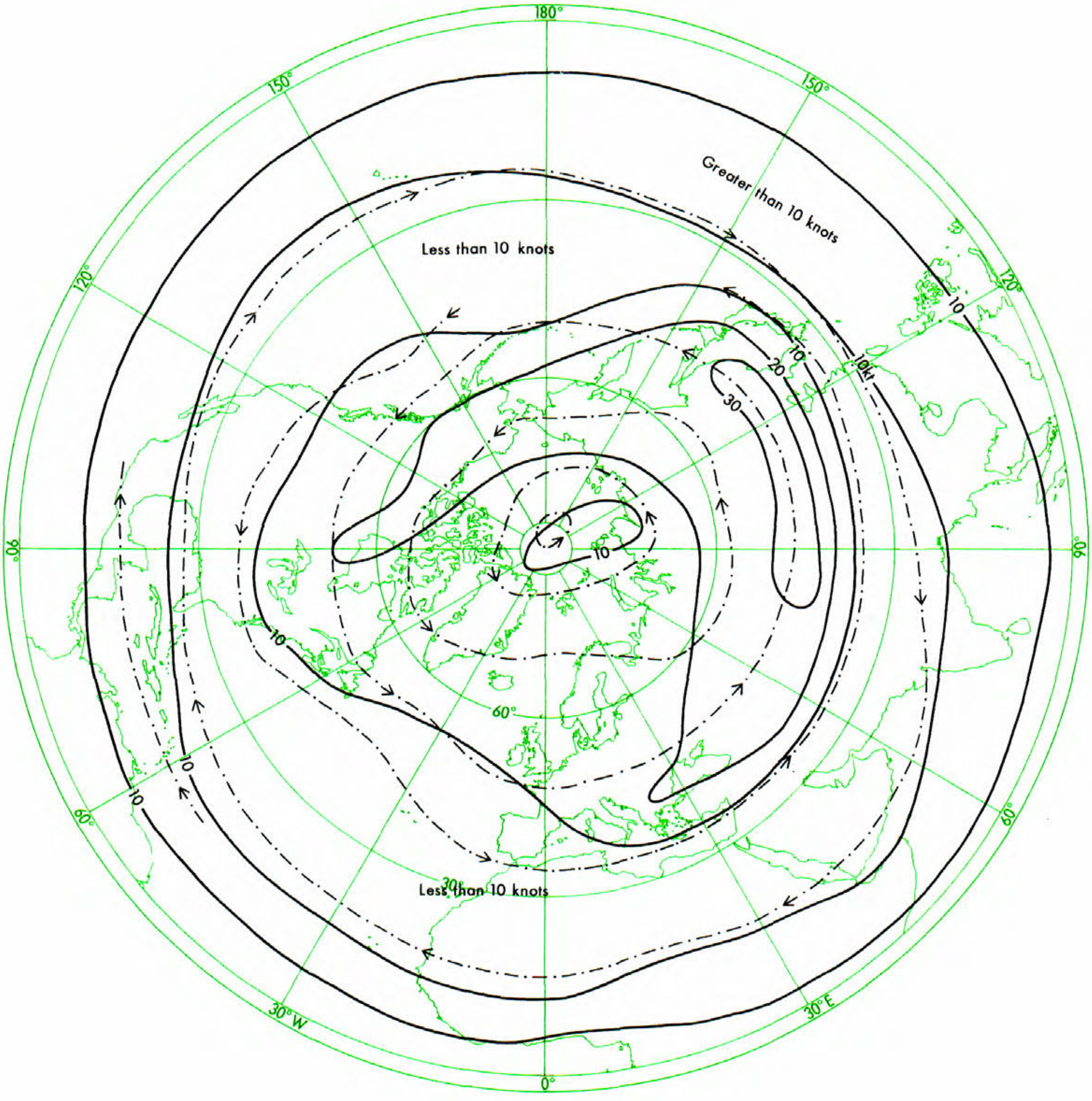


PLATE 25. AVERAGE WINDS AT 50 MILLIBARS OVER THE NORTHERN HEMISPHERE IN OCTOBER, 1957-61

——— Isotachs (knots) —·→·—·→·— Streamlines

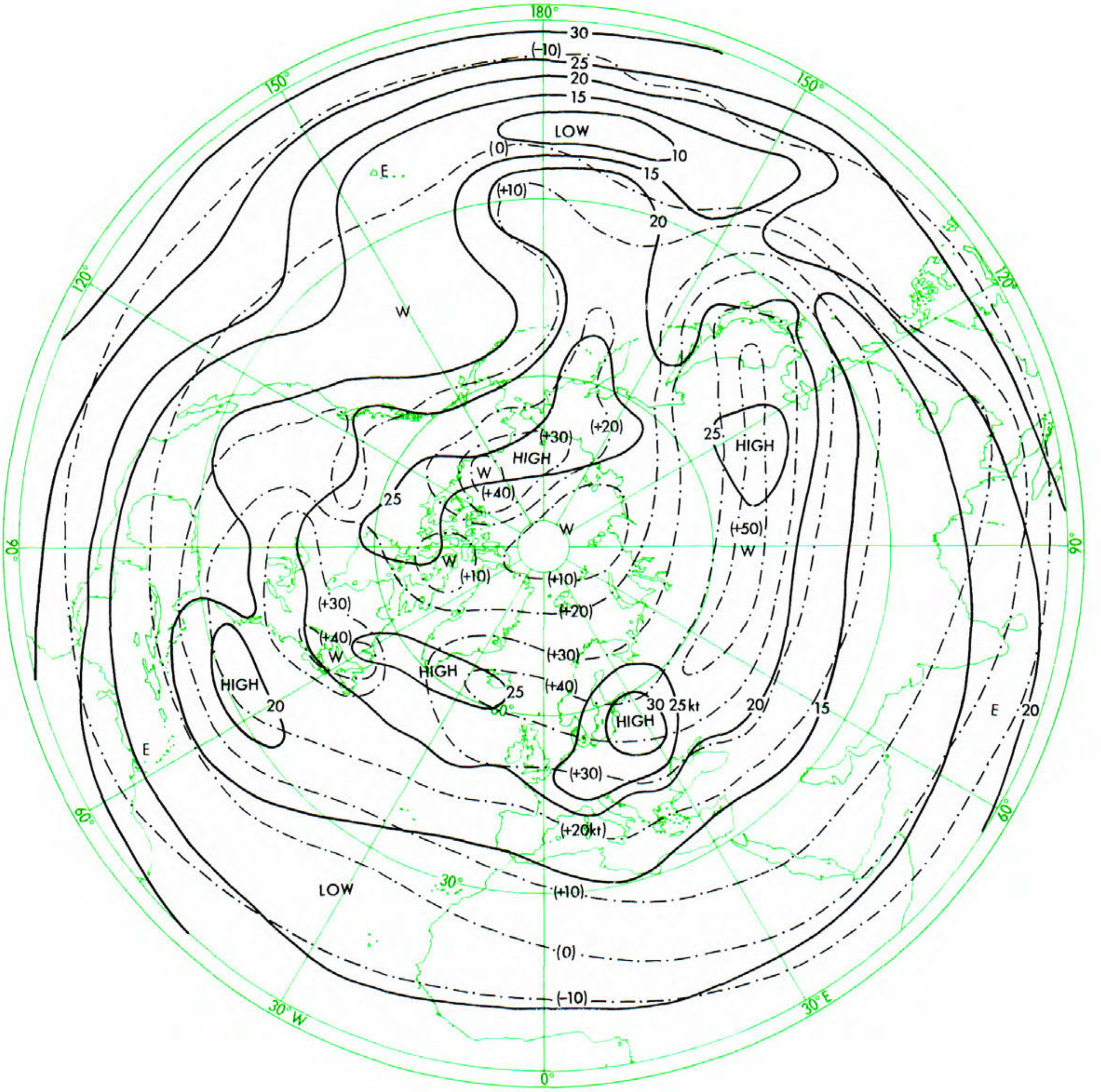
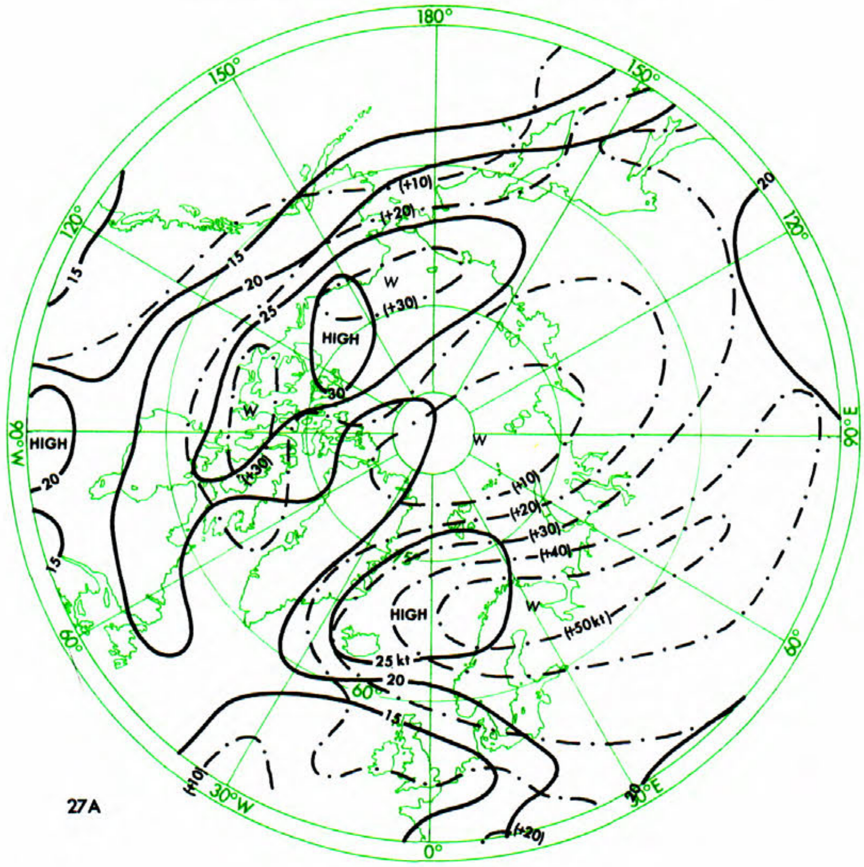
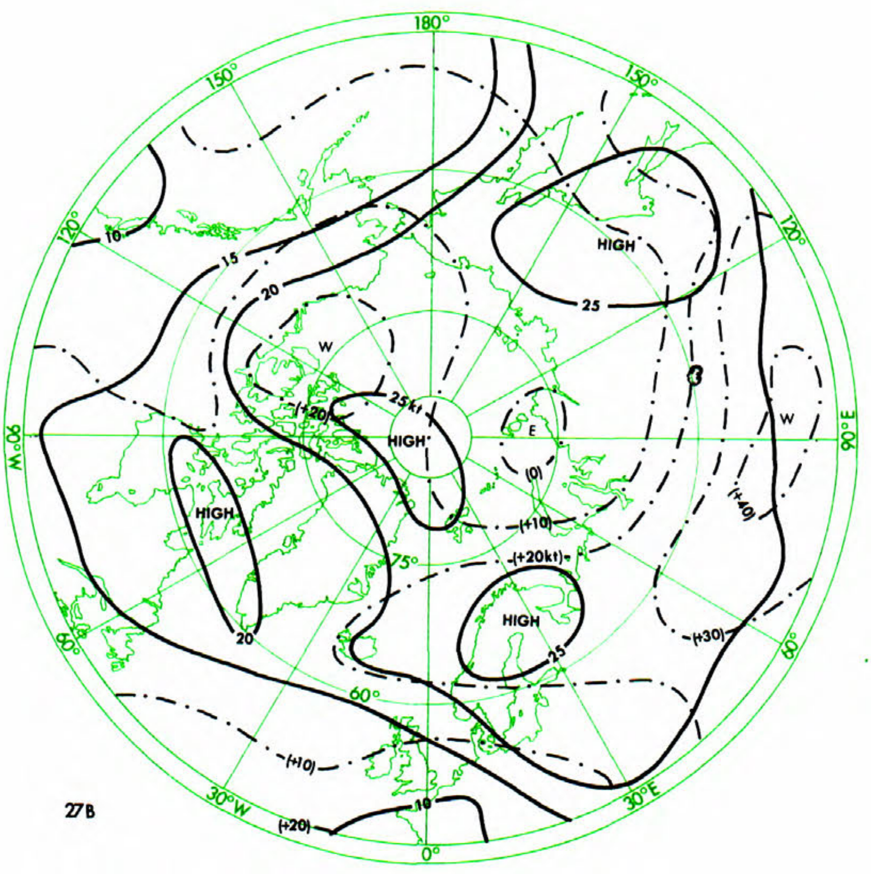


PLATE 26. AVERAGE ZONAL WIND COMPONENT AND STANDARD DEVIATION AT 50 MILLIBARS OVER THE NORTHERN HEMISPHERE IN JANUARY, 1957-61

—·—·—·— Zonal wind component (knots) ——— Standard deviation (knots)



27A



27B

PLATES 27A AND 27B. AVERAGE ZONAL WIND COMPONENT AND STANDARD DEVIATION AT 50 MILLIBARS OVER THE NORTHERN HEMISPHERE (NORTH OF LATITUDE 45° N) IN FEBRUARY (27A) AND MARCH (27B), 1957-61

—·—·—·— Zonal wind component (knots) ——— Standard deviation (knots)

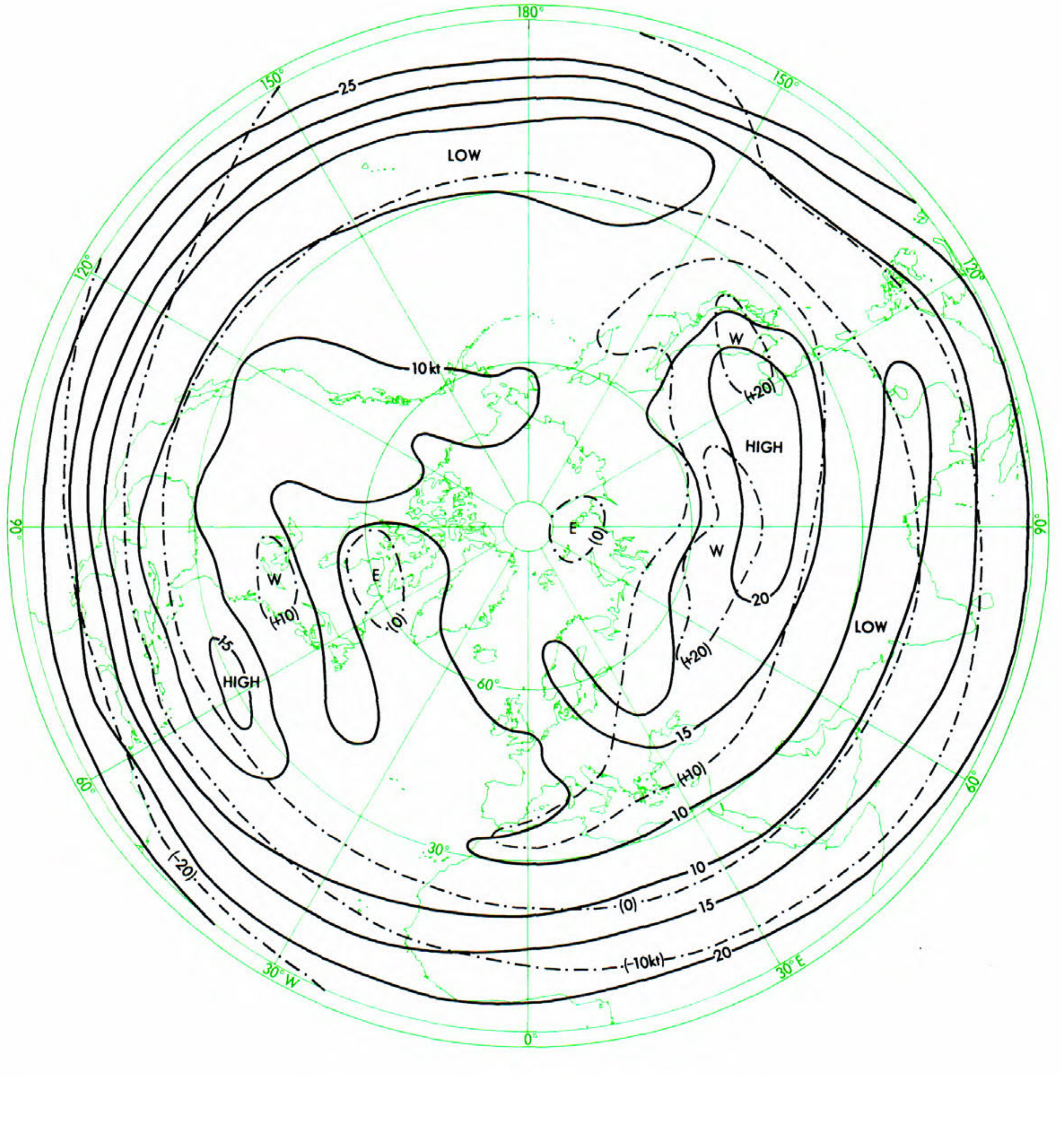


PLATE 28. AVERAGE ZONAL WIND COMPONENT AND STANDARD DEVIATION AT 50 MILLIBARS OVER THE NORTHERN HEMISPHERE IN APRIL, 1957-61

—·—·—·— Zonal wind component (knots) ——— Standard deviation (knots)

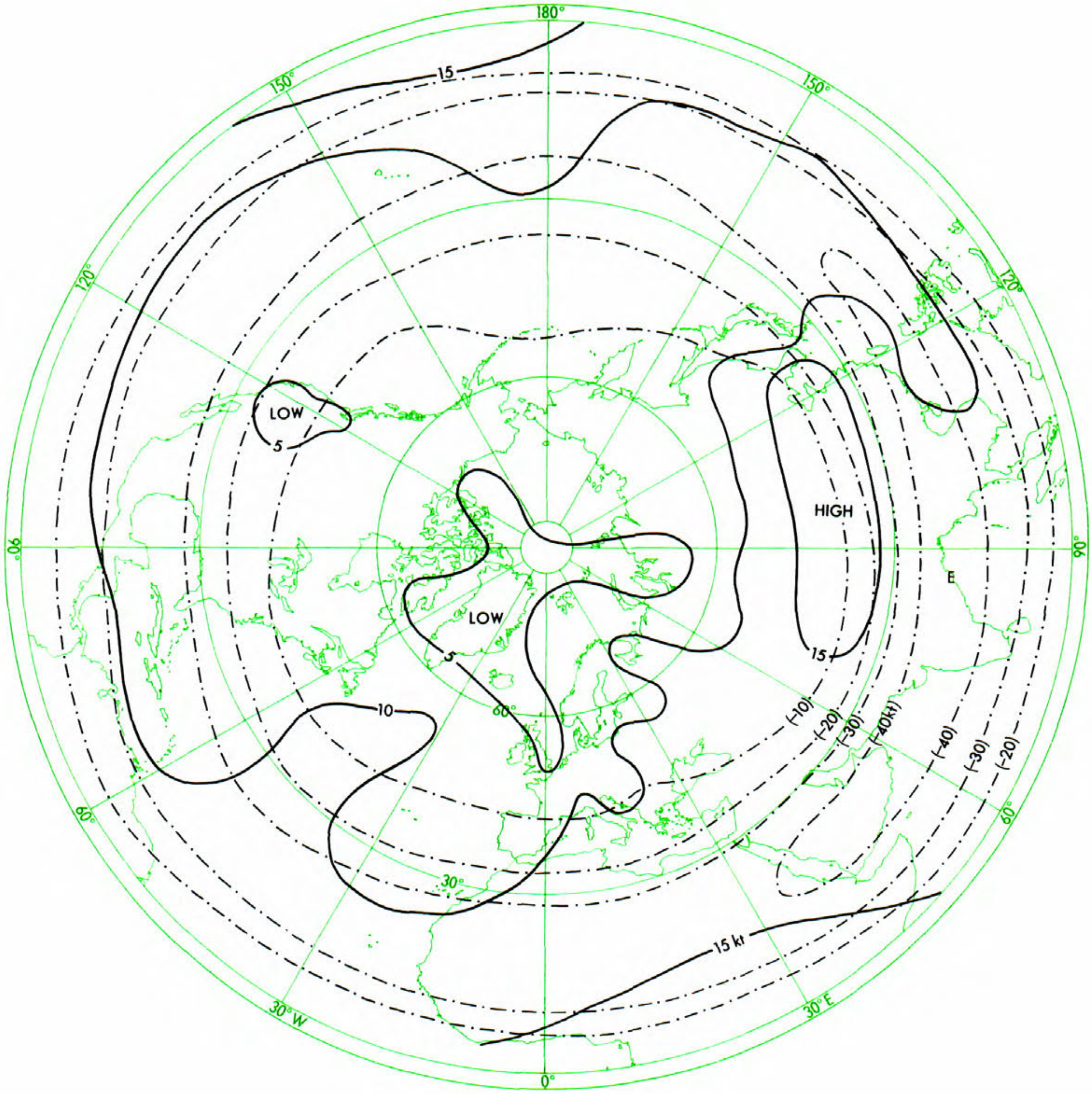


PLATE 29. AVERAGE ZONAL WIND COMPONENT AND STANDARD DEVIATION AT 50 MILLIBARS OVER THE NORTHERN HEMISPHERE IN JULY, 1957-61

—·—·— Zonal wind component (knots) ——— Standard deviation (knots)

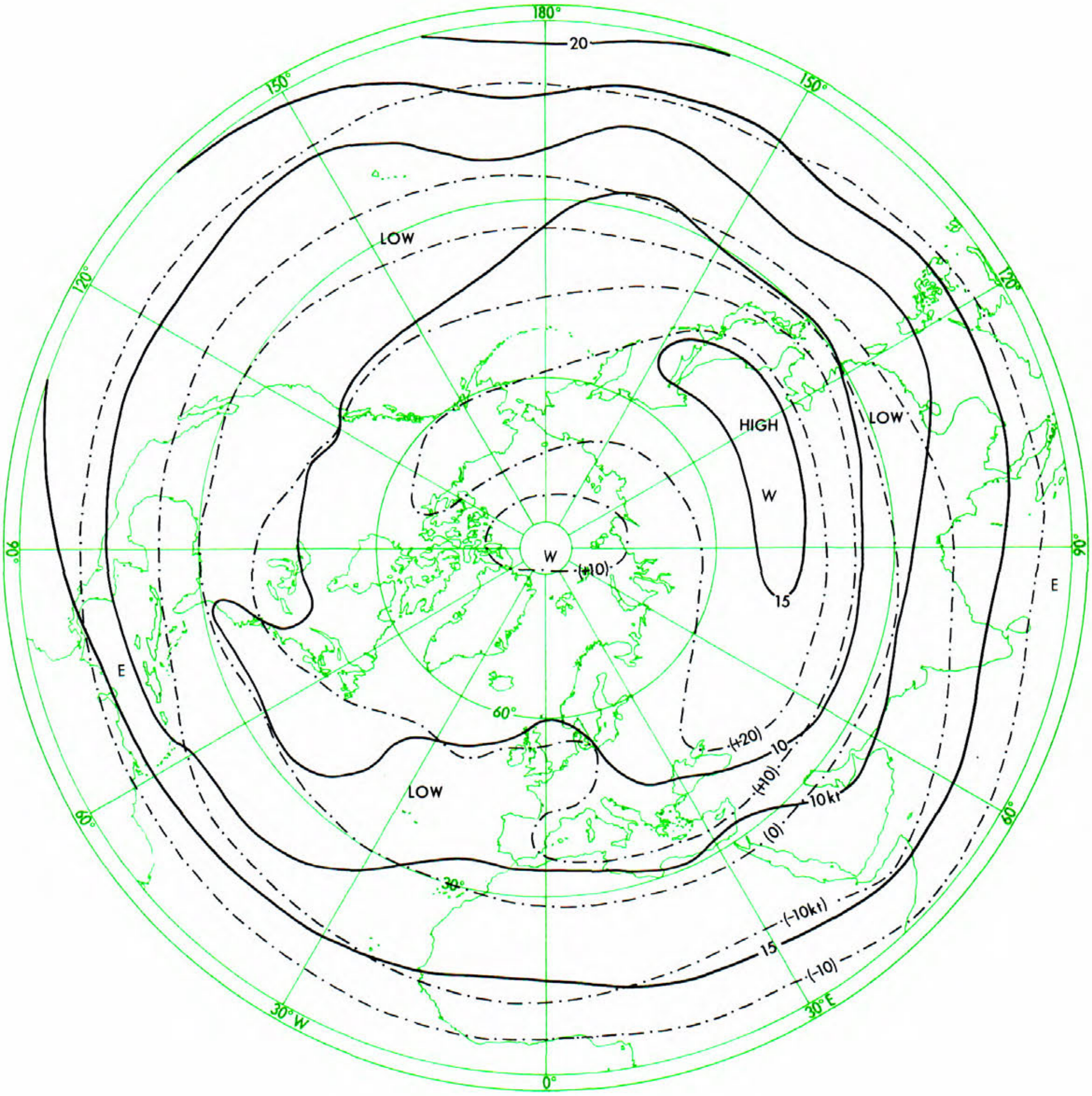


PLATE 30. AVERAGE ZONAL WIND COMPONENT AND STANDARD DEVIATION AT 50 MILLIBARS OVER THE NORTHERN HEMISPHERE IN OCTOBER, 1957-61

-·-·-·- Zonal wind component (knots) ——— Standard deviation (knots)

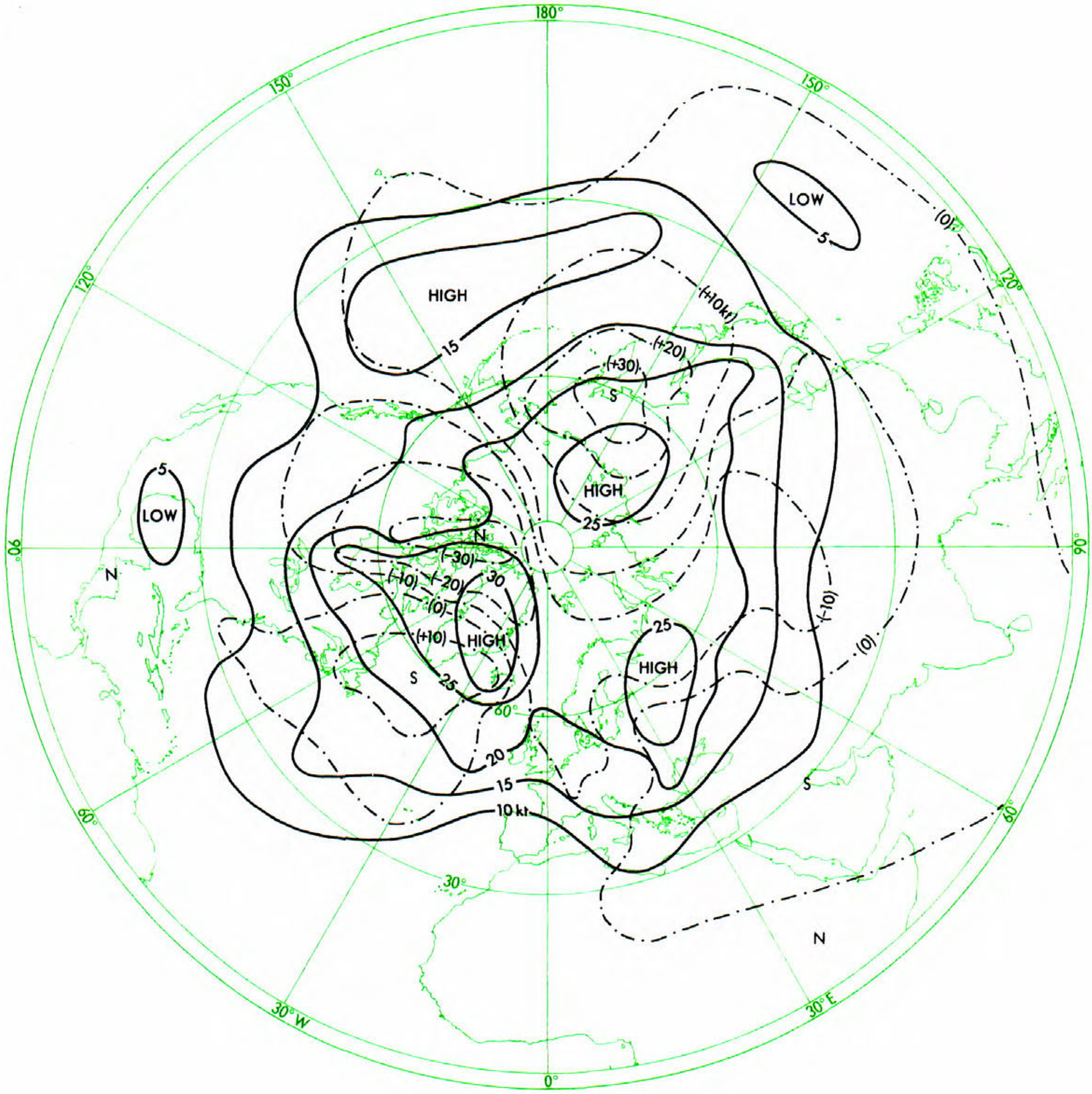
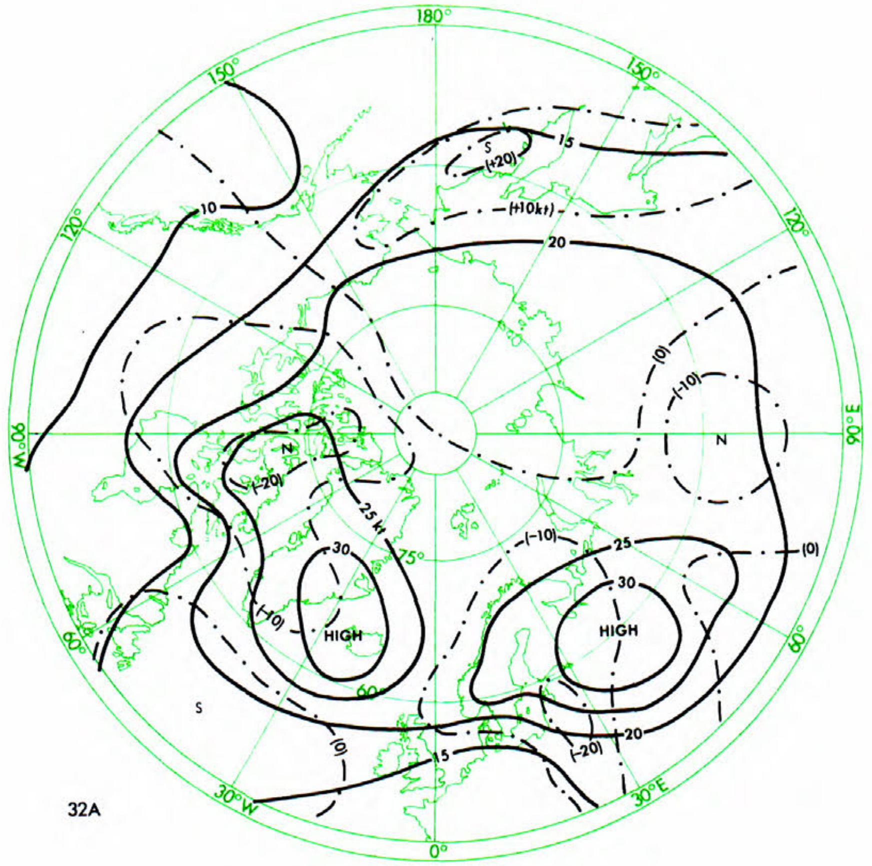
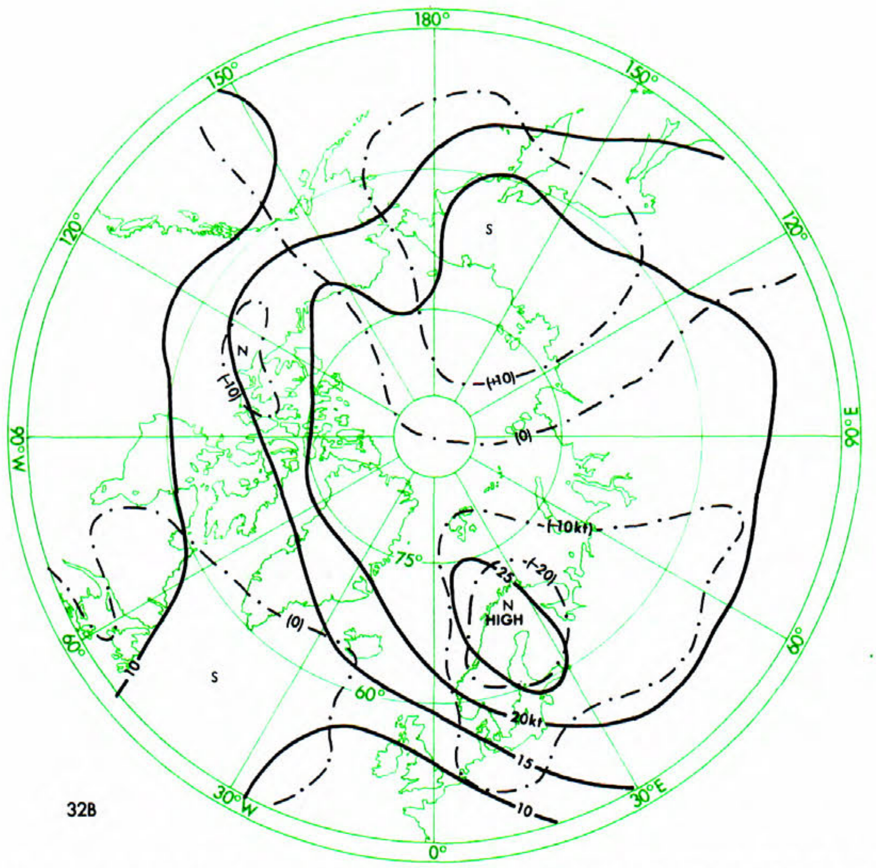


PLATE 31. AVERAGE MERIDIONAL WIND COMPONENT AND STANDARD DEVIATION AT 50 MILLIBARS OVER THE NORTHERN HEMISPHERE IN JANUARY, 1957-61

—·—·—·— Meridional wind component (knots) ——— Standard deviation (knots)



32A



32B

PLATES 32A AND 32B. AVERAGE MERIDIONAL WIND COMPONENT AND STANDARD DEVIATION AT 50 MILLIBARS OVER THE NORTHERN HEMISPHERE (NORTH OF LATITUDE 45°N) IN FEBRUARY (32A) AND MARCH (32B), 1957-61

—·—·—·— Meridional wind component (knots) ——— Standard deviation (knots)

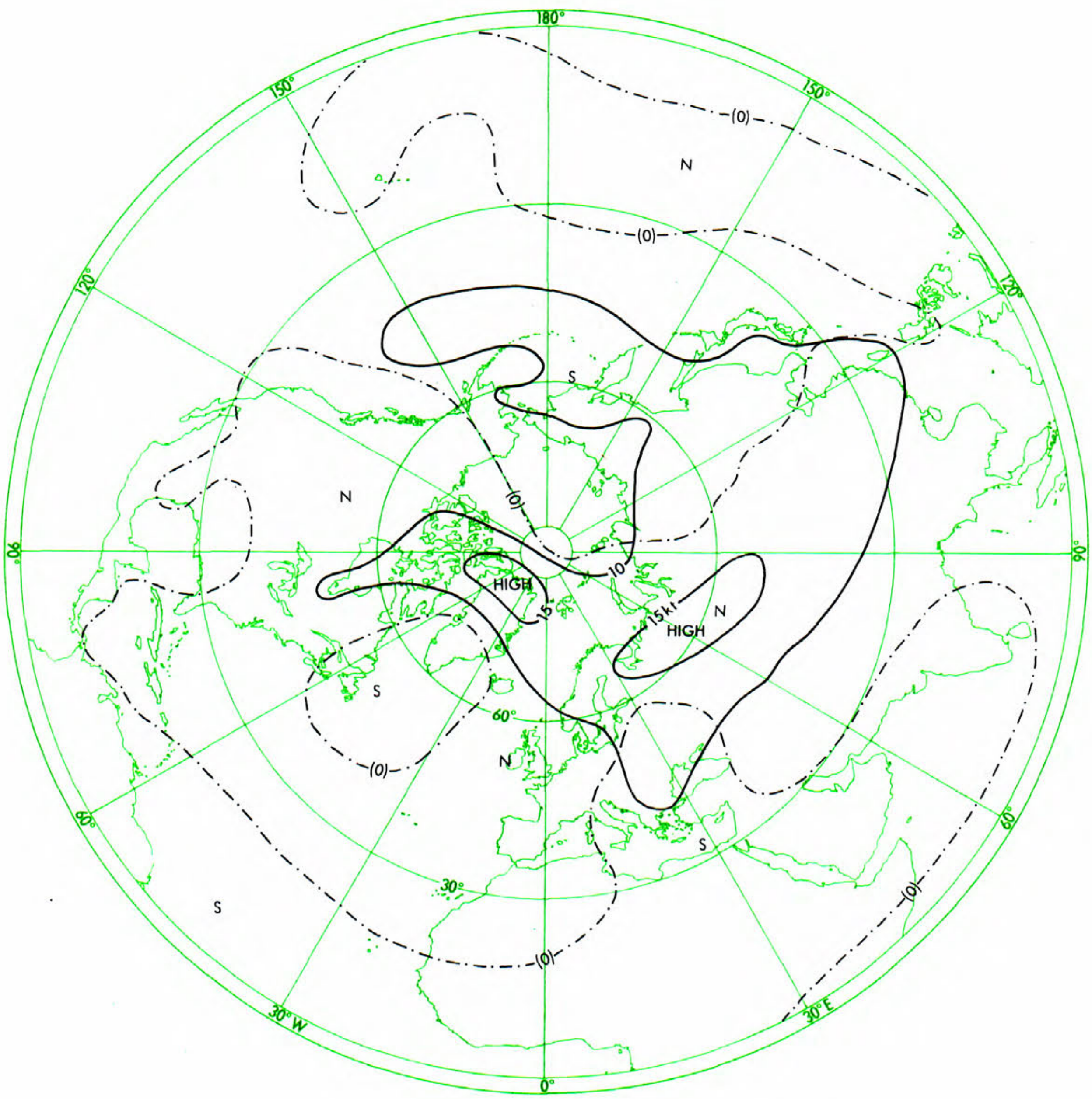


PLATE 33. AVERAGE MERIDIONAL WIND COMPONENT AND STANDARD DEVIATION AT 50 MILLIBARS OVER THE NORTHERN HEMISPHERE IN APRIL, 1957-61

—·—·— Meridional wind component (knots) ——— Standard deviation (knots)

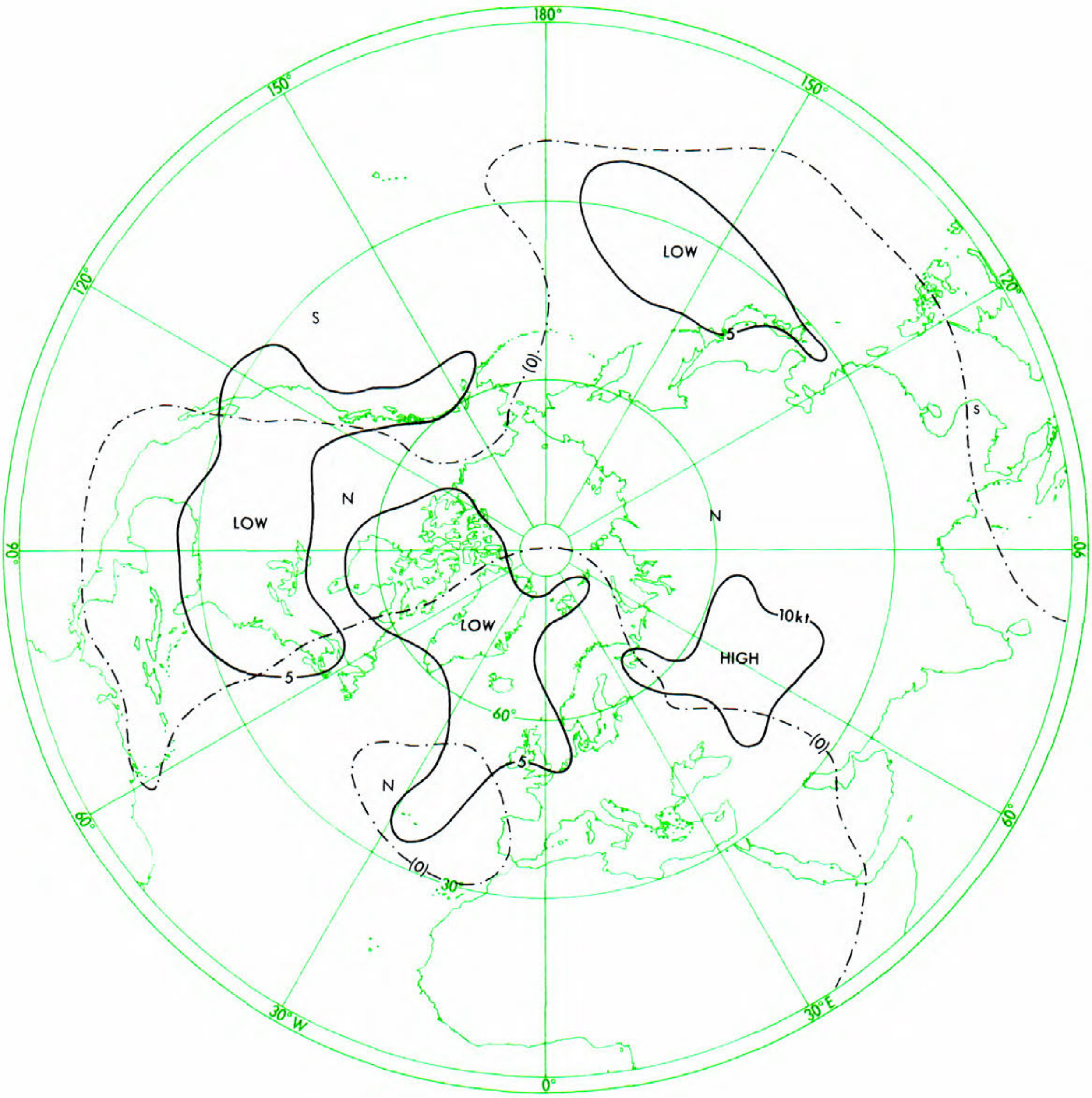


PLATE 34. AVERAGE MERIDIONAL WIND COMPONENT AND STANDARD DEVIATION AT 50 MILLIBARS OVER THE NORTHERN HEMISPHERE IN JULY, 1957-61

-·-·-·- Meridional wind component (knots) ——— Standard deviation (knots).

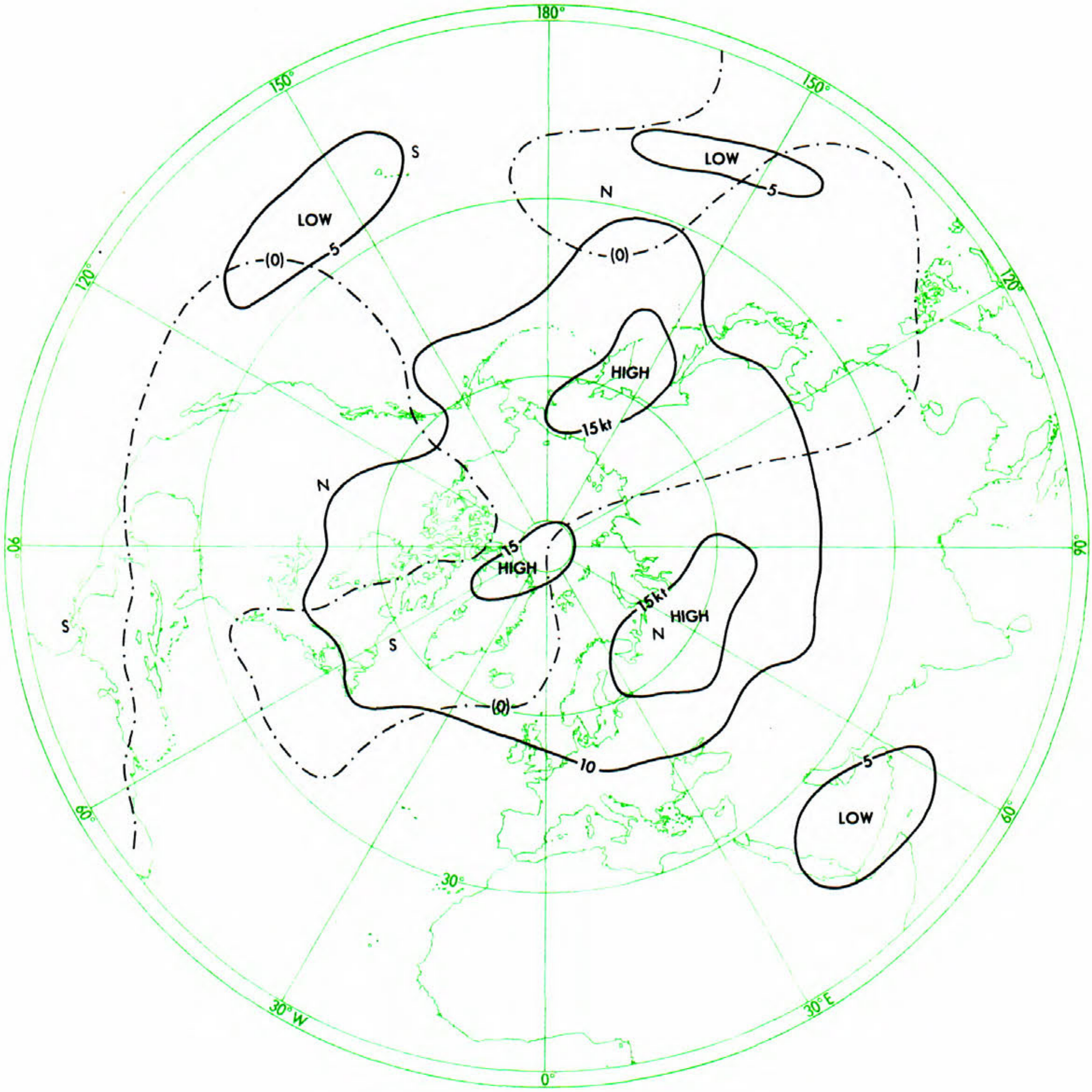


PLATE 35. AVERAGE MERIDIONAL WIND COMPONENT AND STANDARD DEVIATION AT 50 MILLIBARS OVER THE NORTHERN HEMISPHERE IN OCTOBER, 1957-61

—·—·—·— Meridional wind component (knots) ——— Standard deviation (knots)

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