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UPPER AIR TEMPERATURE OVER THE WORLD

BY

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INTRODUCTION

The need for information about the temperature of the upper air, its distribution over the world, its variation through the year and its variability from day to day has become increasingly evident in recent years. This Memoir attempts to meet that need by assembling the available data in maps and diagrams which will be of value alike to the practical aviator and the theoretical meteorologist. The Memoir is a further contribution to the upper air climatology of the world begun in the earlier Memoir on upper winds[1]*.

The Memoir is divided into two parts. Part I deals with the distribution of average temperature both in place and time, and Part II with the variability of the individual values. In both parts the distribution is represented by means of isopleths at standard pressure levels. Pressure levels rather than geometric heights have been used as being more in accord with modern aerological practice ; the levels have been selected from those adopted internationally as standard for synoptic work, namely 700, 500, 300, 200, 150 and 100 mb. The number of radio-sonde ascents reaching levels above 100 mb. is at present inadequate to enable charts to be drawn above that level.

Charts are reproduced for each of the four mid-season months—January, April, July and October—the month rather than the season being used chiefly because of the large variation of temperature from month to month in the transition seasons.

Mercator's projection has been selected for the main charts, which extend from 75° N. to 60° S. ; information for the Arctic is shown on circumpolar charts on an azimuthal projection extending southwards to 55° N. Data were insufficient for similar charts to be drawn for the Antarctic but some information for those regions is included in diagrams of annual variation (Fig. 8).

Throughout the Memoir temperatures are given on the Absolute scale, i.e. degrees Celsius + 273°, but isopleths are labelled also in degrees Celsius.

The basic charts for Part I show the average monthly temperature. They are supplemented by additional charts and diagrams designed to facilitate interpolation between the different levels and the different months. For interpolation between different levels a knowledge of the position and temperature of the tropopause is essential, and although the details of definition have not yet been agreed internationally an attempt has been made to map the average pressure and temperature of the tropopause in the mid-season months. For interpolating between the mid-season months, curves showing the annual variation of the average monthly values at selected stations in different parts of the world are reproduced for each of the six levels and also for the tropopause. As a further guide to the details of the variation of temperature with height,

* The index numbers refer to the bibliography on pp. 49–50.

curves typical in the main of different zones of latitude are given for the four mid-season months. Comparison of conditions in different longitudes for the mid-season months is made by cross-sections from the North Pole to 50° S.

The charts of Part II show the standard deviation of the individual values of temperature in each of the four months. These charts, in conjunction with the charts of average temperature in Part I, enable a reasonable estimate to be made of the frequency with which any given temperature is likely to be experienced at a given level and the probability of temperatures above or below a given value. The circumstances in which such estimates would not be valid are discussed in the text.

The standard deviation for a specified calendar month is understood to be the direct root mean square of the departures from the average of all temperature values observed during that month. No attempt has been made to eliminate variation due to seasonal trend within the month.

Extremes of temperature are often a subject of inquiry. The lowest temperatures are likely to be experienced at the tropopause, and a chart of the lowest temperature likely to occur once in about 20 years is reproduced. A similar chart of maximum temperature is not shown as these temperatures would normally occur at the surface. In order, however, to show the range of temperature to be expected at any level, curves are drawn of the extremes for the world as a whole, and also of the extremes in January and July at the six standard levels in all latitudes of the northern hemisphere.

DATA USED

The charts are based chiefly upon observations by radio-sonde between the years 1941 and 1952. These have been supplemented by pre-war observations by sounding balloons at some stations in Europe and India and by radio-sonde over the U.S.S.R. In regions where data were few, observations from aircraft have also been used for levels up to 300 mb. The number of years of data available at different stations varies considerably, and no attempt has been made to adopt a uniform period, although some adjustment for differences of period has been made when drawing the charts.

The data were taken from many sources, both published and unpublished, the latter being made available by the courtesy of the Directors of the Meteorological Services of the respective countries. References to all the sources used are given in the bibliography, and the principal data are listed in Appendix I.

PART I—AVERAGE TEMPERATURE

§ 1—WORLD CHARTS OF AVERAGE TEMPERATURE AT STANDARD PRESSURE LEVELS

Charts of the average temperature at the standard pressure levels 700, 500, 300, 200, 150 and 100 mb. in the mid-season months are reproduced in Plates 1–32. The charts are arranged according to months; for each month there are double-page Mercator charts for the six levels followed by six supplementary circumpolar charts.

The heights of the pressure levels computed for the standard atmosphere adopted by the International Commission for Air Navigation[2] (I.C.A.N.) are given on the charts and in Table I. The table contains also the estimated range of the monthly averages over the world. The highest

TABLE I—HEIGHTS OF THE ISOBARIC SURFACES

Pressure	Height					
	I.C.A.N.	Approximate range of averages		I.C.A.N.	Approximate range of averages	
		Lowest	Highest		Lowest	Highest
mb.		*feet*			*kilometres*	
100	53,100	49,600	55,500	16·17	15·1	16·9
150	44,600	41,700	47,400	13·60	12·7	14·4
200	38,600	35,400	41,400	11·78	10·8	12·6
300	30,100	27,200	32,100	9·16	8·3	9·8
500	18,300	15,400	19,300	5·57	4·7	5·9
700	9,900	8,500	10,400	3·01	2·6	3·2

The lowest values have been taken from charts of average height of the standard isobaric surfaces over Arctic regions in January[3], and from mean monthly maps of 300-, 200-, 100-, 50- and 25-mb. surfaces over North America[4]; the highest values are from averages at Aden, Habbaniya and Bahrain, 1948–50[5].

values occur over the thermal equator in summer and the lowest over polar regions in winter. The range of the individual values and of the means for individual months will of course be greater.

Computing the averages.—In this publication the term " average " is used to denote the arithmetic mean of observations taken over more than one year. The term " mean " is used when the observations occur within one year only; for example, a monthly mean is the arithmetic mean of all available observations within a single specified month such as January 1949, or April 1952. The term " mean " is used also in the statistical sense in referring to frequency distributions, even though the mean of a distribution may often be, in the climatological sense, an average.

Wherever possible, averages were computed from monthly mean temperatures; unit weight was given to each monthly mean based on at least 10 observations, and a weight proportional to the number of observations (0·7 for 7 observations, etc.) was assigned where the number in the month was less than 10. In the calculation of a long-period average, either a published average or the mean of a frequency distribution was often used as a partial average and combined with other data in the form of monthly means. Generally, the number of years, n say, on which the partial average was based was known as well as the actual or approximate total number, N say, of the observations contributing, or at least an indication of this number. The weight then assigned to the partial average was n or $N/15$ to the nearest integer whichever of these two numbers was the smaller.

Over North America the isotherms of average temperature at the 150-mb. level are based upon less reliable data than at the other standard levels because the Washington publications (see Appendix II) from which the daily observations were extracted, give values at standard levels of 700, 500, 300, 200 and 100 mb. but not of 150 mb. Temperatures at 150 mb. can be estimated (or interpolated) only where significant points near this level have been recorded. It is difficult to determine to what extent the error thus arising is systematic; had the significant points been known to be mainly tropopauses, then one might presume the computed average temperature to be lower than the actual average which would be obtained from all ascents. This, however, cannot be assumed for every station. Some uncertainty also arises in regard to the data for 1941–44 at European stations[6] where values were summarized more often at 225 and 96 mb. than at 200 and 100 mb. In using averages computed from these summaries, it was assumed that the difference between the average temperatures at 100 and 96 mb. would be unimportant; but for 200 mb. an interpolation (according to the logarithm of pressure) was made between the average temperatures at 225 and 150 mb. Where the 200-mb. level was in the region of a tropopause inversion, such interpolation smoothed out the minimum of the temperature–height curve, and so made the average temperature at 200 mb. too high. Allowance was made for this in drawing isotherms over Europe.

Scrutiny of the charts and physical considerations.—Isopleths were drawn to fit the plotted observations as closely as possible without making the lines excessively tortuous. Most weight was given to observations based on the records of longer period as giving the more representative average values.

At tropospheric levels it was easy, on the whole, to fit a smooth pattern of isopleths to the computed values ; there were, however, some areas in which discordant values appeared, and which required a more careful scrutiny. The charts of the three uppermost levels, especially those for 200 mb., were not so simple and required much thought in the fitting of the isotherms.

The main reasons for discordant values and the difficulties in drawing were :

(i) Different periods of record at neighbouring stations.

(ii) Instrumental effects—systematic differences between temperature observations obtained by different types of radio-sondes.

(iii) Scantiness of observations at the higher levels.

The methods of dealing with these are described below.

Variability of the period of record.—Discrepancies arising from this cause were found to be appreciable in winter and spring over the North American and Eurasian continents. Two methods were used to eliminate these discrepancies.

The first, a reduction method, was found suitable for areas such as the United States where there was a fairly close network of stations with periods of record of the order of ten years for some of them. The method consisted in a comparison of monthly means at a short-period station, A say, with those of a nearby station, B, having a much longer record. The average difference, (temperature at A) minus (temperature at B), was determined for the years common to stations A and B and added algebraically to the long-period average at B to give a " reduced " average for A. In the present investigation, the number of years common to A and B was smaller than is generally considered necessary in reducing normals of surface elements ; nevertheless the method appeared to give reasonable results when used with discretion. It is not of course advantageous unless the difference (A — B) is reasonably stable from year to year ; therefore it could not be used, for example, to resolve discrepancies among the averages for Canada at 150 mb. in winter.

This reduction method was unsuitable for areas in which all the available records were for short periods, and for these a method was used which was applicable so long as each year considered was represented by at least one station in each part of the area. This sufficed for the drawing of charts of monthly mean isotherms for the individual years ; these charts were then combined graphically to give an average chart which was considered reasonably accurate. Averages at 700 and 500 mb. were obtained by this method for January and April 1949–52 over Siberia and the northernmost part of the Pacific Ocean. The resulting chart was then adjusted to fit into the world chart, the isotherms being made continuous with those based on longer periods in the neighbouring areas of Russia, Iraq, India, Alaska and the United States.

Instrumental effects.—It was not possible in general to correct the data for differences arising from the use of various types of radio-sonde in different parts of the world. For the most part this difficulty was met by smoothing the isotherms. For certain areas, however, for which the relative characteristics of the radio-sondes were known, more specific corrections were possible. For example, over Canada, two types of instrument were in use and the work of T. J. G. Henry[7] enabled some allowance to be made for such differences. Henry compared monthly mean values of temperature and contour height obtained at stations using Canadian with those using United States instruments. His results showed that the Canadian radio-sondes are more affected by lag and radiation errors than are those of the United States and consequently tend to indicate slightly higher temperatures. Henry suggests the following corrections for lag under conditions of normal lapse rate of temperature :

	700 mb.	500 mb.	300 mb.	200 mb.
	degrees Celsius			
Winter	−0·4	−0·7	−1·1	−0·3
Summer	−0·5	−1·1	−1·9	−1·2

The corrections above 200 mb., where lapse rates are small, are likely to be negligible. For April and October the corrections were taken as the mean between winter and summer. The following stations were known to be using Canadian radio-sondes and Henry's corrections were applied to them.

Aklavik ..	68° N. 135° W.	The Pas ..	54° N. 101° W.
Coppermine ..	68° N. 115° W.	Moosonee ..	51° N. 81° W.
Baker Lake ..	64° N. 96° W.	Port Hardy ..	51° N. 127° W.
Fort Nelson ..	59° N. 123° W.	Sable Island ..	44° N. 60° W.

Ascents over Canada were made at 0300 G.M.T. and were therefore in darkness except at a few stations in the north and west in July and at still fewer in April ; even in these months the altitude of the sun is low. Therefore no corrections for radiation were applied to the results from either type of radio-sonde before the data were plotted ; but, in drawing isotherms, allowance was made for the fact that the values at the stations using Canadian radio-sondes were likely to be slightly too high.

Canadian radio-sondes had been used also at stations maintained by the Weather Bureau of the Union of South Africa. At Pretoria (26° S. 28° E.) and Alexander Bay (29° S. 16° E.) the lag correction was estimated to be of the order of 1½° to 3° C. at 200, 150 and 100 mb. and, in summer, the radiation correction might also be appreciable, even on early morning ascents (0500 G.M.T.). In drawing smooth isotherms for the 150-mb. and 100-mb. surfaces a divergence from the computed average temperatures of up to 4° C. was considered not unreasonable, if it was in the right direction. At Marion Island (47° S. 38° E.) corrections would be smaller.

High-level data.—At the higher levels, values based upon early records or upon scanty observations which were found to be discordant were generally assumed to be too high. The justification for this is two-fold. First, the early observations may not have been corrected sufficiently for radiation errors. Secondly, the scantiness of the observations is believed to be related to the fact that balloons deteriorate quickly at very low temperatures ; for example, very few observations were recorded at high levels over Arctic stations in winter.

General considerations.—In extending the isotherms over regions where there were few reliable data various considerations were borne in mind, in particular the variation of temperature with latitude at different levels, the effects of continentality, and the general pattern of the variation of temperature with height.

A study of the regions where observations are sufficiently numerous to indicate the latitudinal variation shows that in the troposphere at 700, 500 and 300 mb. the temperature in all seasons is highest near the equator and decreases thence towards the poles. At 150 and 100 mb. on the other hand the highest temperatures are found over middle latitudes in winter and they appear to occur further poleward as the year advances until in summer they are approximately over the pole, and in that season the gradient is the reverse of that in the lower troposphere. At 200 mb. the distribution is intermediate between that at higher and lower levels ; temperature is nearly uniform with irregular patches of relatively warm and cold air.

This broad picture is much modified by the distribution of land and sea ; the effects of the heating and cooling of the large land masses are apparent at all levels of the troposphere and probably even in the lower stratosphere also. For example, in the northern winter the lowest temperatures at any level in the troposphere are found not at the pole but over the north-eastern parts of the American and Eurasian continents ; and the highest temperatures in the troposphere occur, on the whole, not over the geographical equator but somewhat to the north of it. Small-scale features of the atmospheric circulation do not affect the average temperature distribution materially, although cold ocean currents are thought to have some slight effect on the run of the isotherms on the 700-mb. and 500-mb. charts. This was borne in mind when drawing isopleths for the southern hemisphere where data were generally scanty.

The general pattern of the variation of temperature with height in different regions was also used as a check on the consistency of the average charts in places such as South America, the Pacific and at high levels over the U.S.S.R. where few or no data were available. The types of variation characteristic of different climatic regions are described in § 3 (p. 16) ; in general the minimum on the average curve may be expected to occur a little above the average position of the tropopause.

Reliability of the charts.—Errors arising from instrumental differences have been discussed above (p. 6). When the corrections mentioned there have been made, it seems unlikely that errors remaining are large enough to affect the general pattern of the isotherms ; the reliability of the charts in any area may then be assessed from the following three factors :

(i) length of the period of record
(ii) general variability of the temperature in the area
(iii) density of the network of observing stations.

The first and second factors are to some extent interdependent. In a region where the standard deviation is small, say 2° or 3° C., as for example over most of the tropics, only a few years' data are needed to give a reliable average. On the other hand where the standard deviation is large a comparatively long period is needed ; thus over the British Isles in January where the standard deviation at 200 mb. is 6° or 7° C. even a seven-year average may differ appreciably from a ten-year average in which the same seven years are included. This was borne out by an examination of discordant values at Leuchars in Scotland on the January charts for 200, 150 and 100 mb. The years 1942, 1943 and 1948, absent from the Leuchars records, happened to be among the four warmest at these levels in this area in the ten-year period 1942–51, and a correction of the order of 3° F. ($1\frac{1}{2}$° C.) was required in order to bring the Leuchars record into accord.

An attempt was made to obtain an estimate of the standard error of the charts by the following procedure. The chart was divided into a number of areas, broadly those operated by the different meteorological services, grouped or sub-divided as convenient geographically (see Appendix I), and for each area assessments were made according to three factors.

(i) For length of period the areas were allocated to one or other of four classes, 8–11 years, 4–7 years, 2–3 years, < 2 years, with an additional sub-division of the second class into " 5–7 years " and " about 4 years " for the 700-mb. and 500-mb. levels.

(ii) The general variability of temperature was measured by the standard deviation which was estimated to the nearest $\frac{1}{2}$° C. from the charts reproduced in Plates 45–76.

(iii) For the density of network the areas were allocated to four classes, A good or very good, B fair, C poor, D scanty, i.e. very few or no observation stations.

Where the density of network is fair to very good (A or B) the standard error of the isopleths will be less than that of an independent value, where it is poor (C) there should be little difference, and in sparsely covered areas (D) the isopleths may have appreciably greater errors than the individual values. Factors corresponding with the four classes of density were assigned somewhat arbitrarily as :—

A 0·5 B 0·7 C 1·0 D 2·0

The standard error for any area was then computed by using the relationship (see Brooks and Carruthers[8])

$$\text{standard error of the mean} = \frac{1}{\sqrt{(N-1)}} \times \text{standard deviation},$$

where N is the number of independent observations. To obtain $\sqrt{(N-1)}$ it was assumed that in any one month ten observations could be regarded as independent, and the following values were computed for periods corresponding roughly with those in (i) above :

Period (years)	8	5	4	$2\frac{1}{2}$	1
$\sqrt{(N-1)}$	9·0	7·0	6·3	5·0	3·0

From these values, using the period of the majority of stations in the area, the standard error was obtained by taking $1/\sqrt{(N-1)} \times$ (standard deviation as read from the chart) and the result was multiplied by the factor corresponding to the density of the network in the area given in (iii). The values so obtained were then divided into five categories : 0·00° to 0·25° C., 0·25° to 0·50° C., 0·50° to 0·75° C., 0·75° to 1·00° C., over 1·00° C.

The results of these assessments are given for January and July in Table II, where for each level values are given of the factor used for the density of the network as well as the final assessment of the standard error. In April standard errors may be assumed to be of the same order as those for January, and in October to be somewhere between those for January and July.

The standard errors computed by this method may be regarded as upper estimates. This is partly because for upper air temperatures a value of 10 is probably a low estimate of the number of independent values in a month, 12 probably being nearer to the average number, and partly because the values used for $\sqrt{(N-1)}$ correspond with a number of years rather below that of the central values of the classes. The chance is rather more than 19 in 20 that the average temperature read from the charts will have an error of less than twice the estimated standard error.

TABLE II—ACCURACY OF THE CHARTS OF AVERAGE TEMPERATURE

Density of network of observing stations: A = good or very good, B = fair, C = poor, D = scanty (very few or no observing stations).

Standard error of the isotherms: $\alpha = 0{\cdot}00°\text{–}0{\cdot}25°$ C., $\beta = 0{\cdot}25°\text{–}0{\cdot}50°$ C., $\gamma = 0{\cdot}50°\text{–}0{\cdot}75°$ C., $\delta = 0{\cdot}75°\text{–}1{\cdot}00°$ C., $\varepsilon = > 1{\cdot}00°$ C.

	Density of network and standard error											
	January						July					
	100 mb.	150 mb.	200 mb.	300 mb.	500 mb.	700 mb.	100 mb.	150 mb.	200 mb.	300 mb.	500 mb.	700 mb.
REGION I*												
Arctic Islands of Canada	Cε	Cε	Bγ	Bβ	Bβ	Bγ	Cγ	Cγ	Bβ	Bβ	Bβ	Bβ
Alaska	Bδ	Bδ	Bγ	Bβ	Bγ	Bδ	Bβ	Bβ	Bβ	Bβ	Bβ	Bβ
Canada	Bδ	Bδ	Bγ	Bβ	Bδ	Bδ	Bβ	Bβ	Bβ	Bβ	Bβ	Bβ
United States of America	Aβ	Aβ	Aβ	Aα	Aβ	Aβ	Aα	Aα	Aα	Aα	Aα	Aα
Caribbean (including the north coast of South America)	Aβ	Aα	Aα	Aα	Aα	Aα	Aα	Aα	Aα	Aα	Aα	Aα
REGION II*												
Greenland, Iceland and the Greenland Sea ..	Cε	Cε	Cε	Cδ	Bδ	Bδ	Cγ	Cγ	Cδ	Cδ	Bγ	Bβ
North Atlantic Ocean	Cδ	Bγ	Bδ	Bγ	Bδ	Bδ	Cγ	Bγ	Bδ	Bγ	Bβ	Bα
British Isles	Aβ	Aβ	Aβ	Aα	Aβ	Aβ	Aα	Aα	Aβ	Aα	Aα	Aα
Southern Scandinavia and Central Europe ..	Bδ	Bβ	Aβ	Aβ	Aβ	Aβ	Bβ	Bβ	Aβ	Aα	Aα	Aα
Mediterranean Area	Bγ	Bγ	Bδ	Bβ	Bγ	Bγ	Bβ	Bβ	Bβ	Bβ	Bα	Bα
Africa (excluding the Mediterranean coast, Rhodesia and the Union of South Africa)	Dδ	Dδ	Cγ	Cβ	Bα	Bα	Dγ	Dγ	Cβ	Cβ	Bα	Bα
South America and the South Atlantic Ocean (north of 30° S.)	Dε	Dε	Dε	Dε	Cε	Cε	Dε	Dε	Dε	Dε	Cδ	Cδ
Rhodesia and the Union of South Africa ..	Bδ	Bγ	Bβ	Bβ	Bα	Bα	Bγ	Bβ	Bβ	Bβ	Bβ	Bβ
REGION III*												
U.S.S.R., west of 100° E.	Dε	Dε	Cε	Cδ	Bγ	Bγ	Dε	Dε	Cε	Cε	Bβ	Bβ
U.S.S.R., east of 100° E.	Dε	Dε	Cε	Cδ	Cδ	Cδ	Dε	Dε	Cε	Cε	Cγ	Cγ
Manchuria, Korea and Japan	Bδ	Bβ	Bβ	Bβ	Bγ	Bγ	Bγ	Bβ	Bβ	Bβ	Bβ	Bβ
Arabia, Iraq and Iran	Cβ	Cβ	Cγ	Cβ	Cβ	Cβ	Cβ	Cβ	Cβ	Cβ	Cβ	Cβ
India	Aγ	Aδ	Aγ	Aβ	Aα	Aα	Aγ	Aγ	Aγ	Aα	Aα	Aα
China	Cδ	Cγ	Cγ	Cγ	Cδ	Cδ	Cδ	Cγ	Cγ	Cγ	Cβ	Cβ
Indo-China, the Philippines and the Malay Archipelago	Cγ	Cγ	Cβ	Cβ	Cβ	Cβ	Cγ	Cγ	Cβ	Cβ	Cα	Cα
Indian Ocean	No data				Cβ	Cβ	No data				Cβ	Cγ
Australia	Bα	Bα	Bα	Bα	Bα	Bα	Bβ	Bβ	Bβ	Bβ	Bβ	Bβ
New Zealand	Bβ	Bβ	Bβ	Bβ	Bβ	Bβ	Bβ	Bβ	Bβ	Bβ	Bβ	Bβ
REGION IV*												
Pacific Ocean, north of 40° N.	Cε	Cε	Cε	Cδ	Cδ	Cδ	Cγ	Cδ	Cε	Cδ	Cγ	Cγ
Pacific Ocean, 40° N. to 30° S.	Cγ	Cγ	Cγ	Cγ	Cβ	Cβ	Cγ	Cγ	Cβ	Cβ	Cβ	Cβ
REGIONS I–IV												
North Pole	No data						No data					
Oceans south of 30° S.	Dε	Dε	Dε	Dε	Dε	Dε	Dε	Dε	Dε	Dε	Dε	Dε

* For details of regions see Appendix I.

§ 2—WORLD CHARTS OF AVERAGE PRESSURE AND TEMPERATURE AT THE TROPOPAUSE

Definitions and data used.—The charts of Plates 1–32 give an incomplete picture of the distribution of temperature in the upper air, unless they are supplemented by information about the position of the tropopause.

The existence of the tropopause has been known for over half a century. It is broadly defined as the region of transition between the troposphere—the convective region of the atmosphere in which temperature decreases with height, and the stratosphere—the region beyond the limit of thermal convection where the change of temperature in the vertical is small. Originally it was thought that the transition was of a comparatively simple character and definitions were formulated which could be applied objectively to curves of variation of temperature with height, the most notable being those of Gold[9] in which three types of transition were distinguished. These definitions were adopted by many countries and form the basis of those used here although they make provision for only a single transition.

The existence of more than one tropopause had been recognized by the Indian Meteorological Service[10] from its ballon-sonde records at Agra at least as early as 1933, but it was not until radio-sonde ascents in the subtropics became frequent that it was realized that in some seasons of the year two tropopauses are an almost everyday occurrence. In endeavouring to map the tropopause from the existing data, therefore, no precise definition could be used. In temperate and tropical regions, however, where a single tropopause is usual, the transition from troposphere to stratosphere is thought to be clearly marked and only small errors are likely to arise from differences in definitions.

A special study was made for the subtropics where two tropopauses are often detected. Individual ascents were examined at a number of stations and estimates of the temperature and pressure at the tropopauses were made. For such ascents the following tentative definitions, which had been provisionally adopted for " Upper air data "[11] were used. A comparison between the results obtained from these definitions and from those recently put forward by the World Meteorological Organization[12] showed that for subtropical regions they differed significantly only at the upper tropopause. When monthly mean values were computed, these discrepancies largely disappeared.

Troposphere. The troposphere is the layer of the atmosphere immediately around the earth's surface in which temperature normally falls with height. The fall must, in general, exceed 2° C. in any kilometre of height, but layers of lower lapse rate may occur in the lowest 2 Km. and at higher levels in the troposphere provided that the thickness of such a layer is less than 1 Km. and that the fall in the subsequent $\frac{1}{2}$ Km. is greater than 1° C.

Stratosphere. The stratosphere is the layer of the atmosphere above the troposphere in which temperature either increases or changes little with height. Any fall in temperature must not exceed 2° C. in any kilometre of height. There may be shallow layers of lapse rate greater than 2° C. in a kilometre of height within the stratosphere provided that the general criterion holds. Such a layer cannot occur at the boundary.

Tropopause. The tropopause is the boundary between stratosphere and troposphere and may be defined either as the top of the troposphere or as the base of the stratosphere. If the two coincide there is a single tropopause. If the top of the troposphere and base of the stratosphere determined from the above definitions do not coincide two tropopauses are reported.

In the subtropics where two tropopauses are frequently found, the upper appears to be a poleward extension of that over the tropics, and the lower appears to be an equatorward extension of that of middle latitudes. These two tropopauses are referred to as the tropical and polar tropopauses respectively.

The data used in the preparation of the charts are set out in Appendix I. They are broadly divided into three main classes :

Class A. Values taken directly from manuscript data of other meteorological services.

Class B. Average values computed from individual ascents using the definitions set out above.

Class C. Values obtained by estimation from average temperatures at standard pressure levels.

As with the charts of average temperature, the data were too scanty for any attempt to be made to adopt a uniform period.

Methods of computing.—In computing the averages for stations in Class B the method adopted was to evaluate the monthly mean values for individual years and to obtain the long-period averages by giving unit weight to each year provided that there were at least ten observations. When the number of observations in any month was less than ten the mean for that month was weighted in proportion, months with nine observations 0·9 and so on.

Data in Class C were used only when no data were available in Classes A or B. For these the pressure and temperature at the tropopause were assessed by a method given by Flohn[13]. In this method the average monthly temperature at the station was plotted against the logarithm of the pressure. Two straight lines, drawn to fit the curve one in the upper troposphere and the other in the lower stratosphere, were extended to intersect. Their intersection was taken as giving the average pressure and temperature at the tropopause. This method can of course only be used in regions where a single tropopause is normally reported and even there it is to some extent subjective. The values thus found will normally differ from those obtained by averaging the values for individual ascents (Class B) which may be regarded as the true values. In order to test the extent to which the two differ a comparison was made of data obtained by the two methods, with the following result.

In regions of polar tropopause it was found that in January and April the difference of pressure was not systematic. The values in general agreed to within about 15 mb. though occasionally the difference was 20 mb. In July and October, on the other hand, the tropopause pressure obtained from the mean curve was always larger than the true mean, the difference being of the order of 15–20 mb. except in the Arctic where it reached 50 mb. in July and 70 mb. in October. Temperature differences showed greater regularity and throughout the year the temperatures assessed from the mean curves (Class C) were some 2° or 3° C. higher than the true values.

In regions of tropical tropopause it was found that assessments of tropopause pressure from the mean curves usually gave a reasonable approximation to the true values, though at some places they appeared to be too high. Values of tropopause temperature obtained from the mean curves were about 3° C. higher than the true values.

In spite of these differences isopleths of pressure and temperature drawn from values obtained from mean curves showed for the most part the same general pattern as the true isopleths even though the actual values of the isopleths differed. This similarity proved of no small assistance in drawing isopleths over regions such as Russia where data were very sparse.

Method of drawing and the reliability of the charts.—The average values of pressure and temperature at the tropopause in the mid-season months are set out on Mercator charts of the world (Plates 33–40) with supplementary charts for the North Polar region (Plates 41–44) similar to those used for temperatures at pressure levels. Isopleths are drawn for intervals of 20 mb. of pressure for the polar tropopause, and 10 mb. for the tropical tropopause. Isopleths of temperature are drawn at intervals of 4° C. for both types of tropopause. Temperatures are given in both degrees Celsius and degrees Absolute. Isopleths for the polar tropopause are shown by broken lines of long dashes, those for the tropical tropopause by broken lines of short dashes, and lines consisting of alternate dashes and dots are used where isopleths for intermediate values of pressure and temperature are drawn.

On the original working charts values for all stations were plotted with an indication of the reliability of the data. In drawing the isopleths more reliance was placed on values in Classes A and B than on those in Class C, and account was taken of the length of period. The lines were smoothed where they appeared unduly tortuous.

In regions where few data for the polar tropopause were available certain general principles were borne in mind : first, that unless there was strong evidence to the contrary the isopleths should not diverge much from the mean wind flow of the middle troposphere, i.e. from the pressure contour lines, and secondly that in temperate latitudes there is a high positive correlation between the height of the tropopause and the temperature of the troposphere[14], and that pressure at the tropopause is therefore likely to be low over regions where the troposphere is relatively warm. In equatorial regions, where data were insufficient the isopleths were drawn largely by analogy with the temperature at 100 mb.

Over the greater part of the northern hemisphere the isopleths have been drawn with reasonable confidence in so far as their main features are concerned, except perhaps over Russia where data were very scanty. In the tropics although data were not numerous, the values at different stations showed good agreement and errors are not therefore likely to be large. The structure of the tropopause in equatorial regions, however, may not be as simple as has been envisaged in this work ; the investigations of Durandin[15] and Vuorela[16] seem to indicate a greater complexity. Over the southern hemisphere except in the region of Australasia, information was available for very few stations and little reliance can be placed on the lines.

The region with two tropopauses.—In the subtropical regions of both hemispheres, roughly between latitudes 30° and 45°, temperature soundings frequently show two tropopauses but on some occasions there may be a polar tropopause only and on others a tropical tropopause only. An attempt was therefore made to determine the frequency with which the different types occurred. In order that the results should not be biased by the loss of records at great heights the data used were as far as possible restricted to those which reached 80 mb., unless below that level an upper tropopause had already been reached or its probable existence had been indicated by the presence of a tropospheric lapse rate above the lower tropopause. The percentage frequencies of the different types of tropopause are shown in Table III.

As can be seen from the table, in any month, as the latitude increases, the polar tropopause occurs more and more frequently until at a certain latitude it is always present, whereas the tropical tropopause occurs less and less frequently until finally it does not occur at all ; similarly, as the latitude decreases the tropical tropopause becomes more and more frequent until, equatorward of a certain latitude, it is always present whereas the polar tropopause becomes less and less frequent and finally ceases to appear at all.

In order to give an indication of the poleward limit of the tropical tropopause and equatorward limit of the polar tropopause, areas on the charts are hatched where the frequency of both types is greater than 10 per cent. These limits are largely conjectural especially in the southern hemisphere. A study of the hatched areas indicates that the boundary of the tropical tropopause lies a little farther poleward in summer than in winter, reaching farthest north in July in the northern hemisphere and farthest south in January in the southern ; and that the boundary of

TABLE III—PERCENTAGE FREQUENCY OF OCCURRENCE OF POLAR AND TROPICAL TROPOPAUSES AND OF TWO TROPOPAUSES IN THE SUBTROPICS

Station and Period	Position	JANUARY Occurrence of tropopauses Polar	Tropical	Two	APRIL Occurrence of tropopauses Polar	Tropical	Two	JULY Occurrence of tropopauses Polar	Tropical	Two	OCTOBER Occurrence of tropopauses Polar	Tropical	Two
			per cent.			*per cent.*			*per cent.*			*per cent.*	
Wakkanai .. 1950–52	45° N. 142° E.	100	11	11	99	22	21	73	81	54	91	56	47
			(119 ascents)			(136 ascents)			(151 ascents)			(158 ascents)	
Ship X 1950–52	39° N. 153° E.	97	74	72	88	64	52	18	95	12	19	98	17
			(78 ascents)			(97 ascents)			(145 ascents)			(129 ascents)	
Shionomisaki .. 1950–52	33° N. 136° E.	43	96	38	83	89	72	4	100	4	2	100	2
			(136 ascents)			(119 ascents)			(144 ascents)			(161 ascents)	
Ship T .. .. July 1950–Oct. 1952	29° N. 135° E.	11	100	11	37	100	37	0	100	0	0	100	0
			(72 ascents)			(101 ascents)			(146 ascents)			(159 ascents)	
Gibraltar .. 1950–51	36° N. 5° W.	97	51	48	98	45	43	35	80	15	63	62	25
			(69 ascents)			(58 ascents)			(72 ascents)			(79 ascents)	
Malta 1950–51	36° N. 14° E.	96	93	89	98	92	89	10	100	10	82	88	70
			(99 ascents)			(83 ascents)			(113 ascents)			(73 ascents)	
Nicosia 1950–51	35° N. 33° E.	95	96	91	100	95	95	2	100	2	67	75	42
			(105 ascents)			(103 ascents)			(111 ascents)			(109 ascents)	
Habbaniya .. 1950–51	33° N. 44° E.	72	100	72	97	97	94	0	100	0	48	98	46
			(110 ascents)			(108 ascents)			(123 ascents)			(112 ascents)	
Benina 1950–51	32° N. 20° E.	57	98	54	78	75	54	0	100	0	19	93	12
			(123 ascents)			(106 ascents)			(96 ascents)			(115 ascents)	
Bahrain 1950–51	26° N. 51° E.	21	100	21	41	100	41	0	100	0	0	100	0
			(97 ascents)			(102 ascents)			(119 ascents)			(116 ascents)	

the polar tropopause extends farther towards the equator in winter than in summer but reaches its lowest latitude in April in the northern hemisphere and in October in the southern.

At most stations in the zone of two tropopauses the polar tropopause is most frequent in spring and least frequent in summer, e.g. at Benina where it occurs on 78 per cent. of occasions in April but vanishes entirely in July. The tropical tropopause is most frequent in summer and generally least frequent in spring, e.g. at Gibraltar where it occurs on 80 per cent. of occasions in July compared with 45 per cent. in April.

In the transition regions from two tropopauses to a single tropopause the isopleths of temperature and pressure of the less frequent tropopause should be treated with reserve because of the relatively few occasions on which the tropopause exists.

The intersections of the average tropopause pressure surfaces with the isobaric surfaces are shown on the average-temperature charts for 300, 200 and 100 mb. by thick pecked lines. At the 150-mb. level, which makes no intersection with either of the average tropopause surfaces, the hatched areas shown on the tropopause charts denoting regions of two tropopauses are reproduced. Poleward of these areas the temperature régimes are predominantly stratospheric, while equatorward they are mainly tropospheric.

Annual variation of average monthly pressure and temperature of the tropopause.—The annual variation of temperature and pressure at the tropopause is illustrated in Fig. 1. Unfortunately monthly averages are available only for very few stations and those reproduced are by no means representative of all areas.

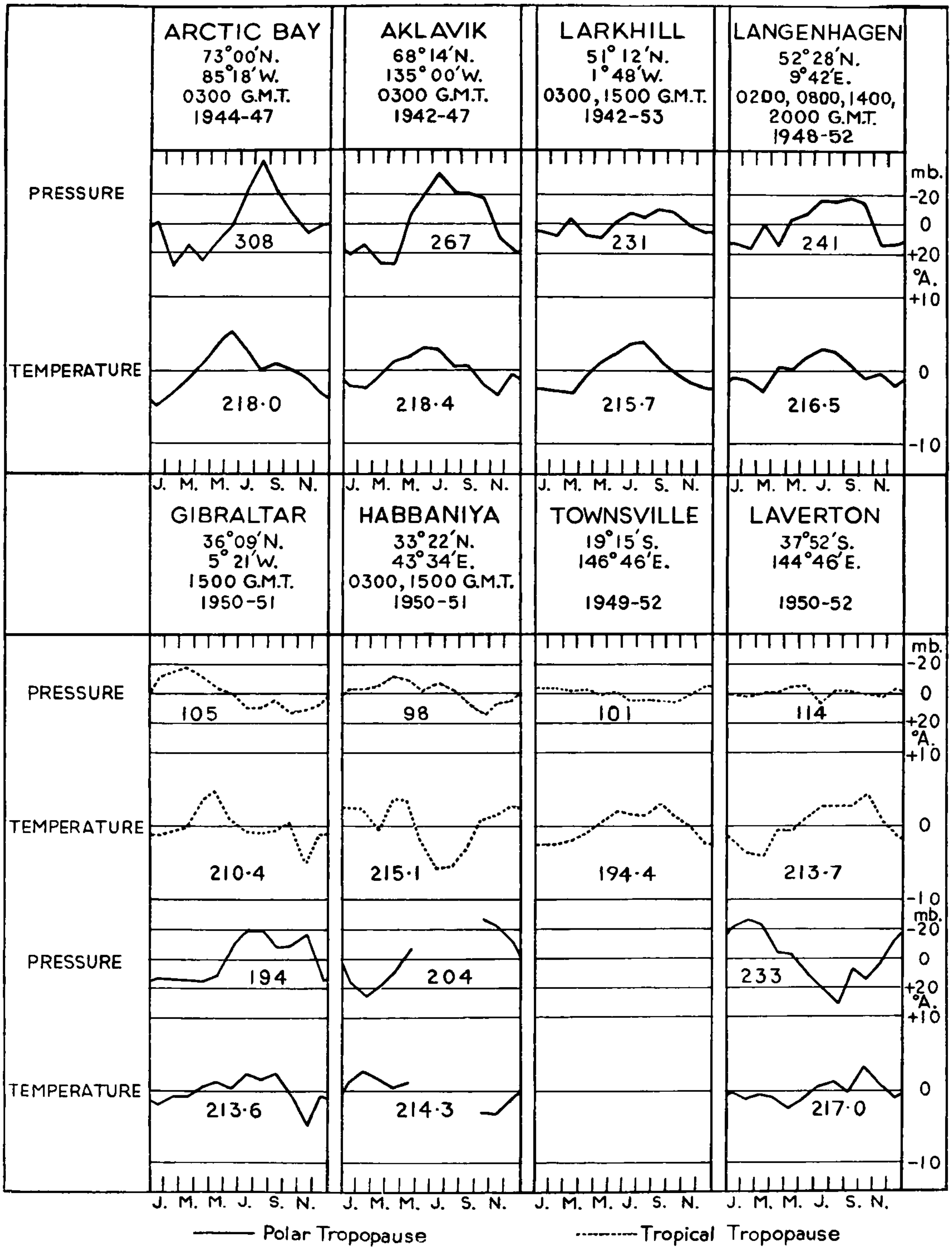


FIG. 1—ANNUAL VARIATION OF AVERAGE MONTHLY PRESSURE AND TEMPERATURE AT THE TROPOPAUSE
The annual mean pressure (mb.) and temperature (° A.) are entered beneath each curve.

For each station curves are given for both pressure and temperature and the monthly averages are plotted as departures from the annual averages ; these are shown in millibars and degrees Absolute in figures below the curves. For pressure, positive departures are plotted below the base line and negative departures above it ; this was done in order that an increase in the height of the tropopause might be shown by a rise in the curve. For each station the position, together with the period and the hours of observation on which the curves are based, are entered at the top of the diagram.

At stations where two tropopauses are normally observed diagrams are drawn for the two separately ; those for the upper or tropical tropopause in a dotted line and those for the lower or polar tropopause in a full line. At Habbaniya where the polar tropopause is not observed during the summer the annual average was computed for the eight months when the polar tropopause did occur.

No attempt has been made to smooth the curves ; and they are in general very irregular. This is partly due to the shortness of the periods and partly to uncertainties in the original assessments. The most notable feature is that in both northern and southern hemispheres the pressure at the polar tropopause shows a fairly well marked variation with a single maximum and a single minimum ; they are not, however, evenly spaced and the pressure appears to be highest in spring (April in the northern hemisphere) and then to fall rapidly to its lowest value in summer. The range is of the order of 50 mb. and is probably greater over large land masses. The range of pressure of the tropical tropopause is smaller, about 15 or 20 mb., and the pressure appears to be lower in winter than in summer ; but this is not true at places which normally have two tropopauses.

§ 3—VARIATION OF AVERAGE TEMPERATURE IN TIME AND SPACE

Annual variation of average monthly temperature at standard pressure levels.—The charts of the distribution of average upper air temperature, Plates 1–32, are for the four mid-season months only. In order to indicate the way in which the transition from one season to another takes place information about the variation of average monthly temperature through the year in different climatic regions is given in Figs. 2–8.

The annual variation, in monthly steps, is shown for each of the six standard pressure levels for a selection of stations, the six graphs for any one station being set out in a vertical column with the highest level at the top. Each graph is drawn with reference to its own average annual value as base ; the appropriate average value in degrees Absolute being entered below each curve. The graphs thus show the departures of the monthly averages from their annual average.

The name of the station, its latitude and longitude, together with the period of the record and the hours of observation are entered at the head of each column. For each station the best data easily available have been used and no attempt has been made to adopt the same period at all stations. In order to avoid errors due to the sun's radiation on the radio-sonde instrument at high levels, the data have been restricted where possible to ascents during the hours of darkness but at many stations such data were not available and at some the hours of observation were not known.

The stations were chosen primarily as being representative of different climatic regions but account was taken also of the reliability of the data. In regions where observations were sparse, or limited to low levels, incomplete diagrams have been drawn to avoid leaving the region entirely unrepresented. Uncertainty or lack of observations is indicated by a broken line.

The diagrams are grouped roughly according to geographical and climatic regions : polar regions north of the Arctic circle, Greenland and northern Europe, North America (25°–60° N.),

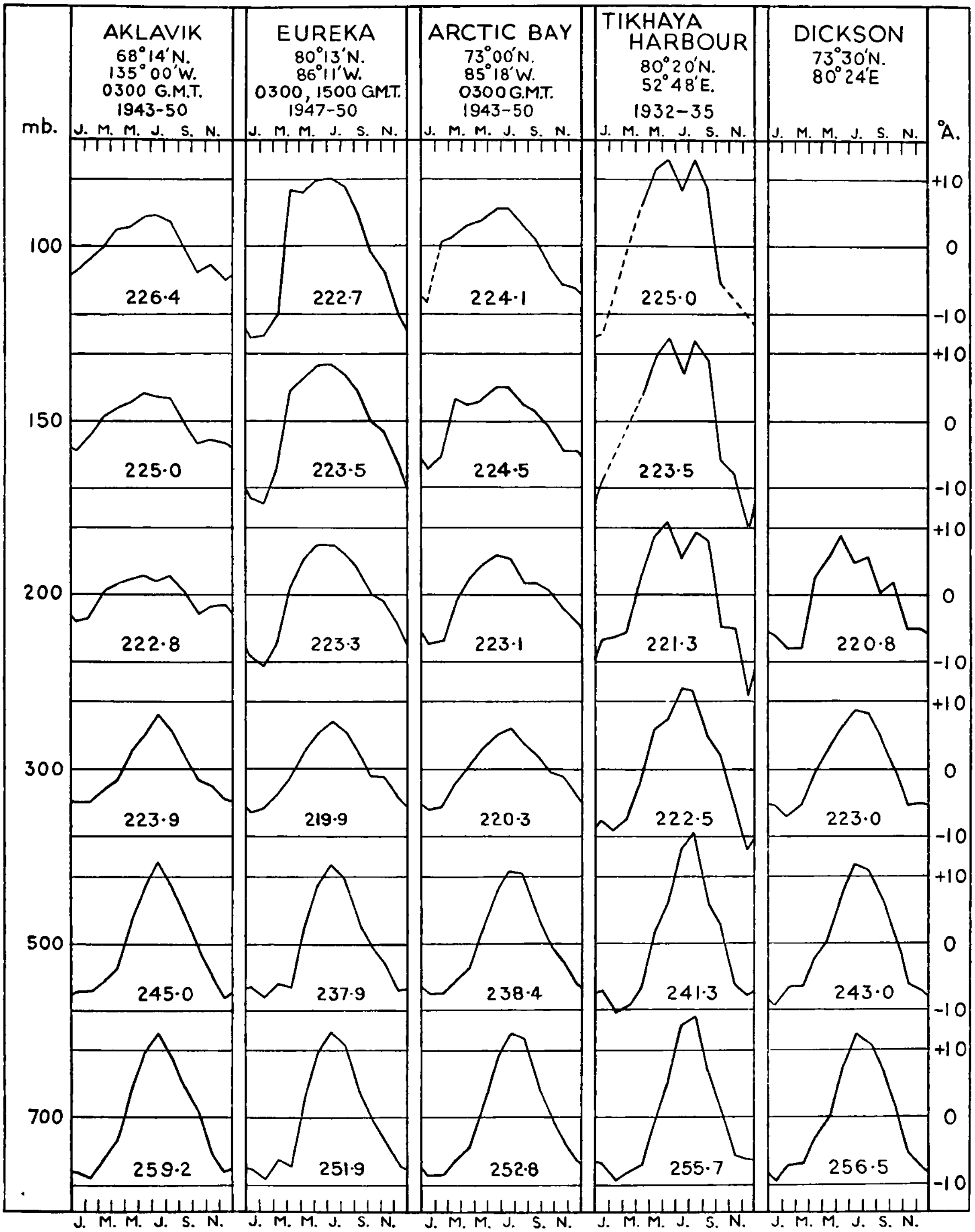


FIG. 2—ANNUAL VARIATION OF AVERAGE MONTHLY TEMPERATURE OVER ARCTIC REGIONS

The annual mean temperature (° A.) is entered beneath each curve.

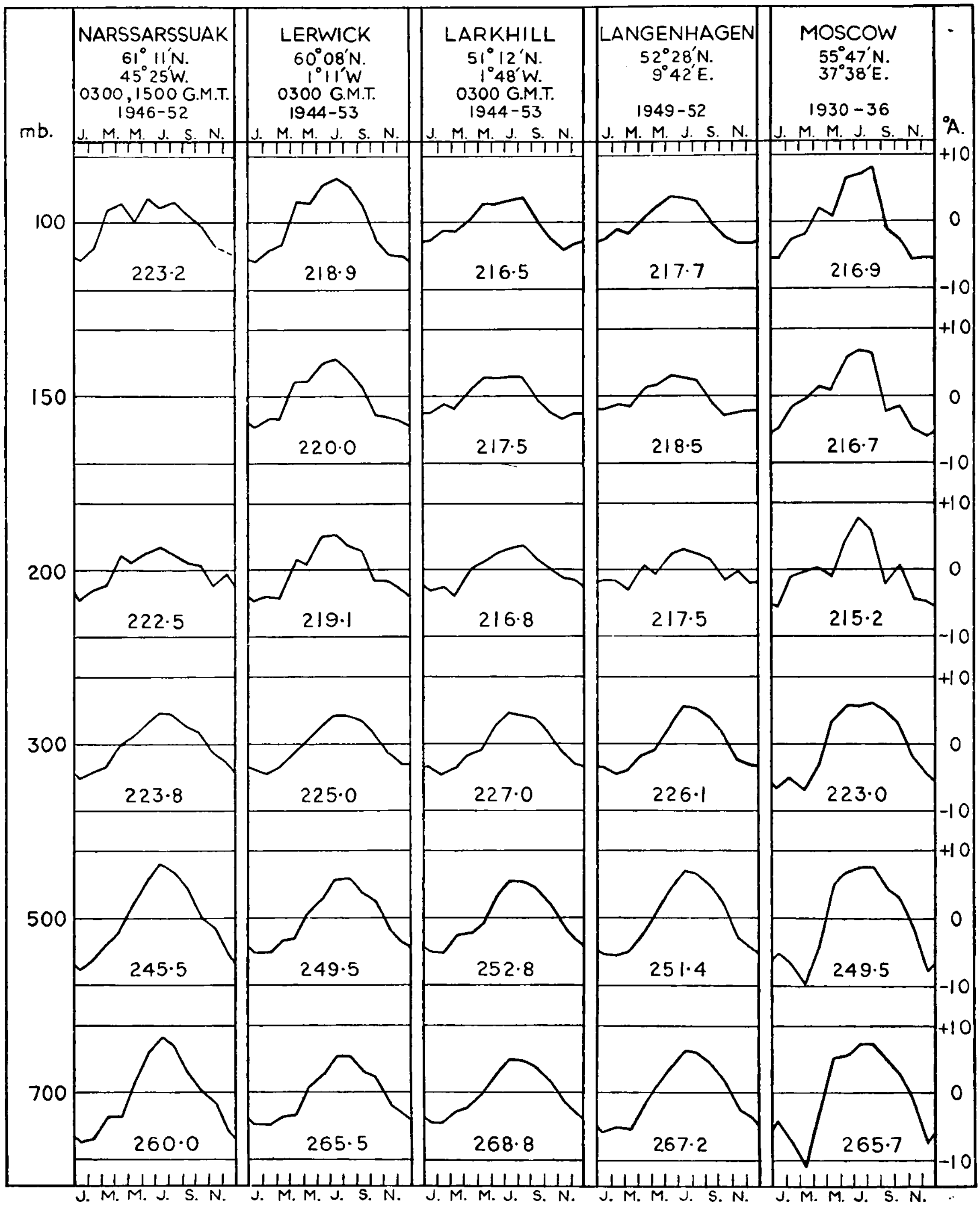


FIG. 3—ANNUAL VARIATION OF AVERAGE MONTHLY TEMPERATURE OVER GREENLAND AND NORTH EUROPE

The annual mean temperature (° A.) is entered beneath each curve.

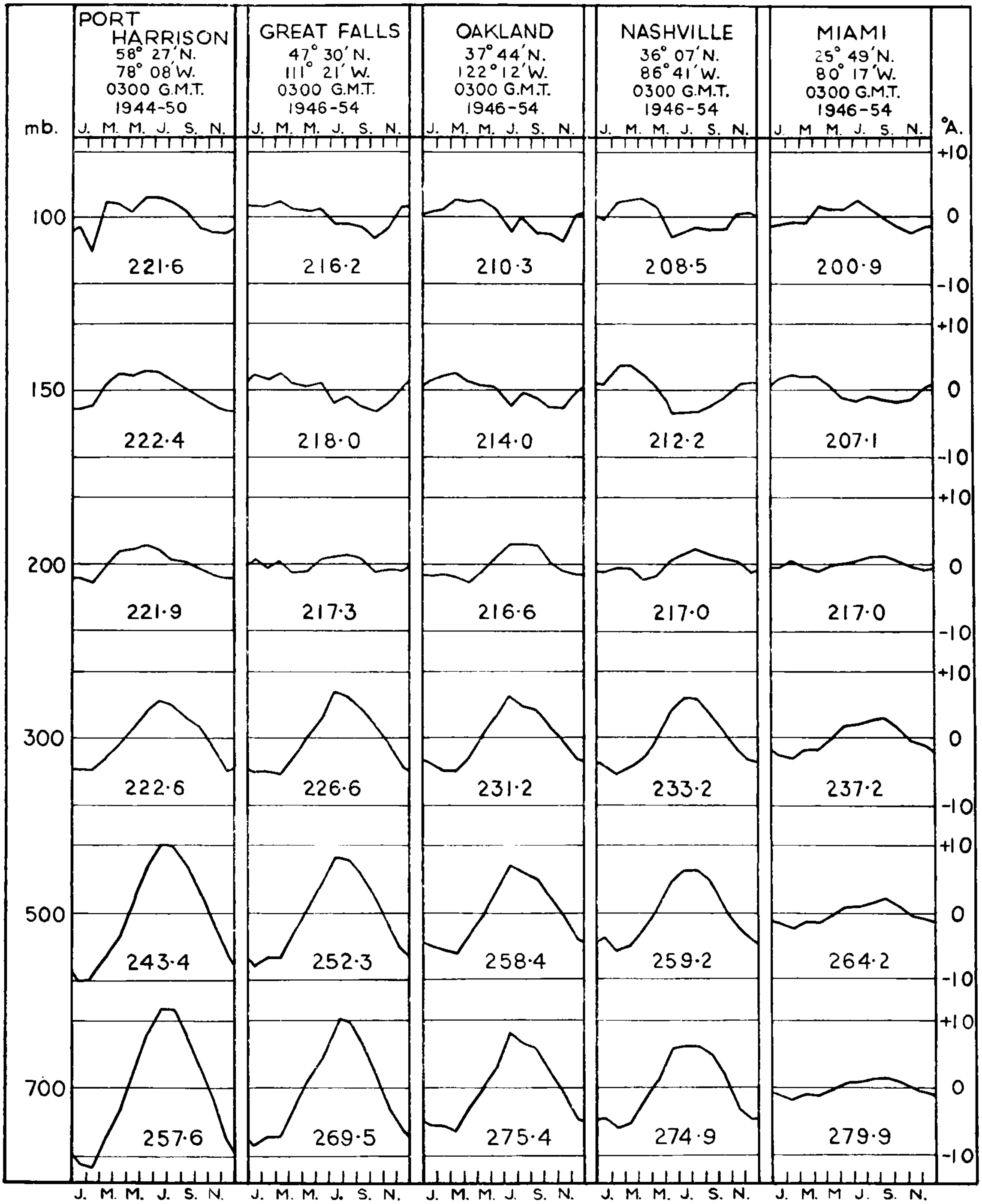


FIG. 4—ANNUAL VARIATION OF AVERAGE MONTHLY TEMPERATURE OVER NORTH AMERICA

The annual mean temperature (° A.) is entered beneath each curve.

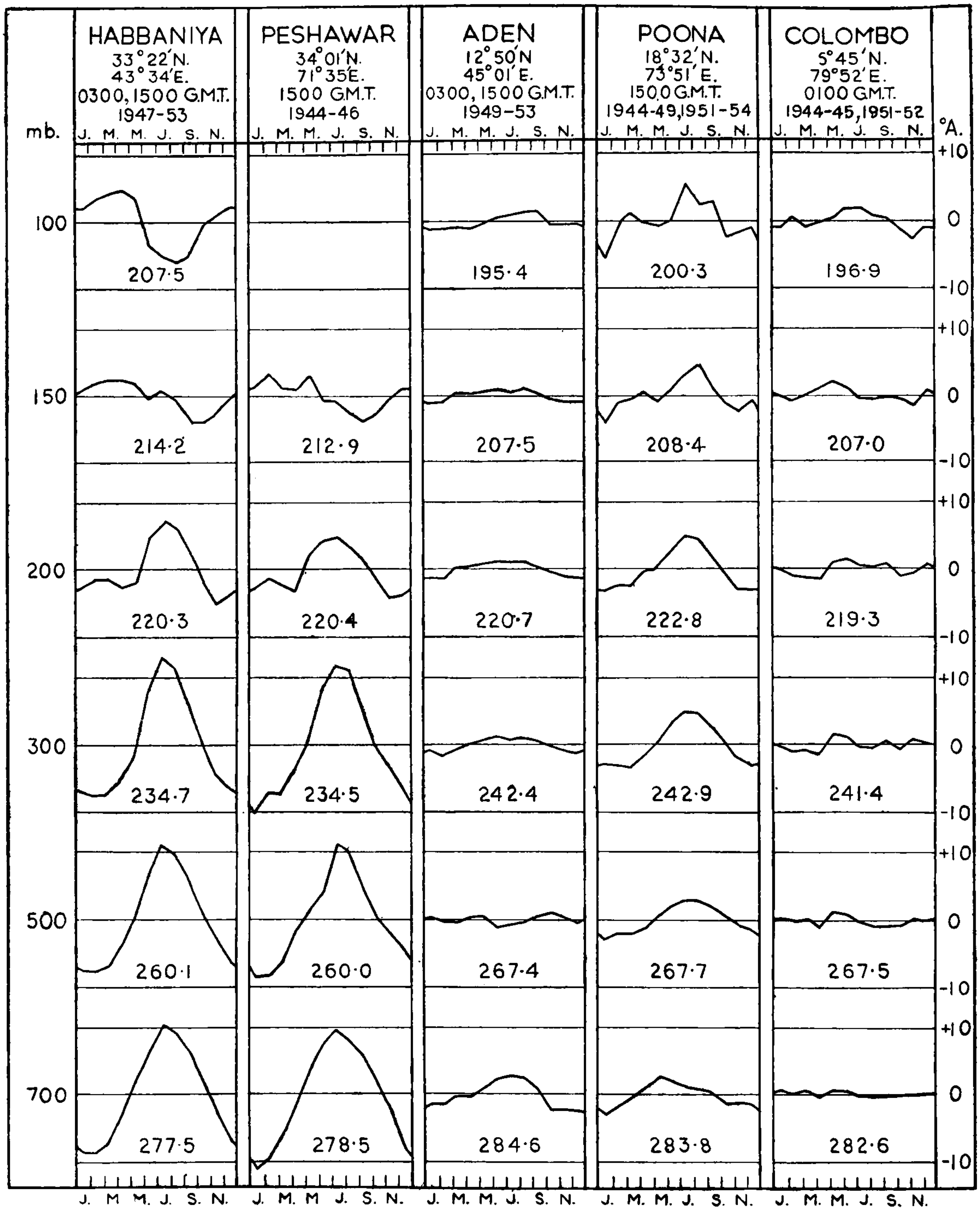


FIG. 5—ANNUAL VARIATION OF AVERAGE MONTHLY TEMPERATURE OVER THE MIDDLE EAST AND INDIA

The annual mean temperature (° A.) is entered beneath each curve.

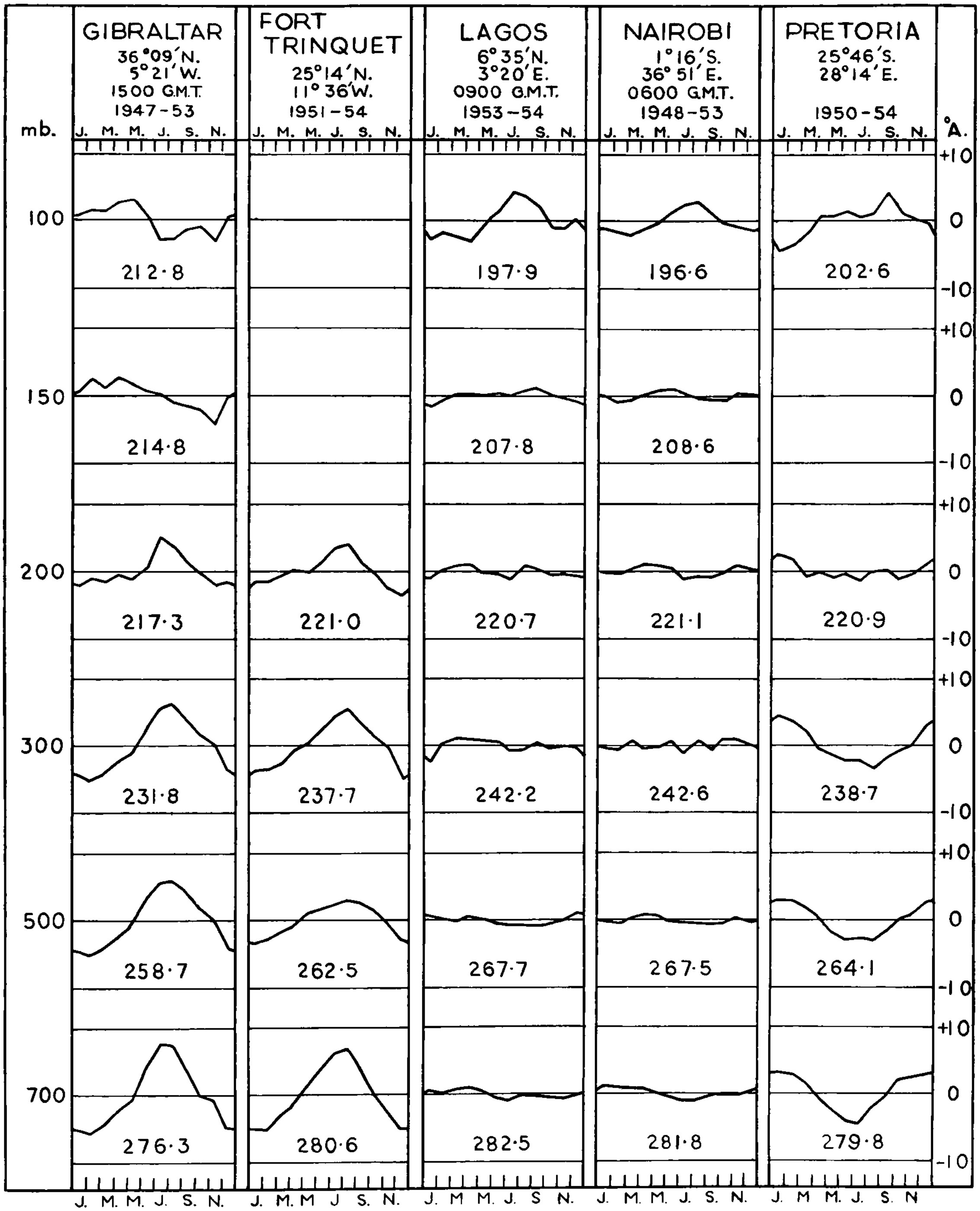


FIG. 6—ANNUAL VARIATION OF AVERAGE MONTHLY TEMPERATURE OVER AFRICA AND GIBRALTAR

The annual mean temperature (° A.) is entered beneath each curve.

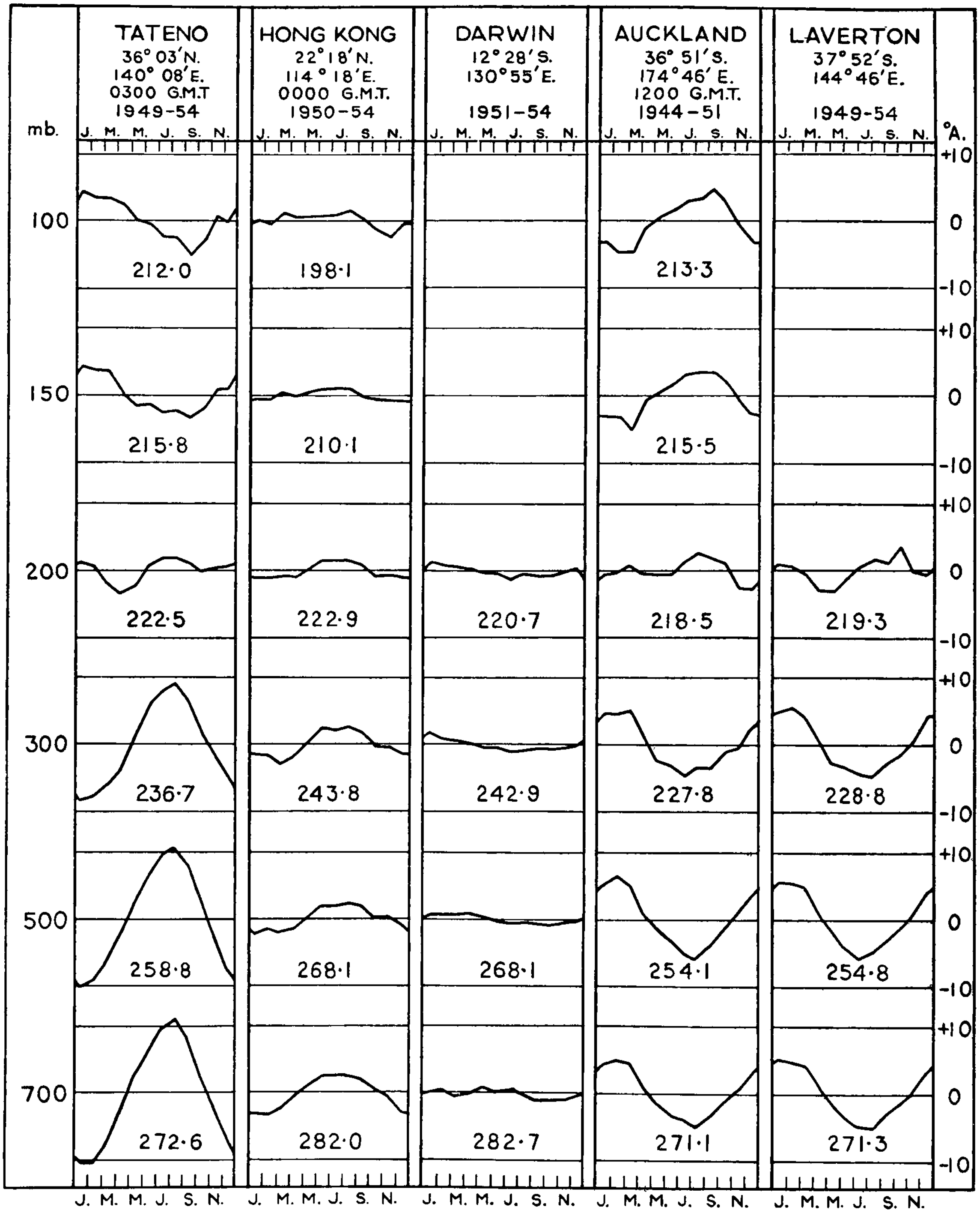


FIG. 7—ANNUAL VARIATION OF AVERAGE MONTHLY TEMPERATURE OVER THE FAR EAST AND AUSTRALIA

The annual mean temperature (° A.) is entered beneath each curve.

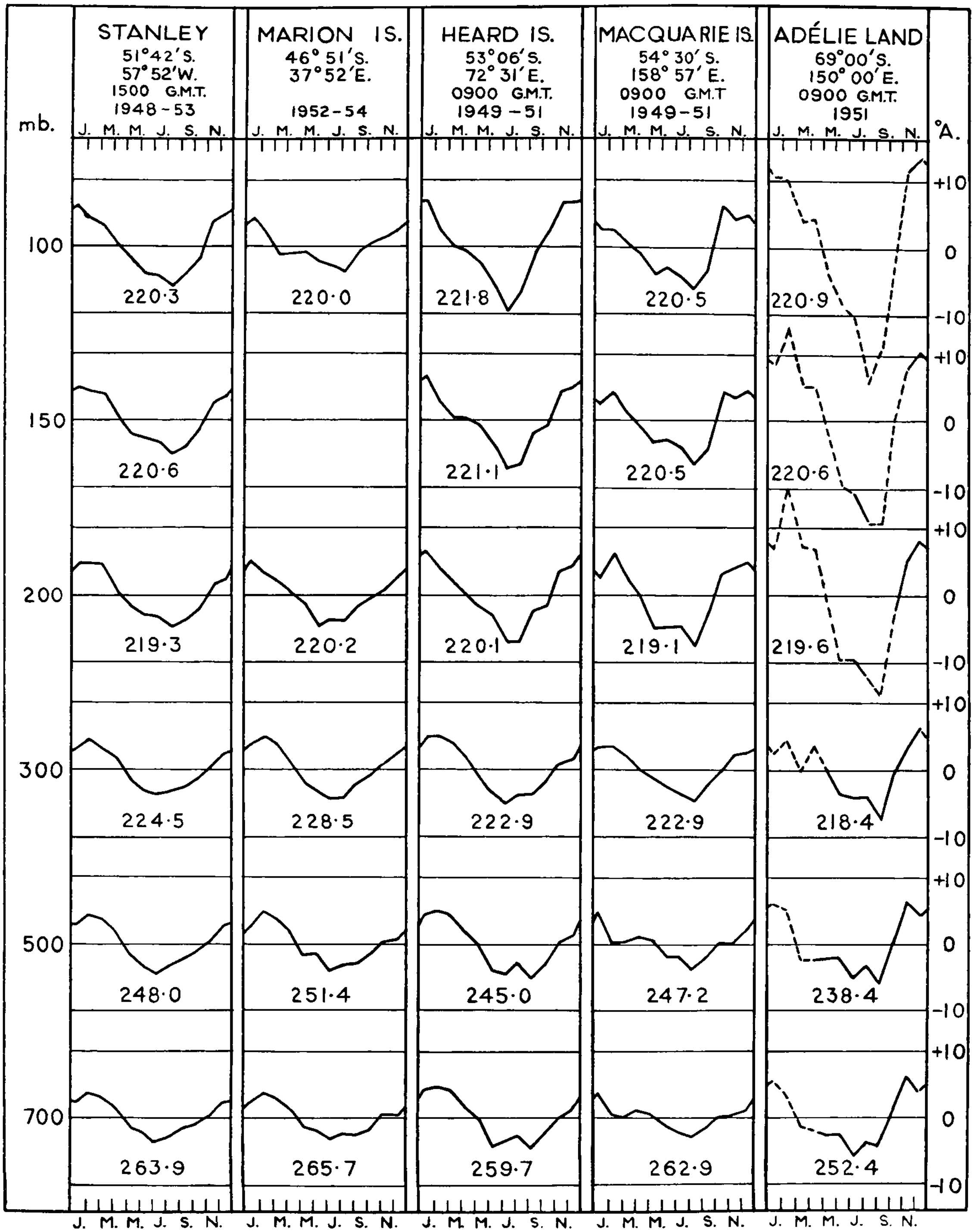


FIG. 8—ANNUAL VARIATION OF AVERAGE MONTHLY TEMPERATURE OVER THE SOUTHERN OCEAN AND THE ANTARCTIC

The annual mean temperature (° A.) is entered beneath each curve.

the Middle East and India, Africa and Gibraltar, the Far East and Australasia, and the Southern Ocean and the Antarctic.

It is not the purpose of this Memoir to discuss the physical implications of the results set out in the diagrams, and only a brief reference to the main features is given here.

The curves for the troposphere are mostly of simple shape ; except in intertropical regions, they show a single maximum in summer and a single minimum in winter. The most conspicuous difference between stations is in the annual range, which is greatest, about 25° C., in polar regions and least, only 3° or 4° C. or even less, in low latitudes. In general, the range decreases with height in the troposphere ; latitude for latitude it tends to be larger over the land masses than over the sea.

In the stratosphere the variation is more complicated. In high latitudes there is a single maximum in summer and a single minimum in winter as in the troposphere ; in both arctic and antarctic regions the range appears, on the whole, to be slightly greater than in the troposphere and to increase with height ; but to what extent this is due to instrumental defects is not yet known. In middle latitudes, equatorwards of about 50° the stratospheric curves show a striking change of phase compared with those of the troposphere, the highest values occurring in spring and the lowest in late summer and autumn. In contrast with conditions in polar regions the range is, in general, much less than in the troposphere. This change in the character of the curves is found in regions where two tropopauses are recorded in some seasons (see p. 11) the minimum in summer being most conspicuous where only a single high-level tropopause is recorded in that season, e.g. Nashville (Fig. 4), Habbaniya (Fig. 5) and Tateno (Fig. 7).

The most notable features of the several diagrams are briefly set out below :

Arctic regions (Fig. 2).—The rise of temperature from winter to summer is very rapid and appears to take place earlier (February–April) in the stratosphere than in the troposphere (April–June). This is shown most clearly at Eureka but is evident also at other stations ; the change in shape of the curves from low to high levels is very striking. At low levels, winter and early spring show almost uniform temperature whereas at high levels uniformity is more conspicuous in summer.

Greenland and northern Europe (Fig. 3).—At the more northerly stations the features characteristic of the Arctic are evident, but are less conspicuous. Other features of interest are the occurrence of the minimum at high levels in late autumn rather than in winter, shown at Larkhill, Langenhagen and Moscow (also at Gibraltar, Fig. 6), and the increased range in the troposphere at stations far from the coast.

North America (Fig. 4).—The chief points of interest are : in the troposphere, the decrease of range with decreasing latitude, particularly in the lower levels ; in the stratosphere, the smaller range than in the troposphere and the reversal of phase of the time of occurrence of the maximum in latitudes south of 50° N. to which reference has already been made.

The subtropics of both hemispheres and the equatorial regions (Figs. 5–7).—The reversal of phase between troposphere and stratosphere is shown clearly in many of the diagrams, notably those for Habbaniya (33° N.), Tateno (36° N.) and Auckland (37° S.). The rapid fall of temperature at 100 mb. over Habbaniya between May and June is associated with the almost complete disappearance of the polar tropopause from that time and throughout the summer months ; the rise of temperature between September and October coincides with the re-appearance of the polar tropopause in October (see Fig. 5).

Uniformity of temperature throughout the year at stations within 15° of the equator is evident at most levels, particularly in the troposphere ; the well defined variation at 100 mb. shown at both Lagos and Nairobi is however a notable exception that is not without interest.

The southern ocean and the Antarctic (Fig. 8).—The diagrams for the four island stations show uniformity of range at all levels in the troposphere in contrast with the decrease shown at most stations in the northern hemisphere where the effect of the larger land masses is felt. In the stratosphere the range is appreciably greater.

The curves for Adélie Land show the sharp rise of temperature at the end of winter and the change in the shape of the curves with height, already described for the Arctic, though, owing to the shorter period, the diagrams are less reliable than those in the north.

Variation of average temperature with height.—In order that average upper air temperature may be interpolated for any pressure level not represented by the charts, some knowledge of the variation of temperature with height, particularly in the neighbourhood of the tropopause, is needed.

In the troposphere in almost all regions, the average temperature decreases steadily upwards from the earth's surface or about one or two kilometres above it to a little below the average position of the tropopause (the lower tropopause where there are two). The rate of decrease of temperature with height is called the lapse rate. The average lapse rate varies with place and season, but its variation with height is usually insignificant. Now height is approximately proportional to the logarithm of the pressure. If therefore the average temperatures at various pressure levels within the troposphere are plotted against the logarithms of the pressure the resulting graph will be very nearly a straight line, except for the levels near the surface and the tropopause. The values of average temperature read off from this graph at intermediate pressures are not likely to be much in error. Exceptions occur in the lowest levels, particularly over the continents in winter where surface inversions are often deep and persistent (see p. 30). Also, in the regions of the trade winds an inversion may be a characteristic feature of the average-temperature curve between about 850 and 700 mb.

Near and above the tropopause, interpolation is more difficult because the curves of average temperature differ widely in shape. An attempt was made to discover whether definite types occur in certain regions and seasons. Curves of average temperature were examined for the four mid-season months from radio-sonde data covering periods of from two to ten years at 70 stations ; in all, 278 curves. Of the 70 stations, 62 were on or near the North American continent in latitudes 80° N. to 17° N. ; and the remaining eight were distributed between the British Isles, the Mediterranean and Middle East, Arabia and East Africa. At most of the stations, averages were available for a sufficient number of levels to allow details to be seen on the curves. The curves given by Ratner[17] for the United States and Alaska are based upon averages at geometric heights. The other curves, drawn (or redrawn) specially for this investigation, were based upon averages at pressure levels ; except that at the Canadian stations[18, 19] data for the pressure levels had been based partially upon curves of monthly mean temperatures at geometric heights.

Figs. 9–12 show, for January, April, July and October, different types of variation of average temperature with height for a selection of stations covering as wide a range of latitude as possible having regard to the data available. Each of the four diagrams consists of graphs for the same five stations, in latitudes 80° N., 64° N., 51° N., 35° N. and 13° N. The diagrams serve also to illustrate the latitudinal range of average temperature at various pressure levels. This is seen to be least at about 200 mb.

The general survey of the 278 curves showed that a specified belt of latitude or type of region is not necessarily represented by only one form of curve, although definite types are characteristic of polar and of tropical and subtropical regions. The commonest type of curve occurs in a wide range of latitudes—from about 40° N. to 80° N. This type is characterized by an inversion at the base of the stratosphere, with the stratosphere above either isothermal or showing only slight increase in temperature with height. This " general " type is illustrated

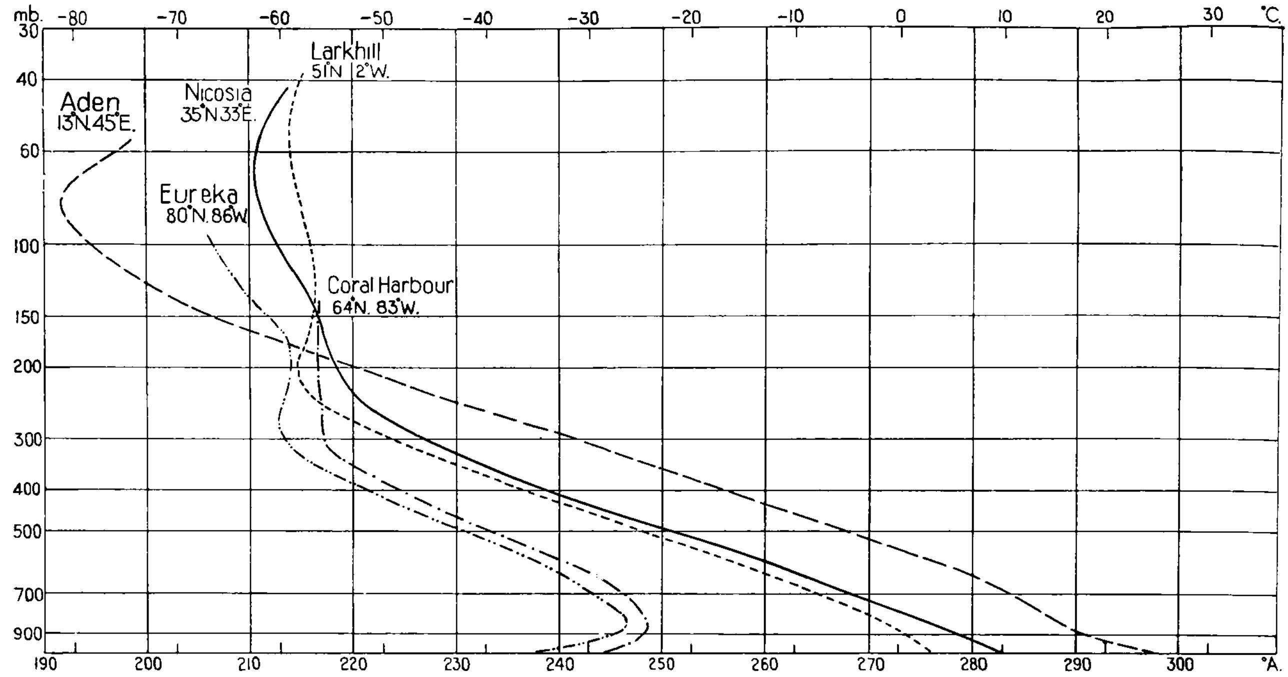


FIG. 9—VARIATION OF AVERAGE TEMPERATURE WITH HEIGHT IN DIFFERENT LATITUDES IN JANUARY

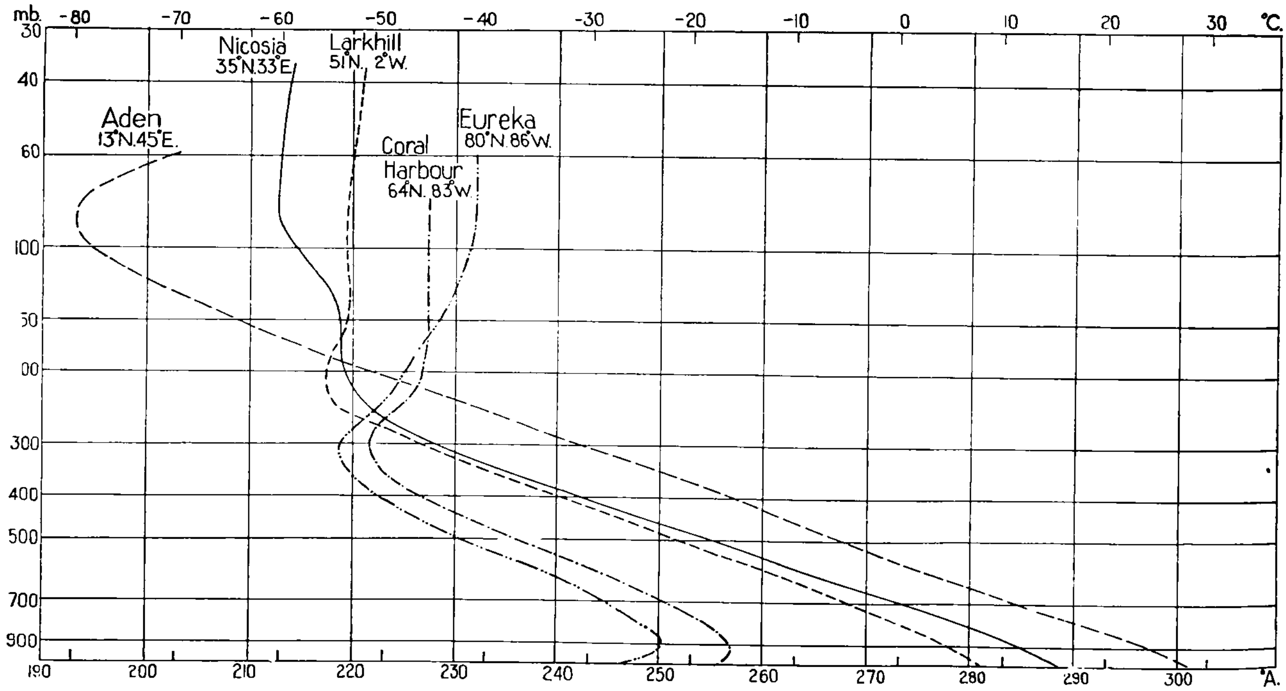


FIG. 10—VARIATION OF AVERAGE TEMPERATURE WITH HEIGHT IN DIFFERENT LATITUDES IN APRIL

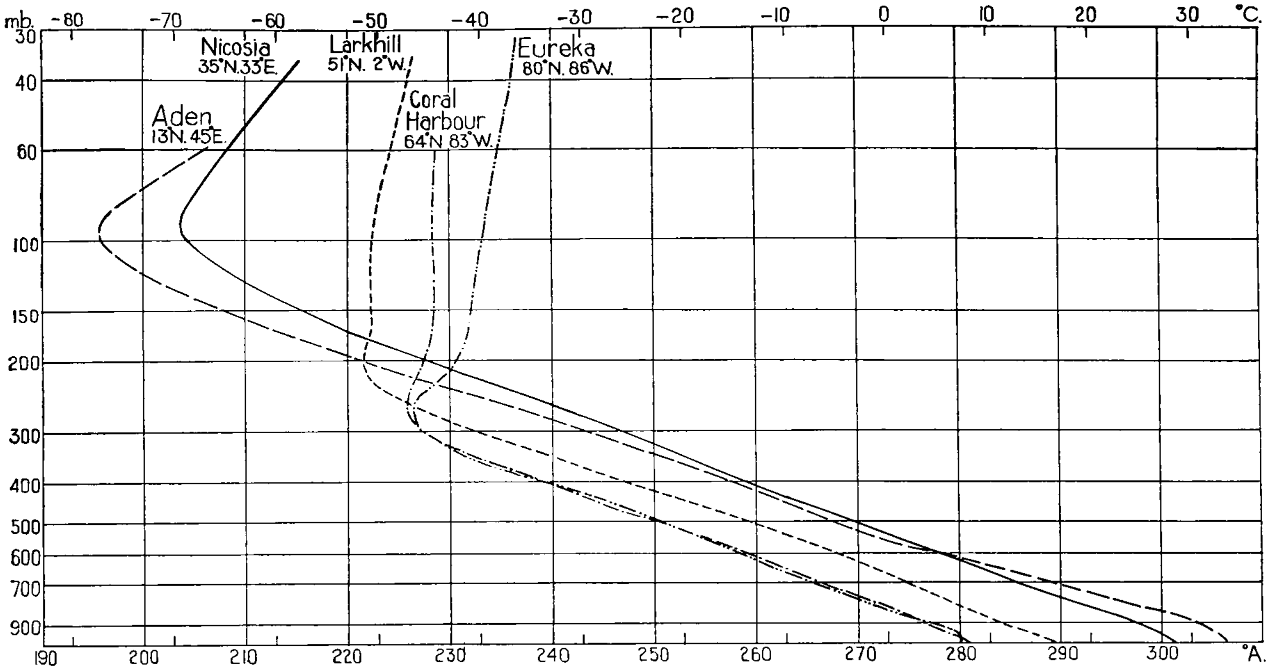


FIG. 11—VARIATION OF AVERAGE TEMPERATURE WITH HEIGHT IN DIFFERENT LATITUDES IN JULY

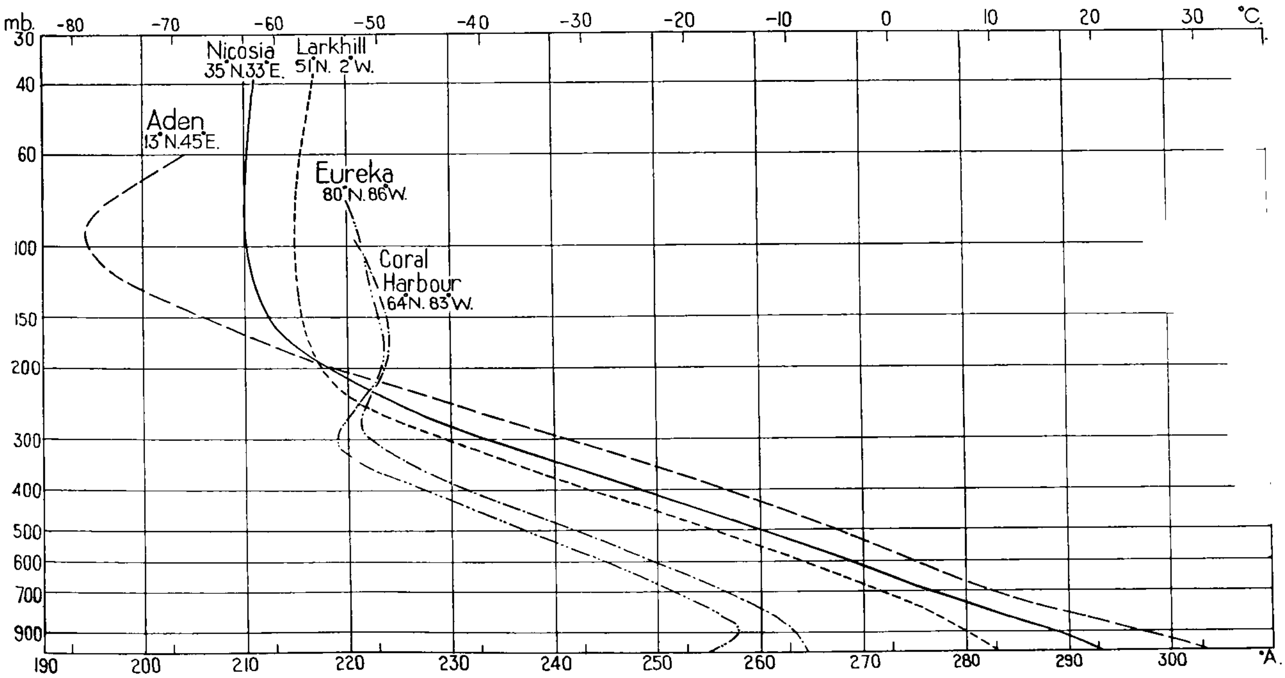


FIG. 12—VARIATION OF AVERAGE TEMPERATURE WITH HEIGHT IN DIFFERENT LATITUDES IN OCTOBER

by the April curve for Coral Harbour (64° N.) (Fig. 10) and, less definitely, by that for Larkhill (51° N.) (Fig. 10) ; also by the January curve for Larkhill (Fig. 9) and possibly by the July curve for Coral Harbour (Fig. 11). The temperature minimum associated with the tropopause occurs at a level which in general is slightly above (i.e. at a lower pressure than) that given by the average tropopause pressure. This level varies with latitude and season (see § 2).

A modified form of the general type of curve occurs in latitudes 30°–65° N. In this type also the stratosphere is mostly isothermal but without the inversion at the base which characterized the first type. Examples of the second type are the curves for January at Coral Harbour (Fig. 9), for July at Larkhill (Fig. 11) and for October at Larkhill and Nicosia (35° N.) (Fig. 12). In subtropical latitudes, this form arises probably somewhat artificially as a result of averaging a set of individual curves consisting of tropical and subtropical types.

A definite type of average curve appears where polar and tropical tropopauses occur with comparable frequencies in the same season. This may be called the subtropical type. It is illustrated by the January and April curves for Nicosia (Figs. 9 and 10) ; the latter especially shows the type clearly. On this curve there are two levels near which the lapse rate of temperature becomes zero. They are slightly above the levels determined by averaging the pressures of the polar tropopause and the tropical tropopause respectively. The portion of the curve associated with the tropical tropopause occurs at an appreciably lower average temperature than the portion associated with the polar tropopause.

The " tropical " type of curve is even more definite. It is shown by Koteswaram[20], and it is illustrated in this Memoir by the average curves for Aden (13° N.) (Figs. 9–12). The striking features are the fairly steady tropospheric lapse, the high level of the tropopause and the sharp temperature minimum associated with it. Aden appears to be typical of stations within the tropics ; there is no appreciable seasonal variation in the troposphere, but the tropopause and the minimum of the average curve tend to occur at a higher level in January and April than in July and October. The July curve for Nicosia (Fig. 11) also is " tropical " in type ; but the minimum is less sharp, the tropospheric lapse of temperature being smaller.

Curves characteristic of very high latitudes can be grouped into two types, " polar winter " and " polar summer ". In both there is an inversion at the base of the stratosphere, as in the first " general " type of curve described above ; at higher levels, temperature decreases again on the " polar winter " curve, but continues to increase on the " polar summer " curve.

The stratospheric lapse of temperature in winter in high latitudes may be considerable ; the January curves for Resolute (75° N.) (not reproduced) and Eureka (80° N.) (Fig. 9) show a decrease of 7° C. between 200 and 100 mb. The October average curve for Eureka (Fig. 12) is similar, but the decrease of temperature in the lower stratosphere is appreciably smaller. This less pronounced form of the " polar winter " type occurs in October north of 60° N. (at five out of the nine stations examined) and in January and April in somewhat lower latitudes. The more pronounced form appears to occur only in winter and at stations poleward of the Arctic (or the Antarctic) Circle. An average July curve for Maudheim (71° S.), based upon two years' data[21], is very similar to the January curve for Eureka but shows higher temperatures near the surface (about 8° C. warmer than Eureka at 1,000 to 850 mb.) and a stratosphere some 12° C. colder than over Eureka.

The " polar summer " type of average curve is illustrated by Eureka in July (Fig. 11). Eureka in April (Fig. 10) is similar but has the low tropopause and well marked ground inversion which are to be seen in the January curve for Eureka. A January (i.e. summer) curve for Maudheim, based on little more than a year's data[21], falls between the Eureka curves for July and April.

Among the detailed curves examined, occurrences of the " polar summer " and pronounced " polar winter " types were few in number ; yet it is believed that they may be typical of the upper air over the polar regions. This belief received some confirmation from the fact that other, less complete, arctic data showed similar characteristics ; and it is in accord with the view now generally accepted that, at a height of 25–30 Km., temperature is very low over the winter pole and increases continuously to the summer pole[22]. Wind observations over the British Isles at very high levels, westerly in winter and easterly in summer, support this view[23].

The types of curves of average temperature, in the order described above, are listed in Table IV with appropriate symbols for ease of reference. Koteswaram's " polar " type[20] is equivalent to G2. The distinguishing characteristics of the general types, G1 and G2, of middle latitudes

TABLE IV—TYPES OF CURVES OF AVERAGE TEMPERATURE

Symbol	Description	Number examined
G1	General type with inversion at the base of the stratosphere ..	89
G2	General type without inversion at the base of the stratosphere	88
St	Subtropical..	35
T	Tropical	41
Pw	Polar winter	17
Ps	Polar summer	8
	Total	278

are less definite than those of the specific types, St, T, Pw and Ps, of lower and higher latitudes. The reason is that the curves for individual years differ considerably among themselves especially as regards the tropopause pressure and the temperature in the stratosphere ; their characteristic shapes therefore become blurred in the process of averaging. To illustrate this point, curves are given in Fig. 13 for Larkhill (51° N.) and Lerwick (60° N.) in January in each of the four years 1942–45. Although the curves are very similar in the troposphere, there are well marked differences in shape near the tropopause ; at Lerwick for example, there is an inversion in 1942, but the fall of temperature continues to high levels in 1945. On the other hand the defining characteristics of the tropical and subtropical curves are better preserved in the process of averaging because there is far less variation among the individual curves.

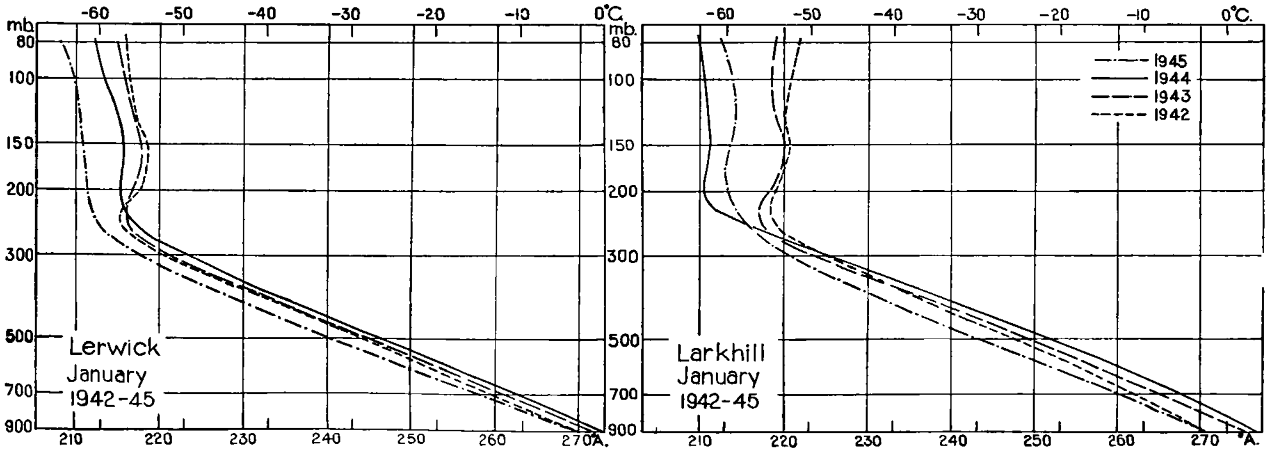


FIG. 13—VARIATION OF MEAN TEMPERATURE WITH HEIGHT IN DIFFERENT YEARS AT LERWICK AND LARKHILL

Some quantitative account of the distribution in latitude and season of the six types of average curve may be of interest ; and so frequencies of occurrence of the types prevailing in five different zones of latitude are given in Table V. The boundaries of the zones, given in the first column of Table V, were chosen for various reasons : 81° N. and 2° S. are the limits of the region for which the curves were examined ; 66½° N. and 23½° N. are respectively the Arctic Circle and the northern tropic ; 37° N. is the approximate northern limit of the region in which the tropical tropopause occurs at all seasons of the year ; and 50° N. is an arbitrary boundary between 37° N. and 60° N. For latitudes north of the Arctic Circle, actual numbers of observations are given, because so few detailed curves could be examined that percentages would have been meaningless. For the other zones, the percentage frequencies are correct only to the nearest 4–7 per cent. These figures do not of course represent temperature conditions over the world as a whole and the figures may also differ appreciably even for the same set of stations if computed over a different period of years.

TABLE V—VARIATION OF AVERAGE TEMPERATURE WITH HEIGHT: TYPES OF CURVE PREVAILING IN DIFFERENT LATITUDES

Zone	Prevailing type*				Occurrence				Obs. per month	Illustrated by
	Jan.	Apr.	July	Oct.	Jan.	Apr.	July	Oct.		
					No. of observations					
81° N. – 66½° N.	Pw	Ps	Ps	Pw	4	4	3	3	6	Eureka, 80° N., Pw, Ps, Ps, Pw
	G1	G1	G1	G1	2	2	3	3		
					percentage					
66½° N. – 50° N.	G1	G1	G1	G2	61	91	67	67	23, 24	Coral Harbour, 64° N., G2, G1, G1, Pw
										Larkhill, 51° N., G1, G1, G2, G2
50° N. — 37° N.	G1	G1	G2	G2	48	57	86	90	21	(G1 as Larkhill, Apr., G2 as Nicosia, Oct.)
37° N. – 23½° N.	St	St	T	G2	80	80	93	53	15	Nicosia, 35° N., St, St, T, G2
23½° N. – 2° S.	T	T	T	T	(Almost no seasonal change in the troposphere)				4	Aden, 13° N., T, T, T, T

* For explanation of symbols see Table IV.

Inversions.—In all regions, shallow inversions are common near the ground at inland stations at night and in the early morning, and such inversions may appear on average-temperature curves of any of the six types described above. Over continental areas in winter, much deeper ground inversions are of regular occurrence and may persist for long periods. Of the 69 curves of average temperature examined for January, 19 showed ground inversions extending to above 900 mb.; they were mainly at stations north of 50° N. and were associated for the most part with curves of types G1 and Pw, and varied in magnitude from 1° to 13° C. In April only five out of 69 curves, all of types G1 or Ps, showed such inversions ; magnitudes varied from 3° to 9° C. Over central Siberia winter inversions of even greater depths occur[24]. Major ground inversions may occur also at coastal stations in summer when air flows on to the land after passing over a cold sea current. For example, the July average curves for Oakland (38° N.) and San Diego (32½° N.), on the coast of California, showed inversions each exceeding a kilometre in depth with temperature increases of the order of 5° C.

In the subtropics over the eastern parts of the oceans the principal characteristic feature is the trade-wind inversion[25], generally situated below the 700-mb. level. Below and above the inversion the lapse rate is usually steep, but the outstanding feature is the marked dryness of the air in the layers adjacent to and above the inversion. The trade-wind inversion is probably sufficiently persistent to show on curves of average temperature. This has not yet been verified.

Discrepancies between estimated and actual average tropopause pressures.—The foregoing examination of the different shapes of curves of average temperature throws some light on the discrepancies, referred to on p.12, between actual values of average tropopause pressure and temperature and estimates of these by Flohn's method[13]. The amount of the discrepancy depends largely upon the position of the tropopause relative to the standard pressure levels for which values of average temperature are known; it also depends on the shape of the curve of average temperature near to the tropopause level. For example, the average tropopause pressures at Eureka in January, July and October (Figs. 9, 11 and 12) and at Coral Harbour in January (Fig. 9) are sufficiently near 300 mb. for the errors involved in estimating the tropopause pressure from the curves of average temperature to be quite small. Errors of 20–40 mb. arise however in estimates made from the Coral Harbour data for October and April (curves of types Pw and G1, Figs. 12 and 10) and in those for Larkhill in October (curve of type G2, Fig. 12). The average curves corresponding to these three sets of data are reproduced in Fig. 14. The fine

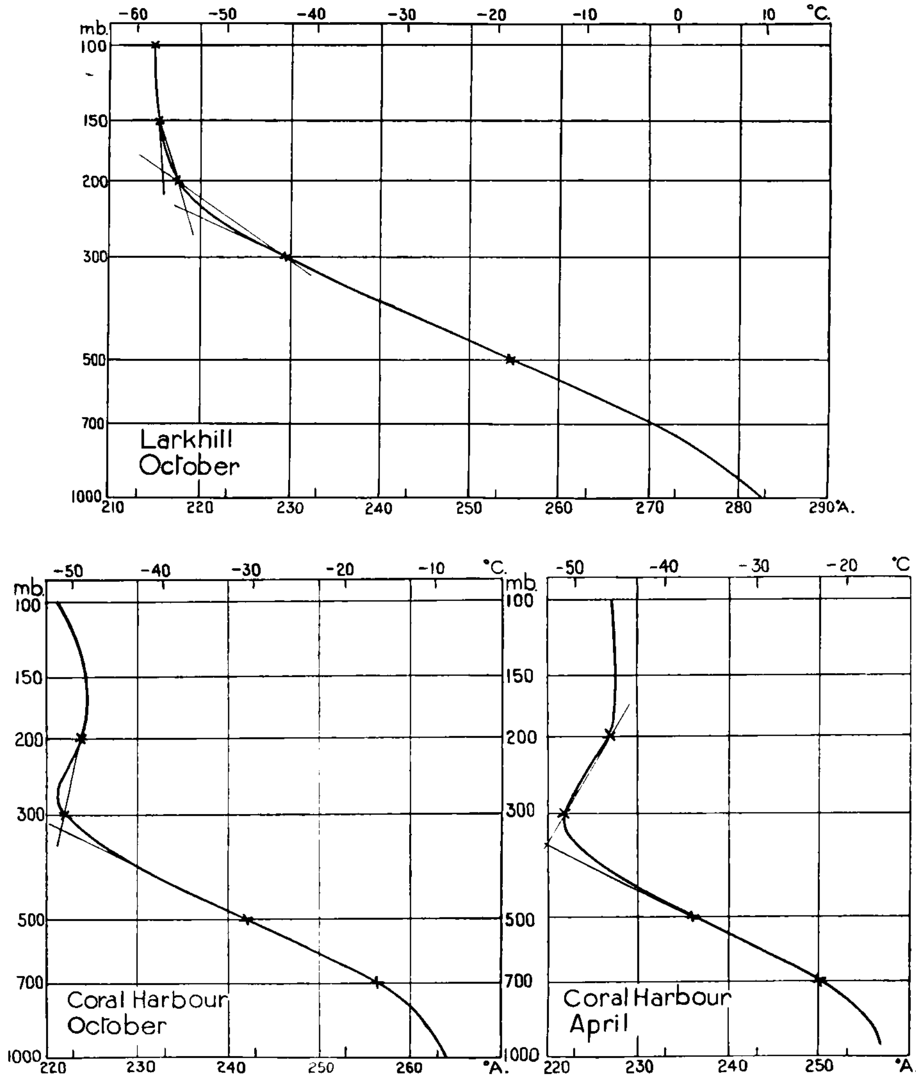


FIG. 14—ESTIMATION OF AVERAGE PRESSURE AT THE TROPOPAUSE FROM AVERAGE TEMPERATURES AT 700, 500, 300, 200, 150 AND 100 MB.. COMPARISON WITH DETAILED CURVES OF AVERAGE TEMPERATURE AGAINST HEIGHT

lines (drawn through the points on the curve at the two standard pressure levels immediately above and the two immediately below the region of the tropopause) show how estimates of its position would be made were the detailed curves not available ; the estimated position of the tropopause is at the intersection of these lines. The data for Larkhill give alternative positions according to which pair of pressure levels are taken. At Coral Harbour this ambiguity does not present itself ; for, in the October data, points plotted for 150, 200 and 300 mb. are roughly collinear and, in the April, a straight line joining 150 and 200 mb. would lie to the right of the point plotted for 300 mb. and would therefore be rejected. The positions determined by Flohn's method are generally at levels lower than those given by actual averages of tropopause pressure and these in turn are lower than those given by the positions of minimum temperature on the average curves. This is seen from the figures in Table VI, derived from Fig. 14.

TABLE VI—ESTIMATION OF AVERAGE PRESSURE AT THE TROPOPAUSE

	Intersecting lines	Intersection		Actual averages		Minimum temperature on average curve	
	join of	nearest 5 mb.	° A.	mb.	° A.	mb.	° A.
Larkhill, Oct.	100–150 mb. and 300–200 mb.	190	216	219	215	Indefinite	215
	150–200 mb. and 500–300 mb.	235	218				
Coral Harbour, Oct.	200–300 mb. and 700–500 mb.	325	222	288	218	250	221
Coral Harbour, Apr.	200–300 mb. and 700–500 mb.	350	220	314	219	300	222

Cross-sections of average temperature.—To complete the representation of average temperature over the world cross-sections extending from 90° N. to 50° S. have been drawn along four selected meridians for each of the four mid-season months (Figs. 15–18).

The meridians were selected mainly for the density of the network of stations and also on account of climatic contrasts, e.g., east and west of continents. The four meridians represented are :—

80° W.—through Baffin Land, Hudson Bay, eastern United States, Cuba and off the west coast of South America.

0° —between Spitsbergen and Greenland, Norwegian Sea, eastern England, western France, Spain, Algeria, Sahara, Ghana and South Atlantic Ocean.

80° E. —through central U.S.S.R., the Indian peninsula and southwards to Amsterdam Island.

140° E. —through eastern Siberia, the main island of Japan, New Guinea, Queensland and South Australia.

The cross-sections were constructed by reading off from the charts (Plates 1–32) the temperature at each 5° of latitude along the selected meridians for each of the six pressure levels. These values were entered on diagrams with the logarithm of pressure as ordinate and latitude as abscissa. The cross-sections extend from the surface to 100 mb. except that in low latitudes they are extended upwards to levels above 100 mb. to include the whole of the troposphere.

As has already been shown on p. 12 the average temperature of the tropopause will not normally be the same as that obtained from the curve of average temperature against the logarithm of pressure. To obtain a tropopause temperature that would be in reasonable accord with the averages at the standard levels the tropopause pressure was read from the charts of Plates (33–44) and the temperature was obtained by the following method.

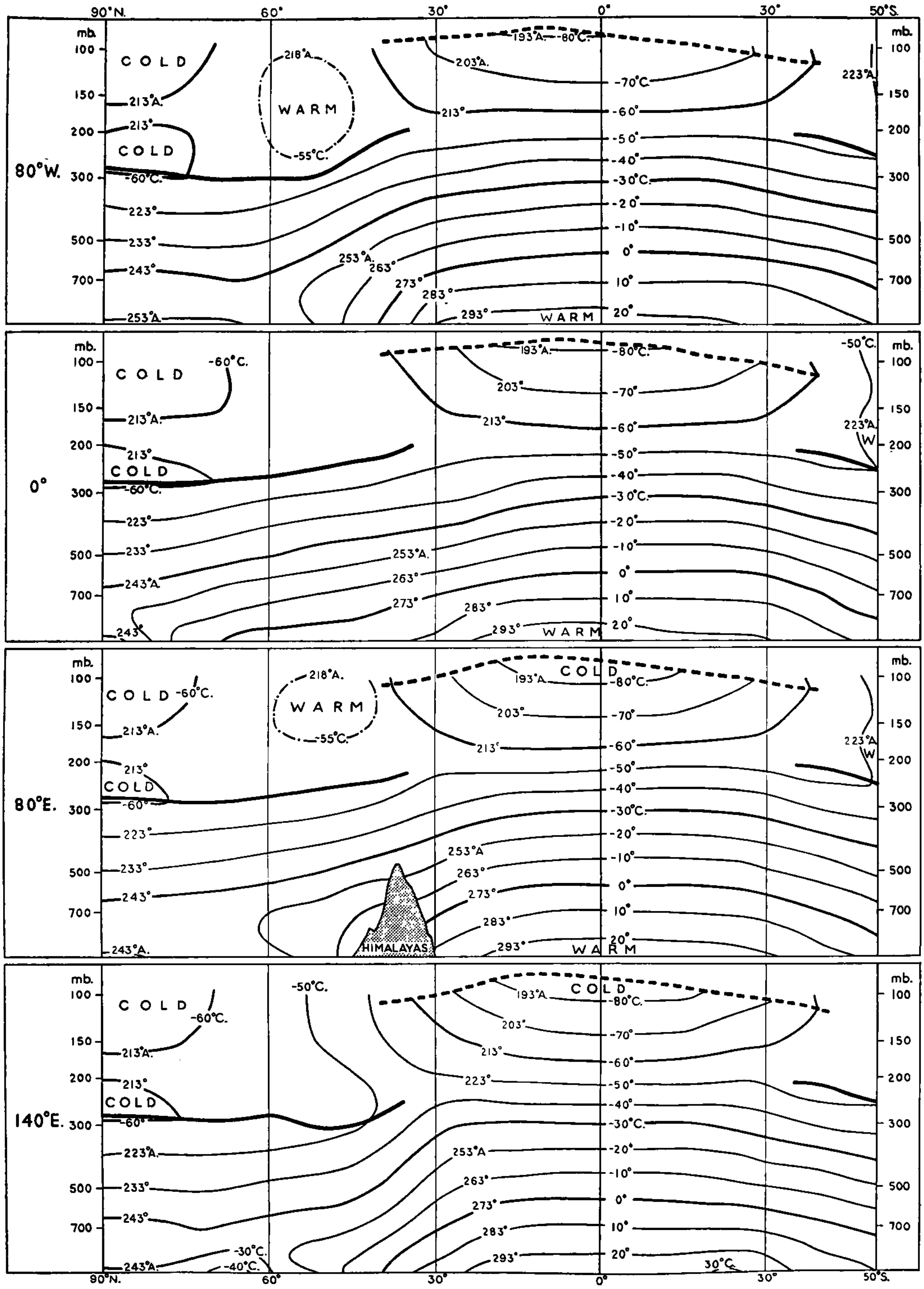


FIG. 15—CROSS-SECTIONS OF AVERAGE UPPER AIR TEMPERATURE IN JANUARY

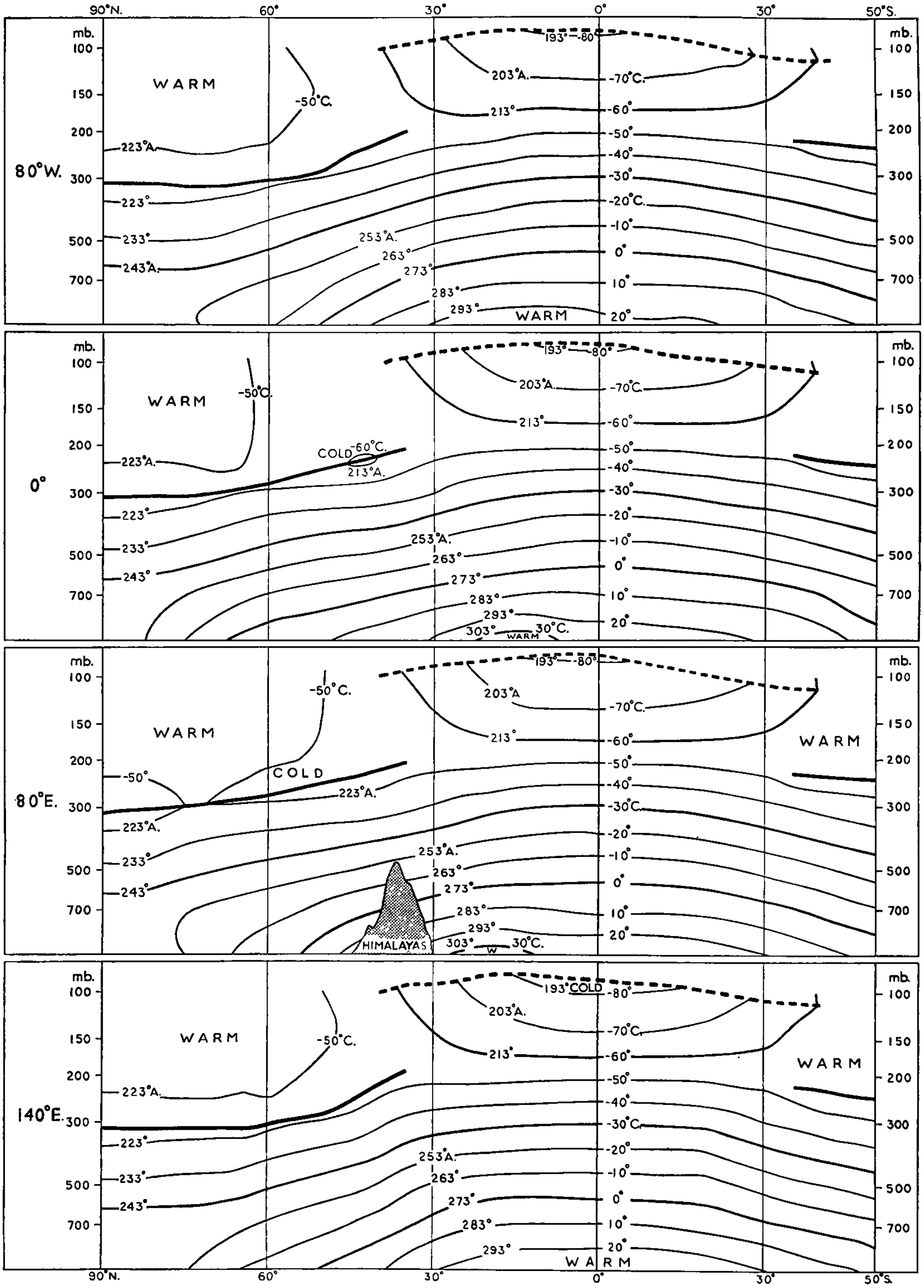


FIG. 16—CROSS-SECTIONS OF AVERAGE UPPER AIR TEMPERATURE IN APRIL

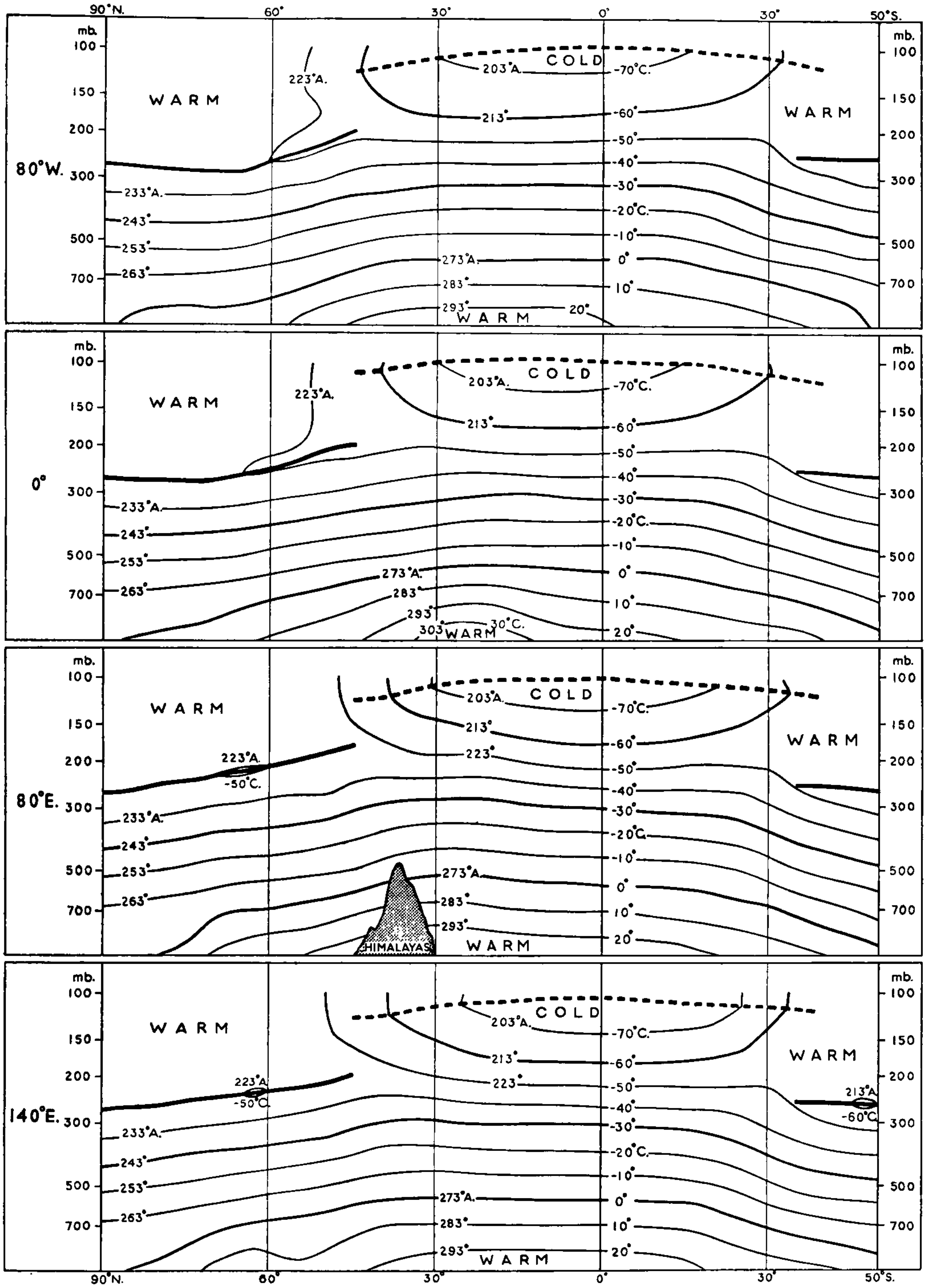


FIG. 17—CROSS-SECTIONS OF AVERAGE UPPER AIR TEMPERATURE IN JULY

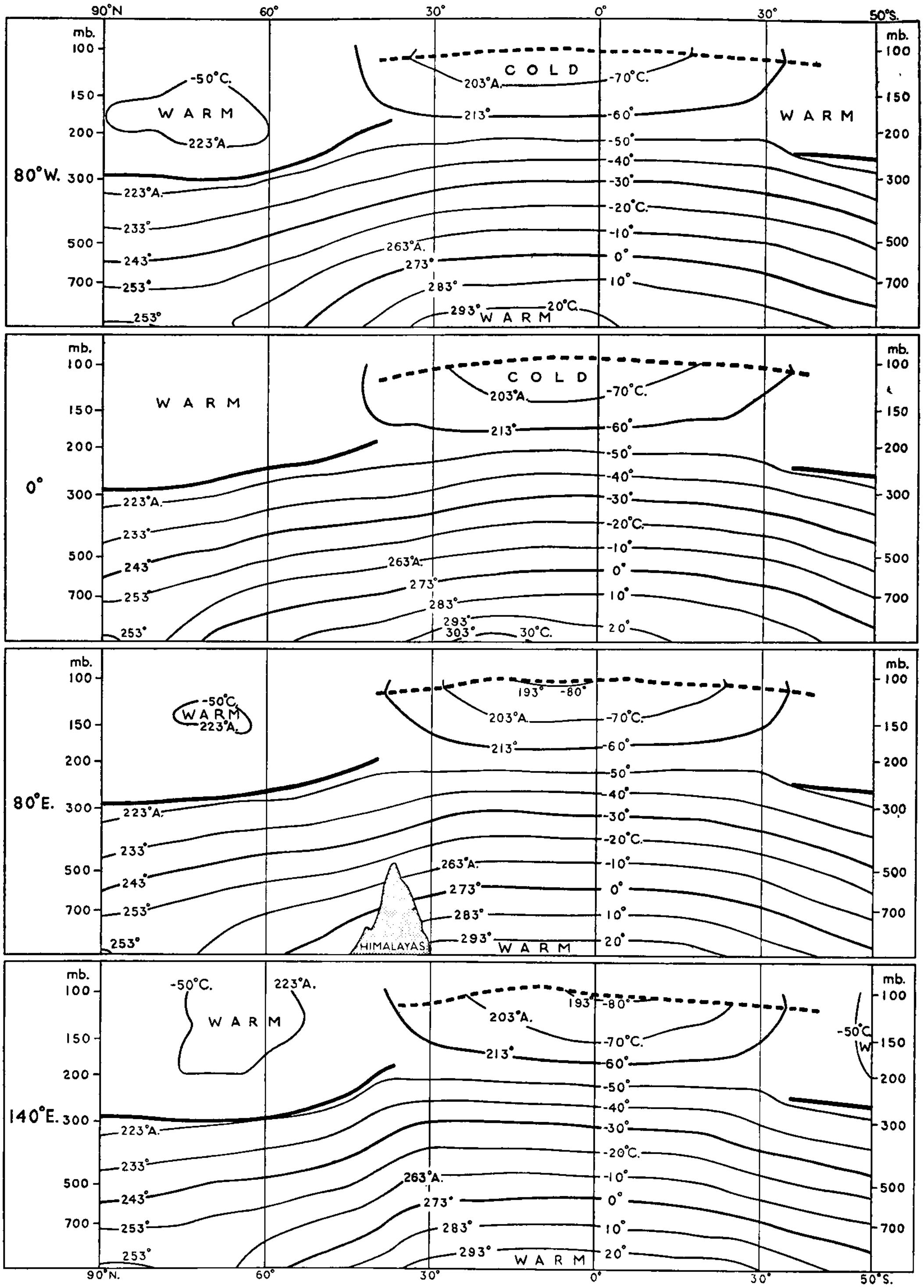


FIG. 18—CROSS-SECTIONS OF AVERAGE UPPER AIR TEMPERATURE IN OCTOBER

The values of tropopause pressure P_T were divided into five classes :—

(*a*) $P_T > 300$ mb.
(*b*) 300 mb. $> P_T >$ 200 mb.
(*c*) 200 mb. $> P_T >$ 150 mb.
} Polar tropopause.

(*d*) 150 mb. $> P_T >$ 100 mb.
(*e*) $P_T < 100$ mb.
} Tropical tropopause.

Diagrams of average temperatures against the logarithm of pressure were plotted for every 5° of latitude along the selected meridians. If the tropopause pressure fell into one of the classes (*a*) or (*c*) the tropopause temperature was obtained by extending the line joining the average temperatures at 200 mb. and 300 mb. (*a*) downwards or (*c*) upwards to the tropopause pressure and the temperature so obtained was taken as the required temperature.

For tropopause pressures between 300 and 200 mb. (*b*) the straight line through the average temperatures at 500 and 300 mb. and that through the average temperatures at 200 and 150 mb. were extended upwards and downwards respectively to the tropopause pressure, giving temperatures T_1 and T_2. The tropopause temperature, T, was computed from the equation

$$T = \left(T_2 \log \frac{300}{P_T} + T_1 \log \frac{P_T}{200}\right) \Big/ \log \frac{300}{200} .$$

This equation assumes that on the temperature–log pressure diagram, T divides the interval between T_1 and T_2 in the same ratio as P_T divides the interval between 300 and 200 mb.

In class (*d*) the pressures rarely differed much from 100 mb. and as there is usually an inversion above a tropical tropopause it was assumed that the tropopause temperature would be slightly lower than that at 100 mb.

For tropopause pressures less than 100 mb. the straight line joining the 150-mb. and 100-mb. temperatures was extended upwards to the tropopause pressure, and the corresponding temperature was used. This method is somewhat crude but gave reasonable results. The temperatures so obtained were entered at the appropriate pressure levels on the cross-sections and isopleths were then drawn for every 10° C., those for 0°, −30° and −60° C. being thickened. The polar tropopause is shown on the diagrams by a thick full line and the tropical tropopause by a thick broken line. In certain latitudes in the subtropics, although two tropopauses occasionally occurred together, the frequency of occurrence of one was not sufficiently high for its presence to be detected on the curve of average temperature. In such regions only one tropopause is shown on the cross-section.

PART II—VARIABILITY OF TEMPERATURE

§ 4—WORLD CHARTS OF STANDARD DEVIATION OF UPPER AIR TEMPERATURE AT STANDARD PRESSURE LEVELS

Charts of the standard deviation of upper air temperature at the standard pressure levels 700, 500, 300, 200, 150 and 100 mb. in the mid-season months are reproduced in Plates 45–76 The charts are arranged according to months in the same way as those of average temperature; with six double-page Mercator charts, one for each pressure level, followed by six circumpolar charts.

As explained on p. 4 the standard deviation, σ, for a specified calendar month is taken to be the direct root mean square of the departures from the average of all temperature observations during the month, and no attempt has been made to eliminate variation due to the seasonal trend within the month. The standard deviation, σ, is expressed as

$$\sigma = \sqrt{[\Sigma (T-\bar{T})^2/N]}$$

where T represents an individual observation of temperature and $\bar{T} = \Sigma T/N$, N being the number of observations.

Choice of a measure of variability of temperature.—The standard deviation is the natural choice as a measure of the variability of temperature. It is a generally accepted standard measure, it is easily computed from grouped observations and it is largely independent of the number of observations used to determine it. It has the advantage also that when the temperature is known to be distributed according to the normal law the percentage frequency of observations that fall within a given range from the average can be computed easily by means of tables of the probability integral. Further, in view of the large number of charts involved, it was essential to use only a single parameter. Hence, provided that the observations are distributed normally in the statistical sense about their average value, the advantages of the standard deviation as a measure of variability outweigh those of any other.

Before making the final choice, histograms showing the frequency distribution of temperature at different levels were examined for different seasons and in different parts of the world to see how far the distributions could be regarded as normal. Examples are given in Fig. 19.

To assist in the comparison, theoretical histograms have been constructed using the mean value and standard deviation appropriate to each of the observed frequency distributions and the same class interval ; these theoretical histograms are shown by shading on the same diagram as the observed frequencies.

The histogram for Larkhill at 200 mb. in January is included as an example of a non-normal distribution. By comparison with the theoretical diagram it is seen to be almost rectangular in shape in contrast with the bell shape of the near-normal distributions.

In general it was found that frequency distributions of temperature are unimodal (i.e. having a single maximum frequency) and symmetrical ; near the ground in middle and high latitudes they may be skew, particularly in summer and winter, but in the free air greater symmetry appears to be the rule provided that a sufficient number of years' data are combined. Between 700 mb. and 100 mb. normality may be assumed with very little error at all levels, apart from some notable exceptions. These exceptions occur where the observations, even within the same calendar month, belong to two or more distinct régimes of temperature. A good example is found in the temperature distribution at 200 mb. over Larkhill (51° N. 1° W.) in January.

When the tropopause occurs at a pressure greater than 200 mb., the 200-mb. level will lie within the stratosphere, whereas, with a tropopause pressure of less than 200 mb., it will lie within the troposphere. When both types occur the resulting frequency distribution of temperature tends to be flat-topped (platykurtic) or even bimodal. If, however, the observations are grouped into two classes according to tropopause pressure the component distributions are both roughly normal in form. This is seen in Fig. 20.

Unfortunately the compound distribution cannot be constructed directly from the average temperature and standard deviation of the aggregate distribution, and although it may eventually be possible with the aid of the charts of the tropopause to estimate what proportion of the observations belongs to the tropospheric and what to the stratospheric régime, and to formulate general rules for obtaining the means and standard deviations of the component frequency distributions, such formulation has not yet been achieved.

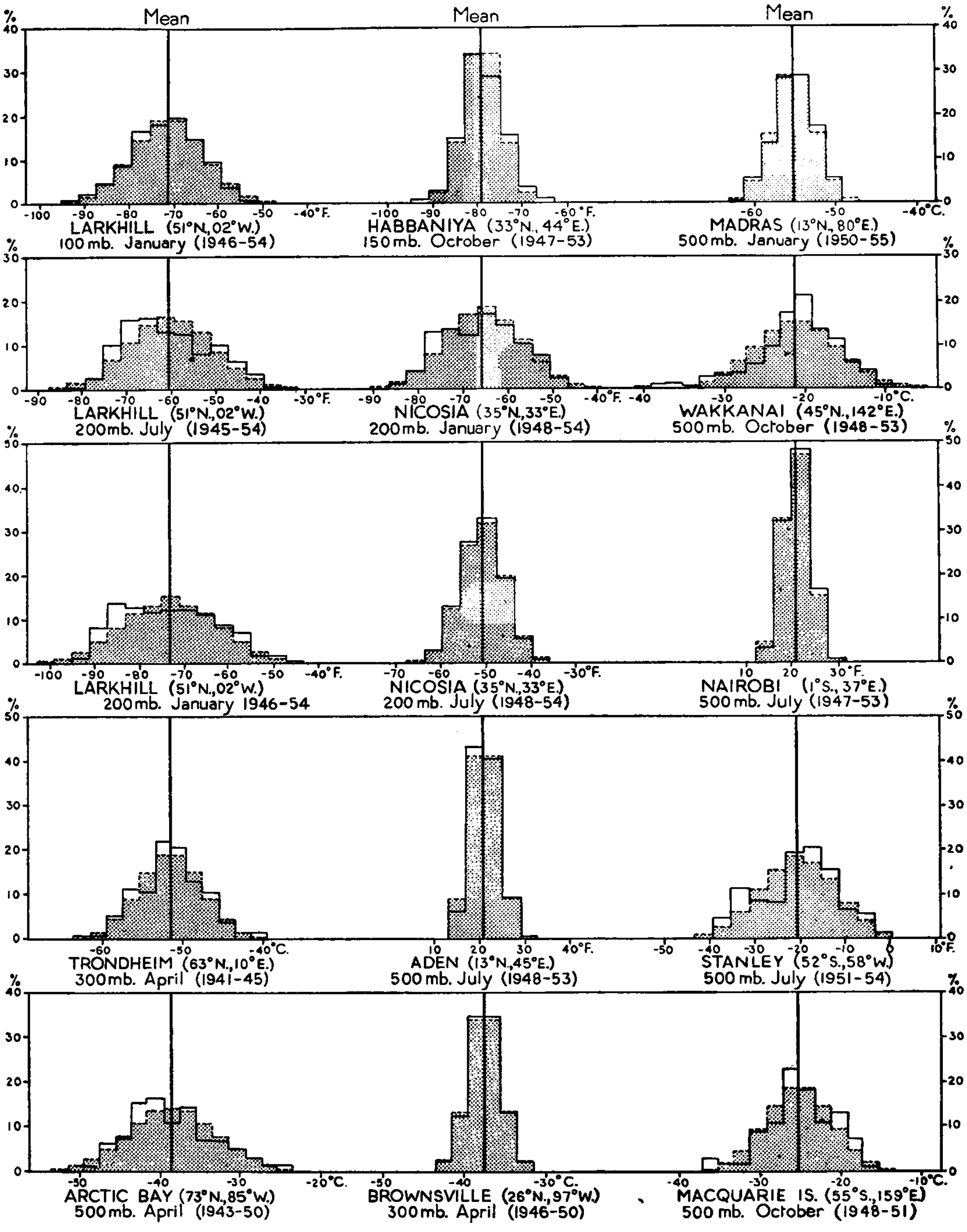
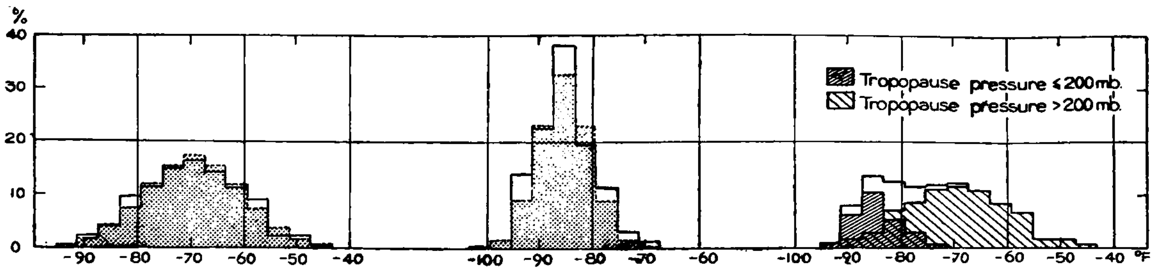


FIG. 19—FREQUENCY DISTRIBUTIONS OF TEMPERATURE AT DIFFERENT LEVELS

Normal histograms having the same average value and standard deviation as the observed distributions are shaded. The class intervals in the histograms for Aden, Habbaniya, Larkhill, Nairobi, Nicosia and Stanley are 4° F. ; those for Arctic Bay, Brownsville, Macquarie Island, Madras, Trondheim and Wakkanai are 2° C.



(*a*) Tropopause pressure > 200 mb. (*b*) Tropopause pressure ⩽ 200 mb. (*c*) Compound distribution.

FIG. 20—EXAMPLE OF THE BIMODAL FREQUENCY DISTRIBUTION AT LARKHILL AT 200 MB. IN JANUARY

Normal histograms having the same average value and standard deviation as the observed distributions are shaded.

Computing the standard deviation.—Standard deviations were computed from tabulated frequencies of different values of temperature for each level for each of the four months. For the most part the frequencies were for every degree Celsius, but at some stations ranges of 2° C. and 2° or 5° F. were used. The standard deviation was then computed from grouped frequencies, using the following formula

$$\sigma = \sqrt{\left[\left\{\frac{1}{N}\,\Sigma(nT'^2) - \left(\frac{1}{N}\,\Sigma nT'\right)^2\right\}\right]},$$

where $N = \Sigma n =$ the total number of observations,

$n =$ the number of observations in any specified frequency class,

and $T' =$ the departure in degrees of the centre of the interval covered by this class, from a conveniently chosen origin.

The origin was generally the centre of the frequency class which, at a rough glance, was expected to contain the mean or the median of the frequency distribution ; but a fixed origin might be adopted for a series of computations (regardless of the position of the origin with respect to the individual frequency distributions) where the results were subsequently to be combined. When the forms were being used for combining two or more sets of observations, in the grouping of which different widths had been taken for the frequency classes, or for extending the period of a published value, then the formula

$$N\sigma^2 = N_1\sigma_1^2 + N_1(\bar{T}_1 - \bar{T})^2 + N_2\sigma_2^2 + N_2(\bar{T}_2 - \bar{T})^2 + \ldots$$

was used. Here N is the total number, and $\bar{T}$ the mean value, of all the observations taken together ; and the suffixes 1, 2,...... refer to the component sets.

For stations where the data available were in the form of frequencies at constant height (classes * and † of Appendix I) two different methods were adopted according to whether or not the data were to be combined with later observations at constant-pressure levels.

For stations in Manchuria and Korea and at some of the Pacific Islands where there were no summaries except those for geometric heights, appropriate heights were selected which corresponded most closely with the pressure levels. The standard deviations were computed directly from the frequencies for those heights and were adopted as applicable to the corresponding pressure levels. Values so derived tend to be too large and this was borne in mind when the isopleths were drawn. Crossley[26] shows that the error increases with height in the troposphere and may be as much as 1° C. in the neighbourhood of the tropopause in the subtropics.

At stations where frequencies at constant heights had to be combined with frequencies at constant pressures, the procedure adopted was to estimate to the nearest degree the difference of temperature between the pressure level required and the nearest height for which frequencies were available. This difference was then applied as a correction to temperatures at the constant height, so as to reduce the observations to the standard pressure level. The standard deviation was then computed in the usual way from the whole set of observations. No correction was applied where there were very few observations or at levels which would normally be above the tropopause.

Scrutiny of the charts and physical considerations.—The range of values on the charts of standard deviation of temperature was in general considerably less than on the charts of average temperature. Hence errors of the same magnitude were of greater importance on the charts of standard deviation and the need for scrutiny was correspondingly greater. The causes of discordant values were similar to those for average temperature, namely differences in the periods of record at neighbouring stations and instrumental effects due to differences in the types of radio-sondes.

A preliminary investigation into the possible magnitude of errors due to shortness of record, showed that the errors in the values obtained from periods of two or three years only might be of either sign. In general the values from short periods were too small because they did not include enough of the year-to-year variability. If, however, there were but two years and these chanced to be very dissimilar, then the frequency distribution of the observations would be of the flat-topped type, characteristic of the combination of two nearly normal distributions. In such a distribution, there are fewer small, and many more medium-sized departures from the mean than would occur in a normal distribution with roughly the same extremes; and so the value obtained for the standard deviation is large in comparison with the actual scatter of the observations.

With regard to instrumental effects, a comparison of observations of radio-sondes of differing accuracies confirmed, as would be expected, that greater observational errors, even if they were largely systematic, tended to give larger values of standard deviation. For example the stations in Canada using instruments known to be liable to errors due to lag and radiation showed larger values than those using instruments not so liable, except at very high levels. It was suspected also that the very high values at high levels over India were in part due to instrumental errors; and allowance was made for this when the isopleths were drawn. Other sources of error investigated were found to be of minor importance. At some stations it was found that a value computed from observations covering only a short period approximated closely to the long-period value because the effect of shortness of period cancelled out the effects due to instrumental errors; thus it was unsafe to assume that the standard deviation computed for a short-period station would always be too low or that a standard deviation based upon observations by instruments with large lag or radiation errors would always be too high.

In drawing the isopleths over areas with few observations, consideration was given to the geographical distribution and to the variation with height found over areas where the network of stations was much closer. In the main, the standard deviation was found to be greatest in middle latitudes between 40° and 65°. It is certainly small near the equator and probably also at the poles. Superimposed on this latitudinal variation there is a seasonal change which is most marked in middle latitudes, standard deviations being smaller in summer than in winter and spring, and intermediate in autumn.

Other factors were also borne in mind though they carried less weight. The influence of topography appeared to give rise to small values over mountainous areas such as the Rockies, the Urals and the Greenland plateau; large values on the other hand were found at 700 and 500 mb. in winter, and to a less extent in spring, over large land masses such as Canada and Siberia where ground inversions are frequent and large. At Yakutsk (62° N. 129½° E.) for example, Flohn[24] found that an inversion extending on the average to 800 mb. and sometimes even to 550 mb. was present on 59 occasions in 60 in winter, its magnitude lying between 4°

and 27° C. These results refer to little more than a single winter so that over a longer period of years a very wide range of temperature may be expected at 700 mb. and also at 500 mb. The passage of depressions seems likely also to affect the pattern of the charts of standard deviation. In areas frequently traversed by vigorous, quick-moving depressions, the standard deviation will tend to be large at both 700 and 500 mb.; but, where depressions are occluded and slow moving, values at 700 mb. will be relatively small although at 500 mb. they may be large. Attempts to obtain correlations with other physical factors were unsuccessful; and no confirmation was obtained of the suggestion that the variability of temperature in the upper troposphere would be high over regions of frequent and heavy rainfall.

The influences by which the variation of standard deviation with height is governed appear to be the presence or absence of ground inversions (referred to in the preceding paragraph) and the position and type of tropopause. In the British Isles and at stations of similar latitude in Europe and America, the standard deviation increases with height to a maximum at about 500 mb. and then decreases to a minimum at a point below the general range of the polar tropopause. Above this there is a fairly rapid increase, with a well defined maximum somewhere between the median position of the polar tropopause and its upper limit. This maximum (at about 170 or 180 mb.) is associated with frequency distributions which are far from normal, being compounded of temperatures belonging to two distinct régimes (*see* p. 38). J. K. Bannon[27], using data for Larkhill in southern England, has shown that when the ascents are grouped according to the height of the tropopause, the standard deviation in each group shows little variation with height. In regions where there is an upper (tropical) tropopause, there is some evidence that the standard deviation falls to a minimum again at about the level of this tropopause, but this has not been fully confirmed.

At tropical stations the variation with height is small and there is no pronounced maximum near the tropopause. There may be a slight increase with decreasing pressure, but the magnitude of the standard deviation does not greatly exceed that which has been shown to arise from random instrumental errors in other latitudes[28], and so no definite conclusions can be drawn.

In arctic and subarctic regions, curves of maximum and minimum temperature compiled by the Toronto Meteorological Division[18] show that the greatest range is to be found at 3 Km. in winter and the least near the average height of the tropopause. This gives some indication of the probable variation of the standard deviation at constant-pressure levels and suggests that it is greatest at about 700 mb. somewhat above the average height of the ground inversion.

In some parts of the charts the isopleths were drawn principally from consideration of the continuity of pattern between one isobaric surface and the next. This was true particularly of the 150-mb. chart, for which data were exceptionally few. Observations from stations over the British Isles, Mediterranean, and Middle East, were regarded as reasonably accurate as were also those from six specially selected stations in Canada and those from New Zealand, but elsewhere the values had to be computed for the most part from published data of "significant points" or were based on very short periods. The chart for 150 mb. was therefore drawn as a rough interpolation between the charts for 200 and 100 mb.

Reliability of the charts.—It is not easy to assess the reliability of the charts but in general greater confidence may be placed in the isopleths over areas where the values of the standard deviation are comparatively small as in the tropics, and where longer periods were used for the computations.

Extratropical regions in which the records used were over four years are shown below:

8–10 years
British Isles, New Zealand.

4–7 years
Australia, United States of America, Iraq.
700 to 150 mb. : Canada, south Scandinavia and central Europe.
700 to 300 mb. : Japan and Korea.
700 and 500 mb. : Alaska, Mediterranean area and U.S.S.R. west of 100° E.

Except in Iraq the network of stations in all these areas was fair and the standard error of the isopleths probably does not exceed 0·3° C. except

(i) at levels affected by surface inversions in January: 700 and 500 mb. in Alaska, Canada and the U.S.S.R., and 700 mb. in Japan and Korea.

(ii) at levels associated with varying polar tropopauses in January and April: 200 mb. and 150 mb. in Canada and 200 mb. in the United States, British Isles, south Scandinavia and central Europe.

Over India the network was good but data were abundant only at 700 and 500 mb. At these levels the standard error in the isopleths is estimated to be about 0·2° C., but at levels above 300 mb. observations fall off very rapidly and the error is likely to be greater.

Estimating frequencies and range from the charts.—Provided that a set of observations is " normally " distributed, i.e. conforms to the Maxwellian or Gaussian law, it is possible by means of the probability integral to compute the range, expressed as a multiple of the standard deviation, within which a given percentage of the observations lies. The figures in Table VII give this information.

TABLE VII—PROBABLE VALUES OF THE RANGE OF TEMPERATURE WITHIN WHICH A SPECIFIED PERCENTAGE OF THE OBSERVATIONS LIES

	percentage									
	20	30	40	50	60	70	80	90	95	99
t	0·25	0·39	0·53	0·67	0·84	1·04	1·28	1·65	1·96	2·58

The table shows the multiple, t, of the standard deviation which must be added to, and subtracted from, the average temperature in order to give the range of temperature within which a given percentage of the observations lies. For example, at Larkhill the average temperature at 500 mb. in January (see Plate 2) is 248° A. and the standard deviation (see Plate 46) is 5·5° A. The table shows that 50 per cent. of the observations lie between the limits 248° $\pm$ (0·67 $\times$ 5·5)° i.e. between 244° A. and 252° A. and that 95 per cent. lie between 237° A. and 259° A.

It must be emphasized that the table applies strictly only to observations which follow the " normal " law. In practice, however, reasonable estimates of the range of temperature can be made wherever the standard deviation does not exceed (as a rough guide) about 4° C. Even at low levels and near to varying polar tropopauses as, for example, in the regions listed under (i) and (ii) above, a very rough estimate of the range of temperature which includes something of the order of 80 per cent. of the observations can probably still be made from Table VII, but because of the abnormal shape of the frequency distribution estimates of smaller ranges or of extreme values will be very badly in error.

§ 5—EXTREMES OF TEMPERATURE

Even when the distribution is approximately normal an estimate of the extremes of temperature to be expected in a specified number of years cannot be derived directly from Table VII. For most meteorological elements there is a tendency for consecutive values to be correlated, the magnitude of the correlation decreasing as the time interval increases. High and low values of temperature for example tend to continue for several days; this tendency is known as " coherence ", " conservation " or " persistence ". Brooks and Carruthers[8] (p. 325) cite a persistence of 2½ days for temperature at screen height.

Very little information is available about the degree of persistence of temperature in the upper air and little is known of its variation with height and with latitude. Bannon[29] made an exploratory examination using 6-hourly and 12-hourly observations at 500 mb. and at either 200 or 150 mb. for three stations. Using Lewis and McIntosh's expression[30] for the " equivalent number of repetitions ", i.e. $1 + (2/n)\{(n-1)r_1+(n-2)r_2+\,..r_{n-1}\}$ where n is the number of observations and r_1, r_2, r_3 are the correlation coefficients between successive terms, two apart, three apart, and so on, he found persistence to vary from 27 hr. to 72 hr., with some indication that it was less in the region of the British Isles than in the Mediterranean.

If the persistence is less than 24 hr. and observations were taken only once a day, then in a 30-day month all 30 observations might be regarded as independent ; if however the persistence is, say, 36 hr. the number of independent observations is only 20, and for 48 hr. only 15. The extent to which this affects the computed extremes may be judged from the following table which shows the multiple t of the standard deviation which is required in order to compute the temperature which has an even chance of being exceeded once in N years, for different values of the number of independent observations in the month.

Table VIII gives the multiple t of the standard deviation which must be added to and subtracted from the average temperature in order to compute the extreme values that will occur in a 30-day calendar month once in N years when the number of independent observations in the month is 30, 20 or 10.

TABLE VIII—EFFECT OF " INDEPENDENCE " ON COMPUTED VALUES OF EXTREMES

Number of independent observations per month	Number of years (N) 1	2	3	5	10	20	30
	multiple of standard deviation (t)						
30	2·1	2·4	2·5	2·7	2·9	3·1	3·3
20	1·96	2·2	2·4	2·6	2·8	3·0	3·1
10	1·65	1·96	2·1	2·3	2·6	2·8	2·9

It is probable that the persistence lies somewhere between 24 and 72 hr. and it will be seen from Table VIII that if the values corresponding with 20 independent observations are used the error in t for values of N greater than 1 does not exceed 0·3 ; which, with a standard deviation of 7° C., gives an error of 2° C. in the computed extreme.

In an earlier tentative inquiry into estimates of range from standard deviation, extreme temperatures were extracted from each year's record for January and July at 700 and 500 mb. at six stations in different latitudes. From these data, extremes occurring on average once in 1, 2, 4, 6 and 8 yr. were obtained and the smoothed mean values of half the range divided by the standard deviation gave the following results :—

Number of years	1	2	4	6	8
Range/2σ (to nearest 0·05)	1·65	2·00	2·30	2·45	2·55

These figures correspond to a persistence of about 2½ days, i.e. they lie between those given for 10 and 20 independent observations in Table VIII.

The average monthly range was found from the same data to be nearly four times the standard deviation, i.e. about the same as that to be expected once in two years.

Extremes of temperature over the world at different pressure levels.—According to Table VIII extreme temperatures likely to be experienced at a given station once in 20 yr. are given approximately by $\bar{T} \pm 3\sigma$. This is based upon two assumptions both of which are liable to error: first, that at the level considered the distribution of temperature is normal; and secondly, that the number of independent observations in an individual month is 20. Nevertheless, even when the errors of these assumptions are large, it may still be supposed that $T + 3\sigma$ and $T - 3\sigma$ give reasonable approximations to maximum and minimum temperatures occurring in periods of the order of 20–30 yr. This supposition has been used to estimate extreme temperatures at different standard pressure levels for the world as a whole.

First, the January and July values of average temperature and standard deviation were read from the charts at each of the standard pressure levels for every 5° of latitude and 20° of longitude. Then the values of $T \pm 3\sigma$ were selected which gave the highest and lowest temperatures and these were plotted on a graph of temperature against the logarithm of pressure. These results are shown by the full lines in Fig. 21. Actual extremes extracted from frequency distributions from among some 200 stations are shown for comparison by small crosses. They were observed at the stations given in Table IX.

TABLE IX—STATIONS RECORDING EXTREMES SHOWN IN FIG. 21

mb.	Minimum	Maximum
100	Poona (19° N. 74° E.)	Fort Nelson (59° N. 123° W.)
150	Albrook Field (9° N. 80° W.) Poona (19° N. 74° E.)	Bergen (60° N. 5° E.)
200	Thule (77° N. 69° W.) Vadso (70° N. 30° E.)	Changchun (44° N. 125° E.)
300	Eureka Sound (80° N. 86° W.) Resolute Bay (75° N. 95° W.) Trondheim (63° N. 10° E.)	Changchun (44° N. 125° E.) Hailaerth (43° N. 120° E.)
500	Cap Cheliuskin (78° N. 104° E.) Gorkii (56° N. 44° E.)	Karachi (25° N. 67° E.)
700	Clyde River (70° N. 68° W.)	Karachi (25° N. 67° E.) Quetta (30° N. 67° E.)

These are based, for the most part, upon records of not more than five years in length at each station; but, since nearly the whole globe is covered by the station network, the results may be supposed equivalent to a much longer period at an individual station.

Extremes at other levels selected from more limited data are shown by dots and triangles in Fig. 21; and the absolute extremes of surface temperature, 203° A. at Verkhoyansk in Siberia in 1892 and 331° A. in Italian Tripoli in 1922, are shown by small circles. In a tentative attempt to complete the picture, the full lines representing extremes of temperature between 700 and 100 mb. are extended upwards to the 40-mb. level, and downwards to connect up the points representing the surface extremes, by broken lines drawn roughly parallel to the general run of the intervening observations.

Zonal means and extremes of upper air temperature over the northern hemisphere in January and July.—In the preparation of Fig. 21, January and July values of average temperature and standard deviation were read at grid points from the charts for each of the standard pressure levels. These data have also been used to show, for the northern hemisphere, the variation

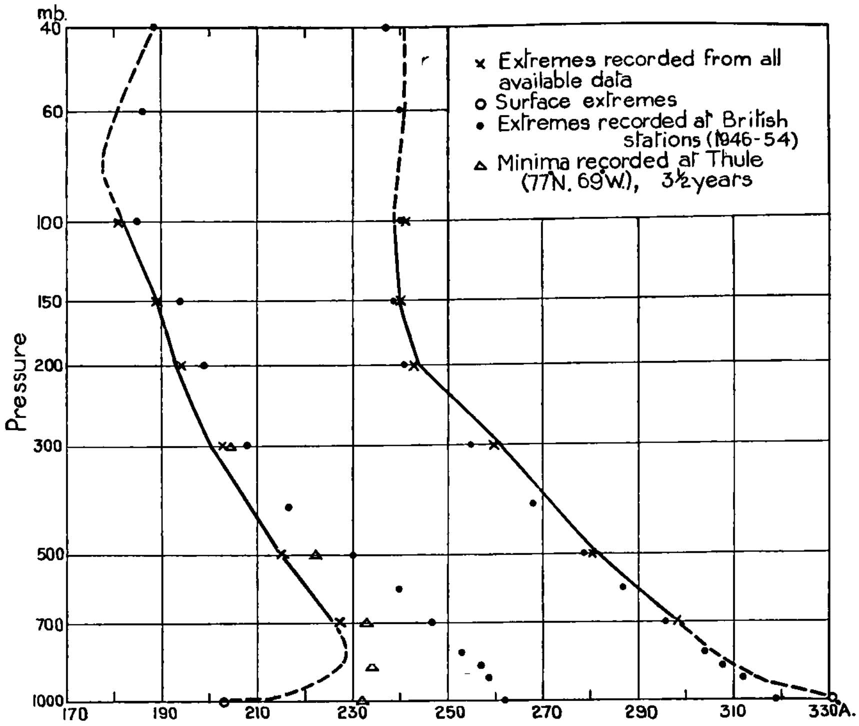


FIG. 21—EXTREMES OF TEMPERATURE OVER THE WORLD

Full lines show extreme values of $T \pm 3\sigma$, deduced from the January and July charts of average temperature, T, and standard deviation of temperature, σ.

of average and extreme values of upper air temperature with latitude in January and July (Fig. 22).

Along each line of latitude in the northern hemisphere, the average temperature (calculated by averaging 18 grid values), the highest and lowest values of average temperature read from the charts, and the expected extreme values of temperature (computed as described on p. 45) were found for each of the standard pressure levels in January and July. These values were plotted on graphs of temperature against latitude and by joining the points the smooth curves reproduced in Fig. 22 were constructed.

A world chart of minimum temperature in the troposphere and lower stratosphere.—The lowest temperature likely to be experienced in the upper air over any specified region is also of considerable importance and is often the subject of inquiry. Except in polar regions in winter the lowest temperatures are, in general, experienced at the tropopause and in order to assess the values of minimum temperature over the world as a whole, use was made of the charts of average tropopause temperature in January and July (Plates 34 and 38) and of charts of the standard deviation of temperature at the tropopause which were specially compiled. In the main, the procedure was similar to that used for obtaining the extremes at standard levels, namely to read off values at every 5° of latitude and 20° of longitude and to compute $T - 3\sigma$, but special treatment was needed in certain areas. For example, in regions of two tropopauses, values of $T - 3\sigma$ were computed for both and the lower temperature of the two was chosen. In polar regions in winter, temperature continues to fall off slowly above the tropopause and in these regions values were obtained by reading values from the 100-mb. charts as well as from the tropopause charts

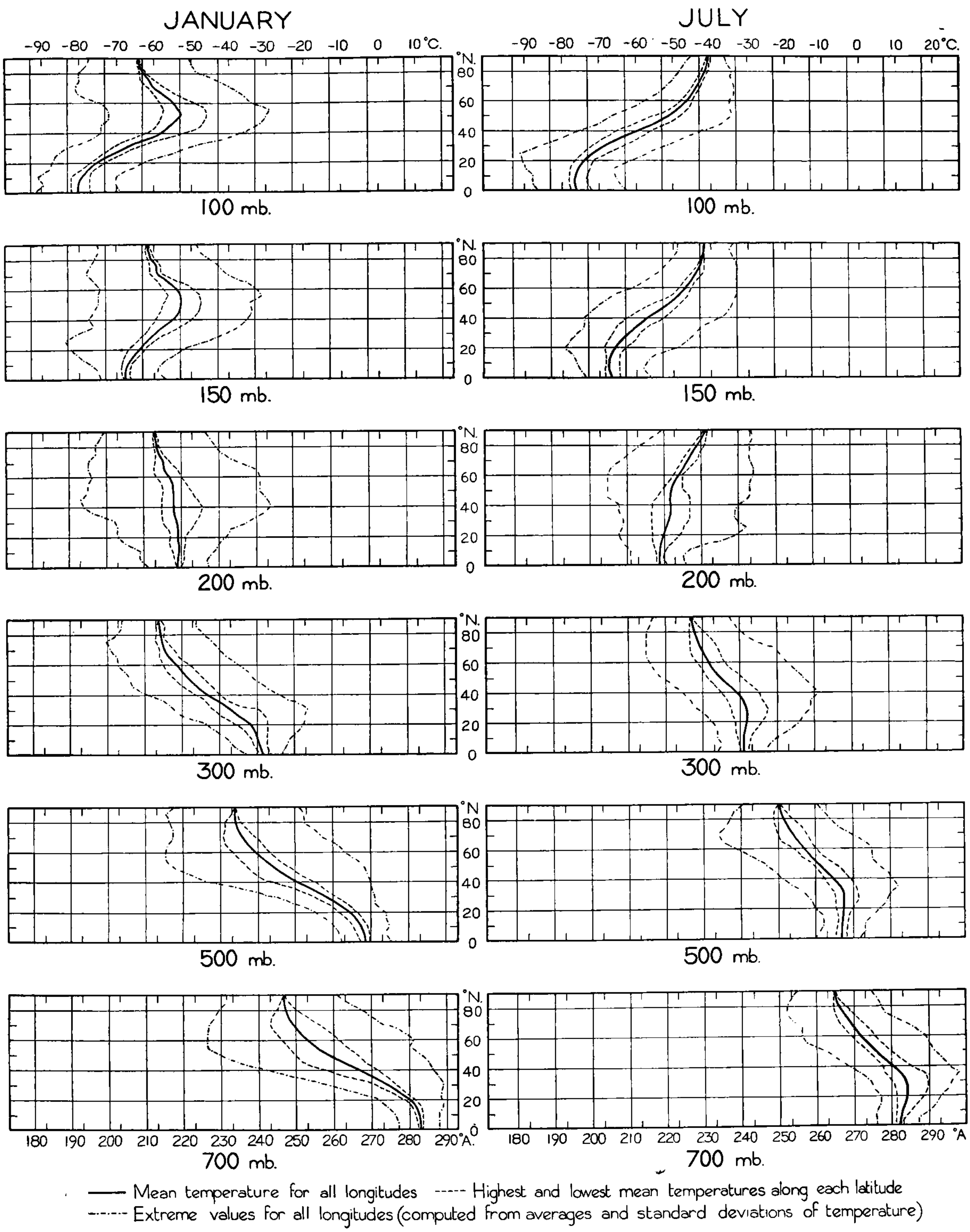


FIG. 22—ZONAL MEANS AND EXTREMES OF TEMPERATURE OVER THE NORTHERN HEMISPHERE IN JANUARY AND JULY

and if the computed minimum temperature at 100 mb. was lower than that at the tropopause, it was used in its place.

The values at the grid-points were then plotted on Mercator and circumpolar charts and isopleths drawn, smoothing where necessary. (Plates 77 and 78.) The area on the charts where the minimum temperature at 100 mb. was found to be colder than that at the tropopause, is indicated by hatching.

As a check on the reliability of the charts and of Figs. 21 and 22, extremes recorded either at pressure levels or at the tropopause were extracted for all stations from the frequency tables and were plotted and scrutinized in relation to the computed extremes. Values which showed appreciable disagreement were re-examined, but in each instance it was found that the observed value was exceptional and differed by several degrees Celsius from the next lowest in the frequency table, which suggested that the observation was in error.

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Assistance in the preparation of the charts has been received from the Directors of Meteorological Services in many parts of the world and without their friendly co-operation and encouragement the preparation of the Memoir would hardly have been possible.

The sources from which the data have been drawn are set out in Appendix I and Appendix II and from these it is clear to how great an extent reliance had had to be placed on manuscript data. Grateful acknowledgement is made to the following Heads of Meteorological Services who have supplied such data, usually in respect of their home territories, but also, where indicated, in respect of certain external dependent territories :

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The Director, Serviço Meteorológico Nacional, Portugal (data for the Azores).
The Inspector General of Meteorology, Director Météorologie Nationale, France (data for Madagascar and Adélie Land).
The Director of the Weather Bureau, Union of South Africa.
The Director of the East African Meteorological Department.
The Government Meteorologist, Sudan Meteorological Service.
The Director of Meteorological Services, Rhodesia.
The Director of the British West African Meteorological Services.
The Director General of Observatories, India Meteorological Department.
The Director of the Meteorological and Geophysical Service of Indonesia.
The Director of the Royal Observatory, Hong Kong.
The Director of the Weather Bureau, Republic of the Philippines.
The Director of the Meteorological Branch, Department of the Interior, Australia.
The Director of the New Zealand Meteorological Service.

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APPENDIX I—CLASSIFICATION OF THE DATA USED

The type of data, and the treatment accorded them in the preparation of each of the three sets of charts are indicated by the following classification :

A Values taken directly from publications and MS. of other meteorological services.

B Tropopause values taken from individual ascents and assessed by the definitions on p. 11.

C Tropopause values estimated from the average temperature at standard pressure levels.

D Average values computed from frequency distributions or by directly averaging individual values for the whole period of record.

E Averages computed from monthly means.

F Averages computed by combining a number of partial averages.

* Data were summarized at constant height levels before 1946 (United States) and before 1948 (Japan) ; pressure data were available so that estimates of average temperature at standard pressure levels could be obtained by interpolation.

† Summaries for geometric heights only.

The data used are listed according to four major geographical regions :

I. The Americas ; contained in the longitude belt 170° W. to 30° W.

II. Greenland, Atlantic Ocean, Europe, Middle East and Africa ; contained in the longitude belt 60° W. through 0° to 60° E.

III. U.S.S.R., Asia (except Middle East), Australia and New Zealand ; contained in the longitude belt 30° E. to 180°.

IV. Pacific Ocean ; contained in the longitude belt 140° E. through 180° to 150° W.

Within these regions, countries or stations are arranged in order from north to south.

	Average temperature ($\bar{T}$)		Tropopause		Standard deviation of temperature (σ)	Sources of data (Appendix II)	
	Period	Type	Period	Type	Period	$\bar{T}$ and σ	Tropopause
REGION I—THE AMERICAS (170° W. to 30° W.)							
Canada							
Resolute .. .. .. Eureka	1948–52	F	..	..	1948–52 (to 300 mb. only) 1949–52 (200 to 100 mb.)	2, 4, 6, 13, 14	..
Aklavik .. .. .. Fort Nelson .. .. Moosonee .. .. Arctic Bay .. .. Port Harrison .. .. Nitchequon	1943–50	E	1942–50	A	1943–50	10	15, 16
Other Canadian Stations	1944–47, 1949–52	F	1942–50	A	1946–47, 1949–52	1–4, 6, 15	15, 16
Alaska	1941–43, 1949–52	F*	1949–51	B	1946, 1949–52	1, 3, 4, 6, 7	2
Pacific Ocean Weather Stations	1950–52	D	1949–52	B	1950–52	2, 4, 6, 9	9, 10
United States	1939–43, 1946–50	F*	1949–51	B	1946–50, 1952	1–7	2
Bermuda	1946–50	D	..	..	1946–50	2–4, 9	..
Caribbean	1939, 1941–43, 1946–51	F*	1940–43	C	1946–52	1–7	7

APPENDIX I—*continued*

	Average temperature ($\bar{T}$)		Tropopause		Standard deviation of temperature (σ)	Sources of data (Appendix II)	
	Period	Type	Period	Type	Period	$\bar{T}$ and σ	Tropopause
Colombia (Barranquilla) ..	1944–45, 1948	D*	..	..	1944–45, 1948	9	..
Trinidad	4–5 yr. between 1943–52	D*	..	..	4–5 yr. between 1943–52	2, 4, 9	..
Brazil							
Natal	1944–45	D†	..	..	1944–45	9	..
Other Stations	1935–40	D†	..	..	..	17	..
Argentina	Not known. 3 and 5 Km. only	D†	..	..	..	18	..
Falkland Is. (Stanley) ..	1948–51	E	1948–53	B	1948–51	12	12
REGION II—GREENLAND, ATLANTIC OCEAN, EUROPE, MIDDLE EAST, AFRICA (60° W. to 60° E.)							
Greenland							
Thule	1947–52	F	..	..	1947–52 (to 300 mb. only); 1949–52 (200–100 mb.)	1, 2, 4, 6, 19	..
Scoresbysund	1950–52	D	..	..	1950–52	2, 4	..
Narssarssuak .. ..; Sondrestromfiord ..	1944–48	D	1949–51	B	1944–48	9	2
Iceland	1942–47	D	1949–51	B	1942–47	1, 9	2
Spitsbergen and Wordie Bay	1943–45	D	..	..	..	12, 20	..
Sweden							
Southern Sweden ..	1940–44, 1949–52	F	..	..	1940–44	6, 21	..
Northern Sweden (Abisko)	1921–29	D	..	..	..	22	..
Norway	1941–44, 1947–50	D	1949–51	A	1941–44, 1947–50	11, 23	23, 24
Jan Mayen Island ..	1944–45, 1948–50	D	1949–51	A	1944–45, 1948–50	23, 24	24
Denmark	1943–45	D	..	..	1943–45	11	..
Faeroes	1951–52	E	..	..	..	6	..
Finland	1942–44, 1950–51	F	..	..	1942–44	6, 11	..
Poland	1941–44	D	..	..	1941–44	11	..
Germany							
Berlin	1941–45	D	..	..	1941–45	11	..
Iserlohn	1947–52	D	..	..	1947–52	12	..
Langenhagen, Schleswig-land	..	..	1948–52	A	..	..	12
Belgium	1941–48	D	..	..	1941–48	11, 25	..
British Isles..	1942–51	E	1946–53	B	1942–51	12	12
Atlantic Ocean Weather Stations	1948–51	D	1949–52	B	1948–51	2, 4, 9, 10, 23, 26, 27	2, 9
France	1941–44, 1949–52	D	..	..	1941–44	6, 8, 11	..
Portugal							
Lisbon and Funchal ..	1948–51	D	..	..	1948–51	28	..
Azores	1944–47	D	..	..	1944–47	29	..
Italy	1939–43	D	..	..	1939–43	11, 30	..
Switzerland	..	..	1948–51	B	..	..	31
Austria	1941–45	D	..	..	1941–45	11	..
Hungary	1941–44	D	1913–14; 1927–40	A	1941–44	11	32
Rumania	1942–44	D	..	..	1942–44	11	..
Greece	1942–44	D	..	..	1942–44	11	..
Mediterranean and Middle East (British Stations) ..	1946–52 (3–5 yr.)	E	1950–51	B	1946–52 (3–5 yr.)	12	12
North Africa	1948–52	F	..	..	1948–49	6, 8, 9	..
Egypt and Palestine ..	1942–47	D	..	..	1942–47	12	..
Sudan	1943–46 (700 and 500 mb. only)	D	1953	A	1943–46 (700 and 500 mb. only)	33	33
Sahara							
Aoulef	1950–52	E	..	..	..	6	..
Tamanrasset	1932–33	D	..	..	..	34	..
West Africa	1943–45 (to 500 mb. only)	D	..	..	1943–45 (to 500 mb. only)	9, 35	..
	1949–51	E	..	..	..	6	..
East Africa							
Nairobi	1947–51	E	1948–53	A	1947–51	36	36
Mombasa	1 yr.	..	..	..	..	37	..

APPENDIX I—*continued*

	Average temperature ($\bar{T}$)		Tropopause		Standard deviation of temperature (σ)	Sources of data (Appendix II)	
	Period	Type	Period	Type	Period	$\bar{T}$ and σ	Tropopause
South Africa (including Rhodesia)	1941–50, 1952	D	1948–50	A	1947–50, 1952	6, 38–41	39, 41
Ascension Island	1944–45	D	..	..	1944–45	9	..
Madagascar	1943–45	D	..	..	1943–45	42	..
Mauritius	1944–45	D	..	..	1945	42	..
REGION III—U.S.S.R., ASIA (except Middle East), AUSTRALIA (30° E. to 180°)							
U.S.S.R.							
Cap Cheliuskin	1949–52	D	1949–51	B, C	1949–52	2, 43, 47	2, 43
Dikson	1949–52 (to 200 mb. only)	D	1949–51	C	1949–52 (to 300 mb. only)	2, 43, 47	43
Yakutsk	1948–51	D	1949–51	B, C	1949–52 (to 200 mb. only)	2, 43, 44, 47	2, 43
Kharkov .. .. .. } Minsk .. .. .. } Riga .. .. .. }	{ 1942–44 / 1948–50 (700 and 500 mb. only) }	D / ..	1949–51 / ..	B / ..	1942–44 / 1948–50 (700 and 500 mb. only)	.. / 2, 11, 47	.. / 2
Kiev .. .. .. } Novosibirsk .. .. } Tashkent .. .. .. }	1936–39, 1948–52 (to 300 mb. only)	D	..	..	1936–39, 1948–52 (to 300 mb. only)	2, 47, 48	..
Moscow	1936–39, 1948–52	D	{ 1930–36 / 1949–51 }	A, B	1936–39, 1948–52	2, 47, 48	2, 45
Tikhaya Harbour ..	1932–35	D	1932–35	A	..	46	46
Other Stations	1948–51 (700 and 500 mb. only)	D	1949–51	B	1948–51 (700 and 500 mb. only)	2, 47	2
Manchuria	1942–44	D†	1942–44	B	1942–44	49	49
Korea	1942–44	D†	..	..	1942–44	50	..
China							
Nanking and Peiping ..	Unspecified period before 1942	A	..	..	..	52	..
Other Stations	1944–46	D	..	..	1944–46	9, 51	..
Hong Kong	{ 1947–48 (700 mb. only) / 1950–52 }	D	1950–53	A	{ 1947–48 (700 mb. only) / 1950–52 }	53, 54	53
Japan	1947–51	E*	1949–52	B	1947–51	9, 55, 56	55
Japanese Ocean Weather Stations	1949–51	D	1950–52	B	1949–51	55, 57	55
India	1944–49	A	1926–40	A	1944–49	6, 60, 62	58, 59, 61, 62
Malay Peninsula	1946–47	D	..	..	1946–47	12	..
Philippines	1949–52	D	..	..	1949–51	63	..
Indonesia							
Medan and Surabaja ..	1949	D	..	..	..	64	..
Batavia	1910–15	D	..	..	..	65	..
Australia	6–8 yr.	E	1949–52	A	1945, 1948–51	70, 71	69, 71
New Zealand	1944–51	D	3–9 yr.	A	1944–51	67, 72	66, 68
Heard and Macquarie Islands	3–4 yr.	D	1949–51	A	1948–51	70, 71	73
Adélie Land	1951	..	..	..	..	74	..
REGION IV—PACIFIC OCEAN (140° E. to 150° W.)							
Islands north of Equator ..	3–4 yr. between 1945–50	D	1950–51	C	3–4 yr. between 1945–50	1, 2, 9	9
Islands south of Equator ..	3–4 yr. between 1941–44 and 1949–51	D	1950–51	C	1949–51	9, 75	9
AIRCRAFT STATIONS and FLIGHTS							
Ptarmigan	1949–52 (700 and 500 mb. only)	D	..	..	1949–52 (500 mb. only)	76	..
Chivenor	1942, 1944, 1945	D	..	..	..	12	..
Epicure	1944–46	D	..	..	..	12	..
Nocturnal	1943–47	D	..	..	..	12	..

APPENDIX II—SOURCES OF DATA

GENERAL

1. Washington, Air Weather Service. *Northern hemisphere historical weather maps, sea level and* 500 *millibar.* Washington D.C., October 1945–July 1947.

2. Washington, Weather Bureau. *Daily series, synoptic weather maps.* Washington D.C., 1949–51.

3. Washington, Weather Bureau. *Daily upper air bulletin.* Washington D.C., October 1948–October 1949.

4. Washington, Navy Weather Central. *Daily upper air bulletin. Radiosondes. Winds aloft.* 1949 and 1952.

5. Washington, Weather Bureau. *Mon. Weath. Rev., Washington D.C.,* **74–77**, 1946–49.

6. Washington, Weather Bureau. *Mon. clim. Data, New Orleans La,* **2–5**, 1949–52. [700 to 200 mb.]

7. RATNER, B. ; Upper air average values of temperature, pressure and relative humidity over the United States and Alaska. *Tech. Pap., Weath. Bur., Washington D.C.,* No. 6, 1945.

8. Paris, Météorologie Nationale. Tableaux numériques de climatologie. Occurrences de températures observées aux niveaux isobariques 850 mb., 700 mb., 400 mb., 300 mb., 200 mb., 150 mb., et 100 mb. au cours des années 1946–50. Paris, 1950.

9. Washington, Weather Bureau. Microfilm data.

10. Toronto, Department of Transport, Meteorological Division. Microfilm data.

11. Hamburg, British Armed Forces of Occupation. MS. data for German occupied territories in Europe, 1941–45.

12. London, Meteorological Office. MS. data.

REGION I

Canada

13. Washington, Weather Bureau. Climatological summary, Resolute, N.W.T., Canada. Section 3. Upper air data for the period November, 1947 through December, 1950. New Orleans La, 1951.

14. Washington, Weather Bureau. Climatological Summary, Eureka, N.W.T., Canada. Section 3. Upper air data for the period June, 1947 through December, 1950. New Orleans La, 1951.

15. HENRY, T. J. G. and ARMSTRONG, G. R. ; Aerological data for northern Canada. Toronto, 1949.

16. Toronto, Department of Transport, Meteorological Division. Summaries of radiosonde observations in southern Canada, stations south of latitude 55° N., June 1941–December 1949. Toronto, 1952.

Brazil

17. SERRA, A. ; Climatologia da troposfera. Ministério da Agricultura, Serviço de Meteorologia, Rio de Janeiro, 1943

Argentina

18. GEORGII, W. ; Beitrag zur aerologie von Mendoza. *Ber. dtsch. Wetterdienstes U.S. Zone, Bad Kissingen,* No. 36, 1952.

REGION II

Greenland

19. Washington, Weather Bureau. Climatological summary, Thule, Greenland. Section 3. Upper air data for the period October, 1946 through December, 1949. Washington D.C., 1950.

Spitsbergen and Wordie Bay

20. TOMMILA, M. and RAUNIO, N. ; Aerologische Beobachtungen mit Radiosonden im Sommer 1937. *Mitt. Met. Inst. Univ., Helsinki,* No. 41, 1939.

Sweden

21. Stockholm, Statens Meteorologisk-Hydrografiska Anstalt. *Årsbok,* **22–26**, 1940–44. Stockholm, 1944–50.

22. ROLF, B. ; Lancers de ballons-sondes d'Abisko de 1921 à 1929. *Medd. met.-hydr. Anst., Stockholm,* **5**, No. 5, 1932.

Norway (including O.W.S.)

23. Oslo, Norske Meteorologiske Institutt. Microfilm data.

24. Oslo, Norske Meteorologiske Institutt. MS. data.

Belgium

25. Brussels, Institut Royal Météorologique de Belgique. Observations aérologiques de la station de radiosondage d'Uccle. Température et humidité relative de l'air aux pressions standards, 1945–48. Brussels, 1946–49.

Atlantic O.W.S. (*See also Norway and General*)

26. De Bilt, Koninklijk Nederlands Meteorologisch Instituut. *Upper air data*, **33**, 1948.

27. Paris, Météorologie Nationale. Microfilm data for Ships K and L.

Portugal (*including Azores*)

28. Lisbon, Serviço Meteorológico Nacional. *Boletim Meteorológico.* [Portuguese daily weather reports] 1948–51.

29. Lisbon, Serviço Meteorológico Nacional. MS. data for the Azores.

Italy

30. Hamburg, Deutsche Seewarte. *Täglicher Wetterbericht.* [North German daily weather reports] 1939–42.

Switzerland

31. Zürich, Schweizerische Meteorologische Zentralanstalt. *Ann. schweiz. met. ZentAnst, Zürich*, 1948–51.

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32. BÉLL, B.; Mittlere Werte der Temperatur in der freien Atmosphäre über Budapest. *Kleinere Veröff. Reichsanst. Met., Budapest*, Neue Reihe No. 10, 1941.

Sudan

33. Sudan Meteorological Office. MS. data for Khartoum.

Sahara

34. BRUYÈRE, P.; Rapport de la mission météorologique française sur les travaux effectués à Tamanrasset pendant l'année polaire. Année polaire internationale 1932–1933, Paris, **3**, 1941.

West Africa

35. Lagos, British West African Meteorological Service. MS. data 1949–51. Aircraft observations 1943–45.

East Africa

36. Nairobi, British East African Meteorological Department. MS. data for Nairobi supplied by the Director of the British East African Meteorological Service.

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South Africa

38. Pretoria, Weather Bureau. Upper air temperatures and humidities (1941–47). Pretoria, 1949.

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41. Rhodesia, Meteorological Department. MS. data.

Madagascar & Mauritius

42. Tananarive, Service Météorologique de Madagascar et Dépendances. MS. data.

REGION III

U.S.S.R.

43. FLOHN, H.; Zur Aerologie der Polargebiete. *Met. Rdsch., Berlin*, **5**, 1952, p. 81.

44. FLOHN, H.; Zum klima der freien Atmosphäre über Sibirien. *Met. Z., Braunschweig*, **61**, 1944, p. 50.

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46. TIKHOMIROV, E. I.; Geofizicheskiye Issledovaniya v Sovyetskoy Arktike. *Probl. Arct., Leningrad*, **3**, 1938, p. 43.

47. London, Meteorological Office. Data from teleprinter network, 1948 and 1950–52.

48. Hamburg, Deutsche Seewarte. *Täglicher Wetterbericht.* [North German daily weather reports] 1936–39.

Manchuria

49. Tokyo, Central Meteorological Observatory. Aerological data of Manchuria, 1942–44. Tokyo, 1950.

Korea

50. Tokyo, Central Meteorological Observatory. Aerological data of Korea, 1942–44. Tokyo, 1950.

China

51. Tokyo, Central Meteorological Observatory. Aerological data of Dairen, Sept.–Dec. 1944 and Jan.–March 1945. Tokyo, 1950.

52. ARAKAWA, H.; Upper-air temperatures and humidities in eastern Asia. *J. met. Soc. Japan, Tokyo*, **20**, 1942, p. 374.

Hong Kong

53. Hong Kong, Royal Observatory. MS. data.

54. Hong Kong, Royal Observatory. Meteorological Results, Pt. II, 1947–48.

Japan (including O.W.S.)

55. Tokyo, Central Meteorological Observatory. *Aerol. Data Japan, Tokyo*, 1947–52.

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Philippines

63. Manila, Weather Bureau. MS. data.

Indonesia

64. Djakarta, Indonesian Meteorological Service. MS. data for Medan and Surabaja.

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REGION IV

Pacific Islands (*south of equator*)

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AIRCRAFT STATIONS & FLIGHTS

76. Washington, Air Weather Service. MS. data (Ptarmigan Flights).

APPENDIX III—AVERAGE TEMPERATURE AT STANDARD LEVELS IN 10 DEGREE ZONES OF LATITUDE

	700 mb.	500 mb.	300 mb.	200 mb.	150 mb.	100 mb.	700 mb.	500 mb.	300 mb.	200 mb.	150 mb.	100 mb.
						degrees Absolute						
° N.			JANUARY						APRIL			
90*	246	234	214	213	211	209	248	234·5	218·5	225·5	226	226
80	246·7	233·6	214·6	213·4	211·9	210·2	249·4	235·6	219·6	225·2	226·3	226·5
70	248·8	235·3	215·2	214·8	213·5	213·2	253·4	239·2	220·9	224·4	226·0	226·2
60	253·1	239·0	218·5	216·4	218·6	218·2	258·6	243·9	222·8	222·7	224·6	224·0
50	258·2	244·1	221·9	218·0	220·3	219·7	264·1	249·1	225·2	219·7	221·5	220·8
40	265·7	250·3	226·5	217·9	217·8	215·0	270·3	254·6	228·8	217·0	217·6	216·1
30	273·5	257·9	232·6	218·9	212·8	205·9	276·9	260·8	234·2	217·4	213·2	208·3
20	279·9	263·8	237·6	219·2	209·0	198·4	281·4	265·3	238·9	218·9	209·0	200·0
10	282·4	267·1	240·4	219·3	206·1	193·7	282·9	267·4	241·8	220·2	206·8	194·8
0	282·8	268·2	241·5	219·1	205·4	192·8	282·9	268·1	242·6	220·8	206·4	193·9
° S.												
10	282·6	268·0	242·0	219·7	205·8	193·5	282·7	267·7	241·8	220·5	206·6	194·8
20	282·2	267·0	241·3	220·2	207·7	196·8	281·4	265·6	239·5	219·7	207·9	198·1
30	280·2	263·6	236·6	219·3	211·0	204·6	277·7	260·5	235·1	217·9	211·2	205·4
40	274·1	258·2	231·7	218·4	216·5	214·7	271·6	254·8	230·1	216·5	215·7	213·8
50	267·0	252·3	228·5	223·5	223·1	223·6	265·8	249·8	225·9	218·8	219·4	218·7
° N.			JULY						OCTOBER			
90*	264·5	250·5	227	231·5	231·5	232	251	237	219	222	222	220
80	266·0	251·4	227·9	229·3	231·1	231·4	253·0	239·3	220·0	222·1	222·5	220·6
70	268·8	253·8	229·8	226·5	229·3	229·3	257·3	243·4	221·9	221·4	222·6	221·4
60	271·7	256·6	231·4	224·2	226·5	226·6	262·0	246·6	224·6	221·0	221·4	220·9
50	275·7	260·6	235·0	222·3	222·1	222·1	267·7	252·4	228·4	219·6	218·4	218·0
40	280·7	264·8	239·3	222·0	215·9	213·1	273·7	258·3	233·1	218·5	214·3	212·2
30	283·4	267·5	241·7	221·5	211·1	204·6	279·5	263·9	237·9	218·6	209·8	204·5
20	283·8	267·7	241·7	220·0	207·8	199·0	282·1	266·6	240·7	219·6	206·6	198·1
10	282·7	267·3	241·3	218·9	206·2	196·7	283·1	267·4	241·7	219·7	204·9	194·9
0	281·9	267·0	241·1	218·8	206·4	197·0	282·9	267·3	241·8	219·5	204·6	194·6
° S.												
10	280·9	266·3	240·5	219·6	207·4	198·7	282·3	266·9	241·0	219·4	206·0	197·0
20	278·3	263·6	238·6	220·4	210·2	202·8	280·2	264·5	238·7	219·4	208·7	202·5
30	272·8	256·4	232·0	220·7	215·3	210·9	275·5	260·3	233·1	219·7	213·6	209·9
40	267·0	249·4	224·4	219·2	218·5	217·2	269·2	254·2	228·6	220·1	219·6	218·1
50	261·3	245·3	220·3	215·7	217·2	215·7	262·9	247·7	223·9	219·6	221·1	221·5

*Average temperatures at 90° of latitude are given to the nearest ½° A.

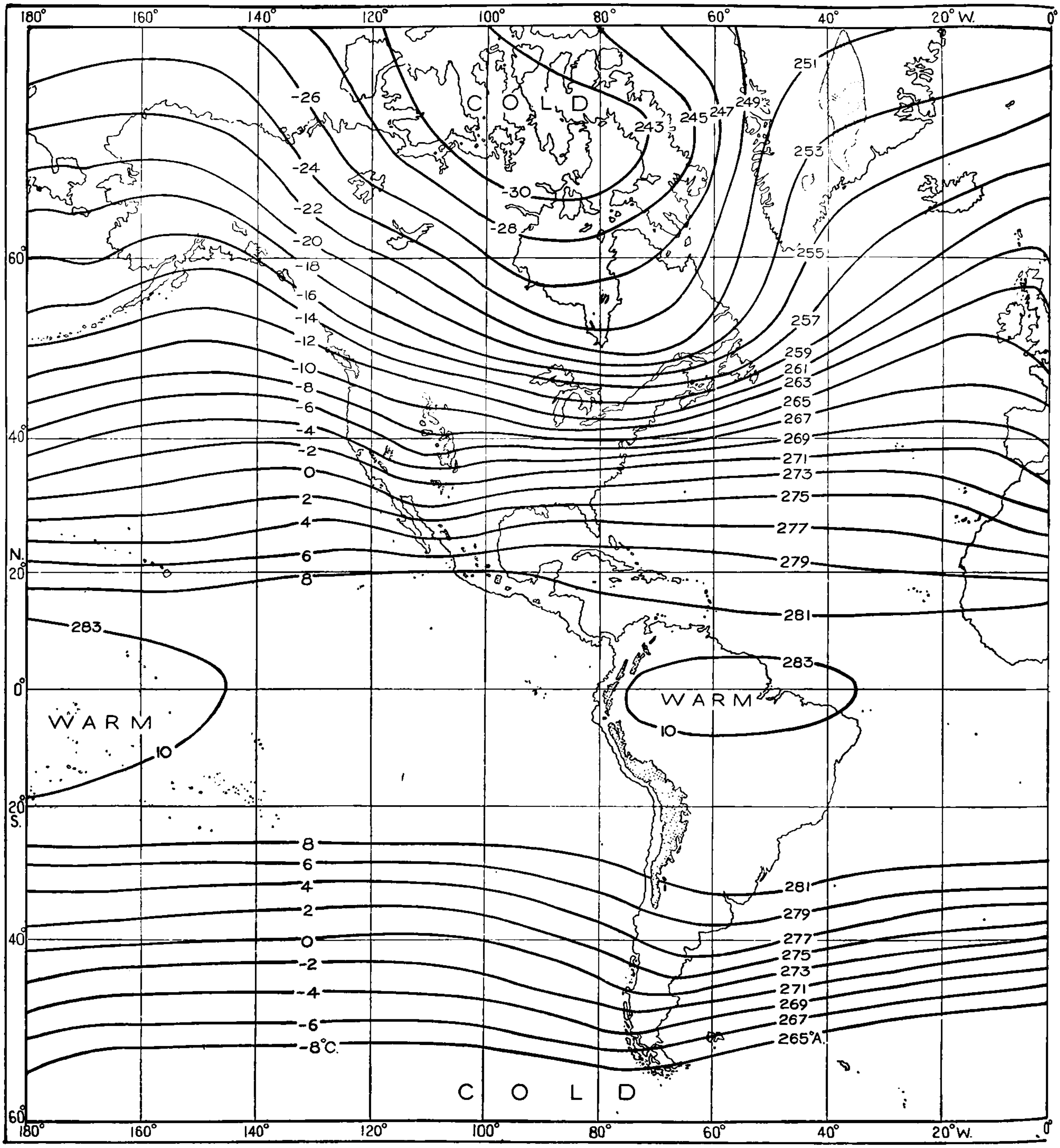

PLATE 1—AVERAGE TEMPERATURE AT 700 MB. IN JANUARY

I.C.A.N. height = 9,876 ft. = 3,010 m.

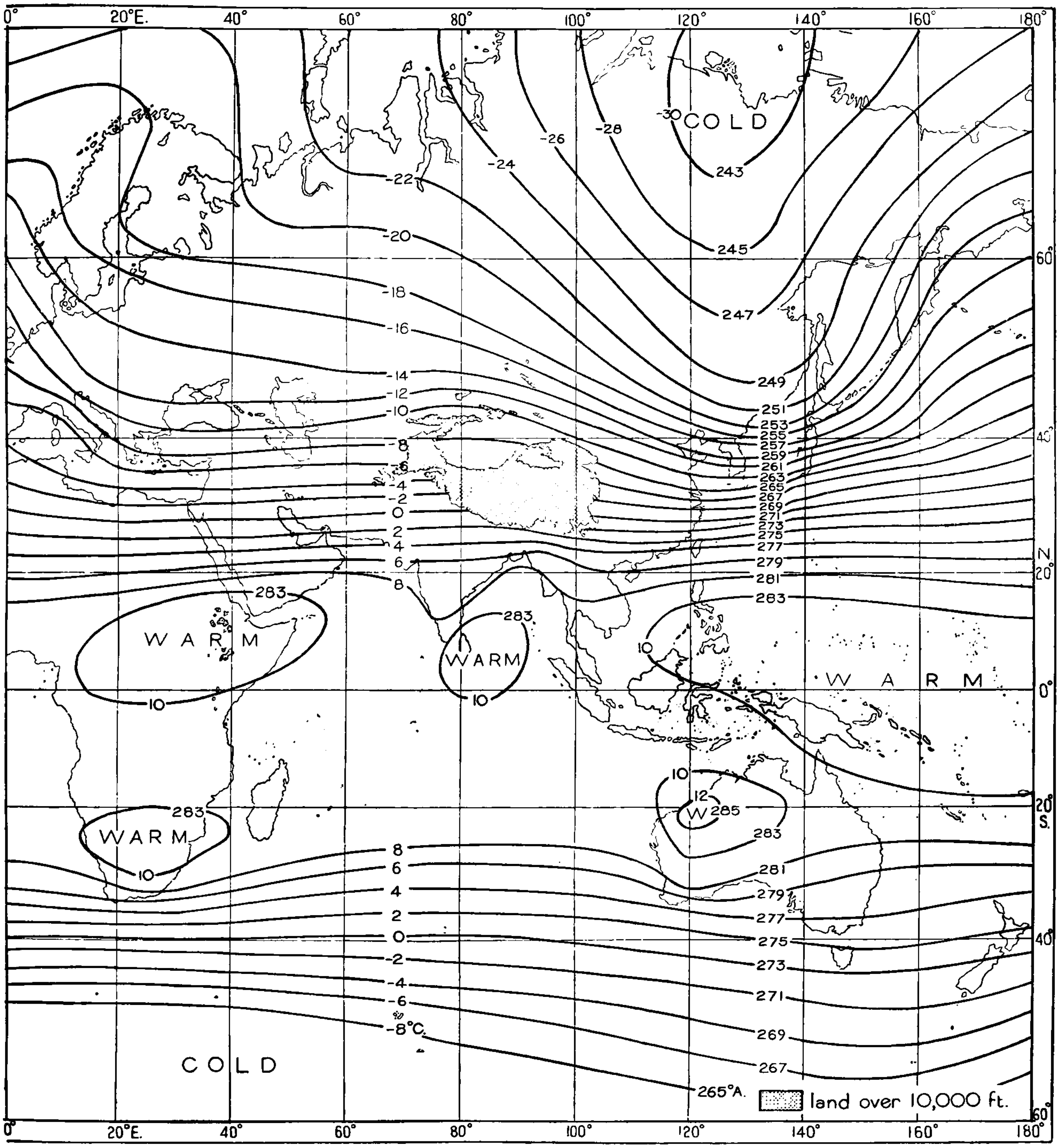

PLATE 1—CONTINUED

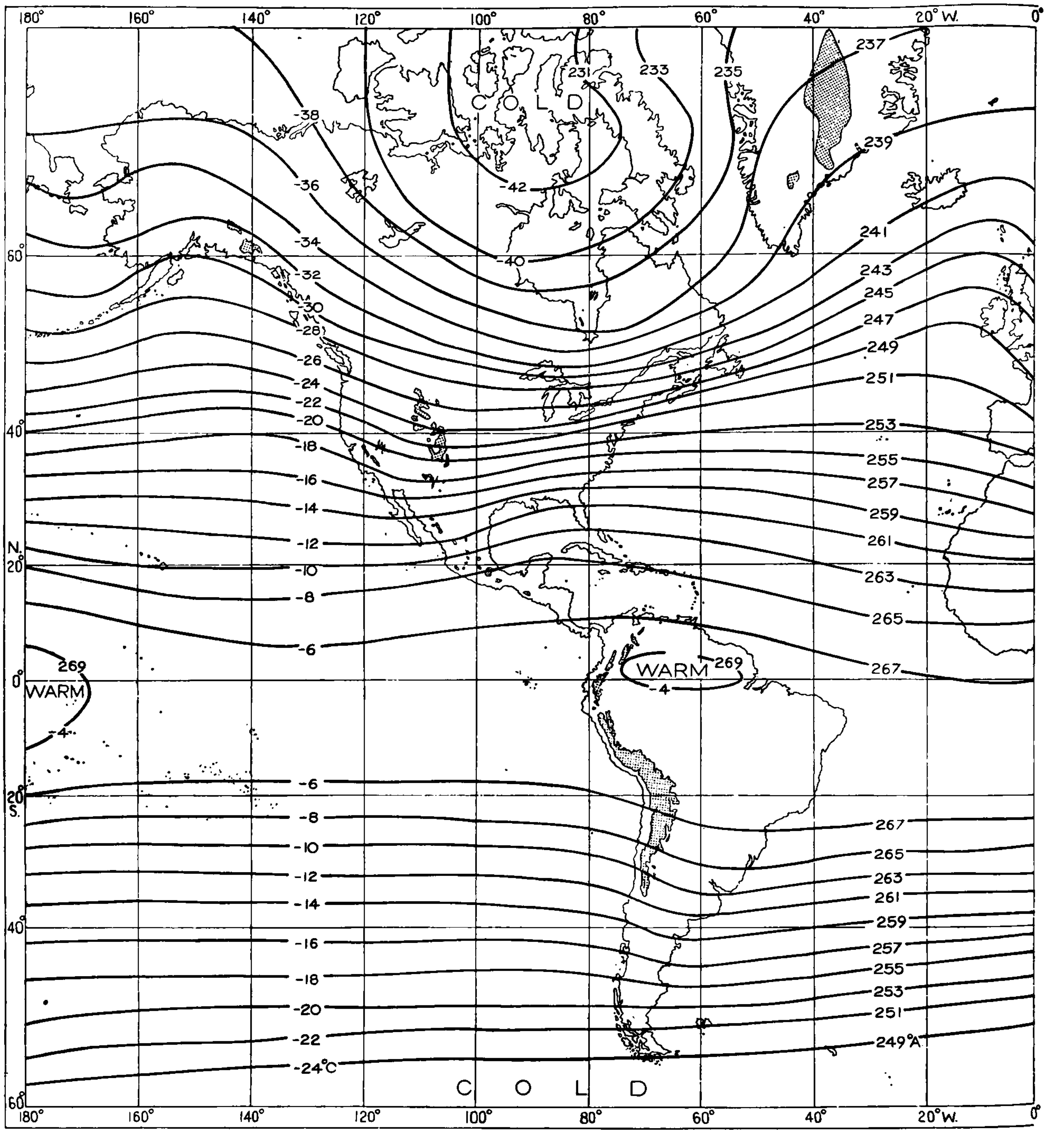

PLATE 2—AVERAGE TEMPERATURE AT 500 MB. IN JANUARY

I.C.A.N. height = 18,278 ft. = 5,571 m.

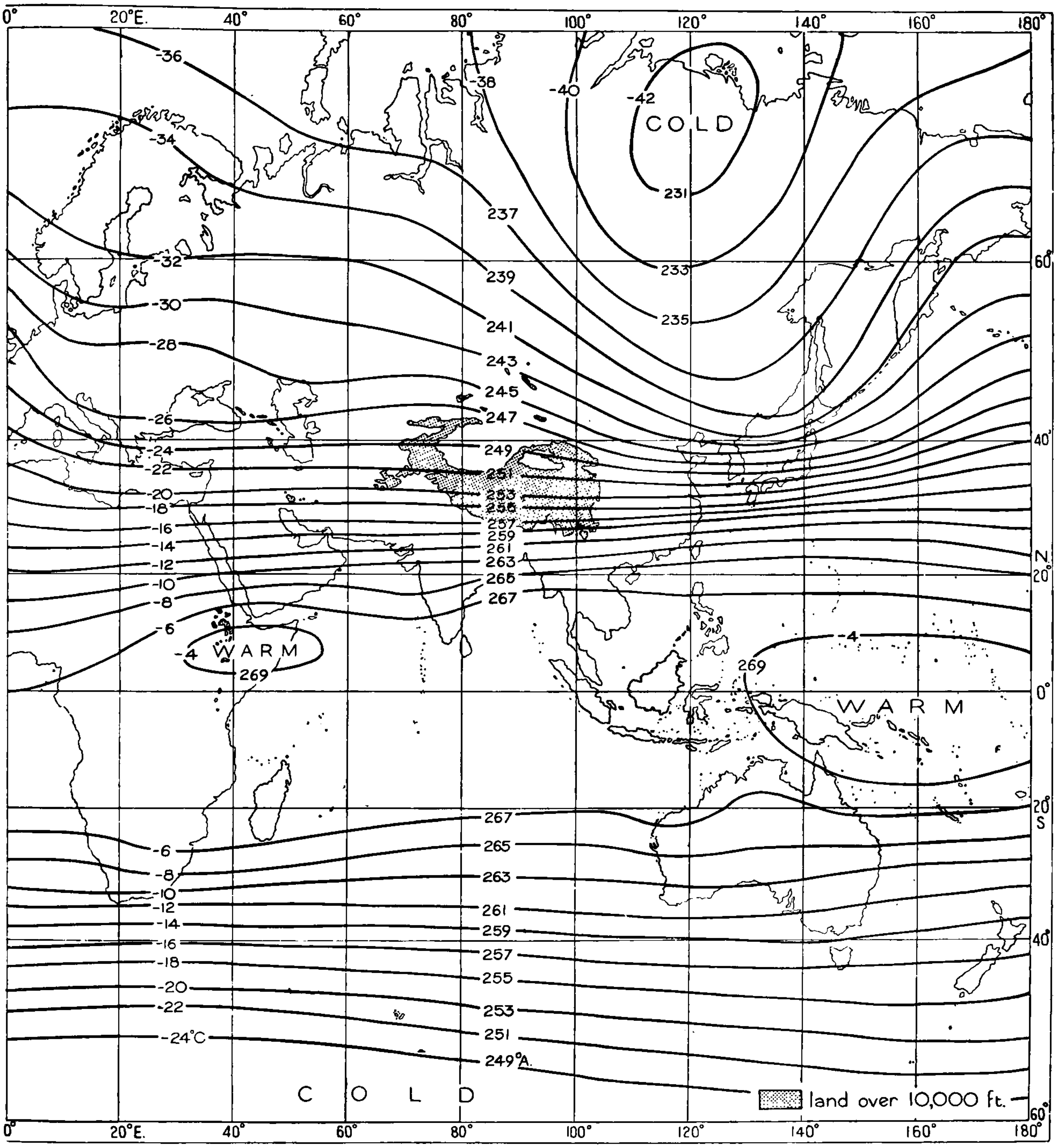

PLATE 2—CONTINUED

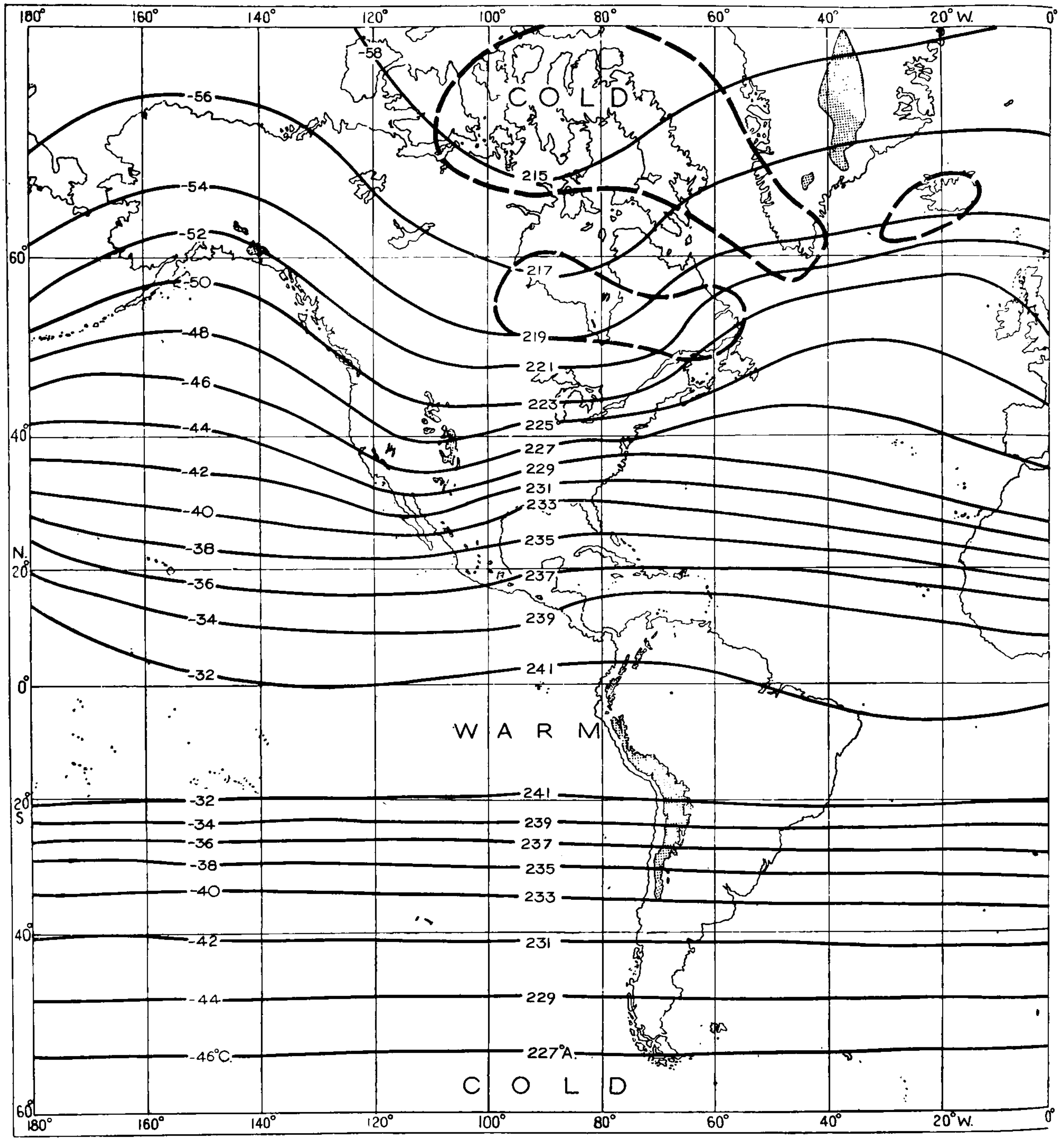

PLATE 3—AVERAGE TEMPERATURE AT 300 MB. IN JANUARY

I.C.A.N. height = 30,059 ft. = 9,162 m.

The thick broken line indicates the intersection of the 300-mb. and average tropopause surfaces.

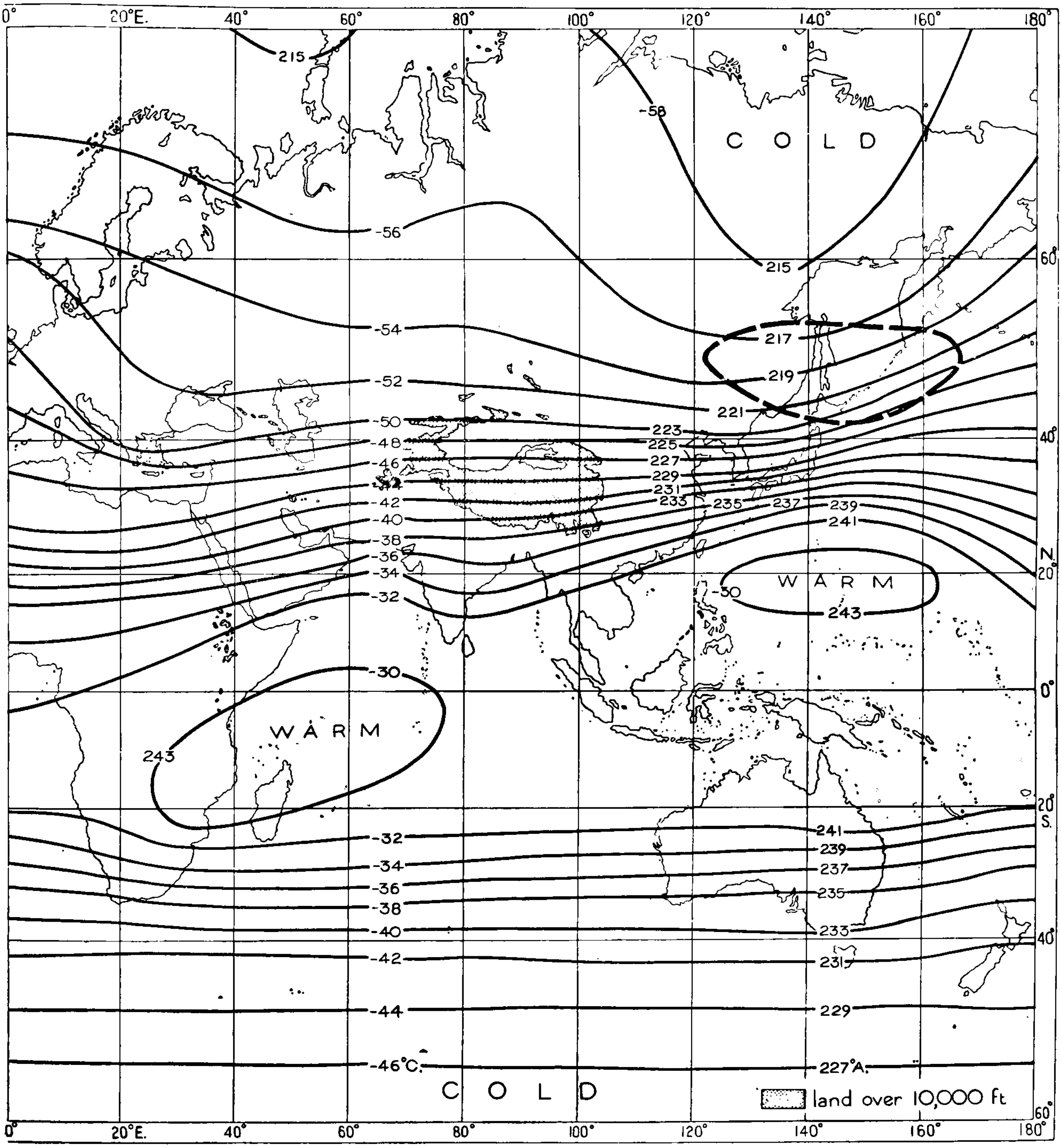

PLATE 3—CONTINUED

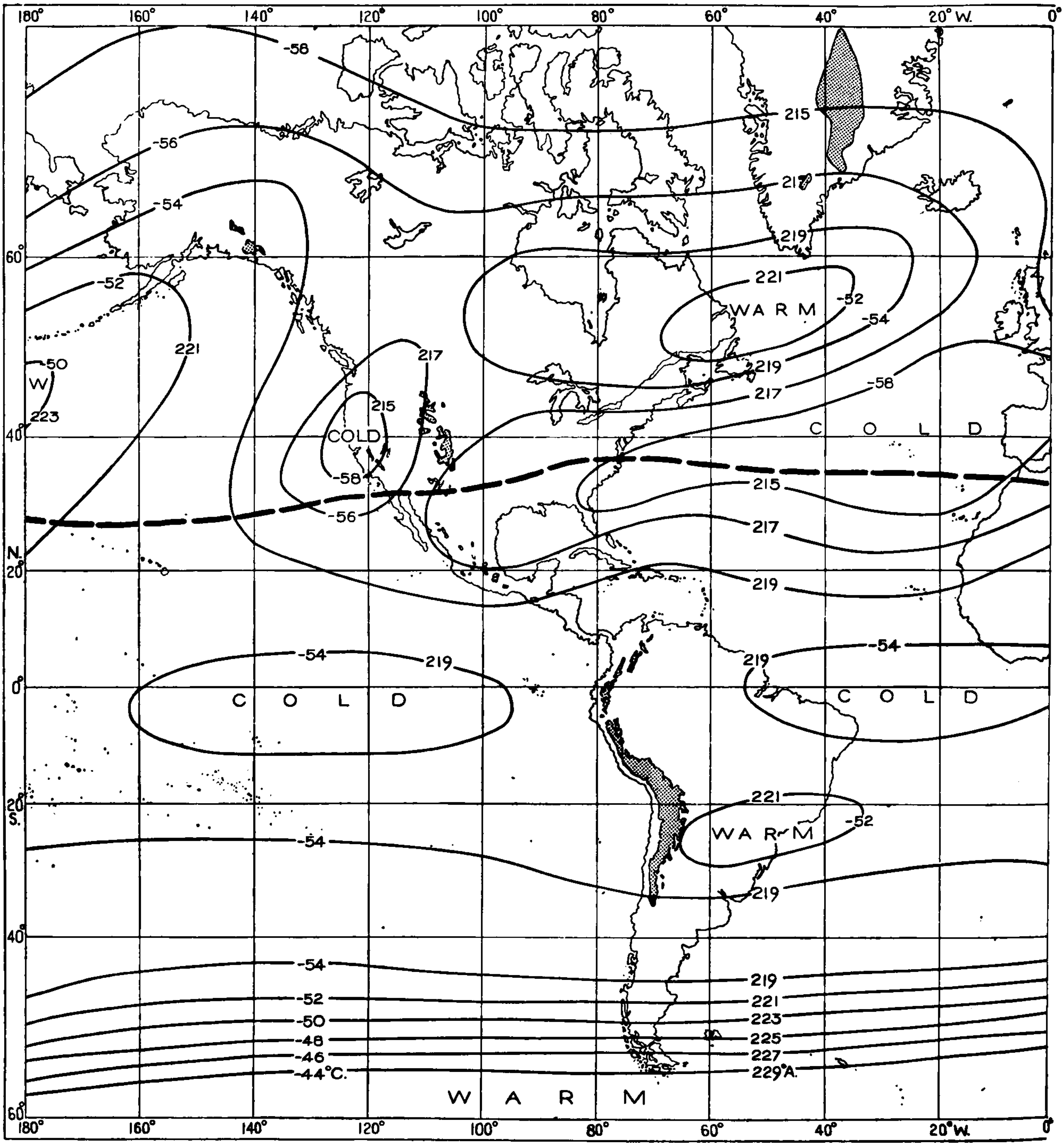

PLATE 4—AVERAGE TEMPERATURE AT 200 MB. IN JANUARY

I.C.A.N. height = 38,644 ft. = 11,779 m.

The thick broken line indicates the intersection of the 200-mb. and average tropopause surfaces.

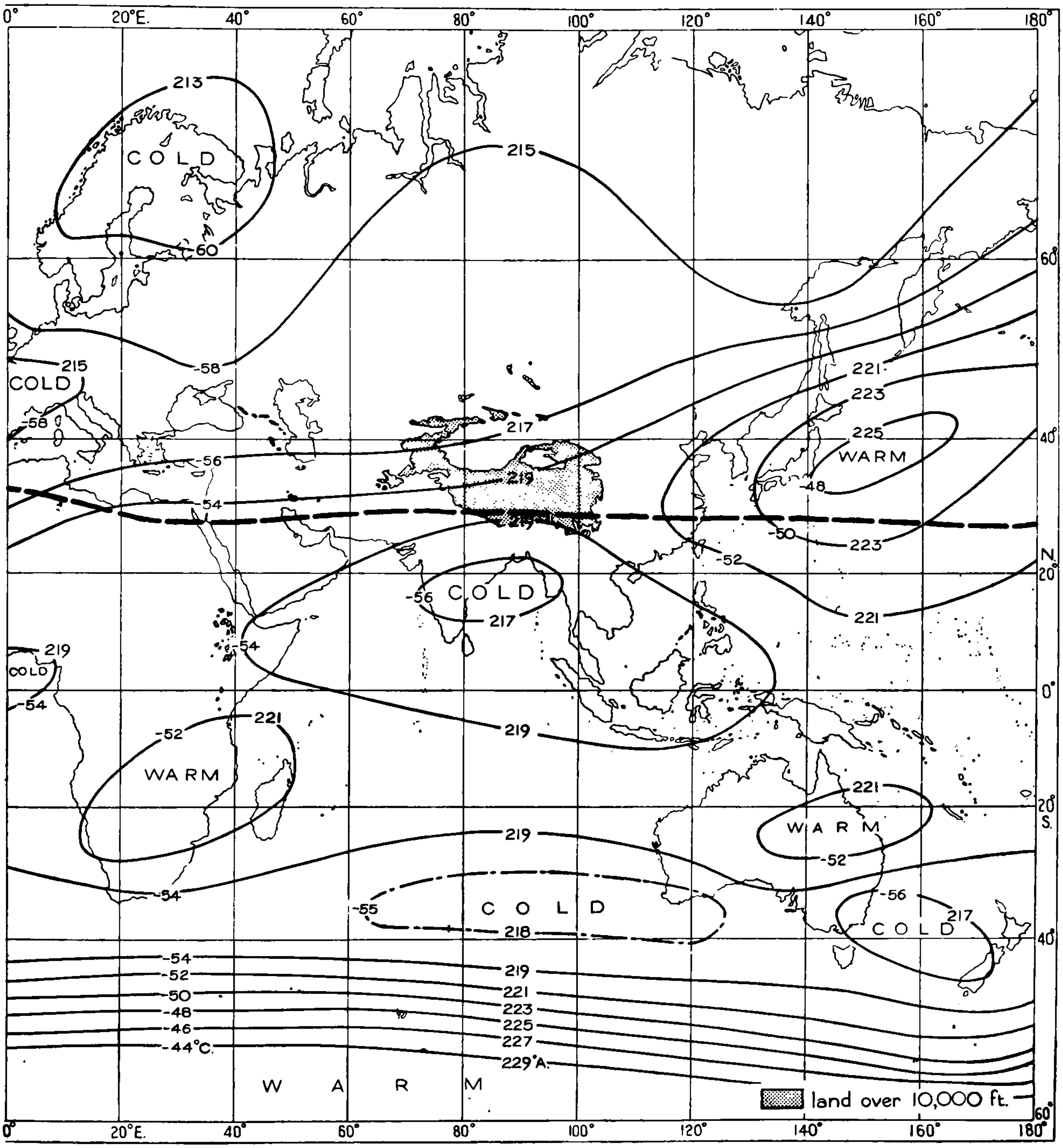

PLATE 4—CONTINUED

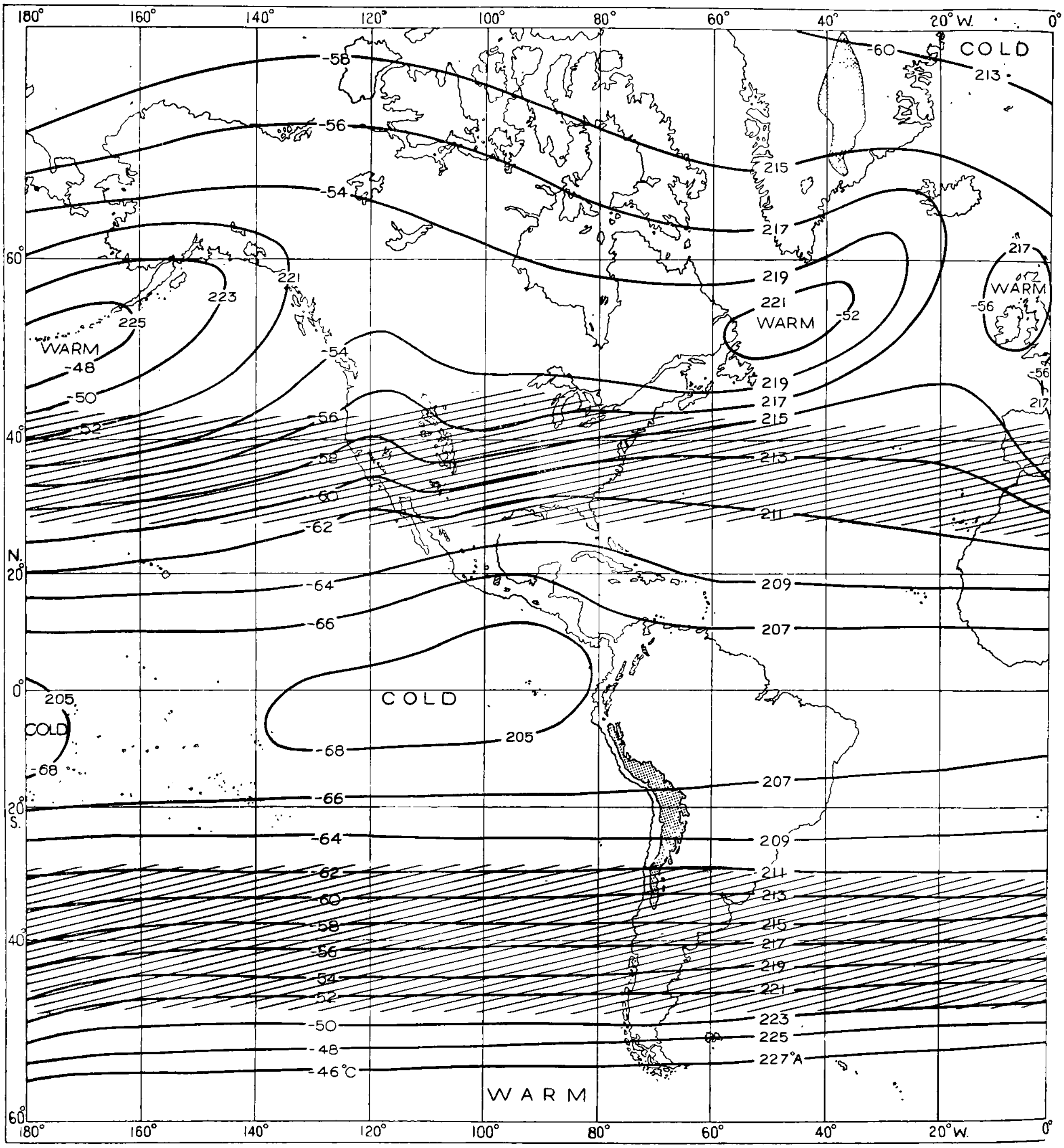

PLATE 5—AVERAGE TEMPERATURE AT 150 MB. IN JANUARY

I.C.A.N. height = 44,625 ft. = 13,602 m.

Areas in which the frequencies of occurrences of both tropopauses are greater than 10 per cent. are shaded.

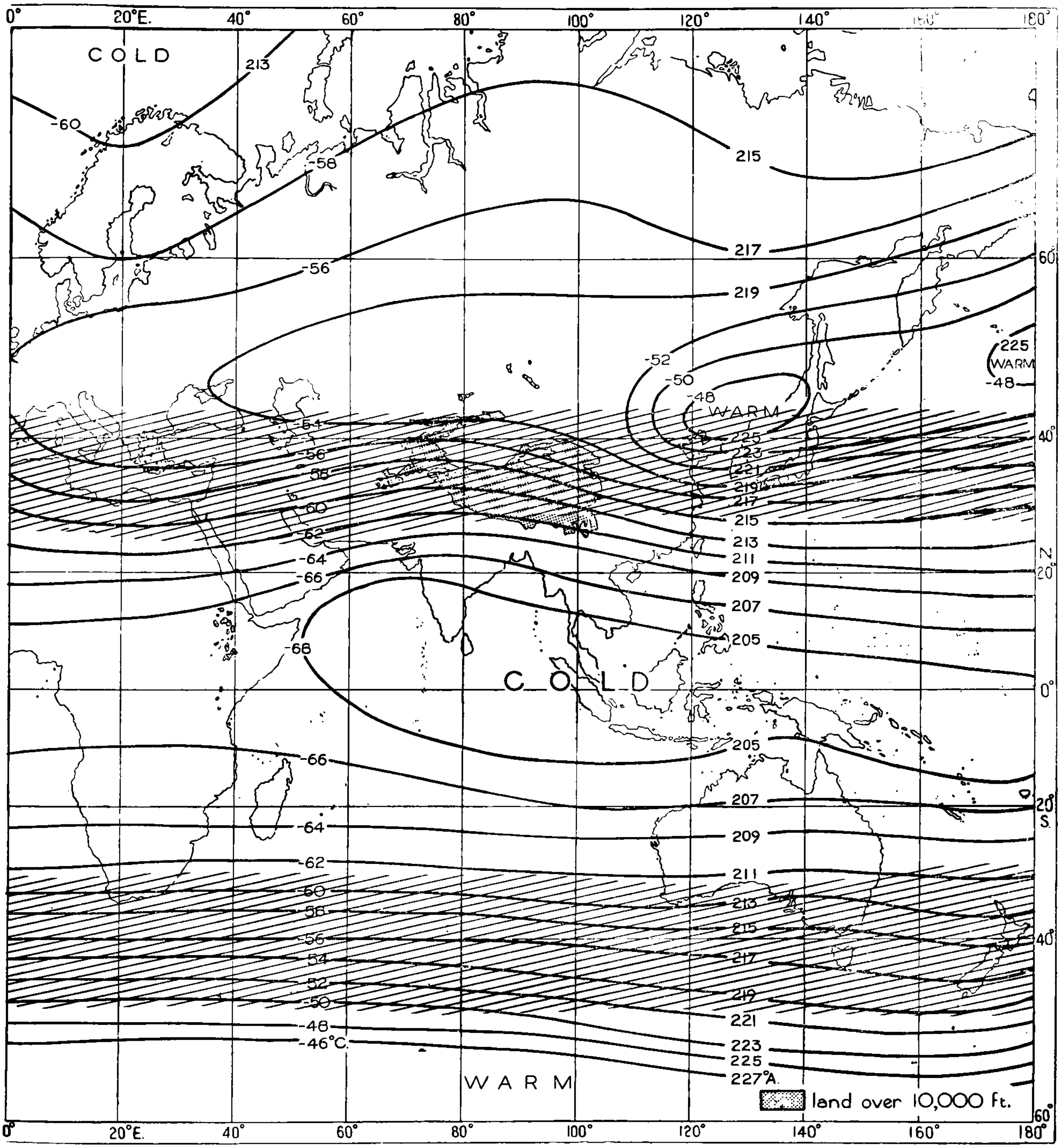

PLATE 5—CONTINUED

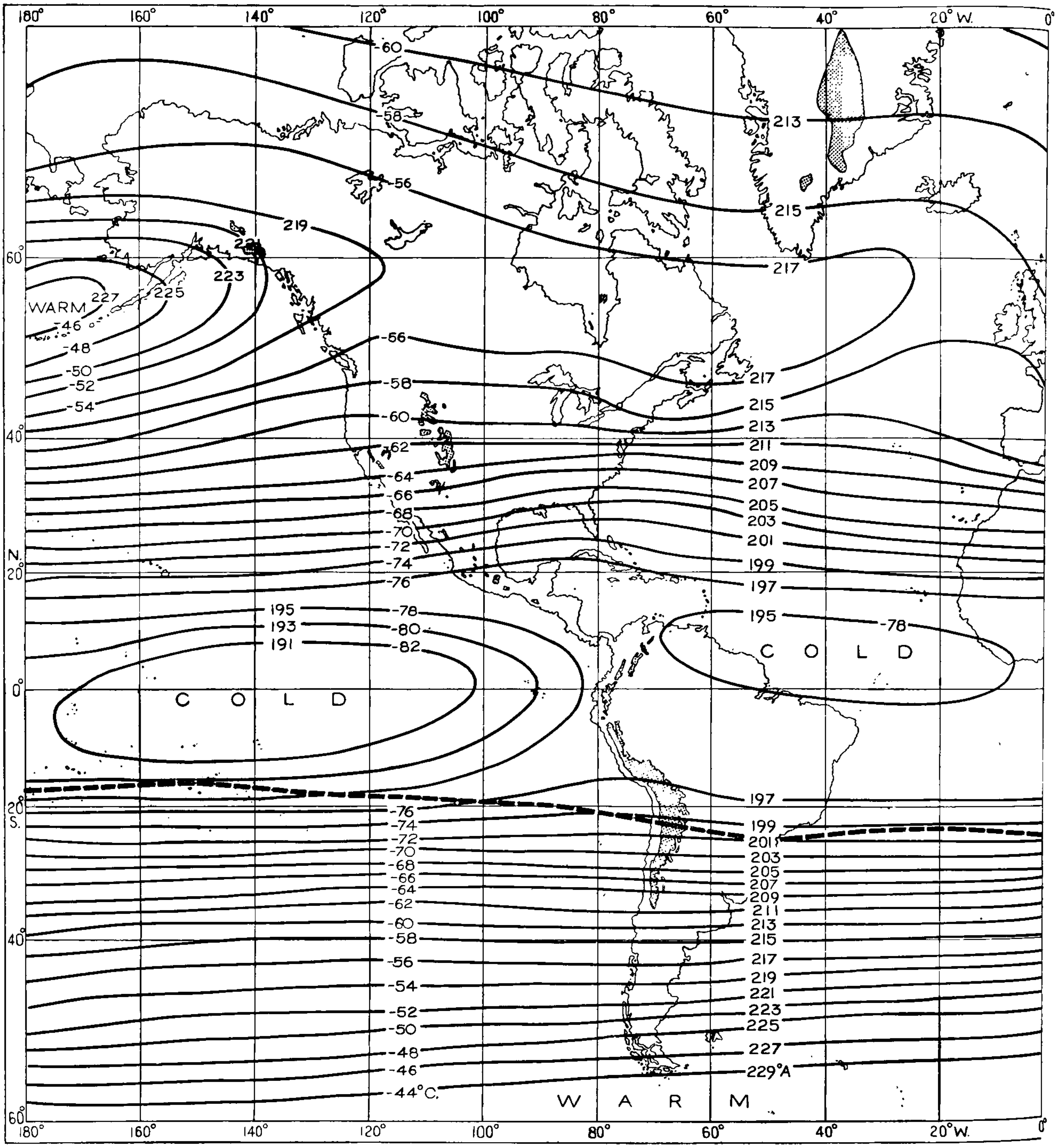

PLATE 6—AVERAGE TEMPERATURE AT 100 MB. IN JANUARY

I.C.A.N. height = 53,054 ft. = 16,170 m.

The thick broken line indicates the intersection of the 100-mb. and average tropopause surfaces.

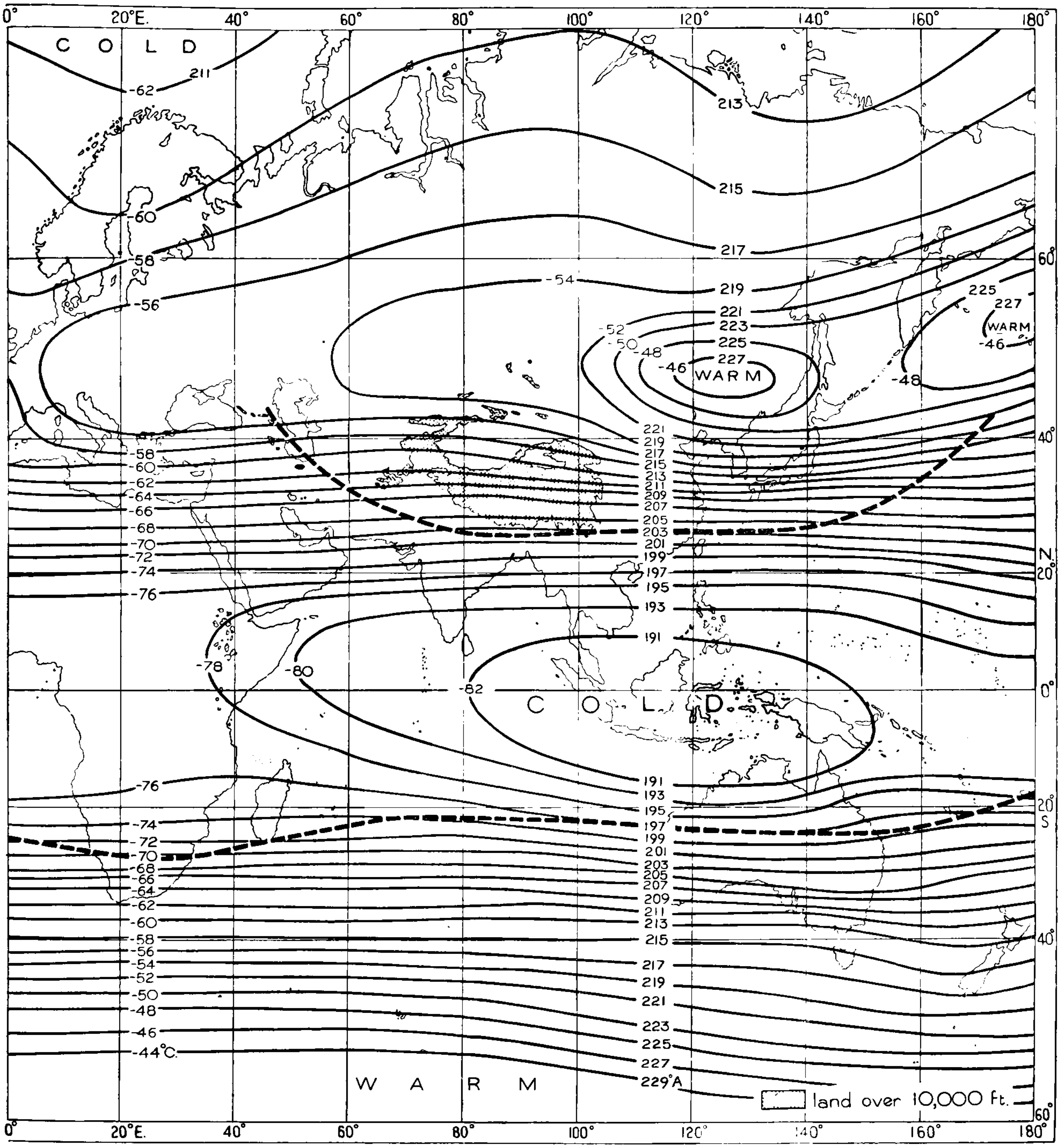

PLATE 6—CONTINUED

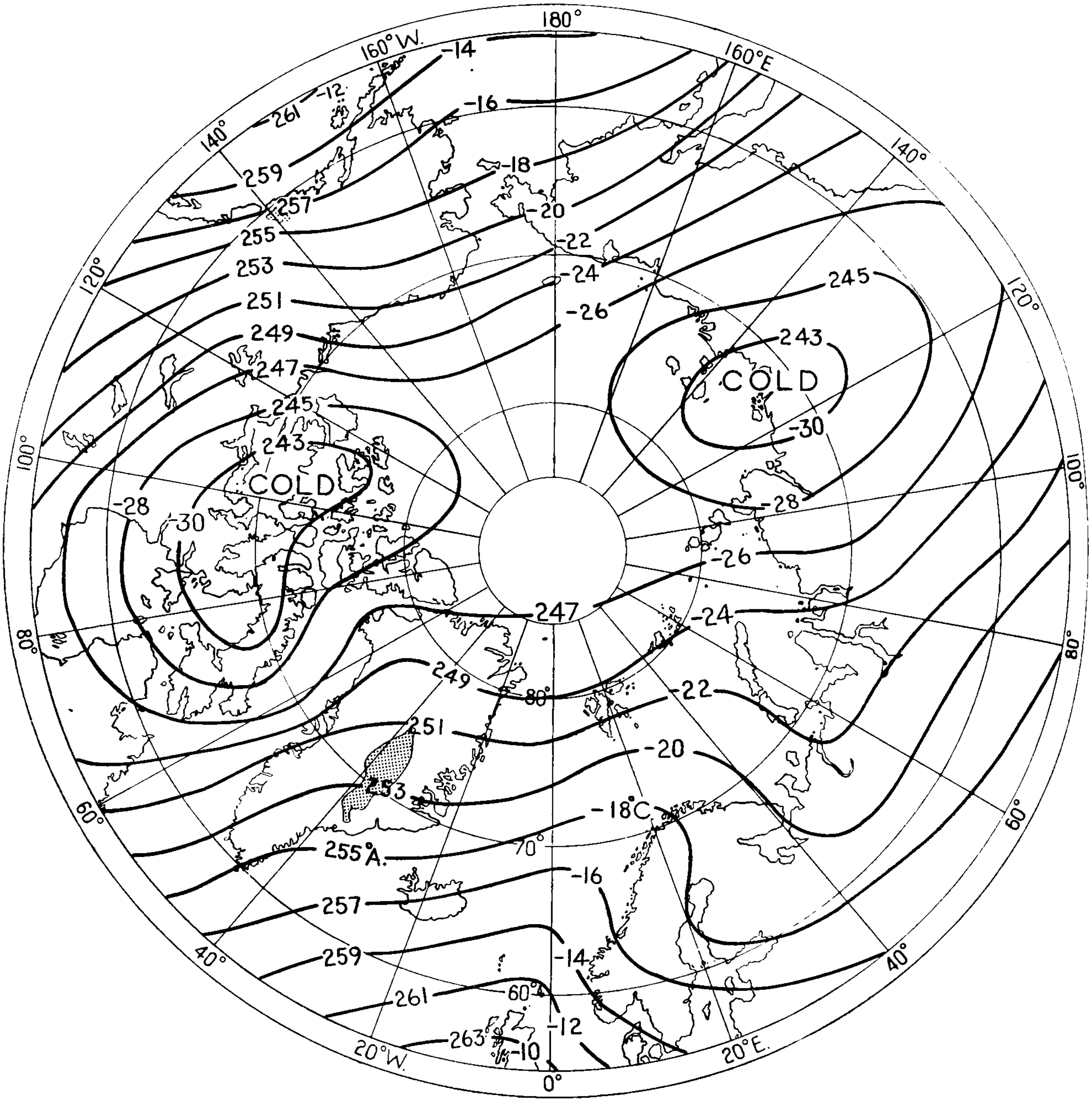

PLATE 7A—AVERAGE TEMPERATURE AT 700 MB. IN JANUARY

I.C.A.N. height = 9,876 ft. = 3,010 m.

Land over 10,000 feet is represented by shading.

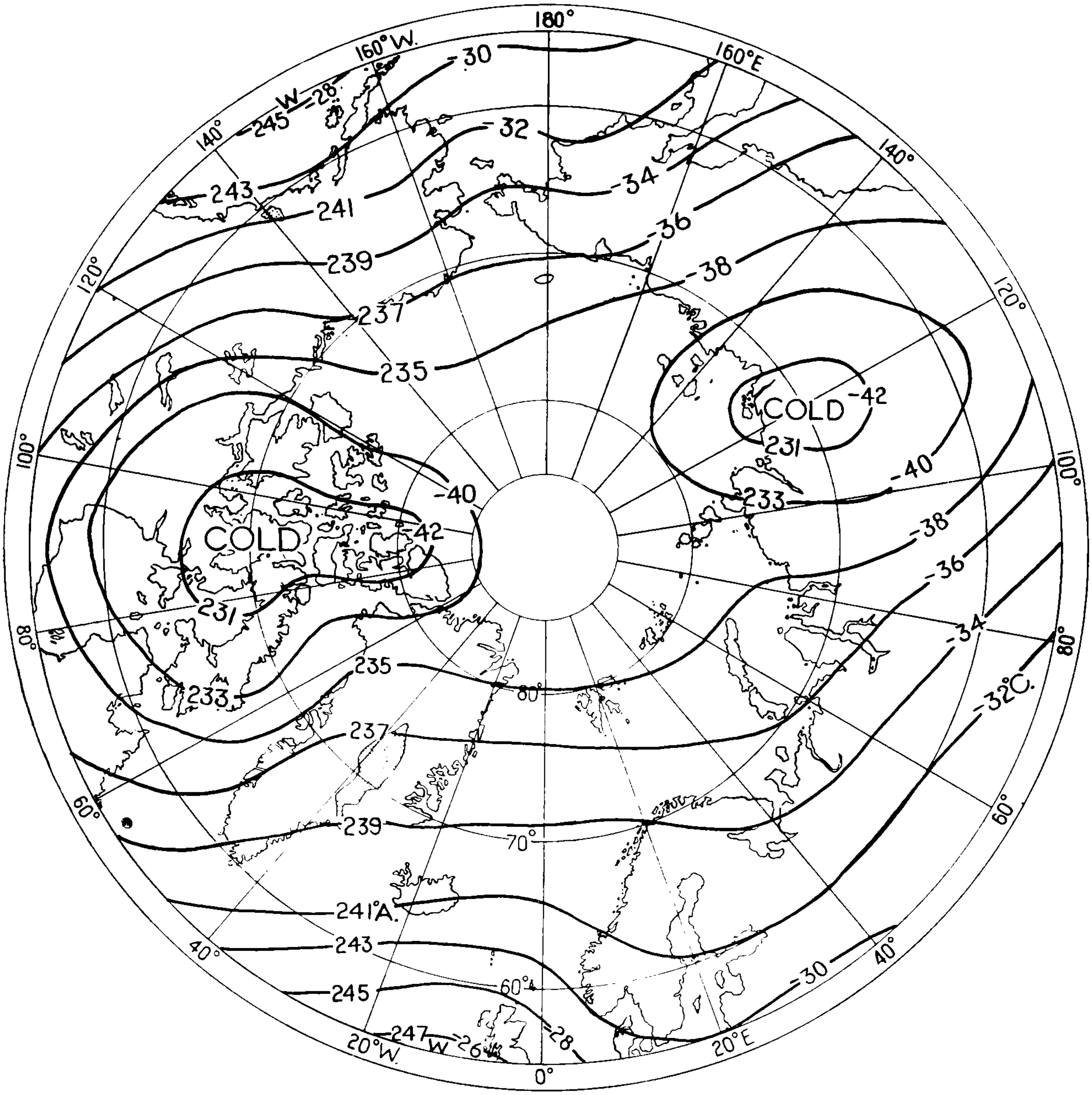

PLATE 7B—AVERAGE TEMPERATURE AT 500 MB. IN JANUARY

I.C.A.N. height = 18,278 ft. = 5,571 m.

Land over 10,000 feet is represented by shading.

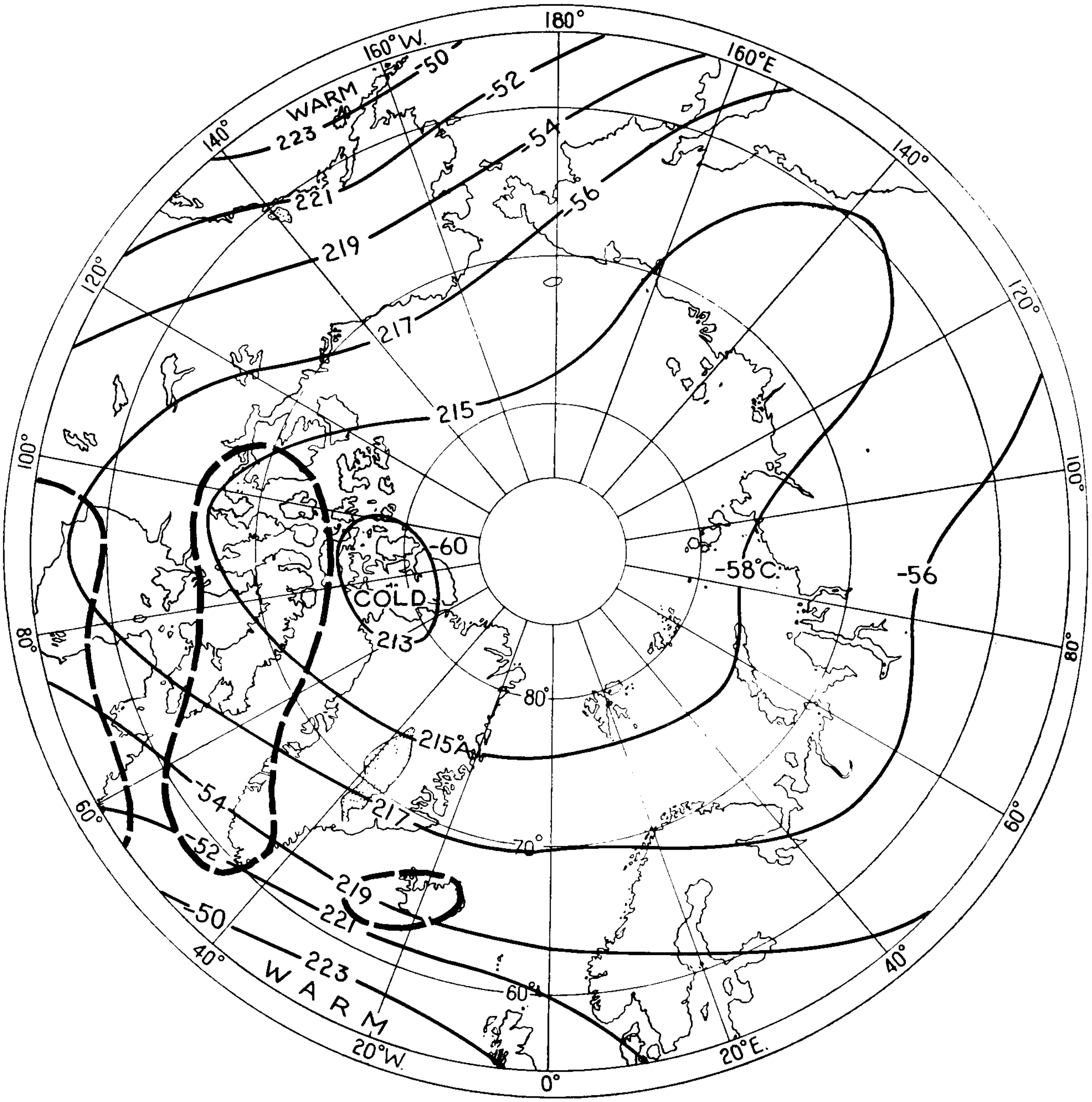

PLATE 7c—AVERAGE TEMPERATURE AT 300 MB. IN JANUARY

I.C.A.N. height = 30,059 ft. = 9,162 m.

The thick broken line indicates the intersection of the 300-mb. and average tropopause surfaces.

Land over 10,000 feet is represented by shading.

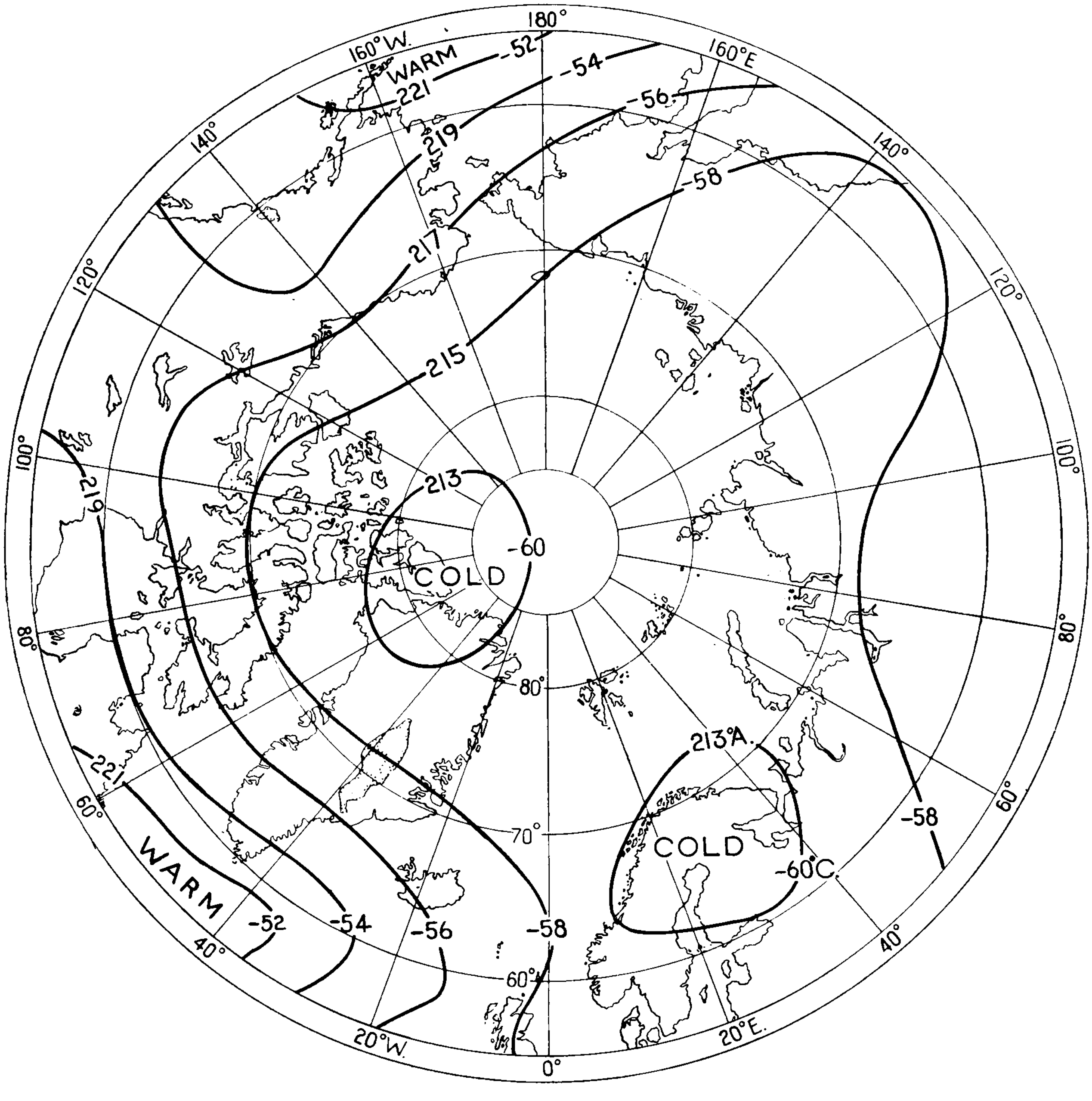

PLATE 8A—AVERAGE TEMPERATURE AT 200 MB. IN JANUARY

I.C.A.N. height = 38,644 ft. = 11,779 m.

Land over 10,000 feet is represented by shading.

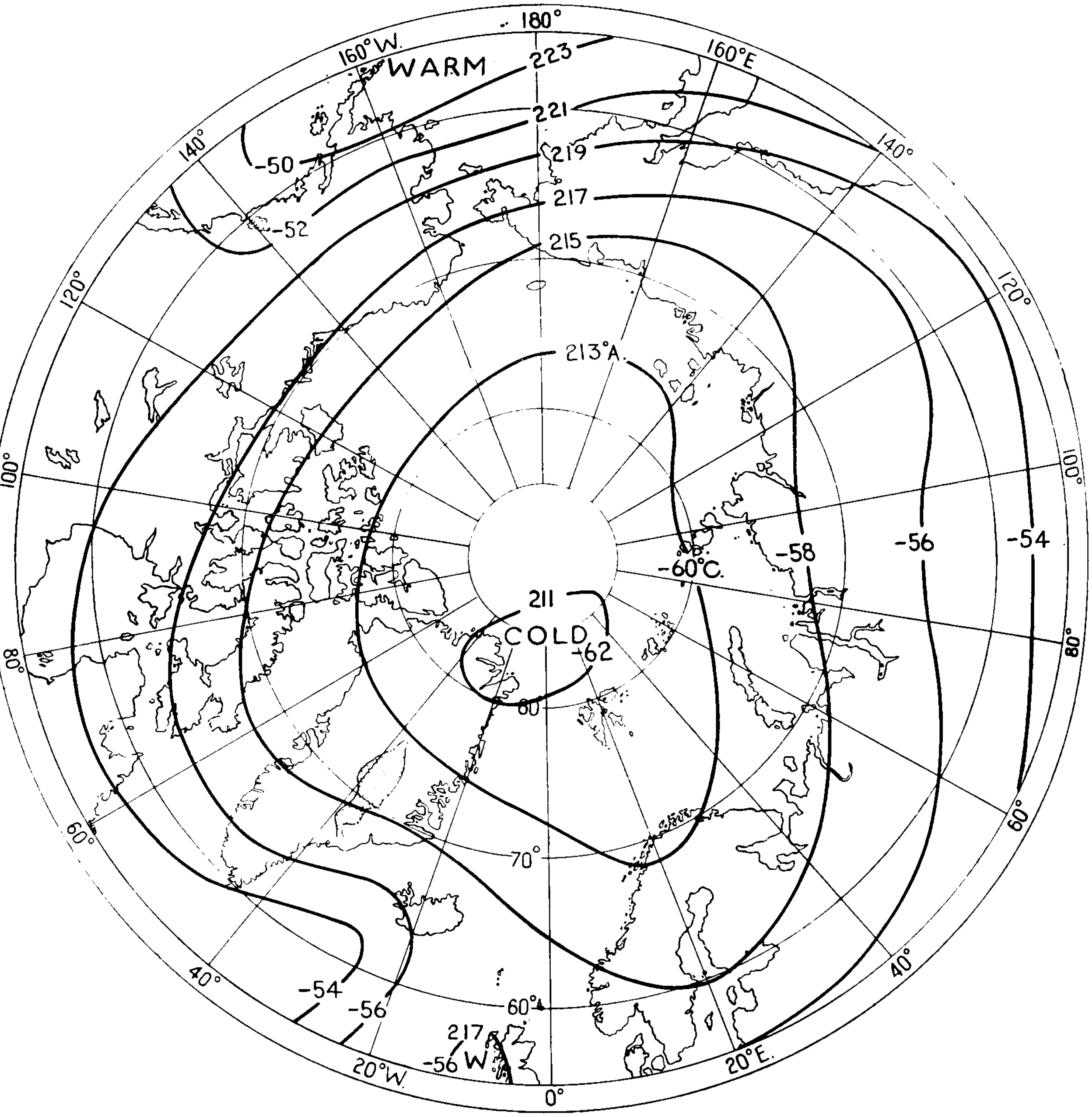

PLATE 8B—AVERAGE TEMPERATURE AT 150 MB. IN JANUARY

I.C.A.N. height = 44,625 ft. = 13,602 m.

Land over 10,000 feet is represented by shading.

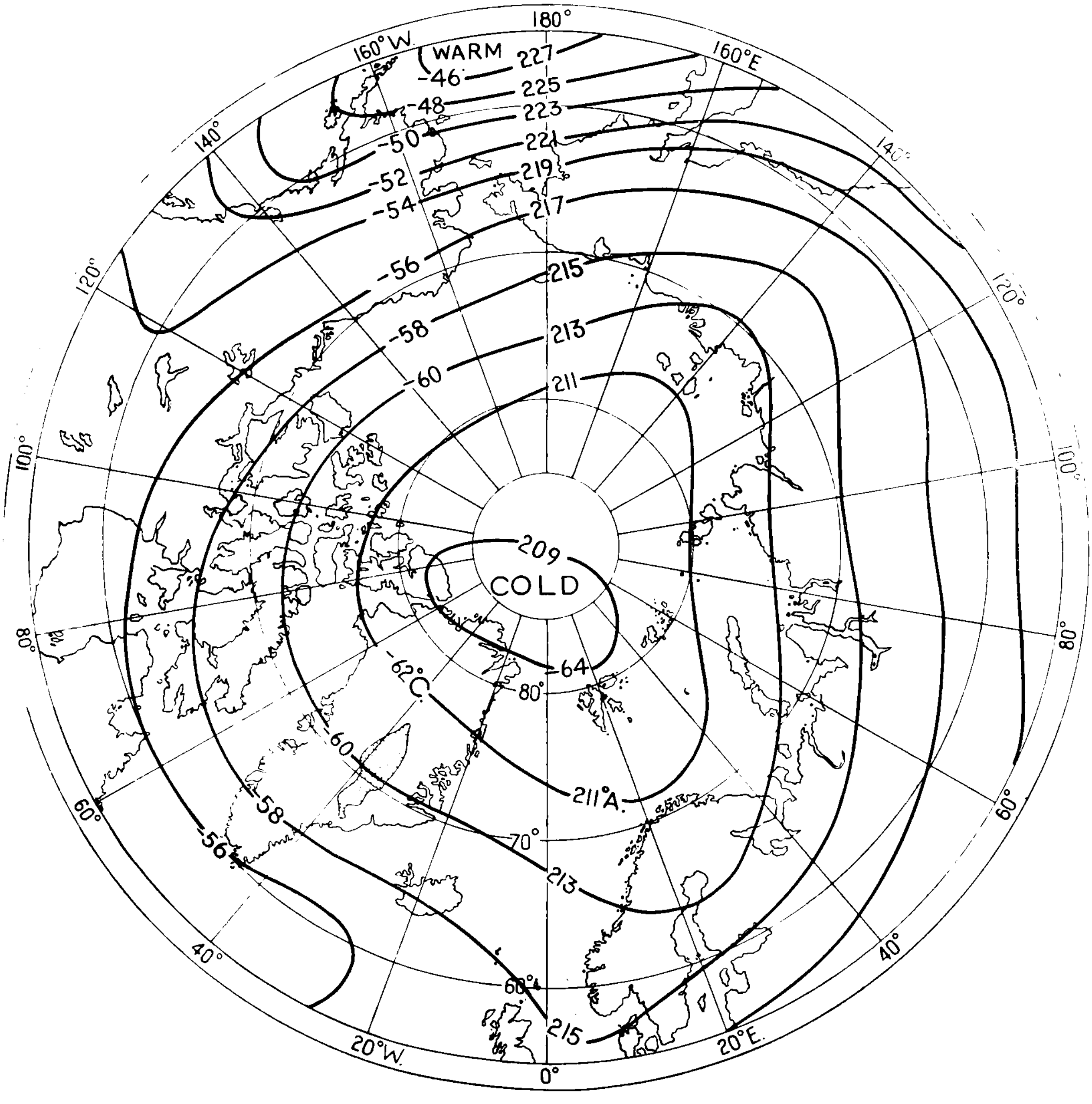

PLATE 8c—AVERAGE TEMPERATURE AT 100 MB. IN JANUARY
I.C.A.N. height = 53,054 ft. = 16,170 m.
Land over 10,000 feet is represented by shading.

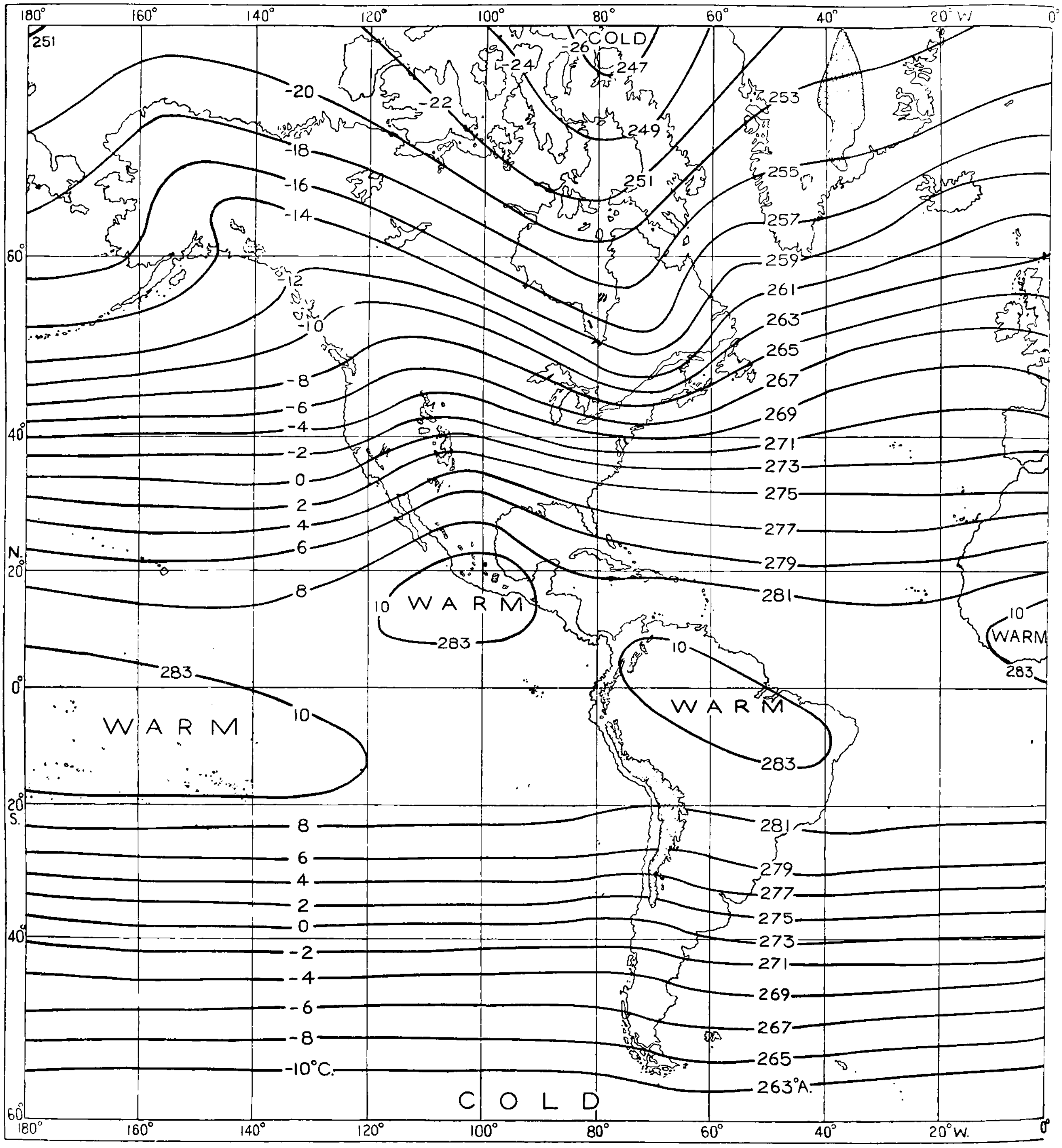

PLATE 9—AVERAGE TEMPERATURE AT 700 MB. IN APRIL

I.C.A.N. height = 9,876 ft. = 3,010 m.

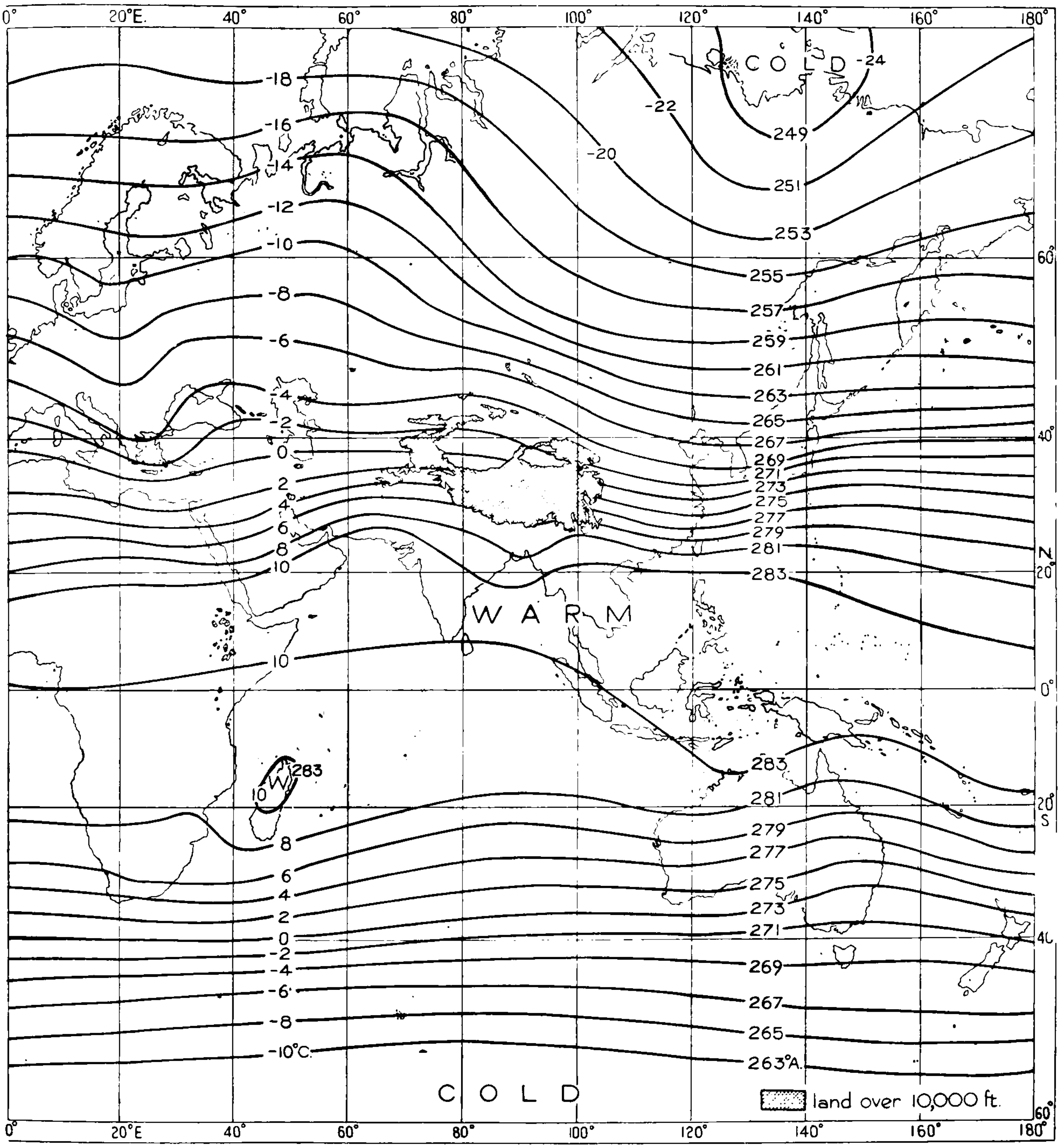

PLATE 9—CONTINUED

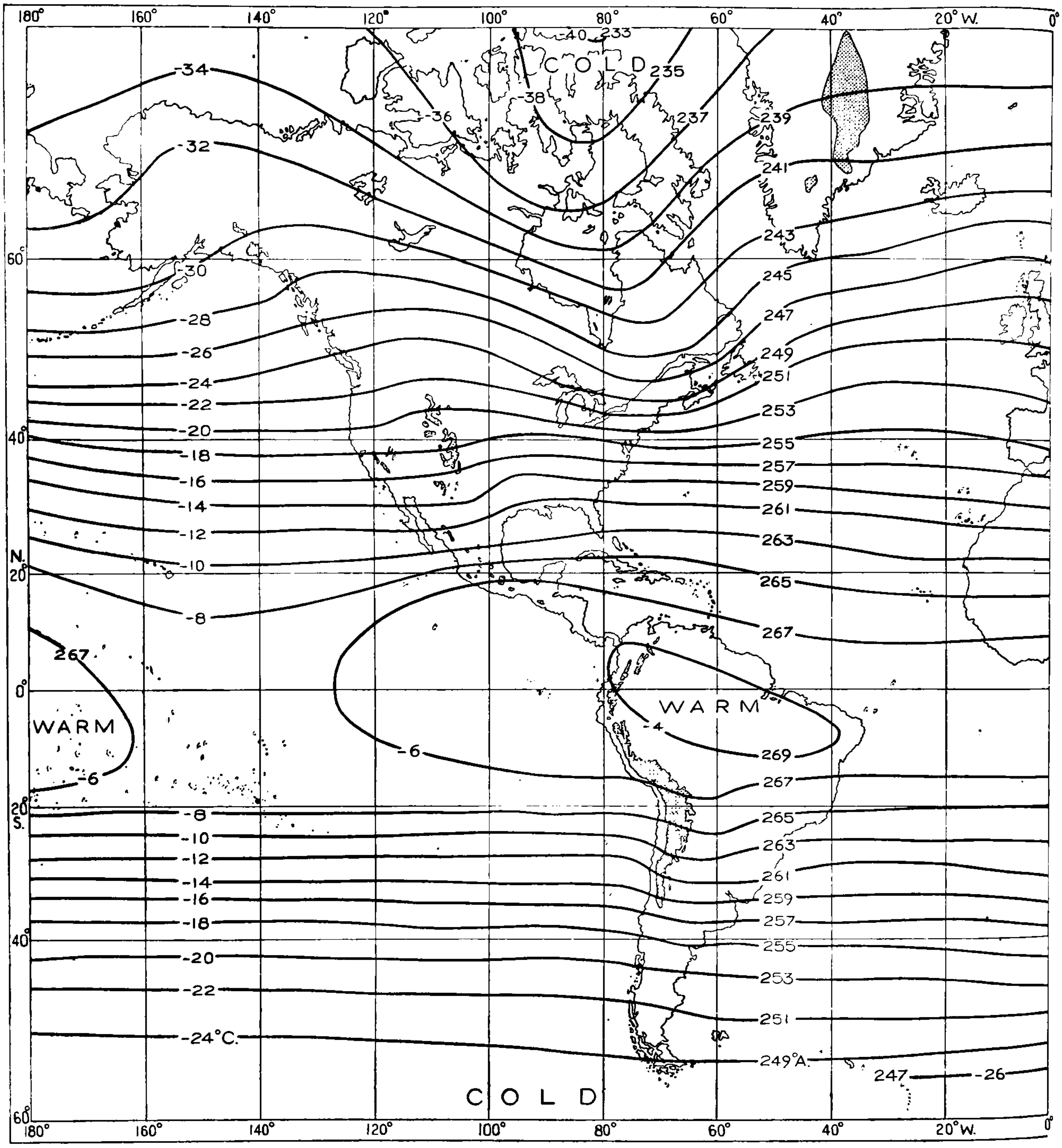

PLATE 10—AVERAGE TEMPERATURE AT 500 MB. IN APRIL

I.C.A.N. height = 18,278 ft. = 5,571 m.

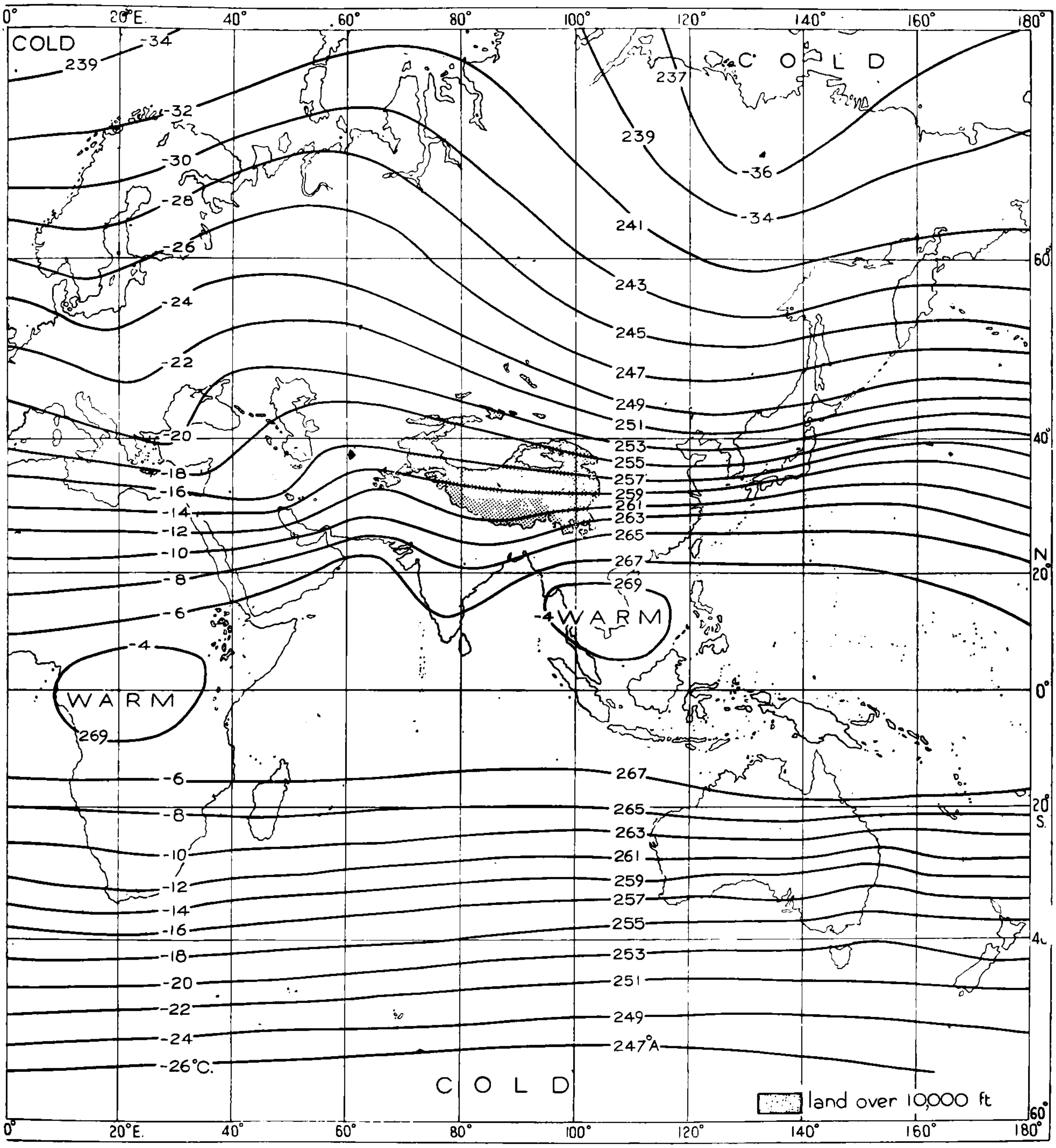

PLATE 10—CONTINUED

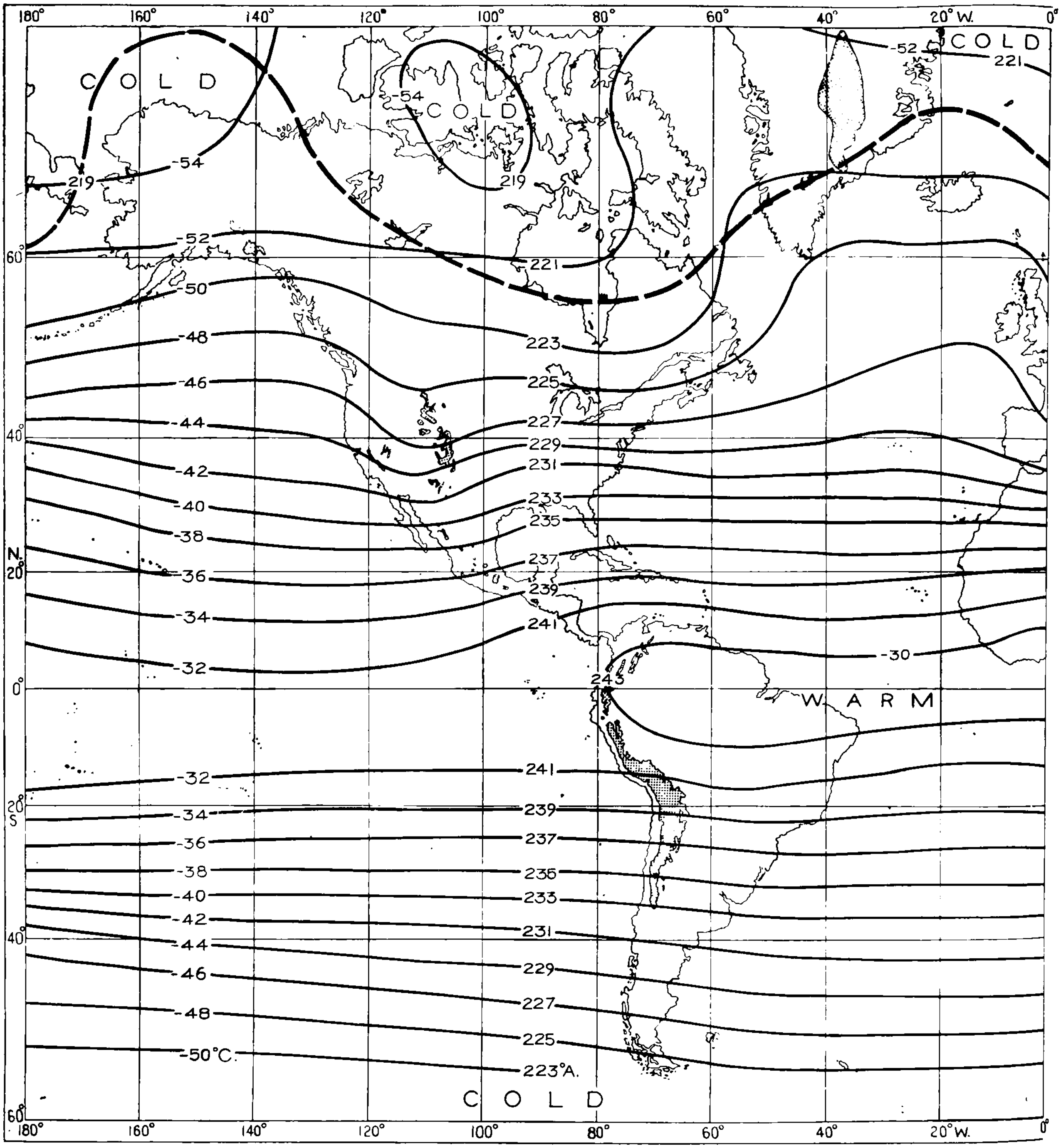

PLATE 11—AVERAGE TEMPERATURE AT 300 MB. IN APRIL

I.C.A.N. height = 30,059 ft. = 9,162 m.

The thick broken line indicates the intersection of the 300-mb. and average tropopause surfaces.

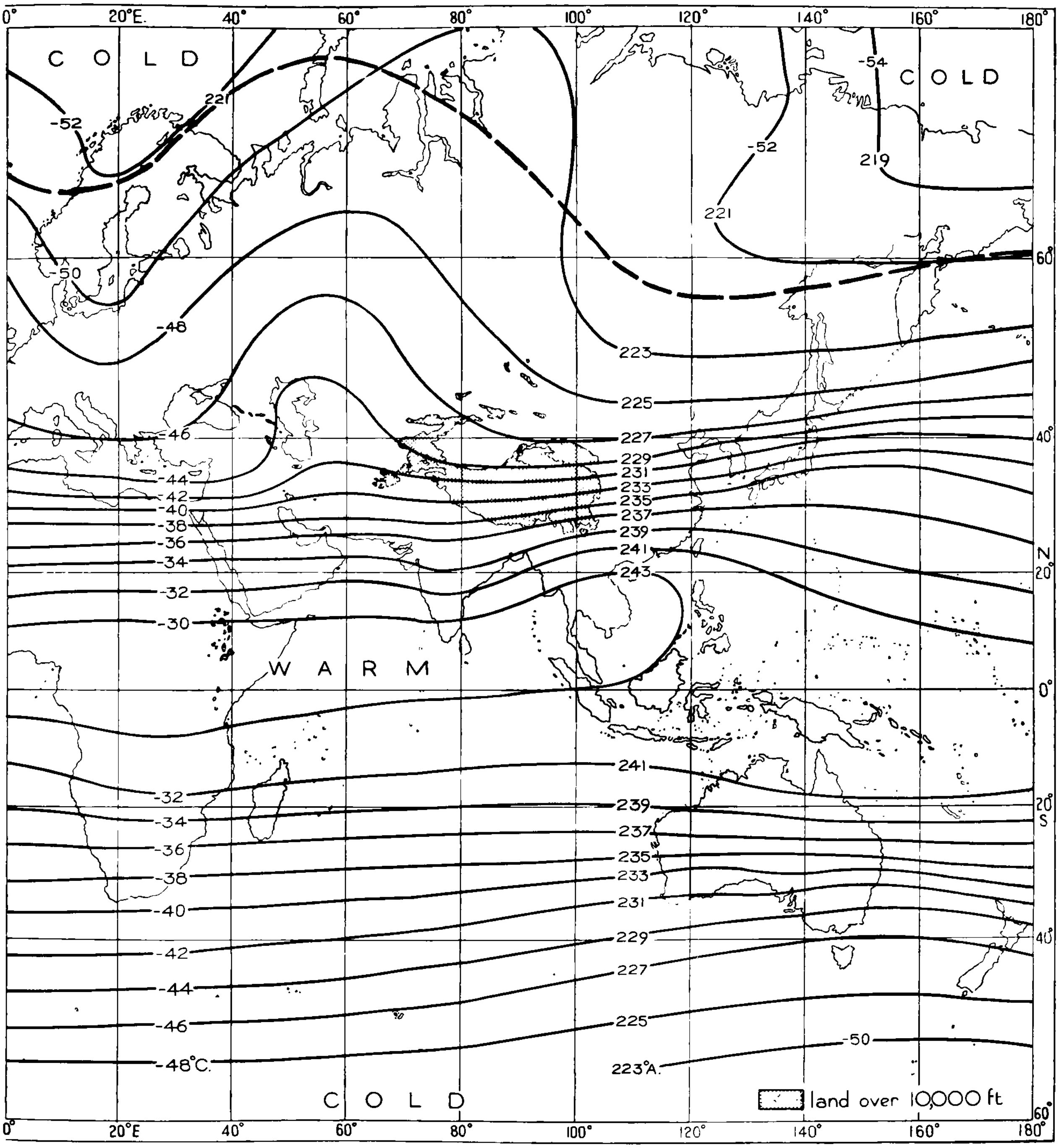

PLATE 11—CONTINUED

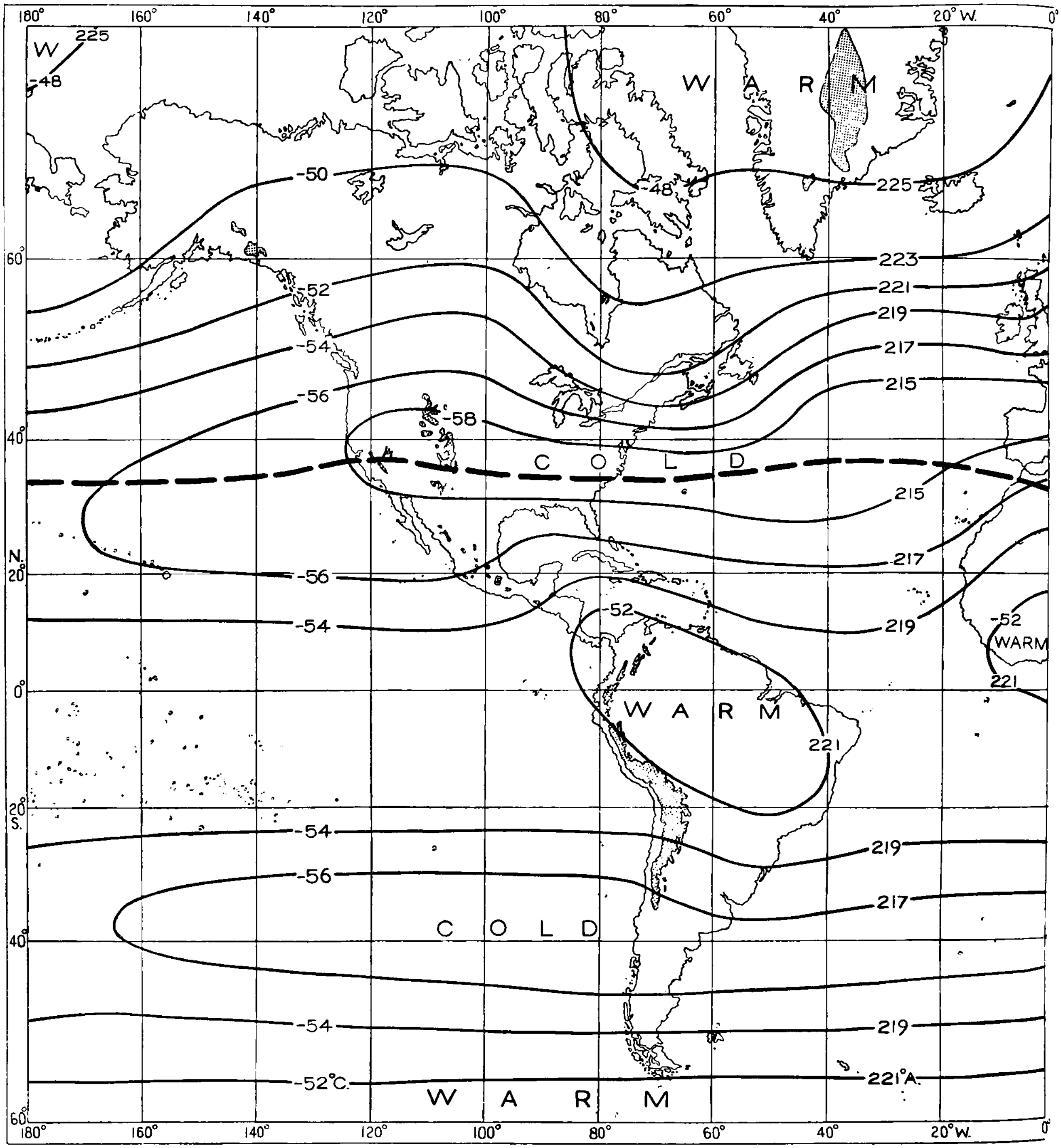

PLATE 12—AVERAGE TEMPERATURE AT 200 MB. IN APRIL

I.C.A.N. height = 38,644 ft. = 11,779 m.

The thick broken line indicates the intersection of the 200-mb. and average tropopause surfaces.

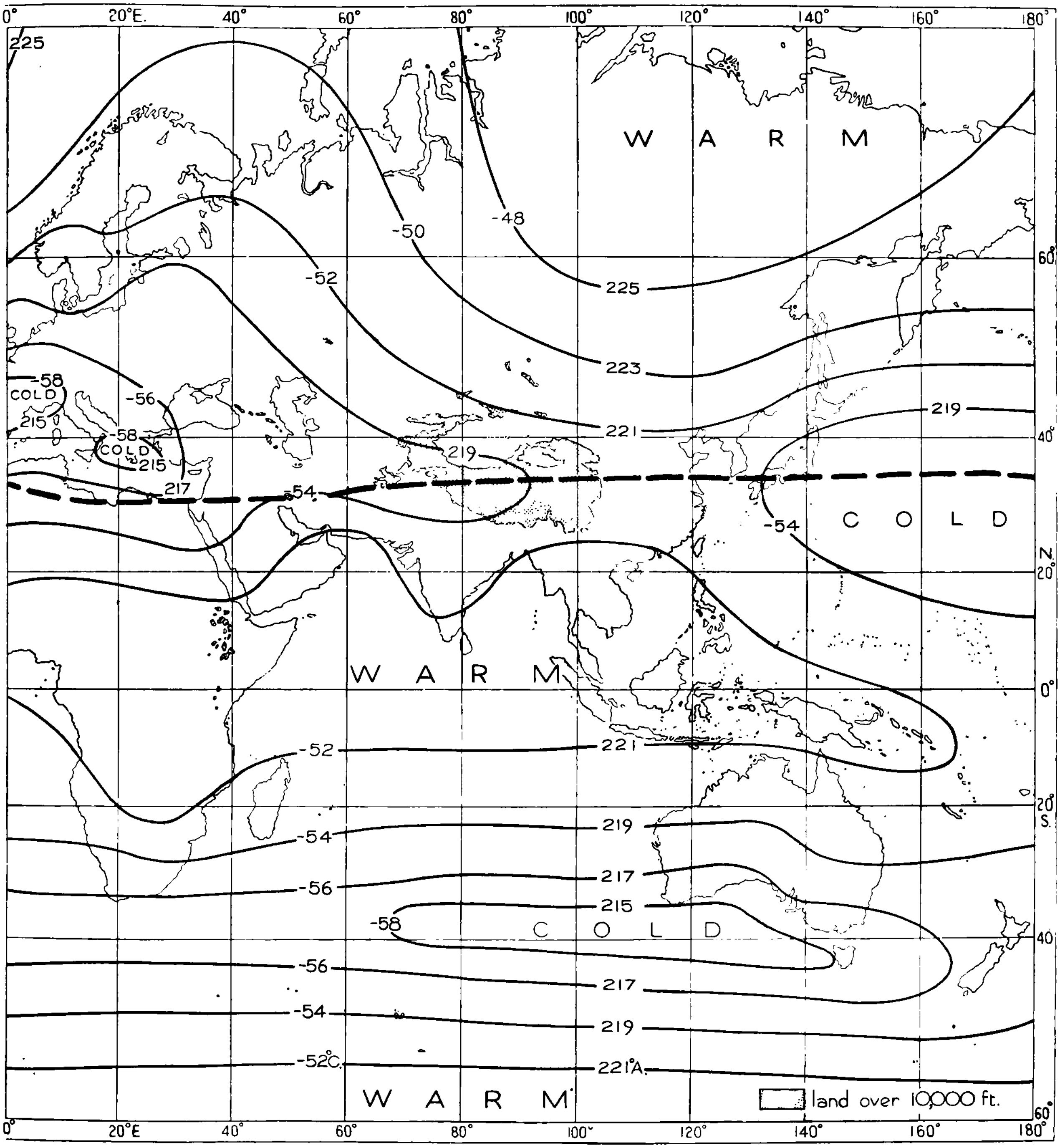

PLATE 12—CONTINUED

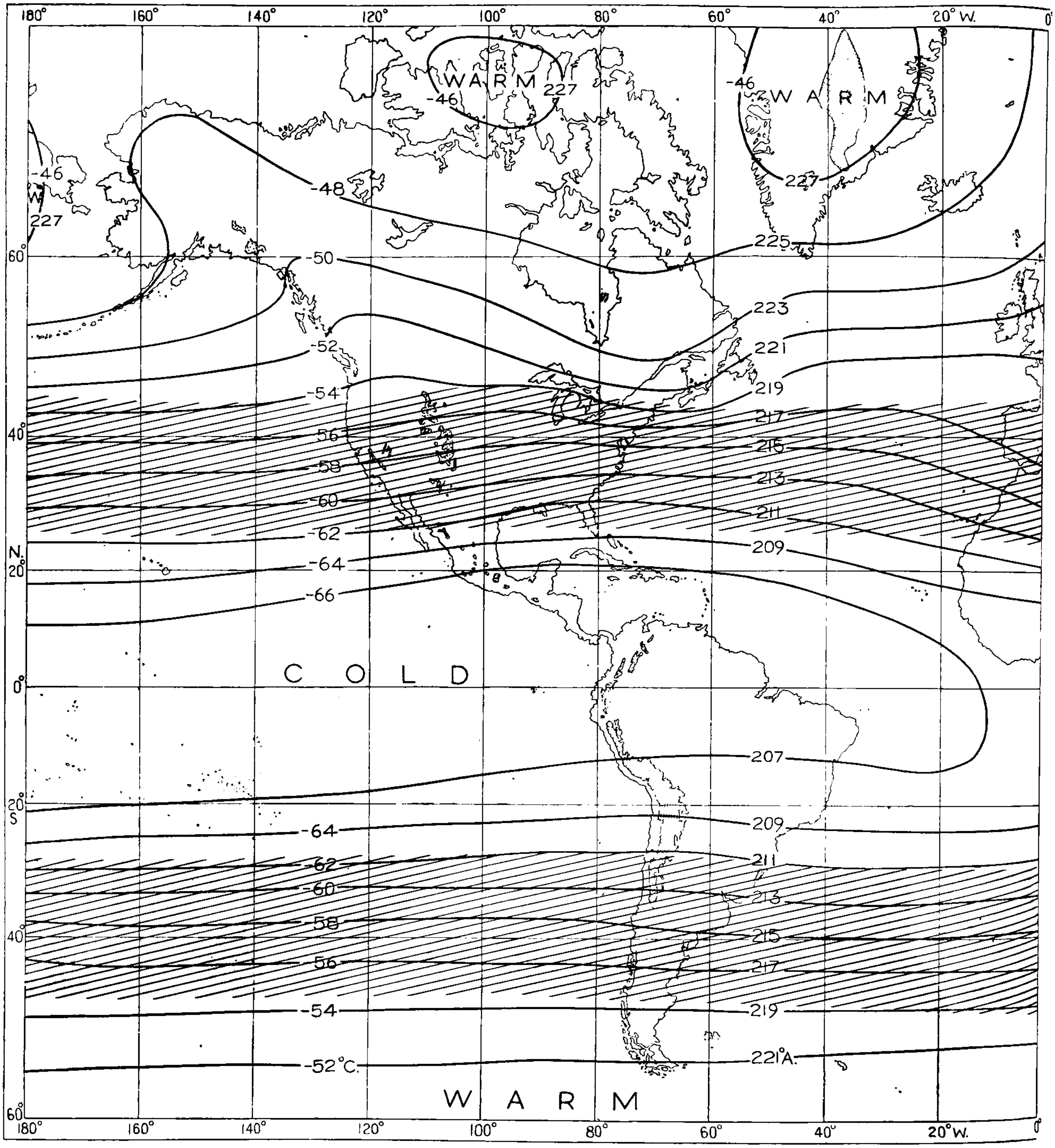

PLATE 13—AVERAGE TEMPERATURE AT 150 MB. IN APRIL

I.C.A.N. height = 44,625 ft. = 13,602 m.

Areas in which the frequencies of occurrences of both tropopauses are greater than 10 per cent. are shaded.

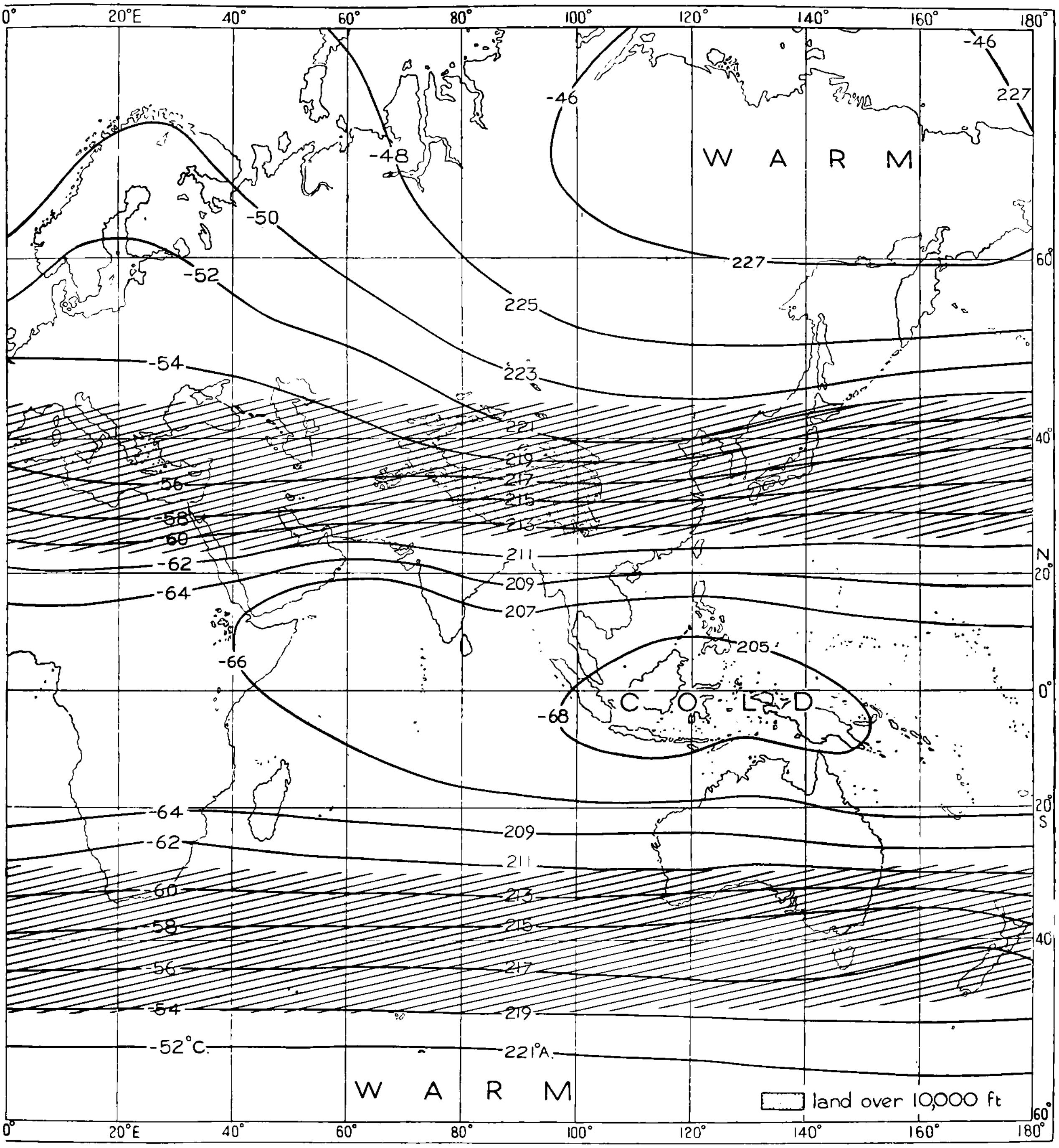

PLATE 13—CONTINUED

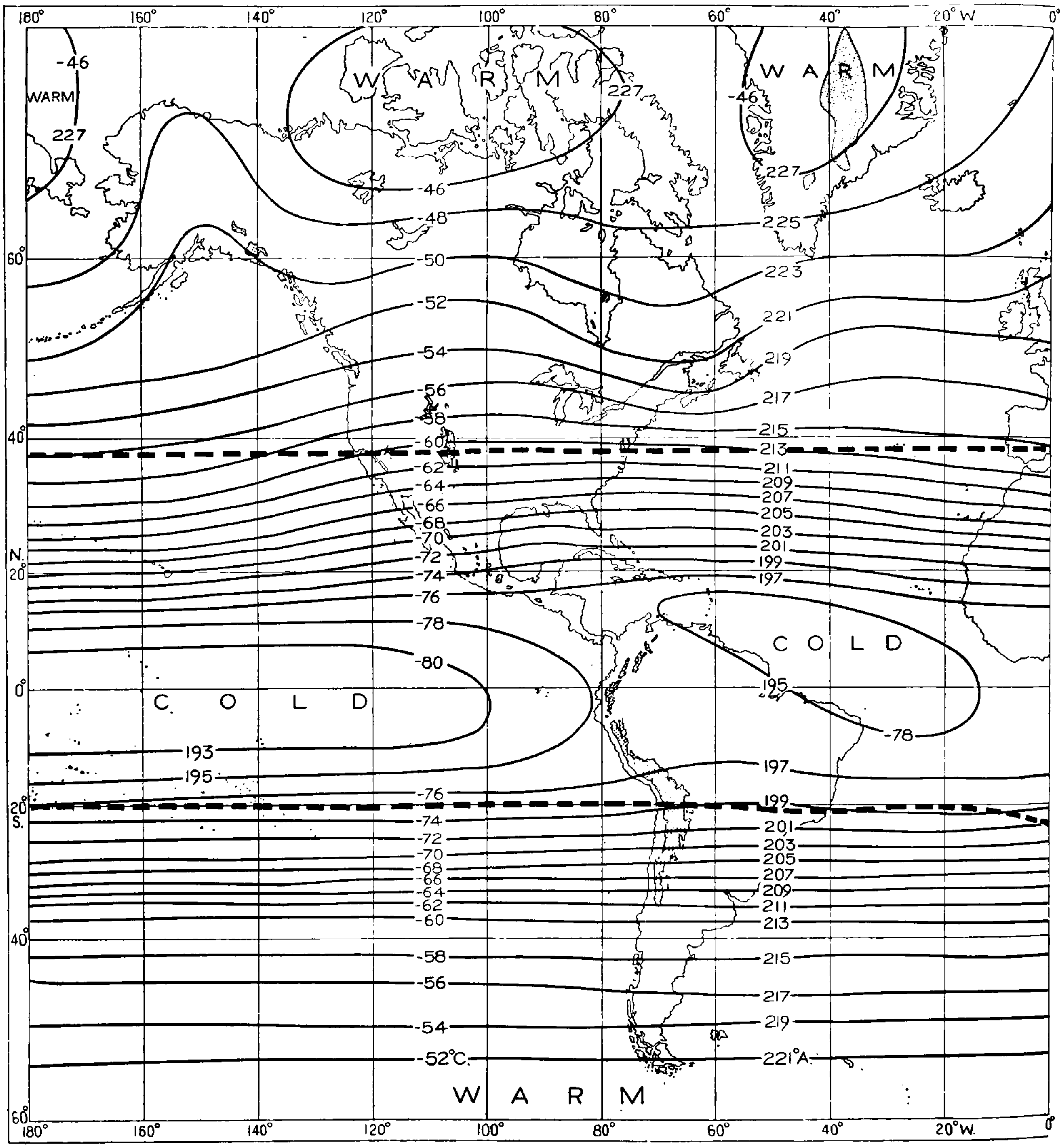

PLATE 14—AVERAGE TEMPERATURE AT 100 MB. IN APRIL

I.C.A.N. height = 53,054 ft. = 16,170 m.

The thick broken line indicates the intersection of the 100-mb. and average tropopause surfaces.

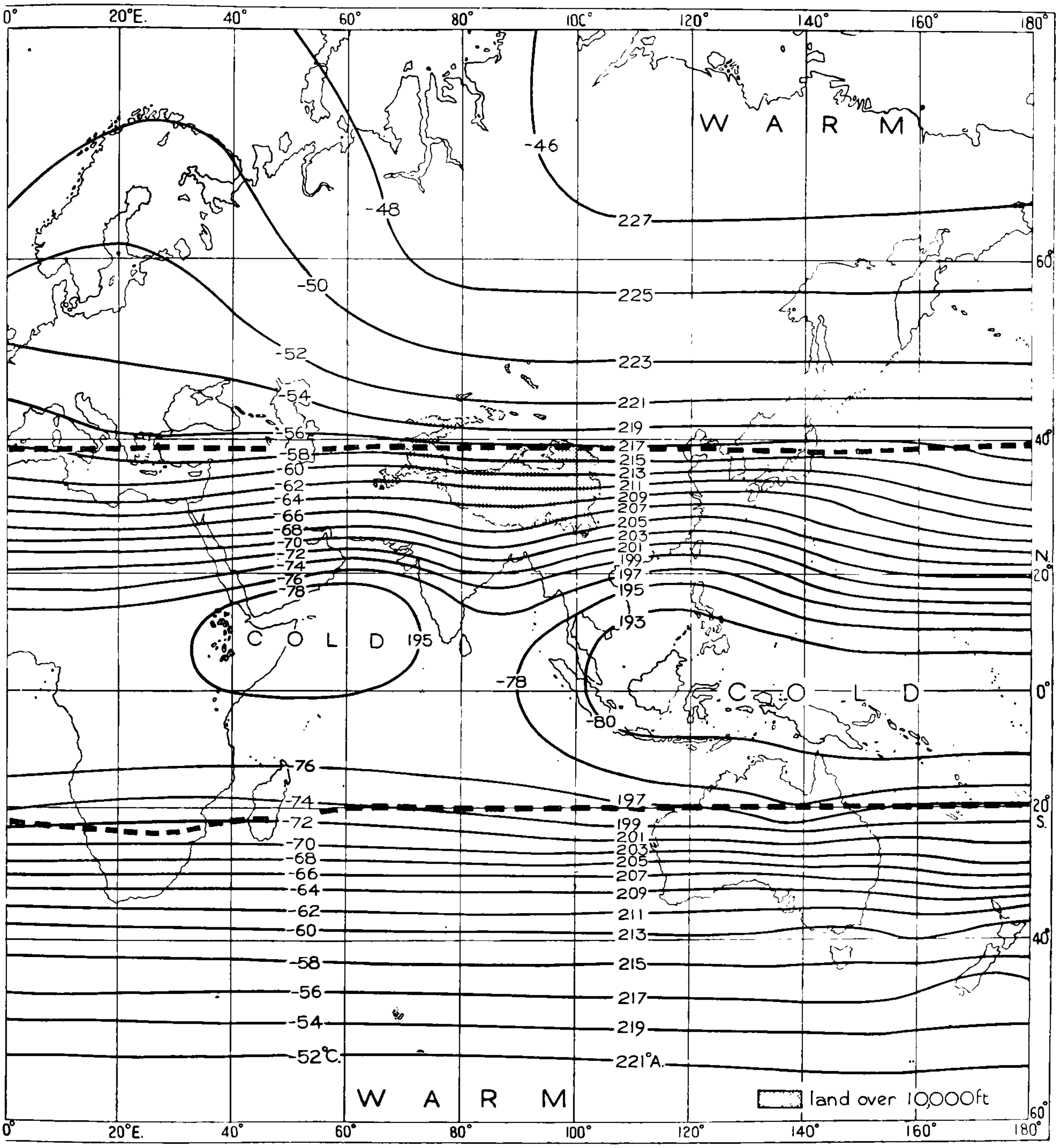

PLATE 14—CONTINUED

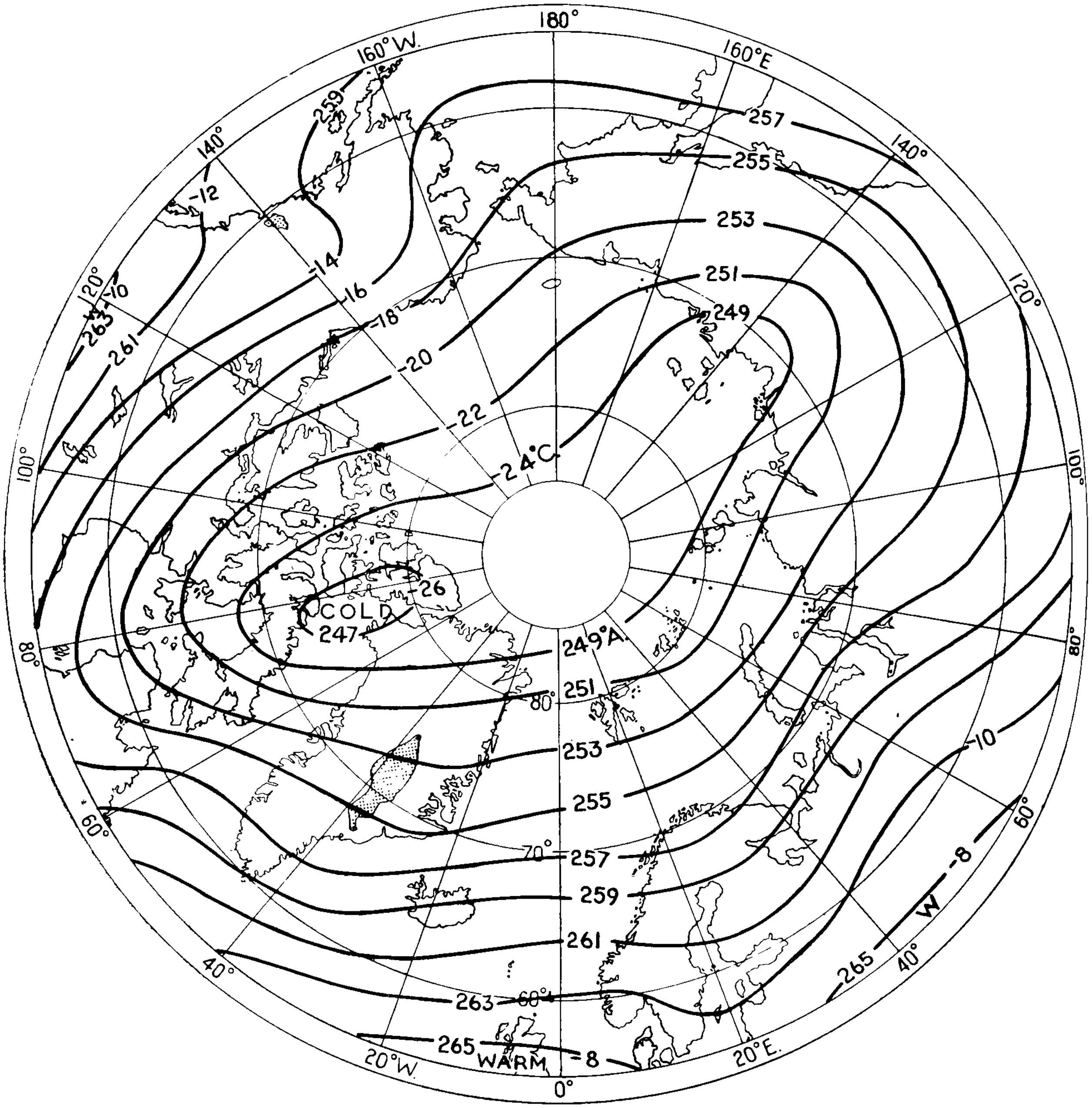

PLATE 15A—AVERAGE TEMPERATURE AT 700 MB. IN APRIL

I.C.A.N. height = 9,876 ft. = 3,010 m.

Land over 10,000 feet is represented by shading.

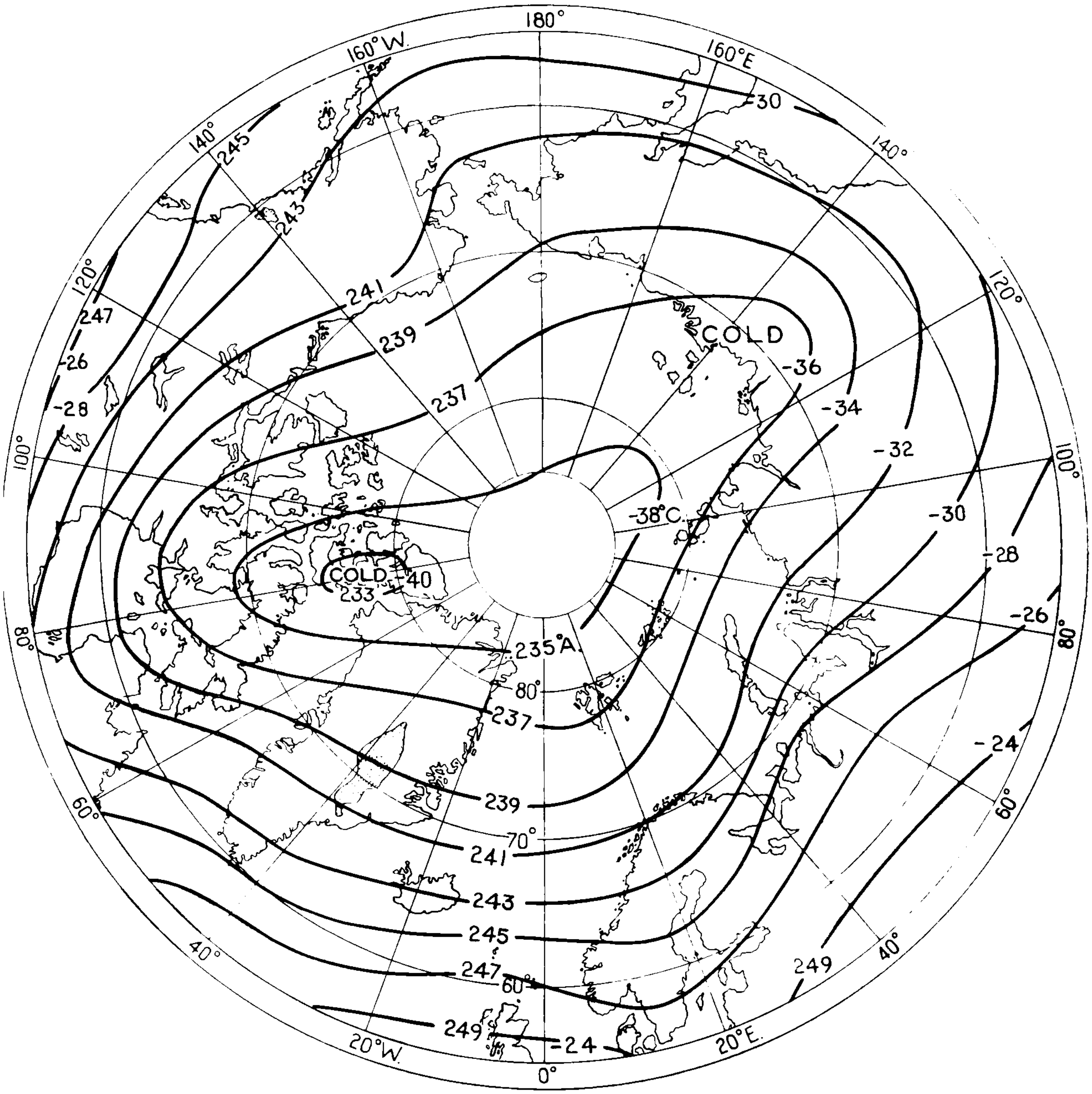

PLATE 15B—AVERAGE TEMPERATURE AT 500 MB. IN APRIL

I.C.A.N. height = 18,278 ft. = 5,571 m.

Land over 10,000 feet is represented by shading.

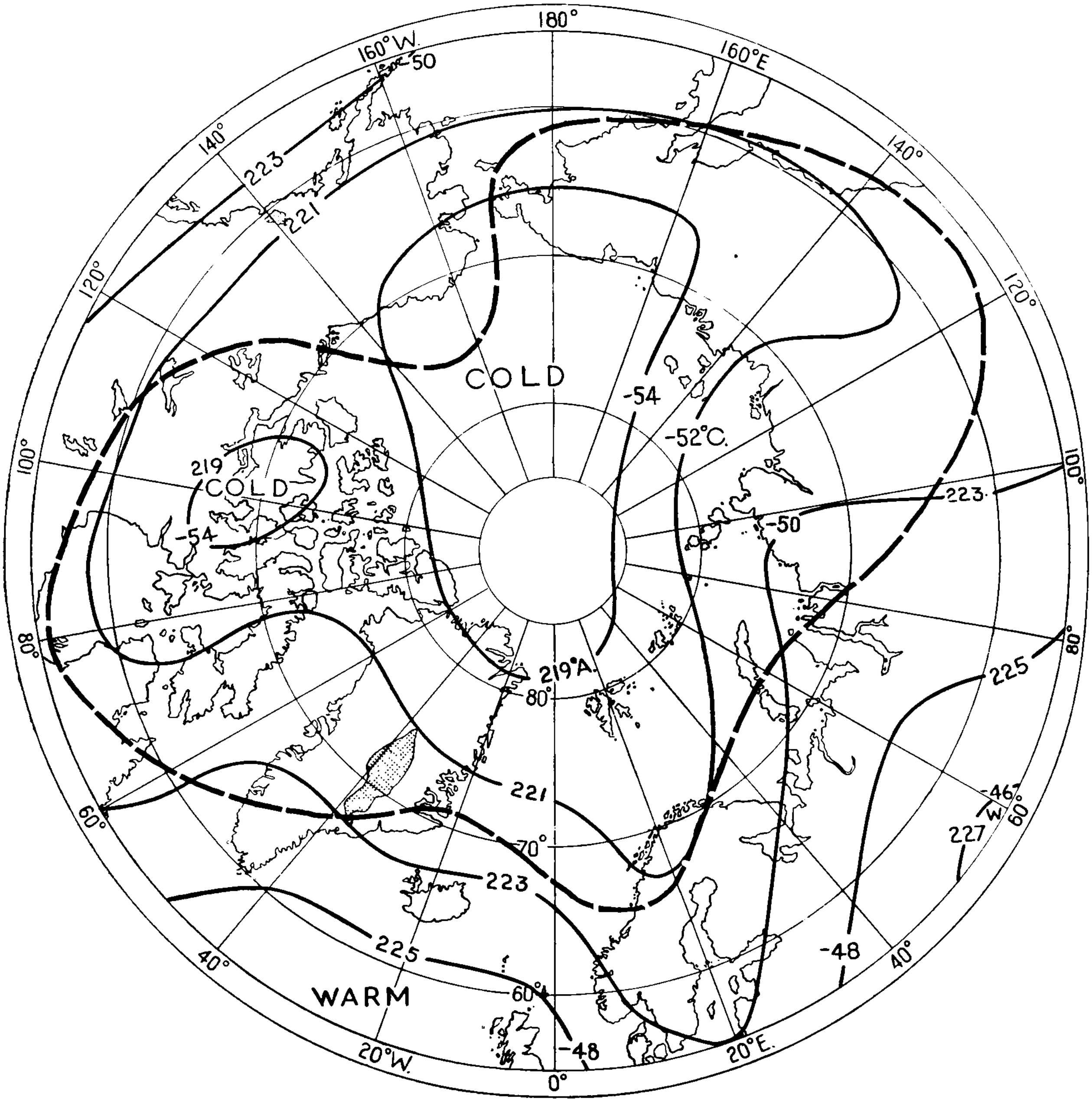

PLATE 15c—AVERAGE TEMPERATURE AT 300 MB. IN APRIL

I.C.A.N. height = 30,059 ft. = 9,162 m.

The thick broken line indicates the intersection of the 300-mb. and average tropopause surfaces.

Land over 10,000 feet is represented by shading.

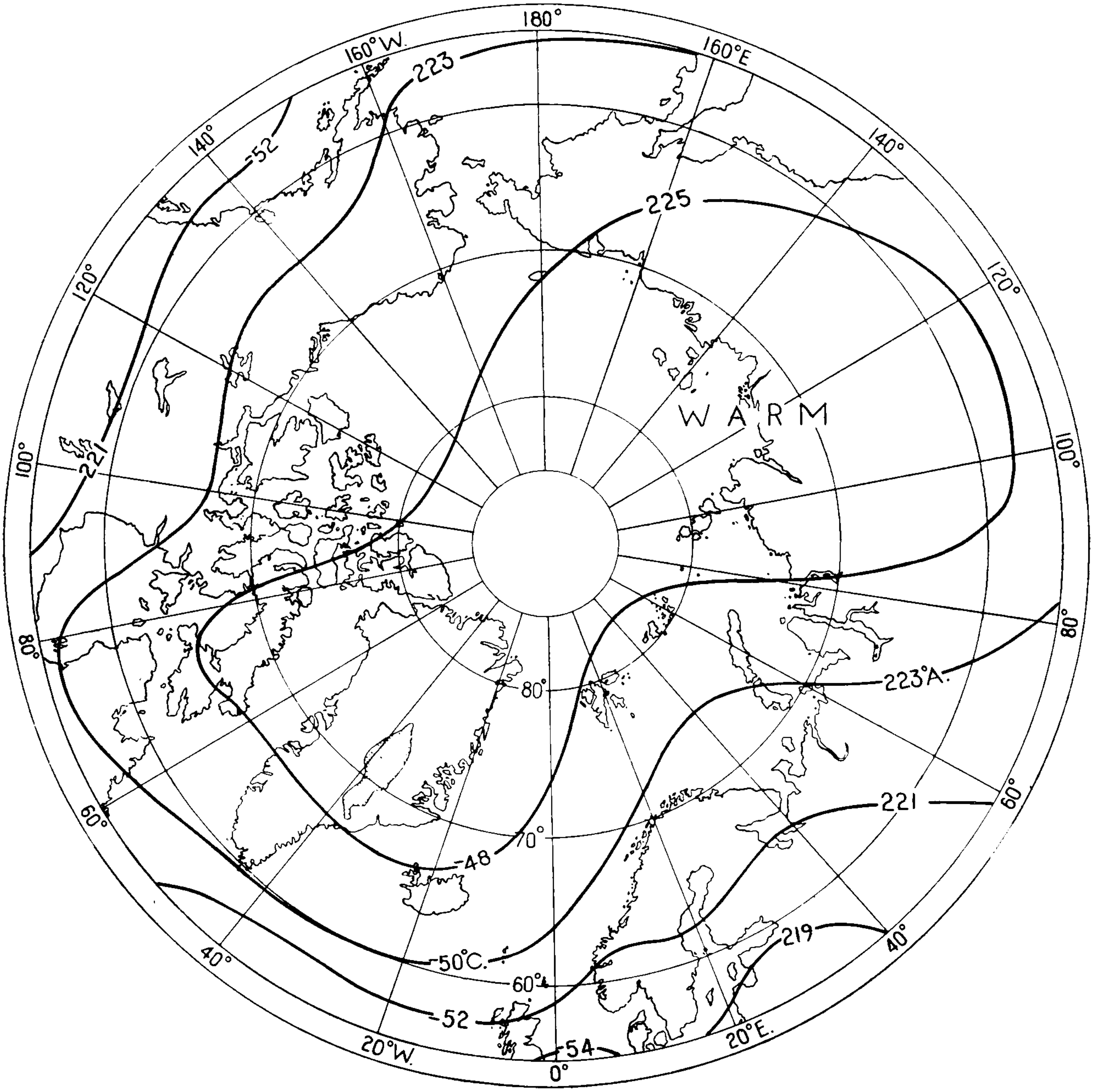

PLATE 16A—AVERAGE TEMPERATURE AT 200 MB. IN APRIL

I.C.A.N. height = 38,644 ft. = 11,779 m.

Land over 10,000 feet is represented by shading.

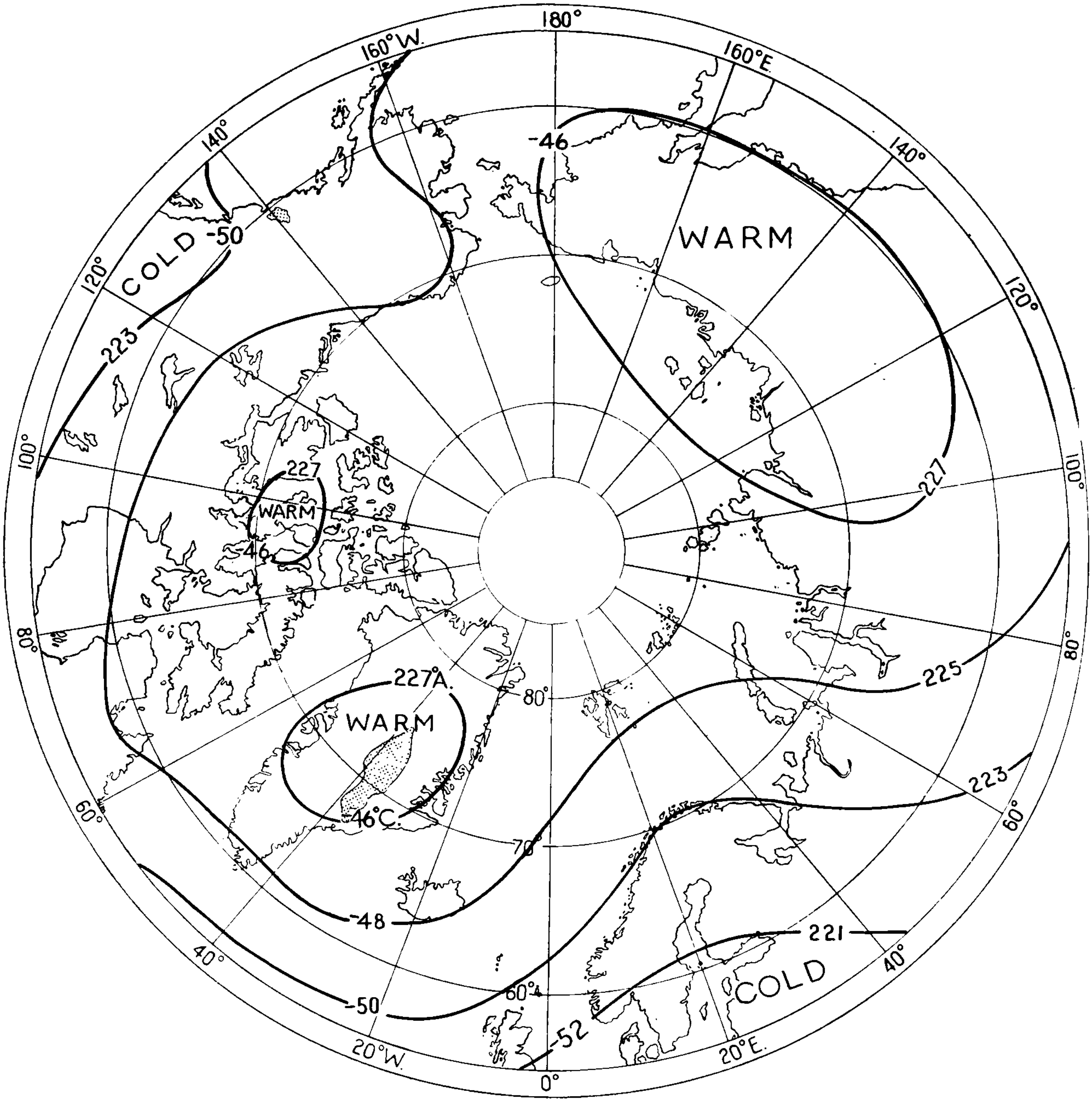

PLATE 16B—AVERAGE TEMPERATURE AT 150 MB. IN APRIL

I.C.A.N. height = 44,625 ft. = 13,602 m.

Land over 10,000 feet is represented by shading.

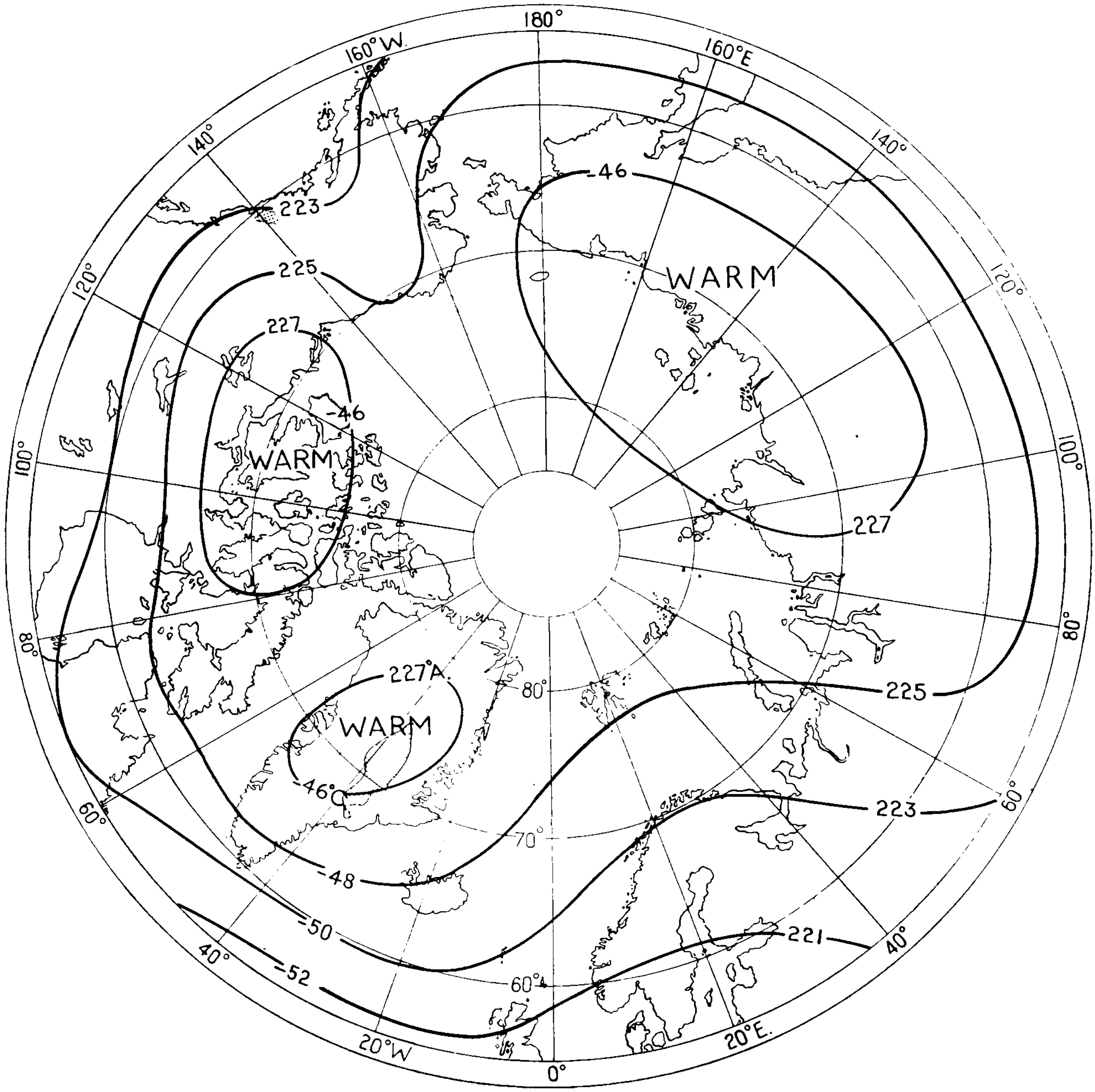

PLATE 16c—AVERAGE TEMPERATURE AT 100 MB. IN APRIL

I.C.A.N. height = 53,054 ft. = 16,170 m.

Land over 10,000 feet is represented by shading.

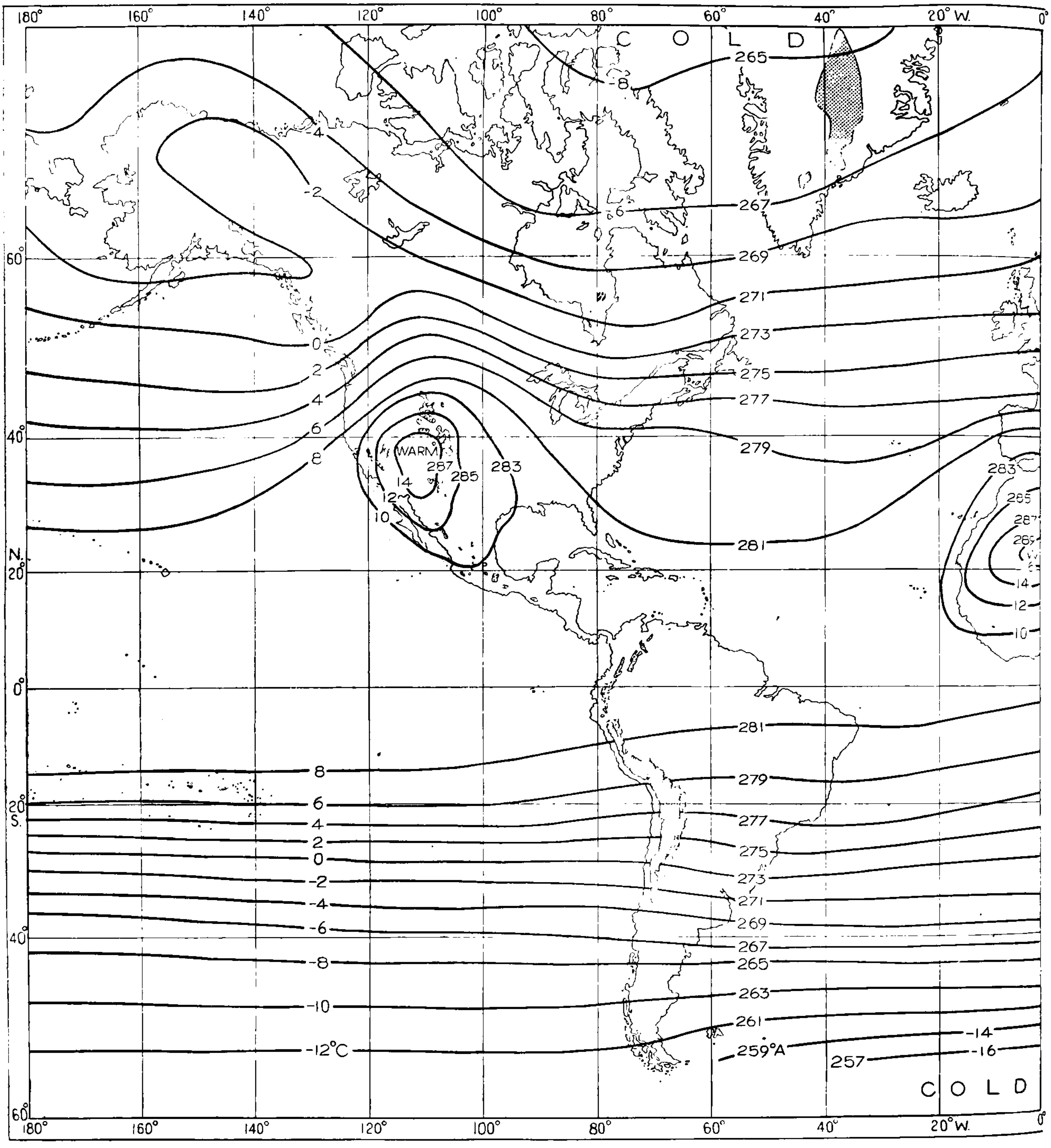

PLATE 17—AVERAGE TEMPERATURE AT 700 MB. IN JULY

I.C.A.N. height = 9,876 ft. = 3,010 m.

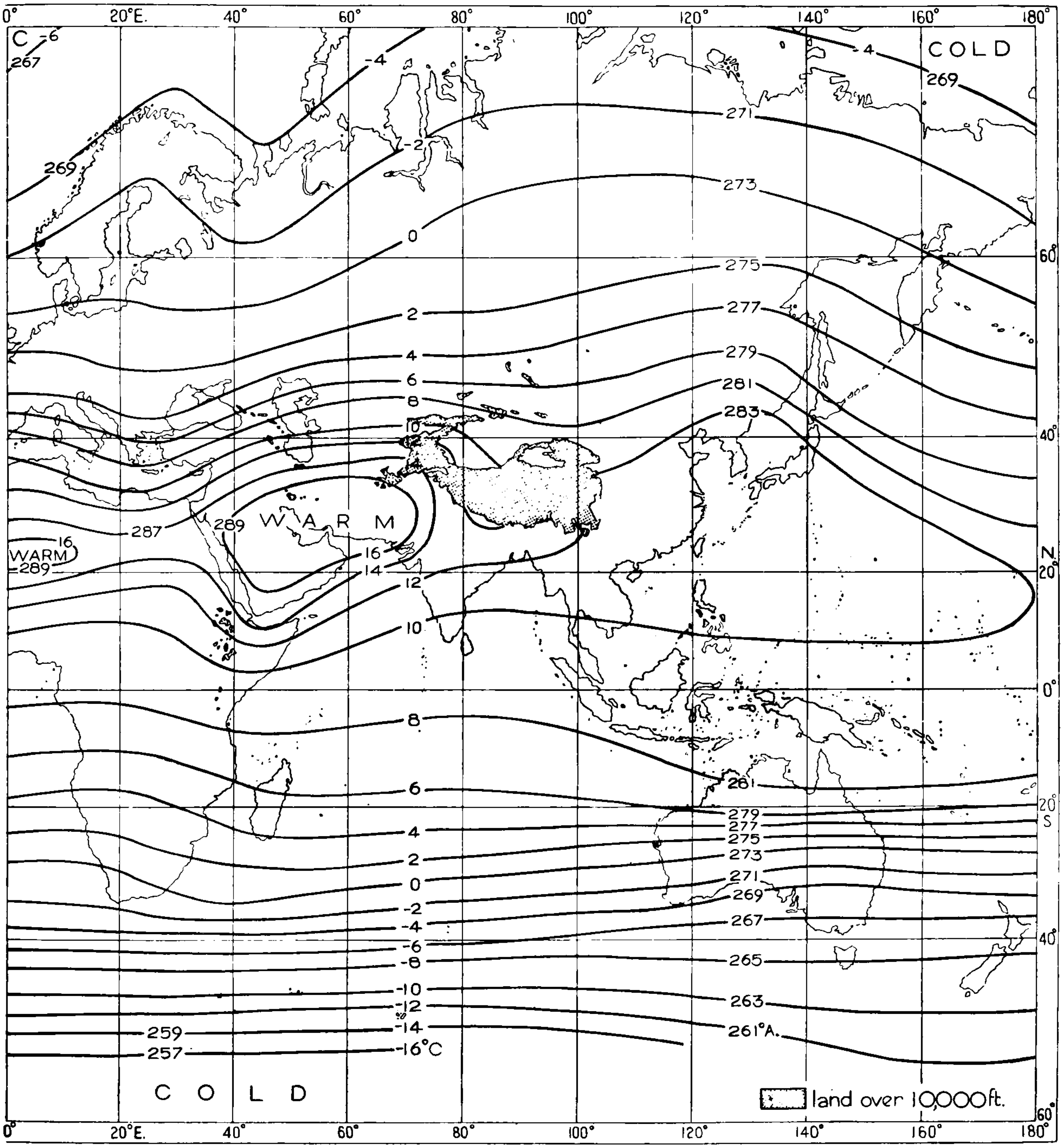

PLATE 17—CONTINUED

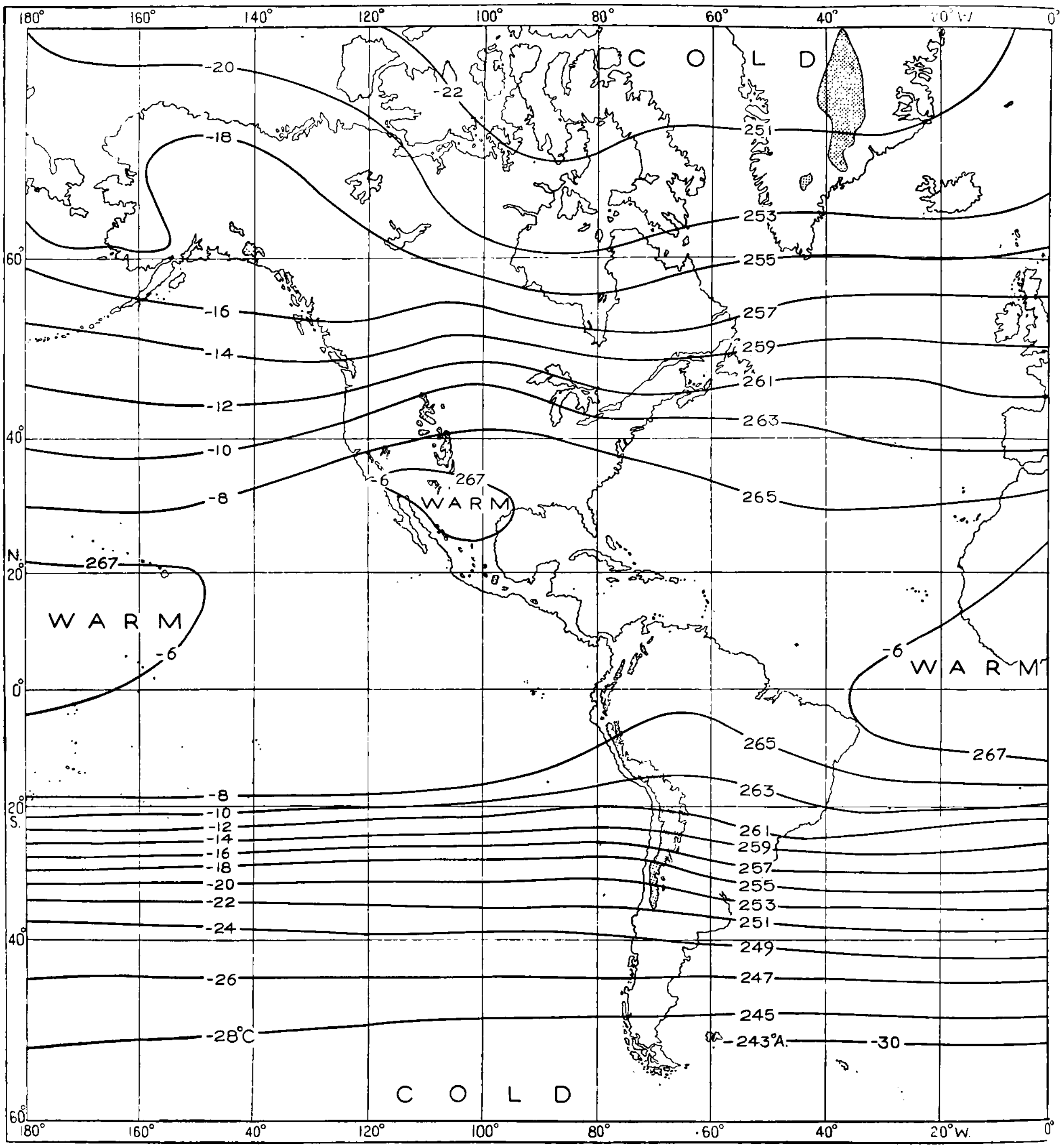

PLATE 18—AVERAGE TEMPERATURE AT 500 MB. IN JULY

I.C.A.N. height = 18,278 ft. = 5,571 m.

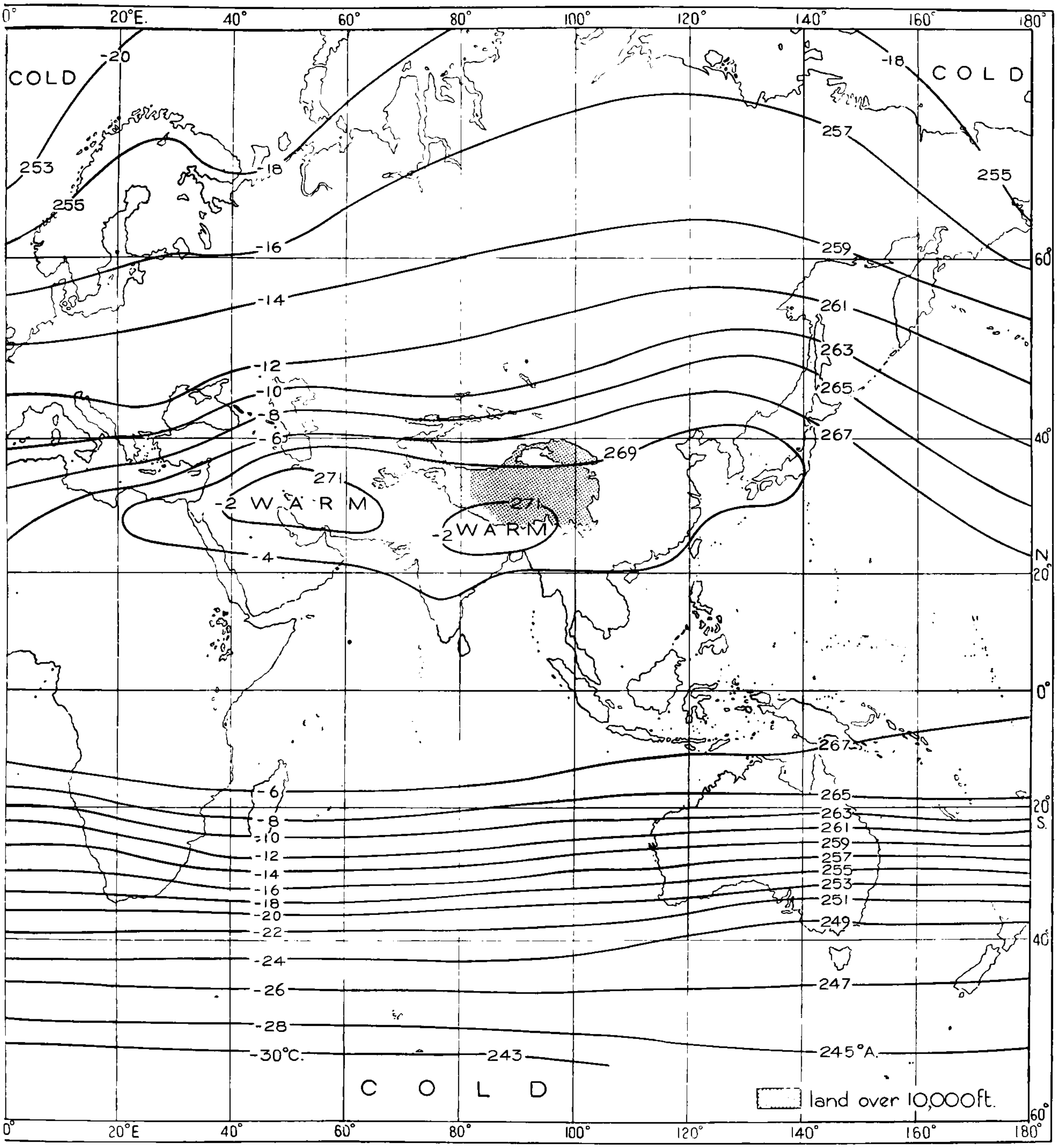

PLATE 18—CONTINUED

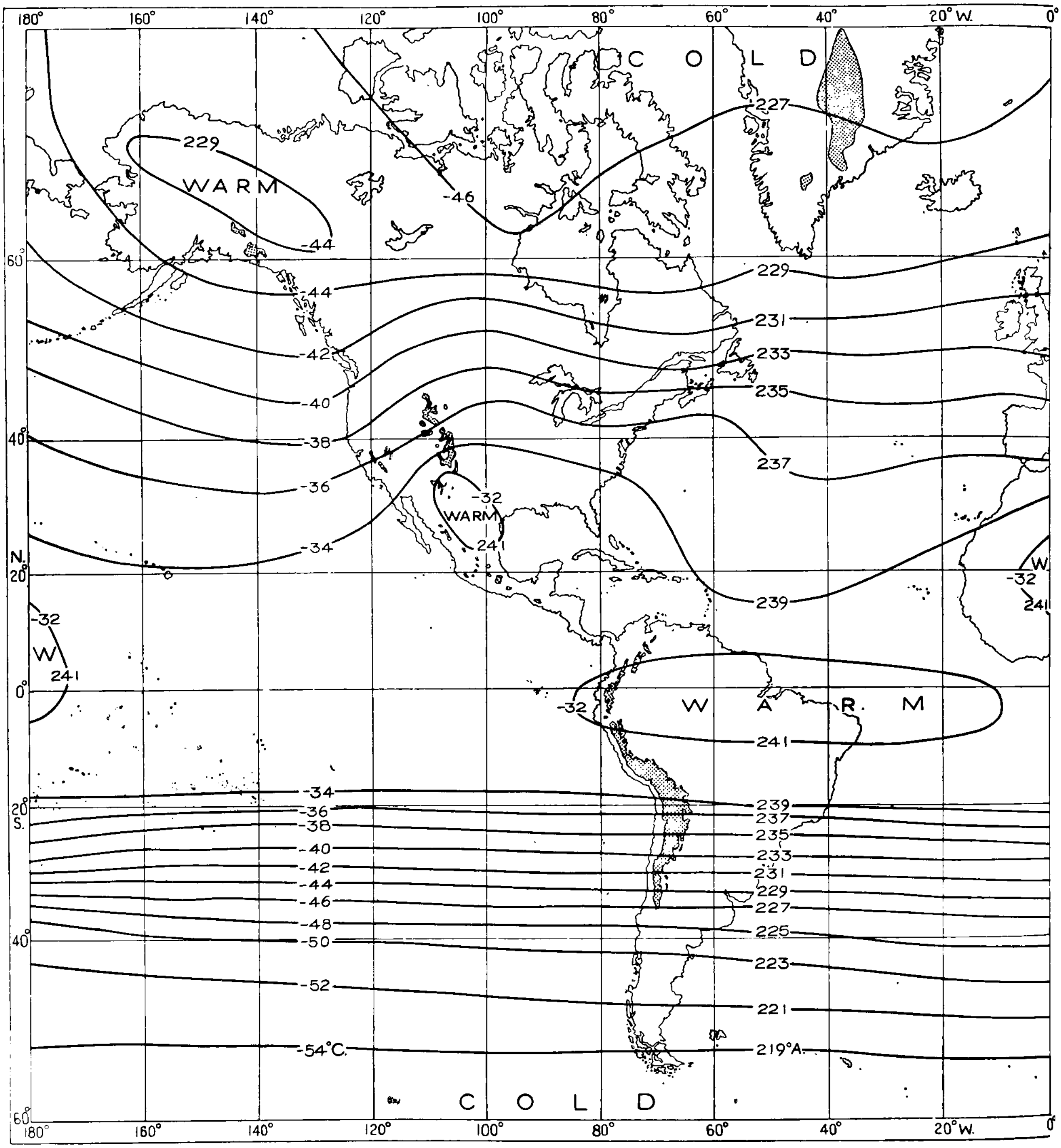

PLATE 19—AVERAGE TEMPERATURE AT 300 MB. IN JULY

I.C.A.N. height = 30,059 ft. = 9,162 m.

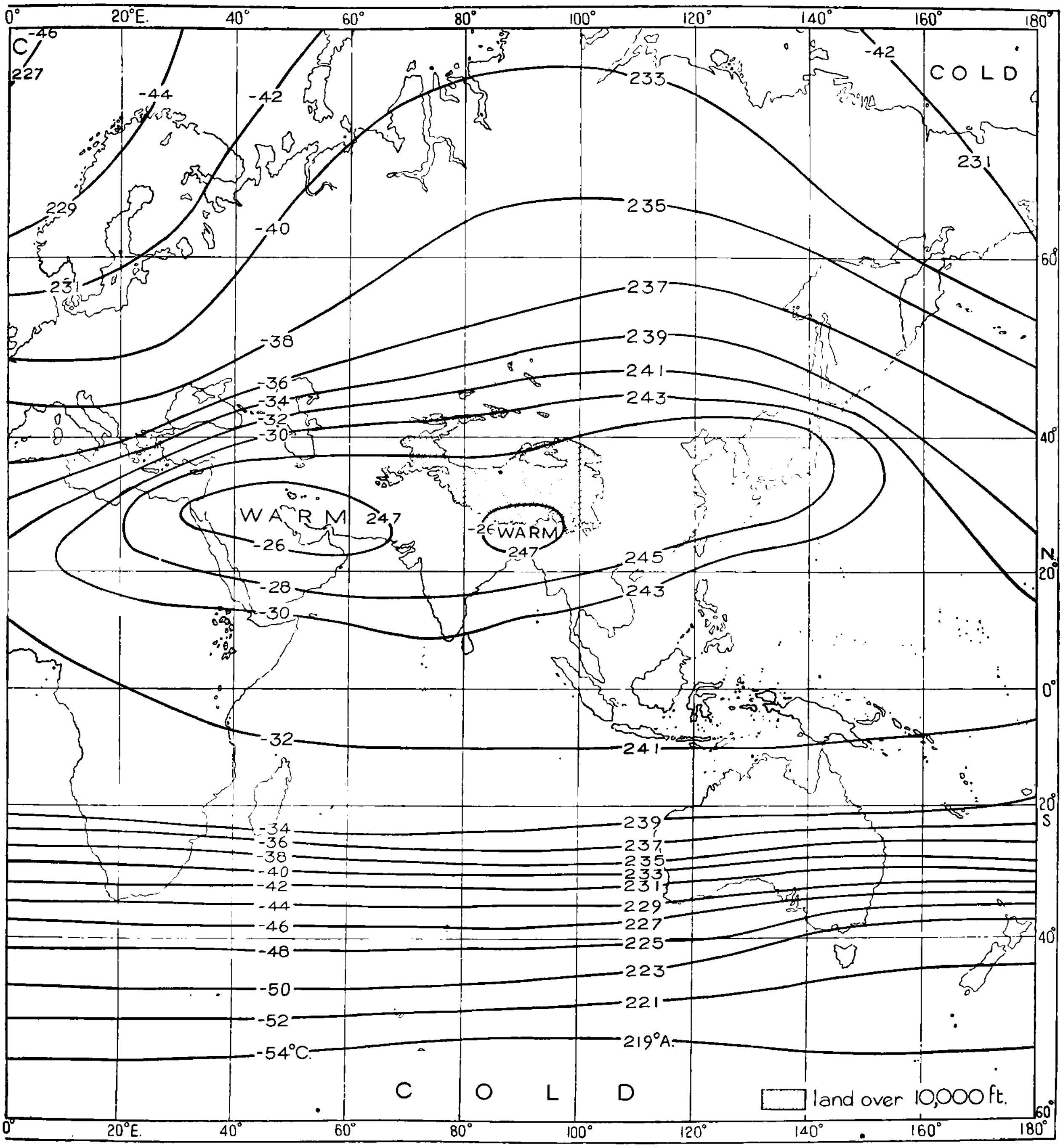

PLATE 19—CONTINUED

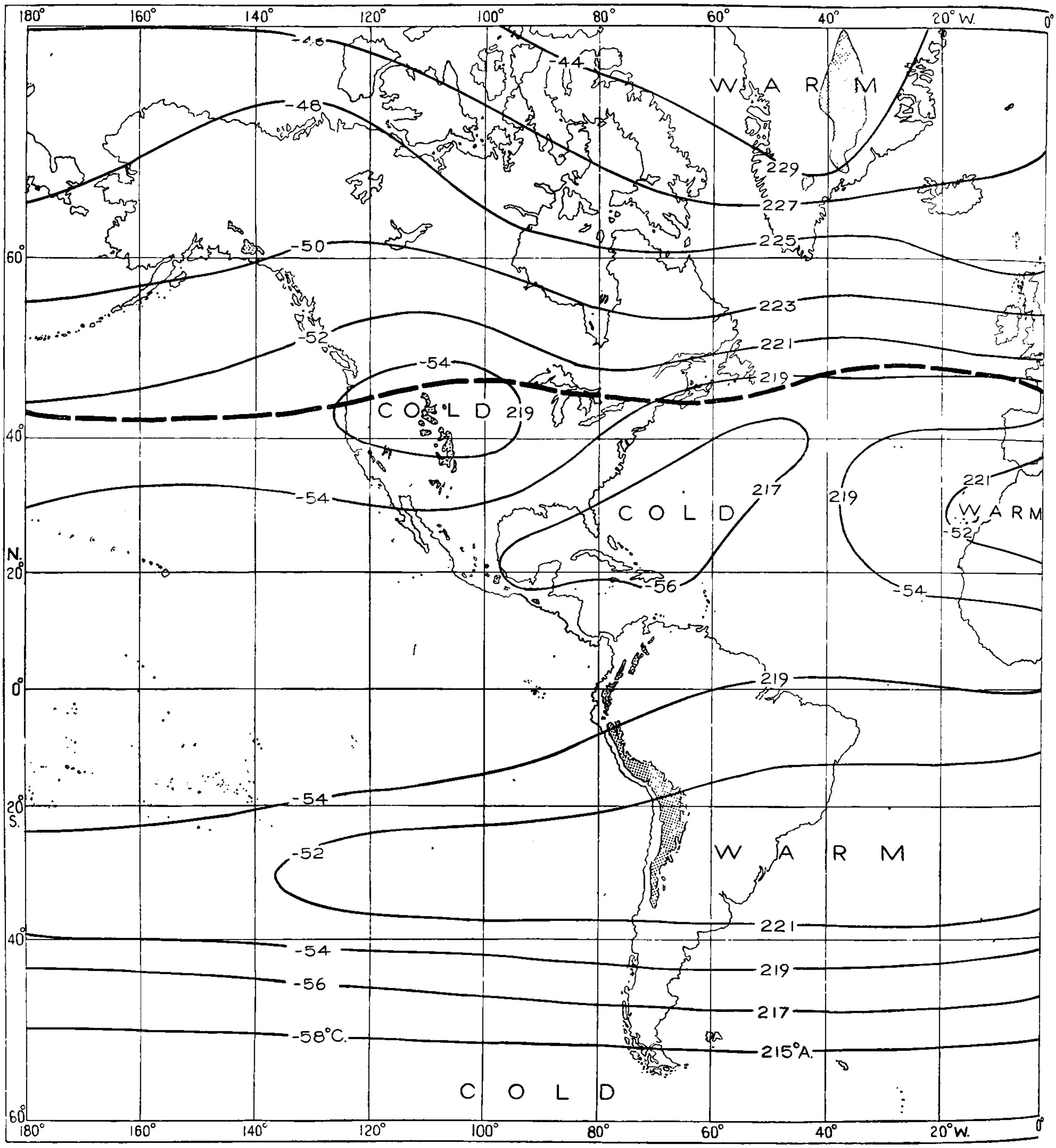

PLATE 20—AVERAGE TEMPERATURE AT 200 MB. IN JULY

I.C.A.N. height = 38,644 ft. = 11,779 m.

The thick broken line indicates the intersection of the 200-mb. and average tropopause surfaces.

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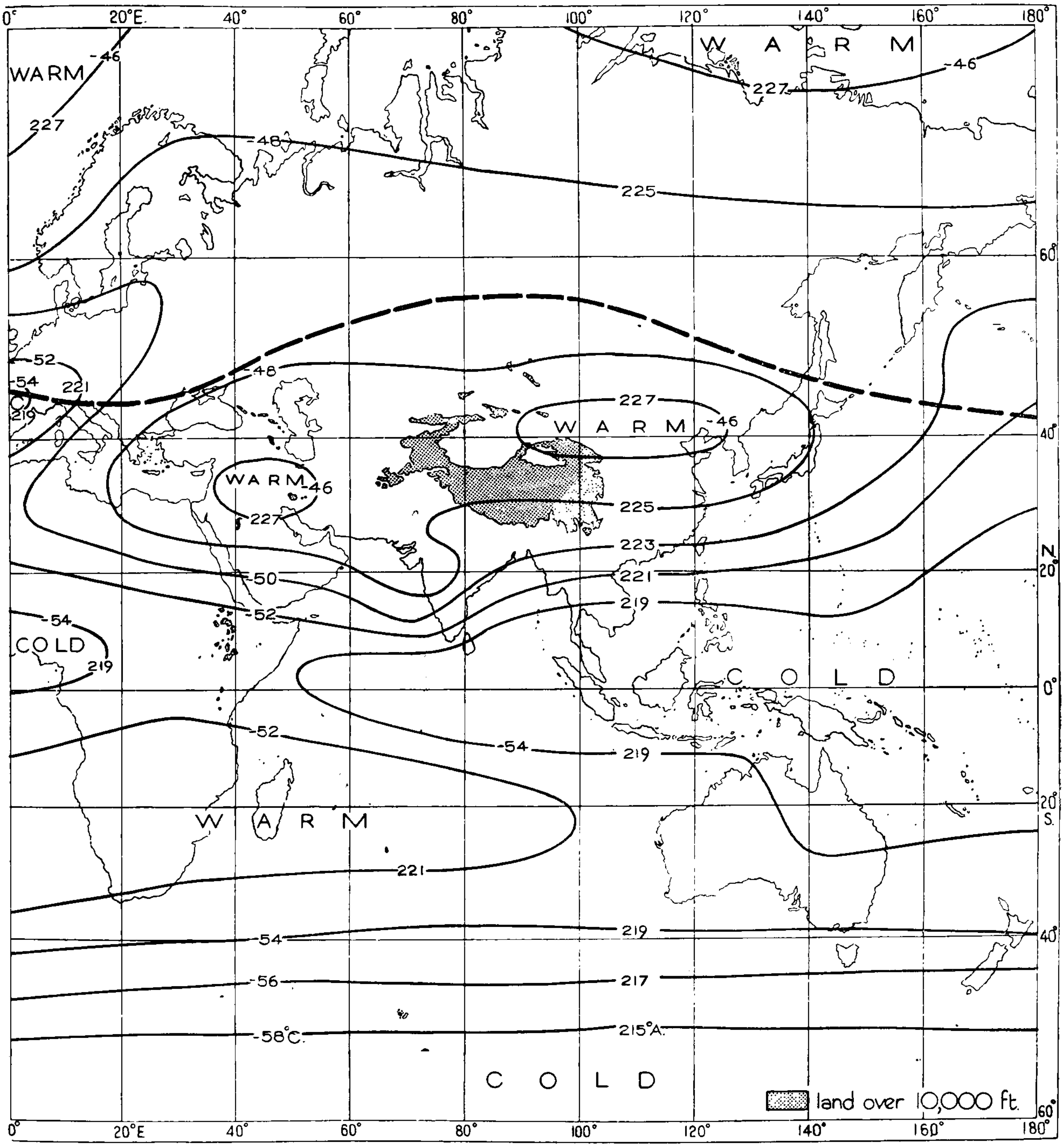

PLATE 20—CONTINUED

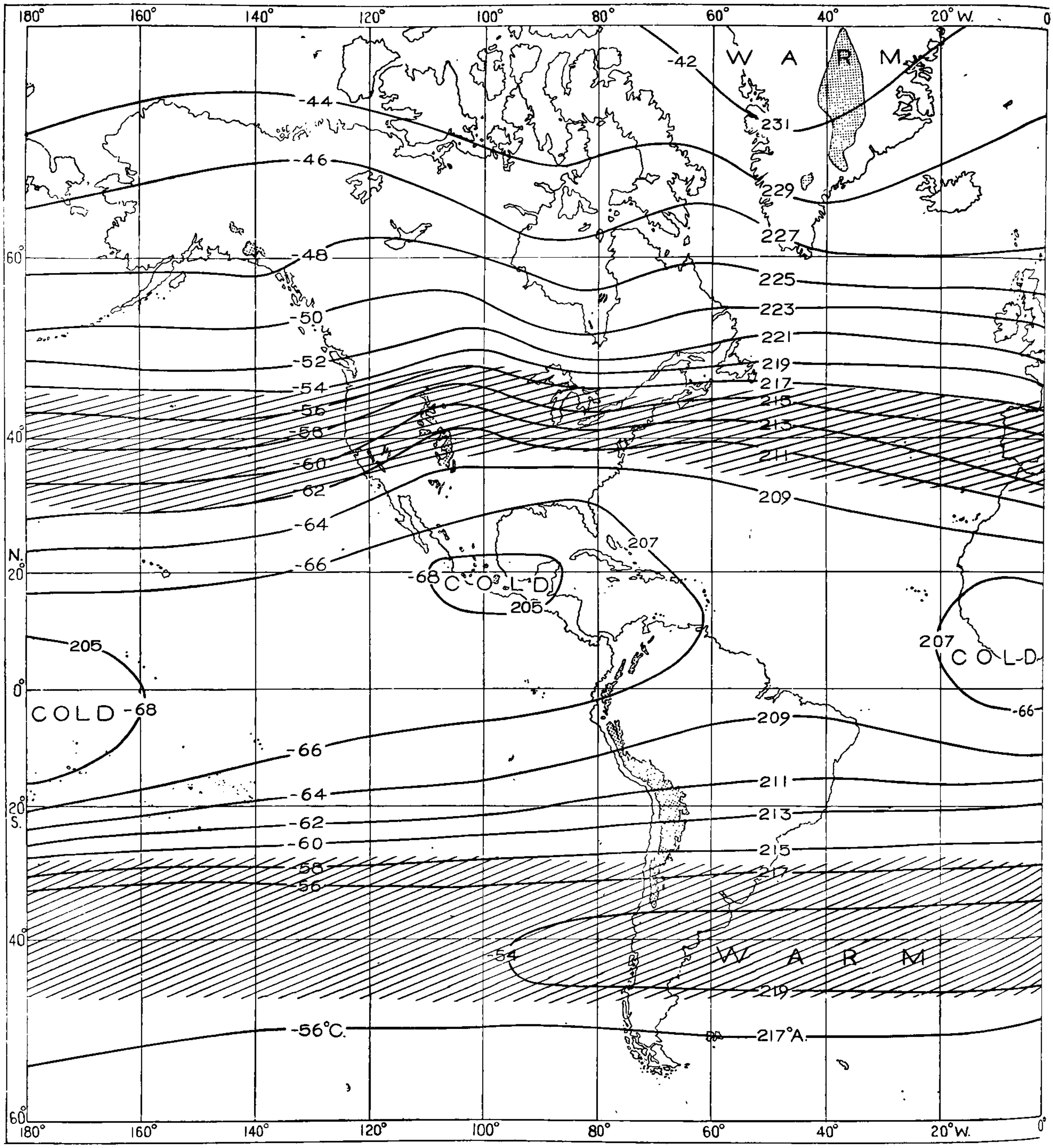

PLATE 21—AVERAGE TEMPERATURE AT 150 MB. IN JULY

I.C.A.N. height = 44,625 ft. = 13,602 m.

Areas in which the frequencies of occurrences of both tropopauses are greater than 10 per cent. are shaded.

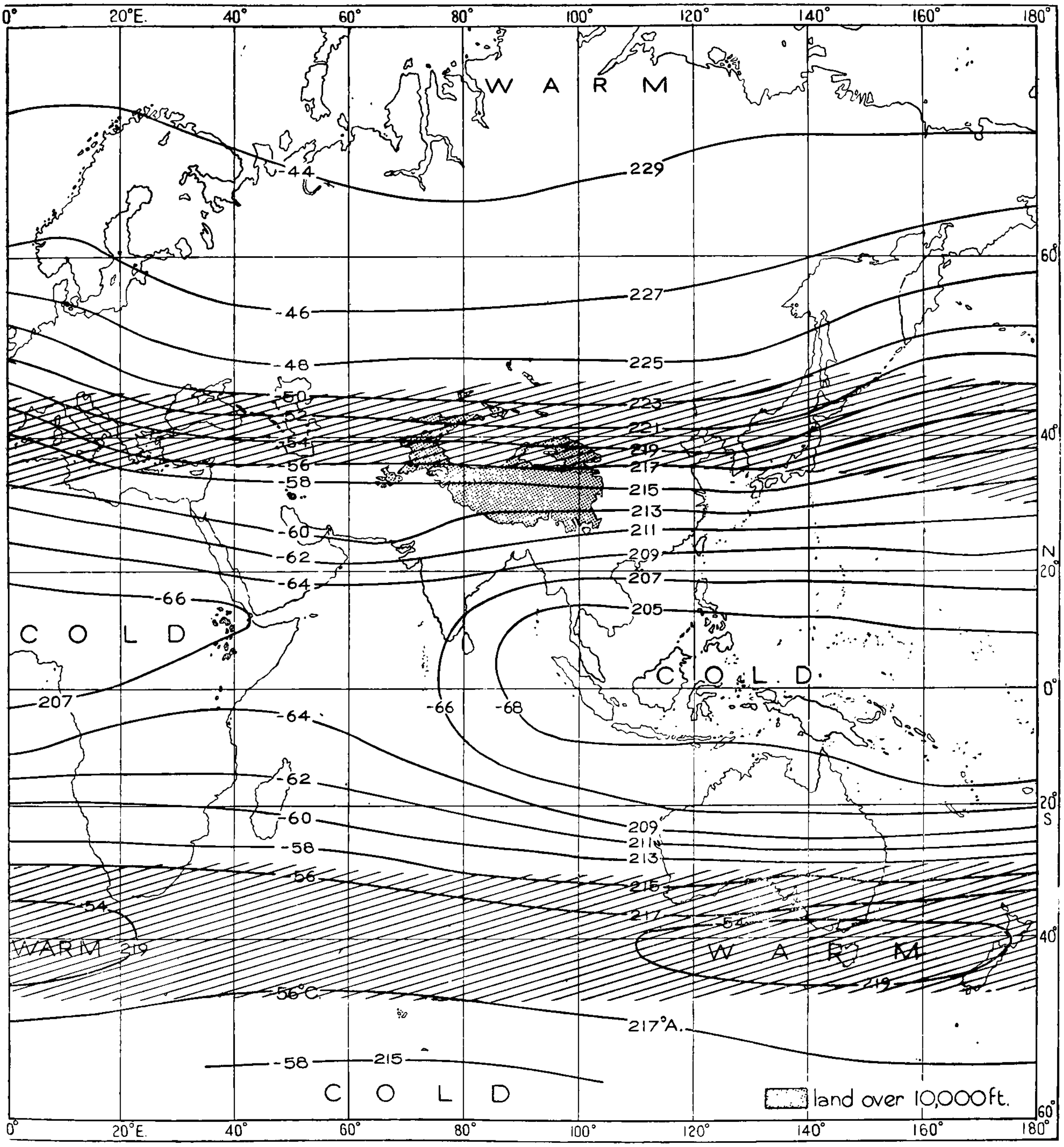

PLATE 21—CONTINUED

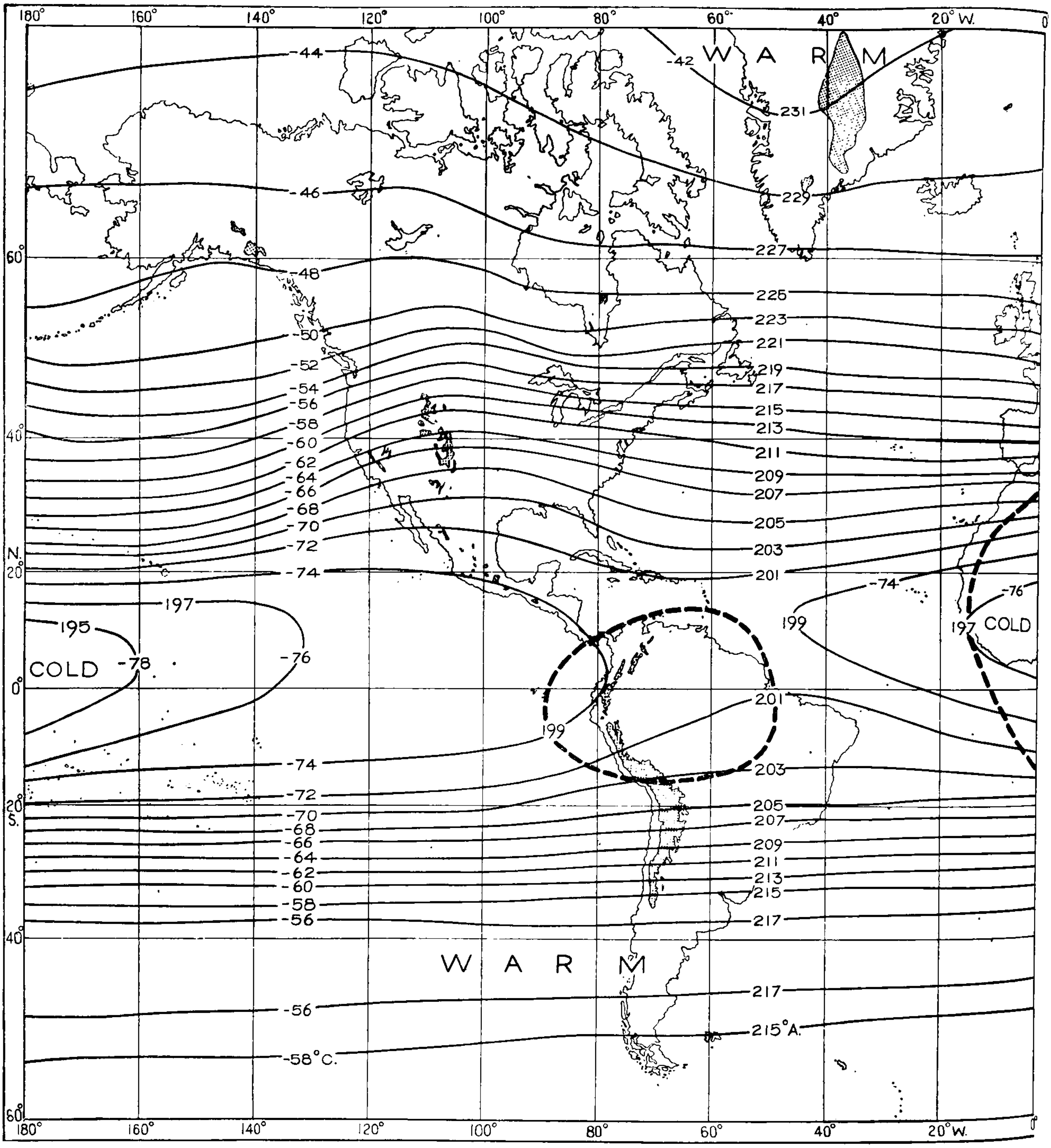

PLATE 22—AVERAGE TEMPERATURE AT 100 MB. IN JULY

I.C.A.N. height = 53,054 ft. = 16,170 m.

The thick broken line indicates the intersection of the 100-mb. and average tropopause surfaces.

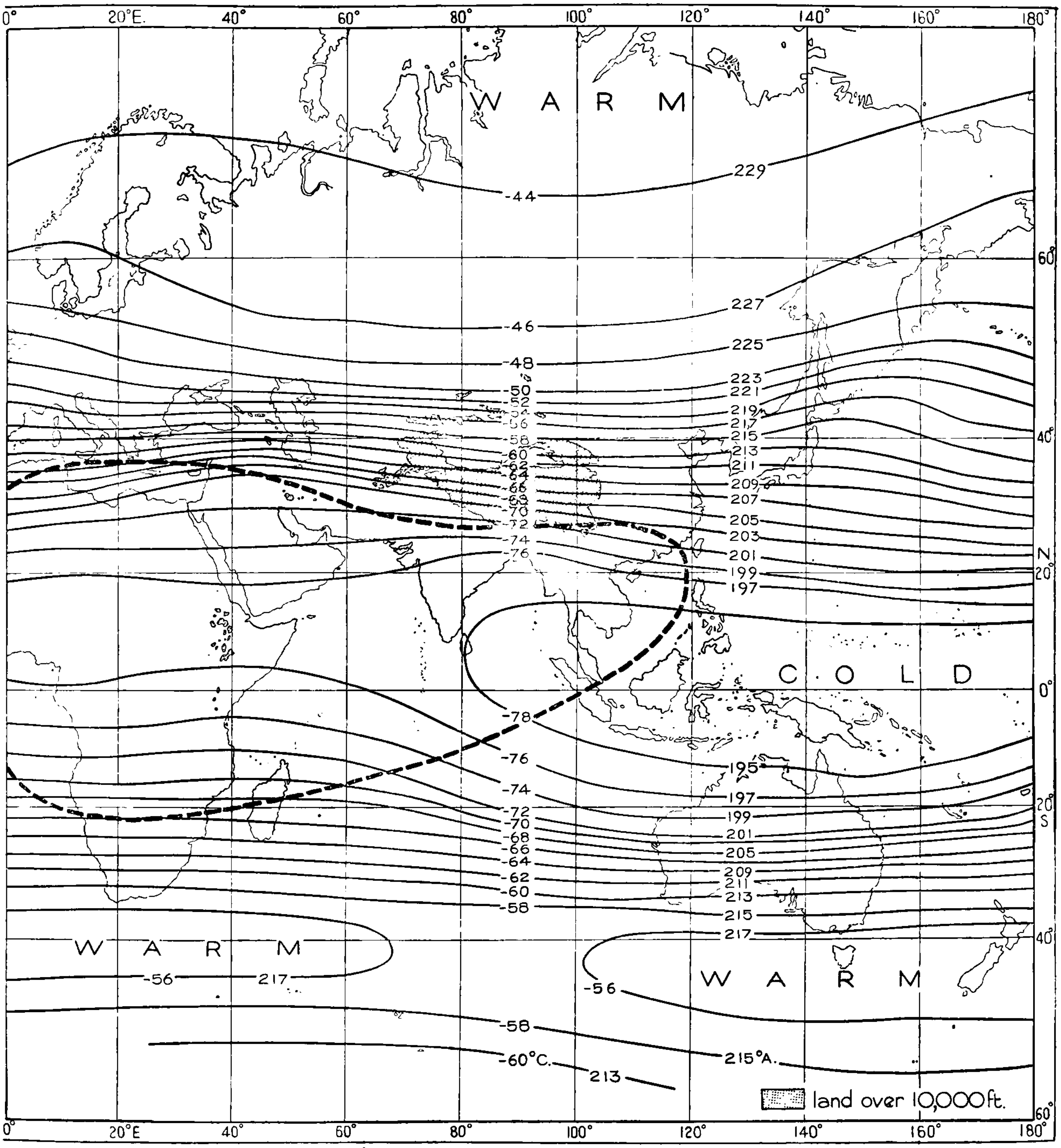

PLATE 22—CONTINUED

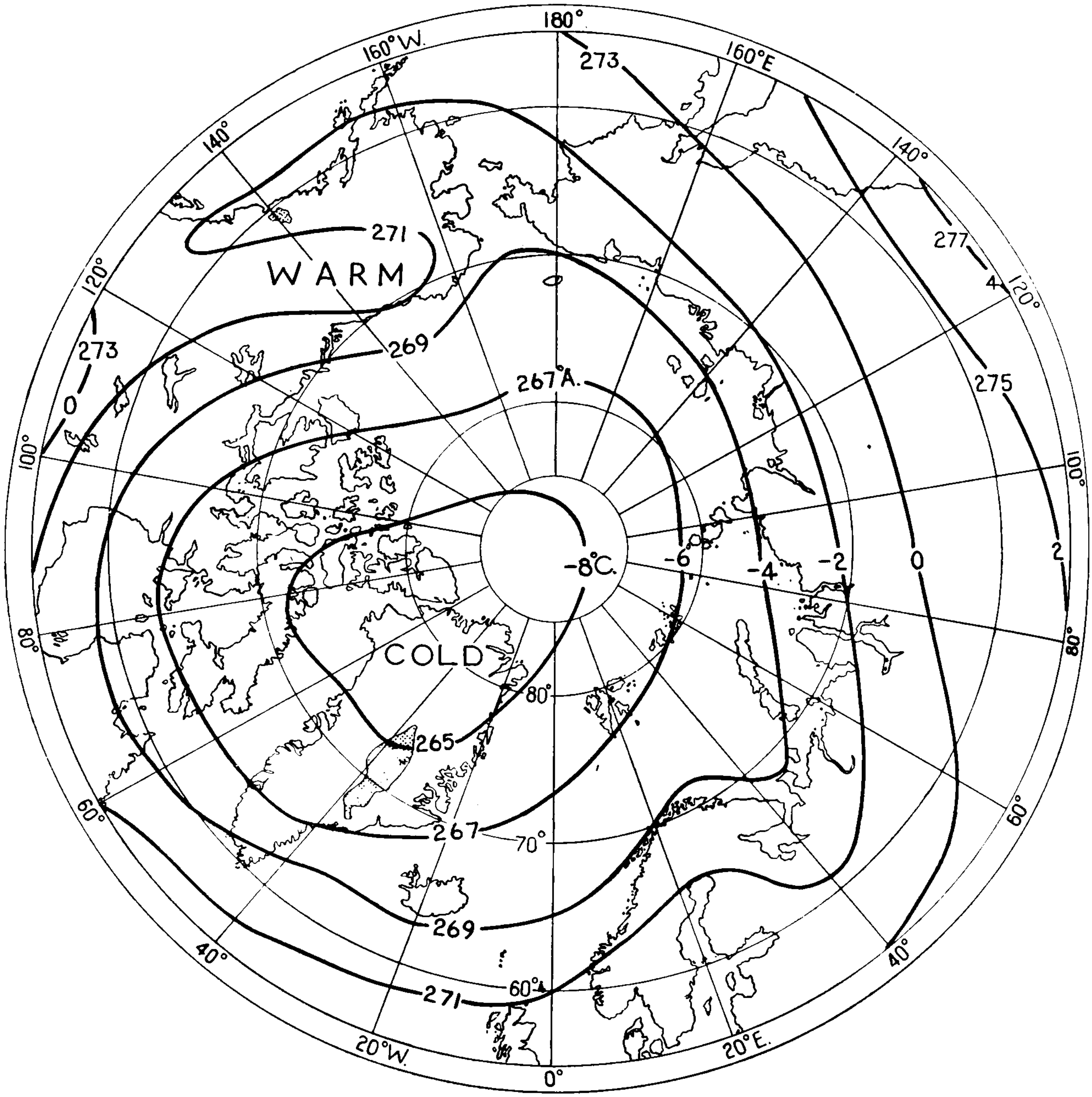

PLATE 23A—AVERAGE TEMPERATURE AT 700 MB. IN JULY

I.C.A.N. height = 9,876 ft. = 3,010 m.

Land over 10,000 feet is represented by shading.

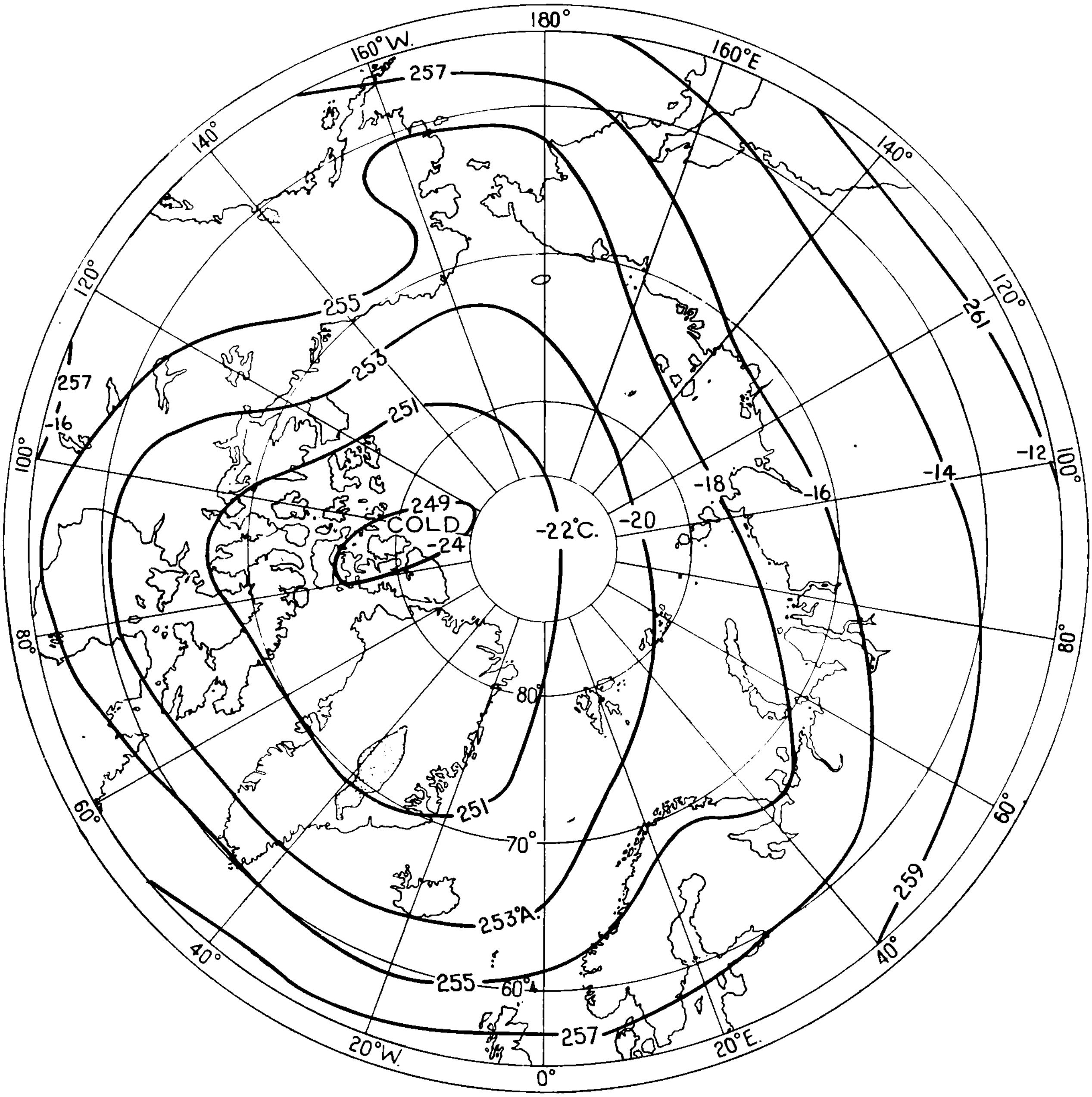

PLATE 23B—AVERAGE TEMPERATURE AT 500 MB. IN JULY

I.C.A.N. height = 18,278 ft. = 5,571 m.

Land over 10,000 feet is represented by shading.

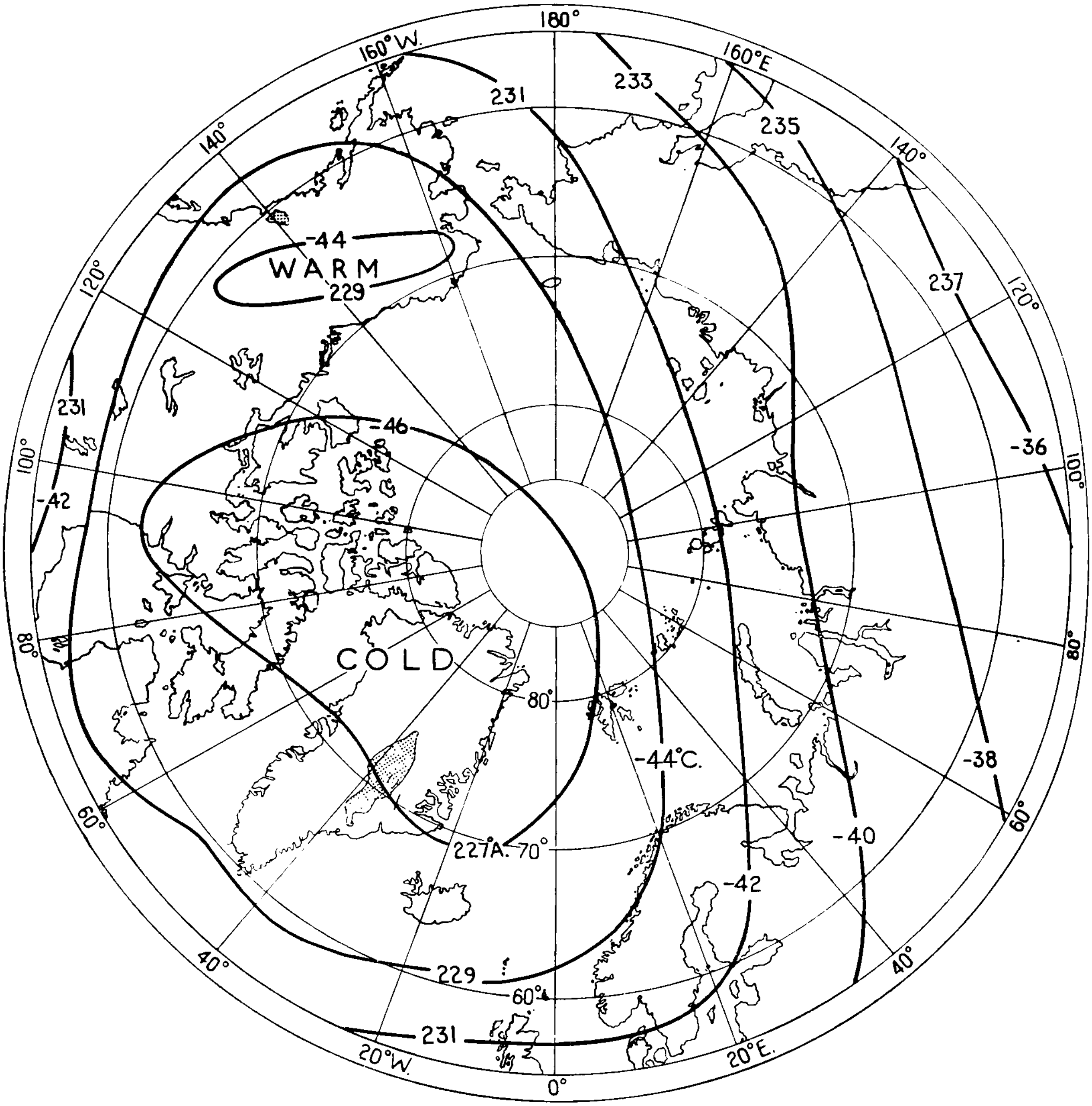

PLATE 23c—AVERAGE TEMPERATURE AT 300 MB. IN JULY

I.C.A.N. height = 30,059 ft. = 9,162 m.

Land over 10,000 feet is represented by shading.

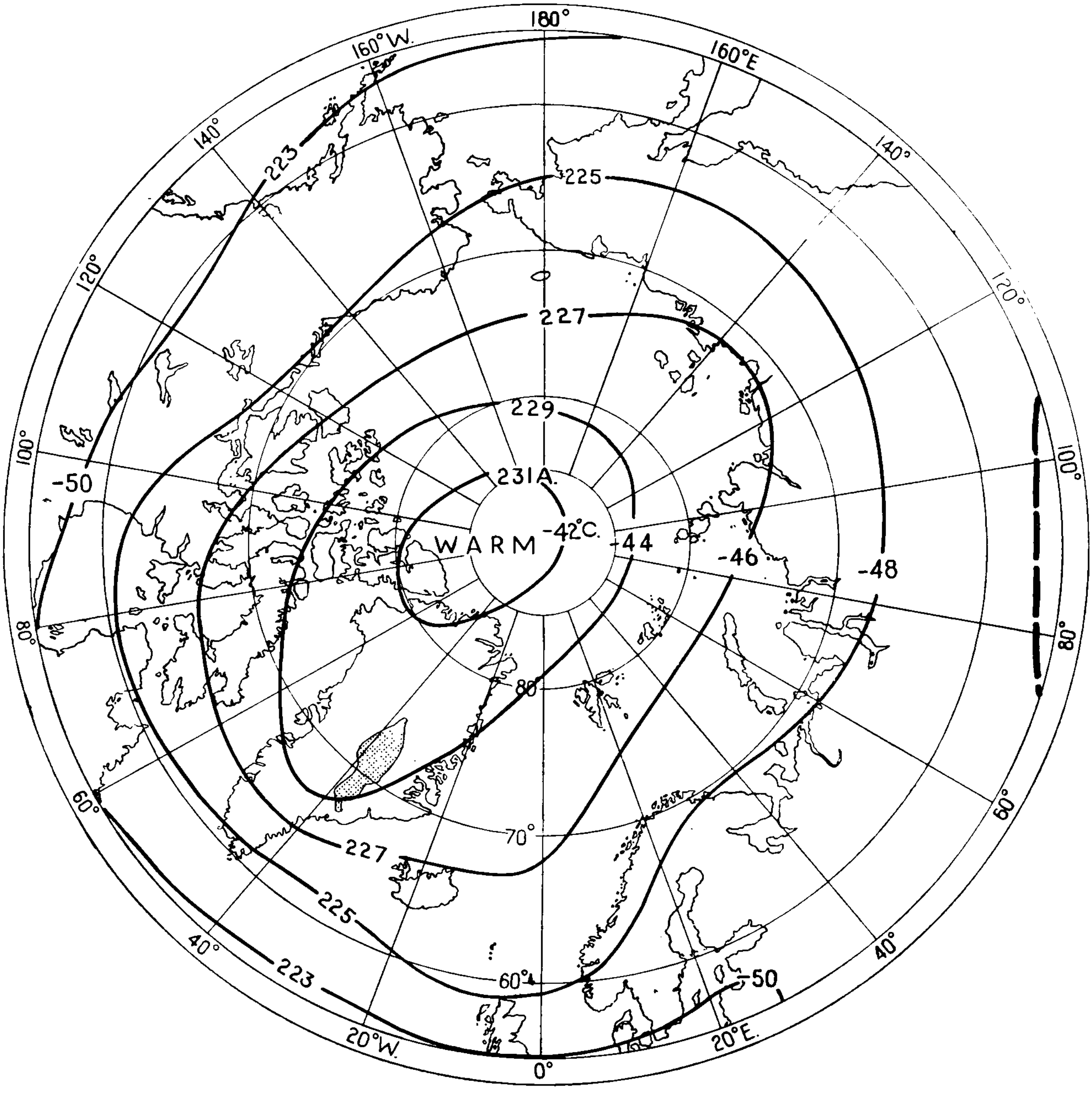

PLATE 24A—AVERAGE TEMPERATURE AT 200 MB. IN JULY

I.C.A.N. height = 38,644 ft. = 11,779 m.

The thick broken line indicates the intersection of the 200-mb. and average tropopause surfaces.

Land over 10,000 feet is represented by shading.

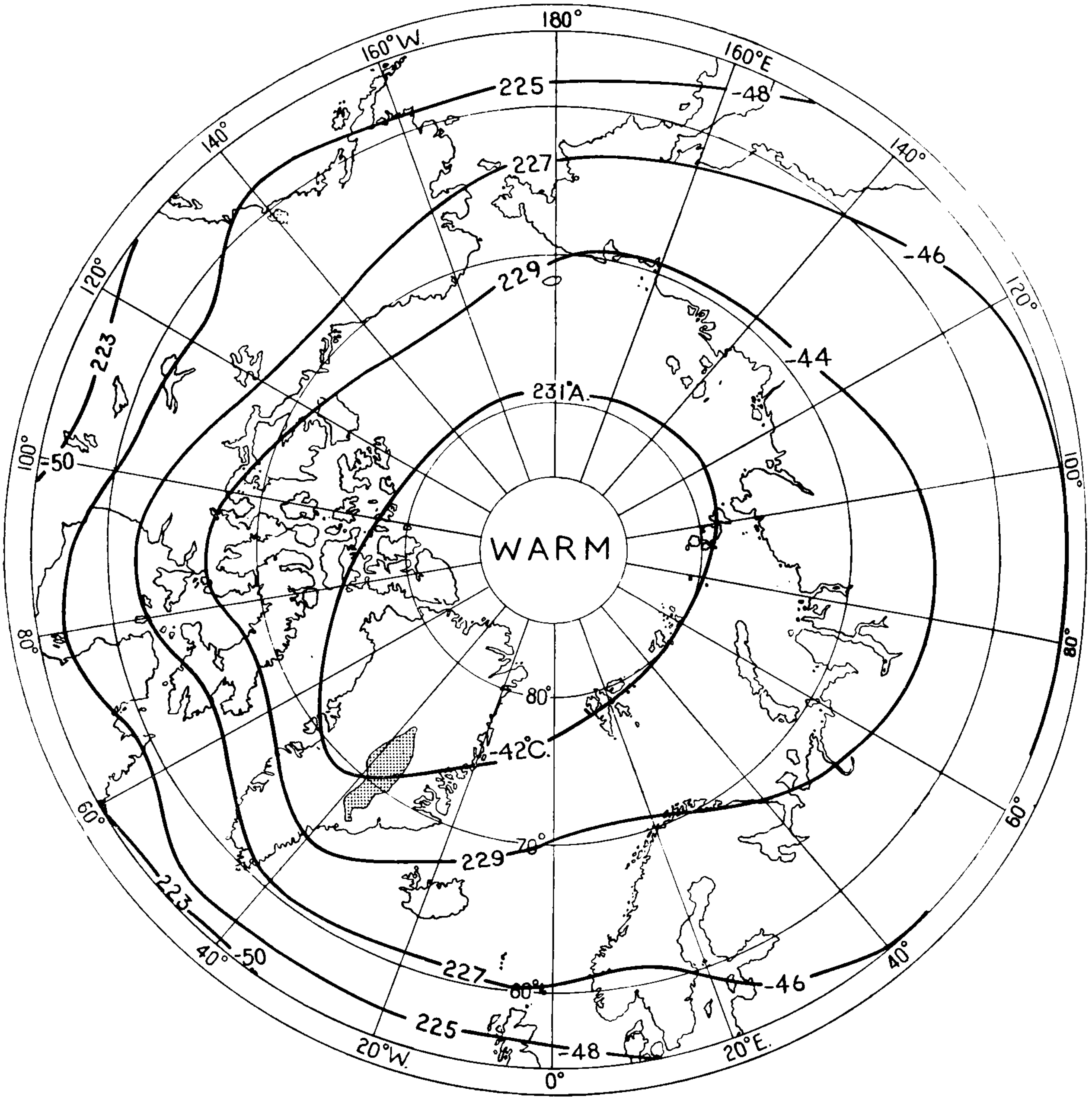

PLATE 24B—AVERAGE TEMPERATURE AT 150 MB. IN JULY

I.C.A.N. height = 44,625 ft. = 13,602 m.

Land over 10,000 feet is represented by shading.

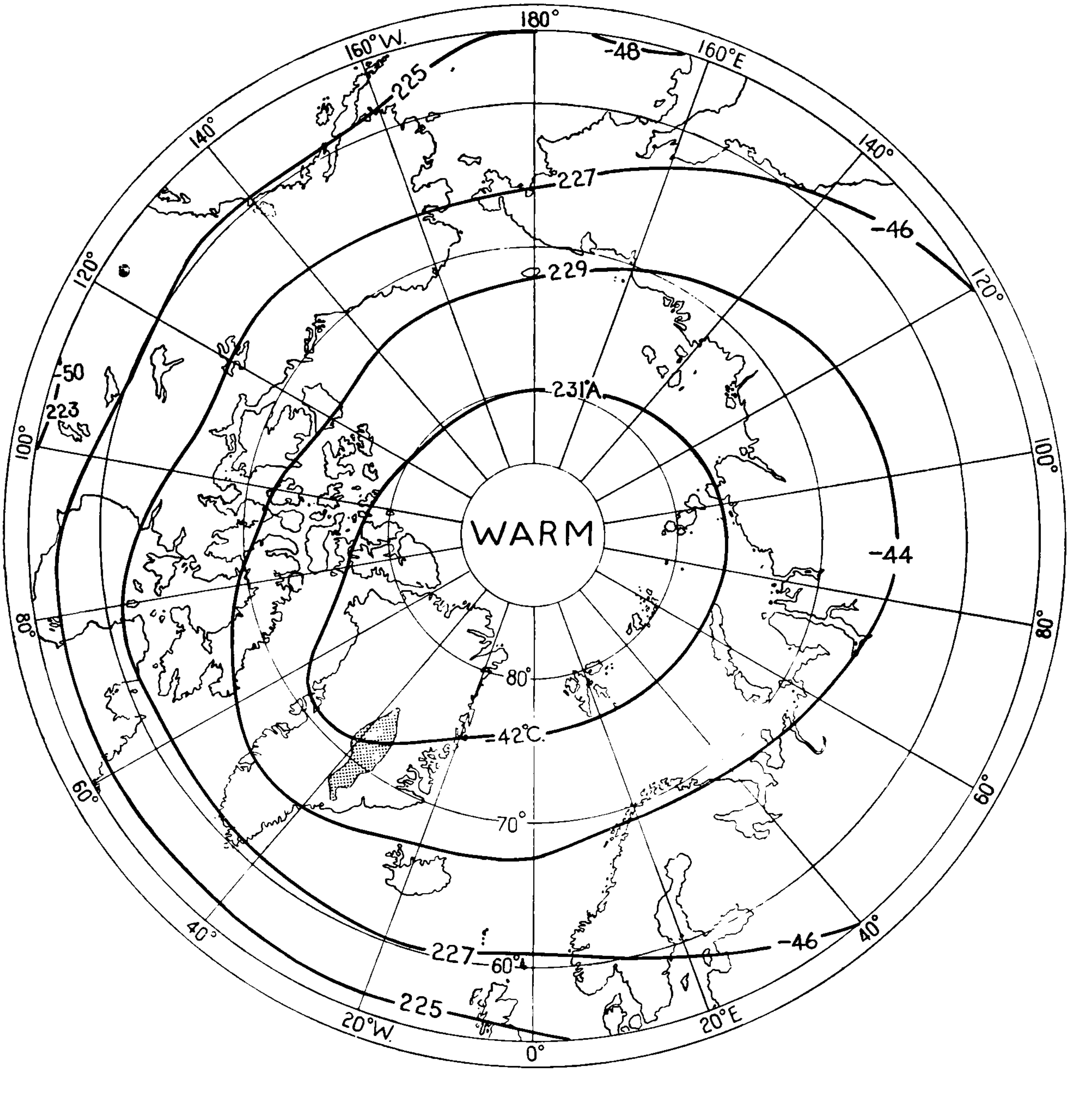

PLATE 24c—AVERAGE TEMPERATURE AT 100 MB. IN JULY

I.C.A.N. height = 53,054 ft. = 16,170 m.

Land over 10,000 feet is represented by shading.

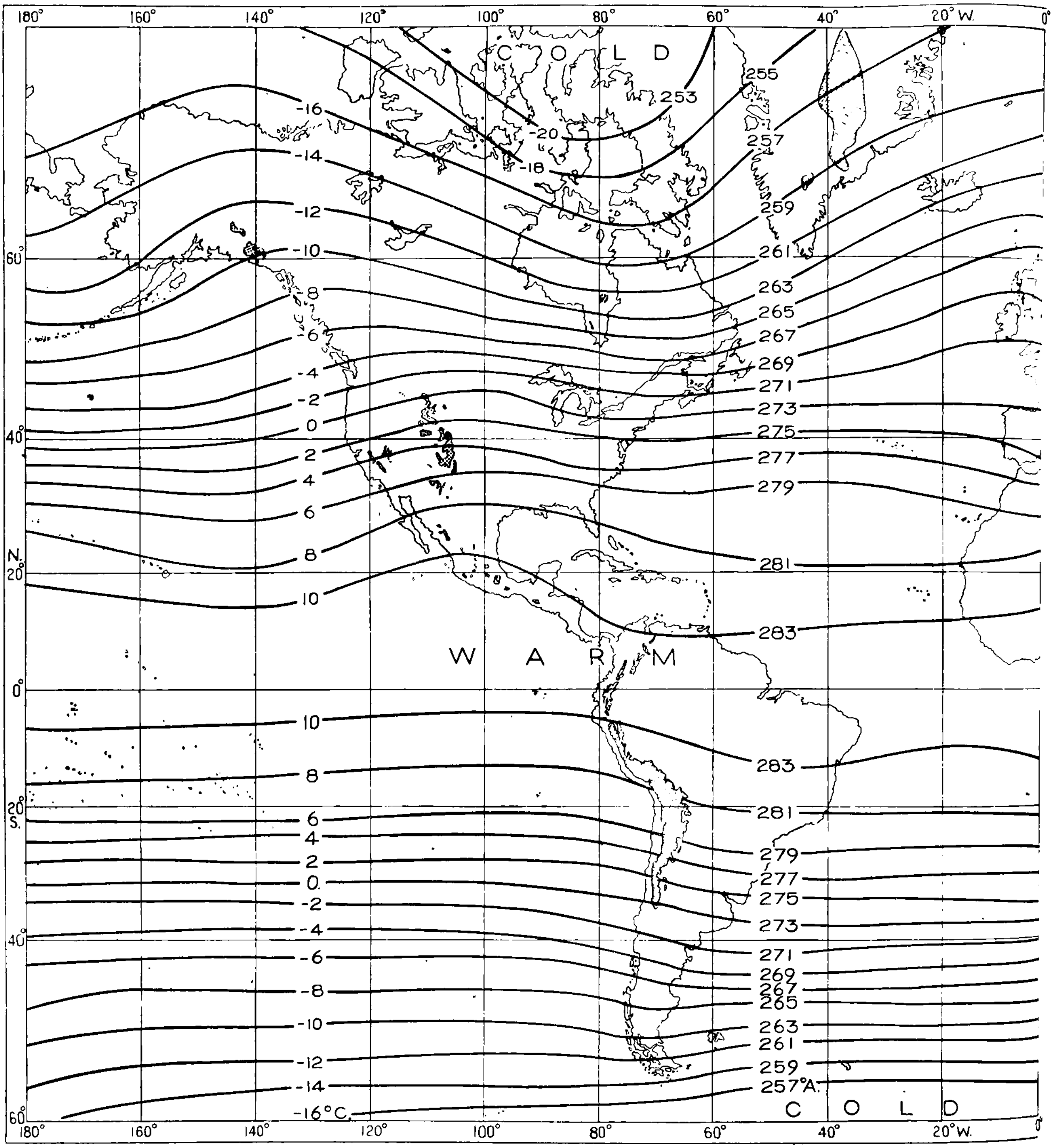

PLATE 25—AVERAGE TEMPERATURE AT 700 MB. IN OCTOBER

I.C.A.N. height = 9,876 ft. = 3,010 m.

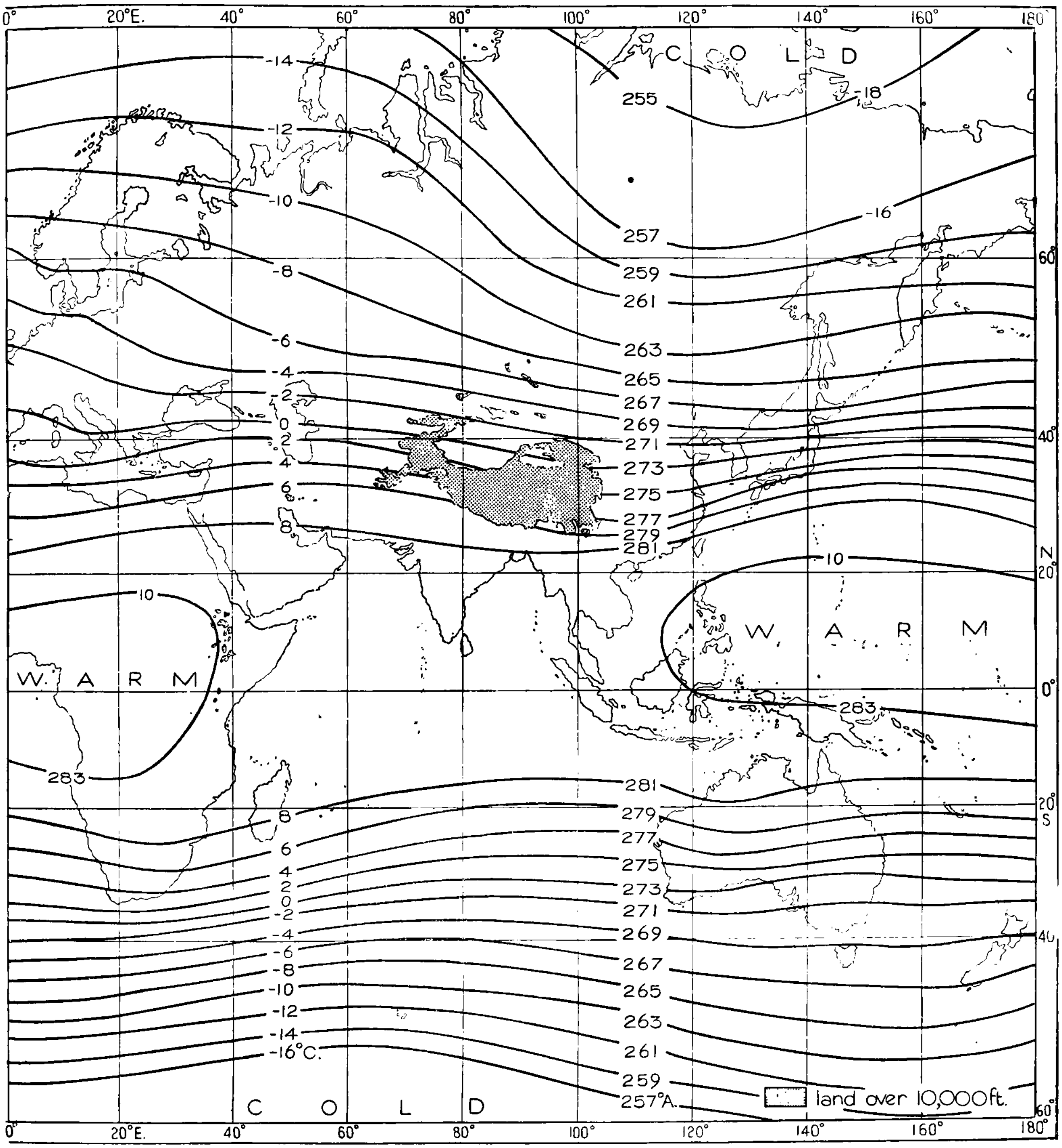

PLATE 25—CONTINUED

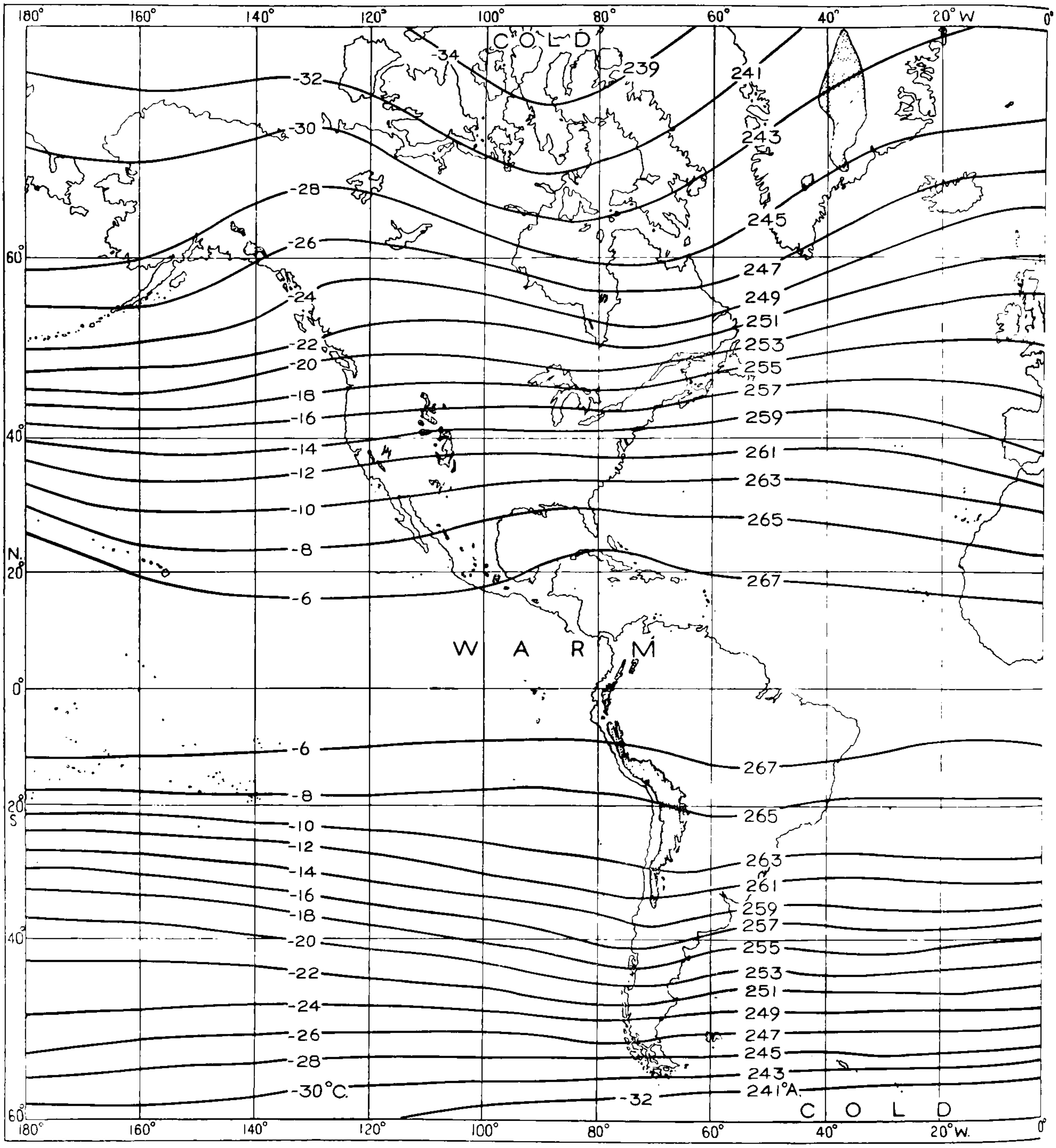

PLATE 26—AVERAGE TEMPERATURE AT 500 MB. IN OCTOBER

I.C.A.N. height = 18,278 ft. = 5,571 m.

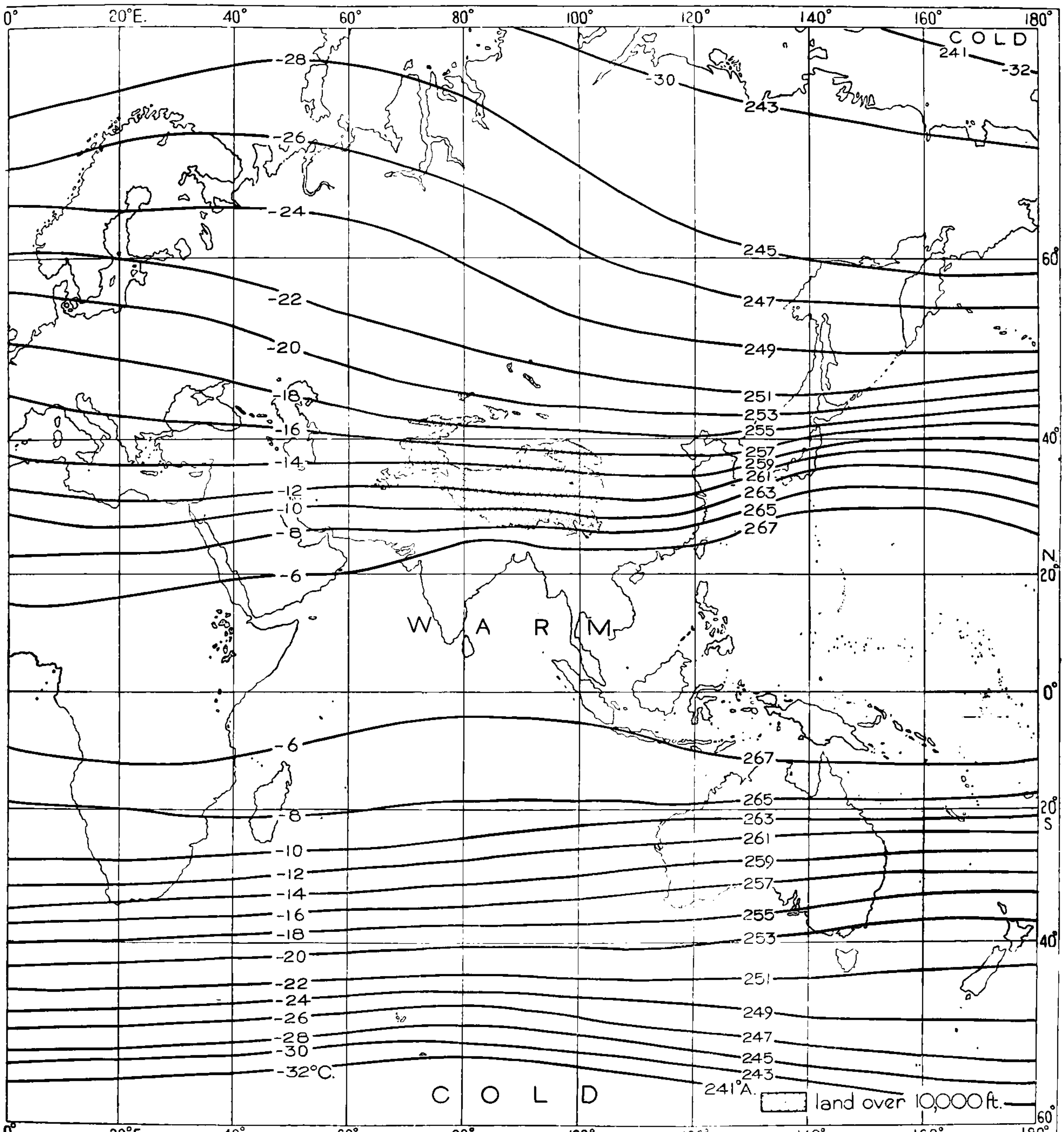

PLATE 26—CONTINUED

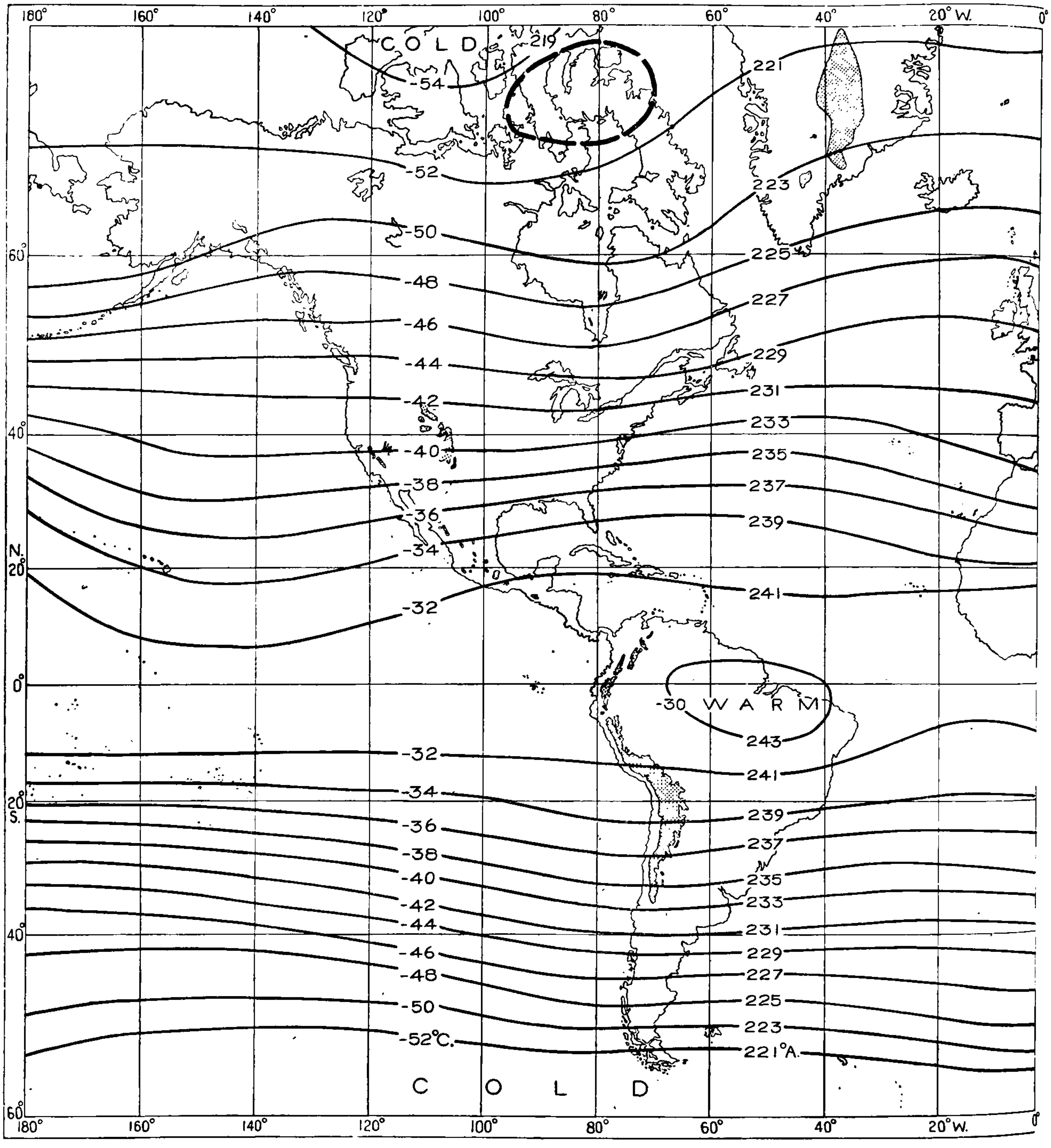

PLATE 27—AVERAGE TEMPERATURE AT 300 MB. IN OCTOBER

I.C.A.N. height = 30,059 ft. = 9,162 m.

The thick broken line indicates the intersection of the 300-mb. and average tropopause surfaces.

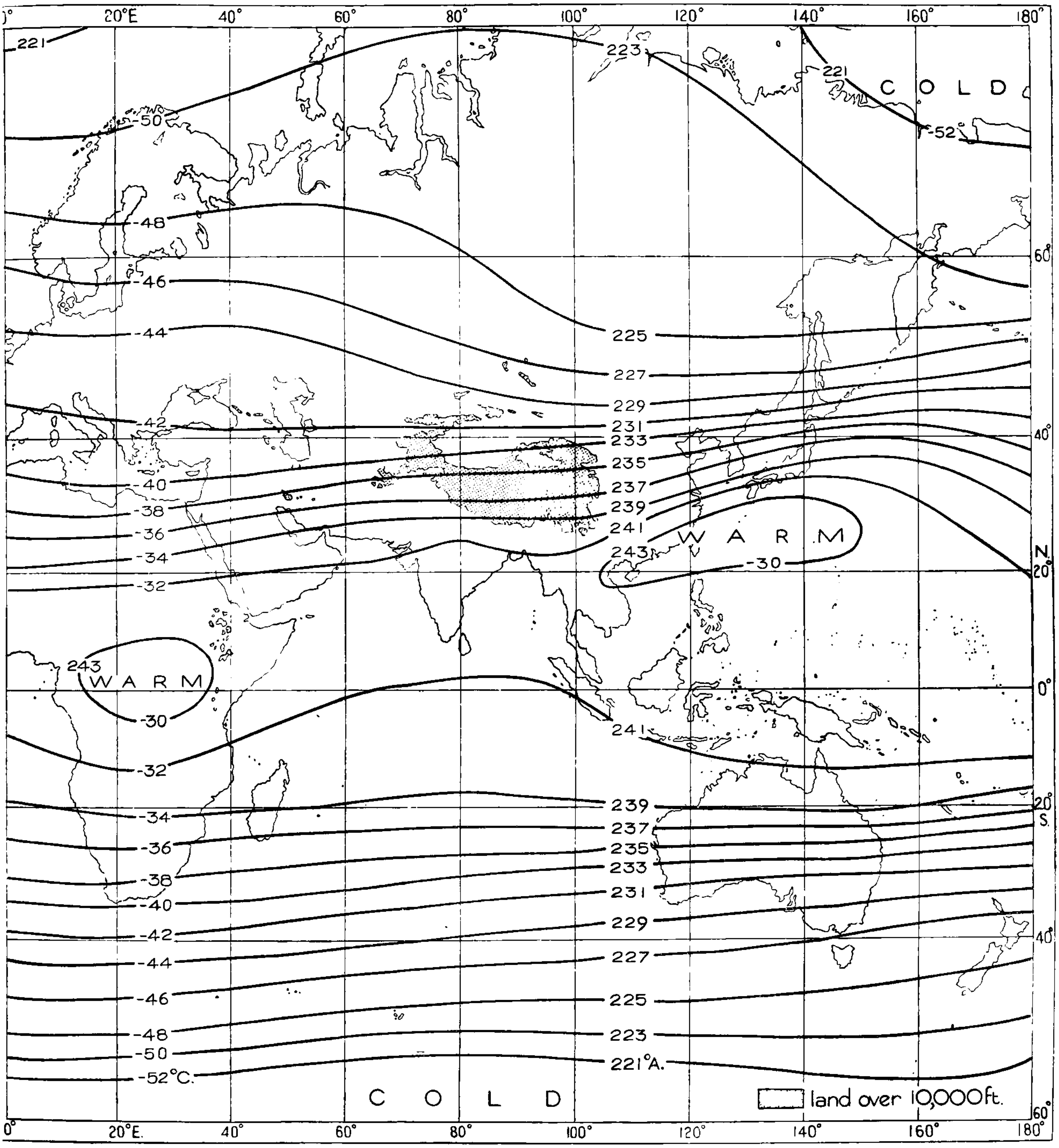

PLATE 27—CONTINUED

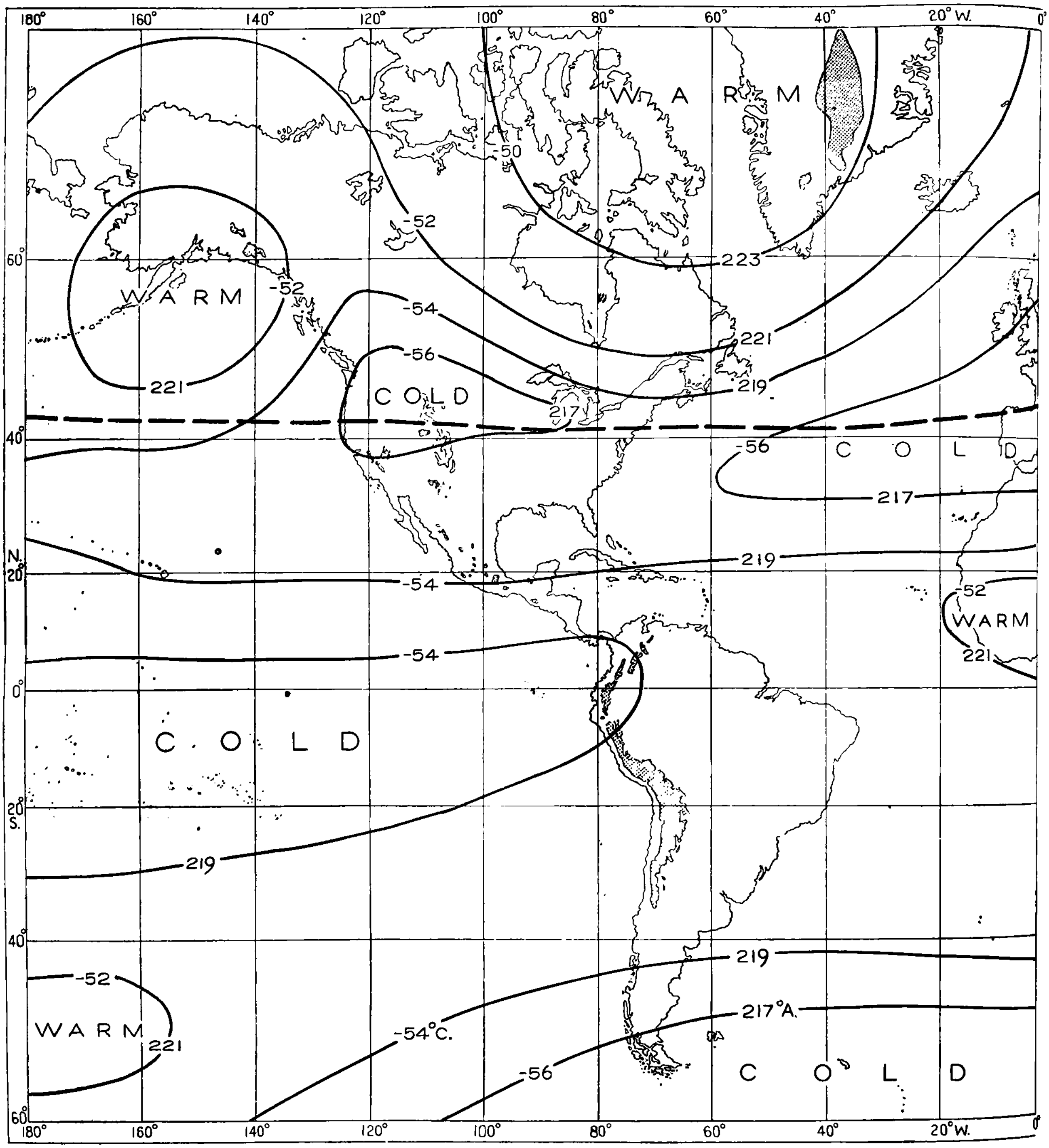

PLATE 28—AVERAGE TEMPERATURE AT 200 MB. IN OCTOBER

I.C.A.N. height = 38,644 ft. = 11,779 m.

The thick broken line indicates the intersection of the 200-mb. and average tropopause surfaces.

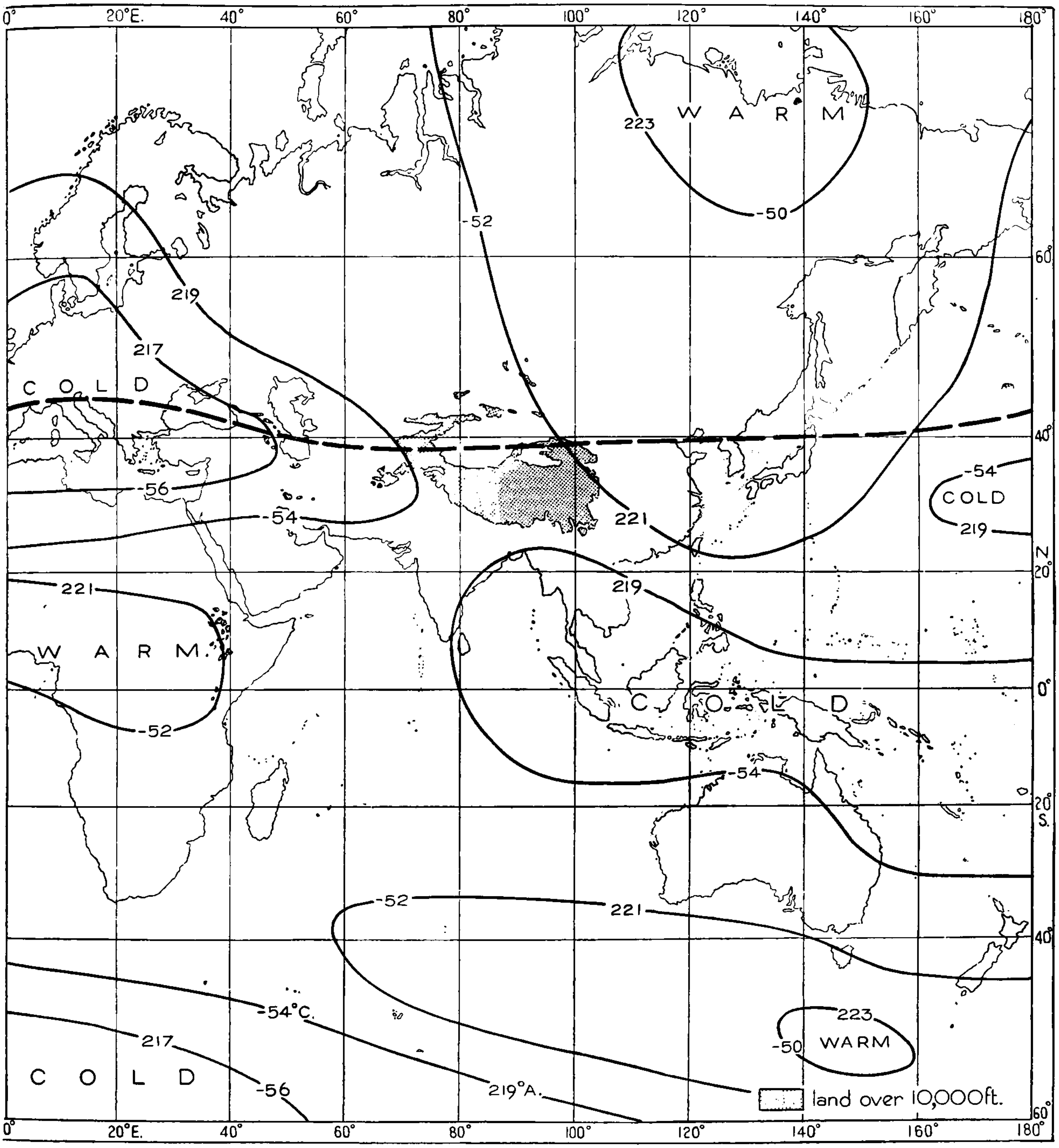

PLATE 28—CONTINUED

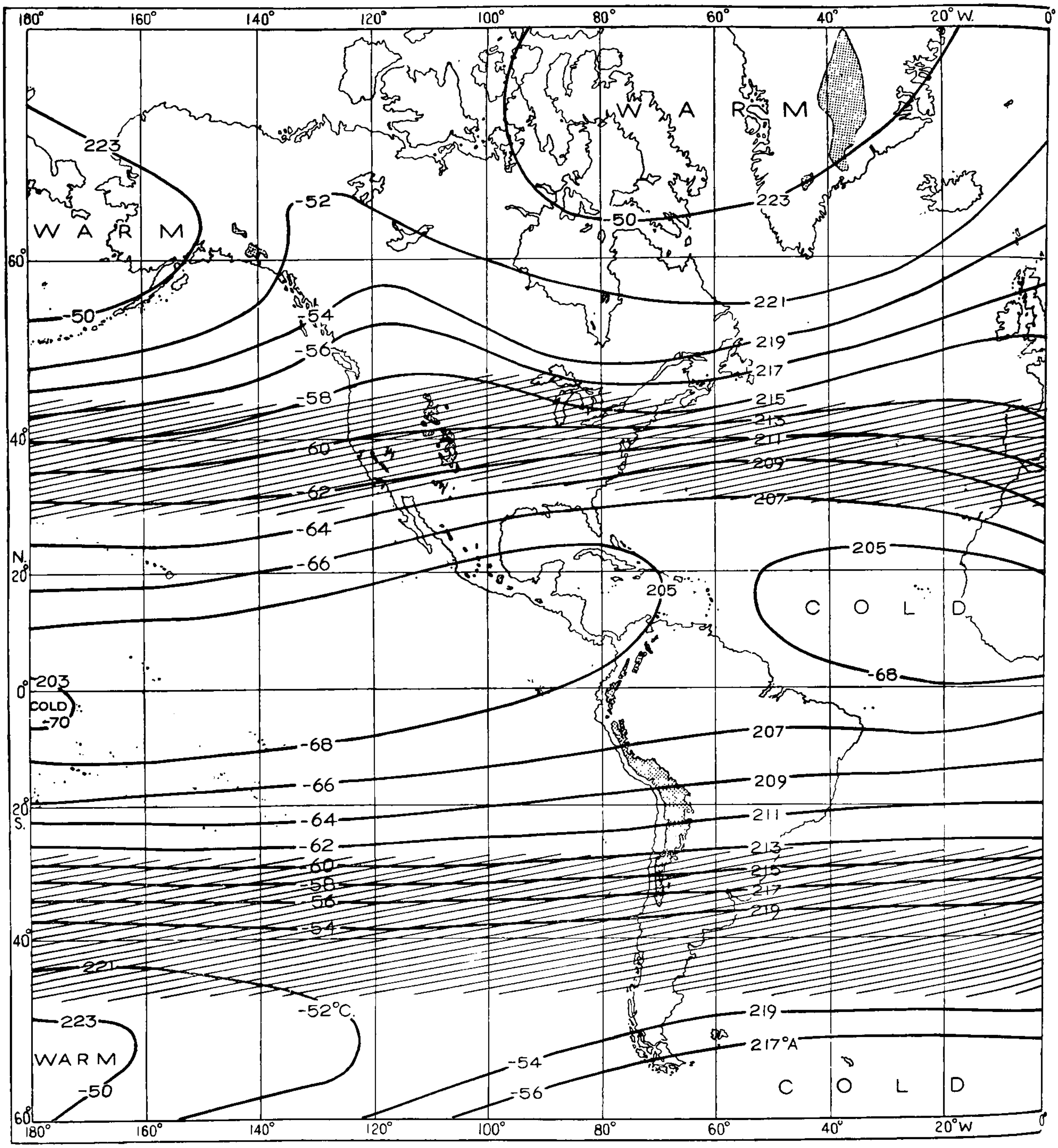

PLATE 29—AVERAGE TEMPERATURE AT 150 MB. IN OCTOBER

I.C.A.N. height = 44,625 ft. = 13,602 m.

Areas in which the frequencies of occurrences of both tropopauses are greater than 10 per cent. are shaded.

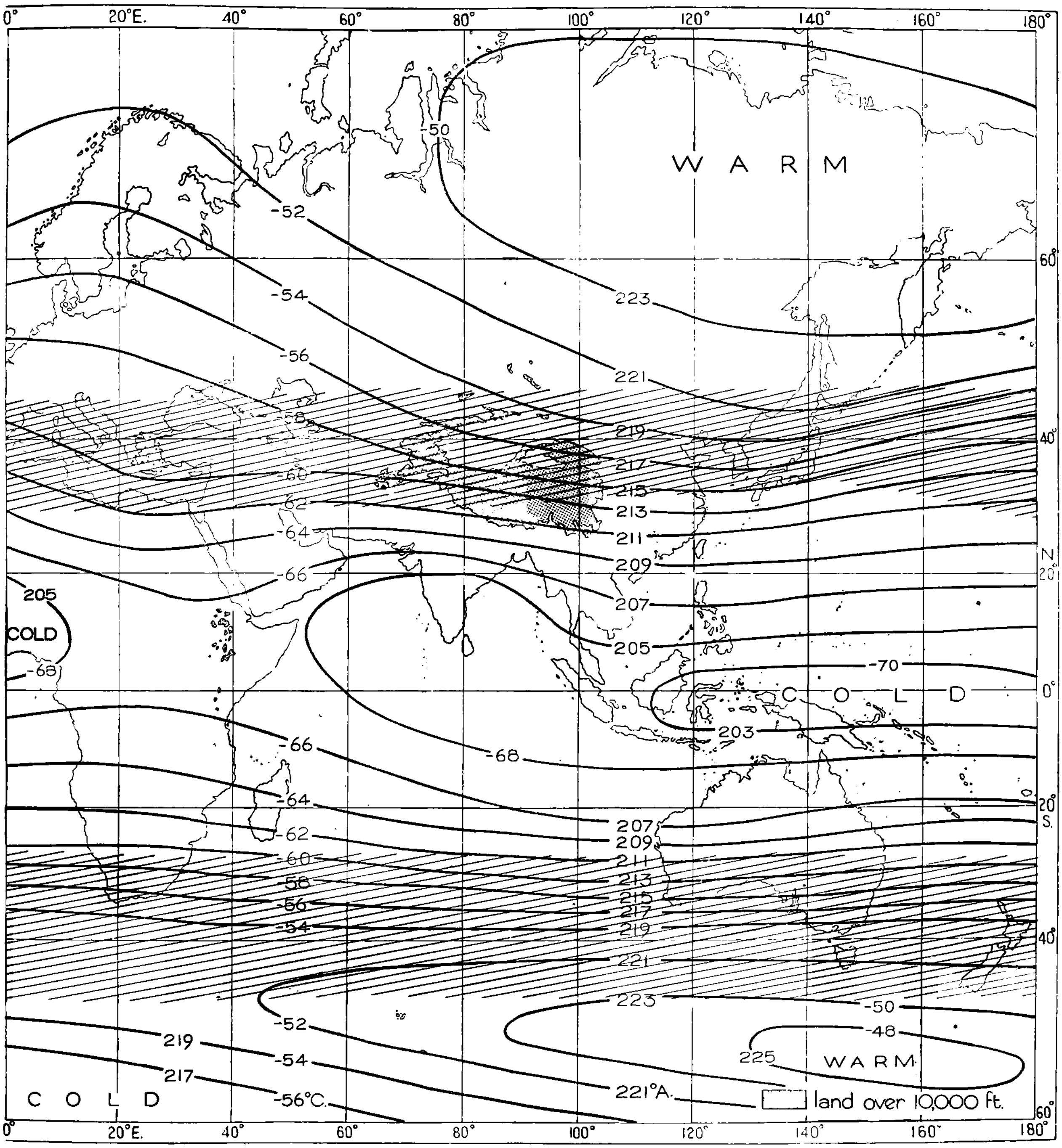

PLATE 29—CONTINUED

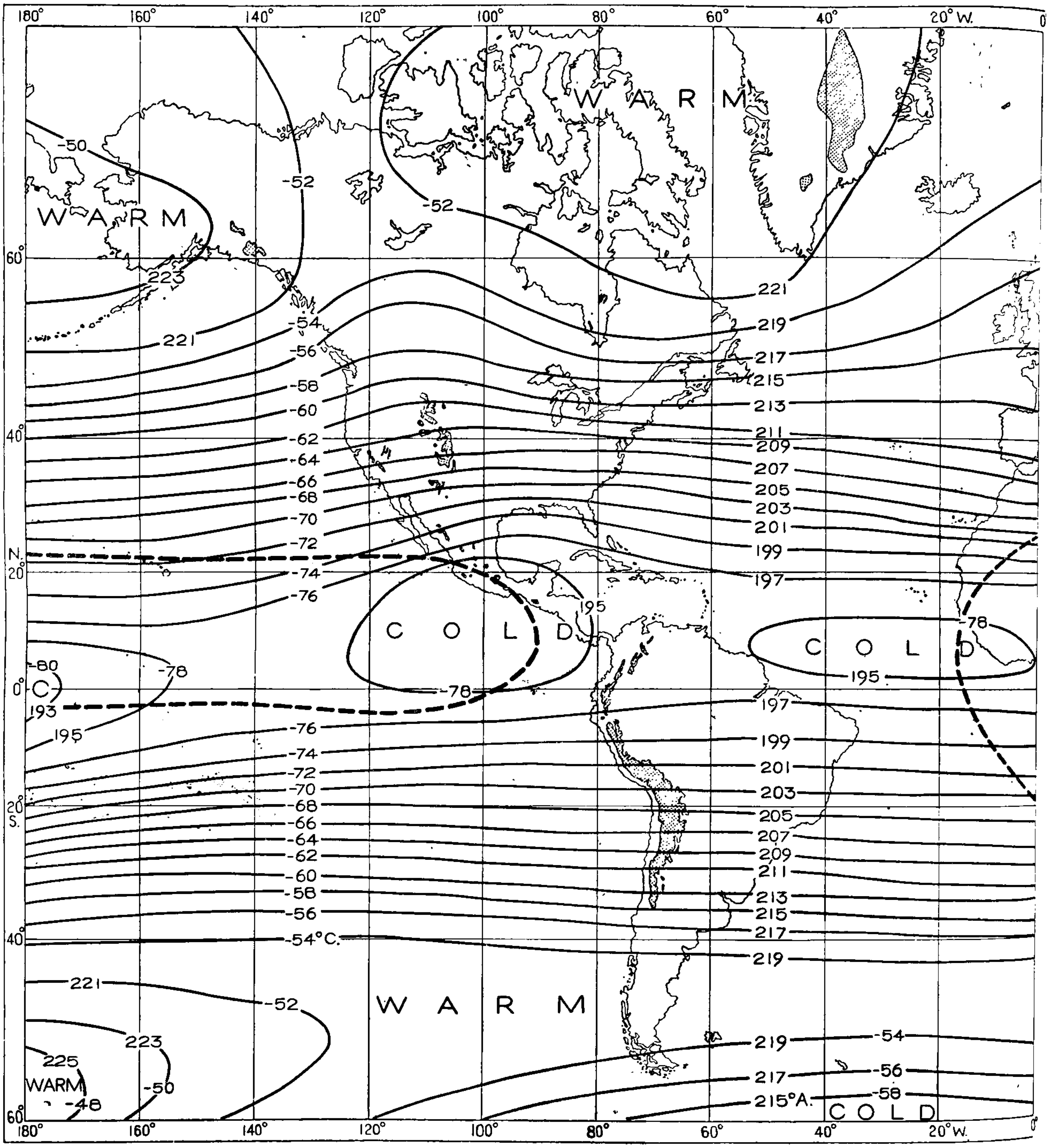

PLATE 30—AVERAGE TEMPERATURE AT 100 MB. IN OCTOBER

I.C.A.N. height = 53,054 ft. = 16,170 m.

The thick broken line indicates the intersection of the 100-mb. and average tropopause surfaces.

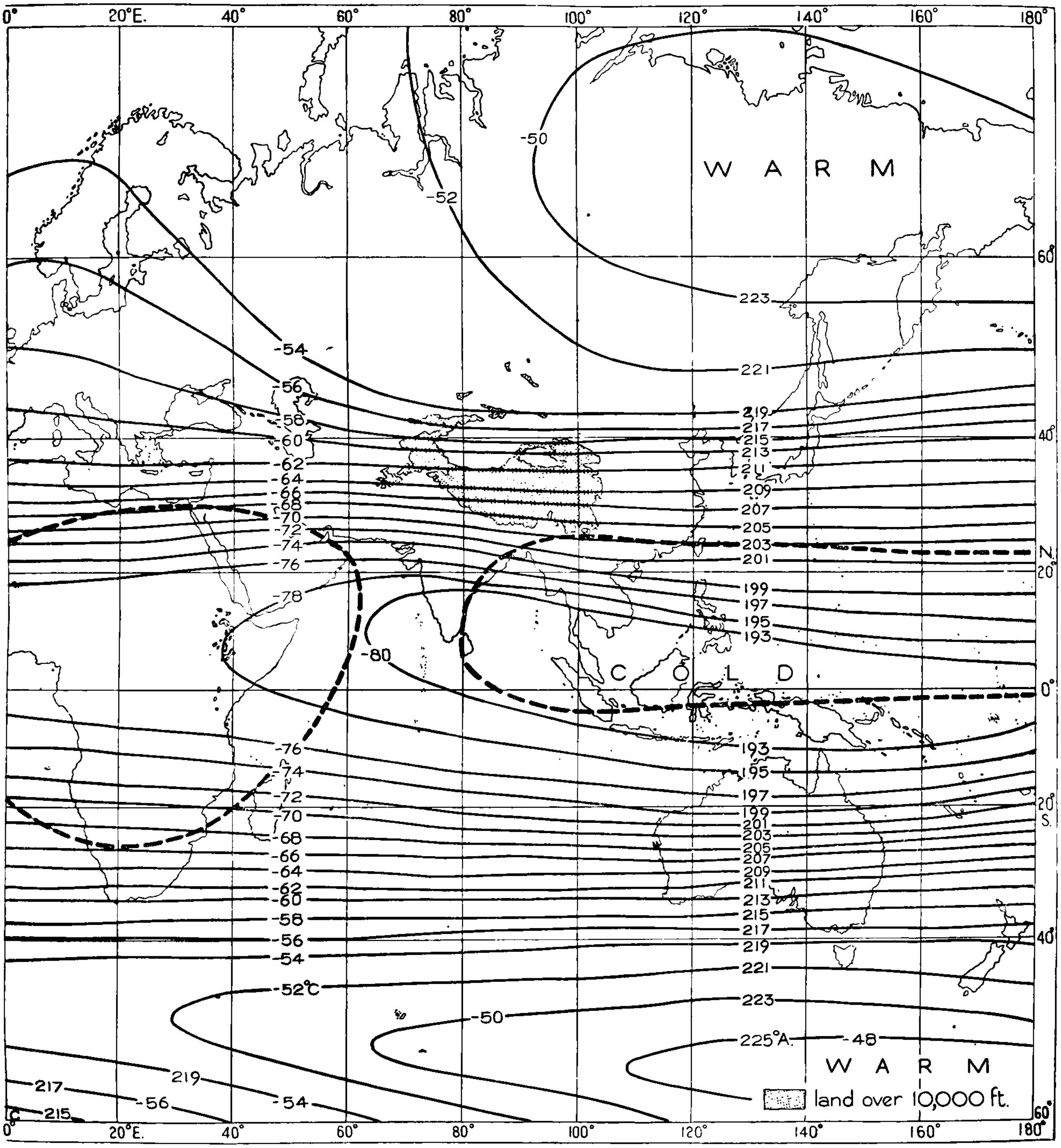

PLATE 30—CONTINUED

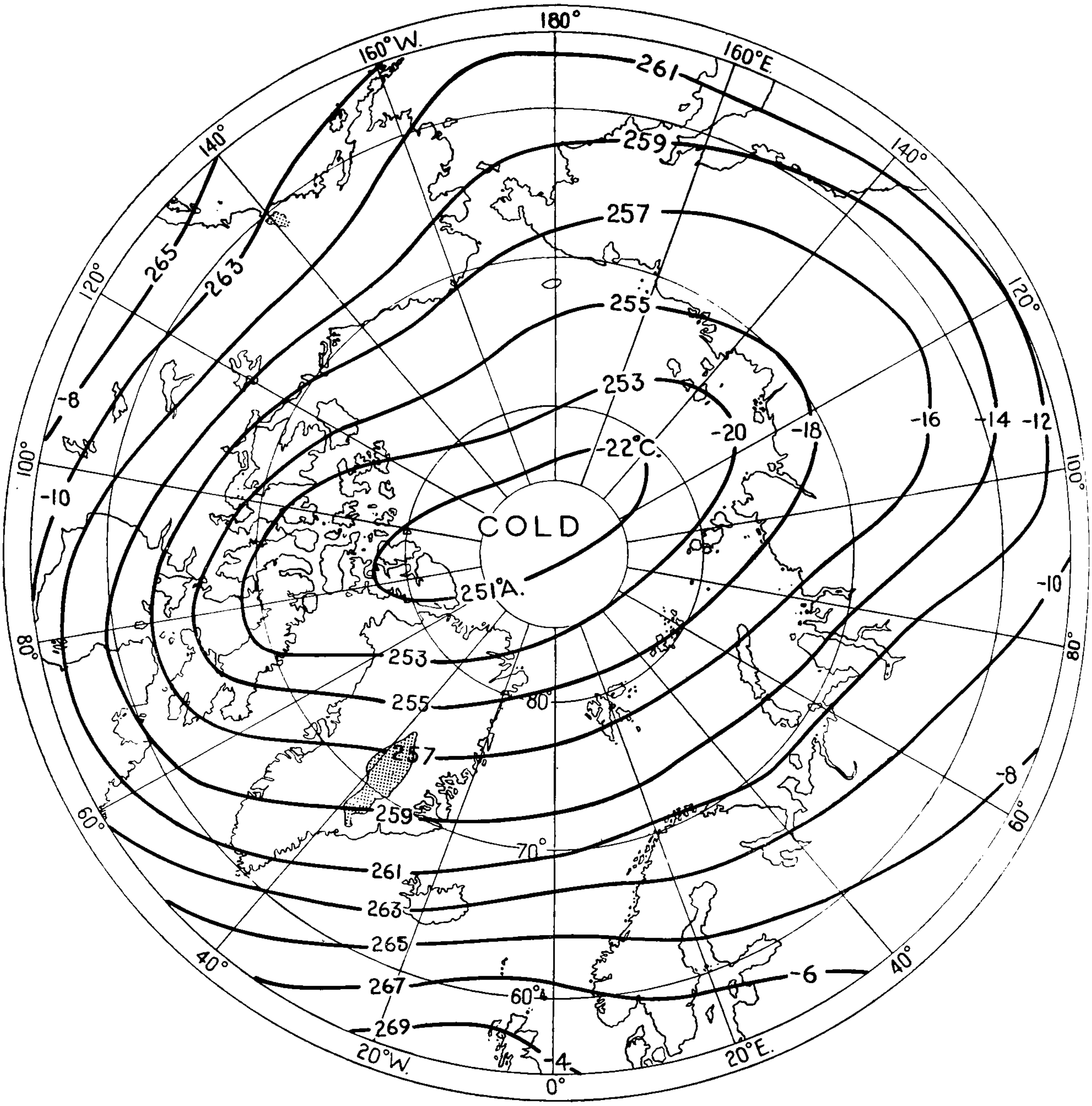

PLATE 31A—AVERAGE TEMPERATURE AT 700 MB. IN OCTOBER

I.C.A.N. height = 9,876 ft. = 3,010 m.

Land over 10,000 feet is represented by shading.

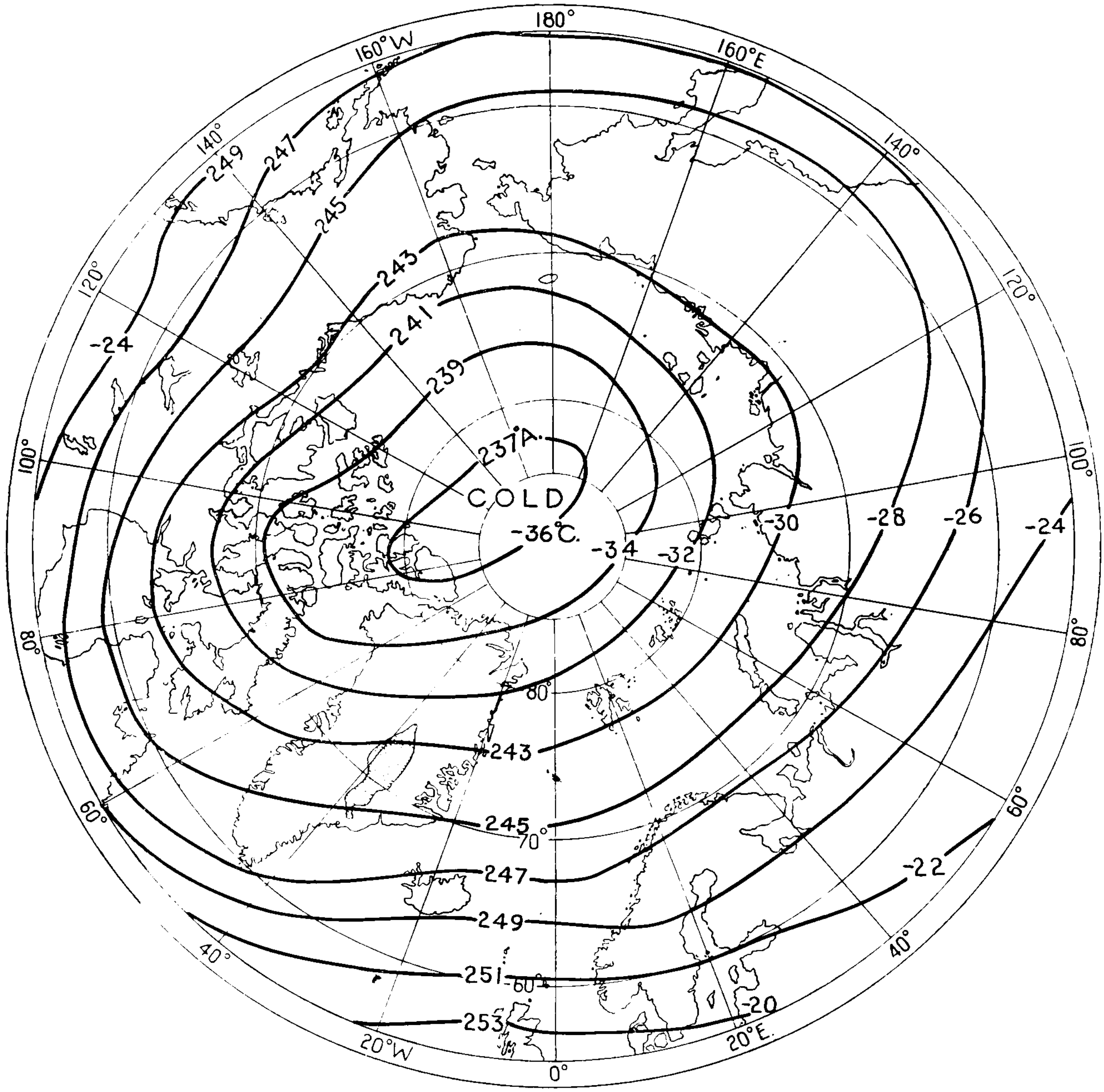

PLATE 31B—AVERAGE TEMPERATURE AT 500 MB. IN OCTOBER

I.C.A.N. height = 18,278 ft. = 5,571 m.

Land over 10,000 feet is represented by shading.

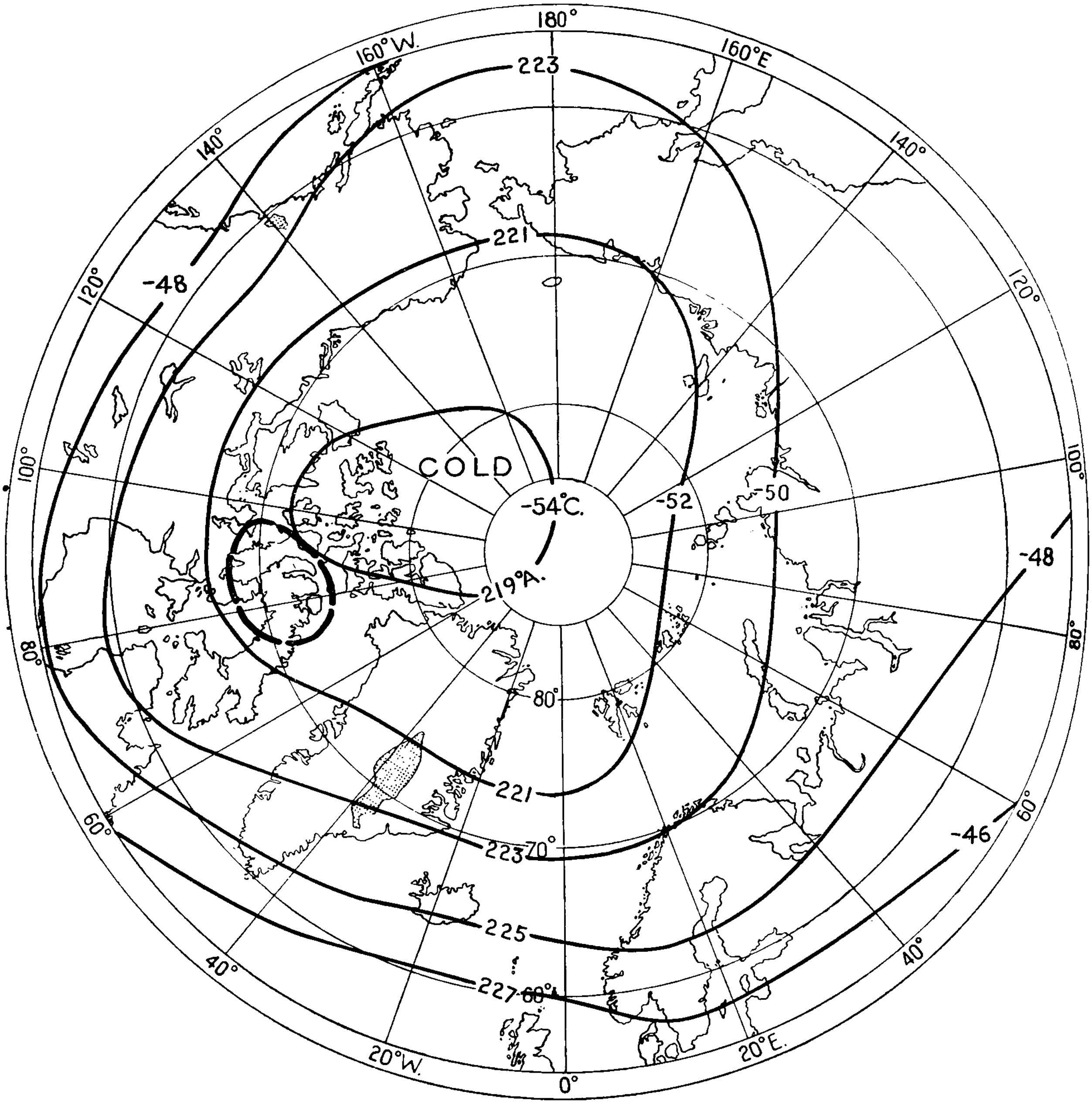

PLATE 31c—AVERAGE TEMPERATURE AT 300 MB. IN OCTOBER

I.C.A.N. height = 30,059 ft. = 9,162 m.

The thick broken line indicates the intersection of the 300-mb. and average tropopause surfaces.

Land over 10,000 feet is represented by shading.

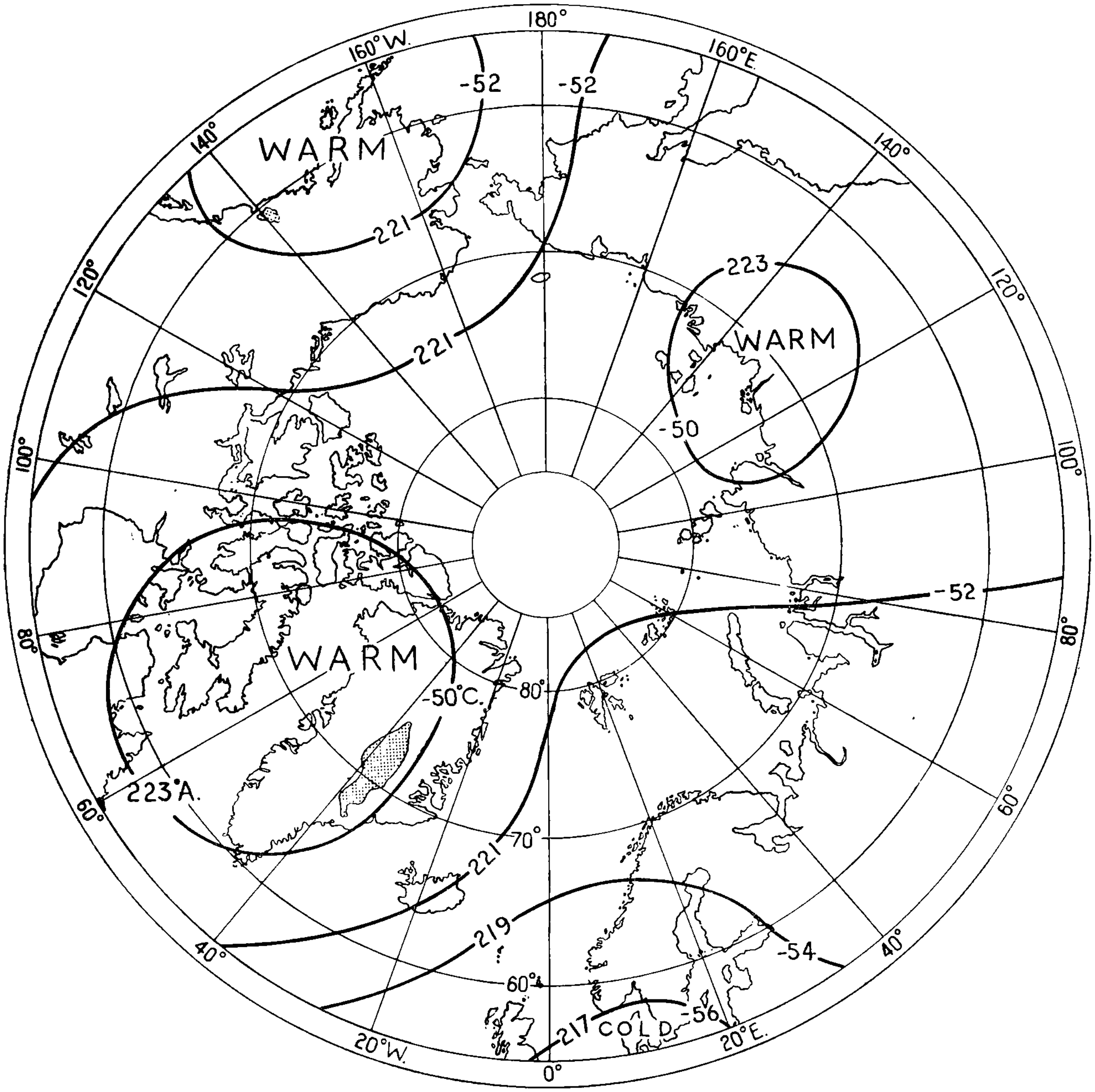

PLATE 32A—AVERAGE TEMPERATURE AT 200 MB. IN OCTOBER

I.C.A.N. height = 38,644 ft. = 11,779 m.

Land over 10,000 feet is represented by shading.

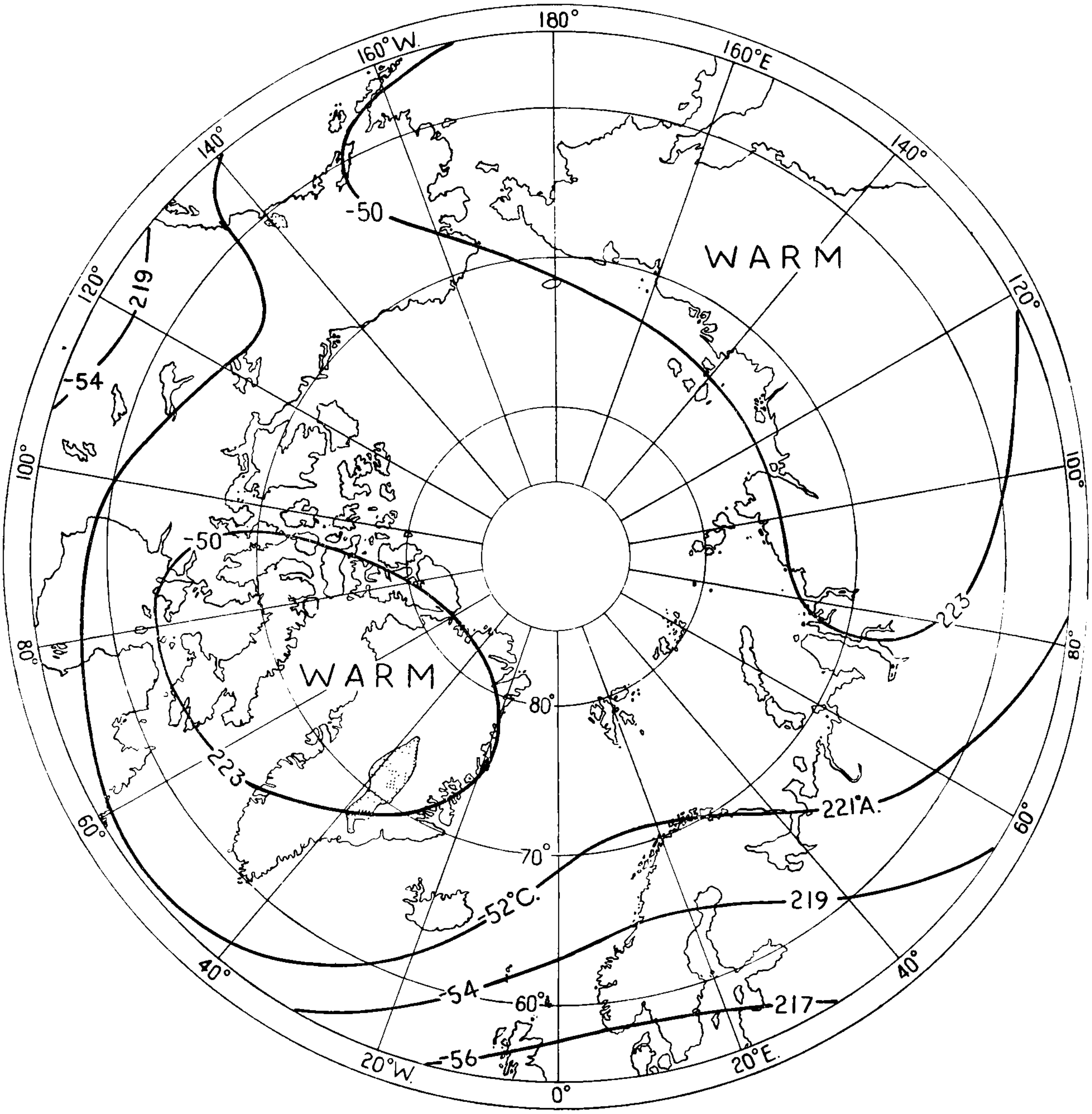

PLATE 32B—AVERAGE TEMPERATURE AT 150 MB. IN OCTOBER

I.C.A.N. height = 44,625 ft. = 13,602 m.

Land over 10,000 feet is represented by shading.

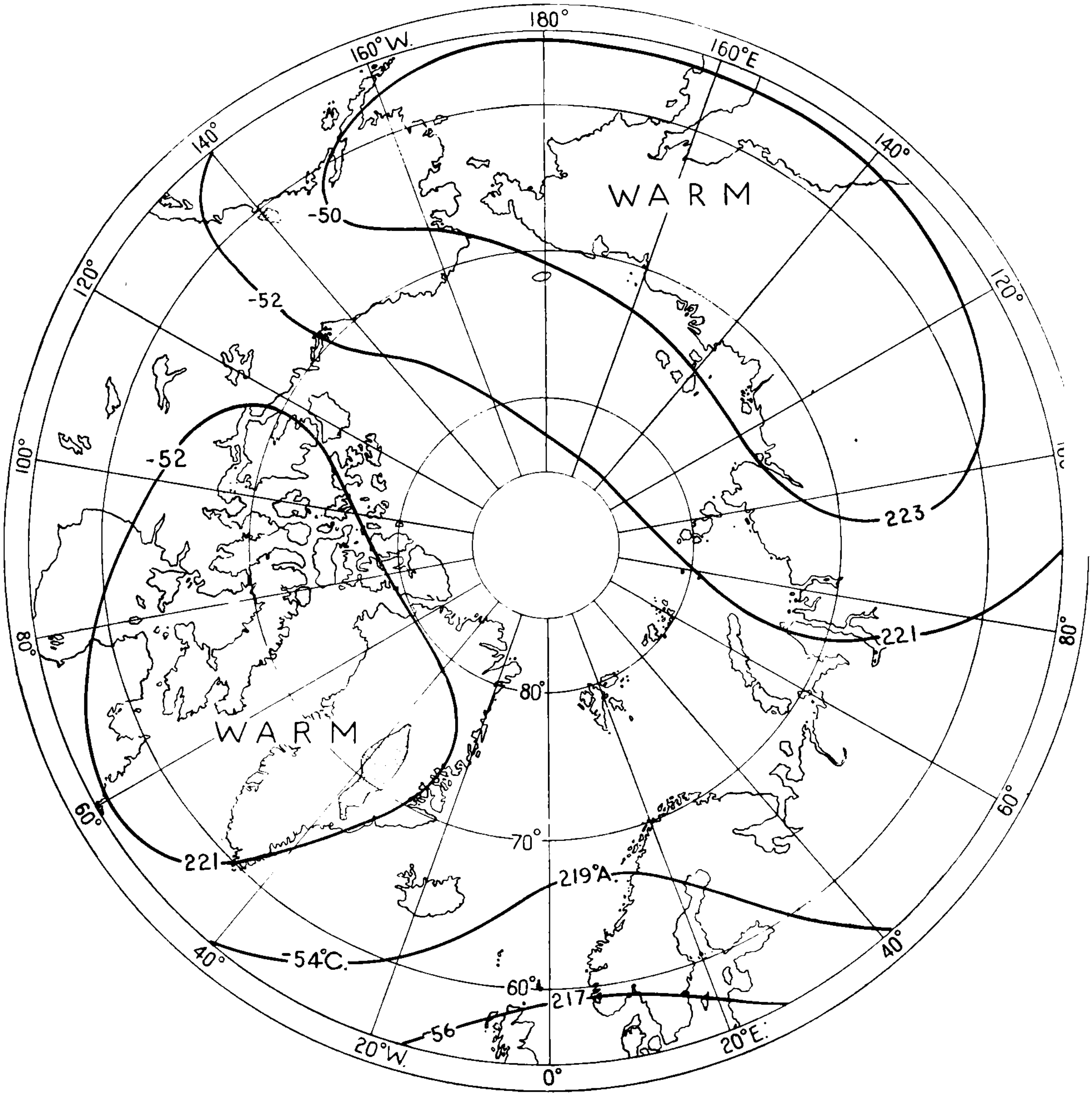

PLATE 32c—AVERAGE TEMPERATURE AT 100 MB. IN OCTOBER

I.C.A.N. height = 53,054 ft. = 16,170 m.

Land over 10,000 feet is represented by shading.

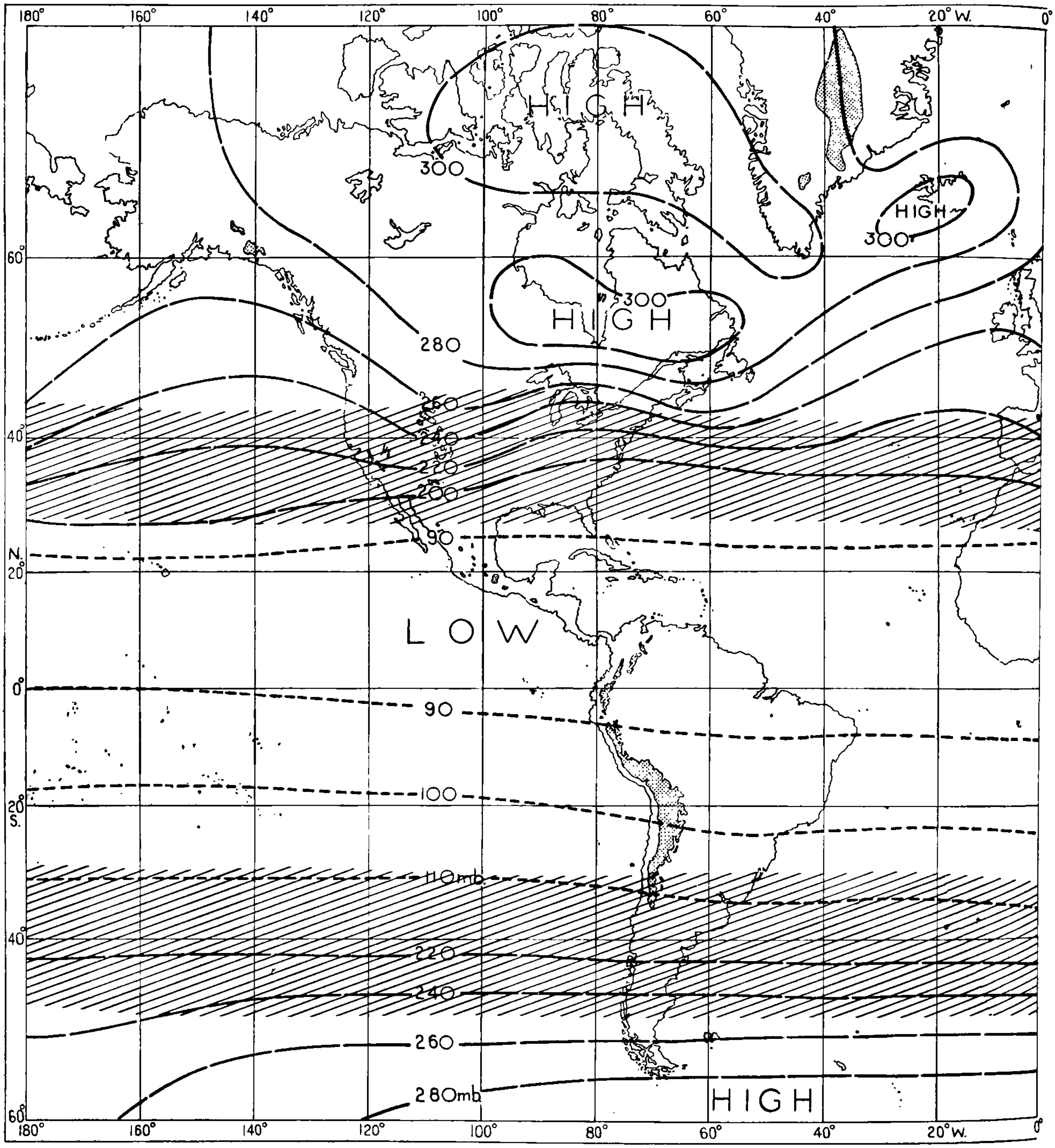

PLATE 33—AVERAGE PRESSURE AT THE TROPOPAUSE IN JANUARY

Isopleths for the polar tropopause are shown by broken lines of long dashes,
Areas in which frequencies of occurrences of both
The legends HIGH and LOW refer to pressure and not to height. Regions

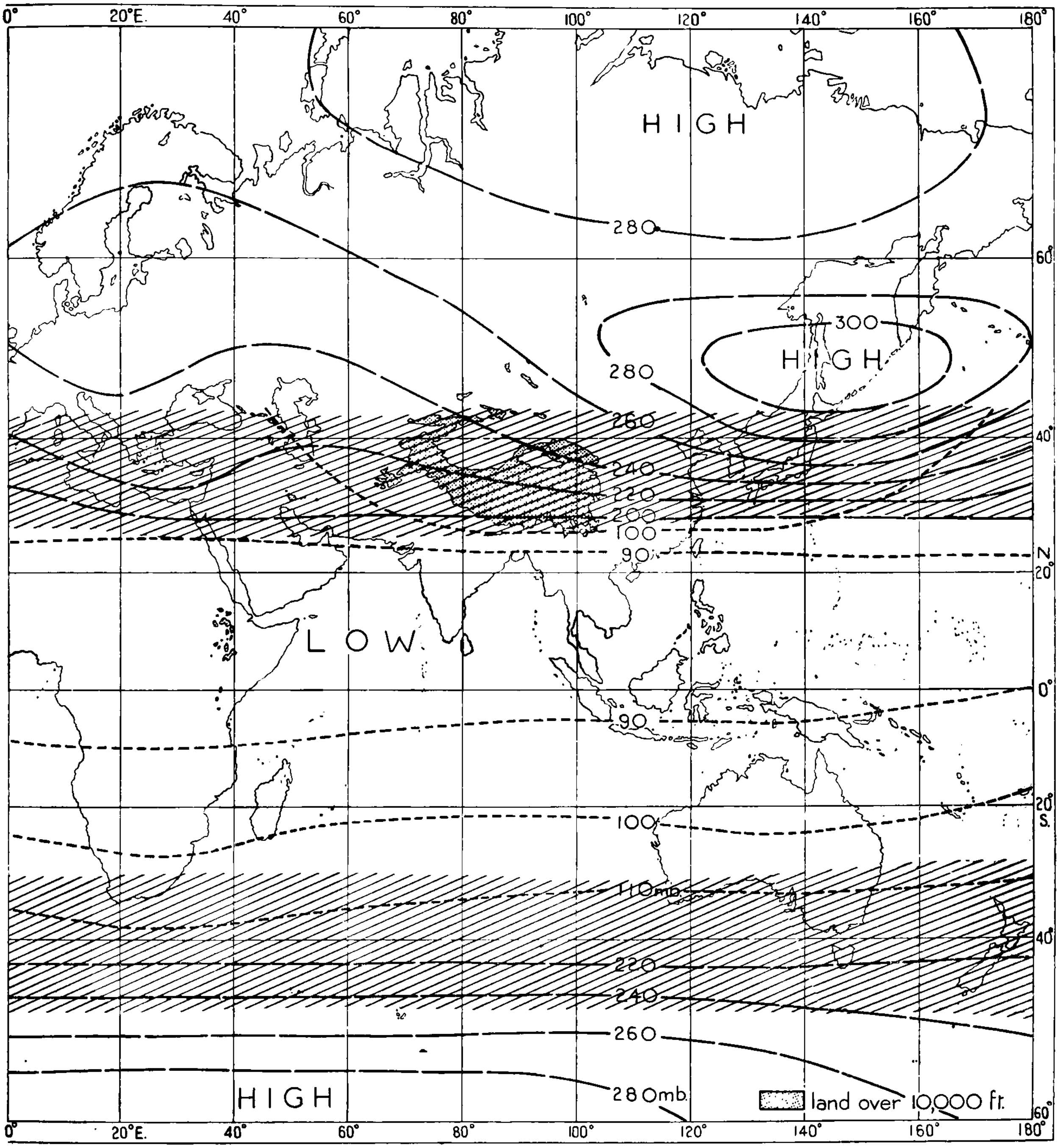

PLATE 33—CONTINUED

and those for the tropical tropopause by broken lines of short dashes.
tropopauses are greater than 10 per cent. are shaded.
labelled HIGH are thus areas of low-level tropopause and *vice-versa*.

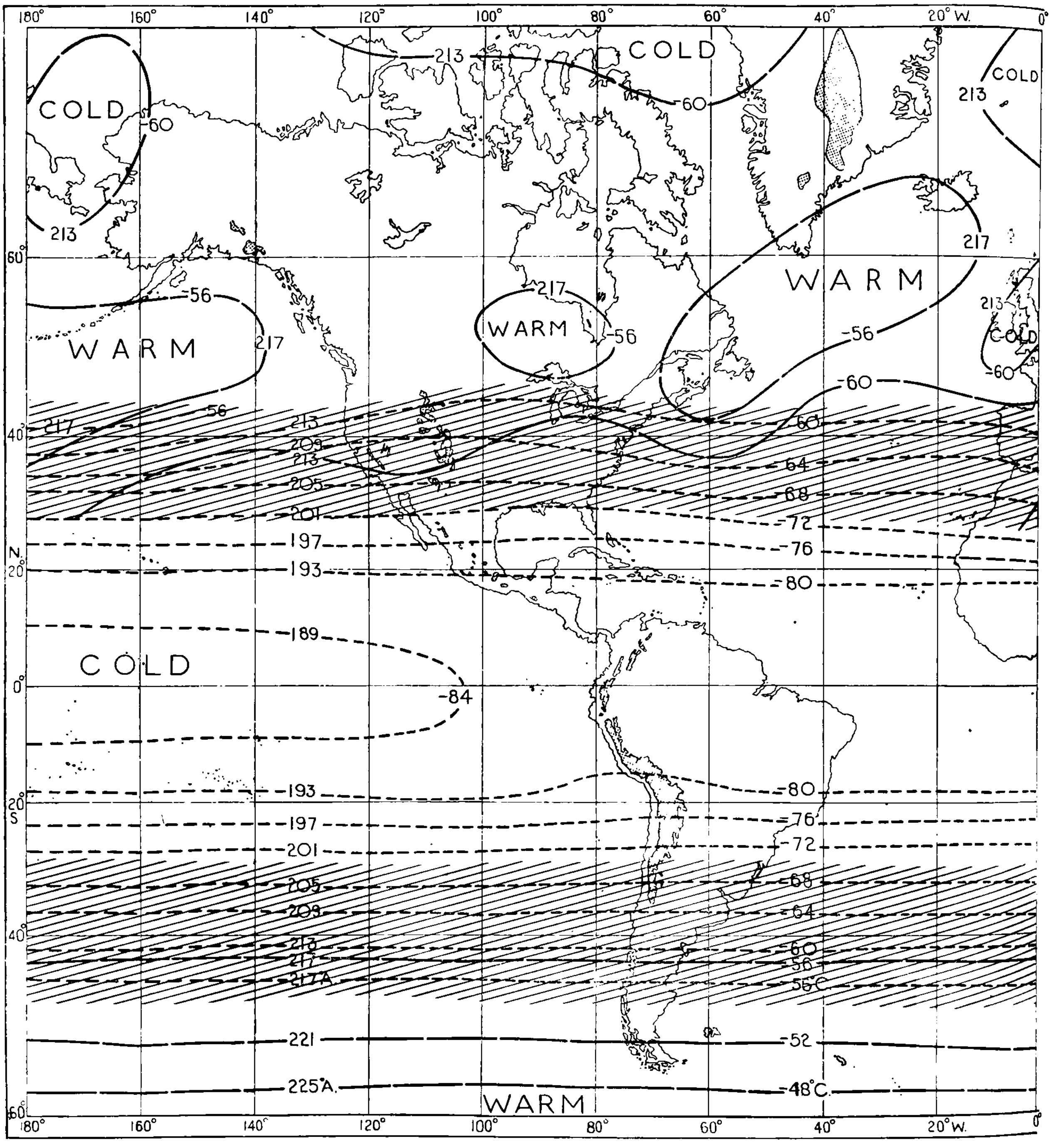

PLATE 34—AVERAGE TEMPERATURE AT THE TROPOPAUSE IN JANUARY

Isopleths for the polar tropopause are shown by broken lines of long
and lines of alternate dashes and dots are used where isopleths
Areas in which frequencies of occurrences of both

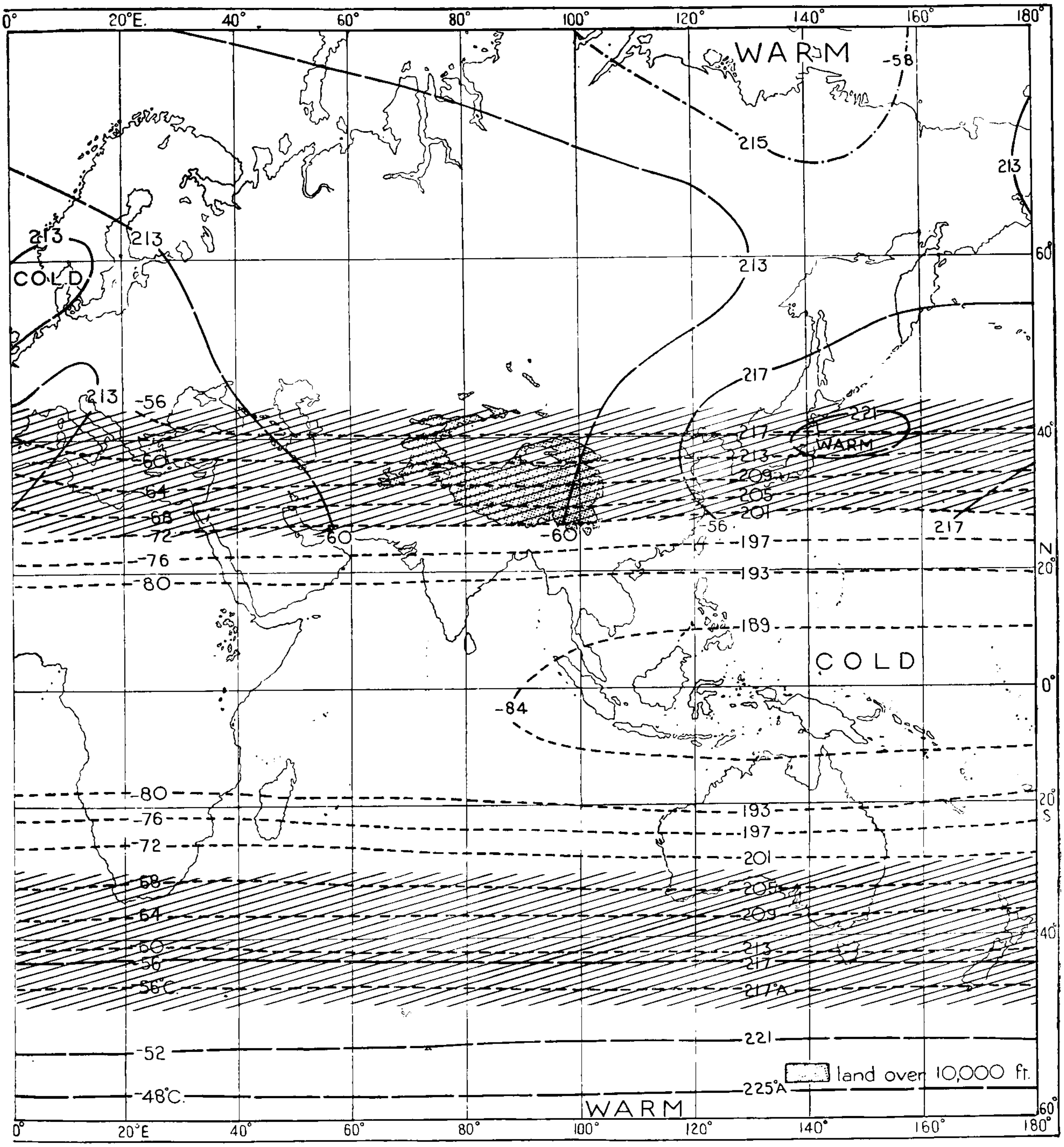

PLATE 34—CONTINUED

dashes, those for the tropical tropopause by broken lines of short dashes, for intermediate values of pressure and temperature are drawn. tropopauses are greater than 10 per cent. are shaded.

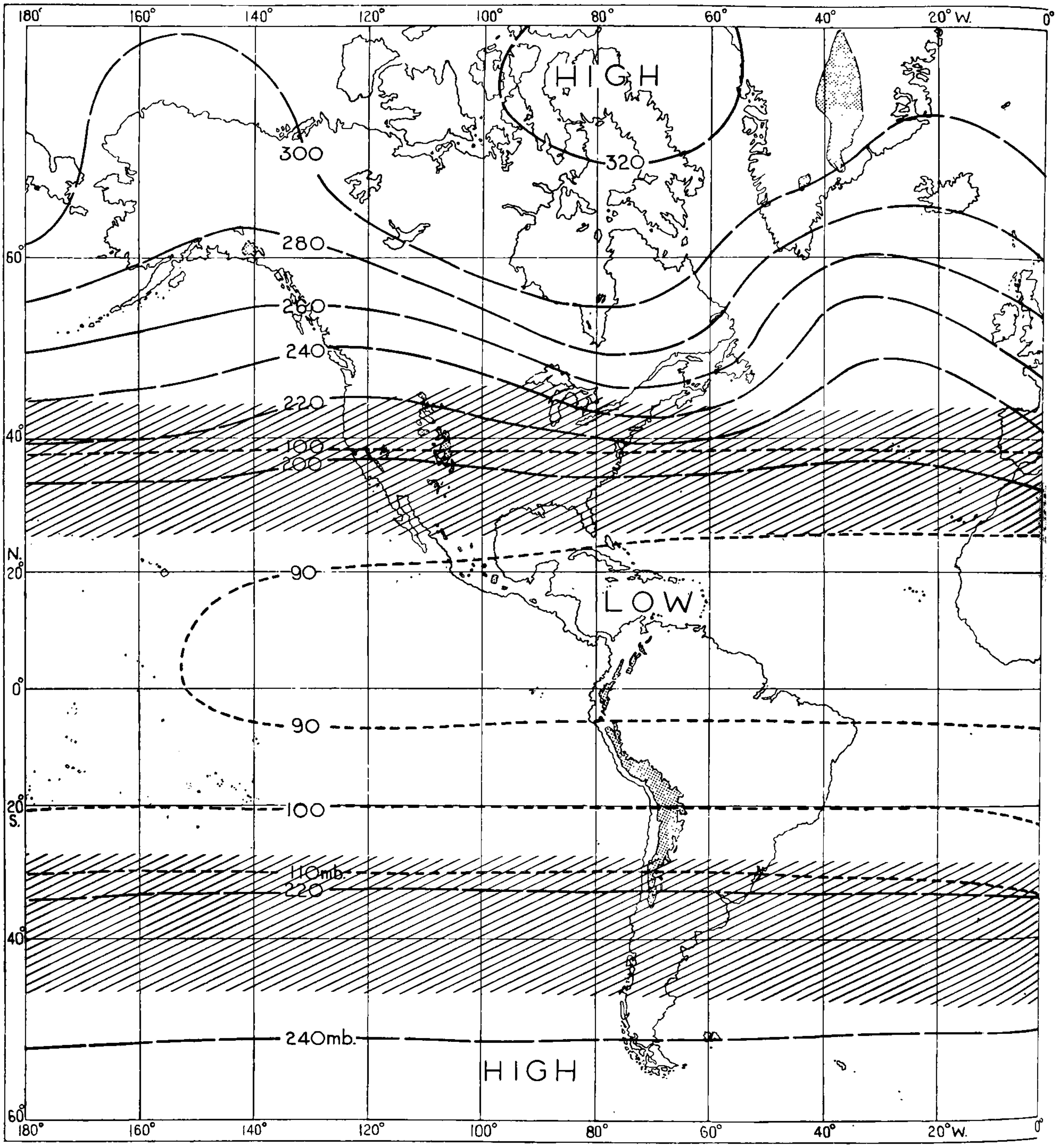

PLATE 35—AVERAGE PRESSURE AT THE TROPOPAUSE IN APRIL

Isopleths for the polar tropopause are shown by broken lines of long dashes,
Areas in which frequencies of occurrences of both
The legends HIGH and LOW refer to pressure and not to height. Regions

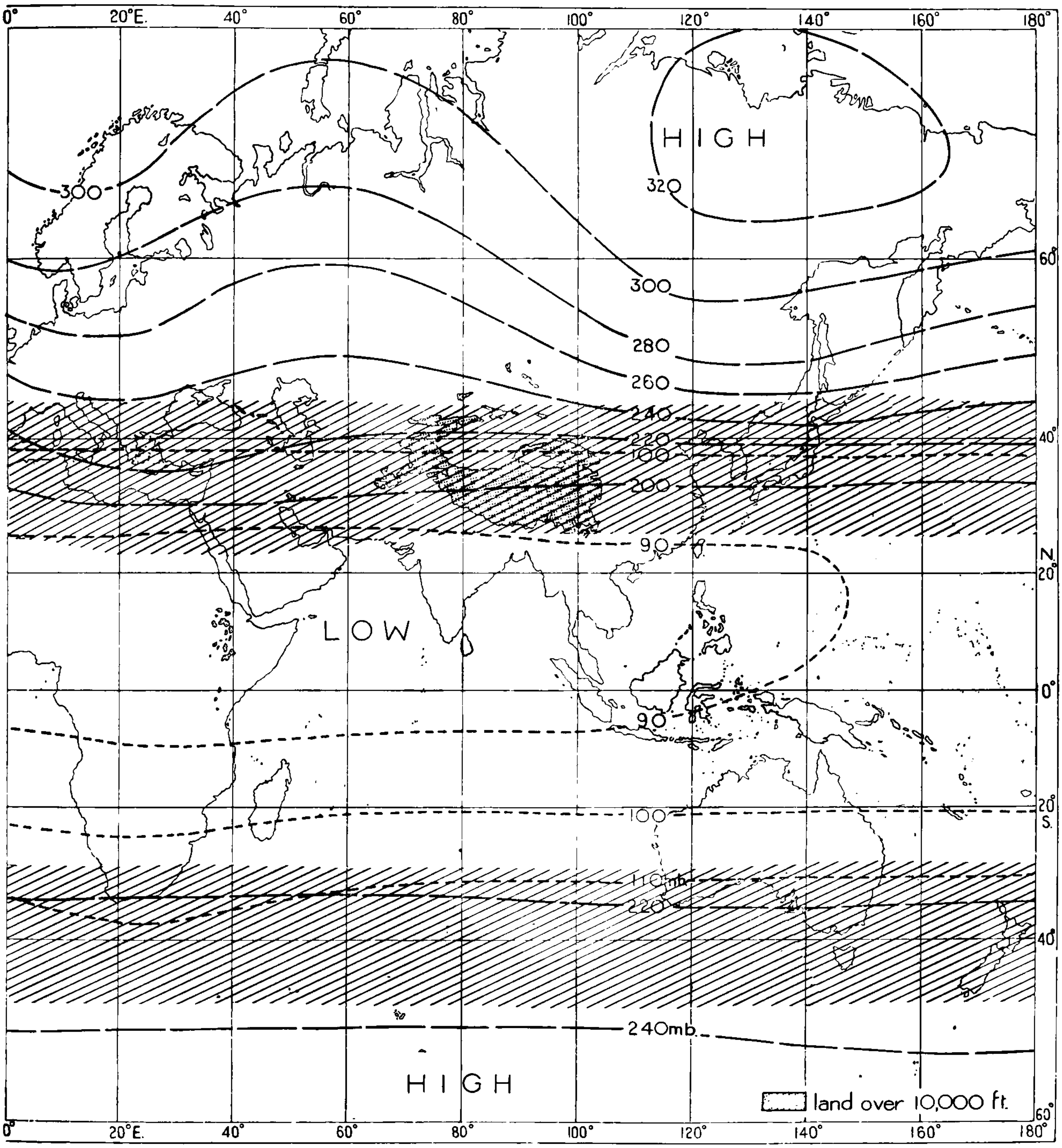

PLATE 35—CONTINUED

and those for the tropical tropopause by broken lines of short dashes.
tropopauses are greater than 10 per cent. are shaded.
labelled HIGH are thus areas of low-level tropopause and *vice-versa.*

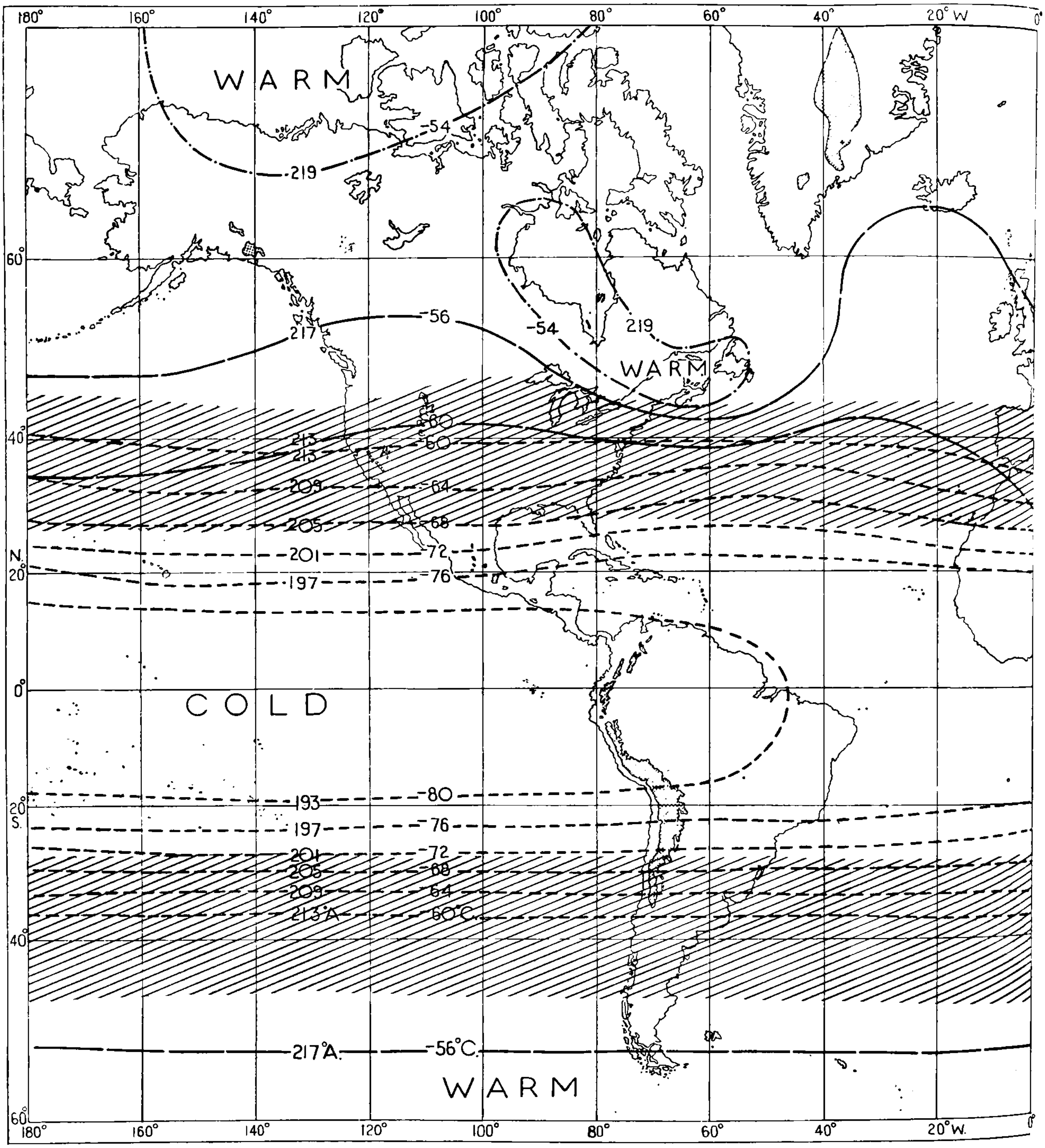

PLATE 36—AVERAGE TEMPERATURE AT THE TROPOPAUSE IN APRIL

Isopleths for the polar tropopause are shown by broken lines of long
and lines of alternate dashes and dots are used where isopleths
Areas in which frequencies of occurrences of both

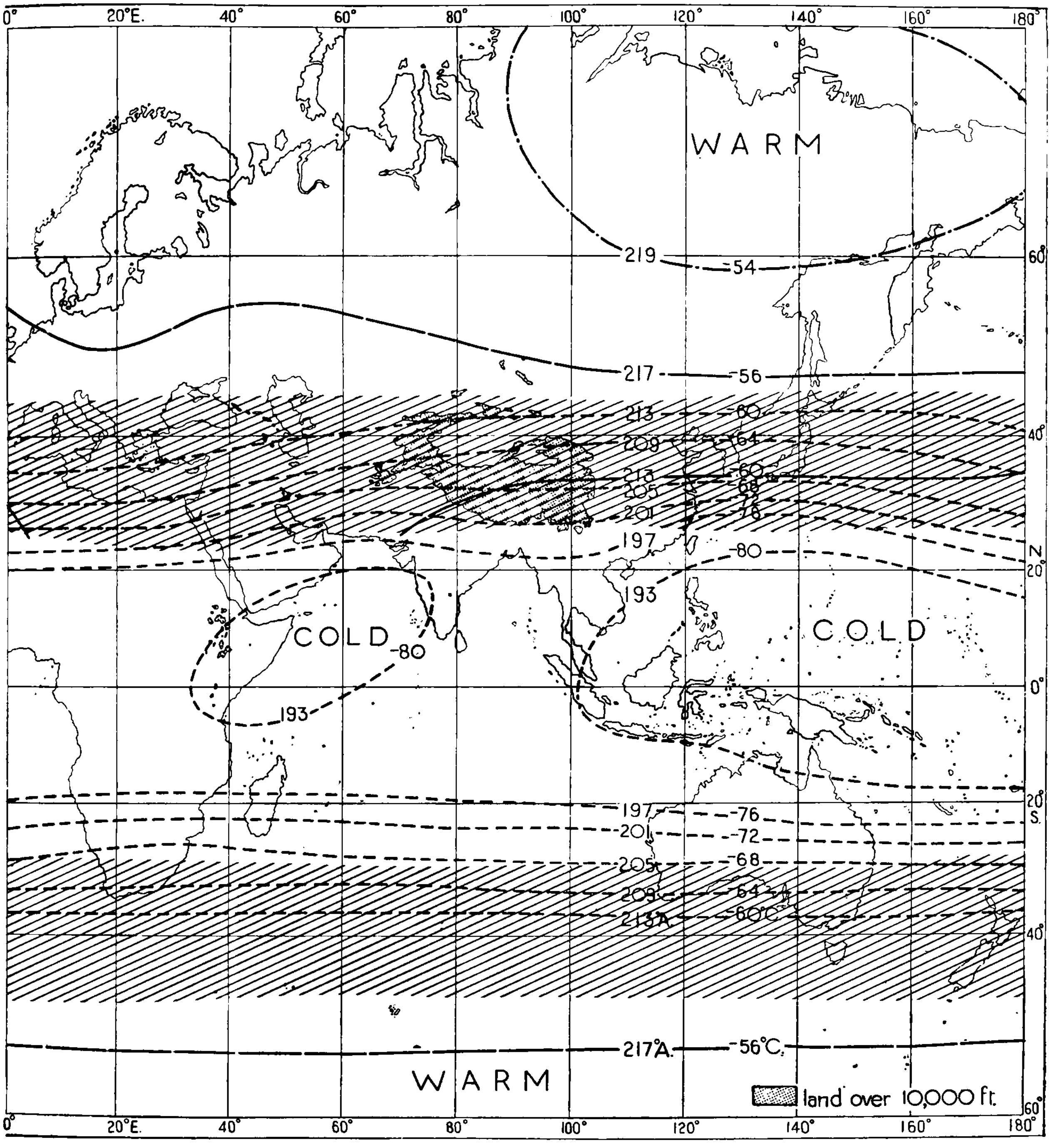

PLATE 36—CONTINUED

dashes, those for the tropical tropopause by broken lines of short dashes, for intermediate values of pressure and temperature are drawn. tropopauses are greater than 10 per cent. are shaded.

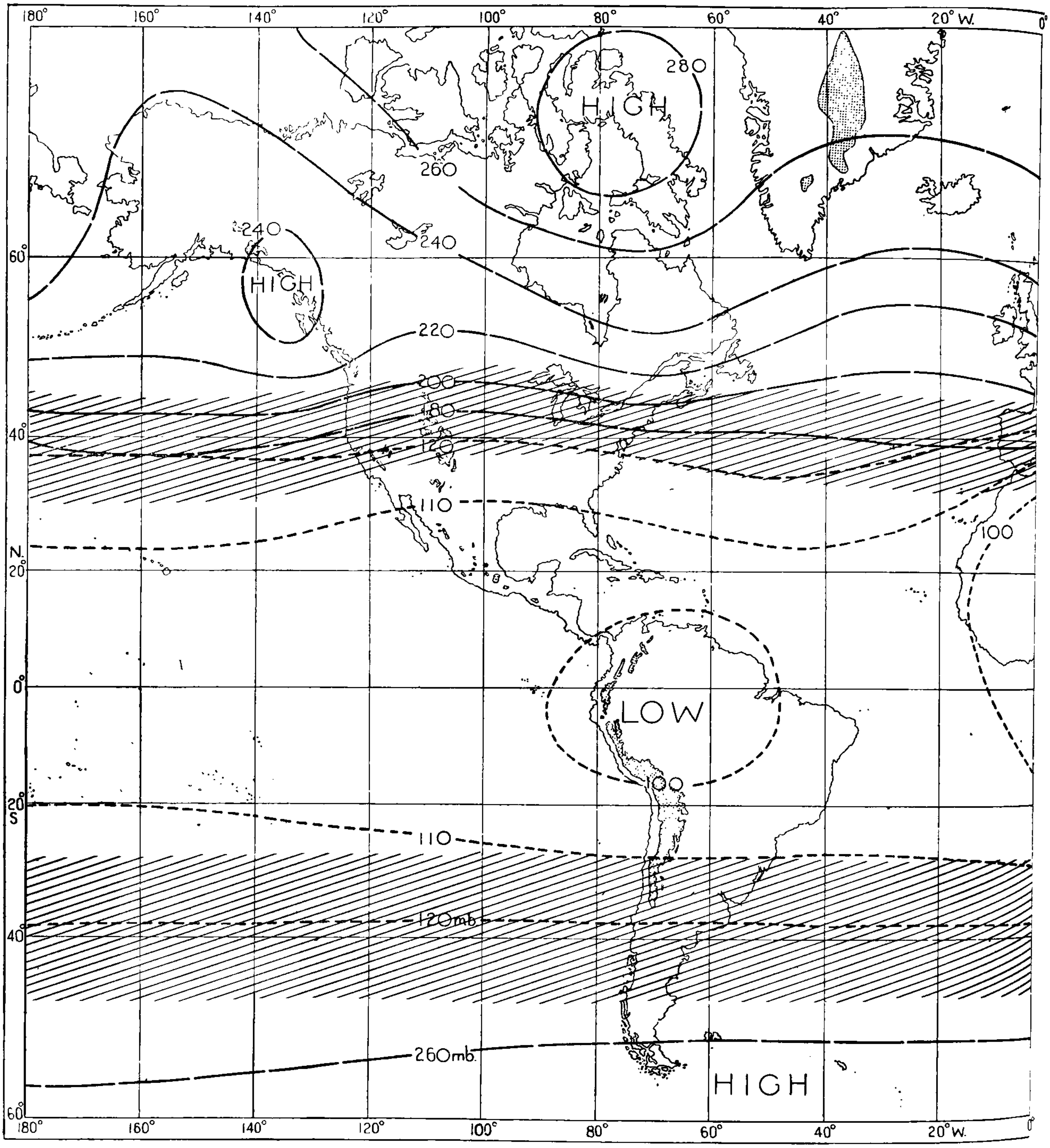

PLATE 37—AVERAGE PRESSURE AT THE TROPOPAUSE IN JULY

Isopleths for the polar tropopause are shown by broken lines of long dashes,
Areas in which frequencies of occurrences of both
The legends HIGH and LOW refer to pressure and not to height. Regions

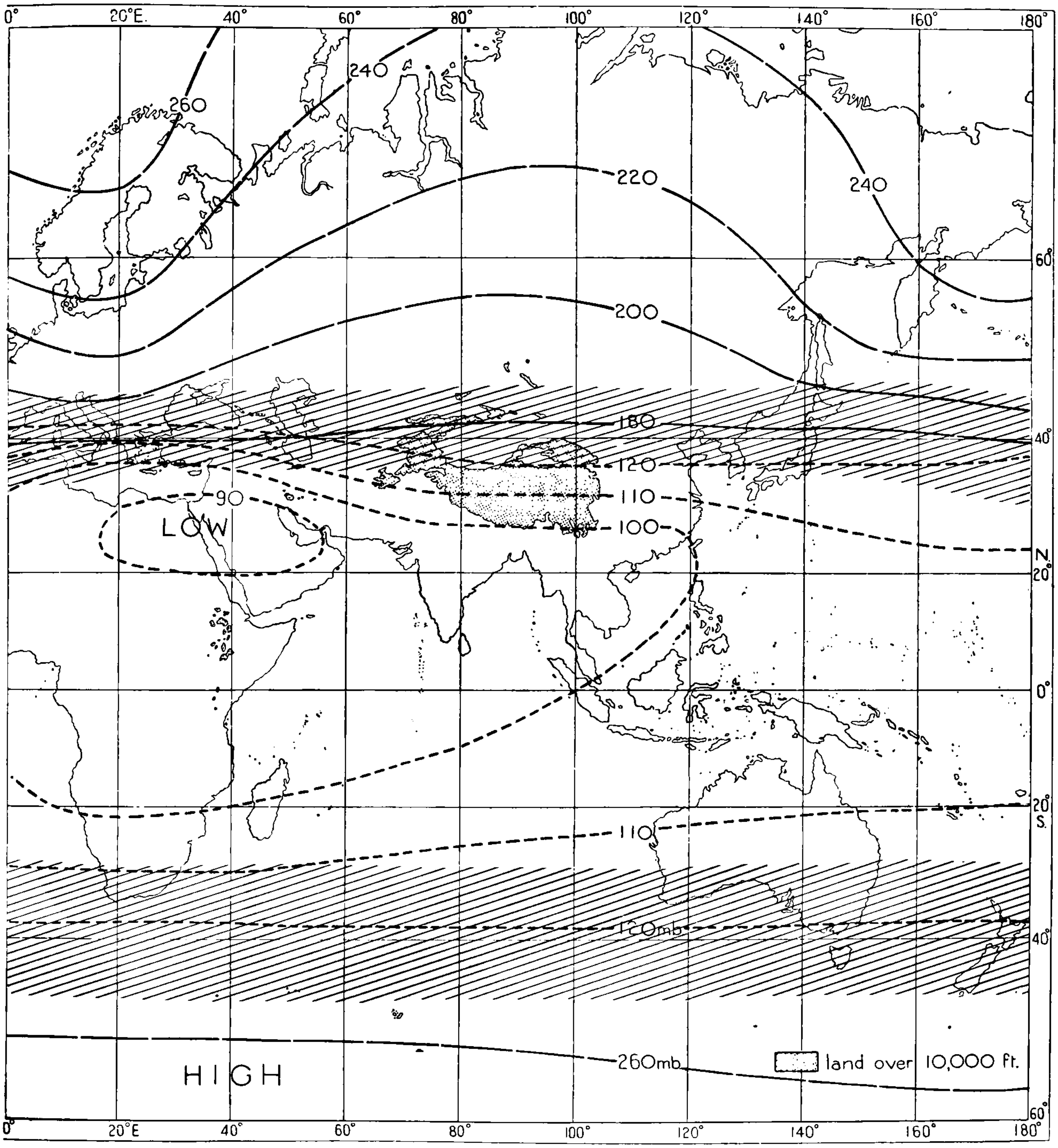

PLATE 37—CONTINUED

and those for the tropical tropopause by broken lines of short dashes.
tropopauses are greater than 10 per cent. are shaded.
labelled HIGH are thus areas of low-level tropopause and *vice-versa*.

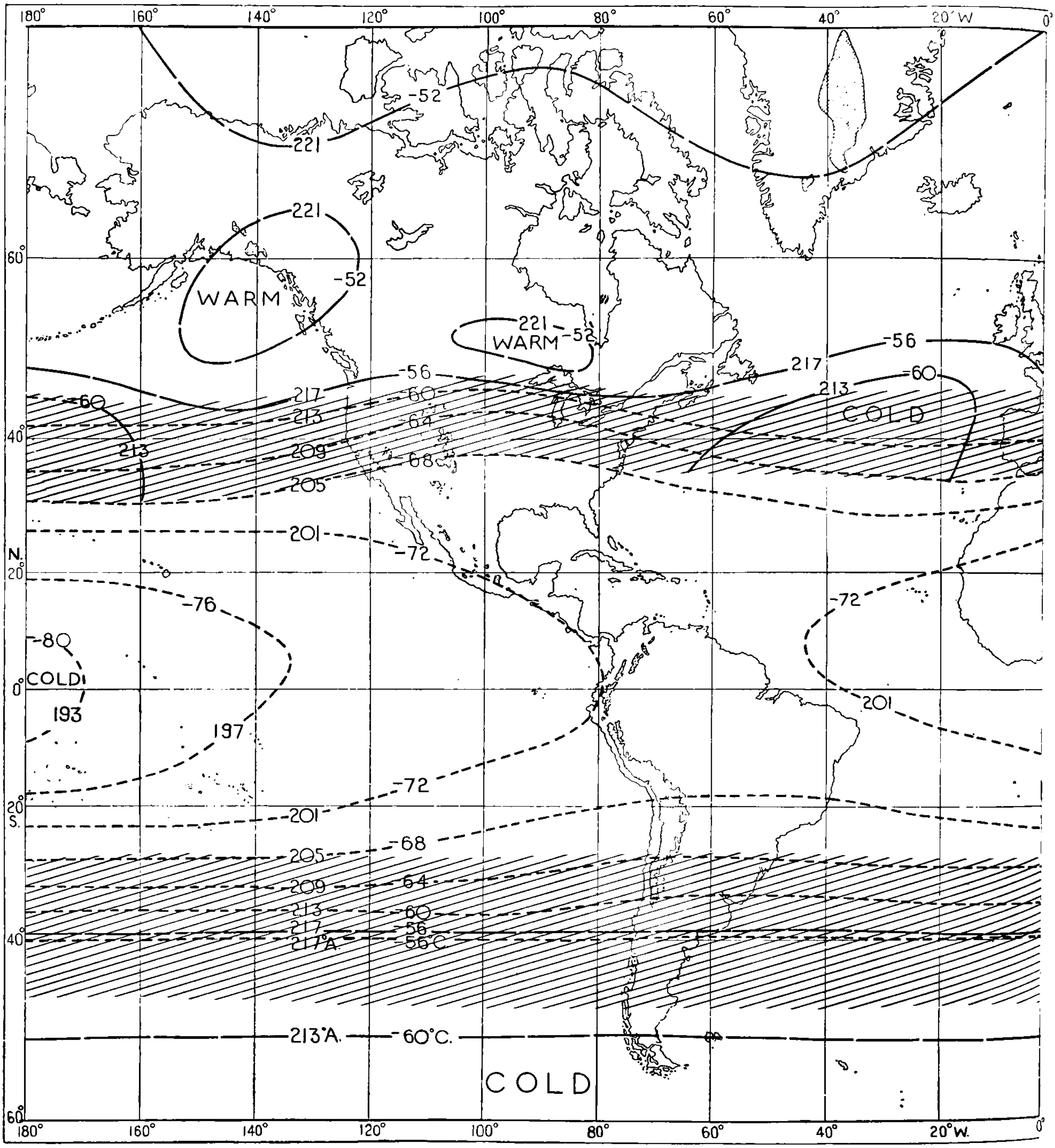

PLATE 38—AVERAGE TEMPERATURE AT THE TROPOPAUSE IN JULY

Isopleths for the polar tropopause are shown by broken lines of long dashes,
Areas in which frequencies of occurrences of both

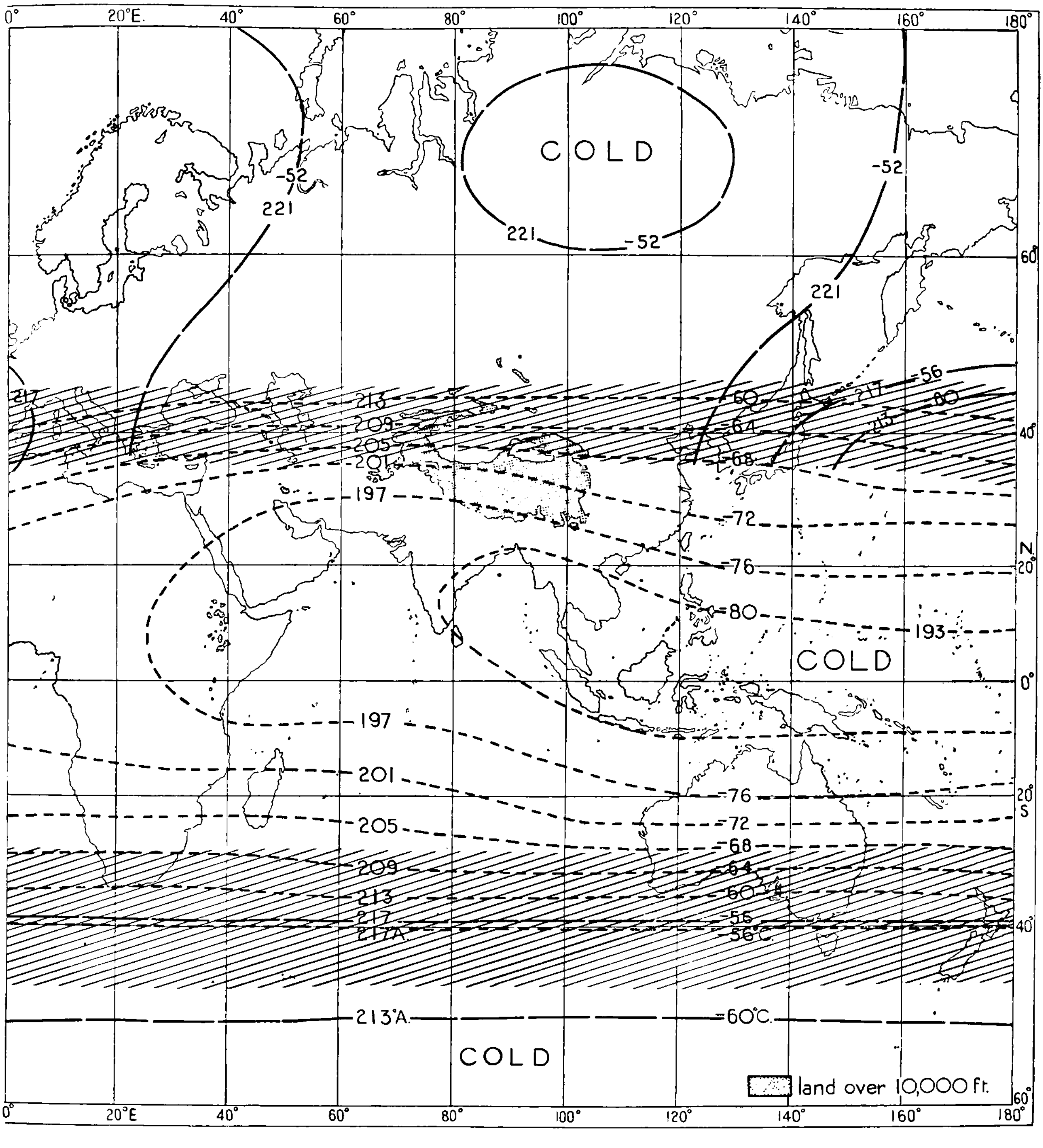

PLATE 38—CONTINUED

and those for the tropical tropopause by broken lines of short dashes. tropopauses are greater than 10 per cent. are shaded.

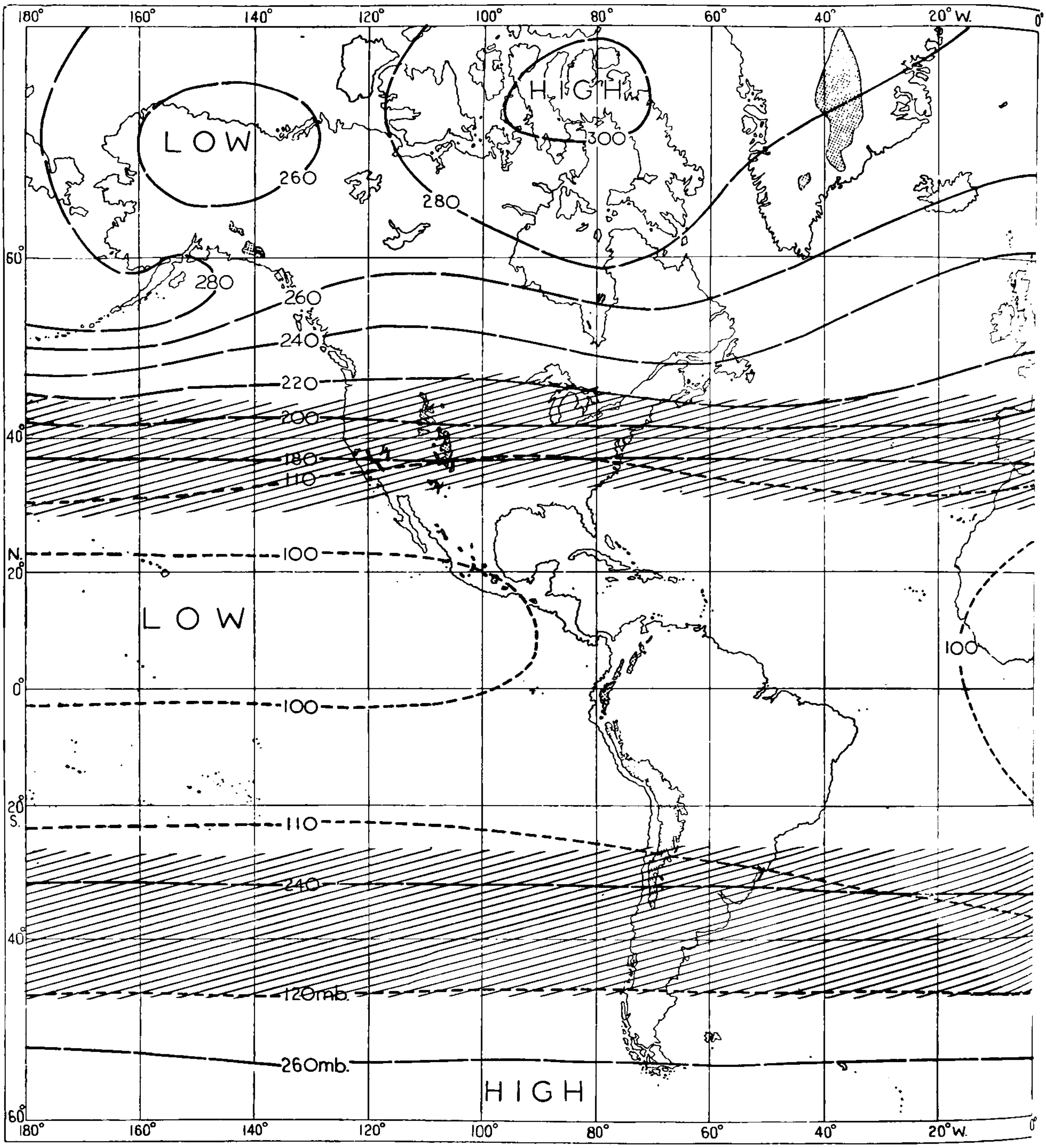

PLATE 39—AVERAGE PRESSURE AT THE TROPOPAUSE IN OCTOBER

Isopleths for the polar tropopause are shown by broken lines of long dashes,
Areas in which frequencies of occurrences of both
The legends HIGH and LOW refer to pressure and not to height. Regions

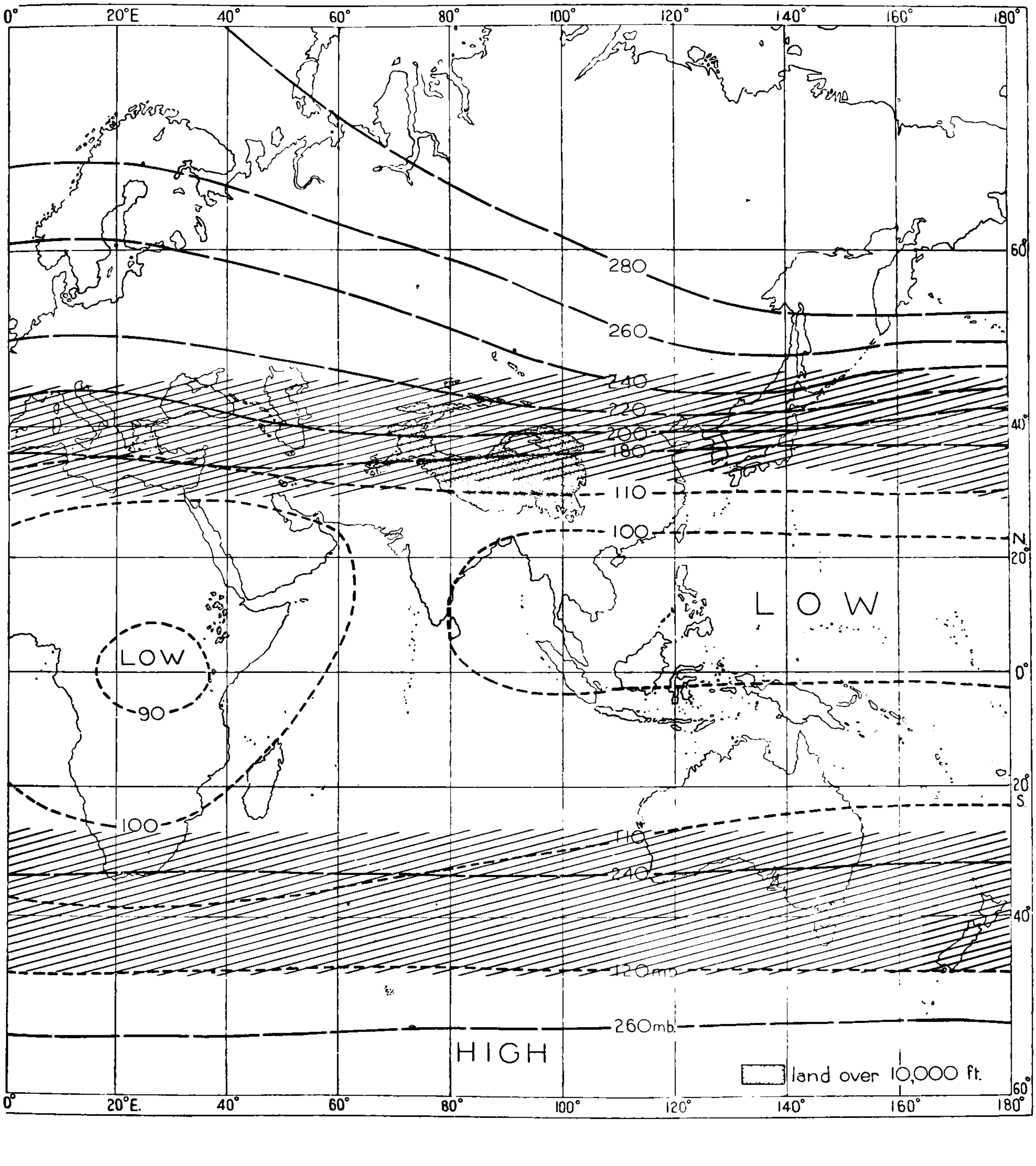

PLATE 39—CONTINUED

and those for the tropical tropopause by broken lines of short dashes.
tropopauses are greater than 10 per cent. are shaded.
labelled HIGH are thus areas of low-level tropopause and *vice-versa*.

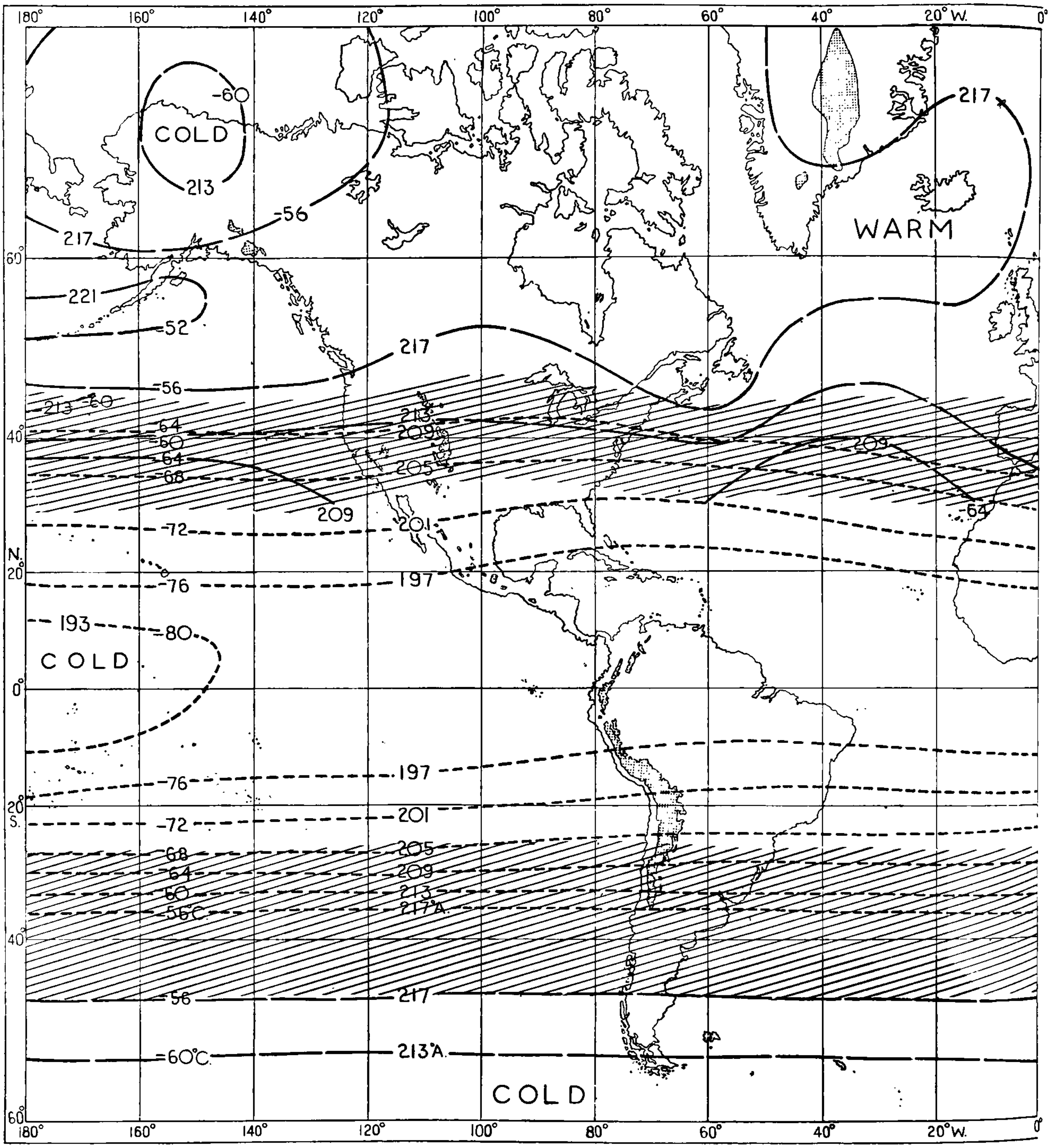

PLATE 40—AVERAGE TEMPERATURE AT THE TROPOPAUSE IN OCTOBER

Isopleths for the polar tropopause are shown by broken lines of long dashes.
Areas in which frequencies of occurrences of both

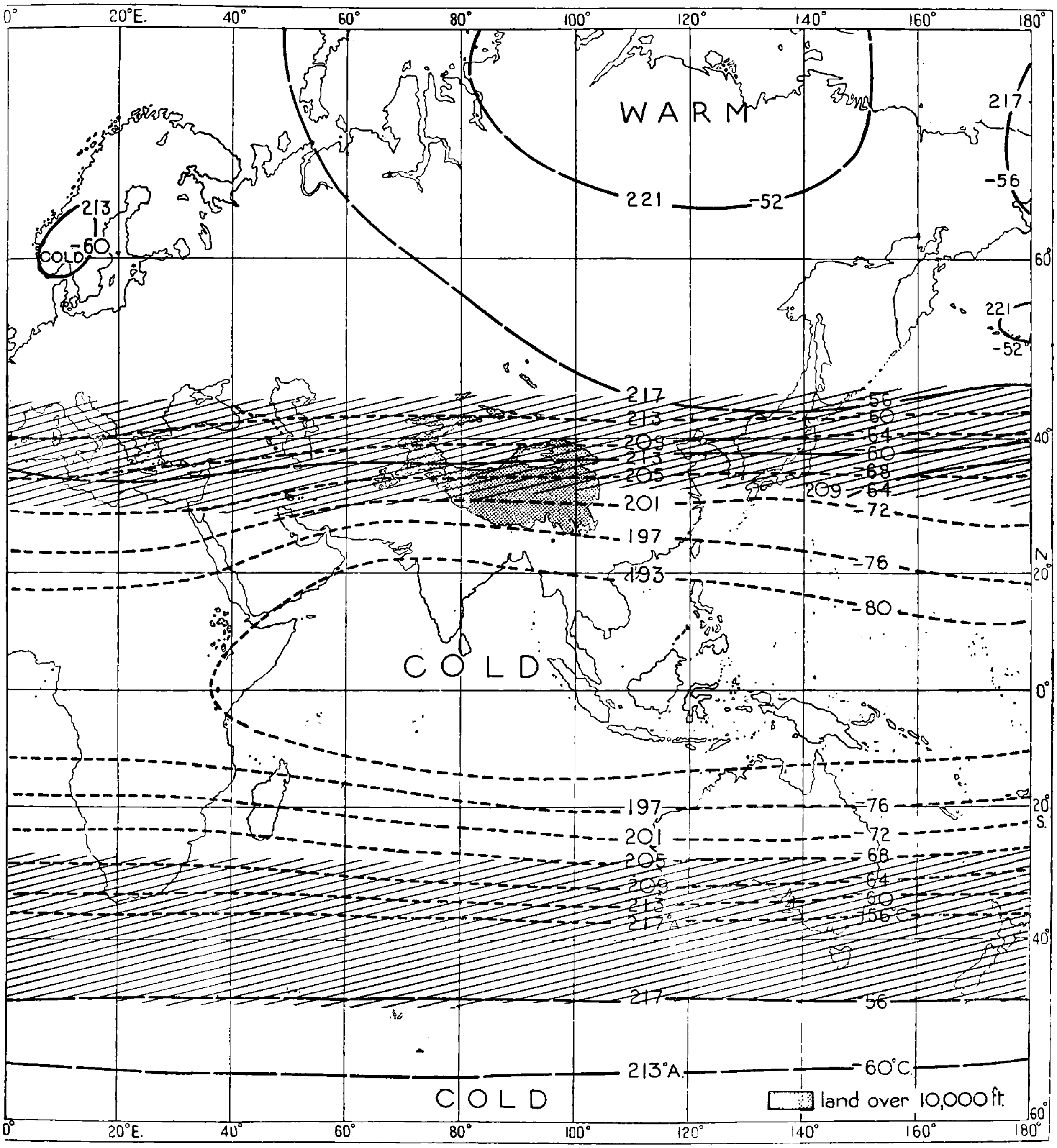

PLATE 40—CONTINUED

and those for the tropical tropopause by broken lines of short dashes. tropopauses are greater than 10 per cent. are shaded.

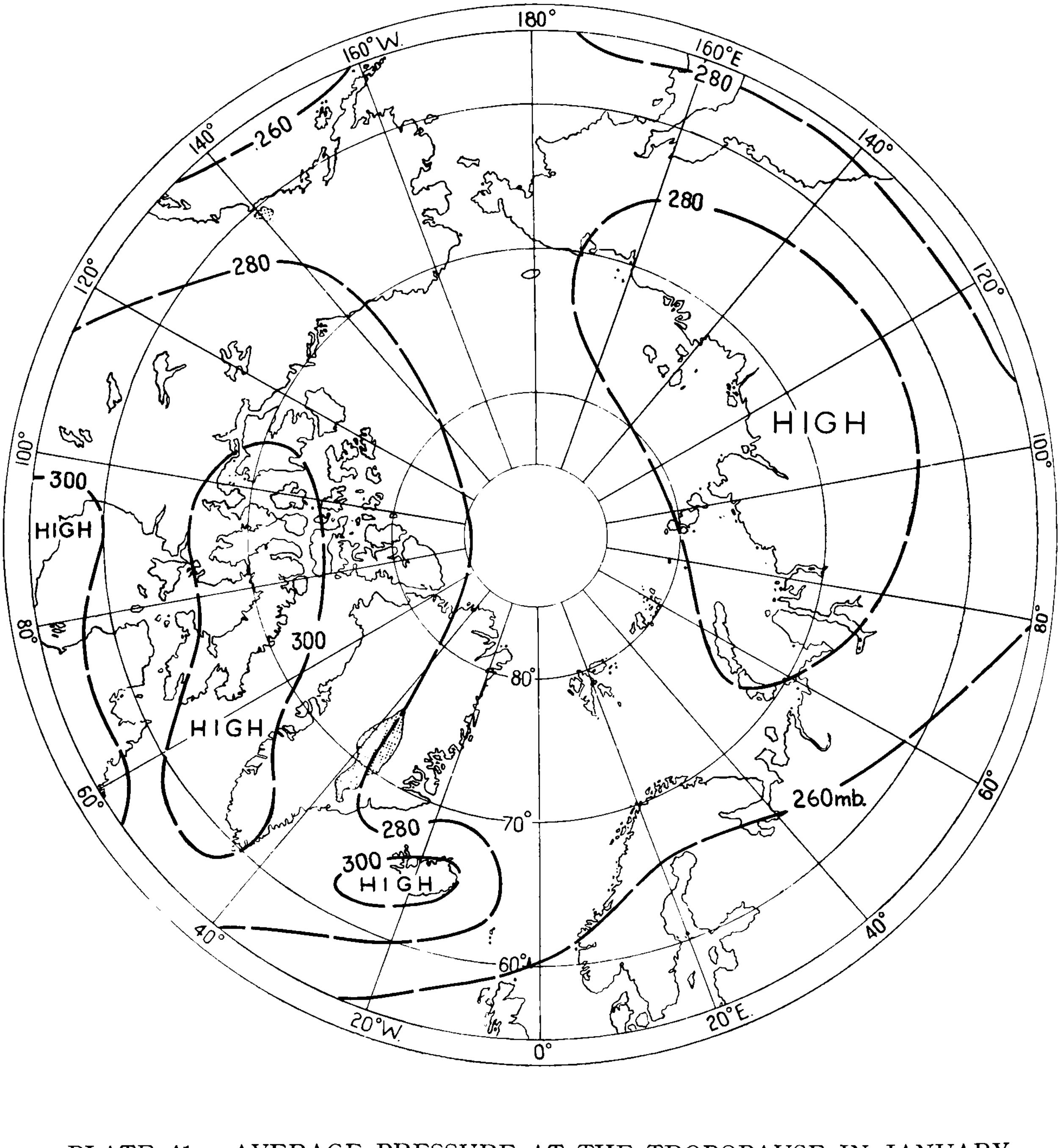

PLATE 41A—AVERAGE PRESSURE AT THE TROPOPAUSE IN JANUARY

Land over 10,000 feet is represented by shading.

Isopleths for the polar tropopause are shown by broken lines of long dashes.

The legends HIGH and LOW refer to pressure and not to height. Regions labelled HIGH are thus areas of low-level tropopause and *vice-versa*.

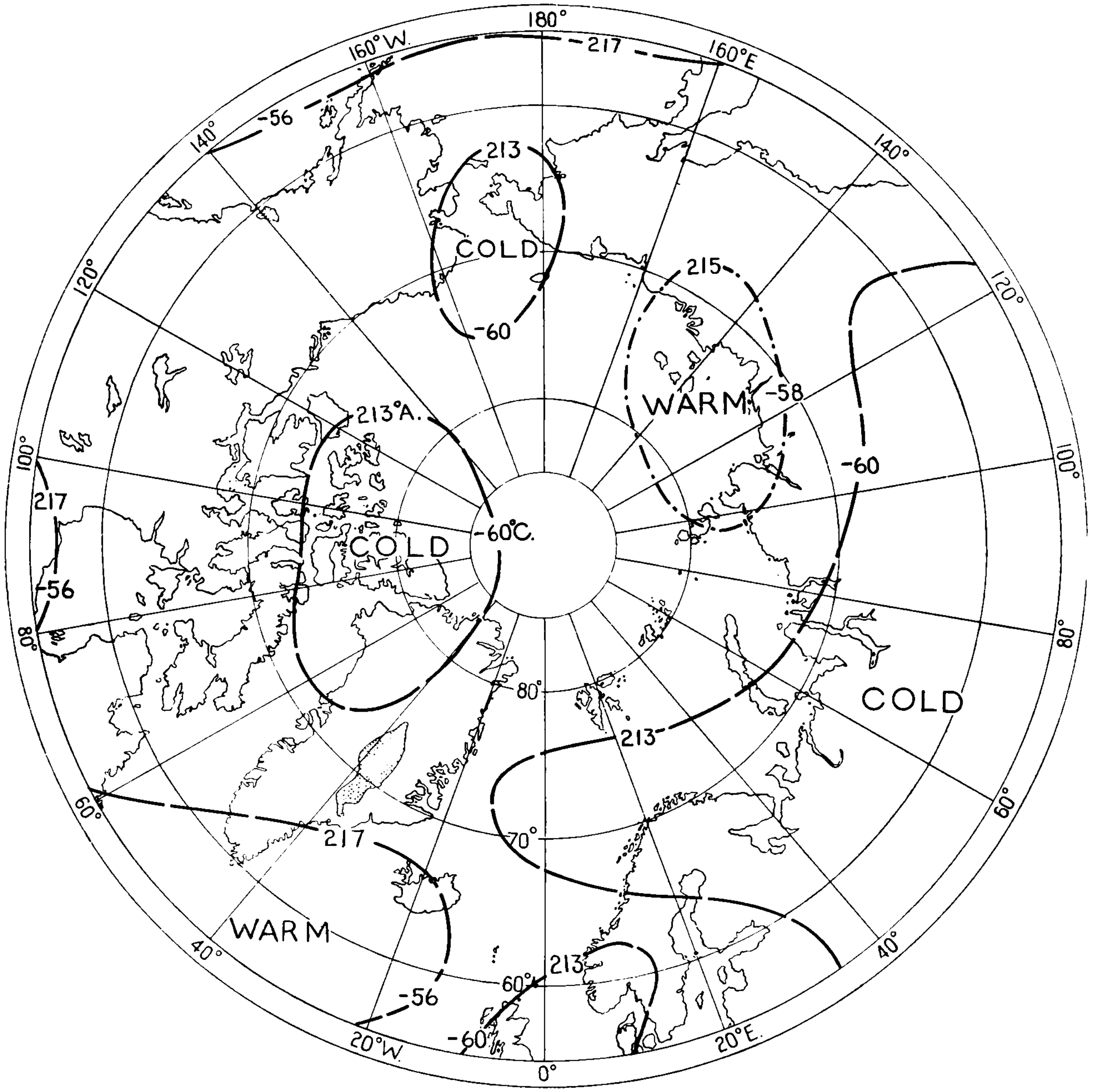

PLATE 41B—AVERAGE TEMPERATURE AT THE TROPOPAUSE IN JANUARY

Land over 10,000 feet is represented by shading.

Isopleths for the polar tropopause are shown by broken lines of long dashes, and lines of alternate dashes and dots are used where isopleths for intermediate values of pressure and temperature are drawn.

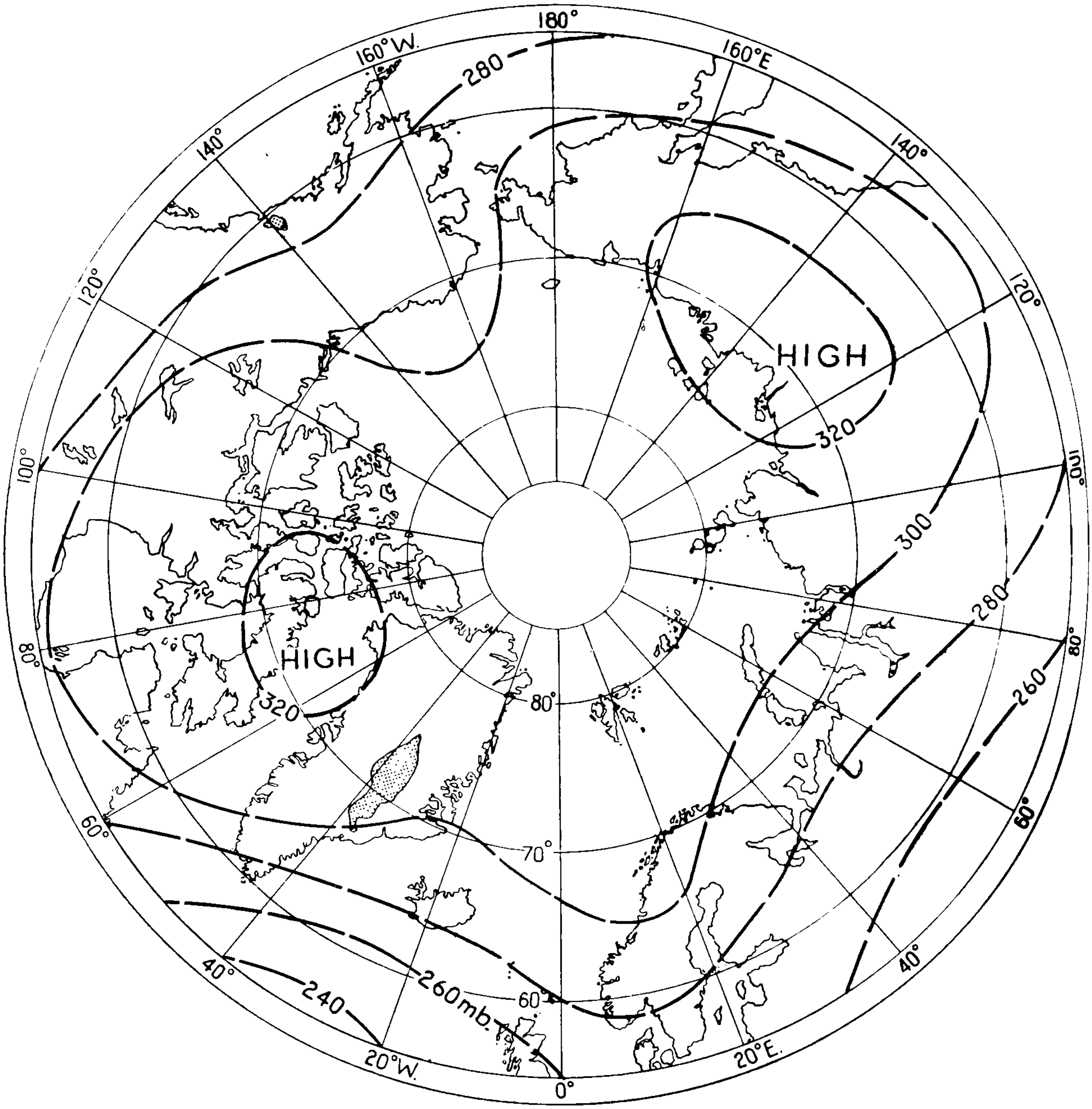

PLATE 42A—AVERAGE PRESSURE AT THE TROPOPAUSE IN APRIL

Land over 10,000 feet is represented by shading.

Isopleths for the polar tropopause are shown by broken lines of long dashes.

The legends HIGH and LOW refer to pressure and not to height. Regions labelled HIGH are thus areas of low-level tropopause and *vice-versa*.

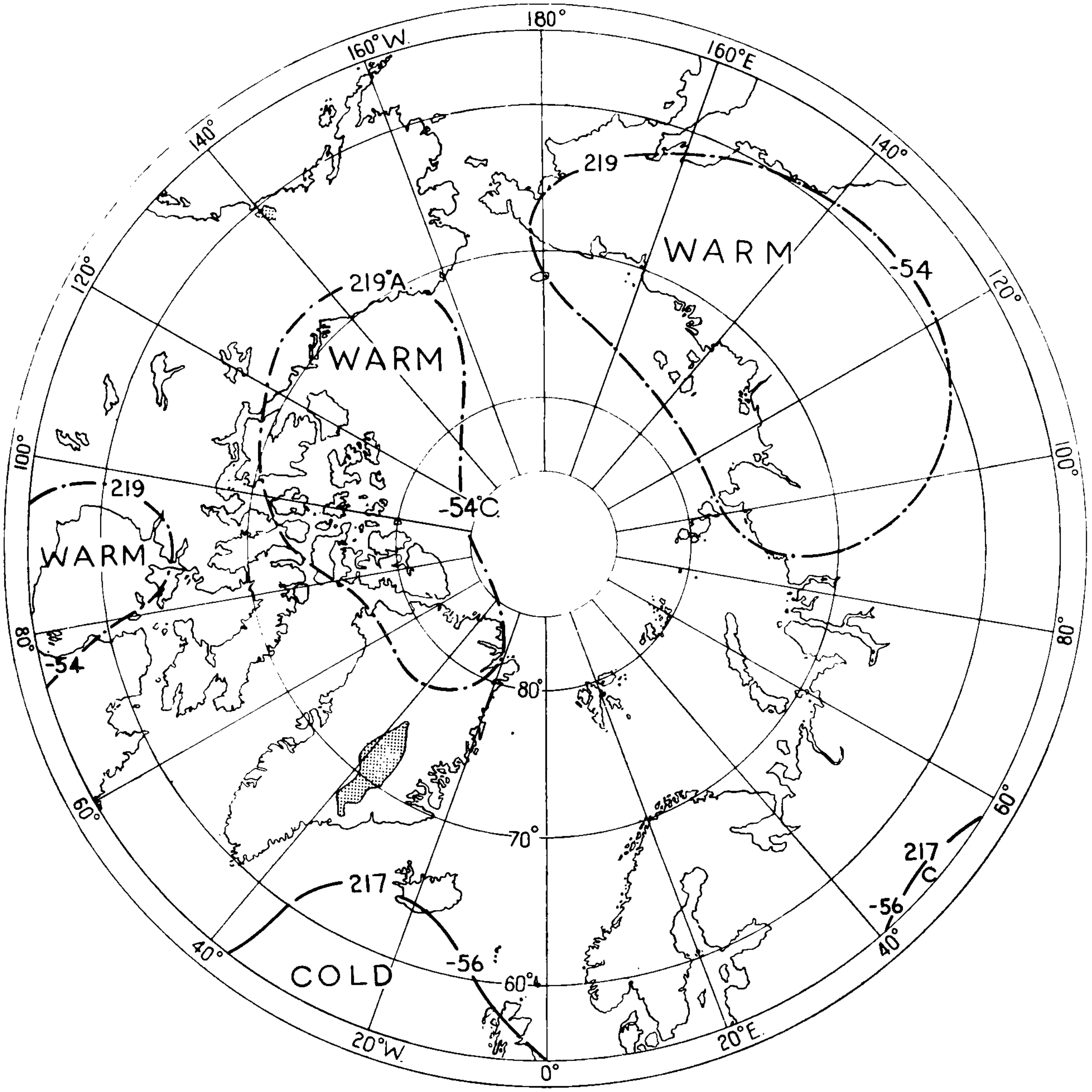

PLATE 42B—AVERAGE TEMPERATURE AT THE TROPOPAUSE IN APRIL

Land over 10,000 feet is represented by shading.

Isopleths for the polar tropopause are shown by broken lines of long dashes, and lines of alternate dashes and dots are used where isopleths for intermediate values of pressure and temperature are drawn.

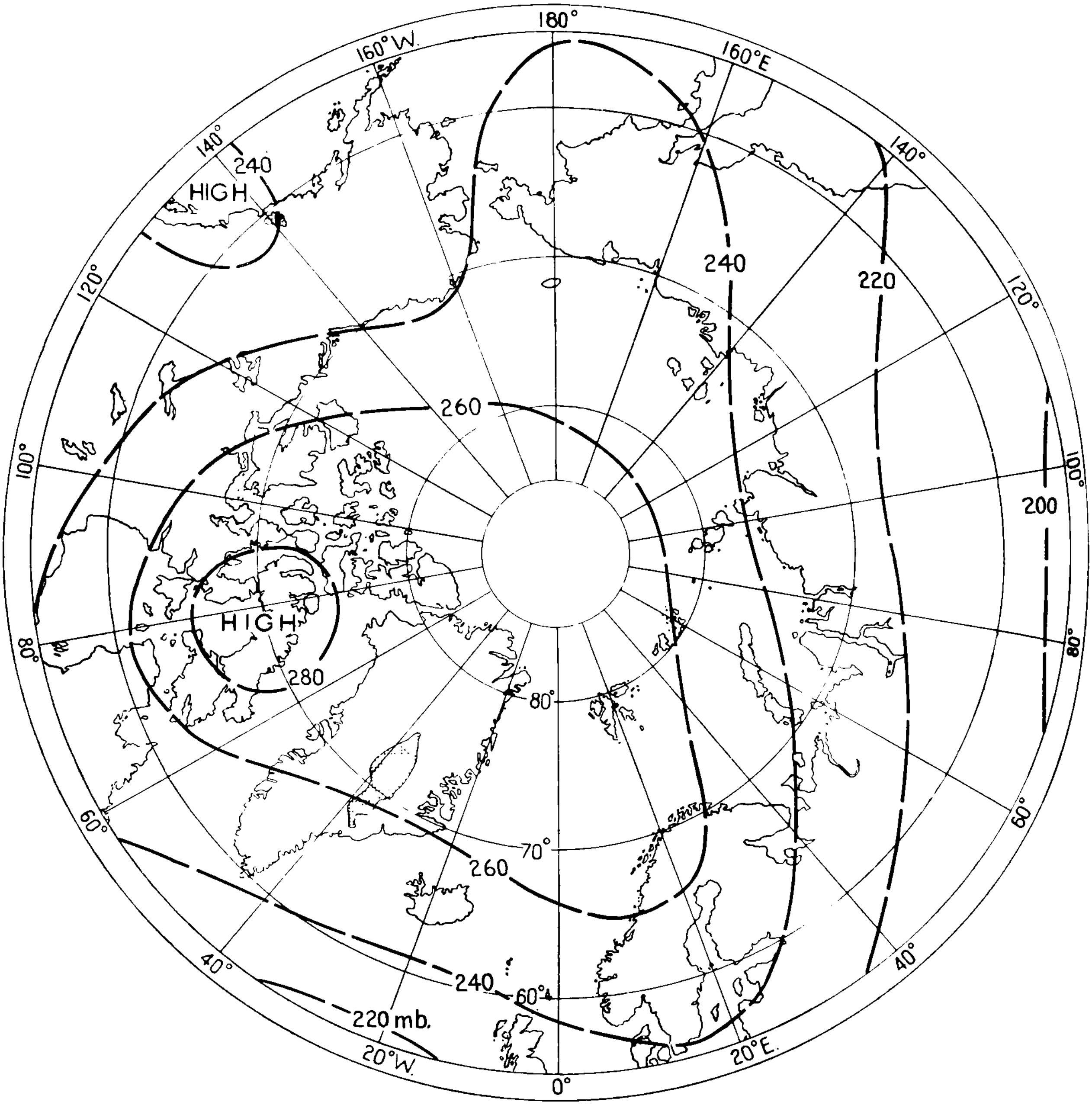

PLATE 43A—AVERAGE PRESSURE AT THE TROPOPAUSE IN JULY

Land over 10,000 feet is represented by shading.

Isopleths for the polar tropopause are shown by broken lines of long dashes.

The legends HIGH and LOW refer to pressure and not to height. Regions labelled HIGH are thus areas of low-level tropopause and *vice-versa*.

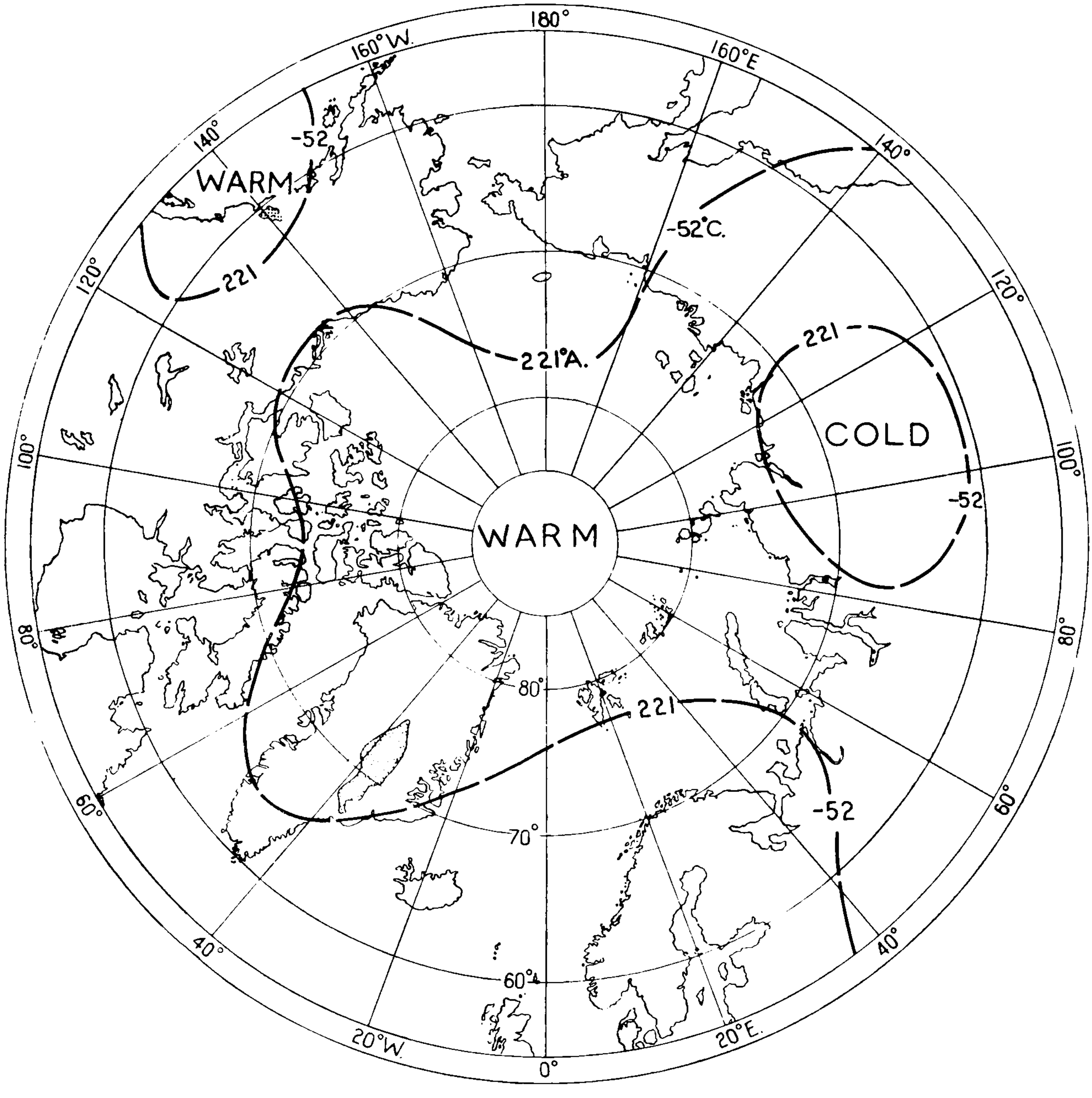

PLATE 43B—AVERAGE TEMPERATURE AT THE TROPOPAUSE IN JULY

Land over 10,000 feet is represented by shading.

Isopleths for the polar tropopause are shown by broken lines of long dashes.

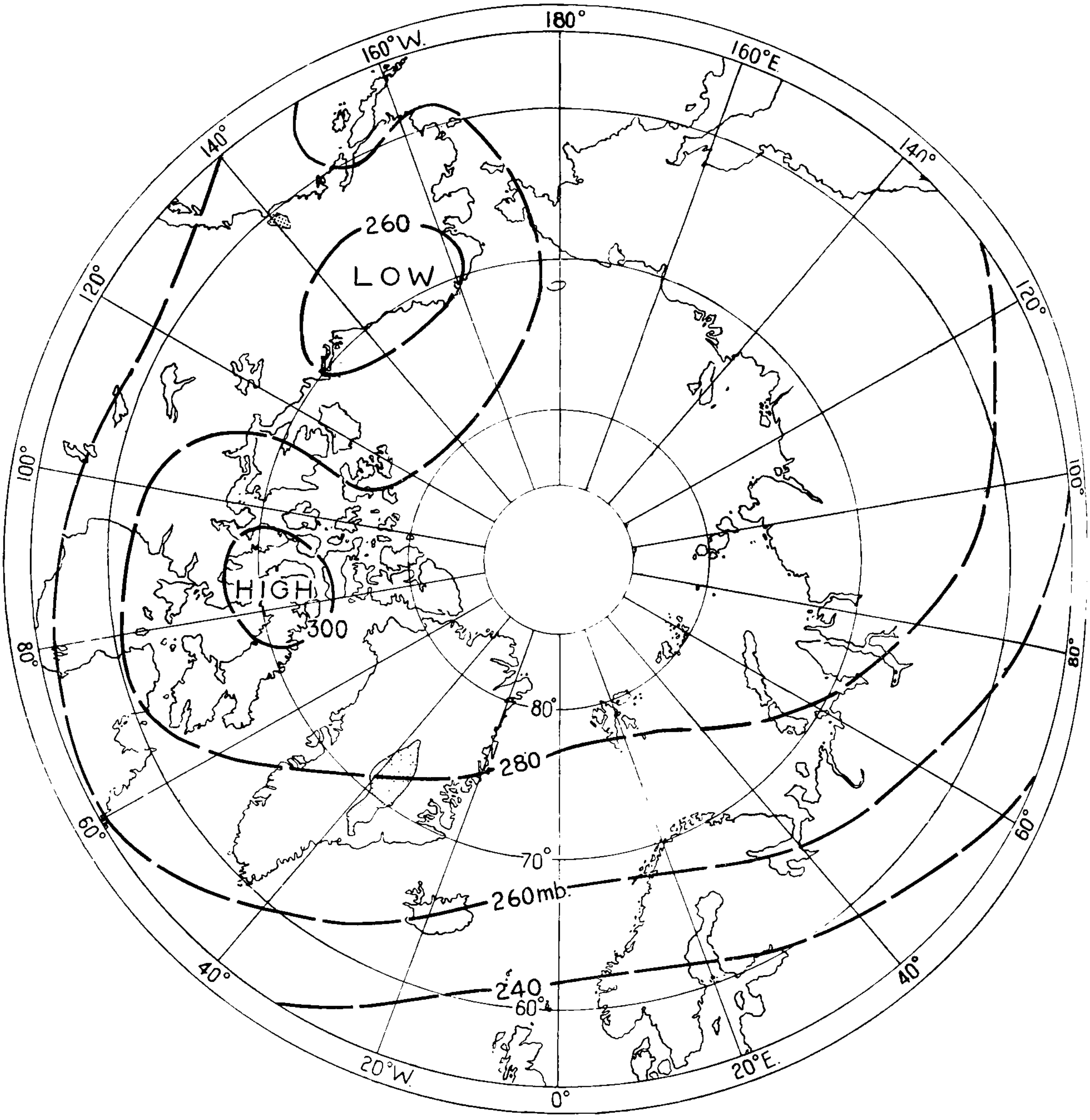

PLATE 44A—AVERAGE PRESSURE AT THE TROPOPAUSE IN OCTOBER

Land over 10,000 feet is represented by shading.

Isopleths for the polar tropopause are shown by broken lines of long dashes.

The legends HIGH and LOW refer to pressure and not to height. Regions labelled HIGH are thus areas of low-level tropopause and *vice-versa*.

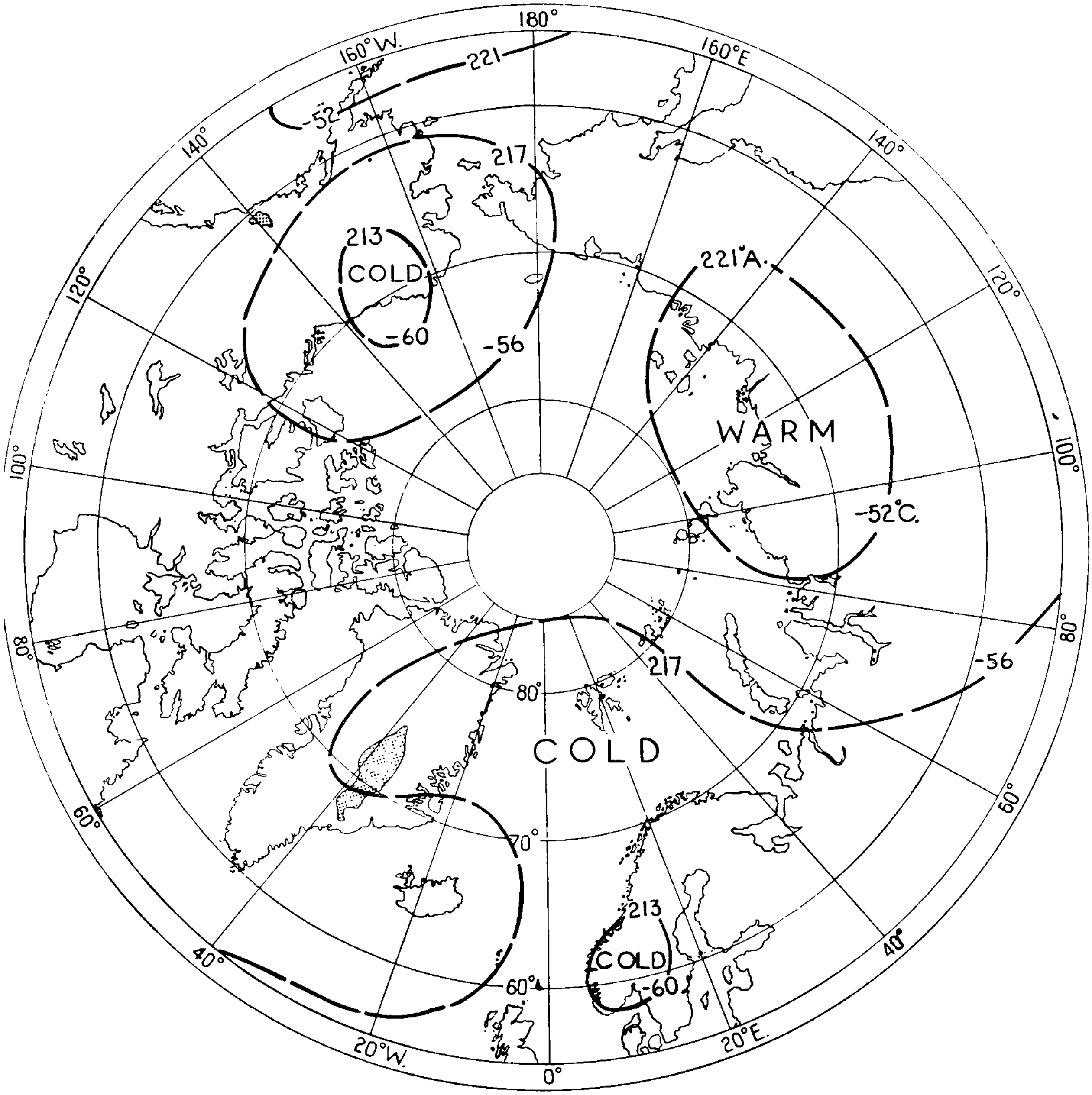

PLATE 44B—AVERAGE TEMPERATURE AT THE TROPOPAUSE IN OCTOBER

Land over 10,000 feet is represented by shading.

Isopleths for the polar tropopause are shown by broken lines of long dashes.

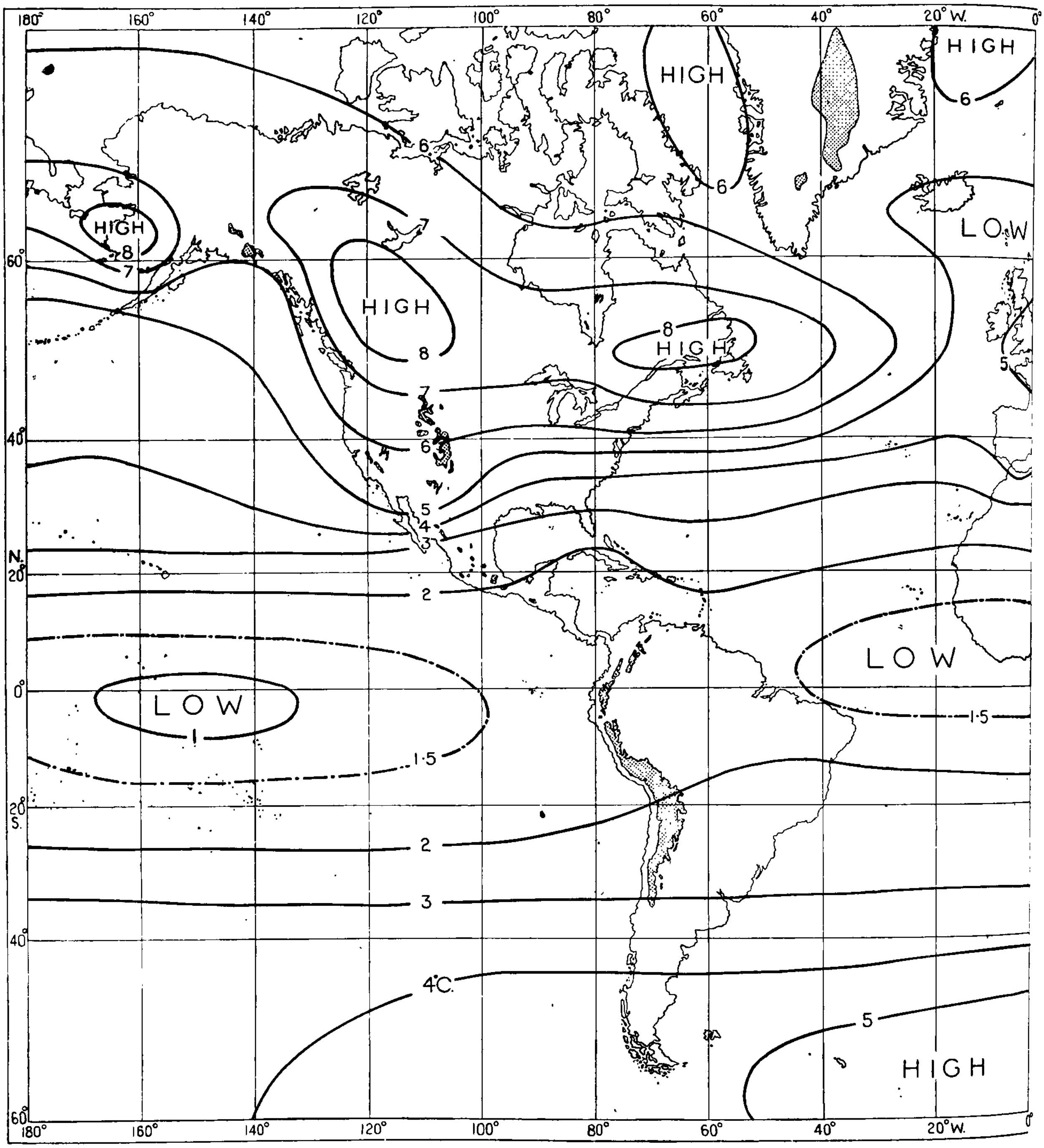

PLATE 45—STANDARD DEVIATION OF TEMPERATURE AT 700 MB. IN JANUARY
I.C.A.N. height = 9,876 ft. = 3,010 m.

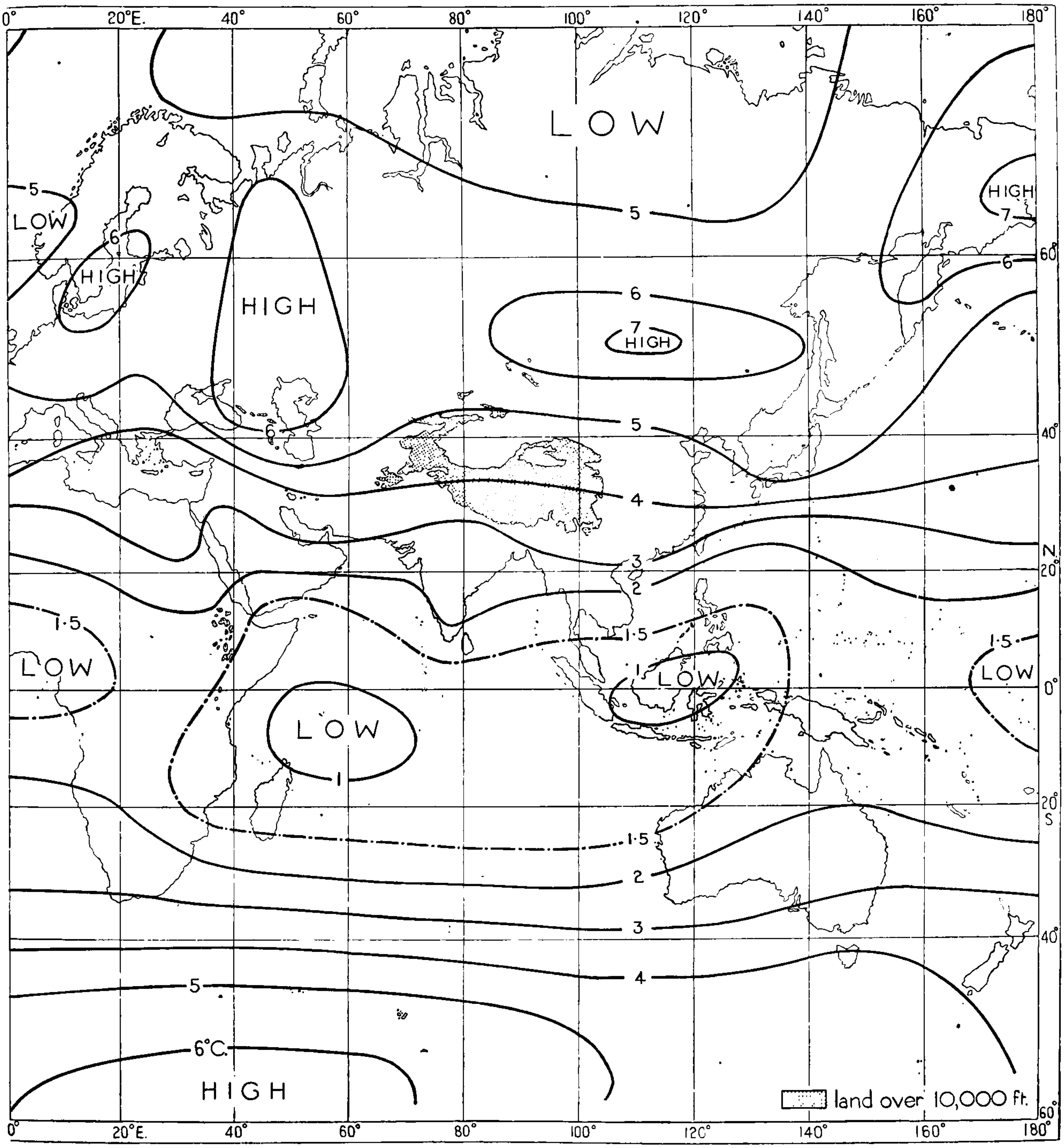

PLATE 45—CONTINUED

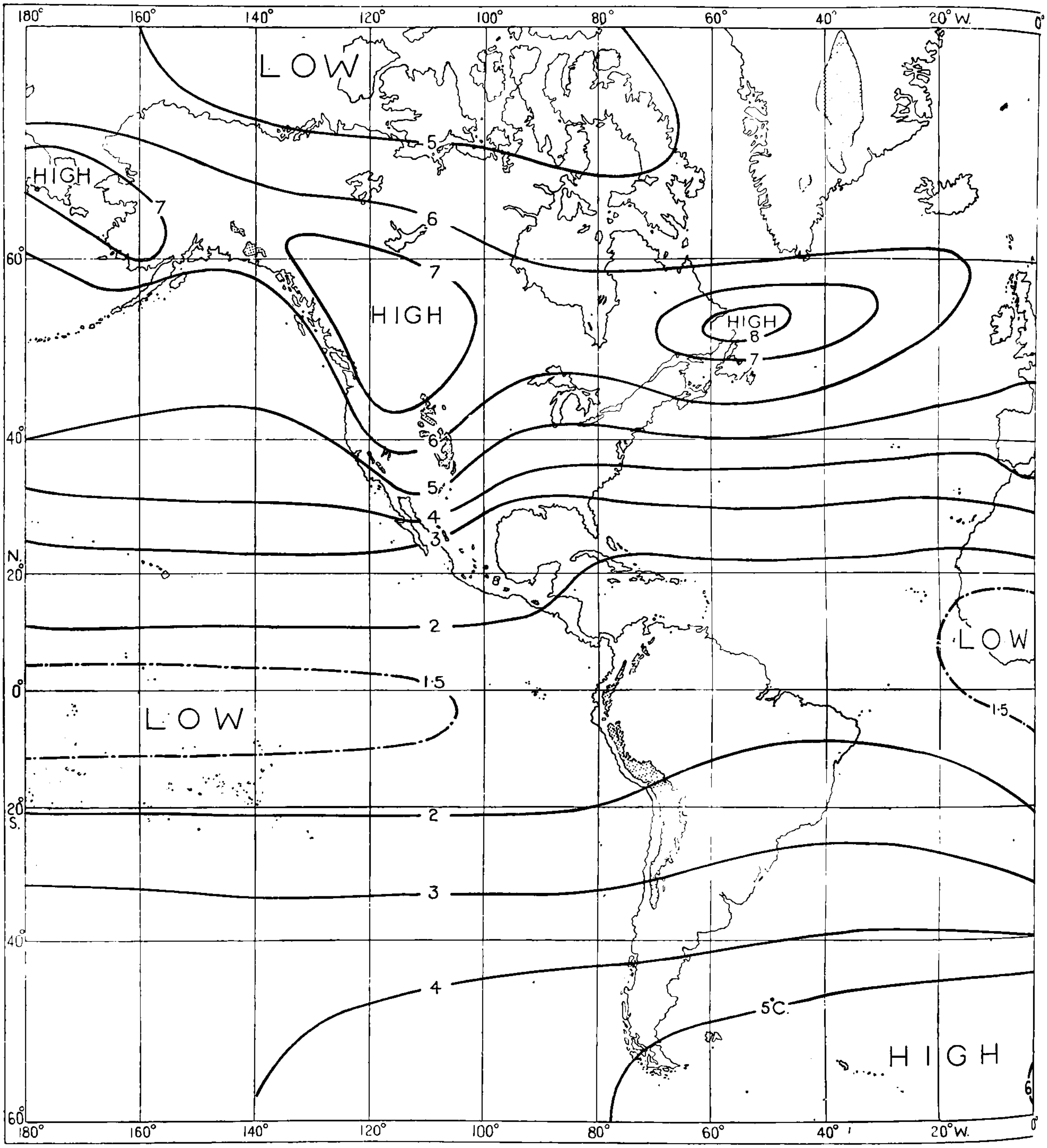

PLATE 46—STANDARD DEVIATION OF TEMPERATURE AT 500 MB. IN JANUARY

I.C.A.N. height = 18,278 ft. = 5,571 m.

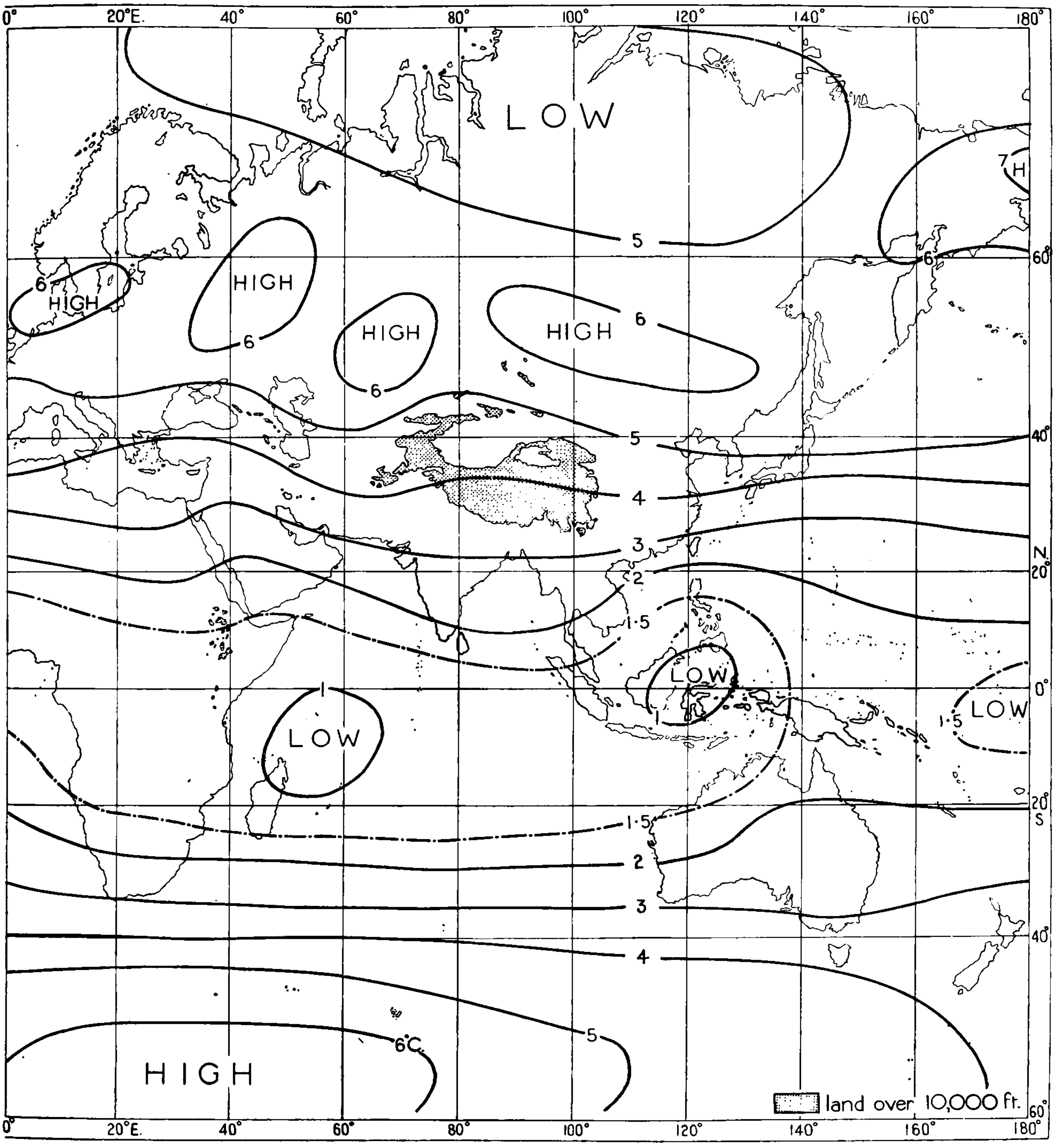

PLATE 46—CONTINUED

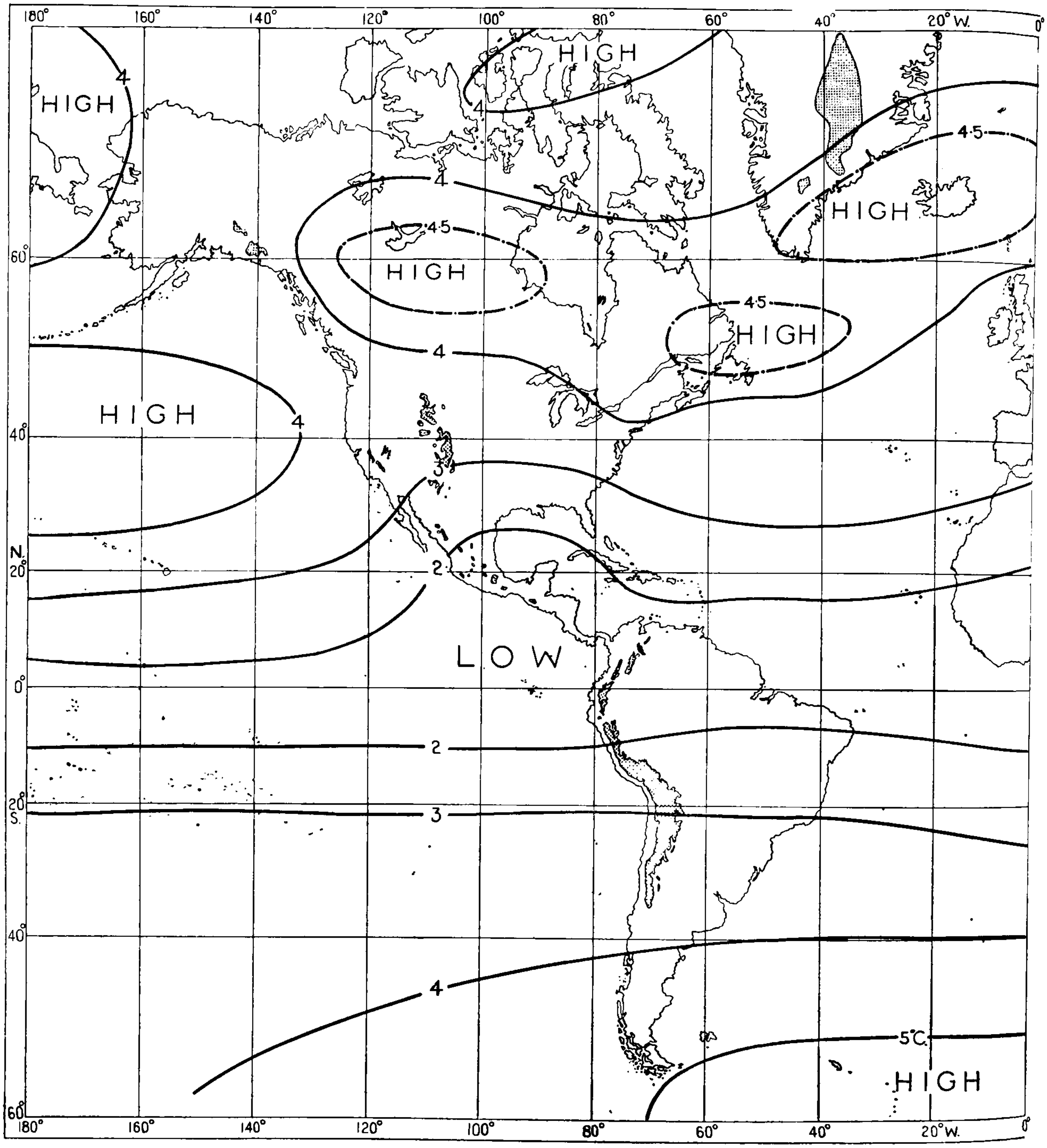

PLATE 47—STANDARD DEVIATION OF TEMPERATURE AT 300 MB. IN JANUARY

I.C.A.N. height = 30,059 ft. = 9,162 m.

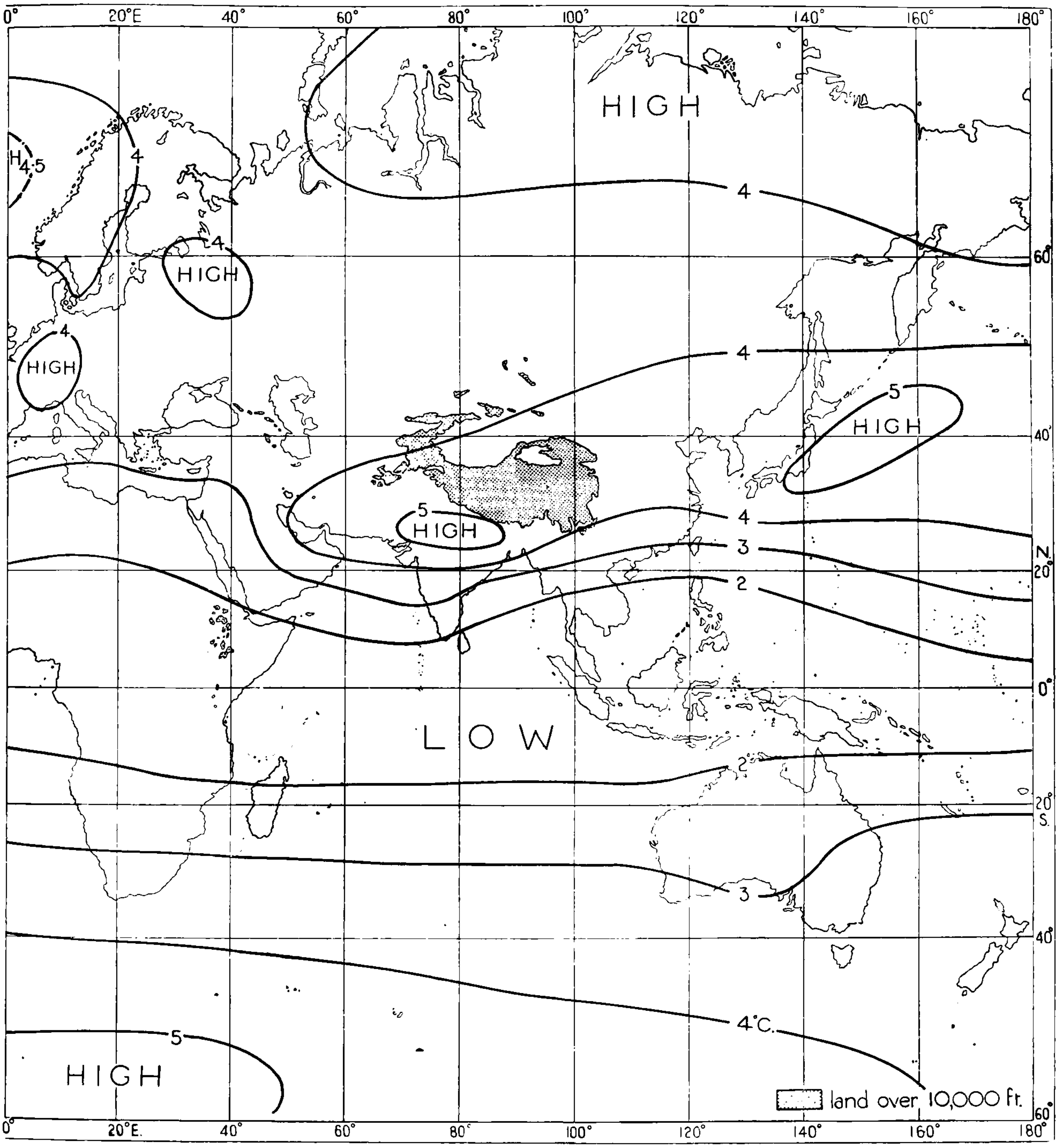

PLATE 47—CONTINUED

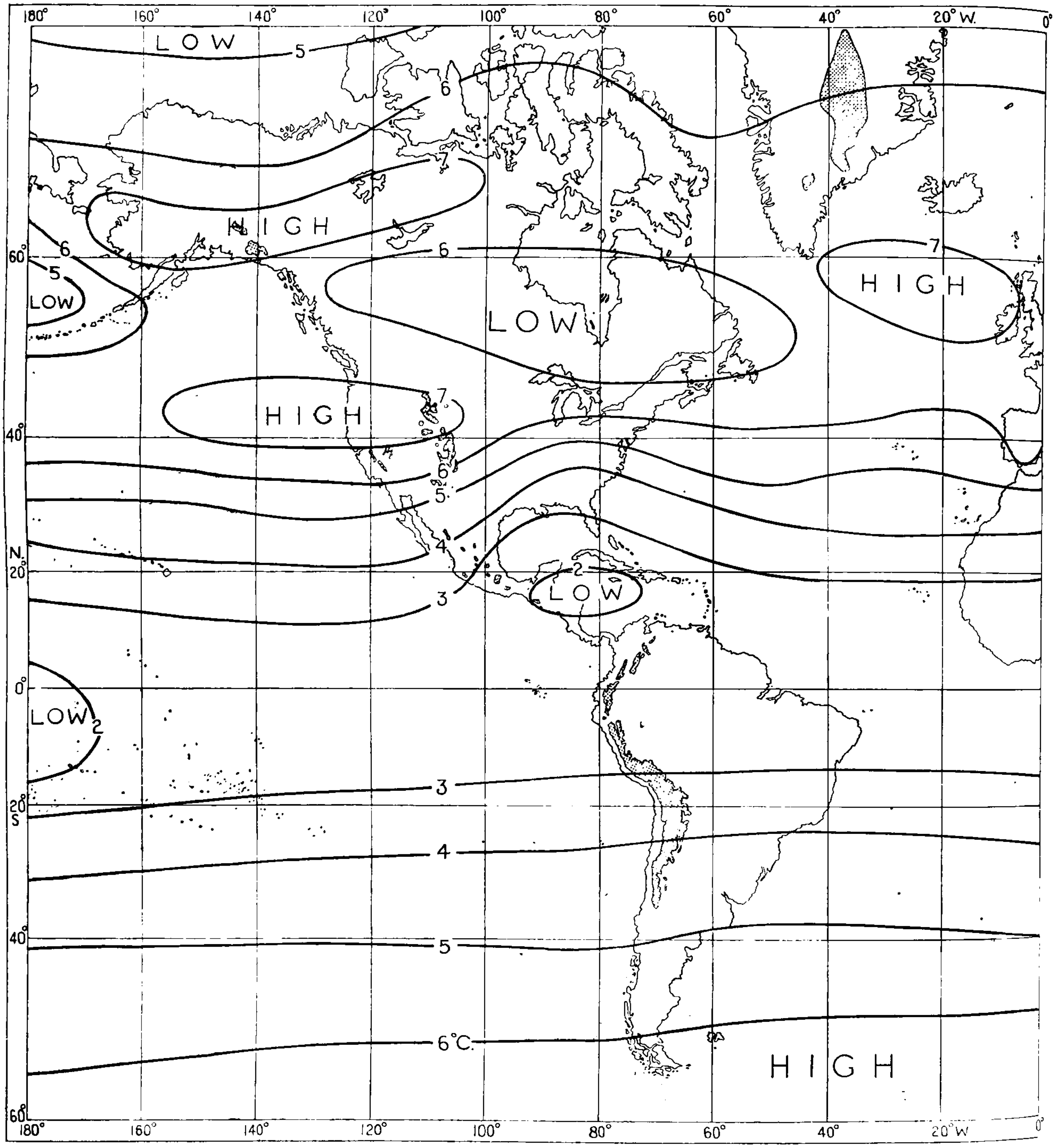

PLATE 48—STANDARD DEVIATION OF TEMPERATURE AT 200 MB. IN JANUARY

I.C.A.N. height = 38,664 ft. = 11,779 m.

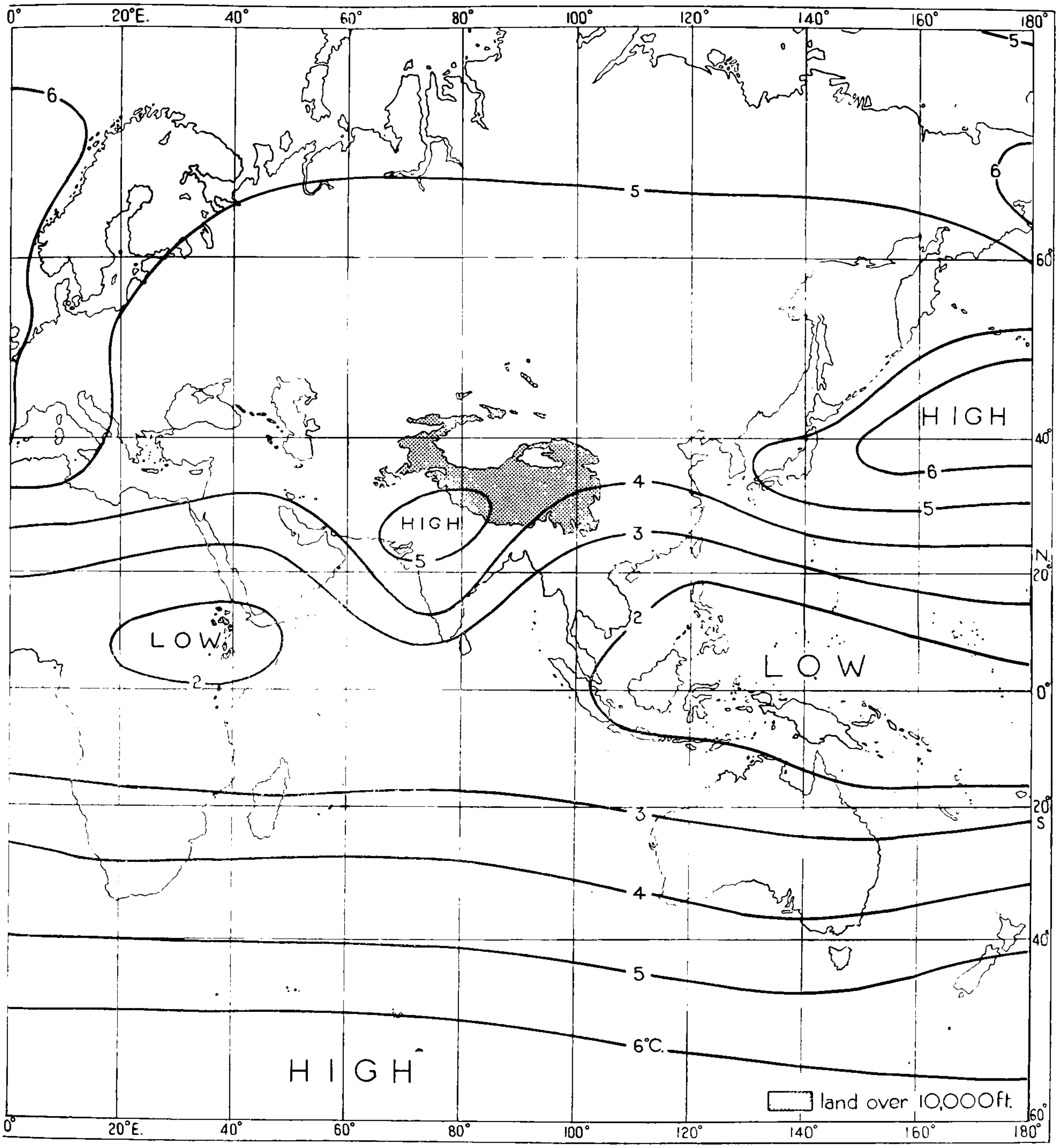

PLATE 48—CONTINUED

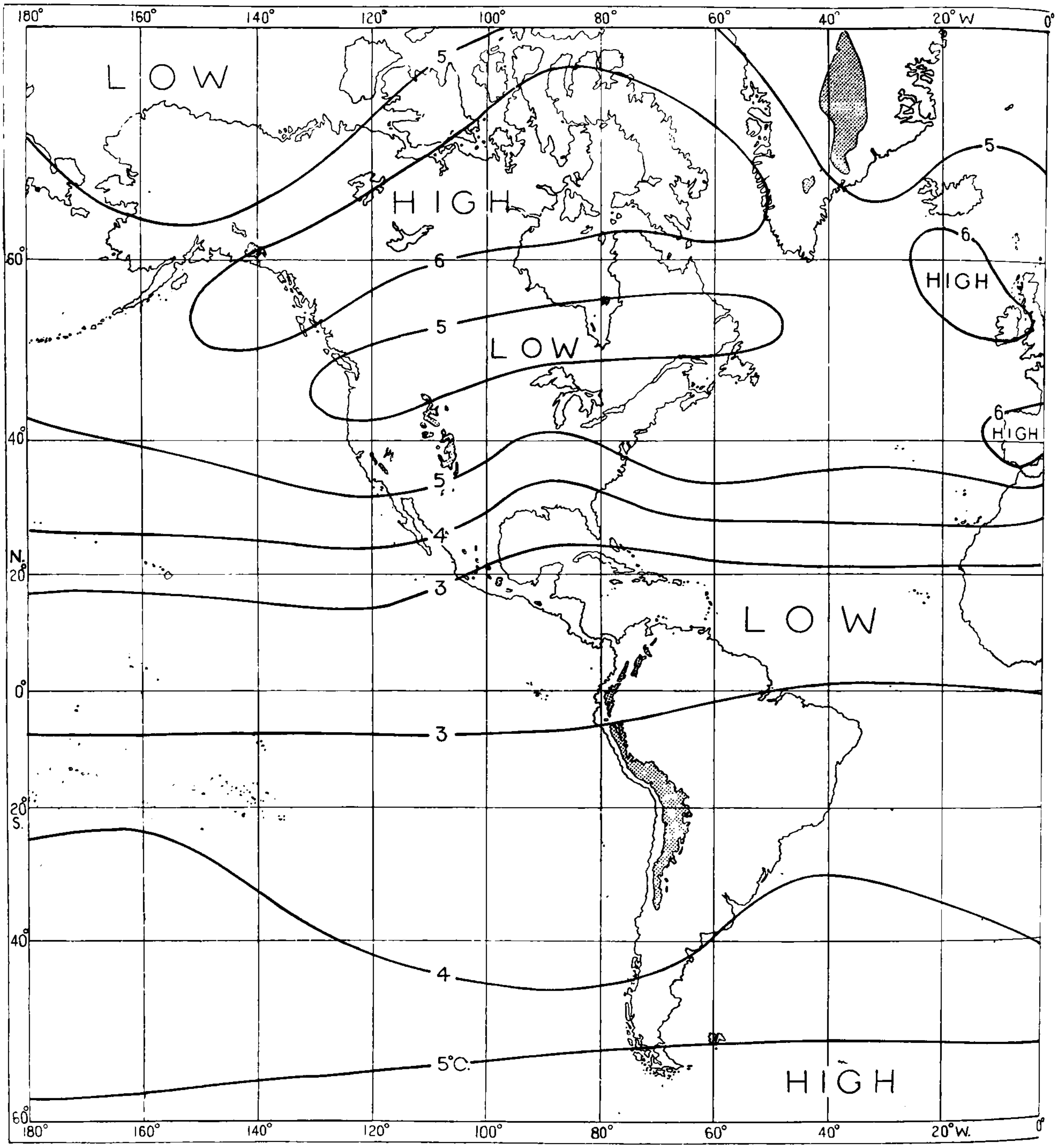

PLATE 49—STANDARD DEVIATION OF TEMPERATURE AT 150 MB. IN JANUARY

I.C.A.N. height = 44,625 ft. = 13,602 m.

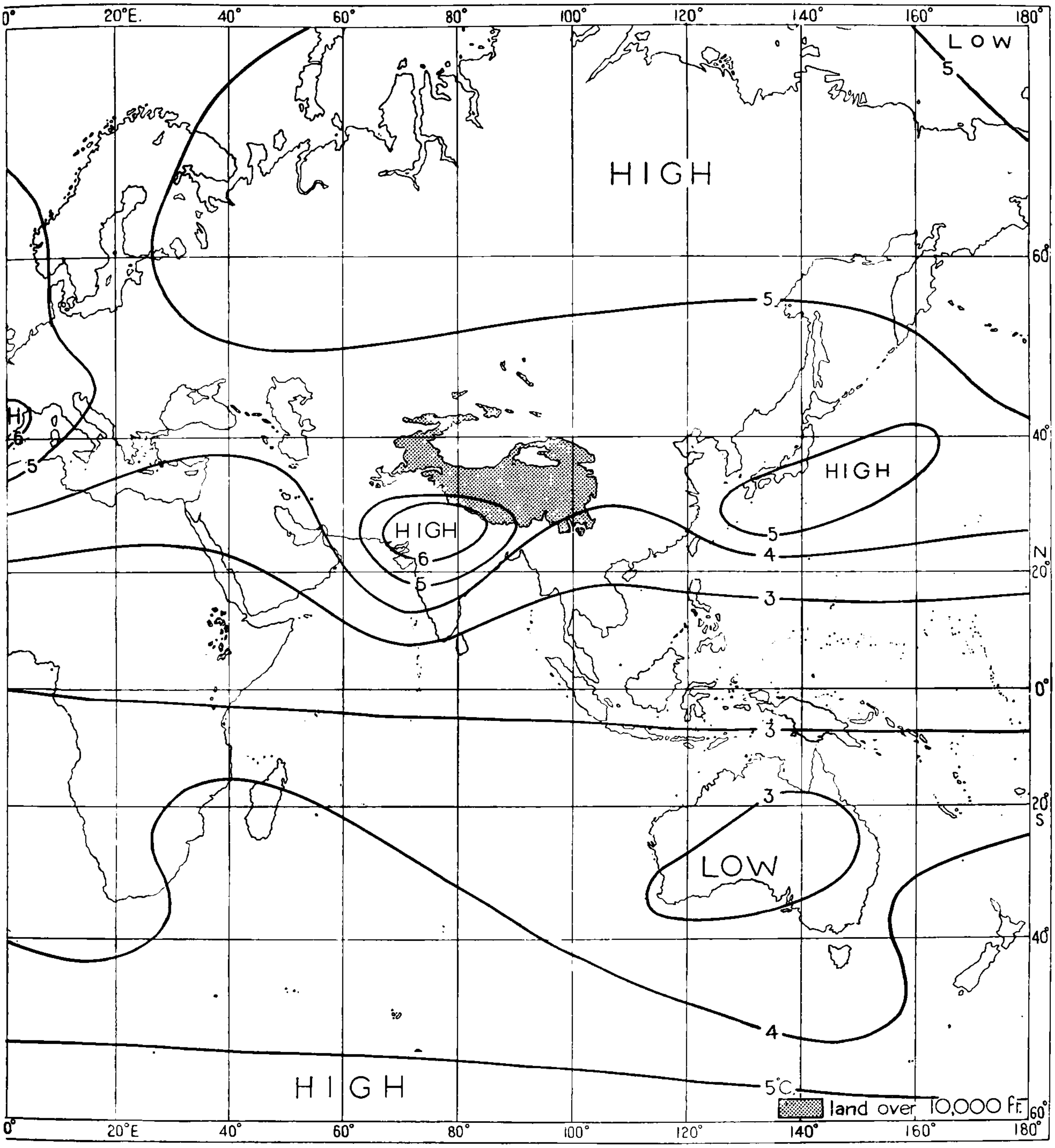

PLATE 49—CONTINUED

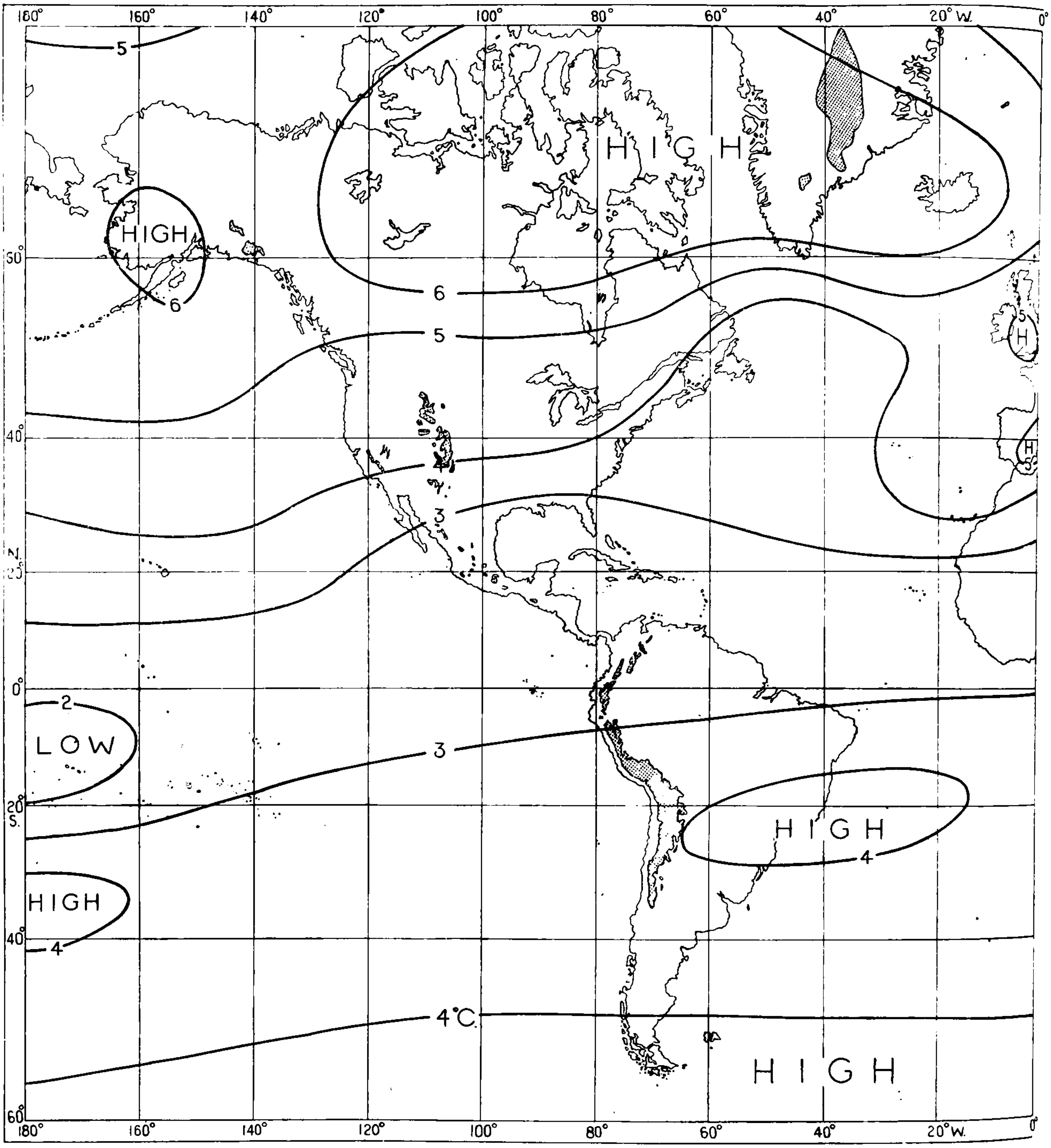

PLATE 50—STANDARD DEVIATION OF TEMPERATURE AT 100 MB. IN JANUARY

I.C.A.N. height = 53,054 ft. = 16,170 m.

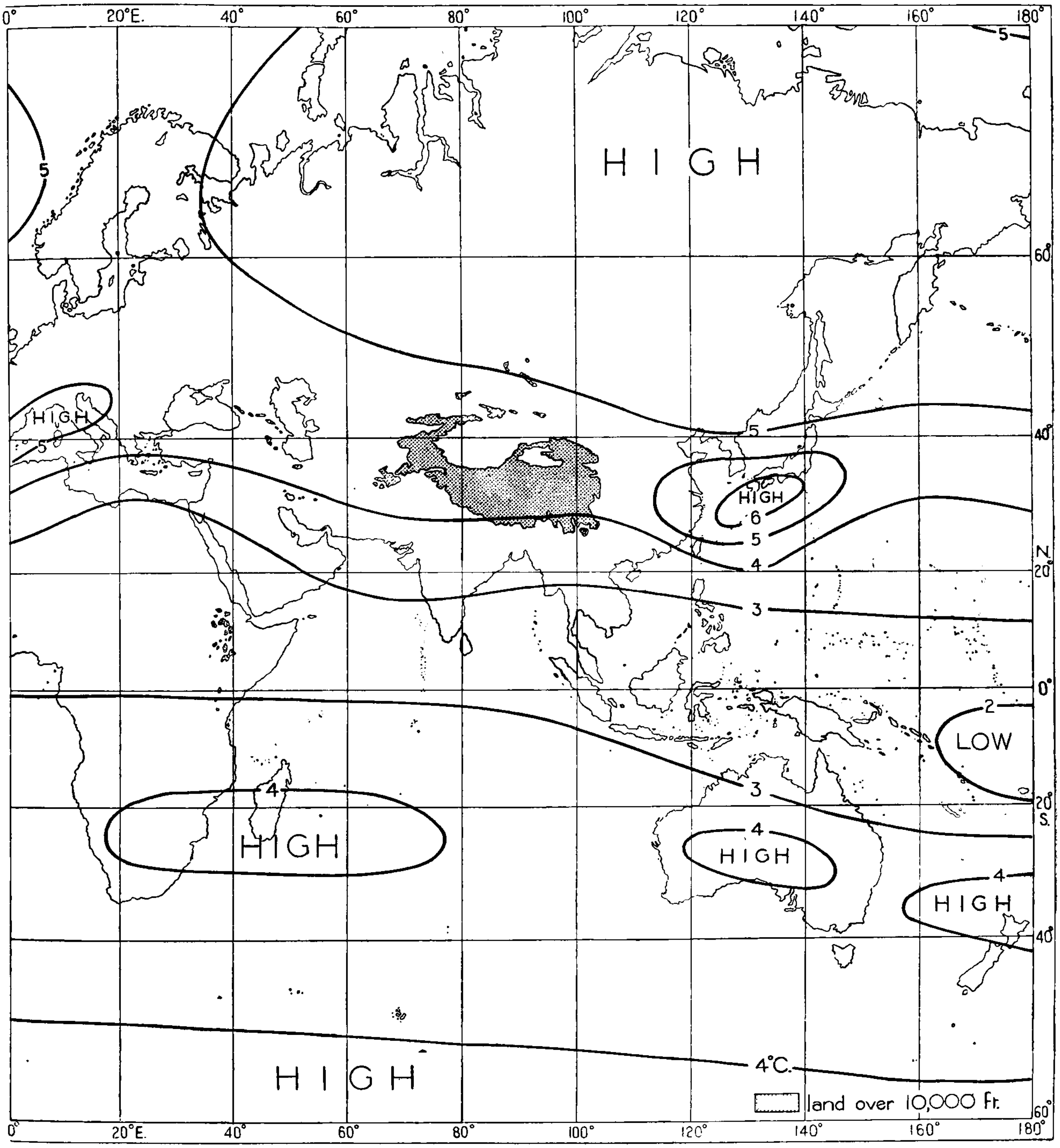

PLATE 50—CONTINUED

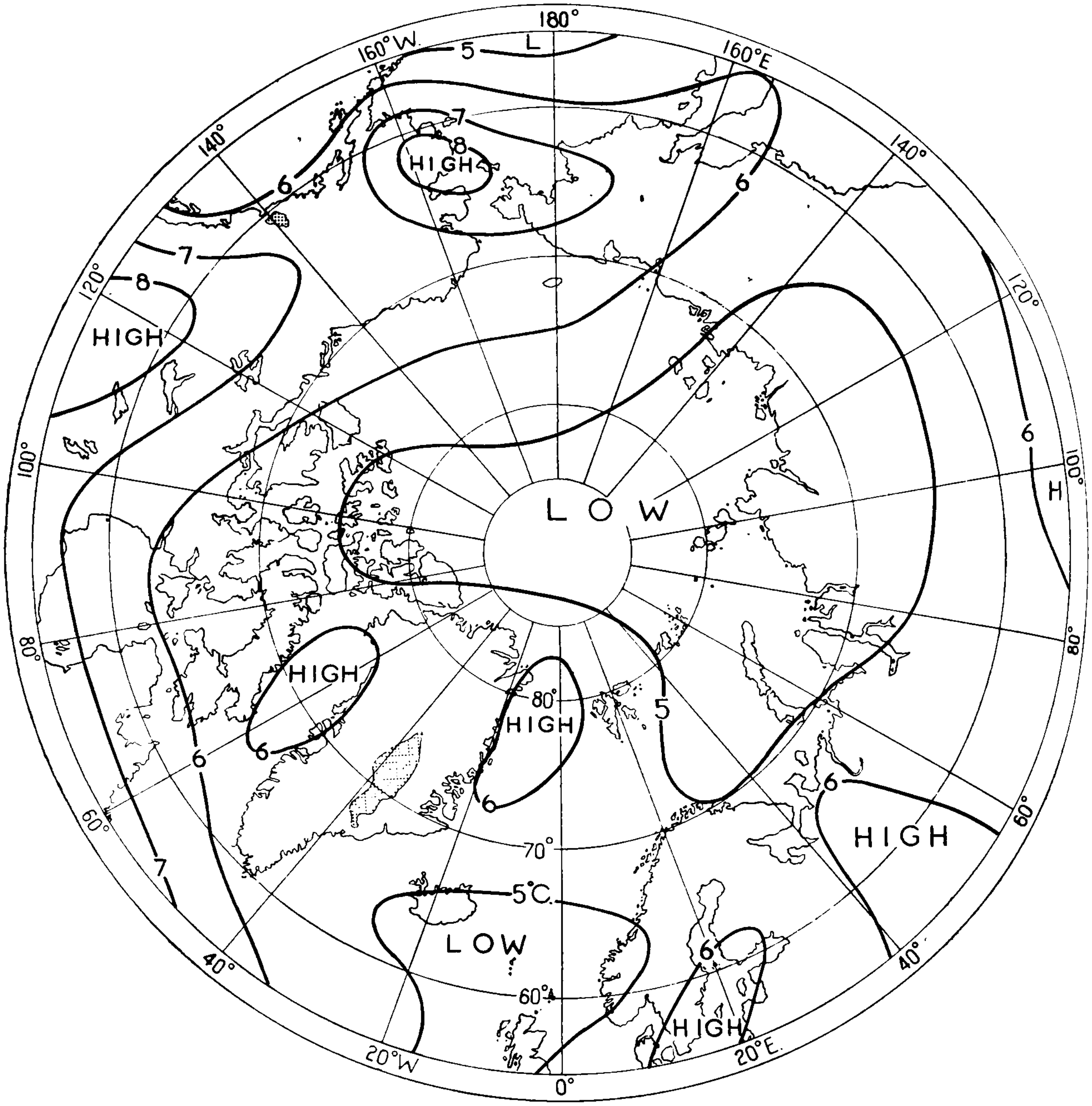

PLATE 51A—STANDARD DEVIATION OF TEMPERATURE AT 700 MB. IN JANUARY

I.C.A.N. height = 9,876 ft. = 3,010 m.

Land over 10,000 feet is represented by shading.

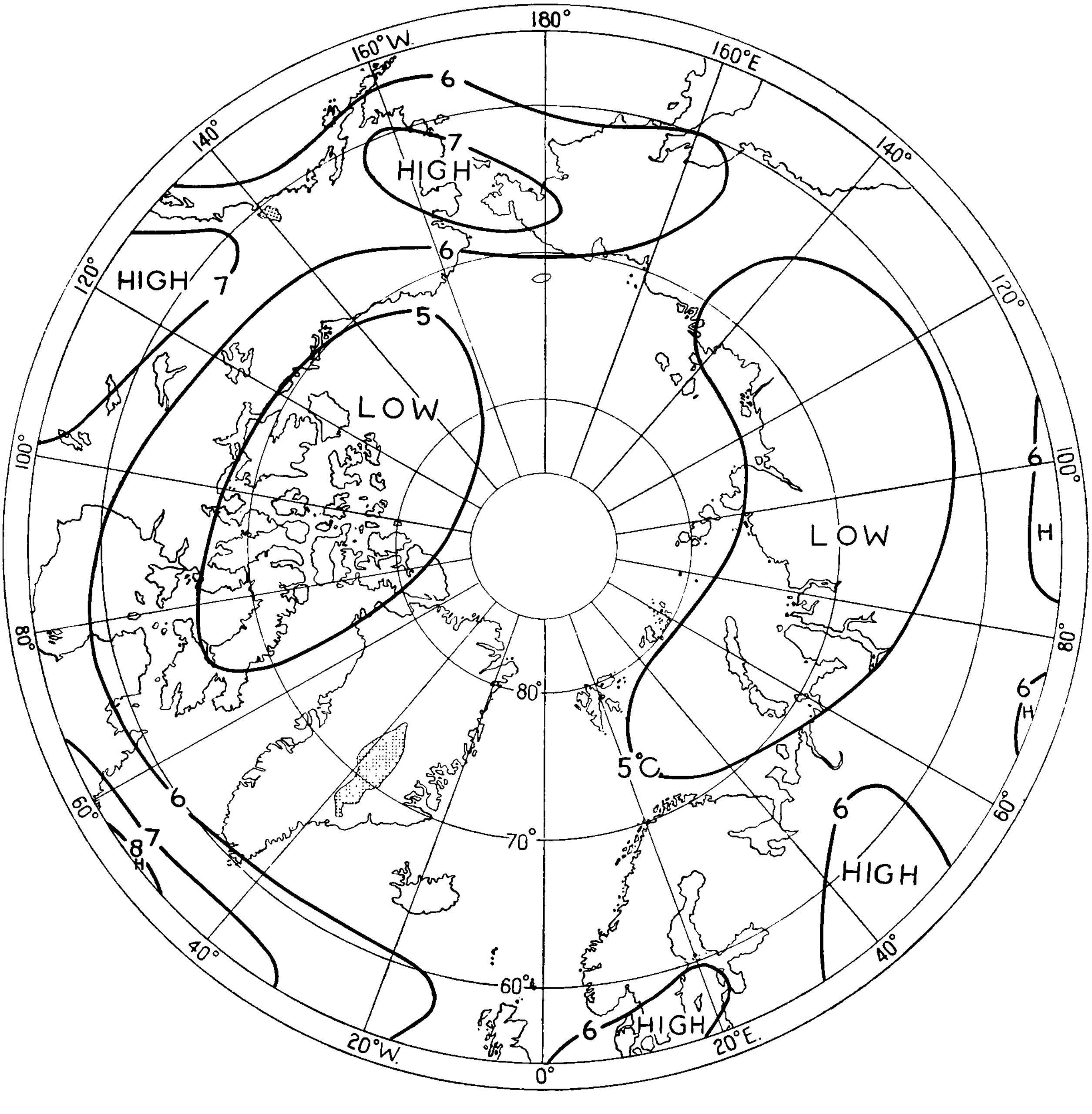

PLATE 51B—STANDARD DEVIATION OF TEMPERATURE AT 500 MB. IN JANUARY

I.C.A.N. height = 18,278 ft. = 5,571 m.

Land over 10,000 feet is represented by shading.

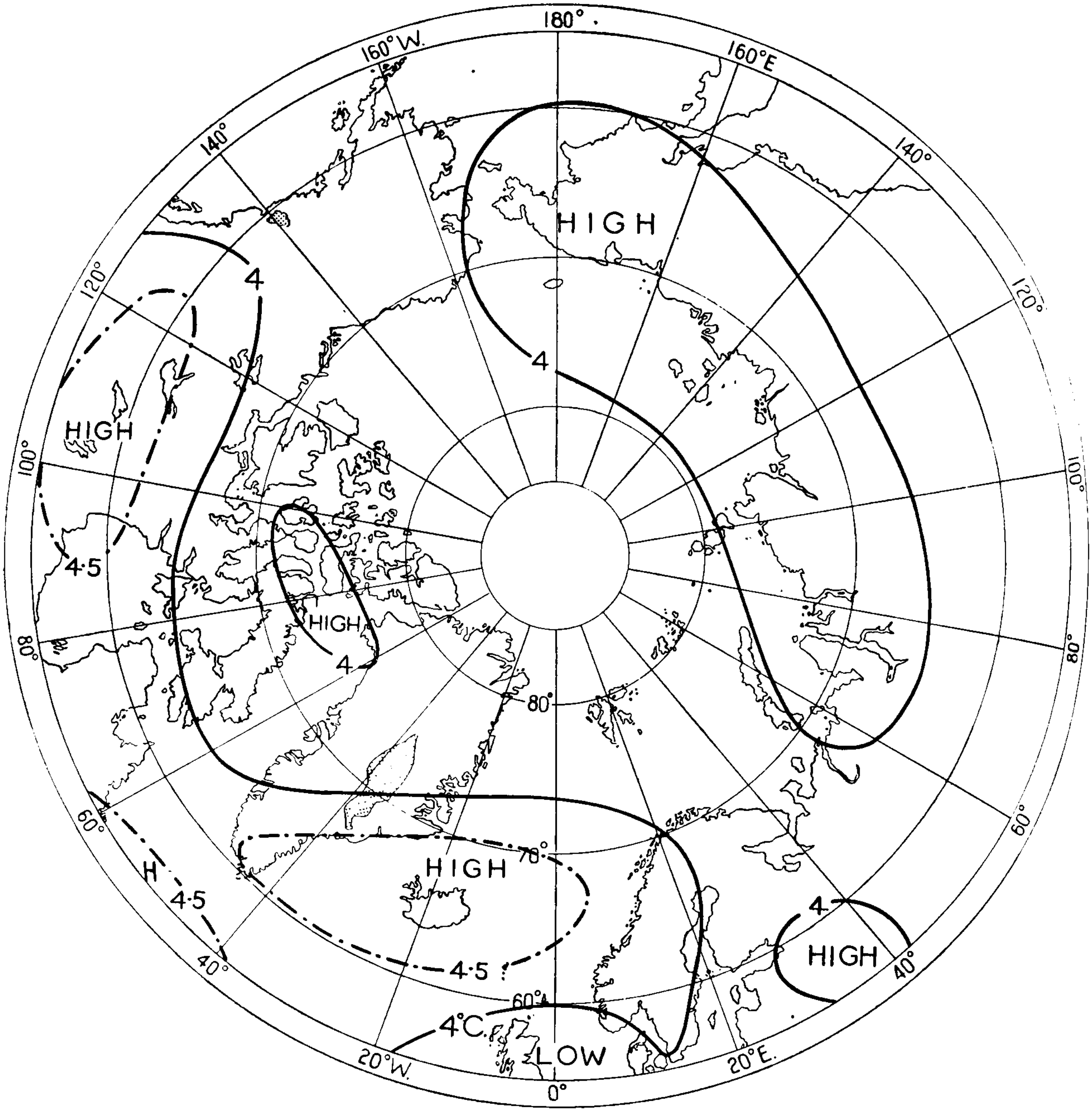

PLATE 51c—STANDARD DEVIATION OF TEMPERATURE AT 300 MB. IN JANUARY

I.C.A.N. height = 30,059 ft. = 9,162 m.

Land over 10,000 feet is represented by shading.

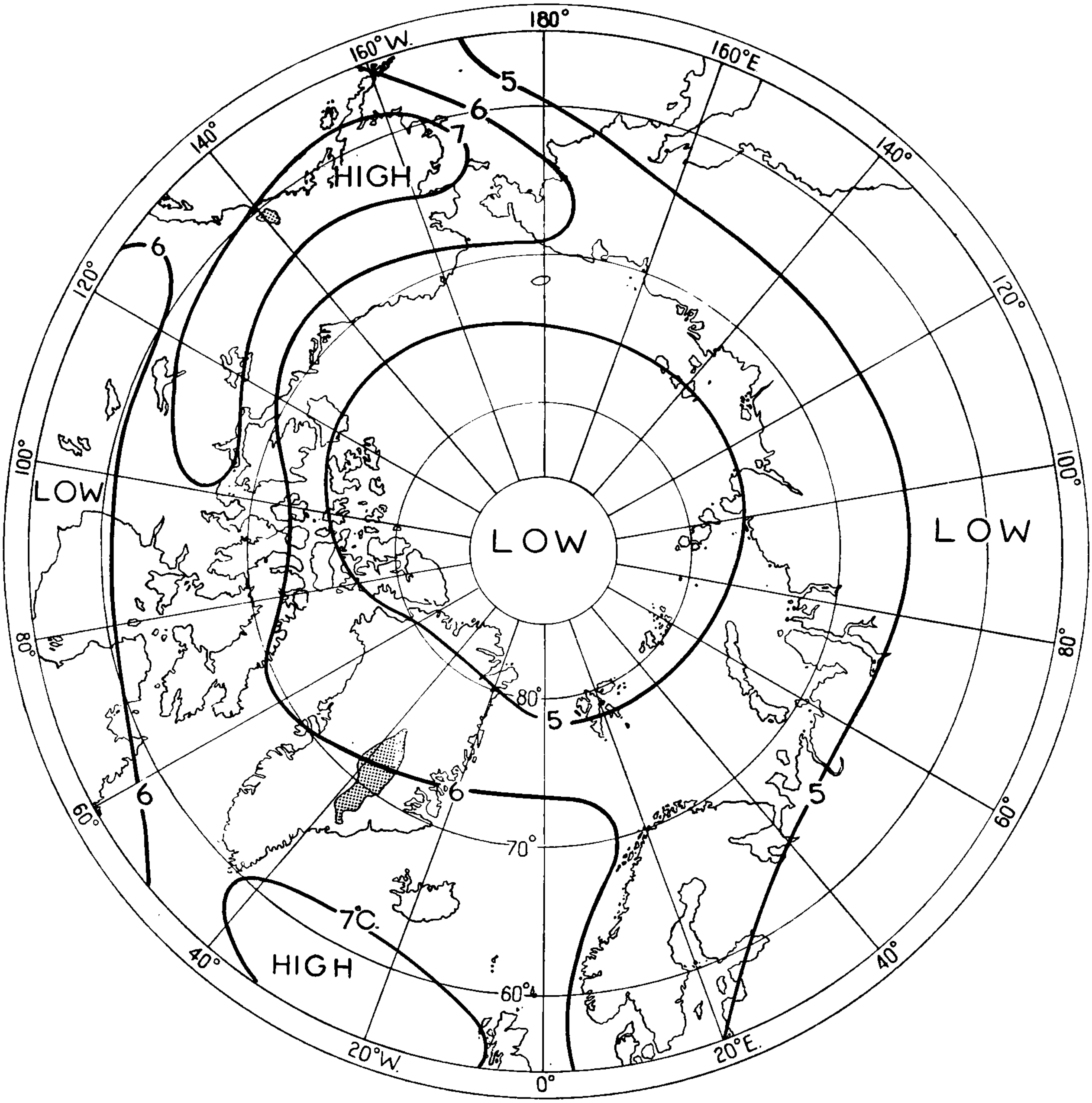

PLATE 52A—STANDARD DEVIATION OF TEMPERATURE AT 200 MB. IN JANUARY

I.C.A.N. height = 38,664 ft. = 11,779 m.

Land over 10,000 feet is represented by shading.

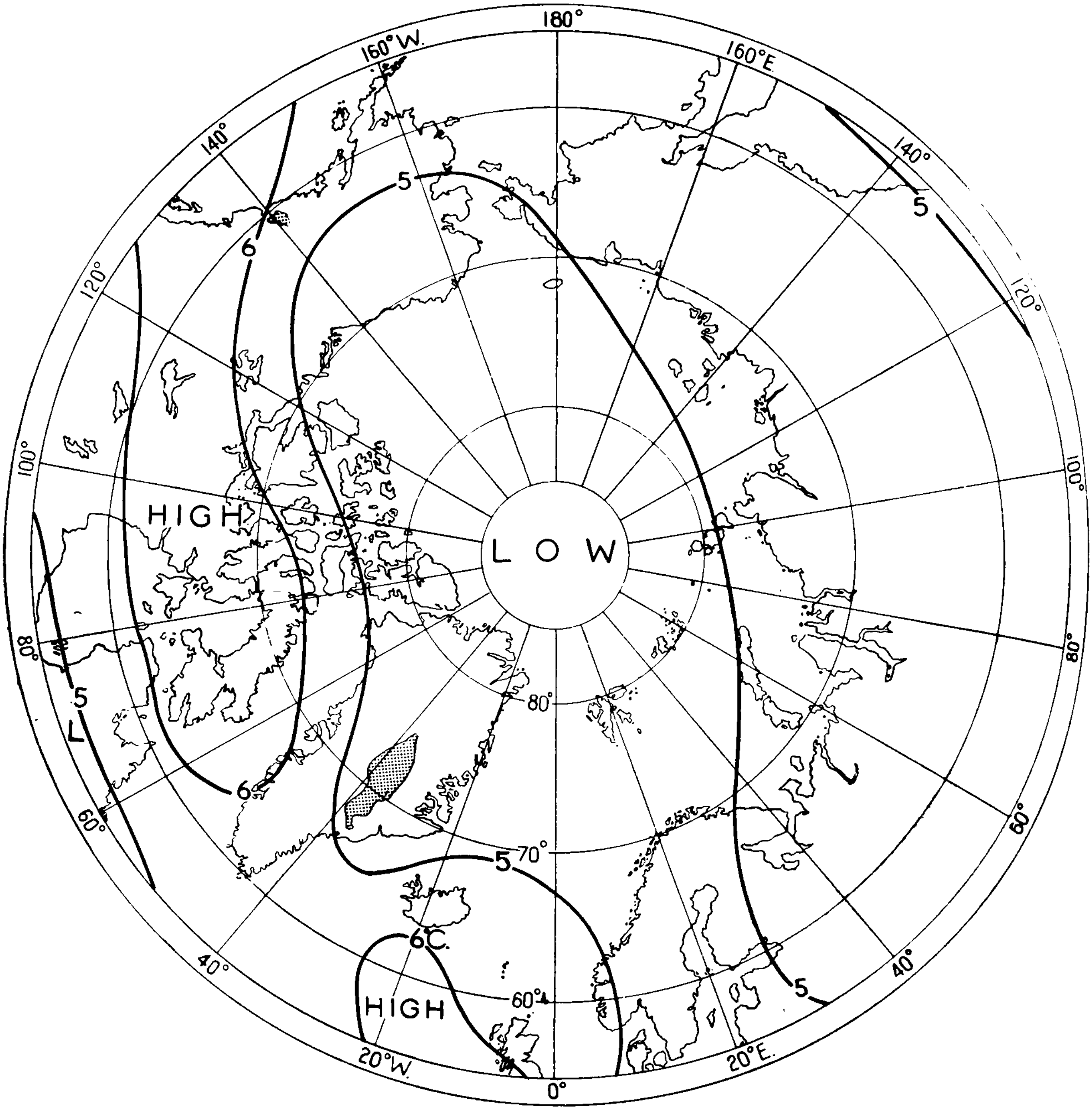

PLATE 52B—STANDARD DEVIATION OF TEMPERATURE AT 150 MB. IN JANUARY

I.C.A.N. height = 44,625 ft. = 13,602 m.

Land over 10,000 feet is represented by shading.

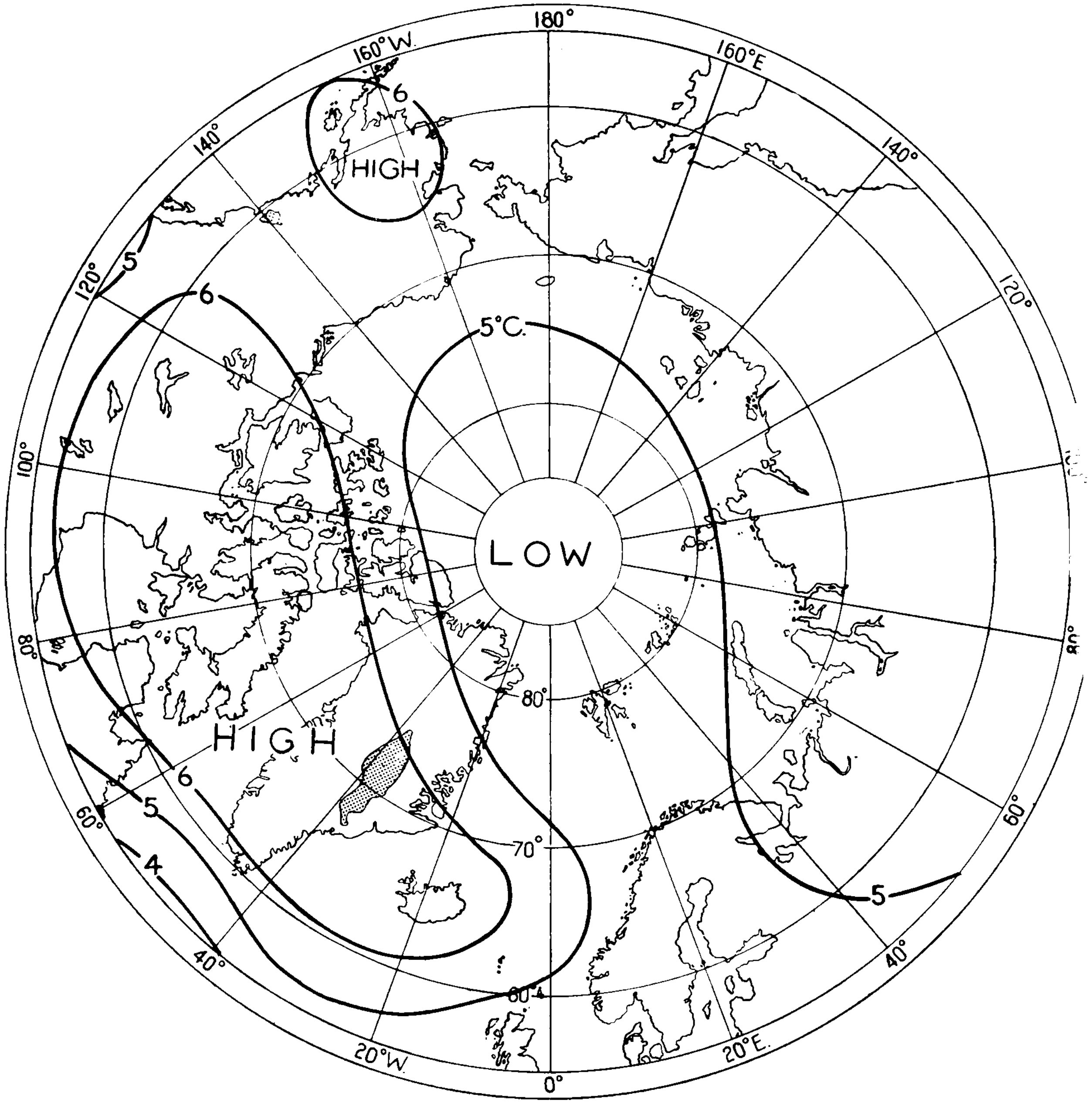

PLATE 52c—STANDARD DEVIATION OF TEMPERATURE AT 100 MB. IN JANUARY

I.C.A.N. height = 53,054 ft. = 16,170 m.

Land over 10,000 feet is represented by shading.

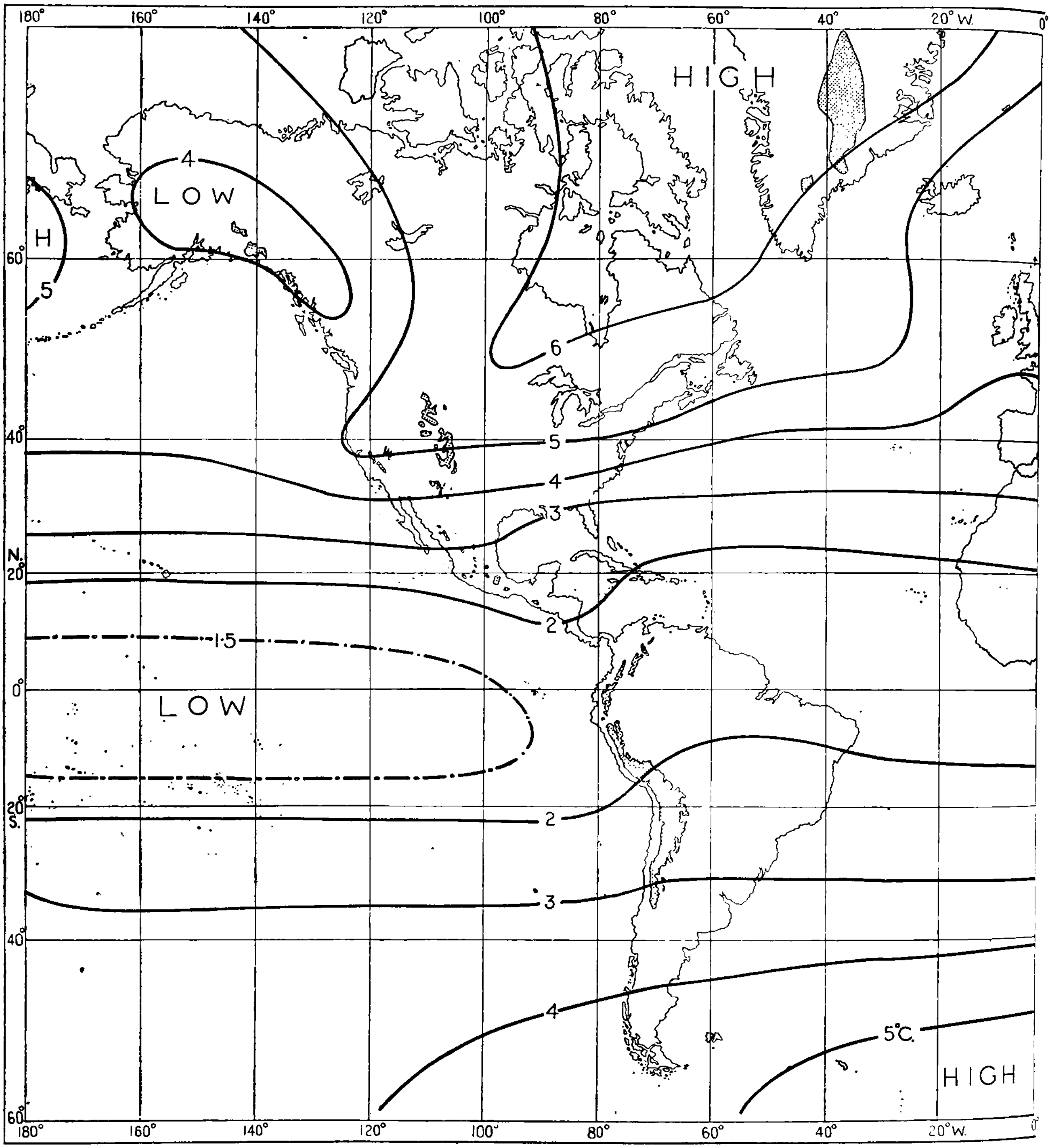

PLATE 53—STANDARD DEVIATION OF TEMPERATURE AT 700 MB. IN APRIL

I.C.A.N. height = 9,876 ft. = 3,010 m.

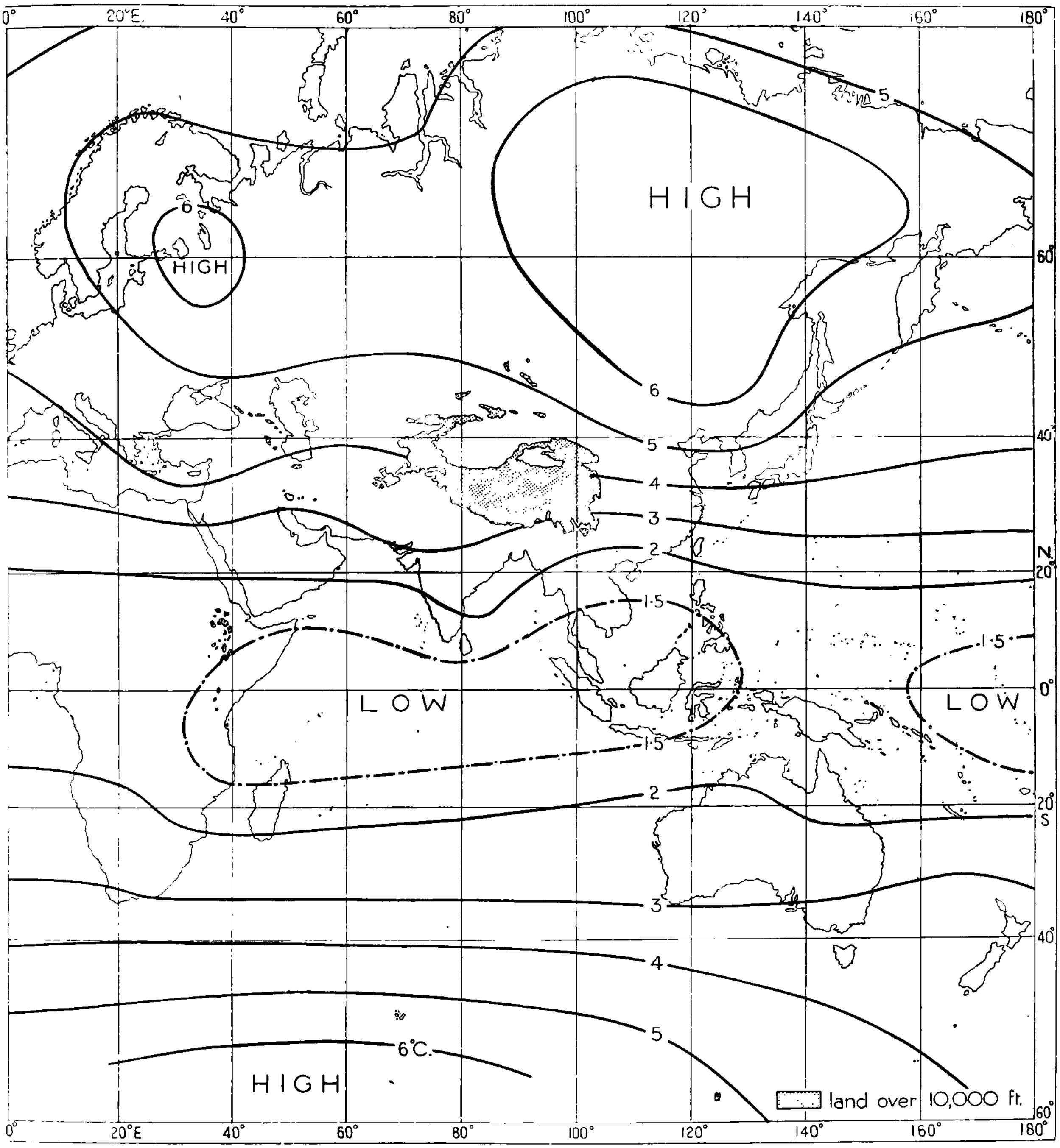

PLATE 53—CONTINUED

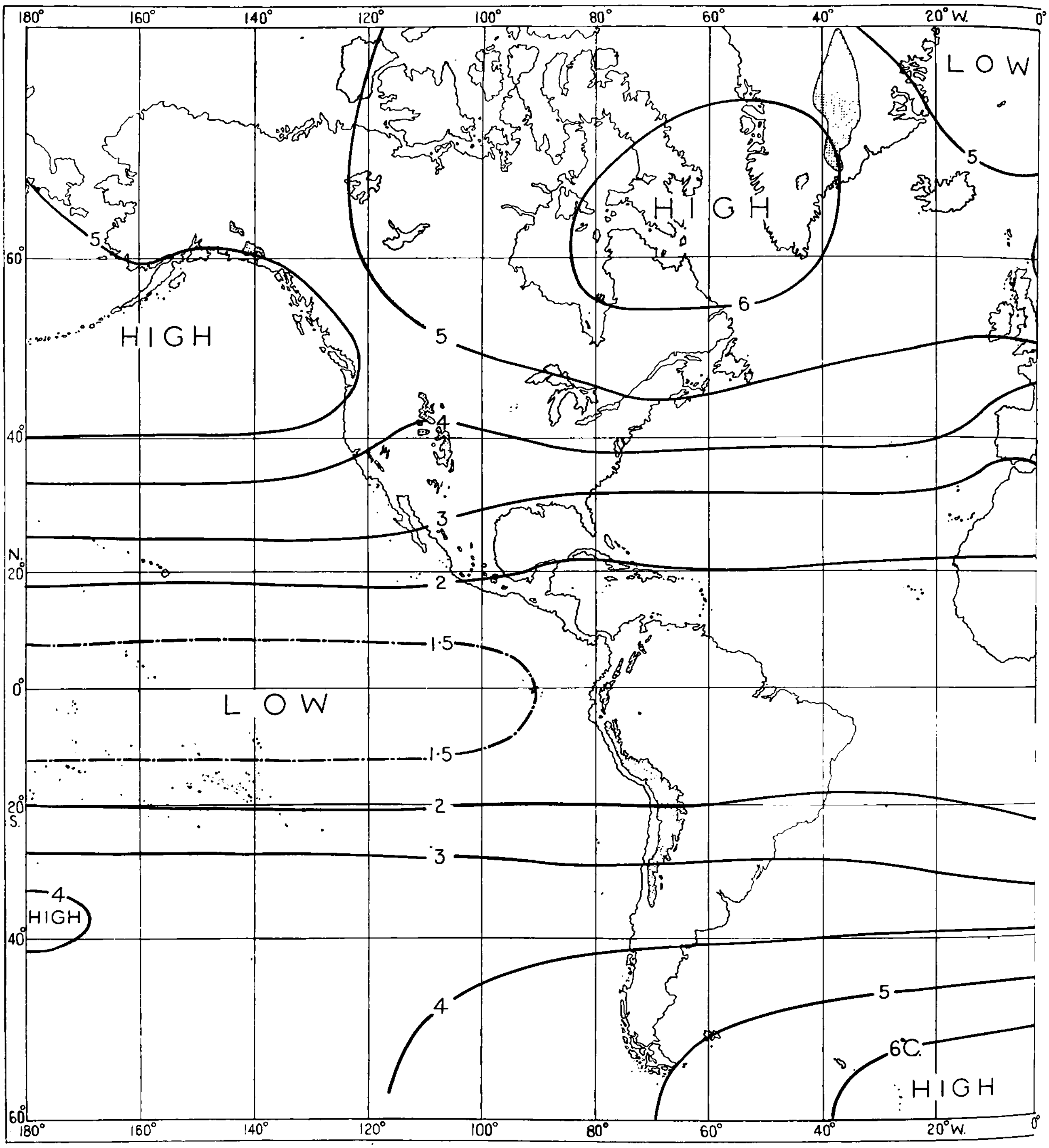

PLATE 54—STANDARD DEVIATION OF TEMPERATURE AT 500 MB. IN APRIL
I.C.A.N. height = 18,278 ft. = 5,571 m.

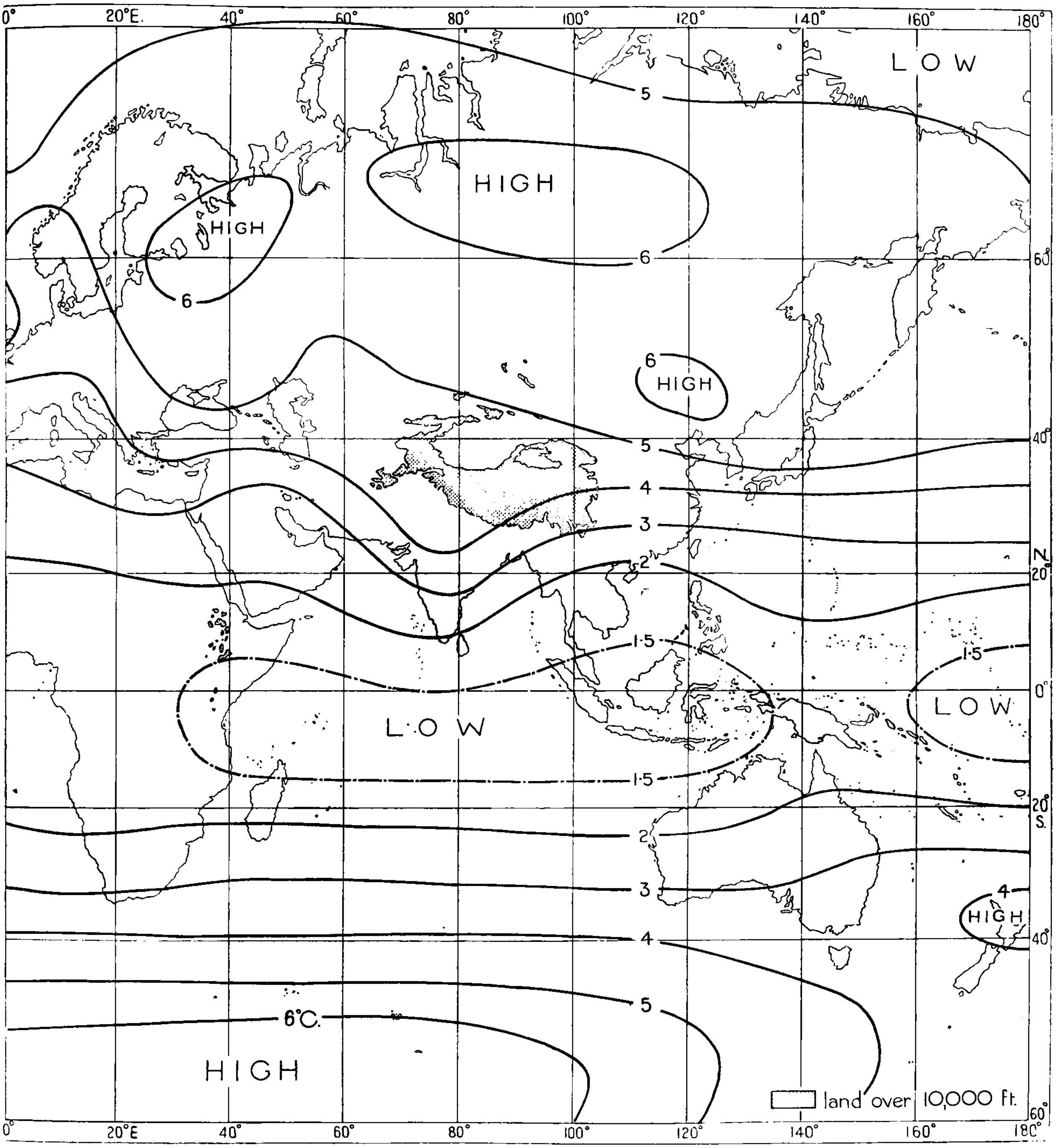

PLATE 54—CONTINUED

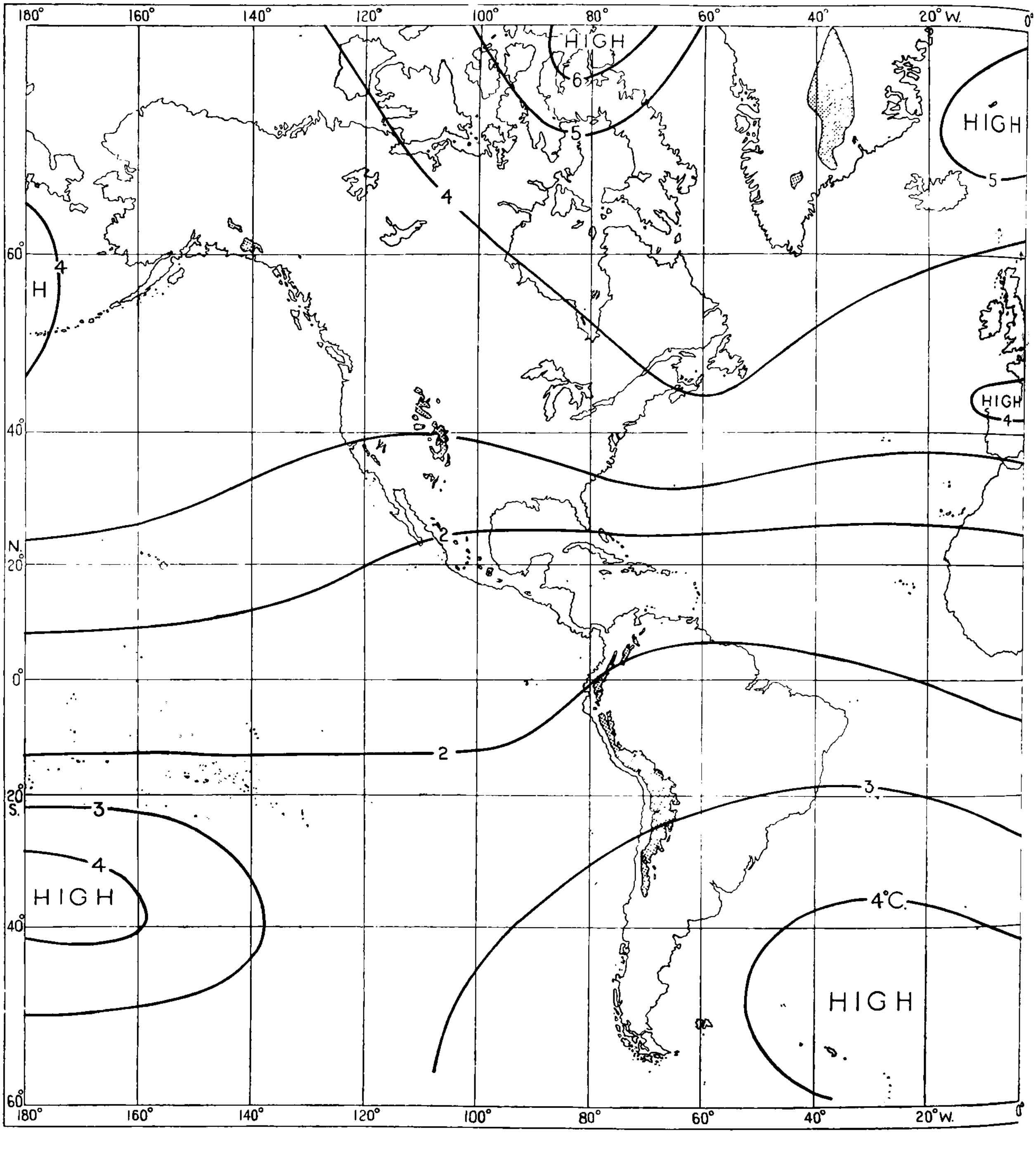

PLATE 55—STANDARD DEVIATION OF TEMPERATURE AT 300 MB. IN APRIL

I.C.A.N. height = 30,059 ft. = 9,162 m.

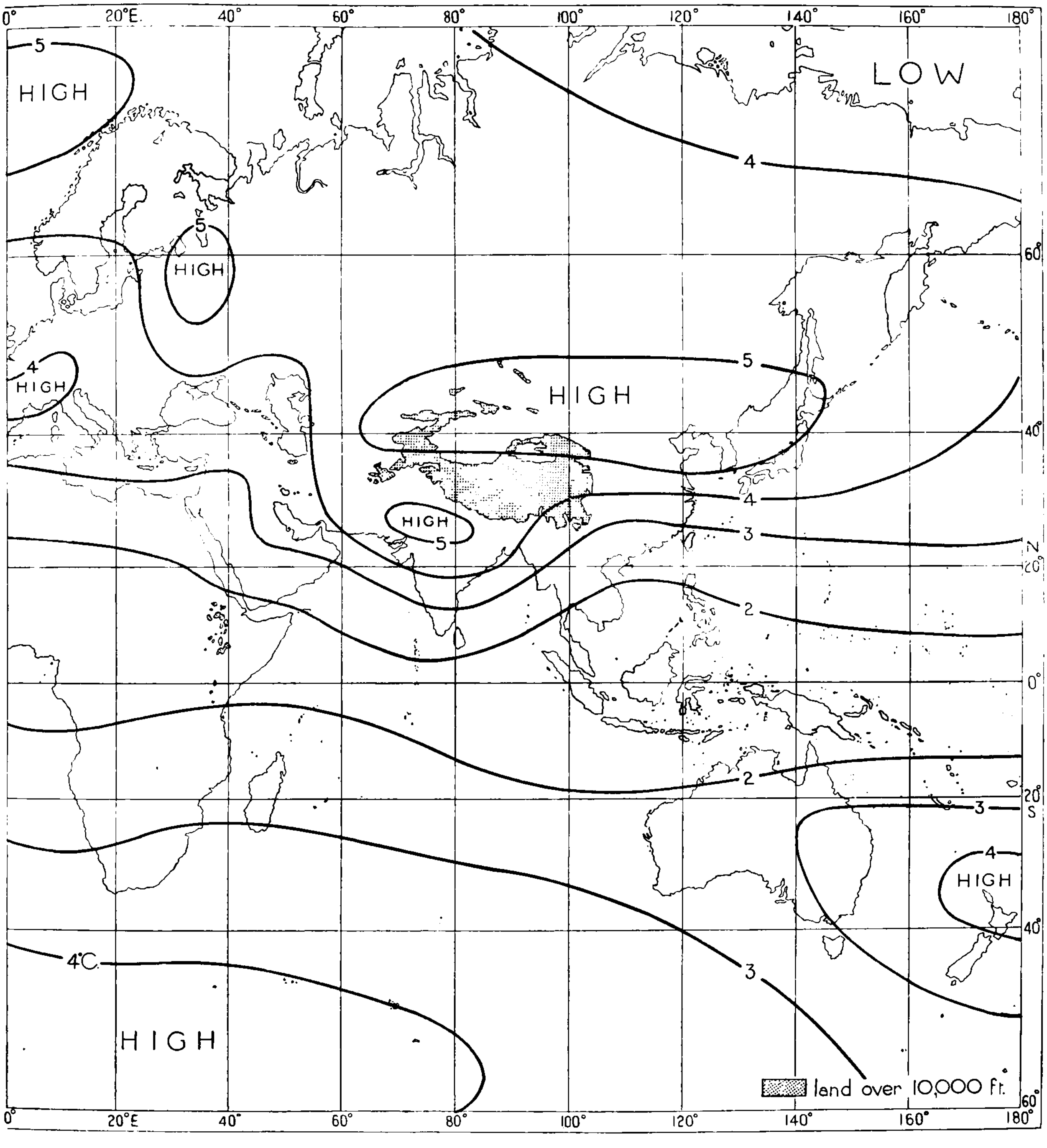

PLATE 55—CONTINUED

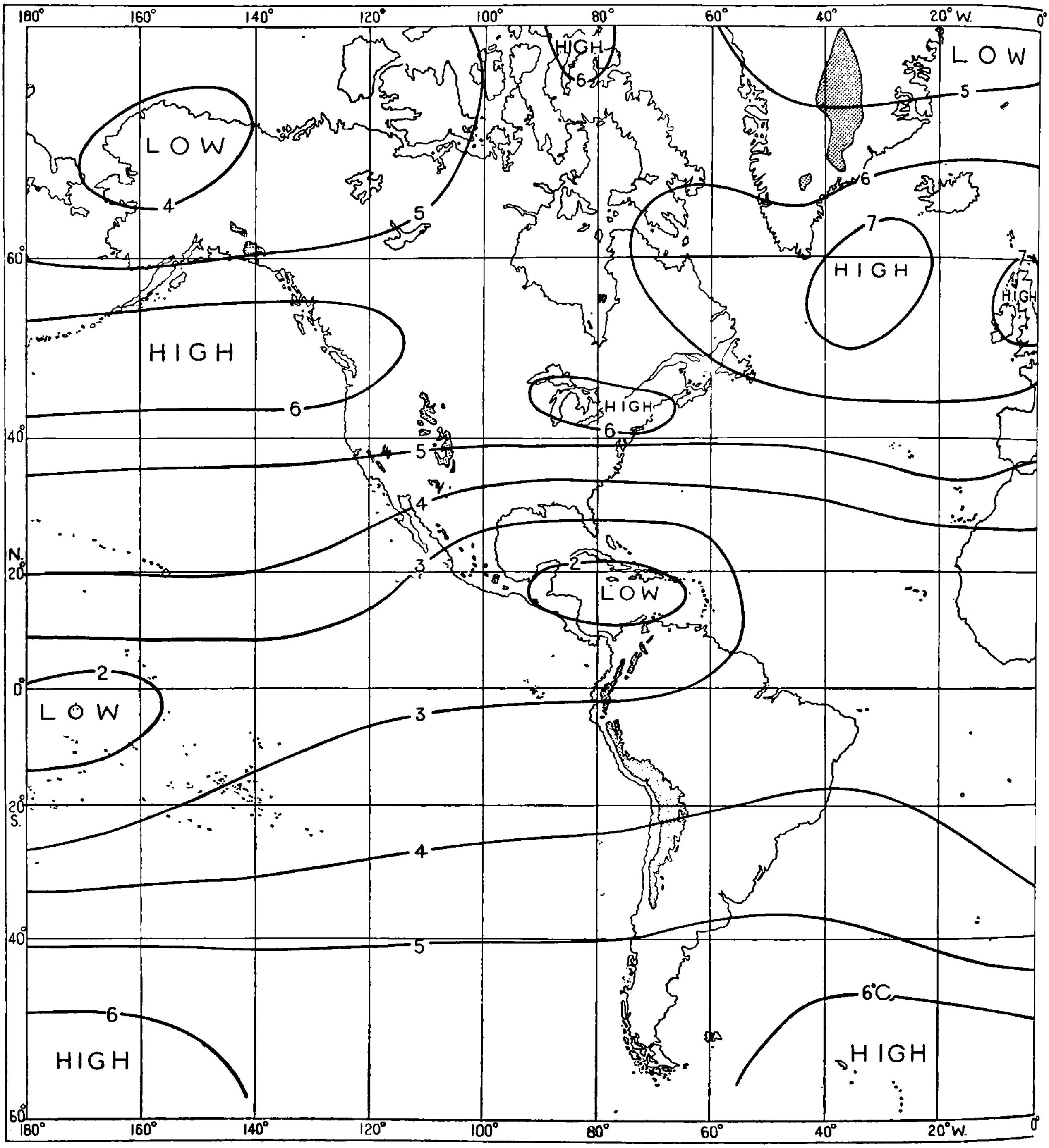

PLATE 56—STANDARD DEVIATION OF TEMPERATURE AT 200 MB. IN APRIL

I.C.A.N. height = 38,664 ft. = 11,779 m.

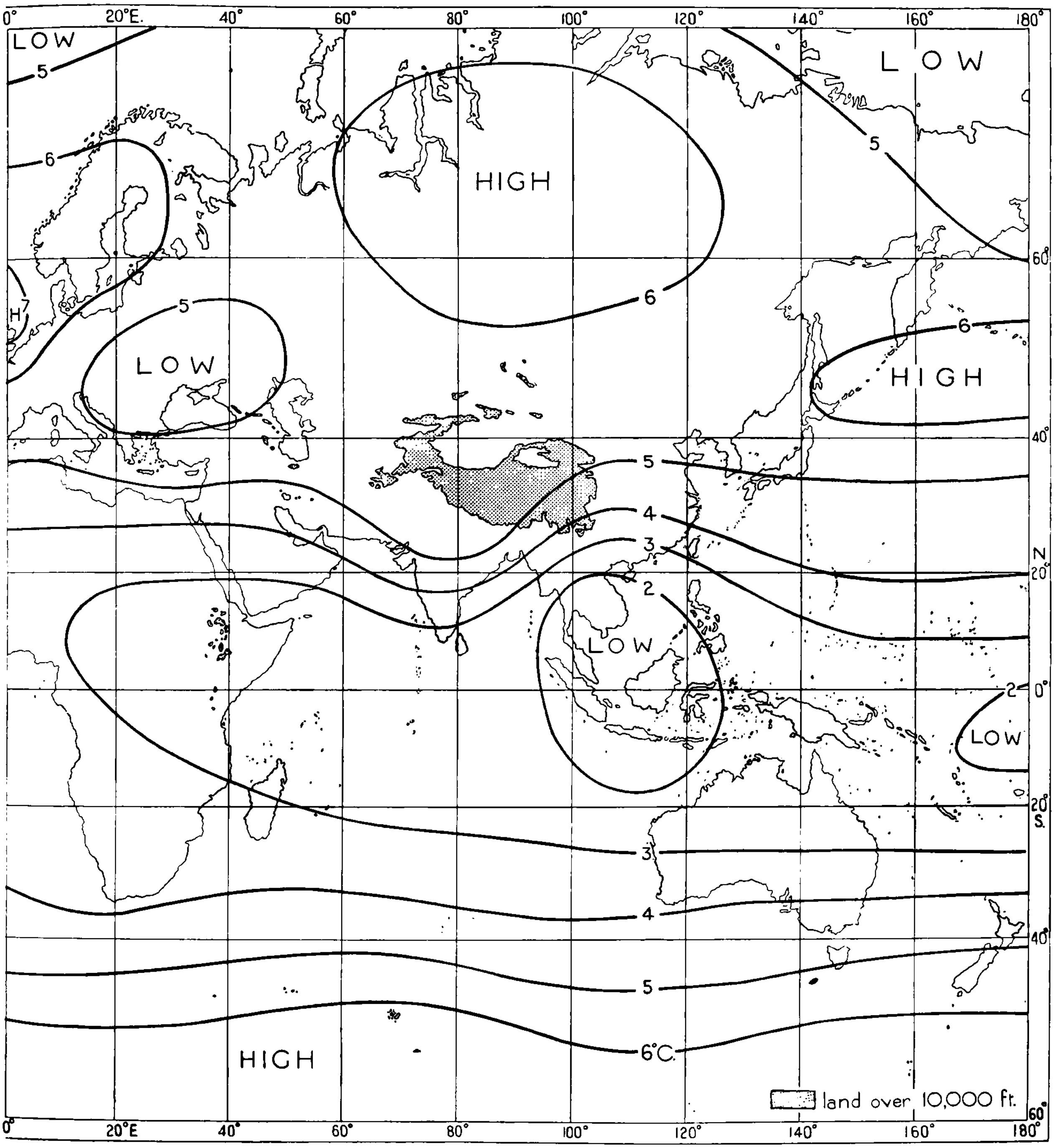

PLATE 56—CONTINUED

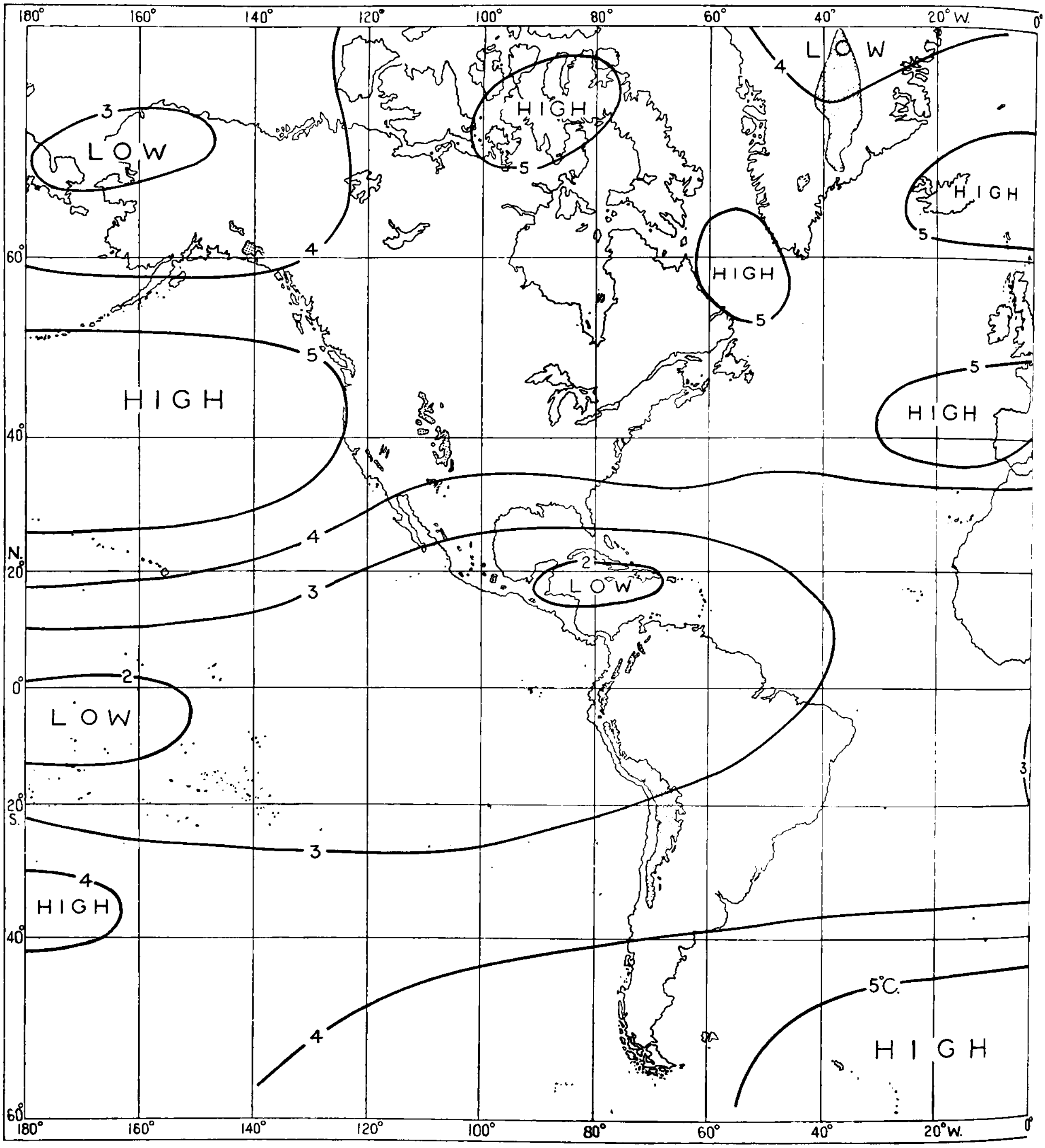

PLATE 57—STANDARD DEVIATION OF TEMPERATURE AT 150 MB. IN APRIL

I.C.A.N. height = 44,625 ft. = 13,602 m.

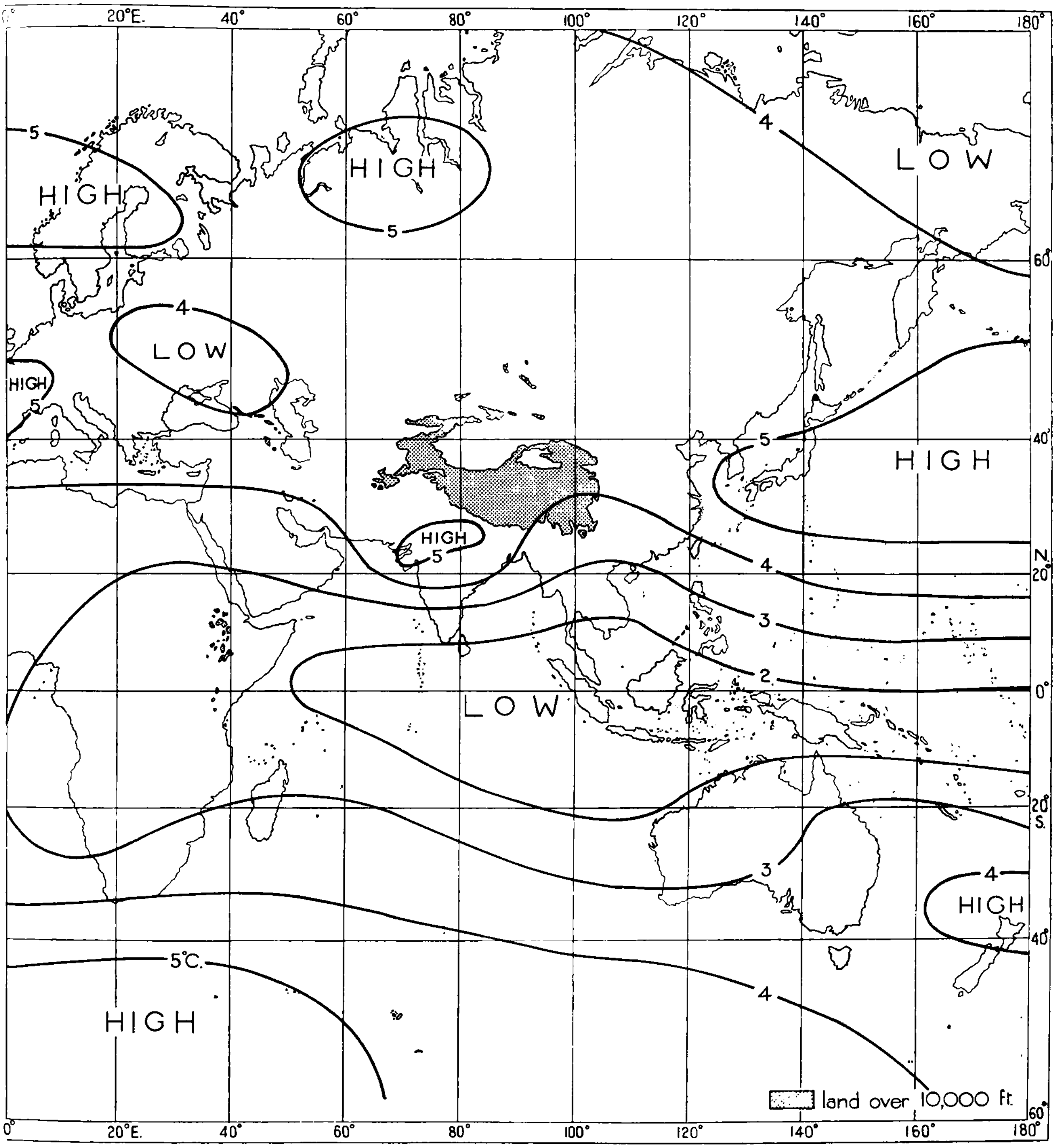

PLATE 57—CONTINUED

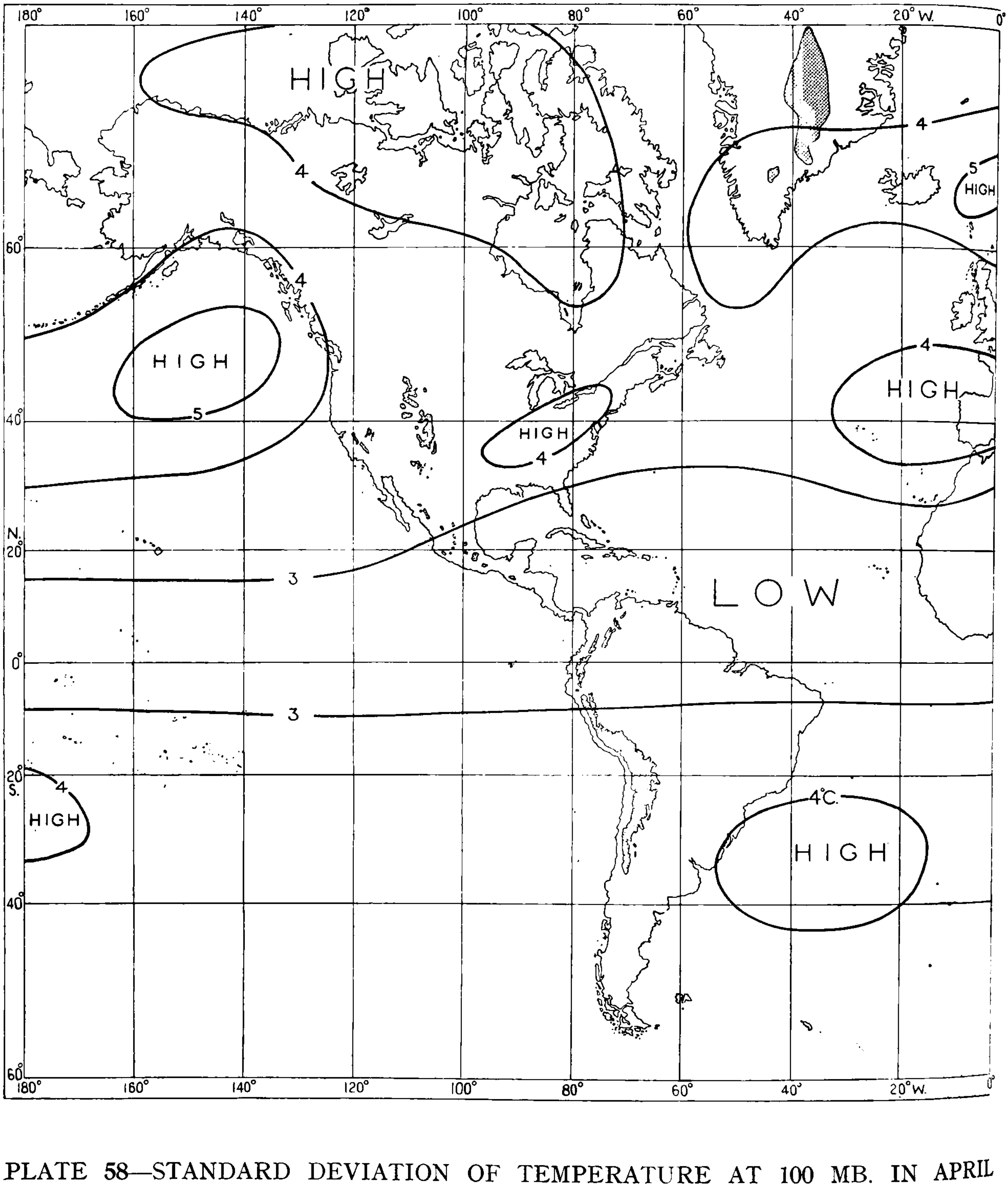

PLATE 58—STANDARD DEVIATION OF TEMPERATURE AT 100 MB. IN APRIL
I.C.A.N. height = 53,054 ft. = 16,170 m.

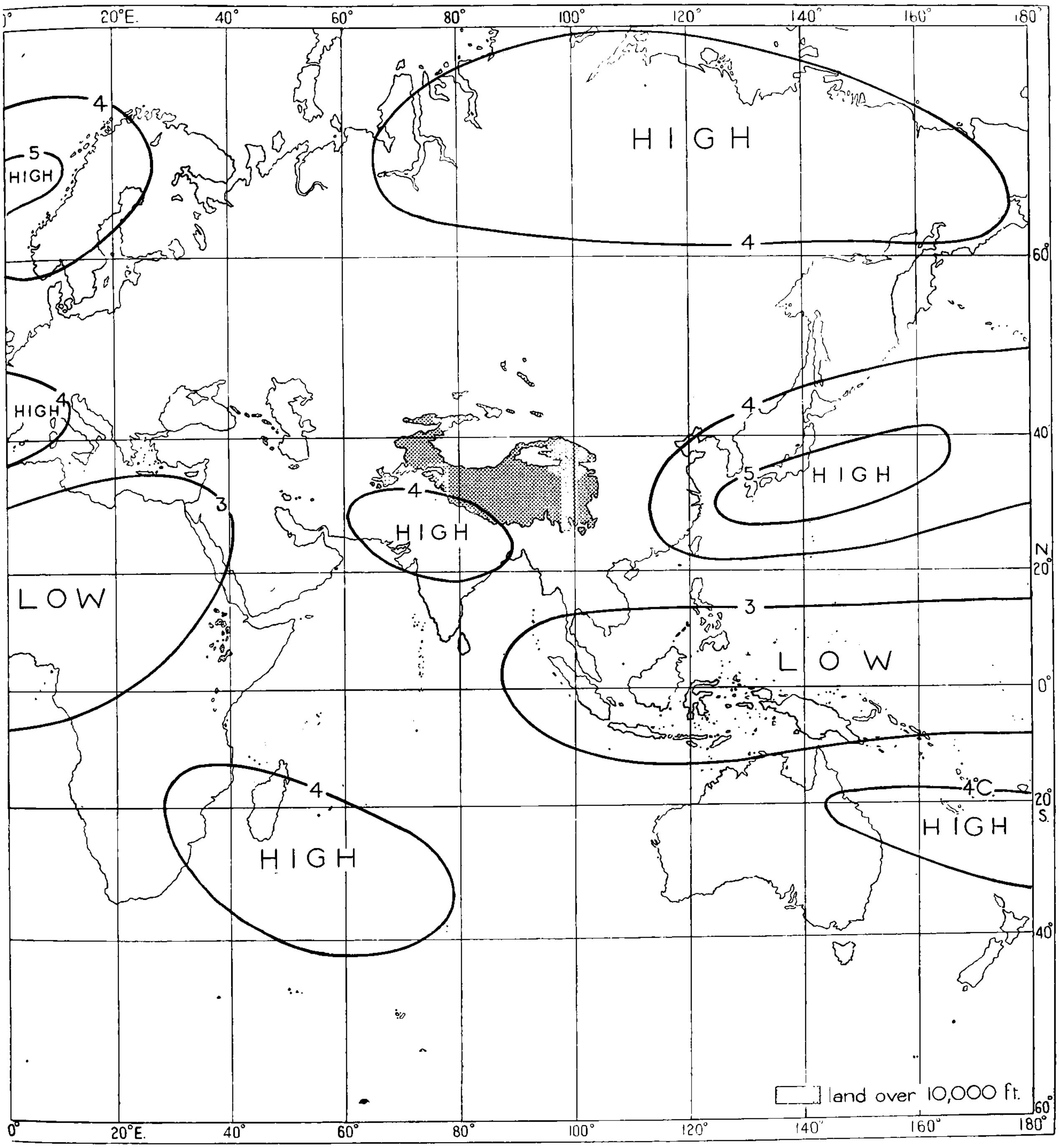

PLATE 58—CONTINUED

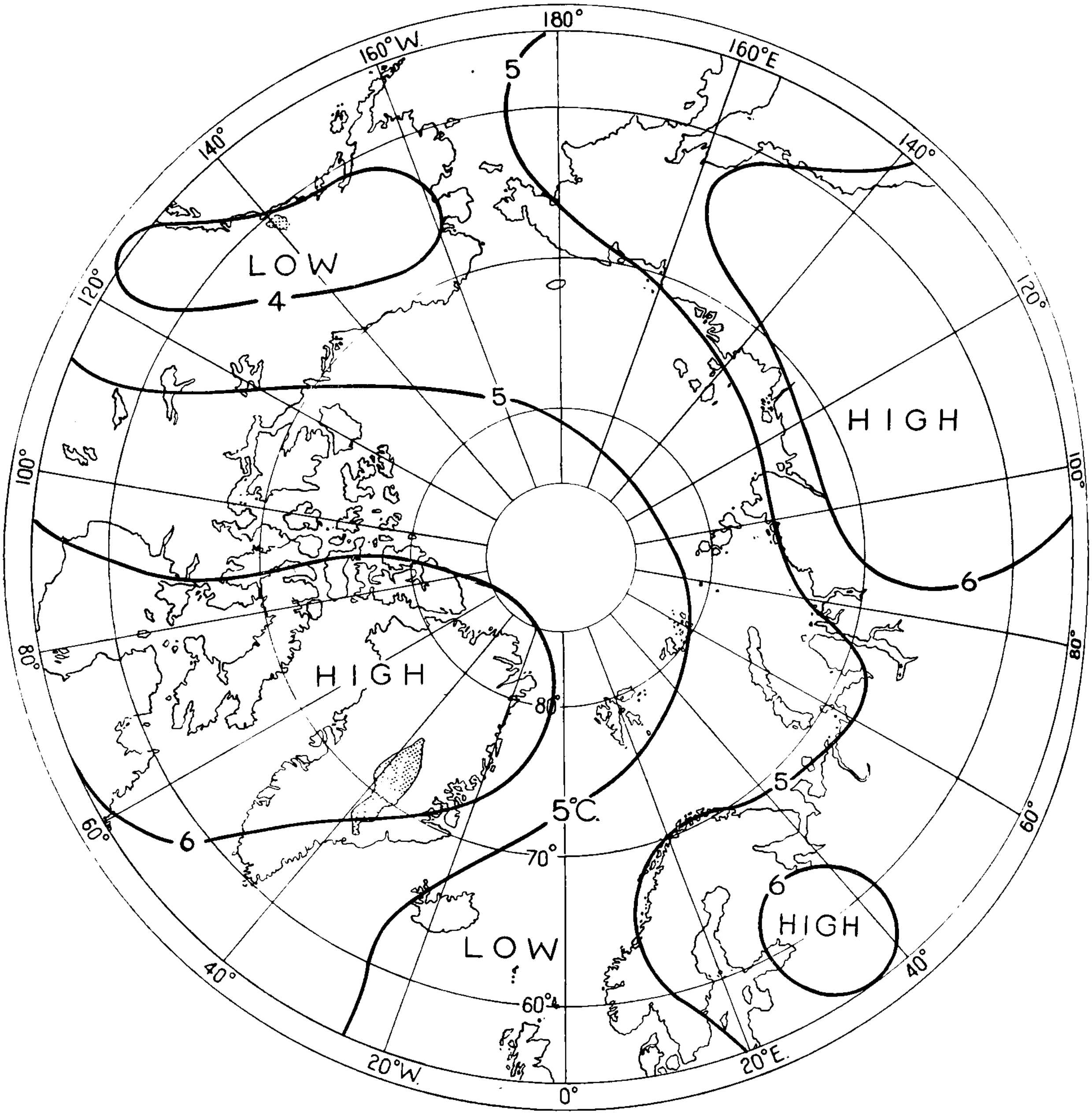

PLATE 59A—STANDARD DEVIATION OF TEMPERATURE AT 700 MB. IN APRIL

I.C.A.N. height = 9,876 ft. = 3,010 m.

Land over 10,000 feet is represented by shading.

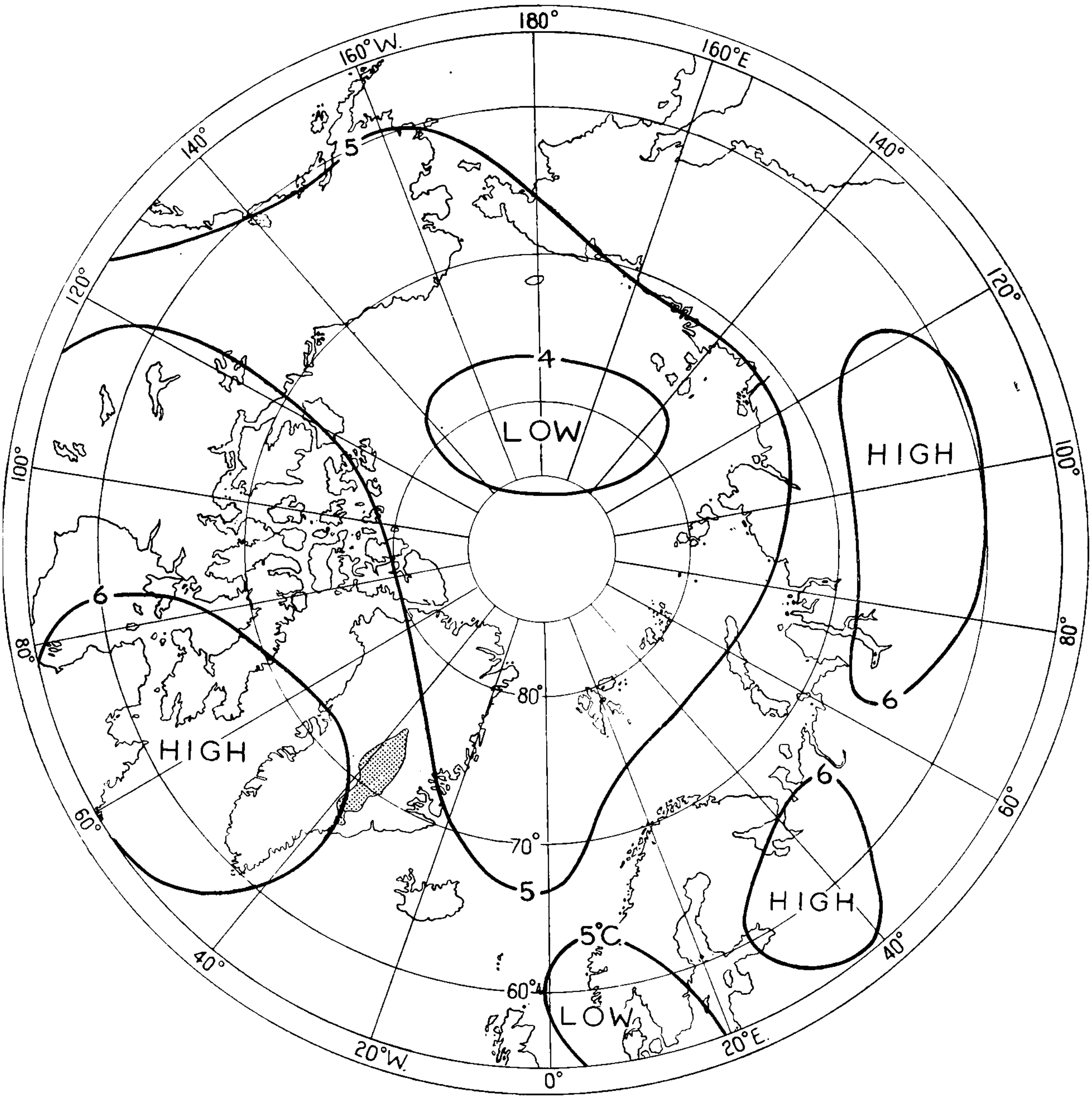

PLATE 59B—STANDARD DEVIATION OF TEMPERATURE AT 500 MB. IN APRIL

I.C.A.N. height = 18,278 ft. = 5,571 m.

Land over 10,000 feet is represented by shading.

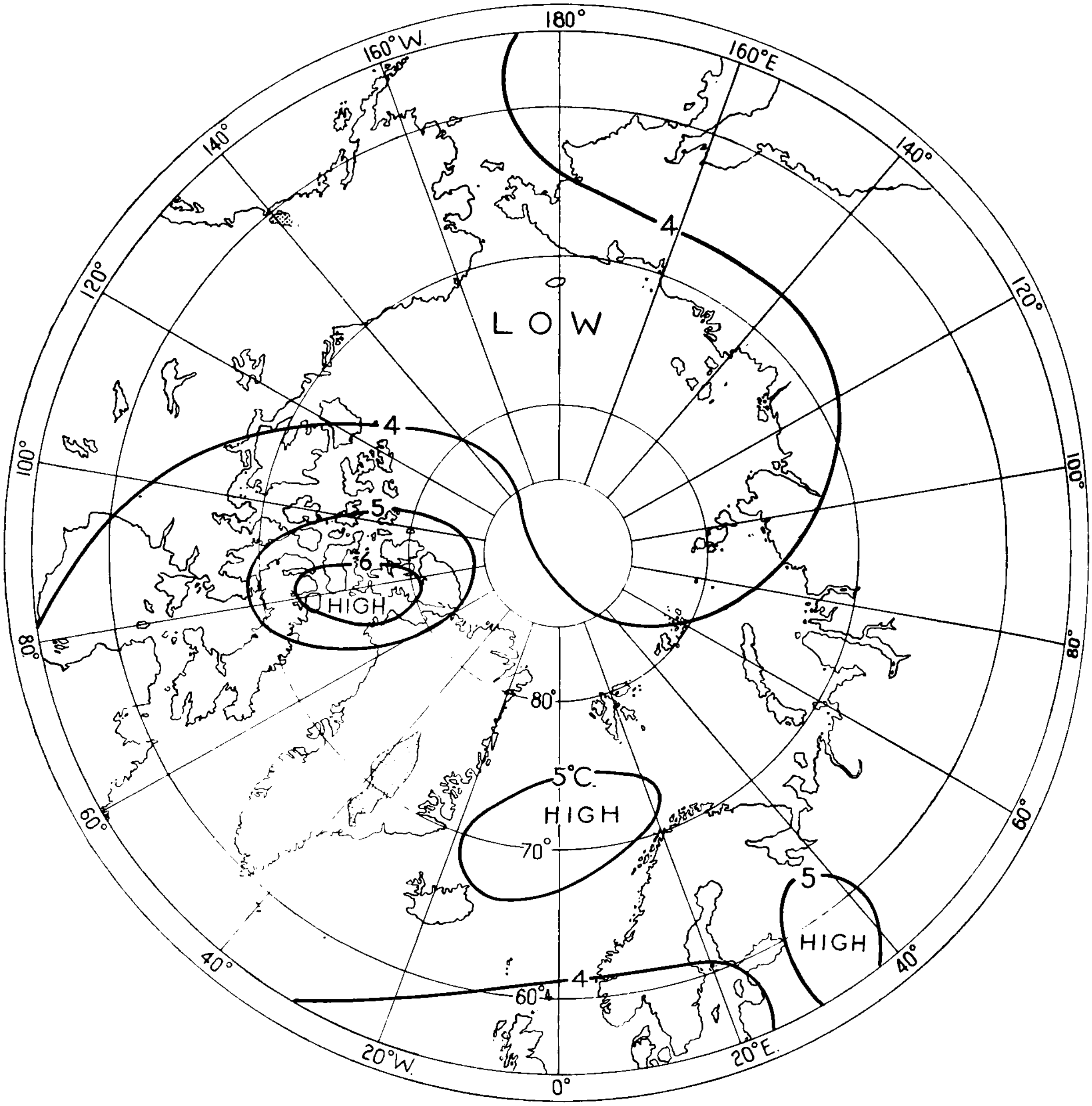

PLATE 59c—STANDARD DEVIATION OF TEMPERATURE AT 300 MB. IN APRIL

I.C.A.N. height = 30,059 ft. = 9,162 m.

Land over 10,000 feet is represented by shading.

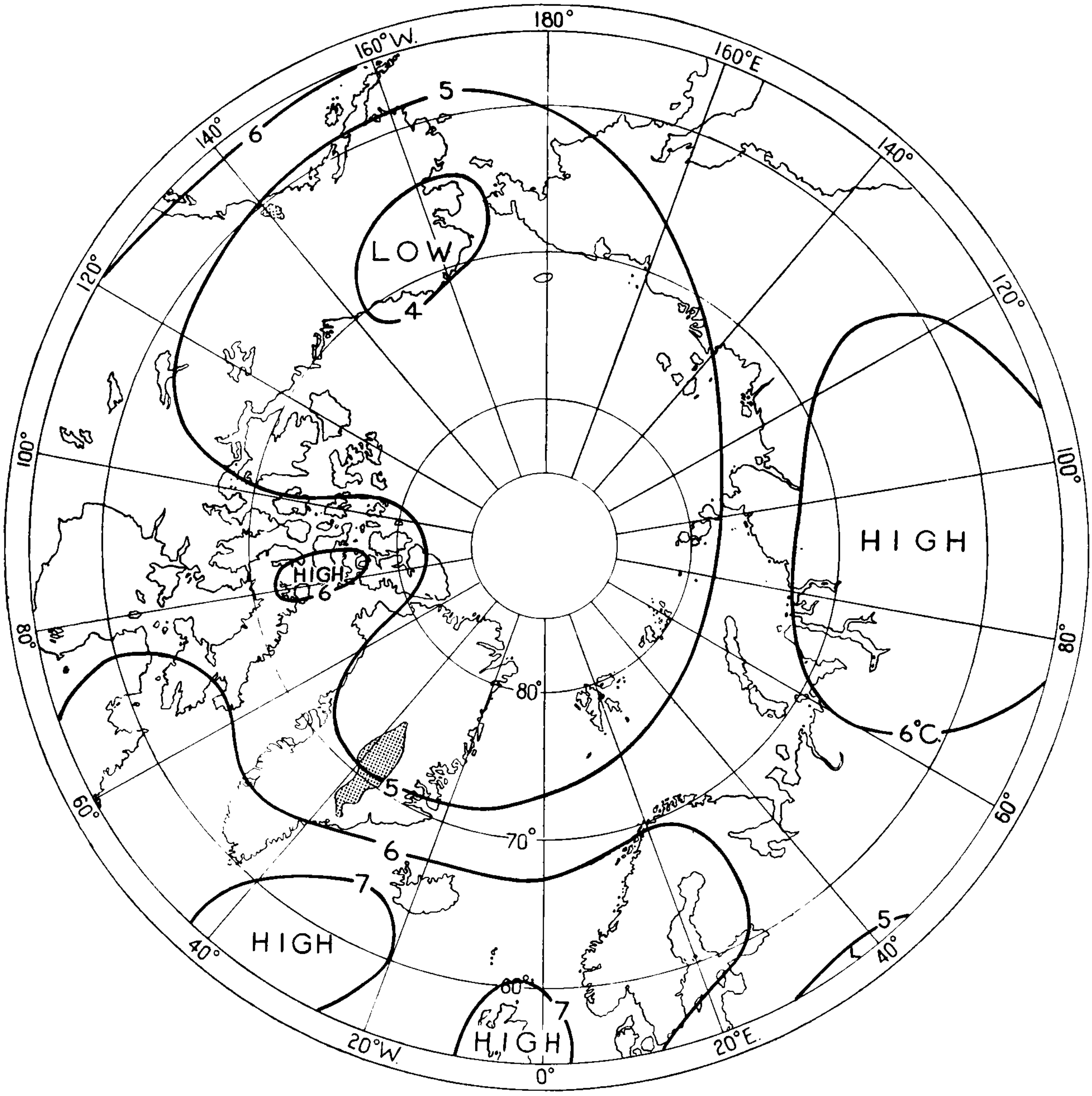

PLATE 60A—STANDARD DEVIATION OF TEMPERATURE AT 200 MB. IN APRIL

I.C.A.N. height = 38,664 ft. = 11,779 m.

Land over 10,000 feet is represented by shading.

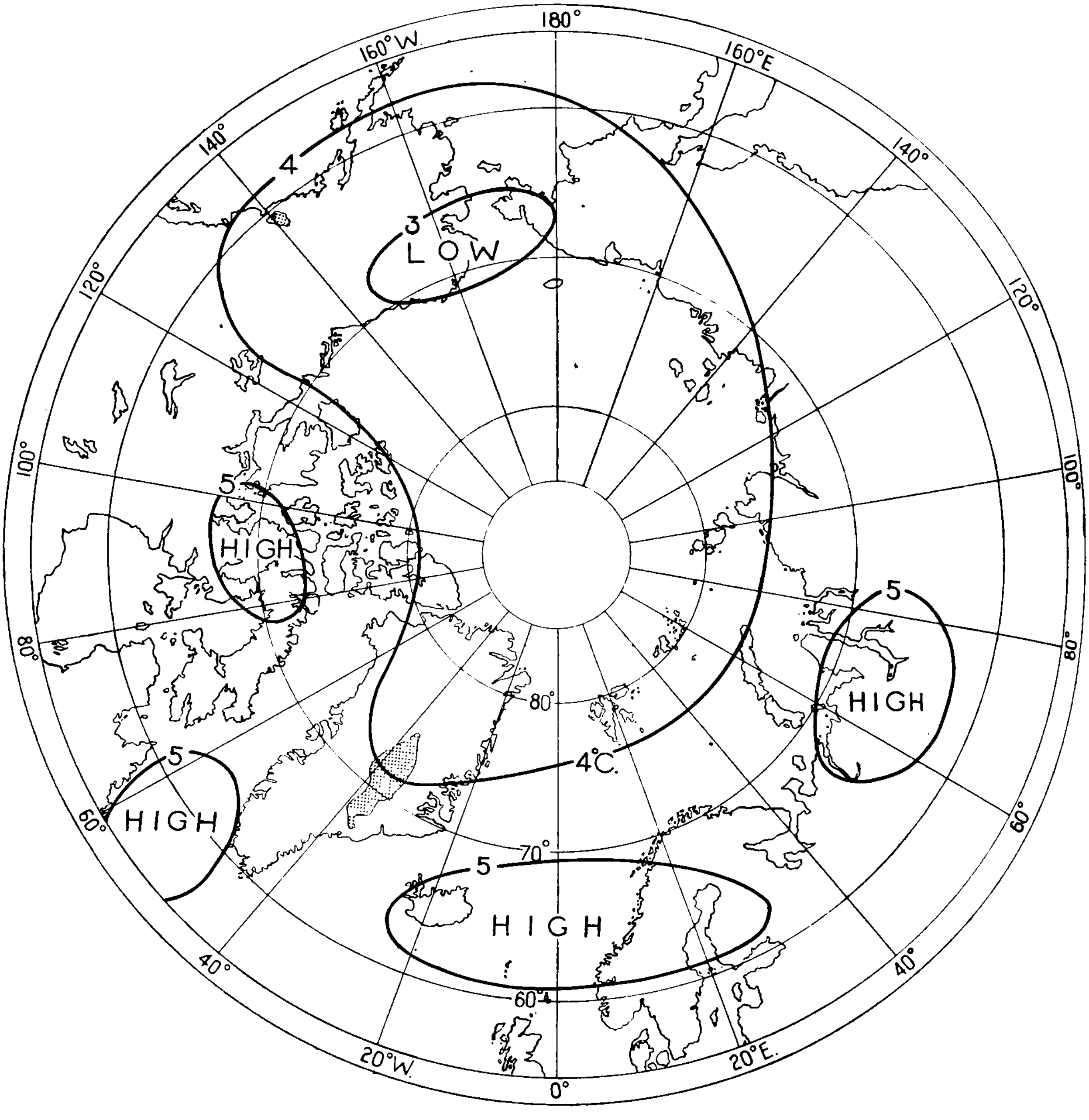

PLATE 60B—STANDARD DEVIATION OF TEMPERATURE AT 150 MB. IN APRIL

I.C.A.N. height = 44,625 ft. = 13,602 m.

Land over 10,000 feet is represented by shading.

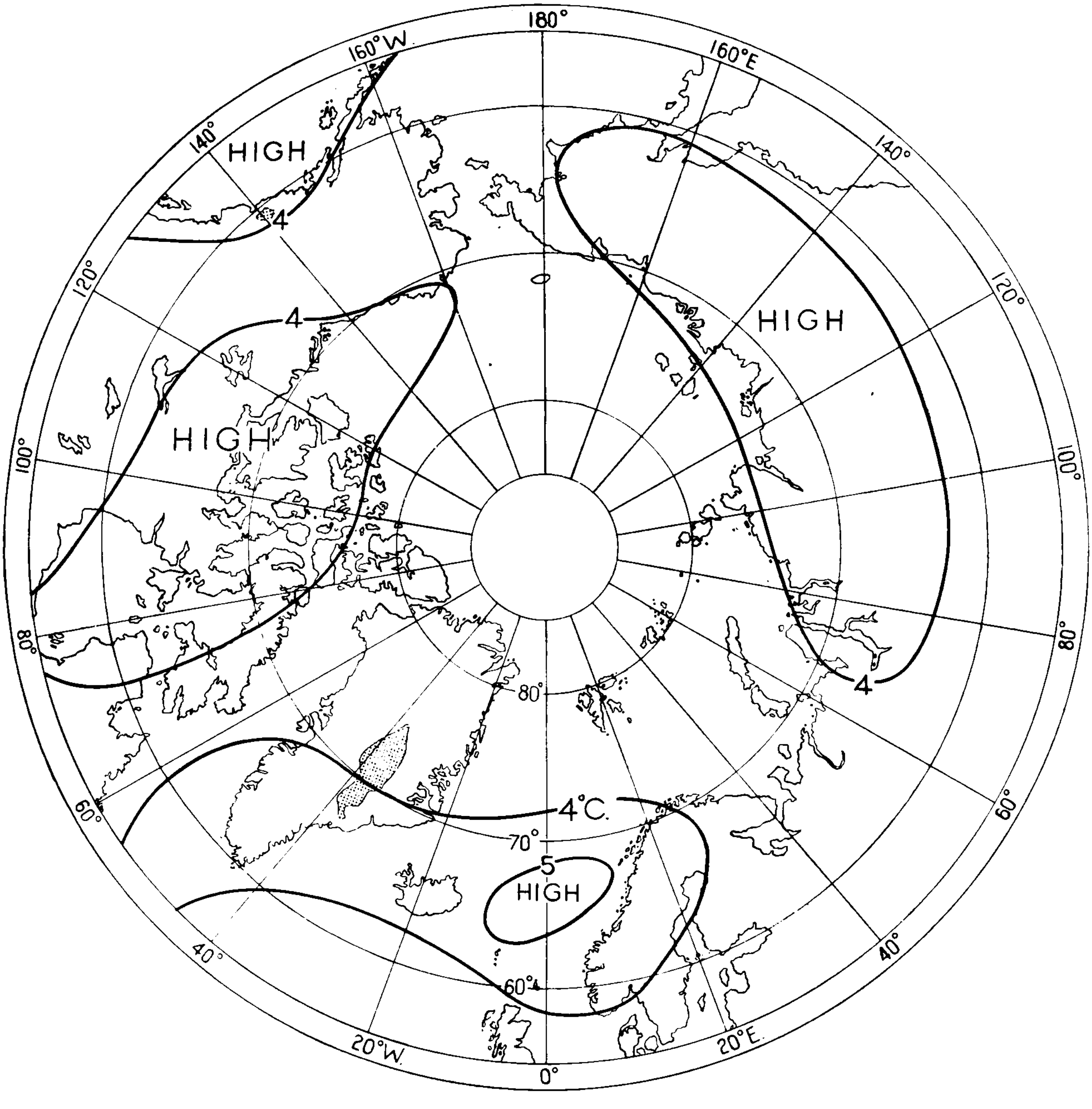

PLATE 60c—STANDARD DEVIATION OF TEMPERATURE AT 100 MB. IN APRIL

I.C.A.N. height = 53,054 ft. = 16,170 m.

Land over 10,000 feet is represented by shading.

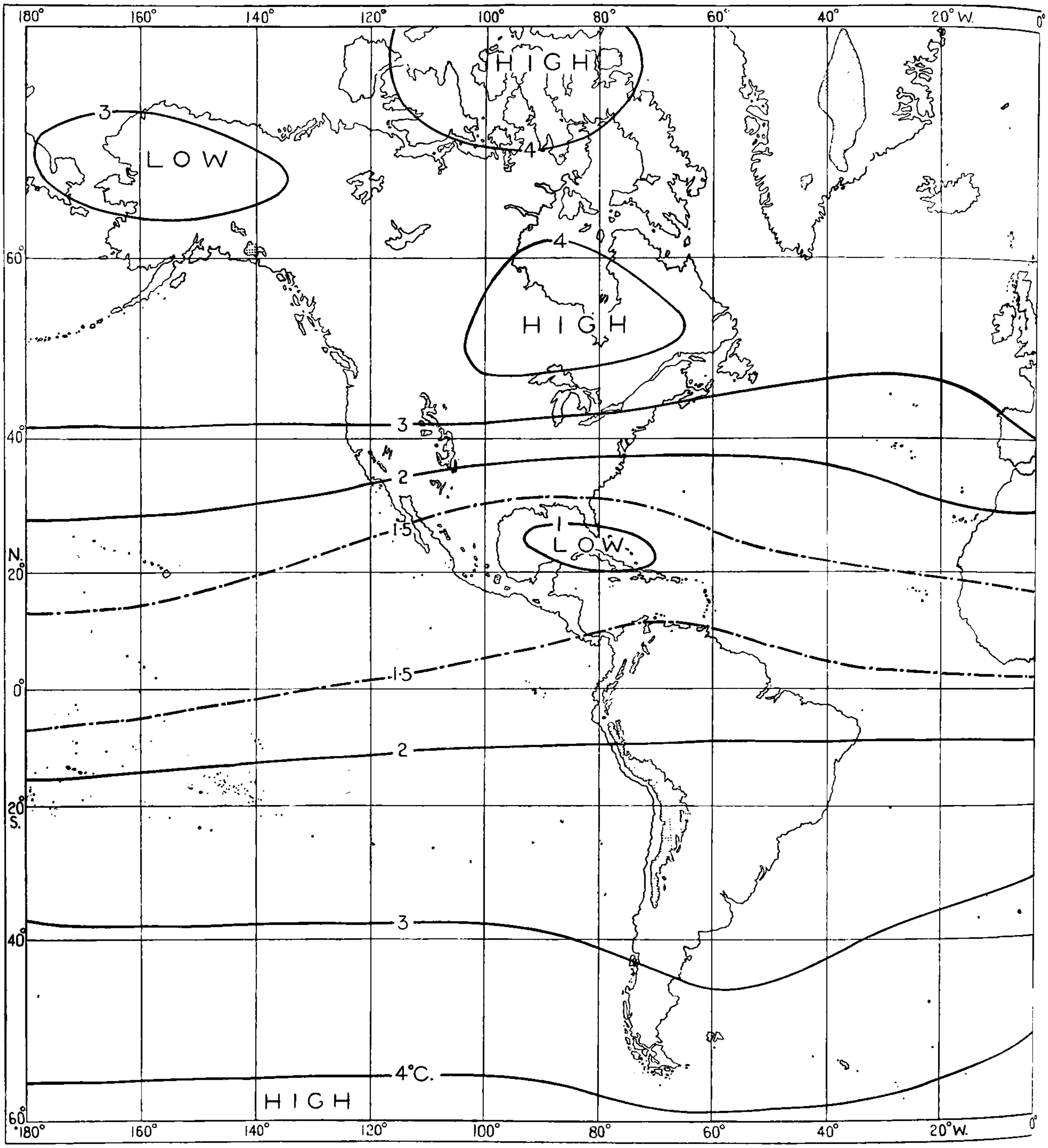

PLATE 61—STANDARD DEVIATION OF TEMPERATURE AT 700 MB. IN JULY

I.C.A.N. height = 9,876 ft. = 3,010 m.

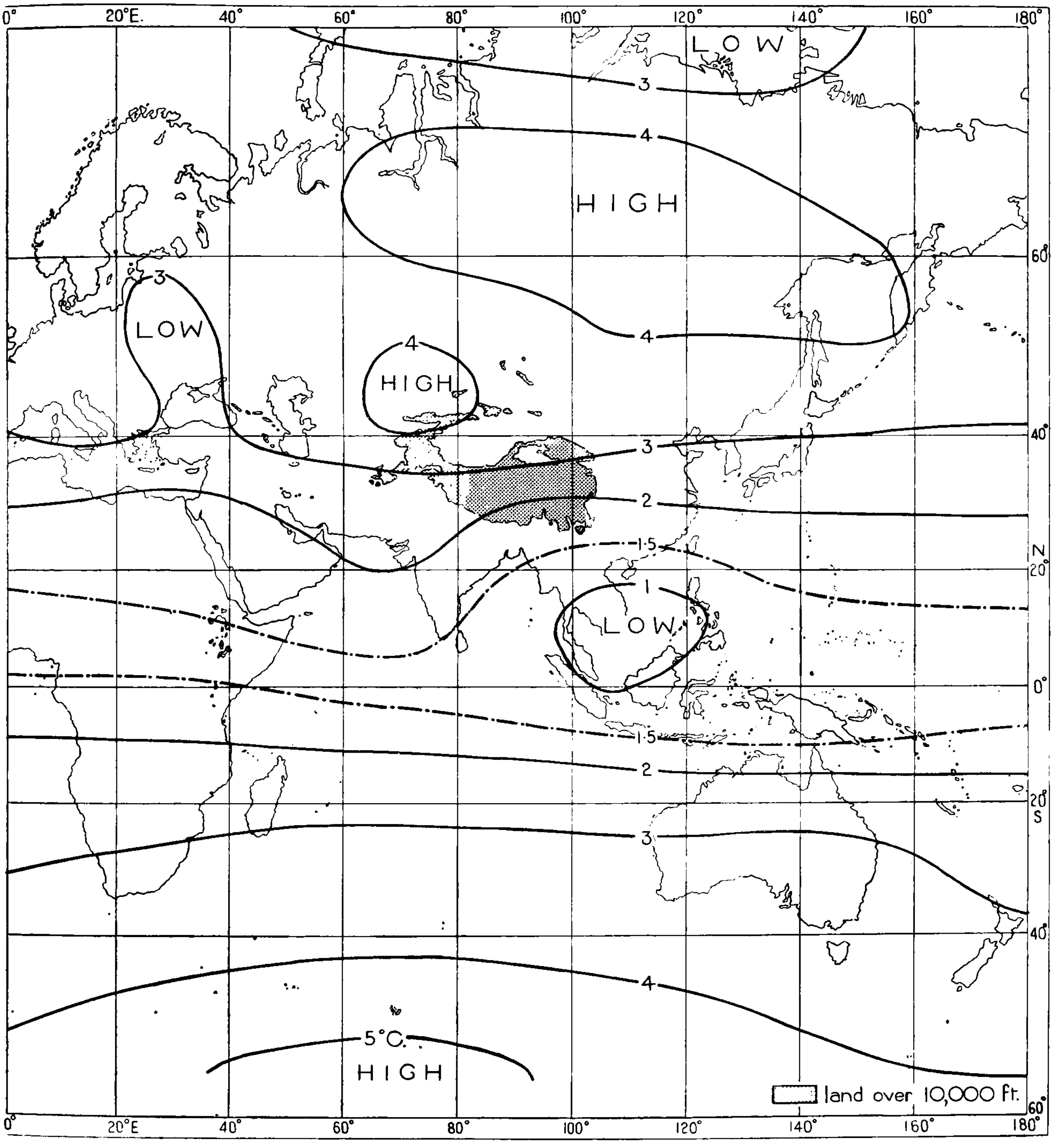

PLATE 61—continued

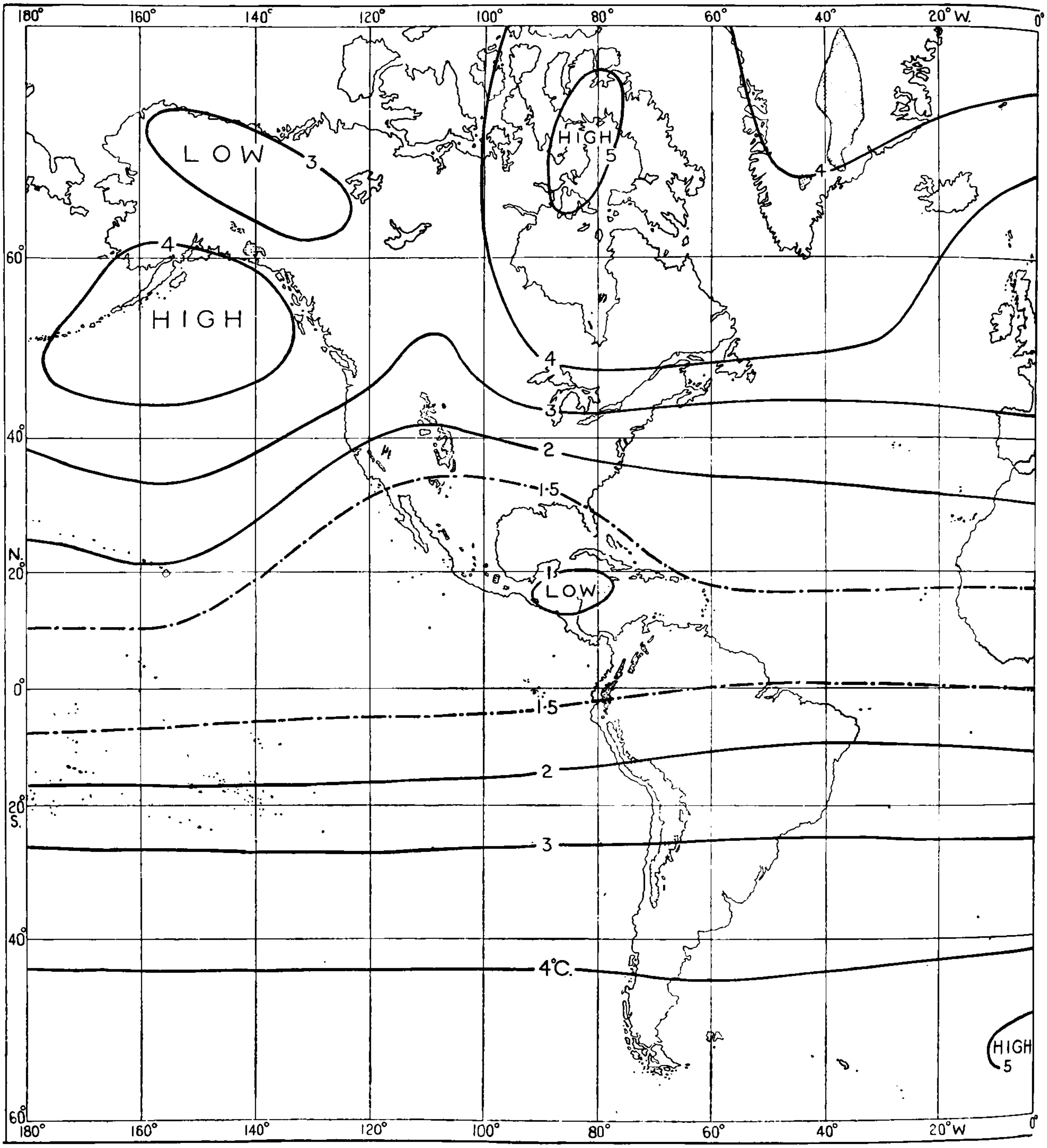

PLATE 62—STANDARD DEVIATION OF TEMPERATURE AT 500 MB. IN JULY

I.C.A.N. height = 18,278 ft. = 5,571 m.

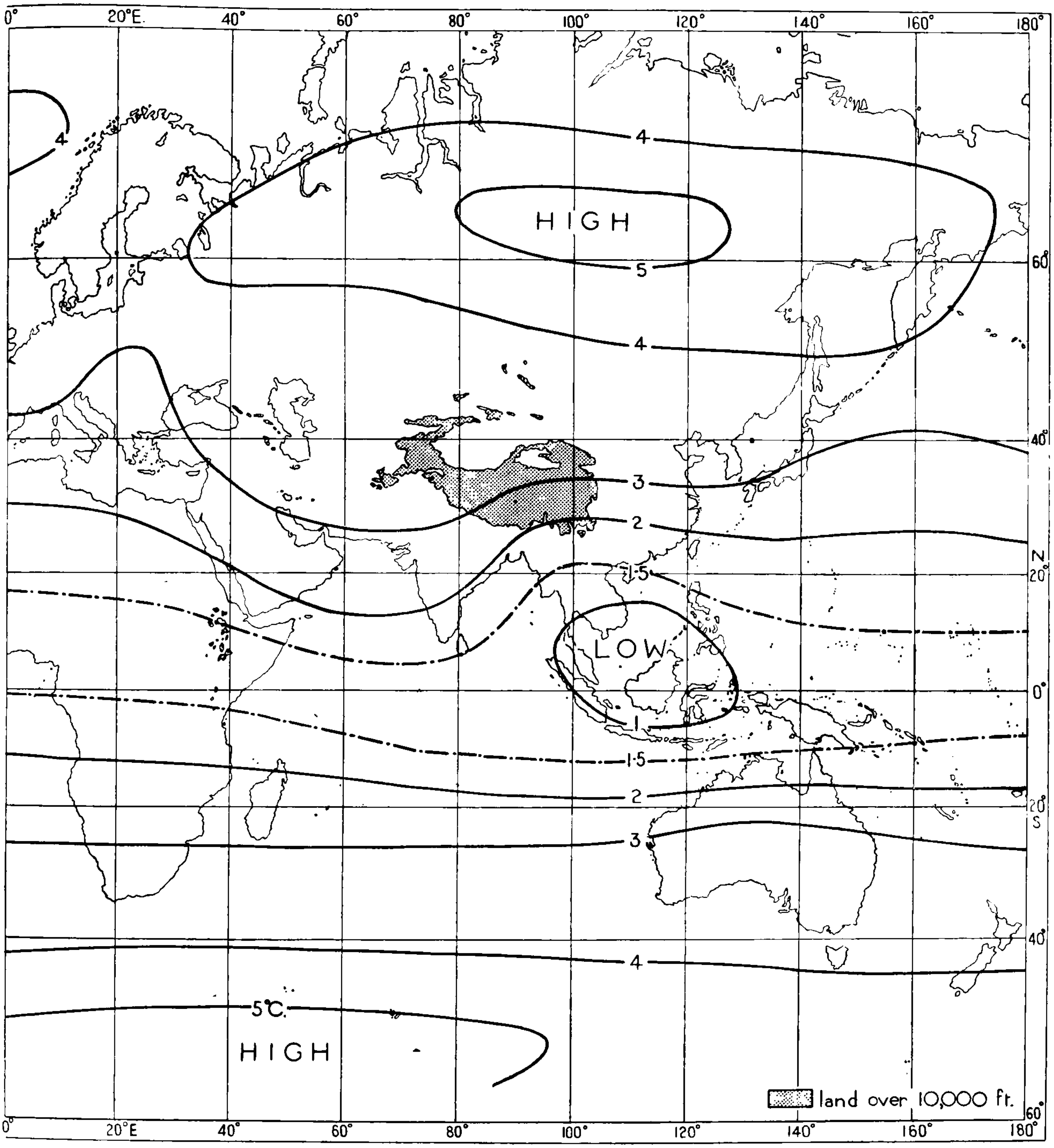

PLATE 62—CONTINUED

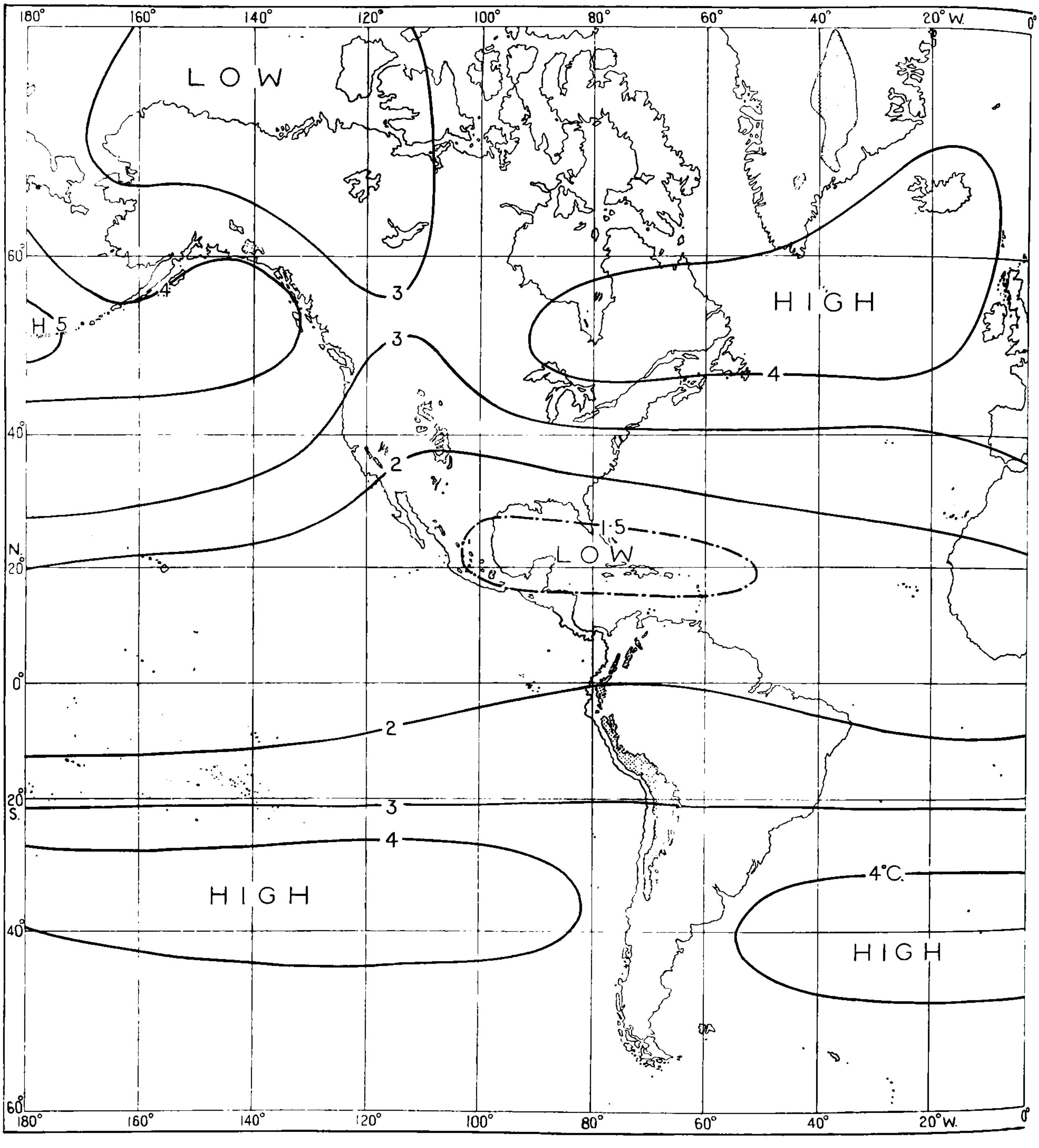

PLATE 63—STANDARD DEVIATION OF TEMPERATURE AT 300 MB. IN JULY

I.C.A.N. height = 30,059 ft. = 9,162 m.

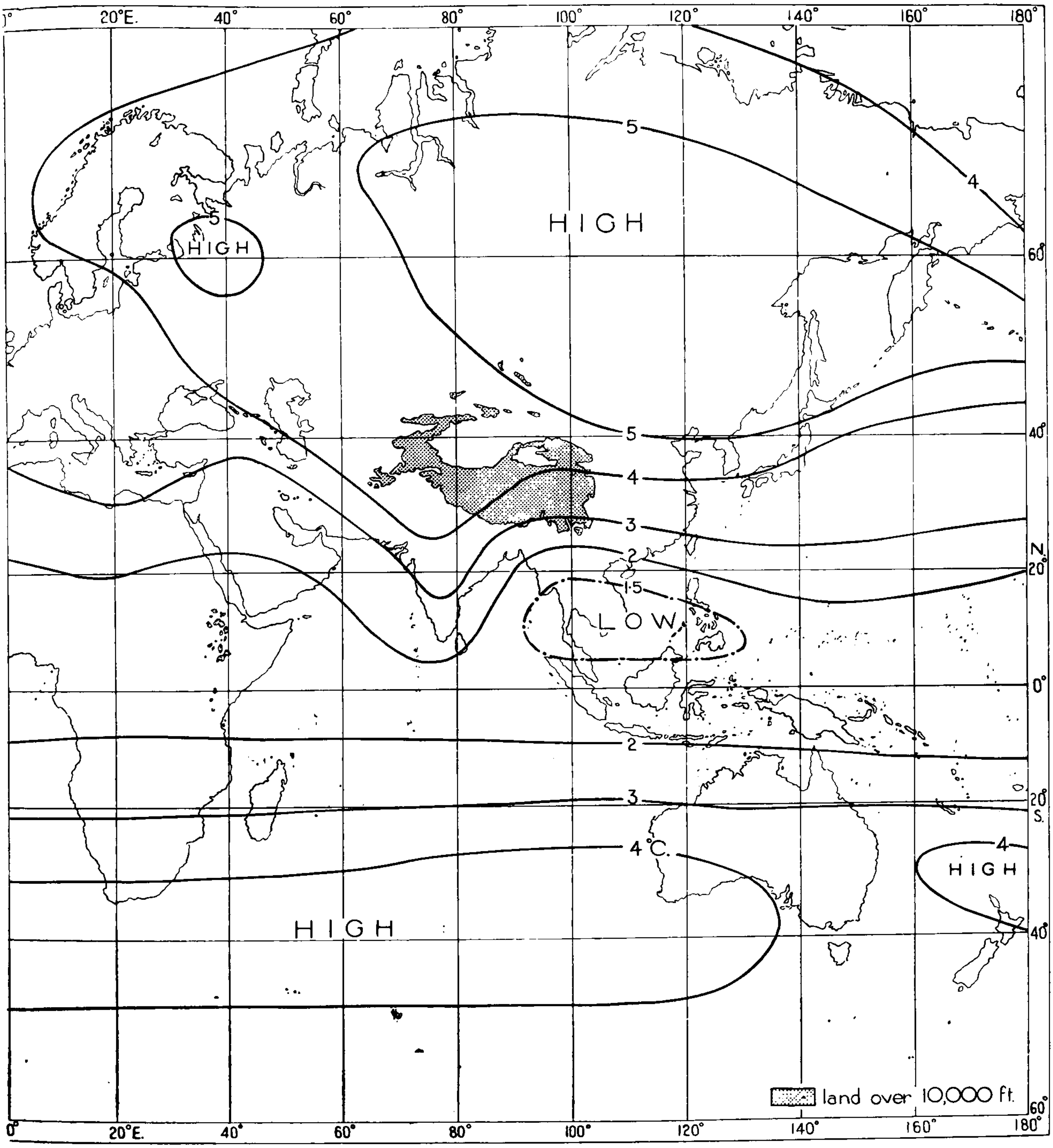

PLATE 63—CONTINUED

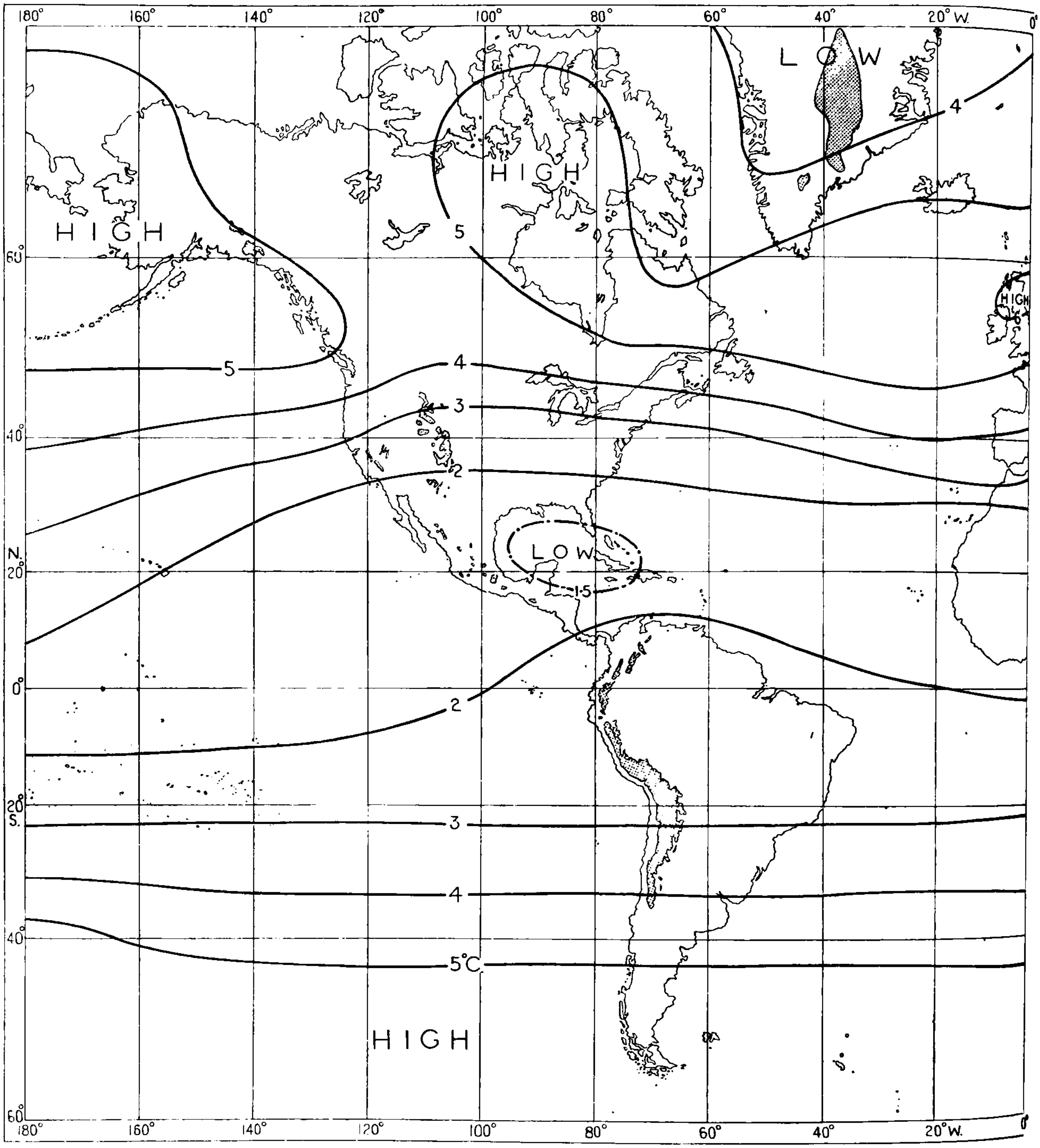

PLATE 64—STANDARD DEVIATION OF TEMPERATURE AT 200 MB. IN JULY
I.C.A.N. height = 38,664 ft. = 11,779 m.

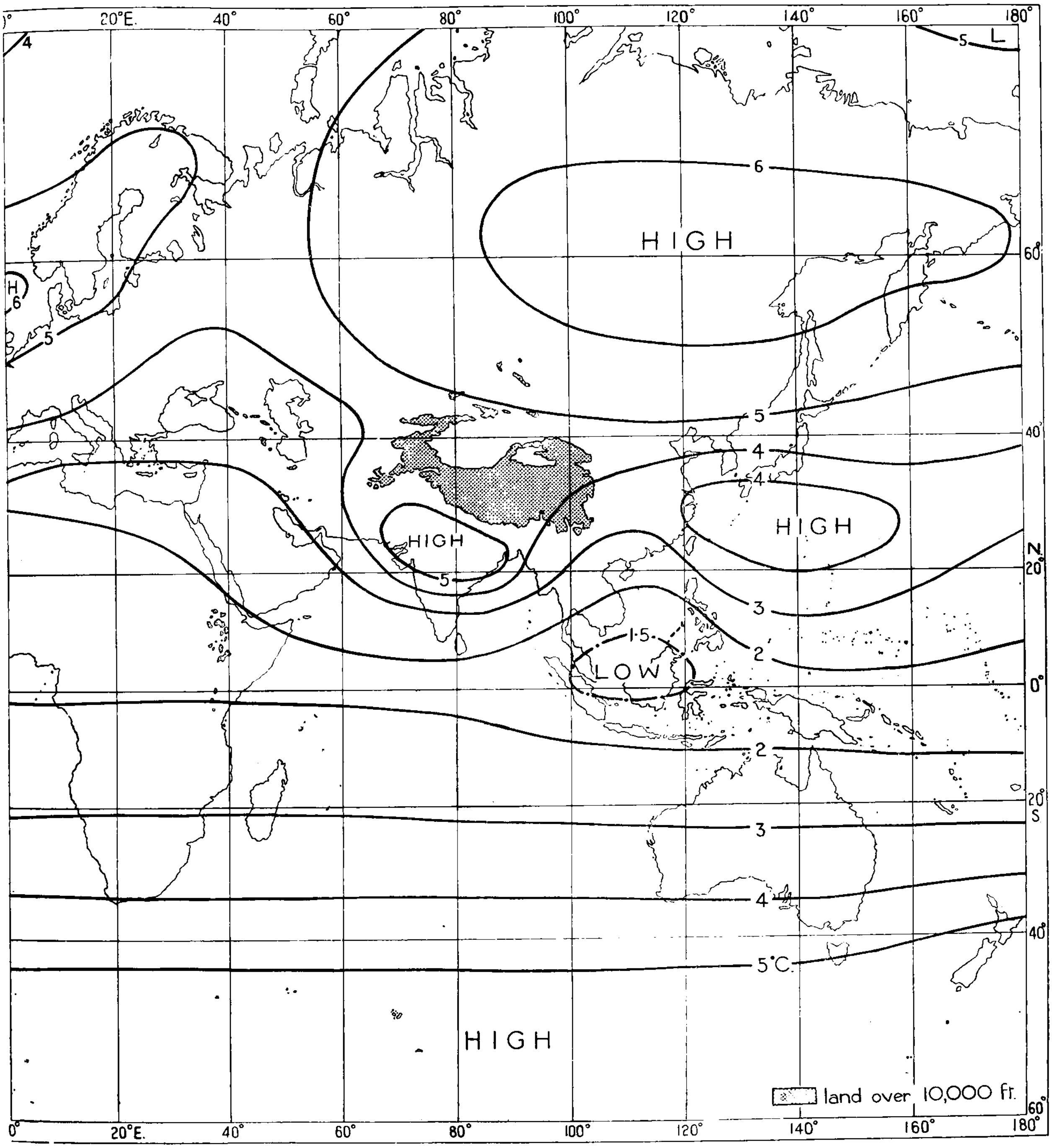

PLATE 64—CONTINUED

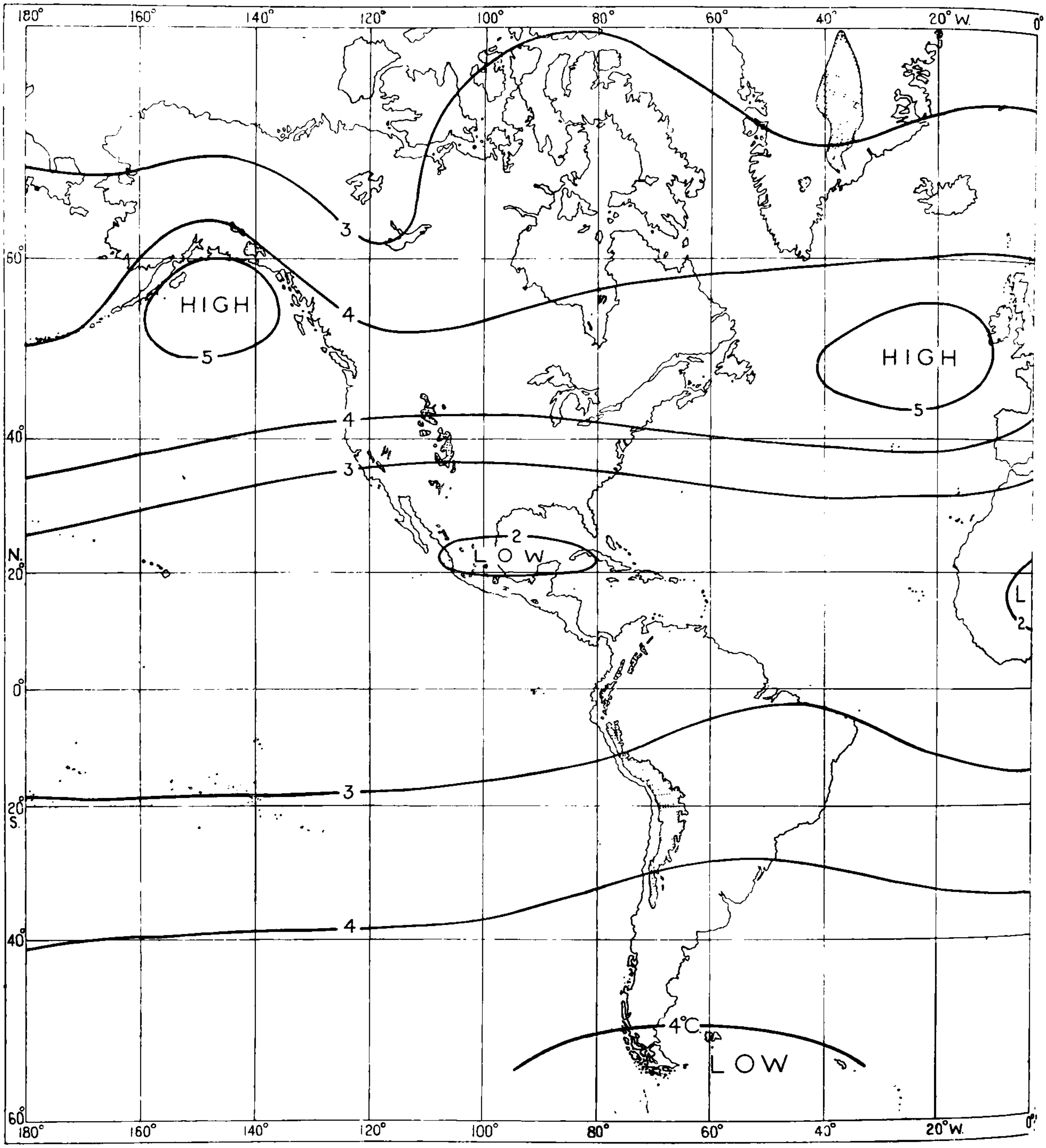

PLATE 65—STANDARD DEVIATION OF TEMPERATURE AT 150 MB. IN JULY

I.C.A.N. height = 44,625 ft. = 13,602 m.

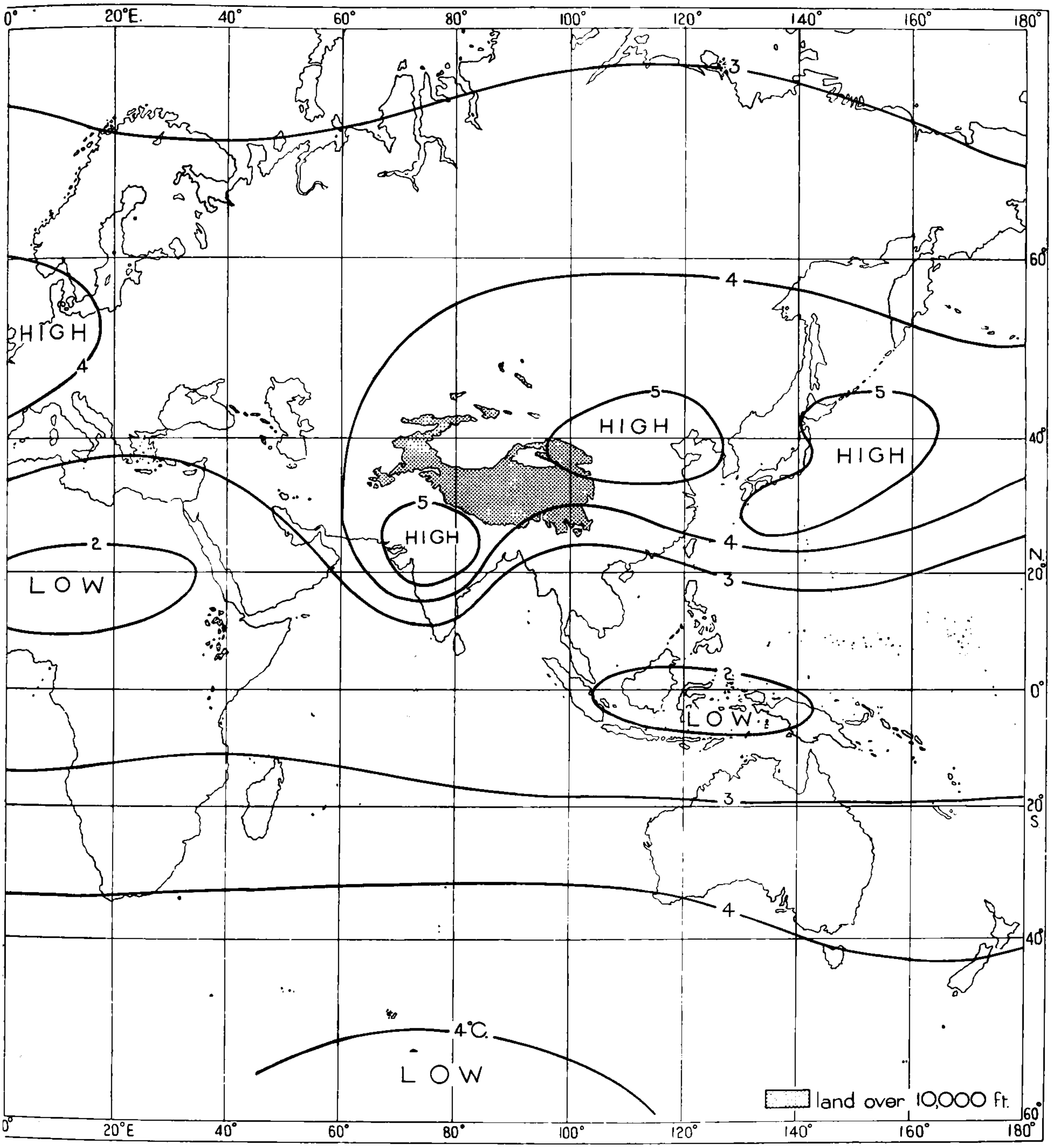

PLATE 65—CONTINUED

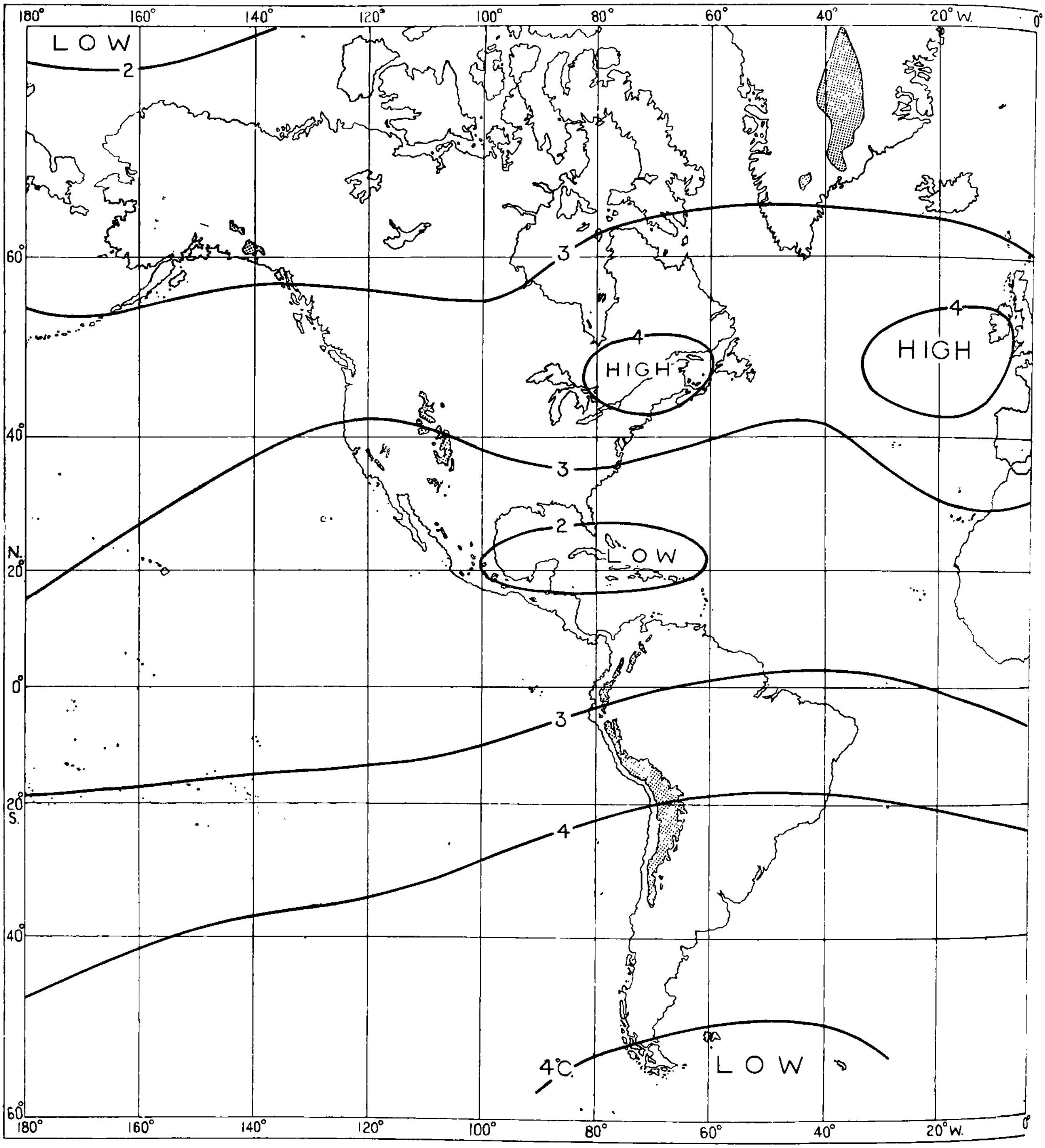

PLATE 66—STANDARD DEVIATION OF TEMPERATURE AT 100 MB. IN JULY
I.C.A.N. height = 53,054 ft. = 16,170 m.

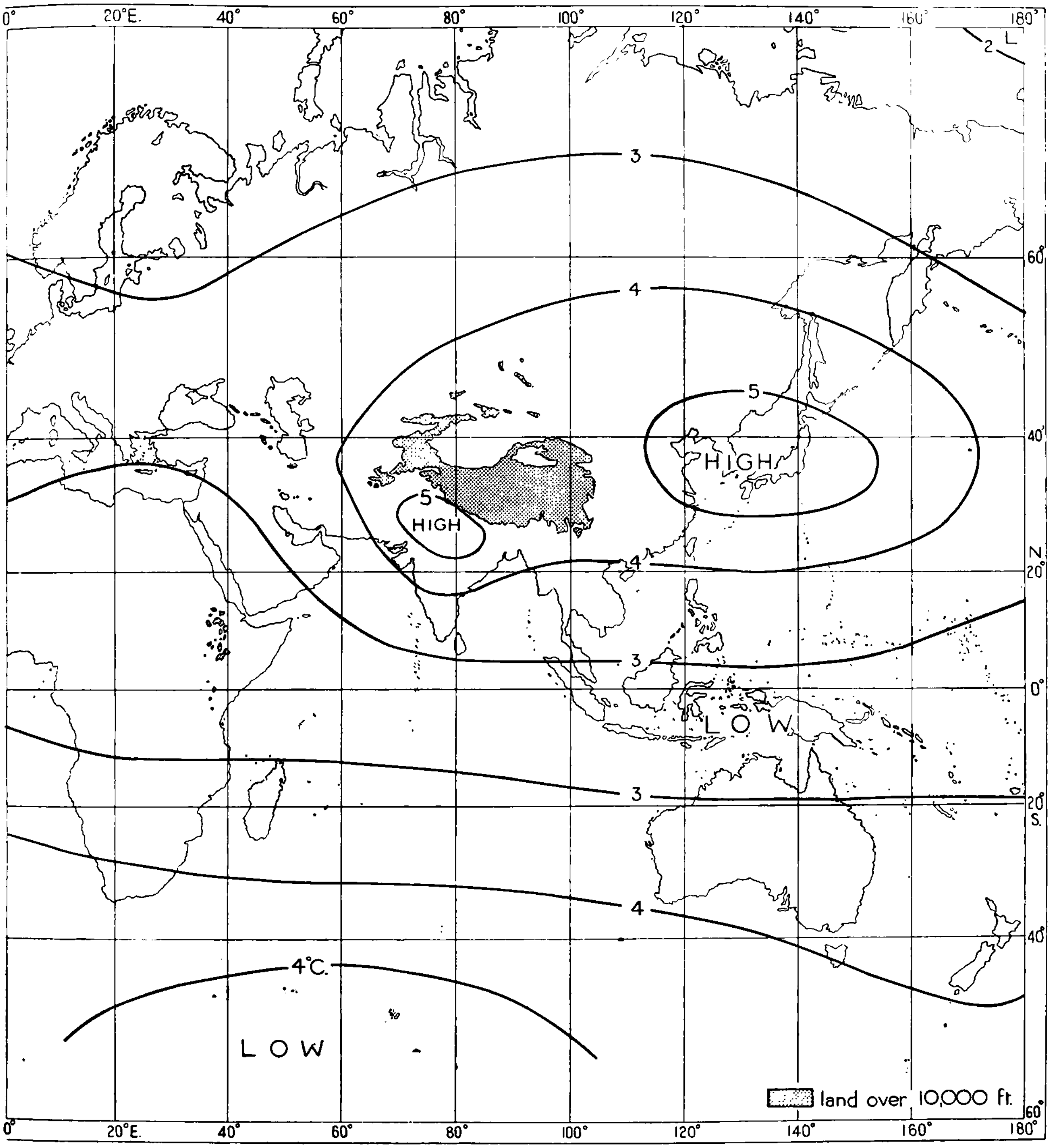

PLATE 66—CONTINUED

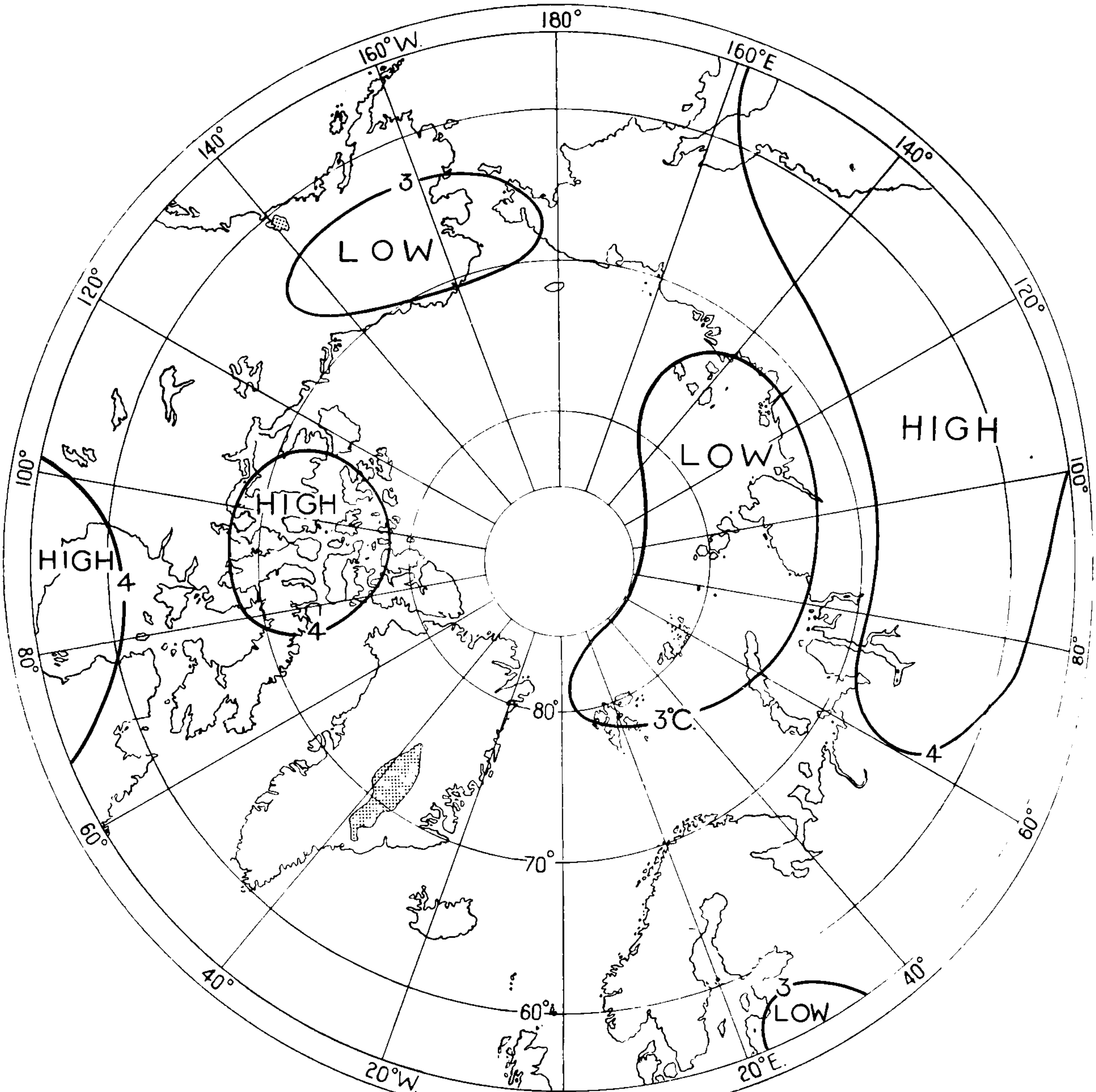

PLATE 67A—STANDARD DEVIATION OF TEMPERATURE AT 700 MB. IN JULY

I.C.A.N. height = 9,876 ft. = 3,010 m.

Land over 10,000 feet is represented by shading.

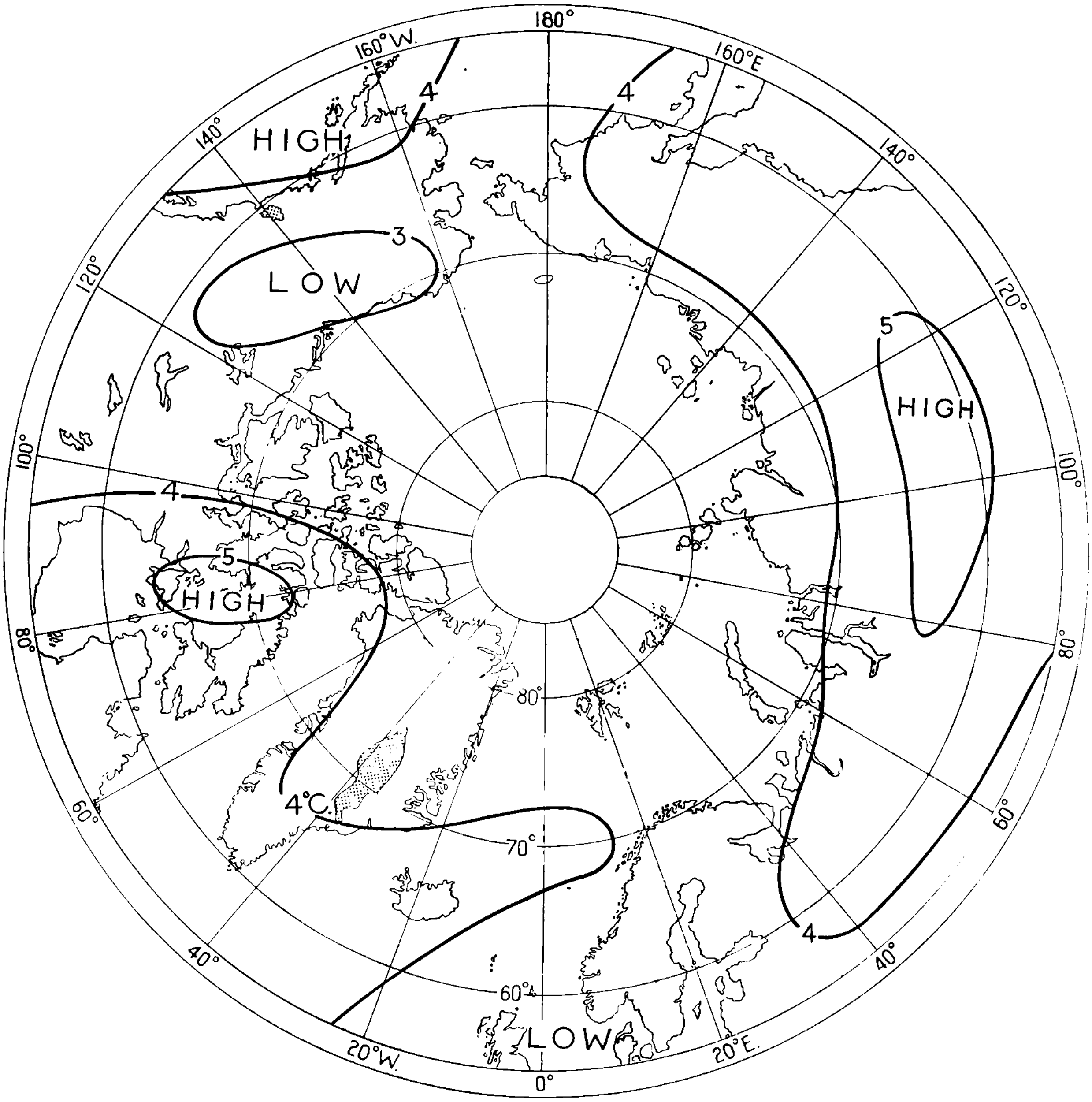

PLATE 67B—STANDARD DEVIATION OF TEMPERATURE AT 500 MB. IN JULY

I.C.A.N. height = 18,278 ft. = 5,571 m.

Land over 10,000 feet is represented by shading.

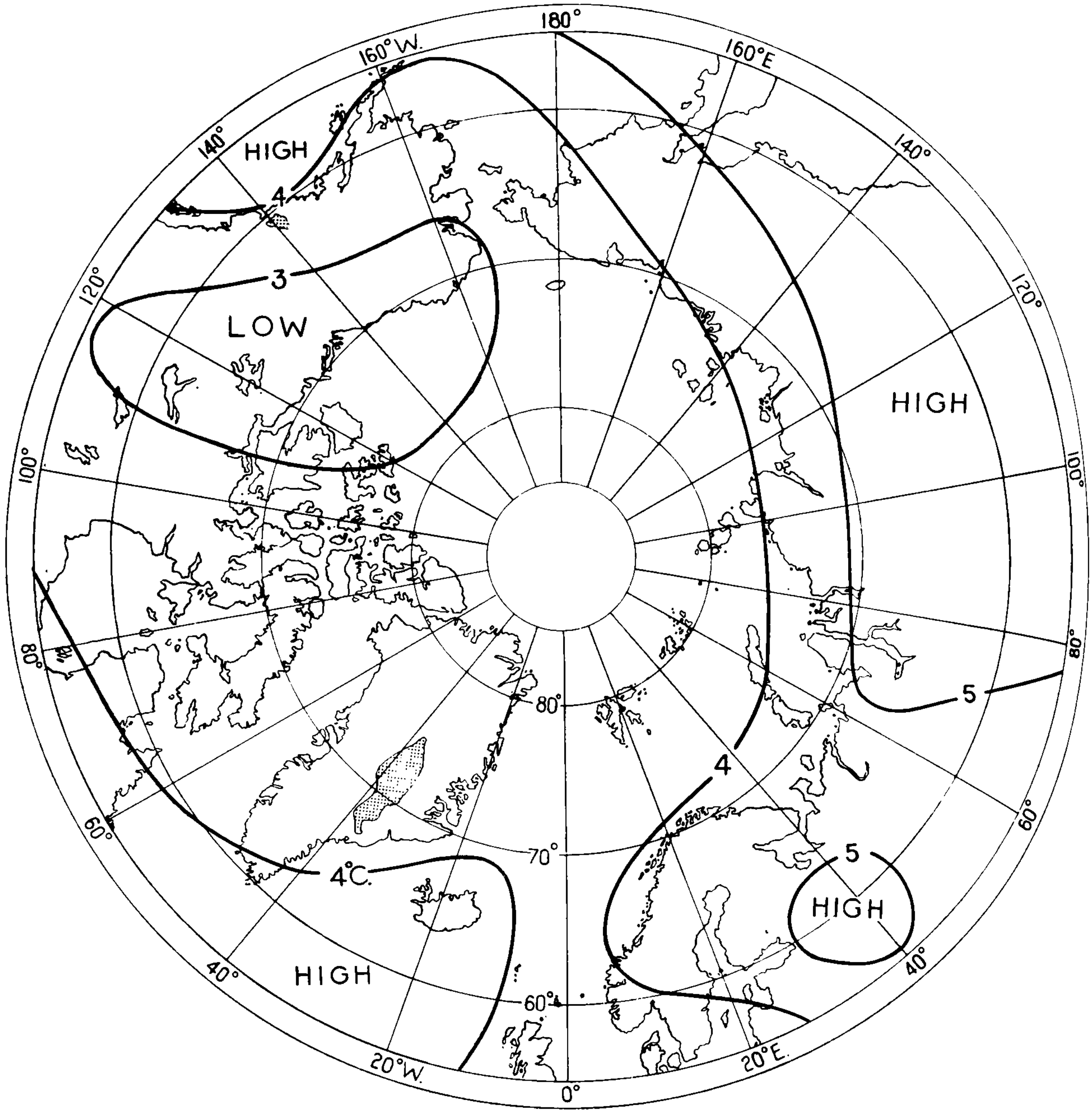

PLATE 67c—STANDARD DEVIATION OF TEMPERATURE AT 300 MB. IN JULY

I.C.A.N. height = 30,059 ft. = 9,162 m.

Land over 10,000 feet is represented by shading.

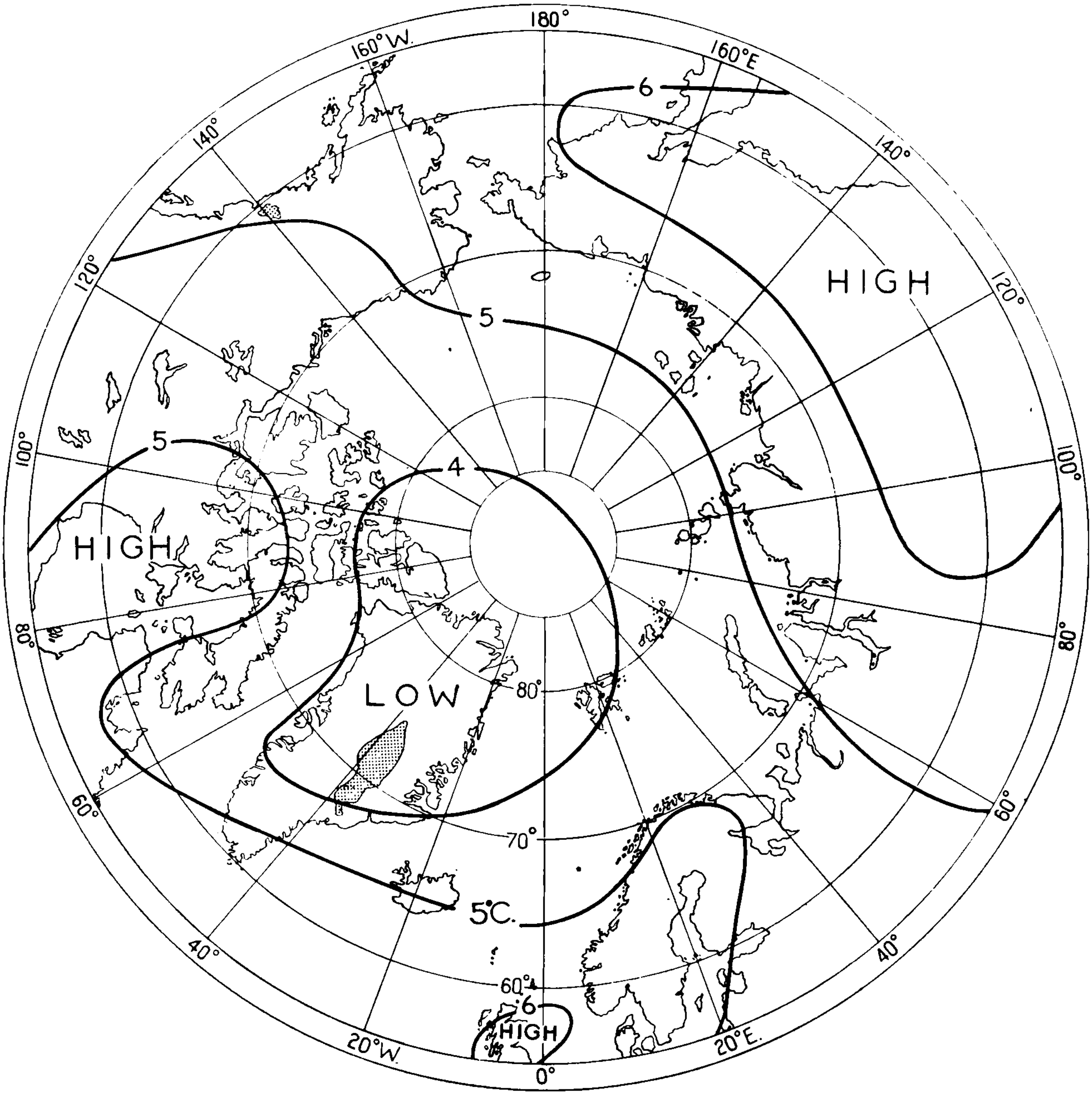

PLATE 68A—STANDARD DEVIATION OF TEMPERATURE AT 200 MB. IN JULY

I.C.A.N. height = 38,664 ft. = 11,779 m.

Land over 10,000 feet is represented by shading.

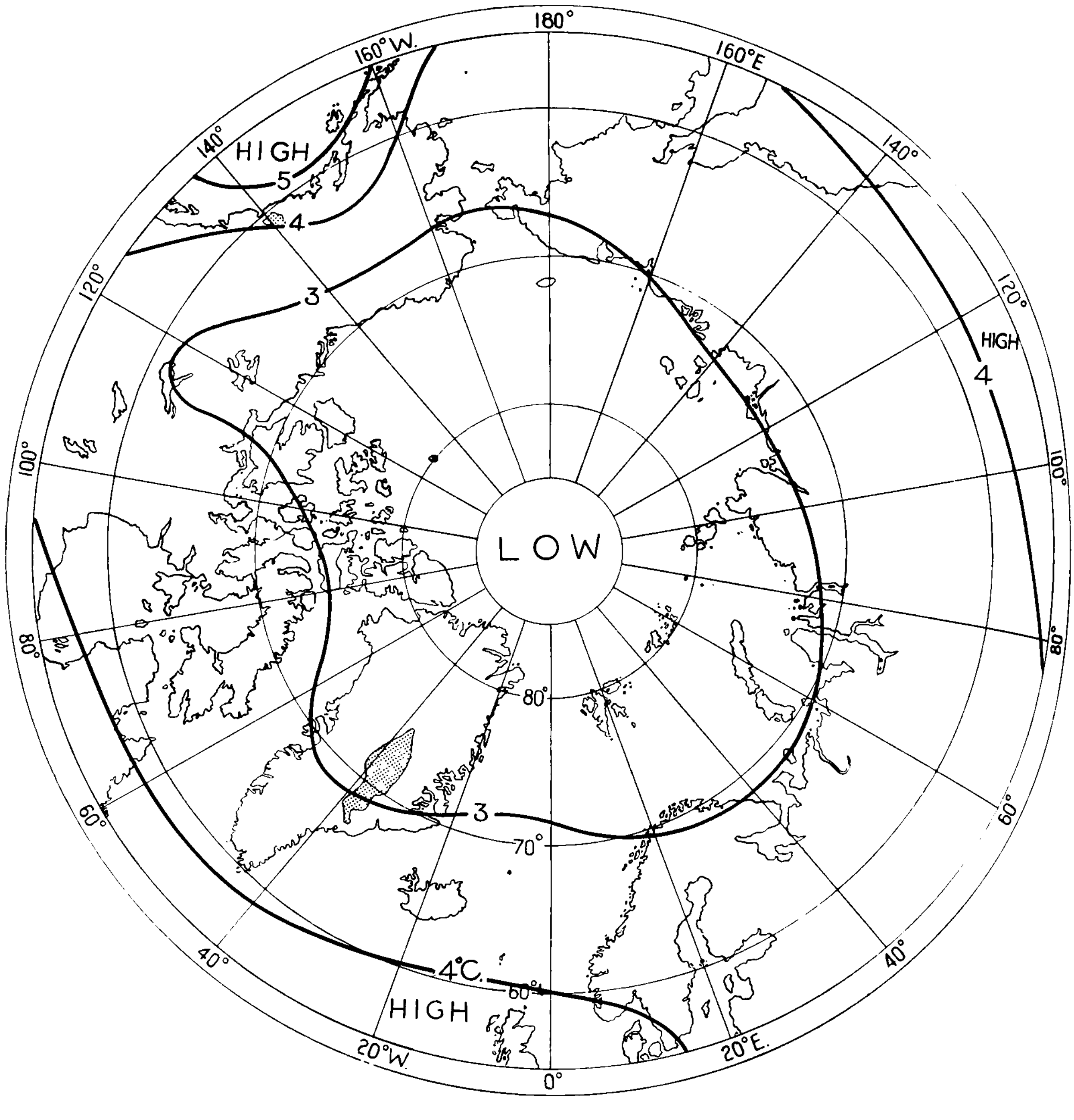

PLATE 68B—STANDARD DEVIATION OF TEMPERATURE AT 150 MB. IN JULY

I.C.A.N. height = 44,625 ft. = 13,602 m.

Land over 10,000 feet is represented by shading.

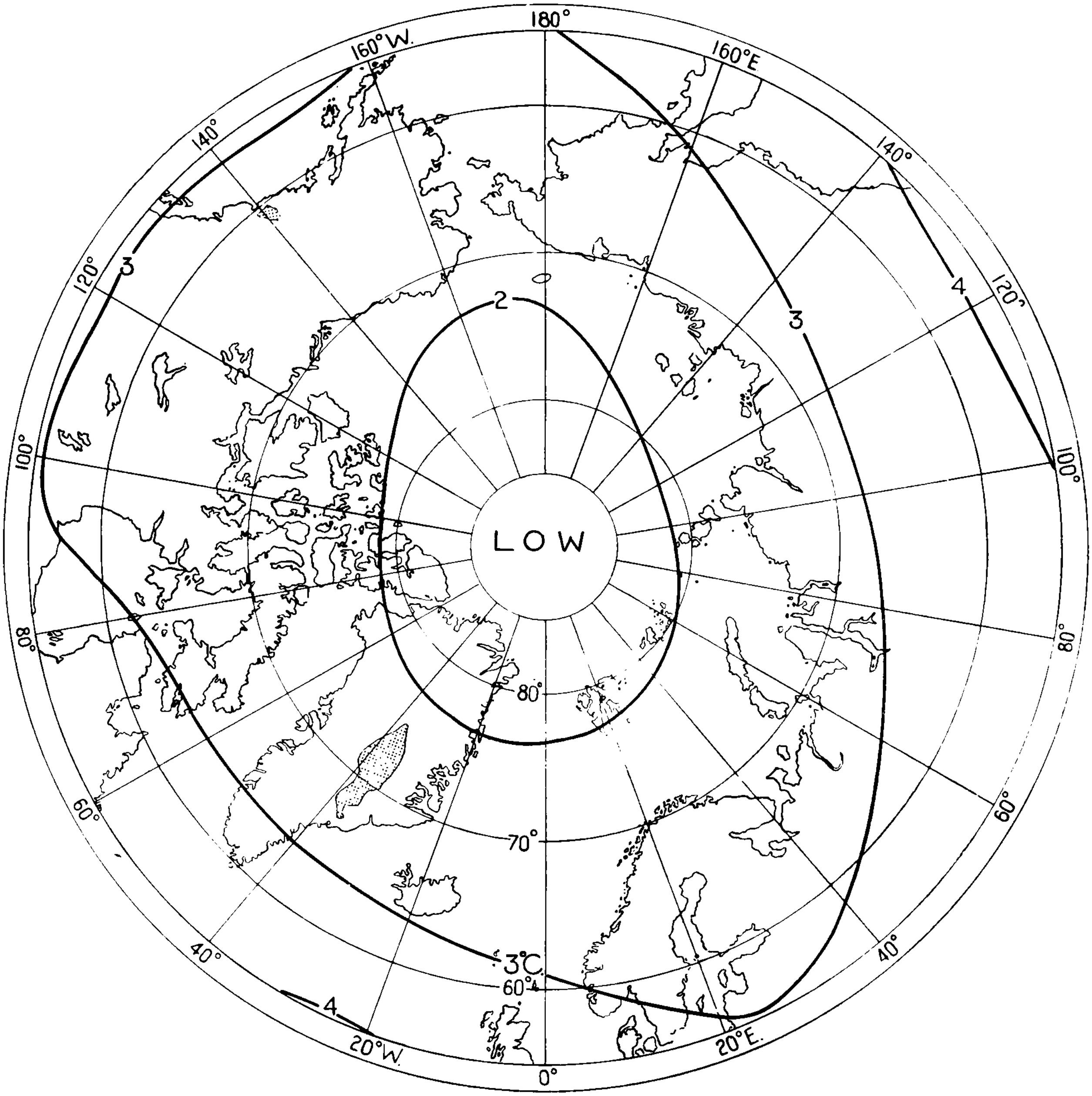

PLATE 68c—STANDARD DEVIATION OF TEMPERATURE AT 100 MB. IN JULY

I.C.A.N. height = 53,054 ft. = 16,170 m.

Land over 10,000 feet is represented by shading.

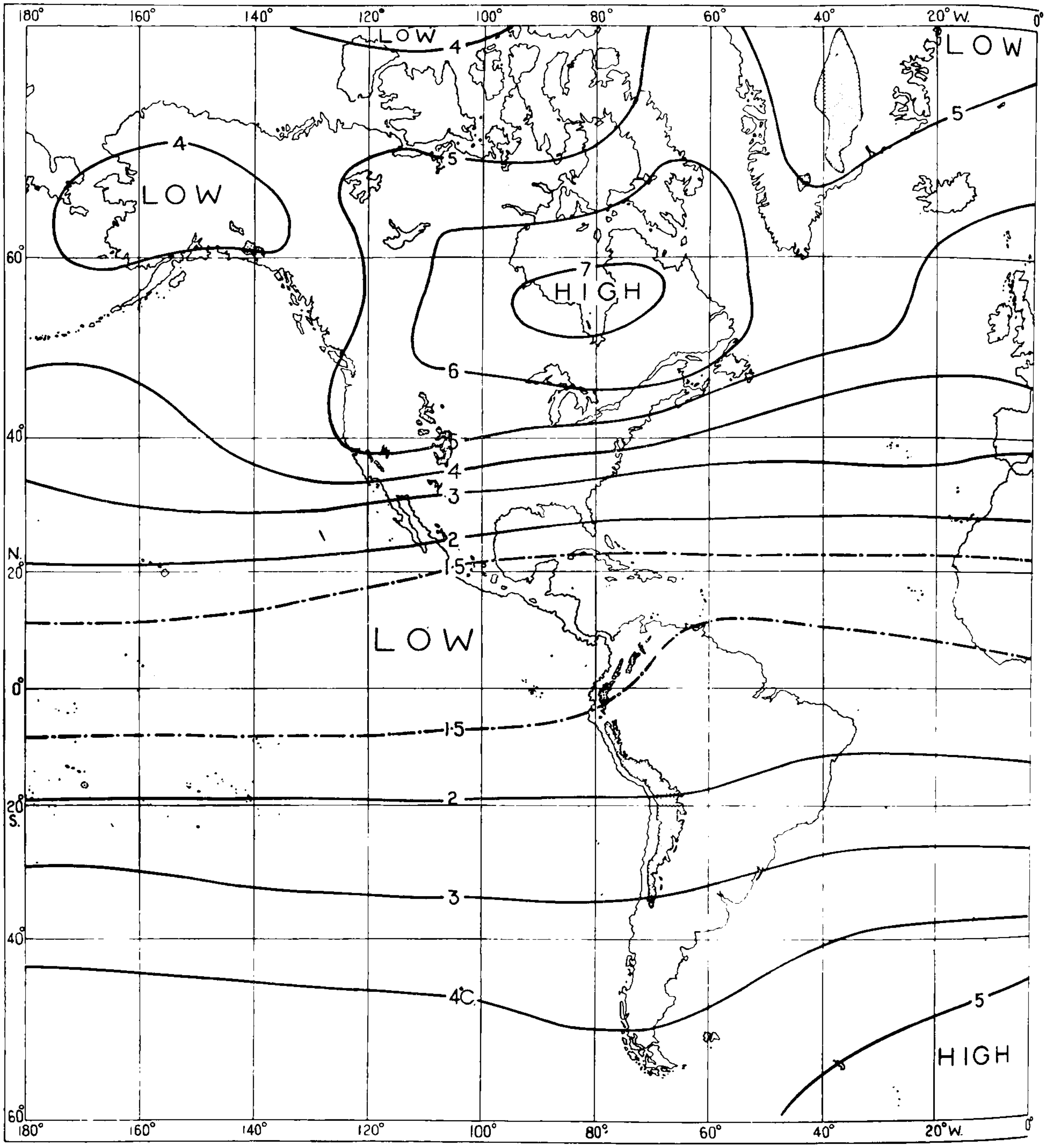

PLATE 69—STANDARD DEVIATION OF TEMPERATURE AT 700 MB. IN OCTOBER

I.C.A.N. height = 9,876 ft. = 3,010 m.

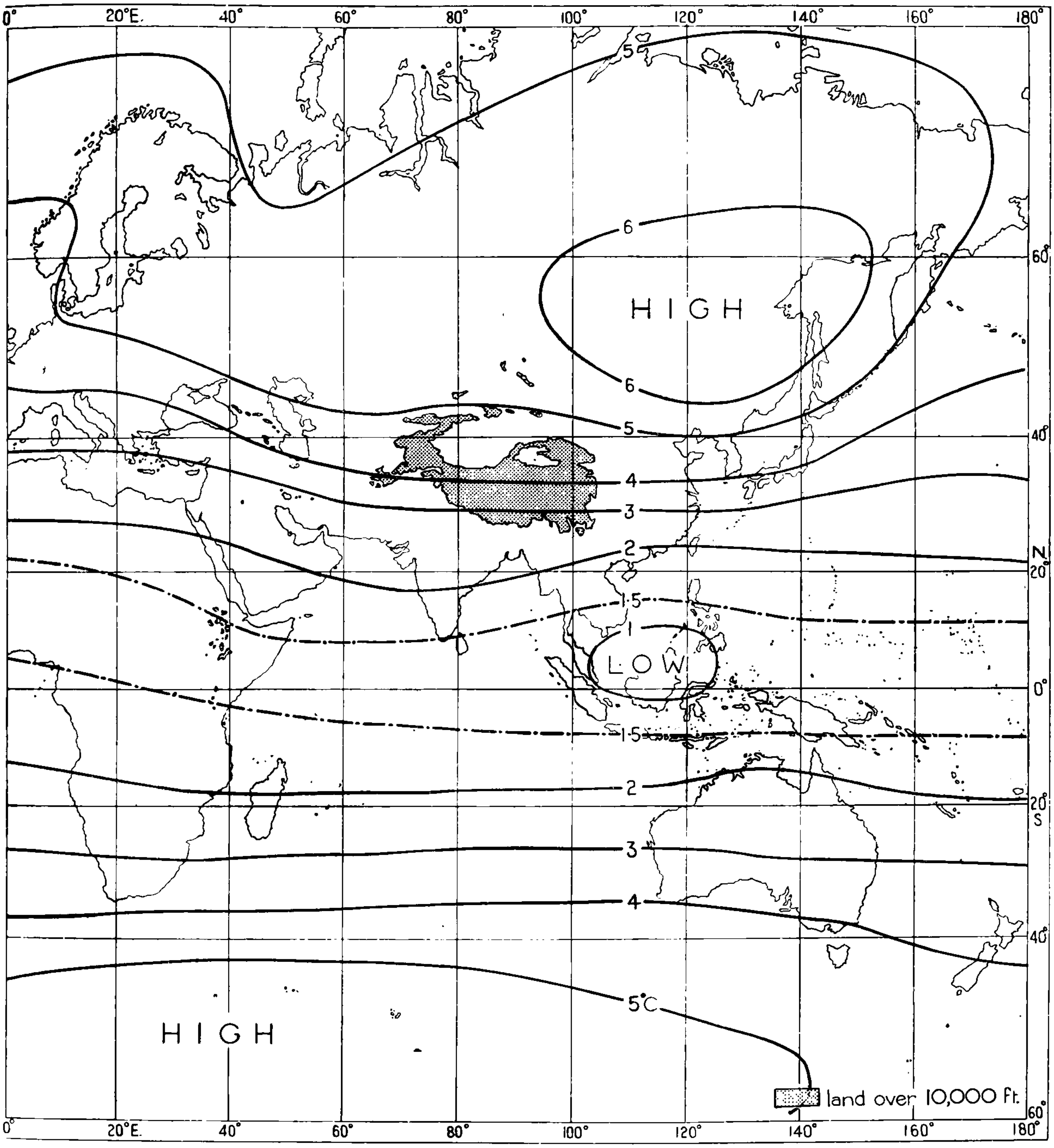

PLATE 69—CONTINUED

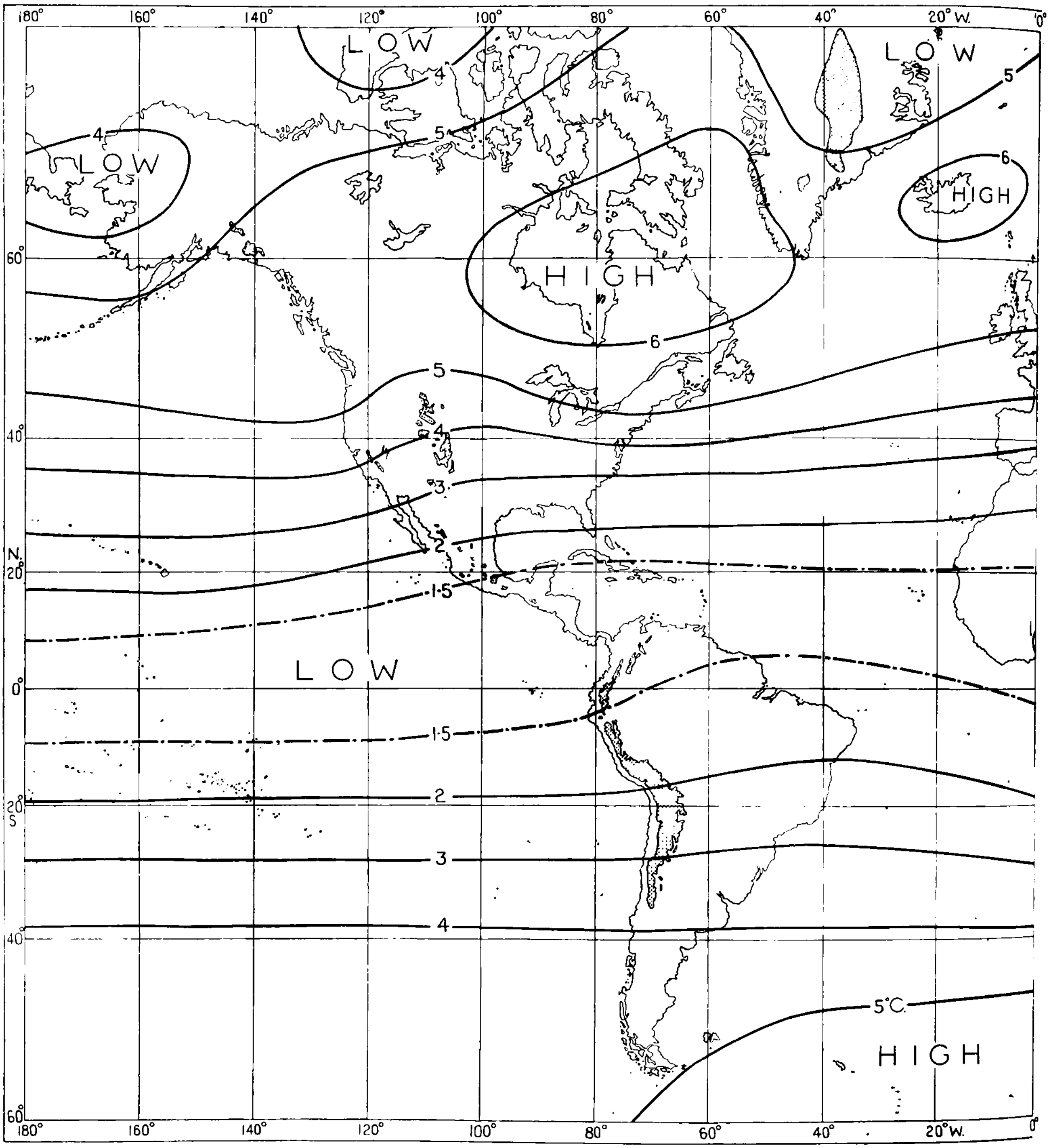

PLATE 70—STANDARD DEVIATION OF TEMPERATURE AT 500 MB. IN OCTOBER
I.C.A.N. height = 18,278 ft. = 5,571 m.

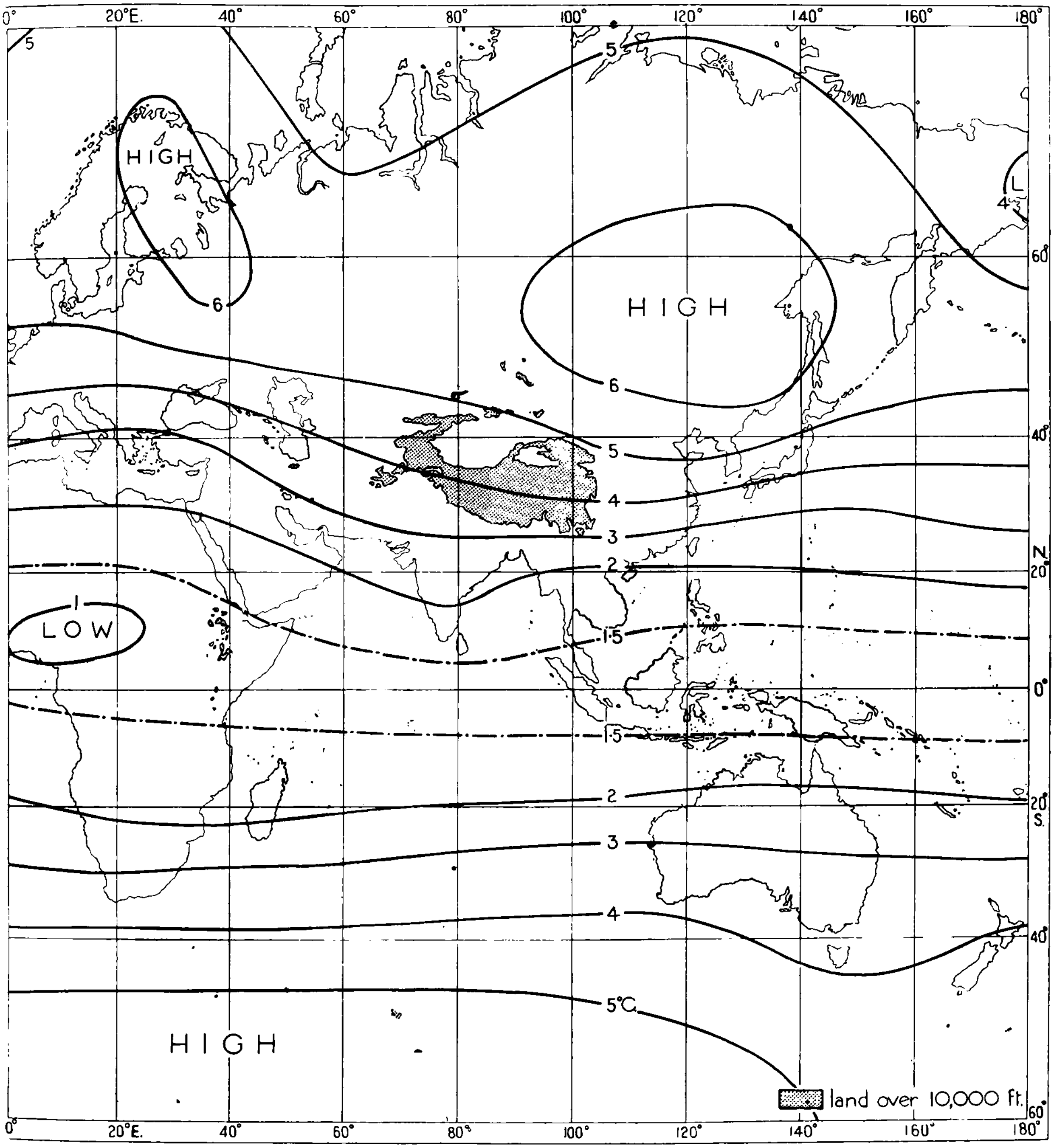

PLATE 70—CONTINUED

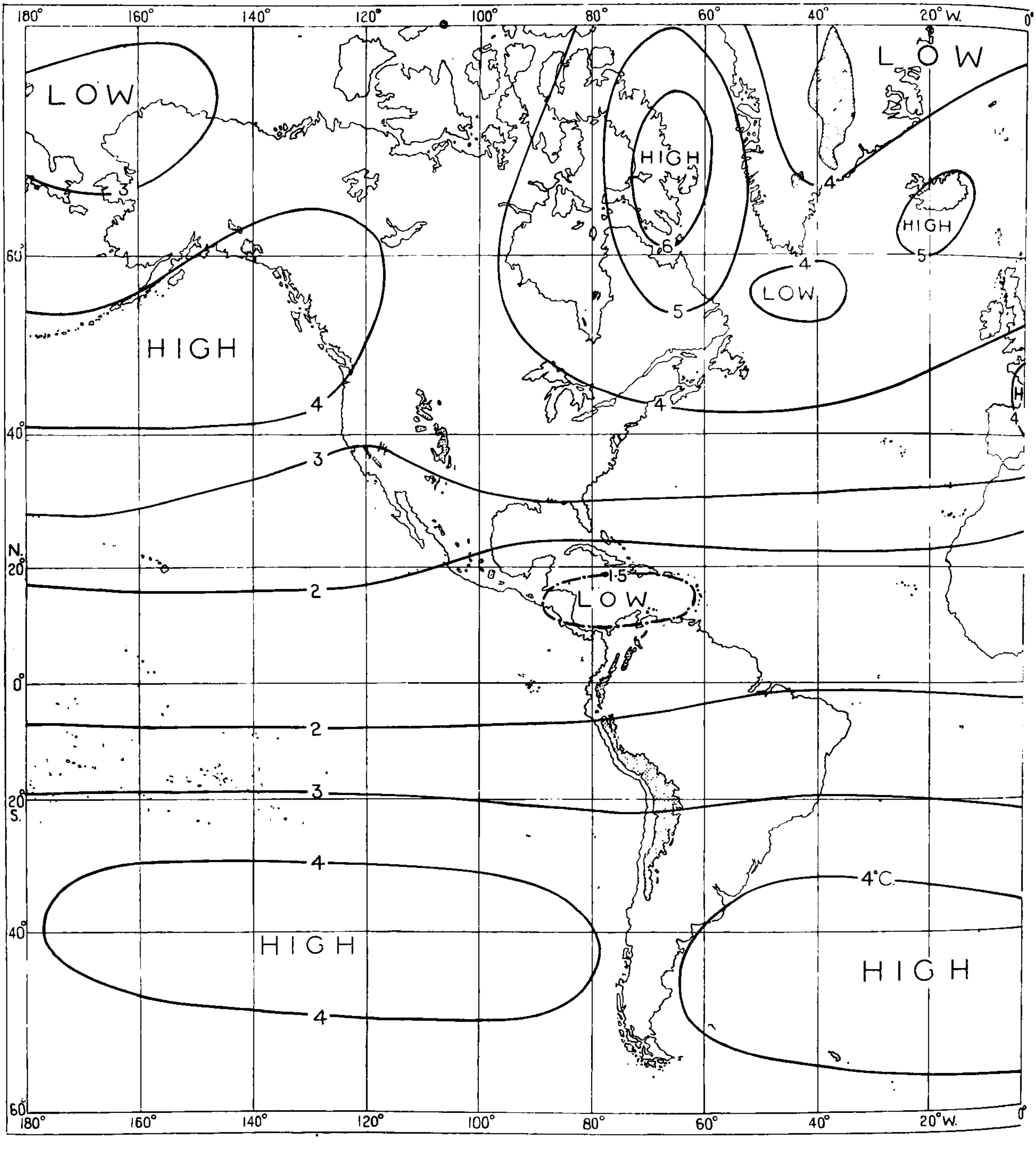

PLATE 71—STANDARD DEVIATION OF TEMPERATURE AT 300 MB. IN OCTOBER

I.C.A.N. height = 30,059 ft. = 9,162 m.

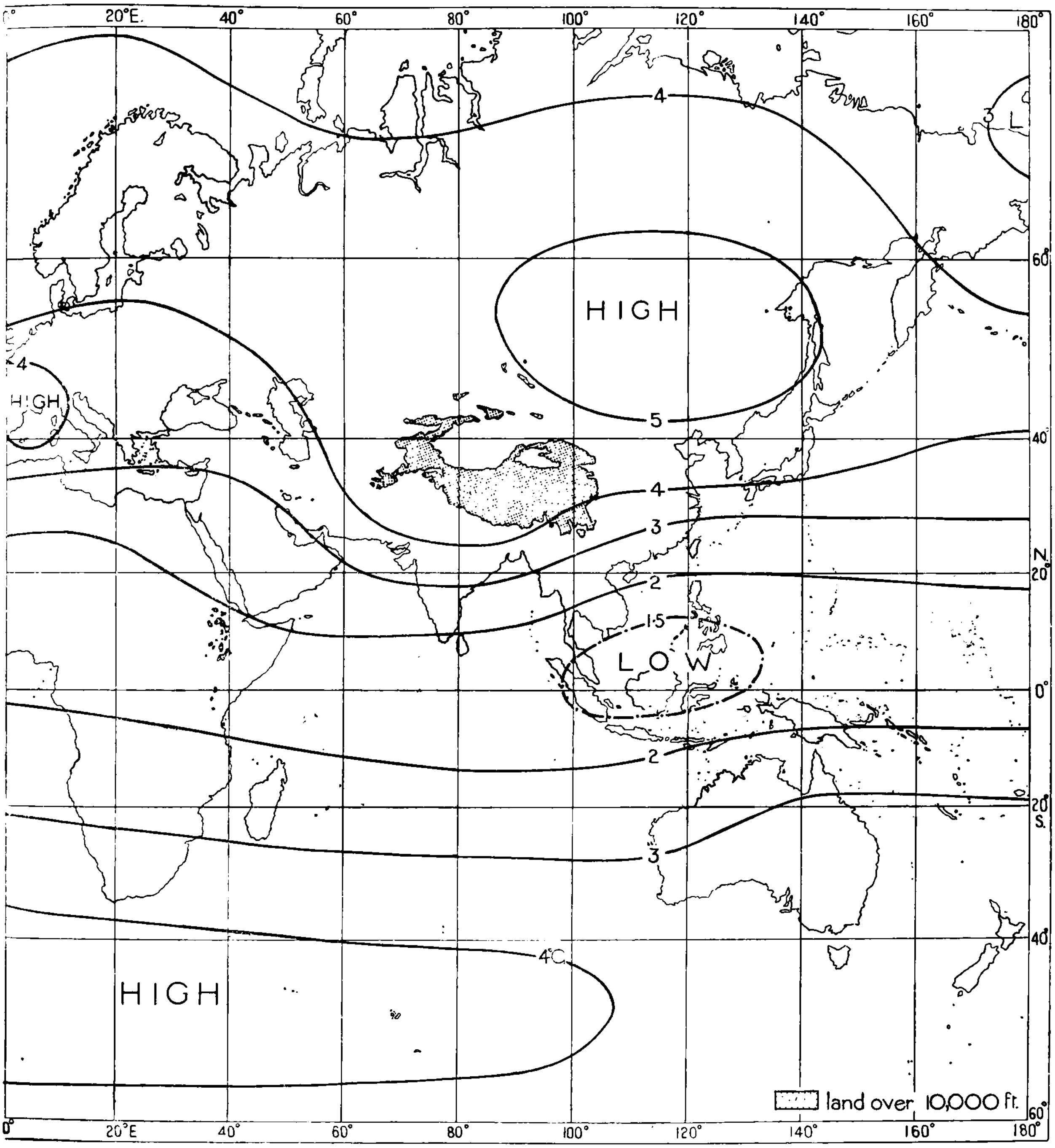

PLATE 71—CONTINUED

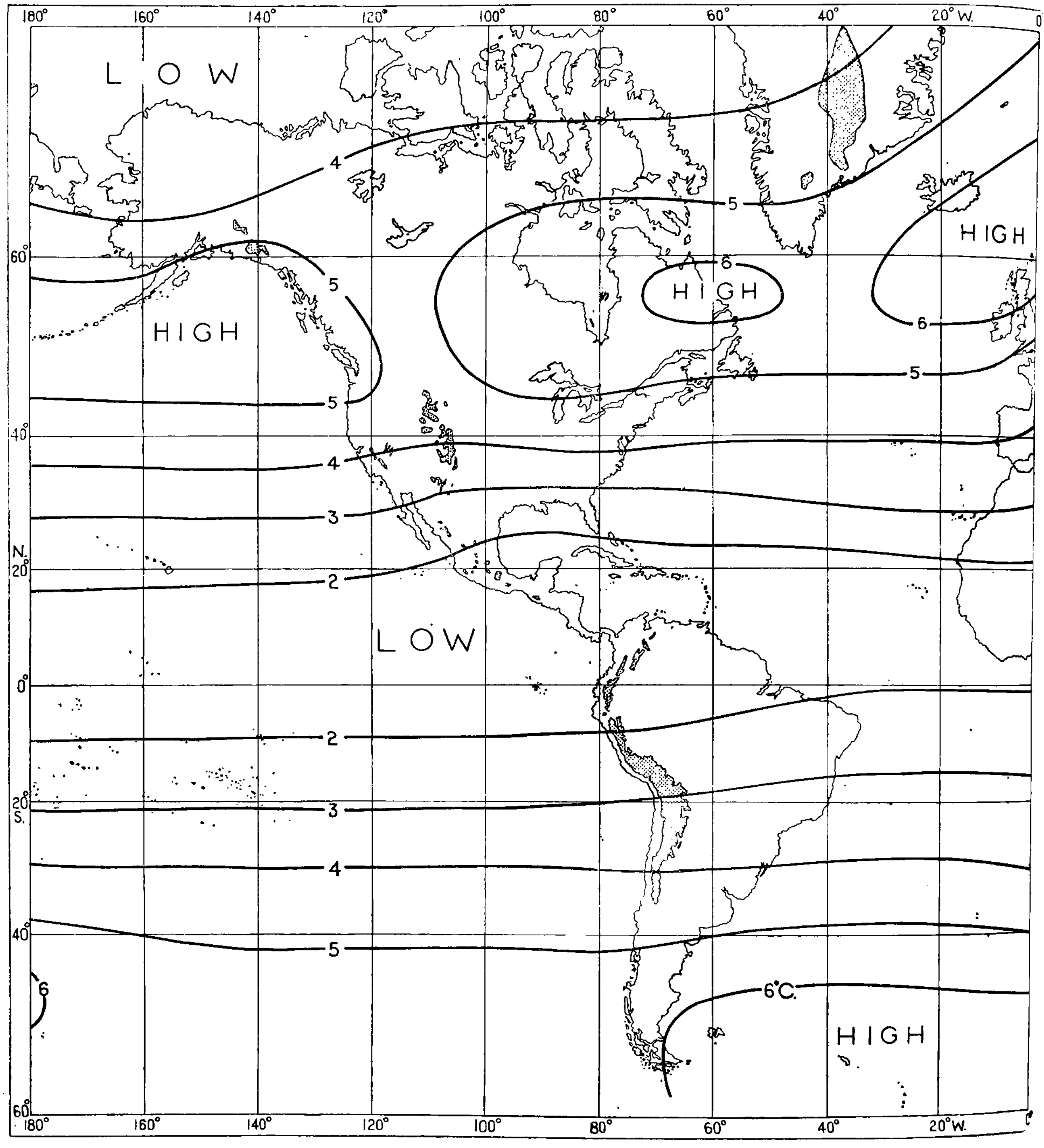

PLATE 72—STANDARD DEVIATION OF TEMPERATURE AT 200 MB. IN OCTOBER

I.C.A.N. height = 38,664 ft. = 11,779 m.

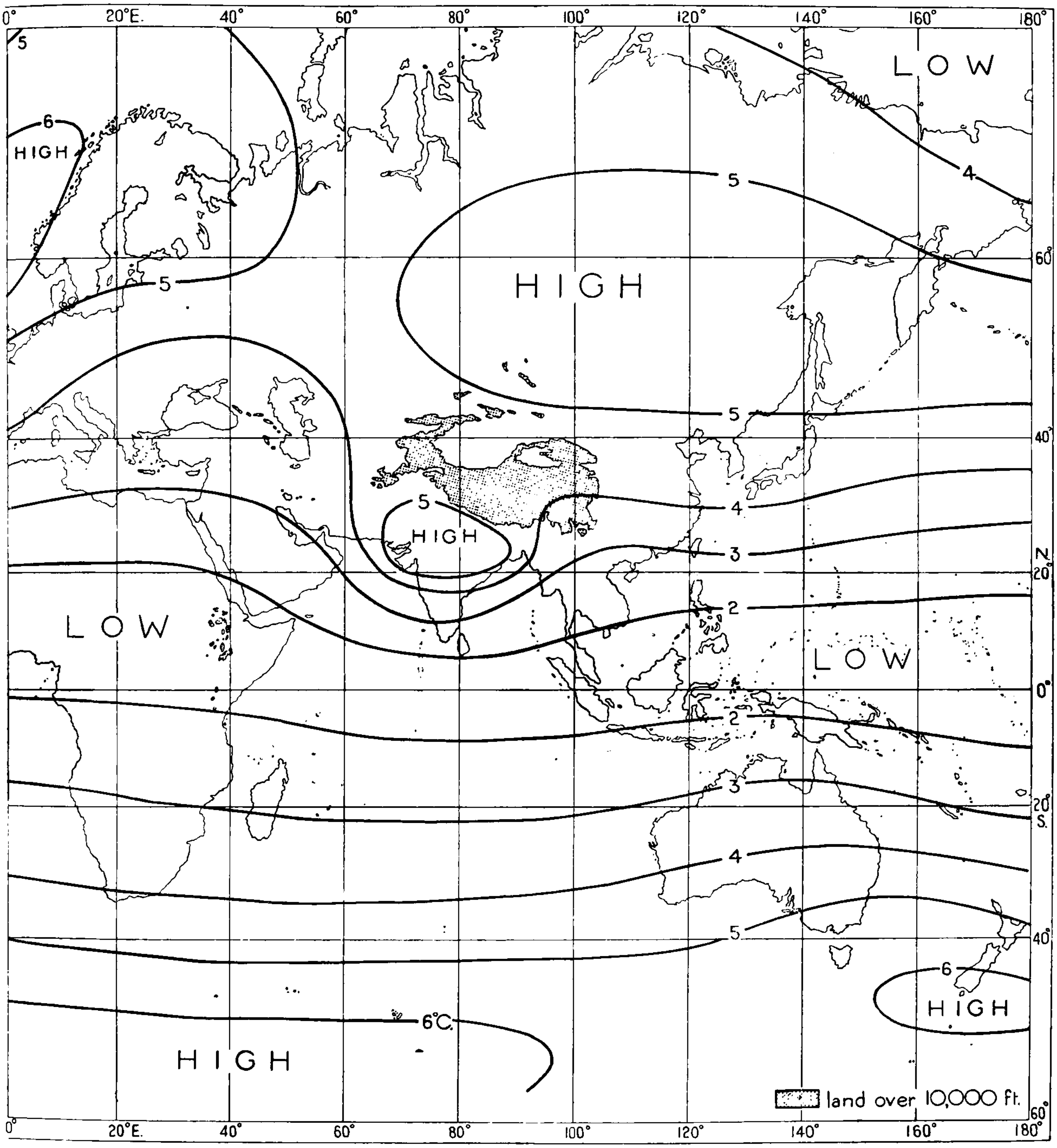

PLATE 72—CONTINUED

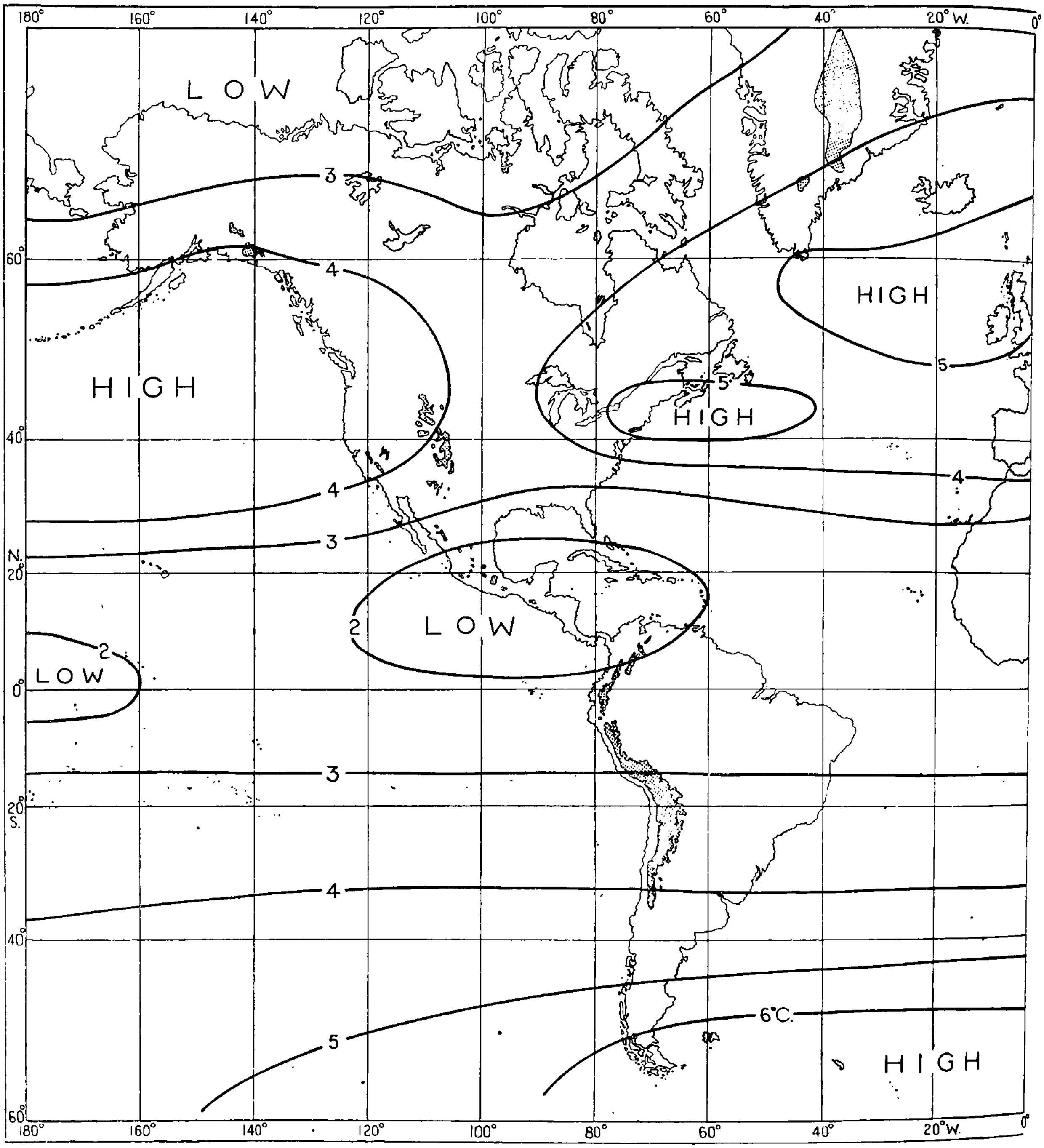

PLATE 73—STANDARD DEVIATION OF TEMPERATURE AT 150 MB. IN OCTOBER

I.C.A.N. height = 44,625 ft. = 13,602 m.

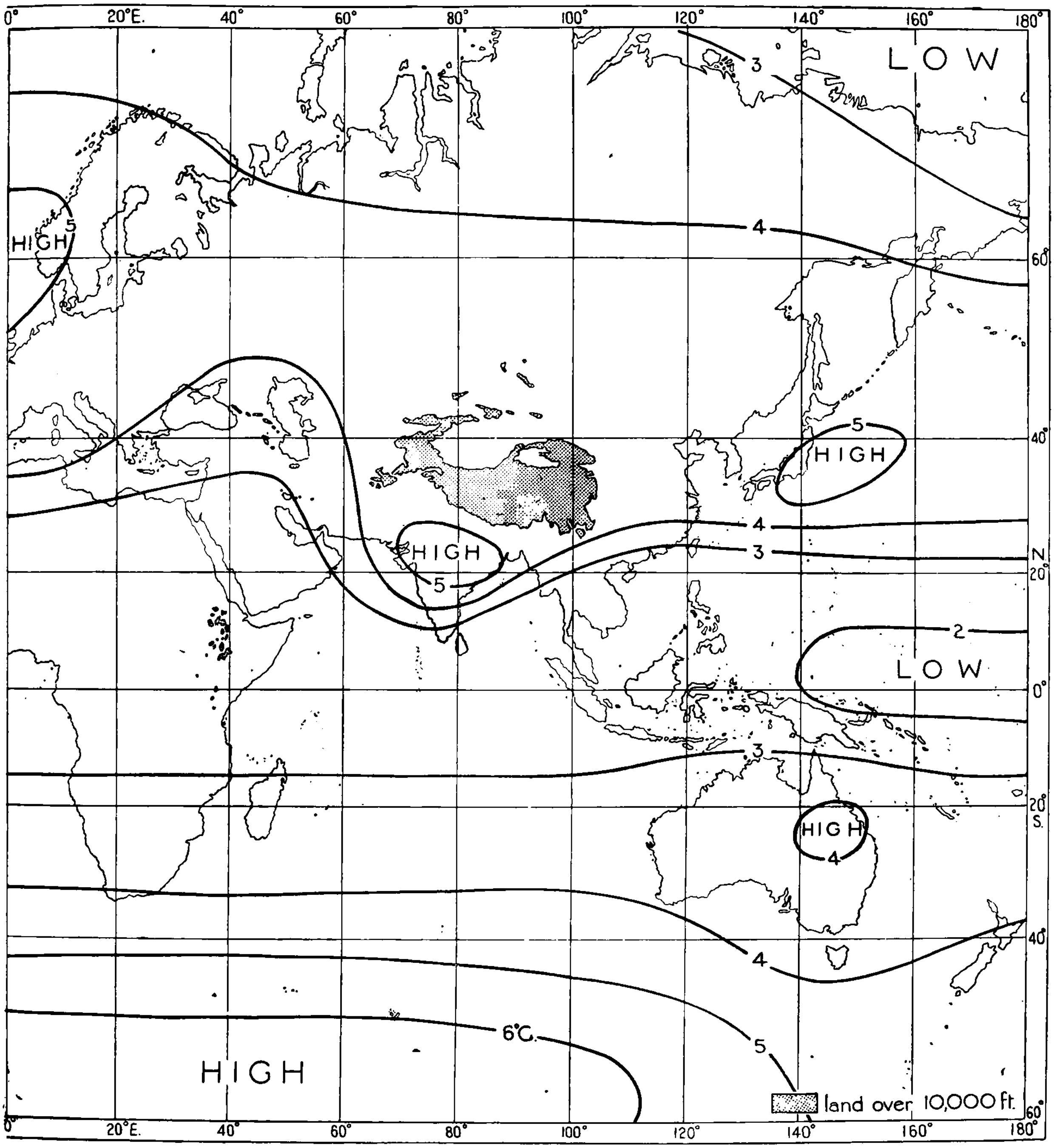

PLATE 73—CONTINUED

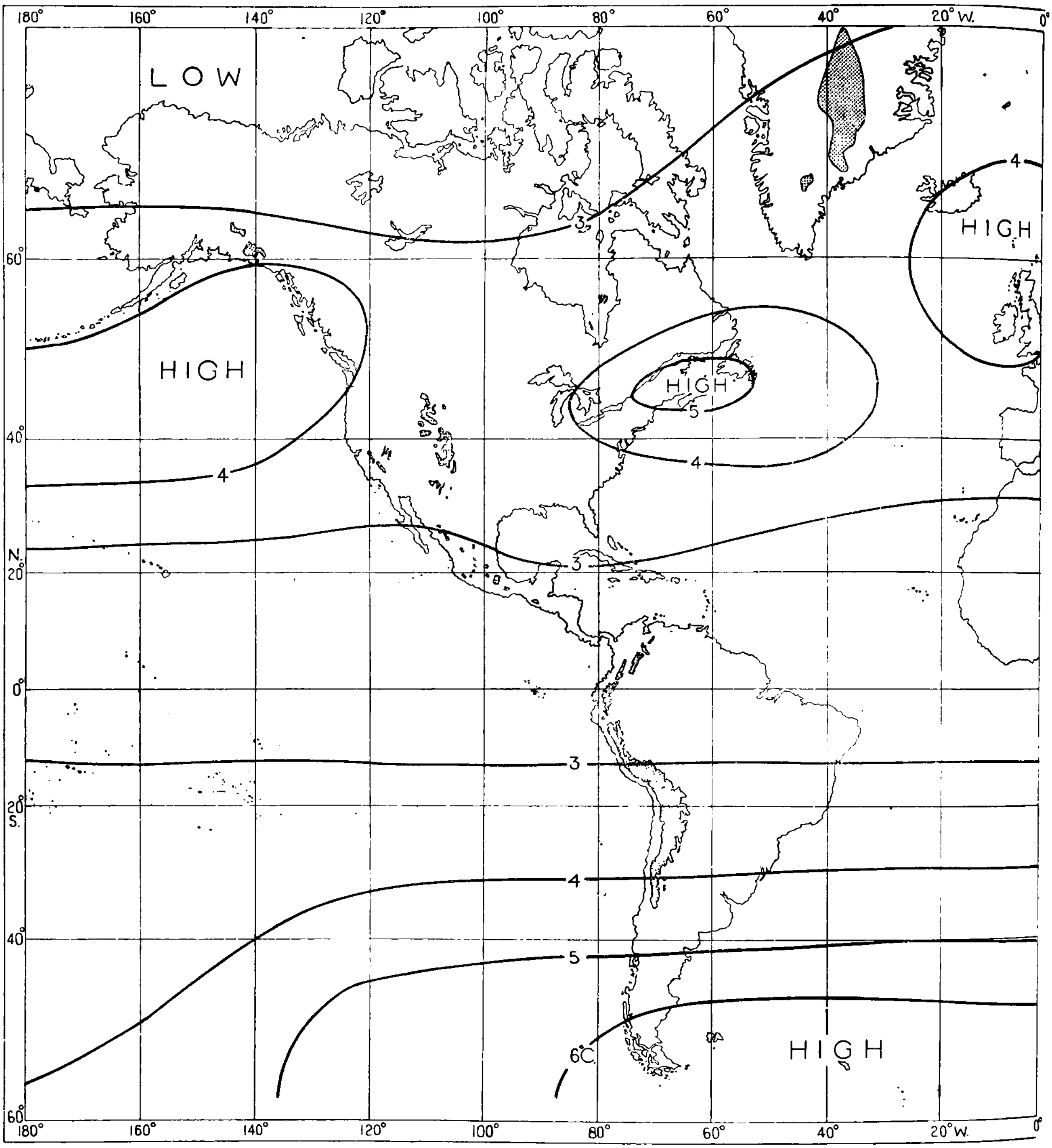

PLATE 74—STANDARD DEVIATION OF TEMPERATURE AT 100 MB. IN OCTOBER

I.C.A.N. height = 53,054 ft. = 16,170 m.

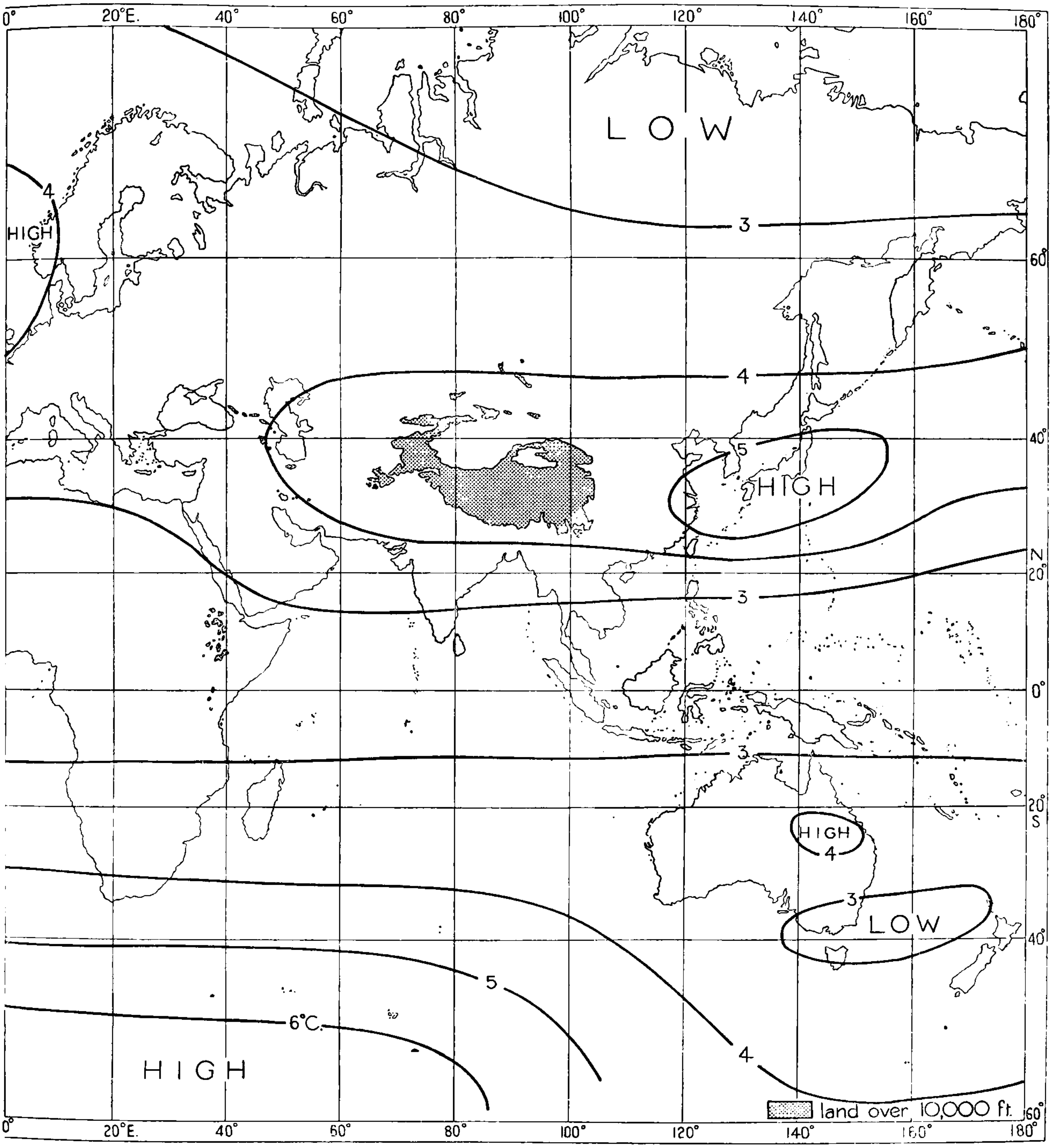

PLATE 74—CONTINUED

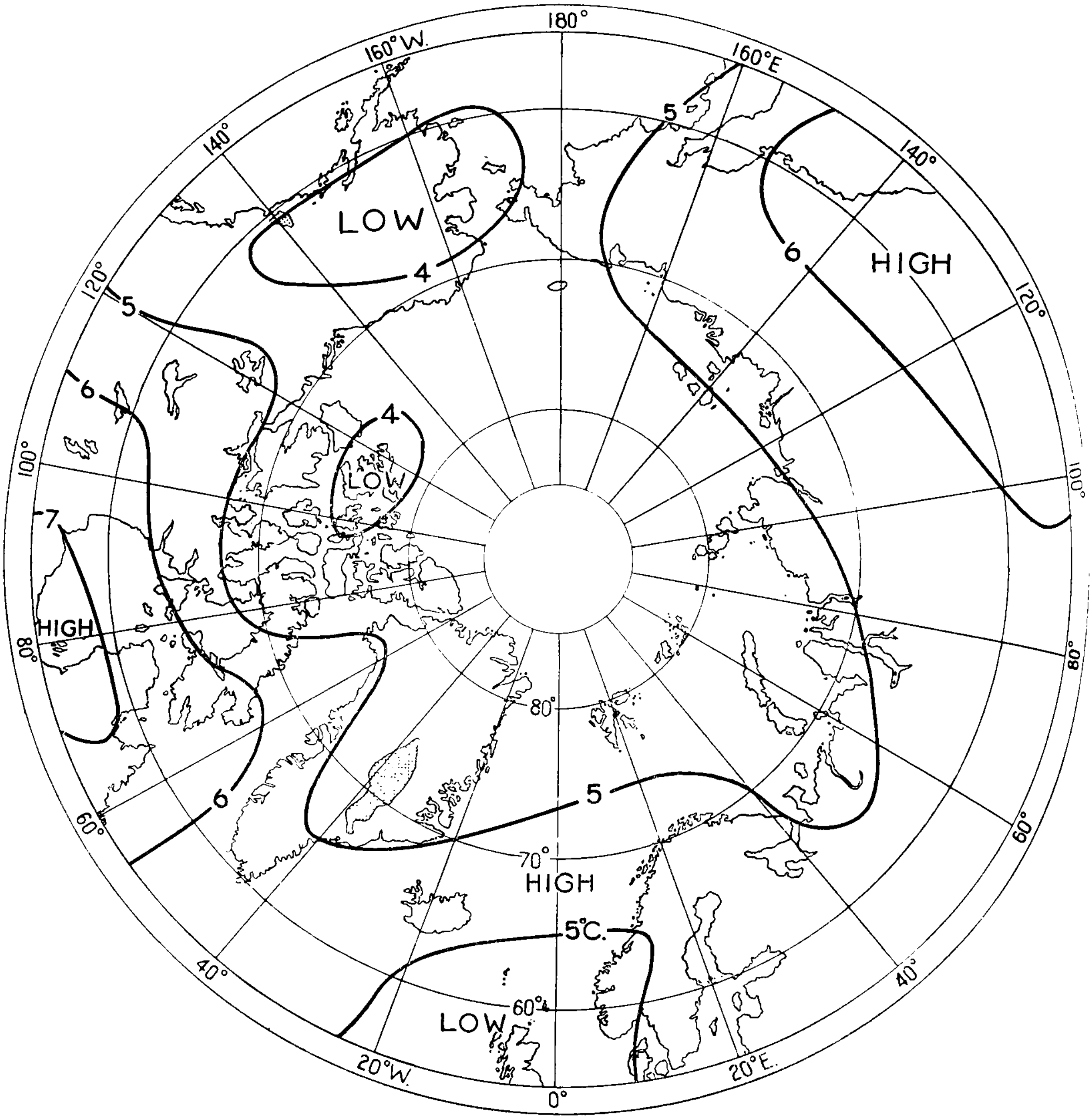

PLATE 75A—STANDARD DEVIATION OF TEMPERATURE AT 700 MB. IN OCTOBER

I.C.A.N. height = 9,876 ft. = 3,010 m.

Land over 10,000 feet is represented by shading.

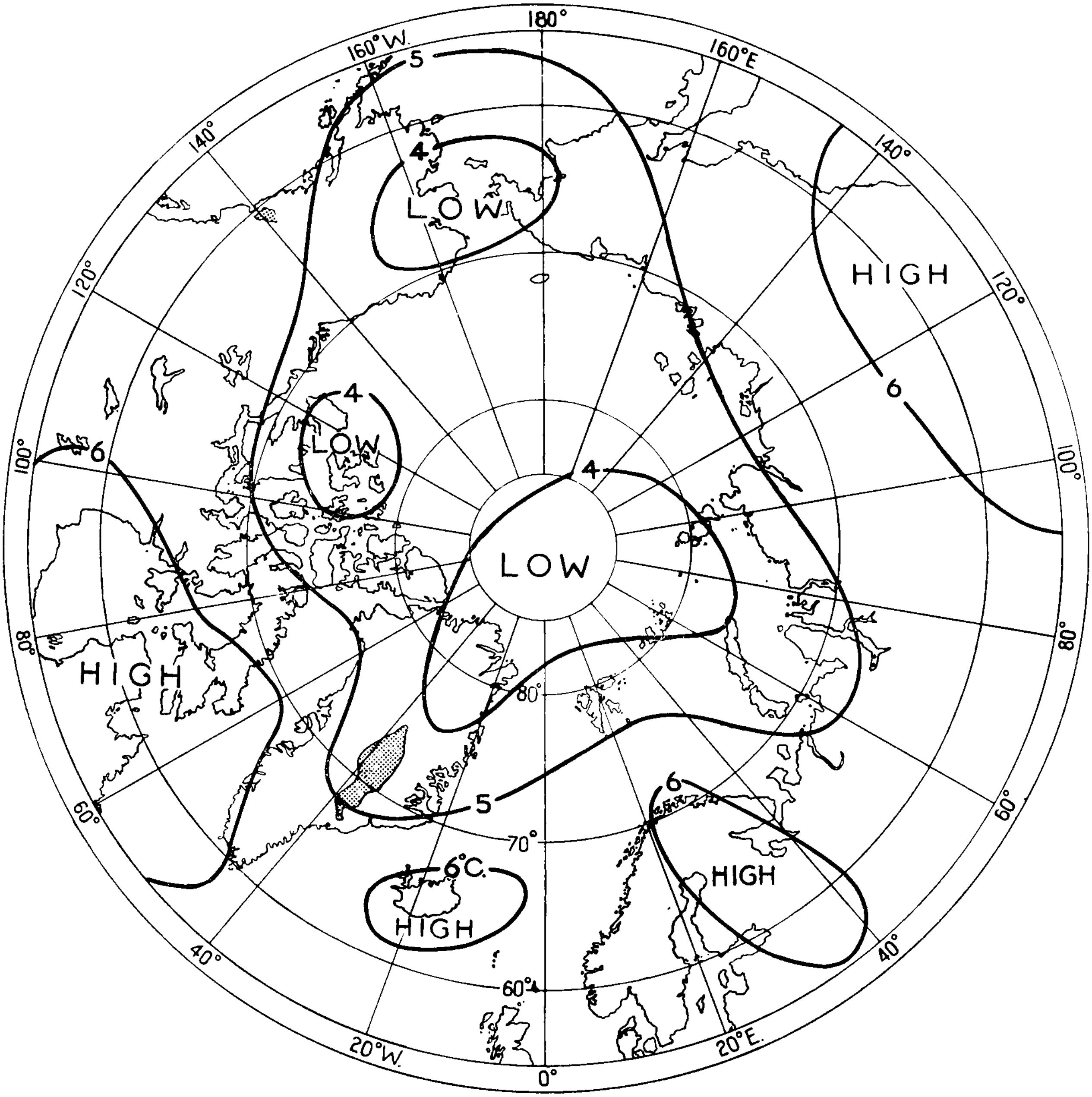

PLATE 75B—STANDARD DEVIATION OF TEMPERATURE AT 500 MB. IN OCTOBER

I.C.A.N. height = 18,278 ft. = 5,571 m.

Land over 10,000 feet is represented by shading.

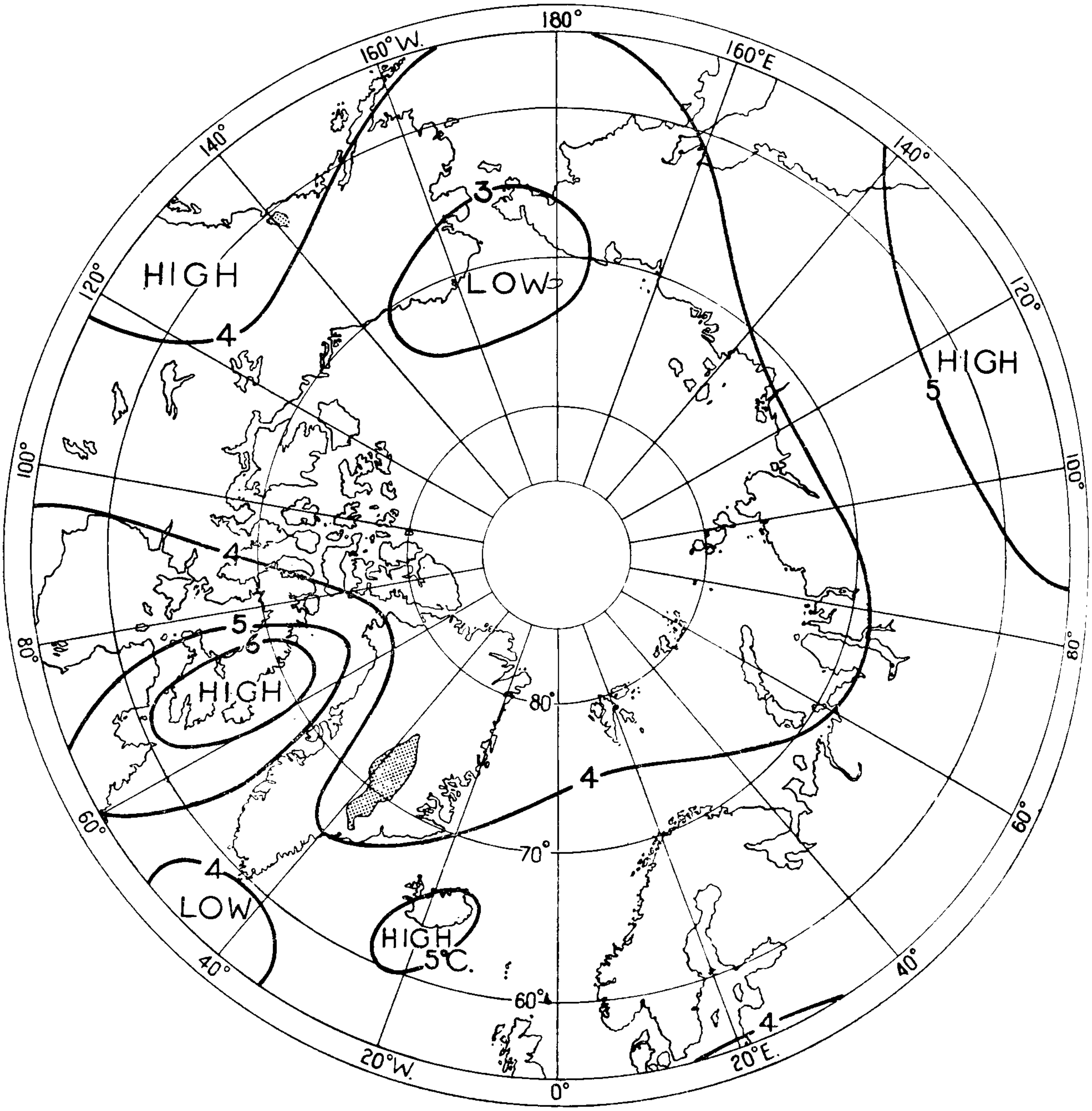

PLATE 75c—STANDARD DEVIATION OF TEMPERATURE AT 300 MB. IN OCTOBER

I.C.A.N. height = 30,059 ft. = 9,162 m.

Land over 10,000 feet is represented by shading.

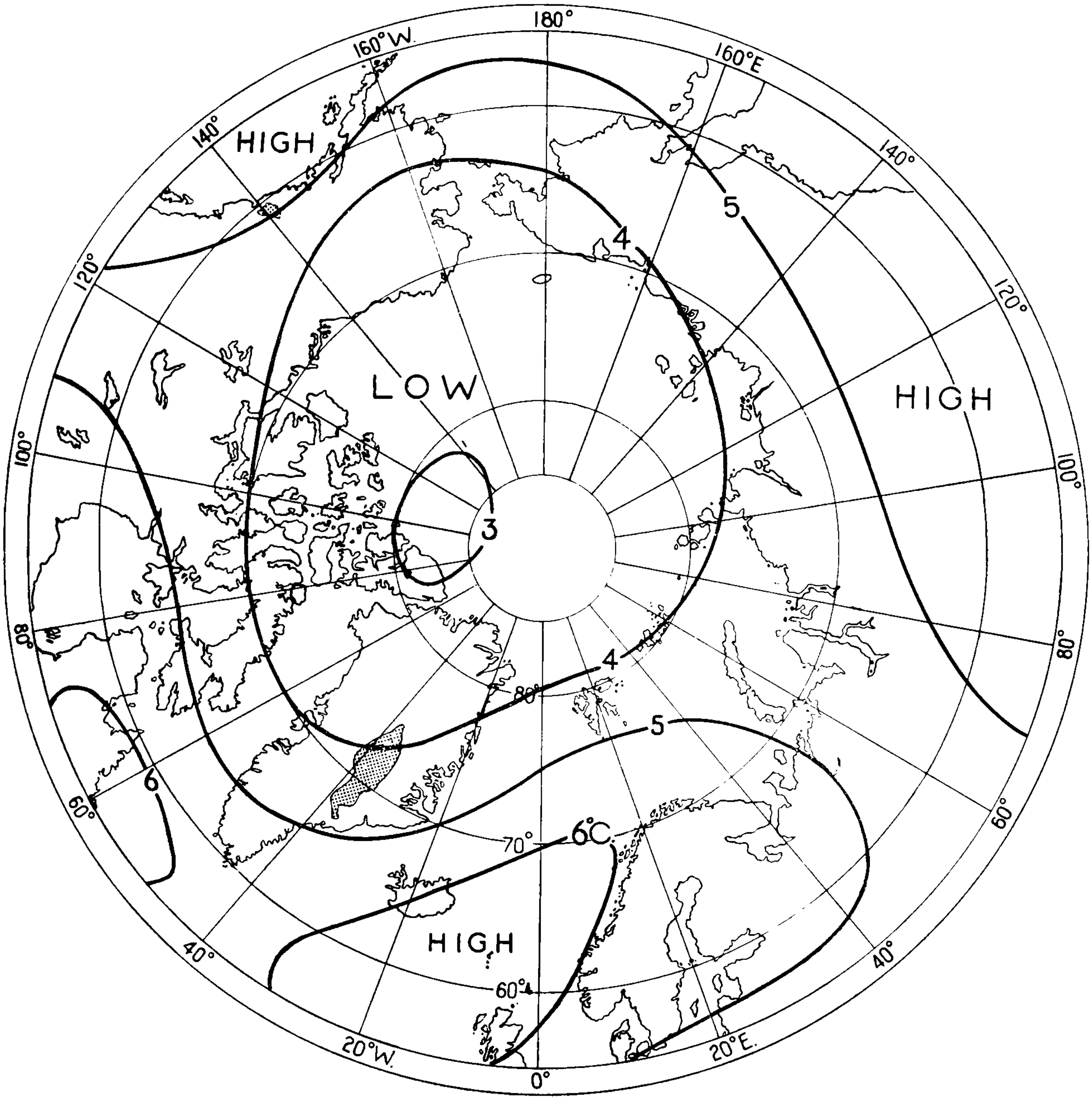

PLATE 76A—STANDARD DEVIATION OF TEMPERATURE AT 200 MB. IN OCTOBER

I.C.A.N. height = 38,664 ft. = 11,779 m.

Land over 10,000 feet is represented by shading.

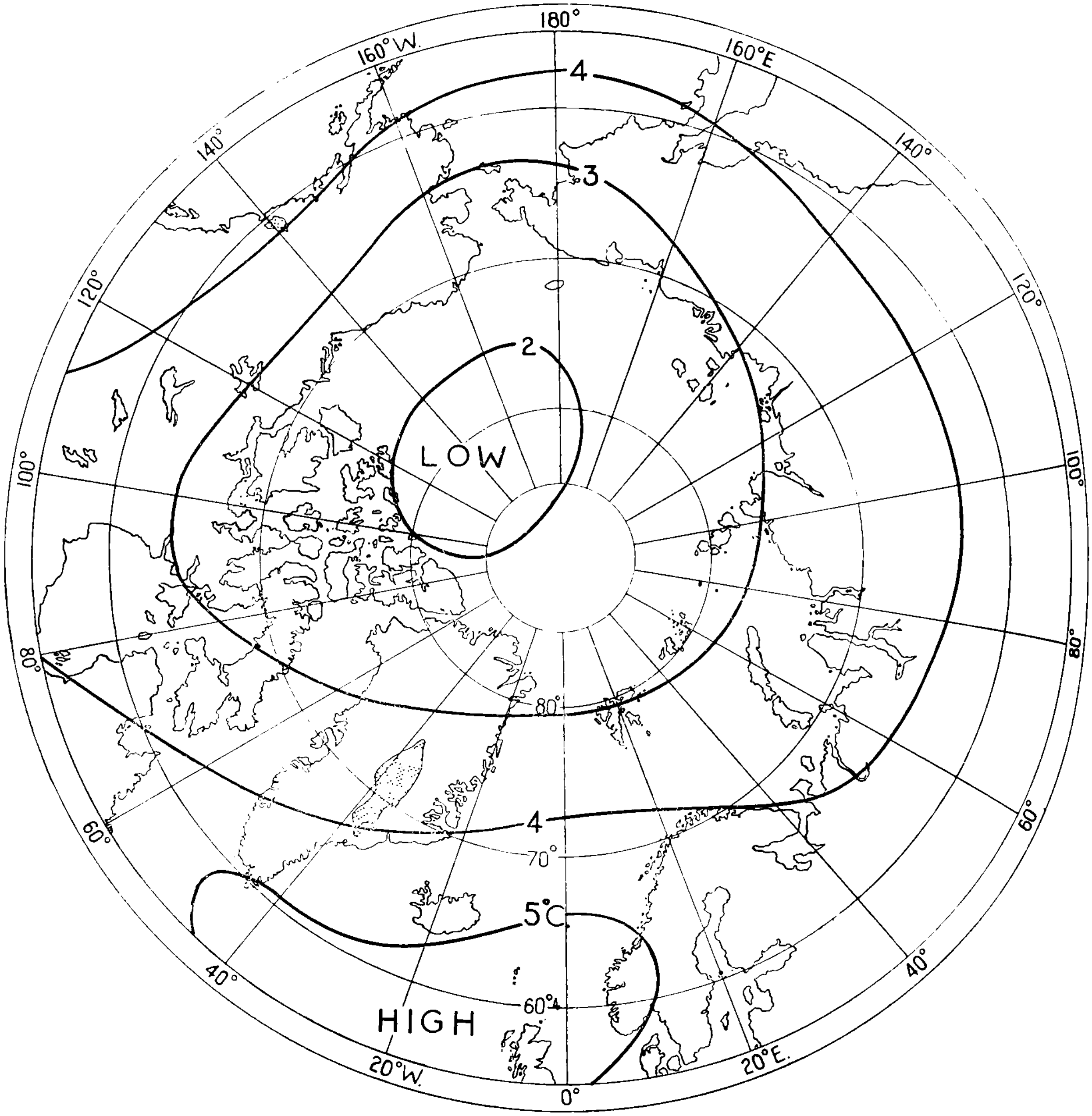

PLATE 76B—STANDARD DEVIATION OF TEMPERATURE AT 150 MB. IN OCTOBER

I.C.A.N. height = 44,625 ft. = 13,602 m.

Land over 10,000 feet is represented by shading.

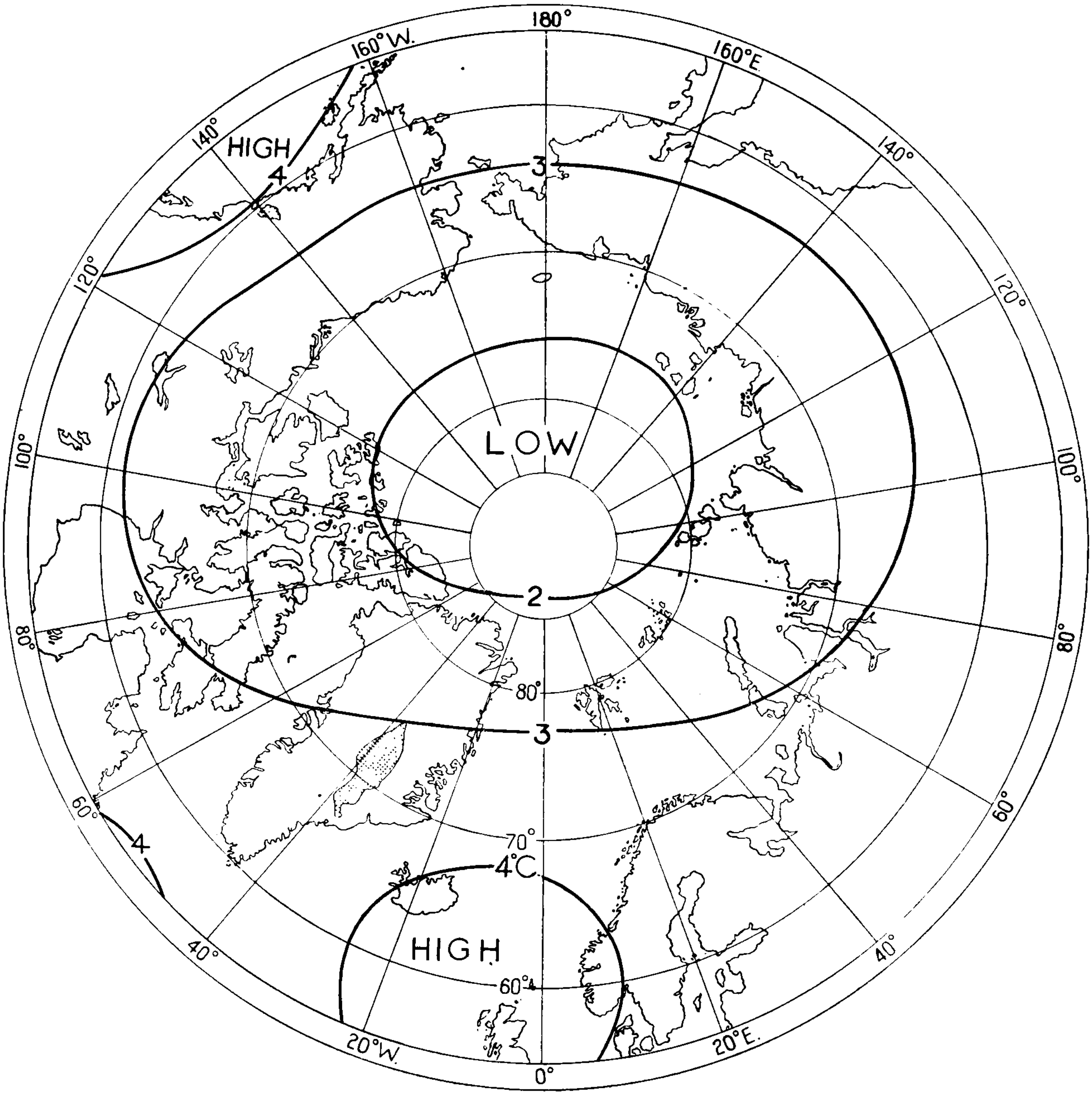

PLATE 76c—STANDARD DEVIATION OF TEMPERATURE AT 100 MB. IN OCTOBER

I.C.A.N. height = 53,054 ft. = 16,170 m

Land over 10,000 feet is represented by shading.

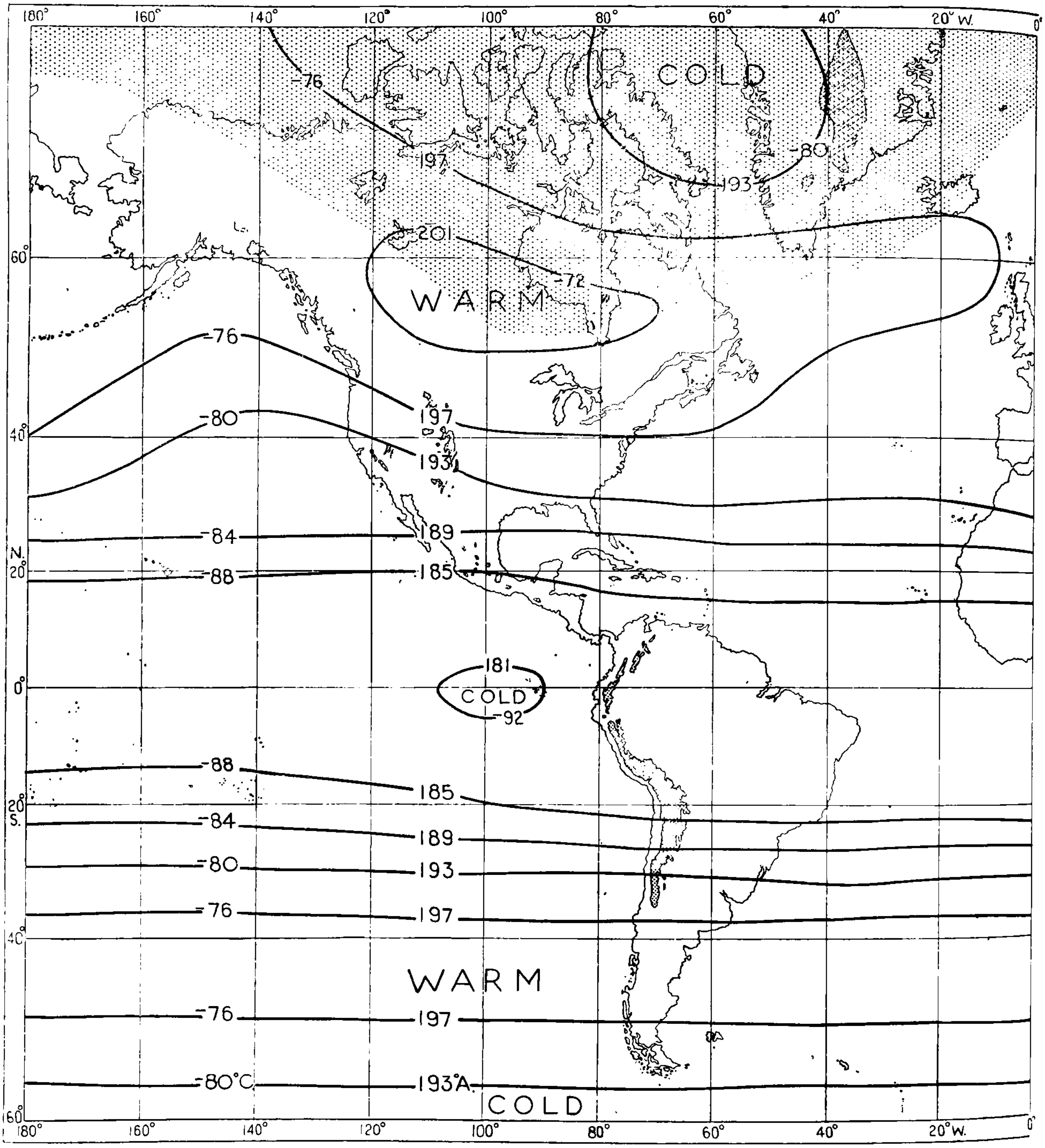

PLATE 77—MINIMUM TEMPERATURE IN THE UPPER TROPOSPHERE AND LOWER STRATOSPHERE

The area where the minimum temperature at 100 mb. was found to be colder than that at the tropopause is lightly shaded.

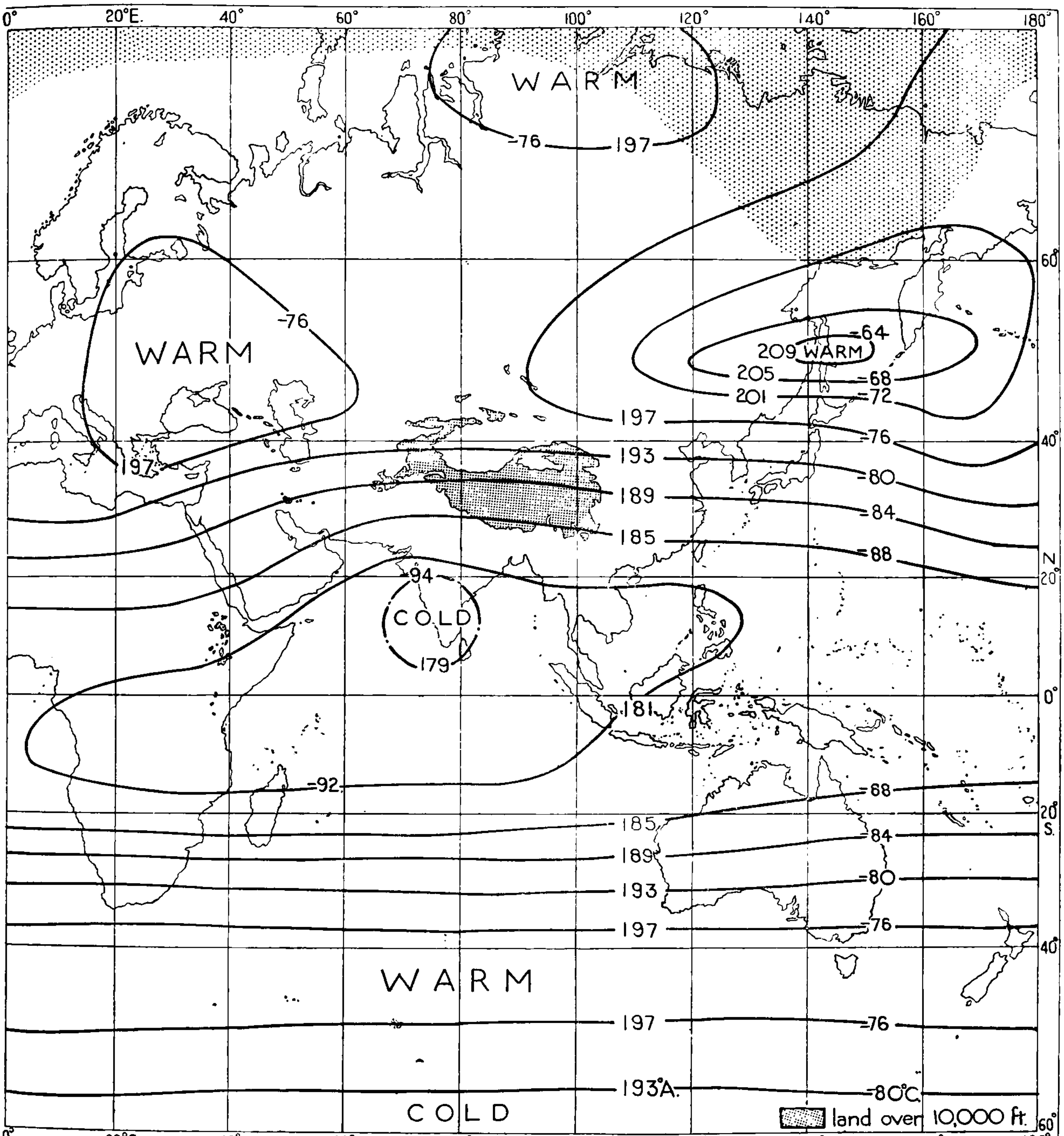

PLATE 77—CONTINUED

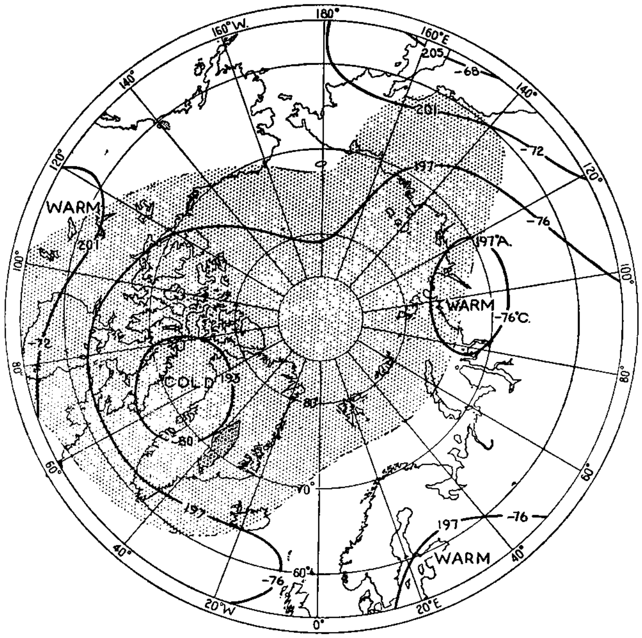

PLATE 78—MINIMUM TEMPERATURE IN THE UPPER TROPOSPHERE AND LOWER STRATOSPHERE

The area where the minimum temperature at 100 mb. was found to be colder than that at the tropopause is lightly shaded ; land over 10,000 ft. is represented by heavier shading.

(69494) Wt. 4392/BM/4416 K.6 5/58 Hw.