A REPORT ON THE CLIMATOLOGY AND TYPICAL SYNOPTIC SITUATIONS OF THE NORTH ATLANTIC

BY MEMBERS OF THE STAFF OF
THE DEPARTMENT OF METEOROLOGY
MASSACHUSETTS INSTITUTE OF TECHNOLOGY

A REPORT ON THE CLIMATOLOGY AND TYPICAL SYNOPTIC SITUATIONS OF THE NORTH ATLANTIC

By Members of the Staff of the Department of Meteorology
Massachusetts Institute of Technology

PUBLISHED BY
MASSACHUSETTS INSTITUTE OF TECHNOLOGY
CAMBRIDGE, MASSACHUSETTS

PREFACE

In the training of weather officers for the armed services, it has become of increasing importance to give instruction in the characteristic weather conditions of many sections of the world because of the global scope of the present conflict. Although climatological and synoptic data are available for much of the world, this information is scattered and is not available in the form required for instructional purposes. At a conference on the training of weather officers held in Washington in February 1942 and attended by representatives of the institutions giving the training, the armed services and the Weather Bureau, this problem was recognized and discussed. At this conference the Massachusetts Institute of Technology agreed to prepare the present report on the North Atlantic region. Although written primarily for instructional purposes, it is hoped that it may also be of some value to meteorologists who are forecasting for this region.

As indicated by the title, the report consists of two sections, one on the climatology of the region and one in which typical synoptic situations are illustrated and discussed. Insofar as possible the climatological data have been presented in the form of maps. An effort has been made to integrate the synoptic and climatological discussions wherever possible, and this has been facilitated, perhaps, by the fact that the climatological section has been prepared by a synoptic meteorologist.

Although the major burden of preparing this report has fallen on Professor H. C. Willett and Professor J. M. Austin, several other members of our staff have made valuable contributions. Special credit is due Miss Margaret Whitcomb, Mrs. Karin Gleim and Miss Esther Hanchett for their work in assembling the climatological data and preparing the many charts. Professor B. Haurwitz has also assisted greatly in the selection and treatment of the climatological data. Mr. E. A. Murphy is responsible for the excellent plotting on the synoptic charts which makes the data readily legible in spite of the considerable reduction in the reproduction process. We are also indebted to the staffs of the libraries of the Blue Hill Meteorological Observatory and of the Institute of Geographical Exploration, both of Harvard University, for their kind assistance in locating much of the data utilized in this report.

H. G. Houghton.

October 1942.

BIBLIOGRAPHY

1. Schott, Gerhard, "Geographie des Atlantischen Ozeans," C. Boysen, Hamburg, 1912.
2. U. S. Department of Agriculture, Weather Bureau, "Atlas of Climatic Charts of the Oceans," G.P.O. Washington, D. C., 1938.
3. Expedition of the "Meteor," Band V, Atlas zu: "Temperatur, Salzgehalt, und Dichte an der Oberfläche des Atlantischen Ozeans," Walter De Gruyter and Co., Berlin and Leipzig, 1936.
4. Brooks, C. F., Connor, A. J. and others, "Climatic Maps of North America," Harvard University Press, Cambridge, Mass., 1936.
5. Petterssen, S., "Weather Analysis and Forecasting," McGraw-Hill Book Co., New York, 1940.
6. Bergeron, T., "Hur vädret blir till och hur det förutsäges," Ymer, H. 2–3, 1937, pp. 199–231.
7. Köppen, W., and Geiger, R., "Handbuch der Klimatologie," Gebrüder Borntraeger, Berlin, 1930.
8. U. S. Hydrographic Office and U. S. Weather Bureau, "Pilot Charts of the Upper Air, North Atlantic Ocean," G.P.O., Washington, 1941.
9. Deutsche Seewarte, "Cartes synoptiques de l'hémisphêre nord."
10. University of Michigan, Greenland Expeditions, Michigan University Studies V, VI. Part I, 1931; Part II, 1941.

CLIMATOLOGY OF THE NORTH ATLANTIC

BY J. M. AUSTIN

1. Introduction.

The principal features of the weather over the North Atlantic Ocean have been treated by various investigators. In general we find that the weather characteristics of a particular region have been based either upon a long period of ship and land station observations or upon specific ship expeditions. Unfortunately, however, the various climatological reports are not readily available to every synoptic meteorologist, and it is the purpose of this report to present this climatological material in an abbreviated form.

Because the climatological data is intended to give the weather forecaster a general background of the weather over the North Atlantic, an attempt has been made to accumulate and condense the available information for various regions into a series of simple ocean charts. Furthermore, since aerological information is of vital importance, it was considered desirable to include upper air data wherever possible. The charts, which will be discussed later, have been drawn for four months of the year — February, May, August and November. These months correspond to winter, spring, summer and fall weather conditions over the Atlantic. In many cases, where the change from winter to summer is obvious, only two maps have been included. Likewise, charts were not drawn for every season when it was considered that the information was of only minor importance.

2. Mean Sea-Level Pressure and Wind Charts.

Figures 1 and 2 show the mean sea-level pressure and wind distribution for the months of February and August respectively. These maps were constructed on the basis of data published by Schott.[1] The persistency of winds in excess of Beaufort Force 3 is indicated approximately by the length of the wind arrows.

Both maps show that, in the mean, there is an anticyclone in the south and a cyclone between Greenland and Iceland with a low pressure trough extending from Davis Strait to northern Scandinavia. North of this trough we find the general easterlies of high latitudes. The significant differences between summer and winter may be summarized briefly as follows:

(*1*) The Icelandic low is considerably deeper in winter and there is a correspondingly more intense circulation in winter than in summer. This is illustrated by the large region which is covered by winds in excess of Beaufort Force 6 in winter. It will be observed that the strongest surface winds in winter shift from 35° N in the western Atlantic to near 65° N in the eastern Atlantic. In summer the strongest winds are found in the middle Atlantic about 55°N and near the coast of Africa in low latitudes.

(*2*) The subtropical anticyclone is more developed and more extensive in summer. In comparison to the cyclonic circulation as far south as 30° N in winter, Figure 2 shows that there is, in general, anticyclonic control to 45° N in summer.

(*3*) The latitudinal displacement of the subtropical anticyclone results in a northward shift of the trades in summer.

(*4*) As a result of the intensification of the subtropical high in summer, the prevailing winds in the southwest Atlantic are generally southerly as compared to the winter westerlies.

Since the May and November mean pressure maps are approximately intermediate between Figures 1 and 2, it seemed unnecessary to include these charts.

As seen on the daily weather maps, the change from the summer to the winter type of circulation does not take place gradually through the intermediate season, but the circulation pattern varies erratically from one type to the other for short periods. As the winter season approaches, the winter circulation pattern is more frequently present, the summer pattern less frequently.

3. Ocean Currents in Winter.

The principal winter ocean currents are illustrated in Figure 3 — extracted from Schott.[1] The strength of the currents is indicated by the closeness of the lines on the chart. It will be observed that the general distribution of the ocean currents conforms closely with the prevailing winds which are given in Figure 1. This close agreement results from the fact that the ocean currents are maintained by the stresses which the winds exert on the sea surface. The principal ocean currents may be summarized as follows:

(*1*) North Equatorial Current. This current flows from east to west in the trade-wind region.

(*2*) Gulf Stream System. This system includes the Florida Current, the Gulf Stream and the North Atlantic Current. This circulation of warm water extends as far north as northern Norway, where it is known as the Norwegian Current.

(*3*) East Greenland Current. This is a cold current which branches into the East Iceland Arctic Current and the northward flowing West Greenland Current.

(*4*) Labrador Current. The West Greenland Current reverses its direction in the vicinity of Davis Strait and joins the cold water drainage from Baffin and Hudson Bays. This cold southward flowing current along the coast of Newfoundland and the northeast coastline of the United States is known as the Labrador Current. It is evident from Figure 3 that this cold current results in the presence of icebergs and drift ice to 40° N in the western Atlantic in late spring.

The change from winter to summer in the general features of the ocean currents is relatively unimportant; consequently no diagram of summer ocean currents has been included.

4. Sea Surface Temperature.

Isotherms for the sea surface are shown in Figures 4–7. On these charts two sets of isotherms have been drawn, corresponding to two different sources of data, viz., the Climatic Charts of the Oceans[2] and the "Meteor" Expedition data.[3] The full lines, which were obtained from a great number of observations, are probably more reliable. The "Meteor" data cover the brief period from 1925 to 1927, but it gives a good indication of the temperature north of 60° N.

It will be seen from the maps that, in all seasons of the year, there is warm water on the western side of the ocean in low latitudes and on the eastern side in high latitudes. This general distribution of sea surface temperatures is a result of the Gulf Stream System and of the Canaries Current off the coast of North Africa. It is further evident that east and south of Newfoundland, where the Labrador and Gulf Stream Currents are in close proximity, there is a pronounced temperature gradient throughout the year. A less intense temperature gradient is observed east of Greenland. In low latitudes the temperature gradient is always small.

Figure 6 shows a minor temperature minimum along the west coast of Africa. This is due to the presence of northerly winds which produce an upwelling of cold water near the coast. As a result of the upwelling, we find that at 30° N in the summer the water on the western side of the Atlantic is about 8° C warmer than the water on the eastern side.

5. MEAN AIR TEMPERATURE.

The mean air temperatures for four months of the year are illustrated in Figures 8–11. The data from which the charts were constructed was obtained from the Climatic Charts of the Oceans[2] (up to 60° N), Schott[1] (north of 60° N) and Brooks[4] (North America).

These figures show that over the ocean the isotherms are similar to those of sea surface temperature in Figures 4–7. This agreement would be expected, since the properties of any air mass are greatly modified by the underlying sea surface, and consequently the air temperature will always approach the sea surface temperature. The principal features of Figures 8–11 are summarized below:

(1) In all seasons of the year the Gulf Stream system causes warmer air to be along the northeast side of the ocean than along the northwest side. In low latitudes in winter there is practically no contrast between the eastern and western Atlantic, whereas in summer the eastern side is colder than the western side. This is due to the upwelling of cold water which is produced by the northerly winds in summer.

(2) In winter the air over the oceans is considerably warmer than the air over the adjacent land masses. Conversely, in summer the air over the land is generally slightly warmer than the air over the ocean. This results from the small variation in ocean temperature with season as compared to the pronounced temperature change from winter to summer over the land.

(3) The largest temperature gradients are found in winter, particularly along the eastern coastline of North America and Greenland. The sharp temperature contrast along the east coast of North America is due to the frequent presence of cold polar continental air over the land, while over the ocean we have warmer maritime air. As the cold continental air is swept over the ocean by the winds (see Figure 1), it is rapidly heated by the warmer underlying surface. The resultant turbulent and convective mixing will produce an unstable stratification. After the air has been over the ocean for a short time, its temperature will be only a few degrees cooler than the ocean temperature. The maximum temperature gradient, therefore, is found where the heating is greatest, viz., near the east coast of North America. The very steep gradient shown east of Greenland can be similarly explained. The extreme gradient is also due to the presence of the high Greenland plateau close to the ocean. The air over the plateau is generally very cold during the winter months.

(4) From the above discussion we should expect to find the maximum difference between air and sea temperature in winter along the northwestern edge of the Atlantic. This expectation is borne out by a comparison of Figures 4 and 8. Because the air over the eastern Atlantic, south of 60° N, will have had a long trajectory over the ocean, we find that the air temperature is approximately the same as the ocean temperature in this region.

(5) Figure 10 shows that the temperature gradients are much less in summer than in winter. This results from the absence of vast differences between the

note: the coastal water is still cooler than the Gulf Stream and is cooler than the land too.

temperature of the land and that of the ocean, and therefore there will be no region where air will be rapidly heated or cooled. A comparison of Figure 6 and Figure 10 shows that in northern latitudes the air temperature is slightly higher than the ocean temperature.

(6) Figures 9 and 11 represent the distribution of temperature in spring and fall, respectively. In general the spring map is similar to the summer map, while the fall chart more closely resembles the winter chart.

(7) In all seasons a temperature trough is observed about longitude 50° W and east of Newfoundland. This is a result of the southward flow of cold water — Labrador Current — as shown in Figure 3.

6. Temperature Extremes.

Figures 12 and 13 give an estimate of mean low air temperatures in winter and summer. These charts have been drawn on the basis of observations of the average temperature in direct polar and arctic air outbreaks. The isotherms were obtained from charts drawn by Petterssen[5] and minor adjustments were made after a study of Northern Hemisphere weather maps. The dotted line in Figure 12 is intended to indicate the southernmost limit of the 0° C isotherm in any winter.

It will be seen that the orientation of isotherms is similar to Figures 8 and 10. The lowest temperatures are observed in the western Atlantic as a result of the cold outbreaks which originate in the Hudson Bay region. The southward dip of the isotherms in the North Sea in winter is due to the proximity of the cold land masses.

7. Frequency of Gales.

The frequency of strong surface winds has been indicated in Figures 14 and 15 for February and August respectively. The data for these charts was obtained from the Climatic Charts of the Oceans,[2] and the isolines represent the percentage frequency of winds of Beaufort Force 7 or higher.

It is evident that the most frequent period of strong winds is found in winter. The strong winds are associated with the deep cyclones of the Icelandic system which is shown in Figure 1; the maximum frequency appears centered southeast of Greenland. The maximum in the western Atlantic is probably the result of the strong winds north of the mean position of the Polar Front, as shown in Figure 16. Figure 2 shows a much weaker circulation, and we see from Figure 15 that gales are much less frequent in summer than in winter. Gales are comparatively rare in low latitudes, due to the presence of the subtropical anticyclone.

In view of the lack of data the charts were not extended beyond 60° N. However, from a study of Figures 1 and 2, it would be expected that the isolines would be approximately parallel to the Norwegian coast. Probably the region of maximum frequency would be located to the north of mean position of the Arctic Front in Figure 16.

8. Mean Air Currents and Air Masses over the Atlantic.

T. Bergeron[6] has investigated the mean position of air masses over the Atlantic in winter, and his conclusions are presented in Figure 16. The wind arrows on the chart were obtained from Schott[1]. The fronts are the mean position of non-occluded fronts. The percentage frequency lines represent the percentage of days when non-occluded fronts were located within the nearest 5° square during January and February for the years 1933 to 1935.

Because the study was made of non-occluded fronts we find a relatively low frequency of fronts south of Greenland. The majority of the low pressure systems near this region will be deep occluded cyclones.

The Atlantic Polar Front, in middle latitudes, oscillates within a wide zone. The main source of temperature contrast is the difference in temperature between the polar continental air of North America and the tropical maritime air of the ocean. The frontogenetical wind field is the field of deformation between the cold continental and warm subtropical anticyclones. It will be seen that the mean position of the front is such that the prevailing wind systems are nearly parallel to the front. When the wind is tangential to the front, the front will be quasi-stationary, and this probably accounts for the observed region of maximum front occurrence. The most intense fronts will most likely coincide with the region of maximum temperature contrast near the east coast of North America when the synoptic situation is favorable for a quasi-stationary front in this vicinity. Since most fronts move off the land with a moderate speed, this region of occasional intense frontogenesis will not be a statistical maximum of front occurrence.

The Atlantic Arctic Front derives its temperature contrast from the difference in the temperature of the cold Arctic air and the warmer air of the western Atlantic. The frontogenetical wind field is the convergent wind system located in the extensive trough from Iceland to northern Scandinavia. Petterssen[5] has stated that frontogenesis is most active in this region when the Icelandic low is located further to the east than normal and that it is non-existent when the cold air from the European continent streams toward the northwest. In the latter case the front will disappear, due to the absence of a warm air mass.

In the eastern Atlantic from the subtropics to about 55° N we find frequent invasions of tropical maritime air. As this air flows northward, it will be cooled from below and the resulting hydrometeors will be fog and drizzle. In the northwestern Atlantic the principal air mass will be modified polar continental air, cold air which has been rapidly heated from below. Due to the instability which arises from this heating, cumulus type clouds and showers should prevail. As this air streams further eastward and finally northeastward, the heating from below will cease, and consequently the shower frequency will be considerably diminished. Orographic lifting along northwestern Europe will give rain over the land.

The high frequency of fogs east of Newfoundland is mainly due to the advection of warm maritime air over the cold Labrador current. The cooling of the maritime air will result in an extensive region of fog.

No attempt has been made to produce a similar map for the summer. In the summer the fronts are much weaker, and we have seen that a vast area of the Atlantic is under the influence of the subtropical anticyclone. The Atlantic Polar Front will be indistinct and the main frontal system will be the Arctic Front which extends from Iceland along the northern coast of Europe and Asia.

9. Average Cloudiness.

The cloudiness maps, Figures 17 and 18, show the average cloudiness in tenths of the sky covered, in winter and summer respectively. The data for these charts was obtained from the Climatic Charts of the Oceans[2] (to 60° N), the Köppen-Geiger Handbuch[7] (beyond 60° N and Scandinavia), and Climatic Maps of North America.[4]

Figure 17 shows that north of 40° N the average cloudiness exceeds 7/10ths throughout the Atlantic. This relatively high cloudiness is the result of the intensive cyclonic circulation which will result in frontal and air mass clouds. South of 35° N frontal clouds will be less frequent, due to the absence of strong frontal systems. Likewise, as the result of subsidence, air mass clouds will be less frequent in the lower latitudes. It is evident that the degree of cloudiness increases considerably in the vicinity of the North American coastline. The presence of polar continental air over the land in winter results in comparatively clear skies over the land, but when this air passes over a warmer water surface the subsequent heating from below will cause an increase in the amount of cloudiness. This effect is present over the Great Lakes, where we find over 7/10ths cloudiness. Observations over the Atlantic have shown that stratus and strato-cumulus clouds are the most frequent north of 40° N.

Over the ocean in summer the amount of cloudiness is slightly less than in winter. Moreover, the type of clouds differs somewhat from winter to summer. In summer we find a higher percentage of cumulus type clouds, especially in the low latitudes. Furthermore, over land the summer heating causes a considerable increase in the cumulus cloud types.

The total amount of cloudiness over the ocean is found to change only slightly from one season to another. The most pronounced change is perhaps the decrease in the cloud frequency near latitude 30° N in summer. This minimum of cloudiness is the result of subsidence within the extensive subtropical anticyclone.

10. Precipitation Frequency.

The frequency of occurrence of precipitation is indicated in Figures 19 and 20. This data was obtained from the Climatic Charts of the Oceans[2] and from the Köppen-Geiger Handbuch.[7] The most frequent region of winter precipitation in the Atlantic coincides with the mean position of the Atlantic Polar Front. Unfortunately there was no data available for the Atlantic beyond 60° N. However, it is quite likely that the maximum region of precipitation frequency is between southern Greenland and Iceland, *i.e.*, near the mean low pressure center of Figure 1. Likewise, precipitation should be quite frequent in the vicinity of the Arctic Polar Front. It is evident from Figure 19 that precipitation is more frequent along western Europe than along eastern North America. This is due not only to the deep cyclones approaching Europe but also to the prevailing winds which give orographic precipitation along northwestern Europe.

As in the case of cloudiness, the frequency of precipitation in summer is less than in winter, but the general features of the two charts vary only slightly from season to season. It is important to note that precipitation is less frequent in low latitudes than in high latitudes. The precipitation of low latitudes is generally in the form of heavy convective showers.

11. Fog Frequency.

In Figures 21 and 22 the frequency of fog has been illustrated for winter and summer respectively. The oceanic data was obtained from the Climatic Charts of the Oceans,[2] whereas the land station data was obtained from the Köppen-Geiger Handbuch.[7]

It is obvious from the maps that fog occurs more frequently over the ocean in summer than in winter. In summer the fog frequency along the northeast coast of North America is very high. This is due to the presence of cold water. Advection of air from the land or the neighboring ocean will result in a cooling from below, and consequently in the formation of fog. Over the North Sea the principal cause of fog is the advection of warm air from Europe. This gives a maximum fog frequency in early summer. The light or moderate winds during the summer are also favorable for the maintenance of fog.

In winter the air from the land is heated from below and therefore this type of advection will not produce fog, except extreme cases of steam fog. Due to the cold coastal water near Newfoundland, fog will be formed when air is brought into this region from the neighboring Atlantic. This is a less frequent occurrence in winter than in summer. Fog due to radiational cooling of the maritime air is found over the land regions of northwestern Europe. In general, the stronger winds during the winter will result in low clouds rather than surface fog.

12. Upper Winds.

An attempt has been made to accumulate all available upper air data in order to show the upper air circulation in the various seasons. The sources of data[7,8,10] for Figures 23 and 24 are given in the Bibliography. The wind roses have been constructed so that the wind direction frequency is indicated by the length of the arrow and the average velocity is given in miles per hour by the number at the end of the arrow.

It is evident from the wind roses in Figure 23 that the upper winds vary not only in direction but also in velocity. At 1½ km. we find a decided maximum of west to northwest winds over the northeastern United States and Canada, with velocities averaging from 30 to 40 m.p.h. In the southern United States the winds are more westerly and the average velocity is about 25 m.p.h. Because the prevailing surface winds south of 55° N are westerly in the Atlantic, we should expect to find general westerly winds at 1½ km. with velocities higher than those at the surface. Consequently, in the middle Atlantic general west winds of about 40 m.p.h. would be expected. Since the Icelandic low is to the west, we find more southwesterly winds in the vicinity of the British Isles. Over Iceland the wind direction is more variable, but, consistent with the mean position of the low pressure to the west, southerly winds are predominant. Likewise, frequent southerly winds are observed on the west coast of Greenland when there is a low in the Baffin or Hudson Bay regions. It is only in low latitudes that consistent east winds are observed — the Trade Wind belt. The 3 km. winds differ only slightly in direction from the 1½ km. winds. Summarizing the main features of the winter upper air circulation, we can say:

(*1*) From 30° N to 55° N the prevailing winds are northwesterly over the western Atlantic, westerly over the mid-Atlantic, and southwesterly along northwestern Europe. These west winds increase in velocity with elevation and are probably strongest about longitude 60° W.

(*2*) South of 25° N the upper winds are easterly and the average velocity diminishes with elevation.

(*3*) Over Greenland the winds are more predominantly southerly, while from Iceland northward there is a considerable variation in wind direction. The direction at any time will depend on the location of the deep cyclones which frequent this region. However, it is evident that when the winds are westerly they increase in velocity with elevation, and when they are easterly the velocity decreases with elevation.

13. Mean Icing Charts.

An attempt has been made to indicate the lower level at which aircraft icing might be expected in winter and summer. Figures 25–28 show the height of the 0° C isotherm; this temperature has been considered as the upper temperature limit for icing. The diagrams were constructed from the sea level temperatures by assuming a moist adiabatic lapse rate above the sea surface. This assumption is a reasonable one in cases of fresh winds, showery weather conditions, cyclonically curved isobars and for air which is being heated from below. When air is cooled from below or when the winds are light, the average lapse rate is probably less than the moist adiabatic. In general, any evidence of atmospheric stability will mean that the existing lapse rate will be less than the moist adiabatic. Whenever the lapse rate is less than the moist adiabatic, the computed height of the 0° C isotherm will always be too low.

In Figure 25 the mean heights are probably approximately correct, due to the strong winds and frequent deep cyclonic systems in winter. In low latitudes near the subtropical anticyclone, the estimated heights may be too low. In Figure 27, when we are considering direct outbreaks of polar continental air, the values should be approximately correct.

During the summer months, general subsidence in the subtropical anticyclone and light winds will result in a lapse rate which is less than the moist adiabatic. An attempt has been made to apply a correction to the summer values. This was achieved by extrapolating from the 10,000-foot temperatures at Newfoundland. On the basis of the Newfoundland check, the corrected height lines were drawn on Figure 26. In all likelihood these average figures are the least accurate of the four icing charts. In Figure 28 the moist adiabatic lapse rate was taken as the average lapse rate. This appears a reasonable assumption for those situations when direct outbreaks of polar air occur in summer.

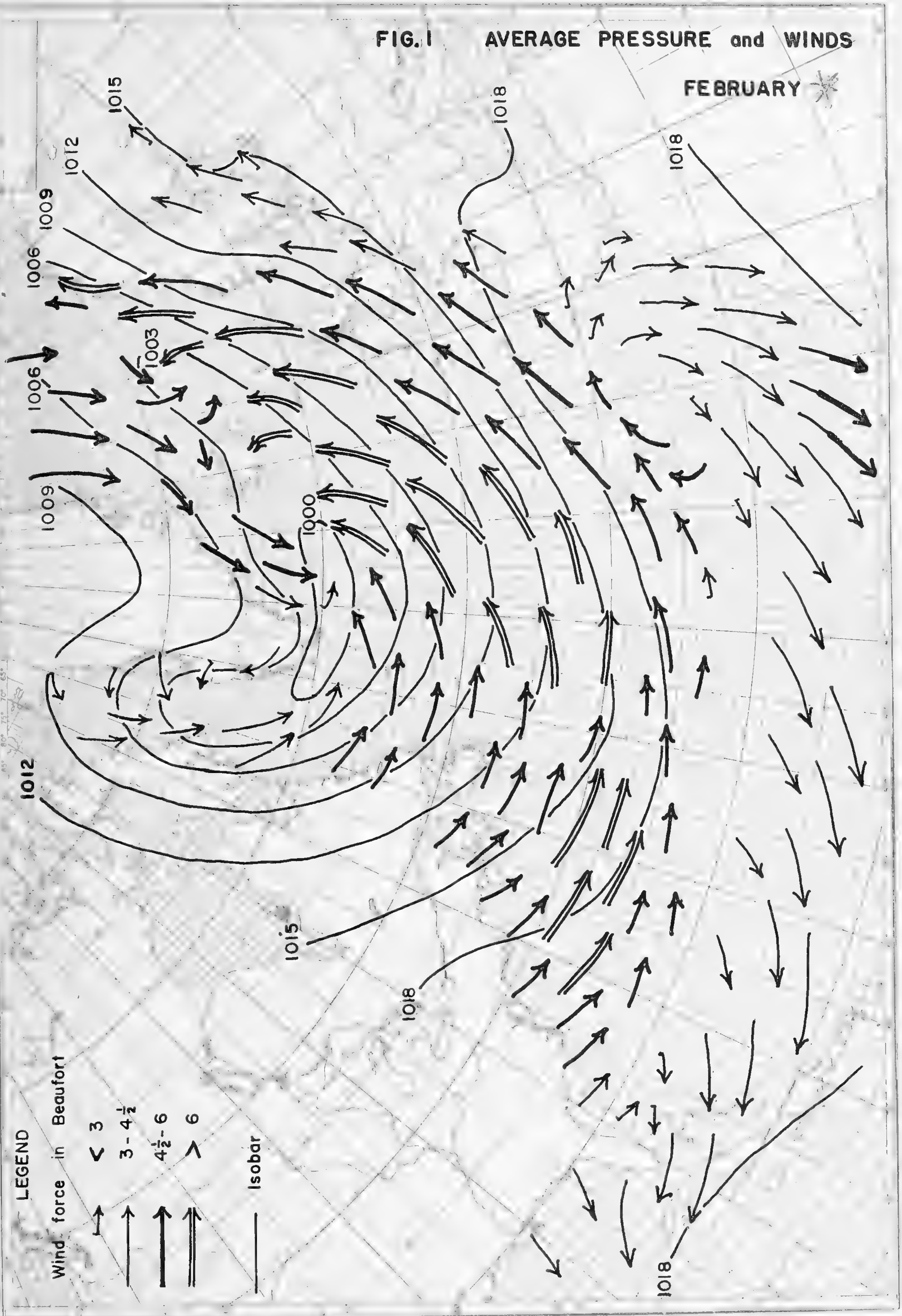
Only the lower limit of icing has been indicated since the upper limit will depend greatly on the particular synoptic situation. An approximate temperature of −15° C might be assumed as a lower temperature limit, and with this temperature we should find the icing region to be about 8,000 feet thick.

In order to illustrate the figures presented in the above diagrams, let us consider the cloudy region 55° N 30° W. In winter the average height of the lower limit of icing would be about 4,000 feet with extreme low values of about 1,000 feet. In summer the average height may be about 10,000 feet with extreme low values of about 6,000 feet.

Due to the complex nature of the icing problem, no attempt has been made to estimate the severity of the icing. On the other hand, more severe icing would, in general, be expected in winter because of the frequent occurrence of unstable weather conditions.

FIG. I AVERAGE PRESSURE and WINDS

FEBRUARY



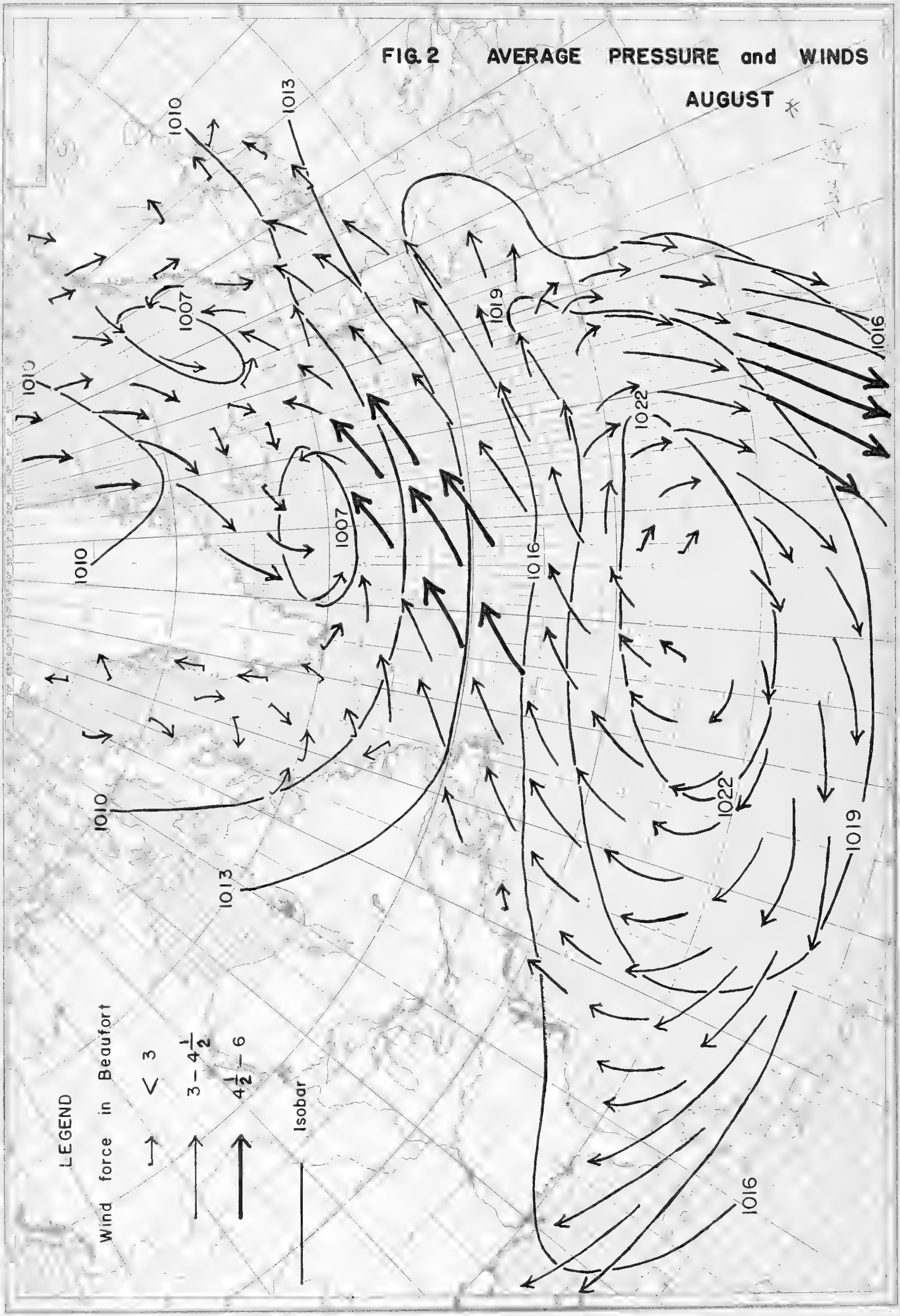


FIG. 2 AVERAGE PRESSURE and WINDS AUGUST

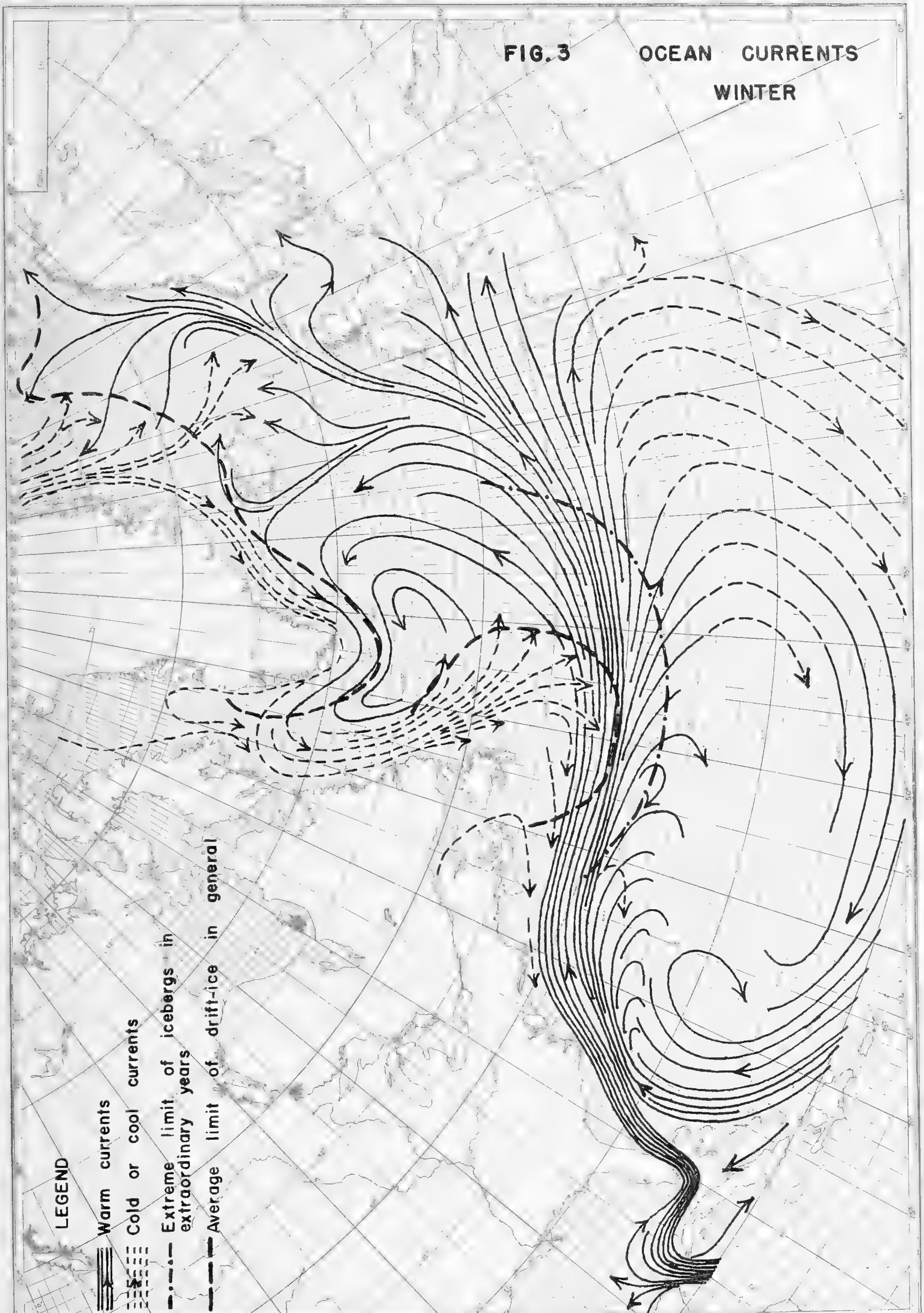
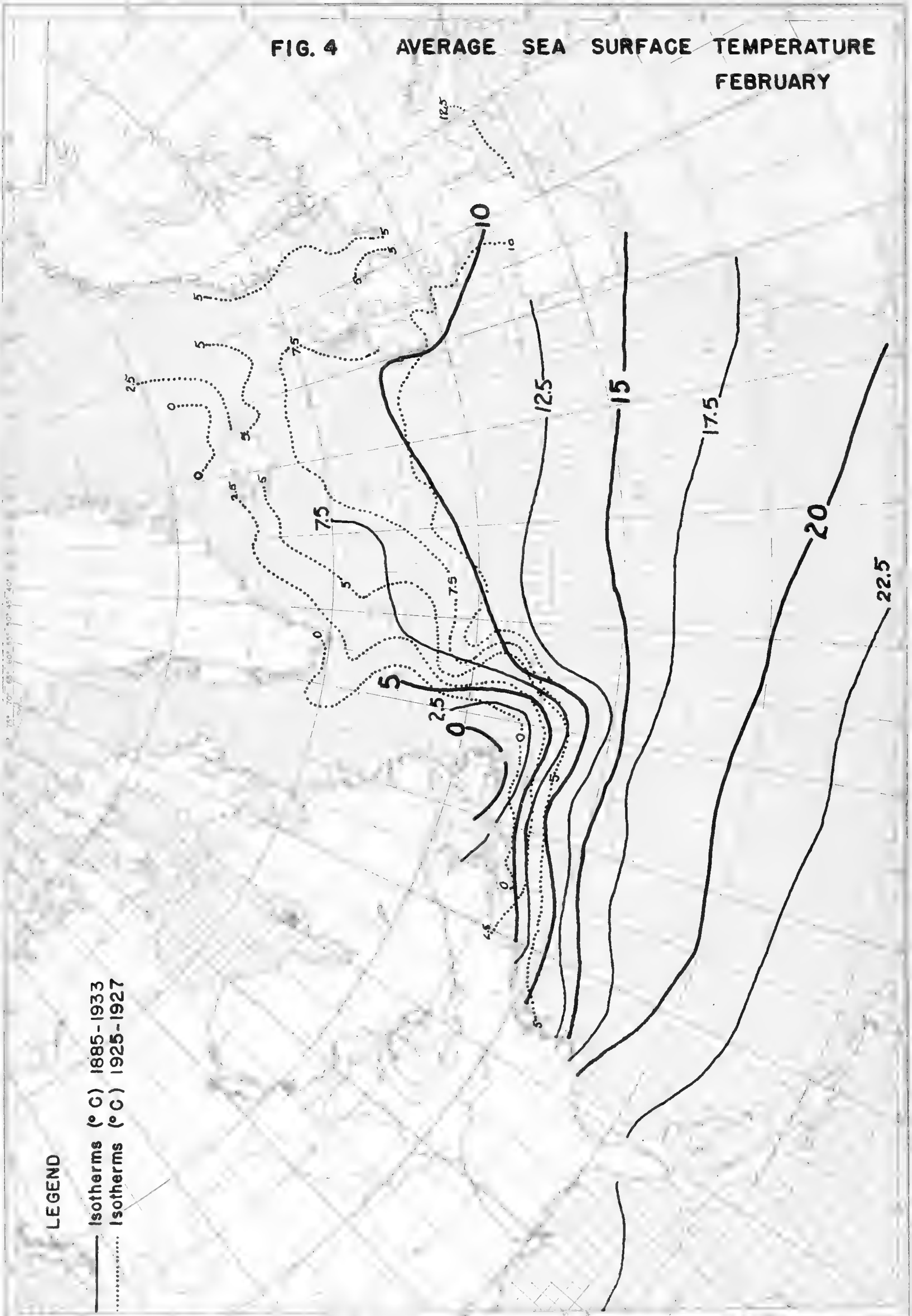


FIG. 3 OCEAN CURRENTS WINTER

FIG. 4 AVERAGE SEA SURFACE TEMPERATURE FEBRUARY



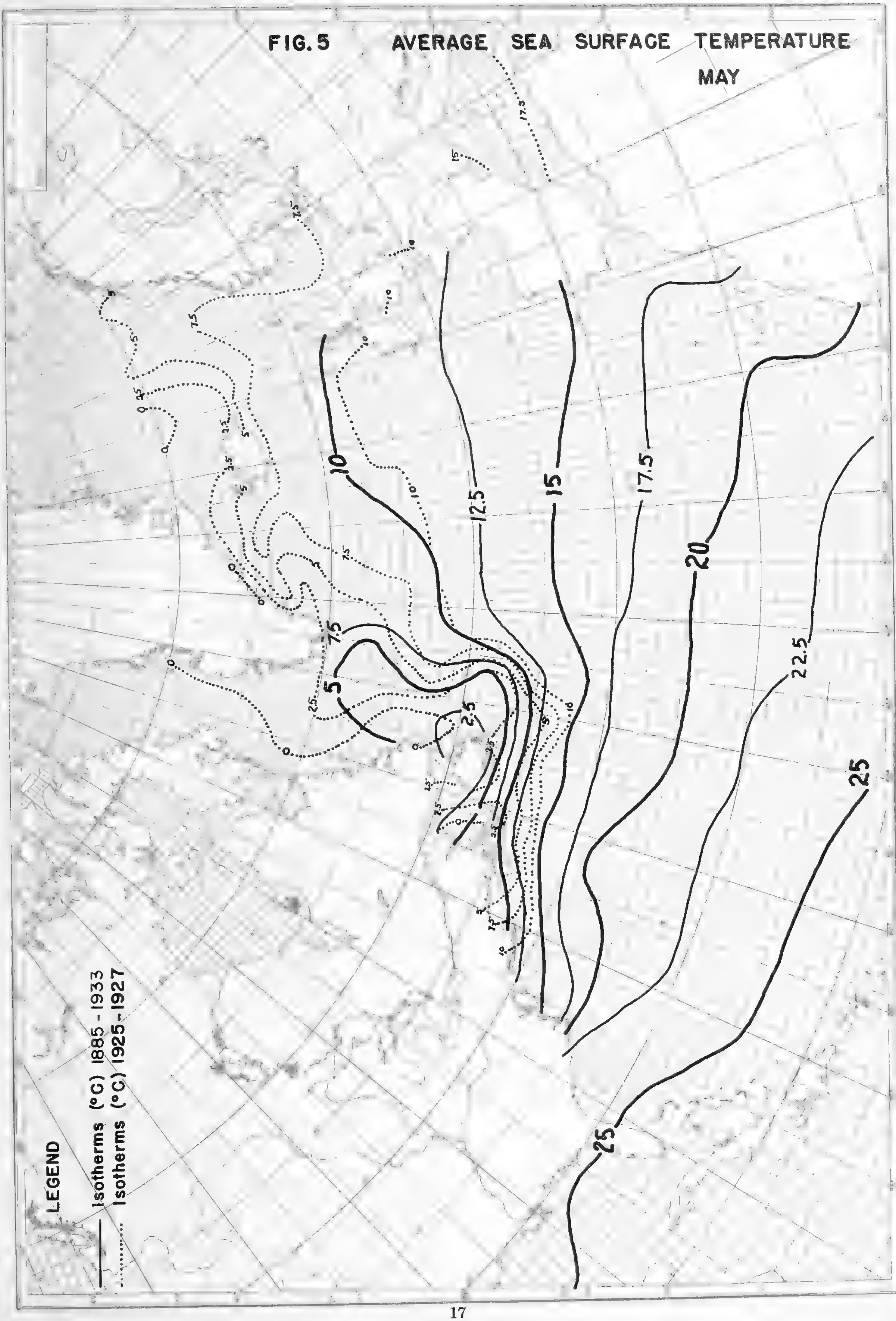


FIG. 5 AVERAGE SEA SURFACE TEMPERATURE
MAY

FIG. 6 AVERAGE SEA SURFACE TEMPERATURE AUGUST

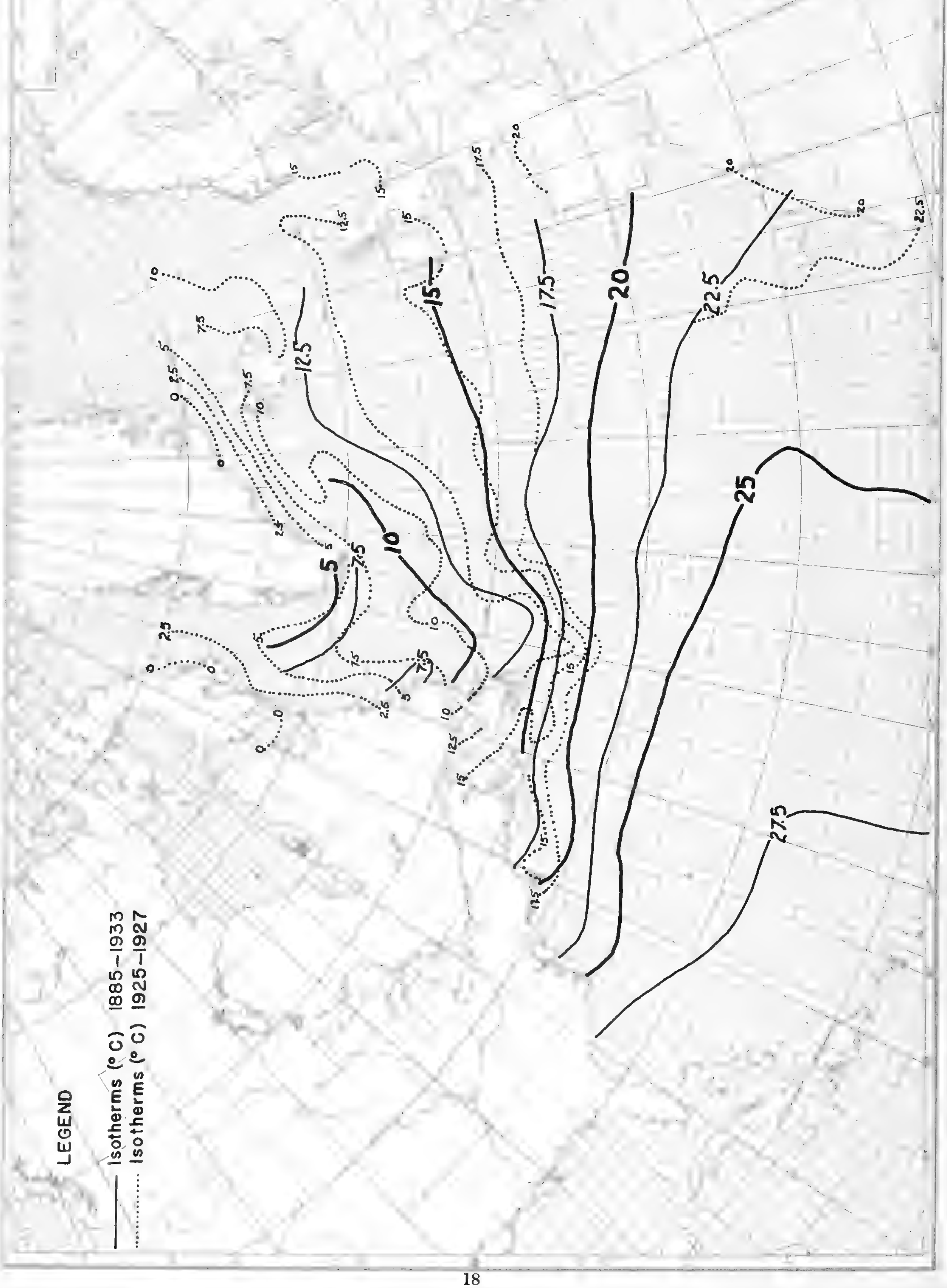
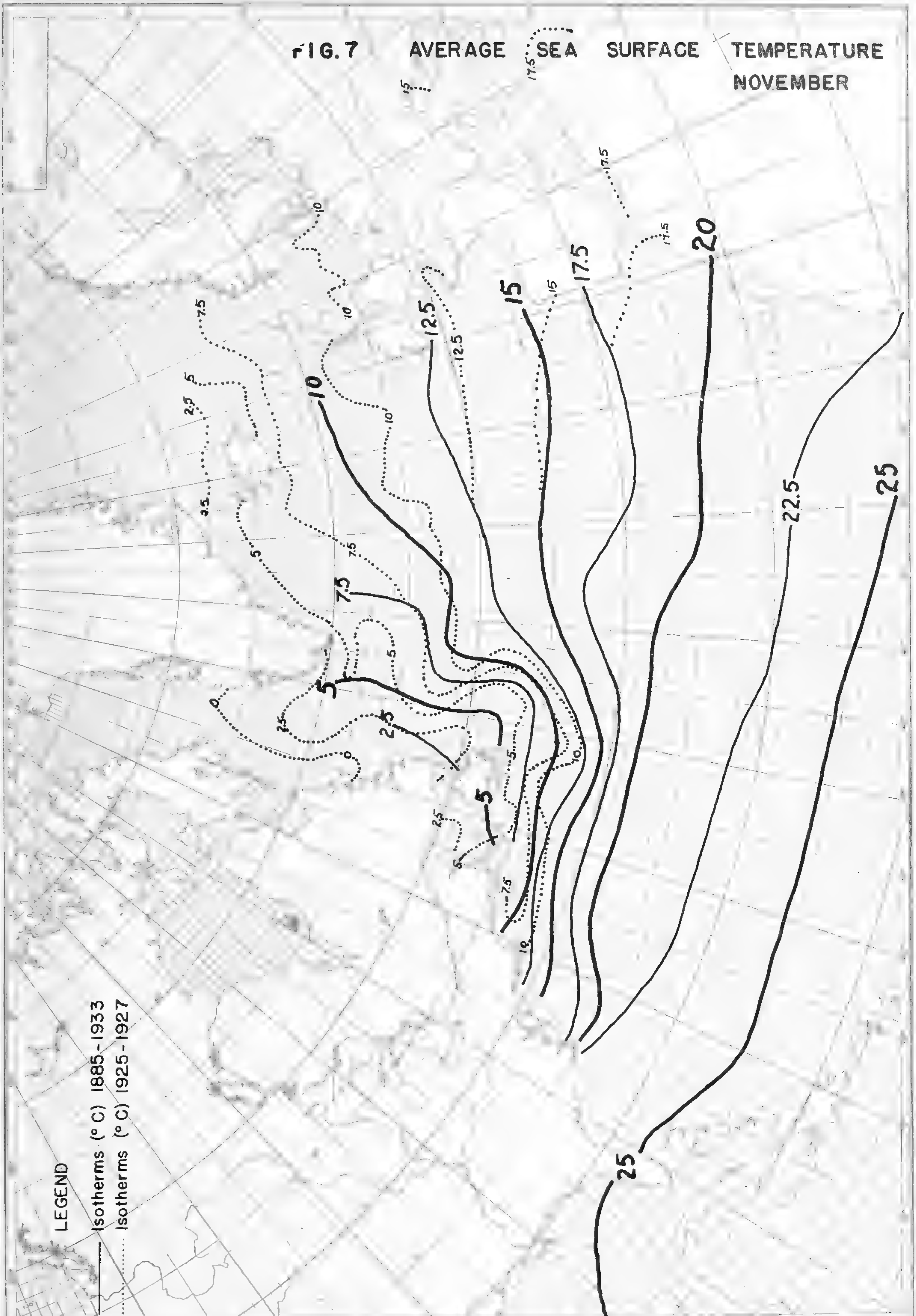


FIG. 7 AVERAGE SEA SURFACE TEMPERATURE NOVEMBER



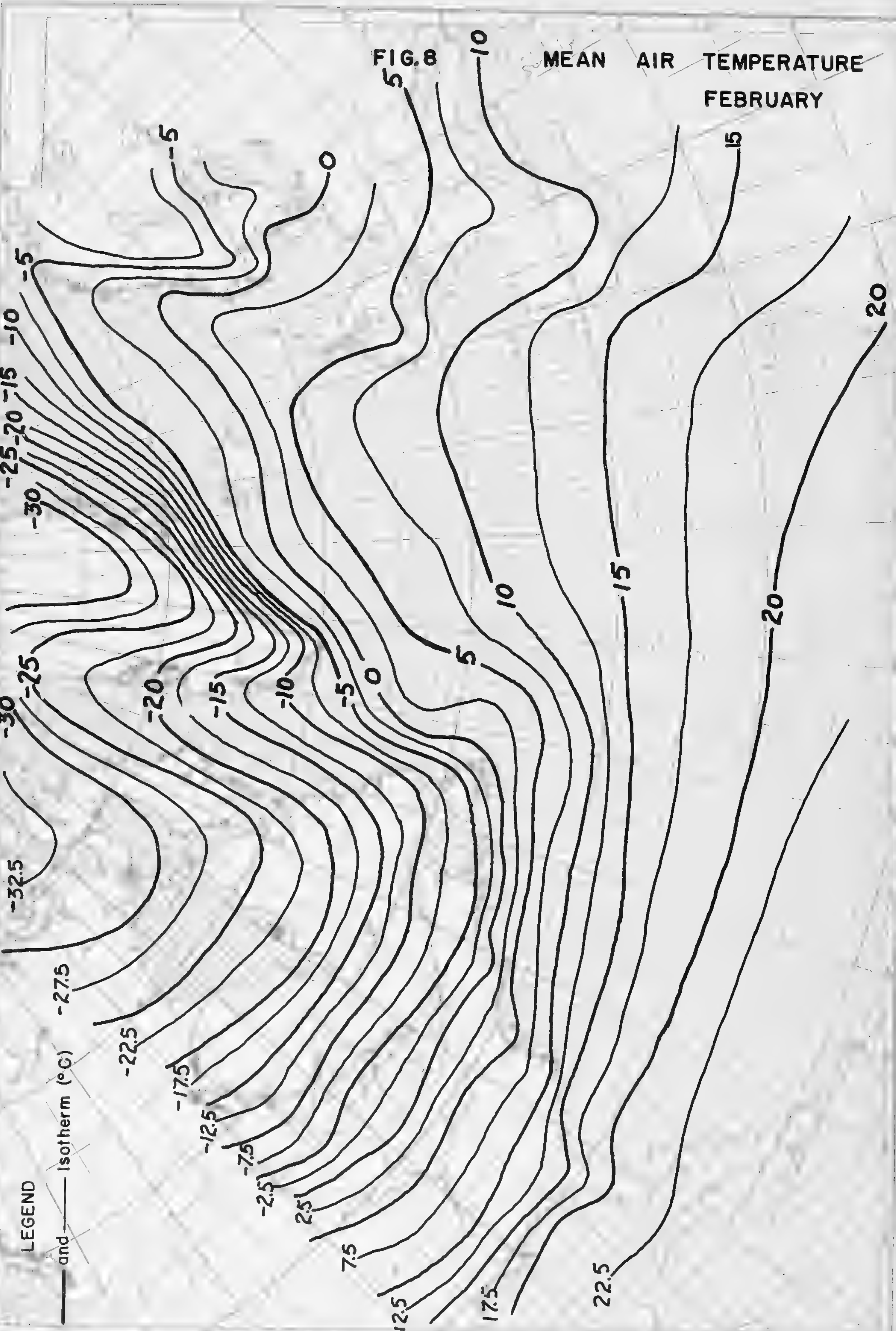
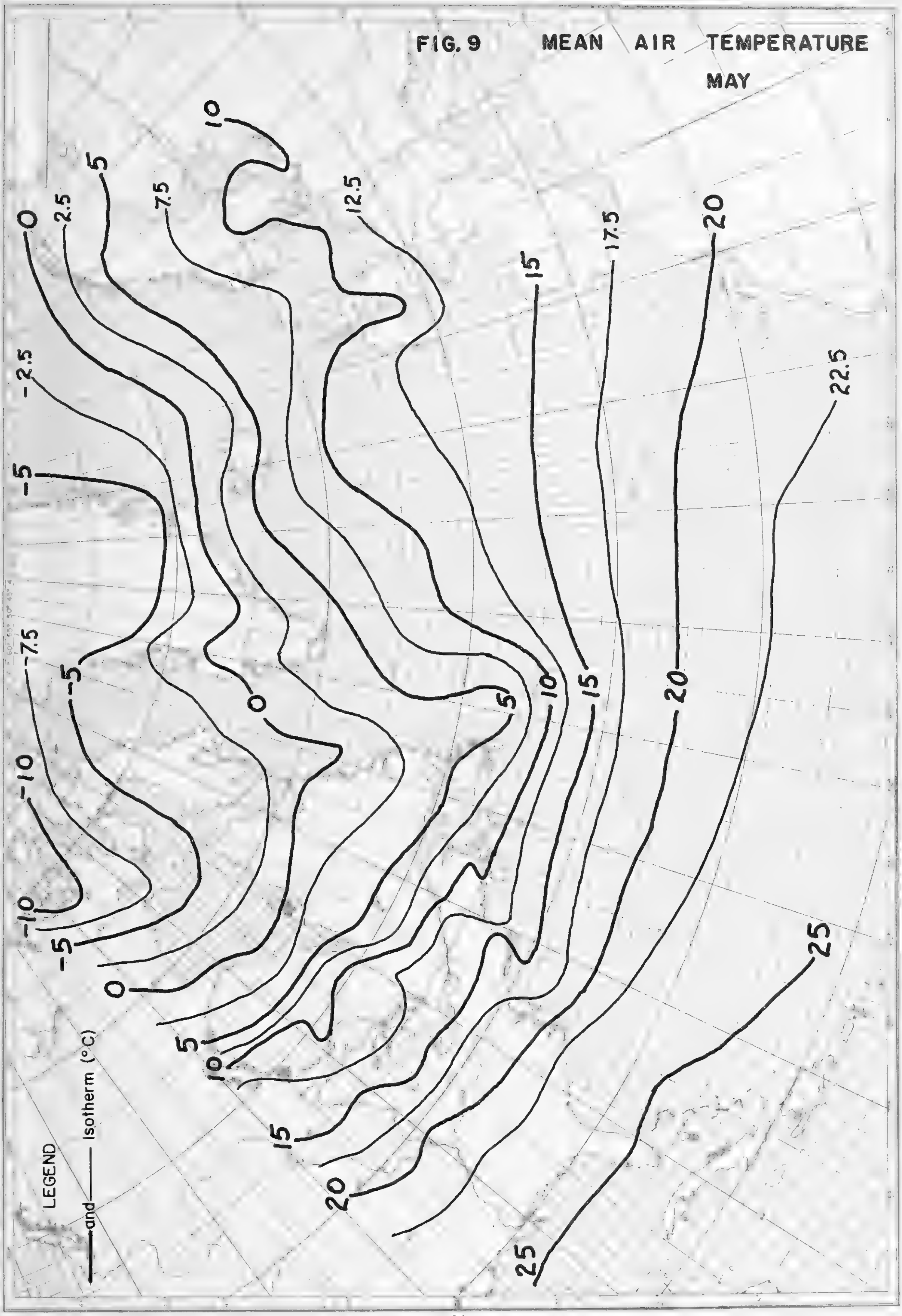


FIG. 8 MEAN AIR TEMPERATURE FEBRUARY

FIG. 9 MEAN AIR TEMPERATURE
MAY



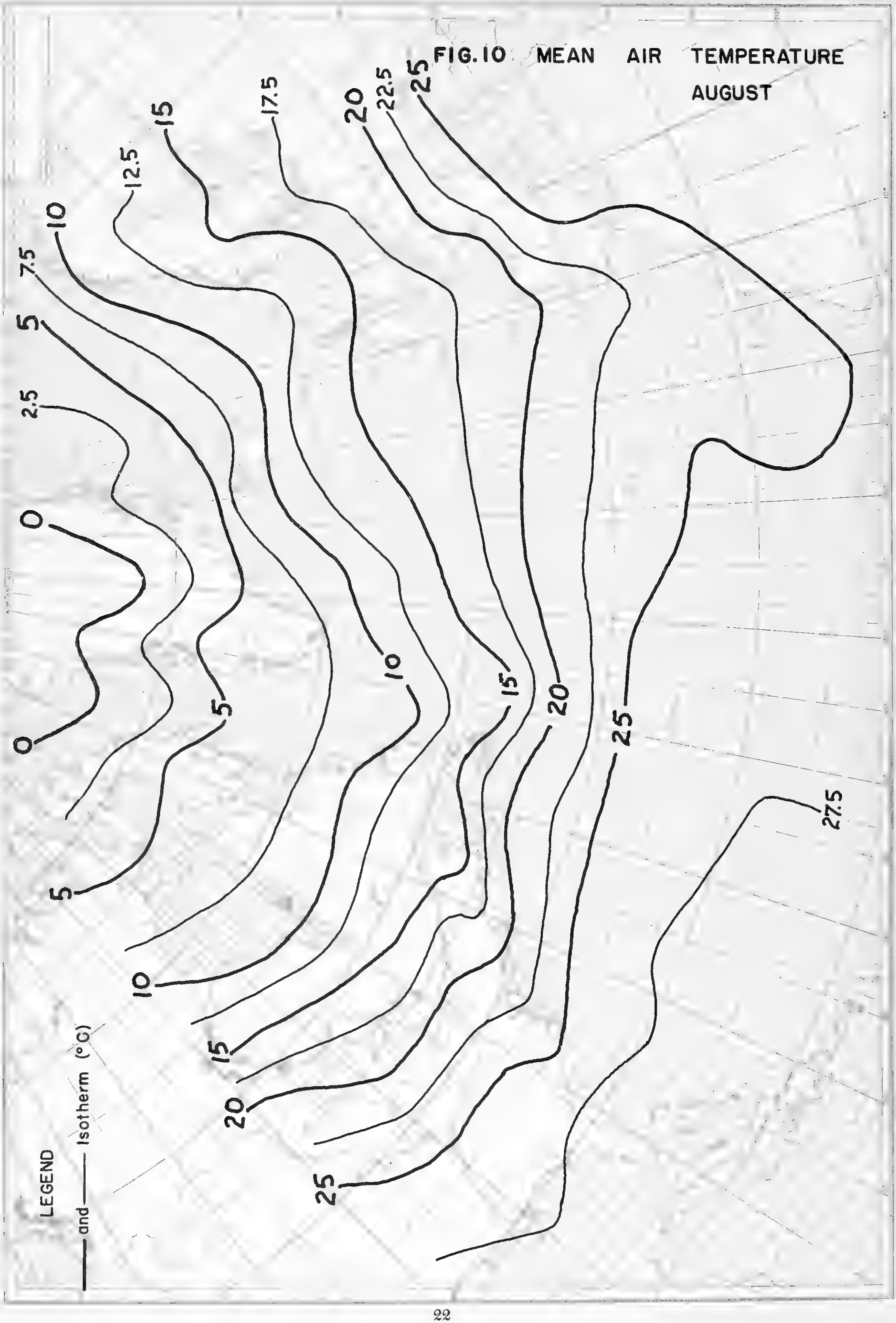


FIG. 10 MEAN AIR TEMPERATURE
AUGUST
LEGEND
—— and —— Isotherm (°C)
0
2.5
5
7.5
10
12.5
15
17.5
20
22.5
25
27.5

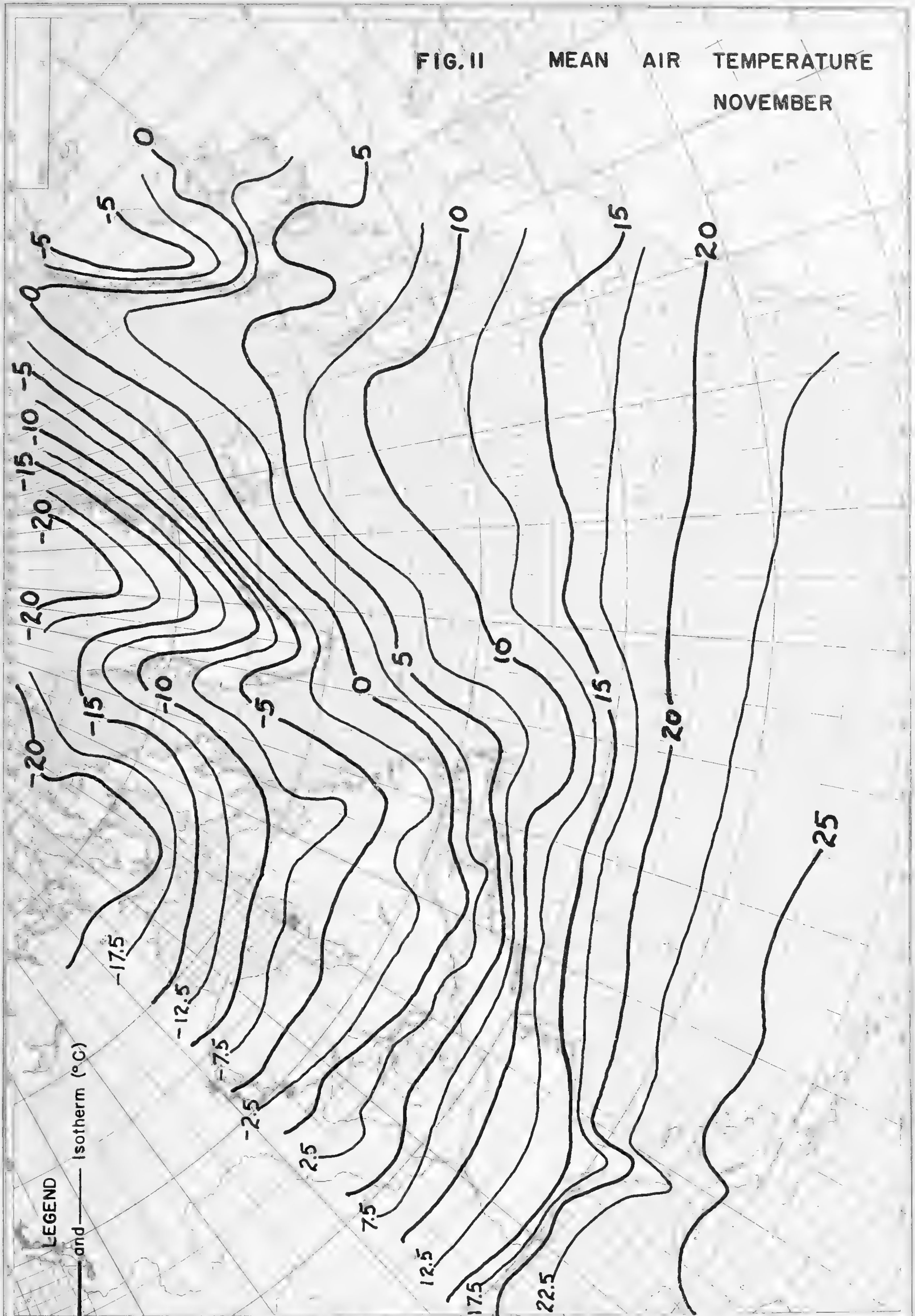


FIG. 11 MEAN AIR TEMPERATURE NOVEMBER

FIG. 12 MEAN AIR TEMPERATURE in DIRECT POLAR AIR MASSES

WINTER

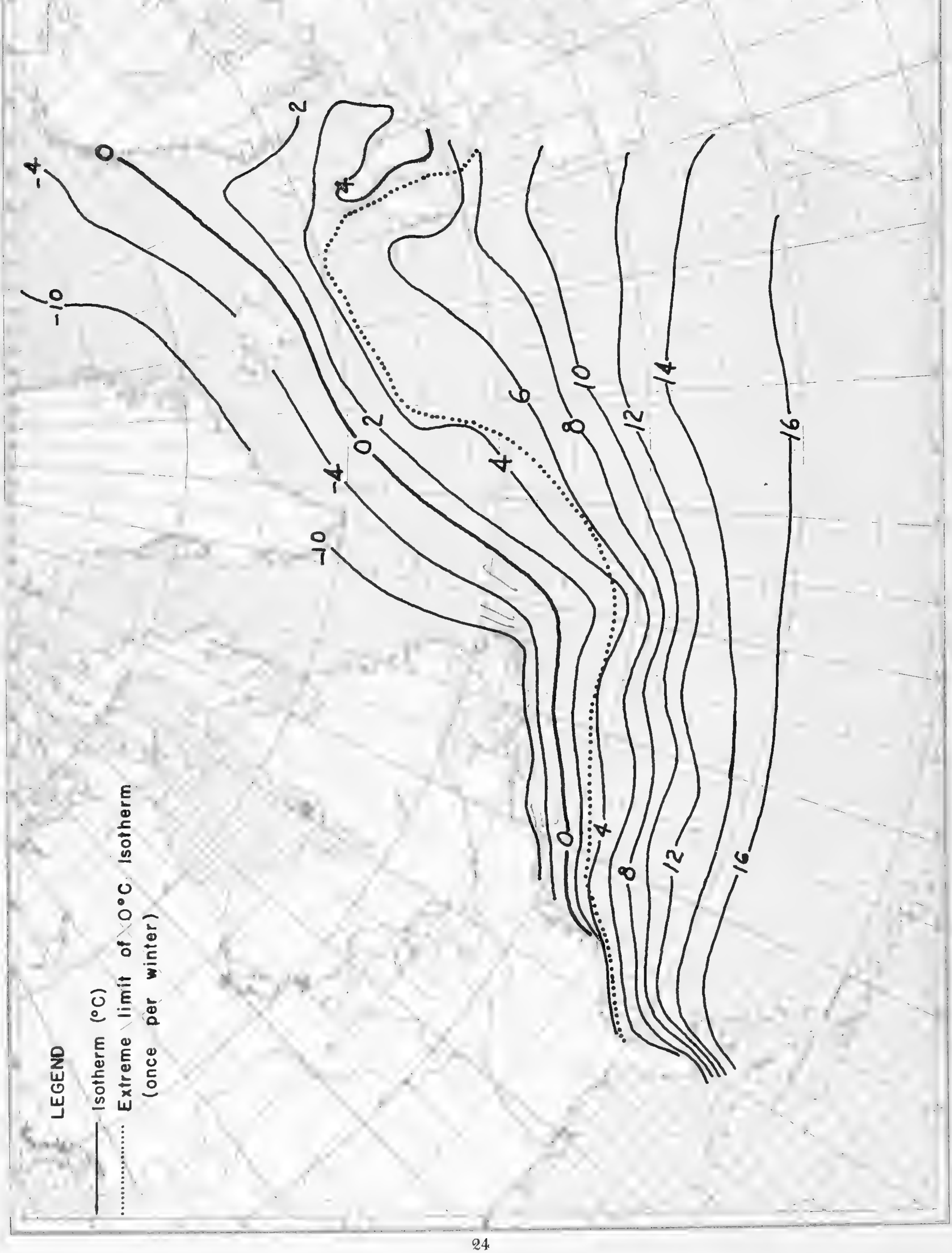
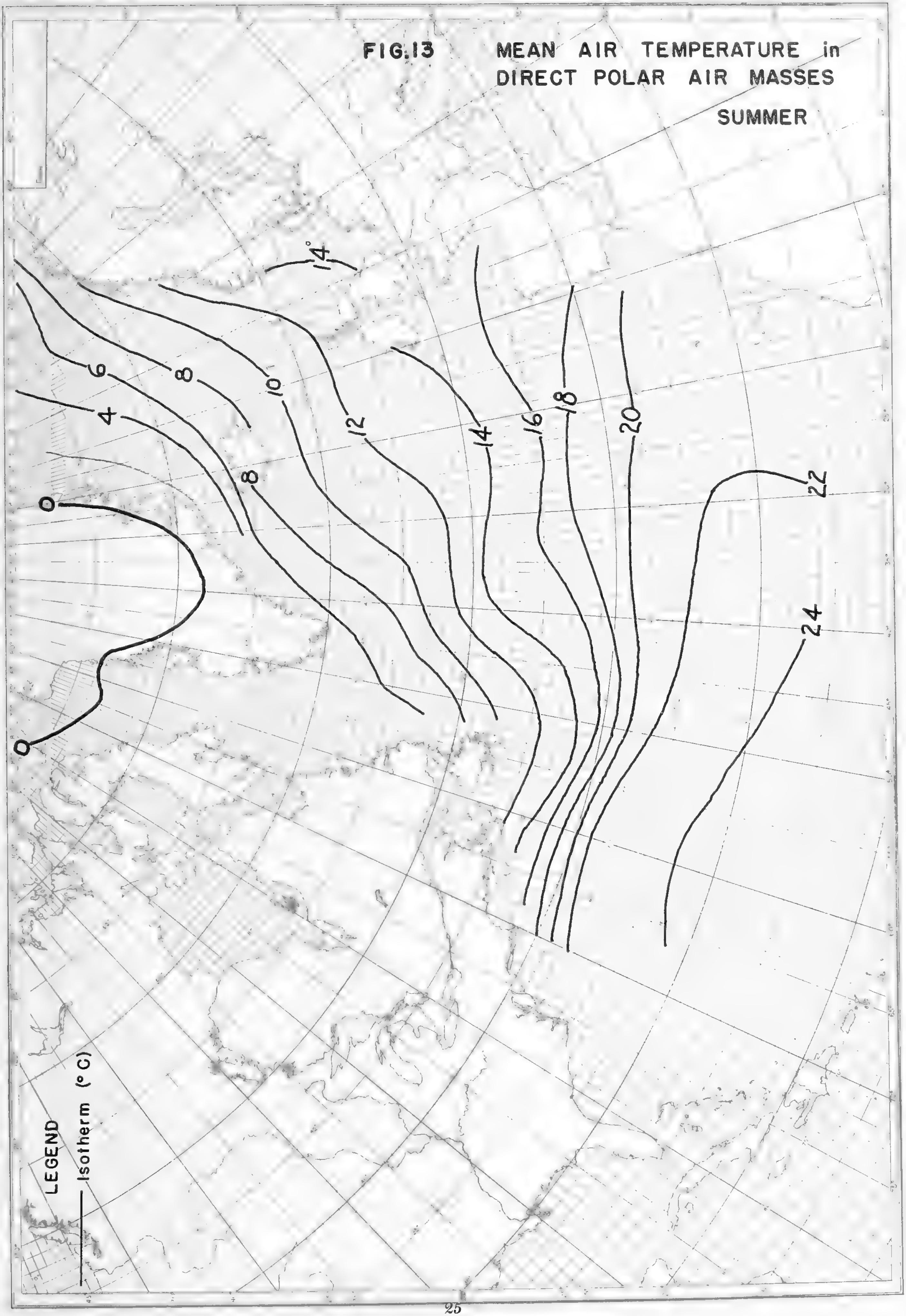


FIG.13 MEAN AIR TEMPERATURE in DIRECT POLAR AIR MASSES

SUMMER



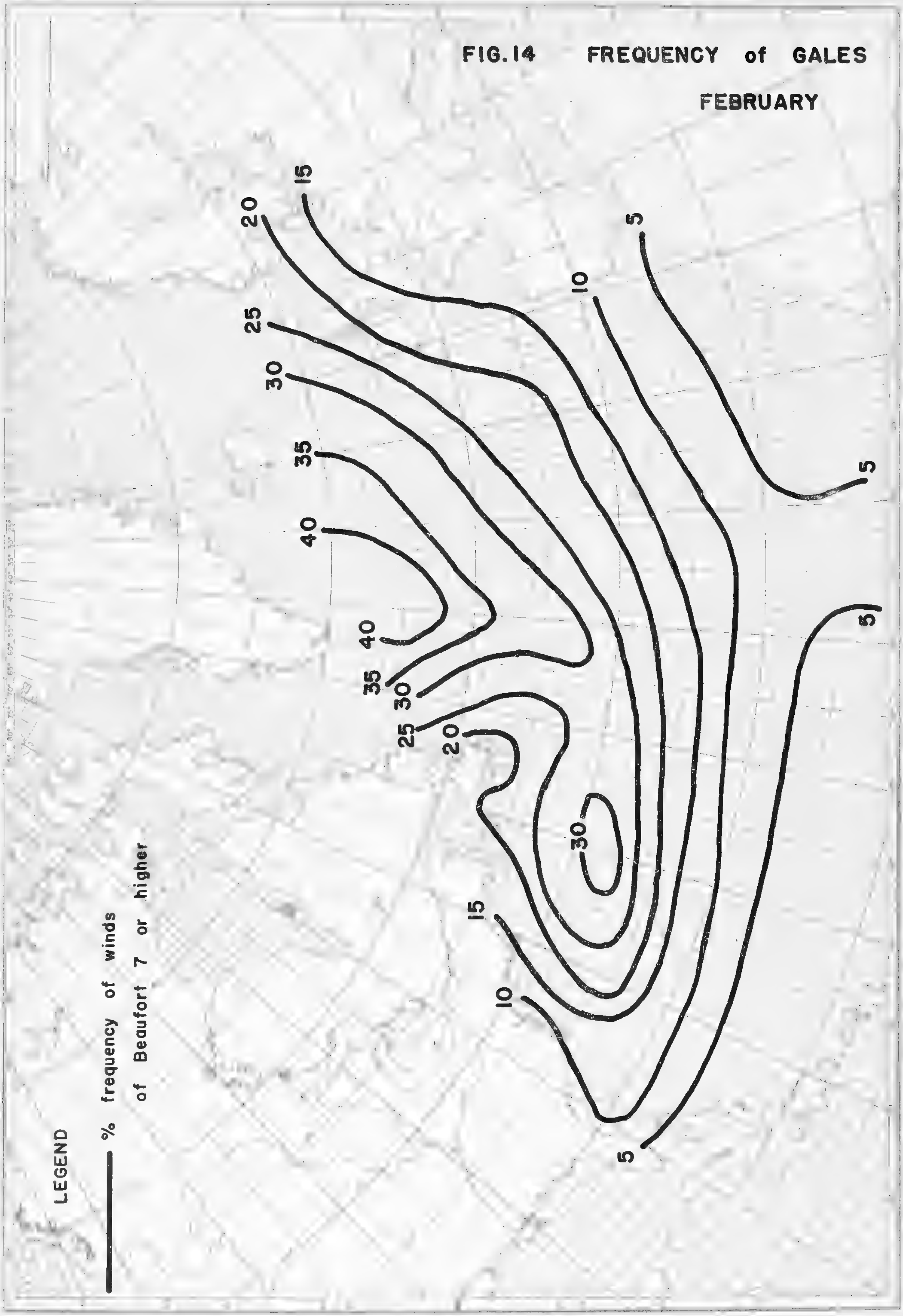


FIG. 14 FREQUENCY of GALES
FEBRUARY

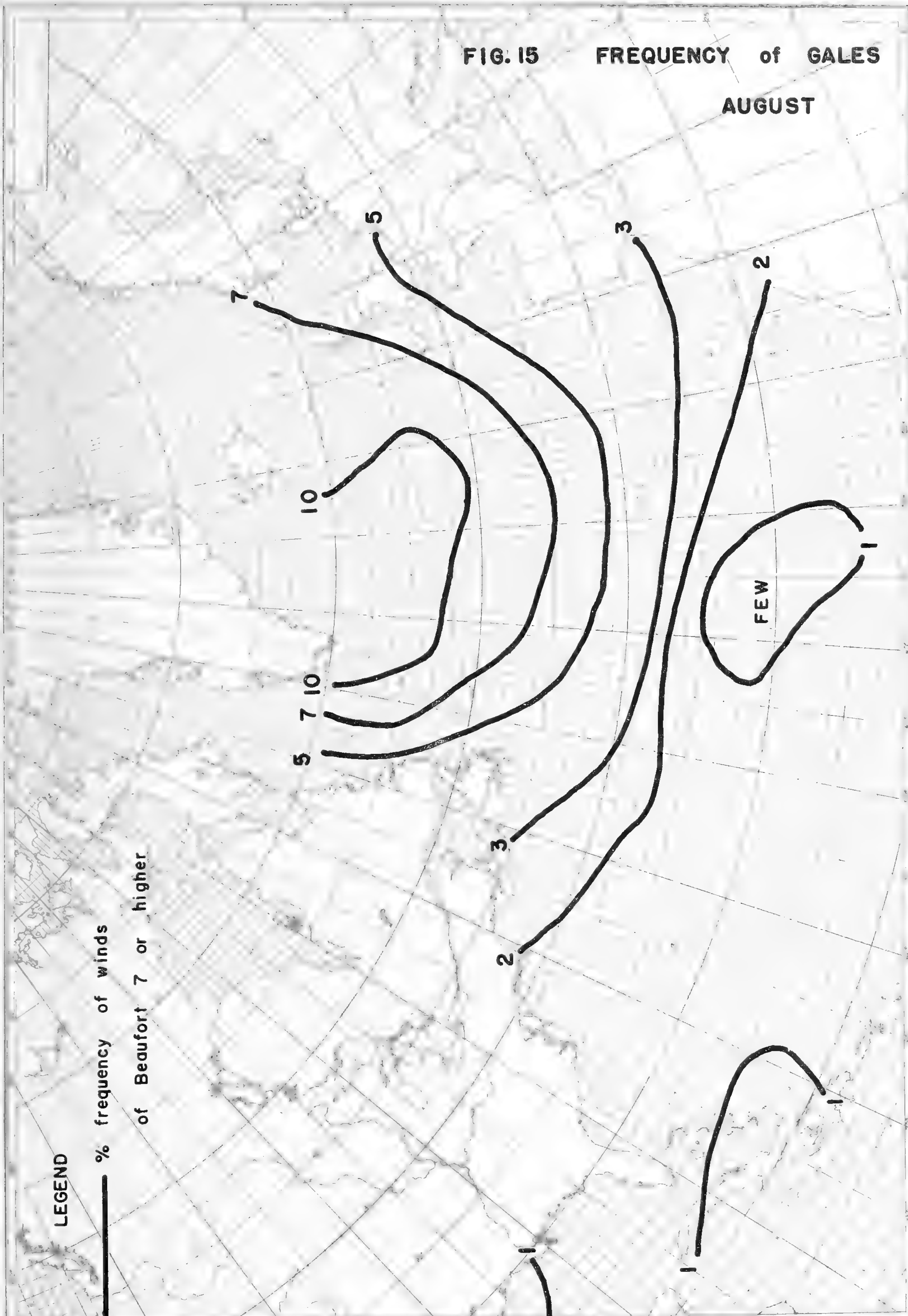


FIG. 15 FREQUENCY of GALES
AUGUST

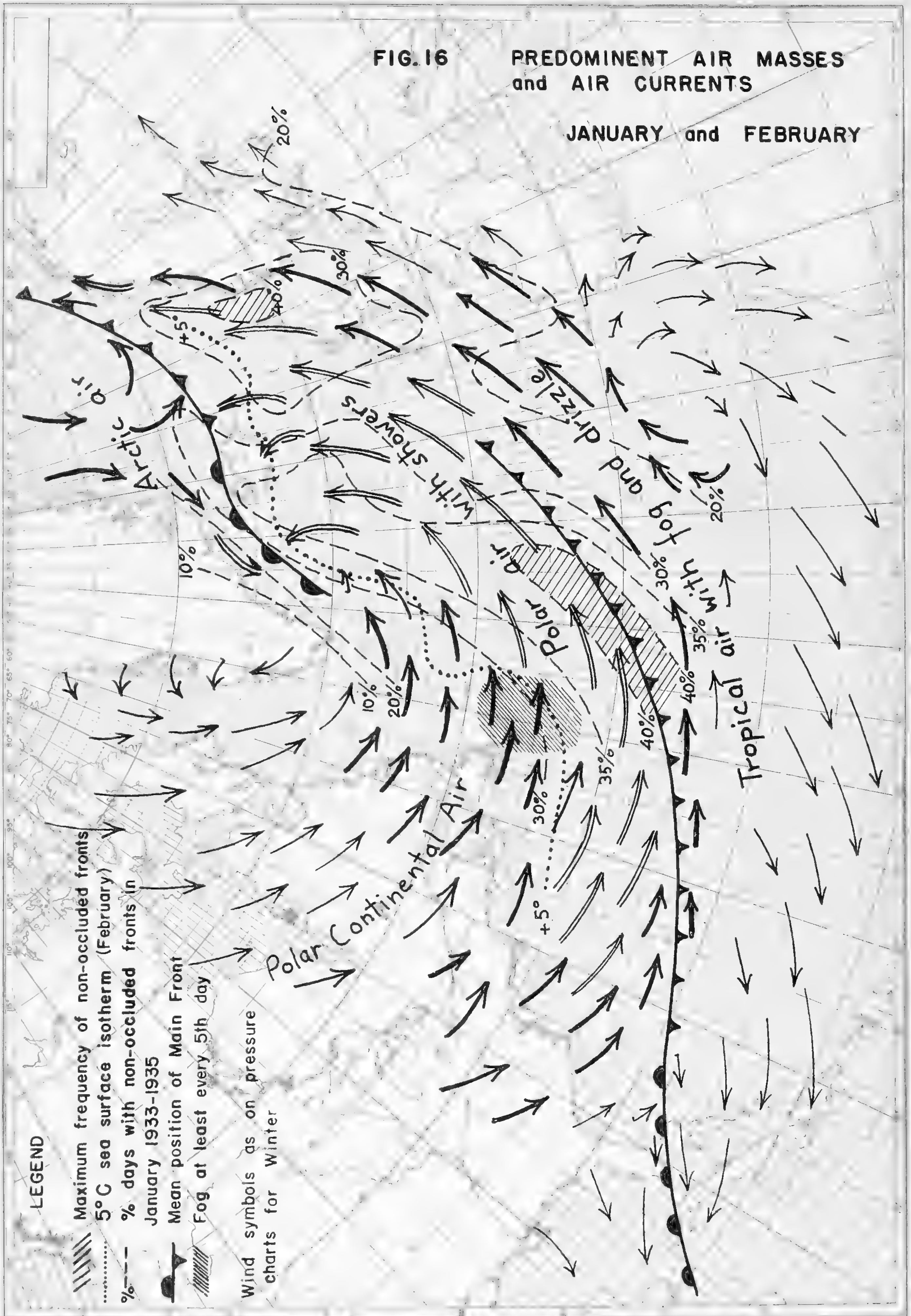


FIG. 16 PREDOMINENT AIR MASSES and AIR CURRENTS

JANUARY and FEBRUARY

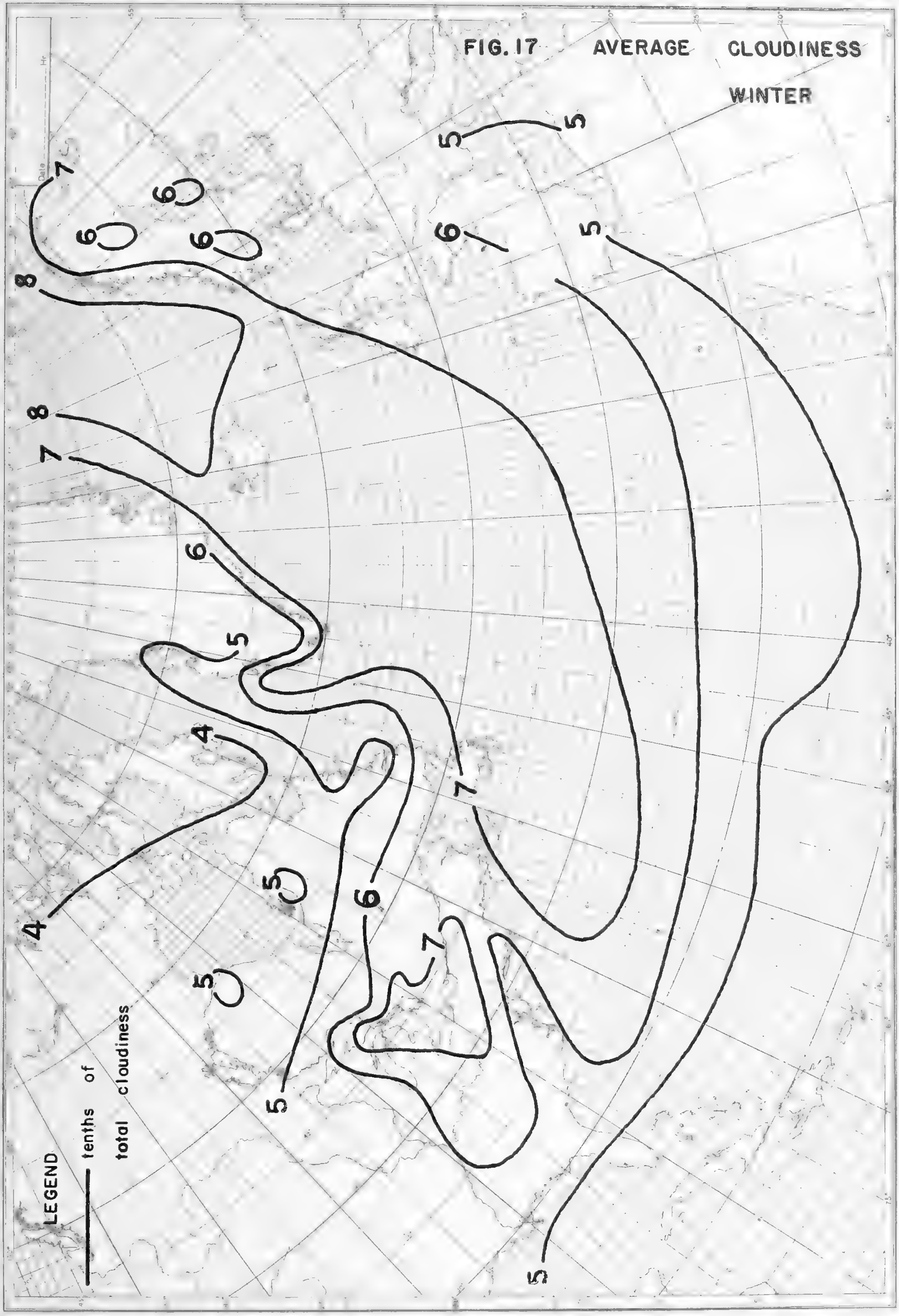
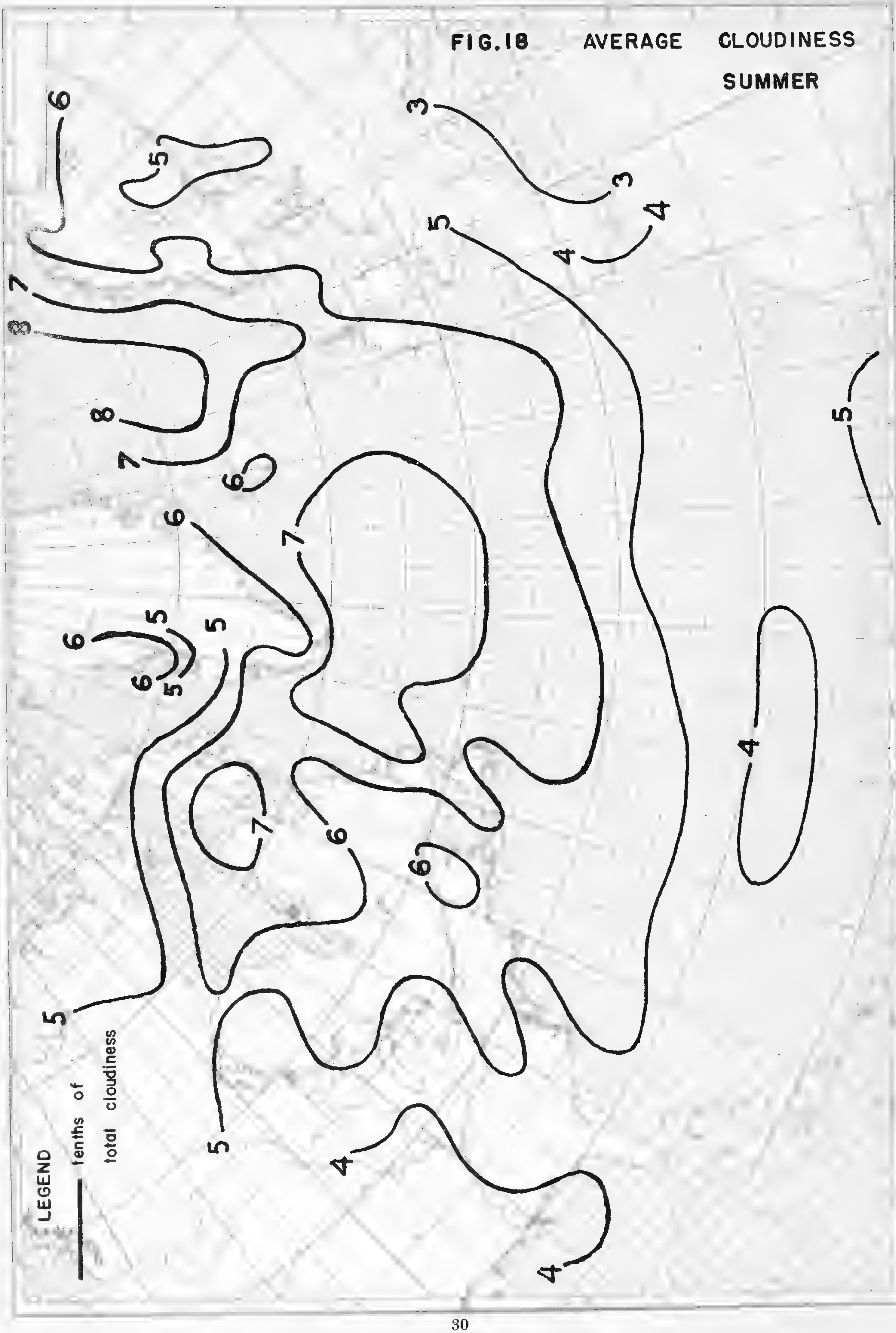


FIG. 17 AVERAGE CLOUDINESS
WINTER

FIG. 18 AVERAGE CLOUDINESS SUMMER



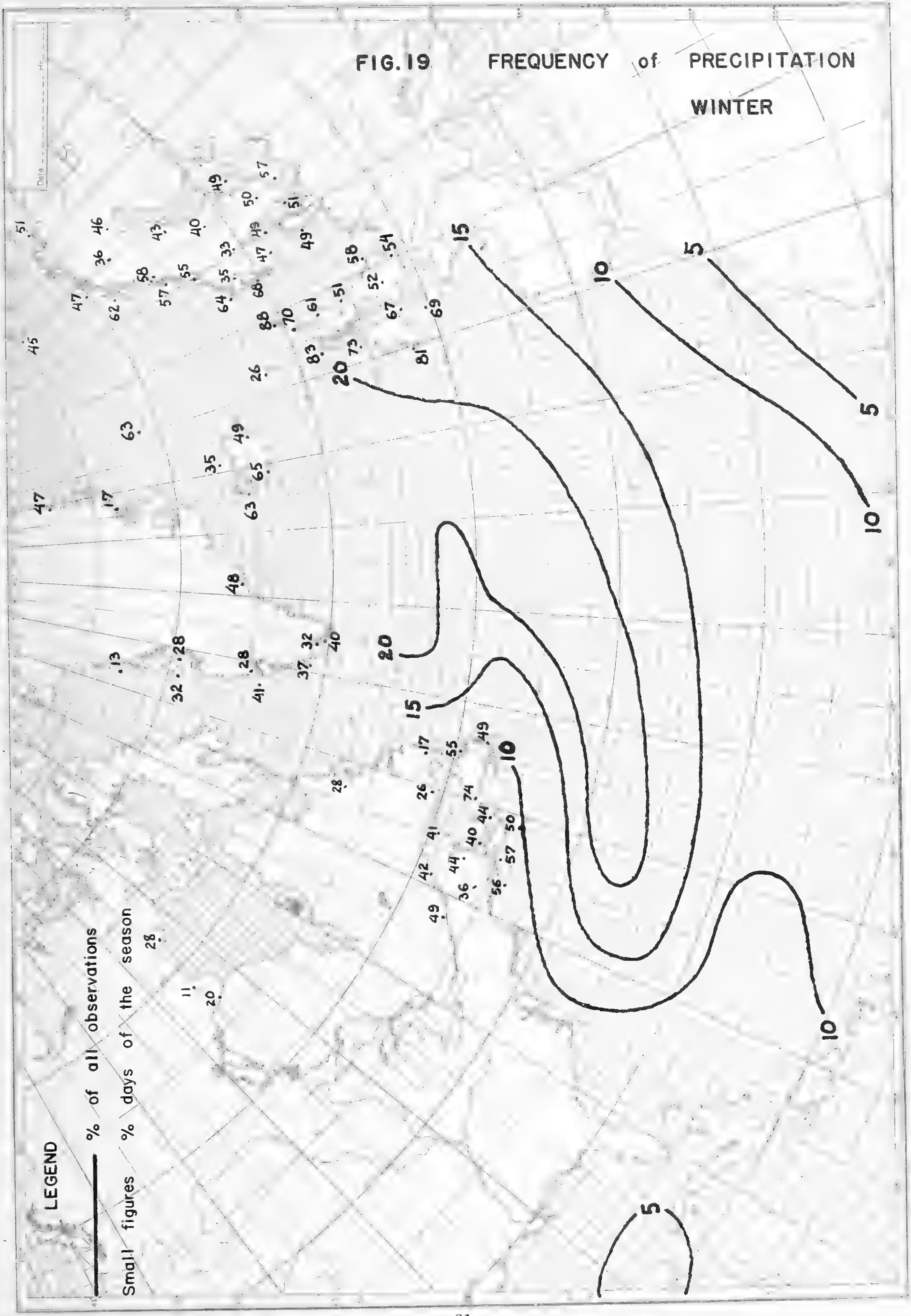


FIG. 19 FREQUENCY of PRECIPITATION
WINTER

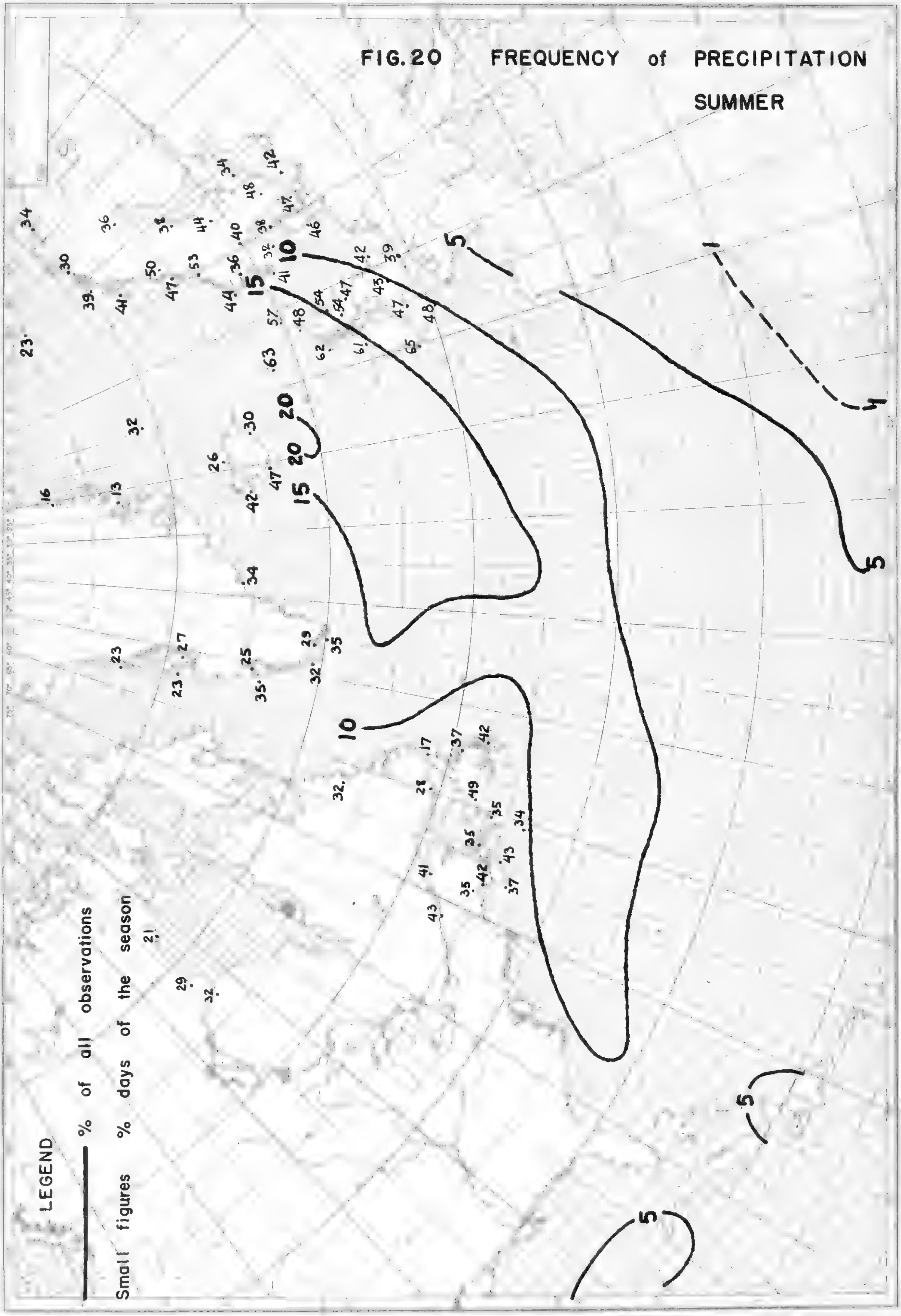


FIG. 20 FREQUENCY of PRECIPITATION SUMMER

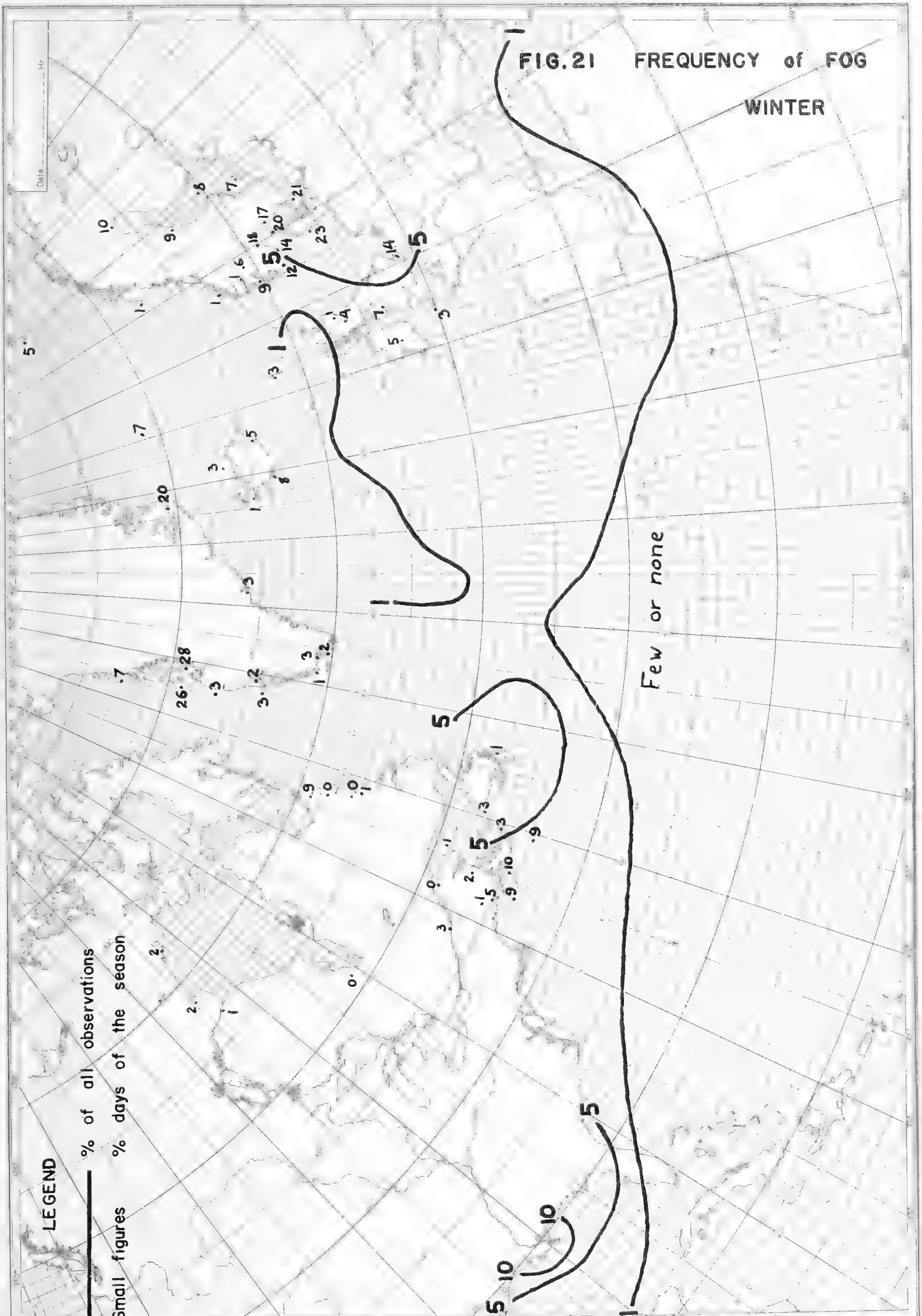


FIG. 21 FREQUENCY of FOG
WINTER

FIG. 22 FREQUENCY of FOG

SUMMER

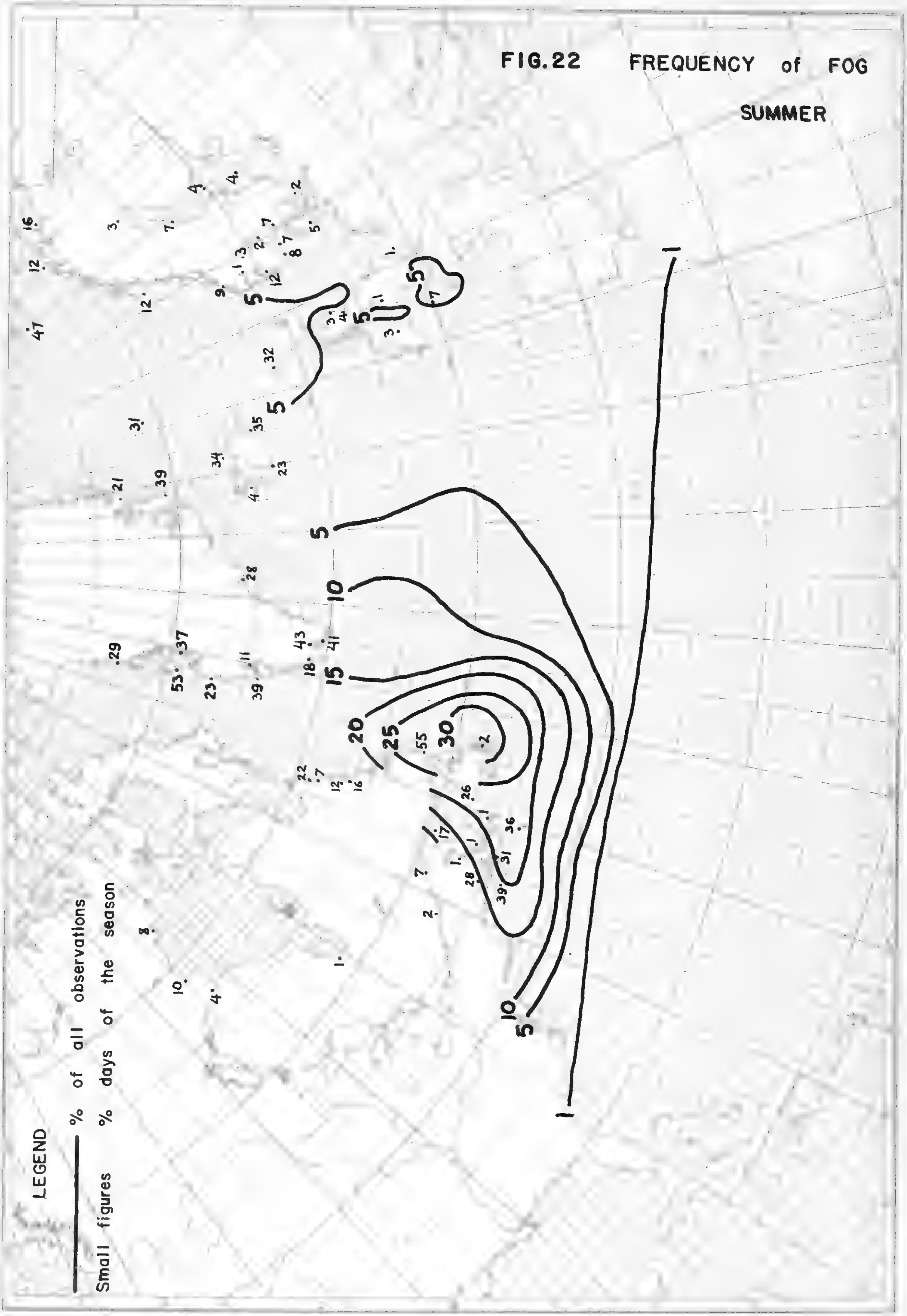


FIG. 23 UPPER WIND CHART
FEBRUARY

FIG. 24 UPPER WIND CHART AUGUST

FIG. 25 AVERAGE LOWER LEVEL of ICING

FEBRUARY

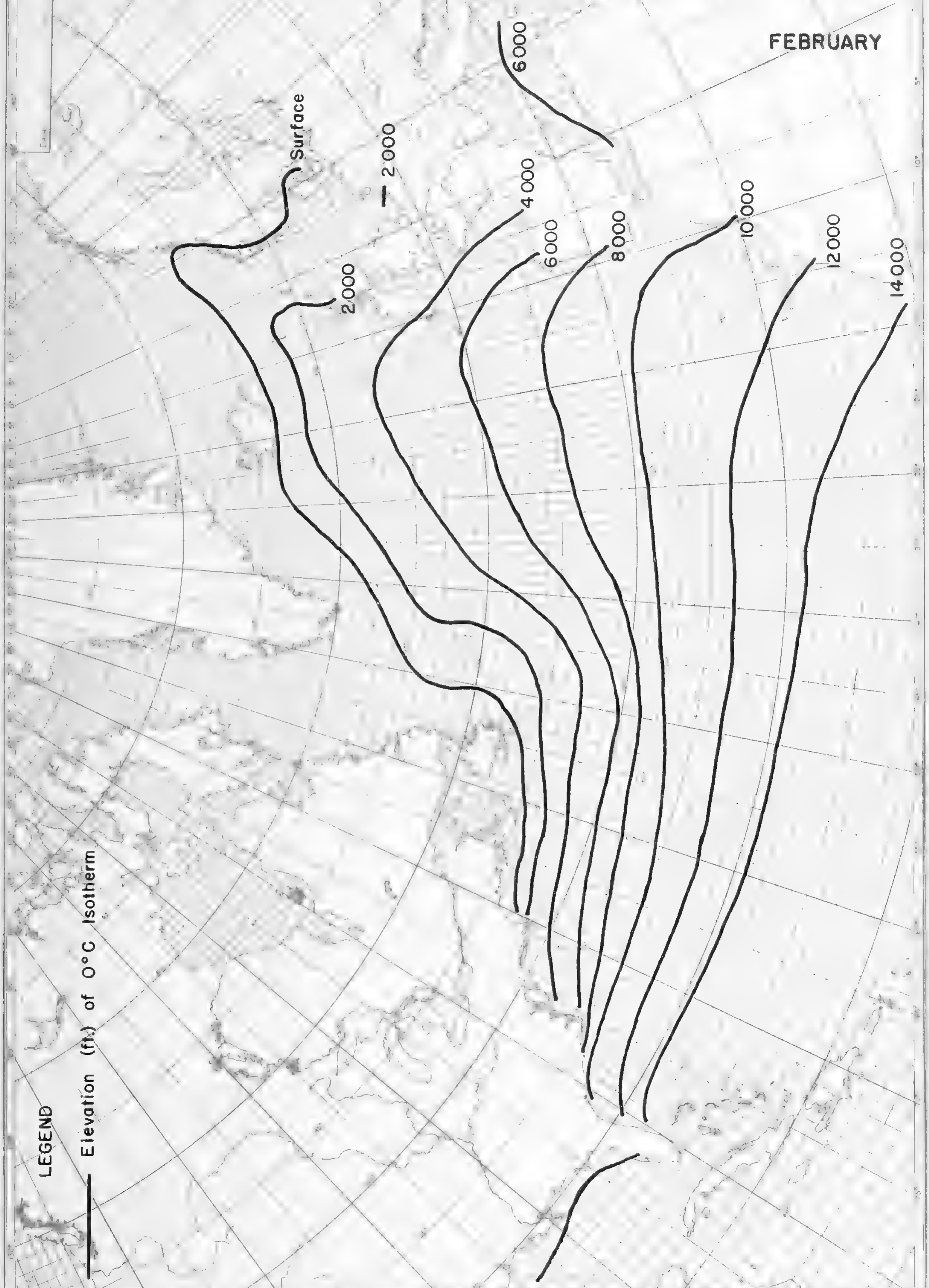
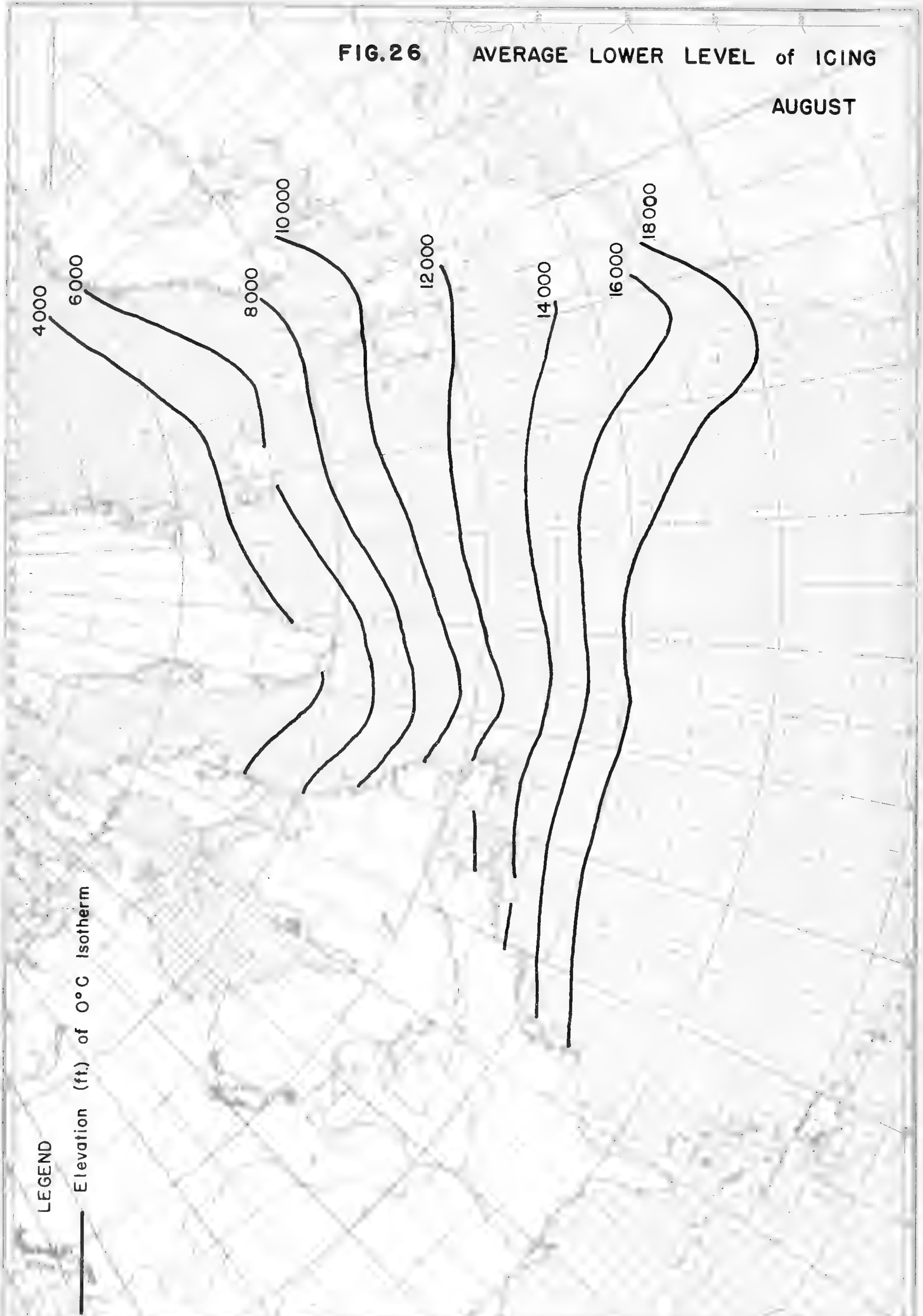


FIG. 26 AVERAGE LOWER LEVEL of ICING

AUGUST



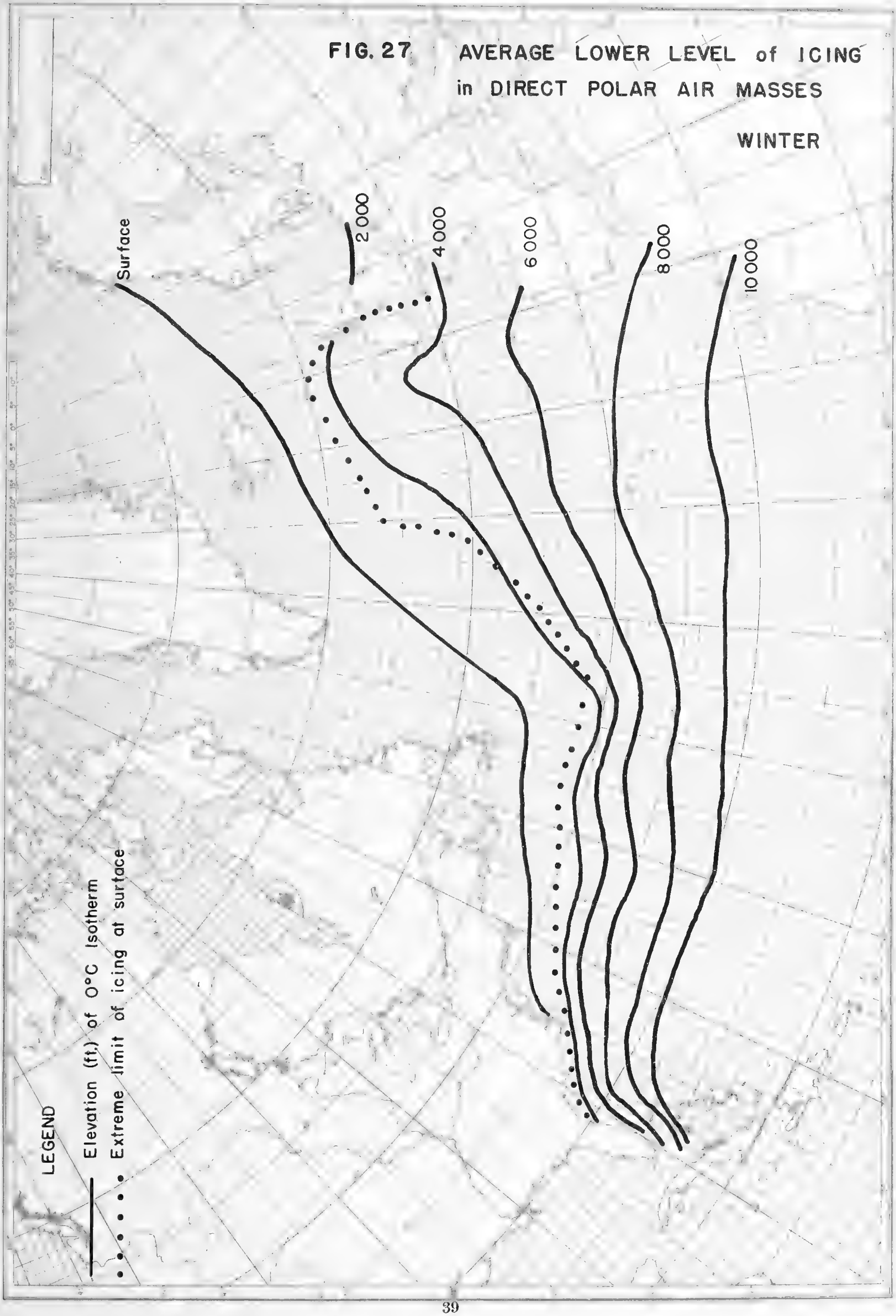


FIG. 27 AVERAGE LOWER LEVEL of ICING in DIRECT POLAR AIR MASSES

WINTER

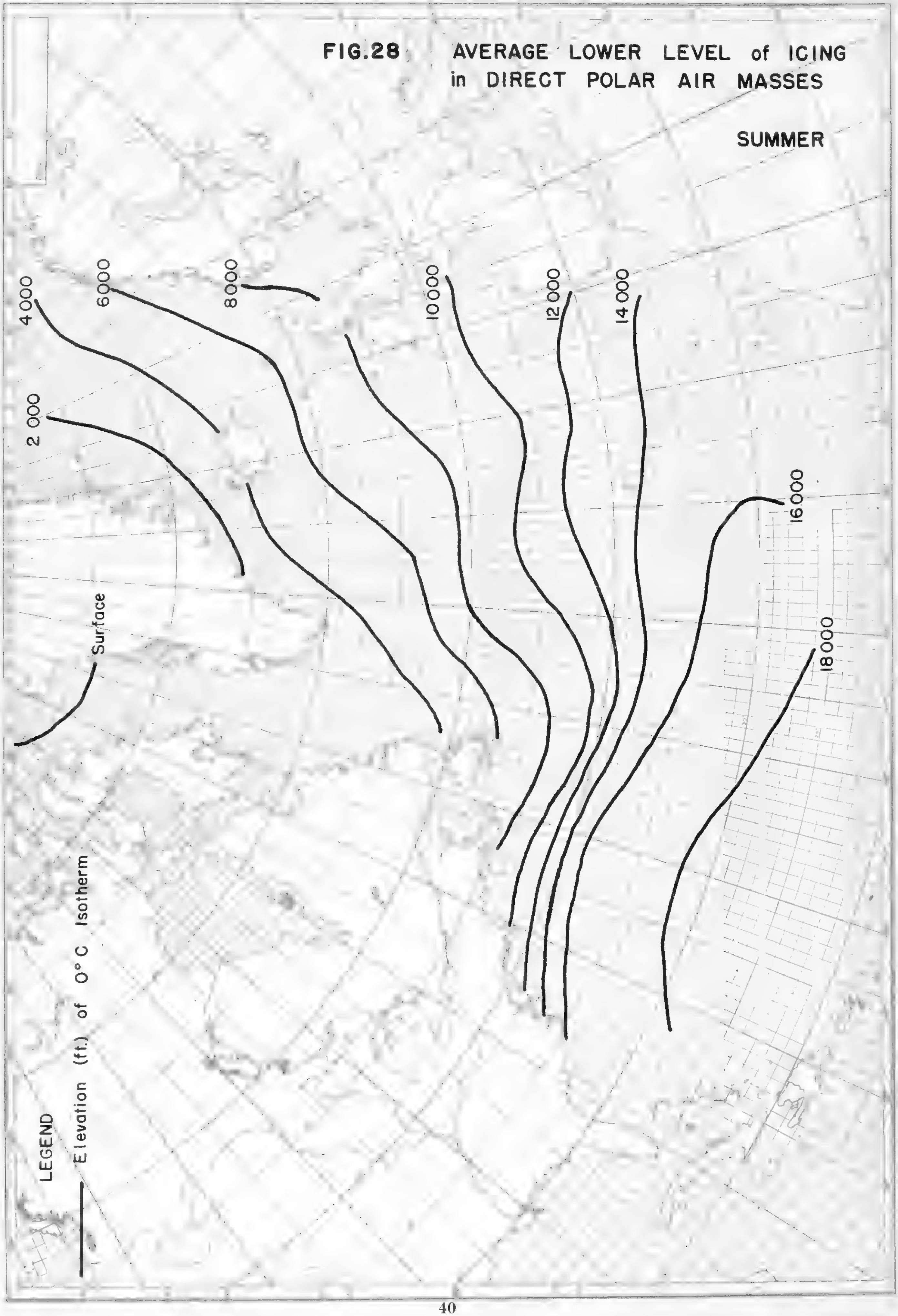


FIG. 28 AVERAGE LOWER LEVEL of ICING in DIRECT POLAR AIR MASSES
SUMMER
Surface
2 000
4000
6000
8000
10000
12 000
14 000
16 000
18 000
LEGEND
Elevation (ft.) of 0° C Isotherm

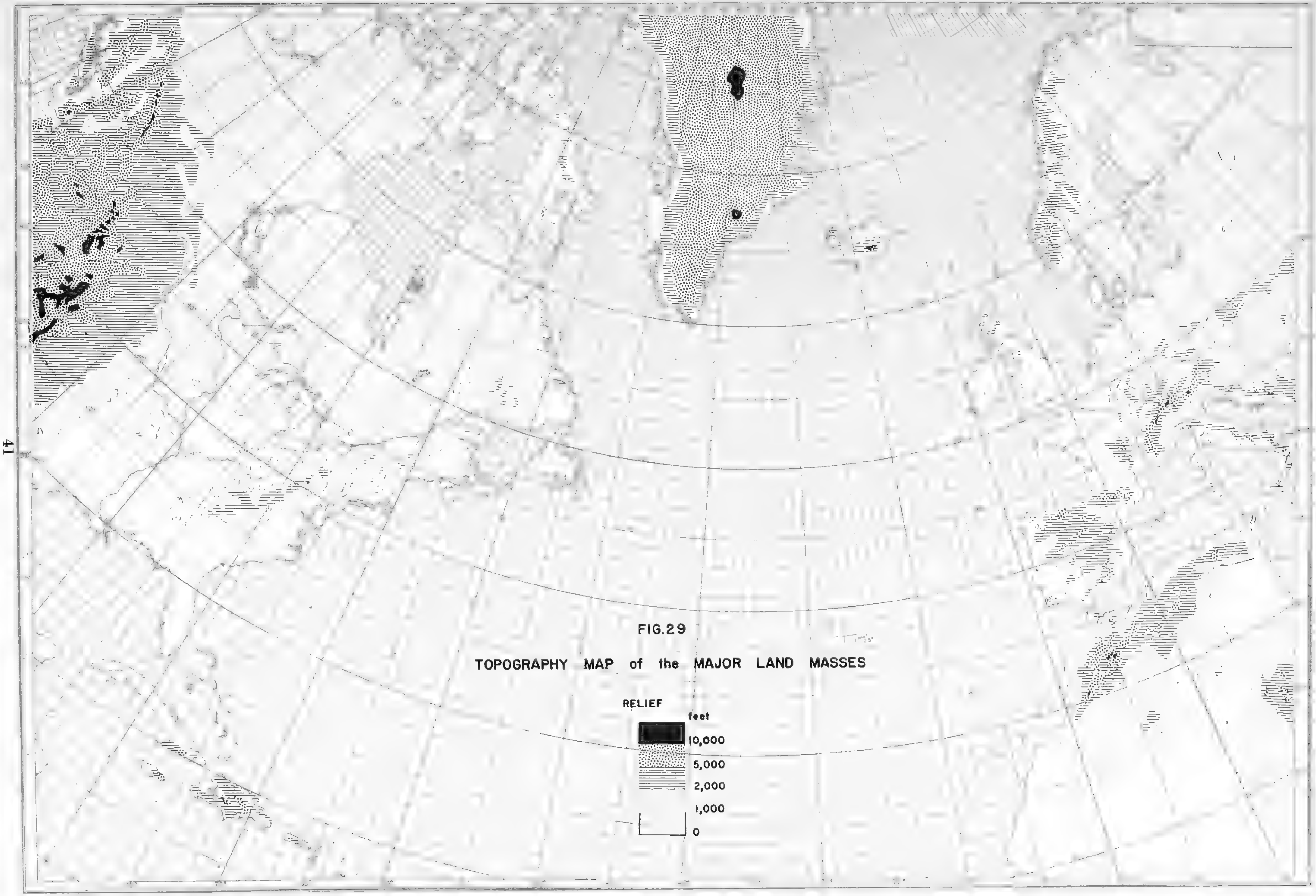


FIG. 29

TOPOGRAPHY MAP of the MAJOR LAND MASSES

DISCUSSION OF SYNOPTIC WEATHER MAPS OVER THE NORTH ATLANTIC FOR SELECTED PERIODS

BY H. C. WILLETT

A. Introductory Remarks.

Familiarity with the climate of a region as expressed by monthly or seasonal charts of the normals of the meteorological elements gives little knowledge of the variety of the day to day weather. This variety of the day to day weather conditions is seen best in the daily synoptic charts. To illustrate this variety of weather over the North Atlantic, by way of supplementing the preceding discussion of the climate of this region, two periods of the daily weather maps were selected for discussion. These two periods, one in January and one in August, were selected as including a rather wide range of weather patterns which are fairly typical of their respective seasons. Obviously, all extremes of weather in the North Atlantic area could not be represented without the inclusion of a prohibitively large number of maps. The inclusion of eastern North America and western Europe is necessary for any intelligent discussion of the synoptic conditions over the ocean. In particular, basic changes in the general circulation pattern tend to progress from Europe to the Atlantic. The selected periods were chosen from the Second Polar Year because the network of surface observations was most complete that year.

The following discussion of the daily synoptic maps is restricted primarily to the departure of the daily weather patterns from the normal conditions as well as to the degree to which, and conditions under which, such departure may be expected. The details of the analysis are accepted without discussion as presented by the maps, although the 24-hour interval between maps and the extremely rapid movement which characterizes part of the winter period especially render the synoptic analysis somewhat uncertain at a few points.

B. The Winter Period, January 9–24, 1933.

The normal distribution of pressure, winds and air masses over the North Atlantic in midwinter is shown in Figures 1 and 16. However, as is so frequently the case in regions where the short period weather patterns fluctuate greatly, the normal or average seasonal pattern is rarely present. The normal charts show most clearly the influence of what is probably the most frequent and strongest circulation pattern over the North Atlantic. That is the pattern which is normally present with a high zonal index, or in other words, an active state of the general circulation as shown by strong zonal westerlies in middle latitudes. Under this condition the Polar Front usually lies in the mid-Atlantic, extending eastward and northeastward from the vicinity of Florida toward the northwest coast of Europe, with a well developed Azores high centered south of 40° in the eastern Atlantic. The lows which develop on the Polar Front off the southeast coast of the United States move rapidly northeastward with increasing intensity. They tend to reach occlusion and maximum intensity somewhere in the area south of Greenland northeastward to Iceland, thus producing and maintaining the so-called Icelandic low, which appears on all mean pressure charts of the North Atlantic. From the vicinity of

Iceland these lows tend to move northeastward and eastward toward Bear Island and Barents Sea, usually with diminishing intensity. This strong circulation pattern brings high temperatures, much rain and south and southwest storm winds to northwestern Europe, and cold showery conditions with strong west and northwest winds to the northwestern Atlantic. This is the weather pattern which is most clearly reflected in the normal charts for the winter season.

However, the normal charts do not convey any impression of the severity of the conditions which *normally* prevail when this weather type is established. The lowest pressure in the Icelandic low region on the daily synoptic charts when this weather pattern is well established runs from 20 to 70 mb. lower than the 1000 mb. minimum indicated on the mean pressure chart. The reason for the failure of the normal charts to indicate the normal severity of the strong circulation pattern over the North Atlantic may be expressed rather obviously in the following two facts, each of which has its synoptic implications:

(*1*) The general circulation pattern of the strong type is subject to considerable longitudinal shifts. The Polar Front may be shifted westward to the east coast of North America, so that the Icelandic low lies in the vicinity of Newfoundland and Labrador, or it may be shifted eastward to the mid-Atlantic at low latitudes and extend thence northeastward into western Europe. In this latter case the severe storms of the North Atlantic are felt with maximum severity over all of western Europe. Such shifts have the effect on a mean or normal chart of smoothing out the extremes which are present on a single synoptic chart. Either of these two extreme longitudinal shifts of the strong circulation pattern usually represents the first stage of the transition or breakdown of the strong type into a weak circulation pattern which is radically different in its characteristics from the strong type.

(*2*) The normal chart includes in its makeup a proportional number of the weak circulation type patterns as well as the strong and the transitional types. Although these weak circulation patterns are not sufficiently frequent nor intense to leave any clear imprint of their characteristics on the normal charts, nevertheless in extreme cases they nearly reverse the characteristics of the strong circulation patterns. This occasional reversal of the more frequent strong type has the effect on the normal chart of greatly weakening the characteristics of the normal patterns from those of the strong circulation type.

Since the weak circulation patterns are the ones which are least reflected in the normal charts of the North Atlantic, they represent the maximum departures of the North Atlantic weather from the conditions represented by the mean charts. For this reason it is important to consider briefly the chief characteristics of the weak circulation patterns, and to include an example of this type of weather in the illustrative daily synoptic charts. The most serious large-scale errors in forecasting the daily weather in the eastern Atlantic and western Europe are usually made at the time that a weak circulation pattern is becoming established.

The weak circulation weather types, or low index patterns, are characterized essentially by the disappearance or reversal of the prevailing zonal westerlies of middle latitudes. This can take place in either of two quite different ways. One of these occurs with the general disappearance of strong pressure gradients. The Icelandic and Aleutian lows over the northern ocean areas tend to fill up and disappear, their places being taken by the northward extension of the subtropical Atlantic and Pacific highs, which tend to be somewhat weakened at the lower latitudes. This type of weak circulation pattern is characteristic of the warmer half of the year, though it may occur in modified form during the winter season. However, it is characterized by the general absence of any very severe weather conditions in middle or northerly latitudes. It represents a rather stable type of weather in the higher latitudes. Consequently it is of less direct concern than is the second type to the synoptic meteorologist, who is concerned principally with the forecasting of unusual or severe conditions, or the sudden change of conditions.

The second low index type is the usual active winter type which is characterized by the formation of large polar anticyclones at the higher latitudes, principally over the continents. Cyclonic activity increases at the lower latitudes. The principal frontal systems take either a north-south orientation, or an east-west orientation at low latitudes. The individual cyclones, which may be quite intense, follow corresponding tracks. Either they move northward, skirting the western edge of a major continental anticyclone that blocks eastward movement in the higher latitudes, or they move eastward across the continents at low latitudes, skirting the southern edge of the polar continental anticyclones.

Especially over western Europe and the eastern Atlantic does the onset of this active winter weak circulation pattern tend to follow a characteristic line of development. An extensive polar anticyclone from the interior of Asia pushes westward over northern Europe to the North Atlantic. The Icelandic low tends to be weakened and displaced westward over southern Greenland. Usually a secondary center develops in the vicinity of the Bay of Biscay from which active lows pass southeastward into the Mediterranean. Northern and central Europe are dominated by the strong westward flow of extremely cold polar continental air from the interior of Asia. Blizzard conditions occur in western Europe wherever strong cyclonic activity in the south leads to marked frontal action along the southern edge of the cold air mass. Most remarkable is the strength of the westward thrust of the continental anticyclone in northern Europe, and its ability to resist the eastward advance of strong lows in the western Atlantic. It is this particular blocking action of the polar anticyclone which most frequently leads to serious forecast errors along the northwest coast of Europe, forecasts of storms which fail to make their influence felt where they are expected. This blocking action in the north terminates only when the polar anticyclone begins to weaken or to move southward. Similar conditions on a somewhat smaller scale occur occasionally along the west coast of North America when a weak circulation pattern is established in the Pacific, with an intense Polar continental anticyclone extending southeastward from Alaska. The Aleutian low is displaced far to the west, with a secondary cell located off the California coast, whence a succession of lows pass eastward along the southern border of the United States, causing heavy rains in southern California and heavy snows in the southern plateau and southern Rockies.

In terms of the circulation pattern over the Atlantic and western Europe the period from January 9–24, 1933, falls into three parts. Between January 9 and January 15 the pattern is fairly typical of strong circulation over the Atlantic. Lows in rapid sequence deepen and move rapidly northeastward to the Greenland-Iceland region, where the Icelandic low reaches its maximum intensity on January 14. Southerly storm conditions with mild temperatures (cf. Figure 8) are recurrent along the northwest coast of Europe. However, it will be noted that the maximum storm activity even during this period is centered rather far west over the Atlantic, so that only the extreme northwest coast of Europe is strongly affected. At the same time it will be noted that in the interior of Europe a weak circulation pattern is already in evidence. This is indicated by persistent abnormally high pressure over western Russia and abnormally low pressure in the central Mediterranean Sea (cf. Figure 1). Thus a cold anticyclonic circulation of polar continental air from the east or southeast already prevails in eastern Europe. Some slight westward progress is made during this period by the cold continental air mass.

During the period from January 15 to January 19, inclusive, a cold anticyclone thrust strongly westward over northern Europe, bringing a marked temperature fall over northern areas. Meanwhile the deep Icelandic low was largely obliterated and displaced westward over southern Greenland. In the western Atlantic the lows followed a northerly route into Greenland, while in the central Atlantic they followed an east-southeastward course into the Mediterranean. This is a typical transition from a strong to a weak circulation pattern in the North Atlantic, with complete blocking of the normal northeastward movement of the Atlantic storms.

From January 20 to 24, inclusive, the continental anticyclone settled slowly southward and southwestward. This displacement brings the strong westward flow of cold continental polar air southward into central and southern Europe and the Mediterranean. It further displaces the track of the eastward moving lows southward to the southern Mediterranean and northern Africa. Meanwhile the southward shift of the continental anticyclone has terminated the blocking action at higher latitudes. Consequently the fronts and warm air masses which were moving northward in the mid-Atlantic at the beginning of this period are carried rapidly eastward at high latitudes around the north side of the receding anticyclone. This has brought a marked moderation of temperature to Scandinavia and the northern Baltic. This change at high latitudes doubtless represents the first stage of the transition back to a typical strong circulation pattern in the North Atlantic. It will be noted that the Polar Front in the western Atlantic is taking an orientation suitable to the regeneration of a strong Icelandic low.

The principal additional step needed to complete the transition to a strong circulation pattern is for the European continental anticyclone to move southwestward into the eastern Atlantic and thus to obliterate the cyclonic activity centered there at low latitudes. However, there is little indication of such a change in progress at the end of the period, but rather a tendency towards frontogenesis and increasing cyclonic activity along the southern edge of the European high. Actually strong cyclonic activity in that area developed and persisted for a week, so that it was the first of February before a strong circulation pattern was reëstablished over the North Atlantic. During this intervening week the Icelandic low was not regenerated, but rather a very strong and nearly stationary low was developed at low latitudes in the western Atlantic. This strong low finally moved up into the Icelandic area at the end of the month. Thus the blocking action and low latitude cyclonic activity of a typical weak circulation pattern actually persisted over the North Atlantic in middle and lower latitudes for a full week beyond the period covered by the daily maps presented here, and beyond the time that normal eastward motion was resumed north of latitude 60°.

There follows a brief discussion of some of the features of the individual daily charts during this period which are illustrative of the variety of the daily weather sequence which may be expected over the North Atlantic.

The map of January 9, 1933, represents a typical strong circulation pattern over the North Atlantic. The open wave character of the zonal westerlies, together with the strong circulation, indicate typical rapid northeastward movement and deepening of the disturbance just beginning to take shape near Cape Hatteras and continued displacement of the occluded southern Greenland center. It will be noted that the Azores high is unusually dominant in the eastern Atlantic, which forces the principal storm centers to follow a route which lies north and west of the normal path (cf. Figures 1 and 16). However, it is only over western Europe, on the frontal system which remains from the disturbance now filling off the east coast of Greenland, that a development which is not consistent with a strong circulation condition is to be noted. The eastward advance of this front is obviously being checked by the strong continental anticyclone to the east, which shows little tendency to give ground. In fact, the negative pressure tendencies and the rain in the warm sector over Germany and northern Italy suggest cyclogenesis along the southern portion of this front and very rapid southward displacement of the cold front over northern France. Such a development does not occur when the strong westerly circulation extends eastward across northern Europe into Asia. It represents the first blocking action of the weak circulation pattern which is already established over Eurasia, as evidenced by the abnormally high pressure over western Russia.

No significant change in the weather pattern is to be noted on the map of January 10. The frontal system over west central Europe has remained nearly stationary, with rapid filling of most of the low pressure trough except for the active cyclogenesis in the central Mediterranean. This development, a consequence of the anticyclonic blocking, was clearly indicated on the preceding chart. The rapid northeastward movement and intensification of the complex disturbance near Cape Hatteras on the preceding chart also proceeded in accordance with the circulation pattern. Also to be noted is the rapid eastward movement nearly halfway across Canada of a strong disturbance from the Pacific Coast of the so-called Alberta low type. Such rapid movement across the North American Continent of intense disturbances which follow a course lying north of the Canadian border is again highly typical of a strong circulation weather pattern extending from the Pacific to the Atlantic. These disturbances usually move eastward to Davis Strait or Greenland and merge with the Icelandic low.

One fact that is worth remarking about the North Atlantic air masses during periods of strong circulation, a fact which holds quite generally in middle latitudes, is the small contrast of properties shown by the air masses which follow eastward in rapid succession. Direct polar and tropical outbreaks do not occur. The rapid eastward motion tends to prevent any marked convergence of polar and tropical currents, and the fronts, especially warm fronts, are correspondingly weak. Usually, however, the typical showery convectively unstable condition of the maritime polar air which follows any cold or occluded front is clearly in evidence, but the tropical air mass characteristics are frequently less clearly in evidence. Much of the warm air is only returning maritime polar which has not become entirely tropical in its characteristics.

The following synoptic chart (January 11) shows no important change in the trend of the weather development from the two preceding days. The eastern European anticyclone holds its position and successfully blocks all eastward progress of the fronts which try to move inland from the North Atlantic, while the central Mediterranean disturbance remains active and stationary. The disturbance which originated two days previously in the vicinity of Cape Hatteras has already reached the southern tip of Greenland with greatly increased intensity, while the Alberta low has moved rapidly to eastern Canada. Thus the strong circulation pattern continues unabated over North America and the North Atlantic, while the low index blocking pattern continues in Eurasia.

The map for January 12 shows little change in the situation, unless perhaps that the Eurasian anticyclone has extended its influence slightly westward in western Europe. The rapid eastward motion continues across the North Atlantic. The Alberta low is approaching southern Greenland with the suggestion of a tendency to merge with the strong Icelandic circulation. The rapid advance of a second strong disturbance into a well developed Icelandic center during periods of strong circulation in the North Atlantic frequently leads to an exceptionally intense development of the Icelandic low.

On the morning of January 13 conditions are little changed. The blocking effect of the continental anticyclone remains unchanged in northern Europe, but the strong circulation and rapid eastward movement of the fronts and low centers at high latitudes over the Atlantic continues unabated. In spite of the fact that the disturbance over southern Greenland now moving into the Icelandic low is an old disturbance and long since occluded, the large negative pressure tendencies in the entire area from southeastern Greenland eastward to Iceland and southward to latitude 50° N indicate that a strong deepening of the center is already in progress. It is to be noted also that this deepening occluded system is carrying northeastward a current of quite warm air, so that a large temperature contrast exists in the low pressure trough between Greenland and Iceland.

The map of January 14 shows that quite a severe storm developed as a result of the marked deepening of the Icelandic center, but the storm center continues to move northeastward with unabated speed. Strong southerly gales are occurring along the outer coast from Scotland northeastward. The strength of these winds, or the exceptionally steep pressure gradient which prevails in this region, is caused in part by the persistence of the continental anticyclone over northern Europe. This is generally true in the North Atlantic that the most severe gales do not necessarily occur with the strongest development of the Icelandic low or similar storms, but rather when strong cyclogenesis occurs in close proximity to an abnormally strong and persistent anticyclone. Both stronger winds and deeper lows than appear in the storm under discussion are observed in the North Atlantic, but they do not necessarily appear together. Only twelve days previous to this date, on January 2, a disturbance which moved northeastward from Newfoundland to Iceland as it occluded and deepened, resulted in an intensification of the Icelandic low to below 930 mb. for two days, but no wind velocity in excess of ten Beaufort was reported. However, winds of eight to ten Beaufort were reported from a much greater area than in this case. The strongest winds reported from Iceland usually blow with an easterly component when the storm center is south of the island.

One additional feature to be noted on this map is another disturbance of the Alberta type which is moving very rapidly eastward in central Canada, a continuation of the strong pattern of the general circulation.

On January 15 some significant changes in the general circulation pattern begin to appear on the weather map. The strong outflow of cold air behind the recently intensified Icelandic low has swept the Polar Front much further south in the eastern Atlantic, so that it has taken an east-west orientation at lower latitudes, and has terminated the domination of the Azores high in the eastern Atlantic. This is the first step necessary for the establishment of a weak circulation pattern in the Atlantic. Disturbances which now develop on the Polar Front should be carried eastward and even southeastward into the Mediterranean. The field of pressure tendencies in southwestern Europe and the Bay of Biscay indicate a strong tendency to a further southeastward displacement of the Polar Front in that region. Meanwhile the continental anticyclone in the north continues to block the eastward advance of the frontal system over the continent at higher latitudes, while the extremely rapid eastward advance of the latest Alberta low has continued across northern North America. It appears also that over North America the eastern extension of the Pacific Polar Front is being displaced southward from Canada into the United States by a major outbreak of cold air which followed the last Alberta low. This development represents further the trend toward a low index pattern of the general circulation.

The map of January 16 shows a continuation of all the trends noted on the preceding day. The Azores high has been largely eliminated in the eastern Atlantic, while the Polar Front and cyclonic activity extend from the central and eastern Atlantic well into the Mediterranean. The continental anticyclone is beginning to push westward at higher latitudes, as indicated by the rise of pressure westward as far as Iceland and Eastern Greenland. The strong low from North America has reached a position in southern Greenland rather similar to that at which the preceding disturbance of similar origin initiated a marked intensification of the Icelandic low. But in this case widespread rising pressure over the northerly portions of the Atlantic, the absence of any significant negative pressure tendencies in advance of the disturbance, and the absence of any strong local temperature contrast in the Iceland-Greenland area, all these conditions indicate strongly that no such intensification of the Icelandic center should occur this time.

By the morning of January 17 a rather typical low index (weak circulation) pattern of the general circulation extends from North America to Europe. Note the southerly latitudes of the frontal action, with two cells of the Atlantic high centered well south of 35° N, the large number of cyclonic centers which move rather slowly eastward without the development of any one center to dominant size or intensity, and finally the significant westward thrust of the continental anticyclone over the Atlantic at high latitudes while active frontal disturbances continue to move from the eastern Atlantic into the Mediterranean, followed by the occurrence of snow in central Europe.

No significant new development of the weather conditions is to be noted on the map of January 18. However, it appears that the northern European anticyclone has intensified markedly since the preceding day, as it continues to extend its influence westward over the Atlantic at high latitudes to the extent of forcing the Icelandic low westward into Greenland. This intensification and westward thrust of the continental anticyclone at high latitudes reaches its maximum on the following day (map of January 19) after which the anticyclone begins to give ground in the north and to thrust southwestward instead.

Since in winter the blocking action and westward thrust of a major Asiatic polar anticyclone is the dominant feature of the typical transition from a high to a low circulation pattern over western Europe and the North Atlantic, with all which that implies for the forecasting of the North Atlantic weather, it is worth noting here the weather sequence over Asia that precedes the change over western Europe and the Atlantic. On January 14 a marked intensification of the Icelandic low combined with a persistent anticyclone over northern Europe established an exceptionally strong southerly current off the northwest coast of Europe. During the next two days, between January 14 and January 16, the northern cell of the Asiatic high, centered near latitude 60° N, longitude 95° E, increased from 1040 to 1060 mb. Between January 16 and January 19 the central pressure of this cell remained above 1060 mb., while it moved westward from 95° E to 60° E. This was the anticyclonic development noted over northern Europe between January 16 and January 19. Not every equally intense development of the Icelandic low leads to a corresponding development of the Asiatic high. Such anticyclogenesis is apparently most favored by the establishment of strong southerly winds along the northwest coast of Europe, *i.e.*, when a persistent high is already well established to the east. When low pressure prevails over northern Europe the newly intensified

Icelandic low moves rapidly eastward into northern Asia. In other words, when a weak circulation pattern is already established over Asia, a good kick from the sudden intensification of the Icelandic low makes the low index pattern back up into the Atlantic, and incidentally at the same time it reëstablishes a strong circulation in eastern Asia, but when the circulation pattern is already strong over Asia, there is no reaction to the kick.

As mentioned above, the maximum retrogression of the Asiatic anticyclone at high latitudes is to be seen on the map of January 19. Otherwise the significant feature to be noted on this chart is the fact that at several points, both in the mid-Atlantic and in eastern North America, currents of tropical air are beginning to reach the higher latitudes as the warm sectors of northward moving disturbances. The north-south orientation of frontal systems, and the northward or southward movement of disturbances, is even more a part of the winter low index pattern than is the east-west orientation of fronts and eastward movement of disturbances at low latitudes. It is such north-south orientation of the frontal systems and of the large scale air mass movements which leads to the extreme longitudinal temperature contrasts which characterize the winter type of weak circulation pattern, with excessive cold in one meridional zone, excessive warmth in the next.

On the map of January 20 the northward advance of tropical air in the mid-Atlantic is seen to be progressing rapidly, so that some moderation of temperature is setting in over the whole eastern Atlantic. The return of milder maritime polar air masses to the most northeastern part of the Atlantic is made possible by the clockwise turning of the isobars in that region as the continental anticyclone begins to push actively southwestward. This southwestward extension of the anticyclone combined with the continued cyclonic activity in the Mediterranean favors the flow of cold continental polar air to extreme southwestern Europe and into the Mediterranean. It is worth noting that the intensification of the continental anticyclone along the west coast of Europe on January 20 and 21 accompanies the establishment of a broad zone of rather strong southerly winds in the eastern and central Atlantic, winds which are produced by the deepening disturbances that are moving northward on these two days in the central and western Atlantic.

There is little to be remarked on the map of January 21 other than the continuation of the trends noted on the previous day, especially the northeastward movement of warm air over the central and eastern Atlantic, the southwestward flow of cold air over southwestern Europe, and the continuation of cyclonic activity in the Mediterranean with widespread snow in central Europe. It will be noticed that in general dense surface fog is seldom reported in the maritime tropical air masses moving northward over the oceans in winter. This is much more likely to occur over a continental area, as evidenced by the widespread air mass and pre-frontal fog in the eastern United States on this day. In summer the conditions are reversed, with the principal incidence of tropical air fog occurring over the cold water areas.

The map of January 22 shows the continued stagnation of a typical weak circulation pattern from North America to Europe, with the north-south orientation of the principal frontal systems and the slow northward advance of disturbances in the mid-Atlantic. It is noteworthy that the southwestward thrust of the continental anticyclone that accompanied the anticyclogenesis along the west coast of Europe on January 21 and 22 is now completed. This is significant in that it suggests that the reëstablishment of the Azores high is not yet to occur, and consequently that a low index weather pattern in the Atlantic may be expected to persist for some time longer.

The extreme characteristics of the temperature anomaly pattern produced over the eastern Atlantic and western Europe by the meridional character of the persistent low index circulation is seen most clearly on the maps of January 23 and 24. A comparison of the temperature distribution presented by these charts with the normals (see Figure 8, February differs little from January) shows that whereas in France, Germany and central Europe the temperatures are 10° to 15° C below normal, in the region from Iceland northwestward to North Cape and Bear Island the temperatures are about 10° C above normal. The air mass in this northern area is really tropical in character. The influence of this warm air has already carried eastward to northwestern Russia.

Another significant feature of these two charts is the steady development of a closed cyclonic center near the Azores, and the development of a low pressure trough with a suggestion of frontogenesis thence eastward to Gibraltar and the Mediterranean. This trend in the development of the circulation pattern practically guarantees a low index pattern in the eastern Atlantic for some time to come. Actually strong cyclonic activity from the Azores to the Bay of Biscay and the western Mediterranean continued for a full week after this date. At the same time an extremely intense and nearly stationary low formed off the east coast of the United States. It was not until the first of February that the Azores high became reëstablished in the eastern Atlantic, and that the storm in the western Atlantic moved northeastward to the point of regenerating the Icelandic low in its normal position. These developments finally terminated the low index pattern over the North Atlantic and western Europe, and marked the return of the more normal strong circulation pattern characterized by the rapid eastward or northeastward movement of strong disturbances across the northern ocean.

C. The Summer Period, August 20–September 3, 1932.

The general circulation of the northern hemisphere, as represented by the zonal westerlies of middle latitudes, is consistently weaker in summer than in winter, and displaced somewhat northward. One consequence of the weakness of the general circulation in summer is a lack of the extreme and clearly contrasting pattern types that occur in winter in such characteristic form. The cyclonic and anticyclonic cells of the general circulation pattern tend to be more numerous, more scattered and less intense than in winter, while the migratory centers tend to move more slowly. However, there remains enough characteristic difference between the weak and the strong circulation patterns to make the distinction significant.

Other than the relative weakness of the circulation patterns in summer compared with those in winter, the principal difference between the warm and the cold seasons lies in the reversal of the monsoon influence. In summer the principal Aleutian and Icelandic centers at time of strong circulation are displaced or develop much more easily over the northern continental areas than they do in winter. On the other hand the strongest polar anticyclonic centers at time of minimum index are much more likely than they are in winter to be located over the northern ocean areas instead of over the continents. Thus in summer the polar highs frequently merge imperceptibly into the subtropical highs which always tend to remain over the oceans, but which are normally more intense and centered at higher latitudes in summer than in winter.

The normal summer weather conditions over the North Atlantic, as represented by the mean charts for August, conform at this season as in winter essentially to the strong circulation pattern in modified form. Comparison of Figure 2 with Figure 1 reveals that the Icelandic low and the zonal westerlies are weaker and are centered about five degrees further north in summer than in winter, while the subtropical high dominates the circulation over much more of the Atlantic Ocean in summer. In summer as in winter it is the weak circulation patterns which bring the greatest departure of North Atlantic weather from the normal conditions as represented by the climatological charts. Consequently it is important to select a series of synoptic charts which includes a period of summer low index conditions over the North Atlantic.

Of the sequence of maps which were selected for discussion here, the period from August 20 to August 26 is one of typically weak circulation. The predominant anticyclonic centers occur at northerly latitudes in the polar air masses, although by the end of this period the polar anticyclones are deteriorating while the subtropical Atlantic high is increasing. During this period the frontal systems over the Atlantic and western Europe have principally a north-south orientation and move slowly. The cyclonic centers are numerous and weak, and also move slowly along the fronts.

The period from August 27 to August 31, inclusive, is one of transition, during which the trend is toward the establishment of large cyclonic cells at higher latitudes with the elimination of the polar anticyclonic centers, and toward the reëstablishment of a dominant subtropical high in the eastern Atlantic. By September 1 a typical summer strong circulation pattern is established, with two moderately strong cyclonic centers at high latitudes and extensive zonal westerlies north of latitude 45° N. This circulation pattern has reëstablished an east-west orientation of the frontal systems at higher latitudes, and the tendency to rapid eastward movement of fronts and centers north of 45°. Only in the southwestern Atlantic, the southeastern United States, and the Gulf of Mexico and Caribbean area is there a marked hangover of typically weak circulation conditions. In this region the subtropical high which dominates the eastern Atlantic is completely broken up by two slowly moving tropical disturbances and one stagnant extratropical cyclonic center, all of which behave with the indecisiveness which is so typical of a low index circulation. Actually it requires another full week before these disturbances are cleared out of the southwestern Atlantic, but otherwise the entire first half of September is marked by an unusually strong state of the general circulation for so early in the autumn. Especially over the North Atlantic and northern Europe the storms during this period repeatedly reach intensities which are characteristic of midwinter conditions.

There follow a few brief remarks on each of the daily synoptic charts from the selected summer sequence. On the map of August 20 the most striking weak circulation features over the North Atlantic are the predominance of anticyclonic cells in the northwestern and in the northeastern Atlantic, and the presence of a frontal system extending from the Azores eastnortheastward over western Europe. Exceptionally warm conditions prevail in central and western Europe south of this front (cf. Figure 10). In summer at time of weak circulation the Polar Front in the eastern Atlantic is more likely to extend eastnortheastward through central Europe rather than to lie further south in the Mediterranean as it so frequently does in winter. The preference for the Mediterranean in winter is doubtless due largely to the relative warmth of this water body during the cold season, as well as to the southward shift of the general circulation pattern in winter.

It will be noticed that widespread fog is occurring in the vicinity of Newfoundland and the Canadian maritime coast. This condition is inevitable in this region in summer when tropical maritime air is being transported northward over the cold off-shore waters. The frequency of this fog condition in summer is to be seen from Figure 22. However, it will be noted from this figure that the fog frequencies along the rugged coast lines of northeastern North America, Greenland and Iceland are locally extremely variable. This is doubtless caused by great variation in the shielding effects on the observation sites of the local terrain. The successful forecasting of fog for coastal sites in any of this region must depend upon an intimate knowledge of local topography and winds. Especially during the daytime a very short haul over land may be sufficient to dissipate an ocean fog or low stratus. Generally, however, widespread fog is likely to be formed in summer over the cold coastal waters off the northeast Atlantic coast of North America whenever the air mass transport is persistently from between southeast and southwest. Even a west wind suffices to produce fog when the continental air mass is moderately warm and humid. Such widespread fogs may extend or be transported eastward as far as longitude 40° W, or even further in exceptional cases. On the other hand, widespread fog formation over the northeastern Atlantic east of 30° W occurs occasionally in summer with the persistent westward transport of warm continental air masses from northern Europe. This is a low index pattern which is usually characterized by the extension of high pressure from northern Russia to northern Scandinavia, while the Polar Front extends west-east across central Europe. In summer this low index pattern brings the warmest weather to Scandinavia, whereas the corresponding winter pattern brings northwestern Europe its coldest weather.

The map of August 21 shows no significant change from the conditions of the preceding day. Note the extremely slow movement both of the frontal systems and the numerous weak cyclonic centers which are associated with these fronts.

On August 22 and 23 there is no further significant change of the weak circulation pattern. Probably the low index characteristics are best shown on the map of August 23, with the maximum development of the polar anticyclonic centers over eastern North America and the northeastern Atlantic, while the fronts in the Atlantic extend nearly north-south. The development of the anticyclonic center in the northeastern Atlantic has displaced the Polar Front in western Europe moderately southward. This development carries with it a return to more nearly normal temperature in western Europe. Northwest of this high, however, in the vicinity of Iceland and southwestern Greenland, temperatures are abnormally high. Note that the slow eastward advance of the cold front along the east coast of North America has displaced the fog-bearing tropical maritime air mass eastward so that the fog condition now extends to 40° W, and northward to southern Greenland.

On August 24 there appears for the first time a noticeable tendency towards cyclogenesis in the vicinity of southern Greenland. This development might be taken as the first sign of the impending gradual change of the general circulation to a highly active state. There is no particular evidence in the current chart either as to whether the trend will continue, or as to why it started at this particular time and place. The location, however, is just that of the most frequent development of the Icelandic low. Consequently, it is a spot which should be watched carefully in the absence of an Icelandic low.

During August 25 and 26 the slow development of cyclonic activity continues over a large area in the vicinity of southern Greenland, but this development is not strong enough to change the weak circulation characteristics of the North Atlantic weather pattern. In particular, the persistence of the large anticyclonic cell over the northeastern Atlantic and northern Europe helps to maintain the low index character of the circulation pattern.

The maps of August 27 and 28 show marked deterioration of the low index characteristics of the general circulation north of latitude 50° N. Note the continued slow genesis of the Icelandic low, the disappearance of the northern European anticyclonic cell as well as the absence of any important polar anticyclone on either map, and finally the first appearance of a significant cyclonic center in northwestern Canada. South of latitude 50° N the circulation pattern remains very weak.

It appears on the map of the 28th that a new tropical air fog condition is being established along the Atlantic coast from Long Island to Newfoundland. Contrary to the conditions in winter (see p. 50) the occurrence of tropical air fog at inland locations in summer is relatively infrequent and of small significance.

An interesting feature of the map of the 28th is the indication of a tropical disturbance located near eastern Cuba. Minor undulations of the isobars in the Caribbean area have been apparent several times during the preceding week, but this is the first such occurrence where the winds have been sufficiently accelerated to give clear evidence of a cyclonic center. The genesis of tropical disturbances in the vicinity of the Sargasso Sea, Caribbean and the Gulf of Mexico is favored by weakness of the Atlantic anticyclone in the region where the formation occurs. Some horizontal convergence seems to be required before the cyclogenesis can begin.

Between August 29 and August 31 the trend towards a stronger circulation pattern continues steadily. Both the Icelandic low and the cyclonic cell over western Canada become slowly larger and stronger, thus intensifying the zonal westerlies south of the centers. Significant anticyclonic centers at the higher latitudes remain conspicuously absent, while a strong Azores high develops in the eastern Atlantic. For the first time during this map series, a cyclonic center crosses from extreme northeastern Canada to southern Greenland and merges with the Icelandic low. It is this development, which is so characteristic of a strong circulation pattern, that leads to the intensification of the Icelandic center between August 31 and September 1 (cf. conditions from January 13 to January 14, p. 48).

It is interesting to note in this case how the increasing strength of the zonal westerlies in the vicinity of latitude 50° N carries the warm foggy maritime tropical air from the Grand Banks region rapidly eastward across the North Atlantic. The fog and drizzle conditions which characterize this warm air mass (more drizzle and less fog as the wind velocity increases) reach the British Isles on September 1. In the preceding case of widespread fog formation in the same Grand Banks fog center (August 20) a typical low index circulation pattern carried the warm foggy air mass northward to Greenland (August 21–23). It is unusual to get a combination of conditions favorable to widespread fog formation (low index pattern) and rapid eastward transport (strong circulation pattern) in such a manner that Newfoundland fog reaches the British Isles.

Only in the southwestern Atlantic does the circulation pattern between August 29 and September 1 manifest a tendency towards weaker rather than stronger characteristics. These characteristics are seen in the slow northwestward drift of the tropical disturbance which is moving through the eastern Gulf of Mexico, and the almost stationary condition of the second tropical disturbance which developed north of Porto Rico on August 30 and 31. The slow movement of the first storm even after it starts to recurve northward, and the almost motionless state of the second storm testify to the absence of any predominant wind movement in this area even as late as September 3. The second disturbance later recurved off the east coast of Florida and moved very slowly northeastward parallel to the coast. It attained full hurricane intensity near the center before it reached 30° N, and apparently retained hurricane intensity at the center as late as September 11 at 43° N, 50° W. At that point the storm was caught by the strong zonal westerlies which then prevailed at higher latitudes and suddenly moved into the Icelandic low, covering as much distance in two days as it had in the previous thirteen days, and losing its hurricane characteristics at the center.

It should be pointed out that also the disturbance centered over Nova Scotia on August 29 followed a low index behavior pattern during the following five days. As the front moved slowly eastward the disturbance developed retrogressively on the front so that the center was displaced actually southeastward in the western Atlantic. By September 3 the center had nearly disappeared in the southwestern Atlantic. The behavior of this disturbance was obviously determined by the weak circulation pattern which continues to dominate this portion of the Atlantic. The fact that the southwestern portion of the North Atlantic should frequently be the last portion to change from a weak to a strong circulation pattern is consistent with the statistical evidence that index changes tend to progress from east to west over Europe and the Atlantic, and that the reëstablishment of strong zonal westerlies occurs first at high latitudes, thence progressively southward.

By September 1 a typical summer strong circulation pattern is well established north of latitude 45°, as is evidenced by the two strong cyclonic centers at high latitudes, by the absence of polar anticyclones, and by a strong Azores high. The extension of the subtropical highs into the western Atlantic and the eastern United States is the final step needed to complete the typical summer high index pattern from North America to Europe. This completion of the strong circulation pattern is delayed for more than a week while the tropical hurricane which was discussed above moves slowly northward. Meanwhile, at high latitudes, the prevailing circulation pattern during the first half of September is exceptionally strong. A sequence of strong lows move rapidly eastward, near latitude 60° N from North America to northern Europe. This tendency to rapid eastward motion of strong lows at high latitudes is quite characteristic of a strong circulation pattern, both summer and winter. It normally extends eastward into northern Europe, as observed in this case on the map of September 3, unless the blocking action of a strong polar anticyclone is present in northern Eurasia (cf. p. 49).

In this case the rapid eastward movement of strong lows continues throughout the first half of September. During this time cyclogenesis recurs repeatedly in the vicinity of Hudson Bay, and between Iceland and northern Europe. Consequently, the mean circulation pattern continues throughout the period to show one principal cyclonic cell in each of these two regions, within a trough of low pressure near the sixtieth latitude circle. This strong circulation pattern terminates quite abruptly about September 15, with a return to a markedly weak state of the general circulation.

LEGEND FOR ALL SYNOPTIC MAPS

Plotting Models

Land Stations

	C_H	
TT	C_M	PP
ww	Ⓝ	±ppa
U	C_L	W

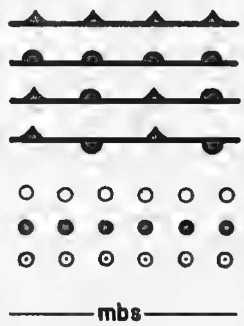
Ship Reports

		C_H	
	TT	C_M	PP
	ww	Ⓝ	±ppa
↗s	±tt	C_L	W

The international weather code is used for all symbols with temperature in degrees centigrade and pressure in millibars. The following letters have the meaning as indicated:

- U Relative humidity (tenths)
- W Past weather
- tt Sea temperature, + used to distinguish it from air temperature
- ↗s Direction and speed of ship (code numbers 0-9)

Analysis Symbols



- Surface cold front
- Surface warm front
- Surface occluded front
- Surface stationary front
- Weak cold front
- Weak warm front
- Weak occluded front
- mbs — Isobar drawn for every 5 mbs.

mT Air

Precipitation

Air Mass Symbols

mP Polar maritime

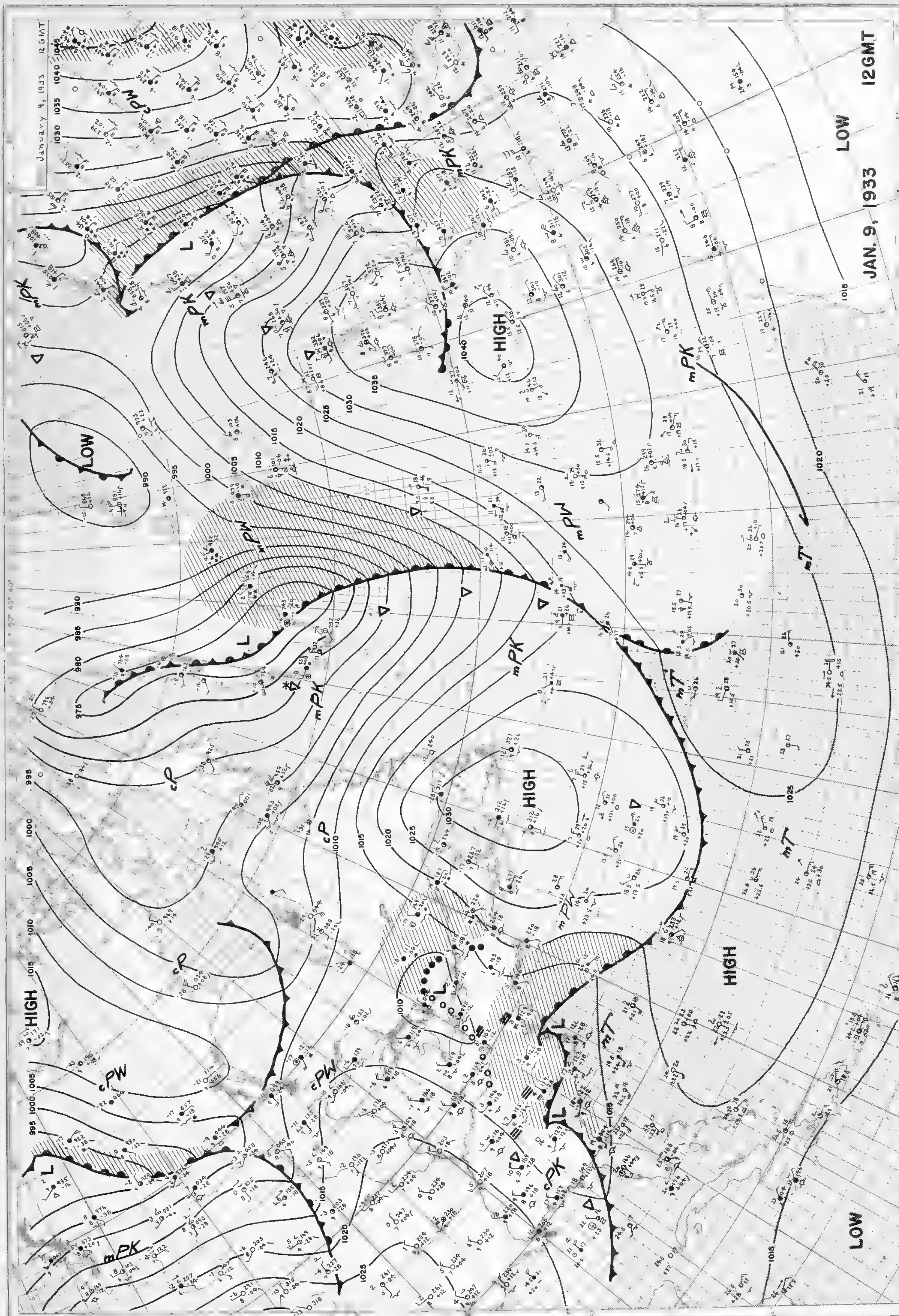
cP Polar continental

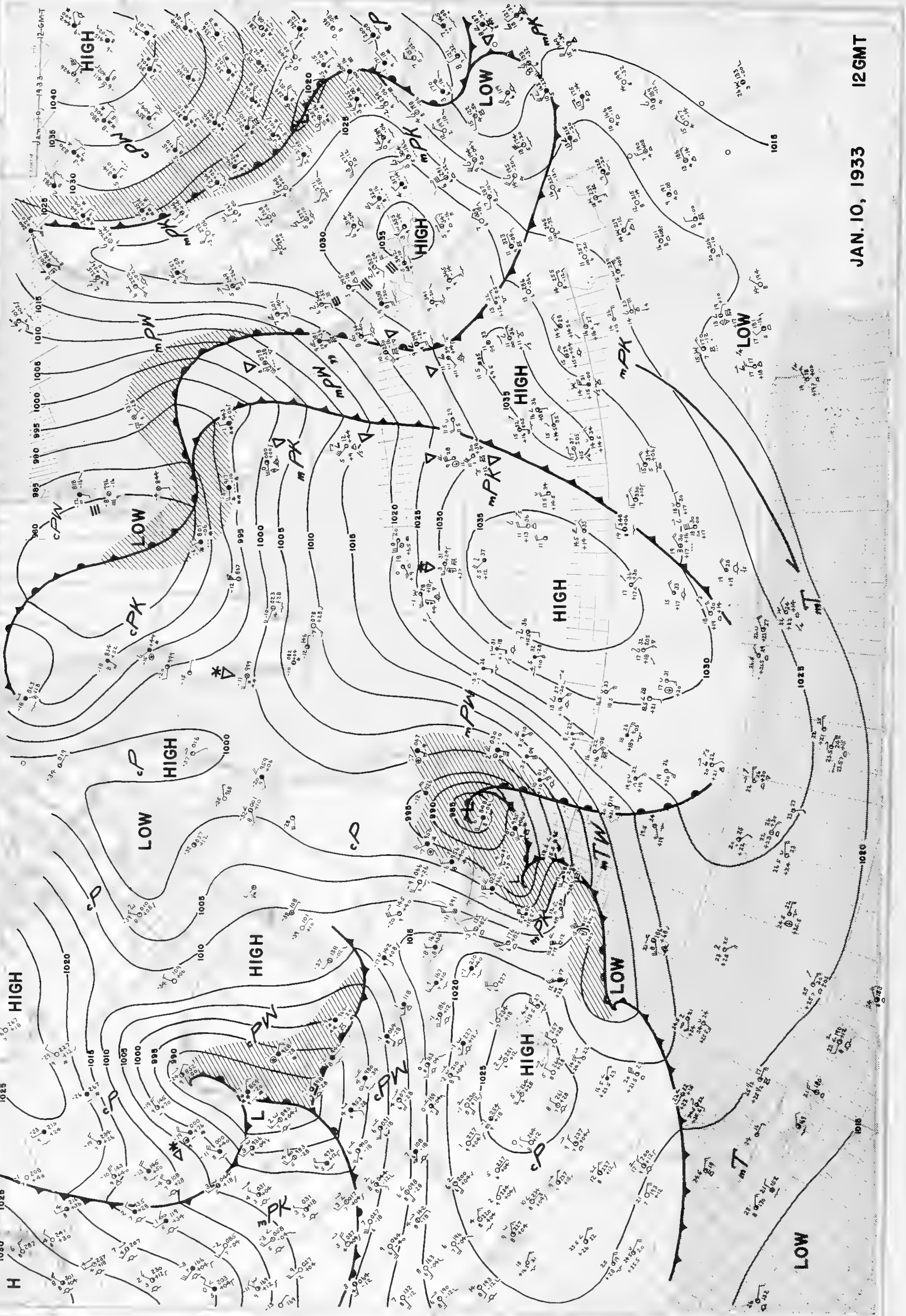
mT Tropical maritime

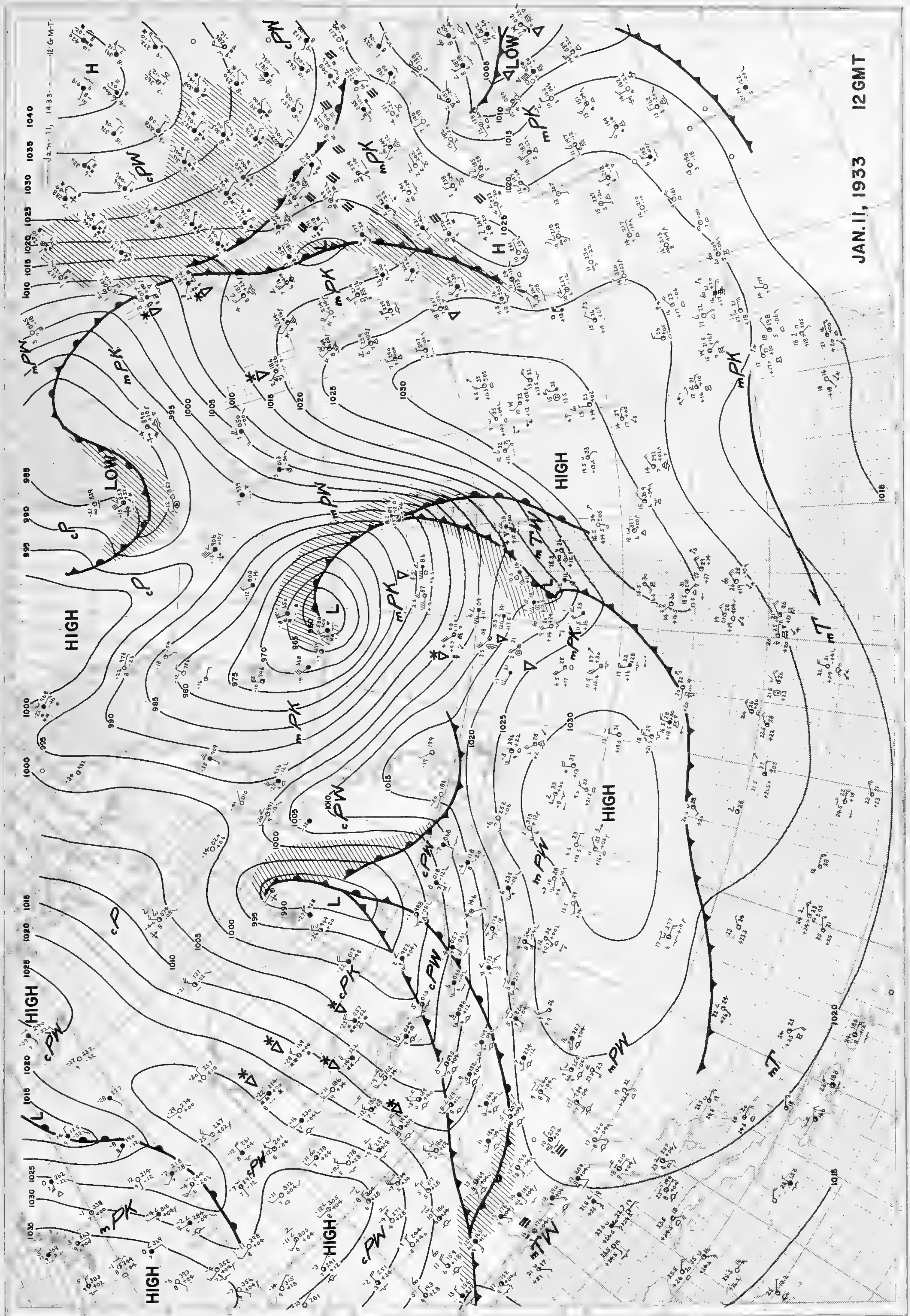
cT Tropical continental

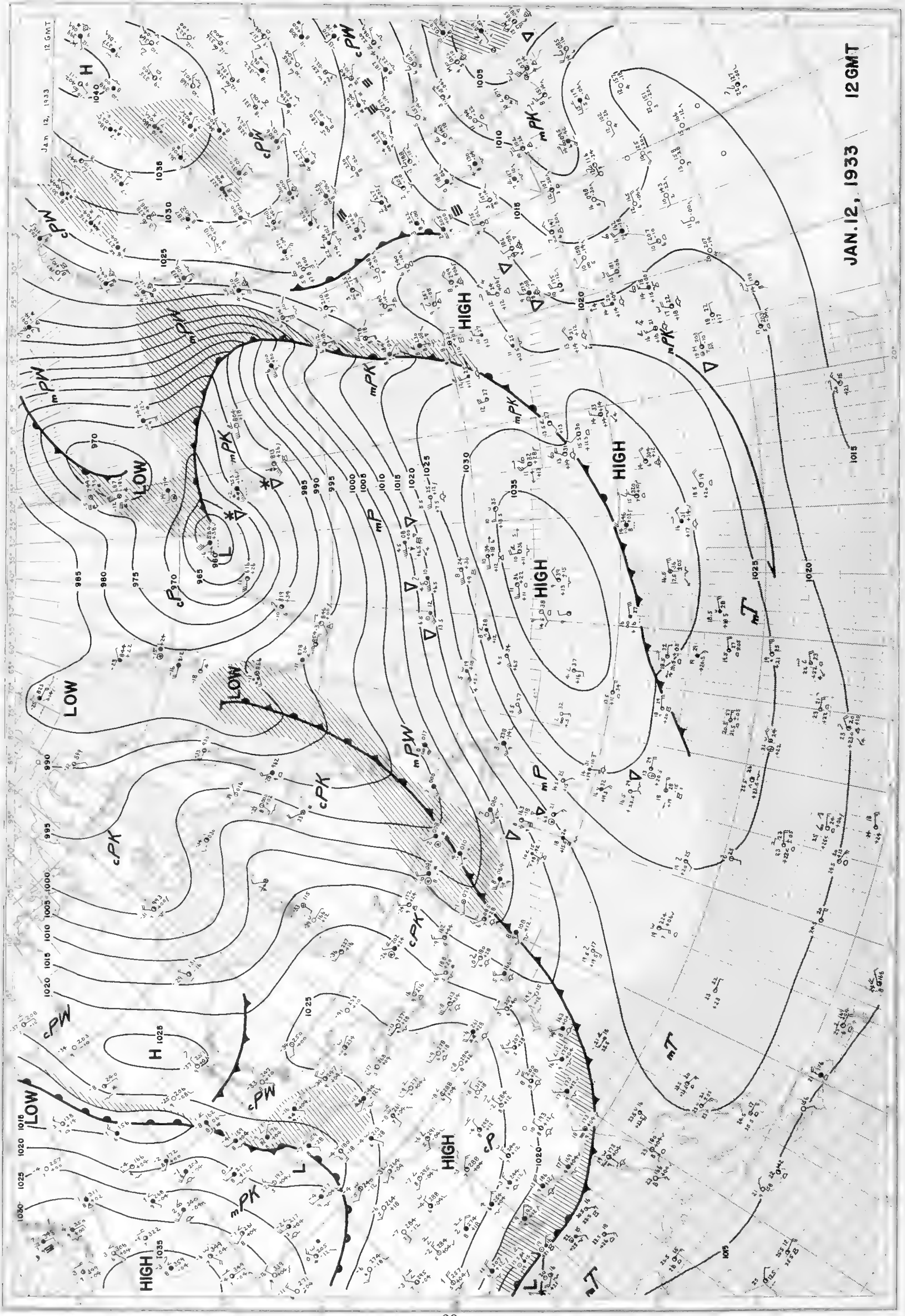
W Air warmer than underlying surface

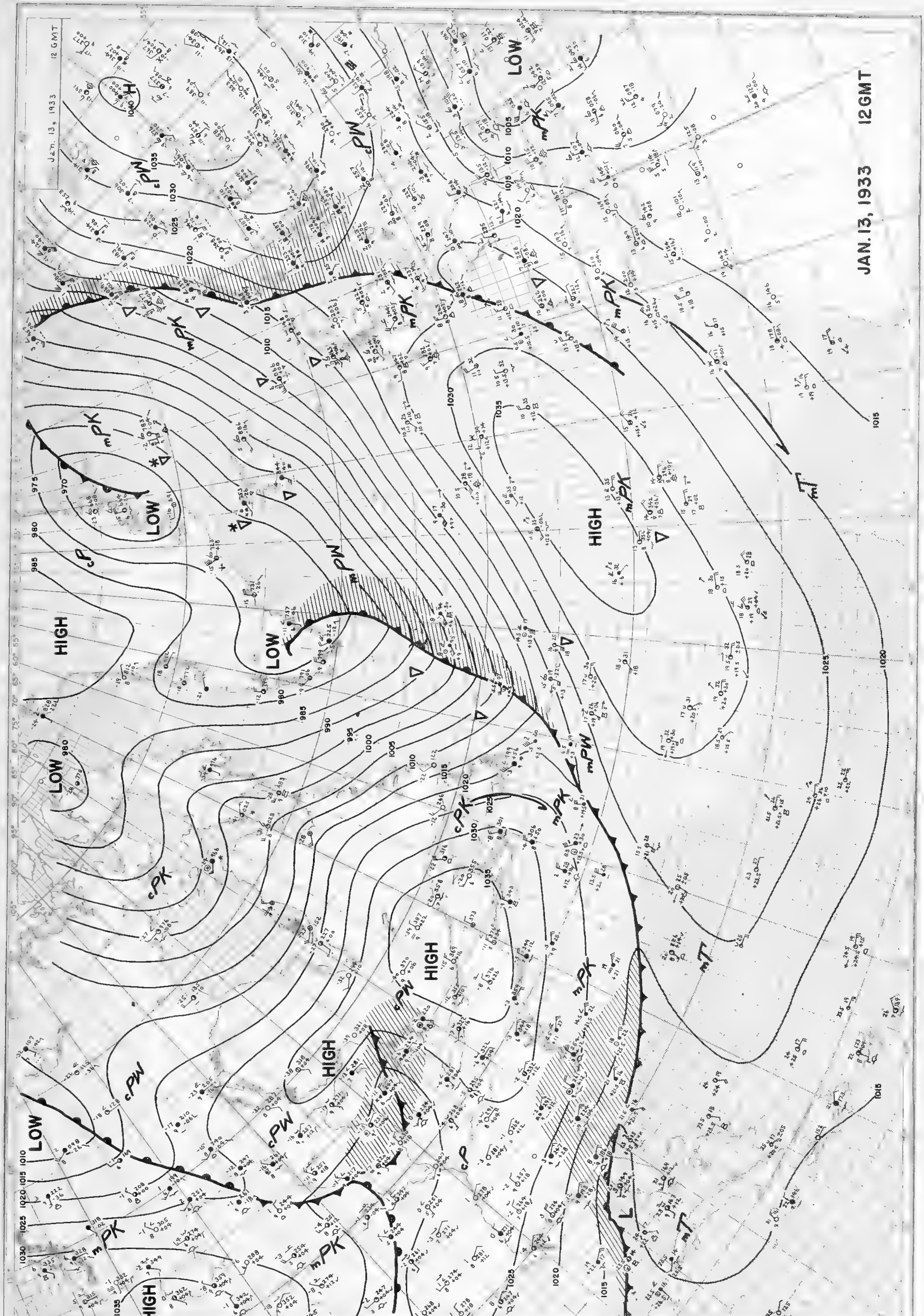
K Air colder than underlying surface

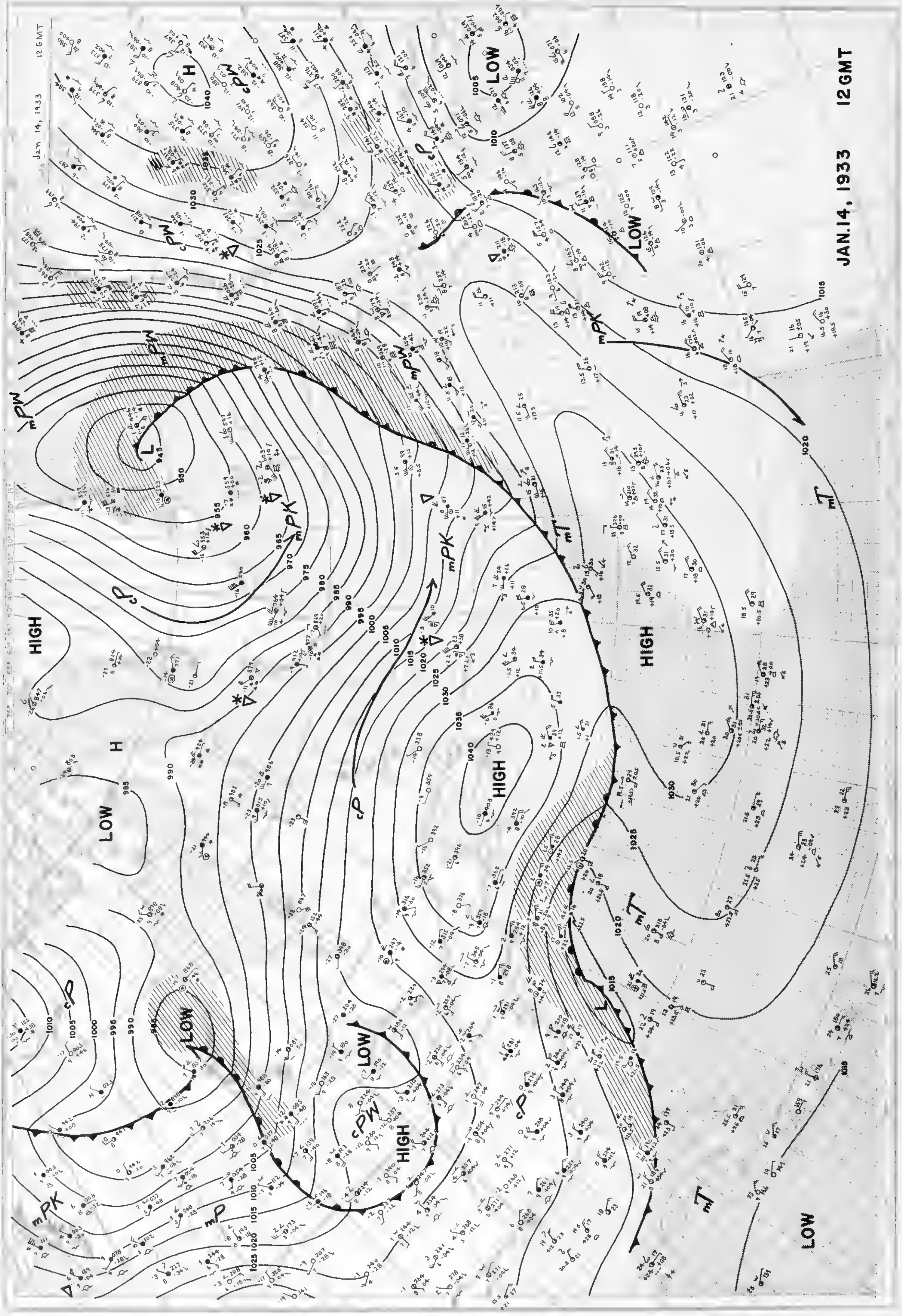

JAN. 9, 1933
12GMT
January 9, 1933 12 GMT
HIGH
LOW
L
mPK
mPW
cP
cPW
cPK
mT
cPM

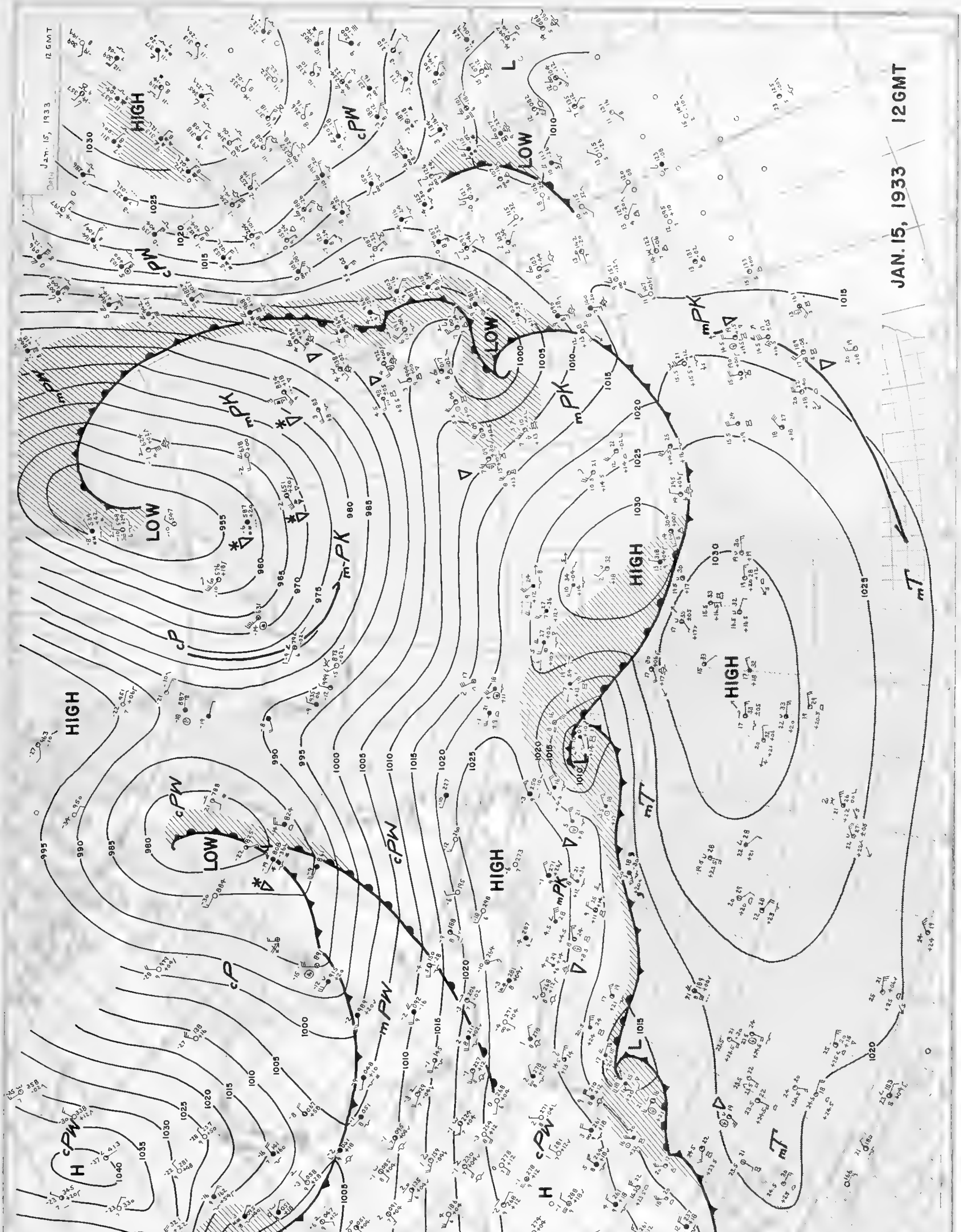

JAN. 10, 1933
12GMT

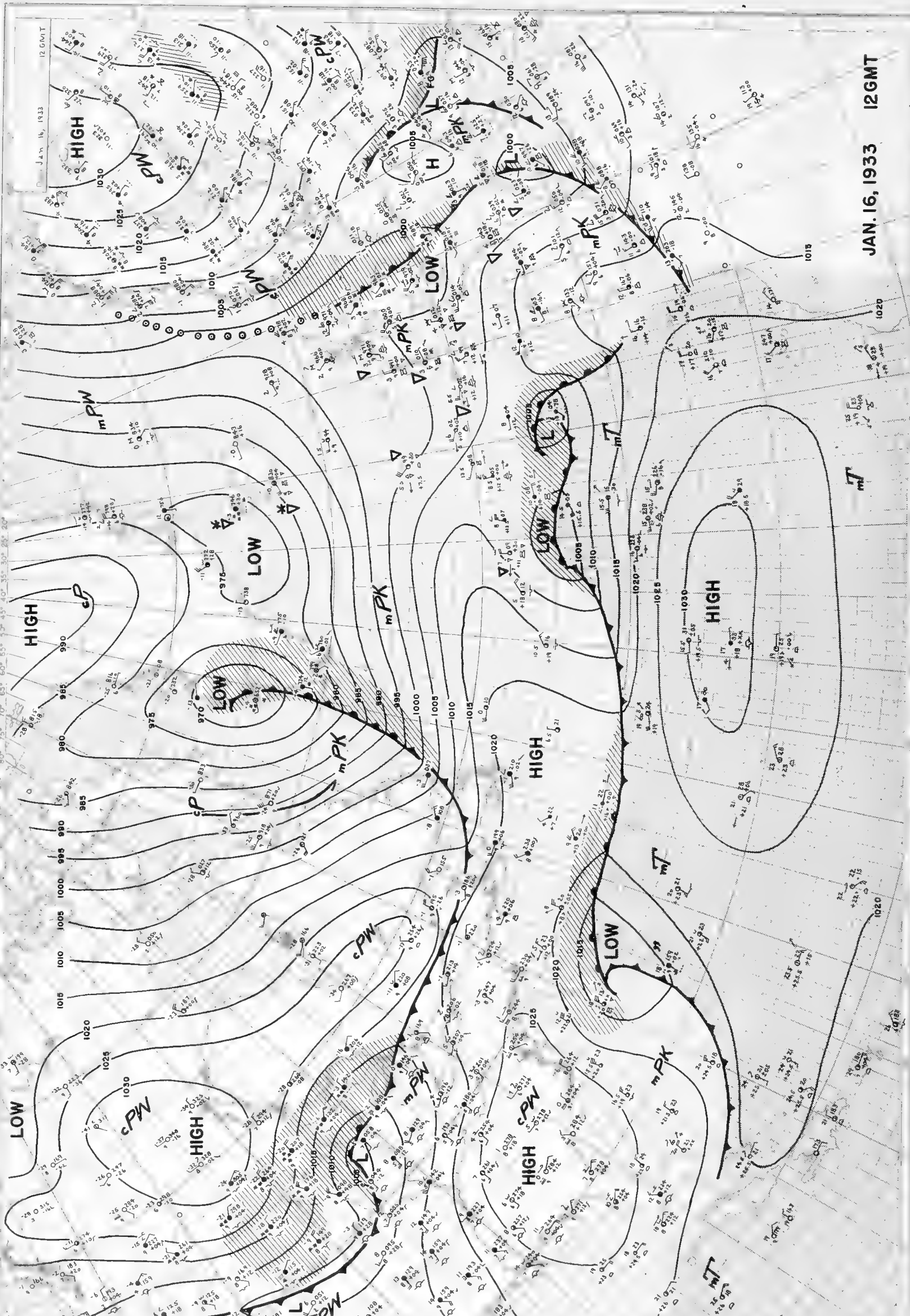

JAN. 11, 1933
12 GMT

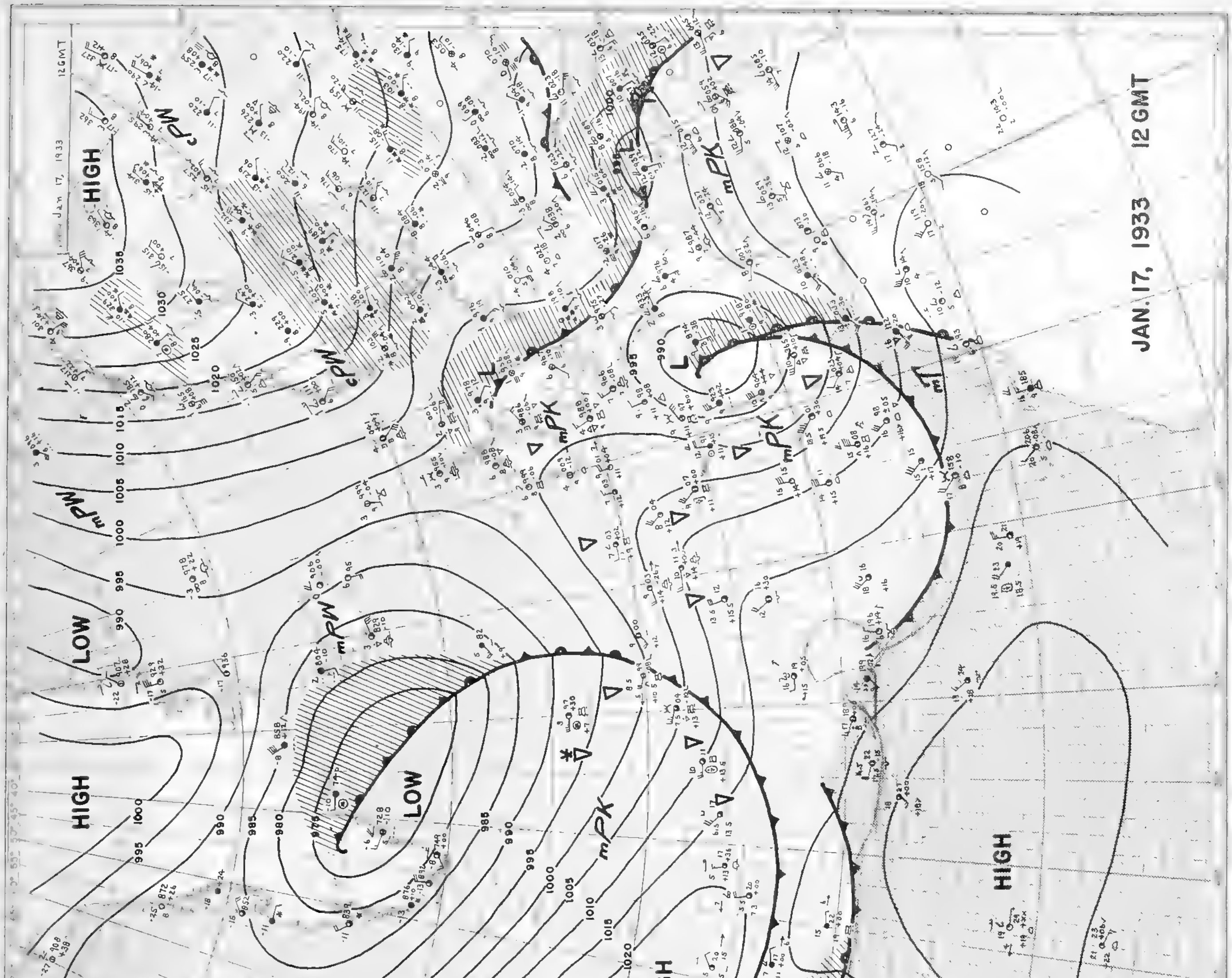

JAN. 12, 1933
12 GMT
HIGH
LOW
mPK
cPW
mPW
cPK
mP
mT
cP


JAN. 13, 1933
12GMT
Jan. 13, 1933
12 GMT
HIGH
LOW

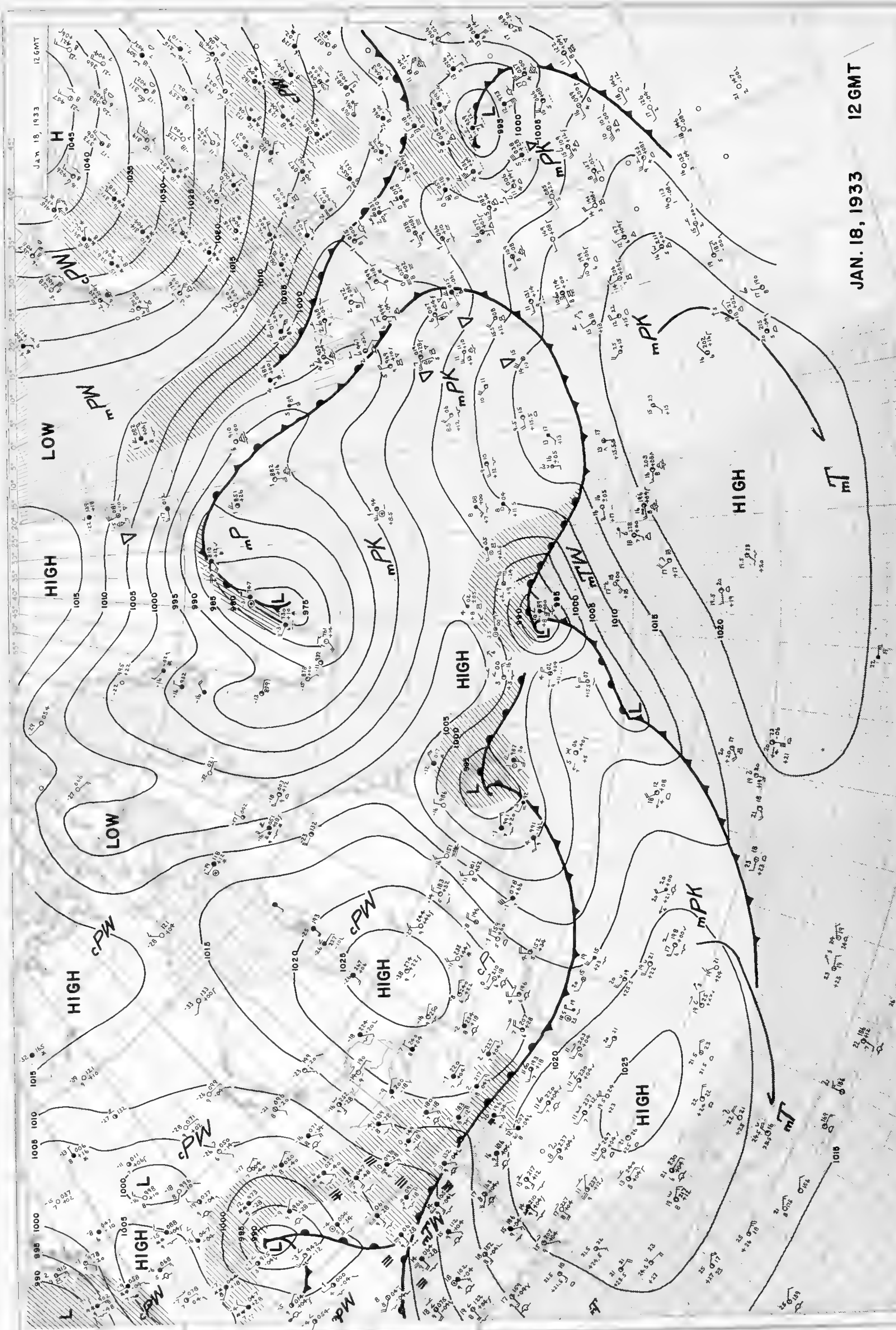

JAN.14, 1933
12 GMT

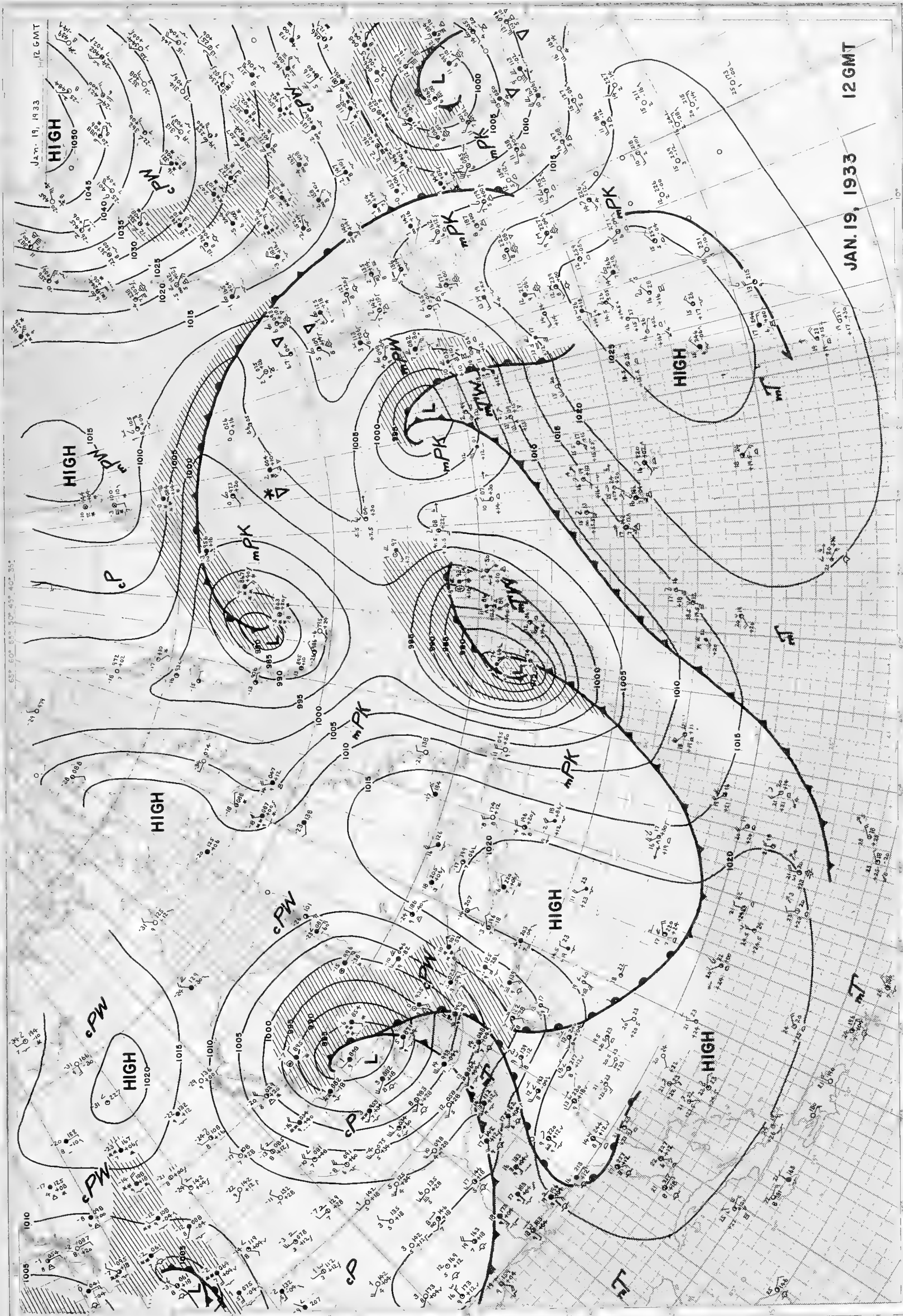

JAN. 15, 1933
12GMT
HIGH
LOW
cPW
mPK
cP
mPW
mT
H
L

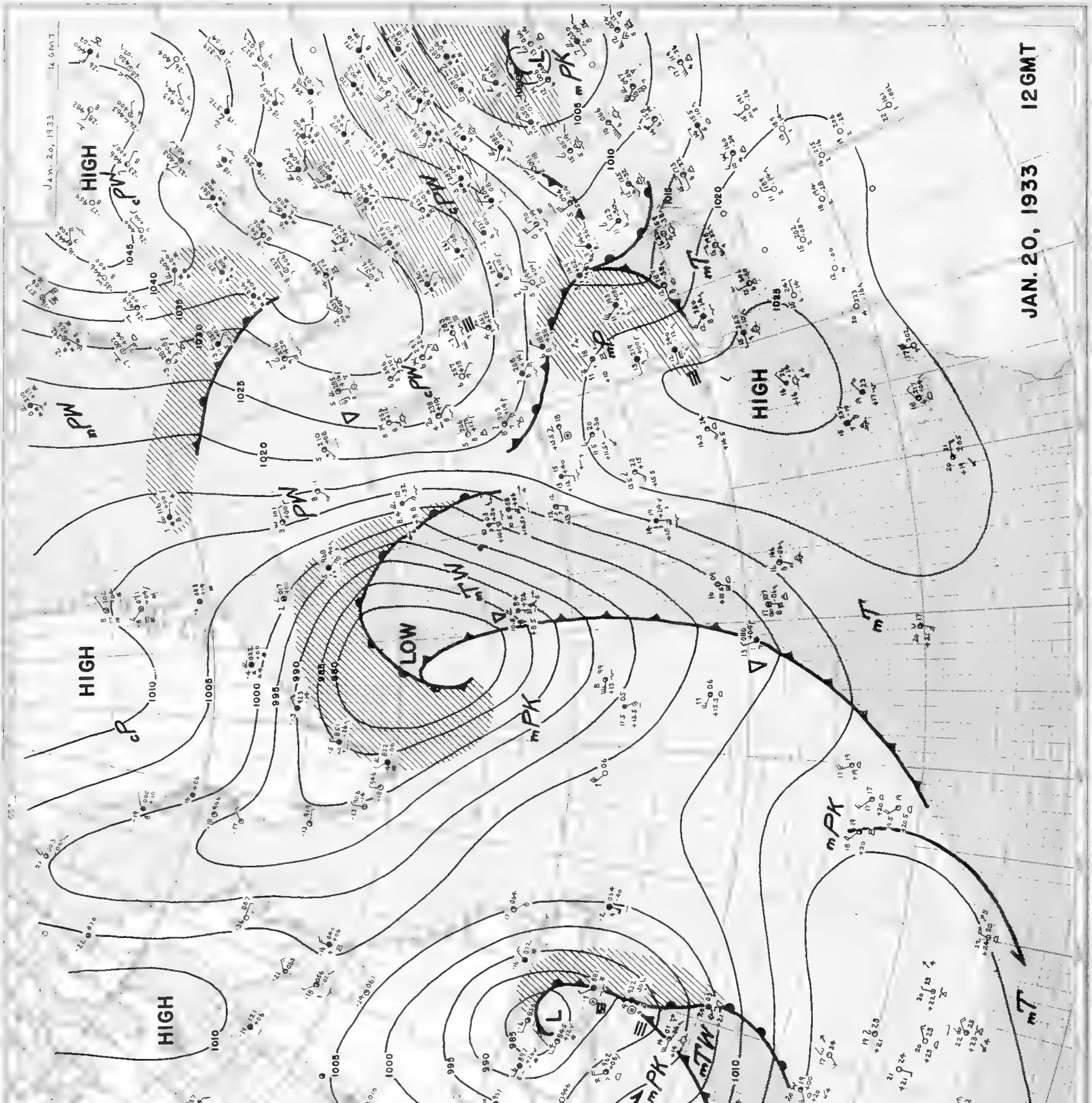

JAN. 16, 1933
12GMT
HIGH
LOW
cPW
mPW
mPK
cP
mT

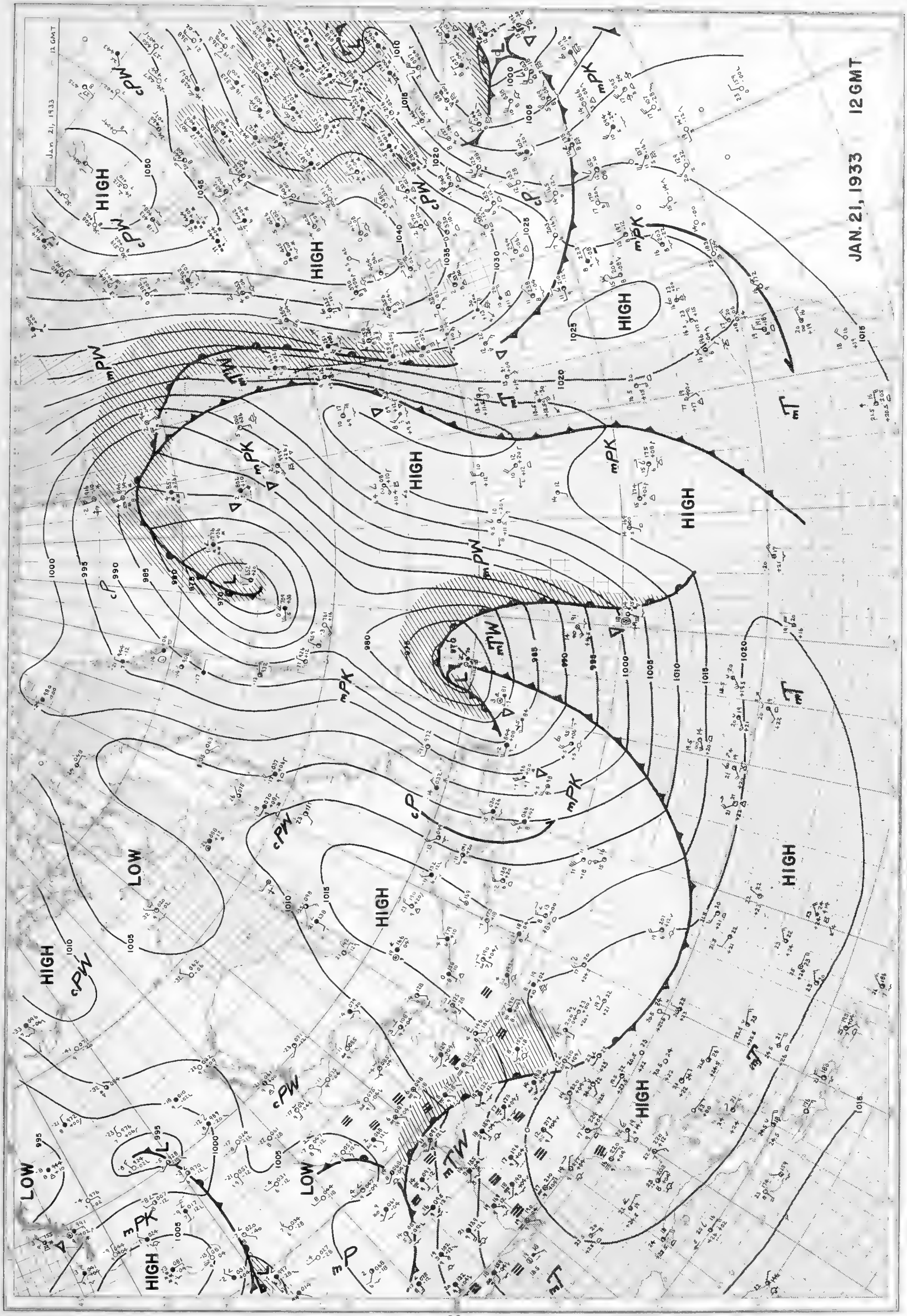


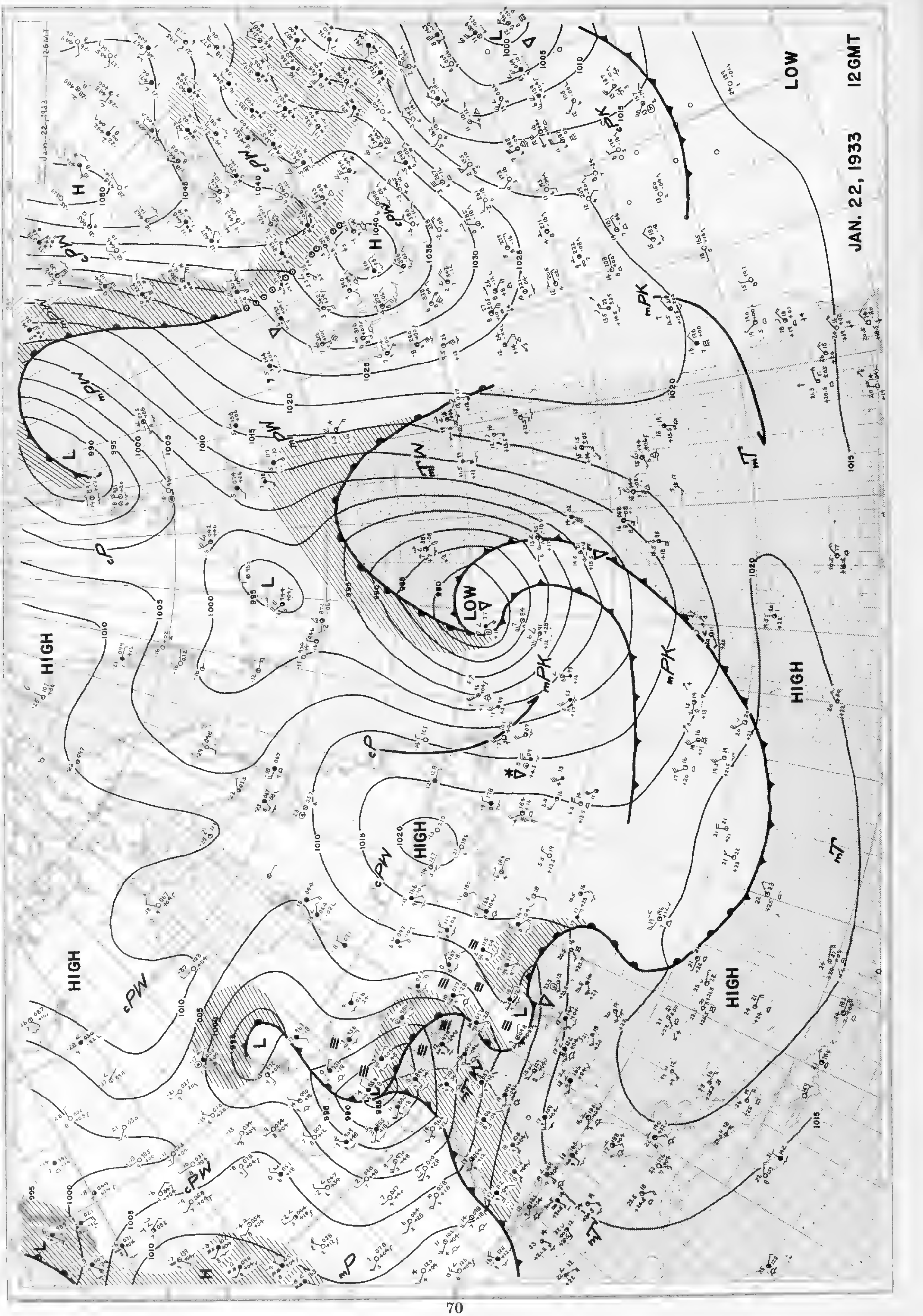
JAN. 17, 1933
12 GMT

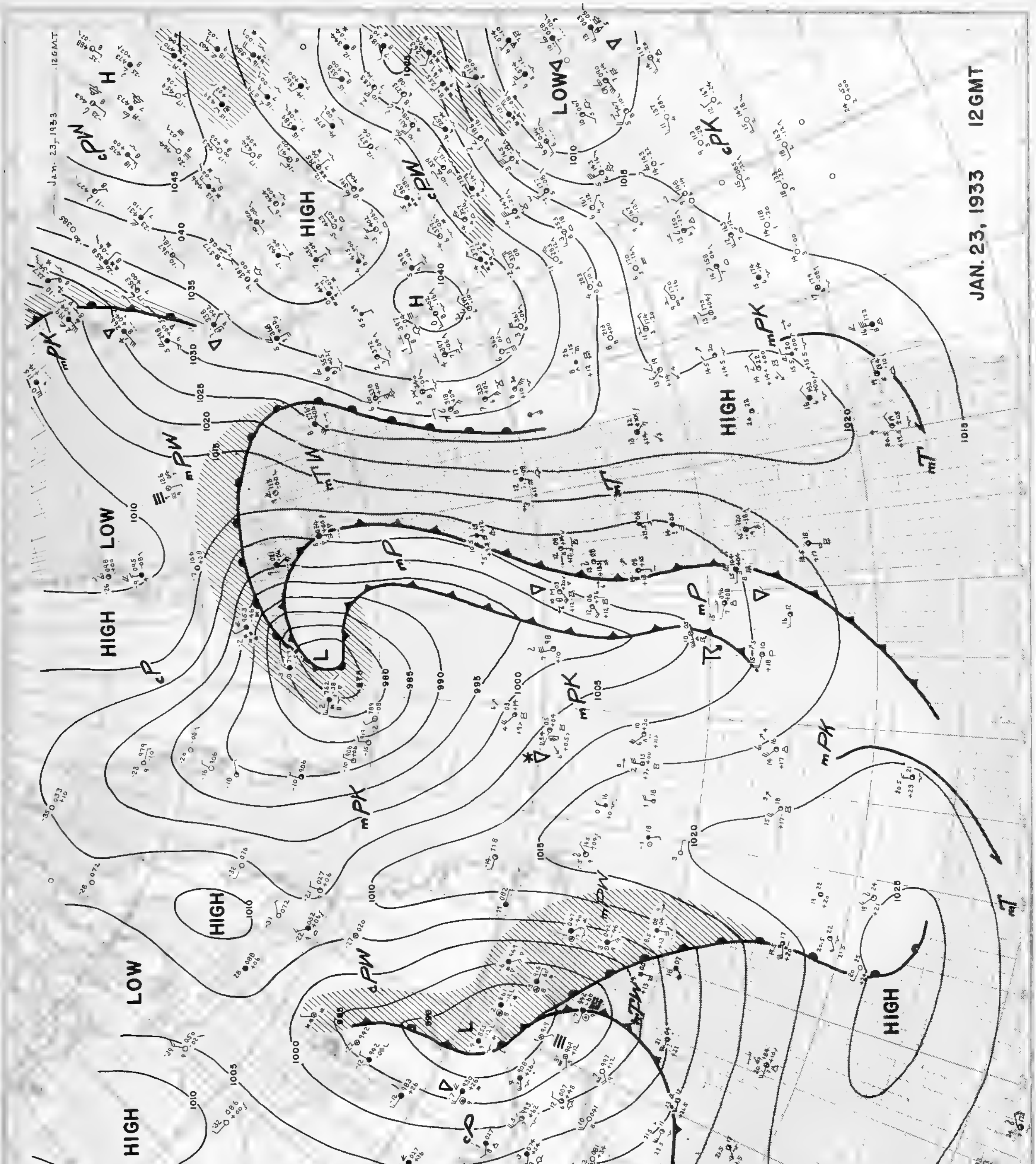

JAN. 18, 1933
12 GMT
HIGH
LOW

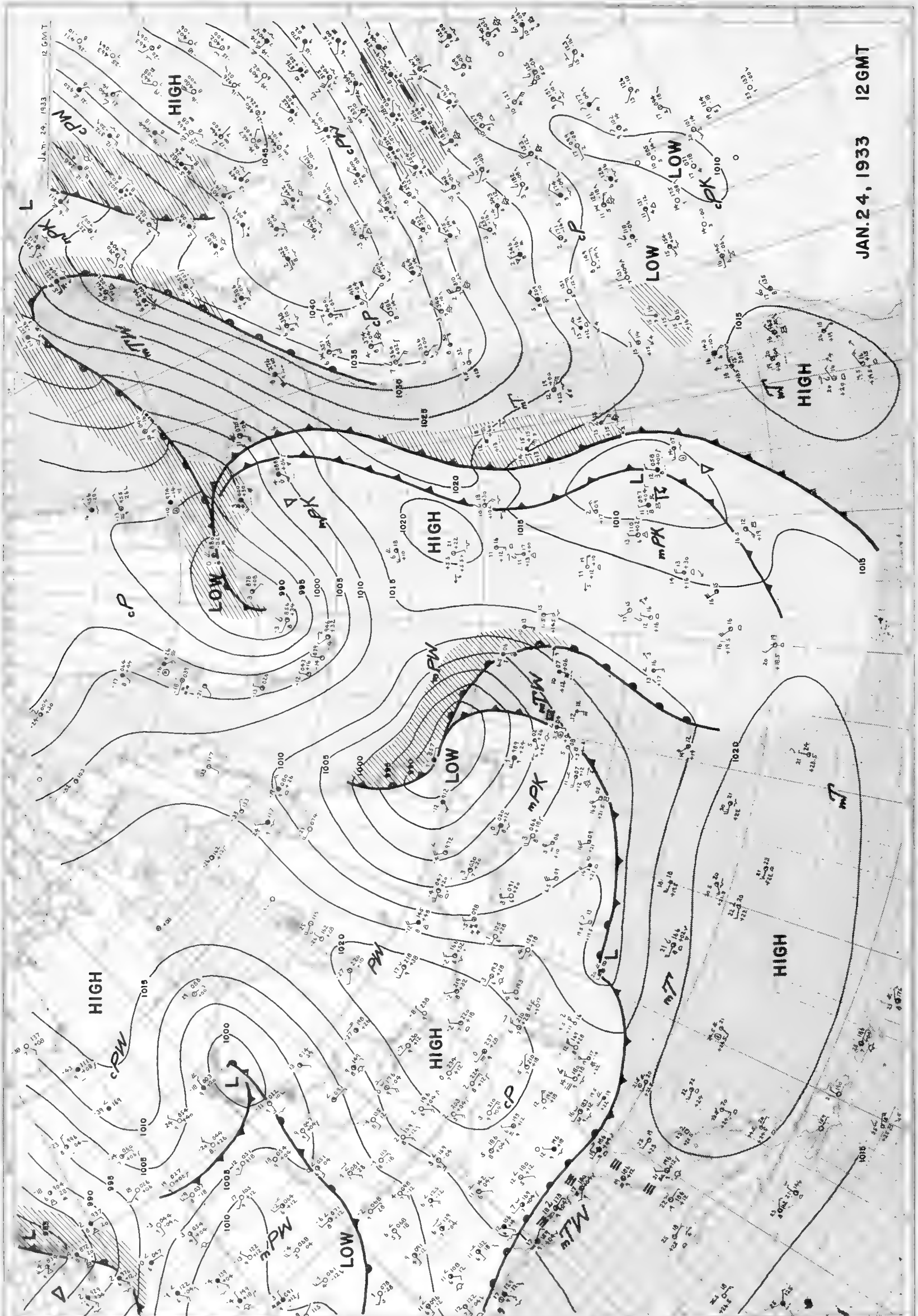

JAN. 19, 1933
12 GMT
HIGH
L

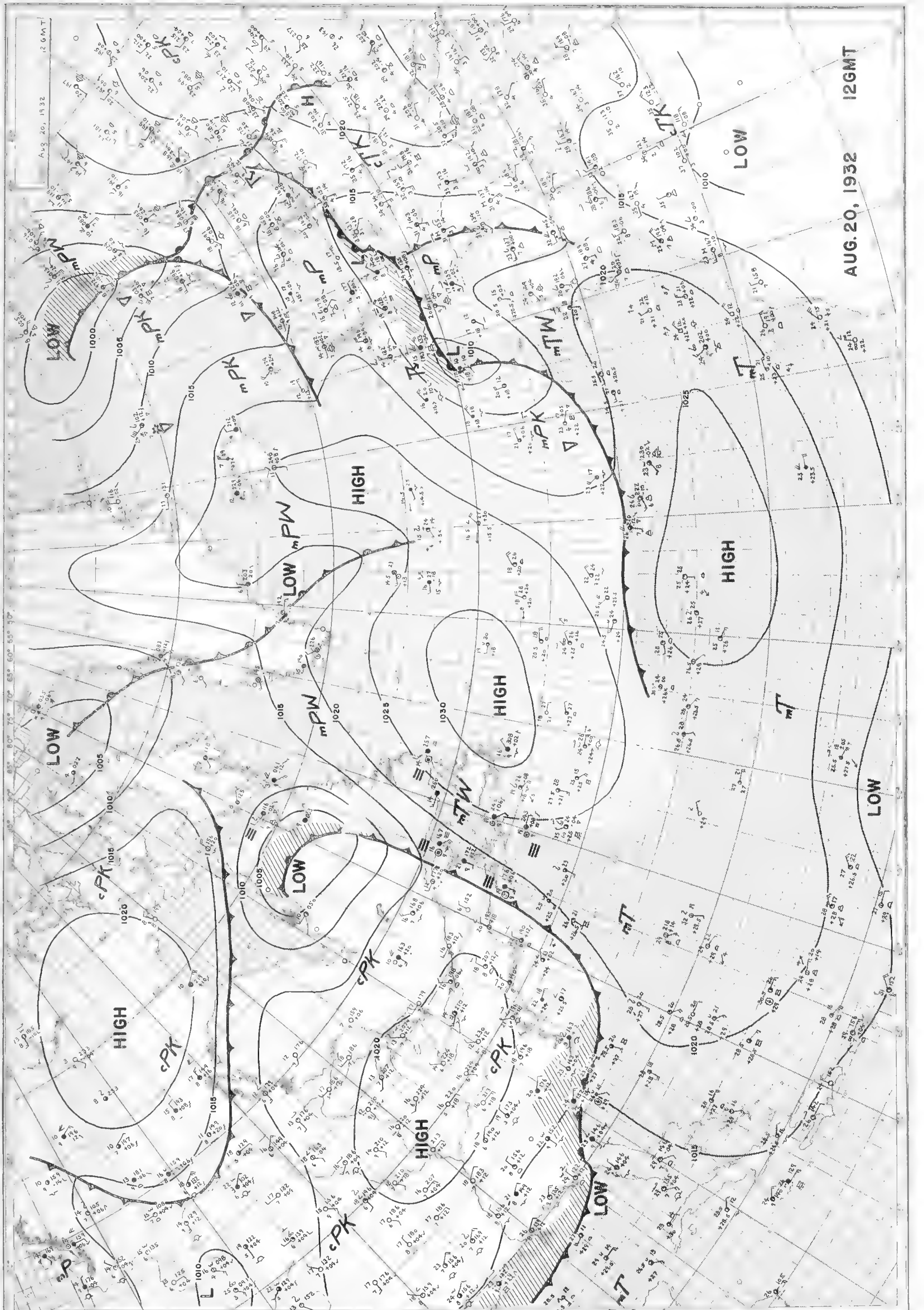

JAN. 20, 1933
12GMT
HIGH
HIGH
HIGH
HIGH
LOW
LOW
L
L
H
H
cPW
mPW
mPK
mTW
mT
cP
1045
1040
1035
1030
1025
1020
1015
1010
1005
1000
995
990
985

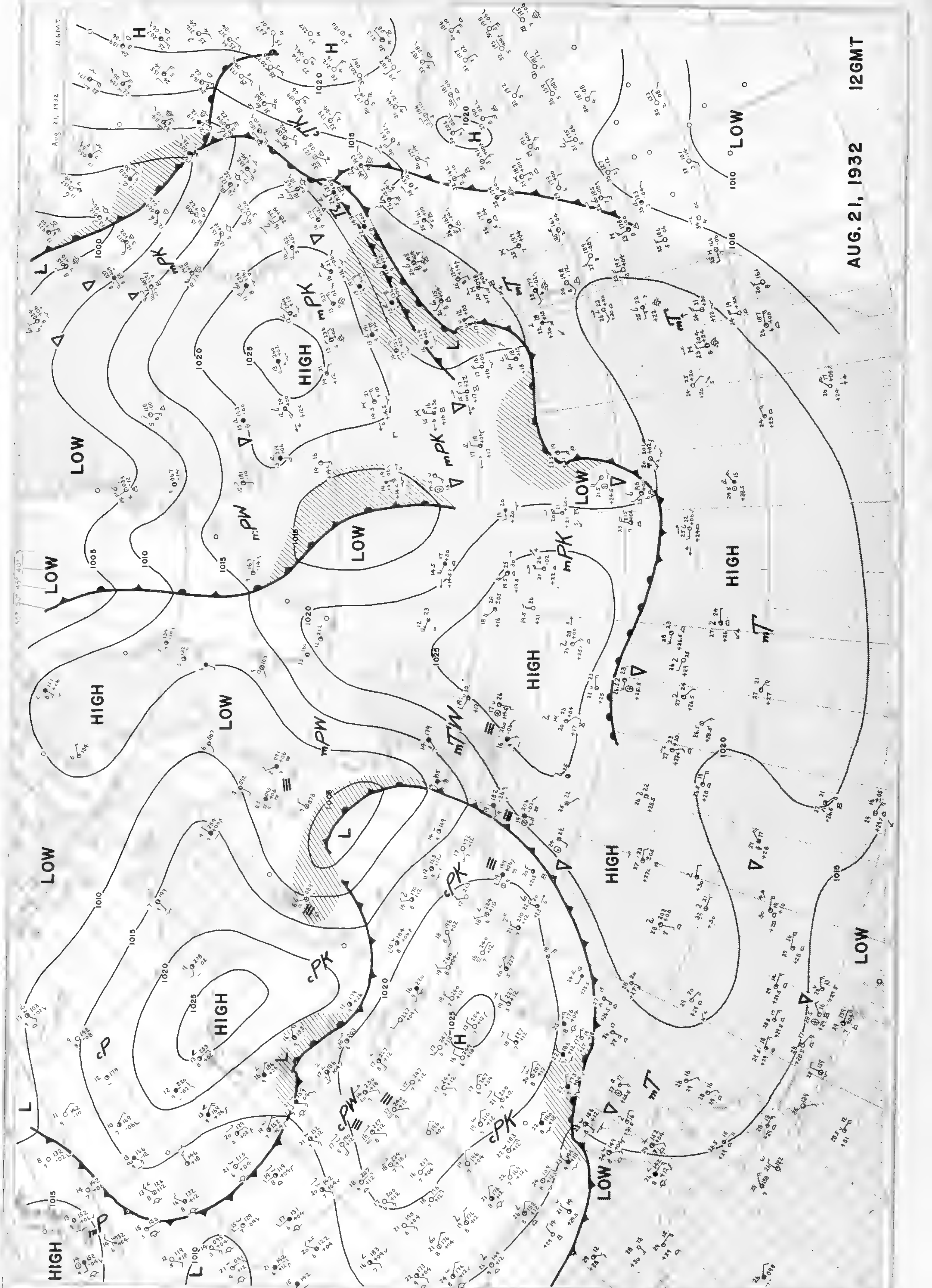

JAN. 21, 1933
12 GMT

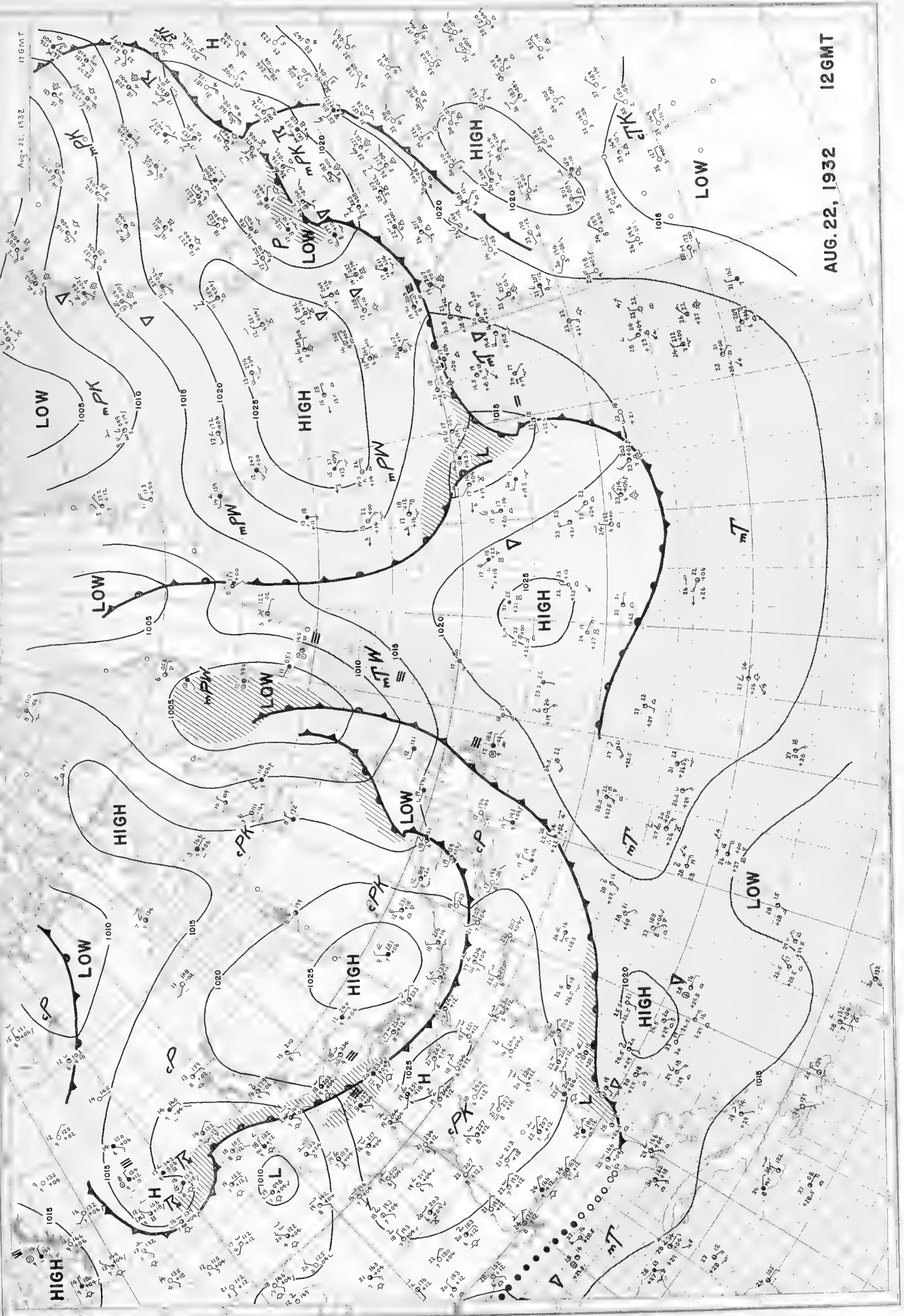

JAN. 22, 1933
12GMT
LOW
HIGH
cPW
mPK
mT
cP
mP

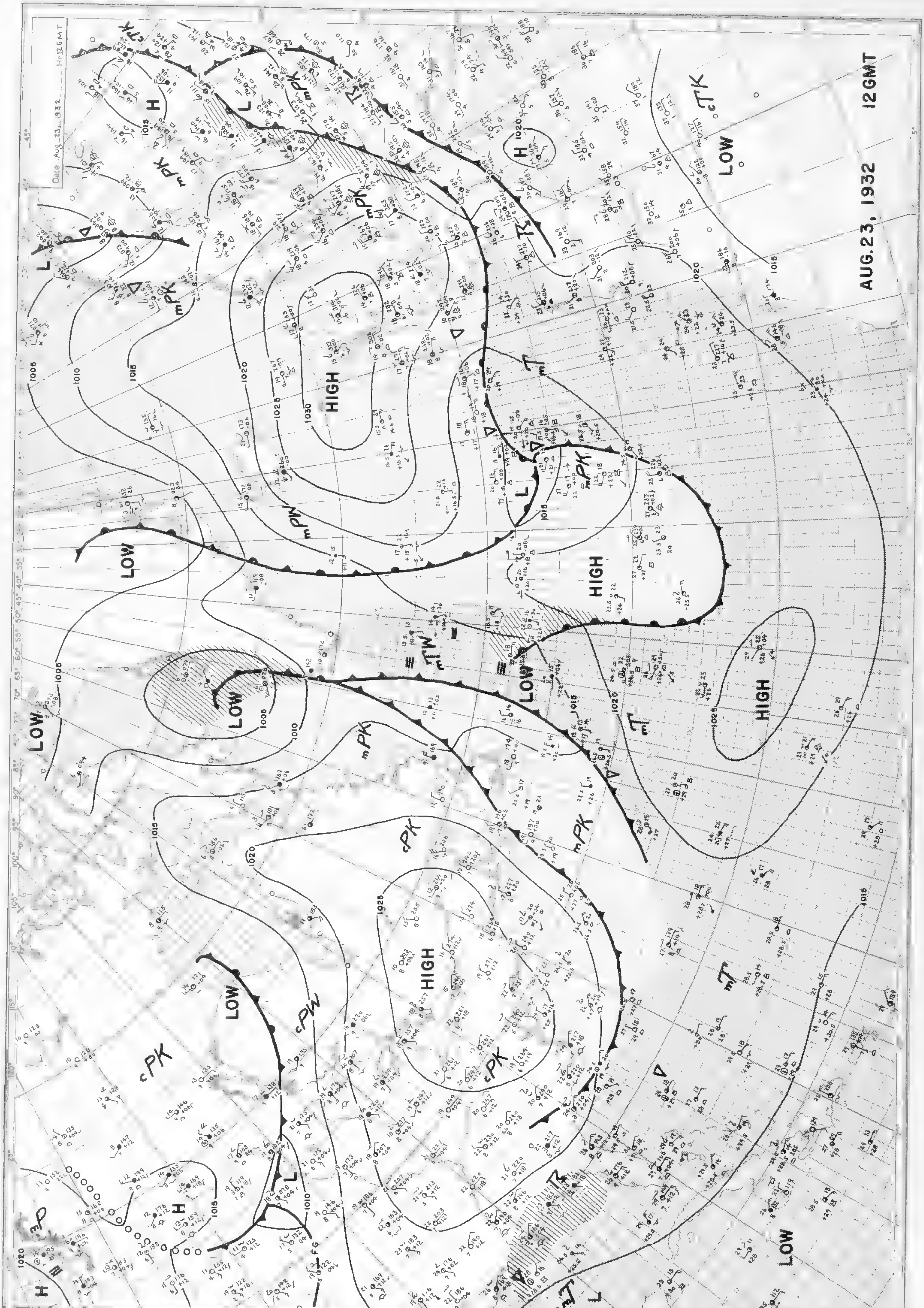

JAN. 23, 1933
12GMT
Jan. 23, 1933
HIGH
LOW
cPW
mPK
mTW
mP
cP
mT
cPK
mPW

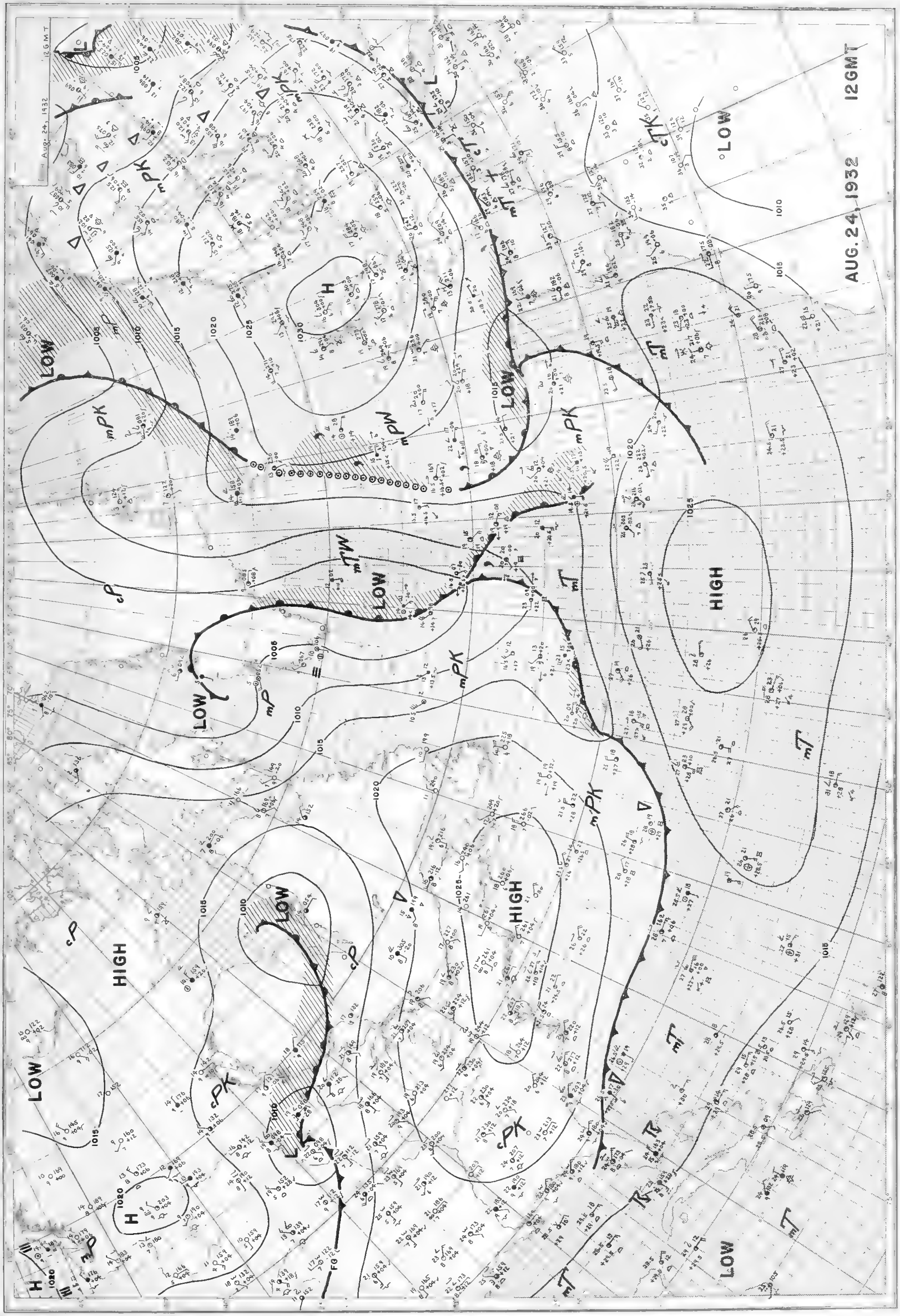

JAN. 24, 1933
12GMT
HIGH
LOW
cP
mPK
mTW
cPW
mPW
mT

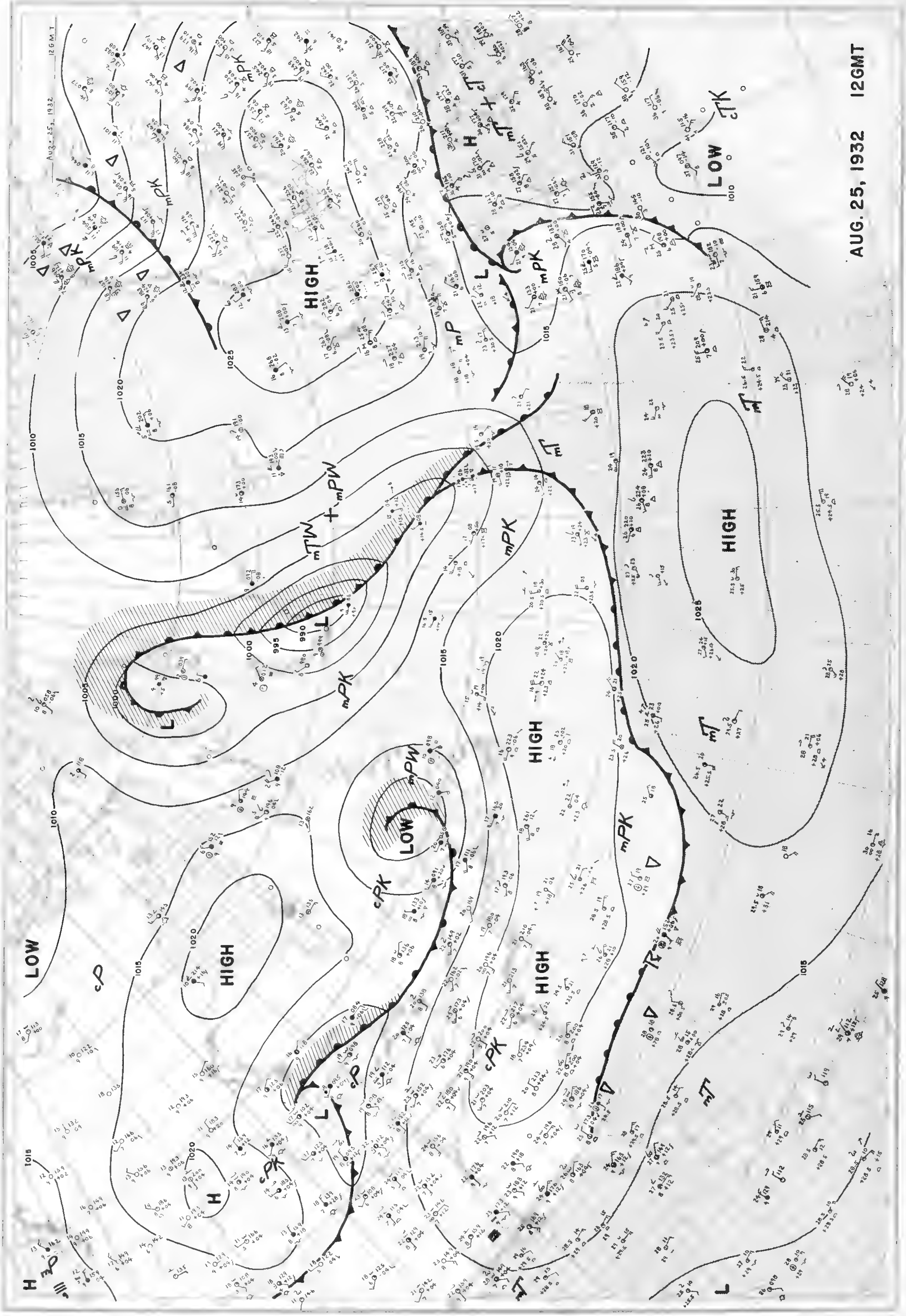

AUG. 20, 1932
12GMT
HIGH
LOW
1000
1005
1010
1015
1020
1025
1030
mPK
mPW
mP
mTW
mT
cPK
cTK
cP

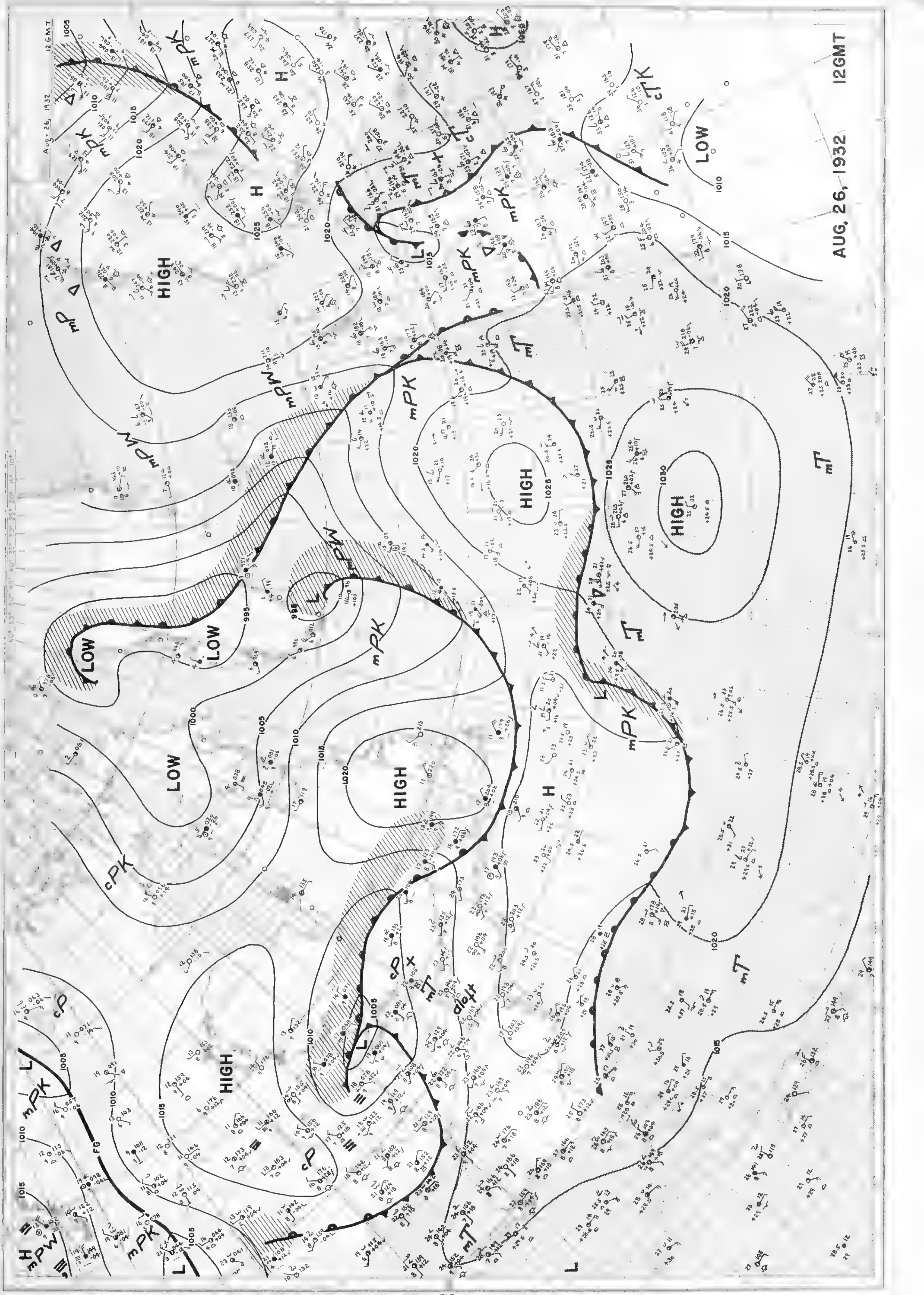

AUG. 21, 1932
12GMT

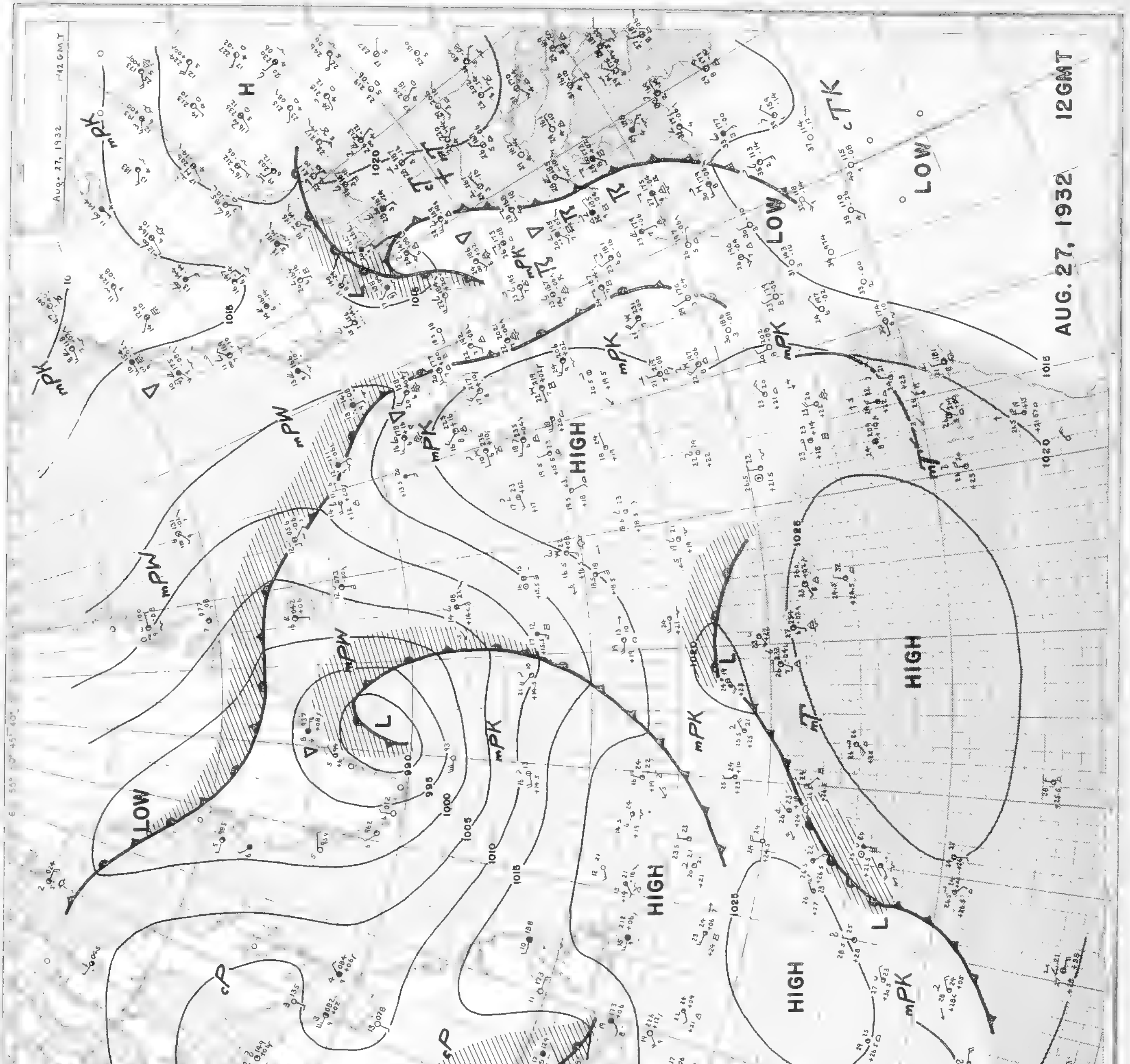

AUG. 22, 1932
12GMT


AUG. 23, 1932
12GMT
HIGH
LOW

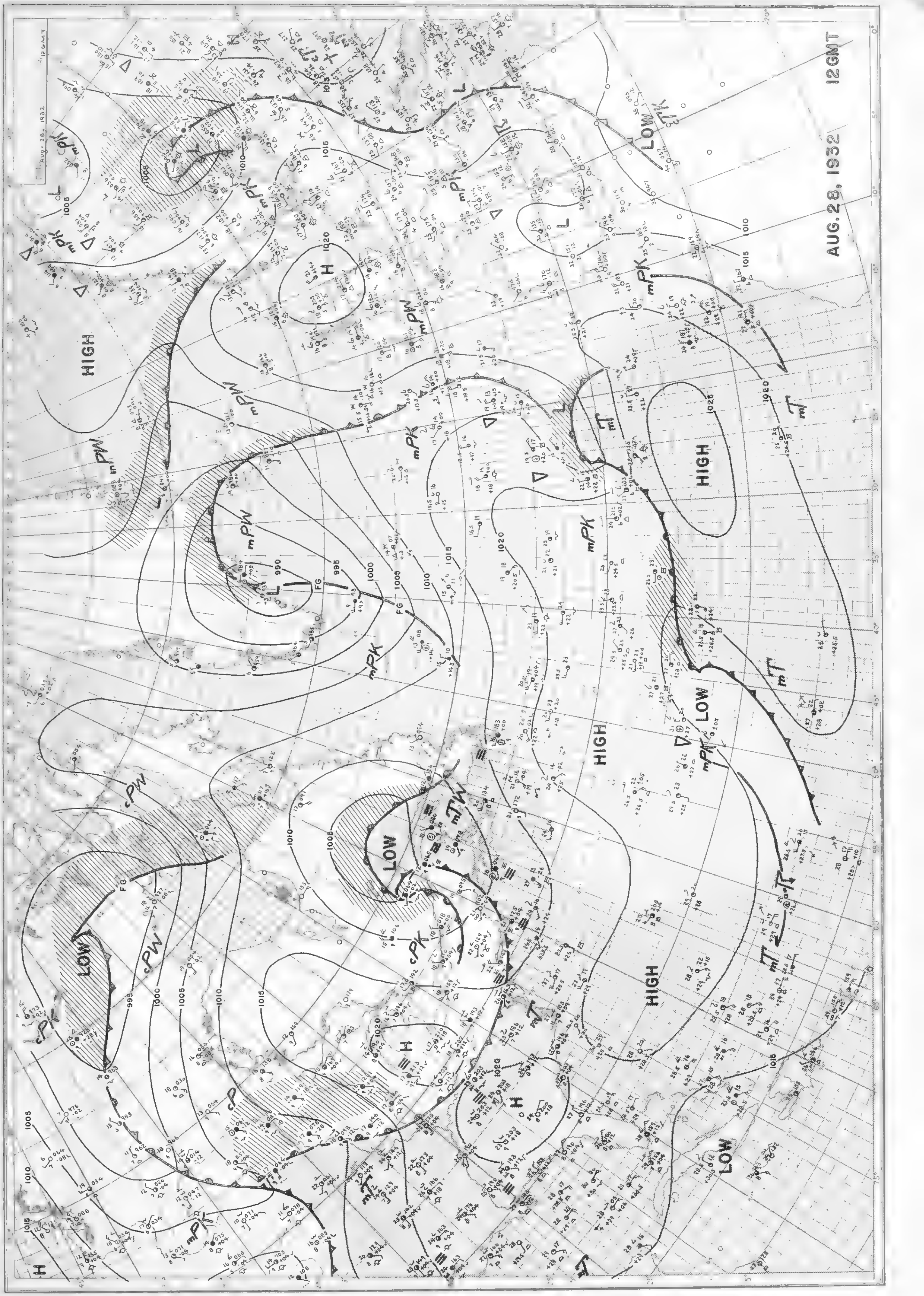

AUG. 24, 1932
12GMT

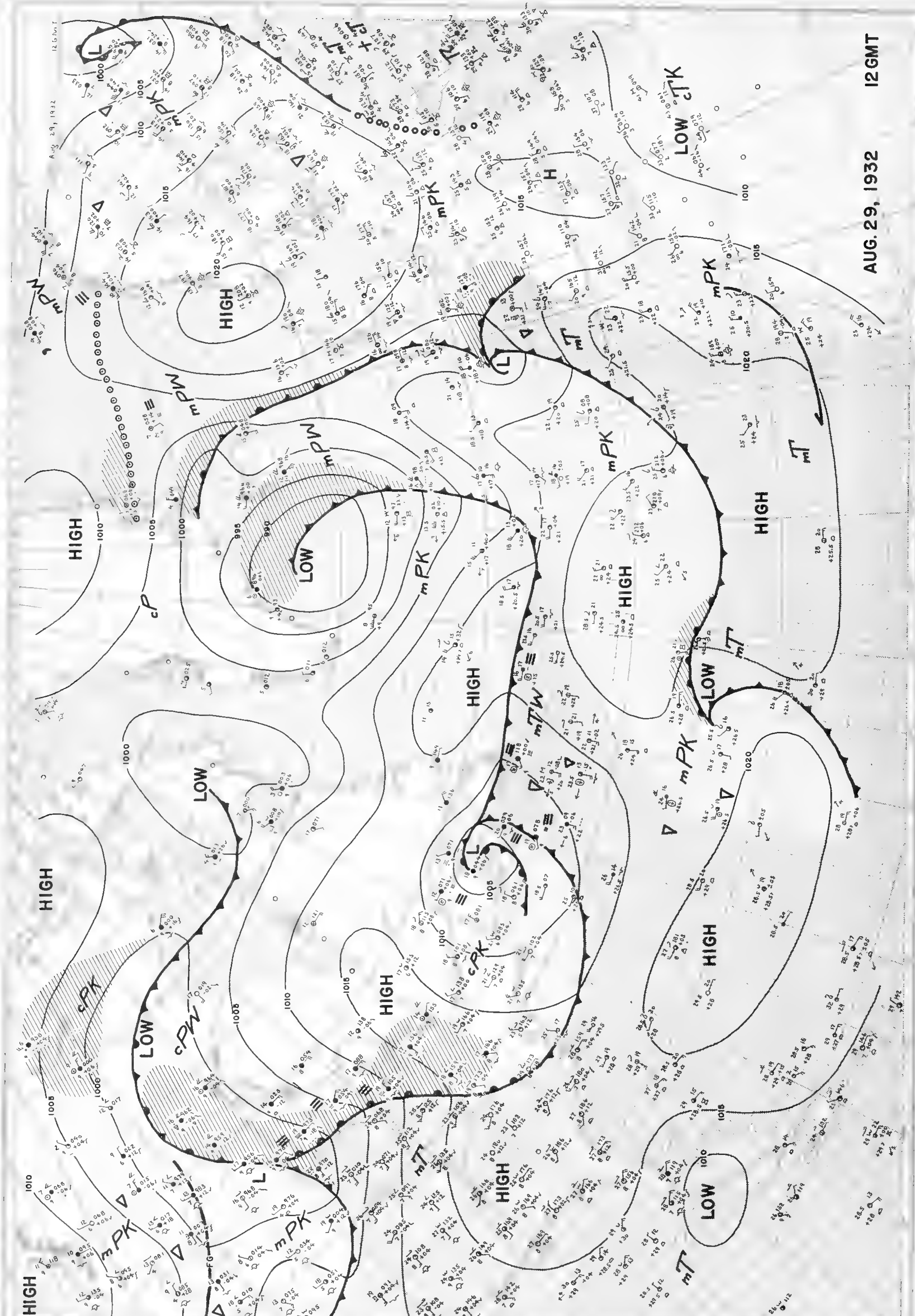

AUG. 25, 1932
12GMT

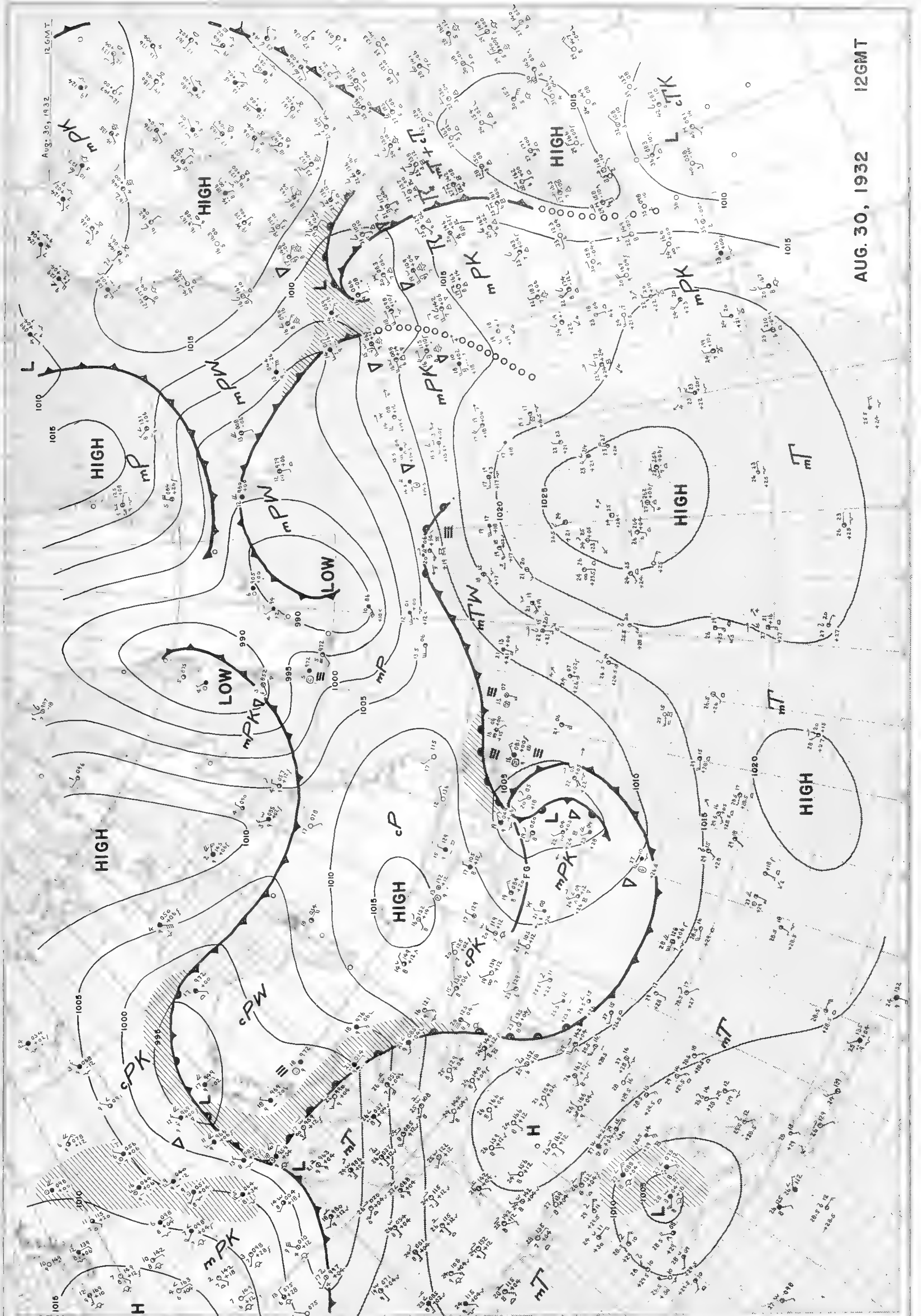

AUG. 26, 1932
12GMT
HIGH
LOW
mPK
mT
cP
cPK
mPW
aloft

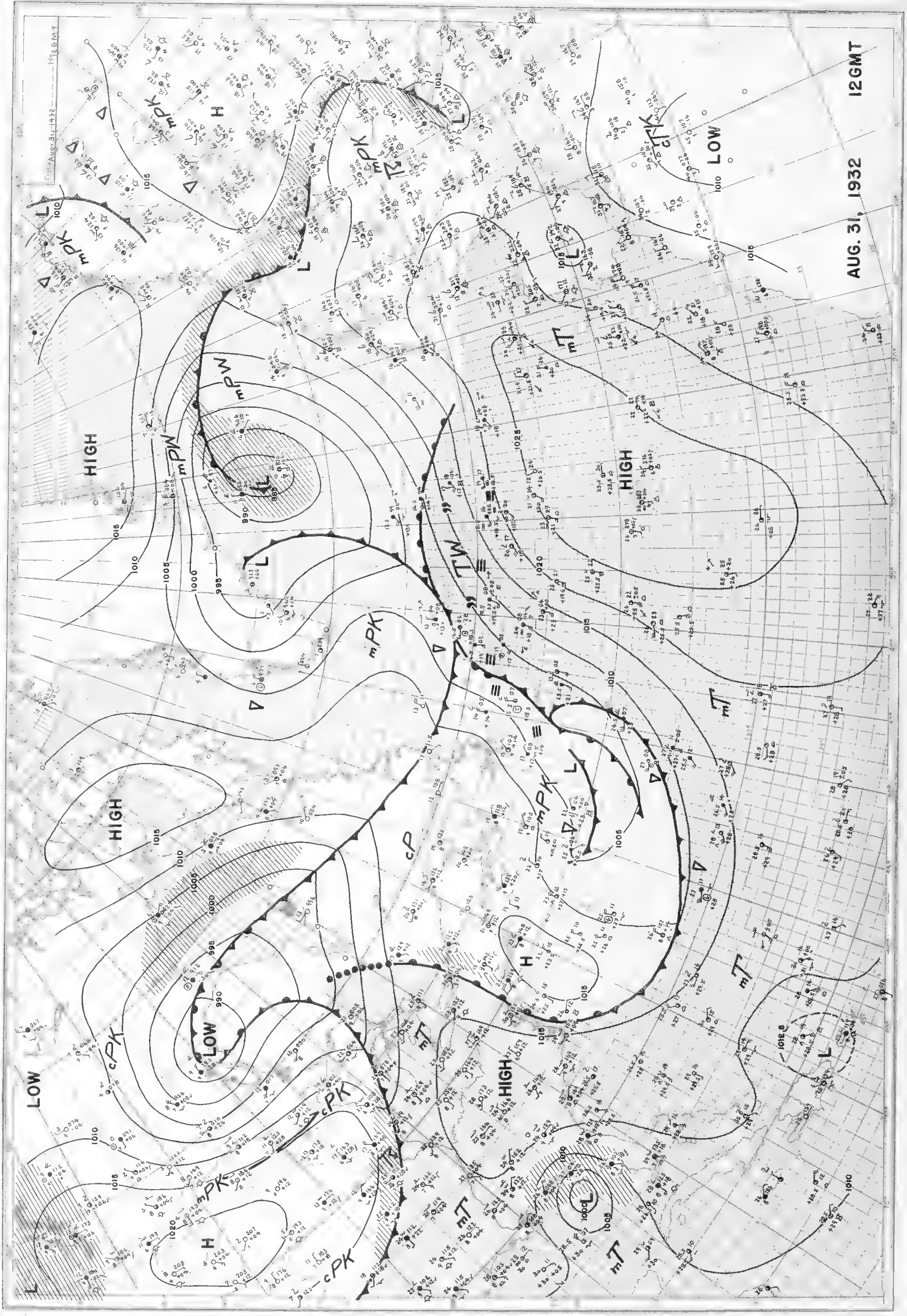


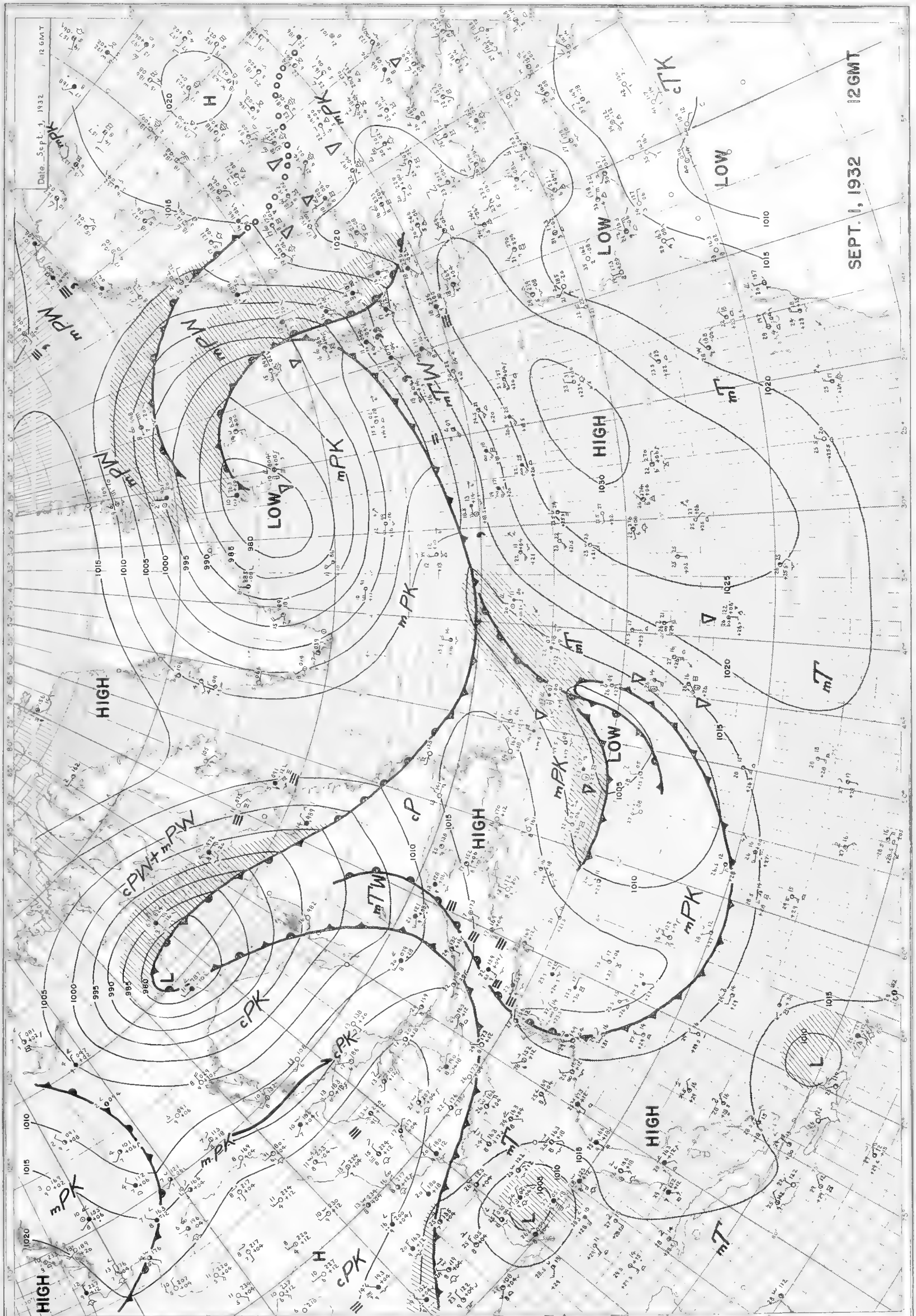
AUG. 27, 1932
12GMT
HIGH
LOW

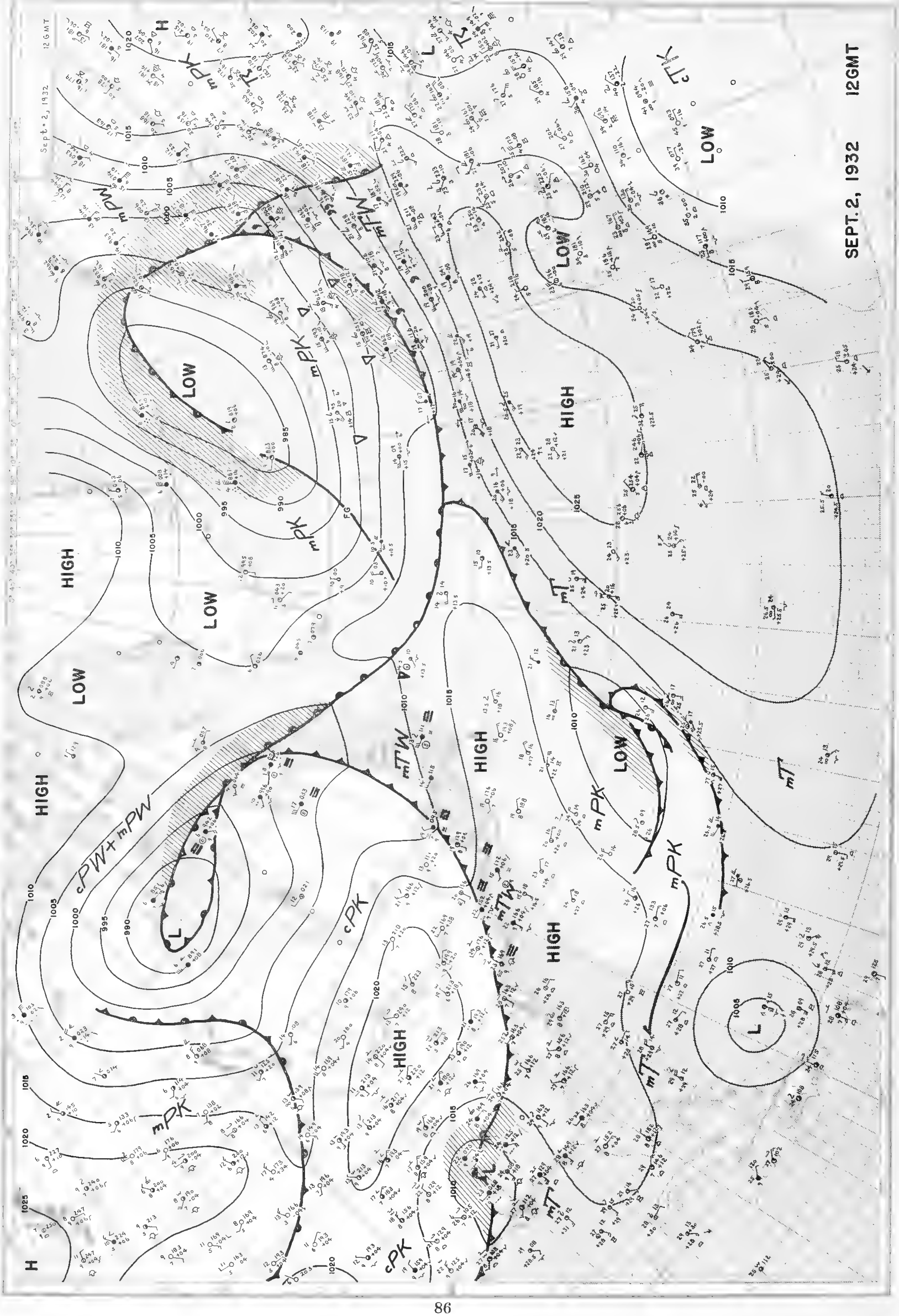

AUG. 28, 1932
12GMT

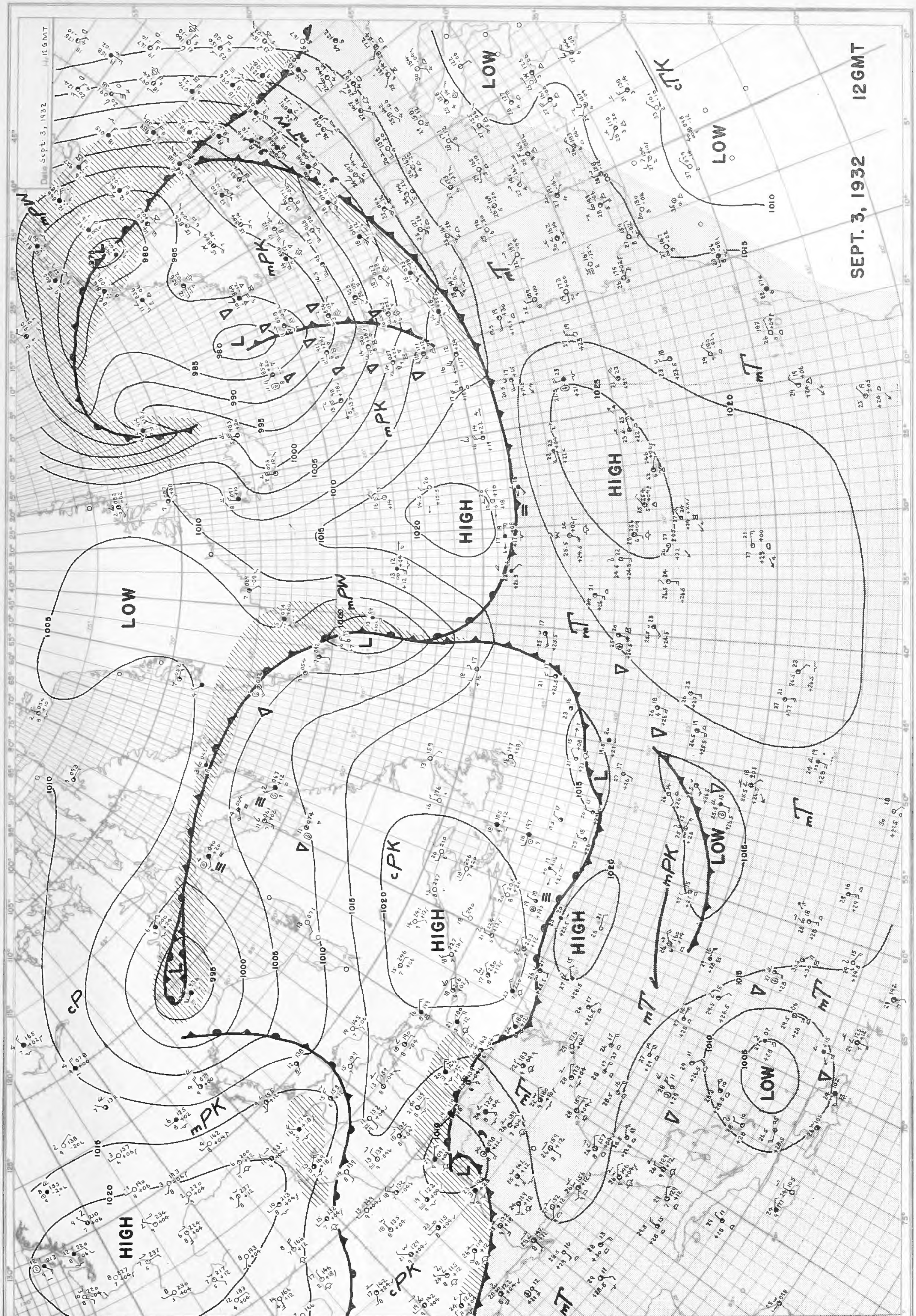

AUG. 29, 1932
12 GMT
HIGH
LOW
H

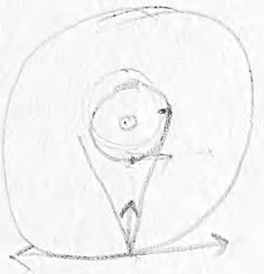

AUG. 30, 1932
12GMT
Aug. 30, 1932
12 GMT
HIGH
LOW
HIGH
LOW
HIGH
HIGH
HIGH
HIGH
HIGH
mPK
mPW
mP
cP
cPK
cPW
mTW
mT
cTK
mPK
1010
1015
1020
1025
1005
1000
995
990


AUG. 31, 1932
12GMT
HIGH
LOW
mPK
mPW
cPK
cP
mT
TW


SEPT. 1, 1932
12GMT
HIGH
LOW
mPK
mPW
cPW+mPW
cPK
mTW
mT
cP
cTK


SEPT. 2, 1932
12GMT
LOW
HIGH
mPK
cPK
mTW
mT
cPW + mPW
mPW


Date Sept. 3, 1932
SEPT. 3, 1932
12GMT
HIGH
LOW
mPK
mT
cPK
cP
cTK
mPW



500

1000