U.S. DEPARTMENT OF COMMERCE
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
OCEAN PRODUCTS CENTER

TECHNICAL NOTE

DEVELOPMENT OF OPEN OCEAN FOG FORECASTING REGIONS

LAWRENCE D. BURROUGHS

FEBRUARY 1987

THIS IS AN UNREVIEWED MANUSCRIPT, PRIMARILY INTENDED FOR INFORMAL EXCHANGE OF INFORMATION

OPC Contribution No. 7
NMC Office Note No. 323

OPC CONTRIBUTIONS

No. 1. Burroughs, L. D., 1986: Development of Forecast Guidance for Santa Ana Conditions. National Weather Digest. (in press).

No. 2. Richardson, W. S., D. J. Schwab, Y. Y. Chao, and D. M. Wright, 1986: Lake Erie Wave Height Forecasts Generated by Empirical and Dynamical Methods -- Comparison and Verification. Ocean Products Center Technical Note, 23pp.

No. 3. Auer, S. J., 1986. Determination of Errors in LFM Forecasts of Surface Lows Over the Northwest Atlantic Ocean. Ocean Products Center Technical Note/NMC Office Note No. 313, 17pp.

No. 4. Rao, D. B., S. D. Steinrod, and B. V. Sanchez, 1986: A Method of Calculating the Total Flow from a Given Sea Surface Topography. NASA Technical Memorandum. (in press).

No. 5. Feit, D. M., 1986 Compendium of Marine Meteorological and Oceanographic Products Center. NOAA Technical Memorandum NWS NMC 68, 98pp.

No. 6. Auer, S. J., 1986: A Comparison of the LFM, Spectral, and ECMWF Numerical Model Forecasts of Deepening Oceanic Cyclones During One Cool Season. Ocean Products Center Technical Note/NMC Office Note No. 312, 20pp.

No. 7. Burroughs, L. D., 1987: Development of Open Fog Forecasting Regions. Ocean Products Center Technical Note/NMC Office Note No. 323, 36 pp.

No. 8. Yu, T., 1986: A Technique of Deducing Wind Direction from Altimeter Wind Speed Measurements. Mon. Wea. Rev. (Submitted).

No. 9. Auer, S. J., 1986: A 5-Year Climatological Survey of the Gulf Stream and Its Associated Ring Movements. Journal of Geophysical Research. (Submitted).

No. 10. Chao, Y. Y., 1987: Forecasting Wave Conditions Affected by Currents and Bottom Topography. Ocean Products Center Technical Note, 11pp.

No. 11. Esteva, D. C., 1987: The Editing and Averaging of Altimeter Wave and Wind Data. Ocean Products Center Technical Note, 4pp.

DEVELOPMENT OF OPEN OCEAN FOG FORECASTING REGIONS

Lawrence D. Burroughs

ABSTRACT. Fog and low visibilities have long been considered serious hazards to navigation at sea. Neither is particularly easy to forecast. Many approaches can be taken to attack the problem. One possible approach to developing forecast equations is through application of statistical techniques. As a part of that approach, regions have been developed which are homogeneous with respect to synoptic weather and oceanographic patterns, fog occurrence, and observation density. This Technical Note describes the statistics which went into the development of the regions, the selection of the appropriate seasons for the regions, and the regions themselves. The regions cover the North Atlantic and North Pacific Oceans from 25 deg north to 70 deg north.

I. INTRODUCTION

Fog and low visibilities have long been considered serious hazards to navigation at sea. Neither is particularly easy to forecast. There are many approaches that can be taken to attack the problem. Among them are numerical models (see, for example Feit, 1972 or Barker, 1973) which require local sounding information and global model input; fog climatologies; decision trees which take synoptic factors into account; statistical approaches, such as regression, discriminant analysis, or markov processes; and decision trees which account for the observed spacial distributions of fog, visibility, and other parameters. The U.S. Navy worked on global fog and visibility guidance from 1982 to 1986 with model output statistics (MOS) (Glahn and Lowry, 1972). They abandoned the MOS approach in favor of the "perfect prog" approach (Fett, 1987 and Tag, 1987) because the Navy's global atmospheric model was being changed. They also decided to develop a local system geared to the movements of individual battle groups and located on board ship (Tag, 1987). The local system being developed is an expert system that uses all of the approaches listed above (Tag, 1987).

At the time we decided to develop statistical open ocean fog and visibility guidance, the Navy was still working on the MOS approach to fog and visibility prediction. We opted not to use the Navy's development because the guidance would not be compatible with other Ocean Products Center products which all depend on NMC models and because operational maintenance and further development of the system and product scheduling would be outside our control. Since our models are in a constant state of change, we decided to use the 'perfect prog' approach which does not depend on model output for development. The statistical equations will use the global spectral model (Sela, 1980) output to make fog and visibility forecasts. As a part of the statistical approach, regions have been developed which are homogeneous with respect to synoptic weather and oceanographic patterns, fog occurrence, and observation density. The plan is to develop forecast equations for fog and visibility less than 1 km and between 1 and 10 km in each of these regions and to produce graphic products showing the forecast.

To characterize the synoptic weather patterns, statistical charts were used which show the number of days low centers, high centers and fronts were located in each 5 degree latitude by 5 degree longitude box in the North Atlantic and North Pacific Oceans. Figures 1 and 2 show the areas of interest in each ocean. These charts were produced monthly from the NMC Northern Hemispheric Surface Pressure Analysis for the period July 1984 through June 1985. Further detail is given in Section II.

The occurrence of fog was taken from a climatology produced for the U.S. Navy by the National Climatic Data Center at Asheville, N.C. (Guttman, 1971).

II. CHART DEVELOPMENT

The monthly synoptic systems statistics were developed from the NMC Northern Hemispheric charts by tabulating how many times fronts or frontal systems, low centers, or high centers were located in each 5 degree latitude by 5 degree longitude box within the areas of interest. This number was divided by the number of synoptic charts per day (4) to give the number of days fronts, low centers, or high centers were located in each box for the month. The statistics reflect not only the number of centers or fronts passing through a given box, but their residency in the box. This method tends to overweight the lower latitudes because of the poleward convergence of the meridians; and, according to Taylor (1986), it also preferentially weights certain storm track directions over others. Taylor estimates that biases of as much as 14 percent occur between 25 and 70 deg north (the area of interest). He concludes that these biases are not sufficient to undermine studies which use this method, but that the subtler characteristics of the cyclone climatology probably cannot be uncovered by the method. Since these biases are small in the areas of interest, and because we are interested only in the gross seasonal patterns, this study is probably not adversely affected by the biases listed above.

To determine what climatic seasons would be used to stratify the fog and visibility data, the monthly fog climatology was studied. Two climatic seasons were selected: a warm season from April through September and a cool season from October through March. These were chosen because the fog climatology was significantly different during the two seasons.

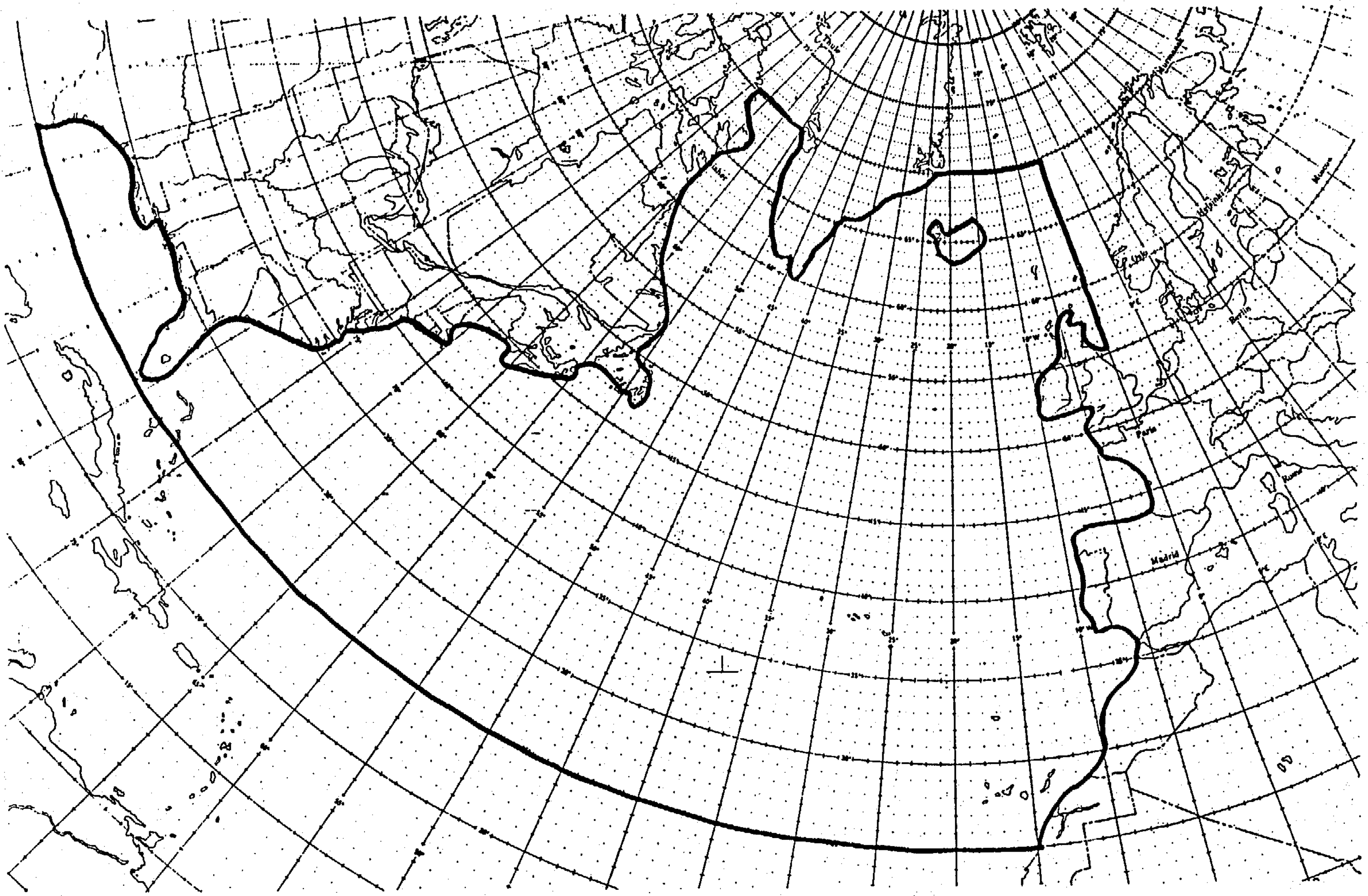

Figure 1. The North Atlantic Ocean area of interest for the fog forecasting project.

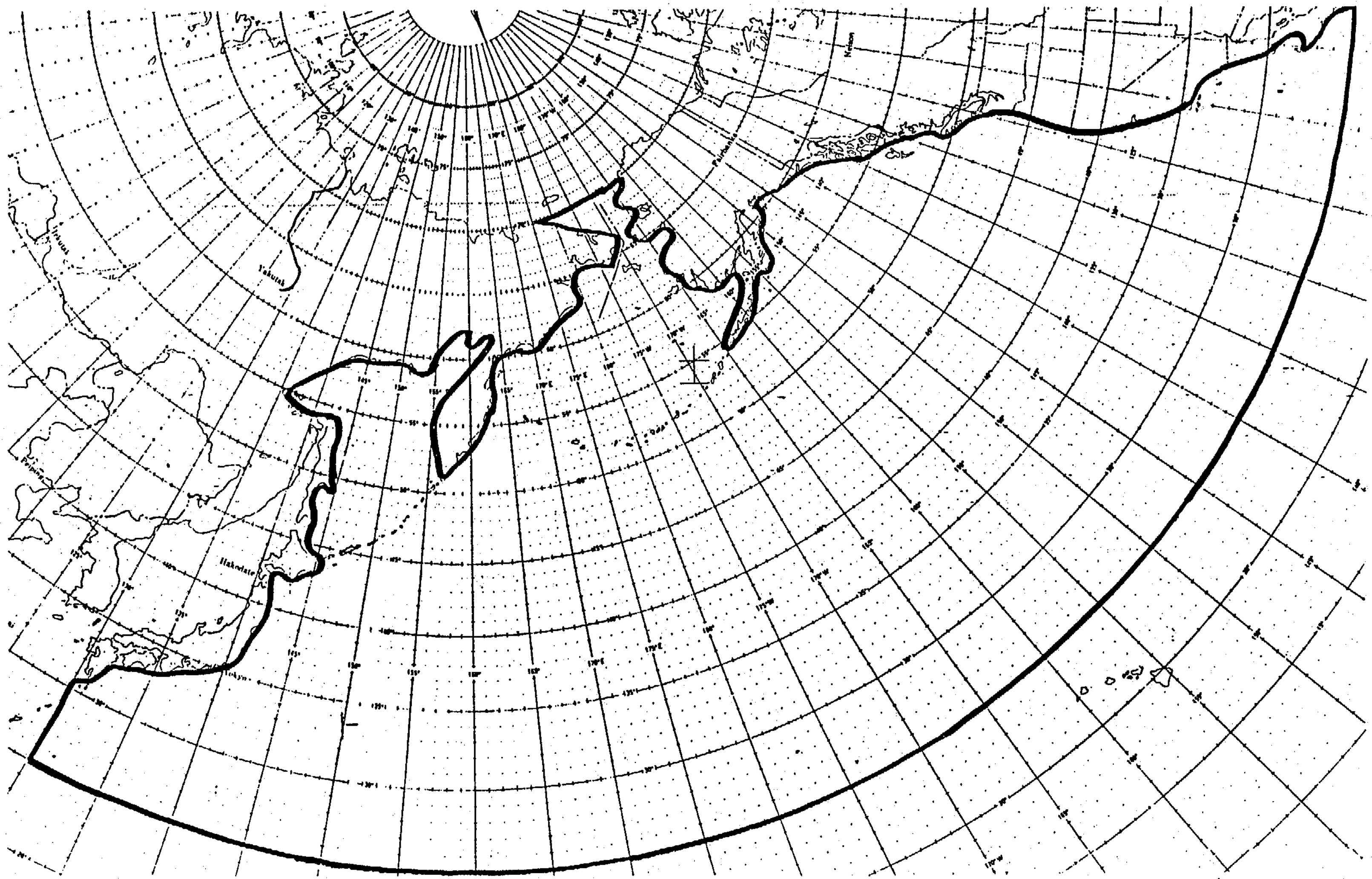

Figure 2. The North Pacific Ocean area of interest for the fog forecasting project.

Once the seasons were chosen, seasonal statistics were tabulated and analyzed. Seasonal charts of the low centers, high centers and fronts were made by adding the monthly frequencies together to give the number of days each parameter occurred during each season and by hand analyzing the data.

The fog climatology was analyzed in percent frequency of occurrence for each month during the year. To be compatible with the other statistics, the fog climatology was converted from monthly percent frequencies to days/season by interpolating the frequencies to the center of each box, taking the average of the monthly frequencies for each season, and multiplying by 183 for the warm season or 182 for the cool season to determine the average number of days/season. These seasonal fog statistics were then analyzed on charts with the same map projection as the other parameters.

III. REGION DEVELOPMENT

The regions were developed by accounting for daily frontal frequency patterns, fog frequency patterns, low and high center frequency patterns, the mean axes of the Gulf Stream (Auer, 1983) and the Kuroshio (Stommel and Yoshida, 1972), areas of upwelling along the west coasts of continents, and the observation density in a given area.

Regions are identified by assigning a coded number (sbr) where s is the season, b is the water body, and r is the region number. s has a value of 1 for the warm season and 2 for the cool season. b has a value of 1 for the Atlantic Ocean, 2 for the Gulf of Mexico, or 3 for the Pacific Ocean, and r is a sequential number from 1 to n assigned from north to south and from the coasts of North America seaward.

The external boundaries were determined by the boundaries of the areas of interest shown in Figs. 1 and 2 as modified and described below. The internal boundaries are those found within the areas of interest shown in Figs. 1 and 2 and were determined as described below. The external boundaries are fixed, while the internal boundaries probably can be moved a degree or two without seriously changing the characteristics of the regions.

A. Warm Season

1. Atlantic Ocean

Factors affecting the development of these regions are shown in Figs. 3 through 7. For the depiction of the regions described below see Fig. 8. Figure 7 depicts the ridgelines of frontal frequency. Primary ridgelines are shown with 2 parallel lines, and secondary ridgelines are shown with single lines. All the Atlantic warm season regional internal boundaries shown in Fig. 8 were primarily determined by the ridgelines shown in Fig. 7. The

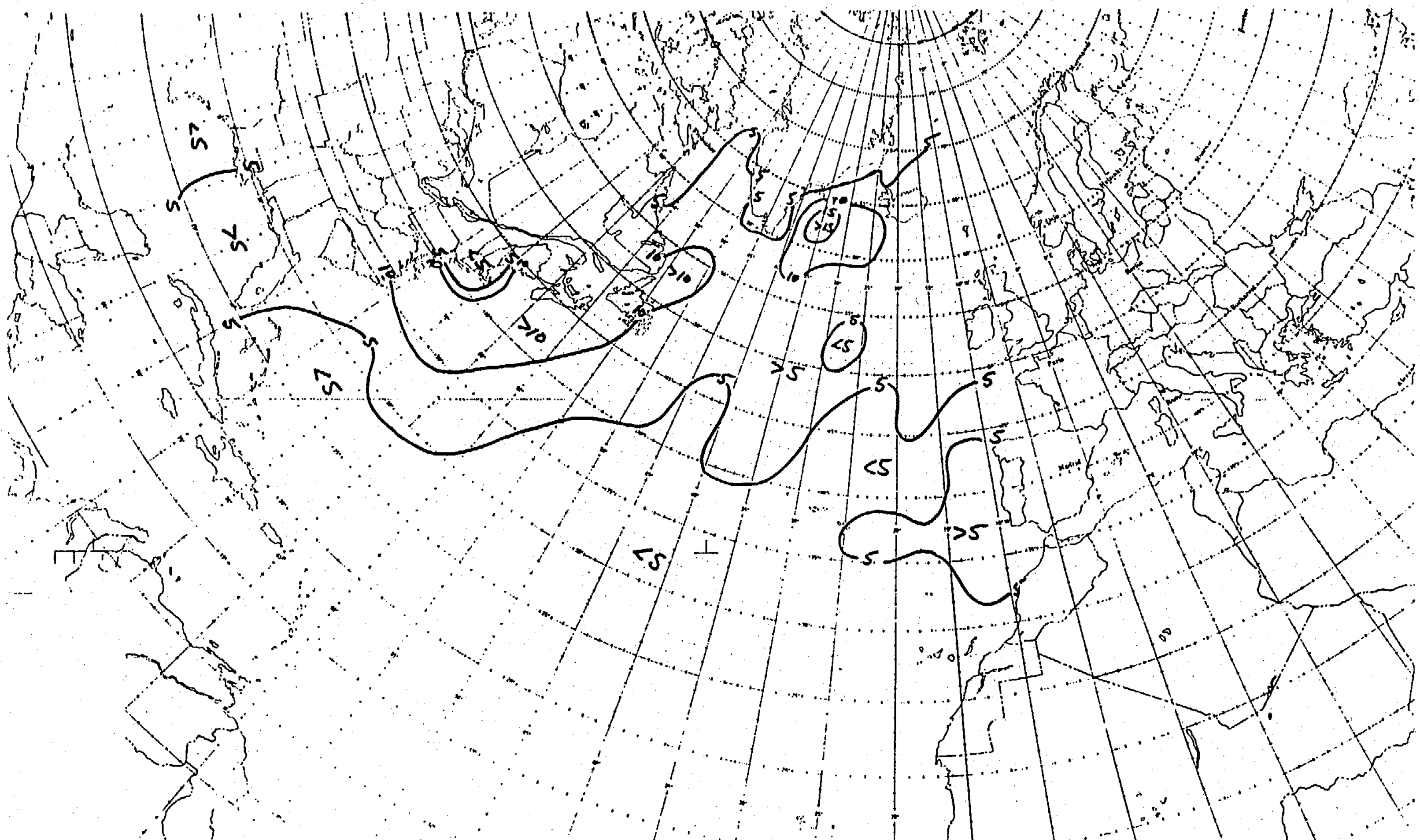

Figure 3. The frequency of low centers over the North Atlantic and Gulf of Mexico for the warm season (April - September). Frequency is determined by the number of days low centers occupied a given 5 degree latitude by 5 degree longitude box during the season.

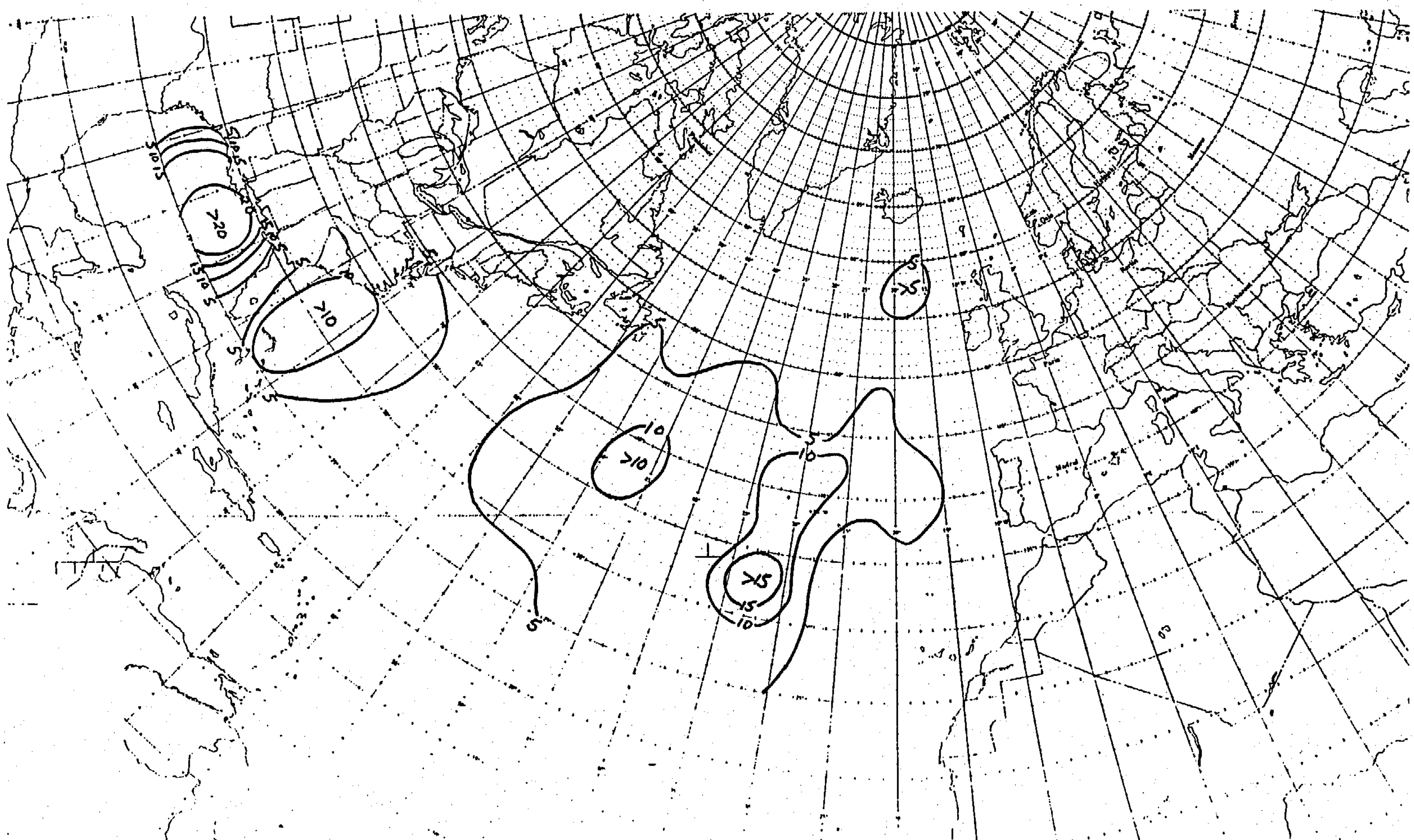

Figure 4. The frequency of high centers over the North Atlantic and Gulf of Mexico. The season and frequency are the same as in Fig. 1.

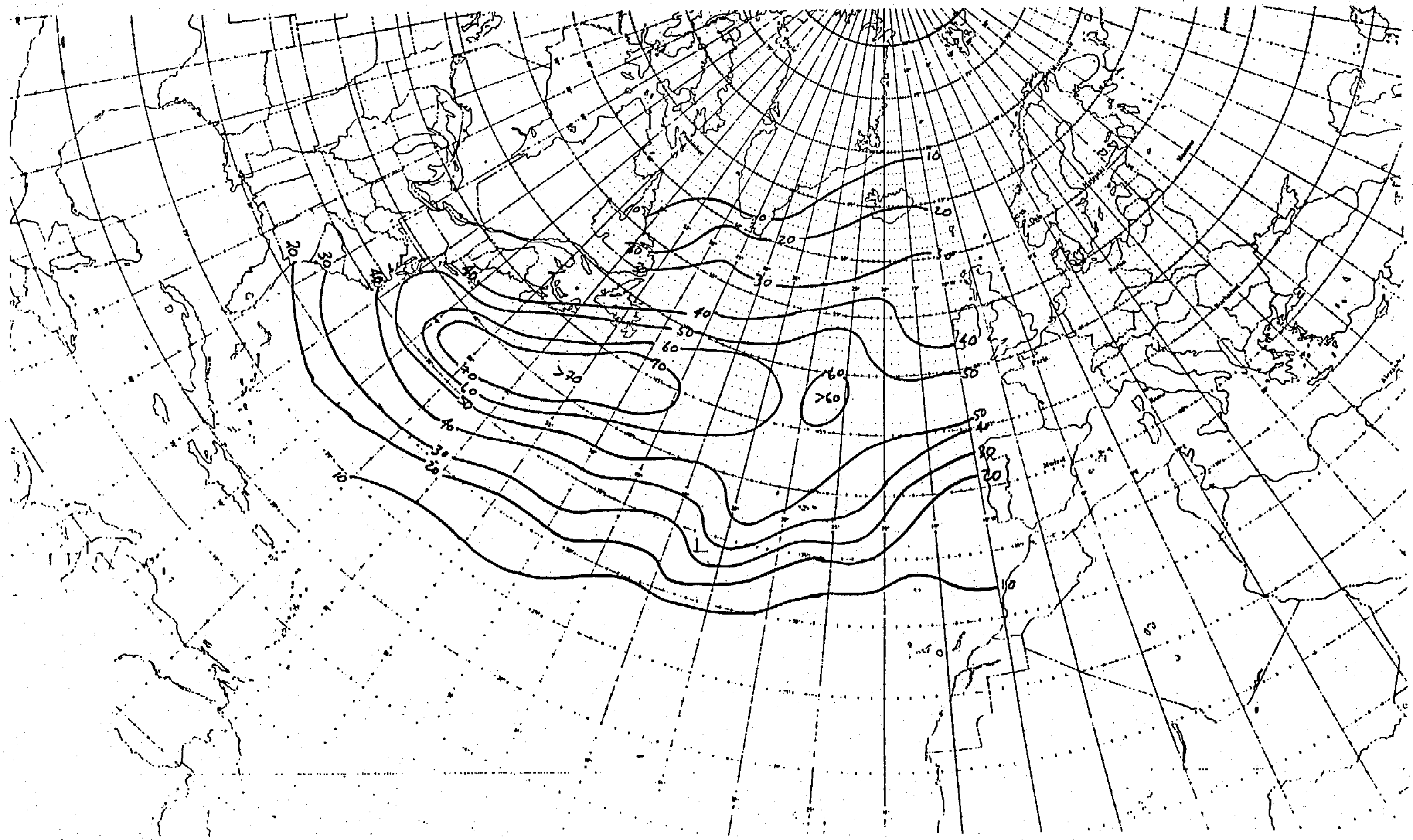

Figure 5. The frequency of fronts over the North Atlantic and Gulf of Mexico. The season and frequency are the same as in Fig. 1.

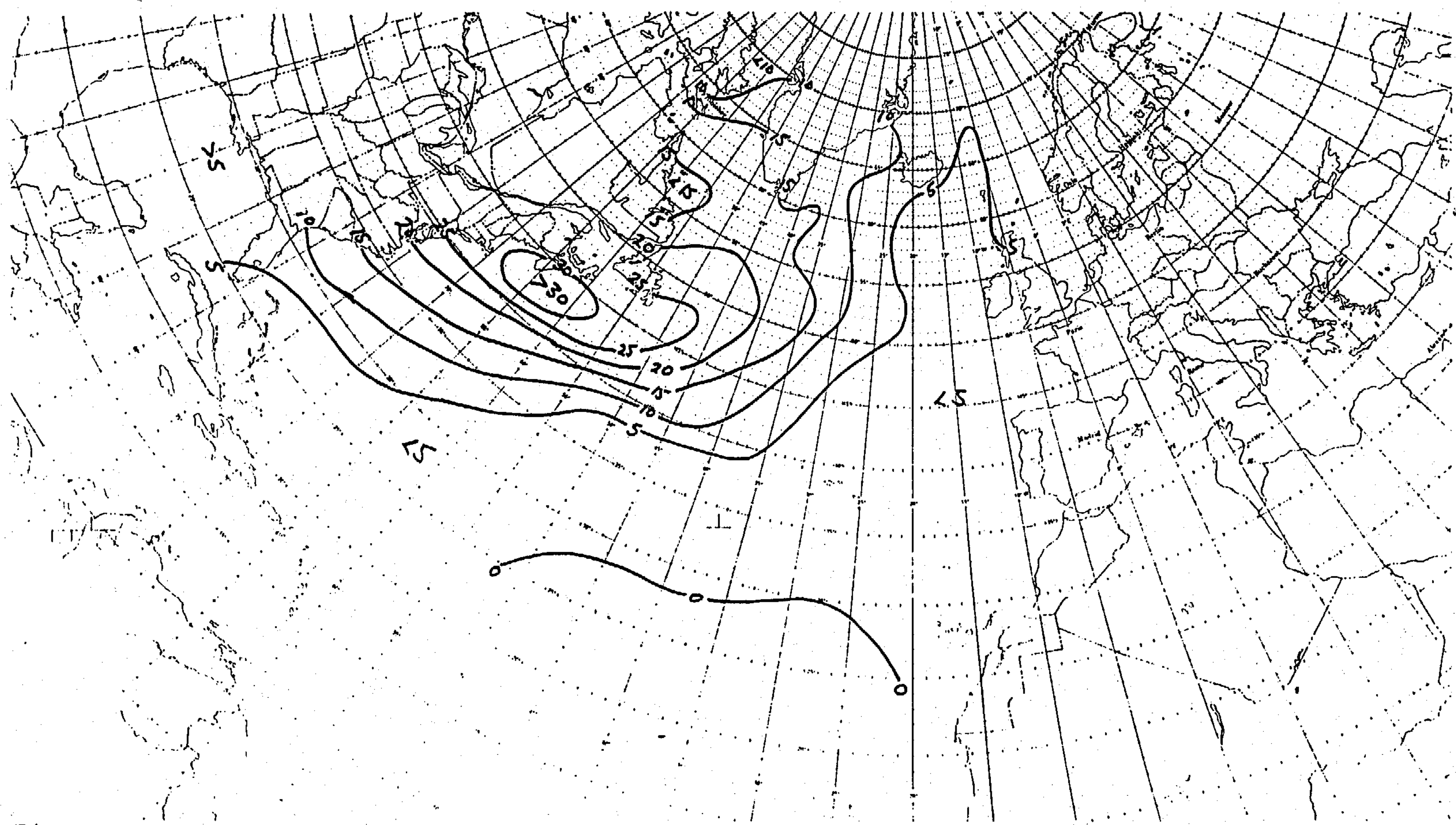

Figure 6. The frequency of fog over the North Atlantic and Gulf of Mexico. The season and frequency are the same as in Fig. 1. These data were abstracted from Guttman (1971).

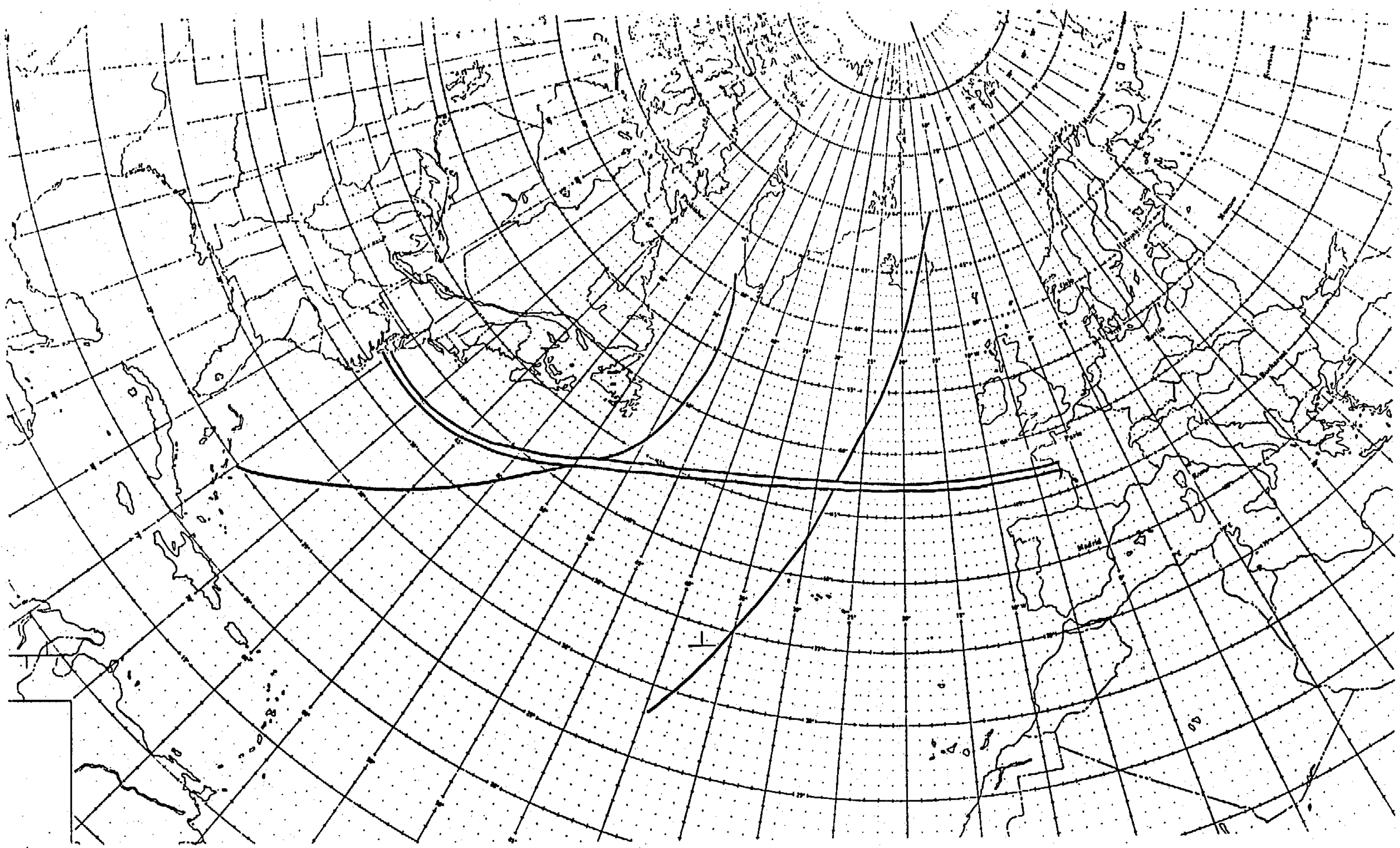

Figure 7. The ridgelines of frontal frequency over the North Atlantic and Gulf of Mexico. The season is the same as in Fig. 3. The major ridgeline is depicted with two parallel lines. Secondary ridgelines are shown as single lines.

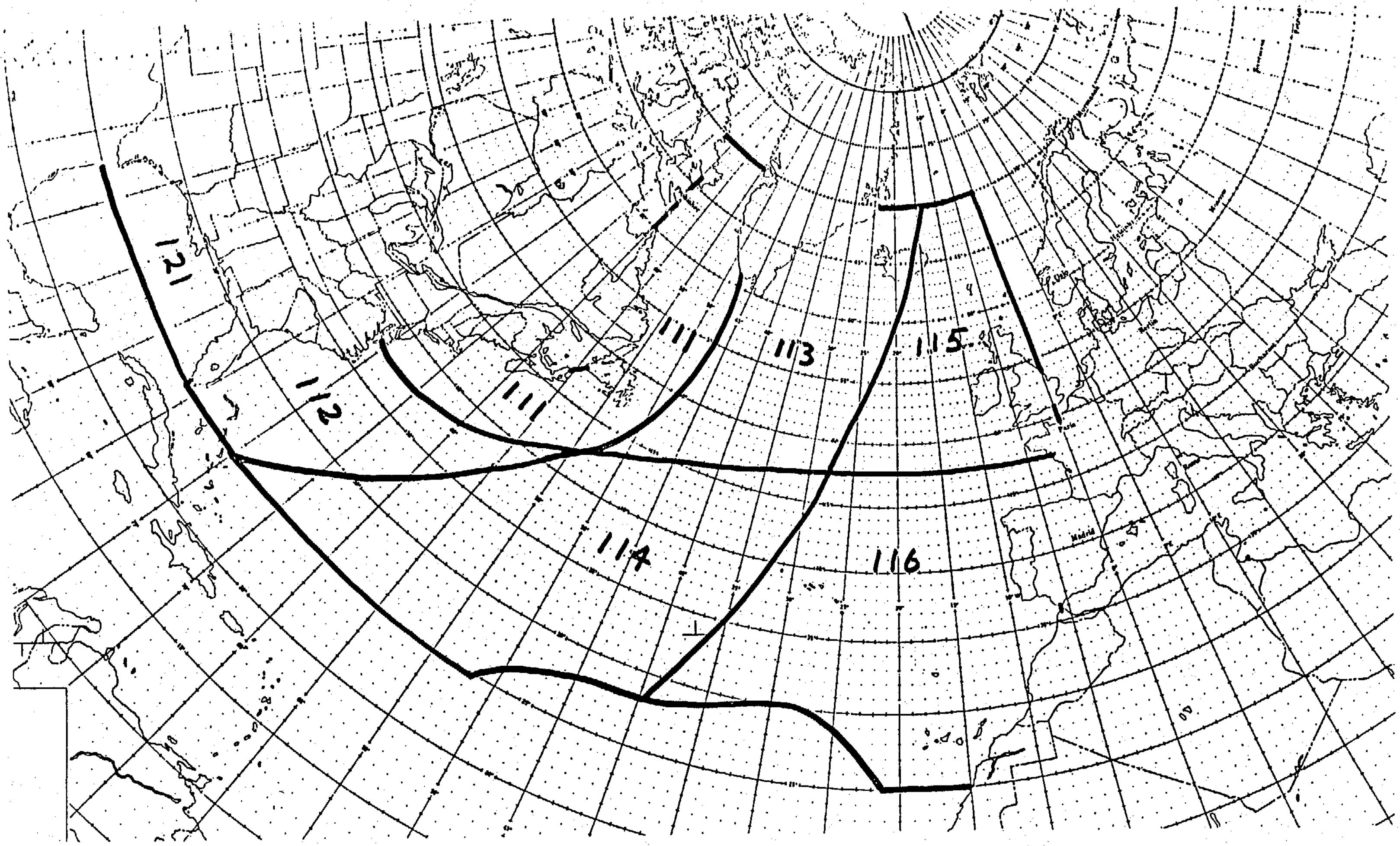

Figure 8. The fog forecasting regions for the North Atlantic and Gulf of Mexico warm season. Regions are generally labeled from north to south and from the coast of North America seaward. The first number is the season 1 for warm and the middle number is the body of water 1 for Atlantic and 2 for the Gulf of Mexico.

southern external boundary was modified to reflect the zero fog frequency line in regions 114 and 116 (see Fig. 8). Specific details are given below.

Region 111 is bounded by the 70th parallel to the north, by a secondary ridgeline of frontal frequency and the west coast of Greenland (see Fig. 7) and to a lessor extent the mean axis of the Gulf Stream (Auer, 1983) to the east, by the major ridgeline of frontal frequency shown on Fig. 7 to the south, and by the coast of North America to the west. The maximum of fog frequency shown in Fig. 6 lies in this region as well as a relative maximum of low center frequency and a minimum of high center frequency (see Figs. 3 and 4).

Region 112 is bounded by the major ridgeline of frontal frequency shown on Fig. 7 to the north, by a secondary ridgeline of frontal frequency to the east (see Fig. 7), by the 25th parallel to the south (see Fig. 1), and by the southeast coast of the United States to the west. A relative maximum of high center frequency covers most of the region (see Fig. 4), while an area of low center frequency lies over the northern quarter of the region (see Fig. 3). The frequency of fog ranges from less than 5 days/season in the south to greater than 25 days/season in the north (see Fig. 6).

Region 113 is bounded by the 70th parallel to the north, by a secondary ridgeline in frontal frequency and the west coast of Iceland to the east (see Fig. 7), by the major ridgeline in frontal frequency shown on Fig. 7 to the south, and by another secondary ridgeline in frontal frequency (see Fig. 7) and the east coast of Greenland to the west. This region contains the maximum in low center frequency shown on Fig. 3, a minimum in high center frequency (see Fig. 5), and fog frequencies from 25 days/season in the west to 5 days/season in the east (see Fig. 6).

Region 114 is bounded by the major ridgeline of frontal frequency shown on Fig. 7 to the north, by a secondary ridgeline of frontal frequency to the east (see Fig. 7), by the 25th parallel and the zero fog frequency line to the south (see Fig. 6), and by another secondary ridgeline of frontal frequency to the west (see Fig. 7). The region has a minimum low center frequency (see Fig. 3), a relative maximum of high center frequency (see Fig. 4), and fog frequencies of from 5 to 20 days/season in the northern half of the region and less than 5 days/season in the rest of the region (see Fig. 6).

Region 115 is bounded by the 70th parallel to the north, by the coasts of England and Ireland and the Greenwich meridian to the east, by the major ridgeline of frontal frequency shown on Fig. 7 and the north coast of France to the south, and by a secondary ridgeline in frontal frequency to the west (see Fig. 7). The region has a minimum of low center frequency (see Fig. 3), a relative maximum of high center frequency (see Fig. 4), and fog frequencies of 5 days/season or less (see Fig. 6).

Region 116 is bounded by the major ridgeline of frontal frequency shown on Fig. 7 to the north, by the southwest coast of Europe and the northwest coast of Africa to the east, by the 25th parallel and the 0 fog frequency line (see Fig. 6) to the south, and by a secondary ridgeline of frontal frequency to the west (see Fig. 7). This region has a maximum in high center frequency to the southwest and west (see Fig. 4), a relative maximum of low center frequency to the east (see Fig. 3), and fog frequencies of less than 5 days/season everywhere (see Fig. 6).

2. Gulf of Mexico

Region 121 is the only region in this body of water. Factors affecting its development are shown in Figs. 3 - 7. It is depicted in Fig. 8.

Region 121 is bounded to the south by the 25th parallel and elsewhere by the coast of the United States and Mexico. The region has a fog frequency of less than 5 days/season (see Fig. 6), a frontal frequency greater than 10 days/season (see Fig. 5), a relative maximum of low center frequency (see Fig. 3), and the maximum of high center frequency depicted on Fig. 4.

3. Pacific Ocean

Factors affecting the development of the regions described below are found in Figs. 9 - 13. Figure 14 depicts the regions. In the Atlantic warm season the internal regional boundaries are all determined by the ridgelines of frontal frequency. In the Pacific most of the internal regional boundaries are determined by the ridgelines of frontal frequency shown in Fig. 13. There are noteable exceptions, however. A secondary ridgeline near the 180th meridian was not used because the observation density in the two regions that would have been developed would have been too small to produce an adequate sample for equation development. Portions of the southern boundaries of regions 132 and 134 were developed with the 2 day/season fog frequency line because this allowed for an adequate sample size in both regions and accounted for the fog climatology as well. The southern external boundary in regions 132, 135, and 134 was extended southward so that fog frequencies closer to the zero fog frequency line could be included in regions 132 and 134 (see Figs. 12 and 14). This means that the frequency of fog in region 135 is very low and that any fog that does occur is found only in the very northern portions of the region.

Region 131 is bounded by the major ridgeline of frontal frequency shown on Fig. 13 to the northwest, by a secondary ridgeline of frontal frequency to the southwest (see Fig. 13), and by the west coast of North America elsewhere. The region has a maximum in high center frequency to the southwest (see Fig. 10), has low center frequencies of about 5 days/season everywhere (see Fig. 9), and fog frequencies of between 10 and greater than 20 days/season (see Fig. 12).

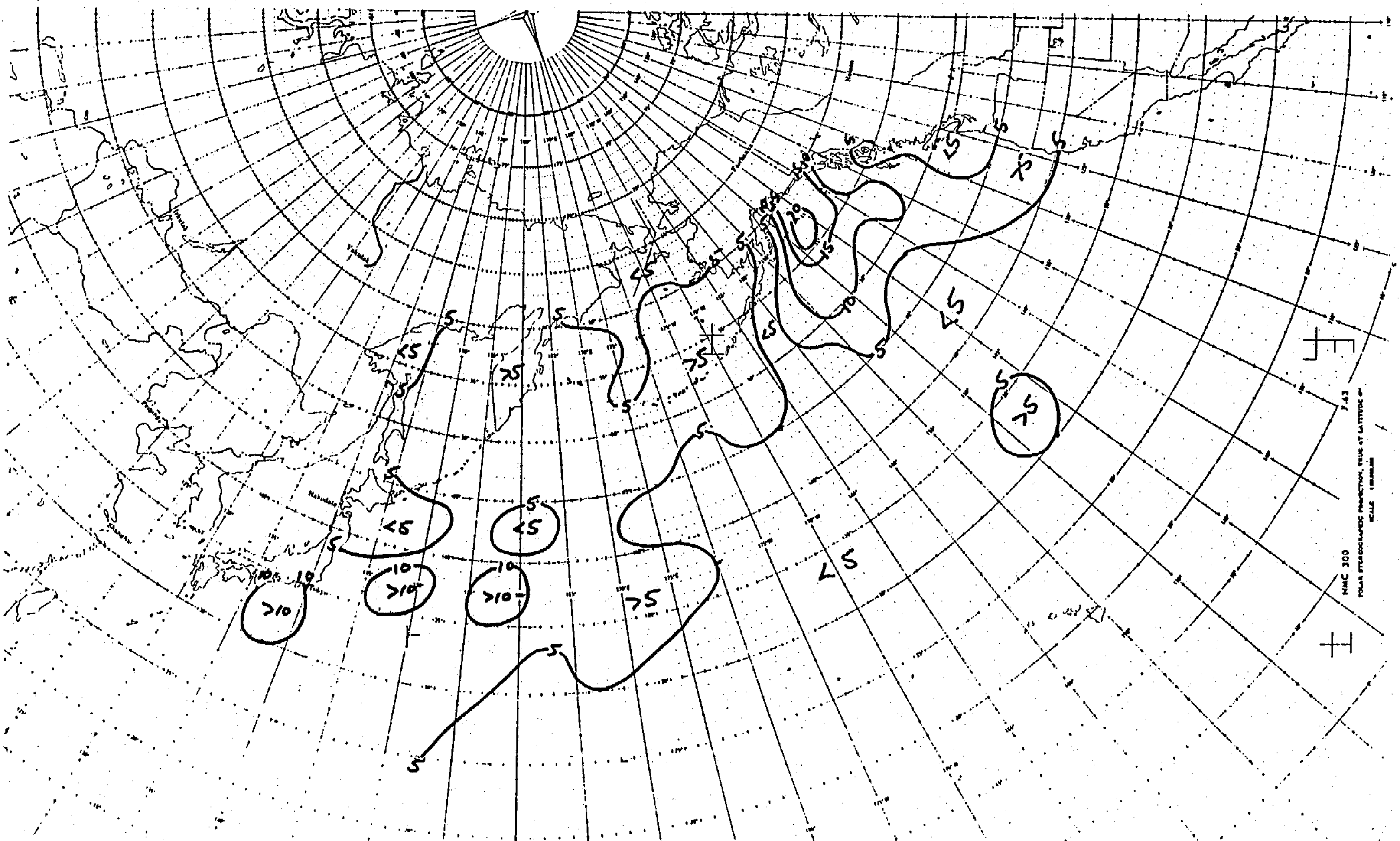

Figure 9. The frequency of low centers over the North Pacific for the warm season (April - September). Frequency is determined by the number of days low centers occupied a given 5 degree latitude by 5 degree longitude box during the season.

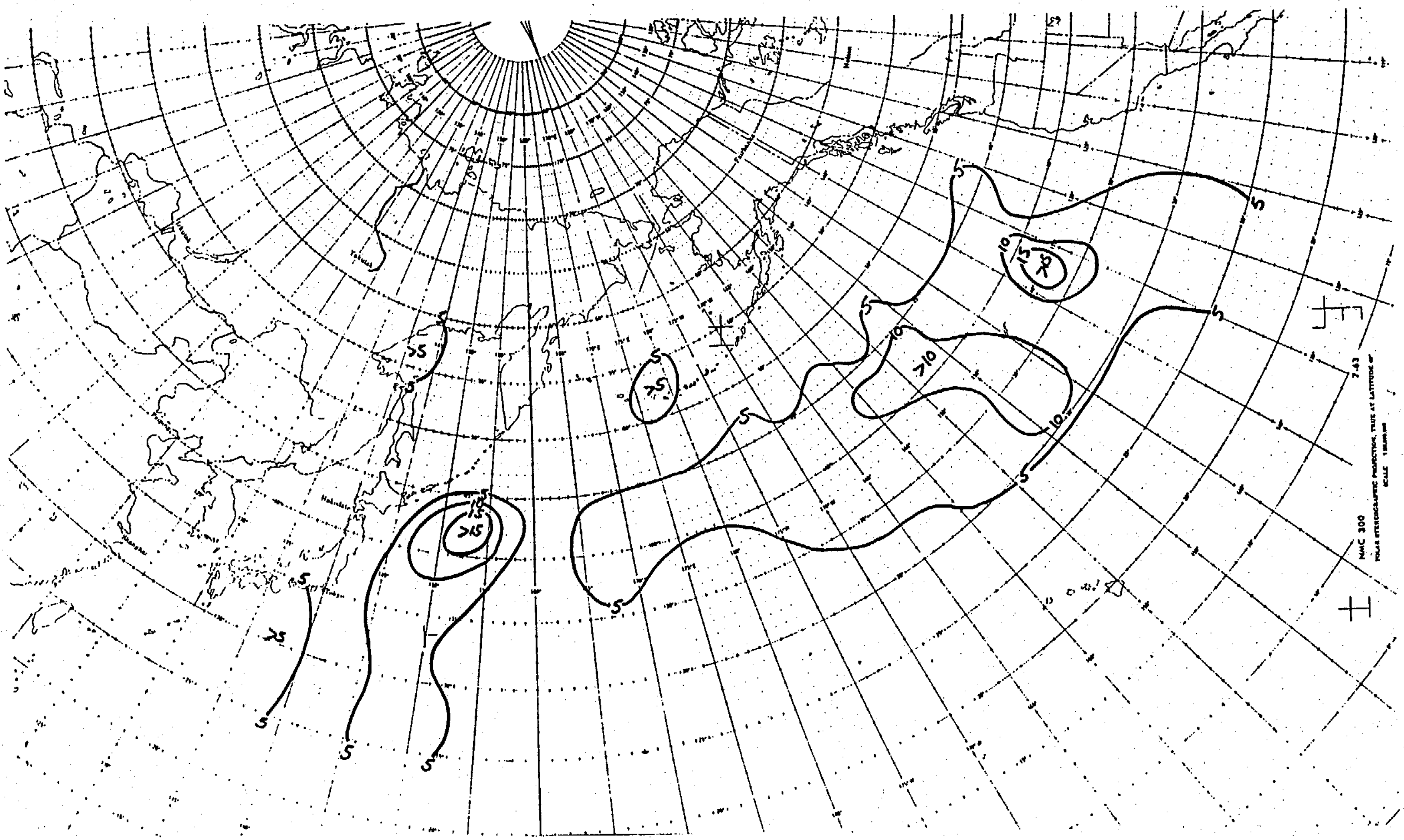

Figure 10. The frequency of high centers over the North Pacific. The season and frequency are the same as in Fig. 9.

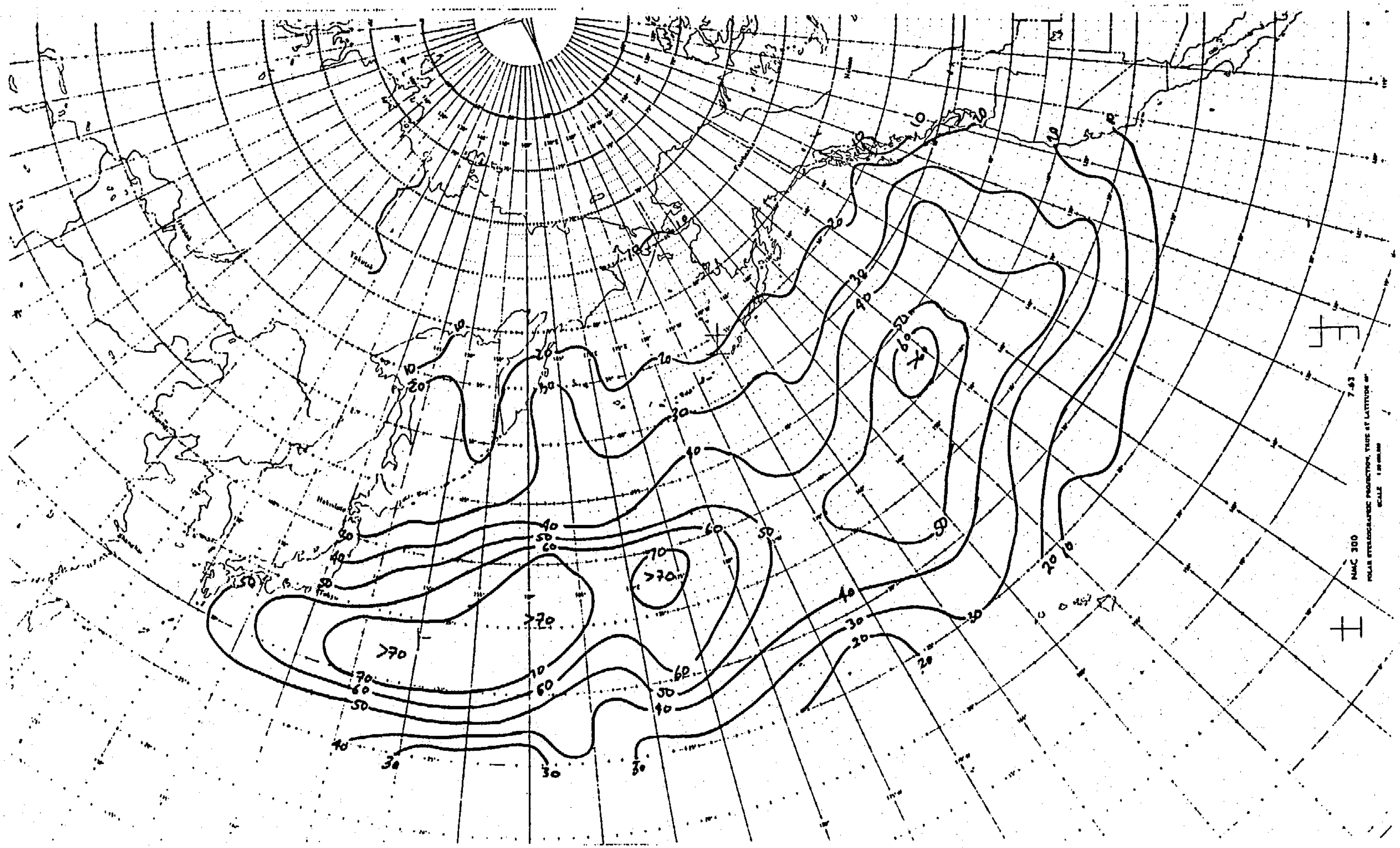

Figure 11. The frequency of fronts over the North Pacific. The season and frequency are the same as in Fig. 9.

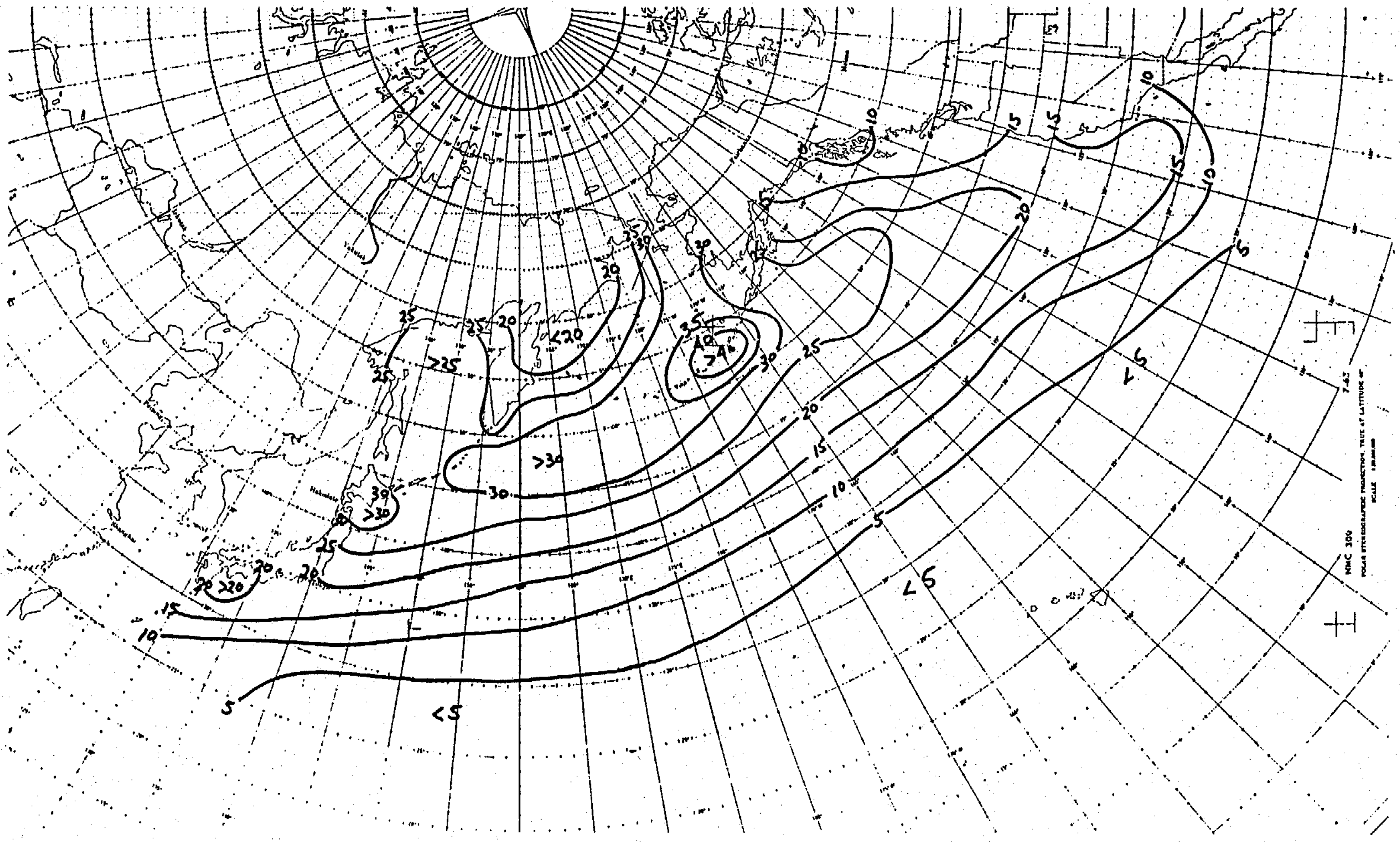

Figure 12. The frequency of fog over the North Pacific. The season and frequency are the same as in Fig. 9. These data were abstracted from Guttman (1971).

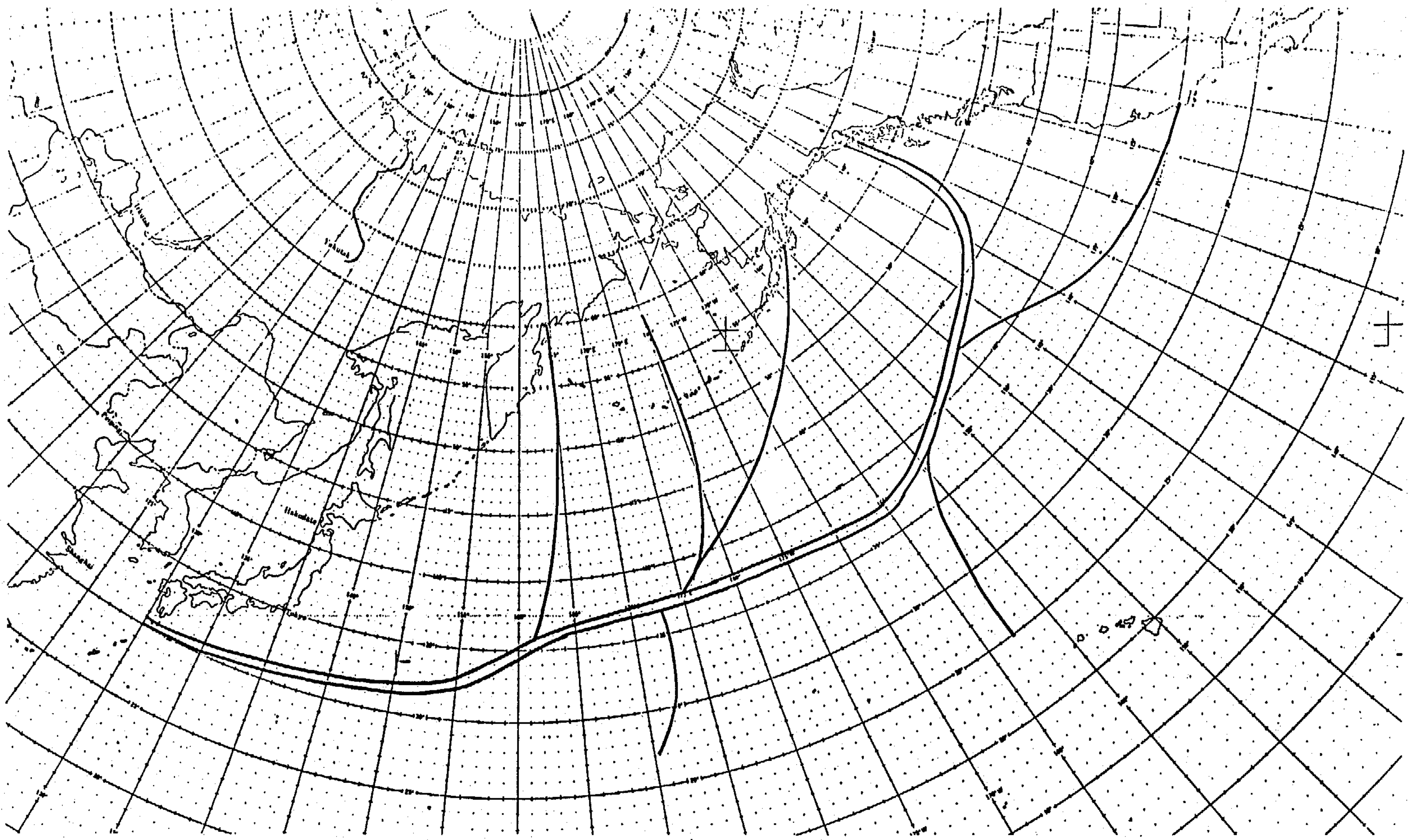

Figure 13. The ridgelines of frontal frequency over the North Pacific. The season is the same as in Fig. 9. The major ridgeline is depicted with two parallel lines. The secondary ridgelines are shown as single lines.

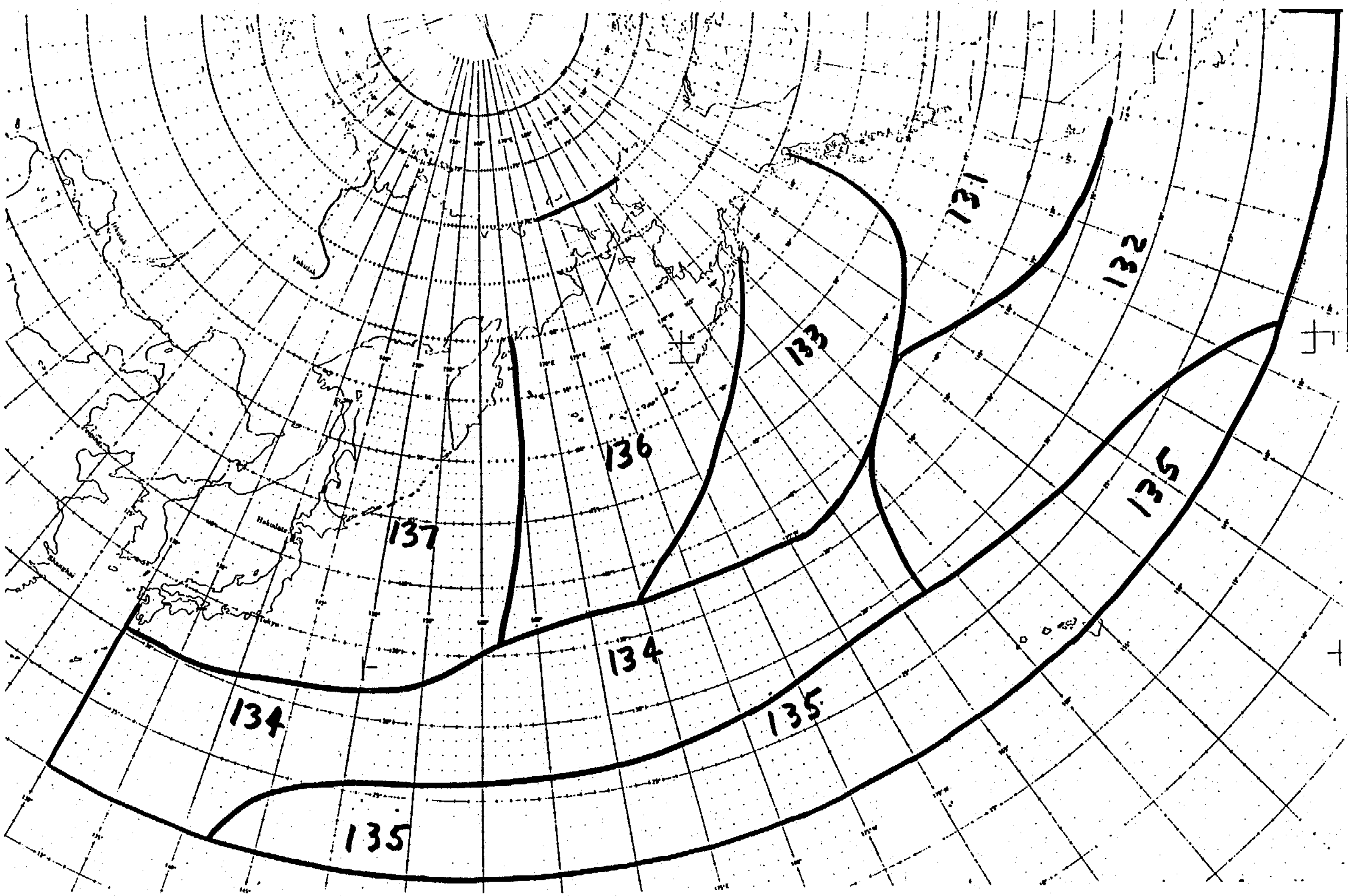

Figure 14. The fog forecasting regions for the North Pacific warm season. Regions are generally labeled from north to south and from the coast of North America seaward. The first number is 1 for warm, and the middle number is 3 for Pacific.

Region 132 is bounded by a secondary ridgeline of frontal frequency to the northeast (see Fig. 13), by the coast of southern California, Baja California, and the 110th west meridian to the east, by the 20th parallel between 110 and 135 west and the 2 day/season fog frequency line to the south (see Fig. 12), and by a secondary ridge of frontal frequency and the major ridgeline of frontal frequency shown on Fig. 13 to the west. The region has a small relative maximum of low center frequency (see Fig. 9), two maxima of high center frequency in the western two thirds (see Fig. 10), and fog frequencies ranging from about 2 to greater than 15 days/season (see Fig. 12).

Region 133 is bounded by the gulf coast of Alaska to the north, by the major ridgeline of frontal frequency shown on Fig. 13 to the east and south, and by a secondary ridgeline of frontal frequency to the west (see Fig. 13). The region has the maximum low center frequency shown on Fig. 9 to the north, a relative maximum of high center frequency to the south (see Fig. 10), and fog frequencies ranging from 10 to 30 days/season (see Fig. 12).

Region 134 is bounded by the major ridgeline of frontal frequency shown on Fig. 13 to the north, by a secondary ridgeline of frontal frequency to the east (see Fig. 13), by the 20th parallel from 130 to 140 east and the 2 day/season fog frequency line to the south, and by the 130th east meridian to the west. The frequency of low centers is about 5 days/season over the region (see Fig. 9). The region has a relative maximum of high center frequency in the western third of the region (see Fig. 10), and fog frequencies ranging from 2 to 12 days/season (see fig. 12).

Region 135 is bounded by the 2oth north parallel to the south and by the 2 day/season fog frequency line elsewhere (see Fig. 12). The region has fog frequencies of 2 days/season or less, high center and low center frequencies of less than 5 days/season (see Figs. 9, and 10). Additionally, the size of the region is largely determined by the paucity of ship data in the area.

Region 136 is bounded by the coasts of Russia and Alaska and the 70th north parallel to the north, by the west coast of Alaska and a secondary ridgeline in frontal frequency to the east (see Fig. 13), by the major ridgeline of frontal frequency shown on Fig. 13 to the south, and by a secondary ridgeline in frontal frequency (see Fig. 13) and the east coast of Russia to the west. The region contains the maximum of fog frequency shown on Fig. 11, a relative maximum in high center frequency near its center (see Fig. 10), and a low center frequency of about 5 days/season (see Fig. 9).

Region 137 is bounded by the east coast of Japan, Sakhalin Island, and the coast of mainland Russia to the north and west (see Fig. 2), by a secondary ridgeline in frontal frequency to the east (see Fig. 13), and by the major ridgeline of frontal frequency shown on Fig. 13 to the south. The region contains several maxima in low center frequency (see Fig. 9), a maximum in high center frequency (see Fig. 10), and fog frequencies ranging from 10 days/season in the south to greater than 30 days/season near the center of the region (see Fig. 12). These strong fog frequencies are found north of the mean axis of the Kuroshio (Stommel and Yoshida, 1972).

B. Cool Season

1. Atlantic Ocean

In the Atlantic during the cool season, fog is primarily a near shore phenomenon. In the western Atlantic shallow fog is formed when cold, dry air flows over the water near the coasts of North America and Greenland. Initially, the air becomes quickly saturated in the lowest few meters, and fog forms. But as the air continues to flow eastward, it mixes with drier air aloft and is warmed from below by relatively warm water so that saturation no longer occurs and the fog dissipates. The air moderates very quickly so that within a few hundred kilometers of the coasts of North America and Greenland fog no longer occurs. In the eastern Atlantic fog is formed by advection of warm, moist air over colder water near the coasts of the British Isles and in the Bay of Biscay. Only two fog regions were developed for the cool season Atlantic. The regional boundaries were determined by the external boundaries shown in Fig. 1 as modified by the zero fog frequency line shown in Fig. 18. The ridgelines of frontal frequency played no role in the development of the cool season Atlantic regions and aren't depicted here. Other factors affecting the regions are shown in Figs. 15 - 17. Figure 19 shows the two regions described below.

Region 211 is bounded by the 70th north parallel and the coast of Greenland to the north, by the zero fog frequency line to the east (see Fig. 18), by the 25th parallel to the south, and by the east coast of North America to the west. The region has maxima in fog frequency near the coasts of Newfoundland and Nova Scotia and the southwest coast of Greenland (see Fig. 18), maxima in low center frequency -- one off Newfoundland and Labrador and one southeast of Greenland (see Fig. 15), and high center frequencies of 5 days/season or less (see Fig. 16).

Region 212 is bounded by the Greenwich meridian and the coasts of France and Spain to the east and elsewhere by the zero fog frequency line (see Fig. 18). The fog frequency is greatest in the English Channel and along the west coast of France (see Fig. 18). The frequencies of both low and high centers is 5 days/season or less (see Figs. 15 and 16).

2. Gulf of Mexico

Only one region has been developed for the cool season. The factors affecting the development of the region are shown in Figs. 15 - 18. The region is depicted in Fig. 19.

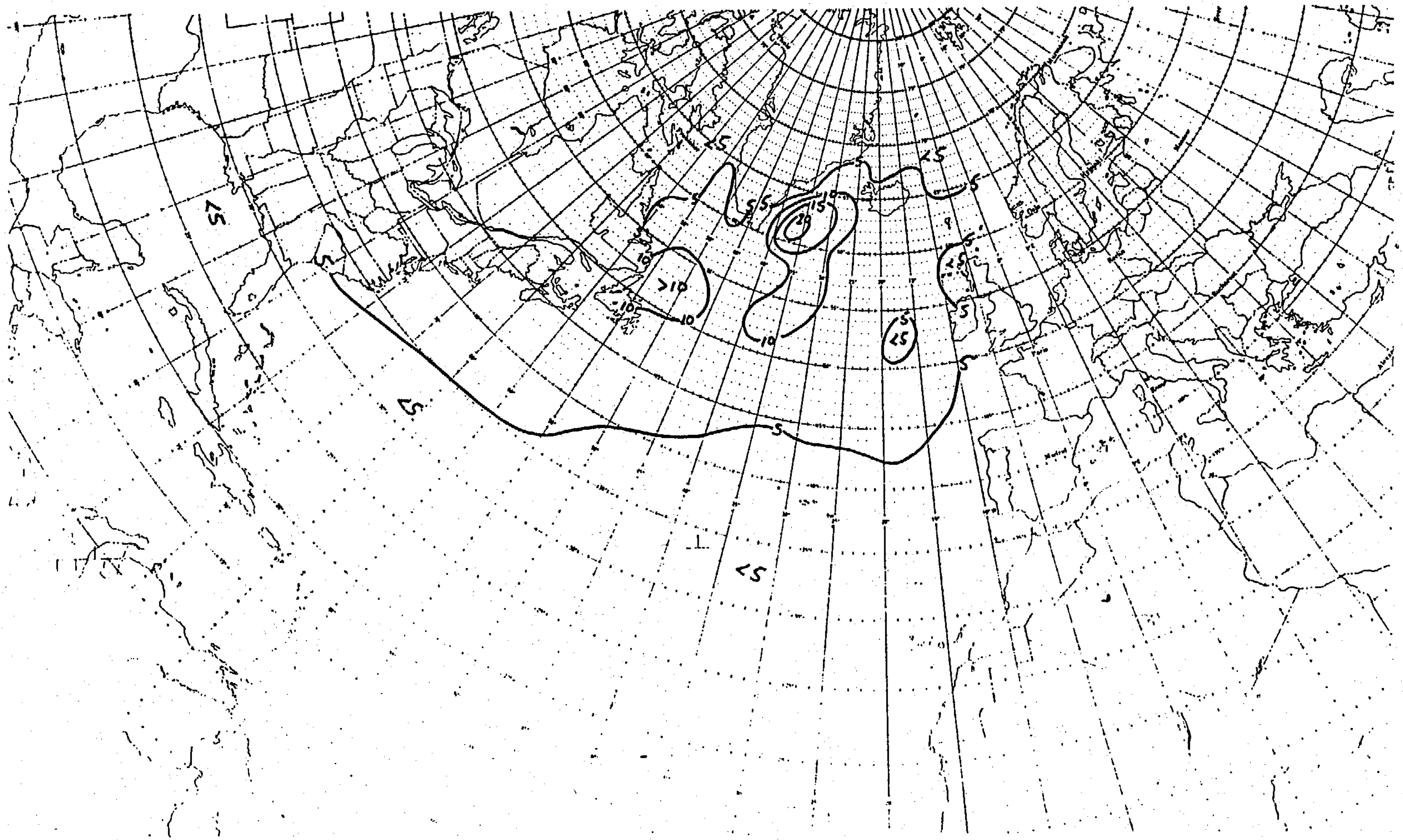

Figure 15. The frequency of low centers over the North Atlantic and Gulf of Mexico for the cool season (October - March). Frequency is determined by the number of days low centers occupied a given 5 degree latitude by 5 degree longitude box during the season.

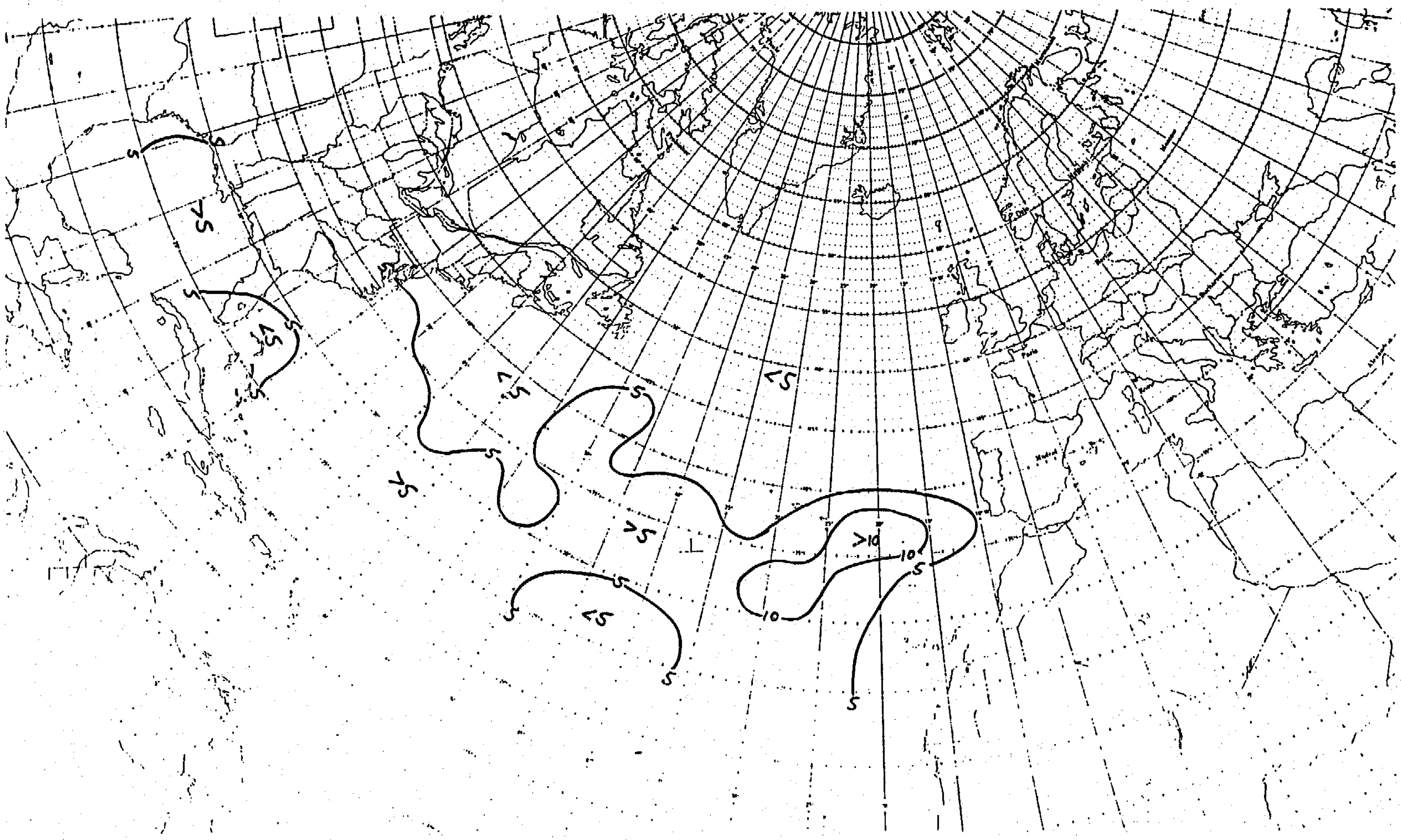

Figure 16. The frequency of high centers over the North Atlantic and Gulf of Mexico. The season and frequency are the same as in Fig. 15.

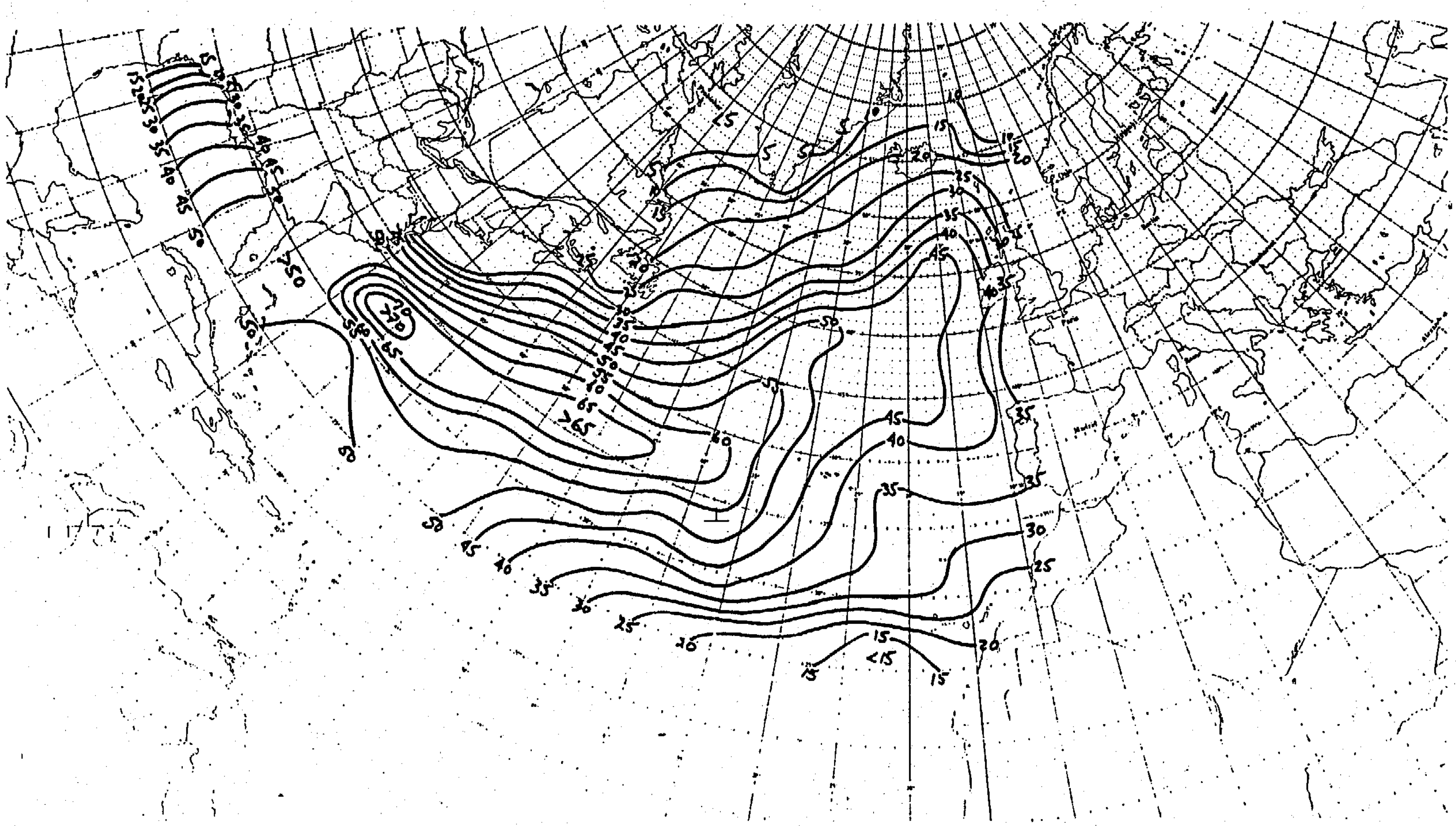

Figure 17. The frequency of fronts over the North Atlantic and Gulf of Mexico. The season and frequency are the same as in Fig. 15.

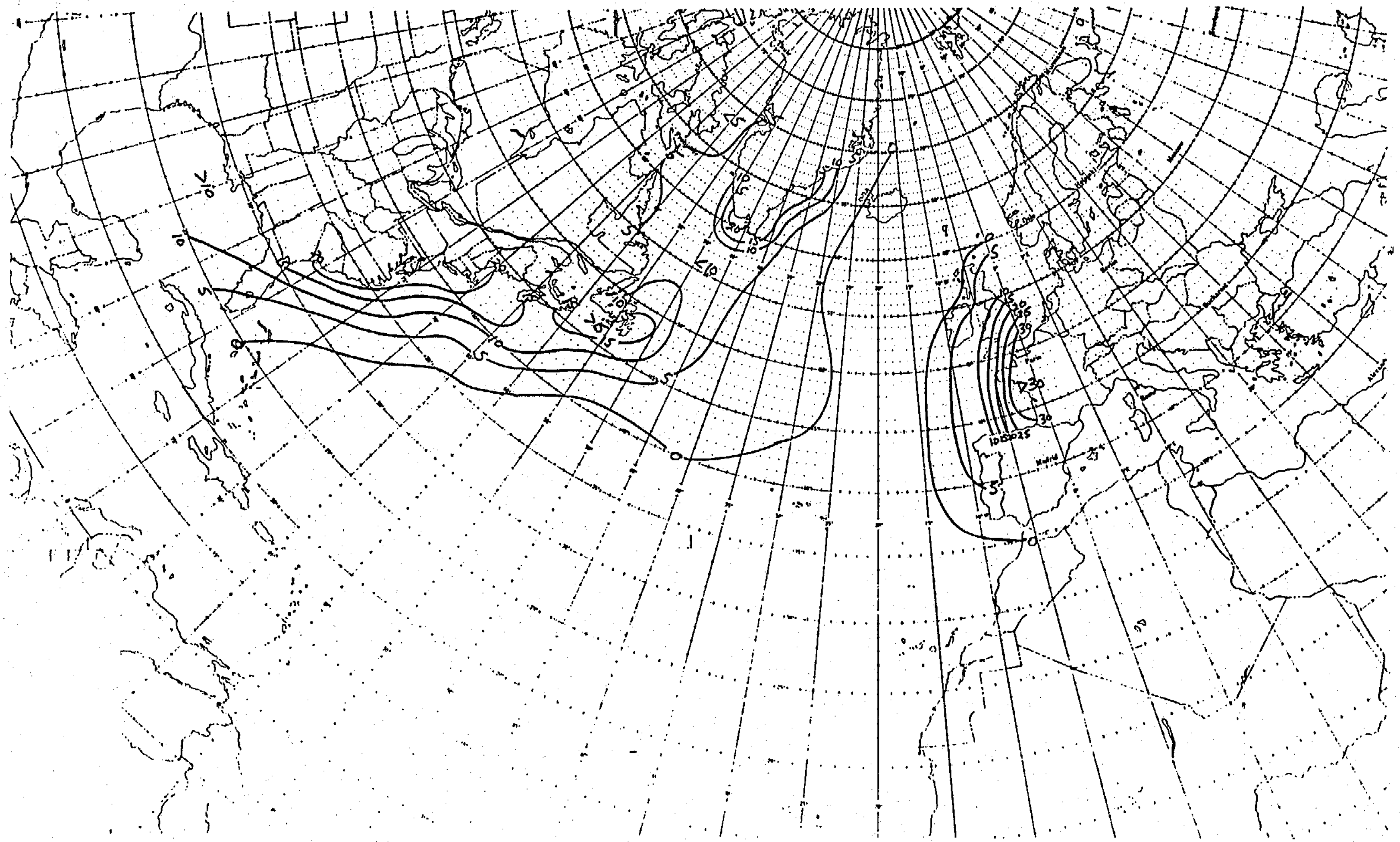

Figure 18. The frequency of fog over the North Atlantic and Gulf of Mexico. The season and frequency are the same as in Fig. 15. These data were abstracted from Guttman (1971).

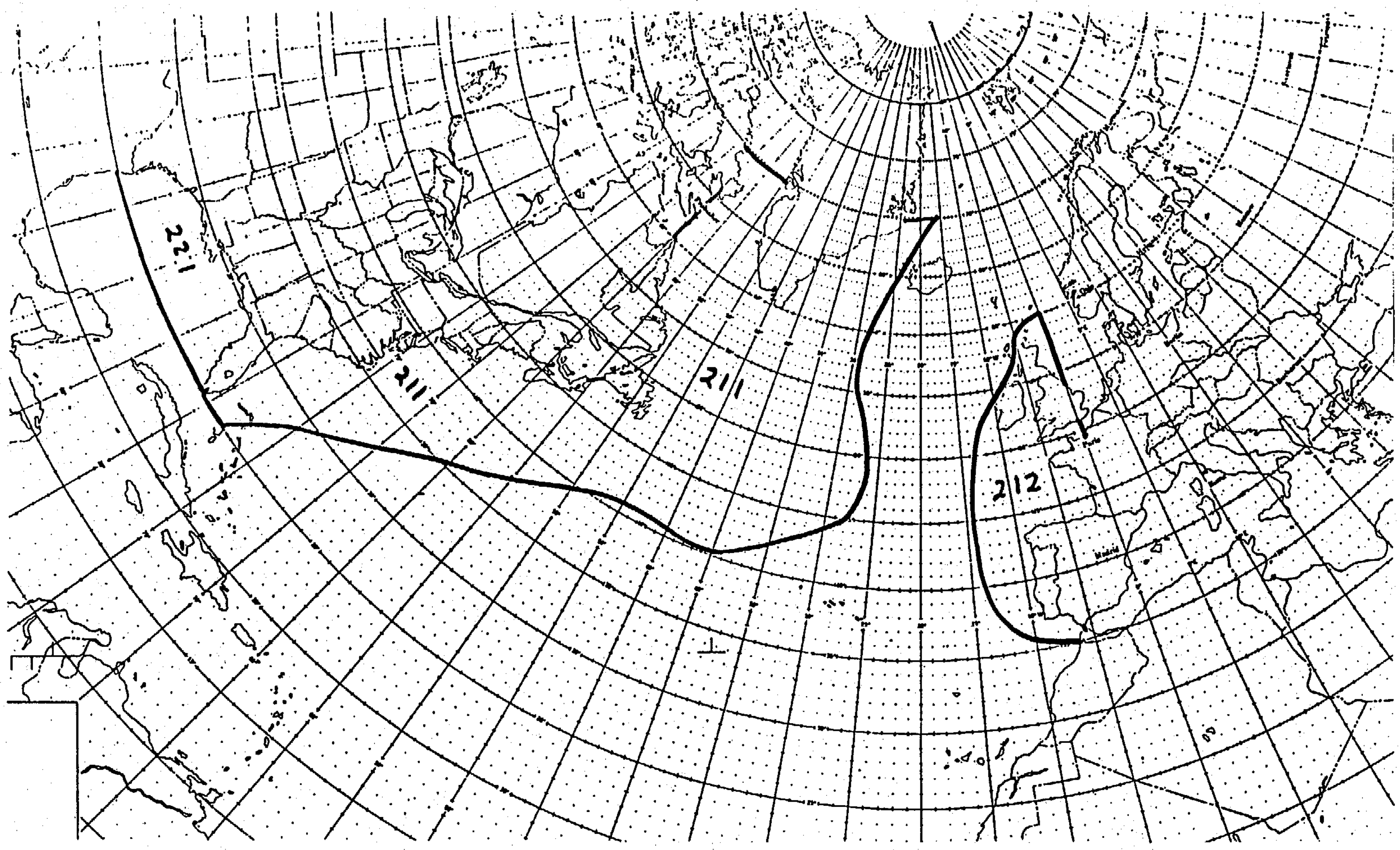

Figure 19. The fog forecasting regions for the North Atlantic and Gulf of Mexico cool season. Regions are generally labeled from north to south and from the coast of North America seaward. The first number is 2 for cool season, and the middle number is 1 for Atlantic or 2 for Gulf of Mexico.

Region 221 has identical boundaries to its warm season counterpart (See description in discussion of region 121.). The region's frequency of fronts ranges from 15 days/season in the west to 50 days/season in the east (see Fig. 17); its fog frequencies are less than 10 days/season (see Fig. 18). The frequency of high centers is less than 10 days/season (see Fig. 16), and the frequency of low centers is less than 5 days/season (see Fig. 15).

3. Pacific Ocean

The total area of the Pacific domain for the cool season is reduced by a modification of the southern boundary to reflect the zero fog frequency line. Hence, although the same number of regions were developed for the cool season as the warm season in the Pacific, the size of the regions is generally smaller, and their boundaries and the factors that went into their development are completely different (see Fig. 25). Some of the internal regional boundaries were determined by the ridgelines of frontal frequency shown in Fig. 24; however, the secondary ridgelines passing into or through regions 235, 236, and 237 were not used because the additional regions would have too small a sample size to be statistically stable. A direct comparison of the cool season regions with the warm season regions in the Pacific is not possible because they were independently developed and their physical sizes and shapes are different. The phenomena related to the production of fog in the Pacific are distributed similarly to those in the Atlantic. In the western Pacific fog is generally produced by large fluxes of moisture into cold, dry air and is mainly found near the coasts. In the central and eastern Pacific fog is formed by advection of warm, moist air over colder water with the largest frequencies near the west coast of North America. Factors affecting the development of the cool season Pacific regions described below are shown in Figs. 20 - 24. The regions are depicted in Fig. 25.

Region 231 is bounded by the west coast of North America north of 25 north and the 115th west meridian between 20 and 25 north to the east, by the 20th parallel between 115 and 125 west the south, and by the 125th west meridian between 20 and 31 north, a trough in fog frequencies between 31 and 47 north (see Fig. 23), and a secondary ridgeline of frontal frequency north of 47 north (see Fig. 24) to the north and west. The region contains the maxima of fog frequency shown in Fig. 23, a relative maximum of low center frequency along the Washington and Oregon coast (see Fig. 20), and high center frequencies of less than 5 days/season (see Fig. 21).

Region 232 is bounded by a trough of fog frequency to the north and east, generally by the 15 day/season fog frequency line to the southwest, and by the 12 day/season fog frequency line to the west (see Fig. 23). The region is dominated by fog frequencies greater than 15 days/season (see Fig. 23), has high center frequencies of less than 12 days/season (see Fig. 21), and low center frequencies of less than 5 days/season (see Fig. 20). The

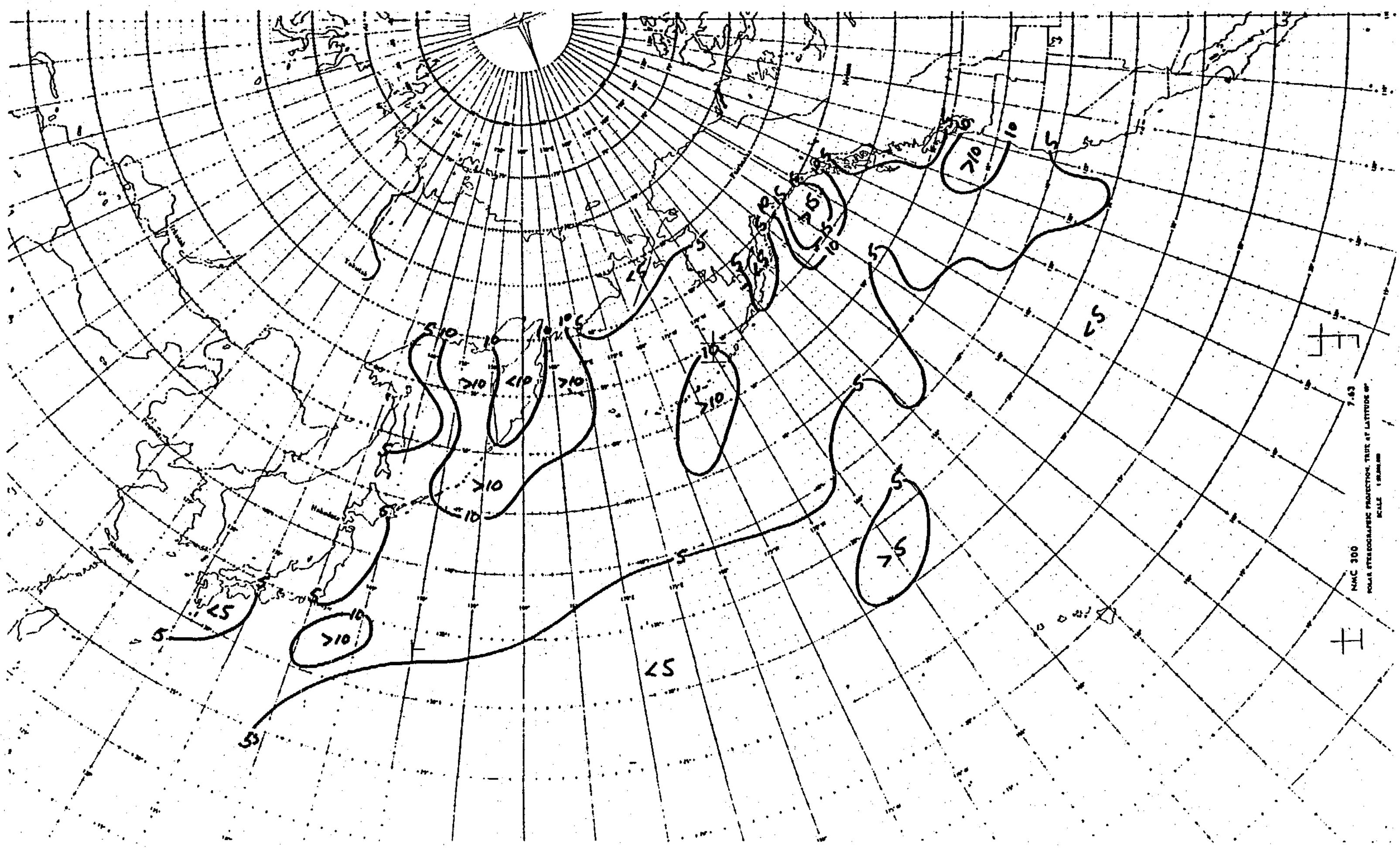

Figure 20. The frequency of low centers over the North Pacific for the cool season (October - March). Frequency is determined by the number of days low centers occupied a given 5 degree latitude by 5 degree longitude box during the season.

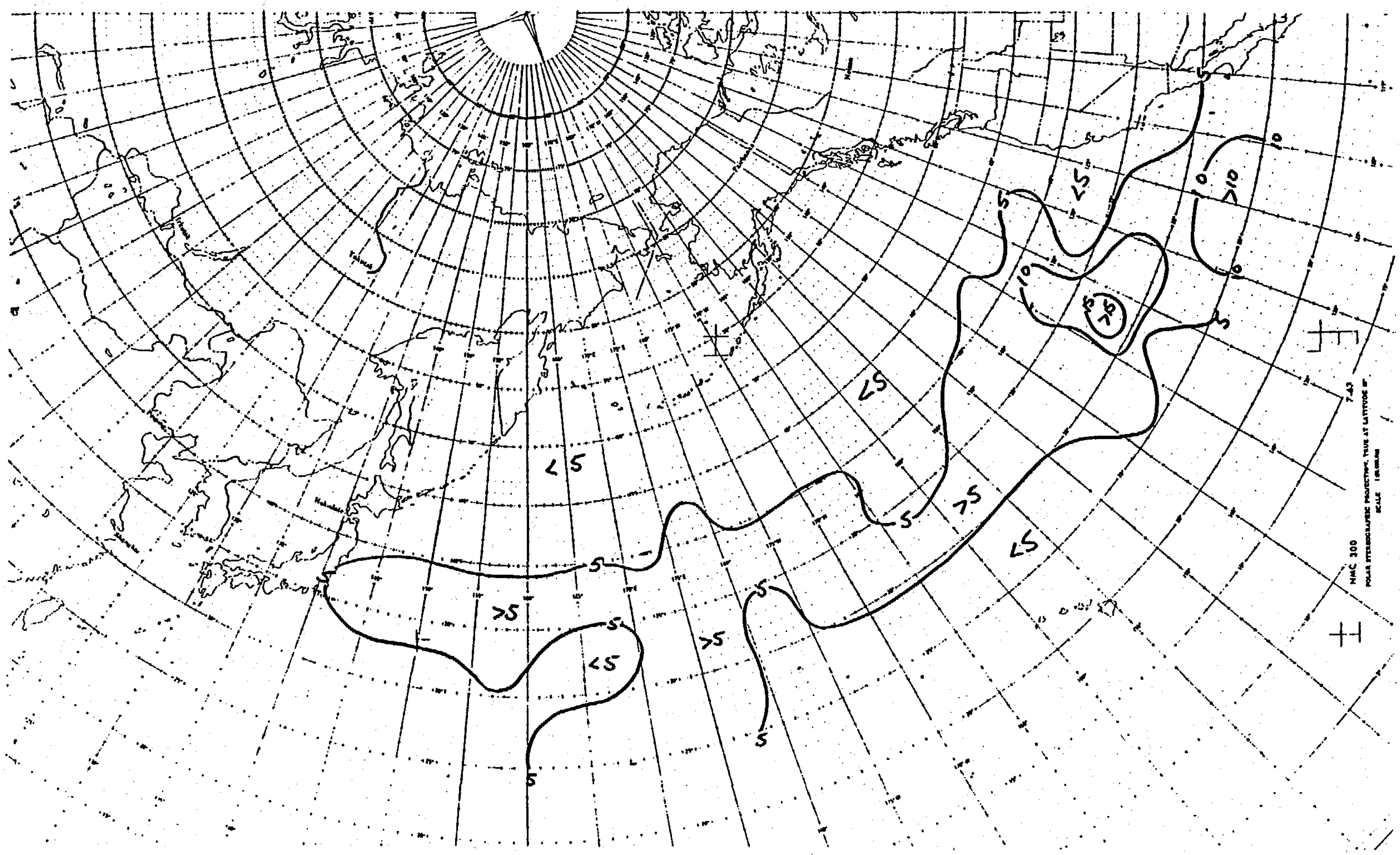

Figure 21. The frequency of high centers over the North Pacific. The season and frequency are the same as in Fig. 20.

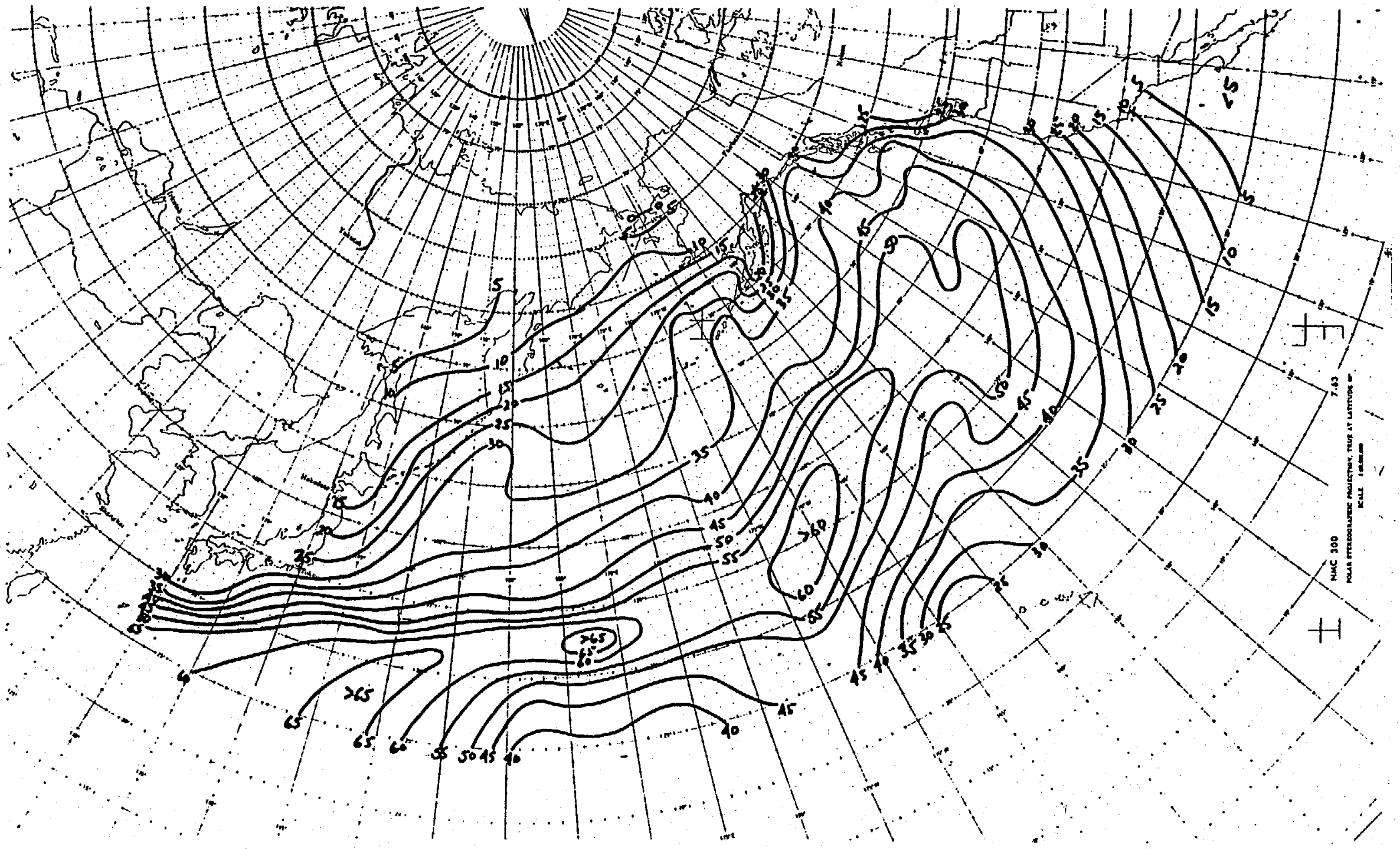

Figure 22. The frequency of fronts over the North Pacific. The season and frequency are the same as in Fig. 20.

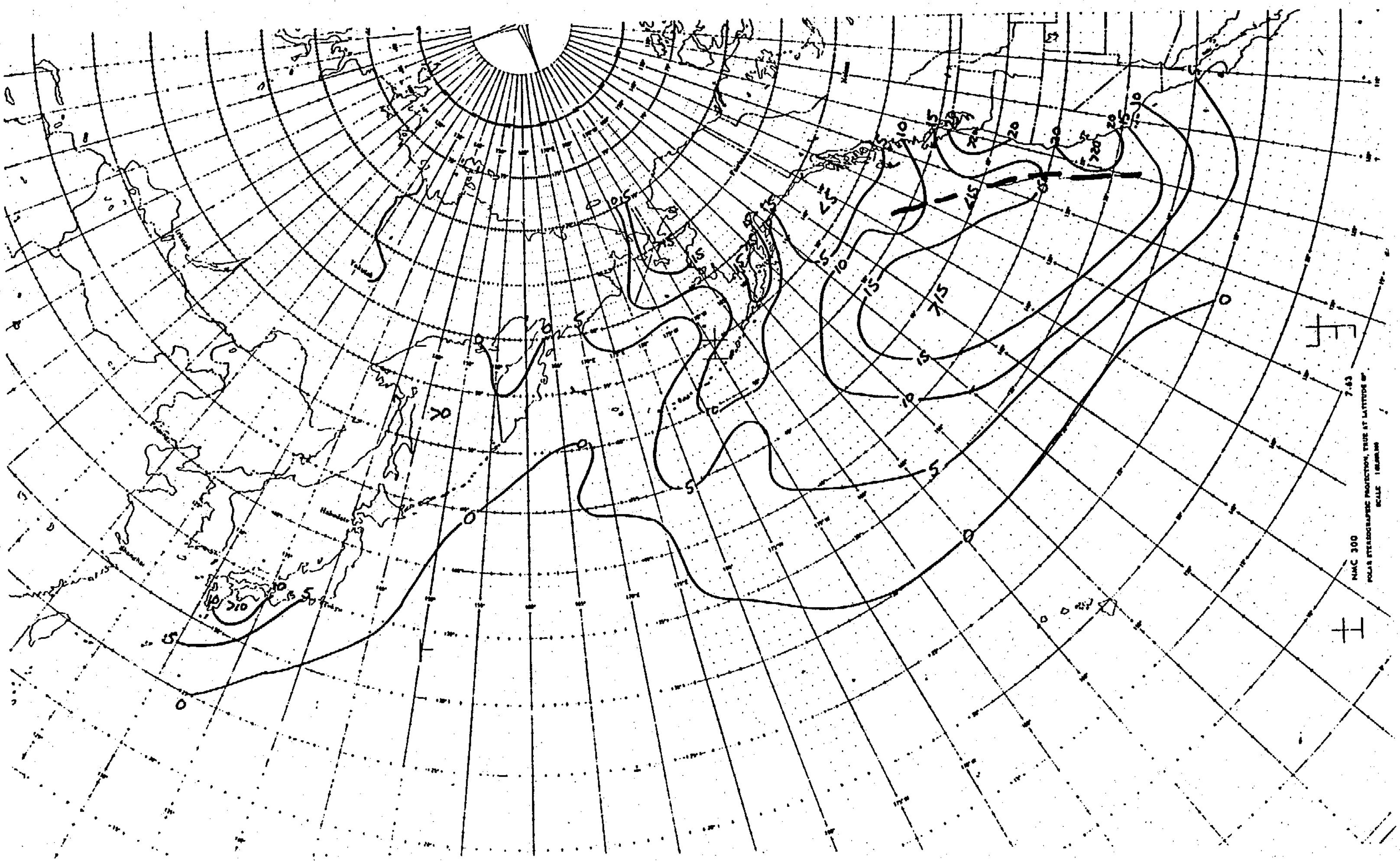

Figure 23. The frequency of fog over the North Pacific. The season and frequency are the same as in Fig. 20. These data were abstracted from Guttman (1971). The dashed line denotes a trough line which has been used as an internal regional boundary.

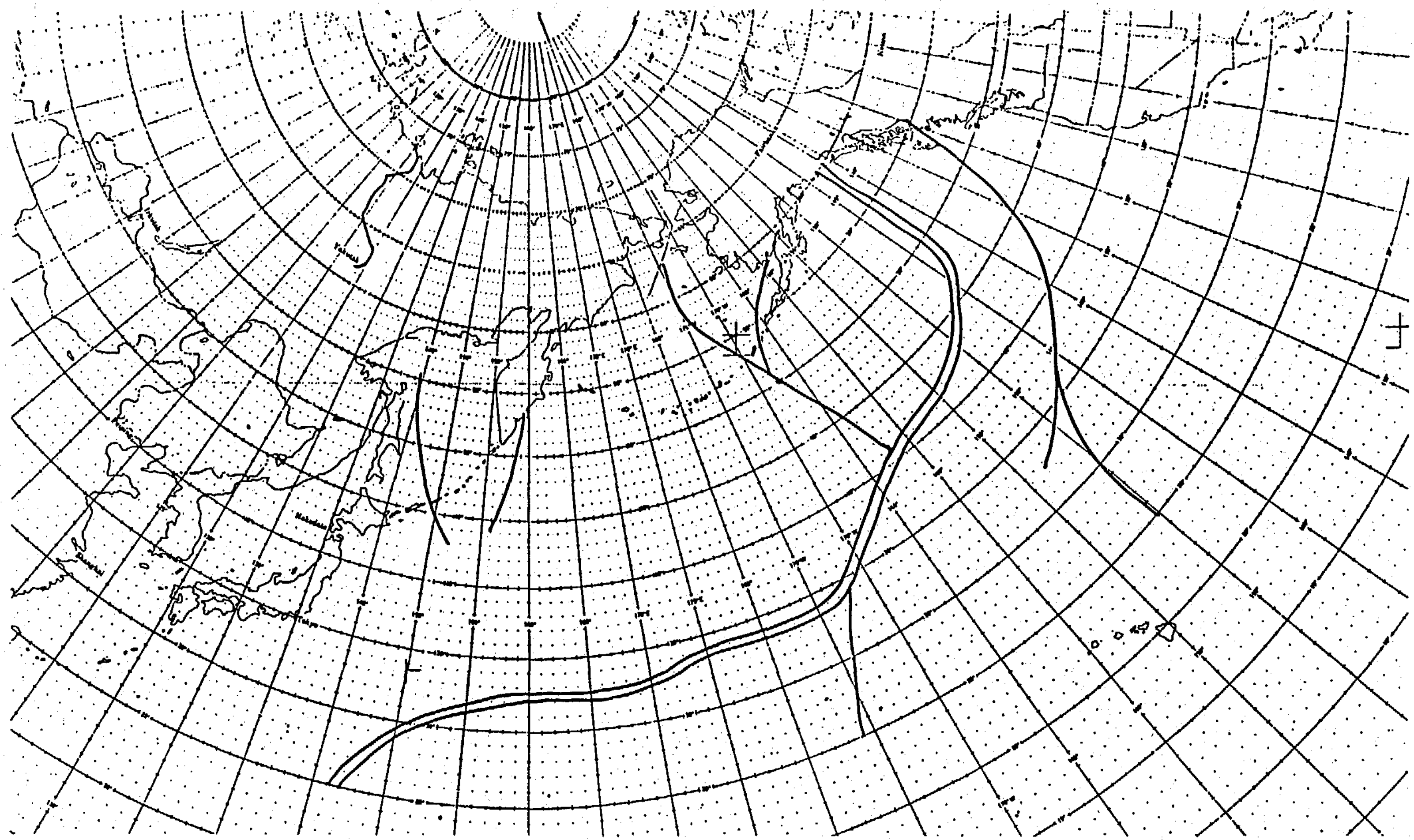

Figure 24. The ridgelines of frontal frequency over the North Pacific. The season is the same as in Fig. 20. The major ridgeline is depicted with two parallel lines. The secondary ridgelines are shown as single lines.

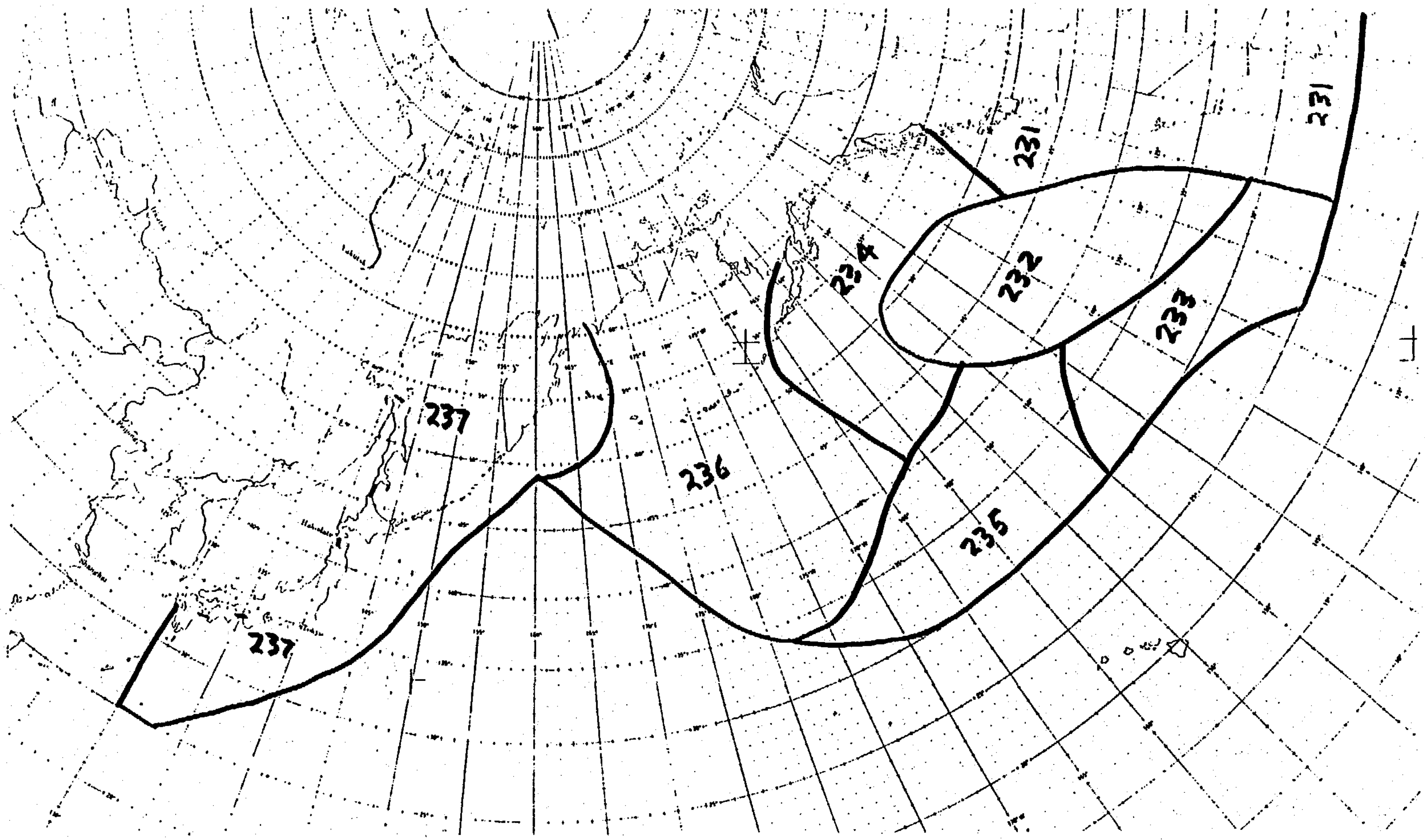

Figure 25. The fog forecasting regions for the North Pacific cool season. Regions are generally labeled from north to south and from the coast of North America seaward. The first number is 2 for cool season, and the middle number is 3 for Pacific.

major ridgeline of frontal frequency and a secondary ridgeline of frontal frequency pass through the region (see Fig. 24).

Region 233 is bounded by the 15 days/season fog frequency line to the northeast (see Fig. 23), by a secondary ridgeline of frontal frequency to the northwest (see Fig. 24), by the zero line of fog frequency between 150 and 130 west (see Fig. 23) and the 20th parallel between 130 and 125 west to the south, and by the 125 meridian between 20 and 31 north to the east. The region contains the high center frequency maximum shown on Fig. 21, has fog frequencies of 15 days/season or less (see Fig. 23), and low center frequencies of less than 5 days/season (see Fig. 20).

Region 234 is bounded by the Gulf of Alaska coast to the north, by a secondary ridgeline of frontal frequency to the east (see Fig. 24), by the major ridgeline of frontal frequency shown on Fig. 24, the 12 day/season fog frequency line (see Fig. 23), and trough in fog frequency (see Fig. 23) to the south, and by a secondary ridgeline in frontal frequency to the west (see Fig. 24). The region contains a maximum in fog frequency over the Alaska Penninsula and a minimum in fog frequency in the Gulf of Alaska (see Fig. 23), has a minimum of low center frequency over the Alaska Penninsula and the maximum of low center frequency shown on Fig. 20, and has high center frequencies of less than 5 days/season (see Fig. 21).

Region 235 is bounded by the 15 day/season fog frequency line to the north (see Fig. 23), by a secondary ridgeline of frontal frequency to the east (see Fig. 24), by the zero fog frequency line to the south (see Fig. 23), and by the major ridgeline of frontal frequency shown on Fig. 24 to the west. Fog frequencies range from 0 to 15 days/season, low center frequencies are generally less than 5 days/season except for a relative maximum found to the south (see Fig. 20), while high center frequencies are greater than 5 and less than 10 days/season over most of the region except the north central third where they're less than 5 days/season (see Fig. 21).

Region 236 is bounded by the 70th parallel to the north, by the west coast of Alaska and a secondary ridgeline of frontal frequency to the east (see Fig. 24), by the major ridgeline of frontal frequency shown in Fig. 24 to the southeast, by the zero fog frequency line between 34 and 49 north to the southwest (see Fig. 23), and by the 10 day/season low center frequency line between 49 and 61 north (see Fig. 20) and the east coast of Russia north of 61 north to the west. The region contains a relative maximum of low center frequency (see Fig. 20), fog frequencies of 0 to greater than 10 days/season (see Fig. 23), and high center frequencies of less than 5 days/season everywhere except the southern quarter where they are greater than 5, but less than 10 days/season (see Fig. 21).

Region 237 is bounded by the coast of Russia to the north, by the zero fog frequency line between 25 and 49 north (see Fig. 23) and the 10 day/season low center frequency line north of 49 north to the east (see Fig. 20), by the 25th parallel to the south, and by the east coast of Japan, Sakhalin Island, and mainland Russia to the west. The region contains a small maxima of low center frequency southeast of Honshu Island and a band of low center frequencies surrounding the Kamchatka Penninsula in excess of 10 days/season, has high center frequencies of less than 5 days/season everywhere except east of Honshu where they are greater than 5 but less than 10 days/season, and has fog frequencies of less than 5 days/season everywhere except greater than 10 days/season southeast of Shikoku and Kyushu Islands.

IV. DISCUSSION

In general, the frequency of low centers is lower in the warm season than in the cool season. The frequency of high centers is higher in the warm season than in the cool season. The maximum frequency of fronts is further north in the warm season than in the cool season and slightly more frequent due to a higher residency time in the warm season than in the cool. The frequency of fog is greater in the warm season than in the cool season. This is due primarily to the increased production of advection fog during the warm season.

The regions described in Section III were developed as an aid in stratifying predictor and predictand data into statistically homogeneous areas with respect to synoptic weather and oceanographic patterns, fog occurrence, and observation density. Such a stratification based on analysis of various factors that potentially contribute to generation of fog is essential to the success of any development of statistical forecast equations. The external regional boundaries which are associated with the bounds of the Atlantic and Pacific areas of interest depicted by Figs. 1 and 2 with the modifications described in Section III are fixed. The internal regional boundaries are based on a long term fog climatology and statistics from a one year sample of synoptic analyses. The statistics from the one year synoptic sample do not necessarily represent long term statistical properties. Consequently, it is possible that the internal boundaries based on those statistics might shift geographically from one year to another. This aspect and the sensitivity of the fog forecast equations to possible shifts in the regions will be studied on a continuing basis when the equations are derived and implemented.

ACKNOWLEDGEMENTS

Thanks are due Steve Auer and Vera Gerald for helping prepare the Northern Hemispheric Charts for tabulation and to Lee Hart and Valerie Neal for tabulating the data. I am also indebted to Dave Feit, Bill Gemmill, and D. B. Rao for their helpful comments.

REFERENCES

Auer, S. J., 1983: Gulf Stream system landward surface edge statistics. NOAA Technical Memorandum NWS NMC No. 67, National Weather Service, NOAA, U.S. Department of Commerce, 20 pp.

Barker, E. H., 1973: Oceanic fog, a numerical study. ENVPRED-RSCHFAC Technical Paper No. 6-73, Environmental Prediction Research Facility, Naval Postgraduate School, U.S. Department of the Navy, 65 pp.

Feit, D. M., 1972: A study of numerical simulation of maritime fog. ENVPREDRSCHFAC Technical Paper No. 13-72, Environmental Prediction Research Facility, Naval Postgraduate School, U.S. Navy, 41 pp.

Fett, R. W., 1987: Private communication. Naval Environmental Prediction Research Facility, U.S. Navy, Monterey, Calif.

Glahn, H. R. and D. A. Lowry, 1972: The use of model output statistics (MOS) in objective weather forecasting. J. Appl. Meteor., 11, 1203 - 1211.

Guttman, N. B., 1971: Study of worldwide occurrence of fog, thunderstorms, supercooled low clouds and freezing temperatures. NAVAIR 50-1C-60. National Climatic Center, Environmental Data Service, NOAA for the Commander, Naval Weather Service Command, 64pp.

Sela, J. G., 1980: Spectral modeling at the National Meteorological Center. Mon. Wea. Rev., 108, 1279-1292.

Tag, P. M., 1987: Private communication. Naval Environmental Prediction Research Facility, U.S. Navy, Monterey, Calif.

Taylor, K. E., 1986: An analysis of the biases in traditional cyclone frequency maps. Mon. Wea. Rev., 114, 1481-1490.

Stommel H. and K. Yoshida, ed., 1972: Kuroshio - Physical Aspects of the Japan Current. University of Washington Press, Seattle, 517pp.