

NOAA Technical Memorandum ERL PMEL-35

SURFACE AND UPPER-AIR OBSERVATIONS IN THE EASTERN BERING SEA,
FEBRUARY AND MARCH 1981

R. W. Lindsay
A. L. Comiskey

Pacific Marine Environmental Laboratory
Seattle, Washington
July 1982



**UNITED STATES
DEPARTMENT OF COMMERCE**

**Malcolm Baldrige,
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**NATIONAL OCEANIC AND
ATMOSPHERIC ADMINISTRATION**

**John V. Byrne,
Administrator**

**Environmental Research
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Director**

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Foreword

Forecasting sea ice extent and condition for the eastern Bering Sea requires an understanding of the interaction between the boundary layer of the atmosphere and the first-year sea ice. This report draws together a new set of meteorological observations essential to this understanding and is intended to stimulate interest in the physics of the air-ice interaction problem for the marginal and seasonal ice zones. This research has been monitored by the Marine Meteorological Studies Group at the Pacific Marine Environmental Laboratory (PMEL) and was carried out, under separate contracts, by R. W. Lindsay of the Polar Science Center at the University of Washington and by A. L. Comiskey of the Arctic Environmental Information and Data Center of the University of Alaska. This work is in keeping with PMEL's Marine Services Project mission to conduct research in marine weather and ocean forecasting and to transfer the information to operational forecasting units in the National Weather Service and to other interested users.

Carol H. Pease
Oceanographer
Marine Meteorological Studies Group
Pacific Marine Environmental Laboratory

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Surface and Upper-Air Observations in the Eastern

Bering Sea, February and March, 1981¹

R. W. Lindsay² and A. L. Comiskey³

ABSTRACT. Results of meteorological studies conducted near the edge of the seasonal pack ice in the eastern Bering Sea on the NOAA ship *Surveyor* from 26 February to 10 March 1981 are summarized. Surface air pressure and air temperature analyses are presented including all late reports for 00 and 12 GMT from 23 February to 21 March. Upper-air observations from the *Surveyor*, and St. Paul and Nome, Alaska, are also presented. Cross sections of the potential temperature in the boundary layer which were made as the ship steamed away from the ice during off-ice winds show the warming and deepening of the atmospheric mixed layer. The regional weather conditions encountered during this period are discussed and compared to climatology including the relationship between the atmospheric boundary layer structure and the synoptic weather.

¹ Contribution number 583 from the NOAA/ERL Pacific Marine Environmental Laboratory, 3711 15th Ave. N.E., Seattle, Washington, 98105

² Polar Science Center, 4057 Roosevelt Way N.E., University of Washington, Seattle, Washington, 98195.

³ Arctic Environmental Information and Data Center, University of Alaska, Anchorage, Alaska, 99501.

1. Introduction

In the early spring of 1981, the Marine Meteorological Studies Group of the Pacific Marine Environmental Laboratory (PMEL) performed a series of investigations of the atmospheric, ice, and oceanic processes near the edge of the seasonal pack ice in the eastern Bering Sea. These studies follow earlier efforts in 1979 and 1980 (Salo et al., 1980; Pease, 1980; Bauer and Martin, 1980; Squire and Moore, 1980; McNutt, 1981; Pease and Salo, 1981).

Specific objectives of the cruise included:

1. The evaluation of the wind and water stress on thin, first-year sea ice by profiling and slab methods.
2. The observation of ice floe motion near the ice edge to determine the relative importance of wind, current, and swell to drift characteristics.
3. The measurement of water property changes relative to sea ice conditions.
4. The observation of the modification of the atmospheric boundary layer by the marginal ice zone and the adjacent water during off-ice winds.
5. Radiometric observations of downward shortwave and longwave radiation.

This report summarizes the regional meteorological observations made during the course of the experiment. A special analysis of the sea level air pressure and air temperature fields was made to provide the best possible input data for ice motion models. In addition, the upper-air observations from the *Surveyor*, St. Paul, and Nome are discussed in relation to the boundary layer characteristics in various weather situations. In particular, the modifications of the boundary layer downwind from the ice edge during off-ice winds were investigated.

2. Surface observations and analyses

2.1 Sources of surface data

Data for the surface analyses consisted of observations of a variety of atmospheric variables including information on wind speeds and directions, pressures, pressure tendencies, temperatures, and cloud cover. These data were obtained daily from the Weather Service Forecast Office (WSFO) in Anchorage, Alaska. The WSFO received data on a real-time schedule (usually less than one hour after observation time) through its normal communications channels. These data can be classified into five groups:

1. Land-based surface aviation observations. These observations are primarily for aviation purposes but are useful for all types of analyses. They are commonly called "aviation observations."

2. Land-based surface synoptic observations. These observations are transmitted in a code different from the aviation observations but contain essentially the same information. They were most frequently used as back-up for missing aviation observations. They are commonly called "synoptic observations."
3. Ship-based synoptic surface observations. These observations are normally transmitted from bulk carriers and other large ships or marine platforms. They are commonly called "ship observations."
4. Boat-based surface observations. These observations are normally transmitted from small ships or fishing boats of 15 to 50 m in length. The observations were not rigidly formatted and were not coded.* They usually do not contain pressure or dew point data but may contain more information about sea conditions, sea ice, or superstructure icing than ship observations. The boat-based surface observations are frequently called "unofficial ship observations."
5. Satellite observations. These visual and infrared observations of large areas are transmitted from both orbiting and geostationary satellites. Satellite imagery of the earth's surface and lower atmosphere is received twice daily from a NOAA polar-orbiting satellites and every 30 min from a geostationary satellite. The observations are commonly called "satellite pictures."

2.2 Analysis procedure

The normal surface analysis procedure consisted of obtaining preliminary analyses from WSFO Anchorage. The preliminary analyses from WSFO Anchorage were generally of good to excellent quality with the bulk of the data entered on the map by an NWS human plotter. An NWS meteorologist then analyzes the data with the aid of satellite pictures.

One of the shortcomings of the WSFO analyses was that there were numerous instances of missing data--particularly on the preliminary analyses. Some data were not plotted due to the short timeframe imposed on WSFO personnel. It is interesting to note that the observations from the NOAA ship *Surveyor* were plotted by NWS personnel only 51.6 percent of the time. This was mostly because of the short timeframe and the fact that most plotters do not plot ship observations when the ships are close to land-based observation stations. Some ships may not be plotted when ships are clustered, etc. Unofficial ship reports are frequently not plotted because of being received too late. During this particular project there were few unofficial observations because of fishing and crabbing closures. Nevertheless, all sources of potential data were considered.

Another shortcoming is that the WSFO aims at acceptable macro-scale analyses while the requirement for this project is a quality meso-scale analysis. Another shortcoming of the WSFO analyses was the additional lack of readability due to the analyses themselves. The rather broad isolines, fronts, and labels obscured data. Individual plotting skills, reproduction, etc. also detracted from the readability of the data.

*The NWS now codes these reports for internal use at the Anchorage forecast office.

In short, the reanalyst obtained copies of all the observations and checked for missing or obscured data. These data were entered on the map. When the missing or obscured data problems were resolved, the WSFO maps were reanalyzed with the additional benefits of hindsight, eased time constraints, and the conscious goal of deriving quality mesoscale analyses. After reanalysis of the NWS map, selected data were transferred to a new base map. The isolines and fronts were also transferred and labeled in a manner to avoid obscuring any data. The reports of the NOAA ship *Surveyor*, the only ship identified here by its call letters, WTES, were plotted wherever possible. These hand-drawn surface pressure analyses for 00 GMT for the period 23 February to 21 March 1981 are presented in Appendix A.

2.3 Discussion of surface analyses

The low-pressure centers, some of which were quite vigorous (i.e., storms), followed climatology rather closely (Klein, 1957). Low-pressure centers normally tended to move from west to east along the central Aleutians and from there into the southeastern Bering Sea or into the northern Gulf of Alaska. In general, if lows move into the southeastern Bering in February and early March, cold- and warm-air advection can be expected, as shown on the 00 GMT 25 February analysis (note the 00 GMT 16 March and 00 GMT 17 March analyses, in which the low-pressure centers are also in the southeast Bering). However, by this time the landmass had warmed so drastically that cold-air advection into the northern and central Bering was minimal.

When intense storms are located south of the Aleutians or in the Gulf of Alaska, the Bering Sea may be under a broad, cold-air advection regime. During our study period there were no good examples of extreme cold-air advection over the Bering Sea area, but the maps of 00 GMT 24 February and 00 GMT 9 March indicate how an extreme cold-air advection situation is produced. Sea ice buildup is greatest during periods of sustained, strong, northeast-to-northwest winds as long as the Arctic and continental land masses remain cold.

During our study period, two storms moved northward into the central Bering Sea causing strong, sustained, warm-air advection and retreat of the sea ice in the Bering Sea east of 180°. The first, more intense storm moved into the central Bering Sea at about 00 GMT 27 February and continued through 3 March. Note that the *Surveyor* reported warming from 10°F (-12°C) on the 00 GMT 27 February analysis to 35°F (+1.7°C) on the 00 GMT 28 February analysis and then remained above freezing for several more days. Peak winds of 25 m s⁻¹ were recorded at 17 GMT 27 February. A weaker but similar storm moved into the central Bering, as shown in the 00 GMT 17 March analysis, and rapidly destroyed the cold-air advection regime in the central Bering that had prevailed for several days.

The most interesting aspect of the map series is the well-organized, cold-air advection that began with the 9 March map. Following that map, a weakening occluded front (not on map) moved northward, and an Arctic front, identified primarily from cloud pictures, began moving southward. Both are first shown on the 00Z 11 March analysis. By 00Z 13 March a strong surface temperature gradient developed along the Arctic front. The continuity of this front was maintained through 00Z 16 March with rapid disintegration thereafter. During the period preceding 00Z 16 March the Bering Sea ice

should have moved southward west of the front, and northward east of the front.

A classic example of the value of mesoscale analysis is shown by the small low-pressure area centered over the Aleutians on the 00 GMT 20 March analysis. The low moved westward and was unusually well verified by a Japanese ship as the low and the ship moved along the great circle route from the Pacific Northwest to Japan. Reports from Adak also verified the existence of this mesoscale feature. Coincidentally, all other analyses, both national and local, failed to detect the low-pressure area even though it was nearly 350 kilometers in length with winds to 15 m s^{-1} . It is believed that such mesoscale features, especially if undetected, could significantly affect the performance of atmospheric, sea ice, and oceanic models.

2.4 Computer drawn maps

To provide sea level pressure fields and sea level air temperature fields for input to ice movement models, additional pressure analyses were done for 12 GMT, and air temperature analyses were done for 00 GMT and 12 GMT. The maps were manually digitized on a 5 x 6 polar stereographic grid with a normal spacing of 381 kilometers at 60°N; the fields were then interpolated to $\frac{1}{2}$ -grid, a 95-kilometer spacing. The plotted pressure fields are in Appendix B; the plotted air temperature fields are in Appendix C. In addition to the pressure contours, an estimate of the surface winds based on a 30° turning and 20% reduction of the calculated gradient wind is included at each grid point. These plots were produced with the aid of the METLIB computer programs (Overland et al., 1980).

3. Upper-air observations

3.1 Techniques and discussion

A total of 38 radiosondes were regularly released from the *Surveyor* at 00 GMT and 12 GMT, with additional soundings made during downwind runs away from the ice. The Airsonde atmospheric-sounding system that was used consisted of an expendable, aerodynamically designed package attached to a 100-gram, helium-inflated balloon. A directional antenna, a ground station to decode the transmitted signal, and an HP-9830 computer to log the data and perform preliminary analysis were on the ship. The Airsonde transmitted dry- and wet-bulb temperatures and pressure approximately every six seconds. No wind information was received. The absolute accuracy of the temperature was $\pm 0.5^\circ\text{C}$, and the accuracy of the pressure was $\pm 3 \text{ mb}$. Because of near-zero surface temperatures, the wet bulb was often in the process of freezing during which time no information on humidity was obtained. In addition, at low temperatures the wet-bulb depression is small and often below the accuracy of the temperature sensors, hence the humidity was not included in the sounding plots.

A total of 38 Airsonde soundings were made from the ship during the cruise. Tables I and II list the time, location, and surface observations for each sounding. The potential temperature for each sounding is plotted in Appendix D. Data in table II are uncorrected ship's bridge observations.

Table 1.--Balloon Ascents.

<u>ID</u>	<u>DAY</u>	<u>TIME (GMT)</u>	<u>LAT.</u>	<u>LONG.</u>
1	Feb 23	0116	57° 08.9'	152° 31.8'
2	25	1200	55° 08.7'	166° 48.5'
3	25	2330	56° 32.7'	170° 19.0'
4	26	1145	57° 45.3'	173° 25.3'
5	26	1903	58° 17.0'	173° 03.3'
6	26	2330	58° 29.0'	172° 37.1'
7	26	1152	58° 25.0'	172° 48.1'
8	27	2328	58° 34.4'	172° 43.9'
9	28	1128	58° 26.8'	173° 15.1'
10	Mar 1	1134	58° 25.7'	172° 45.6'
11	1	2330	58° 47.4'	172° 11.7'
12	2	1135	58° 44.1'	171° 53.0'
13	2	2335	59° 11.0'	171° 38.9'
14	3	1132	59° 12.0'	171° 22.8'
15	3	2334	59° 15.2'	171° 23.1'
16	4	1125	58° 46.1'	170° 47.1'
17	5	1138	59° 10.9'	171° 50.3'
18	5	2358	59° 07.5'	171° 52.1'
19	6	1201	58° 53.5'	171° 05.1'
20	6	2330	58° 52.5'	172° 10.3'
21	7	0512	58° 49.6'	172° 09.5'
22	7	0600	58° 44.9'	172° 12.8'
23	7	0700	58° 35.1'	172° 19.9'
24	7	0755	58° 24.5'	172° 27.8'
25	7	0900	58° 10.7'	172° 37.4'
26	7	1001	57° 57.7'	172° 46.4'
27	7	1130	57° 39.1'	172° 59.0'
28	7	2330	58° 47.6'	172° 20.6'
29	8	1252	58° 41.4'	172° 44.5'
30	9	1130	58° 31.7'	173° 25.4'
31	9	2331	58° 14.2'	173° 30.3'
32	10	1128	58° 38.3'	173° 07.9'
33	10	2334	58° 39.1'	173° 12.1'
34	11	0308	58° 24.8'	172° 43.6'
35	11	0548	58° 12.8'	173° 08.1'
36	11	0729	58° 02.2'	173° 26.5'
37	11	0902	57° 51.5'	173° 40.1'
38	11	2342	56° 11.1'	169° 13.6'

Table 2.--Surface Observations for Balloon Ascents.

ID	DIRECTION (°T)	SPEED ¹ M/S	DRY TEMP (°C)	WET TEMP (°C)	PRESSURE MB	CLOUD COVER
1	149°	2.6	4.2°	3.0°	1003.8	3/10 CA & CIRRUS
2	174°	8.7	3.2°	2.6°	985.6	BROKEN
3	005°	10.8	-4.1°	-4.6°	988.2	OVERCAST, STRATO CU
4	006°	5.7	-9.1°	-9.7°	998.9	OVERCAST, SNOWING
5	047°	3.6	-10.7°	-11.2°	1000.5	OVERCAST, SNOWING
6	003°	3.6	-11.8°	-12.0°	1001.5	8/10 STRATO CU
7	070°	12.9	-6.5°	-7.1°	990.1	OVERCAST
8	100°	15.4	0.8°	0.2°	968.1	OVERCAST
9	115°	11.3	0.8°	0.4°	970.2	CLEAR, STARRY
10	115°	7.2	3.3°	1.1°	970.8	CLEAR, STARRY
11	140°	8.2	1.3°	0.6°	970.9	CLEAR
12	171°	15.4	0.3°	-0.1°	979.0	2/10 CUMULUS
13	182°	12.3	0.5°	-0.5°	989.0	5/10 CUMULUS
14	148°	8.7	-1.7°	-1.7°	998.0	OVERCAST
15		0	-1.2°	-1.7°	997.3	FOG
16	105°	9.3	-1.2°	-1.7°	992.4	CLEAR, STARRY
17	015°	8.2	-7.5°	-8.0°	997.4	OVERCAST
18	356°	10.3	-12.6°	-12.9°	998.3	8/10 CU & SEA SMOKE
19	010°	8.7	-14.0°	-14.4°	998.4	OVERCAST
20	003°	6.2	-13.0°	-13.2°	997.0	OVERCAST, STRATO CU
21	010°	8.7	-10.5°	-11.8°	996.5	OVERCAST
22	026°	6.2	-10.2°	-10.7°	996.8	OVERCAST, SNOWING
23	025°	6.2	-9.6°	-9.8°	996.9	OVERCAST, SNOWING
24	019°	8.2	-7.8°	-7.7°	997.0	OVERCAST, SNOWING
25	036°	6.7	-6.0°	-6.2°	996.7	OVERCAST
26	029°	7.7	-6.5°	-7.0°	996.8	OVERCAST
27	018°	6.2	-5.5°	-6.3°	996.3	OVERCAST, LIGHT SNOW
28	040°	5.7	-6.8°	-7.0°	997.1	OVERCAST
29	050°	12.9	-1.1°	-1.5°	991.8	OVERCAST, SNOWING
30	013°	15.4	-9.5°	-9.8°	994.2	OVERCAST
31	005°	14.4	-8.1°	-8.6°	992.2	OVERCAST
32	048°	10.8	-5.0°	-5.2°	997.3	OVERCAST, LIGHT SNOW
33	045°	9.3	-8.0°	-8.2°	1002.8	OVERCAST, SNOW
34	045°	8.2	-6.3°	-6.8°	1002.0	OVERCAST
35	045°	9.3	-6.1°	-6.3°	1001.0	OVERCAST
36	046°	9.8	-3.0°	-3.5°	1000.5	OVERCAST
37	054°	10.8	-2.8°	-3.1°	1000.0	OVERCAST
38	056°	11.3	2.2°	1.2°	986.2	7/8 STRATO CUMULUS

¹ Uncorrected bridge winds from the ship.

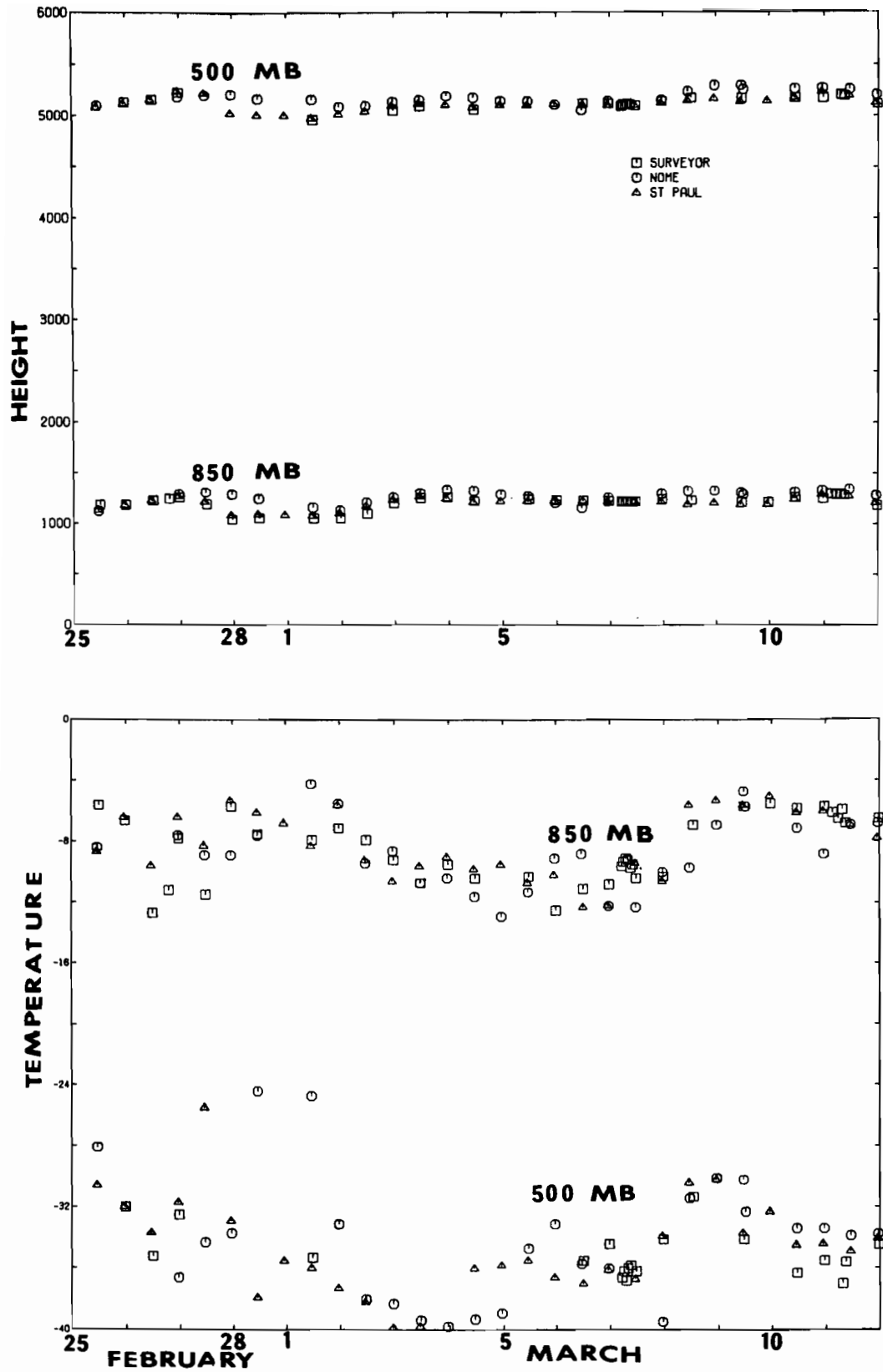


Figure 1.--850- and 500-mb heights and temperatures.

Soundings for Nome and St. Paul for the period 23 February to 16 March 1981 were obtained from the National Climatic Center and are presented in Appendix E.

The height and temperature of the 850- and 500-mb levels for each sounding for all three stations are presented in Figure 1, where we see the range of variability between the stations and the generally good agreement between the Airsonde and the National Weather Service stations.

The characteristics of the soundings at Nome and St. Paul differ significantly. Nome often has a very strong surface inversion, particularly in times of light winds (see, for example, sounding 70200 102 81 2 23 11 15 in Appendix E). Well-mixed layers near the surface are rare during the period of our observations, except during times of higher wind speed when the inversion is mixed mechanically to form a shallow adiabatic layer some 300 m deep (70200 107 81 2 25 23 15). Very strong winds associated with the gale of 28 February and 1 March appear to have nearly removed the boundary layer altogether (70200 113 81 3 1 11 15). (See Pease and Muench, 1981, for a description of the effects of that gale on the MIZ.) While the surface inversion is not always present, the boundary layer appears nearly always stable.

St. Paul, 900 km south of Nome, is in the middle of the Bering Sea, but was not within the pack ice during the period of interest. Measurements here rarely show a surface inversion (70308 129 81 3 5 23 0 is an exception) and almost always exhibit a well-mixed boundary layer. With northerly winds, this layer was substantially cooler and moister than the air aloft and was typically 500 to 1000 m thick (70308 131 81 3 6 23 0), but ranged to 1500 m thick. A well-defined marine boundary layer, moister but not much cooler than the air aloft, was seen before the big storm of February 28 (70308 116 81 2 27 11 0). During this storm the boundary layer was not apparent at all, with winds rising to 30 m s^{-1} , no shear, and uniform temperature gradients to 5000 m (70308 118 81 2 28 11 0). A marine boundary layer finally formed more than two days later when winds slackened and turned from the south to the northeast (70308 123 81 3 2 23 0).

The soundings taken from the ship were similar to those of St. Paul. When the ship was near or within the MIZ and the winds were northerly, the mixed layer was generally shallower, and the inversion stronger. The mixed-layer depth dropped to as little as 200 m, with 10 m s^{-1} winds (25 18 81 3 5 23 53, Appendix D).

The detailed dynamics of how strong inversions such as those seen at the ice edge are formed and maintained is not entirely clear. The existence of the well-mixed layer before the air had crossed any substantial amount of open water indicates a positive heat flux within the pack ice, which is reasonable because of the presence of leads and the thinness of the ice (Bauer and Martin, 1980). Although strong surface inversions are seen at Nome, they are rarely deep enough to survive hundreds of kilometers of travel over the ice. Another mechanism may be operating. Subsidence tends to increase the jump in potential temperature at the inversion base at the top of the mixed layer. Such a stabilizing influence would produce a more uniform layer height even though thermodynamic and mechanical mixing were active. In addition to synoptic

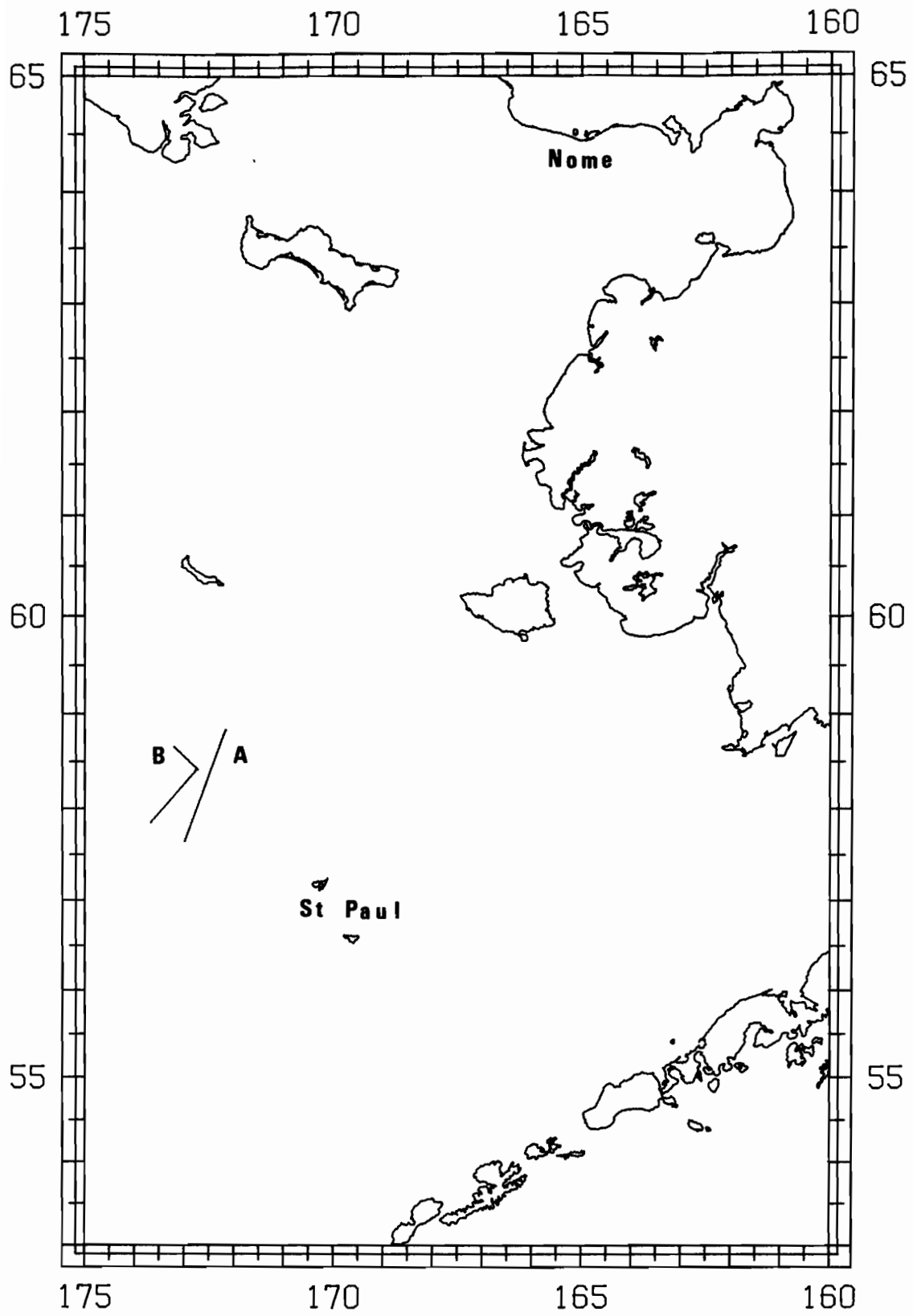


Figure 2.--Map of the Bering Sea with the position of the two transects.

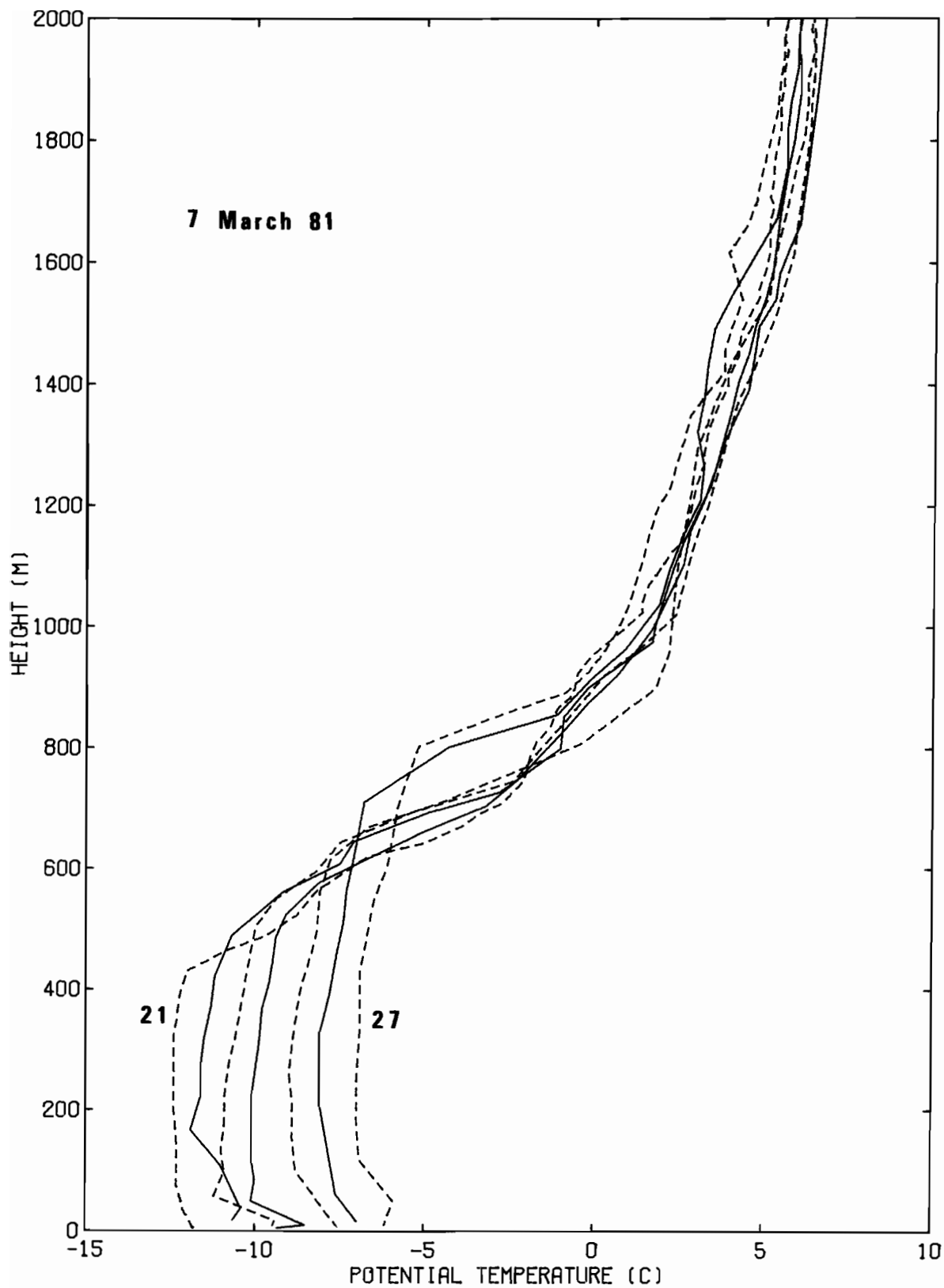


Figure 3.--Potential temperatures for transect A.

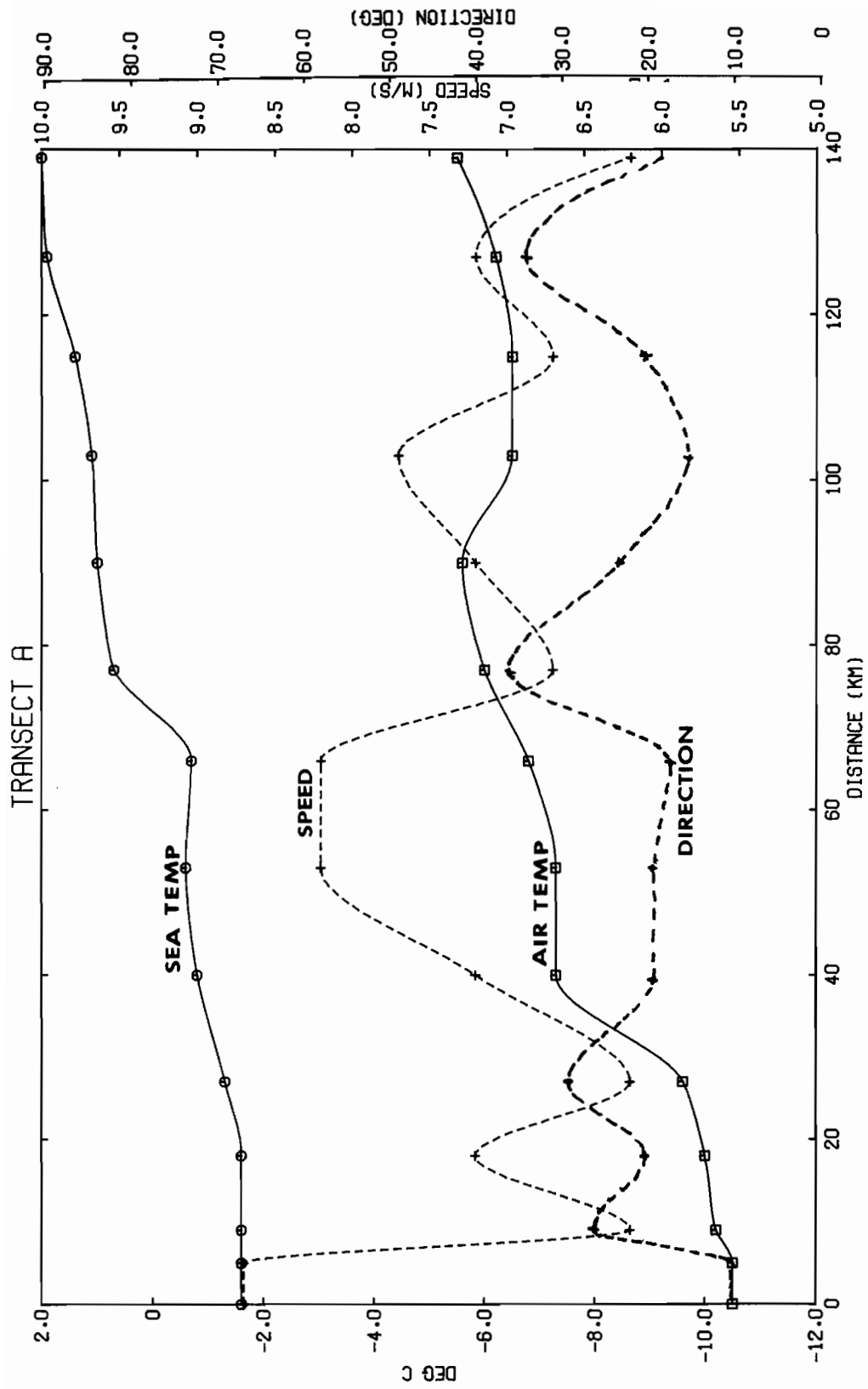


Figure 4.--Surface observations during transect A.

scale subsidence under an anticyclone, subsidence could occur as the air accelerates from the ice to open water, which is relatively smoother.

3.2 Downwind transects

On two occasions transects were made downwind from the ice edge during northerly wind conditions. The positions of the two transects are shown in figure 2. The first, designated A, occurred from 0512 to 1130 GMT on 7 March. Seven soundings were made over a six-hour period (soundings 21-27). In a plot of the potential temperature of all seven soundings (fig. 3), we see a warming of the mixed layer of 6°C and a doubling of the mixed-layer depth from 400 m to 800 m over the 140-kilometer transect. Wind velocities at the surface were 6 to 8 m s⁻¹ from 10° to 40° true, and the air-sea temperature difference was between -8.9 and -6.1°C (fig. 4). A cross section of the potential temperature observations also clearly shows the warming and deepening of the mixed layer (fig. 5).

During most of the transect there was a cloud layer, it was snowing lightly, and darkness obscured the height and nature of the clouds. The sounding for St. Paul (70308 132 81 3 7 11 0) shows a moist layer extending well beyond the inversion to 1300 meters. The wind veered from the north at the surface to the east above the inversion. This strong turning reflects the presence of a large cyclone moving into the region from the southwest. It is curious to note that only a very weak surface inversion existed at Nome, and it was slightly warmer there than at St. Paul.

An estimate of the heat flux may be obtained from the bulk aerodynamic transfer relation:

$$H = \rho C_p \Delta T U_{10} C_T$$

where ρ is the air density, C_p its heat capacity, ΔT is the air-sea temperature difference, U_{10} the wind speed at 10 meters, and C_T the heat transfer coefficient. Taking C_T as 0.0011 (Smith, 1980), $\Delta T = 7.5^\circ\text{C}$, $U_{10} = 7.3 \text{ ms}^{-1}$, the heat flux was 77 Wm^{-2} .

Transect B occurred when the ship was leaving the ice edge. Large ice bands and the need to perform several CTD casts slowed our departure from the MIZ. Five soundings were made between 2234Z on 10 March and 0902Z on 11 March (soundings 33 to 37). The potential temperatures of these soundings are plotted in figure 6. Here we see consistent warming, but not a consistent deepening of the mixed layer. The last four soundings were taken in a straight line going to the southwest, and these four have been used to form the cross section in figure 7. We see that in transect B the mixed layer was shallower and did not show an increase in depth, and that the air above was more neutrally stratified than in transect A. The heat flux was about 70 Wm^{-2} ($\Delta T = 5.5^\circ\text{C}$ and $U_{10} = 9 \text{ m s}^{-1}$), and it was overcast with some light snow. St. Paul at 00 GMT on the 11th showed a moist layer about 1500 m thick and a very shallow and weak inversion at about 200 m. There was a weak occluded front near the ship on 00 GMT 11 March, as seen in Appendix A. This front had disappeared by 12 March when the ship was located between two other fronts. The

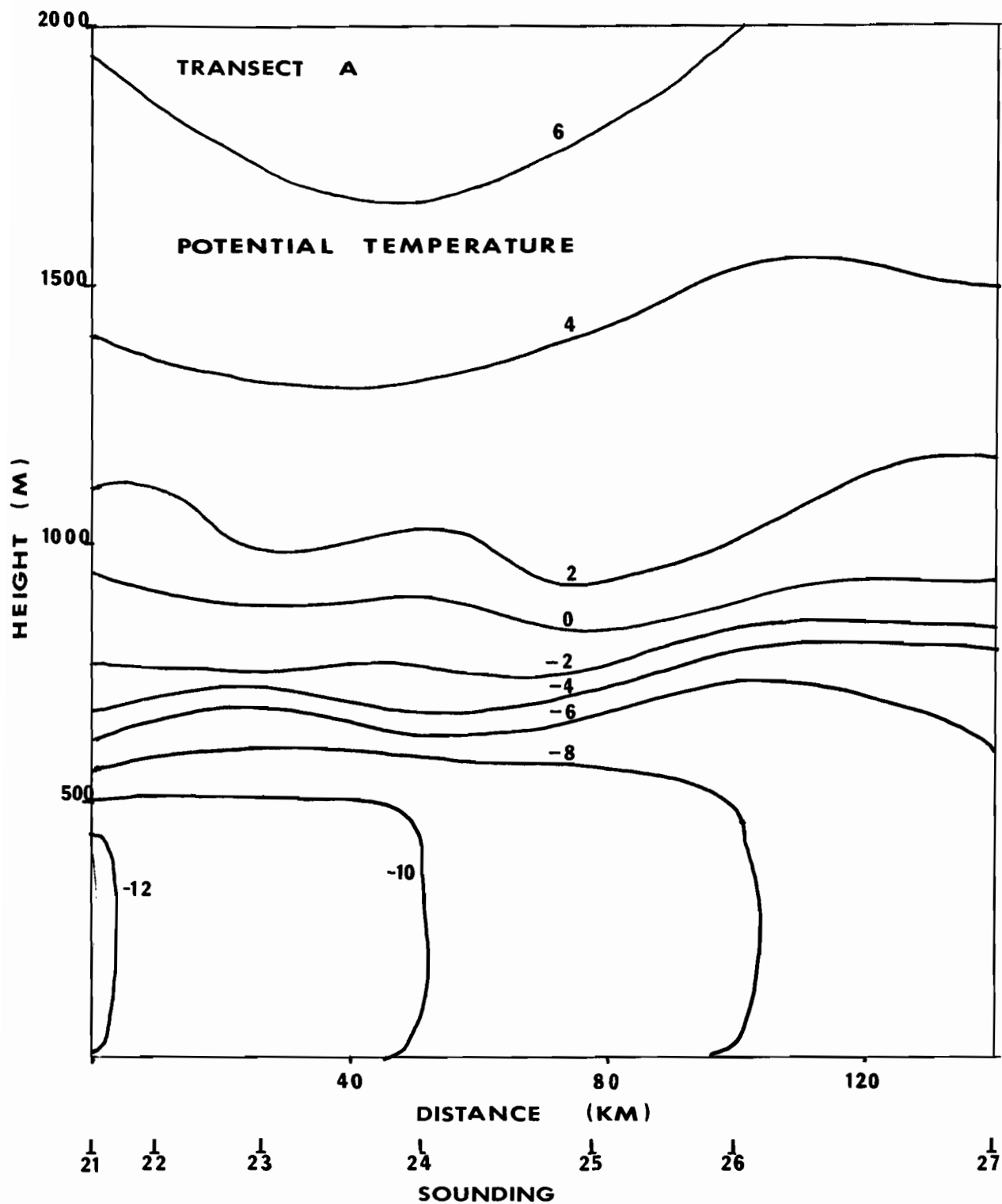


Figure 5.--Cross section of potential temperature for transect A.

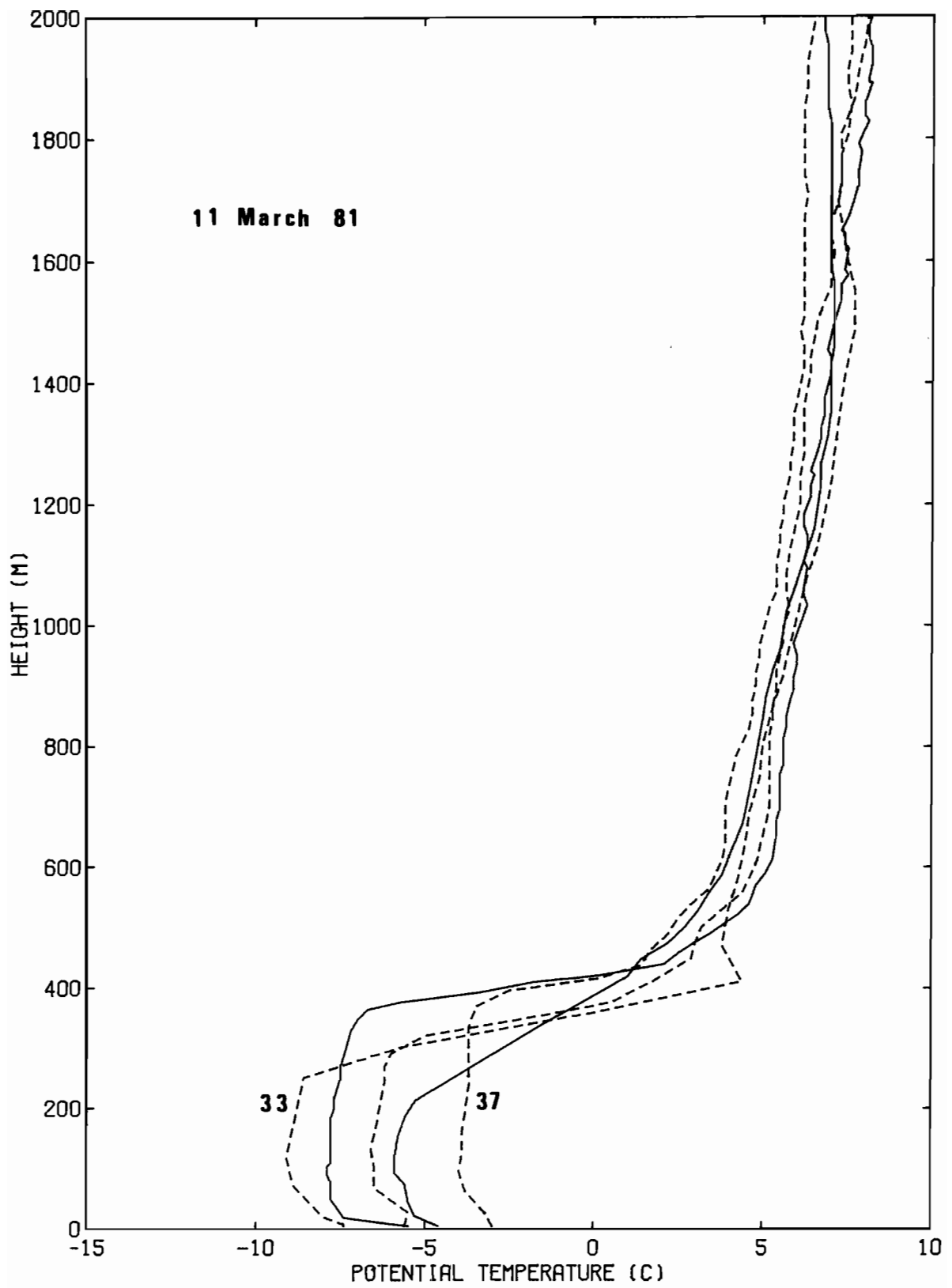


Figure 6.--Potential temperature for transect B.

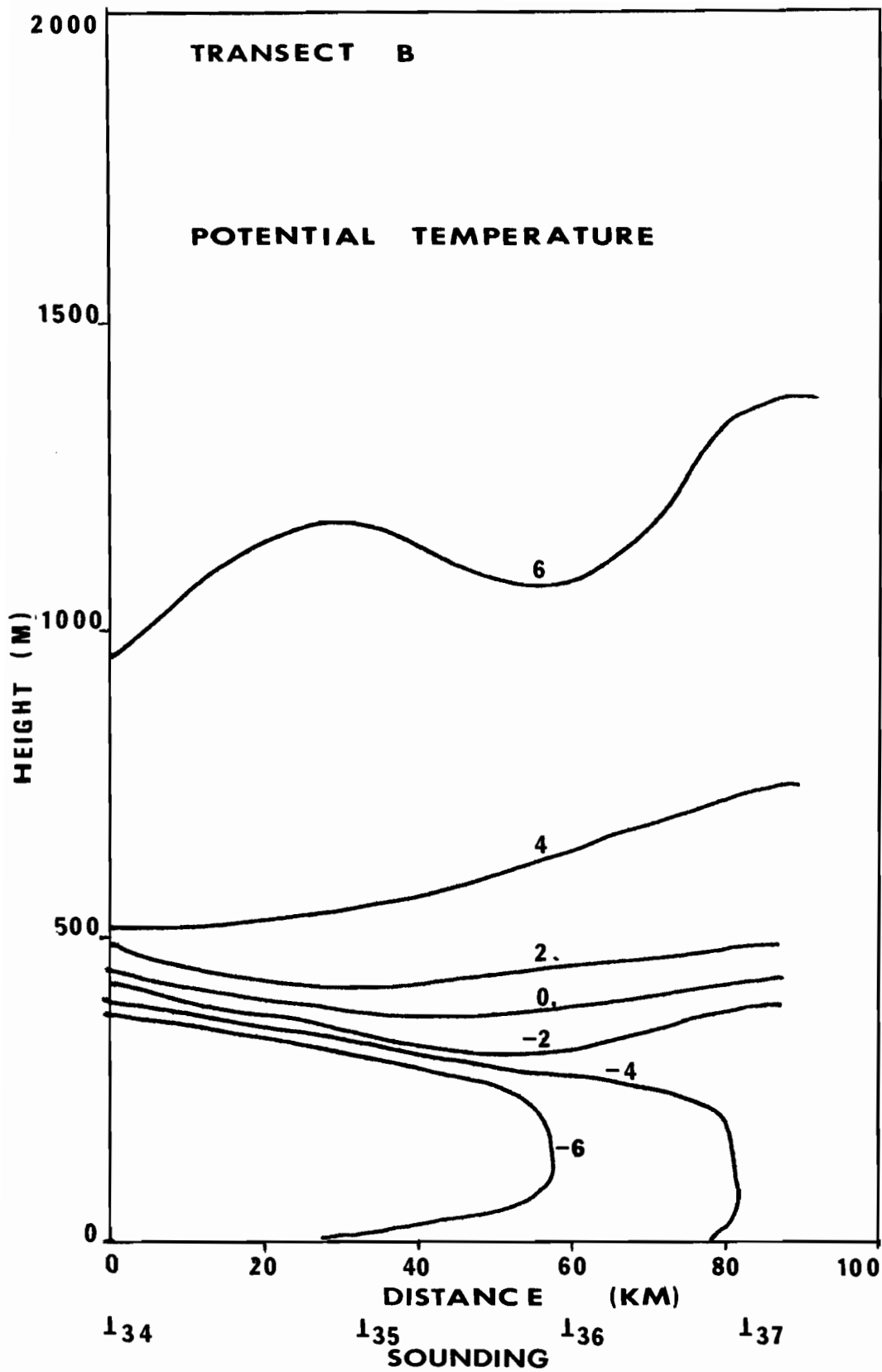


Figure 7.--Cross section of potential temperature for transect B.

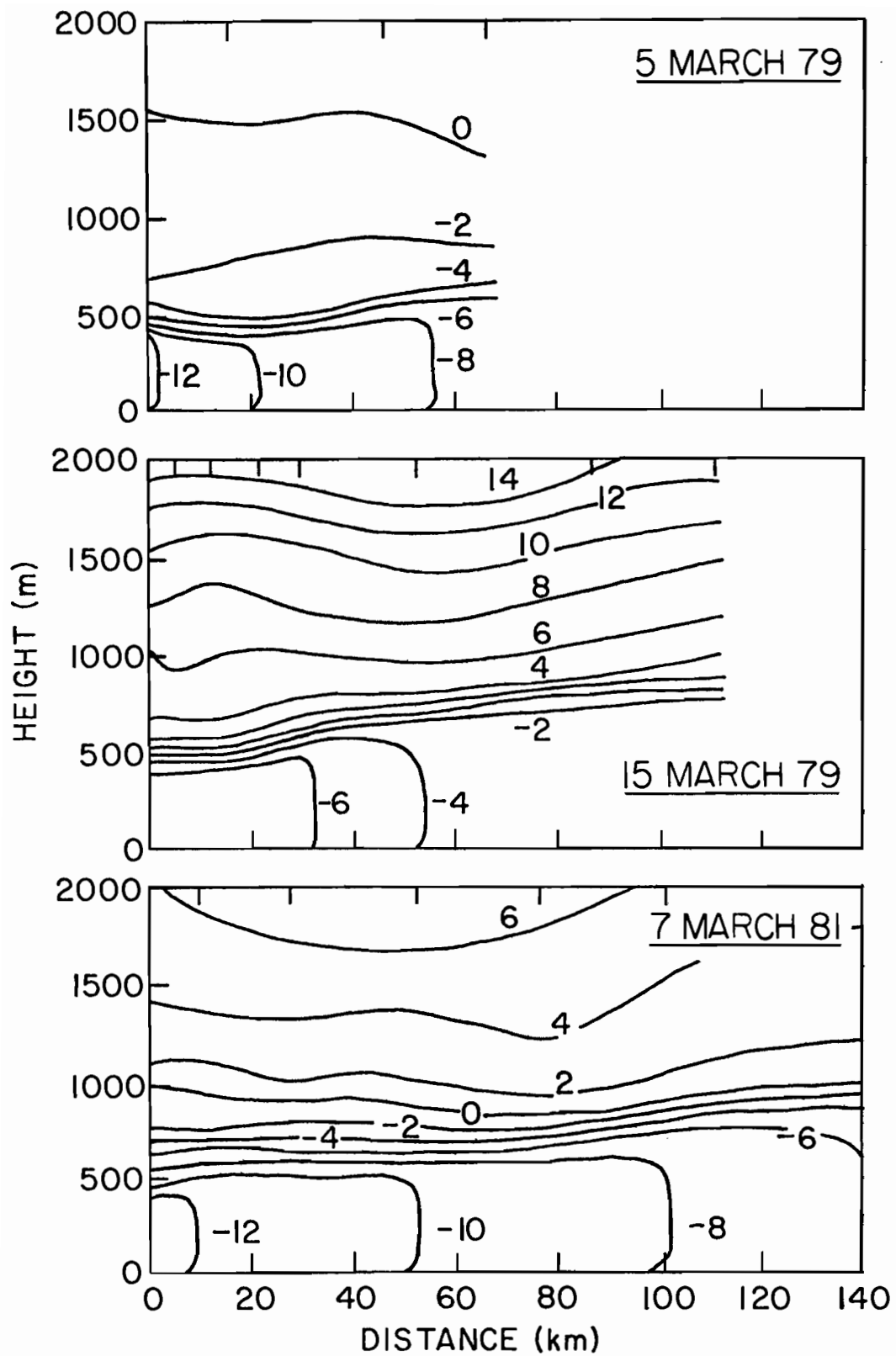


Figure 8.--Cross sections from 1979 and 1981 compared.

existence of the front and the rapidly changing weather situation were apparently responsible for the nonclassic form of boundary layer changes seen in this transect. The classic deepening and warming in the mixed layer appears in figure 8, in which two transects from the 1979 cruise are included with the first of the two made in 1981 (see Salo et al. for a report of the 1979 cruise). We see that the general nature of the boundary layer growth was similar in all three cases.

4. Summary

A coherent picture of the meteorology of the Bering Sea region during a four-week period in the early spring of 1981 has been presented. A special analysis of both the surface air pressure and the surface air temperature was performed every twelve hours for the period 26 February to 10 March. This analysis included all late reports and paid special attention to mesoscale features often missed in conventional analyses. About six separate low-pressure centers passed through the area. The largest and most vigorous moved slowly up the dateline from 27 February to 3 March. This storm produced gale-force winds throughout much of the eastern Bering Sea. These surface analyses will provide the needed atmospheric parameters for Bering Sea ice movement models.

The upper-air characteristics in the region were represented by soundings from Nome and St. Paul, Alaska, and from the NOAA ship *Surveyor* near the marginal ice zone. Soundings from Nome were characteristic of the deep Arctic and often exhibited very strong surface-based inversions. Those from St. Paul were more typical of a marine station with warmer, moister, and deeper boundary layers. The ship's soundings exhibited characteristics of both a marine boundary layer and a cold-air, northerly flow boundary layer, which was shallower and exhibited a stronger and sharper inversion than the marine boundary layer. This northerly flow boundary layer was seen to warm and grow in depth as the ship steamed downwind and away from the ice.

5. Acknowledgements

This study was financed in part by the Marine Services Project of the Marine Meteorological Studies Group at Pacific Marine Environmental Laboratory and in part by the Bureau of Land Management through an interagency agreement with the National Oceanic and Atmospheric Administration under a multiyear program, responding to needs of petroleum development of the Alaskan continental shelf and managed by the Outer Continental Shelf Environmental Assessment Program (OCSEAP) Office. The shipboard measurements were carried out with the help of the survey technicians and other crew members of the *Surveyor* under the command of Captain Bruce I. Williams.

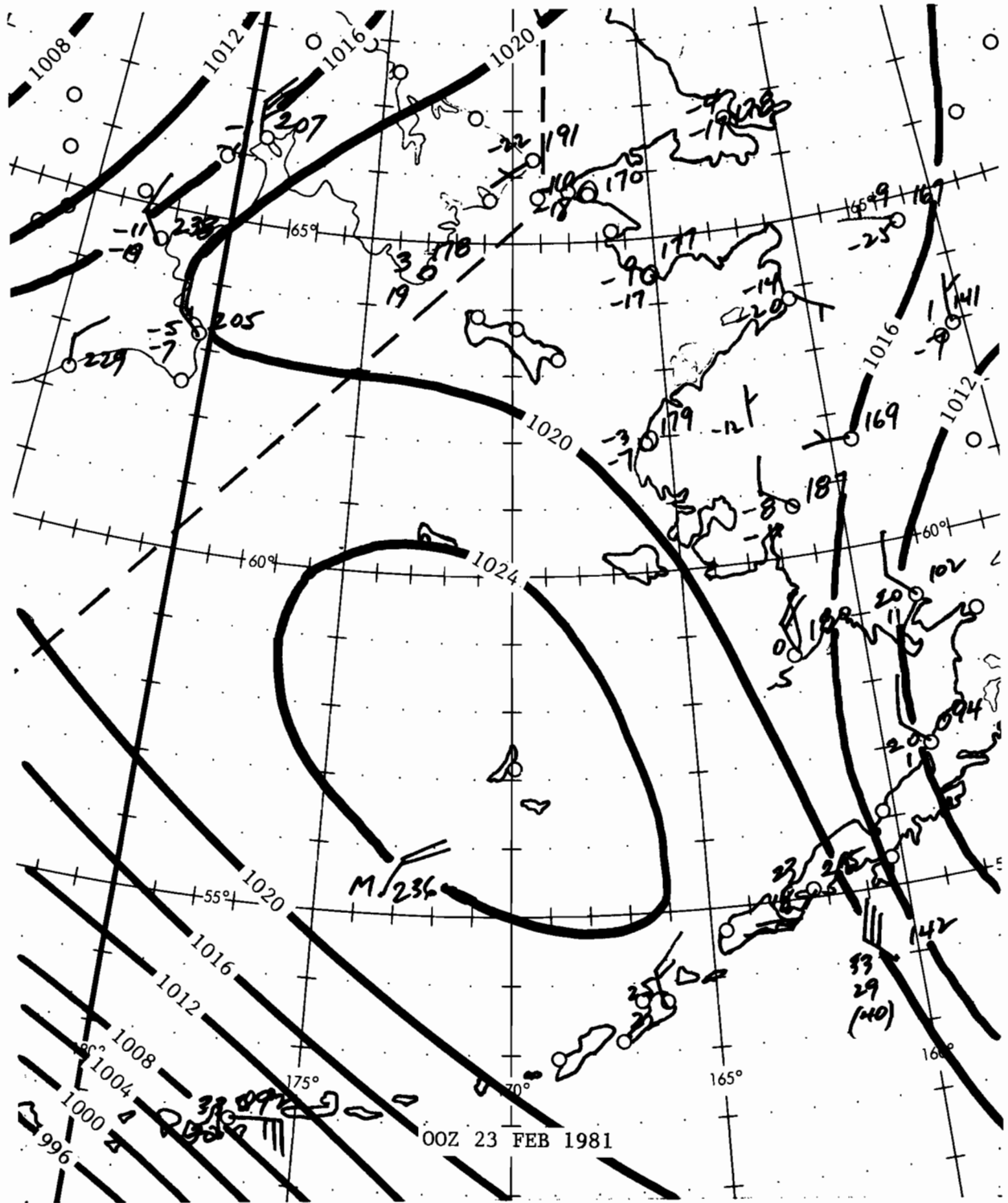
6. References

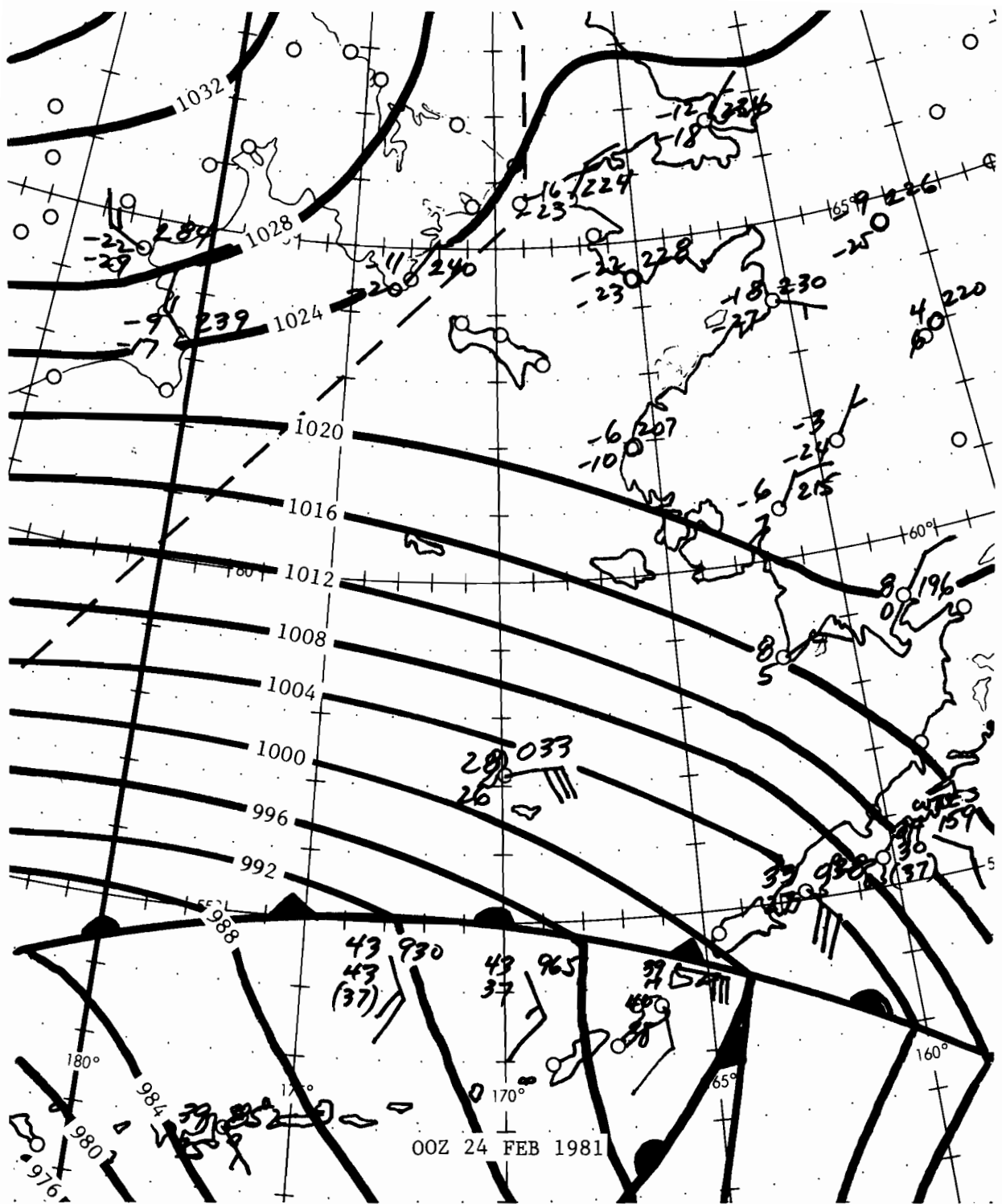
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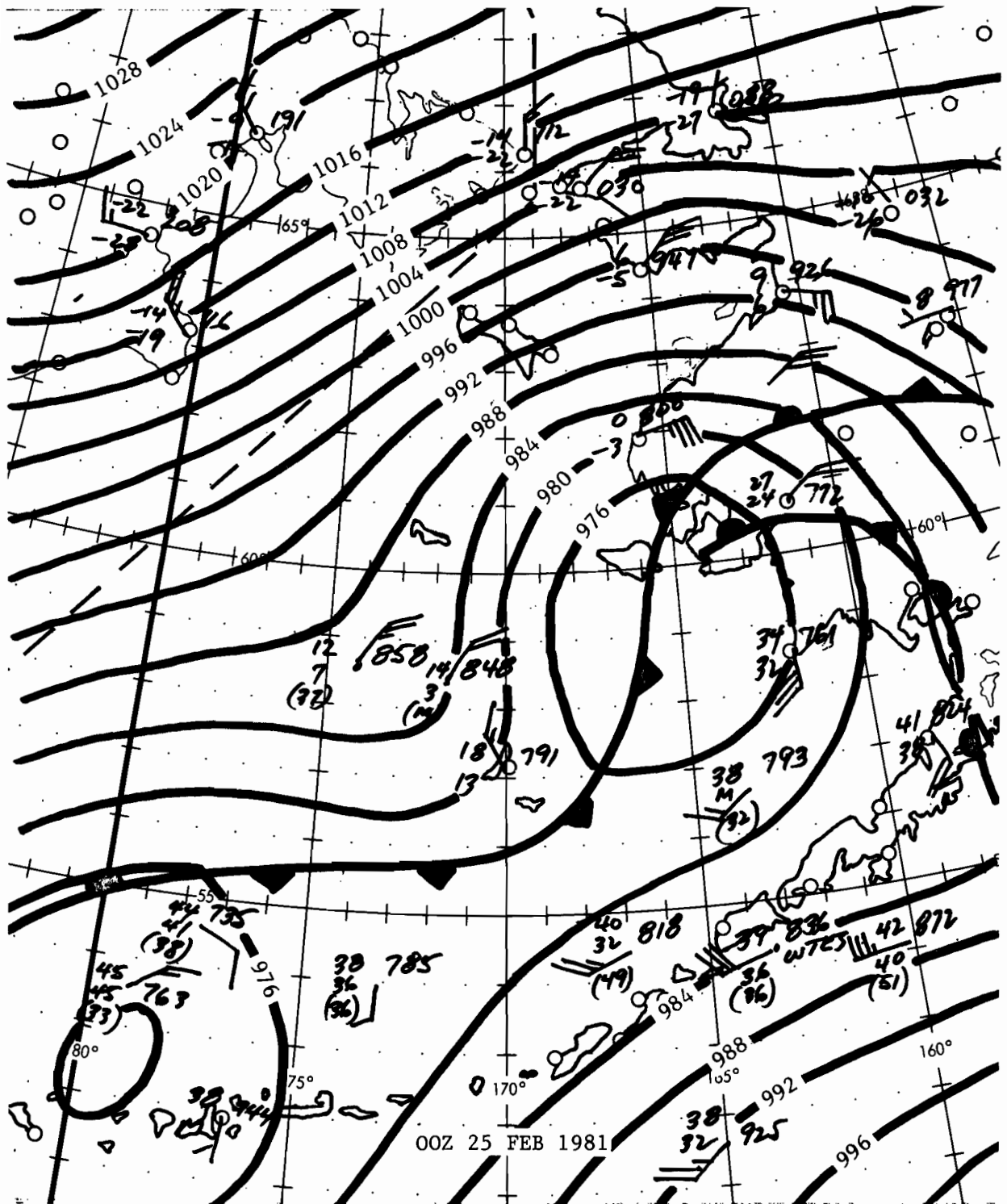
APPENDIX A

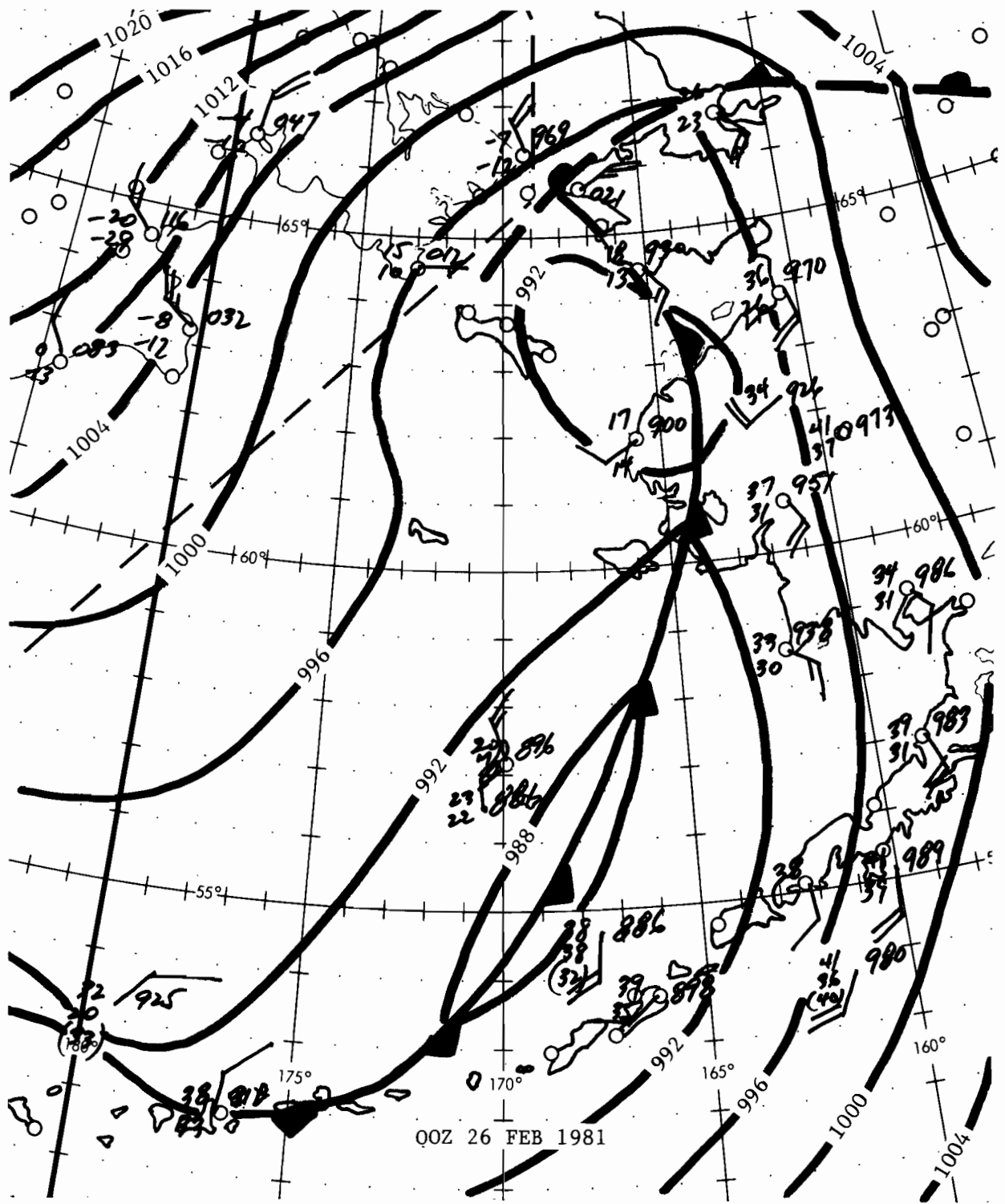
HAND-DRAWN SEA LEVEL PRESSURE ANALYSIS FOR 00 GMT

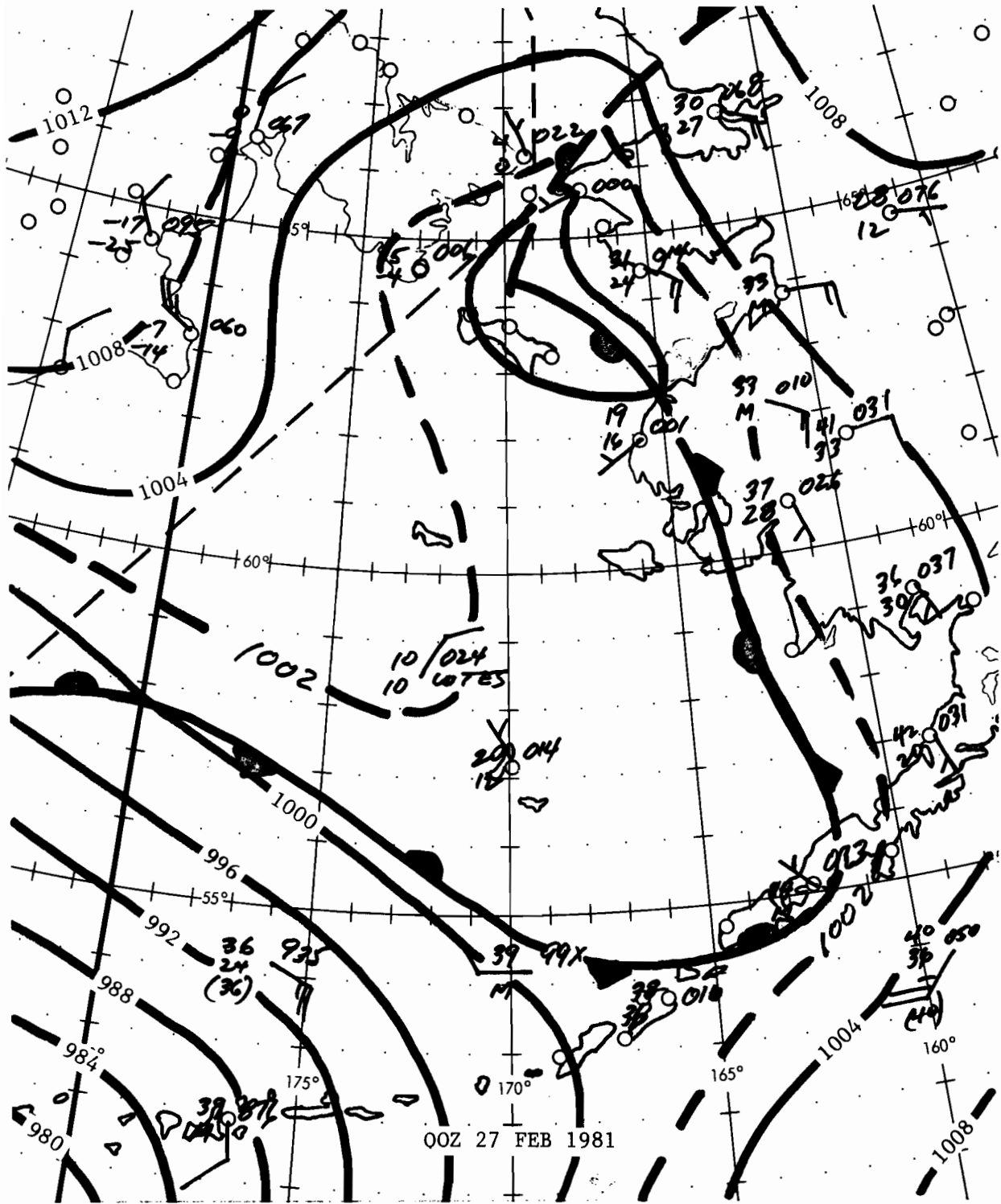
23 February 1981-21 March 1981

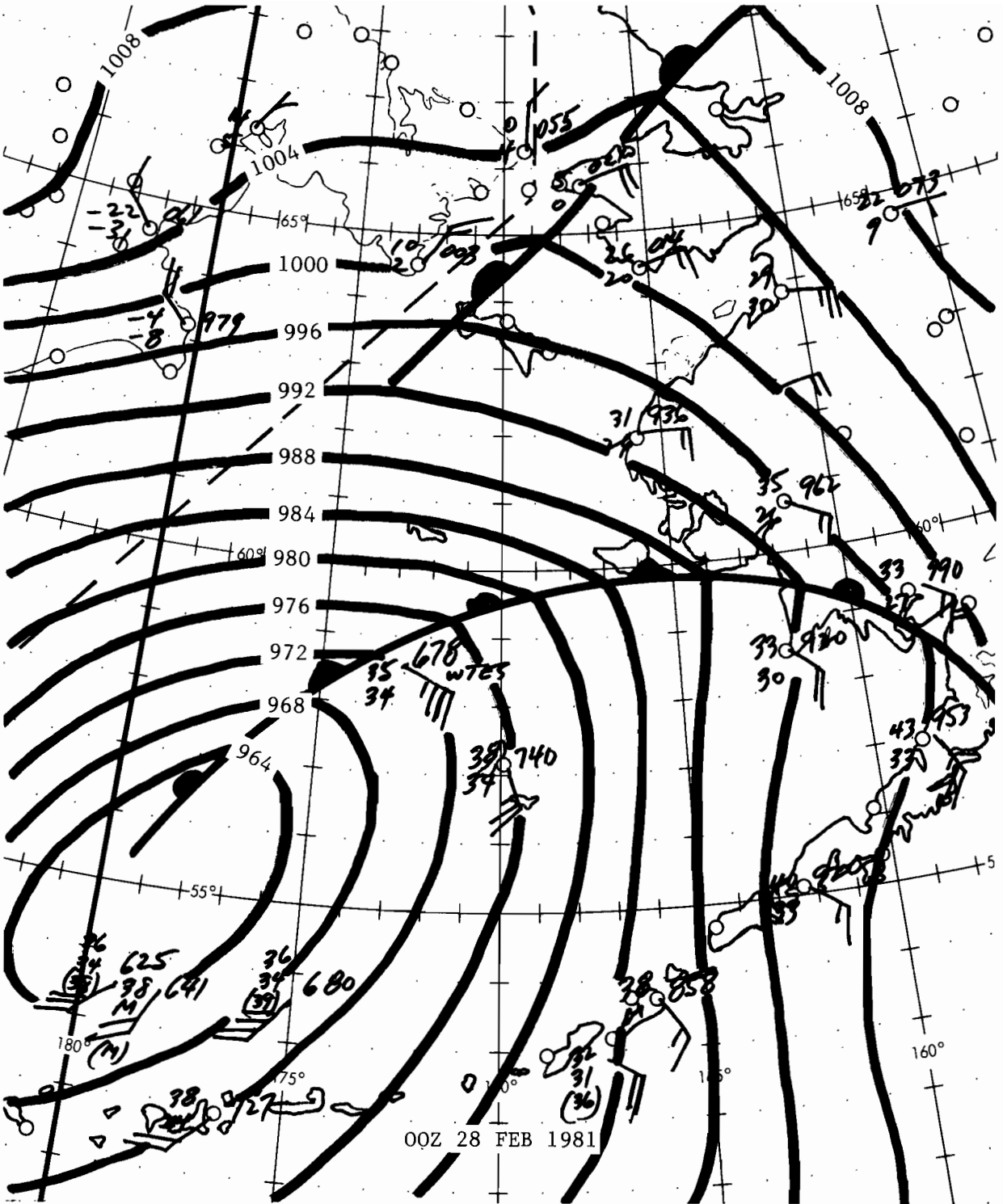


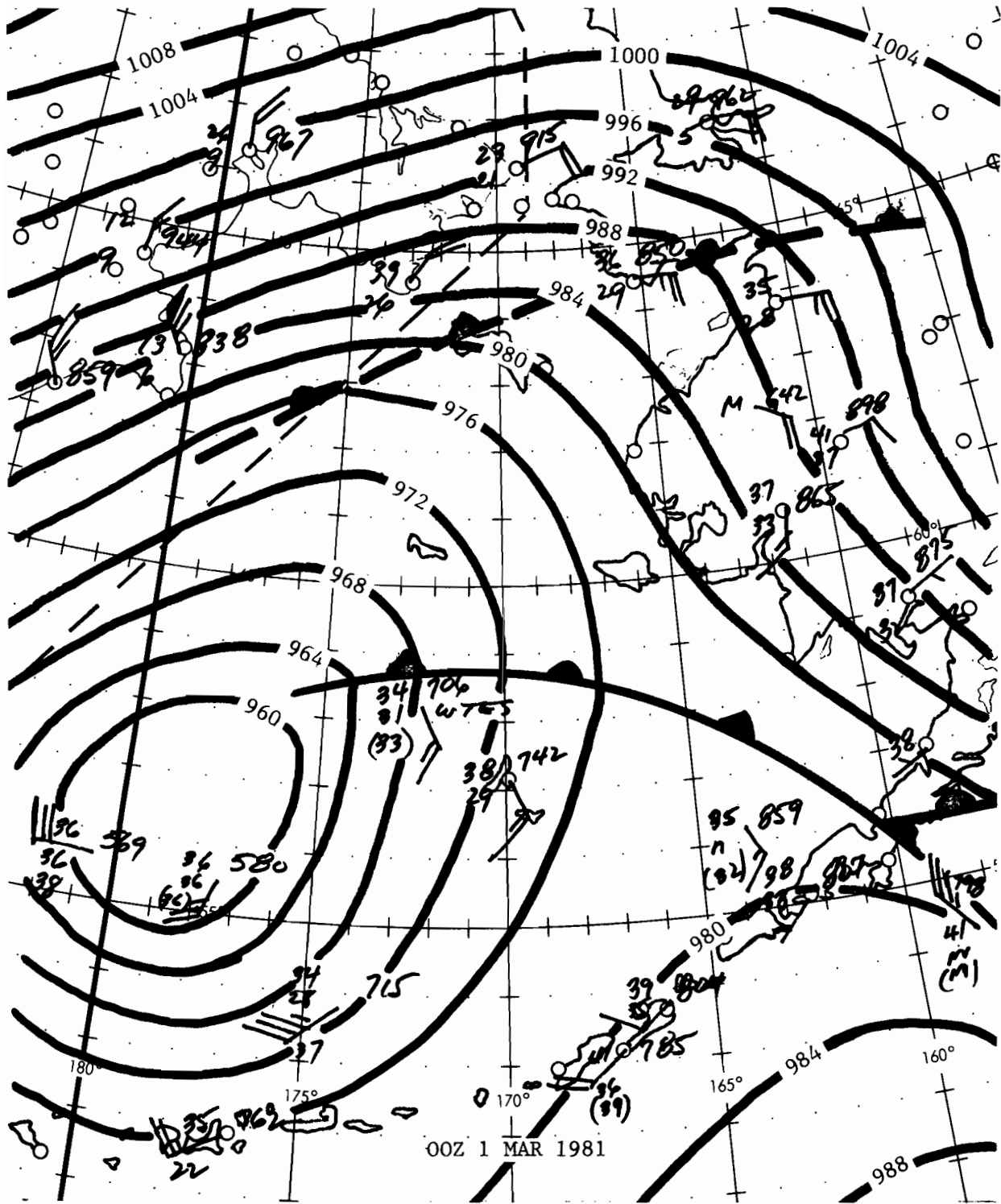


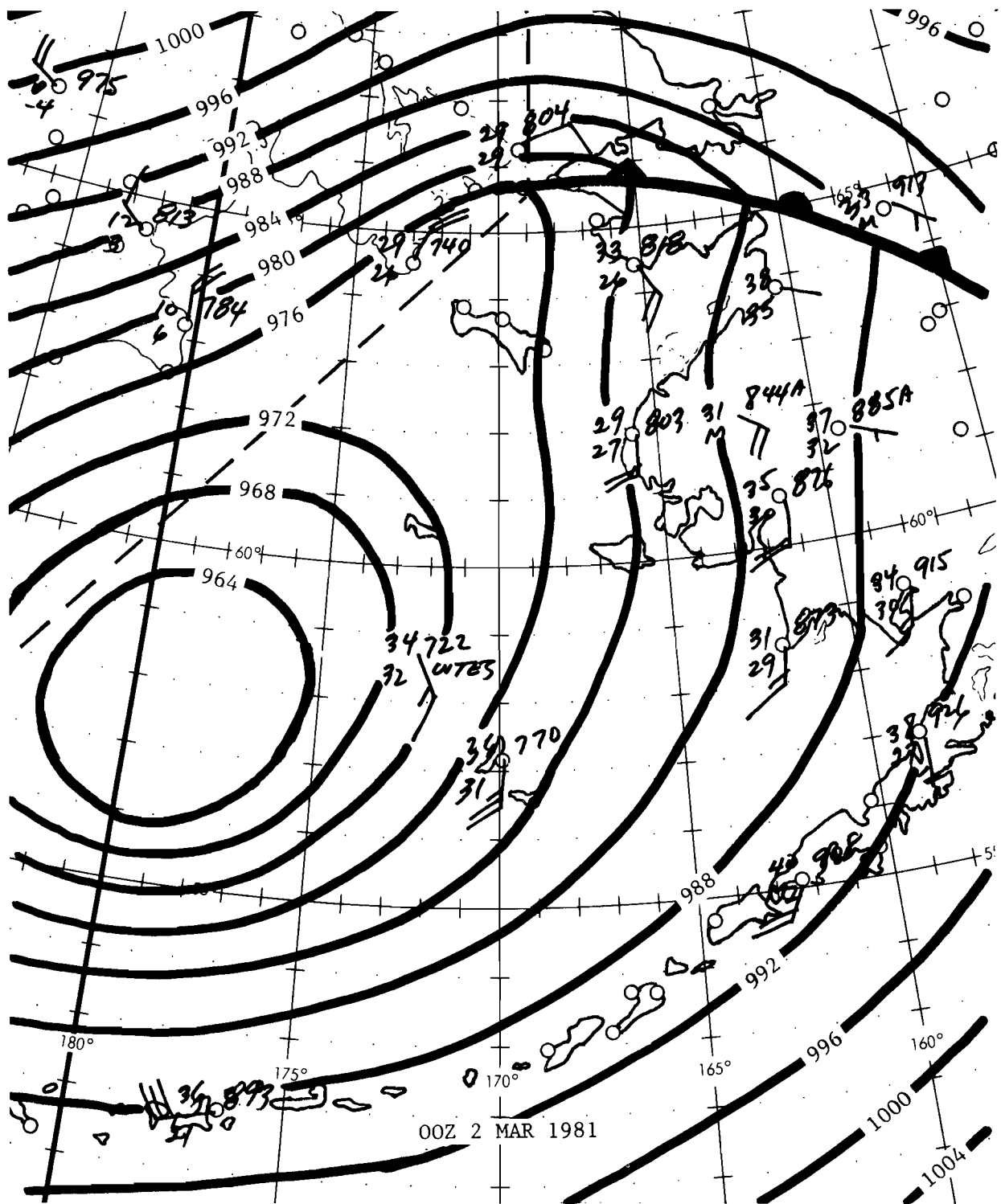


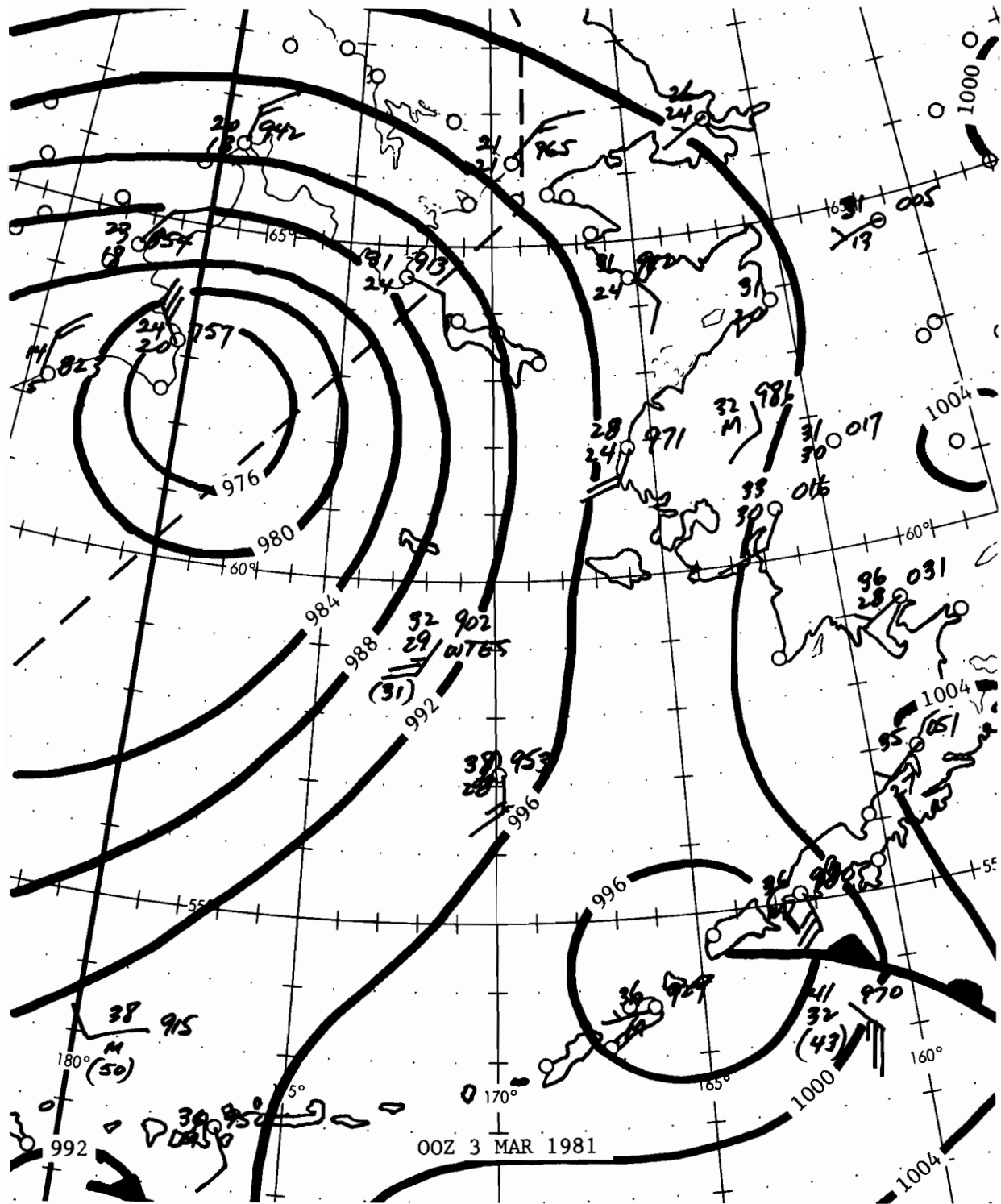


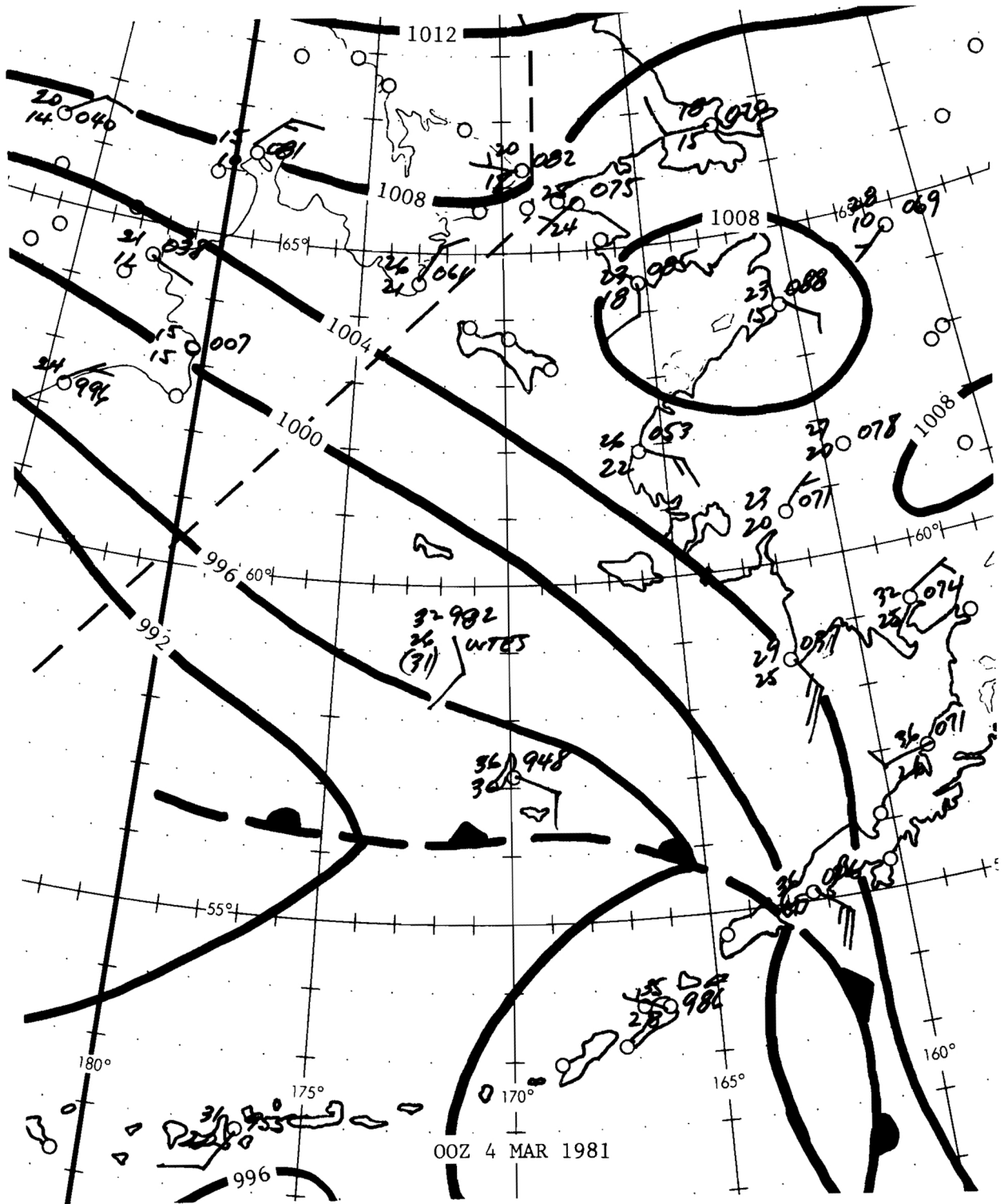


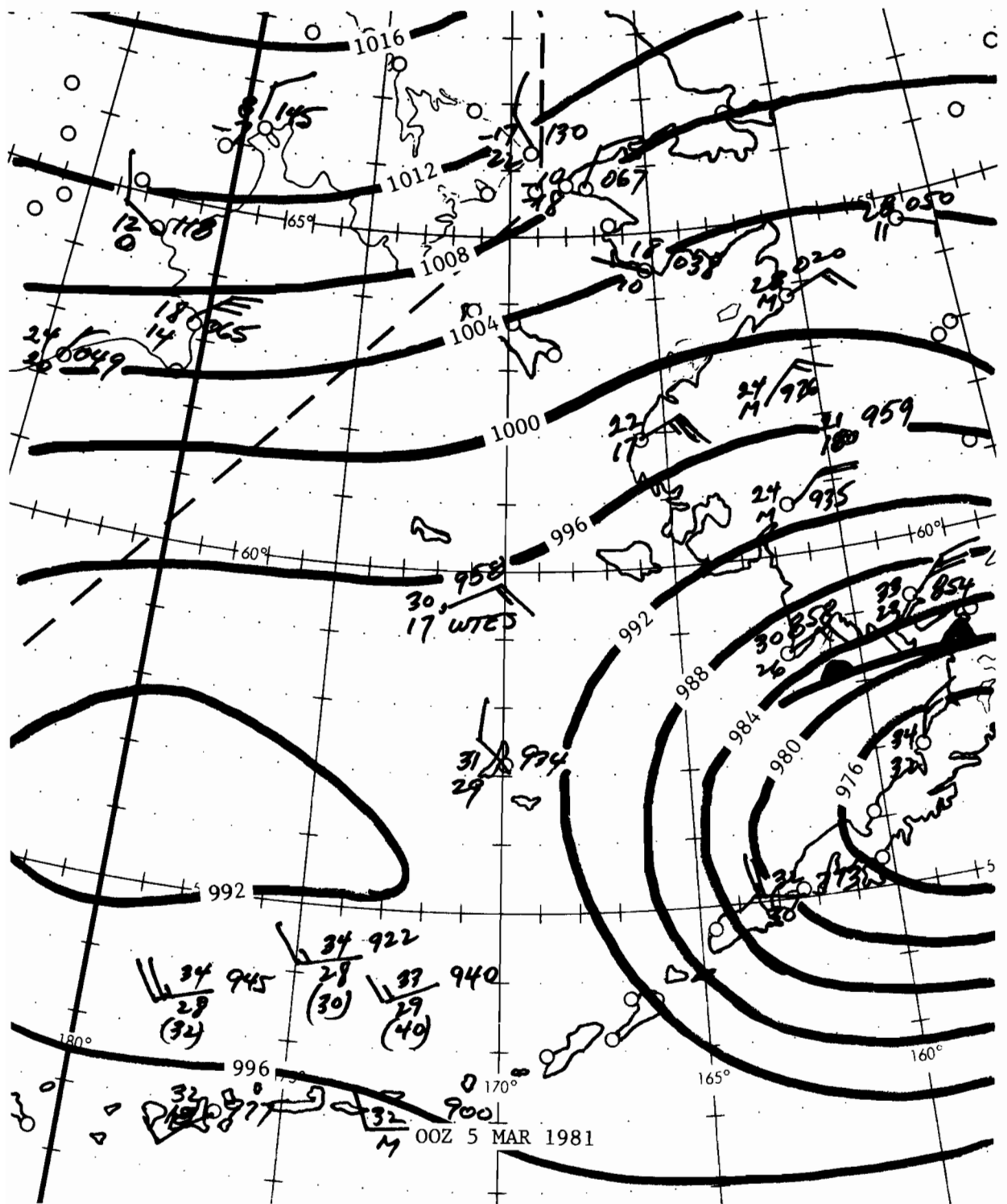


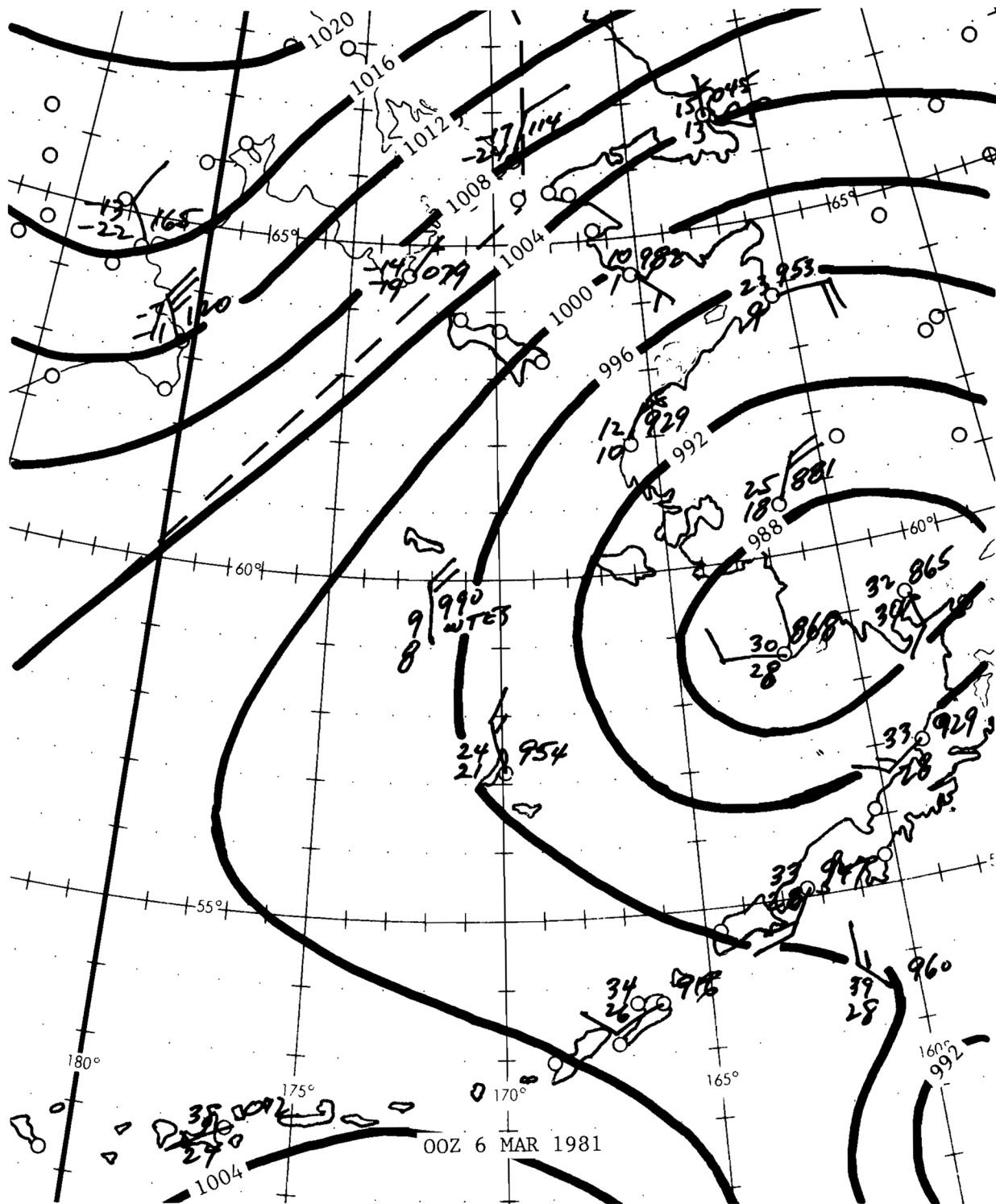


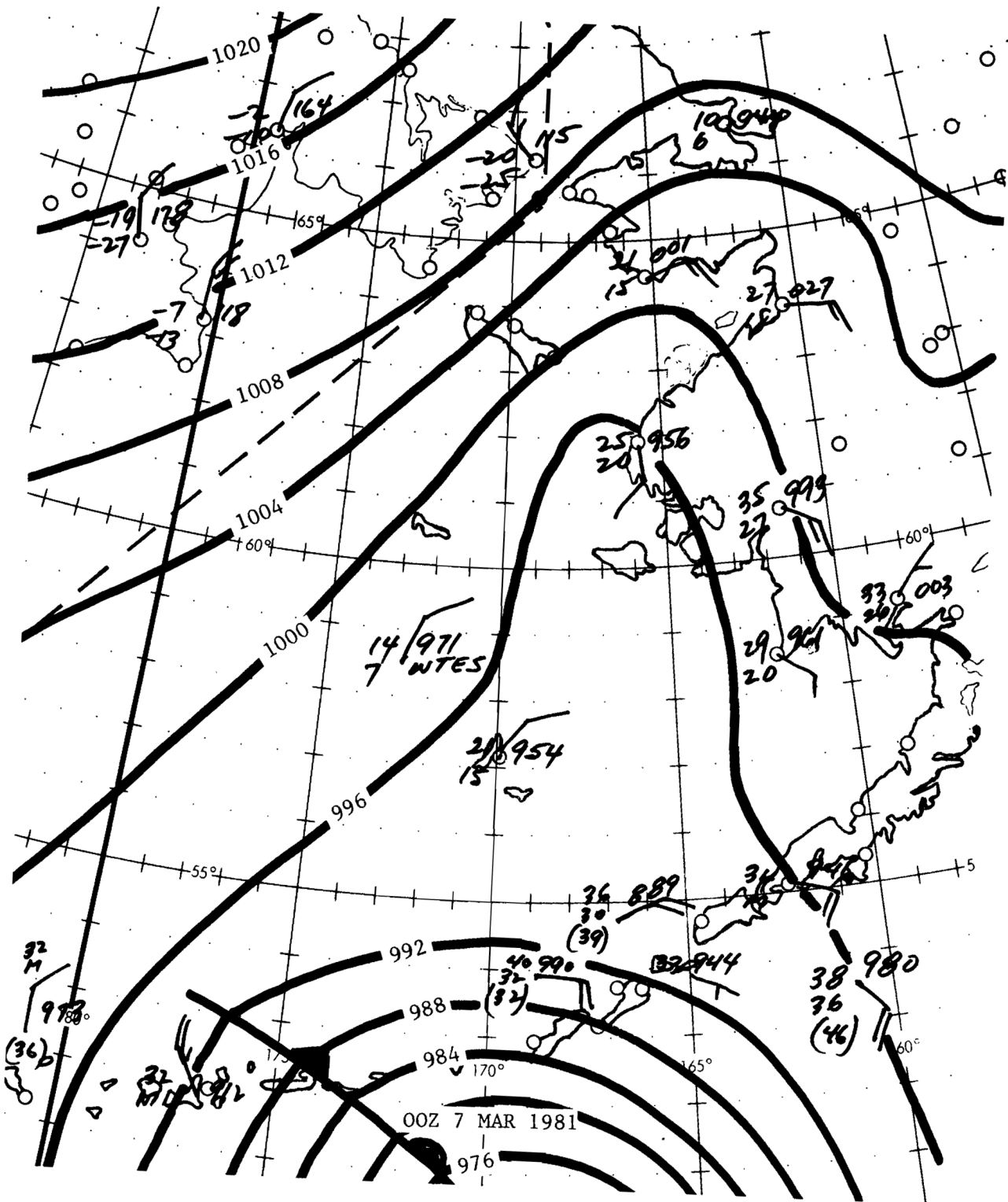


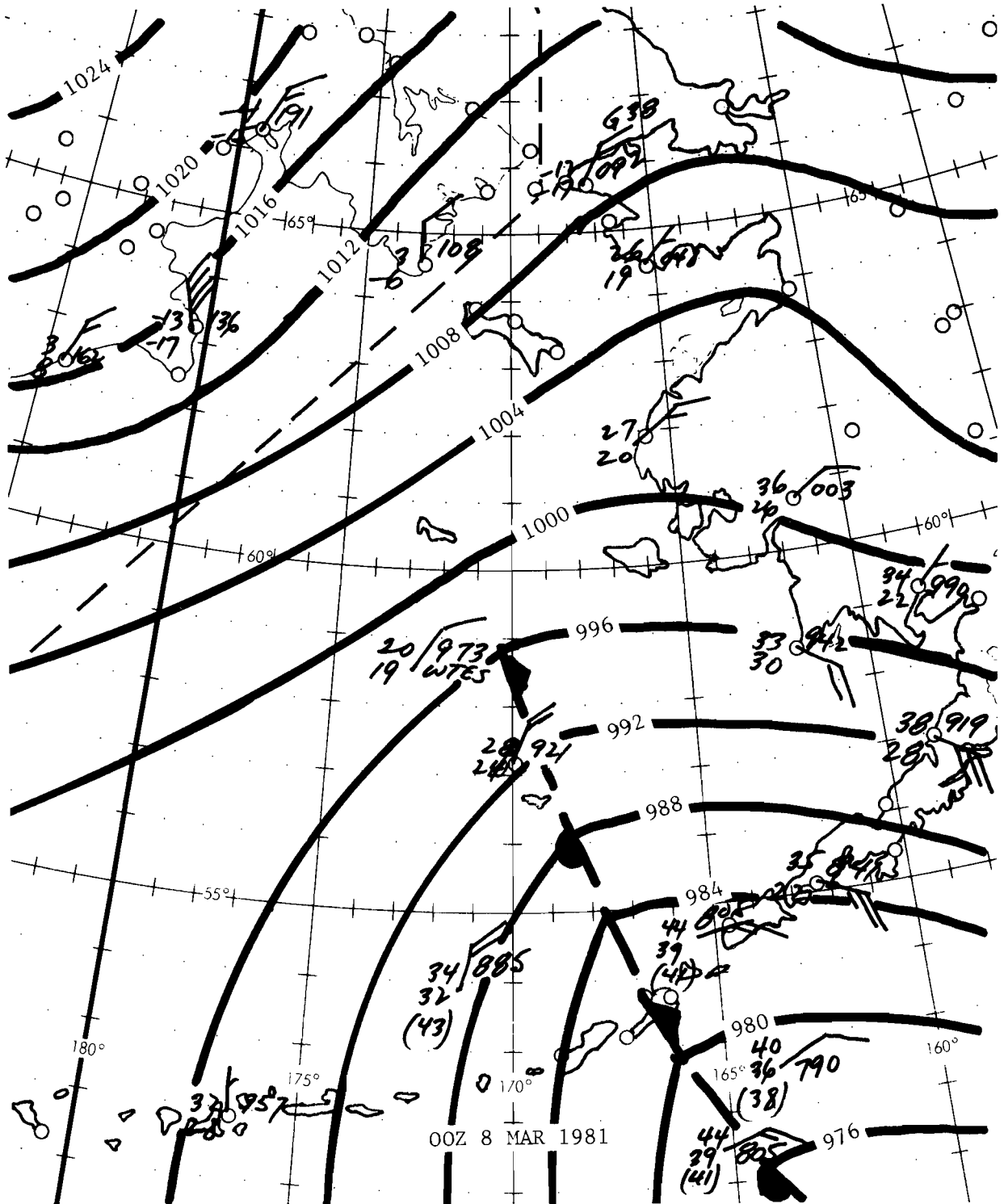


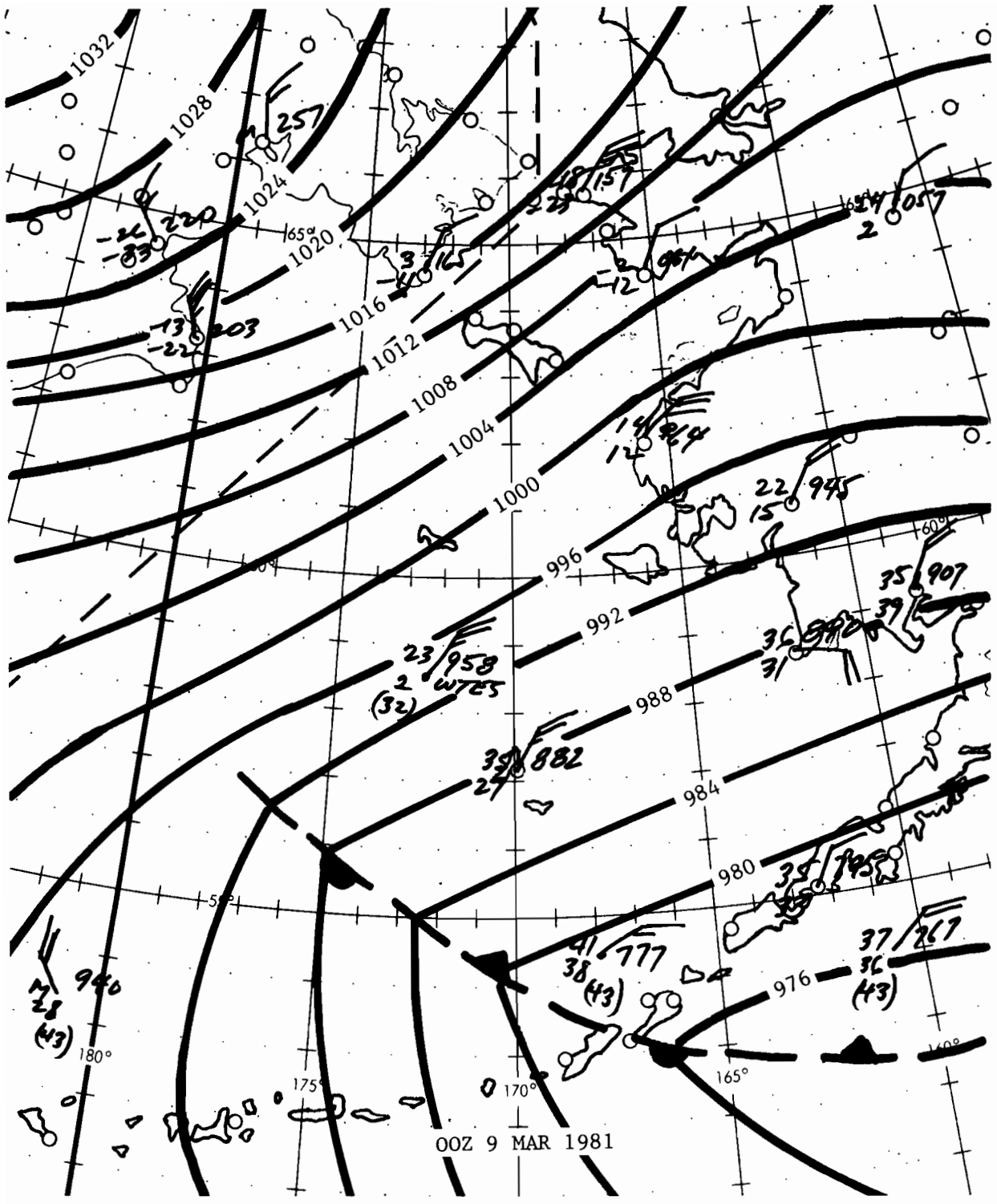


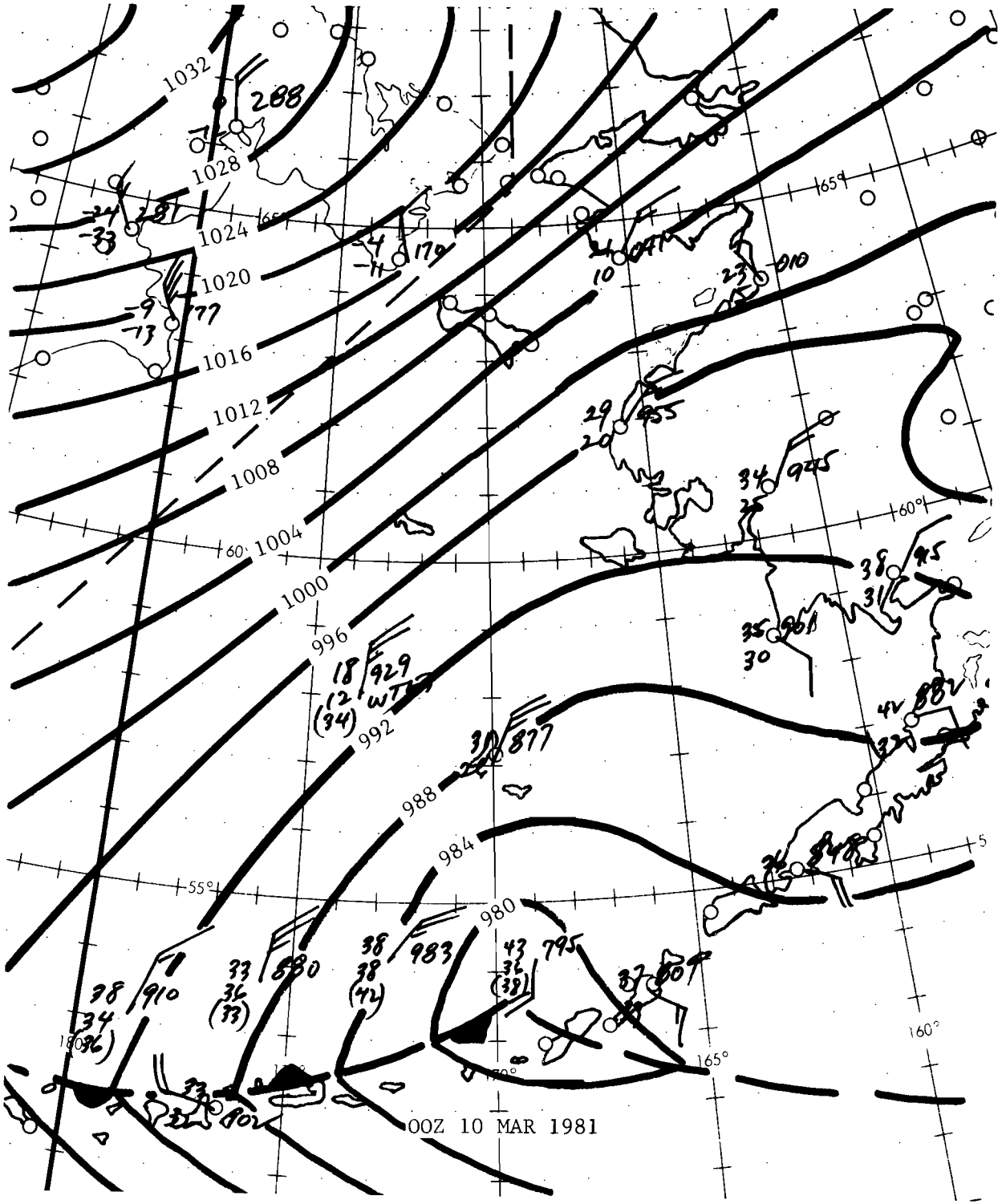


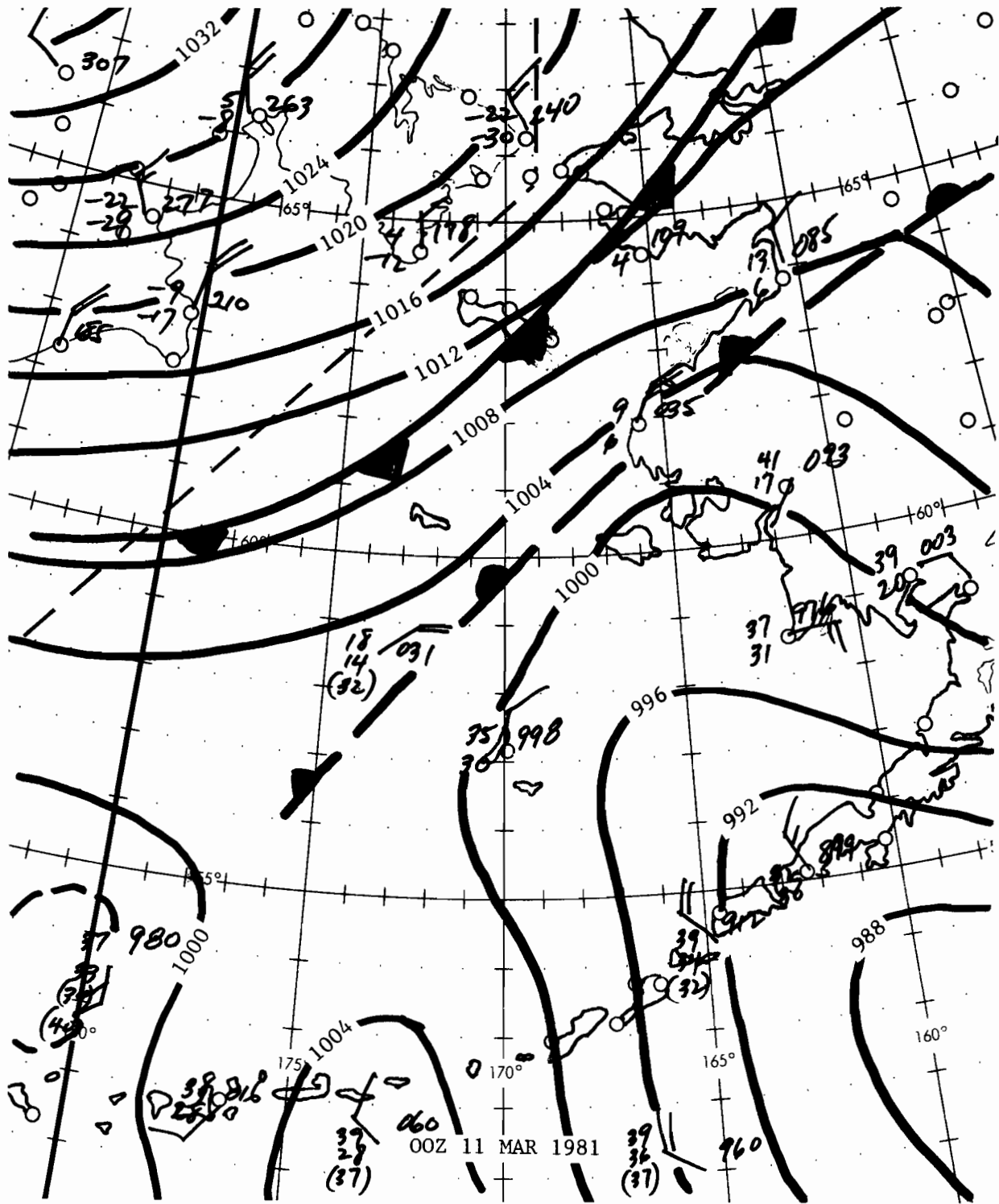


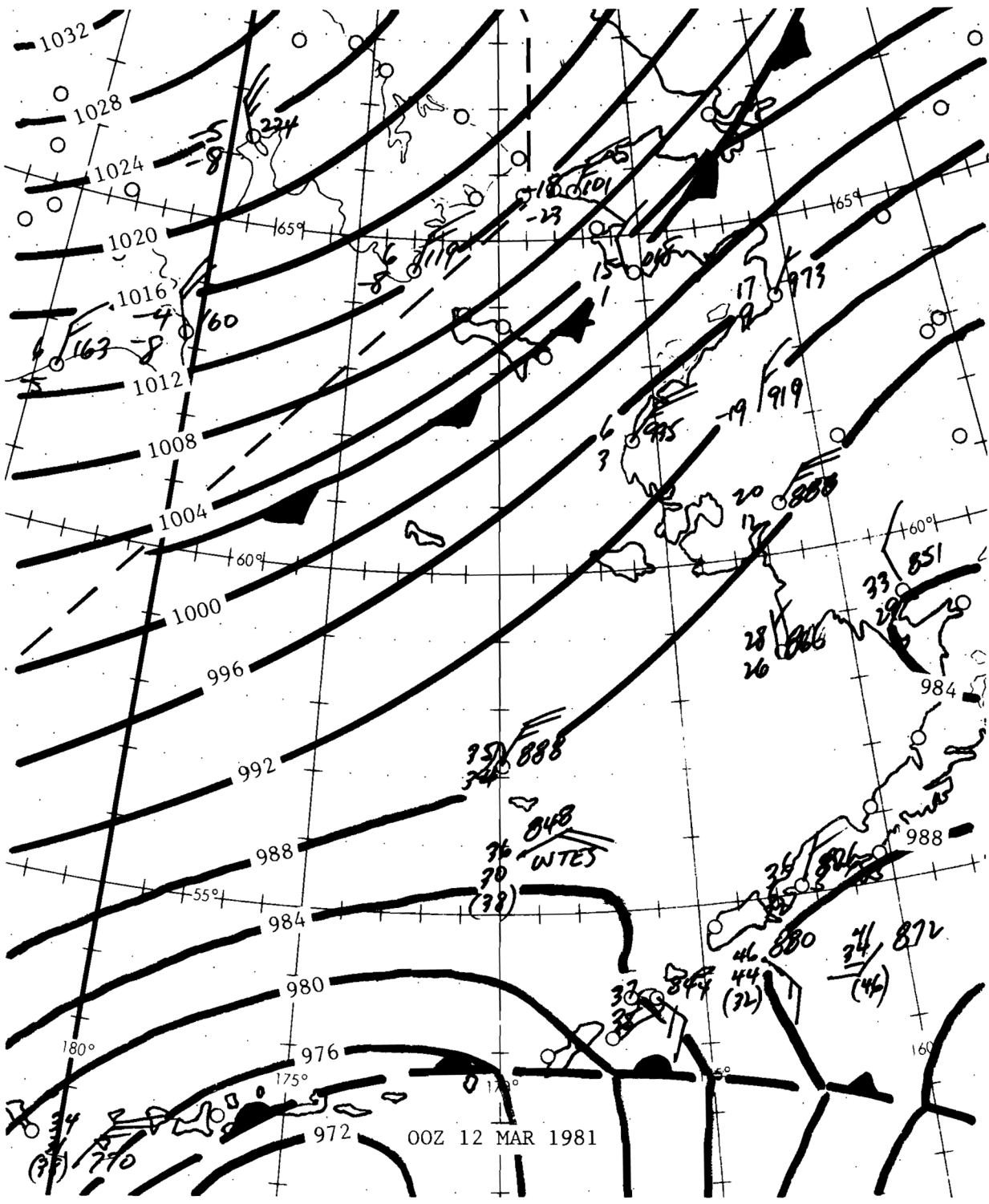


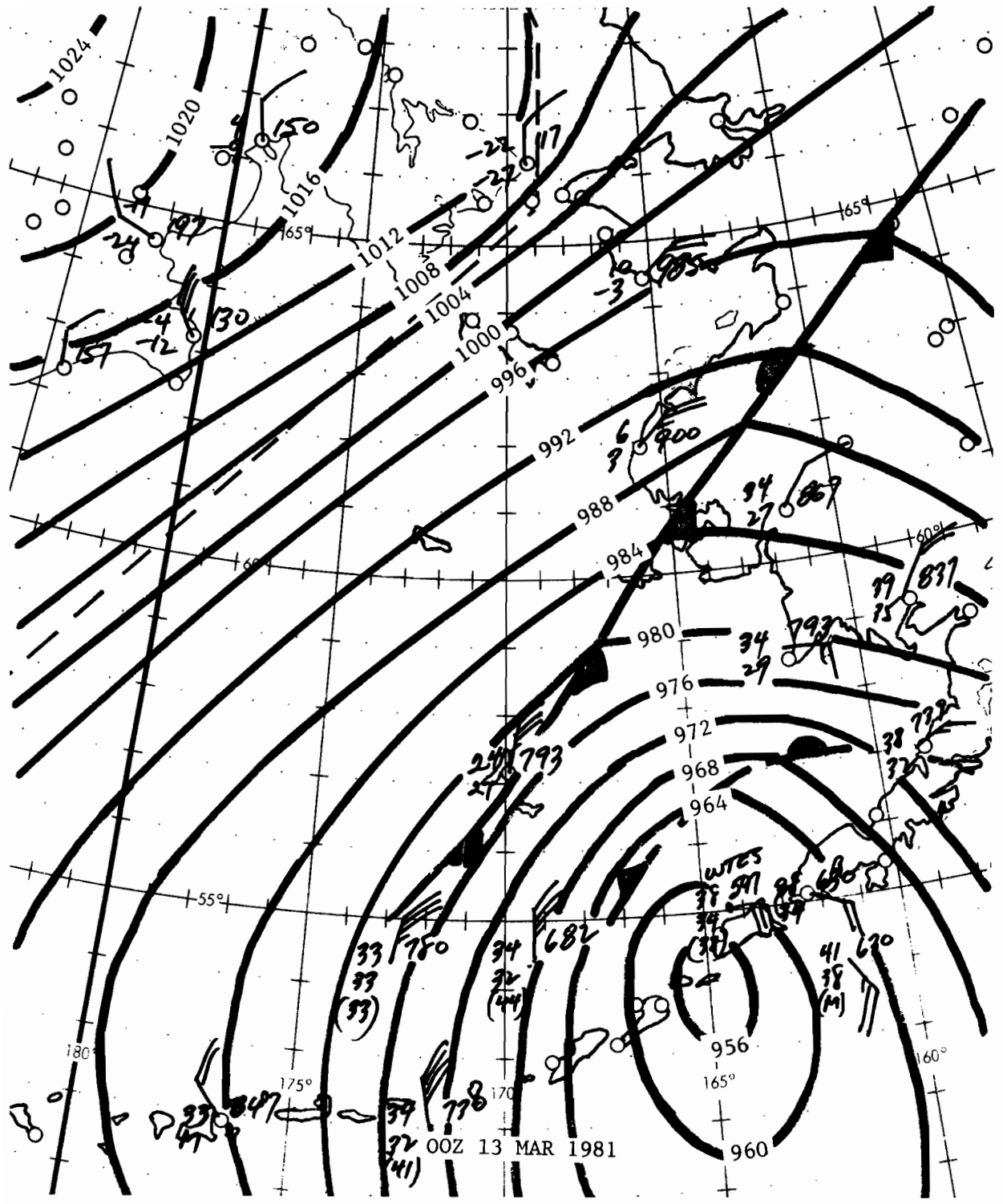


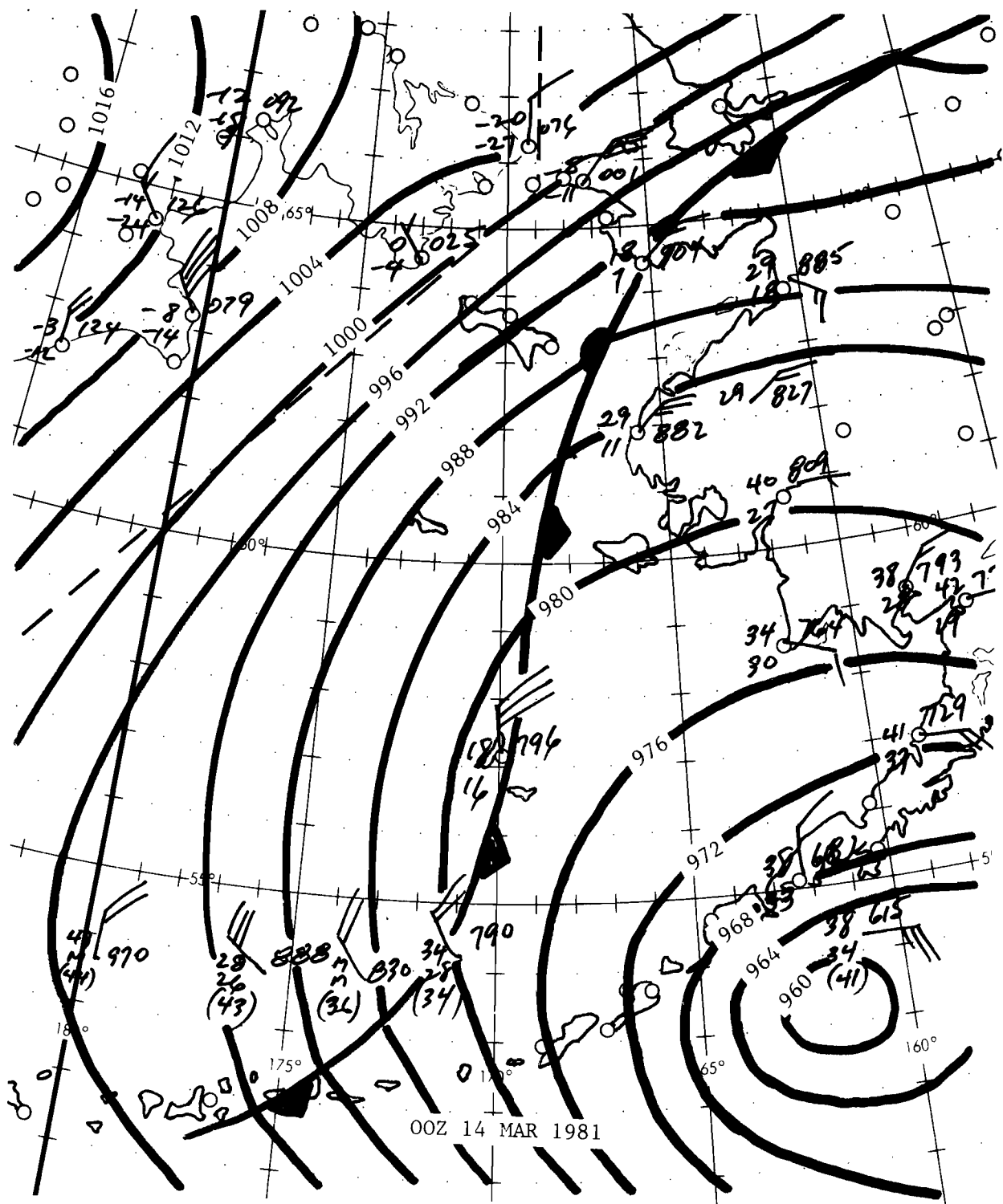


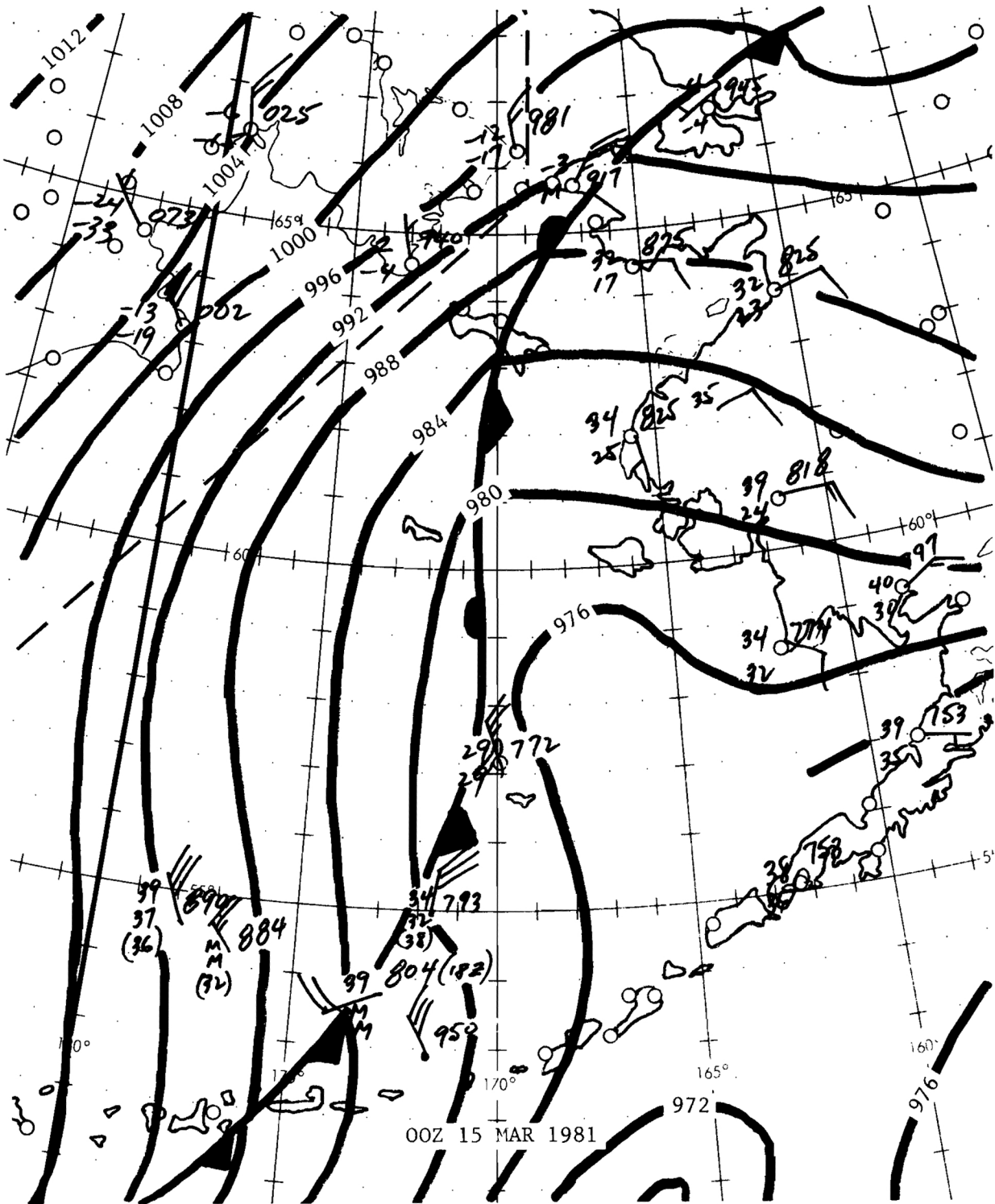


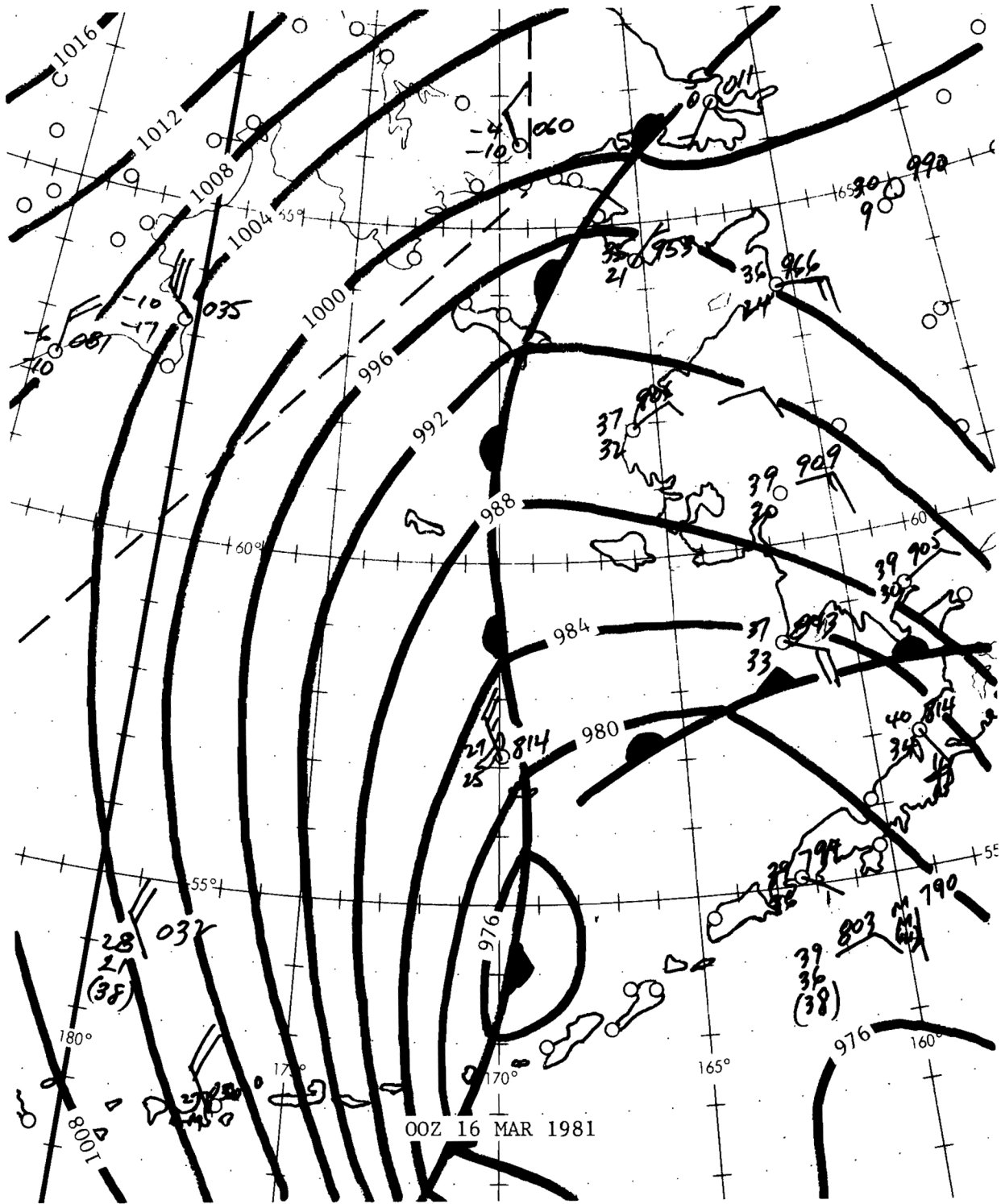


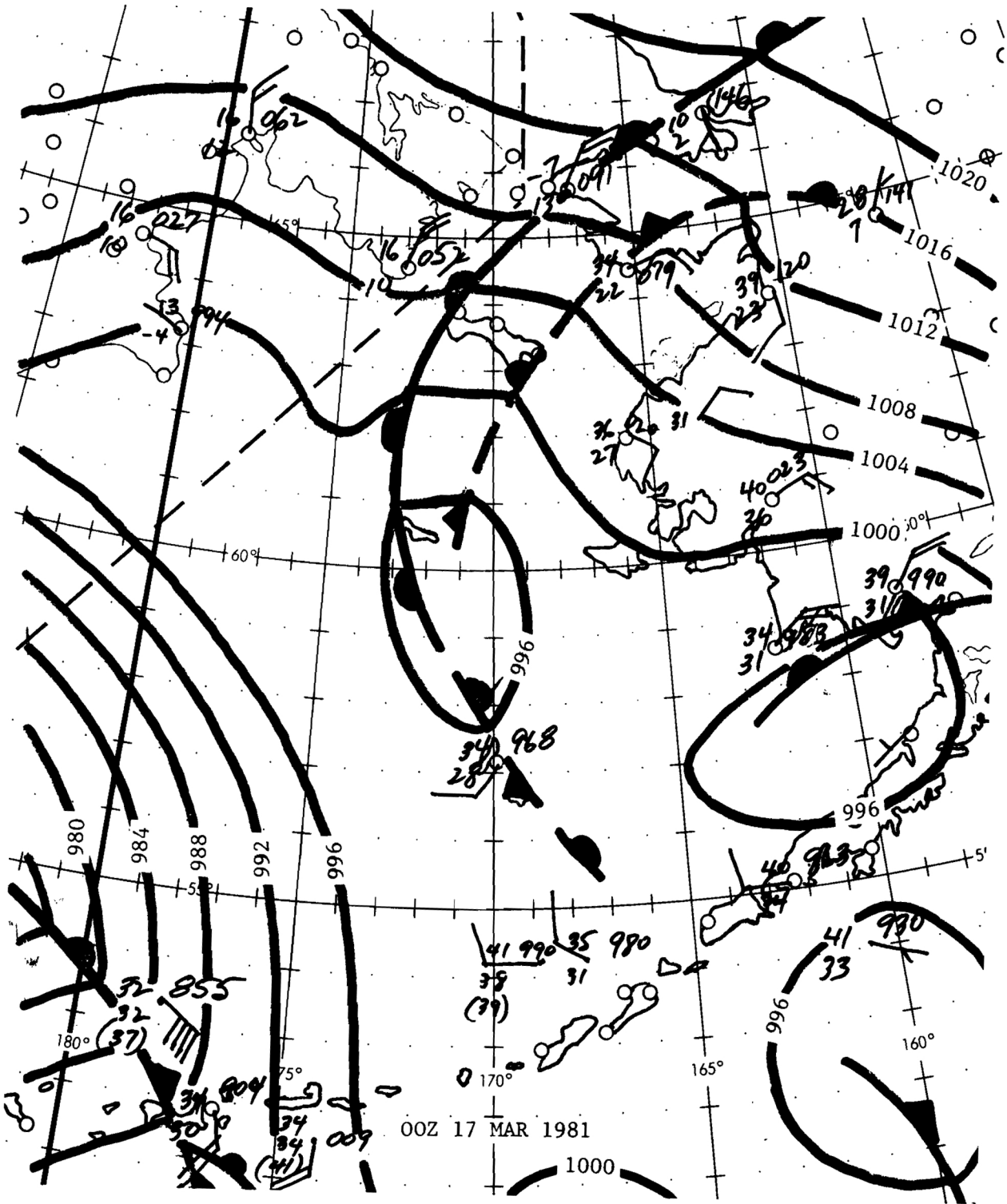


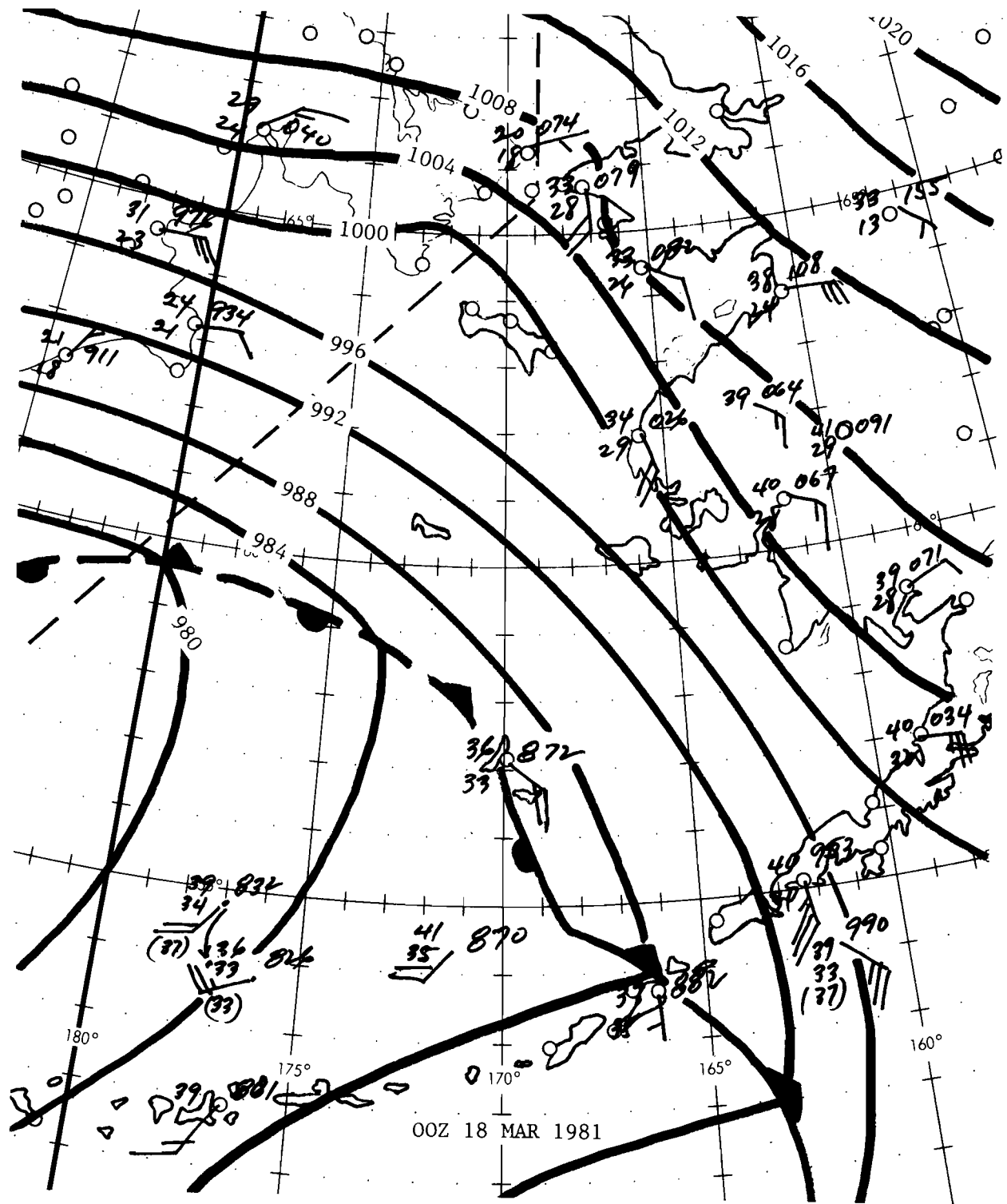


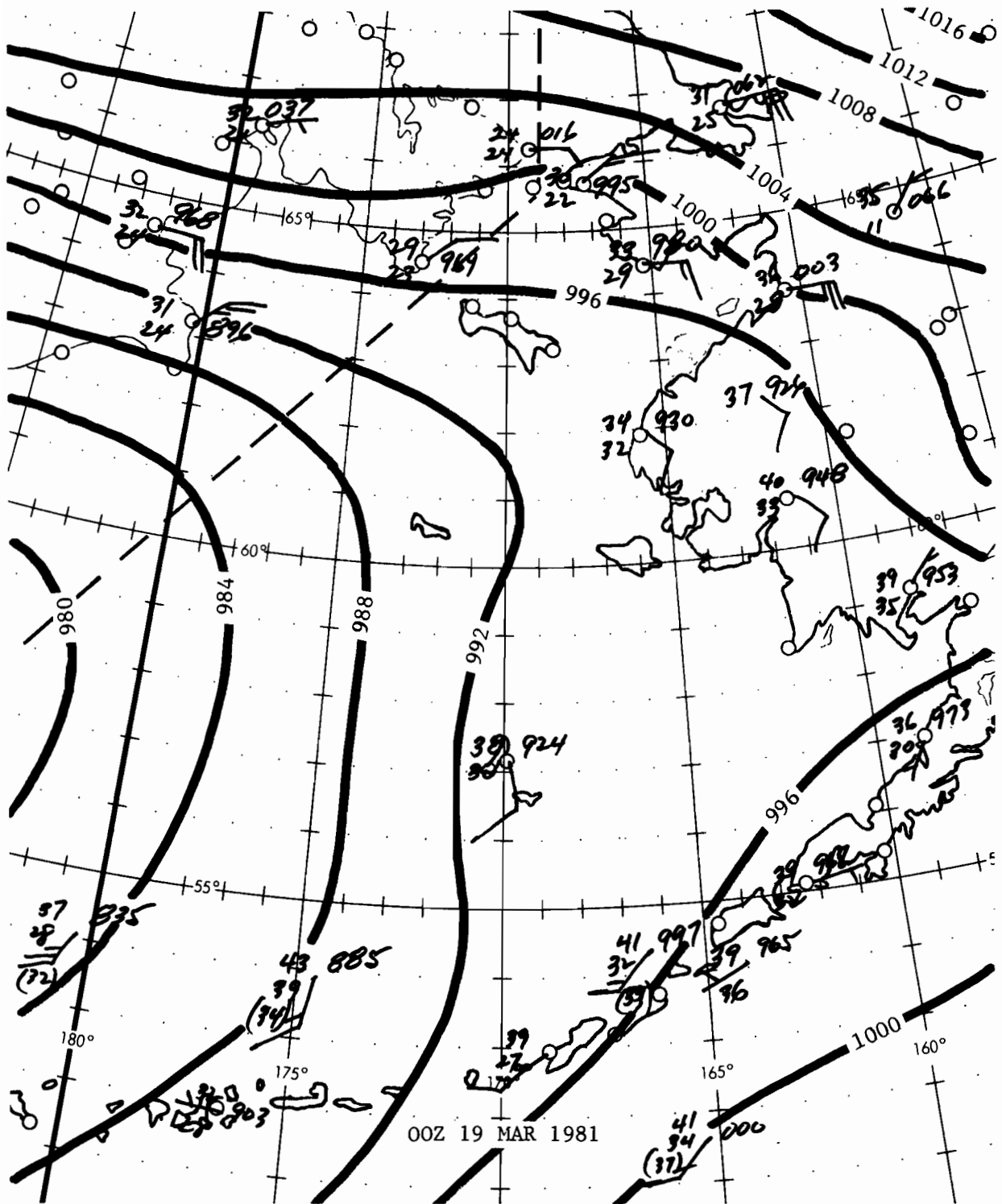


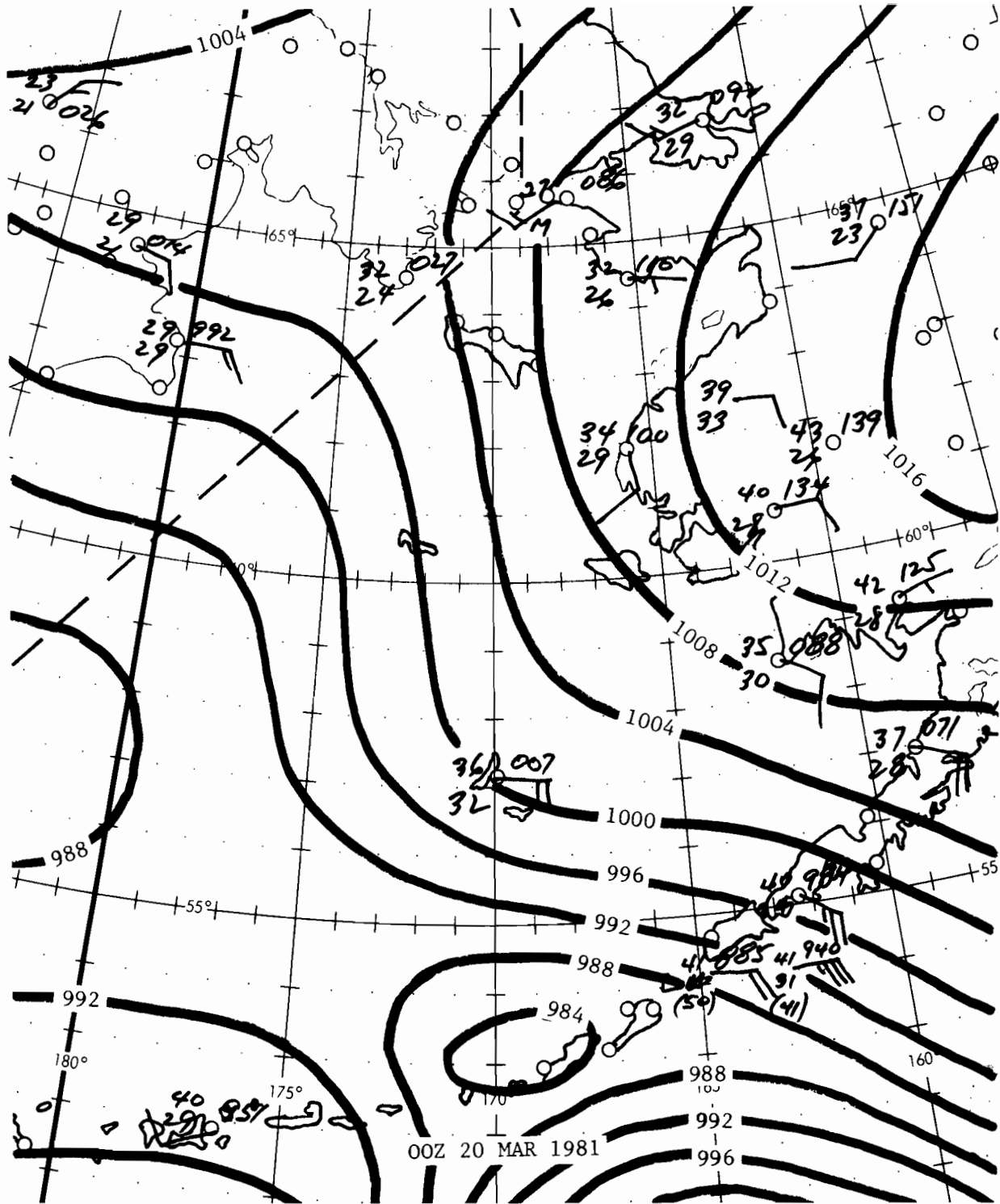


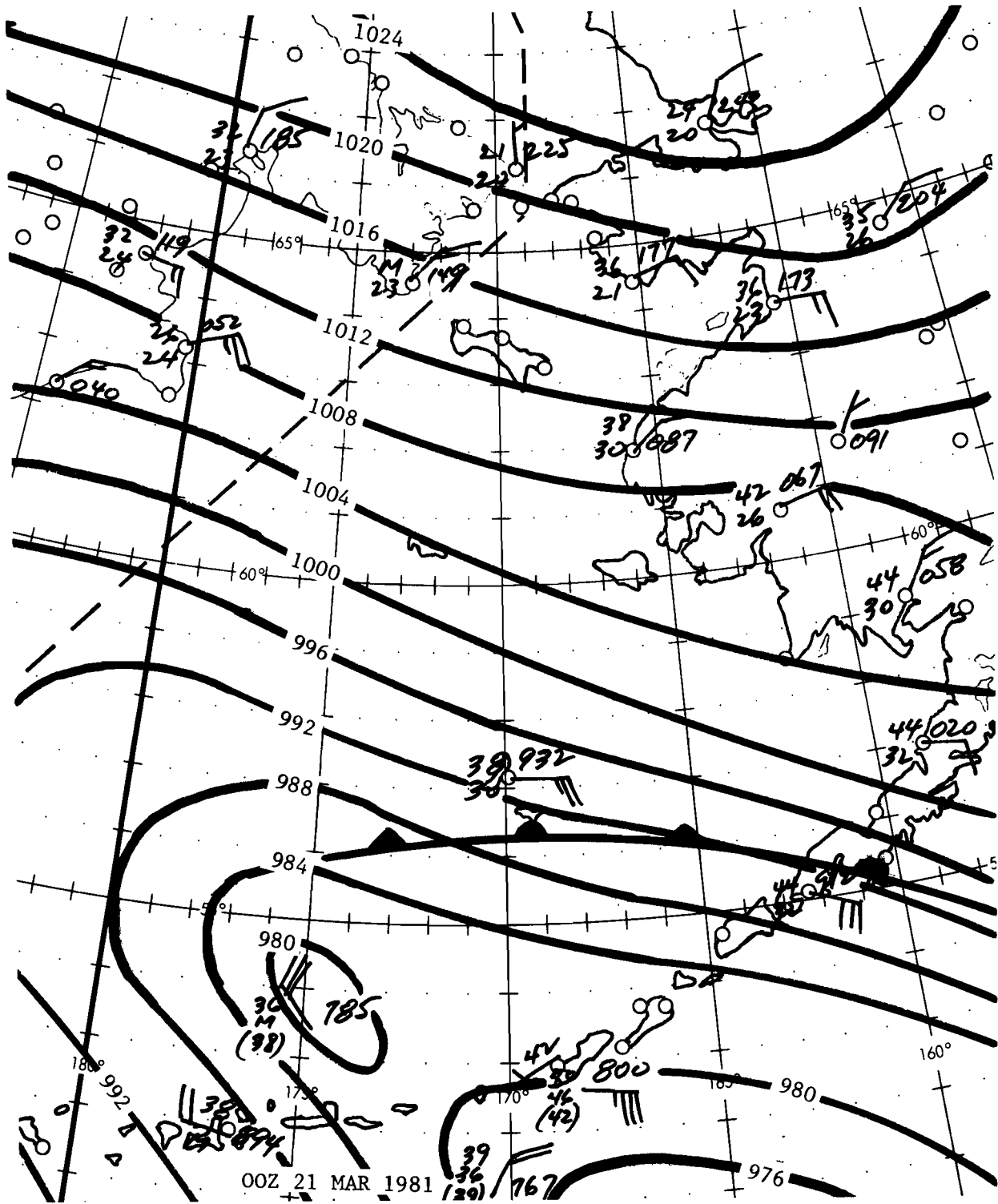












APPENDIX B

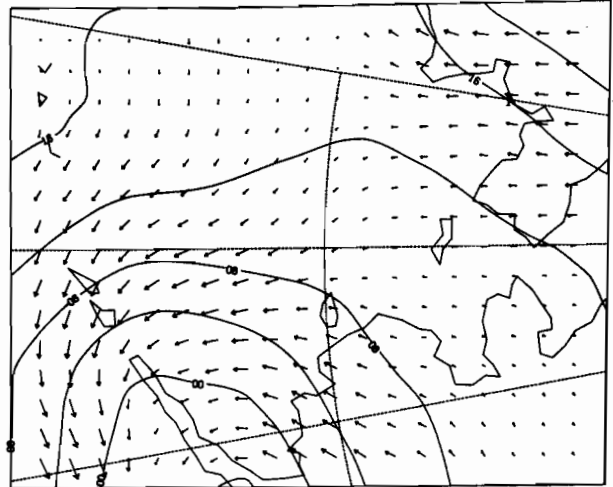
PRESSURE FIELDS AND SURFACE WINDS PRODUCED WITH METLIB

FOR 00 GMT AND 12 GMT

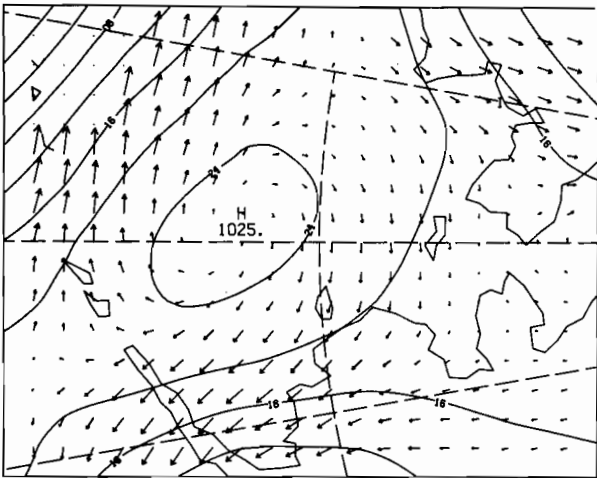
The surface pressure analyses were hand digitized onto a grid compatible with National Meteorological Center's Primitive Equation grid. A program library for calculating and plotting marine boundary layer wind fields called METLIB (Overland, et al., 1980) was used to calculate gradient winds, which were rotated counterclockwise (cyclonically) 30° and reduced in speed by 20% to approximate surface wind conditions.

The following vector wind plots represent the approximate surface wind conditions for 00 GMT and 12 GMT from 12 GMT 22 February through 20 March 1981. The distance between grid points (tails of the vectors) in the enclosed plots is the vector length scale for 20 m s^{-1} wind speeds. Wind speeds higher than this magnitude cannot be handled by the plotting package, resulting in occasional missing vectors with only a dot at the base. Note that north is to the right.

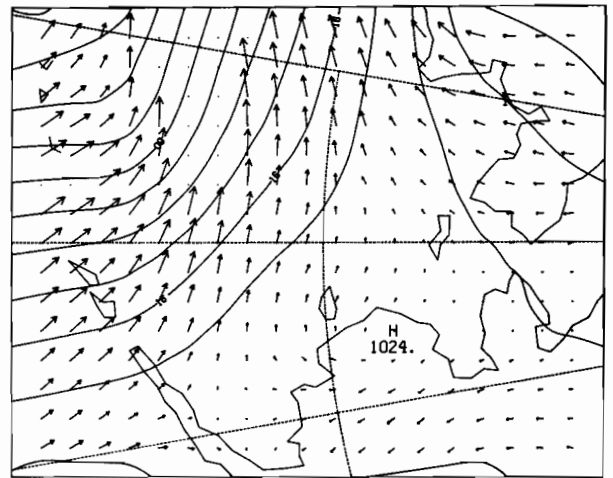
OBSERVED SLP
EMPR WINDS



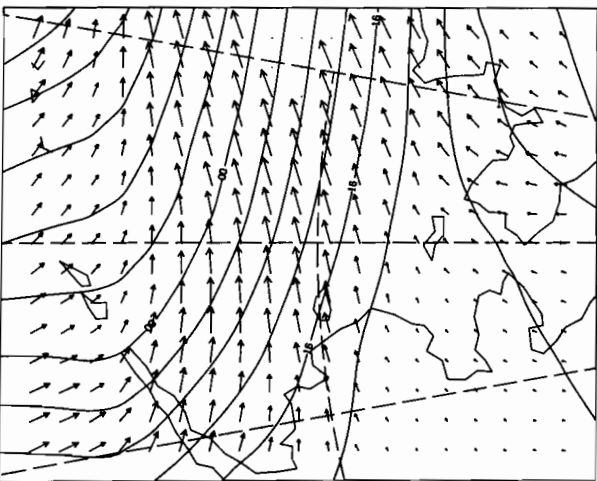
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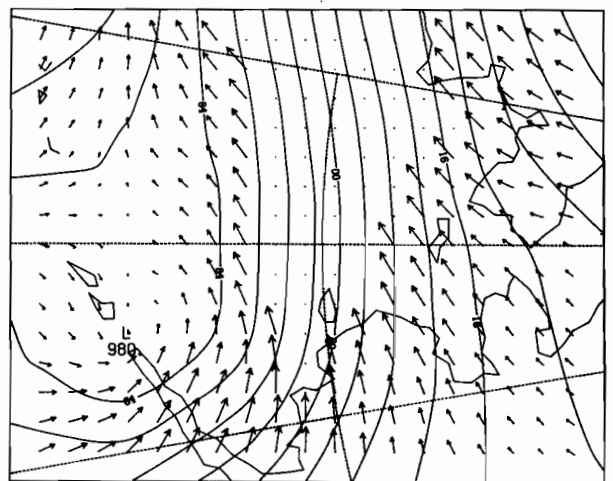
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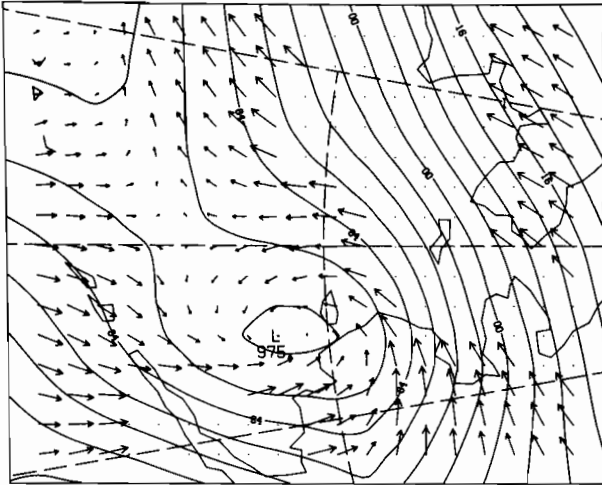
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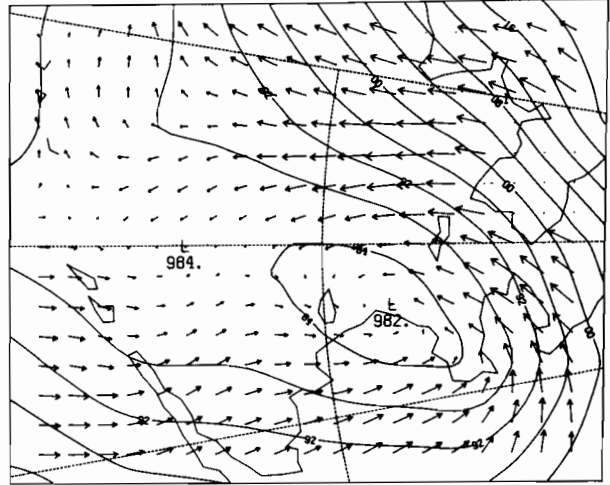
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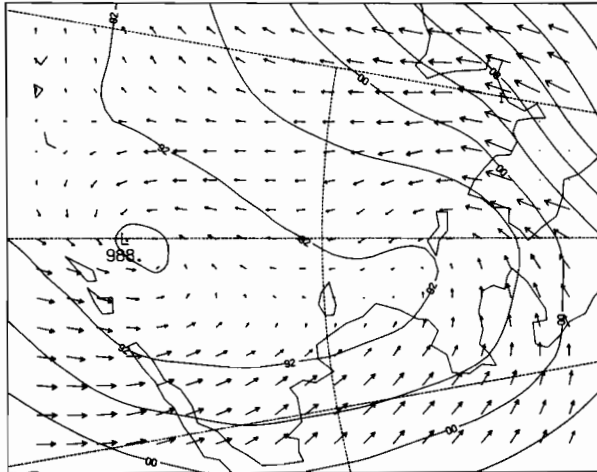
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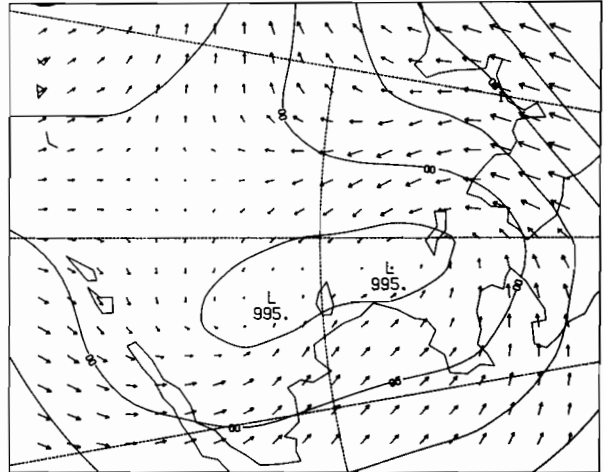
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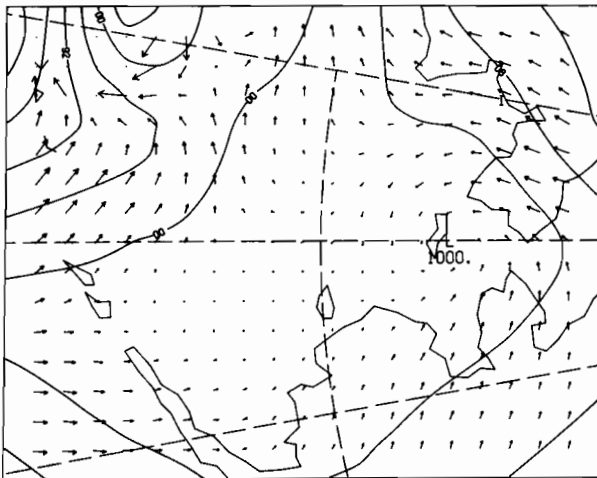
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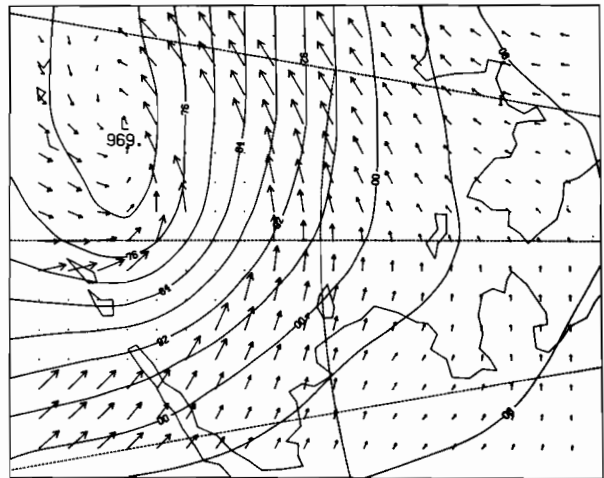
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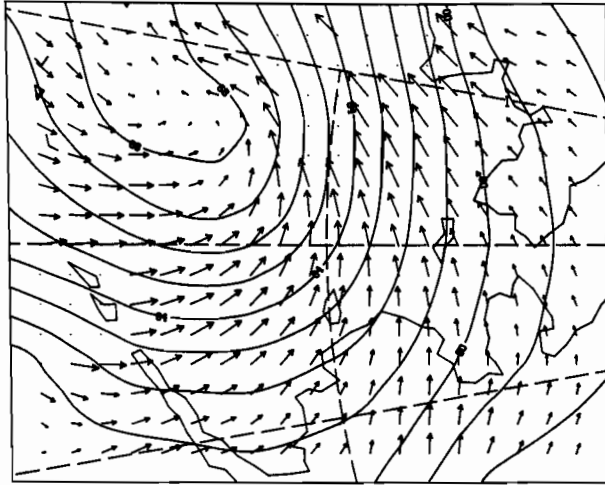
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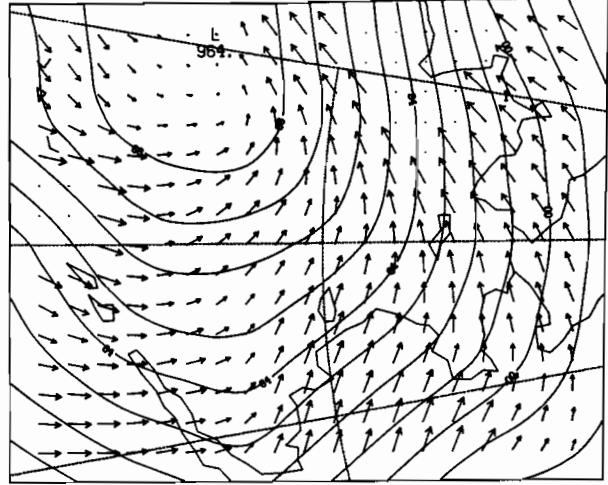
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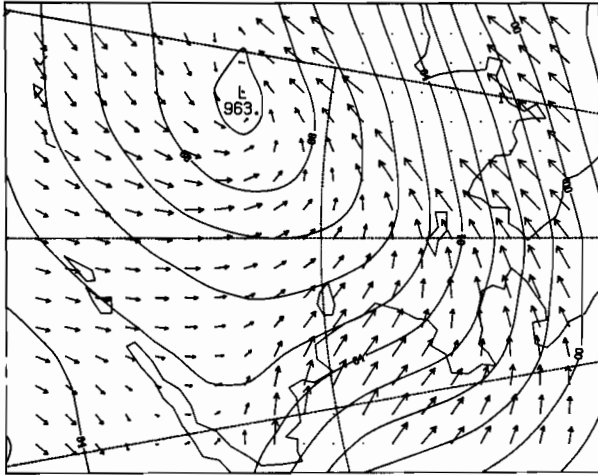
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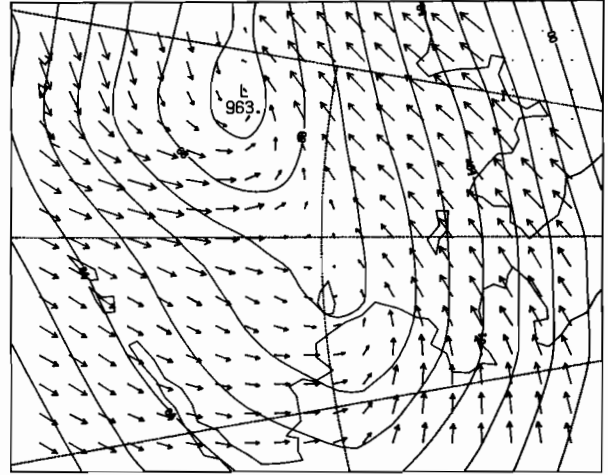
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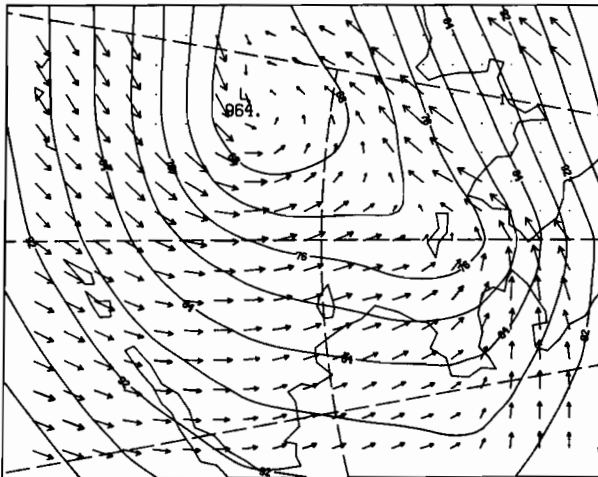
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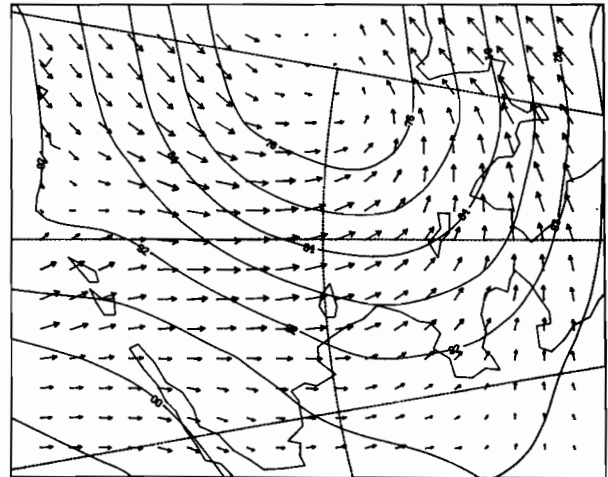
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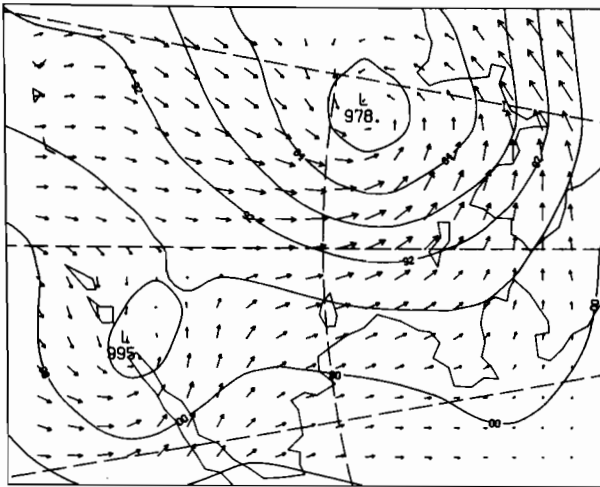
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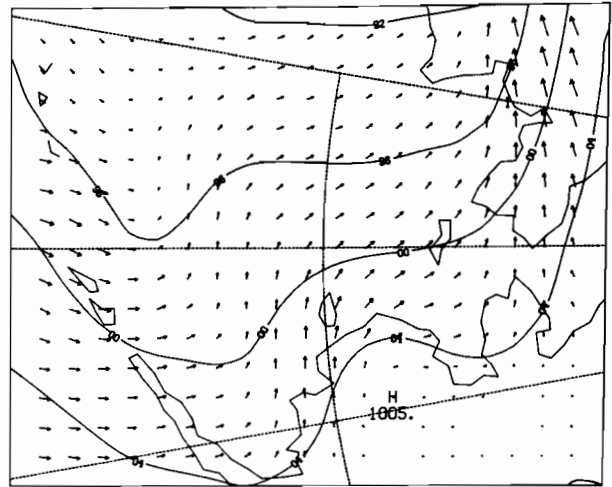
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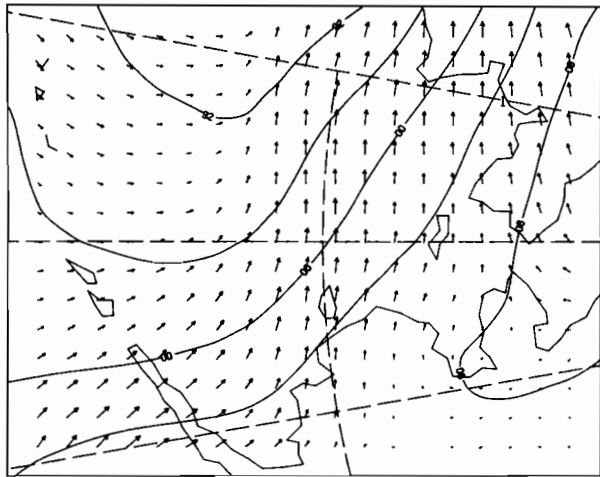
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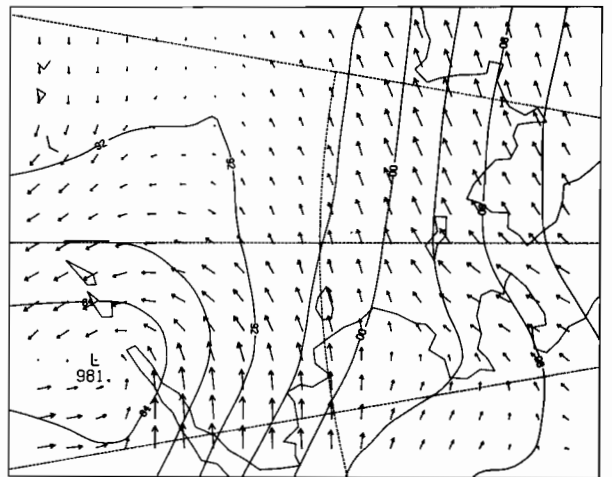
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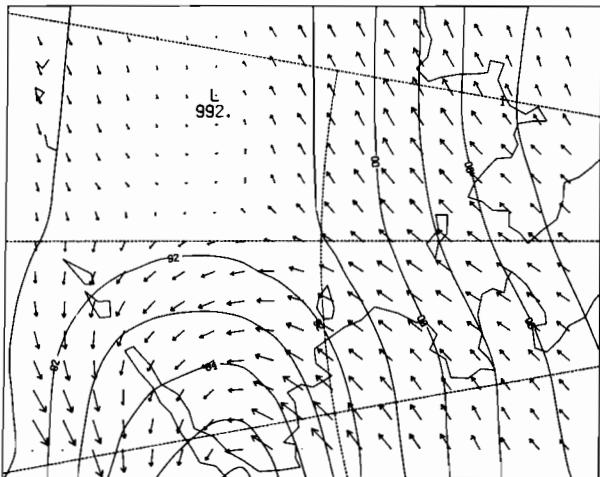
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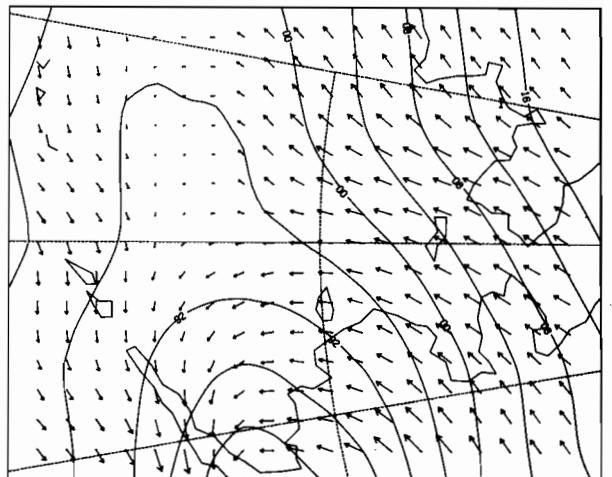
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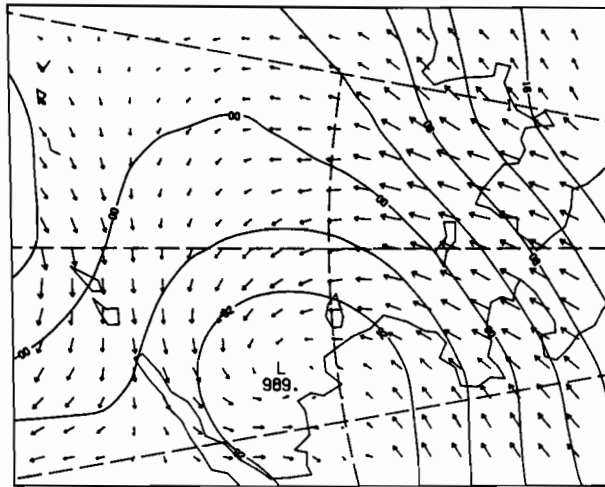
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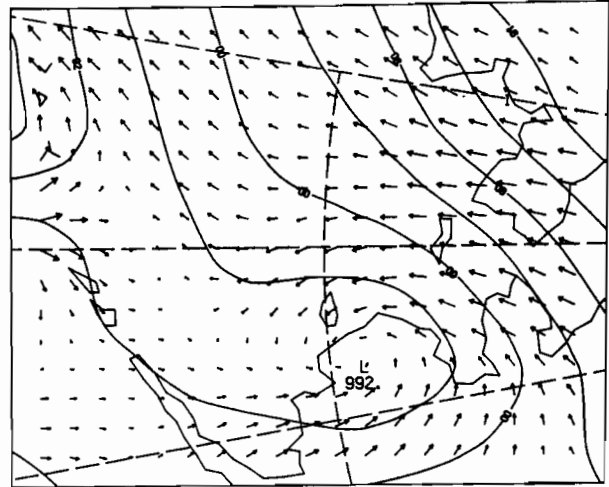
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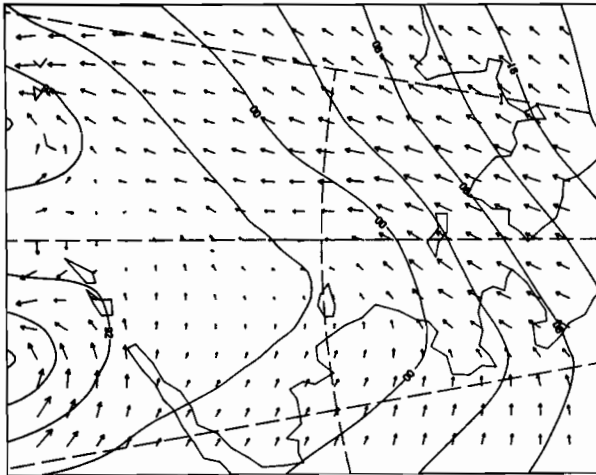
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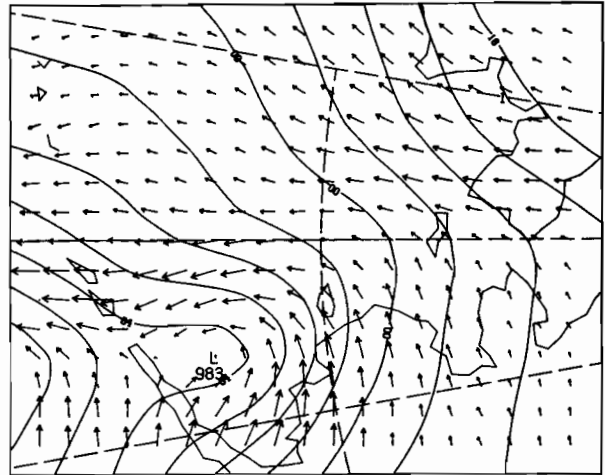
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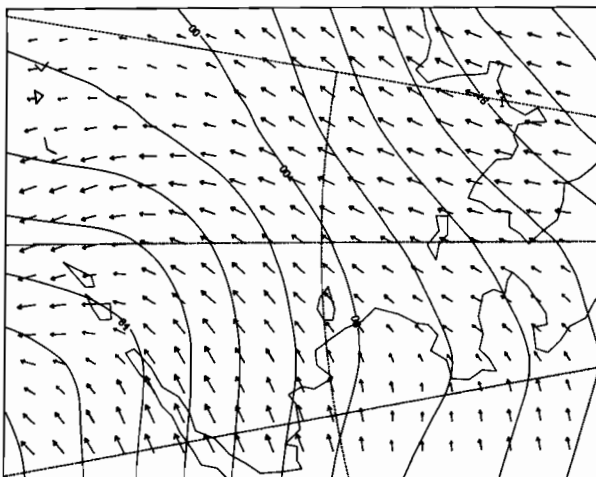
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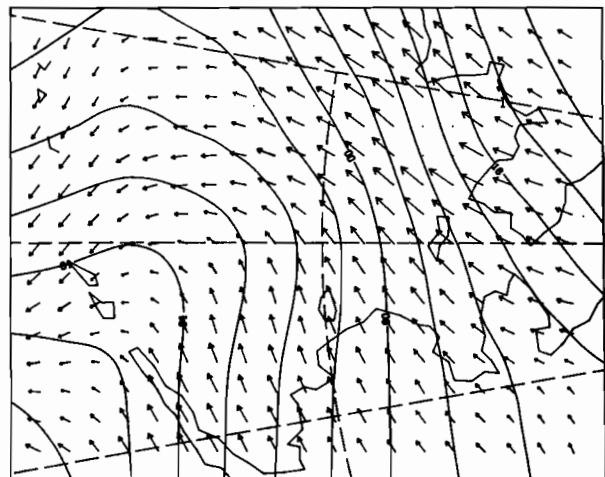
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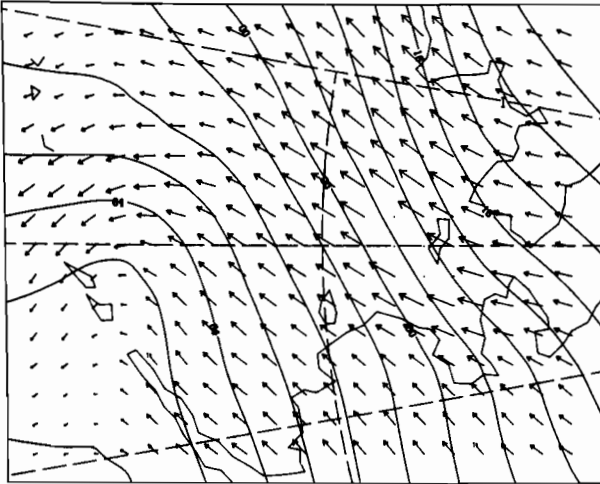
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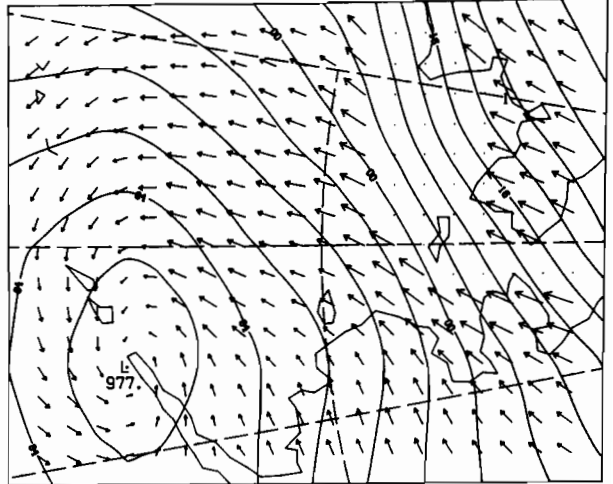
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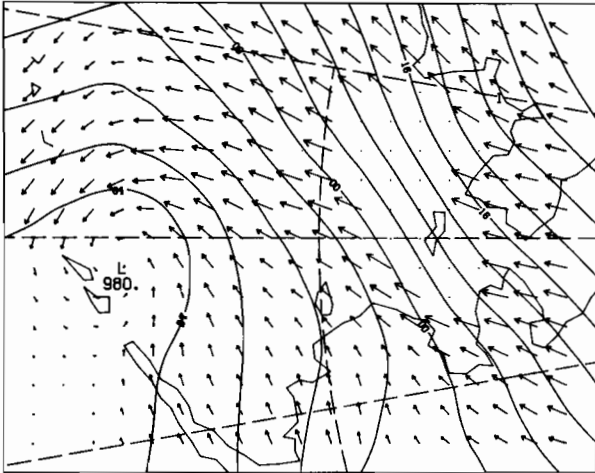
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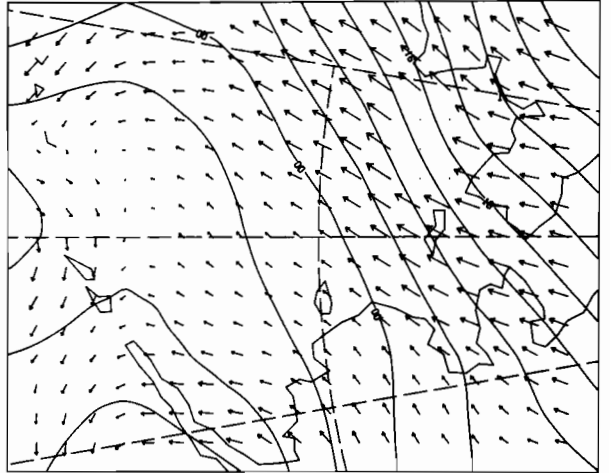
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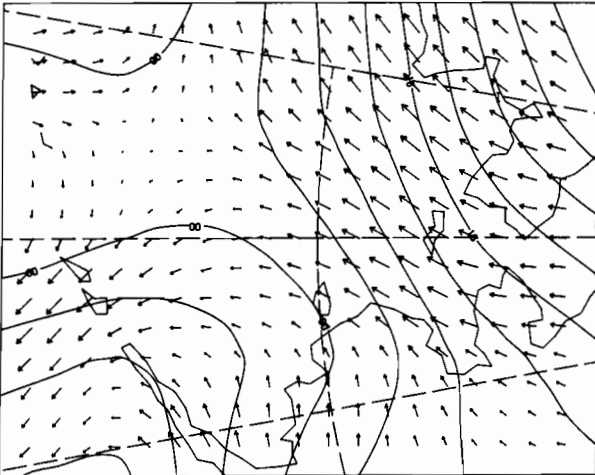
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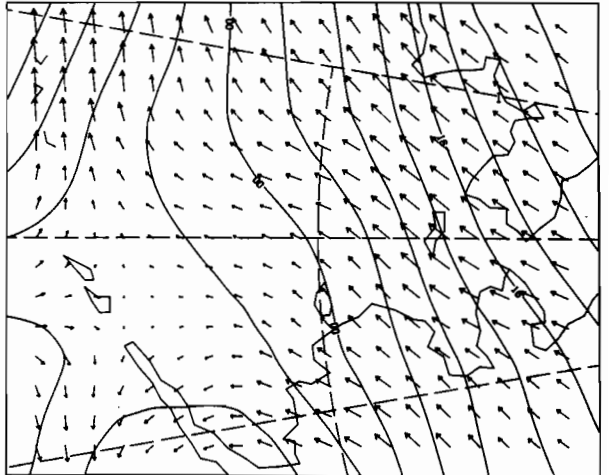
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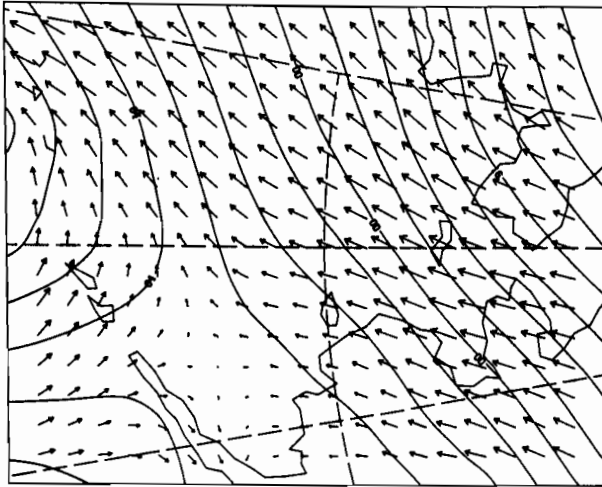
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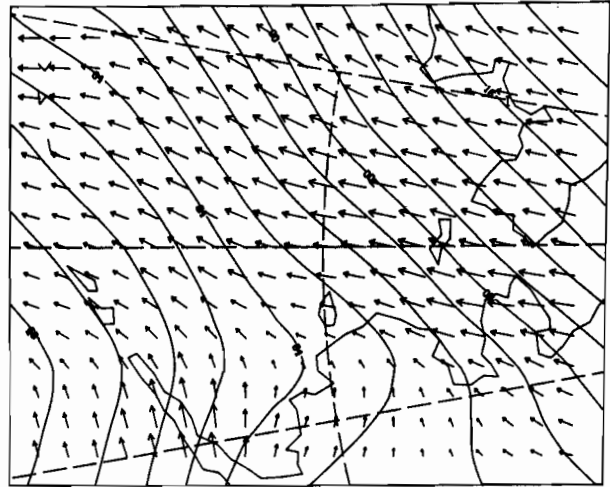
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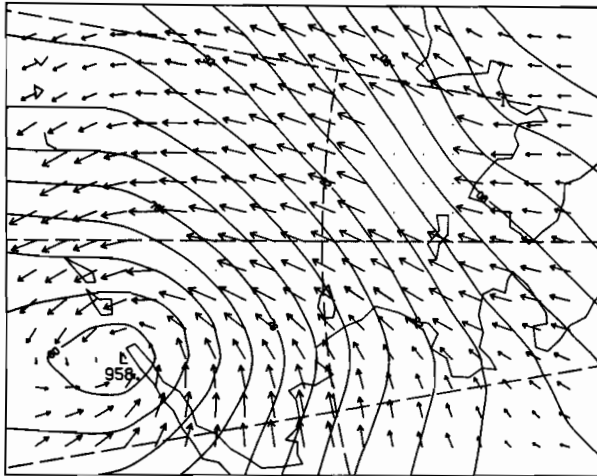
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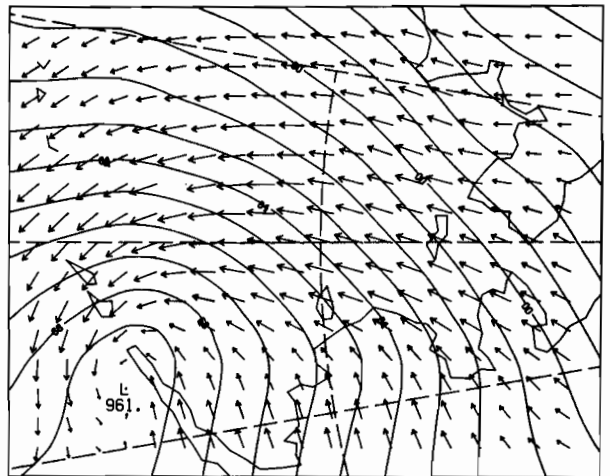
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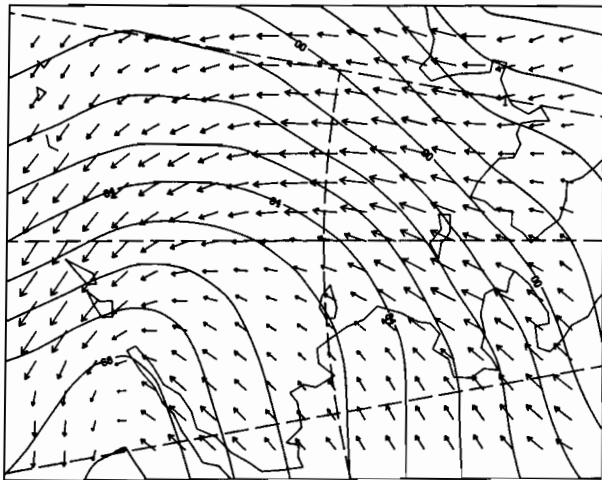
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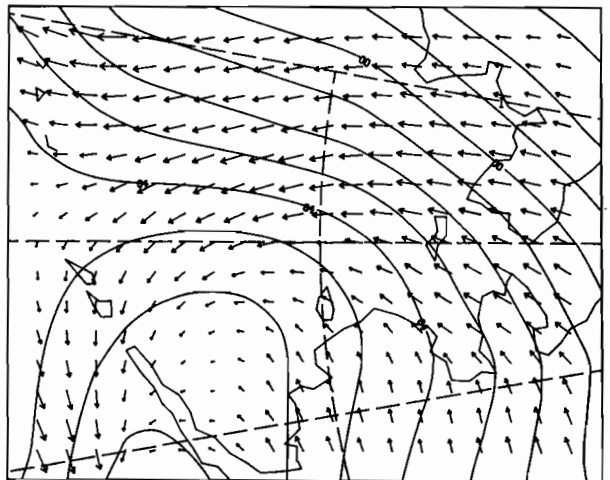
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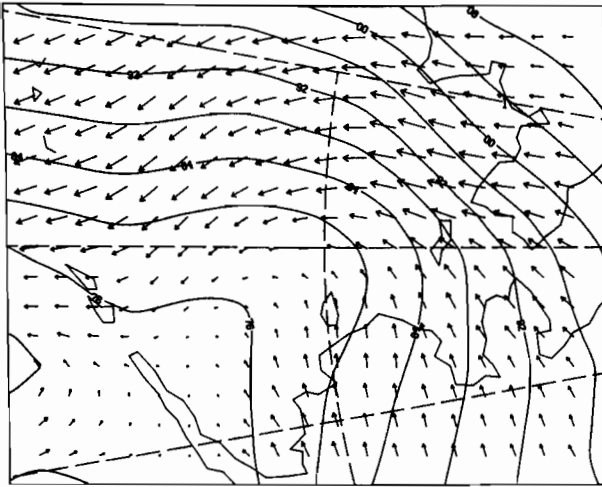
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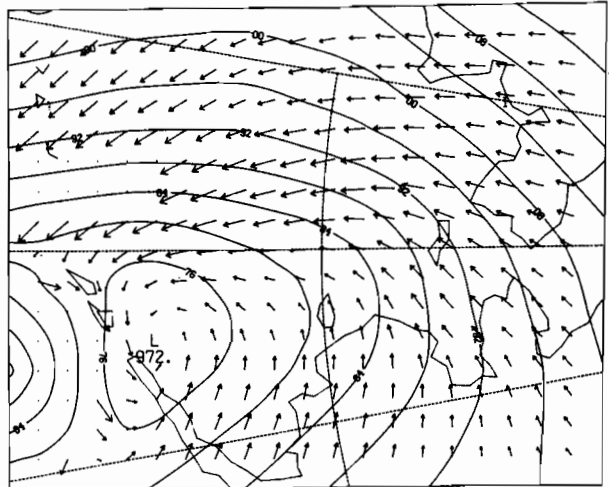
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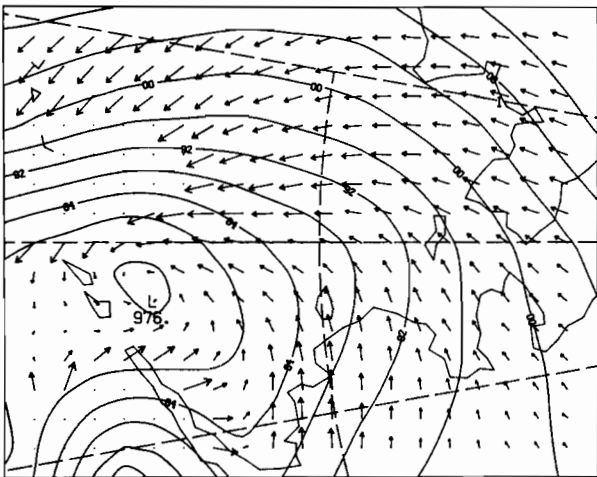
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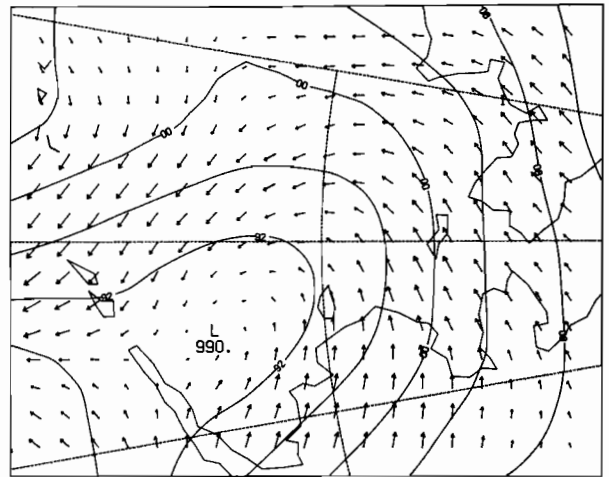
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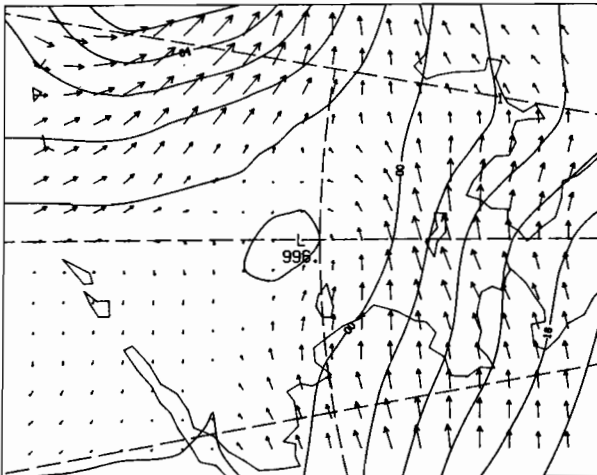
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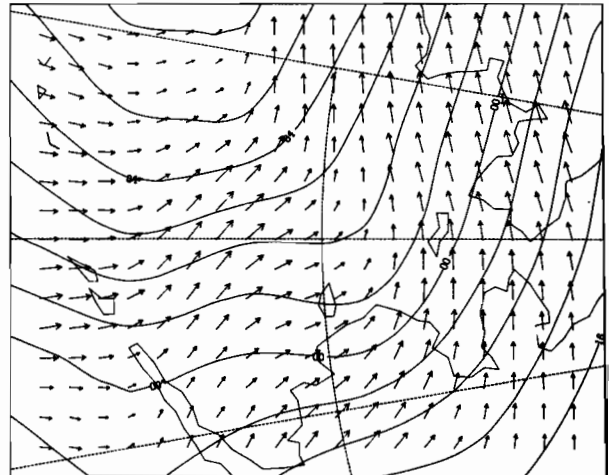
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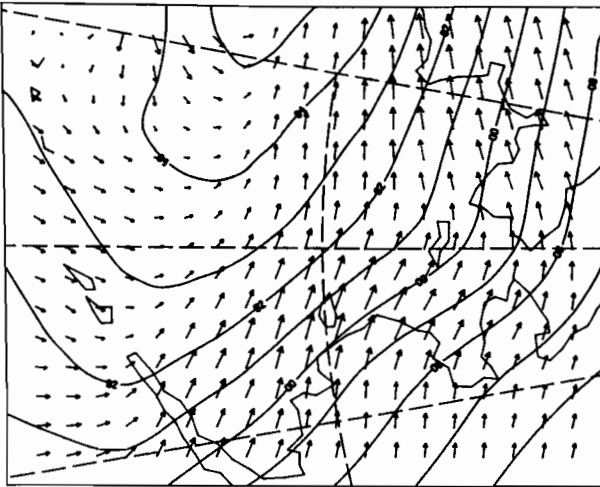
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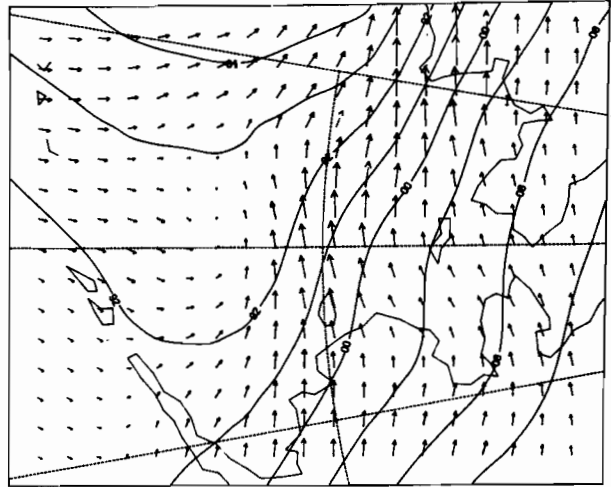
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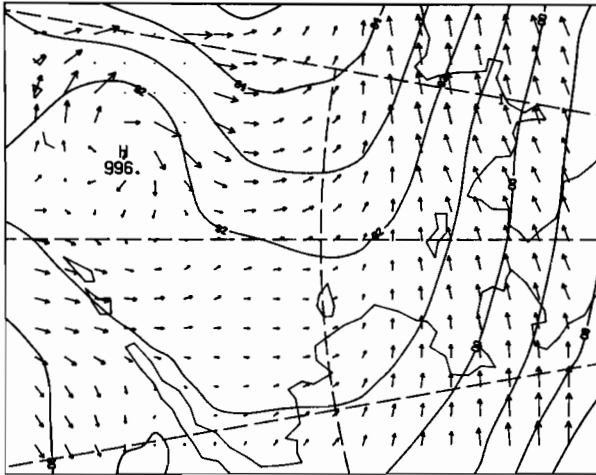
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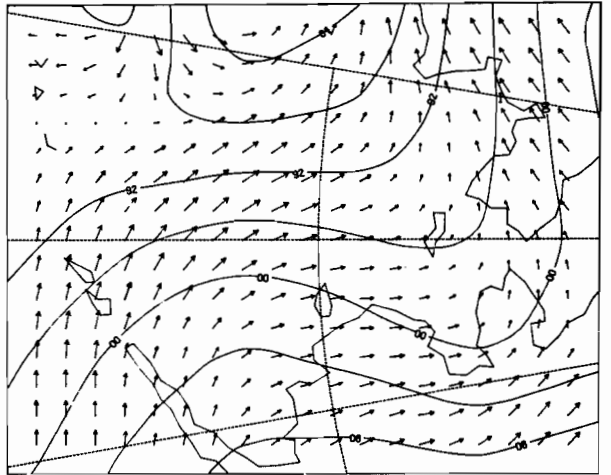
00Z 18 MAR 1981



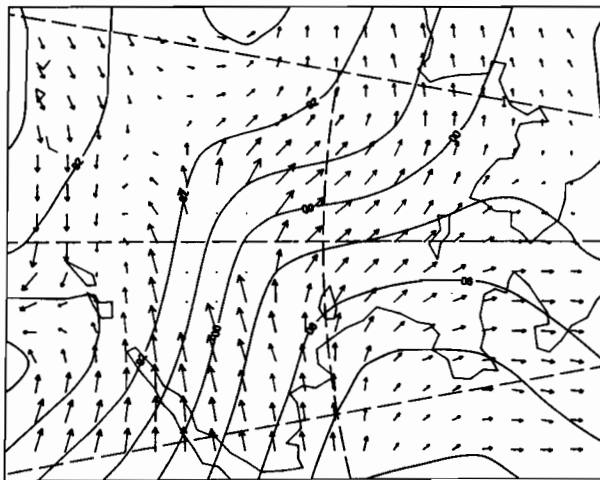
12Z 18 MAR 1981



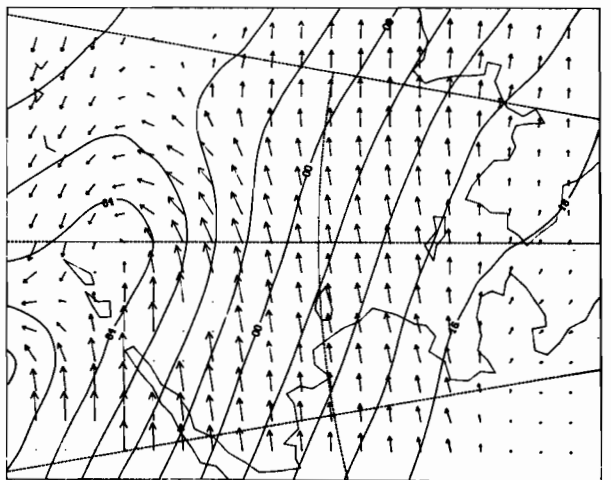
00Z 19 MAR 1981



12Z 19 MAR 1981



00Z 20 MAR 1981



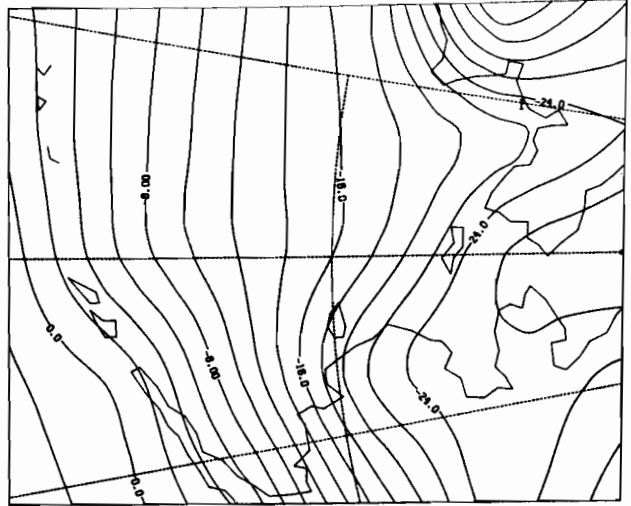
12Z 20 MAR 1981

APPENDIX C

SURFACE AIR TEMPERATURE FIELDS PRODUCED WITH METLIB

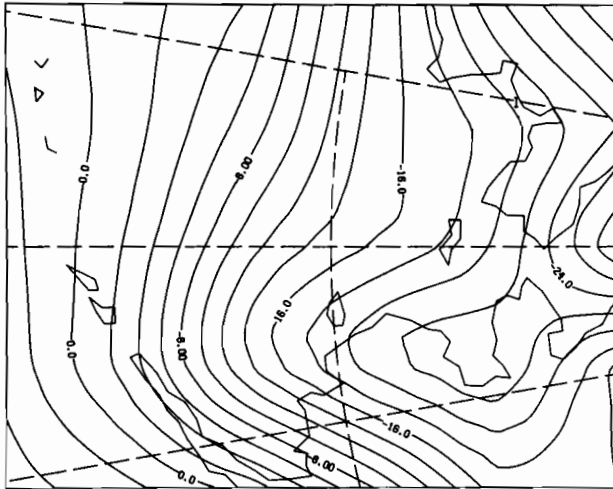
FOR 00 GMT AND 12 GMT

ØBSERVED SAT



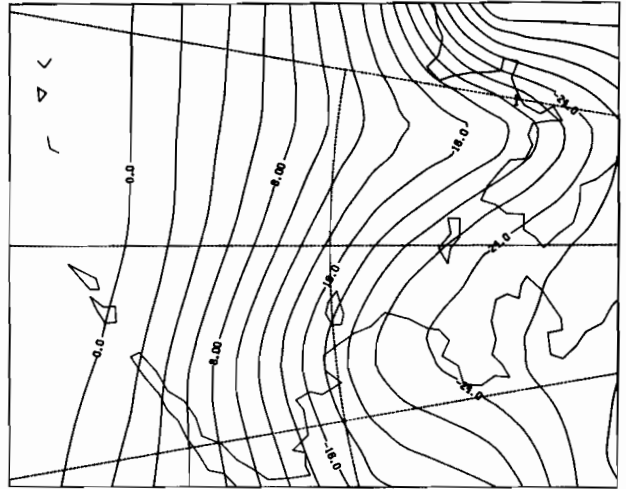
12Z 22 FEB 1981

ØBSERVED SAT



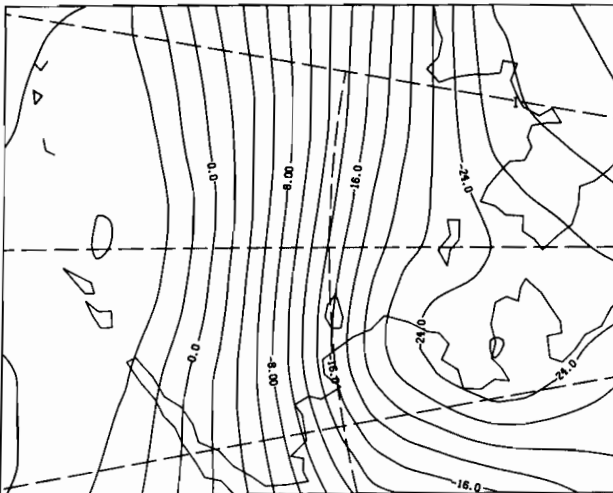
00Z 23 FEB 1981

ØBSERVED SAT



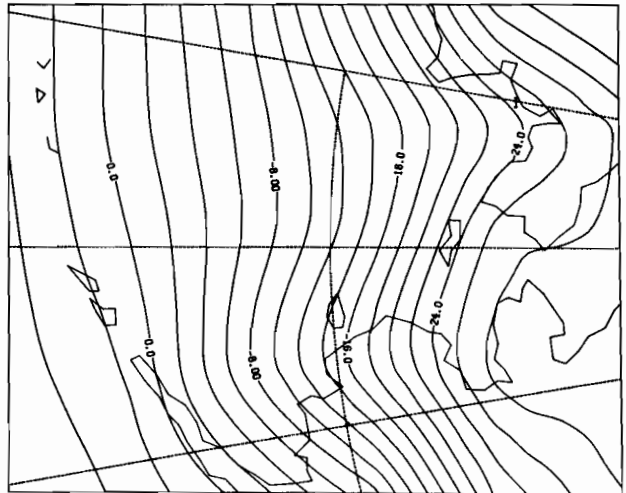
12Z 23 FEB 1981

ØBSERVED SAT

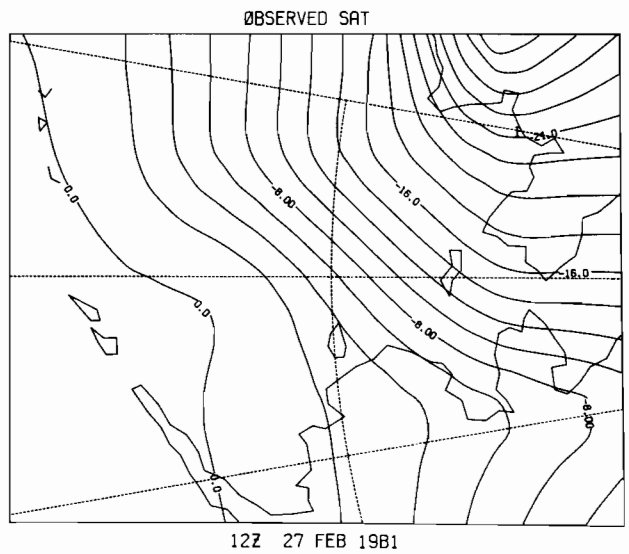
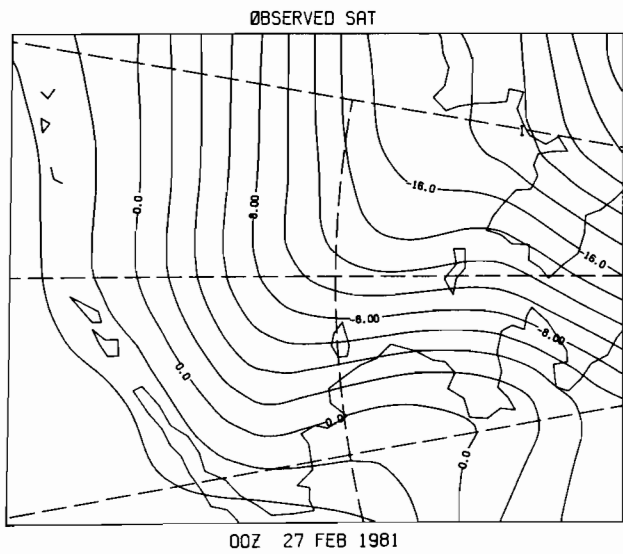
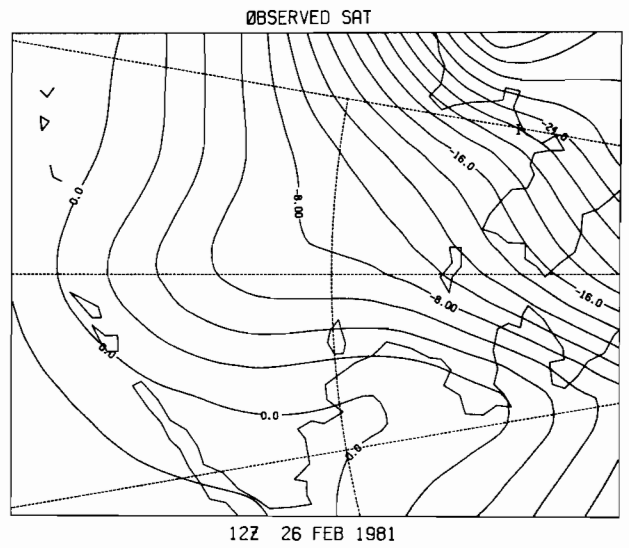
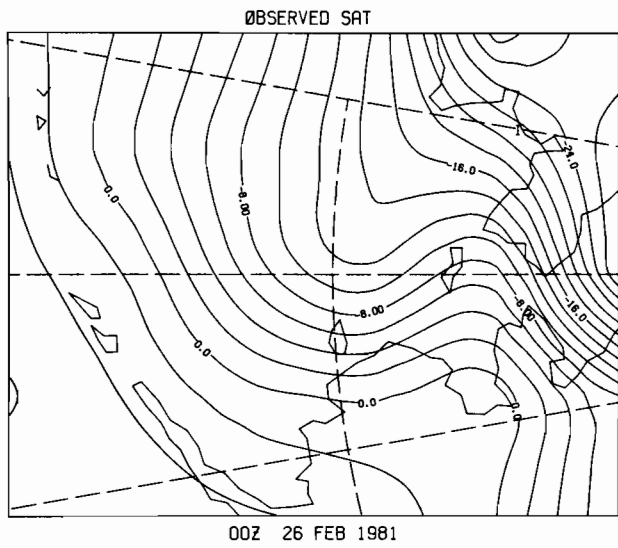
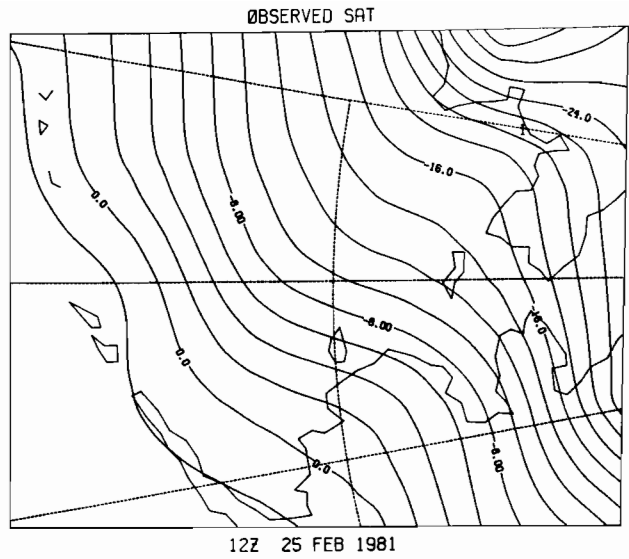
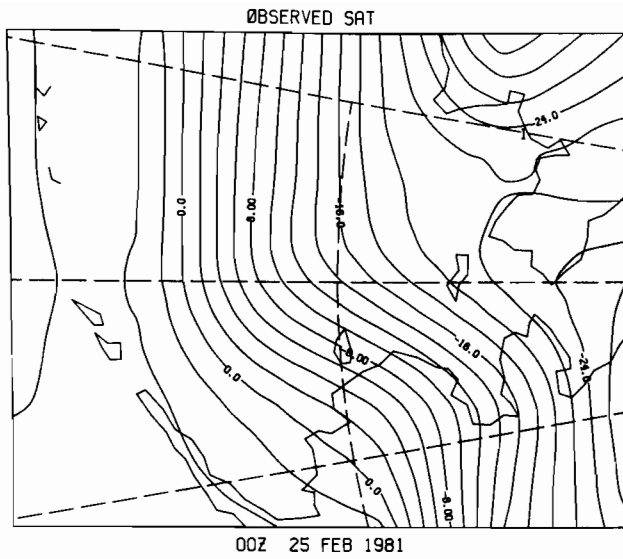


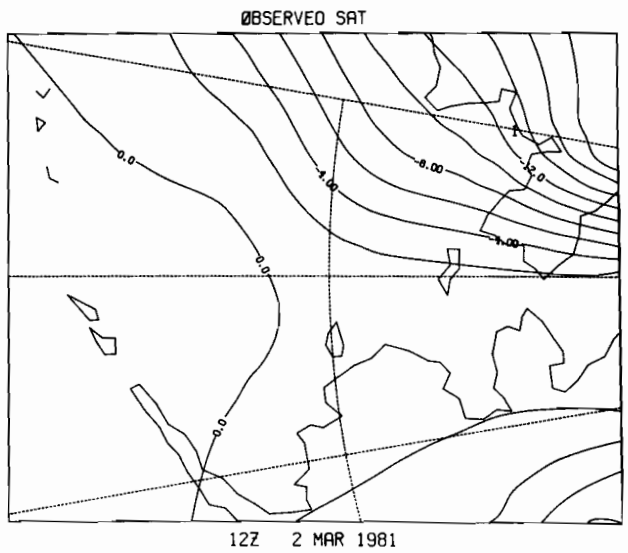
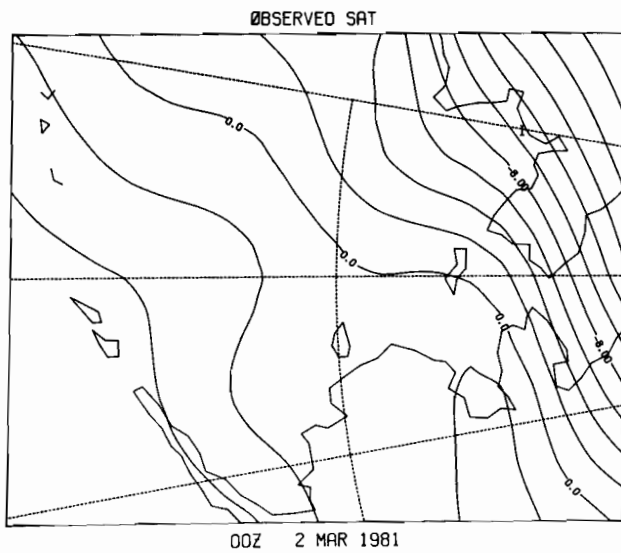
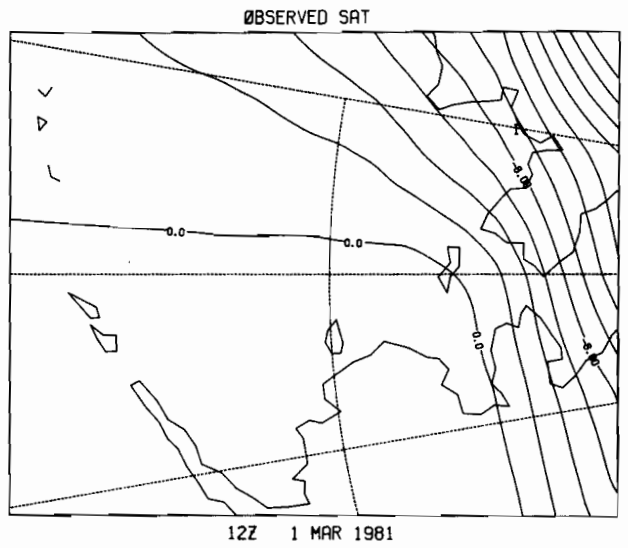
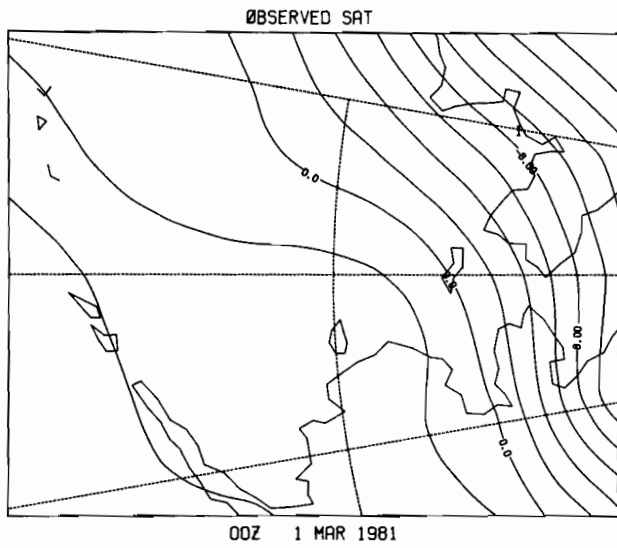
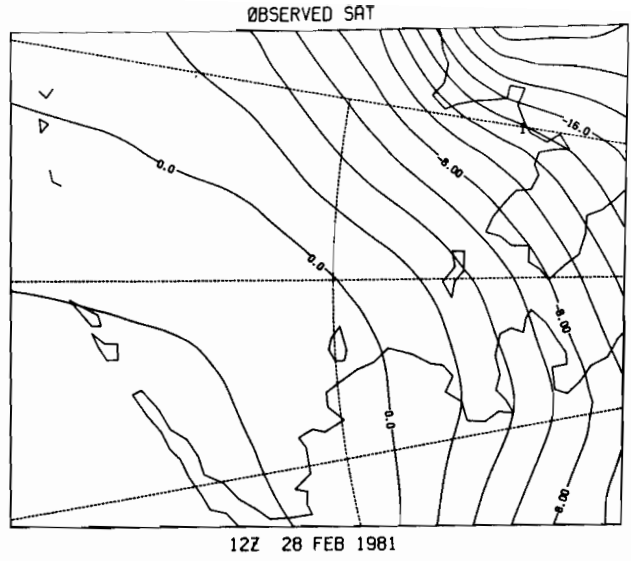
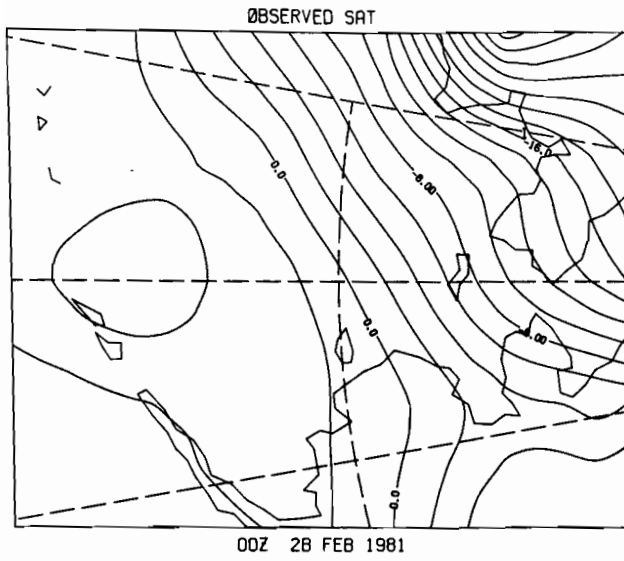
00Z 24 FEB 1981

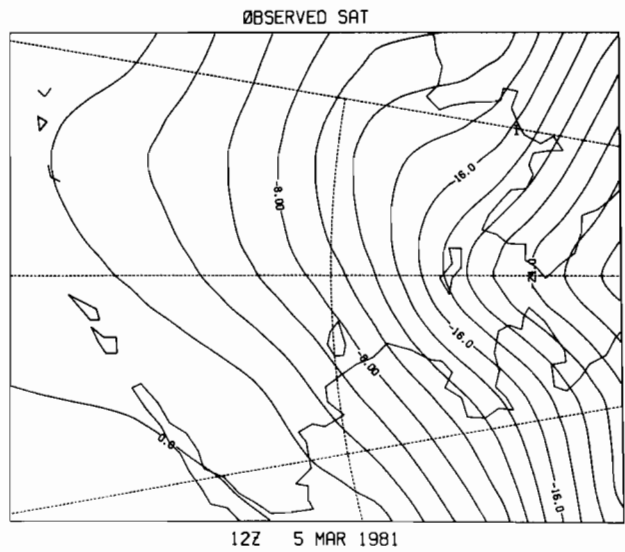
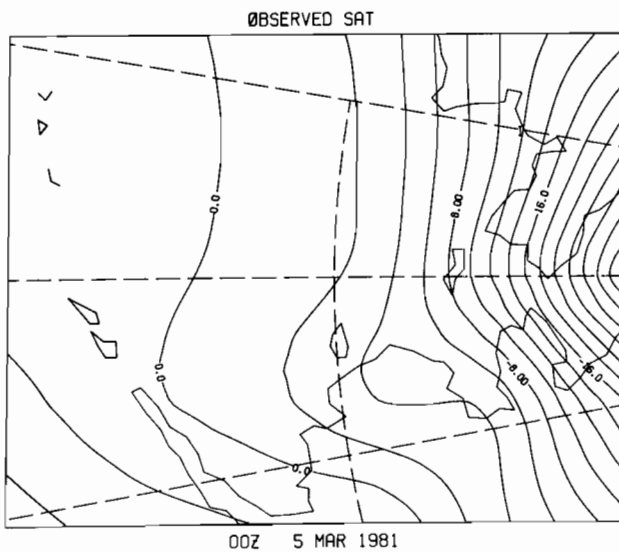
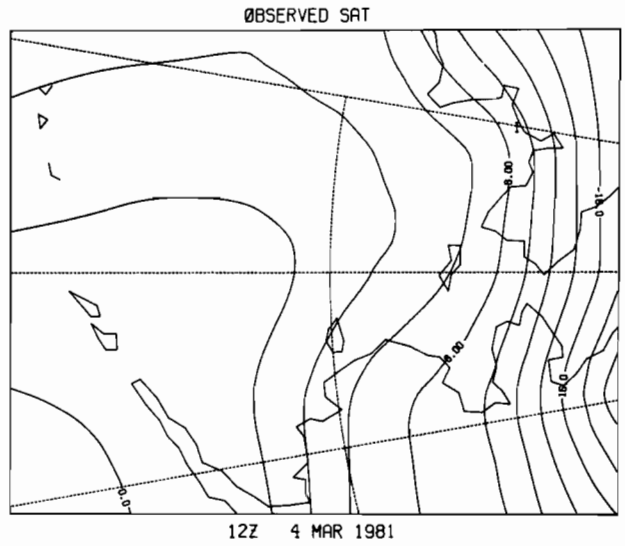
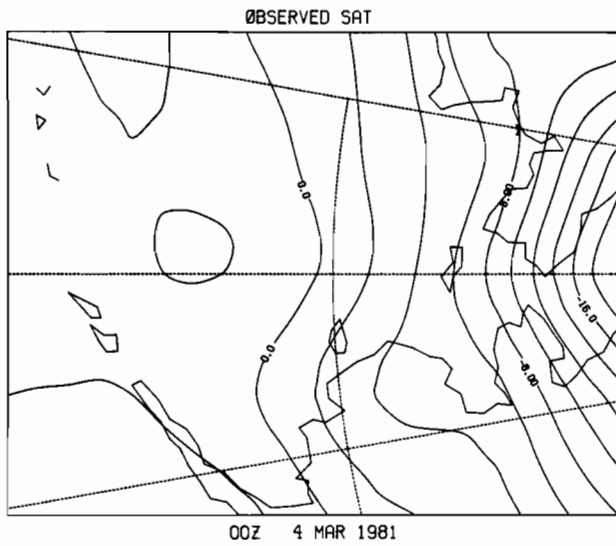
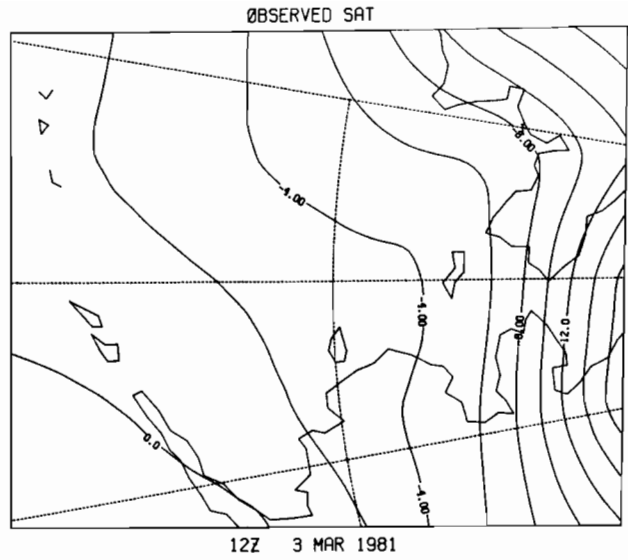
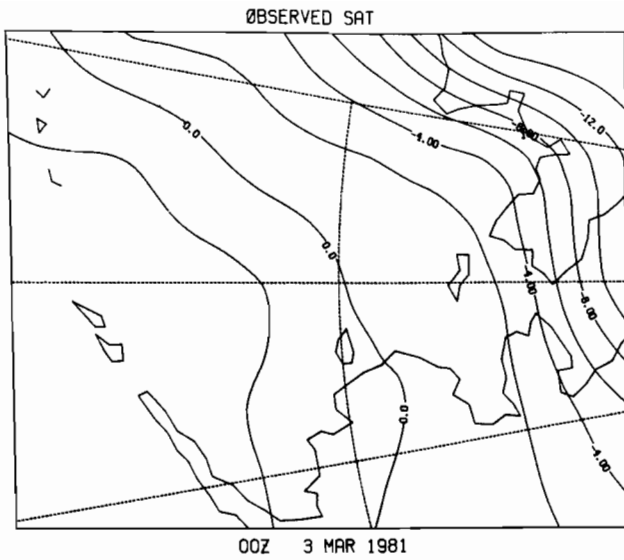
ØBSERVED SAT

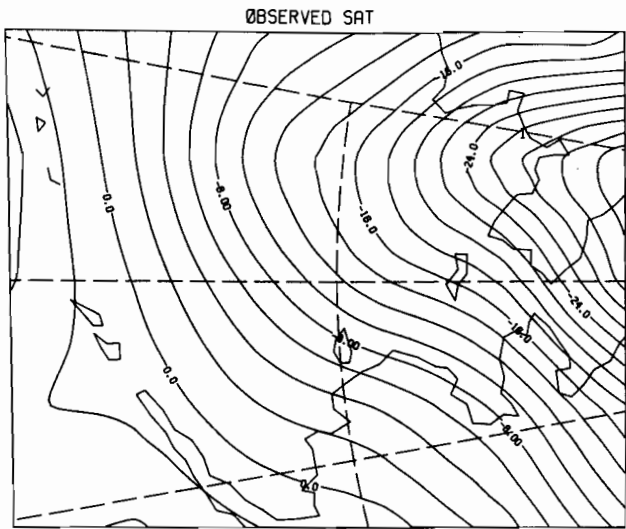


12Z 24 FEB 1981

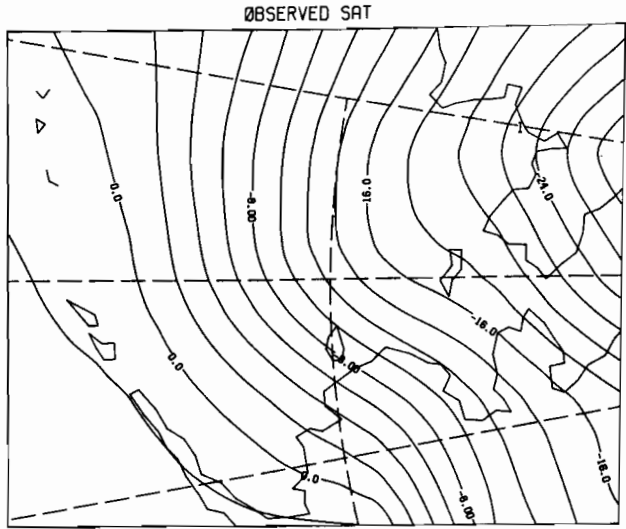




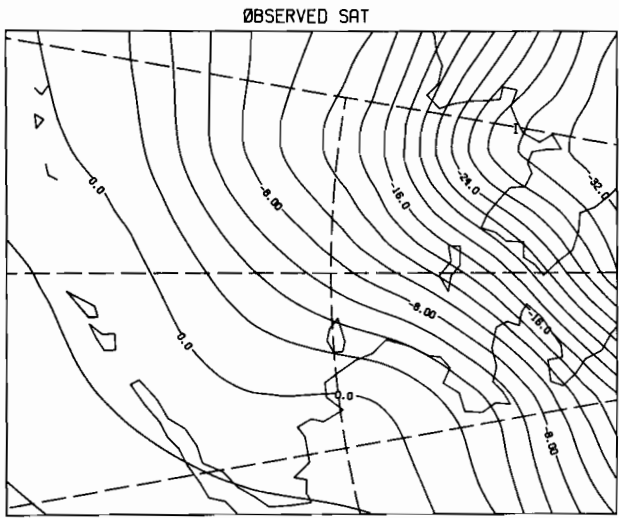




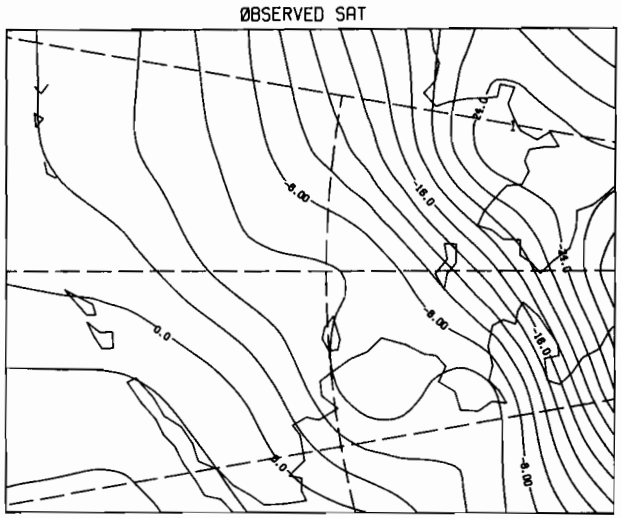
00Z 6 MAR 1981



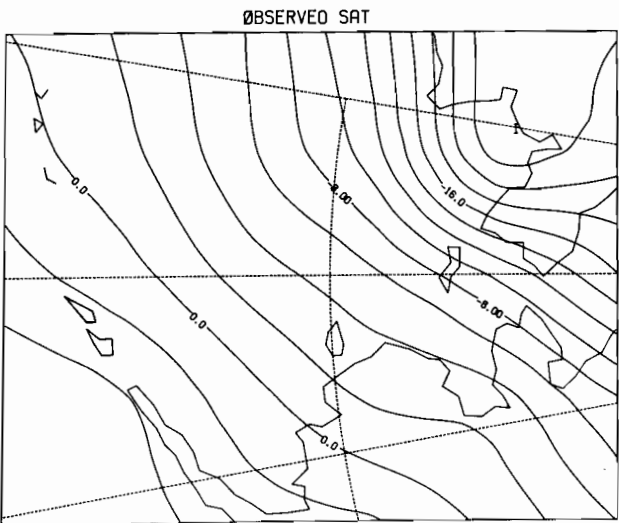
12Z 6 MAR 1981



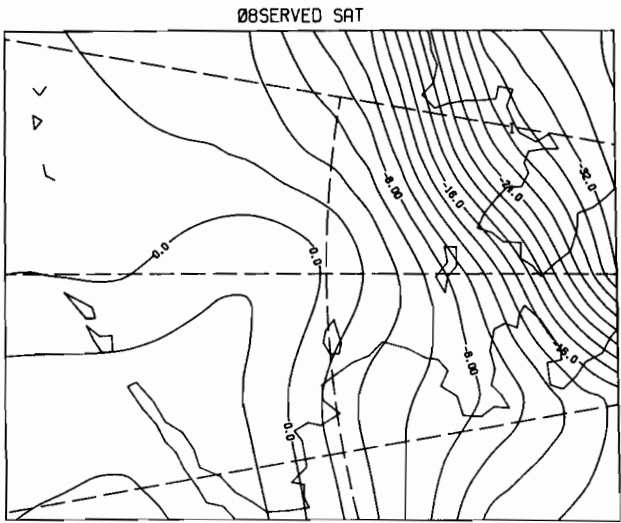
00Z 7 MAR 1981



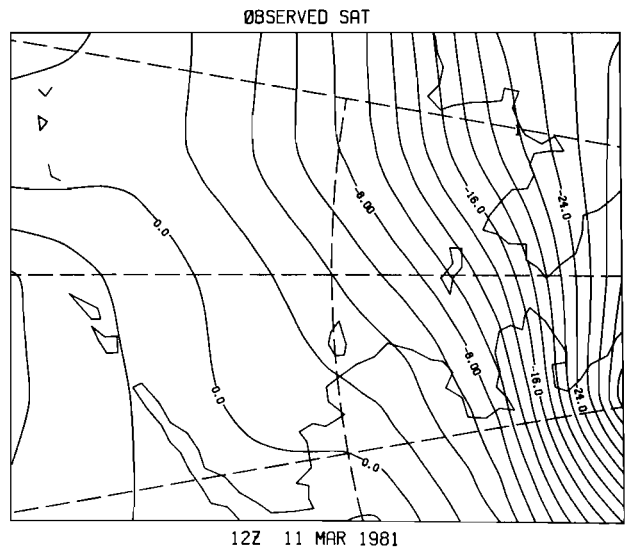
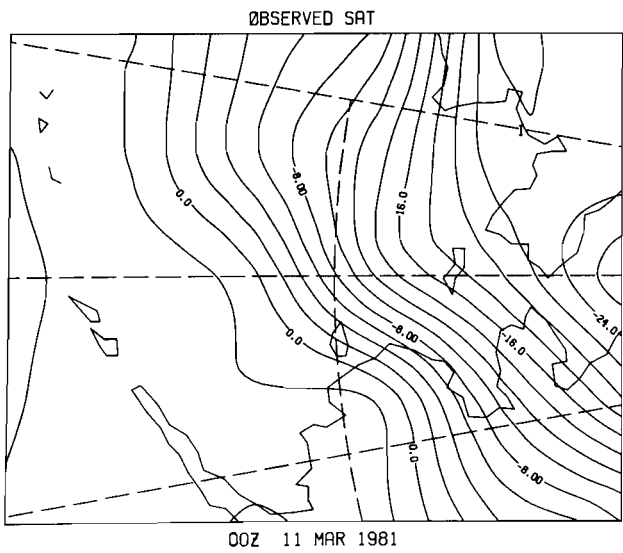
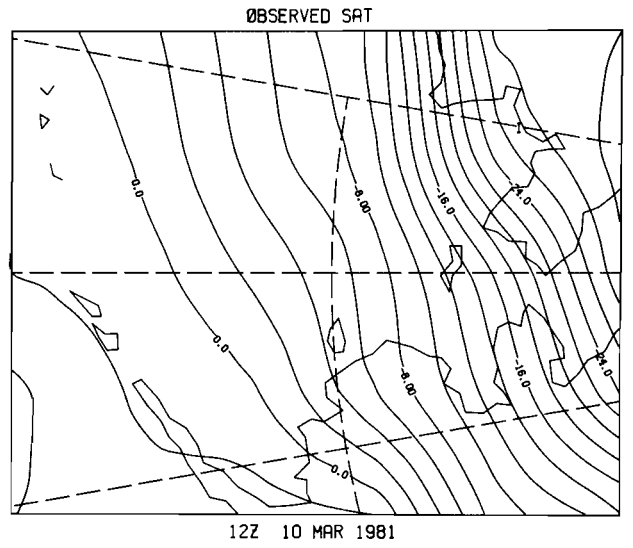
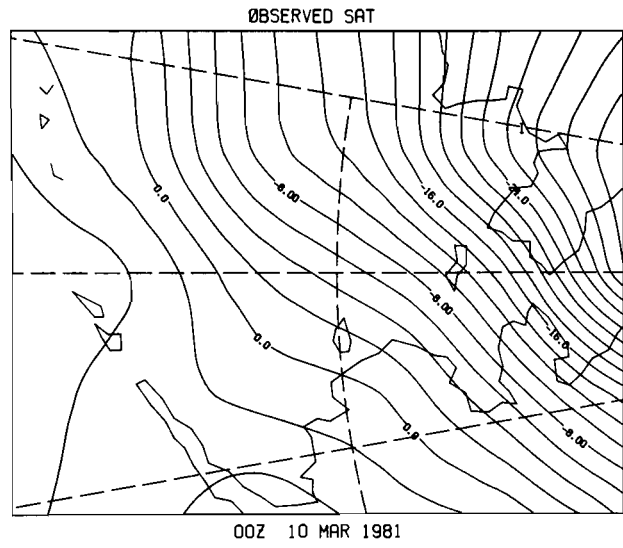
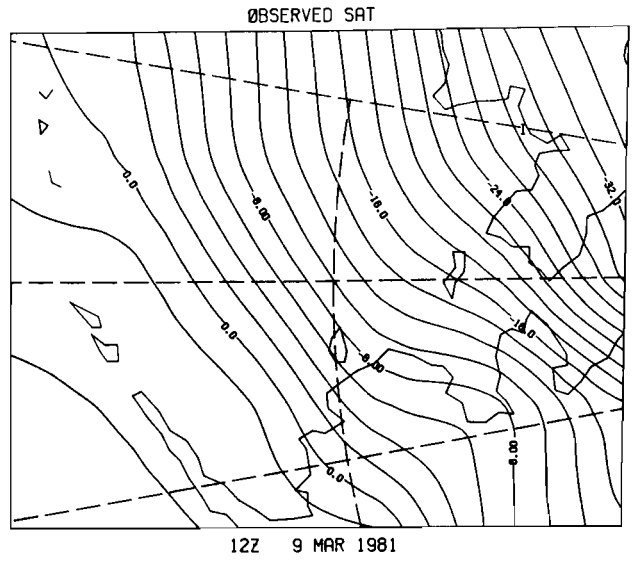
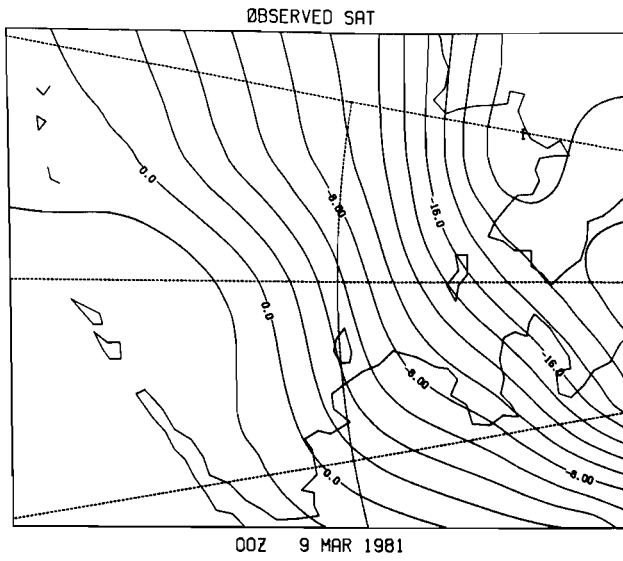
12Z 7 MAR 1981

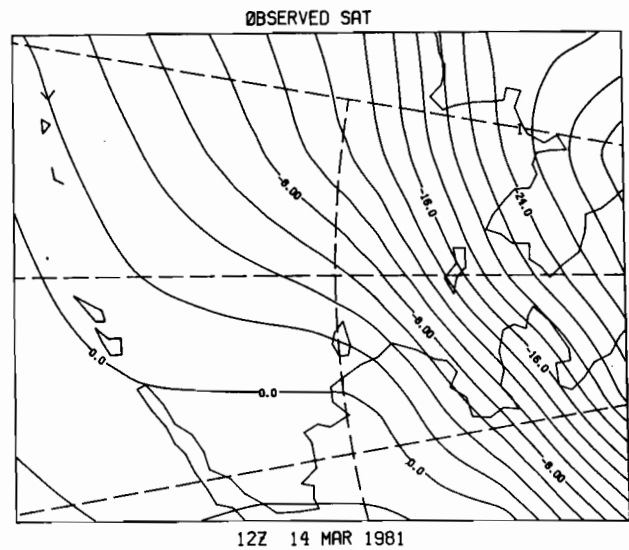
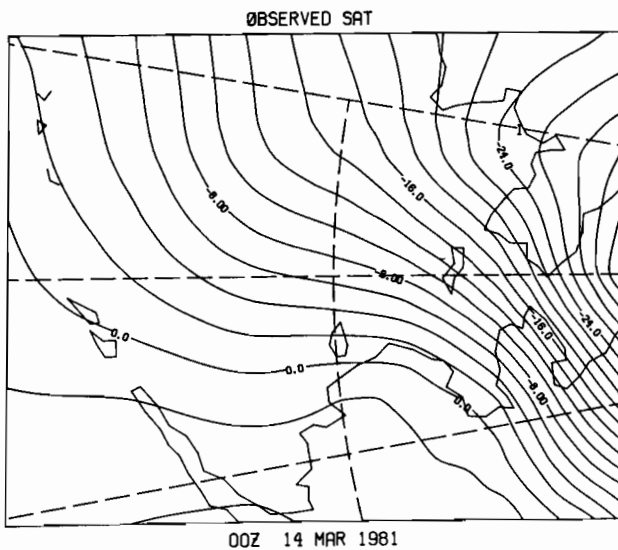
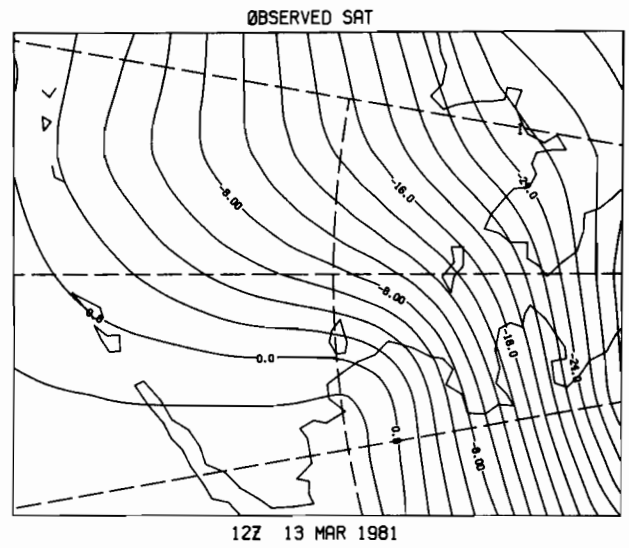
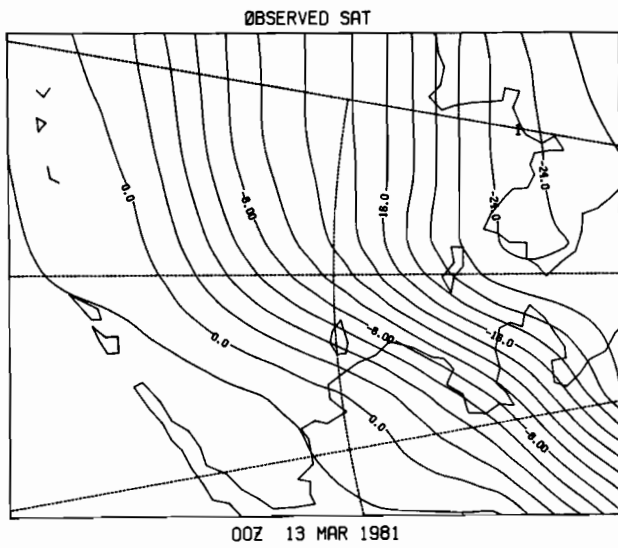
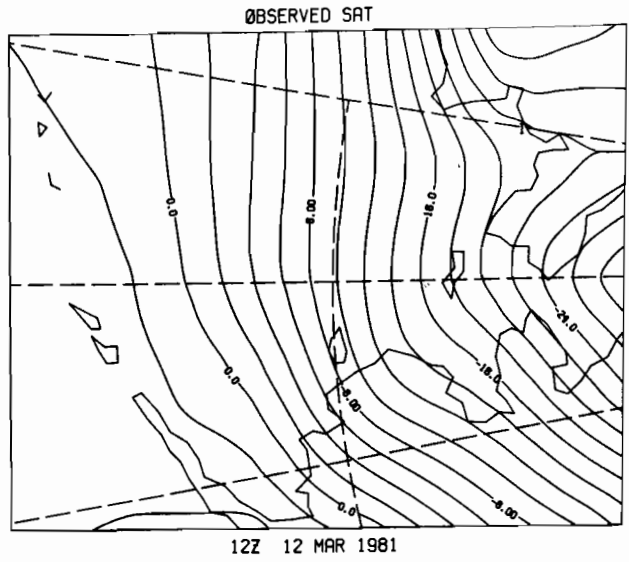
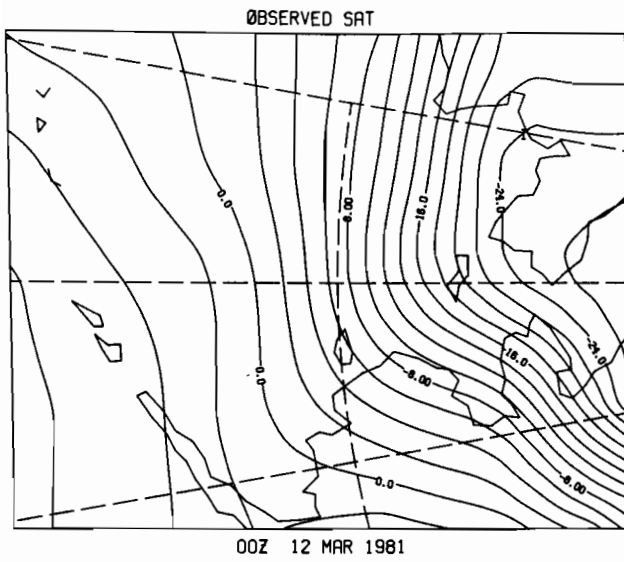


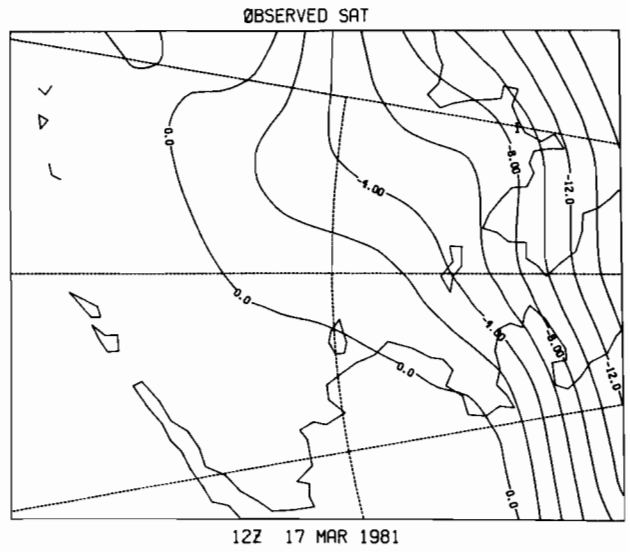
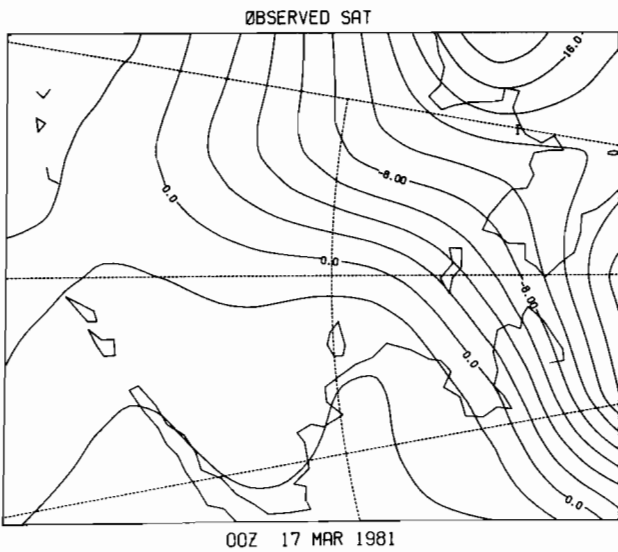
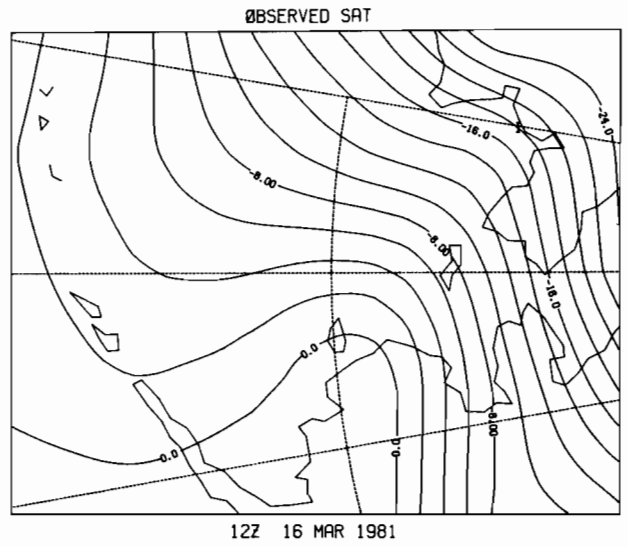
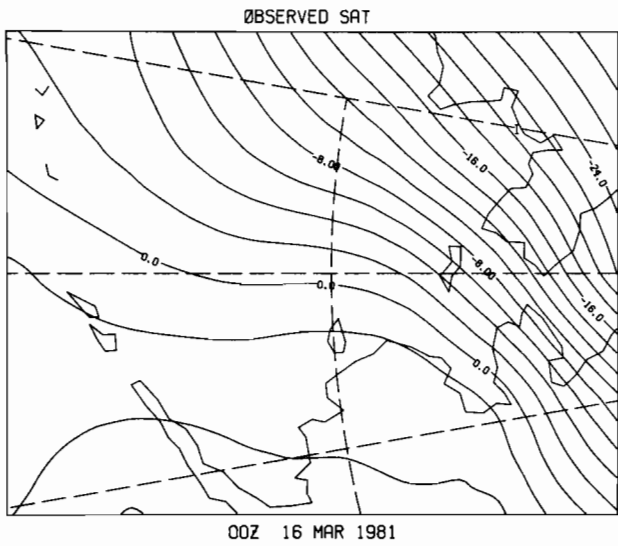
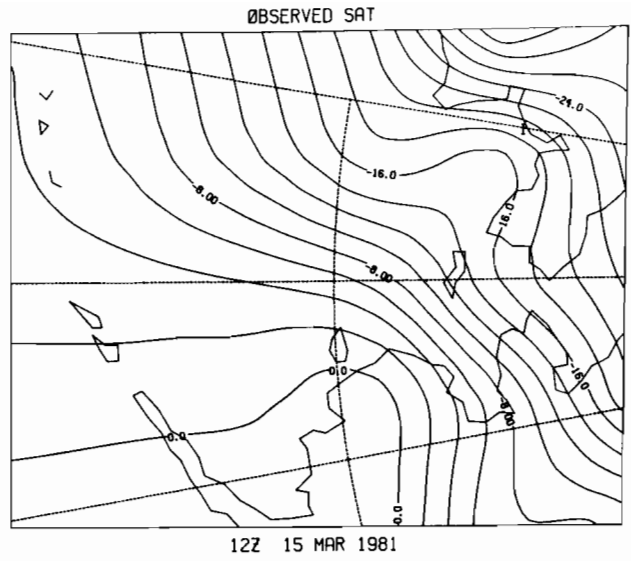
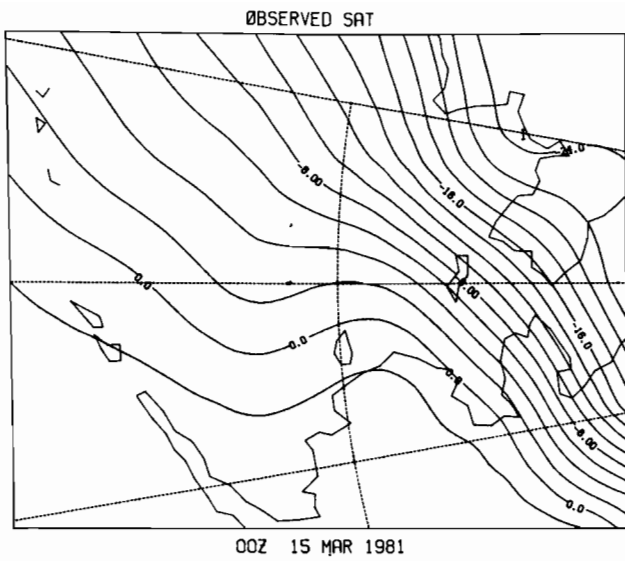
00Z 8 MAR 1981

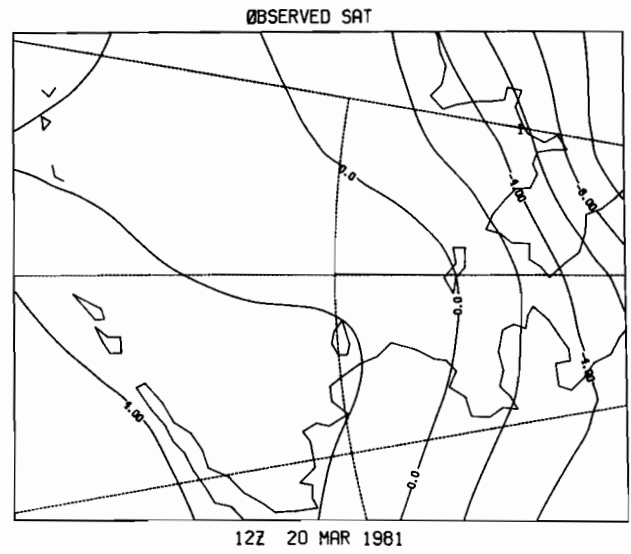
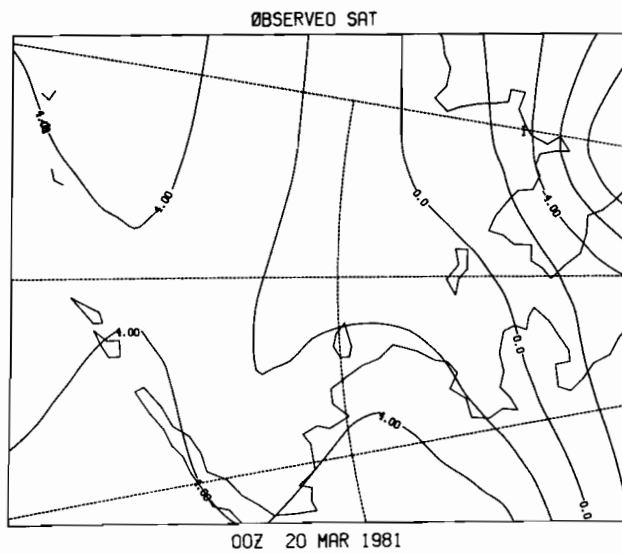
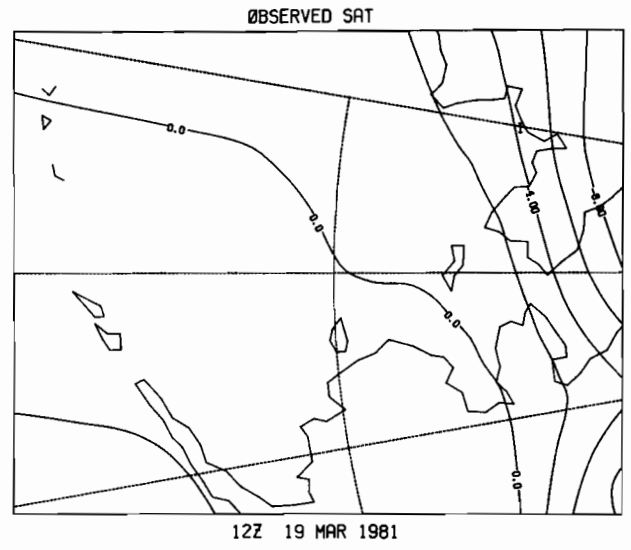
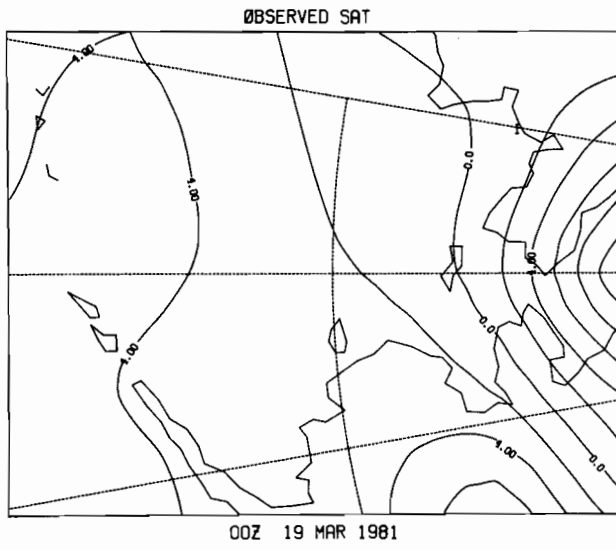
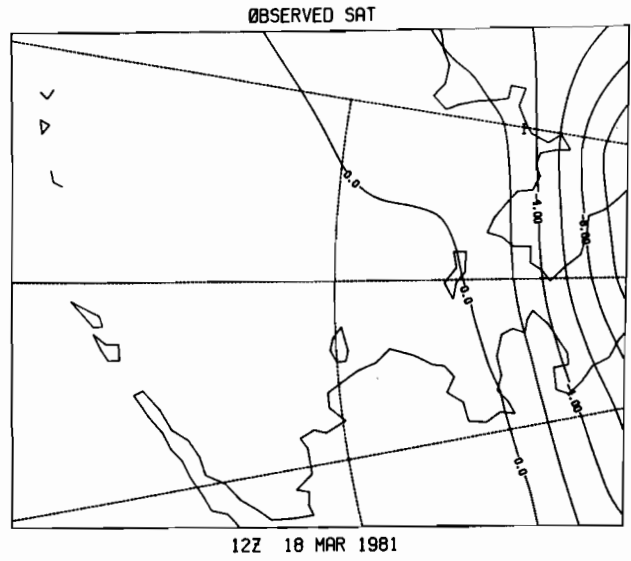
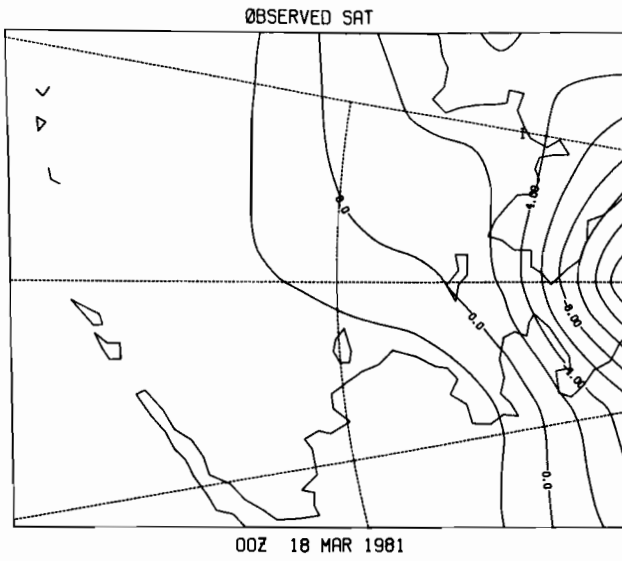


12Z 8 MAR 1981





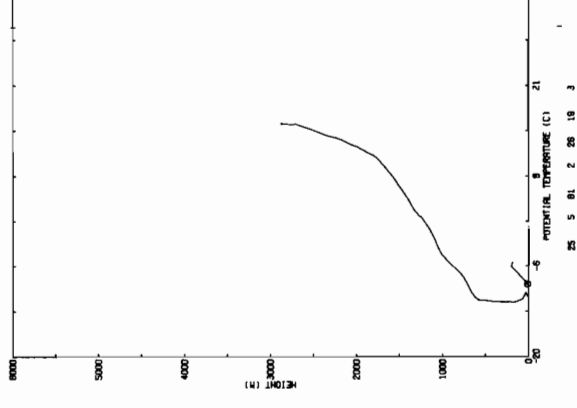
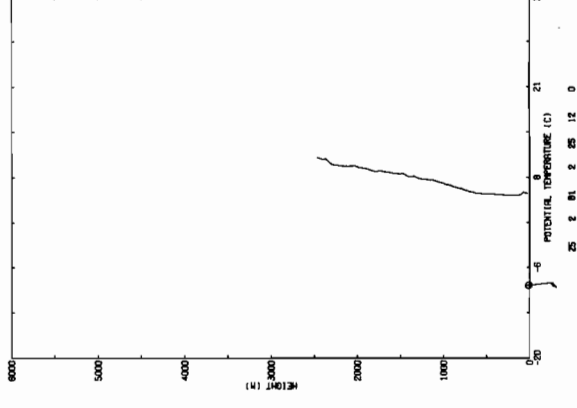
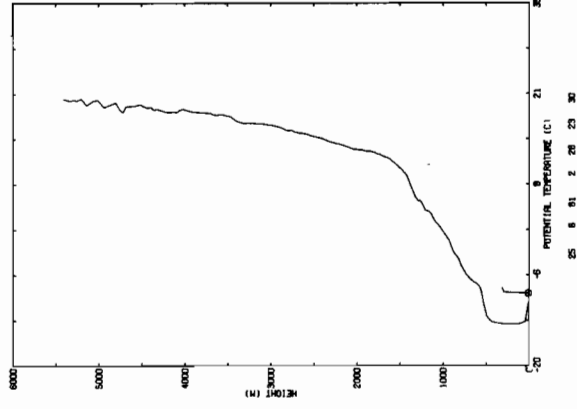
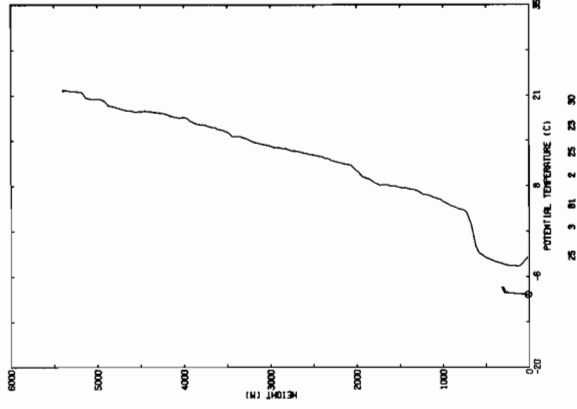
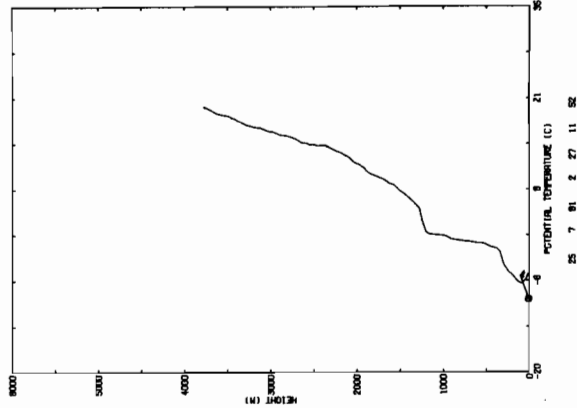
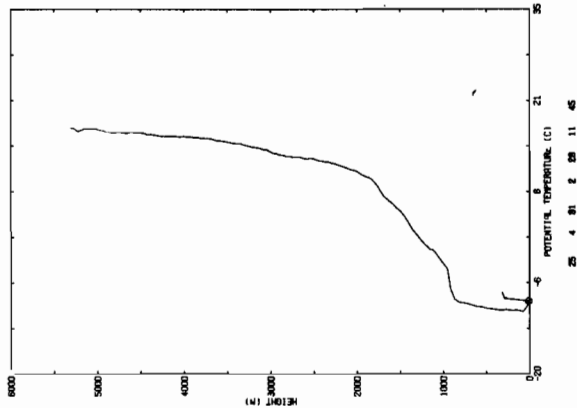


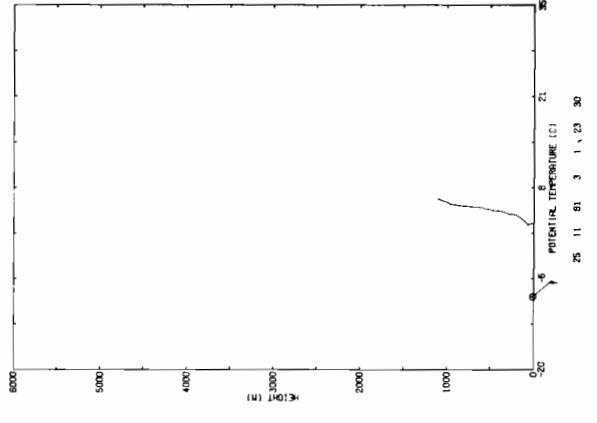
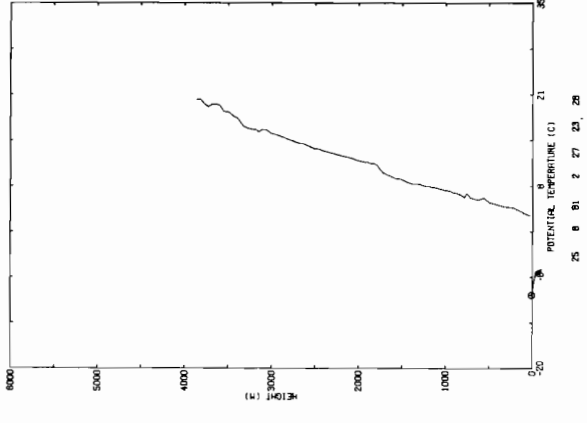
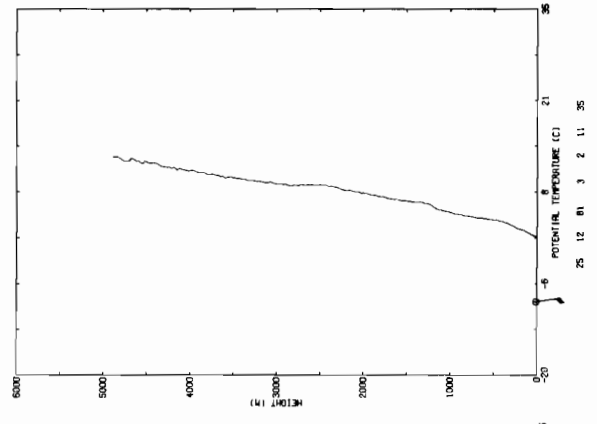
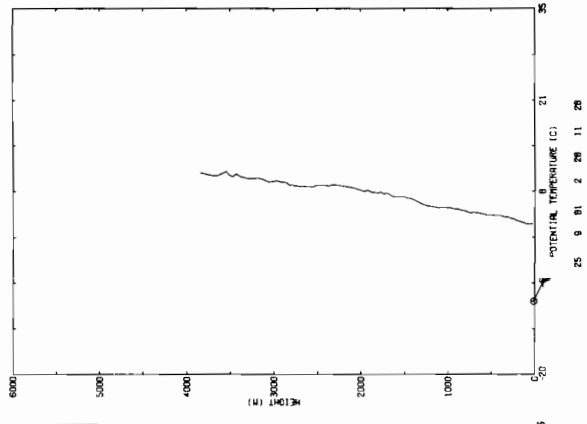
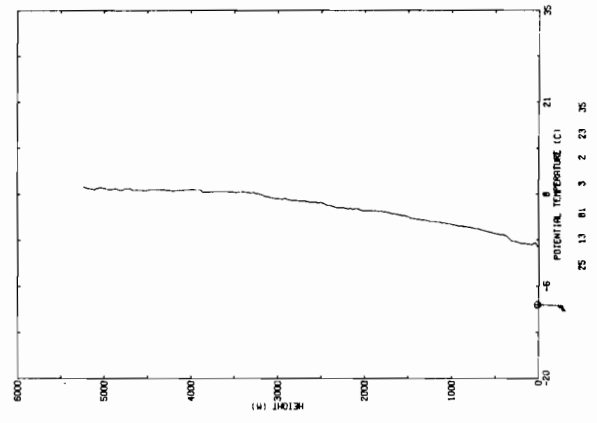
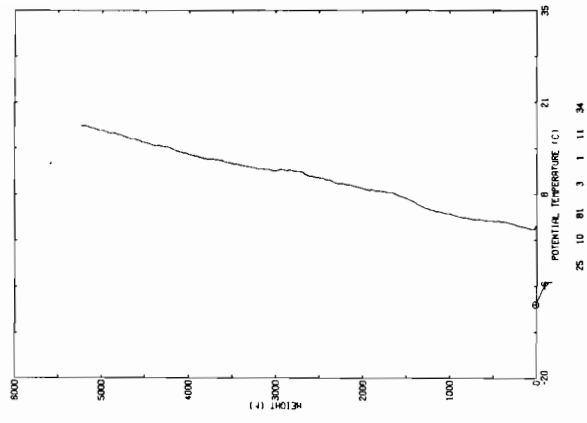


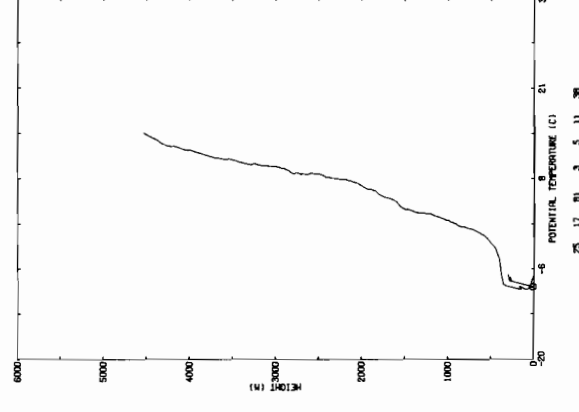
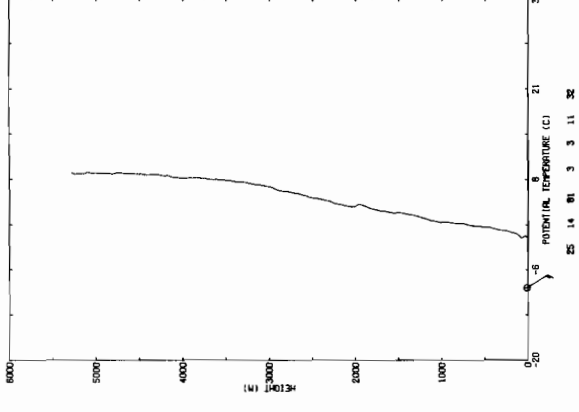
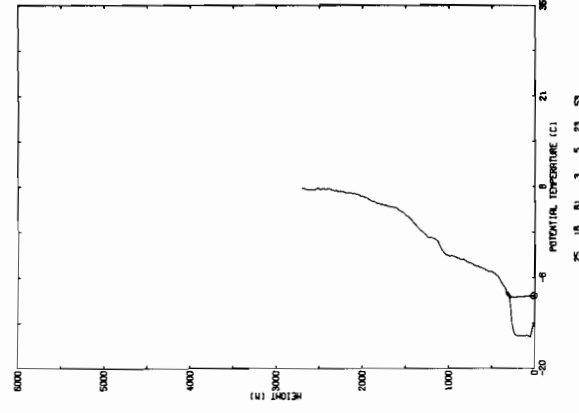
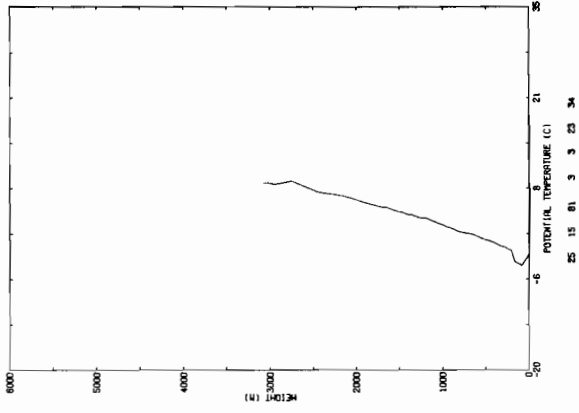
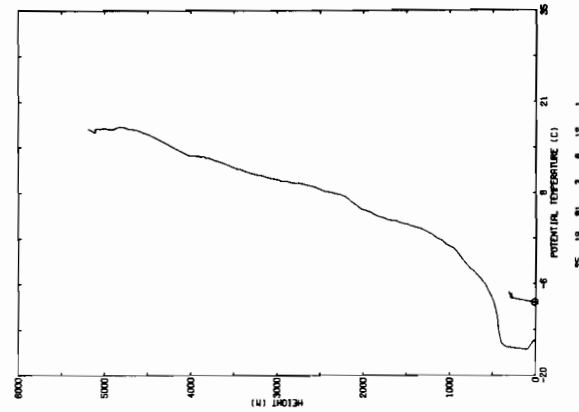
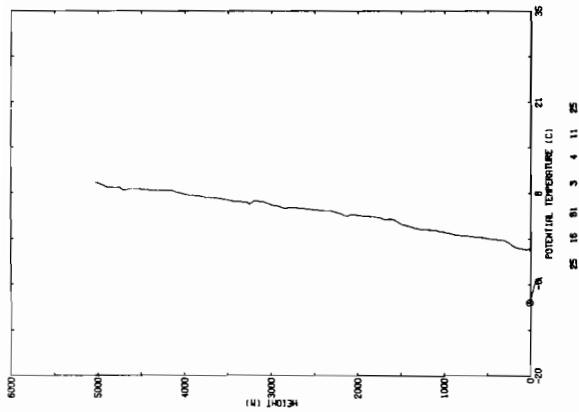
APPENDIX D

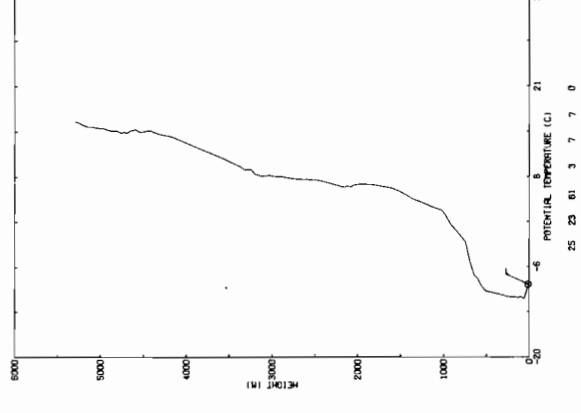
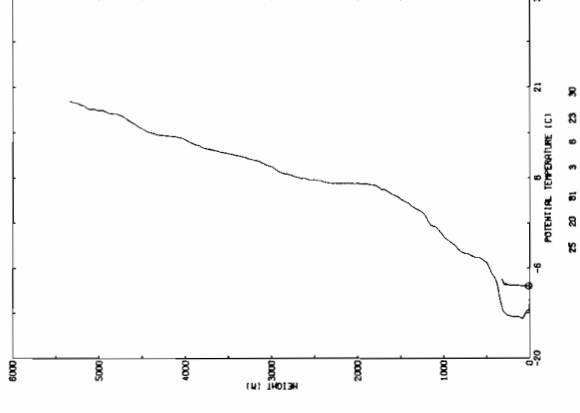
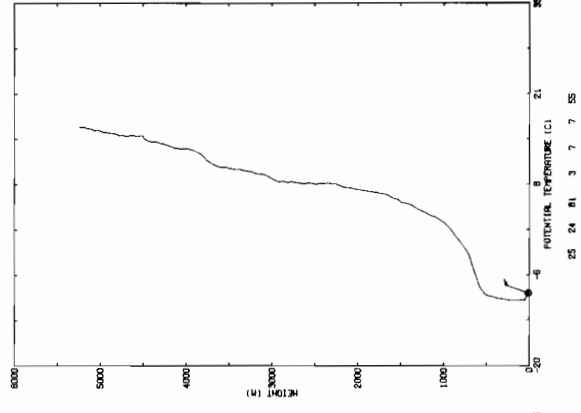
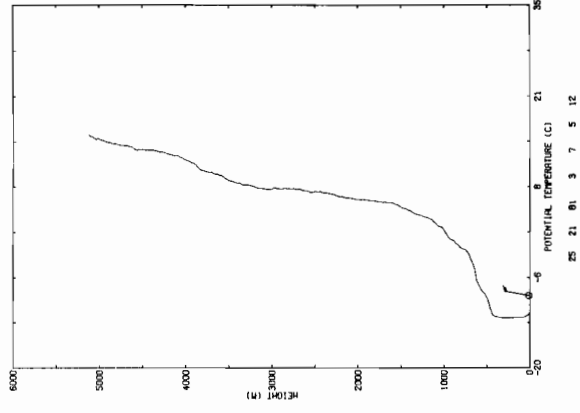
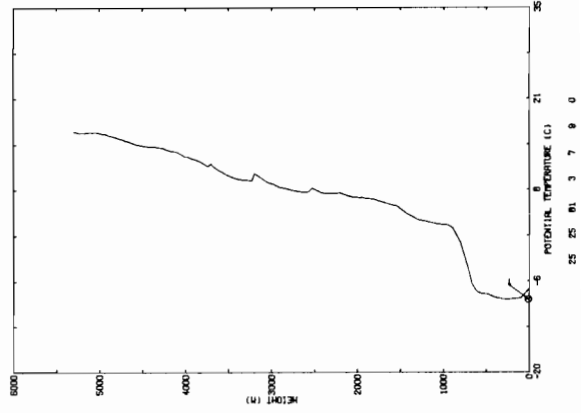
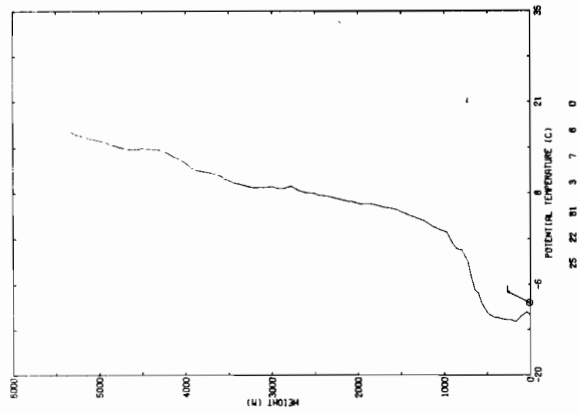
UPPER-AIR OBSERVATIONS FROM THE *SURVEYOR*

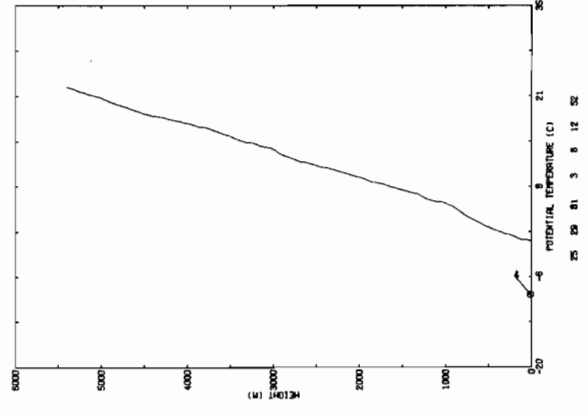
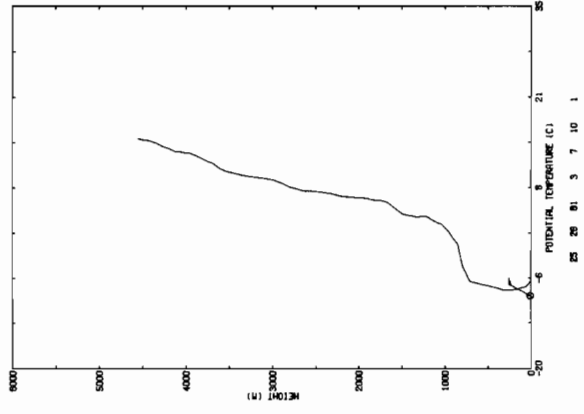
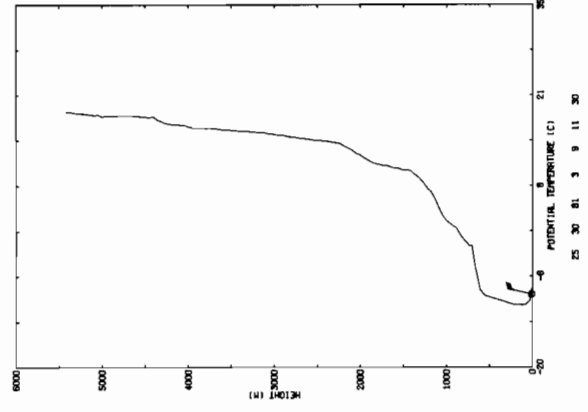
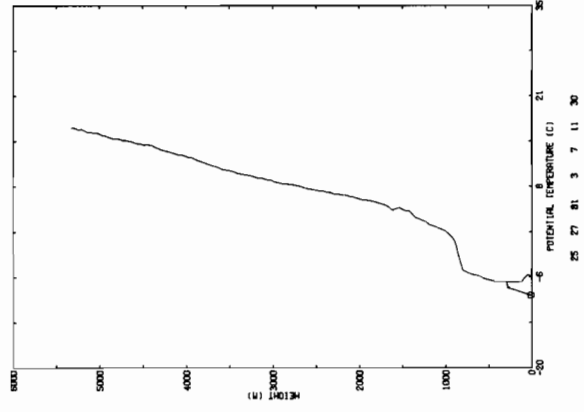
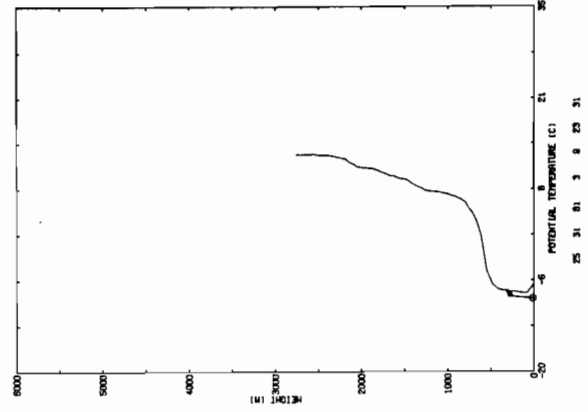
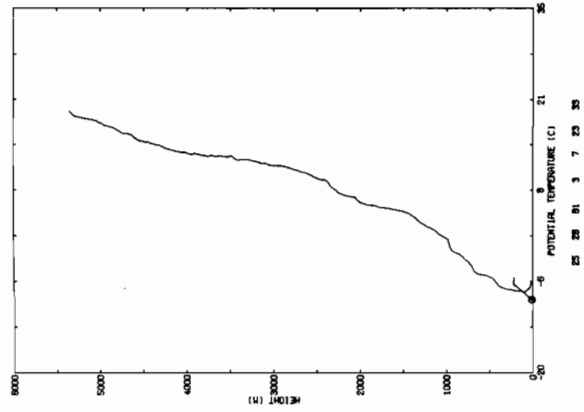
- Solid lines are potential temperature
- Each full barb on the wind indicators represent 5 m s^{-1} . The winds are from the ship at the time of launch.
- The numbers at the bottom of each sounding give the following:
 - Station: 25 *Surveyor*
 - Sounding Number
 - Date and time: Year, month, day, hour, minute of balloon launch

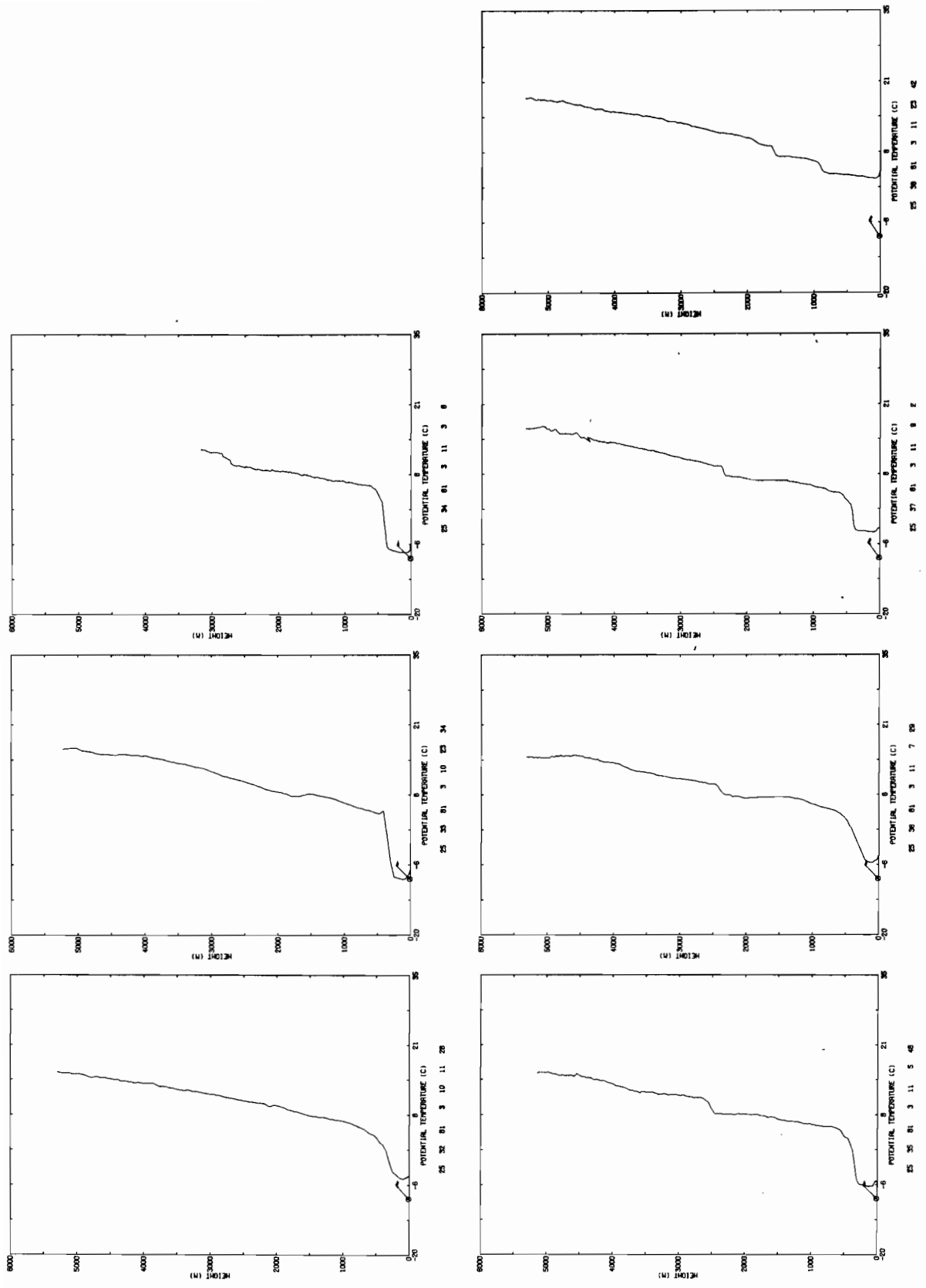












APPENDIX E

UPPER AIR OBSERVATION FOR NOME AND ST. PAUL

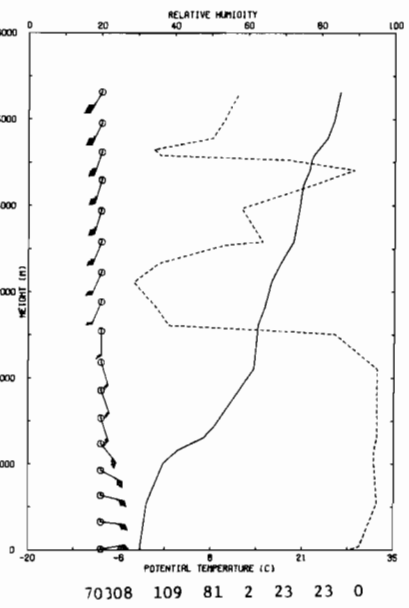
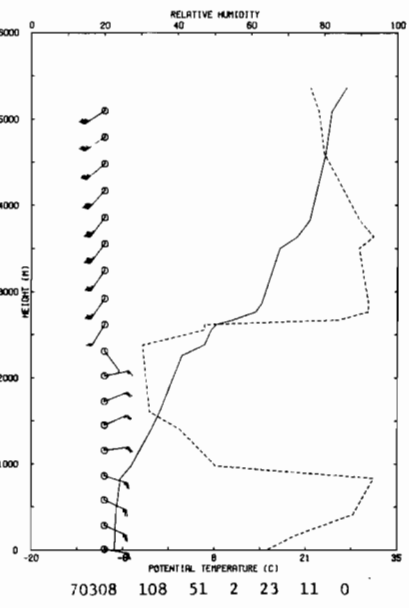
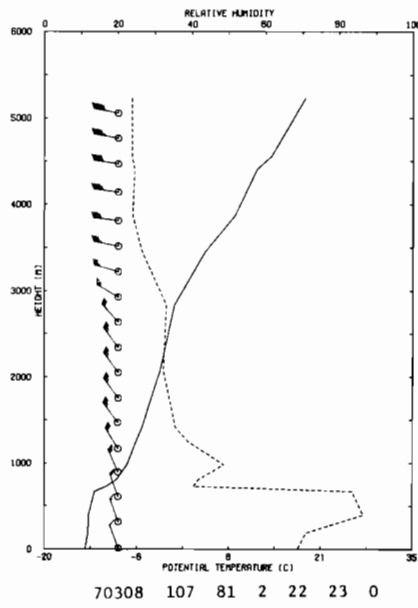
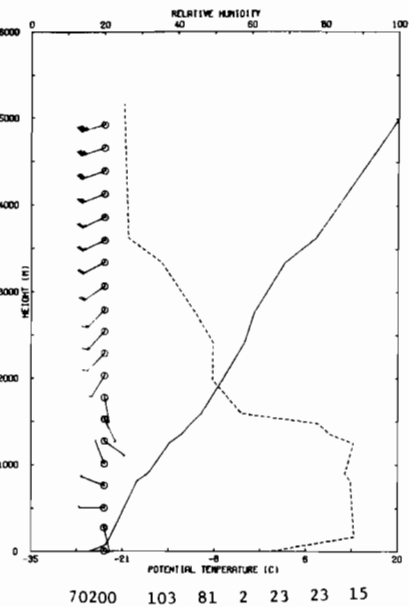
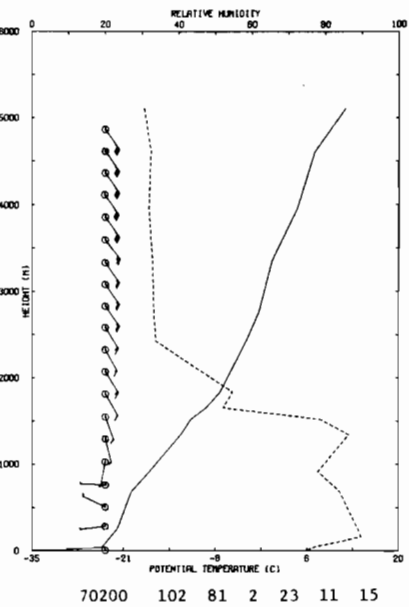
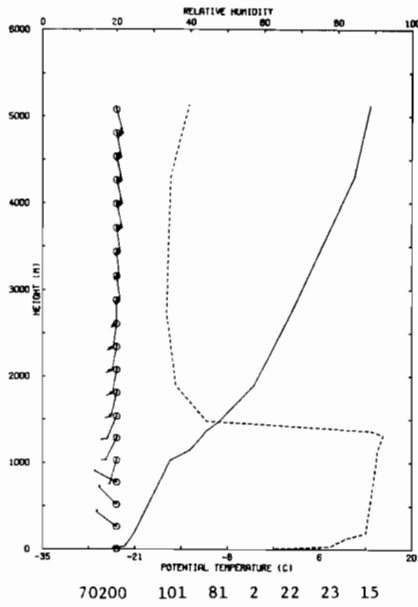
- Solid lines are potential temperature.
- Dashed lines are relative humidity.
- Each full barb on the wind indicators indicate 5 m s^{-1} .
- The numbers at the bottom of each sounding give the following:

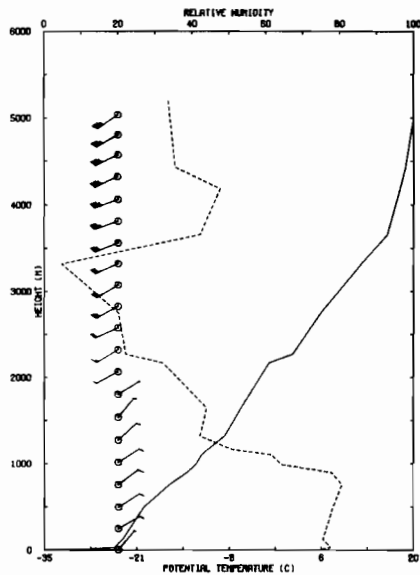
Station: 70200 Nome

70308 St. Paul

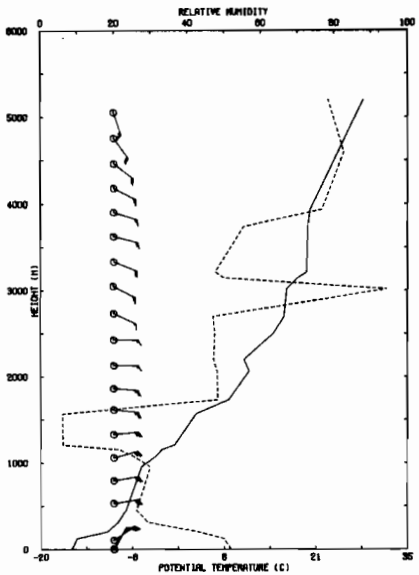
Sounding number

Date and time: Year, month, day, hour, minute of balloon launch.

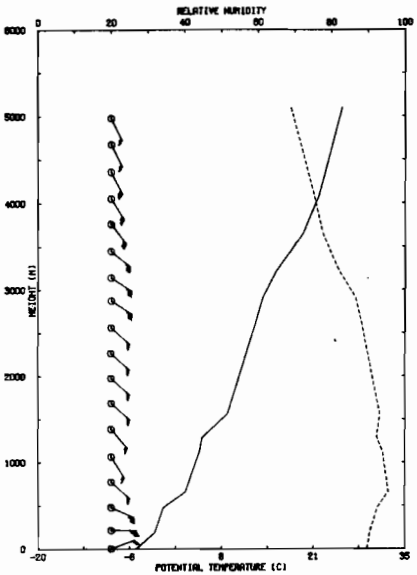




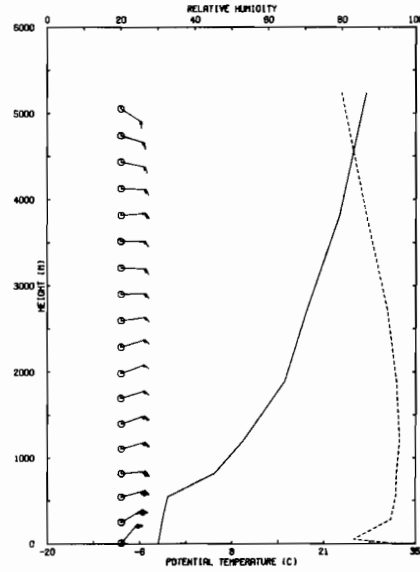
70200 104 81 2 24 11 15



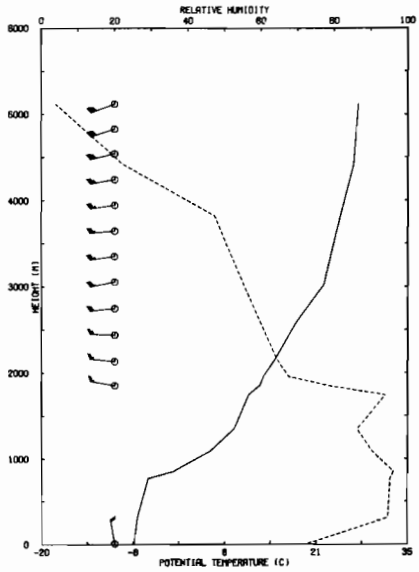
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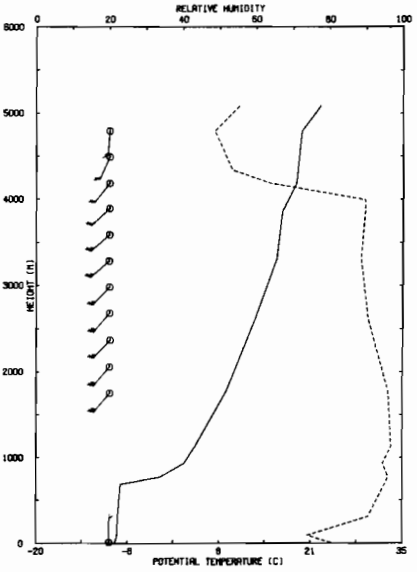
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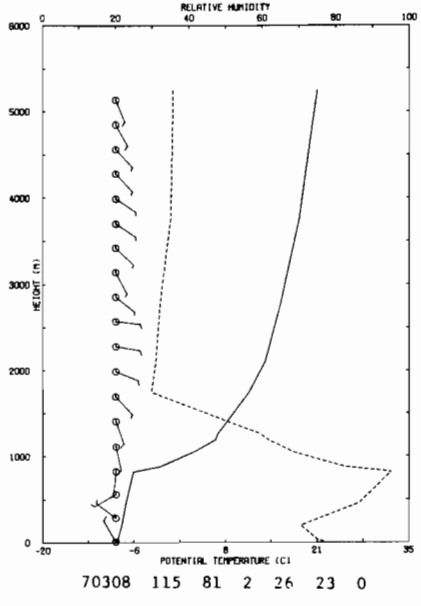
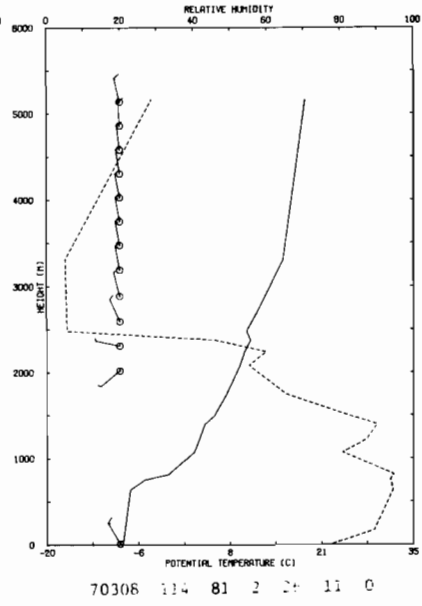
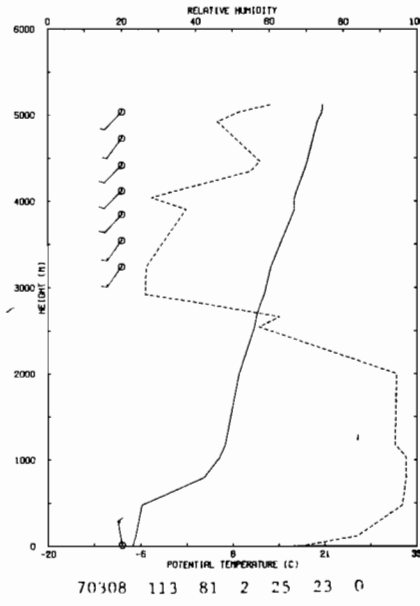
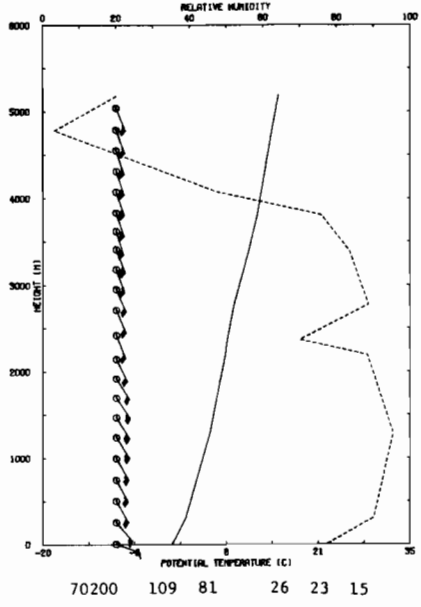
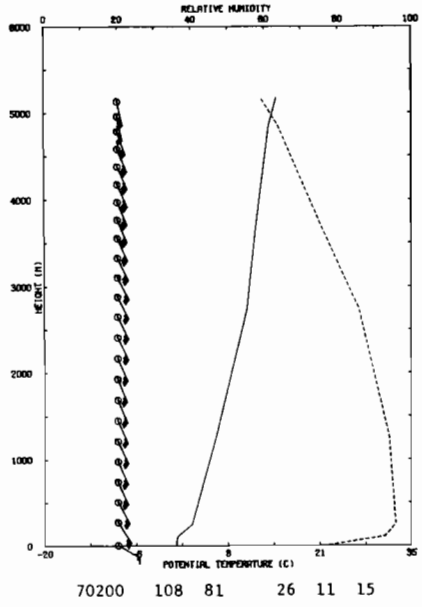
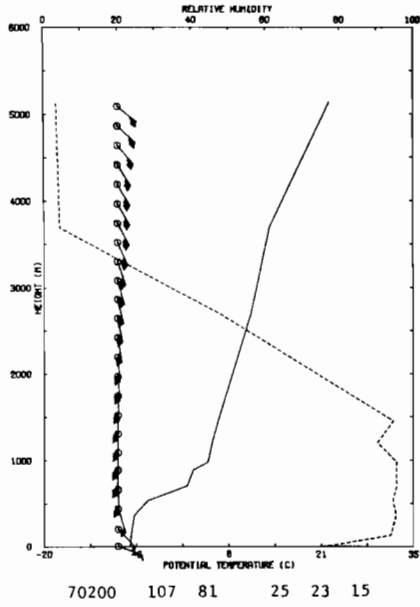
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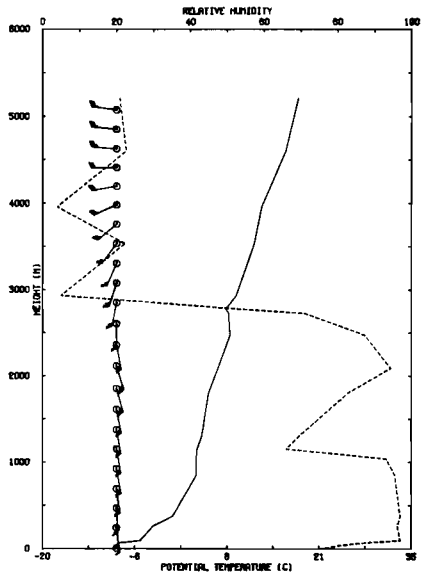


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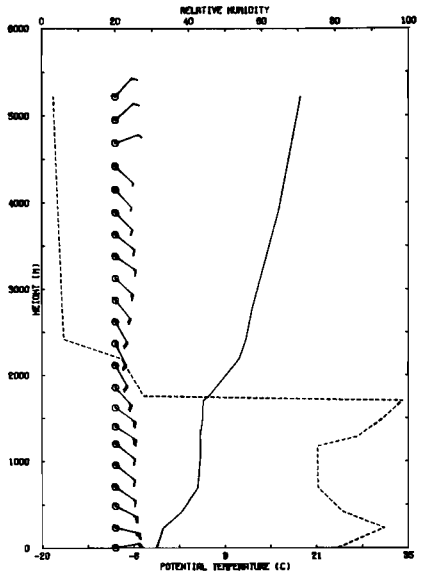


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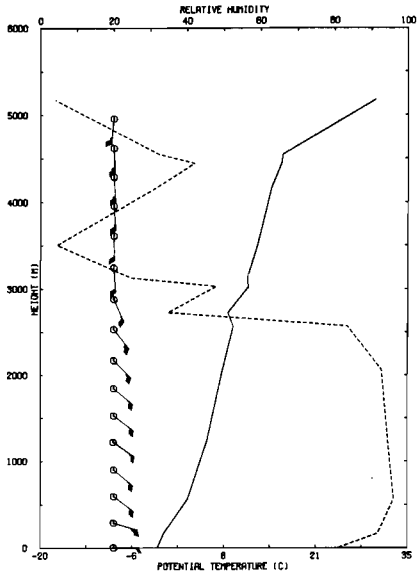




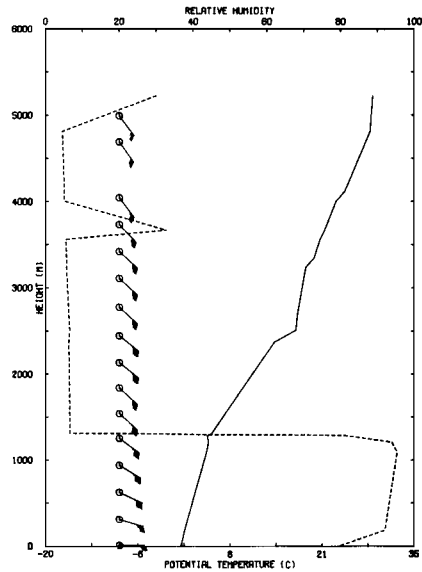
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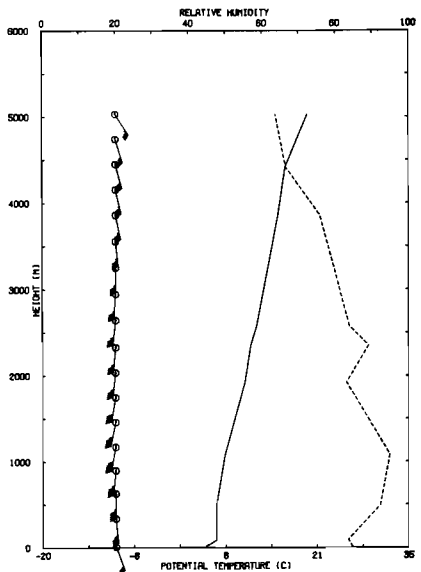
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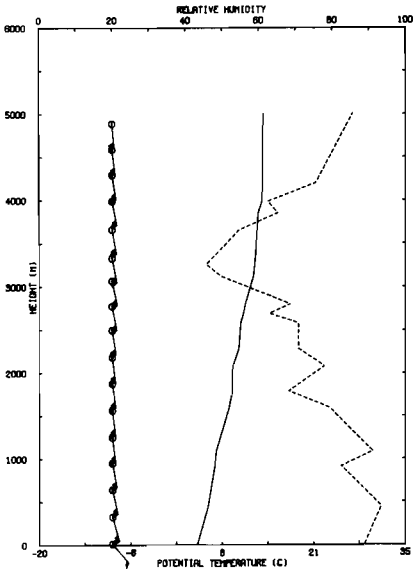
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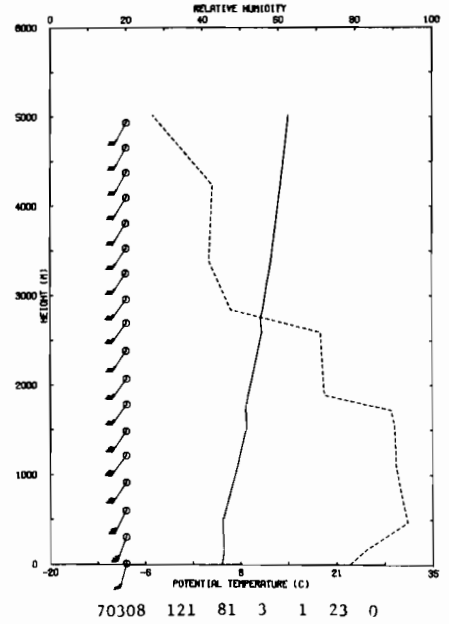
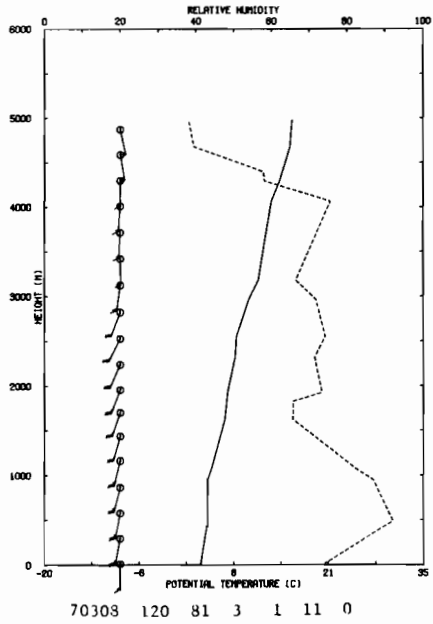
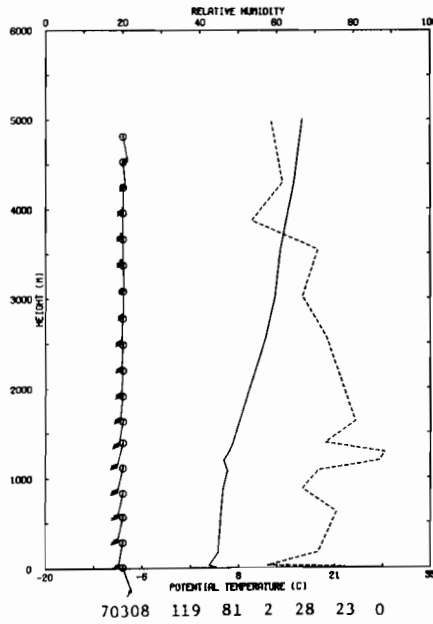
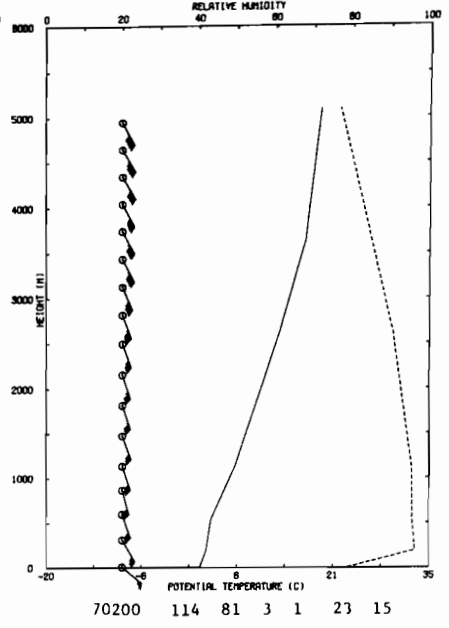
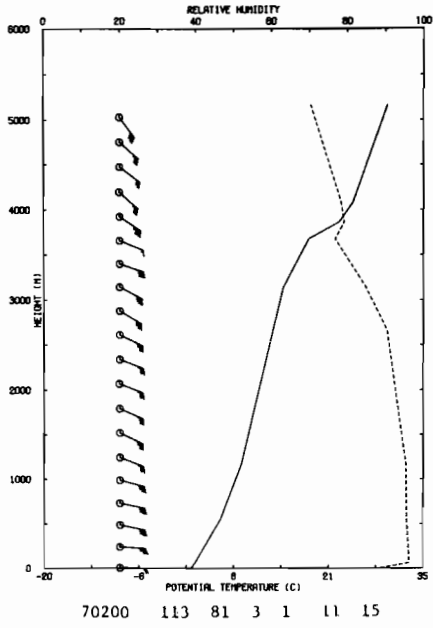
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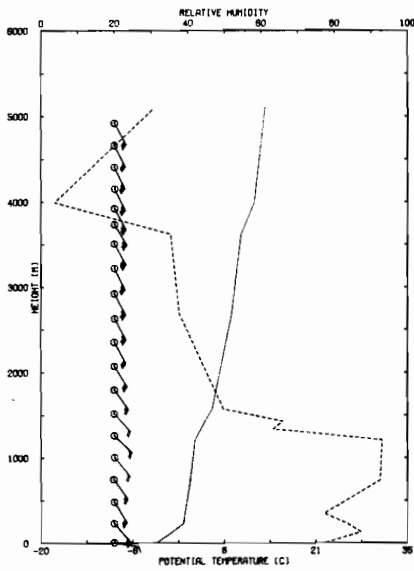


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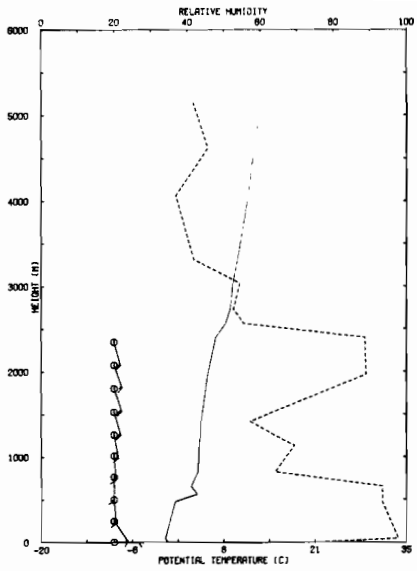


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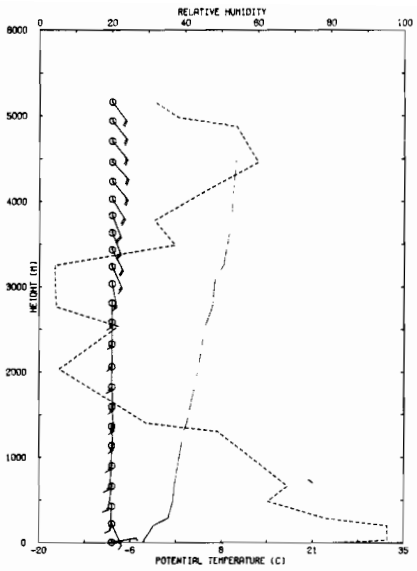




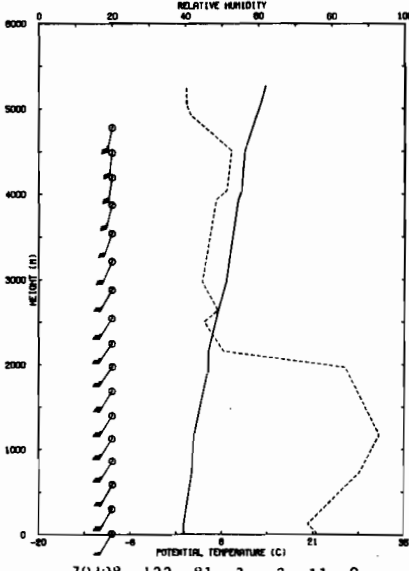
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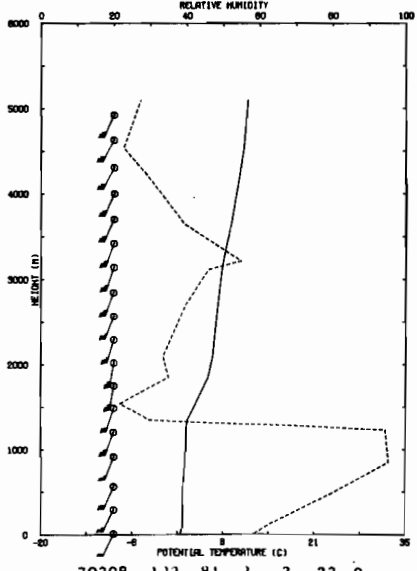
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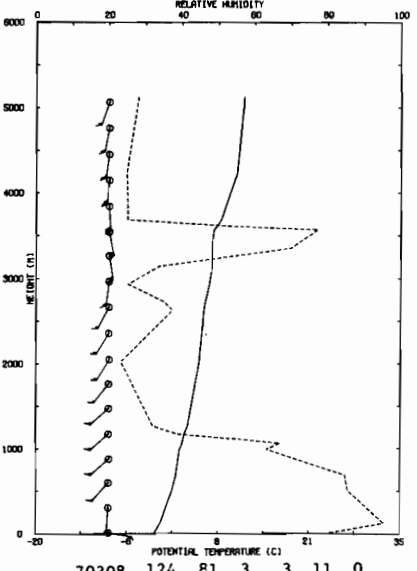
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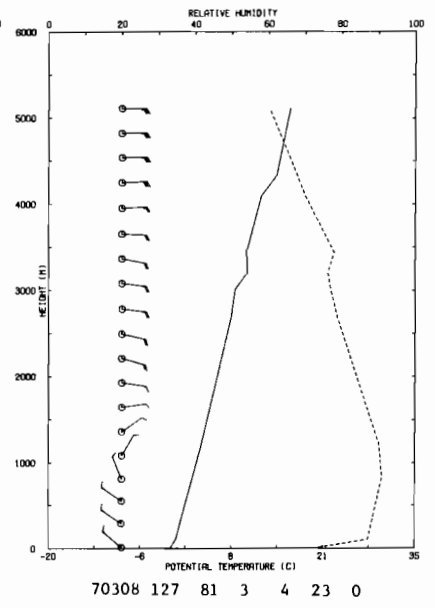
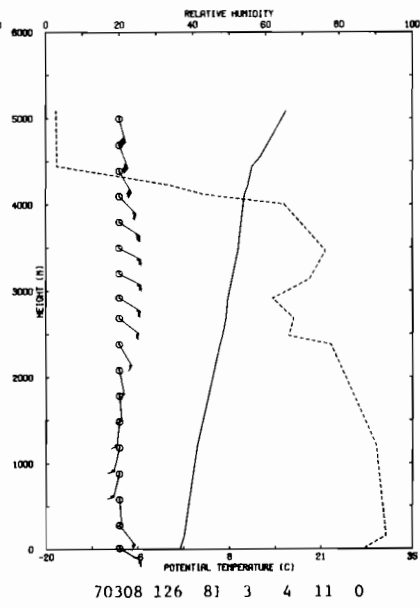
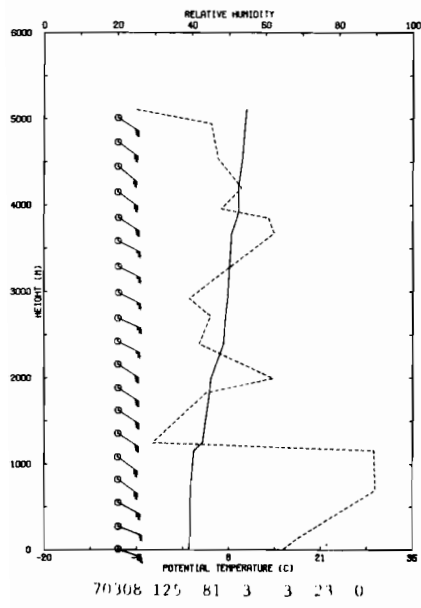
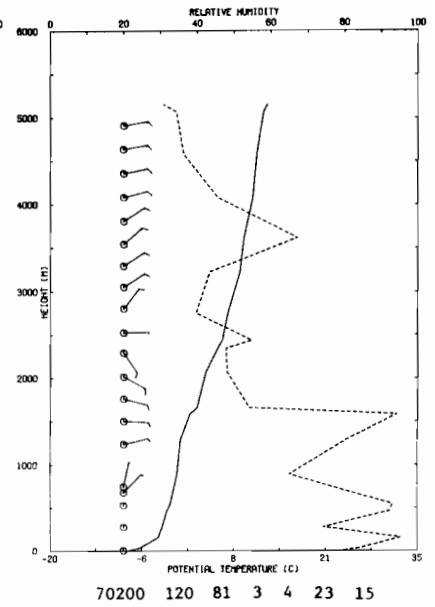
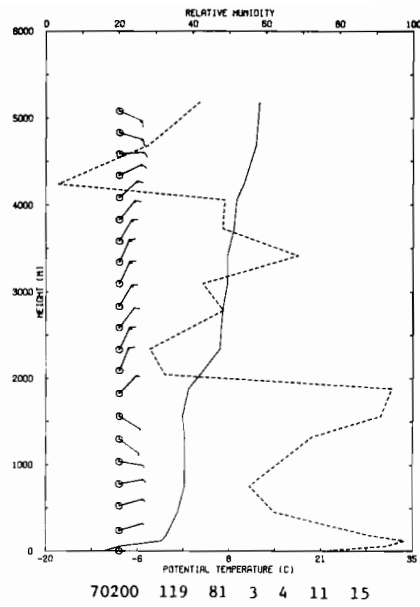
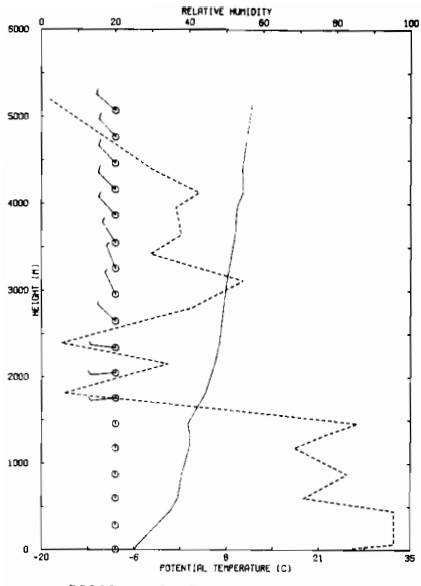
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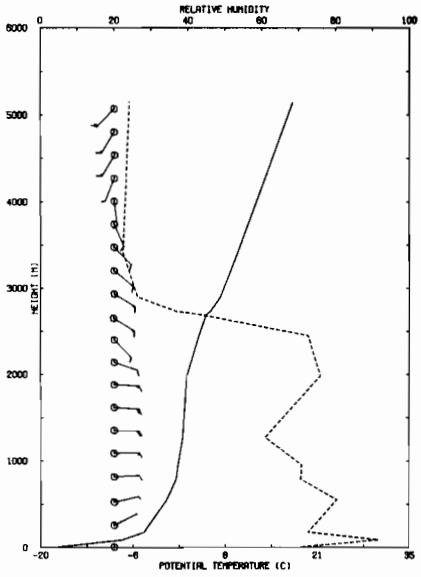


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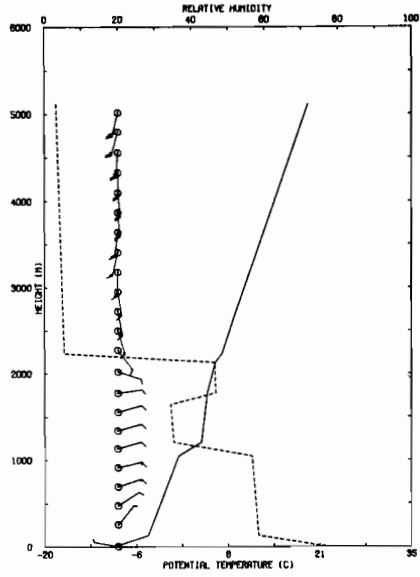


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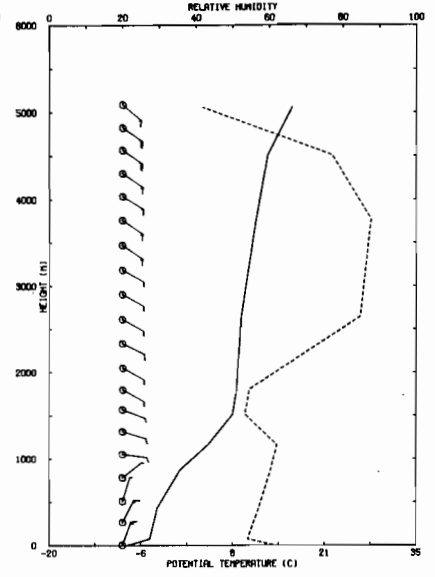




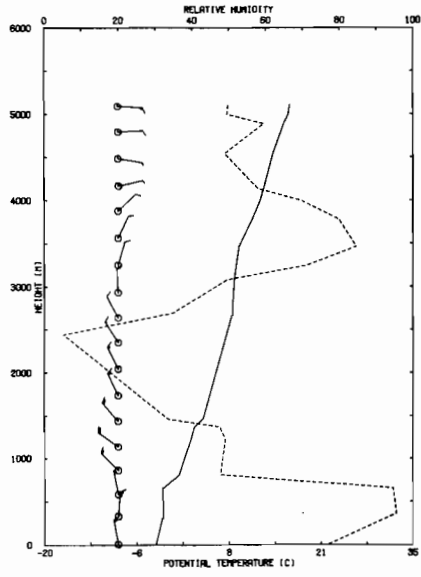
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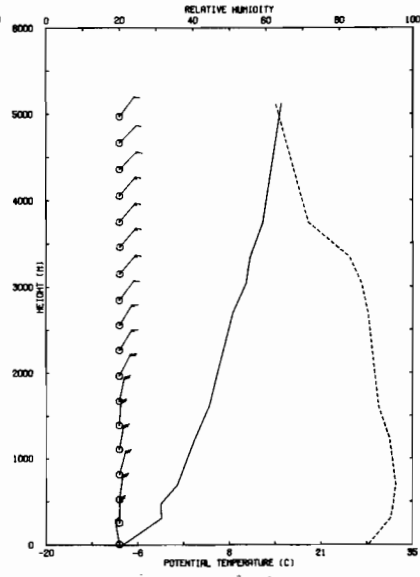
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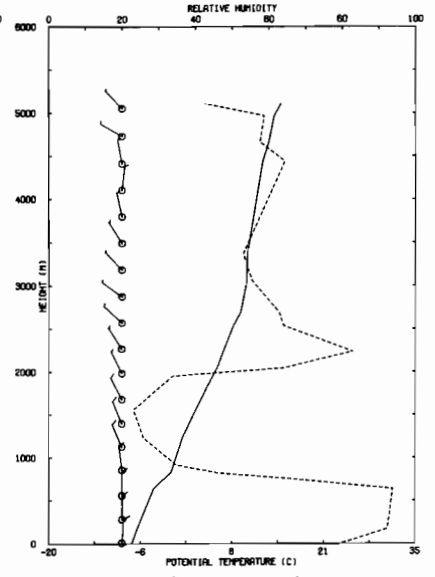
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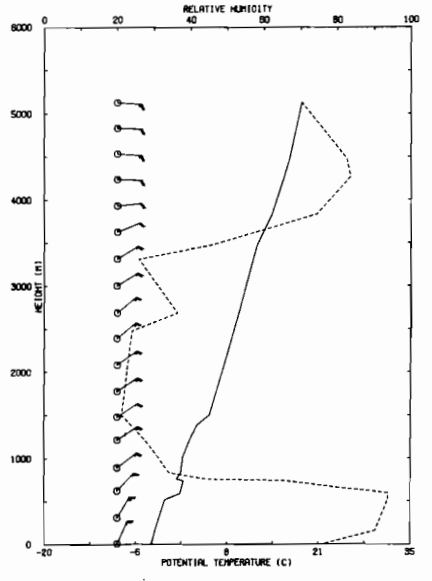
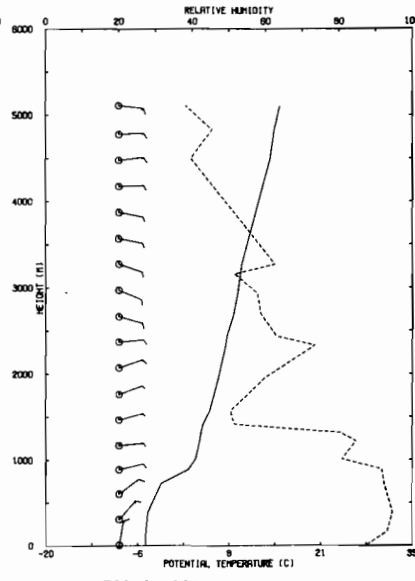
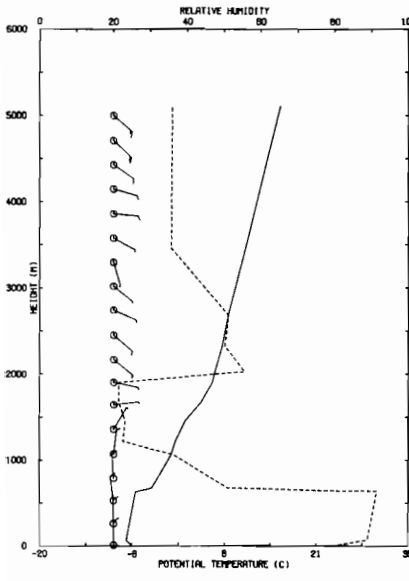
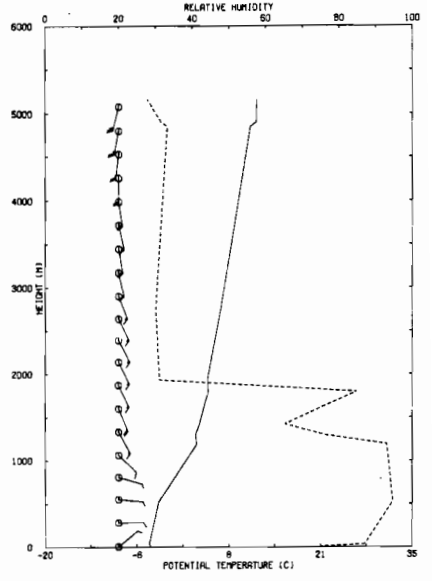
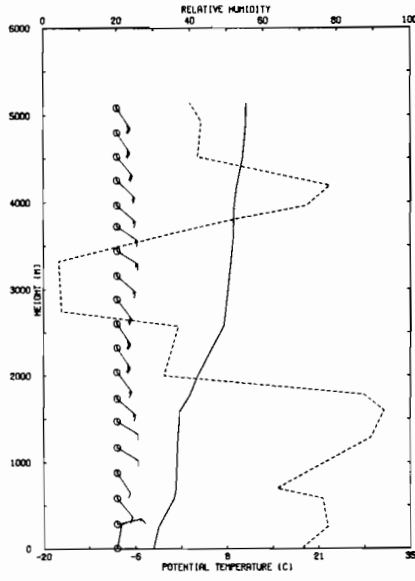
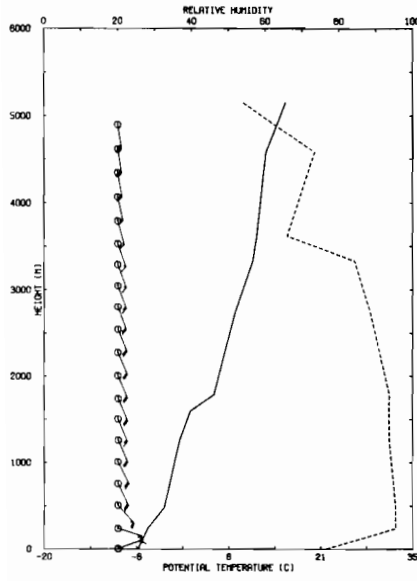
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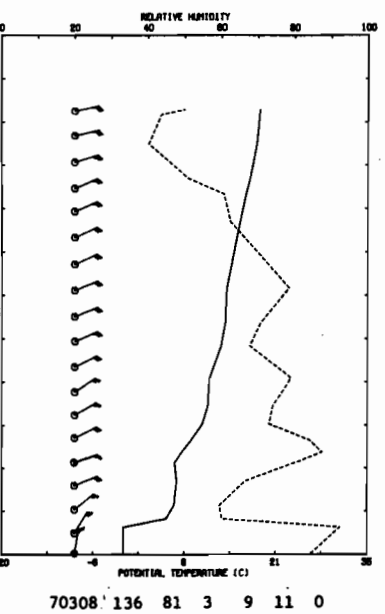
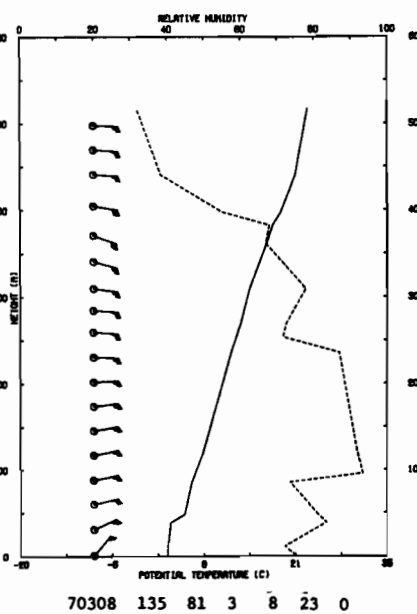
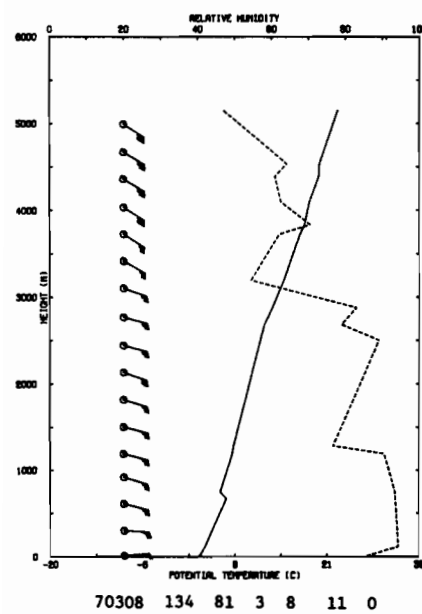
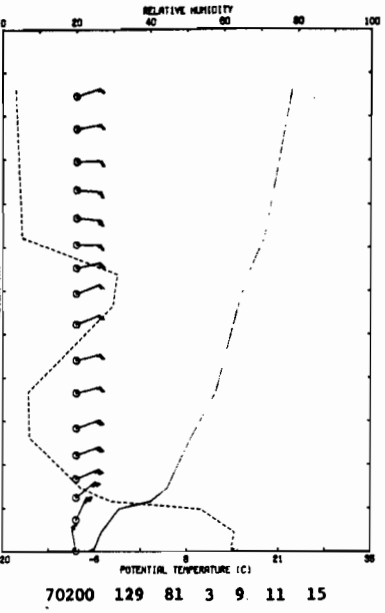
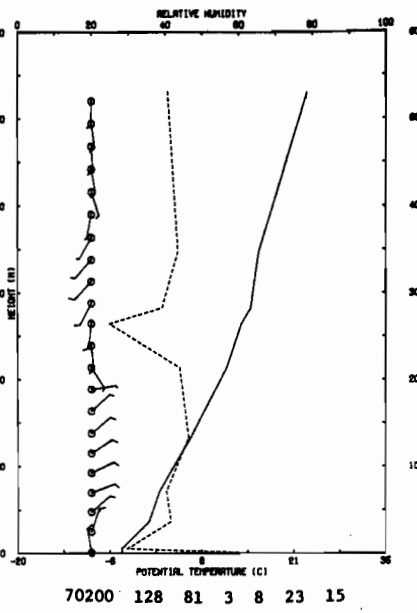
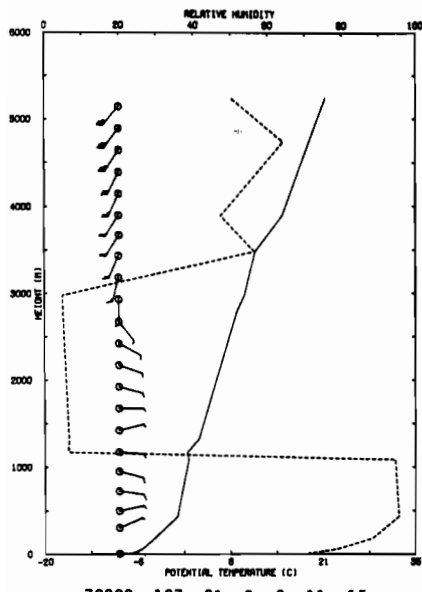


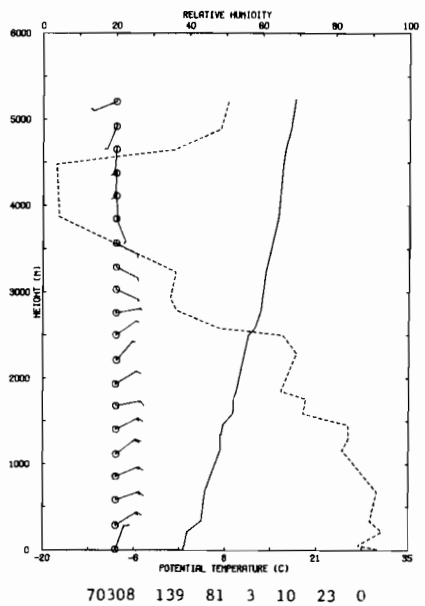
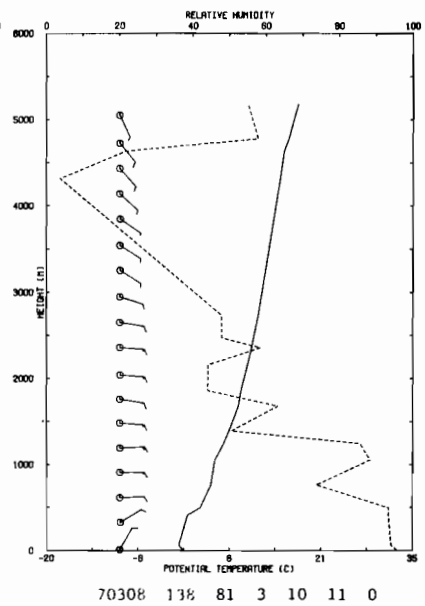
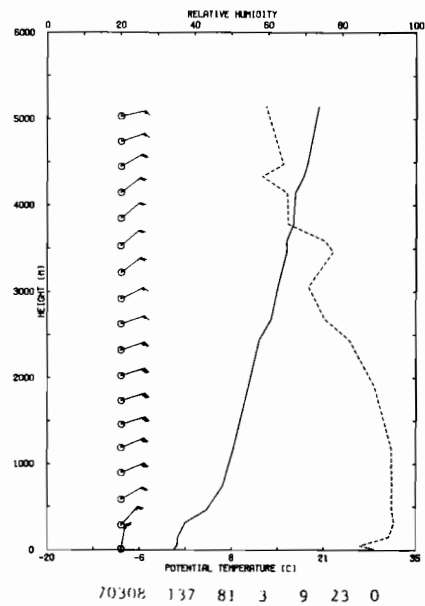
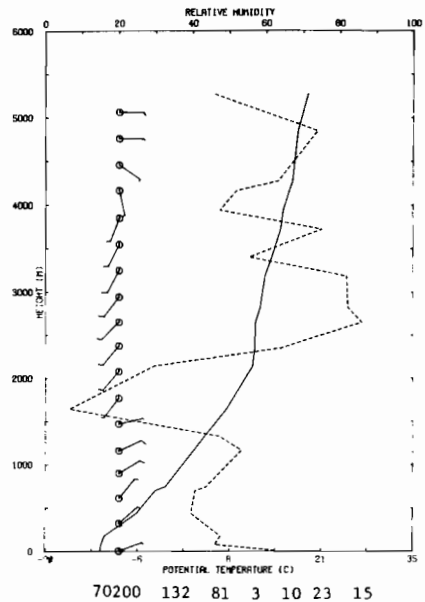
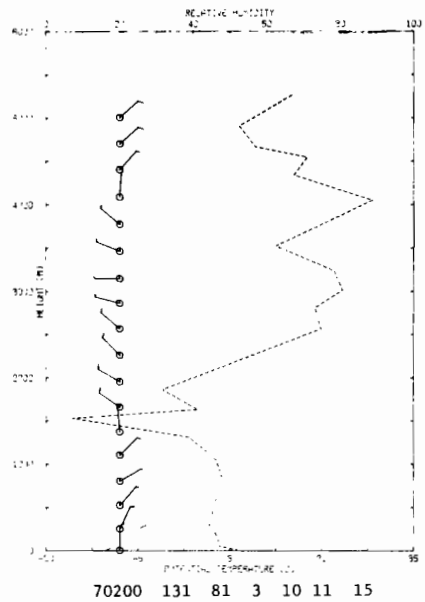
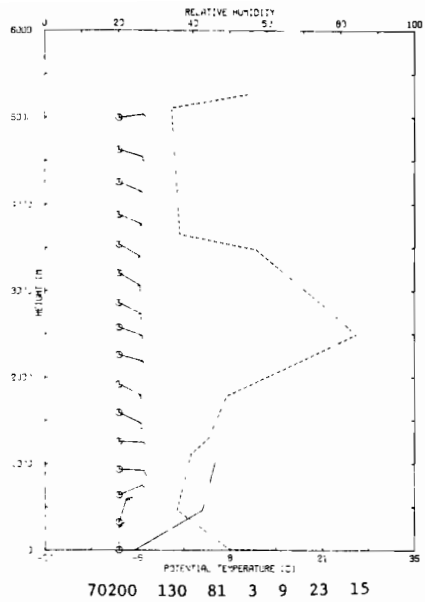
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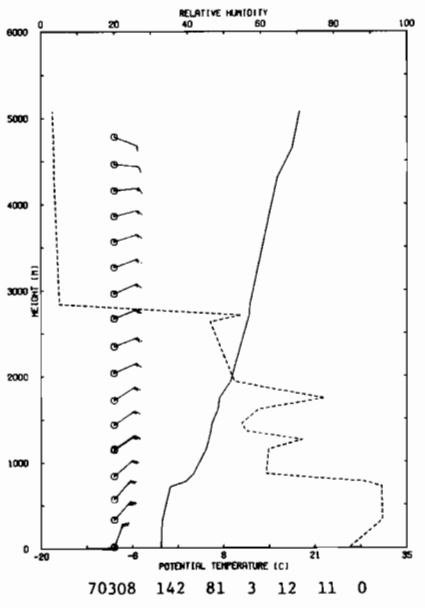
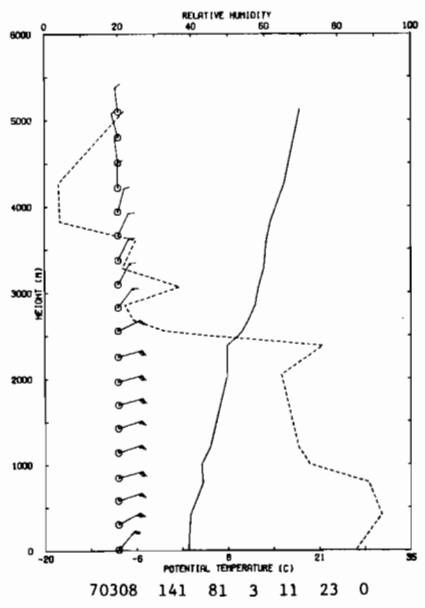
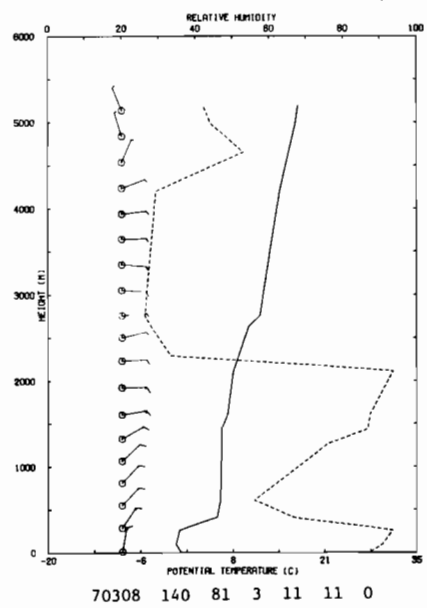
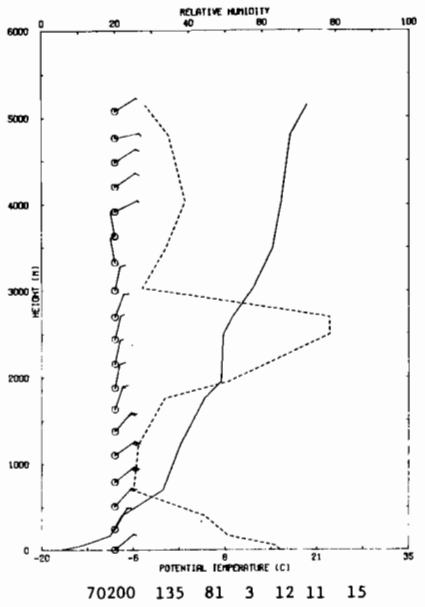
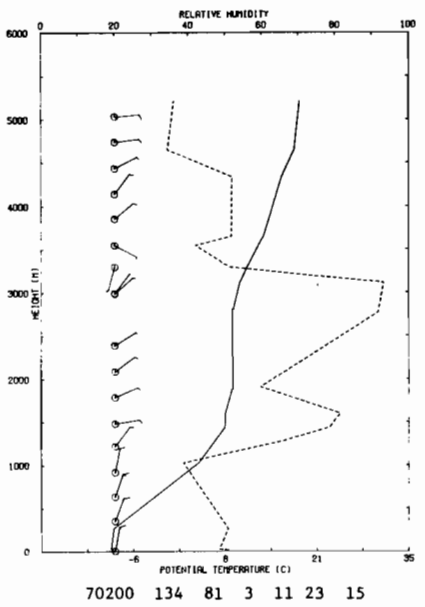
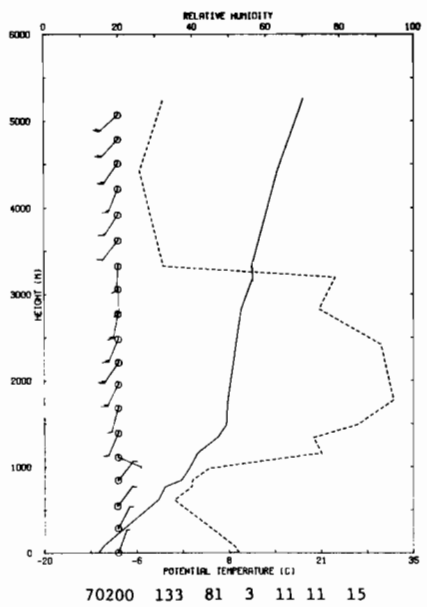


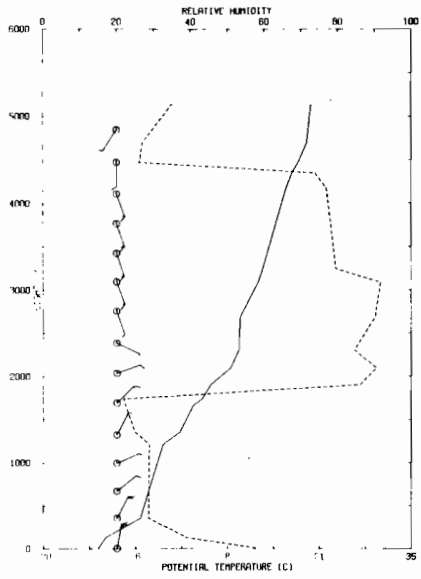
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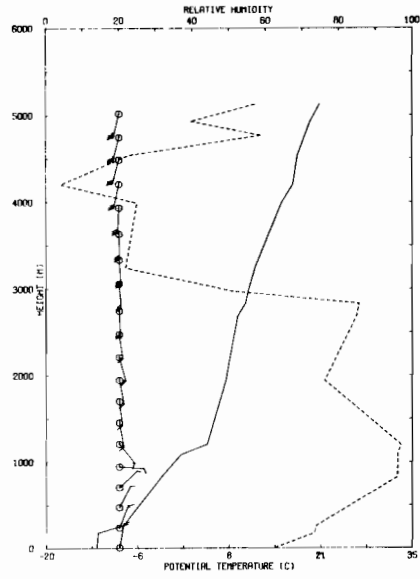




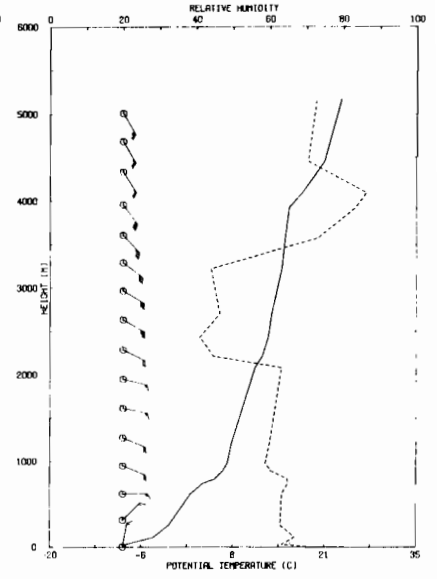




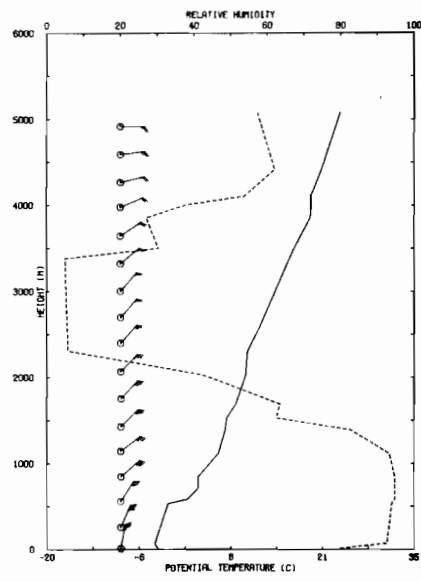
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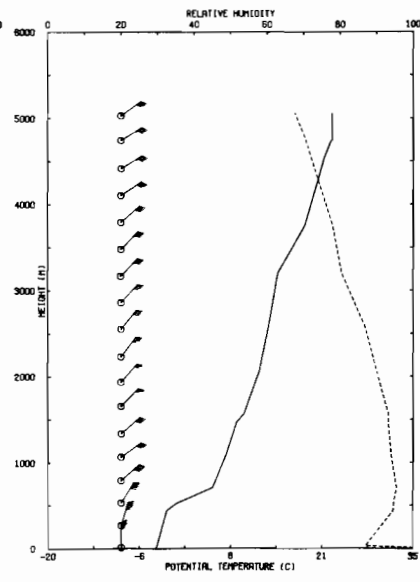
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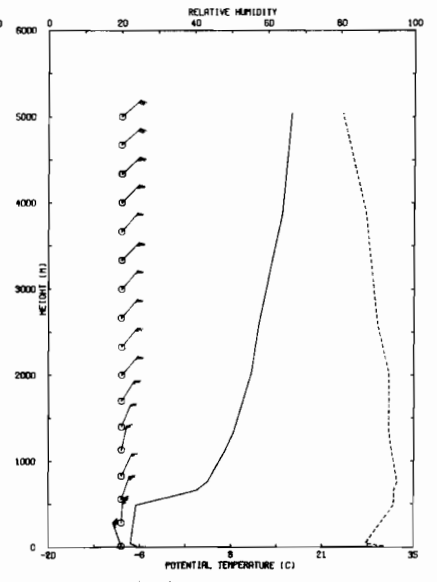
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70308 143 81 3 12 23 0



70308 144 81 3 13 11 0



70308 145 81 3 13 23 25

