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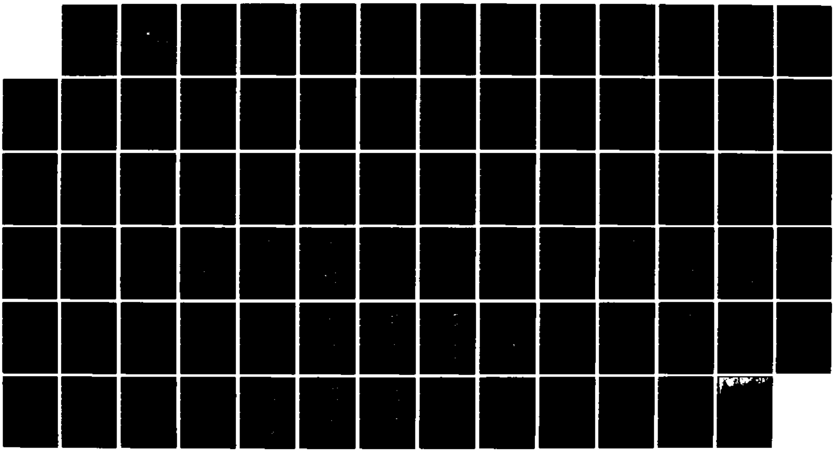

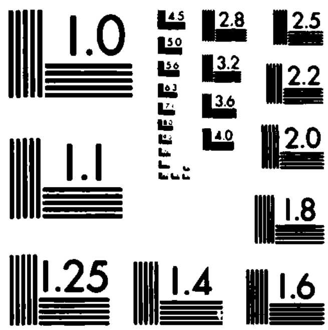
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NPS63-83-003

NAVAL POSTGRADUATE SCHOOL

Monterey, California

OPEN-OCEAN FOG FORECASTING: USE OF LEIPPER AND CLARK FOG INDICES AT OCEAN STATION VICTOR (34N,134E) DURING JULY-AUGUST 1968, 1970, 1971

by

Glenn H. Jung

June 1983

Approved for public release; distribution unlimited

Prepared for: Naval Environmental Prediction Research Facility
Monterey, California 93940

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The work reported herein was supported by the Naval Environmental Prediction Research Facility.

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Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER: NPS-63-83-003

2. GOVT ACCESSION NO.: AD-A130517

3. RECIPIENT'S CATALOG NUMBER:

4. TITLE (and Subtitle): Open-Ocean Fog Forecasting: Use of Leipper and Clark Fog Indices at Ocean Station VICTOR (34N,134E) during July-August 1968, 1970, 1971

5. TYPE OF REPORT & PERIOD COVERED: Technical Report; July-September 1982

6. PERFORMING ORG. REPORT NUMBER:

7. AUTHOR(s): Glenn H. Jung

8. CONTRACT OR GRANT NUMBER(s):

9. PERFORMING ORGANIZATION NAME AND ADDRESS: Naval Postgraduate School, Monterey, CA 93940

10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS: N6685682WR82002

11. CONTROLLING OFFICE NAME AND ADDRESS: Naval Environmental Prediction Research Facility, Monterey, CA 93940

12. REPORT DATE: June 30 1983

13. NUMBER OF PAGES: 78

14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office):

15. SECURITY CLASS. (of this report): Unclassified

15a. DECLASSIFICATION/DOWNGRADING SCHEDULE: Unclassified

16. DISTRIBUTION STATEMENT (of this Report):

Approved for public release; distribution unlimited

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report):

18. SUPPLEMENTARY NOTES:

19. KEY WORDS (Continue on reverse side if necessary and identify by block number):

Fog Forecasting
North Pacific Ocean Fog
Open-ocean Fog
Marine Fog
Leipper/Clark Fog Indices

20. ABSTRACT (Continue on reverse side if necessary and identify by block number):

Fog-forecasting parameters used by Leipper along the California coastline were adapted for open-ocean use by Clark (1981) in the Gulf of Alaska for non-frontal fog situations. Clark's fog-forecasting indices are tested now for another North Pacific Ocean location at OSV "V" (34N,164E) during July-August, 1968-1971. These indices appear to describe frontal as well as non-frontal fog situations in the North Pacific Ocean in the summer. Additional

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S/N 0102-014-6601

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

#20 - ABSTRACT - (CONTINUED)

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ABSTRACT

Fog-forecasting parameters used by Leipper along the California coastline were adapted for open-ocean use by Clark (1981) in the Gulf of Alaska for non-frontal fog situations. Clark's fog-forecasting indices are tested now for another North Pacific Ocean location at OSV "V" (34N, 164E) during July-August, 1968-1971. These indices appear to describe frontal as well as non-frontal fog situations in the North Pacific Ocean in the summer. Additional study is needed to forecast precise start and termination times of such fog occurrence.

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I. INTRODUCTION

The fog parameters developed by Leipper for use in coastal areas along the California coast have been adapted for open ocean use in the eastern North Pacific by Clark (1981) in his study of non-frontal fog occurrences; this study was for summer months at Ocean Station PAPA (OSV "P" at 50N,145W) in 1973 and 1977, and parameters were successfully tested on 1975 data.

To extend the test of Clark's adapted parameters to another open ocean area, the present study was initiated, using data from Ocean Station Vessel VICTOR (OSV "V" at 34N,164E) in the western North Pacific Ocean. Several questions were addressed:

1) Do the parameters used by Leipper and Clark in their studies have application in open ocean areas other than the region studied by Clark (the Gulf of Alaska)?

2) If the parameters are useful in other ocean areas, must they be modified?

3) Do the parameters for non-frontal fog situations have any application for frontal fog situations?

The summer months of July and August were chosen for study at OSV "V" because the best climatology for this region showed maximum fog values then; these climatology values for frequency of fog occurrence are smaller than similar values for the region near OSV "P" used in Clark's study. Years chosen for study were those in which data were most recently recorded at this location (1967-1971). These studies have been confined to ocean locations where atmospheric soundings as well as surface observations are made routinely by trained observers (Ocean Station Vessels meet these conditions).

II. PROCEDURE

The adopted procedure screened the surface observations initially to find those periods when fog was present at OSV "V". No fog was observed in July-August during the years 1967 and 1969; hence no data from those years were used. When a fog period did occur in the other years, upper-air observations were plotted during the intervals before, during, and following the fog period. The Leipper indices were formed from the proper combination of surface and upper-air data values. Sea-level weather charts within the area were reviewed to ascertain the basic weather patterns associated with fog occurrence in this location. A summary of synoptic weather patterns, a representative sea-level weather chart, and upper-air soundings for each occurrence are shown in the Appendix.

III. RESULTS

There were surprisingly few fog occurrences at OSV "V" in the months July-August during 1967-1971. No fog occurred in these months at OSV "V" in 1967 or 1969. In the other three years there were only a few episodes and these varied in duration from one to eighteen hours. In one situation the fog occurred on three consecutive days, with short intervals separating the fog occurrences, to make one fog "event". There were only five fog events in these three years in July-August at OSV "V". These were distributed with only one event in 1968, one in 1970, and three events in 1971. A total of about 135 hours of fog was reported in these five fog events.

It was decided to combine the events of frontal fog with those not associated definitely with fronts because there were so few events to study. In fact, all five fog events occur either in fronts or they are closely associated with fronts; the large amount of frontal activity through this region in July and August was not anticipated.

These results then will provide a limited test as to how well the non-frontal-fog indices describe frontal-fog conditions. To pursue this limited test in more detail, the Leipper-Clark non-frontal-fog parameters and indices were reviewed:

1. The base of the inversion (in mb) as recorded from the 00Z radiosonde observation (RAOB).

2. The highest air temperature above the base of the inversion (if an inversion exists with a base below 3000 feet) measured in degrees C at 00Z.

3. The sea-surface temperature measured in degrees C at 00Z and 12Z.

4. The dewpoint temperature in degrees C at 00Z and 12Z.

5. The surface-wind direction in degrees true, and the windspeed in knots, at 00Z and 12Z.

Items 3-5 are plotted for the three years with fog during the entire months of June-July at OSV "V" and are included in the Appendix, along with sea-level pressure, visibility, present-weather code and past-weather code.

The five parameters just listed are combined into four indices, described below, which all must be favorable on a given day to forecast fog occurrence (Clark, 1981):

1. Height of the inversion base; to be favorable for fog, the value at 00Z must be less than 1000 feet. The present study substituted inversion height measured in terms of atmospheric pressure; to be favorable, the inversion must occur with an atmospheric pressure $\geq$ 1000 millibars.

2. Temperature index; this is calculated by recording the highest air temperature above the inversion base at 00Z and subtracting from it the sea-surface temperature recorded at 00Z the previous day; to be favorable, the difference must be greater than or equal to 0 degrees C.

3. Moisture index; this is calculated by recording the dewpoint temperature at 00Z and subtracting from it the sea-surface temperature recorded at 00Z on the previous day; to be favorable, the difference must be greater than or equal to -0.5 degrees C.

4. Advection index; a combination of wind direction and windspeed at 00Z; to be favorable, wind direction must be between 120 and 290 degrees true, and the windspeed must be between 3 and 15 knots.

Fog occurs when the present-weather symbol (WW) is indicated by Codes 10-11-12; 28; or 40-49; or when the past-weather symbol (W) is Code 4; codes are identified in Table 1.

Fog-forecasting indices were formed for the fog duration and for a period of time preceding and after the observed fog occurrences at OSV "V" in 1968, 1970 and 1971. These are displayed in Table 2 and in the Appendix. The time and duration of the fog also is shown alongside the associated fog-forecasting indices for each fog event.

Index values were evaluated in terms of index conditions favorable for fog at OSV "P" in the Clark study. Values unfavorable for fog according to Clark are marked by "X" adjacent to the values in Table 2.

Consider how well these (Clark) indices performed when fog occurred. In Event (1) the windspeed was too high twice when fog occurred; this was the only non-conforming index. In Event (2) the wind direction one time was outside the Clark limits. In Event (3) one windspeed was too high. In Event (4) fog was indicated successfully by all parameters. No parameters could be determined exactly when fog occurred for its brief duration in Event (5); by extrapolation, it appears that the inversion height and temperature index were unfavorable for fog (and it was observed for only about one hour). These results suggest the indices for OSV "P" probably are important also at OSV "V" to describe conditions favorable for fog occurrence.

TABLE 1

Present-Weather (WW) and Past-Weather (W) Codes with Fog

Code Number	Present-Weather Condition--WW
10	Light Fog
11	Patches of Shallow Fog
12	More or Less Continuous Shallow Fog
28	Fog
40	Fog at a Distance
41	Fog in Patches
42	Fog, Sky Discernible (became thinner preceding hour)
43	Fog, Sky not Discernible (became thinner preceding hour)
44	Fog, Sky Discernible (no appreciable change in preceding hour)
45	Fog, Sky not Discernible (no appreciable change in preceding hour)
46	Fog, Sky Discernible (has begun, or became thicker during preceding hour)
47	Fog, Sky not Discernible (has begun, or become thicker during preceding hour)
48	Fog, Depositing Rime, Sky Discernible
49	Fog, Depositing Rime, Sky not Discernible
	Past-Weather Condition--W
4	Fog, Smoke or Thick Dust Haze

TABLE 2

Fog-Forecast Indices for Ocean Station VICTOR (34N,164E)

FOG CASES		INV. BASE (00Z)		TEMP. INDEX		MOISTURE INDEX	ADVECTION (00Z) Direct.	Speed
EVENT 1 1968		2/00Z	970 mb X	-1.3X		-1.1X	230	18X
		3/00Z	1000	-1.6X	No Fog	-3.4X	120	4
		3/12Z	Surface				170	10
7/3/18Z--7/4/00Z	(6+ hrs)	4/00Z	1000	+0.4	Fog	+0.9	210	18X
7/4/06Z--7/4/12Z	(6+ hrs)	4/12Z	Surface				210	14
7/4/21Z--		5/00Z	1000	+0.9	Fog	+1.0	210	17X
		5/12Z	1000				200	15
7/5/18Z	(21+ hrs)	6/00Z	947 X	-1.6X	No Fog	+0.4	210	4
		6/12Z	Surface				120	3X
		7/00Z	Surface	M		0	180	4
EVENT 2 1970		1/00Z	1018	M		M	130	10
		1/12Z	1020		No Fog		150	6
7/2/00Z--		2/00Z	1020	+1.4		+0.5	60X	5
7/2/18Z	(18+ hrs)	2/12Z	1020		Fog		120	9
7/3/00Z--		3/00Z	1000	+2.7	Fog	+1.9	150	7
7/3/18Z	(18+ hrs)	3/12Z	1018				160	10
7/4/00Z	(1+ hr)	4/00Z	1017	+2.7	Fog	+1.2	150	8
7/4/12Z--7/4/18Z	(6+ hrs)	4/12Z	1016		Fog		180	10
		5/00Z	1000	+1.8	No Fog	+1.8	150	8
		5/12Z	1017				170	10
		6/00Z	950	-0.5X		+0.6	120	14
EVENT 3 1971								
		1/00Z	1014	M	No Fog	M	170	21X
7/1/15Z--		2/00Z	1017	+2.5	Fog	+1.1	180	17X
7/3/03Z	(36+ hrs)	3/00Z	1019	+1.2		+1.2	190	8
7/3/15Z--		3/12Z	1019		No Fog		180	5
7/4/06Z	(15+ hrs)	4/00Z	1019	0	Fog	0	190	7
		4/12Z	1017		No Fog		210	4
		5/00Z	Surface	M		-0.4	200	13

TABLE 2 (CONTINUED)

EVENT 4	13/00Z	1014	+1.6		+0.6	220	13
	13/12Z	1012				200	18X
	14/00Z	1012	+1.9		0	240	10
	14/12Z	1016		No Fog		210	15
7/14/21Z--7/15/00Z (3+ hrs)	15/00Z	1017	+2.3	Fog	+1.5	140	12
	15/12Z	1018		No Fog		190	10
7/15/18Z--7/16/06Z (12+hrs)	16/00Z	1018	+1.6	Fog	+1.1	170	6
	16/12Z	1017				120	5
	17/00Z	Surface	M		-0.3	50X	12
	17/12Z	1013				80X	5
EVENT 5	3/00Z	881 X	-10.2X	No Fog	-5.5X	320X	5
8/4/03Z (1+ hr)	4/00Z	Surface	M		-0.2	240	12
	4/12Z	900 X		Fog		290	13
	5/00Z	850 X	-9.4X	No Fog	-1.5X	290	10

An alternate evaluation considers the index values when fog was NOT present; are the index values always outside those limits which are favorable for fog, before the fog began or after it ended?

The Clark study indicated only one of the several indices needed to be unfavorable for fog NOT to occur. In Event (1), the temperature index is unfavorable both before and after the Event; the moisture index also was unfavorable before the Event; thus, the indices performed well for Event (1) in NO FOG predictions before and after the fog was observed. For Event (2), temperature and moisture indices were missing before the Event; however, both were favorable after the Event, as were all the other indices. Not until 30 hours after the fog ended were the inversion height and the temperature indices unfavorable for fog. Clearly, more work is needed to use these indices to describe the ending of Event (2).

Event (3) was marked also by missing values for the temperature and moisture indices both before and after the Event. However, the windspeed value before the Event and the first moisture-index value (18 hours) afterward are unfavorable. Both temperature and moisture indices showed zero values 6 hours before the last fog observation, which may be significant; the trends of the index values during a fog Event may provide valuable information for predicting the time when a fog Event will end.

Results from Event (4) were discouraging. All indices showed values favorable for fog 45 hours ahead of its occurrence, with the exception of one windspeed value which was too high 33 hours ahead of the fog starting time. The moisture index was unfavorable 18 hours after the fog ended, as was the wind direction (the temperature index was missing then). Both moisture and temperature indices had lower values 6 hours before the end of Event (4) than were the values 24 hours earlier.

Event (5) never would have been predicted from these fog-index values, but it lasted only during one (3-hourly) observation. All index values, except the advection values, were far outside values favorable for fog to occur; even one wind-direction value was unfavorable prior to Event (5).

These tests occurred at times when the general conditions were favorable for fog occurrence, but before it began or after it ended. The definitive test for NO FOG would involve forming indices when general conditions were <u>not</u> fog-favorable, as in the months September-June. This remains to be done in the future.

During most of these fog Events there are short periods free from fog which are interspersed within the Event. Several key fog indices could be evaluated only at 24-hour intervals and so they were useless for precise starting and ending times of fog occurrences. These times appear dependent on extremely local circumstances, whereas the fog indices used in this study are more representative of broader synoptic weather and air/sea-contrast conditions that extend over a considerable geographic area.

It appears that those broad conditions favorable for fog at OSV "P" and along the California coast of the United States are also fog-favorable in the western North Pacific Ocean at OSV "V". The indices were generally favorable when fog occurred. There is a suggestion in these results that windspeed values may be slightly higher to permit fog in the western North Pacific, compared to windspeed values in the Gulf of Alaska or along the United States coastal areas.

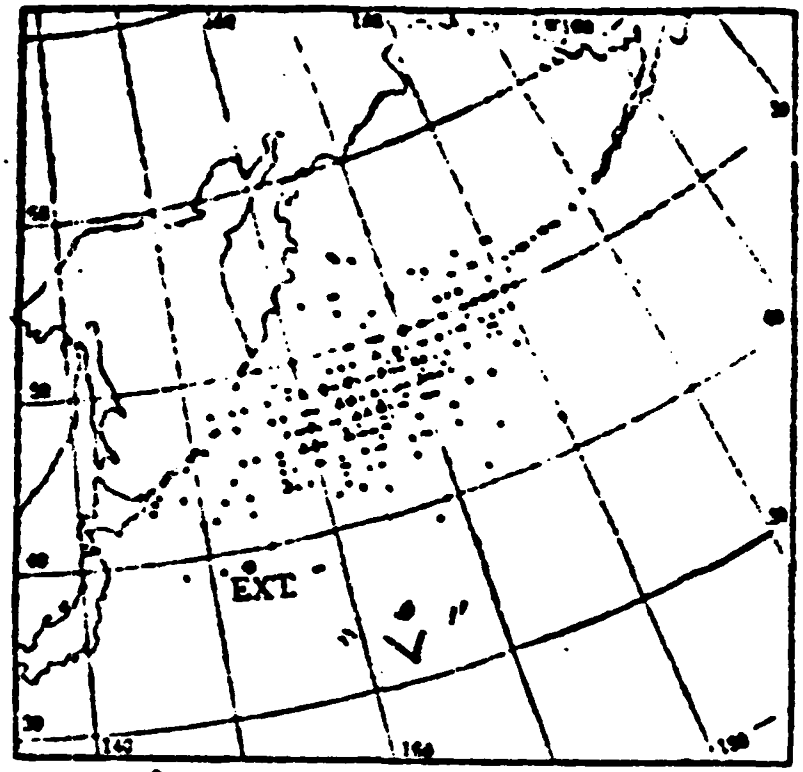


Figure 1   Horizontal distribution of center of fog area during 1950 to 1954

IV. DISCUSSION

These results can be compared with those from two earlier papers that treated this topic from a similar viewpoint in the western North Pacific region (Ogata and Tamura, 1955; Ogata, Kanazawa and Yoshida, 1958). Their studies centered about Ocean Station Vessel EXTRA (OSV "E"; 39N,153E) located about 1100 km northwest of OSV "V" (34N,164E). The relative positions are shown in Figure 1, which indicates fog frequency in the western North Pacific in 1950-1954.

Results from Ogata and Tamura (1955) indicate: 1) the greatest frequency of fog occurs in the northwest Pacific region from the end of May to July; 2) fog duration less than 12 hours is 83% of the total; 3) the fog-layer top averages about 400 meters above the surface; 4) air temperature averages about 2 degrees C higher than sea-surface temperature during fog, although fog can form when the air temperature is lower than that at the sea surface; 5) very small temperature changes occur when fog is forming (+0.3 degrees C) or dissipating (-0.2 degrees C); 6) winds are usually southerly in direction (80% of the time) with fog, and wind force is usually 3 to 5 on the Beaufort Scale (8-24 mph, or 7-21 knots); 7) dense fog is not uniform in distribution over the open sea, but shows "block" structure with the average block's diameter about 20 kilometers; 8) sea level pressure was from 1010-1020 millibars for about 2/3 of the fog occurrences;

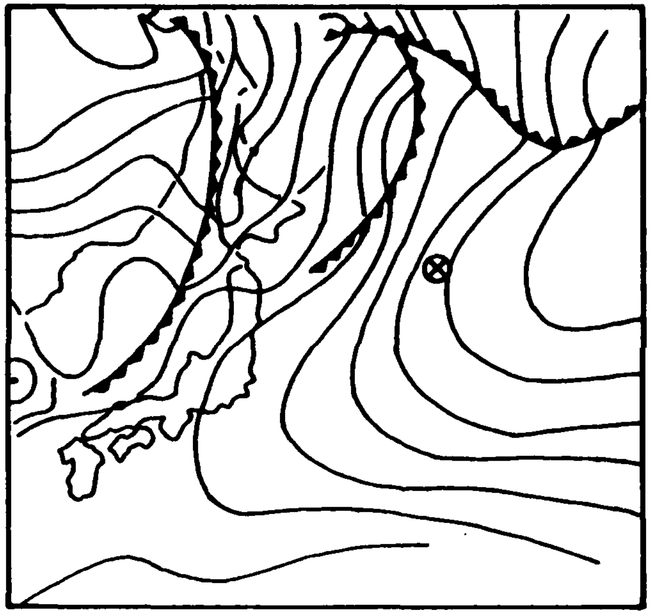
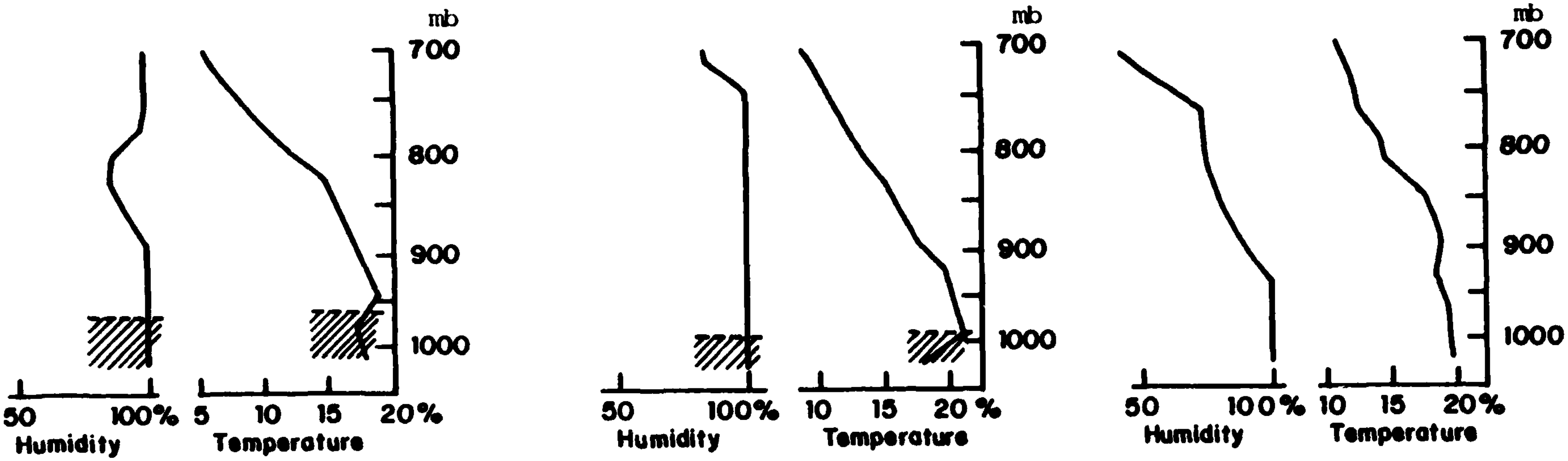


Figure 2(a) Sea-level synoptic chart 0900L
July 28, 1953. ⊗ = OSV E

Figure 2(b) Sea-level synoptic chart 0900L
July 21, 1953. ⊗ = OSV E



(b) 1200L July 15, 1953; upper border of fog layer: 600m.

(c) 0000L July 16, 1953; upper border of fog layer: 300m.

(d) 1200L July 16, 1953; Weather: fog in past hour.

Figure 3. Time changes of vertical temperature and humidity distributions during sea fog occurrence at OSV E (39N, 153E).

9) sample synoptic charts show fronts close to the fog region (see Figures 2a & 2b); 10) soundings for fog show near-surface inversions below 950 millibars, with high humidity adjacent to the surface [see Figure 3(b),(c), & (d)].

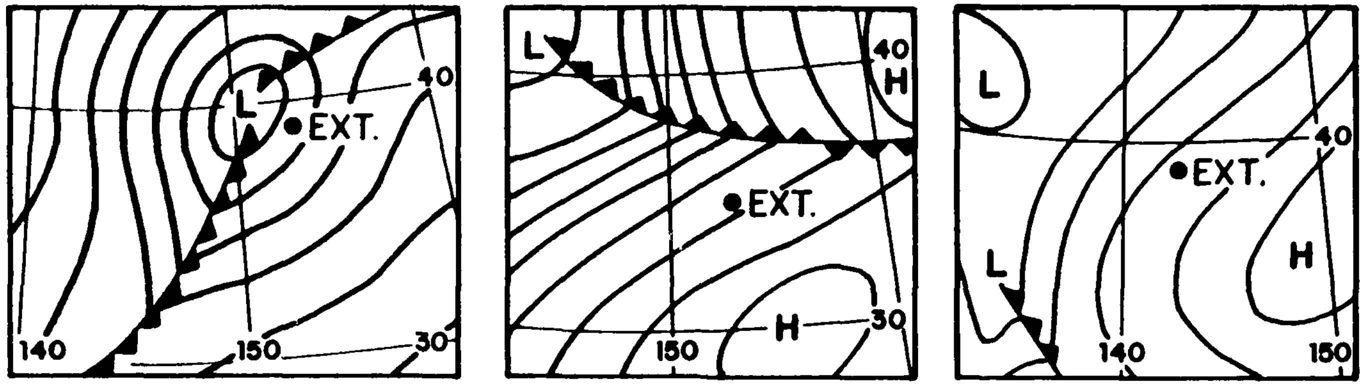
Ogata, Kanazawa & Yoshida (1958) show six typical weather situations accompanied by fog or drizzle at OSV "E"; three are with southerly winds which account for 75% of the observations; three are with northerly winds (25% of the observations of fog and drizzle). In Table 3, 106 of the 128 cases had fog with southerly winds, while 21 cases had fog present of the 43 cases with northerly winds. Examples of the weather

TABLE 3

Frequency of Six Weather Types Accompanying Fog or Drizzle at OSV "EXTRA" (39N,153E) during 1950-1954. (Ogata, Kanazawa & Yoshida, 1958)

Wind Direction	Type	Frequency	Total	Items	%
Southerly	A	51	128	Drizzle: 22/128	75
	B	45		Fog: 106/128	
	C	32			
Northerly	A	19	43	Drizzle: 22/43	25
	B	16		Fog: 21/43	
	C	8			
TOTAL			171		

patterns with southerly winds are shown for their Types A, B, & C in Figure 4; soundings associated with these synoptic



(A) 1200 11 June 1952 (B) 0000 5 May 1952 (C) 0000 9 August 1951

Figure 4. Weather type accompanied by fog or drizzle and southerly wind. EXT. = OSV E

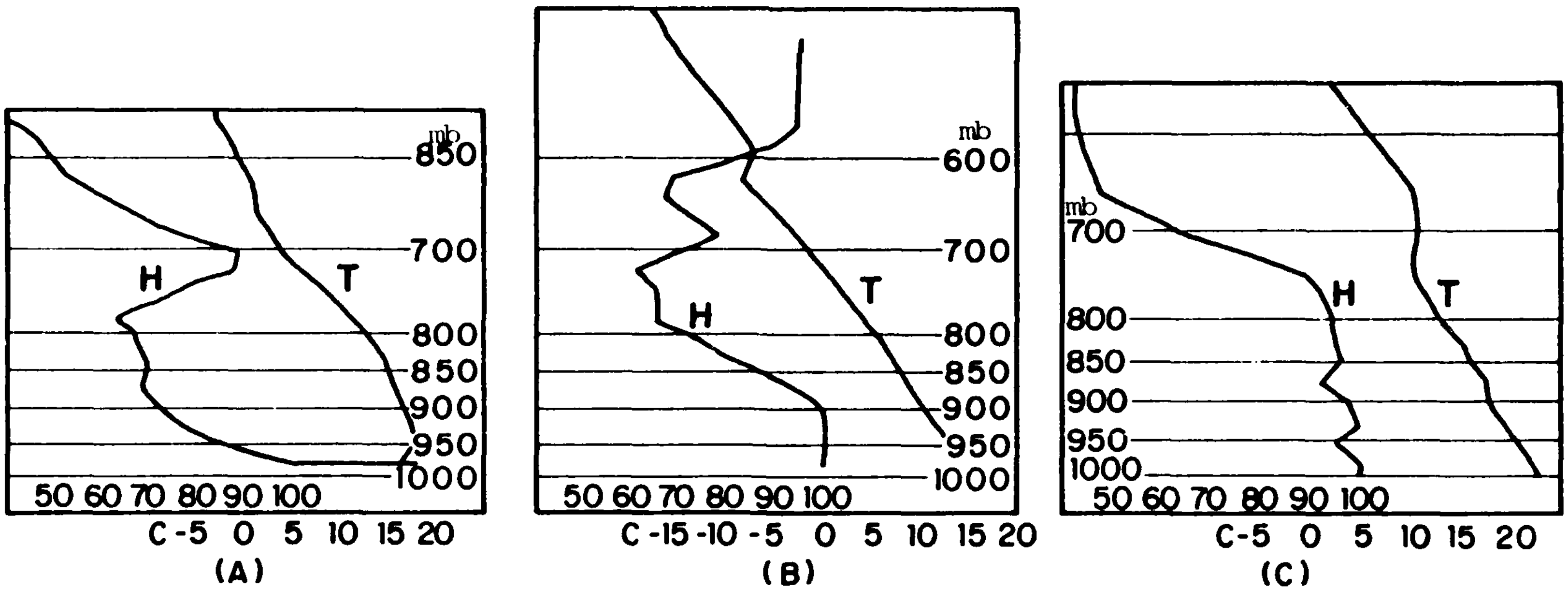
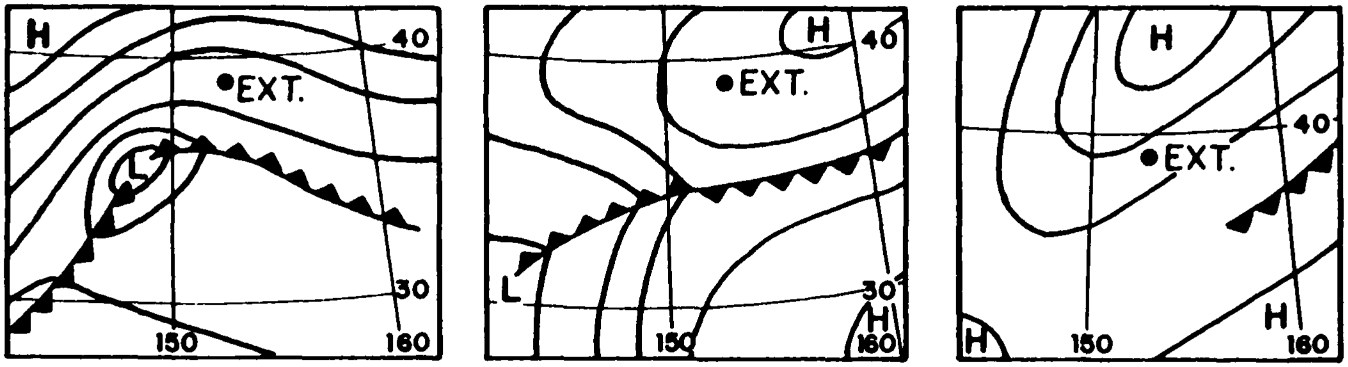
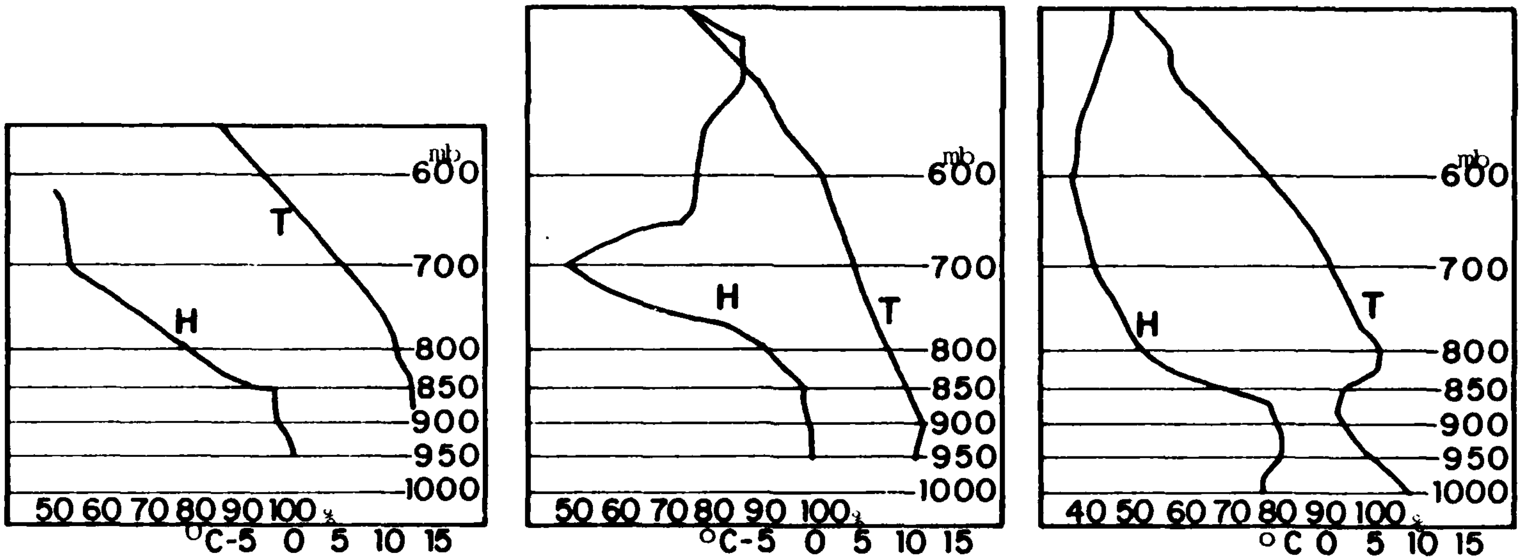


Figure 5. Ascent curves for temperature (T) and humidity (H) versus atmospheric pressure (mb) that correspond to Weather type (a), (b), or (c) in Figure 4 for OSV E.



(A) 0000 23 May 1952 (B) 1200 14 April 1952 (C) 0000 20 April 1952

Figure 6. Weather type accompanied by fog or drizzle and northerly wind. EXT. = OSV E



(A) (B) (C)

Figure 7. Ascent curves for temperature (T) and humidity (H) versus atmospheric pressure (mb) that correspond to Weather type (a), (b), or (c) in Figure 6 for OSV E.

patterns are shown in Figure 5. The soundings for Types A and B are quite similar to the requirements that Leipper & Clark noted with the near-surface temperature inversion, and the humidity soundings show a pronounced decrease with height above the lower layers in the atmosphere.

Examples of synoptic patterns with northerly winds are shown for their Types A, B, & C in Figure 6; soundings associated are shown in Figure 7, with features near the surface much thicker than those associated with the southerly winds as shown in Figure 5.

These results from 25 and more years ago are similar to those from more recent data in different open-ocean fog locations [at OSV "V" of the present study; and by Clark (1981) for OSV "P"]. These two sets of studies, conducted completely independently, provide additional evidence that the basic processes important to fog formation appear to occur similarly in both frontal and non-frontal situations in the open ocean; these basic processes appear to be related as well to the non-frontal processes in fog formation along the California coastline described by Leipper and his students (References 3-6; 9).

Misciasci and Leipper (1974) reviewed conditions favorable for fog occurrence at two additional open-ocean North Pacific locations (OSV "Q" at 43N,167W; and OSV "S" at 48N, 162E). Observations taken during May and June 1953 were analyzed. Fog formation appears associated with specific synoptic flow patterns on sea-level pressure charts.

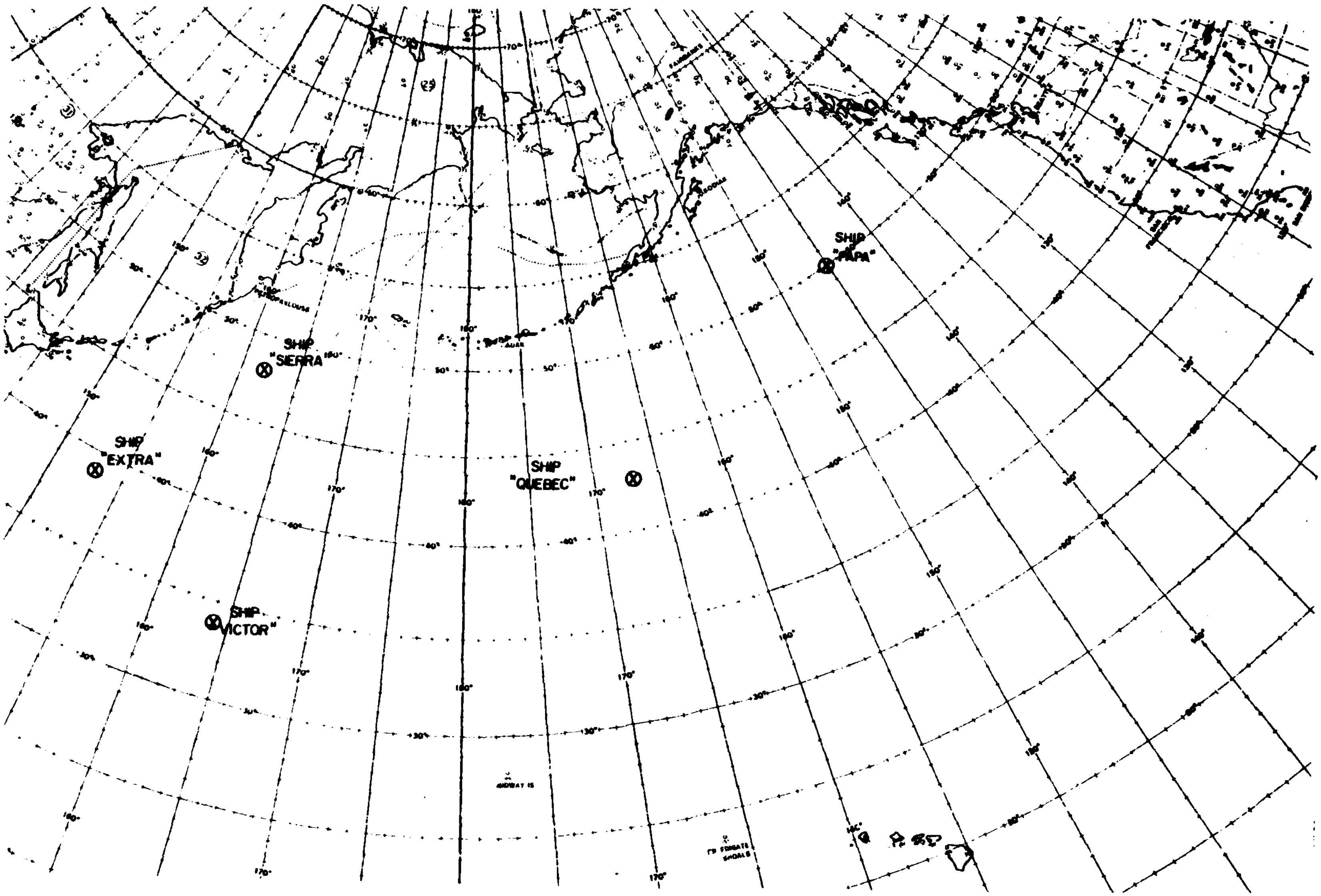


Figure 8. North Pacific Ocean Station Vessel Locations

Dewpoint-sea surface temperature and dewpoint-air temperature relations are critical to fog formation at OSV "Q" and OSV "S" which are shown on Figure 8 in relation to locations of OSV "E", OSV "P" of the Clark (1981) study, and OSV "V" in the present study.

Warm moist air advected across a cooling or isothermal sea-surface-temperature gradient produces advection fog; frontal fogs form when precipitation from above causes saturation in a surface layer that is drier initially. The frontal fogs can occur either ahead of or behind the associated front. These authors note that 93% of the time the quantity $(T_a - T_d)$ associated with fog is less than 0.5 degrees C; when this quantity is greater than 2 degrees C, fog will not occur. Also when the quantity $(T_s - T_d)$ is greater than 2.5 degrees C, no fog is expected. (T_a is air temperature; T_d is dewpoint temperature; T_s is sea-surface temperature).

Conditions described by Misciasci and Leipper for OSV "Q" and OSV "S" in May-June 1953 resemble conditions observed in the present study at OSV "V" in four of the five fog Events described earlier. Although they made detailed forecasts for initial fog-formation time, precise time of fog breakup, and associated visibilities, no such attempt was made in the present study.

Misciasci and Leipper (1974) noted that three types of radiosonde observation (RAOB) soundings were typical that accompanied fog occurrences during May-June 1953 in their study of the open-ocean locations at OSV "S" and "Q".

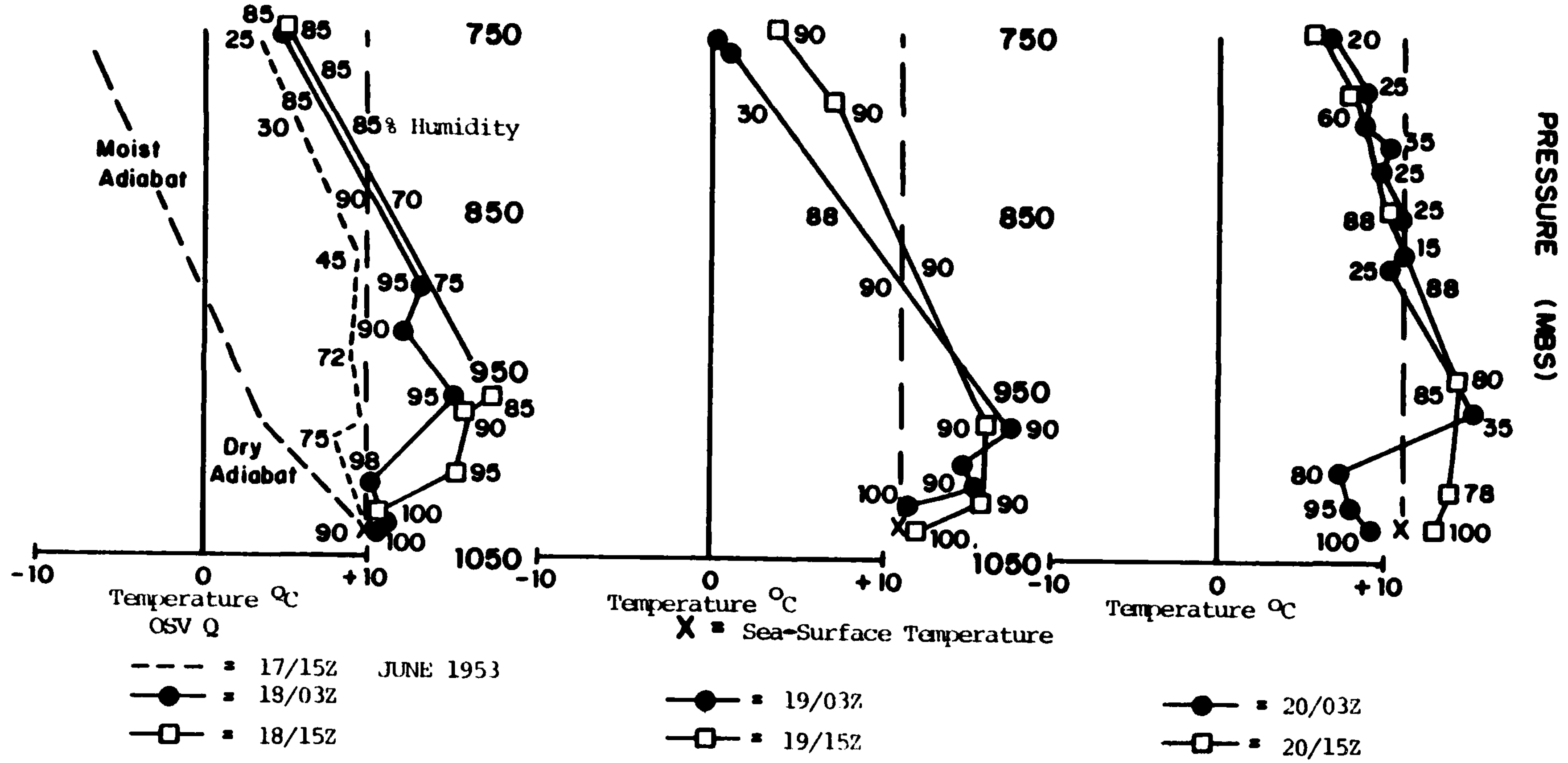


Figure 9. Typical Inversion Series for Airmass Fogs with associated precipitation (after Misciasci & Leipper, 1974).

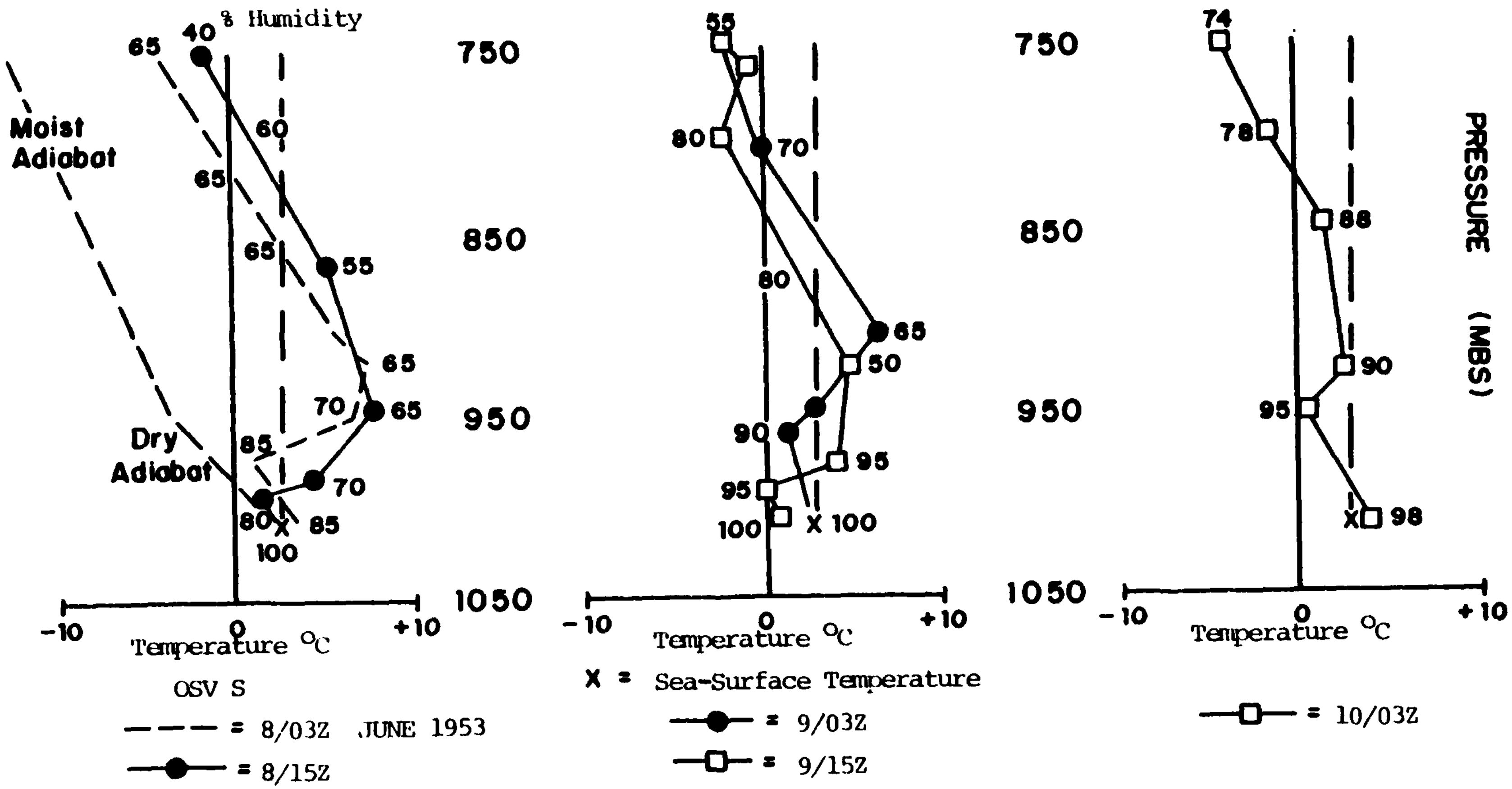


Figure 10. Typical Inversion Series for Airmass Fogs with no precipitation (after Misciasci & Leipper, 1974).

The first type of RAOB sequence is illustrated in Figure 9, that represents fog which developed in a warm sector of a wave cyclone where warm advection occurred in the low atmosphere at OSV "Q" for 17-20 June 1953; intermittent precipitation from a warm front produced saturation in the near-surface layer which was then cooled by the sea surface to produce fog. These authors note 38% of the fog occurrences they studied at OSV "S" and "Q" had situations like this.

Soundings for the present study shown in the Appendix indicate that Events 2 and 3 for OSV "V", in July 1970 and July 1971, had characteristics similar to those shown in Figure 9.

A second type of RAOB sequence is shown in Figure 10, which was observed at OSV "S" from 8-10 June 1953. Warm dry air flowing off the Kamchatka Peninsula has been modified by the ocean surface, in a manner quite similar to the fog development sequence described by Leipper and some of his other students for the California coastal region. Only about 15% of the fog occurrences at OSV "S" in May-June 1953 developed with a history similar to this.

In the present study, only the RAOB soundings for Event 5 are similar to the sequence shown in Figure 10 (see Appendix); even then the RAOB sounding changes, when fog occurs, to a form more like the third type of RAOB sequence noted by Misciasci and Leipper and illustrated next in Figure 11.

Figure 11 shows RAOB soundings from June 1953, made in fronts which had thick stratus clouds and associated moderate

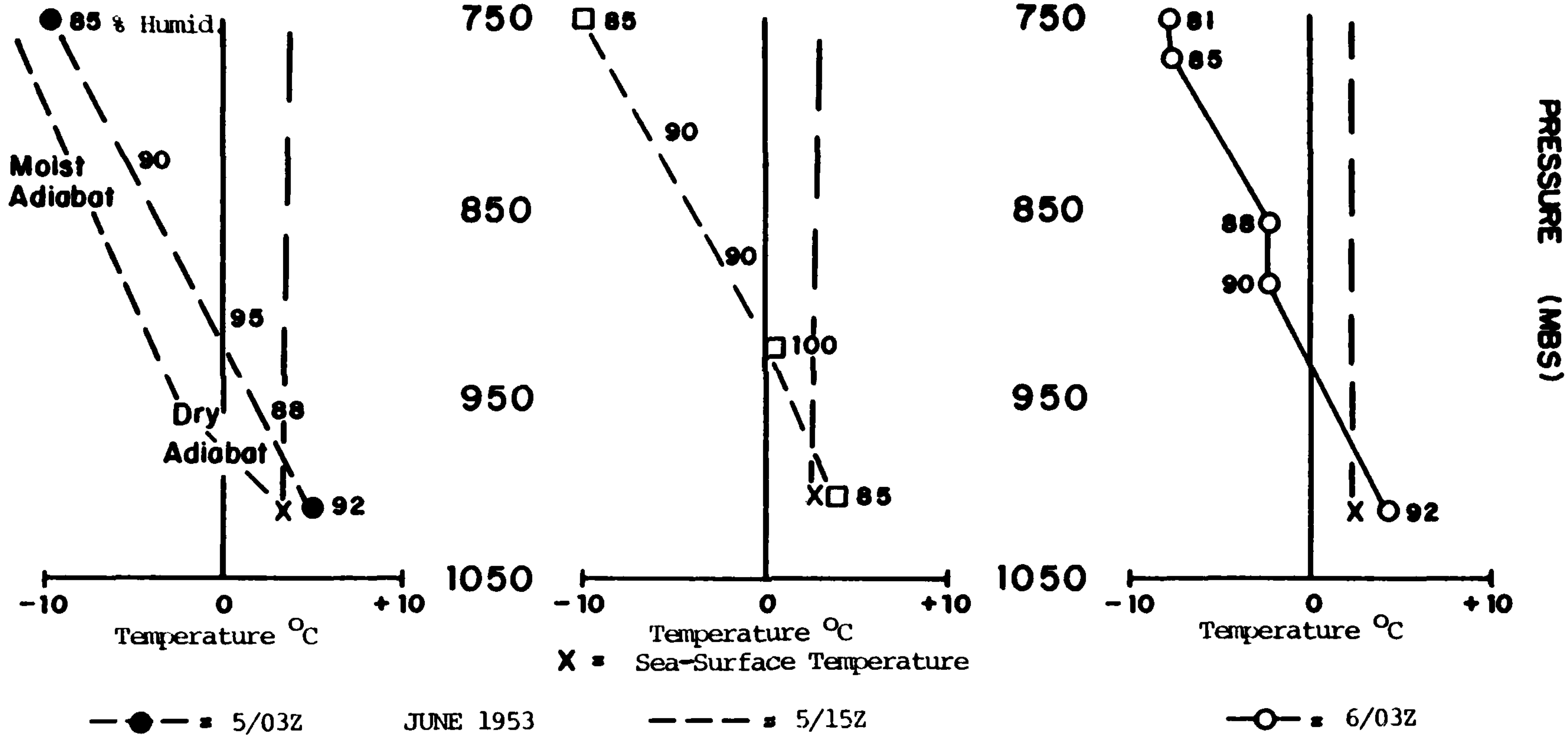


Figure 11. Typical Inversion Series for Frontal Fogs with associated precipitation (after Misciasci & Leipper, 1974).

drizzle. The cyclone center was located immediately east of the station, and cold advection behind the cyclone finally terminated the fog at the end of the RAOB sequence. The soundings are close to moist-adiabatic, without inversions present. Only 10% of the fogs at OSV "S" and "Q" had similar soundings in May-June 1953.

The present study at OSV "V" showed similar soundings for Event 1 (1-7 July 1968), Event 4 (12-17 July 1971) and during the fog itself in Event 5 (4 August 1971).

Thus Figures 9-11, associated with both airmass and frontal precipitation when fog occurred in May-June 1953 at OSV "S" and "Q", describe the soundings very well for all five fog Events (in July 1968, 1970, and 1971, and in August 1971) at OSV "V".

To bring about fog formation in the western North Pacific at OSV "V" (34N,164E), the important synoptic weather features appear to be, in summary:

1) the subsidence inversion in the low atmosphere, that caps a moist layer adjacent to the sea surface;

2) generally southerly flow with low to moderate windspeed that brings in warm and moist air underneath the inversion; convergence within this horizontal flow may be a factor contributing toward fog formation;

3) drier air above the moist layer permits radiational cooling from the top of the moist layer; this promotes instability and mixing in the moist layer adjacent to the sea surface and appears to contribute to fog formation;

4) sea-level pressures in a moderate range of values; this emphasizes the importance of the subsidence inversion, which would disappear with active low pressures and strong surface-pressure gradients (with associated strong surface winds).

The fog events studied here evidently depend as well on otherfactors beyond those considered in these indices. (These indices were favorable long before fog occurred in some events; and in others, the change in index values followed the termination of fog in the event, rather than preceding or accompanying the termination). There is a suggestion that diurnal heating may provide a temporary respite from fog at this open-ocean location during several of the fog events, much as is observed within the California coastal-fog situations. This clearly deserves further study with more adequate data.

V. CONCLUSIONS

1. The Leipper fog indices developed for use along the California coastal area, and modified by Clark for open-ocean use in the Gulf of Alaska, appear to describe the large-scale synoptic conditions which are important to fog formation in the western (open) North Pacific Ocean as well.

2. These indices apply to frontal-fog situations in the summer at OSV "V" (34N,164E). This represents a step forward in the use of these fog parameters, previously applied only to non-frontal-fog occurrences.

3. Additional factors, still to be identified, appear necessary to define precise times of fog formation and termination. These factors may be frontally-related, or may depend on measures of diurnal heating or cooling.

4. Observational data are needed to refine the index parameters and limiting values. Data needed include surface weather and cloud conditions, sea-surface temperature, dew-point temperature, windspeed and wind direction; sea-level pressure values and surrounding synoptic-weather patterns; and frequent radiosonde measurements of the lower atmosphere above the surface-observation point, to include temperature and moisture soundings up to 500 millibars. Satellite photographs of the area are needed to provide useful cloud-cover information. These data should come from an open-ocean location where fog occurs frequently to constitute a navigational hazard.

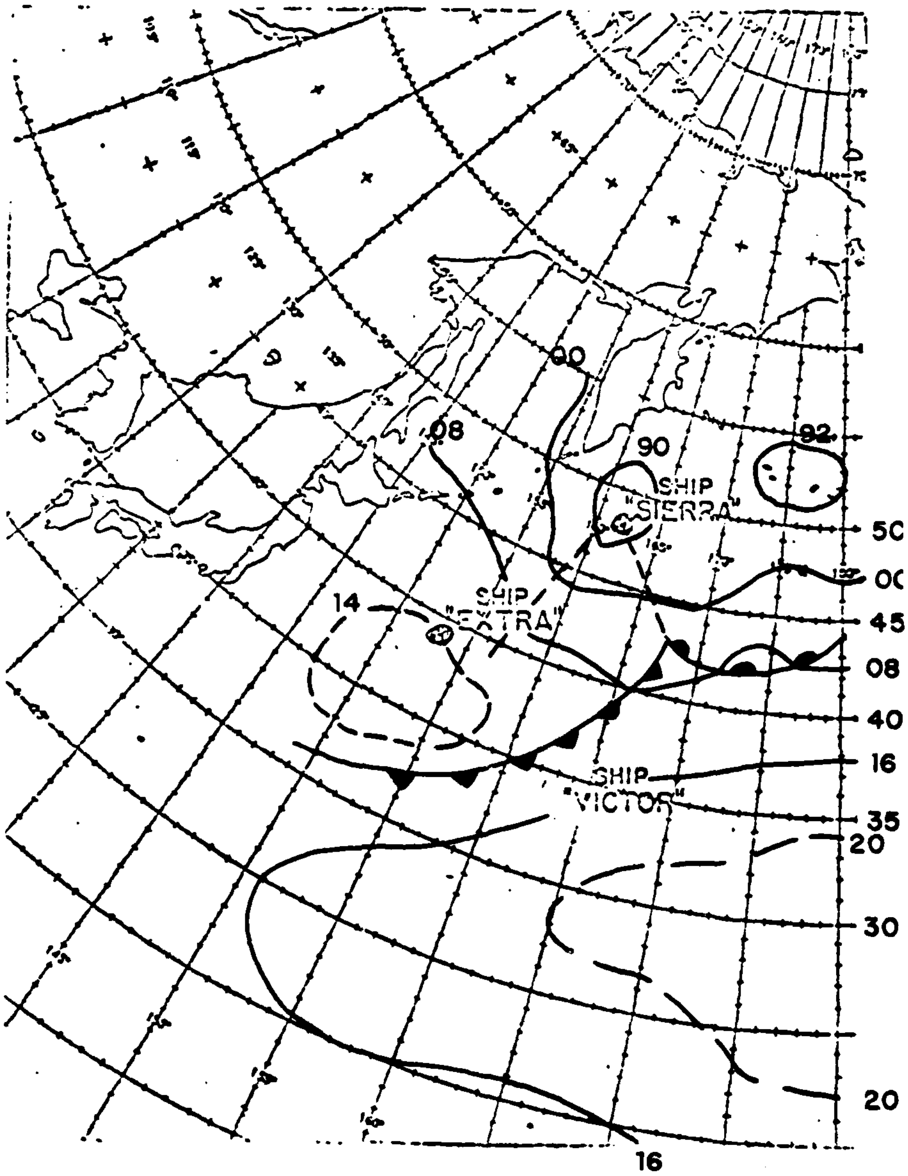
APPENDIX

Fog-Forecasting Parameters, Indices, and Radiosonde Observations before, during, and after each Fog Event, and a representative synoptic Sea-level Pressure Chart. Sea-Surface Temperature, Dewpoint, Wind Direction and Speed, Visibility Code, Present-Weather and Past-Weather Codes, during the month of each Fog Event in this study: July 1968; July 1970; July 1971; and August 1971 at OSV "V" (34N,164E).

Date/ Time	Inversion Height	Max. Temperature above Inversion	Dewpoint	Sea-Surface Temperature	Temperature Index	Moisture Index	FOG/NO FOG
1968 July							
1/00Z	Surface		18.9C	21.5C			
12Z	1013 mb 985 mb top	22C					
2/00Z	970 mb 943 mb top	20.2C	20.4C	21.2C	20.2—21.5 is -1.3	20.4—21.5 is -1.1	NO FOG
3/00Z	1000 mb	19.6C	17.8C	21.4C	19.6—21.2 is -1.6	17.8—21.2 is -3.4	NO FOG
4/00Z	1000 mb	21.8C	22.3C	21.7C	21.8—21.4 is +0.4	22.3—21.4 is +0.9	(FOG)
5/00Z	1000 mb	22.6C	22.7C	21.2C	22.6—21.7 is +0.9	22.7—21.7 is +1.0	(FOG)
6/00Z	947 mb	19.6C	21.6C	22.0C	19.6—21.2 is -1.6	21.6—21.2 is +0.4	NO FOG
7/00Z	Surface	Missing	22.0C	22.0C	Missing	22.0—22.0 is 0.0	NO FOG

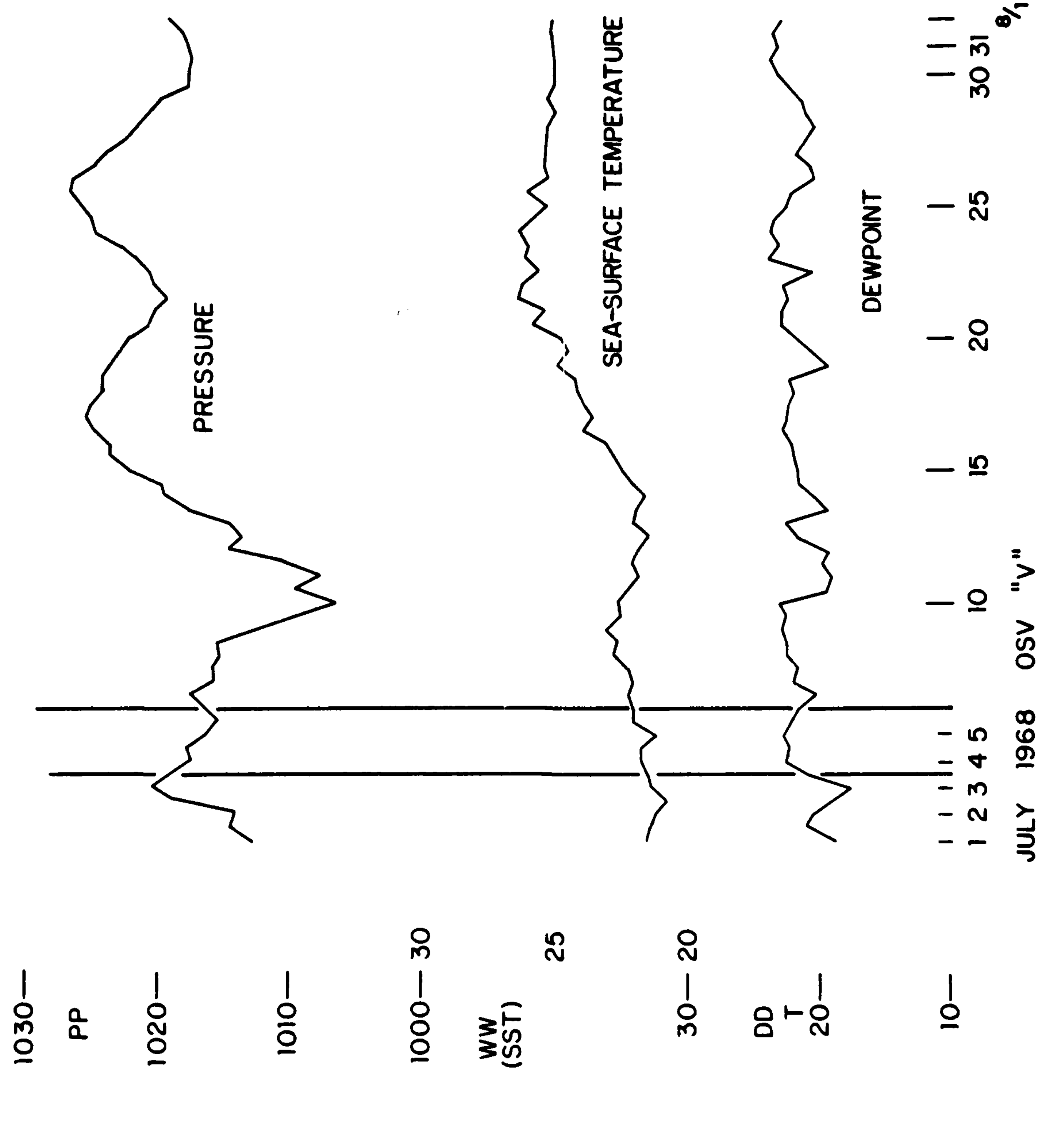
SYNOPTIC WEATHER PATTERN: A sequence of fast-moving, rapidly-developing weather systems were over the station, dominated by lows, frontal passages and fronts during the period. The Fog Occurrences were probably Frontal. The Advection, Temperature and Moisture Indices during the period worked well to define the Fog/No Fog Occurrences.

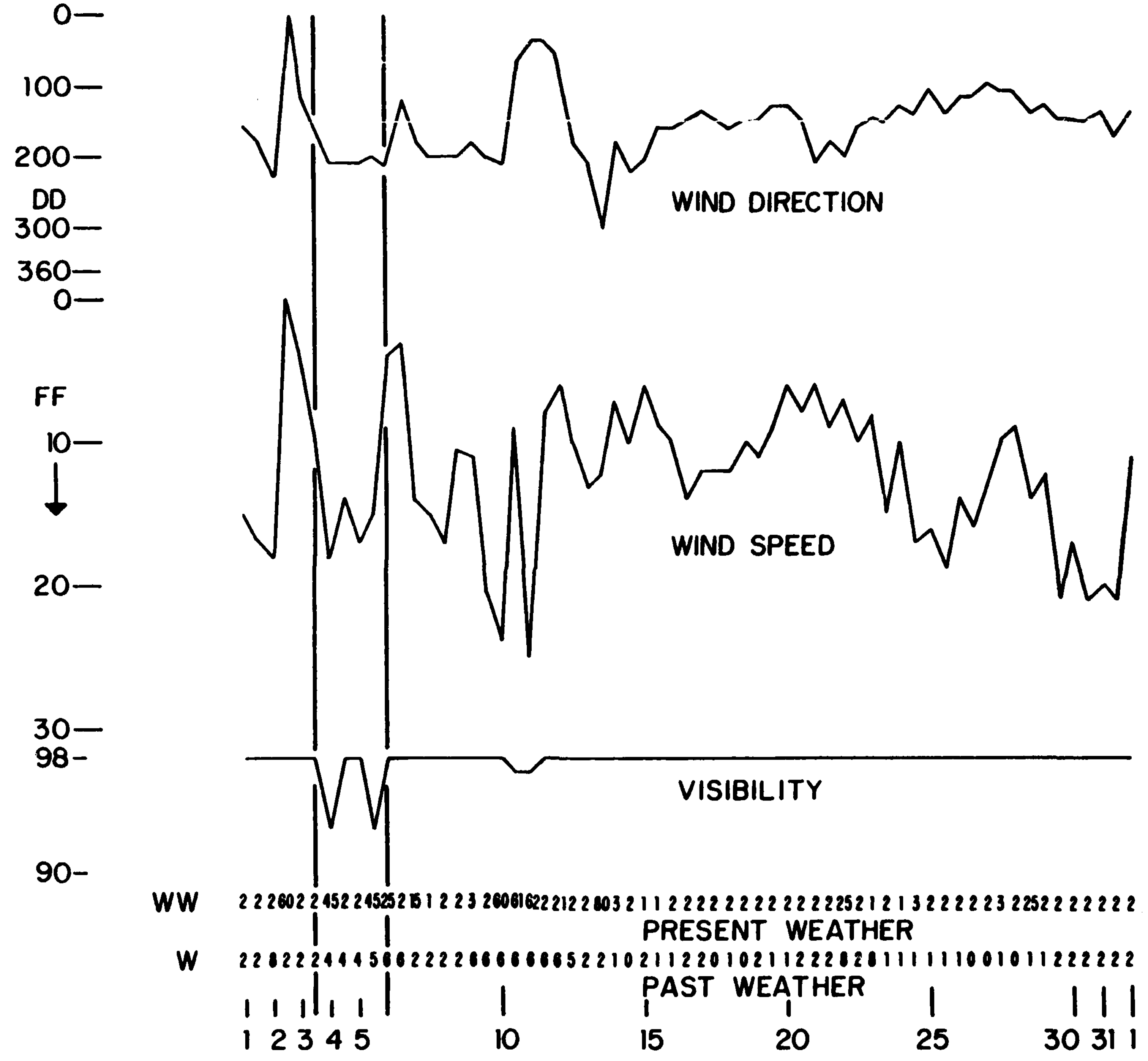
EVENT One: OSV "V", 1-7 July 1968.



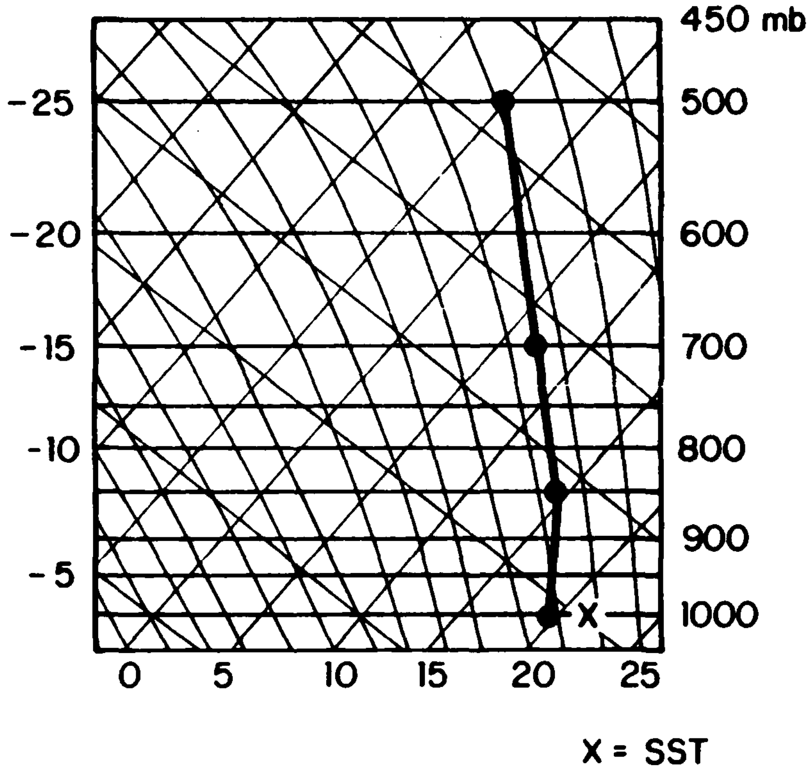
NORTH PACIFIC O.S.V

0000Z 5 July 1968 FOG: 7/3/18Z - 7/5/18Z

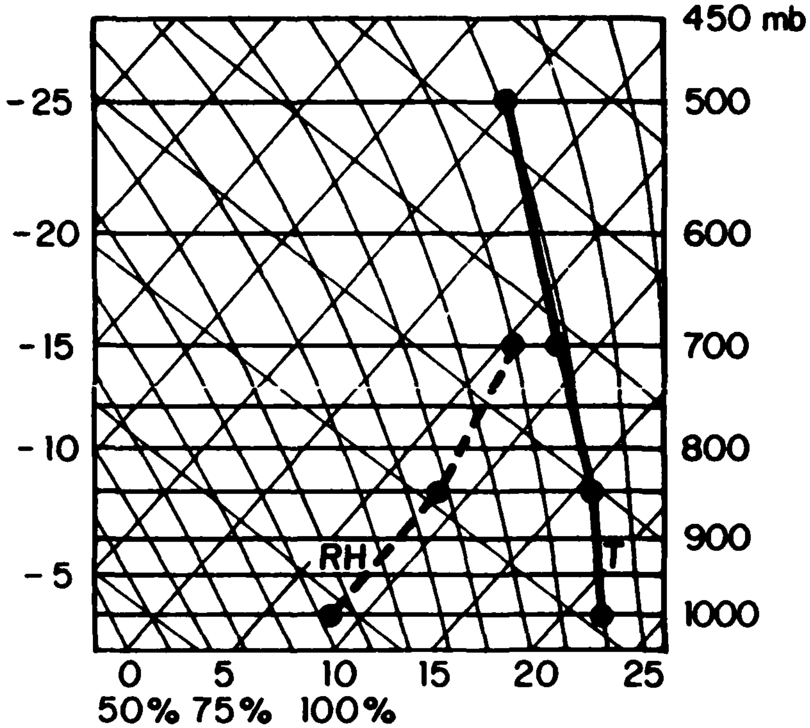

PRESSURE
SEA-SURFACE TEMPERATURE
DEWPOINT
JULY 1968 OSV "V"
1 2 3 4 5
10
15
20
25
30 31
8/1
1030—
PP
1020—
1010—
1000— 30
WW
(SST)
25
30— 20
DD
T
20—
10—



JULY 1968 OSV "V"



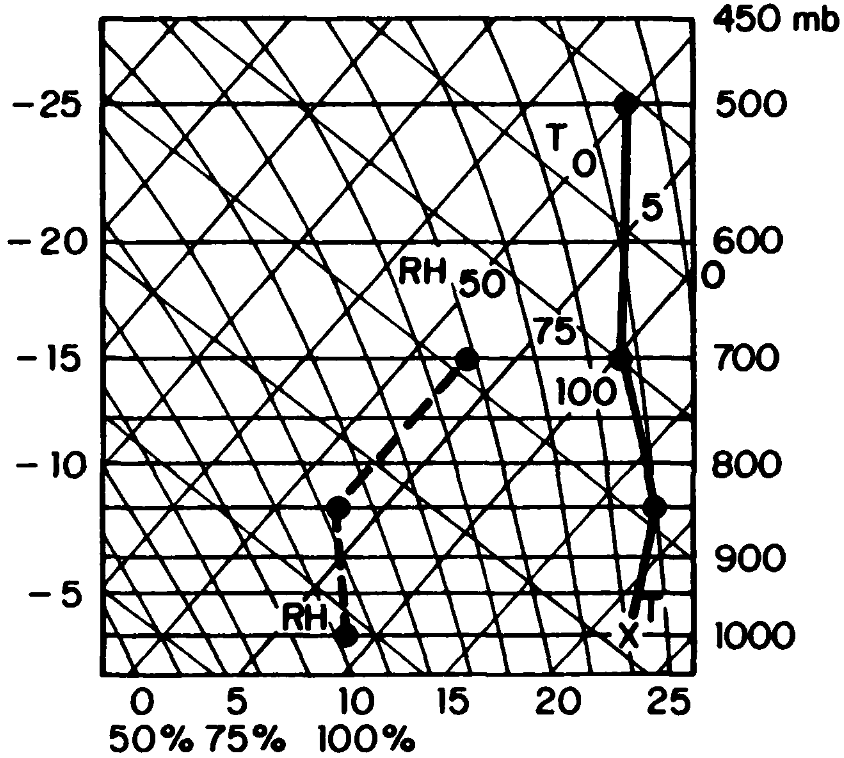
7/3/00Z



7/3/12Z

FOG STARTS 7/3/18

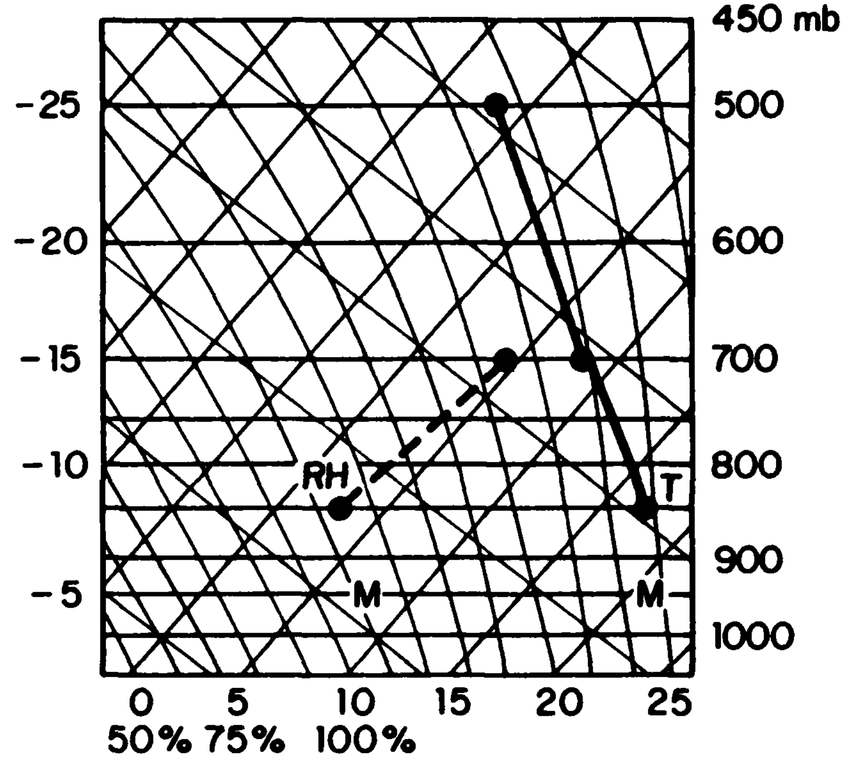
1968



7/4/00 Z X = SST

FOG

7/3/18 – 7/4/00

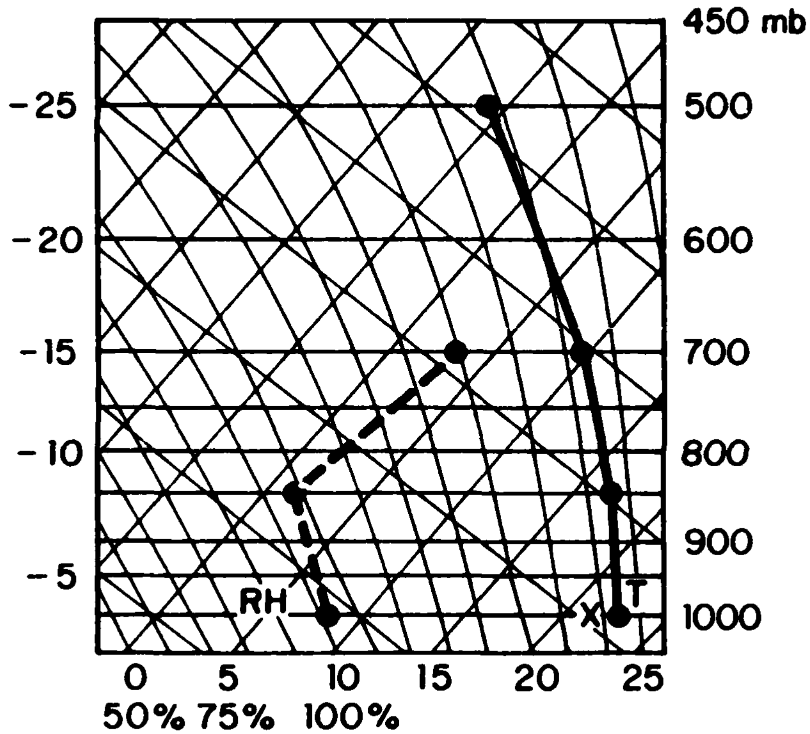


7/4/12 Z

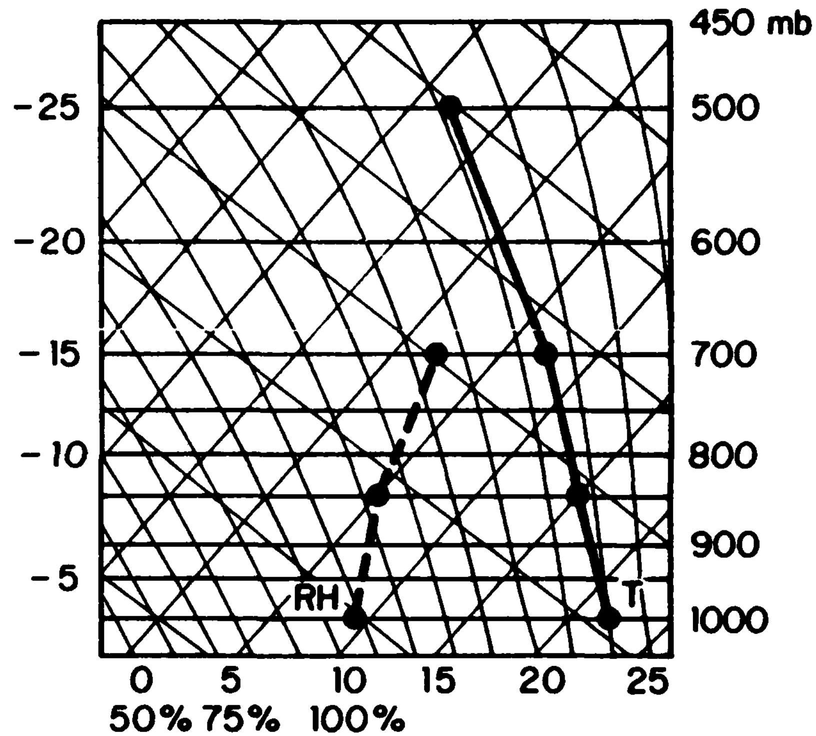
FOG

7/4/06 – 7/4/12

1968



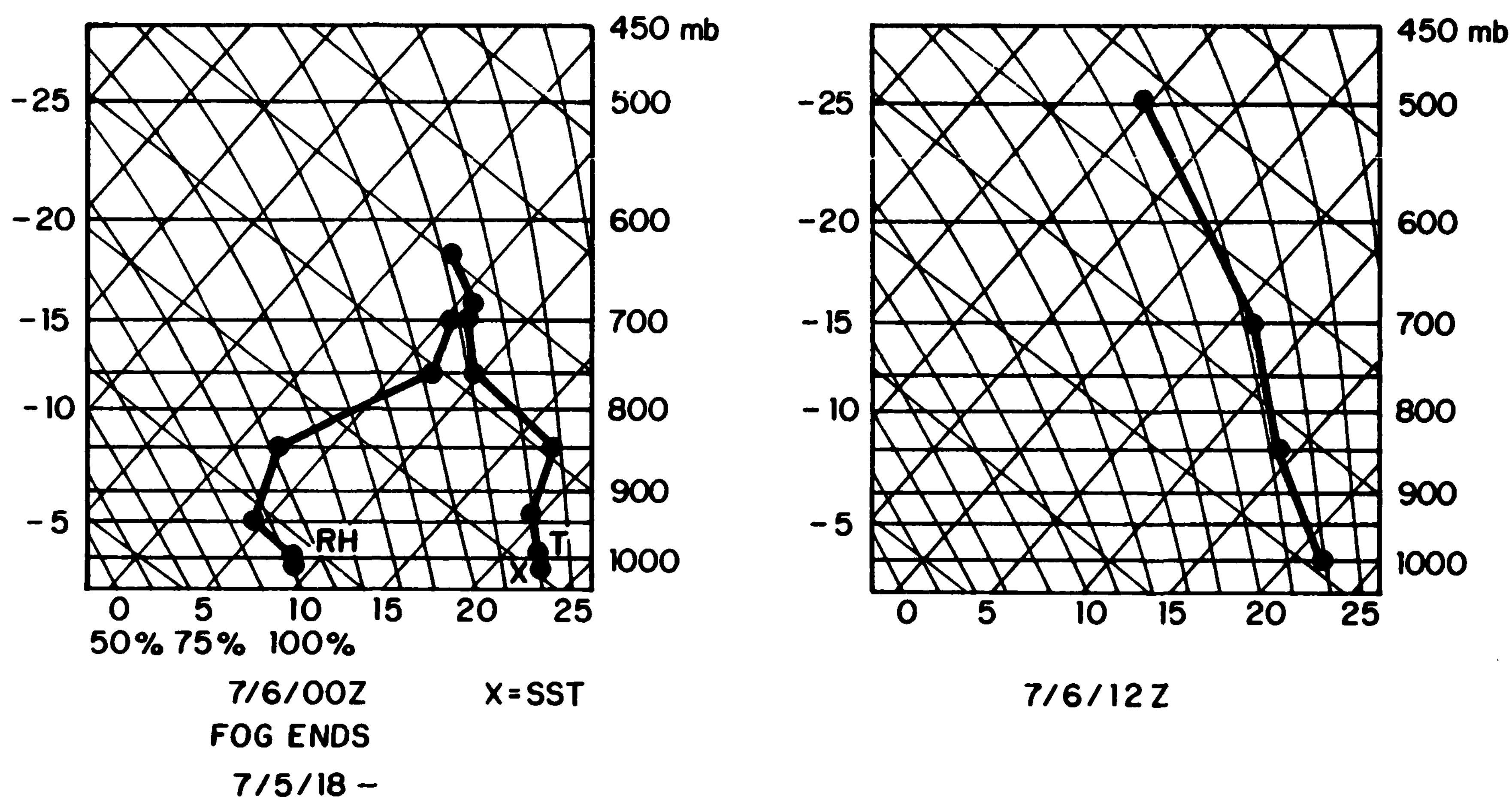
7/5/00Z X = SST
FOG
7/4/21 – 7/5/00



7/5/12Z

7/5/00 – 7/5/18
FOG

1968

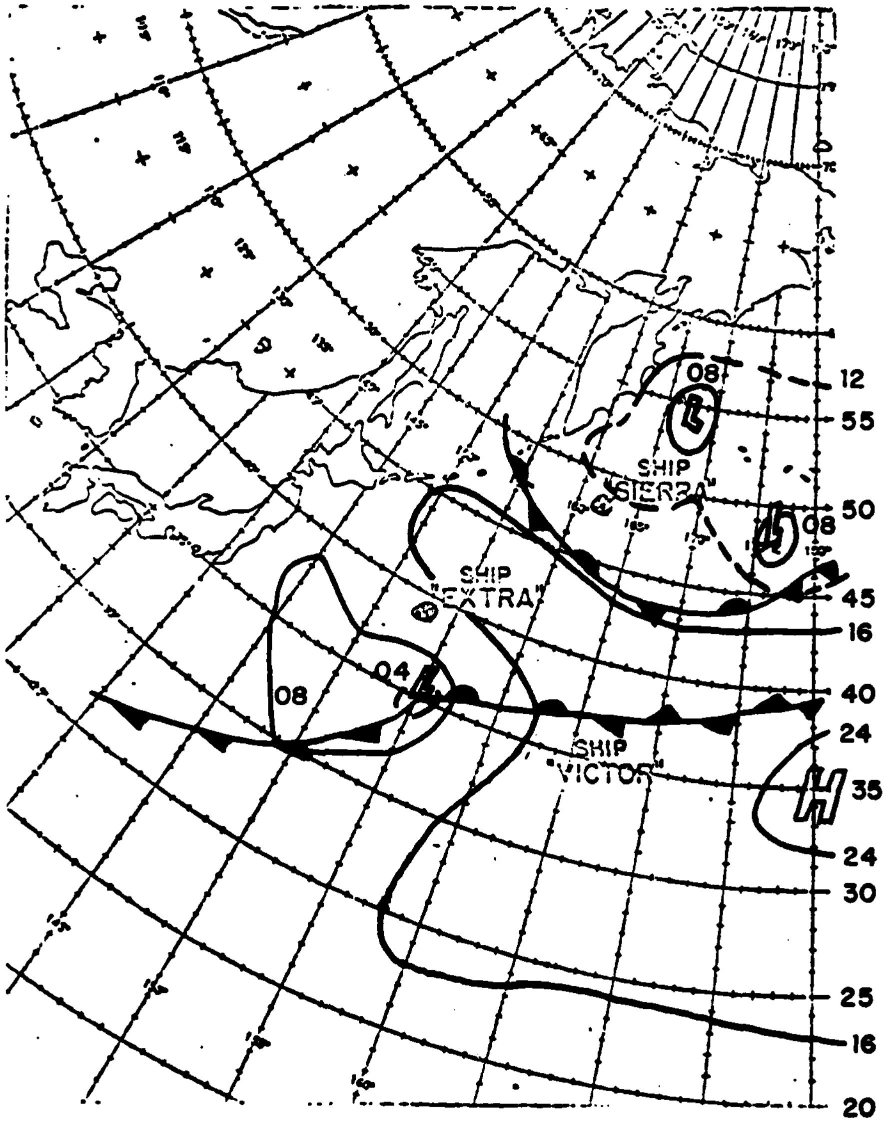

450 mb
500
600
700
800
900
1000
-25
-20
-15
-10
-5
0 5 10 15 20 25
50% 75% 100%
RH
T
X
7/6/00Z
X=SST
FOG ENDS
7/5/18 –
450 mb
500
600
700
800
900
1000
-25
-20
-15
-10
-5
0 5 10 15 20 25
7/6/12Z

1968

Date/ Time	Inversion Height	Max. Temperature above Inversion	Dewpoint	Sea-Surface Temperature	Temperature Index	Moisture Index	FOG/NO FOG
1970 July							
1/00Z	1018 mb	19.8C	19.2C	19.8C			
2/00Z	1020 mb	21.2C @ 1000 mb	20.3C	20.2C	21.2—19.8 is +1.4	20.3—19.8 is +0.5	(FOG)
3/00Z	1000 mb	22.9C	22.1C	20.7C	22.9—20.2 is +2.7	22.1—20.2 is +1.9	(FOG)
4/00Z	1017 mb	23.4C @ 1000 mb	21.9C	21.1C	23.4—20.7 is +2.7	21.9—20.7 is +1.2	(FOG)
5/00Z	1016 mb	22.9C @ 1000 mb	22.9C	22.0C	22.9—21.1 is +1.8	22.9—21.1 is +1.8	FOG @ 7/4/18Z
6/00Z	950 mb 931 mb top	21.5C	22.6C		21.5—22.0 is -0.5	22.6—22.0 is +0.6	NO FOG

SYNOPTIC WEATHER PATTERN: OSV "V" remained in warm sector ahead of slowly-moving low center to west-northwest, and south of a stationary front oriented almost east-west 3-5 degrees of latitude north of the station. Fog Occurrences may be frontally-influenced. Indices generally worked well during Fog (with 1 exception for Advection), but failed to indicate ending of Fog Occurrence until 24 hours later.

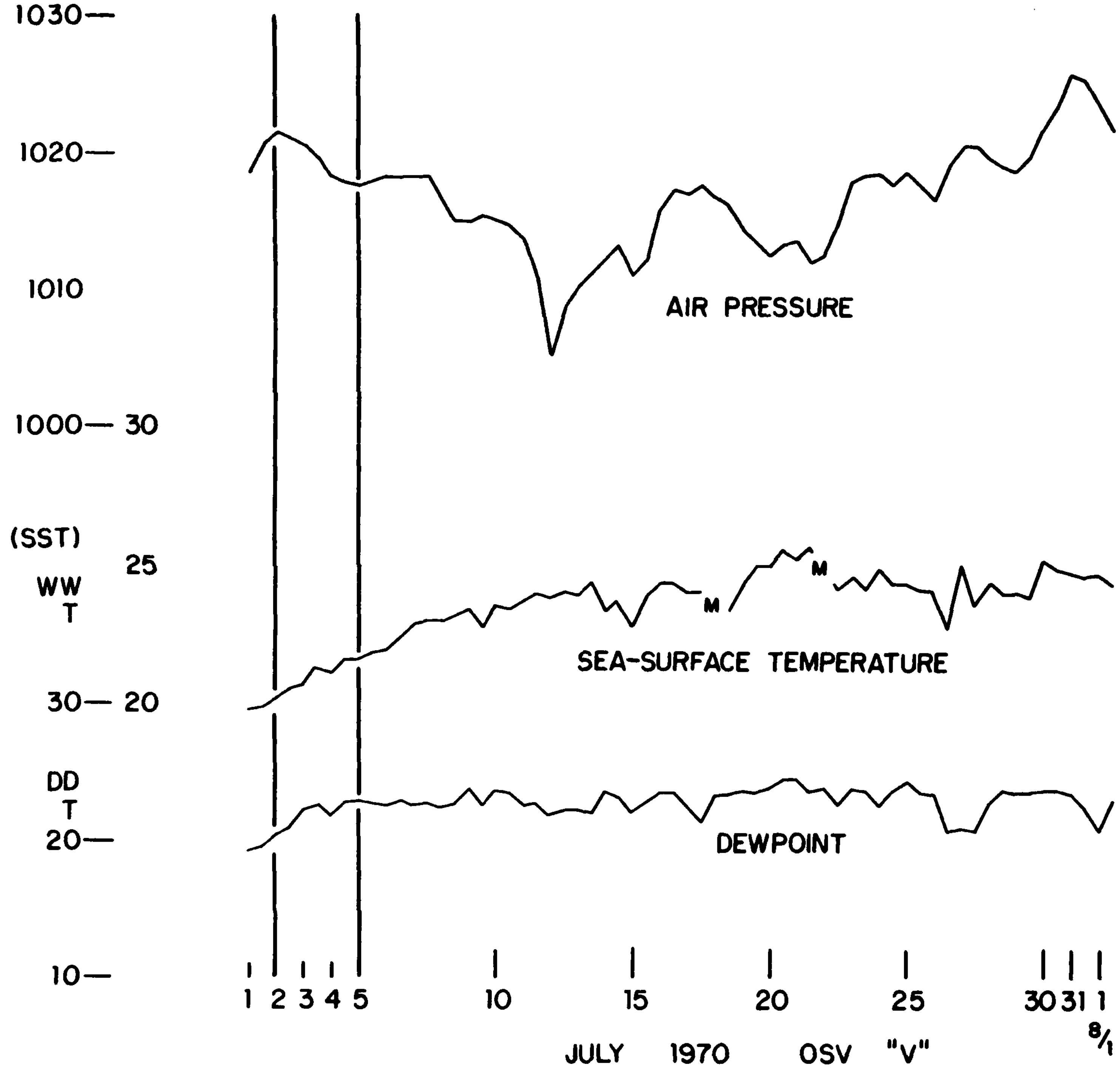
EVENT Two: OSV "V", 1-6 July 1970.

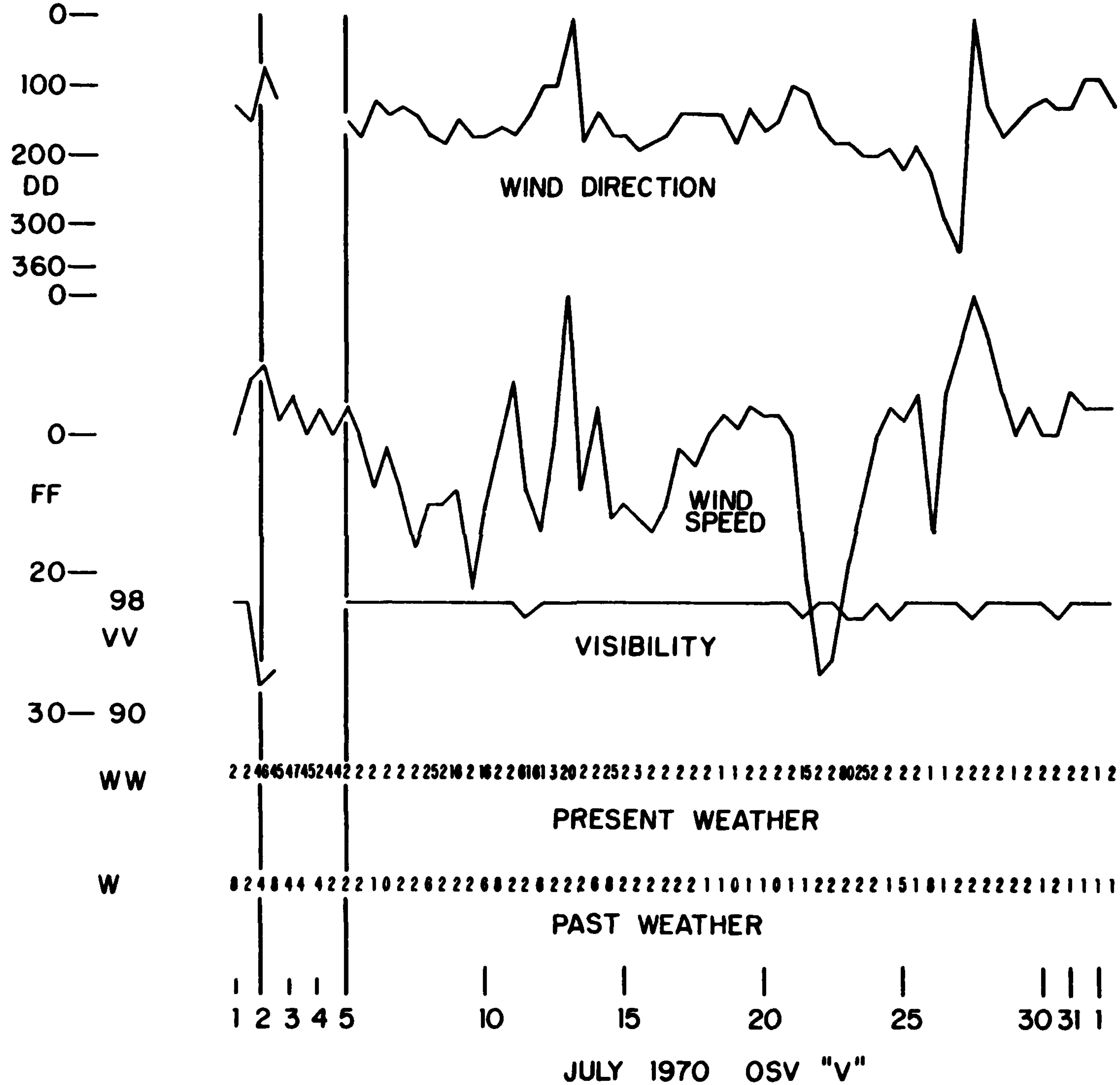


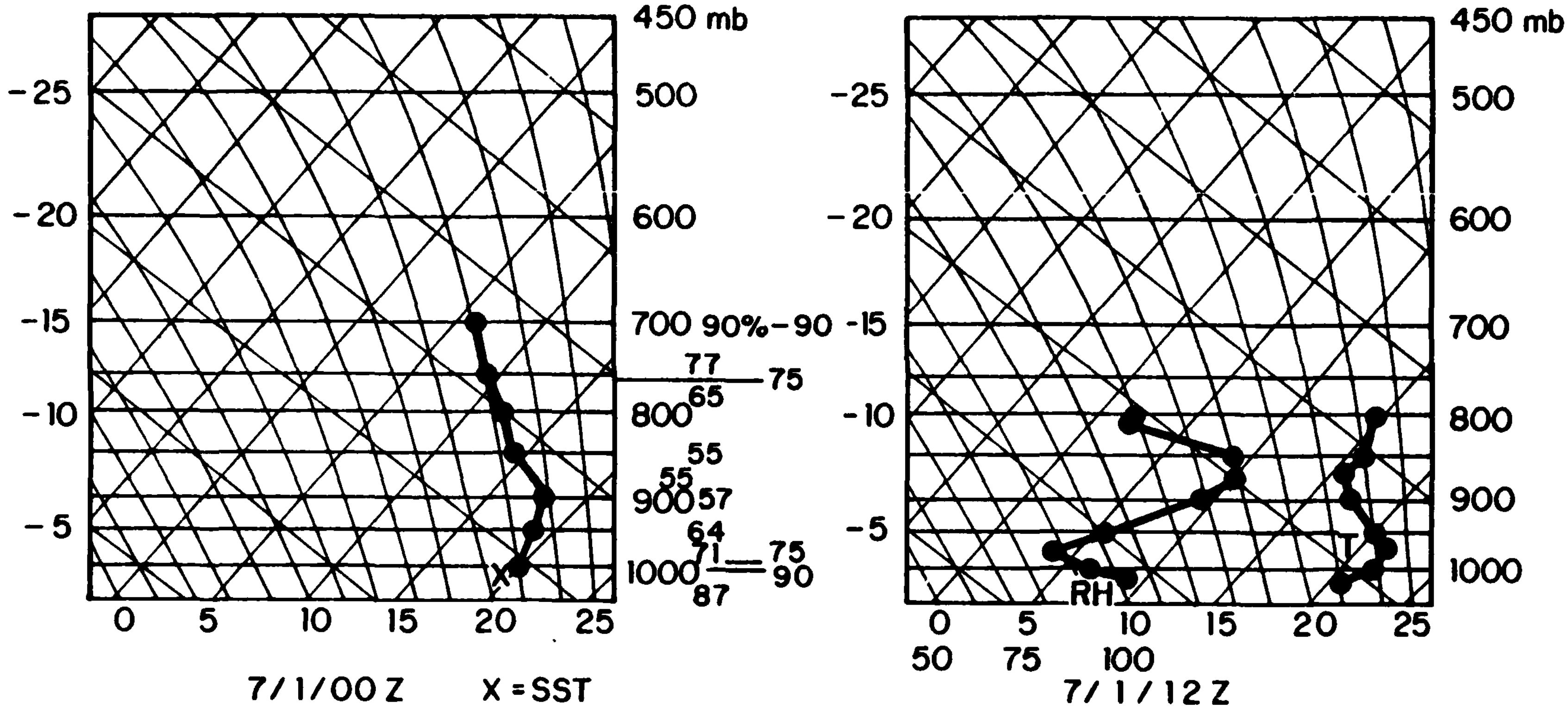
NORTH PACIFIC O.S.V

1200Z 3 July 1970

FOG: 7/2/00-18Z; 7/3/00-18Z;
7/4/00Z; 7/4/12-18Z


1030—
1020—
1010
1000— 30
(SST)
25
WW
T
30— 20
DD
T
20—
10—
AIR PRESSURE
SEA-SURFACE TEMPERATURE
DEWPOINT
M
M
1 2 3 4 5
10
15
20
25
30 31 1
8/1
JULY 1970 OSV "V"


0
100
200
DD
300
360
0
0
FF
20
98
VV
30
90
WW
W
WIND DIRECTION
WIND SPEED
VISIBILITY
PRESENT WEATHER
PAST WEATHER
1 2 3 4 5
10
15
20
25
30 31 1
JULY 1970 OSV "V"


450 mb
500
600
700 90% -90
77
65
75
800
55
55
900 57
64
71
75
1000
90
87
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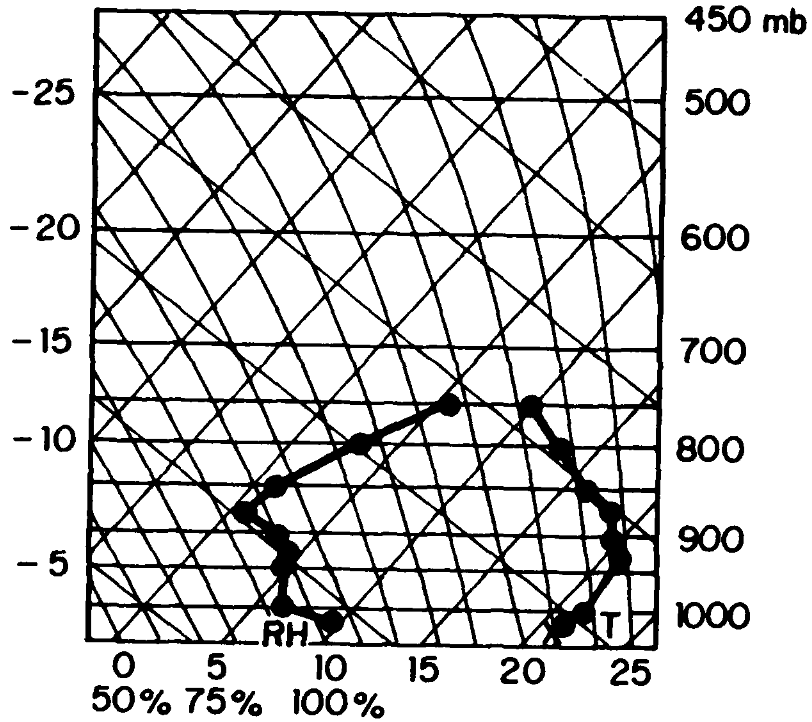
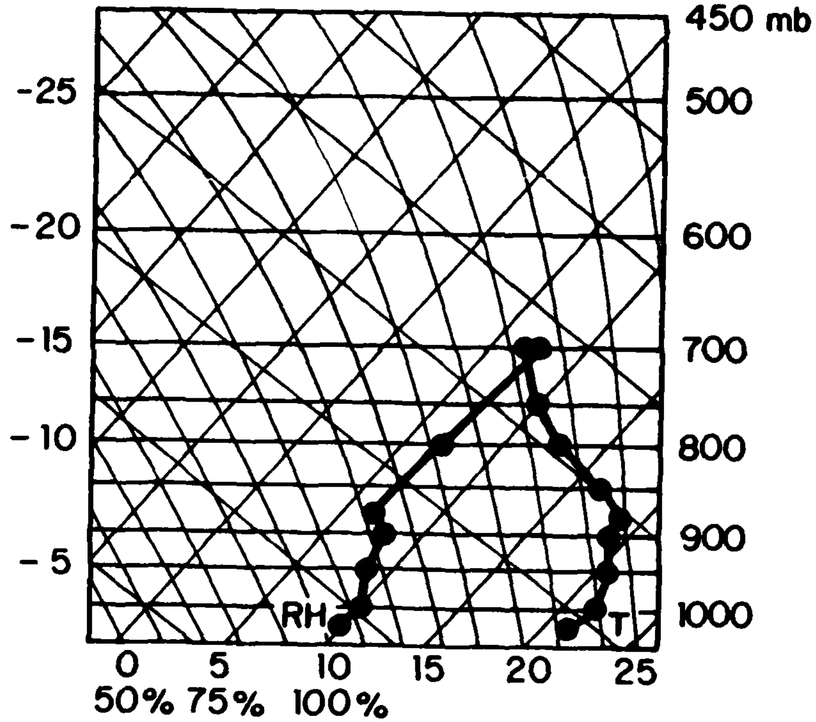
-20
-15
-10
-5
0
5
10
15
20
25
X
7/1/00 Z
X = SST
450 mb
500
600
700
800
900
1000
-25
-20
-15
-10
-5
T
RH
50
75
100
7/1/12 Z

1970



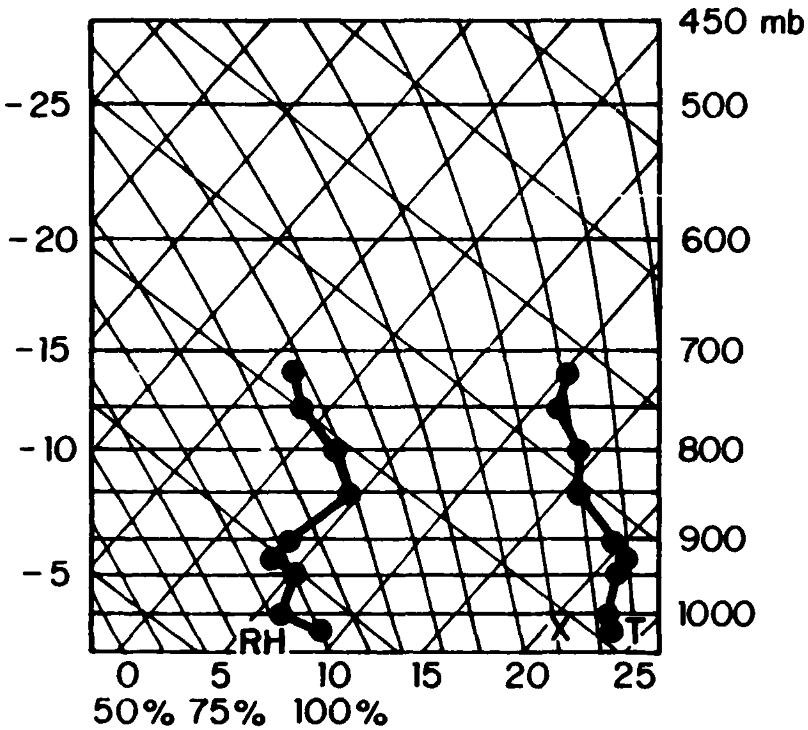
7/2/00Z
FOG
7/2/00 - 7/2/12

X = SST

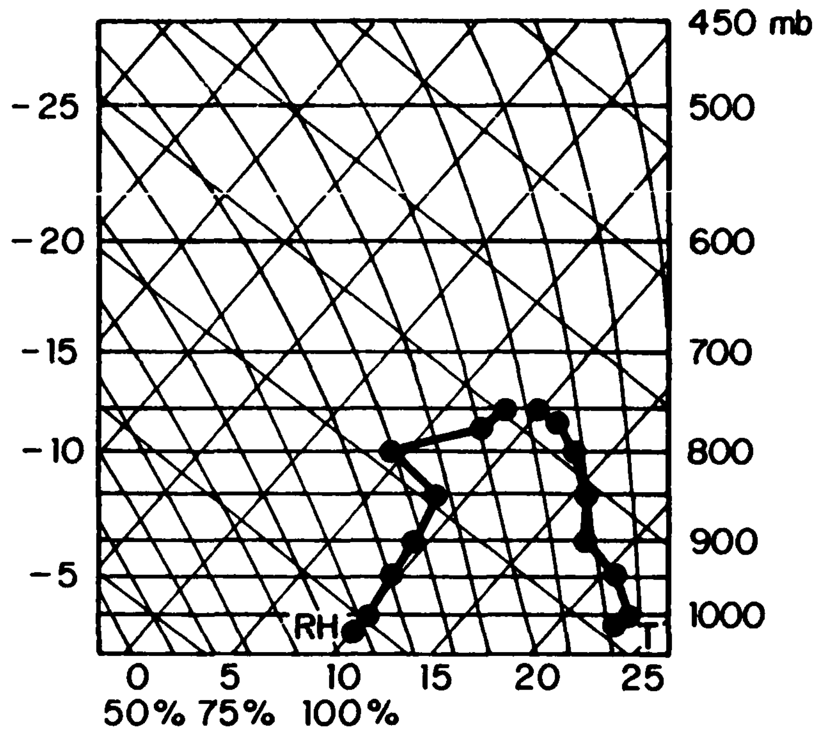


7/2/12Z
FOG
7/2/12 - 7/2/18

1970

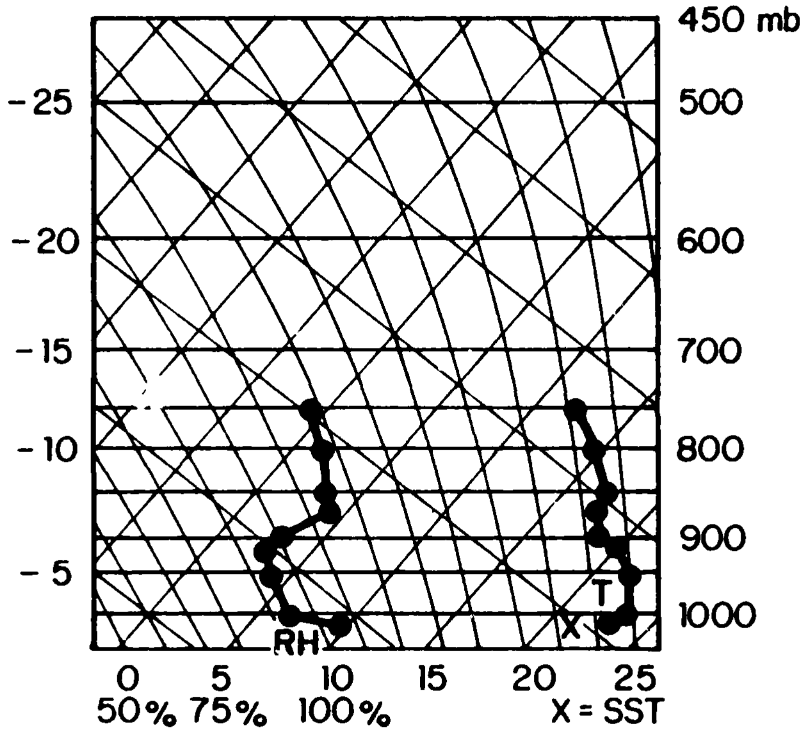


7/3/00Z X = SST
FOG
7/3/00 – 7/3/12

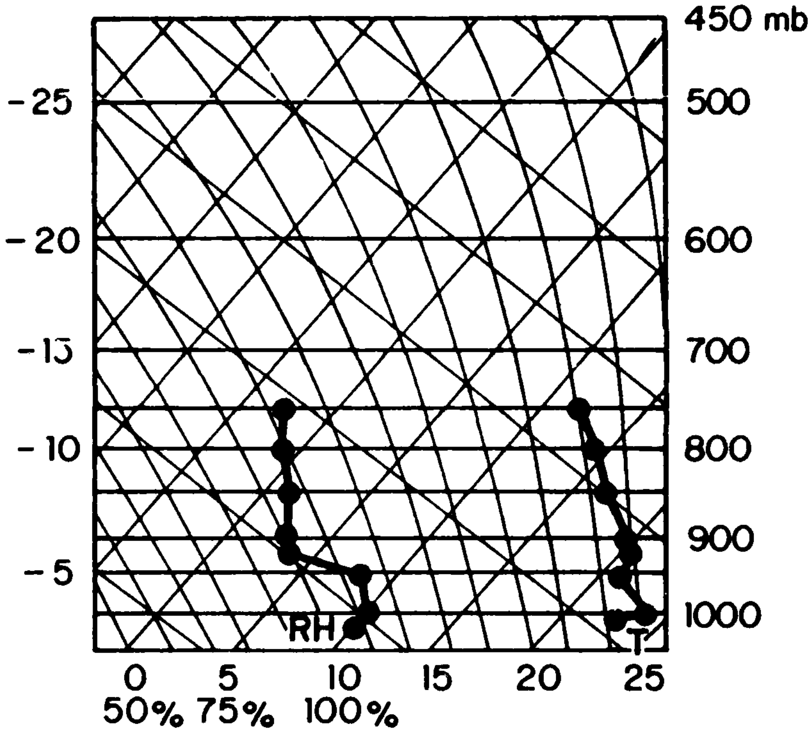


7/3/12Z
FOG
7/3/12 – 7/3/18

1970

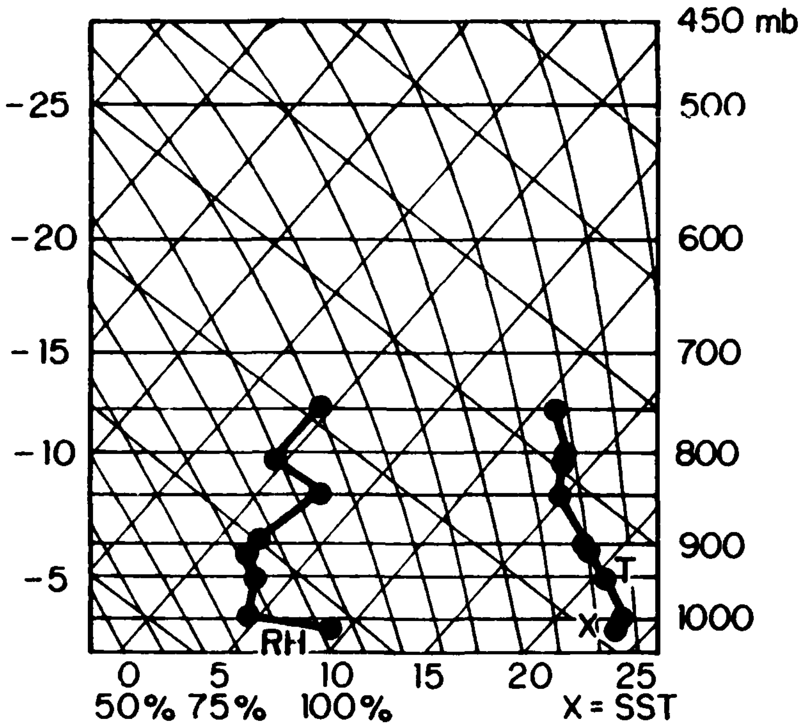


7/4/00Z
FOG
7/4/00

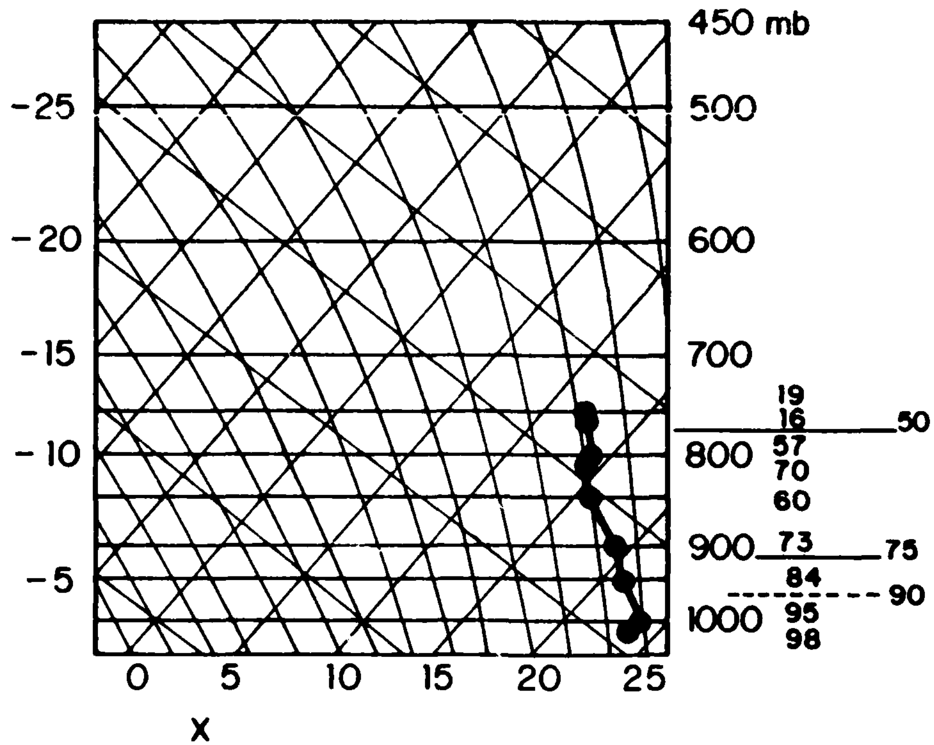


7/4/12Z
FOG
7/4/12 – 7/4/18

1970



7/5/00Z



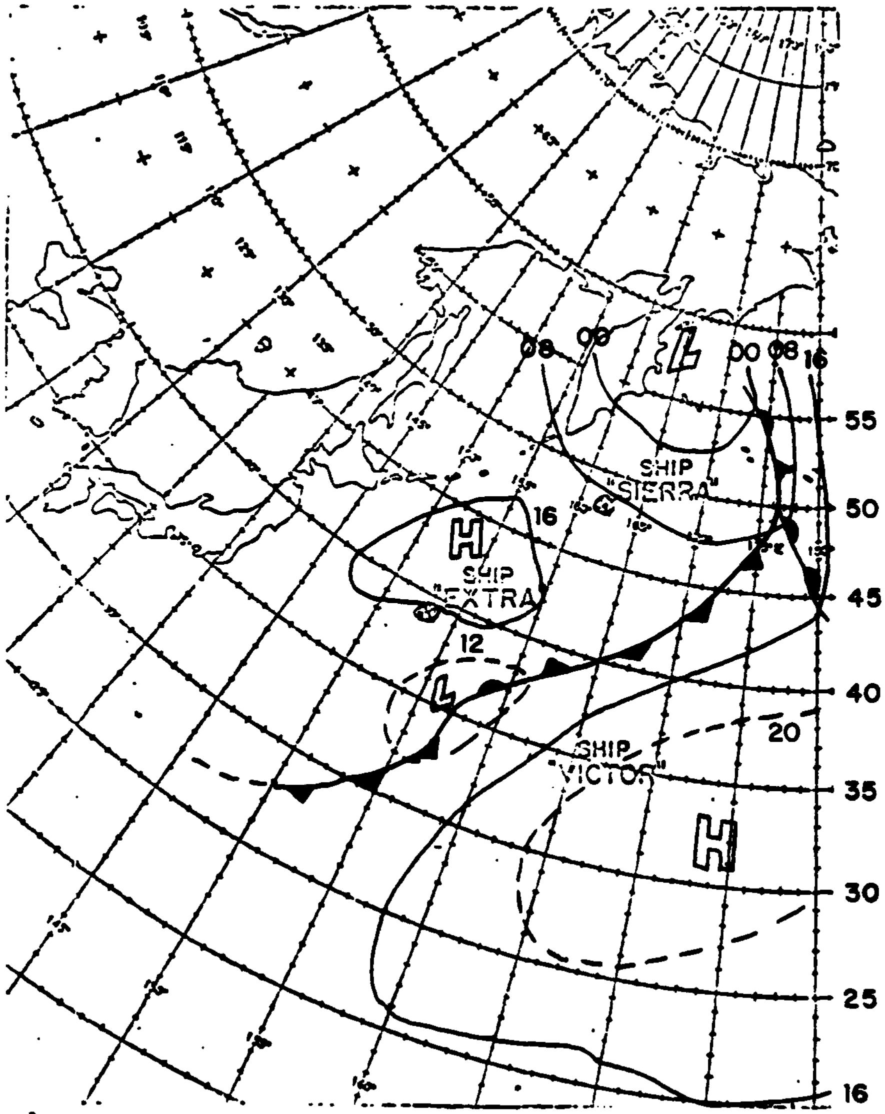
7/5/12 Z

1970

Date/ Time	Inversion Height	Max. Temperature above Inversion	Dewpoint	Sea-Surface Temperature	Temperature Index	Moisture Index	FOG/NO FOG
1971 July							
1/00Z	1014 mb			21.4C			
2/00Z	1017 mb	23.9C	22.5C	21.8C	23.9—21.4 is +2.5	22.5—21.4 is +1.1	(FOG)
3/00Z	1019 mb	23.0C	23.0C	22.5C	23.0—21.8 is +1.2	23.0—21.8 is +1.2	(FOG)
4/00Z	1019 mb	22.5C	22.5C	23.0C	22.5—22.5 is 0	22.5—22.5 is 0	(FOG)
5/00Z	None	None	22.6C	Missing	Missing	22.6—23.0 is -0.4	NO FOG

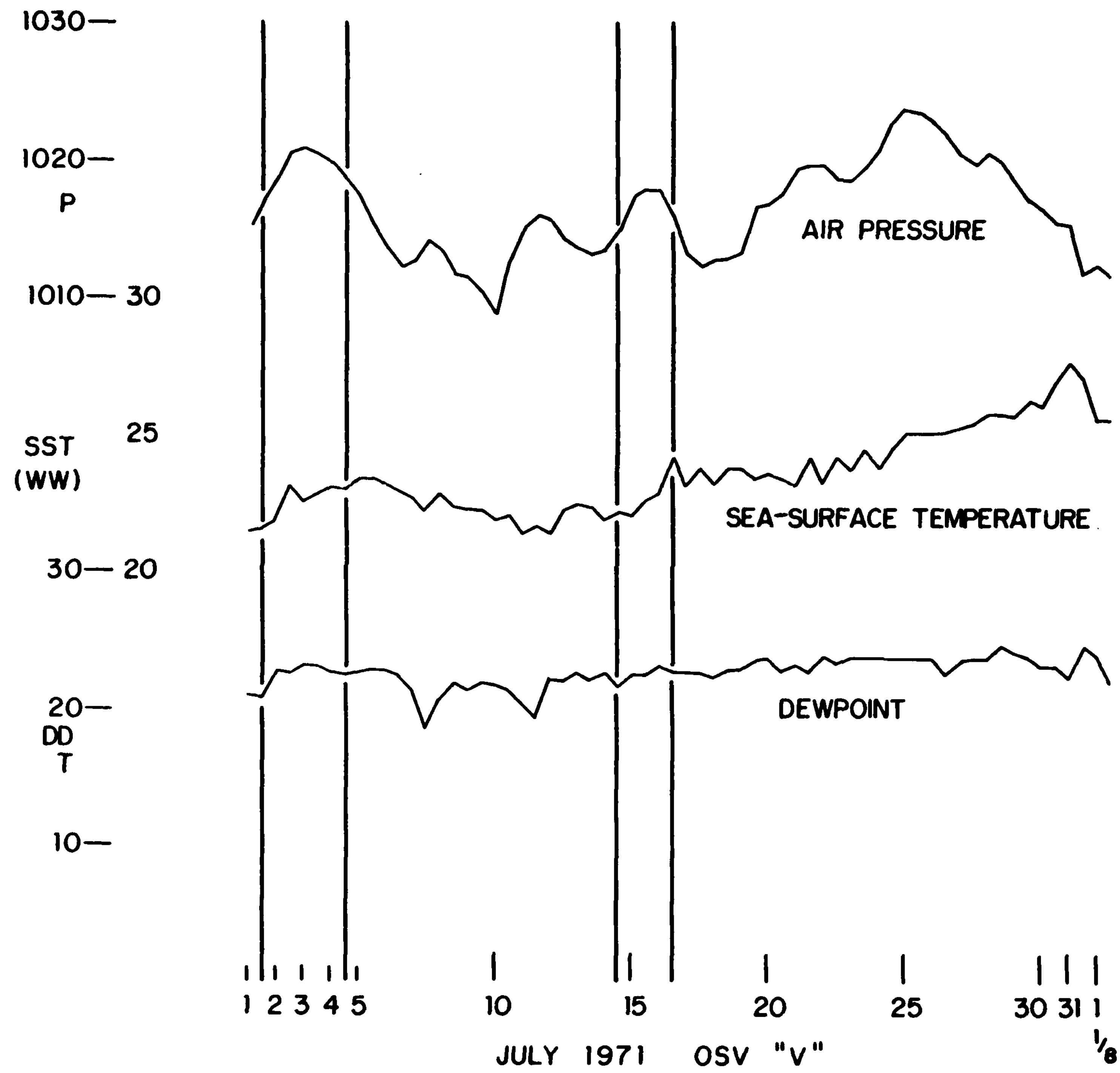
SYNOPTIC WEATHER PATTERN: Much of the time the flow is dominated by a ridge centered east and southeast of the station, providing warm-sector, southwesterly flow ahead of a stationary front which gradually moves toward station; dissipating front is in station vicinity on 4 July. The second Fog Occurrence of this Event is definitely Frontal.

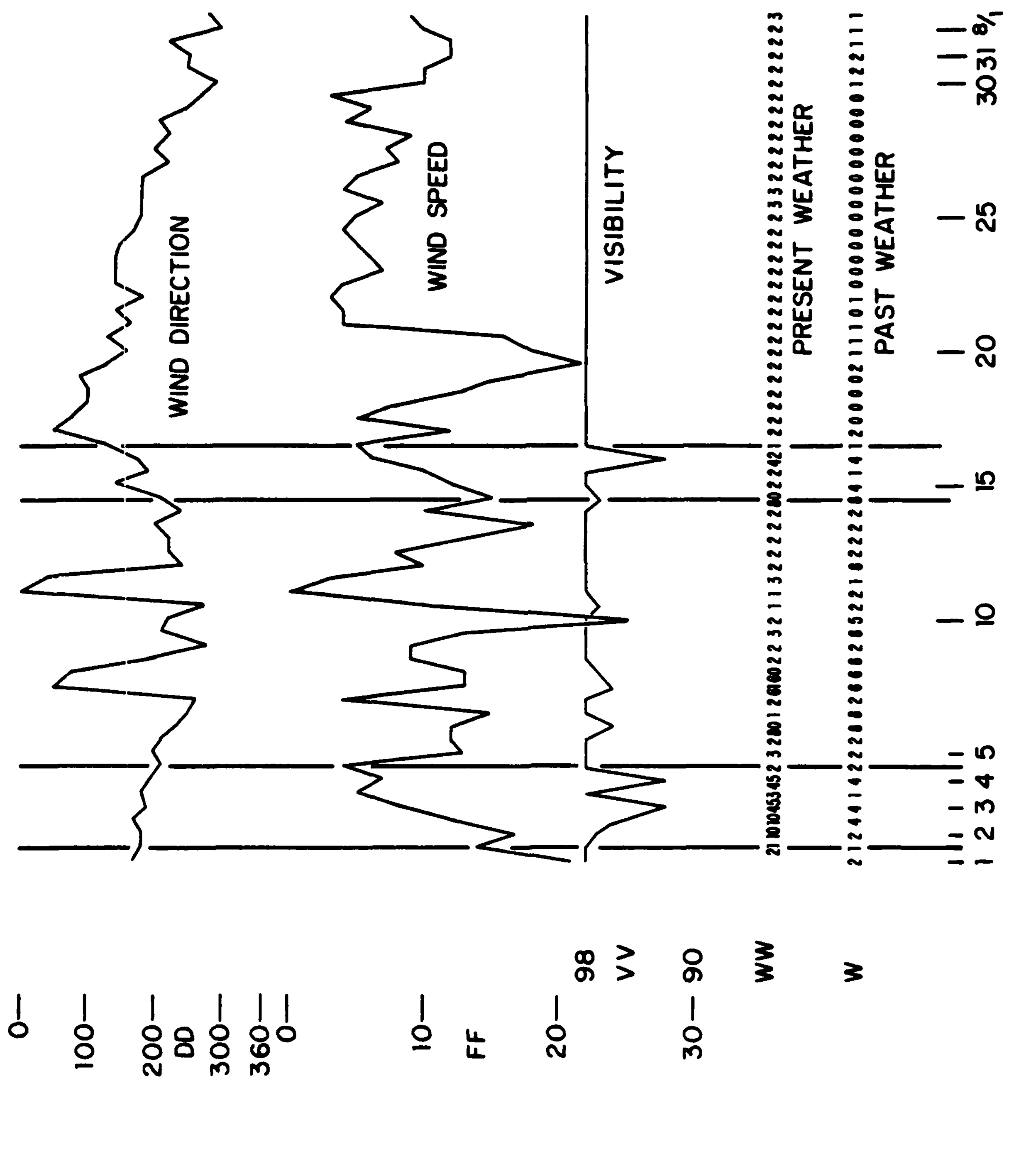
EVENT Three: OSV "V", 1-5 July 1971.

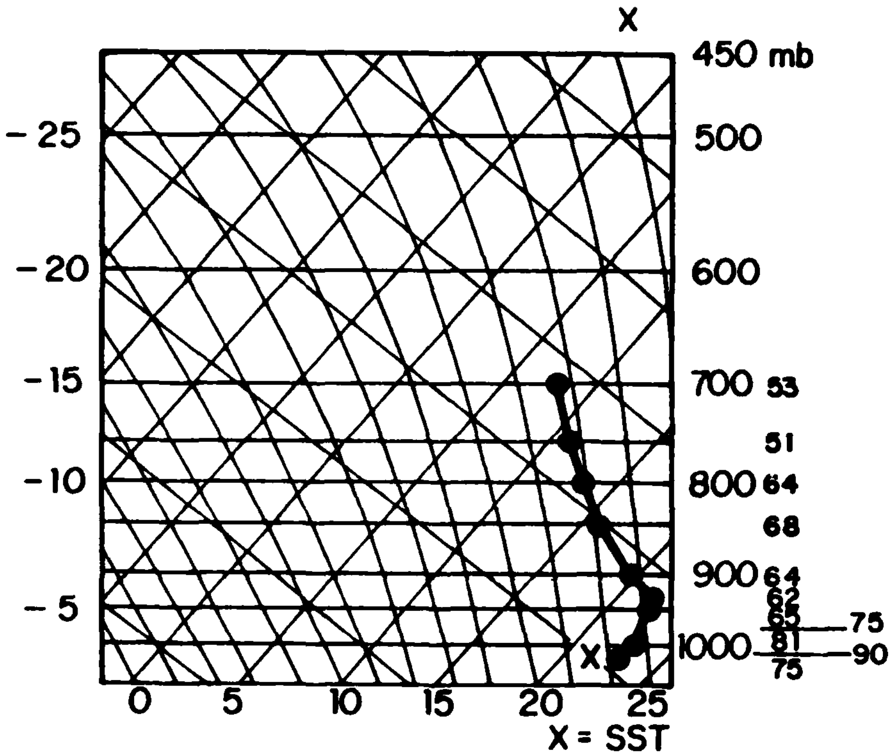


NORTH PACIFIC O.S.V

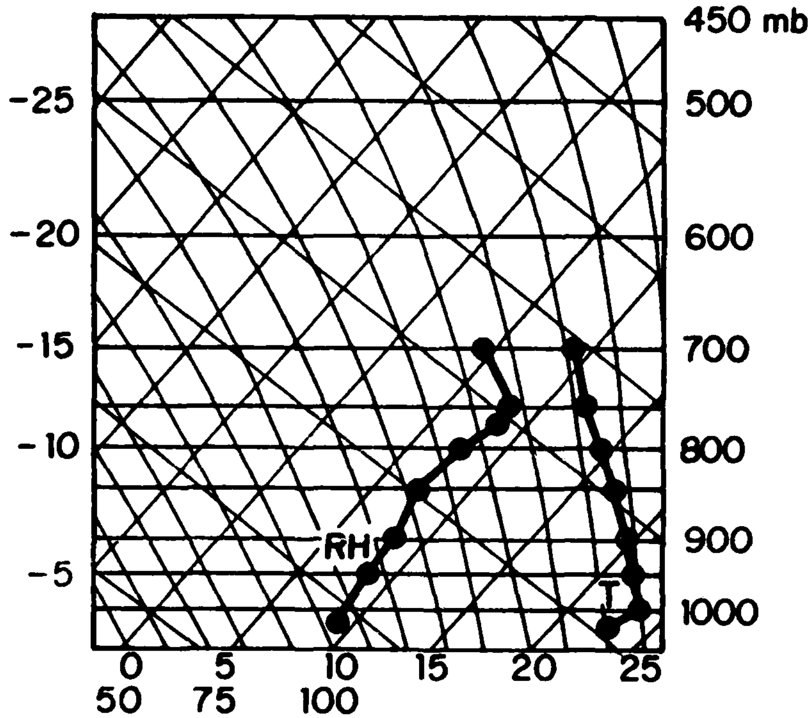
0000Z 2 July 1971 FOG: 7/1/15Z - 7/3/03Z;
7/3/15Z - 7/4/06Z


1030—
1020—
P
1010— 30
SST
(WW)
25
30— 20
20—
DD
T
10—
AIR PRESSURE
SEA-SURFACE TEMPERATURE
DEWPOINT
1 2 3 4 5
10
15
20
25
30 31 1
1/8
JULY 1971 OSV "V"


WIND DIRECTION
WIND SPEED
VISIBILITY
PRESENT WEATHER
PAST WEATHER
JULY 1971 OSV "V"
0
100
200
DD
300
360
0
10
FF
20
30
98
VV
90
WW
W
1 2 3 4 5
10
15
20
25
30 31 8/1

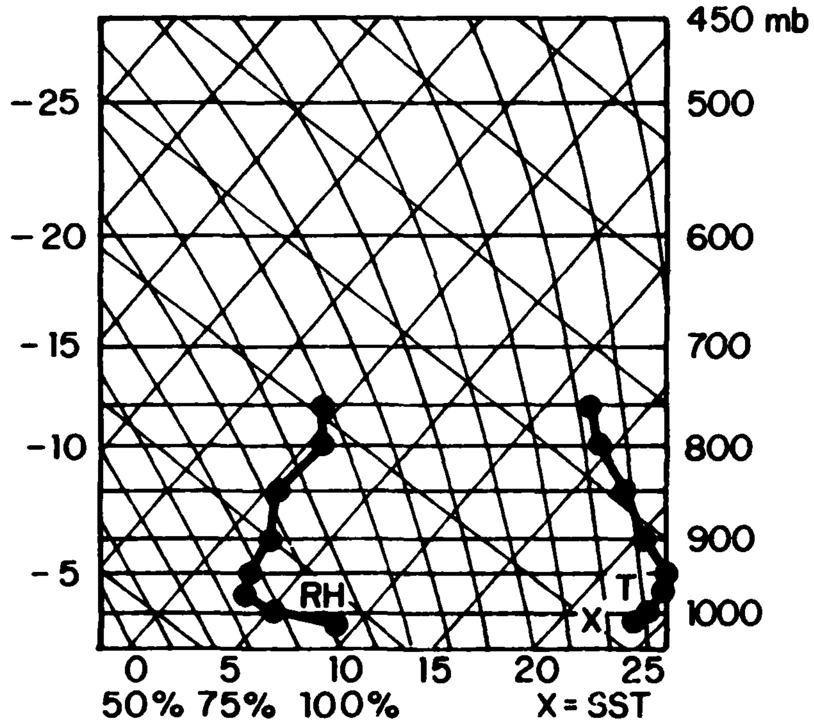


7/1/00Z

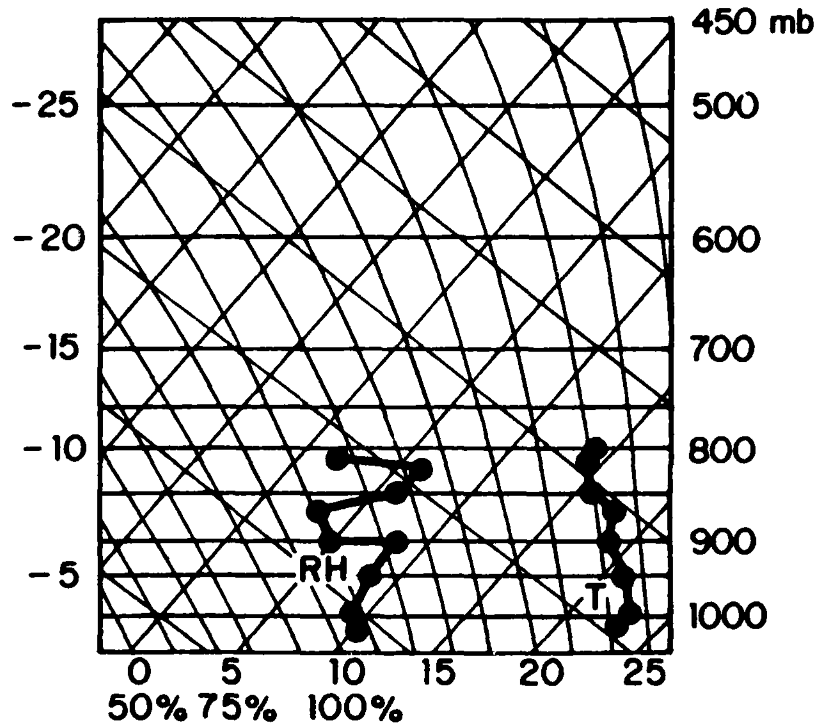


7/1/12Z
FOG
7/1/15 - 7/2/00

1971

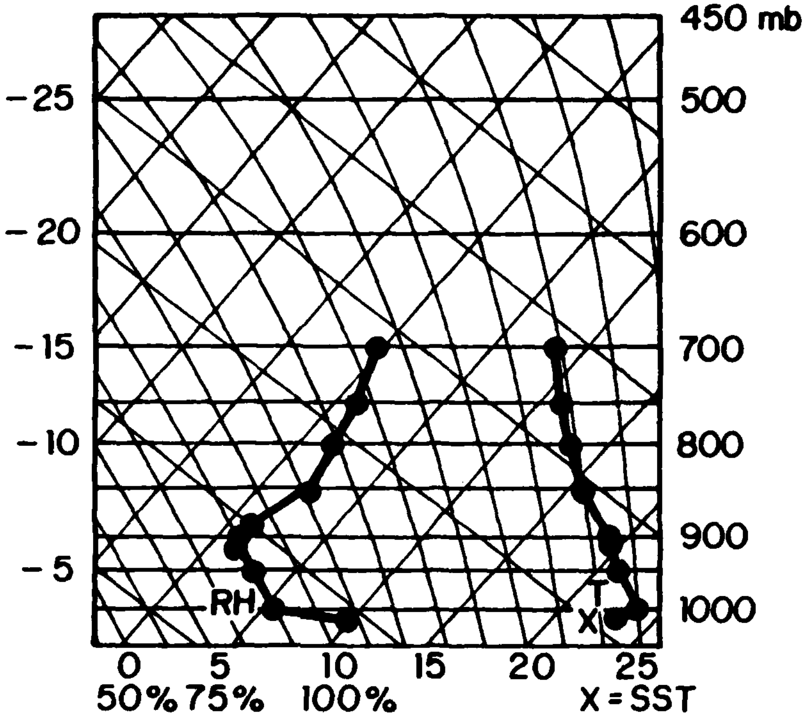


7/2/00Z
FOG
7/2/00- 7/2/12

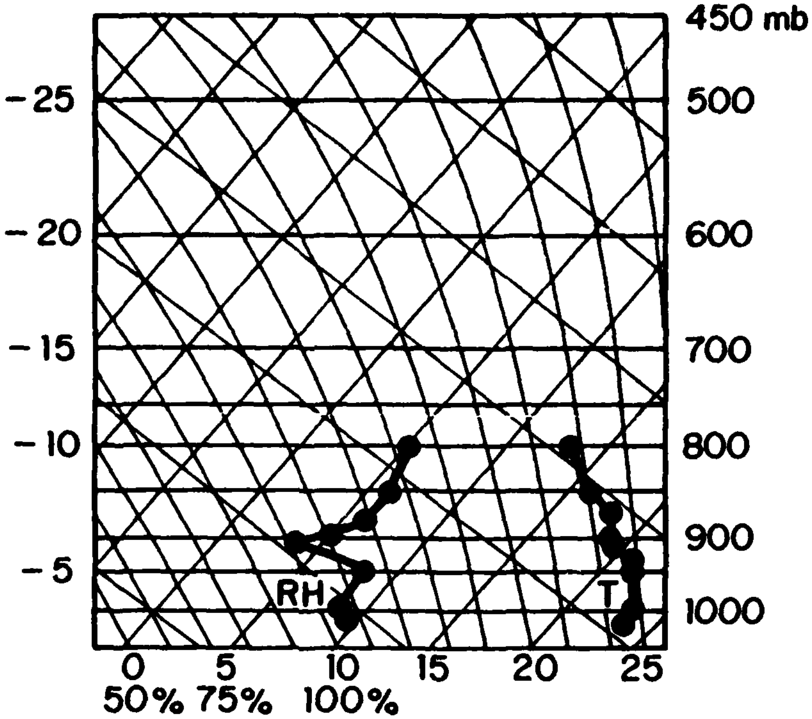


7/2/12 Z
FOG
7/2/12 - 7/3/00

1971

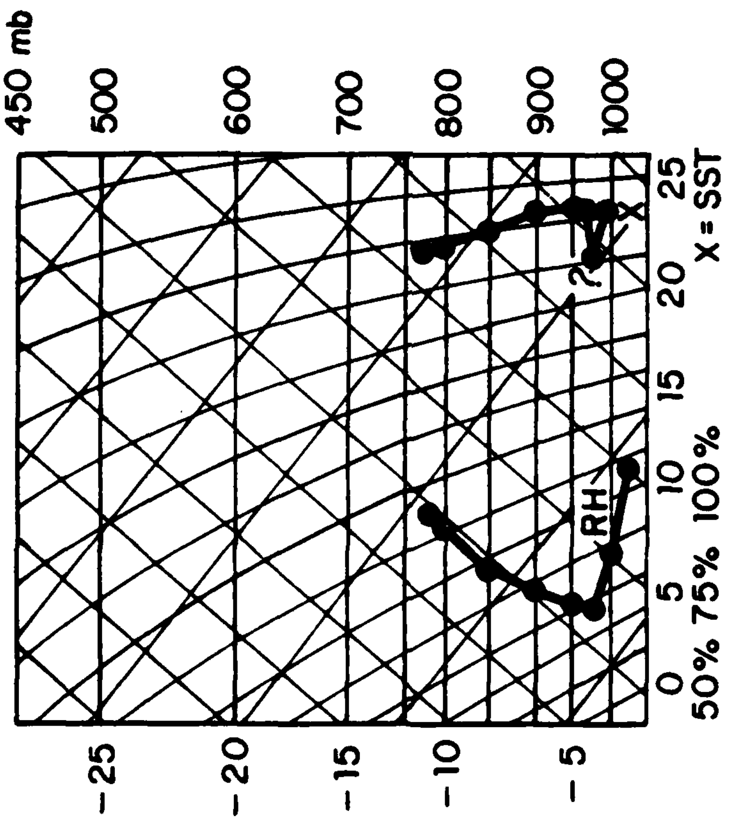


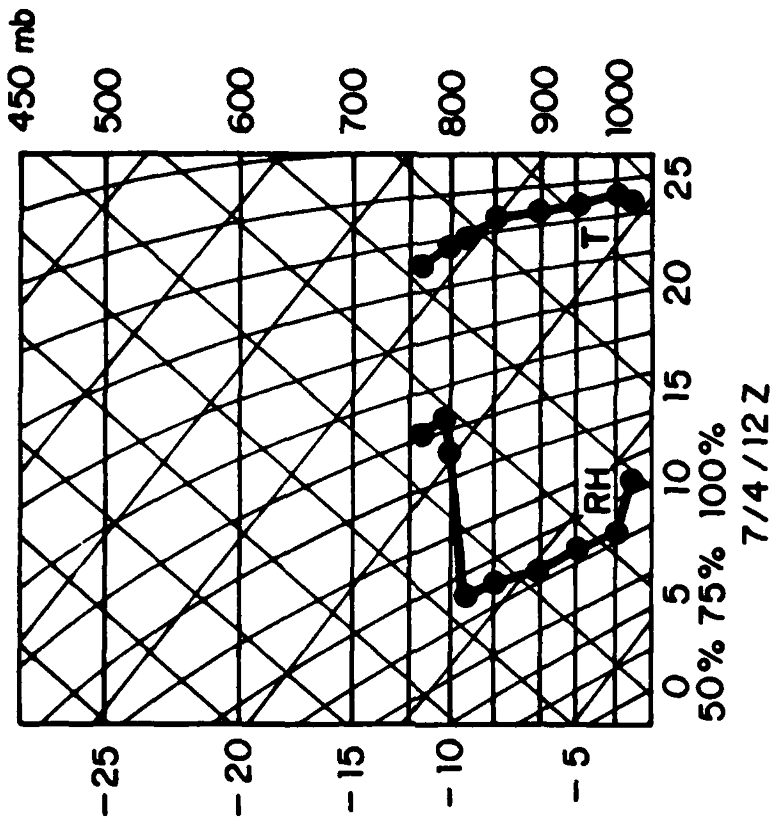
7/3/00Z
FOG
7/3/00 – 7/3/03



7/3/12 Z
FOG
7/3/15 – 7/4/00

1971





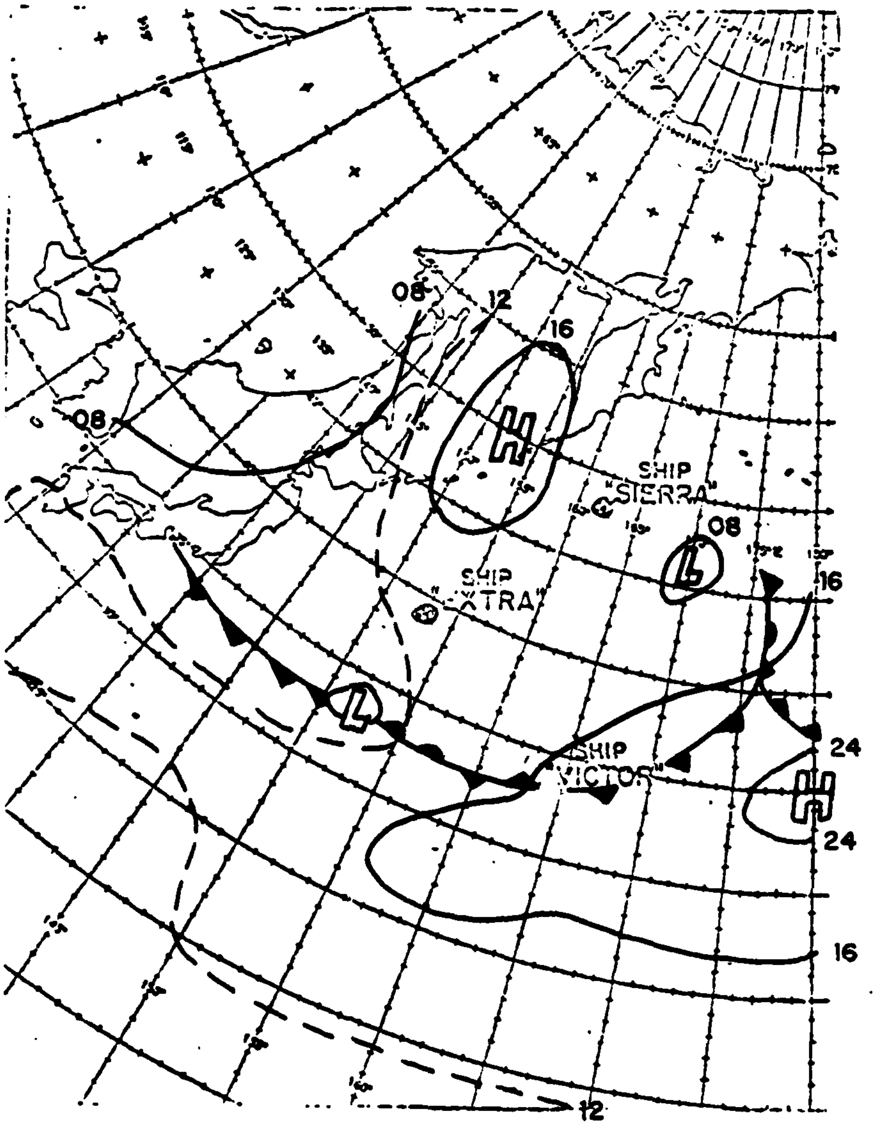
FOG
7/4/00 – 7/4/06

1971

Date/ Time	Inversion Height	Max. Temperature above Inversion	Dewpoint	Sea-Surface Temperature	Temperature Index	Moisture Index	FOG/NO FOG
1971 July							
12/00Z				21.8C			
13/00Z	1014 mb	23.4C	22.4C	22.4C	23.4—21.8 is +1.6	22.5—21.4 is +0.6	NO FOG
14/00Z	1012 mb	24.3C	22.4C	21.8C	24.3—22.4 is +1.9	22.4—22.4 is 0	NO FOG
15/00Z	1017 mb	24.1C	22.3C	21.9C	24.1—21.8 is +2.3	22.3—21.8 is +1.5	FOG
16/00Z	1018 mb	23.5C	23.0C	22.8C	23.5—21.9 is +1.6	23.0—21.9 is +1.1	FOG
17/00Z	None	None	22.5C	Missing	Missing	22.5—22.8 is -0.3	NO FOG

SYNOPTIC WEATHER PATTERN: Warm front is on station on 12 July; it is in the warm sector ahead of an approaching cold front on 13 July; the cold front is on the station 15-17 July. The Fog Occurrences in this Event are Frontal.

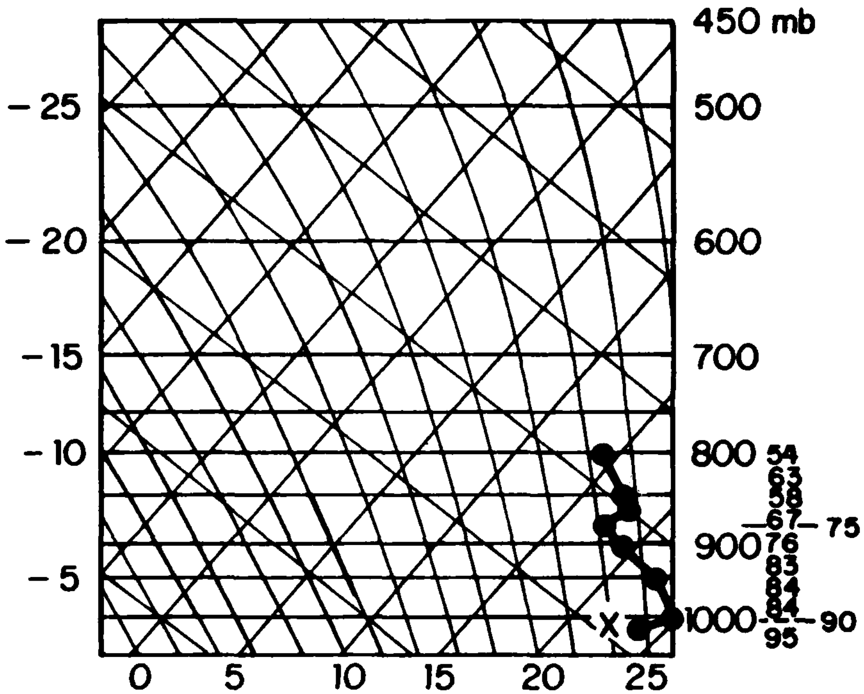
EVENT Four: OSV "V", 12-17 July 1971.



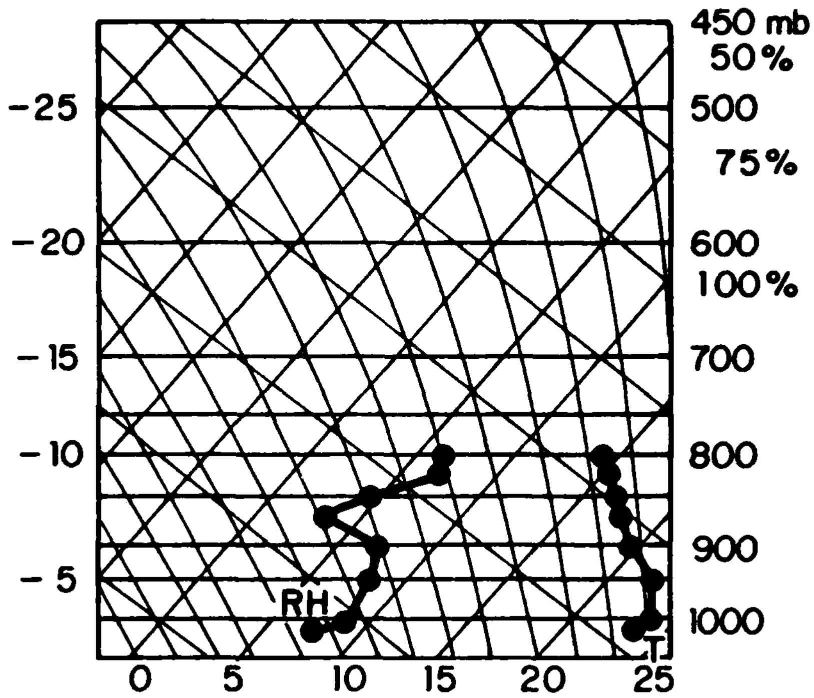
NORTH PACIFIC O.S.V

0000Z 15 July 1971   FOG: 7/14/21Z - 7/15/00Z

7/15/18Z - 7/16/06Z



7/14/00Z X=SST

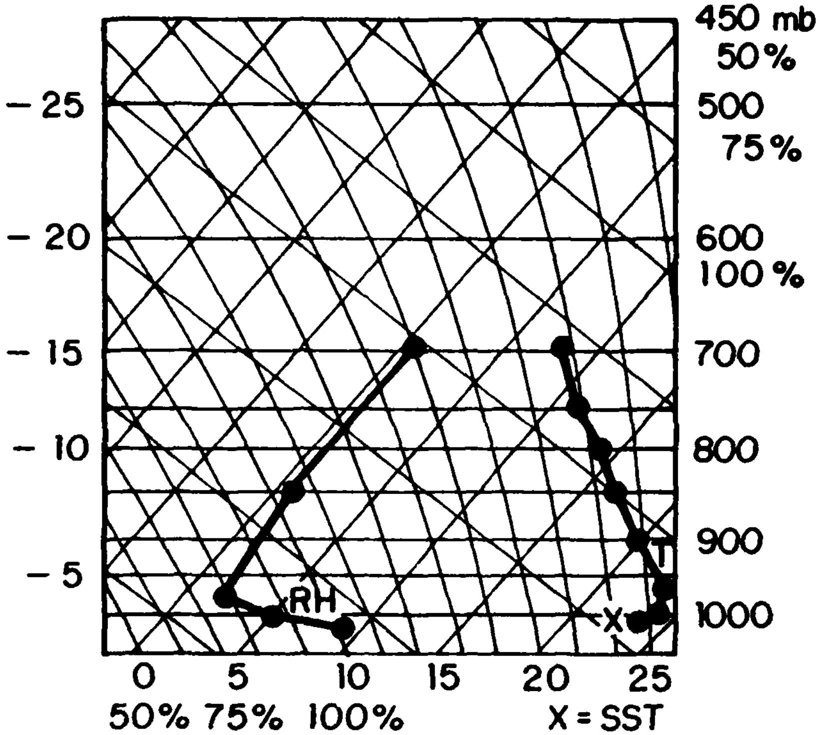


7/14/12 Z

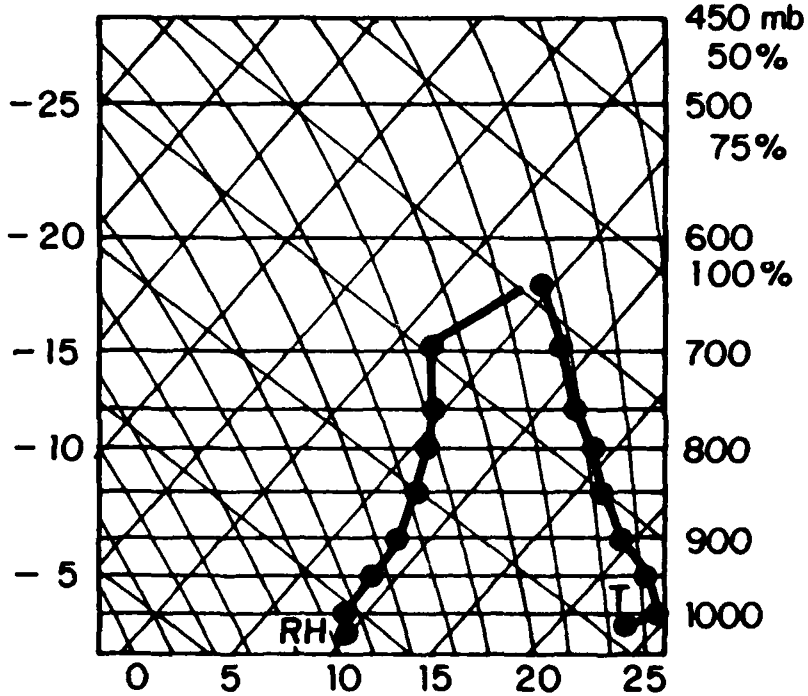
FOG:

7/14/21 - 7/15/00

1971

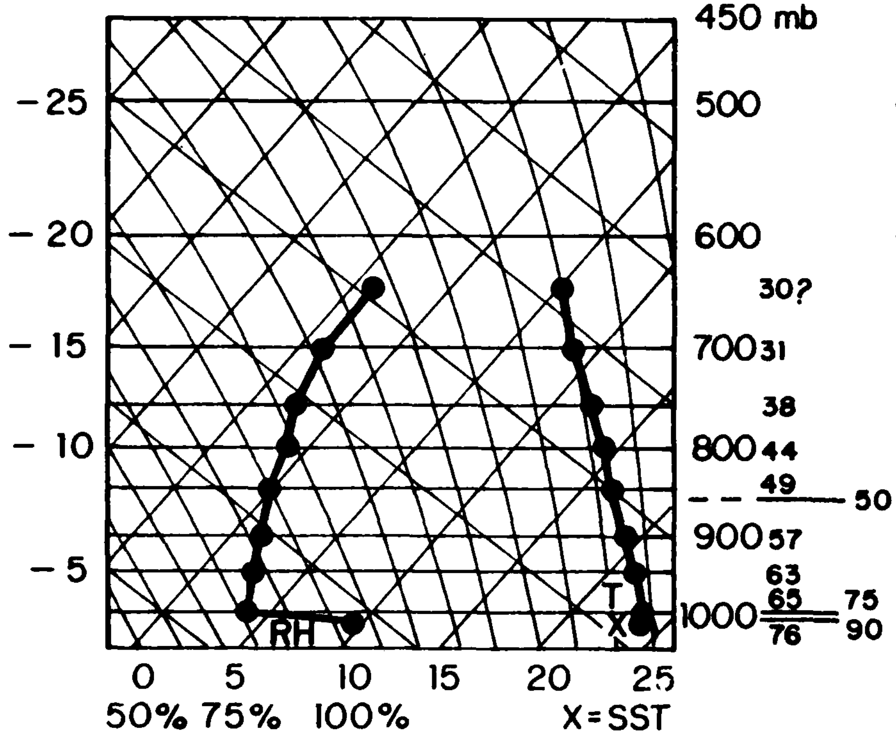


7/15/00 Z
FOG
7/14/21 – 7/15/00

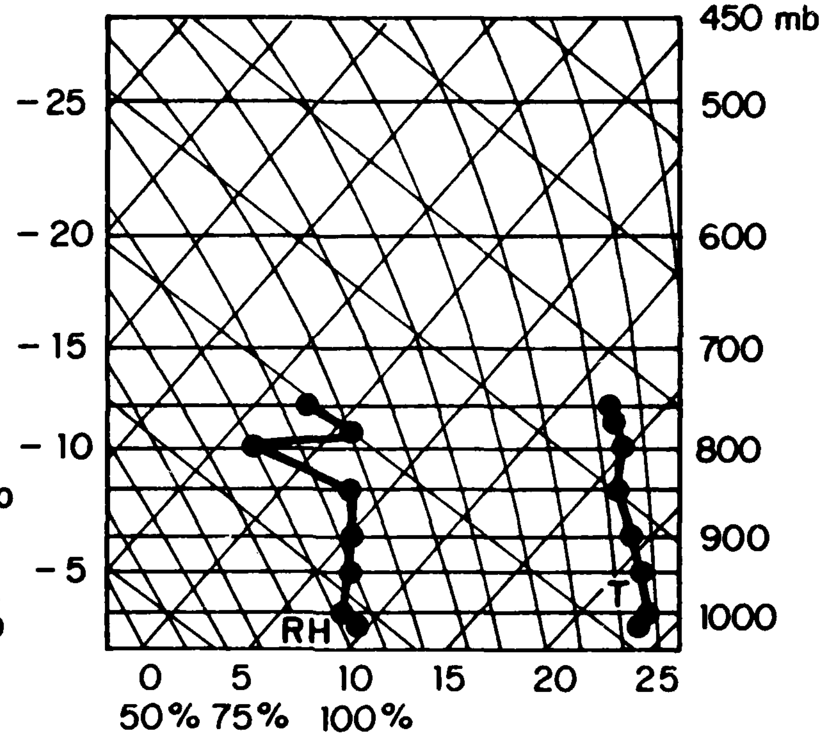


7/15/12 Z
FOG:
7/15/18 – 7/16/00

1971



7/16/00Z
FOG:
7/16/00 – 7/16/06



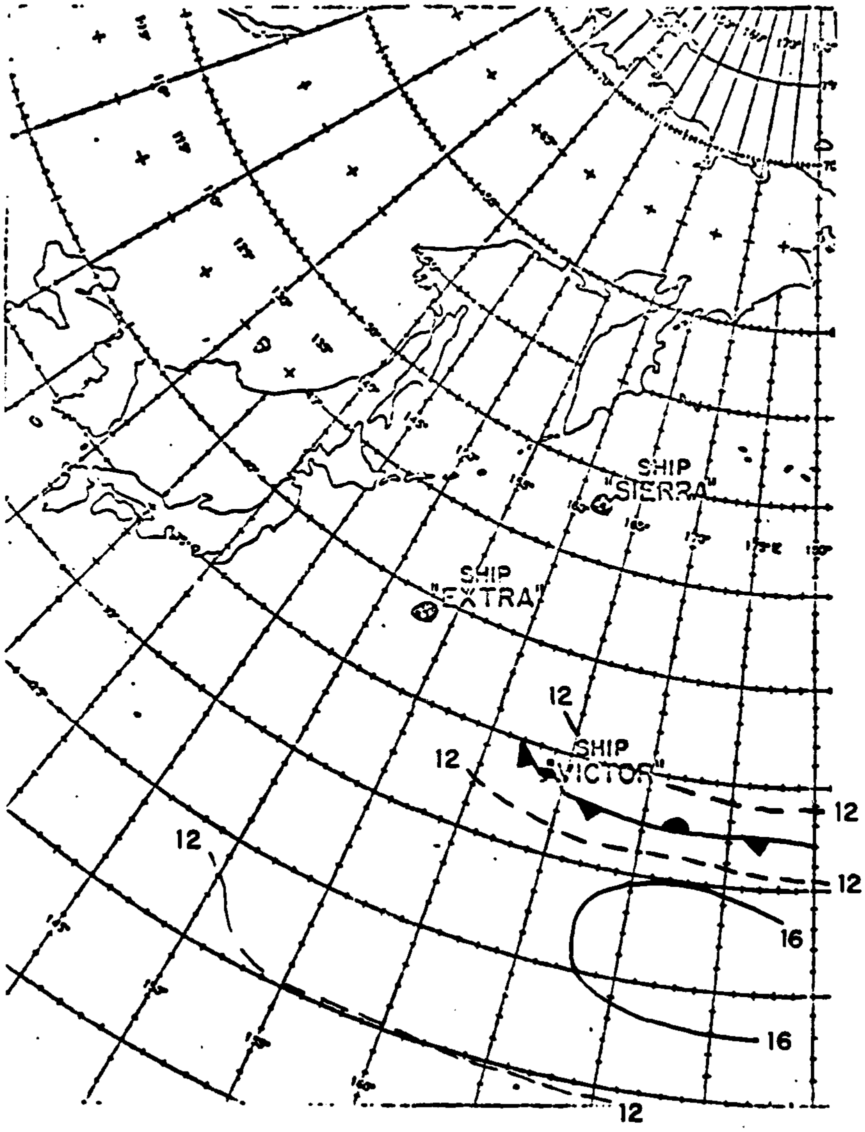
7/16/12Z

1971

Date/ Time	Inversion Height	Max. Temperature above Inversion	Dewpoint	Sea-Surface Temperature	Temperature Index	Moisture Index	FOG/NO FOG
1971 August							
2/00Z				25.7C			
3/00Z	881 mb	15.5C	20.2C	25.0C	15.5—25.7 is -10.2	20.2—25.7 is -5.5	NO FOG
4/00Z	None	Missing	24.8C	25.3C	Missing	24.8—25.0 is -0.2	NO FOG FOG? @ 03Z
5/00Z	850 mb	15.9C	23.8C		15.9—25.3 is -9.4	23.8—25.3 is -1.5	NO FOG

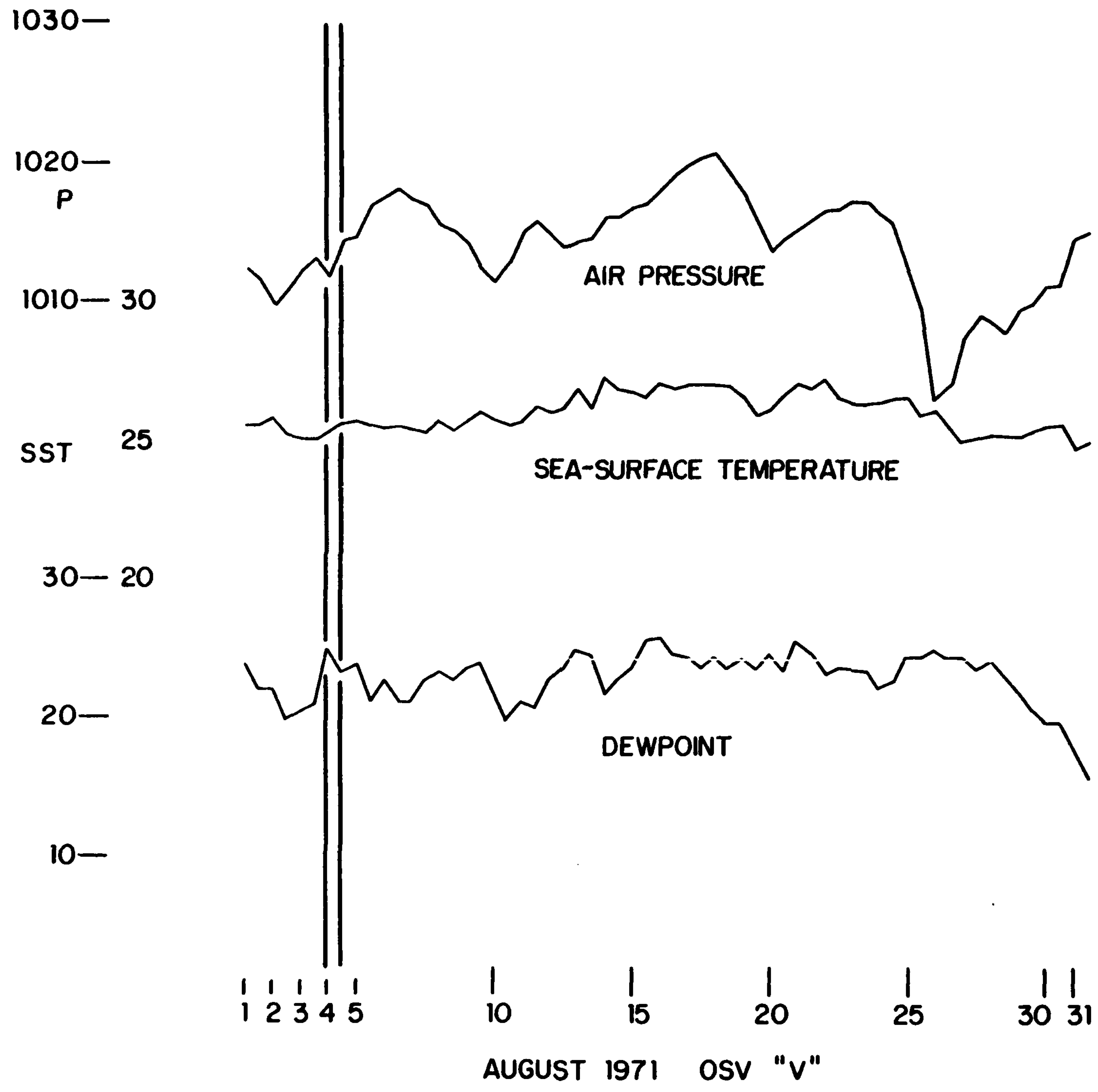
SYNOPTIC WEATHER PATTERN: Stationary Front over station; reduced visibility (fog?) in Event is Frontal.

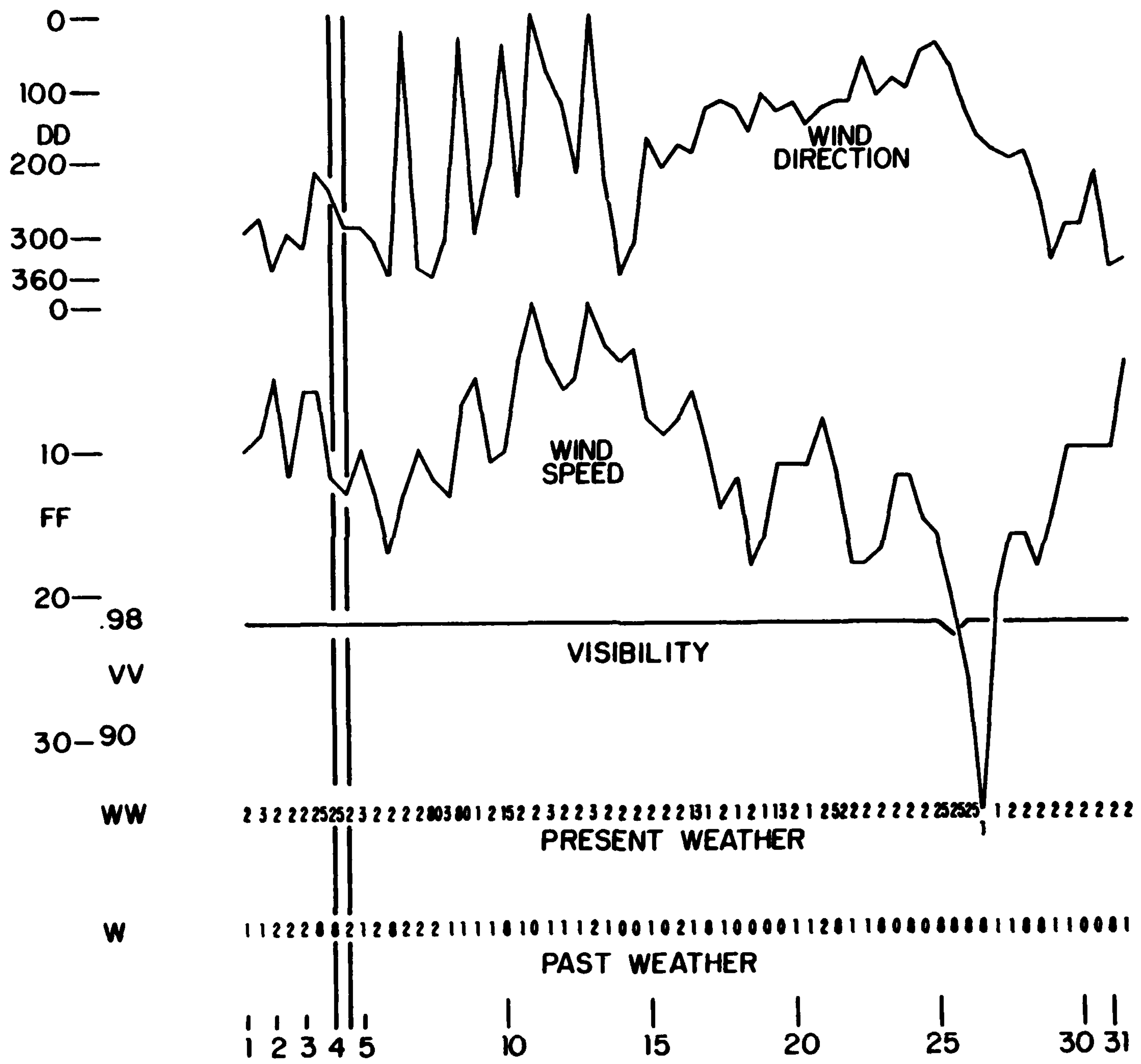
EVENT Five: OSV "V", 4 August 1971.



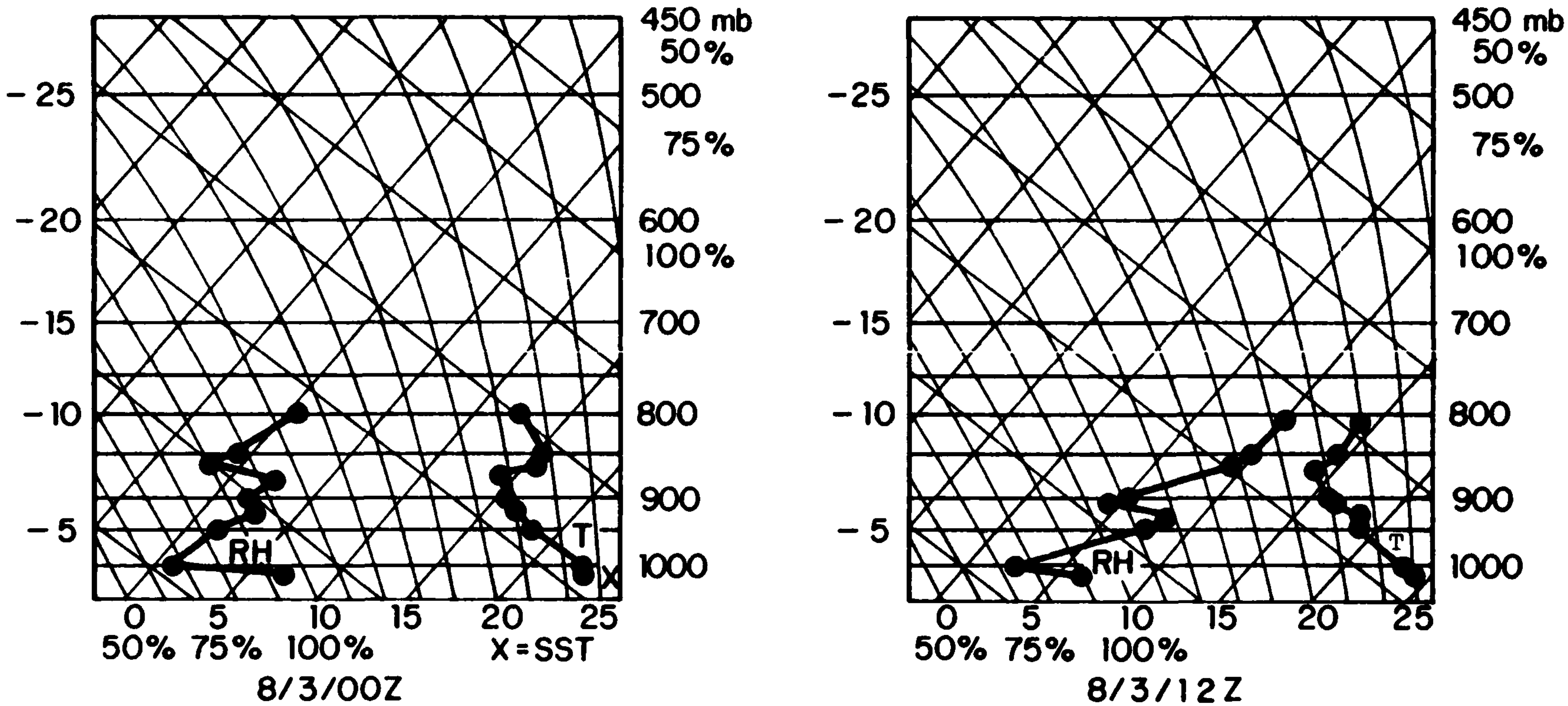
NORTH PACIFIC O.S.V

0000Z 4 August 1971 FOG: 4 August 03Z

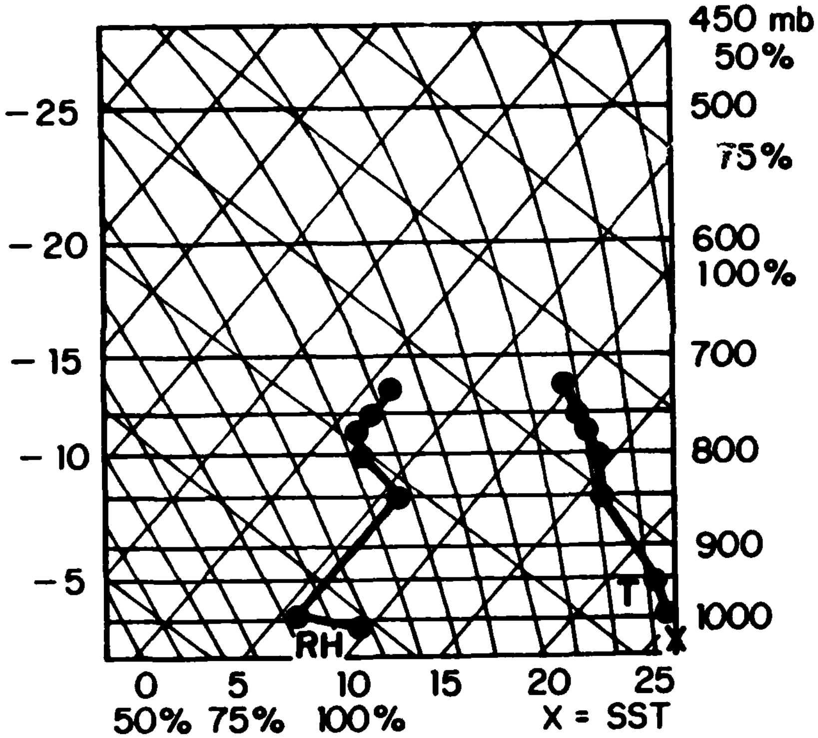

1030—
1020—
P
1010— 30
SST
25
30— 20
20—
10—
AIR PRESSURE
SEA-SURFACE TEMPERATURE
DEWPOINT
1 2 3 4 5
10
15
20
25
30 31
AUGUST 1971 OSV "V"



AUGUST 1971 OSV "V"


450 mb
50%
500
75%
600
100%
700
800
900
1000
-25
-20
-15
-10
-5
0 5 10 15 20 25
50% 75% 100%
RH
T
X = SST
8/3/00Z
8/3/12Z

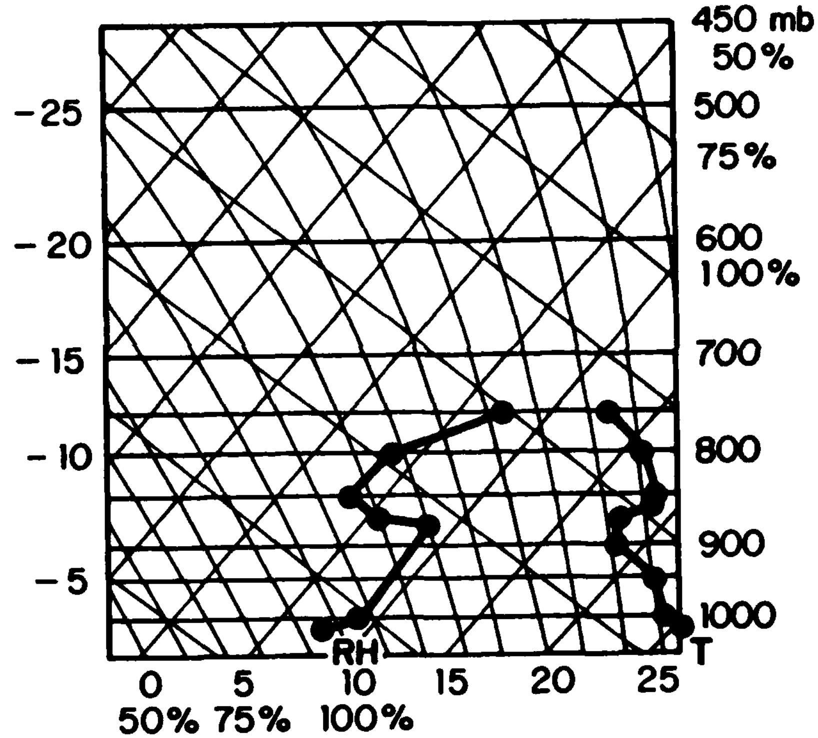
1971



8/4/00Z

FOG

8/4/03

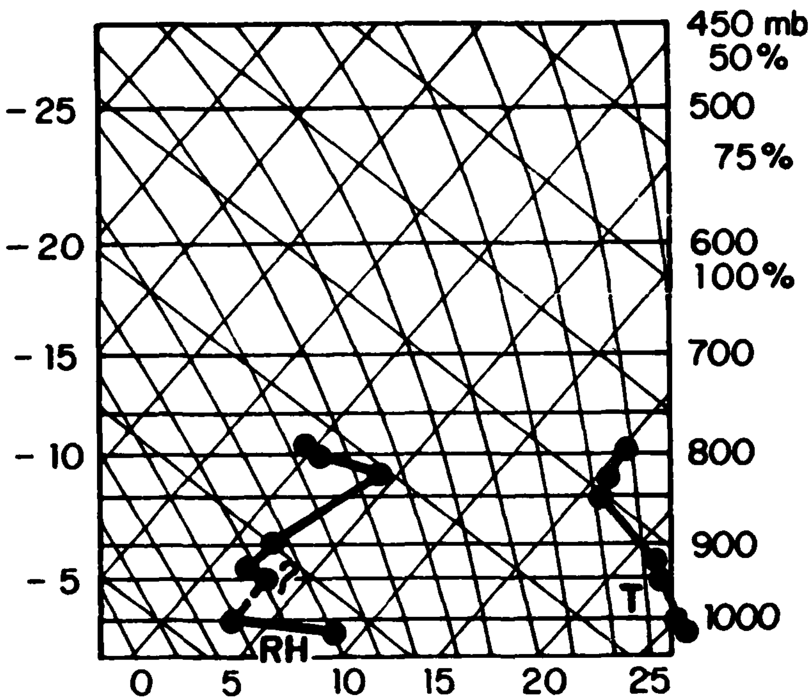


8/4/ 12 Z

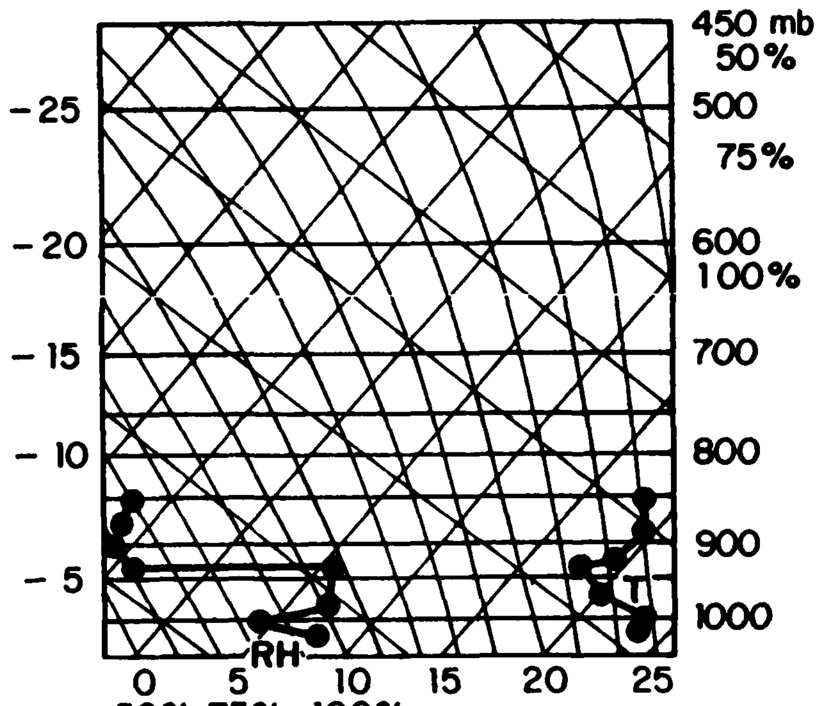
FOG

8/4/03

1971



8/5/00Z



8/5/12 Z

1971

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