NOAA Technical Memorandum NWS WR-232

FOG CLIMATOLOGY AT SPOKANE, WASHINGTON

Paul Frisbie
National Weather Service Forecast Office
Reno, Nevada

July 1995

U.S. DEPARTMENT OF COMMERCE / National Oceanic and Atmospheric Administration / National Weather Service

NOAA TECHNICAL MEMORANDA
National Weather Service, Western Region Subseries

The National Weather Service (NWS) Western Region (WR) Subseries provides an informal medium for the documentation and quick dissemination of results not appropriate, or not yet ready, for formal publication. The series is used to report on work in progress, to describe technical procedures and practices, or to relate progress to a limited audience. These Technical Memoranda will report on investigations devoted primarily to regional and local problems of interest mainly to personnel, and hence will not be widely distributed.

Papers 1 to 25 are in the former series, ESSA Technical Memoranda, Western Region Technical Memoranda (WRTM); papers 24 to 59 are in the former series, ESSA Technical Memoranda, Weather Bureau Technical Memoranda (WBTM). Beginning with 60, the papers are part of the series, NOAA Technical Memoranda NWS. Out-of-print memoranda are not listed.

Papers 2 to 22, except for 5 (revised edition), are available from the National Weather Service Western Region, Scientific Services Division, P.O. Box 11188, Federal Building, 125 South State Street, Salt Lake City, Utah 84147. Paper 5 (revised edition), and all others beginning with 25 are available from the National Technical Information Service, U.S. Department of Commerce, Sills Building, 5285 Port Royal Road, Springfield, Virginia 22161. Prices vary for all paper copies; microfiche are $3.50. Order by accession number shown in parentheses at end of each entry.

ESSA Technical Memoranda (WRTM)

2 Climatological Precipitation Probabilities. Compiled by Lucianne Miller, December 1965.
3 Western Region Pre- and Post-FP-3 Program, December 1, 1965, to February 20, 1966. Edward D. Diemer, March 1966.
5 Station Descriptions of Local Effects on Synoptic Weather Patterns. Philip Williams, Jr., April 1966 (Revised November 1967, October 1969). (PB-17800)
8 Interpreting the RAREP. Herbert P. Benner, May 1966 (Revised January 1967).
11 Some Electrical Processes in the Atmosphere. J. Latham, June 1966.
17 A Digitalized Summary of Radar Echoes within 100 Miles of Sacramento, California. J. A. Youngberg and L. B. Overaas, December 1966.
21 An Objective Aid for Forecasting the End of East Winds in the Columbia Gorge, July through October. D. John Coparanis, April 1967.
22 Derivation of Radar Horizons in Mountainous Terrain. Roger G. Pappas, April 1967.

ESSA Technical Memoranda, Weather Bureau Technical Memoranda (WBTM)

25 Verification of Operation Probability of Precipitation Forecasts, April 1966-March 1967. W. W. Dickey, October 1967. (PB-176240)
26 A Study of Winds in the Lake Mead Recreation Area. R. P. Augulis, January 1968. (PB-177830)
28 Weather Extremes. R. J. Schmidli, April 1968 (Revised March 1986). (PB86 177672/AS). (Revised October 1991 - PB92-115062/AS)
29 Small-Scale Analysis and Prediction. Philip Williams, Jr., May 1968. (PB178425)
30 Numerical Weather Prediction and Synoptic Meteorology. CPT Thomas D. Murphy, USAF, May 1968. (AD 673365)
31 Precipitation Detection Probabilities by Salt Lake ARTC Radars. Robert K. Belesky, July 1968. (PB 179084)
32 Probability Forecasting--A Problem Analysis with Reference to the Portland Fire Weather District. Harold S. Ayer, July 1968. (PB 179289)
36 Temperature Trends in Sacramento--Another Heat Island. Anthony D. Lentini, February 1969. (PB 183055)
37 Disposal of Logging Residues Without Damage to Air Quality. Owen P. Cramer, March 1969. (PB 183057)
39 Upper-Air Lows Over Northwestern United States. A.L. Jacobson, April 1969. PB 184296)
40 The Man-Machine Mix in Applied Weather Forecasting in the 1970s. L.W. Snellman, August 1969. (PB 185068)
43 Forecasting Maximum Temperatures at Helena, Montana. David E. Olsen, October 1969. (PB 185762)
44 Estimated Return Periods for Short-Duration Precipitation in Arizona. Paul C. Kangieser, October 1969. (PB 187763)
46 Applications of the Net Radiometer to Short-Range Fog and Stratus Forecasting at Eugene, Oregon. L. Yee and E. Bates, December 1969. (PB 190476)
47 Statistical Analysis as a Flood Routing Tool. Robert J.C. Burnash, December 1969. (PB 188744)
48 Tsunami. Richard P. Augulis, February 1970. (PB 190157)
49 Predicting Precipitation Type. Robert J.C. Burnash and Floyd E. Hug, March 1970. (PB 190962)
50 Statistical Report on Aeroallergens (Pollens and Molds) Fort Huachuca, Arizona, 1969. Wayne S. Johnson, April 1970. (PB 191743)
51 Western Region Sea State and Surf Forecaster's Manual. Gordon C. Shields and Gerald B. Burdwell, July 1970. (PB 193102)
52 Sacramento Weather Radar Climatology. R.G. Pappas and C. M. Veliquette, July 1970. (PB 193347)
54 A Refinement of the Vorticity Field to Delineate Areas of Significant Precipitation. Barry B. Aronovitch, August 1970.
55 Application of the SSARR Model to a Basin without Discharge Record. Vail Schermerhorn and Donal W. Kuehl, August 1970. (PB 194394)
56 Areal Coverage of Precipitation in Northwestern Utah. Philip Williams, Jr., and Werner J. Heck, September 1970. (PB 194389)
57 Preliminary Report on Agricultural Field Burning vs. Atmospheric Visibility in the Willamette Valley of Oregon. Earl M. Bates and David O. Chilcote, September 1970. (PB 194710)
58 Air Pollution by Jet Aircraft at Seattle-Tacoma Airport. Wallace R. Donaldson, October 1970. (COM 71 00017)
59 Application of PE Model Forecast Parameters to Local-Area Forecasting. Leonard W. Snellman, October 1970. (COM 71 00016)
60 An Aid for Forecasting the Minimum Temperature at Medford, Oregon, Arthur W. Fritz, October 1970. (COM 71 00120)
63 700-mb Warm Air Advection as a Forecasting Tool for Montana and Northern Idaho. Norris E. Woerner, February 1971. (COM 71 00349)
64 Wind and Weather Regimes at Great Falls, Montana. Warren B. Price, March 1971.
65 Climate of Sacramento, California. Tony Martini, April 1990. (Fifth Revision) (PB89 207781/AS)
66 A Preliminary Report on Correlation of ARTCC Radar Echoes and Precipitation. Wilbur K. Hall, June 1971. (COM 71 00829)
69 National Weather Service Support to Soaring Activities. Ellis Burton, August 1971. (COM 71 00956)
71 Western Region Synoptic Analysis-Problems and Methods. Philip Williams, Jr., February 1972. (COM 72 10433)
74 Thunderstorms and Hail Days Probabilities in Nevada. Clarence M. Sakamoto, April 1972. (COM 72 10554)
75 A Study of the Low Level Jet Stream of the San Joaquin Valley. Ronald A. Willis and Philip Williams, Jr., May 1972. (COM 72 10707)
76 Monthly Climatological Charts of the Behavior of Fog and Low Stratus at Los Angeles International Airport. Donald M. Gales, July 1972. (COM 72 11140)
77 A Study of Radar Echo Distribution in Arizona During July and August. John E. Hales, Jr., July 1972. (COM 72 11136)
78 Forecasting Precipitation at Bakersfield, California, Using Pressure Gradient Vectors. Earl T. Riddiough, July 1972. (COM 72 11146)
79 Climate of Stockton, California. Robert C. Nelson, July 1972. (COM 72 10920)
80 Estimation of Number of Days Above or Below Selected Temperatures. Clarence M. Sakamoto, October 1972. (COM 72 10021)
81 An Aid for Forecasting Summer Maximum Temperatures at Seattle, Washington. Edgar G. Johnson, November 1972. (COM 73 10150)
82 Flash Flood Forecasting and Warning Program in the Western Region. Philip Williams, Jr., Chester L. Glenn, and Roland L. Raetz, December 1972, (Revised March 1978). (COM 73 10251)
83 A comparison of Manual and Semiautomatic Methods of Digitizing Analog Wind Records. Glenn E. Rasch, March 1973. (COM 73 10669)
86 Conditional Probabilities for Sequences of Wet Days at Phoenix, Arizona. Paul C. Kangieser, June 1973. (COM 73 11264)
87 A Refinement of the Use of K-Values in Forecasting Thunderstorms in Washington and Oregon. Robert Y.G. Lee, June 1973. (COM 73 11276)
89 Objective Forecast Precipitation Over the Western Region of the United States. Julia N. Paegle and Larry P. Kierulff, September 1973. (COM 73 11946/3AS)
91 Arizona "Eddy" Tornadoes. Robert S. Ingram, October 1973. (COM 73 10465)
92 Smoke Management in the Willamette Valley. Earl M. Bates, May 1974. (COM 74 11277/AS)
93 An Operational Evaluation of 500-mb Type Regression Equations. Alexander E. MacDonald, June 1974. (COM 74 11407/AS)
94 Conditional Probability of Visibility Less than One-Half Mile in Radiation Fog at Fresno, California. John D. Thomas, August 1974. (COM 74 11555/AS)
95 Climate of Flagstaff, Arizona. Paul W. Sorenson, and updated by Reginald W. Preston, January 1987. (PB87 143160/AS)
96 Map type Precipitation Probabilities for the Western Region. Glenn E. Rasch and Alexander E. MacDonald, February 1975. (COM 75 10428/AS)
97 Eastern Pacific Cut-Off Low of April 21-28, 1974. William J. Alder and George R. Miller, January 1976. (PB 250 711/AS)
98 Study on a Significant Precipitation Episode in Western United States. Ira S. Brenner, April 1976. (COM 75 10719/AS)
99 A Study of Flash Flood Susceptibility-A Basin in Southern Arizona. Gerald Williams, August 1975. (COM 75 11360/AS)
102 A Set of Rules for Forecasting Temperatures in Napa and Sonoma Counties. Wesley L. Tuft, October 1975. (PB 246 902/AS)
103 Application of the National Weather Service Flash-Flood Program in the Western Region. Gerald Williams, January 1976. (PB 253 053/AS)
104 Objective Aids for Forecasting Minimum Temperatures at Reno, Nevada, During the Summer Months. Christopher D. Hill, January 1976. (PB 252 866/AS)
105 Forecasting the Mono Wind. Charles P. Ruscha, Jr., February 1976. (PB 254 650)
106 Use of MOS Forecast Parameters in Temperature Forecasting. John C. Plankinton, Jr., March 1976. (PB 254 649)
107 Map Types as Aids in Using MOS PoPs in Western United States. Ira S. Brenner, August 1976. (PB 259 594)
108 Other Kinds of Wind Shear. Christopher D. Hill, August 1976. (PB 260 437/AS)
109 Forecasting North Winds in the Upper Sacramento Valley and Adjoining Forests. Christopher E. Fontana, September 1976. (PB 273 677/AS)
110 Cool Inflow as a Weakening Influence on Eastern Pacific Tropical Cyclones. William J. Denney, November 1976. (PB 264 655/AS)
112 The MAN/MOS Program. Alexander E. MacDonald, February 1977. (PB 265 941/AS)
113 Winter Season Minimum Temperature Formula for Bakersfield, California, Using Multiple Regression. Michael J. Oard, February 1977. (PB 273 694/AS)
114 Tropical Cyclone Kathleen. James R. Fors, February 1977. (PB 273 676/AS)
116 A Study of Wind Gusts on Lake Mead. Bradley Colman, April 1977. (PB 268 847)
117 The Relative Frequency of Cumulonimbus Clouds at the Nevada Test Site as a Function of K-Value. R.F. Quiring, April 1977. (PB 272 831)
118 Moisture Distribution Modification by Upward Vertical Motion. Ira S. Brenner, April 1977. (PB 268 740)
119 Relative Frequency of Occurrence of Warm Season Echo Activity as a Function of Stability Indices Computed from the Yucca Flat, Nevada, Rawinsonde. Darryl Randerson, June 1977. (PB 271 290/AS)
121 Climatological Prediction of Cumulonimbus Clouds in the Vicinity of the Yucca Flat Weather Station. R.F. Quiring, June 1977. (PB 271 704/AS)
122 A Method for Transforming Temperature Distribution to Normality. Morris S. Webb, Jr., June 1977. (PB 271 742/AS)
124 Statistical Guidance for Prediction of Eastern North Pacific Tropical Cyclone Motion - Part I. Charles J. Neumann and Preston W. Leftwich, August 1977. (PB 272 661)
125 Statistical Guidance on the Prediction of Eastern North Pacific Tropical Cyclone Motion - Part II. Preston W. Leftwich and Charles J. Neumann, August 1977. (PB 273 155/AS)
126 Climate of San Francisco. E. Jan Null, February 1978. Revised by George T. Pericht, April 1988. (PB88 208624/AS)
127 Development of a Probability Equation for Winter-Type Precipitation Patterns in Great Falls, Montana. Kenneth B. Mielke, February 1978. (PB 281 387/AS)
128 Hand Calculator Program to Compute Parcel Thermal Dynamics. Dan Gudgel, April 1978. (PB 283 080/AS)
129 Fire whirls. David W. Goens, May 1978. (PB 283 866/AS)
130 Flash-Flood Procedure. Ralph C. Hatch and Gerald Williams, May 1978. (PB 286 014/AS)
131 Automated Fire-Weather Forecasts. Mark A. Mollner and David E. Olsen, September 1978. (PB 289 916/AS)
132 Estimates of the Effects of Terrain Blocking on the Los Angeles WSR-74C Weather Radar. R.G. Pappas, R.Y. Lee, B.W. Finke, October 1978. (PB 289767/AS)
133 Spectral Techniques in Ocean Wave Forecasting. John A. Jannuzzi, October 1978. (PB291317/AS)
134 Solar Radiation. John A. Jannuzzi, November 1978. (PB291195/AS)
135 Application of a Spectrum Analyzer in Forecasting Ocean Swell in Southern California Coastal Waters. Lawrence P. Kierulff, January 1979. (PB292716/AS)
136 Basic Hydrologic Principles. Thomas L. Dietrich, January 1979. (PB292247/AS)
137 LFM 24-Hour Prediction of Eastern Pacific Cyclones Refined by Satellite Images. John R. Zimmerman and Charles P. Ruscha, Jr., January 1979. (PB294324/AS)
138 A Simple Analysis/Diagnosis System for Real Time Evaluation of Vertical Motion. Scott Heflick and James R. Fors, February 1979. (PB294216/AS)
139 Aids for Forecasting Minimum Temperature in the Wenatchee Frost District. Robert S. Robinson, April 1979. (PB298339/AS)
140 Influence of Cloudiness on Summertime Temperatures in the Eastern Washington Fire Weather district. James Holcomb, April 1979. (PB298674/AS)
141 Comparison of LFM and MFM Precipitation Guidance for Nevada During Doreen. Christopher Hill, April 1979. (PB298613/AS)

NOAA Technical Memorandum NWS WR-232

FOG CLIMATOLOGY AT SPOKANE, WASHINGTON

Paul Frisbie
National Weather Service Forecast Office
Reno, Nevada

July 1995

UNITED STATES
DEPARTMENT OF COMMERCE
Ronald H. Brown, Secretary

National Oceanic and
Atmospheric Administration
(Vacant), Under Secretary
and Administrator

National Weather Service
Elbert W. Friday, Jr., Assistant
Administrator for Weather Services

This publication has been reviewed
and is approved for publication by
Scientific Services Division,
Western Region

Delain A. Edman
Scientific Services Division
Salt Lake City, Utah

TABLE OF CONTENTS

TABLE OF FIGURES

CONTENTS OF TABLES

FOG CLIMATOLOGY AT SPOKANE, WASHINGTON

Paul Frisbie
National Weather Forecast Office
Reno, Nevada

Abstract

Fog climatology at Spokane, Washington is established to aid in the preparation of terminal aviation forecasts. Two software applications correlate specific surface weather to fog for parameters five winters of hourly surface observations. The programs only consider data when the spread between the temperature and dewpoint temperatures is 2°F or less. FOGGEG produces graphical outputs for fog probability versus temperature, wind speed, wind direction, barometric pressure, and time of day. FCSTFOG provides conditional probabilities of fog for LIFR, IFR, and MVFR conditions.

Fog and dense fog are most likely to occur under calm winds. For wind speeds under 11 kts, the most favorable wind direction is from the northeast. For wind speeds greater than 11 knots, the preferred direction is south or southwest. Fog rarely forms with a northwest wind. When temperatures are around 5°F, dense fog is possible with a dew-point depression of 3 or 4°F. In this instance, the atmosphere is saturated with respect to ice, not water.

I. INTRODUCTION

Forecasting fog at the Spokane Airport (GEG) can be challenging to any forecaster, particularly during the winter. For the period 1961-1990, climatology shows an average of 37 dense fog days per year during November through February. Excluding periods of precipitation (except when drizzle and ice crystals are observed), fog occurs at Spokane 22 percent of the time. Dense fog forms 6 percent of the time. Since fog frequently occurs at Spokane and affects aviation, there is a need to better understand its formation and dissipation.

The intent of this study is to establish a fog climatology at Spokane for the purpose of preparing terminal aviation forecasts (FTs). When certain meteorological factors as expected, the forecaster may accurately predict fog and visibility in regards to LIFR, IFR, and MVFR conditions, as well as a no fog event. However, only visibility is used in this study without consideration of ceiling. In surface observations, the visibility requirements for fog occurrence is 6 miles or less. When the visibility drops to a quarter mile or less, the fog is considered dense.

There are a number of reasons for dense fog at Spokane during the winter months. Foremost is that Spokane resides in a modified marine air mass during most of the winter. Other factors to consider include: 1) nocturnal radiational cooling; 2) warm air advection over a colder, possibly snow-covered surface; 3) adiabatic cooling (Spokane is upslope in a southwesterly flow); 4) evaporative cooling; and 5) any combination of the aforementioned possibilities.

There are occasions when Spokane does not reside in a marine air mass during the winter months. A dry continental air mass periodically will occupy the region after the passage of a modified arctic front. A mesoscale feature that modifies the air mass, although an infrequent occurrence, is the relatively dry chinook winds that develop off the Washington Cascades.

These winds may partially mix out the maritime air mass, but are uncommon and normally occur during periods of little precipitation.

The Spokane Airport sits in a prairie field on the western edge of the city and is not highly urbanized. Many small lakes and creeks are situated around the airport. Four miles northeast of the airport, Hangman Creek flows into the Spokane River, about 500 feet lower than the airport elevation. These rivers, creeks, and lakes supply moisture to the boundary layer. During the winter months, the Spokane River and Hangman Creek may not necessarily freeze over (occasionally, the river and creek will freeze), consequently, the Spokane River almost always continues to supply moisture to the air mass, even during periods of persistent freezing temperatures. Initially, fog forms and thickens along the river and creek. Once it reaches the prairie level of the airport, it spreads out. When the wind is from the northeast, the fog moves towards the airport.

The waste-to-energy plant, located just northeast of the airport, began operation in November 1991. The impact of the facility on visibility and fog, if any, is not understood. Because of this uncertainty, no consideration will be given to the waste-to-energy plant on fog formation. Therefore, the winter seasons of '91-'92 and '92-'93 are not included in the study.

II. PROCEDURE

Five winters of hourly surface aviation observations were used for a period from November 1986 through February 1991 for a total of 14,400 observations. Hourly observation elements included in this study are visibility, obstruction to visibility, temperature, dewpoint, wind speed and direction, and barometric pressure.

Two programs have been developed utilizing the five-year database. The output from both programs only consider data when the dew-point depression is ≤ 2°F. The first program, FOGGEG, graphs five plots; percentage of fog versus temperature, wind speed and direction, barometric pressure, and time of day. The second program, FCSTFOG, uses specific data input by the forecaster. The program's output is statistical guidance for expected meteorological conditions. All precipitation events, except drizzle, are excluded from any calculation.

The first program, FOGGEG, requires the user to enter the name of the desired datafile. After the user inputs the desired visibility range, the program executes and outputs the four graphs mentioned above. However, since some weather parameters occur more frequently than others, there are spikes in the dataset. To smooth the curve, a weighting function is assigned to each datapoint, for temperature, wind speed, wind direction, pressure, and time of day. Let x_i equal the chance of fog for a given meteorological datapoint defined by i; x_i' represents the new weighted meteorological datapoint. Extreme values for temperature and pressure are thrown out of the dataset because of the small number of cases; the lower limit for consideration is 10 cases.

$$x_i' = \frac{x_{i-2} + 2*x_{i-1} + 4*x_i + 2*x_{i+1} + x_{i+2}}{10}$$

Figures. 1 and 2 show conditional probabilities for dense fog and any fog, respectively, when the dew-point depression is ≤ 2°F. Both figures display five charts of probabilities versus temperature, wind direction, wind speed, surface pressure, and time of day.

The output from the second program, FCSTFOG, is used for statistical guidance. The program user enters meteorological parameters such as temperature (select a value that is expected to be representative for the time period), wind speed and direction, and time of day. Since meteorological parameters are not steady state, the program allows for variance. For temperature, it considers ± 3°F. For wind speed, the variance is within 20 percent of the requested value; for wind direction the variance is ± 30°. The program also considers the time of day, since there is a diurnal variation in fog occurrence. After the program executes, the output displays probabilities for certain visibilities and, if fog occurs, conditional probabilities for those visibilities given. Again, the output is only valid if the temperature and dew-point temperature spread does not exceed 2°F!

Both programs accommodate the special condition of calm winds. In surface observations, calm winds have no direction since it is reported as "0000". There are no reported values for wind speeds of 1 or 2 knots; wind speeds less than 3 knots are entered as "0000". To allow for this, the first program treats wind speeds of 0, 1, and 2 knots as equals. Program FCSTFOG gives no variance for calm winds.

Given the following conditions:

1. Time of Day: AM
2. Wind Direction: 07
   (entered in tens of degrees)
3. Wind Speed: 6 (knots)
4. Temperature: 32°F

The output from FCSTFOG would be:
Number of Events: 198

	#	%
VSBY < = 1/4 MILE	28	46
1/4 MILE < VSBY < 1 MILE	10	17
1 MILE < = VSBY < 3 MILE	7	11
3 MILE < = VSBY < = 5 MILE	13	22
VSBY = 6 MILE	3	4
ANY FOG		60
NO FOG		40

Climatology for the above weather conditions state that fog is probable; however, there is still a good chance for no fog. And if fog does occur, LIFR conditions are likely. The output should only be considered as statistical guidance, i.e., the program does not weight any meteorological possibilities other than the parameters entered.

III. DISCUSSION

The meteorological parameter with the greatest affinity to fog and dense fog is dew-point depression. The probability of fog decreases nearly by one-half with a 1°F increase in dew-point depression. Table 1 summarizes the fog and dew-point depression relationship. The vast majority of fog events occur when the dew-point depression is 0 - 1°F. Since values are rounded when reported, e.g., a temperature of 32.5°F and a dew-point temperature of 32.4°F will show a one degree difference, all cases with the dew-point depression ≤ 2°F are considered. Instances where the dew-'point depression is ≥ 2°F constitutes a special scenario and will be discussed later. (All events and percentages exclude periods of precipitation, except drizzle and ice crystals.)

Table 2 stratifies fog occurrence with respect to wind speed and direction for all particular wind events. Table 3 is the same as Table 2, except it only applies for dew-point depressions ≤ 2°F. Referring to Table 2, fog is most likely to occur with calm winds (i.e. wind speeds less than 3 mph). Of the 749 calm wind observations, 43 percent are associated with fog. For winds 3-5 knots, fog occurrence is relatively similar among all wind directions with a maximum from the southeast (41 percent) and a minimum from the northwest (26 percent). For slightly higher winds (6-8 knots), fog is most likely to occur with a southwest wind (31 percent). The other wind directions are in the 20 percent to 28 percent range, except for the northwest wind (13 percent). The number of fog events drops off significantly with wind speeds greater than 8 knots with the best chance when the wind is from the northeast (18 percent). Fog hardly ever occurs with a northwest wind with speeds greater than 8 knots (0 occurrences in 50 chances). For wind speeds in excess of 15 knots, fog occurrence is extremely rare and only occurs with a south or southwest wind.

The relationship between wind direction and dense fog is different than for fog with any other visibility (Table 2). The best chance for dense fog occurs with calm winds (18 percent), similar to the above cases. Differences arises when there is wind. In the 3-5 knot range, the percentage difference between the extremes is threefold. The maximum (minimum) occurs with an east (south) wind with a percentage of 15 percent (5 percent). For the 6-8 knot range, fog occurrence is 9 percent (98 in 1129) from the northeast versus 2 percent from the southwest (9 in 433). For wind speeds between 9 and 11 knots, dense fog generally occurs when the wind is from the northeast (7 percent) and N (3 percent). In the 12 to 14 knot range, fog formation is relatively rare with the highest chance from a northeast (10 percent) or east wind (12 percent). In excess of 14 knots, fog development, although infrequent, does occur in a south (3 percent) or southwest wind (2 percent).

Table 3 illustrates more trends than Table 2. Dense fog is most likely to occur with east or northeast wind. With wind speeds 9 to 14 knots from the northeast, the chances of dense fog are between 10 to 20 percent. This may be indicative of mixing within the boundary layer and fog advecting from the Spokane River. Strong winds in excess of 14 knots inhibit any fog formation from any direction except in a south to southwest wind. This may reflect upslope fog as well as recent precipitation that saturates the boundary level. Northwesterly winds have a drying effect on the air mass since there are hardly any observations with northwest wind exceeding 9 knots coinciding with a moist air mass. In any instance, the best chance for fog formation is with light and variable winds from any direction.

Another parameter to consider for fog at Spokane is time of day. The chances for fog and dense fog, regardless of dew-point depression, reaches a maximum at 7:00 a.m. (32 percent) and 8:00 a.m. (12 percent), respectively (Fig. 3). The least likely time was 4 p.m. when the chances drop to 13 percent and 2 percent for fog and dense fog, respectively. Table 4 summarizes time of day and fog. The likelihood of fog at sunrise is more than double that at sunset. For dense fog, the difference is significantly greater, in fact, six times greater at sunrise than sunset.

When the dew-point depression stays ≤ 2°F, the implication is significant. Table 5 shows that the chance of any fog is greatest at 12:00 p.m. than at any time in the day (see Fig. 2e). The best times for dense fog are between 1:00 a.m. to 12:00 p.m. with a peak at 8:00 a.m. From 12:00 p.m. to 1:00 a.m., the chances of dense fog are consistently between 10 to 15 percent. Table 4 shows a strong correlation between time of day and fog, but as Table 5 illustrates, if the dew-point depression remains within 2°F, then fog is likely to persist throughout the day.

Lesser correlations could be made with respect to temperature. Fifty-eight percent of the fog events occurred when the temperature is between 26 and 35°F. However, climatology for Spokane shows the temperatures are frequently within that range. Sixty-three percent of the dense fog events also occur within that temperature range. The chances of fog are greater than 20 percent for most temperatures from 1 to 35°F. The chances of fog decreases with temperatures higher than 35°F; dense fog behavior is similar.

A correlation can be made between fog events and surface pressure by looking at Figs. 1d and 2d. Higher surface pressure may be indicative of subsidence; likewise, a lower surface pressure may signify positive vertical motion and no fog. However, Fig. 4 shows this may not always be the case; the best chance for fog development is with constant, steady pressure.

IV. DEW-POINT DEPRESSION GREATER THAN 2°F

This study relies heavily on the dew-point depression. With the presence of ice crystals, this relationship fails. Referring to Table 1, there are circumstances when dense fog occurs with a dew-point depression of either 3 or 4°F. This happens only about 3 percent of the time, and it would be easy to ignore these data as observational errors, rounded temperature values, or faulty instrumentation. Upon closer examination, the data depict a relatively rare phenomena at Spokane. The surface air mass may be saturated with respect to ice!

The equilibrium vapor pressure is less over ice than water at the same temperature. If ice crystals exist with a large number of supercooled (or undercooled) water droplets, the ice crystals grow by the diffusion of water vapor, such that the water droplets evaporate. The transfer of water vapor depends on the difference in equilibrium vapor pressure between water and ice. Temperatures most efficient for these processes are at about 7°F. This description is generally used to explain the Bergeron-Findeisen process and rain initiation, but may justify dense fog events when the dew-point depression is greater than 2°F.

Table 1 revealed 20 dense fog events with a dew-point depression of 4°F. This phenomena occurred between December 23, 1987 through January 2, 1988. The temperature ranged between 0 to 6°F, ideal for vapor transfer from water to ice. Figure 5 shows the probability of fog and temperature specifically for a dew-point depression of 4°F. These particular dense fog events formed after clear days, and many times the observer reported partial obscuration of the sky. Hence, the fog layer was not very thick. Besides one occurrence each day on December 9 and 10, 1986 (the dew-point depression was 3°F), this phenomena did not occur at any other time during the five-year period. Since the phenomena rarely occurs, forecasting this event will be a challenge, especially if one used the dew-point depression to forecast fog.

Examination of the observations prove that the surface air mass is saturated with respect to ice, not water. For temperatures between 0 to 6°F and a dew-point depression of 4°F, the relative humidity with respect to water is 83 percent. Using the relationship below, one can calculate the relative humidity with respect to ice with S = 83 percent (Table 6).

$$S_i = S\frac{e}{e_i}$$

S and S_i are saturation with respect to water and ice, while e and e_i are the saturation vapor pressures (from the Smithsonian Meteorological Tables) with respect to water and ice.

Since ice crystals must be present for this phenomena to occur and are not easily detected by the forecaster, the aviation forecaster must recognize the possibility for dense fog formation with temperatures around 5°F and a dew-point depression of 3 or 4°F. This situation can recur as long as the air mass does not change.

V. OTHER FACTORS TO CONSIDER

There are many factors that contribute to fog development that cannot be discerned on hourly surface observations or are not considered in the programs FCSTFOG and FOGGEG. These factors include the state of the ground, sky cover, and absolutely calm winds.

Ground conditions influence fog formation. Dry ground may inhibit fog development, whereas a moist ground contributes to a radiational fog may not develop because, as mentioned before, the saturation vapor pressure over ice is less than water (fog may still form with recently fallen snow since the boundary layer may remain saturated). The exception to the above statement is at a temperature at 32°F, when the saturation vapor pressure between water and ice is the same.

Clouds have a major role whether fog occurs since they may inhibit development. However, one cannot easily discern cloud cover from surface aviation observations. Fog partially, and sometimes completely, obscures the sky for an accurate cloud observation. ASOS observations only observe sky condition up to 12,000 ft, so forecasters will need to rely more on satellite interpretation skills. IR satellite loops and daytime visual pictures are helpful to resolve cloud types.

When calm winds are reported, how calm are they? Slight air movement is necessary for fog formation; this allows for the coldest air at the surface to mix upward. Absolute calm winds only create dew or frost. This characteristic is difficult to assess in surface aviation observations unless the forecaster communicates with the observer.

Radiosonde information is not incorporated in this study. Even though RADAT observations are included in hourly observations (at 0000 and 1200 UTC), it does not give enough data on the structure of the air mass. The upper-air sounding provides valuable clues related to subsidence, depth of the inversion layer, moisture distribution, etc. A fog forecast is incomplete without considering sounding information.

VI. CONCLUSION

This study provides good statistical guidance for fog forecasting at Spokane, Washington. It should provide insight to the aviation forecaster on whether IFR conditions will prevail or forecasting MVFR will be sufficient. Foremost, the current synoptic conditions, cloud cover, state of the ground, etc., must be considered.

VII. ACKNOWLEDGMENTS

I wish to thank Keith Meier, formerly of SSD, for review and suggestions on the paper. The author also acknowledges the support and encouragement of Ken Holmes, the former Meteorologist in Charge in Spokane, and Brad Colman, the Scientific Operations Officer (SOO) for NWSFO Seattle.

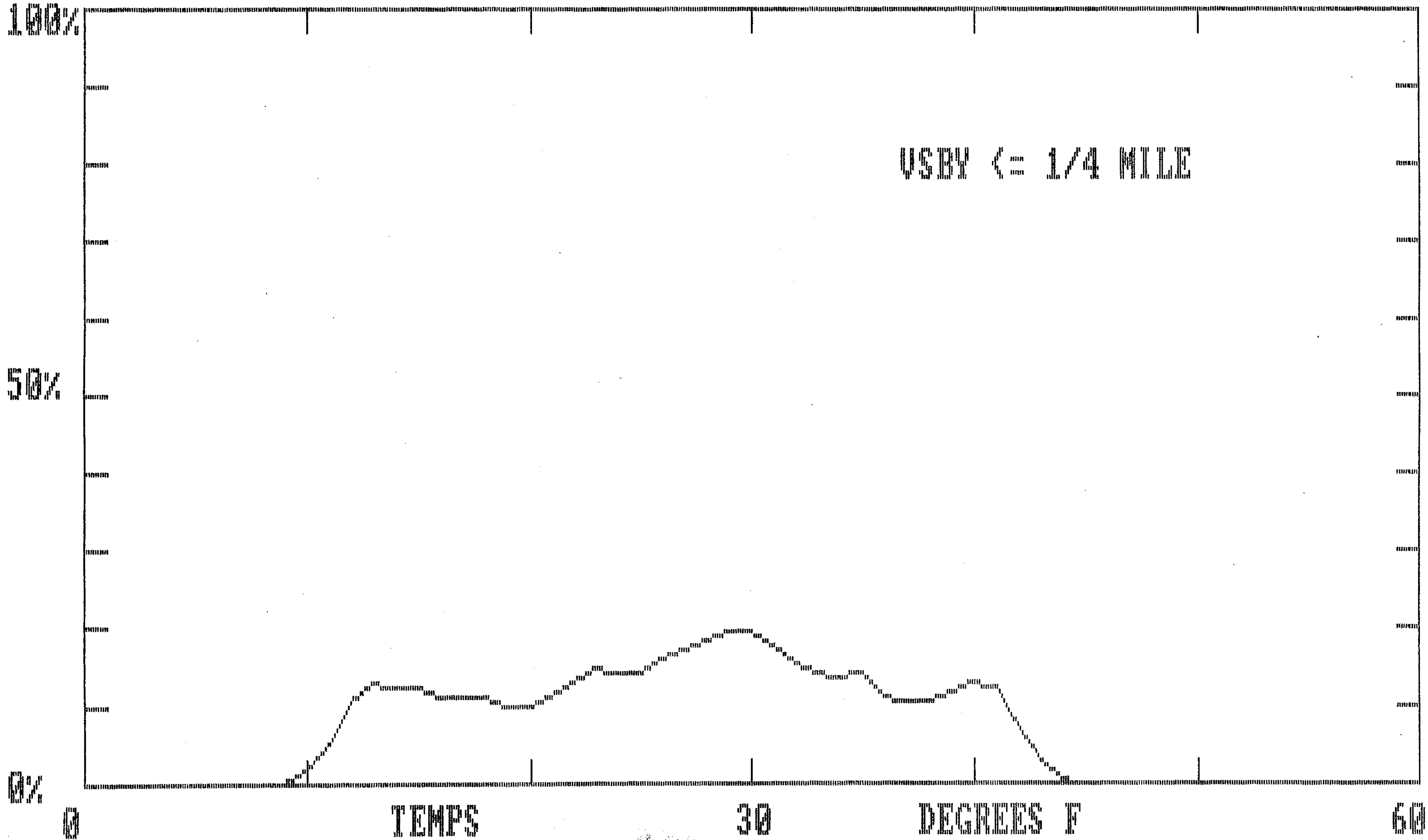

Figure 1a. Probability of Dense Fog versus Temperature

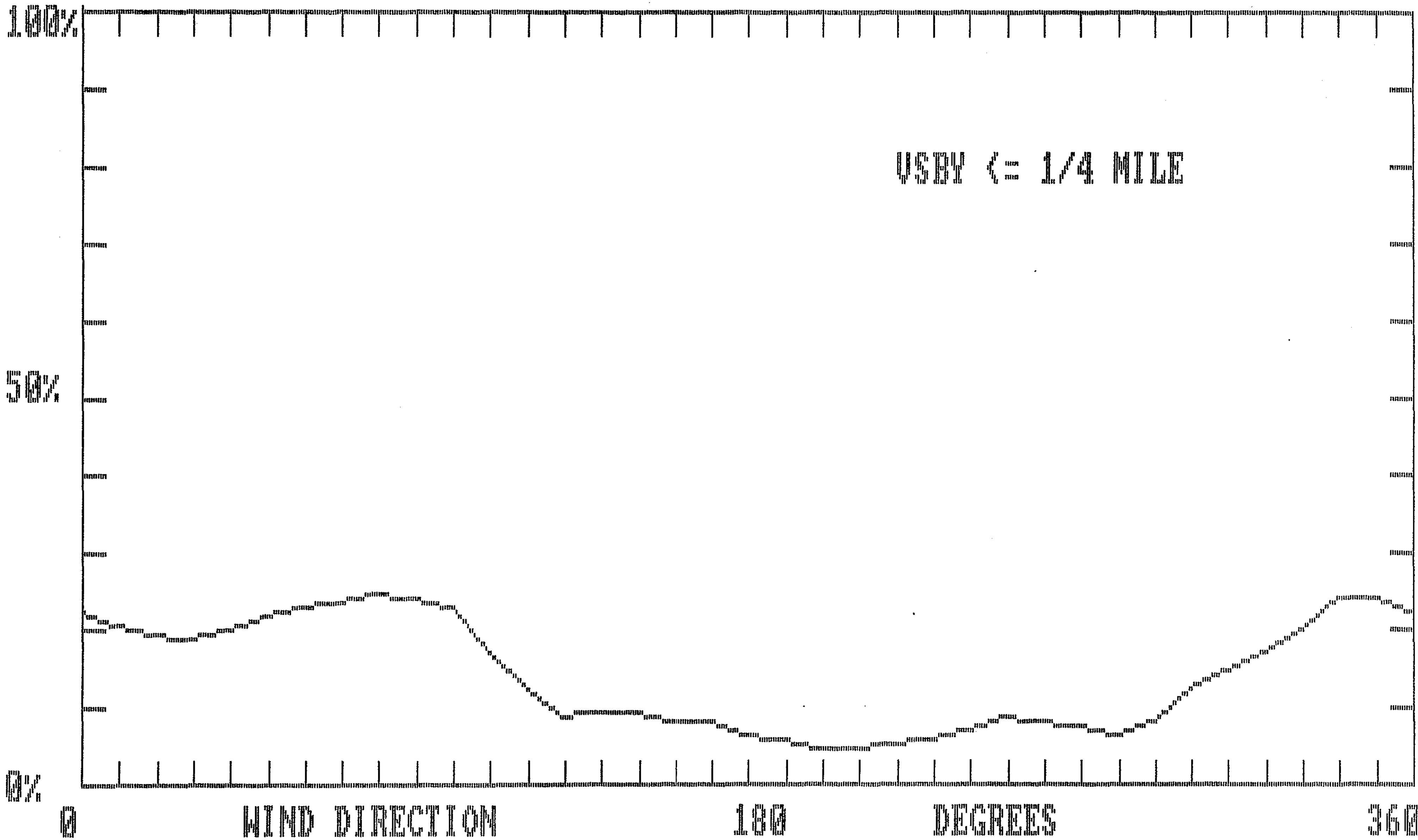

Figure 1b. Probability of Dense Fog versus Wind Direction

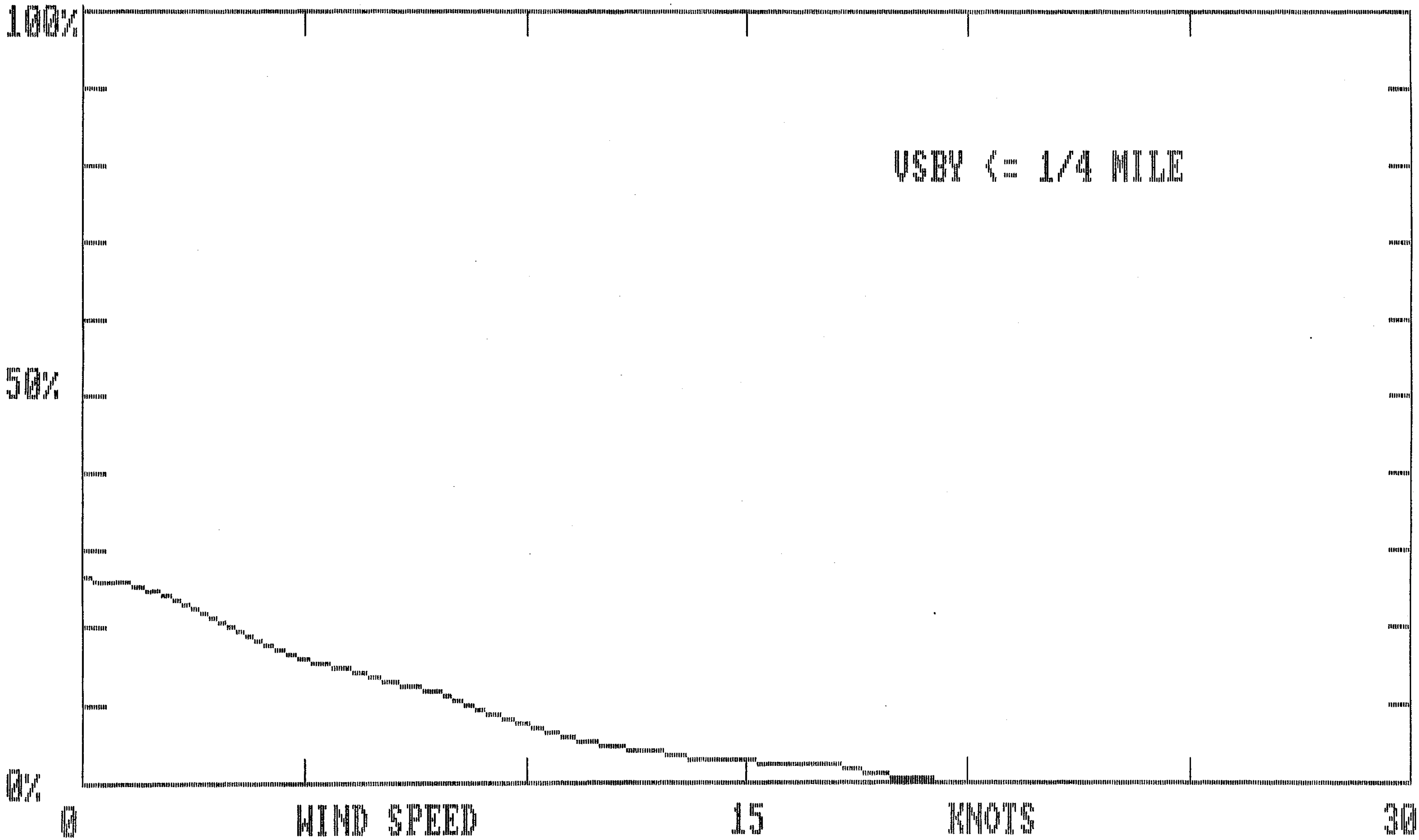

Figure 1c. Probability of Dense Fog versus Wind Speed

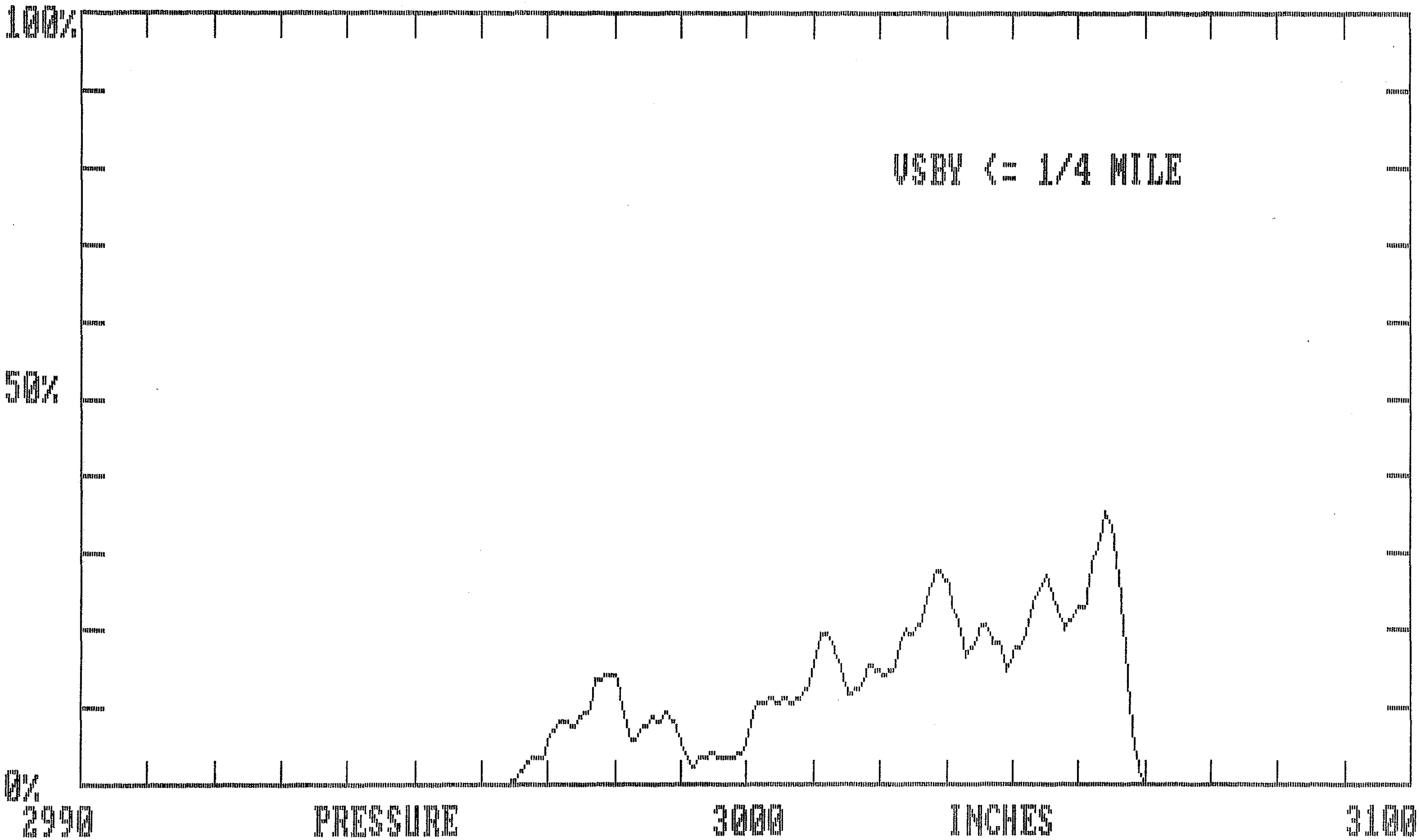

Figure 1d. Probability of Dense Fog versus Surface Pressure

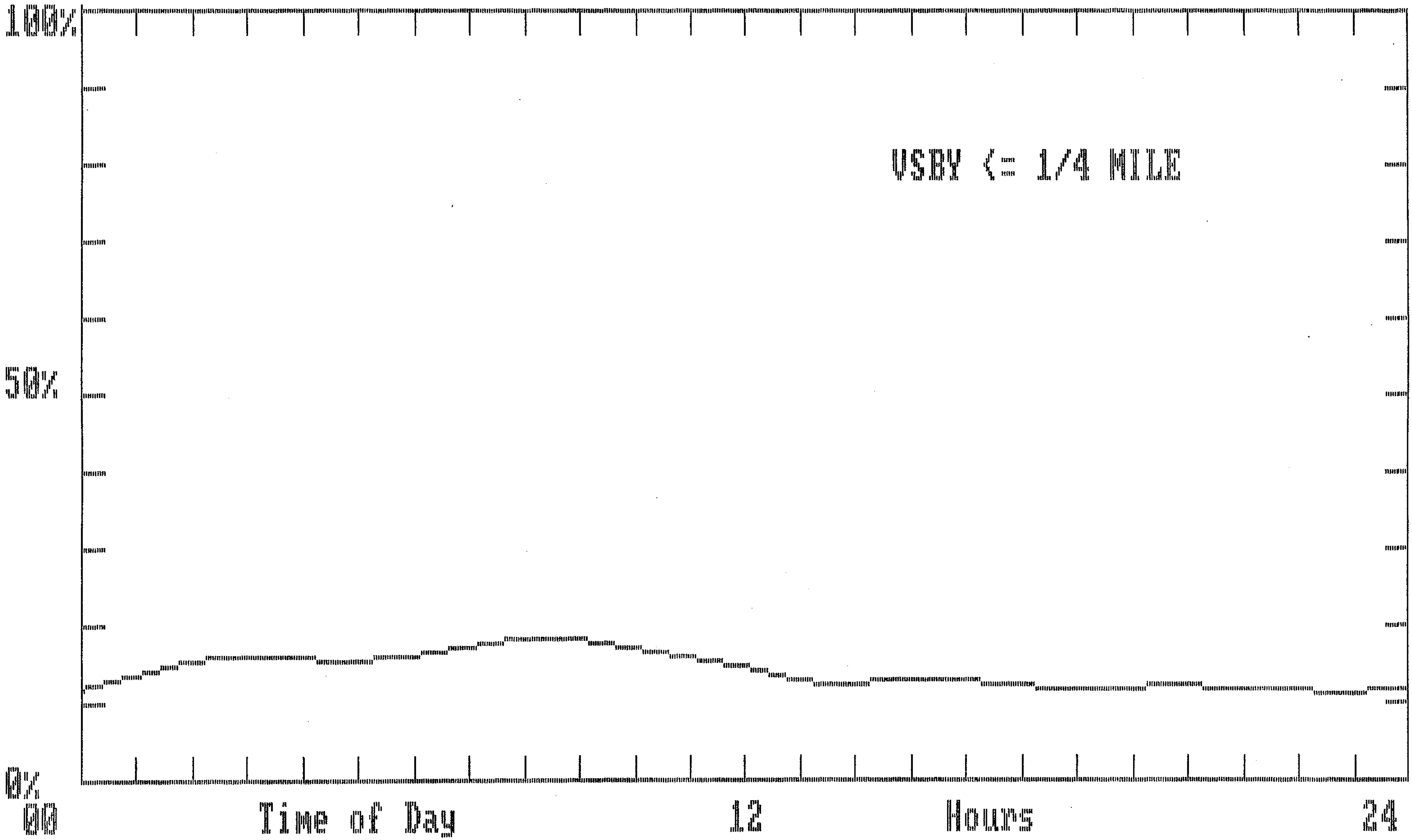

Figure 1e. Probability of Dense Fog versus Time of Day

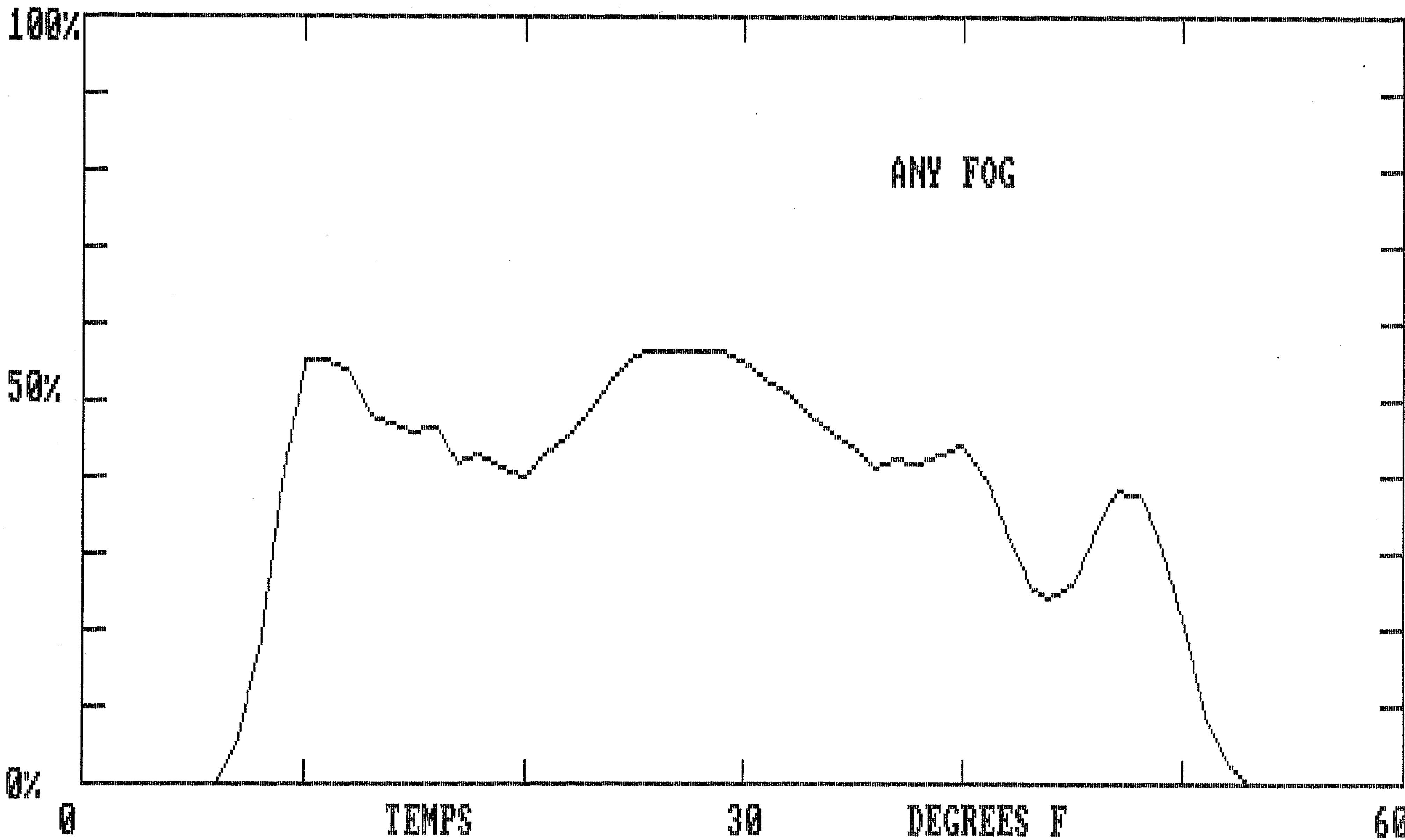

Fig 2a. Probability of Fog versus Temperature

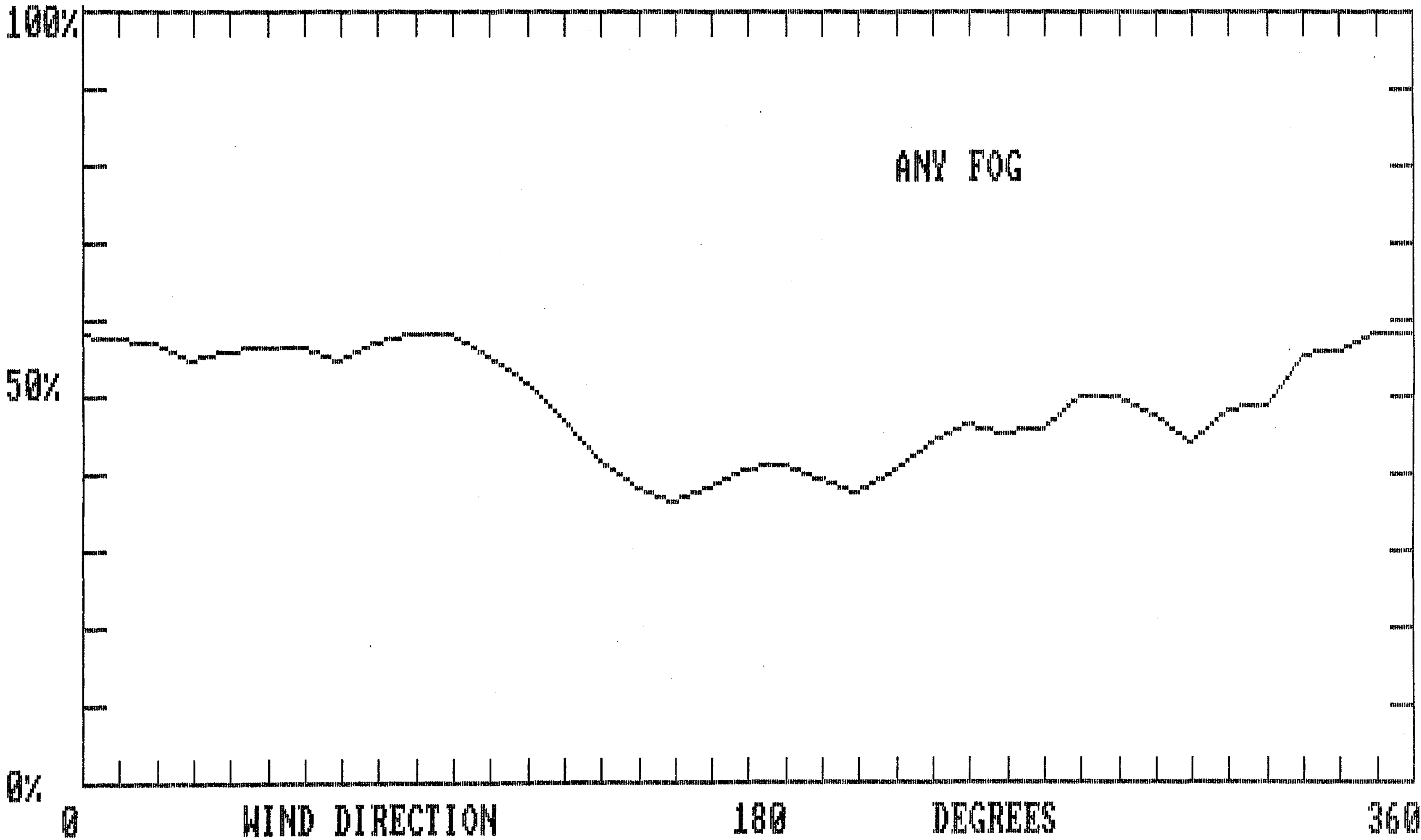

Fig 2b. Probability of Fog versus Wind Direction

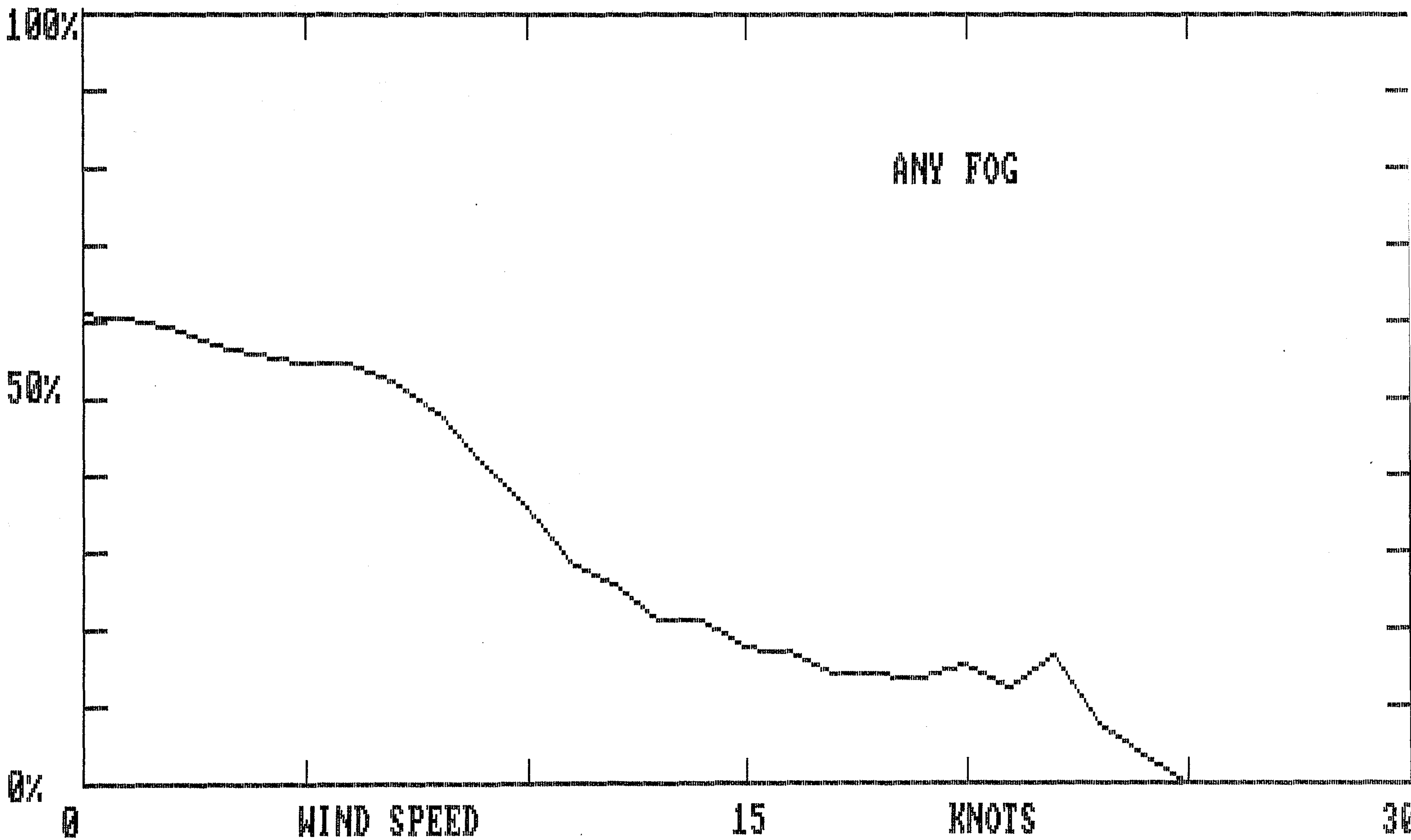

Fig 2c. Probability of Fog versus Wind Speed

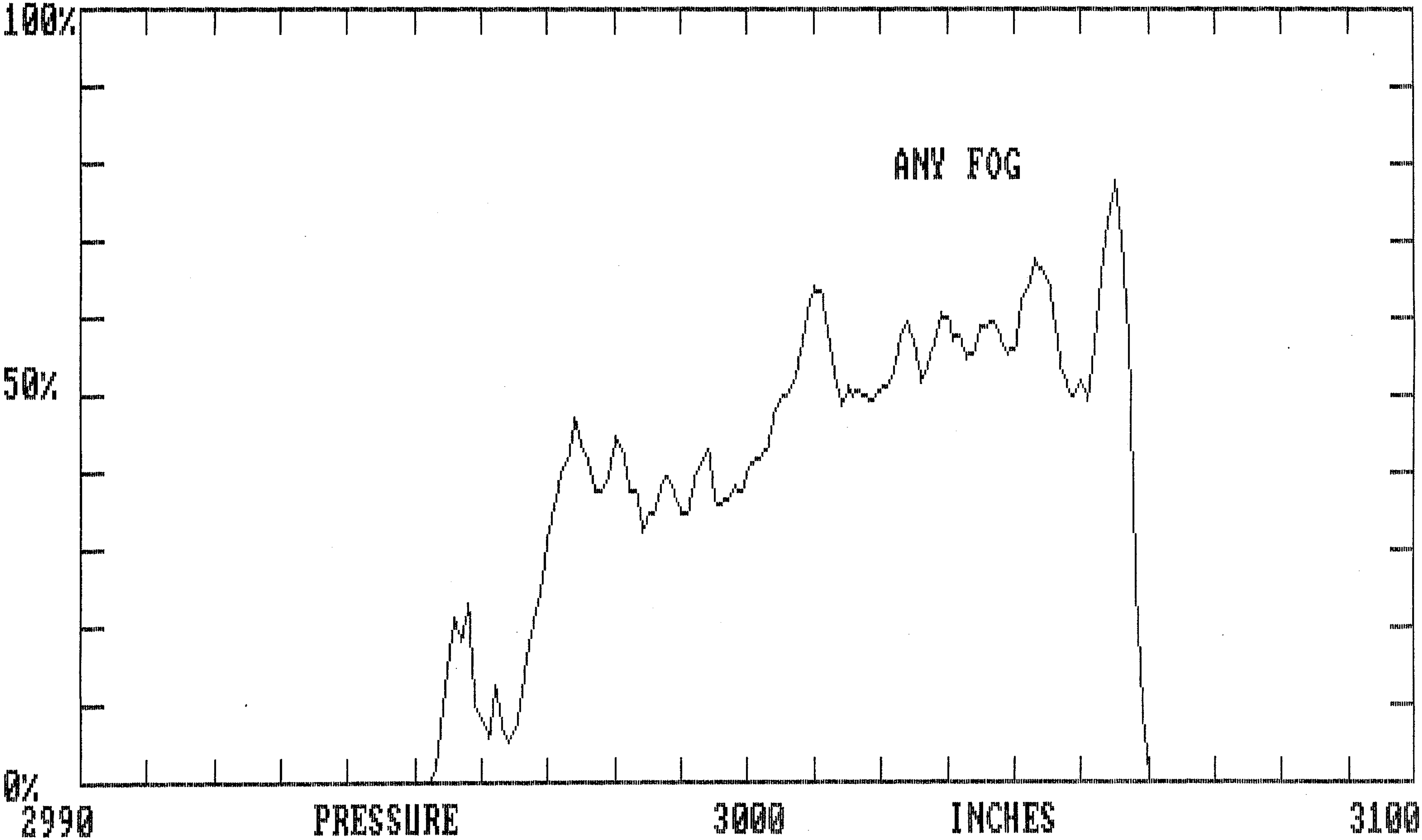

Figure 2d. Probability of Fog versus Surface Pressure.

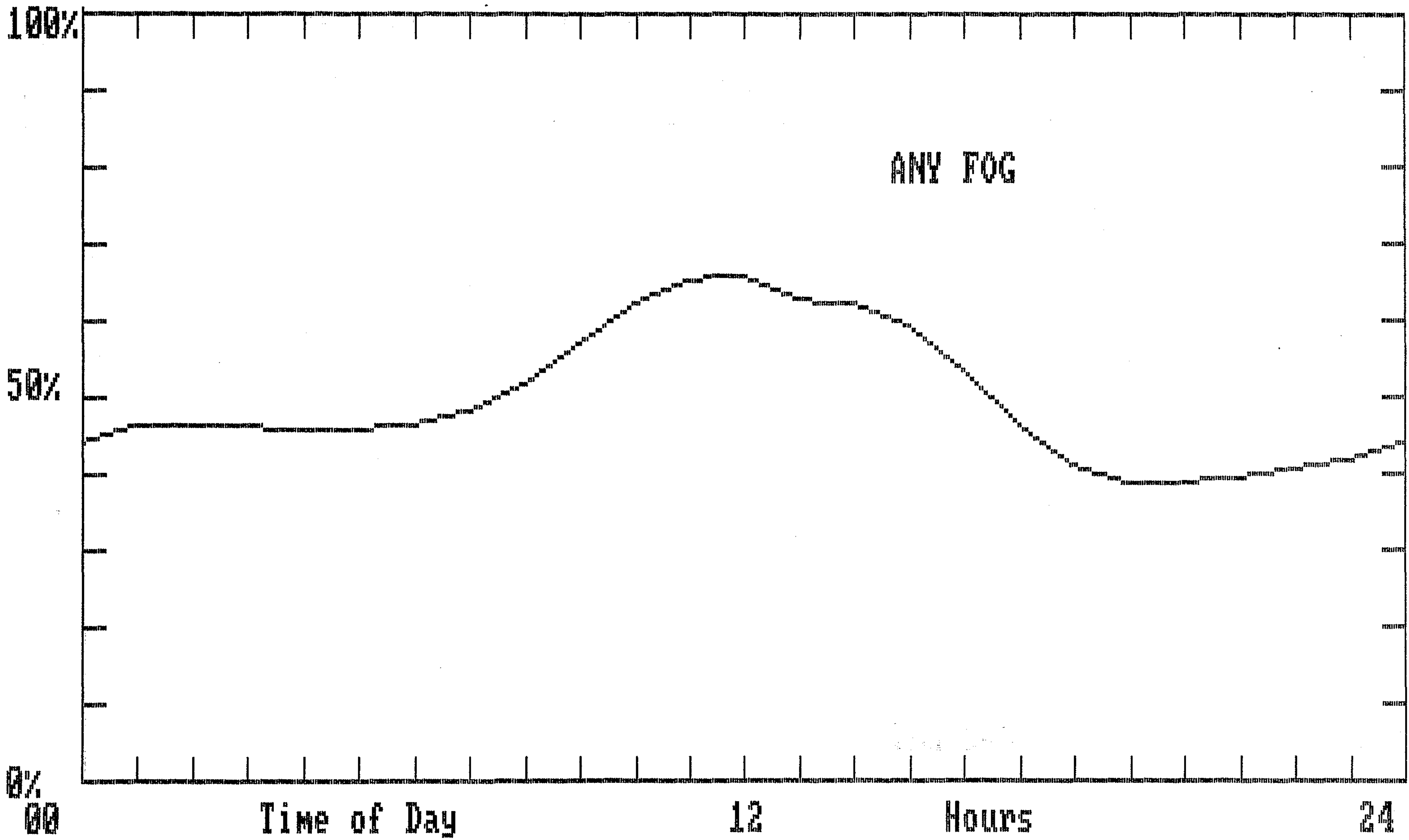

Figure 2e. Probability of Fog versus Time of Day.

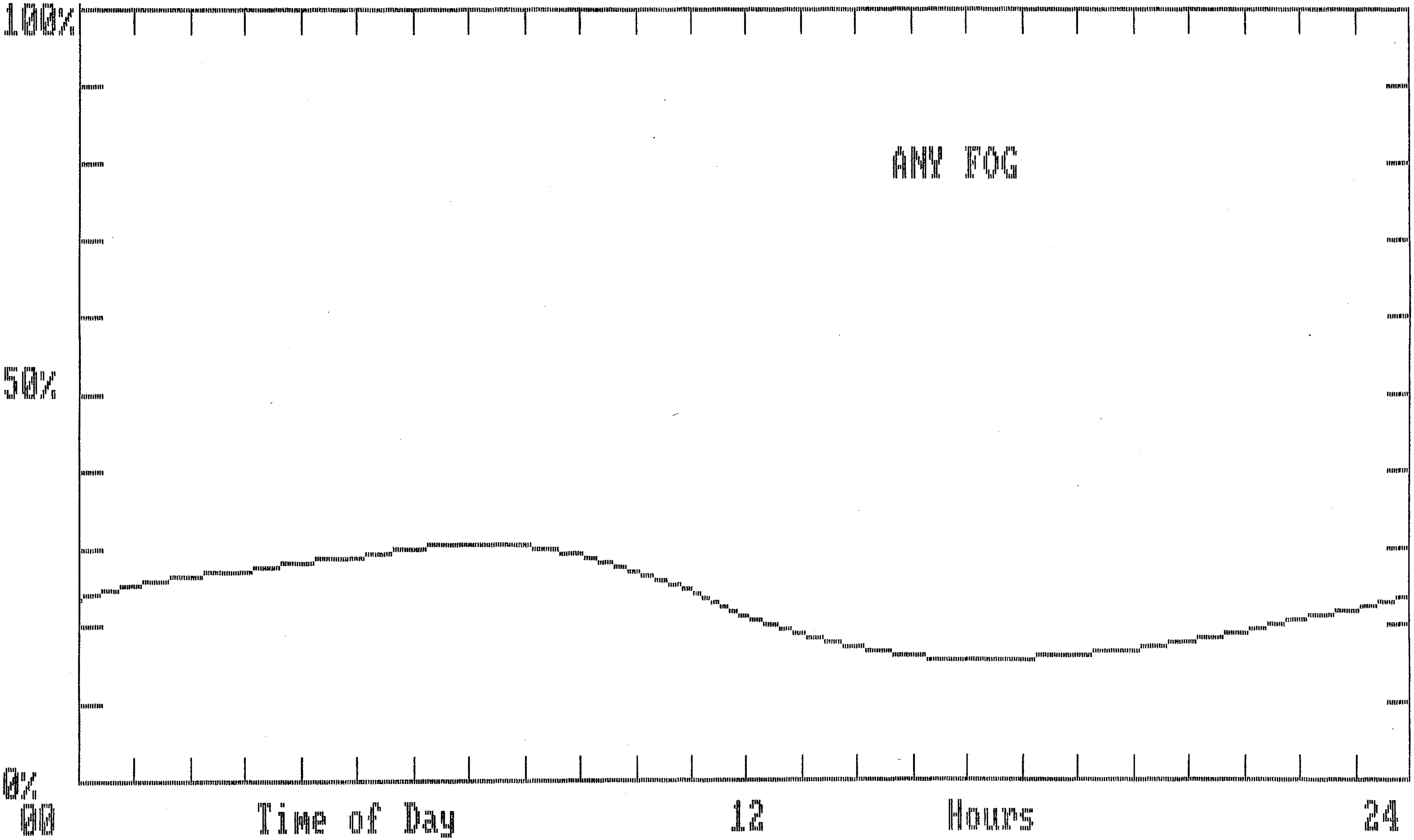

Figure 3. Probability of Fog versus Time of Day Regardless of Dewpoint Depression

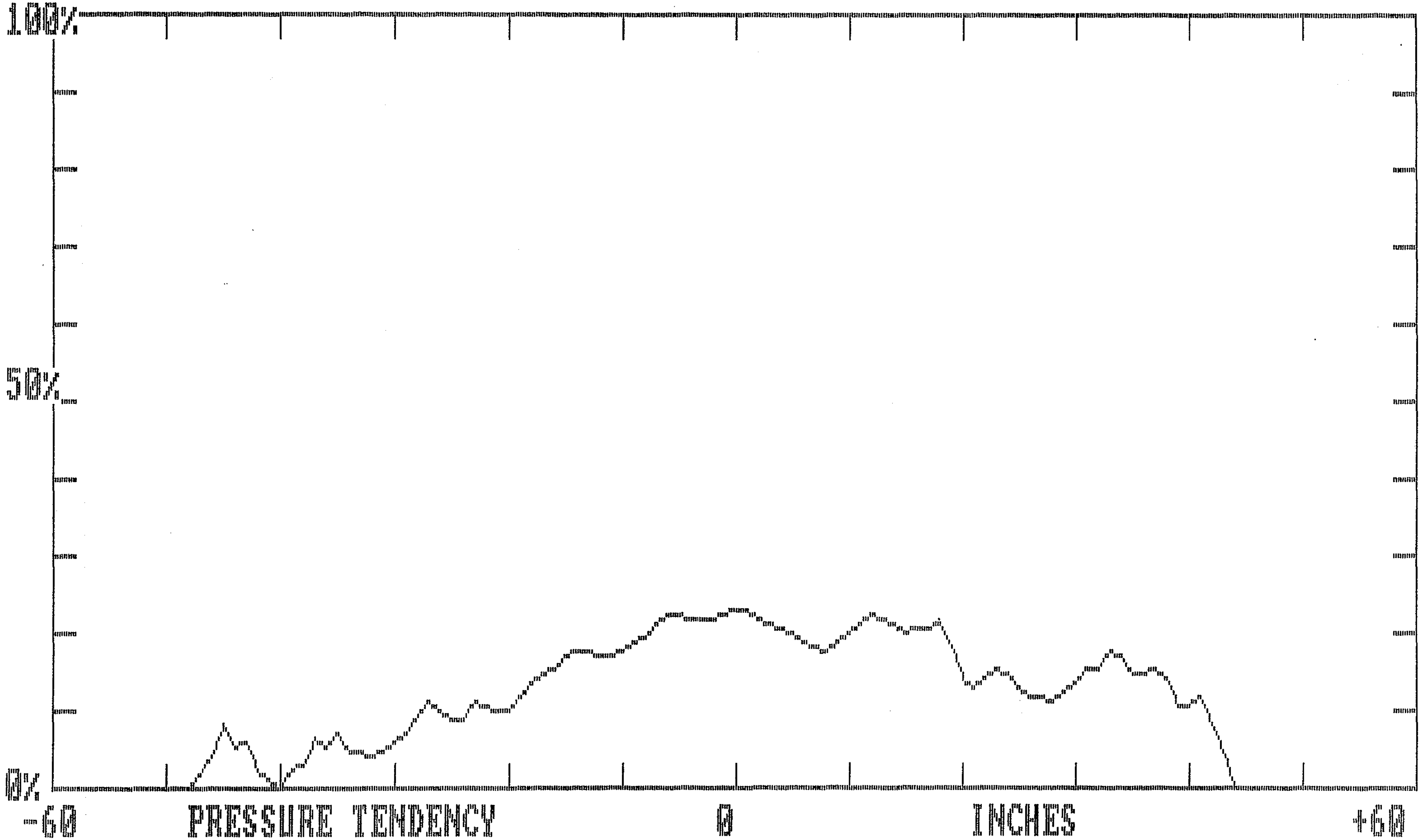

Figure 4. Probability of Fog versus 12-hour Pressure Tendency.

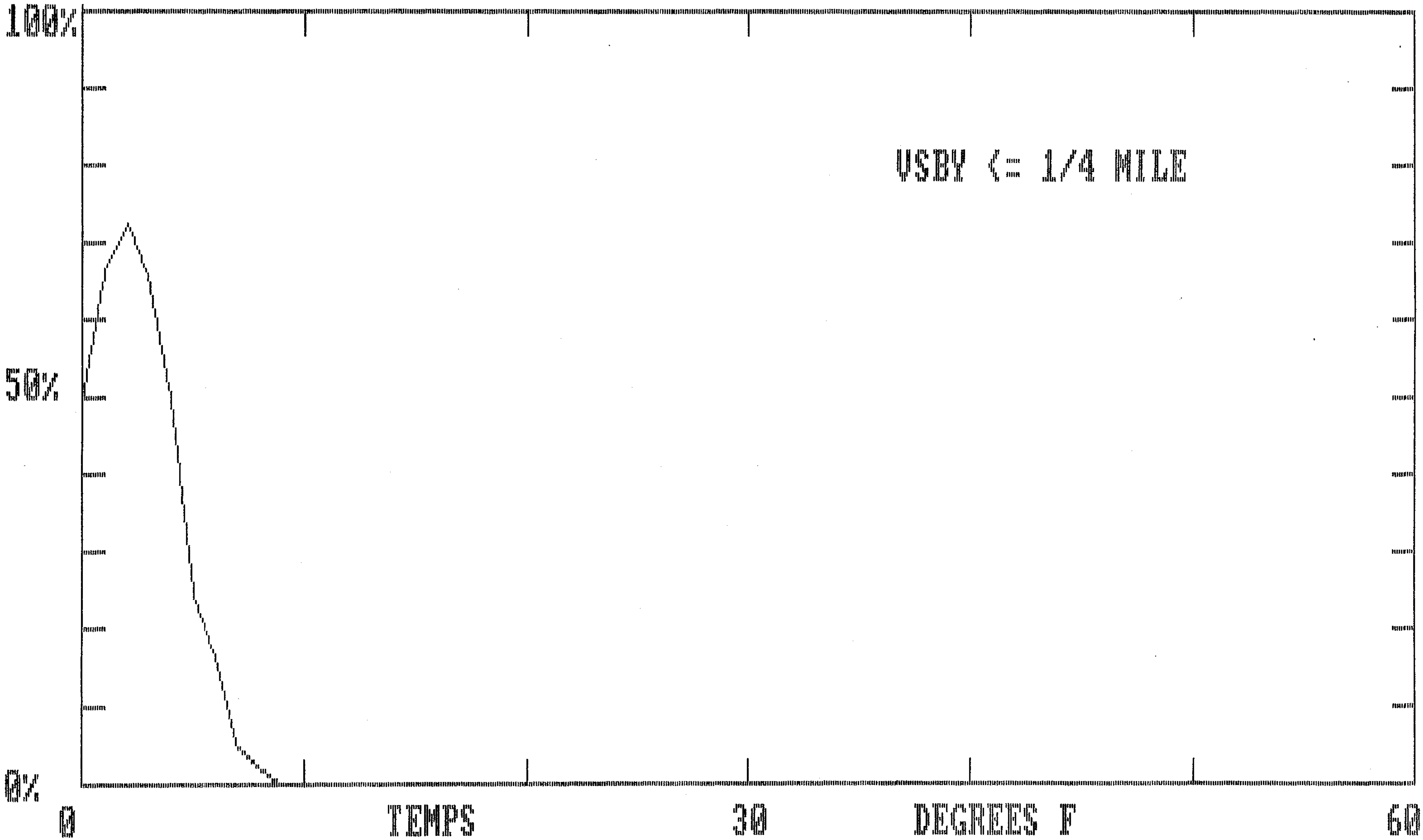

Figure 5. Probability of Dense Fog versus Temperature with Dewpoint Depression of 4°F.

TABLE 1

Dew Depression	# of Events	Fog	%	Dense Fog	%
0	1294	1093	84	429	33
1	1774	888	50	170	10
2	1785	434	24	62	3
3	1357	158	12	36	3
4	1039	56	5	20	2
5	848	10	1	0	0

TABLE 2

Fog probabilities Relative to Wind Speed and Direction

	3-5(kts)	6-8(kts)	9-11(kts)	12-14(kts)	>15(kts)
Calm					
# of Cases	749				
Fog (%)	319 (43%)				
Dense Fog (%)	137 (18%)				
North (340-020)					
# of Cases	564	382	72	36	26
Fog (%)	186(33%)	87(23%)	7(10%)	0(0%)	0(0%)
Dense Fog (%)	62(11%)	25(7%)	2(3%)	0(0%)	
Northeast (030-060)					
# of Cases	854	1129	299	78	145
Fog (%)	267(31%)	288(26%)	53(18%)	8(10%)	0(0%)
Dense Fog (%)	89(10%)	98(9%)	20(7%)	3(4%)	0(0%)
East (070-110)					
# of Cases	436	227	50	16	7
Fog (%)	157(36%)	56(%)	8(16%)	2(12%)	0(0%)
Dense Fog (%)	64(15%)	16(7%)	0(0%)	1(6%)	0(0%)
Southeast (120-150)					
# of Cases	288	422	239	105	56
Fog (%)	117(41%)	103(24%)	17(7%)	0(0%)	0(0%)
Dense Fog (%)	20(7%)	24(6%)	4(2%)	0(0%)	0(0%)
South					
# of Cases	427	434	370	439	776
Fog (%)	149(35%)	196(28%)	80(15%)	25(7%)	14(3%)
Dense Fog (%)	23(5%)	22(3%)	12(2%)	3(1%)	1(<0.5%)
Southwest					
# of Cases	306	164	114	64	125
Fog (%)	99(32%)	33(20%)	16(14%)	1(2%)	0(0%)
Dense Fog (%)	30(10%)	5(3%)	1(1%)	0(0%)	0(0%)
West (250-290)					
# of Cases	306	164	114	64	125
Fog (%)	99(32%)	33(20%)	16(14%)	1(2%)	0(0%)
Dense Fog (%)	30(10%)	5(3%)	1(1%)	0(0%)	0(0%)
Northwest (300-340)					
# of Cases	154	70	29	13	8
Fog (%)	40(26%)	9(13%)	0(0%)	0(0%)	0(0%)
Dense Fog (%)	13(8%)	3(4%)	0(0%)	0(0%)	0(0%)

TABLE 3

Dense Fog Probabilities Relative to Wind Speed and Direction

Calm					
# of Cases	441				
Fog (%)	271(61%)				
Dense Fog (%)	34(8%)				
	3-5(kts)	6-8(kts)	9-11(kts)	12-14(kts)	>15(kts)
North (340-020)					
# of Cases	302	132	9	0	0
Fog (%)	173(57%)	81(61%)	6(67%)	0(0%)	0(0%)
Dense Fog (%)	23(8%)	11(8%)	2(22%)	0(0%)	0(0%)
Northeast (030-060)					
# of Cases	472	477	90	11	0
Fog (%)	248(53%)	280(59%)	52(58%)	7(64%)	0(0%)
Dense Fog (%)	43(9%)	38(8%)	10(11%)	2(18%)	0(0%)
East (070-110)					
# of Cases	257	96	19	6	0
Fog (%)	146(57%)	53(55%)	8(42%)	2(33%)	0(0%)
Dense Fog (%)	24(9%)	9(9%)	0(0%)	0(0%)	0(0%)
Southeast (120-150)					
# of Cases	165	200	76	19	4
Fog (%)	104(63%)	96(48%)	16(21%)	0(0%)	0(0%)
Dense Fog (%)	4(2%)	12(6%)	1(1%)	0(0%)	0(0%)
South (160-200)					
# of Cases	239	373	215	93	91
Fog (%)	131(55%)	183(49%)	73(34%)	20(22%)	12(13%)
Dense Fog (%)	10(4%)	6(2%)	2(1%)	0(0%)	0(0%)
Southwest (210-240)					
# of Cases	133	220	141	123	99
Fog (%)	81(61%)	126(57%)	45(32%)	31(25%)	12(12%)
Dense Fog (%)	3(2%)	2(1%)	0(0%)	0(0%)	1(1%)
West (250-290)					
# of Cases	144	67	36	6	3
Fog (%)	71(49%)	30(45%)	14(39%)	1(17%)	0(0%)
Dense Fog (%)	3(2%)	1(1%)	0(0%)	0(0%)	0(0%)
Northwest (300-340)					
# of Cases	69	24	1	0	0
Fog (%)	34(49%)	8(33%)	0(0%)	0(0%)	0(0%)
Dense Fog (%)	4(6%)	2(8%)	0(0%)	0(0%)	0(0%)

TABLE 4

Relates Fog and Dense Fog with Time of Day
Regardless of Dewpoint Depression

Hour	Event	Fog	%	Dense Fog	%
1	500	130	26	34	7
2	501	136	27	45	9
3	495	134	27	46	9
4	464	138	28	46	9
5	499	146	29	46	9
6	499	150	30	47	9
7	496	158	32	52	10
8	489	150	31	60	12
9	489	153	31	45	9
10	490	132	27	32	7
11	488	121	25	26	5
12	492	102	21	17	3
13	491	81	17	11	2
14	493	69	14	9	2
15	493	66	14	10	2
16	501	64	13	12	2
17	497	68	14	16	3
18	505	72	14	18	4
19	501	74	15	19	4
20	511	87	17	27	5
21	502	94	19	24	5
22	499	102	21	27	5
23	504	106	21	26	5
24	506	121	24	30	6

TABLE 5

Relates Fog and Dense Fog Events to Time of Day
With Dewpoint Depression ≤ 2 F

Hour	Event	Fog	%	Dense Fog	%
1	248	122	49	29	12
2	264	126	48	42	16
3	258	122	47	40	16
4	258	123	48	39	15
5	290	137	47	40	14
6	296	137	46	41	14
7	297	146	49	67	16
8	279	142	49	47	16
9	247	141	57	44	18
10	187	121	65	30	16
11	151	106	70	25	17
12	110	80	73	16	15
13	99	65	66	11	11
14	84	56	67	9	11
15	78	53	68	10	13
16	99	55	56	11	11
17	137	63	43	15	11
18	168	68	40	18	11
19	187	72	93	19	10
20	204	80	39	27	13
21	208	85	41	23	11
22	220	96	44	25	11
23	241	98	41	23	10
24	243	112	46	27	11

142 The Usefulness of Data from Mountaintop Fire Lookout Stations in Determining Atmospheric Stability. Jonathan W. Corey, April 1979. (PB298899/AS)
143 The Depth of the Marine Layer at San Diego as Related to Subsequent Cool Season Precipitation Episodes in Arizona. Ira S. Brenner, May 1979. (PB298817/AS)
144 Arizona Cool Season Climatological Surface Wind and Pressure Gradient Study. Ira S. Brenner, May 1979. (PB298900/AS)
146 The BART Experiment. Morris S. Webb, October 1979. (PB80 155112)
147 Occurrence and Distribution of Flash Floods in the Western Region. Thomas L. Dietrich, December 1979. (PB80 160344)
149 Misinterpretations of Precipitation Probability Forecasts. Allan H. Murphy, Sarah Lichtenstein, Baruch Fischhoff, and Robert L. Winkler, February 1980. (PB80 174576)
150 Annual Data and Verification Tabulation - Eastern and Central North Pacific Tropical Storms and Hurricanes 1979. Emil B. Gunther and Staff, EPHC, April 1980. (PB80 220486)
151 NMC Model Performance in the Northeast Pacific. James E. Overland, PMEL-ERL, April 1980. (PB80 196033)
152 Climate of Salt Lake City, Utah. Wilbur E. Figgins (Retired) and Alexander R. Smith. Fifth Revision, July 1992. (PB92 220177)
153 An Automatic Lightning Detection System in Northern California. James E. Rea and Chris E. Fontana, June 1980. (PB80 225592)
154 Regression Equation for the Peak Wind Gust 6 to 12 Hours in Advance at Great Falls During Strong Downslope Wind Storms. Michael J. Oard, July 1980. (PB91 108367)
155 A Raininess Index for the Arizona Monsoon. John H. Ten Harkel, July 1980. (PB81 106494)
156 The Effects of Terrain Distribution on Summer Thunderstorm Activity at Reno, Nevada. Christopher Dean Hill, July 1980. (PB81 102501)
157 An Operational Evaluation of the Scofield/Oliver Technique for Estimating Precipitation Rates from Satellite Imagery. Richard Ochoa, August 1980. (PB81 108227)
158 Hydrology Practicum. Thomas Dietrich, September 1980. (PB81 134033)
159 Tropical Cyclone Effects on California. Arnold Court, October 1980. (PB81 133779)
160 Eastern North Pacific Tropical Cyclone Occurrences During Intraseasonal Periods. Preston W. Leftwich and Gail M. Brown, February 1981. (PB81 205494)
161 Solar Radiation as a Sole Source of Energy for Photovoltaics in Las Vegas, Nevada, for July and December. Darryl Randerson, April 1981. (PB81 224503)
162 A Systems Approach to Real-Time Runoff Analysis with a Deterministic Rainfall-Runoff Model. Robert J.C. Burnash and R. Larry Ferral, April 1981. (PB81 224495)
163 A Comparison of Two Methods for Forecasting Thunderstorms at Luke Air Force Base, Arizona. LTC Keith R. Cooley, April 1981. (PB81 225393)
164 An Objective Aid for Forecasting Afternoon Relative Humidity Along the Washington Cascade East Slopes. Robert S. Robinson, April 1981. (PB81 23078)
165 Annual Data and Verification Tabulation, Eastern North Pacific Tropical Storms and Hurricanes 1980. Emil B. Gunther and Staff, May 1981. (PB82 230336)
166 Preliminary Estimates of Wind Power Potential at the Nevada Test Site. Howard G. Booth, June 1981. (PB82 127036)
167 ARAP User's Guide. Mark Mathewson, July 1981, Revised September 1981. (PB82 196783)
168 Forecasting the Onset of Coastal Gales Off Washington-Oregon. John R. Zimmerman and William D. Burton, August 1981. (PB82 127051)
169 A Statistical-Dynamical Model for Prediction of Tropical Cyclone Motion in the Eastern North Pacific Ocean. Preston W. Leftwich, Jr., October 1981. (PB82195298)
170 An Enhanced Plotter for Surface Airways Observations. Andrew J. Spry and Jeffrey L. Anderson, October 1981. (PB82 153883)
171 Verification of 72-Hour 500-MB Map-Type Predictions. R.F. Quiring, November 1981. (PB82 158098)
172 Forecasting Heavy Snow at Wenatchee, Washington. James W. Holcomb, December 1981. (PB82 177783)
173 Central San Joaquin Valley Type Maps. Thomas R. Crossan, December 1981. (PB82 196064)
174 ARAP Test Results. Mark A. Mathewson, December 1981. (PB82 198103)
176 Approximations to the Peak Surface Wind Gusts from Desert Thunderstorms. Darryl Randerson, June 1982. (PB82 253089)
177 Climate of Phoenix, Arizona. Robert J. Schmidli, April 1969 (Revised December 1986). (PB87 142063/AS)
178 Annual Data and Verification Tabulation, Eastern North Pacific Tropical Storms and Hurricanes 1982. E.B. Gunther, June 1983. (PB85 106078)
179 Stratified Maximum Temperature Relationships Between Sixteen Zone Stations in Arizona and Respective Key Stations. Ira S. Brenner, June 1983. (PB83 249904)
180 Standard Hydrologic Exchange Format (SHEF) Version I. Phillip A. Pasteris, Vernon C. Bissel, David G. Bennett, August 1983. (PB85 106052)
181 Quantitative and Spacial Distribution of Winter Precipitation along Utah's Wasatch Front. Lawrence B. Dunn, August 1983. (PB85 106912)
182 500 Millibar Sign Frequency Teleconnection Charts - Winter. Lawrence B. Dunn, December 1983. (PB85 106276)
183 500 Millibar Sign Frequency Teleconnection Charts - Spring. Lawrence B. Dunn, January 1984. (PB85 111367)
184 Collection and Use of Lightning Strike Data in the Western U.S. During Summer 1983. Glenn Rasch and Mark Mathewson, February 1984. (PB85 110534)
185 500 Millibar Sign Frequency Teleconnection Charts - Summer. Lawrence B. Dunn, March 1984. (PB85 111359)
186 Annual Data and Verification Tabulation eastern North Pacific Tropical Storms and Hurricanes 1983. E.B. Gunther, March 1984. (PB85 109635)
187 500 Millibar Sign Frequency Teleconnection Charts - Fall. Lawrence B. Dunn, May 1984. (PB85 110930)
188 The Use and Interpretation of Isentropic Analyses. Jeffrey L. Anderson, October 1984. (PB85 132694)
189 Annual Data & Verification Tabulation Eastern North Pacific Tropical Storms and Hurricanes 1984. E.B. Gunther and R.L. Cross, April 1985. (PB85 1878887AS)
190 Great Salt Lake Effect Snowfall: Some Notes and An Example. David M. Carpenter, October 1985. (PB86 119153/AS)
191 Large Scale Patterns Associated with Major Freeze Episodes in the Agricultural Southwest. Ronald S. Hamilton and Glenn R. Lussky, December 1985. (PB86 144474AS)
192 NWR Voice Synthesis Project: Phase I. Glen W. Sampson, January 1986. (PB86 145604/AS)
193 The MCC - An Overview and Case Study on Its Impact in the Western United States. Glenn R. Lussky, March 1986. (PB86 170651/AS)
194 Annual Data and Verification Tabulation Eastern North Pacific Tropical Storms and Hurricanes 1985. E.B. Gunther and R.L. Cross, March 1986. (PB86 170941/AS)
195 Radid Interpretation Guidelines. Roger G. Pappas, March 1986. (PB86 177680/AS)
196 A Mesoscale Convective Complex Type Storm over the Desert Southwest. Darryl Randerson, April 1986. (PB86 190998/AS)
197 The Effects of Eastern North Pacific Tropical Cyclones on the Southwestern United States. Walter Smith, August 1986. (PB87 106258AS)
198 Preliminary Lightning Climatology Studies for Idaho. Christopher D. Hill, Carl J. Gorski, and Michael C. Conger, April 1987. (PB87 180196/AS)
199 Heavy Rains and Flooding in Montana: A Case for Slantwise Convection. Glenn R. Lussky, April 1987. (PB87 185229/AS)
200 Annual Data and Verification Tabulation Eastern North Pacific Tropical Storms and Hurricanes 1986. Roger L. Cross and Kenneth B. Mielke, September 1987. (PB88 110895/AS)
201 An Inexpensive Solution for the Mass Distribution of Satellite Images. Glen W. Sampson and George Clark, September 1987. (PB88 114038/AS)
202 Annual Data and Verification Tabulation Eastern North Pacific Tropical Storms and Hurricanes 1987. Roger L. Cross and Kenneth B. Mielke, September 1988. (PB88 101935/AS)
203 An Investigation of the 24 September 1986 "Cold Sector" Tornado Outbreak in Northern California. John P. Monteverdi and Scott A. Braun, October 1988. (PB89 121297/AS)
204 Preliminary Analysis of Cloud-To-Ground Lightning in the Vicinity of the Nevada Test Site. Carven Scott, November 1988. (PB89 128649/AS)
205 Forecast Guidelines For Fire Weather and Forecasters -- How Nighttime Humidity Affects Wildland Fuels. David W. Goens, February 1989. (PB89 162549/AS)
206 A Collection of Papers Related to Heavy Precipitation Forecasting. Western Region Headquarters, Scientific Services Division, August 1989. (PB89 230833/AS)
207 The Las Vegas McCarran International Airport Microburst of August 8, 1989. Carven A. Scott, June 1990. (PB90-240268)
208 Meteorological Factors Contributing to the Canyon Creek Fire Blowup, September 6 and 7, 1988. David W. Goens, June 1990. (PB90-245085)
209 Stratus Surge Prediction Along the Central California Coast. Peter Felsch and Woodrow Whitlatch, December 1990. (PB91-129239)
210 Hydrotools. Tom Egger. January 1991. (PB91-151787/AS)
211 A Northern Utah Soaker. Mark E. Struthwolf, February 1991. (PB91-168716)
212 Preliminary Analysis of the San Francisco Rainfall Record: 1849-1990. Jan Null, May 1991. (PB91-208439)
213 Idaho Zone Preformat, Temperature Guidance, and Verification. Mark A. Mollner, July 1991. (PB91-227405/AS)
214 Emergency Operational Meteorological Considerations During an Accidental Release of Hazardous Chemicals. Peter Mueller and Jerry Galt, August 1991. (PB91-235424)
215 WeatherTools. Tom Egger, October 1991. (PB93-184950)
216 Creating MOS Equations for RAWS Stations Using Digital Model Data. Dennis D. Gettman, December 1991. (PB92-131473/AS)
217 Forecasting Heavy Snow Events in Missoula, Montana. Mike Richmond, May 1992. (PB92-196104)
218 NWS Winter Weather Workshop in Portland, Oregon. Various Authors, December 1992. (PB93-146785)
219 A Case Study of the Operational Usefulness of the Sharp Workstation in Forecasting a Mesocyclone-Induced Cold Sector Tornado Event in California. John P. Monteverdi, March 1993. (PB93-178697)
220 Climate of Pendleton, Oregon. Claudia Bell, August 1993. (PB93-227536)
221 Utilization of the Bulk Richardson Number, Helicity and Sounding Modification in the Assessment of the Severe Convective Storms of 3 August 1992. Eric C. Evenson, September 1993. (PB94-131943)
222 Convective and Rotational Parameters Associated with Three Tornado Episodes in Northern and Central California. John P. Monteverdi and John Quadros, September 1993. (PB94-131943)
223 Climate of San Luis Obispo, California. Gary Ryan, February 1994. (PB94-162062)
224 Climate of Wenatchee, Washington. Michael W. McFarland, Roger G. Buckman, and Gregory E. Matzen, March 1994. (PB94-164308)
225 Climate of Santa Barbara, California. Gary Ryan, December 1994. (PB95-173720)
226 Climate of Yakima, Washington. Greg DeVoir, David Hogan, and Jay Neher, December 1994. (PB95-173688)
227 Climate of Kalispell, Montana. Chris Maier, December 1994. (PB95-169488)
228 Forecasting Minimum Temperatures in the Santa Maria Agricultural District. Wilfred Pi and Peter Felsch, December 1994. (PB95-171088)
229 The 10 February 1994 Oroville Tornado--A Case Study. Mike Staudenmaier, Jr., April 1995.
230 Santa Ana Winds and the Fire Outbreak of Fall 1993. Ivory Small, June 1995.
231 Washington State Tornadoes. Tresté Huse, July 1995.

NOAA SCIENTIFIC AND TECHNICAL PUBLICATIONS

The National Oceanic and Atmospheric Administration was established as part of the Department of Commerce on October 3, 1970. The mission responsibilities of NOAA are to assess the socioeconomic impact of natural and technological changes in the environment and to monitor and predict the state of the solid Earth, the oceans and their living resources, the atmosphere, and the space environment of the Earth.

The major components of NOAA regularly produce various types of scientific and technical information in the following kinds of publications.

PROFESSIONAL PAPERS--Important definitive research results, major techniques, and special investigations.

CONTRACT AND GRANT REPORTS--Reports prepared by contractors or grantees under NOAA sponsorship.

ATLAS--Presentation of analyzed data generally in the form of maps showing distribution of rainfall, chemical and physical conditions of oceans and atmosphere, distribution of fishes and marine mammals, ionospheric conditions, etc.

TECHNICAL SERVICE PUBLICATIONS--Reports containing data, observations, instructions, etc. A partial listing includes data serials; prediction and outlook periodicals; technical manuals, training papers, planning reports, and information serials; and miscellaneous technical publications.

TECHNICAL REPORTS--Journal quality with extensive details, mathematical developments, or data listings.

TECHNICAL MEMORANDUMS--Reports of preliminary, partial, or negative research or technology results, interim instructions, and the like.

Information on availability of NOAA publications can be obtained from:

NATIONAL TECHNICAL INFORMATION SERVICE

U. S. DEPARTMENT OF COMMERCE

5285 PORT ROYAL ROAD

SPRINGFIELD, VA 22161