

AD-A073 959

NAVAL POSTGRADUATE SCHOOL MONTEREY CA

F/G 4/2

REFINEMENT OF A STATISTICAL DIAGNOSTIC MODEL OF MARINE FOG USIN--ETC(U)

JUN 79 S O OUZTS

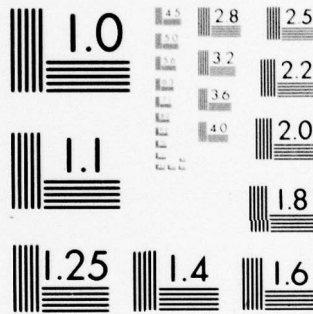
UNCLASSIFIED

NPS63-79-002

NL

| OF |
AD
A073959





MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

14

NPS63-79-002

2

NAVAL POSTGRADUATE SCHOOL Monterey, California

LEVEL II

AD A 073959



9

Master's
THESIS

DDC
SEP 20 1979
A

6

REFINEMENT OF A STATISTICAL DIAGNOSTIC
MODEL OF MARINE FOG USING FNWC
MODEL OUTPUT PARAMETERS,

by

10 Steve O'Neal / Ouzts 12

11 June 1979 88 p.

Thesis Advisor: R. J. Renard

DDC FILE COPY

Approved for public release; distribution unlimited.

251450

79 09 17 105

Y/B

23

OPNAV 5216/144 (REV. 6-70) GPO 789-015
S/N-0107-LF-778-8097

DEPARTMENT OF THE NAVY

Memorandum

*Find in
Gobris
Part in doc*

DATE: 1 Oct 79

FROM: Library, Naval Postgraduate School, Monterey, California 93940

TO: Director, Defense Documentation Center (TIMA), Cameron Station, Alexandria, VA 22314

SUBJ: Errata to Naval Postgraduate School Thesis. Steve O. Ouzts. Refinement of a statistical diagnostic model of marine fog using FNBC model output parameters. Master's Thesis. June 1979. (NPS63-79-002)

1. Forwarded for information and necessary action.
2. Subject thesis was forwarded to your Center on 5 September 1979.

A073 959

S. HORNBECK, Code 1420
Secretary
Library Administrative Offices, Rm 104

NAVAL POSTGRADUATE SCHOOL
Monterey, California

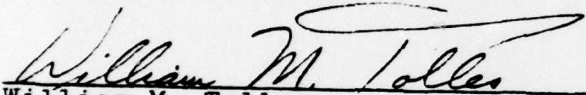
Rear Admiral Tyler F. Dedman
Superintendent

Jack R. Borsting
Provost

This thesis prepared in conjunction with research supported
by the Naval Air Systems Command (AIR 370).

Reproduction of all or part of this report is authorized.

Released as a
Technical Report by



William M. Tolles
Dean of Research

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER NPS63-79-002	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) Refinement of a Statistical Diagnostic Model of Marine Fog Using FNWC Model Output Parameters		5. TYPE OF REPORT & PERIOD COVERED Master's Thesis; June 1979
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Steve O'Neal Ouzts in conjunction with Robert J. Renard		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS Naval Postgraduate School Monterey, California 93940		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS Naval Air Systems Command (AIR 370) Washington, D. C. 20360		12. REPORT DATE June 1979
		13. NUMBER OF PAGES 87
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office) Naval Postgraduate School Monterey, California 93940		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE
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)		
20. ABSTRACT (Continue on reverse side if necessary and identify by block number) The study represents a continuation of the development of a model output statistics scheme to specify marine fog over the open ocean and in coastal waters. Thirty-seven direct and derived Fleet Numerical Weather Central model output parameters, monthly climatological fog frequencies, combinations of the aforementioned parameters (i.e. interactive parameters) and a persistence parameter are used as predictors in a stepwise		

cont

multiple linear regression approach to estimate a predictand defined as marine fog probability. The predictand is categorized in two ways, in one case (FOGCAT I) as smoothed probabilities from 0 to 100% as a function of present weather, past weather, visibility and low cloud type; and, in another case (FOGCAT II) as a limited number of discrete probabilities (to include 0 and 100%) derived from present weather, past weather and visibility only. This study derives diagnostic regression equations only using as a dependent data sample over 24,000 surface synoptic ship observations at 0000 GMT for June through August 1976 and 1977. The predictor parameters contributing most significantly to the variance are sensible and evaporative heat fluxes, monthly climatological fog frequencies, and meridional wind speed. Threat, Heidke skill, and Panofsky-Brier probability scoring methods are applied to a selection of the derived equations. Predictand variance explained reaches .170, threat/skill scores reach 0.42 and probability scores are as low as 0.28 using the FOGCAT I categorization scheme for the predictand. Equations for June and July appear more stable than those for August.

Accession For	
NTAS GMLM	<input checked="" type="checkbox"/>
DDO TAB	<input type="checkbox"/>
Unannounced	<input type="checkbox"/>
Justification	
By	
Distribution/	
Availability Codes	
Dist	Avail and/or special
A	

Approved for public release; distribution unlimited.

Refinement of a Statistical Diagnostic
Model of Marine Fog Using FNWC
Model Output Parameters

by

Steve O'Neal Ouzts
Captain, United States Air Force
B.S., Auburn University, 1969

Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE IN METEOROLOGY

from the
NAVAL POSTGRADUATE SCHOOL
June 1979

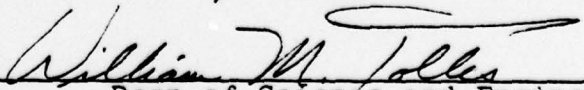
Author



Approved by:


_____ Thesis Advisor


_____ Chairman, Department of Meteorology


_____ Dean of Science and Engineering

ABSTRACT

The study represents a continuation of the development of a model output statistics scheme to specify marine fog over the open ocean and in coastal waters. Thirty-seven direct and derived Fleet Numerical Weather Central model output parameters, monthly climatological fog frequencies, combinations of the aforementioned parameters (i.e., interactive parameters) and a persistence parameter are used as predictors in a step-wise multiple linear regression approach to estimate a predictand defined as marine fog probability. The predictand is categorized in two ways, in one case (FOGCAT I) as smoothed probabilities from 0 to 100% as a function of present weather, past weather, visibility and low cloud type; and, in another case (FOGCAT II) as a limited number of discrete probabilities (to include 0 and 100%) derived from present weather, past weather and visibility only. This study derives diagnostic regression equations only using as a dependent data sample over 24,000 North Pacific Ocean (30-60N) surface synoptic ship observations at 0000 GMT for June through August 1976 and 1977. The predictor parameters contributing most significantly to the variance are sensible and evaporative heat fluxes, monthly climatological fog frequencies, and meridional wind speed. Threat, Heidke skill, and Panofsky-Brier probability scoring methods are applied to a selection of the derived equations. Predictand variance explained reaches .670, threat/skill scores reach 0.42 and probability scores are as low as 0.28 using the FOGCAT I categorization scheme for the predictand. Equations for June and July appear more stable than those for August.

ABSTRACT

The study represents a continuation of the development of a model output statistics scheme to specify marine fog over the open ocean and in coastal waters. Thirty-seven direct and derived Fleet Numerical Weather Central model output parameters, monthly climatological fog frequencies, combinations of the aforementioned parameters (i.e. interactive parameters) and a persistence parameter are used as predictors in a step-wise multiple linear regression approach to estimate a predictand defined as marine fog probability. The predictand is categorized in two ways, in one case (FOGCAT I) as smoothed probabilities from 0 to 100% as a function of present weather, past weather, visibility and low cloud type; and, in another case (FOGCAT II) as a limited number of discrete probabilities (to include 0 and 100%) derived from present weather, past weather and visibility only. This study derives diagnostic regression equations only using as a dependent data sample over 24,000 surface synoptic ship observations at 0000 GMT for June through August 1976 and 1977. The predictor parameters contributing most significantly to the variance are sensible and evaporative heat fluxes, monthly climatological fog frequencies, and meridional wind speed. Threat, Heidke skill, and Panofsky-Brier probability scoring methods are applied to a selection of the derived equations. Predictand variance explained reaches .170, threat/skill scores reach 0.42 and probability scores are as low as 0.28 using the FOGCAT I categorization scheme for the predictand. Equations for June and July appear more stable than those for August.

TABLE OF CONTENTS

I.	INTRODUCTION - - - - -	11
II.	OBJECTIVES AND APPROACH - - - - -	15
III.	DATA - - - - -	17
	A. AREA - - - - -	17
	B. TIME PERIOD - - - - -	17
	C. SYNOPTIC WEATHER REPORTS - - - - -	17
	D. MODEL OUTPUT PARAMETERS - - - - -	18
	E. FOG FREQUENCY CLIMATOLOGY - - - - -	18
IV.	PROCEDURE - - - - -	20
	A. PREDICTAND CATEGORIZATION METHODS - - - - -	20
	B. PREDICTOR INTERPOLATION - - - - -	22
	C. REGRESSION SCHEME - - - - -	22
	D. VERIFICATION SCORING - - - - -	24
V.	RESULTS - - - - -	25
	A. REGRESSION EQUATIONS - - - - -	25
	B. VERIFICATION SCORING - - - - -	28
VI.	CONCLUSIONS AND RECOMMENDATIONS - - - - -	33
	APPENDIX A. Land Stations Used in Study - - - - -	70
	APPENDIX B. Output Parameter Descriptions - - - - -	71
	APPENDIX C. Abridged Version of Inter- nationally Used Weather Code - - - - -	76
	APPENDIX D. FOGCAT I Categorization Scheme - - - - -	78
	APPENDIX E. FOGCAT II Categorization Scheme - - - - -	81
	APPENDIX F. Verification Score Formulae - - - - -	82

LIST OF REFERENCES - - - - - 83

INITIAL DISTRIBUTION LIST - - - - - 86

LIST OF TABLES

I.	Stepwise Regression Coefficients, June 1976 Data - - - - -	36
II.	Stepwise Regression Coefficients, June 1977 Data - - - - -	37
III.	Stepwise Regression Coefficients, June 1976 and 1977 Data - - - - -	38
IV.	Stepwise Regression Coefficients, July 1976 Data - - - - -	39
V.	Stepwise Regression Coefficients, July 1977 Data - - - - -	40
VI.	Stepwise Regression Coefficients, July 1976 and 1977 Data - - - - -	41
VII.	Stepwise Regression Coefficients, August 1976 Data - - - - -	42
VIII.	Stepwise Regression Coefficients, August 1977 Data - - - - -	43
IX.	Stepwise Regression Coefficients, August 1976 and 1977 Data - - - - -	44
X.	Stepwise Regression Coefficients, June, July and August 1976 Data - - - - -	45
XI.	Stepwise Regression Coefficients, June, July and August 1977 Data - - - - -	46
XII.	Stepwise Regression Coefficients, June, July and August 1976 and 1977 Data - - - - -	47
XIII.	Changes in the Amount of Total Variance Explained for Different Fog Categori- zation Methods - - - - -	48
XIV.	Stepwise Regression Coefficients, July 1976 Data with the Persistence Parameter - - - - -	49
XV.	Stepwise Regression Coefficients, July 1977 Data with the Persistence Parameter - - - - -	50
XVI.	Stepwise Regression Coefficients, July 1976 and 1977 Data with the Persistence Parameter -	51

XVII.	Skill, Threat, and P-Scores, June 1976 and 1977 Data - - - - -	52
XVIII.	Skill, Threat, and P-Scores, July 1976 and 1977 Data - - - - -	53
XIX.	Skill, Threat, and P-Scores, July 1976 and 1977 Data with the Persistence Parameter -	54
XX.	Skill, Threat, and P-Scores, August 1976 and 1977 Data - - - - -	55
XXI.	Skill, Threat, and P-Scores; June, July, and August 1976 and 1977 Data - - - - -	56
XXII.	Comparison of Skill and Threat Scores for the Regression Equations and Climatology - - -	57

LIST OF FIGURES

1.	Study area on polar stereographic projection	- - 58
2.	Fleet Numerical Weather Central's 63x63 grid	- - 59
3.	Percent frequency of occurrence of fog in any form - June	- - - - - 60
4.	Percent frequency of occurrence of fog in any form - July	- - - - - 61
5.	Percent frequency of occurrence of fog in any form - August	- - - - - 62
6.	NMC sea-level pressure analysis 0000 GMT 3 August 1976, North Pacific Ocean	- - - - - 63
7.	FNWC EHF field, date and area as in Fig. 6	- - - 64
8.	FNWC SEHF field, date and area as in Fig. 6	- - - 65
9.	FNWC v field, date and area as in Fig. 6	- - - 66
10.	FNWC FTER field, data and area as in Fig. 6	- - - 67
11.	NPS fog probabilities, FOGCAT I, date and area as in Fig. 6	- - - - - 68
12.	NPS fog probabilities, FOGCAT II, date and area as in Fig. 6	- - - - - 69

ACKNOWLEDGEMENTS

I would like to express my appreciation to my thesis advisor, Dr. Robert J. Renard, without whose enthusiasm, patience and guidance the completion of this study would not have been possible.

Special thanks are extended to Mr. Steve Rinard, Department of Meteorology, NPS for his assistance with programming problems and to Ms. Sharon Raney, W. R. Church Computer Center, NPS for her persistent help in recovering from numerous programming difficulties.

Appreciation is also extended to the Faculty of the Meteorology Department, NPS, for their diligent help in my grasping the essential meteorological basis for this study and to the staff of the W. R. Church Computer Center, NPS, for their constant guidance on the essentials of effective program accomplishment, particularly K. Butler, E. Donnellan, M. Anderson, D. Goodwin and R. Donat.

Thanks are also extended to the many friends and colleagues who provided me with incentive and knowledge when the computer wasn't cooperating or a mental block had developed.

I. INTRODUCTION

Marine fog presents a threat to safe nautical activities as well as to low-level aviation over the oceans. Historical monetary and human losses associated with United States Navy operations, attributable solely or mostly to fog, have been documented by Wheeler and Leipper (1974). These types of losses should be significantly reduced as the methods for analysis and forecasting of marine fog become more accurate. The environmental science community would additionally benefit from the increased accuracy of fog analyses/forecasts by a commensurate improvement in specifying fog-associated parameters in various analysis models, especially boundary layer models.

Research in the past several years conducted by the Departments of Meteorology and Oceanography, Naval Postgraduate School (NPS), Monterey, California, has been directed at more adequate diagnoses of marine fog and a better representation of its climatology, as based on ocean-station-vessel and ship-of-opportunity observations (Renard, Englebretson and Daughenbaugh, 1975; Renard, 1976). Additionally, more recent research has attempted to use geostationary weather satellite data to diagnose marine fog areas (Ihli and Renard, 1977; McNab, 1979). The totality and continuity of such satellite observations makes this approach potentially very useful.

However, much further testing is needed before operational application is feasible.

In a more statistical vein, an earlier study by Nelson (1972) developed regression equations using the "perfect prognostic approach" to forecast visibility (and hence fog) at ocean station vessels in the North Atlantic Ocean. This approach is not unlike the Model Output Statistics (MOS) methods used currently by the National Weather Service (NWS) to forecast weather parameters of interest over the continental U.S., Hawaii and Alaska (Glahn and Lowry, 1972), except the "imperfect prognostic approach" is the present mode. Nelson found quite high correlations of visibility with wind speed, relative moisture content and various evaporative parameters, using observed data. However, when he attempted to forecast fog using output parameters from the United States Navy Fleet Numerical Weather Central's (FNWC) numerical prediction models, his regression equations showed little skill. Earlier work, conducted by Schramm (1966), found high correlations between observed values of humidity, air temperature, wind speed and visibility at sea; however, the regression equation developed from these parameters was of little value at times of low visibility.

Additional research into the feasibility of developing regression equations to forecast marine fog, based on FNWC's model output parameters, has been conducted by Van Orman and Renard (1977) and Quinn (1978). Both studies developed schemes which statistically processed up to 37 direct or

derived FNWC model output analysis-time¹ parameters in conjunction with surface synoptic ship observations to generate multiple linear regression equations yielding as a predictand the probability of marine fog occurrence at analysis time over the North Pacific Ocean. The Van Orman /Renard results, based solely on July 1976 data, showed considerable skill over FNWC's advective fog model, FTER, as applied to the analysis of fog (U.S. Naval Weather Service Command, 1975) and climatological fog frequencies developed at the NPS (Willms, 1975). Quinn expanded the data base to also include June and August 1976 and developed regression equations both for the unique probabilistic marine fog predictand introduced by Van Orman and Renard as well as a modification of that predictand. Quinn further introduced interactive predictor parameters into the regression scheme by combining the climatological fog frequency parameter with the two most significant model output parameters to derive a new set of diagnostic regression equations. A clear improvement over climatology and FNWC's FTER was demonstrated using these modified regression equations on dependent data. The equations based on the June 1976 data also showed improvement over FTER and climatology when used on an independent data set from July 1976. These prior studies give clear indication of the relative accuracy of the MOS approach in diagnosing marine fog, with a successful extension to forecast modes yet to be demonstrated.

¹ Some parameters are taken from analysis models, other are diagnostic parameters from prognostic models.

Currently, only FNWC is producing fog analysis/forecasts on a large scale over the oceanic areas through their statistical probabilistic product, FTER. A climatological parameter is not used in their product due to the unavailability of an accurate climatology at the time of its development. A comprehensive uniform climatology of fog occurrence over all of the Northern Hemisphere is now available from the National Climatic Center (Guttman, 1978) and has been incorporated into this study. This inclusion represents a refinement of the fog parameter from the two prior studies.

II. OBJECTIVES AND APPROACH

The primary objective of this study was to continue the development of a multiple linear regression approach begun by Van Orman and Renard (1977) and pursued by Quinn (1978) to specify effectively the distribution and likelihood of marine fog at analysis time over the middle latitude (30° - 60° N) region of the North Pacific Ocean during the summer season. Part of the primary objective was to evaluate the equations' skill in comparison to the climatological fog frequencies derived by Guttman (1978) and FNWC's existing operational scheme for forecasting advection fog probability, FTER. A second objective was to determine whether the predictand categorization scheme FOGCAT I developed by Van Orman and Renard or the FOGCAT II scheme developed by Quinn is superior in defining the occurrence of fog. Additionally, an investigation of the usefulness of persistence as a diagnostic prediction parameter was initiated. The approach follows that of Quinn's (1978) experiments with the addition of June, July and August 1977 data.

Sets of regression equations were developed for both fog categorization schemes for (a) each of the six months June, July and August 1976 and 1977; (b) the combined data for both Junes, both Julys and both Augusts, (c) the combined data for June, July and August 1976, (d) the combined data for June, July, and August 1977, and (e) all of the data for the

six-month period. Those equations which were based on data from both June's, both July's, both August's, and all six months were scored using three methods, skill, threat and probability.

III. DATA

A. AREA

The area of study was confined to the North Pacific Ocean to maintain continuity and consistency with the previous studies of Van Orman and Renard (1977) and Quinn (1978), specifically the area north of 30°N and south of 60°N (Figure 1). A 27×14 grid was superimposed on this region with grid points coincident with their counterparts on the same subarea of the standard FNWC 63×63 grid (Figure 2).

B. TIME PERIOD

Due to the high frequency of marine fog in the summer months over the North Pacific Ocean (Willms, 1975; Guttman, 1978), the additional summer months (June, July and August) of 1977 were added to the available set of the same months in 1976. At 0000 GMT the entire North Pacific Ocean is in daylight with local noon occurring at the international date-line. Only data from this time were used since the accuracy of visibility reports from ships transitting the area should be best during daylight hours.

C. SYNOPTIC WEATHER REPORTS

The June-August 1976 and 1977 synoptic weather reports used in this study were provided by the Naval Weather Service Detachment, physically located with the National Oceanic and Atmospheric Administration's National Climatic Center,

Asheville, North Carolina. These data had been edited to eliminate duplicate reports. The total number of observations received were 4277 for June 1976, 4391 for July 1976, 4134 for August 1976, 4232 for June 1977, 4198 for July 1977 and 3156 for August 1977. All observations were obtained from transitting ships and Ocean Weather Station Papa except data obtained from 11 land stations located in the study area (Appendix A). As all of these land stations are located on islands or immediately adjacent to the coast and have relatively low elevations, the effect of topography is thought to be minimum.

D. MODEL OUTPUT PARAMETERS

FNWC provided the 22 diagnostic model output parameters (MOP's) for the time period and area of interest as output from several of their numerical analysis and prediction models: the Mass Structure Analysis Model, the Primitive Equation Prediction Model, the Marine Wind Model, and the Spectral Ocean Wave Model (U.S. Naval Weather Service Command, 1975). Additionally, a set of 15 parameters were derived from the primary set and eight interactive parameters were developed. A complete listing and description of all these parameters is located in Appendix B.

E. FOG FREQUENCY CLIMATOLOGY

Previous research used the Naval Postgraduate School's North Pacific Ocean marine fog climatology (Willms, 1975). As an updated hemispheric fog frequency climatology (Guttman,

1978) is now available, it was used exclusively throughout this research. Specific values for fog frequency were interpolated to an 89x45 grid in the area of study, which is approximately four times as dense as the FNWC grid over the region. This finer resolution allowed a more accurate specification of the fog frequency climatology. The fog frequency climatologies for each month are presented in Figures 3-5.

IV. PROCEDURE

A. PREDICTAND CATEGORIZATION METHODS

The two methods of predictand (fog) categorization used throughout this study are based on four elements of the synoptic reports, namely: present weather (ww), past weather (W), visibility (VIS), and low cloud type (CL). Observation elements other than present weather are used due to inconsistencies in the reported observations, which result in part from current rules for coding observed data (U.S. Departments of Commerce, Defense and Transportation, 1969) (See Appendix C). For example, fog is not coded as present weather whenever any form of precipitation is occurring simultaneously. Both methods of fog categorization assign a probability of fog occurrence to each synoptic report, differing mainly by the number and combination of observation elements used to assign the probability value.

The Fog Categorization I (FOGCAT I) scheme was developed by Van Orman and Renard (1977) and used all of the four elements listed above. This scheme assigns one of five major fog categories and one of three subcategories to each synoptic report as a function of ww, W, and CL. Then a fog probability, 0 to 100% is assigned to each observation depending upon the major category and subcategory assigned. Appendix D outlines FOGCAT I.

The Fog Categorization II (FOGCAT II) scheme developed by Quinn (1978) uses only present weather, past weather and visibility to assign one of seven discrete fog probabilities (0%, 10%, 15%, 35%, 60%, 85% and 100%) to each synoptic observation. This scheme is more direct in its method of categorization and assigns fog probabilities based on a filtering technique. First present weather is evaluated. If present weather definitely indicates either the presence or absence of fog, then a probability of 100% or 0% is assigned, respectively. In either of these cases, both past weather and visibility are ignored. For all other present weather codes, past weather and visibility are considered in the assignment of a fog probability. Past weather is evaluated first. If the possibility of fog is eliminated by the past weather code, a score of 0% is assigned and visibility is not considered. If the past weather code indicates the possibility of fog, then the visibility is taken into account in assigning one of the choices for an intermediate fog probability (i.e. 10, 15, 35, 60, 80). The assignment of these intermediate values is somewhat arbitrary. Details of FOGCAT II are presented in Appendix E.

Neither the FOGCAT I nor FOGCAT II schemes represent an ideal categorization scheme for fog probability. FOGCAT I, on the one hand, could assign an observation a fog probability as low as 62.1% even though the present weather code definitely indicates the presence of fog, or it could assign a probability as high as 24.1% when fog appears very improbable from

the synoptic report. FOGCAT II was developed to achieve a better fit of probability to occurrence of event. Except for the "100" and "0" values, the FOGCAT II probabilities, like those of FOGCAT I, are somewhat arbitrary. In any case the schemes were accepted as developed by the previous authors, recognizing that some adjustments may improve the physical representation of the categorization along with its verification.

B. PREDICTOR INTERPOLATION

The interpolation method used to determine values of the predictors at the observation points is a natural bicubic spline curvilinear interpolation scheme. The locally developed program, SPLIN, is available at the NPS W. R. Church Computer Center and was used throughout the study.

C. REGRESSION SCHEME

A stepwise multiple linear regression program, called BMDP2R (University of California, 1975) was chosen as the means for deriving the marine fog diagnostic equations. The polynomial regression scheme also available in the BMD computer program series was not used due to its inability to handle data sets of over 1000 cases. As each month has approximately 4000 synoptic observations and combined data sets had at least 7000 cases, the usefulness of the polynomial regression scheme applied to smaller segments of the data was unlikely to give accurate results. A non-linear, non-polynomial scheme also available in the BMD series uses excessive

computer memory for a 45-variable regression, and, therefore, was likewise not used.

BMDP2R computes a sequence of multiple linear equations in a stepwise manner. At each step one variable is either added or removed from the previous step's equation as dependent on the F-to-enter and F-to-remove criteria. In the forward selection procedure the dependent predictor inserted in the equation is the one with the highest coefficient of partial determination (ΔR^2). At each step the regression procedure reevaluates the variables already in the equation, and may find that a variable important at an earlier stage may be less important at a later stage due to the intercorrelation of variables. In this procedure, before a variable is added, the variable already in the equation with the partial F value is dropped if this latter value is less than the maximum F-to-remove value (Wesolowsky, 1976). Selection proceeds until no candidate variables qualify or until all independent variables have been used.

The BMDP2R program permits the specification of the tolerance level. If the tolerance is near zero, the variable being considered is close to being a linear combination of the variables already in the equation. Variables with low tolerances could cause computational difficulties in the method of calculation (Wesolowsky, 1976). Since tolerance is defined as one minus the coefficient of determination, the value of .01 was used as the minimum acceptable tolerance criterion (University of California, 1975).

The approach taken in this study was to treat the y-intercept (Y-INTCP) as a variable and to use the BMDP2R program's default values of 4.0 and 3.9 as the values for the minimum F-to-enter and maximum F-to-remove criteria.

D. VERIFICATION SCORING

Two types of verification scores are used in the study to test the skill of different regression equations in describing the distribution of fog probabilities. The first type, exemplified by the Heidke Skill Score (HSS) and the Threat Score (TS), is used to test the effectiveness in specifying discrete occurrences of fog. The second type (Panofsky-Brier Probability Score) tests the accuracy of probabilities in estimating the likelihood of fog occurrence (PS) (Panofsky and Brier, 1958).

The formulae used for the three scores (HSS, TS, and PS) are given in Appendix F. Currently the Threat Score is popularly used by the Techniques Development Laboratory, National Weather Service (Bermowitz and Best, 1978; Miller and Best, 1978), while the Heidke Skill Score has been traditionally used by meteorologists. The Panofsky-Brier Probability Score is suitable for evaluating the effectiveness of a predictor given in terms of a probability (0-100%).

V. RESULTS

A. REGRESSION EQUATIONS

The sets of equations generated for the individual months of June, July and August 1976 and 1977 as well as combinations thereof, using categorization schemes FOGCAT I and FOGCAT II, are listed in Tables I-XII. They are shown in stepwise order and include Y-intercept, regression coefficients and the amount of variance explained with the inclusion or removal of each variable (R^2 and ΔR^2). Only six steps are given in each table for purposes of brevity. In all cases no two successive steps added a cumulative ΔR^2 of greater than .005 after the sixth step until a variable was removed. Recognizing that variables which explain less than 1% additional variance are normally not included in operational regression equations, six steps were presented so that all variables having a possible effect on further development could be identified.

Since the climatological synoptic regime varies from month-to-month and from year-to-year the regression equations vary accordingly. Several similarities are evident, however. First, in all cases for both FOGCAT I and FOGCAT II the first model output parameter to be entered is one of the heat flux terms, either EHF or SEHF. Second, either CLIMO or an interactive parameter containing CLIMO enters all the equations by step 3 with the exception of the equations

derived from August 1977 data and the equation for all months for FOGCAT I. Finally, the meridional component of the wind, v , or an interactive parameter containing v enters all of the equations no later than step 4 with the exception of the equations derived using FOGCAT I on the combined July 1976/77 data or FOGCAT I and II, on the August 1976 and FOGCAT I on the August 1977 data. Additional similarities are evident at later steps but are not considered significant to this discussion.

In all cases, the first three non-constant variables entered into the regression equations accounts for between 71.9% and 92.5% of the summation of coefficients of partial determination (ΔR^2) determined by the entire set of model output predictors.

As the magnitudes of the coefficients of determination (R^2) vary greatly between those equations derived using the two different categorization schemes, a direct comparison of the effectiveness of the equations based on FOGCAT I versus those based on FOGCAT II is difficult. Although Table XIII indicates that the $\Sigma \Delta R^2$ for FOGCAT II is generally greater than this quantity for FOGCAT I, comparisons are more properly made using standard verification scoring methods, as in Section B following.

The eight interactive parameters used in the regression analysis were formed by either multiplying the parameters found to be most significant by Quinn (1978) by climatology or by multiplying various of these most significant parameters by other significant parameters. The inclusion of these

interactive parameters allows climatology to enter the scheme at an earlier step. Originally, climatology was too highly correlated with the heat flux terms to enter the equations alone, and thus it was rejected by the tolerance criterion.

Having identified the most probable meteorological indicators of fog occurrence by regression analysis, the feasibility of adding a persistence parameter was investigated. Due to lack of time, this investigation was limited to the July 1976 and 1977 data sets. The persistence parameter (PERS) was based only on those observations which had at least one synoptic report within a one degree latitude/longitude box of the reported position on the previous day. This requirement reduced the data set for July 1976 from 4391 to 1368 reports and for July 1977 from 4198 to 1591 reports.

Regression analysis, with PERS included, was then performed on the July data sets, both individually and in unison, using both categorization schemes. The sets of equations for these data sets are listed in Tables XIV-XVI. Persistence displayed a high correlation with EHF, SEHF and CLIMO and was rejected for inclusion in the equations by the tolerance criterion on this basis until the seventh step at the earliest. The similarities among equations which were noted earlier are decreased when PERS is included with only the heat flux term retaining its former importance in all cases. This instability introduced into the equations may be only the result of the reduced data set; the investigation of persistence as a fog indicator should not be abandoned until it is tested on a larger scale, both alone and in interactive combinations.

Fields of selected model output parameters, FTER and regression-computed fog probabilities for the arbitrarily selected observation time, 0000 GMT 3 August 1976, are shown in Figures 6-12. Considerable frontal activity in the mid-latitude central and western North Pacific Ocean is indicated by the sea-level pressure analysis (Figure 6). The two most important fog-related parameters, EHF and SEHF, are shown in Figures 7 and 8. Maximum positive values at the subtropical latitudes give way to a broad zonal band of negative and low positive values centered between 45-55N. Another important regression parameter, the algebraic value of meridional wind speed, v , is displayed in Figure 9. This field closely relates to the geostrophic/gradient wind implied by the sea-level pressure analysis. Figures 10 and 11 show the regression-computed fog probabilities based on three variables for Fog Categorization Schemes I and II. The configuration of these fields resembles that of SEHF, the FNWC variable explaining most of the variance in fog probability. Probabilities on the FOGCAT I version (Figure 10) appear to be about 15% greater than those of FOGCAT II (Figure 11). The difference is particularly noticeable in the subtropics where fog likelihood is climatologically small. The FTER probability field (Figure 12) shows a smaller range of values than the NPS probabilities, and is a closer fit to the FOGCAT II regression probabilities.

B. VERIFICATION SCORING

For purposes of verifying fog occurrence in an observation, major categories S and F were used in the FOGCAT I scheme,

and an assigned probability of fog occurrence of 100% was used in the FOGCAT II scheme (Appendices D and E). An attempt was made to use 85% fog likelihood as also verifying fog occurrence in FOGCAT II, but this criterion yielded significantly poorer results than 100% used alone, as had been found by Quinn (1978). This may indicate that some fine tuning of the assigned fog probabilities in FOGCAT II would yield better results.

Optimum threshold probabilities were also computed for those equations based on the combined June data, combined July data, combined August data, and combined data for June, July and August 1976 and 1977. The threshold probability is that equation-specified probability which best separates the fog/no fog occurrences, hence yielding the best skill and threat scores (Bermowitz and Best, 1978). The threshold Heidke Skill Scores and Threat Scores presented in Tables XVII-XXI are those which maximize the indicated scores. The Panofsky-Brier Probability Score presented in these tables directly evaluates the accuracy of regression probabilities in estimating the likelihood of the event.

The regression equations as derived by the BMDP2R program were not used in their entirety in the verification phase of this study nor were all the equations verified. Only the equations in the form containing the Y-intercept and the first three non-constant variables were used. It is possible to "overfit" the regression equation to the dependent data. Therefore only variables which bear a physical relationship

to the predictand should be included (Panofsky and Brier, 1958). In all the equations verified, the first three variable predictors included had an apparently strong physical relationship with the occurrence of fog, while several equations introduced terms with only a weak physical relationship to fog likelihood at step 5.

The verification scores for the five data sets for which regression equations were evaluated and compared to the verification scores for FTER and climatology are presented in Tables XVII-XXI. Note that the scores for the regression equations as well as for FTER and climatology vary from the FOGCAT I to the FOGCAT II schemes. Since verification in each scheme is against the actual occurrence of fog (Category S or F in FOGCAT I or 100% in FOGCAT II), a relative comparison of the effectiveness in categorizing fog occurrence between FOGCAT I and II for purposes of regression analysis is possible. This is not to imply that observations verify as fog/no fog equally with FOGCAT I and FOGCAT II; there are slight differences not considered important in this analysis.

In four of the five cases verified, the skill and threat scores for the regression equations were higher for FOGCAT I than for FOGCAT II. In all verification scores, the FOGCAT II regression equation outperforms both climatology and FTER, except for the regression equation based on the two August data sets. The FOGCAT I regression equation outperforms climatology and FTER in skill and threat scores for each data set except the full June, July and August 1976 and 1977 set

where climatology is the top performer. In probability scoring, FTER outperforms the FOGCAT I regression equation in four of the five cases and climatology outperforms it in the other cases in the P-score.

The variations of skill and threat scores for climatology from FOGCAT I to FOGCAT II may be taken as a measure of the differences in the verifying scheme (i.e. strong fogger, category S, and foggers, category F, for FOGCAT I and observations assigned 100% probability in FOGCAT II). Thus, a measure of the relative comparison of FOGCAT I and II regression equations might be obtained by noting the changes in the relative improvement over climatology. For example with reference to Table XVII, FOGCAT I skill/threat scores exceed climatologies skill/threat scores by .107/.072, while for FOGCAT II the numbers are only .082/.063, indicating greater merit for FOGCAT I. Table XXII tabularizes this information. On this basis relative improvement over climatology is best using FOGCAT I for equations in Tables XVII, XVIII, XIX (except for threat score) and XXI, while FOGCAT II is better for equations in Table XX.

When the persistence parameter is included in the regression scheme for the two Julys, regression skill and threat scores generally show improvement (Tables XVIII-XIX). Considering the reduced data set, at best, it is to be regarded as giving encouragement to the future refinement of a more comprehensive persistence parameter.

It is to be noted again that all regression equations apply to analysis time, hence are diagnostic. Further all are relative to dependent data. The data were considered too limited to expend even one month as an independent set.

VI. CONCLUSIONS AND RECOMMENDATIONS

From the evaluation of these diagnostic Model Output Statistics regression equations, it can be seen that the MOS approach to prediction of marine fog holds great potential. The developed regression equations show improvement over both climatology and the FNWC advective fog forecasting product, FTER. However, it remains difficult to recommend, without qualifications, the use of either FOGCAT I or FOGCAT II schemes for the predictand.

The comments that follow relate to the equation for each month (for two-year period); the equation for all six months combined are not considered to be operationally useful. Even though FOGCAT II equations score better than CLIMO and FTER (except for August) using all the scoring methods, threat, skill and probability, FOGCAT I equations show higher threat and skill scores than FOGCAT II and excel CLIMO and FTER in two of the scoring methods, threat and skill. It appears quite significant that FOGCAT I shows most skill relative to climatology and FTER as well and therefore this predictand categorization appears to be the best to use. Further development of FOGCAT I and II or another approach may well yield still further improvement in regression results.

The following recommendations are offered as a guide to future work in this area:

1. In order to simplify the analysis procedure and the amount of data manipulation, parameters which have little or no effect on the outcome of the regression equation should be deleted. These include: SOLARAD, DDWW, PPW, PDW, SPW, SDW, WCP, THETAX, THETAR, STABX, ASTDX, ASTDR, CAPV, ADTSEA, AASTDX, AASTDR, and SSTA. See Appendix B.

2. The development of a more realistic persistence parameter should be continued and included in the regression scheme both alone and in interactive combinations. As a first approximation the fog probability assigned by the regression equation (without inclusion of a persistence parameter) to each grid point of the previous day could be interpolated to the actual observation positions of the present day. This would give a persistence value to each observation whether or not a report was available within a one degree latitude/longitude box on the previous day. These first approximations could then be weighted for those observations which had a report within the specified box on the previous day. In this manner the size of the data set would not be reduced as it was in this study.

3. Additional data (perhaps one more year) should be added to further stabilize the regression analysis.

4. A stratification of the set of regression equations by latitude, longitude, or by meteorological phenomena (i.e. wind direction, positive/negative thermal advection, or places where climatological fog frequencies are greater) is likely to improve accuracy.

5. The regression approach should be extended to regions other than the North Pacific Ocean and time periods other than summer.

6. As FNWC predictive model output parameters fields become available for testing they should be incorporated into the regression equations for forecast intervals to at least 48 hours.

TABLE I: Stepwise regression coefficients; June 1976 data, 4277 reports. For brevity only 6 steps presented.

A. FOGCAT I Categorization Scheme. Stepping terminated by BMDP2R program after 8 steps. Total $\Delta R^2 = .082$ (six steps)

STEP	Y-INTCP	EHF	CLIMO X SEHF	CLIMO	V	VVWW	HW	R ²	ΔR^2
0	35.398							.561	
1	45.479	-3.326						.628	.067
2	39.676	-2.220	-.044					.634	.006
3	34.965	-2.047	-.034	.285				.637	.003
4	33.780	-1.913	-.031	.320	.389			.639	.002
5	36.402	-1.841	-.035	.320	.441	-.204		.640	.001
6	35.629	-1.776	-.037	.334	.431	-.509	1.035	.643	.003

B. FOGCAT II Categorization Scheme. Stepping terminated by BMDP2R program after 24 steps. Total $\Delta R^2 = .134$ (six steps)

STEP	Y-INTCP	EHF	CLIMO X V	CLIMO X SEHF	TAIR	EAIR	V X SEHF	R ²	ΔR^2
0	23.174							.250	
1	35.633	-4.111						.356	.106
2	34.144	-3.821	.031					.364	.008
3	29.241	-2.877	.026	-.033				.370	.006
4	34.013	-2.456	.030	-.032	-.472			.372	.002
5	26.701	-1.839	.028	-.036	-2.846	2.671		.382	.010
6	25.816	-1.848	.018	-.034	-2.985	2.853	-.057	.384	.002

TABLE II: Stepwise regression coefficients; June 1977 data, 4232 reports. For brevity only 6 steps presented.

A. FOGCAT I Categorization Scheme. Stepping terminated by BMDP2R program after 14 steps. Total $\Delta R^2 = .070$ (six steps)

STEP	Y-INTCP	SEHF	CLIMO	V	VVWW	ASTDR	CAPU	R ²	ΔR^2
0	35.916							.557	
1	35.847	-1.924						.612	.055
2	29.328	-1.554	.299					.616	.004
3	27.350	-1.356	.350	.510				.619	.003
4	34.677	-1.443	.318	.670	-.477			.623	.004
5	38.218	-1.624	.289	.730	-.545	-1.592		.625	.002
6	38.011	-1.568	.293	1.364	-.510	-1.707	-.728	.627	.002

B. FOGCAT II Categorization Scheme. Stepping terminated by BMDP2R program after 17 steps. Total $\Delta R^2 = .140$ (six steps)

STEP	Y-INTCP	SEHF	VVWW	CLIMO X V	TAIR	EAIR	ASTDX	R ²	ΔR^2
0	24.398							.263	
1	24.308	-2.501						.357	.094
2	30.545	-2.585	-.441					.361	.004
3	31.809	-2.327	-.602	.030				.368	.007
4	39.713	-1.956	-.579	.035	-.673			.372	.004
5	30.843	-1.538	-.562	.035	-4.755	4.584		.396	.024
6	21.929	-.249	-.380	.044	-5.145	4.769	4.272	.402	.007

TABLE III. Stepwise regression coefficients; June 1976 and 1977 data, 8509 reports.
For brevity only 6 steps presented.

A. FOGCAT I Categorization Scheme. Stepping terminated by BMDP2R program after 29 steps. Total $\Delta R^2 = .073$ (six steps)

STEP	Y-INTCP	EHF	CLIMO X SEHF	CLIMO X	CLIMO Y	V	VVWW	ASTDR	R ²	ΔR^2
0	35.641								.559	
1	46.741	-3.374							.619	.060
2	41.264	-2.273	-.037						.625	.006
3	36.725	-2.095	-.030	.226					.627	.002
4	35.374	-1.997	-.025	.264	.426				.630	.003
5	39.100	-1.920	-.026	.251	.504	-.272			.631	.001
6	42.432	-2.135	-.030	.229	.575	-.315	-1.412		.632	.001

B. FOGCAT II Categorization Scheme. Stepping terminated by BMDP2R program after 16 steps. Total $\Delta R^2 = .116$ (six steps)

STEP	Y-INTCP	EHF	CLIMO X SEHF	CLIMO X	CLIMO Y	ASTDR	VVWW	SDW	R ²	ΔR^2
0	23.768								.256	
1	37.713	-4.239							.353	.097
2	31.147	-2.917	-.041						.362	.009
3	31.154	-2.956	-.032	.023					.367	.005
4	33.915	-3.212	-.032	.025	-1.589				.369	.002
5	38.329	-3.153	-.035	.029	-1.776		-.316		.371	.002
6	40.489	-3.168	-.033	.030	-1.713		-.338	-1.195	.372	.001

TABLE IV: Stepwise regression coefficients; July 1976 data, 4391 reports. For brevity only 6 steps presented.

A. FOGCAT I Categorization Scheme. Stepping terminated by BMDP2R program after 28 steps. Total $\Delta R^2 = .102$ (six steps)

STEP	Y-INTCP	EHF	CLIMO	CLIMO X SEHF	V	PDW	ASTDR	R ²	ΔR^2
0	36.563							.562	
1	47.952	-3.244						.646	.084
2	34.805	-2.221	.405					.654	.008
3	30.959	-1.498	.360	-.023				.658	.004
4	28.502	-1.331	.413	-.020	.545			.661	.003
5	34.420	-1.435	.398	-.019	.554	-.268		.662	.001
6	37.066	-1.584	.369	-.021	.592	-.268	-1.207	.664	.002

B. FOGCAT II Categorization Scheme. Stepping terminated by BMDP2R program after 20 steps. Total $\Delta R^2 = .157$ (six steps)

STEP	Y-INTCP	EHF	AASTDX	CLIMO X V	EX	TSEA	R ²	ΔR^2
0	24.691						.265	
1	38.591	-3.959					.395	.130
2	23.639	-2.746	.386				.406	.011
3	19.678	-2.256	.412	.030			.418	.012
4	3.791	-2.388	.582	.027	.741		.421	.003
5	Removed	-2.336	.631	.026	.877		.420	-.001
6	.000	-1.800	.577	.026	3.105	-2.564	.423	.002

TABLE V: Stepwise regression coefficients; July 1977 data, 4198 reports. For brevity only 6 steps presented.

A. FOGCAT I Categorization Scheme. Stepping terminated by BMDP2R program after 18 steps. Total $\Delta R^2 = .110$ (six steps)

STEP	Y-INTCP	SEHF	V	CLIMO	EAIR	TAIR	CLIMO X SEHF	R ²	ΔR^2
0	41.396							.586	
1	42.990	-2.347						.680	.094
2	41.529	-2.188	.751					.684	.004
3	34.823	-1.757	.832	.209				.687	.003
4	9.546	-1.850	.554	.431	1.190			.693	.006
5	15.974	-1.779	.512	.365	2.413	-1.532		.695	.002
6	18.927	-1.852	.517	.332	2.518	-1.852	-.014	.696	.001

B. FOGCAT II Categorization Scheme. Stepping terminated by BMDP2R program after 14 steps. Total $\Delta R^2 = .168$ (six steps)

STEP	Y-INTCP	SEHF	CLIMO X V	EAIR	TAIR	CLIMO X SEHF	SHF	R ²	ΔR^2
0	30.567							.322	
1	32.551	-2.923						.468	.146
2	30.562	-2.652	.027					.474	.006
3	19.455	-2.975	.023	.718				.478	.004
4	24.842	-2.643	.024	3.168	-2.862			.486	.008
5	26.101	-2.023	.021	3.332	-3.229	-.021		.488	.002
6	29.882	-2.880	.019	3.173	-2.834	-.029	2.301	.490	.002

TABLE VI: Stepwise regression coefficients; July 1976 and 1977 data, 8589 reports.
For brevity only 6 steps presented.

A. FOGCAT I Categorization Scheme. Stepping terminated by BMDP2R program after 9 steps. Total $\Delta R^2 = .107$ (six steps)

STEP	Y-INTCP	EHF	CLIMO X SEHF	CLIMO	EAIR	TAIR	CAPU	R ²	ΔR^2
0	38.910							.573	.085
1	51.663	-3.450						.658	.007
2	45.387	-2.435	-.028					.665	.005
3	34.898	-1.663	-.026	.292				.670	.004
4	18.272	-2.027	-.019	.471	.861			.674	.004
5	23.977	-1.498	-.024	.396	2.372	-1.947		.678	.002
6	23.691	-1.277	-.026	.405	2.249	-1.926	.489	.680	

B. FOGCAT II Categorization Scheme. Stepping terminated by BMDP2R program after 15 steps. Total $\Delta R^2 = .161$ (six steps)

STEP	Y-INTCP	EHF	CLIMO X V	EAIR	CLIMO X SEHF	TAIR	TX	R ²	ΔR^2
0	27.548							.292	
1	43.219	-4.239						.424	.132
2	39.774	-3.798	.031					.436	.012
3	37.131	-4.037	.029	.466				.441	.005
4	31.826	-3.202	.022	.489	-.024			.447	.006
5	31.102	-2.951	.021	3.374	-.025	-2.992		.452	.005
6	30.633	-2.884	.023	2.986	-.024	-4.177	1.601	.453	.001

TABLE VII: Stepwise regression coefficients; August 1976 data, 4134 reports. For brevity only 6 steps presented.

A. FOGCAT I Categorization Scheme. Stepping terminated by BMDP2R program after 19 steps. Total $\Delta R^2 = .109$ (six steps)

STEP	Y-INTCP	SEHF	CLIMO X SEHF	SHF	SPW	V	CAPU	R ²	ΔR^2
0	33.712							.550	
1	37.079	-1.883						.650	.100
2	34.667	-1.158	-.052					.658	.003
3	41.990	-1.684	-.069	2.062				.661	.003
4	43.666	-1.692	-.067	2.039	-.375			.662	.001
5	43.242	-1.686	-.064	2.041	-.353	.241		.663	.001
6	43.827	-1.768	-.064	2.225	-.306	.745	-.577	.664	.001

B. FOGCAT II Categorization Scheme. Stepping terminated by BMDP2R program after 17 steps. Total $\Delta R^2 = .177$ (six steps)

STEP	Y-INTCP	SEHF	CLIMO X SEHF	SHF	SDW	ASTDX	CLIMO X V	R ²	ΔR^2
0	20.985							.227	
1	25.030	-2.262						.381	.154
2	22.271	-1.433	-.059					.393	.012
3	31.451	-2.092	-.081	2.584				.398	.005
4	33.304	-2.112	-.077	2.507	-.207			.400	.002
5	31.668	-1.952	-.079	3.331	-.226	2.504		.402	.002
6	30.404	-1.894	-.071	3.500	-.217	3.174	.020	.404	.002

TABLE VIII: Stepwise regression coefficients; August 1977 data, 3156 reports. For brevity only 6 steps presented.

A. FOGCAT I Categorization Scheme. Stepping terminated by BMDP2R program after 25 steps. Total $\Delta R^2 = .133$ (six steps)

STEP	Y-INTCP	SEHF	ADTX	ASTDR	STABX	HW	TX	R ²	ΔR^2
0	36.402							.550	
1	43.358	-2.094						.672	.122
2	42.228	-1.977	25.918					.676	.004
3	44.628	-2.103	33.866	-2.015				.679	.003
4	39.799	-1.895	30.069	-2.016	-85.048			.681	.002
5	36.432	-1.929	27.956	-1.872	-87.639	.669		.682	.001
6	42.464	-1.571	29.959	-1.818	-158.717	.674	-.610	.683	.001

B. FOGCAT II Categorization Scheme, Stepping terminated by BMDP2R program after 17 steps. Total $\Delta R^2 = .217$ (six steps)

STEP	Y-INTCP	SEHF	ADTX	V X SEHF	ASTDR	V	U	R ²	ΔR^2
0	25.079							.268	
1	33.726	-2.603						.462	.194
2	32.249	-2.450	33.899					.469	.007
3	30.761	-2.204	44.906	-.089				.477	.008
4	33.383	-2.358	52.094	-.081	-2.083			.480	.003
5	32.969	-2.337	35.086	-.092	-2.189	.606		.483	.003
6	32.754	-2.342	32.023	-.095	-2.451	.714	.429	.485	.002

TABLE IX: Stepwise regression coefficients; August 1976 and 1977 data, 7280 reports. For brevity only 6 steps presented.

A. FOGCAT I Categorization Scheme. Stepping terminated by BMDP2R program after 32 steps. Total $\Delta R^2 = .113$ (six steps)

STEP	Y-INTCP	SEHF	V	CAPU	DDWW	CLIMO	THF	R ²	ΔR^2
0	34.868							.549	
1	39.649	-1.948						.656	.107
2	38.763	-1.873	.457					.659	.003
3	38.781	-1.859	1.059	-.708				.660	.001
4	42.555	-1.883	1.154	-.860	-.184			.661	.001
5	43.818	-1.930	1.120	-.831	-.194	-.073		.662	.001
6	38.001	-1.784	1.089	-.747	-.187	-.089	-.164	.662	.000

B. FOGCAT II Categorization Scheme. Stepping terminated by BMDP2R program after 34 steps. Total $\Delta R^2 = .180$ (six steps)

STEP	Y-INTCP	SEHF	V	\bar{V}_{SEHF}	CAPU	PDW	ASTDX	R ²	ΔR^2
0	22.745							.245	
1	28.568	-2.375						.412	.167
2	27.447	-2.280	.578					.416	.004
3	26.352	-2.105	.727	-.067				.420	.004
4	26.378	-2.089	1.481	-.066	-.887			.423	.003
5	30.512	-2.106	1.496	-.063	-.927	-.222		.424	.001
6	26.874	-1.800	1.494	-.069	-.860	-.202	1.533	.425	.001

TABLE X: Stepwise regression coefficients; June, July and August 1976 data, 12802 reports. For brevity only 6 steps presented.

A. FOGCAT I Categorization Scheme. Stepping terminated by BMDP2R program after 12 steps. Total $\Delta R^2 = .094$ (six steps)

STEP	Y-INTCP	SEHF	CLIMO	V	CLIMO X SEHF	EHF	PDW	R ²	ΔR^2
0	35.223							.557	
1	34.735	-1.822						.637	.080
2	28.283	-1.467	.338					.642	.005
3	27.155	-1.352	.362	.504				.645	.003
4	26.695	-1.007	.328	.459	-.021			.647	.002
5	36.579	.462	.234	.427	-.036	-2.224		.650	.003
6	39.475	.370	.235	.443	-.035	-2.126	-.178	.651	.001

B. FOGCAT II Categorization Scheme. Stepping terminated by BMDP2R program after 19 steps. Total $\Delta R^2 = .144$ (six steps)

STEP	Y-INTCP	SEHF	CLIMO X V	EHF	CLIMO X SEHF	PDW	R ²	ΔR^2
0	22.958						.247	
1	22.362	-2.228					.372	.125
2	21.413	-2.040	.029				.380	.008
3	29.034	-.931	.030	-1.912			.384	.004
4	31.551	.361	.024	-3.025	-.032		.389	.005
5	30.007	Removed	.024	-2.578	-.028		.389	.000
6	34.923	.000	.025	-2.603	-.028	-.263	.391	.002

TABLE XI: Stepwise regression coefficients; June, July and August 1977 data, 11586 reports. For brevity only 6 steps presented.

A. FOGCAT I Categorization Scheme, Stepping terminated by BMDP2R program after 7 steps. Total $\Delta R^2 = .086$ (six steps)

STEP	Y-INTCP	SEHF	V	EAIR	TAIR	CLIMO	ADTSEA	R ²	ΔR^2
0	38.008							.565	
1	40.369	-2.075						.650	.075
2	39.345	-1.968	.562					.653	.003
3	33.914	-2.140	.444	.376				.654	.001
4	36.746	-1.904	.408	2.246	-2.123			.660	.006
5	32.571	-1.816	.407	2.217	-1.980	.113		.660	.000
6	34.033	-1.829	.485	2.246	-2.022	.107	-14.962	.661	.001

B. FOGCAT II Categorization Scheme, Stepping terminated by BMDP2R program after 25 steps. Total $\Delta R^2 = .150$ (six steps)

STEP	Y-INTCP	SEHF	V	V X SEHF	ASTDX	EHF	R ²	ΔR^2
0	26.792						.285	
1	29.750	-2.605					.422	.137
2	28.416	-2.466	.733				.427	.005
3	27.761	-2.326	.772	-.056			.429	.002
4	22.302	-1.721	.883	-.070	2.577		.431	.002
5	27.096	.232	1.026	-.090	4.547	-2.499	.435	.004
6	26.869	Removed	1.004	-.087	4.240	-2.248	.435	.000

TABLE XII: Stepwise regression coefficients; June, July and August 1976 and 1977 data, 24338 reports. For brevity only 6 steps presented.

A. FOGCAT I Categorization Scheme. Stepping terminated by BMDP2R program after 12 steps. Total $\Delta R^2 = .090$ (six steps)

STEP	Y-INTCP	SEHF	V	CLIMO	CLIMO X SEHF	EHF	EAIR	R ²	ΔR^2
0	36.503							.560	
1	37.262	-1.902						.640	.080
2	36.452	-1.808	.520					.643	.003
3	31.966	-1.559	.561	.215				.646	.003
4	31.723	-1.335	.531	.191	-.014			.647	.001
5	38.436	-.320	.526	.142	-.021	-1.602		.649	.002
6	33.599	-.294	.432	.185	-.019	-1.882	.348	.650	.001

B. FOGCAT II Categorization Scheme. Stepping terminated by BMDP2R program after 22 steps. Total $\Delta R^2 = .147$ (six steps)

STEP	Y-INTCP	SEHF	CLIMO X V	SHF	EAIR	TAIR	CLIMO X SEHF	R ²	ΔR^2
0	24.738							.265	
1	25.678	-2.355						.391	.126
2	24.558	-2.170	.028					.398	.007
3	30.406	-2.811	.029	1.530				.400	.002
4	27.328	-3.035	.028	1.745	.328			.403	.003
5	26.193	-2.593	.028	1.200	2.641	-2.470		.410	.007
6	27.038	-2.471	.022	1.817	2.669	-2.468	-.021	.412	.002

TABLE XIII. Changes in amount of variance explained (ΔR^2) for different fog categorization methods.

Period	Summation of ΔR^2 Due to Inclusion of First Three Non-Constant Variables	
	FOGCAT I	FOGCAT II
June 76	.076	.120
June 77	.062	.105
June 76 & 77	.068	.111
July 76	.096	.153
July 77	.101	.156
July 76 & 77	.097	.149
August 76	.111	.171
August 77	.129	.209
August 76 & 77	.111	.175
June, July & August 76	.088	.137
June, July & August 77	.089	.144
June, July & August 76 & 77	.086	.135

TABLE XIV: Stepwise regression coefficients; July 1976 data, 1368 reports with the persistence parameter included. For brevity only 6 steps presented.

A. FOGCAT I Categorization Scheme. Stepping terminated by BMDP2R program after 15 steps. Persistence entered at the 7th step and explained an additional ΔR^2 of .018. Total $\Delta R^2 = .091$ (six steps)

STEP	Y-INTCP	SEHF	CLIMO	CLIMO X SEHF	ASTDR	SHF	ADTSEA	R ²	ΔR^2
0	37.573							.563	
1	34.176	-1.862						.639	.076
2	24.655	-1.324	.399					.646	.007
3	22.960	-.744	.417	-.019				.648	.002
4	25.764	-.866	.388	-.021	-1.741			.650	.002
5	34.948	-1.621	.311	-.032	-1.940	1.975		.652	.002
6	34.849	-1.609	.342	-.031	-2.463	2.098	16.659	.654	.002

B. FOGCAT II Categorization Scheme. Stepping terminated by BMDP2R program after 10 steps. Persistence entered at the 9th step and explained an additional ΔR^2 of .024. Total $\Delta R^2 = .053$ (six steps)

STEP	Y-INTCP	SEHF	AASTDX	ASTDR	ADTAIR	EX	R ²	ΔR^2
0	25.997						.276	
1	21.684	-2.364					.400	.024
2	10.877	-1.705	.380				.411	.011
3	14.700	-1.961	.357	-2.424			.416	.005
4	13.162	-1.737	.407	-3.135	26.439		.421	.005
5	-1.531	-1.736	.570	-3.234	20.809	.664	.423	.002
6	Removed	-1.748	.550	-3.253	21.191	.605	.429	.006

TABLE XV: Stepwise regression coefficients; July 1977 data, 1591 reports, with the persistence parameter included. For brevity only 6 steps presented.

A. FOGCAT I Categorization Scheme. Stepping terminated by BMDP2R program after 14 steps. Persistence entered at the 14th step and explained an additional ΔR^2 of .005. Total $\Delta R^2 = .096$ (six steps)

STEP	Y-INTCP	EHF	STABR	PPW	V	CLIMO	EAIR	R ²	ΔR^2
0	44.705							.605	
1	56.937	-4.031						.682	.077
2	45.990	-3.136	-129.920					.688	.006
3	33.261	-3.236	-128.887	1.741				.693	.005
4	31.955	-3.010	-124.180	1.680	.713			.696	.003
5	25.290	-2.394	-116.570	1.556	.798	.173		.697	.001
6	9.896	-2.818	-88.211	1.415	.578	.317	.975	.701	.004

B. FOGCAT II Categorization Scheme. Stepping terminated by BMDP2R program after 13 steps. Persistence entered at the 13th step and explained an additional ΔR^2 of .010. Total $\Delta R^2 = .141$ (six steps)

STEP	Y-INTCP	SEHF	AASTDX	PPW	SHF	STABR	EAIR	R ²	ΔR^2
0	34.441							.362	
1	32.369	-2.889						.483	.121
2	32.137	-2.863	-67.231					.489	.006
3	20.435	-2.913	-62.585	1.553				.492	.001
4	29.221	-4.095	-64.661	1.568	2.601			.495	.003
5	26.311	-4.284	-60.375	1.504	5.371	-215.744		.502	.007
6	18.486	-5.028	-44.842	1.483	6.410	-213.477	.756	.505	.003

TABLE XVI: Stepwise regression coefficients; July 1976 and 1977 data, 2959 reports, with the persistence parameter included. For brevity only 6 steps presented.

A. FOGCAT I Categorization Scheme. Stepping terminated by BMDP2R program after 15 steps. Persistence entered at the 14th step and explained an additional ΔR^2 of .010. Total $\Delta R^2 = .093$ (six steps)

STEP	Y-INTCP	EHF	CLIMO	EX	TAIR	CLIMO X SEHF	EAIR	R ²	ΔR^2
0	41.403							.584	
1	52.600	-3.706						.660	.076
2	38.339	-2.645	.339					.666	.006
3	17.869	-2.945	.510	1.113				.673	.007
4	19.170	-2.907	.489	2.419	-1.384			.674	.001
5	20.987	-2.143	.431	2.325	-1.569	-.015		.676	.002
6	21.494	-1.712	.428	1.150	-2.348	-.019	1.761	.677	.001

B. FOGCAT II Categorization Scheme. Stepping terminated by BMDP2R program after 16 steps. Persistence did not enter before termination. Total $\Delta R^2 = .143$ (six steps)

STEP	Y-INTCP	EHF	TX	STABR	CLIMO X V	STABX	EAIR	R ²	ΔR^2
0	30.532							.322	
1	44.478	-4.616						.441	.119
2	39.980	-4.808	.616					.450	.009
3	28.167	-3.956	.642	-130.026				.458	.008
4	27.385	-3.718	.604	-119.727	.016			.461	.003
5	29.924	-3.752	.619	-227.113	.020	169.570		.463	.002
6	28.948	-3.732	-1.007	-290.060	.020	227.331	1.645	.465	.002

TABLE XVII Skill, threat and P-scores June 1976 and 1977 data.

A. FOGCAT I Categorization Scheme. $R^2 = .627$.

	REGRESSION EQUATION	FTER	CLIMATOLOGY
Skill Score	.315*	.178	.208
Threshold	40	14	27
Threat Score	.338*	.258	.266
Threshold	38	21	16
P-Score	.292	.209	.178*

$$\text{Fog Probability (\%)} = 36.725 - 2.095 (\text{EHF}) - .030 (\text{CLIMO})(\text{SEHF}) + .226 (\text{CLIMO})$$

B. FOGCAT II Categorization Scheme. $R^2 = .367$.

	REGRESSION EQUATION	FTER	CLIMATOLOGY
Skill Score	.302*	.207	.220
Threshold	28	23	27
Threat Score	.322*	.250	.259
Threshold	26	21	22
P-Score	.288*	.339	.300

$$\text{Fog Probability (\%)} = 31.154 - 2.956 (\text{EHF}) - .032 (\text{CLIMO})(\text{SEHF}) + .023 (\text{CLIMO})(V)$$

* Indicates best score in each category

TABLE XVIII. Skill, threat and P-scores July 1976 and 1977 data.

A. FOGCAT I Categorization Scheme. $R^2 = .670$.

	REGRESSION EQUATION	FTER	CLIMATOLOGY
Skill Score	.384*	.336	.303
Threshold	46	35	35
Threat Score	.404*	.355	.360
Threshold	42	23	28
P-Score	.330	.216*	.242

$$\text{Fog Probability (\%)} = 34.898 - 1.663 (\text{EHF}) - .026 (\text{CLIMO})(\text{SEHF}) + .292 (\text{CLIMO})$$

B. FOGCAT II Categorization Scheme. $R^2 = .441$.

	REGRESSION EQUATION	FTER	CLIMATOLOGY
Skill Score	.378*	.333	.302
Threshold	38	35	42
Threat Score	.386*	.346	.347
Threshold	34	23	33
P-Score	.299*	.322	.322

$$\text{Fog Probability (\%)} = 37.131 - 4.037 (\text{EHF}) + .029(\text{CLIMO})(\text{V}) + .466 (\text{EAIR})$$

* Indicates best score in each category

TABLE XIX. Skill, threat and P-scores July 1976 and 1977 data with persistence parameter.

A. FOGCAT I Categorization Scheme. $R^2 = .673$.

	REGRESSION EQUATION	FTER	CLIMATOLOGY
Skill Score	.405*	.334	.319
Threshold	48	28	28
Threat Score	.423*	.371	.391
Threshold	47	25	32
P-Score	.356	.237*	.281

$$\text{Fog Probability (\%)} = 17.869 - 2.945 (\text{EHF}) \\ + .510 (\text{CLIMO}) + 1.113 (\text{EX})$$

B. FOGCAT II Categorization Scheme. $R^2 = .458$.

	REGRESSION EQUATION	FTER	CLIMATOLOGY
Skill Score	.394*	.337	.320
Threshold	36	33	41
Threat Score	.414*	.365	.381
Threshold	36	25	33
P-Score	.323*	.370	.350

$$\text{Fog Probability (\%)} = 28.167 - 3.956 (\text{EHF}) \\ + .642 (\text{TX}) - 130.026 (\text{STABR})$$

* Indicates best score in each category.

TABLE XX . Skill, threat and P-scores August 1976 and 1977 data.

A. FOGCAT I Categorization Scheme. $R^2 = .660$

	REGRESSION EQUATION	FTER	CLIMATOLOGY
Skill Score	.403*	.374	.146
Threshold	45	28	26
Threat Score	.378*	.345	.219
Threshold	40	23	14
P-Score	.279	.175*	.202

$$\text{Fog Probability (\%)} = 38.781 - 1.859 (\text{SEHF}) \\ + 1.059 (V) - .708 (\text{CAPU})$$

B. FOGCAT II Categorization Scheme. $R^2 = .420$.

	REGRESSION EQUATION	FTER	CLIMATOLOGY
Skill Score	.402*	.375	.136
Threshold	46	28	25
Threat Score	.368*	.341	.208
Threshold	40	24	16
P-Score	.297	.280*	.336

$$\text{Fog Probability (\%)} = 26.352 - 2.105 (\text{SEHF}) \\ + .727 (V) - .067 (\text{SEHF})(V)$$

* Indicates best score in each category.

TABLE XXI . Skill, threat and P-scores June, July and August 1976 and 1977 data.

A. FOGCAT I Categorization Scheme. $R^2 = .646$.

	REGRESSION EQUATION	FTER	CLIMATOLOGY
Skill Score	.214	.196	.293*
Threshold	27	23	44
Threat Score	.267	.251	.319*
Threshold	16	21	41
P-Score	.304	.201*	.208

$$\text{Fog Probability (\%)} = 31.966 - 1.559 (\text{SEHF}) \\ + .561 (V) + .215 (\text{CLIMO})$$

B. FOGCAT II Categorization Scheme. $R^2 = .400$.

	REGRESSION EQUATION	FTER	CLIMATOLOGY
Skill Score	.370*	.321	.294
Threshold	32	34	40
Threat Score	.382*	.335	.337
Threshold	31	23	32
P-Score	.283*	.322	.318

$$\text{Fog Probability (\%)} = 30.406 - 2.811 (\text{SEHF}) \\ + .029 (\text{CLIMO})(V) + 1.530 (\text{SHF})$$

* Indicates best score in each category.

TABLE XXII: Comparison of Skill and Threat Scores for the Regression Equations and Climatology

Period	FOGCAT I		FOGCAT II	
	Skill Score Difference (Regression Equation - Climatology)	Threat Score Difference (Regression Equation - Climatology)	Skill Score Difference (Regression Equation - Climatology)	Threat Score Difference (Regression Equation - Climatology)
June 76 & 77	.107	.072	.082	.063
July 76 & 77	.081	.044	.076	.039
July 76 & 77 with persistence	.086	.032	.074	.033
August 76 & 77	.257	.159	.266	.160

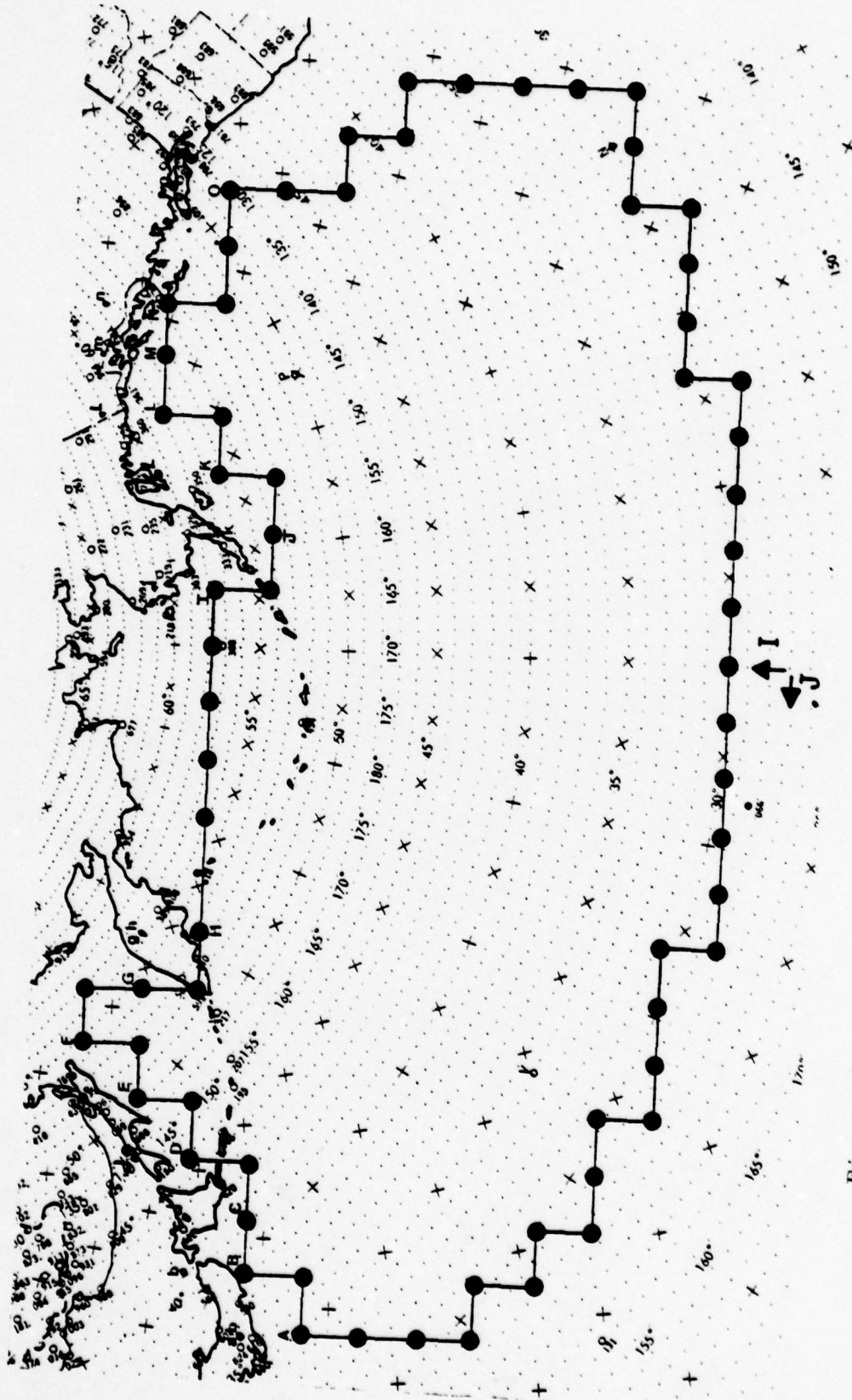


Figure 1. Study area on polar stereographic projection.

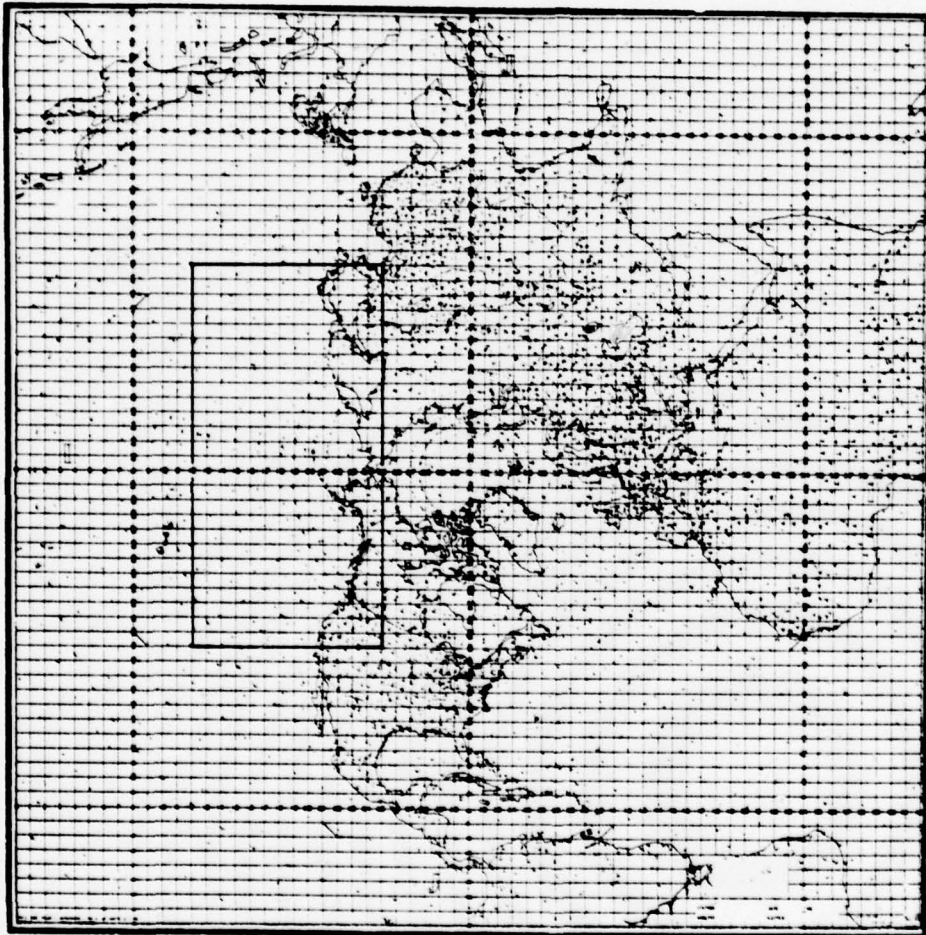


Figure 2. Fleet Numerical Weather Central's 63x63 grid, with outline of North Pacific Ocean rectangular grid area used in study. See text.

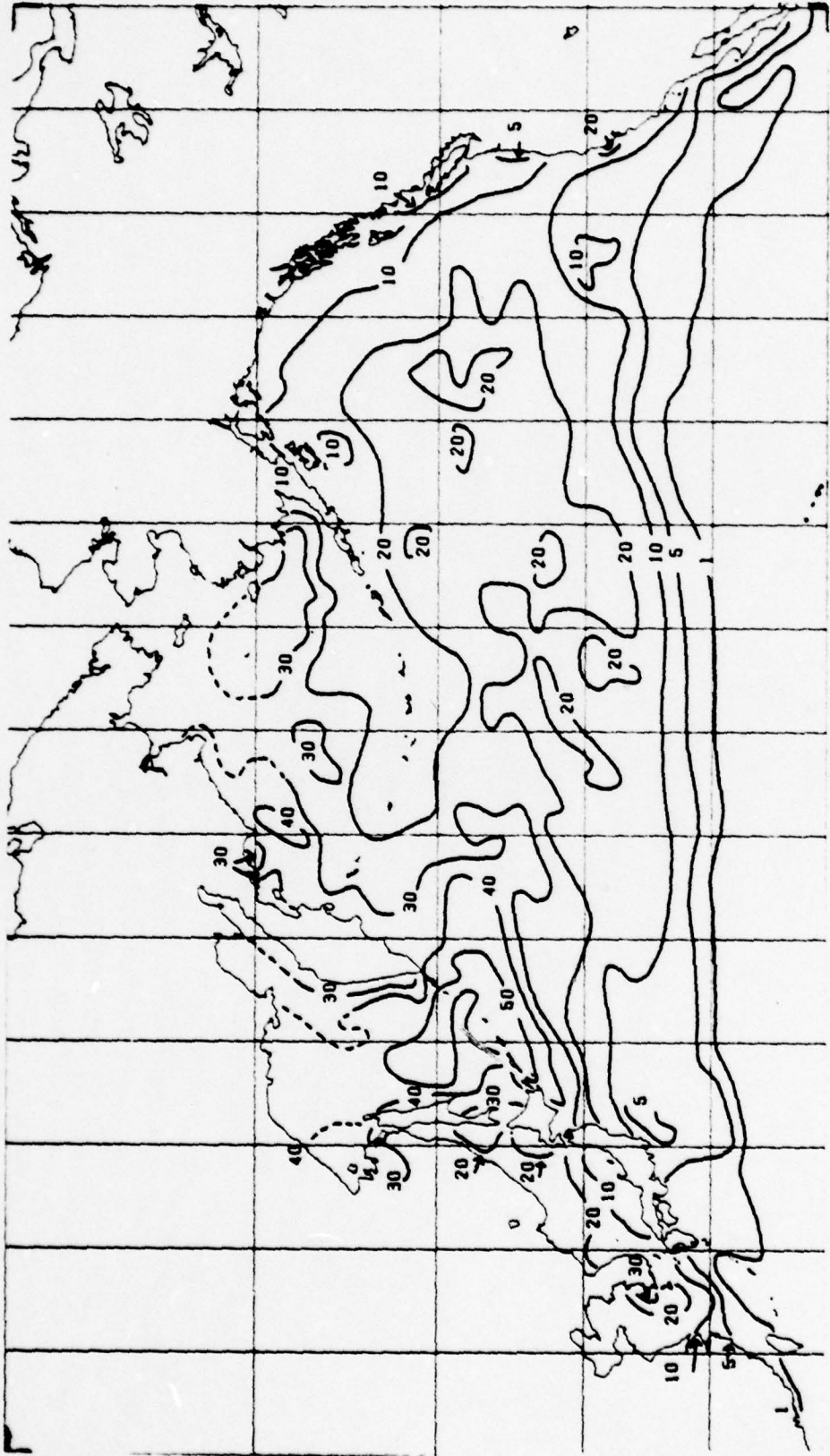


Figure 3. Percent frequency of occurrence of fog in any form - June (Guttman, 1978).

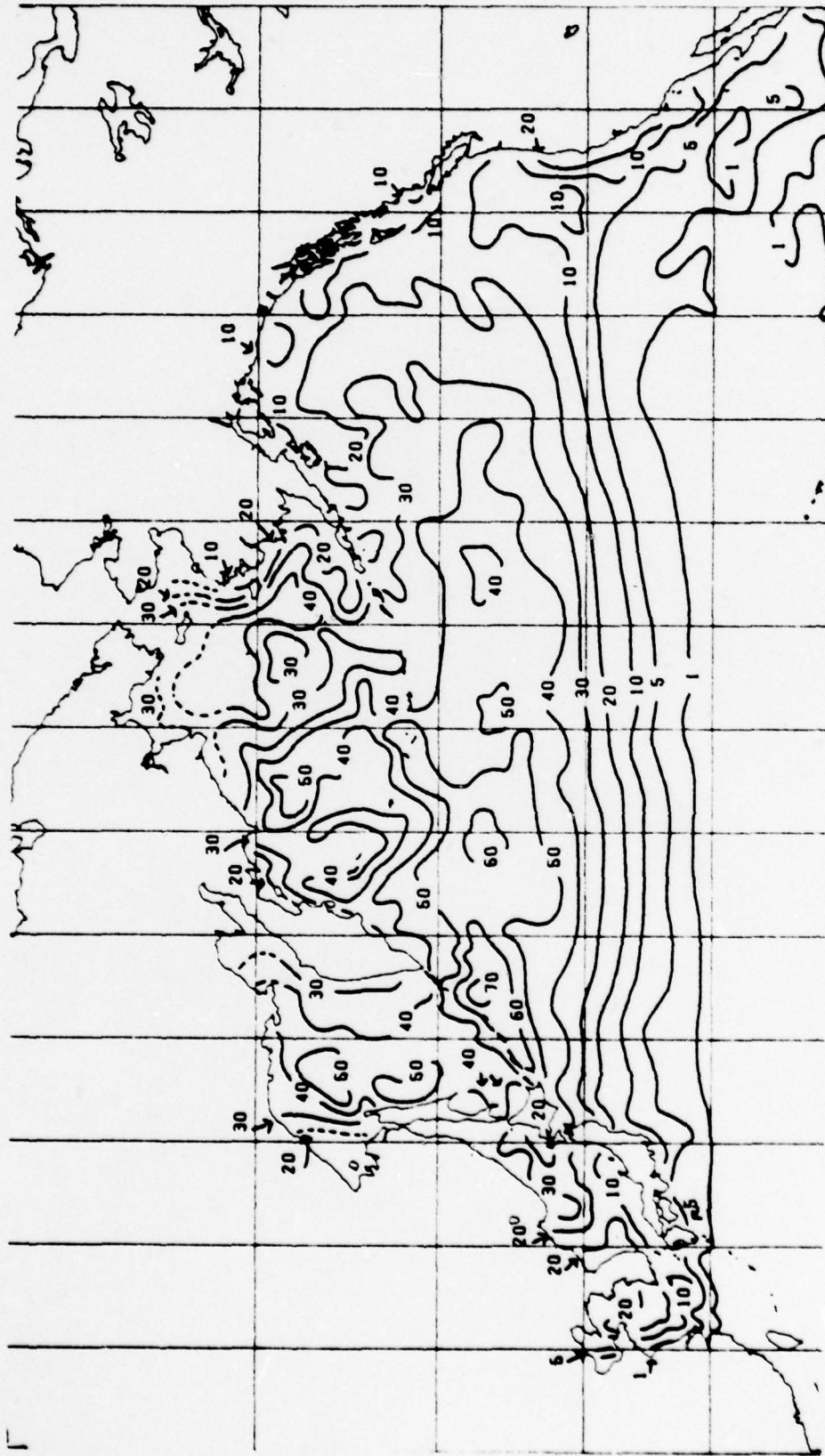


Figure 4. Percent frequency of occurrence of fog in any form -
July (Guttman, 1978).

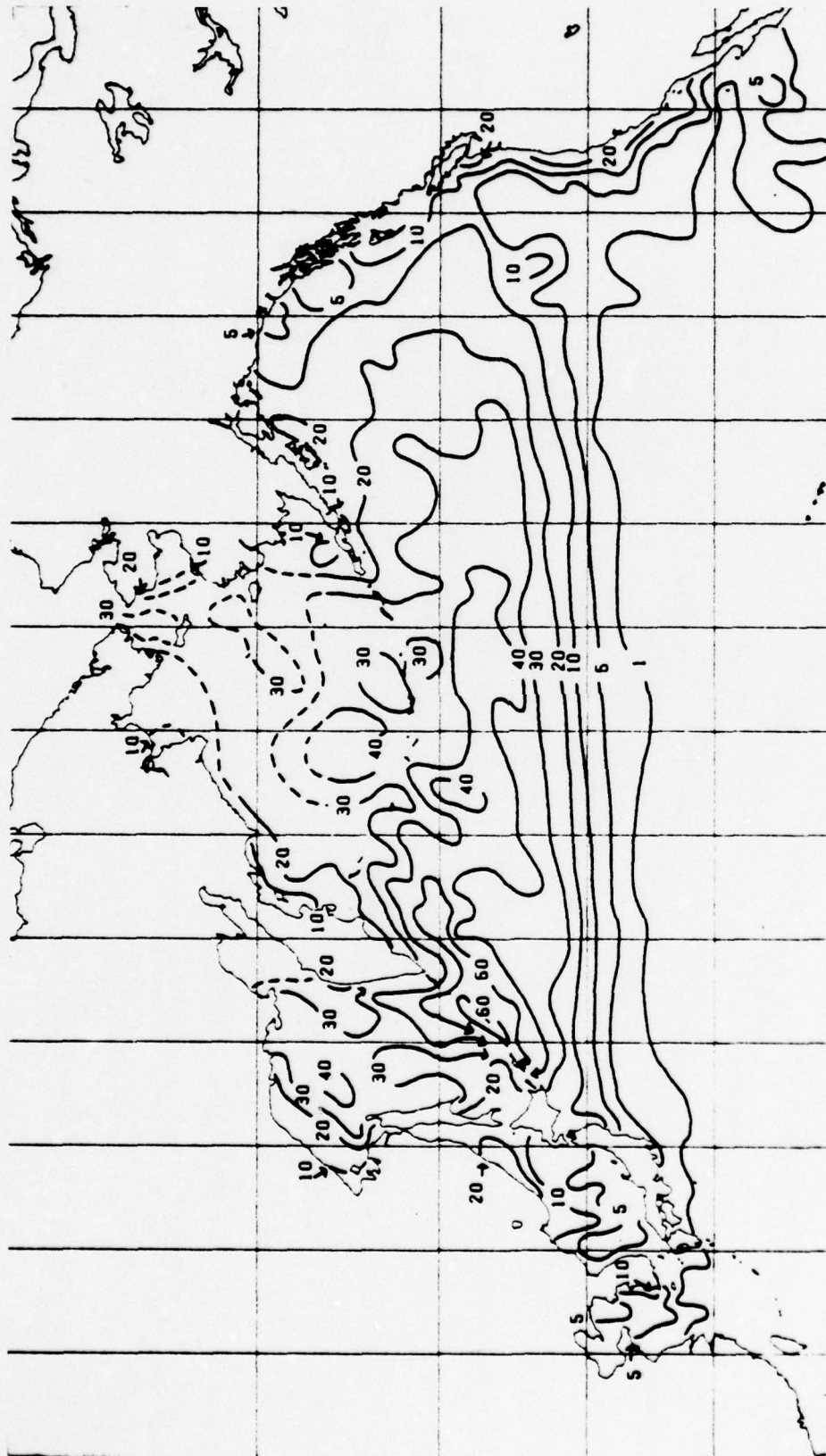


Figure 5. Percent frequency of occurrence of fog in any form - August (Guttman, 1978).

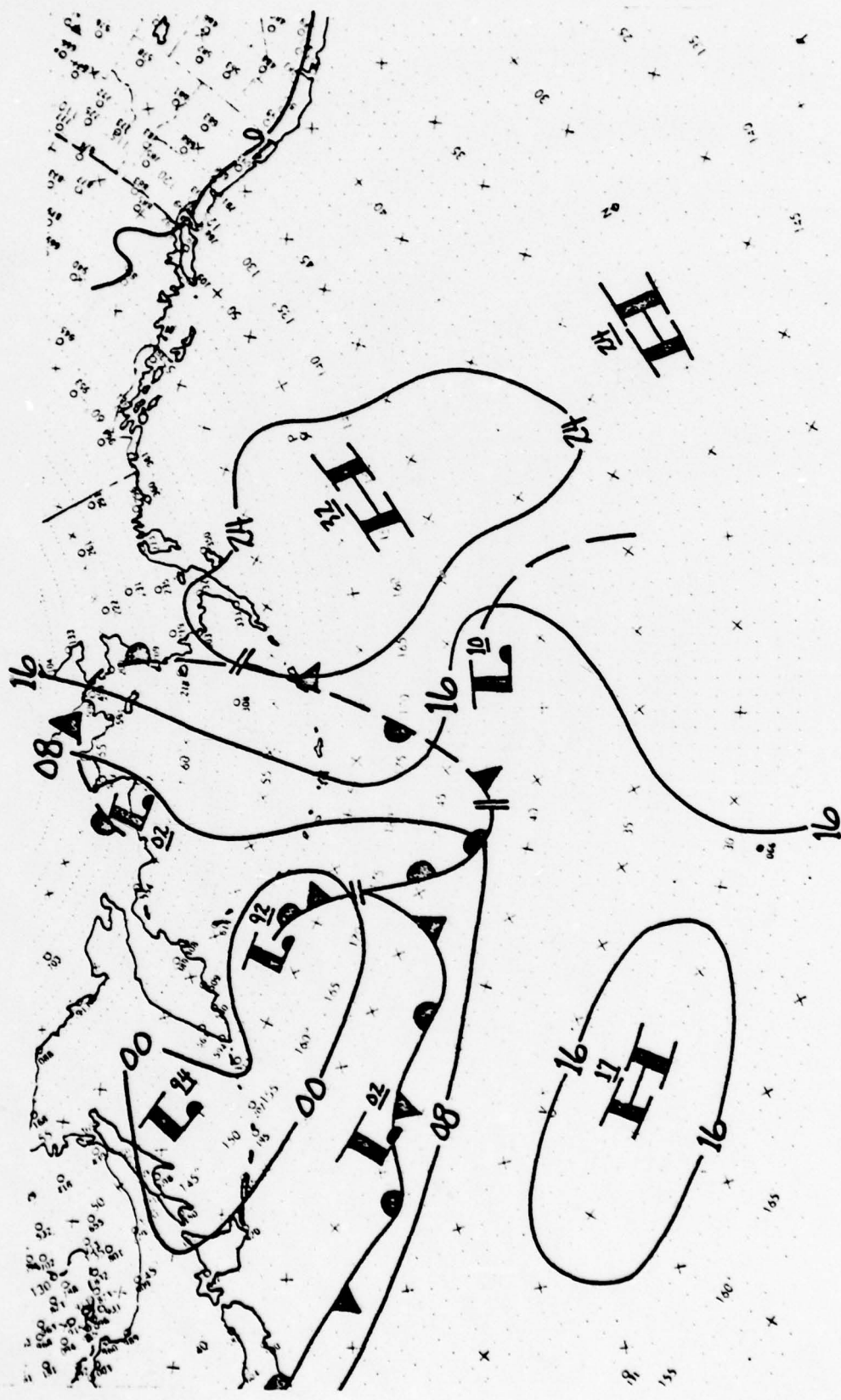


Figure 6. National Meteorological Center's Sea-Level Pressure Analysis, 0000 GMT, 3 August 1976, North Pacific Ocean.

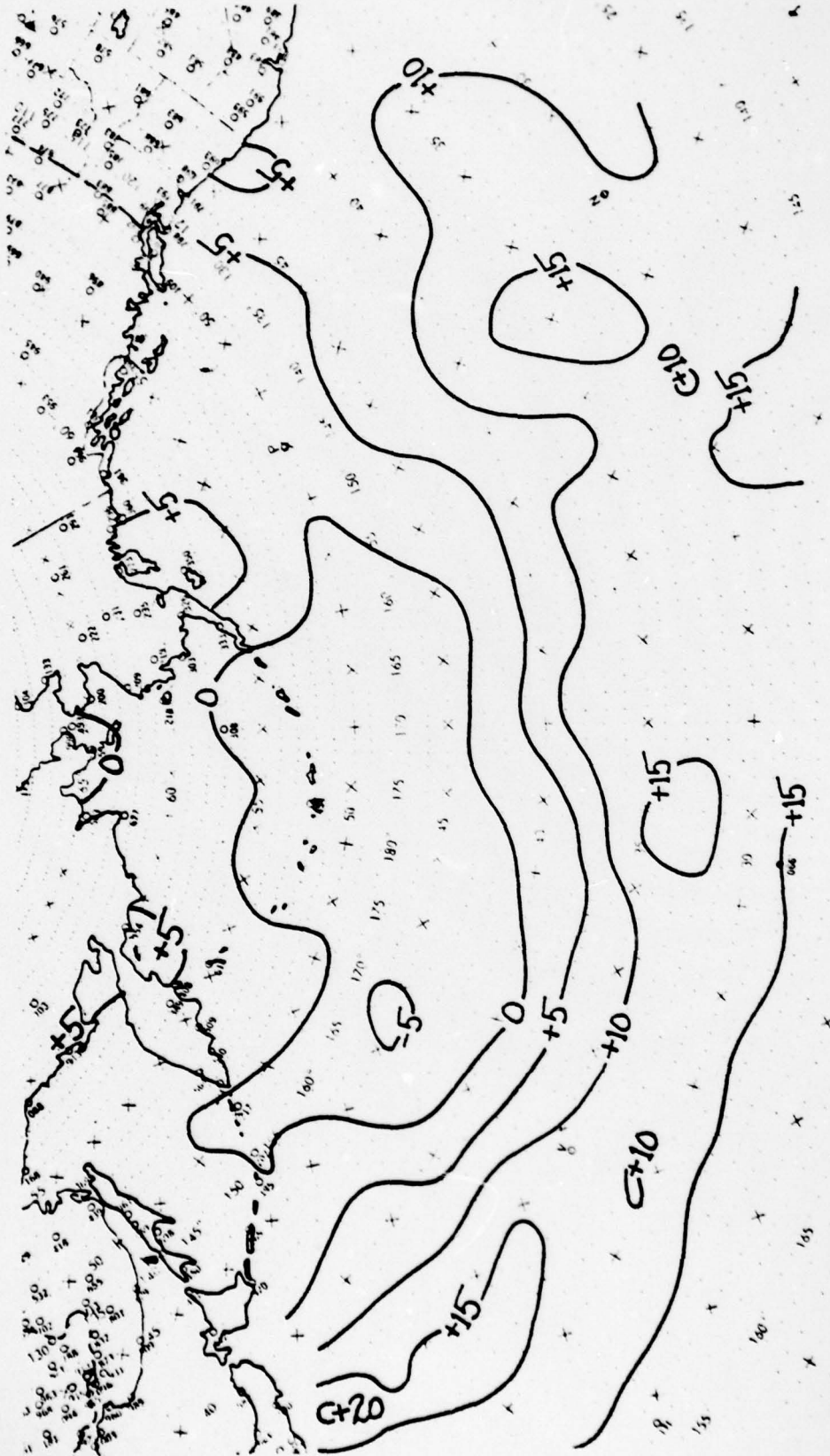


Figure 7. FNC's Evaporative Heat Flux, EHF, 0000 GMT 3 August 1976, North Pacific Ocean.

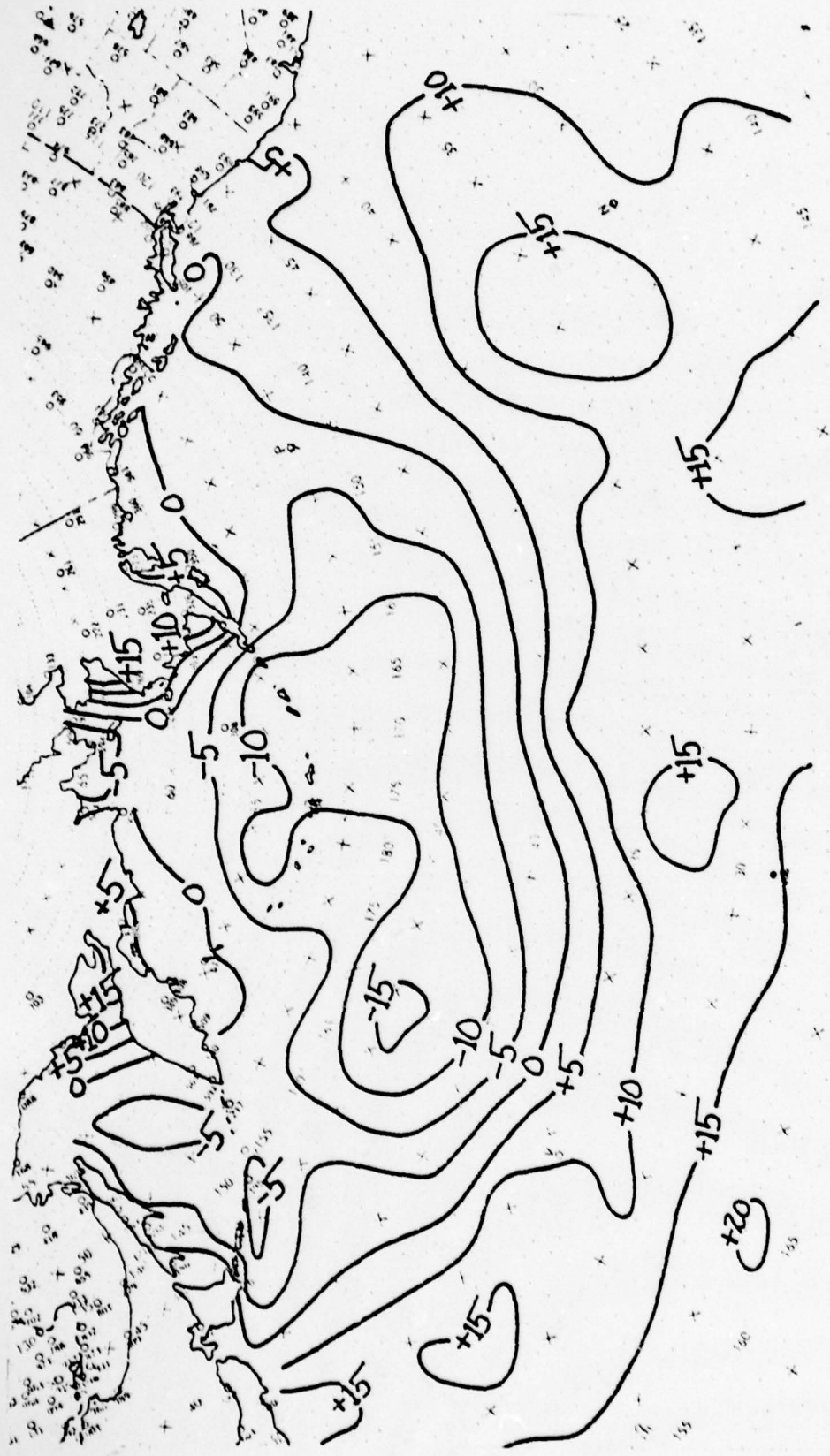


Figure 8. FNC's Sensible/Evaporative Heat Flux, SEHF, 0000 GMT 3 August 1976, North Pacific Ocean.

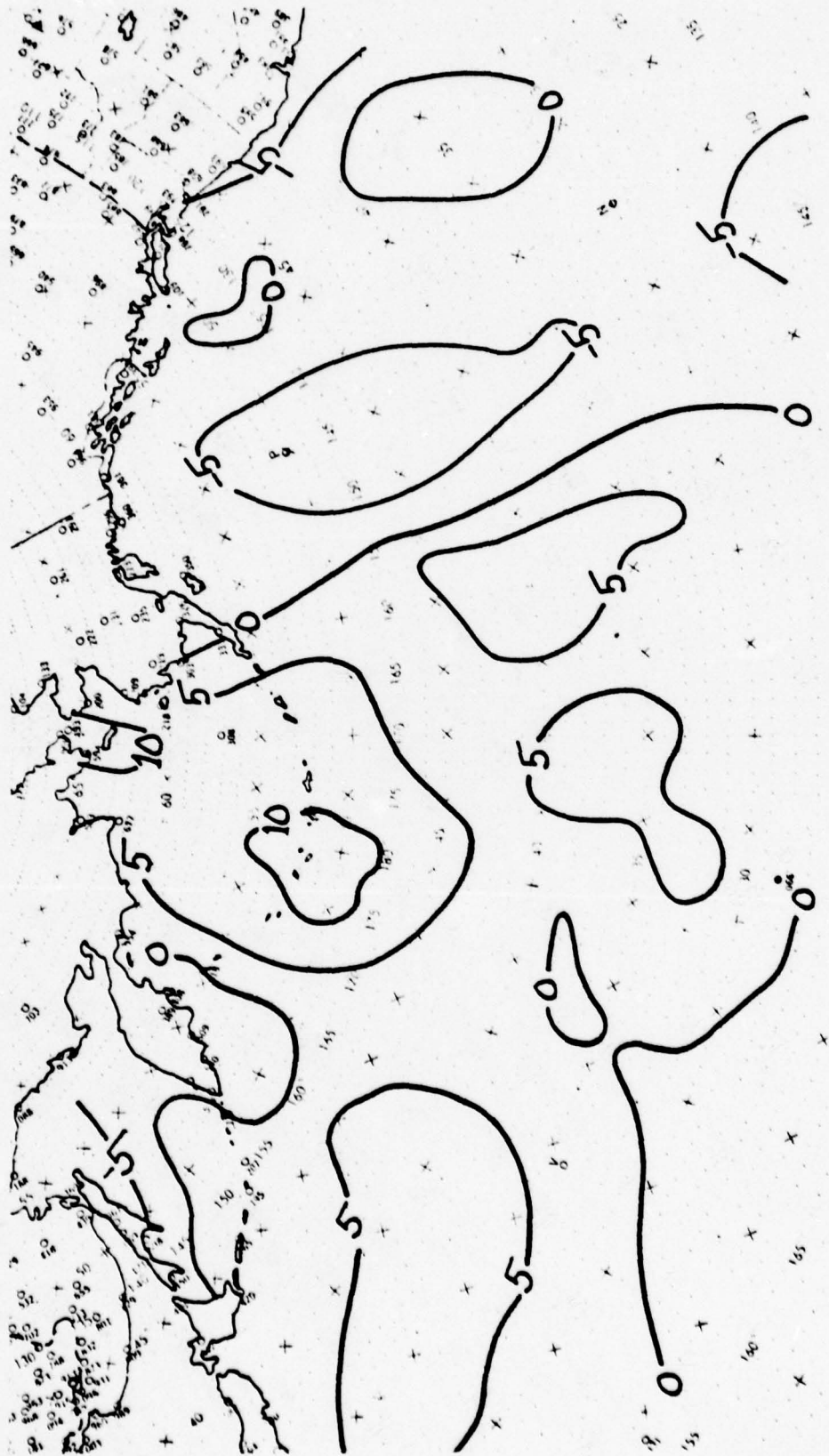


Figure 9. FNWC's (derived) Meridional Wind Component, v, 0000 GMT 3 August 1976, North Pacific Ocean.

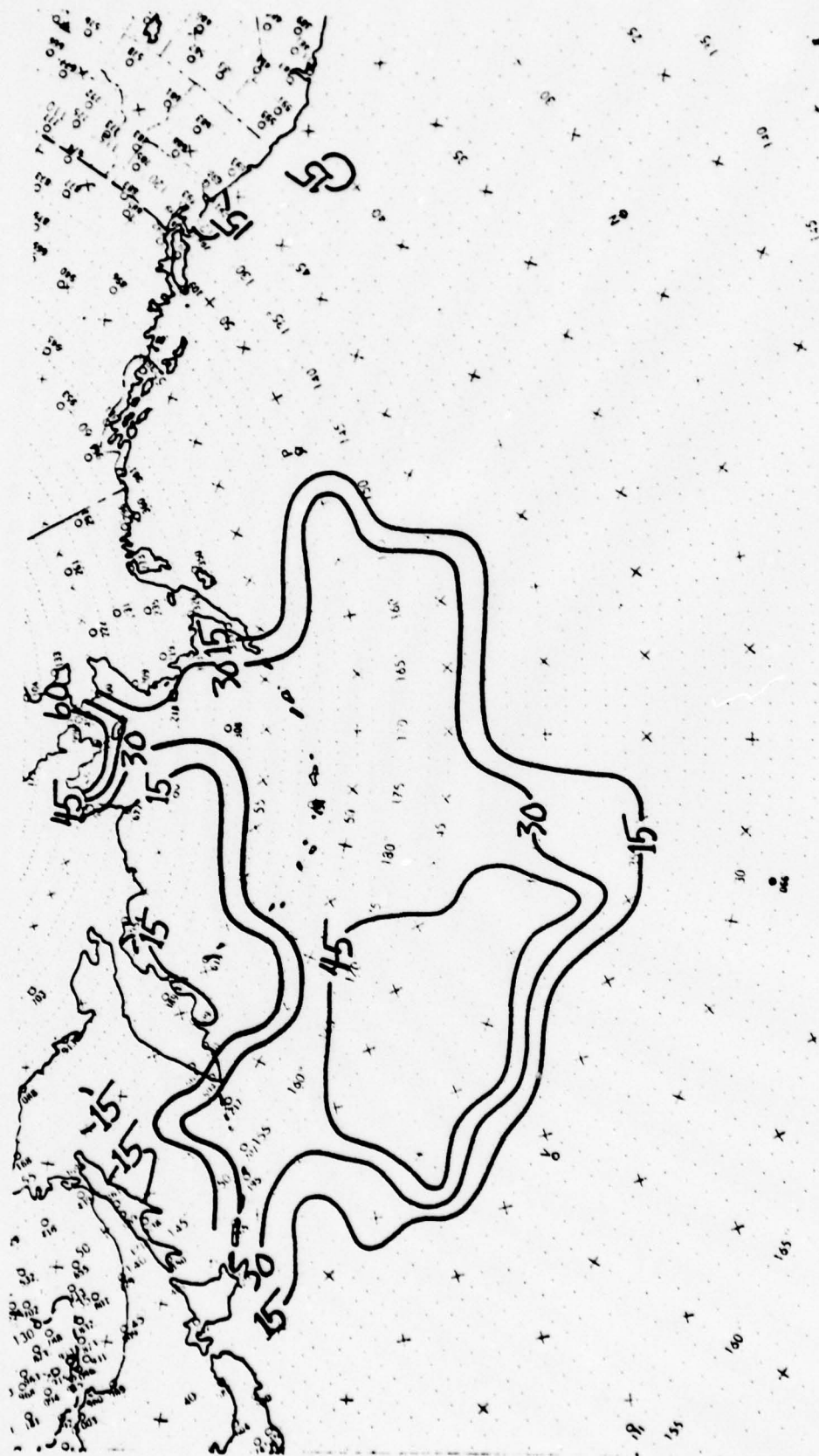


Figure 10. FNC's Advective Fog Probability FTER, 0000 GMT 3 August 1976, North Pacific Ocean.

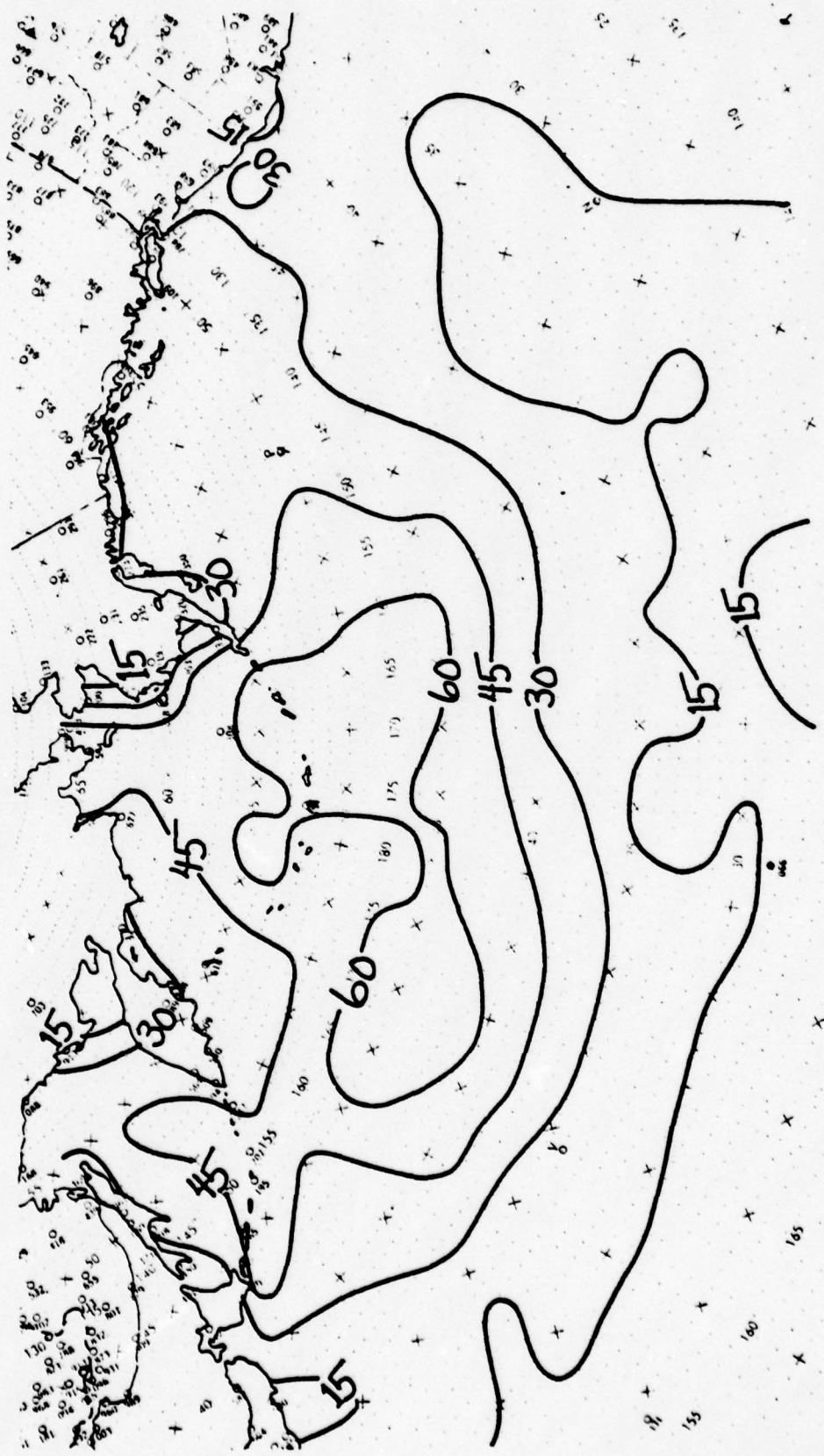


Figure 11. Fog Probability from NPS Regression Equation Derived from August 1976 and 1977 Data, FOGCAT I (Probability 38.781-1.859 SEHF + 1.059 v-0.708 CAPU), 0000 GMT 3 August 1976, North Pacific Ocean.

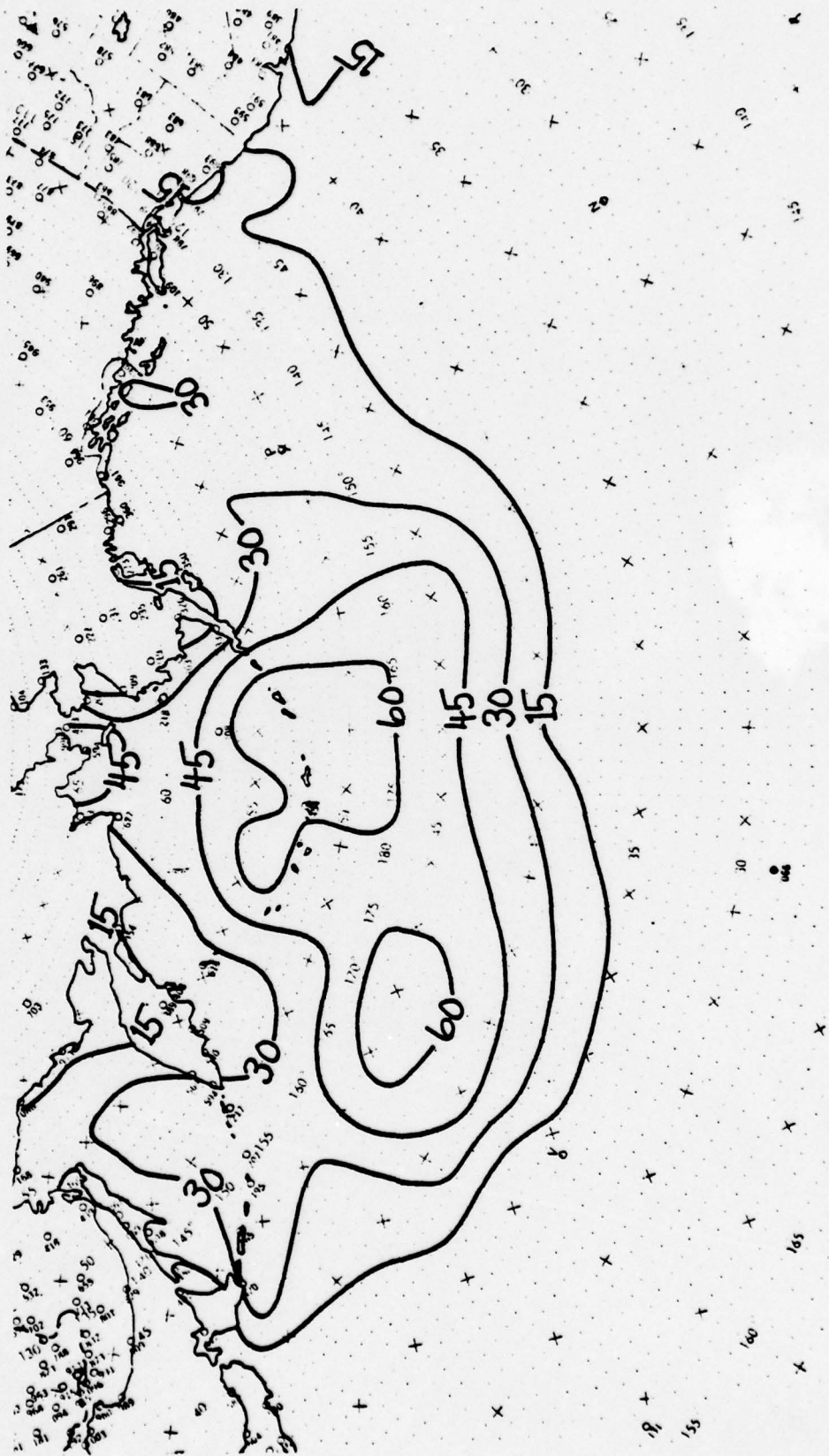


Figure 12. Fog Probability from NPS Regression Equation Derived from August 1976 and 1977 Data, FOGCAT II (Probability = $26.352 - 2.105 \text{ SEHF} + 0.727 \text{ v} - 0.067 (\text{v} \times \text{SEHF})$) 0000 GMT 3 August 1976, North Pacific Ocean.

APPENDIX A

LAND STATIONS USED IN STUDY
(U.S. Air Force, 1972)

Station Number	Latitude	Longitude	Surface Elevation (ft)
32174	45.2 N	147.9 E	38
32186	46.2 N	150.5 E	73
32195	46.9 N	151.9 E	26
32207	48.3 N	153.3 E	55
32213	50.9 N	156.7 E	42
32215*	50.7 N	156.2 E	unknown
32217	50.0 N	155.4 E	11
32559	53.1 N	160.0 E	88
32594	51.5 N	156.5 E	6
32618	54.9 N**	166.2 E**	19
70454	51.9 N	176.7 W	14

* Station not listed in reference. Lat/long values listed are as given with each synoptic report furnished by FNWC.

** Location given slightly removed from actual location of 55.2 N latitude, 166.0 E longitude to accommodate study area.

APPENDIX B
OUTPUT PARAMETER DESCRIPTIONS

Source Model

<u>Symbol</u>	<u>Name Description</u>	<u>Units</u>
<u>A. Analysis Parameters (FNWC's Mass Structure Model)</u>		
PS	Sea Level Pressure Analysis of observed sea level parameter.	(mb)
TAIR	Surface Air Temperature Analysis of observation-level air-temperature.	(°C)
EAIR	Surface Vapor Pressure Analysis of observation-level vapor pressure derived from the dew point.	(mb)
T925	925 mb Air Temperature Analysis of 925 mb air tempera- ture.	(°C)
TSEA	Sea Surface Temperature Once-daily analysis of observed sea-surface temperature.	(°C)
<u>B. P.E. Parameters (FNWC's Primitive Equation Model)</u>		
TX	Surface Air Temperature Derived from surface air and potential temperatures, boundary layer depth, upper-level winds extrapolated to surface, air density, drag coefficient, gusti- ness factor, and empirical con- stants.	(°C)
EX	Surface Vapor Pressure Derived from model's mixing ratio.	(mb)
SOLARAD	Solar Radiation Calculated absorption of incoming short-wave (solar) radiation (positive downward)	(gm-cal/ cm ² hr)

EHF	Evaporative Heat Flux Derived using air density, drag coefficient, extrapolated winds, and mixing ratios.	(gm-cal/ cm ² hr)
SEHF	Sensible Plus Evaporative Heat Flux SEHF = SHF + EHF	(gm-cal/ cm ² hr)
SHF	Sensible Heat Flux Recovered from SHF = SEHF - EHF. Originally derived by FNWC using drag coefficient, extrapolated winds, surface air temperature, TX, density, and constants.	(gm-cal/ cm ² hr)
THF	Total Heat Flux THF = SEHF - SOLARAD + LW, where LW is the heating due to long-wave (terrestrial) radiation.	(gm-cal/ cm ² hr)
C. <u>Marine Wind Model (FNWC)</u>		
VVWW	Marine Wind Speed	(knots)
DDWW	Marine Wind Direction Both variables derived from a dynamic balancing of surface wind and sea-level pressure.	(degrees/ 10)
D. <u>Spectral Ocean Wave Model (S.O.W.M.)(FNWC)</u>		
HW	Significant Wave Height	(feet)
PPW	Primary Wave Period	(sec)
PDW	Primary Wave Direction	(degrees/ 10)
SPW	Secondary Wave Period	(sec)
SDW	Secondary Wave Direction	(degrees/ 10)
WCP	Probability of White Caps	(percent)
E. <u>Other Model Output Parameters (FNWC)</u>		
SSTA	Sea Surface Temperature Anomaly Calculated anomaly of sea-surface temperature from the mean of the day as interpolated from the monthly mean values.	(°C)

F. Derived Parameters

u	Zonal Wind Component $u = -VVWW \sin(DDWW \cdot 10)$	(m/sec)
v	Meridional Wind Component $v = -VVWW \cos(DDWW \cdot 10)$	(m/sec)
CAPU	I Directional Wind Component $CAPU = -u \cdot \sin(LNGA) - v \cdot \cos(LNGA)$, (Haltiner, 1971).	(m/sec)
CAPV	J Directional Wind Component $CAPV = u \cdot \cos(LNGA) - v \cdot \sin(LNGA)$, (Haltiner, 1971), where $LNGA =$ $-10 - (I, J \text{ point longitude})$.	(m/sec)
THETAX	Potential Temperature X Derived using PS, TX.	(°K)
THETAR	Potential Temperature R Derived using PS, TAIR.	(°K)
STABX	Stability X Derived using $[THETAX - (THETA \text{ of } T925)]$ $/(PS-925)$. Value greater than zero indicates absolute instability.	(°K/mb)
STABR	Stability R Derived using $[THETAR - (THETA \text{ of } T925)]$ $/(PS-925)$. Same value effect as STABX.	(°K/mb)
ASTDX	Air-Sea Temperature Difference X $ASTDX = TX - TSEA$	(°C)
ASTDR	Air-Sea Temperature Difference R $ASTDR = TAIR - TSEA$.	(°C)
ADTSEA	Advection of TSEA Formulae and notes below.	(°C/ Hour)
ADTX	Advection of TX Formulae and notes below.	(°C/ Hour)
ADTAIR	Advection of TAIR. Formulae and notes below.	(°C/ Hour)
AASTDX	Advection of ASTDX Formulae and notes below.	(°C/ Hour)

AASTDR Advection of ASTDR ($^{\circ}\text{C}/$
Formulae and notes below. Hour)

G. Climatological Parameters

CLIMO National Climatic Center Fog (percent/
Frequency Climatology 100)

PERS Persistence of Fog Likelihood (percent/
100)

H. Interactive Parameters

CLISEHF CLIMO \cdot SEHF (% gm-cal/
100 cm^2hr)

CLIV CLIMO \cdot v (m %/
100 sec)

VSEHF v \cdot SEHF (100 gm-cal/
cm sec hr)

SEHFSQ SEHF \cdot SEHF (gm -cal /
 $\text{cm}^2 \text{hr}^2$)

CLIEHF CLIMO \cdot EHF (% gm-cal/
100 cm^2hr)

CLIADT CLIMO \cdot ADTAIR (% $^{\circ}\text{C}/$
100 hr)

EHFSQ EHF \cdot EHF (gm -cal /
 $\text{cm}^2 \text{hr}^2$)

EHFADT EHF \cdot ADTAIR (gm-cal $^{\circ}\text{C}/$
 $\text{cm}^2 \text{hr}^2$)

Advection Formulae and Conditions:

For the advection of a quantity (R) the formula, $\text{ADQ} = -\bar{V} \cdot \nabla(Q)$, was used in the following finite difference form:

$$\text{ADQ} = -\frac{\text{RMAP}}{\text{DM}} [\text{CAPU} \cdot (Q_{I+1} - Q_{I-1})_J + \text{CAPV} \cdot (Q_{J+1} - Q_{J-1})_I],$$

where $\text{RMAP} = (1 + \sin(60)) / (1 + \sin(\text{latitude}))$

and $\text{DM} = [(2) \cdot (6.37 \cdot 10^6) \cdot (1 + \sin(60))] / 31.205$

(31.205 = grid mesh lengths, pole to equator, on FNWC's I, J grid).

In the temperature advection calculation for point C, using

the five grid points illustrated below, one or two of the points, namely, A, B, D, or E, may be outside the study area. In the bogusing method suggested by Mr. Leo Clarke, FNWC, when a non-center point (e.g., point A) was judged to probably produce a land and/or dissimilar sea area influence on the resulting advection, the center point value (point C) was substituted for it. This "bogusing" is necessary to maintain a "purely" marine characteristic in the resultant parameter value.

The set of study area boundary grid points used for bogusing (and some double bogusing) are depicted in Fig. 1. The upper case letters denote the points whose values were used for bogusing. The lower case letters mark the positions of the adjacent points being bogused. The only boundary point close enough to land to give concern is the one near station number 32594 (south tip, Kamchatka Peninsula).

APPENDIX C

Abridged version of internationally used weather code figures and definitions for reporting present and past weather and low clouds in the surface synoptic report (U. S. Departments of Commerce, Defense, and Transportation, 1969).

Present Weather

<u>Code Value</u>	<u>Definition</u>
00-03	Characteristic change of the state of the sky (cloud) during the past hour.
04-09	Haze, dust, sand, or smoke.
10	Deep light fog.
11-12	Shallow heavy fog.
13-17	Lightning, thunder, or precipitation within sight, not reaching the ground.
18-19	Squall(s), funnel cloud(s) during the past hour.
20	Drizzle during the past hour.
21-23	Rain, snow, or rain and snow during the past hour.
24	Freezing drizzle during the past hour.
25-27	Shower(s) during the preceding hour.
28	Fog during the past hour.
29	Thunderstorm during the past hour.
30-39	Duststorm, sandstorm, drifting or blowing snow.
40	Fog at distance, but not at station, during the past hour (visibility less than 1 km).
41-49	Deep heavy fog at the time of observation (visibility less than 1 km).
50-59	Drizzle, or drizzle and rain.
60-63	Slight to moderate rain.
64-65	Heavy rain.
66	Slight freezing rain.
67	Moderate or heavy freezing rain.
68	Slight rain or drizzle and snow.
69	Moderate or heavy rain or drizzle and snow.

- 70-79 Solid precipitation not in showers.
- 80-99 Showery precipitation or precipitation with current or recent thunderstorms.

Past Weather

- 0 Cloud covering $\frac{1}{2}$ or less of sky throughout the period.
- 1 Cloud covering more than $\frac{1}{2}$ of sky during part of the period.
- 2 Cloud covering more than $\frac{1}{2}$ of sky throughout period.
- 3 Sandstorm, or duststorm, or blowing snow.
- 4 Heavy fog, thick haze, or smoke.
- 5 Drizzle
- 6 Rain
- 7 Snow, rain and snow.
- 8 Shower(s).
- 9 Thunderstorm, with or without precipitation.

Low Cloud Type

- 0 No low clouds.
- 1 Ragged cumulus of fair weather.
- 2 Generally towering cumulus.
- 3 Cumulonimbus without cirriform or anvil tops.
- 4 Stratocumulus formed by cumulus spreading out.
- 5 Stratocumulus not formed by cumulus spreading.
- 6 Stratus or fractostratus.
- 7 Fractostratus of bad weather.
- 8 Cumulus and stratocumulus, with bases at different levels.
- 9 Cumulonimbus with cirriform top.
- / Low cloud obscured.

Visibility

- 90 Less than 50 m
- 91 0-199 m
- 92 200-499 m
- 93 500 m - 0.99 km
- 94 1 - 1.99 km
- 95 2 - 3.99 km
- 96 4 - 9.99 km
- 97-99 equal to or greater than 10 km

APPENDIX D

FOGCAT I Categorization Scheme
(Van Orman and Renard, 1977)

1. Groupings and symbols used in FOGCAT I categorization scheme.

<u>Present Weather (ww)</u>		<u>Past Weather (W)</u>		<u>Low Cloud (CL)</u>	
Symbol	Associated ww Codes	Symbol	Associated W Codes	Symbol	Associated CL Codes
41G	41-49	4	4	6	6
10G	10,28,40	4,5	4,5	5,7	5,7
11G	11,12,20,24	5G	0,1,2,5	B	/
50G	50-59	2G	0,1,2	*	any CL not listed above
60G	60-63,66,68	*	any W not listed above		
*	any ww not listed above				

G = Group

B = Low clouds obscured

2. Scheme for categorizing observations according to likelihood of fog (FOGCAT I).

Major Category	Sub-Category	Present Weather (ww)	Past Weather (W)	Low Cloud Type (CL)
Strong Foggers = S	a1	41G	4,5	6
	a2	"	"	B
	b1	"	2G	6
	b2	"	"	B
	b3	10G	4,5	6
	b4	"	"	B
	c1	41G	*	6
	c2	"	4,5	5,7
	c3	"	"	*
	c4	10G	2G	6
Foggers = F	d1	41G	*	B
	d2	"	2G	5,7
	d3	50G	4	6
	d4	"	"	B
	d5	10G	*	6
	d6	"	2G	B
	d7	"	4	5,7

	e1	41G	*	5,7
	e2	"	2G	*
	e3	50G	4	5,7
	e4	10G	*	B
	e5	"	4	*
	e6	11G	4	6
	e7	"	"	B
	f1	41G	*	*
	f2	50G	4	*
	f3	10G	5G	5,7
	f4	11G	"	6
	f5	"	"	B
	g1	10G	*	5,7
	g2	"	5G	*
	g3	11G	*	6
	g4	"	4	5,7
	g5	"	"	*
	h1	"	*	B
	h2	"	5G	5,7
	i1	10G	*	*
	i2	11G	*	5,7
	j1	"	5G	*
Past/Weak Foggers = P	k1	50G	5G	6
	k2	60G	4	6
	l1	"	"	B
	l2	*	"	6
	m1	50G	*	6
	m2	*	4	B
	n1	*	5G	6
	o1	60G	4	5,7
	o2	*	4	5,7
	p1	60G	4	*
	p2	*	*	6
	p3	*	4	*
Maybe Foggers = M	q1	50G	5G	B
	q2	"	"	5,7
	q3	"	*	5,7
	q4	"	5G	*
	q5	11G	*	*
	q6	60G	5G	6
	q7	"	*	6
	r1	50G	*	B
	r2	"	*	*
	r3	60G	5G	B
	r4	"	"	5,7
	r5	"	*	B
	r6	"	*	5,7

Non-	u1	60G	5G	*
Foggers	u2	"	*	*
= N	v1	*	5G	B
	w1	*	*	B
	x1	*	*	5,7
	y1	*	5G	5,7
	y2	*	5G	*
	z1	*	*	*

3. Major fog categories and sub-category fog groups with associated Fog Probabilities as a function of visibility.

		<u>Visibility Code Values</u>			
		96-99 (Good)	94-95 (Fair)	90-93 (Poor)	Fog Probability
<u>Major Category</u>	<u>Subcategory Groups</u>				
			a	a	100.0
			b	b	96.6
	a	b	c	c	93.1
S	b	c	d	d	89.7
	c	d	e	e	86.2
	d	e	f	f	82.8
	e	f	g	g	79.3
	f	g	h	h	75.9
F	g	h	i	i	72.4
	h	i	j	j	69.0
	i	j	k	k	65.5
	j	k	l	l	62.1
	k	l	m	m	58.6
	l	m	n	n	55.2
	m	n	o	o	51.7
P	n	o	p	p	48.3
	o	p	q	q	44.8
	p	q	r	r	41.4
	q	r	s	s	37.9
M	r	s	t	t	34.5
not	s	t	u	u	31.0
used	t	u	v	v	27.6
	u	v	w	w	24.1
	v	w	x	x	20.7
	w	x	y	y	17.2
	x	y	z	z	13.8
N	y	z			10.3
	z				6.9
					3.4
					0.0

APPENDIX E

FOGCAT II Categorization Scheme (Quinn, 1978)

Present Weather (ww)	Past Weather (W)	Visibility (VIS)	Fog Probability (%)
0-9	-	-	0
10-12	-	-	100
13-19	-	-	0
20	0-3,6-9	-	0
20	4,5	90-95	35
20	4,5	96-99	0
21-24	0-3,6-9	-	15
21-24	4,5	90-95	60
21-24	4,5	96-99	15
25-27	0-3,6-9	-	0
25-27	4,5	90-95	10
25-27	4,5	96-99	0
28	-	-	100
29-39	-	-	0
40-49	-	-	100
50-59	0-3,6-9	-	35
50-59	4,5	90-95	85
50-59	4,5	96-99	35
60-69	0-3,6-9	-	15
60-69	4,5	90-95	60
60-69	4,5	96-99	15
70-79	-	-	0
80-89	0-3,6-9	-	0
80-89	4,5	90-95	10
80-89	4,5	96-99	0
90-99	-	-	0

Dash indicates that the particular category was not considered in the assignment of a fog probability.

APPENDIX F

Verification Score Formulae (Quinn, 1978)

		EVENT ESTIMATED		
		YES	NO	
EVENT OBSERVED	YES	A	C	Total (T) = A+B+C+D
	NO	B	D	No. of Correct Forecast FC = A+D

Heidke Skill Score = $\frac{FC - EX}{T - EX}$ Range: $\frac{-2BC}{B^2 + C^2} \leq HSS \leq 1$

where $EX = \frac{(A+B)(A+C) + (D+B)(D+C)}{T}$, No. of expected correct forecasts due to chance.

Threat Score = $\frac{A}{T-D} = \frac{A}{A+B+C}$ Range: $0 \leq TS \leq 1$

Both scores indicate more skill with larger positive values.

The Probability Score (PS) is from that given by Panofsky and Brier (1958) and may be written as (Renard, 1975):

P-Score = $\frac{2}{N} \left[\sum_{i=1}^{n_0} p_i^2 + \sum_{j=1}^{n_1} (1-p_j)^2 \right]$ Range: $0 \leq PS \leq 2$

where

N = Total number of cases

n_0 = Total number of non-events

p_i = Associated probability value for the non-event

n_1 = Total number of events

p_j = Associated probability value for the event

The closer to zero, the greater the skill.

LIST OF REFERENCES

- Bermowitz, R. J., and Best, D. L., 1978: An Objective Method for Maximizing Threat Scores, National Weather Service, NOAA, U.S. Department of Commerce, Silver Spring, Maryland, 11 pp.
- Glahn, H. R., and Lowry, D. A., 1972: The Use of Model Output Statistics (MOS) in Objective Weather Forecasting. J. Appl. Meteor., 11, 1203-1211.
- Guttman, N. B., 1978: Study of Worldwide Occurrence of Fog, Thunderstorms, Supercooled Low Clouds, and Freezing Temperatures, NAVAIR 50-1C-60-CH1, National Climatic Center, EDS, NOAA, Asheville, North Carolina, (for Director of Naval Oceanography and Meteorology), 148 pp.
- Haltiner, G. J., 1971: Numerical Weather Prediction, J. Wiley & Sons, 13-17.
- Ihli, C. B., and Renard, R. J., 1977: The Use of DMSP and SMS-2 Digital Satellite Data for Identifying Marine Fog in the Eastern North Pacific Ocean Area, NPS Report 63Ih77031, Department of Meteorology, Naval Postgraduate School, Monterey, California, 99 pp.
- McNab, O. F., 1979: Analysis of Statistical Parameters Derived from Satellite Digital Data (July 1968 GOES-West) for Use in Diagnosing Marine Fog Areas. M.S. Thesis, Department of Meteorology, Naval Postgraduate School, Monterey, California, 68 pp.
- Miller, R. G., and Best, D. L., 1978: A Model for Converting Probability Forecasts to Categorical Forecasts, National Weather Service, NOAA, U.S. Department of Commerce, Silver Spring, Maryland, 10 pp.
- Nelson, T. S., 1972: Numerical-Statistical Prediction of Visibility at Sea. M.S. Thesis, Department of Meteorology, Naval Postgraduate School, Monterey, California, 36 pp.
- Panofsky, H. A., and Brier, G. W., 1958: Some Applications of Statistics to Meteorology, College of Earth and Mineral Sciences, The Pennsylvania State University, University Park, Pennsylvania, 224 pp.
- Quinn, P. F., 1978: Further Development of a Statistical Diagnostic Model of Marine Fog Using FNWC Model Output Parameters. M.S. Thesis, Department of Meteorology, Naval Postgraduate School, Monterey, California, 73 pp.

- Renard, R. J., 1975: A Coevaluation of FNWC's Fog Probability Forecasts and the NPS Marine-Fog Climatology for the Summer Fog Regime of the North Pacific Ocean, NPS Report 51Rd 75081B Naval Postgraduate School, Monterey, California, 25 pp.
- Renard, R. J., Englebretson, R. E., and Daughenbaugh, J. S., 1975: Climatological Marine-Fog Frequencies Derived from a Synthesis of the Visibility-Weather Group Elements of the Transient-Ship Synoptic Reports, NPS Report 51Rd 75041, Naval Postgraduate School, Monterey, California, 47 pp.
- Renard, R. J., 1976: The observation, analysis, forecasting and climatology of marine fog. WMO No. 454, The Applications of Marine Meteorology to the High Seas and Coastal Zone Development. World Met. Organization, Geneva, Switzerland, pp. 211-223.
- Schramm, W.G., 1966: Analysis and Prediction of Visibility at Sea. M.S. Thesis, Department of Meteorology, Naval Postgraduate School, Monterey, California, 54 pp.
- United States Air Force, 1972: Weather Communications (Data Acquisitions Catalog), AWSM 105-2, Volume II, Department of the Air Force, Headquarters Air Weather Service (MAC), Scott AFB, Illinois.
- U.S. Departments of Commerce, Defense, and Transportation, 1969: Federal Meteorological Handbook No. 2, Synoptic Code. (Also NAVAIR 50-1D-2), Superintendent of Documents, U.S. Government Printing Office, Washington, D.C.
- U.S. Naval Weather Service Command, 1975: U.S. Naval Weather Service Numerical Environmental Products Manual, NAVAIR 50-1G-522, Department of the Navy, Washington, D.C.
- University of California, 1975: BMDP Biomedical Computer Programs, W. J. Dixon, editor. Developed at Health Sciences Computing Facility, Department of Biomathematics, School of Medicine, University of California at Los Angeles, under NIH Special Research Sources Grant RR-3 (BMDP2R Program Revised Feb 1976; pp 491-540). University of California Press.
- Van Orman, B. L., 1977: Statistical Diagnostic Modeling of Marine Fog Using Model Output Parameters. M.S. Thesis, Department of Meteorology, Naval Postgraduate School, Monterey, California, 94 pp.

Wesolowsky, G. O., 1976: Multiple Regression and Analysis of Variance, J. Wiley & Sons, 43-80.

Wheeler, S. E., and Leipper, D. F., 1974: Marine Fog Impact on Naval Operations, NPS Report 58Wh74091, Department of Oceanography, Naval Postgraduate School, Monterey, California, 118 pp.

Willms, G. P., 1975: A Climatology of Marine-Fog Frequencies for the North Pacific Ocean Summer Fog Season. M.S. Thesis, Department of Meteorology, Naval Postgraduate School, Monterey, California, 59 pp.

INITIAL DISTRIBUTION LIST

	No. Copies
1. Defense Documentation Center Cameron Station Alexandria, Virginia 22314	2
2. Library, Code 0142 Naval Postgraduate School Monterey, California 93940	2
3. Department of Meteorology, Code 63 Naval Postgraduate School Monterey, California 93940	1
4. Dr. Robert J. Renard, Code 63Rd Department of Meteorology Naval Postgraduate School Monterey, California 93940	10
5. Captain Steve O. Ouzts 640 Robin Way N. Satellite Beach, Florida 32937	3
6. Air Force Institute of Technology (CIPF) Wright-Patterson Air Force Base, Ohio 45433	1
7. Air Weather Service (AWVAS/TF) Scott Air Force Base, Illinois 62225	1
8. Naval Air Systems Command ATTN: Cdr. K. Van Sickle (AIR-370) Washington, D.C. 20360	1
9. Mr. Leo Clarke Fleet Numerical Weather Central Monterey, California 93940	1
10. Commanding Officer Air Force Global Weather Central Offutt Air Force Base, Nebraska 68113	1
11. Commanding Officer Navy Environmental Prediction Research Facility Monterey, California 93940	1
12. Department of Oceanography, Code 68 Naval Postgraduate School Monterey, California 93940	1

13. Director, Naval Oceanography and Meteorology 1
National Space Technology Laboratories
Bay St. Louis, Mississippi 39520
14. Dr. H. R. Glahn 1
Director Technique Development Laboratory
National Weather Service
National Oceanic and Atmospheric Administration
Bldg. 8060, 13th Street
Silver Spring, Maryland 20910
15. Dr. Dale F. Leipper, Code 68Lr 1
Department of Oceanography
Naval Postgraduate School
Monterey, California 93940
16. Mr. Paul R. Lowe 1
Navy Environmental Prediction Research Facility
Monterey, California 93940
17. Mr. Roland Pilie 1
Calspan Corporation
Buffalo, New York 14221
18. Lt. Paul F. Quinn, USN 1
Naval Weather Service Facility
Box 68
FPO, Seattle, Washington 98762
19. Captain Brian L. Van Orman 1
2803 Victoria
Bellevue, Nebraska 68005
20. Air Weather Service 1
(AWVA/TF)
Scott AFB, Illinois 62225
21. Air Force Institute of Technology 1
CITF
Wright-Patterson AFB, Ohio 45433