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PORTFOLIO OF OPERATIONAL AND DEVELOPMENTAL MARINE METEOROLOGICAL AND OCEANOGRAPHIC PRODUCTS*

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ACRONYMS, ABBREVIATIONS AND SYMBOLS

AFOS	Automation of Field Operations and Services
AKFAX	AlasKa FAcsimile circuit
ANL	Analysis
ASCE	American Society of Civil Engineers
AVG	AVeraGe
AVN	AViatioN run of the Global Spectral Atmospheric Model
AWIPS	Advanced Weather Information Processing System
A25	Dedicated communications circuit to Alaska
BIAS	statistical estimate of mean error
BMO	British Meteorological Office
C-MAN	Coastal-Marine Automated Network station
CSTL	CoaSTaL
D	date
dd	wind direction in 10s of degrees
DDS	Domestic Data Service
DEG	degrees
DIFAX	Digital FAcsimile
DIR	DIRection
DMSP	Defense Meteorological Satellite Program
ECOFS	East Coast Ocean Forecast System
EMC	Environmental Modeling Center
ERS1	European Research Satellite 1
F	Feet
FAX	FAcsimile circuit
Fig.	Figure
FCST(S)	forecast/forecasts
ff	wind speed in knots
ft/FT	feet
GAK	Gulf of AlasKa regional spectral wave model
GDAS	Global Data Assimilation System
GFDL	Geophysical Fluid Dynamics Laboratory
GMEX/GMX	Gulf of MEXico regional spectral wave model
GRIB	GRIdded Binary data format
GSAM	Global Spectral Atmospheric Model
h/H	hour/heavy
HFAX	Hawaii FAcsimile circuit
hPa	hecto Pascal
HR/HRS	HouR(S)
HT/HGT	HeiGhT
Hz	hertz
IC	superstructure ICing
km	kilometer

km	kilometer
kt/K/KTS	knot/knots
L	Light
LAT	latitude
LFM	Limited-area Fine-mesh Model
LON	longitude
m	meters
M	Moderate
MCSST	Multi-Channel Sea Surface Temperature
MOS	Model Output Statistics
MPC	Marine Prediction Center
MPP	Modified Perfect Prognosis
MRF	Medium Range Forecast run of the Global Spectral Atmospheric Model
MSW	Maximum Significant Wave Height
MVM	Marine Verification Matrix
N	North
N/A	Not Applicable
NCEP	National Centers for Environmental Prediction
NDBC	National Data Buoy Center
NDS	Numerical Distribution Service of the Family of Services
NE	Northeast
NGM	Nested Grid Model
NIC	National Ice Center
NM	nautical mile/miles
n mi	nautical mile/miles
NMVP	National Marine Verification Program
No.	Number
NOAA	National Oceanic and Atmospheric Administration
NODC	National Oceanographic Data Center
NOW	NOAA Ocean Wave
NP	North Pole
NTIS	National Technical Information Service
NWS	National Weather Service
OCN	OCeaN
OMB	Ocean Modelling Branch
pp.	pages
RAFS	Regional Analysis and Forecast System
RMS	Root Mean Square Error
S	South
s/secs	seconds
SC	Southern California
SCA	Small Craft Advisory
sfc/SFC	surface

SIG	SIGnificant
SJFAX	San Juan FAcsimile circuit
SP	South Pole
SSM/I	Special Sensor Microwave/Imager
SWAMP	Sea Wave Modelling Project
SWH	significant wave height
TOPEX	TOPography EXperiment
TPC	Tropical Prediction Center
UK	United Kingdom
U.S.	United States
UTC	Universal Time Coordinates
VT	Verifying Time
W	West
WAM	WAve Model
WAMDI	WAve Model Development and Implementation
WAV	WAVe
WMO	World Meteorological Organization
WND	WiND
WSFO	Weather Service Forecast Office
WV	WaVe
WVHT	WaVe HeighT
WX	Weather
°	degree(s)/latitude, longitude, temperature
%	percent

Portfolio of Operational and Developmental Marine Meteorological and Oceanographic Products

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ABSTRACT. *In this Technical Memorandum brief descriptions of the current operational and developmental marine meteorological and oceanographic products of the National Centers for Environmental Prediction are presented. Included is information on 1) marine meteorology, 2) ocean waves and wave modeling, 3) coastal ocean forecasting, 4) polar seas and Great Lakes ice modelling, and 5) the National Marine Verification Program.*

I. INTRODUCTION

The primary responsibilities of the Ocean Modeling Branch (OMB) of the Environmental Modeling Center (EMC) of the National Centers for Environmental Prediction (NCEP) are to:

- Prepare and disseminate operational marine guidance material to NOAA field forecast offices and the civil sector.
- Develop improved analysis techniques.
- Develop state-of-the-art numerical forecast model output products.
- Evaluate and improve the quality of the guidance products and develop new products to accommodate user needs.
- Provide special support for the quality control of remotely sensed measurements of winds and waves.

Since the primary function of OMB is to produce operational guidance products, the emphasis is on applied research and technology transfer whenever possible. Hence, a concerted effort is made to keep an active liaison with other NOAA and U.S. Navy operational centers, as well as with the research and academic communities. For convenience the activities dealing with the development and dissemination of products and the preparation of quality controlled data on winds and waves from satellite borne sensors for use in numerical prediction models are carried out in the following broad areas.

- Marine Meteorology
- Ocean Wave Dynamics and Modeling
- Coastal Ocean Forecasting
- Polar Seas and Great Lakes Ice Modeling
- National Marine Verification Program

This NOAA Technical Memorandum replaces the Compendium of Meteorological and Oceanographic Products first published in 1986 (Feit 1986) and in revised form in 1989 (Feit 1989). It provides a comprehensive information source, for the marine community at large, on the many products distributed operationally and experimentally or which are being developed under the *aegis* of the OMB. It contains technical background information, descriptions of the existing product portfolio (including experimental and future products), and information on the frequency and method of product dissemination. Since 1989 a sufficient number of new products have been introduced, existing products modified or terminated, and methods of product generation altered, to warrant a new Technical Memorandum at this time. In addition to these new and modified products, some validation statistics resulting from OMB's internal monitoring are also presented. Further, the National Meteorological Center has been reorganized into NCEP and the Ocean Products Center no longer exists. Some of the products are being taken over by the Marine Prediction Center (MPC). Some are transmitted directly to NWS field offices, while some have been terminated.

II. PRODUCT DESCRIPTIONS

A. Marine Meteorology

The NCEP runs three operational analysis and numerical weather prediction models which are available to provide marine information over the oceans twice a day at 0000 UTC and 1200 UTC. These models include: a global spectral forecast model; a regional nested grid model; and a newly implemented regional "ETA" model (Black *et al.* 1993). The NGM is a "frozen" model (Petersen *et al.* 1991); that is, it is run operationally, but no improvements are made to it; it is used primarily to make operational statistical "MOS" type forecasts. Although it has high-horizontal resolution (80 km), its lowest layer is too thick (35 hPa) to derive variables accurately at the ocean surface (10 m), so most marine applications have been made using the aviation run (AVN) of the Global Spectral Atmospheric Model (GSAM) (Kanamitsu *et al.* 1991) which provides surface fields at 100 km resolution, and at a height of about 45 m over the ocean. The "ETA" model (48 km resolution, with fields at 10 m above sea level) became operational in September 1995. It covers all of North America and large portions of the North Atlantic and North Pacific. This model is enhanced by a 29 km resolution meso-ETA model which primarily covers the contiguous United States and the water bodies off the east and west coasts and Gulf of Mexico coasts.

1. Ocean surface winds.

The wind is one of the most important variables at the sea surface. Since the AVN provides winds at a height of about 45 m over the surface, winds can be computed directly at the ocean surface (10 m) by using the theory of Monin and Obukhov (1954). It is assumed that the winds are in the constant flux layer, and that the vertical wind profile fits the well-known log-profile relation (for neutral surface stability). This method for deriving ocean surface winds was implemented by the OPC in May 1988 (Gemmill and Kidwell 1990) for use by ocean wave forecast models, and dissemination on AFOS (Figs. 7 and 8) and on FAX (Figs. 9 - 12). Figure 1 shows the RMS and BIAS for the analysis and forecasts from 24- through 72-h at 24-h intervals during the 1991-94 period.

2. Coastal and Great Lakes MPP Wind Forecasts

These forecasts are made from statistically derived equations for 99 locations near the coast of the conterminous United States and Alaska (Burroughs 1991a) and for 12 sectors on the Great Lakes. The forecast equations were developed based on the Modified

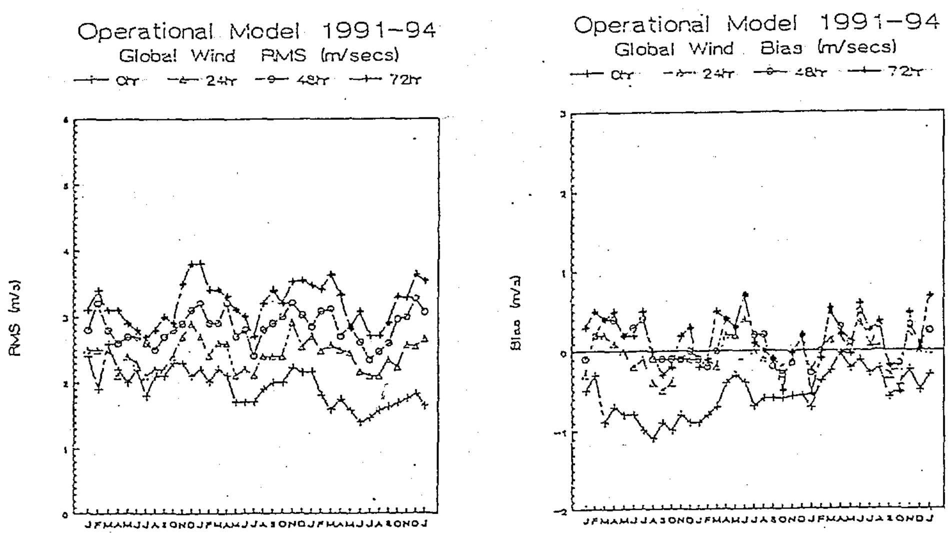

Figure 1. RMS and BIAS statistics for 10 m wind speeds over the ocean's surface comparing analyzed and forecast wind speed out to 72-h at 24-h intervals against fixed buoy wind speed observations.

Perfect Prognosis (MPP) technique. The approach uses LFM (Newell and Deaven, 1981) initialization and 6-h projection data as though they were perfect and relates them to the appropriate observed data. A set of equations was derived for each model cycle and for the warm (April - September) and cool (October - March) seasons. Regional Analysis and Forecast System (RAFS) (Petersen *et al.* 1991) output data are used with these equations to produce forecast guidance from 6- to 48-h at 6-h intervals. Figures 2 and 3 show the locations of the stations and the Great Lakes sectors, respectively.

The forecasts are disseminated twice daily over AFOS, DDS, and a special communications link to Alaska. Figure 13 shows a sample bulletin for the coastal winds along a portion of the east coast of the U.S. In each coastal bulletin the wind forecasts are presented at 6-h intervals from 6- to 48-h given for each station on one line. The wind forecast format is ddff where dd is the wind direction in tens of degrees and ff is the wind speed in knots. The bulletins for the Great Lakes locations are similar (see Fig. 14) except the dates are not included with the time headings for each projection column. For more information on forecast dissemination, see Burroughs (1991a) for the Coastal Wind Forecast System and Burroughs and Dallavalle (1995) for the Great Lakes Wind Forecast System.

3. Santa Ana Regime and Wind Forecasts

Apart from its importance as a hazardous condition over land, Santa Ana winds create a dangerous situation to boating in the southern California coastal waters and to shipping activities in the San Pedro and Santa Barbara channels. Hence the prediction of this event is a matter of great concern to marine interests in general. In 1985, forecasts of Santa Ana regimes and the associated winds at 5 stations near the coast of southern California were implemented operationally (Burroughs 1987). In 1991, the system was changed to use RAFS data rather than LFM data, and two stations were added and one removed to give a total of 6 stations (Burroughs 1991b). The regime forecasts are made from equations developed using discriminant analysis to relate the occurrence (or non-occurrence) of Santa Ana regimes to RAFS grid point data over the southwestern U.S. When a strong Santa Ana regime is predicted, wind forecasts are made from special MPP forecast equations which replace the routine MPP wind forecasts, Santa Ana regime forecasts are made only from October through May which is the normal season for Santa Anas. The bulletin is generated twice daily, and when it is not Santa Ana season, the regime forecasts are replaced with a message stating "NO SANTA ANAS ARE FORECAST." See Fig. 15.

4. Superstructure Icing

Among the hazards to ships operating at high latitudes is the accumulation of ice formed on exposed structural components of ships. This phenomenon, called

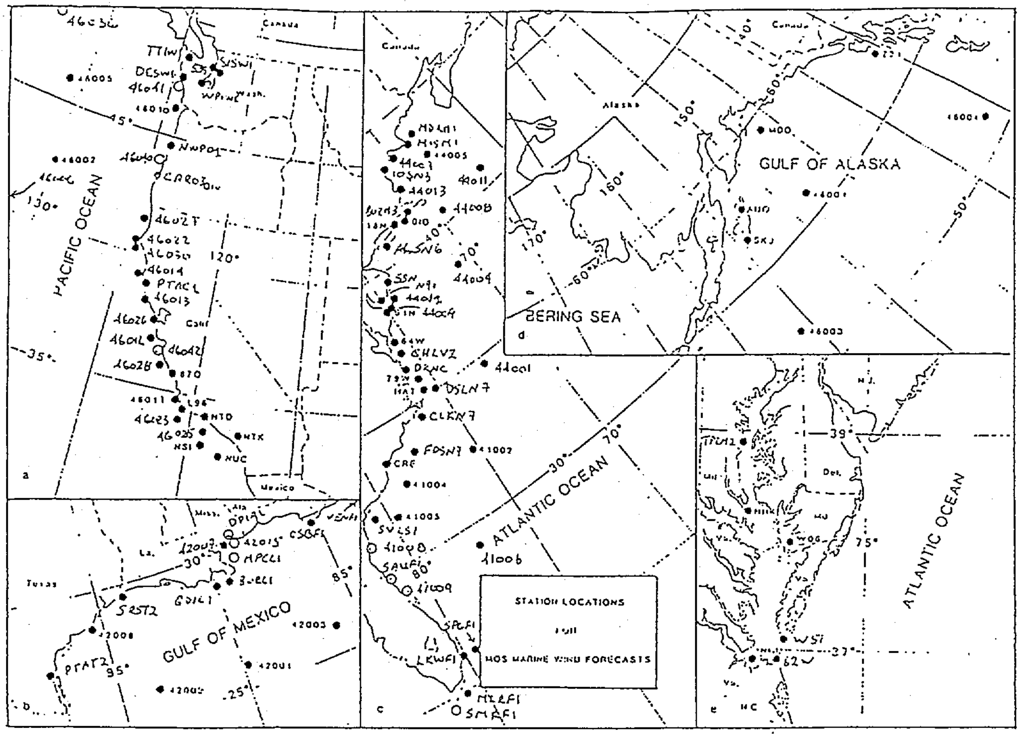

Figure 2. Coastal and offshore locations for MPP marine wind forecasts.

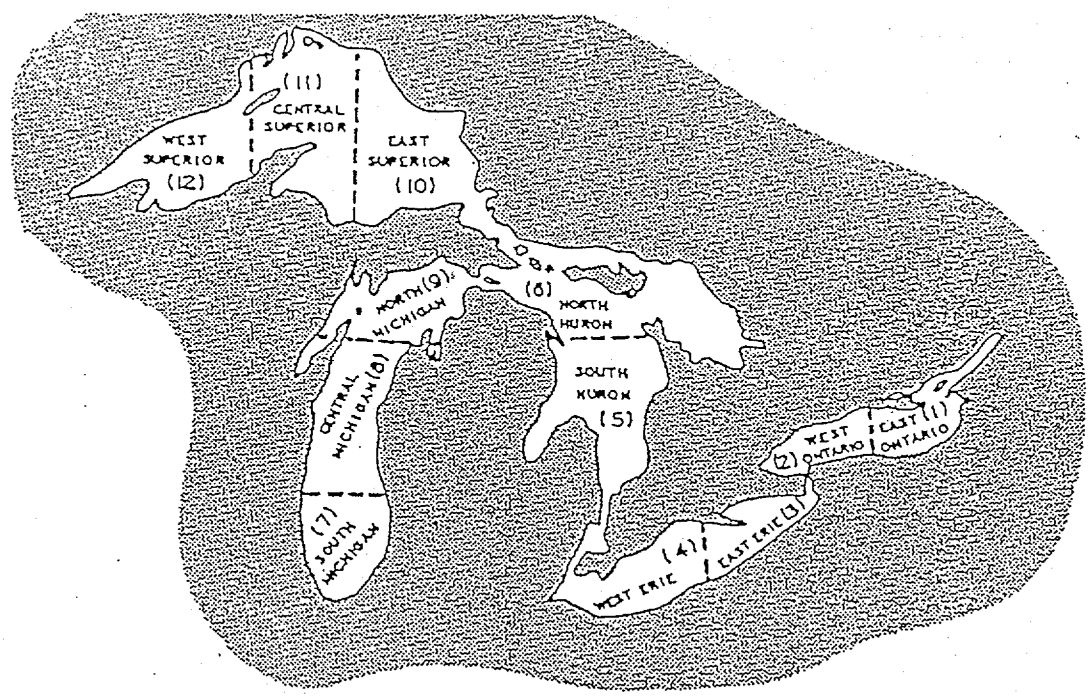

Figure 3. Locations of the 12 sectors for Great Lakes wind forecasts. Forecasts are positioned at the geographic center of each sector.

superstructure icing, is created by the conditions of sub-freezing air temperatures combined with strong winds and near freezing sea temperatures.

Over the years a number of efforts have been made to establish relationships between ice accretion on ships and meteorological and oceanographic parameters. Overland *et al.* (1986) used a robust statistical procedure to develop an algorithm which relates wind speeds, air temperature, sea temperature, and salinity to icing rates. This model was adapted at the NCEP in 1988 using the MRF run of the GSAM to supply the required fields of air temperatures and wind speeds (Feit 1987). The sea surface temperature used is obtained from the NCEP's AVN.

Calculation of the fields of ice accretion were extended to the entire Northern Hemisphere in the winter of 1988 and are displayed on the significant weather chart (see below), available on AFOS. Facsimile charts for Alaskan waters continue to be produced as before, but now use the new algorithm mentioned above. It is distributed on AKFAX; see Fig. 16.

5. Open Ocean Sea Fog

Fog is another weather element that is a hazard at sea, but it is not an intrinsic forecast parameter of either the GSAM or RAFS. It must be diagnosed from predicted moisture and air temperature fields. Tremant (1987) reported that 80 percent of accidents at sea occur with visibilities under one kilometer. WMO requirements specify that fog must be reported when visibility is less than 1 km. In 1989 a statistically based Open Ocean Fog and Visibility Forecast Guidance System was implemented (Burroughs 1989).

The "perfect prognosis" statistical technique was used to develop fog and visibility forecast equations, in the Northern Hemisphere, for the period April through September. Predictand data were obtained from ship observations and the predictor data were obtained from the NCEP's Global Data Assimilation System (GDAS). Fog was designated when fog of any kind was observed, drizzle was observed with visibilities of less than 1 km and past weather of fog, or light rain was observed with visibilities of less than 1 km and past weather of fog. Visibility was separated into 2 categories: less than or equal to 3 n mi and greater than 3 n mi. Discriminant Analysis techniques were used to derive the prediction equations.

These forecasts apply only to the high seas and not to coastal or in-shore areas due to a lack of predictand data. They are produced twice daily (0000 and 1200 UTC) out to 72 hours during April through October. The forecasts are incorporated into the Marine Significant Weather Chart (see below), and depict areas of visibility of 3 n mi or less and areas of fog.

6. Coastal Sea Fog

A Regional Numerical Fog Model has been developed by Alpert and Feit (1990) to predict fog in the coastal zone where the Open Ocean Fog and Visibility Guidance System is not valid as mentioned above. It was implemented for one region (the northeast coast of the U.S.) in March 1993 (Burroughs and Alpert 1993). Eventually regions along other coasts will also be implemented. The guidance from the model is available as a graphic on AFOS (see Fig. 17).

To simulate the formation of fog and stratus, time dependent changes of temperature, water vapor and liquid water content are predicted. The model consists of a variable horizontal region size and seven vertical layers between the earth's surface and a height of two km. Computations are based on standard finite difference techniques. Physical processes included in the fog model are eddy diffusion, horizontal advection, and fog droplet fallout. Horizontal velocity fields over the entire domain of integration and over the entire time of the forecast period are obtained from the AVN on both the 0000 and 1200 UTC cycles. The velocities are used to advect heat, moisture and liquid water. Moisture and air temperature values on the boundaries of the integration domain are prescribed as a function of time from the AVN model. Level 2 of the fog model (25 m) is used to determine visual ranges and fog conditions.

Liquid water content from the fog model is converted to visibility by an empirical formula which relates liquid water content to visual range. Visibility at sea ranges from 0 - 13 km (7 n mi - the maximum range to the horizon from the bridge of most ships). Fog is reported if the visibility is 1 km (0.5 n mi) or less. Fog production is damped in regions where it is known to be climatologically rare and when the liquid water content is great enough to produce larger droplet sizes with a consequent rise in visual range.

The fog model is designed to predict advection fogs and, therefore, will give the best results during the months of April through September when advection fogs are most prevalent. The model is run year around, and adjustments to the post-processor have been made to account for the over production of liquid water during the months of October through March.

There are four plots available on AFOS at 12-h intervals from 12- to 48-h on both the 0000 and 1200 UTC model cycles.

7. Marine Significant Weather Chart

The Marine Significant Weather Chart (see Fig. 18) depicts areas of weather hazards at sea and is distributed via AFOS (Feit 1988). The chart incorporates areas of high wind (greater than 25 kt), high seas (greater than 8 ft), ice accretion, fog and restricted visibility (less than 3 n mi), and ice edge. This chart is produced by a forecaster at the MPC using a manual intervention device and combines information from the appropriate NCEP guidance products. It is sent out once daily on the 0000 UTC cycle with projections from 24- to 48-h at 24-h intervals.

8. Satellite Ocean Surface Wind and Wave Products.

Until recently there was very little ocean surface wind or wave data, except for ships of opportunity, drifting and fixed buoys, and a few platforms. With the advent of real-time (delivered within 3-h of observation) satellite derived ocean surface wind and wave data sets (wind speed from two DSMP satellites, wind vectors from ERS1, and wave heights from ERS1) delivered to the NCEP, there is now a sufficient data base to cover substantial portions of the oceans. Over the next ten years this data base will continue to grow. The NCEP is now evaluating these data against fixed buoy platforms. Further, the NCEP is developing and improving their capabilities to process and use these data. These data will be available in real-time:

- For direct support to the MPC and TPC to improve subjective ocean surface pressure and wind analyses, and
- To data assimilation systems which generate analyses and initial conditions for numerical prediction models.

The NCEP will also be improving quality control procedures on the incoming data flow from the satellites, rederiving the wind data from the raw satellite parameters as needed, conducting experiments to improve the impact of the data on the models, and assimilating the data into global and regional operational models.

Currently, there are two types of satellite ocean surface wind data that are presently available to the NCEP in "real-time": wind speed data, nominally valid at a height of 20 m above the sea surface, from the DMSP-SSM/I sensor which covers a swath of 1500 km, at a horizontal resolution of 25 km; and wind vectors (direction and speed), valid at a height of 10 m above the sea surface, from the ERS1 scatterometer which covers a swath of 500 km, at a horizontal resolution of 50 km. In 1993 the NCEP started using the SSM/I wind speed data from the DSMP-10 satellite in the global data assimilation system (GDAS), as super-obs (within a 1° latitude/longitude box and ±3-h time window), and also by operational meteorologists of the MPC to improve subjective wind analyses over the oceans (Gemmill and Teboulle 1993). In May 1994, assimilation of SSM/I wind speed data from the DSMP-11 satellite also was initiated. The fast delivery ERS1 scatterometer wind data are not being used at present by the NCEP because the wind direction retrievals are often erroneous; but the raw data are being reprocessed to provide better wind vectors (Woiceshyn *et al.* 1993), have been tested in the GDAS, and will be implemented in the operational model during the last quarter of 1995. Table 1 shows a comparison of the satellite and ship data with NOAA fixed buoy data (within 0.5° radius, and ±3-h of observation time). Beginning in June 1995, the DSMP-13 replaced the DSMP-11.

Table 1. Data Comparisons with Buoys

Platform (Adjusted height)	Speed (m/s)		Direction (°)
	BIAS	RMS	RMS
SSM/I (20 m)	-0.1	2.2	N/A
ERS1 (10 m)	-1.0	2.0	66[1]
SHIPS (20 m)	+1.1	3.9	28

[1]fast delivery product

B. Waves

During the last five decades, wind wave forecasts have improved significantly from the empirical approaches based on Sverdrup and Munk (1947) and Bretschneider (1958) to the spectral approaches based on the radiative transport equation (*e.g.*, SWAMP Group, 1985). The NCEP has continuously made a systematic effort to test and develop models based on sound wave dynamics, prediction accuracy and computational efficiency and to employ them to produce operational forecasts. Currently, a deep water global model and two variable depth regional models (for the Gulf of Mexico and the Gulf of Alaska) are operational.

1. Global Spectral Wave Model (NOAA/WAM)

At present, the most advanced spectral wave models for research and forecasting are the third generation wave models of which the WAM (wave model) is an example (WAMDI Group, 1988). This model incorporates the most updated dynamics in wave generation, dissipation, and nonlinear energy transfer processes. The cycle 4 version of the WAM (hereafter referred to as the NOAA/WAM) has been adopted by the NCEP.

Global ocean wave forecasts are operationally generated at the NCEP using the above mentioned NOAA/WAM. Fields of directional frequency spectra in 12 directions and 25 frequencies are generated in 3-h intervals out to 72-h. The 12 directions begin at 0° to the north and have a directional resolution of 30°. The 25 frequencies begin at the lowest frequency of 0.042 Hz. Each frequency is separated by a logarithmic increment of 0.1 of the lowest frequency (Table 2).

Table 2. Wave Period and band width for the 25 frequencies of the NOAA/WAM.

T (s)	Δf (Hz)	T (s)	Δf (Hz)	T (s)	Δf (Hz)	T (s)	Δf (Hz)	T (s)	Δf (Hz)
23.94	0.0021	14.38	0.0064	9.23	0.0103	5.73	0.0166	3.56	0.0268
21.75	0.0044	13.51	0.0071	8.39	0.0114	5.21	0.0183	3.23	0.0295
19.76	0.0048	12.28	0.0078	7.63	0.0125	4.74	0.0201	2.94	0.0324
17.99	0.0053	11.17	0.0085	6.93	0.0138	4.30	0.0222	2.67	0.0357
16.35	0.0058	10.15	0.0094	6.30	0.0151	3.91	0.0244	2.43	0.0187

The spatial resolution in the model is 2.5° of latitude by 2.5° of longitude. The grid is defined from 67.5°S to 77.5°N with an auxiliary land/sea table to exclude calculation over land and water bodies, such as the Great Lakes, Mediterranean Sea, etc., which are of no interest in this global model. Lowest sigma layer winds from the AVN, adjusted to a height of 10 m by using a logarithmic profile (see subsection A.1 above), are used to drive the ocean surface waves. Input to the model are the analysis wind fields from the past 12 hours at 3-h intervals which are used to produce initial conditions for the wave fields through hindcasting, and the wind forecast fields out to 72-h also at 3-h intervals to make the wave forecasts. The model runs twice daily for the 0000 UTC and 1200 UTC forecast cycles.

Statistical evaluation of the significant wave heights calculated by this model shows a generally superior performance when compared to those from the NOW model (Chin 1985), the preceding second generation operational global model of the NCEP. Figure 4 shows the BIAS and RMS of each model for 24-, 48-, and 72-h forecasts, using wave measurements from National Data Buoy Center (NDBC) fixed buoys.

The wave forecasts from the global model are made available to the field forecast offices and other users in the following manner:

(a) 12-, 24-, 48-, 72-h projections of significant wave heights are individually displayed at the grid points on AFOS (see Fig. 19).

(b) Similarly, for each forecast period the mean direction of propagation of the wave spectrum is displayed at grid points (see Fig. 20,) as well as the mean period (eastern Pacific only) (see Fig. 21).

(c) At selected grid points on Atlantic and Pacific oceans near U.S. territory and Gulf of Mexico, a condensed matrix listing the forecast values of spectral energy densities as a function of frequency and direction are provided on AFOS (see Fig. 22). These values are presented for 12- through 60-h at 12-h intervals for all points except two Pacific points where values are at 6-h intervals from 0- through 48-h plus 60-h on the 0000 UTC cycle. On the 1200 UTC cycle values are from 0- through 24-h for the special Pacific points and 12- and 24-h for all other points. The locations in latitude and longitude are:

WSFO	Grid Point Positions					
Washington, D.C.	35.0 N	72.5 W	37.5 N	70.0 W	40.0 N	67.5 W
Miami, Florida	25.0 N	85.0 W				
San Francisco,	47.5 N	130.0 W	45.0 N	125.0 W	42.5 N	130.0 W
California	35.0 N	122.5 W	32.5 N	120.0 W	27.5 N	122.5 W

(d) Forecast products are also disseminated over several facsimile circuits on two charts for each forecast period. One chart displays the significant wave height values and winds at grid points (see Figs. 9 - 12). The second presents the mean wave directions and periods (see Figs. 23 - 26). Forecasts are for 12-, 24-, 48-, and 72-h for both cycles.

(e) Significant wave heights, mean wave periods and directions at all grid points are provided in GRIB code to NDS.

2. Regional Wave Models

Regional wave forecasting models are concerned with forecasting wave conditions over a limited area (less than global) which is characterized by unique environmental conditions (physiographic, meteorological, and oceanographic) such that a global scale wave model is unable to provide adequate wave information for that particular area. There are two regional models currently operational over the Gulf of Mexico and Gulf of Alaska. These are second generation spectral models primarily based on Golding (1985) in which nonlinear energy transfer is treated in a simple parameterized form.

a) Gulf of Mexico Regional Spectral Wave Model (GMEX)

GMEX (Chao 1991) is a second generation spectral wave model applicable for both deep and shallow water areas of the Gulf of Mexico. It solves a spectral energy balance equation involving wave growth by winds, refraction by bottom bathymetry, energy loss due to whitecapping and bottom friction, as well as parameterized wave-wave energy transfer. The essential governing equations and computational procedures follow the model described by Golding (1983). However, the numerical scheme for wave propagation, used in this model, is based on a two-step third order staggered grid scheme suggested by Takacs (1985).

The Gulf is assumed to be an enclosed basin extending from 98°W,18°N to 80°W, 31°N. The model develops estimates of directional frequency spectra in 12 directional bands (each 30° wide) and 20 frequency bands (from 0.04 to 0.42 Hz) on a 30 by 30 n mi grid. The model runs twice daily using winds at 10 m above the sea surface derived from 0000 UTC and 1200 UTC cycle runs of the AVN to generate wave field forecasts up to 48 hours. Figure 5 shows an example of statistical evaluations of GMEX performance with NDBC buoy measurements as the standard of reference. Measurements were obtained from Buoy 42001 located at about the middle of the Gulf.

Forecast significant wave heights and the prevailing wave directions (either of the wind-sea or swell) at selected grid points are issued twice per day for 00-, 12-, 24-, 36- and 48-h on AFOS and DIFAX for the 0000 UTC and 1200 UTC forecast cycles. The AFOS identifiers for these products are NMCGPH6TY, NMCGPH6UY, NMCGPH6VY, NMCGPH6WY and NMCGPH6ZY. The DIFAX numbers are D040C from the 0000 UTC

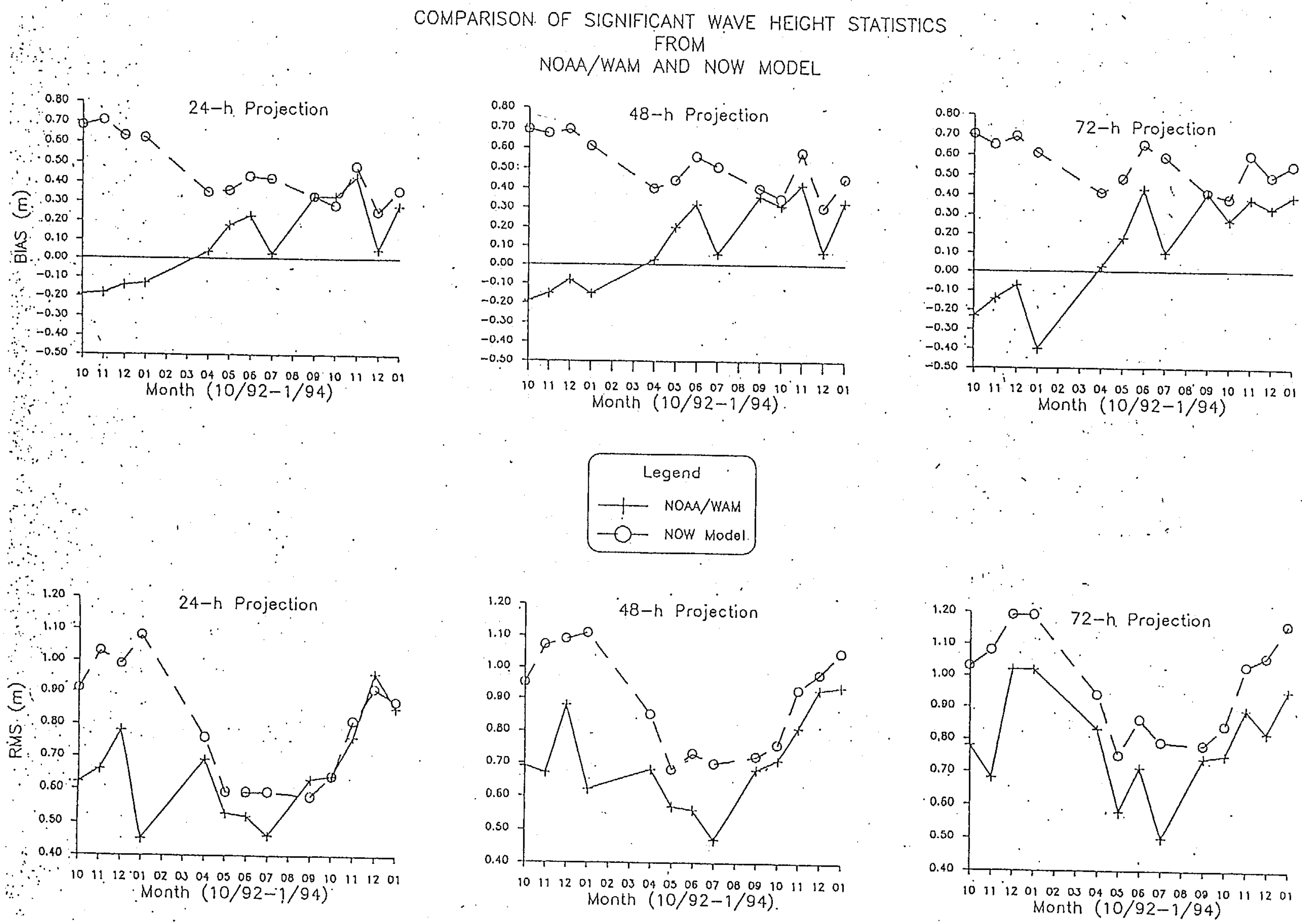

Figure 4. RMS and BIAS comparison statistics between the NOW and NOAA/WAM models for 24-, 48-, and 72-h forecasts.

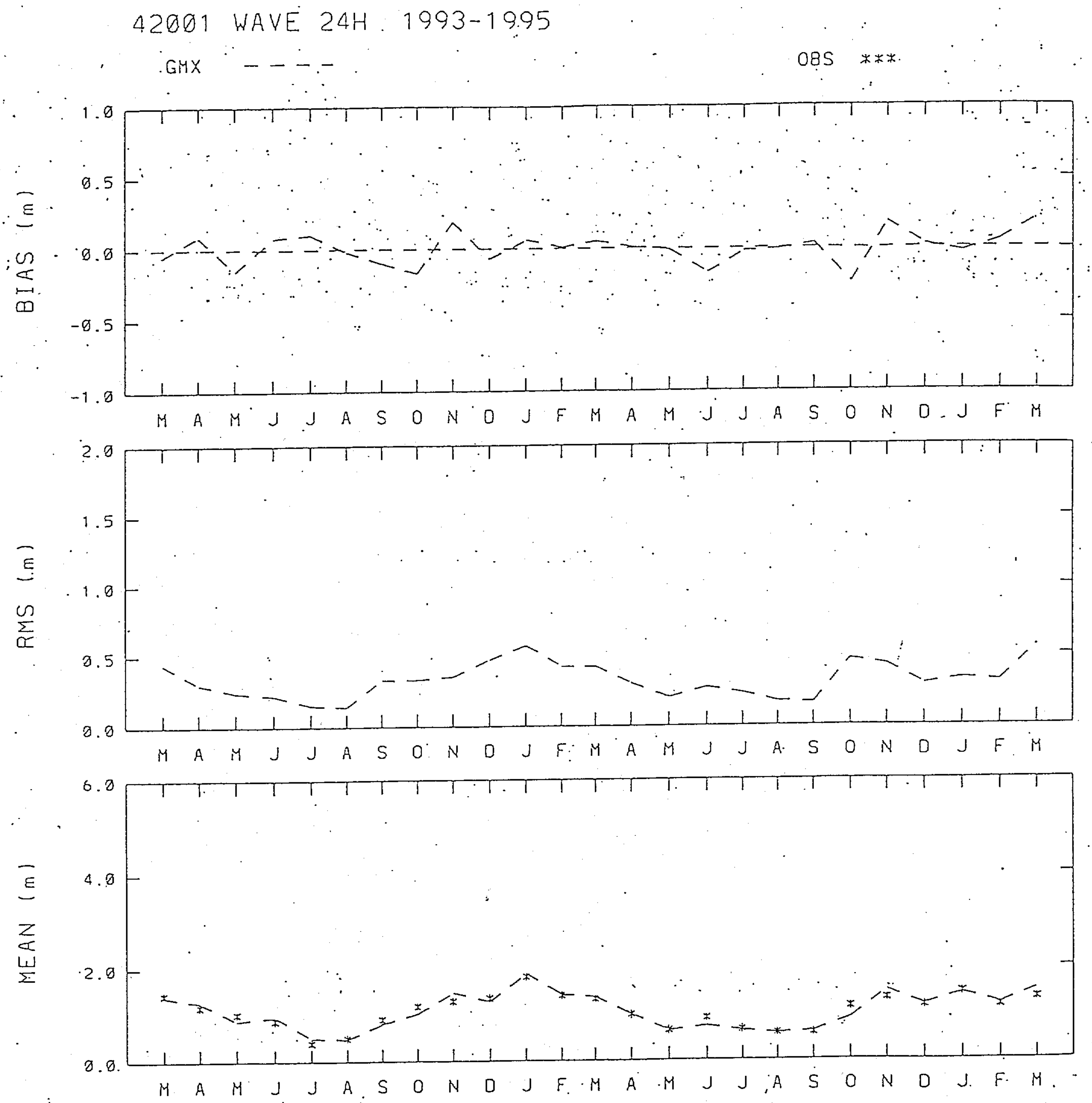

Figure 5. GMEX forecast performance showing BIAS, RMS, and Mean Height statistics for 1993-1995 for 24-h forecast at the location of buoy 42001.

forecast cycle, and D184C from the 1200 UTC forecast cycle. Figure 27 presents a sample AFOS chart and Fig. 28 presents a sample DIFAX chart.

b) Gulf of Alaska Regional Spectral Wave Model (GAK)

The structure of GAK (Chao 1993) is essentially the same as GMEX. However, unlike the Gulf of Mexico which can be considered an enclosed basin, the Gulf of Alaska is open to the Pacific Ocean. Hence, the wave conditions inside the Gulf are determined by the wave trains propagating into the Gulf from the open ocean as well as the local winds over the Gulf. In this model, the waves propagating in from the Pacific across the mouth of the Gulf are obtained from the operational global wave model. A grid mesh of 30 by 30 n mi is established for the Gulf region extending from 53°N to 61°N and 155°W to 132°W. The grid points in the outer portion of the Gulf are overlaid on the global model grid points of 2.5° by 2.5 resolution in latitude and longitude. Wave spectral forecasts by the operational global model in this boundary zone at 3-h intervals are interpolated and weighted linearly onto the regional grids in the boundary zone such that a smooth transition from 100% global wave data at the outer-most grids to 100% regional wave data at inner-most grids is achieved.

The model runs twice daily using wind data also derived from the AVN. Model output for projections from 00- through 48-h at 12-h intervals are transmitted to the NWS Anchorage regional forecast office in GRIB format on the NCEP Storage Grid 214 (polar stereographic, 47.625 km grid size). Transmitted data include the significant wave height of wind-sea and swell combined, the period and direction associated with the peak energy component of the directional spectrum, the significant wave height, mean period and mean direction of swell as well as the mean period and wave height of wind-sea.

Figure 6 shows an example of statistical evaluations of GAK performance with NDBC buoy measurements as the standard of reference. Measurements were obtained from Buoy 46001 located at about the middle of the Gulf.

C. Polar Seas and Great Lakes Sea Ice

Official ice analyses and forecasts are produced by the National Ice Center (NIC) by combined NOAA, U.S. Navy, and U.S. Coast Guard efforts. Numerical guidance is being developed and will be furnished by NCEP. At this time the only product routinely produced and disseminated is a set of drift ice vectors for the northern hemisphere. These vectors are sent to the NIC and are made available to the NWS Alaska Region directly. The drift vectors are forecast out to seven days by using model output from the MRF as input to the Skiles (1968) drift model. Developments and future plans are considered in the Appendix.

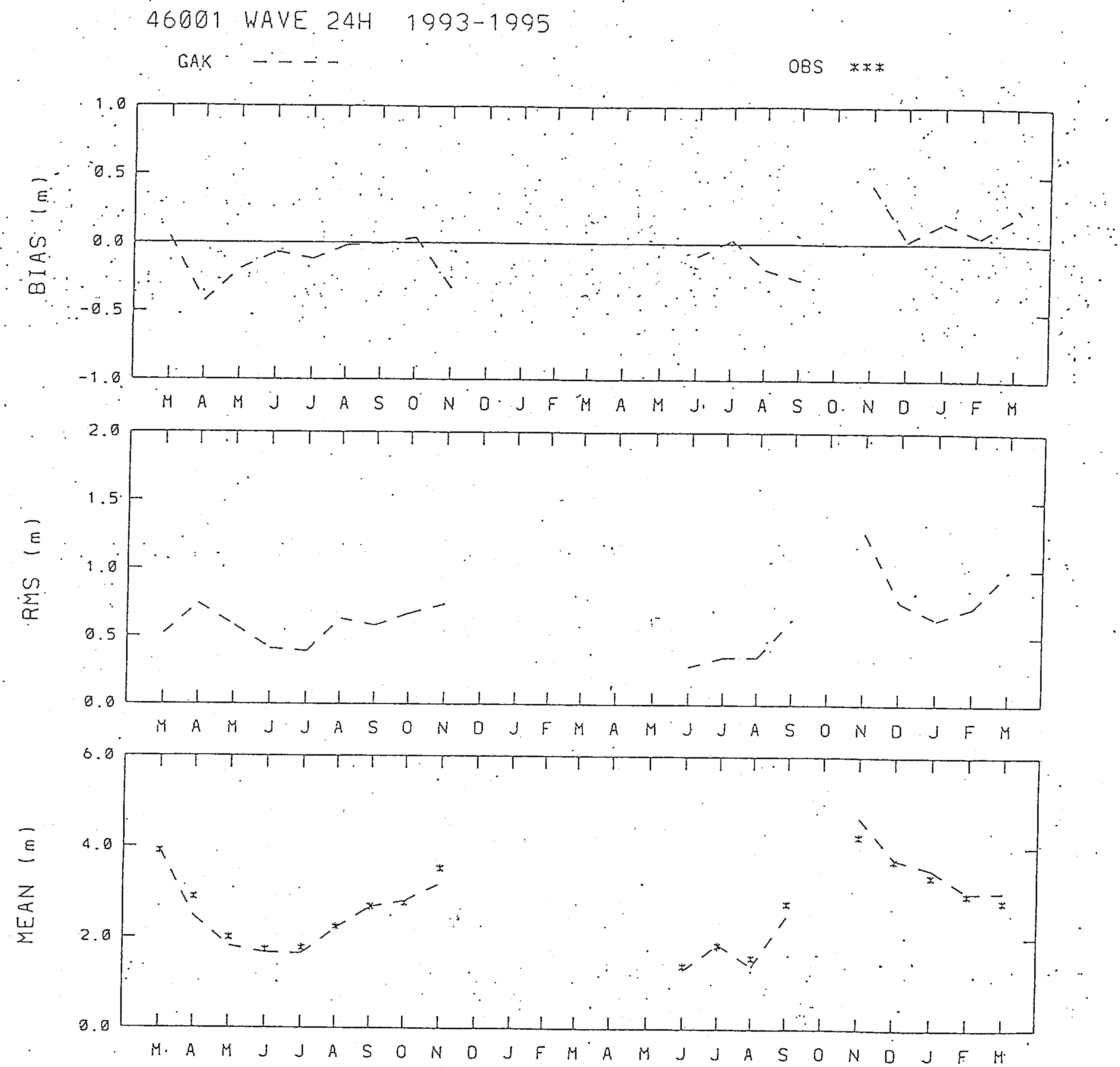

Figure 6. Same as Fig. 5 except for GAK and buoy 46001. Gaps are due to data losses at the buoy.

D. National Marine Verification Program

The objectives of the NMVP are to help

- WSFO forecasters identify strengths and weaknesses in forecast skill,
- NCEP distinguish good and bad points in their guidance, and
- program managers discriminate assets and liabilities in marine services.

Observed data, WSFO forecasts, and NCEP guidance data are merged together for specific verification times into a Marine Verification Matrix (MVM). The data in the matrix are used to evaluate forecasts of four forecast elements: wind direction, wind speed, significant wave height, and SCAs/wind warnings.

1. Marine Verification Matrix

Each WSFO in the program makes forecasts for specific observation points within their marine area of responsibility. Each observation point is either a buoy or C-MAN location from which data are considered to be representative of the forecast area. The forecast points were assigned in coordination with the Regions and WSFOs.

The MVM is produced by the NCEP. It contains 2 coded forecasts per day issued by the WSFOs for the buoy and C-MAN stations; NCEP guidance forecasts interpolated to the station positions, and 5 hourly verifying observations (centered on the verification times) from the stations. These data are collated for two verification times 0600 and 1800 UTC daily. The MVM is sorted by WSFO, and individual floppy disks are created for each WSFO. The individual disks are sent to each WSFO periodically for use with local programs. The MVM is also archived at NCEP and is used to prepare reports and studies as requested. It is used to prepare National reports which are issued annually. For complete details on the MVM, see Burroughs and Nichols (1993).

2. Statistical Evaluations

The forecasts and guidance evaluated are the 18-h and 30-h projections of the 0000 and 1200 UTC NCEP model cycles.[1] Four forecast elements are evaluated: SCAs and Wind Warnings, wind direction, wind speed, and significant wave height. The highest observed wind speed or wave height of the 5 observations is used to verify SCAs. The highest wind speed is used to verify Wind Warnings. The average of the 5 observations is used to verify wind direction, wind speed, and significant wave height. The warning/SCA element is evaluated separately at coastal points and offshore points because the forecast requirements differ. No such separation is made for the wind direction, wind speed, and

[1]The projections are several hours less for the operational forecasts although based on the same guidance (Burroughs and Nichols 1993).

significant wave height evaluations.

A variety of statistics are used to evaluate the forecast elements above which are detailed in Burroughs (1993). Separate statistics sheets are prepared for each element, cycle time, projection, WSFO forecast or NCEP guidance forecast, and station set. Station sets include statistics for each observing point, stations for which each WSFO forecasts, stations in each region, and all stations together. 160 statistical data sheets are used to compile each national report. These data are periodically sent out on floppy disk to the WSFOs, regional focal points, and national focal points. National reports are sent out annually.

III. EXAMPLES OF PRODUCTS

An example of each of the experimental and operational guidance products produced by the OMB is shown below in Figs. 7 - 28.

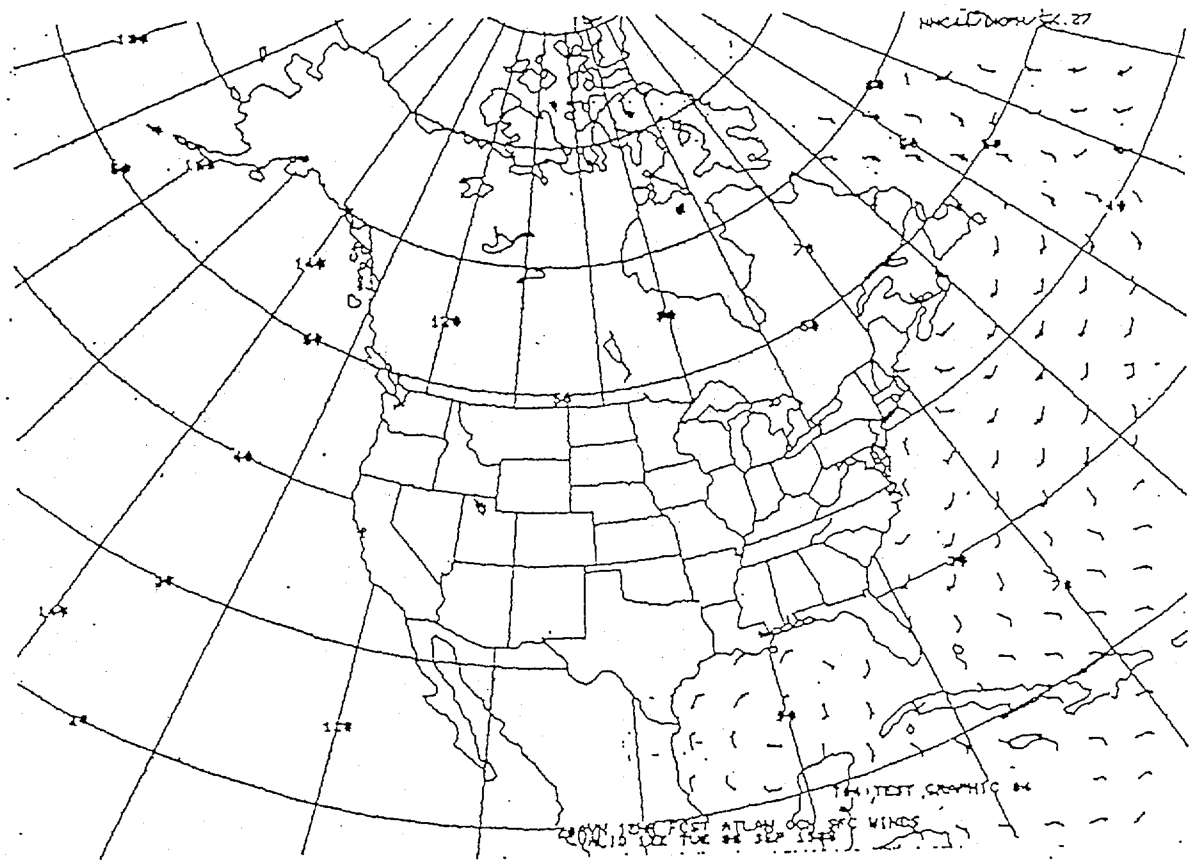

Figure 7. Global ocean surface wind forecasts derived from AVN lowest sigma layer winds as presented on AFOS (Atlantic section).

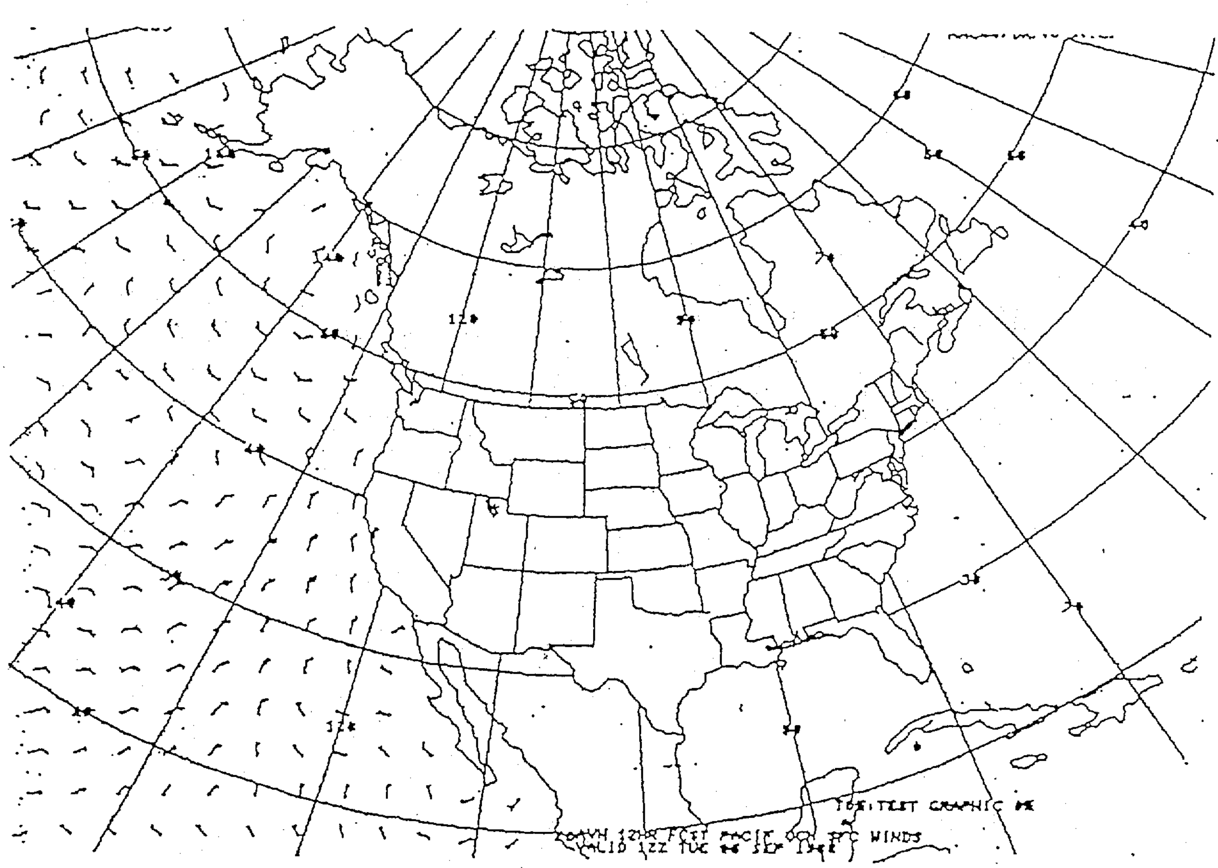

Figure 8. Same as Fig. 7 except Pacific section.

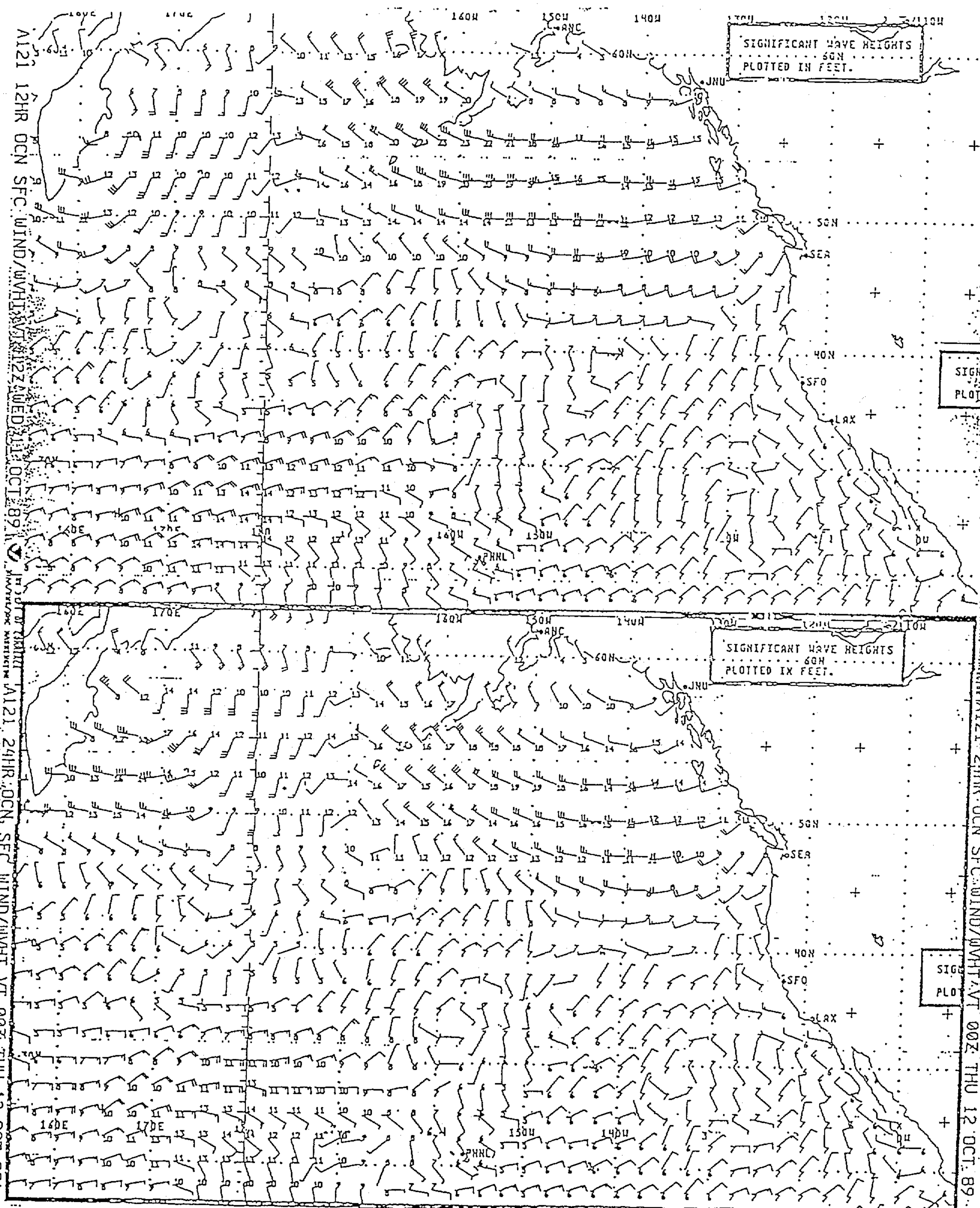

Figure 9. Sample Ocean Surface Wind forecasts, as depicted on the Alaska FAX. Numbers at the heads of the wind barbs are wave heights, in feet.

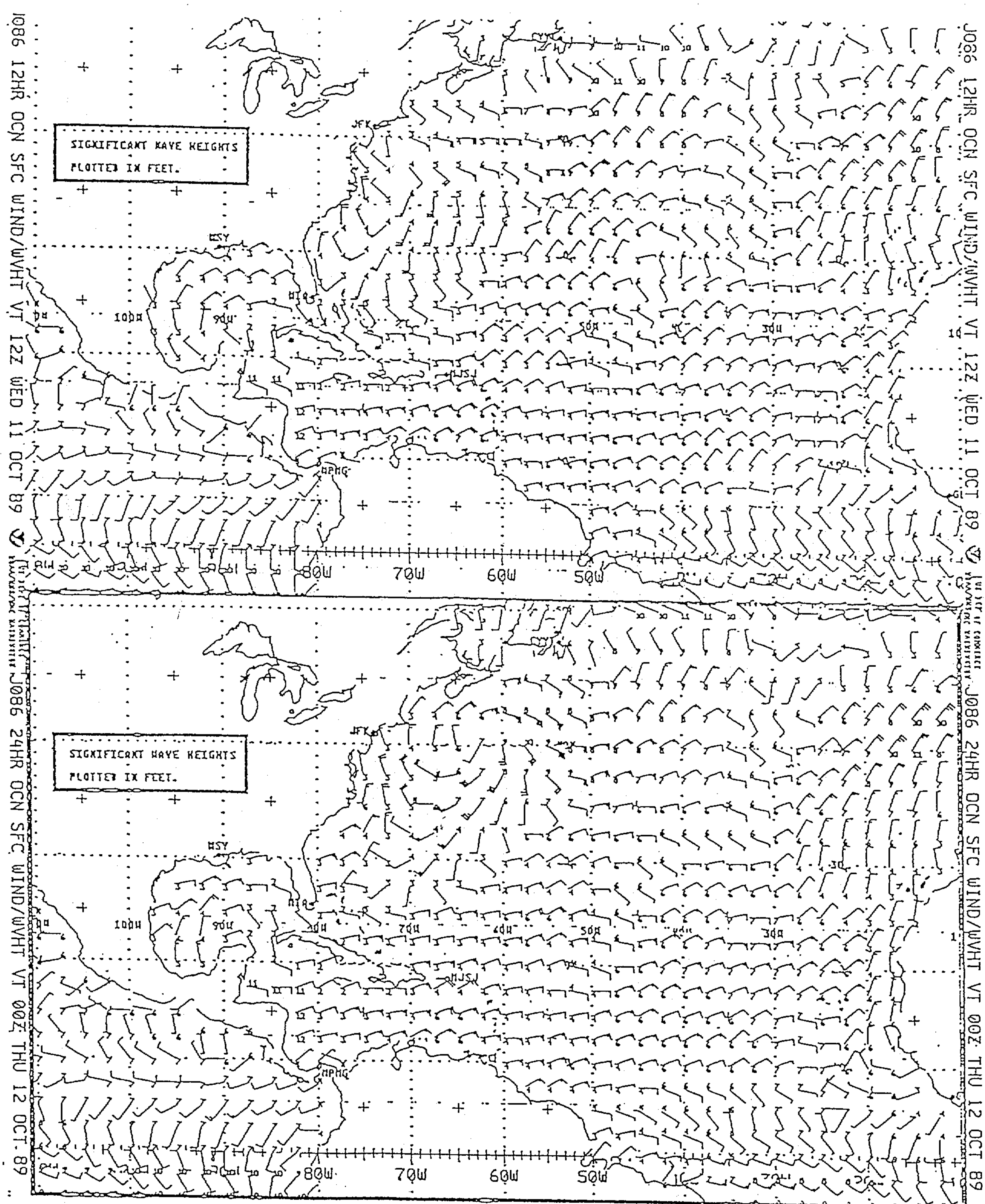

Figure 10. Same as Fig. 9, except as shown on San Juan FAX.

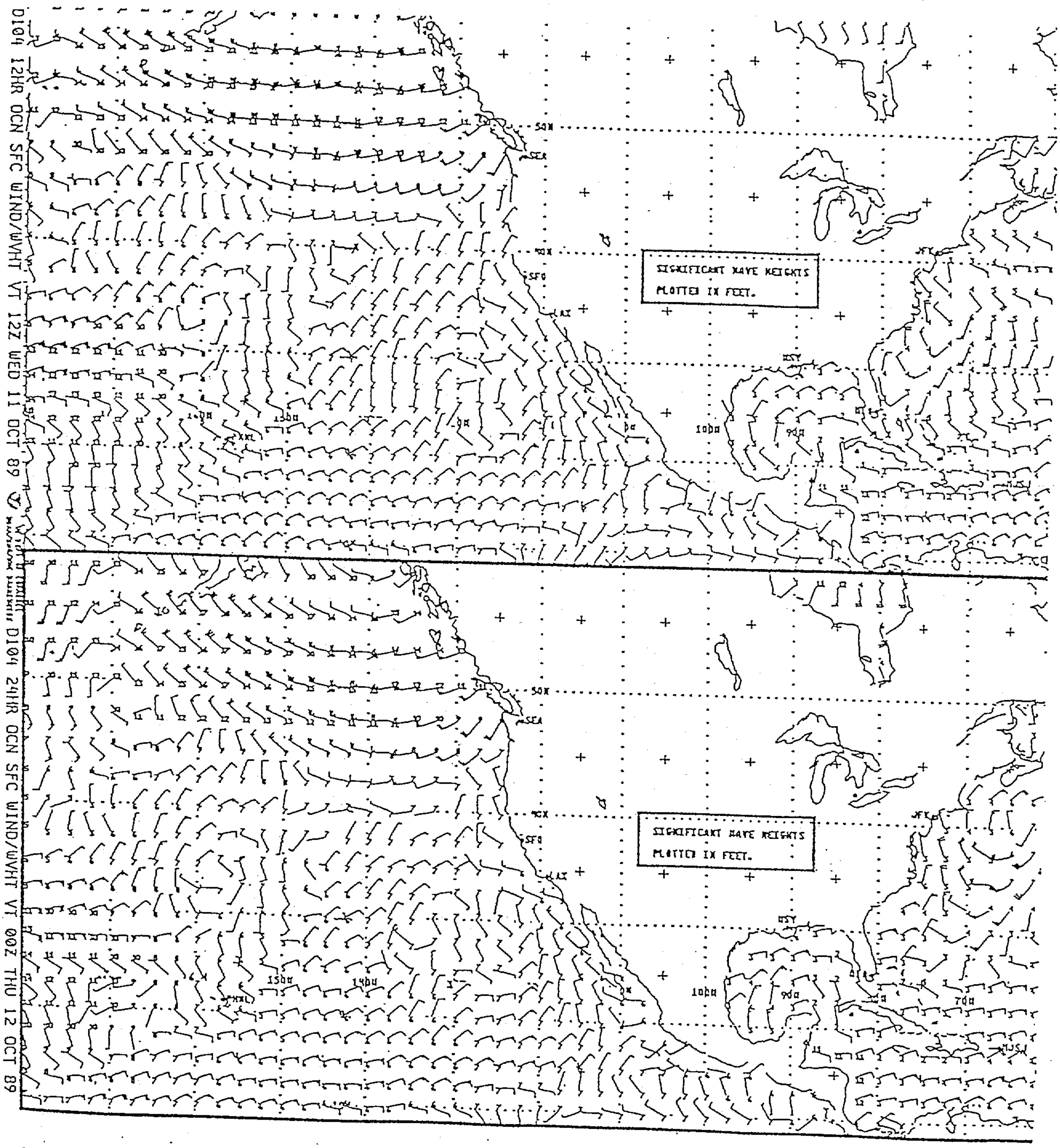

Figure 11. Same as Fig. 9, except as displayed on DIFAX.

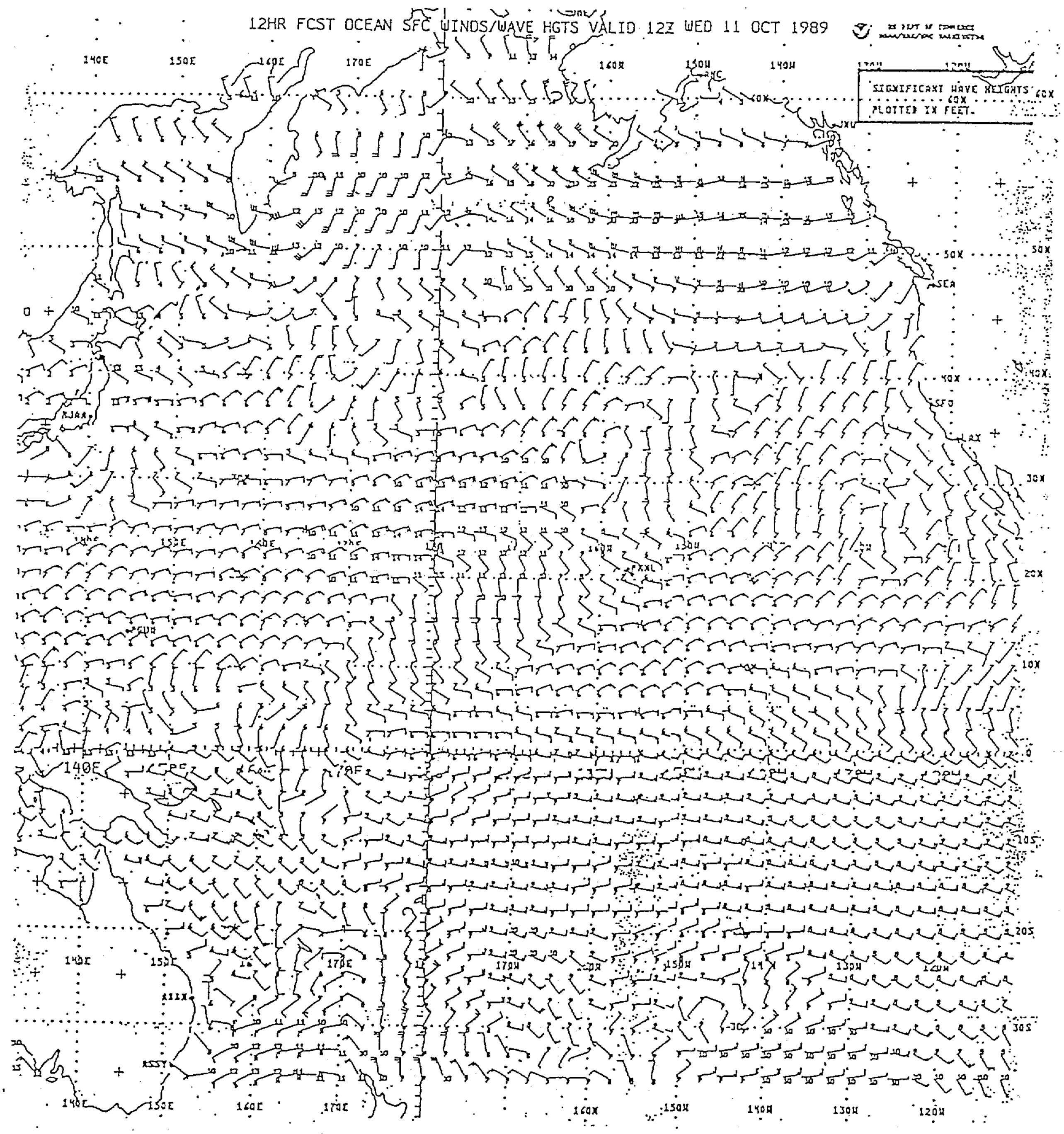

Figure 12. Same as Fig. 9, except as given on Hawaii FAX.

FZUS42 KWBC 201200

FZUS42 CSTL WND FCSTS-CA 02/20/93

D/UTC	2018	2100	2106	2112	2118	2200	2206	2212
55N	2412	3111	3107	2706	2010	2010	2208	2409
44012	2415	3315	3312	3209	2312	2115	2412	2316
61N	2414	3211	3209	3007	2212	2009	2208	2410
N91	2513	3214	3210	3109	2110	2112	2310	2511
44004	2422	2619	3117	3111	2813	2715	2514	2419
44009	2113	3118	3416	3412	2910	2709	2511	2714
64W	2511	3409	3606	3506	2609	2208	2205	2609
CHLV2	2216	2914	3610	3308	2610	1911	2211	2414
DKNC	2211	2413	3509	3508	2809	2007	2407	2509
79W	2216	2018	3611	3609	2707	2608	2408	2510
HAT	2311	2212	3508	3607	2607	3206	2505	2707
DSLN7	2220	2325	3216	3514	2609	2909	2813	2714
41001	2317	2117	2715	3011	2812	3011	2613	2513
CLKN7	2211	2211	3117	3609	2206	3005	2405	2607

Figure 13. An example of the bulletin format for the Coastal Wind Forecast System. See Section II, subsection A.2 for details. CA refers to Central Atlantic Coast

DATE/TIME GROUP		93	07	17	12	
***GREAT	LAKES	WIND	FORECAST***			
	18	24	30	36	42	48
E ONTARIO	1909	2010	2713	2912	3210	0112
WONTARIO	2010	2112	2612	2811	3110	0310
E ERIE	2211	2213	2412	2512	2511	1510
WERIE	2112	2213	2313	2413	2412	2011
S HURON	2111	2013	2213	2212	2212	1711
N HURON	2110	1912	1812	1911	1813	1511
S MICHIGAN	2013	2015	2116	2316	2213	2312
C MICHIGAN	1914	1915	2116	2215	2313	2312
N MICHIGAN	1912	1714	1814	2113	2213	2312
E SUPERIOR	1610	1313	1314	1613	1913	2812
C SUPERIOR	1312	1114	1314	1612	2813	3113
WSUPERIOR	0814	0914	0813	2411	2412	2610

Figure 14. Great Lakes wind forecast. See Section II, subsection A.2 for details.

FZUS45 KWBC 02 / 21 / 93 0000
SANTA ANA RGM FCST

D/UTC	2100	2106	2112	2118	2200	2206	2212	2218	2300
	WEAK	WEAK	WEAK	WEAK	WEAK	WEAK	STNG	STNG	NONE

CSTL WND FCSTS-SC

D/UTC	2106	2112	2118	2200	2206	2212	2218	2300
46023	2504	1204	0808	0709	0510	0622	0617	2506
NTD	2903	0902	0705	0602	0412	0524	0618	2106
46025	2702	1403	0606	0507	0609	0617	0810	2305
NTK	2004	1202	1304	0906	0608	0415	0610	2403
NSI	9999	9999	0503	0405	9999	9999	0708	2804
NUC	2705	1602	1203	0905	0708	0612	1004	2104

Figure 15. Sample Santa Ana bulletin with Santa Ana regime forecast. See Section II, subsection A.3 of the text for details. RGM refers to regime and SC to Southern California.

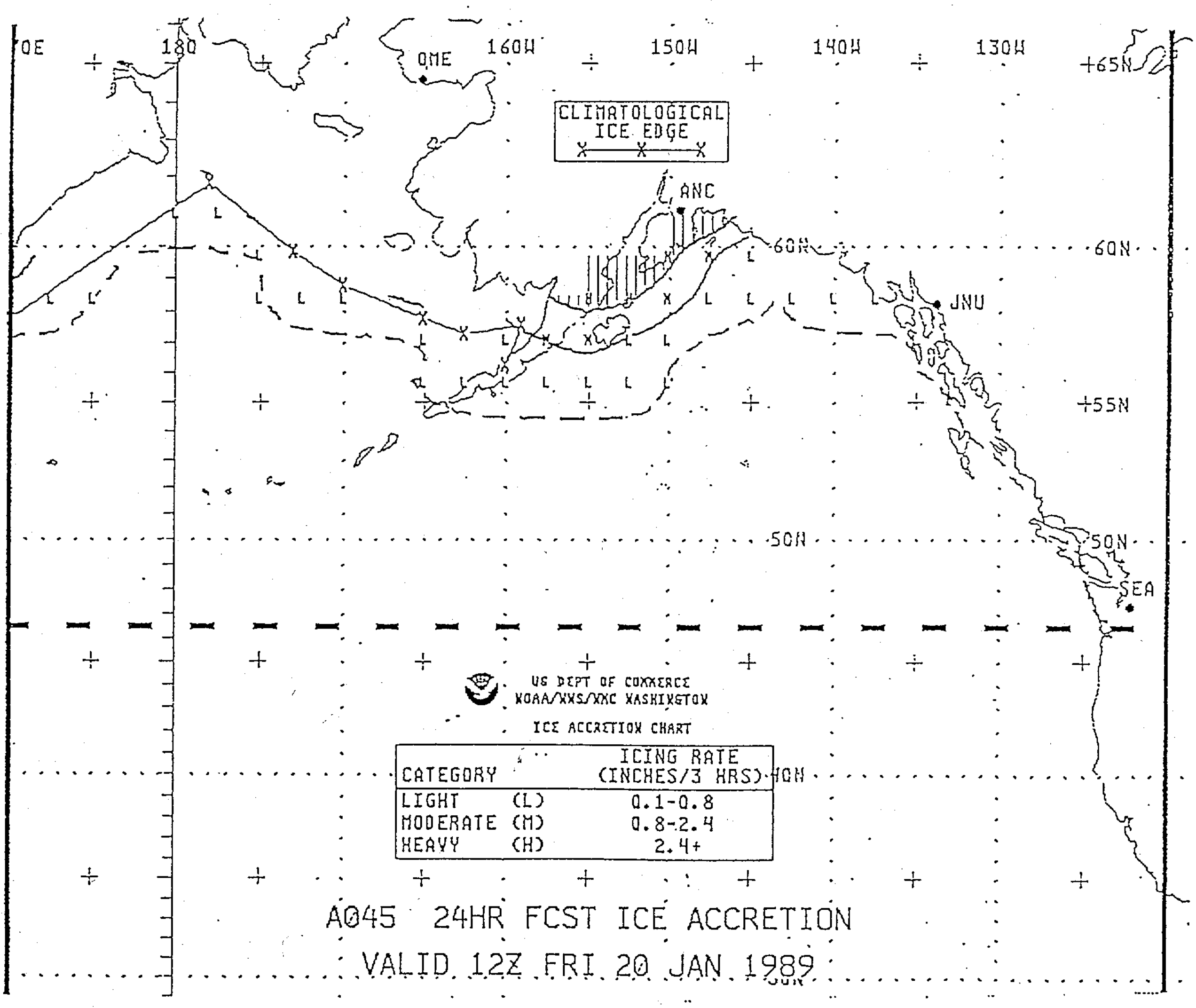

Figure 16. 24 hour superstructure ice accretion forecast.

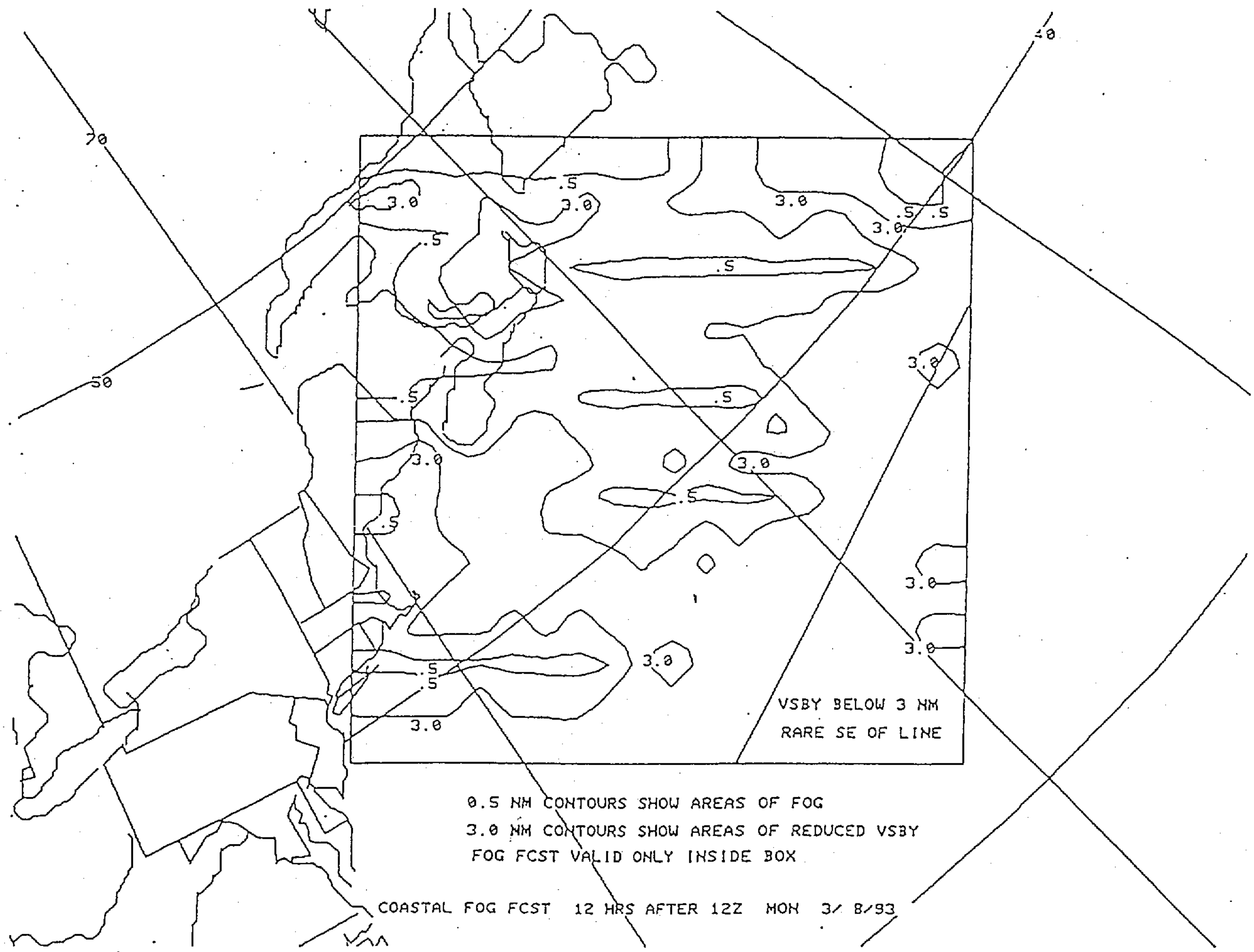

Figure 17. Sample AFOS graphic, at 9:1 zoom ratio, showing the valid region for the Regional Fog Model along the East Coast of the United States and Canada.

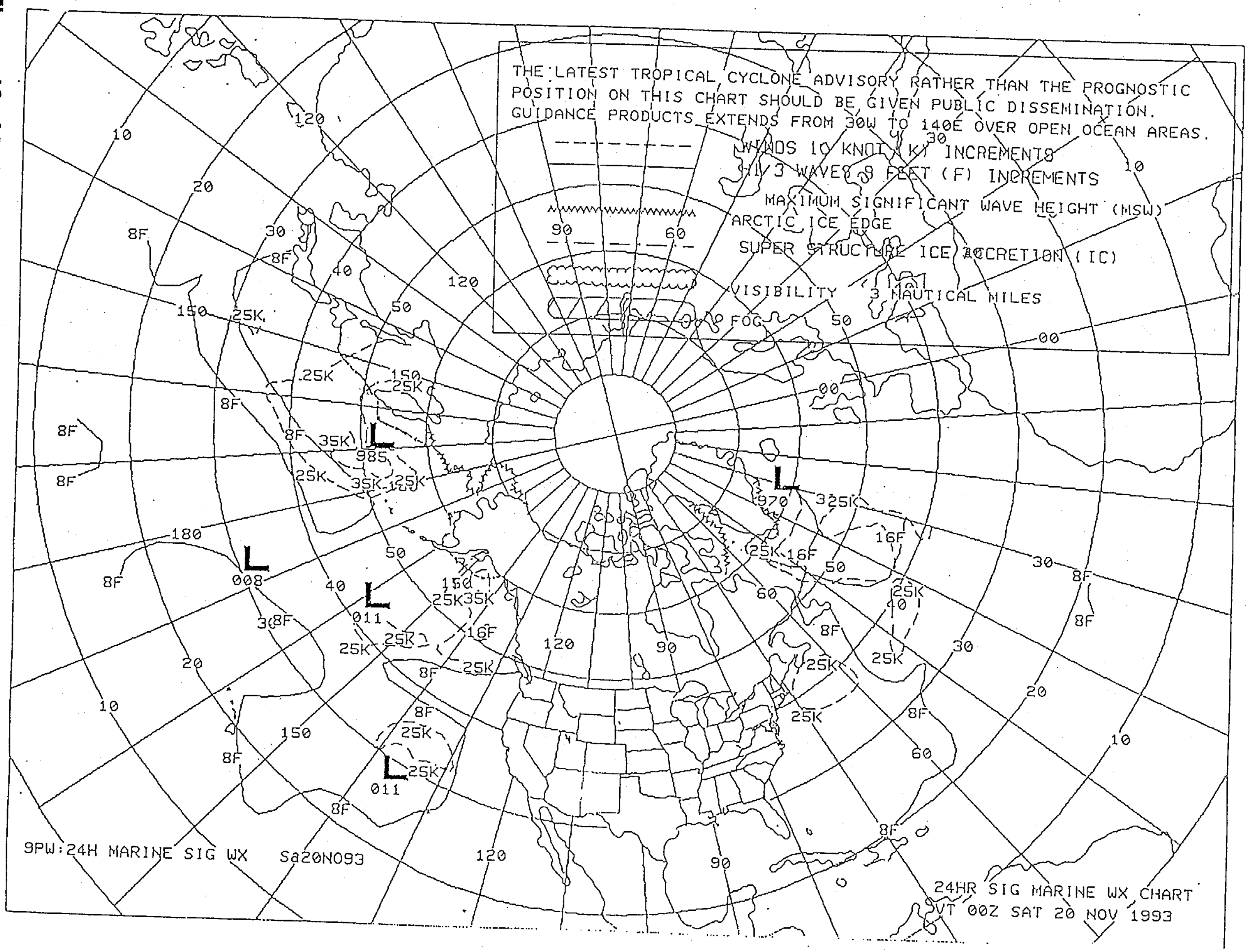

Figure 18. Marine significant weather chart.

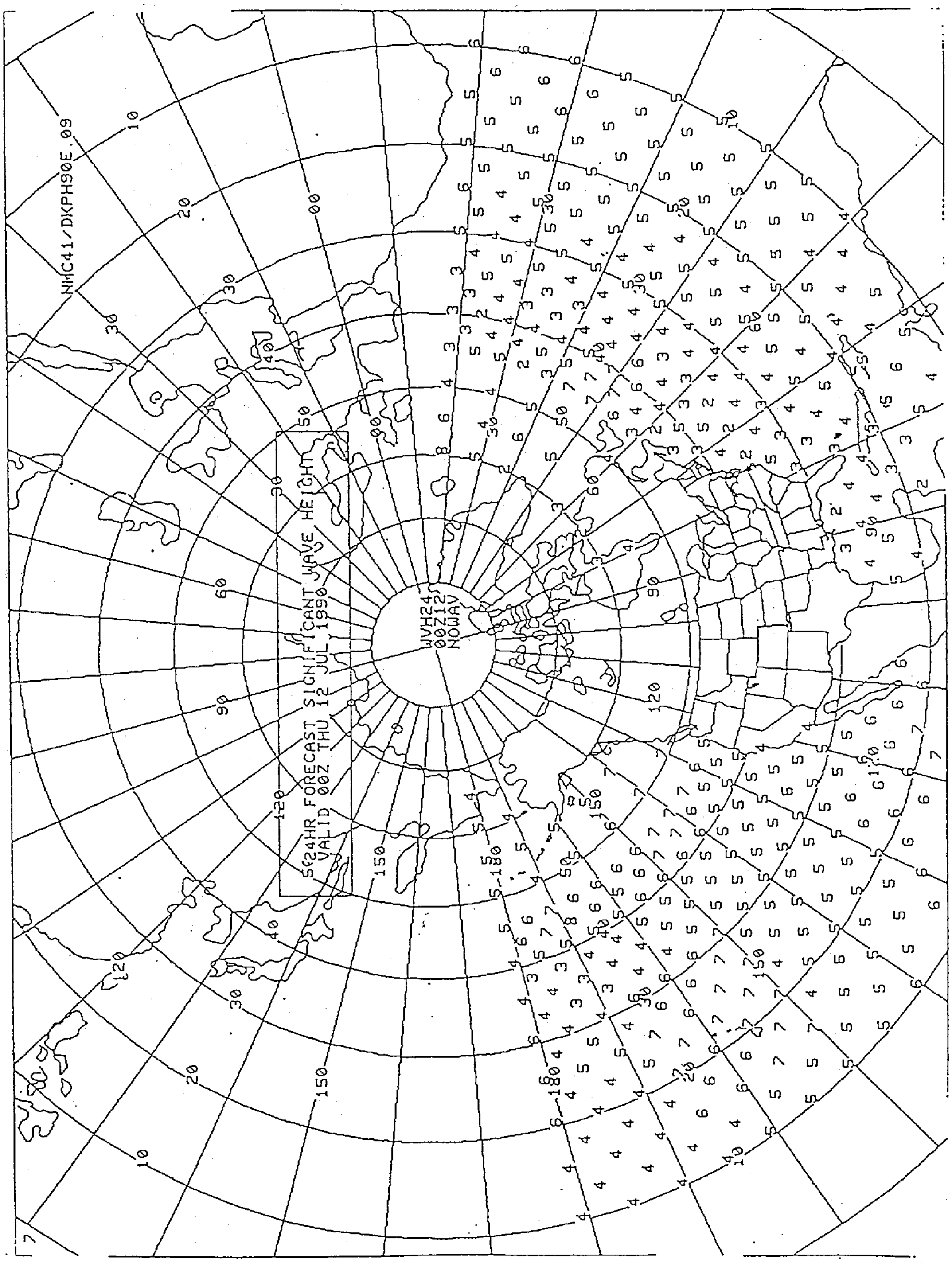

Figure 19. Sample AFOS chart of gridded significant wave height (SWH) in feet.

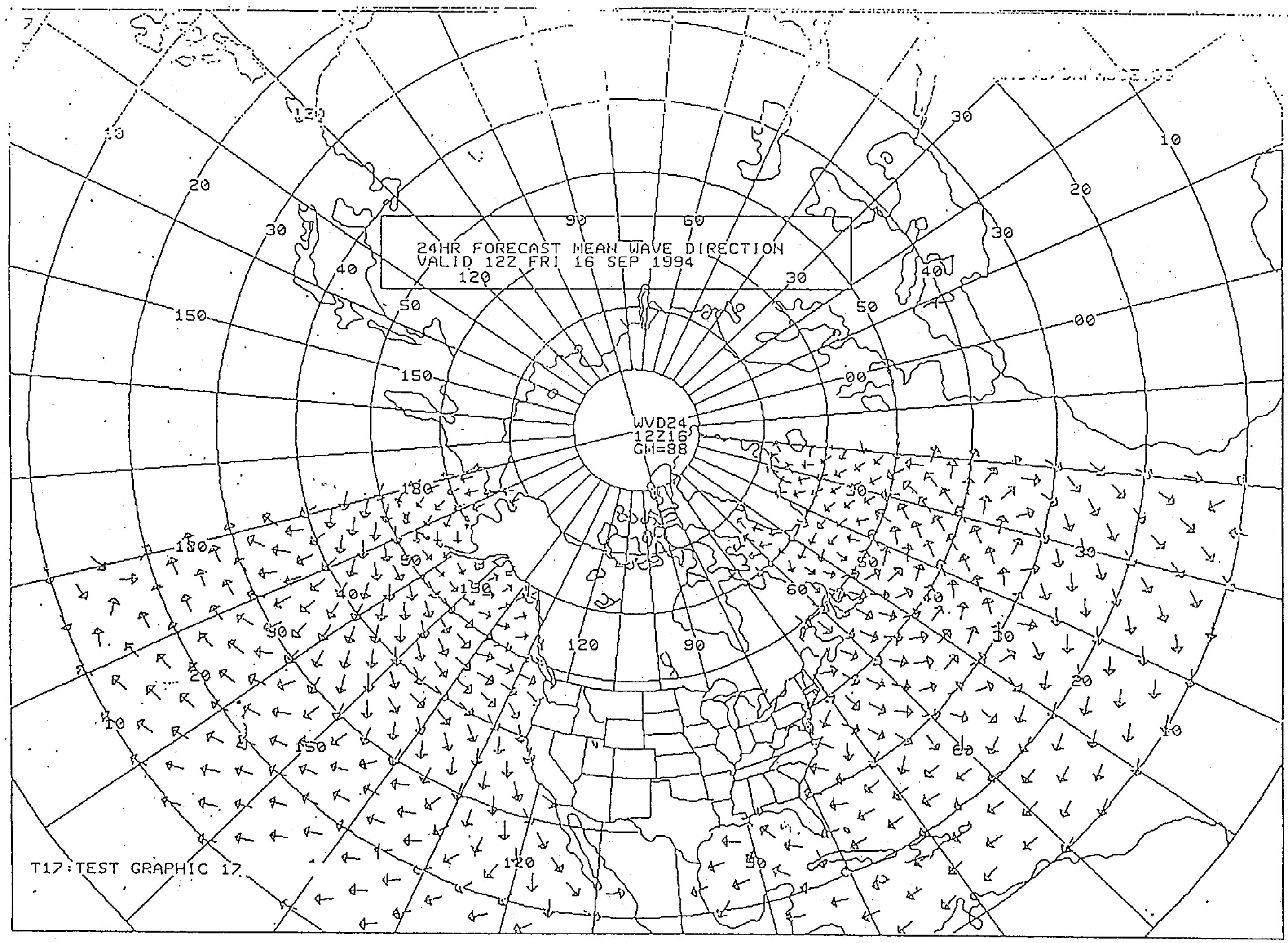

Figure 20. Sample AFOS chart of mean wave direction arrows.

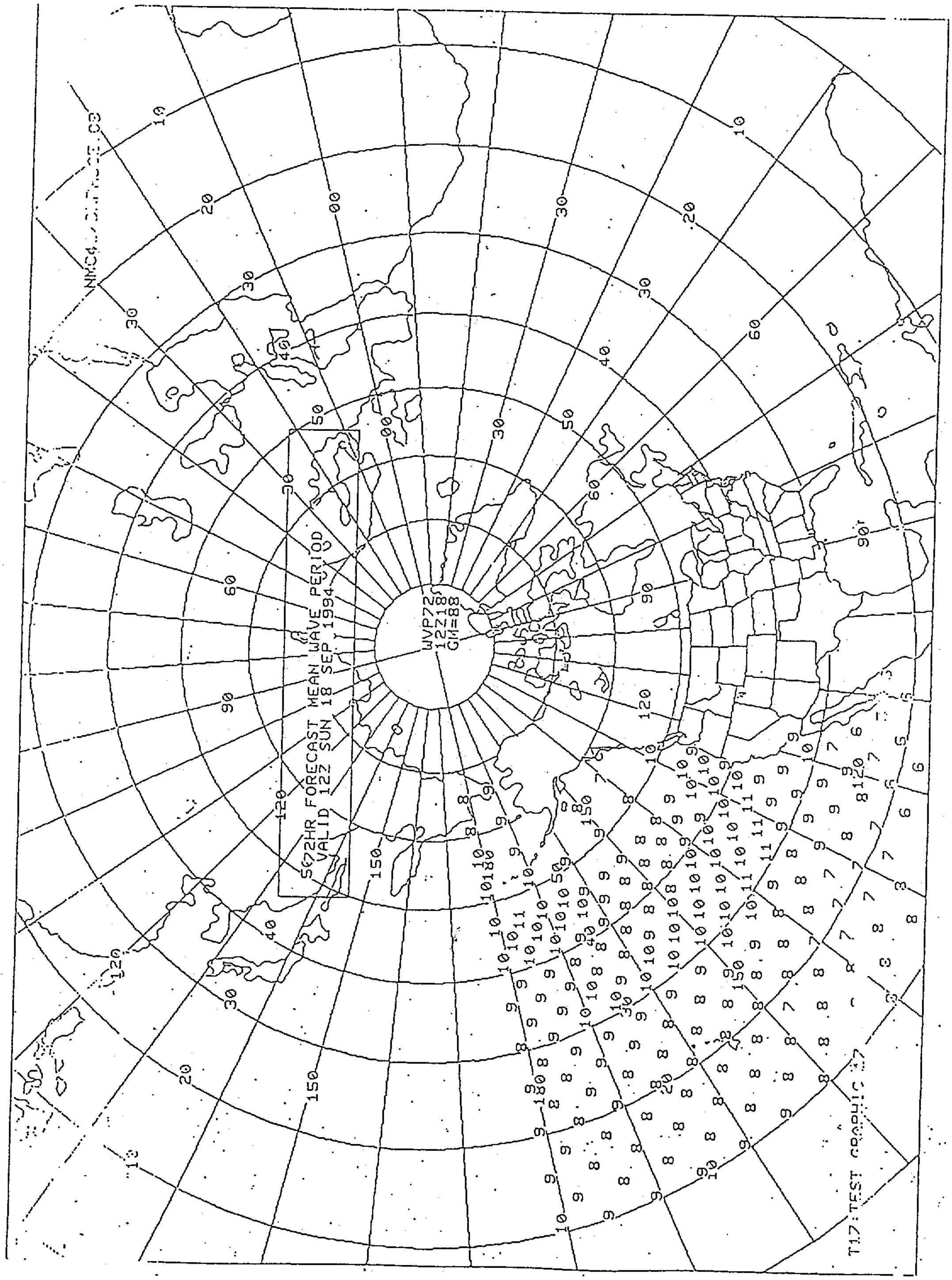

Figure 21. Sample AFOS chart of gridded mean wave period in seconds.

```
NMCOSWSA1
FZNT41 KWBC 082900
 90082900  LAT  35.0N LON   72.5W  00Z 29 AUG 90 TAU 60
 NOAA           DIR(FROM).   -LOCAL WIND 190.8DEG 15.5KTS
 PERIOD(TOTAL)  105 135 165 195 225 255 285
  10.9       1    1   0   0   0   0   0   0
   9.7       3    1   1   0   0   0   0   0
   8.6       6    1   2   0   1   1   0   0
   7.5       8    1   2   1   2   2   1   0
   6.3      22    1   2   2   7   6   3   1
   4.8      29    0   1   5  13   8   2   0
   3.2      14    0   1   4   5   3   1   0
  DIR(TOTAL)      6  10  12  28  20   6   1
      SIG HT   3.8FT
```

```
NMCOSWSP1
FZPZ41 KWBC 082900
 90082900  LAT  47.5N LON  125.0W  00Z 29 AUG 90 TAU 60
 NOAA           DIR(FROM).   -LOCAL WIND 243.5DEG  8.3KTS
 PERIOD(TOTAL)  165 195 225 255 285 315 345
  18.0       1    0   0   1   0   0   0   0
  16.4       2    0   0   1   0   0   0   0
  15.0       2    0   1   1   0   0   0   0
  13.9       4    0   1   1   1   0   0   0
  12.4       8    0   2   3   2   2   0   0
  10.9       7    0   2   1   1   2   0   0
   9.7       6    0   3   1   1   1   0   0
   8.6      14    0   4   4   2   2   1   0
   7.5       9    1   2   2   1   2   1   0
   6.3       7    1   1   1   0   2   2   0
   4.8       7    1   2   1   0   1   2   1
   3.2       5    0   1   2   1   0   0   0
  DIR(TOTAL)      4  20  18  10  12   6   1
      SIG HT   3.5FT
```

Figure 22. Sample AFOS alphanumeric ocean wave spectral messages for the Atlantic Ocean (top) and the Pacific Ocean (bottom).

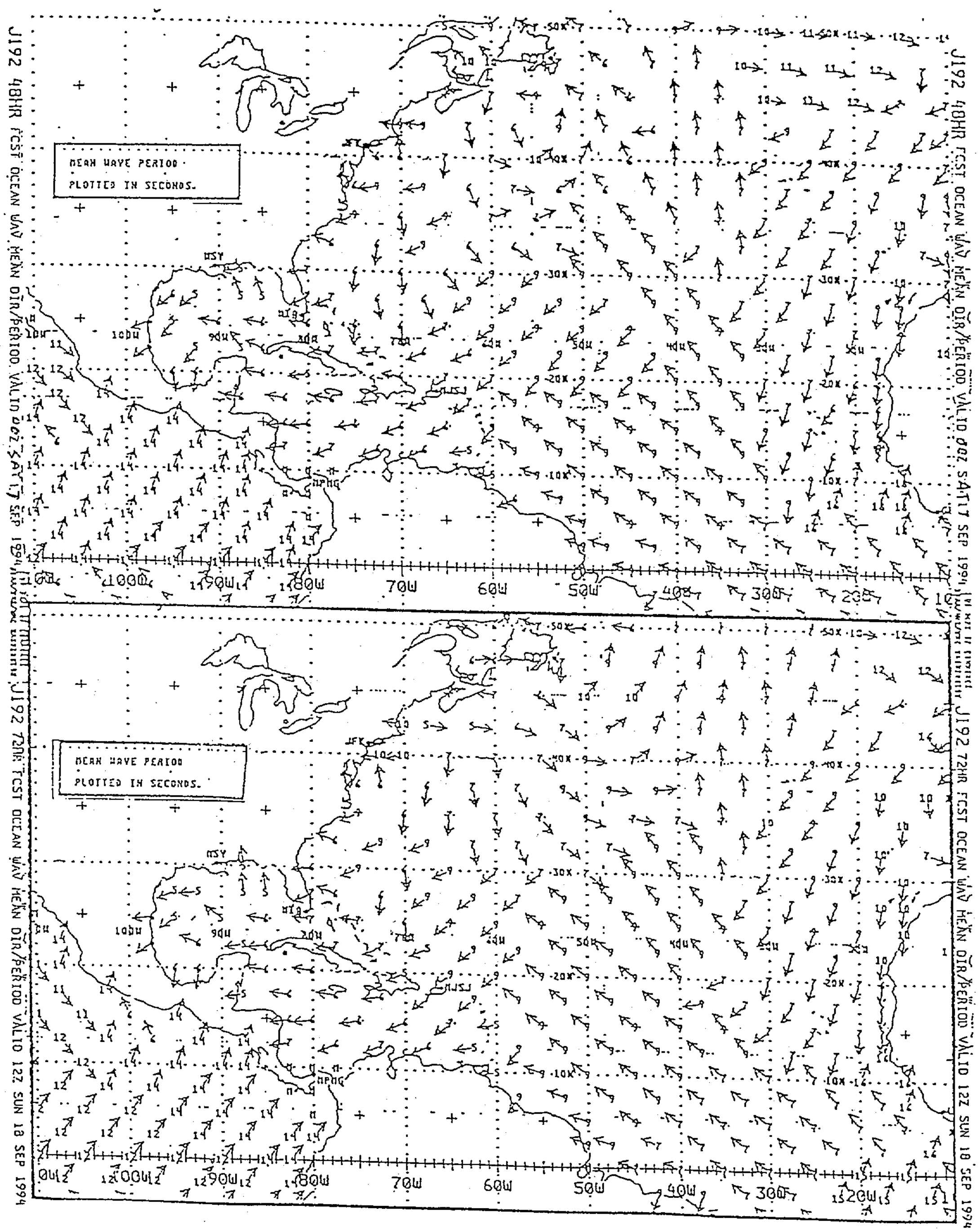

Figure 23. Sample San Juan FAX charts depicting gridded ocean wave period and wave direction for the 48- and 72-h forecasts.

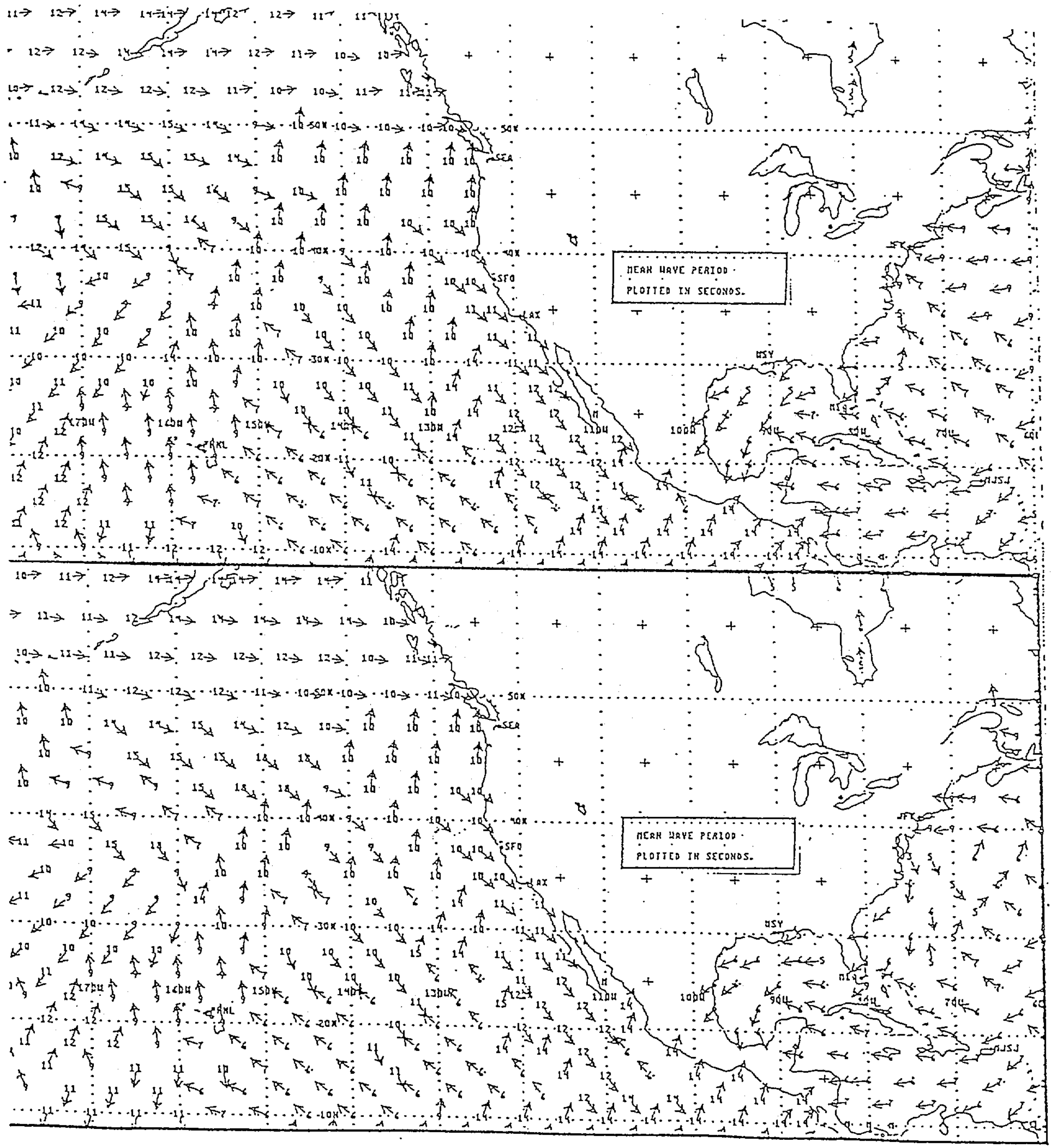

Figure 24. Sample DIFAX charts giving gridded values of wave period and wave direction arrows.

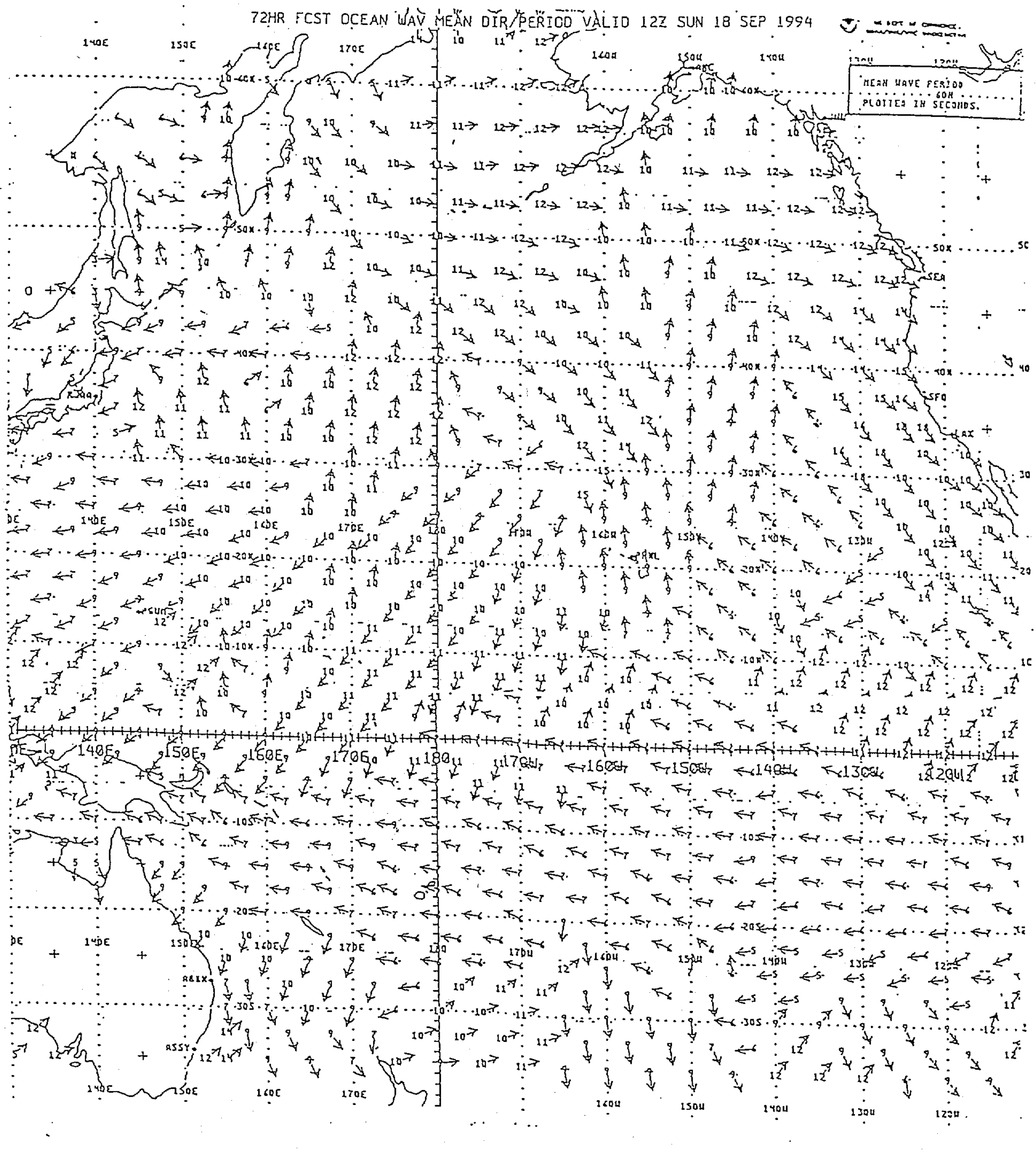

Figure 25. Sample Honolulu FAX charts depicting gridded wave period and wave direction.

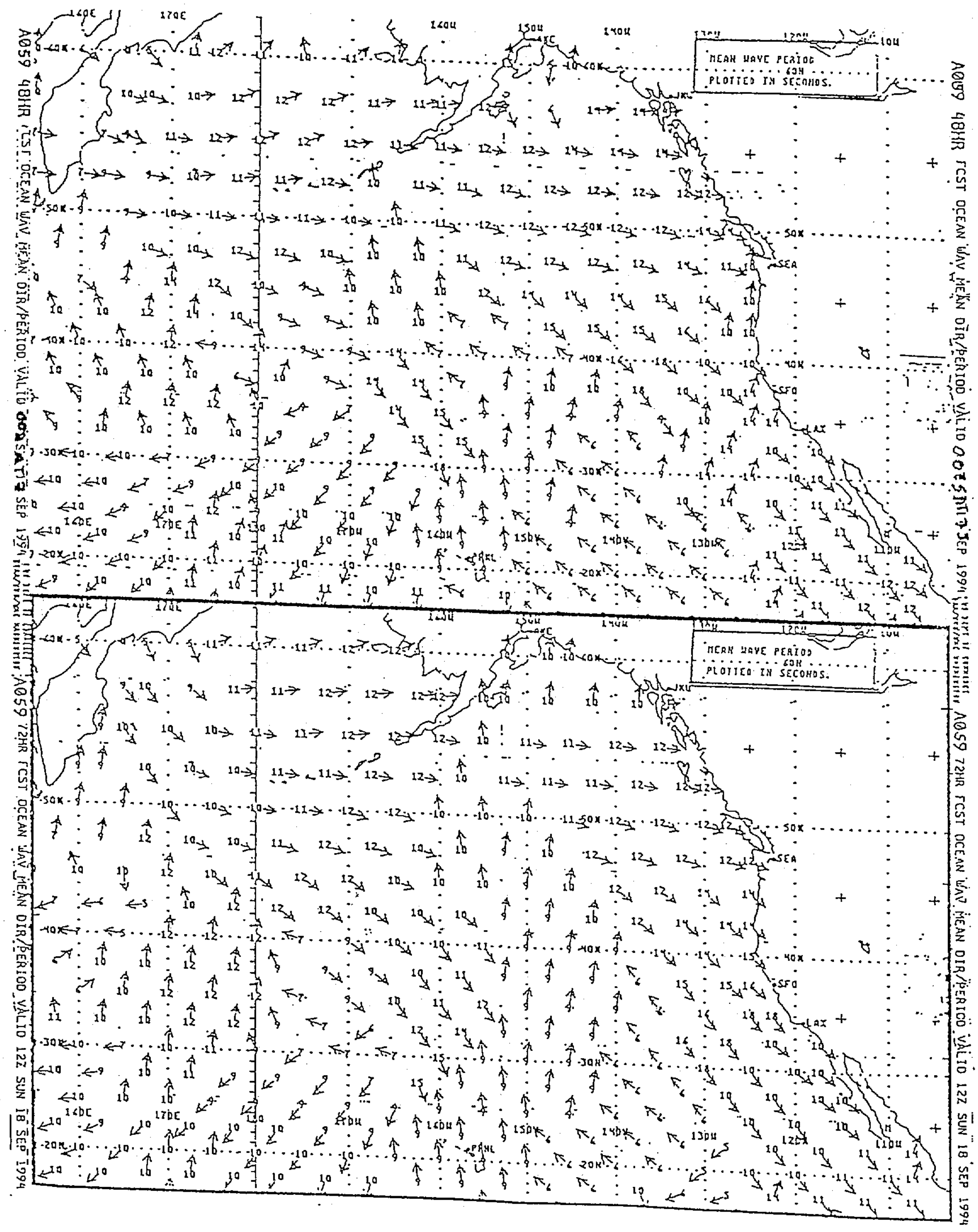

Figure 26. Sample Alaska FAX charts giving gridded wave period and wave direction.

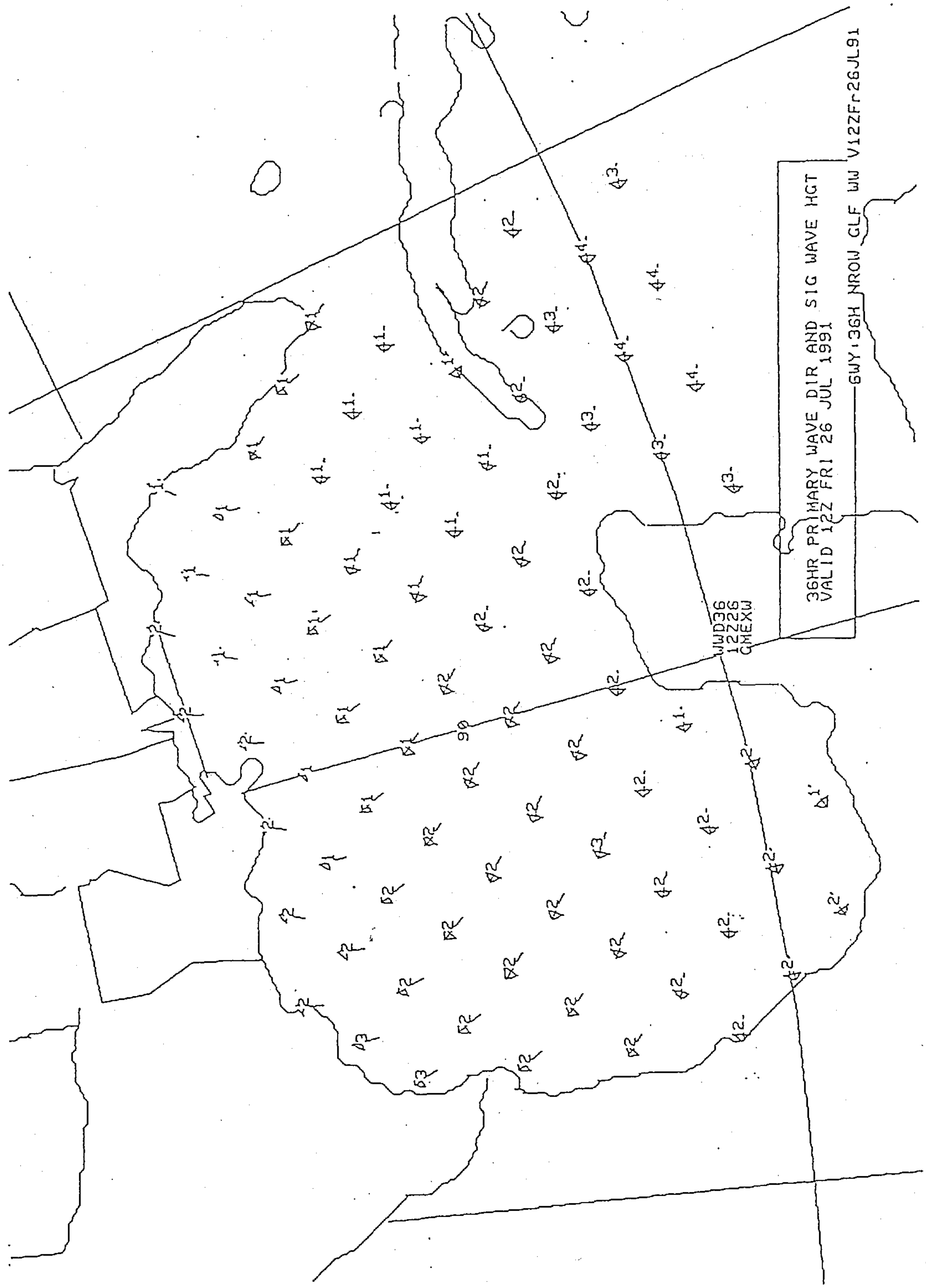

Figure 27. Sample GMEX AFOS graphic displaying the primary wave direction (arrows) and the significant wave height (in feet).

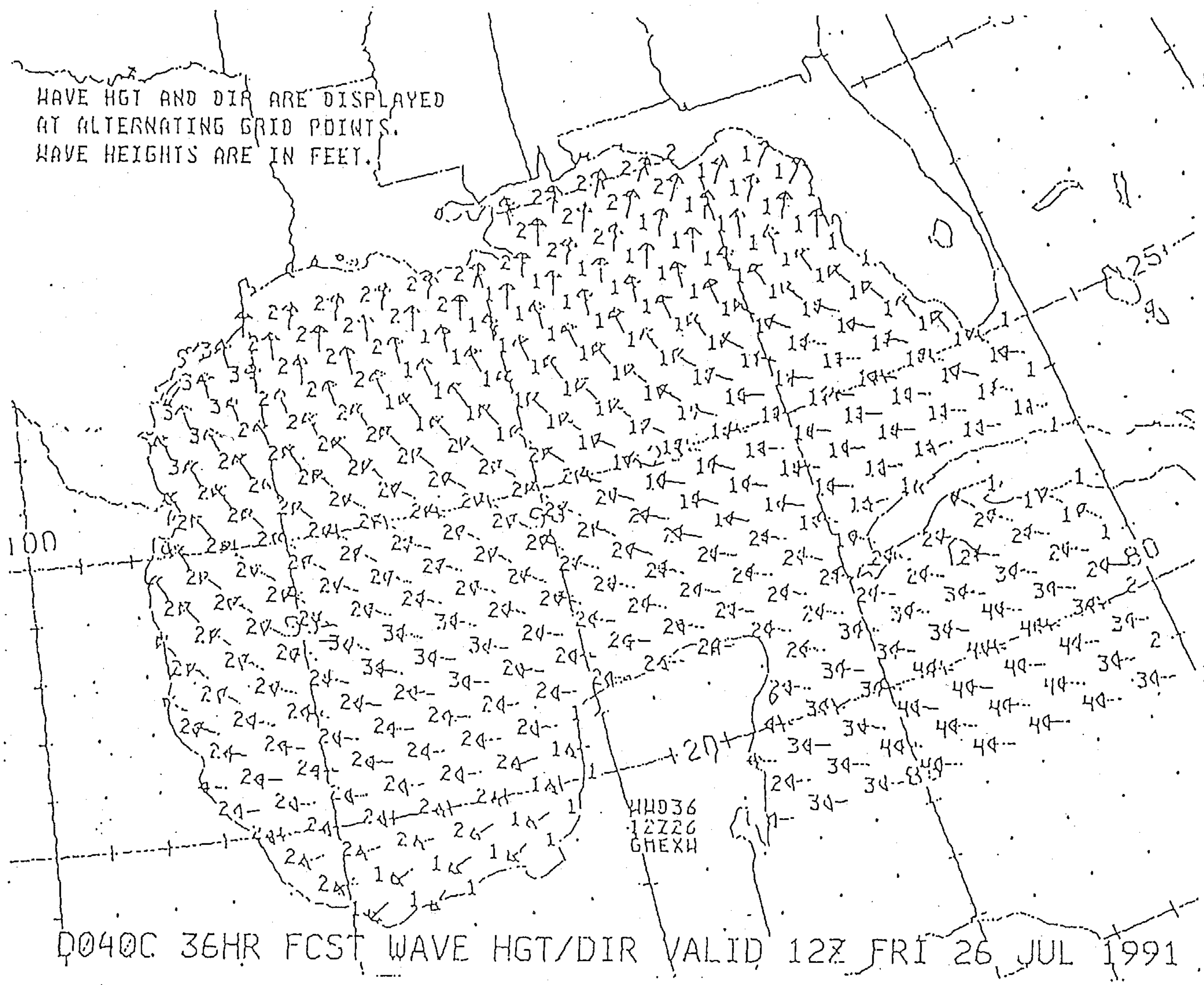

Figure 28. Sample GMEX DIFAX chart rendering the wave direction (arrows) and wave heights in feet (numbers at arrow head) at every other grid point. Note: This is an enlargement of on panel of a five-panel chart.

IV. PRODUCT DISSEMINATION

Table 3 below lists the available NCEP marine guidance products and summarizes the production frequency, times available, and dissemination method. Further details concerning availability, status, and procedures for accessing these products may be obtained by contacting the OMB or the MPC directly.

Table 3. Summary of guidance products available through the NCEP.

PRODUCT	PRODUCTION FREQUENCY	TIMES AVAILABLE (UTC)	DISSEMINATION	REMARKS
MARINE METEOROLOGY				
Surface Wind Analyses and Forecasts				
Global Ocean	2/day	1000, 2200	AFOS, NDS, FAX	AVN based
Coastal U.S.	2/day	0500, 1700	AFOS, DDS	RAFS based
Great Lakes	2/day	0500, 1700	AFOS, DDS	RAFS based
Santa Ana Forecasts (season: May - September)				
Regime	2/day	0500, 1700	AFOS, DDS	RAFS based
Wind	2/day	0500, 1700	AFOS, DDS	RAFS based
Superstructure Ice Accretion Analyses and Forecasts (November - May)				
Global	1/day	1000	AFOS	MRF based [1]
Alaska	1/day	1200	AKFAX	MRF based
Sea Fog Forecasts				
Open Ocean [2]	1/day	1000	AFOS,NDS,A25 [3]	AVN based [1]
Coastal	2/day	1000, 2100	AFOS,NDS,A25 [3]	NE Atlantic [4]
Significant Weather Chart				
Marine	1/day	1000	AFOS	MPC produced
OCEAN WAVES				
Global Analyses and Forecasts				
Graphic	2/day	1000, 2200	AFOS, FAX [5]	
Alphanumeric	2/day	1000, 2200	AFOS	

[1]Displayed on marine significant weather chart.
[2]Season from April through September.
[3]Dedicated communications line to Alaska.
[4]First region of regional numerical fog model (Burroughs and Alpert 1993). Run all year.
[5]Includes DIFAX, SJFAX, AKFAX, and HFAX

Table 3. cont.

PRODUCT	PRODUCTION FREQUENCY	TIMES AVAILABLE (UTC)	DISSEMINATION	REMARKS
		OCEAN WAVES Regional Analyses and Forecasts		
GMEX	2/day	0515, 1735	AFOS, DIFAX [6]	
GAK	2/day	0600,1800	A25 [3]	
		NATIONAL MARINE VERIFICATION PROGRAM Data		
MVM	4/year		NCEP	floppy disk
Statistical data	4/year		NCEP	floppy disk
		Publications		
Special reports	on request		NCEP	

[6]Scheduled times for GMEX DIFAX transmissions are: 0708 and 1827 UTC.

V. SUMMARY AND FUTURE PLANS

The products presented in this publication are not expected to be static and unchanging; rather, they will undergo periodic re-examination, in view of the latest technical advances, to determine their value to users and their validity. Plans for improving the existing material and developing new products are continually evolving and parallel the progress in the art of numerical weather and ocean prediction, improved analysis techniques, increased availability of data from future satellites, and the advent of advanced dissemination systems. The changeover from AFOS to AWIPS products will occur automatically as the modernization and reorganization of the NWS continues.

APPENDIX

There are some products that are currently in the development stage. These products are being internally evaluated and will be released to the concerned forecast offices and other agencies on an experimental basis when a certain level of confidence has been established. They are briefly described below.

A. Regional Wave Models

A wave forecasting system is being developed to forecast wave conditions over coastal waters along the east coast of the U.S. and over the Gulf of Mexico. The wave model used is the third generation WAM cycle 4 version with an option to use a nested grid system. The grid system consists of two grids of different sizes named A- and B-grid. The grid resolutions in latitude and longitude are 1° by 1° for A-grid and 1/4° by 1/4° for B-grid. The A-grid covers the Atlantic Ocean from latitude 78° S to 78° N and longitude 100° W to 35° E. The purpose of this grid is to simulate swell which may propagate northward from the southern ocean and to provide boundary conditions for the B-grid model. The B-grid extends from 98° W to 65° W and from 10° N to 45° N, covering the east coast of the U.S., the Gulf of Mexico, and the Caribbean Sea (see Fig. 29). The required gridded depth fields are derived from bathymetry data obtained from the National Geophysical Data Center.

The input wind data at 10 m height above the mean sea surface are derived from the AVN for the A-grid model and the meso-ETA model for the B-grid model.

B. Coastal Ocean Forecast System for the East Coast of the U.S.

An experimental coastal ocean forecast system for waters offshore of the entire East Coast of the United States has been producing 24-hour forecasts of water levels and three-dimensional temperature, salinity and currents since August 1993 (Aikman *et al.* 1995). The Princeton ocean model (Blumberg and Mellor 1987) is forced by predicted surface fluxes of momentum and heat from NCEP's regional atmospheric ETA model. The East Coast Ocean Forecast System (ECOFS) development is a cooperative effort between NCEP, NOS, and GFDL, supported by NOAA's Coastal Ocean Program Office.

The immediate objective of the ECOFS is to test the effectiveness of such a system. Existing observations are being used to evaluate the system and a number of sensitivity experiments and next-generation enhancements are underway or are soon to be implemented, including data assimilation. The long-term goal for the ECOFS is to develop a system capable of producing useful and accurate nowcast and forecast information to support NOAA's mission for the protection of life and property and to support environmental management and economic development in the coastal domain.

The ECOFS is based on coupling the ocean model with the NCEP regional atmospheric ETA model. The ocean model uses a bottom following sigma-coordinate vertical grid, a coastal-following curvilinear orthogonal horizontal grid, and includes the Mellor-Yamada turbulence sub-model. The prognostic variables of the model are the free surface elevation, potential temperature, salinity (hence density), and velocities. The surface forcing consists of heat and momentum fluxes taken every three hours from consecutive ETA 24-hour forecasts.

The near-real-time operational data sources used in the ECOFS include water level data from eighteen NOS gauges and two Canadian gauges along the North American east coast, analyzed 14-km gridded MCSST data that are derived from SST fields obtained

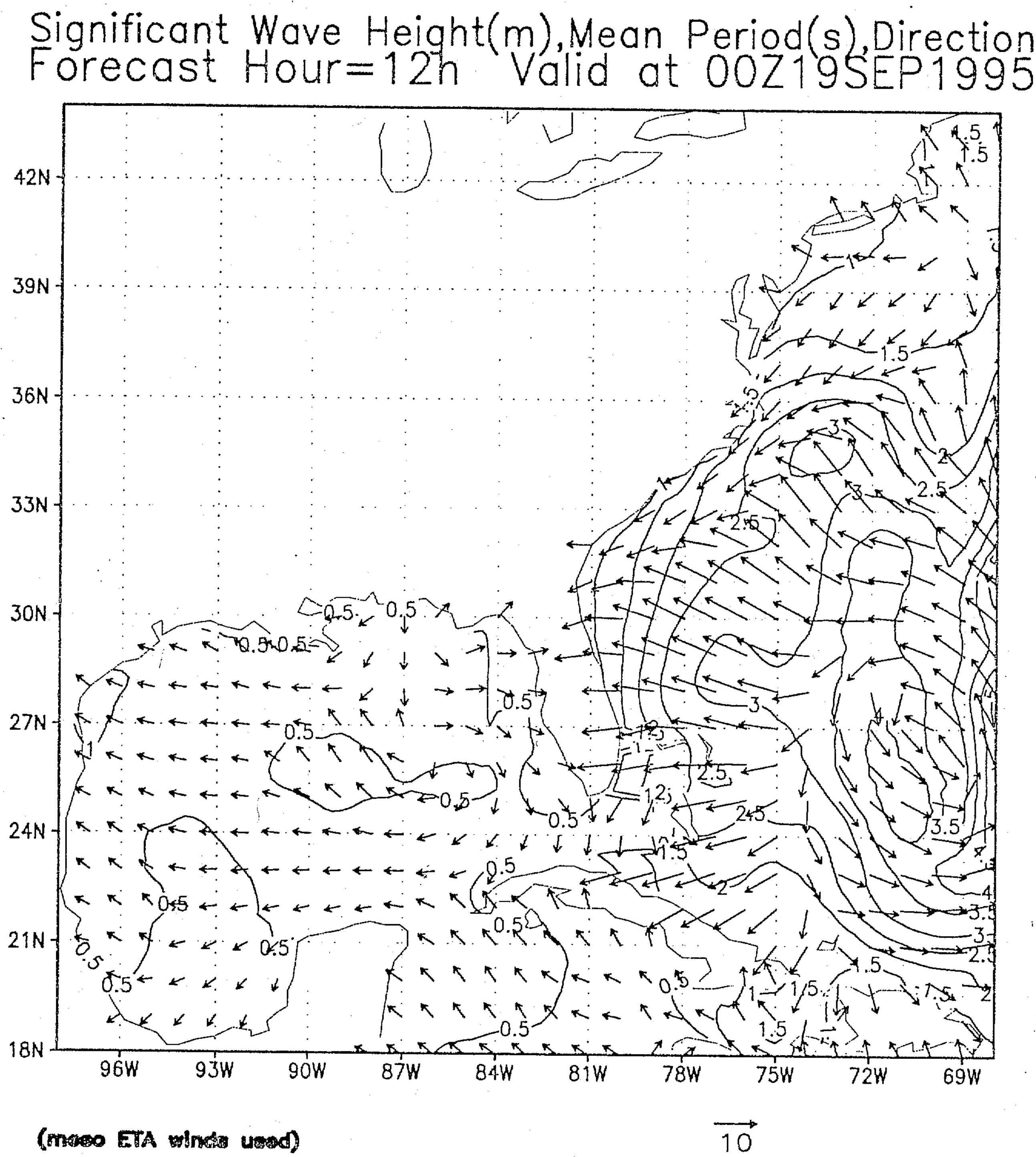

Figure 29. Sample output from the B-grid of the East Coast Regional Wave Model.

from the Advanced Very High Resolution Radiometer on board NOAA's polar-orbiting satellites, and observations of sea surface height derived from the TOPEX/Poseidon and ERS-1 satellite altimeters. These data are initially being used for forecast evaluation purposes and will ultimately be assimilated into the ocean model.

Initial assessment of the ocean model skill has been done through comparison of the 24-hour forecast subtidal water level at the model's shoreward boundary to observations along the coast (Bosley and Aikman 1994). Twenty coastal real-time water level stations, including locations from Florida to Newfoundland, were used for this assessment. Results from comparisons of one year of data between September 1993 and August 1994 show that nearly each subtidal event which is present in the observations is also manifest in the forecast sea level, although some phase and amplitude differences exist (see Fig. 30). Seasonal differences, with lower subtidal sea level variability in the spring and summer and higher variability in the fall and winter are well represented in the model. The forecasts at the two open ocean stations (Bermuda and Settlement Point, Bahamas) show very little subtidal (wind-driven) variability, but the inclusion of atmospheric pressure effects is shown to improve these comparisons considerably.

An example of a comparison between the observed and model surface temperatures is shown in Fig. 31. In general, even without data assimilation, considerable agreement in the SST structure is seen with regard to locations of the gulf stream and other fronts.

B. Polar and Great Lakes Ice Prediction

1. Analyses

The NIC produces the official analyses of sea ice cover. This includes analysis of the current ice edge location, sea ice concentration within the pack, and the development (thickness, type) of sea ice. The OMB will be producing a numerical analysis of ice thickness and concentration based on variational data assimilation from satellite data and the OMB ice model (see Figs. 32 and 33).

2. Forecasts

Two numerical models are run for guidance of the NIC: the drift model and the sea ice model. The drift model (Thorndike and Colony 1982; Martinson and Wamser, 1990) is an updated version of a model OMB has run for several years (Skiles 1968). The sea ice model (Stoessel 1991) is a numerical model of sea ice dynamics and thermodynamics, forced by the atmosphere and ocean. The model includes an interactive ocean mixed layer. The present numerical grid for the OMB ice model (see Table 4 for inputs to model) has a spacing of 127 km on a polar stereographic grid true at 60° North or South. Once these models become operational, experimental models with grid spacings of 47.625 and

23.875 km, respectively, will be tested. These experimental models will permit development to begin on modelling Great Lakes ice.

Table 4. Input data from the MRF to the OMB ice model.

Input Variables	Variable Descriptions
V10	Wind vector at 10 m above the surface
T10	Air temperature at 10 m above surface
q10	Specific humidity at 10 m above surface
ps	Surface pressure
precip	Precipitation in form of snow fall
SW↓	Downwelling short wave radiation
LW↓	Downwelling long wave radiation
LW↑	Upwelling longwave radiation
low cloud	Concentration of low clouds

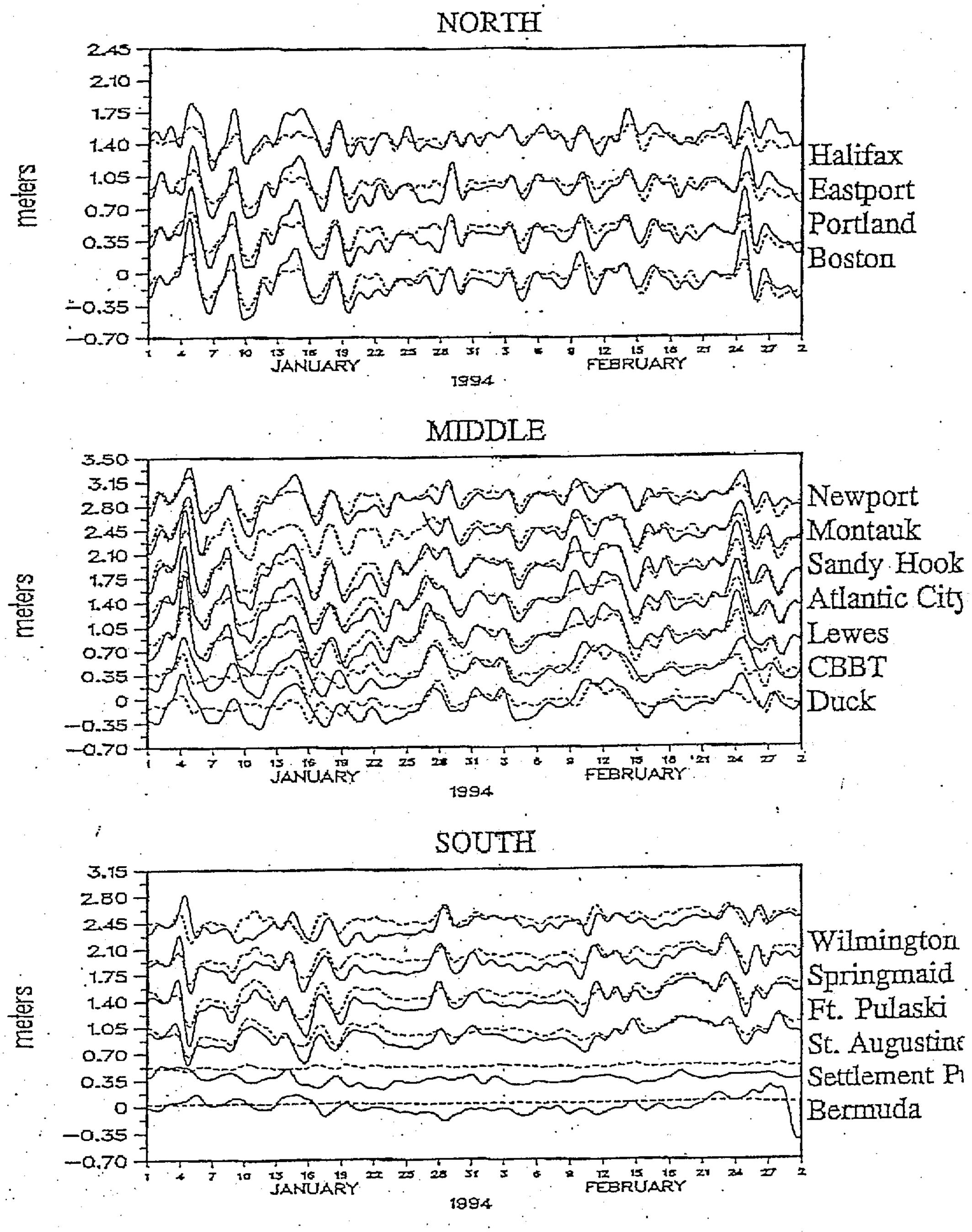

Figure 30. A two month (January and February 1994) sample of comparisons between the forecast (dashed lines) and observed (solid lines) subtidal water level at the East Coast stations indicated.

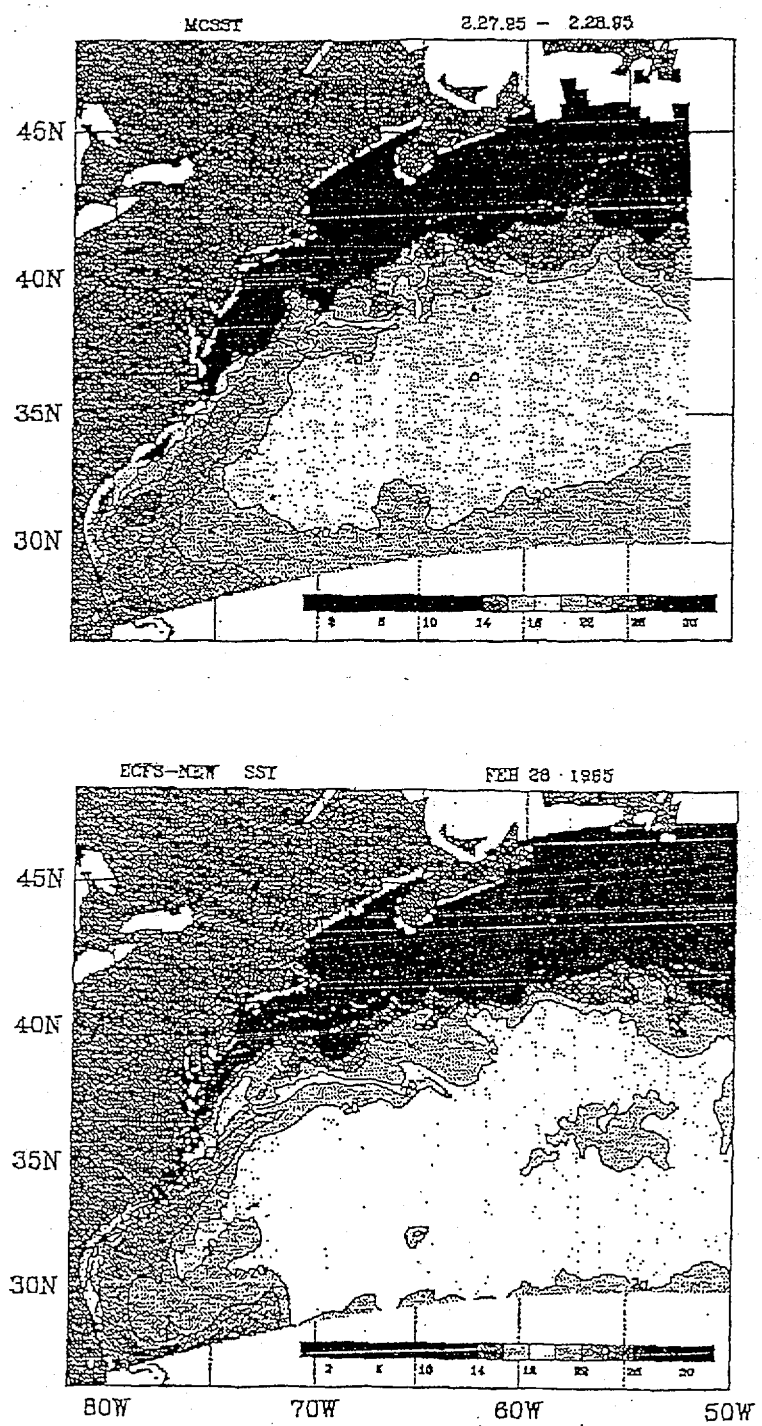

Figure 31. Observed (upper panel) and forecast (lower panel) surface temperatures on February 28, 1995.

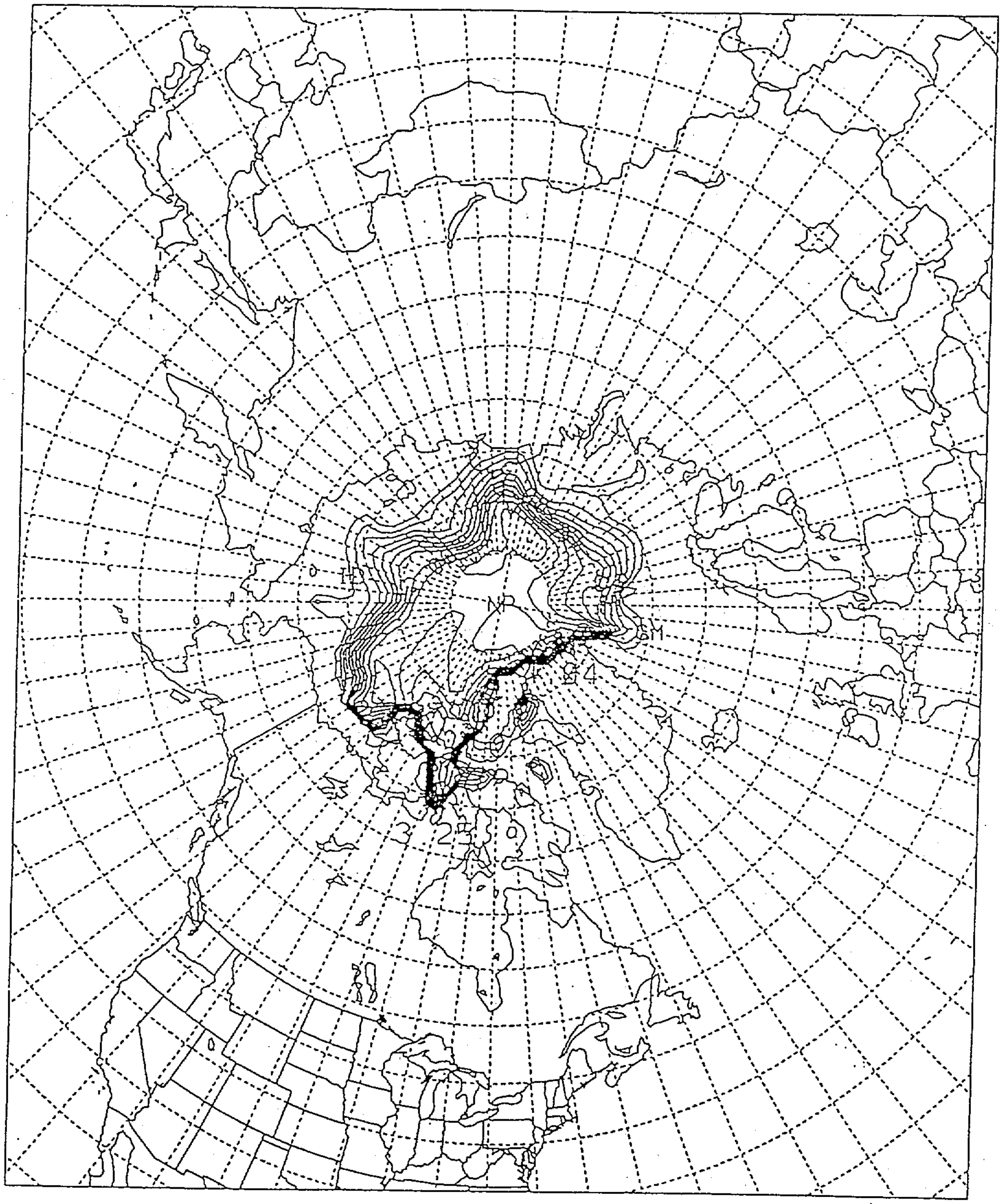

Figure 32. Experimental sea ice concentration chart for the Arctic region.

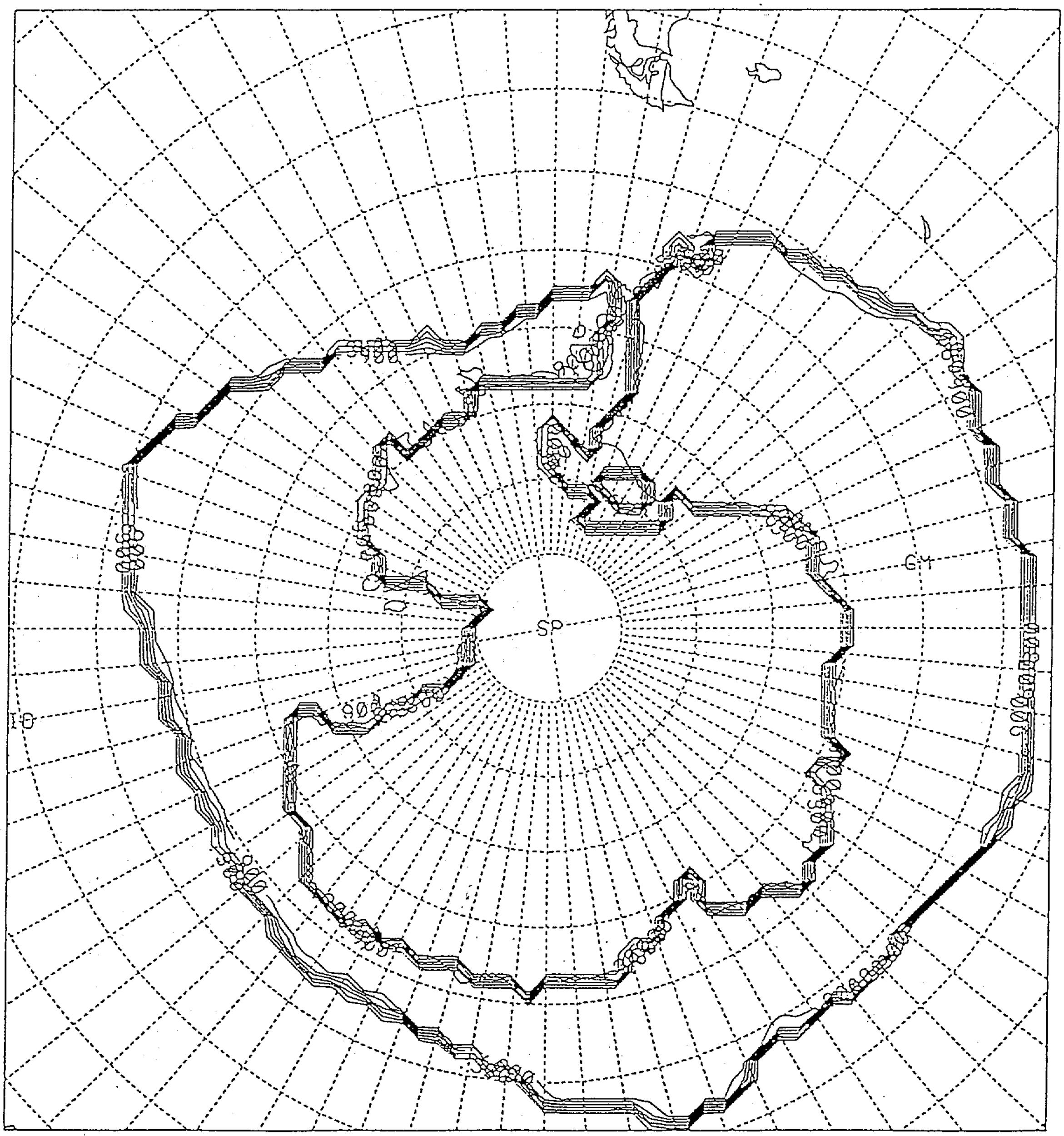

Figure 33. Experimental sea ice thickness chart for the Antarctic region.

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