A Review of the Program of the Ocean Products Center*

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ABSTRACT

The Ocean Products Center (OPC) represents a consolidation of personnel from different parts of the National Oceanic and Atmospheric Administration (NOAA). The purpose of OPC is to generate and disseminate various marine meteorological, and oceanographic analyses and forecasts. Emphasis is placed on using real-time data, analysis, and forecast fields from operational numerical weather prediction models to produce relevant products for marine applications. This article describes some of the operational products that are routinely disseminated to various users, and research activities for improving the quality of the operational products and the generation of new ones.

1. Introduction

The Ocean Products Center (OPC) was established in January 1985 and consists of personnel from the National Weather Service (NWS); the National Ocean Service (NOS); and the National Environmental Satellite, Data, and Information Service (NESDIS). In addition to the personnel from these organizations, the OPC staff is sometimes augmented, for limited periods, by the participation of National Oceanic and Atmospheric Administration (NOAA) Corps officers.

The responsibilities of the OPC include the generation and dissemination of analysis and forecast guidance products in the areas of marine meteorology and oceanography, evaluation of their performance, development of new and improved products, and the quality control of both selected oceanographic data for transmission on the Global Telecommunication System (GTS) and the datasets provided to appropriate archival agencies. The results of the OPC's efforts are used by the forecast offices of the NWS as well as research and commercial user communities.

The OPC is colocated with the National Meteorological Center (NMC) to obtain access to real-time data arriving at NMC via the GTS and NESDIS data links, to take advantage of the availability of analysis and forecast fields from the various operational numerical weather models, and to have access to data transmission and product dissemination systems. The products generated by the OPC are disseminated for use as guidance in meeting the individual responsibilities and interests of the user. In general, the OPC products, both global and regional, deal with time scales of hours to a few days.

In this article, attention will be focused on outlining a few details on selected products as they currently exist, providing a brief description of the ongoing research studies, and describing some of the operational aspects wherever necessary. Readers interested in more information on OPC's products should refer to Feit (1986).[1] The development activities and the resulting products are grouped into four categories: marine meteorology, ocean waves, ocean thermal structure, and polar and Great Lakes ice. The last activity is performed by the OPC in collaboration with the U.S. Navy at the Navy/NOAA Joint Ice Center (JIC). The extent of activities in each of the above groups, with respect to generation of products and development efforts, are quite dissimilar as will be seen from the discussion below. This article is, out of necessity, interspersed with many acronyms. For the convenience of the reader these are explained in the Appendix. References are made to large-scale operational atmospheric prediction models of NMC in several places in this article. Details on these models are provided in some of the other papers in this issue.

2. Marine meteorology

Operational products and ongoing research efforts in marine meteorology are primarily oriented towards

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[1] The NOAA and OPC technical memos referenced in this article can be obtained by writing directly to the author(s) at NMC, Washington, D.C., 20233.

using the analysis and forecast fields that are directly obtained from NMC's operational numerical weather forecast models. The National Meteorological Center runs global and regional models twice each day to provide large-scale forecasts of atmospheric variables. These models, however, do not provide wind, temperature, and humidity fields at the surface and the vertical resolution of these models is too coarse to take into account the profiles of these variables in the atmospheric boundary layer over the ocean surface. Therefore, additional physical or statistical relations must be applied to the numerical model forecasts to derive ocean surface forecasts. Some of these are described in section 2a. Further, the horizontal resolution of the numerical models is too coarse to adequately forecast the wind pattern in coastal areas where the influence of land and topography become important. However, improved forecasts have been provided by applying statistical methods that incorporate some local effects by relating model forecast variables to observations taken at points along the coast.

a. Operational products

1) Ocean surface winds

When the ocean surface wind (considered to be the wind at a height of 10 m above the sea level) forecasts were implemented in late 1985, the lowest sigma layer (LSL) of the global atmospheric prediction model of NMC had a thickness of 35 mb so that the lowest level winds are provided at approximately 175 m above the mean sea level (MSL). Hence, to determine winds at the ocean surface using the forecasts from the global model, the influence of both the constant flux layer and the Ekman layer had to be accounted for. Several techniques are available to perform such diagnostic calculations. Some of these were tested by Gemmill et al. (1988). The results of the study showed that, even though none of the techniques was clearly superior to the others, the one proposed by Cardone (1969) seemed to have a slight advantage over the others and therefore was adopted to produce ocean surface wind forecasts.

The LSL in the global forecast model was later reduced to 10 mb (in October 1986) with the result that the lowest layer winds are given at approximately 50 m above the sea level. Since this height can be considered, to a good approximation, to be in the constant flux layer, the winds are adjusted to the surface (after taking into account the air-sea temperature differences) by assuming a log profile relation. The 10-m winds deduced from the logarthmic reduction of the LSL winds proved to be better than those produced by the use of the Cardone method when compared with winds from fixed buoys. As an example, a comparison of the bias and the rms errors in the forecast wind speeds obtained from both methods is shown in Fig. 1. The wind direction forecasts also agree better with buoy

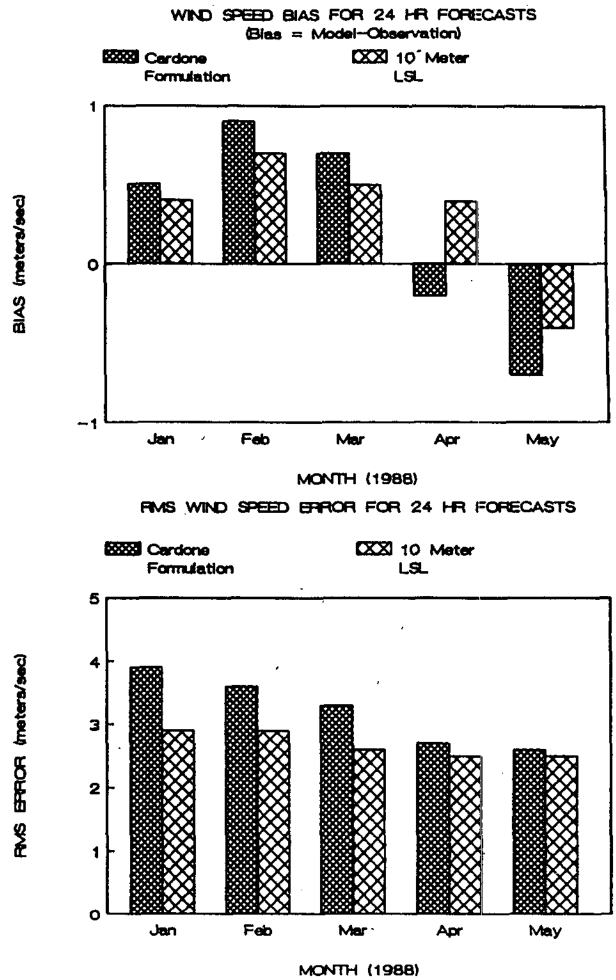

FIG. 1. Performance comparison of the Cardone model and the log profile reduction model for producing ocean surface wind forecasts.

data when the logarthmic profile method is used. The operational wind forecasts now use the logarthmic profile reduction.

A graphic representation of these surface winds is sent to field forecast offices on the automation of field operations and services (AFOS)[2] in two separate panels—one for each coast of the United States. An example is shown in Fig. 2. In addition, alphanumeric messages are sent out on AFOS covering the oceanic domain of the Northern Hemisphere. In using this wind forecast guidance, it should be noted that the winds are derived on a 2.5 × 2.5 lat/long grid from a global model and, as such, the guidance provided is more representative of the conditions over the open ocean and does not reflect the conditions at coastal regions.

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[2] AFOS is a NWS electronic communications network used to exchange information (data, messages, and graphics).

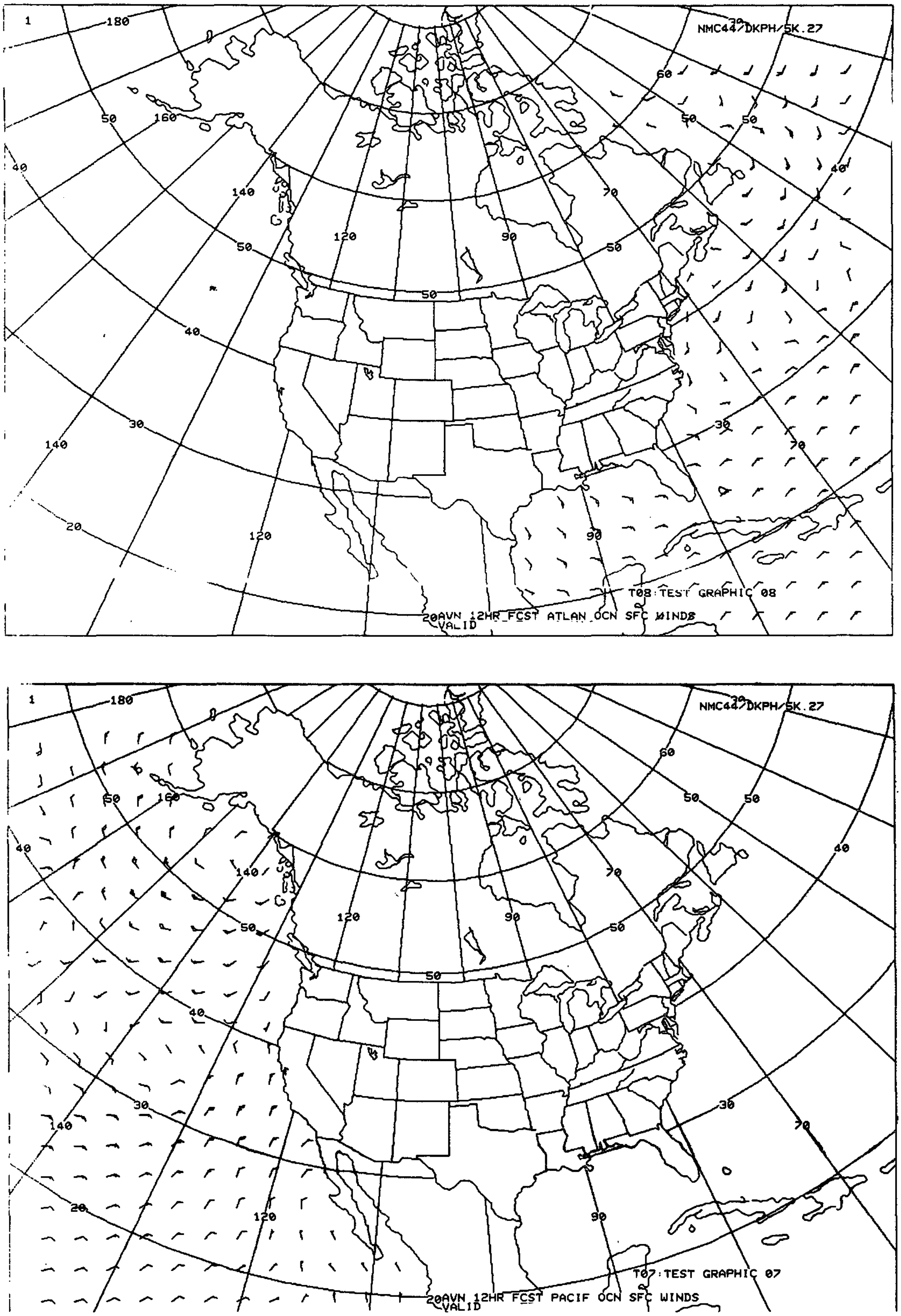

FIG. 2. A display of ocean surface wind forecast fields on AFOS for the East Coast (top) and the West Coast (bottom) of the United States.

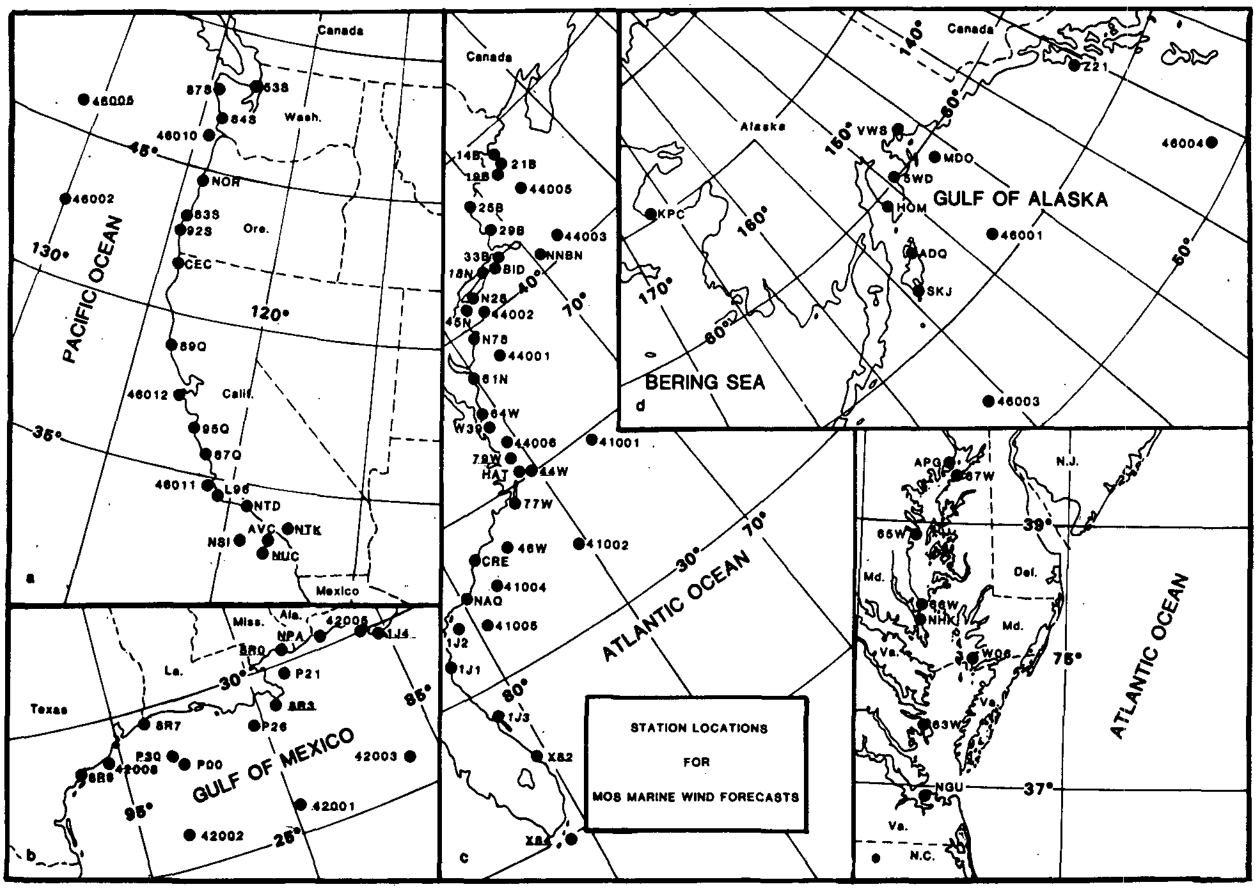

FIG. 3a. Locations of coastal points for MOS wind forecasts.

2) Coastal and Great Lakes winds

Because of the complex nature of wind circulation near the coast, statistical equations have been derived to provide wind forecasts at 91 coastal points for the coterminous United States and Alaska and 12 sectors on the Great Lakes (Fig. 3). The forecast equations were developed by using a regression analysis relating observed ship and buoy data to the limited-area fine-mesh (LFM) model's forecast fields interpolated to each of the coastal locations and Great Lakes sectors. The calendar year was divided into warm (April–September) and cool (October–March) seasons. Separate sets of equations were derived for each run cycle (0000 and 1200 UTC), season (warm or cool), and projection (6–48 h) at 3-h intervals for coastal locations and 6-h intervals for Great Lakes sectors. The statistical approach has the advantage of relating model forecasts to surface winds by taking into account "local" effects as well as systematic errors from the forecast model (Feit and Pore 1978; Burroughs 1982). The forecasts are disseminated twice daily over AFOS and several teletype circuits.

3) Open ocean sea fog

There are physical hazards at sea that are not direct forecast variables of the weather prediction models, but can be derived from the model fields using empirical relations. Fog is one such element, but it is not a parameter of numerical prediction models. A fog guidance product is clearly needed since approximately 80% of the accidents at sea occur with visibilities <1 km.

A statistical technique referred to as the "perfect prognosis" technique was used to develop the fog and visibility forecast equations. In this technique, the prediction equations are derived using the gridded analysis fields (as opposed to forecast fields) from a numerical model. Predictand data were obtained from ship observations. Ship data at 12-h intervals were obtained for the period 1980–84. Fog was designated either when it was observed in any form, or when drizzle was observed and the past weather indicated fog with reported visibility less than 1 km. The visibility data were corrected to be consistent with observed weather and the World Meteorological Organization (WMO) code and to include poor visibility due to fog. The predictor data

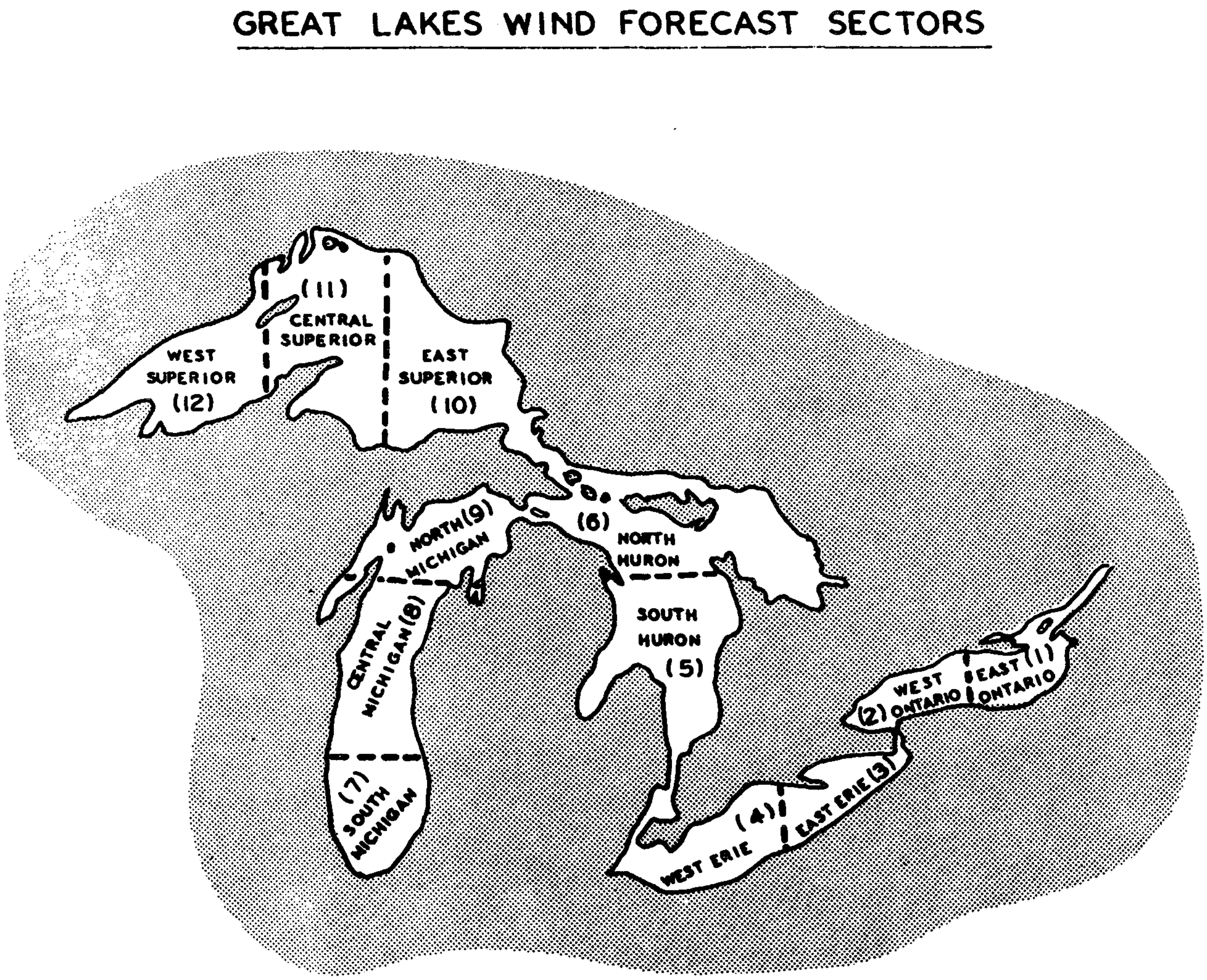

FIG. 3b. Delineation of the Great Lakes regions for MOS wind forecasts.

were obtained from NMC's Global Data Assimilation System (GDAS).

Discriminant analysis techniques were used to derive the prediction equations. These forecasts are produced only for the warm season (April–September), and apply only to the high seas and not to coastal or in-shore areas (Burroughs 1989). The reason for this is that not enough data (ship observations) are available to develop reliable statistical prediction equations. Fog and visibility forecasts are produced twice daily (0000 and 1200 UTC) out to 72 h. The forecasts depicting areas of visibility less than 3 nmi and areas of fog are incorporated on the Significant Marine Weather Chart [described in section 2a(5). below].

4) SUPERSTRUCTURE ICING

Another hazard to shipping is icing on the superstructure of ships. This is an extremely difficult problem to address because the rate of icing on the superstructure and the subsequent threat it poses to a ship's operation are very much dependent on the size and shape of the ship and its heading with respect to the prevailing wind and sea state. The data available on ship icing are few and tend to be qualitative. Nevertheless, since it is a hazard of significant proportions, there is a need to develop forecast guidance on icing.

Using the best available data, a statistical relation was developed by Overland et al. (1986) to estimate the amount of icing on the ship superstructure (in centimeters per hour), using air temperature, wind speed, sea surface temperature (SST) and the freezing point of sea water. The air temperature and wind speed forecasts are taken from the medium range forecast (MRF) model. The SST is taken from OPC's analysis (see section 4a). A typical example of an ice accretion forecast is shown in Fig. 4 and applies to the Alaskan region. For further details, refer to Feit (1987). Such a forecast

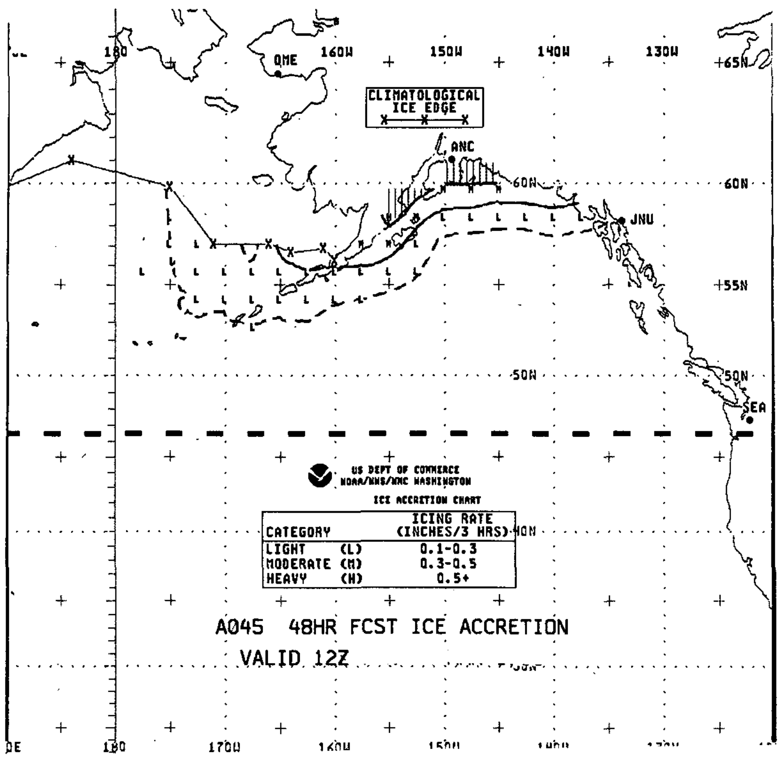

FIG. 4. Example of a ship icing forecast chart for the Alaskan region.

chart depicting the domain and severity of expected icing could be most useful in finding the shortest route out of an icing region and in avoiding hazardous areas. These forecasts are issued once a day out to 48 h during the icing season. The forecasts are now extended to include the polar waters of the Northern Hemisphere.

5) SIGNIFICANT MARINE WEATHER CHART

This is a summary chart that uses operationally produced forecasts and analyses to depict regions of hazard to the mariner in the Northern Hemispheric oceans. Hazardous regions are identified as regions where winds are ≥25 kt, waves are ≥8 ft, they are covered by sea ice, there is potential ship icing, and they have low visibility and fog. An example of the chart is shown in Fig. 5. This chart is produced interactively to delineate the various domains before transmission on the AFOS and helps to quickly identify potentially problematic areas in the Northern Hemisphere oceans.

b. Development activities

The model output statistics (MOS) coastal winds and the Great Lakes wind forecasts were implemented several years ago and are based on the LFM model (Newell and Deaven 1981). The MOS equations are based on a specific model and any change in the forecast model requires a rederivation of the MOS equations. Since there has been a continual evolution in the global and regional operational forecast models at NMC, it has been decided to reevaluate the coastal and Great Lakes wind forecasts with a goal to developing "perfect prog" equations to be used with the new operational nested grid model (NGM) of NMC. The reason for going to the perfect prog procedure is to make the equations derived for forecasts independent of changes in the large-scale meteorological forecast model. Also, the locations of the coastal forecasts will be reexamined to better fit requirements and availability of data. Other developments include extension of superstructure icing forecasts to the Great Lakes after the new wind forecast equations have been developed, and the development of a dynamical prediction system for coastal fog.

Studies are also in progress to explore ways of utilizing the measurements of ocean surface winds from satellite-borne sensors such as altimeters and scatterometers. A technique has been developed by Yu (1987) to derive wind direction by applying a theoretical framework based on bulk Ekman dynamics and NMC's sea level pressure analyses to the wind speed measurements from an altimeter. Results of the study are encouraging when evaluated using buoy measurements. This ability to obtain wind direction from scalar speed measurements enhances the use of the data pro-

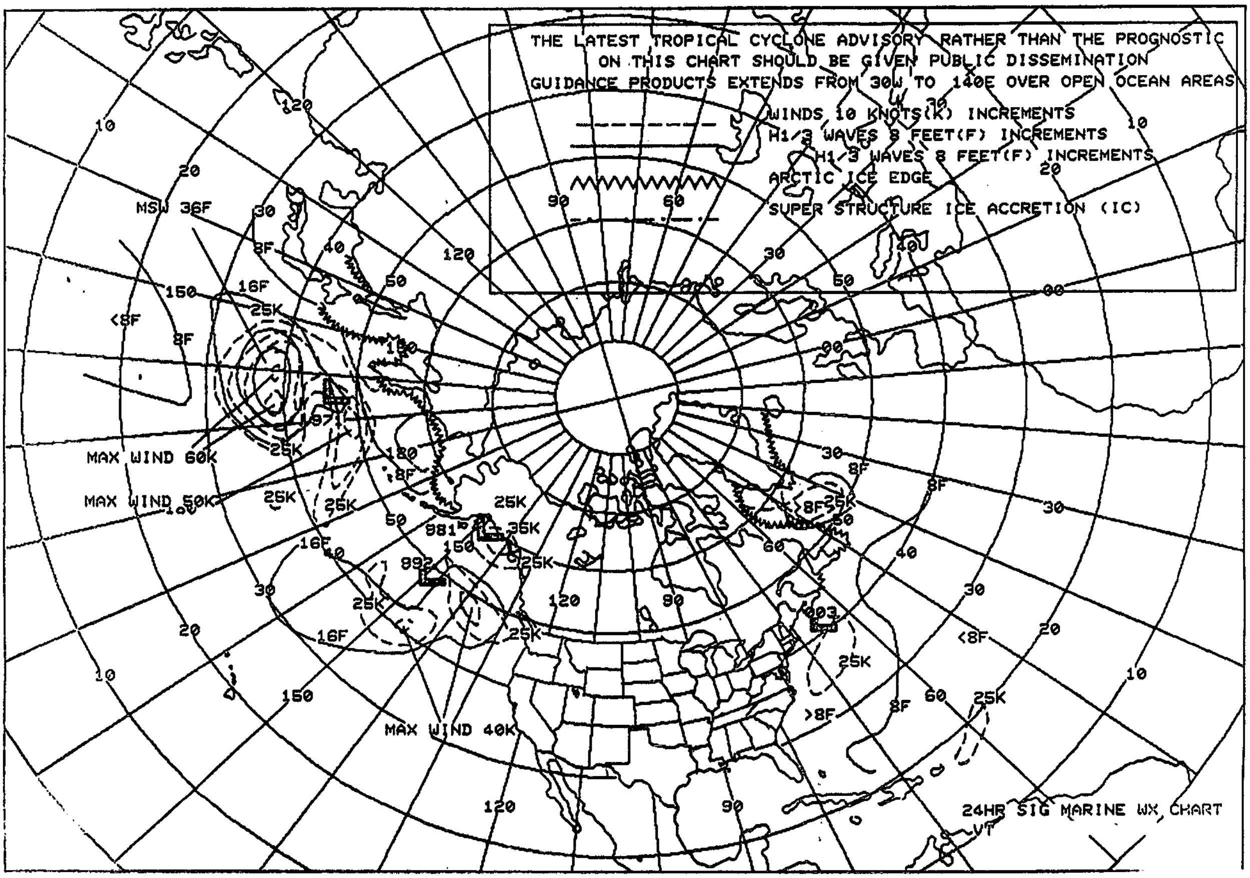

FIG. 5. Sample of a significant marine weather chart as it appears on AFOS.

vided by the altimeters, particularly for the ocean wave prediction studies. The method also provides a simple way to resolve any ambiguities in vector wind retrievals from future scatterometers.

Previous studies (e.g., Yu and McPherson 1984) on the impact of assimilating scatterometer winds from SEASAT in numerical weather prediction models have not been particularly encouraging. However, since the advent of SEASAT, the analysis and prediction models at NMC and elsewhere have undergone substantial improvements. Hence, the question of the impact of satellite measurements on the present generation analysis/prediction systems is being jointly studied with the Goddard Laboratory for Atmospheres.

3. Ocean waves

Prior to the establishment of OPC, NOAA used empirical methods essentially based on the work by Munk and Sverdrup (see Hubert 1964) to produce global and regional ocean wave forecast guidance. This technique provides information on significant wave heights due to swell and locally generated wind sea but does not provide information on the wave spectrum. The state of wave forecasting has gone through significant advances with the development of the first, second, and third generation models (see The Sea Wave Modeling Project (SWAMP) Group [1985] report for a review), and the demand for forecasts based on spectral wave dynamics has been increasing. Hence, a systematic effort was initiated to replace the empirical techniques with the modern methods of wave forecasting. Initial efforts started with development and verification of a global deep water spectral model, a regional shallow water spectral model for the Gulf of Mexico, and preliminary experiments with satellite measured wave data assimilation.

a. Operational products

1) GLOBAL MODEL

The NOAA ocean wave (NOW) model became operational in November 1985. The model solves the spectral energy balance equation with three source terms—energy input from the wind, a parameterized nonlinear interaction term, and energy dissipation due to waves running on to a coast or against the wind.

The model runs daily and forecasts the directional wave spectrum in 24 directional bands (each 15 deg wide) and 15 frequency bands every 3 h out to 72 h. Spectral estimates are available on a 2.5 × 2.5 lat–long grid from 70°S to 75°N. The latitudinal extent is controlled by the Arctic and Antarctic ice edges. Products from the model are distributed on AFOS in the form of graphic contours of significant wave height (SWH) and an alphanumeric spectral bulletin. The model runs daily on the 0000 UTC cycle.

From its implementation date through April 1988 the wind forcing in the model was the 19.5 m height winds derived from the NMC's global spectral atmospheric prediction model fields using Cardone's method (see Gemmill et al. 1988). As of May 1988, the wind field provided to the wave model was obtained directly from a logarthmic reduction of the LSL winds from the global meteorological forecast model for reasons mentioned earlier.

2) REGIONAL MODEL

A regional spectral ocean wave model—NOAA regional ocean wave (NROW) model—applicable for both deep and shallow waters of the Gulf of Mexico was implemented in August 1988. This model is an adaptation to the Gulf of Mexico of the model developed by Duffy and Atlas (1984) to predict the waves associated with the *QE II* storm in the Atlantic. It treats the Gulf of Mexico as an enclosed basin. This model also solves the spectral energy balance equation as in the global model, but unlike the global model, it takes into account the effects of the ocean bottom. The dissipation term in this model includes energy loss due to white capping and bottom effects. Bottom effects included are refraction, bottom friction, and percolation. For details on the treatment of the various processes and numerical schemes, see Chao (1988).

The wind field used to drive the model is the wind at 10 m above the sea surface. These winds are derived from the wind and air temperature forecasts of the NGM. Since the NGM has a 35 mb thick LSL, a modified boundary layer model of Cardone is used incorporating stability effects due to air-sea temperature differences. The model has 20 frequency bands from 0.04 to 0.42 Hz and twelve directional bands. Daily forecasts are made on a grid mesh of 53 km at 3 h intervals to 48 h. The forecasts of significant wave height contours, peak energy frequencies and directions for every 12 h of the forecast period are sent over AFOS. The model forecasts are produced twice a day on the 0000 and 1200 UTC cycles.

b. Development activities

The global model is being verified against the NOAA buoy network, the U.S. Navy global spectral ocean wave model (GSOWM), and the GEOSAT altimeter to evaluate and improve its performance. Comparisons of the monthly bias and rms errors between the NOW and the buoys, and the GSOWM and the buoys are given in Fig. 6 (July 1987–February 1989). In May 1988, the wind field was changed to the lower sigma layer winds, which appear to have reduced the rms

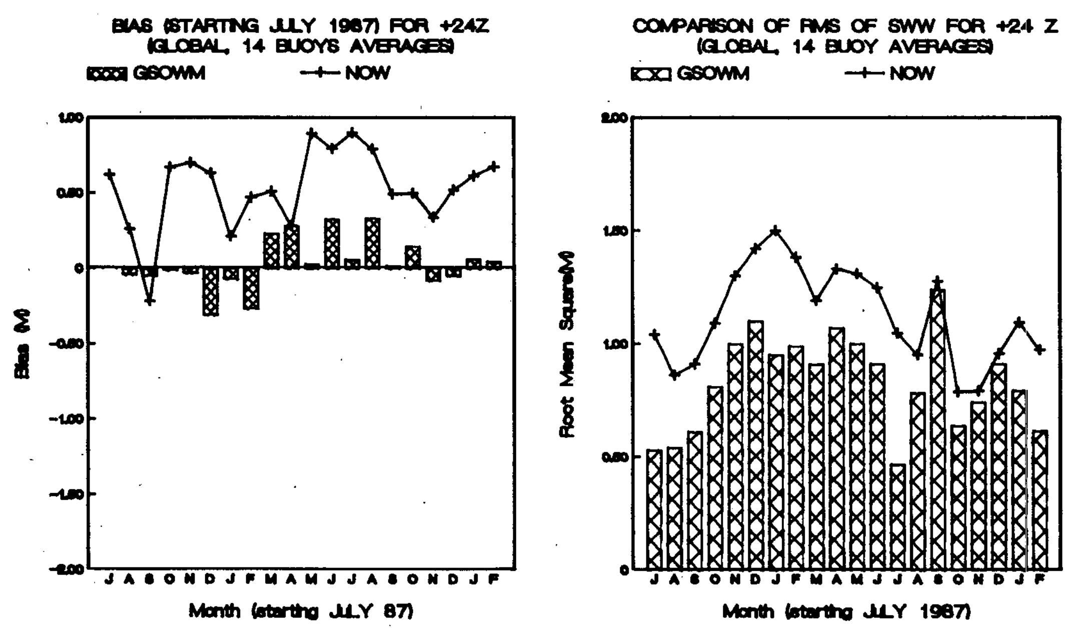

FIG. 6. Bias (left) and rms error (right) for the NOW and GSOWM model forecasts computed from the NOAA buoy data.

error but increased the bias. This increased bias was found to be due to insufficient attenuation of the upwind swell in the NOW model. A swell attenuation factor was added to the model in June 1988 and further tests are being carried out to improve its performance.

Statistical error analysis is performed for SWH forecasts for the regional NROW model, and that of the NWS's Techniques Development Laboratory (TDL). The wave heights forecasted by the models are interpolated to the buoy locations at various forecast projections for this purpose. Figure 7 shows a comparison of the performance of the 24-h forecasts from the NROW and TDL models at a shallow-water buoy in the Gulf from October 1987–February 1989. The superior performance of the NROW model in shallow water is evident. In August 1988 NROW became the operational model and the TDL model was discontinued. Further work is continuing to improve the performance of the NROW model in deep water. In view of the fact that the southern boundary of the innermost grid of the NGM is very close to the southern boundary of the Gulf of Mexico, it is possible that errors in wind forecasts could be propagating into the domain of the gulf over the forecast period due to boundary effects. Hence, the differences in the wave forecasts produced by wind fields derived as mentioned above from the NGM and those derived from the global forecast model's LSL winds (via log profile reduction) are also being examined.

One of the serious deficiencies of ocean forecast models is the lack of adequate data for initializing the model at each forecast cycle as is done in meteorology. Consequently, both the global and regional wave forecast models are normally integrated in time for a few days—typically 3 to 5 days—using analyzed atmospheric winds to generate waves starting from flat seas before the model is put into an operational mode. In the operational mode, the wave forecasts are produced using the wind forecasts from the NWP models. Subsequently, each forecast cycle is started by bringing the initial wave fields from the previous cycle forward to the present time by using analyzed winds. Consequently, the operational wave forecast models are not influenced by measurements of wave heights (or wave spectra). Thus, any errors in the initial wave fields are not rectified.

With the advent of SEASAT and GEOSAT missions, the ability of satellite borne altimeters to provide reliable global measurements of wave heights and sea surface wind speeds has been established. Hence, in order to exploit future altimetric measurements that would potentially be available from the planned European ERS-1 and Japanese JERS-1 satellite missions, experiments have been conducted to assess the impact of assimilating wave height data from the SEASAT and GEOSAT into the NOW model. Two separate studies were conducted, one using only the wave height measurements and the other using both the wind speed and wave height measurements in initializing the model. Both of these studies have shown significant improvements in the model performance, thus establishing a firm basis for the operational use of future

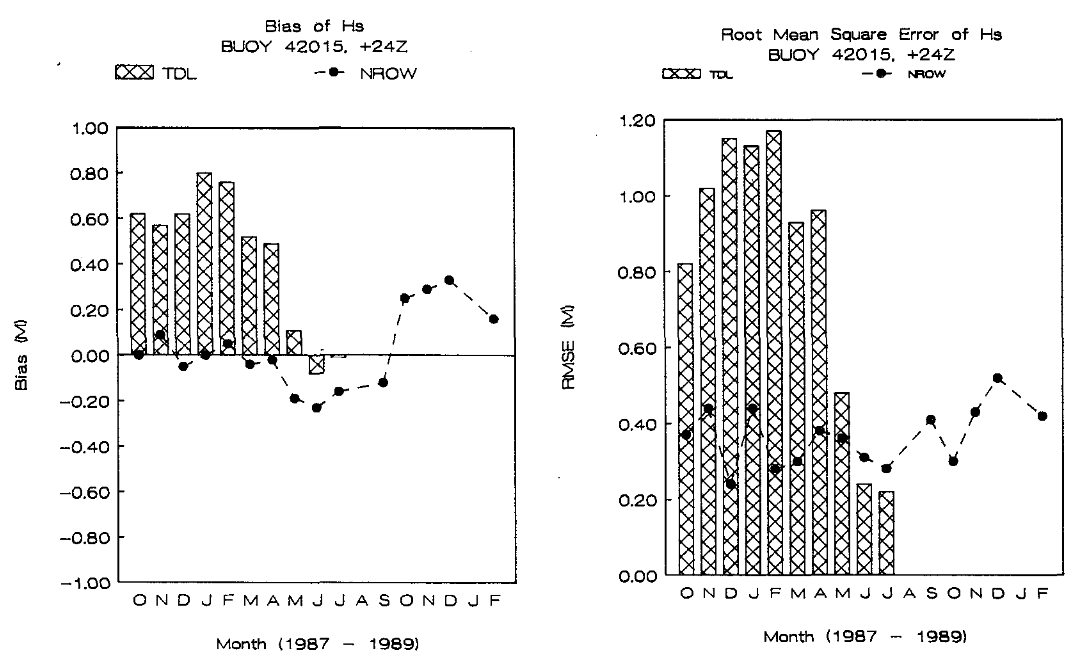

FIG. 7. Comparison of the performance of the TDL and NROW models in shallow water of the Gulf of Mexico.

altimetric data to provide better wave forecasts. See Esteva (1988) for a discussion of some of these experiments.

4. Ocean thermal structure

A major responsibility of the ocean thermal structure group is the production of various global and regional SST analyses. The SST products involve both blended analyses, which combine in situ (from ships, fixed buoys, drifting buoys, etc.), and satellite data, and satellite-only analyses. These products are distributed to a wide range of users including the forecast offices, private sector users, and research communities. Also, the group supports the Tropical Ocean and Global Atmosphere (TOGA) Program activities to fulfill NMC's role as the International TOGA-SST Center and the Integrated Global Ocean Services System (IGOSS) activities to satisfy NMC's role as a World Oceanographic Center (WOC).

a. Operational products

1) Global blended SST analysis

In producing the daily SST maps, all in situ data from ships and fixed buoys and satellite data collected during the last 15 days are used. The in situ and satellite data are independently averaged in 2 deg × 2 deg boxes globally, and analyzed by a technique developed by Reynolds (1988). No data from drifting buoys are used because location and time histories are required to ensure positional accuracy of the data and this is not easily accommodated in real time. A sample of the daily analysis is shown in Fig. 8. This SST field is used in the operational numerical weather prediction models of NMC as well as by the European Centre for Medium Range Weather Forecasts (ECMWF), which receives the data over the GTS.

The TOGA product is essentially the same as the daily SST product except that it is produced once a month and incorporates screened drifting buoy data after quality control checks have been made. Monthly SST maps are provided to the participants of the TOGA program each month. Once every 6 months, tapes of data and gridded analysis fields, as well as charts, are sent to the World Data centers (A and B) as required by the International TOGA Project Office.

2) Satellite-only analyses

Satellite data analysis techniques make use of two thermal infrared (IR), one near IR, and one visible channel on the advanced very high resolution radiometer (AVHRR) aboard NOAA's polar orbiting satellites. Combinations of channel sums, differences, and ratios are used to screen for clouds and calculate SSTs using algorithms described by McClain et al. (1985). Globally, approximately 75 000 daytime and 25 000 nighttime observations of SST are acquired daily at a resolution of 4 km from NOAA's polar orbiting satellites. The observations are box-averaged to 8 km and objectively analyzed on different spacial scales to provide gridded SST fields from which contoured charts are produced. A 100-km global analysis is updated daily. Five regional analyses for waters adjacent to the United States are produced weekly at 50-km resolution. Seven local analyses in the coastal areas of the contiguous United States are produced twice a week at 14 km resolution (see Fig. 9 for locations of these areas).

3) Ocean feature analysis

The OPC produces an ocean-feature analysis chart 5 days a week. This chart, depicting surface characteristics, is produced through subjective analysis of all available satellite IR imagery and in situ data to locate ocean features such as the Loop Current, north wall of the Gulf Stream, warm and cold core eddies, shelf/slope front, warmer and cooler slope and shelf waters, and Sargasso Sea water, etc. The chart is divided into two regional charts: 1) the southeast United States Atlantic Coast and Gulf of Mexico showing the Loop Current and Gulf Stream from the Yucatan Peninsula to Cape Hatteras, North Carolina, and 2) the northeast Atlantic Coast showing the Gulf Stream from Cape Hatteras to the Grand Banks south of Newfoundland. The charts are analyzed on alternate days, twice each week and thrice each week, respectively, and the analysis sent over radiofax. This analysis is extensively used by boating, shipping, and fishing communities. An example of the north panel is shown in Fig. 10.

4) Other products

There are several regional SST analyses that are routinely produced by OPC that have not been discussed here. For further details see Feit (1986).

In the area of subsurface observations, NMC is designated as a WOC in the IGOSS program. In this role, it has a responsibility to collect all expendable bathy thermograph (XBT) data gathered by American ships, perform any quality control needed to correct errors, and transmit them on the GTS to other participating nations in the program. At the end of each month, it is also responsible for providing the National Oceanographic Data Center (NODC) with quality controlled XBT data transmitted over the GTS by all the participating nations.

b. Development activities

The OPC operationally produces several regional blended SST products and a subjectively analyzed 100 m subsurface analysis in the northeast Pacific region. Studies are underway to investigate new analysis methods based on optimum interpolation techniques to replace existing procedures.

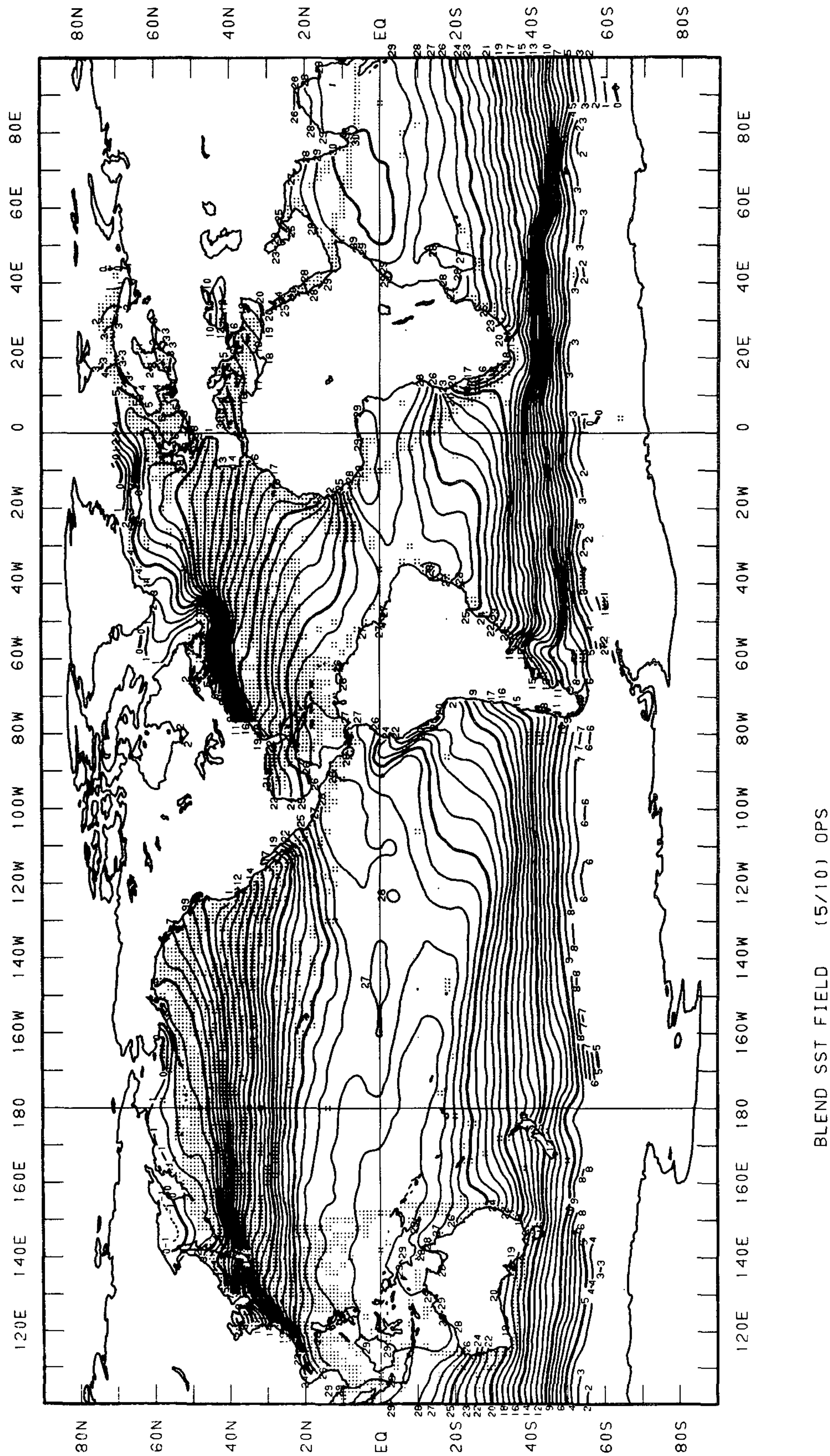

FIG. 8. Example of a daily blended global SST analysis.

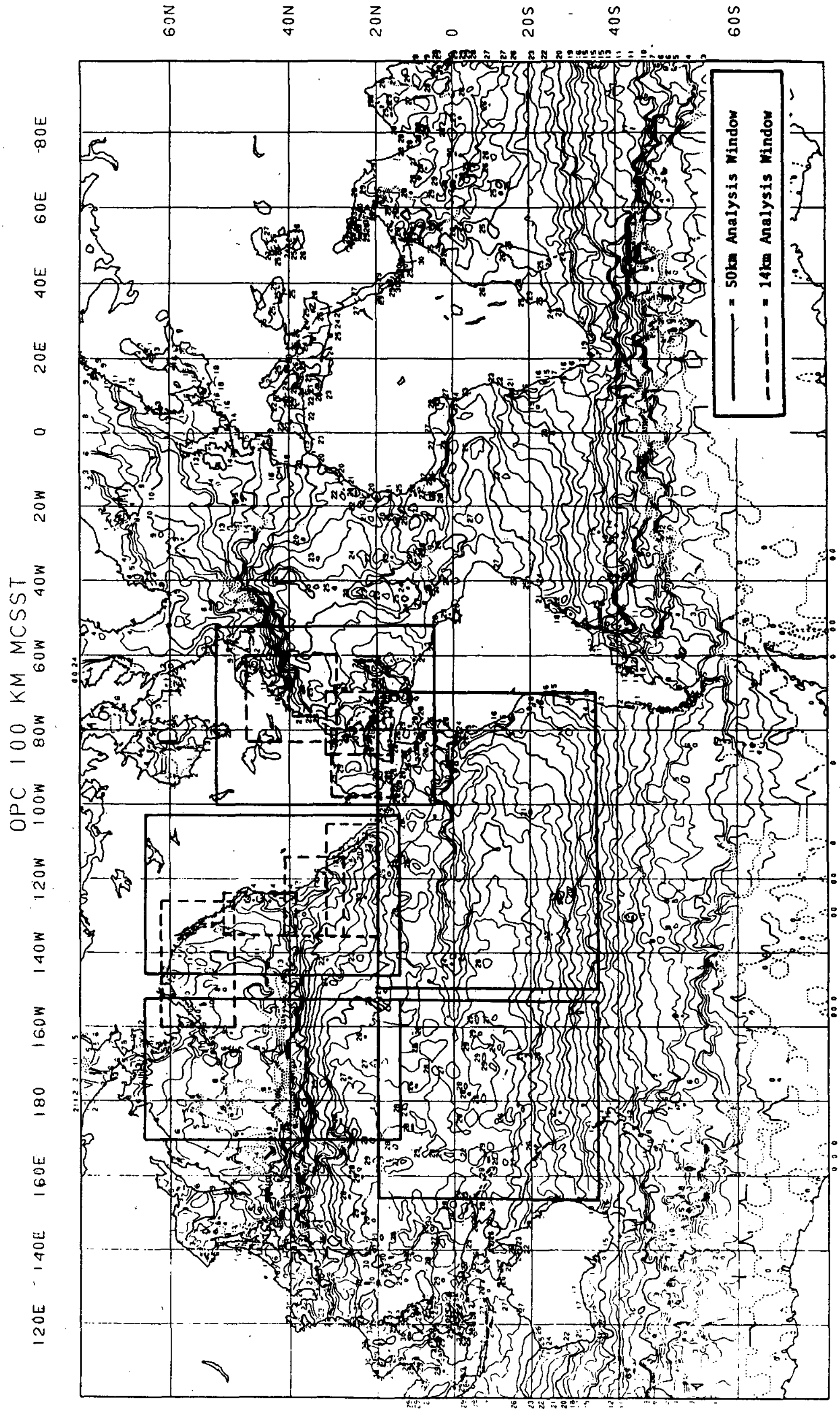

FIG. 9. Example of a 100-km resolution satellite-only SST analysis. On this chart, boxed areas indicate where regional satellite only analyses are performed.

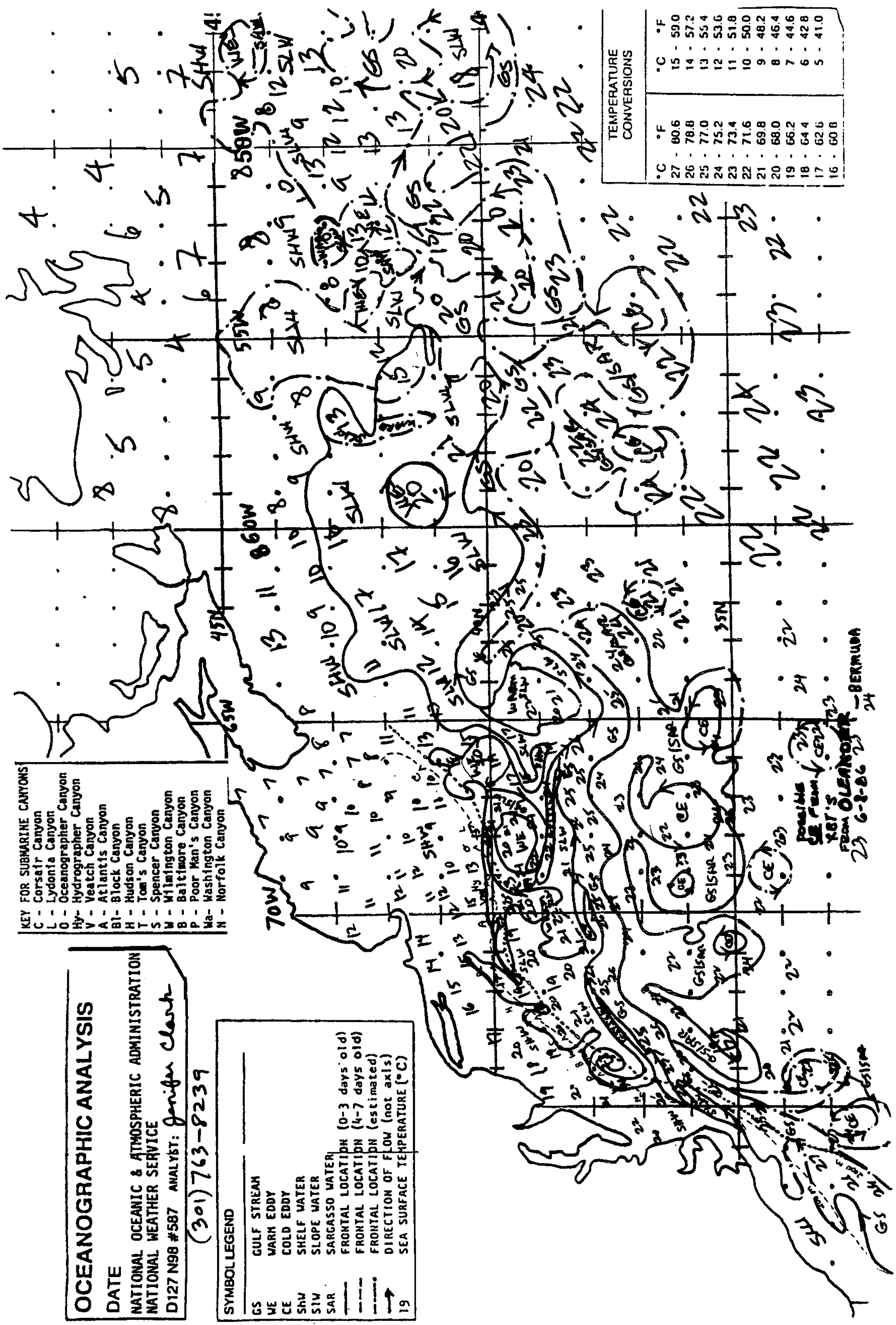

FIG. 10. Ocean feature analysis chart for the northeast Atlantic.

Surface temperature analyses are produced manually for the Great Lakes during ice free periods of each year. The Great Lakes analysis is not automated because of the poor land/sea coastline data currently available. However, a high-resolution digitized coastline for the Great Lakes has been acquired and the analysis technique used for the 14- and 50-km products will soon be applied for the Great Lakes with a 7-km resolution.

A PC-based interactive image processing system has been developed to allow objective analysis of ocean features mentioned earlier (and also ice analysis). The analysis is based on high-resolution (1.1 km/pixel) imagery in near real-time from the AVHRR. This capability is global, allows for image compositing, and was specifically developed to enhance the current methods of producing both the ocean feature analysis and the Great Lakes surface temperature analysis. These new guidance products will be distributed over telecopiers or as a digital data/character stream.

5. Polar and Great Lakes ice

NWS/NOAA is responsible for providing sea ice analyses and forecasts for the Alaskan region through the Anchorage Weather Service Forecast Office (WSFO), and ice analyses and forecasts to the Great Lakes region through the Cleveland WSFO. These specific responsibilities and other global and regional aspects of sea ice analyses and forecasts are met by OPC through its participation with the U.S. Navy in the activities of the Navy/NOAA JIC. The JIC is part of the Navy Polar Oceanography Center. A brief description of the unclassified products resulting from this joint effort is presented in section 5b.

a. Data sources and interpretation

Satellite image products are the primary source of sea ice data at the JIC. Satellite images are received from the NOAA polar orbiting series as well as from the Defense Meteorological Satellite Program (DMSP) series. These images are presently manually analyzed on gridded overlays, but soon an automated system will be operational. This new system is the PROFS equipment with tailored software for the JIC missions. Sea ice information is also derived from the passive microwave sensor—special sensor microwave imager (SSMI)—on-board the DMSP satellite. It provides ice concentration information. Limited but accurate sea ice edge location information is obtained from the GEOSAT satellite. Finally the JIC also receives observations from aerial reconnaissance missions conducted by the Canadian Atmospheric Environment Service (AES) and the U.S. Navy, ships, and shore stations. Additional observations are received from a Danish program in the Greenland region and from a German program which compiles ice observations from all the nations bordering the Baltic Sea. Drifting buoy tracks are employed, when available, to infer ice motion on scales that cannot be easily resolved from satellites. Ice motion information is generally most useful in sea ice forecasting but it is also employed in estimating sea ice boundaries when cloud cover persists over a region from days to weeks in some cases. In addition to sea ice data, the JIC makes extensive use of meteorological observations and forecasts received from NMC and Fleet Numerical Oceanography Center (FNOC). Weather data and SST analyses directly aid the ice analyst in estimating the rate of sea ice growth, decay, and motion.

The Great Lakes ice analysis is produced in much the same manner as the sea ice analysis. However, NOAA satellite imagery and the Canadian AES comprise nearly all of the data. Passive microwave algorithms are tuned for sea ice and are not as accurate over the Great Lakes. Their coarse resolution further limits their usefulness. The JIC sends the completed Great Lakes chart to the Cleveland Forecast Office where it is modified to include shore station reports received over local communication networks.

b. Operational products

Each week the JIC issues a set of charts illustrating the extent and concentration of sea ice. Two charts are issued for the Arctic and one for the Antarctic. An example is shown in Fig. 11. These charts are distributed by mail, telefax, and radiofacsimile. Special ice analyses—produced for the Alaskan and Great Lakes regions—are telefaxed to NWS forecast offices in Anchorage and Cleveland, respectively. Figure 12 shows the Alaska regional product. For users unable to receive a graphic product, the JIC creates a text message delineating the ice edge and boundaries found on the charts.

Routine forecasts are also issued on a 7- and 30-day basis. A 7-day forecast is produced for the Arctic each week in message format and a 30-day forecast in graphic format is drawn for the Northern Hemisphere every 2 weeks based upon the predictions of the Climate Analysis Center. Antarctic forecasts are issued on a similar basis, but only for the Ross Sea during the austral summer. Once each year the JIC produces a seasonal outlook for the Alaskan, Baffin Bay, and Ross Sea regions. These forecasts indicate the date of breakup and beginning of the shipping season several months in advance, relying upon statistical methods. These outlooks are made available through the mail.

The JIC routinely supports ships at sea anywhere ice poses a threat. Support is generally intended for United States government supported vessels and those of allied nations. However, in cases where there is a clear danger to a vessel or where other support is un-

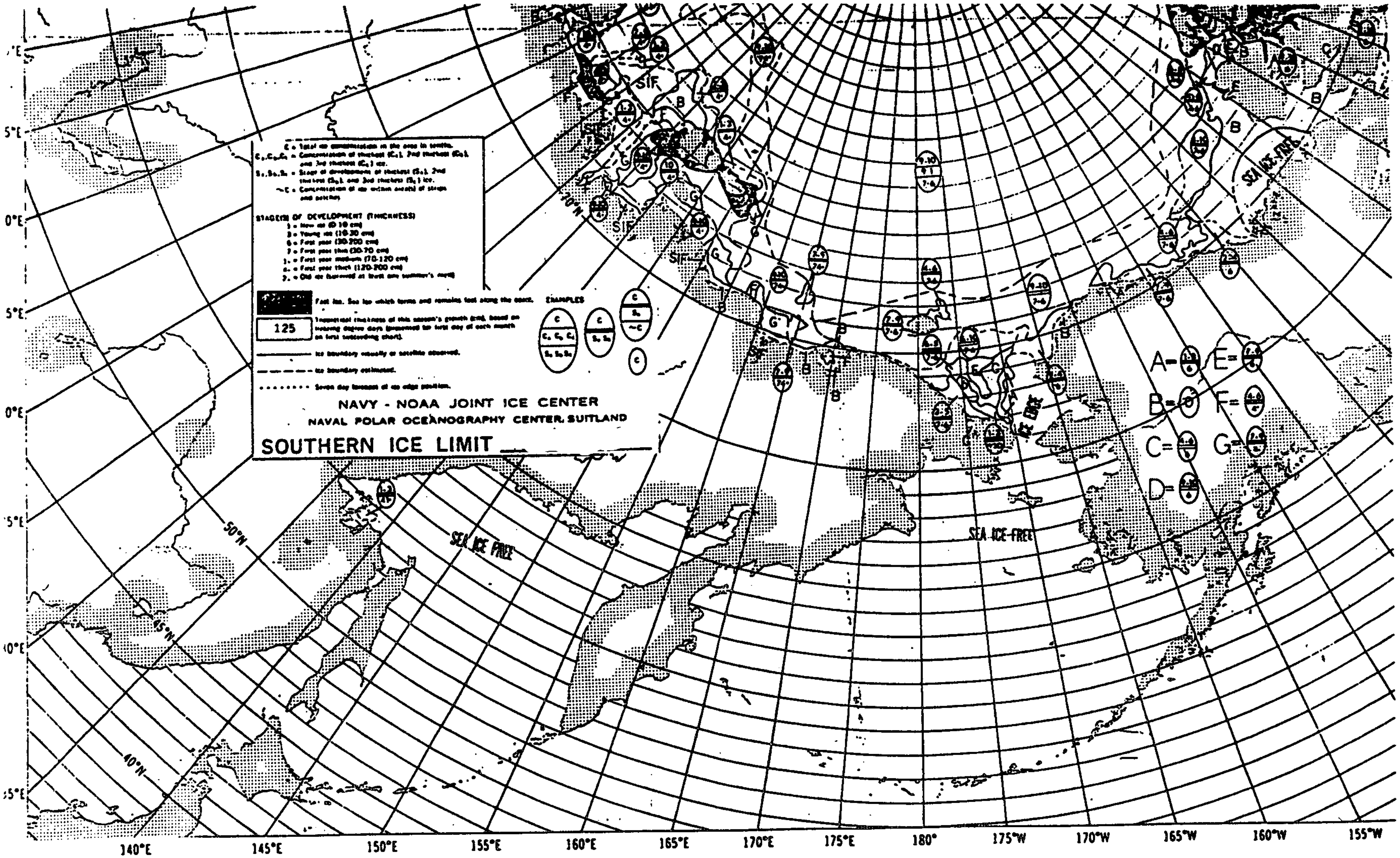

FIG. 11. Arctic sea ice analysis chart (western).

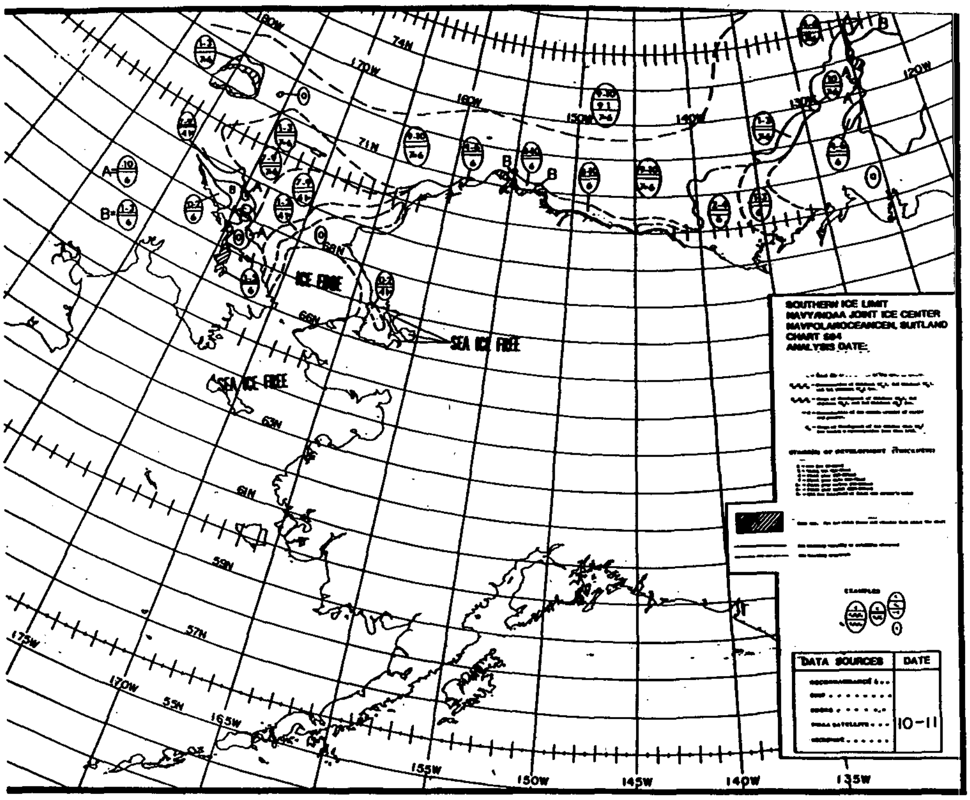

FIG. 12. Alaskan regional analysis chart.

available (especially in the Antarctic), the JIC will provide support directly to any vessel that requests help.

c. Development activities

The JIC is participating in the development of more accurate sea ice algorithms for the SSMI instrument now being flown on the DMSP satellite. The SSMI and the new passive microwave instrument, the advanced microwave sounding unit (AMSU), designed for the future NOAA polar orbiting satellites, promise to be the mainstay of global sea ice work until the advent of an operational active synthetic aperture radar (SAR) system.

The JIC is working with NASA and the Alaska SAR facility to transmit the SAR image products collected by future European ERS-1 and Japanese JERS-1 research satellites. These products will be used in a demonstration of the ability of SAR to improve the sea ice analysis capabilities of the JIC in the Alaskan region.

Dynamic models including ice mechanics are under development for use on regional scales at the Naval Oceanographic Research Facility (NORDA) and the Pacific Marine Environmental Laboratory (PMEL) and on a global scale at NORDA. These efforts should greatly enhance the JIC's short term ice forecasting capabilities.

6. Summary

This article has presented an outline of the marine meteorological and oceanographic activities of the OPC with some descriptions of selected operational products and a discussion of some of the research activities in progress. The compendium (Feit 1986) will be updated periodically to report on development of new products or changes incorporated into existing products to improve their quality of performance.

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APPENDIX

List of Acronyms

AES	Atmospheric Environment Service (Canada)
AFOS	automation of field operations and services
AMSU	Advanced Microwave Sounding Unit

AVHRR	advanced very-high resolution radiometer
DMSP	Defence Meteorological Satellite Program (U.S. Air Force)
ECMWF	European Centre for Medium-range Weather Forecasting
ERS-1	Environmental Remote-sensing Satellite (of ESA)
FNOC	Fleet Numerical Oceanography Center
GEOSAT	geodetic satellite (U.S. Navy)
GSOWM	global spectral ocean wave model (of U.S. Navy)
GTS	Global Telecommunication System
IGOSS	Integrated Global Ocean Services System
JIC	Joint Ice Center (a U.S. Navy/NOAA operation)
JERS-1	Japanese ERS-1
LFM	limited area fine mesh model (of NMC)
LSL	lowest sigma layer
MOS	model output statistics
MRF	medium range forecast model (of NMC)
NASA	National Aeronautics and Space Administration
NESDIS	National Environmental Satellite, Data, and Information Service
NGM	nested grid model (of NMC)
NOAA	National Oceanic and Atmospheric Administration
NODC	National Oceanographic Data Center
NORDA	Naval Oceanographic Research and Development Activity
NOS	National Ocean Service
NOW	NOAA's ocean wave model
NROW	NOAA regional ocean wave model
NWS	National Weather Service
PMEL	Pacific Marine Environmental Laboratory (of NOAA)
rms	root mean square
SAR	synthetic aperture radar
SEASAT	SEA Satellite
SSMI	special sensor microwave imager
SST	sea surface temperature
SWAMP	Sea Wave Modeling Project
SWH	significant wave height
TDL	Techniques Development Laboratory (of NWS)
TOGA	Tropical Ocean and Global Atmosphere
WOC	World Oceanography Center (for IGOSS)
WSFO	Weather Service Forecast Office
XBT	expendable bathythermograph

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