WILLARD J. PIERSON, JR.

WIND DATA AND THE MARINE BOUNDARY LAYER

The disparities in the various estimates of wind fields from the Labrador Sea Extreme Waves Experiment can be explained by the lack of agreement on the methods used for the analysis of the marine boundary layer, the poor quality of the wind reports, and the criteria for the acceptance of the wind reports from both ships and buoys.

INTRODUCTION

The data used to define the winds in the marine boundary layer come predominantly from transient ships of opportunity and from the national data buoys. The ship data are of extremely poor quality as shown by numerous recent investigations. Ships and buoys do not adequately cover the world oceans.[1] Even if the ship and data buoy reports were absolutely correct and represented the synoptic-scale wind, difficulties would still exist because of poor coverage and inadequate physical models. A striking result of the LEWEX (Labrador Sea Extreme Waves Experiment) analyses is that the wind speeds and directions at the two ships, the CFAV *Quest* and HNLMS *Tydeman*, as specified by the Fleet Numerical Oceanography Center (FNOC), the National Meteorological Center (NMC), Ocean Weather, Incorporated, the European Centre for Medium Range Weather Forecasts, and the United Kingdom Meteorological Office, were all different. The wind fields generated by various centers also differed from one another over the entire North Atlantic.[2]

Any one of the spectral wave models, if run one at a time with each sequence of the different wind specifications, would produce different spectra. Different wave models used by the forecast centers and analyzed at The Johns Hopkins University Applied Physics Laboratory were run for a common input wind field. The wave spectra that resulted for a given model differed for the same time and place compared with the wave spectra that resulted from separately derived winds. Further, the different models still differed from one another when driven with identical winds.

All of the wind fields produced for the LEWEX spectral intercomparisons are based on the same "raw" data, that is, data from synoptic reports from land stations, ships of opportunity, and data buoys, along with both conventional and remote atmospheric soundings. Thus, differences result from variations in both the models and the methods used by the different forecast centers to analyze the synoptic data and produce the resulting gridded synoptic-scale winds.[3]

Wave modelers often assume that, at least for specifying the wave spectra, the input driving winds are a "given" and are correct. This assumption is not necessarily true. Wave models that are "tuned" to the wind output of a particular model inherit the errors of that model.

A major reason for these differences is that the winds reported by ships at sea are of poor quality.

Of the various wind fields, it would be difficult to show that one was more nearly correct than the others. Wave models will have inherent errors as hindcasts because of wind field errors; yet to be determined is how the errors in wave hindcasts, which are the initial value specifications for wave forecasts, affect errors in those forecasts.

ANALYSIS PROCEDURES

The various national weather forecasting centers all follow the same general procedure to produce the wind fields that would be used to drive a wave model. Their procedures differ in details, however. The objective of the analysis at a center is to produce the initial value specification as a function of latitude, longitude, and elevation of the quantities needed to time-step the finite-difference atmospheric model used by that center to forecast changes. Of particular interest are the formation, movement, and deepening or filling of low centers for wind forecasts and the advection of water vapor for the release of latent heat and the prediction of rainfall.

The details of how each center produces a marine boundary-layer wind field are difficult to find in the published literature. Moreover, in the day-to-day operation of a center changes are sometimes made. (See Ref. 1 for a description of the methods used by the NMC and Ref. 4 for those used by the FNOC in 1982. Marine applications of the NMC product are described in Ref. 5.) For example, the procedures of the FNOC produce a "blended" wind field, in which weights are assigned to various kinds of data and co nputer products on the basis of recent past data. The NMC method depends on ideas introduced by Bergman.[6] As with the famous product from Scotland, the blends produced by other centers could have quite distinct characteristics.

The atmosphere is divided into layers, and the heights of surfaces on which the atmospheric pressure is constant are part of the initial value specification, along with the winds at each of those surfaces. The number of layers used in a model probably varies at each center, but they all may start with the height of the 1000-hectopascal (hPa $\approx$ 1 mbar in the previous system of international units)

surface and use a standard procedure to convert this surface to an isobaric pattern at sea level, even over land. The thicknesses of the layer nearest the Earth's surface in a model vary at each center. In addition, the velocity field in that layer must represent, by single vectors at each grid point, the behavior of a large volume of air as defined by an area around each grid point (thousands of square kilometers) and the various thicknesses of the layer (hundreds of meters) used for that particular model.

The map projections used in these models also differ, and the equations for describing the various fields are modified to account for those projections. One wonders about the effect of smoothing on different projections. A closed contour for the 1000-hPa surface on one map projection will not have the same shape on another.

Data from the land affect the analysis over the ocean by continuity. A separate research study would be necessary to find out how the various models treat the Greenland Ice Cap, the winds over the water around Greenland, the Tibetan Plateau, the various mountain ranges of the Earth, and the winds around islands. The variable winds described by Ezraty in this issue may be the effect of nearby land. Also, synoptic updates are usually available only every six hours. An interpolation for three-hour intervals may or may not be made.

The winds used for the numerical weather forecasts are not necessarily those used for the marine boundary layer, and an additional analysis step[5] is required to specify the winds at either 10 or 19.5 m as the driving winds for specifying (hindcasting) or forecasting the wave spectra at each grid point of the wave model. Wave models may require a different grid than the weather forecasting model, so that an interpolation is often needed.

All analysis schemes smooth the wind fields. Sharp wind shifts at fronts are not well modeled. Smoothing tends to alter gradients in the pressure field, so that winds computed from the pressure field in areas of "true" high winds are lowered, and winds in areas of "true" low winds are made higher. (Reference 7 compares model winds from the FNOC Global Spectral Ocean-Wave Model with winds from data buoys.)

DATA ASSIMILATION

Meteorological forecasts are typically made every 12 hours for several days into the future. The forecast cycle begins with an initial value update. The forecast outputs for the previous 12-hour cycle are the startup data for the present forecasts, and these are reinitialized for the current time by assimilating the newly observed data for the present synoptic time.

These forecast 12-hour data fields are called first-guess fields for an initial value update. The measured and reported new synoptic data, such as reports from ships, are used to attempt to correct the first-guess field for changes in the meteorological fields that were not predicted by the past 12-hour forecast.

For the marine boundary layer, the available ship reports are apparently used only one at a time at some centers. The reported sea-level pressure is compared with the model value, and the accuracy of the value is judged on the basis of how close it is to the first guess. Different centers use different methods to judge the accuracy of the report. If correct, the pressure field is changed by an area smoothing technique to agree with the new data. The reported winds are compared with the model winds. The report is then used with some sort of boundary layer model to change the wind and adjust the pressure gradient near the ship to agree with the corrected wind.

In the data assimilation procedure, the accuracy of the wind reports now becomes important. As I will discuss, very large errors in these wind reports exist. These errors are in part systematic.

Given a number of ships around a low center, some reports will agree with the first-guess winds within the required differences and will thus be used to correct the initial guess. Nevertheless, both the ship winds and the initial value update can be incorrect and contain large errors. In addition, many ships in an area of high winds may all report high winds. If the initial value update calls for lower winds, as each ship report is tested one by one, that update can be rejected. Thus, all ship reports would be rejected, and the initial value update would not show that a cyclone had deepened.

In data-sparse areas, a single report, which may or may not be accurate, may influence an area of 5° of latitude and 5° of longitude; the first-guess field may or may not be correct; and the choices as to whether to assimilate the report may or may not improve the initial value update.

A cyclone moving into an area devoid of data is carried forward by continuity as part of the first-guess field. If the field has errors (e.g., a low center at the wrong place, with a central pressure that is not low enough), it cannot be corrected.
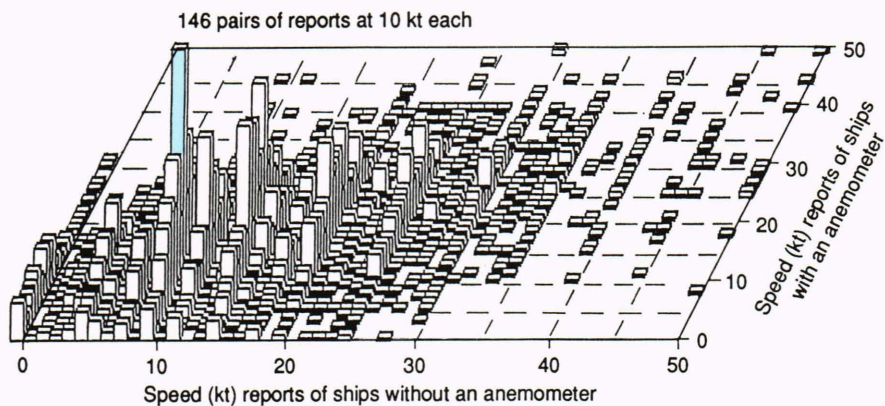
Thus, each wind field for the different meteorological centers could evolve from one synoptic time to the next, while still being different and accepting some subset of the available ship report data. Errors in the specification of the marine boundary layer, in the form of an incorrect 1000-hPa surface, propagate upward to great heights because the remotely sensed atmospheric soundings over the ocean are integrated upward to define the surfaces of constant pressure for the model.

All analysis methods must balance the field of mass and the field of motion. The winds over the ocean are an essential input to the marine boundary layer. Potentially important information is omitted if pressure data alone are used. Even if the winds were to be derived solely from the pressure field, one would still need to validate the derived winds against measurements of the winds.

THE POOR QUALITY OF SHIP REPORTS

Reference 8 contains the results of comparing wind reports that were made at the same synoptic time by pairs of ships within 100 km of each other. That article is a reevaluation and an extention of a report by Dischel and Pierson.[9] It demonstrates the poor quality of ship reports in many different ways and recommends corrective measures. The data for Figure 1 here comprise 8265 pairs of reports from ships in the region 30°N to 40°N and 70°W to 80°W. Only one ship of the pair had an anemometer. The observer on the ship without an anemometer esti-

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Figure 1. Perspective three-dimensional plot of counts (vertical axis) of the number of times ships with anemometers (into the perspective plane) and ships without anemometers (horizontal axis) within 100 km of each other reported wind speeds from 0 to 50 kt at a synoptic time for a North Atlantic location somewhere in Marsden Square 116 (30°N to 40°N; 70°W to 80°W). The largest number of counts occurred 146 times when ships both with and without an anemometer reported 10 kt. (Reprinted, with permission, from Ref. 8, p. 13,317: ©1990 by American Geophysical Union.)

mated the wind according to the instructions of the World Meteorological Organization. This difficult task in part depends on the assumption that there is a one-to-one relation between sea state and wind speed.

The perspective plot of Figure 1 shows a plane from which rectangular parallelepipeds project upward. The horizontal axis in the plane shows a scale from 0 to 50 kt for reports by ships without anemometers. The projection into the figure shows a scale from 0 to 50 kt for reports by ships with anemometers. The small number of omitted reports of winds over 50 kt does not affect the interpretation of this figure. The vertical height of each parallelepiped shows the total number of times pairs (one with an anemometer and one without) of ships reported the plotted speeds. For example, ships without anemometers reported 10 kt when ships with anemometers reported 10 kt 146 times. Once, a ship without an anemometer reported 50 kt while one with an anemometer reported 9 kt. Had the wind speeds reported by each pair of ships been correct for the synoptic scale, the counts would have fallen close to the 45-degree line of perfect fit.

Wind speeds for the synoptic scale separated by 100 km or less should not differ by the large amounts shown in Figure 1. For example, when ships without anemometers reported a wind of 30 kt, ships with anemometers reported speeds from 3 to 43 kt.

In Figure 7 (A through G) of Gerling (Ref. 3), the synoptic-scale common wind fields for LEWEX have values every 1.25° of latitude (139 km or 75 nmi) and every 2.5° of longitude (at 40°, 212 km; at 50°, 178 km; at 60°, 138 km). Over these distances the wind speeds may change by 5% to 10%. They surely cannot change from one grid point to the next by the amounts shown in Figure 1. The distance between the ships is less than the distance between the winds in Gerling's figures. Moreover, the standard deviation for the wind directions (not shown) was 45°. Skeptical readers with adequate computer graphics might find it interesting to plot wind vectors from ship reports at these synoptic times to scale in some contrasting color along with the LEWEX winds.

Ships without anemometers tend to over-report speeds of 5, 10, 15, 20, or more knots in 5-kt steps along with winds of 8, 12, 16, 18, and 22 kt. The latter represent centers of Beaufort ranges and values originally in meters per second, converted to knots. These very large differences in reported speeds result from the very poor quality of wind reports by ships. Many reasons exist for the poor quality of these reports. Even for ships with anemometers, the equipment provided to the observer makes a good synoptic-scale observation difficult.

CONCLUSIONS

The poor quality of ship reports creates difficulties in obtaining correct descriptions of the winds in the marine boundary layer. Incorrect descriptions not only make it difficult to specify and forecast wave properties, but they also make weather forecasts poor and climatological studies suspect.

Scatterometers on the European Remote Sensing Satellite (known as ERS-1) and the Japanese Advanced Earth Observing System (known as ADEOS) will help to provide better wind fields for the marine boundary for use in wave forecasts, weather forecasts, and, eventually, climatological studies. The methods used by ships at sea to measure the winds are obsolete. They could be improved using modern technology. Presently, some of the deep-sea national data buoys report six consecutive 10-min averages of the wind each hour. These data can be used to validate wave model winds and to provide conventional validation winds for remotely sensed winds.

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THE AUTHOR

WILLARD J. PIERSON, Jr., is professor of meteorology at the City University of New York Institute of Marine and Atmospheric Sciences, City College of New York.