AN INTERACTIVE OBJECTIVE KINEMATIC ANALYSIS SYSTEM

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1. INTRODUCTION

The need for high-quality wind fields for ocean response models arises in hindcast studies of operational and extreme climate, in coastal and offshore structure design, and in forecasting for ocean platform operation and ships. Ocean response models such as the third generation (3G) wave model (WAM) and the Oceanweather's 3G wave model have shown great skill in producing nearly perfect hindcasts of significant wave height and peak period in severe tropical and extratropical systems when driven by high quality wind fields. The Surface Wave Dynamics (SWADE) study special Intense Observational Period (IOP) of the October 1990 US East coast event put several wind fields using both objectively derived and hand-drawn man-intensive wind fields through a common wave model (WAM 3G). The results show (Cardone et.al., 1995) that the suite of hindcasts produced by very sophisticated purely objective analysis schemes was clearly beaten by hand-drawn kinematic analysis (Figure 1). Unfortunately, this man-intensive, tediously produced analysis took approximately 100 man-hours to produce a 10 day hindcast, which is a time frame clearly inapplicable to long term hindcast studies and forecasting applications.

The Interactive Objective Analysis (IOKA) system was developed at Oceanweather to combine the advantages of manual analysis both shown during SWADE study and emphasized by Sanders (1990) and Uccellini et al. (1992), with the speed of a purely objective analysis scheme in deriving high quality marine surface winds. Using the SWADE winds as a control, Oceanweather first developed the objective analysis algorithm, Seidel, for the express purpose of analyzing wind fields. The interactive part of IOKA consisted of manual editing/deleting of wind inputs in ASCII format. This procedure worked well in SEAMOS (Southeast Asia Meteorological and Oceanographic Hindcast Study) where ships, typhoon model output winds and a background climatology wind fields were combined using Seidel to achieve high quality wind fields for some 200 typhoons and monsoons. While the procedure was considerably faster that manual-kinematic analysis and yielded better results than running pure typhoon winds by including observations, the system needed a final component: an interactive graphical workstation. The Wind WorkStation was developed to allow the user to display and manipulate the wind inputs to Seidel. This work station is already used operationally in Oceanweather's global 7-day wind/wave forecasting service and has been used in several hindcast studies, the most recent being the addition of 10 storms to the Canadian Climate Center (CCC) East Coast Storm Study (CCC, 1991; see also Swail et. al., 1995). This paper will present the steps involved in the IOKA process, and describe the development and use of a graphical Wind WorkStation.

2. INTERACTIVE OBJECTIVE KINEMATIC ANALYSIS

2.1 Overview

The heart of the IOKA system is the graphical interface known as the Wind WorkStation (WWS). The WWS is an analyst-friendly MS Windows based program (version 3.1, Windows 95 or Windows NT) which allows the analyst to view and manipulate wind inputs for the objective analysis algorithm. The display is very flexible and allows the user to both scroll and use a true zoom capability (the wind barbs are redrawn to the best possible resolution) to display any region of the basin. The analyst may also customize the wind inputs displayed by the WWS to plot optional information such as Significant Wave Height, Peak Period, Surface Pressure and Station/Call Sign Identification, and may display any or none of the wind inputs (useful for a final check of the analyzed wind field). A selectable latitude/longitude grid may be displayed with the data, and the final objective analysis wind field can be displayed from every barb to every 4th barb according to the user's preference. The program also supports printing on a true Mercator projection with a fine resolution digitized coastline.

The WWS can be set up very easily in any basin, and supports any latitude/longitude grid which is a sub-multiple of 2.5 degrees down to .25 degrees. The latitude and longitude grid spacing need not be identical, which is very useful in northern latitudes where less resolution in longitude is desirable for computational speed considerations. Currently, the objective analysis algorithm, Seidel, supports up to 200 by 200 parallel grid (a 30 by 30 degree latitude/longitude area with a .25 degree resolution, 300 by 300 degree area at 2.5 degree resolution) although this limit can be easily increased should the need ever arise. Typically, grids between 60 and 70 parallels square are used as a trade-off between resolution and computational speed. The basic objective analysis method follows the approach of Ooyama (1987) by fitting quadratic forms to the velocity components and wind speed separately, minimizing the differences between the analysis and the observations in the least-squared sense:

$$\sum_{\mathbf{k}*1}^{\mathbf{n}} \mathbf{wt_k} \sum (F_k - F_{\text{int}})^2 + \beta \left[\Sigma \left(\frac{\Delta F}{\Delta X}\right)^2 + \Sigma \left(\frac{\Delta F}{\Delta Y}\right)^2 \right]$$

where wt_k is the weight assigned to the inputs of class k; F_k is a measurement of class k, F_{int} is the analysis value at the location of the measurement, and β is a scale factor which is used to achieve the desired level of smoothing. The fitted velocity components are used to recover the wind direction only, the wind speed is directly analyzed (Cardone, et. al. 1993, see also Cardone and Grant, 1994).

The WWS uses a flexible storm database file to contain all wind inputs and output (objectively analyzed) winds. This provides a single source file for a particular storm/hindcast period and is very convenient for archiving purposes. The WWS makes no assumptions as to the length of a particular hindcast (though the storm database file can grow rather large) and more importantly imposes no restrictions on the time difference between maps. For instance, maps can be analyzed every 12 hours for a spin-up period, every 6 hours during the initial stages of a storm, then every 3 hours during the intense period. The resulting wind fields can then be time-interpolated to the desired time step for input into a wave model. This flexibility greatly decreases the time the analyst needs to spend on spin-up periods and greatly enhances his/her ability to do a fine time step analysis during the storm peaks. This is also very useful for long term operational climate studies where long periods of inactivity can be hindcast with a larger time step and important storm events can use a shorter time step.

2.2 Meteorological Inputs

The first stage in the IOKA system is the preprocessing of meteorological inputs. Typically wind observations from buoys, ships, off-shore platforms, coastal manned stations (CMANS), cloud track winds, well exposed land stations and satellite-derived scatterometer winds are used in the analysis of the marine wind field. The WWS places no restrictions on the number of types of data, or the inclusion of other types of data. Typically a pressure-derived background wind field is also used, although this is optional if the data density is significantly fine (grid spacing dependent). The inclusion of other wind fields such as typhoon model output for tropical locations is also commonly done. All data to be brought into the WWS is first adjusted for stability and brought to a common reference level, typically 20 meters, following the methodology developed by Cardone (1969; see also Cardone et. al., 1990). Standard buoy wind measurements (usually 5 to 10 minute averages) are temporally smoothed to effective hourly averages. Averaging is done on meridional and zonal wind components of the wind to calculate the wind direction, and on scalar wind speed to recover the average wind speed. Buoy wind speeds derived by the "vector -averaging" method are inflated to effective "scalar-averaged" using the empirical relationship described by Gilhousen (1987). Asynoptic observations can be optionally repositioned to on-hour locations via moving centers relocation, which is essentially similar to the procedure that relocates aircraft flight level winds to a moving vortex. Asynoptic observations can also be included without moving centers by giving them a lower weight in the objective analysis scheme, and signifying to the analyst that it is an asynoptic observation and should be given extra scrutiny to determine its representativeness in the wind field. All wind inputs are put into the WWS input format, so-called 'uvw' file, and brought in the WorkStation storm database. Weights can be assigned to each type of wind input; common wind inputs such as buoys, ships, scatterometer winds, CMAN stations, typhoon model input and background pressure-derived winds can be assigned default weights in the objective analysis scheme which were determined by Oceanweather to be representative of the wind's reliability. Typically, buoys get a very high weight, while ships get lower weight in the objective analysis scheme. The analyst can also over-ride these standard default weights, if they are deemed inappropriate for a certain data type. Types of winds are also assigned standard colors (although these can be customized for individual preference and display types), which is very useful for the analyst when all the data is plotted on the screen.

2.3 Interactivity with the Wind WorkStation

Once the wind data is incorporated into the WorkStation, it is displayed as color-coded wind barbs (by type) over a coastline map on an xy plot projection. The wind field can be viewed as a full basin, or zoomed and scrolled to display any section. The analyst can 'point and click' on any wind observation to bring up a text box which displays the latitude, longitude, wind speed, wind direction and station identification of the wind observation and its neighbors. The analyst has the ability to delete individual wind observations; deleted data, displayed in a light blue color, can be undeleted if the analyst changes his/her mind. Usually quality control of the wind inputs is done at this step, although automatic quality control can be performed in the preprocessing step before bringing the winds into the WWS. The analyst typically uses the background wind field, hand-drawn pressure charts, continuity analysis and other sources to determine the quality and reliability of each piece of data.

The most important feature of the WWS is the ability to add highly weighted Kinematic Control Points (KCP) to the wind analysis. This is the analyst's most powerful tool in shaping the resulting wind field. With the KCP, the analyst can input and define the fine-scale frontal features, and add and maintain jet streaks and other features which have proven to be very important in extreme storm seas (ESS) and are often missed by purely objective methods. The analyst can use KCPs to define data-sparse areas using continuity analysis, satellite interpretation, climatology of developing systems and other analysis tools. Winds can be run (put through the objective analysis) on an individual map for instant feedback to the analyst, or run for the entire length of the storm. When the winds are run interactively (one map at a time) the analyst has the ability to add KCP points, run the winds, analyze the changes reflected in the final winds, and either make more changes or accept the winds as final. This interactivity greatly enhances the analyst's ability to make changes to the wind field and boosts his/her confidence in the final wind product.

2.4 Export and Interpolation of the Wind Field

Once the final wind field is run through the objective analysis scheme and accepted by the analyst, the final winds can then be exported from the stormfile database. If the output of the WWS is not at a regular time step, or if a finer time step is required, a general time interpolation program, TIME_INTERP, is used. This program can produce time interpolated wind fields on any time step, and can be optionally used with a file of moving centers to help preserve features in the interpolated maps. Output of the time interpolator can be sent directly into a matching grid wave model, or put though a separate spatial interpolation program, WIND2WAVEGRID, which can place the winds onto any target wave model grid.

3. APPLICATION IN THE CCC EAST COAST STORM UPDATE STUDY

The IOKA system is currently being implemented in the addition of 10 recent storms to the CCC East Coast storm population. The previous 68 storms were hindcast using the same hand-drawn kinematic analysis technique that was proven to give high quality winds in the SWADE study. In this update study, the WWS was set up on a area from 22.5° N to 77.5°N and 82.5°W to 0°E. Grid spacing was selected to be 1.25° in longitude and .8333° in latitude, resulting in a 4489 grid point wind grid (Figure 4). A three-hour time step was selected to do the wind analysis; this is also the time step of the wave model. Winds were spatially interpolated to the CSOWM (Canadian Specral Ocean Wave Model) wave grid (Khandekar et. al., 1994) using the WIND2WAVEGRID utility.

Wind inputs for the 10 update storms include US and Canadian buoys, ships and CMAN stations. All data inputs are adjusted for height and stability to 20 meters neutral. The buoy observations are temporally smoothed to effective hourly averages. Asynoptic data are not currently being used in this study. The background field used for this study is the ECMWF wind analysis for storms through 1994, and Oceanweather's wind analysis from its real-time global forecast for the February and April 1995 storms. Both background wind fields are on 2.5 by 2.5 degree grids, and both have had real-time observations already blended into the wind fields. However, Oceanweather's global winds have gone through the IOKA process and have had some analyst interaction in a forecast mode.

Initial work on the April 1995 event has shown the WWS to be a time-saving tool in the analysis of the winds. The analyst was able to complete the analysis of the wind field in less time, due to the ability to view all the input and output winds together on one display, and the ability to run winds interactively to achieve a final wind product. Further significant time savings were also achieved by not having to manually grid and enter a kinematic winds fields by hand, which had been done in previous hindcasts. While some kinematic sketches were done on printouts of the wind field, most work was done directly on the WWS. Time histories (Figure 5) at two Canadian buoys (44138 and 44141) show good agreement between the measured significant wave height and the hindcast wave heights using the CSOWM 3G shallow wave model. These wave time histories are equivalent to those expected with hand-drawn kinematic analysis.

4. SUMMARY AND FUTURE DEVELOPMENT

IOKA system has proven to be an effective and time-saving tool for the analysis of marine surface winds. It successfully blends the man-intensive kinematic analysis with the speed of a purely objective analysis. The development of the graphical Wind WorkStation has increased both the efficiency with which an analyst can produce a final wind field, and the analyst's confidence in the final wind fields delivered to the wave model. Additional tools such as the general time interpolation and spatial interpolation routines have allowed the analyst to use flexible intervals between maps, and easily port the wind output to any target grid.

Development of and improvements to the Wind WorkStation continue almost on a daily basis, owing to the number of current hindcasting and forecasting studies the system is being used on. As the system is applied to different basins, both tropical and extratropical, the need for new tools arises and most users' requests have already been implemented into the current system. Areas of future development include: the addition of a manipulative moving-centers table in the WWS which can used for repositioning of asynoptic data as well as in the time interpolation of wind fields; addition of continuity tools which would better allow the user to track and smooth such weather features as fronts, troughs, ridges, and jet streaks; looping of final wind fields in a movie sequence for final check of the continuity of the wind fields; and contouring of the final wind fields.

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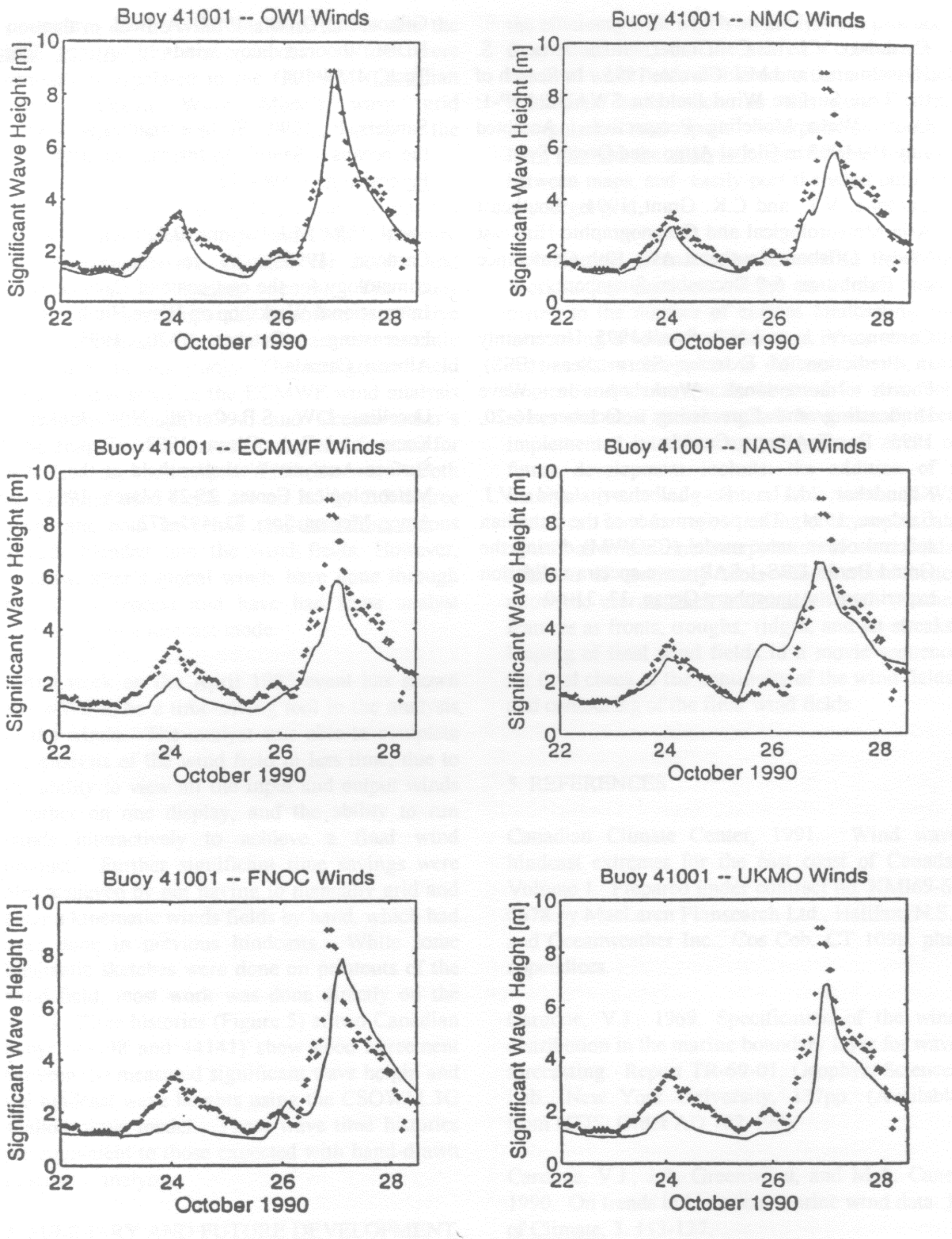

Figure 1. Comparison of Wave Heights derived from five objective analysis winds (NMC, ECMWF, NASA, FNOC, UKMO), and Oceanweather's (OWI) hand-drawn kinematic analysis winds during SWADE IOP2.

Interactive Kinematic Analysis Flow Chart

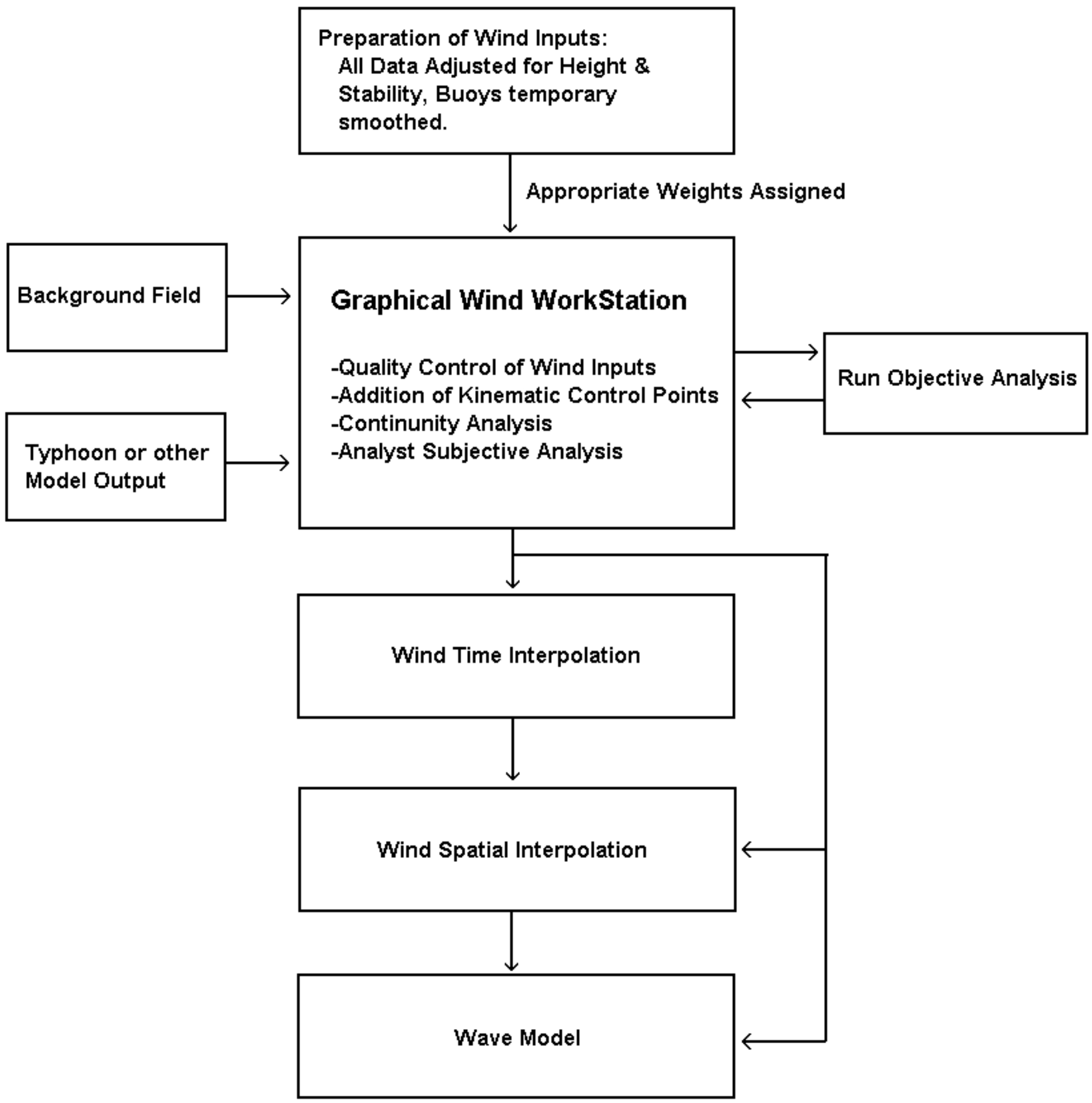

Figure 2.

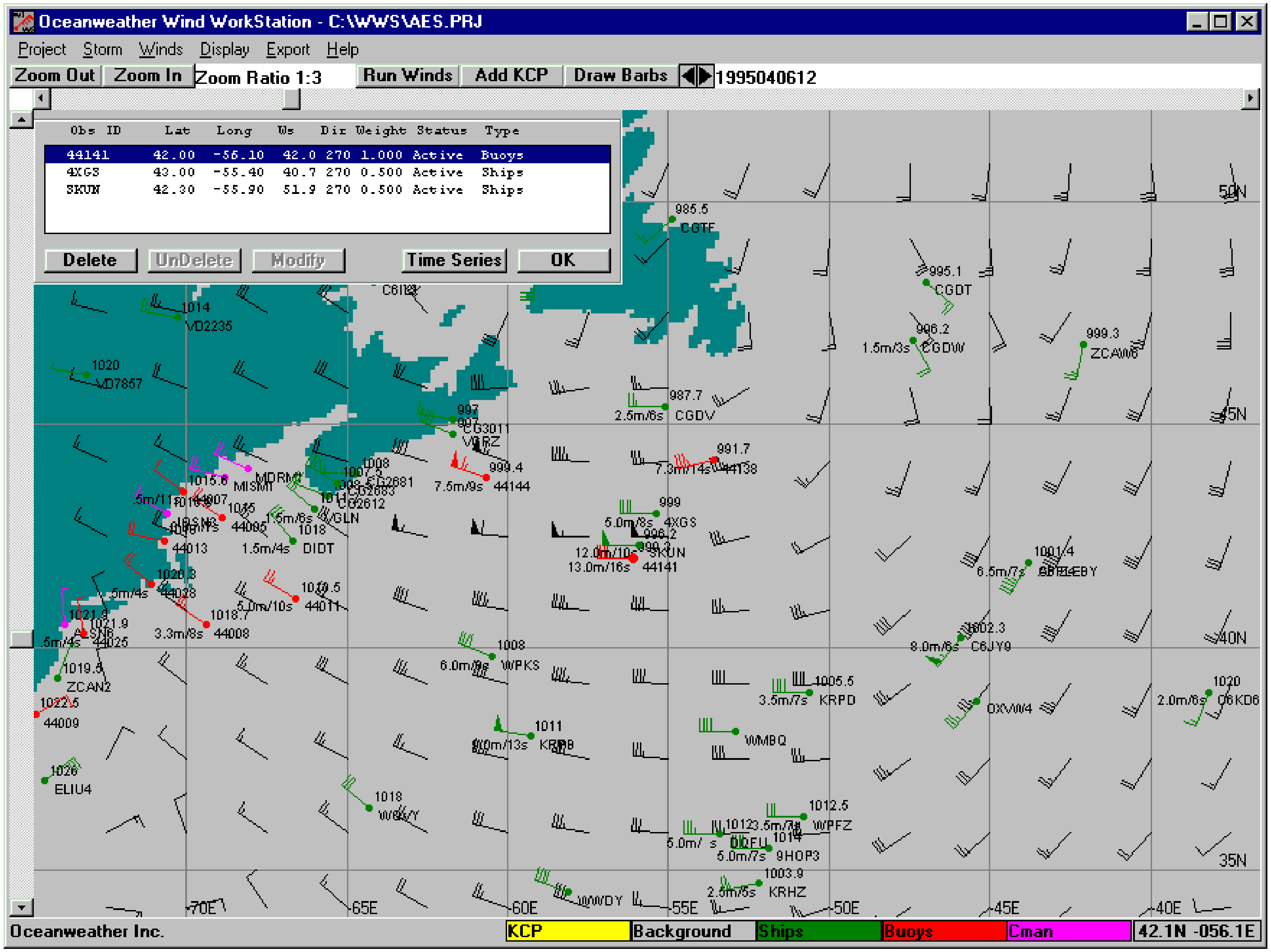

Figure 3. Wind WorkStation sample display.

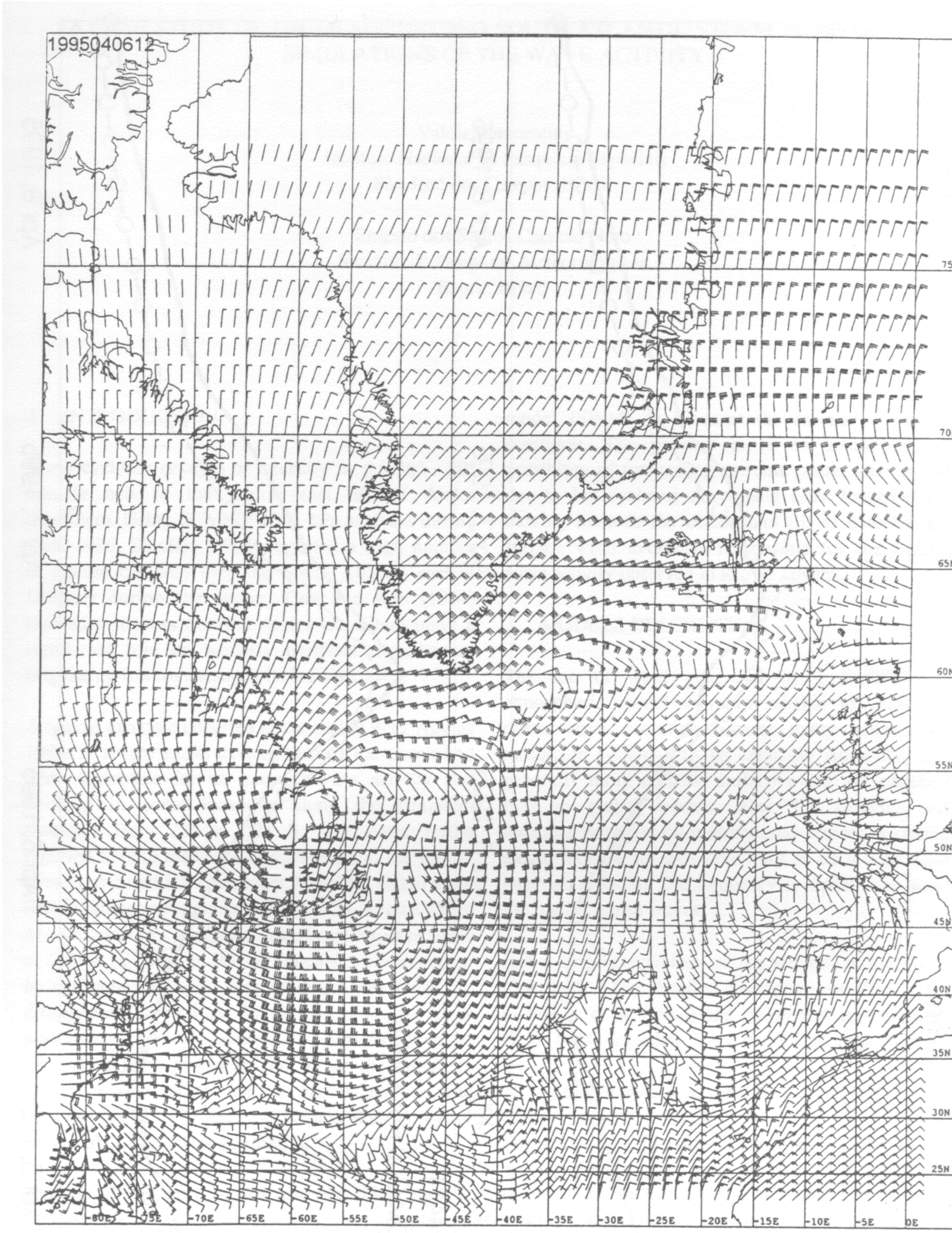

Figure 4. Final Wind Barbs in the April 1995 CCC Storm. (Note: Winds are allowed to fall off in the Baffin Bay since the basin is enclosed by ice.)

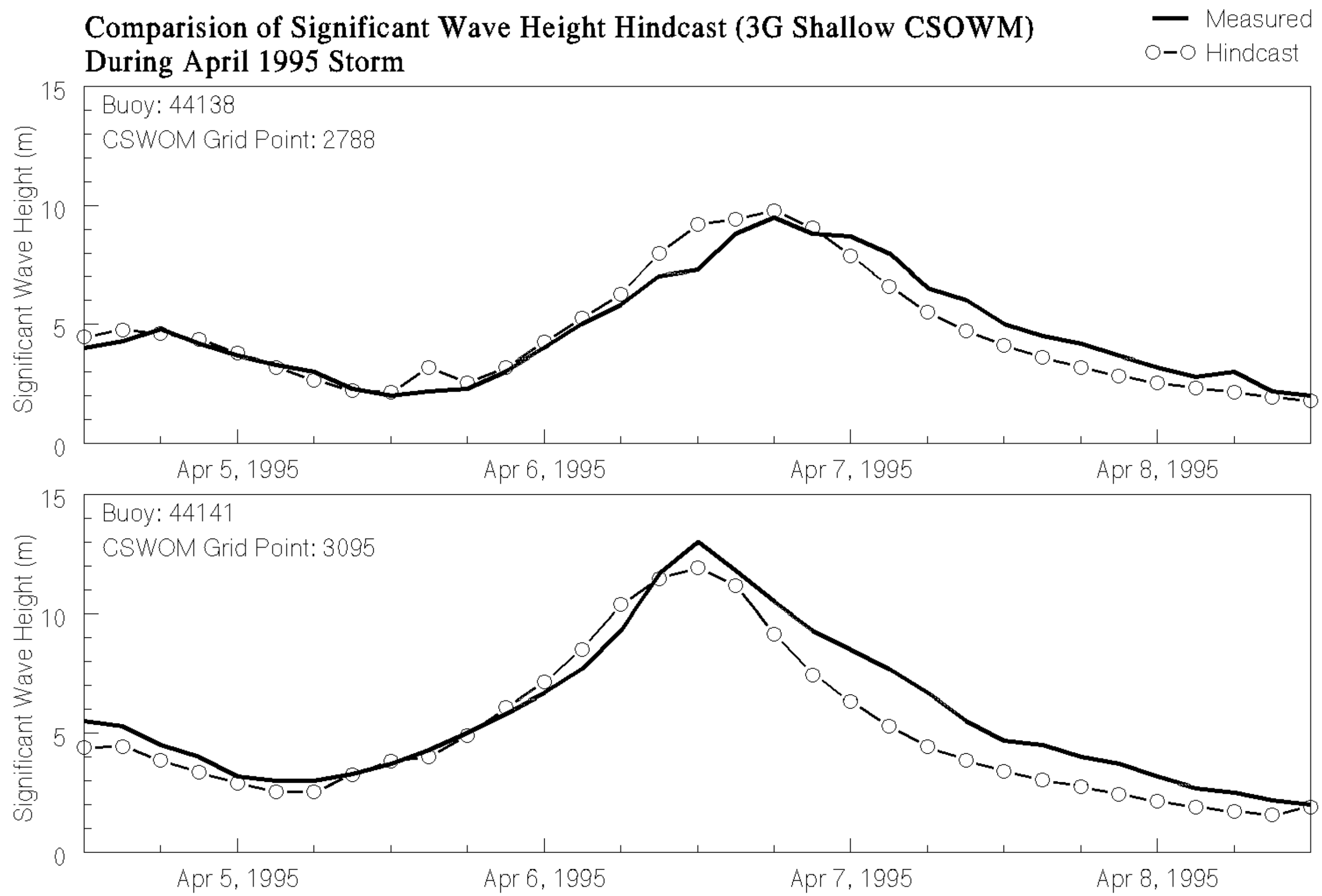

Figure 5. Wave Height Comparison During April 1995 Storm.