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THIS IS THE FIRST TPB ON THIS PRODUCT

This bulletin, prepared by Yung Y. Chao, Lawrence D. Burroughs, and Hendrik L. Tolman, describes a new wave model, which is designed to predict wind waves generated by hurricanes in the Eastern North Pacific Ocean (NPH). This model uses the same 0.25^{o} x 0.25^{o} grid as the Eastern North Pacific wave model (ENP) and the same computational and physics schemes as the NOAA WAVEWATCH III model. The NPH uses a blend of model wind outputs from the Geophysical Fluid Dynamics Laboratory (GFDL) Hurricane Model runs for each hurricane being followed and from the Global Forecast System (GFS).

The NPH was implemented during the summer of 2003. Output from the model is available to the forecast community on a dedicated line to the Tropical Weather Center/National Hurricane Center, over the Satellite Broadcast to AWIPS, and on NAWIPS.

National Oceanic and Atmospheric Administration **National Weather Service**

The North Pacific Hurricane Wind Wave Forecasting System (NPH)[1]

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1. Introduction

The present NCEP operational wave model for predicting global and regional ocean wind waves, NOAA WAVEWATCH III (NWW3; Tolman *et al.* 2002), uses wind data derived from the Global Forecast System (GFS; Kanamitsu *et al* 1991; Caplan *et al* 1997). It is well known that the details of highly intense and rapidly varying nature of the wind field associated with a tropical cyclone is poorly resolved by the GFS because its grid isn't fine enough. As a result, predicted wave conditions in areas under the influence of tropical storms usually are under predicted when GFS winds are used. Also, predicted directions and arrival times of swells in coastal areas tend to be inaccurate.

In order to provide a more accurate forecast of the storm track, intensity, and wind distribution, NCEP uses a separate model to generate the hurricane wind structure. This model, developed by the Geophysical Fluid Dynamics Laboratory (GFDL), is called the multiply nested movable mesh hurricane model (*e.g.*, Kurihara and Bender 1980; Kurihara *et al* 1990, 1995, and 1998) and is used during the hurricane season to produce forecast guidance for the National Hurricane Center. The model, however, considers only one storm at a time. When multiple storms exist simultaneously, a frequent event, one storm is considered at a time within the fine inner mesh grid, while the others are dealt with in the course outer mesh only. The details of their wind field structures for those storms not under consideration are again not adequately described. The GFDL hurricane model must be run for each storm currently occurring, so that the storm track and the detailed wind field structure of each storm can be captured. Consequently, the combined effects of various wind fields associated with multiple storms on ocean waves cannot be adequately predicted by using a single run of the GFDL model. Furthermore, since the hurricane model uses a movable grid system, the domain for each model run does not necessarily cover the entire wave model domain. These two problems must be resolved so that the benefits of detailed wind fields produced by the GFDL model can be fully utilized to produce more realistic wave fields.

A procedure for unifying the wind from the GFS and that from the GFDL model for single or multiple storms has been developed. The procedure has been used operationally to predict hurricane associated wind waves over the North Atlantic Ocean since the 2002 hurricane season (Chao *et al*, 2003a). Further improvements on GFDL hurricane model were made in 2003 (Bender *et al*, 2003). The products of the improved hurricane model were incorporated in the North Atlantic hurricane wave model (NAH). The same procedure for specifying the hurricane wind field has been applied to develop the hurricane wave model for the eastern North Pacific basin (NPH). For completeness, in what follows, we will describe the procedure for predicting hurricane winds and waves, show the results of validation against observations, and present available products and dissemination routes for the hurricane season.

2. **Hurricane Wind Field Specification for Wave Forecasting**

The present operational GFDL hurricane model produces output data for the outer and inner mesh 4 cycles per day at hourly intervals up to 126 hours, and we currently use winds out to 78 hours. The outer mesh has a grid resolution of 1/3 by 1/3 degree covering an area of 75 by 75 degrees in latitude and longitude. The inner mesh has a grid resolution of 1/6 by 1/6 degree covering an area of 11 by 11 degrees. The center of the inner mesh is coincided with the center of the storm (the location of the lowest pressure). The operational GFS model

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provides output 4 cycles per day at 3-h intervals up to 168 hours. At this time we use the GFS winds from the 0000, 0600, 1200 and 1800 UTC cycles out to 78 hours, but will be increasing this to 120 hours when we increase the use of the GFDL winds to 120 hours. The first step is to interpolate the lowest level wind data from the GFS and GFDL grids at the same projection hour onto the North Pacific Hurricane wave model (NPH) domain, which is identical to the domain and grid resolution (0.25o x 0.25o lon/lat) of the Eastern North Pacific wave model (ENP, Chao *et al* 2003) and adjust it to a height of 10 m. Since the GFDL hurricane model runs for each selected storm separately, discrepancies in the wind field features for the same storm from different model runs may occur if multiple storms co-exist. In order to resolve this problem, the concept of an area of influence (AOI) for each storm is introduced. Various definitions of AOI have been considered and tested. We have found that the following procedure provides the most realistic and consistent wind field structure:

- Determine the box area, which has the shortest distance from the storm center to the 1015 MB isobar.

- Determine the box area, which extends from the storm center to where the wind speed decreases to 7.5 m/s on each side of the box.

- Form a new box area with each side taken from the side of these two boxes, which has the smaller distance to the storm center.

- The AOI is assumed to be the formed box area provided that it is not greater than 12.5 degree or less than 3.5 degree longitude-latitude box.

- Replace the GFS winds in the AOI of each storm with GFDL winds.

- Use a weighted averaging procedure to have a smooth transition from one set of winds to the other in the vicinity of four boundaries of the AOI.

3. Operational Procedure of Hurricane Wind-Wave Forecasting

The NPH wave model is nearly identical to the ENP, a description of which can be found in Chao, Burroughs and Tolman (2003b). The hurricane-generated wind-wave forecasting procedure for the NPH is quite straight-forward and is used during the entire hurricane season.

- Initialize the NPH at the official start of the hurricane season by initializing the wave field with output from the ENP and by using the winds from the GFS.

- Search for output from the GFDL model and continue running NPH at each model cycle for the duration of the hurricane season.

- Use procedure developed in section 2 above when GFDL output is available:
    - mean sea level pressure to determine storm center, and
    - the surface wind field in each AOI.

- Obtain output spectra from the NWW3 to furnish boundary wave conditions at the boundaries of the NPH domain at each computational step.

- Use GFS winds to continue the NPH operations when no tropical storms exist during the hurricane season.

4. Performance Evaluation

The NPH forecasting system was implemented in August 2003. Following implementation, Hurricane Jimena developed and waves caused by her were recorded on several NDBC buoys. The structure of model hurricane wind fields was constructed according to the procedure described above and the results of the predicted wave fields were compared with buoy observations and are presented below.

Hurricane Jimena moved westward from the Eastern Pacific and reached the Hawaiian Islands around September 1, 2003. Figure 1.a shows an example of GFS wind field for the 20030901 12 UTC run cycle, which is used by ENP regional wave model. Figure 1.b depicts the blended GFS and GFDL wind field used by NPH wave model to predict wave conditions associated with Hurricane Jimena. Immediately noticeable are the differences in scale, intensity and position of the storm center between GFS wind field and blended wind field. Here, the GFS wind field is considerably lower than the blended wind field both in size and strength. This difference is due to the use of GFDL wind field, as shown in Figure 1.c, for blending.

Figure 2.a shows the time series comparisons of measurements at Buoy No. 51004, and the NPH and ENP model predictions of the significant wave height, wind speed and wind direction interpolated to the buoy location from the surrounding grid point values. Buoy 51004 is located at 17.52° N 152.48° W about 185 nm southeast of Hilo Hawaii at a water depth of 5300 m. Figures 2.b shows similar time series plots for Buoy 51002, which is located at 17.14° N 157.79° W about 215 nm southwest of Hilo Hawaii at a depth of 5000 m. It can be seen from these figures that ENP wave model has substantially under predicted wave heights at both buoy locations as a result of under predicting the wind speed by the GFS model. In contrast, the NPH has over predicted the wave height at buoy 51004 as a result of over predicting the wind speed by GFDL model. However, the NPH's prediction of the wave height at buoy 51002 agrees quite well at the occurrence of the peak both in time and magnitude even though the GFDL predicted slightly lower wind speeds than occurred.

The result of these comparisons is quite encouraging in that the NPH (blended winds) may provide more accurate prediction of waves than those of the ENP (using GFS winds only).

5. Products and Dissemination

The following wind and wave parameters are available in GRIB format at

ftp://polar.wwb.noaa.gov/pub/waves and

on AWIPS as GRIB bulletins (see Table 1):

- significant wave height,
- peak wave period and direction,
- wind speed and direction, and
- u- and v- wind components.

Spectral text bulletins are also available on the web at the site above and on AWIPS. The spectral text bulletins on the web and on AWIPS have different formats because of legacy constraints on AWIPS. The headers for the AWIPS spectral text bulletins with the location name and position are found in Table 2.

6. Concluding Remarks

An operational system for forecasting North Pacific Hurricane wind waves and swells (NPH) using blended GFDL and GFS model winds was implemented in August 2003. Results of the performance evaluation presented in this bulletin show that the NPH forecasting system may provide more realistic hurricane wave predictions than ENP, which uses GFS winds solely. Further validation studies of the new system will be made once more data associated with hurricane winds and waves become available.

7. References

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Table 1. WMO GRIB bulletin descriptors.

T_1	T_2	A_1	A_2	dd	Station id
O	A B C J K M N P Y	S	A C E G I J K L M X N Y O P Q Z R	88	KWBC

Where:

T_1 is the bulletin type descriptor; O – oceanographic.
T_2 is the parameter descriptor

A – 10 meter U-wind
B – 10 meter V-wind
C – Total Significant Wave Height
J – Period of Waves at Spectral Peak
K – Direction of Ocean Waves at Spectral Peak
M – Mean Period of Wind Waves
N – Mean Direction of Wind Waves
P – Mean Direction of Wave Frequency Spectrum
Y – Mean Period of Wave Frequency Spectrum

A_1 is the grid and domain descriptor; S - NPH grid.
A_2 is the forecast hour descriptor; see notes below.
dd is the surface descriptor; 88 – ocean surface.

Notes:

1. Forecast hour descriptors are at 3-h intervals from A – I (00 – 24 hours), at 6-h intervals from 30 to 72 hours, and at 12-h intervals after that.

Table 2. Station name, position, and headers for spectral text bulletins for the North Pacific Hurricane Wave Model.

Station Name	Position (N and W, except where indicated)		AWIPS and WMO Header
	Latitude	Longitude	
46002	42.50	130.30	AGPZ46 KWBJ OSBP01
46006	40.90	137.50	AGPZ46 KWBJ OSBP02
46059	38.00	130.00	AGPZ46 KWBJ OSBP03
46011	34.88	120.87	AGPZ46 KWBJ OSBP04
46012	34.45	122.70	AGPZ46 KWBJ OSBP05
46013	38.23	123.33	AGPZ46 KWBJ OSBP06
46014	39.22	123.97	AGPZ46 KWBJ OSBP07
46022	40.72	124.52	AGPZ46 KWBJ OSBP08
46023	34.71	120.97	AGPZ46 KWBJ OSBP09
46026	37.75	122.82	AGPZ46 KWBJ OSBP10
46027	41.85	124.38	AGPZ46 KWBJ OSBP11
46028	35.74	121.89	AGPZ46 KWBJ OSBP12
46030	40.50	124.50	AGPZ46 KWBJ OSBP13
46042	36.75	122.42	AGPZ46 KWBJ OSBP14
46047	32.43	119.53	AGPZ46 KWBJ OSBP15
46050	44.62	124.53	AGPZ46 KWBJ OSBP16
46062	35.10	121.01	AGPZ46 KWBJ OSBP17
46063	34.25	120.66	AGPZ46 KWBJ OSBP18
TPC50	30.00	118.00	AGPZ46 KWBJ OSBP19
TPC51	20.00	135.00	AGPZ46 KWBJ OSBP20
TPC52	20.00	117.00	AGPZ46 KWBJ OSBP21
TPC53	06.00	120.00	AGPZ46 KWBJ OSBP22
TPC54	15.00	95.00	AGPZ46 KWBJ OSBP23
TPC55	09.00	88.00	AGPZ46 KWBJ OSBP24

TPC56	06.00	80.00	AGPZ46 KWBJ OSBP25
46025	33.75	119.08	AGPZ46 KWBJ OSBP26
46053	34.24	119.85	AGPZ46 KWBJ OSBP27
46054	34.27	120.45	AGPZ46 KWBJ OSBP28
SGX01	32.64	117.75	AGPZ46 KWBJ OSBP29
OPCP01	48.10	130.50	AGPZ46 KWBJ OSBP30
OPCP02	48.10	126.60	AGPZ46 KWBJ OSBP31
OPCP03	45.30	129.70	AGPZ46 KWBJ OSBP32
OPCP04	45.30	125.60	AGPZ46 KWBJ OSBP33
46015	42.75	124.85	AGPZ46 KWBJ OSBP34
OPCP05	41.75	129.90	AGPZ46 KWBJ OSBP35
OPCP06	41.90	125.80	AGPZ46 KWBJ OSBP36
OPCP07	38.50	129.0	AGPZ46 KWBJ OSBP37
OPCP08	39.20	125.50	AGPZ46 KWBJ OSBP38
OPCP09	36.40	125.40	AGPZ46 KWBJ OSBP39
OPCP10	33.30	125.00	AGPZ46 KWBJ OSBP40
OPCP11	34.60	122.30	AGPZ46 KWBJ OSBP41
46086	32.50	118.00	AGPZ46 KWBJ OSBP42
OPCP12	30.90	121.50	AGPZ46 KWBJ OSBP43
0PCP13	29.60	117.00	AGPZ46 KWBJ OSBP44
46004	50.97	135.80	AGGA47 KWBJ OSBP01
46184	53.90	138.87	AGGA47 KWBJ OSBP02
46205	54.17	134.33	AGGA47 KWBJ OSBP03
46207	50.86	129.91	AGGA47 KWBJ OSBP04
46208	52.50	132.70	AGGA47 KWBJ OSBP05
46083	58.25	138.00	AGGA47 KWBJ OSBP06

46084	56.39	136.16	AGGA47 KWBJ OSBP07
46082	59.61	143.67	AGGA47 KWBJ OSBP08
46005	46.10	131.00	AGPZ47 KWBJ OSBP01
46029	46.12	124.50	AGPZ47 KWBJ OSBP02
46036	48.35	133.92	AGPZ47 KWBJ OSBP03
46041	47.34	124.67	AGPZ47 KWBJ OSBP04
46132	49.73	127.92	AGPZ47 KWBJ OSBP05
46206	48.84	126.00	AGPZ47 KWBJ OSBP06
46001	56.30N	148.30W	AGGA48 KWBJ OSBP01
46066	52.65	155.00	AGGA48 KWBJ OSBP02
46080	58.00	150.00	AGGA48 KWBJ OSBP03
51001	23.40	162.30	AGHW40 KWBJ OSBP01
51002	17.20	157.80	AGHW40 KWBJ OSBP02
51003	19.10	160.80	AGHW40 KWBJ OSBP03
51004	17.40	152.50	AGHW40 KWBJ OSBP04
HNL01	24.00	158.00	AGHW40 KWBJ OSBP05
HNL02	22.50	153.00	AGHW40 KWBJ OSBP06
HNL10	22.00	157.75	AGHW40 KWBJ OSBP07
HNL11	21.00	158.25	AGHW40 KWBJ OSBP08
HNL12	19.75	156.50	AGHW40 KWBJ OSBP09

Notes:

1. The WMO/AWIPS headers follow the form given for oceanographic data, *i.e.*, AGA$_1$A$_2$i1i2, where i1 is 4 and always means spectral wave data.

2. i2 is the geographic location, where:
   0 - means Pacific Ocean, particularly in proximity to U.S. held islands (Hawaii and Guam's areas of responsibility)
   1 - means proximity to NE Atlantic States from Virginia northward
   2 - means proximity to SE Atlantic States from North Carolina southward and Puerto Rico
   4 - means proximity to southern Gulf of Mexico states
   6 - means proximity to Pacific States and southern British Columbia
   7 - means proximity to Panhandle of Alaska and northern British Columbia (Juneau's areas of responsibility)
   8 - means proximity to southern and southwestern Alaska (Anchorage's areas of responsibility)

3. A1A2 is used by the originating office (NCEP/NCO) to identify the oceanic area of the point, where:
   NT - Western Atlantic
   GX - Gulf of Mexico
   CA - Caribbean Sea
   PZ - Eastern Pacific
   GA - Gulf of Alaska
   PN - North Pacific including Bering Sea
   AC - Arctic Ocean
   HW - Hawaiian Waters
   PW - Western Pacific
   XT - Tropical Belt
   PS - South Pacific

4. The AWIPS identifier form is NNNxxx: where NNN is OSB - Oceanographic Spectral Bulletin, and xxx takes the form: mnn - where m is the wave model and nn is the number of the point in a given geographic location according to note 2 above. nn can range from 01 - 99.

5. m is the wave model where:
   N is the NOAA WAVEWATCH III global wave model
   A is the Alaska Waters regional wave model
   W is the Western North Atlantic regional wave model
   H is the North Atlantic Hurricane wave model
   E is the Eastern North Pacific regional wave model
   P is the North Pacific Hurricane wave model
   X is the Western North Pacific regional wave model
   T is the Western Pacific Typhoon wave model

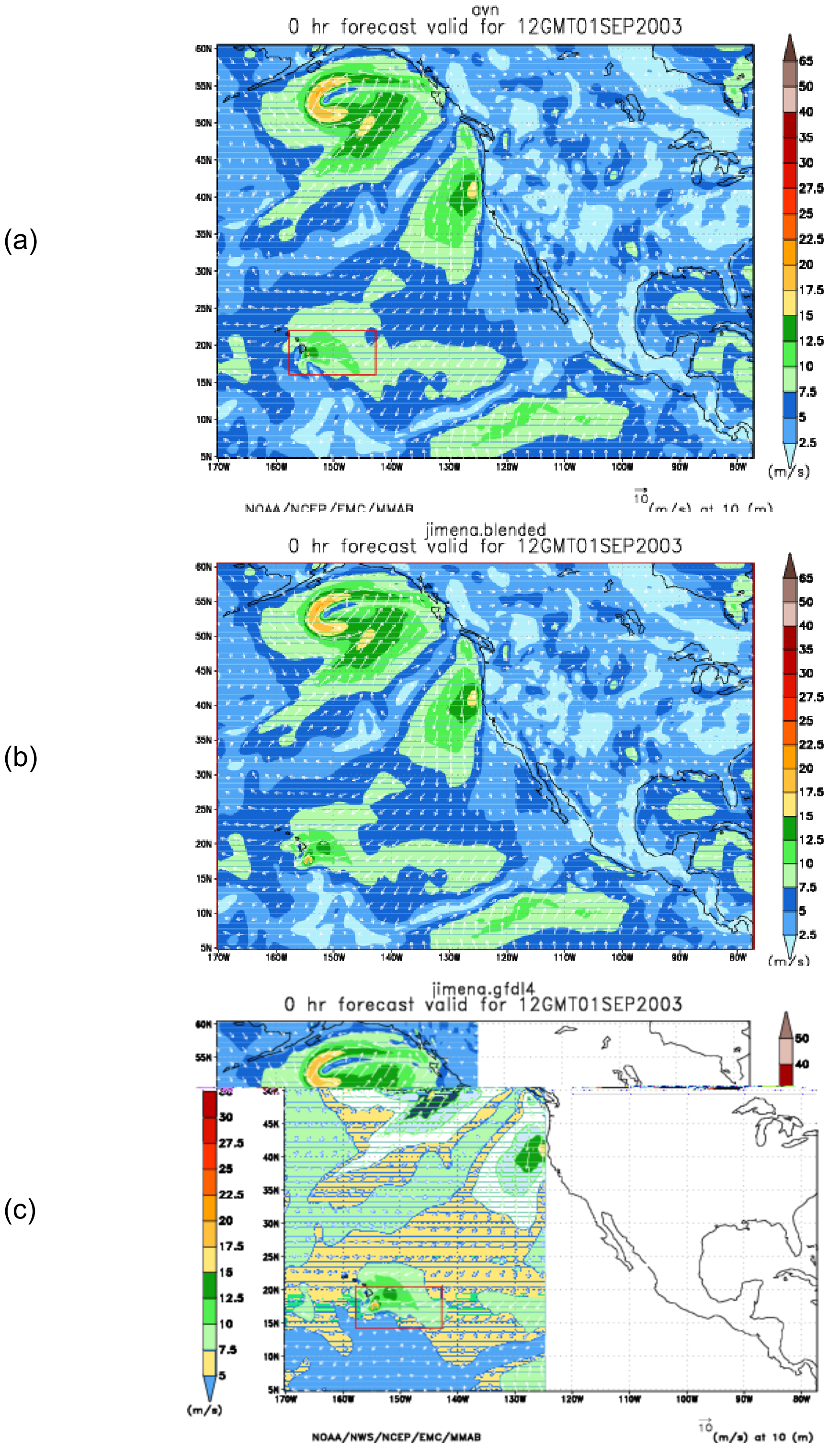

Figure1. Hurricane Jimena wind field. Boxes shown in (a) and (c) indicate Jimena’s area of influence (AOI) as specified in the text.

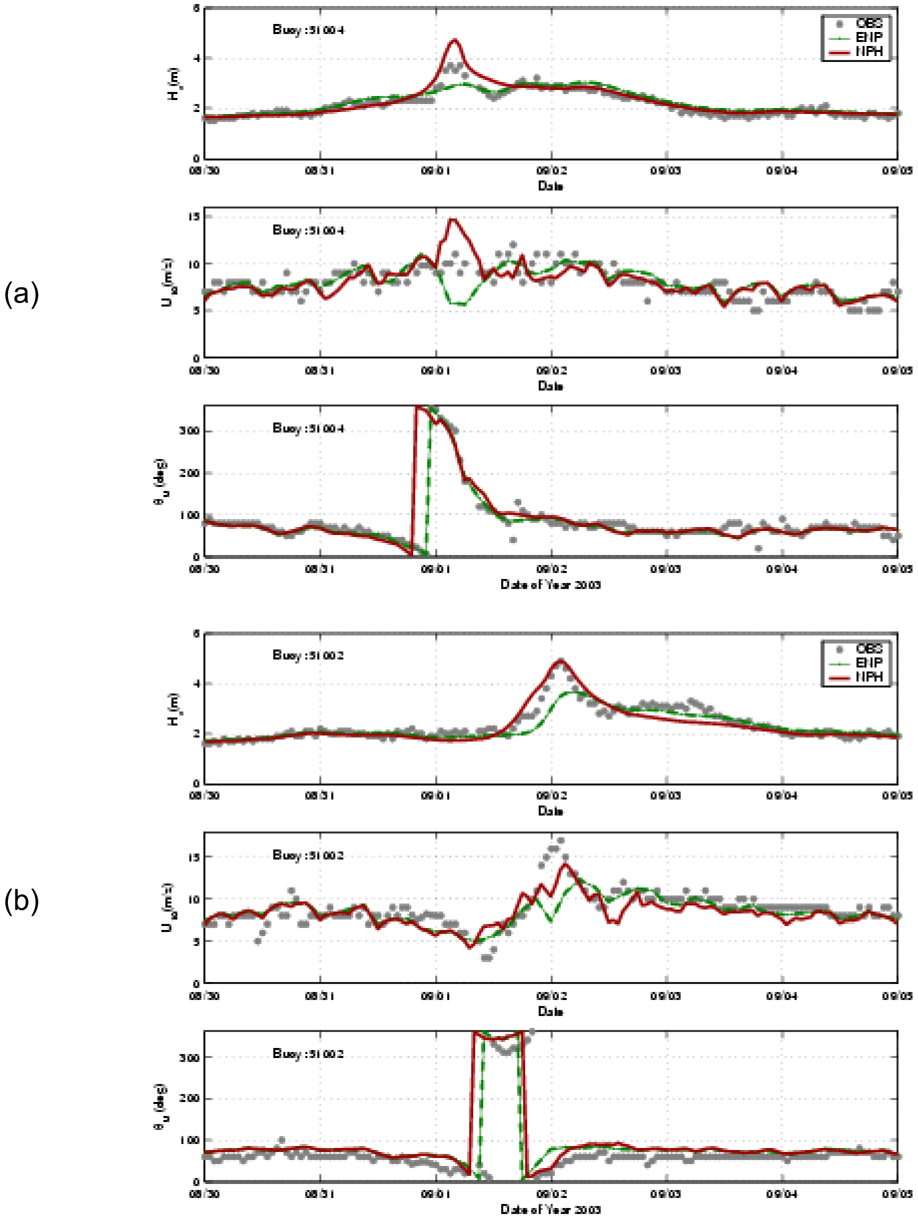

Figure 2. Comparison of significant wave height, wind speed and direction predicted by NPH and ENP wave models with measurements at buoys: (a) 51002; (b) 51004.