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FINAL REPORT

COMET OUTREACH PROJECT: **S07-66838**

Towards development of a "rapid response" local wave model for the Melbourne, Florida National Weather Service Forecast Office

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1 Introduction

The marine forecast region for the NWS Melbourne Weather Forecast Office (WFO MLB) covers approximately 250 km along the east coast of central Florida (including Cape Canaveral) and is heavily used by small craft. Census data reveals that the population along the east-central Florida coast continues to steadily grow, suggesting increasing demand for accurate and timely marine forecasts in the future. This increasing demand also comes at a time of greater NWS emphasis on closer partnerships with government agencies for incident support (e.g. hazardous material spills, homeland security assistance at coastal ports).

The region's wave environment is affected not only by waves generated by large-scale systems such as coastal lows/troughs (primarily in the "cool season", November-April) and tropical cyclones (June-November), but also by meso-scale systems such as the diurnal sea breeze circulation (strongest May-October) and cool season squall lines. Many of these systems can produce a rapid onset of dangerous and varied wind and wave conditions that endanger small craft and present a challenge for WFO MLB marine forecasters.

The task covered by this COMET-funded project was to implement and test prototype elements of an in-house high resolution "rapid response" wave forecast system for WFO MLB. One key purpose of such a system would be to assist forecasters in assessing and forecasting the effects of rapidly evolving, meso-scale weather systems on local wave conditions. The envisioned final system would use wind data output from the WFO MLB 2.5-km resolution Weather Research and Forecast (WRF) model and lateral wave boundary data available from operational NCEP wave models. Such a system would thus complement the information available from existing NCEP models.

The main activities of this project were to a) for development of a prototype implementation for the Wavewatch III wave model covering the WFO MLB forecast region and b) to perform a proof-of-concept demonstration simulation for a past case of strong local winds using archived output from the WFO MLB 2.5-km and 6 km WRF models. Major elements of the prototype system are envisioned as serving as a foundation for an eventual operational in-house system.

The funded work has resulted in development of foundation data sets (bathymetry) and software (WWIII implementation, WRF data handling code, graphical software) necessary for an operational system. In addition a number of proof-of-concept simulations have been performed. These roof-of-concept simulations have a) allowed WFO MLB marine forecasters to envision how they would operate and interact with such a system, and b) highlighted various issues that must be considered when implementing an operational system of this sort. These issues include following:

i) An operational system must include spectral wave boundary conditions on the ocean boundaries of the domain. Such boundary conditions could be produced by NCEP MMAB.

ii) An operational system (WRF and WAVEWATCH) would either have to be run regularly (every 6 hours) or use winds from previous (regularly run) WRF analyses from the past 12-24 hours or so; this to assure that spin-up transients are cleared from the wave model domain

iii) An operational system will have to be tuned (through comparisons with buoy data) over a period of months to allow appropriate adjustment of a wave model boundary profile parameter that accounts for the apparent height of the wind data supplied to the model. These settings would be specific to the WFO MLB high and low resolution WRF implementations.

iv) The exact spatial locations of the WRF grid point locations need to be defined.

2 Data and Methods

2.1 Wind Data

Winds used for the wave modeling described here come from the WFO MLB high (~1.75 km) and low resolution (~6 km) WRF implementations. WFO MLB supplied HRC with NETCDF files for high resolution WRF forecasts initialized at 06Z, 09Z and 15Z on April 14, 2007. These forecasts go out to a lead of 12 hours. Also supplied were data from low resolution WRF forecasts initialized at 06Z and 09Z and going out 27 hours. Computer code was created to extract the 10 meter AGL winds from the NETCDF files and interpolate the wind data onto the wave model grid and output the results in a format suitable for ingestion the wave model.

A difficulty in processing the wind data is that the exact latitude-longitude coordinates of the WRF grid point locations could not be determined (the WRF grid points not on an evenly spaced in latitude and longitude). For this pilot study, the location of the WRF data were estimated from information in the file giving the latitude-longitude coordinates of the most southwesterly and most northeasterly corners in the WRF domains. Data processed using the corner coordinates alone as a guide had remaining spatial offsets (topography data in the WRF output files showed this), and further adjustments were done to bring the topography into approximate congruence with known coastline locations. The wind data were then processed using these spatial adjustments.

2.2 Wave Modeling

The wave modeling was performed using the NOAA Wavewatch III model v. 2.22 (WWIII). Some aspects of the WWIII model configuration used in the study are listed below.

- Spatial Resolution: 0.025 degrees latitude–longitude [~2.7 km (1.5 nm) meridionally].
- Domain: 81.5W to 78.9W longitude, 26.525N to 29.75N latitude (105 x 130 grid points).
- Spectral resolution: 25 frequency bins (log-spacing, 2.8 – 27.1 seconds), 5 degree directional resolution.
- Output time step: 3 hours.
- WRF winds assumed to be from 10 m MSL.
- No lateral wave boundary conditions.
- Bathymetry interpolated from US NOAA coastal data at approximately 0.5 nm resolution.

Two sets of wave model simulations were conducted, one using the high resolution WRF forecast wind data (WW-HIRES) and the other using low resolution WRF forecast wind data (WW-LORES). The WW-HIRES simulations were begun with a run using the April 15 06Z WRF high resolution forecast winds. The model was run from a cold start (using a JONSWAP spectrum appropriate for grid point winds to provide initial conditions for the model) from 06Z April 14 through the end of the forecast at 18Z April 14 and a restart file was created for 09Z. A second WW_HIRES run used the 09Z WRF (high resolution) forecast winds and used the initial conditions produced during the 06Z simulation. This simulation ran out to 21Z and wrote out a restart file at 15Z. The third WW_HIRES run used the 15Z WRF April 14 high resolution forecast winds and used the initial conditions produced during the 09Z simulation. This simulation ran out to 03Z April 15.

The WW-LORES simulations were produced in an analogous fashion to the WW-HIRES runs but using the low resolution WRF winds. One simulation was run out from a cold start at 06Z April 14 to 09Z April 15 and produced a restart file at 09Z April 14. A second simulation initialized at 09Z April 14 used the restart file produced in the 06Z run and ran out to 12Z April 15.

Because these simulations are so short, waves produced during the cold-start initialization procedure contaminate parts of the simulations (see Fig. 4A). The lack of lateral boundary conditions (i.e. the closed lateral boundaries) further limits the reality of the simulations to short period waves generated entirely within the domain.

3. Results

Winds

Figure 1 shows 10-m wind data (prior to interpolation onto the wave model grid) from a) the high resolution WRF run initialized April 14 at 15Z and valid April 15 at 00Z (Fig. 1A) and b) the low resolution WRF run initialized April 14 at 09Z and valid April 15 at 00Z (Fig. 1B). The differences between the two forecast wind fields are considerable – in particular, the low resolution results show southeasterly winds off the coast while the high resolution results show southwesterly winds off the coast. As shown later, these differences in wind direction produce large differences in wave conditions at the inshore buoy comparison locations. Figure 2 shows time series of wind speed and direction from NOAA Buoy 41009 off Cape Canaveral. Between 10Z April 14 and 00Z April 15 measured buoy wind speeds increase from about 5 ms^{-1} to over 10 ms^{-1} and wind direction veers from easterly to south-southeasterly (approximately parallel with the general trend of the coastline). The wind data for this location from the two low resolution WRF forecast runs agree well with the buoy data for both speed and direction (particularly the 06Z results). The high resolution WRF forecast winds reasonable agreement with the buoy data with respect to speed, but show in each simulation the directions rotate too far clockwise (towards more westerly directions) as the forecast lead time increases.

Waves

Figures 3A-C compare measured and simulated significant wave height (H_S) at three wave buoy locations in the WWIII domain (see Fig. 1 for buoy locations). The results for Buoy 41009 (Fig. 3A), located about 15 nm east of Cape Canaveral, show obvious spin-up effects in the first 12 hours of each wave model run. Following this, the simulated wave heights increase in qualitative agreement with the buoy measurements, though the WW-LORES wave height changes lag the buoy data by 2-8 hours. At Buoy 41113 (near shore, Cape Canaveral; Fig. 3B), the 1500 WW-HIRES simulation does not show the increase in wave heights observed at the buoy after 15Z on April 14. The fact that the high resolution WRF winds are directed too much in an offshore direction certainly contributes importantly to the low bias in wave height at this location. The WW-LORES forecasts do show an increase in wave heights (beginning about 4 hours late), but maximum wave heights are too small. At Buoy 41114 (towards the southern part of the domain; Fig. 3C), measured wave heights show much smaller increases during April 14^{th} and 15^{th} than seen at the two buoys to the north. The forecasts agree fairly well with the buoy data at this location (after spin-up transients pass), though as at the other two locations, wave heights tend to be biased low. Given its location close to the southern boundary of the domain the wave model results from Buoy 41114 should be interpreted with caution.

Dominant wave periods at the all of the buoys were 4-6 seconds during the period of interest and the wave forecast results are in good agreement with that range.

Figure 4A shows H_S and dominant wave direction from the 09Z WW-LORES forecast at 00Z on April 15 (15 hour lead). The effect of the closed boundary in the east is clearly apparent in these results and this shortcoming likely has some effect on simulated wave heights (too low) through most of the domain. Nevertheless, the results are believed to be qualitatively realistic (i.e., for this event they qualitatively resemble those that would be produced by an operational system) an in the west-central and northwest parts of the domain. Figure 4B shows dominant wave period and winds for the same forecast and validation time shown in Fig. 4A. At this time, dominant wave periods are in the 3-4 second range and increase in period from south to north reflects both the increasing wind speeds in that direction and distance from the closed boundaries to the south and east.

4. Summary and Discussion

Proof-of-concept wave modeling forecast simulations have been conducted with the WAVEWATCH III wave model using winds from the WFO MLB high and low resolution WRF implementations. The main findings are listed below.

- The results demonstrate that an operational implementation of WAVEWATCH (with appropriate lateral boundary conditions) with MLB WRF winds could provide near-term warnings of impending locallygenerated wave episodes allowing reduction in risks to small craft operators and other marine interests in the WFO MLB region of responsibility.

- In the very limited set of simulations analyzed here, the low resolution WRF winds were superior to those from the high resolution WRF. The winds from the two implementations show consistent differences in wind direction at longer forecast lead times. Based on the single set of buoy wind measurements, the high resolution wind direction appear to have been directed too much to the east, reducing wave heights near the coast.

- For an operational system, the WWIII / WRF pairing would need to be tuned to account for a) details in the way the 10 meter MSL winds are produced in WRF and b) how they are interpreted by the wave model (which has its own surface boundary parameterization for converting wind data to surface stress). This tuning would require a few months of validation simulations and comparisons with buoy wave measurements.

- An operational wave forecast system would require spectral wave conditions to be prescribed at the lateral boundaries. These boundary data could be produced (by NCEP MMAB) from the NCEP MMAB North Atlantic Hurricane (NAH) WWIII implementation and made available via Internet.

  An operational WWIII-WRF wave forecast system for WFO MLB would also have to be either i) run regularly (e.g. every 6 hours) – this would require routine runs of the MLB WRF model or ii) always have available wind data from MLB WRF analyses covering the previous 12-24 hours. This second alternative would allow wave model forecasts to be produced on an as needed basis, but also requires regular operation of the WRF system, if only to produce the analysis winds.

The first alternative for design of an operational system given above appears better from several perspectives. First, the regular availability of the wave forecast information fosters familiarity with the products. Second, such a system is somewhat simpler in design and operation. Both alternatives require some regular operation of the MLB WRF model.

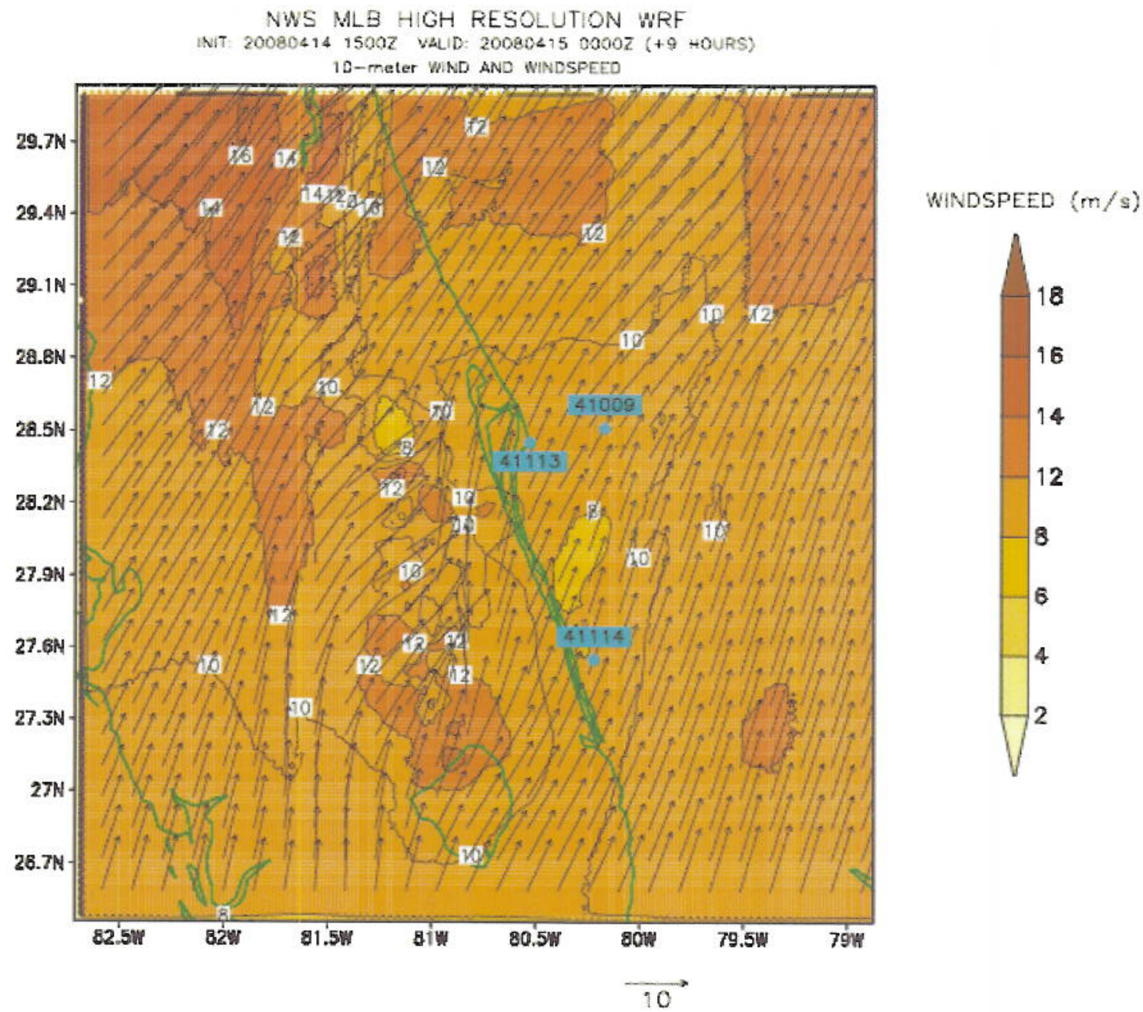

Fig. 1A. 10 m winds from the WFO MLB high resolution WRF implementation forecast initialized at 15Z April 14, 2007 valid at 00Z April 15, 2007. Colors and contours show wind speed, arrows indicate wind direction and are scaled to wind speed. Blue labels show buoy locations.

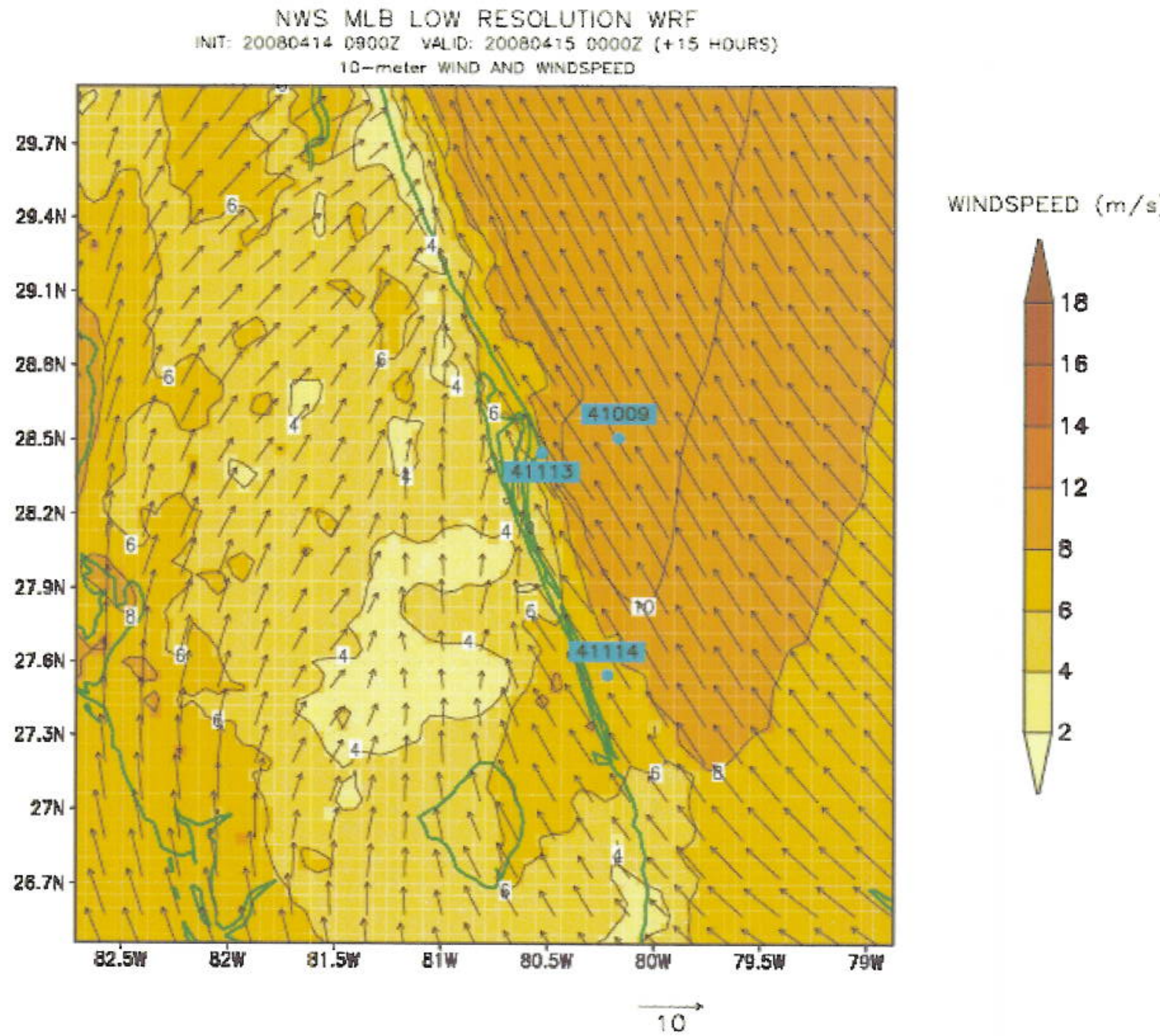

Fig. 1B. 10 m winds from the WFO MLB low resolution WRF implementation forecast initialized at 09Z April 14, 2007 valid at 00Z April 15, 2007. Colors and contours show wind speed, arrows indicate wind direction and are scaled to wind speed. Blue labels show buoy locations.

BUOY 41009 – Lat: 28.51 N Lon: 80.17W depth: 41.5 m

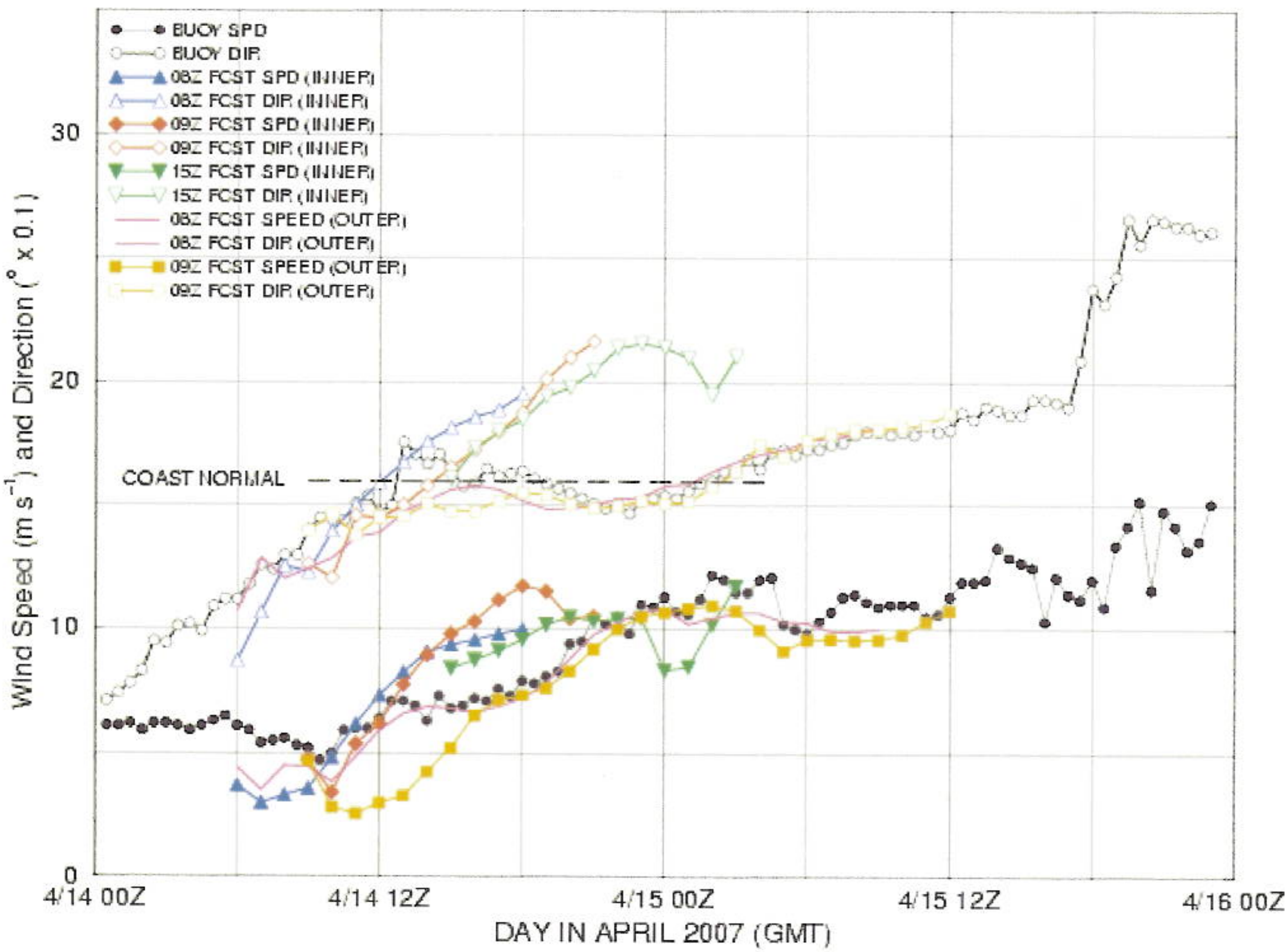

Fig. 2 – Time series of wind speed (lower curves) and direction (upper curves) from NOAA Buoy 41009 and from the WFO MLB WRF forecast runs discussed in the text. Data from high resolution WRF runs are denoted "INNER" in the key and those from low resolution runs are denoted "OUTER".

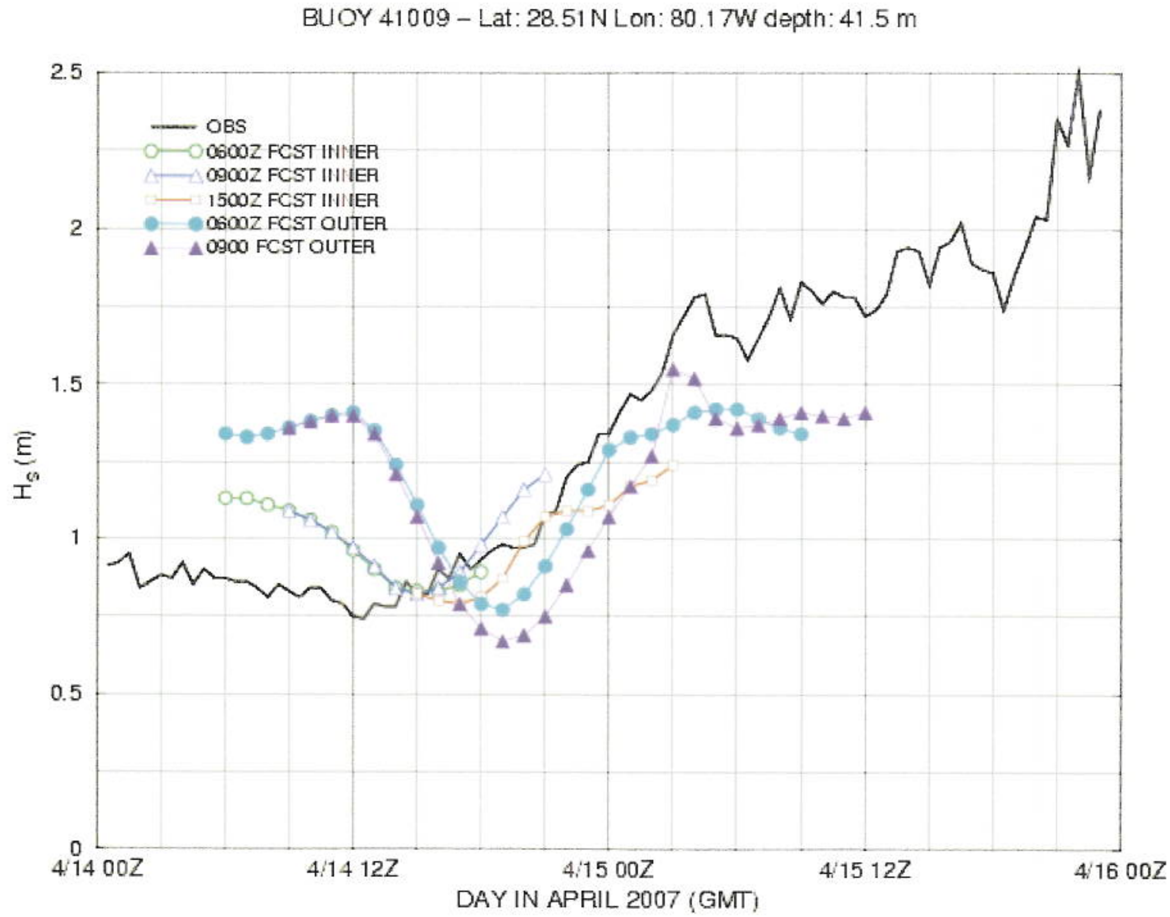

Fig. 3A – Evolution of measured and simulated significant wave height (H_S) from Buoy 41009 (NOAA). Simulated data come from the three runs forced with WW-HIRES simulations (marked "INNER" in the key) and the two WW-LORES simulations (marked "OUTER" in the key).

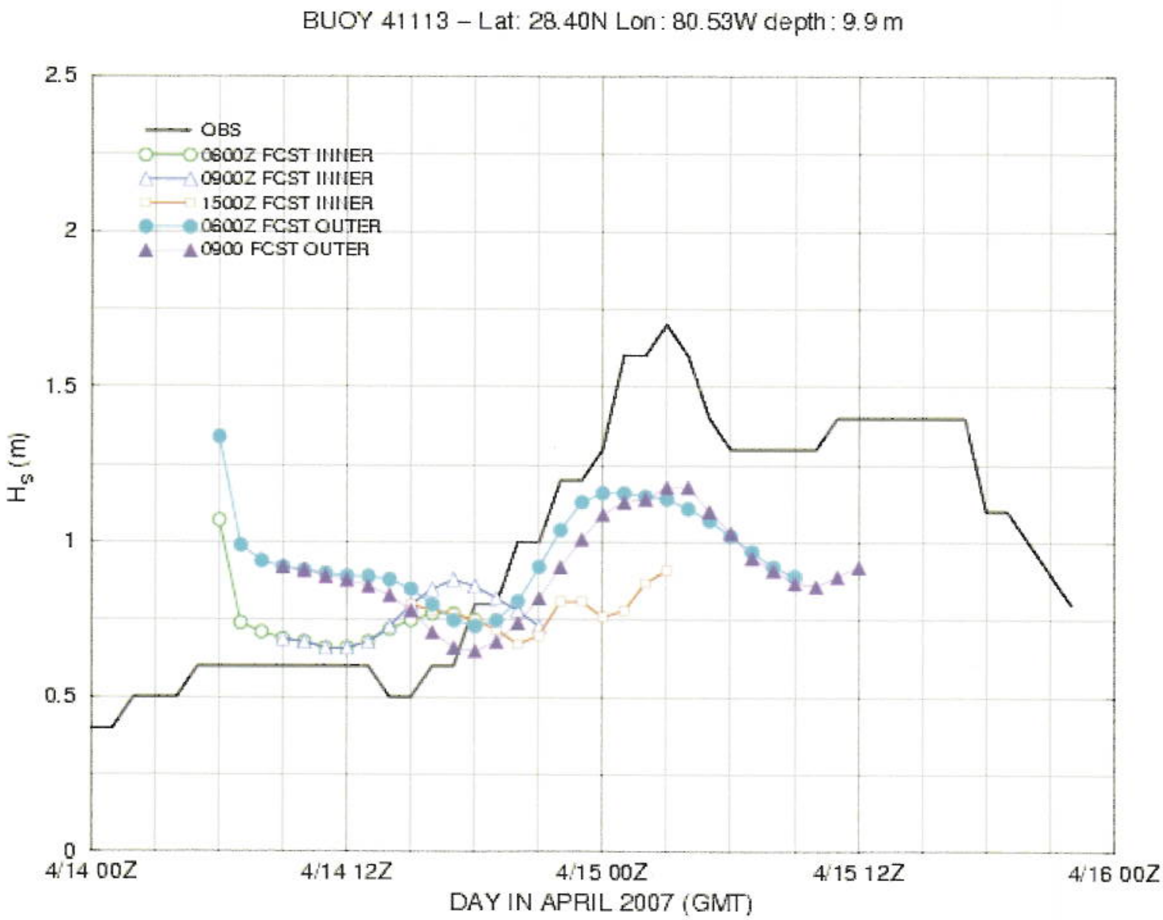

Fig. 3A – Evolution of measured and simulated significant wave height (H_S) from Buoy 41113 (CDIP). Simulated data come from the three runs forced with WW-HIRES simulations (marked "INNER" in the key) and the two WW-LORES simulations (marked "OUTER" in the key).

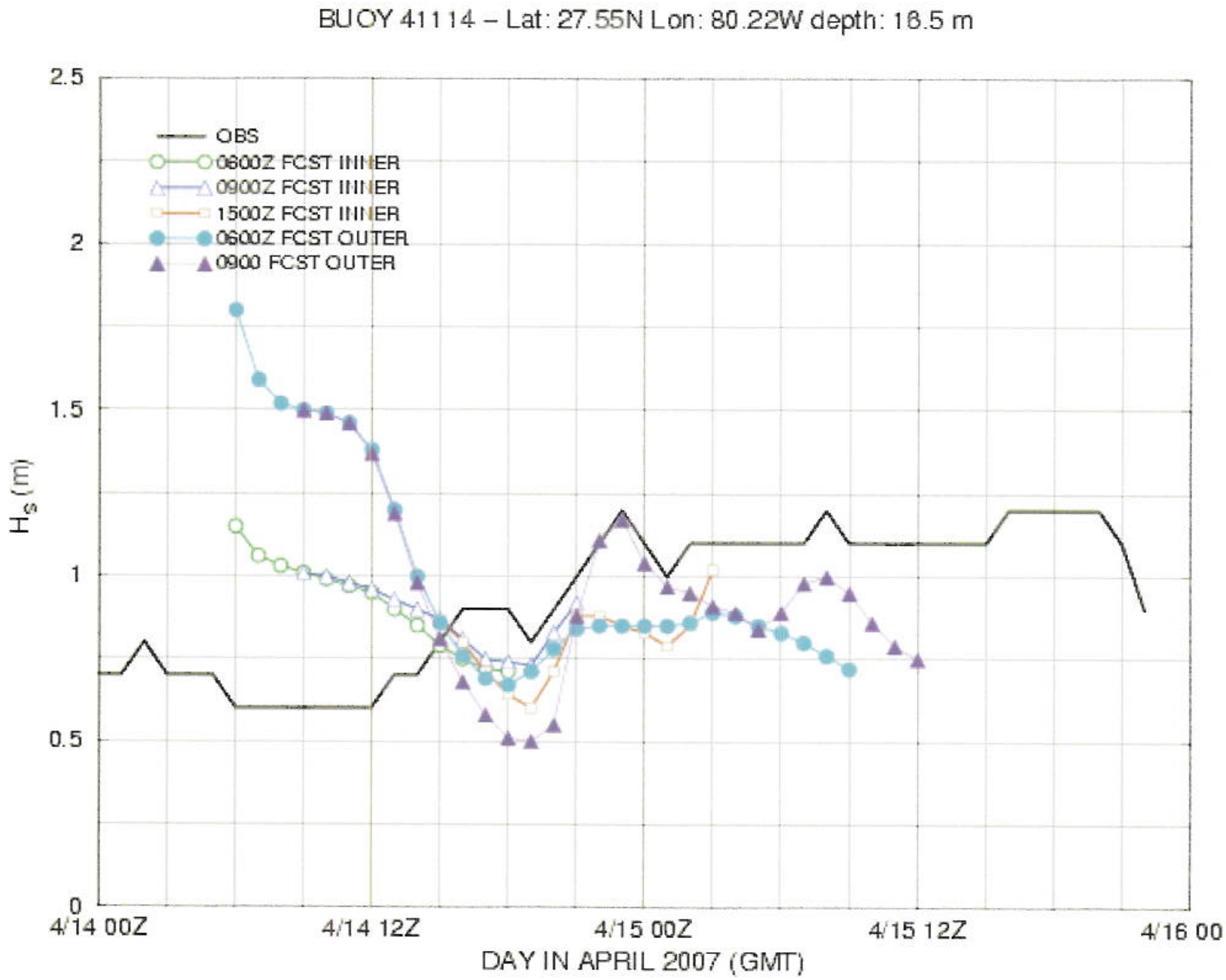

Fig. 3A – Evolution of measured and simulated significant wave height (H_S) from Buoy 41114 (CDIP). Simulated data come from the three runs forced with WW-HIRES simulations (marked "INNER" in the key) and the two WW-LORES simulations (marked "OUTER" in the key).

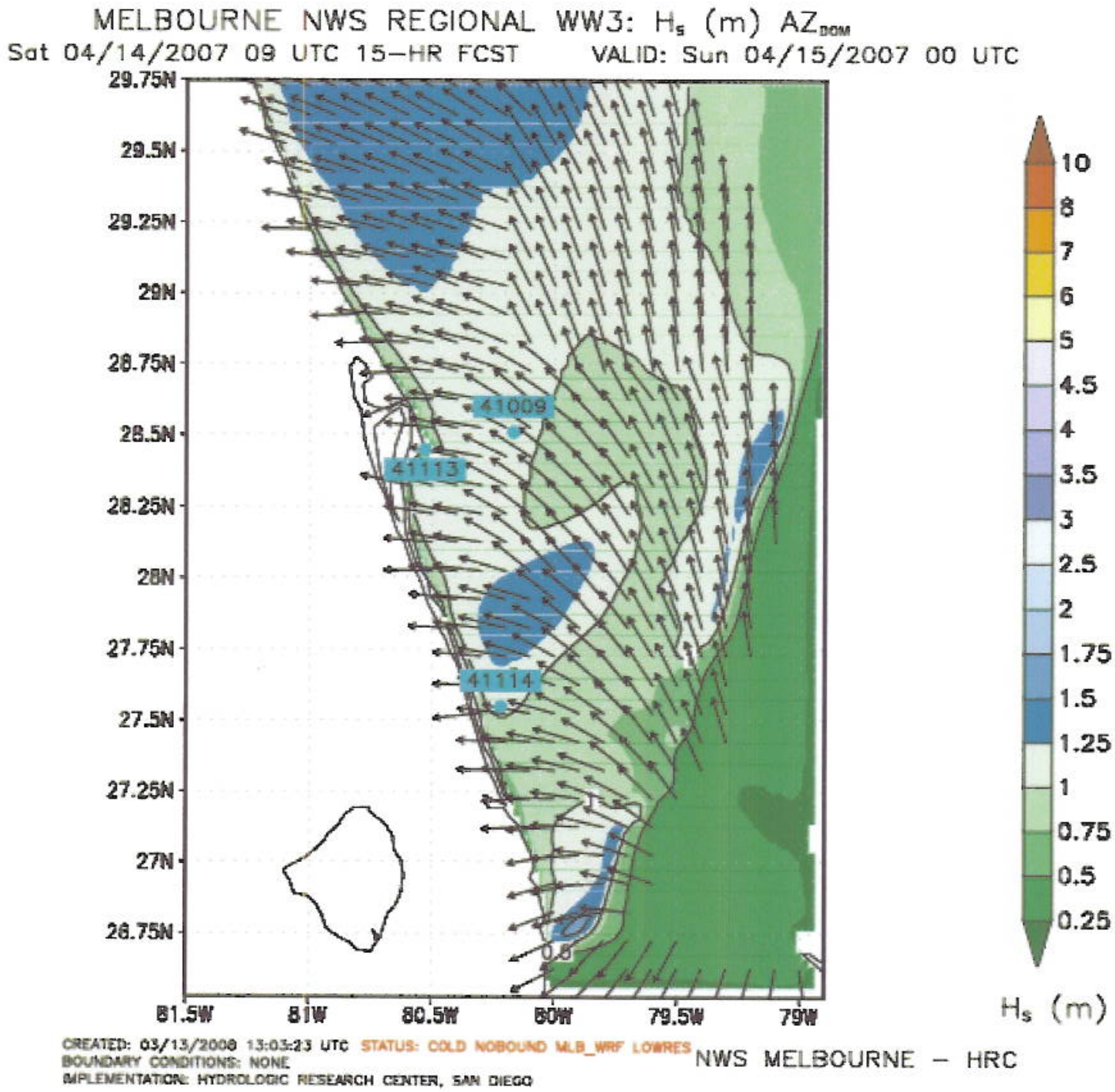

Fig. 4A – H_S (color) and dominant wave direction (arrows) from the WW-LORES simulation initialized at 09Z April 14 and valid at 00Z April 15 (15 hour lead time). WW-III does not calculate dominant wave direction when waves are very low, hence the missing arrows in parts of the graphic. Locations of wave buoys are indicated.

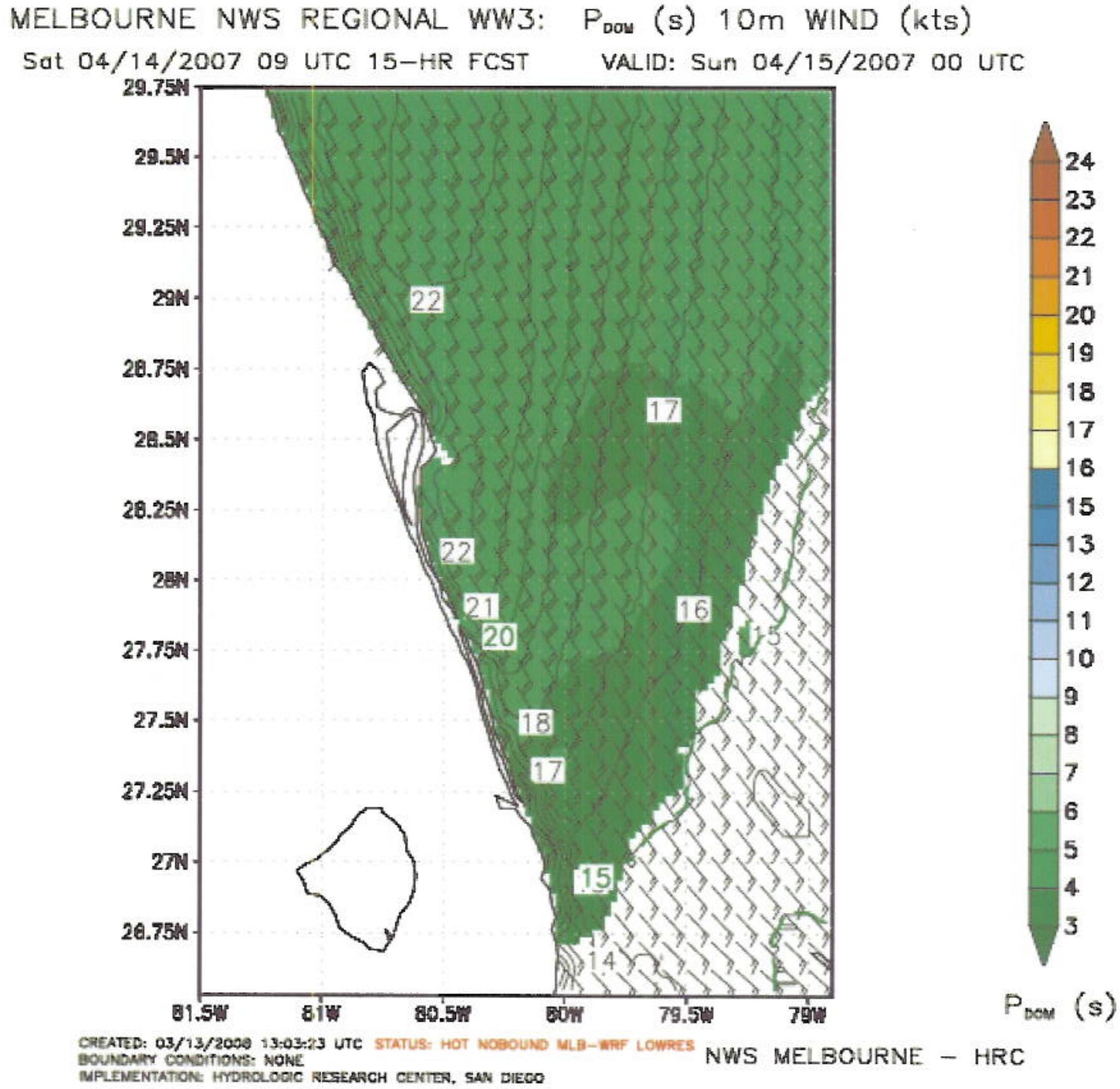

Fig. 4B – Dominant period (color), wind speed and direction (kts, arrows with barbs) and wind speed (contours) from the wave model simulation using low resolution WRF forecast winds from the forecast simulation initialized at 09Z April 14 and valid at 00Z April 15. WW-III does not calculate dominant period when waves are very low, hence the lack of color in parts of the graphic.