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NUMERICAL VALIDATION OF A COUPLED PROBABILISTIC RIP CURRENT MODEL AND NEARSHORE WAVE PREDICTION SYSTEM FOR SOUTH FLORIDA

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1. INTRODUCTION

A probabilistic rip current model (Dusek et al. 2014) coupled with the Nearshore Wave Prediction System (NWPS, Van der Westhuysen et al., 2013) has been expanded and validated across the South Florida region. The rip current model is a statistical model configured to predict the likelihood of hazardous rip currents. The model is forced by waves and water levels from the NWPS across high-resolution nested grids. The coupled system was originally developed and tested at two locations over the Outer Banks of North Carolina in 2013, where initial results indicated performance improvements over the present index-based approach (Dusek and Seim, 2013a) that was originally created in 1991 (Lushine, 1991).

Initial model results along the southeast Florida coast through the 2014 winter and summer periods showed similar results and revealed moderate to strong correlations between rip current intensity observations and the model output. Significant advantages of the modeling system over the traditional index-based rip current assessment that are resolved more efficiently include: diurnal or temporal trends associated with water levels (tidal influences), winds (weakening/strengthening or mesoscale features with land-sea breezes) and wave conditions. Additionally, rip current model-based projections out to 90-hours allow operational forecasters to provide enhanced decision support services to core partners locally (i.e. Lifeguards, Ocean Rescue and Emergency Managers).

This paper presents the main purpose of this modeling effort and motivation for the development in Section 2. The configuration and design elements of the coupled modeling system are described in Section 3. Results from the validation period are discussed in Section 4. This is followed by future goals and conclusions in Section 5.

2. MOTIVATION

The southeast Florida metropolitan area includes: Palm Beach, Broward and Miami-Dade Counties. The average annual beach attendance ranges from 3.4 million in Palm Beach, to around 5 million in the City of Fort Lauderdale (Broward County) and up to 10 to 15 million in the Miami-Dade area. Unlike other parts of the East Coast, beach attendance is high year-round, with peak tourism typically occurring from November through April. Water temperatures along the southeast Florida coast generally range from the lower to middle 70s from December through March to the middle to upper 80s through the warm months. Hazardous rip current frequency is the highest through the winter period. Most of the events through these cool season months are

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associated with northerly winds following strong cold fronts or moderate northerly swells from distant synoptic-scale features northeast of the local area. Over the warmer months, rip current events are typically associated with tropical cyclones that are directly impacting the local region or re-curving northward east of the area. All these factors support numerical rip current modeling development in the local region. Figure 1 shows a gradual increasing trend in ocean rescues related to rip currents each year between 2006 and 2013 in this region with an average of 332 rescues per year. Preliminary reports from the United State Lifesaving Association (USLA) and Fire Ocean Rescue Division in Miami-Dade indicate 261 rescues and one fatality in the first eight months of 2014. There were 116 rescues and zero fatalities from January through April and 145 rescues from May through August with one fatality.

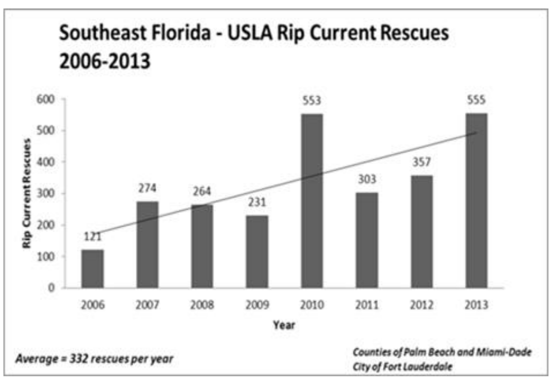

Figure 1. Reported USLA rip current rescues, 2006-2013.

3. MODEL SETUP

3.1 Wave Model

Three high-resolution (~100m) nested NWPS grids are configured and setup on structured grids across the southeast Florida coast at: Haulover Inlet in the north Miami Beach area, Lauderdale-by-the-Sea in Fort Lauderdale and Juno Pier north of West Palm Beach (Figure 2). The wave spectrum is resolved with angular increments of 10 degrees between 0 and 360 degrees, 37 logarithmically spaced frequencies between 0.05 and 1.5 Hz (increment of 0.005). The nests are operationally run in nonstationary mode with a time step of 600 seconds.

3.2 Wave Model Input Sources

Bathymetric input is from the 3 arc-sec (~90 m) Coastal Relief Model (CRM) provided by the National Geophysical Data Center (NGDC). Wave boundary conditions from a coarser 1.8 km outer grid encompassing the South Florida region are used to initialize the nested grid boundaries.

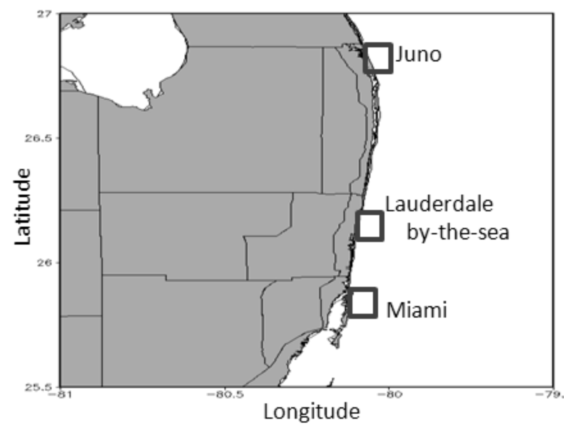

Figure 2. Three high-resolution (~100m) NWPS grids along configured along the along the southeast Florida coast.

Forecaster-developed gridded wind fields (2.5 km) from the Graphical Forecast Editor (GFE) are used as atmospheric forcing to the outer grid as well as the nests. This results in wave forecasts consistent with the local wind forecasts as model solutions used can vary from cycle to cycle and the local wind forecasts are constructed from the model forecasts based on the forecaster’s analysis and confidence of the different model solutions (i.e. local wind forecasts can be based from NAM, WRF, GFS, ECMWF, Statistical, Consensus and/or blends of these numerical solutions). In order to capture or more effectively resolve mesoscale features at the land-sea interface, higher resolution models are generally blended in the official wind forecast each cycle particularly in the short range.

Wave-current interactions associated with the Gulf Stream that impact the coastal wave fields over the South Florida region are accounted for by including the surface current fields from NCEP's Global Real-Time Ocean Forecast System (RTOFS-Global, Mehra et al., 2011) across the outer coarser grid through one-way coupling. Although the Global RTOFS solution is too coarse to use at the scale of the nested grids, wave boundary conditions from the outer grid can have a significant impact on the wave fields in these shallow coastal regions, especially when the area is being impacted by northerly swell or synoptic-scale events (i.e. strong northerly winds across the Gulf Stream associated with cold fronts). In these events, the Gulf Stream dramatically influences the wave kinematics (i.e. wave straining, shortening and blocking), which translates to strong directional change within the wave fields in and around the current horizontally. These directional changes are reflected in the incoming wave fields at the grid boundaries of the nested grids and can alter the output from the rip current model, that will be explained further in Section 3.4.

Water levels (tides and surge) are incorporated through one-way coupling with: ESTOFS (Extratropical Surge and Tide Operational Forecast System; Feyen et al., 2013) or P-Surge (probabilistic approach to produce coastal surge predictions during tropical cyclone events based on the Sea, Lake, and Overland Surges from Hurricanes (SLOSH) model; Jelesnianski et al., 1992). Properly resolving water levels in and around the surf zone is an important process in rip current prediction and has a large influence on the model-simulated significant wave heights. The wave height differences between simulations with and without water levels are especially apparent in coastal regions with at least moderat tidal ranges or during surge events.

3.3 Wave Model Output

Wave model output along critical bathymetric contours are configured for each of the nested grids. Utilities built within the wave model allow the user to define a set of rays that intersect the desired contour depth, for which the wave fields will be provided as input to the rip current model that will be discussed in Section 3.4. For the purposes of this coupled system, the 5m contour is used and tested during the validation period. Each model cycle writes the wave data along the 5m isoline at evenly-spaced intervals defined by the user to an ASCII file in tabular format. Figure 3 is a graphical illustration of the ray and isoline configuration used from the Fort Lauderdale grid.

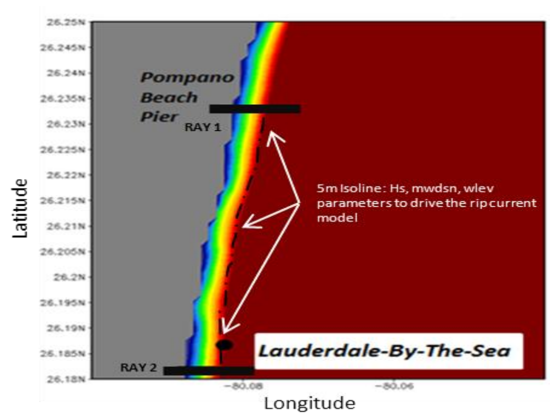

Figure 3. A set of rays built within the Fort Lauderdale NWPS grid that intersects the desired 5m bathymetric contour. Wave output along this contour is used as input to force the rip current model.

3.4 Rip Current Model

A probabilistic rip current model, shown in Figure 4, was developed through a logistic regression to predict the likelihood of hazardous rip currents occurring (from 0 to 1) (Dusek and Seim, 2013a). This development was based on relating wave field, water level and rip current intensity observations collected by lifeguards in the Outer Banks of North Carolina. As shown in Dusek and Seim, 2013a, four wave model input parameters that are used to force the rip current model along the aforementioned 5m isoline illustrated in Figure 3 include: total significant wave height, mean wave direction, and water level (ESTOFS; relative to MSL). An additional 72-hour post wave event parameter is included to account for surf zone bathymetry favorable for rip currents following wave events.

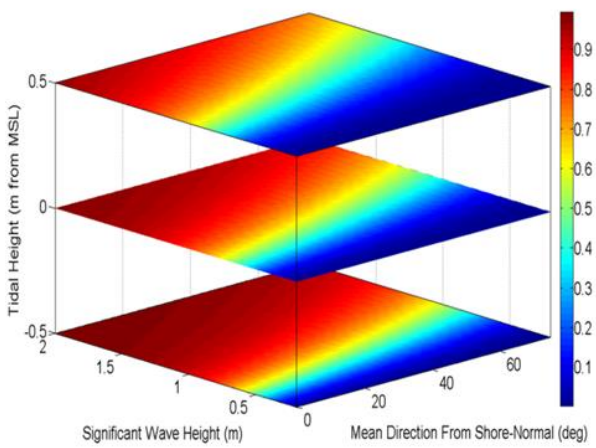

Figure 4. 3D graphical depiction of the rip current model that outputs the likelihood of hazardous rip currents from 0 to 1 based on: total significant wave height (y), mean wave direction (x) and water level (z).

3.4 Wave and Rip Current Model Output

For the South Florida region, critical points along the isolines (i.e. near jetties and piers) from each nested grid were locally extracted from the wave model output at three hour time steps and used as input to force the rip current model. Rip current probabilities and wave parameters output from the model are post-processed and archived. An ASCII table that includes the model output and probabilities along with a 1D time series plot at each of the locations defined in each grid are made available to operational forecasters following each model cycle. Figure 5 shows an example 90-hr forecast time series for a point just seaward of the southern jetty at Haulover Inlet along the 5m isoline that includes: dual y-axis for significant wave height and period, likelihood of hazardous rip currents and wave period.

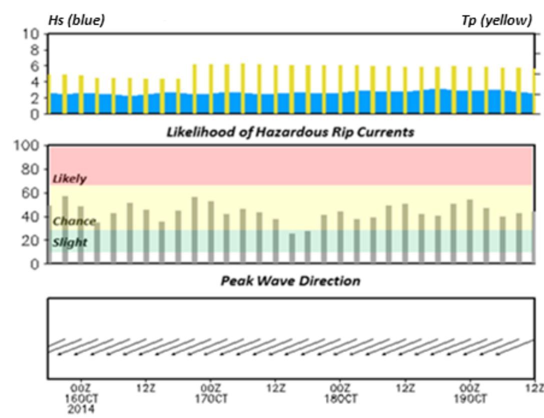

Figure 5. Three panel time series highlighting the total significant wave heights and periods (top panel), likelihood of rip currents (middle panel), and wave direction (bottom panel).

4. VALIDATION

Daily observations of estimated rip current intensity were correlated to the modeled rip current likelihood through the 2014 summer months for each grid along the southeast Florida coast from June through August. An additional validation period from January through March of 2014 was conducted for the North Miami Beach area (Haulover Inlet) during the initial phase of the model configuration. Each observation accounted for within the regression analyses are matched with photographic images of the surf zone for each location at the time of the observation. A combination of these images (on-site or through a beach camera) and local lifeguard reports (beach flag system for rip current risk assessment; green (low risk), yellow (moderate risk) and red (high risk) were considered for the final rip current intensity estimate. Following a similar approach to Dusek and Seim (2013b), intensity estimates were recorded on a scale ranging from 0 to 3:

- 0 – 0.4 - No rip currents present
- 0.5 - 1.4 – Some low intensity rip currents present, may be hazardous to some swimmers
- 1.5 – 2.4 – Medium to strong rip currents present, will likely be hazardous to swimmers
- 2.5 – 3.0 – Very strong rip currents present, hazardous conditions

In order to retain some degree of consistency between the intensity estimates, only three trained observers participated through the validation period. In several borderline cases, where the small tidal ranges in the region influence breaking waves and resulted in different intensity level estimates between tide cycles, multiple observations were taken and discussed between the high and low tide cycles through the day. Determining the correlations between intensity observations and the model likelihood output for these borderline days was a critical phase of the validation period for operational implementation locally.

Overall results reveal moderate to strong correlations at each point along the coast between the observations and model output (Figure 6). The most active rip current period was observed through the initial development phase through the winter months in the North Miami Beach region. The bottom of Figure 6 also shows a reliability diagram that was created from these winter observations by grouping the forecast probabilities into bins along the vertical axis and the observed frequency plotted along the horizontal axis. Although a larger sample set is desired, initial results during this active period indicate a low bias for the high-end events (meaning when the model output is greater than 45 to 55 %, the likelihood of hazardous rip currents being observed is typically high).

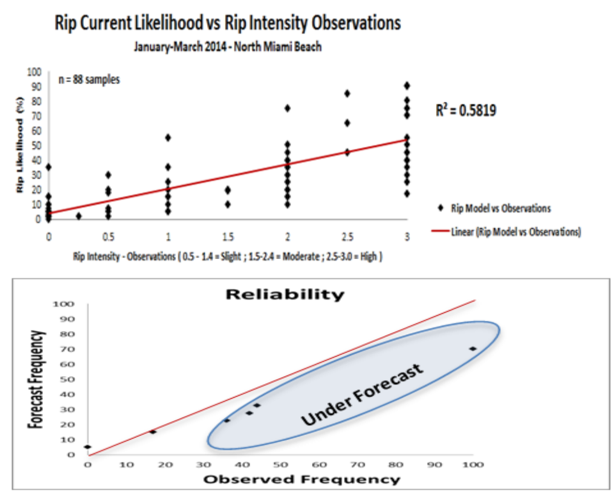

Figure 6. Linear regression (top) analysis shows moderate to strong correlations between rip current intensity observations and the model output in the Miami Beach area from January through March 2014. A reliability diagram (bottom) indicates a low bias for the high-end events (meaning that strong rip currents are likely when the model output is greater than 45 to 55 %).

Several outlier days, where the intensity observations were not reflected in the model output, were typically due to the rip current model sensitivity to the wave model significant wave height output. Slight under or over-forecasts of the simulated-wave heights translated to substantial differences in the final rip current likelihood on these days. An additional potential weakness within the model that rarely occurred during the validation period was exposed during small swell events with long periods (i.e. 0.3 to 0.7m swell at 12 to 15 seconds). Since the rip current model does not account for wave period, observations and the model output were comparatively different during these periods. As an example, days with small swell events of this magnitude would result in rip current intensity observations ranging from low to moderate, whereas, the model output likelihood would remain very low (< 10 % likelihood).

National Weather Service (NWS) products communicate the risk of rip currents to the public as: None, Low, Moderate, and High. In order to fully incorporate this probabilistic rip current guidance into operations, thresholds relating the rip current intensity observations to the model output must be determined locally.
Given the initial results from the validation periods, the model output likelihood thresholds between None, Low, Moderate and High have been determined for each location along the southeast Florida coast. Figure 7 shows a preliminary set of thresholds based on the limited results from this study. These likelihood thresholds are used by operational forecasters to assess the final rip current likelihood in the daily Surf Zone forecast product at the local Weather Forecast Office in Miami, Florida.

5. FUTURE GOALS

Future goals in the local area include incorporating rip current observations and rescue data from the lifeguards and Ocean Rescue through improved reporting utilities. A data-entry online application developed and supported by the National Weather Service

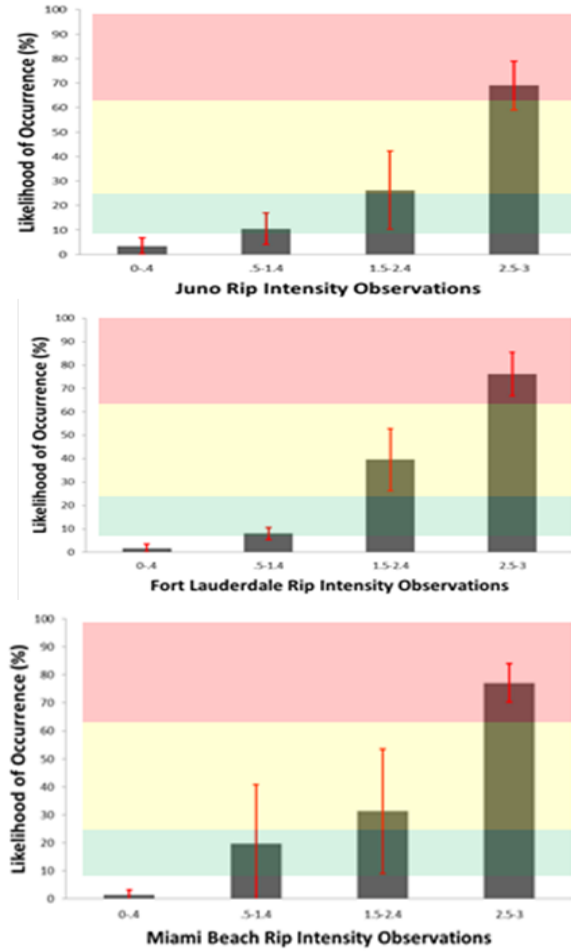

Figure 7. The final likelihood thresholds between: None (white), Low (green), Moderate (yellow) and High (red) that relate intensity observations with the model output averages and standard deviations through the validation period are shown for each location

(NWS) Meteorological Development Laboratory (MDL) has been introduced to the local partners and will support further validation of the coupled modeling system. To expand on the present output provided to forecasters and the local partners, future plots along the critical bathymetric contours along a particular coast could be added. Advantages of this expansion would include entire segments of a coastline versus one location or point forecast. Future implementation of the high-resolution Digital Elevation Model (DEM) from NGDC (~10m) (Friday et al., 2012) could be explored for the Palm Beach region, which would allow testing at higher spatial resolutions in the region. Such an application could be introduced once the NWPS has migrated to the projected two-way, tightly-coupled system, featuring a flow and wave model within the NWPS.

6. CONCLUSIONS

An operational rip current forecast model coupled with the Nearshore Wave Prediction System (NWPS) is presented. A combination of year-round warm waters, a large tourist base and reports from the USLA and Ocean Rescue supports numerical rip current modeling development in the local region. Rip current projections from the modeling system out to 90-hours allow beach officials to plan accordingly for upcoming large events and holidays. Although initial results from the coupled system reveal favorable comparisons between the observations and model output along the southeast Florida coast through the validation period described, further evaluation of the system is desired in the future as the project continues due the limited sample size of the data upon which the present results are based. Data-entry forms online created by MDL will support live observations from the local Ocean Rescue divisions and the ability to further evaluate the model results at each location along the coast. Additional development of the system could be expanded to include larger segments of the coast that would support visual enhancements to better communicate the likelihood of hazardous rip currents.

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