SIMULATING WAVES NEARSHORE (SWAN) MODELING EFFORTS AT THE NATIONAL WEATHER SERVICE (NWS) SOUTHERN REGION (SR) COASTAL WEATHER FORECAST OFFICES (WFOs)

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1. INTRODUCTION

The guidance from numerical weather prediction models is an integral part of the NWS forecast process. As technology continues to steadily advance, numerical models are no longer run exclusively on large, central computing facilities, but can now be run locally on computer workstations. This has resulted in an explosive increase in the use of local high-resolution models by NWS field offices during the past decade. Such models not only provide higher resolution guidance, but are also used as training tools or as a mechanism for collaboration with partners in research projects addressing local forecast problems. Furthermore, the models have not been limited to atmospheric modeling but also are used to model such fields as wave height and currents, useful for offices with marine responsibility.

Within the NWS Southern Region (NWSSR), there are 13 Weather Forecast Offices (WFOs) that have coastal waters forecast responsibilities. To successfully deliver upon the NWS' mission to protect life and property and to enhance the nation's economy, it is vital that our weather forecasts issued over the coastal waters be as accurate as possible. As a means to improve the guidance available to NWSSR offices when producing their marine forecasts, we have implemented the Simulating WAves Nearshore (SWAN) locally-run numerical model in all of the NWSSR coastal offices. Having the ability to run a high resolution nearshore wave model on demand, based on model wind fields edited by the forecaster, provides an immediate service enhancement to the local marine forecast.

The focus of this paper is to describe this initiative led by NWSSR to implement the SWAN model at all coastal offices in the Region. This technology infusion has been a multi-faceted effort requiring the attention and contributions from several individuals within the Region. The science and technology decisions that were made will be outlined. These include decisions such as how to configure inner-nests that permit sub-kilometer modeling along complex segments of the coast, as well as including wave interactions with the Gulf Stream by coupling the model with the Real Time Ocean Forecast System (RTOFS). Additionally, examples of how the model output is being applied will be shared. Preliminary verification results from studies currently being conducted will also be presented along with future plans and possibilities.

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2. MOTIVATION

Our motivation for engaging in this local nearshore wave modeling effort has been driven by a number of issues:

- Complex near shore coastlines and topography not properly resolved by NOAA Wave Watch (Tolman, 2007) guidance and ability to run the model at a much higher resolution locally
- Need to provide more detailed wave information across the critical nearshore environment as part of NWSSR increasing decision support services.
- Ability to experiment with different model configuration options
- Ability to introduce waves resulting from Gulf Stream current interactions
- Need to develop a local tool that serves as a means to engage in collaborative research efforts to address local marine forecast problems
- Group of interested and skilled collaborators (science-, user-, technology-based interest) with an innovative spirit willing to work together to make this happen at a regional scale

First, the complex near shore coastlines and topography involved; the nearshore environment across the Gulf of Mexico and the east coast of Florida that comprises the SR modeling domains includes a combination of broad and gradually sloping shelves (lower refraction) and very narrow and steeper shelves (higher refraction). The increasing demand for more detailed marine forecasts over these areas has driven us to seek ways to better our overall coastal waters forecasting. NWSSR coastal offices serve large commercial interests across the region, including the oil and fishing industries, as well as a very large recreational boating industry. Since our NWSSR office's marine area of responsibility is confined to 60 nautical miles from the coast, it becomes paramount to properly resolve the nearshore coastal processes involved as wave energy transitions from deep to shallow water and transforms to the local coastline. Therefore, there is a need to model these processes at the local level at resolutions not currently provided by the standard national guidance.

Second, in an era of increased emphasis on providing decision support, it is paramount our NWSSR offices have the local tools that can produce the detailed information to facilitate their provision of these enhanced services. This was recently highlighted very well by the decision support provided by the NWS during the Deep Water Horizon incident and, in the past, at other minor near shore spills where NOAA Hazardous Materials Response Teams require very detailed wave and current information from coastal WFOs, sometimes at the scale of inlets.

Third, running a model locally gives offices the ability to experiment with different model configurations.

Fourth, several offices across the NWSSR face the need to account for wave and Gulf Stream current interactions, most notably, WFOs Key West, Miami, and Melbourne. Since this key wave-generating interaction is not provided by the national NOAA Wave Watch III model guidance at this time, WFOs continue to depend on empirical nomograms developed decades ago. Running a model locally that is coupled with Gulf Stream interactions fills this important void.

Fifth, the provision of a local model gives offices a tool to engage in local research/collaboration projects with universities to help them address local forecast problems. In fact, the software used as part of the NWSSR SWAN package to couple the SWAN with RTOFS Gulf Stream forecasts was developed in collaboration with the Florida Institute of Technology (FIT) (Lazarus and Splitt, 2010).

Sixth, given the advancements in technology, we have been seeking to make the most efficient use of local weather forecast modeling to realize any and all forecasting improvements we can in this challenging nearshore environment with very limited observations.. This project has been the result of motivated field-office level individuals willing to work together to make the best use of the technology and science available to deliver this tool all to the offices.

3. NEARSHORE WAVE MODELING OVERVIEW

The SWAN model is a third-generation wave model that computes random, short-crested wind-generated waves in coastal regions and inland waters. This model was developed by the Environmental Fluid Mechanics Section of the faculty of Civil Engineering and Geosciences at the Delft University of Technology (The SWAN Team, 2010a,b). Computations within the model directly address the previously-listed issues regarding the highly-variable elevations/topography and accounts for wave propagation and transitions from deep to shallow water at finite depths by solving the spectral wave action balance equation. This equation includes each source term: wind input, nonlinear interactions, whitecapping, bottom friction and depth induced breaking.

Over the past several years, efforts led by WFO Eureka with follow-ups by WFOs Wakefield, VA, Newport/Morehead City, and Wilmington, NC, in combination with the U.S. Army Corp of Engineers (Devaliere et al. 2007, 2008, 2009; Nicolini and Crawford, 2005; Willis et al., 2010), have resulted in a SWAN package that other field WFOs can benefit from. THE NWSSR SWAN effort built on this by developing the package further resulting in the following enhancements: 1) development of documentation, 2) building a baseline set of configuration as well as installation scripts for the package (allowing any office in the region to set up an operational domain within an hour), 3) configuring and implementing a non-stationary computational version of the model allowing for better simulations associated with rapidly changing wind conditions, 4) added RTOFS Gulf Stream coupling, 5) re-compiled and built the model in a 64-bit platform in multi-thread mode allowing the setup of longer/higher resolution runs, 6) added a standard, free plotting package using the Grid Analysis and Display System (GrADS), and 7) developed configuration scripts to display the model output in its native resolution in the WFOs AWIPS D2D systems. This package (referred to as SRSWAN) has allowed for the quick deployment of the model across all of the SR offices during 2010, including a version of the model running at NWSSR covering all of the Gulf of Mexico and SW Atlantic.

In the follow subsections we discuss briefly some of the issues encountered as part of this process.

3.1 Science and Technology Challenges

A number of science and technology challenges have been encountered. Some have been solved, while others are still being worked on as we move forward to make use of the SWAN model at our Southern Region coastal forecast offices. In more detail, these include:

- Preparing the code to make it work within, or integrate, with our operational AWIPS environment (security issues)
- Achieving parallelism using MPI in 64-bit mode. This was an important milestone as it allowed us to set up high resolution model domains with the ability to run them out to 5 days, enough to cover the entire marine forecast period and area of responsibility typical of a WFO.
- Using very high resolution gridded data from the Coastal Relief Model for bathymetry input along complex coastal locations
- Domain decision/choices (location, size, less land, etc.), consideration/use of sub domains or nests at sub-kilometer resolutions
- Transitioning from stationary runs to non-stationary computational mode for more realistic output across larger domains during rapidly-changing weather events
- Providing the forecaster with the ability to choose several forcing options (winds edited by the forecaster, winds directly from a model source, spectral input at the grid boundaries using the WaveWatch III multi-gridded data produced by NCEP, Gulf Stream integration through RTOFS, creating model web graphics, etc.
- Creating modularity in the code
- Exploring operating systems (OS), hardware (last-minute need for more memory), software (ideally remove any non-free code), and software-refresh options (SVN for ease of maintenance/patch releases)
- Communicating/Implementing this across 13 coastal offices
- Providing training for implementation
- Present/Future challenges (integration back to/with NCEP, even more code modularity, added system independence, move to wave partitioning, etc.)

3.2 Domains

Domains across the NWSSR coastal offices were configured with a default 1.5 km resolution and 24/24 (directions/frequencies) for spectral resolution. The size of each domain was chosen to expand at least 50 to 75 km beyond a given office's outermost marine zones of responsibility, which typically expands 111 km offshore. The reason for this is to populate the official Significant Wave Height grid element of the office's National

Digital Forecast Database with the SWAN output. Those grids are populated across the office's marine zones. Therefore, one would want enough distance between the open grid boundary of the model and the outermost portion of the critical forecast waters to compensate or resolve any discontinuities near the grid boundary of the model and to allow SWAN enough distance and fetch to resolve these issues. This distance also allows the model time to spin-up the wave fields in the cases where no boundary conditions are provided (mainly for testing or strong offshore flow events with no other significant wave energy incoming from outside the domain).

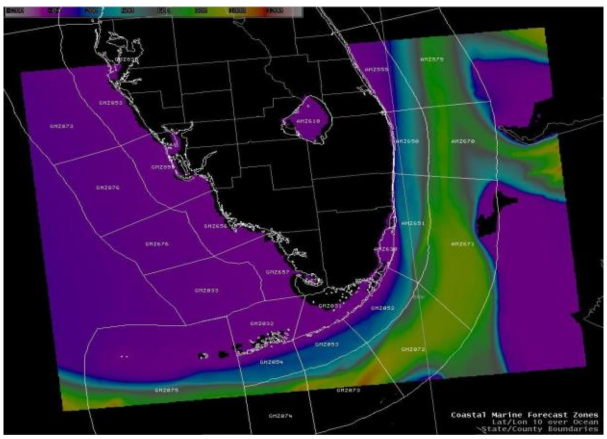


Figure 1. SWAN domain as configured for the NWS Office in Miami, FL showing bathymetry.

Figure 1 shows the "outer" SWAN domain as configured at the Miami forecast office. This domain, like many of the other domain choices for offices in the Southern Region, was made with the issues discussed earlier in mind--primarily expanding the domain well beyond the marine zones of responsibility for the given office (marine zones are plotted in Fig. 1 in white). Additional considerations in this case included capturing the Gulf Stream, enough of the Bahamian islands to the east to capture their effect on energy coming from that direction and with primary swell source regions in mind (to the NE of the domain).

In addition to the primary domain associated with any given office, instructions were provided on how to configure very high resolution inner nests. Figure 2 illustrates and example of high resolution inner nests set up within WFO Miami's SWAN domain. This can be a very good tool when dealing with high marine impact events in critical points along the coast.

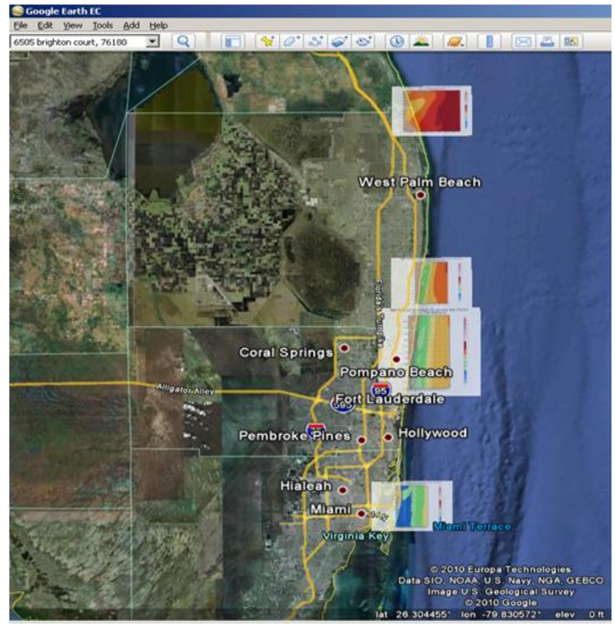


Figure 2. SWAN 90m resolution inner nests configured at WFO Miami.

Daily runs are executed over the outer domain using the forecaster-edited wind grids as forcing (the option to run directly from GFS or NAM winds was provided also), NOAA Wave Watch III spectral output for boundary conditions, and RTOFS Gulf Stream forecasts. The inner domains are forced by the forecaster specified wind forcing, but more importantly, they use the outer nest output for boundary conditions.

Figure 3 illustrates well the concept of nests. In addition to domains created across every WFO in SR, a regionwide domain has been configured at SR headquarters which is shown in Fig. 3. The regional domain uses NOAA Wave Watch III boundary conditions and GFS winds for forcing. It also incorporates RTOFS Gulf Stream forecasts. In the future, this domain can also be an alternate source of boundary conditions for the offices' domains.

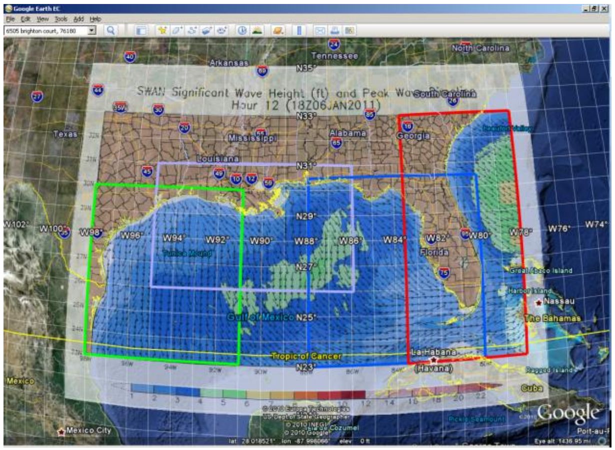


Figure 3. SWAN domain, and sample 12-hr forecast of Significant Wave Height and Peak Wave Direction, used at Southern Region HQ configured to cover the entire Gulf of Mexico and waters of the western Atlantic. This domain encompasses all the forecast office domains, and also has 4 sub-domains (shown by the four colored boxes) that are also configured.

Figure 4 shows an example 500m run from the WFO in Tallahassee for a segment of their coast (Panama City) depicting both the output of the model (top) and the input high resolution bathymetry (bottom) used. This example illustrates the need for a high resolution run that utlizes high resolution gridded bathymetry data along a coastline with many directional variations. .

3.3 Non Stationary versus Stationary Computational Modes

One of the key issues identified during the model setup across SR was that of running the model in stationary versus non-stationary mode. In the SWAN model documentation, it states that running in non-stationary mode should be considered for model domains exceeding 100 square km. That is the case with all primary SWAN domains across all of the SR offices. The issue is illustrated nicely in the sequence of images shown in Fig. 5.

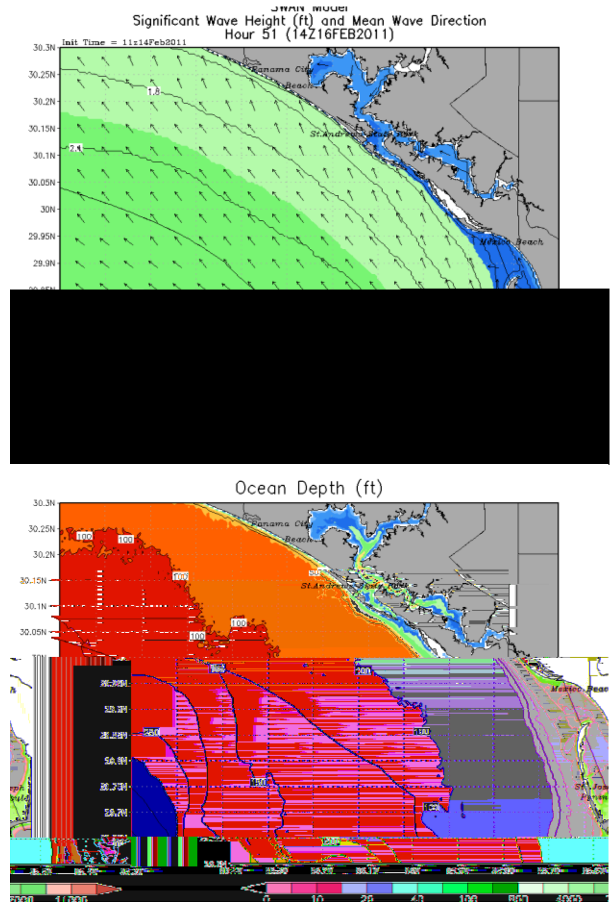


Figure 4. An example SWAN run along the Panama City, Florida coast at 500 m resolution. The bottom image displays the bathymetry input into this SWAN run, which is derived from the 3 arc-second (~90m resolution) gridded data from the Coastal Relief model of the National Geophysical Data Center (NGDC).

Figure 5 illustrates a sequence of wind forecasts valid on 21 UTC 10 December 2009 and 00 UTC 11 December 2009, respectively, in the top two images. The bottom two images show the resulting significant wave height forecasts from the model in stationary and non-stationary mode, respectively also. Notice that the stationary run resulted in wave heights of 6 to 7 feet (yellow) across NE areas of the domain whereas in the same areas the non-stationary run yielded 2 to 4 feet (light blue). Across NW areas of the domain the same sequence shows heights in excess of 7 feet versus 4 to 6 feet. Non published results by the U.S. Army Corp of Engineers (email communication with Eve Devaliere and Jeff Hanson) corroborate this based on verification

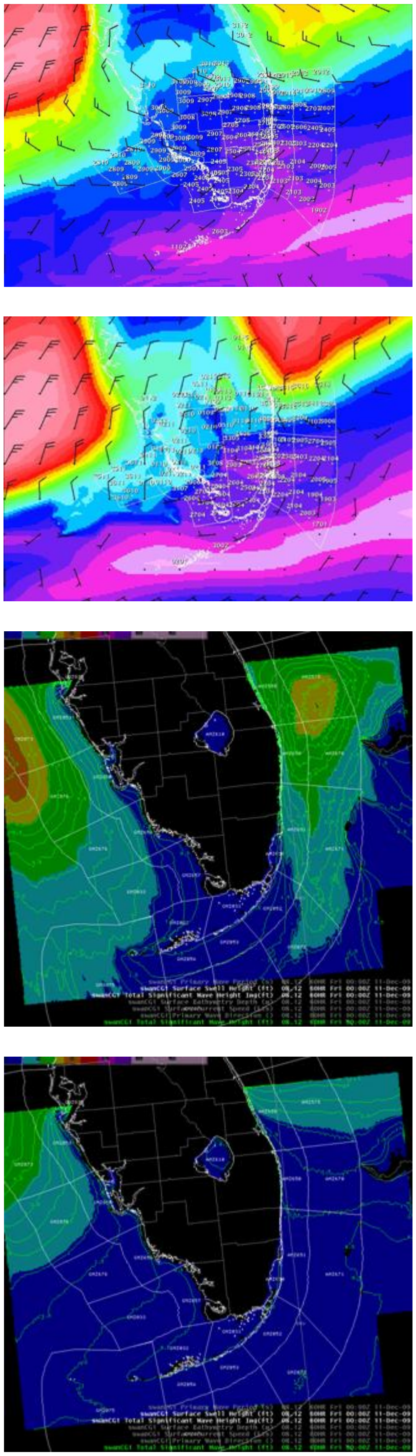


Figure 5. Sequence of wind forecasts valid at 21 UTC on 10 December 2009 (top) and 00 UTC on 11 December 2009 (second from top). The bottom two images that follow are the forecasts of significant wave height from SWAN in Stationary mode and Non Stationary mode, respectively, valid on 00 UTC 11 December 2009.

studies they ran at buoys 41025 and 41036 off the mid Atlantic coast. This issue was also briefly mentioned in their final project report (Devaliere *et a.*, 2009). In essence, when one runs the SWAN model in stationary mode the output is based on the assumption that that wind has been in a steady state for any given time step (time derivative term from the wave equations is dropped). In non-stationary mode, that term is kept and the incremental changes in the wind play a critical role in the output of the model.

The problem, however, of running the model in non-stationary mode is that one pays the price of much longer computational times. Furthermore, if the time step is not the proper one for a given spatial resolution and domain size, one also runs the risk of numerical instability. We found, however, that building the model on a 64-bit system, with support for parallel processing, alleviated this problem greatly making operational non-stationary mode runs feasible.

Given these findings and concerns, and based on sensitivity studies run by WFOs Tallahassee and Miami, the domains across the SR coastal offices were set up using by default non-stationary computational mode with a time step of 30 minutes and a spatial resolution of 1.5 km. This, however, required tweaking computational options such as the propagation scheme. For that, we settled on BSBT (a first order scheme) in order to achieve computational stability. For more details on this option you can consult the SWAN documentation (The SWAN Team, 2010b). One last issue that is important when using non-stationary mode is that the model needs a spin-up period to generate the wave energy before its output can be deemed reliable (in the absence of a hot start). That spin-up period is typically 12 to 18 hours based on sensitivity studies run at WFOs Tallahassee and Miami and accounted for in the region-wide implementation. This will also be dealt with in future upgrades by introducing a hot start option, but that is still in development mode.

3.4 Gulf Stream Forecasts Coupling

Some offices across the SR, most notably WFOs Key West, Miami, and Melbourne, have the Gulf Stream current cutting across much of their Marine Area of Responsibility (MAOR), or marine zones. Proper wave forecasts mandate accounting for wave and Gulf Stream current interactions. SWAN accounts for these interactions, if inclusion of Gulf Stream current input is specified. As part of the SRSWAN package, software was added to extract real-time Gulf Stream forecasts from RTOFS which writes it into a format that SWAN can ingest. This software package was written and developed by the Florida Institute of Technology (FIT), under the auspices of the NWS Collaborative Science, Technology, and Applied Research (CSTAR) Program (Lazarus and Splitt, 2010), and incorporated into the SRSWAN.

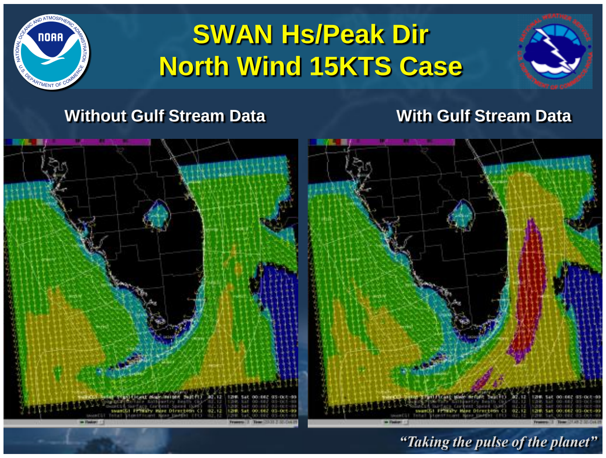


Figure 6. Significant wave heights (image) and peak wave direction without Gulf Stream interactions (left) and with Gulf Stream interactions (right) under a homogenous north wind of 15 knots across the entire domain opposing the Gulf Stream to the east of southeast Florida.

Figure 6 illustrates an example of wave forecasts without (left) and with (right) Gulf Stream interactions. Without Gulf Stream data SWAN output shows wave heights of mostly 2 to 4 feet east of southeast Florida (green) with some 4 to 6 feet (yellow) farther south. The forecast across much of the same area with the Gulf Stream data show heights of 4 to 6 feet with a good portion showing heights above 7 feet (red) even in areas where without that data the heights were just 2 to 4 feet. Although no buoy data is available to corroborate this, extensive studies demonstrate the effect of an opposing current on a given wind forcing is to magnify the resulting wave heights. This is well-established based on previous empirical, as well as theoretical, studies (Holthuijsen and Tolman, 1991). In essence, waves traveling against an opposing current will slow down. Given period is a conserved quantity, this means the wavelength shortens resulting in increased heights and steeper waves. This is consistent with the results seen in Figure 6. Based on that, and quasi-operational use of this data at WFOs Miami and Key West for almost a year now, we believe SWAN is properly accounting for the wave/Gulf Stream interactions.

3.5 SWAN Output

SRSWAN provides output of significant wave height, peak period and direction, and a scalar called SWAN Swell, which is simply the significant wave height for wave components with a period of 10 seconds or greater. Additionally, the model provides output for the input Wind and Gulf Stream forcing information. Figure 7 provides a sample output of these parameters from WFO Miami.

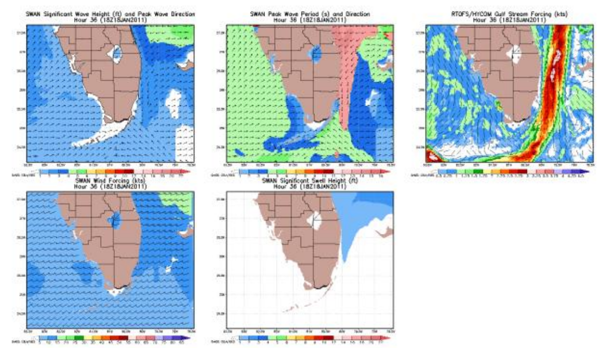


Figure 7. Sample output from SWAN for WFO Miami. Significant wave height (top left), peak period and direction (top middle), Gulf Stream input current (top right), input wind forcing (bottom left), and a scalar SWAN Swell parameter (bottom right).

Current efforts are concentrated on adding the same wave-partitioning code to the SRSWAN package that is used in the operational NOAA Wave Watch III. Although more elaborate partitioning software was provided to include with the SWAN SR package, modeled after the version of the same used by WFOs Eureka and its mid Atlantic counterparts, it was left out because it was developed on a licensed platform and is computationally-expensive. So a decision was made to use software developed by the National Center for Environmental Prediction (NCEP) Marine Modeling and Analysis Brach (MMAB) and incorporate it into the SRSWAN package. This software will require no additional license, while being, computationally, more efficient. In addition to plotting the SWAN output with GrADS as shown in Fig. 7, SRSWAN SWAN also includes instructions to plot the output in AWIPS at its native resolution. This allows forecasters to interrogate the output in greater detail and to quickly analyze and compare output parameters and boundary input from the WWIII solution through 4-panel procedures readily available in their operational display system--D2D.

4. PRELIMINARY VERIFICATION

Now that SWAN has been deployed in every coastal WFO across the SR, the emphasis is shifting to verification, as well as future enhancements while offices complete their training and operational spin-up of this new tool. This section will describe different verification efforts currently under way.

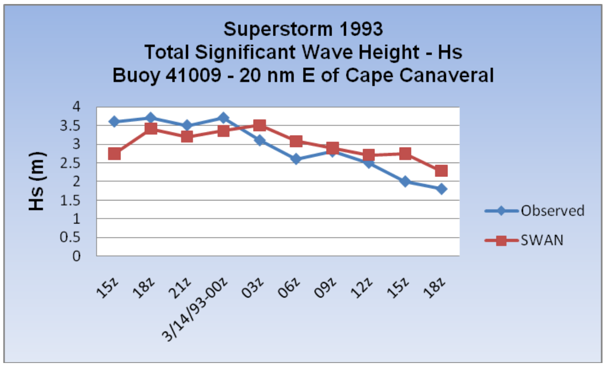
4.1 Verification based on hindcasts

The SWAN model performance has been evaluated during high-end marine events such as winter gales and tropical cyclones through hindcasts of historic events. The SWAN forcing for these events was generated by the Advanced Research WRF (ARW) model, which was initialized by the North American Regional Reanalysis (NARR) data. In each hindcast scenario, a gridded spatial resolution of 12 km was used over the Gulf of Mexico and portions of the East Coast. These runs did not account for wave Gulf Stream interactions and were primarily forced by the wind output from the NARR/WRF simulations. Topography over the region was derived from the one minute (~1.8km) gridded database (ETOPO1) provided by NGDC. Non-stationary compute mode was used in these SWAN simulations, so an initial model spin-up period was accounted for. Several National Data Buoy Center (NDBC) stations within the domain were used for verification purposes. Wind speed (WSPD) and total significant wave height (Hs) model parameters were evaluated at each station. Model results strongly indicated that SWAN was highly dependent on the model wind input. Total mean error values were very small when the wind input was accurate.

One such hindcast scenario is the Superstorm of March 12-14, 1993, which was a multi-faceted weather event that impacted the nation with a wide range of weather, including winter and severe weather, to marine and coastal flooding. This was arguably one of the most prolific non-tropical events the nation has observed. For the scope of this paper, the marine observations archived at buoy platforms over the Gulf of Mexico and the Georgia and Florida east coast were evaluated and compared to the SWAN model output through the simulation. There was an initial model spin-up period due to the lower resolution NARR wind input at the WRF boundaries, which resulted in initial wind speed output typically lower than the observed values. The 12 km WRF, however, quickly began to phase with the observed data at the selected buoy platforms around the 24 hour forecast period. Thus, these data from March 13, 1993 through March 14, 1993 were used to verify the SWAN model output. Total mean error through this selected period was 0.4407 m for the total significant wave height output and 2.349 ms-1 for the NARR/WRF wind speed. Below are the details of the model configuration used for this hindcast:

Domain: 18.2N -98.2 – 35.8N -79.00
Spatial Resolution (SWAN): 12km
Spectral (Direction/Frequency) Resolution: 31/31
Bathymetry: 1 minute (~1.8km) gridded ETOPO1 data
Temporal Resolution (SWAN): 1800s
Spatial Resolution of WRF wind input: 12km
Spatial Resolution of NARR: 32km
Model Init: 1993MAR12_1500z

The total mean error for the SWAN Hs forecasts for all buoys combined was .4407 m and 2.349 ms-1 for the NARR/WRF wind speed. Figures 8, 9, and 10 show comparisons of observed versus forecast Hs as well as input wind forcing. The general pattern in these figures indicate SWAN is sensitive to errors in the input wind forcing but this sensitivity is location-dependant and that, in general, when the wind forcing is closest to observed, SWAN errors are small. Additionally, there was an intial slow spin-up period noticed in the wave fields approaching the peak of the curve due to the large propagation time step of 1800s. Further simulations will include comparisons to the output using a temporal resolution of 900s and 300s.



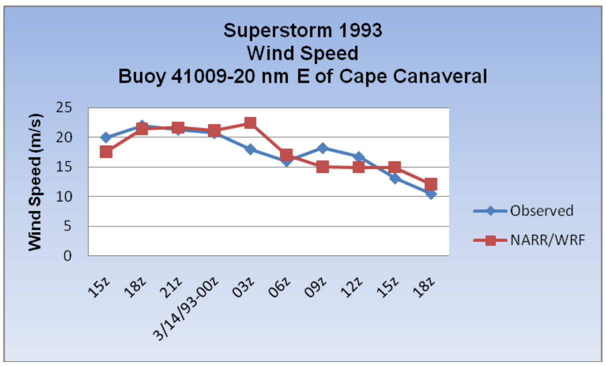
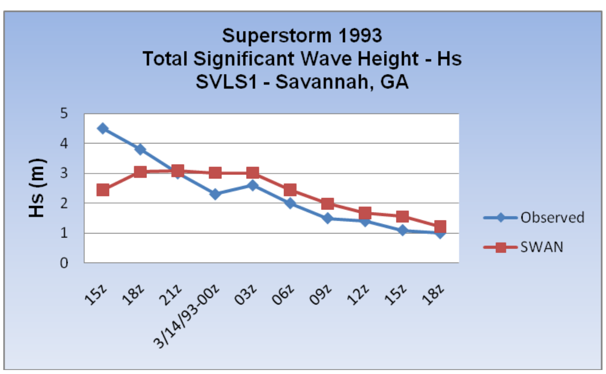


Figure 8. Comparisons of observed and SWAN forecasts Hs as well as observed and NARR/WRF forecast input wind speed forcing for buoy 41009 east of Cape Canaveral for the March 1993 Superstorm scenario.



4.2 Verification efforts at WFO Miami

A second verification effort is also underway more specifically across the WFO Miami SWAN domain shown in Fig. 1. This verification effort makes use of buoy data within the domain, but given this data is very limited, it also uses the European Space Agency (ESA) ESR2 Radar Altimeter (RA) data. The ESR2-RA is a nadir-looking polar orbiting instrument with a sampling interval of 1 second and a spatial resolution of 6 to

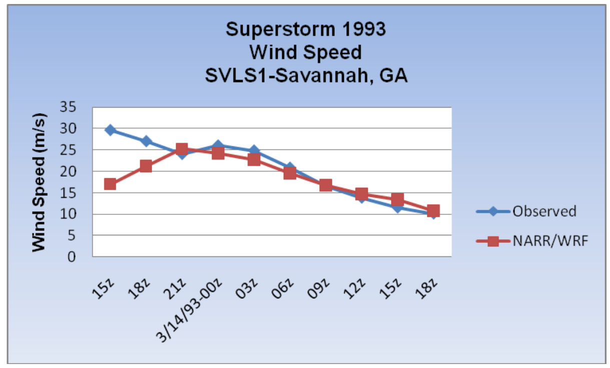
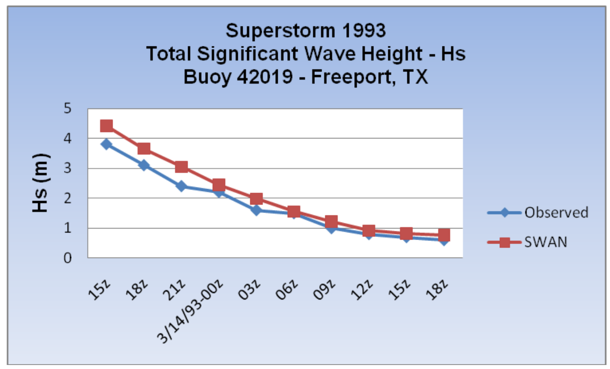


Figure 9. As in Fig. 8, but for SVLS1, Savannah, GA.



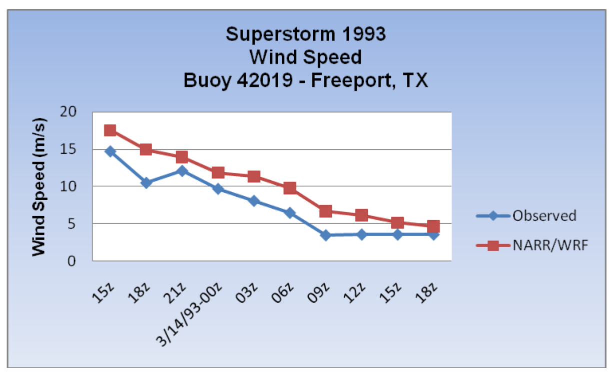


Figure 10. As in Fig. 8, but for buoy 42019, Freeport, TX.

7 km. Its applications include wind speed as well as significant wave height (Hs) retrievals over oceans. For this study SWAN model archives from April to October of 2010 were matched in space and time for each forecast hour against buoys, as well as ESR2-RA data. Given the resolution of the SWAN (1.5km) model output, the data was averaged to closely match the footprint resolution of the ESR2-RA. Furthermore, ESR2-RA data was quality-controlled to remove unrealistic radar

backscatter for open water as well as unrealistic wind speeds and Hs retrievals.

Figure 11 shows the scatter plots of observed Total Significant Wave Height (Hs) at buoy 41114 east of Fort Pierce, Florida versus SWAN forecasts for all forecast hours combined (top) and for forecast hour 12 and beyond only (middle). The bottom plot shows the mean hourly forecasts comparison for the season between the SWAN forecasts for all runs combined and the buoy observations. The figure clearly shows the spin up problem resulting from the non-stationary mode when comparing the top two plots (notice the concentration of points with large buoy observations and low SWAN Hs forecasts in the top plot). With those points removed the middle plot shows fairly good results with a correlation coefficient of 0.88, very small negative bias in the SWAN forecasts, and a root mean squared error (RMSE) of less than 1 foot. This is indeed a good result when one considers buoy 41114 has no wind reports and therefore the data have not been filtered to remove outliers when the observed and forecast winds did not agree. The bottom plot in Fig. 11 illustrates that on the seasonal scale, SWAN was able to replicate rather well the observed Hs as function of forecast hour. The plot also illustrates the spin up problem in the first twelve hours of the forecast.

It is important to highlight here that buoy 41114 is the only surface instrument with wave height observation capability within the WFO Miami SWAN domain. Fig. 11 illustrates that on the seasonal scale, SWAN was able to replicate very well the observed data as far as the mean hourly forecasts is concerned with an overall small bias. However, the spread in the scatter plots is not small either.

Figure 12 shows comparisons of ESR2-RA retrieved wind speed and Hs against the SWAN input wind forcing (top) and forecasts Hs (middle/bottom). The top plot shows a correlation coefficient of 0.66, a RMSE of 3.28 kts, and an overall small bias between the SWAN input forcing and the retrieved wind speed from the altimeter. However, the spread in the scatter is considerable. The middle plot in Fig. 12 shows a similar analysis but for ESR2-RA Hs versus SWAN Hs constrained to points when the ESR2-RA and the SWAN wind speeds were within 3 knots of each other. This analysis shows a much smaller correlation coefficient (0.42) with a very large spread in the

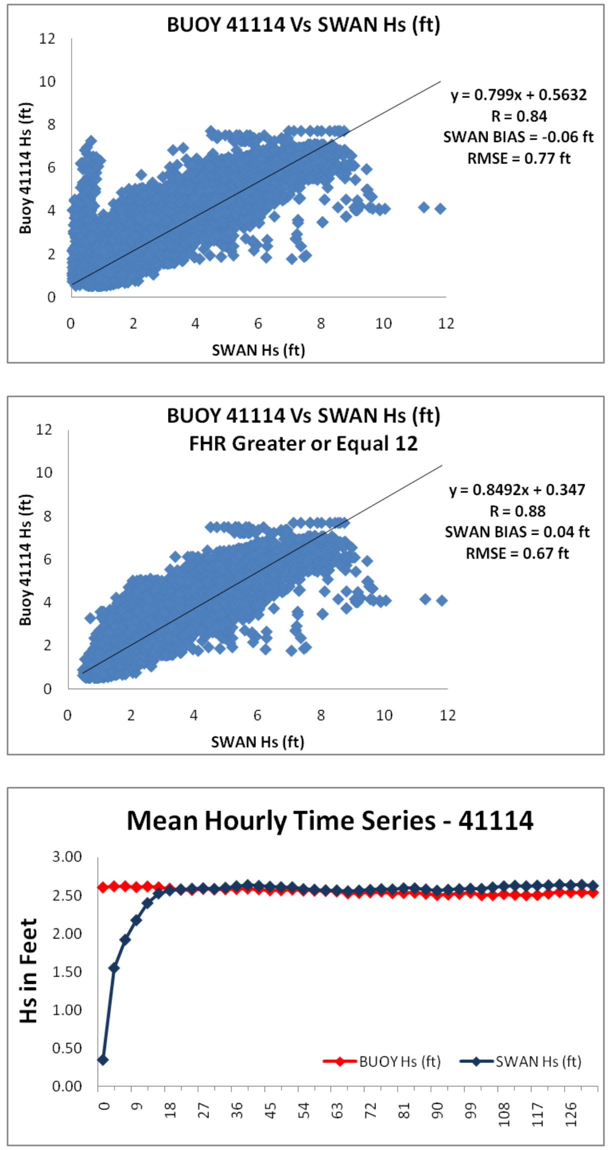


Figure 11. Scatter plots of observed Hs at buoy 41114 east of Fort Pierce, FL and forecast Hs from SWAN for all model cycles and forecast hours (top) as well as forecast hours 12 and beyond (middle) combined between April and October of 2010 across WFO Miami SWAN domain. Bottom plot is the mean time series as a function of forecast hour between the observed (buoy) data and the SWAN forecasts.

scatter plot, a negative bias in the SWAN retrievals of -0.71 ft, and a RMSE of 0.73 ft. The bottom figure shows the mean forecast hour time series for the period of study. It illustrates (as before with the buoy data) that in the seasonal scale, the SWAN captured the observed cycle in the Hs with a negative bias. Also, this plot shows the negative bias being the largest early in the forecast as expected.

The altimeter-based verification will be further looked into, especially as it relates to the noisiness in its retrievals. The data used in this study was preprocessed data obtained from NCEP/MMAB. It is not clear if this data had been calibrated prior to conducting this analysis as described in their ESR2 verification page. Although the authors did some quality control of the data as described earlier, it is possible additional calibration is needed and that that in part could explain the large scatter observed in Fig. 12.

Overall, this analysis indicates SWAN's ability to replicate the observed mean behavior of the Hs field with an overall small bias despite the inability to determine the error in the input forcing when comparing the data to the only buoy available (41114) in the WFO Miami SWAN domain. Ultimately, this analysis needs to be expanded to look at individual cases, or groups of cases, with large variability in the wave height regime to see how well SWAN truly performs without cases when the observed and input forcing did not match well, because SWAN is very sensitive to the forcing as shown in Figs.8 through 10. This is particularly important given the observed spread in the data in Figs. 11 and 12.

5.0 FUTURE PLANS

The NWS Southern Region has initiated a collaboration project with NCEP/MMAB in an effort to improve the SRSWAN package. Over the long-term, the collaboration will result in the integration of SWAN into the site-specific wave watch III (SSWWIII) being developed by NCEP through Operations and Services Improvement Process (OSIP) Project number 06-093. This project seeks to develop a fully integrated Nearshore Wave Prediction System (NWPS) that will also enable offices to run a quasi-stationary nearshore version of WWIII supported by NCEP. In the near-term, NCEP/MMAB will assist the NWSSR SWAN Team to make enhancements to the SRSWAN package over the next year including: 1) optimizing physics and numerics options, 2) integrating wave-partitioning software into the SRSWAN source code, allowing the SRSWAN to produce output of height, period and direction for Wind Waves, and the dominant Swell groups in addition to Hs efficiently, and 3) coupling the model with a flow model such as ADCIRC.

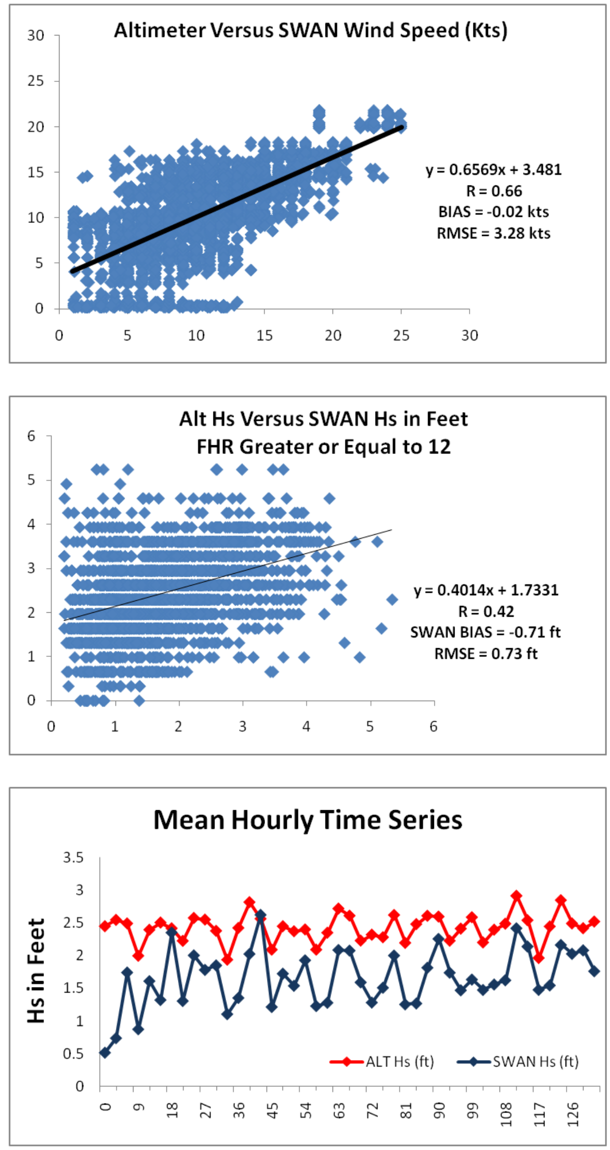


Figure 12. Scatter plot of ESR2-RA retrieved wind speed versus SWAN wind forcing for all model cycles and forecast hours (top). A similar plot for ESR2-RA retrieved Hs versus SWAN Hs forecasts follows in the middle (for forecast hours 12 and beyond only) but constrained for points when the ESR2-RA retrievals and input SWAN wind speeds were within 3 knots of each other. Bottom plot is the mean time series of Hs for ESR2-RA and SWAN as a function of forecast hour for all model cycles.

With the first version of the SRSWAN already running in every SR coastal office, emphasis in 2011 will be put on enhancing marine products and services including:

- Populating the official NDFD WaveHeight (Hs) grid element with SWAN (already being done by most offices)
- Publishing an enhanced web site with plots of the SWAN output at its native resolution. This will include point-specific products. The graphics that will be used to post in this website are created with GrADS which is included in the SRSWAN package. In fact, as of this writing, all of the SR coastal offices are already routinely creating and posting these graphics of the web. Sample pages with SWAN output can be found at the TAE or MFL SWAN pages. A common web interface for all the offices is currently under development at SR headquarters.
- Adding detailed wave information to the suite of marine forecast products. This will be enabled once the enhanced-partitioning software is incorporated into the SRSWAN package over the coming year. Some offices have already begun by including fields such as dominant wave period in their marine forecasts.
- This, combined with the implementation of higher resolution nested runs over critical forecasts areas along the coast, and coupling with ADCIRC, will enable more detailed decision support services during marine incidents nearshore such as the recent Deep Horizon Oil Spill.

As technology and computing power continue to advance, additions to the SRSWAN package could also include probabilistic marine forecasts at the local and regional scale. The ability to provide timely wave model guidance with different model members (i.e. NAM, GFS, ECMWF, WRF, etc.) will provide the marine forecaster multiple possibilities for the official forecast. This is significantly important, due to the fact that wave development and generation is very sensitive to wind forcing. Providing multiple guidance options to the marine forecaster, combined with wave height probability forecasts across the local marine area and the ability to express periods of greater uncertainty will not only enhance the forecasts, but provide the marine user and decision maker the capability to make clear and decisive operational plans over the coastal waters. Figure 13 illustrates and example of a simple SWAN wave ensemble forecast based on 4 different wind inputs: WRF/ARW 12 km, NAM 12 km, GFS, and ECMWF.

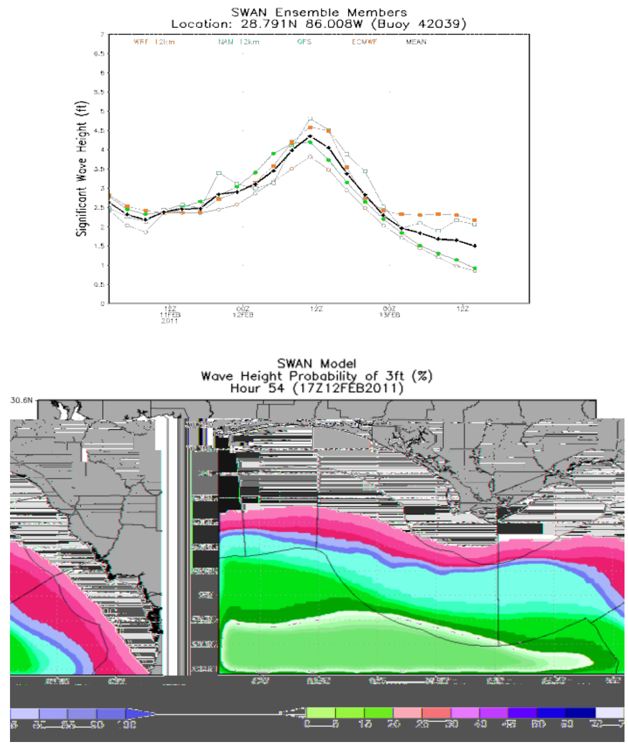


Figure 13. Time series of SWAN Hs forecasts as a function of time (Hs) for the specified point (top) using 4 different wind forcing: WRF/ARW 12km, NAM 12km, GFS, and ECMWF. Derived probabilities of wave heights exceeding 3 feet from a distribution function fitted to the ensemble members (bottom).

Additional possibilities, that are currently ongoing at WFOs TAE and LIX, include integrating the newly-available one arc-second (~30m resolution) and one-third arc-second (~10m resolution) gridded bathymetry data of the Coastal Relief Model (CRM) as input to the high-resolution inner nest options. Currently, these additional areas covered by the CRM include: the northern-central Gulf Coast (Fig. 14) from New Orleans to Panama, City (~30m option), Lake Pontchartrain (Fig. 15), Panama City and Tampa Bay (~10m options).

6.0 SUMMARY AND CONCLUSIONS

Over the past, year the NWSSR has enabled the development and deployment of a local high resolution wave model using SWAN at each coastal office. This effort included supplying each office a modeling machine and facilitating the development of a package that offices could use to implement the model operationally. The package was distributed using a managed configuration which made it easier to not only

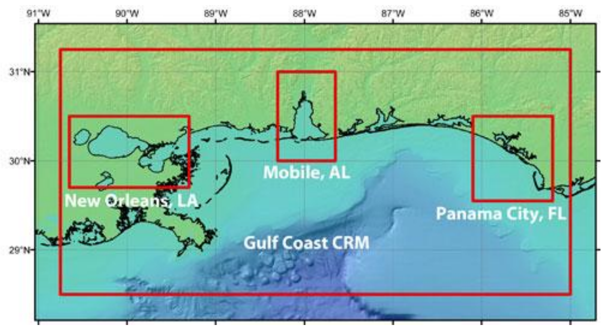


Figure 14. WFO's LIX, MOB and TAE each have the option to move forward using 1/3 and 1 arc-second gridded bathymetry data as input to the SWAN model. The outer domain represents the 1 arc-second domain and the inner 3 domains represent the 1/3 arc-second domains.

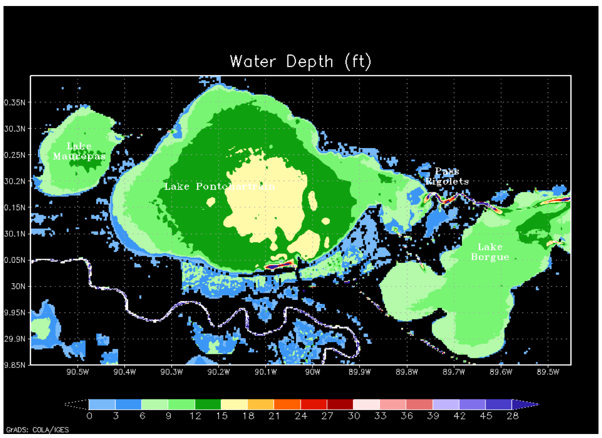


Figure 15. WFO LIX has recently configured an inner-nest option covering the Lake Pontchartrain, Maurepas and Borque. This example is from a coarser SWAN run with a spatial resolution set at 300 m using the 1/3 arc-second gridded data (~10m) as input for bathymetry.

deploy but also to distribute upgrades and/or patches of the underlying software. The deployment of the tool included the provision of at least two training seminars over the past six months with offices currently going through an implementation phase. By the summer of 2011, the plan involves each office fully integrating SWAN into operations to enhance marine forecasts and web graphics. These tools could then be used to provide more detailed decision support services during high impact marine and/or coastal incidents such as the recent Deep Horizon Oil Spill.

On the development side, the SR SWAN Team is now collaborating with NCEP/MMAB to get their help making improvements to the SRSWAN package over the coming year. Over the longer term, NCEP/MMAB has decided to merge the SRSWAN into their development of a site specific WWIII package as part of OSIP Project number 06-093.

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