UNIVERSITY: Florida Institute of Technology
PI: Dr. Steven M. Lazarus, Florida Institute of Technology
NWS OFFICE: Melbourne Florida
COMET PARTNERS PROJECT FINAL REPORT
PROJECT TITLE: Ensemble prediction of estuary set-up and set-down using operational WRF winds and their error characteristics. Component 1: Error Analysis.
AWARD #: Z12-98077
DATE: August 30, 2013

Project Overview
The goals of this project were 1) to examine the error characteristics of the NWS Melbourne configured WRF-EMS 10 m wind forecasts and 2) use the errors to generate a poor man’s wind ensemble to force a hydrodynamic model that is being configured as part of a second grant (see Dr. Weaver’s complementary proposal “Ensemble prediction of estuary set-up and set-down using operational WRF winds and their error characteristics. Component 2: Hydrodynamic Modeling”). The focus of these objectives, are high impact wind events.

SECTION 1: Project Objectives and Accomplishments
1.1 Summary of Progress
• FIT continues to archive daily NWS WRF flat files of 10 m wind and SLP. The archived began in July 2012. The data are provided by Peter Blottman (Melbourne WFO).

• FIT graduate student Robbie James has been working on this project since its inception and will complete his Master’s degree this fall (2013).

• Using R, we are ‘sampling’ (see Section 1.1b) from the directional and speed bias pdfs generated from the NWS WRF cycles between 03 UTC 26 and 12 UTC 28 October (see previous report for the actual PDFs). The sampling is used to generate short-term ensembles by adjusting the forecast winds. The chosen time period captures the closest approach of hurricane Sandy’s in the off-shore Florida waters. As mentioned in our prior report, the error pdfs were calculated using the 3 h WRF forecasts as ‘truth’ in lieu of 0 h RAP. This allows the higher resolution (3 km) NWS WRF to build in local scale features (using the RAP initial conditions and thus should provide a more representative ‘estimate’ of the forecast error.

• We have completed WRF-EMS (V3.2.1.5.45.beta) simulations for seven hurricanes (Noel, Ike, Hannah, Earl, Irene, Issac, Sandy) and seven non-tropical ‘high’ wind events (2006 to present). The criteria¹ used to identify cases includes:

1) Must have at least a 24-hour window where hourly wind observations from KMLB are greater than 10 mph.

¹ For the non-tropical cases, no precipitation can impact the area of interest/24-hour forecast window.
2) Wind direction must lie within the range from E to NW.

For each of the 14 high wind cases, we are running 4 FIT-WRF cycles (one per 6 h) each over a 12 h interval. In addition we are running different PBL schemes (see Table 2).

• We are assessing/examining the WRF winds for these simulations. Given the expanded scope of the project, the surface observations identified in the original proposal were not sufficient and we are now incorporating wind data from the KSC tower network (see Section 1.1c).

a. Hindcast Wind/Pressure Forcing

We generated two distinct sets of wind/pressure forcing that are intended to represent the “best” possible scenario. The two forcings are comprised of a sequence of either F00 or F03 forecasts from successive NWS WRF forecast cycles. In order to ensure proper spin-up of the hydrodynamic model, the wind forcing has been expanded to cover a twelve day period starting 00 UTC 18 October 2012 and ending 00 UTC 30 October 2012. The hydrodynamic model output for the perturbed wind field (see next Section) will be compared against these ‘best-case’ winds.

b. The ‘Poor-Man’ Ensemble

The speed and directional errors (pdfs – see previous report) are sampled using the R statistical package. The ‘sample’ function mines a vector x of size n with or without replacement. The probabilities of selecting a particular element can be the same for each element, or a vector of weights (e.g., frequency) given by the user. We independently sample each of the speed and directional bias pdfs for forecast hours 6 though 24\(^2\) and apply these errors (uniformly) to a forecast cycle. Although there is no unique way

\[ \text{Fig. 1. Wind speed bias pdf (m/s) computed from 20 6 h forecasts from the NWS WRF cycles from 03 UTC 26 October through 12 UTC 28 October 2012.} \]

---

\(^2\) Because we use the 3 h forecast as our ‘analysis’, error statistics are available only for f06 and beyond.
to accomplish this – some approaches are more rigorous than others. Consider the F06 wind speed bias pdf shown in Fig. 1. The error bounds (i.e., the maximum/minimum wind speed error estimated from the 20 F06 WRF forecasts – see previous report) are +/- 11 m/s – however these errors represent only a sliver of the probability space (total frequency for these two combined is less than 0.03% (hence no bar is visible on the histogram). Results are shown in Table 1 for which we apply the R ‘sample’ algorithm (with replacement) to obtain the maximum and minimum values as a function of the number of samples (n). The max/min values are shown for 10 realizations of size n. A sample size on the order of 1000 is sufficient to saturate the selection (i.e., the model minimum and maximum wind speed errors are both pulled from the dataset). It appears as if the n = 10 or 100 might suffice to ‘reasonably’ bound the wind speed error for the 6 h forecast period ([−7, 9] m/s for the error at this time). The forecast wind speed error bounds for n = 10 (dotted lines) and n = 100 (dashed lines), each with 10 realizations, is given in Fig. 2. In addition, we also show the mean bias (solid black line), and an estimate (linear extrapolation) of the 6 h forecast error to the initial time (light gray lines). Here, we use the n = 10 wind speed errors to perturb a sequence of F03 forecasts for the 24 h period starting 00 UTC 26 October. The left panel in Fig. 3, valid 15 UTC 26 October 2012, depicts the unadjusted 3 h forecast (from the 12 UTC NWS WRF cycle). The center (right) panels are generated from the same 3 h forecast wind field – except that wind magnitude has been adjusted down (up) using the aforementioned error sampling methodology. Since our evaluation forecast cycle begins at 00 UTC 26 October 2012, the perturbations shown in the Fig. 3 were sampled from the F15 error pdf. The ‘bounded’ wind forcing for the 24 h period thus consists of a sequence of 3 h WRF forecasts (starting with the 21 UTC 25 October cycle)

Table 1. Minimum (min) and maximum (max) wind speed (m/s) errors as a function of sample size (n) for the PDF shown in Fig. 1.

<table>
<thead>
<tr>
<th>n</th>
<th>min</th>
<th>max</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>-3</td>
<td>1</td>
</tr>
<tr>
<td>10</td>
<td>-5</td>
<td>9</td>
</tr>
<tr>
<td>100</td>
<td>-7</td>
<td>9</td>
</tr>
<tr>
<td>1000</td>
<td>-11</td>
<td>11</td>
</tr>
<tr>
<td>10000</td>
<td>-11</td>
<td>11</td>
</tr>
</tbody>
</table>

Fig. 2. Forecast wind speed error (m/s) bounds (i.e., maximum error – dashed lines) sampled from the relevant pdfs (see text for details). Also shown are the mean bias (solid black line) and extrapolated errors (f00-f06, gray lines).
with the successive error perturbations added (i.e., the 03 UTC 26 October 2012 winds consist of the 3 h error added to a F03 forecast from the 00 UTC cycle, the 06 UTC winds consist of the combination the 6 h error added to the F03 forecast from the 03 UTC cycle, etc.). Note that the 3 h error is estimated using a linear extrapolation between the F06 error and the initial forecast time (gray lines, Fig. 2). Since we are adding (or subtracting) a constant magnitude from the wind field, the images look similar (note the scale changes however). Here we preserve the features of the approaching tropical cyclone, but account for “potential” wind speed error.

As per the proposal, this approach is meant to bound the error – rather than generate a true ensemble. Also, we have limited the error to the wind magnitude only – however the directional error pdfs could be sampled/applied in a similar fashion as described above for the speed error. Also, a caveat, the pdfs used here were generated from a single event (hurricane Sandy) and are thus not fully representative high wind events in general. In reality, a ‘true’ ensemble would be generated from permutations of the model physics, initial conditions, boundary conditions, etc. These types of simulations are on-going in association with an accompanying graduate thesis (using various PBL parameterizations – see next section), but are beyond the scope of this proposal.

c. FIT-WRF
   i. Simulations
A total of 14 wind events (Table 2) have been identified in an effort to more closely examine the performance of the WRF wind forecasts along the IRL (thesis work). Given that the surface winds depend explicitly on the PBL and surface layer parameterizations, we feel these types of simulations are complementary to this work. The FIT WRF version 3.2.1.5.45.beta with ARW core was installed on the Blueshark cluster at Florida Tech. There are three model configurations used for the fourteen events (see Table 3) with the permutations defined by a combination of planetary boundary layer (PBL) scheme and accompanying surface layer physics (the surface layer is dependent on the chosen PBL scheme). Each of the events consist of four twelve-hour forecasts over a 24 h period beginning at 00, 06, 12, or 18 UTC, for a total of 36 h (Table 2).

**Fig. 3.** WRF F03 (from 12 UTC 26 October 2012 cycle) wind speed (m/s) valid 15 UTC 26 October. LEFT: unadjusted; CENTER: adjusted downward using the lower error bound (the dotted line) in Fig. 2; RIGHT: adjusted using the upper error bound (the dotted line) in Fig. 2. The sampled error for these panels are those for a 15 h forecast.
Table 2. FIT-WRF simulation summary.

<table>
<thead>
<tr>
<th>Event Name</th>
<th>Date Range</th>
<th>Model Initializations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Non-Tropical #1</td>
<td>04/29 – 04/30/2006</td>
<td>06, 12, 18 UTC (04/29); 00 UTC (04/30)</td>
</tr>
<tr>
<td>Non-Tropical #2</td>
<td>05/30 – 05/31/2007</td>
<td>00, 06, 12, 18 UTC (05/30)</td>
</tr>
<tr>
<td>Hurricane Noel</td>
<td>10/29 – 10/30/2007</td>
<td>12, 18 UTC (10/29); 00, 06 UTC (10/30)</td>
</tr>
<tr>
<td>Hurricane Hannah</td>
<td>09/02 – 09/03/2008</td>
<td>00, 06, 12, 18 UTC (09/02)</td>
</tr>
<tr>
<td>Hurricane Ike</td>
<td>09/09 – 09/10/2008</td>
<td>12, 18 UTC (09/09); 00, 06 UTC (09/10)</td>
</tr>
<tr>
<td>Non-Tropical #3</td>
<td>03/17 – 03/18/2009</td>
<td>18 UTC (03/17); 00, 06, 12 UTC (03/18)</td>
</tr>
<tr>
<td>Non-Tropical #4</td>
<td>04/17 – 04/18/2009</td>
<td>00, 06, 12, 18 UTC (04/17)</td>
</tr>
<tr>
<td>Non-Tropical #5</td>
<td>05/11 – 05/12/2010</td>
<td>06, 12, 18 UTC (05/11); 00 UTC (05/12)</td>
</tr>
<tr>
<td>Hurricane Earl</td>
<td>08/31 – 09/01/2010</td>
<td>12, 18 UTC (08/31); 00, 06 UTC (09/01)</td>
</tr>
<tr>
<td>Non-Tropical #6</td>
<td>09/21 – 09/22/2010</td>
<td>12, 18 UTC (09/21); 00, 06 UTC (09/22)</td>
</tr>
<tr>
<td>Hurricane Irene</td>
<td>08/25 – 08/26/2011</td>
<td>06, 12, 18 UTC (08/25); 00 UTC (08/26)</td>
</tr>
<tr>
<td>Non-Tropical #7</td>
<td>02/25 – 02/26/2012</td>
<td>00, 06, 12, 18 UTC (02/25)</td>
</tr>
<tr>
<td>Hurricane Isaac</td>
<td>08/26 – 08/27/2012</td>
<td>06, 12, 18 UTC (08/26); 00 UTC (08/27)</td>
</tr>
<tr>
<td>Hurricane Sandy</td>
<td>10/26 – 10/27/2012</td>
<td>00, 06, 12, 18 UTC (10/26)</td>
</tr>
</tbody>
</table>

**ii. Evaluation**

We have begun extensive evaluation of the WRF surface layer winds for the configurations given in Table 3. To do this, we are using tower data at the Kennedy Space Center (KSC). We are focusing on the four KSC towers with 3 or more levels of wind observations (3131, 0002, 0006, and 0110 – Fig. 4). In particular, we are interested how well the different parameterizations capture the roughness transitions that take place at the coastal (and intra-coastal) interface.

**Fig. 4.** LEFT: The location of the 4 multilevel KSC towers (3131, 1101, 0006, and 0002) used for the evaluation of WRF surface layer winds. RIGHT: Wind speed (kt) profiles during hurricane Sandy (26 October 2012). There are six profiles shown, three centered +/- 5 minutes at 1500 LST from instruments mounted on the northeast and southwest sides of the tower. The mean profile is shown as a solid line while two least-square fits (log law) are show for which the profile is forced to pass through the 12 foot level (dashed line) and through the 54 foot level (solid gray line).
Table 3. FIT-WRF Configurations.

<table>
<thead>
<tr>
<th>Options</th>
<th>Config. 1</th>
<th>Config. 2</th>
<th>Config. 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>PBL</td>
<td>Yonsei</td>
<td>Asym./Conv. Model V2</td>
<td>Mellor-Yamada-Janjic</td>
</tr>
<tr>
<td>Land Sfc. Physics</td>
<td>Noah LSM</td>
<td>Noah LSM</td>
<td>Noah LSM</td>
</tr>
<tr>
<td>Sfc. Urban Physics</td>
<td>Off</td>
<td>Off</td>
<td>Off</td>
</tr>
<tr>
<td>LW/SW Radiation</td>
<td>Dudhia</td>
<td>Dudhia</td>
<td>Dudhia</td>
</tr>
<tr>
<td>Microphysics</td>
<td>Lin et al.</td>
<td>Lin et al.</td>
<td>Lin et al.</td>
</tr>
<tr>
<td>Cumulus Physics</td>
<td>Off</td>
<td>Off</td>
<td>Off</td>
</tr>
<tr>
<td>Time Step</td>
<td>Auto_S</td>
<td>Auto_S</td>
<td>Auto_S</td>
</tr>
<tr>
<td>Vertical Levels</td>
<td>45</td>
<td>45</td>
<td>45</td>
</tr>
<tr>
<td>Top Pressure Level</td>
<td>5000 Pa</td>
<td>5000 Pa</td>
<td>5000 Pa</td>
</tr>
</tbody>
</table>

Fig. 5 depicts wind speeds at 1013 hPa (left) and at 10 m (right) at the end (F12) of an ACM simulation (Configuration 2, Table 3). The IRL is clearly evident at 10 m, while less so at the 1013 hPa level (approximately 45 m). In Fig. 7 we show a vertical W-E cross-section (along the ‘orange’ line segment in Fig. 5) of the WRF wind speed in the lowest 400 m and at select points along the cross-section. The acceleration/deceleration of the wind is apparent from these figures as the flow moves off of the barrier island over the IRL and then over the mainland. The local roughness is evident at z = 10 m, while above that the larger scale effect of the peninsula extends up to about 300 m. For the hydrodynamic forcing in the IRL, it is important that the WRF model resolves the land/water mask as well as has an accurate representation of the ‘upstream’ roughness. This can be problematic given the model roughness is a bulk estimate (i.e., does not vary with flow) and, at 3 km resolution, will likely not capture the ‘local’ heterogeneity of the landscape. The NWS WRF roughness for the KSC region as well as a roughness estimate (derived from C-CAP land surface classification) from Hirth et al. (2012) is shown in Fig. 6. These issues are currently being investigated as an extension to the COMET work.

Fig. 5. Wind speed (contour interval of 0.5 m/s) for the ACM-7 model configuration (Table 3) valid 00 UTC 30 October 2007 (hurricane Noel). LEFT: 1013 hPa (approximately 45 m); RIGHT: 10 m.
Fig. 6. Bulk roughness ($z_o$) from the NWS WRF (left) and from land surface data (Hirth et al. 2012, Fig. 5).

Fig. 7. TOP: Wind speed (m/s) vertical cross-section along the taken along the orange line segment in Fig. 5. BOTTOM: Wind speed at evenly spaced points along the same cross-section for $z = 10$ m and various pressure levels up to 975 hPa.
d. Hydrodynamic Forcing Related Activities

*Software has been written that maps the NWS WRF 3 km output to the Advanced CIRCulation model (ADCIRC, see http://chl.erdc.usace.army.mil/adcirc) grid. This work was completed and reported in the Year 1 report.

*We have expanded the assessment of the WRF wind fields as discussed above. Because ADCIRC was designed to downscale winds from a large scale NWP model rather than a high resolution model output – we are examining the level of redundancy present using the winds from the high resolution (300 m) FIT-WRF nest.

*As originally proposed, we present and apply a methodology that samples the wind speed/directional bias pdfs. The sampled speed errors, which vary as a function of forecast time, are applied uniformly to an analysis (i.e., a short term forecast). We have delivered four distinct wind forcing sets to Dr. Weaver – two of which consist of a 12 day “best scenario” wind forcing (associated with hurricane Sandy) that are pieced together using a sequence of 0 h RAP analyses and 3 h forecasts respectively. The additional two forcing data sets span an embedded 24 h window and were created using the 3 h forecasts with superposed perturbations obtained via sampling the wind speed bias pdfs for both the high and low bias.

1.2 Division of Labor

FIT: Wind error evaluation; in-house high-resolution ensembles, wind forcing, WRF evaluation.

NWS: Operational WRF output; provide supporting WRF configuration files; provide feedback/input.

SECTION 2: Related Accomplishments and Activities

The project has supported, in part, some of the thesis work of MS student Robert James, and a related proposal that was unfortunately rejected by Florida Sea Grant. However, because this grant provided the seed money to develop a hydrodynamic grid for the East-Central Florida coast, we anticipate that this effort will eventually develop into something more substantial as it is unique in that it focuses on high resolution forcing of an intra-coastal water body.

SECTION 3: Summary of Benefits and Current Work

3.1 FIT
This work will provide insight regarding the impact of high-wind events on the IRL; the quality of the WRF wind forecasts; insight on the value added from the high resolution
NWP; optimizing the WRF configuration as it relates to the surface layer wind field; the impact of high resolution wind forcing on a hydrodynamic model; a better understanding of the impact of surface roughness and fetch on driving IRL circulations.

3.2 NWS
NWS Melbourne has a better feel for the character of high-resolution model forecast winds in vicinity if the IRL during high impact wind events; what is forecast and what speed errors may be reasonably expected with time. This project has also revealed aspects where refinements can be made to the methodology. As we move toward the eventual availability of IRL hydro-dynamic model output, as forced by model winds, forecasters will have an appreciation for this output and the inherent uncertainties of the forecast.

It will be a subsequent desire to force the IRL hydro-dynamic model with forecaster provided winds from the operational gridded forecast. Again, inherent uncertainties will be better accommodated at such time.

SECTION 4: Presentations and Publications
Robby James has scheduled his departmental seminar in December 2013.

Mr. James successfully defended his thesis proposal, based on this work, in February.

SECTION 5: Summary of Problems Encountered and Issues/Questions raised
5.1 FIT
No problems.

5.2 NWS
No problems.

SECTION 6: Project Future
The project has expanded well beyond the scope of the original proposal – especially as it relates to the WRF performance with respect to the boundary layer parameterizations. We anticipate that we will be able to provide feedback to the Melbourne NWS as a result of this work. As discussed in Section 3.1, we believe that the seed money will eventually pay off with additional projects/funding.