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APPLYING THE NEW WEATHER RESEARCH AND FORECAST (WRF) MODEL TO NATIONAL WEATHER SERVICE FORECAST OFFICE OPERATIONS

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1. INTRODUCTION

Under the auspices of a nationwide effort led by NOAA known as the Coastal Storms Initiative (CSI), a locally run version of the new Weather Research and Forecast (WRF) mesoscale numerical weather prediction (NWP) model has been installed at the Jacksonville (JAX), Florida National Weather Service Weather Forecast Office (WFO). CSI is a collaborative effort between various local, state, and federal organizations to lessen the impacts of storms on coastal communities. The effort to install WRF at JAX is but one component of the initiative, designed to improve accuracy and detail of forecasts of coastal winds, precipitation, and visibility. This local modeling effort represents collaboration between the NWS Office of Science and Technology, the JAX WFO, the NOAA Forecast Systems Laboratory (FSL), and the Florida State University (FSU) Department of Meteorology.

This project seeks to address three pertinent issues related to local modeling within the NWS WFO environment. First, can public forecast services provided by a WFO be enhanced through the use of a locally run mesoscale modeling system? Second, does the use of a data assimilation component improve local model forecasts compared to simply initializing a local model directly from the NCEP national forecast models? Third, can the new WRF model serve as the local model component in the WFO environment in a similar manner as the workstation Eta system has in other WFOs?

To address these questions, the group of collaborators designed a local configuration that would meet the operational needs while providing data and a verification method that could provide insight into these issues. This paper provides an overview of the CSI WRF modeling system as installed at the JAX WFO, including the data assimilation component, post-processing, and limited quantitative results. Information on the perspective of the operational forecasters regarding value added by this system is contained in Welsh et al. (2004). A verification study of the operational WRF forecasts are provide in Bogenschutz et al. (2004).

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2. SYSTEM DESCRIPTION

2.1 WRF Configuration

The version of WRF in use at JAX is version 1.3, available to the general community for download at http://www.wrf-model.org. The dynamic core used for the CSI system is the third-order Runge-Kutta solver (Wicker and Skamarock 2002) formulated for the mass-based vertical coordinate. No explicit numerical filters are used during model integration (diffusion constants are set to zero).

The horizontal model domain is shown in Figure 1. The grid uses a Lambert Conformal map projection with grid spacing of 5 km, which was chosen to match the resolution of the grids used to populate the National Digital Forecast Database (NDFD) via the Interactive Forecast Preparation System (IFPS, Ruth 2002). The analysis grid consists of 145 points in each direction. Since WRF utilizes an Arakawa-C stagger, this results in 144 mass points in each direction, which allows an equal number of points in the grid to be distributed across the 16 processors available on the computational platform. The Runge-Kutta solver allows a long time step of 30 s to be used despite the 5 km grid spacing.

In the vertical, 42 full levels (41 computational layers for the mass variables) are used, with a minimum vertical increment of approximately 20 m at the lowest levels, increasing to approximately 1000 m at the model top, which is set at 100 mb.

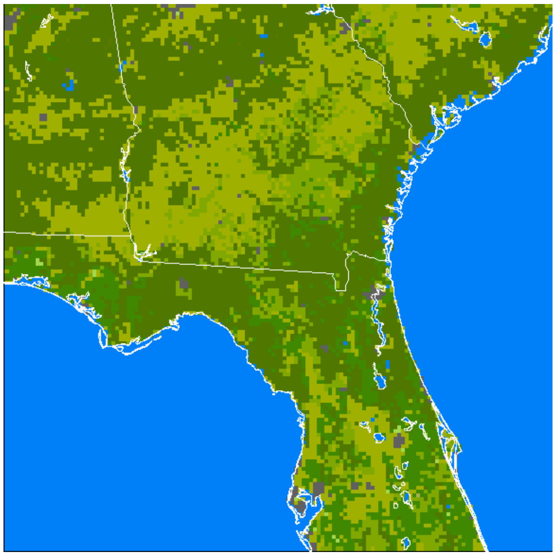

Figure 1. Horizontal model domain for the CSI JAX WRF runs. The domain consists of 145x145 points on the non-staggered grid with 5-km grid spacing. Image is USGS 24-category land use class as provided via the WRF Standard Initialization package.

Physics options employed include the NCEP 5-class microphysics, Dudhia shortwave radiation, RRTM longwave radiation, the MRF (Hong-Pan) PBL scheme, and the OSU Land Surface Model. No cumulus parameterization is employed.

The model initial and lateral boundary conditions are provided via the WRF Standard Initialization (WRFSI) package, version 1.3.2, also available to the public at the above web site. The WRFSI is configured to read analysis grids from the Local Analysis and Prediction System (LAPS, Albers et al. 1996) for the initial atmospheric conditions, and NCEP Eta grids on the 12 km NCEP grid 218 for the initial soil and sea conditions and for the lateral boundary conditions.

2.2 Data Assimilation

For the WRF runs used by the operational forecasters, the initial conditions are provided by LAPS, using the diabatic initialization technique described in Shaw et al. (2002). LAPS is able to use a wide variety of observational data, including GOES imagery, GOES soundings, WSR-88D reflectivity and radial velocity data, wind profilers, RASS temperature profiles, METAR and maritime surface observations, mesonet observations, GPS-MET total precipitable water, and ACARS data. In the JAX implementation, the data sets available for assimilation are limited by availability on the NOAAPORT data feed and what is available via the Local Data Acquisition and Distribution (LDAD) feed. The table below shows the various sources of data currently used by the CSI LAPS analysis and typical number for each hourly run of the system. It is anticipated that additional data sets will be added as they become available via various means.

The unique diabatic initialization relies on the LAPS three-dimensional cloud analysis, which includes a cloud model to partition the condensate into the various species and determine cloud type information. Using the cloud type information, a vertical motion profile is derived, and these profiles are used as “observations” in a final three-dimensional variational (3DVAR) adjustment to ensure the mass and momentum fields are in balance with the analyzed cloud field. The 3DVAR balance step is fully described in McGinley and Smart (2002), and the details of the cloud analysis and vertical profile assignment are discussed in Schultz and Albers (2002). Note that LAPS is under continuous development, and the version described here is much newer than the versions currently fielded within the AWIPS platform. At JAX, the forecasters have reconfigured the standard AWIPS version to match the CSI domain, and they are able to view the analyses from the standard AWIPS LAPS as well as the advanced CSI LAPS.

2.3 Hardware Platform and WFO Integration

The computer used for the LAPS and WRF runs is a Linux cluster consisting of 9 nodes. Each node contains dual Athlon 2GHz processors, and inter-processor communication is handled via the Gigabit Ethernet interface. LAPS and all model pre- and post-processing is performed on the master node. The WRF model runs on 16 processors, spanning the remaining 8 nodes, using the MPI version of the model. The model configuration described earlier is able to complete a 24-h forecast in approximately 2.5 h.

The cluster interacts with the Advanced Weather Interactive Processing System (AWIPS) via the LDAD system. LDAD is used to transfer observational data and national model grids to the cluster for ingest by LAPS. Output from LAPS and WRF is transferred back to AWIPS via the same LDAD exchange mechanism. The WRF model is post-processed incrementally by a model post-processor that is provided with LAPS. The output is de-staggered onto the analysis grid, vertically interpolated to isobaric levels, and written into GRIB files that are sent to AWIPS as the model is running. Thus, forecasters are able to view each output hour of the forecast as they are produced rather than waiting for the entire run to be completed. The post-processor also provides tabular text forecasts for a list of points specified by the JAX WFO.

By sending the grids to AWIPS, forecasters are able to use and evaluate the forecasts on their operational workstations, which allow overlay of other data such as observations, satellite and radar imagery, and other grids. Additionally, providing the data to AWIPS provides the opportunity to import the WRF grids into the IFPS.

2.4 Experiment Design and Verification

The computing capacity at the WFO and the model configuration allow for multiple model runs per day. The schedule of runs was configured to best meet the needs of the local forecast operations while providing meaningful data to study the impact of adding a local data assimilation component and/or the value of local modeling compared to the national products. All runs discussed below are run out to a 24-h forecast length with a 1-h output increment (i.e., 25 frames per forecast run).

Each day, two runs with a 0600 UTC initial time are run. Both runs are identical in every aspect except for the initial conditions. Both runs utilize the 0000 UTC NCEP Eta run on a 12 km Lambert Conformal grid for lower and lateral boundary conditions. The "operational" run (hereafter referred to as WRF-Hot) is initialized with LAPS and is started at 0645 UTC and completes by 0815 UTC. The second "comparison" run (hereafter referred to as WRF-Eta) begins when the operational run is complete, and uses the 6-h forecast from the 0000 UTC Eta as the initial condition instead of LAPS. Since the first-guess used for LAPS in the operational run is also the 6-h forecast from the 0000 UTC Eta, these two runs serve the purpose of determining the value of adding additional local data and performing a reanalysis in the context of the LAPS diabatic initialization. Furthermore, since they have a 0600 UTC initial time, they can be directly compared to the 0600 UTC Eta run from NCEP to see what if any value is added by local models compared to the national guidance.

In addition to the 0600 UTC runs, two more WRF-Hot runs are performed each day at 1500 UTC and 2100 UTC to meet the needs of the JAX office. These two runs provide updated, high-resolution model output between the national Eta and GFS runs using the LAPS diabatic initialization. The 1200 UTC and 1800 UTC runs of the operational NCEP Eta model provide the boundary conditions for these runs.

For all four runs each day, a subset of the post-processed model output in GRIB is transferred back to FSL for processing through the Real-Time Verification System (RTVS, Mahoney et al. 2002). RTVS verifies the forecasts of surface temperature, humidity, wind speed and direction, and precipitation against surface observations within the domain. For the wind, temperature, and humidity parameters, typical statistical measures of error and bias are computed. For the precipitation forecasts, equitable skill score (ESS) and frequency bias are computed.

In addition to the CSI WRF runs, the 12 km national Eta model is also processed through RTVS using the same algorithms and observations. When comparing more than one model run, RTVS provides "equalization" to ensure only those model cycles for which all models being compared were available are used in the statistics. Finally, RTVS provides a web-based interface to view the results of the verification interactively at http://www-ad.fsl.noaa.gov/fvb/rtvs/csi.

In addition to the quantitative validation being provided via RTVS, the GRIB data retrieved by FSL is also provided to Florida State University, where Bogenschutz et al. (2004) are performing detailed case studies and mesoscale feature-based assessments.

3. RESULTS

3.1 Successes

The most important measure of success when testing a new application in a WFO environment is whether or not the forecasters find the application useful. Making the WRF grid available on AWIPS provided the incentive for the forecasters to look at the model forecasts, and over time more and more of the forecasters have become comfortable with the WRF model and have begun to rely on it in various situations. In particular, early in the experiment, forecasters discovered that WRF forecasts of visibility reductions due to fog were very accurate. One of the first area forecast discussions issued by JAX referencing the WRF actually indicated a change in their thinking for the visibility forecast based solely on the WRF forecast and its previous performance in similar situations.

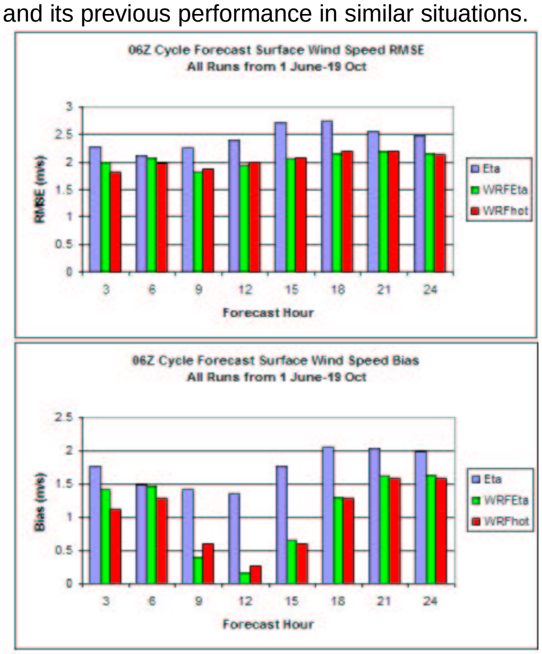

Figure 2. RMSE (top) and bias (bottom) for forecast surface wind speed by forecast hour from the 06Z cycle of Eta, WRF-Eta, and WRF-Hot.

Surface winds are another important forecast parameter within the JAX area of responsibility. The CSI project specifically calls for improved forecasts of wind speed and direction for input into a new wave model being developed under CSI. Quantitative verification of the WRF wind speed forecasts via RTVS show the WRF forecasts significantly outperformed the NCEP Eta forecasts at all hours of the 24-h forecast period. Root mean square error (RMSE) and bias of the surface wind forecasts for the 0600 UTC run of Eta, WRF-Hot, and WRF-Eta are shown in figure 2.

The southeast US and adjacent coastal areas are dominated by convective activity during much of the year. Quantitative precipitation forecasts (QPF) via numerical methods are traditionally poor for these types of events due lack of model resolution and the inherent chaotic nature of air mass thunderstorm development and evolution. The LAPS diabatic initialization attempts to improve explicit short-range QPFs by initializing the NWP models with active clouds and precipitation. This experiment provides further evidence that finer scale models coupled with advanced initialization techniques using satellite and radar information can provide improvements. Figure 3 depicts the ESS and frequency bias scores for the 0-6 h QPF for various thresholds of precipitation from the 0600 UTC run of the NCEP Eta, the WRF-Eta, and the WRF-Hot.

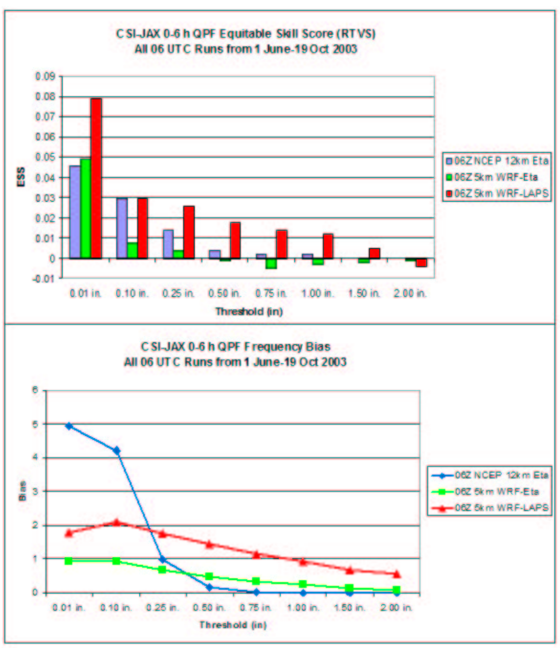

Figure 3. ESS and bias for the 0-6 h forecast period from the NCEP Eta, CSI WRF-Eta, and CSI WRF-Hot. Statistics are from RTVS for the period 1 June through 19 October 2003.

The WRF-Hot demonstrates better ESS and a more consistent bias across all thresholds of precipitation than either the NCEP Eta or the WRF-Eta run. This figure also shows the benefit of adding local data to the initialization using the LAPS diabatic method, as the WRF-Eta forecasts had a low bias for all thresholds, indicative of the typical model "spin-up" problem for precipitation processes. The Eta suffers much less from the spin-up problem, likely due to its advanced 3DVAR data assimilation cycle, but is still outperformed in the 0-6 h forecast period by WRF-Hot.

3.2 Challenges

Several challenges presented themselves during this project. First and foremost, network security requirements and lack of bandwidth between JAX and the rest of the NWS network made it difficult to engineer and optimum solution to ensure all required input data is made available in a timely manner. The first-guess grids and observational data, including radar and satellite, are made available via the LDAD system, whereas the Eta tiles for the lateral and lower boundary conditions are obtained via FTP from either the NWS Southern Region Headquarters in Fort Worth, TX, or from the NCEP anonymous FTP server. Many of the run failures during the experiment were due to slow or incomplete data transfers, either due to network performance or unanticipated impacts when router configurations were changed while applying security patches.

Network bandwidth available to a WFO varies by location, and JAX happens to be more limited than most in the Southern Region. Plans for the LAPS analysis included the acquisition of multiple wideband WSR-88D radar feeds from within the region by making use of the CRAFT network. Unfortunately, at the time of writing, this was still not possible. To mitigate this, FSL has been providing narrowband radar from a national composite on the CSI domain via a routine FTP process. It is expected that the LAPS diabatic initialization will benefit greatly from multiple wideband radar sites as demonstrated in the International H2O Project (Shaw et al. 2003).

Planned upgrades to AWIPS during the experiment provided additional challenges, as various changes and additions made to allow ingest of the local model, as well as custom scripts to provide data to the cluster via LDAD, were overwritten during the upgrades and had to be recovered. As local modeling within the WFOs becomes more prevalent, support for custom configurations on AWIPS will likely improve.

Initial integration of the Linux cluster was made a bit difficult due to the configuration in which it arrived. The vendor provided a configuration more suited to "high availability" computing rather than "high performance" computing, and some time and learning was spent reconfiguring the system for use with parallelized software. Lessons learned from the CSI project can be used to prevent this in future offices. Additionally, minor hardware failures, including a failed network card and a failed main processor, were responsible for a few model failures during the project. These were generally discovered and repaired quickly by the JAX Information Technology Officer (ITO).

Meteorologically, the WRF forecasts did not perform as well as the Eta model and other national guidance for surface temperature (Figure 4). Both the WRF-Hot and WRF-Eta runs exhibit a negative temperature bias (too cool) during the afternoon hours (at peak heating) and a positive temperature bias (too warm) at night. This is fairly typical for many models, including the Eta, but was much more exaggerated for the WRF forecasts. However, it is important to remember that the Eta model and its associated post-processed fields (e.g., 2m temperature) has undergone extensive tuning since its implementation several years ago, whereas the WRF model is new and was used in an "off-the-shelf" configuration. Officially, WRF is not yet considered to even be a research-grade model. Despite the deficiencies in forecasting surface temperatures, its performance in other categories is still quite encouraging given the state of its development. The problems with the temperature forecasts warrant some investigation into the implementation of the PBL, land surface, and radiation schemes and their interactions within the WRF model.

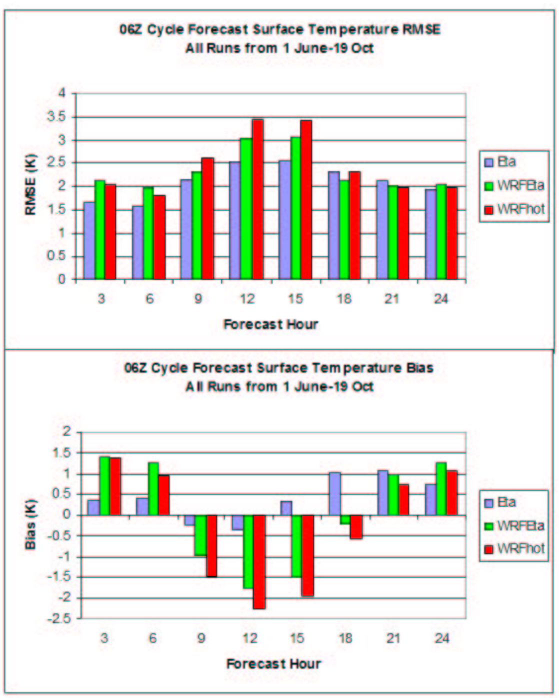

Figure 4. RMSE and bias for the Eta, WRF-Eta, and WRF-Hot surface temperature forecasts for all forecast hours of the 06 UTC runs from 1 June through 13 October 2003.

4. CONCLUSIONS AND FUTURE WORK

Despite the challenges faced in implementing the WRF as a quasi-operational tool within the WFO, this project has made progress in answering the questions posed in the introduction. The quantitative statistics and anecdotal evidence show that local models can and do add value in the local forecast process, particularly in the area of QPF and wind forecasts. For short-term forecasts (0-6 h), initializing these models using additional local data appears to provide even more values. For longer term forecasts, lateral boundary conditions tend to dominate the source of forecast error for such small domains as the CSI area, but in some cases (e.g., wind speed), the additional resolution of the model appear to still provide advantages.

Finally, even though it is in the early stages of development, the performance of the WRF model is very encouraging. Groundwork laid by the CSI project may serve as a foundation for developing a standardized WRF-based local NWP package suitable for use in all NWS WFOs.

We hope to continue upgrades to the JAX system, including the addition of the wideband WSR-88D reflectivity and radial velocity data from JAX and surrounding offices, GPS total precipitable water retrievals, ACARS data, and local wind profilers, all of which are currently supported by the version of LAPS being used but are unavailable to the cluster at the time of writing. A second evaluation period during the winter may also provide useful verification data to assess WRF performance in a different weather regime.

5. REFERENCES

Albers, S., J. McGinley, D. Birkenheuer, and J. Smart, 1996: The Local Analysis and Prediction System (LAPS): Analysis of clouds, precipitation, and temperature. *Wea. Forecasting,* **11**, 273-287.

Bogenschutz, P., P. Ruscher, P. Welsh, J. Mahoney, J. A. McGinley, M. Kay, B. Shaw, J. Smart, J. Savadel, and J. McQueen, 2004: Summer season verification of the first NWS operational WRF model forecasts from the NOAA Coastal Storms Initiative project in northeast Florida. *20th Conf. on Wea. Anal. and Forecasting/16th Conf. on NWP,* Seattle, WA, Amer. Meteor. Soc., [this volume].

Mahoney, J. L., J. K. Henderson, B. G. Brown, J. E. Hart, A. Loughe, C. Fischer, and B. Sigren, 2002: The Real-Time Verification System (RTVS) and its application to aviation weather forecasts. *10th Conference on Aviation, Range, and Aerospace Meteorology*, Portland, OR, Amer. Meteor. Soc.

McGinley, J. A., and J. R. Smart, 2001: On providing a cloud-balanced initial condition for diabatic initialization. *14th Conference on Numerical Weather Prediction.* Fort Lauderdale, FL, Amer. Meteor. Soc., 40-44.

Ruth, D. P., 2002: Interactive forecast preparation – the future has come. *Interactive Symposium on AWIPS*, Orlando, FL, Amer. Meteor. Soc., 20-22.

Schultz, P., and S. Albers, 2001: The use of three-dimensional analyses of cloud attributes for diabatic initialization of mesoscale models. *14th Conference on Numerical Weather Prediction.* Fort Lauderdale, FL, Amer. Meteor. Soc., J122-124.

Shaw, B. L., J. A. McGinley, and P. Schultz, 2001: Explicit initialization of clouds and precipitation in mesoscale forecast models. *14th Conference on Numerical Weather Prediction.* Fort Lauderdale, FL, Amer. Meteor. Soc., J87-J91.

Shaw, B. L., S. Albers, J. Brown, D. Birkenheuer, J. McGinley, P. Schultz, J. Smart, and E. Szoke, 2004: Application of the Local Analysis and Prediction System (LAPS) diabatic initialization of mesoscale numerical weather prediction models for the IHOP-2002 field experiment. *20th Conf. on Wea. Anal. and Forecasting/16th Conf. on NWP,* Seattle, WA, Amer. Meteor. Soc., [this volume].

Welsh, P. T., A. Wildman, B. Shaw, J. Smart, P. Ruscher, J. Savadel, and J. McGinley, 2004: Implementing the Weather Research and Forecast (WRF) model in a National Weather Service Weather Forecast Office (WFO). *20th Conf. on Wea. Anal. and Forecasting/16th Conf. on NWP,* Seattle, WA, Amer. Meteor. Soc., [this volume].

Wicker, L. J., Skamarock, W. C., 2002: Time-splitting methods for elastic models using forward time schemes. *Monthly Weather Review*, 130, 2088-2097.