Providing NWS Forecasters with Mesoscale Domain Options of the WRF-EMS for Enhancing Local Decision Support, Continuity of Operations, and Service Backup

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Abstract

The use of local mesoscale models has significantly increased during the past decade. The availability of the Weather Research and Forecasting - Environmental Modeling System (WRF-EMS) and its high degree of configurability has brought modeling capabilities to many Weather Forecast Offices (WFOs) within the National Weather Service. The WFO in Melbourne (MLB), FL is exploring enhancements to their local modeling approach. Development and testing is centered on giving WFO meteorologists detailed depictions of alternative forecast outcomes during hazardous weather situations and improving the ease and flexibility of on-demand model execution according to selectable pre-configurations. Alternative outcomes help bolster forecaster confidence regarding the measure of relative uncertainties associated with a particular weather situation, while on-demand capabilities allow forecasters to request certain domain options and configurations tailored to fit their current need.

With science-steering in mind, the purpose is to develop and test functionalities that might enhance a WFO's ability to more effectively exercise local decision support, continuity of operations, and service backup to sister offices. This paper will discuss the configuration of multiple two-way and three-way nested domains for each of its service backup areas, including West Central Florida, the Florida Keys, and Puerto Rico (including the U.S. Virgin Islands). The development of unique software designed to function as the forecaster interface by which domain and configuration selections can be made will also be discussed.

I. Introduction

The mission of the National Weather Service (NWS) is to *"Provide weather, water, and climate information - observations, forecasts, and warnings - for the* ***protection of life, property, and the environment,*** *as well as toward the enhancement of the national economy."* To meet the mission, across *East Central Florida* and the adjacent coastal waters, WFO Melbourne (MLB) is responsible for weather coverage (24 hours per day; 365 days per year). Among their major operational commitments include observations, forecasts, and warnings for ten airports, the coastal waters between Flagler Beach and Jupiter Inlet out to 60 nmi, river sections of the Saint Johns River, and ten counties comprising the public and fire weather communities. Notable cities within MLB's area of responsibility include Orlando and Daytona Beach, FL. With a population of nearly 4 million residents (visitors aside), the user community is large, diversified, and demanding (United States Census Bureau, 2013). As the need arises, Emergency Management (at all levels) within each of the ten counties is provided specialized support to facilitate decision-making in the face of threatening weather.

In addition to its own area of responsibility (AOR) WFO MLB has three service backup areas: *West Central Florida* (as routinely serviced by WFO Tampa Bay, FL), *the Florida*

Keys (as routinely serviced by WFO Key West, FL), and *Puerto Rico & U.S. Virgin Islands* (as routinely serviced by WFO San Juan, PR). At times it becomes necessary for a WFO to transfer operations responsibility over to a service backup site. That is, service backup is rendered when a WFO becomes partially or fully impaired for whatever reason, and unable to effectively deliver products and/or services. In worst case situations it may even entail exercising aspects of respective continuity of operations plans. Regardless, it is incumbent upon the WFO assuming backup responsibilities to temporarily deliver the mission to partners and customers of the impaired site, and with comparable quality.

Forecasting for the Florida Peninsula and Keys can be difficult. Accounting for the varying influences of sizeable land/sea interfaces, the Gulf Stream, large inland lakes, etc., make convective forecasts a challenge. The same is true for Puerto Rico, and perhaps more so in the presence of mountainous terrain. In terms of model data from the NWS Environmental Modeling Center (EMC), only the High Resolution Rapid Refresh (HRRR) offers non-nested output at the sub-10 km grid scale sufficient for capturing mesoscale convective signals through cloud-resolving and convective-allowing configuration schemes (ESRL, 2015). Yet, the operational HRRR (CONUS) domain does not yet provide adequate guidance to southern island locations such as Puerto Rico, the Virgin Islands, or the Florida Keys. Locally-tailored mesoscale models have helped bridge this short-coming for these locations, while at the same time offering the Florida WFOs alternate output for comparison. This project is an opportunity for WFO Melbourne to provide these dedicated forecasters and service meteorologists with new tools and resources that critically support them with the completion of the NWS mission.

A. Some Previous Work

Prior to configuring multiple versions of the WRF-EMS over recent years, the MLB office has established a rich history of local data assimilation and modeling collaborations involving working versions of the Mesoscale Atmospheric Simulation System (MASS), the Regional Atmospheric Modeling System (RAMS), the 5th Generation Mesoscale Model (MM5), the Advanced Regional Prediction System (ARPS), the Workstation ETA, and early versions of the portable WRF. Since the mid 1990s, much of this work was done in collaboration with government research laboratories such as the Applied Meteorology Unit and Short-term Prediction Research and Transition Center within NASA, as well as the National Severe Storms Laboratory and Hurricane Research Division within NOAA (AMU, 2013). Meaningful work was also accomplished through collaborations with the Florida Institute of Technology.

For WFO MLB, recent variations in WRF-EMS configurations have accommodated a two-way nested ARW with a 6 km outer domain covering all of the state and a 2 km resolution inner domain covering East Central Florida. Both runs have 45 vertical levels. The outer domain encompasses a grid of 190 by 142, while the inner grid is 217 by 199. The models run with no cumulus parameterization, so that convection is explicit. The WRF is run 8 times a day at 00, 03, 06, 09, 12, 15, 18, and 21 UTC. Model output is available around 2.5 hours after the initialization time. The runs generate forecasts out to 48 hours for the outer domain, and 27 hours for the inner 2 km domain. This configuration of the WRF-ARW uses the Rapid Refresh model (RAP) to initialize the model (hot start). The RAP generates analyses that combine in situ and remote data sets to depict the current state of the atmosphere. High resolution MODIS satellite data is used to initialize the sea surface temperatures. A high resolution Land Information System (LIS) is also used for initial conditions (Kumar et al., 2006). Lateral boundary conditions are provided by the 12 km North American Mesoscale model (NAM).

Output from the WRF may be experimentally used to populate elements within WFO gridded forecasts, or used to drive the locally run nearshore wave prediction system (Simulating Waves Nearshore; SWAN) or particle trajectory and plume dispersion prediction system (Hybrid Single Particle Lagrangian Integrated Trajectory model; HYSPLIT) (Blottman et.al., 2015). Each provides opportunity for forecasters to impose configuration adjustments through a user interface.

The WRF-EMS is also locally-configured at WFO Key West (KEY) and WFO San Juan (SJU) for experimental use. During the summer months, these regions are characterized by the easterly trade winds that move tropical disturbances into the area. In addition, many of the islands are smaller than grid spacing of many coarser NWP models. The WRF-EMS models run at these offices assist in forecasting disturbances and island effects that might otherwise be under represented. These sites also represent locations that WFO MLB may have to provide service backup support in times of need (e.g., emergency). It is important that WFO MLB have similar capabilities. Results of this project and paper represent the substantial achievement of acquiring this functionality in an easy to use on-demand fashion at the forecaster level.

B. Scope of this Project

This project represents a proactive measure for rendering higher caliber service backup to customers and partners of down WFOs. WFO MLB has executed two major efforts in this regard. The first is the configuration of multiple two-way and three-way nested WRF-EMS domains around West Central Florida, the Florida Keys, and Puerto Rico & the Virgin Islands. The second effort is the development of new software called the Domain Selection Graphical User Interface (GUI). The Domain Selection GUI allows forecasters to easily interact with the WRF-EMS models and saves time by allowing them to make key choices regarding the model domains.

C. Motivations

Providing forecasters with these mesoscale domain options presents the practical advantages of local modeling. Local modeling has the ability to provide higher spatial and temporal resolution than the current operational NCEP models. Additionally, these alternative depictions of single model solutions help account for ambiguity related to mesoscale and sub grid scale features. Model output can be quickly generated on an operational time scale, and because it's available locally it helps circumvent office bandwidth limitations that would otherwise slowdown office operations.

II. Methods

A. Mesoscale Domain Options

Figure 1 shows the three mesoscale domains options for West Central Florida, the Florida Keys, and Puerto Rico & the Virgin Islands respectively. The domains were defined using the WRF Preprocessor System Domain Wizard software. The West Central Florida Domain is centered near WFO Tampa Bay. Its upper left corner is at 31.3°N and 88.0°W and its lower right corner is at 23.8°N and 76.3°W. The Florida Keys Domain is centered near WFO Key West. Its upper left corner is at 28.1°N and 88.1°W and its lower right corner is at 20.3°N and 74.2°W. The Puerto Rico & Virgin Islands Domain is centered near WFO San Juan. Its upper left corner is at 21.3°N and 74.8°W and its lower right corner is at 15.4°N and 58.7°W. All three domains are Mercator projections and have 45 vertical levels.

WRF-EMS Domain Settings and Parameterizations:

Version: 3.4.1.14.16	**West Central Florida**	**Florida Keys**	**Puerto Rico & the Virgin Islands**
Number of nests:	2	2	3
Resolution:	6km /2km	6km/ 2km	12km/4km/1.33km
Forecast Period:	48hrs/27hrs	48hrs/27hrs	48hrs/27hrs/12hrs
Run Time:	~3 hours	~3 hours	~3 hours
Initial/ Boundary Conditions:	Rapid Refresh (RAP)/ North American Mesoscale (NAM)	Rapid Refresh (RAP)/ North American Mesoscale (NAM)	Global Forecasting System (GFS)
Cumulous Physics:	(Explicit)	(Explicit)	Betts-Miller-Janjic*
Microphysics:	WSM Single- Moment 6-Class Scheme	WSM Single- Moment 6-Class Scheme	WSM Single- Moment 6-Class Scheme
Planetary Boundary Layer Scheme:	Mellor- Yamada-Janjic	Mellor- Yamada-Janjic	Mellor- Yamada-Janjic

Table 1: Backup WRF configurations. Additional information can be found in Appendix A.

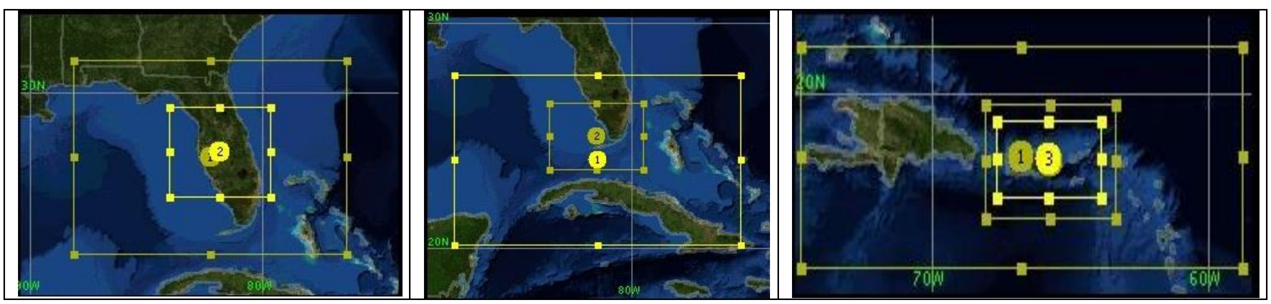

Figure 1: Experimental, on-demand modeling domains configured at NWS Melbourne, FL for supporting service backup operations, continuity of operations, and decision support services. The West Central Florida domain (left) is centered on Tampa Bay, FL using ~68 thousand points covering ~357,000 mi². The Florida Keys domain (center) is centered on Key West, FL using ~71 thousand points covering ~455,600 mi². The Puerto Rico and the Virgin Islands domain (right) is centered on San Juan, PR using ~69 thousand points covering ~421, 400 mi².

B. Domain Selection Graphical User Interface

The Domain Selection GUI (Figure 2) is newly developed software coded by the lead author specifically to obtain the desired functionality. It is an executable tcl/tk script within the AWIPS2 environment. Its function is to allow forecasters to choose which pre-configured model domain option to run, and whether to run it once or continuously. Through the GUI, forecasters can easily cancel active continuous model runs.

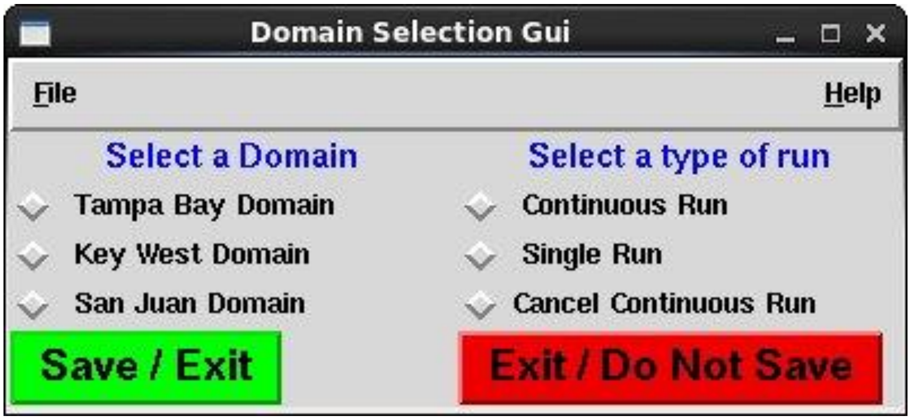

Figure 2: The Domain Selection Graphical User Interface was independently developed by the lead author and WFO MLB to allow forecasters to interact directly with the WRF-EMS mesoscale domain options.

The domain_GUI.tcl works by interacting with another independently developed software script called domain.pl. It executes as follows:

1) At an AWIPS workstation, the forecaster selects a domain and a type of run.
2) A text file with the selection information is sent from the AWIPS2 workstation to computer that executes the WRF model (Table 1).
3) At a pre-designated time (defined within the Linux Command Run on Notice cron), a Perl script is executed.
4) The Perl script reads the text file and designates which model domain option to run.
5) After the model completes its run and post-processes, the output is sent back to AWIPS2 where it can be displayed by the forecaster.

The Domain Selection GUI simplifies complex tasks as it interfaces with model servers outside of the AWIPS2 environment. Its function allows forecasters to interact with model domain configurations beyond what was previously available to them in accordance with their service backup needs. The Domain Selection GUI also promotes better behind the scenes management of computational resources. Developing and transitioning innovations are a necessity for growth in any applied science field. This new software represents another step toward on-demand modeling capabilities, whether on a local cluster or central server.

III. Results

A. West Central Florida Domain Option Utilized in Service Back Up

A scheduled service backup for WFO TBW occurred on 28 October 2015 which granted the opportunity to assess the West Central Florida backup domain in an operational setting. The WFO TBW was undergoing a new AWIPS2 upgrade and continuity of operations required a primary service backup posture. Service backup transpired between 12 UTC and 16 UTC. The main objectives for testing the West Central Florida domain option included: assessing the experimental domain GUI, confirming that the model version executed on an operational time scale, and making sure the transfer of model output onto an AWIPS workstation for forecaster use was smooth and efficient. These functionalities are paramount since primary service backup is a more likely posture compared to secondary and tertiary backup responsibilities.

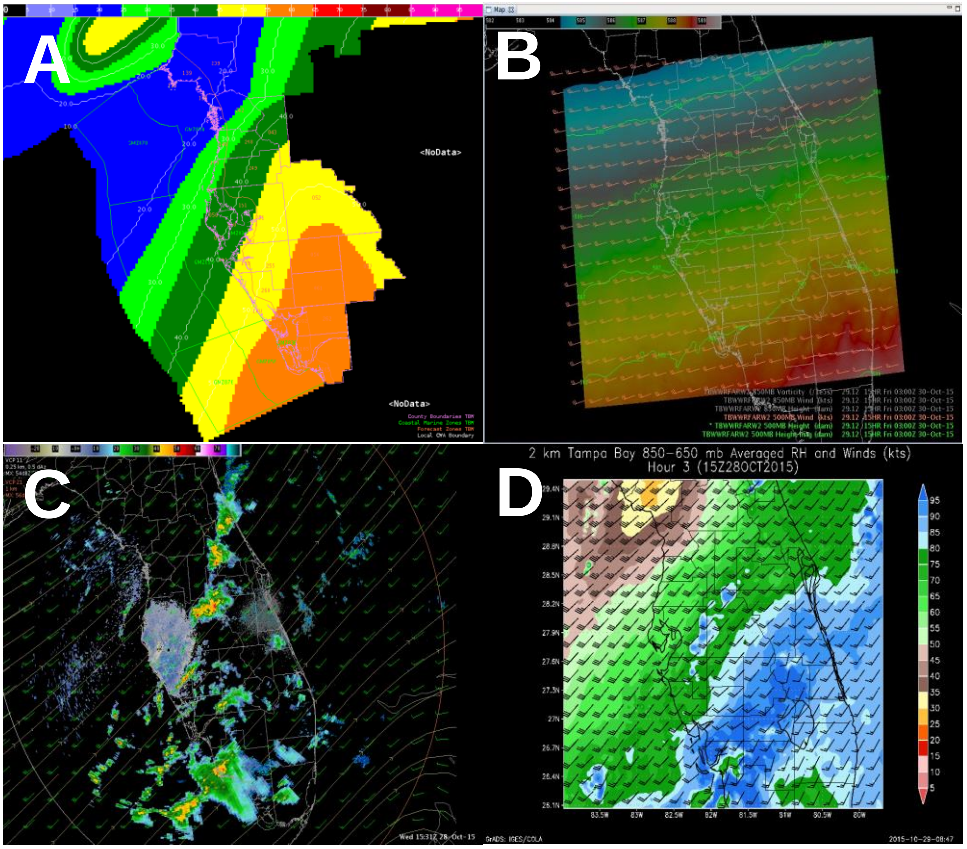

Figure 3: Case event on 28 October 2015. a. Graphical Forecast Editor (GFE) of WFO Tampa Bay AOR displaying shaded probability of precipitation % (POP); b. West Central Florida domain option loaded into AWIPS workstation displaying shaded/contoured 500mb height (dam) and 500mb wind barbs (kts); c. Mosaic of KTBW and KMLB WSR 88D Radar at 1530 UTC with GFS 850mb-650mb wind streamlines and wind barbs (kts); d. GrADS output of West Central Florida domain option at 15 UTC displaying 850mb-650mb wind barbs (kts) and shaded average relative humidity.

Primary meteorological threats on 28 October 2015 were lightning from thunderstorms moving into Central Florida from the southwest. In Figure 3.a, highest probability of precipitation (POPs), in orange, are seen in southern portion of the WFO TBW area with decreasing POPs to the north, in blue. Thunderstorms can be seen in Figure 3.c at 1531 UTC nearing the Orlando International Airport.

Using the Domain Selection GUI, a single run of the backup West Central Florida domain option was performed. The model was initialized with 12 UTC RAP initial conditions and 12 UTC NAM boundary conditions. Model run time was 2 hours and 20 minutes. Multiple model runs are necessary to better simulate rapidly evolving environments. Ideally in a 24 hour back up situation a minimum four model runs per day would be comparable to the GFS. With a model completion time of approximately 3 hours, WFO MLB can execute 8 runs per day twice as often the national model. Unlike this case event, in a real emergency requiring more deliberate service backup the model would be initiated at 9 UTC for completion by the 12 UTC start time.

After completion, the 27 hour model solution from the 2 km resolution inner domain was successfully loaded into the AWIPS work station. Figure 3.b shows an example of 500 mb height and winds from the backup model output as seen by WFO MLB meteorologists. The 3h forecast of the 850mb-650mb 'steering winds' is displayed in Figure 3.d. WFO MLB forecasters using both the GFS 'steering winds' in Figure 3.c and domain option steering winds in Figure 3.d along with other model data available can emulate a *"poor man's"* modeling ensemble method. While using this method, forecasters can at least gain a measure confidence in storm motions, their potential areas of impact, and timing of arrival.

The aforementioned objectives for the West Central Florida domain test were met, i.e., the Domain Selection GUI was correctly implemented; the mesoscale model was successfully completed within the operational time frame; and the model data was loaded into the AWIPS workstation.

IV. Summary

The on-demand ability to select pre-configured versions of local model domains and parameterizations is a viable solution for aiding forecasters in service backup situations. Providing them with access to multiple high resolution mesoscale models helps to clear ambiguity and increases confidence in the forecast. Although this project produced three separately configured WRF-EMS packages on in house computing resources, the same configurations could be built central servers. Through the use of a unique GUI, designed herein for domain selection, three locally configured model versions were run on an operational time table for testing purposes. The domain GUI executes efficiently and allows forecasters to easily interact with the WRF-EMS directly. It also helps to manage the bandwidth used to support running these backup domains in addition to the other office operations that require computational resources (e.g., HYSPLIT, SWAN, etc.)

With each innovation the NWS must remain true to its mission. This consideration is important before transition to operations can take place. This project constitutes a proactive step by WFO MLB that allows WFO forecasters to respond quickly to weather emergencies in efforts to protect life and property, especially if service backup is requested from a sister office WFOs TBW, KEY, and SJU. The output from a locally configured WRF-EMS can enhance DSS by providing WFO MLB forecasters with alternate depictions of high resolution forecasts while performing service backup of its sister offices and is very helpful when tasked with communicating local hazards to their partners.

Several future prospects for this project revolve around more configurability options for the GUI such as length of model run and adjustable model physics parameterizations. Another proposal would be setting up additional domains around high risk areas for event driven scenarios. Increased computing capabilities have accelerated the use of locally configured models. This project shows one of the many applications of the WRF-EMS and is part of a continual effort to further advance applied meteorology through creative uses of NWP.

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