

2011 Experimental Warning Program

NOAA Hazardous Weather Testbed, Norman, Oklahoma

OUN Weather Research Forecast Model Experiment

Project Overview

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1. Introduction

Recently, advances in numerical modeling have made it feasible to represent thunderstorms explicitly. Convection-allowing models introduce many advantages for near-term forecasts (6 – 8 hours). For example, forecasters can use high-resolutions models to directly forecast storm mode and the timing of convective initiation, rather than infer the relevant processes through other means.

Clearly, the next step (in creating better convective forecasts) is to examine the impact of high-frequency, convection-allowing models in an operational setting. This is very well-addressed by the goals of the Warn-on-Forecast project (Stensrud et al. 2009). Based on this, the primary research question becomes “What benefits can be derived by using a high-frequency output, high-resolution model in an operational setting?” The Norman Weather Forecast Office – Weather Research Forecast Model (OUN WRF) is uniquely suited to investigate this question. In the 2011 Experimental Warning Program, forecasters will interrogate OUN WRF output to work toward an answer.

a. Overview of the OUN WRF

The National Weather Service – Weather Forecast Office (NWS WFO) at Norman (OUN) recently acquired a large computational cluster dedicated to running a local version of the Weather Research Forecast model (WRF, Version 3.2). The cluster features 10 nodes composed of 80 Intel E5620 processors running at 2.8 GHz. Communication between nodes is achieved using the scalable, high-speed, and low latency InfiniBand communication link. Collectively, this system is referred to as “The OUN WRF”.

The domain of the model covers the Southern Plains and is centered on Norman, Oklahoma (Figure 1). In order to resolve the storms that produce the majority of severe weather (i.e., squall lines and supercells), 3-km grid-spacing is used: this allows features of spatial extent greater than 15 km to be resolved. Since severe weather is produced on relatively short time scales, the OUN WRF runs every hour, out to 8 hours, with 15-minute output. The model uses the North American Mesoscale (NAM) model forecasts (12-km grid-spacing) initialized at 12 and 00 UTC to supply the lateral boundary conditions. In order to generate initial conditions, the OUN WRF uses the Advanced Regional Prediction System’s (ARPS) 3D-VAR. The ARPS 3D-VAR assimilates surface, upper air, and satellite observations into every analysis, as well as radar data from the WSR-88D Radar Network (this is known as a “hot start”, since the model does not have to “spin up” storms).

The model is configured to use the Advanced Research WRF (ARW) dynamics core, which uses the fully-compressible mass continuity equation. Since the OUN WRF is convection-resolving, neither a cumulus nor a convective parameterization is employed. For the model microphysics, the WRF Double-Moment 6-Species (WDM-6) bulk microphysics parameterization scheme is used. Research has shown that double-moment schemes are more accurate in predicting atmospheric processes wherein the mixing ratio and number concentration are independent than single-moment schemes (Dawson et al. 2010). Some of these processes--

e.g., evaporation--are known to be important for the formation of tornadoes, hail, and severe wind gusts. The OUN WRF uses the Yonsei University Scheme to simulate the planetary boundary-layer; the NOAA Model for land-surface interactions; the Rapid Radiative Transfer Model for longwave radiation; and the Dudhia Scheme for shortwave radiation.

b. Motivation

The Norman WFO acquired the OUN WRF with several advantages in mind. First, unlike high-resolution models run at national centers, the configuration of a local model is flexible, allowing for parameterization sets to be optimized for expected local weather. Second, forecasters acquire expertise in identifying the impact of parameterization at high-resolution, enabling them to account for its impact on a forecast. Finally, best practices for incorporating local modeling--once they are known--can be disseminated to other NWS offices. While the number of offices running local numerical models is small, it is likely--as computational power improves and technology costs decrease--that more offices will acquire the equipment required to run a high-resolution model.

Additionally, the OUN WRF is highly-suited to explore the operational impacts associated with the Warn-on-Forecast paradigm. In Warn-on-Forecast, it is envisioned that, as a result of increasingly sophisticated data assimilation techniques and burgeoning computer technologies, ensemble predictions of storm-scale phenomena (e.g., tornadoes, hail, etc.) will become possible. Currently, however, the infrastructure of the National Weather Service only supports the "Warn-on-Detection" paradigm: that is, tornado warnings are only issued when Doppler radar detects a tornado; Doppler radar detects strong rotation and the storm environment supports tornadoes; or, when a tornado has been sighted. Thus, in order to facilitate future advancement toward the implementation of Warn-on-Forecast, work needs to be done to create an operational infrastructure suitable for its instantiation. In particular, there is a need to properly balance forecaster workload in warning situations, in order to maintain optimal situational awareness. Ensemble prediction of severe local storms will provide many advantages, but also, a burgeoning amount of products. Adding these products to the existing suite of observational products must be done with care, for a large amount of ensemble products could detract from situational awareness during warning operations. Thus, it is important to develop a new operations infrastructure that can incorporate the most important ensemble products while still allowing frequent perusal of critical observational products (e.g., radar, mesoanalysis data, etc.).

Since the OUN WRF is an experimental model, it is a good candidate to test the operational impact of high-resolution modeling. Unlike operational models, the OUN WRF can be adapted immediately to examine specific attributes of modeling, with a view toward Warn-on-Forecast. Specifically, the grid-spacing of the model, the domain, initialization package, model physics, and model parameterizations can be adjusted with impunity. This allows the principal investigators, along with the Experimental Warning Program (EWP) participants, to take an active role in forging the role of high-resolution modeling in warning operations.

2. Experiment Objectives and Methods

In recent years, forecasters have watched seemingly realistic convective scenarios play out on their computer monitors before they happen: the realization of advances in high-resolution modeling. Unfortunately, these explicit forecasts never verify with precision. This is--of course--true of every model, including models that feature very high-resolution, state-of-the-art parameterizations, and cutting-edge data assimilation packages. Yet, it is apparent that convection-allowing models do retain some skill in forecasting some features. In particular, it has been noted that some processes with storm-scale implications--e.g., the processes that determine storm mode, timing of convective initiation, cap strength, etc.--can be forecast with some skill. In this experiment, the forecasters will examine the OUN WRF output to determine if any skill is added to the short-term forecast of these processes--and, consequently, an increase in situational awareness (SA) during warning operations.

For example, a forecaster notices that a high-resolution model consistently initiates convection in a specific area. Could the forecaster trust that forecast? If so, how would it modify their expectations for warning operations? Or, in another scenario, supercells develop quickly, but move into an area of higher convective inhibition and dissipate. Could high-resolution output add skill to the short-term forecast, such that warnings are given the appropriate duration?

Additionally, research has shown that convection-allowing models might add value in forecasting the magnitude and location of severe local storms. According to Kain et al. (2008), the development of "severe storms proxies"--products that imply the presence of a particular type of hazardous weather--might add skill to a short-term forecast of convective hazards. Some of these proxies include updraft-helicity (proxy for rotating updrafts), vertically-integrated graupel (proxy for hail), and 10-m wind speed (proxy for severe wind). It is conjectured herein that severe storms proxies from the OUN WRF may benefit forecasters in their attempt to maintain SA during warning operations. (The details regarding these proxies will be covered in a later section.)

Also, since the OUN WRF runs every hour, it seems natural to inquire as to whether this higher frequency of model output would benefit forecasters or not. On the surface, it would seem that forecasters would be advantaged in having a large volume of data from which they could inform their decisions. At some point, however, it seems likely that a forecaster's ability to properly analyze high-frequency model output would compete with the necessity to peruse critical observational products. During the OUN WRF Experiment, we will investigate the issue of forecaster workload.

The following is a list of research questions related to these topics.

1. Do severe storm proxies add skill to a convective forecast?
2. Does the OUN WRF forecast of relevant, large-scale processes (e.g., evolution of storm mode) increase situational awareness during warning operations?

3. Does the high frequency of OUN WRF output increase forecaster SA?
4. How does the introduction of high-resolution model data impact forecaster workload?
5. What new, high-resolution model products might increase forecaster SA?
6. How can high-resolution model data be streamlined into warning operations?

In order to begin to answer these questions, participants will be asked to produce the following during each “Intensive Operations Period” (IOP).

First, forecasters will write detailed forecast discussions in which they will specify the products they viewed, their interpretation of the products, and their forecast reasoning upon viewing the products. After the Spring Experiment, these discussions will be reviewed by the PIs to assess the evolution of forecaster reasoning. After storms have formed, participants will then issue in-house Severe Thunderstorm and Tornado Warnings. These warnings will provide a good indication of how participants interpreted the convective situation, using the products provided in the HWT. Finally, at the end of each IOP, forecasters will fill out a survey in which they will be asked for their impressions of the day. Please note that, since there are two shifts--one morning and one evening--not every forecaster will participate in the same daily activities. The details of the schedule are in the following section.

3. Weekly Activities

a. Monday

On Monday at 1 p.m., forecasters will arrive at the Hazardous Weather Testbed (HWT) in the National Weather Center (NWC). Once they have arrived, an orientation session for the Experimental Warning Program will begin (EWP). After the orientation, the principal investigator (PI) for the OUN WRF Experiment, as well as the PIs for the GOES-R Satellite Experiment and the Multi-Radar, Multi-Sensor (MRMS) Experiment will present overviews of their projects; the visiting forecasters will become acquainted with the experimental objectives of these projects, as well as guidelines for using the experimental products. Around 3 p.m., forecasters will be given training to use the Weather Events Simulator (WES). Finally, project participants will work an informal IOP, which will give forecasters an opportunity to become familiar with the experimental operations.

b. Tuesday - Thursday

On Tuesdays through Thursdays, project participants will arrive at the HWT in two shifts. The morning shift will arrive at 9 a.m.; the afternoon shift, at 1 p.m. Upon arriving, the morning shift will collaborate with the Experimental Forecast Program (EFP) to identify a geographical area suitable for experimental operations. The normal suite of operational products, as well as experimental products from the OUN WRF, will be perused.

Around 11 a.m., morning-shift participants will write their first Area Forecast Discussion. At noon, there will be a break to take lunch. After 30 minutes, the group will re-convene in the HWT for the joint EFP/EWP briefing. At 1 p.m., the afternoon shift will arrive and begin their day listening to the briefing prepared by the EFP and morning shift forecasters. Following the conclusion of the joint briefing, the EWP participants will move to the Development Lab to participate in an EWP-specific briefing which will outline the focus of the days experimental activities.

After an hour, the EWP forecasters will return to the HWT to monitor for signs of convective initiation. During this time, participants will regularly examine the GOES-R satellite products and OUN WRF products. Before 4 p.m, the forecasters will have issued their last forecast discussion.

Around 4 p.m.--or, whenever deep-convection initiates--an IOP will begin. During this period, the forecasters will be using products related to the other EWP experiments. After the conclusion of the IOP, the forecasters will be asked to fill out the EWP Web-Survey. In the event that severe weather is not present anywhere in the CONUS, an archive IOP will be conducted, in lieu of operations. The morning forecasters will finish their day at 5 p.m.; the afternoon forecasters, at 9 p.m.

c. Friday

On Friday, the project participants will arrive at the HWT at 10 a.m. to participate in a review of the week. Forecaster impressions will be recorded by project PIs, in order to aid the research process. Forecasters may participate in an optional brown bag lunch at noon. The week's activities will conclude at lunch.

4. Products

Each week, project participants will be asked to evaluate the following severe storm proxies:

1. Updraft-Helicity
2. 1-km Reflectivity
3. 10-m Windspeed
4. Updraft Velocity
5. Downdraft Velocity
6. Layer Storm-Motion
7. Vertically-Integrated Graupel

A detailed description of each product is provided next.

a. Updraft-Helicity

Updraft-helicity is used as a surrogate for supercell thunderstorms. It is defined as

where z_0 and z_1 are the lower and upper vertical bounds (respectively), w is the vertical velocity, and ζ is vertical vorticity (Sobash et al. 2010). As the name implies, updraft-helicity is defined by the product of the updraft speed (w) and vertical vorticity (ζ) integrated over some depth. As it turns out, the depth of this layer is important. During the fall, winter, and early spring months (when supercells tend to be smaller due to small convective instability), a layer starting near 1 km and ending near 4 km may be sufficient to serve as proxy for mesocyclones. Later in the spring and into the summer, however, convective instability tends to increase, leading to taller storms and mesocyclones. During this time, the best integration layer is generally from 2 to 5 km. The deeper the layer, the more likely that mesocyclones will be found (Hitchcock et al. 2010). However, increasing the depth of the updraft-helicity layer also increases product noise. For this experiment, the 2 to 5 km layer will be used.

The threshold value of updraft-helicity for which one can imply a rotating updraft varies with season, location, and model resolution. As model grid-spacing increases, the model is able to resolve higher velocities, due to a better representation of turbulence. Consequently, the wind field tends to increase with higher model resolution. As a result, the vertical velocities increase and vertical vorticity increases (as the wind gradients increase), leading to higher values of updraft-helicity. For the OUN WRF, which has a grid-spacing of 3-km, $50 \text{ m}^2 \text{ s}^{-2}$ is a good threshold value for which one can imply a rotating updraft (during the months of May and June). A moderately strong mesocyclone is implied by values between 100 and $200 \text{ m}^2 \text{ s}^{-2}$ and a strong mesocyclone, by values greater than $200 \text{ m}^2 \text{ s}^{-2}$.

b. Simulated 1-km Reflectivity

The simulated 1-km reflectivity is a derived product that serves as a proxy for storm intensity. Generally, this product is useful for determining the timing and location of convective initiation, and the intensity of storms. The usual threshold values for interpreting radar apply to this product, though maximum simulated reflectivity tends to be 5 – 10 dBZ less than the base reflectivity (units are dBZ).

c. 10-m Wind Speed

The 10-m wind speed can be used as a proxy for severe wind gusts. As explained in the updraft-helicity description, the magnitude of the wind in a model depends on model

resolution. At 3-km grid-spacing, the OUN WRF is not able to resolve processes with a characteristic length less than 15 km; thus, the processes that produce severe gusts are not fully resolved. However, this product may still imply the presence of severe gusts in a forecast - albeit, with lower severe thresholds than in reality. For a baseline threshold, 10-m wind speed values around 20 m s^{-1} may correspond to severe wind gusts.

d. Updraft Velocity

Updraft velocity can be used as a proxy for an intense updraft. This product may be a good surrogate for severe hail, when environmental conditions favor its development. Strong updrafts generally feature updraft velocities greater than 20 m s^{-1} . (It should be noted that this product has not been formally calibrated; the observations of project participants will be very important in deciding which proxies are worth further inquiry.)

e. Downdraft Velocity

Downdraft velocity can be used as a proxy for an intense downdraft. The presence of a strong downdraft in the vicinity of strong 10-m wind speeds may imply a higher probability of severe wind gusts. Additionally, this product--in conjunction with updraft velocity--has implications regarding the intensity of convective overturning (Kain et al. 2010).

f. Layer Storm-Motion

Layer storm-motion can be used as guidance for storm motion. Since storm motion can vary with time, layer storm-motion can be used to anticipate environmental changes that could affect thunderstorm arrival times. This product uses wind barbs with flags, and the units are knots.

g. Vertically-Integrated Graupel

Vertically-integrated graupel has been used as a proxy for thunderstorm electrification (since charge separation is implied in its vertical integration), but it may also be useful for the prediction of severe hail. Values of vertically-integrated graupel greater than 40 kg m^{-2} may imply the presence of severe hail.

5. References

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