2014 Experimental Warning Program

NOAA Hazardous Weather Testbed, Norman, Oklahoma

OUN Weather Research Forecast Model Experiment

Project Overview

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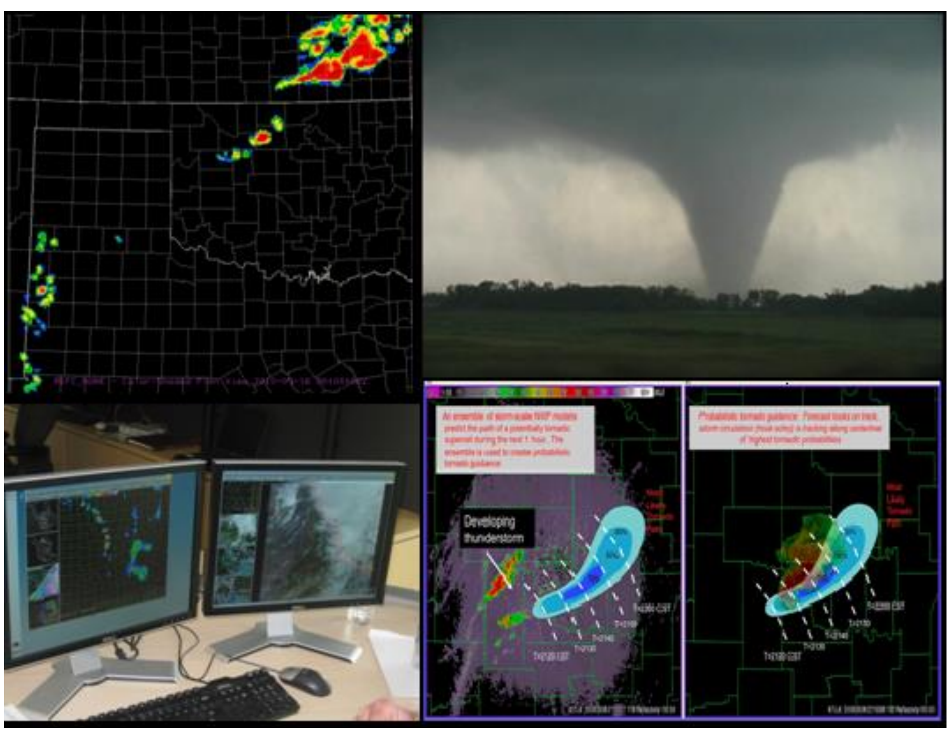

1. Introduction

Recent advances in numerical modeling have made it feasible to represent thunderstorms explicitly. These model forecasts present many advantages in the near-term (6 – 12 hour) prediction of severe convection. Previously, processes that could only be inferred by coarse models – i.e., storm mode and the convective initiation – can now be represented explicitly. While convection-resolving models have been around for some time, the impacts of high-resolution convective forecasts in the operational warning environment are not well-understood. In this study, we prepare to examine these effects, especially as they pertain to the goals of the Warn-on-Forecast project (Stensrud et al. 2009). In particular, we ask the question "How can a high-resolution model with high-frequency output be used in an operational warning setting?" The Norman Weather Research Forecast Model (OUN WRF) is uniquely suited to investigate this question.

a. Overview of the OUN WRF

In 2010, the National Weather Service Weather Forecast Office (NWS WFO) in Norman (OUN) 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. 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 other 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 00, 06, 12, and 18 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).

Modeling research has shown that severe weather events are highly dependent on their mesoscale environment, so improvements in the representation of these environments is critical for successful forecasts (Aksoy et al. 2009, 2010; Stensrud and Gao 2010). One way to improve this representation is to incorporate multiple mesoscale observations, through a process called "cycling". In cycling, the analysis system is run multiple times per in order to produce a more accurate set of initial conditions. This year, we are utilizing cycling within the OUN WRF. Since the number of nodes hasn't changed, this will result in one hour more latency than last year's version (i.e., a run every other hour).

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 necessary. For the model microphysics, the Thompson (double moment) 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 MYNN scheme to simulate the planetary boundary-layer; the NOAH 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 bourgeoning 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 and the storm environment is supportive; or a tornado has been sighted; or all of the above. Thus, in order to facilitate future advancement toward the implementation of Warn-on-Forecast, work needs to be done to create an operational structure 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 growing number 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 system that can incorporate the most important ensemble products while still allowing frequent perusal of critical base 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 do not 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 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.)

In the vision of Warn-on-Forecast, probability graphics derived from an ensemble of explicit convective forecasts will allow forecasters to issue highly-accurate, highly-specific alerts in the 1 – 2 hour time frame. At this time, though, the OUN WRF produces only one such run. Nevertheless, it is possible to create such probabilities from an ensemble of consecutive OUN WRF forecasts - i.e., a time ensemble. From this, forecasters may be able to establish meaningful model trends on the short-term. In particular, we have created time-lagged ensemble graphics for 2-5 km Updraft-Helicity, Vertically-Integrated Graupel, and Composite

Reflectivity. Changes of the forecast values of those parameters from run to run might positively affect forecaster situational awareness.

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. Do time-ensemble graphic increase forecaster SA?
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 forecasts on weblogs. In these, they will specify the products they used and their forecast reasoning. Moreover, bi-hourly interviews will be conducted by the principal investigator to assess the run-to-run 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.

3. Products

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

- Composite Reflectivity*
- 1-km Reflectivity
- Instantaneous Updraft Helicity
- Maximum Hourly Updraft Helicity*
- Maximum Hourly Column Hail*
- 10-m Windspeed

A detailed description of each product is provided next.

* Indicates a time-ensemble product.

1. Composite Reflectivity

The composite 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).

2. *1-km Reflectivity*

This product description is identical to the description for composite reflectivity.

3. *Instantaneous Updraft Helicity*

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

$$\int_{z_o}^{z_1} w\zeta dz$$

where z_o 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 $m^2 s^{-2}$ 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 $m^2 s^{-2}$ and a strong mesocyclone, by values greater than 200 $m^2 s^{-2}$.

4. *Maximum Updraft Helicity*

Similar to the instantaneous updraft helicity, except hourly maxima are plotted. Continuous swaths of this path may imply longer-lived supercells.

5. *Maximum Hourly Column Hail*

Maximum hourly column hail 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 maximum hourly column hail greater than 40 kg m^{-2} may imply the presence of severe hail.

6. *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.

4. References

Aksoy, Altuğ, David C. Dowell, Chris Snyder, 2009: A multicase comparative assessment of the ensemble Kalman filter for assimilation of radar observations. Part I: storm-scale analyses. *Mon. Wea. Rev.*, **137**, 1805–1824.

____________, 2010: A multicase comparative assessment of the ensemble Kalman filter for assimilation of radar observations. Part II: short-range ensemble forecasts. *Mon. Wea. Rev.*, **138**, 1273–1292.

Dawson, D.T., M. Xue, J.A. Milbrandt, M. K. Yau, 2010: Comparison of evaporation and cold pool development between single-moment and multimoment bulk microphysics schemes in idealized simulations of tornadic thunderstorms. *Mon. Wea. Rev.*, **138**, 1152–1171.

Hitchcock, S.M., P.T. Marsh, H.E. Brooks, and C.A. Doswell III: Impacts of varying the integration depth on performance of updraft helicity as numerical guidance for severe thunderstorms forecasting. *25th Conf. on Local Severe Storms.* P7.7.

Kain, John S., and Coauthors, 2008: Some practical considerations regarding horizontal resolution in the first Generation of operational convection-allowing NWP. *Wea. Forecasting*, **23**, 931–952.

Stensrud, David J., Jidong Gao, 2010: Importance of horizontally inhomogeneous environmental initial conditions to ensemble storm-scale radar data assimilation and very short-range forecasts. *Mon. Wea. Rev.*, **138**, 1250–1272.

___________, 2009: Convective-scale warn-on-forecast system: A vision for 2020. *Bull. Amer. Meteor. Soc.*, **90,** 1487–1499.