WRF Enhancements for Operational Simulations

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1. Introduction

WSI Corporation has developed a real-time modeling system that uses the Weather Research and Forecast modeling system (WRF) as the forecast engine. Operational WRF simulations over the continental United States (CONUS) began in April 2004. Since then, European and North Atlantic domains have been added (Fig 1). Currently, the CONUS domain is run with 12-km grid-point spacing every 3 hours out to 51 hours while the European domain is run every 6 hours with 14-km grid-point spacing out to 48 hours and the North Atlantic domain is run every 6 hours with 36-km grid-spacing out to 24 hours. Additional configuration details can be found in Hutchinson et. al. (2004). Output forecasts are used by WSI's energy and aviation forecasting groups and provided to media outlets under the brand name *Rapid Precision Mesoscale (RPM)* model.

In developing the system, several enhancements were added to WRF in order to support rapid and robust operational simulations. A module for gridded binary version 1 (GRIB1) output was added, and a module for gridded binary version 2 (GRIB2) is currently under development. The WRF Standard Initialization routines were setup to run in parallel. Further, a verification method called acuity-fidelity (Marshall et. al. 2004) was developed and is being used to verify the operational simulations. Finally, several post-processing routines were developed to generate isobaric output, and several severe weather, winter weather and aviation products.

The purpose of this paper is to provide an overview of the WSI WRF operations with emphasis on the operational enhancements we have made to the modeling system.

2. Operational Enhancements

a. GRIB Input and Output

In order to interface with existing WSI systems, output of WRF data in GRIB1 format was required. A WRF module for direct output of forecast data in GRIB1 format was written. This module was delivered to NCAR and has been included with the standard WRF release since version 2.0.3. To output WRF data in GRIB1, simply set the WRF namelist variable *io_form_history* to 5. Full WRF I/O support is included in the module, including the ability to use additional processors for "quilting" the output tiles together.

We have found significant benefits when writing to GRIB1 as compared to netCDF format. As indicated in Table 1, file sizes are reduced by over 2/3 for GRIB1 as compared to netCDF. Additionally, GRIB1 output can be written faster than netCDF output. In the example presented here, model run time is reduced by over 25% when writing to GRIB1 as compared to netCDF. Admittedly, this is an extreme example since the output is relatively frequent at every 10 minutes.

Currently, a module for GRIB1 input and output for the WRF standard initialization and WRF preparation routines (real.exe, ideal.exe, etc.) is under development. This module is expected to reduce the I/O time and memory usage for the WRF SI and data preparation programs. Additionally, a module for GRIB2 input and output for all WRF programs is under development. Output in GRIB2 format is expected to further reduce output file sizes to about 1/3 of GRIB1 output size. Run-time performance for GRIB2 I/O has not yet been determined. Both the

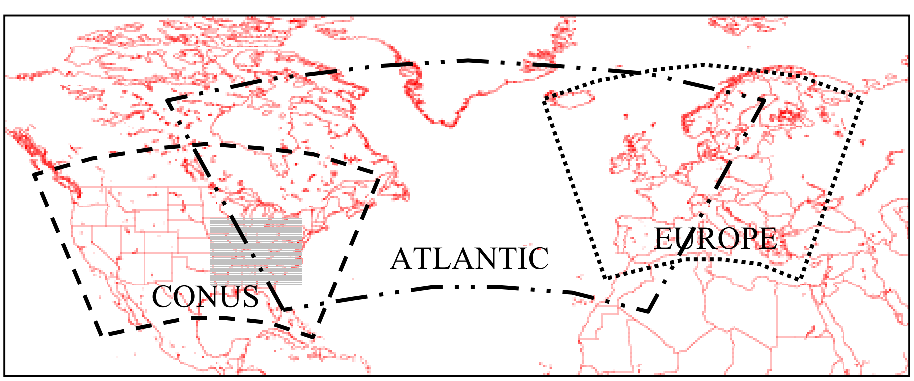

Fig. 1. Domains over which the WRF is run operationally. The shaded region is the verification domain referred to in the text.

GRIB1 input and GRIB2 modules will be delivered to NCAR this summer in preparation for release to the community later this year.

b. Parallel pre-processing

In order to reduce WRF pre-processing time, the WRF SI processes were divided such that the horizontal interpolation (hinterp.exe) and vertical interpolation (vinterp.exe) programs run independently on separate compute nodes (within a linux cluster) for each of the initial and boundary condition times. In order to reduce network traffic and prevent the parallel processes from overwhelming the network file system on the cluster, the necessary input for the programs (i.e., the output from grib_prep.exe) is copied to a local disk on the compute node, the hinterp.exe and vinterp.exe programs are run, then the output is copied back to the primary system-wide accessible disk in preparation for input to real.exe. For our 51-hour CONUS simulations (with 3-hourly boundary condition data), the time for pre-processing (WRF SI plus copying data to and from machines in the cluster) was reduced from 21 minutes to 8 minutes.

3. Acuity-fidelity verification

Because of added spatial and temporal resolution when mesoscale models are run with fine grid-point spacing, traditional verification (i.e., equitable threat score) of precipitation can appear worse than verification of precipitation from forecasts with coarser grid-point spacing (Mass et al. 2002). The acuity-fidelity method was designed to evaluate high-resolution mesoscale model forecasts more accurately and fairly compared to traditional methods. The objective of this acuity-fidelity technique is to account for temporal and intensity errors as well as spatial errors and then to cast the result in terms of a unidimensional score

Acuity-fidelity verification quantifies the skill of a forecast using the three dimensions of space, time and intensity. Acuity represents the model's skill at detecting the features of the observed data. The acuity of a forecast is calculated for each observed data point by finding the best matching forecast for that observation. Instead of automatically associating an observation with the forecast that shares its location and time, the best match is obtained by minimizing a cost function calculated between the target observation and many candidate forecast data. The candidate forecast datum that produces the smallest penalty is deemed the best match, and is therefore associated with the observation. Fidelity represents the faithfulness of the model's predictions to the observed data. The fidelity of a forecast is calculated much like the acuity, except roles of the observations and forecasts are reversed. Thus for each target forecast datum, the best matching observation is found within a multidimensional field of candidate observations.

Table 1. Comparison of file size, model run-time, and output time (I/O) for 3-hour CONUS WRF simulations (360x485 grid points) with output every 10 minutes.

Format	Size(MB)	Run Time(s)	I/O time(s)
netCDF	368	719	1.26*
GRIB1	109	519	0.28*
GRIB2	22-36	TBD	TBD

*Note: When outputting netCDF, the time-step after each output takes 1.4 s longer than when outputting GRIB1.

Acuity-fidelity results for WRF, Eta and RUC simulations between 23 April 2005 and 3 June 2005 are presented in Fig. 2. The area for these verifications is centered in the east-central United States and is shown as the shaded area in Fig. 1. NCEP Stage IV precipitation analyses were used as truth. Acuity values for each observed precipitation point greater than ¼ in are averaged together to generate a value for each forecast (Fig 2a). Fidelity values for each model grid-point with a forecast precipitation greater than ¼ in/hr (6.35 mm/hr) are averaged together to generate a value for each forecast (Fig. 2b). The sum of the acuity and fidelity is plotted in Fig 2c. Acuity values are not shown if there are fewer than 12 observed grid points within the verification region with precipitation >= ¼ in/hr. Fidelity values are not plotted if the number of forecast points that meet these criteria is less than 12.

For nearly all days presented, acuity for WRF is lower than that for RUC and Eta, indicating that WRF is more closely forecasting observed precipitation greater than ¼ in/hr. However, fidelity is most often largest (worst) for WRF as compared to RUC and Eta. This indicates that WRF often predicts precipitation greater than ¼ in/hr that is not observed nearby (in space, time and intensity). Our WRF simulations tend to predict heavy precipitation (greater than ¼ in/hr) at many more grid points and with more precision than RUC or Eta. Often, this increased precision leads to larger fidelity values than those for the relatively smooth forecasts of the RUC and Eta.

Shown in Fig. 3 are the acuity and fidelity results for 48 hour forecasts. In this case, only WRF and Eta are shown, since RUC is not run out to 48 hours. Again, the acuity for WRF is lower (better) than for Eta. However, for the same reasons as discussed above, fidelity for WRF is larger (worse) than for Eta.

4. Post-processing routines

Several post-processing routines for generating isobaric output, severe weather, winter weather and aviation products have been implemented. Winter weather products include a snowfall algorithm described by Dube (2003), precipitation type algorithms based on work by Baldwin et. al. (1994) and Bourgouin (2000). Severe weather products include an internally developed lightning intensity algorithm, a hail size algorithm based on algorithms presented by Brimelow et. al. (2002) and Moore and Pino (1990), and the Nimrod convective gust algorithm (Hand, 2000). Algorithms useful for aviation forecasting include a cloud ceiling and visibility algorithm based on work by Stoelinga and Warner (1999) and Kuchera et. al. (2004), and a turbulence algorithm based on work by Sharman et. al. (2002). The products are currently being evaluated. However, the ceiling and visibility algorithms have proven to be especially beneficial to WSI's aviation forecasters.

5. Summary

In developing a forecasting system for use by WSI forecasters and clients, the WRF was used as the forecast engine. Several enhancements were made to WRF and we expect that these enhancements will be useful in operational WRF simulations. Further, a verification module was developed, and its results suggest that WRF is more accurate in predicting heavy precipitation than existing operational models.

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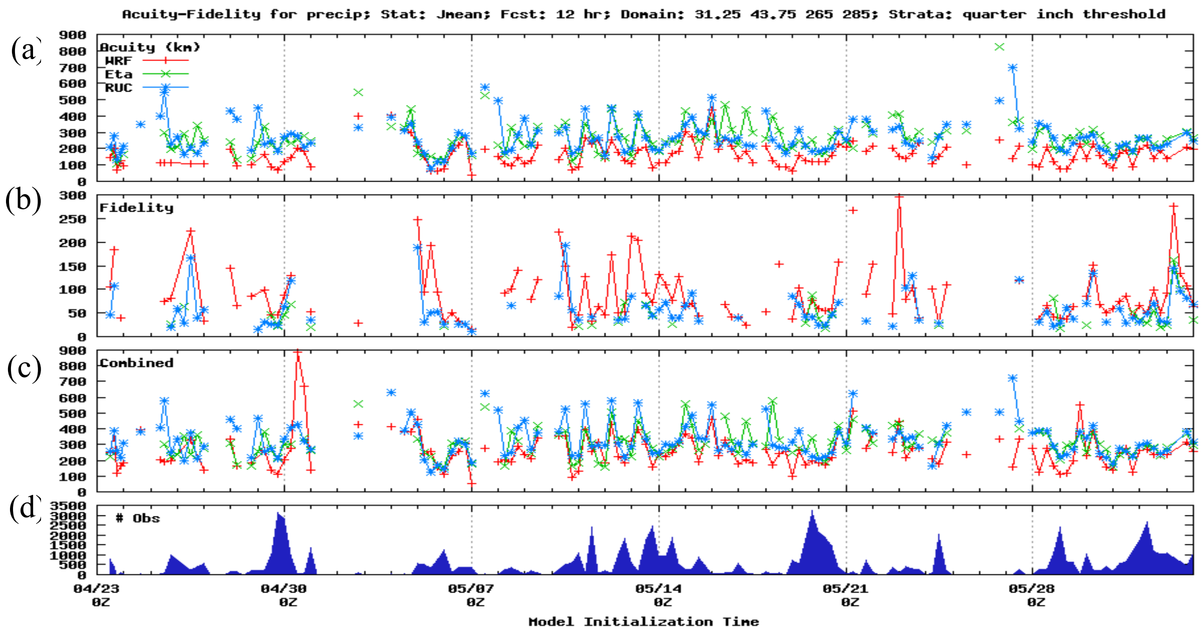

Fig. 2. Scores (km) of 12 h forecasts of CONUS WRF, NCEP Eta and NCEP RUC for (a) acuity, (b) fidelity and (c) the sum of acuity and fidelity for precipitation greater than ¼ in/hr for a verification domain of 31.25^o-43.75^o N, 95^o-75^o W between 23 April and 3 June 2005. The number of observed points with precipitation greater than ¼" is shown in (d).

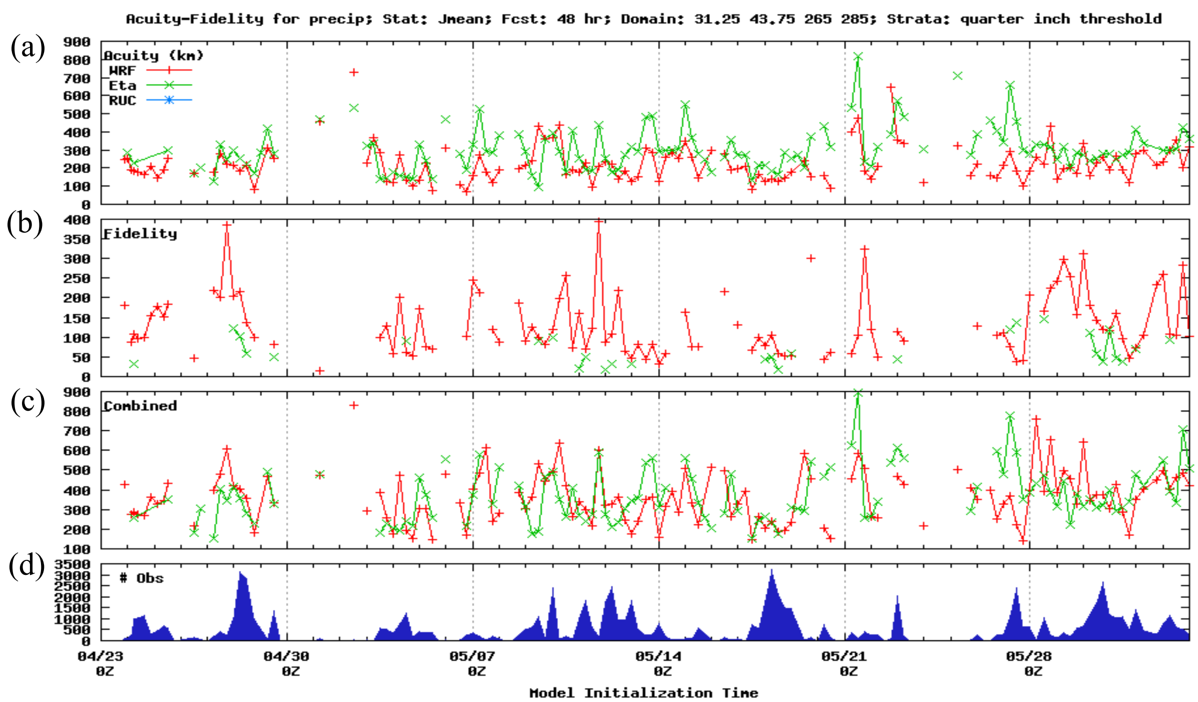

Fig. 3. Same as Fig.2 except for 48 hour forecasts.