The Comparison of the Unified Model (UM) and Global Forecast System (GFS) as Input Data for the Weather Research and Forecasting Model

by Jeffrey E. Passner, James L. Cogan, and Patrick A. Haines

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The Comparison of the Unified Model (UM) and Global Forecast System (GFS) as Input Data for the Weather Research and Forecasting Model

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The fielded Meteorological Measuring Set-Profiler (MMS-P) and the Computer Meteorological Data-Profiler (CMD-P) were evaluated by the Battlefield Environment Division, U.S. Army Research Laboratory (ARL) to compare the Computer Meteorological Message (METCM) on each system using the same input data. Both rely on the Navy Operational Global Atmospheric Prediction System (NOGAPS) forecast data and regional surface and upper-air soundings (if available and current in time) transmitted from the Air Force Weather Agency (AFWA) to initialize and update the on-board mesoscale model. The model for both systems is the Fifth-Generation Penn State/National Center for Atmospheric Research Mesoscale Model (MM5). The product manager for the CMD-P has agreed that future versions of the CMD-P will incorporate a new modeling environment with the Weather Research and Forecasting Model (WRF) as the modeling basis. This upgrade would include a new, coarse-scale model for the input of initial and boundary conditions. This paper discusses two different sources of model initialization data for the proposed follow-on CMD-P; the Global Forecast System (GFS) and the United Kingdom Meteorological Office’s (UKMO’s) Unified Model (UM).
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1. Introduction

The fielded Meteorological Measuring Set-Profiler (MMS-P) and the Computer Meteorological Data-Profiler (CMD-P) were evaluated by the Battlefield Environment Division (BED), Computational and Information Sciences Directorate (CISD), U.S. Army Research Laboratory (ARL) to compare the Computer Meteorological Message (METCM) on each system using the same input data. Both rely on the Navy Operational Global Atmospheric Prediction System (NOGAPS) forecast data and regional surface and upper-air soundings (if available and current in time) transmitted from the Air Force Weather Agency (AFWA) to initialize and update the onboard mesoscale model. The model for both systems is the Fifth-Generation Penn State/National Center for Atmospheric Research Mesoscale Model version 5 (MM5) with a post-processor developed by Pennsylvania State University. The product manager for the CMD-P has agreed that future versions of the CMD-P will incorporate a new modeling environment with the Weather Research and Forecasting (WRF) Model as the modeling basis (1). This upgrade would include a new, coarse-scale model for the input of initial and boundary conditions. This technical note discusses two different sources of model initialization data for the proposed follow-on CMD-P; the Global Forecast System (GFS) and the United Kingdom Meteorological Office’s (UKMO’s) Unified Model (UM).

2. Global Forecast System (GFS)

The current version of the GFS is a global numerical weather prediction computer model run by the Environmental Modeling Center (EMC) of the National Weather Service’s National Centers for Environmental Prediction. The model is run four times per day and produces forecasts for up to 16 days in advance (but with decreasing spatial and temporal resolution over time). The model’s predictions are done spectrally, but the horizontal grid spacing of its output is approximately at 0.2 × 0.2 degree latitude/longitude. The vertical grid spacing is a sigma pressure hybrid coordinate system with 64 layers with enhanced resolution near the surface (2).
3. **UKMO Unified Model (UM)**

The UM is continually being developed, taking advantage of improved understanding of atmospheric processes and steadily increasing supercomputer power. It can be run on a global scale, or as a limited area model and can also be coupled to land surface, ocean models, wave models, chemistry, and Earth system components. The UM was originally 25-km grid spacing; however, AFWA, in collaboration with the UKMO, has decreased the horizontal spacing of the UM from 25 to 20 km. The UM has 70 vertical levels and runs 144 hours (h) in the future twice daily (3). Additionally, AFWA is running the model four times a day out to 240 h with 3-h output (4).

4. **Comparison of the GFS and UM**

There have been numerous studies of model effectiveness and statistical output. Many of these involve comparisons of different models, case studies of a certain parameter, or models of different resolutions in many locations. Statistical output and results can be interpreted in many ways, but in the following sections, only straightforward results and comparisons are discussed or displayed.

4.1 **Environment Canada Study**

Environment Canada has calculated Root Mean Square Errors (RMSE) from nine models from many of the world meteorological centers for many years. Currently, they compare the models’ 500 mb geopotential height forecasts against the North American radiosonde observation network; previously, RMSEs were also calculated for vector winds at 500 and 250 mb along with bias errors in the models’ 500 mb geopotential height forecasts. Here, we focus on the forecasts at both 0000 UTC and 1200 UTC compared to soundings at the same time over a period of three years from 2009 to 2012. The displayed results of the RMSE in meters show that for the 24-h forecast the UKMO’s UM was among the highest performing models while the GFS was ranked in the middle of the pack in terms of statistical accuracy. One unique characteristic of the data was that the GFS and UM were close statistically during the summer months, but the UM outperformed the GFS during the winter months (5).
4.2 EMC Study

The EMC evaluates many upper-air meteorological variables between the GFS and UM compared to model analysis (data assimilation) including temperature, height, and wind speed. Table 1 shows the RMSE and Bias Error at different height levels.

Table 1. RMSEs for the GFS and UKMO UM for global 24-h forecast from 6 February 2012 to 7 March 2012.

<table>
<thead>
<tr>
<th>Variable</th>
<th>GFS (RMSE)</th>
<th>UM (RMSE)</th>
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<tbody>
<tr>
<td>Temperature</td>
<td>1000 mb (C)</td>
<td>0.795</td>
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<td>Temperature</td>
<td>850 mb (C)</td>
<td>0.849</td>
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<td>500 mb (C)</td>
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<td>Height</td>
<td>1000 mb (m)</td>
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<td>Height</td>
<td>850 mb (m)</td>
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<tr>
<td>Height</td>
<td>500 mb (m)</td>
<td>8.359</td>
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<tr>
<td>Wind Speed</td>
<td>1000 mb (ms \textsuperscript{-1})</td>
<td>2.201</td>
</tr>
<tr>
<td>Wind Speed</td>
<td>850 mb (ms \textsuperscript{-1})</td>
<td>2.539</td>
</tr>
<tr>
<td>Wind Speed</td>
<td>500 mb (ms \textsuperscript{-1})</td>
<td>3.200</td>
</tr>
</tbody>
</table>

Table 1, shows that the UM has lower RMSEs in all parameters and at all levels except for the low-level temperature field. For artillery applications, the two main meteorological (MET) contributors to error in predicted fire are density and vector wind errors. The table 1 differences in pressure and temperature, at maximum, constitute less than a 0.1% inaccuracy in density. We can assume that the wind speed error differences along with likely wind direction error differences would mean about a 50% larger difference in vector wind error or about 0.5 ms\textsuperscript{-1}. This alone could cause radial distance errors that are a bit larger than those from the density error. Since wind vector and density errors can be additive depending on the direction of fire, the combined effects on artillery accuracy translate to the potential for as much as a 15 to 20% improvement in predicted fire accuracy using the UM as the CMD-P initial condition. Additional improvement is also possible if the CMD-P model forecast benefits from more accurate initialization. The UM does show greater accuracy in geopotential height and wind speed with increasing height. While not shown here, the UM also has lower RMSEs for all parameters for the 72-h forecast.

For the model bias, both models have a tendency to slightly under forecast the wind speed near the surface, but the UM has a strong tendency to over forecast the wind speeds at both 500 mb and 200 mb. Additionally, while not shown in table 1 it is uncertain which model provides smaller bias errors at both 24 h and 72 h.

4.3 University of Washington Study

This study investigated many of the models and different surface and upper-air data sources over the Pacific Northwest for one day, 7 June 2011, over slightly different domains. The overall results seem to indicate that the UM had a lower RMSE than the GFS for upper-air wind speeds while the GFS had a slightly better RMSE for upper-air temperature than the UM (6) when compared to sounding data.
4.4 AFWA Study

AFWA is continually studying models for their effectiveness and skill. They have created an index called the “GO” index, which is based on a combination of weighted daily skill scores for a number of operationally significant forecast parameters at 12 h, 48 h, 72 h, and 120 h into the forecast cycle. From 1 July 2011 to 30 September 2011 the UM scored slightly better than the GFS. The only obvious differences were that the UM did better with surface dew points and 400 mb moisture, while the GFS performed better with the 400 mb temperature and surface pressure. The UM and GFS wind speeds were similar with both models underforecasting wind speeds out to 120 h at levels from 30,000–38,000 ft above ground level (AGL) (about 9.1 to 11.6 km, affecting zones 16–18). The UM did have slightly less wind-direction error than the GFS. Also, it did not appear to make any difference in which hemisphere the tests were conducted. Another test in February 2012 evaluated 24-h surface and upper-air forecasts over CONUS. The UM had less error than the GFS in surface temperature forecasts, surface relative humidity, and 200 mb wind speed. The GFS was far better in precipitation forecasts and only slightly better in 700 mb relative humidity and 500 mb heights (7).

5. Conclusions

With the potential use of the WRF as the modeling basis for the CMD-P, it is hoped that the improved modeling system will provide more accurate artillery MET messages. In an effort to improve the WRF even more, a question was raised as to which model should be used to initialize the WRF — the GFS or UM. The UM is a higher-resolution model than the GFS, with a few more vertical levels, but statistical comparisons between the two models do not show many significant differences. However, one thing to consider is that wind data is perhaps the most vital variable when creating the METCM. The Environmental Canada study noted that the UM performed better than the GFS when evaluating 500 mb heights. The EMC study indicated lower RMSE for the UM at 500 mb and better wind speeds aloft by the UM. The University of Washington showed lower RMSE for the upper-air statistics when using UM to initialize the WRF. The AFWA study was less conclusive however, and while the UM had higher skill than the GFS, it was not certain if the results were significant. Still, it appears that the UM may provide better initialization fields than the GFS, although both models seem to do as well or better than similar models. While it appears that the UM will offer a better source for model initialization, our recommendation is that we test some cases with both GFS and UM to initialize the WRF and verify which initial data helps to provide more accurate model output.
6. References


<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
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<tbody>
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<td>AFWA</td>
<td>Air Force Weather Agency</td>
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<tr>
<td>AGL</td>
<td>above ground level</td>
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<tr>
<td>ARL</td>
<td>U.S. Army Research Laboratory</td>
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<td>BED</td>
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<td>CISD</td>
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<td>CMD-P</td>
<td>Computer Meteorological Data-Profiler</td>
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<td>EMC</td>
<td>Environmental Modeling Center</td>
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<tr>
<td>GFS</td>
<td>Global Forecast System</td>
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<tr>
<td>h</td>
<td>hour</td>
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<tr>
<td>MET</td>
<td>meteorological</td>
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<tr>
<td>METCM</td>
<td>Computer Meteorological Message</td>
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<tr>
<td>MM5</td>
<td>Mesoscale Model version 5</td>
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<td>MMS-P</td>
<td>Meteorological Measuring Set-Profiler</td>
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<tr>
<td>NOGAPS</td>
<td>Navy Operational Global Atmospheric Prediction System</td>
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<tr>
<td>RMSE</td>
<td>Root Mean Square Error(s)</td>
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<td>UKMO</td>
<td>United Kingdom Meteorological Office</td>
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