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Using Abridged Atmospheric Data in Mesoscale Modeling: Applications to Incident Meteorology Scenarios

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1. INTRODUCTION

The arrival of more powerful computing per unit cost and user availability has made Numerical Weather Prediction (NWP) more economical in recent years. These advances, along with developments in parallelization and distributed computing, has also led to correspondingly finer resolution numerical models more adept at studying complex mesoscale processes. These advancements allow mesoscale models to be used operationally even without access to supercomputing. However, finer resolution alone does not provide better model skill. A synergy of appropriate model resolution, physics, and data assimilation is necessary to produce the best possible NWP forecasts. With this in mind, numerical modeling done both operationally and in a research setting should involve careful considerations of model type, configuration, and the method and amount of data assimilated into the model.

Research regarding NWP usually focuses on one (or more) of the aforementioned considerations. Typically, the practice of modeling studies is to improve numerical forecasts by ingesting as much data as possible. This study, however, takes the approach of testing the sensitivity of model forecasts when abridged atmospheric data is assimilated into the model. In particular, the role of assimilating truncated atmospheric data in incident/event meteorology scenarios will be addressed. We first provide the premise for this type of research and then describe our experiment design. Some preliminary results with case study simulations are also presented.

2. NWP AND INCIDENT METEOROLOGY

Incident meteorology generally describes specific real-time weather and weather forecasts used by incident management, resource management, and emergency response teams during episodic hazardous events. For example, since the 1930s, incident meteorology has often been used to aid wildfire management teams in charge of monitoring both controlled burns and wildfires. However, in recent years, incident meteorology has branched out to include more "all-risk" or non-wildland fire incidents (Querciagrossa-Sand, 2003). With its broader interpretation, incident meteorology can be expanded to include all hazardous situations where timely, site-specific forecasts are needed. Furthermore, these real-time, site-specific (mostly short-term) forecasts are also an extremely important component of aviation meteorology as well as influencing decision making in various "weather-sensitive" industries and the planning of sporting events (May *et al.,* 2004). For the remainder of this paper, the term incident meteorology will be used to describe event forecasting in all scenarios with both hazardous and non-hazardous implications.

Most real-time models run operationally at national centers, such as the National Centers for Environmental Prediction (NCEP), typically produce forecasts every 6-12 hr. Even with modest horizontal grid spacing, large forecast areas require significant computational power, and the time it takes to run these models and transmit the data to a public domain is usually 2-3 hours past the initialization time. In addition, both the spatial and temporal resolution is too coarse to resolve mesoscale features with rapidly changing conditions (Mass and Kuo, 1998). As the result, most current operational forecast models are inadequate in providing the information needed in incident meteorology. NWP forecasting in incident meteorology is a particularly difficult area in numerical modeling because of the short time available to give timely forecasts to the public or incident managers. The challenge is to produce forecasts that can be generated quickly without compromising the accuracy of predicted variables.

Ultimately, incident meteorological forecasts will depend on the compromises that are made between computation time, physics options, and ingested data. Furthermore, operations at incident sites may have limited bandwidth to acquire data and limited computing resources. One of the ways to try and compensate for this problem is to scale back the large-scale forecasts and observational data ingested into the model. This, in combination with the inclusion of less computationally intensive physics options and fewer vertical layers, will reduce the computational expense required to perform a numerical simulation. This is applicable to incident situations where there may not be access to a large amount of data and high speed transmission. In this study, we are looking to go against "best practices" in initializing models. The term "best practices" is typically used to describe a model configured with adequate physics, that ingests enough data to provide an accurate forecast, and can be run at a reasonable cost relative to the time available to complete a simulation. We wish to further degrade the information being ingested into models, where decreasing the data ingested into models means less information has to be transferred across the NWP system.

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The experiment design that follows will look to address this dilemma. Using a degraded first guess (FG) or background field and cheaper model configuration, we can effectively reduce the computational expense and then assess the influence of these changes on our model solutions. Observations can be assimilated into the model before initialization to nudge the FG fields closer to reality. This type of study has broader implications on NWP research, but it is particularly important if a special incident sounding is used to adjust the FG fields in a locally-run model.

3. EXPERIMENT DESIGN

A hierarchical series of simulations has been designed to test the sensitivity of forecasts as the amount of information used to initialize the model is gradually scaled back, shown in Figure 1. The "*optimal*" simulations are similar to what is done in a research setting where there is no regard for computation time. These are initialized with detailed gridded retro analyses (North American Regional Reanalysis; Messinger *et al*., 2006) nudged by every available observation contained in the model domain, including observations made after the initialization time. In addition, these simulations are produced with more vertical levels (39 sigma levels) and use expensive physics options. This setup does not represent a real forecast because the simulations are driven by analyses and observations that would not be available until after the model is started.

The next set of simulations is closer to what would be used operationally. These are initialized from a continental-scale MM5 to provide a large-scale forecast run for boundary conditions, include select observations, and use more modest physics with 29 vertical levels. These forecasts are designed to mimic the "*best practices*" scenario described earlier. The continental-scale MM5 forecast also uses 29 levels and 40 km horizontal grid spacing. The final set of simulations use FG fields with much coarser vertical and horizontal resolution. These simulations have FG fields degraded to 0.5 horizontal resolution and 13 vertical levels. In addition, the spatial extent of the FG fields is much smaller than the continental-scale coverage supplied in both the operational best practices and optimal scenarios. These are what we consider "*abridged*" scenarios. These simulations are also run with less computationally intensive physics options and include fewer vertical levels (19 sigma levels). The abridged scenarios go against best practices, because these are initialized with coarse-resolution FG fields, possibly less than adequate physics, and use fewer vertical levels. Comparisons of the various simulations will support the body of knowledge on the subject of incident meteorology. The broader modeling goal is to determine how forecasts change as the information used to initialize the model is scaled back.

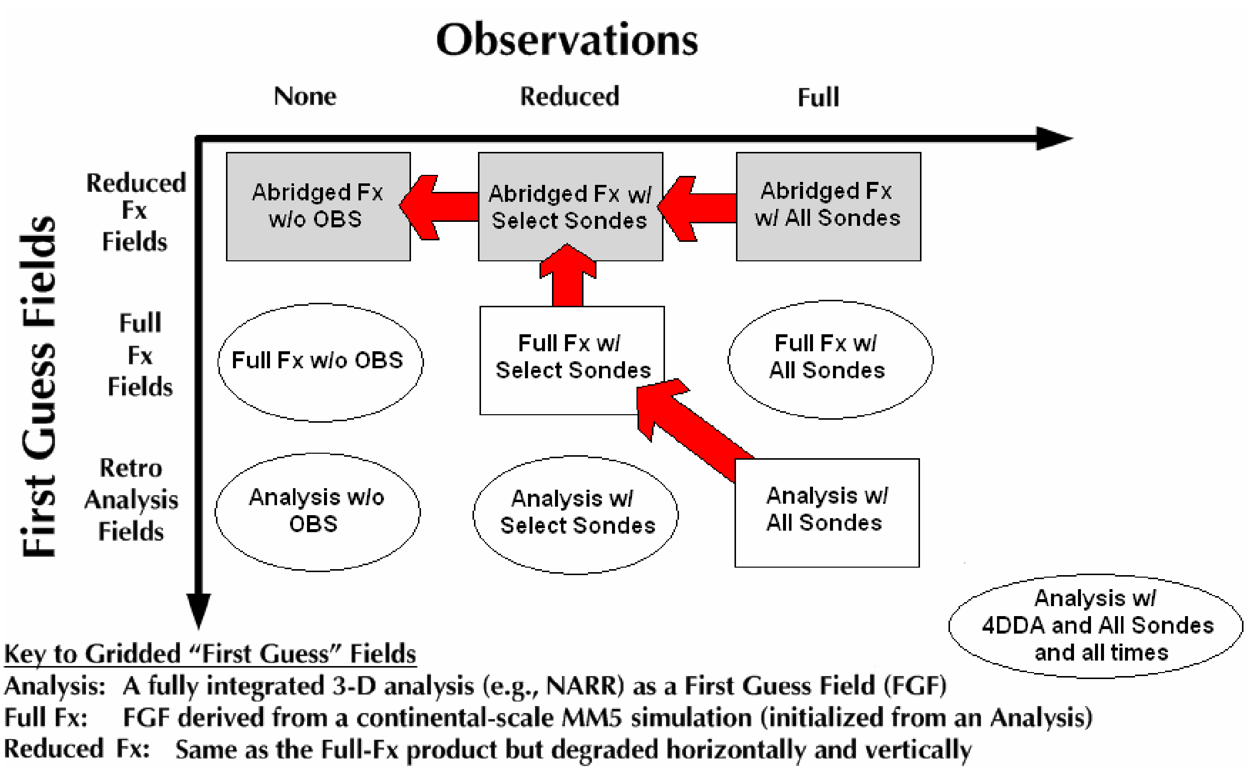

Figure 1. *This is a scenario matrix showing the simulations performed in this study. The white rectangles represent "best practices" and "optimal" type simulations for the operational and research scenarios respectively. The gray rectangles are the "abridged" scenarios with decreasing observations from right to left. The bubbles were not used in this experiment.*

The model employed for this study is the nonhydrostatic NCAR/PSU Fifth Generation Mesoscale Model (MM5) version 3.7 (Grell *et al.,* 1994). The MM5 is a limited-area, terrain-following sigma-coordinate model with two-way interactive nests. The simulations performed in this study implement a three-domain setup shown in Figure 2, with the outermost domain (Domain 1) centered at 44.00°N and 103.75°W (over the Black Hills in western South Dakota and eastern Wyoming). The horizontal grid spacing for the outer domain is 45 km (29 X 29 grid points), the second domain is 15 km (43 X 43 grid points), and the inner domain has spacing at 5 km (67 X 67 grid points). Thus, the outer 45-km domain covers an area approximately 1300 km X 1300 km, while the inner 5-km domain covers 300 km X 300 km. In terms of the vertical resolution, the research simulations used the largest number of sigma layers with 38. The operational and abridged scenarios are run with coarser resolutions of 28 and 18 respectively. A summary of physics options used for each of the scenarios is provided in Table 1.

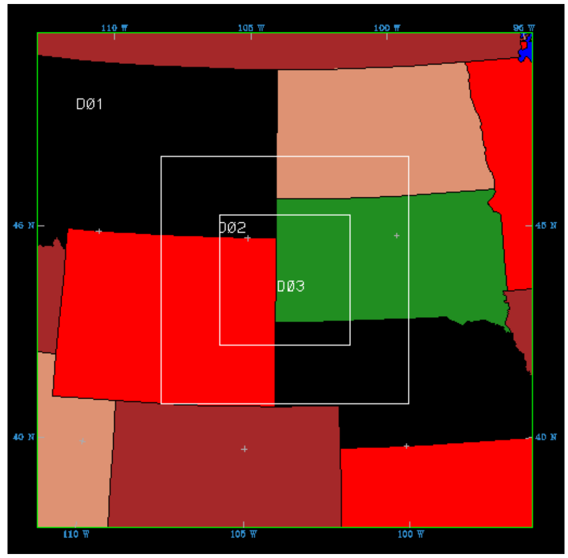

Figure 2. *Domains used in the 10-11 April 1999 and 17-18 April 1999 simulations. Grid spacing for Domain 1, Domain 2, and Domain 3 are 45 km, 15km, and 5 km, respectively.*

Table 1. *Summary of physics options chosen for simulations from the three protocol situations: research (a), operational (b), and abridged (c).*

1.a.) Research Setting		
Phsyics Options	**Domain(s)**	**Scheme**
Explicit Moisture Scheme	ALL	Reisner Graupel (Reisner 2)
Cumulus Parameterization	ALL	Kain-Fritsch 2
Planetary Boundary Layer Scheme	ALL	MRF-Hong-Pan
Atmospheric Radiation	ALL	Cloud-Radiation Model
Surface Scheme	ALL	NOAH Land-Surface Model
Shallow Convection	none	none

1.b.) Operational Setting		
Phsyics Options	**Domain(s)**	**Scheme**
Explicit Moisture Scheme	ALL	Mixed Phase (Reisner 1)
Cumulus Parameterization	ALL	Grell
Planetary Boundary Layer Scheme	ALL	MRF-Hong-Pan
Atmospheric Radiation	ALL	Cloud-Radiation Model
Surface Scheme	ALL	Five-Layer Soil Model
Shallow Convection	none	none

1.c.) Abridged Setting		
Phsyics Options	**Domain(s)**	**Scheme**
Explicit Moisture Scheme	ALL	Simple Ice (Dudhia)
Cumulus Parameterization	1 and 2	Grell
	3	None
Planetary Boundary Layer Scheme	ALL	MRF-Hong-Pan
Atmospheric Radiation	ALL	Simple Cooling
Surface Scheme	ALL	Five-Layer Soil Model
Shallow Convection	none	none

Two 24-hr periods during the April 1999 Upper Missouri River Basin Pilot Project (UMRBPP; Farwell and Smith, 2001) are simulated to test the sensitivity of model forecasts as first guess (FG) fields and observations are scaled back. The first is a significant precipitation event that occurred in and around the Black Hills on 10 and 11 April 1999. Moderate snowfall fell over the Black Hills and surrounding plains as the result of an extratropical cyclone that developed on the lee side of the Rocky Mountains and moved to the northeast across the area. The second period (17-18 April 1999) represents a null case, where no strong forcing or significant precipitation occurred within the modeling domains. The extra upper air observations taken during the field campaign of the UMRBPP and the routine National Weather Service launches were included in order to provide a full suite of observations in the model domain, which can then be scaled back. The sounding sites and the terrain have been plotted in Figures 3 and 4 for Domains 1 and 3, respectively. The blue lettering indicates observations taken as part of the UMRBPP.

4. PRELIMINARY RESULTS

We confirm that forecasts are highly sensitive to both the FG fields and various configuration options used to initialize the model. Most of our simulations show the largest forecast discrepancies between the optimal and abridged setting, as seen by the yellow isosurfaces plotted in Figure 5. Differences between the optimal setting and operational best practices are often larger than differences that arise when switching from operational to abridged, especially within the first few hours after the model is initialized. In some cases, the largest differences are found at the time of initialization. As seen with Figure 5, the spatial extent of the differences decreases as time progresses, but discrepancies are still maintained to some degree throughout the simulation. This was observed in the vertical velocity fields and in other model variables (i.e. horizontal velocity). However, some plots of temperature and specific humidity did not follow this trend.

The slightly larger differences between optimal and operational best practices scenarios are likely due to the effect of switching from an analysis to a forecast used to initialize and drive the model. Less forecast discrepancy was observed between best practices operational and abridged simulations. These simulations both used a large-scale MM5 forecast as initial input, but the abridged scenario’s FG fields have degraded horizontal and vertical resolution, as well as a smaller domain area. This seems to suggest that the type of FG field used may have a more pronounced effect on model forecasts than the resolution of these fields.

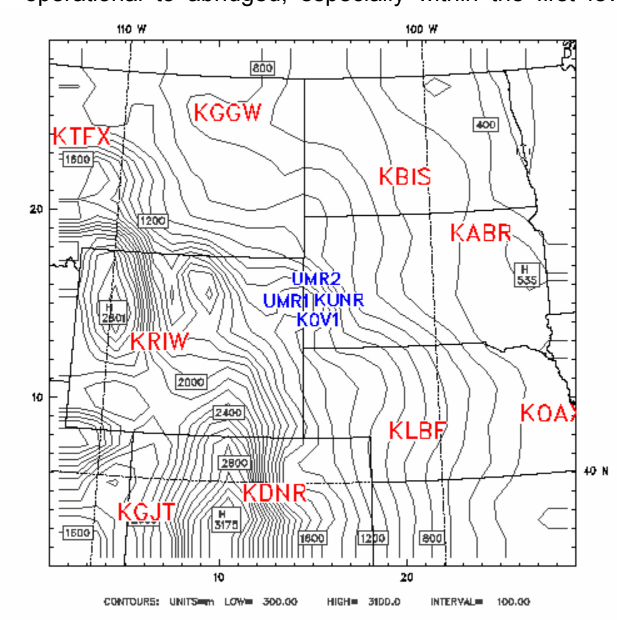

Figure 3. *Terrain (m) for the 45-km outermost domain centered over the Black Hills. Contour interval is 100m. Radiosonde sites from around the region are shown in red and the UMRB project upper air sites are shown in blue.*

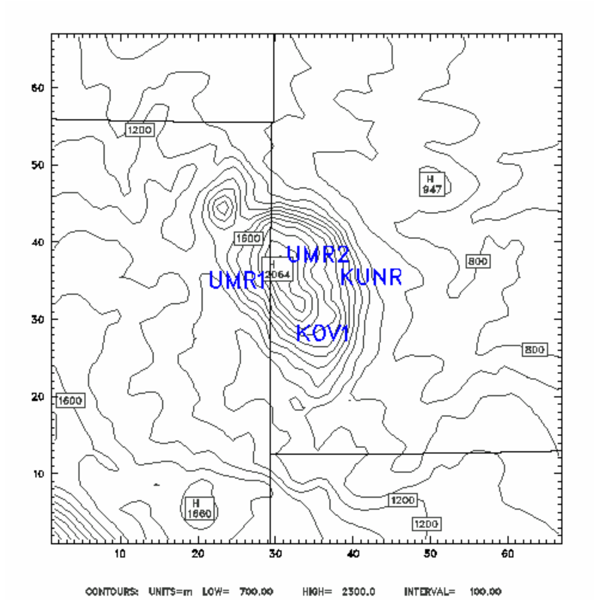

Figure 4. *Terrain (m) for the 5-km innermost domain centered over the Black Hills. Contour interval is 100m. Radiosonde sites shown at Four Corners, WY (UMR1), Custer Crossing (UMR2, and Rapid City, SD (KUNR). Custer Airport (K0V1) is included as a reference and was also used as a profiler site during the UMRB project.)*

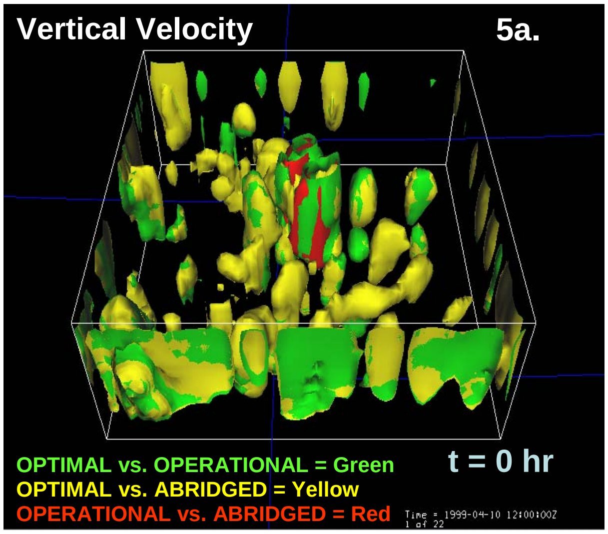

Figure 5a. *Three comparisons plotted on the Domain 3 centered over the Black Hills. The shaded areas indicate forecast differences of vertical velocity equal to or greater than 0.2 m/s. The green shading denotes the absolute difference between the optimal (research) and best practices (operational) solutions. Yellow shows optimal vs. abridged (with no ingested observational data) and red indicates differences generated between operational best practices and abridged. This plot is at time of initialization (12 UTC).*

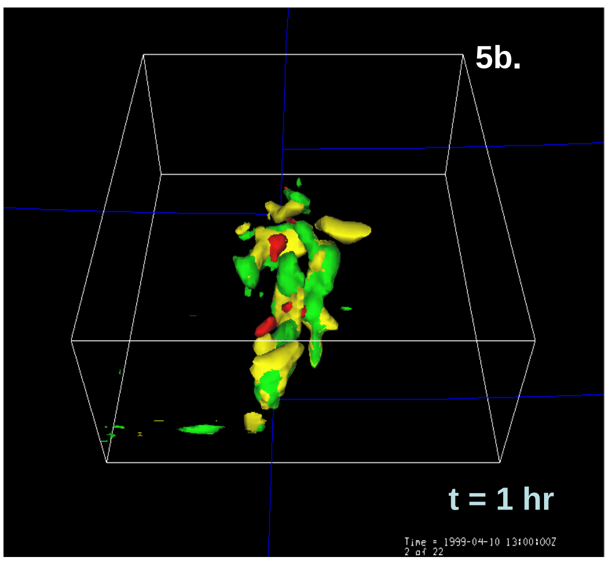

Figure 5b. *Same as Figure 5a but for one hour after initialization time.*

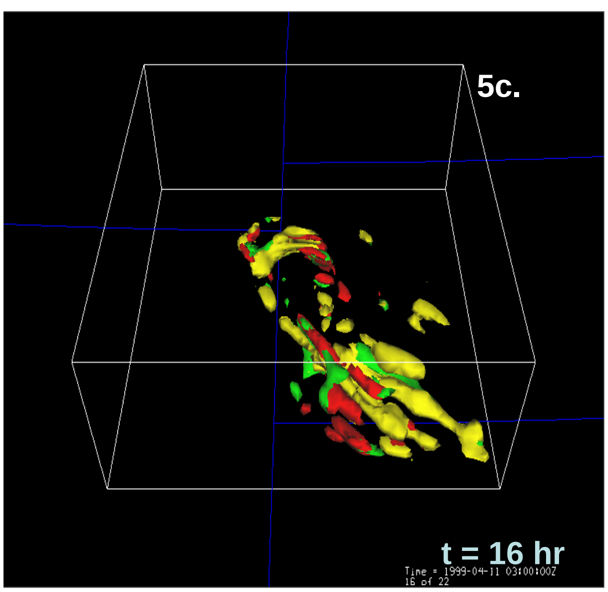

Figure 5c. *Same as Figure 5a. but sixteen hours into the simulation.*

Figure 6 depicts modeled differences in vertical velocity between the operational best practices and abridged scenario, where the perturbation shows the effect of including an additional radiosonde launch. At 12 UTC (t = 0 hr), a balloon launch at Custer Crossing, SD (UMR2 from Fig. 4) was ingested into the MM5 objective analysis program and effectively altered the initial FG field. This alteration created a perturbation within the modeling domain in the vicinity of the launch. Even more impressive is the fact that this feature is strong enough as to not be masked by differences generated from variations in the FG fields and changes in physics options. This suggests that extra soundings do have the potential to effectively alter model forecasts. Assuming that the error in these observations is relatively small, the newly ingested data can be used to nudge a potentially stale forecast/FG field toward reality. Furthermore, altering the initial field by including or excluding observational soundings can create perturbations that linger within the modeling domain well into the simulation. These perturbations (observed differences in the mass and momentum fields) seem to propagate through the model domain in the direction of the prevailing winds. This factor may have some implications on where special soundings are taken during incident events. At this point, it seems upwind observations are better than those taken downwind.

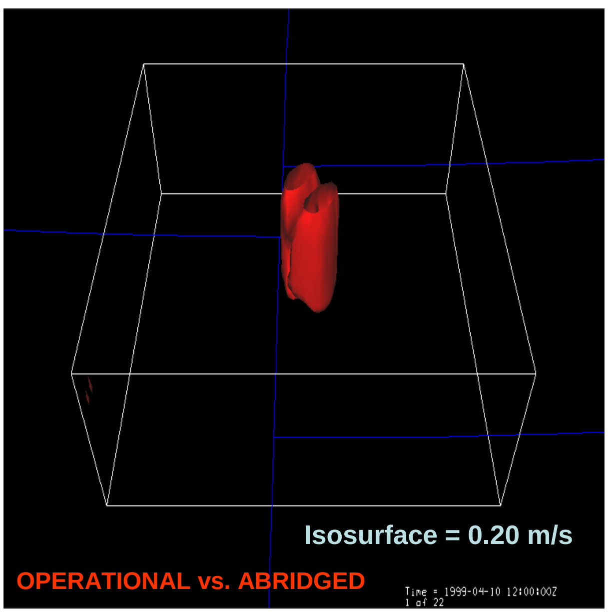

Figure 6. *Same comparison presented in Figure 5 but without the isosurface differences for the other two comparisons. This is presented to point out the effect of the Custer Crossing upperair observation include at 12 UTC. This demonstrates the effectiveness of an observation adjusting a FG or background field.*

Because the 10-11 April 1999 event did bring significant precipitation to the modeling domains, we also wish to discuss the differences in model generated precipitation. The total accumulated precipitation for the optimal simulation shows a maximum centered over the Black Hills, SD/WY with another localized maximum near Pine Ridge along the Nebraska/South Dakota border (Figure 7). A similar pattern is observed in the operational best practices simulation; however, the totals are significantly higher (Figure 8).

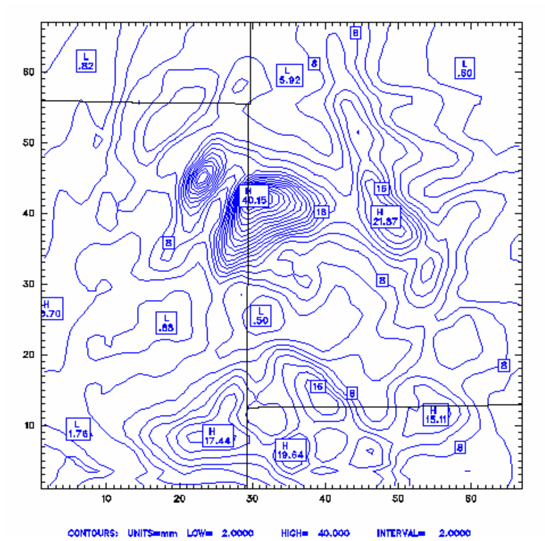

Figure 7. *Total accumulated precipitation (mm) for the optimal simulation in the innermost domain (Domain 3) during the 10-11 April 1999. For this simulation all available observations within the modeling domains were used. The maximum amount is 40.15 mm and the contour interval is 2 mm.*

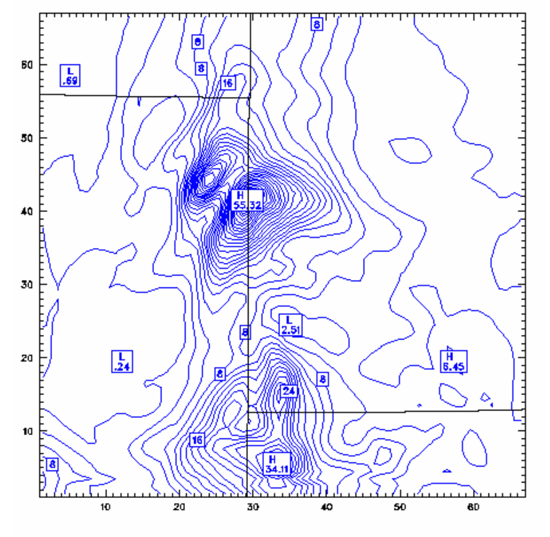

Figure 8. *Total accumulated precipitation (mm) for the operational best practices simulation in the innermost domain (Domain 3) during the 10-11 April 1999. For this simulation, only the Custer Crossing soundings were used to adjust the FG fields. The maximum amount is 55.32 mm and the contour interval is 2 mm.*

The simulations using degraded FG fields (abridged scenario) also show similar precipitation patterns with some variability in overall magnitude. These are seen in Figures 9 and 10. The simulation that produced the precipitation pattern in Figure 9 was initialized with an FG field that has been modified by including all available upperair launches within the modeling domain. Similarly, the optimal simulation included all the same observations at the time of initialization. On the other hand, the simulated precipitation in Figure 10 was generated with a degraded FG field forced only by the 12 UTC observation at Custer Crossing. Likewise, the operational best practices FG field was modified with this sounding only. One of the interesting features to point out is that even though the magnitude of precipitation varies from simulation to simulation, the forecasts that were ingested with similar observational data showed more pattern agreement. For example, Figures 7 and 9 both resolve a localized maximum to the east of the Black Hills and the area of most significant precipitation. It also appears that these two simulations are in closer agreement with the magnitude and spatial extent of the precipitation in the lower third of the domain near the NE/SD border. Figures 8 and 10, which include the same observational data, also suggest closer agreement both in magnitude and overall pattern compared to other the simulated plots.

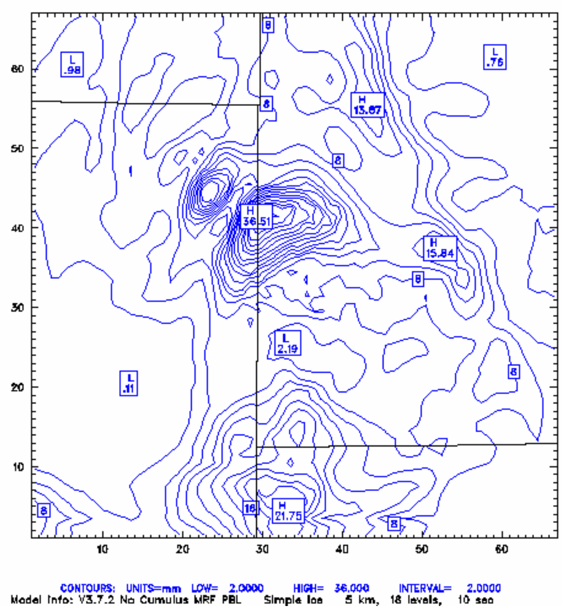

Figure 9. *Total accumulated precipitation (mm) for the abridged simulation with FG fields modified by all available observations, both UMRBPP and routine NWS launches (Domain 3) during the 10-11 April 1999. The maximum amount is 36.51 mm and the contour interval is 2 mm.*

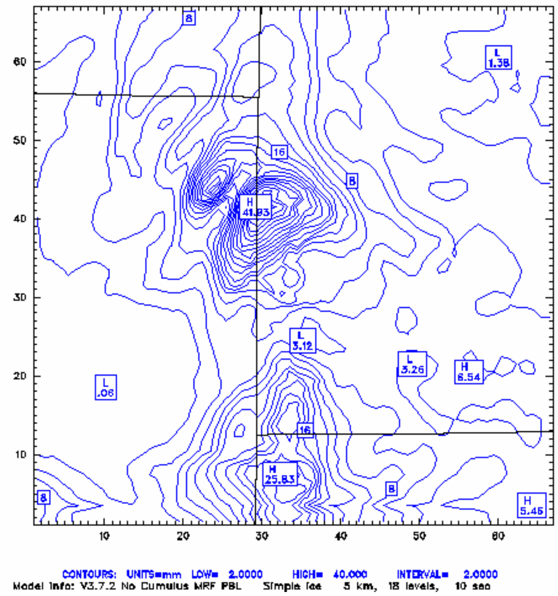

Figure 10. *Total accumulated precipitation (mm) for the abridged simulation with FG fields modified by including Custer Crossing observations (only) in the innermost domain (Domain 3) during the 10-11 April 1999. The maximum amount is 41.93 mm and the contour interval is 2 mm.*

At this point, an examination of the null case does not reveal any dramatic dissimilarity from the observed features mentioned previously. Future comparisons may yield different conclusions as research is still ongoing at the present time. To summarize the results to date, both variations in FG fields and configuration options (i.e. model physics) combine to produce differences in model forecasts, in some cases these were more pronounced early in the simulations. The deviation of the observational sounding from the FG input field is an important factor in creating perturbations in forecasts which can linger in the modeling domain throughout the entire simulation. These perturbations are sufficiently large to be observed even in comparing scenarios where differences in FG fields and model physics create their own variations in model results.

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