J2.6 EXPLICIT INITIALIZATION OF CLOUDS AND PRECIPITATION IN MESOSCALE FORECAST MODELS

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1. INTRODUCTION

In recent years, operational numerical weather prediction (NWP) models have become more sophisticated in their treatment of microphysical processes as the cost of high−performance computing has decreased. Microphysical schemes and computer parameterizations that were once only used in research are being adopted by operational agencies in the hope that explicit forecasts of clouds and precipitation will improve. While this has been the case for the "day 2" forecast and beyond, the short range (0−12 h) period remains the bane of numerical model accuracy due to the infamous "spin−up" problem, despite various attempts to mitigate this problem using dynamic initialization or more sophisticated data assimilation systems. Now that fast computing systems allow us to run mesoscale models and have the output available within 1 or 3 h after the initialization time, the importance of a useful and accurate short−range explicit forecast of clouds and precipitation has been heightened, particularly if this portion of the explicit numerical forecast is to be used operationally. To address this problem, a new version of the NOAA Forecast Systems Laboratory's (FSL) Local Analysis and Prediction System (LAPS, Albers et al. 1996) is being used to diabatically initialize mesoscale NWP models with all microphysical species present in the initial condition and in dynamic balance with the mass and momentum fields.

A real−time forecast system based on the new diabatic initialization has been running routinely at FSL since the fall of 2000, with output provided on the Internet (http://laps.fsl.noaa.gov) as well as to the collocated National Weather Service (NWS) Weather Forecast Office (WFO) in Boulder for operational evaluation. It is also made available on FSL's Advanced Weather Information Processing System (AWIPS) workstation for use in daily weather briefings.

This paper provides a brief description of the analysis procedure and some preliminary quantitative verification results compared to other initialization methods. A qualitative assessment of operational utility based on feedback from the Boulder WFO is discussed in Shaw et al. (2001).

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2. THE LAPS ANALYSIS

LAPS was initially developed over a decade ago and has undergone continuous upgrades and improvements throughout this time period. It was designed to provide a means of combining all available meteorological data sources into a single, coherent three−dimensional depiction of the atmosphere at high spatial and temporal resolution for use by operational forecasters. The operational nature of LAPS dictated the necessity for flexible and reliable data ingest, quality control, and computational efficiency. LAPS has demonstrated capability in all of these areas and is now used by a variety of government and private agencies, both inside and outside of the United States, including every NWS WFO as part of AWIPS. Within the WFO, LAPS is able to

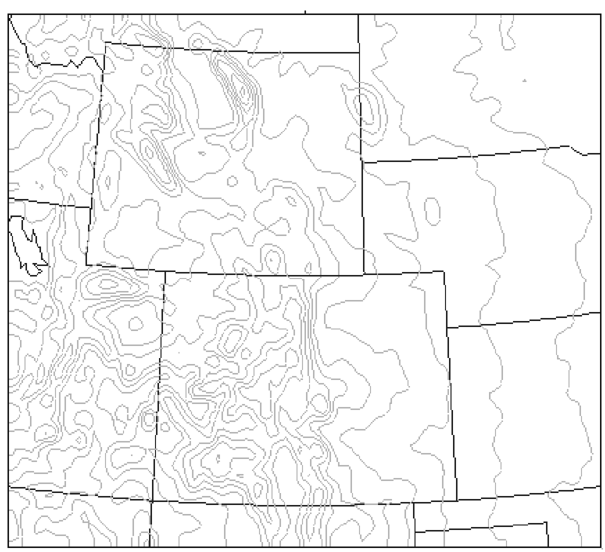

Figure 1. The LAPS−MM5 domain with contours of MM5 terrain height in 300−m increments overlaid.

capitalize on AWIPS' ability to ingest local data sources (e.g., mesonets, etc.) that are not routinely available for the regional and global−scale models run at the national centers.

Within FSL, LAPS is run routinely on a domain covering approximately 1.3 million square kilometers (Figure 1) using 125 by 105 horizontal grid points with a 10 km grid spacing. This LAPS domain contains 21 pressure levels with a 50 mb vertical spacing ranging from 1100 mb through 100 mb. On this domain, hourly analyses of the atmospheric state variables, clouds, precipitation, and a variety of surface variables (snow cover, accumulated precipitation, etc.) are produced using the following sources of data: GOES imager and sounder radiances, WSR−88D reflectivity and VAD winds, NOAA wind profilers, aircraft observations (ACARS and PIREPs), and surface observations (including various mesonets and locally acquired data). For use as a first guess, this domain typically relies on the operational national−scale grids from the National Centers for Environmental Prediction (NCEP), typically the RUC−2 or Eta model. Additionally, when configured to initialize a local mesoscale model, LAPS can use that model's output as a first guess so that a full data assimilation cycle can be established.

Although LAPS has been used for some time to initialize mesoscale NWP models, it has been used to initialize only the state variables for a model "cold start" or within a pre−forecast period during which the model is run using analysis "nudging" toward the LAPS−analyzed state variables.

Cram et al. (1995) tested the use of LAPS to initialize clouds for mesoscale NWP forecasts with limited success. However, the lack of a dynamic balance between the initial cloud and momentum fields prevented the clouds from being completely sustained during the early hours of the forecast.

Two recent improvements to the LAPS analysis system address the initialization of clouds and precipitation. First, an improved cloud analysis scheme (Schultz and Albers 2001) provides a three−dimensional depiction of the water content in all phases (cloud liquid, rain, ice, snow, and graupel) based on the radar, satellite, and conventional temperature and moisture analyses. In addition, vertical motion profiles consistent with the cloud type and depth are derived during this process.

Second, a dynamic balance package (McGinley and Smart 2001) uses the analyses of clouds (and their vertical motions) in conjunction with the initial analyses of the state variables to produce a final analysis suitable for initializing the forecast model. This balance package uses a three−dimensional variational (3DVAR) approach to ensure that the fields of mass and horizontal divergence are consistent with the cloud−derived vertical motions. The cost function used in this approach includes terms to ensure mass continuity as well as a minimization of the time tendency of the *u* and *v* wind components. The mass continuity term ensures that the temperature and height field are consistent with the cloud analysis (in a hydrostatic sense), and the minimization of the *u* and *v* fields ensure a quiet start (i.e., minimal gravity wave perturbations due to initial imbalances) for the NWP model.

Once the final analysis of the mass, momentum, and microphysical species are produced, a final adjustment to the relative humidity field is made by saturating any cloudy updrafts. This step was added to account for the model physics schemes which require saturation for cloud water to exist. While not necessarily ideal, especially for grids coarser than those that can resolve clouds, tests indicate that this approach provides additional improvement to the short−range (0−3 h) forecasts of clouds and precipitation without adversely impacting the later hours of the forecast.

2. FORECAST MODEL SETUP

Initial testing of the LAPS explicit cloud and precipitation initialization method has been done using version 3 of the NCAR/PSU Mesoscale Model 5 (MM5) with slight modifications to the preprocessing programs and the model initialization routines to account for the presence of the hydrometeorological species in the initial conditions.

FSL has been running a domain matching the LAPS domain shown in Fig.1 in real time since the fall of 2000 using the diabatic initialization procedure described above. The model is run four times daily to produce 24−h forecasts with hourly output. The model is run on FSL's high−performance computing system and is typically available on the Internet and to the Boulder NWS forecasters within 2 h after the model initial time, so the quality of the early forecast hours is of significance for their use.

The model domain uses a grid spacing of 10 km and consists of 125 by 105 points with 41 vertical levels. Vertical grid spacing is finest in the lower levels to ensure the resolution in the boundary layer is adequate for the use of the Blackadar PBL scheme. For the microphysical processes, the Schultz (1995) explicit scheme is used along with the Kain−Fritsch convective parameterization.

3. VERIFICATION EXPERIMENT

To determine what improvement, if any, is gained in forecast quality using the diabatic initialization, three model forecasts per 6−hourly cycle were run from October 2000 through January 2001. The primary run, MM5HOT, was configured as discussed above, using the LAPS diabatic initialization for initial conditions and the NCEP operational Eta (on the AWIPS 40−km grid) as the lateral boundary conditions (LBCs). The Eta run used for LBCs was the 6−hourly cycle prior to the MM5 cycle (e.g., the 1200 UTC MM5 run used the 0600 UTC Eta run). The remaining two runs, MM5ETA and MM5WARM, were configured identically, including the LBCs, but were initialized differently. The MM5ETA used no LAPS analysis, but rather was simply initialized from a 6−h Eta forecast (state variables only). This method is typical of many real−time mesoscale models, and relies solely upon the higher−resolution terrain to improve upon the larger scale forecast provided by the regional model. The MM5WARM used a 3−h preforecast analysis nudging period (state−variables only) to attempt to reduce the model spin−up time. This method has been used operationally at the Air Force Weather Agency as part of their LAPS and MM5 implementation. While it does improve the forecast of clouds and precipitation during the early hours of the forecast, it has the disadvantage of requiring additional computational time. Table 1 summarizes the three configurations.

CASE	***IC***	***LBC***
MM5HOT	LAPS Diabatic Initialization	6−30 H Eta Forecast
MM5WARM	LAPS 3−H Nudging Period	6−30 H Eta Forecast
MM5ETA	6−H Eta Forecast	6−30 H Eta Forecast

Table 1. Initial conditions (IC) and lateral boundary conditions (LBC) used for the three members of the validation experiment.

For each model cycle, each of these three configurations was verified against LAPS gridded analyses. Note that the same LAPS analysis was used to verify all three MM5 runs, and that these LAPS analyses used the NCEP operational RUC as their first guess to ensure their independence. Only the first 12 h of each run were verified. Basic error statistics (RMSE and bias) were computed for the forecast surface temperature, relative humidity, and sea−level pressure. Additionally, to determine relative improvements to quantitative precipitation forecasts (QPFs) and cloud forecasts due to the different initialization techniques, several different skill scores were computed, including probability of detection (POD), false alarm rate (FAR), equitable threat score (ETS), bias, and correlation coefficient. The skill scores were computed by comparing the analysis and forecast fields, which are on identical grids, on a gridpoint by gridpoint basis; i.e. the scores are not made more optimistic by using multiple analysis points for a single forecast point. Thus, slight timing or spatial errors (1 h or 1 gridpoint error in the forecast) will negatively impact these scores. The skill scores were computed as follows:

$$POD = C/O$$

$$FAR = B/F$$

$$ETS = (C - E)/(F + O - C - E), E = F * O/T$$

where F is the total number of points where the forecast exceeds the threshold, O is the total number of points observed to exceed the threshold, C is the total points where the threshold was both observed and forecast (successful forecasts), and B is the total number of points where the threshold was forecast but not observed (false alarms). In the computation of ETS, T is the total number of points in the horizontal domain, and the E term represents the chance of the event occurring anywhere on the domain, based on the product of the total number of points forecast and the total number of points observed.

4. RESULTS

Quantitative statistics computed over 39 forecast runs during January 2001 demonstrate that the MM5HOT has more skill in predicting the occurrence of precipitation, cloud cover, and surface temperature and moisture than either the MM5WARM or the MM5ETA during the early hours of the forecast. Figure 2 is depicts the ETS for each of the three configurations for hourly snowfall in excess of 1 mm. Figure 3 shows the ETS for cloud cover greater than 50%. Since a slight timing or spatial error makes a large difference in these scores, it is not the actual ETS value that is important, but rather the relative scores between the three initialization types, since

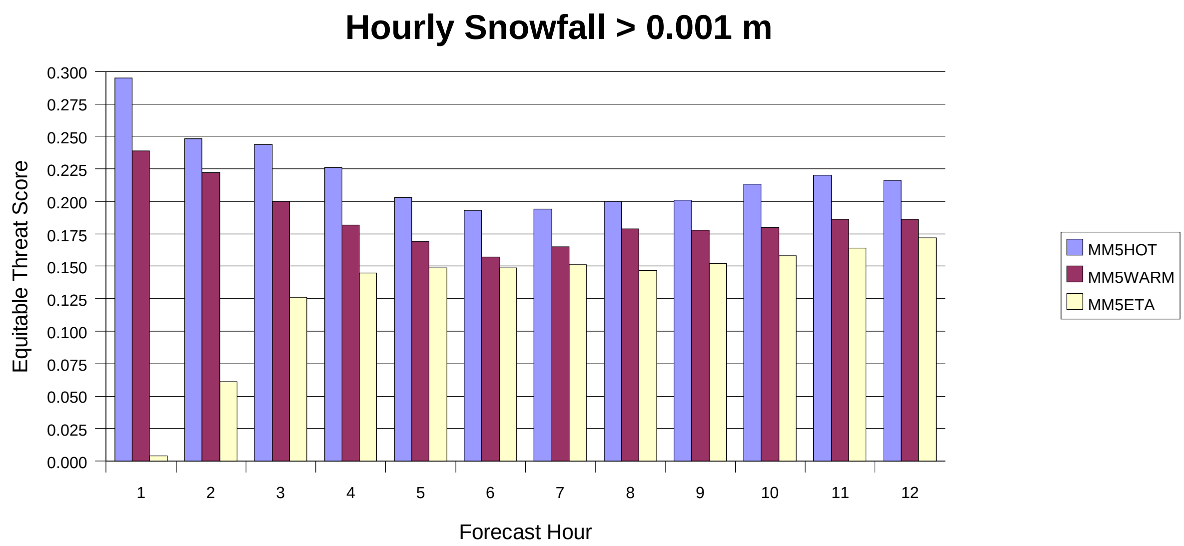

Figure 2. Equitable threat score for hourly snowfall in excess of 1 mm for each model configuration. Values are shown for each hour of the 0−12 h forecast. Higher scores indicate more skill.

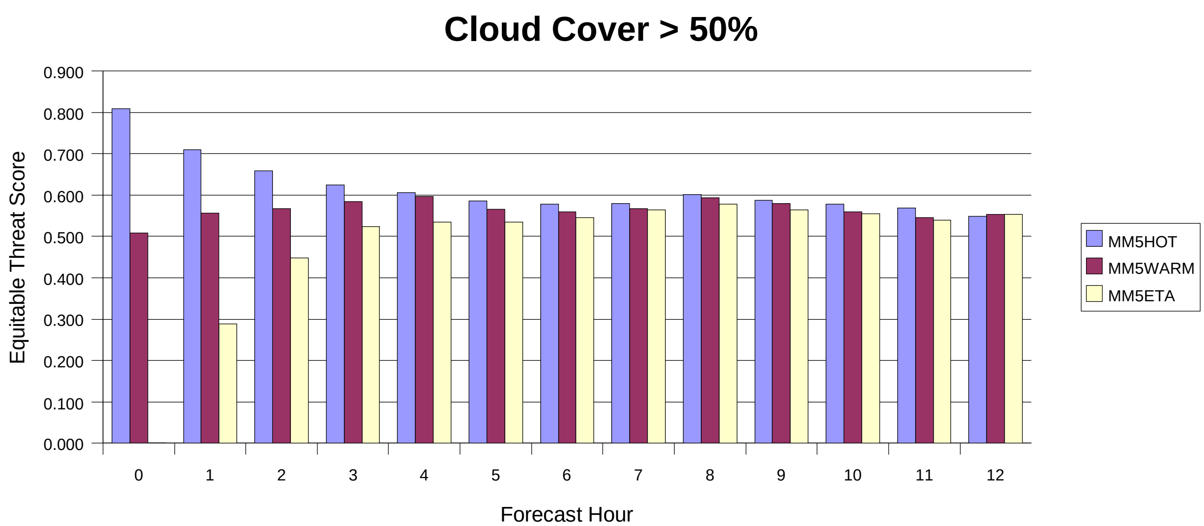

Figure 3. Equitable threat score for cloud cover in excess of 50% for each model configuration. Values are shown for each hour of the 0−12 h forecast. Higher scores indicate more skill.

they were all verified against the same "truth" field.

Both of these graphs visually demonstrate the improvement in the short−range forecast of clouds and precipitation due to the diabatic initialization technique. Additionally, both the MM5HOT and MM5WARM values demonstrate that skill is improved during the early hours when additional data are assimilated using an analysis system rather than using a simple "nestdown" from a regional model (in this case, the operational Eta model). Furthermore, the model spin−up time for this particular domain can be inferred from the graphs by noting the length of the period between the initial time and the time that the MM5ETA skill is statistically comparable to the MM5HOT and MM5WARM cases. For our domain, this appears to be on the order of 5 or 6 h. Since these grids are available to the forecasters within 2 h of model initialization time, the additional skill provided by the diabatic initialization would be beneficial, particularly for automated forecast systems which use NWP grids as their input.

Finally, the convergence of model skill in the later hours demonstrates the dominance of the lateral boundary conditions on the resulting forecast for this limited domain, as well as the inherent low predictability with time of small−scale meteorological features. We speculate that the use of a land surface model component in the forecast model combined with a rapid data assimilation cycle may lengthen the time period prior to this convergence due to the earlier spin−up of precipitation processes (and thereby changes to the soil moisture field) using the diabatic initialization compared to the simple nestdown technique. While the MM5WARM has comparable skill scores at an earlier time, the diabatic initialization has the advantage of not requiring the additional computations of a preforecast analysis nudging period.

5. CONCLUSIONS AND FUTURE WORK

This work is still in progress, but shows potential for improving short−range forecasts of clouds and precipitation without the use of computationally expensive dynamic initialization periods or the use of 3D/4DVAR data assimilation systems used at the national centers for medium range and longer forecasts. For local users with limited computing resources, this system could provide a means for explicit forecasts of short range weather conditions by taking advantage of local data sources. Such a system running in real−time within a local forecast office could greatly complement the regional and national scale products provided by centralized facilities.

Future work is primarily focused on the following areas:

- Improving the LAPS dynamic balance scheme by adding thermodynamic terms to the cost function equation such that anomalous clouds and precipitation in the first guess field can be gracefully removed based on the LAPS cloud analysis.

- Improving the forecast model microphysical scheme to account for fractional cloud cover (i.e., the existence of cloud water in non−saturated grid boxes).

- Improving grid−scale dependency when assigning vertical motions based on derived cloud type.

- Computing first−guess background errors for use in the full 3D error matrices in the balance package cost function.

- Testing the scheme with other NWP models, including the new Weather Research and Forecast (WRF) model.

- Improving verification, to include point verification against observations.

- Implementing full 4DDA data assimilation system running on an hourly cycle to improve the first guess used by the LAPS analysis.

- Running the system at cloud−resolving resolution (e.g., 1−3 km horizontal grid spacing).

Additionally, this version of LAPS and MM5 will be installed at three NWS WFOs and the two USAF space launch facilities for operational use. This will provide additional opportunities for operational feedback.

6. References

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