EXPLICIT INITIALIZATION OF CLOUDS AND PRECIPITATION AND IMPLICATIONS FOR MICROPHYISCAL PARAMETERIZATIONS

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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.

This paper provides a brief description of the analysis procedure and some preliminary quantitative verification results. Plans for future work, including changes to the forecast model's microphysical scheme, are discussed.

2. THE LAPS ANALYSIS

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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.

The result of the improved cloud analysis and balance scheme is a fully specified field of atmospheric state variables and a realistic hydrometeor distribution that are in dynamic balance with one another, making the fields suitable to diabatically initialize a forecast model.

3. 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.

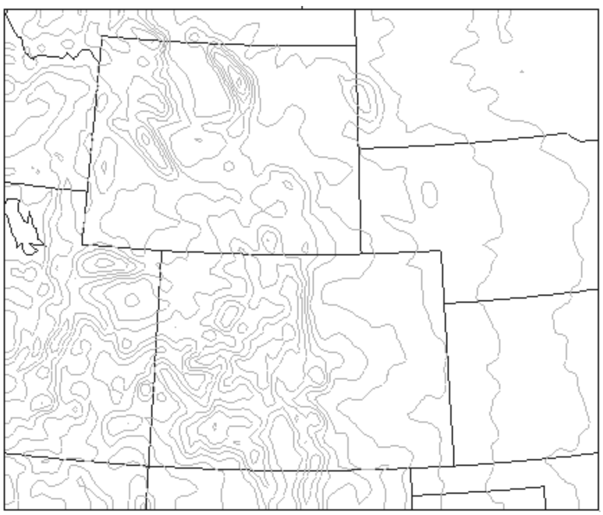

Figure 1. LAPS−MM5 domain used for FSL realtime products and verification experiment.

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.

4. RESULTS

Quantitative verification and subjective evaluation during the past winter season by operational forecasters demonstrated that the diabatically initialized model forecasts had significantly improved skill in forecasting clouds and precipitation in the early hours of the forecast period compared to other methods of initialization. Figures 2 and 3 show the equitable threat scores of three different initialization techniques for forecasting cloud cover and snowfall from a period during the winter of 2000−2001. All three configurations of the model were identical except the initialization. The MM5HOT represents the diabatic initialization method described here. The MM5WARM used a 3−h analysis nudging period prior to the initial hour where standard (non−balanced, no hydrometeor fields) LAPS analyses provided the nudging targets. The MM5ETA simply nested down from the prior 6−hourly Eta run that was used for lateral boundary conditions for all three runs. These graphs clearly demonstrate the additional skill of the MM5HOT configuration. More detailed discussion of the verification experiment and the results are contained in Shaw et al. (2001a). Operational subjective evaluation is discussed in Shaw et al. (2001b).

During initial testing of the scheme during the late summer of 2000, there was significant initial dissipation of cloud condensates during the first hour of model integration, although not as drastic as that observed during previous attempts discussed earlier. Careful analysis confirmed that the problem was related to inconsistencies between the LAPS treatment of cloud fraction vs. relative humidity within a gridbox and the MM5's microphysical scheme. Where clouds existed in the initial conditions in boxes with less than 100% relative humidity, the cloud condensate was rapidly evaporated until the relative humidity reached 100%. Thus, only the "largest" cloud features survived the first hour (although clouds quickly redeveloped in subsequent hours in areas originally containing cloud due to the moistening of the atmosphere). Additionally, the model microphysical scheme tended to convert liquid to ice at sub−freezing temperatures much more aggressively than the LAPS analysis, which uses a linear ramping function to convert liquid to ice based on the temperature, stability, and cloud type.

As a temporary solution, an additional step was added to the LAPS analysis procedure. After the balance procedure is completed, the relative humidity is raised to 100% (with respect to liquid) for all grid boxes containing a cloudy updraft.

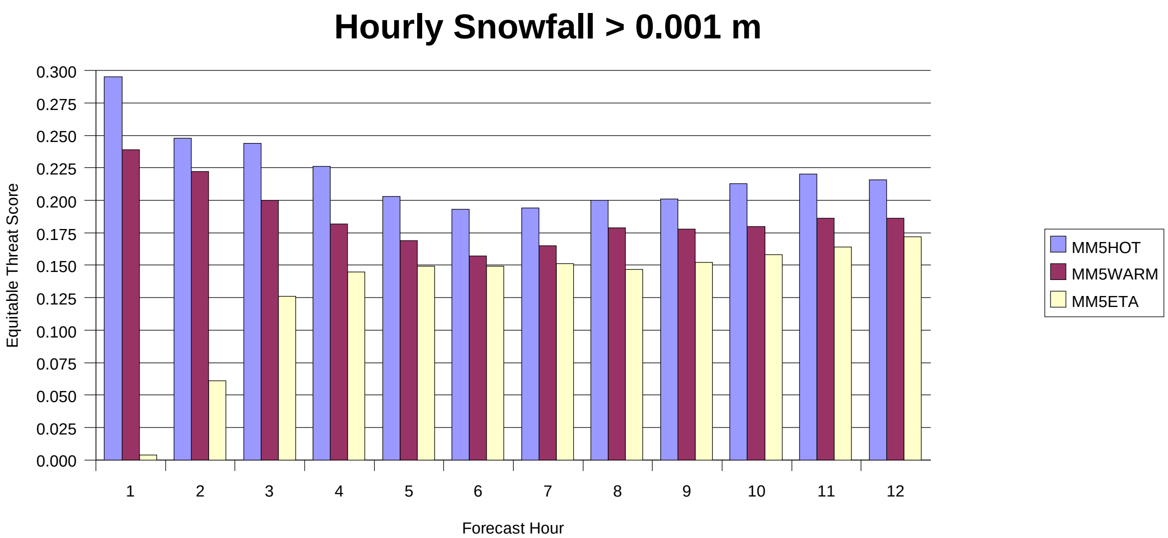

Figure 2. Equitable threat score for hourly snowfall in excess of 1 mm for each model configuration. Values are shown for each hour of the 0−12 h forecast. Higher scores indicate more skill.

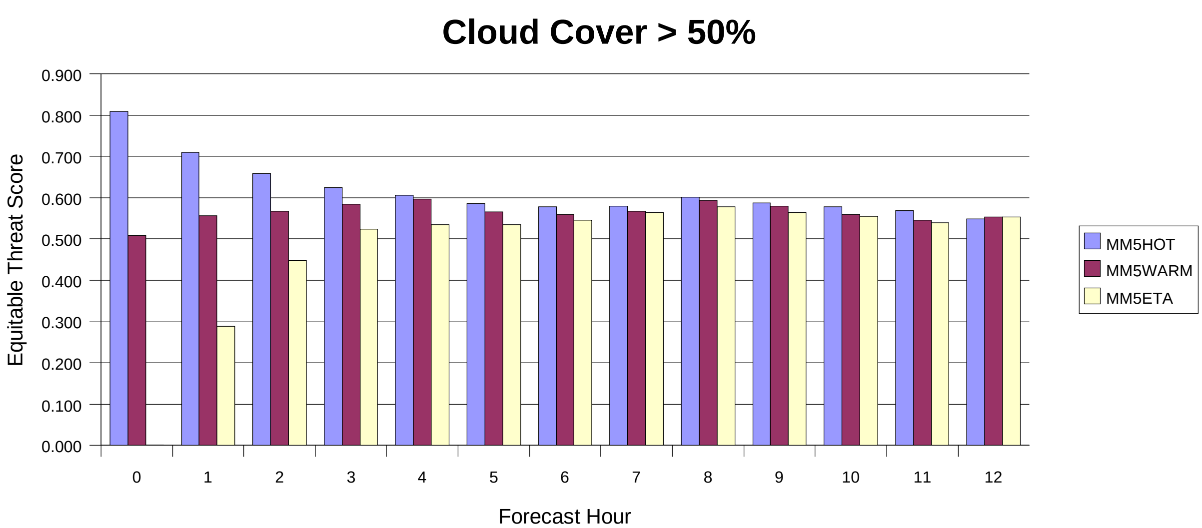

Figure 3. Equitable threat score for cloud cover in excess of 50% for each model configuration. Values are shown for each hour of the 0−12 h forecast. Higher scores indicate more skill.

While not necessarily physically appropriate when running the model at non−cloud resolving resolutions (as is the case here), this adjustment greatly improved the sustainment of the clouds during the early portion of the forecast without any noticeable degradation of the forecasts. However, this is viewed as a short−term corrective action. Although not yet substantiated via the analysis done thus far, the addition of moisture to the analysis (as opposed to a redistribution of existing moisture) may be a partial contributor to the model's tendency to over−forecast precipitation amounts, which has been noted by the operational forecasters (Shaw et al. 2001b). A more appropriate solution should attempt to account for cloud fraction as a function of grid spacing and relative humidity.

5. CONCLUSIONS AND FUTURE WORK

The LAPS diabatic initialization technique shows promise as an efficient and effective means of improving short−range, explicit NWP forecasts of clouds and precipitation. Such a capability could fill the void between nowcasting techniques that perform well in the 0−3 h forecast period and the operational regional and national−scale models that provide the 12 h and beyond guidance.

More generally, this work has highlighted the need to focus on improving microphysical schemes for use on grids that are approaching, but not quite reaching, cloud−resolving resolution. It is imperative that any fields handled by the NWP model in the form of parameterizations be initialized in a manner that is consistent with the parameterization. Work is underway to develop a modified version of the Schultz (1995) scheme to handle cloud fraction in a manner consistent with the LAPS analysis. Additional work will include:

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