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# AN ENSEMBLE STRATEGY FOR ROAD WEATHER APPLICATIONS

Paul Schultz[1]
NOAA Research - Forecast Systems Laboratory
Boulder, Colorado

## 1. INTRODUCTION

In 1999 the Federal Highways Administration (FHWA) initiated a 5-year program to explore the applicability of technologies developed at national research laboratories to the problem of winter road maintenance. The first specific goal was to develop an automated decision support system to generate snow plowing and pavement chemical application guidance for use by state departments of transportation. The project, and the system, were named the Maintenance Decision Support System (Mahoney and Myers 2003).

A block diagram of MDSS is shown in Figure 1. The gridded outputs from an ensemble of mesoscale model forecasts generated by the NOAA Forecast Systems Laboratory (FSL) are transmitted in real time to the National Center for Atmospheric Research's Research Applications Laboratory. There, the FSL models are ingested along with the models produced by the National Weather Service's National Center for Environmental Prediction (NCEP), namely the Eta and Aviation (AVN) models, into the Road Weather Forecast System (RWFS). RWFS uses dynamic model output statistics (DMOS) techniques to optimize forecasts of temperature, wind, humidity, insolation, and precipitation for several dozen prediction points along targeted roadways. Most of these prediction points correspond to the locations of Road Weather Information Systems (RWIS) of automated sensors that provide verification for the RWFS forecasts. The point forecasts generated by RWFS are used to inform pavement temperature and chemical concentration modules developed by the Cold Regions Research and Engineering Laboratory (CRREL). The pavement condition predictions are used with encoded rules of practice, developed by the Massachusetts Institute of Technology Lincoln Laboratories (MIT/LL), to suggest plowing and chemical applications strategies (e.g., "plow Highway 10 three times between midnight and 6 AM and spread 150 lbs of salt per lane mile"). Finally, the weather and guidance information is transmitted to a graphical user interface running on personal computers in the offices of snowplow garage supervisors.

## 2. DEMONSTRATIONS

Development of MDSS has been an iterative process, with successive improvements in all aspects of the system, including the local modeling component (Schultz and Shaw 2005), implemented between field demonstrations.

For the 2002-2003 MDSS demonstration, which was conducted in the vicinity of Des Moines, IA, the FSL model ensemble consisted of three different mesoscale models: MM5 (Grell et al. 1995), WRF (Michelakes et al. 2001), and RAMS (Pielke et al. 1992), configured with nearly identical grids and projections. Lateral boundaries were provided by two different large-scale models (Eta and AVN, as provided by the NWS National Center for Environmental Prediction), for a total of six members. The mesoscale models runs were started following receipt of the NCEP model grids, which at the time were provided four times daily. Each ensemble member was initialized using the LAPS hot-start method of diabatic initialization (McGinley and Smart 2001; Schultz and Albers 2001; Shaw et al. 2001) at 0300, 0900, 1500, and 2100 UTC (3 AM, 9 AM, 3 PM, and 9 PM CST). The models were run out to 27 hours, to provide a 24-hr forecast service.

Changes to the ensemble modeling system were made prior to the 2003-2004 demonstration, also in Iowa, in response to verification statistics (Schultz and Shaw 2005) and practical experience during the prior demonstration. Users' experience with the forecasting services suggested that the local models were adding value mainly in the first 12 hours of the forecast, and the users were displeased with the fact that sometimes the system predictions made large changes when a new set of model runs were provided, which occurred every six hours. Thus, the reconfigured ensemble used two models (MM5 and WRF), both using the same model (Eta, mostly

[1] *Corresponding author address:* Paul Schultz, NOAA/Forecast Systems Laboratory, R/FS1, 325 Broadway, Boulder, CO 80305; *e-mail* paul.j.schultz@noaa.gov

because its grids were available almost an hour earlier than AVN) for lateral boundary conditions, both models reinitialized every hour and run out to 15 hours. The Eta lateral boundaries were time-interpolated for mesoscale model runs not coincident with Eta model runs. QPF verification skill statistics are presented in Figure 3.

This ensemble configuration takes advantage of frequently-updated radar and satellite data, which are the most important inputs for diabatic initialization because of their impact on the specification of cloud parameters. The previous configuration took much less advantage of initialization-related dispersion, since new initializations were performed only every six hours. The current configuration also allows for reduced latency in forecast updates, since fresh information is provided every hour. Whereas, in the previous configuration, forecast information could be as much as seven hours old during certain times of the day, in the current configuration new forecasts arrive each hour, and the complete forecast runs are never more than two hours old.

The current configuration also allows for the application of time-lagged ensembling techniques (e.g., Brankovic et al. 1990), in which the production of, say, a four-hour ensemble prediction uses the current four-hour forecast, the previous five-hour forecast, and the six-hour forecast from the cycle before that, etc. This would seem to violate the requirement that all ensemble members are equally skillful, since forecast skill decreases with lead time, but the earlier forecasts do add value to the final result, and the ensemble forecasts benefit from temporal consistency resulting from hour-to-hour (weighted) averaging of the ensemble members. Figure 2 shows how 1-h QPF skill scores for the 0.01" threshold fall off with lead time. (Note that skill scores fall off monotonically with time, which indicates that precipitation spin-up common to most modeling systems is eliminated by the LAPS hot start method of diabatic initialization.)

This configuration of the MDSS ensemble proved successful enough that it was used for the most recent demonstration, which was conducted in the vicinity of Denver, CO, from October 2004 through April 2005. Verification statistics will be presented at the Conference.

For MDSS, the requirement is for predictions such as probability of precipitation at discrete points; this is done using NCAR's Road Weather Forecast System. However, for many other operational applications there exist requirements for maps (or grids) of probabilistic predictions. Figure 3 shows MM5 forecasts covering Colorado from three successive model runs, all valid at the same time (1600 UTC, 21 September 2004). These images were used in the context of a presentation on probabilistic forecasting given to NWS forecasters to illustrate the opportunity and challenges of using this kind of information in future automated post processing systems that will generate precipitation probabilities as well as probabilities of a large variety of predictands. The Forecast Systems Laboratory has recently initiated a program to develop this type of forecast guidance.

## 3. TACTICAL NWP

One of the most important goals of the Local Analysis and Prediction branch of the Forecast Systems Laboratory is to develop NWP solutions to local, quickly-evolving weather problems. Furthermore, since the client base for any such solution system is unlikely to draw on large resources, we focus our development work on implementations on affordable computers. For example, the MDSS ensemble runs on a Linux-based cluster of 20 processors that can be replaced for about $30,000.

This places great emphasis on computational efficiency not only in the forecast models but also in data collection, data quality control, analysis, model initialization, and post processing. Figure 4 shows the status of those efforts. Model forecasts are available to users less than one hour after the datasets that initialize them. For example, numerical forecasts based on 1200 UTC initialization data (satellites, radars, profilers, aircraft, GPS vapor, surface sensors, etc.) are flowing to users before 1300 UTC; i.e., the 1-h forecast arrives before the datasets that will be used to validate it. By contrast, NCEP's Eta model forecasts begin to arrive 2:15 after the initialization datasets. RUC forecasts from NCEP are intended to improve turnaround time, but there is still 1:20 of latency in those services. Furthermore, LAPS-based model forecasts have consistently demonstrated superior precipitation forecast skill relative to both Eta and RUC in the first hours of integration.

Given that extrapolation-based precipitation forecasting is generally skillful out to 60 to 90 min, it becomes feasible to develop automated extrapolation/NWP-based prediction systems applicable to a variety of weather-sensitive problems on tactical time scales, including highway and aviation traffic management, flash flooding, public event management (concerts, games, etc.), wildfire response, and military operations.

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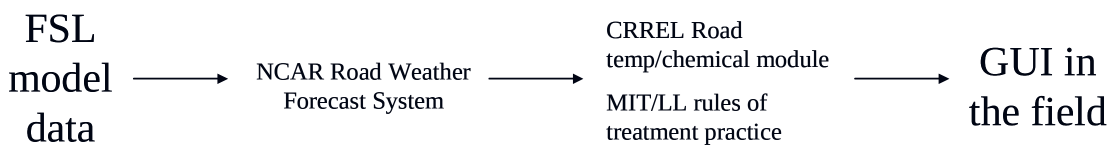


*Figure 1. The components of MDSS, and the laboratories that contributed them.*

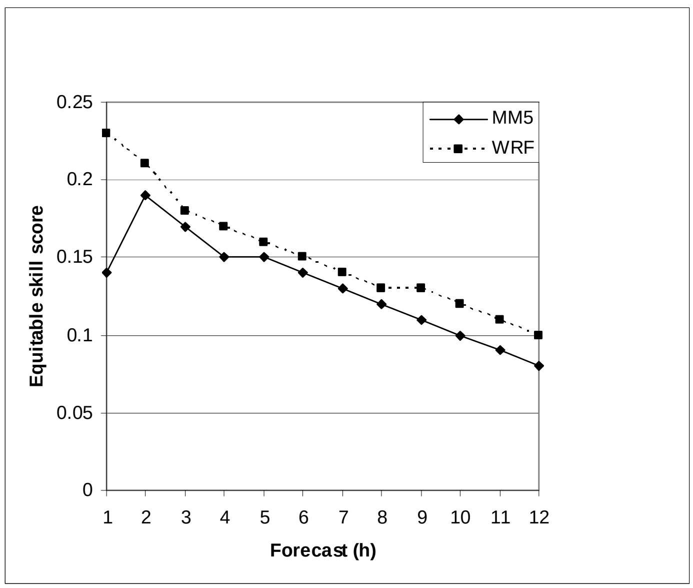


*Figure 2. 1-hr QPF=.01" equitable skill scores during the 2003-2004 MDSS demonstration. The curve for the WRF model indicates that QPF "spin-up" is addressed by the LAPS hot-start method for diabatic initialization. There was an error in the initialization processing that led to the low ESS value in the 1-h MM5 QPF; verification from other experiments (not shown) indicate success similar to the WRF results in the first hour of QPF forecasting by MM5.*

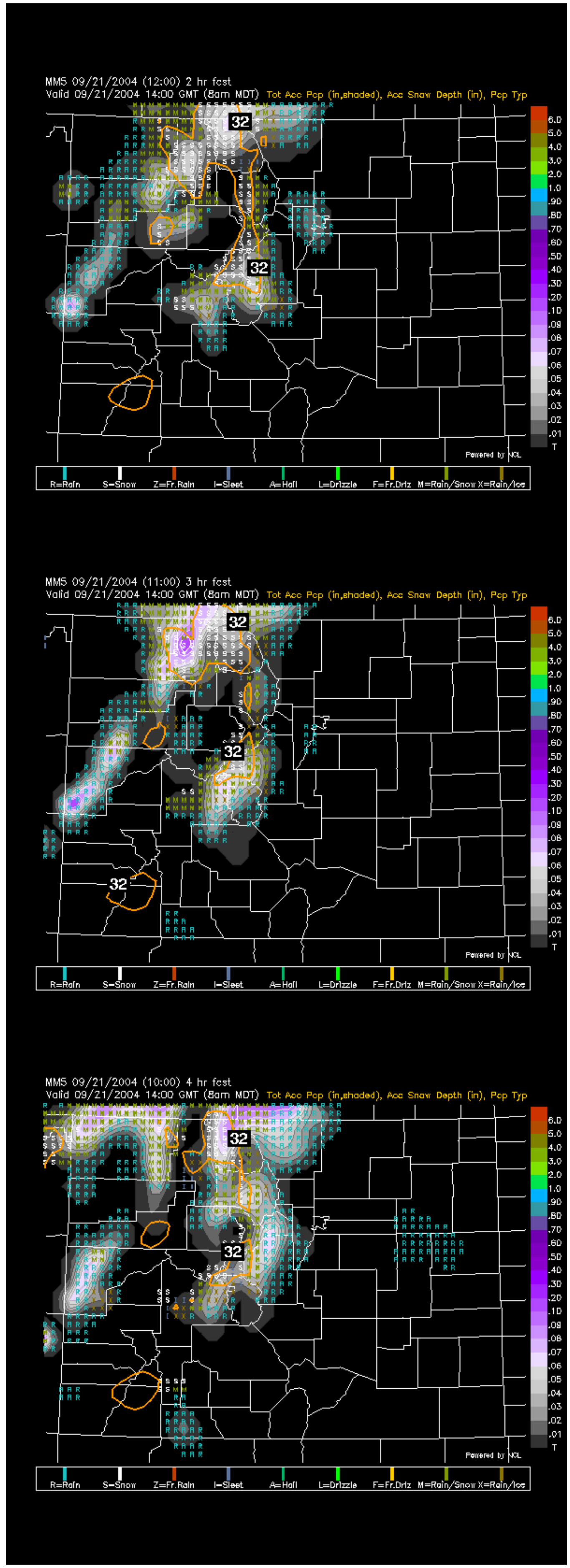


*Figure 3. Three MM5 forecasts, from successive hourly model runs, all valid at the same time (1600 UTC, 21 September 2004), illustrating the opportunities and challenges of automated forecasts of such products as probability of precipitation. The image is 1-h precipitation accumulation; the plotted icons show active precipitation at the valid time of the forecast.*

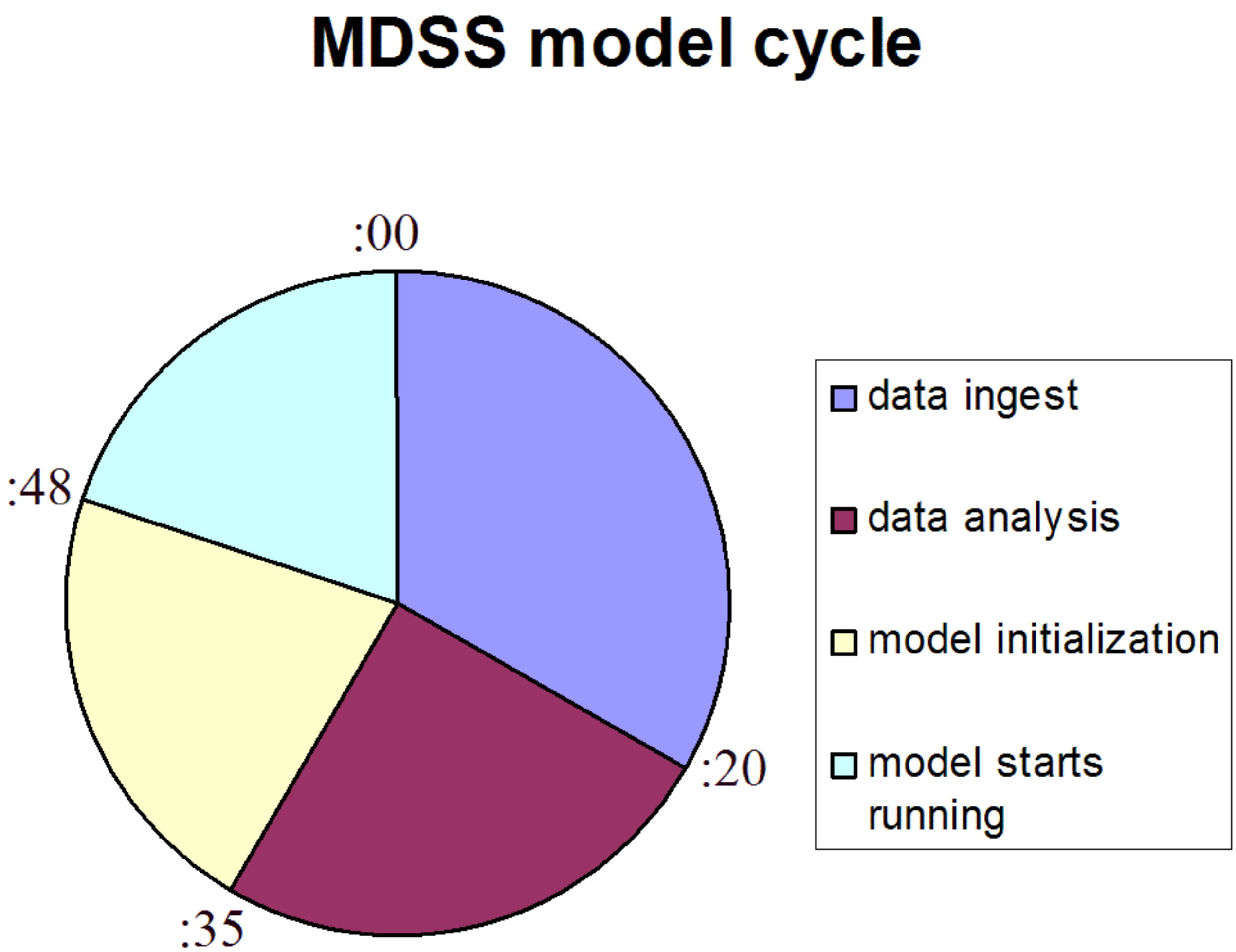


*Figure 4. An MDSS modeling cycle, illustrating FSL's current minimum turnaround time for data ingest, analysis, model initialization, and execution.*