The Evolution of METRo in a Roadway DSS

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Introduction

Throughout the year road maintenance operators face many challenges when making decisions about how to keep the roadways safe during adverse weather and also when to perform general pavement and roadside operations. These decisions have considerable impact on roadway safety and efficiency and poor decisions can have unfavorable safety, economic, and environmental consequences. These decisions are also highly dependent on knowing the projected weather and pavement conditions at the time of operations. Thus, accurate weather and pavement condition forecasts are very important in helping maintenance managers make effective decisions.

Until recently, the road maintenance community has relied on conventional methods of acquiring, synthesizing, and applying road weather-related intelligence in the treatment and operations decision process, which sometimes resulted in poor decisions and wasteful spending (Linden and Petty 2008). In order to provide road operators with better forecast information, the Federal Highway Administration (FHWA) initiated a program in 2001 aimed at winter weather. Through this program, a version of the Maintenance Decision Support System (MDSS) was created at the National Center for Atmospheric Research (NCAR) to provide objective guidance regarding the most appropriate treatment strategies to employ during adverse winter weather events (Linden and Petty 2008).

The MDSS has evolved considerably over the last 8 years and MDSS concepts are now being applied to non-winter decision support systems aimed at helping practitioners make warm season maintenance decisions, such has when to pave, install new signs, and mow or weed along the roadside. This paper describes the use of METRo as a pavement model within the MDSS and the new summer DSS framework, as well as its use as a tool for determining road-temperature quality control (QC) values. Discussion topics include the benefits and limitations of using METRo in a DSS, improvements made to the model by the METRo developers, improvements in the implementation of METRo in NCAR's real-time systems, and the use of METRo in determining quality-check (QCh) values for *Clarus* road-temperature observations. Verification results will also be presented showing METRo's performance during both winter and non-winter months. Based on these results, recommendations are made on how METRo can perform better to the serve the needs of both a winter and non-winter maintenance decision support system.

Background / Current Implementations

In 2001, the MDSS concept came to fruition. FHWA's vision was an automated end-to-end decision support system that had the capacity to provide users with diagnostic and prognostic weather and road condition information, as well as guidance about how to treat roadways prior to and during winter weather events (Linden and Petty 2008). In an effort to create a system that would fulfill this vision, the FHWA initiated the MDSS project. Although the prototype was put together and designed by NCAR, numerous labs contributed to the development of the MDSS including the Massachusetts Institute of Technology – Lincoln Laboratory (MIT/LL), the National Oceanic and Atmospheric Administration (NOAA), and Mixon-Hill, Inc.

The FHWA MDSS Functional Prototype (FP) was released for public use in 2002 and tested for the Iowa Department of Transportation. After considerable research and development, the system was next configured and implemented over Colorado. Since 2004, MDSS has been run operationally by NCAR for the Colorado Department of Transportation and E470. Two years ago, the system was upgraded to provide runway forecasts for Denver International Airport (DIA).

Recently, MDSS concepts were implemented for use in a new project to asses the use of *Clarus* observation data in improving road weather forecasting over Iowa, Indiana, and Illinois. Initially the system is being used to assess whether the addition of *Clarus* observations improve weather and road-temperature forecasts for specific meteorological cases. Eventually the system will be used to provide weather and road forecast information to an operational summer maintenance decision support system that will be implemented in 2010.

The MDSS supplies end users with strategic information in the form of hourly forecasts of atmospheric and road conditions at user-defined locations; forecasts are updated every hour. Since the system utilizes numerical model data, it can be configured to provide forecasts as far out as the longest-range model. The current Colorado implementation goes out 48hour whereas the new summer DSS is configured to go out 162 hours. Atmospheric predictions include, but are not limited to, forecasts of ambient air temperature, dew point temperature, wind speed, and precipitation occurrence, type, and rate. The system also provides probabilities of precipitation and conditional probabilities of precipitation type. Forecasts of road-related parameters such as road and bridge temperature, road mobility, and chemical concentration are also provided to decision makers. The system can also combine predicted environmental and road condition information, along with standard maintenance practices to derive route-specific treatment recommendations (Linden and Petty 2008).

The MDSS has two primary components: a road weather forecasting system (RWFS) and a road conditions and treatment module (RCTM). Figure 1 shows a system overview of the MDSS. The RWFS is based on a point forecasting system called DICast designed at NCAR. The RWFS ingests reformatted meteorological data (observations, models, statistical data, climate data, etc.) and produces meteorological state variable forecasts (e.g., air temperature, dewpoint, wind speed, etc.) at user-defined sites and forecast lead times. A single consensus forecast, created from statistically combining the set of individual forecasts, is provided for each user-defined forecast site and is based on a processing method that takes into account the recent skill of each forecast model. This consensus forecast is nearly always more skillful than any component forecast. The RWFS is designed to optimize itself using available site observations (e.g., RWIS, ASOS, AWOS).

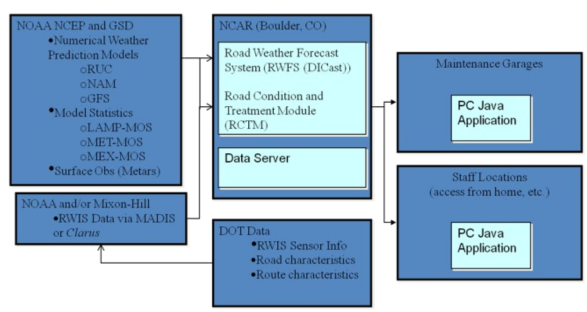

Figure 1. MDSS / Clarus DSS System Overview

The RWFS feeds weather forecast data to the RCTM, which produces road condition forecasts and treatment recommendations. A detailed depiction of the RCTM is provided in Figure 2. Note that the RCTM comprises several modules including a road temperature and snow depth module, net mobility module, rules of practice module, and chemical concentration module. The heart of the RCTM is the pavement model. Up until 3 years ago, the RCTM utilized a pavement model called SNTHERM, but METRo was implemented after support for the SNTHERM model was dropped.

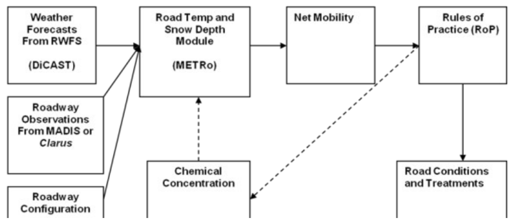

Figure 2. RCTM Overview

METRo Overview

METRo is an operational model developed and used by the Meteorological Service of Canada to forecast local pavement temperatures (surface and subsurface) and road condition. METRo uses road surface observations along with a weather forecast to predict the evolution of pavement temperatures and the accumulation of precipitation on the road (liquid and solid forms) (Linden and Petty 2008).

METRo is composed of three parts: an energy balance module for the road surface, a heat-conduction module for the road material, and a module to deal with water, snow and ice accumulation on the road. In determining the surface energy balance, METRo examines and computes short, long-wave, and turbulent fluxes, as well as the flux related to the phase change of precipitating water. A one-dimensional heat diffusion equation serves as the basis for computing the subsurface temperature profile, with key parameters being heat capacity and ground heat flux. METRo is capable of computing profiles for both roads and bridges. Finally, METRo has the capacity to simulate liquid water and snow or ice on the pavement surface by tracking and calculating key elements such as precipitation, evaporation, and runoff. The removal of snow resulting from the traffic can also be parameterized in the model (Crevier and Delage 2001).

METRo includes an observation assimilation mechanism to help initialize the forecast. This allows the system to be tuned to site-specific observations (Crevier and Delage 2001). The model requires at least some road surface and, if available, subsurface observations to initialize the road temperature profile. This requirement will be discussed in more detail later in the paper. Further METRo documentation is available at http://documentation.wikia.com/wiki/METRo).

Using METRo in a DSS: Challenges, Limitations, and Improvements

As with all forecast models, there are some challenges and limitations associated with using METRo. The issues described herein are related to implementing the model within NCAR's DSS framework(s) but may also pertain to running the model in a standalone mode.

One of the biggest issues with using METRo is the time it takes to run. METRo takes approximately 2 seconds to generate a 48-hour road forecast for 1 site. This can be attributed to the fact that METRo uses the industry standard XML format, and the parsing of XML input files and/or writing the XML output files takes a significant amount of the processing time. It's estimated that METRo's input/output process takes up roughly 90% of the processing time (Linden and Petty 2008). The run time is negligible for a few sites at short forecast lead-times but can become problematic when running over a large number of sites at longer lead-times. Recently this problem became apparent in NCAR's new DSS, which is configured to generate road forecasts out to 162 hours for 150 sites. In the original winter MDSS the system is set-up to recommend treatments during adverse weather and run METRo iteratively to get at the affects the recommended treatment has on the road forecast. In the new DSS, the recommended treatment version of METRo was taking far too long to run for a 162 hour forecast for 150 sites and the developers were forced to use a different configuration that is not as robust. NCAR has explored some ways to make METRo run faster, such as using comma separated (csv) input/output files. This method did improve the run time but was never used operationally because all of the new

METRo releases are still in the standard XML format. The METRo developers are aware of NCAR's research in this area and may be open to making this change to the code in the future.

As mentioned earlier, METRo requires an observational history of the road surface and, if available, the road subsurface. Using this history, METRo generates its own estimate of the current surface to subsurface temperature profile. At least a 2 hour history is required, and a longer history can be utilized and is preferred. This presents a challenge in a real-time system where there is typically latency in the observations. Generating this history also presents a challenge at non-observing sites. In the MDSS, software was developed to create a history (or pseudo-history) from the combination of a previous METRo forecast and recent observations to ensure that there would be an obs-history for all sites including non-observing sites. This original method required a previous road forecast to fill in gaps in the obs-history but this becomes a "chicken and the egg" problem for new sites. In recent years NCAR has made significant improvements to the obs-history software. For new sites (for which there is no previous road forecast), atmospheric forecast data (specifically soil-temperature and air-temperature forecast data) is used to create pseudo road-temperature and subsurface-temperature observations. Forecast soil-temperature is used directly for road surface values and a 24-hour average of the forecast air-T is used to create psuedo subsurface values. This allows the system to produce an initial METRo forecast, then for subsequent runs the system uses the previous METRo forecast to supplement the obs-history. This ensures an obs-history at every site even if the system goes down.

Another issue with METRo is its poor performance during summer. METRo was originally developed for winter road conditions, so it's not that surprising that it has some problems during the warm season. As mentioned earlier, NCAR is using METRo in a new DSS to assess the value *Clarus* observations have on improving the forecast and eventually as a summer DSS. As part of this project several case studies were examined include a few during the summer. The initial verification results show that METRo over-forecasts road-temperatures during the summer. For some of the sites, METRo produced forecast values that were 15-20°C higher than the actual observations. Obviously errors of this magnitude are unacceptable if METRo is going to be used in a DSS that supports summer pavement operations. The METRo developers are aware of this issue and are currently working on improving the model during the warm season.

The ongoing implementation of METRo in NCAR's decision support systems has helped expose some minor bugs and limitations in the METRo code. The METRo developers have been very responsive in addressing these issues and have released several new versions of METRo over the past year that fix these problems.

Using METRo as a tool for road-temperature quality control (QC):

As part of the *Clarus* quality control work, NCAR investigated developing climatological bounds for pavement and subsurface temperature observations. NCAR focused on evaluating METRo in conjunction with extreme values from archived pavement and subsurface temperature observations to develop a set of improved climate range values for the *Clarus* System. The METRo data resulted in improved bounds for pavement temperature QCh, but not for subsurface temperature QCh.

Recent Verification / Performance Assessment:

The verification results are based on METRo's implementation and performance in two of NCAR's decision support systems: the standard winter MDSS over Colorado and the new DSS used for the *Clarus* project over IA, IL and IN.

The verification results for the Colorado MDSS are based on bulk statistics calculated over the entire 2008-2009 winter season. The plots show median average error (MAE) and bias values per lead time out 48 hours. Errors are calculated by taking the difference between the forecast value and the actual point observation value. The point observations come from Road Weather Information Stations (RWIS). The forecast points used in this analysis are at the RWIS locations. The statistics are based on all 12z (5am MST) road-temperature forecasts generated throughout the season, for 10 RWIS sites near Denver.

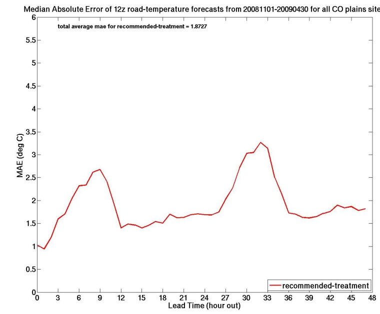

Figure 3. MAE of 12z METRo forecasts from Colorado MDSS

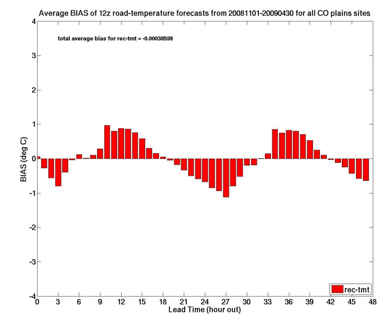

Figure 4. Bias of 12z METRo forecasts from Colorado MDSS

Figure 3 shows that METRo (recommended-treatment) has an MAE of approximately 1.9°C. The largest average errors (2-4°C) occur during the afternoon (lead times 06-12 and 30-36) and this corresponds to the time of maximum solar radiation /heating. During the night METRo exhibits errors less than 2°C. The BIAS plot (Figure 4) shows that METRo has a cold bias in the morning and a warm bias in the afternoon. This suggests that METRo is slightly out of phase with the observed road temperature. It warms the road up too late in the morning and cools the road surface off too late in the afternoon. These results are consistent with previous verification results for METRo.

The first part of the verification from the *Clarus* DSS compares MAE values from forecasts generated with actual observations (rc-rec-tmt-yes-clarus) to forecasts generated with psuedo-observations (rc-rec-tmt-no-clarus). The MAE values are based on all 18z (12pm CST) forecasts generated over three days in June 2008 for 150 Clarus sites in IA, IL and IN. This was for a heavy prolonged rain case in the upper-midwest. The forecasts with observations used road-temperature observations from *Clarus* to initialize the road temperature profile whereas the forecasts without obs used psuedo-observations (based primarily on forecast soil-temperature values) to initialize the road profile. It should also be noted that the weather forecast used to drive METRo were different for each set. The road-forecasts with obs used weather forecasts that were tuned with *Clarus* data whereas the road-forecasts without obs used weather forecast that were not tuned with *Clarus* data.

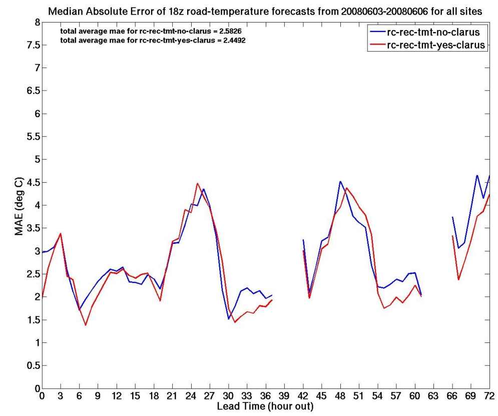

Figure 5. MAE of 18z METRo forecasts from *Clarus* DSS

Figure 5 shows that overall, the average error is less for the forecasts generated using the actual observations. This is most evident in the first 3 hours of the forecast, where having the observations reduces the forecast error by about 1°C. At the later lead times any improvement in the forecast skill can only be attributed to using an improved weather forecast tuned with the *Clarus* observations. It is interesting to note that at the later lead times there is little to no improvement during the afternoon (lead times 0-6, 24-30, etc.) but there is a noticeable improvement during the night (lead times 30-36 and 54-60).

The second part of the verification from the *Clarus* DSS highlight the issue that METRo has problems forecasting road temperature during the summer. The plot shows a forecast versus observations time series for a 72 hour forecast generated at 18z on July 17th, 2008 for a site on IA-9 near Decorah, Iowa. This is for a record high temperature case. The observations come from the RWIS located at this site. Note that the observations are missing beyond 42 hours out. The plot is based on data shown below (only the first 6 hours of text data is shown here to highlight the problem). The columns are: site id, forecast generation date, valid date, valid time (UTC), forecast lead time (hour out), valid unix time (seconds since 1970), forecast value, obs value, error value.

72643086 20080717 20080717 18 0000 1216317600 43.6300 36.0800 7.5500

72643086 20080717 20080717 19 0001 1216321200 45.8300 25.5900 20.2400

72643086 20080717 20080717 20 0002 1216324800 47.3700 24.0600 23.3100

72643086 20080717 20080717 21 0003 1216328400 46.3400 22.6100 23.7300

72643086 20080717 20080717 22 0004 1216332000 43.5700 21.7500 21.8200

72643086 20080717 20080717 23 0005 1216335600 40.3500 22.2600 18.0900

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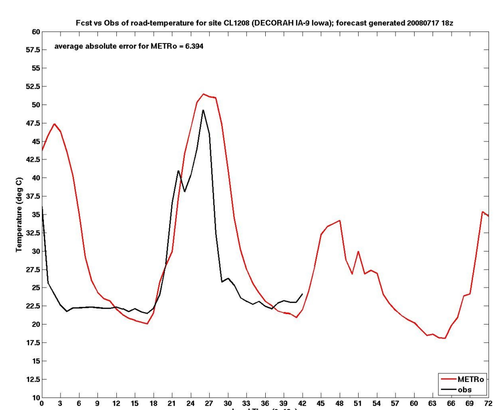

It is evident from both the data and the plot (Figure 6) that METRo quickly diverges from the observation at lead-time 0 and over-forecasts the road-temperature during the afternoon (lead times 01-09 and 24-33) producing errors in excess of

20°C. It should be noted that this is only one forecast for one site and although METRo exhibits similar behavior for other sites, this is an extreme case.

Conclusion / Future Recommendation:

A maintenance decision support system is dependent upon a reliable and accurate pavement conditions model. METRo has proven to be a good pavement model to use in winter decision support systems but there is some uncertainty about using it in a summer DSS.

METRo is easy to install and fairly easy to use in a complex software infrastructure such as NCAR's MDSS. There are some inefficiencies that would make it easier to use in a real-time system. The dependency on a non-missing obs-history can present a real challenge for non-observing sites or new sites. It would be much more ideal if the METRo software internally could come up with a default obs-history if any of the critical observations were missing. The other big issue with running METRo in a real-time system is the length of time it takes to run. It's recommended that the developers move away from the XML input and output format and use a format that is much more efficient, this would improve the run-time significantly.

Figure 5. Forecast vs. Observations of 18z METRo

The biggest concern going into the future is METRo's performance during the summer. In order for METRo to be used in a DSS that supports summer pavement operations it must be able to accurately predict pavement temperatures year around, not just in the winter. It's recommended that the METRo developers improve the model's performance during the warm season. If improvements are made to the model, and it can more accurately predict pavement temperatures during the summer then METRo would be a could fit in all roadway maintenance decision support systems.

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