The Maintenance Decision Support System (MDSS) Project

TECHNICAL PERFORMANCE ASSESSMENT REPORT

IOWA FIELD DEMONSTRATION WINTER 2003

Version 1.1

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## RELEASE NOTES

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<th>Version Number</th>
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<td>Version 1.0</td>
<td>5 September 2003</td>
<td>First version delivered to FHWA for review.</td>
</tr>
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## ACRONYM GLOSSARY

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Description</th>
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<tbody>
<tr>
<td>AMW</td>
<td>Ames, Iowa airport identifier</td>
</tr>
<tr>
<td>AOTR</td>
<td>Agreement Officer’s Technical Representative</td>
</tr>
<tr>
<td>ASOS</td>
<td>Automates Surface Observing System (NWS)</td>
</tr>
<tr>
<td>AVN</td>
<td>National Weather Service model</td>
</tr>
<tr>
<td>AWOS</td>
<td>Automated Weather Observing System (FAA)</td>
</tr>
<tr>
<td>CRREL</td>
<td>U.S. Army Cold Regions Research and Engineering Laboratory</td>
</tr>
<tr>
<td>CTRE</td>
<td>Center for Transportation Research and Education (Iowa State University)</td>
</tr>
<tr>
<td>DMOS</td>
<td>Dynamic Model Output Statistics</td>
</tr>
<tr>
<td>DOT</td>
<td>Department of Transportation</td>
</tr>
<tr>
<td>DSM</td>
<td>Des Moines, Iowa airport identifier</td>
</tr>
<tr>
<td>DSS</td>
<td>Decision Support System</td>
</tr>
<tr>
<td>EMC</td>
<td>Environmental Modeling Center</td>
</tr>
<tr>
<td>EMFP</td>
<td>Ensemble Model Forecast Provider</td>
</tr>
<tr>
<td>ESRI</td>
<td>Environmental Systems Research Institute</td>
</tr>
<tr>
<td>Eta</td>
<td>National Weather Service Model</td>
</tr>
<tr>
<td>ETL</td>
<td>NOAA, Environmental Technology Laboratory</td>
</tr>
<tr>
<td>FAA</td>
<td>Federal Aviation Administration</td>
</tr>
<tr>
<td>FHWA</td>
<td>Federal Highway Administration</td>
</tr>
<tr>
<td>FSL</td>
<td>NOAA, Forecast Systems Laboratory</td>
</tr>
<tr>
<td>FTP</td>
<td>File Transfer Protocol</td>
</tr>
<tr>
<td>GFS</td>
<td>Global Forecast System</td>
</tr>
<tr>
<td>GRIB</td>
<td>Gridded Binary</td>
</tr>
<tr>
<td>HRDO</td>
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<td>HOTO</td>
<td>Office of Transportation Operations</td>
</tr>
<tr>
<td>IADOT</td>
<td>Iowa Department of Transportation</td>
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<tr>
<td>IKV</td>
<td>Ankeny, Iowa airport identifier</td>
</tr>
<tr>
<td>ITS</td>
<td>Intelligent Transportation System</td>
</tr>
<tr>
<td>JPO</td>
<td>Joint Program Office (FHWA)</td>
</tr>
<tr>
<td>LAPR</td>
<td>Local Analysis and Prediction System</td>
</tr>
<tr>
<td>LEDWI</td>
<td>Light emitting diode weather indicator (ASOS sensor)</td>
</tr>
<tr>
<td>LDADS</td>
<td>Local Data Acquisition and Dissemination System</td>
</tr>
<tr>
<td>LDM</td>
<td>Local Data Manager</td>
</tr>
<tr>
<td>MADIS</td>
<td>Meteorological Assimilation Data Ingest System (NOAA/FSL)</td>
</tr>
<tr>
<td>MDSS</td>
<td>Maintenance Decision Support System</td>
</tr>
<tr>
<td>MDSS FP</td>
<td>Maintenance Decision Support System – Functional Prototype</td>
</tr>
<tr>
<td>METAR</td>
<td>Meteorological Surface Observation</td>
</tr>
<tr>
<td>MIT/LL</td>
<td>Massachusetts Institute of Technology - Lincoln Laboratory</td>
</tr>
<tr>
<td>MM5</td>
<td>Mesoscale Model – Version 5 (NCAR &amp; Penn State)</td>
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<td>MOS</td>
<td>Model Output Statistics</td>
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<tr>
<td>NCEP</td>
<td>National Centers for Environmental Prediction</td>
</tr>
<tr>
<td>NSF</td>
<td>National Science Foundation</td>
</tr>
<tr>
<td>NSSL</td>
<td>NOAA, National Severe Storms Laboratory</td>
</tr>
<tr>
<td>NOAA</td>
<td>National Oceanic and Atmospheric Administration</td>
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</table>
NCAR - National Center for Atmospheric Research
NVD - Non-Verifiable Data
NWP – Numerical Weather Prediction
NWS – National Weather Service
OCD – Operational Concepts Description
QPF – Quantitative Precipitation Forecast
RAMS – Regional Atmospheric Modeling System (Colorado State University)
RCTM – Road Condition & Treatment Module
RMSE – Root mean squared error
RWFS – Road Weather Forecast System
RWIS – Road Weather Information System
RWMP - Road Weather Management Program
STWDSR - Surface Transportation Weather Decision Support Requirements
UTC – Universal Time Coordinated (same as Greenwich Mean Time)
VAMS - Value Added Meteorological Services
WIST-DSS - Weather Information for Surface Transportation Decision Support System
WMO – World Meteorological Organization
WRF – Weather Research & Forecasting Model
Z – Zulu time (same as Greenwich Mean Time)
ACKNOWLEDGEMENTS

The development of the MDSS concepts and functional prototype is a team effort involving several U.S. national laboratories, several State DOTs and the University of Iowa Center for Transportation Research and Education (CTRE). Each national laboratory has contributed by providing technologies that support MDSS objectives. The authors are particularly grateful to George Koenig and George Blaisdell (CRREL), Robert Hallowell (MIT/LL), Paul Schultz (NOAA/FSL), and John Cortinas (NOAA/NSSL). The MDSS development team at NCAR consists of several scientists, software engineers and managers including Paddy McCarthy, Arnaud Dumont, Jim Cowie, Ben Bernstein, Jamie Wolff, Jamie Yee, Claudia Tebaldi, Seth Linden, Sue Dettling, and Bill Mahoney. The development team appreciates the field support provided by CTRE, particularly Dennis Kroeger.

The FHWA’s Office of Transportation Operations, Road Weather Management Program, sponsors this project. The MDSS development team is grateful for the leadership provided by Shelley Row, Paul Pisano, Henry Lieu, Rudy Persaud, and Andy Stern. More than twenty State DOTs have been active participants and their feedback has been critical.

The MDSS Iowa demonstration could not have been conducted without the hard work of staff from the Iowa Department of Transportation (IADOT). We want to give special thanks to Dennis Burkheimer, Paul Durham, Edward Mahoney, and Richard Hellund.

The project development team would like to thank Curt Pape (MN-DOT), Steve Conger (formerly UT-DOT), Bill Brown (formerly WA-DOT), and Ken Kyle (NH-DOT) for helping in the design of the MDSS user interface.
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1 PURPOSE

This document describes the technical performance of the prototype MDSS weather and road condition prediction products and treatment recommendations based on the winter 2003 Iowa field demonstration. For detailed information on the winter 2003 Iowa field demonstration, the reader is directed to the document titled “Winter 2003 Field Demonstration & Evaluation Plan” dated 27 January 2003 (reference provided in Table 1). Technical points of contact for the prototype MDSS Project are provided in Appendix A. A map showing the Iowa roads and local weather observations (ASOS and RWIS) used for the winter 2003 MDSS demonstration is provided in Appendix B.
2 INTENDED AUDIENCE

The intended audiences of this document are persons directly involved in the MDSS field demonstration (e.g., FHWA, Iowa State DOT, National Laboratories), stakeholders with an interest in the MDSS project (private sector meteorological service providers and State DOTs), and casual observers who wish to follow developments related to winter road maintenance technologies. The reader should have a working knowledge of meteorological verification methods and statistical analysis.
3 BACKGROUND

This MDSS Project is part of a federal procurement for research projects and deployment advocacy, which is funded through the Intelligent Transportation System (ITS) Joint Project Office (JPO) of the FHWA.

It is envisioned that components of the prototype MDSS system developed by this project will be further developed, integrated with other operational components, and deployed by road operating agencies, including State Departments of Transportation (DOTs), and generally supplied by private vendors (often called Value Added Meteorological Services or VAMS).

Five national research centers have participated in the development of the MDSS Functional Prototype (FP). The participating national labs include:

- Army Cold Regions Research and Engineering Laboratory (CRREL)
- National Center for Atmospheric Research (NCAR)
- Massachusetts Institute of Technology - Lincoln Laboratory (MIT/LL)
- NOAA National Severe Storms Laboratory (NSSL)
- NOAA Forecast Systems Laboratory (FSL)
4 RELATED DOCUMENTS

For additional information on the MDSS Project, the reader is directed to the related project documents and web sites listed in Table 1.

Table 1. MDSS Project Related Documents

<table>
<thead>
<tr>
<th>Document and/or Web Sites</th>
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<td>STWDSR– Version 1.0 (Needs Analysis)</td>
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<td>STWDSR--Preliminary Interface Requirements (PIR), Version 2.0</td>
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<td>Maintenance Decision Support System (MDSS) Project Web Site at FHWA:</td>
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<td>Maintenance Decision Support System (MDSS) Project Web Site at NCAR:</td>
<td>National Center for Atmospheric Research</td>
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<tr>
<td>Maintenance Decision Support System (MDSS) Winter 2003 Field Demonstration &amp; Evaluation Plan</td>
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5 INTRODUCTION

This document provides objective and subjective verification of winter 2003 MDSS weather forecasts and road treatment recommendations, respectively. In addition, analyses of the road temperature model and rules of practice components are provided.

Surface weather observation quality is assessed via coincident observations of state and road parameters. Differences apparent in the observations, themselves, set a lower bound for the accuracy one can expect from the MDSS forecasts, for if the observations can only be measured within a certain tolerance, then differences between such observations and the MDSS forecasts are attributable to the uncertainty in the observations themselves.

Objective verification is achieved via direct comparisons of MDSS forecasts and observations from National Weather Service and RWIS weather stations, including scatter diagrams, and overall values of RMSE and bias for state parameter fields (e.g. air temperature, wind speed) as well as road temperature. The complexity and subjective nature of the verification of road treatment recommendations lends itself well to a case-study approach. This approach places the recommendations into the necessary context of the forecast, itself, as well as the actual conditions that occurred. Contrast between the forecast and reality are often at the root of differences between the recommended and actual treatments. Several case studies are presented here, including both light and heavy precipitation events, and one that includes important changes in precipitation type.
6 PERFORMANCE RESULTS

6.1 Observation Quality

In this section, coincident observations from National Weather Service (NWS) METAR stations and Iowa DOT RWIS sites are compared. Differences can be attributable to slight differences in location (geographic, elevation, shielding/blocking for wind, low/high spots for air temperature), instrument type and instrument quality. While NWS sites are usually placed within large open spaces on airport grounds, RWIS sites are often located near bridges, hills, groves of trees, etc. Both instrument suites are calibrated, but the calibrate practices and expectations are different.

Comparisons were made between NWS and RWIS sites for Ames, Des Moines and Ankeny, Iowa. The Ames RWIS site was located along I-35, about 2 miles to the northeast of the NWS site at Ames Airport, and just north of the I-35/US-30 interchange (see Appendix B). The Ankeny RWIS site, near Des Moines, was also located along I-35, just to the north of the NWS site at Ankeny Airport, and to the north of the I-80/I-35 interchange.

To gather some information of the accuracy of road temperature measurements, data from two temperature sensor ‘pucks’ located along the surface (non-bridge) of I-80 are compared. Also, an Iowa DOT comparison between puck measurements and a hand-held radiometer will be summarized.

6.1.1 Air Temperature

Surface air temperature is important for correctly forecasting precipitation type and for thermal interactions with the road surface, especially bridges. In general, NWS and RWIS observations matched quite well, with most coincident observations matching within 2.5°C. At Ames, the RWIS site observations tended to be slightly warmer than those from the NWS site, usually by 1-2°C (Figure 1). The Ankeny stations had the reverse, with RWIS observations tending to be cooler than NWS observations. No systematic differences were noted at Des Moines. Comparison between the Ankeny and Des Moines NWS observations show no systematic differences, either, implying that the Ankeny RWIS station may be under reporting air temperature.
Figure 1. NWS METAR and RWIS temperature scatter plots for Ames (AMW), Ankeny (IKV) and Des Moines (DSM). The +/− 2.5°C thresholds are shown.
6.1.2 Relative Humidity

Relative humidity (RH) is important for forecasts of fog, ceiling height and frost, and can have an impact on evaporation and sublimation aspects of precipitation forecasts. Because NWS temperature and dew point measurements are reported in degrees Celsius, rounded to the nearest degree, there is a tendency for banding of the RH around certain values. This is especially true for high RH situations when the dew point depression is less than about 3°C and temperatures tend to hover within a given range (within 10°C of freezing during winter and spring periods of precipitation). When drier conditions are present, the banding is less evident because a wider range of temperatures and dew point depressions are present. RWIS temperature and dew point data are reported in 0.1°C increments, minimizing such banding in their values. The comparison chart for Ames (Figure 2) nicely demonstrates this issue. Despite this, RH measurements were typically within 10% of one another. This was true at Des Moines and Ankeny, as well, though the Ankeny METAR RH values were often 10-15% higher than the RWIS RH values when the RH was below about 50%.
RH Comparison for IKV METAR and vs Ankeny RWIS

RH Comparison for DSM METAR and vs Des Moines RWIS

Figure 2. Relative humidity scatter plots for AMW, IKV and DSM. The +/- 10% thresholds are shown.
6.1.3 Wind Components and Wind Speed

Wind is important for predictions of drifting and blowing snow, likely a future component of the MDSS. Because of the discontinuous nature of the wind direction field, it is best to compare wind data via its individual u and v components. The u and v components represent the east-west and north-south wind components, respectively. In general, the wind component measurements were within 2 ms$^{-1}$, however there were some exceptions (Figure 3). The Ames RWIS tended to show somewhat more negative v-components in situations with a strong northerly wind component, while southerly components were quite similar. Ankeny had a similar trend with easterly winds, with larger negative u-component values when a strong easterly component was present. There was a good bit of scatter for both the u and v components between the two Des Moines sites.

Wind speed comparisons generally showed matching within 2 ms$^{-1}$, but the DSM NWS site tended to report higher speeds than the RWIS site, especially at relatively low wind speeds (<6 ms$^{-1}$) as shown in Figure 4. This may indicate that the DSM RWIS site has a slight under exposure issue. The reverse is true at Ankeny, perhaps indicating the same issue at the NWS site. Instrument problems and differences may also have contributed. For the most part, wind values seem to be accurate within a few meters per second, except at DSM, where it is unclear whether the NWS, RWIS or neither sites’ wind observations are comparable within several meters per second. This may simply be due to siting differences.
U-Comp of Wind comparison for AMW METAR vs Ames RWIS

V-Comp of Wind comparison for AMW METAR vs Ames RWIS
U-Comp of Wind comparison for IKV METAR vs Ankeny RWIS

V-Comp of Wind comparison for IKV METAR vs Ankeny RWIS
Figure 3. U and V wind component scatter plots for AMW, IKV and DSM. The +/- 2m/s thresholds are shown.
Wind Speed Comparison for AMW METAR vs Ames RWIS

Wind Speed Comparison for IKV METAR vs Ankeny RWIS
Figure 4. Wind speed scatter plots for AMW, IKV and DSM. The +/- 2m/s thresholds are shown.
6.1.4 Cloud Cover and Precipitation

The cloud cover and precipitation fields are important for correctly getting the energy balances at the road surface, for downstream buildup of precipitation (and its type) on the road, and for subsequent treatment recommendations. There are several reasons why it is unwise to compare NWS and RWIS observations of cloud cover, precipitation amount and precipitation type. RWIS stations do not report cloud cover, so there is no way to directly compare cloud cover observations. NWS ASOS stations do not accurately indicate liquid equivalent precipitation during snow events because of problems with the heated tipping bucket gauge\(^1\). During multiple events, including one that resulted in \(~13''\) of snow, the reported liquid equivalent during the snow portion of the event was nil. At this time, we do not have an assessment of the quality of RWIS precipitation amount measurements in snow situations. Thus, there is no point in comparing the observations.

During the winter 2003 MDSS field demonstration in Iowa, several precipitation events were under-reported by NWS ASOS systems and at least one significant event was missed entirely. An under-reported event is defined as an event where light snow was known to be falling for several hours before any liquid was recorded. A missed event is an event where no liquid was recorded during the entire event. To further demonstrate the problems with the ASOS tipping bucket gauges, data from an example case is described below. The February 14-15, 2003 case began as rain, and then changed over to snow (see observations below), which was moderate and even heavy at times, and accumulated up to a foot or more in places. ASOS observations from Des Moines show that the ASOS tipping bucket captured the rain, but after the snow began, no liquid was reported by the gauge. Observations here extend through 12 UTC, but this problem persisted throughout the event. Similar problems were observed during every snow event during the MDSS demonstration, regardless of snowfall intensity.

There are numerous examples where the instruments reported present weather (snow and/or rain) and little or nothing in the way of accumulated precipitation.

\(^1\) The NWS is aware of the problems that the current tipping bucket technology has measuring winter precipitation and have announced a plan to upgrade ASOS sites with weighing gauge technology.
Accumulated precipitation field groups are reported as “Prrrr” for hourly precipitation amounts in tens and hundredths of an inch and “6RRRR” for 6 hour total precipitation amounts (including water equivalent) in the 00, 06, 12 and 18 UTC reports and 3 hour totals in the 03, 09, 15, and 21 UTC reports. A trace is reported as “P0000” and “60000”.

Examples of reporting discrepancies are provided below:

KDSM 1554 5 1010.3 29.81 1 -2 080 8 -99 -RA OVC011 AO2 RAB12 SLP103 P0000
T00601022=
KDSM 1654 7 1010.3 29.81 2 -2 090 11 -99 OVC013 AO2 RAE10 SLP103 P0001 T00171022=
KDSM 1716 6 -999.9 29.81 2 -1 090 7 -99 -RA OVC015 AO2 RAB04 P0000=
KDSM 1754 6 1009.7 29.79 2 -1 090 11 19 -RA OVC015 AO2 RAB04 SLP097 P0000 60001
T00221006 10022 20000 57012=
KDSM 1854 6 1009.0 29.78 2 -1 090 11 19 HZ OVC015 AO2 RAE47 SLP090 P0000
T00221006=
KDSM 1954 6 1008.2 29.75 2 -1 080 12 20 -RA BR OVC015 AO2 RAB00 SLP082 P0001
T00171006=
KDSM 2054 4 1008.2 29.75 1 -1 090 12 19 -RA OVC015 AO2 SLP082 P0001 60002
T00601006 56015=
KDSM 2133 4 -999.9 29.74 1 -1 080 11 22 -RA OVC013 AO2 P0001=
KDSM 2154 3 1008.1 29.75 1 0 070 13 19 -RA OVC011 AO2 CIG 007V014 SLP081 P0002
T00060000=
KDSM 2203 3 -999.9 29.74 1 -1 070 15 22 -RA BR OVC009 AO2 CIG 007V014 P0000=
KDSM 2254 2.5 1009.0 29.77 1 -1 080 16 22 -RA BR OVC009 AO2 CIG 006V012 SLP090
P0007 T0061006=
KDSM 2313 3 -999.9 29.77 0 -1 070 17 24 -RA BR OVC009 AO2 CIG 006V013 P0002=
KDSM 2354 5 1009.8 29.79 1 -1 070 17 25 -RA BR OVC011 AO2 PK WND 07026/2340
SLP098 P0004 60015 T0061006 10022 20000 53015=
KDSM 0154 1 -999.9 29.87 0 -1 070 16 23 -SN BKN007 OVC011
KDSM 0254 .75 1013.0 29.89 0 -1 070 20 28 -SN BKN007 OVC012 AO2 PK WND
07029/0225 CIG 004V010 SLP130 P0000 60003 T10061011 51031=
KDSM 0354 .75 1013.8 29.91 0 -1 070 14 26 -SN BLSN OVC006 AO2 PK WND 08028/0341
SLP138 SNINCR 1/2 P0000 T10061011=
KDSM 0454 .75 1014.4 29.93 0 -1 060 16 22 -SN OVC006 AO2 PK WND 07028/0442 SFC
VIS 1 1/2 CIG 005V010 SLP144 P0001 T10061011=
KDSM 0554 .25 1014.9 29.95 -2 -2 060 15 26 +SN SCT002 OVC008 AO2 PK WND
06026/0550 SLP149 SNINCR 2/3 4/003 P0000 60004 T10171022 1006 21017 400221017
51019=
KDSM 0654 .75 1015.7 29.97 0 -3 050 17 23 -SN BLSN FEW002 BKN008 OVC012 AO2 PK
WND 06027/0601 SLP157 SNINCR 1/5 P0000 T10221028=
KDSM 0754 .75 1016.9 30.00 -3 -3 050 18 24 -SN BLSN FEW003 BKN007 OVC012 AO2
SLP169 P0000 T10281033=
KDSM 0827 1.2 -999.9 30.02 -3 -4 060 19 26 -SN BLSN FEW003 OVC009 AO2 PK WND
06026/0824 P0000=
KDSM 0832 1.5 -999.9 30.01 -3 -4 060 19 26 -SN BLSN SCT007 OVC012 AO2 PK WND
06026/0824 P0000=
KDSM 0839 1.7 -999.9 30.01 -3 -4 050 23 29 -SN BLSN BKN009 OVC014 AO2 PK WND
06029/0838 P0000=
During the 63-day field demonstration, 11 winter storm events occurred in the Des Moines and Ames, Iowa region. Seven of the 11 events contained significant periods where snow or mixed precipitation occurred and zero liquid equivalent was reported by the ASOS for the entire event.

The lack of credible winter precipitation data from automated weather stations poses a significant problem for the MDSS. The MDSS, for example, uses a data fusion technology that tunes itself depending on the recent prediction skill of individual forecast modules. The MDSS optimizes forecasts by; 1) generating statistical relationships between observations and predictors, and 2) giving more weight to forecast modules that have more skill. The calculation of skill requires accurate observations of the parameter being predicted. If the observation data are not available for a given parameter, the system will not tune itself properly resulting in a less skillful prediction. A worse condition is when observation data are available, but of poor quality or outright bad. If this situation occurs, the system could tune itself in the wrong direction, which would result in very poor performance. For winter road maintenance, accurate observations of precipitation type and liquid equivalent rate are critical. These are two of the most poorly observed parameters.

6.1.5 Road Temperature

Road temperature is one of the most important parameters to forecast correctly, yet it is also one of the most difficult to measure and forecast. It is measured using
temperature sensors (hereafter referred to as “pucks”) embedded within the pavement. Expected errors reported in these measurements are on the order of a few degrees Celsius.

At most RWIS sites, multiple pucks are used to measure pavement and bridge temperatures, often on multiple roads at an interchange. One site within the MDSS demonstration area had two pucks embedded within the same pavement type, in non-bridge situations, along the east- and west-bound lanes of I-80, at the Altoona interchange with US-65 (Figure 5). Time-series charts for the demonstration period show that the two pucks track each other very closely, and a scatter plot shows that most observations are well within 2°C of one another, though the I-80 eastbound sensor appears to read a bit warmer than the westbound sensor (Figure 6). There do not appear to be any significant differences in the measurements with changes in cloud cover, occurrences of precipitation or its type. The sensors do appear to match most closely when temperatures are around or below freezing, which is the range of particular interest for this program. Overall, the puck-to-puck comparison is quite good.

Although the two pucks may compare quite well, the sensors could still have measurement flaws that are present in both pucks. Iowa DOT personnel performed a comparison between puck road temperature reports and independent measurements made with an infrared radiometer. This was done (by request) at multiple sites around the demonstration region, in different pavement types and different weather/surface situations during February and March 2003. Comparisons tended to be best when skies were cloudy and the pavement was either wet or damp, with differences of less than 2°C in most cases. Clear sky and daytime situations brought about the greatest discrepancies between the observations, with many differences on the order of 4-5°C. It is impossible to be certain if the measurements from the puck, the radiometer, or perhaps both instruments, are accurate. However, the test does indicate that they were most consistent when the weather conditions were of greatest interest for winter highway maintenance.
Figure 5. RWIS road temperature measurement locations at Altoona interchange
Figure 6. Time-series and scatter plots for I-80 east and west bound road temperature measurements.
6.2 Verification of FSL’s Ensemble of Mesoscale Forecast Models

For the 2003 MDSS demonstration, the FSL model ensemble consisted of three different mesoscale, or regional models (MM5, WRF, and RAMS) with lateral boundaries provided by two different large-scale models (Eta and AVN), for a total of six members. The large-scale models were provided by the NWS National Center for Environmental Prediction via NOAAport. The regional modeling domain is illustrated in the figure to the right. This is an image of a forecast surface temperature with wind barbs plotted and contours of relative humidity overlaid, an example of how the MDSS model outputs were presented in real time on FSL’s web page.

The mesoscale model runs were kicked off following receipt of the NCEP models, which are provided four times daily. Each ensemble member was initialized using the LAPS hot-start method of diabatic initialization 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.

The MDSS model forecasts are evaluated by comparisons against observations of surface temperature, wind, dewpoint (humidity) and precipitation. Although the observations are taken hourly, for the 2003 demo the model outputs were provided in 3-h increments. Hourly precipitation observations were binned for comparison to 3-h model precipitation accumulations.
The following sections present statistical summaries of the model forecast verification. The object of verifying these or any forecasts is to determine if predictors are adding quality to the forecast service. The concept behind ensemble modeling is that a properly combined group of forecasts can provide a better forecast than any single predictor in the ensemble. However, for this advantage to be consistently realized, the ensemble should consist of predictors (model forecasts) each of which is equally likely to be the most accurate predictor for a given forecast event. Furthermore, the ensemble members should be as different as possible, so that errors among the different models are uncorrelated. In other words, if the models are all making the same kinds of errors for the same reasons, the ensemble forecast will not be optimum. Thus, verification efforts are also aimed at determining progress toward the goal of good dispersion among the ensemble members. The design of an ensemble, and the methods to evaluate it, depend greatly on the forecasting requirements. Leading up to the 2003 demo, the MDSS objectives were oriented toward improvements in the 12-24 h range, to assist in planning shift staffing, materials management, etc. However, during the demo it became apparent that the greater need and opportunity may be in the shorter time ranges, perhaps the 2-12 h forecasts, particularly in the starting and ending times of precipitation events. Some of the comments of assessment to follow reflect this shift in emphasis.

6.2.1 State Variables

Six-hour forecast verification statistics (rms and bias) for the state variables temperature, wind speed, and dewpoint are given in Table 2:
Table 2. Verification statistics for the mesoscale models run for the MDSS.

<table>
<thead>
<tr>
<th>Model Configuration</th>
<th>Temperature (K)</th>
<th>Wind speed (m/s)</th>
<th>Dewpoint (K)</th>
</tr>
</thead>
<tbody>
<tr>
<td>MM5-AVN</td>
<td>3.1</td>
<td>-0.7</td>
<td>2.5</td>
</tr>
<tr>
<td>MM5-Eta</td>
<td>3.0</td>
<td>-0.5</td>
<td>2.5</td>
</tr>
<tr>
<td>RAMS-AVN</td>
<td>5.8</td>
<td>-1.1</td>
<td>2.6</td>
</tr>
<tr>
<td>RAMS-Eta</td>
<td>5.9</td>
<td>-1.1</td>
<td>2.6</td>
</tr>
<tr>
<td>WRF-AVN</td>
<td>3.1</td>
<td>-0.4</td>
<td>2.4</td>
</tr>
<tr>
<td>WRF-Eta</td>
<td>3.1</td>
<td>-0.4</td>
<td>2.4</td>
</tr>
</tbody>
</table>

Several trends are apparent. All the model configurations produced forecasts with a positive wind speed bias and somewhat similar rms errors. The RAMS model configurations have significantly larger errors in temperature and to a lesser extent, dew point temperatures. All the models made too cold, 6-hr forecasts.

The deviations between configurations that are different only in the lateral bound models are very small compared to deviations among configurations with different mesoscale models. This conclusion is somewhat disappointing from the perspective of building a robust ensemble, because it is likely that such model pairs are making the same errors and thus add little dispersion to the ensemble. To illustrate this problem more clearly (see Figure 6.2a), we computed temperature statistics for only the 0300 UTC (9 pm CST) model runs, which demonstrates how the various models handle the diurnal temperature wave. The red curve is simply the observations of temperature at all the reporting stations in the forecast domain. Note that both of the MM5 curves track quite close to each other, and the same is true for the two WRF curves, and the two RAMS curves. This clearly indicates that varying the lateral bounds models (Eta, AVN) has little effect on adding dispersion to this ensemble.
Figure 6.2a. Observed air temperature vs. predicted air temperature for the FSL model ensemble.

Direct, formal statistical comparisons with the NCEP model services were not conducted for the 2003 MDSS demo (although this is planned for the 2004 demo). However, for the purposes of rough comparison, Figure 6.2b from the NCEP web page is provided. These statistics are computed over all 0000 UTC model runs from the month of March 2003. Also, they are computed over a slightly different domain and go out to 48 h, so while there are significant differences in the information being shown, the basic indication that the NCEP models are quite accurate for temperature forecasts: about 2 degrees C rms vs. about 3C rms for the MDSS models. The NCEP models are also more accurate than the mesoscale models in humidity forecasts (but not wind). This comes as no surprise; the surface fields area was not expected to be an area in which the regional models would add much value. This is because the NCEP models have surface flux
formulations that are closely tied and tuned to their respective Land Surface Modules (LSMs), which characterize the earth surface by vegetation type, roughness, albedo, moisture content, land use, etc. By contrast, the regional models inherit surface information from the NCEP models and use different surface flux formulations. We point this out because the **LSM coupling with the WRF model is seen by the WRF modeling community as an opportunity for significant progress in forecasting surface state variables in regional weather modeling in the next few years.**

The biases in the model predictions can be removed to some degree through post processing. A model output statistics (MOS) process is used in the RWFS to improve the performance of individual model predictions.

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**Figure 6.2b.** RMSE comparison between NCEP models for temperature.
6.2.2 Precipitation Verification.

Figure 6.2c show 3-hr precipitation verification. The statistics are nearly identical for model configuration pairs that differ only in their lateral bounds models and are not shown separately. In the top frame, it is clear that the MM5 and WRF configurations make similarly skillful precipitation forecasts, and much better than the RAMS forecasts for light amounts, whereas the RAMS forecasts appear to be somewhat better for larger amounts. The RAMS model has a very large over-forecasting bias (too much precipitation predicted). Regular visitors to the model output display web site find this bias obvious in virtually every model run. While the WRF model has a moderate bias problem, the MM5 bias values are nearly perfect (1.0 at all levels). We have reason to believe that microphysics parameterizations in the WRF and RAMS models can be optimized to improve their bias problems.
The similarity between precipitation forecasts from model runs that differ only in the lateral bounds models may be best illustrated by example. Figure 6.2.d shows six 27-hour run-total precipitation accumulation images for the same case. The top row contains MM5 results, the middle row is WRF, and the bottom row is RAMS. The left column contains results from models that used Eta lateral boundary conditions, the right column is AVN. Clearly, each model run from a given mesoscale model is quite similar to its counterpart with other lateral boundaries. The variety of “opinions” coming from the various mesoscale models is the dispersion we seek for a well-designed ensemble modeling system.
Figure 6.2d. Example of differences between precipitation forecasts between the MM5, WRF and RAMS models for the same case from spring 2003.
We have not included a graphic of the NCEP model performance because the precipitation forecast performance of those models is not organized in a similar manner. However, direct head-to-head comparisons were conducted during a separate experiment during the summer of 2002 that indicated a distinct advantage of the diabatically-initialized regional models compared to the NCEP services. Even if the skill advantage for the mesoscale models is not as pronounced for the wintertime context (we believe it is), they can provide the advantages of finer temporal definition of precipitation events, and they can provide explicit precipitation-type forecasts. Unlike the regional models, the NCEP models do not use continuity equations for various precipitation types; instead there is a single precipitation variable, and the precipitation type is determined as a post-process by considering surface temperature and humidity.

6.2.3 Model System Design for the 2004 Demo

Following statistical evaluation of the models’ performance during the 2003 MDSS demonstration, we have begun experiments with alternate configurations of the ensemble modeling system. The pertinent lessons learned were:

1) Using two different models (AVN and Eta) for lateral boundary conditions did not provide much diversity.
2) The models did not provide much added value beyond 18 hours.
3) The RAMS model routinely had large errors in precipitation and temperature.
4) The WRF model generated too much precipitation.
5) The 3-hourly model output frequency was inadequate to convey the timing of fronts, snowbands, etc. at the precision these models are capable of.

In light of this experience, we are considering a strategy to take better advantage of what these models do best, which is exploit more of the available observations (particularly radar and satellite) to improve forecasts in the range up to 12 hours. One candidate configuration consists of running MM5 and an improved version of WRF every
hour and using “time-lagged” ensembling techniques. For example, a 6-hour ensemble forecast uses the current 6-hr forecast, the previous 7-hour forecast, and the 8-hour forecast from the cycle before that. It is expected that such practice will reduce the cycle-to-cycle “shock” in the RWFS results that was sometimes caused during the 2003 demo when the models updated.

Other changes to the modeling system include extending the verification system to allow for direct comparisons between the NCEP model services and those provided by the ensemble. Also, FSL will be generating and validating probability of precipitation (PoP) gridded forecasts. Behind the scenes there have already been significant changes to the verification software and the model output display web pages. Many of these changes are intended to make the software more generally useful for a variety of users and applications.

6.3 Objective Verification of State Parameters

In this section, the 1 through 24-hour MDSS forecasts of state parameter, cloud cover and precipitation (including precipitation type) forecasts from each day’s 18:00 UTC forecast run were compared with observations made at the NWS and RWIS sites between 3 February and 8 April 2003. The 18:00 UTC MDSS update was chosen because it includes updated NWS model runs and because it is mid-day, the verification data are likely to be more complete. Additional comparisons of the precipitation type forecasts are made only at the NWS sites. Note that bias values are the reverse of standard convention. A positive (negative) bias indicates that the forecasts were too low (high).

6.3.1 Air Temperature

For tests including all NWS and RWIS stations within the state of Iowa, air temperature forecasts were accurate within ~2.5°C in the first 24 hours. RMSEs gradually increased with forecast length (Figure 7a). These values are similar to the discrepancies in the observations, indicating that MDSS air temperature forecasts were
generally accurate. A slight cool bias (<0.5°C) was present in the forecasts (Figure 7b). Scatter plots and time-series plots for individual sites show very good correlation. Some slight over and under-forecasting of relatively low and high temperatures, respectively, was evident at Ames and Ankeny, usually in relatively cloud free situations (Figure 8). The same thing was present at Des Moines, but the cloud cover in these situations was not nearly as consistently clear during the mismatches. In general, temperatures were most accurate during precipitation and very cloudy periods, and least accurate during clear periods. This result may reflect some issues in the quality of the radiation budgets in the upstream model forecasts or poor forecasts of the clear conditions (some cloud cover was predicted when none existed).

Figure 7a. RMSE for air temperature at all sites combined. The label ‘post proc’ represents the MDSS final prediction. Data labeled ‘eta dmos’ and ‘avn dmos’ represent MDSS statistical forecast modules that are based on the NWS Eta and AVN models.
Figure 7b. Bias for air temperature at all sites combined.
Temp Comparison w/ Wx for AMW METAR vs RWFS

Temp Comparison w/ Wx for IKV METAR vs RWFS
Figure 8. Scatter plots for air temperature at AMW, IKV and DSM. Coincident cloud cover and/or precipitation are indicated via the symbol shape and color.
6.3.2 Relative Humidity and Dew Point

Comparisons between RH and dew point forecasts and observations produced much wider scatter at all three sites, as well as overall (Figure 9). Scatter plots showed no obvious trends with RH (e.g. higher accuracy with higher RH) or biases. For all stations combined, the RMSE was 2-2.5°C for dew point, increasing with forecast length (not shown). These results are reasonable for good general public forecasting, but may be problematic for fog and frost predictions.
Figure 9. Scatter plots of relative humidity for AMW, IKV and DSM.
6.3.3 Wind Components and Wind Speed

Wind forecasts were quite good, overall, with most matched forecast and observed u and v components and overall wind speed falling within 2 ms$^{-1}$ of one another for the NWS and RWIS sites at AMW, DSM and IKV (Figure 10). RMSE values for all sites combined were $\sim$1.5 ms$^{-1}$ (Figure 11). This is approximately the amount of accuracy apparent in the measurements, themselves. Note that the MDSS wind speeds, labeled post-proc for post-processing, have lower RMSE values than the individual Eta and AVN model forecasts. This result indicates that the MDSS should provide good quality wind data for forecasting blowing and drifting snow. Accuracy was good at very low wind speeds, as well, which could be important for the formation of fog and/or frost. MDSS blending of the forecasts produces higher accuracy wind forecasts, overall.
V Comp Comparison for AMW METAR vs RWFS

Wind Speed Comparison for AMW METAR vs RWFS
Figure 10. Scatter plots of U and V wind components and wind speed for AMW, IKV and DSM.
Figure 11. RMSE plot for wind speed for all sites combined.
6.3.4 Cloud Cover

Cloud cover observations are made categorically, with categories related to the number of octants of sky cover. The categories and coverage values are as follows: clear skies (CLR; 0 octants, 0.00), a few clouds (FEW; 1 octant, 0.1875), scattered clouds (SCT; 3 octants, 0.4375), broken skies (BKN; 6 octants, 0.75), and overcast skies (OVC; 8 octants, 1.0). Cloud cover forecasts are floating point values ranging from 0.0 (completely clear) to 1.0 (completely overcast). Differences between forecasts and observations may not be smooth, because of the categorical nature of the observations.

Cloud cover results are in terms of RMSE and bias values for all stations combined. Overall, the RMSE for cloud cover forecasts was on the order of 0.3-0.35 and trended slightly upward with forecast length, as expected (Figure 12). A comparison with results for the NWS Eta model DMOS, and Aviation (AVN) model DMOS forecasts shows that the MDSS forecast was comparable to the Eta DMOS forecasts throughout the first 24 hours. MDSS had slightly lower errors in the first few hours, then slightly larger errors in the hours beyond. Both forecasts had much better accuracy than the AVN DMOS forecasts. Overall, the 0.3-0.35 forecast errors indicate that both the ETA and MDSS forecasts tended to be about one category off. This can be significant for air and especially, road temperature forecasts, since the shortwave and longwave energy fluxes that are important for these fields may be significantly off. This is a common problem in all weather models and a continuing topic of research in the weather model community. Until the models make better moisture (and thus, cloud cover) forecasts, the only likely way to improve upon these forecasts is with a forward correction scheme, such as that planned for future upgrades to the MDSS.

Bias results show that there was a slight negative bias (absolute value was less than 0.1; Figure 13) in the cloud cover forecasts, indicating that the forecasts were slightly too cloudy, overall.

Another way to examine the cloud cover forecasts is to show the distribution of predicted cloud coverage (tenths) for each cloud cover category (Figure 14). When clear skies were observed (FAI/CLR), the predicted cloud cover was usually less than 0.3. The
most frequent cloud coverage predicted was 0.21-0.30. Greater cloud coverage was predicted at other times, but CLR skies occurred with decreasing frequency with increasing cloud cover in the forecast. CLR skies never occurred when the cloud cover forecast was for >0.9 coverage. The reverse trend was found for OVC skies, with cloud cover >0.7 forecast most of the time, peak frequency in the 0.81-0.90 range, and no OVC skies when the predicted cloud cover was <0.1. BKN skies had their peak frequency when the cloud cover forecast was 0.61-0.7, which is very good. However, the same was true for SCT skies, where we should expect the peak in the 0.41-0.50 range. Overall, there was good discrimination among the extreme cloud coverages and reasonable discrimination in the partial cloud cover categories (FEW, SCT, BKN).

Figure 12. RMSE plot for cloud cover for all sites combined.
Figure 13. Bias plot for cloud cover for all sites combined.
Figure 14. Percentage of all observations of different cloud cover amount matched to predictions of cloud cover in tenths at AMW and DSM.
6.3.5 Precipitation Occurrence

The occurrence of precipitation at a given station is difficult to diagnose. Reports of liquid in heated tipping bucket gauges can be useful, but as described earlier, the NWS ASOS stations have serious problems during snowfall. The “present weather” field indicates the lack or presence of precipitation and its type. Both fields can normally be used as a simple on/off flag, indicating that precipitation was occurring (probability of precipitation, POP=1.0) or it was not (POP=0.0). MDSS forecasts indicate POP in terms of a floating-point number. For example, they will indicate a POP of 0.68, meaning that the probability of precipitation is 68% during the period. If precipitation did or did not occur, then the errors associated with this POP forecast are 0.32 (absolute difference between 1.0 and 0.68) and 0.68 (absolute difference between 0.0 and 0.68), respectively. The only opportunity for a “perfect” POP forecast is when the POP forecast is 1.0 and precipitation does occur or 0.0 or it does not occur. These combinations are rather unusual, especially the latter (a 0.0 POP forecast). Thus, significant errors are expected in the POP field.

RMSE values for all stations combined were on the order of 0.3-0.35 for POP, with a slight upward trend with forecast length, as expected (Figure 15). Such errors are quite reasonable, as described above. No significant biases were present, so the MDSS forecasts were predicting precipitation at about the correct frequency, overall. An examination of individual stations sometimes shows some bias. For example, the bias was somewhat positive (on the order of 0.1) at DSM, indicating that the system was consistently under forecasting the POP by about 0.1 (Figure 16).
Figure 15. RMSE of probability of precipitation forecasts for all sites combined.
Figure 16a. Bias of probability of precipitation forecasts for all sites combined
Figure 16b. Bias of probability of precipitation forecasts for Des Moines NWS site.
6.3.6 Precipitation Type

Precipitation type is forecast in terms of a conditional probability, indicating the chance of a particular type of precipitation, given that precipitation will occur. The values are floating point, from 0.0 to 1.0, for each of three categories: rain (CPOR), snow (CPOS), and ice (freezing precipitation; CPOI). At all times, CPOR+CPOS+CPOI=1.0. For example, if precipitation is expected, the temperature is expected to be near freezing and if the situation is right, the forecast could have the following conditional probabilities: CPOR=0.4, CPOS=0.4, CPOI=0.2. As the CPOS rises, for example, the system thinks that there is a better chance that the precipitation will fall as snow. If the forecasts are calibrated, then snow should fall 30% of the time when the CPOS is 0.3, and it should be some other type 70% of the time. Results are discussed for each category, and for each range of CPOx (e.g. 0.71-0.8), the percentage of precipitation that fell in each category is shown (Figure 17). Results are based on observations taken at AMW and DSM only.

When the CPOS was greater than 0.7, the precipitation type was nearly always snow (~95% of the time), and “UP” (unknown precipitation type – often precipitation that is too light for the ASOS LEDWI precipitation type sensor to determine a type) was reported almost all of the rest of the time. In the middle ranges (0.2 < CPOS < 0.7), a variety of precipitation types occurred, and snow fell 15-60% of the time. The correlation was poor, but there were relatively few cases, so the results are not very robust. For very low CPOS ranges (<0.1), snow essentially never occurred. Rain fell ~95% of the time.

High CPOR values were nearly always associated with rain, with almost all of the remaining precipitation falling as (above-freezing) drizzle. In the middle CPOR ranges (0.3-0.8), rain typically fell 20-30% of the time and much of the rest of it fell as snow. Little correlation may again be attributable to the low number of data points in this range. At low CPOR values (<0.3), rain rarely occurred, and it never occurred when the CPOR was less than 0.1. Snow dominated at the low CPOR values.

There were very few situations during the field demonstration when freezing precipitation was expected. In the few forecast runs where freezing precipitation was a
real possibility (mostly during the Feb. 13-15 case), the CPOI never exceeded 0.4, and it only exceeded 0.2 in 49 out of over 1000 forecasts. Freezing rain was never reported during that or any other event, and freezing drizzle was only reported once. During the few times that CPOI was greater than 0.3, rain fell ~85% of the time and UP fell the remainder of the time. This was because the air temperature forecast was incorrectly low during the expected period of FZRA in the 13-15 February case. When CPOI was in the 0.21-0.3 range, rain, snow and UP fell about an equal amount of time. Snow dominated when CPOI was less than 0.2. This season did not provide an adequate test for the CPOI field, since freezing precipitation and, in particular, freezing rain did not occur over the test domain. Note that the CPOI field was designed to catch freezing rain, rather than freezing drizzle.
Figure 17. Distribution of precipitation type occurrences for conditional probabilities of snow, rain and ice (freezing rain). Stacked columns are for each 0.1 range of CPOx (e.g. 0.11-0.20 for the 2nd set of stacked columns). For CPOI, no forecast values exceeded 0.40, so only 4 sets of columns are shown. All others have 10 sets. Total number of forecasts within each CPOx bin range is shown at the bottom of each column.
6.3.7 Road Temperature

MDSS provides three sets of road temperature forecasts for each segment of road: untreated, suggested treatment and current treatment. The “untreated” forecast is the expected road temperature given that the weather occurs (snow fall on the road, etc.) and no treatments are inserted into the system (the road is left “as is”). “Suggested treatment” is the expected road temperature, given that the treatment suggested by the MDSS is applied (e.g. the road is plowed at 13 UTC, as suggested by the system). “Current treatment” is the expected road temperature, given the treatment that was entered into the system by IADOT personnel during the event.

The “untreated” forecast is the most unrealistic, since treatment will nearly always take place. The “current treatment” forecast was not always captured well, as IADOT personnel sometimes became far too busy during snow events to enter the actual treatments done for each road segment they covered. Because the users did not routinely enter actual treatments, roads within the MDSS database were sometimes left with snow on the road for days following the event, or excess chemical stayed on the road, affecting the forecasts for a significant amount of time. The best field to verify is the “suggested treatment” field, since it represents a reasonable attempt at a treatment scenario for each event. Only results for that field are discussed here for individual road segments that were home to the Ames and Des Moines (I-35, to the southwest of DSM airport) RWIS sites. All forecast data is based on the 18UTC MDSS runs.

A scatter plot of the Ames data (Figure 18) shows that much of the data fall within a 2.5°C error range, and that the RWFS forecasts tended to be slightly low (cool), regardless of the temperature range. Errors were maximized during daytime clear sky situations, with under forecasts of 5-10°C. Recall that radiometer tests showed the biggest discrepancies (~5°C) under these same conditions, so the largest errors may be largely attributable to measurement error. Forecasts were accurate under cloudy and precipitating conditions, when the measurements appeared to be more credible. Forecasts were at their most accurate (vast majority within 2°C) when precipitation was falling, especially snow. RMSE results for Ames show a baseline error on the order of 2.5°C and spikes of error up to 5.5°C during times of peak daytime heating (0-3 and 24-27 hour forecasts, equivalent of 18-21UTC; Figure 19). Again, this may be largely attributable to
measurement error, but errors in cloud cover forecasts and sensitivity of the road temperature calculation schemes to insolation may also have contributed. Forecasts accuracy was best at night and during the morning, when these factors are minimized. Bias calculations indicated an overall cold bias to the forecasts, on the order of 2°C during most of the day, but near 3°C, during peak heating periods (Figure 19). The cold bias was also evident on the scatter plot. Rarely were forecasts more than 2°C too warm, but they were more than 2°C too cold on many occasions.

Results for Des Moines were fairly similar, except that the cold bias was not as evident in the scatter plot or bias plot (Figures 18 and 19). Errors were on the same order, and the diurnal pattern was still present in the bias results. However, the entire plot was shifted downward, with over-forecasts (negative bias) on the order of 2°C during the peak heating periods and under-forecasts (positive bias) on the order of 1°C during the night. Accuracy did not appear to be as dependent on cloud cover as they were at Ames, perhaps indicating less puck sensitivity to insolation at DSM.

To further demonstrate this point, scatter plots for different parts of the day were made. The plots for Ames clearly show that the scatter is much greater during the day than it is at night (Figure 20). These plots were done using the “current treatment” dataset.

An analysis of the performance of the road temperature model, SYNTHERM-RT, using actual weather data, rather than predicted weather as is described in this section, is presented in Section 6.5. That analysis provides a better indication of the accuracy limits of the model independent of weather prediction accuracy.
Figure 18. Same as Figure 8, but for road temperature.
Figure 19a. RMSE of road temperature forecasts for Ames. The peaks are associated with daytime heating.
Figure 19b. Bias of road temperature forecasts for Ames. The peaks are associated with daytime heating.
Figure 19c. RMSE of road temperature forecasts for Des Moines. The peaks are associated with daytime heating.
Figure 19d. Bias of road temperature forecasts for Des Moines.
Figure 20. Road temperature scatter plots from Ames for day (a) and night (b).
6.4 Case Study Analyses

In this section, events are subjectively examined to determine the accuracy of precipitation start and stop times, as well as how closely suggested treatments matched actual treatments made during the events. Both light and heavy precipitation events are investigated. Iowa DOT personnel recorded actual treatments performed on survey forms. Forecasts and observations of the overall precipitation amounts and patterns are also discussed, for MDSS runs made 6-12 hours before the event, both with and without the supplemental models run by FSL. In the MDSS, precipitation was declared by the system if the POP was 0.25 or greater and the QPF was 0.1mm/3hr or greater. These thresholds were used to determine the start and stop times of the predicted event, while actual observations of precipitation in the METARs were used to determine actual start and stop times. For intermittent events, the earliest and latest precipitation was considered to be the start and stop time.

A total of five events will be discussed in this section. The first two (3-4 February and 14-15 February 2003) will be discussed in greatest detail, including a) event start and stop time, b) temperature trends, c) precipitation amount, type and distribution, and d) treatment recommendations and actual treatments. The latter three events (23-24 February, 4-5 March and 6-8 April) will be discussed in terms of a) and b).
6.4.1 3-4 February 2003 – Light snow

During this event, about 1 inch of snow fell across the project domain; while up to 3 inches fell elsewhere in Iowa (Figure 21). Liquid equivalents were on the order of 0.05 to 0.25” (inches). The snow was associated with the passage of a strong cold front (Figure 22) and temperatures fell sharply during and following the snowfall. This feature was very important to the treatments applied late in the event.

The overall precipitation and snowfall predictions from the 6 UTC, 3 February 2003 MDSS run were of the right magnitude, with liquid equivalents of less than 0.2” and snowfalls of less than 2” forecast (Figure 23). The precipitation amounts were roughly correct, and the geographic distribution of the precipitation across the state was quite good. Highest values were expected in the northeast corner, with more moderate snow in the southwest corner and lowest values in the northwest and southeast corners of Iowa. In reality, the heaviest snows (up to 3”) fell in both the northeast and southwest corners, while lowest values fell in the northwest and southeast corners, as predicted.

Snow started and ended at DSM at 1830 (3 Feb) and 0423 UTC (4 Feb), respectively (Figure 24). The initial snow came over a 5-hour period, followed by a 4-hour break, then another short period of snow. QPF and POP thresholds indicated that precipitation should have begun and ended at ~16 and ~03 UTC without the FSL models and ~17 and ~03 UTC with the FSL models. In both cases, the forecasts started and ended the precipitation too early, but the MDSS forecasts that included the FSL models were slightly better on the start time. Neither system indicated a break in the precipitation during the middle of the event, but both did indicate peak POP and QPF values during the period where nearly all of the snow fell. At Ames, the snow was again predicted to start a bit too early, but the end of the event was captured nicely.

The temperature time series shows that the forecasts were quite accurate before and during the early part of the snowfall (through 20 UTC), forecasting temperatures that were slightly too low (Figure 25). After 20 UTC, temperatures quickly fell at DSM. The models were slow to catch this trend, resulting in forecast temperatures that were 4°C too warm for the latter part of the snowfall and the cold, windy period that followed it,
through 14 UTC on 4 February. This same trend was observed at Ames, but the temperature drop was associated with the beginning of the snowfall.

With good precipitation timing, type (all snow) and amounts, the overall case was predicted quite well. Such light precipitation prompted the system to suggest a pre-treatment of 110 lb per lane mile at ~17 UTC (not shown on the charts), followed by a single plowing and treatment cycle (150 lb per lane mile) at both Des Moines and Ames, with treatments beginning at ~20 UTC and finishing at ~22 UTC (Figure 26). This nicely matched the timing of the snow buildup on the road and should have allowed enough chemical to melt the snow that fell after the plowing was complete. Actual treatments at Ames and Des Moines did not include any pre-treatment. Plowing and salt application started an hour or so earlier and later, respectively, than the suggested plowing and treatment. The amount of salt applied was 300 lb per lane mile. The problem with both the suggested and actual treatments was that the sharp temperature drop was not expected and the salt put down caused the snow to melt, then freeze to make icy roads. Also, winds were on the order of 5-10 ms\(^{-1}\), causing blowing snow, something the current version of the MDSS does not try to handle. Because of the ice and blowing snow conditions, garages in the area had to continue treatments throughout the night and into the morning, until the sun came out the next day and helped to melt off the snow. These overnight and morning treatments were not suggested by the MDSS because of the combination of the lack of a blowing snow scenario and the poorly forecast sharp temperature drop.
Figure 21a. Observed snowfall (inches) for 3-4 February from Iowa COOP observers.
Figure 21b – Observed liquid equivalent (inches) for 3-4 February from Iowa COOP observers.
Figure 22. National Weather Service surface analysis for 18UTC on 3 February 2003.

Figure 23a. MDSS forecast snowfall (inches) for 3-4 February without FSL models.
Figure 23b. MDSS forecast snowfall (inches) for 3-4 February with FSL models.
Figure 23c. MDSS forecast liquid equivalent (inches) for 3-4 February without FSL models.
Figure 23d – MDSS forecast liquid equivalent (inches) for 3-4 February with FSL models.
Figure 24. Time series of POP and QPF forecasts at DSM and AMW for 3-4 February.
Figure 25 – Time series of forecast and observed air temperatures at DSM and AMW for 3-4 February.
Figure 26a. Time series of forecast wind speed (top red line), observed precipitation type (stars=snow, dots=rain, open circles=unknown precipitation type, M=missing), forecast QPF, POP, conditional probabilities of snow (blue line), rain (green line), and ice (red line), actual salt applications (upper, discontinuous, green dotted line with amount in pounds per lane mile), actual plowing periods (upper, discontinuous, black dotted line) and suggested salt applications (lower, green dotted line with amount in pounds per lane mile) and suggested plowing periods (lower, discontinuous, black dotted line) for highway segment along I-35, just south of Ames on 3-4 February.
Figure 26b – Same as part (a), but for highway segment along I-35, just southwest of Des Moines.
6.4.2 14-15 February 2003 – Heavy Snow

This storm was quite strong and posed a rather complex forecast situation. The MDSS, as well as the NWS, did poorly early in the forecast period, but the predictions improved with each update. A low pressure center formed to the southwest of Iowa and tracked northeastward across the Plains states, staying to the south of Iowa (Figure 27). Model forecasts for the days leading up to the event showed a very strong signal that precipitation would begin in the form of freezing rain, lasting for as much as 15 hours, then change over to a moderate snow event, with on the order of 3” expected on top of the ice. Such forecasts are very sensitive to the placement and strength of the cold air, low-pressure center and its attendant warm advection aloft. In this case, the surface cold air did not become well established across Iowa in advance of the precipitation, causing much of it to initially fall in the form of rain, rather than freezing rain. The changeover to snow also occurred much earlier than expected, causing a more significant snowfall event. All of this adds up to predictions and suggested treatments that were significantly in error.

Liquid equivalent predictions for the event from the 3 UTC 14 February 2003 MDSS run showed amounts ranging from ~0.1” in the north to ~0.8-0.9” in the south, with a fairly smooth north-south gradient across the state. Slightly higher amounts were predicted when the FSL models were included in the forecast (Figure 28a,b). The actual liquid equivalent pattern was quite complex, with a more east-west orientation to the precipitation amount gradient and peak values that exceeded 1.0” (Figure 28c). Snowfall forecasts had the lowest amounts (1-2”) predicted in the north and a pocket of about 5-6” predicted in small pockets near the center of the state, both with and without the FSL models (Figure 29a,b). Actual snowfall amounts and patterns were quite different, with peak snowfalls on the order of 10-13” falling in two swaths across southern Iowa, with a widespread area of more than 6” falling across the southern half and 2-6” across the northern half of the state (Figure 29c).

Temperature forecasts for the event were low by several degrees Celsius throughout the event (Figure 30 – note that the Des Moines RWIS air temperatures were faulty during this event). This was critical, because they were expected to be just below
freezing at the beginning. This made the difference between freezing rain in the forecast and rain in reality, between 21 UTC on 14 February and 00 UTC on 15 February. Freezing rain was predicted to fall at Des Moines throughout the period 12 UTC on 14 February to 2 UTC on 15 February, a 15-hour freezing rain event. In reality, no freezing rain fell at Des Moines. Snow was expected to follow, from ~2 UTC to 16 UTC on 15 February, with a total of ~3”. Instead, snow fell through ~20 UTC, and ~10” fell at DSM. Strong winds were predicted and did verify well. The precipitation began 6-9 hours later than was predicted, so the event start time was poorly predicted. The snow event conclusion was reasonably well forecast, considering it was a 30+ hour forecast (Figure 31).

The MDSS road treatment scenario suggested 250 lb per lane mile during the expected freezing rain at the beginning of the event, but no treatments between 12 and 19 UTC, since road temperatures were expected to rise above freezing for a couple of hours surrounding 18 UTC (Figure 32). When the forecast road temperatures again fell below freezing, and freezing rain was expected to continue, additional treatments of 200 lb per lane mile were suggested (Figure 33). These continued during the period of predicted snowfall. Actual treatments did not begin until ~21 UTC on 14 February, with 250 lb per lane mile of salt at Des Moines during the rain that preceded the snow that evening. By this time, local NWS and MDSS forecasts changed dramatically, indicating a mixed precipitation (rather than freezing rain) event that was to be followed by snow. When the snow began to fall (sometimes heavily) at DSM, plowing and treatment with salt was fairly frequent and continued into the morning of 15 February. Wind and blowing snow were also a factor in the actual treatment scenario.

Overall, forecasts for this event were quite poor, both from the MDSS and other standard sources (e.g. NWS). The poor quality of the precipitation timing, precipitation type and amount, in combination with the bad temperature forecasts caused the suggested treatments at DSM to be far off the mark for the first 12 hours of the event. Later in the event, when snow dominated, the treatment suggestions were more reasonable. Similar results were found for Ames, but no treatments were suggested for the latter portion of the event (Figure 33).
Figure 27. National Weather Service surface chart for 12UTC on 15 February 2003.
Figure 28a. MDSS forecast of liquid equivalent (inches) for 14-15 February without FSL models.
Figure 28b. MDSS forecast liquid equivalent (inches) for 14-15 February with FSL models.
Figure 28c. COOP network observed liquid equivalent (inches) for 14-15 February.
Figure 29a. MDSS forecast of snowfall (inches) for 14-15 February without FSL models.
Figure 29b. MDSS forecast of snowfall (inches) for 14-15 February with FSL models.
Figure 29c. COOP observations of snowfall (inches) for 14-15 February.
Figure 30. Time series of forecast and observed air temperatures at DSM and AMW for 14-15 February.
Figure 31. Time series of POP and QPF forecasts at DSM and AMW for 14-15 February.
Figure 32a. Time series of MDSS forecast state parameters for 14-15 February.
Figure 32b. Time series of MDSS forecast road parameters for 14-15 February.
Figure 33a – Same as Figure 26a, but for 14-15 February and for I-35 segment southwest of Des Moines.
6.4.2.1 Ensemble model performance: Case of 14-15 February 2003

Further illustration of the characteristics of the MDSS ensemble models and performance comes from examining model runs from selected cases. We use the case of 14-15 February, an event with significant snowfall, for this purpose. Reference is made to the depiction of observed storm-total liquid equivalent precipitation (Figure 28c) and snowfall (Figure 29c) from the 14 February storm. Light precipitation was reported in the northeast corner of Iowa, but most of the rest of the state received about an inch of precipitation. However, a substantial portion of the precipitation in the northwest corner of the state fell as rain, whereas most of the precipitation in the southern part of the state fell as snow.

Figure 33c shows a 6-hr forecast from one of the ensemble members (MM5 with Eta lateral bounds). It is valid at 3 p.m. CST. This is quite early in the event; note that the 32°F isotherm (orange line) goes through the center of the state, near Ames and north
of Des Moines. Along this line, mixed precipitation is indicated with snow to the north and rain to the south. Most of the rain shown in the observations in the northwest part of Iowa fell before this model run.

Figure 33c. Six-hour precipitation prediction from the MM5 (using AVN boundary conditions) valid at 3pm CST, 14 February 2003.

Note that the model allows the precipitation of snow in air warmer than freezing (at the NE/IA/SD border point), and rain in air colder than freezing (east of Ames).

By contrast, Figure 33d shows a precipitation forecast from the Eta model, valid at the same time as the previous image. Note that indications of various precipitation types (i.e., rain, snow, mixed types) are not evident here because the Eta model (and
AVN) does not distinguish between precipitation types. Instead, RWFS uses precipitation type algorithms that take into account temperature and humidity profiles to estimate snowfall where applicable. Note also that the Eta model precipitation forecast field is much smoother than the local model forecast.

Figure 33d. Six-hour precipitation prediction from the Eta model valid at 3pm CST, 14 February 2003.

In comparing the two model forecasts it can be seen that the Eta model starts the precipitation in central and eastern Iowa later than the mesoscale model run, which for this situation is closer to reality.
Figure 33e compares the forecast surface temperature time series from two ensemble members against the observations at Des Moines (top) and Ames (bottom).

**KDSM (Des Moines) temperature verification starting 1500 UTC 14 Feb 03**

**IA004 (Ames) temperature verification starting 1500 UTC 14 Feb 03**

Figure 33e. Forecast surface temperature time series from two ensemble members against the observations at Des Moines (top) and Ames (bottom)
This is not a case characterized by a distinct frontal passage; the main front went through the area well before the heaviest precipitation began. In the early hours both forecasts are very accurate. Discrepancies arise resulting from the timing of model precipitation. In forecast frames (not shown), both models generated precipitation about 9 hours into the forecast at Ames, which caused a drop in model temperatures; however, the precipitation was stronger in the MM5 run causing a sharper drop-off than that indicated in the WRF trace. Then the temperature recovers quite rapidly in the MM5 run, probably owing to the fact that the MM5 long wave cooling parameterization deals more effectively with clouds than the WRF parameterization at slowing radiative cooling when clouds are present. Thus, the MM5 surface flux physics are allowed to warm the lowest model layers after a precipitation event, very effectively in this particular case. At Ames, both models had the precipitation event; again the MM5 result shows better post-rain response in the temperature prediction.

The storm total precipitation forecast from the MM5-Eta model run is shown in Figure 33f. This can be compared to the hand-drawn contour of observations shown in Figures 28c and 29c. The distribution of forecast snowfall shows good agreement with the 1-3” amounts in the northeast part of the state, and highlights the relatively heavy precipitation in the southern half of the state. There is reason to question the accuracy of the N-S band of lighter precipitation suggested in the observations in the southern part of the state. If that is in fact erroneous, then the model forecast of snow distribution is quite consistent with that observed, although the model has apparently over predicted both the total equivalent liquid and the snow depth. Given the generally minimal bias in precipitation shown in the MM5 forecasts shown earlier, the bias shown here is atypical.

Results from this case and others not presented herein are encouraging and indicate that the mesoscale models have potential for improving the prediction of precipitation type, rate and timing.
Figure 33f. MM5 model storm total precipitation forecast from 14 February 2003.
6.4.3 23-24 February 2003

This was a short snow event that resulted in a total of ~1 inch (.6 at DSM) over a period of ~6-8 hours between ~21 UTC on 23 February and ~5 UTC on 24 February. The timing of this event was nicely captured in the MDSS run from 9UTC on 23 February. At both Ames and Des Moines, the snow started within ~1 hour of the times that the POP and QPF thresholds were first exceeded, and the event ended about 1 hour after the expected end time (Figure 34). Considering the 3-hour granularity of the MDSS forecasts and the fact that hourly POP and QPF values are interpolated from the 3-hourly values, capturing an event within ~1 hour is quite good. At Ames, the MDSS runs that included the FSL models captured the start of the event almost exactly, showing improvement over the MDSS runs without the FSL models. No improvement was evident at Des Moines. Temperatures were well below freezing (near –8°C) and wind speeds were on the order of 5 ms⁻¹. Both were captured quite well throughout the event, though the temperature forecasts were a bit too warm (1-3°C) during and following the snowfall (Figs. 34, 35). Observed patterns of snowfall and liquid equivalent were not forecast well (Figs. 36, 37), which is expected when such light amounts occur.
Figure 34. Time series of POP and QPF forecasts at DSM and AMW for 23-24 February.
Figure 35a. Time series of forecast and observed air temperatures at DSM and AMW for 23-24 February.
Figure 35b. Time series of forecast and observed wind speeds at DSM and AMW for 23-24 February.
Figure 36a – MDSS forecast of liquid equivalent (inches) for 23 February without FSL models.
Figure 36b. MDSS forecast of liquid equivalent (inches) for 23 February with FSL models.
Figure 36c. COOP network observed liquid equivalent (inches) for 23 February.
Figure 37a. MDSS forecast of snowfall (inches) for 23 February without FSL models.
Figure 37b. MDSS forecast of snowfall (inches) for 23 February with FSL models.
Figure 37c. COOP network observed snowfall (inches) for 23 February.
6.4.4  4-5 March 2003

This 8-10 hour light snow event dropped 2.5 inches and 4.5 inches of snow at AMW and DSM, respectively between ~17 UTC on 4 March and ~3 UTC on 5 March. The MDSS run from 3UTC on 4 March did a poor job at predicting the start time of this event, indicating that snow should begin ~4 hours earlier than it actually did, both with and without the FSL models (Figure 38). Event end time was captured within ~1.5 hours, which is good. Temperatures during the event were quite cold again (near –12°C) and the MDSS forecast was too warm by ~3°C during and immediately following the event. A period of moderate winds associated with and following the snowfall was captured quite well (Figure 39). Forecast patterns of liquid equivalent and snowfall showed a gradual increase from north-northwest to south-southeast. Observed patterns were much more complex, but did tend to have higher amounts to the south and east (Figures 40 and 41).
Figure 38. Time series of POP and QPF forecasts at DSM and AMW for 4-5 March.
Figure 39a. Time series of forecast and observed air temperatures at DSM and AMW for 4-5 March.
Figure 39b – Time series of forecast and observed wind speeds at DSM and AMW for 4-5 March.
Figure 40a. MDSS forecast of liquid equivalent (inches) for 4 March without FSL models.
Figure 40b. MDSS forecast of liquid equivalent (inches) for 4 March with FSL models.
Figure 40c. COOP network observed liquid equivalent (inches) for 4 March
Figure 41a. MDSS forecast of snowfall (inches) for 4 March without FSL models.
Figure 41b. MDSS forecast of snowfall (inches) for 4 March with FSL models.
Figure 41c. COOP network observed snowfall (inches) for 4 March.
6.4.5 6-8 April 2003

This prolonged event was rather warm, with temperatures near freezing during ~36 hours of snowfall that dropped between 3-5 inches of snow at AMW and DSM between ~19-23 UTC on 6 April and ~12-15 UTC on 8 April. A 3-6 hour break in the snowfall occurred at both sites around 0 UTC on 8 April. The MDSS run from 6UTC on 6 April had a difficult time with the start of the event, indicating its inception about 3 and 7 hours too early at Des Moines and Ames, respectively (Figure 42). The end of the event occurred beyond the 24-hour period examined for the 6UTC, 6 April MDSS run, so the 18UTC, 7 April run was examined for the event end time. The end of the event was not captured well, regardless of whether the FSL models were included or not. Without the FSL models, the snow was predicted to end too early, while the reverse was true when the FSL models were included. In both runs, the MDSS showed that the chances for snow were significantly diminished around the time that the main snowfall ended, but held on to the chance for continued light snow during the second period of snowfall, with POP and QPF values hovering near the thresholds for “precipitation=yes” in the system.

Temperatures and wind speeds were forecast quite well for the event (Figure 43). The good quality temperature forecasts were particularly important for precipitation type during this event, since it occurred near 0°C. The liquid equivalent patterns for this event were well forecast, with minimum values in the northeast corner of the state and generally higher values toward the southwest and west, with the exception of one inconsistent observation in southwestern Iowa (Figure 44a, b, c). Snowfall patterns were not as well captured; a broad swath of significant snow that occurred across the middle of the state was pretty well forecast (Figure 45). Little reliable data was available to verify the relative minimum in snowfall forecast for the northwest corner of the state.
Figure 42a. Time series of POP and QPF forecasts at AMW for 6-8 April.
Figure 42b. Time series of POP and QPF forecasts at DSM for 6-8 April.
Figure 43a. Time series of forecast and observed air temperatures at DSM and AMW.
Figure 43b. Time series of forecast and observed wind speeds at DSM and AMW.
Figure 44a. MDSS forecast of liquid equivalent (inches) for 6-8 April without FSL models.
Figure 44b. MDSS forecast of liquid equivalent (inches) for 6-8 April with FSL models.
Figure 44c. COOP network observed liquid equivalent (inches) for 6-8 April.
Figure 45a. MDSS forecast of snowfall (inches) for 6-8 April without FSL models.
Figure 45b. MDSS forecast of snowfall (inches) for 6-8 April with FSL models.
Figure 45c. COOP network observed snowfall (inches) for 6-8 April.
6.5 Detailed Analysis of the Road Temperature Model – SYNTHERM-RT

6.5.1 Introduction

The application of chemicals to clear ice and snow from road surfaces depends, in part, on the road surface temperature. During the 2003 Maintenance Decision Support System (MDSS) field program conducted on several roads in and around Des Moines and Ames, Iowa, a modified version of the Cold Regions Research Engineering (CRREL) laboratory’s SNTHERM model was used to predict the road surface temperatures. The main modification to SNTHERM involved ‘turning off’ the latent heat exchange between the road and the atmosphere. The modified version of SNTHERM, referred to as SNTHERM-RT, assumes the road moisture content is zero. Therefore, the latent heat exchange between the road and the overlying atmosphere is not part of the road/atmosphere energy balance. During the MDSS field program forecast weather information was used to drive the model. Operating in this mode precludes comparing the SNTHERM-RT predicted road surface temperatures with measured road surface temperatures since temperature differences could be attributed to weakness in the model, incorrect forecasted weather conditions, or errors in the measured data. In order to get a handle on the performance of SNTHERM-RT, observed weather conditions were used to rerun SNTHERM for the period of the field program, and the resulting predicted road surface temperatures were compared to the measured temperatures. There still exists the issue of the ‘goodness’ of the measured road surface temperature data. The following section deals with the approach while the last section of this report presents the results of the analysis.

6.5.2 Approach

SNTHERM-RT requires information on the roadbed vertical structure, an initial temperature profile, an initial moisture profile for the soil layers under the roadbed, and hourly weather information (pressure, temperature, relative humidity, cloud amount and type, precipitation rate, and precipitation type). The Air Force Combat Climate Center (AFCCC) provided the hourly weather information for the period of interest at two locations: Ames and Des Moines, Iowa. These observations were reformatted to be
compatible with SNHERM_RT and missing information was either derived from other information or flagged as missing. For example, the surface observations report temperature and dew point temperature, but SNHERM-RT requires relative humidity. The relative humidity was derived from the temperature information. The observed precipitation information frequently does not contain the precipitation type. SNHERM-RT can determine the precipitation type based on the ambient temperature, but what is important in terms of the road surface energy budget is the state of the moisture (snow, ice, or water) on the road surface. Even if the precipitation falls as snow, heating due to tire friction as vehicles move over the road, effects of reside chemicals, or the effects of newly applied chemicals may result in the melting of the snow on the road. Since the state of the moisture on the road was not available we decided to set the precipitation type to rain, forcing the road surface to be wet during periods of precipitation. After reformatting the AFCCC information and taking the appropriate actions to handle missing parameters, we obtained an hourly database of weather information for the period from 15 January to 15 April 2003. CRREL tabulated, through an extensive literature search, the thermal, physical, and optical properties of road surface materials (asphalt and concrete). Average values along with a valid range of values for the thermal, physical and optical properties for several asphalt and concrete types were provided. During the field test the users of SNHERM-RT either used the thermal, physical and optical properties provided or supplied their own properties. For this research effort the road properties used during the field test that coincided with 15 January were used to initialize the SNHERM-RT run.

6.5.3 Analysis

Table 3 provides information on the data sources used to develop the meteorological files used as boundary conditions for SNHERM-RT, measured road surface and sub-surface temperature information for comparison with the model predicted values, and the road vertical structure and profile information used to initialize SNHERM-RT. The measured values used for the comparison at each site are an average of several measurements.
Table 3. Sources of weather information, measured road surface and sub-surface temperature information, and SNThERM-RT initialization information (layer.in files)

<table>
<thead>
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<th>Source</th>
<th>Lat. (deg.)</th>
<th>Long. (deg)</th>
<th>Elev. (m)</th>
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<tbody>
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<td>41.52</td>
<td>-93.65</td>
<td>294</td>
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<td>RWIS Mesonet Ames</td>
<td>Iowa Environmental Mesonet Website <a href="http://mesonet.agron.iastate.edu/sites/site.php?id=RAME">http://mesonet.agron.iastate.edu/sites/site.php?id=RAME</a></td>
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<td>-93.76</td>
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<td>41.55</td>
<td>93.78</td>
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</tr>
</tbody>
</table>

Four road surface temperature sensors were averaged to get an average surface temperature for the Des Moines site. Figure 46a represents the average road surface temperature computed from the four Des Moines sensors and the range of the temperatures (maximum temperature minus the minimum temperature). In general, the range of temperatures at any given time is not symmetrical about the average. The range of values associated with the four sensors never exceeds 10 C and the average value of the range is 2.2 C. The relative location of the sensors is unknown. But, we believe all the sensors are in close proximity to each other. The average road surface temperature for
Figure 46a. The average (avg) road surface temperature and the range for Des Moines

Figure 46b. The average (avg) road surface temperature and the range for Ames
Ames (Figure 46b) is based on three sensors. Information on the average temperature and the range of temperatures associated with the three sensors is presented in Figure 47. The maximum range does not exceed 5 C and the average value of the range is 1.5 C.

*Des Moines, Iowa Site*

The SNTHERM-RT predicted road surface temperatures are compared to the average measured road surface temperatures for Des Moines. In general, the predicted temperatures compare favorably with the measured values even though precipitation in SNTHERM-RT was forced to be rain.

Figure 47. Comparison of the averaged measured surface road temperature and the SNTHERM-RT predicted values for Des Moines.
A graph (Figure 48) of the difference between the predicted values and the measured values (predicted minus measured) indicates a trend that oscillates around zero with a maximum difference of 11.9 C and an average difference of -1.1 C. There is a definite change in the air temperature pattern after day 70 with three pronounced warming cycles. The average predicted minus measured road surface temperature difference after day 70 is approximately –1.0 C, while before day 70 it is approximately –1.1. The linear regression of the scatter plot of the measured vs. the predicted (Figure 49) has an R² of 0.97, a slope near 1.0, and an offset of approximately –1.0. The predicted values corresponding to measured temperatures warmer than 10 C show more scatter than values less than 10 C. Fortunately, these conditions are not conducive to snowfall and we can only speculate on why these differences occur. One possible explanation is the fact that we did not have measured solar and infrared fluxes and had to rely on the nearest cloud observation information to compute these fluxes. If there was more cloud cover in the vicinity of the road measurements, the measured temperatures should be cooler than the predicted values.

Figure 48. The predicted minus the measured road surface temperature difference and the air temperature.
Because of the assumption we invoked to handle the precipitation, we took a closer look at the ability of SNTHERM-RT to predict the road surface temperatures during periods of precipitation and periods of non-precipitation. From the ambient temperatures it is obvious that some of the precipitation fell as snow, but because we did not have information on how the Iowa DOT handled these situations we decided to not let it snow in the model. In reality, intervention by DOT can remove the snow by chemical application or plowing. In addition, traffic can compact the snow on the roads and tire friction can result in melting. SNTHERM-RT can only remove snow by melting resulting from natural energy sources. To look closer at this we plotted (Figure 50) the time series of the precipitation rate and the road surface temperature difference (predicted minus the measured). There is no apparent correlation between the precipitation rate and the difference in the predicted and measured road surface temperature. Figures 51 and 52 represent the scatter diagram of the predicted vs. the measured road surface temperature difference for non-precipitation periods and precipitation periods, respectively. $R^2$ for the precipitation periods is less than the value for non-precipitation periods, the offset is greater, and the slope of the linear equation is less indicating less agreement between the predicted and measured temperatures during periods of precipitation.
Figure 49. Scatter plot of the predicted vs. the measured road surface temperatures with a linear fit.

Figure 50. Time series of the predicted minus the measured road surface temperature and precipitation rate.
Figure 51. Scatter plot of the predicted vs. the measured road surface temperatures for non-precipitation periods with a linear fit.

Figure 52. Scatter plot of the predicted vs. the measured road surface temperatures for precipitation periods with a linear fit.
**Ames, Iowa Site**

The data from the Ames site was analyzed using the same procedures as the Des Moines site. The time series of the predicted and measured road surface temperature is given in Figure 53. The road surface temperatures are similar to those at the Des Moines site with a break in the temperature pattern around day 70 (11 March 2003).

![Graph](image_url)

**Figure 53.** Predicted and measured road surface temperatures.

The maximum difference between the predicted and measured road surface temperatures for the Ames site is 15.5 C with an average difference of -0.8 C (see Figure 54). The average difference for the period prior to day 70 is approximately -0.9 C while after day 70 it is approximately -0.8. Again, there is good agreement between the predicted and measured road surface temperatures as can be seen in Figure 55. An examination of the ‘goodness’ of the model for precipitation and non-precipitation periods (Figures 56 and 58) indicates the model tends to be more aligned with the measured values during non-precipitation periods. In general, the model appears to be...
fairly well behaved and mirrors the measured values. SNTHERM has been tested extensively with analyzed results indicating an absolute accuracy on the order of 3 to 5 degrees. SNTHERM-RT has not undergone the level of validation that SNTHERM has, but differences between the predicted and measured values greater than 5 degrees should be investigated. As indicated earlier, these differences could be associated with the model, inaccuracies in the measurement data, or incorrect or erroneous meteorological data. Additional measurements will be required to shed light on the absolute accuracy of SNTHERM-RT.

Figure 54. The air temperature and the difference of the predicted minus the measured road surface temperature.
Figure 55. Scatter plot of the predicted vs. the measured road surface temperatures with a linear fit.

Figure 56. Time series of the predicted minus the measured road surface temperature and precipitation rate.
Figure 57. Scatter plot of the predicted vs. the measured road surface temperatures for non-precipitation periods with a linear fit.
Figure 58. Scatter plot of the predicted vs. the measured road surface temperatures for precipitation periods with a linear fit.

6.5.4 SNTHERM-RT Enhancements

SNTHERM-RT validation indicates the model has skill in predicting the road surface temperature. SNTHERM-RT is an adaptation of the SNTHERM model developed at CRREL. Certain features should be added to SNTHERM_RT that will better support the prediction of the road surface temperature. Presently, the model does not handle the impact of vehicles on snow-covered roads. Tire friction can potentially result in melting of snow on road surfaces and if the snow is deep enough compaction of the snow will occur and the changes in the snow density will impact the snow energy budget. Wind-blown snow is not handled in the model at the present time even though CRREL has developed models of blowing snow. One of the difficulties of handling blowing snow is a GIS approach and would have to be used to model the surrounding terrain and the variations of snow depth. The approach would also require the prediction of a ‘lofting index’ to determine how easily the snow can be moved around. The model does not handle the impact of chemicals on the snow/road energy budget, including residual moisture on the road surface that may have a high concentration of chemicals. Another issue is the chemical residue that remains on the road surface after the chemical laden snowmelt evaporates. On an asphalt road this residue may change the albedo significantly. We need to look at procedures for integrating field information into SNTHERM-RT. For example, after plowing, the snow layers in SNTHERM-RT should be reset to reflect the artificial removal of the snow. While we have provided a capability to model bridge surface temperatures, it was not used during the winter 2003 Iowa demonstration because of the user interaction required to set up the model properly. Automation of this capability is required in addition to a comprehensive validation of the bridge surface temperature prediction module.

At the present time setting up SNTHERM-RT and running the model is fairly interactive and requires knowledge that may not be available in a DOT setting. If SNTHERM-RT is used in an operational MDSS setting, the model must be more ‘user
friendly’ and the initialization procedures must be automated to the greatest extent possible. Observed road and weather conditions should be used to nudge the model output toward the observed conditions.

6.6 Detailed Analysis of the Rules of Practice

The case studies presented in Section 6.4 discuss the treatment recommendations as they were forecasted in real-time operations (note that in some cases software fixes that were put in place after the event may have required that a particular case be re-run so that all the data shown is from the same final version of the demonstration software). However, the treatment recommendations presented in real-time are subject to the ambient weather forecast at the time the treatment is captured. Forecast errors will necessarily result in inaccurate or incomplete treatment recommendations. An alternative analysis method was used in an attempt to isolate the performance of the Road Condition Treatment Module and more specifically the Rules of Practice from the weather forecast system.

6.6.1 “Perfect” Weather Ingest

The first method was intended to remove the inaccuracies of both the weather forecast process and the road temperature model by replacing the precipitation rate and type and road pavement temperatures with actual values gathered during the storm. This allows the rules of practice and chemical concentration modules to be driven by “perfect” weather inputs. In theory, this method should produce a clear picture of the treatments that would have been generated by the RCTM if the system had produced a 100% accurate weather forecast. However, several factors in the gathering of actual weather conditions make this performance measure less than ideal. The ingested weather data replaced in this analysis are the precipitation rate and type, and the road pavement temperature.
6.6.1.1 Using RWIS as “perfect” road temperatures

RWIS sensors on or near the identified route were averaged together to obtain a route wide estimate of the actual pavement temperatures during the storm. There are two factors that must be considered in replacing the modeled pavement temperature. First, the RWIS sensor only measures the pavement temperature at one point on the route. Thermal mapping performed by Vaisala on the Iowa DOT routes during cloudy conditions indicate that temperatures along the route can vary by as much as 14 deg F. Although differences are likely significantly smaller during precipitation events, they are still a potential source of error. Second, the RWIS reported temperatures are impacted by the actual Iowa DOT treatment strategy. If roads had times where they were snow/ice covered then the road would be insulated and the temperatures would be warmer than might be expected if the road surface was clear. We are making an assumption that for the Level A and B routes we are concentrated on, the impact of such insulation will be short-lived and therefore not impact the overall road temperature profile.

6.6.1.2 Obtaining precipitation rate and type information

At first glance this task seems straightforward; simply take the hourly and special observations from the nearest ASOS site to a specific route. However, analysis has shown that the precipitation rate values reported by many of the NWS ASOS sensors are often suspect. Rate values in snowstorm situations, in particular, were problematic (more details are discussed in Section 6.1.4). ASOS precipitation type values were, in general, accurate except in cases where transitions from one precipitation type to another occurred (for example rain to snow). This inaccuracy was primarily due to spatial variability along the route and the inability of a point on the route to accurately represent the entire route. Qualitative measures of the snowfall by ASOS as light, moderate and heavy as determined by visibility sensors were also deemed to be reasonable. Total snowfall amounts for the storm as reported by observers were also of reasonable quality for most events. As a compromise to obtain quantitative precipitation estimates, the total snowfall for the storm was distributed over the life of the storm by weighting the ASOS qualitative measurement (light=1, moderate=2 and heavy = 4 parts). As an example, Table 4 shows a
4-hour storm with a total snowfall of 10 inches yielding 1.0 inches of liquid water. The hourly precipitation rate is calculated by dividing the total storm liquid water by the sum of the precipitation weights as measured by the ASOS qualitative report.

Table 4 Estimation of precipitation rate from total storm liquid water and hourly ASOS reports

<table>
<thead>
<tr>
<th>Hour</th>
<th>0</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>TOTAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>ASOS report</td>
<td>Light</td>
<td>Mod</td>
<td>Light</td>
<td>Heavy</td>
<td>--</td>
</tr>
<tr>
<td>Weighting</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>4</td>
<td>8</td>
</tr>
<tr>
<td>Precipitation Rate (in/hr)</td>
<td>0.125</td>
<td>0.250</td>
<td>0.125</td>
<td>0.500</td>
<td>1.0</td>
</tr>
</tbody>
</table>

This is clearly a crude estimate of the actual precipitation rate and given that precipitation rate is crucial to both the estimation of the amount of chemicals to be used and the eventual dilution of those chemicals with time, it adds a fair amount of uncertainty to the analysis. It is anticipated that during the winter 2004 demonstration, the MDSS project will utilize an advanced snow gauge near specific verification routes to reduce the uncertainty in measuring precipitation rate.

6.6.2 Case Studies

The case studies presented here focus on the analysis of the Rules of Practice algorithm. The general conditions of the storm are described as needed to support the performance analysis. An extended discussion of the synoptic weather situation, forecast and state variable verification for these cases can be found in Section 6.4. Four of the five cases discussed in Section 6.4 are used here. The fifth case, March 3-4, could not be used because the RWIS pavement temperature data and some of the recorded Iowa DOT treatments were unavailable.

The figures illustrating the storm situation, Iowa DOT treatments and MDSS “perfect” forecast treatments are designed to show the general conditions and treatments. Detailed charts of road temperature and precipitation type and rate have been replaced by color-coded hourly timelines. A key for the color-coding is illustrated in Figure 59.
Precipitation type and rate are shown on the left: green for rain, light blue for light snow (<0.25 inches/hour), blue for moderate snow (0.25-0.50), and red for heavy snow (>0.5). Pavement temperature is represented as green for road temperatures above 35 deg F, yellow for 14-35 deg F and red for temperatures below 14 deg F. Iowa DOT requested that temperatures below 35 deg F should be used to trigger treatment recommendations. In addition, the MDSS considered rain falling on roads below 35 deg F as freezing rain for treatment purposes since it represents a conservative approach. Finally, the effective range of NaCl (the selected treatment for Iowa DOT) ends at 14 deg F. The red zone for road temperatures is critical because it indicates that chemical treatments will essentially be ineffective.

<table>
<thead>
<tr>
<th>Precipitation</th>
<th>Road Temperature</th>
</tr>
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<tr>
<td>Rain</td>
<td>&gt; 35 F</td>
</tr>
<tr>
<td>Light Snow</td>
<td>14 – 35 F</td>
</tr>
<tr>
<td>Mod Snow</td>
<td>&lt; 14 F</td>
</tr>
<tr>
<td>Heavy Snow</td>
<td></td>
</tr>
</tbody>
</table>

Figure 59. Key for precipitation and road temperature values on MDSS vs. Iowa DOT timelines

The top row of each treatment evaluation figure shows the time in UTC with the MDSS treatment directly underneath. The bar signifies the recommended treatment time and the number above the bar gives the rate of chemical to be used (lbs/lane-mile). Initial pre-treatments of liquid brine at 50 gals/lane-mile are represented on the chart as 110 lbs/lane-mile. The next row on the chart illustrates the timeline of precipitation (rain, snow). This is followed by the actual Iowa DOT treatments performed for this storm. Treatment information was gathered in real-time from supervisors and plow operators and, as is the nature of manually gathered information, should be taken as a guide to the general treatments performed rather than as the exact application performed. Finally, the last row shows the timeline of the road temperature.
6.6.2.1 3-4 February 2003

This event was a short-lived (5-7 hour) light snowstorm (roughly 1” snowfall and 0.1” liquid water equivalent in both Des Moines and Ames), although there was a brief period of heavy snowfall recorded. Looking at the timeline shown in Figure 60 and starting from the bottom we can see that the road temperatures started off relatively warm and slowly cooled as we neared the precipitation event. Precipitation began as light snow around 1900 and ended 5 hours later in Ames and 7 hours later in Des Moines. The MDSS treatment strategy for Ames was limited while the Des Moines treatment was more extended because the snow continued longer in Des Moines.

**Ames treatment comparison**

In Ames (Figure 60), the MDSS recommended a pre-treatment of liquid salt brine at 50 gal/lane-mile (110 lbs/lane-mile) starting sometime before 1500. Pre-treatment was followed by 2 successive 150 lbs/lane-mile treatments applied during the storm. The actual Iowa DOT storm treatment started mid-storm consisting of one treatment at 300 lbs/lane-mile. All of the successive DOT treatments were a result of the rapid drop-off in air and road temperatures. The initial treatment melted the remaining snow, but the lateness of the day meant that the road was unable to dry before the cold temperatures arrived. In order to prevent the remaining water from refreezing Iowa DOT treated the road surface throughout the night until the morning sun was able to dry the road surface.

The treatment recommended by the MDSS was reasonable. Pre-treatment was indicated because the road surface was dry prior to the event and pavement temperatures were within the chemical effective range. However, winds were strong > 10 m/s (>18 knots) and this will generally cause the DOT to abandon pre-treatment as the blowing snow will be captured by the chemically treated road surface, instead of simply blowing off the road, causing the chemical solution to fail prematurely. The MDSS will suspend pre-treatments if the road temperature is expected to be below 20 deg F during the initial portion of the storm. However, road temperatures in this case were above 25 deg F so the pre-treatment was recommended. Iowa DOT chose not to pre-treat at least in part because
temperatures were expected to drop and the forecasted winds were expected to strengthen. The MDSS pre-treatment suppression will be refined to capture the Iowa DOT practices.

The follow-on MDSS treatments of two 150 lbs/lane-mile rounds were roughly equivalent in effectiveness as the single 300 lbs/lane-mile treatment delivered by Iowa DOT. Iowa DOT delayed and increased its’ treatments due to the blowing snow concerns until enough snow had fallen and stuck to the road surface thereby necessitating action. The MDSS did not recommend any further treatments, precipitation had stopped and the last round of chemicals was expected to last until the road surface was dry. However, the lateness of the day and the continued impact of blowing snow kept the road surface wet as temperatures continued to plummet. Iowa DOT was forced to continue adding chemical to prevent the now wet road surface from refreezing. An alternative treatment strategy would have been to simply plow the road surface, recognizing that road temperatures would soon drop and blowing snow would continue. The MDSS currently examines only the weather and road conditions along a single run of a particular route. It does not examine the whole storm to evaluate post-storm conditions that may impact treatment strategy. Enhancements are being considered that will give the MDSS the ability to add or suppress treatments based on a whole storm methodology.
DSM treatment comparison

For the same reason as noted above, the MDSS recommended a liquid-brine pre-treatment for the DSM route (Figure 61). This was followed by four treatments of increasing intensity. Two treatments during the height of the storm of 150 and 200 lbs/lane-mile, a third treatment of 300 lbs/lane-mile covering a brief period of snow several hours after the main storm, and one treatment at 0800 on the 4th well after the snow had ended. This last treatment, while matching the Iowa DOT treatments, was apparently the result of logic in the MDSS to keep treatments from stacking up on one another and should not have been recommended. Like the Ames garage treatments, the initial application of salt to this storm followed by a rapid drop in air and road temperatures caused the potential for a hazardous re-freeze of the remaining solution. Des Moines – West garage applied treatments throughout the night until the morning sun was able to dry out the road surface.
6.6.2.2 14-15 February 2003 - Heavy Snowstorm

The heaviest snowstorm of the demonstration period occurred from February 14th-15th dumping approximately 11” of snow in the Des Moines and Ames region (liquid water of ~0.5 inches). Snow began in Ames at 0300 on the 15th (Figure 62), road temperatures were consistently below 35 deg F and in general below freezing. The light snow lasted 15 hours with no recognized periods of moderate or heavy snow. In Des Moines (Figure 63), the event began as rain, initially warming the road surface. At 0000 on the 15th the rain changed to snow and lasted for almost 20 hours with several hours of moderate and heavy snow. As the snow intensified, road temperatures steadily dropped although they never reached below the critical 14 deg F.

**Ames treatment comparison**

The MDSS began by recommending a liquid-brine pre-treatment of 50 gals/lane-mile (110 lbs/lane-mile equivalent) anytime prior to 1600 on the 14th. The Ames garage
performed a pre-treatment run at 1200. The MDSS recommended seven chemical treatments during the storm ranging from 150 to 250 lbs/lane-mile. Similarly, Ames garage performed four 200 lbs/lane-mile treatments during the storm. However, Ames supplemented these chemical treatments with separate plowing operations and two heavy applications of abrasives. Blowing snow, after the falling snow ended, necessitated additional chemical treatments of 450 and 300 lbs/lane-mile. These treatments were not captured by the MDSS.

Figure 62. Ames I35N route treatment analysis for Feb 14-15, 2003 heavy snowstorm.

**Des Moines treatment comparison**

The MDSS also recommended a pre-treatment for the Des Moines West; however, DSM garage did not perform a pre-treatment. The rain that fell from 1600-2300 would have reduced the effectiveness of any pre-treatment. The MDSS is designed to suspend pre-treatment recommendations if significant rain is likely to fall after the expected application. However, only the hours near the pre-treatment operation are examined for rain potential and in this case the significant rain fell much later than the
treatment. An adjustment will be made to capture rain falling over an extended period of time. The MDSS then recommended twelve chemical treatments ranging from 100 to 350 lbs/lane-mile. The overall treatment recommendation was about twice the tonnage actually applied by DSM-West garage. However, DSM did also supplement their treatments with plow only operations (something not currently possible as a recommendation by MDSS). Finally, DSM applied some chemicals to combat blowing snow early on the 16th.

Figure 63. Des Moines - West I35S route treatment analysis for Feb 14-15, 2003 heavy snowstorm.

6.6.2.3 23-24 February 2003 - Light Snowstorm

This late February light snowstorm occurred in extremely cold temperatures (at or near the ineffective range for NaCl). The snow was very dry and winds were moderately strong resulting in blowing snow problems for DOT operations. The storm lasted longer
in DSM (Figure 65) than it did in Ames (Figure 64), but the blowing snow was more of an issue in Ames.

**Ames treatment comparison**

The MDSS began by recommending a liquid-brine pre-treatment of 50 gals/lane-mile (110 lbs/lane-mile) six hours before the snow began. Once the snow began, the MDSS recommended four heavy sequential treatments ranging from 400 to 500 lbs/lane-mile. The heavy treatments were recommended because the road temperatures were extremely cold. Ames garage did not pre-treat because the temperatures were so cold and winds were expected to pick-up causing the potential for the same problems the DOT had on the Feb 3-4 storm. Ames decided to simply plow the route as needed, and did not apply chemical treatments until after the snow had stopped. These post-treatments were needed because traffic had caused the snow that had been blowing onto the road to melt. This storm re-enforces the need to look at the whole storm as suggested in the Feb 3-4 analysis. Recognizing that increasing winds and cooling temperatures, even after the main precipitation, may have an impact on treatments is an important feature to capture.
The MDSS again began by recommending a liquid-brine pre-treatment of 50 gals/lane-mile (110 lbs/lane-mile) six hours before the snow began. This initial treatment was followed by a single 250 lbs/lane-mile treatment several hours into the storm. Unlike the Ames storm that had temperatures during the storm that were within the chemical effectiveness range, DSM’s storm had temperatures primarily below 14 deg F. Therefore, the MDSS stopped recommending treatments after the 00 UTC run. No plowing operations were recommended because the snow was very light. Des Moines garage did not pre-treat, likely due to the cold temperatures and blowing snow potential. They performed two rounds of 350 lbs/lane-mile and then they stopped treating as MDSS had also recommended.

Figure 64. Ames I35N route treatment analysis for Feb 23-24, 2003 snowstorm.

**Des Moines treatment comparison**

The MDSS again began by recommending a liquid-brine pre-treatment of 50 gals/lane-mile (110 lbs/lane-mile) six hours before the snow began. This initial treatment was followed by a single 250 lbs/lane-mile treatment several hours into the storm. Unlike the Ames storm that had temperatures during the storm that were within the chemical effectiveness range, DSM’s storm had temperatures primarily below 14 deg F. Therefore, the MDSS stopped recommending treatments after the 00 UTC run. No plowing operations were recommended because the snow was very light. Des Moines garage did not pre-treat, likely due to the cold temperatures and blowing snow potential. They performed two rounds of 350 lbs/lane-mile and then they stopped treating as MDSS had also recommended.
6.6.2.4 6-8 April 2003 - Warm Snowstorm

This late season light snowstorm occurred on relatively warm roadways. In addition, winds were not a factor in this storm because not only were the winds lighter but the precipitation was more dense. The light snow extended over a long period of time especially in Des Moines where snowflakes fell for more than 24 hours. Overall snow totals for this storm, however, were generally less than 3 inches. Road temperatures were generally above 35 deg F, except during the nighttime period where they cooled below freezing.

Ames and Des Moines treatment comparison

The MDSS recommended that no treatments be performed for this storm. The warm road temperatures were deemed sufficient to melt any snow that was falling on the road. Both Ames (Figure 66) and Des Moines (Figure 67) garages felt some treatments...
were necessary, in particular at around 0400 on the 7th when temperature began to drop towards freezing. The Rules of Practice for these warm events will be re-valuated to see if any adjustments should be made in light of the actual treatments performed by Iowa DOT.

Figure 66. Ames I35N route treatment analysis for April 6-8, 2003 warm snowstorm.
Figure 67. Des Moines - West I35S route treatment analysis for April 6-8, 2003 snowstorm.
7 SUMMARY

The overall success of the MDSS project will be measured by the system’s ability to predict weather and road conditions with enough accuracy that decision makers will feel comfortable with its treatment recommendations. The 2003 winter field demonstration provided the first opportunity to assess its potential over a broad range of environmental conditions. The results were mixed, but not unexpected given the complexity of the problems being addressed. The results of the field season will be used to identify system improvements and focus areas.

Overall, the quality of the observations from both NWS and RWIS sites was quite good, except for precipitation rate and amount (liquid equivalent). There was good site-to-site agreement in the observations of air temperature and wind, in particular. Dewpoint/relative humidity comparisons were not as good, but still reasonable. One should expect larger variations in water vapor over shorter distances than wind and temperature. Variations in height and location will impact humidity measurements. Low sites and sites near lakes and streams will tend to have higher humidity values on average.

Puck-to-puck comparison of road temperature was also quite good for the one RWIS station near the Altoona interchange on I-80. Comparisons between RWIS and radiometer measured road temperatures were good in cloudy and precipitating conditions, but significantly worse when the sun shone on the roadway.

Precipitation measurements were quite poor when snow was occurring at ASOS sites. The heated tipping bucket gauges provided no valuable liquid precipitation data, whatsoever. Cloud cover comparisons were not possible.

The RWFS forecasts of most state parameters was generally good, with most forecasts falling within about 50% of the range of error found in the measurements, themselves. Relative humidity forecasts were not as good and although they may be accurate enough for general public forecasts, they may not be accurate enough to predict fog or frost. Cloud cover forecasts were generally off by about one category, which could have a significant impact on downstream road temperature forecasts, due to incorrect insolation. Methods to correct for this uncertainty should be investigated.
Precipitation forecasts were difficult to verify, overall, and were better suited to a case study approach. Several in-depth case studies were completed. They showed that the mesoscale precipitation pattern in the forecast varied in quality significantly from event to event. This is not surprising, considering the use of synoptic-scale models as significant inputs to the forecast. They are not designed to forecast such patterns well. COOP observations were also used for pattern comparisons and these observations were somewhat sparse and of limited quality. Time series assessments showed fairly good precipitation timing (start and stop) for most events, with the notable exception of the 14-15 February case. Precipitation type forecasts were reasonable, in general, both for case studies and overall. Again the 14-15 February case was a notable exception, when the precipitation type was badly forecast as freezing rain at the beginning of the event by both the RWFS and the NWS. This was corrected in later runs.

Case studies were critical to the analysis of suggested and actual treatments applied. In general, the MDSS suggested treatments were reasonable, given the RWFS forecast available at that time. For some cases, the forecasts were incorrect, so the treatments did not match reality. In cases where the forecasts were more accurate, the suggested and actual treatments matched fairly well. One case, in particular, demonstrated that a "whole-event" approach to treatment suggestion could be quite valuable. In that case, rapidly falling temperatures were expected during and immediately following the snowfall, causing melted snow to freeze onto the highways. Treatments were required through the night, but not suggested by the system because it expected the roads to have been clear. These treatments were also partially necessitated by blowing snow, which the RWFS does not currently handle.

Based on the analyses presented herein, we can conclude that the first demonstration of the MDSS had mixed results. It was a successful demonstration of a prototype research system in that it identified several areas that need additional development, but it was also somewhat disappointing because it means the system, as a whole, is not ready for deployment.
8 PRIMARY LESSONS LEARNED OR CONFIRMED

Several lessons were learned or confirmed during the Iowa field demonstration. They are summarized below.

1) The MDSS requires highly specific forecasts of precipitation, which are pushing the limits of predictability. An evaluation of the modeling component will be conducted to determine how to improve the performance of the forecasts.

2) The RCTM, which includes the rules of practice, needs additional development to handle a wider variety of weather and road condition scenarios and treatment responses. It’s performance was encouraging given “perfect” weather inputs, but additional logic is needed to look at the whole storm scenario and treatment trigger thresholds need tuning.

3) The availability and quality of real time precipitation rate data are very poor. The NWS and RWIS providers need to address this issue. The MDSS will be configured differently in the future so that it is not as dependent on these data for self-tuning as it was during the 2003 demonstration. Real time snow gauges may be deployed in 2004 to test MDSS performance given improved precipitation measurements.

4) During a winter storm, users do not have time to enter actual treatments for each route; therefore, the system loses track of the actual road conditions. A system ‘reset’ will be added to the system that will allow users to clear the snow on the road and chemical concentration after a storm. In the future, it is anticipated that a database of treatments and road conditions updated in real time could be used for this purpose.

5) Light snow events and intermittent events are critical and particularly hard to predict. The MDSS event trigger settings (e.g., minimum precipitation rate and
probability of precipitation thresholds) will be evaluated to determine if it could be more sensitive to these types of events.

6) The road temperature model SYNTHERM-RT does a good job at predicting road temperatures given adequate weather inputs and road characteristic data. More work is needed to account for the impact of traffic, chemicals, compact snow and blowing snow on the model.

7) The users have a strong desire for tactical decision support. The user of radar and real time snow gauge data for identifying treatments and predicting chemical failure should be explored in the future.

8) Because weather will never be predicted perfectly at road scales, probabilistic products should be developed. This will be explored more thoroughly during the winter 2004 field demonstration.

Several shortcomings and issues have been raised that will need to be addressed before the MDSS is considered mature. Known limitations of the MDSS prototype include:

1) **Blowing Snow:** The MDSS prototype is not designed to provide treatment recommendations for blowing snow conditions. Once precipitation has ended and the final treatment recommended the MDSS does have any way to predict and estimate the impact of blowing snow (ground blizzards) on the road conditions. A method to alert users that treatments are likely for blowing snow conditions will be developed.

2) **Road Frost:** The MDSS does not contain explicit algorithms that identify road segments that may need treatments due to frost. Road frost algorithms are under development at some universities and it is anticipated that this capability may be added to the MDSS in the future.
3) **Confidence:** The MDSS was designed to provide an indication of confidence associated with weather and road condition predictions. Due to funding limitations, the development of this capability was suspended. Users indicate that a measure of confidence and/or probabilistic information would be beneficial. Probabilistic products for some parameters will be introduced during the winter 2004 demonstration.
## Appendix A: Technical Points of Contact

The points of contact at each Lab sorted by the MDSS technical modules are listed below.

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<thead>
<tr>
<th>MDSS Technical Component</th>
<th>Source Lab</th>
<th>Technical Point of Contact</th>
</tr>
</thead>
<tbody>
<tr>
<td>Road Temperature Model SNTHERM-RT</td>
<td>CRREL</td>
<td>George Koenig CRREL 72 Lyme Road Hanover, NH 03755-1290 Ph: 603-646-4556 Fax: 603-646-4730 Email: <a href="mailto:gkoenig@crrel.usace.army.mil">gkoenig@crrel.usace.army.mil</a></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Lindamae Peck CRREL 72 Lyme Road Hanover, NH 03755-1290 Ph: 603-646-4261 Fax: 603-646-4397 Email: <a href="mailto:Lindamae.Peck@erdc.usace.army.mil">Lindamae.Peck@erdc.usace.army.mil</a></td>
</tr>
<tr>
<td>Chemical Concentration Algorithms</td>
<td>CRREL (Algorithm Science)</td>
<td>Marian Rollings CRREL 72 Lyme Road Hanover, NH 03755-1290 Ph: 603-646-4822 Fax: 603-646-4820 Email: <a href="mailto:mrollings@crrel.usace.army.mil">mrollings@crrel.usace.army.mil</a></td>
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<tr>
<td></td>
<td>LL (Algorithm Software)</td>
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</tr>
<tr>
<td>Chemical Concentration Algorithms</td>
<td>LL (Algorithm Software)</td>
<td>Robert G. Hallowell MIT Lincoln Laboratory 244 Wood Street Lexington MA 02420-9180 Ph: 781-981-3645 Fax: 781-981-0632 Email: <a href="mailto:bobh@mitll.edu">bobh@mitll.edu</a></td>
</tr>
<tr>
<td>Coded Rules of Practice</td>
<td>CRREL (Algorithm Science)</td>
<td></td>
</tr>
<tr>
<td>Road Mobility Algorithm</td>
<td>CRREL &amp; NCAR</td>
<td>George Blaisdell CRREL 72 Lyme Road Hanover, NH 03755-1290 Ph: 603-646-4474 Fax: 603-646-4820 Email: <a href="mailto:blaisdell@cr02.crrel.usace.army.mil">blaisdell@cr02.crrel.usace.army.mil</a></td>
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<tr>
<td></td>
<td></td>
<td>Jason Weale CRREL 72 Lyme Road Hanover, NH 03755-1290</td>
</tr>
</tbody>
</table>
| Road Weather Forecast System (based on DICAST©) | NCAR | Bill Myers  
NCAR  
3450 Mitchell Lane  
Boulder CO 80301  
Ph: 303-497-8412  
Fax: 303-497-8401  
Email: [myers@ucar.edu](mailto:myers@ucar.edu) |
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<td>Road Condition &amp; Treatment Module</td>
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<td>Mobility Algorithm</td>
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<tr>
<td>Lead Software Engineer System Integration</td>
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</tr>
</tbody>
</table>
| MDSS-FP Display Application                     | NCAR | Paddy McCarthy  
NCAR  
3450 Mitchell Lane  
Boulder CO 80301  
Ph: 303-497-8461  
Fax: 303-497-8401  
Email: [paddy@ucar.edu](mailto:paddy@ucar.edu) |
|                                                 |      | Arnaud Dumont  
NCAR  
3450 Mitchell Lane  
Boulder CO 80301  
Ph: 303-497-8434  
Fax: 303-497-8401  
Email: [dumont@ucar.edu](mailto:dumont@ucar.edu) |
| Meteorological Assimilation Data Ingest System (MADIS) | FSL | Patty Miller  
NOAA/Forecast Systems Lab  
325 Broadway, R/FS1  
Boulder CO 80303  
Ph: 303-497-6365  
Fax: 303-497-7256  
Email: [miller@fsl.noaa.gov](mailto:miller@fsl.noaa.gov) |
| RWIS Data Ingest                                |      |                                                  |
| Ensemble Modeling System                        | FSL | Paul Schultz  
NOAA/Forecast Systems Lab  
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Email: [schultz@fsl.noaa.gov](mailto:schultz@fsl.noaa.gov) |
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### Iowa Maintenance Routes for the winter 2003 MDSS Field Demonstration

<table>
<thead>
<tr>
<th>Garage</th>
<th>Segment Number</th>
<th>Route</th>
<th>Start Mile Post</th>
<th>End Mile Post</th>
<th>ADT Range</th>
<th>Service Level</th>
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</tbody>
</table>

**Service Levels:**

- **A**  Interstates
- **B**  5,000+ vehicles per day
- **C**  2,500 – 5,000 vehicles per day
- **D**  less than 2,500 vehicles per day