The Maintenance Decision Support System (MDSS) Project

TECHNICAL PERFORMANCE ASSESSMENT REPORT

SECOND IOWA FIELD DEMONSTRATION WINTER 2003-2004

Version 1.1

20 November 2004

Prepared for:

Federal Highway Administration
Office of Transportation Operations
Road Weather Management Program

Prepared by:

National Center for Atmospheric Research (NCAR)
P.O. Box 3000
Boulder, Colorado 80301
REPORT CONTRIBUTORS

National Center for Atmospheric Research (NCAR):

Jamie K. Wolff  Arnaud Dumont
Ben C. Bernstein  Jim Cowie
Seth Linden  Paddy McCarthy
Bill Myers  Bill Mahoney
Jaimi Yee

Lincoln Laboratory (LL):

Robert Hallowell

NOAA/Forecast Systems Laboratory:

Paul Schultz
Brent Shaw

Cold Regions Research and Engineering Laboratory (CRREL):

Gary Phetteplace
George Koenig

Center for Transportation Research and Education (CTRE)

Dennis Kroeger

Iowa Department of Transportation (IADOT)

Dennis Burkheimer
Paul Durham
Edward Mahoney
Richard Hedlund
Jim Dowd
## RELEASE NOTES

<table>
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<tr>
<th>Version Number</th>
<th>Date</th>
<th>Notes</th>
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<td>30 September 2004</td>
<td>Submitted to the FHWA</td>
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<tr>
<td>Version 1.1</td>
<td>20 November 2004</td>
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<td>AOTR</td>
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<tr>
<td>C</td>
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<td>- Dynamic Model Output Statistics</td>
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</tr>
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</tr>
<tr>
<td>DOY</td>
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<td>- Decision Support System</td>
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</tr>
<tr>
<td>EMC</td>
<td>- Environmental Modeling Center</td>
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</tr>
<tr>
<td>EMFP</td>
<td>- Ensemble Model Forecast Provider</td>
<td></td>
</tr>
<tr>
<td>ESRI</td>
<td>- Environmental Systems Research Institute</td>
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</tr>
<tr>
<td>ESS</td>
<td>- Equitable Skill Score</td>
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</tr>
<tr>
<td>Eta</td>
<td>- National Weather Service Model</td>
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</tr>
<tr>
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<td>FSL</td>
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<tr>
<td>FTP</td>
<td>- File Transfer Protocol</td>
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<td>GFS</td>
<td>- Global Forecast System Weather Service Model</td>
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<td>GPS/AVL</td>
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<tr>
<td>GRIB</td>
<td>- Gridded Binary</td>
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<td>- Hydrometeorological Automated Data System of the NWS</td>
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<td>HOTO</td>
<td>- Office of Transportation Operations</td>
<td></td>
</tr>
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<td>IADOT</td>
<td>- Iowa Department of Transportation</td>
<td></td>
</tr>
<tr>
<td>IKV</td>
<td>- Ankeny, Iowa airport identifier</td>
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</tr>
<tr>
<td>ITS</td>
<td>- Intelligent Transportation System</td>
<td></td>
</tr>
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<td>JPO</td>
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<td></td>
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<tr>
<td>LAPS</td>
<td>- Local Analysis and Prediction System</td>
<td></td>
</tr>
<tr>
<td>LEDWI</td>
<td>- Light emitting diode weather indicator (ASOS sensor)</td>
<td></td>
</tr>
<tr>
<td>LDADS</td>
<td>- Local Data Acquisition and Dissemination System</td>
<td></td>
</tr>
<tr>
<td>LDM</td>
<td>- Local Data Manager</td>
<td></td>
</tr>
<tr>
<td>MADIS</td>
<td>- Meteorological Assimilation Data Ingest System (NOAA/FSL)</td>
<td></td>
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<tr>
<td>MDSS</td>
<td>- Maintenance Decision Support System</td>
<td></td>
</tr>
<tr>
<td>MDSS FP</td>
<td>- Maintenance Decision Support System – Functional Prototype</td>
<td></td>
</tr>
<tr>
<td>METAR</td>
<td>- Meteorological Surface Observation including ASOS (DSM and AMW) and</td>
<td></td>
</tr>
<tr>
<td>AWOS (IKV)</td>
<td>- Meteorological Surface Observation including ASOS (DSM and AMW) and</td>
<td></td>
</tr>
<tr>
<td>MIT/LL</td>
<td>- Massachusetts Institute of Technology - Lincoln Laboratory</td>
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</table>
MM5 – Mesoscale Model – Version 5 (NCAR & Penn State)
MOS – Model Output Statistics
NCEP - National Centers for Environmental Prediction
NEXRAD – NEXt generation RADar program
NSF – National Science Foundation
NSSL – NOAA, National Severe Storms Laboratory
NOAA – National Oceanic and Atmospheric Administration
NCAR - National Center for Atmospheric Research
NVD - Non-Verifiable Data
NWP – Numerical Weather Prediction
NWS – National Weather Service
OCD – Operational Concepts Description
QPE – Quantitative Precipitation Estimate
QPF – Quantitative Precipitation Forecast
RCTM – Road Condition & Treatment Module
RMSE – Root mean squared error
RoP – Rules of Practice
RTVS – Real Time Verification System (RTVS)
RUC – Rapid Update Cycle (NWS weather prediction model)
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 MDSS concepts and functional prototype is a team effort involving several U.S. national laboratories, several state DOTs, the University of Iowa Center for Transportation Research and Education (CTRE), and Professor Wilf Nixon of the University of Iowa. The authors are particularly grateful to Gary Petteplace and George Koenig (CRREL), Robert Hallowell and Darin Meyer (MIT/LL), and Paul Schultz and Brent Shaw (NOAA/FSL). The MDSS development team at NCAR consists of several scientists and software engineers including Paddy McCarthy, Arnaud Dumont, Jim Cowie, Ben Bernstein, Jamie Wolff, Jaimi Yee, Seth Linden, Sue Dettling, and Bill Mahoney. The development team appreciates the 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 support and leadership provided by Regina McElroy, Paul Pisano, Rudy Persaud, Randall VanGorder, Andy Stern and Ray Murphy. More than twenty state DOTs have been active participants and their feedback is greatly appreciated.

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, Jim Dowd, Paul Durham, Edward Mahoney and Richard Hedlund.
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1 PURPOSE

This document describes the technical performance results of the prototype MDSS weather and road condition prediction products and treatment recommendations based on the winter 2003-2004 Iowa field demonstration. The field demonstration ended on 24 March 2004. Data analysis began shortly after its completion and has proceeded for several months. Many different aspects of the Road Weather Forecast System (RWFS) and MDSS are addressed here, including their performance for the entire field demonstration for all sites, and during individual events that impacted roadways in the region of interest (near Ames, Iowa). Individual components of the system are also evaluated, including the road temperature module, road treatment module, mesoscale weather models and the display.

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. It is recommended that the reader have a working knowledge of meteorological verification methods and statistical analysis metrics.

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 anticipated that components of the prototype MDSS developed by this project will be enhanced, integrated with other operational components, and deployed by road operating agencies, including state Departments of Transportation (DOTs), and generally supplied by commercial weather service providers.

Four national research centers participated in the development of the prototype MDSS in 2003-2004. 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 Forecast Systems Laboratory (FSL)
The Center for Transportation Research and Education (CTRE) of Iowa State University provided valuable support to the field demonstration. Professor Wilf Nixon of the University of Iowa provided additional support and recommendations to the development team.

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 4.1.

Table 4.1. MDSS Project Related Documents

<table>
<thead>
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<td>Surface Transportation Weather Decision Support Requirements (STWDSR) Project documents:</td>
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<td>Maintenance Decision Support System (MDSS) Release 3.0 Technical Description – 19 November 2004</td>
<td>National Center for Atmospheric Research</td>
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<td>Maintenance Decision Support System (MDSS) Project Web Site at FHWA:</td>
<td>Federal Highway Administration</td>
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<td><a href="http://ops.fhwa.dot.gov/weather/index.asp">http://ops.fhwa.dot.gov/weather/index.asp</a> under Mitigating Impacts/Projects &amp; Programs; under Projects &amp; Activities</td>
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<td><a href="http://www.rap.ucar.edu/projects/rdwx_mdss/index.html">http://www.rap.ucar.edu/projects/rdwx_mdss/index.html</a></td>
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</table>
5 METHODS

This document provides objective and subjective verification of winter 2003-2004 MDSS weather forecasts and road treatment recommendations, respectively. In addition, analyses of the road temperature model, rules of practice and mesoscale weather model components are provided. Results and recommendations have been summarized throughout the report to provide guidance to organizations planning on implementing MDSS components or similar technologies.

Obtaining sufficient high quality verification data continues to be a challenge for this project and similar efforts. Issues related to verification data limitations are described throughout this document.

Surface weather observation quality was assessed in 2003 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 uncertainty in the observations themselves.

Objective verification is achieved via direct comparisons of MDSS forecasts and observations from National Weather Service and Road Weather Information System (RWIS) weather stations, including diagrams of root-mean squared error (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 road treatment verification 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 light snow, heavy snow, mixed precipitation, cold rain and blowing snow events.

6 MDSS VERIFICATION ROUTES

A total of 16 routes were configured in the MDSS for the 2003-2004 field demonstration. The selected routes are shown in Fig. 6.1 and a corresponding description of the routes is provided in Table 6.1. Separate treatment plans were generated by the MDSS prototype for each of the routes. Much of the verification will focus on Route ID #3 (I-35, north of Ames), due to the proximity of an RWIS, the Ames Airport METAR and the Ames Garage, where efforts were focused during the demonstration.
Fig. 6.1. Map of routes to be supported by the MDSS prototype during the winter of 2003-2004 Iowa field demonstration. Key observation sites are annotated. In addition to the verification routes, one bridge used for verification is also included.
Table 6.1. Iowa Maintenance Routes for the 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>
</tr>
</thead>
<tbody>
<tr>
<td>Ames</td>
<td>1</td>
<td>US 65</td>
<td>98.38</td>
<td>112.09</td>
<td>1500-2000</td>
<td>C</td>
</tr>
<tr>
<td>Ames</td>
<td>1</td>
<td>US 30</td>
<td>164.93</td>
<td>172.30</td>
<td>5000-6000</td>
<td>B</td>
</tr>
<tr>
<td>Ames</td>
<td>2</td>
<td>US 65</td>
<td>112.09</td>
<td>132.59</td>
<td>1000-2000</td>
<td>C</td>
</tr>
<tr>
<td>*Ames</td>
<td>3</td>
<td>I-35</td>
<td>111.60</td>
<td>128.46</td>
<td>20000-23000</td>
<td>A</td>
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<td>Ames</td>
<td>4</td>
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<td>96.60</td>
<td>111.60</td>
<td>23000-26000</td>
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<td>*Ames</td>
<td>5</td>
<td>US 30</td>
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<tr>
<td>Ames</td>
<td>6</td>
<td>IA 210</td>
<td>13.79</td>
<td>34.43</td>
<td>1000-3000</td>
<td>D</td>
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<tr>
<td>Ames</td>
<td>-</td>
<td>I-35</td>
<td>Bridge</td>
<td>Bridge</td>
<td>20000-23000</td>
<td>A</td>
</tr>
<tr>
<td>*Des Moines North</td>
<td>7</td>
<td>I-35</td>
<td>93.20</td>
<td>96.60</td>
<td>26000-53000</td>
<td>A</td>
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<tr>
<td>Des Moines North</td>
<td>8</td>
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<td>86.94</td>
<td>93.20</td>
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<td>9</td>
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<td>137.82</td>
<td>142.10</td>
<td>50000-61000</td>
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<tr>
<td>Des Moines North</td>
<td>10</td>
<td>I-35/1-80</td>
<td>131.50</td>
<td>137.82</td>
<td>59000-63000</td>
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<tr>
<td>Des Moines West</td>
<td>11</td>
<td>I-35/1-80</td>
<td>123.53</td>
<td>131.50</td>
<td>32000-72000</td>
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<tr>
<td>Des Moines West</td>
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<td>22000-33000</td>
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<tr>
<td>Des Moines West</td>
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<td>14.26</td>
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<tr>
<td>Des Moines North</td>
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<td>0.00</td>
<td>21.93</td>
<td>1000-21000</td>
<td>B-D</td>
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</table>

Service Levels:

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

Road condition data were only collected for a subset of the total routes supported by the prototype MDSS in 2004. This decision was based on the need to collect quality data and the fact that obtaining accurate road condition data throughout a storm is difficult, manually intensive and time consuming. Road condition data were collected for the following routes (see Fig. 6.1):

- **Ames Garage:**  
  Routes #3 (I-35) and #5 (US 30)

- **Des Moines Garage:**  
  Route #7 (I-35)

The three verification routes are highlighted in bold in Table 6.1 and annotated with an asterisk. The selection of routes was based on several factors including proximity to an RWIS, service level (traffic count), diversity of expected treatment plans, and proximity to Lab, Iowa DOT Headquarters and CTRE support staff who were responsible for collecting verification data and were staying in Ames.
7 MDSS SYSTEM CONFIGURATION

The MDSS core components (e.g., Road Weather Forecast System, Road Condition and Treatment Module and data server) were operated centrally at NCAR in Boulder, Colorado. A server at NCAR communicated (via the Internet) with local PCs running the display application at the Iowa DOT maintenance garages. Supplemental weather forecast models were run at FSL in Boulder and the data forwarded to NCAR for inclusion in the RWFS. Iowa DOT RWIS data were provided to NCAR via FSL as part of the Meteorological Assimilation Data Ingest System (MADIS) program.

The MDSS displays were located in three maintenance garages. Each garage had an instance of the MDSS display running at the supervisor’s desk. Data were exchanged between the display and server over the Internet (client-server approach). As new updates were available, the data were pushed to the display. A simplified illustration of the system configuration is provided in Fig. 7.1.

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**Fig. 7.1.** Depiction of the prototype MDSS configuration for the winter 2003-2004 Iowa field demonstration. All network MDSS connections to the sites were via the Internet.
7.1 Supplemental Numerical Weather Prediction Models

For the 2003-2004 MDSS demonstration FSL configured multiple, high-resolution models to run over the identical area, all centered on Iowa, with identical grid configurations and execution schedules. FSL elected to use two different local-scale models, each of which used different physics packages for parameterizing clouds and precipitation. The configuration consisted of running MM5 and an improved version of WRF every hour, and using “time-lagged” ensembling techniques. For example, a 6-hr (hour) ensemble forecast used the current 6-hr forecast, the previous 7-hr forecast, and the 8-hr forecast from the previous model cycles.

There were no obvious alternatives to the FSL method for initializing the local models (other methods for diabatic initialization are too computationally intensive to use in real time), so the Local Analysis and Prediction System (LAPS) hot start initialization was used for all models. A hot start initialization is a method to generate cloud water and precipitation processes at the start of the model run. This is a new and promising technique that improves the ability of models to predict clouds and precipitation, particularly in the 0-6 hr forecast period.

The local-scale models used for the MDSS field demonstration were:

MM5: http://www.mmm.ucar.edu/mm5/mm5-home.html

WRF: http://wrf-model.org/

The lateral boundary model was the Eta model provided by the NWS National Centers for Environmental Prediction (NCEP). The Eta model was delivered to NWS field offices and FSL four times daily.

The supplemental modeling configuration used for the Iowa MDSS field demonstration is summarized in Table 7.1.

Table 7.1. Configuration of the MDSS Supplemental Models

<table>
<thead>
<tr>
<th>Forecast Model</th>
<th>Boundary Condition Source</th>
<th>Forecast Period</th>
<th>Grid Spacing</th>
<th>Update Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>WRF</td>
<td>NWS: Eta</td>
<td>15 hours</td>
<td>12-km</td>
<td>1-hr</td>
</tr>
<tr>
<td>MM5</td>
<td>NWS: Eta</td>
<td>15 hours</td>
<td>12-km</td>
<td>1-hr</td>
</tr>
</tbody>
</table>

The mesoscale models (WRF and MM5) ran every hour providing a new 15-hr forecast to the RWFS. Even though the fine scale models were run hourly, the MDSS only updated every 3 hours. The hourly mesoscale model forecasts out to 15 hours ensured that there were forecasts available from the fine scale models out to 12 hours at all times with the 3 hour update cycle for MDSS. The grid spacing used in the fine scale models was 12-km (~7.5 miles). The MM5 and WRF supplemental models run by FSL had a domain centered on Iowa as shown in Fig. 7.2.
FSL’s Experimental Rapid Update Cycle (RUC) Model was also added in fiscal year 2004 and those data were acquired by NCAR from FSL. No special runs were generated to provide the RUC model as it runs daily as part of ongoing NOAA and FAA research programs. The domain of the RUC model is the continental U.S. For information on the RUC model, please see:


### 7.2 MDSS Prototype Optimization Period

The RWFS is tasked with ingesting reformatted meteorological data (observations, models, statistical data, climate data, etc.) and producing meteorological forecasts at user defined forecast sites and forecast lead times. The forecast variables output by the RWFS are used by the RCTM to calculate the road surface temperature and to determine a suggested treatment plan. In order to achieve this goal, the RWFS generates independent forecasts from each of the data sources using a variety of forecasting techniques.

A single consensus forecast from the set of individual forecasts is provided for each user defined forecast site. Forecast variables that had corresponding high quality observations were tuned based on a processing method that takes into account the recent skill of each forecast module. This consensus forecast is nearly always more skillful than any component forecast. The RWFS is designed to optimize itself using available observations near the routes (e.g., RWIS, METARS). The forecast modules that perform the best are given more weight over time. In addition, Dynamic Model Output Statistics (DMOS) are calculated weekly using observations and model output. The DMOS process is used to remove model biases. The optimization period of the RWFS is approximately...
90-100 days and because the revised version of the RWFS was not fully operational until October 2003, the MDSS route specific forecasts were not fully ‘tuned’ until late December 2003. For more information on the RWFS, the reader is directed to Appendix A of the MDSS Prototype Release-3.0 Technical Description (see reference in Table 4.1).

8 DATA COLLECTION PROCESS

The national labs were responsible for analyzing the MDSS technical performance. A critical component of the verification process was the collection of weather, road condition and actual treatment data. During the winter 2003 field demonstration, Iowa DOT personnel were primarily responsible for collecting the road condition and treatment data using special data collection forms. This process put a large burden on the DOT staff during winter storms. The data collection process during the winter of 2003-2004 was changed to reduce the impact on DOT staff. In addition, road condition data were only collected for a subset of the total routes supported by the prototype MDSS as described earlier in this document. This was designed to allow for a more intensive data collection process so that a more thorough analysis of the road conditions before and after treatment could be performed.

The Center for Transportation Research and Education (CTRE) provided support for the demonstration effort, particularly in the area of verification data collection and processing. In addition, the University of Iowa, Dr. Wilfred Nixon, provided feedback to the development team on the MDSS, particularly the road condition and treatment module, which contains the rules of practice for anti-icing and deicing.

The MDSS field demonstration began following a demonstration readiness telecom on 30 December 2003. A daily summary of the weather, DOT actions, system issues and software updates is provided in Appendix B.

The first weather event occurred on 7 January 2004 and the last weather event occurred on 16 March 2004. The demonstration officially ended on 24 March 2004. There was excellent diversity in the types of cases this year. Central Iowa experienced heavy and light snow events, mixed rain and snow, brief freezing rain, refreezing water on the road, and several blowing and drifting snow events. There were 15 winter weather event days during the course of the 88 day demonstration.

The MDSS operated quite well throughout the period; however, there were several periods when the supplemental mesoscale models from FSL were unavailable, primarily due to hardware problems associated with their computer cluster. An evaluation of the impact of these models on the MDSS performance is provided later in this report.

To facilitate the collection of weather and road condition data during the field program several MDSS project members traveled to Iowa to participate in the field program. A list of the personnel participating in the field program is provided in Table 8.1.
Table 8.1. MDSS Project Visitors to Iowa for the MDSS Demonstration.

<table>
<thead>
<tr>
<th>Week #</th>
<th>Date</th>
<th>Name</th>
<th>Organization</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>28 December 2003</td>
<td>Open (Holidays)</td>
<td>N/A</td>
</tr>
<tr>
<td>2</td>
<td>4 January 2004</td>
<td>Robert Hallowell</td>
<td>LL</td>
</tr>
<tr>
<td>3</td>
<td>11 January 2004</td>
<td>Gary Phetteplace</td>
<td>CRREL</td>
</tr>
<tr>
<td>4</td>
<td>18 January 2004</td>
<td>Bill Myers</td>
<td>NCAR</td>
</tr>
<tr>
<td>5</td>
<td>25 January 2004</td>
<td>Brent Shaw</td>
<td>NOAA/FSL</td>
</tr>
<tr>
<td>6</td>
<td>1 February 2004</td>
<td>Darin Meyer</td>
<td>LL</td>
</tr>
<tr>
<td>7</td>
<td>8 February 2004</td>
<td>Arnaud Dumont</td>
<td>NCAR</td>
</tr>
<tr>
<td>8</td>
<td>15 February 2004</td>
<td>Andy Stern &amp; Ray Murphy</td>
<td>Mitretek &amp; FHWA</td>
</tr>
<tr>
<td>9</td>
<td>22 February 2004</td>
<td>Bill Mahoney</td>
<td>NCAR</td>
</tr>
<tr>
<td>10</td>
<td>29 February 2004</td>
<td>Open</td>
<td>N/A</td>
</tr>
<tr>
<td>11</td>
<td>7 March 2004</td>
<td>Paul Schultz</td>
<td>NOAA/FSL</td>
</tr>
<tr>
<td>12</td>
<td>14 March 2004</td>
<td>Goeff Koenig</td>
<td>CRREL</td>
</tr>
<tr>
<td>13</td>
<td>22 March 2004</td>
<td>Open</td>
<td>N/A</td>
</tr>
</tbody>
</table>

8.1 Supplemental Data Collection

To augment the weather data collection activities, NCAR installed a suite of weather sensors at the Ames garage on 17 December 2003. The weather sensors include a GEONOR snow gauge with an Alter shield, air temperature and dew point sensor, R.M. Young anemometer, sonic snow depth sensor, and pyranometer. A photo of the Ames Garage site is provided in Appendix C. Several technical problems delayed the availability of the data. For example, about 7 days after the installation, the power to the site failed. In addition, access to the Iowa DOT network was delayed due to computer system security concerns. The GEONOR gauge also suffered a rare power conditioner failure. All of the problems were resolved by 9 February 2004.

To reduce the workload of the Iowa DOT staff, GPS/AVL data recording systems were installed on the 8 snowplows covering the three verification routes. These data were downloaded after the events and processed by CTRE.

The goal of the data collection process was to capture the evolution of the weather and road conditions during the life cycle of winter storm events near the MDSS demonstration routes. Verification data were obtained and archived from several sources near the selected MDSS routes.

Several data collection methods were used this year including:

a) Automated collection of actual treatments using Iowa DOT maintenance vehicle recording systems (e.g., GPS/AVL systems)
b) Manual data collection of actual treatments using standard Iowa DOT post-treatment (shift) forms
c) Automated collection of weather data (local ASOS, AWOS, and RWIS)
d) Manual collection of weather and road condition data using specialized forms filled out by CTRE, Iowa DOT, Lab staff and other supporting project participants either riding in private cars or in DOT maintenance vehicles along selected routes

8.2 Data Sources: Weather Observations

The following weather observation data sources were used for verification and analysis:

a) Iowa RWIS (primarily sites in Des Moines, Ames, and Ankeny)
b) NWS ASOS/AWOS (DSM=Des Moines, IKV=Ankeny, AMW=Ames)
c) Local observer surface data
d) Weather satellite
e) Weather radar
f) NWS storm summaries
g) Iowa DOT observations
h) CTRE, Iowa DOT and Lab staff observations using forms along verification routes
   i) GEONOR snow gauge (Ames Garage)
j) Other sources as available

8.3 Data Sources: Road Condition Observations

The following road condition data sources were used for verification and analysis:

a) Iowa RWIS road temperature (primarily sites in Des Moines, Ames, and Ankeny)
b) CTRE, Lab and Iowa DOT staff and other supporting project participants on-site data collection using forms along selected verification routes
c) Iowa DOT operator and supervisor observations
d) Iowa DOT maintenance vehicle data
   i. Pavement temperature
   ii. Freezing point
   iii. Truck location and time

8.4 Data Sources: Actual Treatment Performed

The following data sources were used to obtain data describing the actual winter maintenance treatments:
a) CTRE, Lab and Iowa DOT staff and other supporting project participants on-site
data collection using forms along selected verification routes
b) Iowa DOT standard shift forms
c) Iowa DOT maintenance vehicle data
   i. Material distribution setting
   ii. Treatment type
   iii. Treatment rate
   iv. Plow position
   v. Date, time and location

8.5 Verification Data Forms

In order to fully estimate the weather and road conditions performed during each event, it
was necessary for CTRE and Lab personnel, as well as other supporting project
participants, to fill out data collection forms. The weather and road condition forms used
by CTRE, Iowa DOT Lab staff and other supporting project participants were designed to
capture the following information about weather and road conditions:

- Date
- Time
- Route
- Treatment performed (if riding in maintenance vehicle)
  - Treatment start and stop times
  - Chemicals used (NaCl, solids, liquids, etc.)
  - Chemical amount (tonnage and/or pounds per lane mile or gallons per lane
    mile)
  - Plowing performed
- Estimated road condition per route
  - Wet, dry, icy, snowpacked, blowing snow, snow depth, slush, rain,
    freezing rain, frost, etc.
  - Road temperature (if available)
- Weather conditions along route
  - Precipitation type, precipitation rate, precipitation start and stop times,
    blowing snow, snow depth, frost, air temperature, wind speed, etc.
- Any other pertinent observations such as chemical dispersion rate, condition of
  road before and after treatment, precipitation start and stop times.

A digital camera was also used by CTRE, Lab staff and other supporting project
participants to capture images of the road conditions throughout the life of a storm.
9 MDSS ENHANCEMENTS FOR 2004

Using the 2003 post-demonstration evaluations, technical performance results, and the lessons learned from meetings with Iowa DOT and support personnel, a list of system development activities was compiled that was considered important for the success of the winter 2004 field demonstration. The list below includes enhancements for 2004 to the RCTM, the RWFS, the mesoscale model ensemble and the client display application.

RCTM module modifications focused on the preparation of better road treatment recommendations. The RWFS updates were centered on improved handling of the quantitative precipitation forecast data, increasing the temporal resolution of the output, and better quality control and use of observations in the preparation of weather forecasts. The mesoscale model ensemble configuration was changed to use a better selection of models with a higher temporal resolution in an attempt to improve the detection of weak weather events. And finally, several refinements were made to the display application based on Iowa DOT feedback.

9.1 Road Condition and Treatment Module (RCTM)

The following enhancements were made to the Road Condition and Treatment Module including the road temperature model (SNTHERM-RT) and coded Rules Of Practice:

1) **Road Temperature Model Initialization:** Revised the road temperature model (SNTHERM-RT) so that it could be initialized using road temperature surface and subsurface observations for routes with RWIS stations that had both surface and subsurface data. For evaluation purposes, this method was applied to two RWIS stations (Ames RWIS and I-235 RWIS).

2) **Plowing Rules:** Fixed a software bug that was introduced in the middle of the winter 2003 demonstration that did not allow ‘plow only’ treatments to be recommended.

3) **System Reset:** Added ability for the users to reset the road conditions (road snow depth = 0 and chemical concentration = 0) for each route or a group of routes.

4) **Blowing Snow Potential:** In the absence of a more sophisticated solution, created a ‘blowing snow’ alert when blowing snow conditions were likely. The blowing snow potential algorithm is based on precipitation type, snowfall rate, air temperature, wind speed, number of diurnal cycles, and occurrence of other precipitation types since the last snowfall.

5) **Rules Of Practice:** Refined the coded Rules Of Practice using Iowa weather and treatment case data. Several significant improvements were made to the code for 2004. Logic was added within the MDSS system to recognize the overall storm...
situation. During the winter of 2003, the treatment module essentially determined the next treatment recommendation based on the weather that was forecasted from the current trigger to the time it would take to traverse a given route. This approach was too short-sighted, as it was unable to handle changing weather situations predicted to occur several hours into the future.

6) **Dry Road Time**: A critical factor in after-storm maintenance is the time at which the road surface becomes “dry”. If chemicals fail before a road is completely dry then subsequent treatments will be needed to mitigate refreezing. An algorithm was developed to determine the factors affecting dry road time and the treatment recommendations sensitive to this factor.

7) **Bridge Segment Support**: Configured and tuned MDSS to support bridges as weather and road condition forecast points. For the winter of 2004, a bridge on I-35 near Ames was added for evaluation purposes.

### 9.2 Road Weather Forecast System (RWFS)

The following enhancements were made to the Road Weather Forecast system:

1) **Forward Error Correction**: Implemented a technique to adjust the RWFS predictions to better match observations when the forecast time is the current time (t=0). This technique was applied to verifiable parameters.

2) **Spatial Consistency**: Added ‘neighborhood DMOS’ (Dynamic Model Output Statistics) to the system so there would be more consistency between nearby prediction points that have similar characteristics.

3) **Quality Control Flags**: Developed software to take advantage of the quality control flags provided with the MADIS data stream.

4) **Hourly Forecasts**: Revised the RWFS to accept, process and output hourly data out to at least 15 hours into the forecast period. This provided an opportunity to take advantage of the higher temporal resolution of the mesoscale models. The hourly output was merged with the 3-hr NWS model data (interpolated to hourly) for the first 15 hours, while only NWS models were used for the 16-48-hr time period.

5) **Probabilistic Information**: Using the data contained in the RWFS, generated probabilistic information for select data fields (e.g., precipitation, and precipitation type).

6) **Bridge Support**: Added the capability in the RWFS to predict weather and road temperatures for bridge segments.
9.3 Mesoscale Model Ensemble

The following changes or enhancements were made to the mesoscale ensemble component of the prototype MDSS:

1) **Ensemble Configuration**: Updated the selection of models, the model output frequency, the run schedule, and the output products. The MM5 and WRF models were included in 2004. Also, FSL's Rapid Update Cycle (RUC) experimental model runs (which are separate from those RUC runs conducted by NOAA’s National Centers for Environmental Prediction (NCEP)) were included.

2) **System Stability**: Made changes to the scripts for the ensemble modeling system in order to make the software system more robust.

9.4 MDSS Display Application

The following enhancements were made to the MDSS display application:

1) **Digital Values**: Provided digital values to the state and route view graphics.

2) **System Reset**: Added ability of the users to reset the road conditions (road snow depth = 0 and chemical concentration = 0) for each route or all routes via the user interface.

3) **RWIS Observations**: Added ability to view the most current road temperature data from RWIS stations via the display interface.

4) **Dynamic Range**: Added dynamic range code for the time-series parameters to reduce the chance of having data go out of range.

5) **Recent Treatment History View**: Provided a way to view actual treatment information for a 6 hour period prior to the last update.

6) **Display Summary Page**: Users indicated that they needed a quick-look summary page of weather and road variables for each forecast period and for each plow route. Summary page products include maximum and minimum predicted air and road temperatures, total new snow accumulation, and an indication of conditional probabilities of precipitation type.

7) **Blowing Snow Potential**: Created a treatment recommendation alert graphic on treatment page when blowing snow conditions were likely.
10 SELECTED CASE STUDIES

While bulk statistics are useful in the assessment of the quality of RWFS forecasts, it is quite valuable to first examine their quality for a variety of weather events. Such case studies reveal the reasons behind forecast errors and the scale of errors that it is reasonable to expect under the circumstances most important to users – when the roads are being impacted by winter weather.

The case studies include the following events:

- Cold Rain Case 16 January 2004
- Light Snow Case 26 January 2004
- Blowing Snow Case 9 February 2004
- Mixed Precip Case 20 February 2004
- Heavy Snow Case 15 March 2004

Bulk statistical analysis will follow the case studies, since such proper context will then be in place. Using information from the case studies and the entire program, the performance of several MDSS modules (road treatments, road temperatures, mesoscale models) is discussed, including the quality of some verification datasets. Several case studies were chosen for analysis. The cases were chosen to include several weather and treatment scenarios which occurred during this year’s demonstration.

10.1 Verification Methods

For the demonstration this year a suite of weather sensors (see Appendix C) was also installed at the DOT garage in Ames for additional observations and verification tools. Sensors at this site included temperature, humidity, propeller-driven anemometer, pyranometer, sonic sensor to measure snow depth on the snow board, and GEONOR precipitation gauge to measure snowfall (Fig. 10.1). A higher confidence is placed in the accuracy of the GEONOR measurements, with its correction for wind speed, then the hourly precipitation measurements made at the METAR site for snow depth. These sensors became operational on February 9, 2004.
Fig. 10.1. Sample web depiction of traces from the Ames weather sensors.
For the case studies presented here a technique was used to derive the actual snowfall from the Light Emitting Diode Weather Identifier (LEDWI) sensor located at the ASOS site. LEDWI has been on ASOS since its inception in the early 1990s as the "present weather indicator" or precipitation identifier (PI) which reports once per minute during times of falling precipitation. Its primary use to date has been to distinguish between rain and snow, and to provide the intensity of the rain or snow (light, moderate, heavy). However, the LEDWI raw channel data can also be used to estimate precipitation rates: the High channel is proportional to rain rates, and the Low channel is proportional to snowfall accumulation. LEDWI can be used to estimate precipitation rates for both frozen and liquid precipitation. Research is still being conducted on the finding liquid equivalent amounts for frozen precipitation with the LEDWI sensor.

The real advantage of using LEDWI to derive precipitation amounts is that it doesn't need to capture the precipitation in order to measure it. Thus, it doesn't have the problems that conventional precipitation gauges have (i.e. needing wind shields, needing to be heated to prevent snow from sticking to the sidewalls, maintenance, etc.). However, this is not to say that the LEDWI does not have its own set of challenges. Very heavy snowfall (rates in excess of 3 inches/hr) tend to saturate the signal and produce incorrect rates. This is rare, however, and can be dealt with by limiting the rates to 3 in/hr. Occasionally snow will stick to the LEDWI lens (wet snow with strong northerly winds) and block the signal. Finally, LEDWI only estimates accumulations when it is snowing. After the snow stops there is no information on what happens to the snow accumulation. Also, if the surface temperature is above freezing the snow may melt.

For these case studies, in order to convert the liquid precipitation measurements to snowfall accumulation, a snow to liquid ratio must first be identified. Time periods with relatively light winds were used because they had fairly good liquid precipitation measurements from the NWS heated tipping bucket. An algorithm was then applied to the rest of the time period where the LEDWI data was available to get the total estimated snowfall accumulation.

Within the RWFS the data used for actual liquid amounts comes from the tipping bucket at a METAR site as well as from NOAA’s Local Analysis and Prediction System (LAPS) data. For this demonstration a special LAPS grid was set up over the state of Iowa. Fifteen-minute composite reflectivity WSI NOWRAD radar at 1 km resolution was put through the LAPS precipitation accumulation analysis using a fixed Z-R relationship1 to form an hourly 12 km grid of Quantitative Precipitation Estimate (QPE) observations, distributed hourly. If the LAPS QPE data has a higher amount for a given hour then the METAR QPE report from the tipping bucket, then LAPS was used as “truth”.

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1 A Z-R relationship is used to correlate radar reflectivity (intensity) to precipitation amount. Using a fixed relationship can be problematic because different types of clouds (i.e. convective, stratiform) may have different Z-R relationships. A Z-R relationship for winter precipitation was used in this application.
10.2 Case Studies

10.2.1 Cold Rain Case – 16 January 2004

Rain moved into the Ames area around 22 UTC\(^2\) on 16 January 2004 and continued through 03 UTC on 17 January 2004. According to the observations at the Ames METAR site, the precipitation fell in the form of light rain much of the time with brief, intermittent periods of “unknown precipitation” (UP). UP may indicate that the precipitation was just too light to be identified by the LEDWI sensor or it may indicate a mixture of rain and snow.

The precipitation was associated with a stationary front draped down through the southwest corner of Iowa (Fig. 10.2). The front extended from a low pressure system that moved slowly from the northwest to the southeast corner of North Dakota. The precipitation moved across the demonstration area from southwest to northeast (Fig. 10.3).

\(^2\) A time conversion of -6 hours is used to convert from UTC to CST.
Fig. 10.2. Surface maps showing the progression of the synoptic setup. The red lines are isobars and the cold fronts are represented by the blue triangles.
Fig. 10.3. Radar images showing the progression of the precipitation throughout the day. The blue shades are 10-25 dBZ, green shades 25-40 dBZ and yellow shades 40-50 dBZ.
For this event, the 12 UTC MDSS run from 16 January 2004 was examined for all parameters. The 18 UTC run from 16 January 2004 was also used to further assess precipitation end time predictions. The air temperature forecasts for this case were fairly close to the observed air temperature for much of the time series, but tended to be warm by 1-2°C (Degrees Celsius; Fig. 10.4). Because actual air temperatures were just above 0°C during the time of the rain event, the slightly warm forecasts could have resulted in a missed forecast of the precipitation type. This did not end up being the case, however.

**Air Temperature Comparison for Jan 16, 2004**

![Air Temperature Comparison for Jan 16, 2004](image)

*Fig. 10.4. Air Temperature (°C) time-series plot comparing the Ames METAR and Ames RWIS observations to the RWFS forecasts (both with and without the FSL supplemental models) for the METAR and RWIS site. The vertical lines represent the time period that the Ames METAR was reporting falling precipitation.*

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3 For the time series graphs several lines are plotted. The AMW METAR (RWIS) OB is the observations from the METAR (RWIS) site. The AMW METAR (RWIS) wFSL is the RWFS forecast for the AMW METAR (RWIS) site with the FSL supplemental models and AMW METAR (RWIS) woFSL is the RWFS forecast for the AMW METAR(RWIS) site without the FSL supplemental models. The x-axis on all of the time series graphs will be time in UTC.
Wind speeds were fairly light (~4 m/s; Fig. 10.5) during the event and the forecasts nicely matched the observations, even during a period of sharp increase after the precipitation ended. Visibility forecasts were also quite good during the period of rainfall, but after the precipitation ended, fog was present and held the observed visibility down (Fig. 10.6). The RWFS did not capture the low visibility associated with the fog.

Wind Speed Comparison for Jan 16, 2004

![Wind Speed Comparison for Jan 16, 2004](image)

**Fig. 10.5.** Wind speed (m/s) time-series plot comparing the Ames METAR and Ames RWIS observations to the RWFS forecasts (both with and without the FSL supplemental models) for the METAR and RWIS site. The vertical lines represent the time period that the Ames METAR was reporting falling precipitation.
Fig. 10.6. Visibility (mi) time-series plot comparing the Ames METAR and Ames RWIS observations to the RWFS forecasts (both with and without the FSL supplemental models) for the METAR and RWIS site. The vertical lines represent the time period that the Ames METAR was reporting falling precipitation.

From the 12 UTC run the forecast precipitation start time was 22 UTC both with and without the FSL supplemental models at both the METAR and RWIS sites. This was essentially the time that the actual precipitation started at the Ames METAR site (Fig. 10.7). In this run, the precipitation was predicted to end at ~11 UTC on 17 January, which was about 7 hours later than it actually ended. The 18 UTC run also predicted the precipitation start time very well and was somewhat closer in its forecast of the end time (Fig. 10.8). Still, the system predicted the rain to last for 5 hours beyond its actual end time. The forecast issued by the NWS office at 415 AM CST on 16 January (1015 UTC) called for:

.TODAY...RAIN SHOWERS LIKELY IN THE AFTERNOON. HIGH IN THE UPPER 30S. SOUTHEAST WIND 10 TO 15 MPH. PRECIPITATION CHANCE 60 PERCENT.

.TONIGHT...WARMER. RAIN THEN RAIN LIKELY AFTER MIDNIGHT. LOW IN THE LOWER 30S. SOUTHEAST WIND 10 TO 15 MPH SHIFTING TO THE EAST AROUND 5 MPH AFTER MIDNIGHT. PRECIPITATION CHANCE 80 PERCENT.
It is seen here that the NWS also called for the rain to continue after midnight when in reality it ended by 10 PM CST on 16 January (4 UTC 17 January). At 100 PM CST (19 UTC) the NWS issued a new forecast for the day but the wording was left the same for both the remaining portion of the day and that night. These forecasts are very similar to the timing of the precipitation predicted by the RWFS for this event.

Fig. 10.7. Probability of Precipitation (%) and Quantitative Precipitation Forecast (mm/hr), both of which are shown on the y-axis, time-series plot comparing the RWFS forecasts (both with and without the FSL supplemental models) for the METAR and RWIS site. The vertical lines represent the time period that the Ames METAR was reporting falling precipitation. The orange arrows indicate the forecasted start (with and without FSL) and stop (with and without FSL) times at the METAR and RWIS sites.
Fig. 10.8. Probability of precipitation (%) and quantitative precipitation forecast (mm/hr) time-series plot for the 18 UTC 16 January 2004 RWFS run comparing the RWFS forecasts (both with and without the FSL supplemental models) for the METAR and RWIS site. The vertical lines represent the time period that the Ames METAR was reporting falling precipitation. The blue arrow indicates the forecasted start with FSL time at the METAR and RWIS sites, the green arrow indicates the forecasted start without FSL time at the METAR and RWIS sites, and the orange arrow indicates the stop time with and without FSL at the METAR and RWIS sites.

For this event the LEDWI data were unavailable. However, the hourly observations for the ASOS tipping bucket gauge indicated a total of 0.45 inches of precipitation. The 12 UTC RWFS run had comparable total QPE forecasts, including 0.39 inches with the FSL models and 0.41 without the FSL models. However, had the predicted end time of the event been closer to reality, the RWFS with and without the supplemental models would have under-forecast the total precipitation.

The road temperature forecasts were within about 1°C before and during precipitation (Fig. 10.9). After the precipitation ended, forecasts were too warm by as much as 5°C during the daylight hours of the next day. This is likely due to the fact that the cloud cover forecasts (Fig. 10.10) moved out the clouds too quickly resulting in a forecast of greater insolation (solar radiation) for the road.
Fig. 10.9. Road Temperature (°C) time-series plot comparing the Ames RWIS observations to the RWFS forecasts (both with and without the FSL supplemental models) for the RWIS site and segment 3(I-35 North of Ames). The vertical lines represent the time period that the Ames METAR reported falling precipitation.
Cloud Comparison for Jan 16, 2004

Fig. 10.10. Cloud cover time-series plot comparing the Ames METAR only to the RWFS forecasts (both with and without the FSL supplemental models) for the METAR and RWIS site. The vertical lines represent the time period that the Ames METAR reported falling precipitation. CLR = Clear skies, SCT = Scattered clouds, BKN = Broken skies, OVC = Overcast skies.

A comparison of RMSE values for all the sites in Iowa combined versus the site at Ames (Fig. 10.11) reveals the same pattern of errors, however the errors were larger at Ames than for all sites. The temperature and dew point errors are consistently about 1°C higher at Ames then for all the sites. This may be, in part, due to the dampening of the error when averaging all the sites together rather than looking at one individual site. When combining the errors for all the sites, the RMSE values for wind speed gradually increased with time and at Ames they were much more variable, but again, increased with time. The cloud cover forecast was worse at Ames, especially later in the forecast run. The bias plot comparison (Fig. 10.12) again shows that biases at Ames were similar to those at all sites.
Fig. 10.11a. RMSE plots for all sites across Iowa. From left to right, top to bottom; temperature, dew point temperature, wind speed, and cloud cover. Hr 0 = 12 UTC 16 January 2004.
Fig. 10.11b. RMSE plots for Ames only. From left to right, top to bottom: temperature, dew point temperature, wind speed, and cloud cover. Hr 0 = 12 UTC 16 January 2004.
Fig. 10.12a. Bias plots for all sites across Iowa. From left to right, top to bottom: temperature, dew point temperature, wind speed, and cloud cover. Hr 0 = 12 UTC 16 January 2004.
Overall at Ames, the RWFS predicted the start of the precipitation quite well, but had some problems with the end time. Air temperature forecasts were accurate, but even slight errors could have resulted in a blown precipitation type forecast if the actual temperature had been just a degree or two colder. Wind speed forecasts were excellent and visibility forecasts were reasonable, except that the drop in visibility associated with the fog that followed the precipitation event was not forecasted.

10.2.2 Light Snow Case – 26 January 2004

This event was a long-lived light snowfall event that affected the demonstration area between approximately 03 UTC on 26 January and 11 UTC on 27 January 2004. During much of this time the snowfall was fairly light with an occasional period of more moderate snowfall. In all, about 4-8 inches of snow fell in the Ames area. With cold temperatures and high winds during this event there was significant blowing and drifting
snow which made it difficult to determine exact accumulation amounts (see Fig. 10.13). The official snow accumulation reported by the National Weather Service (NWS) was 7.9 inches for Ames, but lab personnel on-site indicated amounts closer to 4-5 inches at the Department of Transportation (DOT) garage in Ames.

![Snow drifts along US-30 about 3 miles east Ames DOT garage.](image)

The synoptic setup (Fig. 10.14) for this system featured an inverted trough (dashed orange line) that moved from the west into central Iowa. The trough was associated with a low pressure system that progressed eastward along the southern Missouri/northern Arkansas border. The trough was just to the west of Iowa around 03 UTC on 26 January, around the time it started snowing in Ames, and passed through the demonstration domain as the low moved off to the northeast. A fairly strong pressure gradient built behind the low as it moved off, causing the winds to shift to north-northwesterly and become quite strong across the state of Iowa toward the end of the event. Temperatures fell sharply as the northerly flow also advected cold air into the area.
Fig. 10.14. Surface maps showing the progression of the synoptic setup. The surface low pressure area of interest is circled.
For this case the 18 UTC, 25 January MDSS run was used which would have provided a 9 hour forecast for the start of the event. Comparisons between the observed and forecast air temperature (Fig. 10.15) show that they matched quite well during the snow event. Unfortunately, there was a 10-hour gap in all RWIS observations toward the end of the event. These data were unrecoverable. With the close match of the RWIS observations to the METAR observations for this parameter during the prior portion of the time series it is fair to assume that this trend continues during the RWIS data outage.

\[\text{Fig. 10.15. Air Temperature (°C) time-series plot comparing the Ames METAR and Ames RWIS observations to the RWFS forecasts (both with and without the FSL supplemental models) for the METAR and RWIS site. The vertical lines represent the time period that the Ames METAR was reporting falling precipitation.}\]

Prior to the start of the snowfall the air temperature forecasts were low by a few degrees Celsius, but they were very closely matched during much of the snowfall event. Towards the end of the event, the forecast air temperatures again started to diverge and eventually became too warm by as much as 5°C. One possible reason for this warm forecast may be that the forecast dew point temperatures (Fig. 10.16) only fell to -17°C while the actual air temperature dropped to -20°C. This implies that forecasted air temperature could not possibly go lower then -17°C even if the air was saturated, which was not the case. The dew point temperature time series shows fairly good agreement during most of the event,
except that the forecasts were too high before and after the event. Considering the
difficulty in predicting this parameter the forecasts were reasonably good. Neither the air
temperature nor dew point temperature forecasts were significantly different between the
runs made with and without the FSL models.

![Dew Pt Temperature Comparison for Jan 26, 2004]

**Fig. 10.16.** Dew point temperature (°C) time-series plot comparing the
Ames METAR and Ames RWIS observations to the RWFS forecasts (both
with and without the FSL supplemental models) for the METAR and RWIS
site. The vertical lines represent the time period that the Ames METAR
was reporting falling precipitation.

Wind speed and direction forecasts were important for this case because blowing and
drifting snow occurred toward the end of the event. The wind speed (Fig. 10.17) and
direction (not shown) forecasts matched the METAR and RWIS observations quite well
during the entire event. The blowing snow alert algorithm had not yet been added to the
MDSS at the time of this event, so no alerts were issued in real time. However, post-
analysis runs of the algorithm for this case indicated the highest level alert (of 3 levels)
would have been activated from 06 UTC to 16 UTC on the 27th along road segment 3.
The second highest level was indicated from 18 UTC on the 26th to 21 UTC on the 27th,
except for a couple of hours where winds speeds were low. Even though there were no
real time alerts issued, the accurate wind speed and direction forecasts gave maintenance
personnel a heads up to the shift in wind direction and increase in speed at the end of the
event and they could take this into account in their planning process. Again, there were no significant differences between the forecasts with and without the FSL models.

Wind Speed Comparison for Jan 26, 2004

Fig. 10.17. Wind speed (m/s) time-series plot comparing the Ames METAR and Ames RWIS observations to the RWFS forecasts (both with and without the FSL supplemental models) for the METAR and RWIS site. The vertical lines represent the time period that the Ames METAR was reporting falling precipitation.

As mentioned above, snow started falling in the Ames area around 03 UTC on 26 January. A few radar images are included, corresponding to the times of the surface maps, to demonstrate the progression of the snow throughout the event (Figs. 10.12, 10.18). A time series chart of the forecasts of probability of precipitation (POP) and quantitative precipitation forecast (QPF) indicate the forecasted start and stop times of the event as predicted 9 hours before the actual start time (Fig. 10.19). The RWFS uses POP and QPF thresholds of 25% and 0.1 mm/hr, respectively, to determine when precipitation will fall.
Fig. 10.18. Radar images showing the progression of the snowfall. The radar is in clear air mode so the yellow shades are 0-8 dBZ, the red shades 8-24 dBZ and the white to grey is greater than 24 dBZ.
For this event the forecast start of the snow at the METAR site with FSL model input included was predicted to be essentially the same time as the actual precipitation start (03 UTC 26 January). The start time for the RWIS site was predicted to be one hour later, but since RWIS stations typically do not have a precipitation gauge there is no way to verify the actual start time at that site. The “with-FSL” run did indicate a two hour break in the snow from 05 – 06 UTC 26 January for both sites, which did not occur. Without the FSL models the start time for both the METAR and RWIS site was not predicted until 07 UTC 26 January due to the fact that the POPs were below the threshold, so the FSL models helped significantly for the timing of the precipitation initiation for this event. The actual end time for this event was 41 hours out from the run time of this time series. Since the FSL models only go out to 15 hours, only the forecasts without the FSL models could be evaluated after that point. The end time for the RWIS site was forecast to be 23 UTC on 26 January and for the METAR site was 01 UTC 27 January, 10 – 12 hours off from the actual end times. Examination of a later RWFS run from 18 UTC on 26 January revealed that the end times were still forecast to be too early compared to the observations at the METAR site (Fig. 10.20). The end times were pushed back a few hours from the 18 UTC, 25 January run, but still occurred about 10 hours before the actual end time.
Fig. 10.19. Probability of precipitation (%) and quantitative precipitation forecast (mm/hr time-series plot comparing the Ames METAR and Ames RWIS observations to the RWFS forecasts (both with and without the FSL supplemental models) for the METAR and RWIS site. The vertical lines represent the time period that the Ames METAR was reporting falling precipitation.). The blue arrows indicate the forecasted start (with FSL) and stop (with and without FSL) times at the METAR site, the green arrows indicate the start (with FSL) and stop (with and without FSL) times at the RWIS site and the orange arrow indicates the start time at both the METAR and RWIS site without FSL.
The NWS office forecasts for 1 PM CST on 25 January (19 UTC) called for a winter weather advisory through Monday.

.TONIGHT...BLUSTERY. CHANCE OF SNOW THEN SNOW AFTER MIDNIGHT. SNOW ACCUMULATION OF 2 TO 5 INCHES. LOW 10 TO 15. EAST WIND 15 TO 25 MPH.
.MONDAY...SNOW LIKELY. SNOW ACCUMULATION UP TO 2 INCHES. TOTAL SNOW ACCUMULATION 8 INCHES. HIGH 15 TO 20. NORTHEAST WIND 15 TO 20 MPH. PRECIPITATION CHANCE 70 PERCENT.
.MONDAY NIGHT...CHANCE OF SNOW IN THE EVENING. LOW ZERO TO 5 ABOVE. NORTH WIND 15 TO 20 MPH. PRECIPITATION CHANCE 30 PERCENT.
.TUESDAY...MOSTLY SUNNY. HIGH 15 TO 20. WEST WIND 10 TO 20 MPH.
The start time forecast by the NWS was fairly close to the actual start time of the precipitation with the wording “a chance of snow” changing to “snow after midnight”. The snow began around 10 PM CST (04 UTC, 26 January). The end time was forecast to be Monday night, but according to the observations the snow continued through Tuesday morning until 11 UTC. When the NWS updated their forecast at 1 PM CST on 26 January (18 UTC) they added the chance for snow after midnight on Monday night and extended the winter weather advisory through the night.

**TONIGHT...BLUSTERY...COLDER. AREAS OF BLOWING SNOW. SNOW THEN SNOW LIKELY AFTER MIDNIGHT. SNOW ACCUMULATION AROUND 2 INCHES. LOW ZERO TO 5 ABOVE. NORTHWEST WIND 15 TO 25 MPH...WITH GUSTS AROUND 30 MPH.**

**TUESDAY...PARTLY SUNNY IN THE MORNING THEN CLEARING. HIGH NEAR 15. NORTHWEST WIND 10 TO 20 MPH.**

So the update did extend the length of snowfall through early morning on Tuesday. The original forecast from the NWS matched the RWFS precipitation timing before the event started, but the updated forecast by the NWS indicated a closer end time for the event than was predicted by the RWFS update.

Another important precipitation variable to look at is the total forecast snow depth, which has major implications on winter road maintenance decisions. This is a difficult parameter to forecast because the snow to liquid ratio can be very sensitive to many atmospheric conditions such as surface temperature, temperature within the cloud where the precipitation formed, vertical motion within the cloud, available moisture, surface wind speeds and others.

LEDWI data from the start of this event was missing so actual hourly liquid precipitation measurements from the heated tipping bucket gauge, also located at the METAR site, were used in its place between 03 UTC and 12 UTC, 26 January. For this case the time period between 12 UTC and 15 UTC, 26 January is used to find the snow to liquid ratio for reasons stated earlier. During this time period a ratio of 20:1 was estimated and applied to the beginning portion of the data. From this estimation, the total snowfall was about 6 inches at the METAR site (Fig. 10.21). Also shown on this graph is the liquid precipitation, on the right axis. Note how poorly the tipping bucket gauge caught the snowfall once the winds pick up about half way through the event.
Also examined is the method used to forecast the snowfall within the RWFS. Using both the tipping bucket at the METAR site as well as the LAPS data, a 20:1 snow-to-liquid ratio was found to be appropriate for this case. Fig. 10.22 compares the approximate actual snow depth from this method to the forecasted snow depth from the RWFS. The estimated actual snow depth was approximately 6.5 inches while the forecast was only 2.5 inches. In the RWFS a straight 10:1 ratio is used for all cases regardless of the atmospheric conditions. Since this case had closer to a 20:1 ratio the forecasts were a factor of 2 off. If a 20:1 ratio had been applied to the forecast the forecasted snow depth would have been around 5 inches, which was much closer to reality. The NWS forecast from 18 UTC 25 January called for 8 inches of snow, which was a good forecast compared to the observations.
Fig. 10.22. Snow depth (inches) time-series plot comparing the Ames METAR and Ames RWIS observations to the RWFS forecasts (both with and without the FSL supplemental models) for the METAR and RWIS site. The vertical lines represent the time period that the Ames METAR was reporting falling precipitation.
Road temperatures were also compared between the RWIS and the forecasts for the RWIS site and segment 3, which is along I-35 from mile marker 112 – 128, north of Ames (Fig. 10.23). For the time periods where RWIS data were available for verification of road temperature during this event, forecasts are generally within about one degree Celsius.

![Road Temperature Comparison for Jan 26, 2004](image)

**Fig. 10.23.** Road Temperature (°C) time-series plot comparing the Ames RWIS observations to the RWFS forecasts (both with and without the FSL supplemental models) for the RWIS site and segment 3. The vertical lines represent the time period that the Ames METAR was reporting falling precipitation.

Cumulative verification results calculated for the entire state of Iowa for this event indicate that many of the errors observed at Ames were also evident throughout the domain, in general. In particular, forecast air temperatures and dew points were reasonably good throughout the event, but errors grew to be quite large for forecasts beyond 30 hours (Fig. 10.24). Relatively large errors in dew point (up to 7°C) air temperature (up to 3°C) noted at Ames before the event appeared to be outliers compared to the entire domain, which experienced only slightly larger than normal errors though hour 10. The relatively small amplitude to the all-station error may partially be a matter of larger, short-lived errors at different stations occurring at different times as the cold front moved across Iowa, resulting in relatively low overall RMSE values at any one time.
across the entire state. This is true for all fields. Cloud cover errors before and well after
the event appeared to be more significant at Ames than overall. Still, there was evidence
of significant errors in this field for all stations combined. Bias plots (Fig. 10.25) show
that cloud cover was under forecast by roughly one category (~0.25) across the state after
about 8 hours, and was particularly bad at Ames after 36 hours. Because of large gaps in
the road temperature data for this case, assessment of the overall trends for that field are
not advisable.

Fig. 10.24a. RMSE plots for all sites across Iowa. From left to right, top
to bottom: temperature, dew point temperature, wind speed, and cloud
Fig. 10.24b. RMSE plots for Ames only. From left to right, top to bottom: temperature, dew point temperature, wind speed, and cloud cover. 
Hr 0 = 18 UTC 25 January 2004.
Fig. 10.25a. Bias plots for all sites across Iowa. From left to right, top to bottom; temperature, dew point temperature, wind speed, and cloud cover. 
Hr 0 = 18 UTC 25 January 2004.
Overall the weather and road conditions were forecast well for this event. The forecast temperatures (air, dew point, and road) as well as wind speeds were all quite close to the observations during the most critical time to the maintenance personnel; during the snowfall. The precipitation start time 9 hours before the event was nearly perfect when FSL models were included. However, the forecast of the end of the event was about 10 hours too early. The total snowfall depth forecast was about half the estimated actual snow depth, but this is primarily attributable to an underestimated snow to liquid ratio for such a cold event. A key lesson learned from this case is that the snow to liquid ratio should vary with surface temperatures, at the very least, increasing to 20:1 during very cold events and decreasing to about 6:1 during very warm events.

10.2.3 Blowing Snow Case – 9-11 February 2004
At about 03 UTC on 10 February 2004 there was a short period of very light snowfall that dusted the demonstration area with around 0.2 inches of snow. The next day strong westerly winds moved into the area and created dangerous blowing snow conditions across parts of the domain for much of the day. Several cars ended up in the ditch and the Iowa DOT had to treat and plow roads because of all the blowing and drifting snow. According to lab personnel in Ames that week, there were portions of US-69 that had over 10 inches of drifting snow on the road late in the afternoon and the plow truck could not keep up with the drifts. Conditions on US-65 also deteriorated, with some locations having 2 inches of snow on the roadway by early afternoon, however I-35 stayed in fairly good shape and only needed one spot treatment during this event.

A cold front associated with a low pressure system centered near the Great Lakes pushed through central Iowa overnight on 9 - 10 February (Fig. 10.26). Along with the passage of the cold front came a few snow flurries between 03 and 04 UTC on 10 February (Fig. 10.27). After the first low pressure system pushed off to the east another low began influencing the area with a tight pressure gradient as it moved east-southeast from North Dakota through Minnesota. This pressure gradient caused westerly winds to pick up in the Ames area. Significant drifting snow developed in the late morning and lasted through much of the day on 11 February. The light snow that fell the previous night was believed to be just enough to really be blown around and create extensive drifts in some locations.
Fig. 10.26. Surface maps showing the progression of the synoptic setup.
Fig. 10.27. Radar images showing the progression of the precipitation. The blue shades are 10-25 dBZ, green shades 25-40 dBZ and yellow shades 40-50 dBZ.

For this case two runs from the RWFS were examined, one to look at the prediction of precipitation start and stop times for the very light snowfall and the other to look at the prediction of blowing snow alerts and treatment recommendations. The first run is from
18 UTC on 9 February, about 9 hours before the snow event occurred, and the second run is from 06 UTC on 11 February.

Air temperature forecasts from the 18 UTC, 9 February run started out matching the RWIS observations quite well, but an hour or two before the light snow fell, the observations actually rose while the forecasts kept declining (Fig. 10.28). This suggests that there was a push of warmer air just prior to the cold front moving through the area. Such a small scale process is difficult to forecast and the RWFS temperature forecast never recovered through the rest of the time series. The forecast was as much as 6°C off at times, with an average error of about 3°C. Another possible reason for the poor air temperature forecasts is a poor cloud cover forecast (Fig. 10.29). The forecast and observed air temperatures really start to diverge during the hours just after sunset, when the RWFS under-predicted the cloud cover. This should have resulted in an over-prediction of surface cooling. Forecasts for the next day had overpredictions of cloud cover during daylight hours, so the air temperature was held down further because of a thicker cloud cover compared to reality.

Fig. 10.28. Air Temperature (°C) time-series plot comparing the Ames METAR and Ames RWIS observations to the RWFS forecasts (both with and without the FSL supplemental models) for the METAR and RWIS site. The vertical lines represent the time period that the Ames METAR was reporting falling precipitation.
The very light snowfall was not predicted by the RWFS at all (Fig. 10.30). The POP did increase during the time of the event however the QPF never increased enough to trigger a forecast of precipitation. The NWS forecast for the case at 330 PM CST on 9 February stated:

.TONIGHT...PARTLY CLOUDY. SCATTERED FLURRIES. LOW NEAR 15. WEST WIND AROUND 15 MPH.
.TUESDAY...PARTLY SUNNY. HIGH IN THE MID 20S. WEST WIND AROUND 10 MPH.
.TUESDAY NIGHT...PARTLY CLOUDY. SCATTERED FLURRIES. LOW 15 TO 20. SOUTHWEST WIND AROUND 10 MPH.
.WEDNESDAY...PARTLY SUNNY. BLUSTERY. AREAS OF BLOWING SNOW. HIGH IN THE MID 20S. WEST WIND 10 TO 15 MPH SHIFTING TO THE NORTHWEST 15 TO 25 MPH IN THE AFTERNOON.
According to this forecast the scattered flurries were expected during the overnight hours. Blowing snow was also forecast for 11 February two days in advance.

**Fig. 10.30.** Probability of precipitation (%) and quantitative precipitation forecast (mm/hr) time-series plot comparing the Ames METAR and Ames RWIS observations to the RWFS forecasts (both with and without the FSL supplemental models) for the METAR and RWIS site. The vertical lines represent the time period that the Ames METAR was reporting falling precipitation.
The GEONOR gauge at the DOT garage site did not indicate any precipitation for this event. According to the LEDWI sensor and algorithm there was about 0.03 inches of snow accumulation at the METAR site which is about a factor of 10 different from the lab personnel observations at the Ames garage (Fig. 10.31). This difference may be due to the extremely light snowfall during this time, which is difficult for any instrument to measure, or due to differences in location.

![Graph](image)

**Fig. 10.31. Estimated snow accumulation (inches) from the LEDWI sensor located at the METAR site.**

The forecasts of air temperature from the 06 UTC 11 February run (closer to the time of the blowing snow event) were good for the first ~24 hours, but they diverged from the observations during the 24 hours following the blowing snow event (Fig. 10.32). The winds increased significantly at ~15 UTC, 11 February and the forecast winds matched those observed during much of the event (Fig. 10.33).
Fig. 10.32. Air Temperature (°C) time-series plot for 06 UTC, 11 Feb 2004 RWFS run comparing the Ames METAR and Ames RWIS observations to the RWFS forecasts (both with and without the FSL supplemental models) for the METAR and RWIS site. The vertical lines represent the time period that the Ames METAR was reporting falling precipitation.
Fig. 10.33. Wind speed (m/s) time-series plot for 06 UTC, 11 Feb 2004 RWFS run comparing the Ames METAR and Ames RWIS observations to the RWFS forecasts (both with and without the FSL supplemental models) for the METAR and RWIS site. The vertical lines represent the time period that the Ames METAR was reporting falling precipitation.

The blowing snow algorithm did not exist when this case took place, but post-analysis runs indicate that low-level (1 out of 3) blowing snow alerts would have been given for the Ames area (indicated for I-35 N (closest road to US-69 N), US-30 and US-65 N) from the start of the run (18 UTC on 9 February) to 22 UTC on the 10 February. The alerts were based on snow which fell 13 hours before the RWFS initialization time, adequate winds (4-7 m/s; see Fig. 10.33), temperatures which did not exceed freezing (Fig. 10.32) and a lack of observed or forecast liquid precipitation (Fig. 10.31). The low level of the alert was based on relatively meager wind speeds near Ames.

A comparison between forecast errors at Ames and for all of Iowa for the 18 UTC, 9 February RWFS run reveals that errors were relatively large at Ames (Fig. 10.34). This was especially true for temperature and dewpoint early in the run, though unusually large errors were present throughout the domain at times near +12 hrs (6 UTC, 10 Feb). Bias plots (Fig. 10.35) show that this was primarily due to significantly cold forecasts, like those found in the Ames time series analysis (e.g. Fig. 10.28). Wind speed forecasts were
reasonable across the domain, while cloud cover forecasts were underdone early and
overdone late in the run.
Fig. 10.34a. RMSE plots for all sites across Iowa. From left to right, top to bottom; temperature, dew point temperature, wind speed, and cloud cover. Hr 0 = 18 UTC 9 February, 2004.
Fig. 10.34b. RMSE plots for Ames only. From left to right, top to bottom: temperature, dew point temperature, wind speed, and cloud cover. Hr 0 = 18 UTC 9 February, 2004.
Fig. 10.35. Bias plots for all sites across Iowa. From left to right, top to bottom; temperature, dew point temperature, wind speed, and cloud cover. 

Hr 0 = 18 UTC 9 February, 2004.
It is evident from this rather difficult case that cloud cover forecasts were, again, a key parameter in order to get the air and road temperature predictions closer to reality. The precipitation forecast for this light event was missed because the QPF was just too low. This is an issue with very light snow events, which are inherently difficult for both models and human forecasters to predict. RWFS wind speed forecasts looked good during the time of the blowing and drifting snow, but may have underestimated locally higher wind speeds where drifting was prevalent (e.g. to the west of Ames). Reruns of the blowing snow algorithm produced low-level alerts for the Ames area during this event, primarily due to forecasts of relatively meager wind speeds.

10.2.4 Mixed Precipitation Case – 20 February 2004

The February 20, 2004 case was a complex system to forecast because of the changing phase of the precipitation during the event. The event started as rain around 06 UTC on 20 February. According to observers, the precipitation changed fairly quickly from rain to sleet and then to snow at ~1130 UTC. It then snowed through 13 UTC, after which
time the precipitation ended. The NWS models predicted a fairly lengthy period of snow to follow the rain in early forecasts prior to the start of the event. In later RWFS runs, where the end of the event was within the FSL models’ 15-hr run time, their inclusion resulted in a more accurate prediction of event end time.

The synoptic setup at 00 UTC on 20 February featured a low pressure system over the northeastern section of Kansas with an inverted trough along the western portion of Iowa (Fig. 10.36). The low moved toward the east-northeast with time and the trough was near Ames by 06 UTC. The low continued to move in this fashion and a fairly tight pressure gradient formed on its west side, causing increasing winds over the state of Iowa. By 12 UTC the low was in the southeastern portion of Iowa and the synoptic-scale lift quickly pulled out of the demonstration domain soon thereafter.

NEXRAD radar images (Fig. 10.37) indicate that showery precipitation initially moved into Ames area from the southwest. Rain was observed at the Ames METAR site just after 06 UTC. Light precipitation dominated the event, but a few heavier bands were present over the area as well. After the precipitation turned to snow at ~11 UTC, the reflectivity decreased quickly and shifted off to the southeast.
Figs. 10.36. Surface maps showing the progression of the synoptic setup.
Figs. 10.37. Radar images showing the progression of the precipitation. For the first three images in clear air mode the yellow shades are 0-8 dBZ, the red shades 8-24 dBZ and the white to grey is greater than 24 dBZ. For the last three images the blue shades are 10-25 dBZ, green shades 25-40 dBZ and yellow shades 40-50 dBZ.
For this case the RWFS forecast initialized at 00 UTC on 20 February RWFS was examined. Air temperatures were fairly steady around 0 to 2°C during much of the period (Fig. 10.38). Forecasts of air temperature were quite good before the precipitation began, but decreased too rapidly just before and during the precipitation period, becoming ~2°C too cold. This is critical for predictions of precipitation type at these temperatures because of the possibility for a mixed phase case such as this. After the event the forecast air temperatures rebounded to match the observations briefly during the evening hours, then again were much too low during the overnight hours. There are some missing observations toward the end of the time series, but it is clear that the forecasts never recovered to match the observations for this model run. The dew point temperature comparison shows a very similar trend (Fig. 10.39).

**Fig. 10.38.** Air Temperature (°C) time-series plot comparing the Ames METAR and Ames RWIS observations to the RWFS forecasts (both with and without the FSL supplemental models) for the METAR and RWIS site. The vertical lines represent the time period that the Ames METAR was reporting falling precipitation.
Fig. 10.39. Dew point temperature (°C) time-series plot comparing the Ames METAR and Ames RWIS observations to the RWFS forecasts (both with and without the FSL supplemental models) for the METAR and RWIS site. The vertical lines represent the time period that the Ames METAR was reporting falling precipitation.

Part of the temperature forecast problem after the event may be due to poor cloud cover forecasts (Fig. 10.40). Following the cessation of precipitation, the forecast cloud cover decreases dramatically from overcast (OVC) to scattered (SCT). Ames METAR observations indicated that skies remained overcast for the next ~24 hours. This lack of forecast cloud coverage may have allowed for the predicted air temperatures to fall off more during the night because less cloud insulation was forecast than observed.
Wind speeds increased significantly as the low pushed off to the east-northeast and the pressure gradient tightened behind it. The forecasts for wind speed (Fig. 10.41) looked very good for the entire time series, especially during the time of the event. With the increasing winds came decreased visibility during the short time period of snow. Fig. 10.42 shows the visibility comparison between the forecasts and the observations. Forecasts are for good, but variable visibility during the time of reported rain. The RWIS reported visibility is closer to the MDSS prediction than the METAR reported visibility. During the time of reported snow the forecasted visibility is reasonably close to the observations. Overall, the visibility pattern seemed to lag the observations, decreasing too slowly before and during the precipitation and rising too slowly after it ended. This lag is likely associated with forecasts of the precipitation ending well after it ended in reality, as will be discussed in subsequent paragraphs.
Fig. 10.41. Wind speed (m/s) time-series plot comparing the Ames METAR and Ames RWIS observations to the RWFS forecasts (both with and without the FSL supplemental models) for the METAR and RWIS site. The vertical lines represent the time period that the Ames METAR was reporting falling precipitation.
As mentioned above, this case was a very complex system to forecast. The timing and type of precipitation expected were difficult to capture with much certainty until just prior to the start of the event. The run time compared here is for a 6 hour lead time forecast before the start of the event. Forecasts of POP and QPF (Fig.10.43) without the FSL models result in a prediction of very light precipitation to start about 3 hours too early at the METAR site. When the FSL models were added the start time was over-corrected and ended up being about 2 hours too late. That same later start time was also indicated for the RWIS site both with and without FSL. The POP and QPF forecasts remained quite high well after the actual end of the event, and the stop times were predicted to be 7-10 hours later than observed. In this case, the event ended at hour 13, which is at the tail end of the period where FSL models are used. Looking at a later RWFS run from 06 UTC on 20 February, the same problem is exhibited with the end time prediction (Fig. 10.44). With the end time of the precipitation within 7 hours of the run time, the cessation of the event is still predicted to be 5 hours too late. This latter run was better than the 00 UTC run, however, even with the FSL models in the mix the end of this event was not well predicted.
Fig. 10.43. Probability of precipitation (%) and quantitative precipitation forecast (mm/hr) time-series plot comparing the Ames METAR and Ames RWIS observations to the RWFS forecasts (both with and without the FSL supplemental models) for the METAR and RWIS site. The vertical lines represent the time period that the Ames METAR was reporting falling precipitation. The blue arrows indicate the forecasted start (without FSL) and stop (with and without FSL) times at the METAR site, the orange arrow indicates the start time (with FSL) at the METAR site and (with and without FSL) at the RWIS site, and the green arrow indicate the stop (with and without FSL) times at the RWIS.
According to this forecast, rain was predicted after midnight and then rain or snow during the day on Friday, 20 February. From the observations it is seen that the rain did start at 1 AM CST but then ended by 8 AM CST and did not last through the day on 20
February. The NWS had the same problem as the RWFS with the timing of the end of this event.
The precipitation type was an important parameter for this case. For forecasts without the FSL models in the mix the predicted precipitation type went briefly from snow to freezing drizzle before the time of observed rain and then back to snow around the time of the actual snow (Fig. 10.45). When the FSL models were included, the precipitation type was initially expected to be rain and then freezing rain for a few hours. At about the time that the observations changed from rain to snow, the forecast precipitation type also changed over to snow and remained so for the rest of the predicted event. It is again seen that the snow prediction lasted much longer then the observations indicated for both with and without FSL models. As was mentioned above, the NWS forecast also had a mix of precipitation but the timing of the phase change was also hard to identify.

**Fig. 10.45.** Precipitation type comparison between the Ames METAR observations and the RWFS forecasts of type both with and without FSL at the RWIS site and Segment 3 (along I-35, north of Ames). Rain corresponds to 1, Rain/Snow mix to 1.5, Snow to 2, Freezing Rain to 5 and Freezing Drizzle to 6.
Because temperatures were just above freezing during the event, any snow that fell was likely to have melted soon after impact. According to one report there was about 0.1 - 0.2 inches of slush on the ground around the end of the event at ~13 UTC. From the tipping bucket there was about 0.3 inches of liquid accumulation during this event with about 0.28 inches falling as rain and 0.03 inches falling as snow (Fig. 10.46). Blowing snow was essentially never forecast or observed along I-35 N during this case, due to the warm temperatures and presence of rain near the time of the snow.

Fig. 10.46. Liquid precipitation (inches) from the heated tipping bucket gauge located at the METAR site.
The RWFS (which uses a 10:1 ratio) predicted over 2 inches total of snow accumulation (Fig. 10.47). This over-forecast may be attributable to two things. First, the forecast called for snow an extra 7 - 10 hours longer than actually occurred. Second, the actual snow:liquid ratio for the case was probably closer to 5:1 at these surface temperatures, which would put the predicted total closer to 1-1.5 inches. Predicted snow depths, applying both 10:1 and 5:1 ratios to the observations from the METAR and LAPS data are also shown on this graph, resulting in 0.25 – 0.5 inches of snow.

**SN Depth Comparison for Feb 20, 2004**

![SN Depth Comparison for Feb 20, 2004](image)

*Fig. 10.47. Snow depth (inches) time-series comparison of the Ames METAR observations versus the RWFS forecast for both the METAR and RWIS sites using a ratio of 5:1 and 10:1.*
The road temperature (Fig. 10.48) predictions for this case were quite good during the time of the event. After the event is over the temperatures are too warm during the day and too cold during the overnight hours. Again, the cloud cover forecasts are likely to have played a role. With fewer clouds forecast than were actually observed the forecasted road temperatures were able to decrease and increase more quickly during the night and day, respectively.

Error comparisons between Ames and the entire domain (Figs. 10.49 and 10.50) reveal that problems were similar across the domain for the 0 UTC, 20 February RWFS run. Of particular importance for this case were the gross under forecasts of cloud cover across the domain during hours 18 to 36, resulting in low temperature and dew point predictions after hour 24.

![Road Temperature Comparison for Feb 20, 2004](image)

*Fig. 10.48. Road Temperature (°C) time-series plot comparing the Ames RWIS observations to the RWFS forecasts (both with and without the FSL supplemental models) for the RWIS site and segment 3. The vertical lines represent the time period that the Ames METAR was reporting falling precipitation.*
Fig. 10.49a. RMSE plots for all sites across Iowa. From left to right, top to bottom; temperature, dew point temperature, wind speed, and cloud cover. Hr 0 = 00 UTC 20 February 2004.
Fig. 10.49b. RMSE plots for Ames only. From left to right, top to bottom: temperature, dew point temperature, wind speed, and cloud cover. Hr 0 = 00 UTC 20 February 2004.
Fig. 10.50a. Bias plots for all sites across Iowa. From left to right, top to bottom; temperature, dew point temperature, wind speed, and cloud cover. Hr 0 = 00 UTC 20 February.
Overall, this was a very difficult case to forecast because of the changing precipitation type. The NWS models had a problem with the timing of the precipitation forecasts but the mesoscale models did help the forecasts as the event approached. The cloud cover forecasts were not very good for this case, which was likely to have had a negative impact on the air and road temperature forecasts.

10.2.5 Heavy Snow Case – 15 March 2004

The 15 March 2004 storm was one for the record books in portions of Iowa. A swath of snow from western to central Iowa dumped nearly 18 inches of snow at Sioux City in western Iowa. In central Iowa, Des Moines got over 15 inches and Ames received 10 inches. For Des Moines this was the third-highest single-day snowfall in the city record.
The snow began at Ames around 13 UTC on 15 March and lasted through 0730 UTC on 16 March 2004. According to the METAR observations the snowfall was moderate to heavy from the onset to about 21 UTC. There was a brief period around 21-22 UTC when only light snow was indicated in the METAR observations, followed by more moderate to heavy snow through 01 UTC. Additional light snow fell between 0100 and 0730 UTC, then the snow ended.

Synoptically, this event featured an elongated low pressure system that was positioned over western Nebraska and eastern Colorado at 06 UTC on 15 March (see Fig. 10.51). By 12 UTC, approximately 1 hour prior to the onset of snow in Ames, the low had moved to south-central Nebraska and western Kansas. Snow began to form over Iowa due to strong overrunning of warm air pushing up over cold air ahead of the low. By 18 UTC, the low was centered over northeastern Kansas with a trough extending across eastern Iowa. Heavy snow was falling at Ames during this period. The low continued to move slowly east-southeastward into Missouri, and the trough slid southeastward and out of the state of Iowa just after 06 UTC March 16. With the loss of dynamic forcing the snow pulled off to the southeast and out of the Ames area by 08 UTC.

Fig. 10.52 shows radar images corresponding to the times of the surface maps in Fig. 10.51. It is seen here that the precipitation moves in from the west and then off to the southeast. Areas in southwestern Iowa received very little snow as most of the precipitation in that area fell as rain because of slightly higher temperatures. High reflectivity (for snow) is seen over the Ames area in both the 18 UTC and 00 UTC image. This is consistent with the moderate and heavy reports of snow at the METAR site at these times.
Fig. 10.51. Surface maps showing the progression of the synoptic setup.
Fig. 10.52. Radar images showing the progression of the snowfall. For the first image in clear air mode the yellow shades are 0-8 dBZ and the red shades 8-24 dBZ. For the last five images the blue shades are 10-25 dBZ, green shades 25-40 dBZ.
For this case, the 06 UTC 15 March RWFS run was used to compare the forecasts with the observations. This initialization time provides about a 7-hour forecast lead for the start and a 26-hour forecast for the end of the main snow event. The air temperatures for this case were fairly stable around 30°F (-1°C). Fig. 10.53 shows a time series comparison of the forecast and observed air temperatures for the 48 hour period covered by this forecast. There are noticeable periods where the air temperature forecasts were too warm, including some where the forecast temperature exceeded freezing, while the observed temperature did not. In general, however, the forecast for both the METAR and RWIS sites were within 1.5°C during the entire case. The slightly warm forecasts during the main snow event could have potentially affected the precipitation type forecast by the system, but snow was, in fact, predicted for this entire event. One possible reason that the system continued to predict snow with above freezing temperatures may be due to the fact that the dew point temperature (wet bulb temperature) forecasts were less than 0°C.

Fig. 10.53. Air Temperature (°C) time-series plot comparing the Ames METAR and Ames RWIS observations to the RWFS forecasts (both with and without the FSL supplemental models) for the METAR and RWIS site. The vertical lines represent the time period that the Ames METAR was reporting falling precipitation.

The dew point temperature time series (Fig. 10.54) shows good agreement between the forecast and the observations as well. There was a point at the beginning of the event
where the METAR and RWIS observations diverge and the forecasts for the corresponding sites show a similar divergence. The inclusion of the FSL models did not appear to have a significant impact on the forecasts of air temperature and dew point temperature for this event.

**Fig. 10.54.** Dew point temperature (°C) time-series plot comparing the Ames METAR and Ames RWIS observations to the RWFS forecasts (both with and without the FSL supplemental models) for the METAR and RWIS site. The vertical lines represent the time period that the Ames METAR was reporting falling precipitation.

Visibility forecasts for this event (Fig. 10.55) are not very good during most of the snowfall period. The forecasts are too slow to decrease during the early portion of the snowfall and too fast to increase near the end of the main event. The visibility forecast never decreased for the secondary, minor snowfall towards the end of the time series even though the snowfall, itself, was well forecast by the system. Wind speeds during this event were never more then 8 m/s and the forecasts of wind speed (Fig. 10.56) and direction (not shown) were of good quality, with an average difference of less than 1 m/s (2 kt - knots) throughout the time series. Intermittent, low-level (1 out of 3) blowing snow alerts were indicated in the Ames area, starting at 15 UTC on 15 March, about 2 hours after snow began falling. Initially, winds were too light for blowing snow, but they
increased by 15 UTC (Fig. 10.56). Blowing snow alerts were somewhat intermittent through 21 UTC because of forecasts of mixed rain and warm temperatures, implying wet snow that was less likely to be lofted. More consistent, low-level blowing snow alerts were given from 22 UTC on 15 March until they ended at 2 UTC on 16 March, when forecast winds again became too light for blowing snow to be a concern.

Visibility Comparison for Mar 15, 2004

![Visibility Comparison for Mar 15, 2004](image)

Fig. 10.55. Visibility (mi) time-series plot comparing the Ames METAR and Ames RWIS observations to the RWFS forecasts (both with and without the FSL supplemental models) for the METAR and RWIS site. The vertical lines represent the time period that the Ames METAR was reporting falling precipitation.
Cloud cover forecasts generally indicated greater than observed coverage before the precipitation began (Fig. 10.57). The observed cloud cover quickly became overcast just before the start of the snow event and remained that way throughout the main period of snowfall. Forecasts of cloud cover were fairly good early in the main snowfall event but incorrectly decreased from overcast to broken skies much earlier than the observations indicated. A few hours of clear skies were reported at Ames between the two snow events, then overcast skies returned during the second event, but the forecasts remained in the broken range through this period. Thus, cloud cover was first over- then under-forecast during the break and the second snowfall. This misforecast of cloud cover may have had an affect on the diurnal temperature swings during this case (Fig. 10.53).
Fig. 10.57. Cloud cover time-series plot comparing the Ames METAR only to the RWFS forecasts (both with and without the FSL supplemental models) for the METAR and RWIS site. The vertical lines represent the time period that the Ames METAR was reporting falling precipitation.

The QPF forecasts (Fig. 10.58) from the RWFS had very high values at the beginning of the event, matching the heavy snow falling at that time quite well. Forecasts of POP and QPF resulted in an expected event start time that was about 2 hours earlier than the start of the actual precipitation at the METAR site when the FSL supplemental models were not included. When the FSL models were included the start time was improved somewhat, occurring within an hour of the actual start time at the METAR site. Since the primary snow event’s end time occurred more than 15 hours beyond the initialization time, the FSL models were not a factor in its determination. The end time at the METAR and RWIS sites were forecast to be about the same time compared to the actual end time reported at the METAR site. For the second, smaller event, both the start time and end time forecast were predicted quite well, especially considering a lead time of more than 40 hours. This was an impressive aspect of this particular RWFS run. The NWS forecast was not as good on the timing of this heavy snow event as the RWFS. The forecast at 400 AM CST on 15 March (10 UTC) was a follows:

.TODAY...COLDER. SNOW LIKELY THEN SNOW IN THE AFTERNOON.
ACCUMULATION OF 1 TO 3 INCHES. HIGH IN THE MID 30S. EAST WIND AROUND 10 MPH. CHANCE OF SNOW 80 PERCENT.

TONIGHT...CLOUDY IN THE EVENING THEN BECOMING PARTLY CLOUDY. CHANCE OF LIGHT SNOW THEN SLIGHT CHANCE OF LIGHT SNOW AFTER MIDNIGHT. LITTLE OR NO ADDITIONAL ACCUMULATION. LOW IN THE MID 20S. NORTHEAST WIND 5 TO 10 MPH. CHANCE OF MEASURABLE SNOW 40 PERCENT.

TUESDAY...PARTLY SUNNY. CHANCE OF RAIN AND SNOW IN THE AFTERNOON. HIGH IN THE UPPER 30S. SOUTH WIND 10 TO 15 MPH. CHANCE OF PRECIPITATION 30 PERCENT.

TUESDAY NIGHT...MOSTLY CLOUDY IN THE EVENING THEN BECOMING PARTLY CLOUDY. CHANCE OF SNOW. LOW IN THE LOWER 30S. WEST WIND 10 TO 15 MPH. CHANCE OF SNOW 30 PERCENT.

The snow ended early on Tuesday, 16 March but according to the forecast there was another chance of rain and snow in the afternoon that day. The NWS did have a 30 percent chance of snow in the forecast for the second, short-lived snow event that occurred on Tuesday night. Overall the RWFS forecast for this event was much more accurate and precise than the NWS forecast.
Fig. 10.58. Precipitation (%) and quantitative precipitation forecast (mm/hr) time-series plot comparing the Ames METAR and Ames RWIS observations to the RWFS forecasts (both with and without the FSL supplemental models) for the METAR and RWIS site. The vertical lines represent the time period that the Ames METAR was reporting falling precipitation. The blue arrows indicate the forecasted start (with FSL) and stop (with and without FSL) times for the first event at the METAR site, the green arrows indicate the start (with FSL) and stop (with and without FSL) times for the first event at the RWIS site and the orange arrows indicates the start and stop (both with and without FSL) times for the second event at both the METAR and RWIS site.
As mentioned above, according to the NWS, about 10 inches of snow fell in Ames during the main snow event. LEDWI data from the METAR site indicates a total snowfall of just over 9 inches (Fig. 10.59). The liquid equivalent precipitation as measured by the tipping bucket gauge appeared to be reasonable early in the case, when wind speeds were quite low, providing a snow to liquid ratio near 10:1. During the more windy periods later in the event, the tipping bucket gauge indicated a far higher ratio. However, given the steady temperatures during this event it is likely that the 10:1 ratio was appropriate, and could be applied to the entire event for a fairly accurate prediction of the actual snowfall accumulation. Thus, roughly 0.9” of liquid is estimated to have fallen at Ames during this event.

![Fig. 10.59. Estimated snow accumulation (inches) from the LEDWI sensor on the left axis (black) and liquid precipitation (inches) from the heated tipping bucket gauge (blue), both located at the METAR site.](image)

The RWFS forecast of snowfall depth (Fig. 10.60), had about 8 to 8.5 inches of snow at the METAR and RWIS sites, based on forecasts of 0.8-0.85” of liquid equivalent (QPF) and a 10:1 ratio. This ratio worked quite well in this case. The observations as used in the RWFS, acquired from the METAR and LAPS QPE data, indicated only about 6
inches for this case, using the 10:1 ratio. The NWS only forecast 1 to 3 inches of snow for this event in their forecast issued at 09 UTC on 15 March so they were well below reality before the event started.

Fig. 10.60. Snow depth (inches) time-series plot comparing the Ames METAR to the RWFS forecasts (both with and without the FSL supplemental models) for the METAR and RWIS site. The vertical lines represent the time period that the Ames METAR was reporting falling precipitation.
Road temperature forecasts for this event (Fig. 10.61) were within about 1 to 1.5°C for both the RWIS site and Segment 3 prior to and during the first snow event. Between the two events the road temperature forecast were about 2°C too low, probably due to the overestimate of cloud cover during this period. Recall that the observations indicated clear skies, while the forecasts predicted broken skies. For the second event the road temperatures were again within 1 to 2°C.

A comparison of errors and biases between Ames and the entire forecast domain (Figs. 10.62 and 10.63) shows that for this event, the errors at Ames were fairly typical. Cloud cover forecasts were error prone across the domain in the 0-9 and 27-42 hr ranges, especially at Ames. Air temperatures were a bit too warm across the domain just before the snow began, and more so at Ames.

Fig. 10.61. Road Temperature (°C) time-series plot comparing the Ames RWIS observations to the RWFS forecasts (both with and without the FSL supplemental models) for the RWIS site and segment 3. The vertical lines represent the time period that the Ames METAR was reporting falling precipitation.
Fig. 10.62a. RMSE plots for all sites across Iowa. From left to right, top to bottom; temperature, dew point temperature, wind speed, and cloud cover. Hr 0 = 06 UTC 15 March 2004.
Fig. 10.62b. RMSE plots for Ames only. From left to right, top to bottom; temperature, dew point temperature, wind speed, and cloud cover. Hr 0 = 06 UTC 15 March 2004.
Fig. 10.63a. Bias plots for all sites across Iowa. From left to right, top to
bottom: temperature, dew point temperature, wind speed, and cloud cover.
Hr 0 = 06 UTC 15 March 2004.
For this case the start and stop times for both events were very well forecast. The total snowfall accumulation predicted for the Ames area was also very close to the actual reported snowfall total. There is some evidence in this case that poor cloud cover predictions may have caused some problems in the air temperature forecasts, though both are still fairly well forecast to within a few degrees Celsius most of the time. Visibility forecasts were quite poor during times of snowfall, indicating that the visibility algorithm may need to be revisited.
11 OVERALL PERFORMANCE RESULTS

In this section performance results are described for the entire winter 2003-2004 Iowa field demonstration for specific components of the MDSS. All aspects of the system that were examined showed improvement over the first field demonstration.

11.1.1 Configuration

The RWFS was configured to utilize and integrate ten different forecast modules for the winter 2003-2004 demonstration. Models that were ingested into the RWFS included the Eta, GFS, MM5, RUC and WRF. MM5 and WRF were initialized using the NWS Eta model for boundary conditions and run hourly. MM5 and WRF forecasts from the current run and previous two runs (valid at the same time) were utilized. Aviation model Model Output Statistics (MAVMOS) were also used as input, and Dynamic Model Output Statistics (DMOS) were calculated within the RWFS for each of the model inputs. The ten weather forecast modules that were used to predict the weather parameters for each MDSS forecast point were:

1) NWS Aviation MOS (MAVMOS)
2) Eta DMOS
3) GFS DMOS
4) MM5 Eta4 (run from 4 hours previous)
5) MM5 Eta3 (run from 3 hours previous)
6) MM5 Eta (run from 2 hours previous, the most current run)
7) WRF Eta4 (run from 4 hours previous)
8) WRF Eta3 (run from 3 hours previous)
9) WRF Eta (run from 2 hours previous, the most current run)
10) RUC DMOS

The RWFS integration process independently optimized the forecasts based on recent skill at each prediction site for each parameter and forecast lead-time. The forecast modules with the most skill were weighted more heavily. A final consensus forecast was the ultimate output of the RWFS.

11.1.2 Overall Performance Assessment

The performance of the RWFS was analyzed via comparison of the forecast skill of individual inputs (forecast modules) to the consensus forecast. The system was designed to optimize forecast skill using recent skill and statistical techniques, to produce better forecasts than the individual inputs, overall.

Seasonal assessments of RMSE and bias (forecast-observation) were performed for the ten input forecast modules and the final consensus forecast for six meteorological state
variables (temperature, dewpoint, wind speed, cloud cover, wind-u, and wind-v). Results were based on weighted average RMSE and bias values at every lead time for all forecasts initiated at 18 UTC over the entire season (29 December 2003 thru 24 March 2004) for all sites across the state of Iowa. Note that the mesoscale models only covered a 15 hour forecast period, whereas the NCEP model products covered a 48-hour period.

For all variables except cloud cover, the RWFS forecast has a lower RMSE than its components for a majority of the lead times (0-48 hours out; Fig. 11.1). For the air temperature forecasts, it is interesting to note that the individual inputs are clustered between 2.0 and 2.5 C. The MM5 based air temperature forecasts were slightly more accurate than WRF and AVN MOS is slightly better than both. For dew point predictions, the AVN MOS again had the best skill of the individual components, while the mesoscale models had less skill. The RMSE for the RWFS at 12 hours was 2.2 C. The increased skill of the RWFS air and dew point temperatures over the first demonstration is good news as these fields were important to predictions of road temperature and frost. The RMSE of the RWFS wind speed predictions was 1.5 meters per second (~3 mph). For cloud-cover, the ETA-DMOS was better than the RWFS beyond 6 hours. This may have been due in part to the module weights being static instead of dynamic for this field and the empirical weights were fixed so that the MM5 and the WRF dominated the forecasts. This approach appears to have resulted in a less than ideal weight distribution for this parameter. For temperature and wind speed, there is a slight increase in RMSE during the heat of the day (24-30 hr lead times). In general, the RMSE values increased with forecast lead-time, as one would expect.
Fig. 11.1. Seasonal analysis of RMSE for six meteorological parameters including, (from left to right, top to bottom) air temperature, dew point temperature, wind speed, cloud cover, u-component of the wind direction, and v-component of the wind direction. Hour 0 = 18 UTC.

A forward error correction approach was implemented for the 2004 field season, significantly improving RWFS forecasts in the first 6 hours. During this time window,
RWFS forecast RMSEs were markedly smaller than those for the individual components for all variables (see Fig. 11.1). For example, the temperature forecasts in the 0-6 hour lead times from the RWFS have RMSE values were 0.75-1.75°C, whereas its components had RMSE values of 2-3°C.

Comparing the RWFS forecasts with and without the FSL supplemental models (black solid and dashed lines, respectively), the RMSE values were very similar at each lead time for most fields. The RWFS without the FSL models is slightly better for a few lead times for the temperature and wind variables (see Fig. 11.1). For cloud cover the FSL models (MM5 and WRF), themselves, performed better than the other components. Case studies elsewhere in this document demonstrate that the FSL models contribute the most to precipitation type and timing forecasts.

Some trends are apparent in the bias plots for the season (Fig. 11.2). Positive bias (over-forecast) is evident in the RWFS for temperature, dew point, and wind speed around sunrise (6am-8am; 18-20 and 42-44 hr lead times). This bias quickly turns to negative (under-forecast) during the remainder of the daylight hours (8am-6pm; 20-30 hr lead times). The negative temperature bias is strongest during the afternoon hours (24-30 hr lead times). For temperature and dew point, a slight, but consistent negative bias was present during the coldest part of the night (12am-6am; 12-18 hr and 36-42 hr lead times). A consistent, weak positive wind speed bias was also present at those same times, and a persistent negative bias was present for wind-u and a positive bias for wind-v at all lead times. For cloud-cover there was essentially no bias at any lead time, implying that the system did not consistently over- or under-forecast cloud cover. However, Fig. 11.1 reveals that the cloud cover forecasts were consistently off by ~0.3, or roughly one cloud cover category (e.g. broken instead of overcast).

**Results and Recommendations:** The data fusion methods and statistical techniques utilized in the Road Weather Forecast System (RWFS) improves the overall weather prediction skill for parameters that are measured and available in real time. The use of multiple inputs also makes the system more robust as it is not prone to down time with the loss of individual forecast modules. The use of techniques and methods similar to those of the RWFS is recommended. Dynamic weighting of the cloud cover field may be more robust than using fixed weights based on forecaster experience.
Fig. 11.2. Seasonal analysis of bias for six meteorological parameters including, (from left to right, top to bottom) air temperature, dew point temperature, wind speed, cloud cover, u-component of the wind direction, and v-component of the wind direction. Hour 0 = 18 UTC.
An RMSE comparison for multiple forecast initialization times (Fig. 11.3) indicates that all run times had RMSE values that increased similarly with forecast length. No run time has outstanding performance compared to the other run times.

Fig. 11.3. Seasonal analysis of forecast initialization times for six meteorological parameters including, (from left to right, top to bottom) air temperature, dew point temperature, wind speed, cloud cover, u-component of the wind direction, and v-component of the wind direction. Hour 0 = 18 UTC.
11.1.3 Quantitative Precipitation Forecasts (QPF)

The RWFS is designed to optimize forecasts based on feedback it receives from observations collected at or nearby the RWFS forecast points. One of the most difficult weather prediction problems is forecasting precipitation amounts. Part of the problem is in the forecasting process (model physics and knowing the state of the atmosphere) and the other part is related to the poor observation network and the inability to verify actual precipitation amounts, particularly for winter precipitation (e.g., snow, sleet, etc.).

The lack of quality winter precipitation observations across Iowa hindered the RWFS in that it was unable to tune itself for the QPF parameter. When the RWFS was initialized in the fall of 2003, each of the ten forecast modules had a 10% weight. A few fall rain cases were enough to move the weights from the initial values, but they never had a chance to adjust fully before the winter precipitation season began.

Without the tuning process, all the QPF modules would essentially be averaged (10-member average) and the MDSS would not be able to take advantage of the skill of any particular model or dataset. This could result in a worse precipitation prediction than directly using the more skilled models. It could also result in the inability for the system to declare a light precipitation event that may have been well predicted by one or more of the forecast modules. This of course is opposite of what the RWFS was designed to do. The project staff monitored the weights during the first 45 days of the demonstration and, based on the lack of adjustment, decided to intercede.

Because of the poor quality of real time winter precipitation measurements, it was necessary to modify the RWFS to fix the QPF weights across the ten modules based on expert opinion. The weights for the QPF parameters were fixed on 10 February 2004 as shown in Table 11.1.

Table 11.1. Weights given to each of the ten RWFS quantitative precipitation forecast modules.

<table>
<thead>
<tr>
<th>Des Moines &amp; Ames Area</th>
<th>RWFS QPF Weights</th>
<th>GFS</th>
<th>Eta</th>
<th>MM5 2hr</th>
<th>MM5 3hr</th>
<th>MM5 4hr</th>
<th>Total MM5</th>
<th>WRF 2 hr</th>
<th>WRF 3hr</th>
<th>WRF 4hr</th>
<th>Total WRF</th>
<th>RUC</th>
<th>MAV-MOS</th>
<th>Total %</th>
<th>TOTAL MM5+WRF Contribution</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 hr Forecast</td>
<td></td>
<td>9</td>
<td>11</td>
<td>15</td>
<td>12</td>
<td>10</td>
<td>37</td>
<td>17</td>
<td>14</td>
<td>12</td>
<td>43</td>
<td>0</td>
<td>0</td>
<td>100.00</td>
<td>80</td>
</tr>
<tr>
<td>3 hr Forecast</td>
<td></td>
<td>9</td>
<td>11</td>
<td>15</td>
<td>12</td>
<td>10</td>
<td>37</td>
<td>17</td>
<td>14</td>
<td>12</td>
<td>43</td>
<td>0</td>
<td>0</td>
<td>100.00</td>
<td>80</td>
</tr>
<tr>
<td>6 hr Forecast</td>
<td></td>
<td>9</td>
<td>11</td>
<td>15</td>
<td>12</td>
<td>10</td>
<td>37</td>
<td>17</td>
<td>14</td>
<td>12</td>
<td>43</td>
<td>0</td>
<td>0</td>
<td>100.00</td>
<td>80</td>
</tr>
</tbody>
</table>
The subjective opinion was that the time-lagged ensemble of mesoscale models (WRF and MM5), which were being run hourly out to 15 hours, had a better handle on precipitation timing and amount. In addition, because of the “hot start” process, it was felt that the models did a better job of identifying the prediction of very light precipitation cases. As can be seen above, the WRF and MM5 data were given 80% of the total weight for QPF in the RWFS.

Subjective analysis of the performance of the RWFS QPF predictions, both with and without the inclusion of the FSL models, was conducted as part of the case studies in Section 10.

**Results and Recommendations:** The ability of models to predict precipitation start and stop time and amount varies greatly between models. If a data fusion system that adjusts itself based on observations similar to the RWFS is utilized, care must be taken to ensure that the weights given to individual prediction modules are appropriate. If only low quality verification data are available, the weights should be fixed based on experience and/or expert opinion.

### 11.1.4 Insolation

It is well recognized that incoming solar radiation (insolation) is a critical parameter for predicting road temperature. During the winter of 2003, insolation values were calculated in SNTHERM-RT from weather model cloud layer data. This approach was used because, until recently, operational weather models did not explicitly output insolation data. For the 2004 season, it was the opinion of the labs that it would be better to employ the explicit calculation of insolation provided by the mesoscale models, rather than using RWFS cloud layer predictions to estimate insolation in SNTHERM-RT; therefore, the MDSS was configured to utilize the insolation values from the models this year. This was the right approach as some test cases indicated that the road temperature error was reduced by about 50%, but several data quality issues related to modeled insolation had to be resolved during the demonstration period.

As part of the performance assessment task in 2003, CRREL analyzed SNTHERM-RT using actual weather measurements in Iowa to determine its skill given “perfect” weather inputs. The goal was to assess the skill of the model itself and this could only be done if the model was provided highly accurate weather inputs. Without insolation data near the Iowa routes, it was difficult to fully assess model skill as the insolation values had to be estimated from cloud cover observations. As part of the MDSS project in 2004, a pyranometer was installed at the Ames garage. The primary objective was to measure short wave radiation so that a more thorough analysis of SNTHERM-RT could be performed after the field demonstration.
The insolation data did provide an opportunity to evaluate the skill of the individual weather models in predicting incoming short wave radiation. The data proved to be quite valuable as it identified several issues and problems related to modeled insolation data. Short wave radiation data were available from the MM5, WRF, Eta, and GFS, but there were significant differences in the way they were calculated and provided. For example, the GFS short wave radiation field is a 3-hour time-averaged value, while the Eta provides an instantaneous value. Listed below are descriptions of the issues that arose with the short wave radiation fields used in the MDSS.

**Eta Model:** The short wave radiation data from the Eta model was an instantaneous value, but it had a time lag problem. On 17 March 2004, an NCEP bulletin identified that the Eta model insolation data were offset by one hour. For example, the data values given for 06:00 hrs were really valid at 05:00 hrs. In addition, NCEP corrected a problem with long wave radiation where low cloud and fog were not accounted for properly. These problems were observed during the MDSS field program. NCEP corrected these problems on or about 17 March 2004\(^4\). Although this was too late to help the MDSS this year, these changes should result in better forecast skill in the future for those using the Eta model. Hourly output of the Eta insolation data are not available reducing the utility of these data.

**GFS Model:** The short wave radiation data from GFS model was a time averaged value over a 3 hr period. Because of the time averaging characteristic, it was not practical to use it as an input to a road temperature model.

**WRF Model:** The radiation data from the WRF model provided instantaneous values, but early in the field program, the WRF provided the net radiation, which was not separated into long and short wave fields. Later on, an underestimation of the insolation was discovered on clear days and it was determined that WRF had retained too many cloud particles (thin clouds), which attenuated short wave radiation on the clear days. On 17 February, the WRF model was corrected and the insolation data more closely matched the Ames pyranometer data on clear and cloudy days.

**MM5 Model:** The MM5 provided instantaneous radiation values and matched the field data more closely than any of the other models, at least until the WRF was corrected. After that time, the two models values were very close on clear days.

The RWFS was configured to use the MM5 and WRF insolation data for the part of the forecast period where those data were available (0-15 hrs) and the Eta insolation data for the 15-48 hour forecast period. The real-time insolation data from Ames were not used in the RWFS; therefore, the weight blending values for insolation had to be fixed. In the future, it may be desirable to utilize real time insolation data to forward correct model data, but additional research is required to assess this approach.

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\(^4\) Note that the NCEP fixes were not due to MDSS project feedback, but were being addressed independently.
At the start of the MDSS demonstration, when it was believed that the WRF and MM5 had equally valid values, the RWFS was configured to weight each of them 50%. On 27 January 2004, an analysis showed that the WRF was underestimating the insolation values on clear days so the weights were changed to 75% to 25% in favor of the MM5 model. On 16 February 2004, the WRF model insolation calculation was corrected and the weight blending was returned to 50% for each model. The purpose for changing the values was to provide the best input available to the road temperature model (SNTHERM-RT) and to get a feel for the response.

A comparison of the modeled insolation (short wave radiation) values with the pyranometer measurements for a 7 day period after the WRF was corrected is provided in Fig. 11.4 and a separate figure of the same except for just the RWFS (Fig. 11.5). During this period there were two clear days (18 and 22 February 2004) where the insolation values were near the theoretical maximum (~630 watts per square meter), and several partly cloudy days.

The comparison illustrates the differences between models and their respective physics for determining cloud characteristics. For example, MM5 had a tendency to overestimate insolation (underestimate clouds) on partly cloudy days while WRF tended to underestimate insolation (overestimate clouds). Eta was closer to MM5 than to WRF. The blending used by the RWFS provided the best overall results even though the weights were fixed. Because the dynamic data blending process used in the RWFS works well for verifiable parameters, it is believed that this would hold true for insolation. Real time insolation data would need to be available over a broad region to prove this concept.

Results and Recommendations: The ability of models to predict insolation varies greatly between models, particularly in partly cloudy conditions. Care must be taken to ensure the model values compare well with measured values. Changes to both research and operational models may impact insolation calculations so routine comparisons should be made. Because insolation measurements are critical for road temperature prediction, it is recommended that insolation measurements be added to surface observing stations and be provided in real time to weather service providers. Real time access to insolation data would provide an opportunity for systems like the RWFS to utilize the data and optimize predictions.
Fig. 11.4. Comparison between MM5, Eta, WRF, and RWFS output (12Z model runs) of short wave radiation and pyranometer data.
Fig. 11.5. Comparison between RWFS output (12 Z model runs) of short wave radiation and pyranometer data.
11.1.5 Conditional Probability of Precipitation Type

Feedback received after the 2003 field demonstration indicated that the end users had a strong desire for information related to the evolution of precipitation phase during winter weather events. Given the complexity of the physics and the difficulties that arise in providing a deterministic output, the MDSS team chose to develop a probabilistic precipitation type product and present it in an intuitive graphical form. Because it was very well received by the end users, the graphical product is described here so that future implementers can use this example to guide their own product design process.

The conditional probability of precipitation type describes the probability that the precipitation will be rain, snow or ice if any precipitation occurs. The MDSS graphical product combines the probability of precipitation and the conditional probability of precipitation type. The conditional probability of precipitation type is normalized to the total probability of precipitation so the user can get a quick sense of the likelihood of any precipitation and the probability that it will be a specific precipitation type or mix of types. An example of the product is shown in Fig. 11.6.

In this case, the total probability of precipitation rose to a peak of 71% between 6 and 7 AM CST on 19 February 2004. The event was predicted to start as rain and then slowly transition to snow at around 9 AM. The MDSS is configured to declare a specific precipitation type based on criteria that includes a combination of total probability of precipitation, conditional probability of precipitation type, and precipitation rate. To declare a precipitation event, the MDSS was configured as follows (for the winter 2003-2004 demonstration):

a) Probability of precipitation was >= 25%
b) Precipitation rate was >= 0.01 mm/hour

Fig. 11.6. Sample graphic showing the 48 hour forecast of conditional probability of precipitation type for I-35 North of Des Moines, Iowa on 19 February 2004.
These values were chosen based on subjective analyses prior to and during the early part of the field demonstration. The precipitation type was declared when the following criteria were met:

a) Ice declared, if the conditional probability of ice was $\geq 25\%$

b) If the conditional probability of ice was $< 25\%$, the declared precipitation type is the maximum conditional probability between rain and snow.

The users indicated and reiterated several times that ice is a large winter maintenance problem and they wanted to have a conservative heads-up if there was any chance of freezing rain; therefore, the 25\% threshold was chosen. In the graphic example above, the declared precipitation type is shown above the precipitation probability graph in icon form.

The performance of the precipitation type field was judged based on what conditional probability values were forecast for each precipitation type when a given precipitation type was forecast. This was done for all METAR sites in Iowa and the results were combined. For example, snow was observed 1697 times (hourly observations) during the project, and on 81\% of those occasions, the conditional probability of snow forecast for all of those times fell within the highest bin (90-100\% chance that precipitation will fall as snow; Fig. 11.7a). For those same times, the conditional probabilities of rain and ice were 0-20\% almost every time. Rain was observed 694 times during the project, and on two-thirds of those occasions, the conditional probability of rain exceeded 80\%, while the conditional probability of snow rarely exceeded 80\% (17 times; Fig. 11.7b). Results for the freezing rain were inconclusive because it was almost never observed during the 2004 demonstration.
Fig. 11.7. Conditional probabilities of rain, snow and ice predicted for all cases when a) snow and b) rain occurred within the state of Iowa.
11.2 Road Temperature Predictions

Road temperature predictions were made for each of the 16 road segments (including one bridge) and for each RWIS site in the Des Moines and Ames area (see Fig. 6.1). The MDSS provides three sets of road temperature forecasts for each segment of road: untreated, recommended treatment and actual treatment. The “untreated” forecast is the expected road temperature given that the weather occurs (snow fall on the road, etc.) and no treatments are made (the road is left “as is”). “Recommended treatment” is the expected road temperature, given that the treatment suggested by the MDSS is applied. “Actual 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 most appropriate field to verify is the “recommended treatment” field, since it represents a treatment scenario for each event. Only results for that field are discussed here.

RMSE and bias plots of road temperature forecasts using the recommended treatments were examined for the entire season. The statistics are broken down into monthly periods (January, February and March). The stats are cumulative, using selected segments/points that have nearby RWIS observations used for calculating road temperature forecast error.

For all of the months there were considerably higher RMSE values during the heat of the day (9am – 3pm; 0-3 hr, 21-27 hr and 45-48 hr lead times; Fig. 11.8). These spikes in RMSE were more prominent during the months of February and March when solar influx was stronger, resulting in a larger diurnal temperature swing. In January, daytime RMSE values were up to 4.5°C, while they were as high as 6°C during March. During the night the RMSE values were between 1.5-3°C during all months. Strong positive (warm) road temperature biases were found during the morning hours (lead times 18-24 and 42-28 hr), followed by weaker negative (cold) biases in the afternoon (Fig. 11.9). This daytime swing in bias may be attributable to differences in the depth over which road temperature is forecast (skin) and the depth of pavement that surrounds the measuring device (“puck”, several centimeters). Response time differences may have caused a phase shift in the diurnal heating/cooling cycle. Cold biases up to 1.5°C were present during the night, and were typically strongest during the hours between midnight and sunrise. Road temperature RMSE values were very similar at each lead-time, both with and without the use of FSL models. A comparison of RMSEs for the month of January using four different forecast initialization times showed very similar results to those found for state parameters (Fig. 11.10). Similar trends are seen when looking at the seasonal data.
Fig. 11.8. Seasonal analysis of RMSE for road temperature, broken down by month (left to right, top to bottom) January, February and March. Hour 0 = 18 UTC.
Fig 11.9. Seasonal analysis of bias for road temperature, broken down by month (left to right, top to bottom) January, February and March. Hour 0 = 18 UTC.
As an alternative to RMSE, the median absolute error (MAE) has also been calculated for road temperature. Commercial weather service providers often use this metric over RMSE. The big difference between RMSE and MAE is that extreme values are discarded when MAE is calculated. Thus MAE values are, in general, lower than RMSE values. This is clearly evident in the plot that compares RMSE and MAE for the 18z initialized forecasts, using recommended treatments. While diurnal and forecast length trends were very similar using both error calculations, the error magnitudes were 2-5.5°C for RMSE and only 1.25-3.5°C for MAE (Fig. 11.11).
In an attempt to assess forecast quality at times when it is of greatest interest and consequence to MDSS/RWFS users, RMSE and bias were assessed for times when the road temperature was observed to be less than 40°F (4.44°C), and compared to those for any observed temperature. The RMSE values were very similar at night (6-18 and 30-42 hr lead times). This was expected since the observed nighttime road temperatures were usually less than 40°F during the winter and spring (Fig. 11.12). During the day (18-30 hr lead times), the RMSE values for forecasts made when the observed road temperature was less than 40°F were better than the forecasts made over all times. The bias values for forecasts made when the road temperature was less than 40°F were relatively insignificant and the diurnal trends were similar to those seen for forecasts made over all times (Fig. 11.13). Overall, the RCTM made better forecasts of road temperature when the observed road temperature was less than 40°F.
Fig. 11.12. Seasonal analysis of RMSE for road temperature less than 40°F (4.44°C), (red line) and observed road temperatures (blue line).
Fig. 11.13. Seasonal analysis of bias for road temperatures less than 40°F (4.44°C).
To assess the importance of cloud cover and snowfall on road temperature forecasts, RMSE and bias were calculated for times when the Ames, Iowa METAR site (KAMW) reported: a) sky cover was <10% (clear skies), b) sky cover was >90% (overcast skies), c) snow was falling, and d) any conditions (Fig. 11.14). Observed and forecast road temperatures were for highway segment #3, which is a portion of I-35 located close to KAMW. Overall, road temperature forecasts had the lowest RMSE for a given forecast length when snow was occurring. Daytime road temperature forecasts were far better when conditions were overcast, rather than clear. At night, however, this trend was reversed, though more weakly. The daytime improvement is likely due to the removal of a strong cold bias that is present when clear skies are observed (Fig. 11.15). A weaker, clear sky cold bias was still present at night. A stronger nighttime cold bias was found when skies were cloudy. This was likely due to under-prediction of cloud cover on cloudy nights, allowing more radiational cooling. Under-prediction of cloud cover during cloudy daytime periods may partially account for the warm bias with that combination of conditions. Biases during snowy periods showed similar, but weaker diurnal trends, compared to those found with cloudy skies. This was likely due to dampening of shortwave and longwave effects by the deeper, snow producing clouds above. The relatively good quality of road temperature predictions during snowfall is encouraging, however, given the purpose of the MDSS/RWFS.
Fig. 11.14. Season analysis of RMSE for road temperature forecasts for all sky conditions (black line), sky cover <10% (clear skies, red line), sky cover >90% (overcast skies, green line), and when snow was falling (blue line).
Fig. 11.15. Season analysis of bias for road temperature forecasts for all sky conditions, sky cover <10%, sky cover >90%, and when snow was falling (from left to right, top to bottom).

The road temperature predictions were the most accurate during snowy periods, particularly at night. During nighttime snow events, the RMSE ranged from 0.5 to 1.5 C. The next best skill occurred during cloudy days and the least skill occurred during clear or partly cloudy days. It is no surprise that these results strongly suggest that the prediction of insolation is critical and that the weather models have difficulty predicting insolation on partly cloudy days. Additional research focused on insolation prediction is required. If real time insolation data become available, perhaps some statistical correction techniques may helpful. Model physics and data fusion techniques may also provide opportunities for improvement.
Results and Recommendations: Road temperature prediction skill varied greatly between day and night and between cloudy and clear conditions. When solar radiation values were low, the road temperature prediction accuracy was quite good (within 1 to 2 C). The analysis suggests that an improvement in the prediction of insolation may provide a major improvement in road temperature skill. Methods and techniques aimed at improving insolation prediction should be investigated.

11.3 Treatment Recommendations

11.3.1 Overview

One of the biggest improvements to the MDSS in 2004 was the total revision of the Rules of Practice (RoP) code based on lessons learned and experience gained from the first MDSS field demonstration. The primary improvement in the RoP was in considering the entire storm life-cycle for characterizing the overall storm conditions and for recommending treatment strategies. Referring to Fig. 11.16, the storm life-cycle includes not only the in-storm conditions when precipitation is falling but also the pre- and post-storm road conditions. Pre-storm conditions control the application or pre-treatment chemicals (such as liquid brine) that are used to prevent icing at precipitation onset. Post-storm conditions (including road temperature and residual water on the pavement) are utilized to protect against re-freezing of the roads after the precipitation has stopped.
Verification of the recommended treatment strategy vs. the actual treatment strategy is detailed for three Iowa events. Actual treatment recommendations are estimated from eight GPS/AVL equipped maintenance vehicles. There are some technical issues with these data that are discussed in the next section, but overall, these data were very valuable in understanding the treatment strategies utilized by Iowa DOT. There are three components to the verification study. First, we detail a single treatment strategy for a forecast period 6-12 hours in advance of the storm onset (start of precipitation). Second, we compare the recommended treatment and weather forecast to the actual Iowa DOT treatment and recorded weather observations. Finally, we examine the variability of the treatment recommendations over multiple forecast periods.

As background, there are several time series shown for each event: precipitation, pavement temperature and treatment. The keys for each parameter are shown in Fig. 11.17 (A-C). Precipitation categories (A) are color coded for Rain (Green), Light Snow (light blue), Moderate Snow (royal blue) and Heavy Snow (red). Road temperatures (B) are categorized by the effective anti-icing range of salt: >35 F or warm roads (green), 14-35 F or in-range roads (yellow) and <14 F or too cold (red). Finally, treatments (C) are illustrated by color coding and symbols. A plow-only treatment is shown in purple, an in-storm treatment of anti-icing chemicals is shown in green with the number inside the box representing the recommended application rate lbs/lane-mile to drop, pre-treatments are...
shown in brown with an “L” in the box (liquid brine at 50 gal/lane-mile - 110 lbs/lane-mile dry salt equivalent - is the expected Iowa DOT treatment), and binoculars to represent a time period where the roads should be monitored closely for hazardous conditions (only seen on actual treatment plots).

![Legend keys for RCTM verification variables: (A) Precipitation, (B) Road Temperature, and (C) Treatments.](image)

The synoptic conditions and observational data for each case study have already been detailed in the road weather forecast system verification section (11.1). Therefore, the data presented here are presented in a more generalized form conducive to verifying the specific thresholds of the treatment recommendation (Rules of Practice) algorithm. All times are in local Iowa time (Central Standard Time).

### 11.3.2 Verification report for March 15-16, 2004 storm

The March 15\textsuperscript{th} storm (see section 10.2.5) was a heavy snow event with precipitation totaling about 10” of snow in the Ames area and lasting approximately 21 hours. Fig. 11.18 shows the RWFS forecasted conditions and RCTM recommended treatment actions for this storm as shown for the March 14\textsuperscript{th} midnight (local time) forecast. The selected route is the I35N route serviced by the Ames garage. Light snow was predicted to begin at 0600 (6AM), and quickly ramp up to moderate and heavy snow over the next 10-15 hours before trailing off at around 0300 on March 16\textsuperscript{th}. The road water timeline is used to show that the road is forecasted to remain wet even after the precipitation stops. In this case, the road isn’t expected to dry out until after 1000 on the 16\textsuperscript{th}. Road temperatures were forecasted to start in-range (14-35 F) but temperatures were borderline during most of the storm and, in fact, were forecasted to warm up above 35 F during some of the most intense portions of the storm.
The RCTM characterized the storm as a heavy snowstorm with warm/in-range road temperatures. The system suppressed pre-treatment because the road surface was predicted to be warm during the storm. An initial treatment of 100 lbs/lane-mile is recommended at the start of the storm. A follow-on treatment of 500 lbs/lane-mile isn’t recommended until 1400 (2PM on the 15th) just before the road temperature is predicted to drop back below the freezing level. A final treatment of 350 lbs/lane-mile is also recommended just after midnight on the 16th to protect the road from refreezing after the precipitation stops but the road is still considered to be wet.

The warm/in-range, borderline road temperatures were a source of sensitivity for this storm. The freeze-point threshold of 35F was chosen to represent the temperature at which the road is reasonably susceptible to freezing. Iowa DOT selected 35 F because (1) this is a number they were comfortable with given years of using RWIS in-road temperature sensors and (2) they felt this buffered temperature gave them some level of confidence that they err on the side of caution. However, the MDSS road temperature model was proving more accurate during storms in both simulation and live test cases. A decision was made mid-way through the demonstration to adjust the freeze-point threshold from 35 F to 33.5 F (closer to the expected +/- 1.5 F error of SNTHERM during snowstorm events).
If we re-examine the treatment recommendations given a freeze-point threshold of 33.5 F, we find the results shown in Fig. 11.19. Not surprisingly, we see a wider area of warm road temperatures. The initial treatment recommendation is the same, however the system has added a plow-only treatment at 1100 on the 15th. This treatment is to be followed by a 300 lbs/lane-mile at 1700 to protect the road at the end of the storm.

![March 15th-16th: Freeze-point adjustment](image)

**Fig. 11.19. March 15-16 forecast timeline with freeze-point adjustment.**

### 11.3.2.1 Actual conditions and operations

Verifying treatment recommendations against actual operations is dependent on two factors: (1) how close the forecasted weather and road conditions match observed conditions and (2) how well the Rules Of Practice match DOT operations. Fig. 11.20 illustrates how well the MDSS verified against actual observations and operations. The forecasted precipitation was fairly close in duration and strength, although the forecast started the precipitation sooner. Road temperatures were also fairly close, although the RWIS in-road sensors tended to show slightly warmer roads overall and warm roads in the pre-storm environment. Post-event discussions with Iowa DOT indicated that they expected that the roads would be fairly warm throughout the event, therefore, they performed an initial treatment of chemicals followed by a series of plow-only operations. As shown previously, the treatment recommendations were fairly sensitive in this case to the borderline road temperature regime. The fact that overall road conditions were
warmer than forecast would have likely resulted in more plow-only recommendations from MDSS. The application of freeze-point thresholds will be looked at further for future demonstrations.

### March 15th-16th: Weather Verification

#### Precipitation

<table>
<thead>
<tr>
<th></th>
<th>3/15 (Local Iowa Time)</th>
<th>3/16</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>00</td>
<td>04</td>
</tr>
<tr>
<td>Forecast</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Verification</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Rain**
**Light Snow**
**Moderate Snow**
**Heavy Snow**

#### Pavement Temperature (33.5 °F threshold)

<table>
<thead>
<tr>
<th></th>
<th>3/15</th>
<th>3/16</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>00</td>
<td>04</td>
</tr>
<tr>
<td>Forecast</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Verification</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**> 33.5 F**
**14 – 33.5 F**
**< 14 F**

#### Actual Iowa DOT Operations

- Warm roads suppressed pre-treatment
- Road temperatures were marginal throughout (32 lowest forecast)
- Initial application designed to “soften” snow
- Post-storm temperatures very high allowing plow only operation

<table>
<thead>
<tr>
<th>Iowa DOT Operations</th>
<th>00</th>
<th>04</th>
<th>08</th>
<th>12</th>
<th>16</th>
<th>00</th>
<th>04</th>
<th>08</th>
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<tr>
<td></td>
<td></td>
<td></td>
<td><strong>300</strong></td>
<td>140</td>
<td><strong>P</strong></td>
<td><strong>P</strong></td>
<td><strong>P</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**P** Plow
**#** Anti-ice
**L** Pretreat
**Patrol**

*Fig. 11.20. March 15-16 weather and treatment verification.*

#### Variability of the treatment recommendations with time

Previous demonstrations have shown a marked variability in treatment recommendations in successive forecast periods. Fig. 11.21 shows the treatment recommendation for March 15-16 on successive forecast periods. For this verification we are utilizing the MDSS runs from real-time that are using the higher freeze-point threshold (35 F). The midnight run (06Z run) shows both thresholds. In general for this case, the total tonnage of chemicals is similar ranging from 750 to 950 lbs/lane-mile. Additionally, all but one of the MDSS runs shows three treatment applications that are applied at roughly the same times. This represents an improvement over the winter demonstration of 2003 where treatment recommendations, even for fairly similar weather forecasts, yielded very different treatment rates and application times.
11.3.3 Verification report for January 25-26, 2004

The January 25-26 event (see section 10.2.2) was a light snow event that lasted roughly 20 hours starting just around midnight on the 25th. The selected route is the I35N route serviced by the Ames garage. Fig. 11.22 shows the RWFS forecasted conditions and RCTM recommended treatment actions for this storm as shown for the January 25 noon (local time) forecast. Post storm roads were expected to dry out within 3 hours of the end of the event because winds were strong and the air was expected to dry out quickly. Pavement temperatures were forecast to remain in-range throughout the storm until the roads had dried out. Road temperatures after the roads dried out were expected to plummet below 14 F. Another row has been added to this plot to illustrate the level of blowing snow potential. Blowing snow potential increased throughout the storm, and was expected to peak just after the storm precipitation ended.

The RCTM does not consider the impact of blowing snow on the amount of chemicals to apply. It does, however, use the potential for blowing snow to control whether pre-treatment chemicals should be applied and whether any chemicals should be applied during a storm. In both cases, sufficiently cold roads combined with blowing snow will suppress treatment. In this case, the pre-treatment was suppressed because the snow was
expected to blow across the relatively cold road surface. Applying chemicals would only contribute to the accumulation on the road surface. Thresholds within the storm are higher, and therefore, treatments were recommended during the precipitation. A total of 5 treatments were recommended, each in the 100-150 lbs/lane-mile range. The liquid water accumulation was expected to be very light in comparison to the level of snow, so despite relatively cold roads, the treatment recommendations were kept quite low.

### January 25th-26th Light Snow (I35N of Ames)

<table>
<thead>
<tr>
<th>PRECIPITATION</th>
<th>Based on 1/25 Noon RWFS forecast</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type</td>
<td></td>
</tr>
<tr>
<td>Road</td>
<td></td>
</tr>
<tr>
<td>Blowing Water</td>
<td></td>
</tr>
<tr>
<td>Blowing snow level</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>PAVEMENT TEMPERATURE</th>
</tr>
</thead>
<tbody>
<tr>
<td>12</td>
</tr>
<tr>
<td>Yellow</td>
</tr>
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</table>

<table>
<thead>
<tr>
<th>RECOMMENDED TREATMENTS (real-time)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Light snow with in-range road temperatures</td>
</tr>
<tr>
<td>Suppressed pre-treatment due to blowing snow level</td>
</tr>
<tr>
<td>However, winds too weak to suppress in-storm chemicals</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Treatments</th>
</tr>
</thead>
<tbody>
<tr>
<td>P Plow</td>
</tr>
<tr>
<td># Anti-ice</td>
</tr>
<tr>
<td>L Pretreat</td>
</tr>
<tr>
<td>Patrol</td>
</tr>
</tbody>
</table>

Fig. 11.22. Forecasted precipitation, road temperatures and treatment recommendations for I35N (Ames) during January 25-26.

### 11.3.3.1 Actual conditions and operations

As shown in Fig. 11.23 the actual levels of snow activity were fairly heavy at the start of the storm (in terms of snow accumulation, but remember the snow to liquid water equivalent for this case was quite high, roughly 20:1). Fig. 11.24a shows a picture taken by an MDSS observer on nearby US30 early in the morning of January 26. Snow is falling at a moderate pace and is accumulating on the road surface. I35N has the advantage of having a more elevated deck that was perpendicular to the strong winds allowing snow to blow across the road surface quite readily. Observer notes from this period indicate the I35N was blowing clear during much of this period. Road temperatures verified quite well for this storm. Although the RWIS road temperature is
missing at the very end of the period, trends in the RWIS data just prior to the missing data indicate it in all likelihood would have verified against the <14 F forecast.

Ames supervisors indicated that this storm presented a tough choice between chemically treating and just plowing. Ames maintenance vehicles spent the first 8 hours patrolling and monitoring road conditions. After 0800, Ames began treating but typically only treated the southbound lanes of the I35 route. Winds were blowing the snow across the northbound lanes quite readily, however, the grassy median area between the north and southbound lanes was capturing much of this snow and slowly spilling it onto the southbound lanes. The RCTM does not currently take into account the impact of blowing snow and, as such, we would expect that the recommended treatments would more accurately match the more wind-protected southbound lanes.

Total treatment recommendations for I35 were 600 lbs/lane-mile while the actual southbound operations exceeded 900 lbs/lane-mile. In anti-icing operations, applying the chemical earlier often results in less chemical being needed overall. The Ames garage struggled with a difficult asymmetric treatment condition that was out of the scope of the current MDSS system. Fig. 11.24b shows that by late morning on the 26th conditions on US30 (and I35) were already improving dramatically.
Fig. 11.23. Forecasted and actual precipitation, road temperatures and treatment recommendations for I35N (Ames) during January 25-26. Striped shading in the pavement temperature verification timeline indicates that the data was estimated due to missing observations.
Fig. 11.24. MDSS observer photographs of (a-left) US30 early morning on January 26 and (b-right) US30 late morning on January 26.

11.3.3.2 Variability of the treatment recommendations with time

Fig. 11.25 shows the treatment recommendation for January 26 on successive forecast periods. For this verification we are utilizing the model runs from real-time that are using the higher freeze-point threshold (35 F). In general for this case, the total tonnage of chemicals is similar, ranging from 650 to 800 lbs/lane-mile. Additionally, all of the MDSS runs show between 5 and 6 treatment applications that are applied at roughly the same times. The trend of the treatment applications toward lower overall treatment applications and tonnage as the event approaches also stays consistent.
11.3.4 Verification report for January 16-17 cold rain event

The January 16-17 event (see section 10.2.1) is the earliest of the verification case studies and occurs just prior to full operations of the GPS/AVL equipped maintenance vehicles. As such, actual DOT operations were estimated from observer reports and garage logs. This event was primarily a rain event with marginally warm roads. Fig. 11.26 shows the forecasted precipitation and road temperatures for the I35N route in Ames, IA. Rain was predicted to fall from 1600 (4PM on the 16\textsuperscript{th}) until 0600 on the 17\textsuperscript{th}. Road temperatures were expected to remain above 33.5 F throughout the 48 hour forecast period. Not surprisingly, the MDSS did not recommend any treatments for this route and the Iowa DOT didn’t perform any. However, the forecast for the US30 route in Ames was just slightly different with the road temperatures expected to slip just below the threshold of 33.5 F. This temperature drop occurred after the precipitation was forecasted to stop, but before the road surface was expected to dry out. Consequently, the MDSS recommended a treatment at 0500 on the 17\textsuperscript{th} to protect the road from freezing.

Garage logs and post-event discussions with the Ames personnel determined that the US30 route was indeed treated just after midnight on the 16\textsuperscript{th}. Supervisors felt that the roads were in jeopardy of freezing after the end of the precipitation, but applied the
treatment early because the shift ended at 11PM. No treatments were made on the I35N route because the garage anticipated that the higher traffic flow on I35 would keep the road warm enough to prevent any potential ice formation. The road temperature algorithm does not currently take into account heat from vehicles, so the temperature differences on the route are primarily caused by the differing profiles and heat retention properties of the underlying pavement. RWIS verifications of road pavement temperatures (Fig. 11.27) indicate that there was a differential along the routes, but that neither route ultimately experienced temperatures below 32 F (although the <33.5 F period did verify).

Fig. 11.26. Forecasted precipitation, road temperatures and recommended treatments along with actual treatments for I35N Ames route on January 16-17.
11.3.5 Overall treatment verification summary and conclusions

Interviews with Ames and Des Moines garage supervisors indicated that there was a general comfort level with the treatment recommendations this year that they did not have last year. On several occasions, on less traveled routes, the DOT used the recommended treatment strategy with little modification. Results in most cases were satisfactory unless storm conditions varied greatly from the forecast. Unfortunately, quantifying the verification of treatment strategies is a formidable task. Storm conditions are often significantly different during a storm than originally forecast, and even seeming minor changes in parameters like road temperature or dry road time can greatly impact the optimal treatment strategy.

Once those factors are addressed, there is also the puzzling task of ascertaining whether seemingly different treatment applications might yield the same ice-free road conditions. It is onerous, but manageable, to determine if the selected Iowa DOT strategy did or did not keep the roads at the desired level of service. But it is almost impossible to take an unimplemented recommended treatment strategy and determine the exact road conditions.
However, in each of the three case studies detailed above we have found strengths and weaknesses in the RCTM. The lack of logic for dealing with blowing snow conditions in the RCTM continues to be a noticeable weakness in the system causing the recommended treatments to be below what might be needed. Even incorporating the direction of potential blowing snow might be an improvement. Based on the cold rain case of January 16-17 and the heavy rain / warm road case of March 15-16 it appears that the road temperature predictions are sufficiently accurate during storms to allow a tightening of the freeze-point threshold. But, the rigidity of a fixed freeze-point threshold may also need to be addressed, perhaps by making the freeze-point threshold dependent on the duration of the below freezing temperatures. Additionally, modifications made to the RCTM and improvements in the RWFS forecast have yielded recommended treatment strategies are fairly consistent from MDSS run to run. Enhancements made to suppress pre-treatments under warm road and cold road/ blowing snow conditions are effective. Finally, the added ability to protect the wet road surface after the storm precipitation ends was also effective.

Results and Recommendations: Significant improvements to the Rules of Practice module in 2004 resulted in treatment recommendations that better matched DOT operations. In some cases, the treatment recommendations were implemented without modification with excellent results. The Rules of Practice code (as provided in MDSS Release-3.0), although not perfect, provides a solid starting point for further development and tailoring to specific road operating authorities by the private sector.

11.4 Mesoscale Modeling System Reliability

One of the major concerns of those who would consider running NWP models for their own operational applications (such as MDSS system implementations) is the labor intensiveness of the process and the system reliability. The first aspect is addressed here by simply stating that the entire system runs automatically without any human intervention, unless a failure occurs, in which case a system restart brings everything back to life. The second aspect will be illustrated by statistics comparing the number of forecast frames promised for delivery to NCAR’s RWFS system to the number actually delivered. This number was 90.3% (compared to 99% for the NCEP model grids) for the entire period of the experiment, which is probably not adequate for actual operations. However, a day-by-day depiction of reliability (Fig. 11.28) reveals that improvements are within reach simply by applying the usual full-time scrutiny to operational computing systems, which was not done during this experiment. In such an application, the head-node crash would have been corrected in a few hours by installing a spare processor, and the hack attack would have been detected and repaired within an hour or two of its occurrence. The hacker had about a full day to cause damage with lasting repercussions in this case.
The difference between reliability numbers in WRF (90.9%) and MM5 (89.7%) is not considered to be indicative of anything beyond random effects in dropout events.

Fig 11.28. Daily percentage of expected model outputs that were successfully transmitted from FSL to NCAR/RAP during the 2004 MDSS Demonstration.

11.5 Mesoscale Model Performance

For the 2004 MDSS demonstration in Iowa the FSL model ensemble consisted of two different mesoscale, or regional, models (MM5 and WRF) with lateral boundaries from the Eta model provided by the NWS National Centers for Environmental Prediction. The models were initialized with updated satellite, radar, and RWIS data each hour and run out to 15-hr. The RWFS module uses time-lagged ensemble prediction techniques; for example, an 8-h RWFS forecast uses as inputs the current 8-h forecasts from the regional models along with the previous runs’ 9-h forecasts and the 10-hr forecasts from the runs before that.

The ensemble modeling domain is illustrated in Fig. 11.29. This is an image of forecast surface temperature with wind barbs plotted and contours of relative humidity overlaid. This is an example of how the model outputs were presented in real time on FSL’s web page (http://laps.fsl.noaa.gov/mdss).
Each ensemble member was initialized using the LAPS hot-start method of diabatic initialization. The Eta model, which provided lateral boundary conditions, was updated only four times daily 0300, 0900, 1500, and 2100 UTC (9 PM, 3 AM, 9 AM, and 3 PM CST), so lateral boundary data were interpolated in time for the off-cycle MDSS model runs.

The MDSS model forecasts are evaluated by comparisons against hourly observations of surface temperature, wind, dewpoint (humidity) and precipitation. For this report, hourly precipitation observations were binned for comparison to 3-h model precipitation accumulations.
The object of verifying these or any forecasts is to determine if predictors are capable of 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.

12-h forecast verification statistics (RMS and bias) for the state variables temperature, wind speed, and dewpoint are given in the following table.

Table 11.1. Verification statistics for the two mesoscale models, MM5 and WRF, as well as the Eta, which is the "large scale" model that supplies the lateral boundary conditions for MM5 and WRF. The mesoscale models are generated at FSL; the Eta model is generated by NWS/NCEP. For each variable, the left column is RMS error, the right column is bias (defined as forecast minus observation; a positive temperature bias means the model forecast was too warm).

<table>
<thead>
<tr>
<th></th>
<th>Temperature (°C)</th>
<th>Wind speed (m/s)</th>
<th>Dewpoint (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>RMS</td>
<td>bias</td>
<td>RMS</td>
</tr>
<tr>
<td>MM5</td>
<td>3.2</td>
<td>+0.2</td>
<td>2.4</td>
</tr>
<tr>
<td>WRF</td>
<td>3.0</td>
<td>+1.3</td>
<td>2.3</td>
</tr>
<tr>
<td>Eta</td>
<td>2.7</td>
<td>+0.5</td>
<td>2.7</td>
</tr>
</tbody>
</table>

Shelter-level (2m) temperature and dewpoint. All the models had warm-biased 12-h temperature forecasts; the same is true for the dewpoint forecasts. Neither of the MDSS supplemental models (MM5 and WRF) were as consistently accurate as the large-scale Eta model, which has the lowest RMS error. The slight advantage for the Eta model is because it has surface flux formulations that are closely tied and tuned to its Land Surface Modules (LSM), which characterizes the earth surface by vegetation type, roughness, albedo, moisture content, land use, etc. By contrast, the MDSS models use LSM information from outside sources. In the report following the 2003 MDSS Demo, improvement in this area was identified as an opportunity for advancement in quality because of changes expected in the LSM data preparation and parameterizations. While the temperature forecast errors are about the same as in last year’s results, the dewpoint forecast RMS errors are two full centigrade degrees smaller than last year’s errors. This is significant improvement in humidity forecast quality from last year.
**Tower-level (10m) winds.** The Eta model showed almost identical wind speed errors in this year’s results compared to last year’s results (not shown). However, both of the MDSS models showed a slight improvement in wind forecast errors and may have actually surpassed the Eta model, although these margins of error magnitude are not large enough to claim significant advancement in this area.

These statistics are calculated over all model runs. Stratifying the statistics by time of day reveals additional interesting information about their respective performance characteristics. In the example of Fig 11.30, the wind error statistics are computed for all model runs initialized at 00 UTC, for the 01 UTC runs, etc., and the resulting time series of 12-h error statistics graphed. Note that MM5 and WRF forecasts initialized between 06 and 11 UTC have lower bias errors than model runs initialized at other times. These forecasts are valid between 18 and 23 UTC, which is 12 PM to 5 PM CST. During these hours, daytime heating mixes and homogenizes the lowest part of the atmosphere and increases the effective friction encountered by the air. This process links upper-level flow with surface wind and enhances predictability. At night, the near-surface air is effectively decoupled from the flow aloft by radiative cooling. This allows the surface air to more easily respond to small, subgrid-scale forcing effects such as radiation-driven drainage flows, which the models do not accurately predict. The errors are caused by overestimation of the frictional effect, resulting in positive wind speed bias at night.
Fig. 11.30. Twelve-hour wind speed forecast errors from the MDSS ensemble models and the NWS Eta model. Bias (above) and RMS (below).
Another analysis of the temperature forecast errors was performed to illustrate the models’ performance for the critical task of properly forecasting the diurnal temperature wave. In Fig 11.31, a time series was constructed from all the forecast models initialized at 06 UTC, or 12 AM CST. The red line is the corresponding observations. Note that the amplitude of the WRF wave is smaller than reality, resulting in a warm bias at night and a cool bias during the day. The MM5 model is remarkably close to reality until sunrise, and then a significant warm bias during the daytime hours becomes evident.

**Fig. 11.31. Time series of temperature forecast errors from the 06 UTC (1 AM CST) model runs and verifying observations.**
Fig. 11.32 illustrates precipitation forecasting performance. The reported statistics are ESS, which is the equitable skill score, and areal bias. ESS ranges from 1.0 for perfect performance to 0.0 for forecasts of no skill at all, essentially equivalent to a random variable being used as a predictor. Areal bias, not to be confused with biases in magnitude which are used above for the state variables, is 1.0 if the model covers the correct fraction of the domain with precipitation at or above a particular precipitation threshold; values above 1.0 indicate overforecasting.

In the 3-h precipitation forecast graph (Fig. 11.32a), both of the MDSS models have equal or greater ESS scores than the Eta model, and both models have areal bias values that are closer to unity for all thresholds of precipitation. This is consistent with last year’s results, and the results from several other tests FSL has conducted in summertime weather applications as well. This is the expected result of the “hot start” diabatic initialization technique implemented in the MDSS models; it is consistent with and similar to the results from the 2003 MDSS demonstration as well. In the 6-h results (Fig. 11.32b), the performance of the local models relative to the Eta model reveals a similar signal but the benefits of the FSL initialization method begin to “wear off”.

**Results and Recommendations:** The mesoscale model configuration used for the 2004 MDSS field demonstration outperformed the NCEP Eta model for quantitative precipitation forecasting. In addition, the *hot start* and time lagged ensemble methods also provided improvements to the forecast product. Given the impact that precipitation forecasts have on winter road maintenance, consideration should be given to the use of mesoscale models in operational versions of the MDSS.
Fig 11.32a. 3-h precipitation forecast verification.
Fig 11.32b. 6-h precipitation forecast verification.
12 ANALYSIS OF ROAD TEMPERATURE PREDICTION

12.1 Comparing Predicted and Measured Road Temperatures

The heat balance at the Earth’s surface is complicated by heat and moisture flows occurring in many modes. Heat can be transferred to and from the surface from above by all three principal methods of heat transfer: conduction, convection, and radiation. Radiation components include both shortwave and longwave. Evaporation and condensation are additional modes of heat transfer at the surface. Phase change heat transfer is also a factor with freezing and melting of moisture occurring frequently in cold regions. Heat and mass transfer with the soil underlying the surface also impacts the surface energy balance. If the surface itself is assumed to have no finite mass, then its temperature will be determined by the balance of these energy transfers at that point. Accurately modeling all of these heat flow components to achieve an accurate surface temperature prediction is a challenging task.

Equally challenging is the task of making an accurate measurement of surface temperature, particularly on the surface of a high traffic roadway. Essentially any effort to measure a surface temperature will in some manner disturb the surface temperature distribution by introduction of a material with differing thermal or optical properties. A temperature sensor placed right at the surface may not mimic the surface itself with respect to thermal, optical, and textural properties, each an important factor in heat transfer with the surrounding.

A third complicating factor in comparing measured and modeled results for surface temperature is the input data used to drive the surface temperature model. Most often complete measured weather data are not available at the site where the comparison is to be done and local dissimilarities due to terrain as well as variation in weather over even moderate distances can generate significant errors. Our task here is compounded by the fact that for the operational use of our surface temperature model we need to rely on forecasted weather data with its inherent inaccuracies. In the post analysis we can at least eliminate this impact by using measured weather data, understanding fully that it is still encumbered with the other limitations discussed above.

Hence when making comparisons between modeled and measured surface temperatures it’s imperative that we keep in mind the limitations of each result. While we are keenly aware of the limitations of the surface temperature model presented here, and our ability to generate precise weather to drive the model, we did not have a good grasp of what expected measurement errors might be. For this reason we decided to make some surface temperature measurements at several of the locations where the roadway temperatures were being measured. We used two devices, a FLIR ThermaCAM® S60 infrared camera and a portable infrared surface thermometer. Measurements were taken under both day and night clear sky conditions when we felt thermal and optical properties of the roadway
temperature measurements “pucks” could be causing measurements errors. Sample infrared images of the same roadway temperature measurement sensor under these two conditions are shown in Fig. 12.1. The very fact that the roadway temperature measurement sensors appear much different in gray-tone in the infrared image is an indication that they either are at different temperatures, or they have different optical properties, or both. To understand what sort of temperatures differences we might be witnessing, these images were analyzed with our infrared image analysis software. Areas within the center of the “puck” as well as areas of similar size in the pavement area adjacent to the puck were selected and their apparent mean temperature was calculated. While assumptions used in the analysis, such as surface emissivity and prevailing weather conditions will have some impact on absolute temperatures inferred from the observed infrared signature, the impact on relative temperatures will be much smaller.

Across all sites where we made the measurements, trends were very apparent as can be seen from Fig. 12.2. It is apparent that during the nighttime clear sky condition that the roadway temperature measurements appear to underestimate the adjacent pavement temperatures. During the day the opposite impact was observed, the roadway temperature measurements appear to be overestimating the adjacent pavement temperatures. One interpretation of these data could be that the roadway temperature sensors have a lower specific heat and/or higher thermal conductivity resulting in them having a higher thermal diffusivity than the adjacent roadways. Another possible interpretation would be that the thermal coupling between the roadway temperature sensor and the roadway underneath it is inadequate for the sensor in the roadway to emulate a solid, unbroken material. Of course, a possible combination of these effects would be another reasonable interpretation. Unbeknownst to us, regrettfully many of the RWIS sites were not operational when we took these measurement so we have very little in the way of data that the sensors were reporting when these infrared measurement were
made. However, we must conclude from these results that the measurements taken by the road temperature sensors can not be taken as an absolute standard against which models can be compared, or for that matter should be calibrated against. It is important to point out that it is quite likely that the apparent temperature differences we observed would be lower or possibly nonexistent in times of lower radiant loadings. This is just one factor that we’d suggest be investigated in a future study.

Fig. 12.2. Infrared roadway temperature sensor analysis, “puck” temperature minus roadway temperature.

12.2 Iowa MDSS Demonstration Background

During the Iowa DOT MDSS field program conducted on several roads and overpasses in and around Des Moines and Ames, Iowa, a modified version of the Cold Regions Research Engineering Laboratory’s (CRREL) 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. In addition, for bridges the bottom soil layer was replaced with a layer that represented atmospheric conditions. For every hour the temperature of this bottom layer was set to the ambient atmospheric
temperature. 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. But, rain and snow are permitted to accumulate on the road surface and the exchange of latent heat between either the layer of water or snow on the road surface and the atmosphere is modeled.

SNTHERM-RT requires a number of initialization parameters including a time series of meteorological information. In order to provide Iowa DOT with a prognostic capability, the road surface temperatures were based on an ensemble forecast of the meteorological conditions rather than observed meteorological conditions. Even though the model exhibits considerable skill, there were still periods when the predicted road surface temperature differed from the observed values by 4°C, especially during periods of high solar flux (cloud free mid day periods). In order to investigate the potential underlying cause(s) of these differences, we reran SNTHERM-RT for selected MDSS periods using the observed meteorological conditions and compared the predicted road surface temperatures with the observed temperatures and the predicted temperatures based on the ensemble forecast meteorological conditions. We employed the following approach and obtained the following results.

### 12.3 Analysis Approach

Two sites were selected for reanalysis based on the proximity of these sites to observed meteorological data and road surface temperature measurements. The sites selected were the Ames RWIS site on I-35N and the Ames bridge site. The ambient temperature, and relative humidity from the Ames RWIS site; the solar flux from the instruments installed at the nearby Ames garage; wind and precipitation information from the Ames municipal airport; and cloud information from either the observations from the Ames municipal airport or the ensemble forecast model were used in the reanalysis. The observed meteorological information from the three (RWIS, Ames garage, and the Ames municipal airport) sites, each with different temporal resolutions, was merged to provide an hourly meteorological information database used to drive SNTHERM-RT. Since the solar flux was recorded every minute at the Ames garage we decided to use two different approaches for computing the hourly solar flux for the SNTHERM-RT reanalysis. In the first approach we used the solar flux recorded on the hour. In the second approach we average 60 minutes of solar flux measurements centered on the hour. That is, the solar flux used in the second approach was the average of the 60 measurements that spanned the period from 30 minutes before the hour to 29 minutes after the hour. The infrared flux used in the reanalysis was computed from cloud information obtained from the hourly Ames municipal airport surface observations or from the ensemble forecast model cloud information. The following table summarizes the meteorological data combinations used as boundary conditions for the reanalysis of the MDSS road and bridge temperatures. For all scenarios based on the observed meteorological conditions the ambient temperature, relative humidity, wind speed, and precipitation were the same, only the solar flux and the cloud information used to compute the IR fluxes varied.
Table 12.1. Meteorological combinations used for the different SNTHERM-RT model runs based on the observed meteorological conditions

<table>
<thead>
<tr>
<th>Solar Flux</th>
<th>Cloud information</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hourly average values</td>
<td>Ames municipal airport surface observations</td>
</tr>
<tr>
<td>Values on the hour</td>
<td>Based on the forecast model</td>
</tr>
<tr>
<td>Values on the hour</td>
<td>Ames municipal airport surface observations</td>
</tr>
<tr>
<td></td>
<td>Based on the forecast model</td>
</tr>
</tbody>
</table>

12.4 Results

We also decided to look at the spatial variability in the road surface temperature using the CRREL infrared camera. Infrared camera imagery of the road temperature sensor located on I-35N just north of the Ames DOT garage was obtained for 3/17/2004 at approximately 16:25 local on a sunny day (see Fig. 12.3). Four Areas Of Interest (AOI) surrounding the location of the road temperature sensor were selected. Histograms of the temperature information associated with the four AOIs were generated. These AOIs cover a fairly small aerial extent. The approximate diameter of the road temperature sensor is less than one foot. The striations in the AOIs are associated with the grooves in the concrete road surface and we believe are due to differential heating associated with shadowing. The temperature distributions associated with the AOIs is not symmetrical. The temperature range for the distributions is on the order of 1.5 to 2.0 degrees centigrade. The surface road temperature sensor is on the order of 5 degrees centigrade hotter than the road surface temperature in the AOIs. We believe this is because the material that is used to embed the sensor (referred to as the ‘hockey puck’) in the road has thermal properties that differ significantly from the road. Additionally, there may be thermal contact resistance on the underside of the temperature sensor puck. The temperatures as observed in the IR camera imagery may not reflect the temperature measured by the internal sensor in the puck. SNTHERM-RT is a one-dimensional energy-mass balance model and is not capable of predicting the temperature variability evident in the IR imagery. The road surface temperature predicted by SNTHERM-RT will depend on the physical, thermal, and optical properties of the road layers used in the model; the hourly meteorological information used to drive the model; and the model physics. Because of uncertainties and spatial variability in the physical, thermal, and optical properties of the road layers, we should not be surprised to see differences of several degrees centigrade between the SNTHERM-RT predicted road surface temperatures and the measured road temperatures.

To provide Iowa DOT with a prognostic capability, the meteorological conditions used to drive SNTHERM-RT were obtained from an ensemble forecast model. During the reanalysis, observed meteorological data was used to determine if there was any significant difference between the predicted road surface temperatures using the two different sources of meteorological information, the observed meteorological conditions and the ensemble forecast model meteorological conditions. The ensemble forecast model produced a 48-hour forecast. To simplify the analysis we used the SNTHERM-RT
road surface temperatures based on the 18 UTC ensemble forecast. For all hours except 18 UTC we had two road surface temperature forecast values available; one from the latest forecast and one from the previous forecast.

For 18 UTC we had three values: the zero-hour ensemble forecast model meteorological conditions from the present forecast plus the information from the two previous 18 UTC ensemble forecasts. We used all information and plotted the maximum and minimum predicted road surface temperature. Fig. 12.4 presents the predicted road surface temperatures based on the average solar flux, the observed meteorological conditions, and the IR flux computed from the ensemble forecast cloud conditions plus the minimum and maximum road surface temperatures predicted using the ensemble forecast meteorological information. For the observed meteorological conditions (using the forecast cloud amounts) the first SNTHERM-RT prediction was Day Of the Year (DOY) 73 at 18:00L. For approximately the first 4-6 hours the model ‘spins up’ and the predicted values are less than the observed road surface temperatures. The areas blocked in yellow are periods when SNTHERM-RT model runs based on the observed meteorological conditions predicts snow on the road surface. Temperature comparisons should not be made during these periods since the snow was not artificially removed to correspond to

Fig. 12.3. Infrared imagery for 03/17/2004 on I-35N near the Ames DOT garage. The histograms of the radiometric temperatures obtained from the analysis of the IR imagery for the four AOIs are also presented.
removal of snow by plowing or the application of chemicals or salt and sand. In the SNTHERM-RT model runs using the ensemble forecast meteorological conditions the snow was artificially removed when the Ames garage reported plowing or the application of chemicals. In either scenario SNTHERM-RT does not model the impact of traffic on the road surface conditions.

**MDSS AMES ROAD TEMPERATURES**

*Average Solar & Forecast Clouds*

![Graph showing road temperatures over the year 2004](image)

**Fig. 12.4.** SNTHERM-RT predicted road surface temperature using the average solar flux, observed meteorological conditions, and the forecast cloud conditions. Also plotted is the maximum and minimum predicted road surface temperatures based on the ensemble forecast model meteorological conditions.

An analysis of the Root Mean Square Error (RMSE) for the SNTHERM-RT predicted road surface temperatures using the observed meteorological conditions, average solar flux, and the forecast cloud conditions from the ensemble forecast model (denoted as “Based on Obs” in Fig. 12.5) and the predicted maximum (based on fcst red line) and minimum (“Based on Fcst” blue line) road surface temperature based on the ensemble forecast meteorological conditions is given in Fig. 12.5. Prior to 06:00L on DOY 75 all three curves in Fig. 12.5 have similar RMSE values. In the periods after 12:00L on DOY 76 when there was no snow on the road surface, the RMSE values based on the observed weather conditions tend to be higher than the RMSE based on the ensemble forecast conditions. This is an artifact of how SNTHERM-RT was run using the observed weather conditions. As indicated earlier, snow was not artificially removed from the road surface in these model runs. The snow was allowed to melt naturally. In the SNTHERM-RT runs based on the ensemble forecast model meteorological conditions the snow was removed from the road surface if the Ames DOT garage indicated plowing or chemicals had been applied to the road. The effect of not removing the snow is evident in Fig. 12.4 in the
time period from 21:00L DOY 75 to 12:00L DOY 76. During the afternoon of DOY 75 the solar flux values were on the order of 400 W/m². Since there was snow on the road the energy associated with the solar flux melted the snow and was not available to heat the road. When the snow does finally melt, the predicted road surface temperatures start to increase, but lag behind the observed road surface temperatures. In the model runs using the ensemble forecast information, the snow had been artificially removed from the road the solar flux heated the road and the predicted road surface temperatures mimic the observed road surface temperatures.

![MDSS Ames Road Temperatures](image)

**Fig. 12.5.** Root Mean Square Error (RMSE) for SNTHERM-RT road surface temperature predictions based on the observed weather conditions, average solar flux, and ensemble forecast model clouds (black line) and the maximum (red line) and minimum (blue line) predicted road surface temperatures based on the ensemble forecast model meteorological conditions.

Fig. 12.6 is the same as Fig. 12.4 except the observed cloud conditions are used rather than the ensemble forecast model cloud conditions. The predicted snow cover on the road surface at the beginning of DOY 77 predicted by SNTHERM-RT based on the precipitation and the ensemble forecast model cloud amounts does not agree when SNTHERM_RT predicted snow cover based on the observed cloud conditions, even though the same precipitation information is used in both SNTHERM-RT model runs. SNTHERM-RT was also run for the following cases; instantaneous solar flux and forecast cloud conditions, and instantaneous solar and observed cloud conditions. All reanalysis model runs were repeated for the bridge north of the Ames garage. Figs. 12.6
and 12.7 present the results using the instantaneous solar flux and the ensemble forecast and observed cloud conditions. Finally, we summarize the results by presenting the Root Mean Square Error (RMSE) for the different scenarios for both the road and the bridge in Tables 12.2 and 12.3, respectively. The time periods that SNTHERM-RT predicted snow cover on the road was not used in the calculation of the RMSE. In both tables the first number in each column is the RMSE value for the entire period when the road surface was bare. The second number in each column is the RMSE value for the period from DOY 73 at 18:00 L to DOY 75 at 06:00 L. As indicated above, by not removing the snow from the road to correspond to removal or chemical application by Iowa DOT we do not correctly represent the road surface conditions.

![MDSS AMES ROAD TEMPERATURES](image)

**Fig. 12.6.** SNTHERM-RT predicted road surface temperature using the average solar flux, observed meteorological conditions, and the observed cloud conditions. Also plotted is the maximum and minimum predicted road surface temperatures based on the ensemble forecast model meteorological conditions.
Fig. 12.7. SNTHERM-RT predicted bridge surface temperature using the instantaneous solar flux, observed meteorological conditions, and the ensemble forecast cloud conditions. Also plotted is the maximum and minimum predicted road surface temperatures based on the ensemble forecast model meteorological conditions.
Fig. 12.8. SNATHERM-RT predicted bridge surface temperature using the instantaneous solar flux, observed meteorological conditions, and the observed cloud conditions. Also plotted is the maximum and minimum predicted road surface temperatures based on the ensemble forecast model meteorological conditions.

Table 12.2. RMSE (degree centigrade) for the reanalysis of the Iowa MDSS road surface temperatures. See text for explanation.

<table>
<thead>
<tr>
<th>Weather</th>
<th>Fcst Meteorology Minimum road temp</th>
<th>Fcst Meteorology Maximum road temp</th>
<th>Weather Observations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Avg solar Fcst clds</td>
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<td>2.8/3.2</td>
<td>4.2/3.4</td>
</tr>
</tbody>
</table>

Table 12.3. RMSE (degree centigrade) for the reanalysis of the Iowa MDSS bridge surface temperatures. See text for explanation of the scenarios.

<table>
<thead>
<tr>
<th>Weather</th>
<th>Fcst Meteorology Minimum road temp</th>
<th>Fcst Meteorology Maximum road temp</th>
<th>Weather Observations</th>
</tr>
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<tbody>
<tr>
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</table>
12.5 Road Temperature Analysis Summary

In an earlier study conducted under controlled conditions at the CRREL road test site SNTHERM-RT exhibited considerable skill in predicting the road surface and sub-surface temperature information. This level of skill was only achieved after using SNTHERM_RT and measured field data to ‘back out’ the optical, and thermal properties of the road and underlying gravel and soil layers. We feel that this same level of skill can be achieved using SNTERM-RT for ‘real world situation’ if a similar procedure is used to ‘back out’ the road thermal and optical properties. The physical properties (road layer thickness, etc) should be available from DOT information. To implement this approach it would entail collecting data before the winter season for the desired road sites and tuning SNTHERM-RT for each site by ‘backing out’ the desired road surface properties. The ensemble forecast meteorological information used in conjunction with SNTHERM-RT provided high quality prognostic road surface temperature information for Maintenance Decision Support to the Iowa DOT. The limited reanalysis presented here should be extended since an extensive data set was collected for the Iowa MDSS field program. Its completeness makes it an ideal data set for future research and road surface energy budget model development. Since SNTHERM-RT does not model the impact of chemicals on the road surface energy budget, snow removal by plowing, or the influence of traffic, future modeling efforts should focus on developing procedures to handle these situations.

13 CHEMICAL CONCENTRATION SAMPLING

In order to verify the chemical concentration algorithms, which have been implemented in the RCTM, CRREL developed techniques to sample the on-road chemical concentration. A method was sought that would offer laboratory quality concentration results while being acceptable for collecting samples under open and operating roadways during winter storm conditions. The approach we evaluated during the 2004 MDSS demonstration involved using an absorbent glass wool to collect a sample directly from the road surface. Small sections of the glass wool absorbing medium where each pre-weighted along with a numbered plastic bag. For the field sampling we used forceps to remove the glass wool from the bag and wipe it around in the solution on the road until it became saturated. Once the glass wool was saturated to the maximum extent possible it was replaced in the bag from which it was removed and the bag was sealed. The bag number, time, date and location of the sample were then recorded in a log sheet. All samples were returned to CRREL where they were analyzed in our chemistry laboratories.

The results from a portion of the chemical concentration sampling are presented in Table 13.1. The concentrations observed appear to be low based on expected concentrations. This approach could have excluded some salt that was not fully dissolved. Although the
sorber technique gives a reliable estimate of the material that the sorbers collected, it is difficult to relate that salt concentration to surface-area of road, because we do not know the area that is represented by the sample. Based on the results of this trial and some encouraging results obtained by others using a technique that recovers a sample by vacuum (Fig. 13.1) we are now pursuing that alternate approach. We will adapt the technique to obtain an accurate measure of the solution temperature as well when it is being retrieved. We expect this method of sampling to have a number of advantages including the ability to collect samples containing slush and undissolved chemical solids. With proper design we feel that inexpensive tubing and traps will allow us to take multiple samples rapidly in the field and then clean all equipment for future reuse. We will also, by use of a template, be able to determine effective concentrations over an area when samples are obviously non-uniform.

### Table 13.1 Results of chemical concentration sampling.

<table>
<thead>
<tr>
<th>Sample</th>
<th>Sampling Date</th>
<th>Time</th>
<th>Location</th>
<th>Cl⁻ Concentration (ppm)</th>
<th>Cl (%)</th>
<th>Salt (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1/26/2004</td>
<td>1500</td>
<td>US30 E mile 146 shoulder</td>
<td>20,951</td>
<td>2.10</td>
<td>3.45</td>
</tr>
<tr>
<td>2</td>
<td>1/26/2004</td>
<td>1504</td>
<td>US30 East mile 147</td>
<td>20,667</td>
<td>2.07</td>
<td>3.41</td>
</tr>
<tr>
<td>3</td>
<td>1/26/2004</td>
<td>1514</td>
<td>US30 SW corner S 80th Ave</td>
<td>38,286</td>
<td>3.83</td>
<td>6.31</td>
</tr>
<tr>
<td>4</td>
<td>2/6/2004</td>
<td>1002</td>
<td>US30 East mile 144</td>
<td>15,704</td>
<td>1.57</td>
<td>2.59</td>
</tr>
<tr>
<td>5</td>
<td>2/6/2004</td>
<td>1010</td>
<td>US30 East mile 146</td>
<td>19,746</td>
<td>1.97</td>
<td>3.25</td>
</tr>
<tr>
<td>6</td>
<td>2/6/2004</td>
<td>1027</td>
<td>I35 North mile 114.5</td>
<td>17,938</td>
<td>1.79</td>
<td>2.96</td>
</tr>
<tr>
<td>7</td>
<td>2/6/2004</td>
<td>1033</td>
<td>I35 North mile 119</td>
<td>26,942</td>
<td>2.69</td>
<td>4.44</td>
</tr>
<tr>
<td>8</td>
<td>2/6/2004</td>
<td>1050</td>
<td>I35 South mile 128</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>9</td>
<td>2/6/2004</td>
<td>1052</td>
<td>I35 South mile 128</td>
<td>16,910</td>
<td>1.69</td>
<td>2.79</td>
</tr>
<tr>
<td>10</td>
<td>2/6/2004</td>
<td>1104</td>
<td>I35 South mile 121</td>
<td>14,535</td>
<td>1.45</td>
<td>2.40</td>
</tr>
</tbody>
</table>
Fig. 13.1 Functional schematic of a vacuum based sampling system.

14 DISPLAY SOFTWARE

14.1 New Display Features

There were few new features added to the display for the MDSS 2003-2004 winter demonstration.

The display's screen resolution was increased to 1280x760. Coupled with larger monitors, this provided the ability to display more information. Users were generally happy with the updated format, though a few complained of difficulty in seeing information.

A button was added to display parameter values directly on the map next to the colored dots (Fig. 14.1). Seeing the actual numbers on the map is a common presentation format used by other weather tools at the garages. Users had requested this feature during the MDSS 2002-2003 winter demonstration. They were happy to see it implemented.
A new dialog was added to show the most frequently requested storm summary information on one screen. The “Event Summary” dialog presented users with the declared precipitation type on the roadway, conditional probabilities of rain, snow, and ice precipitation, snow accumulation, road temperature, wind speed, blowing snow alerts, and the recommended treatment (Fig. 14.2). Users were pleased with this new dialog, as it provides a good overview of an upcoming storm. The combined probability of precipitation graph is an innovative way to present multiple variables. It was well received.
Fig. 14.2. Event summary dialog example for I-35 South.

Treatment history was added to the selected route and a new “Treatment History” dialog was created to show recommended and selected treatments for the two prior model runs. This feature was of primary interest to Iowa DOT supervisors and observers. Although plow operators did not typically use the new dialog, they benefited from supervisors' post-storm analyses.

Performance was unchanged this year from last year, but some users reported higher satisfaction due to increased loading speeds. This can only be attributed to improved networking on the part of the Iowa DOT. It does, however, indicate the importance of bandwidth to the quality of users' experiences.

14.2 User Survey

A survey of MDSS display users was conducted to identify how they used the various features of the display. It found consistent agreement on some features and widespread
disagreement on others. All users were generally in agreement that the display is “easy to learn and use,” while they typically disagreed on the best way to use it.

The MDSS Display presents weather and road conditions using several presentation techniques. Several of these techniques overlap, allowing users to customize both the medium and the order in which data are presented to them. Techniques include:

- Individual parameter values as:
  1) Colored dots in the map
  2) Values in the map
  3) Plots in mouse-over graphs
  4) Plots in click graphs
  5) Tabulated values in click graphs
  6) Plots in the Treatment Selector dialog
  7) Plots and min/max values in the Event Summary dialog

- Computed alerts as:
  8) Colored forecast areas in the state view map
  9) Time bars in the upper left of the display
  10) Colored route segments in the map
  11) Time bars in mouse-over graphs
  12) Time bars in click graphs
  13) Time bars for the selected route at the bottom of the display

- Treatments as:
  14) Icons along a time line for the selected route at the bottom of the display
  15) Icons along a time line in the Treatment Selector and Storm Summary dialogs
  16) Icons along a time line and a textual list in the Treatment History dialog

- Precipitation probabilities as:
  17) Bar chart in the Event Summary dialog

The different strategic requirements put on supervisors and operators, as well as conditioned preferences for certain tools and data, result in a wide variety of approaches to meeting the road maintenance “challenge.” Because the display provides many ways to look at the data, users fell into patterns that supported their approach. The results of surveys with 5 garage supervisors at 3 locations are shown below. Numbers in column headings correspond to the techniques listed above. Numbers in the cells indicate the order of preference (and/or execution) for the different techniques.

<table>
<thead>
<tr>
<th></th>
<th>Parameter</th>
<th>Alert</th>
<th>Treatment</th>
</tr>
</thead>
<tbody>
<tr>
<td>User</td>
<td>1 2 3 4 5 6 7</td>
<td>8 9 10 11 12 13</td>
<td>14 15 16 17</td>
</tr>
<tr>
<td>Supervisor</td>
<td>2 1 3</td>
<td></td>
<td>5</td>
</tr>
<tr>
<td>Supervisor</td>
<td>2 1 3</td>
<td>5</td>
<td></td>
</tr>
</tbody>
</table>
Such drastic differences in the use of the display from users with similar responsibilities are surprising. The differences between users with other responsibilities (DOT officials, meteorologists, and the general public), although not presented here, is even more pronounced.

Despite their differing uses of the display, all users found the tool to be “easy and fast” and “not too complicated.” The display designer determined that all features of the display were useful to at least one user. As a result, the designer's occasional desire to simplify the display seems to be unwarranted.

15 IOWA DOT USER FEEDBACK

During the latter part of the field demonstration, several Lab staff met with Iowa DOT personnel to obtain feedback on the prototype system. A sample of the feedback is provided in this section. Following the demonstration the FHWA visited Iowa and participated in a post demonstration meeting to gather additional feedback. The results of that debriefing are not reported here.

Dennis Burkheimer - Winter Operations, IADOT HQ, Ames (Feb 24, 2004)

- There were noticeable improvements made to the MDSS for the winter 2003-2004 demonstration.

- The garage PC's only have 196 MB of memory, which causes some slow loading and response of the MDSS display application software.

- There was some "disappointment" this year that the high resolution models only went out 12-15 hours. The most important forecast of the day occurs at noon so that overnight and morning plans can be made before personnel leave by 3:30 PM.

- There is an ongoing desire to have frost prediction and alerts on the prototype MDSS.

- Adjustments to the blowing snow algorithm to make it more sensitive were welcomed.
• The MDSS products and GUI were well received. There is a desire to have several other data sets integrated with an MDSS including radar and satellite products, alert notification (cell, pager, e-mail etc.). There was a discussion of how this is the path that the commercial sector should certainly move along.

• Observed that the MDSS "nails the bigger storms". It also did pretty well on precipitation timing (when it knows about an event). Some weaker events were missed, particularly early in the demonstration period and when the mesoscale models were unavailable.

• Discussed how the MDSS is an integrated test bed of methods, techniques, and algorithms that are designed to compliment and not compete with commercial sector offerings. Commercial entities should combine their best technologies with those demonstrated in the MDSS to improve the overall services provided to the DOTs.

Paul Durham - Garage Supervisor, Ames, IADOT (Feb 25, 2004)

• Indicated that significant progress was seen between last year and this year. His staff very much likes the MDSS capabilities and it is viewed by staff as becoming very credible. The staff sees great potential for the MDSS technology. He is concerned that the program may fade away just when it is getting its feet.

• The staff would very much like to see the program continue as “you are on the edge of having something very special that will significantly support our decision making”. Reiterated that the "golden goose" would be for MDSS to incorporate actual treatments directly into the system. This capability should be included in commercial offerings.

• The MDSS is doing much better overall than the first winter.

• Discussed the 15-hr period for the high-resolution models. Paul reiterated that the most critical forecast of the day occurs between 12 PM and 3 PM when they make their plans for that night and the following morning.

• Paul liked the blowing snow alert product and was supportive of the adjustments made to the sensitivity of the blowing snow alert.

• They believe that a "human in the loop" should be included in an operational service as it would improve the chances of catching some otherwise missed events and provide for some analysis.

• The garage has an increasing "mass" of weather information to sift through. In the old days, you looked out the window. Then, they waited for the local news to see
the radar. Now, with cable TV and the Internet, all of this information rushes at you. At times the amount of information is a detriment. They need one system that they can build confidence in. The MDSS is rapidly developing a following and more credibility.

- Beside road/bridge frost, they are all satisfied that the prototype system contains all of the tools to meet their needs.

- Paul would like to see his favorite features and functions of the MDSS and commercial services combined into a single system. They are becoming more reliant on weather system technologies such as MDSS.

**Gary McDaniel - Garage Assistant, Des Moines North, IADOT (Feb 16 2004)**

- The MDSS was generally conservative on alerts, wind speed and snow amounts. However, it appeared to do a good job on precipitation timing. For the most part, it worked quite well.

- The system needs to be able to "stack treatments". For example, when temperatures become marginal (10 - 15F), they will simultaneously treat with both salt brine and salt either by using 2 trucks or by towing a trailer. The current system does not allow for multiple, simultaneous treatments to be entered.

- For some small events (<1-2 inches), the MDSS showed no precipitation at all. [This issue was addressed later in the period as described in Section 11.1.3]

- When first logging on to the system, he immediately zooms to the DSM route region. He looks at recommended treatments. He finds the graphical display easier to digest than the tabular form.

- He has found that the treatments are pretty close especially in melting (not blowing snow) situations.

- He absolutely supports continued development of MDSS and technology transfer to the private sector.

- The system was "head and shoulders above" last year's prototype.

**Ed Mahoney - Garage Supervisor, Des Moines North, IADOT (Feb 25, 2004)**

- Indicated that the MDSS was very useful this year and the staff members were more comfortable using it.

- Found that the application rate for the total storm period to be very close to what was actually used. Some treatment timing sometimes differed during the storm
because of small scale features like snow bands and rush hour issues. He described a case where the MDSS had a total forecast of 700 tons of salt predicted. He estimated that they used around 725 tons during the storm. He indicated that he was impressed with its recommendations this year.

- During the January 29-30, 2004 storm, they wanted to experiment on one route by applying exactly what the MDSS forecast. For the 17 miles on IA route 415, they followed the guidance and in 3 (or 4) passes dropped 24 tons of salt at the times recommended by MDSS. Upon inspection of the road after the treatment, it was deemed to be “perfect”.

- Overall, the system is somewhat conservative on early snow projections and on material rates. He has found the precipitation ending time to be very good.

- The rules of practice need to be modified to take into account the time of day and direction (inbound vs outbound) during rush hours. A prediction of 200 lbs/lane mile will be increased to 350 lbs/lane mile during rush hours because it will take the trucks longer to complete a route.

- Was comfortable with the changes recently made to make the blowing snow algorithm more sensitive.

- He and his staff trusted the system much more for reference this year. It appears that the system is better within 12 hours of a storm than in the 12-24 hour planning stage. This may be due to the loss of the mesoscale models after that period.

- Indicated that the road temperature predictions were much better this year.

- The most important forecast of the day is from noon to 3 PM for crew scheduling.

- Successfully used the “what if” scenario generation function to create treatment plans.

**Rich Hedlund - Garage Supervisor, Des Moines West, IADOT (Feb 25, 2004)**

- Because Rich was not involved in the verification program this year, he did not routinely use the system, but his sense was that it was more complete and accurate. It was mainly used to plan for upcoming storms.

- The lack of consistent bandwidth at this garage (due to line sharing) made using the MDSS more difficult.

- Was comfortable with the changes recently made to make the blowing snow algorithm more sensitive and wished the MDSS had a road/bridge frost product.
• Stated that he would like to see the research program continue given the rapid progress being made. He indicated that he appreciates the outreach that is being done on road weather issues.

• The interface is intuitive and easy to navigate.

• They never just "plow". If they are out there, they will always drop something. The only time that they just plow is if the snow is falling too fast.

• He really likes the addition of the blowing snow alert. Bridge frost forecasts would be helpful. He would like to have a program running in the background that would pop up an alert window if an element crosses a threshold (e.g. blowing snow).

• The MDSS would best be used in an organization with a dedicated "snow desk" where someone could help in coordinating the different garage operations. Currently, the garages use a "waterfall effect" for coordination. As the weather affects one route area, the supervisor calls the next downstream office that passes the information on.

16 LESSONS LEARNED OR CONFIRMED

This second MDSS field season provided a wealth of information to the development team. Lessons learned or confirmed are listed below.

Road Weather Forecast System (RWFS)

• There were many cases were the human could see light snow in the raw model data, but the RWFS filtered it out. The weights used for QPF drifted due to poor observational data and the regression process added negative biases to the data, which filtered weak cases. Corrective actions included:
  a. Fixing the weights using expert opinion until good winter precipitation observations become available
  b. Negating automatic bias correction on QPF data due to poor winter precipitation observations

• The data fusion used in the RWFS performed well for verifiable parameters. It was demonstrated that performance skill varies between models. The NCEP models and MOS products tended to perform better on air temperature, dew point, wind direction, and to a lesser extent, wind speed. However, the mesoscale models tended to have better performance at precipitation type and rate, particularly in the first 6 hours of the forecast period.
• The forward error correction scheme worked well. A strong data quality control process is important for this method.

• The blowing snow potential product was beneficial. A more sophisticated blowing snow product is desired. The algorithm should also include a road direction factor to account for crosswinds vs. along-road winds. The users continue to request information on areas that may be prone to drifting snow. Snowdrift models should be investigated for this application.

• Probabilistic/Confidence Products: Work should continue to provide probabilistic information for key parameters (e.g., road temperature, precipitation amount, etc.). The conditional probability of precipitation type graphical product was well received by the users.

Road Condition & Treatment Module (RCTM)

Road Temperature Model

• SNTHERM Initialization: Using surface and subsurface data from RWIS helps predictions, particularly when the sun angles are high and the temperatures are not driven as much by air temperature.

• Use of insolation data from the mesoscale models (instead of calculating it from modeled cloud layer data) improves the road temperature predictions.

Rules Of Practice

• Addition of storm characterization logic significantly improved the product.

• Adjustment of chemical amounts upward to be less idealistic about amount of scatter and splatter was the correct approach.

• Rules need to account for multiple treatments being performed at the same time (e.g., more than one truck on a route).

• Inclusion of logic to incorporate blowing snow effects would be beneficial.

• The Rules Of Practice should be enhanced to automatically recommend different chemicals based on the predicted road conditions.

Weather Modeling

• The “hot start” model approach improved the prediction of precipitation.
• Forecast Period: Because winter maintenance decisions are often made 24 hrs in advance, it would be best to run the “best” models out to at least 24 hrs.

• Overall, predicting weather at plow route scales is extremely challenging and more research is required to improve weather observations and numerical weather prediction models. Improvements in characterizing the land surface and modeling the atmospheric boundary layer are required.

• Prediction of solar radiation on cloudy and partly cloudy days remains a challenge and more research is required to optimize methods than may improve insolation prediction.

Display

• System Status: The operational versions of the MDSS needs to show the users when critical parts or inputs to the system are unavailable and the forecasts may be impaired.

• Operational MDSS systems should incorporate radar data into the display to support tactical snow fighting operations.

General

• Tactical Support: The DOTs require guidance once a storm has begun. A tactical DSS solution will need to include radar products (precipitation type, rate, liquid equivalent, etc.), snow gauge data and advanced nowcasting algorithms.

• Real-time Precipitation Observations: Developing a capability that provides precipitation rate information in real-time would help tactical decision making and will provide verification data to help tune predictions systems. A new sensor or the application of an existing technology reapplied to this problem could be very beneficial. If proven, the real time precipitation rate sensor could become an enhancement to automatic weather stations.

• Weak Events: Weak snow events turn out to be more important than strong events for two reasons: (1) they occur more frequently and (2) they usually catch the operators by surprise. Unfortunately, forecasting these events 12 hours in advance is as challenging as trying to determine where/when small thunderstorms will develop. The hot start modeling approach, which takes advantage of radar data appears to help.
- **Start/Stop Time**: The end-users may want to see a dynamic range of likely start and stop times. For example, snow will start between 6AM and 9AM and end between 4PM and 5PM. This will give them some feel for the confidence we have in the forecast. The range could be based on the spread of the individual forecast modules.

- **Snow drifting**: Drifting snow creates dangerous driving conditions, particularly when the drifts are intermittent. The users continue to seek solutions that provide guidance on drifting snow. The feasibility of using snow drift models in real time should be analyzed.

### 17 SUMMARY

The MDSS prototype improved significantly between the first and second field demonstration periods. The end users, primarily Iowa DOT maintenance supervisors, indicated that they felt much more comfortable with the system and that the treatment recommendations were much closer to the actual treatments. The 2003-2004 winter field demonstration included a broad range of weather and road conditions and provided an excellent dataset for analysis.

Weather and road condition prediction on road scales is complex and poses significant challenges for decision support systems for winter maintenance operations. The MDSS project has been very useful in highlighting areas that need attention as well as capabilities (techniques, methods, features, and functions) that are ready or nearly ready for transition to operational use.

There were several successes this year. They include:

a) An improved understanding of numerical weather prediction, particularly mesoscale modeling, and its current capabilities and limits for decision support applications such as the MDSS.

b) The success of the Road Weather Forecast System’s data fusion methods (e.g., model output statistics, dynamic weighting, forward error correction, etc.) in providing additional weather forecast skill above and beyond the individual inputs.

c) The use of direct insolation (short wave solar radiation) data from the mesoscale models instead of calculating the insolation from cloud field data improved the road temperature predictions.

d) The use of “hot start” models improved precipitation forecasts. Maintenance personnel have indicated on several occasions that a better prediction of precipitation start and end times would be a major benefit.
e) The revised Rules of Practice code that included logic to characterize the pre-storm, during storm and post storm conditions and covered more weather and road condition scenarios, was a significant success.

f) The provision of probabilistic information on precipitation type allowed users to get a much better feel for not only the probability of precipitation, but the timing and evolution of the transition of precipitation type (e.g., rain to snow, snow to rain, etc.).

g) The addition of a blowing snow potential product allowed users to get a better feel for the duration of an event.

There were also some issues that arose during the field season that were problematic. These issues and lessons learned also provide useful information for future researchers and developers of MDSS like capabilities. Some of the outstanding issues are listed below.

a) Forecast Period: The decision to shorten the forecast period of the mesoscale models from a 24 to 15 hour period in favor of hourly runs was flawed because storm staffing decisions were made about 15 hours beforehand, typically 12 to 3 PM the day before the event. Many of the decisions were based on forecast data from 15-24 hours, which was the period not covered by the mesoscale models. There were cases where the mesocale models were correctly predicting rain up to 15 hours and then the MDSS precipitation type switched to snow at hour 16 because of the data source changed to the older runs of the NWS models (Eta or GFS).

b) Road Frost: The lack of guidance on road frost remains a hole in the prototype MDSS. Users have frequently asked for improved road frost guidance. There are several road frost research efforts that could be leveraged toward the development of a more mature product. The inclusion of a road frost product (based in part on work performed by Iowa State University) in the 2004-2005 MDSS prototype will be beneficial to the user of the Colorado MDSS Test Bed.

c) Winter Precipitation Measurements: The lack of quality winter precipitation measurements impacts the ability to identify snowy regions, determine where blowing snow may be occurring, and impacts the skill of predicting quantitative precipitation amount.

d) Weather Prediction Models: Weather prediction models are evolving over time and improving. Care must be taken to ensure that the data used is what is expected. The MDSS team discovered several issues related to short wave radiation fields from GFS, Eta, and WRF that were not resolved or addressed until mid way through the demonstration. NCEP corrected some of the Eta problems in late March, too late for the field demonstration. Those using data from both the
research and operational models are cautioned to monitor the output and track updates to ensure the data are actually what was expected.

Based on the analyses presented herein, we can conclude that the second demonstration of the MDSS was successful as the performance of the prototype was significantly improved, particularly the RCTM. Several outstanding issues were resolved between the first and second year. Several key capabilities (e.g., methods, techniques, code, algorithms, etc.) of the system have matured and provide a solid template and framework for an operational capability.

Additional research and development are still needed to improve several aspects of the system as it is still somewhat ideal in its calculations. Additional research is required in the areas of fine scale weather modeling, road frost, blowing and drifting snow, and road condition modeling. The Rules of Practice were improved, but are still limited.

Additional research and development are required to handle an expanded number of chemical types (e.g., MgCl₂ and specialized formulations), treatment scenarios (e.g., multiple concurrent treatments), water and chemical solution runoff, and traffic effects on anti- and deicing chemicals.
Appendix A:  
Technical Points of Contact

The primary points of contact for the MDSS project are listed below.

<table>
<thead>
<tr>
<th>MDSS Technical Component</th>
<th>Source Lab</th>
<th>Technical Point of Contact</th>
</tr>
</thead>
</table>
| Road Temperature Model SNThERM-RT | CRREL | Gary Phetteplace  
CRREL  
72 Lyme Road  
Hanover, NH 03755-1290  
Ph: 603-646-4248  
Email: [Gary.E.Phetteplace@erdc.usace.army.mil](mailto:Gary.E.Phetteplace@erdc.usace.army.mil)  
George Koenig  
CRREL  
72 Lyme Road  
Hanover, NH 03755-1290  
Ph: 603-646-4556  
Fax: 603-646-4730  
Email: [gkoenig@crrel.usace.army.mil](mailto:gkoenig@crrel.usace.army.mil) |
| Chemical Concentration Algorithms  
Coded Rules of Practice | LL | Robert G. Hallowell  
MIT Lincoln Laboratory  
244 Wood Street  
Lexington MA 02420-9180  
Ph: 781-981-3645  
Fax: 781-981-0632  
Email: [bobh@ll.mit.edu](mailto:bobh@ll.mit.edu) |
| Lead Software Engineer  
System Integration  
Road Weather Forecast System (based on DICast©)  
Road Condition and Treatment Module | 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) |
| MDSS 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) |
<table>
<thead>
<tr>
<th>Role/Programmatics</th>
<th>Contact Person</th>
<th>Contact Details</th>
</tr>
</thead>
</table>
| Meteorological Assimilation Data Ingest System (MADIS) | Arnaud Dumont | NCAR  
3450 Mitchell Lane  
Boulder CO 80301  
Ph: 303-497-8434  
Fax: 303-497-8401  
Email: dumont@ucar.edu |
| RWIS Data Ingest | Patty Miller | NOAA/Forecast Systems Lab  
325 Broadway, R/FS1  
Boulder CO 80303  
Ph: 303-497-6365  
Fax: 303-497-7256  
Email: Patricia.A.Miller@noaa.gov |
| Ensemble Modeling System | Paul Schultz | NOAA/Forecast Systems Lab  
325 Broadway, R/FS1  
Boulder CO 80303  
Ph: 303-497-6997  
Fax: 303-497-7262  
Email: paul.j.schultz@noaa.gov |
| MDSS Lab Lead Programmatic Issues and Questions | Bill Mahoney | NCAR  
3450 Mitchell Lane  
Boulder CO 80301  
Ph: 303-497-8426  
Fax: 303-497-8401  
Cell: 303-817-7975  
Email: mahoney@ucar.edu |
| Leader, Road Weather Management Program FHWA | Paul Pisano | FHWA  
HOTO-1 Room 3408  
400 Seventh St SW  
Washington, D.C. 20590  
Ph: 202-366-1301  
Email: paul.pisano@fhwa.dot.gov |
| MDSS Project COTR | Rudy Persaud | FHWA/HRDO  
Turner Fairbanks Research Center  
6300 Georgetown Pike  
McLean, VA 22101  
Ph: 202-493-3391  
Email: rudy.persaud@fhwa.dot.gov |
| MDSS Program Support for the FHWA | Andy Stern | Mitretek  
3150 Fairview Park Drive South  
MS-530  
Falls Church, VA 22042  
Ph: 703-610-1754  
Email: astern@mitretek.org |
The primary points of contact for the Iowa DOT staff that participated in the 2004 winter field demonstration are provided below.

<table>
<thead>
<tr>
<th>Name</th>
<th>Agency</th>
<th>Address</th>
<th>Phone</th>
<th>Fax</th>
<th>E-mail</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dennis Burkheimer</td>
<td>Iowa DOT, Winter Operations Administrator</td>
<td>800 Lincoln Way, Ames, Iowa 50010</td>
<td>515-239-1355</td>
<td>515-239-1005</td>
<td><a href="mailto:dennis.burkheimer@dot.state.ia.us">dennis.burkheimer@dot.state.ia.us</a></td>
</tr>
<tr>
<td>Richard Hedlund</td>
<td>Iowa DOT, Supervisor, Des Moines West Garage</td>
<td>12493 University Ave. Clive, IA 50325</td>
<td>515-986-5726</td>
<td>515-986-0736</td>
<td><a href="mailto:richard.hedlund@dot.state.ia.us">richard.hedlund@dot.state.ia.us</a></td>
</tr>
<tr>
<td>Edward Mahoney</td>
<td>Iowa DOT, Supervisor, Des Moines North Garage</td>
<td>1530 N.E. 53rd Ave. Des Moines, IA 50313</td>
<td>515-265-1614</td>
<td>515-265-4122</td>
<td><a href="mailto:edward.mahoney@dot.state.ia.us">edward.mahoney@dot.state.ia.us</a></td>
</tr>
<tr>
<td>Gary McDaniel</td>
<td>Iowa DOT, DSM North Garage Office, Asst.</td>
<td>1530 N.E. 53rd Ave. Des Moines, IA 50313</td>
<td>515-265-1614</td>
<td>515-265-4122</td>
<td><a href="mailto:gary.mcdaniel@dot.state.ia.us">gary.mcdaniel@dot.state.ia.us</a></td>
</tr>
<tr>
<td>Claude Frazier III</td>
<td>Iowa DOT, Des Moines West Garage Office Assist.</td>
<td>12493 University Ave. Clive, IA 50325</td>
<td>515-986-5726</td>
<td>515-986-0736</td>
<td><a href="mailto:claudie.frazieriii@dot.state.ia.us">claudie.frazieriii@dot.state.ia.us</a></td>
</tr>
<tr>
<td>Paul Durham</td>
<td>Iowa DOT, Supervisor, Ames Garage</td>
<td>U.S. 30 East Ames, IA 50010</td>
<td>515-232-8226</td>
<td>515-232-8227</td>
<td><a href="mailto:paul.durham@dot.state.ia.us">paul.durham@dot.state.ia.us</a></td>
</tr>
<tr>
<td>Jim Van Sickle</td>
<td>Iowa DOT, Garage Office Asst., Ames Garage</td>
<td>U.S. 30 East Ames, IA 50010</td>
<td>515-232-8226</td>
<td>515-232-8227</td>
<td><a href="mailto:jim.vansickle@dot.state.ia.us">jim.vansickle@dot.state.ia.us</a></td>
</tr>
<tr>
<td>Jim Dowd</td>
<td>Iowa DOT, MDSS HQ Liaison</td>
<td>800 Lincoln Way, Ames, Iowa 50010</td>
<td>515-239-1724</td>
<td>515-239-1005</td>
<td><a href="mailto:jim.dowd@dot.state.ia.us">jim.dowd@dot.state.ia.us</a></td>
</tr>
</tbody>
</table>
The primary points of contact for the CTRE staff that participated in the 2004 winter field demonstration are provided below.

<table>
<thead>
<tr>
<th>Name</th>
<th>Agency</th>
<th>Address</th>
<th>Phone</th>
<th>Fax</th>
<th>E-mail</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dennis Kroeger</td>
<td>CTRE</td>
<td>ISU Research Park, 2901 S. Loop Dr., Suite 3100, Ames, IA 50010-8632</td>
<td>515-296-0910</td>
<td>515-294-0467</td>
<td><a href="mailto:kroeger@iastate.edu">kroeger@iastate.edu</a></td>
</tr>
<tr>
<td>Jill Mascarello</td>
<td>CTRE</td>
<td>ISU Research Park, 2901 S. Loop Dr., Suite 3100, Ames, IA 50010-8632</td>
<td>515-296-0910</td>
<td>515-294-0467</td>
<td><a href="mailto:jrmascar@iastate.edu">jrmascar@iastate.edu</a></td>
</tr>
</tbody>
</table>
APPENDIX B

MDSS Field Demonstration Event Summary

*Winter weather cases are highlighted*

<table>
<thead>
<tr>
<th>Demo Day</th>
<th>Date</th>
<th>Weather</th>
<th>System Notes</th>
<th>System Upgrades, Fixes and Refinements</th>
<th>Lab Member in Iowa</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>29 Dec 2003</td>
<td>No significant Weather</td>
<td>Demonstration began</td>
<td>None</td>
<td>None</td>
</tr>
<tr>
<td>2</td>
<td>30 Dec</td>
<td>No significant Weather</td>
<td></td>
<td>None</td>
<td>None</td>
</tr>
<tr>
<td>3</td>
<td>31 Dec</td>
<td>No significant Weather</td>
<td></td>
<td>None</td>
<td>None</td>
</tr>
<tr>
<td>4</td>
<td>1 Jan 2004</td>
<td>No significant Weather</td>
<td></td>
<td>None</td>
<td>None</td>
</tr>
<tr>
<td>5</td>
<td>2 Jan</td>
<td>No significant Weather</td>
<td></td>
<td>None</td>
<td>None</td>
</tr>
<tr>
<td>6</td>
<td>3 Jan</td>
<td>Approaching event</td>
<td></td>
<td>None</td>
<td>None</td>
</tr>
<tr>
<td>7</td>
<td>4 Jan</td>
<td>Cold (teens), snow event</td>
<td>MDSS started the event several hrs too early. Highly variable snowfall totals across demo routes.</td>
<td>None</td>
<td>None</td>
</tr>
<tr>
<td>8</td>
<td>5 Jan</td>
<td>No significant Weather</td>
<td>Display: Corrected snow total label on event summary page and brine label on history page.</td>
<td>Robert Hallowell</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>6 Jan</td>
<td>No significant weather</td>
<td>RCTM: Installed temporary fix to short wave radiation field by using only MM5 radiation data starting with 3:15 pm update.</td>
<td>Robert Hallowell</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>7 Jan</td>
<td>No significant weather</td>
<td>Display: Added blowing snow button to replace dew point selection on radio buttons.</td>
<td>Robert Hallowell</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>8 Jan</td>
<td>Light snow began at ~4 pm CST. Air temperatures in mid twenties. Based on the 6 pm CST update, 100 lb treatments were recommended at 7 pm CST for a small number of Ames routes. Some Ames sites got 0.4 inches of snow.</td>
<td>Lost FSL model data starting at 6UTC to 17UTC. This may have impacted the ability of the MDSS to fully capture the light snow event. MDSS Missed Event</td>
<td>Robert Hallowell</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td></td>
<td>No significant weather</td>
<td></td>
<td></td>
<td>Robert Hallowell</td>
</tr>
<tr>
<td>Date</td>
<td>Day</td>
<td>Weather Events</td>
<td>Comments</td>
<td></td>
<td></td>
</tr>
<tr>
<td>------</td>
<td>-----</td>
<td>----------------</td>
<td>----------</td>
<td></td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>9 Jan</td>
<td>No significant weather</td>
<td>Gary Phetteplace</td>
<td></td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>10 Jan</td>
<td>No significant weather</td>
<td>Gary Phetteplace</td>
<td></td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>11 Jan</td>
<td>No significant weather</td>
<td>Gary Phetteplace</td>
<td></td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>12 Jan</td>
<td>No significant weather</td>
<td>Gary Phetteplace</td>
<td></td>
<td></td>
</tr>
<tr>
<td>17</td>
<td>13 Jan</td>
<td>No significant weather</td>
<td>Gary Phetteplace</td>
<td></td>
<td></td>
</tr>
<tr>
<td>18</td>
<td>14 Jan</td>
<td>No significant weather</td>
<td>Gary Phetteplace</td>
<td></td>
<td></td>
</tr>
<tr>
<td>19</td>
<td>15 Jan</td>
<td>No significant weather</td>
<td>Gary Phetteplace</td>
<td></td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>16 Jan</td>
<td>Rain event moving in with a slight period of freezing rain for NE Iowa. Chance of black ice conditions after sunset.</td>
<td>Gary Phetteplace</td>
<td></td>
<td></td>
</tr>
<tr>
<td>21</td>
<td>17 Jan</td>
<td>No significant weather</td>
<td>Gary Phetteplace</td>
<td></td>
<td></td>
</tr>
<tr>
<td>22</td>
<td>18 Jan</td>
<td>No significant weather</td>
<td>No one</td>
<td></td>
<td></td>
</tr>
<tr>
<td>23</td>
<td>19 Jan</td>
<td>No significant weather</td>
<td>Bill Myers</td>
<td></td>
<td></td>
</tr>
<tr>
<td>24</td>
<td>20 Jan</td>
<td>Very light snow mid morning for brief period. Air temperatures in low 20s, road temps in mid 20s.</td>
<td>Bill Myers</td>
<td></td>
<td></td>
</tr>
<tr>
<td>25</td>
<td>21 Jan</td>
<td>No significant weather</td>
<td>Bill Myers</td>
<td></td>
<td></td>
</tr>
<tr>
<td>26</td>
<td>22 Jan</td>
<td>Light event predicted in the evening after 10 pm mainly east of the routes</td>
<td>Bill Myers</td>
<td></td>
<td></td>
</tr>
<tr>
<td>27</td>
<td>23 Jan</td>
<td>No significant weather</td>
<td>Bill Myers</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

200-300 lb treatments recommended early due to wetness with road temperatures predicted to fall to 33-35F and air temperatures at 32F. Ames garage did treat this event.

MDSS not showing the light snow flurries. No models showing flurries either. Very light snow blowing across roads. Treatments were not required since snow totals minimal.

Insolation field (short wave) from WRF now corrected by FSL and the MDSS is now blending based on a subjective analysis of skill.

Display: Now, the number of significant digits shown depends on range of values over 48 hr period.

Event Trigger: The precipitation rate threshold for declaring an event was changed from 0.1 mm/hr to 0.05 mm/hr to be more sensitive to light.
<table>
<thead>
<tr>
<th>Date</th>
<th>Day</th>
<th>Weather Event</th>
<th>Notes</th>
<th>Author</th>
</tr>
</thead>
<tbody>
<tr>
<td>28</td>
<td>24 Jan</td>
<td>No significant weather</td>
<td></td>
<td>Bill Myers</td>
</tr>
<tr>
<td>29</td>
<td>25 Jan</td>
<td>Weather event approaching from southwest and west. Snowfall of 1-3 inches predicted across routes. Snow start time approximately 01:00 on 26&lt;sup&gt;th&lt;/sup&gt;.</td>
<td></td>
<td>Brent Shaw</td>
</tr>
<tr>
<td>30</td>
<td>26 Jan</td>
<td>Snow event. Snow (4-5 inches) falling over routes for long period (~12 hrs). Road temperatures cold and treatments were recommended.</td>
<td>Chemical treatments and plowing recommended. Some actual treatments were entered.</td>
<td>Brent Shaw</td>
</tr>
<tr>
<td>31</td>
<td>27 Jan</td>
<td>Clear and cold</td>
<td>Insolation field (short wave) from WRF seems to be underestimating insolation on clear days. Changed weight blend to be 75% MM5 and 25% WRF.</td>
<td>Brent Shaw</td>
</tr>
<tr>
<td>32</td>
<td>28 Jan</td>
<td>Cloudy with light snow north and east of Ames routes, but not over the Ames routes</td>
<td>Lost FSL model data after 05Z due to H/W problem</td>
<td>Brent Shaw</td>
</tr>
</tbody>
</table>
| 33    | 29 Jan| Light snow early in the morning. Not picked up by MDSS (sans FSL models). Treatments required around morning rush hour. Some sand/salt mix used. | FSL model data unavailable  
MDSS Missed Event | Brent Shaw  |
| 34    | 30 Jan| Light snow event of ~3 inches. Temperatures near zero.                         | FSL model data unavailable  
MDSS Missed Event | Brent Shaw  
Paul Pisano  |
| 35    | 31 Jan| Light snow in morning. Temperature -2F. Not clear if treatments needed.        | FSL model data unavailable  
MDSS Missed Event | Brent Shaw  |
| 36    | 1 Feb | Snow event. Temps in 20s. MDSS predicted 4-6 for Ames and 3-4 for DSM. Long event with light rates. | FSL model data unavailable  
Iowa DOT input several 'actual' treatments. Good | Darin Meyers |
<table>
<thead>
<tr>
<th>Date</th>
<th>Weather</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 Feb</td>
<td>Clear and cold.</td>
<td>FSL model data partially back with temporary reconfiguration</td>
</tr>
<tr>
<td>3 Feb</td>
<td>Snow event continues in early morning.</td>
<td>FSL model data unavailable</td>
</tr>
<tr>
<td>4 Feb</td>
<td>Cloudy and cold. Temps in the 20s. Storm approaching from southwest. Snow predicted to start around midnight. Snow started near midnight in DSM and later in Ames.</td>
<td>FSL model data back online...all systems normal.</td>
</tr>
<tr>
<td>5 Feb</td>
<td>Snow all day. MDSS showed 5” for Ames and 4” for DSM. Actuals were ~5 for Ames and 7” for DSM.</td>
<td>Actual treatments entered. Good agreement early in event.</td>
</tr>
<tr>
<td>6 Feb</td>
<td>Light snow fell in morning. Not shown on MDSS, but shown in FSL models.</td>
<td>MDSS missed light event even though models showed light snow.</td>
</tr>
<tr>
<td>7 Feb</td>
<td>No significant weather.</td>
<td>MDSS showed some very light snow early in the forecast cycle, but dropped snow as time progressed. Geonor snow gauge voltage regulator replaced. Data normal.</td>
</tr>
<tr>
<td>9 Feb</td>
<td>Scattered snow flurries for short time at some locations followed by wind causing some blowing snow. Snow accumulation of ~0.3 inches in some places. Plowing of drifts occurred for some northern routes.</td>
<td>RWFS: Added new code to fix the weights given to predicted precipitation (QPF). Also added code to remove all bias corrections on the final precipitation forecasts.</td>
</tr>
<tr>
<td>10 Feb</td>
<td>Clear. No significant weather. Weak front to move through in evening with NWS calling for chance of light scattered flurries.</td>
<td>MDSS not showing any precipitation from front. No models show precipitation in central Iowa.</td>
</tr>
<tr>
<td>11 Feb</td>
<td>Partly cloudy. No snow fell overnight, but winds did kick up and blow older snow around. Light snow flurries and blowing snow predicted by NWS.</td>
<td>At noon, MDSS not showing any accumulating precipitation today or tonight.</td>
</tr>
<tr>
<td>12 Feb</td>
<td>Brief period of snow flurries, not predicted by MDSS models. One</td>
<td>MDSS missed weak event (~0.3 inches)</td>
</tr>
<tr>
<td>Date</td>
<td>Weather</td>
<td>Notes</td>
</tr>
<tr>
<td>--------</td>
<td>--------------------------------</td>
<td>---------------------------------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>48</td>
<td>13 Feb</td>
<td>No significant weather</td>
</tr>
<tr>
<td>49</td>
<td>14 Feb</td>
<td>No significant weather</td>
</tr>
<tr>
<td></td>
<td></td>
<td><strong>Blowing Snow:</strong> Based on feedback from the mid-demo telecom, the blowing snow algorithm was refined to be more sensitive to wind and snow age.</td>
</tr>
<tr>
<td>50</td>
<td>15 Feb</td>
<td>No significant weather</td>
</tr>
<tr>
<td>51</td>
<td>16 Feb</td>
<td>Andy Stern &amp; Ray Murphy</td>
</tr>
<tr>
<td>52</td>
<td>17 Feb</td>
<td>Foggy in the morning followed by partly cloudy skies. A very brief flurry was reported at Ames. No action required.</td>
</tr>
<tr>
<td></td>
<td></td>
<td><strong>Insolation:</strong> WRF model revision to remove microphysical species from grid boxes with low concentrations. This improved the WRF insolation values on clear days.</td>
</tr>
<tr>
<td>53</td>
<td>18 Feb</td>
<td>Clear and mild (temps in mid 30s to low 40s). Rain even predicted by MDSS starting near midnight on the 20th.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Road temperatures well above freezing during daytime.</td>
</tr>
<tr>
<td>54</td>
<td>19 Feb</td>
<td>Cloudy. Storm approaching from southwest. Rain predicted to start late in the evening then change to snow at sun rise on the 20th. About 2-3 inches predicted for Ames and 1 inch for DSM.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>MDSS shows rain to snow case. Treatments recommended for rain and cold roads, then for snow.</td>
</tr>
<tr>
<td>55</td>
<td>20 Feb</td>
<td>Rain to light snow event. Rain to begin near midnight and briefly change to snow near dawn, then to rain again.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>MDSS had rain start well predicted. Late evening (19th) updates downplayed snow accum. Meso models did well with type. NWS models predicted too much snow the day before.</td>
</tr>
<tr>
<td>56</td>
<td>21 Feb</td>
<td>No significant Weather</td>
</tr>
<tr>
<td>57</td>
<td>22 Feb</td>
<td>Rain showers in morning through early afternoon in DSM. No snow in DSM.</td>
</tr>
<tr>
<td></td>
<td></td>
<td><strong>MDSS lost FSL models</strong> from 11-22Z (inclusive). The first forecast with the restored data would have been the 9 pm update.</td>
</tr>
</tbody>
</table>


<table>
<thead>
<tr>
<th>Date</th>
<th>Day</th>
<th>Weather Conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>23 Feb</td>
<td>58</td>
<td>Low clouds. Temps near 35F. Road temps near 40F.</td>
</tr>
<tr>
<td>24 Feb</td>
<td>59</td>
<td>Low clouds. Temps near 37F. Road temps in 40s.</td>
</tr>
<tr>
<td>25 Feb</td>
<td>60</td>
<td>Clear and mild. No significant weather.</td>
</tr>
<tr>
<td>26 Feb</td>
<td>61</td>
<td>Clear and mild. No significant weather.</td>
</tr>
<tr>
<td>27 Feb</td>
<td>62</td>
<td>Mild. No significant weather.</td>
</tr>
<tr>
<td>28 Feb</td>
<td>63</td>
<td>Mild. No significant weather.</td>
</tr>
<tr>
<td>29 Feb</td>
<td>64</td>
<td>Cloudy and mild. No significant weather. Missed some FSL model runs.</td>
</tr>
<tr>
<td>1 March</td>
<td>65</td>
<td>Rain showers developing during day. Mild, temps in mid 40s to low 50s.</td>
</tr>
<tr>
<td>2 March</td>
<td>66</td>
<td>Cloudy and cold. Temps in mid to upper 30s. Lost FSL data from 13-18Z due to failed NCAR disk.</td>
</tr>
<tr>
<td>3 March</td>
<td>67</td>
<td>Cloudy and mild. Air temperatures in 40s. Rain and some snow showers becoming all rain by mid day. Road temps in mid 40s. Rain with period of mixed snow verified. NWS servers down in Washington. National data feed lost since 00z runs. Also, 04-08Z runs of FSL models lost due to FSL problem. NWS servers back up for 6 pm MDSS update.</td>
</tr>
<tr>
<td>4 March</td>
<td>68</td>
<td>Cloudy. Steady rain period after mid afternoon. Air temps in low 40s. Road temps in mid 40s. Rain overnight also.</td>
</tr>
<tr>
<td>5 March</td>
<td>69</td>
<td>Cold rain fell overnight. About 1 inch was recorded at the Ames site. Some rain/snow fell north of MDSS routes. NWS servers down in Washington. National data feed lost since 00z runs. Also, 04-08Z runs of FSL models lost due to FSL problem. NWS servers back up for 6 pm MDSS update.</td>
</tr>
<tr>
<td>6 March</td>
<td>70</td>
<td>Cool. No significant weather.</td>
</tr>
<tr>
<td>7 March</td>
<td>71</td>
<td>Cool. No significant weather.</td>
</tr>
<tr>
<td>8 March</td>
<td>72</td>
<td>Cool and partly cloudy. No significant weather. Temps in 50s. Road Temps to hit 60s.</td>
</tr>
<tr>
<td>9 March</td>
<td>73</td>
<td>Mild. No Significant Weather</td>
</tr>
<tr>
<td>10 Mar</td>
<td>74</td>
<td>Mostly cloudy. Temps in 50s. Front may result in a few light isolated rain showers.</td>
</tr>
<tr>
<td>11 Mar</td>
<td>75</td>
<td>Partly cloudy and cold. Front passage resulted in isolated snow flurries, but no accumulation.</td>
</tr>
<tr>
<td>12 Mar</td>
<td>76</td>
<td>Clear and mild.</td>
</tr>
<tr>
<td>Date</td>
<td>Weather Conditions</td>
<td>Additional Notes</td>
</tr>
<tr>
<td>------</td>
<td>--------------------</td>
<td>------------------</td>
</tr>
<tr>
<td>13 Mar</td>
<td>Cloudy with some rain showers. Mild.</td>
<td></td>
</tr>
<tr>
<td>14 Mar</td>
<td>Partly cloudy. Mild in 40s. Snow event expected on 15th. NWS calling for 1-3 in Ames.</td>
<td>At 6 pm, MDSS calling for 7-8 inches of snow in Ames and ~9 inches in DSM. Snow to start at 6 am on the 15th.</td>
</tr>
<tr>
<td>15 Mar</td>
<td>Snow started at ~6 am. Air temps in low 30s. Road temps in low 30s. By 7 pm, Ames had ~7 inches and DSM ~ 9 inches.</td>
<td>MDSS did well on snow totals. Treatment recommendations given all day – both plowing and chemicals. According to NWS: Ames – 10 inches DSM - 13.2 inches</td>
</tr>
<tr>
<td>16 Mar</td>
<td>Cold. Period of light snow. About 1 inch fell.</td>
<td>MDSS predicted this event pretty well, both timing and amount.</td>
</tr>
<tr>
<td>17 Mar</td>
<td>Partly Cloudy. Temps in upper 30s to low 40s.</td>
<td></td>
</tr>
<tr>
<td>18 Mar</td>
<td>Cool. No significant weather.</td>
<td></td>
</tr>
<tr>
<td>19 Mar</td>
<td>No significant weather.</td>
<td></td>
</tr>
<tr>
<td>20 Mar</td>
<td>No significant weather.</td>
<td></td>
</tr>
<tr>
<td>21 Mar</td>
<td>No significant weather.</td>
<td></td>
</tr>
<tr>
<td>22 Mar</td>
<td>No significant weather.</td>
<td></td>
</tr>
<tr>
<td>23 Mar</td>
<td>No significant weather.</td>
<td></td>
</tr>
<tr>
<td>24 Mar</td>
<td>No significant weather.</td>
<td>Demonstration Ends</td>
</tr>
</tbody>
</table>
APPENDIX C

Ames Garage Weather Sensor Suite

Ames Garage Weather Site

Anemometer
Wind Vane

Pyranometer

Alter Shield

Geonor Snow Gauge

Electronics Box

Temp/RH (hidden from view)

Snow Depth Sensor (Ultrasonic)

Snow Depth Pad