Collaborative Research on Road Weather Observations and Predictions by Universities, State Departments of Transportation, and National Weather Service Forecast Offices

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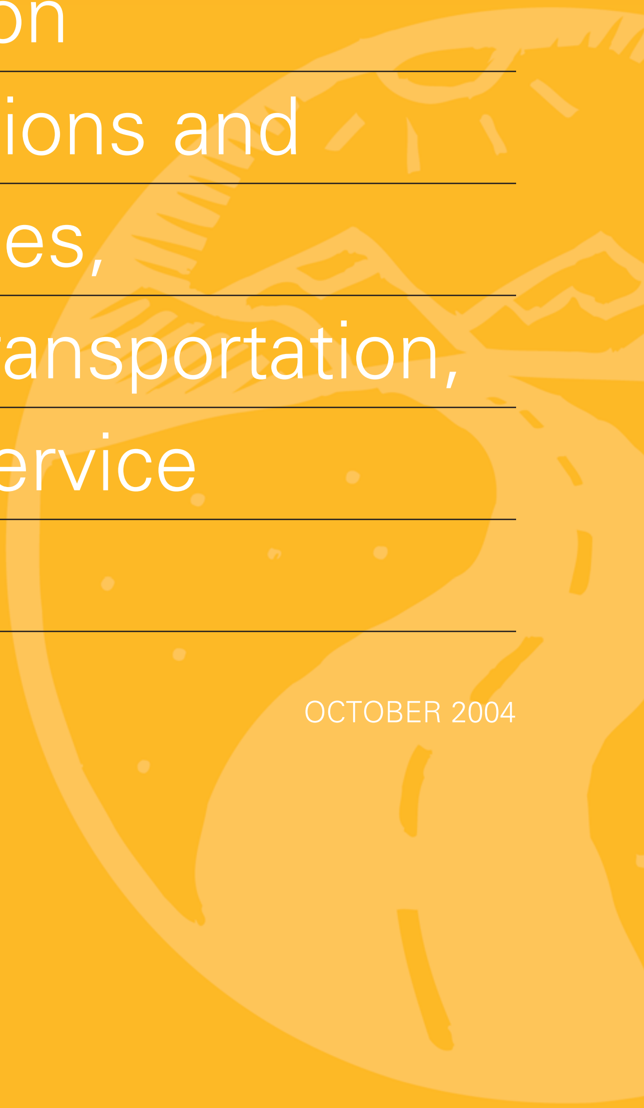

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Federal Highway Administration

Research, Development, and Technology
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FOREWORD

This report documents the results of five research projects to improve the sensing, predictions and use of weather-related road conditions in road maintenance and operations.

The primary purpose for these projects was to evaluate the use of weather observations and modeling systems to improve highway safety and to support effective decisions made by the various jurisdictions that manage the highway system. In particular, the research evaluated how environmental sensor station data, particularly Road Weather Information System (RWIS) data, could best be used for both road condition forecasting and weather forecasting. The collaborative efforts also included building better relations for training and sharing information between the meteorological and transportation agencies.

These projects are unique because they each involved collaborated partnerships between National Weather Service (NWS) Weather Forecast Offices (WFOs), State departments of transportation (DOTs), and universities. Lessons learned from these projects can help all State DOTs improve how they manage RWIS networks and achieve maximum utility from RWIS investments. Sufficient copies are being distributed to provide one copy to each Federal Highway Administration (FHWA) Resource Center, two copies to each FHWA Division, and one copy to each State highway agency. Direct distribution is being made to the FHWA Divisions Offices. Additional copies may be purchased from the National Technical Information Service (NTIS), 5285 Port Royal Road, Springfield, VA 22161.

Toni Wilbur
Director, Office of Operations
Research and Development

Notice

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This report is a part of a study for FHWA titled, "Collabortative research on road weather observation and predictions." FHWA Contracting Officer's Technical Representatives (COTRs) are Paul Pisano HOTO and Rudy Persaud HRDO.

16. Abstract
The Federal Highway Administration (FHWA) Road Weather Management program partnered with the National Weather Service (NWS) to sponsor five research projects through the Cooperative Program for Operational Meterology, Education, and Training (COMET). The goal was to create teams of personel from State departments of transportation (DOT), NWS Weather Forecast Offices (WFO), and universities to foster collaborative and productive relationships between meterological and transportation agencies. These teams were to use data from Road Weather Information Systems (RWIS) to improve the utilization of these data in both weather and transportation operations and to create new predictive algorithms for use in road maintenance activities. Such advances in road weather management ultimately will improve mobility on the roads, and DOT productively in operations.

17. Key Words
Mesonet, Artificial Neural Network, IceCast pavement model, Integrated Weather Data Network, MesoWest meso-meterological network

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		NOTE: volumes greater than 1000 L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
^{o}F	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	^{o}C
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact degrees)		
^{o}C	Celsius	1.8C+32	Fahrenheit	^{o}F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380.
(Revised March 2003)

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EXECUTIVE SUMMARY

From 2001 to 2003, the Road Weather Management Program of the Federal Highway Administration (FHWA) Office of Operations partnered with the National Weather Service (NWS) to sponsor five research projects to improve the sensing, prediction, and use of weather-related road conditions in road maintenance and operations. These projects are unique because they each involved collaborative partnerships between NWS Weather Forecast Offices (WFOs), State departments of transportation (DOTs), and universities. Participants and their project titles are listed in the table below:

Table 1. Program participants and projects.

Partners	Project Title
Pennsylvania State University, Pennsylvania Department of Transportation (PennDOT), and the State College, PA NWS WFO	"Developing an Interactive Mesonet for PennDOT"
Iowa State University, Iowa DOT, and the Des Moines, IA NWS WFO	"Improved Frost Forecasting through Artificial Neural Networks"
University of Nevada (Desert Research Institute), Nevada DOT, and the Reno, NV NWS WFO	"Use of Road Weather Information Systems in the Improvement of Transportation Operations in the Complex Terrain of Western Nevada"
State University of New York at Albany, New York State DOT (NYSDOT), and the Albany, NY NWS WFO	"The New York Integrated Weather Data Network"
University of Utah, Utah DOT, and the Salt Lake City, UT NWS WFO	"Applications of Local Data Assimilation in Complex Terrain"

The primary purpose for these projects was to evaluate the use of weather observations and modeling systems to improve highway safety and to support effective decisions made by the various jurisdictions that manage the highway system. In particular, the research evaluated how environmental sensor station data, particularly Road Weather Information System (RWIS) data, could best be used for both road condition forecasting and weather forecasting. The collaborative efforts also included building better relations for training and sharing information between the meteorological and transportation agencies.

The Cooperative Program for Operational Meteorology, Education and Training (COMET®), an organization funded primarily by the NWS, received project funding from the Road Weather Management Program. The awards, made in early 2001, were for 2-year projects and primarily supported university researchers, with matching efforts from local NWS WFOs and State DOTs.

COMET solicited proposals, conducted the review process, and managed the project contracts. This was the first time that the COMET Program had extended its usual university-

NWS collaborations to the transportation community, an important step in building institutional relations for further research and operations.

The project reports, written by the project participants, make up the main body of this report. Below is a summary of each project and its accomplishments.

PENNSYLVANIA STATE UNIVERSITY: “DEVELOPING AN INTERACTIVE MESONET FOR PENNDOT”

Both the NWS and FHWA are interested in evaluating use of RWIS data for road condition forecasting and broader weather forecasting. For example, the NWS is interested in creating mesoscale networks (mesonets) that include RWIS sites, while FHWA would like to establish guidelines that define the optimal density for a network of RWIS sites in different seasons and various locations. For both parties, the usefulness of RWIS observations depends on several factors including site considerations and data quality, which varies according to performance specifications for equipment and maintenance practices.

One of the main goals of this project was to construct a mesonet of hourly weather reporting sites across Pennsylvania. These sites include 32 Automated Surface Observing Systems (ASOS) and a few Automated Weather Observing Systems (AWOS), both operated by the Federal Aviation Administration (FAA), 82 RWIS operated by PennDOT, and 47 Commonwealth of Pennsylvania Air Monitoring System (COPAMS) sites maintained by the Pennsylvania Department of Environmental Protection (PADEP). In addition, the State’s approximately 200 hourly precipitation gauges of the Integrated Flood Observing and Warning Systems (I-FLOWS) are also being incorporated in the network. More than 300 daily observations will be available when the NWS’s cooperative weather stations (about 125 sites) submit their data on a daily basis, including their reports of maximum temperature, minimum temperature, and 24-hour precipitation.

The data from these sites are stored in a database and processed each hour for real-time information (http://pasc.met.psu.edu/MESONET) of weather-derived parameters and time series displays from each site. Streamlines are overlaid on a topographic map to help identify patterns over the complex terrain in the State.

Developing the mesonet was particularly challenging because PennDOT contracted with three different manufacturers to provide, install, and maintain the sensors in various regions of the State. The result is data in three different formats within this single network. In addition, ground-based network connections and limited server capacities posed a serious challenge to including the RWIS data in the mesonet, and irregular polling times added difficulty to developing an automated quality control system. Delays in reporting the observations also hampered production of real-time products that are useful in “nowcasting” hazardous weather and highway conditions. Another problem in managing the data flow resulted from lower reliability in RWIS data during the seasons when the DOT has a reduced need for the observations.

All the RWIS data were converted to network Common Data Form (netCDF), a machine-independent format for representing scientific data. Once decisions were made regarding how to handle the data collection issues, a quality control system was designed using the Oklahoma mesonet standards. Concerns about instrument siting and calibration still exist, which can add further errors to the quality control process. Once the data quality is assured, the plan is to make the observations available to all involved parties, including the PennDOT Technology Division and the District offices.

Another major goal of the project was to include near real-time RWIS and other mesonet data sets into the NWS Advanced Weather Interactive Processing System (AWIPS) data display and the Pennsylvania State Climate Office database. This initially required both management and quality control of the data feed. Parameters to collect from the different networks were determined. To be chosen, a parameter had to contribute to augmenting or improving general surface observations, climatology, forecast verification, modeling, or the welfare of the general public. Nineteen parameters met these criteria and are collected in the database.

An additional task arose when researchers found there was little or no station history—records of movement due to construction or other reasons—for the RWIS and COPAMS sites. Assimilating the data into NWS system and the State Climate database requires precise geospatial information that was not readily available from PennDOT. As a result, State Climate personnel visited each of the 82 sites with a global positioning system (GPS) device and digital camera and created comprehensive metadata files for all RWIS sites. Images of the station (and GPS records) are a relatively new but increasingly important part of station history and metadata.

Preparing and delivering 3 training sessions for more than 160 roadway weather managers was the last task in this project. The NWS Warning Coordination Meteorologist (WCM) taught the fundamentals of weather and products available from the NWS WFOs. The State climatologist (the principal investigator on this project) taught forecasting techniques using RWIS data and winter weather and conducted a desktop exercise for all participants. The training occurred during the week of October 7, 2002.

The following summarizes the findings of this project:

- The State of Pennsylvania has hundreds of observational systems that, if integrated, can provide a powerful tool for monitoring and forecasting road conditions and improving general weather forecasts.
- Integration is difficult because different manufacturers use different data formats. Similarly, there are instrument siting and maintenance issues related to data from various sources in various formats. Data need to be converted to a common format for the broadest possible usage.
- Communication problems also inhibit integration, including unreliable transmission via phone lines and polling procedures that delay data transmissions.
- Quality control (including having complete station metadata) must be addressed for the data to have maximum utility.
- Providing a good training program on weather forecasts and using weather data is important to road weather managers.

IOWA STATE UNIVERSITY: “IMPROVED FROST FORECASTING THROUGH ARTIFICIAL NEURAL NETWORKS”

Frost is one of the least predictable weather parameters requiring anti-icing or deicing treatment of road surfaces. It often occurs in localized regions under generally quiescent weather conditions. Ice deposition onto road surfaces can occur if road surface temperatures drop below the dewpoint temperature of the nearby air. A previous collaboration between the Iowa DOT and Iowa State University (ISU) produced a frost prediction model, which is currently being tested. Inputs required for the model include predictions of road surface temperature, air temperature, dewpoint temperature, and wind speeds. These predictions could come from raw or statistically post-processed numerical weather model output, such as Model Output Statistics (MOS) derived from the NWS Nested Grid Model (NGM). However, output from these weather models is typically limited to every 3 or 6 hours, and therefore is not available at the high temporal frequency required for good frost predictions. In addition, these models do not normally predict road temperatures. Statistical methods, such as artificial intelligence, can be used to overcome these problems.

Artificial Neural Networks (ANN) are one type of artificial intelligence technique, patterned loosely after the human brain. Different weightings are assigned to different relationships in a training set of data to create a system that can predict one variable based on a range of other variables. These techniques are potentially better than the sole use of forecast model data because the training technique should allow biases in the model data to be corrected. For instance, if the NGM model is always too cold in its forecasts of air temperature (compared to RWIS observations), the neural network will likely determine that the air temperature is going to be equal to the model prediction plus a small correction term.

This project used ANN data to develop a time series prediction system that could be coupled with the frost prediction model to improve roadway frost forecasting. NGM MOS data and RWIS data were collected for 3 years from 1996–98 and used to train and test the system. Results of the project indicated that in general, ANN-derived weather data compared better with RWIS observations than with the NGM-MOS forecasts alone. However, in some circumstances, the ANN predictions were only better than MOS for the first 6 to 9 hours of the prediction period. Nonetheless, the use of ANN data to predict roadway temperature, air temperature, dewpoint, and wind speed appears promising.

A second part of the study used the ANN data in the ISU frost deposition model; “yes” frost predicted and “no” frost predicted results were compared with observations of roadway frost. For the winters of 1996–98, the ANN-based predictions were not particularly good. The poor results may have been due in part to frost observations obtained by maintenance personnel looking out the windows of their vehicles on the way to work, perhaps not a very accurate method. Poor agreement was also attributed to ANN system’s physically impossible predictions of a dewpoint exceeding the air temperature.

In the winter of 2001–2002, ISU students closely monitored conditions on one bridge during the early morning hours, likely a more accurate verification technique. During this period, frost predictions using the ANN data were very accurate, nearly matching the forecasts made after the fact when RWIS data were fed into the frost deposition model. However, during the winter of 2002–2003 when students monitored three bridges, the performance was worse with relatively high false alarm rates and low probabilities of detection.

The third part of the project determined if data from the NWS and FAA observation systems, RWIS and AWOS/ASOS respectively, are comparable. The comparisons suggest that RWIS temperature readings have a high bias when wind speeds are light. The behavior is attributed to the fact that, unlike AWOS/ASOS sensors, RWIS temperature and dewpoint sensors are not aspirated. In addition, wind speed data from the RWIS stations was typically a few knots lower than the AWOS/ASOS sensors, probably due to siting differences. Other parameters (such as dewpoint) showed systematic differences that could be quantified and taken into account when using the data. A Web site was developed to allow direct comparisons between the different measuring systems in real time (http://mesonet.agron.iastate.edu/compare/). The NWS found the results particularly useful because data from these sensors have been combined into a mesonet (as part of another, earlier project), providing valuable information for monitoring conditions and validating forecasts.

The final task extended the ANN application to an NWS problem forecasting precipitation amounts during the warm season. As was the case with the ANN data for the frost predictions, results for this study were mixed, but generally suggest that ANN data can provide an improvement compared to model forecasts. Further work needs to be done in this area.

The conclusions of the principal investigators are as follows:

- ANN data used in the frost prediction model (as well as in precipitation forecasting) appears promising, but more testing and validation is needed. The ANN was initially trained on 3 years of data. Additional data collected since that time would likely improve forecast skill if the system were trained with the larger data record.
- Preliminary work from another project suggests that the use of weather parameters predicted by a mesoscale model such as Mesoscale Model 5 (MM5), may provide significant improvement, and further investigations might reveal whether ANN data trained on the mesoscale predictions provides the best results.
- Some calibration of data contained in the mesonet is probably necessary to account for differences in RWIS and AWOS/ASOS sensors and siting.
- Finding a project topic that benefits both the DOT and NWS partners equally is challenging. Both partners have a need for quality data, and both have mutually beneficial data sets. However, the NWS did not have a need for a frost prediction technique, so their participation in the project was more limited.

UNIVERSITY OF NEVADA (DESERT RESEARCH INSTITUTE): "USE OF ROAD WEATHER INFORMATION SYSTEMS IN THE IMPROVEMENT OF TRANSPORTATION OPERATIONS IN THE COMPLEX TERRAIN OF WESTERN NEVADA"

The complex terrain of western Nevada presents a challenge to both weather forecasters and transportation managers, particularly when winter snows cause road closures and delays. The economic impacts of winter storms can be significant. On a typical winter weekend, as many as 1.5 million people travel into the Sierra Nevada to Lake Tahoe and Reno, NV, bringing about $2 million into the economy. A winter storm warning by the NWS on a Thursday for a weekend in the Sierra Nevada can result in an estimated $800,000 decrease in potential revenue due to cancelled room reservations alone. Snow removal operations for road management and public safety are also costly. These impacts highlight the need for improved road-related forecasts that to date are hampered by limited weather observations and imperfect model guidance.

Predicting local weather features, such as high winds and heavy snow, is extremely difficult due to small-scale terrain features and hence large variations in weather over small distances. Forecasters and transportation managers need a dense network of weather observations to better "see" these small-scale features. Critical data is provided by additional State DOT weather stations to the NWS network and weather stations already available for forecasting.

The first task in this project was to develop programs to automatically access and download the data from Nevada Department of Transportation (NDOT) computers and to integrate and archive the data in the database of the Western Regional Climate Center at the Desert Research Institute (DRI). At the same time, NDOT was upgrading 11 mesonet sites and installing 5 new sites. A Web site on the DRI server was established to provide interactive graphical displays of the data once it was acquired (http://www.ndot.dri.edu). The site is still active, but some of the NDOT stations are not currently operational, transmission software in some have changed, and some stations simply do not transfer data to DRI.

A related task was to establish a data assimilation system to transfer data from NDOT to the NWS. The task was difficult due to slow models and frequent computer crashes at the beginning of the project. By the second year, better file transfer procedures were established, and faster computers were installed at both the NWS and NDOT. The collection of this data continues and has been expanded to other areas of the State outside of the local Reno, NV mesonet area. The collection of these additional sites was not part of the original scope of work for this project.

The second goal was to improve NWS operational forecasts through better model guidance and knowledge. The NWS is in the process of implementing a National Digital Forecast Database (NDFD) to give the NWS forecaster the ability to predict weather at spatial and temporal resolutions far greater than previously possible. The high resolution forecast model used by the Reno NWS WFO and the NDFD rely on a dense network of surface data, including the NDOT sites. Verification of high wind warnings and improvement to fire weather forecasts occurred as a direct result of having these data.

One of the main goals of this study was to establish a data assimilation system for the MM5 at DRI. The model was used both with and without the enhanced data set that included NDOT sites for two winter storm case studies. In the first case, the model successfully simulated a frontal system passing through Reno, NV, on March 8, 2002. One finding was that it is important to use an optimum set of data stations. However, each of the surface stations has micro location characteristics and generally is not representative for the larger area that needs to be captured by the model. Nonetheless, additional data from the NDOT stations significantly improved model results.

The second winter storm study looked at a storm that occurred in March of the next year. Again, the results indicated that the model runs that used assimilated NDOT data compared better with measurements for both temperature and wind speed when compared to model runs that did not include NDOT data.

From an NDOT perspective, improving weather forecasts is a benefit, but another important challenge is forecasting whether ice will form on roads. To evaluate how sensitive minimum pavement temperature forecasts are to meteorological inputs, DRI researchers tested NDOT's IceCast™ pavement model using the MM5 model results from the first case study as the baseline simulation. They then changed each of the input meteorological parameters by a certain value and ran the pavement model again for each case. These tests resulted in a large variation in the minimum pavement temperature, ranging from –7 to –12 °C. Researchers learned that predicted pavement minimum temperature appears to be mostly sensitive to air temperature changes and to the total cloud cover and precipitation. Inaccuracies in the air temperature of 1 and 2 °C cause a change in the minimum pavement temperature of more than 0.5 and 1 °C, respectively. Significant underestimation of precipitation can yield a change in the minimum pavement temperature of about 2 °C; inaccurate predictions of cloudiness can yield a change in the predicted minimum pavement temperature of more than 3 °C.

The last project goal—to create a travelers' forecast Web site as one source of all information on road and traffic conditions—was not realized. The researchers plan to continue to work with NDOT to achieve this goal.

The conclusions of the principal investigators can be summarized as follows:

- A Web site that provides interactive graphical and statistical displays is a useful tool after the complexities of handling data streams are resolved.
- Expanding the data available for NWS analyses and weather forecasts by including NDOT data in the mesonet database is valuable for a variety of operational forecasts.
- Model results improved in two cases that included NDOT data as part of the set used to initialize a mesoscale model that can better capture the small-scale weather features.
- Pavement model forecasts are highly sensitive to air temperature, precipitation, and cloud cover forecasts. Improving model predictions of these parameters (which is related to the previous bullet) should greatly help improve predictions of icy conditions on roads.

- Having additional upper air measurements would probably provide stronger guidance to the models, which could then improve both NWS mesoscale forecasts and NDOT pavement temperature forecasts.
- In addition to creating the travelers' forecast, another component that should be completed is to fully integrate the MM5 model with the pavement temperature model, creating a fully operational tool. Verification of model results should also be carried out.
- A quality assurance system that would continuously report the status of all NDOT stations in real or near-real time is needed.
- Future projects should ensure that NDOT collaborators (whose main priority is to work on direct NDOT operations) have dedicated time to accomplish projected objectives.

STATE UNIVERSITY OF NEW YORK AT ALBANY: "THE NEW YORK INTEGRATED WEATHER DATA NETWORK"

As was the case with the Nevada and Pennsylvania projects, the main objective of the State University of New York at Albany (SUNYA) project was to create a mesonet by integrating the data from the New York State DOT (NYSDOT) RWIS systems with other data sources. Other project goals included:

Assessing the quality of the RWIS data.

- Making the data available to the NWS to improve local forecasting skill.
- Archiving the data for climatological analyses.
- Assisting NYSDOT in evaluating various automatic weather stations for secondary road monitoring sites.
- Evaluating how local obstacles can change the near-road environment.
- Testing a road surface forecasting model.

Good progress was made on some of the objectives, but others had to be abandoned, partly because of the loss of personnel at NYSDOT and partly because of difficulties that arose in dealing with the RWIS data. These difficulties included delays in the installation of new RWIS sites and problems downloading data from sites that use proprietary software. As a result, the major focus of the project shifted to an effort to download data from a few sample NYSDOT RWIS sites and to audit data quality from the RWIS sites by comparing them to nearby NWS sites.

Data quality for the RWIS stations proved to be a large problem. For example, data from one station indicated an apparent change in calibration and resolution in the wind sensor occurred midway through 2002, but the contractor indicated that there was no reason to question the data. Nonetheless, the data appears to be suspect, at least for part of the year. These kinds of issues still need to be resolved.

The program to establish a network of secondary road monitoring sites was delayed indefinitely. SUNYA tested one system, but this general objective was not achievable during the span of this project.

SUNYA completed a one-dimensional energy balance model for curing concrete bridge decks (the SUNY/Local Atmosphere Bridge Simulation (SLABS) model), which they intended to adapt to predict the state of road surfaces. However, for this task and the one to evaluate local obstacles, a data archive from the stations was needed. Because the data acquisition step required more time than expected, not enough time was available to develop a database for a large number of stations.

UNIVERSITY OF UTAH: "APPLICATIONS OF LOCAL DATA ASSIMILATION IN COMPLEX TERRAIN"

Three of the projects described above sought to build mesonets. The University of Utah project could be characterized as constructing a "mega-mesonetwork." The efforts funded by FHWA built on a project that began several years ago when the University of Utah began developing one of the first mesonets in the country. At the time this project began, the mesonet (called MesoWest) accessed data from approximately 2500 observing stations in the western United States. In 2001, most of the RWIS stations in the database were located in Montana, with a few along major interstates in Wyoming, Utah, and the Lake Tahoe area of California and Nevada. Over the course of this project, the network expanded considerably to more than 6000 stations with many sites (including RWIS stations) added from Colorado, Idaho, Oregon, and Washington.

Another important addition to the MesoWest database is weather information at 264 locations along the major Union Pacific rail corridors in the West. Most of the stations report temperature only; however, wind conditions are reported at many critical locations.

A specialized Web interface to the MesoWest database (www.met.utah.edu/mesowest) was developed and maintained for use by Utah Department of Transportation (UDOT) personnel. This interface has been used extensively for winter road maintenance as well as road construction and summer paving projects.

High resolution forecast models used in complex terrain will resolve the weather in adjacent valleys independently. However, observation corrections to the initial background field obtained from a model can bleed laterally through the terrain. To deal with this problem, which has affected the suitability of the analyses along some transportation corridors, a graduate student developed anisotropic weighting functions for the Advanced Regional Prediction System (ARPS) Data Analysis System (ADAS), a data assimilation system. These anisotropic weights are critical to resolving a systematic source of error in the analyses where weather observations in one valley affect the analysis in adjacent valleys.

An additional benefit of the relationships between the NWS, UDOT, and University of Utah was that all three groups worked closely to provide weather and road state information, as well as forecasts, to Olympic organizers, public safety personnel, and the public for the 2002 Winter Olympics and Paralympics. These efforts were judged to be highly successful by representatives of many different organizations involved in the Olympics.

DEVELOPING AN INTERACTIVE MESONET FOR PENNDOT

University: Pennsylvania State University (PSU)
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NWS WFO: State College, PA
Name of Primary NWS Collaborator: David Ondrejik
DOT Office: Pennsylvania Department of Transportation (PennDOT)
Name of Primary DOT Collaborators: Alfred Uzowke, and formerly Douglas Schmitt
Cooperative Project, UCAR Award No. S01-32792

SUMMARY OF ORIGINAL PROPOSED SCOPE OF WORK

The original proposal called for collaboration between PennDOT, the NWS WFO for Central Pennsylvania, and the State Climate Office at Pennsylvania State University. The plan had several components, including assuring the quality of and validating the Roadway Weather Information System (RWIS) network, training PennDOT roadway weather managers, incorporating the RWIS data into both NWS forecasts and warnings, developing a mesoscale climatology, and testing the utility of RWIS data to enhance initial conditions for regional mesoscale models. Many of these goals were met. A few unplanned projects developed, specifically the design of a metadata system for the fledgling mesonet. The final goal of the project was not addressed for several reasons that will be discussed in the recommendation section.

WORK ACCOMPLISHED

The final project had four focal points. The first was to integrate the various data sets into a cohesive mesonet and to create methods to easily retrieve archived mesonet data. The second was to incorporate quality controlled RWIS data into the local NWS forecasts and the State Climate Office database. In the process of tackling the first two tasks, it became clear that the RWIS and COPAMS sites lacked important station information, and so a third task was added to create this station metadata. The NWS and State Climate Office staff trained PennDOT roadway weather managers in the final task. Each of the main components of the project is described in more detail below.

Mesonet Observations System

One of the main accomplishments of this project was the construction of a network of hourly weather reporting sites across Pennsylvania. These sites include:

- Thirty-two ASOS operated by the FAA.
- A handful of new AWOS operated and maintained by the FAA and the Aviation Division of PennDOT.
- Eighty-two RWIS operated by PennDOT.
- Forty-seven COPAMS sites, maintained by PADEP.

All reporting stations measure hourly temperature, wind direction, and wind speed. In addition, the Climate Office is incorporating the State's approximately 200 hourly precipitation gauges of the Integrated Flood Observing and Warning System (I-FLOWS) in the network (see figure 1). When the NWS cooperative weather stations' (about 125 sites) daily submissions are included with their reports of maximum temperature, minimum temperature, and 24-hour precipitation, the network will provide more than 300 daily observations for the Commonwealth of Pennsylvania.

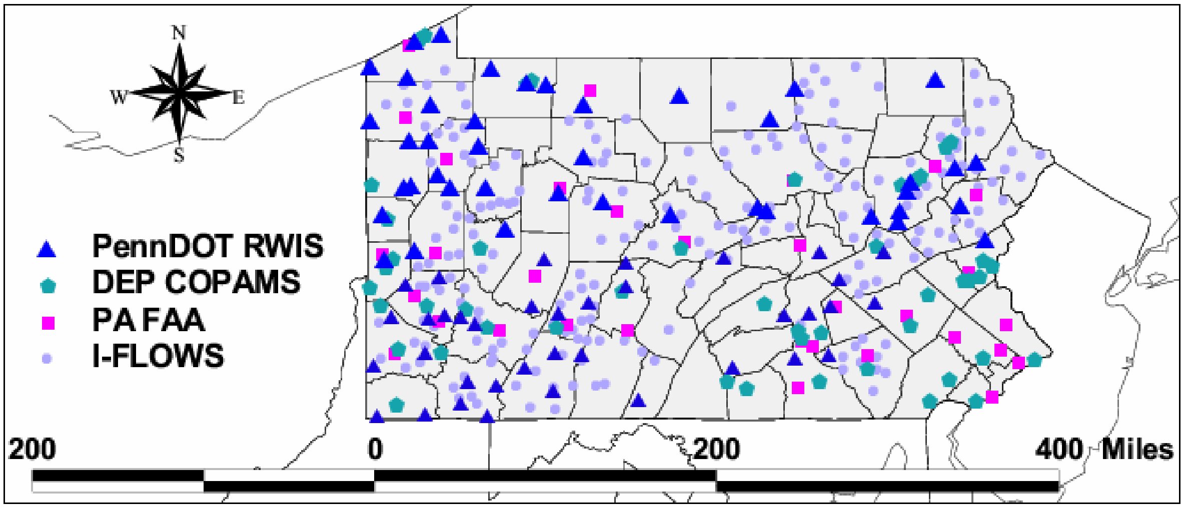

Figure 1. Stations included in the Pennsylvania mesonet.

These reports are being stored in a MySQL database and are processed each hour for real-time display (http://pasc.met.psu.edu/MESONET) of weather-derived parameters, including wind streamlines, temperatures (see figure 2), dewpoint contours, and time series displays from each site. The streamlines are overlaid on a topographic map to discern channeling and air motions over the complex mountain-valley system of the State.

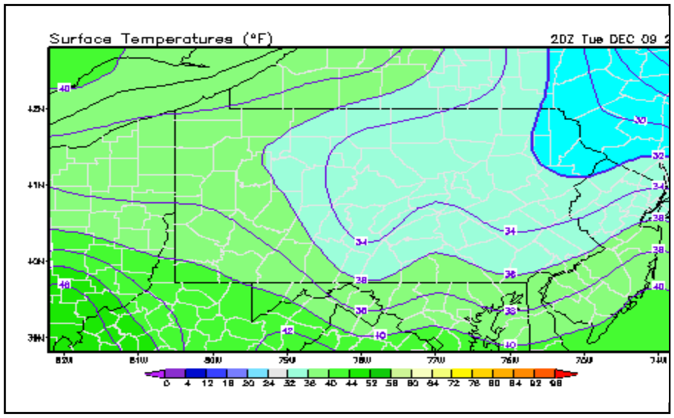

Figure 2. Contours of isotherms (temperature lines).

Assembling data from a range of agencies to serve the function of a meteorological mesonet presented challenges in handling differing data formats that were a function of different priorities for the meteorological parameters measured within each individual network. These factors are related to the primary purpose of the stations within each individual network.

Another complicating factor was the fact that, in an effort to maximize the benefit of competition in the RWIS market, PennDOT selected three different manufacturers to provide, install, and maintain 82 RWIS stations along various highways across the State. All three types serve the primary objective to monitor roadway surface conditions and secondarily to monitor atmospheric conditions. Most of the sensors that are used on an ASOS are also present on the RWIS stations. However, variables vital to a surface weather observation mesonet, such as air pressure and rainfall accumulation, are not available from these 82 hourly stations. Nonetheless, the absence of these two parameters is compensated by an abundance of roadway surface and subsurface parameters, such as temperature, condition of ground (snow cover, icy, wet), and average speed of vehicles. The data can be applied to conduct research on the effects of adverse weather on public transportation. This large volume of information obtained from each RWIS observation (and the proprietary nature of the output by each RWIS manufacturer), such as number of highway lanes at each station, units of visibility, wind variables, and methods of reporting weather phenomena, lead to three varying formats of data output within this single network.

Ground-based network connections and limited server capacities also posed a serious challenge for including the RWIS data into the mesonet. In addition, irregular polling times complicated the development of an automated quality control system.

Incorporation of Data into NWS Forecast Office System and State Climate Office Database

Another aim of the project was the inclusion of near real-time RWIS and other mesonet data sets into the NWS AWIPS[1] data display and the Pennsylvania State Climate Office database. This initially required both management and quality control of the data feed. After deciphering the unique formats from each data source, Perl scripts were written to transfer the data from a flat file into a MySQL relational database on an hourly and even half-hourly basis. Most recent efforts have focused on access to RWIS five-minute data streams.

One issue that arose was determining which parameters to collect from the different networks. First, it was necessary to confirm the routine collection of the parameter by all of the instruments within a network. This allowed for an adequate spatial representation of the data across Pennsylvania and provided enough of a database to perform quality control using neighboring sites within the network. For a parameter to be chosen, it needed to augment general surface observations, climatology, forecast verification, modeling, or the welfare of the general public. Nineteen parameters met these criteria (see table 2) and are collected in the database as frequently as available to the State Climate Office.

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[1] AWIPS: An integrated suite of automated data-processing equipment that supports complex analysis, interactive processing, display of hydrometeorological data, and the rapid dissemination of warnings and forecasts in a highly reliable manner.

Table 2. Parameters collected on an hourly basis.

Weather	Wind Direction	Accumulated Precipitation	Roadway Surface Temperature
Temperature	Wind speed	Precipitation rate	Roadway surface conditions
Dewpoint	Wind gust	Snow depth	Roadway average speed
Relative humidity	Ceiling	Cloud cover	Subgrade (at 17 inches or 43.2 centimeter- depth) temperature
Air pressure	Visibility	Solar radiation	

Data flow quality proved more challenging than expected. The primary difficulty was the means of communication of the data from the sensor to a central location. The observations taken at the COPAMS and RWIS sites use external modems to communicate with their respective control centers, leading to delays in the observations. COPAMS reports arrive 90 minutes after the observation is taken, and the RWIS stations average a 30-minute to 1-hour delay depending on the time the call was made. This hampers production of real-time products that are useful in "nowcasting" hazardous weather and highway conditions. It also prevents many reports from being included in the AWIPS Statewide surface analysis fields. Another drawback to using modems and traditional telephone lines is their lack of reliability in hazardous conditions when the observations are in highest demand.

Yet another challenge of the RWIS network was that each of the three manufacturers transmits their data through a different method to a central computer at PennDOT. Adding this link between the observing station and the State Climate Office database increases the risk of communication failure. Figure 3 shows the large difference in the number of observations taken by each RWIS station during a late autumn month. More than 750 observations indicate approximately one report per hour during that 30-day period. The uncertainty of the frequency and timing of RWIS observations curtailed attempts to refine mesoscale model initial conditions based on RWIS reports.

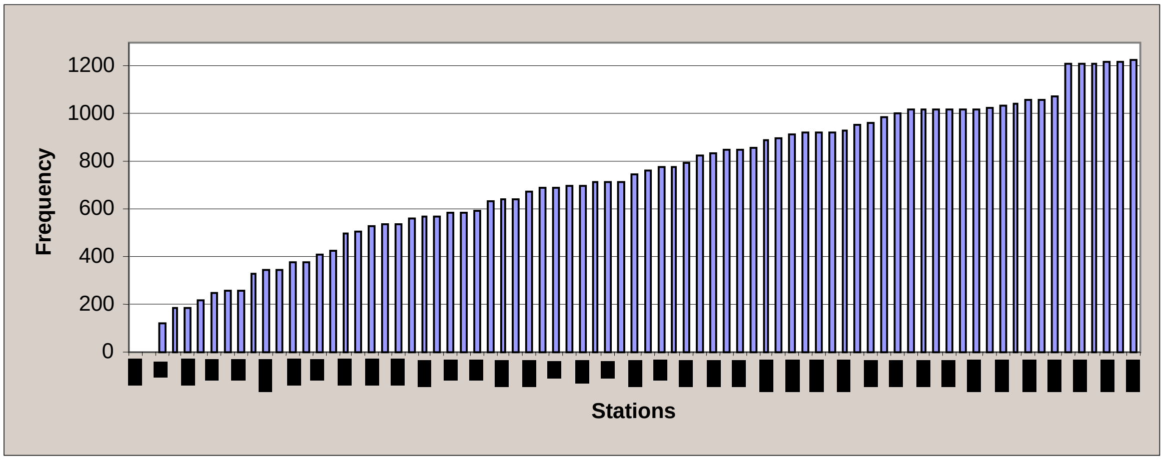
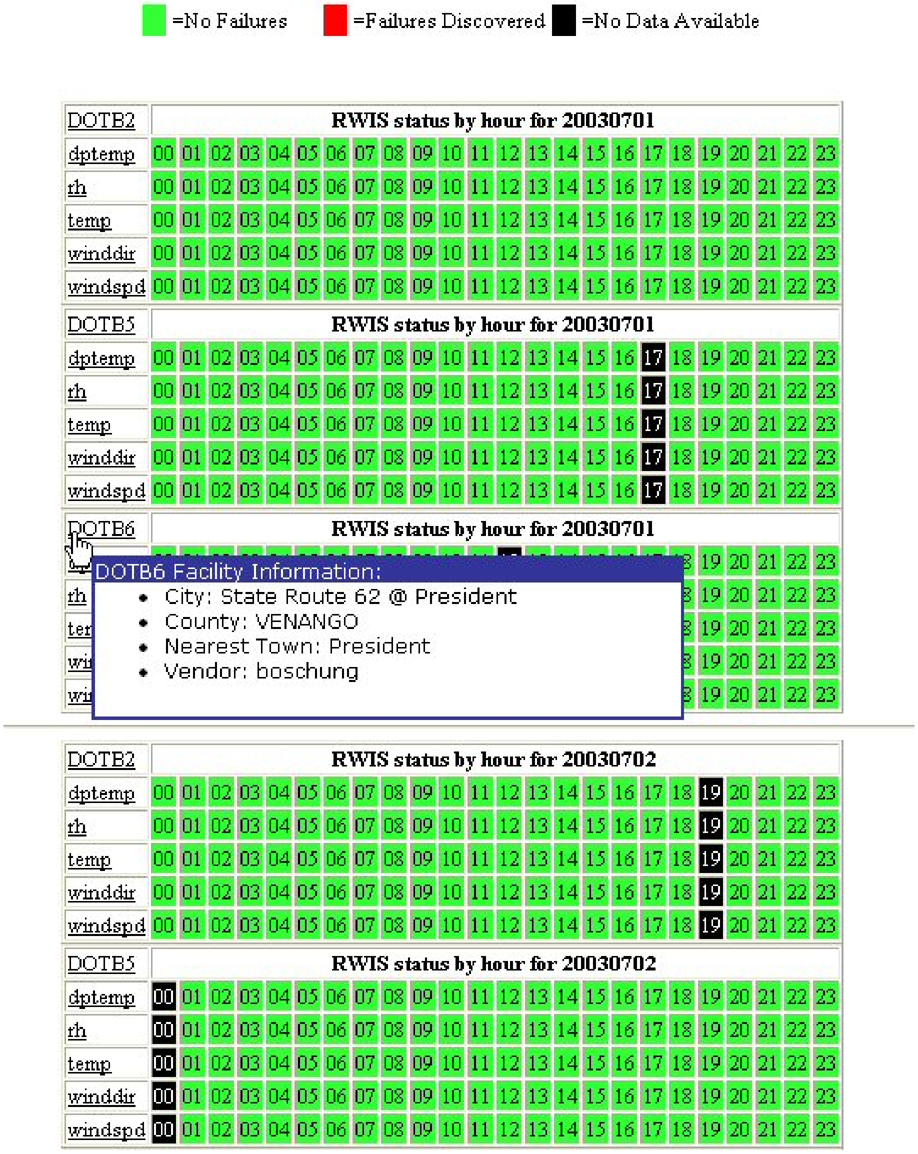


Figure 3. Frequency of observations taken by RWIS network during 1 month. The horizontal axis represents one vertical bar per RWIS station.

Another data flow issue is the RWIS stations' reliability during the seasons when PennDOT has less of a need for frequent observations. A gradual increase in the number of reporting stations and frequency of reports was noticed from the summer of 2001 through late winter 2003, at which time nearly 82 stations were regularly reporting data.

After the data flow issues were addressed, a quality control system was designed to the same standards as the Oklahoma mesonet. A conversion to netCDF was undertaken to facilitate storing all RWIS data and help retrieve archived mesonet data sets. The RWIS conversion was completed during the late autumn 2003. A robust quality assurance of the RWIS data is under development with a user-friendly interface being tested for both internal and external users. Figure 4 shows an early example of the quality assurance interface.



🟩 =No Failures 🟥 =Failures Discovered ⬛ =No Data Available

DOTB2	RWIS status by hour for 20030701																							
dptemp	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23
rh	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23
temp	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23
winddir	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23
windspd	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23

DOTB5	RWIS status by hour for 20030701																							
dptemp	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23
rh	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23
temp	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23
winddir	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23
windspd	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23

DOTB6	RWIS status by hour for 20030701				
	19	20	21	22	23
rh	19	20	21	22	23
ter	19	20	21	22	23
wi	19	20	21	22	23
wi	19	20	21	22	23

DOTB6 Facility Information:

- City: State Route 62 @ President
- County: VENANGO
- Nearest Town: President
- Vendor: boschung

DOTB2	RWIS status by hour for 20030702																							
dptemp	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23
rh	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23
temp	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23
winddir	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23
windspd	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23

DOTB5	RWIS status by hour for 20030702																							
dptemp	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23
rh	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23
temp	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23
winddir	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23
windspd	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23

Figure 4. Early example of a quality assurance report on RWIS data. Clicking on the station designation provides facility details.

In addition to these issues, there are still concerns about instrument siting and calibration that add errors to the quality control process.

After the data quality is assured, the goal is to make the data available for all involved parties, including PennDOT’s Technology Division and the District offices. Early applications include plotting critical isotherms for PennDOT, tracking airborne pollutants in wind streamlines for DEP, developing a microclimate database in the Office of the State Climatologist, and verifying warnings for the NWS in Pennsylvania.

Mesonet Metadata

As the data networks were being assembled, it became obvious that there was little or no station history for the RWIS and COPAMS sites. In fact, assimilating the data into AWIPS and the State Climate database required precise geospatial information that was not readily available from PennDOT. Therefore, the State Climate Office endeavored to create comprehensive metadata files for all RWIS sites. A State Climate Office staff member traveled to each site with a GPS device and digital camera. This was a substantial commitment of personnel time, since there were 82 sites to visit.

The specific metadata parameters were discussed with the local Data Acquisition Program Manager and the National Cooperative Program Manager. Because a modernization of the NWS cooperative network is imminent, it was decided to acquire and display the site information that will best match the new network. Figure 5 shows a sample metadata page for an RWIS site along U.S. Interstate 80 in Pennsylvania. The metadata for other RWIS sites can be found at http://pasc.met.psu.edu/MESONET/metadata/. Site maintenance records will be added later, and the COPAMS network metadata is nearing completion.

Site Description

Station DOT337_2

Station Identifier	DOT337_2
Station Name	I-80 Exit 192 @ Milepost 194
Station Organization	Pennsylvania Department of Transportation
Station Type	RWIS
Station Manufacturer	SSI
Station Latitude	41.046°
Station Longitude	-77.146°
Station Elevation	1518 feet
Distance from Nearest Town Center	3.5 miles east of Carroll
County	CLINTON
Climate Division	7
NWS Forecasting Office & Zone	State College #5

Figure 5. Sample metadata page for an RWIS site.

Road Manager Training

PennDOT's Bureau of Maintenance and Operations scheduled three consecutive training sessions for more than 160 roadway weather managers on their staff. Each PennDOT district sent representatives to a central location. At the request of the winter-storm project manager, a four-part training plan was drafted and submitted for PennDOT's approval. This was beta-tested at a local district office, and adjustments were made based on important feedback from PennDOT personnel. In the first and second part, the NWS Warning Coordination Meteorologist (WCM) taught the fundamentals of weather and products available from the NWS WFOs. The State climatologist taught the third and fourth parts that centered on utilizing RWIS data and winter weather forecasting techniques, including a desktop exercise for all participants. The training occurred during the week of October 7, 2002.

A group of roadway weather managers arrived midday for 4 hours of training, followed by a session of the same length the next morning. At midday of the second day, the first group departed and was replaced by another set of roadway weather managers. This process continued through three cycles.

Approximately 1 hour of the course was devoted to essentials of atmospheric circulations. Another hour covered the climatology of winter weather in Pennsylvania. Time was also committed to reviewing the forecast products available from local NWS WFOs. The second half of the training focused on interpreting radar, reading numerical model forecasts, and connecting RWIS observations to local forecasts. Figure 6 illustrates a component of the training sessions from a sample Microsoft® PowerPoint® slide. A month after the initial sessions, another smaller group of managers was also trained, and the WCM spent a day at a District office in western Pennsylvania conducting further training.

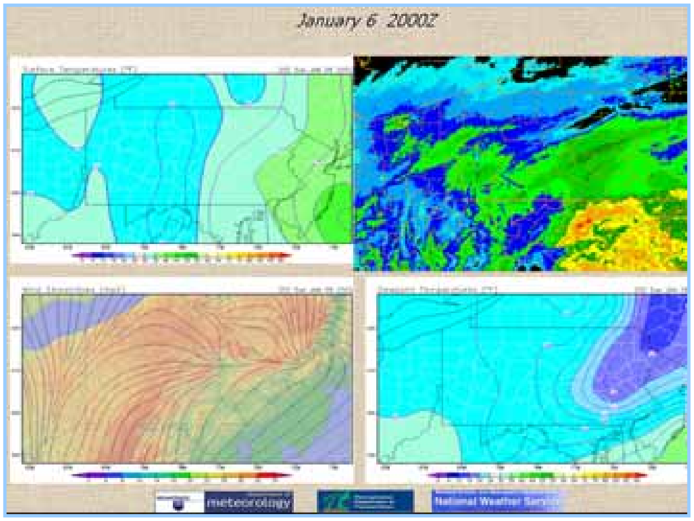


Figure 6. Tabletop exercise from roadway managers training session.

CHANGES TO SCOPE

As mentioned above, researchers intended to use the RWIS to refine mesoscale model initial conditions to improve weather forecasts. However, a large amount of time was spent resolving the uncertainty of the frequency and timing of RWIS observations and other issues related to the variety of data formats required. Researchers also determined that the lack of station history and precise location information was critical. A major effort was expended to provide this documentation, something not initially planned for in the proposal. Additionally, it is debatable whether RWIS data would enhance mesoscale model initial conditions in light of recent sensitivity studies that indicate the need for a denser upper air, rather than surface, network of observations. Therefore, this part of the project was postponed.

PROBLEMS ENCOUNTERED

As indicated, most of the problems encountered revolved around data transmission and data format issues.

DIVISION OF LABOR

The State Climate Office was responsible for creating the database and its reports, developing quality assurance procedures, visiting the RWIS sites to obtain station metadata, and conducting part of the road managers training.

The NWS wrote some of the programs to capture the RWIS data and helped design the forecast Web page that links to all pertinent NWS WFO zone forecasts within PennDOT. PennDOT amended software so NWS and the State Climate Office could receive RWIS reports, and provided valuable guidance to training session designs and finances for all RWIS managers to attend. They also sought advice on siting two new RWIS sites and sought PSU’s assistance in designing the quality assurance for all RWIS sites. They made their field offices available to NWS and the State Climate Office to test receiving 5-minute data.

RECOMMENDATIONS

In retrospect, communication with PennDOT personnel is critical to the success of the collaboration. Awareness of the different infrastructures within PennDOT would be useful for future endeavors, especially in light of the various hierarchies within State agencies. A designated staff member within PennDOT is needed for continuity of the project. It is strongly recommended that all State DOTs move toward wireless technology for their RWIS networks. Future partnerships must also include a comprehensive metadata of the RWIS networks for ready inclusion into the National Oceanic and Atmospheric Administration’s (NOAA) plans for a national mesonet and modernization of their cooperative network.

IMPROVED FROST FORECASTING THROUGH COUPLED ARTIFICIAL NEURAL NETWORK TIME-SERIES PREDICTION TECHNIQUES AND A FROST DEPOSITION MODEL

University: Iowa State University (ISU)
Name of University Researcher Preparing Report: William A. Gallus, Jr.
NWS WFO: Des Moines, IA
Name of Primary NWS Collaborator: Karl A. Jungbluth
DOT Office: Iowa Department of Transportation
Name of Primary DOT Collaborator: Dennis Burkheimer
Cooperative Project, UCAR Award No. S01-32791

SUMMARY OF ORIGINAL PROPOSED SCOPE OF WORK

The project originally proposed to develop a time-series prediction system for parameters needed as input by a frost deposition model (road surface and air temperatures, air dewpoint, winds) by training an artificial neural network (ANN) on meteorological observations and model output. The project's objectives also included comparing RWIS observations with those of standard ASOS/AWOS instruments to determine the quality of the data. In addition, plans included working with the NWS WFO so that they could use the neural network system to improve forecasting of other parameters.

WORK ACCOMPLISHED

ANN Forecasting System

MOS data were gathered from the NWS NGM model for the 3-year period (1996–1998) that matched the frost observation record period. Researchers also collected an appropriate data set of RWIS measurements. They accessed the RWIS archive valid over this time period, interpolated the data to a standard 20-minute time interval, performed some quality control of the data, and flagged those time periods when gaps between observations exceeded 4 hours or could interfere with important time periods when frost was possible.

The corrected and usable data from both MOS and RWIS observations were organized into a very large database, which was used to train the ANN. The training set used 85 percent of all of the data, with the remaining 15 percent saved as a test set; 181 possible inputs to the model were tested. It was decided that the best approach would be to limit the inputs to the 8–10 found to be most important for each parameter. Programs were developed to collect the data automatically in real-time with a regular 20-minute resolution for future applications.

Staff tested several different neural network configurations to predict the four variables needed as inputs for the frost prediction model—roadway surface temperature, air temperature, dewpoint, and wind speed. Despite the ANN's ability to predict multiple outputs with one model, it can only predict at one point in time. Therefore, researchers determined that the best way to predict the necessary parameters with a time frequency of 20 minutes was to create separate neural network models for each weather parameter. Consequently, 288 neural network models were needed for the 4 weather parameters. Many configurations were tested to determine the best one for each parameter at each time.

When validation was done over the entire training and test set, the ANN predictions correlated well with the RWIS observations and generally performed better than the NGM MOS output alone. However, for the test set, the ANN predictions of temperature and wind speed were better than MOS only for the first few hours of the prediction period (corresponding to forecasts 6–9 hours in the future). MOS forecasts had smaller root mean square errors (RMSE) later in time. The ANN had smaller RMSEs for wind speed, but the smaller average errors were achieved by always forecasting light winds, even when strong winds occurred. MOS does not include a forecast for roadway temperature. Thus, the ANN system provided much better forecasts during daylight hours when compared to the 2-meter MOS air temperature as a proxy for road temperature. At nighttime, the ANN showed a small improvement over the crude estimate based on MOS. In general, the errors with the ANN system were smaller than those obtained from three mesoscale models. The mesoscale models ran with two different sets of initial conditions for the Maintenance Decision Support System (MDSS) project[1] in Iowa during the winter of 2003. As in that project, dewpoint errors are much larger than temperature errors.

The ANN output was then tested in the frost deposition model for the winters of 1996–1998, 2001–2002 and 2002–2003. The verification statistics for the winters of 1996–1998 were provided by the Iowa DOT. During this time, “yes” and “no” observations of frost were made by maintenance personal looking out the windows of their vehicles on the way into work. Therefore, great uncertainty is present about the quality of the verification statistics. The ANN-based predictions of frost for this period were not particularly good. False alarm rates were very high—generally .90 to .98 at most stations tested. Probability of detection tended to be in the .2 to .6 range. Although the lack of skill in the forecasts was likely partly related to poor verification data, it was observed that the ANN system often predicted a dewpoint exceeding the air temperature. This is a physically impossible condition, and it stems from the independent nature of the ANN models forecasting each parameter.

For the winter of 2001–2002, frost verification data was available from an Iowa DOT-sponsored project in Ames, IA, where Iowa State University (ISU) students closely monitored a bridge in the region during the early morning hours. These “yes” and “no” frost observations are believed to be highly accurate, although frost is a very microscale phenomena, again complicating interpretation of verification data. For this period, the ANN predictions were very accurate, nearly matching the forecasts made after the fact when RWIS data from Ames, IA, were fed to the frost deposition model. Thus, for this period, the ANN forecast approached the “best” value that might be expected. False alarm rates (FAR),[2] though still high, were around 0.56. The probability of detection (POD)[3] was 0.57. Even more promising, the forecasts were much more skillful than those of the private forecasting firm that had been contracted by the Iowa DOT to forecast frost during this winter.

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[1] MDSS: A large, multiagency project that began with a prototype experiment in Iowa in winter 2002-03. The goal was an automated system that uses weather data as accurately as possible and that is easy to read and understand, and that recommends courses of action for road maintenance.

[2] FAR: A measure of how often an event is forecast and fails to materialize; lower numbers are desirable.

[3] POD: A measure of how often an event is forecast and does occur; higher numbers are desirable.

In the winter of 2002–2003, the Ames, IA, frost verification project was expanded using Aurora[4] funding, so that three bridges were monitored. This again complicated verification. Data for verification were not available until the end of the COMET project, and thus verification statistics are preliminary. It appeared that forecast skill was much less in 2002–03 than in the previous winter, with the FAR rising to 0.79, and the POD falling to 0.30. Nonetheless, the threat score, a combined measure of skill, was still comparable to that of the private firm the previous winter. At the time of this report, no other verification data was available from 2002–2003 for comparison to the ANN.

In summary, the ANN forecasting system showed promise, and the performance during the 2001–2002 winter was very encouraging. The fact the system earned much better scores than a contracted forecasting agency also was considered a success. However, some other winters exhibited much worse performance of the ANN system. The independent nature of the predictions for different parameters allows for some nonphysical situations to be predicted. An improved ANN system in the future could predict the dewpoint depression instead of temperature and dewpoint as separate quantities. This would avoid the problem of unrealistic forecasts and may help improve performance.

RWIS-ASOS Comparison

Detailed comparisons of RWIS and AWOS/ASOS observations were performed. During the COMET project, a separate initiative was established at ISU to combine all mesoscale data into one convenient mesonetwork, known as the Iowa Environmental Mesonet (IEM). Several meetings occurred at ISU that included NWS Des Moines personnel, Iowa DOT personnel, and other interested parties from State agencies. Establishing the IEM enhanced the ability to compare RWIS observations to more standard meteorological observations of surface conditions, particularly ASOS readings.

A thorough comparison was performed for several weather parameters by averaging RWIS and ASOS or AWOS data over an entire year. The comparisons suggest that RWIS temperature readings have a high bias when wind speeds are light, with the worst problem at the lightest wind (figure 7). This behavior is expected because RWIS sensors are not aspirated, while ASOS and AWOS are aspirated.

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[4] Aurora is an international program of collaborative research, development and deployment in the field of road weather information systems (RWIS), serving the interests and needs of public agencies.

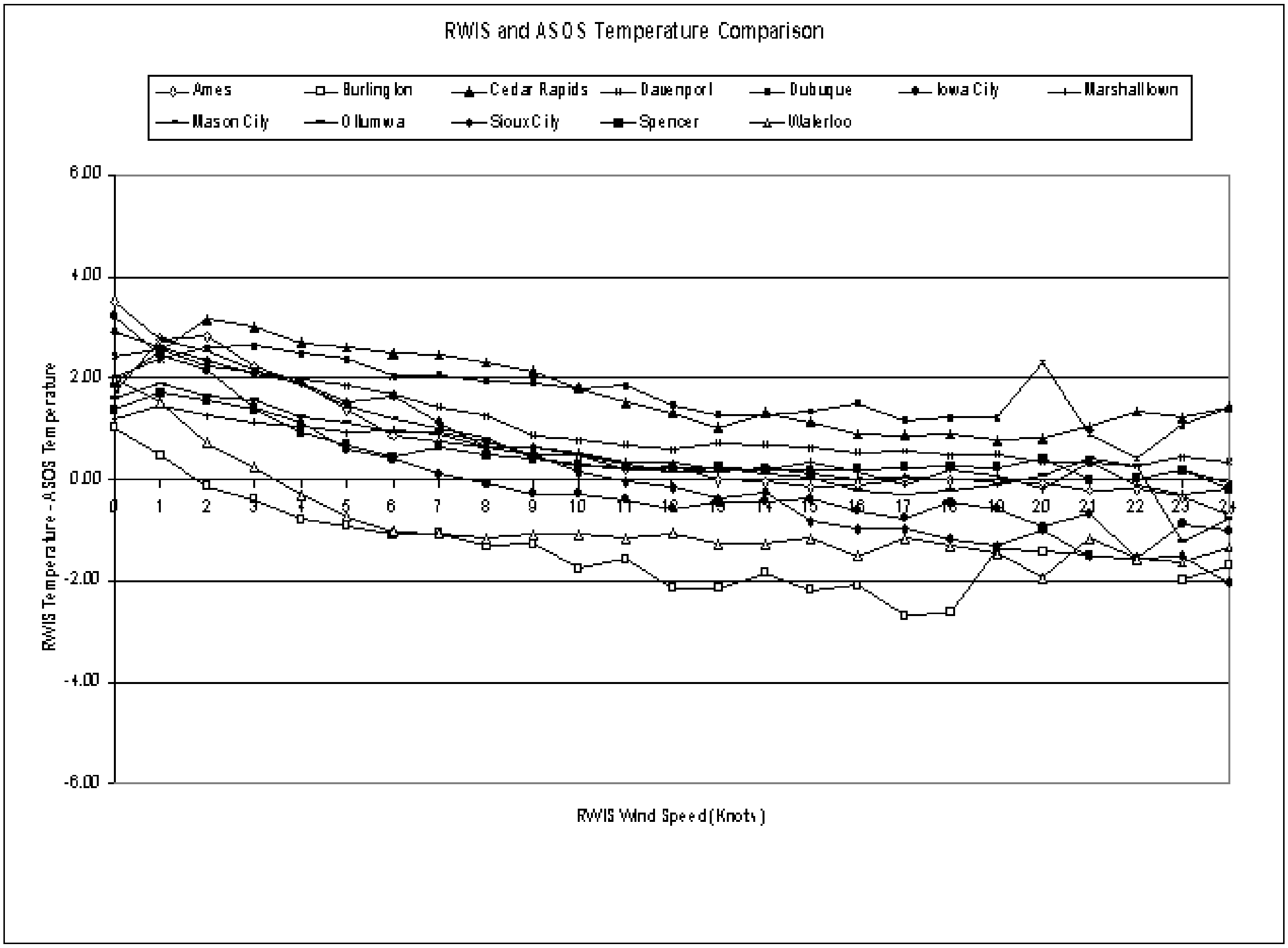
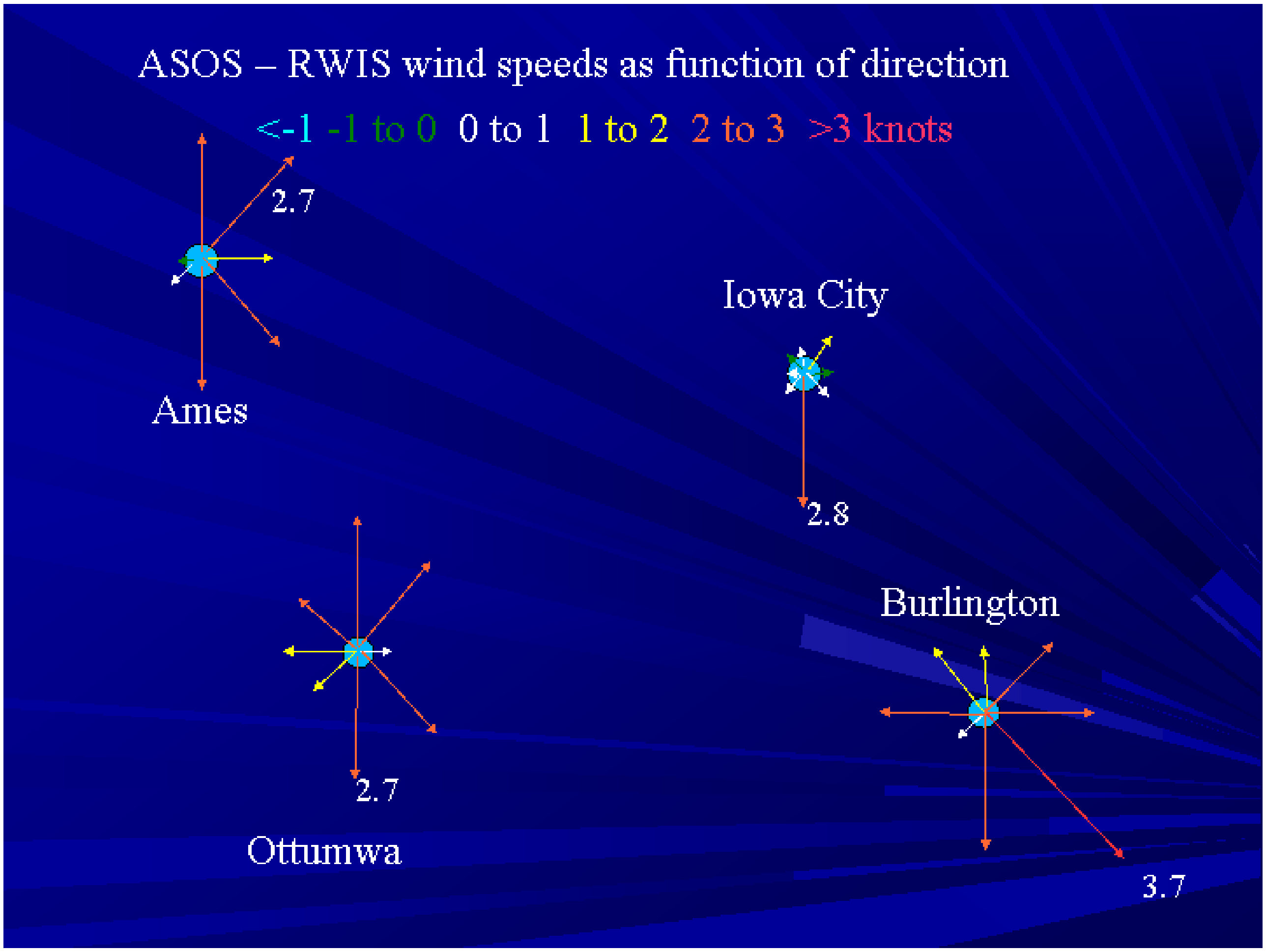


Figure 7. Comparison of RWIS temperatures with ASOS temperatures as a function of RWIS wind speed for 12 stations.

RWIS winds also typically read a few knots less than AWOS/ASOS (figure 8) at the stations where RWIS sensors were within 8.7 nautical miles (nm) (16.1 kilometers (km)) of AWOS or ASOS sensors. Although both platforms are designed to record wind at the same elevation (32.8 feet (ft) or 10 meters (m)), many RWIS platforms are sited in ditches that may somewhat shelter the instruments. Average wind speeds were computed for RWIS and ASOS instruments as a function of wind direction (octants) at 12 stations. The impact of siting clearly can be seen when average wind speed differences vary from around zero at a particular site for a given wind direction to roughly 3 knots for other directions, a roughly 40 percent decrease in magnitude from the ASOS values. The RWIS values are less than the ASOS for most directions at all sites.



ASOS – RWIS wind speeds as function of direction

<-1 -1 to 0 0 to 1 1 to 2 2 to 3 >3 knots

Figure 8. Comparison of ASOS-RWIS wind speeds as a function of direction for four stations.

Comparisons of other parameters as a function of hour of the day or of wind speed also were performed. See figure 9 for the comparison of dewpoints. It appears that systematic differences can be quantified; this should allow for calibration to improve use of the combined data set. At the time of this report, a paper on the comparison was being developed. Some of the results were discussed at COMET/FHWA meetings in Washington, DC, in September 2002 and in Albany, NY, in August 2003.

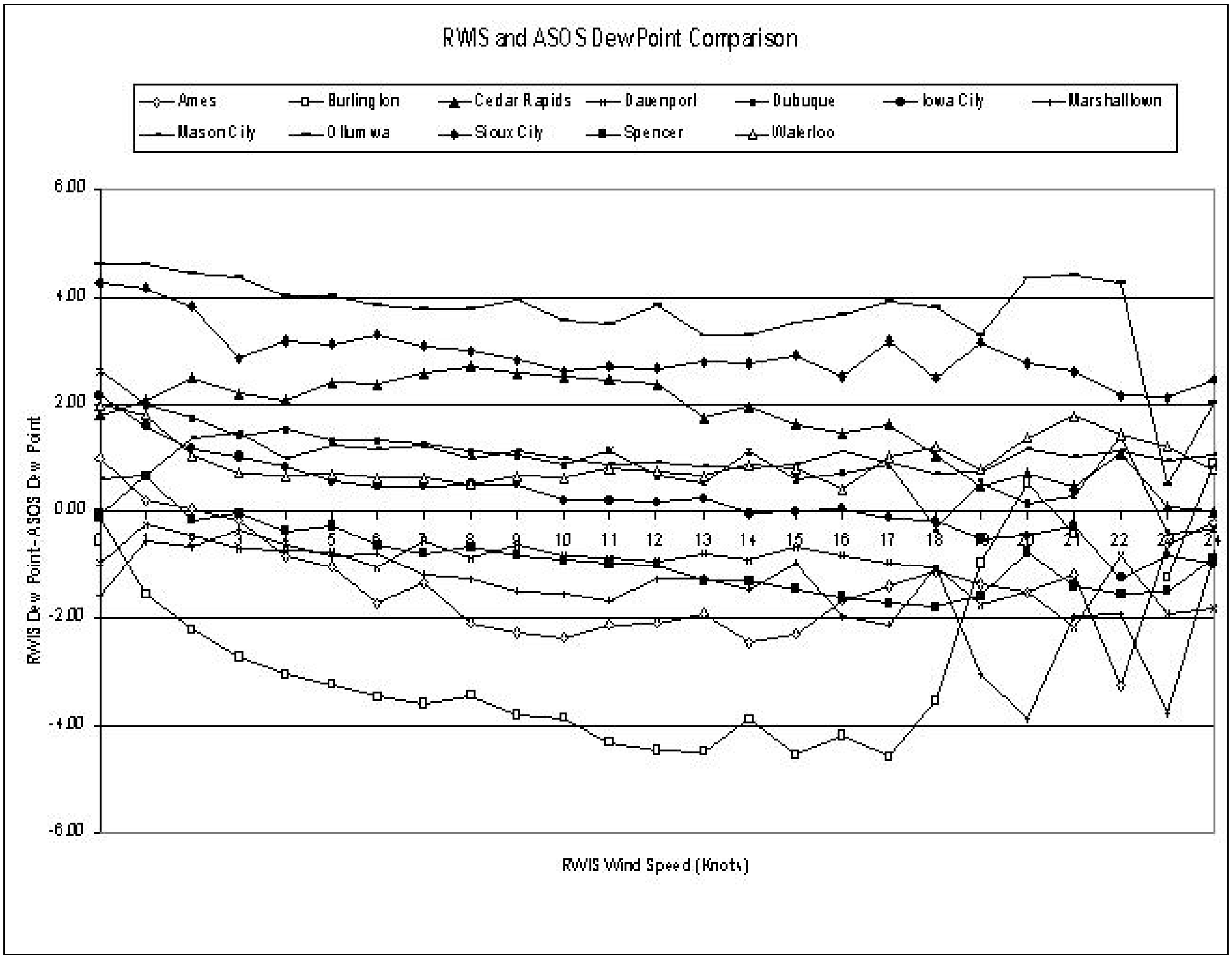


Figure 9. Comparison of RWIS dewpoint temperatures with ASOS dewpoint temperatures as a function of RWIS wind speed for 12 stations.

In addition to the detailed comparisons discussed above, researchers established a Web site that allows direct comparisons between the different measuring systems in real time. It can be accessed at http://mesonet.agron.iastate.edu/compare/. Some results from these comparisons were published in the preprints of the 18th International Conference on Interactive Information and Processing Systems (IIPS) in Orlando, FL, January 2002.

Extension of ANN Applications to the NWS

The graduate student also explored an additional use of neural networks designed to assist the NWS Des Moines office in forecasting. A neural network predictive system for warm season quantitative precipitation forecasting (QPF) was designed. For this neural network system, the technique of Hall et al. was followed.(1) A neural network was trained on data collected from the NWS Eta model and soundings valid for both Omaha, NE, and Davenport, IA, (DVN) over the warm seasons of 1998–2001. More than 30 variables were used as input parameters in the model. Results using just the Omaha (OMA) data were very encouraging, so more than 400 cases from Davenport (DVN) were added to expand the number of patterns used by the neural network. The expansion was necessary because early results implied some memorization or over parameterization might have been occurring. Results using the OMA and DVN data together indicated that the neural network system still performed better than either the operational Eta model, or 10-km meso-Eta simulations in predicting 24-hour rainfall, particularly for heavier amounts that are generally unpredictable in grid point models. However, combining the data seemed to harm the results, because errors were larger than using OMA alone.

Results from the Omaha, NE, training were presented at the 18th International Conference on IIPS in Orlando, FL, in January 2002. A discussion of all results was given at the U.S. Weather Research Program Science Symposium in Boulder, CO, in April 2002 and at the World Weather Research Programme's QPF Conference held in September 2002 in Reading, United Kingdom. The neural network system based on the combined data was run in real time during summer 2002, and results were made available to the NWS via a Web page. In this real-time test period, the system was altered to allow inputs directly from the Eta model instead of a mixture of model and rawinsonde output. This allowed forecasts to be made at grid points across Iowa. This output was also made available via the Web page. The summer 2002 test, however, indicated a high bias in the neural network predictions. It appears that some calibration would be necessary to improve the forecasts.

CHANGES TO SCOPE

There were no changes to scope of this project. Researchers benefited from a running start on the neural network modeling and by the fact the IEM project allowed for easier-than-expected comparison of RWIS observations to ASOS and AWOS.

PROBLEMS ENCOUNTERED

No serious problems were encountered in conducting the research, apart from some Microsoft Windows® operating system-related computer crashes that occasionally caused data losses.

DIVISION OF LABOR

The primary method of interaction during this project occurred through occasional meetings, phone calls, and e-mails with the NWS Des Moines office and the Iowa DOT. The vast majority of the work, because it involved very site-specific neural network software, occurred at ISU. The Iowa DOT's involvement extended beyond the 2.5 years of this project, because they provided the 1996–1998 frost observations before the start of the COMET project.

RECOMMENDATIONS FOR FUTURE WORK RELATED TO THIS PROJECT

Creating a neural network forecasting system is very labor intensive. Much of the project period was used to gather all necessary data, quality control the data, and enter it into the appropriately formatted input tables required by the ANN software. Although extensive testing was performed to find the best neural network models for each parameter, there are enough degrees of freedom to the problem that additional improvements would be likely if more experimenting could be done with the ANN software.

A future project evaluating the forecasting skill of a combined MOS-ANN system could benefit both the Iowa DOT and NWS. In addition, it may be possible to run an ensemble of MOS and ANN systems. The mean would likely provide the most valuable input to the frost deposition model. Also, an ongoing project at ISU has hinted that a mesoscale model such as MM5 may have more skill than the NGM-MOS that was used to train this project's ANN. It would be very interesting to test the performance of an ANN system that used MM5 output for training instead of NGM-MOS. When this project began, there were only 3 years of RWIS data useful for training. That period has now nearly doubled. With all ANN systems, the more data to train on, the better the forecast skill. In summary, this project clearly showed that with more study, artificial intelligence systems such as neural networks may offer valuable improvements in forecasting.

BROADER RECOMMENDATIONS

Although researchers were able to follow the original scope of work closely without major problems, it was still difficult to emphasize one core project of significant benefit to both the Iowa DOT and NWS partners. In fact, of the five groups that received funding, this was the only group whose main focus was not primarily to create a mesonet (merger of DOT data with NWS and other data sources). The creation of the mesonet is perhaps the only project that seems to benefit both partners roughly equally. Even this project included a task involving mesonet applications—the comparison of RWIS data with ASOS and AWOS. This project may have differed from the others, because the Iowa DOT has a long history of being at the cutting edge of initiatives. Researchers had access to the Iowa DOT RWIS data before the COMET request for proposal, and the establishment of the Iowa mesonet was likely the furthest along of any such effort in the Nation. It is possible that future combined COMET/FHWA projects will primarily assist the Iowa DOT or the NWS, but not both, unless the project simply manipulates multiple data sources. Traditional COMET projects benefit the NWS. Future FHWA collaborations may yield very little interaction and direct benefit to the NWS. For this project, the data comparison was believed to help the NWS, and they were welcome to use the ANN system. However, the system was designed to forecast road frost, which is something the NWS is not permitted to do. Thus, at best, the NWS would only be able to use the software system secondarily.

USE OF ROAD WEATHER INFORMATION SYSTEMS IN THE IMPROVEMENT OF NEVADA DEPARTMENT OF TRANSPORTATION OPERATIONS AND NATIONAL WEATHER SERVICE FORECASTS IN THE COMPLEX TERRAIN OF WESTERN NEVADA

University: Desert Research Instate (DRI), University of Nevada System
Name of University Researcher Preparing Report: Darko Koracin, Ph.D.
NWS WFO: Reno, NV
Name of Primary NWS Collaborators: Mr. Jim Fischer, and formerly by Ms. Mary Cairns
DOT Office: Nevada Department of Transportation (NDOT)
Name of Primary DOT Collaborators: Mr. Richard Nelson, Ms. Inda Denise, and Ms. Pamela Klessig
Cooperative Project, UCAR Award No. S01-32790

SUMMARY OF ORIGINAL PROPOSED SCOPE OF WORK

Prediction of mesoscale weather features is extremely difficult where small-scale terrain features create large variations in weather over small distances. Locally high winds and heavy snow induced by the orographic features, and flash floods that occur in small drainage basins are examples of mesoscale weather features in the Western United States. To better evaluate these small-scale features, a dense network of weather observations is desirable. The addition of reliable and good quality State DOT weather stations that report at temporal resolutions of typically one hour provides data in areas critical to the protection of life and property.

According to our proposal, the primary goals of this project were to:

- Improve pavement forecasts through improved model input.
- Improve NWS operational forecasts through better model guidance.
- Improve operational decisions regarding snow and control operations.
- Develop an NDOT public travelers' forecast.

The proposed project was originally divided into the following main tasks. Partners with primary responsibility for each task are indicated in parentheses:

- Acquire and organize relevant data sets (NDOT, DRI, and NWS).
- Assimilate the NDOT data into MM5 (DRI and NWS).
- Test improved pavement forecasts (DRI and NDOT).
- Implement data assimilation techniques into local NWS MM5 model (NWS and DRI).
- Test real-time MM5 model output for pavement temperature model (DRI and NDOT).
- Develop pavement travelers' forecasts (NDOT and DRI).
- Write project reports, participate in seminars and workshops, and use project results for thesis (DRI, NWS, and NDOT).

WORK ACCOMPLISHED

This multidisciplinary project was a valuable experience for the collaborating partners: NDOT, the NWS WFO in Reno, NV, and the DRI. The project resulted in significant advancements by accomplishing the following proposed main objectives:

NDOT Perspective: RWIS Network

- Provide high quality meteorological data from the operational network of NDOT RWIS stations.
- Integrate the data from the NDOT station network to improve NDOT operations and for a possible larger community use.
- Understand the input uncertainties and provide guidance on improving NDOT pavement temperature forecasts.

NWS Perspective: Using NDOT Data to Improve Mesoscale Forecasts in Complex Terrain

- Improve the operational mesoscale/regional scale forecasts at the NWS WFO in Reno, NV.
- Use the NDOT operational network for model evaluation and weather warnings.

DRI Perspective: Using NDOT Data to Improve Mesoscale Forecasts in Complex Terrain

- Integrate NDOT data into the DRI-Western Regional Climate Center data network.
- Improve mesoscale forecasts of weather in the complex terrain of northern Nevada by using data from the operational network of NDOT stations.
- Develop an optimum Four-Dimensional Data Assimilation (FDDA) system to improve MM5.

DRI Perspective: Testing and Improving the NDOT Pavement Temperature Model

- Study the sensitivity of pavement temperature model predictions to input meteorological parameters.

NDOT: Road Weather Information System Network

There is a significant need to improve road-related weather forecasts from the point of view of NDOT operations, and from a traffic and economic perspective. To address this issue, NDOT has implemented a variety of snow and ice control strategies, including developing a RWIS. The system includes a network of remotely located environmental sensor stations that collect, process, and disseminate information on road and weather conditions relevant to highway transportation.

Several major questions arise:

- What is the main use of these data for NDOT, NWS, other institutions, and the community?
- Can this system be a part of other networks?
- What is the quality of the collected data?

In the beginning of the project, researchers established the links and a data stream from the NDOT weather stations network to DRI and NWS. Programs were developed at DRI to automatically access and download the data from NDOT computers and integrate the data into the database of the Western Regional Climate Center at DRI. The operational Web site has been developed on the DRI server computer at http://www.ndot.dri.edu.

This site provides an interactive graphical display of the data. It is in continuous operation and receives all available NDOT data in two different formats and sampling intervals (10 and 15 minutes). Incoming data is archived. Researchers have been working with the NDOT staff to ensure a continuous stream of information and to include the newly established NDOT stations in DRI's Western Regional Climate Center information system. However, at the current time, some stations are not operational, some have changed their transmission software, some have not been transferred to DRI, and some are still reporting.

The DRI Web site provides access to statistical and graphical analyses of current and past data, including time series, wind roses, monthly and daily statistics, and the ability to download data of interest. Figure 10 shows the main page of the Web site with stations that are available for statistical and graphical analysis.

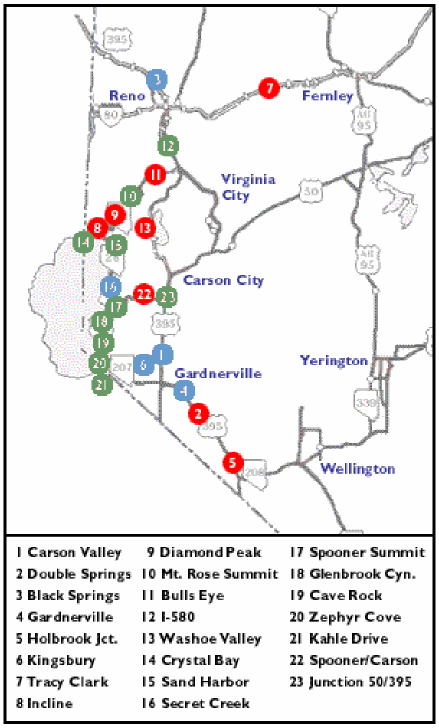


Figure 10. Locations of the NDOT stations that are available for analysis on the DRI Web site.

Recently, NDOT has undertaken major steps to reorganize their network of operational stations. Eleven sites have been upgraded, and five new sites have been installed. The Remote Processing Unit (RPU) type was upgraded from the Zeno® or Vaisala Milos models to the Vailsala ROSA Weather Station RPU. The Zeno® RPUs were used with the now defunct coastal system.

The Milos system will soon be obsolete, and replacement parts will be unavailable. However, parts salvaged from the upgraded sites will be available for troubleshooting the remaining sites operating on the Milos RPUs.

The 11 Nevada sites that were upgraded cover the following: Black Springs, Cave Rock, Diamond Peak, Gardnerville, Holbrook Junction, Kahle Drive, Mount Rose, Secret Creek, Spooner Summit, Tracy Clark, and the U.S. I-395/U.S. I-50 junction. The five new sites that are now functional include Highland Flats, U.S. I-580 at the NDOT Reno, NV, yard, Moundhouse, Toulon, and Walker Lake. With these sites, there are now 21 operational sites in District II. Eight sites are operational in District III, and work continues to bring additional sites online.

A new server has been installed to provide a redundant backup in the event of a major failure. In addition, the new server will provide an increased hard drive memory capacity and will operate at higher speeds.

NWS: Using NDOT Data to Improve Mesoscale Forecasts in Complex Terrain

The first goal was to establish a data assimilation system. This was the most difficult goal because of the state of technology when the project began. Frequent computer crashes and the use of dial-up modems between the NWS and NDOT challenged the information technology (IT) staff of both NWS and NDOT. By the second year of the project, file transfer protocol (FTP) procedures were set up, and faster computers were installed at both NWS and NDOT, which improved the reliability of data assimilation. Both NWS and DRI archived the data at the Western Region Climate center.

Data collection continues today and has been expanded to other areas of the State outside of the local Reno, NV, mesonet area. This change in scope to this project was not anticipated when the project was started.

The second goal was to improve NWS operational forecasts through better model guidance and knowledge. As mentioned in the proposal, NWS is in the process of implementing an NDFD. The proposal mentioned the resolution of this database would be less than 5.4 nm (10 km) and, indeed at this time it is at 1.3 nm (2.5 km) and will be reduced to 0.67 nm (1.25 km) some time in the future. This gives the NWS forecaster the ability to forecast weather at spatial and temporal resolutions far greater than previously possible. However, high resolution forecast models are necessary for guidance. Initialization of these models and the NDFD relies on a dense network of surface data, including the NDOT sites.

The NWS in Reno is using a local model at 4.9 nm (9 km) resolution and hourly time steps for some of the sensible weather elements in the NDFD, including wind and temperatures. The University of Utah's ADAS model has become a starting point for verifying the NDFD data, and a side benefit of the project is that NDOT data is entered into this model through Utah's MesoWest database.

Verification of high wind warnings and improved fire weather forecasts came as a direct result of this data. As an example, on June 30, 2000, a wildfire near Reno, NV, started near the Mt. Rose highway, where several of the NDOT sensors are located. Weather forecasters used the NDOT data to support fire weather forecasts for that fire. Also, several high wind warnings were verified using the Washoe Valley NDOT sensor. This sensor is sited in a particularly windy area, and several times a year trucks overturn due to high winds along this stretch of highway.

DRI: Using NDOT Data to Improve Mesoscale Forecasts in Complex Terrain

One of the main goals of this proposed study was to establish a data assimilation system for the MM5 at DRI. Figure 11 shows a schematic of the data assimilation and the weather forecasting system that uses NDOT data to improve model initial conditions. The improved weather forecasts were then used to improve results from the NDOT Pavement Temperature Model.

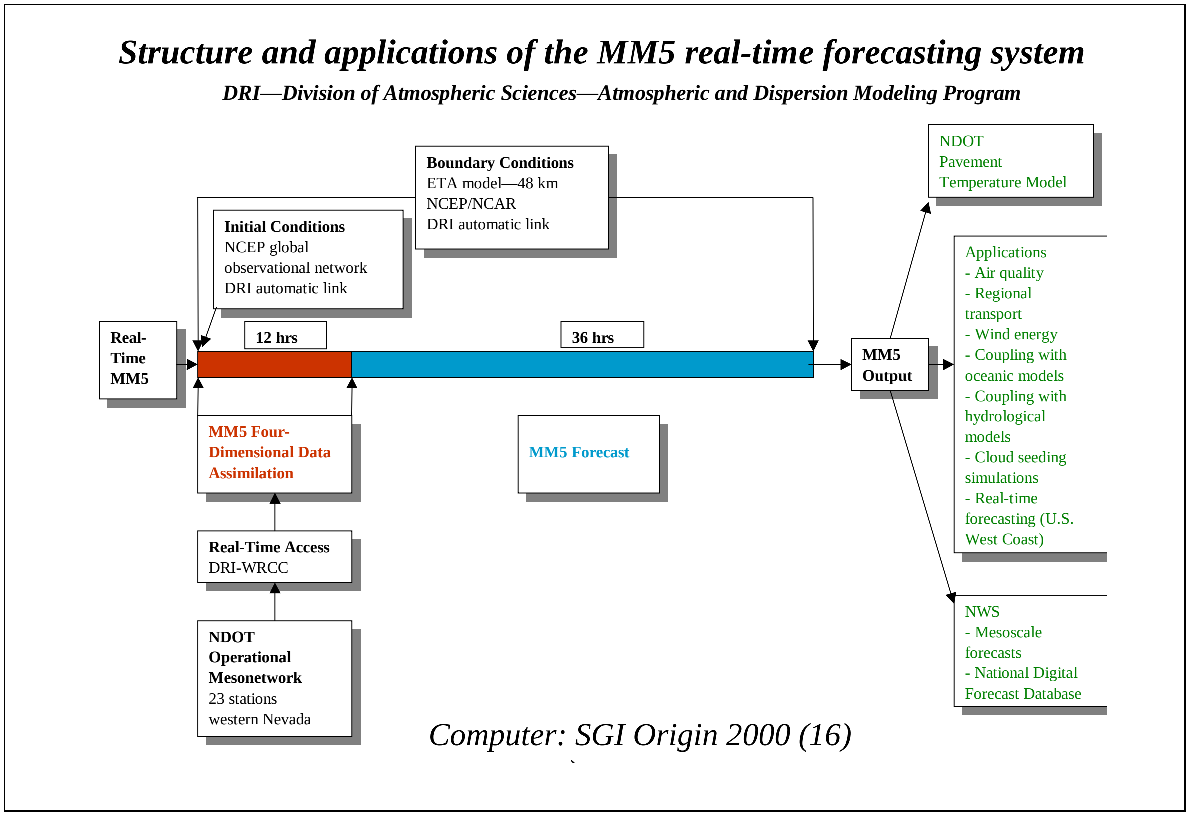


Figure 11. A schematic of the DRI-developed real-time forecasting system that assimilates NDOT data in the first 12 hours of the pre-forecasting time. (NCEP is the National Centers for Environmental Prediction, NCAR is the National Center for Atmospheric Research, and SGI® represents Silicon Graphics Incorporated)

To achieve the proposed objectives of the study, we applied our developed system shown in figure 11 to two winter storm cases. The forecasting periods were:

- March 7–9, 2002.
- April 1–2, 2003.

Case 1: Mesoscale modeling using NDOT data for March 7–9, 2002

Since the reporting and quality of data improved in the beginning of 2002, FDDA tests focused on a case study of a significant snowstorm that occurred during March 7–9, 2002. During that time, 11 stations were reporting. During the same period, the National Center for Atmospheric Research (NCAR) in Boulder, CO, and DRI were conducting the Integrated Sounding System field program in the Reno, NV, and Washoe, NV, basins. Surface and upper air measurements were collected at two locations from February 26 to March 26, 2002.

A heavy snowstorm occurred in the Sierra Nevada Mountains during March 6–8, 2002, with a maximum snow-water equivalent of 77.97 centimeters (cm) measured on March 8 at the Central Sierra Snow Lab in the Donner Pass area near Truckee, CA. A frontal system passed over the Reno area on March 8 at 02:00 universal time coordinated (UTC) with measured rain amounts of 5 to 10 millimeters (mm). The system was associated with a strong southerly flow preceding the front. It appears that this frontal system was merging with the significant moisture advection from southern California and over the Central California Valley. Radar images showed wide areas of convective precipitation moving from the valley over the Sierras. The precipitation started over the Sierras on March 6 and propagated into the Reno area later on March 7. Severe driving conditions on I-80 due to gusty winds and snow were reported in the area, especially east of Reno near Fallon, NV.

This snowstorm event has been simulated with the DRI MM5 real-time operational model using a coarse grid with 18-km horizontal resolution (133 x 121 x 28 grid points) and a nested grid with a horizontal resolution of 6 km (148 x 169 x 28 grid points). The setup of the MM5 modeling domains is shown in figure 12.

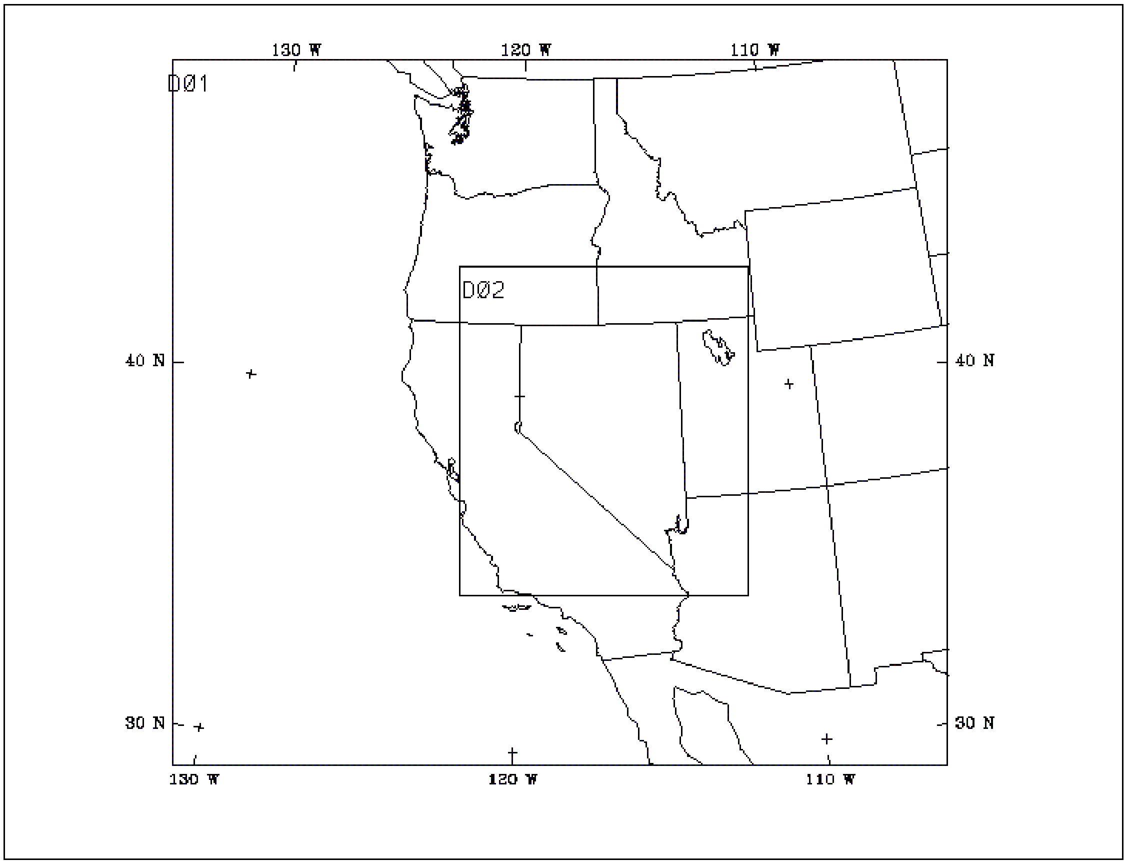


Figure 12. Geographical setup of the real-time MM5 forecasting domains.

The model was able to forecast a frontal system passing through Reno, NV, on March 8, 2002 between 00:00 and 02:00 UTC. The main objective of the study in this period was to use FDDA to improve the accuracy of the MM5 forecasts. Results indicate that the two major FDDA parameters are the nudging coefficient and the radius of influence of the data that is being assimilated into the model.[5] In addition, it is important to use an optimum set of stations; however, it should be emphasized that each of the surface stations has micro location specifics and generally is not representative for the larger area that needs to be captured by the model. Figure 13 shows a wind speed time series comparing NDOT Station 13 data (Washoe Valley, 39° 16’ 26.28” N, 119° 49’ 7.90”W) with the model results without data assimilation (base case) and with several FDDA runs with varied nudging coefficients, radii of influence[1], and a number of selected stations entered into the FDDA system.

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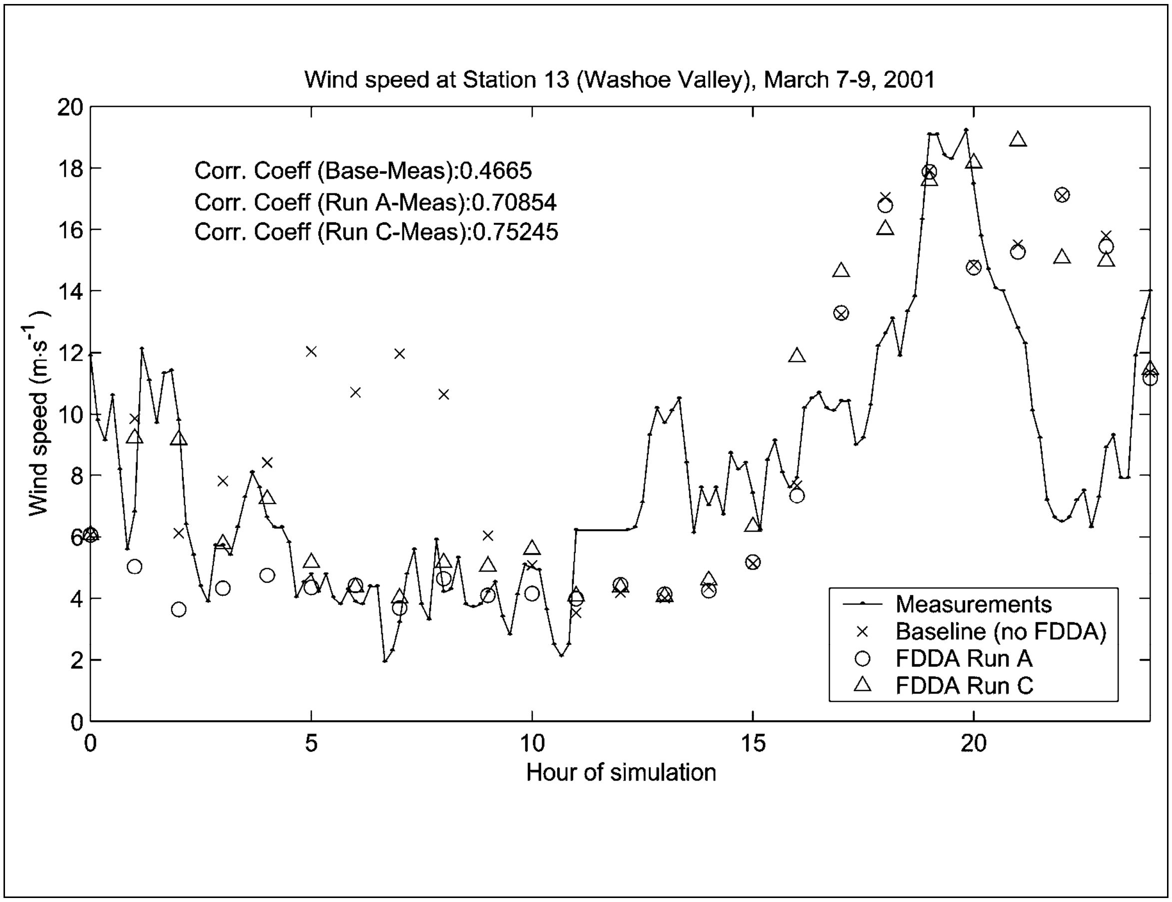
[5] FDDA is a method of including present and past data in a numerical model. The data incorporated in the model continuously correct (nudge) model results toward measured data at the point where the measurements took place and also for model results within a certain radius (the radius of influence) of the measurement point. [1]The model corrects its results strongest at the measurement point and weaker as it goes further from the point within the radius of influence.



Run A: radius of influence = 240 km, nudging coefficient = 4e-3.
Run C: radius of influence = 50 km, nudging coefficient = 4e-2.

Figure 13. Time series of wind speeds measured at NDOT Washoe Valley station and simulated with MM5 without FDDA, with Run A FDDA options, and with Run C FDDA options.

The figure clearly shows the efficiency of using NDOT data in the FDDA mode to improve the accuracy of forecasts. Both the A and C FDDA tests agree better with measurements than the MM5 run without data assimilation (baseline simulation). The correlation coefficient is significantly greater in the FDDA cases (0.71 and 0.75) compared to the baseline case without data assimilation (0.47).

Case 2: Mesoscale Modeling Using NDOT Data for March 1–2, 2003

The system was also tested on a case from winter 2002/2003. An unusually late winter storm occurred in western Nevada in the beginning of April 2003. The storm was characterized by an intense frontal system, high winds, a significant drop in temperature, and snow showers. The severity of the weather conditions can be illustrated by the radiosonde observation taken before and during the storm (Figure 14).

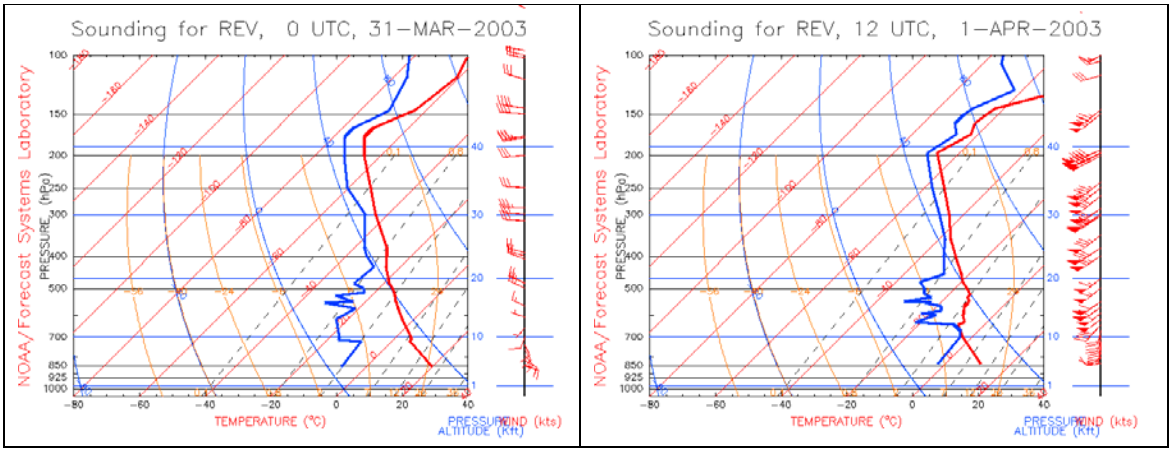


Figure 14. Vertical profiles of temperature, dewpoint temperature, and winds measured by radiosonde in Reno, NV, on March 31, 2003 at 00 UTC (4 p.m. local time) (left panel) and on April 1, 2003 at 12 UTC (4 a.m. local time) (right panel).

The figure shows a large temperature drop below 500 millibars (mb) during the storm as compared to the pre-frontal sounding. There was a significant increase of moisture in all tropospheric layers and consequent increase of atmospheric instability, clouds, and precipitation. The westerly winds increased significantly in the atmospheric boundary layer and at all elevations, with peaks to about 80–90 knots aloft.

Figure 15 shows a time series of measured and simulated air temperature and wind speeds for the April 2003 case. The figure shows the MM5 simulations for a baseline run and an FDDA run. The simulations were able to reproduce the observed strong, almost monotonic drop, in temperature of about 20 °C within 36 hours. The model runs that used assimilated NDOT data compared better with measurements for both temperature and wind speed.

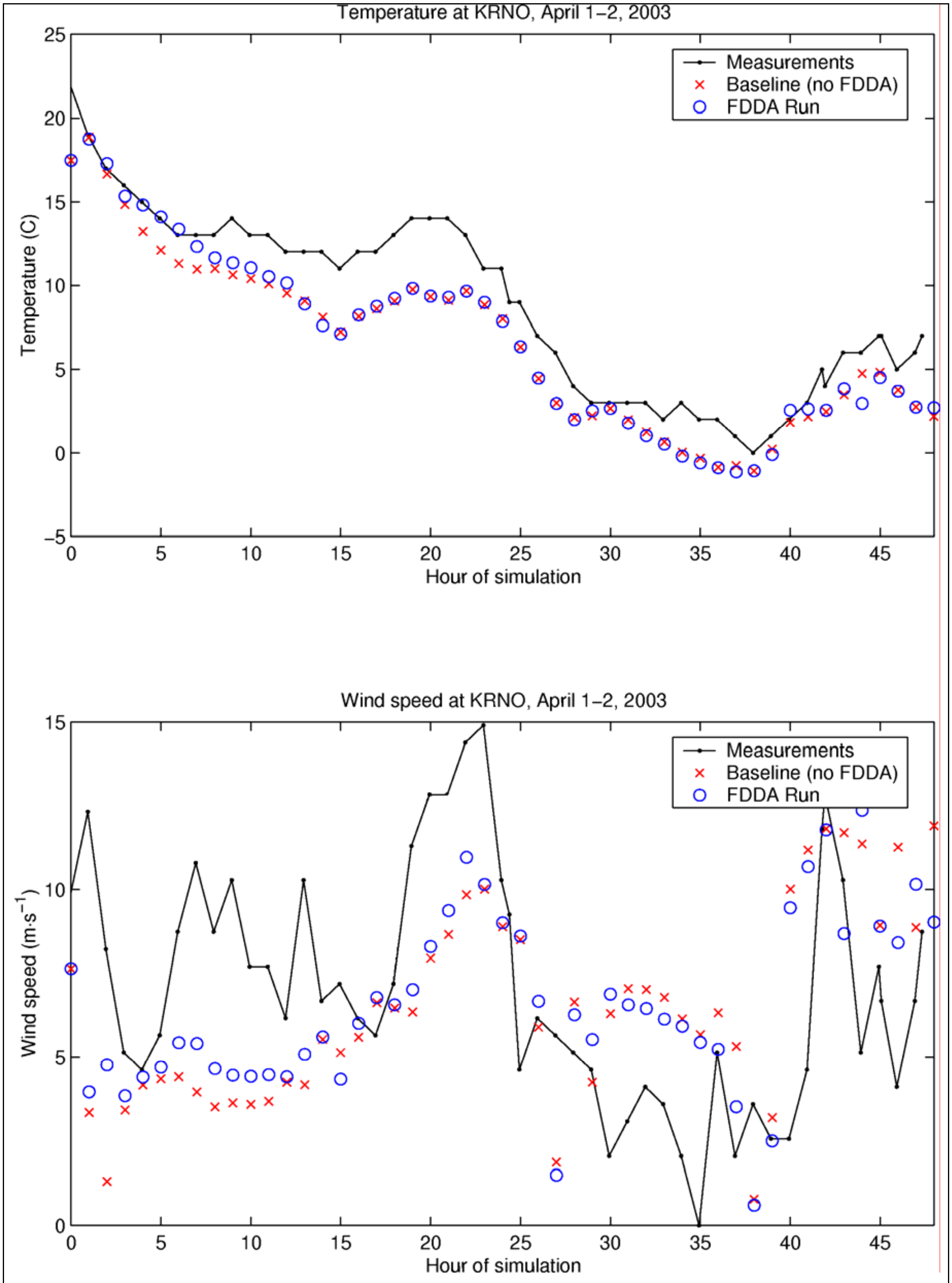


Figure 15. Time series of temperature (upper panel) and wind speed (lower panel) at the Reno, NV, station for the period from April 1–2, 2003.

DRI: Testing and Improving the NDOT Pavement Temperature Model

In the later phase of the study, researchers obtained the code for the pavement temperature forecast model. The model was installed and setup on a computer. For the remaining time on the project, researchers tested the code and examined various input data options. In particular, they focused on meteorological input parameters such as air temperature, dewpoint temperature, humidity, cloudiness, radiation, and precipitation.

NDOT has been using an IceCast^{tmi} [6] Pavement Model to coordinate its winter operations. IceCast is a numerical model of surface pavement temperature and surface conditions. This is essentially a surface-heat balance model, in which the surface temperature responds to changes in the various heat fluxes that affect the pavement. A schematic of the basic components of the model is shown in figure 16.

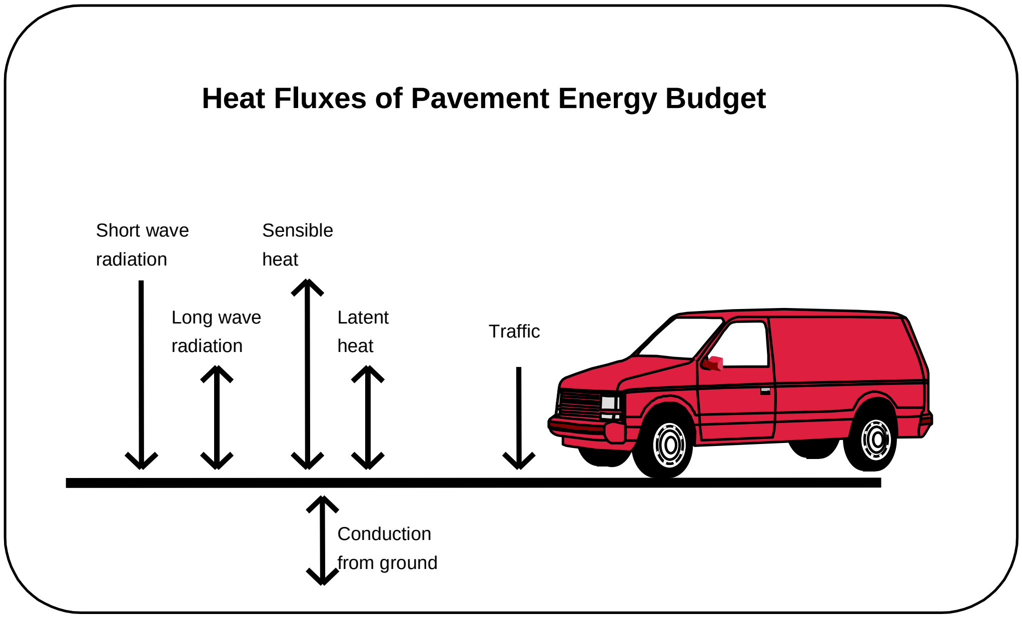


Figure 16. A schematic of the NDOT pavement temperature model with its major physical components.

The main inputs to the pavement temperature model are technological and meteorological parameters. To the authors' knowledge, the sensitivity of the forecasted pavement temperature on the meteorological inputs is not known or documented. Consequently, researchers examined the effects of changes in the meteorological input parameters on the forecasted pavement temperature obtained by IceCast. In particular, they examined how the minimum pavement temperature would change if each of the meteorological parameters was changed.

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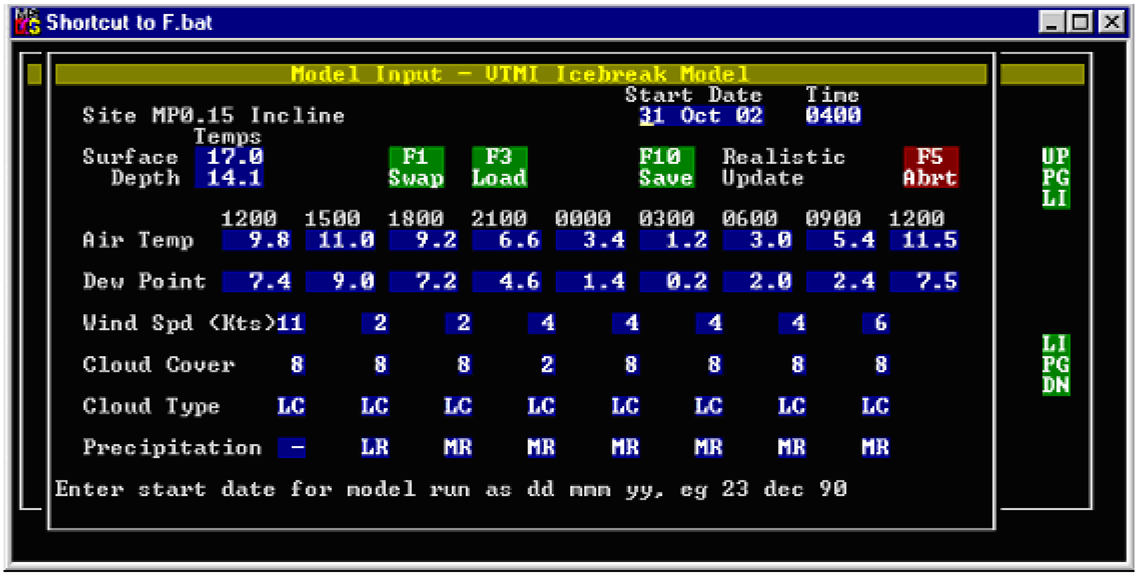
[6] IceCast^{tmi} is a pavement temperature model of the Vaisala Corporation

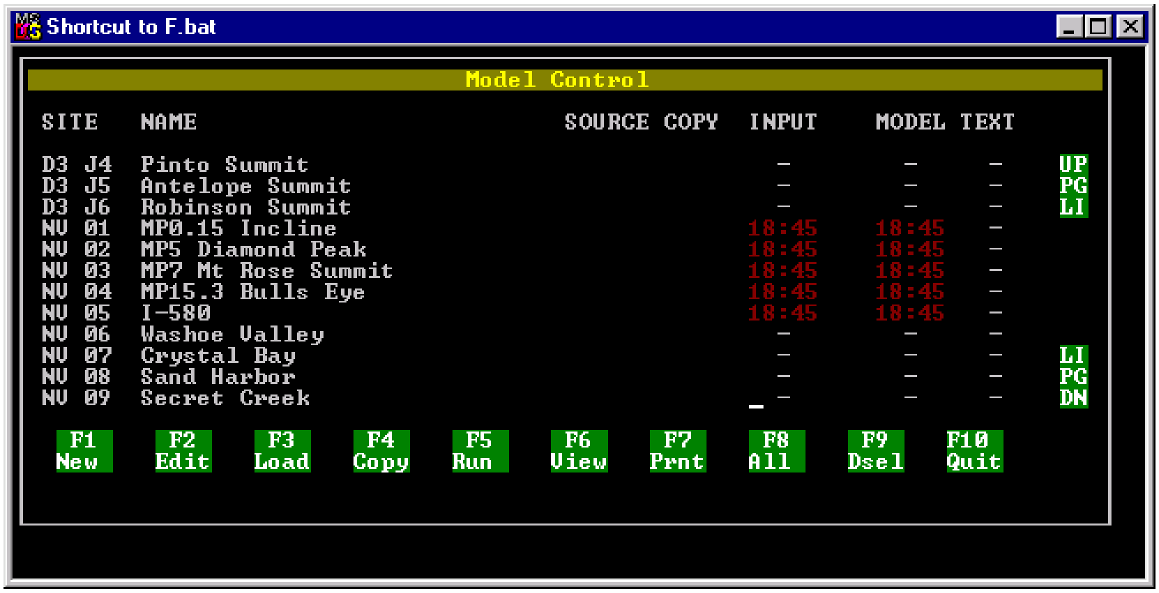
Figure 17 displays an image of a computer screen with a menu showing the main meteorological inputs to be inserted for the pavement temperature model run. The meteorological input consists of air temperature, dewpoint temperature, wind speed, cloud cover, cloud type, and precipitation intensity. These parameters must be predicted for the desired period of the pavement temperature forecasts.



```
                     Model Input - UTMI Icebreak Model
                                                 Start Date    Time
  Site MP0.15 Incline                            31 Oct 02     0400
                Temps
  Surface  17.0             F1   F3             F10  Realistic       F5
    Depth  14.1             Swap Load           Save Update          Abrt

                 1200  1500  1800  2100  0000  0300  0600  0900  1200
  Air Temp        9.8  11.0   9.2   6.6   3.4   1.2   3.0   5.4  11.5

  Dew Point       7.4   9.0   7.2   4.6   1.4   0.2   2.0   2.4   7.5

  Wind Spd (Kts)11      2     2     4     4     4     4     6

  Cloud Cover      8     8     8     2     8     8     8     8

  Cloud Type      LC    LC    LC    LC    LC    LC    LC    LC

  Precipitation    -    LR    MR    MR    MR    MR    MR    MR

Enter start date for model run as dd mmm yy, eg 23 dec 90
```

Figure 17. Computer screen with a menu for predicted meteorological parameters to be input for the pavement temperature model run.

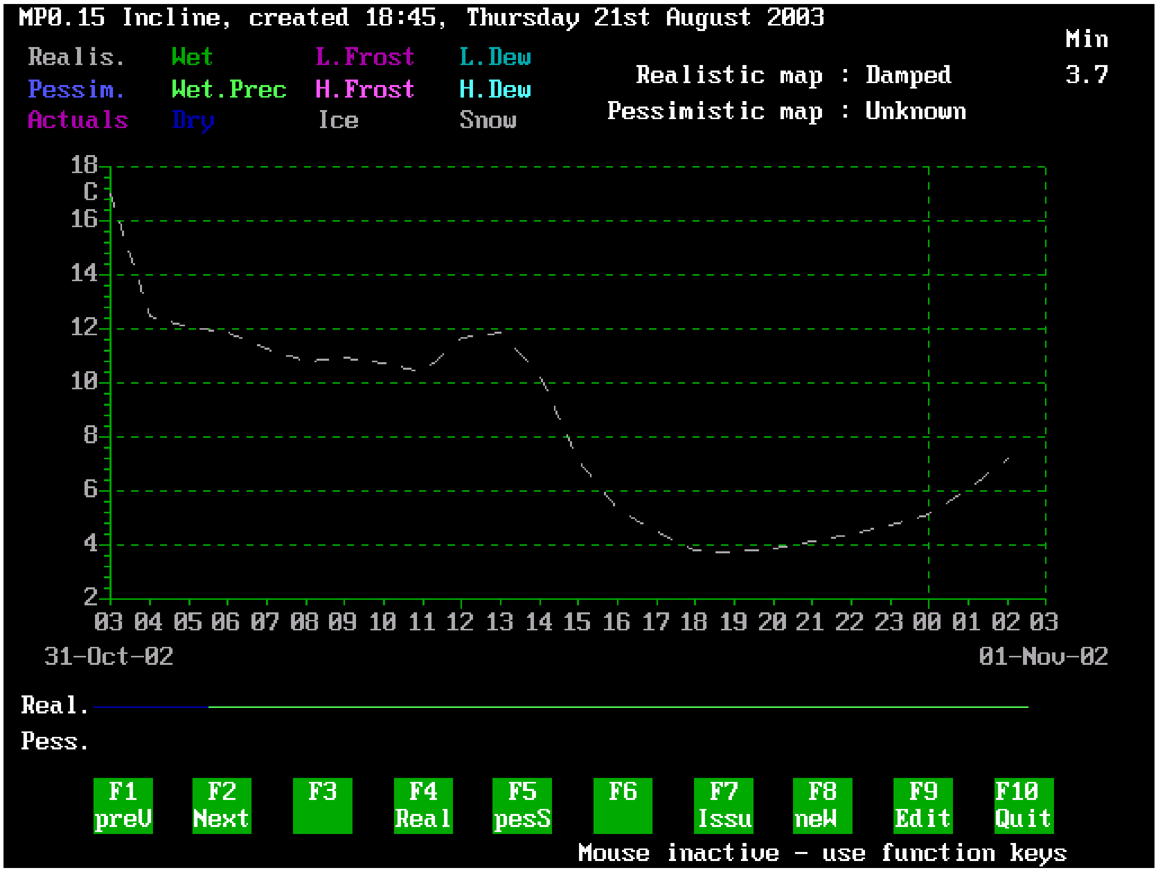
These necessary meteorological inputs have been extracted from the MM5 real-time forecasts for the period of interest at all locations at which the pavement model will generate forecasts. Figure 18 shows the stations for which the NDOT data exist for the test case.



```
                                 Model Control

 SITE   NAME                            SOURCE COPY  INPUT     MODEL  TEXT

 D3 J4  Pinto Summit                                   -         -      -     UP
 D3 J5  Antelope Summit                                -         -      -     PG
 D3 J6  Robinson Summit                                -         -      -     LI
 NV 01  MP0.15 Incline                               18:45     18:45    -
 NV 02  MP5 Diamond Peak                             18:45     18:45    -
 NV 03  MP7 Mt Rose Summit                           18:45     18:45    -
 NV 04  MP15.3 Bulls Eye                             18:45     18:45    -
 NV 05  I-580                                        18:45     18:45    -
 NV 06  Washoe Valley                                  -         -      -
 NV 07  Crystal Bay                                    -         -      -     LI
 NV 08  Sand Harbor                                    -         -      -     PG
 NV 09  Secret Creek                                   -         -      -     DN
```

Figure 18. Computer menu screen with a list of stations for which the pavement temperature forecast can be obtained.

After all data are input, the model computes the predicted pavement temperature at each of the considered stations. An example of a time series of the pavement temperature at the Incline Village station is shown in Figure 19.



MP0.15 Incline, created 18:45, Thursday 21st August 2003

Realistic map : Damped

Pessimistic map : Unknown

Min 3.7

Mouse inactive - use function keys

Figure 19. A time series of the forecasted pavement temperature at the Incline Village station for the test case for the period of 3 a.m. on October 31, 2002, to 3 a.m. on November 1, 2002.

The first step of testing the effects of the meteorological input on the pavement temperature model took the MM5 results for the first case study (March 7–9, 2002) as a baseline simulation. Then researchers changed each of the input meteorological parameters by a certain value and ran the pavement model for each of these cases. The final results are shown in figure 20. Various line colors and symbols indicate sensitivity tests in which meteorological variables were changed with respect to the baseline run. The specific change for each test is shown in the legend on the right side of figure 20. These tests resulted in a large variation in the minimum pavement temperature, ranging from –7 to –12 °C.

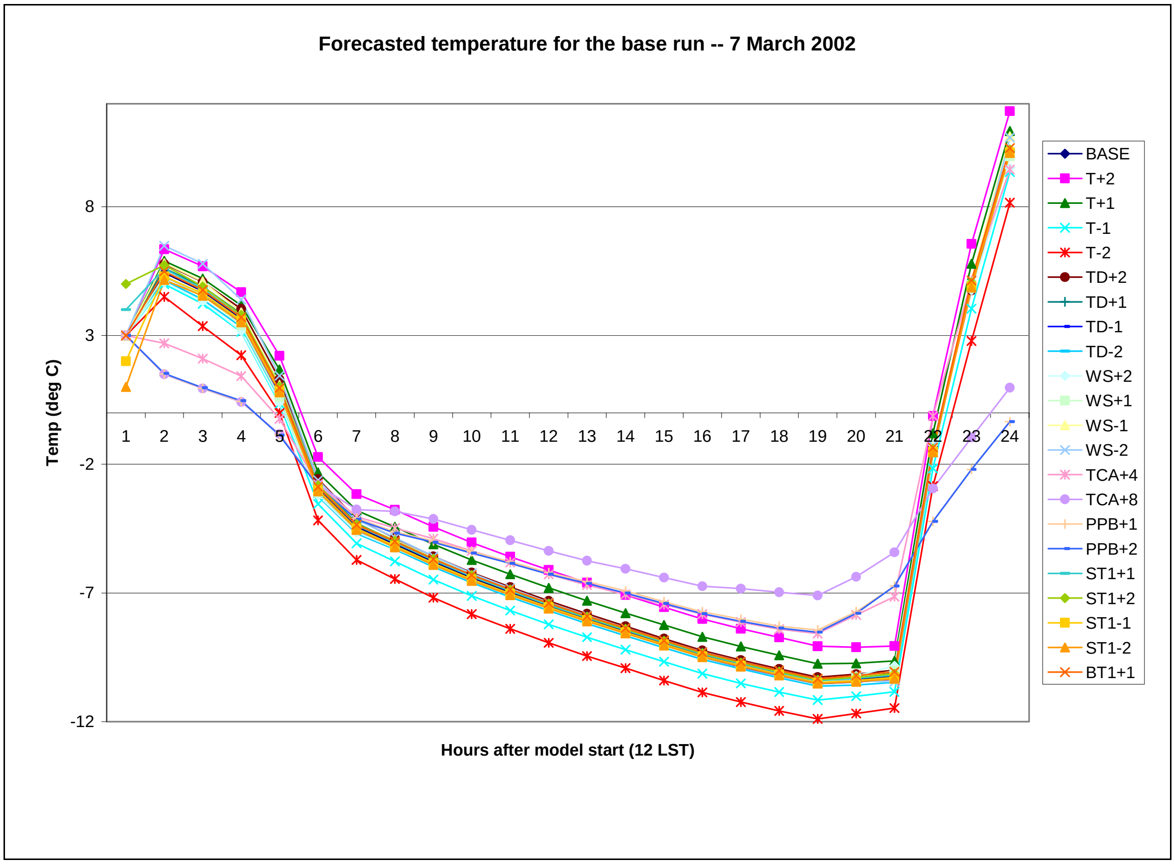
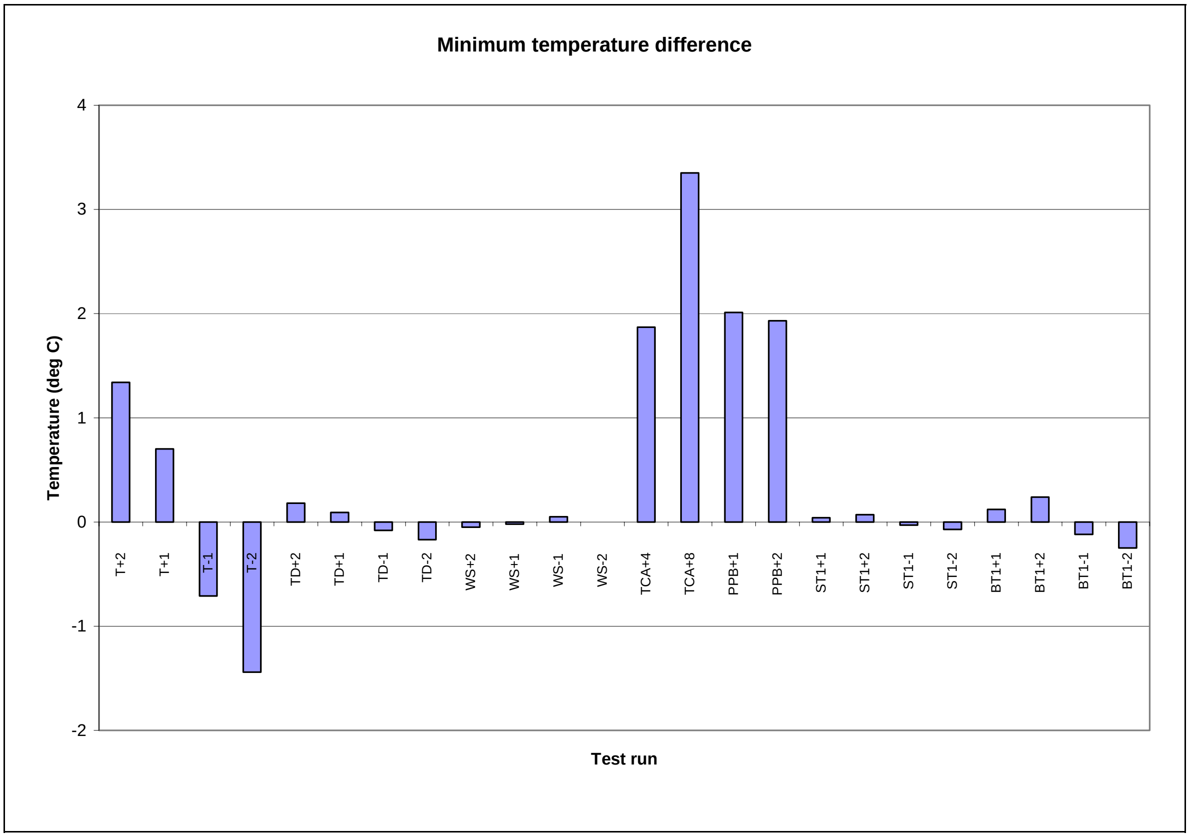


Figure 20. Time series of the pavement temperature predicted by the NDOT IceCast Pavement Model for various changes in meteorological input parameters with respect to the baseline run.

Because the minimum temperature is a crucial parameter for road conditions, researchers analyzed the effects of each input parameter on the minimum pavement temperature. Figure 21 shows results from the sensitivity tests that can be used to identify the most important meteorological inputs for the pavement temperature model.



T = temperature; TD = dewpoint; WS = wind speed; TCA = total cloud cover;
PPB = precipitation; ST = surface temperature; and BT= depth temperature (-25 cm).

Figure 21. Change of the predicted minimum pavement temperature as a function of changing meteorological inputs by step units.

Figure 21 indicates several important features. Predicted pavement minimum temperature appears to be mostly sensitive to a change in air temperature, as well as to the total cloud cover and precipitation. Inaccuracies in the air temperature of 1 and 2 °C induce a change of the minimum pavement temperature of more than 0.5 and 1 °C, respectively. Significant underestimation of precipitation can yield a change of the minimum pavement temperature of about 2 °C, while inaccurate prediction of cloudiness can yield the change of the minimum pavement temperature of more than 3 °C.

The project results were presented at meetings in Washington, DC (September 17, 2002), Albany, NY (Aurora Board Meeting, August 26, 2003), and at the 10th Annual Workshop on Weather Prediction in the Intermountain West.(2)

CHANGES TO SCOPE

Researchers completed all major components of the proposed study as stated in Section 1 and elaborated above, but did not have an opportunity to work with the NDOT to develop a travelers' forecast system. Instead, researchers developed a dedicated Web site that can be used to catalog and access the data and process them numerically and graphically.

PROBLEMS ENCOUNTERED

The main problems of establishing the NDOT data network and incorporating data into the information network were solved during the first year. However, there are still problems with data recovery, data reliability, nonexistent detailed quality check controls, and interrupted communications.

Regarding the NWS partner, the main problem was that the co-primary investigator left NWS in the summer of 2002, and the collaboration with the NWS Reno, NV, office was interrupted after her departure. Fortunately, the new Science Operations Officer at the NWS Reno, NV, office was helpful in completing the project.

Regarding DRI, the main problem was computational resources. To solve this problem, computers that run the Linux operating system will be used in the future. Researchers learned that the MM5 real-time model setup (forced by the available computer resources) with a horizontal resolution of 18 km and 6 km is not sufficient to resolve details of the mesoscale weather. Resolutions of less than 3–4 km are needed for more accurate mesoscale forecasts.

Researchers demonstrated that assimilating the NDOT data can improve MM5 real-time forecasts and consequently improve the predicted pavement temperature. However, they believe that the use of upper-air measurements such as remote sensing would provide stronger guidance to the model in improving mesoscale forecasts. Even one or two remote sensing instruments (such as wind profilers and acoustic sounders) in the mesoscale area would provide data that would most likely improve the meteorological performance. An additional benefit would be the use of the vertical profile data from these remote sensing instruments to improve NWS operational forecasts.

Links with DRI/NWS/NDOT regarding inputs and use of the NDOT pavement model for sensitivity tests using actual forecast data from the MM5 model were resolved in the final stage of the project. The pavement temperature model was obtained and sensitivity tests were performed as promised in the proposal.

Because operations is the primary line of work for NDOT and NWS, a research component that improves operations is still an additional (secondary) effort.

DIVISION OF LABOR

NDOT’s primary role was to provide access to the RWIS meteorological stations, perform and improve necessary sensors and communication protocols, and establish computer links between the DRI’s Western Regional Climate Center and NDOT. NDOT has improved the monitoring network significantly and, jointly with DRI, improved data acquisition, data processing, communication software, and the Web-based data presentation.

The NWS was responsible for assimilating data and using it in it the forecast process. This was done and continues to this day. NWS also distributes this data to other interested parties, including the University of Utah and the Western Region Climate Center. This data, when used for verification of high winds, is also archived in the Storm Prediction Center’s database as a severe weather report. NWS has gained more experience running local mesoscale models by installing the workstation Eta and MM5 on local Linux machines.

In addition to coordinating the overall project, DRI's primary role was to develop methods of using NDOT data to improve mesoscale forecasts and, consequently, the pavement temperature predictions. DRI managed to operationally incorporate and archive data from the NDOT stations into the database of the DRI Western Regional Climate Center. NDOT data is being included in the University of Utah's MesoWest database, which includes over 3000 automated sites in the western United States. This database has a wide range of uses, including initialization of local mesoscale models such as the MM5 and Meso Eta.

In addition, DRI provided guidance and assistance in designing the sampling times, requirements, and software analysis for the NDOT network data. DRI set up a dedicated Web site for NDOT data access, statistical evaluation, and graphical representation.

DRI gained significant experience and expertise in using the MM5 FDDA technique and demonstrated that the use of the NDOT data improves the accuracy of the mesoscale forecasts in complex terrain.

RECOMMENDATIONS FOR FUTURE WORK RELATED TO THIS PROJECT

Due to delays caused by some problems encountered during the execution of the projects (as described in the previous section), there are several issues remaining that should be addressed, if the funding and time are available. The main component to be completed would be to integrate the pavement temperature model with the MM5 real-time operational forecast into the unique forecasting system.

A travelers' forecast, including all aspects of road and traffic conditions, has not been realized. NDOT, NWS, and the community in general would use this forecast. Researchers will continue to work with NDOT to complete the project, which supports the NWS goal of creating new and innovative products. A Web site should be established with all relevant information on weather and road and traffic conditions. This information should be shared with broadcasting companies.

BROADER RECOMMENDATIONS

This project was a very valuable experience and provided great benefits in linking the NDOT operations, NWS forecasting, and university (DRI) research and applications. The partnerships formed for this project will be lasting and will go beyond the scope of this particular project. For future projects, it would be valuable to ensure some dedicated time to the NDOT collaborators (whose main priority is to work on direct NDOT operations) to accomplish projected objectives.

Regarding possible future projects, it would be essential to evaluate the quality of the NDOT station data and write detailed quality assurance software that continuously would report the status of all stations in real or near-real time.

A comprehensive evaluation of the use of the NDOT data and a plan for additional possible use should be conducted.

It also would be valuable to perform a comprehensive study to verify mesoscale weather forecasts and actual predictions of the pavement temperature. The particular pavement temperature model used by NDOT should be analyzed critically and compared with other pavement temperature models used worldwide. New techniques such as artificial neural networks (ANNs) should be tested as possible options and improvements.

THE NEW YORK INTEGRATED WEATHER DATA NETWORK

University: University at Albany, State University of New York (SUNYA)
Name of University Researcher Preparing Report: David R. Fitzjarrald, Atmospheric Sciences Research Center, SUNYA
NWS WFO: Albany, NY
DOT Office: New York State Department of Transportation (NYSDOT)
Name of Primary DOT Collaborators: Joe Doherty, formerly Anthony Sambuca
UCAR Award No.: S01-24243

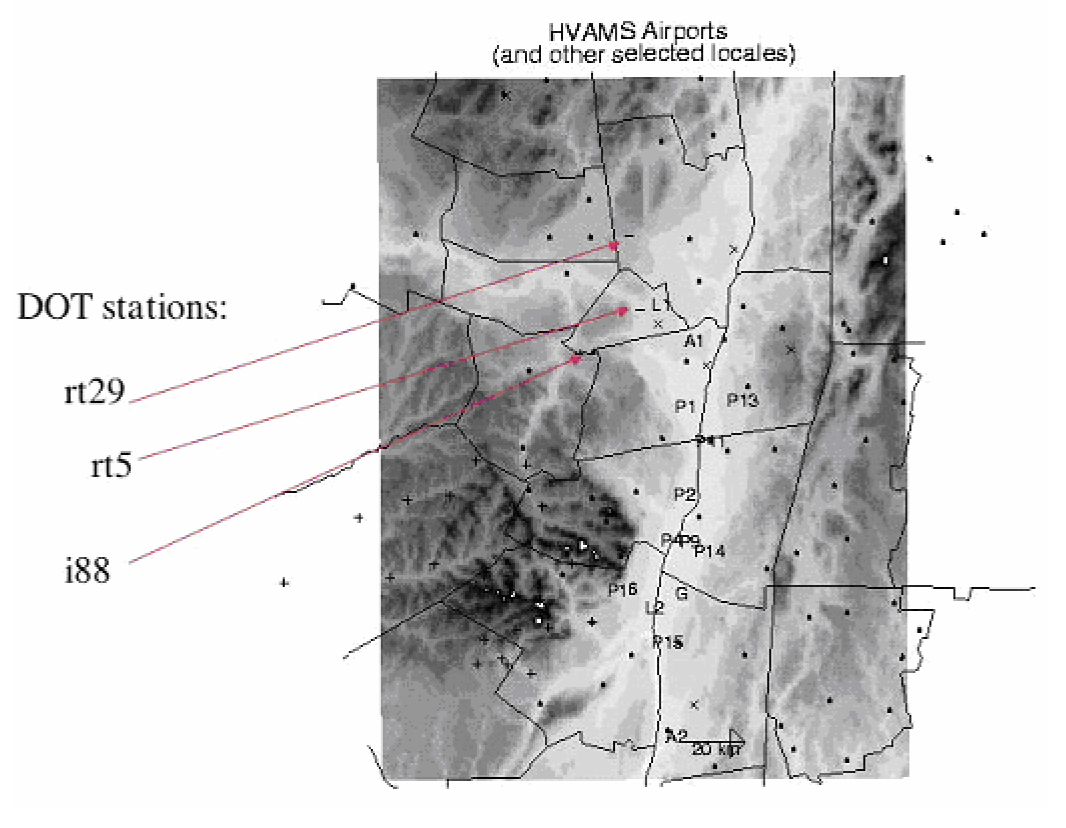
SUMMARY OF ORIGINAL PROPOSED SCOPE OF WORK

The objectives of the project were to:

- Integrate data from NYSDOT RWIS.
- Make these data available to the NWS to improve local forecasting skill. Develop initial codes to import RWIS data into standard NWS processing packages.
- Archive data for climatological purposes and to determine significant local variations in microclimate from the regional airport standard.
- Assess the quality of RWIS data to facilitate integration of surface station data from disparate sources. Establish an independent procedure for assessing data obtained by commercial RWIS stations and analyzed using proprietary software.
- Assist the NYSDOT in evaluating different low cost automatic weather stations to serve as the basis for a network of secondary road-monitoring sites.
- Understand how local obstacles can change the near-road environment.
- Identify local terrain influences on local weather.
- Exercise the State University of New York (SUNY)/National Institute of Standards and Technology (NIST)/Local Atmosphere Bridge Simulation (SLABS) model to make road surface forecasts using NWS forecast output products after a network of data are obtained.

WORK ACCOMPLISHED, PROBLEMS ENCOUNTERED, CHANGES TO SCOPE

Useful progress was made on some of the original objectives. Though the team members at NYSDOT provided steady encouragement and goodwill, they became understaffed during the course of this project. As a result, the major focus of the project shifted from the points listed above to an effort to download data from a few sample NYSDOT RWIS sites. Researchers attempted to audit data quality from the RWIS sites by comparison with nearby NWS sites (the forth objective listed). The process was done manually for the most part; details were outlined in an earlier interim report. The three stations identified in figure 22 were analyzed, and their regression statistics are shown in table 23.



Notes: Stations P1 through P9 are NCAR weather stations deployed during October 2003 as part of the SUNYA Hudson Valley Ambient Meteorological Study. Red arrows indicate stations that were compared to NWS sites.

Figure 22. NYSDOT RWIS stations for which manually downloaded data have been analyzed.

Table 3. Details of the intercomparison regression statistics (RWIS sites i88, rt5, and rt29) compared with NWS sensor at the Albany, NY airport.

Station	**Period**	**Temperature**		**Humidity**		**Wind Speed**	
		Intercept	Slope	Intercept	Slope	Intercept	Slope
i88	1- 95, 2002	-1.2	1.00	0.5	0.79	**3.1**	**0.88**
	195-366, 2002	-1.2	1.00	0.2	0.88	1.7	0.30
	1-100, 2003	-1.0	0.97	0.1	0.97	1.8	0.38
rt5	1-195, 2002	0.4	0.92	0.4	0.85	**2.6**	**0.50**
	195-366, 2002	0.3	0.93	0.3	0.87	2.1	0.14
	1-200, 2003	-0.2	0.94	0.2	0.91	2.2	0.19
rt29	1-195, 2002	-1.4	0.99	0.2	0.89	**2.1**	**0.55**
	195-366, 2002	-1.2	0.98	0.1	0.89	1.5	0.18
	1-200, 2003	-1.2	0.98	0.1	0.89	1.5	0.22

State University of New York (SUNY)

Progress was made in determining how individual RWIS station reports differ from those regularly reported by the NWS at the Albany, NY, airport. This comparison is important, because forecasters currently rely on such “Class 1” stations for information. In a companion project, the Hudson Valley Ambient Meteorological Study (HVAMS), SUNYA deployed five HOBO® weather stations and nine sophisticated surface meteorological stations on loan from NCAR (at P1–P9 in figure 22).

RWIS stations are not sited ideally for capturing wind and temperature characteristics of the wider region; in fact, they were not designed to do so. The stations are often in locations near obstacles that affect wind and temperature measurements (such as foliage, structures or terrain) (figure 23).

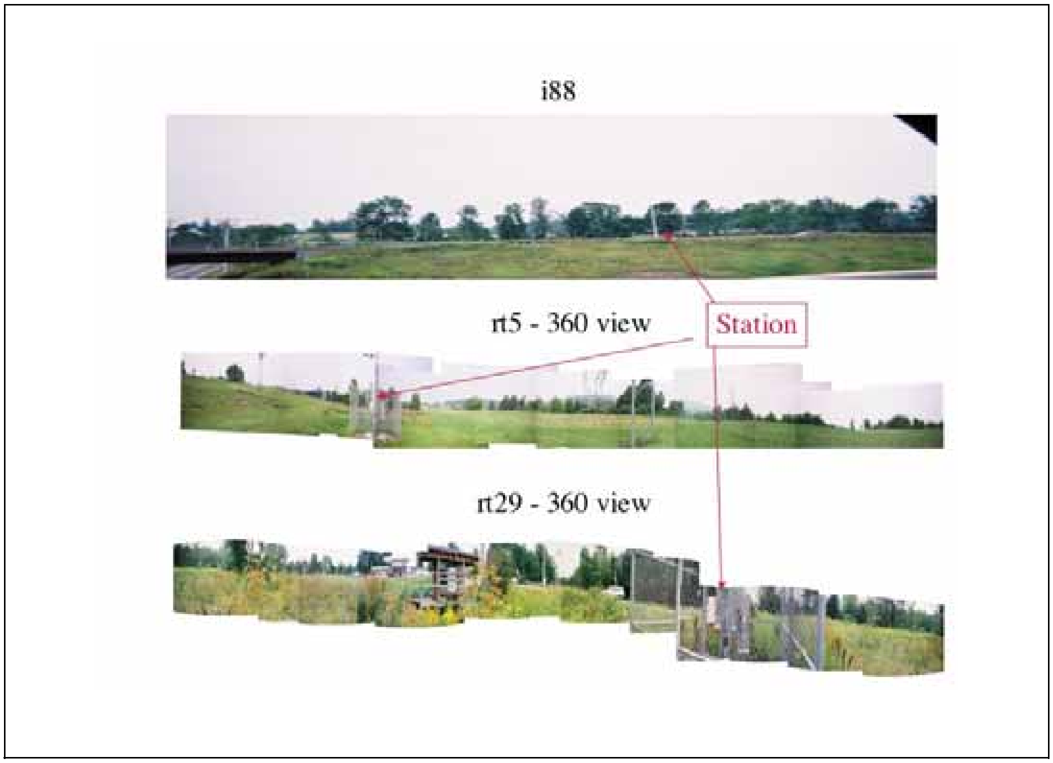
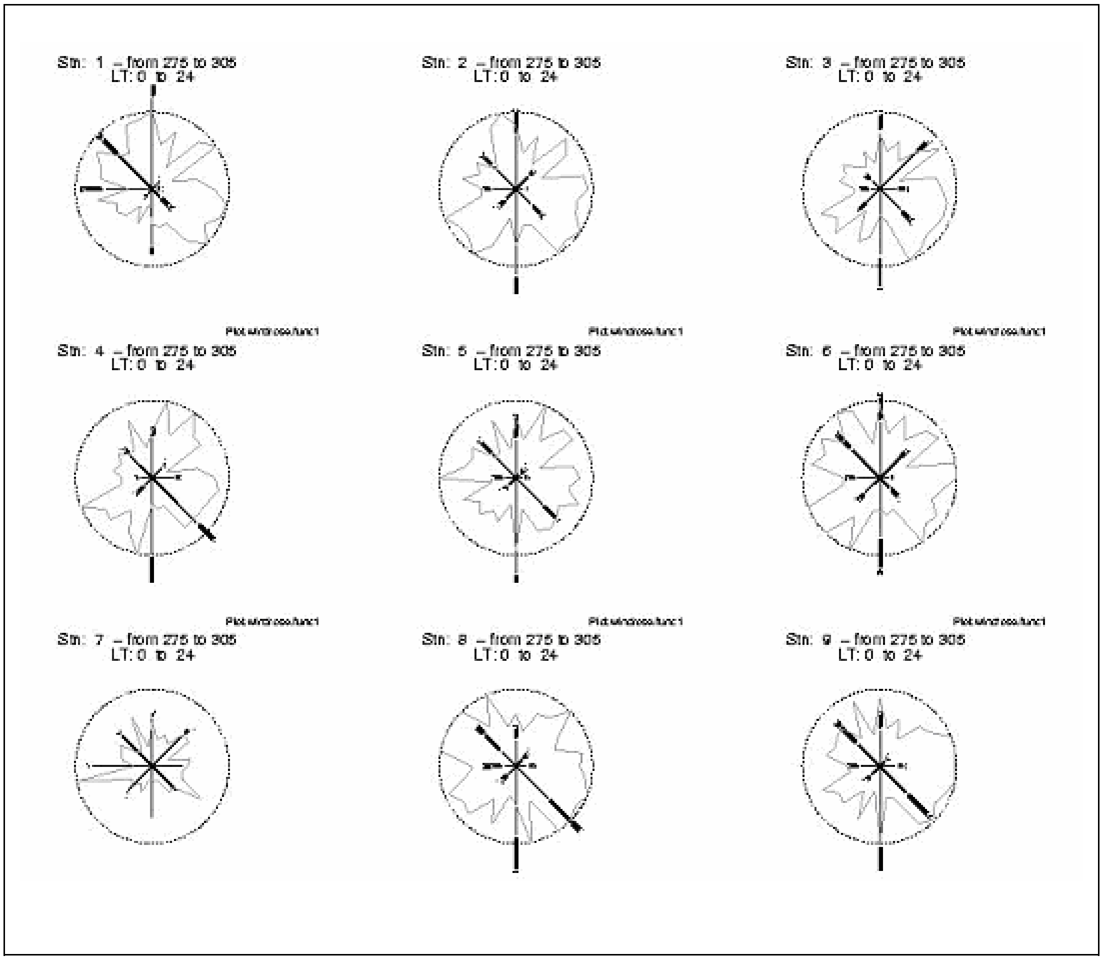


Figure 23. Panoramic views of three of the weather stations studied.

Figure 24 illustrates the kinds of analyses researchers attempted with the Statewide network of RWIS sites (the sixth and seventh objectives). Each station is illustrated by the "transmission factor" in gray (essentially the degree of blockage compared to an unobstructed station, the circle) and a "wind rose" (the solid bars) that shows the observed distribution of wind speed and direction. The key point is to illustrate the two competing ambitions inherent in this type of project. On one hand, NWS wants surface information that is as representative as possible of the area for it to be relevant to understanding the wider weather event. On the other hand, the State DOT wants to know the conditions directly at the road surface. Researchers will continue this work even though the COMET project is complete.



Notes: Stations P1 through P9 correspond to the stations depicted in figure 22. The thin gray polygon represents the transmission for wind coming from the given direction. The circle represents an ideal, representative station. The wind rose gives frequency and intensity of wind from the designated direction. Changes of line thickness indicate break points of 3 m/s.

Figure 24. Wind roses and transmission factors for surface weather stations.

One obstacle to creating the New York Integrated Weather Data Network (related to the first three objectives) is continued delays in installing new RWIS sites and issues with the older RWIS sites that remain under the proprietary SCAN® software. For 2 years, SUNYA researchers acquired data through a tedious manual process, and data quality is still not up to standard. NYSDOT personnel are aware of the problems and are working with SCAN® manufacturers as they can, in an environment of drastically reduced resources. The details of these problems were described in the COMET project interim report of August 2003.

Researchers encountered a number of difficulties dealing with the contractor for the NYSDOT RWIS sites, as detailed in the interim report. The authors believe that data acquisition glitches are not fundamental; the glitches could be resolved eventually if State DOT personnel worked more diligently with the RWIS contractor. However, this work could not be completed by the end of this COMET project. Data assembled up to this point will be folded into the other surface data obtained during HVAMS. Thus, though the project with

COMET is now over, certain aspects of the effort will continue. Data gathered to date, along with the NOAA's ASOS station reports, have been collated and are available at the researchers' anonymous file transfer protocol (ftp) site for public access.

Though NYSDOT's program to establish the network of low cost stations has been delayed indefinitely (fifth objective), making this task unachievable, researchers will continue to explore this possibility after the end of this particular grant.

In regard to the eighth objective, the plan was for SUNYA to begin research related to natural and artificial surface state prediction for the local area when the data were available in real time. SUNYA would have sought input from NWS staff in developing one-dimensional energy balance models that predict surface temperatures and state (i.e., wet, dry, icy, snowy) by determining the exchange of energy between the surface, the atmosphere above it, and the ground below it. The idea was to apply the models to both natural surfaces such as fields, and artificial surfaces such as roads, gaining valuable insight into the differences between the energy balances of different surfaces.

This work was postponed when researchers realized that the RWIS data downloads did not include information about the road surface temperature. The road temperature sensors are installed, and the observations appear in certain graphical displays. However, road temperature information did not survive the "exporting" command to the SUNYA database.

With the publication of the SUNY SLABS model paper, researchers are now in a position to apply this work to road surface state modeling.(3) However, for this and the remaining tasks not detailed, researchers cannot reasonably proceed until an archive of data from many stations is available. It was not anticipated that the major effort would be the initial data acquisition step; therefore, researchers have not been able to develop a database from a large number of stations.

DIVISION OF LABOR

In this study, the team of students and staff from the SUNYA Atmospheric Sciences Research Center (ASRC) did most of the data acquisition and analysis work. Throughout the project, NYSDOT personnel were very cooperative. In November 2002, NYSDOT contracted consultants to facilitate data availability. These consultants visited ASRC/SUNYA and the NWS WFO in Albany, NY; there was a subsequent meeting to solidify data requests. This work is still ongoing. Through the NYSDOT efforts, researchers logged onto NYSDOT computers, downloaded data from a small number of stations, and established the protocols for possible future work. One NWS partner helped demonstrate how additional surface information could be integrated into the NWS standard.

RECOMMENDATIONS FOR FUTURE WORK RELATED TO THIS PROJECT

The SUNYA team will continue to work with the RWIS data it has. Without explicit resources, this will be done as work that can serve several broader goals. After the NYSDOT RWIS data network matures and data are readily available, the team will return to this problem.

BROADER RECOMMENDATIONS

This effort shows that the same data can serve several disparate purposes. Both NYSDOT and NWS have mandated responsibilities that require them to maintain a narrowly defined view regarding how data are managed. The mandates of weather forecasting and road surface treatments lead both institutions to seek real-time displays of information, and they have less interest in the history of events. The key element is to identify repeated patterns, such as stretches of roads prone to weather-related difficulties, and use this selective microclimatology to make generalizable models of road state and local meteorological effects that benefit both operational groups.

APPLICATION OF LOCAL DATA ASSIMILATION IN COMPLEX TERRAIN

University: University of Utah, Cooperative Institute for Regional Prediction
Principal Investigators: John Horel, Mike Splitt, CIRP
NWS WFO: Salt Lake City, UT
Name of Primary NWS Collaborator: Larry Dunn
DOT Office: Utah Department of Transportation
Name of Primary DOT Collaborators: Ralph Patterson, and formerly Steve Conger
Cooperative Project, UCAR Award No.: S01-24244

SUMMARY OF ORIGINAL PROPOSED SCOPE OF WORK

This study expanded work originally funded by the Utah Department of Transportation (UDOT), "Implementing Roadway Weather Information Support Management of Winter Maintenance," UDOT Contract No. 98-8298. That project helped coordinate and identify weather resources in Utah pertinent to winter road maintenance. Results from that study were presented at a special session on the RWIS at the AMS Interactive Information and Processing Systems Conference (IIPS).(4) As a result of previous work, researchers began this project having worked toward several of the objectives of the FHWA, NWS and COMET programs. For example, they had already established cooperative working relations between State DOTs, the university community, and WFOs. They also had fostered an open repository of RWIS observations that were integrated with other weather observations around the West as part of the MesoWest project.(5)

The specific goals of this project were to:

- Facilitate and improve access to RWIS observations in Arizona, Idaho, Nevada, Montana, Utah, and Wyoming.
- Evaluate special weather statements for the 2002 Winter Olympics and Paralympics to be issued by the Salt Lake City, UT, WFO on hazardous winter weather along major transportation corridors in northern Utah.
- Develop and evaluate RWIS applications of weather data in areas of complex terrain on the basis of local data assimilation.
- Establish guidance on factors that affect the utility of environmental sensor stations (ESS) and weather observations for RWIS decision making in complex terrain.

WORK ACCOMPLISHED

Access to RWIS Observations

A major accomplishment of this project was to continue to facilitate and improve access to RWIS observations in the western United States. Figure 25 shows the locations of RWIS stations from which weather information is obtained routinely (additional road state information is available from many of these stations, as well). Researchers currently collect, archive, and disseminate RWIS information from stations in California, Colorado, Idaho, Montana, Nevada, Oregon, Utah, Washington, and Wyoming, for a total of 6,000 stations in the West.

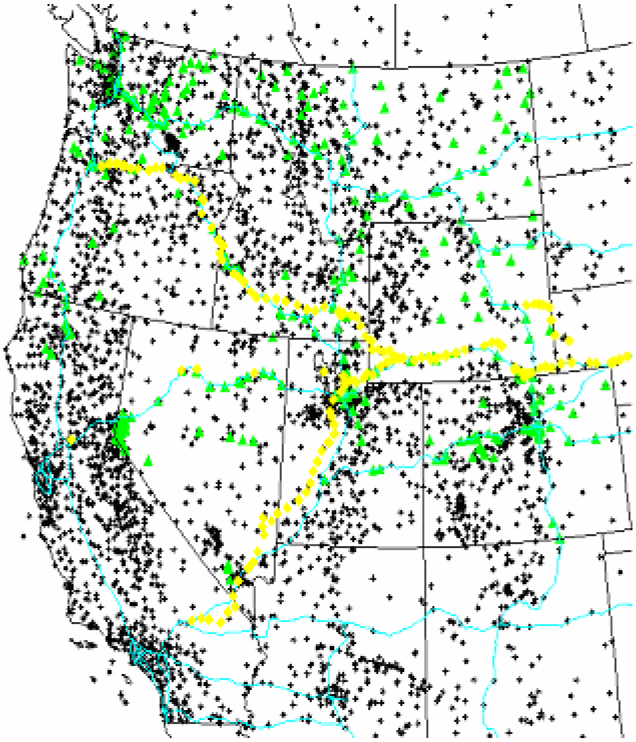


Figure 25. Locations of MesoWest stations (plus symbols), RWIS stations (green triangles), and Union Pacific Railroad stations (yellow diamonds).

The scope of data collection efforts expanded as opportunities to collaborate with State DOTs developed. This component of the study represents the largest fraction of effort. The following summarizes this ongoing data collection effort.

California: The Meteorologist-in-Charge at the Eureka, CA, WFO provided the initial contact with the California Department of Transportation (CalTrans) representatives in northern California to facilitate access to 11 stations along I-5 north of Redding, CA. Updates every 30 minutes are available via ftp.

Colorado: NOAA Forecast Systems Laboratory (FSL), as part of the Meteorological Assimilation Data Ingest System (MADIS), in cooperation with the Boulder, CO, WFO, provides access to Colorado DOT observations from 55 stations. The data are distributed via Unidata's Local Data Manager (LDM). In addition, winter road maintenance observations in support of avalanche control work are collected in cooperation with the Grand Junction, CO, WFO. As part of this project, researchers helped install software at the Grand Junction WFO to dial weather stations at several mountain passes, and researchers continue to help the WFO troubleshoot problems in data collection as they occur.

Idaho: Part of this project involved considerable effort to develop software to collect RWIS data (weather and road state) from the Idaho Transportation Department (ITD). This initially involved writing software and installing that software on an ITD computer. ITD now has installed a system to collect the data, which is accessed via ftp. ITD depends on MesoWest for access to real-time weather information for its Road Weather Integrated Data System (see http://164.165.237.41/RWIDS_Public/default.asp). Activities as part of this project in support of ITD were second only to that provided to the UDOT.

Montana: The Montana Department of Transportation (MDT) and Great Falls, MT, WFO have collaborated for years to share weather and road state information. Researchers obtain the weather and road state data from 59 stations via LDM and have worked with MDT personnel to identify data quality problems as they become evident.

Nevada: Data from 47 stations in Nevada are obtained via ftp from NDOT. Staff at the DRI and the Reno, NV, WFO have facilitated this work.

Oregon: Staff at the Pendleton, OR, WFO helped facilitate access to weather information at 28 stations supported by the Oregon Department of Transportation (ODOT). The weather information is collected via access to the DOT Web server.

Utah: Researchers worked closely with UDOT to facilitate access to weather and road state information at 53 locations around the State. Information is collected directly via ftp from a RWIS server supported by UDOT, as well as through a computer at the Salt Lake City, UT, WFO.

Washington: Weather and road state information are collected from 72 stations maintained by the Washington State Department of Transportation (WSDOT). These data are accessible as a result of the efforts of staff at the Seattle, WA, WFO and the University of Washington. The data is collected via ftp from the University of Washington.

Access to Union Pacific Railroad Observations

As shown in figure 25, researchers obtained access to weather information at 264 locations along the major Union Pacific rail corridors in the West. Most of the stations report temperature only (to detect track contraction/expansion), and wind conditions are reported at many critical locations.

Data Handling Issues

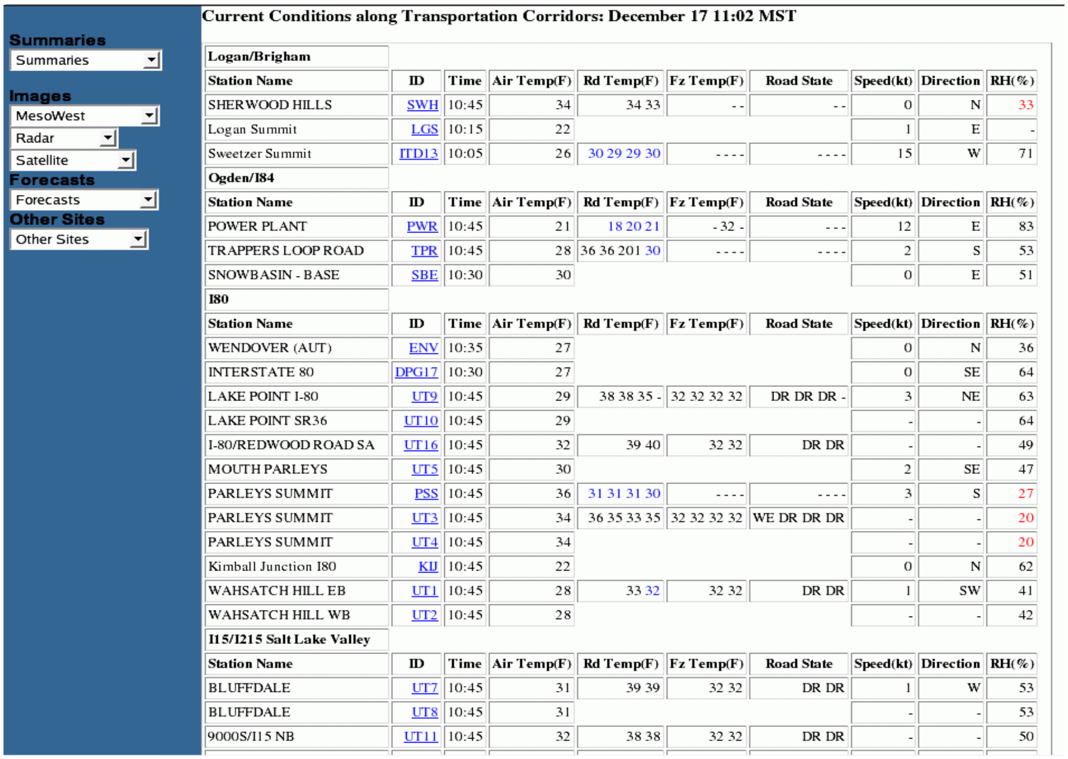
Because MesoWest was a well-established database, researchers were experienced in handling data in a variety of formats and implementing a quality control program. Quality control procedures based on three-dimensional linear regression have been implemented to assess temperature, dewpoint temperature, and pressure. Researchers improved simple checks for wind data (gust to sustained wind ratio, for example) so that poor wind observations could be identified. Precipitation is the most difficult to manage; this was left to the data providers.

Olympic Weather Support

The NWS, UDOT, and University of Utah worked closely to provide weather and road state information as well as forecasts to Olympic organizers, public safety personnel, and the public for the 2002 Winter Olympics and Paralympics.(6) Many different representatives of organizations related to the Olympics judged these efforts to be highly successful. Formal evaluation of the NWS weather forecasts issued along the transportation corridors was not pursued.

MesoWest RWIS Data Interface

A specialized Web interface to the MesoWest database (www.met.utah.edu/mesowest) was developed and maintained for UDOT personnel to use. This interface has been used extensively for winter road maintenance as well as road construction and summer paving projects. An example of the summary of current conditions is provided in figure 26.



Current Conditions along Transportation Corridors: December 17 11:02 MST

Logan/Brigham

Station Name	ID	Time	Air Temp(F)	Rd Temp(F)	Fz Temp(F)	Road State	Speed(kt)	Direction	RH(%)
SHERWOOD HILLS	SWH	10:45	34	34 33	- -	- -	0	N	33
Logan Summit	LGS	10:15	22				1	E	-
Sweetzer Summit	ITD13	10:05	26	30 29 29 30	- - - -	- - - -	15	W	71

Ogden/I84

Station Name	ID	Time	Air Temp(F)	Rd Temp(F)	Fz Temp(F)	Road State	Speed(kt)	Direction	RH(%)
POWER PLANT	PWR	10:45	21	18 20 21	- 32 -	- - -	12	E	83
TRAPPERS LOOP ROAD	TPR	10:45	28	36 36 201 30	- - - -	- - - -	2	S	53
SNOWBASIN - BASE	SBE	10:30	30				0	E	51

I80

Station Name	ID	Time	Air Temp(F)	Rd Temp(F)	Fz Temp(F)	Road State	Speed(kt)	Direction	RH(%)
WENDOVER (AUT)	ENV	10:35	27				0	N	36
INTERSTATE 80	DPG17	10:30	27				0	SE	64
LAKE POINT I-80	UT9	10:45	29	38 38 35 -	32 32 32 32	DR DR DR -	3	NE	63
LAKE POINT SR36	UT10	10:45	29				-	-	64
I-80/REDWOOD ROAD SA	UT16	10:45	32	39 40	32 32	DR DR	-	-	49
MOUTH PARLEYS	UT5	10:45	30				2	SE	47
PARLEYS SUMMIT	PSS	10:45	36	31 31 31 30	- - - -	- - - -	3	S	27
PARLEYS SUMMIT	UT3	10:45	34	36 35 33 35	32 32 32 32	WE DR DR DR	-	-	20
PARLEYS SUMMIT	UT4	10:45	34				-	-	20
Kimball Junction I80	KIJ	10:45	22				0	N	62
WAHSATCH HILL EB	UT1	10:45	28	33 32	32 32	DR DR	1	SW	41
WAHSATCH HILL WB	UT2	10:45	28				-	-	42

I15/I215 Salt Lake Valley

Station Name	ID	Time	Air Temp(F)	Rd Temp(F)	Fz Temp(F)	Road State	Speed(kt)	Direction	RH(%)
BLUFFDALE	UT7	10:45	31	39 39	32 32	DR DR	1	W	53
BLUFFDALE	UT8	10:45	31				-	-	53
9000S/I15 NB	UT11	10:45	32	38 38	32 32	DR DR	-	-	50

Figure 26. Summary of current weather and road state in Utah available in MesoWest.

Local Data Assimilation

Researchers developed anisotropic weighting functions for the ADAS data assimilation system.(7) These anisotropic weights are critical to resolving a systematic source of error in the analyses where weather observations in one valley affect the analysis in adjacent valleys.(8) This error is particularly problematic because a forecast model at very high resolution will resolve the weather in adjacent valleys independently. However, observation corrections to the initial background field obtained from a model can bleed laterally through the terrain. This affected the suitability of the analyses along some transportation corridors.

The NWS is interested in data assimilation efforts over complex terrain to initialize and validate Integrated Forecast Preparation System (IFPS) gridded forecasts at WFOs around the West. The support from COMET helped develop ADAS further for these applications.

RWIS Decision-making

In part as a result of the increased data collection efforts, less effort was placed on evaluating the utility of RWIS observations in the decisionmaking process. Questionnaires were distributed to winter maintenance personnel during the 2001 winter season to collect information on the utility of local RWIS data. Preliminary analysis of data collected from shed foremen in Idaho, Montana, and Utah during the following spring was inconclusive; therefore, this effort was suspended for the 2002 winter season.

PROBLEMS ENCOUNTERED

Access to RWIS data in some States was difficult to obtain. Researchers were not able to develop contacts at the CalTrans district level in many parts of California, waited several years to access RWIS data from Arizona, and have not identified an appropriate contact in New Mexico.

DIVISION OF LABOR

The greatest level of interaction between the Salt Lake City, UT, WFO, UDOT, and University of Utah took place during the first year of the project as a result of the need for preparation and coordination of research, development, and operations for the 2002 Winter Olympics and Paralympics. The interaction was very positive and beneficial to all three organizations. A major goal of the Olympic weather support effort was to provide a legacy of improved understanding of winter storms and enhanced capabilities to predict weather in the region. This legacy is in place in part because of projects such as this.

RECOMMENDATIONS

The FHWA/NWS COMET program provided a framework to approach State DOTs to share weather and road state information. However, support to sustain this effort is unclear. Ways to sustain this effort are being explored initially with UDOT and ITD through their participation in the Cooperative Institute for Regional Prediction (CIRP) Consortium. CIRP has developed innovative tools to conduct research and assist government and commercial operations that are sensitive to weather around the Nation, in part with funding from research and development efforts supported by the NWS, FHWA, and other agencies. These tools include MesoWest, which provides real-time monitoring and analysis of environmental conditions, and the authors' data assimilation and modeling efforts. The CIRP Consortium was established to further develop and apply these tools for the unique environmental problems of the Intermountain West and other regions of the Nation. The consortium is intended to provide support for the continued real-time operations of MesoWest and provide the foundation for further applied research and development related to real-time weather and emergency management operations, air quality, fire weather, winter road maintenance, wind power, and water resource management. The CIRP Consortium is modeled after the Northwest Regional Modeling Consortium developed at the University of Washington.

The initial feedback from UDOT and ITD to the Consortium funding approach is favorable. However, is it reasonable to expect those States to fund researchers' efforts to access weather and road state information in other regions of the West? There is a clear need for FHWA and NWS to support data collection efforts on a national scale that relies, in part, on the local partnerships that already exist in some regions of the country.

Further research is also required to improve the utility of local analysis and forecast grids for road weather applications. The NDFD under development by the NWS potentially provides a tool to improve road weather decision-making. However, a number of technical issues must be resolved regarding how to best to use that information.

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ADDITIONAL PUBLICATIONS AND CONFERENCE PRESENTATIONS

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