COMET – FHWA/NWS Collaborative Project

Use of Road/Weather Information System in the Improvement of Nevada Department of Transportation Operations and National Weather Service Forecasts in the Complex Terrain of Western Nevada

Final Technical Report (April 2001 – April 2003)

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1. Summary of original proposed scope of work

According to our proposal, the primary goals of this project were to 1) improve pavement forecasts through improved model input; 2) improve NWS operational forecasts through better model guidance; 3) improve operational decisions regarding snow and control operations; and 4) develop an NDOT public travelers forecast.

The proposed project was originally divided into the following primary tasks relating to the objectives stated above:

1.1 Acquire and organize relevant data sets. /NDOT, DRI, and NWS/
1.2 Assimilate the NDOT data into Mesoscale Model 5 (MM5). /DRI and NWS/
1.3 Test improved pavement forecasts. /DRI and NDOT/
1.4 Implement data assimilation techniques into local NWS MM5 model. /NWS and DRI/
1.5 Test real-time MM5 model output for pavement temperature model. /DRI and NDOT/
1.6 Develop pavement travelers' forecasts. /NDOT and DRI/
1.7 Write project reports, participate in seminars, workshops and use project results for thesis. /DRI, NWS, and NDOT/.

2. Work accomplished, changes of scope, and problems encountered

Work accomplished

This multi-disciplinary project was a valuable experience for the collaborating partners: the Nevada Department of Transportation (NDOT), the National Weather Service (NWS)

– Reno Office, and Desert Research Institute (DRI). The project resulted in significant advancements by accomplishing the following proposed main objectives:

NDOT perspective:

- Provide high quality meteorological data from the operational network of Nevada Department of Transportation RAWIS stations.
- Integrate the data from the NDOT station network to be used for improving NDOT operations as well as for possible larger community use.
- Understand the input uncertainties and provide guidance on improving NDOT pavement temperature forecasts.

NWS perspective:

- Improve the operational mesoscale/regional scale forecast at the NWS Office in Reno.
- Use the NDOT operational network for model evaluation and weather watch warnings.

DRI perspective:

- 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 System to improve Mesoscale Model 5 (MM5).
- Provide a sensitivity study of the Pavement Temperature model predictions on input meteorological parameters.

a) 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 as well as traffic and economics. To address this issue, NDOT has implemented a variety of snow and ice control strategies including the development of a Road/Weather Information System. This system includes a network of remotely located environmental sensor stations which collect, process, and disseminate information on road and weather conditions relevant to highway transportation.

Several major questions are arising:

- 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 projects, we established the links and datastream 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: http://www.ndot.dri.edu

This site provides a graphical display of the data interactively with the user/visitor. It is in continuous operation and is set up to receive all available NDOT data in two different formats and sampling intervals (10 and 15 min). We are also archiving the incoming data. We 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. Online access to the DRI web site allows statistical and graphical analysis of current and past data including time series, wind roses, monthly and daily statistics, and downloading data of interest. Figure 1 shows the main page of the web site with stations that are available for statistical and graphical analysis.

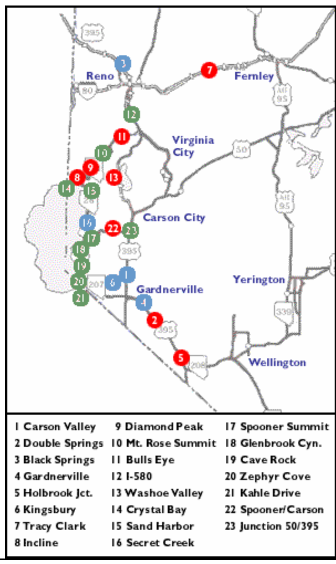

Fig. 1. Locations of the NDOT stations that are available for analysis on the DRI web site.

Recently, NDOT has undertaken major steps in organizing the network of their operational stations. Eleven sites have been upgraded and five new sites have been completed. The Remote Processing Unit (RPU) type was upgraded from the Zeno or Milos models to the ROSA RPU. The Zeno RPU's were used with the Coastal system which is now defunct.

The Milos system will soon be obsolete and replacement parts will be unavailable. However parts salvaged from the sites that were upgraded will be available for trouble shooting the remaining sites operating on the Milos RPU's.

The eleven 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 US395/US50 junction. The five new sites that are now functional include Highland Flats, I-580 at the NDOT Reno yard, Moundhouse, Toulon, and Walker Lake. These sites now bring the number of operational sites to twenty-one in District II. Eight sites are operational in District III and work continues to bring additional sites on line.

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

b) NWS - Use of NDOT data to improve mesoscale forecasts in complex terrain

The first goal was establishment of a data assimilation system. This was the most difficult goal due to the state of technology when the project started. Frequent computer crashes and dial-up modems between the NWS and NDOT provided significant challenges to the IT staff of both NWS and NDOT. By the second year of the project FTP procedures were set up and faster computers installed at both NWS and NDOT. Data assimilation became reliable after that. Archiving the data was done by both NWS and DRI at the Western Region Climate center.

The collection of this data continues today and has been expanded to other areas of the state outside of the local Reno mesonet area. This is a change in scope to this project that 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 the NWS is in the process of implementing a National Digital Forecast Database. The proposal mentioned the resolution of this database would be <10km and indeed at this time it is at 2.5 km and will be reduced to 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 9 km resolution and hourly time steps for some of the sensible weather elements in the NDFD, including wind and temperatures. Another item beyond the scope of this proposal is the use of NDOT data in the University of Utah's ADAS model which has become a starting point for gridded verification. The data from NDOT is put into this model through the MesoWest database.

Verification of high wind warnings and improvement to fire weather forecasts came as a direct result of this data.

c) DRI - Use of 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 Mesoscale Model 5 (MM5) at DRI. A schematic of the data assimilation and the weather forecasting system that uses NDOT data to improve model initial conditions is shown in Fig. 2. The improved weather forecasts can be then used to improve the NDOT Pavement Temperature Model.

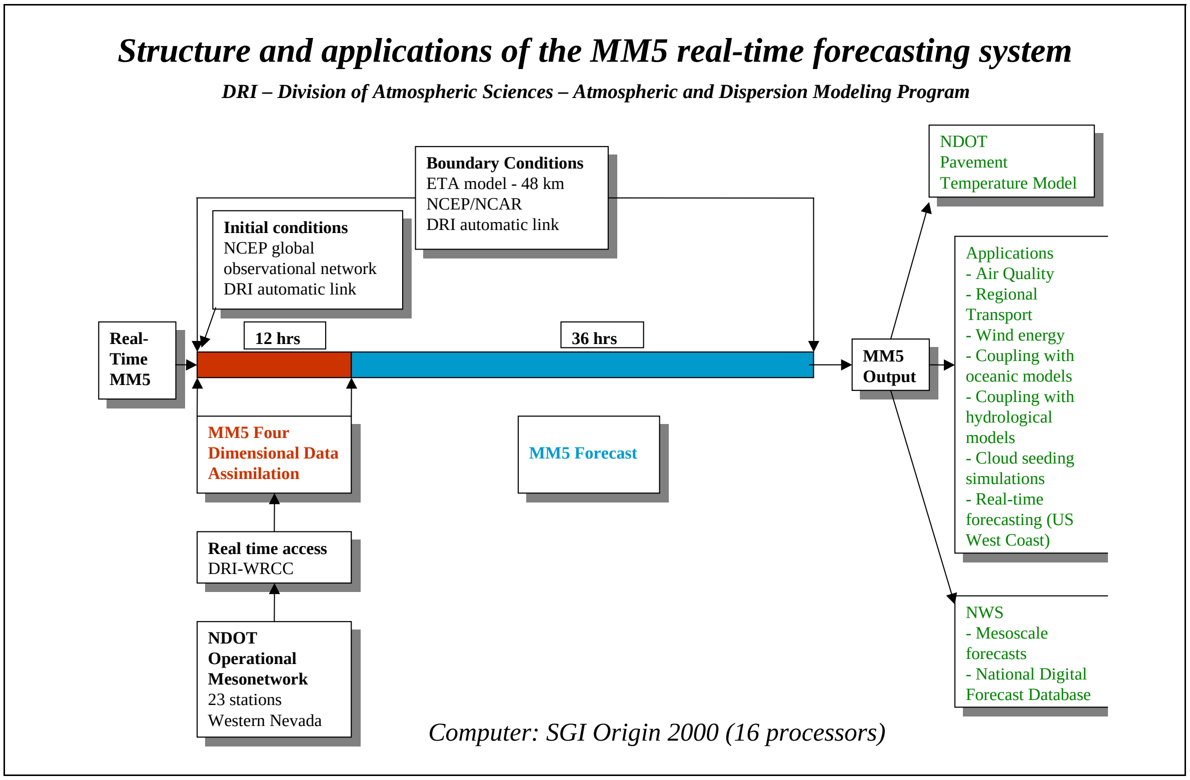

Fig. 2. A schematic of the DRI-developed real-time forecasting system that assimilates NDOT data in the first 12 hrs of the pre-forecasting time.

To achieve the proposed objectives of the study, we applied our developed system shown in Fig. 2 to two winterstorm cases. The forecasting periods were:

- 7-9 March 2002
- 1-2 April 2003.

CASE 1: Mesoscale modeling using NDOT data for 7-9 March 2002

Since the reporting and quality of data improved in the beginning of 2002, we focused our Four Dimensional Data Assimilation tests on a case study of a significant snowstorm that occurred during 7-9 March 2002. During that time, 11 stations were reporting and their data were available to us. In addition to the NDOT and NWS stations, during the same period the Integrated Sounding System field program in the Reno and Washoe basins was being conducted by the National Center for Atmospheric Research, Boulder, Colorado, and DRI. At two locations surface and upper air measurements were conducted from 26 February to 26 March 2002.

A heavy snowstorm occurred in the Sierra Nevada Mountains during 6-8 March 2002 and a maximum snow-water equivalent of 30.7" was measured on 8 March at the Central Sierra Snow Lab in the area of Donner Pass. A frontal system passed over the Reno area on 8 March at 02 UTC with measured rain amounts of 0.2 to 0.4". 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 6 March and propagated into the Reno area later on 7 March. Severe driving conditions on I-80 due to gusty winds and snow were reported in the area, especially east of Reno near Fallon.

This snowstorm event has been simulated with the DRI Mesoscale Model 5 (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 Fig. 3.

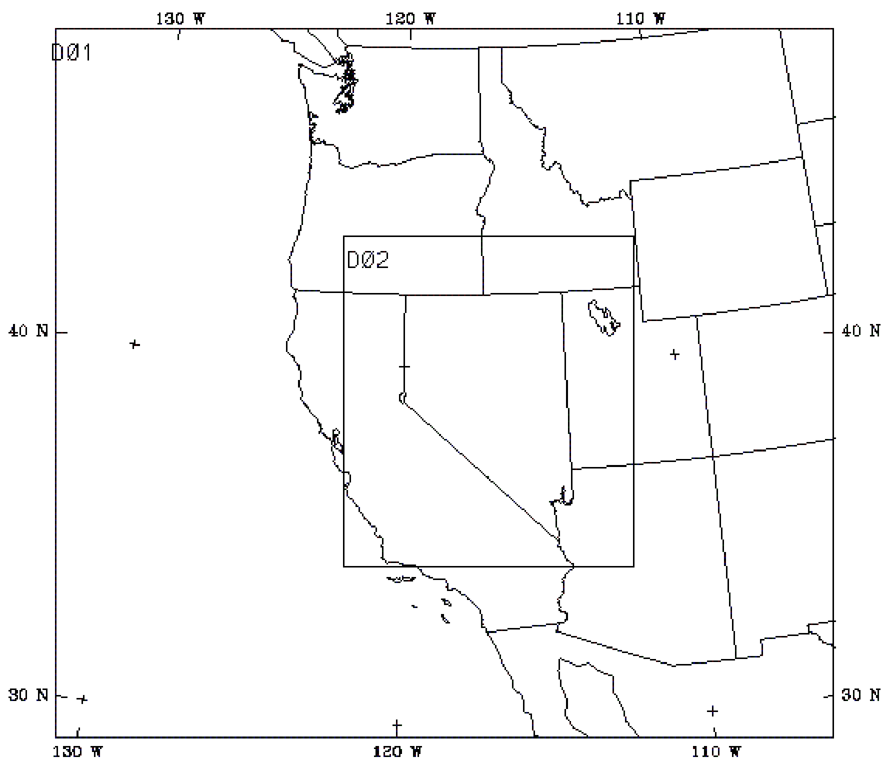

Fig. 3. Geographical setup of the real-time MM5 forecasting domains.

The model was able to forecast a frontal system passing through Reno on 8 March 2002 between 00 and 02 UTC. The main objective of the study in this period was to use Four Dimensional Data Assimilation to improve the accuracy of the MM5 forecasts. Our 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. In addition, it is important to use an optimum set of stations; however, it should be emphasized that each of the surface stations has microlocation specifics and generally is not representative for the larger area that needs to be captured by the model. Figure 2 shows a time series of wind speed 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 various FDDA runs with varied nudging coefficients, radii of influence, and number of selected stations entered into the FDDA system.

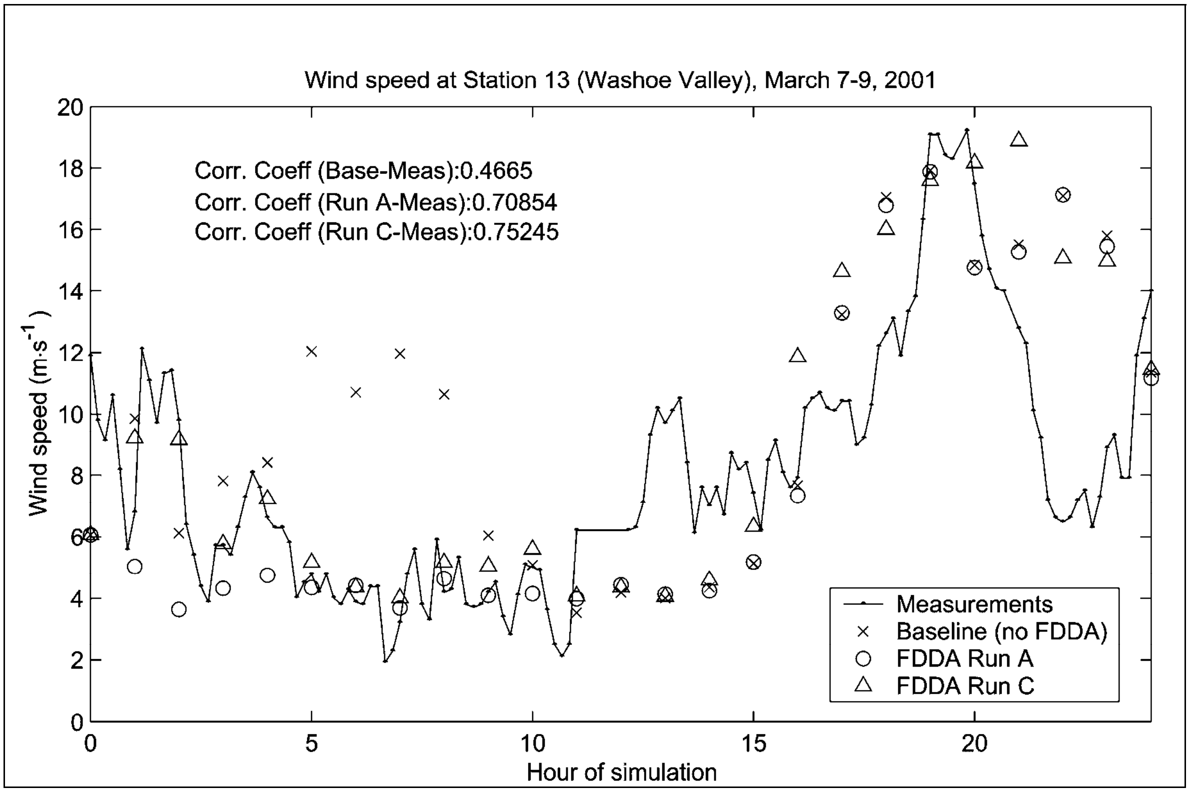

Fig. 4. Time series of wind speed measured at NDOT station Washoe Valley and simulated with MM5 without FDDA (Baseline, x), with “A” FDDA options (circle), and with “C” FDDA options (triangle). Run “A” - radius of influence: 240 km, nudging coefficient: 4e-3. Run “C” - radius of influence: 50 km, nudging coefficient: 4e-2.

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 1-2 March 2003

We have tested our system on a case from the next winter, 2002/2003. An unusually late winter storm occurred in western Nevada in the beginning of April. 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 radiosoundings taken prior to and during the storm (Fig. 5).

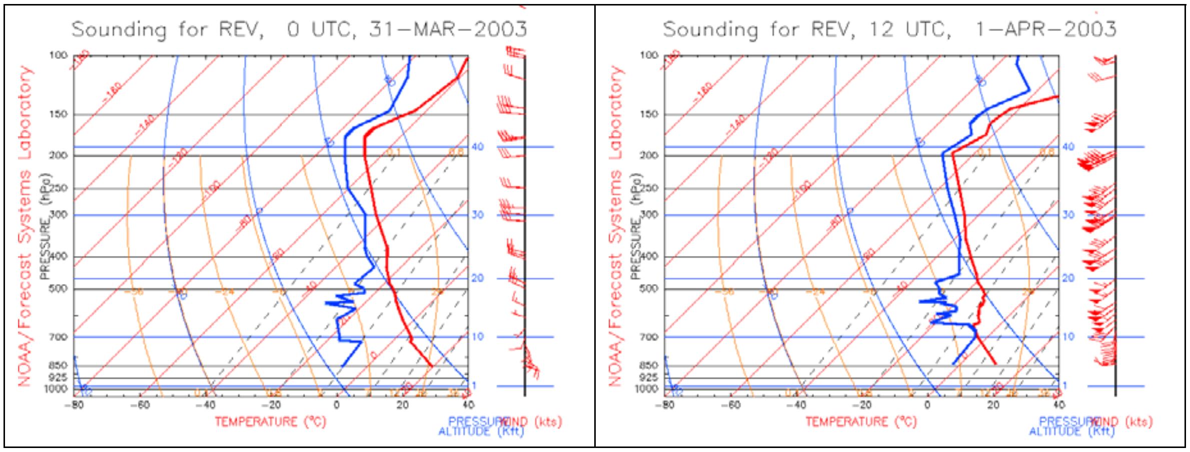

Fig. 5. Vertical profiles of temperature, dew-point temperature, and winds measured by radiosonde in Reno, NV, on 31 March 2003 at 00 UTC (4 pm local time) (left panel) and on 1 April 2003 at 12 UTC (4 am local time) (right panel).

The figure shows a large temperature drop below 500 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. Notice that the westerly winds increased significantly in the atmospheric boundary layer and at all elevations, with peaks to about 80-90 knots aloft.

Figure 6 shows a time series of measured and simulated air temperature and wind speed 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 simulations that assimilated NDOT data compared better with measurements for both temperature and wind speed.

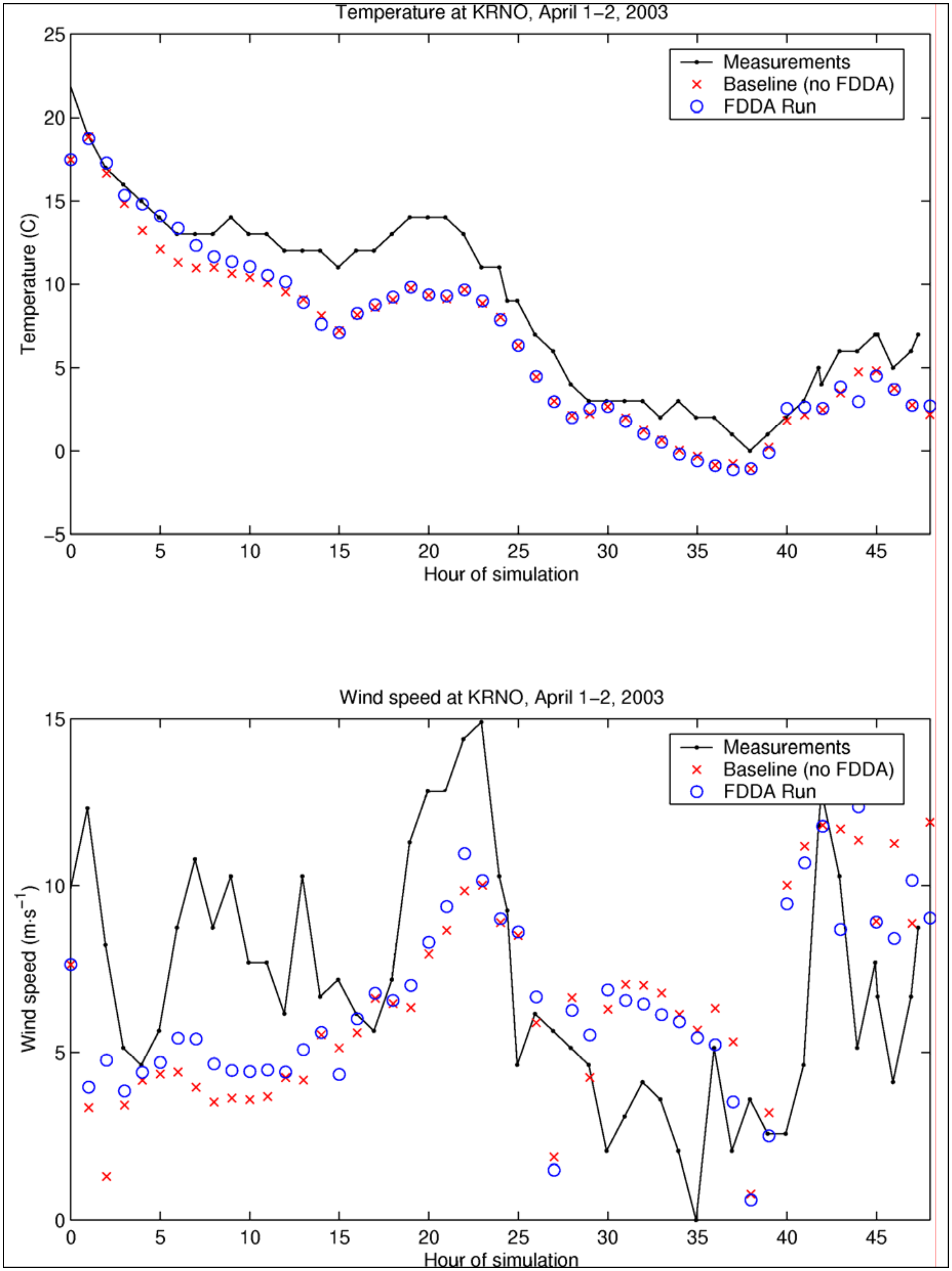

Fig. 6. Time series of temperature (upper panel) and wind speed (lower panel) at the Reno station for the period from 1 to 2 April 2003.

d) DRI - Testing and improvement of the NDOT Pavement Temperature Model

During the execution of the project we worked jointly with NDOT. In the later phase of the study, we obtained the code for the Pavement Temperature forecast model. The model was installed and set up on our computer. For the time left on the project, we have been testing the code and examining various input data options. In particular, we have been focusing on meteorological input parameters such as air temperature, dew-point temperature, humidity, cloudiness, radiation, and precipitation.

NDOT has been using an *IceCast*^{tmi} Pavement Model, developed by Vaisala Co., to co-ordinate their 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 Fig. 8.

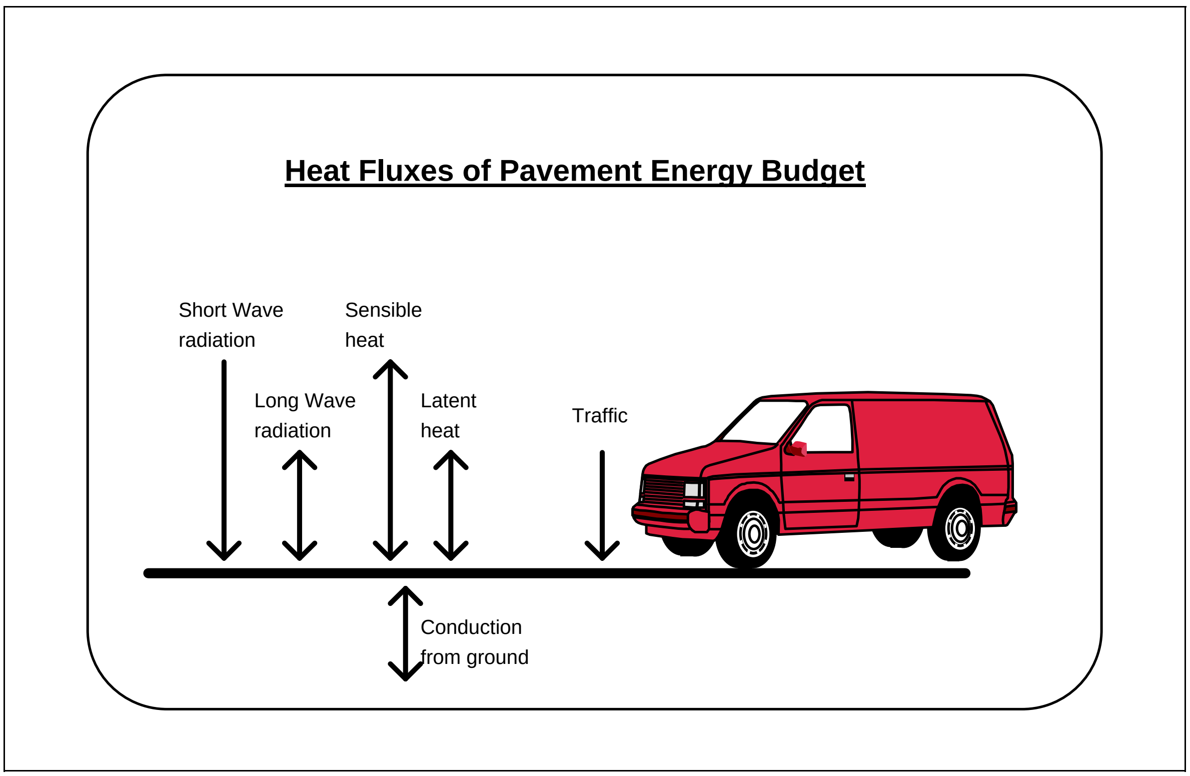

Fig. 8. A schematic of the NDOT Pavement Temperature model with its major physical components.

The main inputs to the Pavement Temperature model are technological and meteorological parameters. So far, to our knowledge, it is not known and documented what is the sensitivity of the forecasted pavement temperature on the meteorological inputs. Consequently, we have examined the effects of changes in the meteorological input parameters on the forecasted pavement temperature obtained by the Pavement

Temperature Model. In particular, we were examining how the minimum pavement temperature will change if we change each of the meteorological parameters.

Figure 9 shows an image of a computer screen with a menu with main meteorological inputs to be inserted for the Pavement Temperature model run. The meteorological input consists of air temperature, air dew-point temperature, wind speed, cloud cover, cloud type, and precipitation intensity. These parameters need to be predicted for the desired period of the pavement temperature forecasts.

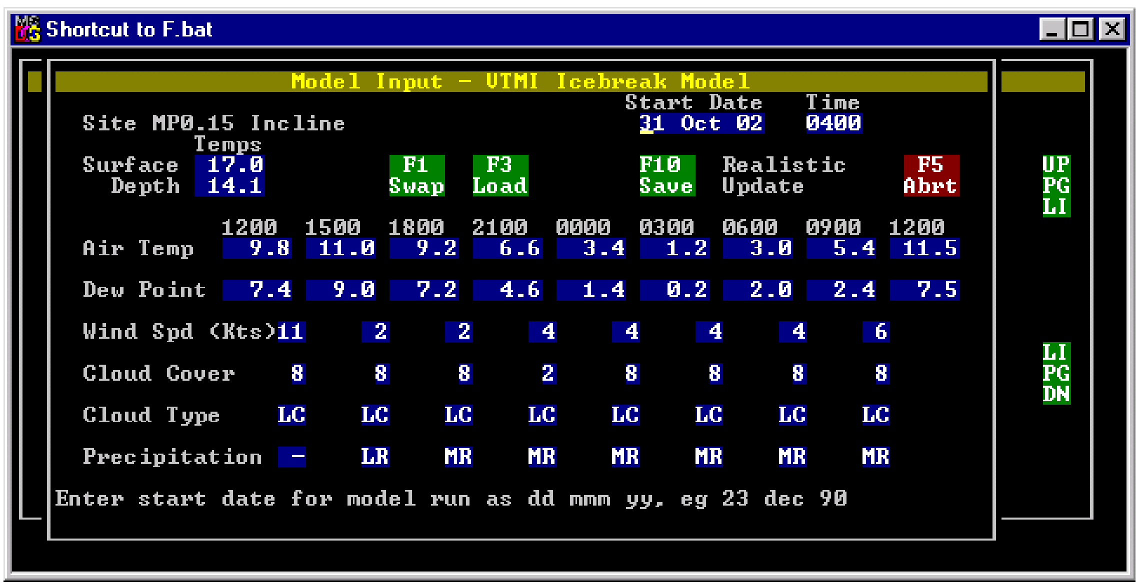

Fig. 9. Computer screen with a menu for predicted meteorological parameters to be inserted for the Pavement Temperature Model run.

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 10 shows the stations for which the NDOT data exist for the test case.

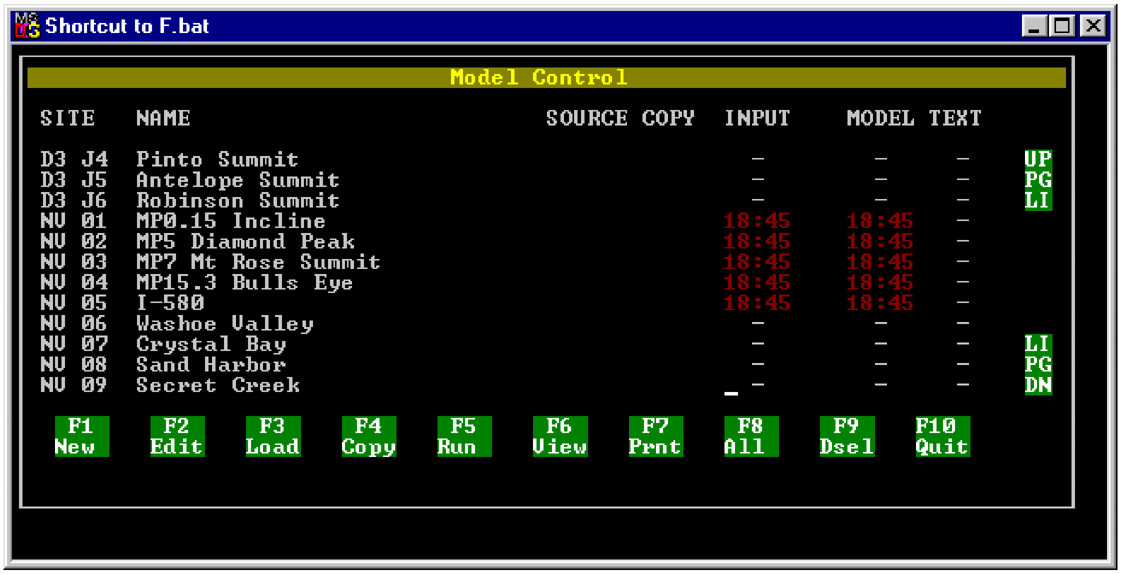

Fig. 10. Computer menu screen with a list of stations for which the pavement temperature forecast can be obtained.

After the all inputs are inserted in the model, the model computes the predicted pavement temperature at each of the considered stations. An example of a time series of the pavement temperature at one of the stations (Incline Village) is shown in Fig. 11.

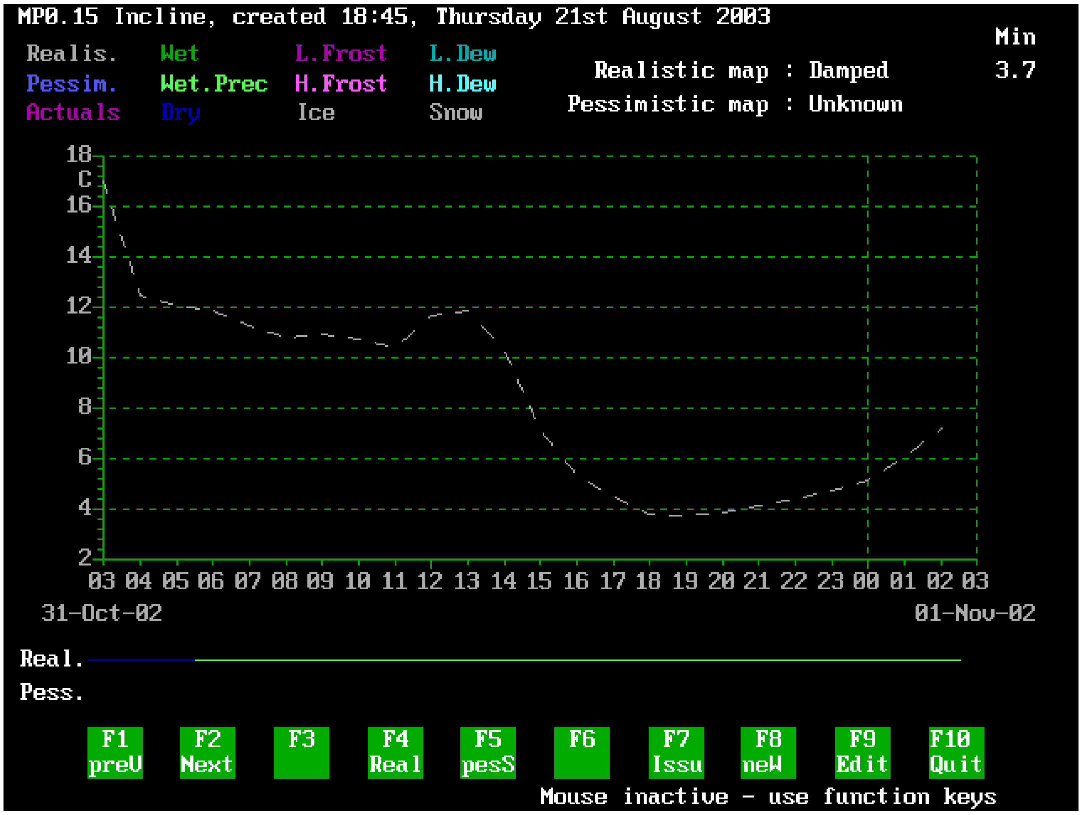

Fig. 11. A time series of the forecasted pavement temperature at Incline Village for the test case for the period of 3 am on 31 October to 3 am on 1 November 2002.

In the first step of the sensitivity study of the Pavement Temperature Model on the meteorological input, we took the MM5 results for the first case study (7-9 March 2002) as a baseline simulation. Then we changed each of the input meteorological parameters by certain value and ran the Pavement Model for each of these cases. The final results are shown in Fig. 13. 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-hand side of Fig. 13. It is important to notice that these tests resulted in a large variation of the minimum pavement temperature ranging from –7 to –12°C.

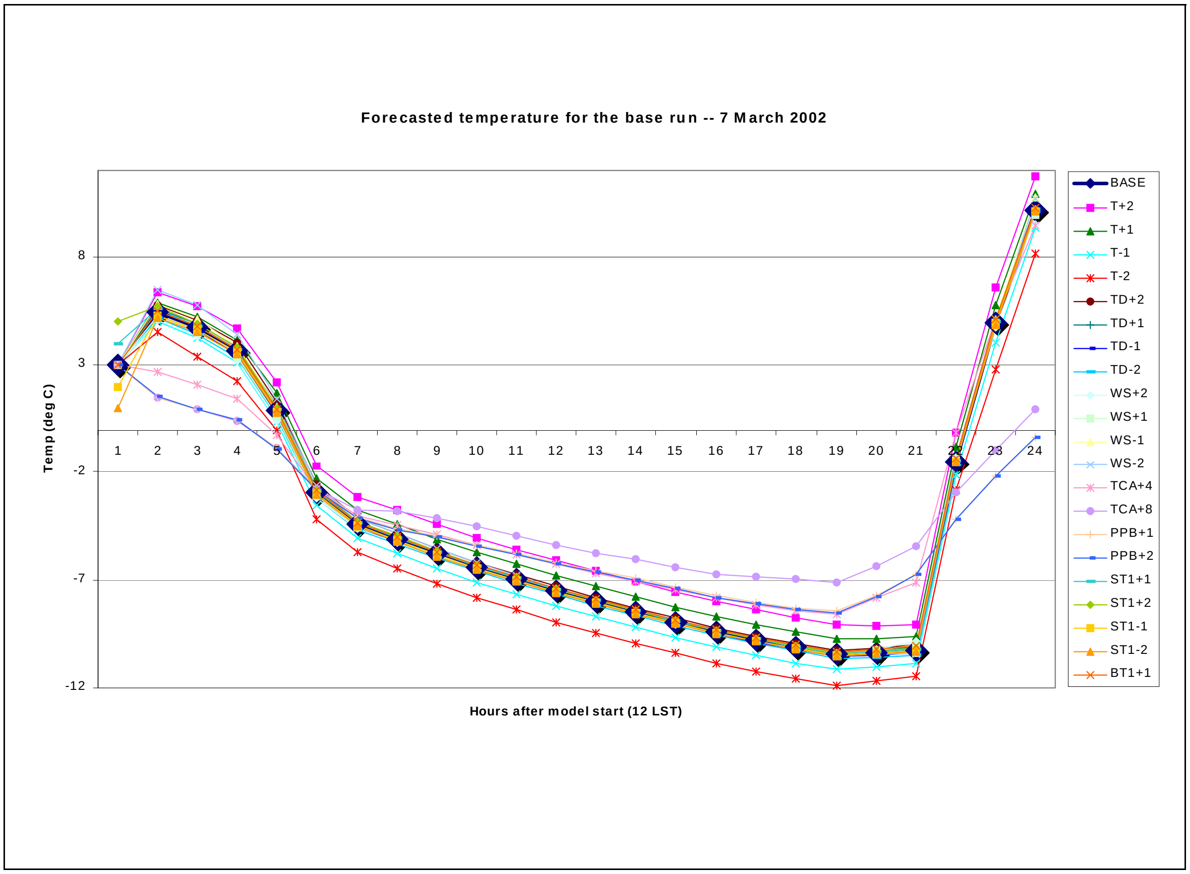

Fig. 13. Time series of the pavement temperature predicted by the NDOT *IceCast*^{tmi} Pavement Model – Vaisala for various changes in meteorological input parameters with respect to the baseline run.

Since the minimum temperature is a crucial parameter for road conditions, we analyzed the effects of each input parameter on the minimum pavement temperature. Figure 14 shows results from the sensitivity tests that can be used to identify the most important meteorological inputs for the Pavement Temperature Model.

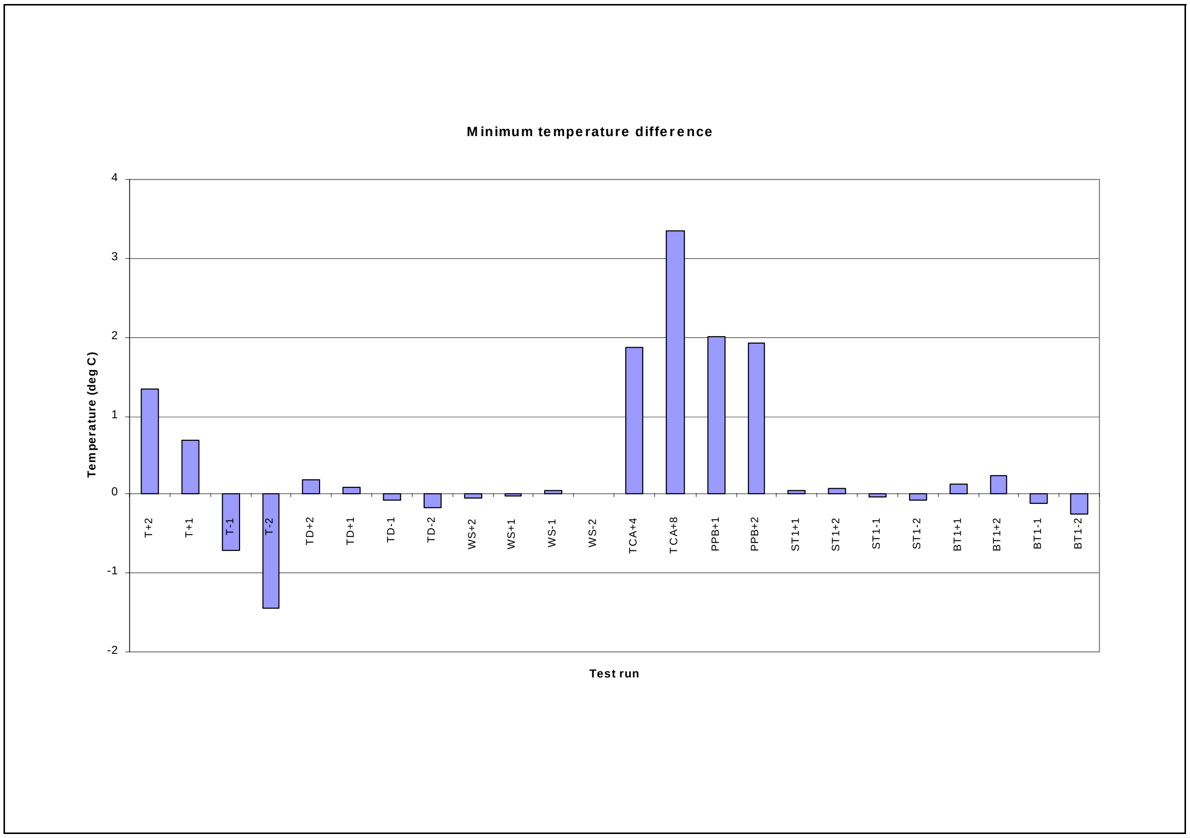

Fig. 14. Change of the predicted minimum pavement temperature (Y axis) as a function of changing meteorological inputs by step units (X axis). Explanation of symbols is as follows: *T – temp.; TD – dewpoint; WS – wind speed; TCA – Total cloud cover; PPB – Precipitation; ST – Surface temperature; and BT – Depth temperature (-25 cm).*

Figure 14 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 have been presented at the meetings in Washington D.C. (17 September 2002) and Albany NY (AURORA, 26 August 2003), and at the 10th Annual Workshop on Weather Prediction in the Intermountain West (Koracin, Nelson, and Fischer, 2003; see our reference below).

Koracin, D., R. Nelson, and J. Fischer, 2003: Improving mesoscale forecasting using data from the Nevada Department of Transportation operational network. *10th Annual Workshop on Weather Prediction in the Intermountain West*, 6 November 2003, Reno, NV.

Changes of scope

We have been able to complete all major components of the proposed study as stated in Section 1 and elaborated above. We did not have an opportunity to work with the NDOT on developing a travelers' forecast system, and instead of that we have 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 them into the information network have been solved during the first year. However, there are still problems with data recovery, data reliability, non-existent detailed quality check controls, and interrupted communications.

Regarding our NWS partner, the main problem was that our co-P.I. Mary Cairns left NWS in summer 2002 and the collaboration with NWS, Reno office was interrupted after her departure. Fortunately, Mr. Jim Fischer, a new SOO at the NWS Reno Office, has provided great help in completing the project.

Regarding DRI, our main problem is computational resources and we have been taking steps in solving that in the near future using PCs running Linux operating system. We have also found that the MM5 real-time model setup (forced by the available computer resources) with a horizontal resolution of 18 and 6 km is not sufficient to resolve details of the mesoscale weather. We believe that the resolutions of less than 3-4 km are needed for more accurate mesoscale forecasts.

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

Links with DRI/NWS/NDOT regarding inputs and use of the NDOT pavement model for sensitivity tests using actual have been resolved in the final stage of the project. We have been able to obtain the Pavement Temperature Model and perform sensitivity tests as promised in the proposal.

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

3. Division of labor among university, forecast office, and DOT partner

The division of labor was performed as follows:

NDOT

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

NWS

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 Centers 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.

DRI

Besides the coordination of 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 U.S. This database has a wide range of uses including; initialization of local models 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 Four Dimensional Data Assimilation technique and demonstrated that the use of the NDOT data improves the accuracy of the mesoscale forecasts in complex terrain.

4. Recommendation for how this project might be continued to complete any goals that were not finished

Due to some problems encountered during the execution of the projects (as described in the previous section), there are several issues that should be completed, 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 come about. The travelers forecast would be used by NDOT, NWS, and the community in general. We will continue to work with NDOT to realize this. The NWS has a goal of creating new and innovative products. This would fit in with those goals. We would like to collaborate with NDOT and develop specifications for that product. 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.

5. Broader recommendations of how the program as a whole might be improved, or what kind of things are necessary to ensure that future projects are successful

We believe that this project was a very valuable experience and benefit 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 be able to accomplish projected objectives.

Regarding the future possible projects, it would be essential to evaluate the quality of the NDOT station data and write detailed quality assurance software that would continuously 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 would be also valuable to perform a comprehensive study of verifying mesoscale weather forecasts and also verifying actual predictions of the pavement temperature. The particular Pavement Temperature Model used by NDOT should be critically analyzed and compared with other pavement temperature models used worldwide. New techniques such as artificial neural networks should be tested as possible options and improvements.

Future funding should be sufficient to fully support a graduate student who would gain expertise and training that can allow him/her employment at NDOT and NWS.