4A.9 MODELING ROAD PAVEMENT TEMPERATURES WITH SKIN TEMPERATURE OBSERVATIONS FROM THE OKLAHOMA MESONET

Jessica M. Rathke* and Renee A. McPherson
Oklahoma Climatological Survey, University of Oklahoma, Norman, Oklahoma

1. INTRODUCTION

Winter weather can adversely affect maintenance operations at the Oklahoma Department of Transportation (ODOT). In a survey conducted during September 2005, ODOT officials indicated that ice or freezing rain, snow accumulation, and blowing or drifting snow most affect their maintenance operations (Dubois and Rathke 2005). Road pavement surface temperatures, in particular, determine how these weather phenomena influence road surface conditions. To meet ODOT maintenance needs, *currently available* weather information can be used to forecast road pavement surface temperatures.

Observations and forecasts of road pavement surface temperatures are used in winter maintenance decision-making processes to select treatment strategies, advise operators, and begin preparation processes. Decision makers use "the temperature and wetness of a roadway surface for tactical (< 6 hours) and strategic (> 6 hours) purposes" (NRC 2004). The Federal Highway Administration (FHWA) has identified critical ranges of road pavement surface temperatures for treatments of specific winter weather events: less than or equal to 0°C are important during snow, freezing rain, and sleet; between -2 and 2°C are important during frost or black ice events; and less than -10°C are critical for all winter weather events because maintenance crews must plow or apply abrasives (FHWA 1996).

This study quantitatively analyzed the relationship between road pavement surface temperature measurements from Road Weather Information System (RWIS) sites in Oklahoma City and skin temperature measurements from surrounding Oklahoma Mesonet sites. The results will help determine if skin temperature can be used to model road pavement surface temperature.

Corresponding author address: Jessica M. Rathke, Oklahoma Climatological Survey, Norman, OK 73072-7305; e-mail: jrathke@ou.edu.

2. DATA

2.1 *Road Weather Information Systems*

2.1.1 *Overview*

For the past 30 years, RWIS has supplied road weather observations to transportation decision makers in the United States (Boselly et al. 1993). The City of Oklahoma City Public Works owns three RWIS sites within Oklahoma City, Oklahoma (Fig. 1). The Oklahoma City RWIS sites measure air temperature, relative humidity, wind speed, precipitation type, and precipitation accumulation. The sites also measure road surface variables including pavement surface temperature, pavement subsurface temperature, and pavement surface status (i.e., wet, dry, chemically wet). The three RWIS sites were placed near bridges that are known to develop icy conditions and where Oklahoma City Public Works focuses their winter weather maintenance (J. C. Reiss, personal communication).

2.1.2 *Road Pavement Surface Temperature Measurements*

Road pavement surface temperature (hereafter called pavement temperature) is the temperature of pavement at the atmosphere-roadway interface. The pavement temperature sensors installed at the Oklahoma City RWIS sites are "hockey puck"-type sensors manufactured by Surface Systems, Inc. (Fig. 2*a*). The passive sensors are embedded in the pavement with the top of the sensor flush with the road pavement surface (Fig. 2*b*). The accuracy of the sensor is ±0.2°C when pavement temperatures are between -30 and 80°C (J. Tarleton, personal communication). Differences between actual pavement temperatures and sensor measurements occur because the sensor material has different thermal and optical properties than the road surface (NCAR 2004).

There is a total of eight pavement surface temperature sensors among the three RWIS sites. The Penn Ave and Britton Rd RWIS sites each have one sensor placed in the approach or

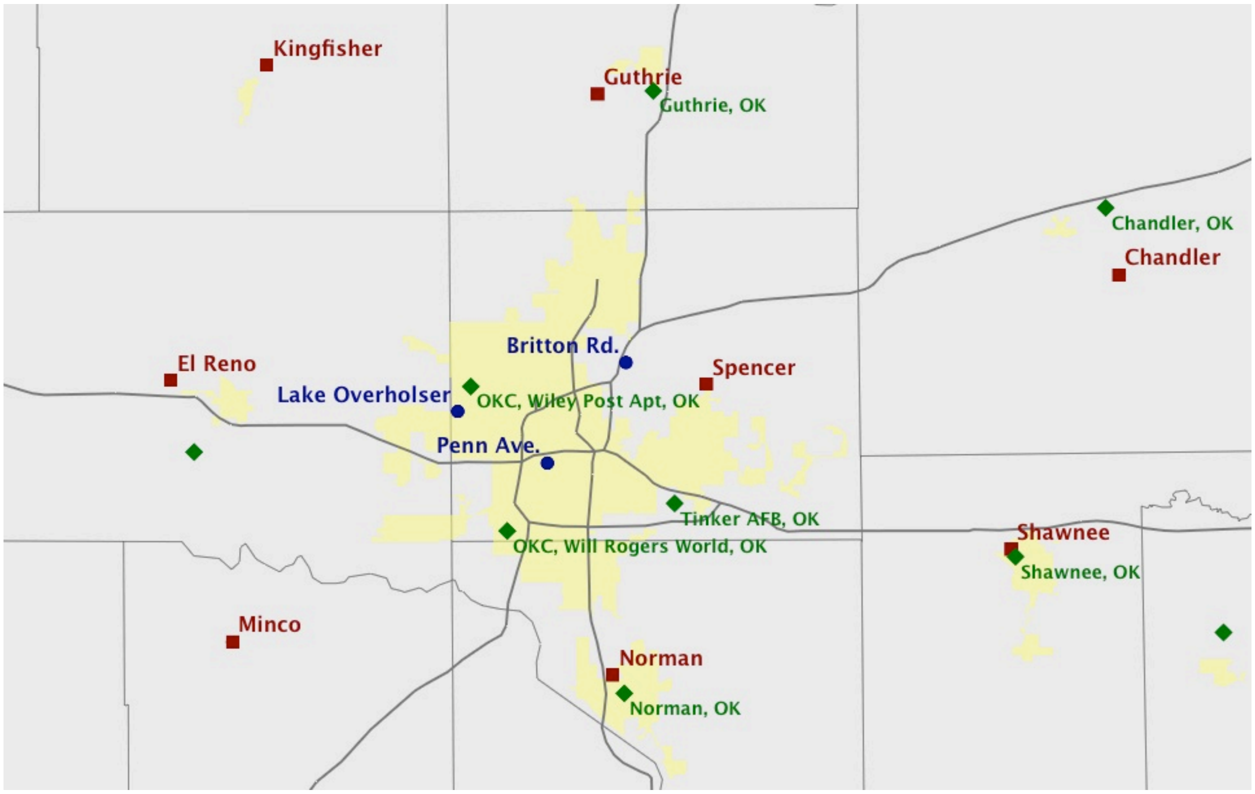


Fig. 1. Oklahoma City RWIS sites (blue dots), Oklahoma Mesonet sites (red squares), and ASOS sites (green diamonds). Also shown are county lines (thin gray line), interstate highways (thick gray line), and urban areas (yellow shading).

departure of a bridge and two sensors placed in the bridge deck. The Lake Overholser RWIS site has one sensor placed in the approach of the bridge and one sensor placed in the bridge deck. Pavement temperature sensors placed in the approach or departure of a bridge are embedded in asphalt, while pavement temperature sensors placed in the deck of a bridge are embedded in asphaltic concrete. All sensors are installed within the wheel track of the roads.

No studies have compared road pavement temperatures measured by the "hockey puck"-type sensors at RWIS sites to skin temperatures measured at remote atmospheric sites. However, a recent study compared skin temperature at Oklahoma Mesonet sites and infrared temperature (IRT) measurements taken over different types of pavement (K. Painter, personal communication).

This study used pavement temperatures measured at the three Oklahoma City RWIS sites from 1 October 2004 – 31 March 2005 and 1 October 2005 – 31 March 2006. These dates were chosen because ODOT had indicated that winter weather most affects their maintenance operations. Pavement temperatures within five minutes of each hour were extracted from the datasets.

RWIS pavement temperatures were manually quality checked using range and step tests. The range of the pavement temperature sensors is -51 to 80°C (J. Tarleton, personal communication). The step test performed was similar to that performed on air temperature observations at the Oklahoma Mesonet (i.e., air temperature at 1.5 m cannot change more than 10°C in 5 min; Shafer et al. 2000). All pavement temperature

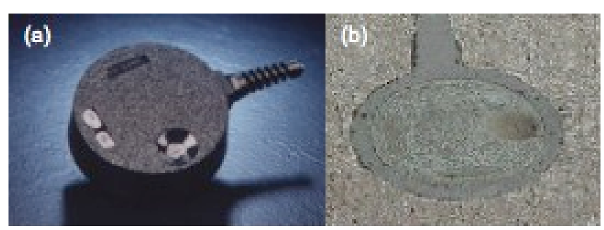


Fig. 2. (a) "Hockey puck"-type road pavement surface temperature sensor (courtesy FHWA) and (b) sensor embedded in pavement (courtesy Government of Newfoundland and Labrador).

observations passed both tests. Quality assurance tests performed on pavement temperature data were less rigorous than those performed on Mesonet air temperature data because one objective of this study was to analyze the nature of pavement temperature measurements.

2.2 *Oklahoma Mesonet*

2.2.1 *Overview*

The Oklahoma Mesonet (Brock et al. 1995; McPherson et al. 2006), a cooperative program of the University of Oklahoma and Oklahoma State University, provides observations of weather variables every five minutes from every county in Oklahoma. The Mesonet is an automated network of 116 stations that measure standard weather variables including air temperature and dewpoint at 1.5 m, wind speed and direction at 10 m, accumulated rainfall, and incoming solar radiation. IRT sensors that measure skin temperature are installed at 89 of the Oklahoma Mesonet sites. Quality-assured data are available to users within five minutes of observation.

2.2.2 *Skin Temperature Measurements*

Skin temperature is defined to be the “temperature of the interface between the earth’s surface and its atmosphere” (Fiebrich et al. 2003). A downward-pointing IRT sensor measures the emission between 8 and 14 μm. The emission is converted to a temperature using the Stefan-Boltzmann law and an emissivity of 1.0.

This study utilized skin temperature measurements from six Oklahoma Mesonet sites surrounding Oklahoma City (Fig. 1): Chandler, El Reno, Guthrie, Minco, Norman, and Spencer. Skin temperatures observed on the hour were extracted from the datasets on the same days that the pavement temperatures were collected.

2.3 *Automated Surface Observing Systems*

Hourly observations of cloud cover from the Automated Surface Observing Systems (ASOS) at the Will Rogers World Airport (KOCK) and the Wiley Post Airport (KPWA), shown in Figure 1, also were used.

3. RESULTS

This study quantitatively analyzed the relationship between pavement temperatures in Oklahoma City and skin temperatures surrounding Oklahoma City to determine if skin temperature measurements can be used to model pavement temperatures. The relationship between pavement temperature and skin temperature during different conditions (e.g., time of day, critical temperature ranges, cloud cover, wet/dry pavement) and the relationship between sensors at each RWIS site also were analyzed.

Results for pavement temperatures on the southbound approach and on the southbound bridge at the Penn Ave RWIS site and skin temperature at the Minco Mesonet site are shown for January 2005.

3.1 *Analysis Between Pavement Temperatures on the Approach and on the Bridge*

A linear fit of pavement temperatures on the approach versus pavement temperatures on the bridge (Fig. 3) for all hours in January 2005 resulted in a correlation of 0.9824. Pavement temperature on the approach was an average of 1.4°C warmer than pavement temperature on the bridge. Approach temperatures ranged from -8.8 to 32.4°C, and bridge temperatures ranged from -12.2 to 30.0°C.

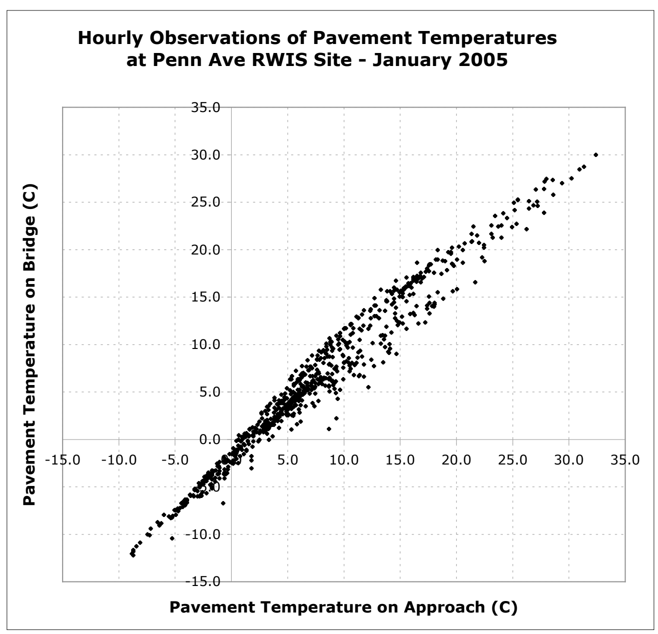


Fig. 3. Hourly observations of pavement temperatures on the approach versus pavement temperatures on the bridge at the Penn Ave RWIS site during Jan. 2005.

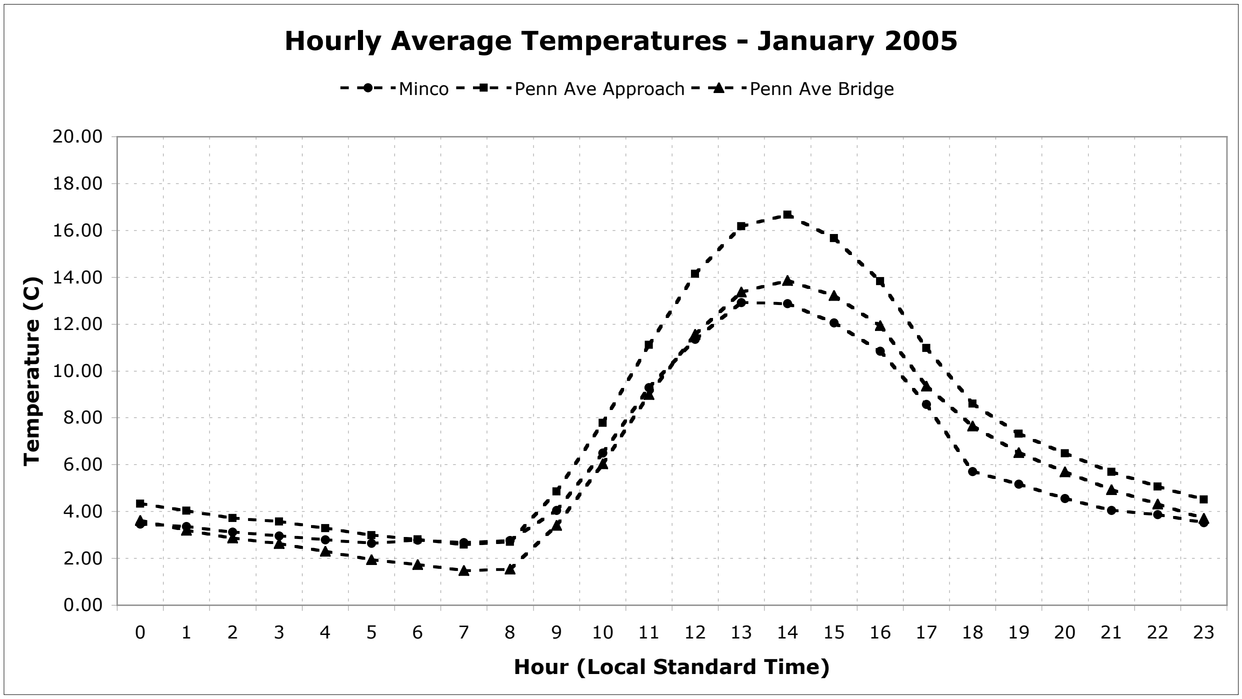


Fig. 4. Average of hourly skin temperature measurements at Minco Mesonet site (circle), pavement temperatures on the Penn Ave approach (square), and pavement temperatures on the Penn Ave bridge (triangle) during Jan. 2005.

Average pavement temperatures of each hour in January 2005 were calculated (Fig. 4). Hourly averages of approach temperature ranged from 2.6 to 16.7°C. Hourly averages of bridge temperature ranged from 1.5 to 13.5°C. Differences between pavement temperature on the approach and on the bridge ranged from -2.6 to 7.6°C. The difference between approach temperature and bridge temperature was almost a constant 1°C during the night (from 1800 to 800 LST), then increased during the day to 3°C around 1300 LST.

3.2 *Analysis Between Pavement Temperatures and Skin Temperatures*

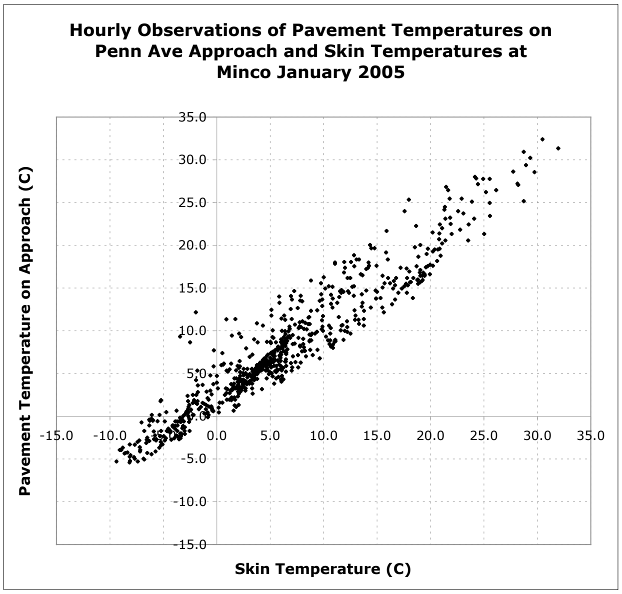
Pavement temperatures on the approach and on the bridge versus skin temperature were plotted for all hours in January 2005 (Fig. 5), and linear equations were fit to the scatterplots. The correlation between pavement temperature on the approach and skin temperature was 0.955. The correlation between pavement temperature on the bridge and skin temperature was 0.9761.

Pavement temperatures were modeled by the linear equations solely using skin temperature values from the Minco Mesonet site. The linear model of pavement temperature on the approach yielded a rmse of 2.19°C and a bias of 0.29°C. The linear model of pavement temperature on the bridge yielded a rmse of 1.70°C and a bias of 0.31°C.

Figure 6 shows a histogram of the linear model errors (modeled temperature minus observed temperature) for pavement temperature on the approach. Errors of approach pavement temperature ranged from -11.29°C to 4.63°C. Figure 7 shows a histogram of the linear model errors for pavement temperature on the bridge. Errors of bridge pavement temperature ranged from -6.53°C to 3.76°C.

3.3 *Conditional Analyses Between Pavement Temperatures and Skin Temperatures*

Quantitative analyses also were performed during different conditions: when the measured pavement temperatures were less than 2°C; overcast skies (i.e., overcast at any level at KOKC) versus clear skies (i.e., clear at every level at KOKC); when the pavement was dry versus when the pavement was not dry (e.g., wet, damp,



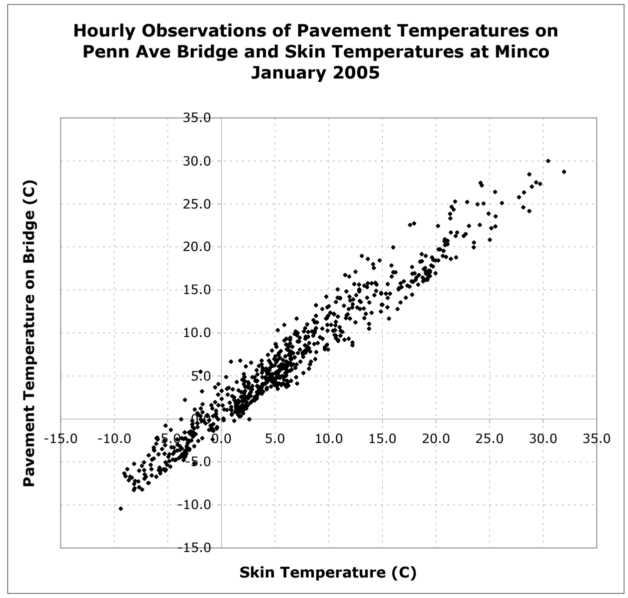


Fig. 5. Hourly observations of pavement temperatures on the approach (left) and pavement temperatures on the bridge (right) at the Penn Ave RWIS site versus skin temperatures at the Minco Mesonet site during Jan. 2005.

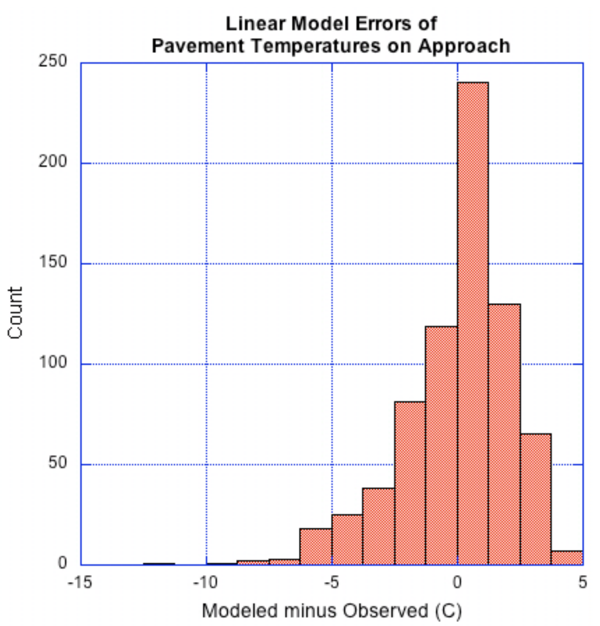


Fig. 6. Histograms of linear model errors of pavement temperatures on the approach at the Penn Ave RWIS site during Jan. 2005.

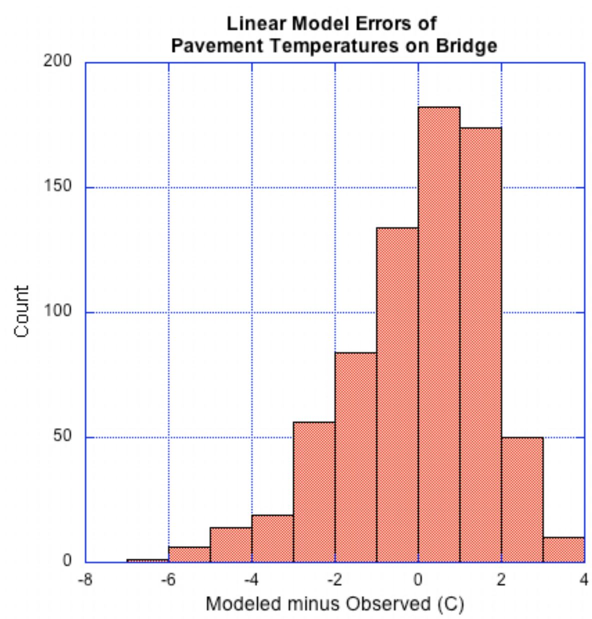


Fig. 7. Histograms of linear model errors of pavement temperatures on the bridge at the Penn Ave RWIS site during Jan. 2005.

chemical wet, snow/ice warning); and during different times of day. Table 1 summarizes the conditional results of the linear models of pavement temperatures. Compared to the overall results, the rmse values for the linear models improved for all conditions except when the pavement surface was dry. The models predicted pavement temperatures best when observed pavement temperatures were less than 2°C.

Table 1. Root mean-square errors (°C) of linear models of pavement temperatures on the approach and on the bridge at the Penn Ave RWIS site during different conditions in Jan. 2005.

Jan 2005	Approach	Bridge
All data	2.19	1.70
Pavement Temps < 2°C	1.38	1.36
Overcast Skies	1.74	1.53
Clear Skies	1.85	1.39
Dry Surface	2.28	1.92
Wet Surface	2.08	1.48

4. SUMMARY AND CONCLUSIONS

Quantitative analyses were performed to determine if road pavement surface temperatures at RWIS sites within Oklahoma City could be modeled by skin temperature measurements from Oklahoma Mesonet sites surrounding Oklahoma City. This study analyzed the performance of linear models of pavement temperatures on the approach of a bridge and on the deck of a bridge, using skin temperature measurements as input. The relationship between pavement temperatures on the approach of a bridge and on the deck of a bridge also was examined.

Pavement temperatures on the approach and on the bridge exhibited a strong linear correlation. On average, pavement temperatures on the approach were warmer than those on the bridge. Also, pavement temperatures on the approach had a greater range than those on the bridge.

A linear model of pavement temperature on the approach yielded a rmse of 2.19°C. A linear model of pavement temperatures on the bridge resulted in a rmse of 1.70°C. The models predicted pavement temperatures on the approach and on the bridge better at night than during the day. Also, the models predicted pavement temperatures best when the observed pavement temperature were less than 2°C and worst when the pavement surface was dry. Pavement temperatures on the bridge were predicted better than pavement temperatures on the approach for all conditions.

This presentation will include results from 1 October 2004 – 31 March 2005 and 1 October 2005 – 31 March 2006 for all RWIS and Mesonet sites used in this study.

5. ACKNOWLEDGMENTS

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6. REFERENCES

Boselly, S. E., G. S. Doore, J. E. Thornes, C. Ulberg, and D. D. Ernst, 1993: Road Weather Information Systems Volume 1: Research Report. SHRP-H-350, 219 pp.

Brock, F. V., K. C. Crawford, R. L. Elliot, G. W. Cuperus, S. J. Stadler, H. L. Johnson, and M. D. Eilts, 1995: The Oklahoma Mesonet: A technical overview. *J. Atmos. Oceanic Technol.,* **12,** 5-19.

Dubois, J. A., and J. M. Rathke, 2005: A prototype tool to improve weather services for decision making by the Oklahoma Department of Transportation. Senior Thesis, School of Meteorology, University of Oklahoma, 36 pp.

Federal Highway Administration (FHWA), 1996: manual of practice for an effective anti-icing program: A guide for highway maintenance personnel. FHWA-RD-95-202. [Available online at http://www.fhwa.dot.gov/reports/mopeap/eapcov.htm.]

Fiebrich, C. A., J. E. Martinez, J. A. Brotzge, and J. B. Basara, 2003: The Oklahoma Mesonet's skin temperature network. *J. Atmos. Oceanic Technol.,* **20,** 1496-1504.

McPherson, R. A., and Coauthors, 2006: Statewide monitoring of the mesoscale environment: A technical update on the Oklahoma Mesonet. *J. Atmos. Oceanic Technol.,* accepted.

NCAR, 2003: The MDSS project technical performance assessment report: Iowa field demonstration winter 2003 version 1.1, 174 pp.

-----, 2004: The MDSS project technical performance assessment report: Second Iowa field demonstration winter 2003-2004 version 1.1, 194 pp.

NRC, 2004: *Where the Weather Meets the Road: A Research Agenda for Improving Road Weather Services.* The National Academies Press, 173 pp.

Office of the Federal Coordinator for Meteorology (OFCM), 2002: Weather information for surface transportation. National Needs Assessment Report FCM-R18-2002, 259 pp.

Shafer, M. A., C. A. Fiebrich, and D. S. Arndt, 2000: Quality assurance procedures in the Oklahoma Mesonetwork. *J. Atmos. Oceanic Technol.,* **17,** 474-494.