METRo Model Testing at Slovenian Road Weather Stations and Suggestions for Further Improvements

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ABSTRACT

Efficient road system has become more important than ever. Reliable road weather forecasts (road surface temperature and condition) are crucial for winter maintenance service to establish efficient anti-icing strategy. The most common approach to forecasting the road conditions is the energy-balance model based on a one-dimensional diffusion equation. METRo is one of the widely used models for road weather prediction. Together with the input of atmospheric forecasts and observations from a Road Weather Station (RWS), METRo produces local road forecast (roadcast).
CGS plus d.o.o. is the leading company for Road Weather Information Systems in Slovenia. The company has developed the Road Weather Information System for DARS (Motorway Company in the Republic of Slovenia) and upgraded the system with the METRo roadcast in winter 2011/2012.
The main objective of this paper is to present the tests of the METRo model and results of its implementation on several Slovenian RWSs in the winter time 2011-2012, focused primary on the road surface temperature. Beside the RWSs data, short-term weather forecasts of good temporal and spatial resolution from the INCA/ALADIN meteorological systems are used.
The results show that the RMS error for the road surface temperature predictions is generally satisfactory but can be too high at some sites, especially for the predictions around noon. To solve this problem, some suggestions for further improvements are given in this paper.

Keywords: Road Surface Temperature (RST), METRo, Road Weather Station (RWS), Road Weather Information Systems (RWIS)

1 INTRODUCTION

During the winter period, many countries experience severe winter conditions. Especially snow and ice make the transportability difficult and present several challenges for the winter maintenance service. Optimization of maintenance locations, timing, types and rates has an important impact on the road efficiency and safety. Accurate prediction of meteorological conditions on the road can have great benefits for:

- Providing safer roads [1-2]. The influence of weather on the road safety is not directly derivable from statistics; however, there is no doubt that weather conditions determine road conditions and influence the driver's behaviour. The estimated economic cost of weather-related crashes alone amounts to nearly $42 billion annually [3].
- Reducing winter road maintenance costs (i.e. salt consumption, work hours). Efficient ice control and snow removal is based on anti-icing strategy which involves the application of chemicals to the road before the forecasted event. Studies have shown that it should take place not more than 1–2 hours before snowfall. Smaller amount of salt (5–10 g/m²) is usually applied compared to the de-icing technique. There are many reports or quotations of substantial savings on winter road maintenance costs, i.e. [4-5].
- Reducing the environmental damage from over-salting [6].

2 METRo MODEL

More detailed weather information, such as road surface temperature (RST) and road condition, is needed to support anti-icing and other winter maintenance operations. The most common approach to forecasting road conditions is the energy-balance model, based on a one-dimensional diffusion equation [7-8]. Physical models can predict the RST, which is the most important parameter for determining the road surface condition (i.e. dry, wet, ice, snow).

A widely used physical model for forecasting the RST and road condition is METRo [8], which was first implemented in 1999 at the Ottawa Regional Centre in Canada and is now used also in many countries in Europe and USA, Russia and New Zealand. The METRo is composed of three modules:

- the energy balance of the road surface model which describes the energy fluxes at the road surface,
- the heat-conduction module for the road material which can predict the RST, based on one-dimensional diffusion equation, and
- the surface water/ice accumulation model.

It is reported that about one-half of the time the error in RST is within ±2 K, and the nighttime RMS error is about 2 K [8].

3 METRo IMPLEMENTATION ON SLOVENIAN MOTORWAYS

Slovenia (Figure 1) is located in a meteorologically diverse territory between the western Alps, northern Adriatic and Pannonian Plain. Average temperatures in the coldest months do not drop below -3*°C*, and at least four months, the average temperature is above *10°C*.

Slovenia has more than 38,000 km of public and 13,000 km of forest roads. Frequent daily and seasonal variations in temperatures and precipitation cause rapid changes in road conditions and require frequent and quick responses from the winter maintenance service. There are nearly 90 road weather stations (RWSs) on Slovenian roads, situated mostly on motorways and regional roads. All of them are equipped with embedded or remote road sensors and meteorological sensors. The most common measurements on RWSs are: road temperature on the surface and at different depths, thickness of water film on the road, salt concentration, road condition, air temperature and humidity, dew point, air pressure, amount and type of precipitation, visibility, and speed and direction of the wind.

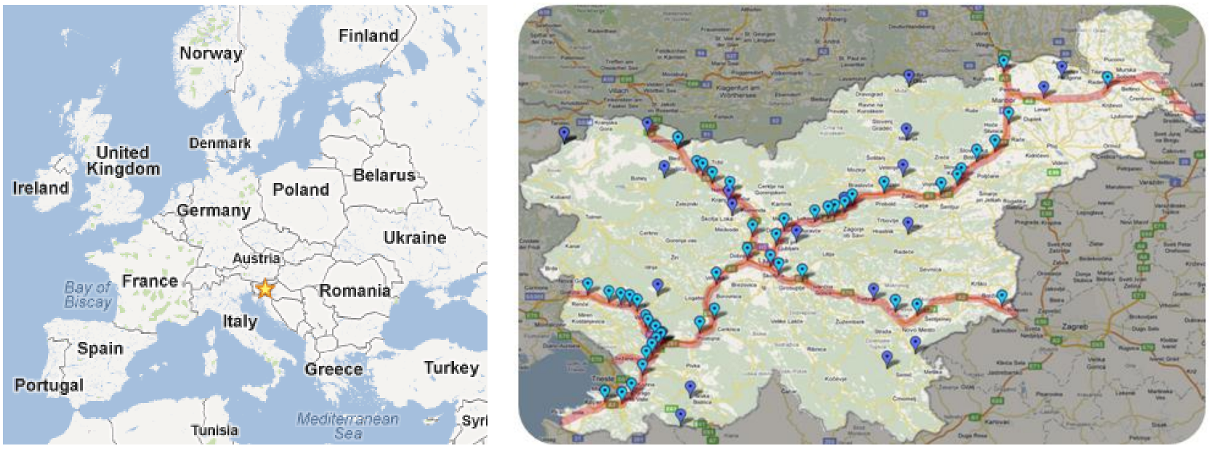

Figure 1. Location and map of Slovenia with RWSs marks.
[Source: http://maps.google.com/, DARS d.d.]

The Road Weather Information Systems (RWIS) has become a critical component of winter maintenance decision-making (Figure 2). CGS plus d.o.o. is the leading company for RWIS in Slovenia. The company developed the RWIS (detailed description in [9]) for DARS (Motorway Company in the Republic of Slovenia) and upgraded it with the METRo roadcast in the winter 2011/2012.

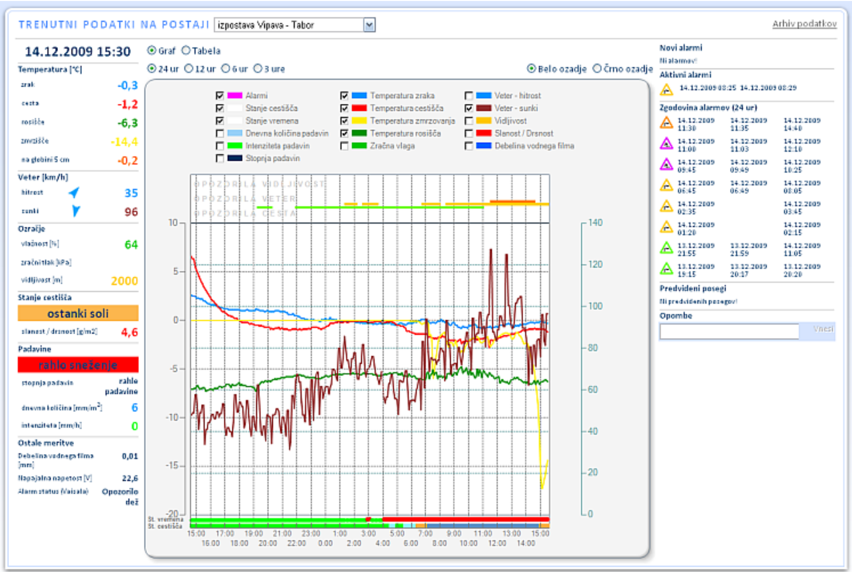

Figure 2. RWIS in Slovenia: detailed overview of events at a chosen RWS.
[Source: DARS d.d.]

4 METHODS

The main objective of this paper is to present the most current tests of the METRo model and results of its implementation on 51 Slovenian RWSs in different geographical regions in the winter time 2011-2012, focused primary on the RST.

Beside the RWSs data, short-term weather forecasts of good temporal and spatial resolution from INCA/ALADIN meteorological systems are used. The INCA (Integrated Nowcasting through Comprehensive Analysis) system has been developed primarily for providing improved numerical forecast products in the nowcasting with very short time range (up to 12 hours) and good spatial resolution of 1 km [10-12]. The INCA analysis and nowcasting data include temperature, humidity, wind, and the amounts and types of precipitation. The model proposed in this paper also uses predictions of radiation fluxes, pressure and cloudiness data from ALADIN numerical weather prediction model with a coarser spatial resolution of 9.5 km.

The specific road construction parameters for the METRo model that require road coring were not available; therefore, standard road construction profiles (which are not necessarily correct) from the road data bank were used. In order to obtain the road structure data for the METRo model to better describe the RST, some road construction values on most RWSs were adapted. It turned out in our case that decreasing the depth of the top road layer (typically asphalt) significantly increased the accuracy of most RST predictions.

For every RWSs, the sky-view factor estimation (value between 0 and 1) was determined from detailed topographical maps around each station. These values were directly multiplied with forecasts for incoming solar fluxes to gain more realistic situations on the RWS locations. A more optimal approach for simulation of the shading effect is described in [13].

The time period of detailed analysis was from the beginning of February 2012 until 20 February 2012. The period was rather short but it represented ‘ideal’ and many times severe winter conditions (low air temperatures with great daily variations, snow precipitations, a lot of weather changes, etc.). Unfortunately, the winter conditions before the end of January 2012 were mild.

In the testing period, the METRo model was run every hour and it produced roadcasts for up to 12 hours.

5 RESULTS AND DISCUSSION

To observe the error of the METRo model, the RMS (Root Mean Square) error was calculated for RST predictions. A general RMS error, averaged through all RWSs in the system and averaged for predictions for up to 6 hours and up to 12 hours was 1.7*°C* and 2.2*°C*, respectively, with the standard deviation of 0.2*°C* for both errors. Results are comparable to or better with the previous studies (i.e. [8]) and are helpful for winter road maintenance personnel. Some more detailed analysis and interesting findings are described below.

Detailed error analysis on the RWS *Verd* (this station achieved average results; its RMS error was 2.13*°C*) shows that the lowest RMS errors can be obtained for the roadcasts calculated after 10:00 UTC, lasting until late night hours (Figures 3 and 4).

The error distribution for 6-hour RST predictions on the RWS *Verd* is shown in Figure 5. 58 % of forecast errors are between the interval [-2, 2] and 88 % between the interval [-4, 4].

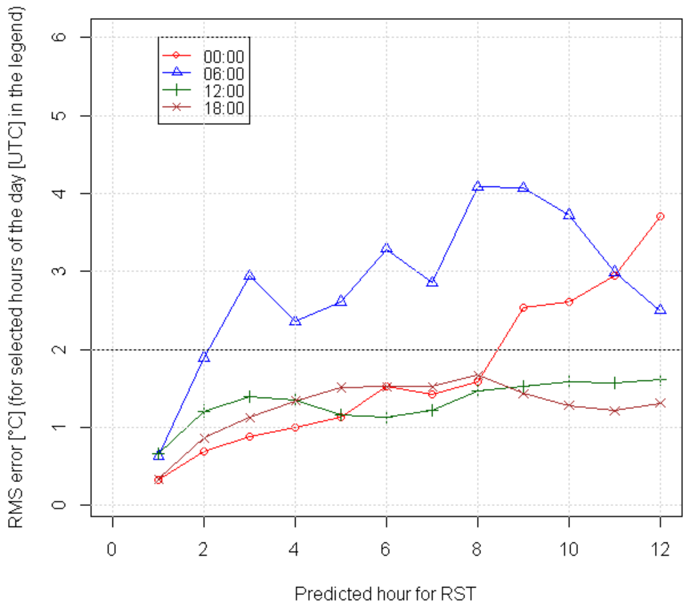

Figure 3. RMS errors for selected hours of the day (roadcasts calculated at 00:00, 06:00, 12:00 and 18:00 UTC) from 1-12 predicted hours for RWS *Verd*.

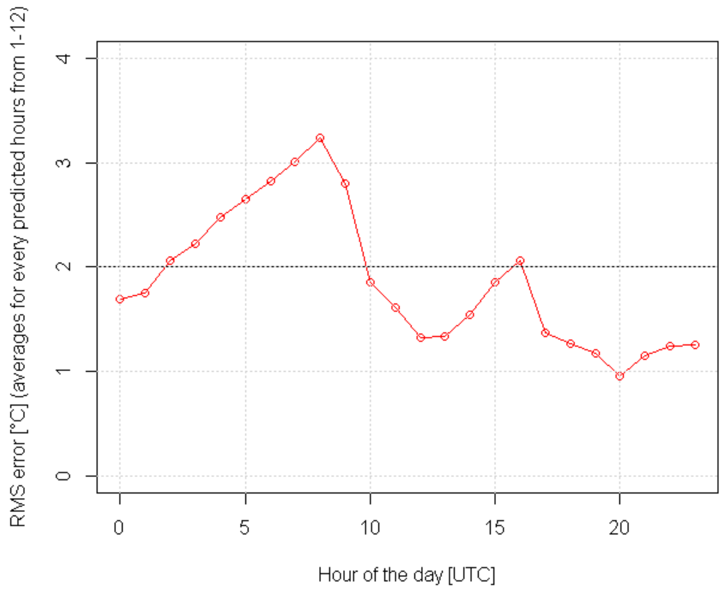

Figure 4. RMS errors (averaged for every predicted hours from 1-12) for every hour of the day on RWS *Verd*.

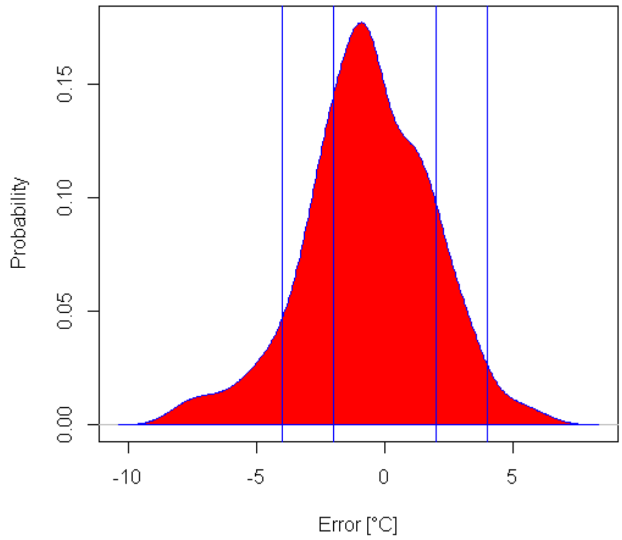

Figure 5. Probability distribution for RST prediction errors (= predicted values – measured values) for RWS *Verd*. Vertical lines represent abscissa values at -4, -2, 2 and 4.

The roadcasts calculated in early morning hours show large RST prediction errors always when there is a large influence of the incoming solar radiation. As these predictions correspond to the daytime when temperatures typically increase, this does not represent a substantial road safety problem. One of the more problematic examples is shown in Figure 6 (the RMS error for air temperature forecasts was as high as 4.27*°C*). As seen in Figure 7, the roadcasts calculated around and after 12:00 [UTC] were better. Two typical RST predictions with low RMS error are shown in Figures 8 and 9.

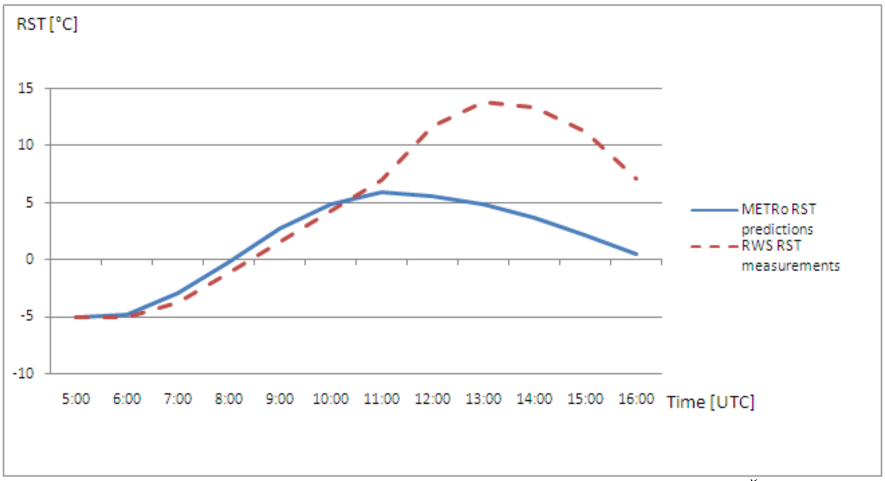

Figure 6. RST predictions calculated at 04:00 and RST measurements at the RWS *Šentožbolt* on 18 February 2012. RMS error for the RST was 5.39*°C.*

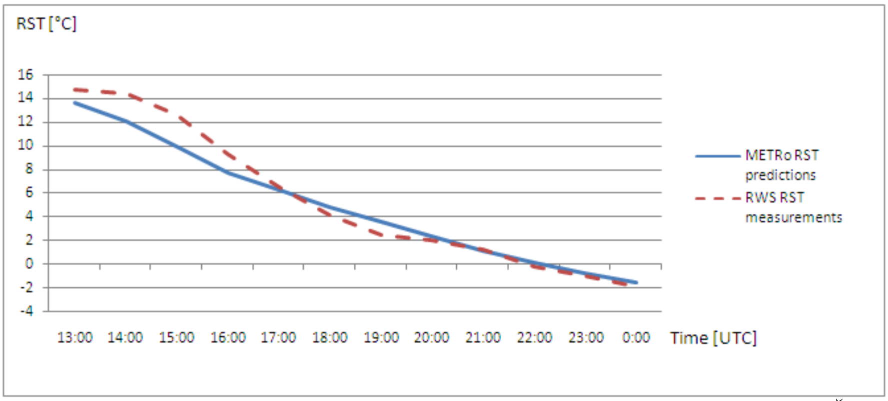

Figure 7. RST predictions calculated at 12:00 and RST measurements at the RWS *Sava Šentjakob* on 18 February 2012. RMS error for RST was 1.25*°C.*

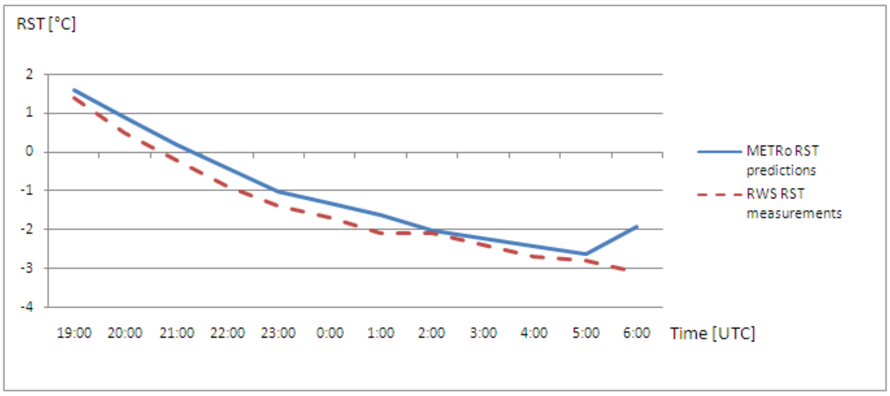

Figure 8. RST predictions calculated at 18:00 and RST measurements at the RWS *Slatina* on 18 February 2012. RMS error for RST was 0.48*°C.*

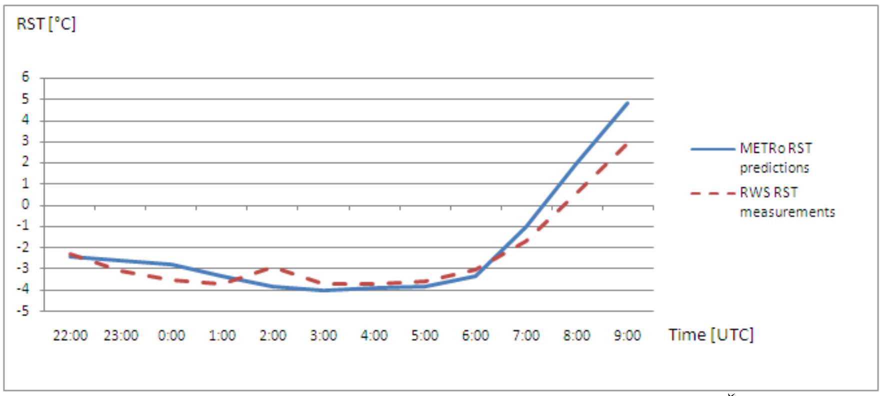

Figure 9. RST predictions calculated at 21:00 and RST measurements at the RWS *Šumljak* on 16 February 2012. RMS error for RST was 0.82*°C*.

6 SUGGESTIONS FOR IMPROVEMENTS

The results show that the RMS error for the RST predictions are generally satisfactory but can be too high at some sites, especially for the predictions around noon. Generally, to solve this problem, physical models can be improved with further parameterisations of the relevant physical phenomena (i.e. anthropogenic influence, traffic influence, shadowing from the near objects, road physical characteristics) or combined with statistical techniques (i.e. regression, neural network) to improve the quality of input or output variables.
With the latter approach, it is possible to correct the systematic errors and deal with nonlinear and non-systematic influences since the historical data from previous winters are mostly available. In comparison with the models based purely on physical simulation, statistically upgraded physical models have the ability to fit a particular location (physical models require assessing the properties of the road and the environment of the location, which is difficult and error-prone).
Pure statistical approaches have also been tested and show promising results. For example, [14] proposes two statistical methods for forecasting the probability of ice formation and [15] proposes a statistical method for forecasting RST based on the stepwise linear regression analysis with appropriate selection of the input parameters and separate models for different time intervals.

In order to improve the METRo model roadcasts, some possible upgrades are proposed:

- include anthropogenic flux predictions as an optional input (this is already done in the METRo version 3.2.7);
- include water freezing point predictions as an optional input;
- include number of predicted vehicles as an optional input;
- include sky-view factor as an optional input;
- include the depth of the RWS's subsurface temperature sensor as an optional input;
- include the RWS's subsurface road temperature measurements on bridge locations;
- ability to add new road layer types with optional physical properties.

7 CONCLUSIONS

The METRo model was successfully implemented into Slovenian RWIS, showing very satisfying results. It is also planned to implement some suggested METRo upgrades so that next winter the METRo model will be fully operational and further improved.
Recent research considers geomatics to help in creating a detailed geographical database along the road system [16]. Appropriate weather forecasts are then used to interpolate the RST and road surface condition across the entire road network with high spatial and temporal resolutions. The METRo model, as a source of the point-based RST predictions on RWS locations, could provide the necessary reference points to compute the route-based RST predictions and thus achieve a complete coverage of the road system. An accurate prediction of road weather conditions along the whole road system is important in cutting the winter road maintenance costs, reducing the environmental damage from over-salting and providing safer roads.

8 REFERENCES

[1] Fridstrøm L, Ifver J, Ingebrigtsen S, Kulmala R, Thomsen LK. 1995. Measuring the contribution of randomness, exposure, weather, and daylight to the variation in road accident counts. *Accident Analysis & Prevention* **27**: 1–20.

[2] Norrman J, Eriksson M, Lindqvist S. 2000. Relationships between road slipperiness, traffic accident risk and winter road maintenance activity. *Climate Research* **15**: 185–193.

[3] OFCM. 2003. *Weather Information for Surface Transportation: A National Needs Assessment Report.* Office of the Federal Coordinator for Meteorological Services and Supporting Research: Washington, D.C.

[4] McClellan T, Boone P, Coleman MA. 2009. *Maintenance decision support system (MDSS)*. Final report. Indiana Department of Transportation: Indiana, USA.

[5] Chapman L, Thornes JE, Bradley AV. 2001. Modelling of road surface temperature from a geographical parameter database. Part 2: Numerical. *Meteorological Applications* **8**: 421–436.

[6] Ramakrishna DM, Viraraghavan T. 2005. Environmental impact of chemical deicers – a review. *Water, Air, and Soil Pollution* **166**: 49–63.

[7] Sass BH. 1992. A numerical model for prediction of road temperature and ice. *Journal of Applied Meteorology* **31**: 1499–1506.

[8] Crevier LP, Delage, Y. 2001. METRo: A new model for road-condition forecasting in Canada. *Journal of Applied Meteorology* **40**: 2026–2037.

[9] Beden A, Ivačič M. 2010. Integrated road weather information systems in Slovenia. Paper presented at *15th International Road Weather Conference (SIRWEC 2010)*, Quebec, Canada.

[10] Haiden T, Kann A, Wittmann C, Pistotnik G. Bica B, Gruber C. 2011. The integrated nowcasting through comprehensive analysis (INCA) system and its validation over the eastern Alpine region. *Weather and Forecasting* **26**: 166–183.

[11] Bica B, Kann A, Meirold-Mautner I. 2012. Enhanced road weather warnings and improved communication strategies within central Europe as part of the INCA-CE project. Paper presented at *16th International Road Weather Conference (SIRWEC 2012)*, Helsinki, Finland.

[12] Šajn Slak A, Kršmanc R, Čarman S. 2012. Improved weather information for road sector in Slovenia (INCA-CE project). Paper presented at *16th International Road Weather Conference (SIRWEC 2012)*, Helsinki, Finland.

[13] Shao J, Lister PJ. 1995. The prediction of road surface-state and simulations of the shading effect. *Boundary-Layer Meteorology* **73**: 411–419.

[14] Berrocal VJ, Raftery AE, Gneiting T, Steed RC. 2010. Probabilistic weather forecasting for winter road maintenance. *Journal of the American Statistical Association* **105**: 522–537.

[15] Kršmanc R, Šajn Slak A, Demšar J. 2012. Statistical approach for forecasting road surface temperature. *Meteorological Applications* **19**: in press.

[16] Chapman L, Thornes JE. 2011. What spatial resolution do we need for a route-based weather decision support system? *Theoretical and Applied Climatology* **104**: 551-559.

[17] SIRWEC. 2007. A guide to road weather systems. Available from: http://www.sirwec.org/documents/rwis_web_guide.pdf

[18] Ye Z, Strong C, Fay L, Shi X. 2009. *Cost Benefits of Weather Information for Winter Road Maintenance*. Final report. Iowa Department of Transportation, April 2009. Available from: http://www.westerntransportationinstitute.org/documents/reports/4w1576_final_report.pdf

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