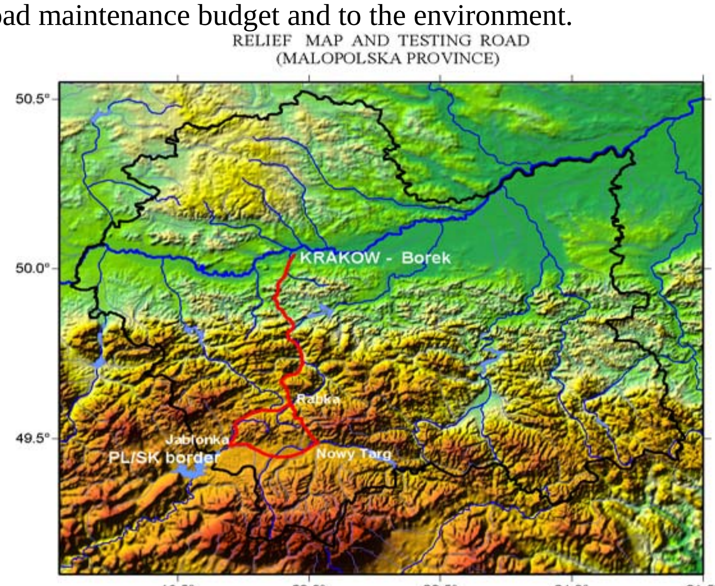
THE USE OF GIS AND ICEMISER TO PREDICT WINTER ROAD SURFACE TEMPERATURES IN POLAND

Dr John E. Thornes, Gina Cavan & Dr Lee Chapman
(j.e.thornes@bham.ac.uk)
School of Geography, Earth and Environmental Sciences
The University of Birmingham, UK

Introduction

Poland has a transitional climate with both maritime and continental elements. The dominance of maritime or continental air masses causes annual variations in the seasons. Winters are variable - sometimes mild or sometimes severe, and similarly, summers can be cool and rainy or hot and dry. Sub-zero temperatures are recorded between November and March. Annual precipitation varies between the lowlands and mountains, with totals ranging between 500-600mm. New technology has recently been invested into Poland's road network, including the installation of a network of about 70 RWIS. The study road links the City of Krakow to the mountainous border with Slovakia, as shown in Figure1. This is a very busy road approximately 200km in length, and includes a variety of land uses, road constructions and changes in topography. There are 10 RWIS along the road, provided by Vaisala and a local company. Krakow has an average winter temperature of -3°C and an average temperature in March of -1°C. This marginal winter weather in Poland creates a problem for road maintenance, and there is little emphasis on ice prediction to optimise salt use. This means that roads can be treated up to three or four times a day (Bartlett and Logiewa, 2002), at a great cost to the road maintenance budget and to the environment.



<u>Figure 1</u>: Study area in Krakow, Poland
(Source: Dyras, 2003).

The rapid growth of commercial 'off the shelf' geomatics technology including GIS and GPS, has enabled the development of a new ice prediction technique called IceMiser (Chapman and Thornes, 2003). The ESRI GIS program ArcView is used in this study to run the IceMiser model.

IceMiser Numerical Model

Numerical models provide a tool to investigate inaccessible phenomenon, such as environments in the future, which create concern for possible impacts of decisions made for future generations (Lane, 2003). There are two approaches to mathematical modelling: empirical and physically based. Lane (2003) notes that it is possible to conceive of a continuum from models that are largely built around a set of observations (empirical models) to models that are built around a set of laws (physically based models). The IceMiser model was developed by Chapman *et al*. (2001), and comprises an empirical geographical database within a physically based numerical model. IceMiser accounts for the influence of site-specific geographical parameters on the climatology of the road. The model simulates the energy transfer regime at a location by calculating the unique equilibrium temperature which balances energy flow across a surface:

$$(1-\alpha)(Q+q) + \sigma T_{sky}^{4} - \sigma T_{0}^{4} = LE + H + S$$

where: α is surface albedo, Q is direct beam solar radiation, q is diffuse radiation, σ is the Boltzman constant, T_{sky} is the radiation temperature of the sky hemisphere, T_0 is the surface temperature, R_N is net radiation, LE is latent heat flux, H is sensible heat flux and S is heat flux to soil. Thus, it uses a zero-dimensional energy balance approach (Chapman and Thornes, 2001). Meteorological data is combined with a high resolution geographical parameter database (incorporating SVF, landuse and elevation data) in the forecast model, to predict the road surface condition at thousands of sites around the road network (at spatial and temporal resolutions of approximately 20 meters and 20 minutes respectively). This enables the RST to be displayed for any site along the road network, at any particular time (Chapman *et al*., 2001b). This model is a vast improvement on existing techniques using thermal mapping. The benefits of this new approach are outlined in Figure 2.

Benefits of IceMiser:

- Allows users to identify exactly where the road needs treating at a continuous range of atmospheric stability
- Enables salting route optimisation, as times when each section of roads needs treating are indicated
- Cheap to survey and install, as no specialist software or training is required and an operational system can be set up in a few days
- Easily integrated with winter maintenance fleet fitted GPS units for GPS monitoring
- Easily incorporated and validated with existing thermal maps and sensors

Figure 2: Benefits of IceMiser (Source: Chapman and Thornes 2003b).

Chapman and Thornes (2002) note that due to climate data being typically point source in nature, the biggest challenges facing meteorology is the extrapolation of point climate data across a wide spatial domain. This can be overcome by the extraction of climate data using digital terrain models (DTMs), which enable a good estimate of an area's climatology without the need of extensive climate records and networks of weather stations. Unfortunately, a DTM was not available for this study, and instead, meteorological data from two climate stations were chosen to be representative of two geographical regions.

Meteorological Database

The meteorological database is comprised of retrospective data from two climate stations in Poland; Krakow and Zakopane. The meteorological data input into the model are listed in Table 1. These parameters were recorded hourly and were obtained for the month of March 2003. Retrospective data was chosen because this would identify the validity of the IceMiser model, rather than highlight errors in the forecasting of meteorological variables.

Table 1

Meteorological Data	**Geographical Data**	**Survey Technique to get Geographical Data**
RST at noon	Latitude	GPS
Air temperature*	Longitude	GPS
Dew point*	Altitude	GPS
Wind speed*	Sky-view factor	GPS
Rainfall*		
Cloud cover**		
Cloud type**		

* Nine values at 12:00, 15:00, 18:00, 21:00, 00:00, 03:00, 06:00, 09:00, 12:00.
** Eight values averaged over the time periods 12:00-15:00, 15:00-18:00, 18:00-21:00, 21:00-00:00, 00:00-03:00, 03:00-06:00, 06:00-09:00, and 09:00-12:00.

Road surface temperature data was obtained from 10 RWIS along the route, and was recorded at 10-minute intervals. The locations of these RWIS are shown in Figure 3. Validation data for road surface temperature was also used from the RWIS. A simple cloud classification procedure was used to allocate cloud type to three classes as supplied by the Polish Met Office.

Geographical Database

The geographical database is comprised of variables collected using a GPS, during a Short Term Scientific Mission (STSM) for COST 719. The geographical variables collected and the method of data collection are listed in Table 1. Landuse, road construction type, aspect, slope, drainage and topography were not collected for this study. These parameters have been set to default values in the model. This does affect the accuracy of the results, as results will be the most accurate with the maximum input into the model. These parameters could be collected at a later stage and input into the model to improve these preliminary results.

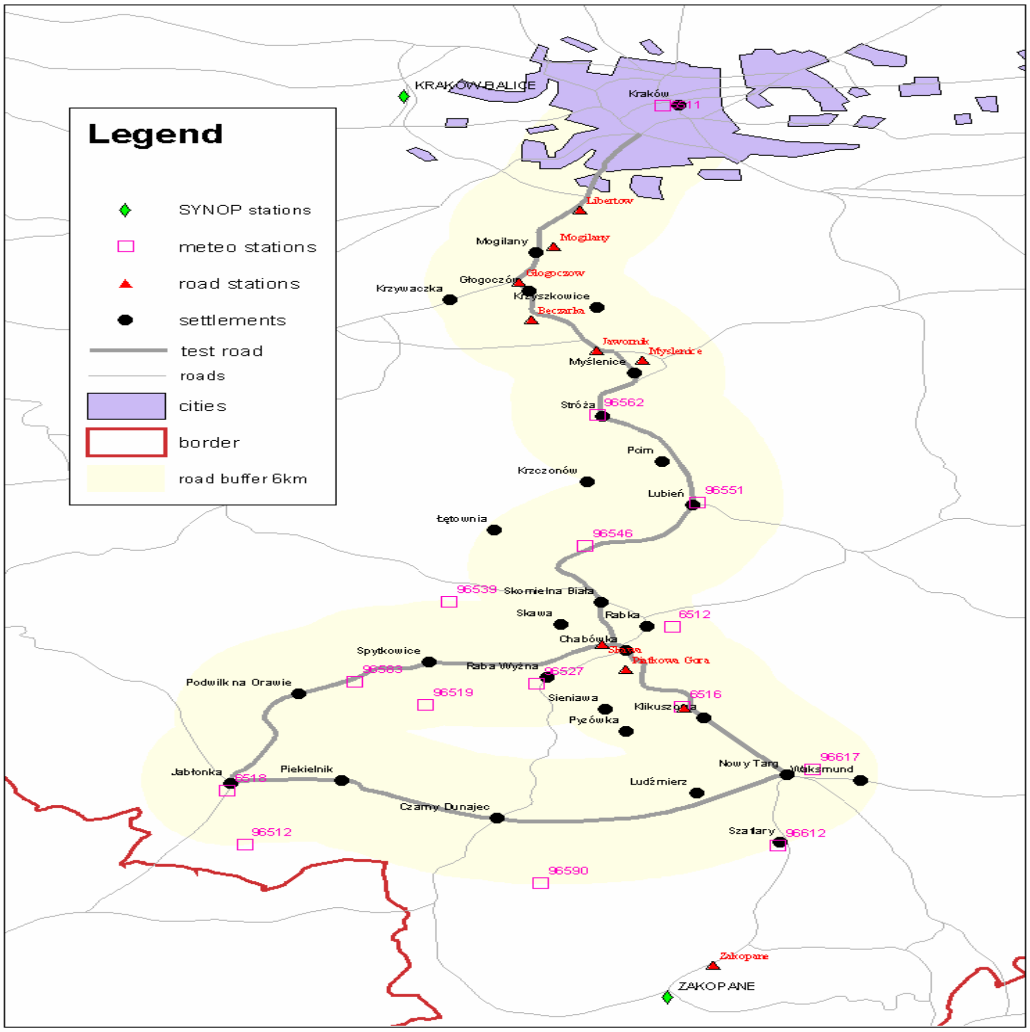


Figure 3: Location of the study area and RWIS

The geographical variables provided included: eastings, northings, altitude, latitude and sky-view factor, and enabled the creation of a shapefile. The geographical database was firstly created in Excel, and converted into a .dbf file before being converted into a shapefile. This enabled the road to be displayed spatially in ArcView as a series of points. Each point has a field representing the geographical data which was input into the database created in Excel. This allowed the creation of two separate shapefiles for each of the geographical regions; Krakow and Zakopane, based on altitude. Experiments with the number of classes (using the natural breaks technique) indicated a clear divide in the road at 400m. Krakow was chosen to be representative of lower topography (0m-400m). Zakopane is situated on the mountainous Polish border, and was chosen to represent mountainous topography and climate (400+ m).

The accuracy of the IceMiser model forecasts

The model has been run for two RWIS from each section of the road (four RWIS in total). IceMiser model results are compared to actual RST data from the RWIS. A 24hr forecast has been made for each day in March for each of the meteorological stations (Krakow and Zakopane). This has been displayed in ArcView as a series of colourcoded maps. The nearest coordinate to each of the 4 selected RWIS along the road has been obtained, and actual and forecast data has been compared for each day.

Results from the IceMiser model

IceMiser forecasts were displayed in ArcView as hourly thermal projections for each night. Figure 4 illustrates that the RST falls below zero first at the higher altitude sites around 22:00h (at the settlement of Klikuszowa) and remains below freezing for about 12 hours. These are the coldest areas of the route throughout the night. Krakow city centre remains above freezing throughout the night, and the RST along the route does not fall below freezing until it reaches the settlement of Lubien (see Figure 3 for location). It is clear that the route in the higher altitude area of Zakopane is colder than Krakow throughout the night. At 09:00h in the morning, the road is above freezing at all sites. This information is of significance for winter maintenance engineers. It indicates that the Zakopane region needs priority salting, and only selective salting needs to take place in the Krakow region around 06:00h.

The IceMiser model was run for each of the 4 stations for the number of nights available: Libertow (18), Myslenice (22), Skawa (21), Piatkowa Gora (25). Model outputs were then plotted against actual RST data from the RWIS. These were plotted in graphs of forecast versus actual RST, and samples are displayed in Figure 5. Figure 6 shows the mean hourly root mean square (RMS) error for a sample of stations.

Table 2 illustrates sample IceMiser results for Libertow. It can be seen that on most days, the model predicts RST extremely accurately, and the hourly RMS error decreases to below 2.5°C. The minimum RST occurs at Libertow at about 06:00am every night, and the model predicts the temperature at this time very accurately, with an average RMS error of 1.4°C. Analysis of the frequency of snow at Libertow revealed that snow occurred on 10 of the 18 nights – far more frequently than at the other road monitoring stations. Despite suggestions that the model is insensitive to snow, these results indicate that a high accuracy is achieved at Libertow.

Table 2

Libertow		**Actual**	**Forecast**	**Category**	**Error**
1/2 March	1	-2.20	-4.00	F/F	-1.80
2/3 March	2	-2.20	-4.20	F/F	-2.00
3/4 March	3	-2.10	-3.20	F/F	-1.10
4/5 March	4	-6.10	-7.20	F/F	-1.10
5/6 March	5	-3.60	-4.40	F/F	-0.80
7/8 March	6	-5.50	-4.90	F/F	0.60
8/9 March	7	0.50	2.10		1.60
11/12 March	8	3.50	6.80		3.30
12/13 March	9	-1.30	-2.60	F/F	-1.30
13/14 March	10	-1.20	-1.70	F/F	-0.50
14/15 March	11	-0.30	-0.90	F/F	-0.60
15/16 March	12	0.10	1.00		0.90
16/17 March	13	-2.60	-1.80	F/F	0.80
26/27 March	14	2.10	3.20		1.10
27/28 March	15	5.90	4.60		-1.30
28/29 March	16	4.70	7.70		3.00
29/30 March	17	2.70	4.80		2.10
30/31 March	18	8.20	8.00		-0.20
	Mean	0.03	0.18		**0.15**

F/F = frost forecast/frost occurred

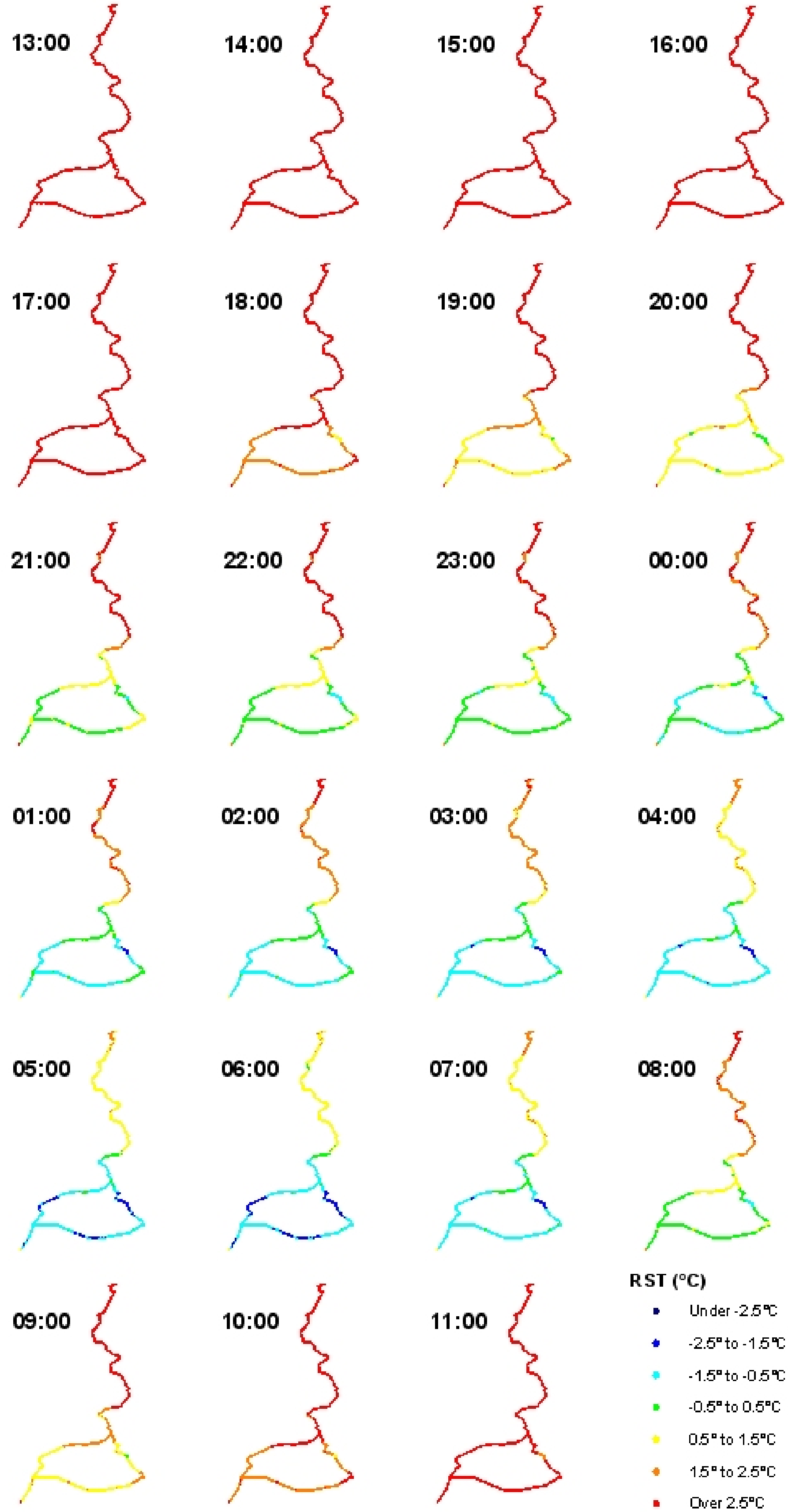


Figure 4: Hourly time-slices of the numerically predicted RST along the study route

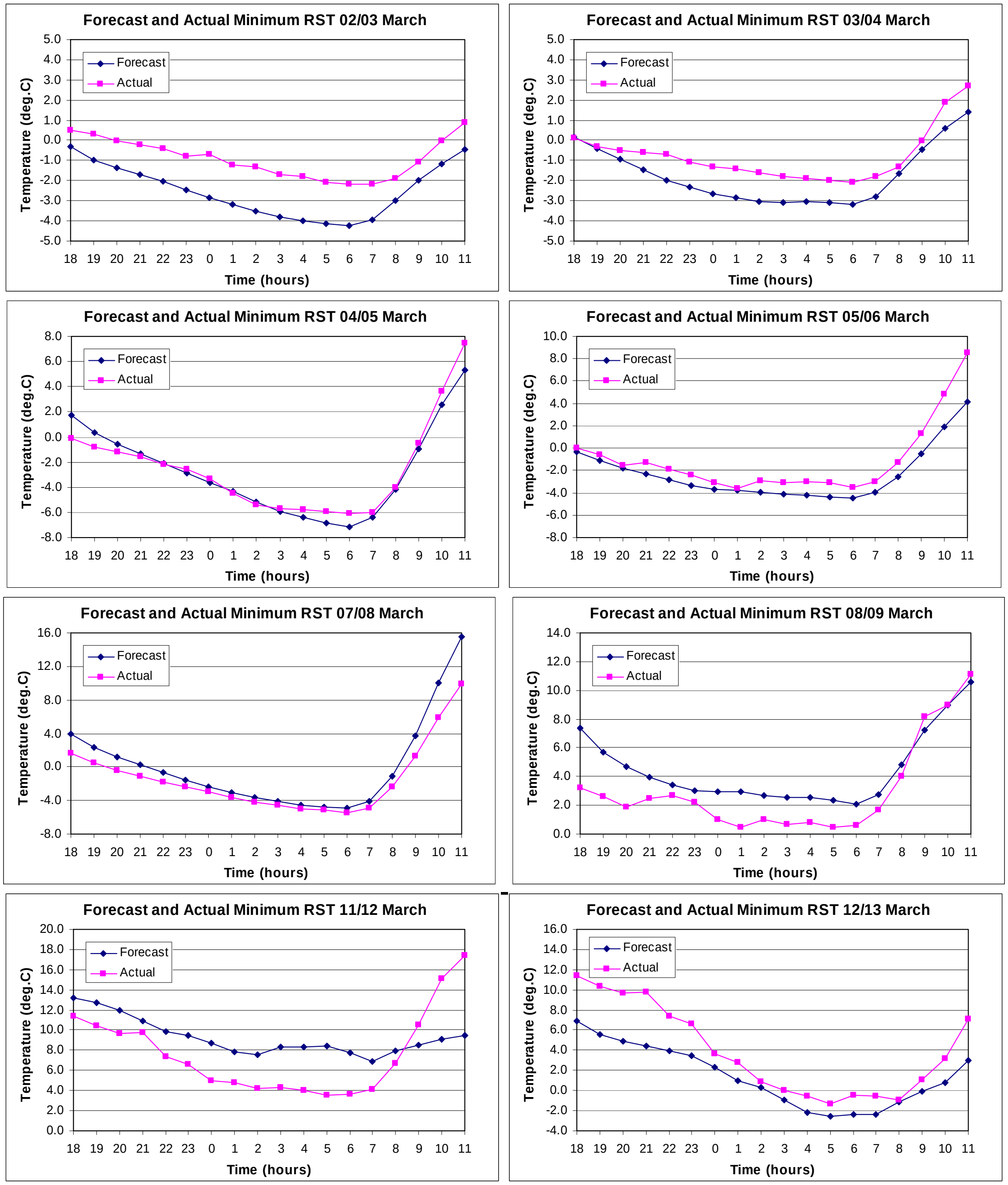
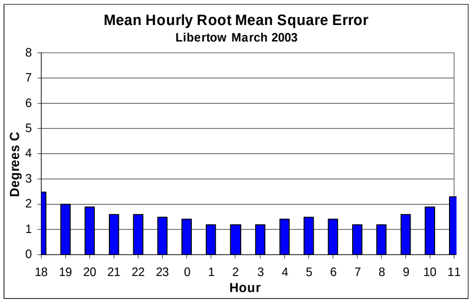
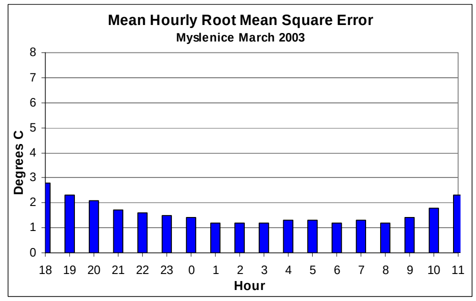


Figure 5: Sample Forecast versus actual minimum RST at Libertow (264.2m)





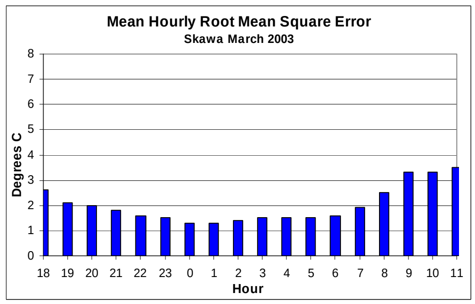


Figure 6 Sample Root Mean Square Errors in the Forecast

Conclusions

The results indicate that the model was able to forecast RST for the study route in Poland with a high level of accuracy. At best, the model forecast RST with 100% accuracy, and a bias of just 0.15°C. Additionally, the model was able to forecast the time of freezing and daily minimum RST (which occurred at about 0600h every morning) very accurately. Forecasts of RST using meteorological data from Krakow were found to be the most accurate, possibly due to the closer proximity of the RWIS, or the higher SVF explanation in an urban area.

References

Bartlett, R. and Logiewa, R. (2002). Poland: Looking to a wider Europe. World Highway Road Notes. www.worldhighways.com

Chapman, L and Thornes, J. E. (2001). A blueprint for 21st century road ice prediction. In: Proceedings of the 11th SIRWEC Conference, 26-28 January 2002, Sapporo, Japan.

Chapman, L and Thornes, J. E. (2002). The use of geographical information systems in climatology and meteorology. Theoretical and Applied Climatology, 69, 81-89

Chapman, L and Thornes, J. E. (2003). Geomatics inspire winter maintenance revolution., APWA Reporter, 70, 22-23

Chapman, L. Thornes, J. E. and Bradley, A. V. (2001). Modelling of road surface temperature from a geographical parameter database. Part 2: Numerical,. Meteorological Applications, **8**: 421-436**.**

Lane, S. N. (2003). Numerical modelling in physical geography: understanding, Explanation and Prediction. In N. J. Clifford, and G. Valentine (eds.), Key Methods in Geography. Sage Publications, pp 263-290.

Acknowlegement: COST 719 GIS in Meteorology and Climatology Programme

Short Bibliography:

Dr John E. Thornes is a Reader in Applied Meteorology at the University of Birmingham, UK. He is currently Editor of the journal Meteorological Applications and Chairman of Working Group 3 of the COST 719 GIS in Meteorology and Climatology programme. He was President of SIRWEC twice 1992-1994 & 1996 - 1998 and was Vice President in 1994 – 96. He has been to every SIRWEC conference and helped to draw up the constitution in Birmingham in 1984.