# Forecasting Road Surface Temperature for Specific Site Characteristics Using an Energy Balance Model

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## Abstract

In 1992/93 the Deutscher Wetterdienst (DWD) began to introduce SWIS (Straßenzustands- und Wetterinformationssystem) as a nationwide road weather information system. In order to forecast road surface temperature an energy balance model is used. The original model version was provided by the UK Met Office, however, in the meantime the DWD has completed significant developments of the model. Now it is possible to run the model for specific site characteristics (open and flat road sections, shaded sites) and for bridges. The course of the energy fluxes is estimated by the course of meteorological parameters. To evaluate the model's quality the technique of hindcasting was employed by running the model for a day in the past (runnig time 09 UTC of a chosen day to 12 UTC at the follo wing day), using measured values of a specific road weather monitoring station complemented by observations from a nearby synoptic station. Preliminary results show that from the afternoon to the evening there are still deviations of up to 2 degrees, afterwards, however, deviations are often less than 1 degree with better results during clear sky conditions. It could be shown that in most cases the new version of the energy balance model is better than the original one especially towards the end of the model run.

## 1 Introduction

Beginning in 1992/93 the Deutscher Wetterdienst (DWD) started to issue forecasts of road conditions and road surface temperature as a part of the German road weather information system, called SWIS (Straßenzustands- und Wetterinformationssystem). The main objective of SWIS is to improve the efficiency of winter road maintenance. Since 1995/96 all road authorities in Germany participate in the SWIS project.

The main part of the SWIS-forecast products is the 24-hrs-detailed area forecast. This forecast refers to a climatic region, subdivided by altitude (200 metres intervals), leading to so-called forecast areas.

Road authorities have installed road weather monitoring stations along the German motorways. One road weather monitoring station is chosen to be representative for a forecast area. For this station an energy balance model is run to forecast road conditions and road surface temperature. The results obtained are then again assumed to be representative for the whole forecast area.

## 2 Model description

The energy balance model (DWD version 3.0) follows to a certain extent the original version of an energy balance model developed by the UK Met.Office and as it is still used operationally in OpenRoad. However, in the DWD version the radiation scheme has been altered significantly and the model is capable to consider five specific road site characteristics, a) "Regular traffic" (an unobstructed road section with steady and dense traffic), b) "Little traffic" (an unobstructed road section but with little traffic), c) "Shaded sites", d) "Bridges", e) "Urban sites".

The energy balance model runs for a forecast period of 27 hours. It starts at 9 UTC and ends at 12 UTC the following day. The course of the energy fluxes is estimated by the following meteorological parameters:

a) initial values at 9 UTC

Some of the initial values have to be provided by the forecaster. They describe the overall road state at the start of the model run: the road surface temperature, sub-surface temperature, road surface condition. In addition, the soil temperature profile at 9 UTC as calculated by the model run of the previous day is used automatically.

b) meteorological/synoptic input data

The synoptic input data are provided by the numerical weather prediction model of the Deutscher Wetterdienst (Deutschland-Modell) in the form of Kalman-filtered direct model output (DMO) and are checked by the forecaster. They include for every three hours forecast values of air temperature, dewpoint and surface pressure. In addition, mean values (over a period of three hours) are provided for the following input parameters: cloud cover (total, low, middle, high), wind speed and direction, rain amount and snow amount.

c) supplementary meteorological data

In order to improve the calculations of short and long wave radiation, respectively, a general estimate of the prevailing conditions is required concerning snow cover in the surrounding area and overall visibility.

d) invariable input data describing the properties of the road weather monitoring station

These properties include: latitude, longitude and altitude of the site; albedo, emissivity, thermal conductivity and capacity, depth of the road bed. At present, standard values are used for all sites.

The output-table as presented to the forecaster contains the forecast values from 12 UTC of the actual day to 12 UTC of the following day in time increments of 3 hours and referring to weather elements, which are relevant for winter road maintenance.

# 3 Verification

## 3.1 Procedure

To evaluate the model's quality, the technique of hindcasting was employed by running the model for a day in the past using measured air temperature and dewpoint of a specific road weather monitoring station and observations of cloudiness and precipitation taken at a nearby synoptic station.

In the following discussion, only the quality of model simulations of the parameter road surface temperature will be presented. The verification of the parameter road condition is excluded: a) due to uncertainties of the measurements taken at the road weather monitoring station, and b) because the model is unable to account for any influence by winter maintenance activities. The differences of the sub-surface temperatures at a depth of 30 cm between the model calculations and the corresponding measurements are generally less than 0.5 Kelvin, and hence, do not warrant further discussion. The mean error ("model" minus "measurement"), which represents the systematic part of the error, and the root mean square (RMS) error, which represents the non-systematic part, will be discussed.

The database originates from the two winter seasons of 1993/94 and 1994/95, respectively, from measurements taken at 14 road weather monitoring stations in the state of Hesse. For statistical purposes it is always useful to consider large data ensembles. But due to data losses, only 40 days for the first winter and 60 days for the second winter are available. In order to achieve a homogeneous data set consisting of measurements taken at synoptic stations and road weather monitoring stations, periods of time were selected when the overall weather situation exhibited a wide spatial homogenity, e.g. uniform cloud cover over a large area. The following time periods based upon cloud cover were chosen:

| | | | |
|---|---|---|---|
| overcast conditions: | 23.01.-10.02.1994 | and | 18.01.-01.02.1995 |
| | (for each period 10 data sets are available) | | |
| clear sky conditions: | 14.02.-18.02.1994 | and | 09.03.-12.03.1995 |
| | (for each period 4 data sets are available) | | |

## 3.2 Results

Only verification results for "Regular traffic", "Shaded sites" and "Bridges" can be presented here. Data from road weather monitoring stations of the site characteristics " Little traffic" and "Urban sites" are not available. The results are presented as mean values for several road weather monitoring stations in order to average out individual peculiarities of a specific station. In the case of "Regular traffic", hindcasting was also carried out with the UK Met.Office model. The comparison is included in Fig. 1 and will be discussed in section 4.

a) Regular traffic

Fig. 1 presents average values based upon 4 road weather monitoring stations in Hesse. During the forecast period after 21 UTC, the mean error shows a tendency to slightly underestimate the road surface temperature, exceeding 1 Kelvin occasionally. During the early period of the forecast up to 21 UTC, errors of 2 Kelvin are possible. The reason is not understood, because under similar conditions during the following morning the errors are relative small.

For overcast and clear sky conditions the RMS error varies between 1 and 2 Kelvin during daytime and between 0.3 and 1.7 Kelvin during the night. Averaging over the entire winterseason (not shown), the RMS error increases around midday up to 3.3 Kelvin, probably due to the discrepancies of cloudiness between the specific road weather monitoring station and the observations at the nearby synoptic station. It should be pointed out that for clear sky conditions the results are better than for overcast conditions.

b) Shaded sites

Only data from one road weather monitoring station were available in order to verify this site characteristic. The time period from 01.11. to 20.02. of each winterseason was considered, because only during this time period the shadow of a nearby forest fell on to the road sensor.

As presented in Fig. 2 only small errors occur for the forecast period after 18 UTC. The mean error varies between -0.5 and 0.4 Kelvin (entire winter periods) and -0.3 and 1.1

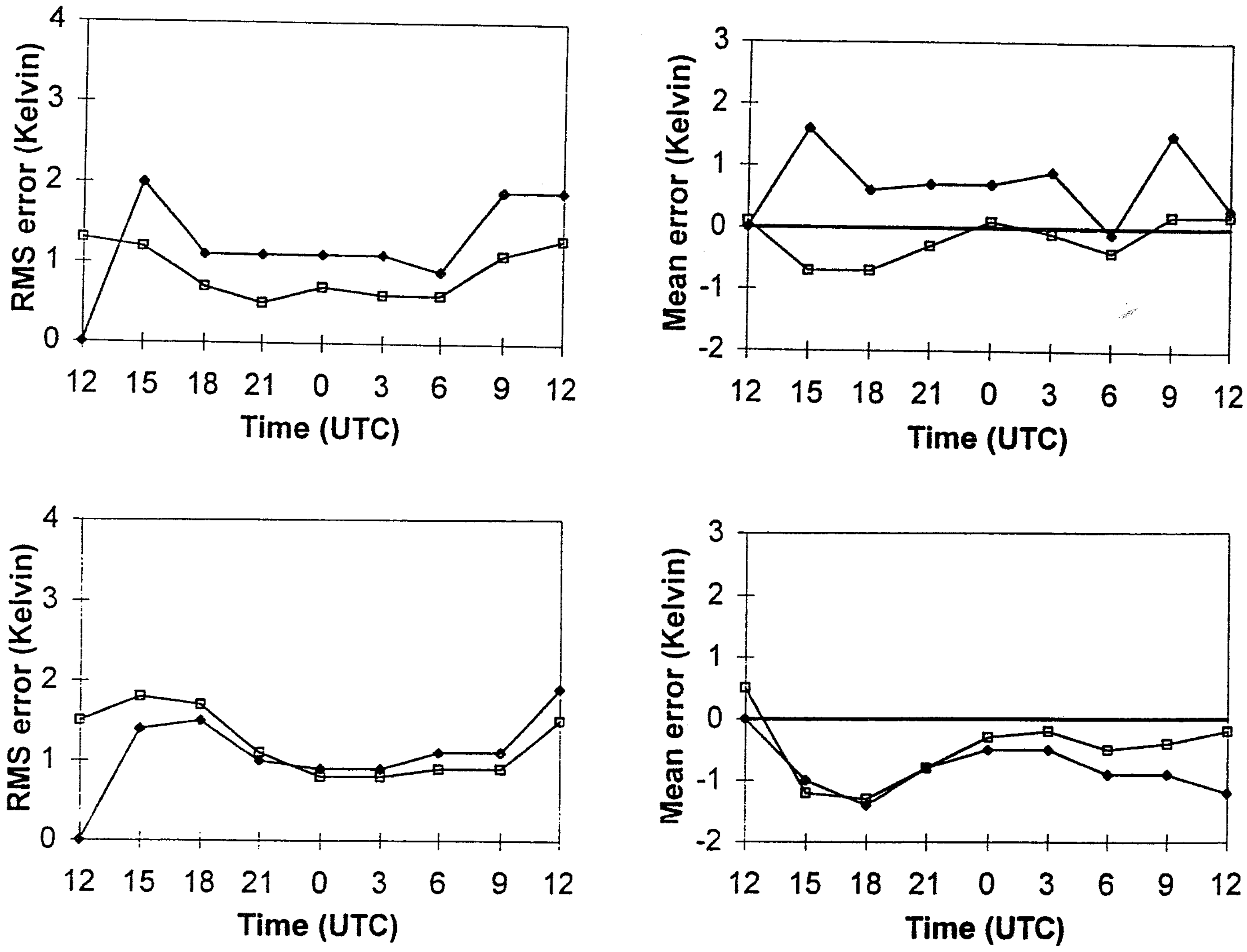


Fig. 1 Root-mean-square (RMS) error (left) and mean error (forecast minus measurement, right) of road surface temperatures, averaged over four road weather monitoring stations in Hesse

Site characteristic: Regular traffic
DWD-version: □ Met.Office-version: ◆
Top: Average of time period 14.02.1994 to 18.02.1994 (clear sky conditions)
Bottom: Average of time period 23.01.1994 to 10.02.1994 (overcast conditions)

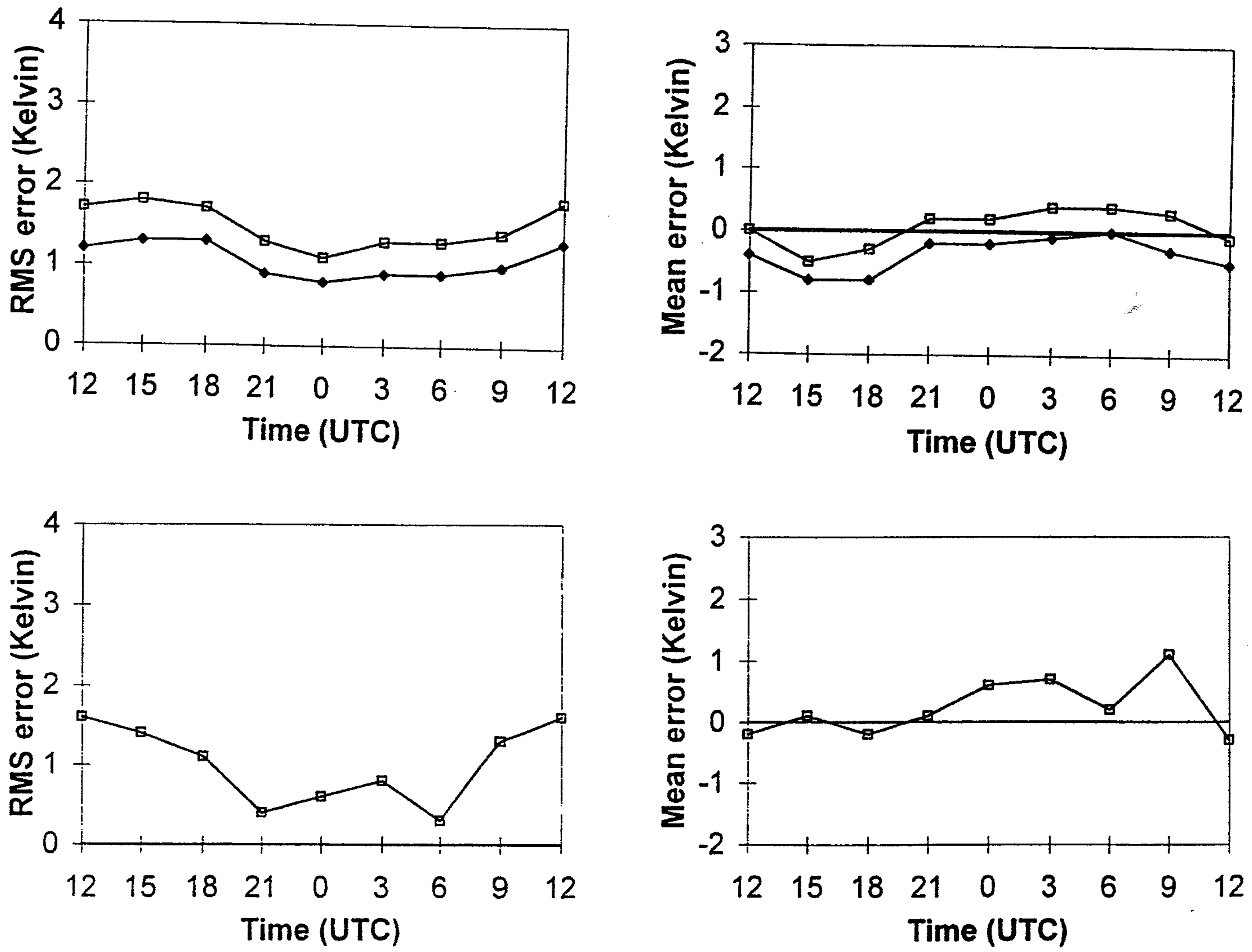


Fig. 2 Root-mean-square (RMS) error (left) and mean error (forecast minus measurement, right) of road surface temperatures for one road weather monitoring station

Site characteristic: Shaded sites

Top: Average of entire winter periods 1993/94 (□) and 1994/95 (◆)

Bottom: Average of time period 14.02.1994 to 18.02.1994 (□) (clear sky conditions)

Kelvin (clear sky conditions). The RMS error shows values from 0.8 to 1.8 Kelvin and 0.3 to 1.6 Kelvin, respectively.

c) Bridges

The verification results presented in Fig. 3 are average values based upon 9 bridges of different construction types (steel, concrete). During the forecast period after 18 UTC the following errors are observed:

| | Mean error [K] | RMS [K] |
|---|---|---|
| Both winter periods | -1.0 to 0.4 | 1.0 to 2.8 (not shown) |
| Cloudy conditions | -1.1 to 0.1 | 0.8 to 2.0 |
| Clear sky conditions | -0.8 to 0.9 | 0.8 to 1.4 |

Again, at 15 and 18 UTC larger mean errors between -0.7 and -1.9 Kelvin and larger RMS errors from 1.7 to 2.4 Kelvin occur.

## 4 Discussion

Based upon an energy balance model originally introduced by the UK Met.Office, the Deutscher Wetterdienst has developed a model version which includes a) a more sophisticated radiation scheme; b) a forecast period of 27 hours starting at 9 UTC; and c) model calculations for five different site characteristics.

The performance of the energy balance model was verified by applying the method of hindcasting, thus, a correct synoptic input as well as correct measurements of the road sensors are assumed. Results show that the road surface temperature for the forecast period after 21 UTC is predicted with mean deviations between 0 and -1 Kelvin and with RMS errors between 0.5 and 2 Kelvin. The results are generally better during clear sky conditions than during overcast conditions. For the forecast period up to 21 UTC, the results are less accurate with deviations up to -2 Kelvin. The reason for this is unknown, because under similar conditions during the morning of the following day only small deviations occur. Therefore, a statistical correction is applied during the forecast period 15 to 21 UTC to minimize these errors.

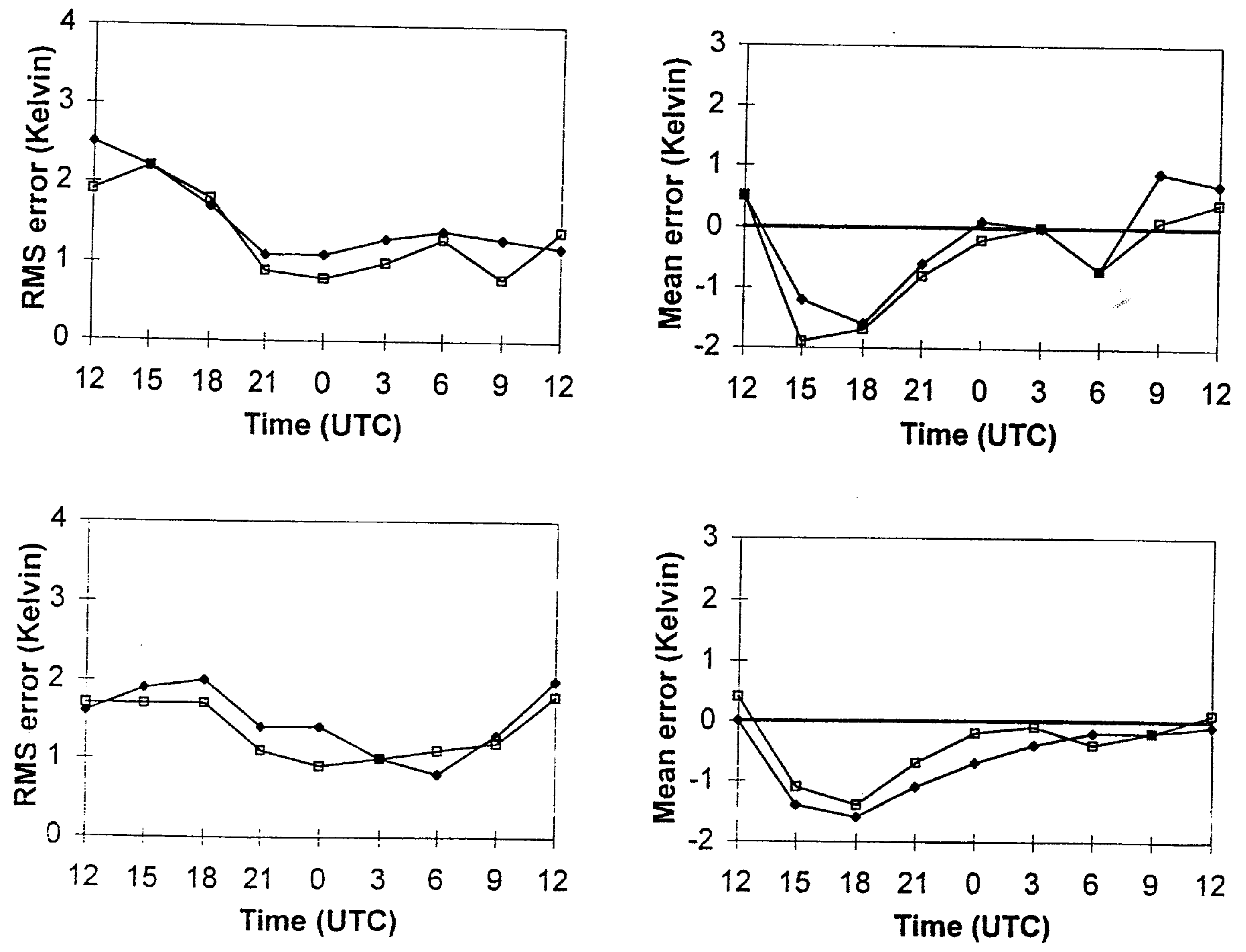


Fig. 3 Root-mean-square (RMS) error (left) and mean error (forecast minus measurement, right) of road surface temperatures, averaged over nine road weather monitoring stations in Hesse

Site characteristic: Bridges

Top: Average of time periods 14.02.1994 to 18.02.1994 (□) and 09.03.1995 to 12.03.1995 (◆) (clear sky conditions)

Bottom: Average of time periods 23.01.1994 to 10.02.1994 (□) and 18.01.1995 to 01.02.1995 (◆) (overcast conditions)

It should be pointed out that the results presented here are mean values based upon several road weather monitoring stations. In the case of the site characteristic "Regular traffic", four road weather monitoring stations have been investigated, all of which show only small deviations from the mean values. In the case of "Bridges", nine road weather monitoring stations have been considered. During overcast conditions, only one bridge exhibits a larger range of deviations as compared to the mean value (after 18 UTC up to -2 Kelvin). During clear sky conditions, however, most bridges show a strong individual behaviour, resulting in deviations with a larger range (after 18 UTC: -3.6 to +2.3 Kelvin). This may be explained by the different types of bridge construction.

Comparing the original version of the Met.Office with the model of the Deutscher Wetterdienst (Fig. 1), results show that up to 18 UTC the version of the Deutscher Wetterdienst shows a small tendency to produce lower road surface temperatures than the version of the Met.Office. At 21 UTC both versions show a similar quality. For the forecast period after 21 UTC, however, the model of the Deutscher Wetterdienst produces both mean errors and RMS errors, which are by 0 to 1 Kelvin better than in the case of the Met.Office model.

The results suggest that the current version of the model is sufficient to produce forecasts which can be used in operational winter road maintenance. It should be pointed out that the energy balance model produces a forecast for a single point with the assumption that this forecast is representative for a larger area or a long road section of the same site characteristic. Therefore, it would only be of academic interest to produce absolutely exact forecasts for this single point, because natural variations of the road surface temperature are possible to the order of several degrees. For practical purposes, it might be sufficient to forecast road surface temperatures to an accuracy of 0.5 to 1 Kelvin.

The capability of forecasting road surface temperature for a period of 27 hours depends to a large extent on the capability of predicting correctly the energy balance model's synoptic input data, in particular cloud cover (a parameter difficult to predict) and air temperature. Thus, only improving the quality of the energy balance model may not lead to better overall results if the forecaster's or the numerical weather prediction model's skill are not sufficiently taken into consideration.