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The application of METRO model to the Czech road data – preliminary results

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ABSTRACT

The goal of this paper is to adopt the METRo model to Czech road data and to present the first experiences. The METRo, a physically based model developed by the Meteorological Service of Canada, produces a 30-hours forecast of road conditions and its temperature. The METRo requires measurements from the road weather stations and forecasts of a numerical weather prediction model as an input data. This first test was performed with road data for the Svojkovice station located at 70.3 km of the motorway D5 (Prague-Plzeň) and the ALADIN-CZ NWP model forecasts were used. The test was performed for data from the winter 2009/2010. The forecasted surface temperature yielded higher values comparing to the measured ones during the daytime and lower values during the night time. These differences were more pronounced when considering the beginning (October) and the end (March) of the winter season only as a probable impact of high insolation. The accuracy of the forecasted road conditions expressed by the code specifying road conditions ranged between 65 and 80% for all lead times of the forecasts.

Keywords: METRO model – forecast – temperature of roads – road condition – Czech Republic

1 INTRODUCTION

During winter, many roads located in cold or temperate regions are influenced by severe climatic conditions associated with snow and ice. These conditions have serious consequences on driving conditions, reducing the traffic flow dramatically, because the failure in maintaining roads in winter often leads to road closures. Ice and snow also increase the risk of accidents. In this context, road–weather forecasting systems can help to organize the maintenance services, reduce accident risks, and maintain the road network.

In the last decades various numerical models were developed to predict road surface conditions (e.g. Shao and Lister, 1996; Crevier and Delage, 2001; Bouilloud et al., 2009). The numerical prediction of road ice and frost has been accepted by both highway engineers and meteorologists as an appropriate and valuable technique for cutting winter road maintenance costs, protecting the environment, and keeping and raising road safety standards.

At present, forecasts of surface conditions are issued by numerical road prediction models and/or numerical weather prediction models. Numerical road prediction models use weather forecasts and road condition data as inputs and forecast future road conditions applying a surface energy-balance equation, which describes the flux of energy between the atmosphere and a road (e.g. Crevier and Delage, 2001). Numerical weather prediction models forecast weather by integrating coupled differential equations representing physical processes that govern the atmosphere forward in time.

This paper presents our first experience with the application of the METRo model which we chosen to predict the condition and temperature of the Czech roads. The paper deals with: (i) application of the METRo model with Czech road data, (ii) evaluation of the model forecasts by observed values and (iii) determination of the model parts which should be adjusted to conditions and climate of the Czech roads.

2 METRO MODEL

METRo is a physically based model developed and operationally used by Meteorological Service of Canada to forecast road conditions (Crevier and Delage, 2001). The model code is freely provided by Environment Canada. Two types of data are used as the METRo inputs: (1) measurements from the road weather stations and (2) forecasts of a meteorological prediction model. METRo predicts a time evolution of the road surface and subsurface temperatures and the road surface conditions such as dry road, water/ice/snow or their mixtures on the road.

The model consists of a surface energy balance module, a road heat conduction module, and a surface water/ice accumulation module. For the surface energy balance, METRo calculates the net shortwave and longwave radiation fluxes, the turbulent fluxes of sensible and latent heat, the heat flux caused by phase changes of water at the road surface. A constant value (either user-specified or default) represents the effect of traffic in the energy balance equation. If the downward radiation fluxes are not available from the meteorological model, METRo uses a simple parametrization to calculate them as a function of total cloudiness. The second module computes a fine-resolution vertical temperature profile in an ordinary road or in a bridge by solving numerically the one-dimensional heat conduction equation. The third module is a simplified model of either water or ice accumulation on the road if the surface temperature is above 0°C or below 0°C, respectively. Precipitation, evaporation, and water runoff or snow removal rates are taken into account in this module. Water and ice/snow are allowed to coexist on the road only at 0°C. Then an additional term describes the phase transfer in the water and ice budget equations.

If both data from a road station and a meteorological model are available for a certain period preceding the beginning of a forecast, METRo runs in three subsequent phases: initialization, coupling, and forecast. In the first phase, the heat conduction module generates a road temperature profile that matches with the measured road temperatures. The coupling is a period when the downward radiation fluxes are modified iteratively until the surface energy balance module with the road station atmospheric forcing gives the road surface temperature that is within 0.1 K of the measured value at the time of the forecast beginning. However, METRo can start the forecast even if the pre-forecast data are completely missing. In this case, the analytical solution of the heat conduction equation is used for the initialization, and the coupling is skipped.

3 DATA

In this contribution, data from the winter season (October-March) 2009/2010 were employed.

Table 1. List of meteorological road stations along the motorway D5. The station highlighted by bold font represents the station applied in the first experiment.

Location	Manufacturer	Road-kilometer	Latitude: N [°]	Longitude: E [°]	Altitude [m a.s.l.]
Rudná	Vaisala	0,3	50,0488	14,2632	390
Rudná	CrossMet	4,2	50,0336	14,2158	380
Rudná	Vaisala	12	49,9861	14,1392	290
Rudná	Vaisala	23,7	49,9259	14,0109	250
Svojkovice	Vaisala	35	49,8636	13,8894	360
Svojkovice	Vaisala	41,5	49,8404	13,8138	410
Svojkovice	Vaisala	53	49,781	13,6881	470
Svojkovice	Vaisala	62,5	49,7511	13,5679	360
Svojkovice	**Vaisala**	**70,3**	**49,7252**	**13,4704**	**430**
Svojkovice	Vaisala	73,1	49,7092	13,4405	340
Svojkovice	Vaisala	77,8	49,6809	13,4036	380
Svojkovice	Vaisala	78,2	49,6813	13,3984	325
Ostrov	Vaisala	83,6	49,6771	13,3272	350
Ostrov	Vaisala	84,5	49,6777	13,3141	320
Ostrov	Vaisala	96,8	49,7077	13,1761	345
Ostrov	Vaisala	112,4	49,7039	12,9736	410
Ostrov	Vaisala	118,1	49,7208	12,9001	505
Ostrov	Vaisala	128,5	49,746	12,7713	490
Rozvadov	Vaisala	136,2	49,7021	12,6943	560
Rozvadov	Vaisala	141,7	49,6796	12,6286	580
Rozvadov	Vaisala	145,8	49,6654	12,5816	520

3.1 Meteorological observations

Meteorological data are measured on the road stations located along the main motorways in the Czech Republic. The data from the motorway D5 connecting Prague, Plzeň and Rozvadov (border with Germany) were processed (20 stations) in the first experiment. As the data contained a lot of missing values, we selected the only station which contained all required observations and used it in the first experiment presented in this paper. This station is named Svojkovice and is located in the proximity of Plzeň. Detailed information about the stations is given in Table 1.

Data were available with a time step of approximately 15 minutes. The list of measured variables includes time of measurements, air temperature, dew-point temperature, road surface temperature, road subsurface temperature, road condition, rain rates, relative humidity, air pressure, wind speed, direction of wind, solar radiation and visibility.

3.2 Model prognostic fields

Atmospheric prognostic fields were provided by the ALADIN-CZ (Aire Limitée Adaptation dynamique Développement InterNational) NWP model. The ALADIN-CZ is operationally applied in the Czech Hydrometeorological Institute (CHMI). Data were available with a horizontal resolution of 9 km and with a time step of 3 and 6 hours for the surface and atmospheric variables, respectively.

4 EXPERIMENTAL SET-UP

In this case study, we used data from the station of Svojkovice (70.3km) for the evaluation of the METRo model. The original detailed physical parameters of the road subsurface structure (10 layers) had to be simplified and aggregated to the four METRo types. The resulting two layers consisted of 11 cm of asphalt and 54 cm of crushed rock.

Organizing model tests we stemmed from the future planned operational setup of the road forecast. The road model is supposed to utilize 12 hrs of past observations and the lead time of the road model will be 30 hrs. The start of the road forecast is 6 hrs after the start of the ALADIN-CZ model which yields a 6-hour overlap with observations and this can be used for the coupling. The road forecast covers remaining 30 hours of input data.

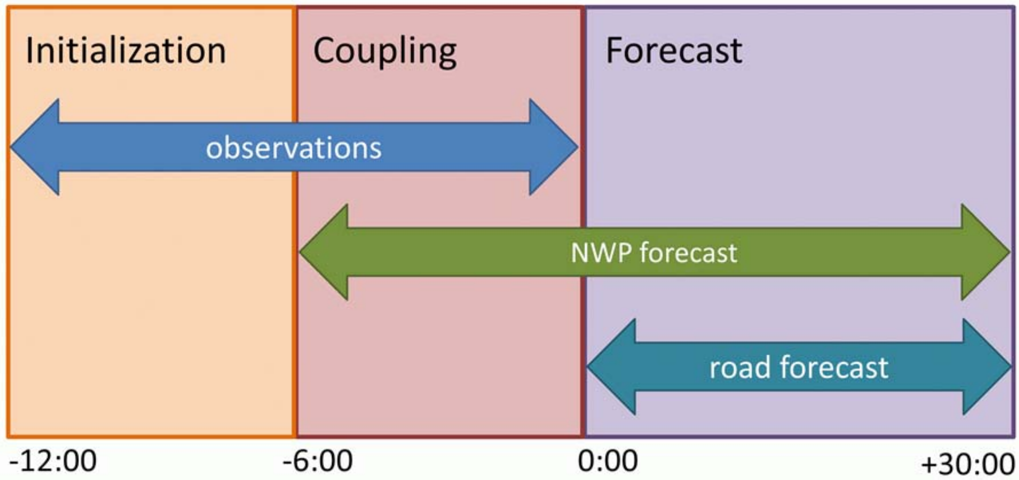

Figure 1. Time scheme of the road forecast process.

5 VERIFICATION

The forecasts from the METRo model were verified with the observed values during the winter 2009/2010 at the Svojkovice station. The forecasts were issued at 06 and 18 UTC every day and their length were 30 hours with a time step of 20 minutes. The model forecasts were integrated in one hour and compared with the observed values. Hourly observations were obtained by the integration of the 15 minutes instantaneous values. Our quantitative verification stemmed from the following accuracy statistics:

- Mean Error (ME):

$$ME = \frac{1}{N}\sum_{i=1}^{N}(F_i - O_i) \quad (1)$$

- Mean Absolute Error (MAE):

$$MAE = \frac{1}{N}\sum_{i=1}^{N}\left|F_i - O_i\right| \quad (2)$$

- Root Mean Square Error (RMSE):

$$RMSE = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(F_i - O_i)^2}, \quad (3)$$

where F_i and O_i were the forecasted and observed values, respectively, and N was the number of values. The verification was calculated for the surface temperature (ST) and separately for the starting times 06 and 18 UTC. The examples of the results for the ST are depicted in Fig. 2a and 2b.

The forecasts of the ST are generally overestimated around the midday which can be caused by the increased insolation during the day. This assumption proves Fig. 3 that shows the verification of the ST forecast for each month separately. According to the expectations, the biggest overestimation of the forecasted ST during the daytime is observed at the beginning (October-November) and the end (February-March) of the winter season. On the other hand, the forecasted ST is underestimated during the night time which can be caused by underestimation of the downward longwave radiation. Similarly, all the errors are smaller in December and January.

Road condition (RC) which is expressed by the specific code (for instance number 1 corresponds to a dry road) was verified using true/false technique (i.e. when the forecasted RC code coincided with the observed one the result was true; otherwise false). In order to compare the both data sets, it was necessary to unify the RC codes of the observed values with the forecasted ones. Some codes had to be excluded from the verification process because they were not presented in both data sets together. Only the following RC codes were evaluated: dry road (1), wet road (2), ice/snow on the road (3), and frost/black ice (7). The results are shown in Fig. 2c and Fig. 2d for the forecasts starting at 06 and 18 UTC respectively. Both pictures indicate a high proportion of correctly issued forecasts ranging between 65 and 80 %. However, apparent differences are visible for various lead times.

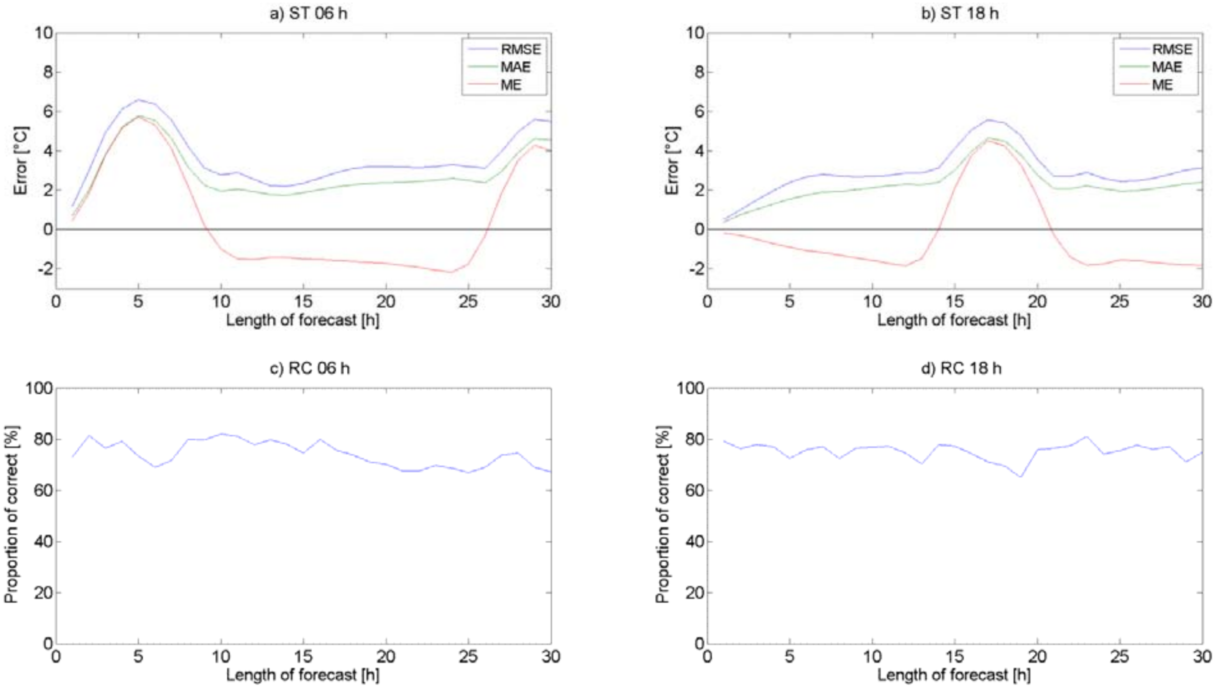

Figure 2. Verification of the surface temperature (ST) and the road condition (RC) for the time 06 UTC (left columns) and 18 UTC (right columns). The quantitative accuracy of the ST is expressed by RMSE, MAE and ME. The black solid line divides the errors into the positive and negative values. The accuracy of the RC shows how many percentage of the forecasts were correctly issued. Dry road, wet road, ice/snow on the road, and frost/black ice codes only were evaluated. The verification was calculated for all winter season 2009/2010.

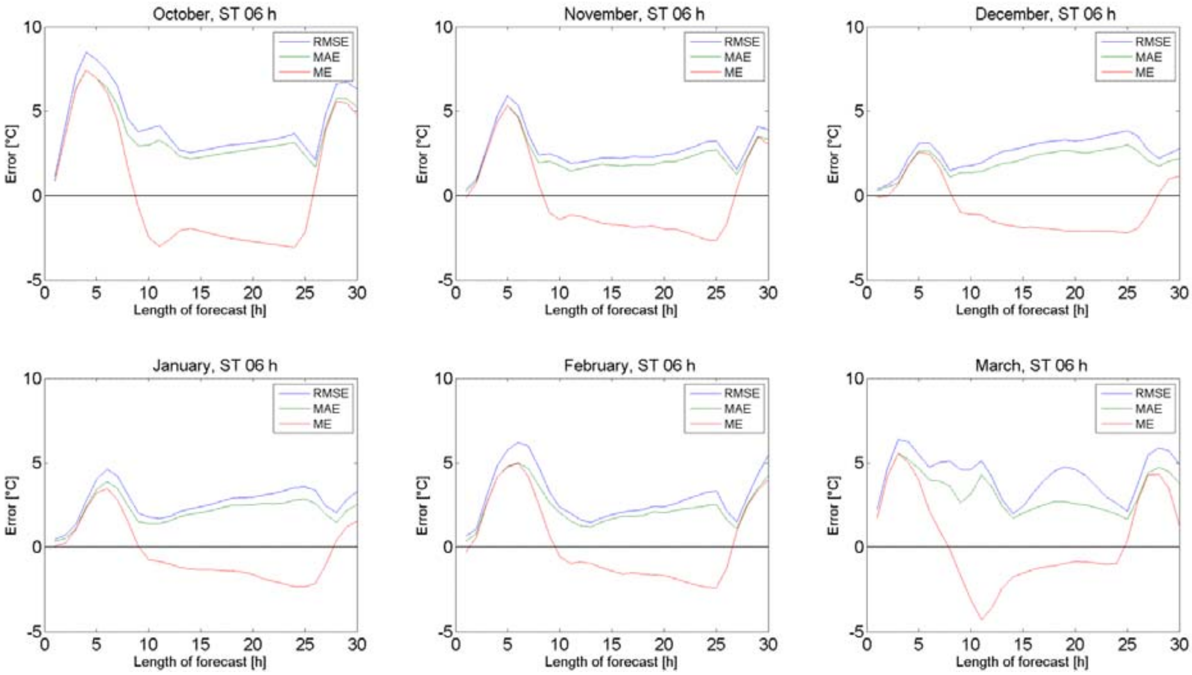

Figure 3. Verification of the surface temperature (ST) for the time 06 UTC and for each month separately. The quantitative accuracy of the ST is expressed by RMSE, MAE and ME. The black solid line divides the errors into the positive and negative values.

6 CONCLUSIONS AND OUTLOOK

The first experience with the METRo model using Czech road data is presented in this paper. The test was performed for the road station called Svojkovice located at 70.3 km of the motorway D5 connecting Prague, Plzeň and Rozvadov. The preliminary results revealed significant differences between the day and night forecasts. During the day the solar insolation heats the road surface which makes the ST more difficult to predict. Such a fact results in bigger errors (ME, MAE and RMSE) comparing to the night when the predicted ST is smaller than the observed values. These differences are more evident at the beginning (October) and the end (March) of the winter season (i.e. in the period when the air temperature can reach high values during the day and low values during the night).

The next work will be aimed at the testing of different lengths of the initialization of the road temperature profile. In this paper, we used past 12 hours of observations. On the contrary, Crevier and Delage (2001) used road temperature observations at the surface and subsurface from the last 48 hours to force the heat-conduction model. Future work should also investigate whether a change of parameters of the cloud transmissivity can improve the issued road forecast. All the experiments should be performed with road weather data from all the stations along the motorway D5 completed with the relevant values. The outputs from the NWP model which are required by the METRo will be corrected by the model output statistics post-processing technique (Glahn and Lowry, 1972).

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