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First experience with the application of the model METRo in the Czech Republic

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ABSTRACT

This paper presents our first experience with the application of the METRo model, which forecasts road surface temperature and road conditions in the Czech Republic. The model uses measurements from road weather stations (RWS) and weather forecasts from the operational numerical weather prediction model ALADIN operated by the Czech Hydrometeorological Institute. The METRo model was quasi-operationally tested during the winter season from November 2012 to February 2013. This contribution is focused on the evaluation of the METRo application in a nowcasting mode. In this mode the model starts every hour using new measurements available from the RWS.

Keywords: Road meteorology, road surface temperature, model forecast.

1 INTRODUCTION

Road surface temperature and consequently road surface conditions is very variable. The temperature depends on several factors and may rapidly change in time. Therefore its forecast is a difficult task.

In this contribution we present the implementation and evaluation of the METRo model ([1], [3]) in a nowcasting mode, where the model starts a new forecast every hour using all measurements available from road weather stations (RWS). The METRo model has been implemented in the Czech Republic (CR) and it has been running in a semi-operational application since the winter season 2012-2013.

2 APPLICATION OF THE METRO MODEL IN THE CR

We chose to use the Model of the Environment and Temperature of Roads (METRo), which was originally developed at Environment Canada [1] to be implemented in the CR, because METRo is a frequently used model and its code is freely available and well-documented (http://home.gna.org/metro/). The METRo model describes the complex physical interactions between a road surface and the atmosphere, such as short-wave and long-wave radiation fluxes and the phase changes of moisture that occur on the road surface. METRo is a 1-D model, which performs forecasts at single points independently. Our model implementation and data flow corresponded to the recommendations of the model's authors [1]. METRo runs in three phases: initialization, coupling and forecast.

2.1 DATA

The model requires three types of input data: data measured at RWS, prognostic atmospheric data and data describing a road construction. Data at RWS contain: (i) temperature measurements at the road surface, 30 cm below and 2 m above the surface; (ii) humidity measured at 2 m above the surface; (iii) some of the stations also measure wind speed and wind direction at 10 m above the road surface and precipitation. When these data were not available, we used the prognostic data of the ALADIN numerical weather prediction (NWP) model interpolated in space and time for the station position and observation time. The measurement frequency is usually between 10 and 20 minutes. Data from RWS are provided by Road and Motorway Directorate of the Czech Republic **(**RSD). RSD also provided the description of road constructions including their physical parameters.

Prognostic atmospheric data were obtained from the ALADIN NWP model, which is operated by the Czech Hydrometeorological Institute. ALADIN is a hydrostatic model integrated at a horizontal resolution of 5 km; the integration is started four times per day (00, 06, 12 and 18 UTC). The lead time of the model forecast is 54 h, but we used forecasts for the first 24 h only.

2.2 NOWCASTING

In the nowcasting mode the model starts a new forecast every hour using all measurements available at the time when the forecast is calculated. ALADIN calculates forecasts only four times in a day which means that the same ALADIN run is used for 6 forecasts by METRo prepared in 1 h step and atmospheric data comes from the same ALADIN forecast but correspond to different lead times. RWS data contain measured data up to the hour when the forecast is issued. By adding data the coupling phase of METRo prolongs. Organization of the forecasts is shown in Fig. 1.

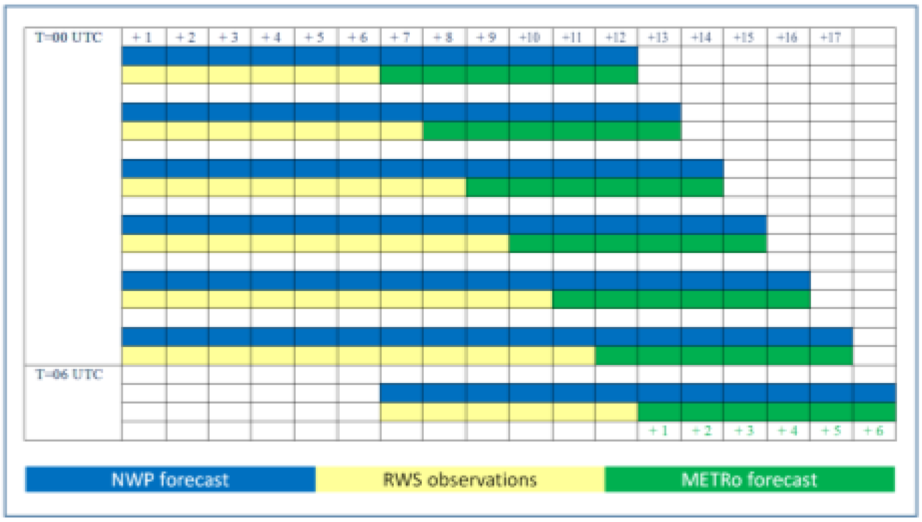

Fig. 1. The scheme of the METRo application in the nowcasting mode. The blue numbers show the lead time of ALADIN forecast, green numbers indicate lead time of METRo.

3 FORECAST EVALUATION

An evaluation of METRo was performed using data for the winter of 2012-2013, from 1 November 2012 to 28 February 2013. The model forecasts started at every hour and we evaluated forecasts up to 6 h of the lead time. Note that the local time is UTC plus 1 h. The forecasts were produced for 25 selected RWS; their positions and descriptions are displayed in Fig. 2 and Table 1, respectively. These stations had little or no downtime and most of the stations were located on motorways. The other stations were located at first class main roads and represent various road conditions in mountainous areas where motorways are not present.

We verified the surface temperature using mean absolute error (MAE) and bias (BIAS) defined as:

$$MAE = \frac{1}{n}\sum_{k=1}^{n} abs(y_k - o_k), \qquad (1)$$

$$BIAS = \frac{1}{n}\sum_{k=1}^{n} (y_k - o_k), \qquad (2)$$

where y_k and o_k are forecasted and measured values, respectively, and n is the number of verified data points. We concentrated on the verification of the forecasts corresponding to the full hours. When no measurement was available for the full hour, the required value was obtained through linear interpolation from neighbouring measurements in time. Because the frequency of the measurements did not exceed 20 minutes in the vast majority of the cases, the interpolation did not cause significant inaccuracies.

Fig. 2. Positions of road weather stations (black triangle) and their numerical indicatives used in this study. The figure also shows the network of highways and first class roads in the CR and major cities.

Station	Longitude	Latitude	Elevation [m]	Elevation ALADIN [m]	Wind obs.	Precipitation obs.
75003	50.1011	12.3986	440	483	x	x
75301	50.0307	12.7883	745	690		x
76001	50.6337	15.1112	400	279	x	x
76002	50.6867	15.1050	398	365	x	x
76003	50.5962	15.1192	280	266	x	x
76004	50.8662	15.0366	540	408	x	x
76006	50.8115	14.9662	320	443	x	x
80002	49.7810	13.6881	470	441		x
80004	49.7077	13.1761	345	383		x
80006	49.7460	12.7713	490	527		x
80007	49.7021	12.6943	560	550		x
80009	49.6654	12.5815	520	511		x
80011	49.1665	13.2864	950	905	x	x
80013	49.6772	13.3272	350	362	x	x
80019	49.7252	13.4704	430	378	x	x
83015	49.9861	14.1392	290	322		x
83018	49.8404	13.8138	410	480		x
83019	50.1090	14.6386	270	249	x	x
83022	50.1902	14.4436	285	256	x	x
83024	49.9417	14.6665	450	380	x	x
83026	49.7799	14.9328	330	401		x
83034	50.1292	15.4146	210	224	x	x
85009	50.7317	13.7627	865	657	x	x
85024	50.7741	13.9482	620	563	x	x
85032	50.7893	14.2873	437	278	x	

Table 1. The list of road weather stations used in tests. The list shows station elevations and the elevations of the ALADIN topography obtained by bilinear interpolation of grid values into the station positions. The stations with precipitation and wind observations are indicated by x.

The results are presented in Figs 3 and 4. Fig. 3 presents MAE and BIAS of METRo forecasts with the lead times of 1, 2, 3, 4, 5 and 6 hours. The x-axis shows the hours for which the forecasts apply. The forecasts for the given hour can be obtained in several ways, depending on the data used. For example, the forecasts for 03 UTC in the upper left subfigure can be gained using RWS data only from the terms up to 00 UTC (red column) and the lead time of 3 h. The second possibility is that data up to 01 UTC (green bar) are used and the lead time of 2 h. The final prediction is obtained by applying the data up to 02 UTC (purple bar) and the lead time of 1 h in this case. The equally coloured columns correspond to the forecasts with the same initial data in Fig. 3.

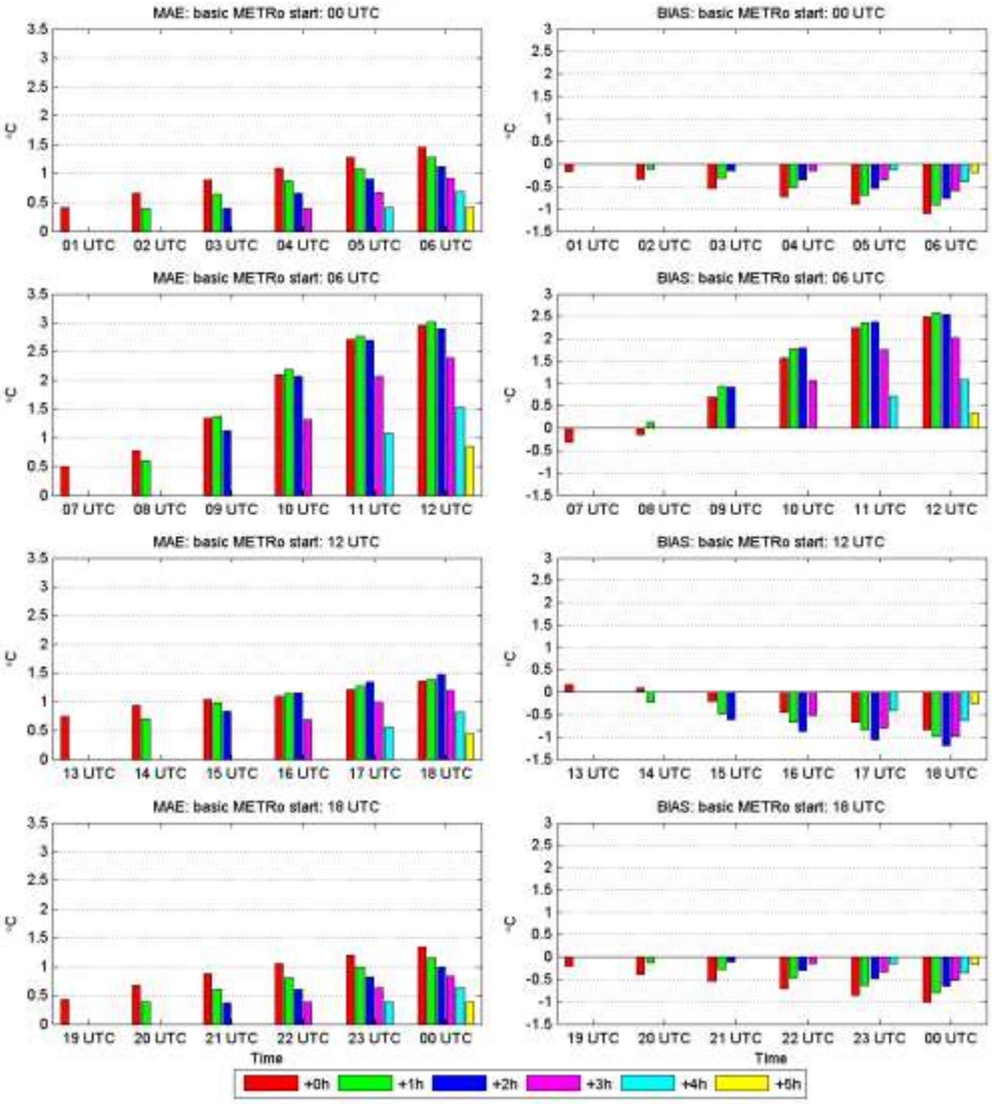

Fig. 3. The evaluation of the sequence of METRo forecasts. MAE and BIAS (°C) are calculated as means across all stations. The basic METRo forecasts started at 00, 06, 12 and 18 UTC. The legend indicates the length of time during which measurements were added to the input data used by the basic METRo forecasts. The horizontal axis displays the lead times.

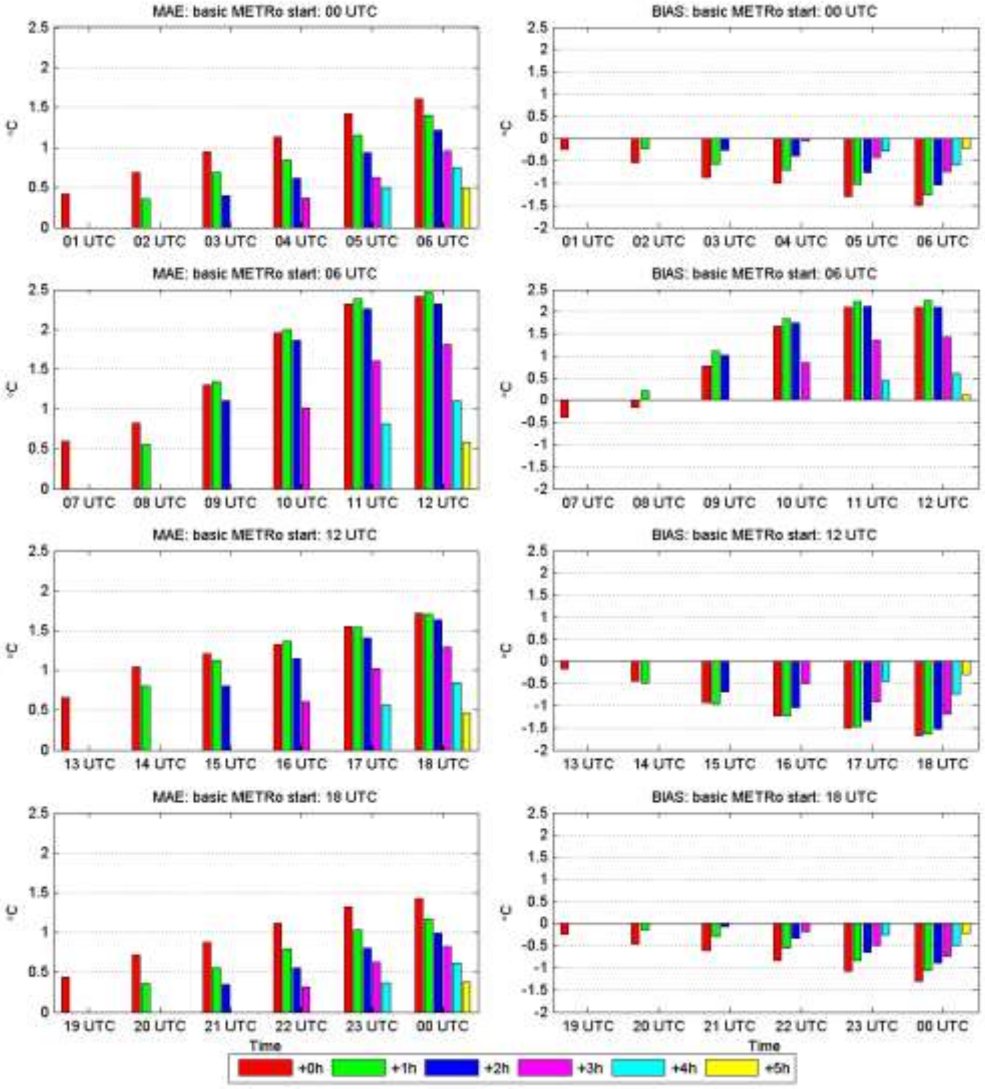

Fig. 4. The same as in Fig. 3 but for RWS 76006.

Figure 3 shows that the accuracy of the forecasts for the night-time period (19 to 06 UTC; forecast start at 18 and 00 UTC) did not substantially depend on the hour when the forecast is issued but rather on the lead time. The ALADIN forecasts were sufficiently accurate for this part of the day, and the absence of short wave radiation partially simplifies the METRo forecasts. Forecasts of the road temperature during the daytime (07 to 15 UTC) are more complicated because the temperature is fundamentally affected by short wave radiation when the sun is above the horizon (November to February). The impact of short wave radiation causes the forecast accuracy to depend on the current hour rather than on the lead time. It confirms the fact that two-hour and longer forecasts for morning hours 09-12 UTC have MAE between 2 and 3°C. In comparison, the MAE for forecasts of the same length and other terms do not exceed 1.5°C. Another example is that the least precise one-hour and two-hour forecasts are for 10 UTC (purple and blue columns). The MAE values of these forecasts are 1.31 and 2.07°C, which are significantly greater than the average values of 0.6 and 1.0°C for the one-hour and two-hour forecasts, respectively. Thus, it is important to correctly predict whether the sun will dissolve low clouds and fog or whether the sky will be overcast.

The majority of the forecasts are substantially biased, which may have several reasons. One of them is that ALADIN and other numerical weather prediction models are not usually able to correctly reproduce the diurnal variation of surface temperatures and this error further intensifies by METRo. Large values of BIAS is possible to reduce by postprocessing METRo outputs (e.g., [2]) and thus increase forecast accuracy. On average, the ratio of the absolute value of BIAS to MAE is approximately 0.6, but in extreme cases, this ratio reaches almost 0.9.

Figure 4 displays results for one specific station RWS 76006 located in mountainous terrain. Figures 3 and 4 demonstrate that upgrading the forecast every hour using all available measurements in most cases improves forecast accuracy up to the lead time of 3 h. For example, if we look at two-hour forecasts averaged over all the stations (the second column from the right for each hour), we obtain a more accurate prognosis. The only exception is the prediction starting at 14 UTC in Fig. 3 (subfigure with the title “MAE basic METRo start 12 UTC”, Time 16 UTC), where the basic predictions (red columns) issued in the six-hour cycle were more accurate. Average improvement of MAE is 0.43°C, and the improvement in the surface road temperature exceeds 1°C in some cases. The mean decrease of MAE is higher in mountainous terrain (0.54°C for RWS 76006, Fig. 4), and lower in flat terrain (not shown here).

For lead times longer than 3 h, the inclusion of RWS data improves forecasts only for early morning and night times (upper and bottom subfigures in Figs 3 and 4). For longer lead times this improvement may not be found, which is caused by the fact that the short wave radiation forecasted by ALADIN disagreed with the RWS observations. Because the METRo parameters adapt to the last surface observation, during the coupling phase, and simultaneously the METRo is driven by the tendency of forecasted short wave radiation from ALADIN, the mentioned disagreement may deteriorate forecasts for longer lead times (more than 3 hours in our case). This disagreement may be related to differences between actual local conditions (e.g., orographic height and shape, shading) and conditions that are considered by ALADIN.

4. Example of the METRo application

To illustrate the performance of METRo and the impact of the hourly forecasts we present the model results for an event in which the weather caused a serious traffic accident. The accident happened on 16 December 2012 around 07 UTC in the morning on the motorway close to Plzeň in western CR near station 80004 (Fig. 2).

Advection of warm air from the southwest was preceded by a frosty period, which developed a pronounced upper temperature inversion. During the night of 14/15 December, an occluded frontal system with freezing rain passed over the study area. In the basin around Plzeň, a cold air mass persisted due to the temperature inversion stratification and strengthened due to a temporarily clear sky overnight on 15/16 December.

In the early morning on 16 December 2012, the measured road surface temperature remained below 0°C (Fig. 5) in the study area (basin bottom), although the air temperature rose above 0°C and was accompanied by non-freezing rain. When the rain stopped and the sky began to clear the road surface temperature dropped (Fig. 5). Frost formed on the road, causing an accident of a truck and several other cars. Shortly afterwards, the road temperature rose well above 0°C because of solar radiation.

The sequence of the METRo forecasts for this station is shown in Fig. 5. Because the modelled road surface temperatures are close to the measurements at the end of the coupling phase of the METRo run, the crosses in Fig. 5 are located close to the black curve representing the measurements. However, the shape of each of the coloured curves is similar to the shape of the preceding red curve because all additional forecasts (starting at T + 1 h, …, T + 5 h) were driven by the same ALADIN output.

Although all of the surface temperature forecasts for the critical time of frost appearance (around 07 UTC) were warmer than the measurements, the forecasts that started at 03 UTC or later preserved the temperature at 0°C or below. This is caused by the temporary decrease in surface temperature after 02 UTC due to the sky clearing, demonstrating the advantage of hourly forecasts and the sensitivity of road surface temperature to cloudiness. The critical temperature decrease that appeared shortly before 07 UTC cannot be forecasted without precise knowledge of the temporal changes in cloudiness.

The length of the period for which METRo kept the road surface temperature at 0 °C is related to the amount of water or snow at the road surface, phase changes, evaporation and runoff in the model. From Fig. 5, it is evident that later in the morning on 16 December, the measured temperature curve crossed zero at about 08 UTC without stopping. In contrast, most of the METRo forecasts delay the start of the temperature rise above zero by more than one hour.

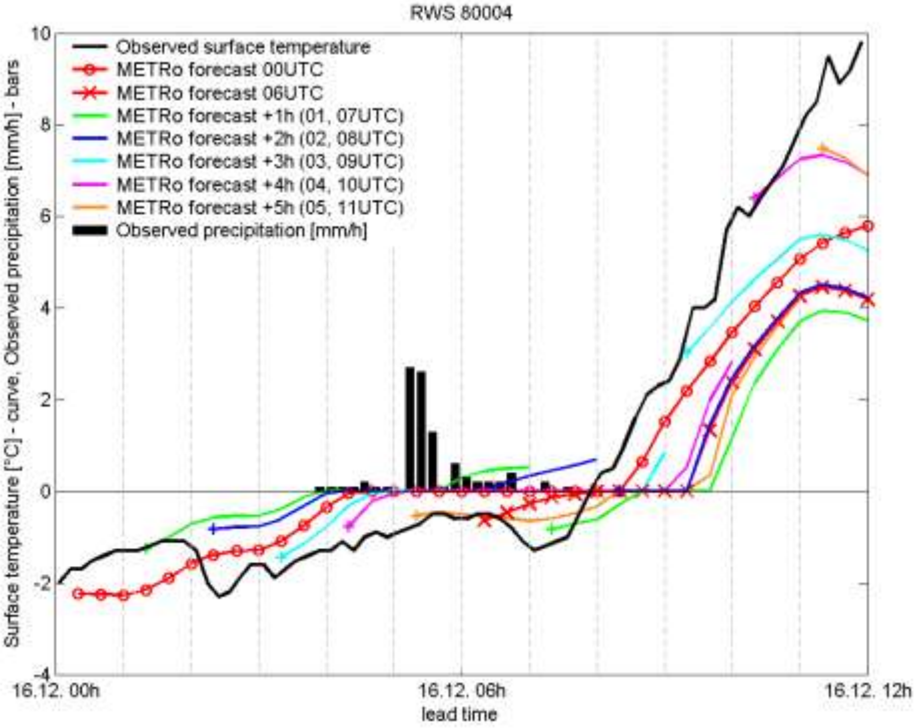

Fig. 5. A case study exhibiting the application of METRo in the nowcasting mode for the morning of 16 December 2012, at RWS 80004. In the upper left corner the organization of the forecasts between 06 UTC and 11 UTC is indicated. The figure contains observed (thick black curve) and forecasted values of road surface temperatures. The first plotted values of the road surface temperature forecasts (20 min after the forecasts started) are marked by crosses at the beginning of the coloured curve, which represent the forecasts issued every hour. The red lines with circles and crosses represent the basic forecasts starting at 00 and 06 UTC. The blue columns indicate rain intensities in mm/h for 10-minute intervals.

5. Conclusions

We implemented the METRo model by pairing it with current measurements from road weather stations and the ALADIN NWP model, which is operated by the Czech Hydrometeorological Institute and used it in a semi-operational mode for the 2012-2013 winter period. We applied METRo every hour in a nowcasting mode and evaluated its results.

The METRo model predictions are generally characterised by large biases, whose mean values are approximately 60% of the mean absolute error but up to 90% for certain stations. Two reasons are proposed for this finding. The first reason is that ALADIN does not adequately forecast diurnal variations of temperature and cloudiness, leading to large errors in the road surface temperature forecasted by the METRo model. The second reason is related to the differences between actual local conditions (e.g., orographic height and shape, shading) and conditions that are considered by ALADIN. These differences may frequently lead to large systematic errors.

The application of the nowcasting scheme proved to be useful for lead times from 1 to 3 h. The use of additional RWS data apparently improved the accuracy of the forecasts of the road surface temperature in comparison with the application of METRo model four times in a day for each run of the ALADIN model. On average, one-hour, two-hour and three-hour forecasts improved the mean absolute error of the standard forecast by 0.43, 0.40 and 0.17°C, respectively. For longer lead times (4 h or more), the positive impact of additional RWS measurements disappeared and new data may even deteriorate the forecasts. In some cases, issues are caused by inconsistencies between the radiation derived from the ALADIN forecast of cloud cover and added surface temperature. The coupling used in the METRo model assimilates RWS data and nudges the model to yield the last measured road surface value. If the last measurement was influenced by short-term changes in cloudiness that could not be forecasted by ALADIN, then the METRo forecast may be deteriorated.

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