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SURFEX compared to FMI's road weather model and road weather observations

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ABSTRACT

SURFEX is a physically-based model of air-surface interactions, included in the HARMONIE numerical weather prediction system employed at Finnish Meteorological Institute (FMI). Urban and built-up surfaces are treated by a town energy balance model, where the temperature, water reservoir and snow cover of road surfaces are calculated.

FMI's road weather model (RWM) is an energy balance model calculating what happens on the road surface due the weather. The model gives information e.g. if the road surface is covered by ice or snow and it calculates the road surface temperature. The influence of traffic is taken into account as well.

In this study the modelled road surface temperature is compared to road weather observations in the winter of 2011-2012. Road weather temperature modelled by SURFEX and FMI's road weather model are studied. Also, the modelled air temperature is compared and presented.

Three locations are chosen as test sites. The criterion for the selected places is that the points need to be urban and there need to be a road weather station to measure road surface temperature. The selected places are Helsinki, Tampere and Rovaniemi which all present different kind of climate area.

The main goal of this study is to find out the reliability of the road surface temperature calculated by SURFEX model. In Helsinki SURFEX and RWM perform equally well, but in the colder conditions of Tampere and Rovaniemi RWM is clearly superior.

Keywords: Road surface temperature, SURFEX, road weather model.

1 INTRODUCTION

Snowy and icy roads increase the risk of traffic accidents. Slippery road surface and low visibility are the most difficult situation for drivers and sometimes both of those difficult weather phenomena can exist at the same time causing very bad driving condition [1].

In Finland, as in many other countries located in high latitudes or mountainous areas, road weather forecasts are issued to reduce the risk of traffic accidents and increase the safety on the roads [2]. The model supports the forecasters when giving warnings considering of difficult driving conditions. Also, the outputs of road weather model are helping road maintenance personnel when planning the road maintenance actions, like snow removal or salting.

The road weather model is a specified weather model designed specifically to taking into account what happens on the road surface because of weather. FMI's road weather model is calculating e.g. road surface temperature, road condition, traffic index and friction.

Road surface is affected by different parameters, so usually it is easier to predict the ambient temperature than road surface temperature. In addition to basic weather parameters, also environmental parameters and past weather have an influence on the road surface temperature and road conditions [3]. A list of quantities affecting to local road weather is presented on table 1.

Meteorological	***Geographical***	***Road construction***	***Other***
Solar radiation	Latitude	Depth of the construction	Traffic
Terrestrial radiation	Altitude	Thermal conductivity	Maintenance activities
Air temperature	Topography	Thermal diffusivity	
Cloud cover and type	Screening	Density	
Wind speed	Sky-view factor	Emissivity	
Humidity / Dew point	Land use	Albedo	
Precipitation	Topographic exposure		

Table. 1. Quantities affecting to the local road weather [3].

The SURFEX module of the meso-scale numerical weather prediction (NWP) system HARMONIE provides potentially an alternative data source for predicting the condition of roads and pavements anywhere in its domain. We therefore compare the output from HARMONIE to results of the road weather model, and to observations in order to assess the usefulness of this new forecasting tool in the context of road weather forecasting.

2 OBSERVATIONS IN USE

Three different locations have been selected as test places in this study; Helsinki, Tampere and Rovaniemi. Two separate points are studied in Helsinki: Jakomäki and Pirkkola. The distance between the two locations is almost ten kilometres. Helsinki is located on the coastal area, but the distance between sea and the observation stations is more than five kilometres. Tampere is situated inland, but there are two big lakes located close to the observation site. Rovaniemi is located in northern Finland, where icy conditions prevail longer than in the southern places. Also, the traffic density in Rovaniemi is much lower than in Tampere and Helsinki. In all places a road weather station is located relatively close to the city centre so the observations are available. And all of those places may be considered to be urban or semi urban. Road weather stations are measuring different weather and road condition parameters, like road surface temperature, the amount of water/snow/ice on the surface, precipitation and friction. Observations are measure every ten minutes or so. The road weather stations are maintained by the Finnish Road Administration but the data is freely available.

The results of SURFEX and FMI's road weather model are compared to road weather observations. Air temperature and road surface temperature are compared and statistically analysed. The main interest is to study how well SURFEX predicts road surface temperature but air temperature is compared as well.

3 SURFEX

FMI participates in the development of the HARMONIE NWP system [4], which is the main meso-scale numerical forecast engine of the weather service. The model is run with a horizontal mesh-size of 2.5 km and 65 terrain following levels, with the lowest level at approximately 12 m above the surface, and 20 levels in the lowest 1000 m. The dynamical core is a non-hydrostatic spectral model, based on a two-time level semi-implicit semi-lagrangian discretization of the fully elastic equations. Parametrizations of sub grid-scale physical processes are the same as in the AROME-model [5], accounting for radiative transfer, turbulence, convection, the micro physics of clouds and precipitation formation, and interactions with the surface. The latter are taken into account in the frame of the autonomous surface interaction module SURFEX [6], describing up to 4 different surface types including vegetated and built-up areas). Characteristics of the surface are obtained from the global 1 km resolution ECOCLIMAP data base [7]. HARMONIE includes separate data assimilation modules for generating initial conditions of upper air and surface variables.

In SURFEX, each tile responds to the same atmospheric forcing at the lowest model level, but is handled by a separate module. Urban areas are handled by the Town Energy Balance model TEB [8]. Forced by incoming radiation, rain, snow fall, and by wind speed, air temperature, and humidity above the roof-tops, TEB returns the upward radiative and turbulent heat fluxes as well as the wind, temperature and humidity within the urban canopy. The energy and water budgets are solved separately for roofs, walls, and roads, taking into account the shading effect of the walls and the radiative heat exchange between the wall and road surfaces. Heat conduction within the roofs, walls and roads takes place through several layers of materials. Roofs and roads may be partially of totally covered by water or snow. The snow cover evolves in response to the predicted snow-fall, melting, and transpiration, and to a parametrization of snow removal in the form of an exponential decay with a time scale of one day.

The present study is based on short-range forecasts from HARMONIE stored with a 15 minute interval and having a lead time between 6 and 12 hours. At these lead times the general evolution of synoptic weather patterns is usually well predicted, so errors in the forecast are likely to be dominated by systematic effects.

4 FMI'S ROAD WEATHER MODEL

FMI has developed an own road weather model. The model calculates what happens on the road surface because of weather. Basically the model is a one point energy balance model that calculates vertical heat transfer in the ground and at the ground-atmosphere interface. Also, the influence of traffic is included (mechanical heating, wearing, turbulence). The more details about the FMI's road weather model are presented on presentation *The FMI road Weather Model* by Kangas et al [9].

The ground is divided into separate layers and ground temperature is calculated for all levels, respectively. The uppermost layer presents the road surface and it is three centimetres thick layer. Overall there are 16 layers on the ground and the deepest layer is located on the depth of four meter from the surface where ground temperature is assumed to follow a sinusoidally-varying climatological temperature. Temperature is assumed to vary linearly between each layer. The near surface layers are thinner than the layers located deeper on the ground.

Road structure is taken into account in FMI's road weather model, but the information about the used material on the road surface and below it is not clearly known. So, only average values have been used for different materials and thermal conductivities in each layer. The lack of real information about the road structure materials may cause errors when modelling the road weather.

FMI's road weather model has been run for selected test points. Observations have been used as an input data so the influence of uncertain forecast can be ignored. Observations are stored into 10 km grid and the nearest grid point has been chosen to present the observation point. Input parameters of FMI's road weather model are air temperature, dew point temperature, relatively humidity, wind speed, precipitation, incoming short and long wave radiation. For this study precipitation data are taken from the radar observations, radiation from model data and other parameters are interpolated from synop observations.

5 COMPARISON BETWEEN MODEL DATA AND OBSERVATIONS

Figures 1-4 are presenting modelled and measured the air temperature and road surface temperature, respectively. The studied time period is from 17th December 2011 to 15th February 2012. During that time period weather was very wintry at all places and temperature was varying with large variation from plus degrees down to minus 25 degrees.

Air temperature (figures a on the left hand side, a) is usually well forecasted by HARMONIE, although the model tends to be too warm during the cold spell in late January and early February in Tampere and Helsinki. In Rovaniemi, HARMONIE tends to underestimate the air-temperature during most of the period. The evolution of the road surface temperature (figures on the right hand side, b) matches the observations well for both models, and yields linear correlation coefficients in excess of 0.9 at all stations, but the correspondence is not as close as for air temperature.

HARMONIE/SURFEX persistently gives too low temperatures during cold spells, and throughout the period at Rovaniemi. Both models typically underestimate the temperature at all stations except Pirkkola, but the road weather model is clearly the better one in this respect. It can be seen that errors are relatively small at temperatures near zero degrees. This is good, because the most difficult and slippery cases tend to occur when road surface temperature is near the freezing point.

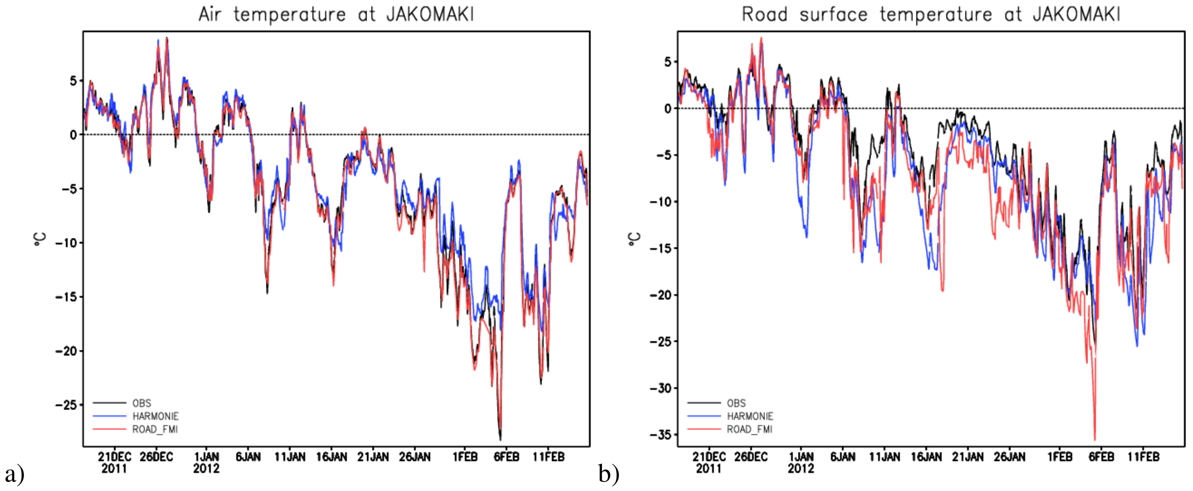

Figure 1. Observed (black line) and modelled by HARMONIE (blue) and FMI's road weather model (red) temperatures on Jakomäki, Helsinki. Air temperature on the left (a) and road surface temperature on the right (b).

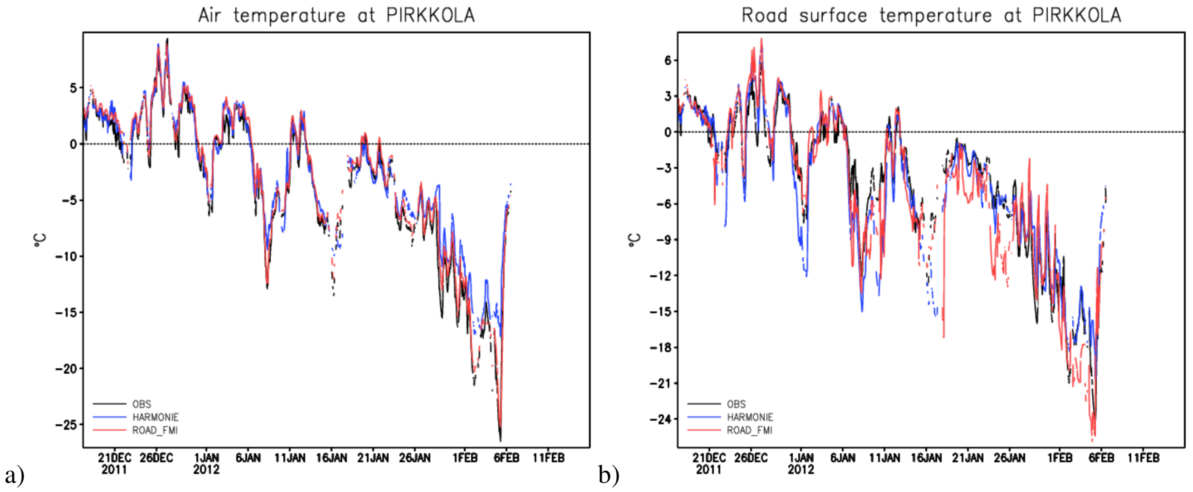

Figure 2. Observed (black line) and modelled by HARMONIE (blue line) and FMI's road weather model (red) temperatures on Pirkkola, Helsinki. Air temperature on the left (a) and road surface temperature on the right (b).

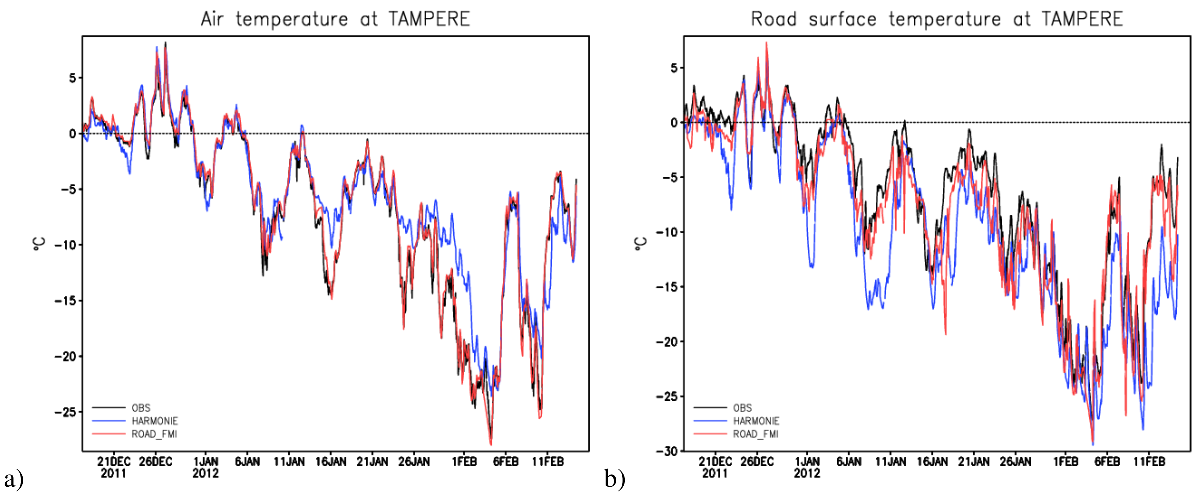

Figure 3. Observed (black line) and modelled by HARMONIE (blue) and FMI's road weather model (red) temperatures on Tampere. Air temperature on the left (a) and road surface temperature on the right (b).

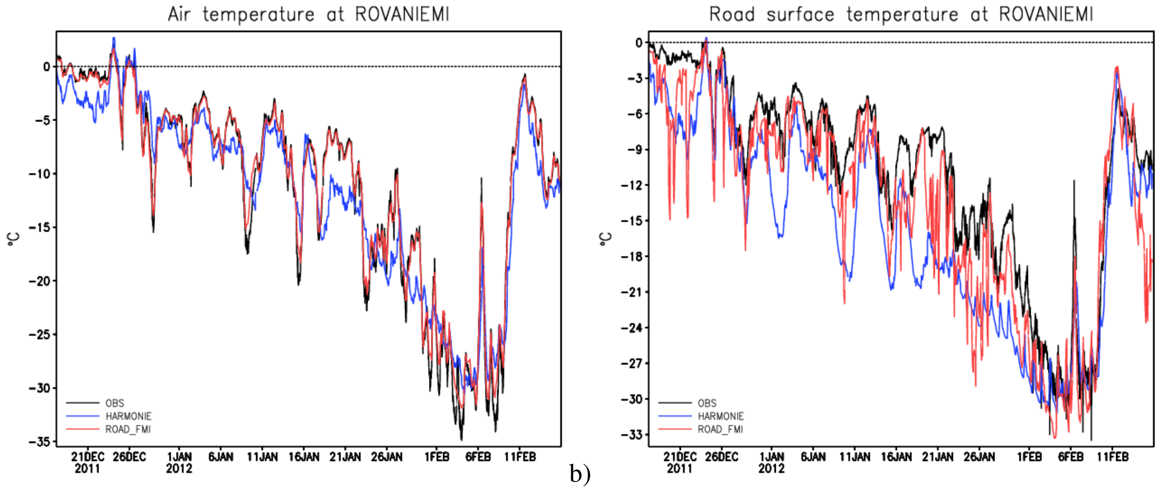

Figure 4. Observed (black line) and modelled by HARMONIE/SURFEX (blue) and FMI's road weather model (red) temperatures on Rovaniemi. Air temperature on the left (a) and road surface temperature on the right (b).

Table 2 summarizes bias and rms errors of the road surface temperature, and shows a universal cold bias of both models, increasing from south to north in HARMONIE/SURFEX. At Jakomäki and Pirkkola the two models perform equally well, while at Tampere and Rovaniemi, FMI RWM is clearly the superior model.

The error-distributions shown in fig. 4 confirm the impression given by the table. At Jakomäki and at Pirkkola there is very little difference between the two models, but at Jakomäki the distributions are skewed, and peak to the left of zero, while the distributions of Pirkkola are more symmetrical. The time period of observations on Pirkkola is a little shorter than in Jakomäki but that is not the cause of the difference. The difference is explained rather by differences in the observed surface temperatures; the modelled ones are nearly identical at these nearby locations. Perhaps the location of the road weather station at Pirkkola close to a pedestrian underpass may be a reason for the colder temperatures measured here. Also, the quality of the instruments and the calibration on the observation site is not known.

At Tampere, the error-distribution of the road weather model is similar to the one at Jakomäki, but the one of HARMONIE/SURFEX is skewed to the left, which explains the larger negative bias of that model here. At Rovaniemi the distribution of HARMONIE/SURFEX is more symmetrical, but shifted to the left, while the one of the RWM is only broadened but not clearly shifted.

	HARMONIE Bias	**HARMONIE RMS**	**RWM Bias**	**RWM RMS**
HKI, Jakomäki	-2.34	3.49	-2.44	3.62
Helsinki, Pirkkola	-0.38	2.23	-0.60	2.48
Tampere	-3.25	4.56	-1.30	2.49
Rovaniemi	-4,38	5.50	-2.46	3.97

Table 2. Statistical parameters, bias and rms, between modeled and observed values.

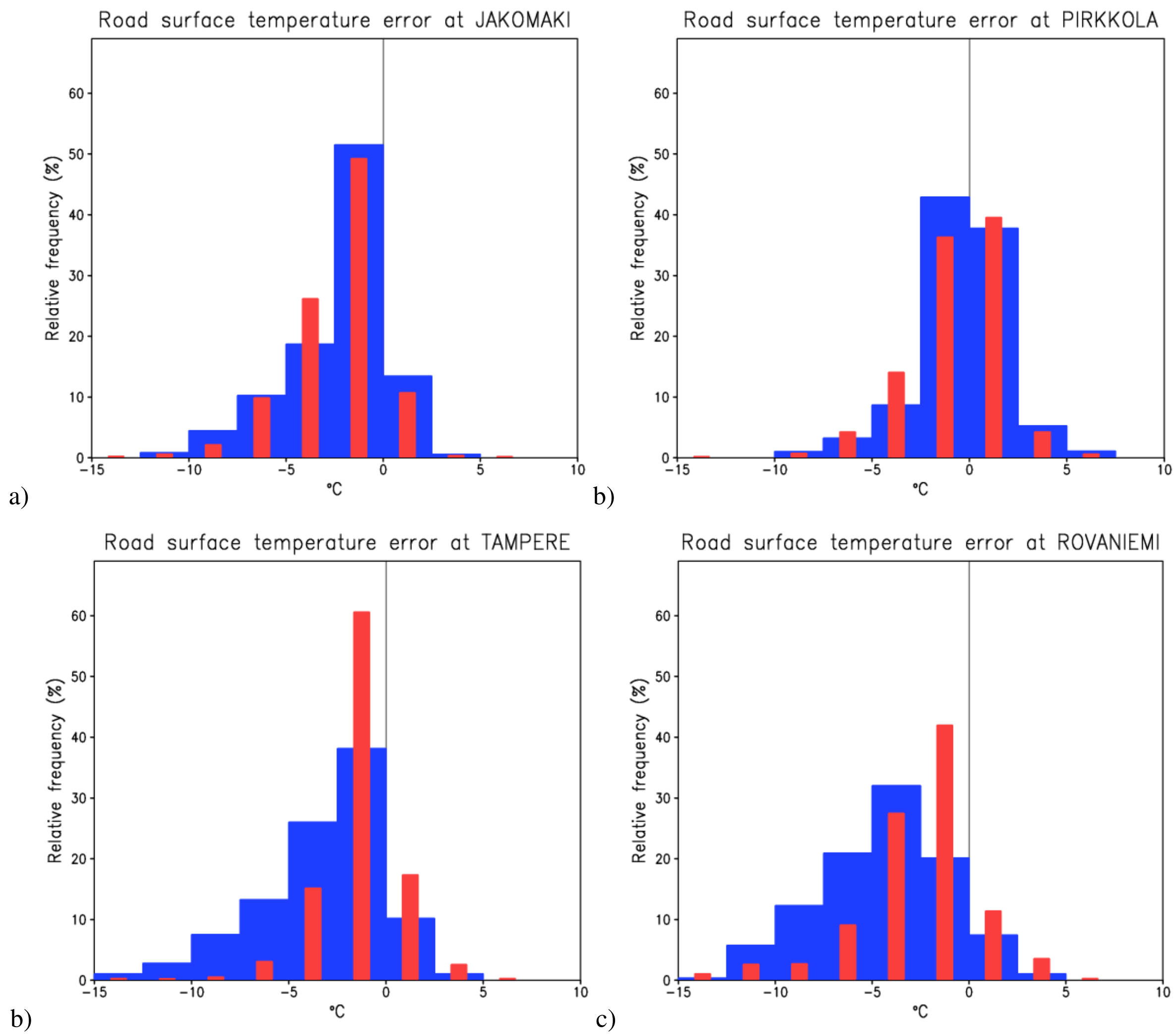

Figure 4. Road surface temperature error between modelled and observed values in four studied places; Jakomäki, Helisnki (a), Pirkkola, Helsinki (b), Tampere (c) and Rovaniemi (d), respectively. Blue colums are presenting HARMONIE/SURFEX and red columns FMI's road weather model.

6 CONCLUSIONS

Correlation between modelled road surface temperature and observed temperature is good with both models. However, both models have a cold bias, so the modelled road surface temperature is typically a little bit colder than observed. The models seem to be more reliable when temperature is near zero and the errors are larger in the colder temperatures.

The specialized road weather model seems to have more accurate values for the modelled road surface temperature than the HARMONIE/SURFEX model, especially in the north. It is likely that results could be improved, by adjusting the thermal properties of the road materials or the treatment of the snow cover on the road surfaces in the model. Even at its present stage of development, it should be possible to use output from the HARMONIE system to support road weather forecasting.

7 REFERENCES

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