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The effect of local features to road surface temperature

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ABSTRACT

Local features have significant effects to road surface temperatures. These can cause great differences in road condition in different parts of the road network. There have been many previous studies about these local features and how they can be modeled. However, the road weather model of the Finnish Meteorological Institute does not take the local features into account. This study focuses on examining the significance of the local effects in the model. The results of the study can be used in further development of the model to make more accurate forecasts. Precise forecasts are important as they can used to optimize the times of ploughing and other operations and reduce the costs of winter road maintenance. The amount of accidents is likely to be reduced also when slipperiness can be prevented and people can be informed for bad driving conditions.

Studied local features are road surface albedo, asphalt depth, slope angle and screening. The road weather model was run for 16 road points using different values for variables describing the different features. Also the reliability of road weather forecasts was tested. In addition it was studied how model could be modified to simulate bridge points.

Keywords: Road weather, road surface temperature, sensitivity analysis

1 INTRODUCTION

The effects of local features to road temperature are very significant when predicting the slipperiness of the road according to previous research. It is important to know how different factors change on road network and how much these effects affect forecasted temperatures when included to the road weather model. In this study the effect of local factors to the forecast was tested using the Finnish Meteorological Institute's (FMI) road weather model. The results can be used when making local forecasts and when adjusting the model to regions where geography differs from Finland's terrain.

The sensitivity of road weather model to local features has not been researched in detail. The effect of sloping to surface temperature was tested in the Coldspots campaign [9], but in this study research is more encompassing. Model's sensitivity for screening, asphalt depth, and albedo hasn't been studied previously almost at all. Also modeling bridge points with the model has not been tested before. This study presents more insight about the effect of these features.

In some situations a 1°C difference in the temperature can have significant effect to the slipperiness of the road. For example when temperature is just above zero according to the model and surface for some reason receives less sun radiation than excepted the temperature could then be below zero and ice can be formed. A 1°C difference can be also significant when temperature is few degrees below zero, because it can affect the decision whether to salt the roads or not. The salting has no effect to ice if temperature is too low. In other situations this small temperature difference is not significant for the condition of the road.

2 LOCAL PARAMETERS

The parameters affecting the road surface temperature can be divided into meteorological, geographical and road construction parameters (table 1). Meteorological factors are radiation of

Meteorological	Geographical	Road construction
Solar radiation	Latitude	Depth of construction
Earth radiation	Altitude	Heat conductivity
Atmosphere radiation	Topography	Heat diffusivity
Air temperature	Screening	Emissivity
Cloudiness	Sky view	Albedo
Wind speed	Land use	Traffic
Humidity/ dew point	Topographical exposure	
Precipitation		

Table1. Local parameters affecting to road surface temperature. Based on Thornes and Shao (1991) [11] with some modifications.

the sun, long wave radiation emitted by atmosphere and earth and other parameters related to weather. Geographical parameters, like latitude, altitude, height differences in the environment, land use and screening, affect meteorological parameters. The construction of the road determines how the surface temperature reacts to the weather. Construction parameters are for example depth of construction, surface albedo, heat capacity and emissivity. However the effect of local features is difficult to verify, because of the observations are not available everywhere.

There have been quite accurate researches about the effects of local parameters during past decades. Bogren et. al. (2000) [1] studied the temperature changes in different microclimates and weather situations. According to their research the temperature differences in different road points can be calculated with topographic location and weather parameters. In another research Eriksson and Norrman (2001) [5] examined the effect of local features to different types of slippery situations. They used multiregression analysis and found that the effects are significant.

Chapman et. al. (2001a and 2001b) [2], [3] made research in which road surface temperature was modeled using geographical data. There was two parts in the research. In the first part the temperature was modeled statistically and in the second part numerically. The research included eight different terms: latitude, altitude, sky view factor, screening, roughness, road construction, traffic intensity and topography. The effect of these factors to surface temperature was studied by regression analysis and it was found out that statistical model could explain significant part of temperature variations. The second part of the study leaded to result that 72 % of the variation in the road surface temperature can be explained by projecting geographical factors to the temperature field.

In Finland the effect of local features has been previously studied in the Coldspots campaign [9]. The aim of the Coldspots campaign was to develop accurate and local road condition forecasts by acquiring information about especially slippery points on road network and by developing the models. The obtained information was about roadprofiles, vicinity of water areas, locations of forests and open places and sky view factors. Also the road maintenance personnel helped to find especially slippery spots on the road network. It was found out that local temperature and friction variations can be significantly large and to obtain more accurate forecast mobile measurements are needed.

3 ROAD WEATHER MODEL

The FMI's road weather model is one dimensional energy balance model [6], [7]. As input parameters it requires forecasted time series of air temperature, dew point temperature, relative humidity, wind speed, precipitation, short wave radiation and long wave radiation. These are provided by a weather model. As output parameters road weather model gives surface temperature, condition of the road, traffic index, friction and the amount of snow, sleet, ice and water on the road. Condition of the road can be dry, wet, wet snow, deposit, deposit/icy, icy and dry snow. Traffic index describes the driving conditions and it can be normal, difficult or very difficult. Model describes the amount of snow, deposit ice and water as separate storage terms telling the amount of substance in water equivalent millimeters.

Model calculates the energy balance on the road surface as $G=I_{net}-H-LE$, where G is heat flux to the ground, I_{net} is the total radiation on the surface, H is the sensible heat flux and LE is the latent heat flux. In the ground heat flux is calculated using equation $G=\lambda\delta T/\delta z$, where T is temperature and z is height. Temperatures profile inside the ground is calculated to the depth of over four meters. Ground is divided to 15 layers with different thicknesses. The temperature of the lowest layer is climatological temperature depending on the time of the year. Surface and ground layers are described with density, heat conductivity, heat capacity and porosity [8].

4 DATA

In this study input data to the road weather model was taken from forecasts made with HARMONIE weather model. Each forecast was made at 00 UTC and the length of it was 24 hours. Data was interpolated to coordinates where the studied 16 road weather stations were located. Three of the stations were on a bridge, five were on a slightly sloping surface and the rest were selected so that they were near the other stations. The locations of the stations can be seen in the figure 1.

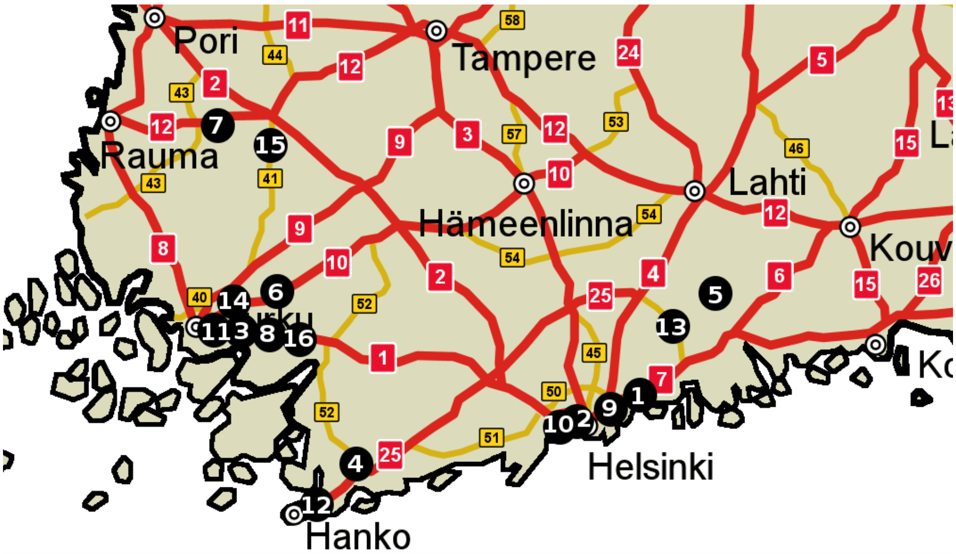

Figure 1. Locations of the road weather stations. Stations 1-3 are on a bridge, 4-8 are on slightly sloping hills and 9-16 are reference stations.

5 METHODS AND RESULTS

5.1 Reliability of forecasts for different stations

The question if surface temperature forecasts for stations on bridge or on sloping surface were less reliable than for stations on flat ground was studied using time period 25.1. -25.3.2013. Reference stations on flat ground nearby were selected for each station on bridge or on sloping surface. Forecasted temperatures on each station were compared to measurements and root mean square error (RMSE) was calculated for each day. Then the difference between RMSE mean values on stations on bridge and reference stations was studied. Same was done for stations on sloping surface and their reference stations. The question was if the differences were statistically significant on 5% confidence level.

Only the differences of two station pairs' RMSE mean values were significantly different. However the difference of the other station pair was so low that it can be result of small sample. It seems that there is no difference between reliability of forecasts on stations on bridge or on sloping surface and reference stations. Nevertheless this can be caused by the fact that there are many other variables affecting to the road surface temperature. Distances between stations were from 1 km to 16 km and the temperature differences caused by other local features were greater than the differences caused by location on bridge or on sloping surface. Road weather model has a tendency to forecast too low temperatures, so if station location is dark and cold its RMSE is smaller than on open and sunny area.

5.2 Albedo

Albedo means the reflectivity of the surface. If albedo is small, surface absorbs a lot of radiation warming up the surface. The sensitivity of the model to the surface albedo was tested using two different albedo input values. Albedo 0.04 corresponds to new asphalt and albedo 0.12 describes worn gray asphalt. Studied days were 18.1., 30.1., 9.2., 3.3., 6.3., 15.3. and 20.3.2013. These were selected so that different weather situations would be represented. It must be noted that when surface is covered with snow model uses snow albedo instead of asphalt albedo, so in these situations different asphalt albedo does not affect the forecasted temperatures. Also when there is ice on the surface the used albedo in the model depends linearly on the amount of ice. In table 2 there are absolute differences between forecasted surface temperatures with different albedos for each day. Values are absolute day time means of 16 station and here daytime was considered to be time period 10.00 a.m. – 2.p.m for each day.

The biggest temperature difference between surfaces was 1.13 °C on 15.3. The amount of radiation affects greatly to difference, because then the difference between absorbed amounts of radiation among different surfaces is greatest. 15.3. was almost cloud free day and sun zenith angle was greater than in January. On cloudy days in January the difference was much smaller.

Date	T(α=0,04)-T(α=0,12)(K)
18.1.2013	0,28
30.1.2013	0,02
9.2.2013	0,24
3.3.2013	0,34
6.3.2013	0,44
15.3.2013	1,13
20.3.2013	0,58

Table 2. The daytime mean differences of surface temperatures in forecasts made with different surface albedos. Values are averages over 16 stations.

5.3 Asphalt thickness

In winter the depth of the asphalt in the model is 3 cm. Specific heat for surface layer is $1.94*10^6$ J/(m^{3}K) and density $2.11*10^3$ kg/m^3. Model sensitivity to asphalt thickness was researched running the model with asphalt depths between 2 cm and 21 cm. The model was ran for 16 stations for days 18.1., 30.1., 9.2., 3.3., 6.3. and 15.3.2013. Difference between highest and lowest temperature was calculated for each run. Then the mean variation of stations for each thickness and day was calculated. Temperature variation had quite much alternation depending on the day because of different weather situations. Differences were greatest 15.3. when there was much sun radiation. The increase of the asphalt depth did not affect very much surface temperatures unless the air temperature variation during the day was very large. The temperature variation differed from 1 to 5 °C on different days between asphalt thicknesses of 2 cm to 21 cm. On cloudy days the depth of the asphalt seems not to have significance, but on sunny days temperature variation during day can differ by 2 °C depending on whether the thickness is 2 cm or 6 cm.

5.4 Sloping surface

Temperature simulations on sloping surfaces were done by changing long and short wave radiation input values. The road weather model assumes that surface is completely flat. As input parameter model takes direct short wave radiation for flat surface which has been calculated by weather model. Direct radiation for sloping surface can be calculated from equation:

$$S_{slope} = fS_{flat} = \left[1 + \frac{\tan(h_m)}{\tan(h_s)}\cos(a_s - a_m)\right]S_{flat}\,, \qquad (1)$$

where S_{slope} is direct radiation for sloping surface, S_{flat} is direct radiation for flat surface, f is slope factor, h_m is slope angle, h_s is solar height angle, a_s is sun azimuth angle and a_m is slope direction [10]. In the model short wave radiation was calculated using this equation. On slope part of the sky is obscured by the hill, which affects to incoming and outgoing long wave radiation. The portion of visible sky is described with sky-view factor (f_{sky}) and on slope it can be calculated with equation:

$$f_{sky} = \frac{1+\cos(\beta)}{2}, \qquad (2)$$

where β is the angle between horizon and horizontal plane [8]. In the model incoming and outgoing long wave radiation was calculated by multiplying them with f_{sky}. In case of north hillside also the sun being fully behind the hill was considered. In those situations short wave radiation was multiplied by 0.165, which is the portion of diffuse radiation in very clear situations [4].

Simulations were done for south hillside and north hillside with sloping angles between 1° and 10° for days 15.-17.3.2013. Those days were almost cloud free and all short wave radiation was considered to be direct radiation. Simulations were done for station 11 (see figure 1) for each day. Then the average differences between flat and sloping surface at 12 UTC for every slope angle were calculated. Results are shown in table 3.

Only the slope angle of 3 degrees or more changes the temperature more than 1 °C. For south hillside the increase of temperature when increasing slope angle by 1 °was 0.40 °C and for north hillside it was -0.46 °C. The results are same order of magnitude as results of Senkova et. al. (2007) and Saarikivi et. al. (2007), whose research also included the effect of slope to surface temperature. However in Finland slope angles on the roadways are usually low and slopes are rarely orientated straight to south or north, which decreases the significance of the slope to the road temperature.

Slope angle (°)	f_{sky} (both hillsides)	f (South hillside)	f (North hillside)	T_{slope}-T_{flat} (°C) (South hillside)	T_{slope}-T_{flat} (°C) (North hillside)
0	1,0000	1,00	1,00	0,0	0,0
1	0,9999	1,03	0,97	0,4	-0,4
2	0,9997	1,07	0,93	0,8	-0,9
3	0,9993	1,10	0,9	1,3	-1,3
4	0,9988	1,13	0,87	1,7	-1,7
5	0,9981	1,17	0,83	2,1	-2,2
6	0,9973	1,20	0,8	2,5	-2,6
7	0,9963	1,24	0,76	2,9	-3,1
8	0,9951	1,27	0,73	3,3	-3,5
9	0,9938	1,31	0,69	3,8	-4,0
10	0,9924	1,34	0,66	4,0	-4,5

Table 3. Temperature differences between sloping and flat surfaces. In the first row there is sloping angle, in the second sky-view factor, in the third and fourth sloping factor for south hillside hand north hillside and in the fifth and sixth temperature difference on slope compared to temperature on flat surface for south hillside and north hillside. Values are averages of 12 UTC values for 15.-17.3.32013 for station 11.

5.5 Screening

The effect of screening to road surface temperature in the model was studied simulating the obscuring barrier which hided full southern horizon. The obscuring times were selected so that in the first run sun was over the horizon at 9-16 o'clock Finnish time, in the second 10-15 o' clock, in the third 11-14 o'clock, in the fourth 12-13 o'clock and in the fifth run sun was obscured the full day. Runs were done for station 11 for three almost cloud free days, which were 15.-17.3.2013. Results for 17.3. are shown in figure 2. Results for other days were similar. Solar height angle was at its highest 27.3°. When sun was obscured in the model all radiation was considered to be diffuse and they were multiplied by 0.165 in a same way as in previous section when sun was behind the hill.

Temperature differences between screened and not screened surface are significant on a sunny day especially if sun is obscured several hours. The screening effect seems to be smaller in the morning than in the afternoon when temperature decreased rapidly after sun went behind the barrier. This can be because of the temperature is lower in the morning than in the afternoon and temperature balance is more sensitive to sun radiation on warm situations. To keep itself warm surface needs continuous radiation and when it ends the cooling is fast. Nevertheless temperature differences in the morning are still several degrees. In the model run when the sun was obscured for the full day the temperature difference compared to the normal run reached 13 °C at 14 o'clock Finnish time. Temperature differences between these runs continued during night varying between 0.3 °C and 2 °C.

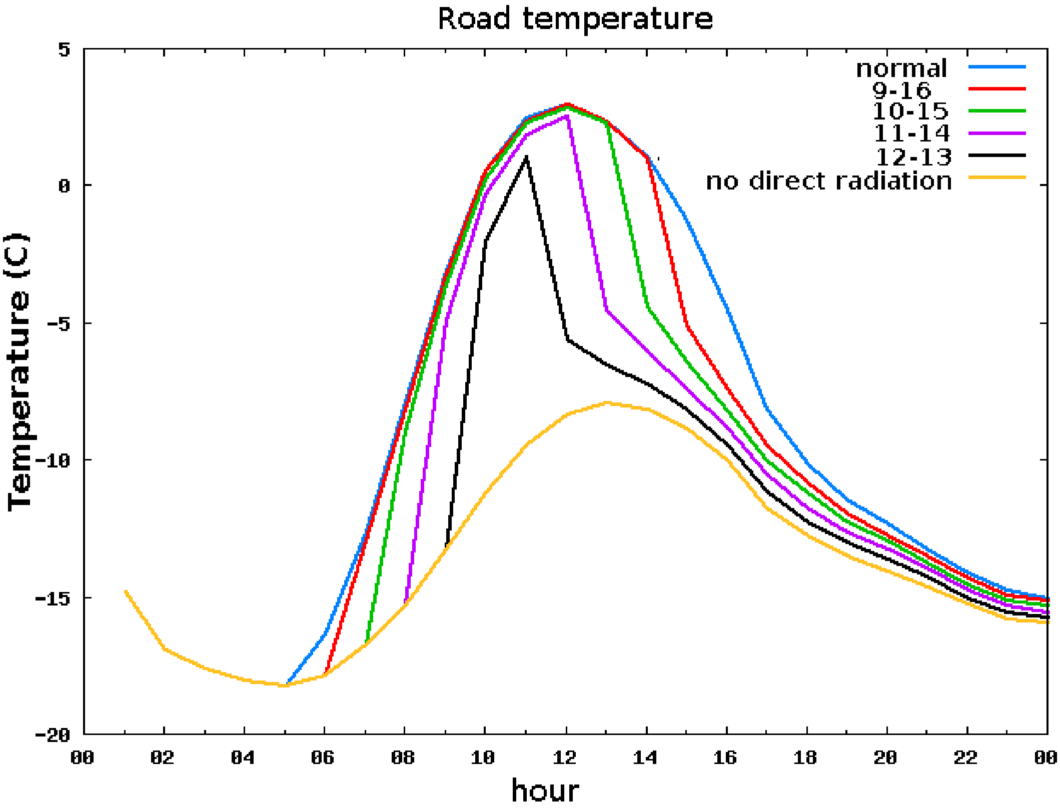

Figure 2. Forecasted temperatures for Kaarina road station, 17.3.2013, when sun was obscured part of the day. Blue line represents forecast when sun was not obscured. Obscuring times were 09-16 Finnish time for simulation on red line, 10-15 for simulation on green line, 11-14 for simulation on violet line and 12-13 for simulation on black line. Yellow line represents simulation when sun was obscured full day. Hours are in UTC time on the x-axis.

5.6 Bridge

Temperatures on bridge were simulated by modifying the number and depth of ground layers and changing the temperature of the lowest layer to the air temperature in the road weather model. The properties of surface layer remained same, but the parameters for other layers were changed to describe reinforced concrete. Used value for density was 2450 kg/m^3 and for heat capacity 2.13*10^6 J/(m^{3}K). Simulations were done for bridges with thicknesses 1 m, 0.5 m and 0.2 m. Model were run for 16 stations for days 18.1., 30.1., 9.2., 3.3., 6.3.,15.3. and 20.3.

Temperature differences between bridges and normal ground were not very significant. At the greatest the difference was only 1.5 °C. These results are strange, because of there should be more variation. This can be due to different surroundings, for example increased humidity of bridge sites were not taken into account. However the temperature differences vary sign and size depending on day and thickness of the bridge. On midday all the bridges were either warmer than or as warm as normal road because bridges have smaller heat capacity. On mild nights bridges were colder than normal road, but on cold nights bridges were warmer. The explanation for this phenomenon requires further research.

6 CONCLUSIONS

According to the results the most important factor of the tested features is screening. Other important factors were asphalt depth and sloping of the surface. The significance of these features is much greater on sunny than cloudy days. Albedo had the smallest significance to the road temperature. The reliability of forecasts for stations on bridges or slopes weren’t worse than forecasts for stations on flat solid ground. However it is possible that errors in weather forecast hide the errors caused by local effects. Also the model’s tendency to forecast too low temperatures harmed the comparison. The simulations of the bridge points succeeded by doing minor modifications to the model.

The reliability of forecast obtained with road weather model depends greatly on the reliability of input data. As the accuracy of weather model increases also the road weather model gives better forecast. In addition, road weather model itself can be modified. One important modification could be adding one or more local parameters to the road model. However, this won't be easy, because the mapping of the local features, e.g. sky-view factors, is very time consuming. Moreover, it is not certain if the reliability of forecasts would increase. As currently the model tends to forecast too low temperatures regardless. Also before applying the model to operational weather forecasting the problems in forecasting higher temperatures need to be addressed in addition to careful and thorough testing of the model.

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