Temperature patterns during cloudy situations

Ulrika Postgård

Göteborg University, Dept. of Earth Sciences, Physical Geography, Lab. of Climatology
Box 460, S-405 30 Göteborg, Sweden
E-mail: Ulrika@gvc.gu.se

1. Introduction

During the latest twenty-year period several countries with severe winter road climate have developed models to be able to decide when and where maintenance action is needed to prevent road slipperiness. The Local Climate Model (LCM) that has been developed at the department of Physical Geography in Göteborg gives now-casting of the surface temperature along the road. The model therefore provide more diversified information compared to using only site specific field station and makes the right maintenance decision easier. The model uses cloud cover prognoses developed by SMHI (Swedish Meteorology and Hydrological Institute), surface temperature and wind speed from field stations in the Road Weather Information System (RWIS) as input data. An algorithm is choosing the prevalent temperature pattern in the actual area and then finally extrapolate the surface temperature for the entire road stretch.

Until today the local climate model have distinguished between four different main temperature categories: 1) Clear and calm night, 2) Clear day, 3) Cloudy/windy situations and 4) Situations with variations in clouds and wind. A question is however, if this division into four situations is optimal or if it is possible to distinguish more patterns. Frequency analysis of data from the synoptic weather station, Jönköping airport (57°27'N, 12°42'E), shows that 56 % of the night-time situations during January to March 1996 are sorted into category four. Since such a large part of the situations will be classified into that category the study is focused on the temperature patterns during this weather type. The cloudy and windy class is also studied to determine to which wind speed the decrease with increased altitude yields and where category four starts.

2. Data

For this study an area of the county of Jönköping, near Lake Vättern in the south-inland part of Sweden was chosen. The variation in topography in this part of the county range between 80 to 260 m above sea level. The areas close to the lake is open, while the rest of the county is a mixture of open arable land and forests with an undulating topography.

Night-time synoptic weather observations during the period January- March 1996 and 1997 were taken from the SMHI-station at Jönköping airport. Cloud cover and wind speed are recorded every third hour and the observation at LST 01:00 was selected for this study. Only those days where the amount of cloud cover at LST 22:00 did not differ more than one octas from the observation at 01:00 were selected to exclude weather changes during the studied period. As a first step in the analysis, only situations with cloud cover 7 and 8 octas was used, resulting in 89 days during 1996 and 1997 which full filled this criteria.

Seven field stations, within the RWIS that are situated close to the synoptic reference station, were selected to obtain air and road surface temperature for the area (see table 1 for description of the stations). The altitude of the stations varies from 90 to 235 m above sea level. The variation in altitude is a factor that is important during cloudy and windy conditions, which also is a reason why they were selected. Some of the stations are open, while others are situated in forest to be able to study the effect of wind shelter. The field stations take measurement every half-hour and for this study the mean of the observations at 00:30, 01:00 and 01:30 were used in the analysis.
Station 605, which is open and wind exposed, was used as a reference and the temperature differences between the other six stations and the reference were studied.

Table 1. *Station description*

Station no.	Wind sensor	Extra probe	Altitude (m.a.s.l.)	Characteristics
605			220	Open and wind exposed.
612		Y	90	Relative open terrain with scattered bushes and low deciduous trees. In the lower part of a large hill close to the bridge over Taberg river.
613			230	On a hilltop surrounded by medium high coniferous trees.
614			235	Local low point surrounded by high forest.
615	Y		225	Open on the southern side and medium high coniferous forest on the northern side of the station. Situated in a small valley.
616		Y	220	Hilly site. Open on the eastern side and medium high forest on the western side of the station.
617	Y		135	Open and wind exposed. Arable fields on both sides of the station.

3. Result

3.1 Influence of wind speed on the surface temperature

For the selected cloudy situations the temperature differences between the reference station and the other six stations were calculated. These differences were further analysed in relation to prevailing wind speed. This was to determine if local parameters have any effect on surface temperature. The study showed that wind speed has a clear influence on the surface temperature difference during cloudy conditions, but the magnitude of the influence varies at different field stations. If the surface temperature differences at the stations are plotted versus wind speed, it can be seen that the location of the stations have an impact on to what degree the wind speed will influence the differences. Station 612 for example, which is situated in a valley and is relatively open, has nearly constant temperature differences during high wind speeds. However, below 7 ms^{-1} the temperature differences are more scattered (see figure 1). The surface temperature differences, at station 614 situated at a local low-point in forest, do not differ much when the wind is over 2 ms^{-1} . Below 2 ms^{-1} they differ slightly more (see figure 2). Station 617, which is well exposed and situated in flat terrain, shows the same pattern as station 614 but starts to have scattered temperature differences at 4 ms^{-1} (see figure 3). The rest of the studied stations indicate the same trends.

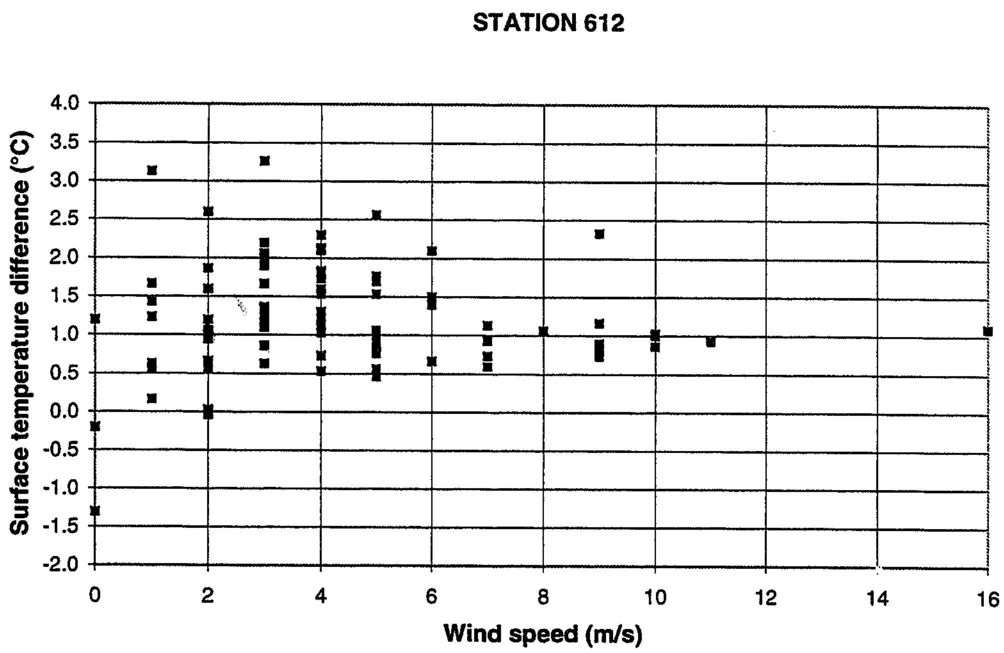

Figure 1. *Surface temperature difference between station 612 and the reference station (605) versus the regional wind speed during situations with cloud cover 7-8 octas.*

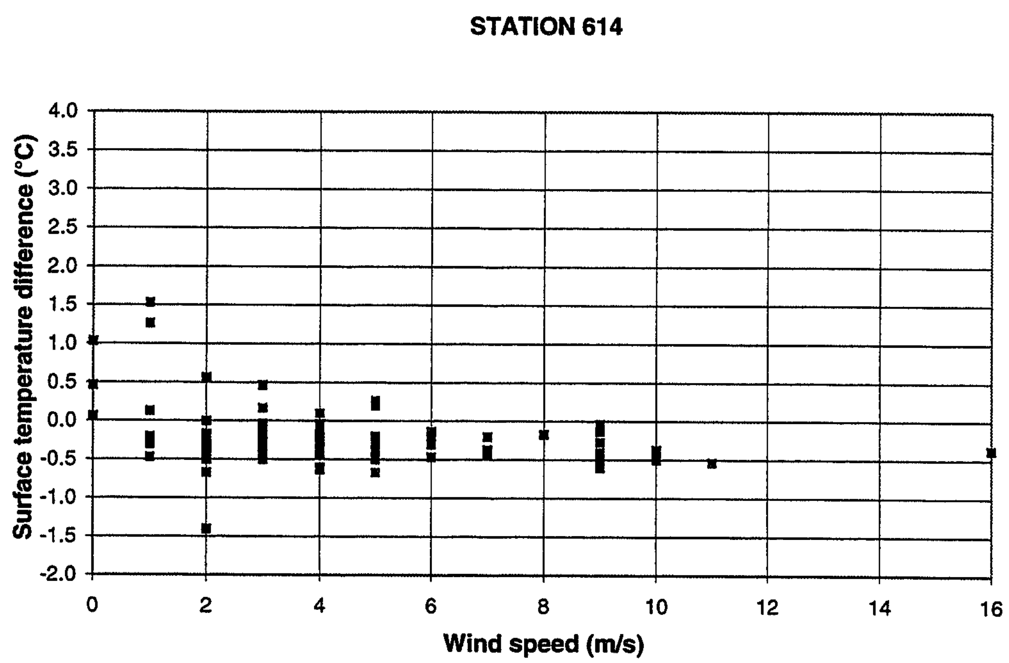

Figure 2. *Surface temperature difference between station 614 and the reference station (605) versus the regional wind speed during situations with cloud cover 7-8 octas.*

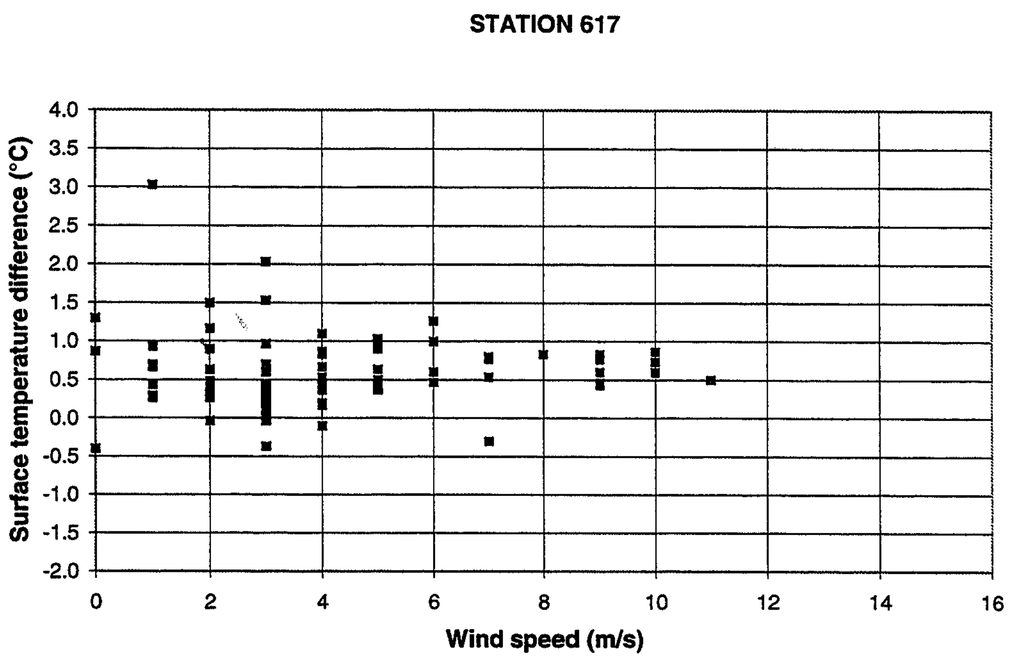

Figure 3. *Surface temperature difference between station 617 and the reference station (605) versus the regional wind speed during situations with cloud cover 7-8 octas.*

The surface temperature differences occurring when the wind speed is high, which mean over the levels where the differences start to become scattered, reflect the altitude difference between the studied station and the reference station. Station 612 is for example approximately 1 °C warmer than the reference station (see figure 1) and is situated 130 m lower than the reference. This shows that the temperature decrease with altitude yields during cloudy and windy conditions. Under these conditions the atmosphere becomes fully mixed and the temperature will change with elevation, approaching the dry adiabatic lapse rate as described earlier by several authors (Thornes 1989, Bogren and Gustavsson 1991). The results also show that the altitude dependence yields to different wind speeds at different stations due to degree of exposure.

3.2 Regional perspective on the influence of wind speed - Case studies

To study the regional temperature variations in the county and to analyse if other stations show the same pattern as above, all 32 stations in the county of Jönköping were studied during cloudy nights with high and low wind speeds. Two days from the data set were selected to determine how the temperatures in the county correlates with the altitude of the stations.

During the 11:th of February 1996 the cloud cover was 8 octas and the regional wind speed 6 ms^{-1}. During this situation the air temperature shows a clear decrease with increasing altitude (fig 4) and the decrease is almost 1°C*100m^{-1}. The surface temperature on the other hand varies more and the correlation is weaker. The decrease with altitude is also less, 0.7°C*100m^{-1}. This example shows that surface temperature is more sensitive to other parameters than altitude. When only the seven stations selected in the study were analysed both air and surface temperature decreased with altitude with 1°C*100m^{-1} and the correlations, R^2, were 0.9 and 0.7 respectively. One possible cause for this difference between the results can be an effect of local differences in wind speed. When the mean wind speed, of the stations with wind sensors, was calculated the wind speed was 4.4 ms^{-1}, which is lower than at the weather station. As seen above, local factors at the stations become important during low wind speeds.

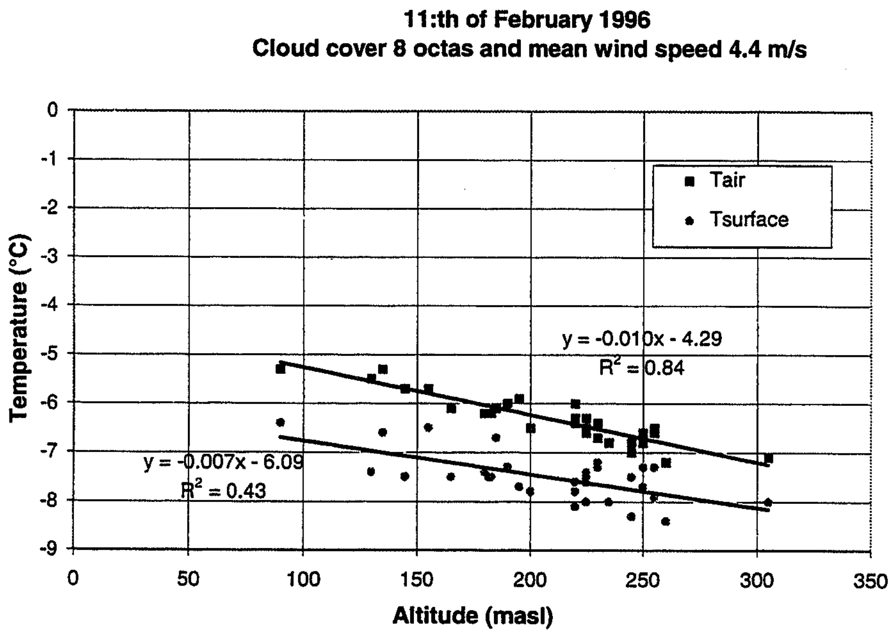

Figure 4. *Air and road surface temperature versus altitude above sea level the 11:th of February 1996 when the cloud cover is 8 octas and the regional wind speed 6* ms^{-1}. *The equation of the linear regression and correlations are also shown in the figure.*

During the 2:th of February 1996 the cloud cover at Jönköping airport was 8 octas and the wind speed 2 ms^{-1} and this day was chosen as an example of cloudy and calm situations. The mean wind speed of the stations in the county with wind sensors was lower, 0.5 ms^{-1}.

During this situation both air and surface temperature have low correlation with altitude, 0.47 and 0.59 respectively. The maximum surface temperature range in the county was 4.2°C, which is 2.1°C larger than during the cloudy windy situation above. The surface temperature decrease is also higher (1.6°C*100m^{-1}).

In order to study which stations that differ between the windy and calm situations described, the residual from the linear regression between surface temperature and altitude in each situation were plotted in the same diagram versus station number (see figure 5). Error bars for the measurement were also included in figure 5 and according to the manufacturer of the sensors the errors in the surface temperature measurements are ± 0.3°C. Ten of the 32 stations in the county have significant differences between the two situations, that is have differences of 0.6°C or larger (the accuracy) and they are listed in table 2.

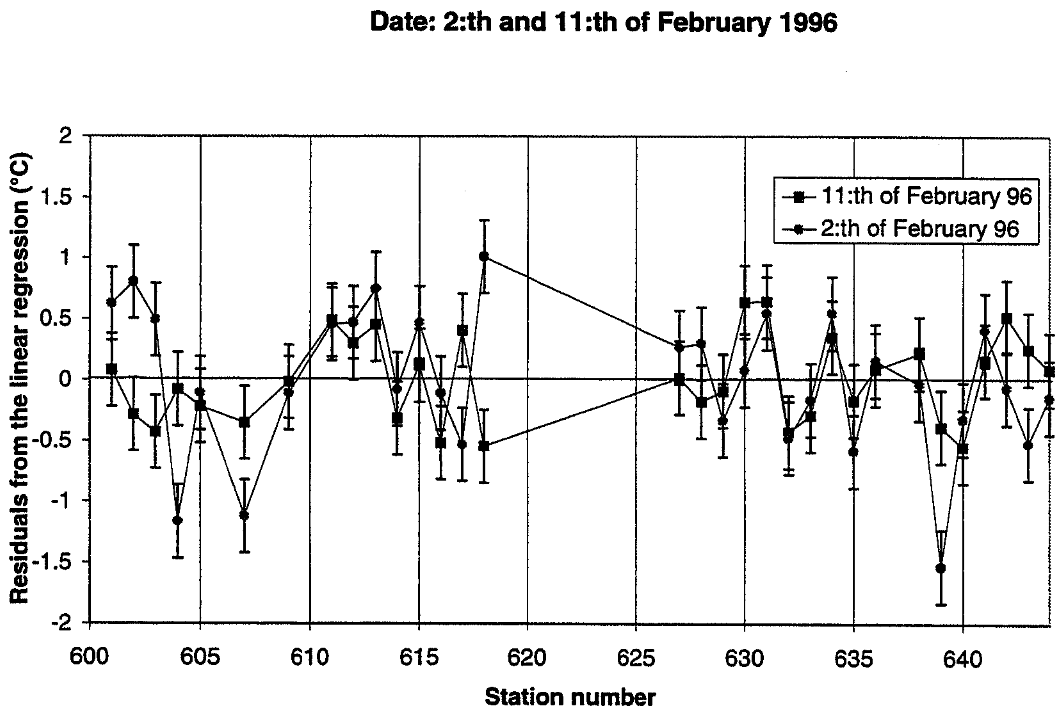

Figure 5. *The residuals from the linear regression between surface temperature and altitude above sea level during a cloudy and windy day (11:th of February 1996) and a cloudy and calm day (2:th of February 1996) versus the station number.*

All four stations that are warmer (601, 602, 603 and 618) during the cloudy situation with low wind speed (rather than during the cloudy and windy situation) are situated close to Lake

Vättern. This indicate that the lake has a warming effect. The ambient temperature in the county during this day was below 0°C. Of the six stations that are colder than during the cloudy and windy situation, three of them develops cold air pools during clear calm nights (607, 630 and 639). Station 630 and 639 are situated on bogs and 607 are close to a small lake. Station 639 and 617 are open. The last two stations (604 and 643) are both situated in forest.

Table 2. *Description of the stations which residuals from the linear regression between surface temperature and altitude differ more than the measuring error.*

Station number	altitude (masl)	Residual difference 2/2-11/2 (°C)	Description
601	130	0.6	Wind exposed, close to lake Vättern
602	195	1.1	Local low-point close to lake Vättern. High slope on the eastern side that screen the station during the morning.
603	130	0.9	Road cut at the eastern side and open on the western side of the station. Close to lake Vättern
604	255	-1.1	Local low-point in forest
607	200	-0.8	Close to a small lake. Develop cold air pool during clear and calm night and are screened during afternoon of terrain and trees
617	135	-0.9	Open and wind exposed field
618	260	1.6	Height surrounded by road walls. Close to lake Vättern
630	155	-0.6	Bog, surrounded by trees. Develop cool air pools during clear and calm nights
639	255	-1.1	Bog/open, flat terrain. Develop cool air pools during clear and calm nights
643	245	-0.8	Wind exposed height in forest

4. Conclusions

The results so far indicate that local factors around the stations influence the surface temperatures during cloudy situations when the wind speed is low. Important factors can be nearness to lakes, exposure/openness and occurrence of low points. Open stations situated in low-points and valleys seem to have the largest surface temperature difference ranges during low wind speeds and the dependence of local factors starts earlier than at the other stations. At different stations different wind speed limits exists, over which temperature dependence with altitude yields. The wind speed need to be higher than 5-6 ms^{-1} at all stations to obtain this relationship. Surface temperature differences do not have as large correlation with altitude as with that of air temperature differences. Also, the temperature decrease with altitude is not as high.

However, further studies will investigate if these results hold for more days and situations and will also explain more detailed why these particular stations differ from the rest. It is possible that key stations need to be selected in the model during cloudy and windy situations to exclude local effects at some stations. Otherwise the model will classify this situation as another temperature pattern.

Acknowledgements

This study was supported by Carl Trygger Foundation (CTS), Hierta-Retzius Foundation, Adlerbertska Foundation and the Swedish National Road Administration.

References

Bogren J. and Gustavsson T., 1991: A Review of methods for applied road weather climatological studies. Preprint Volume of the Seventh Conference on Applied Climatology, September 10-13, Salt Lake City, Utah. American Meteorology Society, Boston, Mass, 91-96.

Thornes J.E., 1989: A preliminary performance and benefit analysis of the UK national road ice prediction system. *The Meteorological Magazine*, **118**, 93-99.