The effect of weather changes on air and road surface temperatures

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INTRODUCTION

In the field of road climatology it is of main interest to study factors that influence air and road surface temperature along the road. With this information it is possible to develop accurate road climatological models to forecast the status of the road surface and make it possible to prevent road slipperiness. The use of road weather information systems (RWIS) and field stations have made further improvements possible and provides a large amount of data available for analysis. The Swedish RWIS consist today of more than 600 field stations situated in different topographical and geographical environments and provide information about air temperature, road surface temperature, humidity, wind and precipitation. To be able to decide when and where maintenance action is needed the point data from the field station is not enough, knowledge about the temperature pattern at road stretches in between the stations is also important. A local climatological model (LCM) has been developed at Göteborg University that provide this information (Bogren et al., 1992). The model uses synoptic data, recordings from field stations and topoclimatological factors to predict temperature variations in between the stations. During different weather situation different areas are prone to risk of slipperiness for example valleys, screened areas and hilltops. These temperature patterns that are established along the road are often classified into different categories dependent on during which weather situation they occur (Thornes 1989, Bogren et al. 1992).

To make it possible to take preventive actions against a risk of slipperiness, it is not only important to study these main categories but also the transition between different patterns. Changes in weather, especially from cloudy to clear conditions are traditionally known for the risk of lag conditions (Wood et al. 1999). However, during a change from clear to overcast conditions there can also occur lag effects. Gustavsson and Bogren (1990) have shown that the distribution of slipperiness during warm-air advection is controlled by the weather situation preceding the advection. If the preceding weather is characterised by clear and calm conditions, temperature differences can develop between different sites due to their topographical environments. Bogren et al., 1999 showed that solar insolation is a factor that influences the night-time surface temperature decrease with altitude during cloudy situations due to the slow thermal reaction of the surface compared to the air.

The objective of this study is to focus on weather changes and how long time it takes for the air and the road surface to adjust to the new conditions. During a change from clear to overcast condition, large temperature variations can develop and that is the reason why this situation has been chosen for this case study. Furthermore the importance of different siting will be investigated.

METHOD

Study area and instrumentation

The study area is situated close to Göteborg on the Swedish west coast and covers an area of 65*45 km^2. The variation in altitude in the area range between 40 to 300 m above sea level. Synoptic weather observations for the area were taken from the Säve airport , (57°47´N, 11°52´E), which is run by the Swedish air Force. At this station cloud cover and wind speed are recorded every hour. During the studied case, the 2nd -3rd March 1999, the weather was characterised by a change from clear to overcast condition.

Mobile thermal mappings were carried out along road no. 156 in the study area in order to study the temperature development along the stretch when the fronts arrived. Road 156 has a NW-SE direction and is characterised by undulating topography with a mixture of open arable land and forests. The thermal mappings along the road stretch were performed by a car. Air temperature and road surface temperature were recorded every tenth meter. Instrument specifications are shown in Table 1. The measuring runs were performed in approximately 30 min and no time corrections were considered to be necessary. Seven measurements (I -VII) were performed between 17:38 LST the 2nd March and 01:48 LST the 3rd March.

Twelve RWIS-stations with different site characteristics were also analysed in order to study the air and road surface temperature variation in a larger area and also to study the effect of different siting. Four of the stations are open and eight stations are screened during the day by topography or threes. The stations have an altitude ranging between 40 to 300 m above sea level.

Table 1. *Instrument specifications for the measuring equipment*

	Level	Response time	Accuracy	Range	Sampl.freq.	Instrument
Mobile						
Air temperature	2 m		< ± 0.2°C	-30-150°C	every 10th m	RTD Pt-100
Surface temperature		1s	± 0.5°C	-25-75°C	every 10th m	Heimann KT 15 SMD/KT 14 SMD
RWIS-stations						
Air temperature	2 m		± 0.3°C	-60-70°C	30 min	Lambrecht 8091100
Surface temperature	lowered 2 mm in the asphalt top layer		± 0.3°C	-60-70°C	30 min	Pt100 DIN 43760 K1A

Data analysis

To decide how long time it takes before the air has adjusted to the new conditions after a front linear regressions between air temperature and altitude were calculated together with correlation coefficients, R^2. The reason why the temperature variation with altitude is used is that several studies have concluded that the temperature variations during cloudy and windy situations to a great deal are determined by altitude above sea level (Thornes 1989, Bogren et al. 1992, Shao et al. 1997 and Bogren et al. 1999). By studying how long time it takes from the front arrival to receive a high correlation between temperature and altitude a value of the adjustment time can be obtained. When the correlation coefficient between temperature and altitude above sea level is above 0.7, the air and surface are considered to have adjust to the new weather condition. To calculate the temperature variation with altitude for the different runs the altitudes were obtained from a topographical map in scale 1:50000 and the points are taken where there are a change in altitude. Surface temperature variations were analysed in the same way as described above to investigate if there are any differences between air and surface temperature during the studied period. To calculate the temperature variation with altitude in a larger area the different stations and their respective altitude were used.

RESULTS

Mobile measurements

Analysis of the air temperatures show that there is a change in weather during the runs. Measurements number I, IV and VII are plotted in Figure 1. The variation in air temperature along the road became less between the first and the last measurement. The air temperature decreased between the measurement at 17:38 LST (I) and at 21:26 LST (IV) and then it increased. When the measurement at 21:26 LST is compared against the altitude profile it can be seen that some valleys, for example at the distances 3.4, 5.3 and 12 km respectively, have developed cold air pools since it is coldest in the valley bottom. These three valleys are all open and during this measurement the wind speed was low. During the last measurement the front has arrived and the air temperature decreases with increasing altitude.

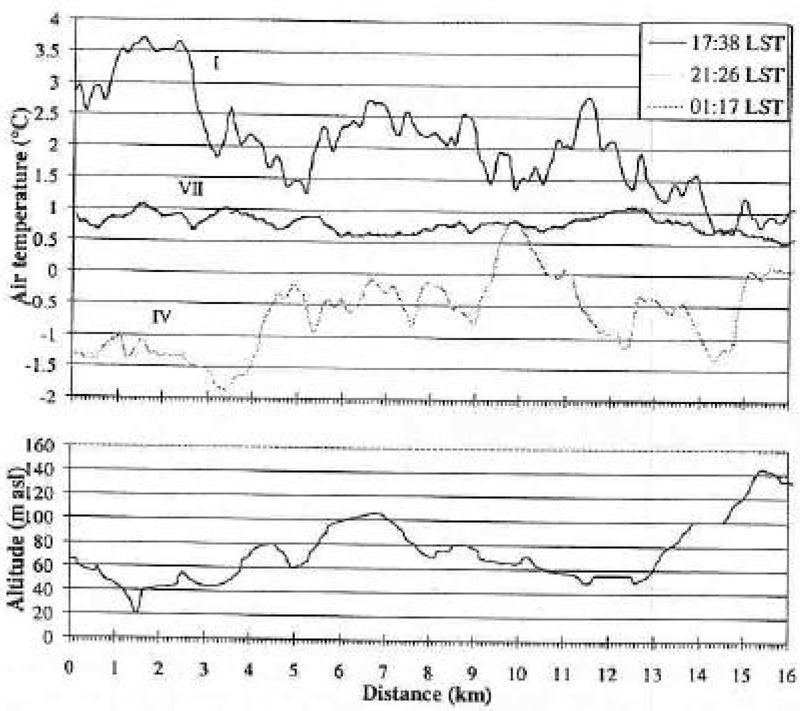


Figure 1. *Air temperature and altitude variation versus distance for measurement number I, IV and VII the 2nd to 3rd March 1999.*

If the relation between temperature and altitude are analysed both for air and surface during the last measurement at 01:17 LST the 3rd March 1999 it can be seen that the result differ, see Figure 2. Air temperature decrease with increasing altitude and has a correlation coefficient of 0.66 (figure 2a) while the road surface temperature does not correlate at all with altitude (figure 2b).

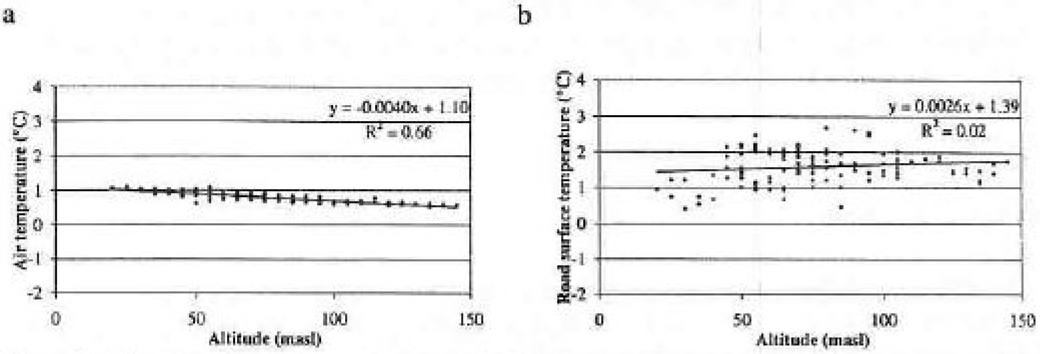


Figure 2. *Air and surface temperature versus altitude above sea level (a and b) for the last measurement at 01:17 LST the 3rd March 1999. Air temperature have a high correlation with altitude (R^2 =0.66) while road surface temperature has low correlation.*

The effect of screening during the day is still seen at the road surface. In Figure 3, the road surface temperatures along the stretch is plotted for measurements I, IV, and VII. In the bottom of Figure 3, open and screened areas are presented. White areas represent open areas while dashed areas have different type of screening objects.

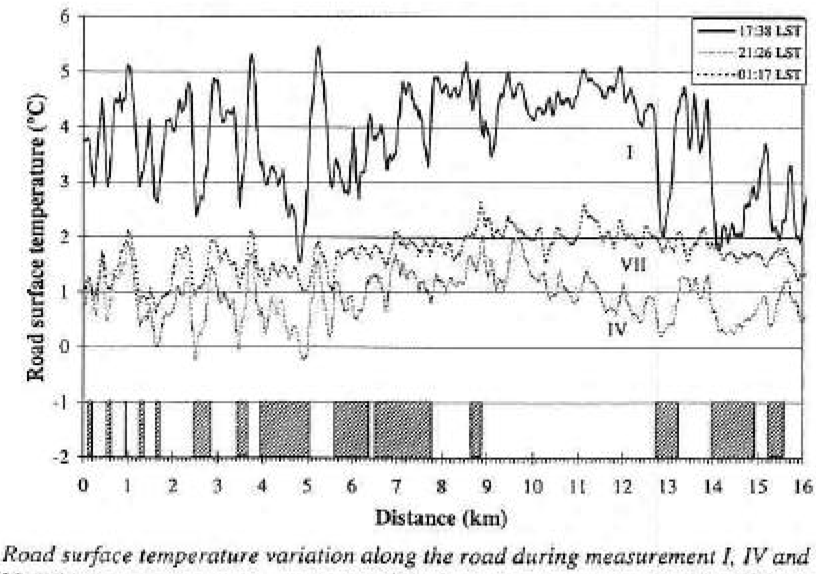


Figure 3. *Road surface temperature variation along the road during measurement I, IV and VII the 2nd to 3rd March 1999. White areas represent open areas while dashed areas are screened by different type of objects.*

The recordings in the figure show that the surface temperature closely follows the screening pattern. Areas that are screened by topography or trees develop the coldest temperature during the measurements and open areas the warmest. The largest surface temperature differences between open and screened areas were found during the first measurement and then the differences decreased, but the pattern is still found at the last measurement even if the area is effected by the warm front. There have though been some changes of the locations with minimum temperatures. The area with coldest temperature during the first measurement is no longer coldest at the last.

RWIS-stations

Since the road surface was not adjusted to the new conditions during the last measurement above twelve selected stations were used in order to study the temperature variations with altitude during a longer time period than what could be done with the car measurements. It was also possible to study the air and road surface temperature variation in a larger area and the reaction time at different siting. Table 2 present station siting, when air and road surface temperature increase as a cause of the front, difference in reaction time between air and road surface and when it started to rain and snow at the stations.

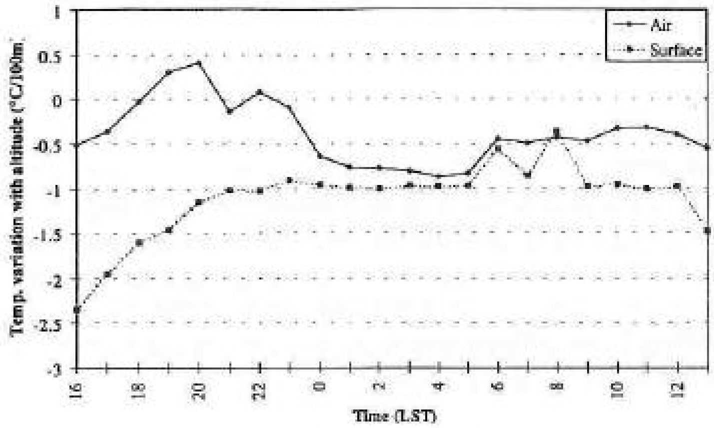
Table 2. *Siting of the stations, time for increase in temperature for both air (Ta) and surface (Ts), difference in reaction time and time for precipitation at the stations.*

Station	Siting	Time for increase Ta (LST)	Time for increase in Ts (LST)	Reaction time, Ts-Ta	Time for precipitation (LST)
1414	open	20:00 h	20:00 h	0 h	05:00 h
1418	screened	20:30 h	23:30 h	3.0 h	05:00 h
1430	open	20:30 h	23:30 h	3.0 h	05:00 h
1503	screened	20:30 h	00:00 h	3.5 h	05:00 h
1504	open	23:00 h	23:00 h	0 h	05:00 h
1505	screened	23:00 h	23:30 h	0.5 h	05:30 h
1506	open	21:30 h	00:00 h	2.5 h	05:00 h
1508	screened	23:00 h	00:00 h	1.0 h	05:30 h
1509	screened	-	22:00 h	-	05:30 h
1541	screened	20:30 h	23:00 h	2.5 h	05:00 h
1543	screened	20:30	23:30	3.0 h	05:00 h
1546	screened	20:30	23:00	2.5 h	05:00 h

In the table it can be seen that the front arrived between 20:00 LST and 23:00. The difference in reaction time between air and road surface at the different stations varied between 0 and 3 h. Most of the screened stations has a high time-lag while two of the open stations have no time-lag at all. Between 05:00 and 05:30 LST the 3rd March precipitation started to fall at the stations.

The temperature variation with altitude for the entire area and the correlation coefficient between temperature and altitude were calculated for both air and surface during the studied period, see Figure 4a and b. The wind speed at Säve airport are also presented in Figure 4c. The air temperature decrease with -0.5°C/100m at 16:00 LST and after 18:00 LST the situation has changed and the air temperature increases with increasing altitude instead. Here it is still a cooling at the stations and the front has not yet arrived. When the front arrived this situation changed and air temperature started to decrease with increasing altitude again. Between 23:00 LST and 05:00 LST the air temperature decrease with altitude increased from -0.64°C/100m to -0.82°C/100m but when it started to rain with a mixture of snow the temperature decrease became less. The correlation coefficient between air temperature and altitude have an inverse pattern compared to the air temperature decrease, see Figure 4a and 4b.

a



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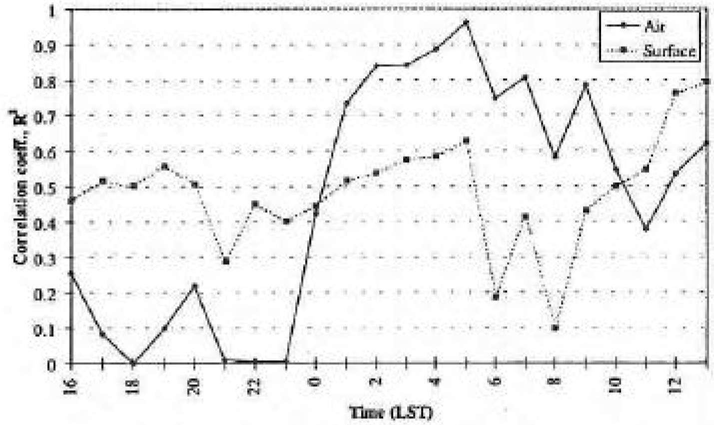

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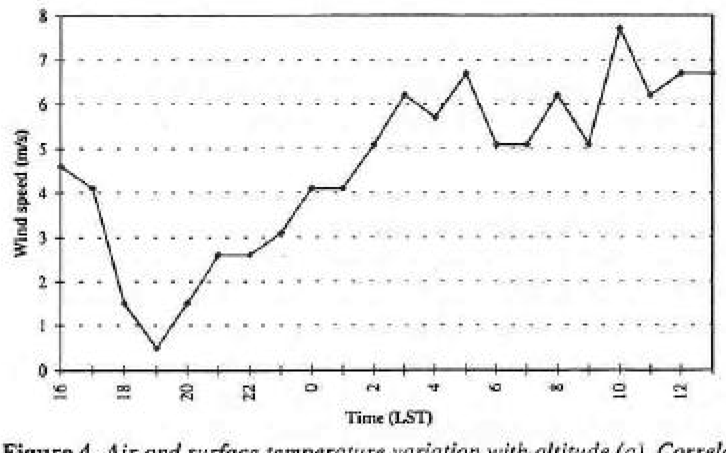
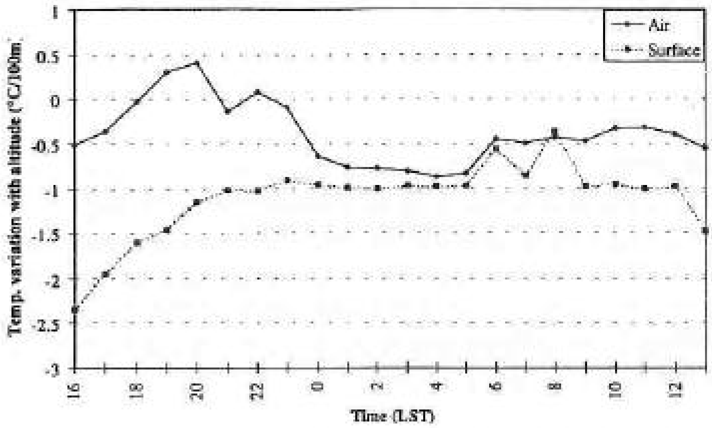


Figure 4. *Air and surface temperature variation with altitude (a), Correlation coefficient R^2 between temperature and altitude (b) and wind speed at Säve airport the 2nd to 3rd March 1999 (c).*

a



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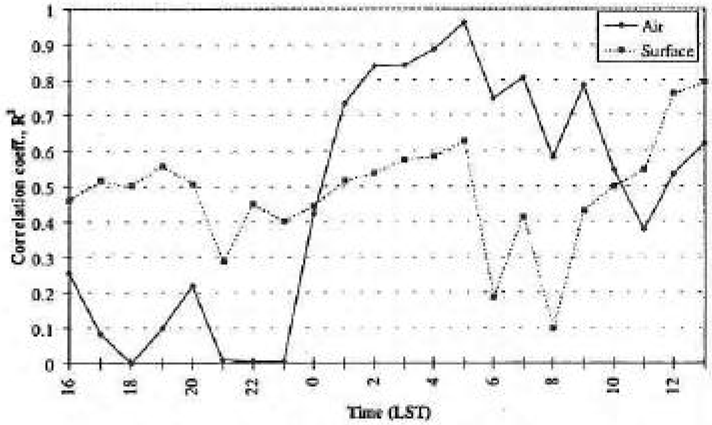

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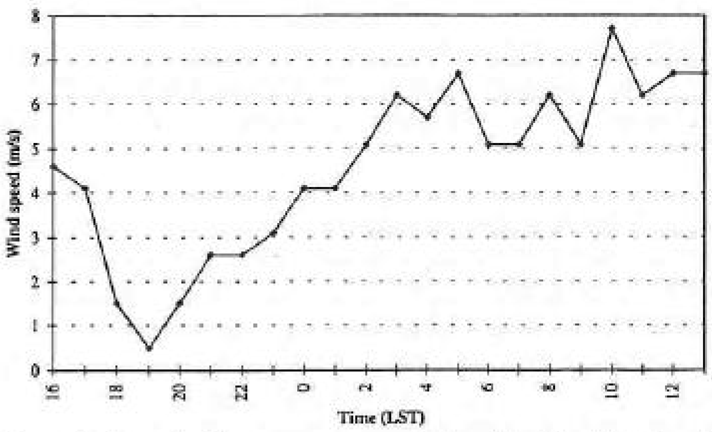

Figure 4. *Air and surface temperature variation with altitude (a), Correlation coefficient R^2 between temperature and altitude (b) and wind speed at Säve airport the 2nd to 3rd March 1999 (c).*

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