Temperature fluctuations in the air layer close to the road surface

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1 Introduction

One of the most important factors in making prognosis of slipperiness and road surface temperature is knowledge about the processes active in different environments along a road. Other important factors are the fluctuations of temperature and humidity in the air layer closest to the ground.

Several studies have proved the importance of the environment for the development of large temperature differences, during calm, clear nights. Bogren & Gustavsson (1991), used mobile temperature measurings to determine the influence of for example valleys on the variations in air and road surface temperature. In a frost risk study Kalma et al. (1986) showed the relationship between minimum temperature, elevation and terrain effect.

The temperature pattern developed during calm, clear weather gives a variation in risk of sublimation as a result of varying local topography and other factors. Bogren & Gustavsson (1990) showed that the spatial distribution of slipperiness during a warm air advection is to a large extent controlled by the preceding weather situation. The individual variations in local climate between sites resulted in differences in the occurrences of risk for slipperiness. In a study on the hoar frost deposition on roads, Hewson & Gait (1992) also mentioned the importance of the preceding weather for the hoar frost deposition. Another important factor mentioned in their study is the moisture gradients in the lowest air layers.

The aim of this study is to investigate:

- the temperature pattern that develops, during clear, calm weather, in different environments along a road.

- the variations in the air layers closest to the ground during a rapid weather change and for how long time a temperature pattern persists after a change in the weather.

The knowledge of both these processes are very important when used in models trying to predict the development of road surface and air temperature along a stretch. Studies on these processes are performed parallel to the development and improvement of the Local Climate Modell, (LCM) developed at the Department of Physical Geography, Univercity of Göteborg.

The study is divided into two parts. The first part concerns the temperature fluctuations in different environments and has been conducted along Road 47 in the county of Skaraborg which provides a good opportunity to study temperature fluctuations in different environments.

The second part concentrates on the temperature and humidity fluctuations close to the road surface during rapid weather changes and road icing. Several studies have confirmed that the moisture gradient in the atmospheres lowest air layers is one of the most important factors in determining the hoar frost deposition. This part has been conducted at the Swedish National Road Administration (SNRA) test site at road 45 in the county of Bohuslän.

2 Method

A measuring stretch along road 47, in the county of Skaraborg, was chosen to study the variation in temperature development caused by topography and land cover. The road runs through undulating terrain in open cultivated land, meadow and forests. This particular road stretch was chosen due to the fact that several interesting topo-climatological factors could be covered in a relatively short distance. Over the 22 kilometre long stretch, the road crosses a number of valleys of different sizes and there is also a variation in land cover. The first 16 km is open terrain and the last six km runs through a forest. Previous studies of this area have documented that large temperature differences develops during clear, calm nights, e.g. Bogren & Gustavsson (1989,1991).

Three sources of data were used to obtain information on temperature variations in the study area. The permanent stations in the Swedish Road Weather Information System (RWIS) were used as a basic measuring network. To obtain information from a denser network, data loggers of the Tiny Talks type were placed in areas of interest. Mobile temperature measurements were also carried out during clear nights. Data from all three sources were collected during the winter period from February to April, 1994.

The temperature and humidity variations during a rapid weather change are studied at the Swedish national road administration test station at road 45 in the county of Bohuslän. The test station is situated near a four lane highway at Surte. The area consists of an approximately 30 m long and 10 m wide asphalt plane in contact with the lane of the highway.The test station is equipped with a monitoring system with sensors at 0.3, 0.9 and 2.0 m. At all these levels temperature, humidity and wind speed and direction are measured every half hour during the winter season, i.e. from November to March. A denser measuring profile with measurements of humidity, wet and dry temperature above and across the road are used during occasions with rapid weather change. The surface temperature is measured with a probe in the middle of the slow speed lane. Sensors are also installed at 0.05, 0.10 and 0.50 m depth for measurement of heatflow in the road bed. This part of the study is in its initial stage and further measurings will take place during the winter of 96/97.

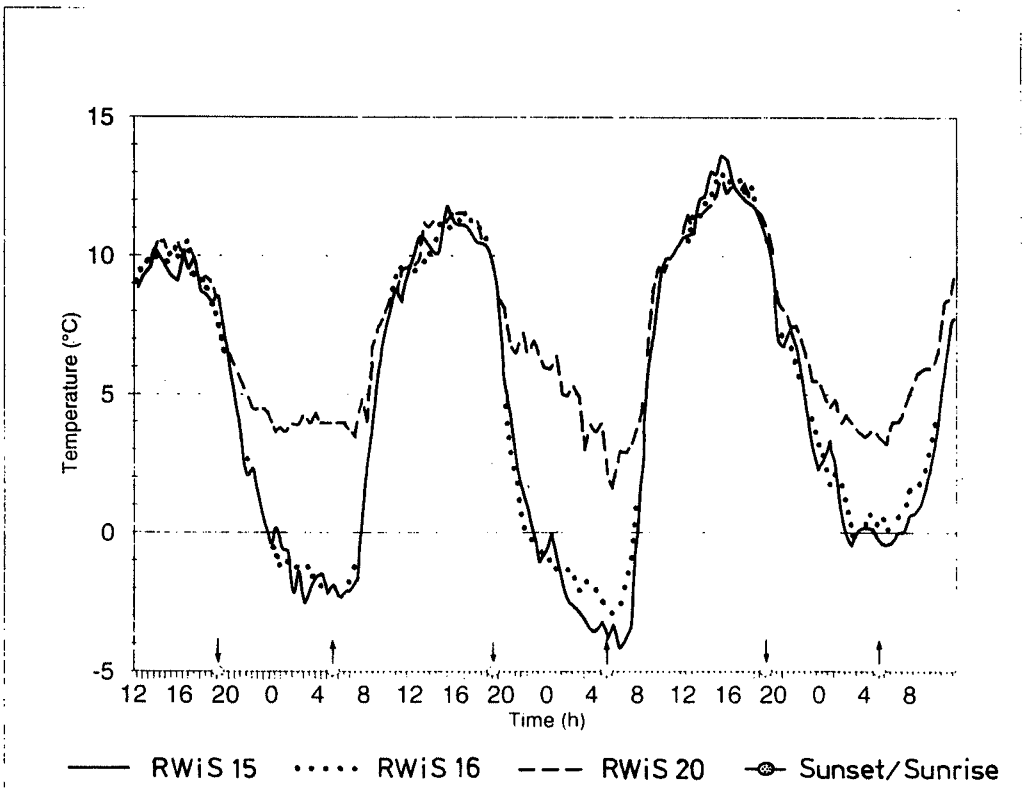
3 Results

The temperature measurements from the measuring stretch reveals that a very large variation in temperature occurs in the study area. These large variations develop despite the fact that the topography in question must be considered as moderate. Previous studies by Bogren & Gustavsson (1989) and Gustavsson (1990) in the same area also documented that great temperature variations develop during appropriate weather conditions. The present study is focused mainly upon determining the factors that control the possibilities for such large variation to develop. It has been especially important to study the cooling process in order to assess the required time period for the variation to develop.

3.1. Development of temperature patterns

The air temperature recorded at the RWiS stations in the study area between 11 and 13 April, 1994, is shown in Figure 1. These stations are located in different types of topographies, stations 15 and 20 on sloping surfaces where no gathering of cold air occurs and station 16 in a wide shallow valley. Station 15 is located in the forested part of the study area and stations 16 and 20 are located in open terrain.

Figure 1 Temperature development at RWIS 15, 16 and 20, 10-13 April 1994.

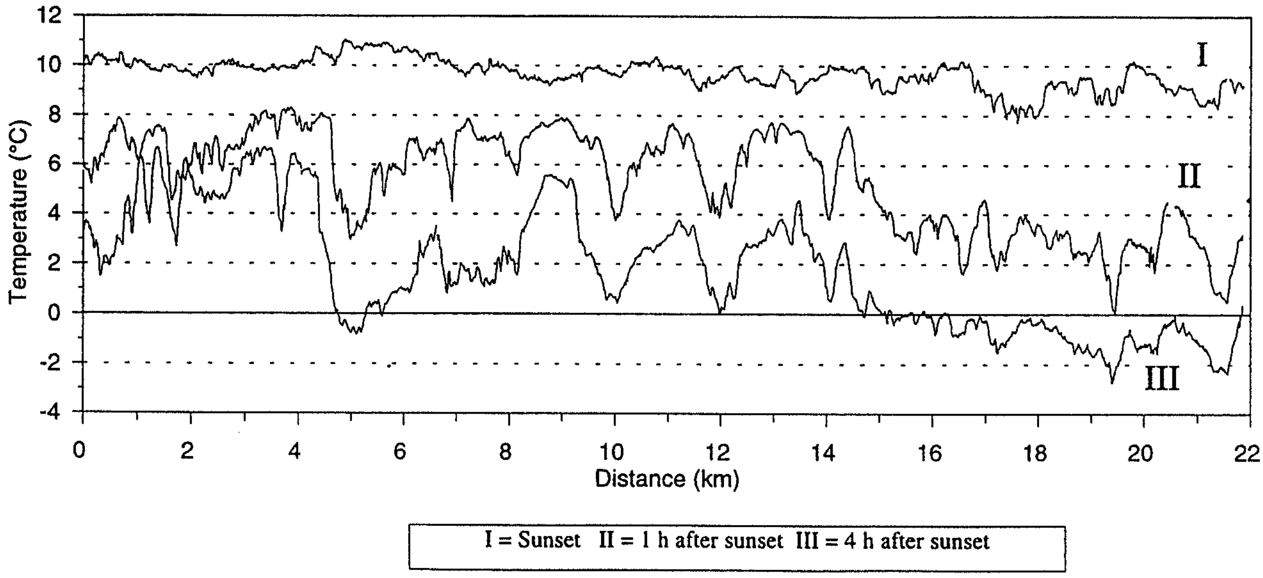


The stations show a similar temperature development during the daytime but there is a significant variation during the evening and night. From sunset, the cooling rate is much greater at stations 15 and 16 than at 20. The development of air temperature differences between the stations is, as shown in the figure, a very rapid process. One hour after sunset, stations 15 and 16 are 1.9 and 1.5°C colder, respectively than station 20. At midnight, the differences amount to 4.3 and 4.4°C respectively. After midnight, the variation in cooling rate diminishes but the temperature differences established are maintained until sunrise. The temperature curves in Figure 1 reveal that stations 15 and 16 have a similar temperature development during the night, despite the fact that they are located in such different environments. From Figure 1, it is also clear that this pattern is repeated during following nights with the same weather conditions. A small variation could be seen on the April 13 when a weak breeze blew during the night.

From the recordings presented in Figure 1, it is obvious that a number of factors must be taken into account when analysing the development of temperature variations after sunset. The fact that stations 15 and 16 have such similar temperatures indicates that different factors can be of importance - unobscured long wave radiation cooling in the valley location (No. 16) leading to an early development of ground-based temperature inversion which prevents a vertical mixing with warmer air at higher level. The rapid cooling at station 15, on the other hand, can not be attributed to an accumulation of cold air, as the station is situated on a gently sloping surface and there are trees on both sides of the road stretch at this location. The relative warm night-time temperature at station 20 is most probably a result of the horizontal advection of air resulting in no occurrence of stabilisation of the cold air close to the ground. This air flow must be very weak (U<1m/s) and shallow, as it is not recorded by the wind speed sensor at 5 m above the ground.

To analyse the relative influence of the above discussed factors on temperature variations, repeated mobile temperature recordings were carried out along the selected measurement route; see Figure 2. The advantages of these measurements were that several different types of areas were covered and that they could be compared with respect to variation in cooling rate and cold air pool intensities. Figure 2 shows an example of three measurements at different hours: one at sunset, one hour later and four hours after sunset.

Figure 2 Temperature patterns on 11-12 April 1994 at sunset, and 1 hour and 4 hours later at road 47.



The measurements were made during the first night presented in Figure 1. At sunset, there was no correlation between topographical lowpoints and temperature. The temperature change along the route was also small, indicating that no gathering of cold air had started or that shading from the sun had only a small effect on the temperature difference. The greatest screening effect was found at approximately 18 km along the stretch where the air temperature reached its minimum (+8°C). One hour after sunset (measurement II, in Figure 2) the temperature pattern was well developed and a close resemblance was found between valleys and minimum temperature recordings. As previously mentioned, the first 16 km of the road stretch is open and the following 6 km runs through a mainly forested area. The largest drop in temperature occurred in the forested part; for example, at 19.5 km, the drop in air temperature amounted to 8.5°C in one hour. Temperature curve III in Figure 2 is from midnight, i.e. four hours after sunset. It can be seen that there is a close correlation between the temperature pattern observed during this recording and the one carried out one hour after sunset. The difference between recordings II and III is that the lateral extension of the low temperature zones increased and that the temperature difference between lowpoints and summits increased further. There was also a general decrease in temperature over the time period.

The greatest drop in air temperature occurred in the forested parts of the study area. In a small valley surrounded by a forest, the temperature difference amounts to 9.1 (II) and 12.0°C (III) compared with the recorded temperature at sunset. This difference should be compared with the largest valley along the route, with large cold air production area around it. At both the measurements made after sunset, the valley in the forest was colder than the largest valley. Another important fact shown in Figure 2 is that the general temperature decreased more (7°C) in the forest as compared with the open field, where the decrease amounted to 2°C. This indicates that other factors than free long wave radiation are of importance for the cooling of the air close to the ground.

A theory on this great temperature decrease in the forested area is that the trees prevent turbulent mixing of surface- cooled air with the warmer air aloft. In a study by Gustavsson (1995), it was shown that wind shelter had a pronounced effect on the development of temperature differences. That study was carried out in a coastal area (the county of Halland in the south-western part of

Sweden) but the same phenomenon as emerges in Figure 2 was found and is in support of this theory.

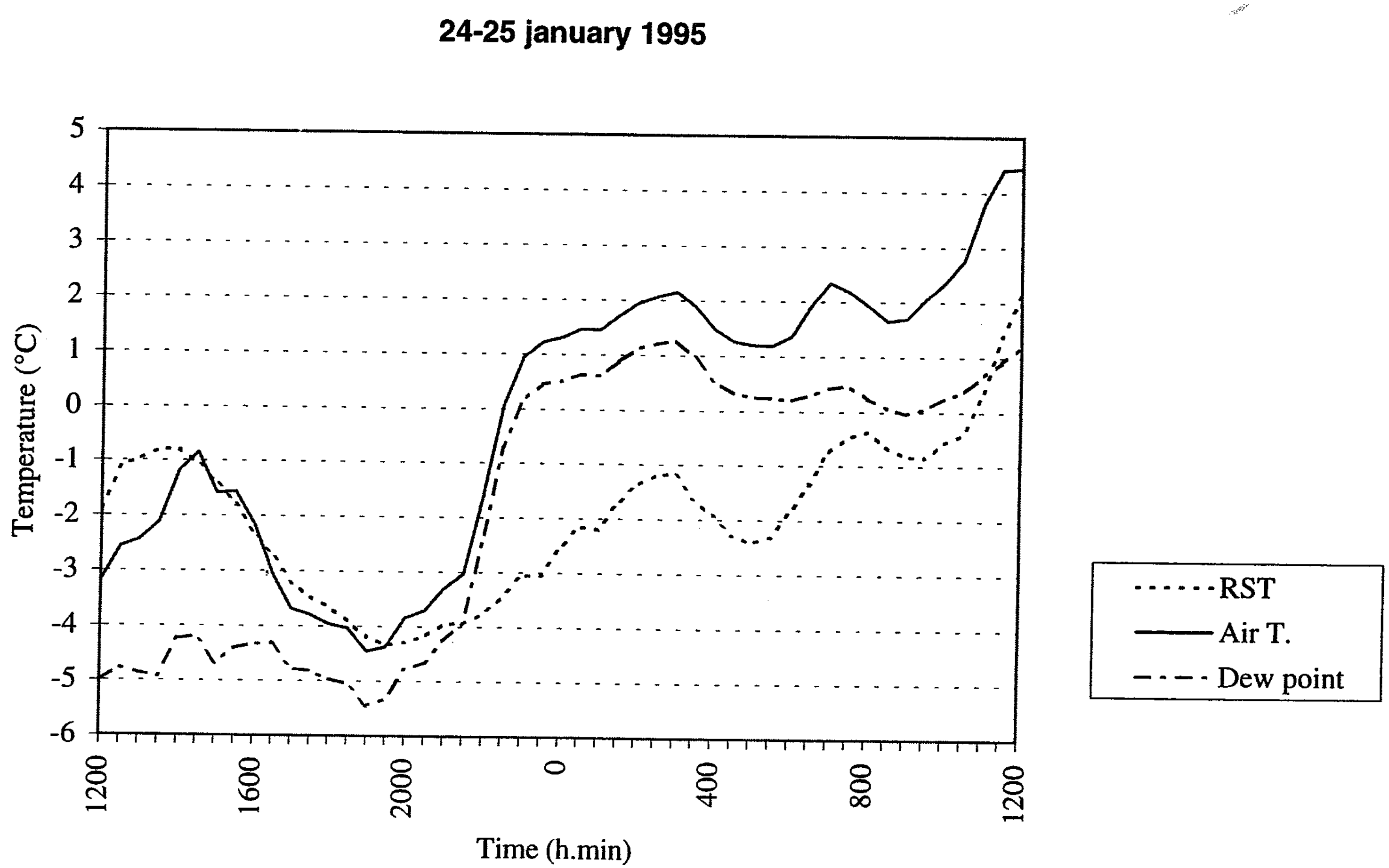
3.2 Temperature fluctuations during rapid weather change.

During rapid weather change the temperature differences mentioned in the previous section creates large variations in the risk for slipperiness. That previous weather is important for the slipperiness risk has been shown by for example Hewson & Gait (1992) and Gustavsson & Bogren (1990). Several measurings from the test station at road 45 have shown that, during a warm air advection, the air layer warms more quickly than the road surface, see Figure 3. During occasions when the temperature is around zero degrees this could result in that the air layer above the ground is above zero degrees and that the road surface is below. This situation is very dangerous when it comes to road icing and it is therefore very important to study the temperature and humidity exchange close to the road surface during these occasions.

Figure 3 shows the temperature development on the road surface and in the air during a warming situation between the 24 to 25 January 1995. The warming is preceded by calm, clear weather. When the warming starts in the evening the air and road surface has the same temperature. Within a few hours the air warmed substantially and temperatures above zero degrees were recorded whereas the road surface warmed slower and it did not reach zero degrees until 12 hours later. The maximum warming rate of the air was 2.13 °C/h whereas the warming rate for the surface during the same time was only 0.5 °C/h. The largest temperature difference between air and road amounted to 4 °C. It is important to know the variation of temperature and humidity in the air layers closest to the ground during these occasions to be able to estimate the risk for slipperiness in different environments. The dew point temperature is also showed in Figure 4. From when the warming starts and for several hours following the dew point temperature is several degrees warmer than the road surface temperature. Gustavsson & Bogren (1990) argued that the difference between the dew point and the RST are proportional to the risk for slipperiness.

To be able to estimate the risk for slipperiness in different environments and for different weather situations it is important to use the knowledge from both studies. The study along road 47 shows how the temperature pattern develops in different environments and the study in Surte deals with how the temperature and humidity fluctuates above the road fluctuates during changing weather

Figure 3. Air temperature, surface temperature and dewpoint development at Surte test station, 24 - 25 January 1995.



situations. Combined these two studies will give a general three dimensional picture of how the temperature and humidity behaves above the road in different environments.

4 Further measurings

During the coming measuring season, the winter 96/97, the study will concentrate on the measuring of humidity and temperature in the air layers closest to the road surface during occasions with hoar frost.

The first part has been divided into two separate parts which will concentrate more on specific phenomenon in different environments. One study will further investigate the influence of the forests on the minimum temperature and the other study will concentrate on the processes working in cold air pools during calm, clear nights.

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