Detailed climatic measurements above and beside the road.

Esben Almkvist

Physical Geography, Department of Earth Sciences, Göteborg University
Box 460, SE-405 30 Göteborg, Sweden. esben@gvc.gu.se

1 Introduction

The instruments used for measuring climate variables by the road should be placed as close to the road as possible, without causing safety problems for the cars. This often means one or two meters into the vegetation surrounding the road. It is important to understand what is measured and how it reflects the conditions of the road. The purpose of the measurements performed in this study was to define the scope of the road climate system. Thereby knowing more in detail how the measured temperatures reflect the conditions of the road in different climatic situations. During the winter 2000 measurements were made at Surte, 20 km north of Gothenburg, Sweden. This has been a road climatological test site for almost 20 years. The area is flat and the vegetation is low. In the winter 2000-2001 the measurements were made at Strängsered, 120 km east of Gothenburg, well into the country. This site is situated at an altitude of about 300 m and the landscape is dynamic, with large topographical features causing cold air pooling; open and shaded areas causing large differences in temperature on small distances (Norrman et al., 1999), (Bogren et al., 1999).

The two stations complete each other. The station at Surte is useful because of the simplicity of the site. The influences from the surroundings are limited, whereas the site at Strängsered is much more complex and sets the results from Surte in a context of influences from topography and surroundings.

The results from Surte show that although the air in the vegetation can be 8 °C colder than the air above the road, the road surface itself is not significantly affected by the temperature difference. The heat storage in the road is large, which keeps the surface warm and thereby making the air above the road unstable. This favors the mixing of the air. When topographical effects are present, as in Strängsered, the temperature difference can be very important. If the cold air drains onto the road surface and gathers at topographical minimums, it can cause local hazardous areas. It is important to remember that the Surte measurements were made in late winter when the solar elevation was rather high. This is necessary for the heat storage in the road to be as high as it was. At Strängsered the simple micro-scale processes are not as evident as at Surte. The road and the surroundings are rather reacting to the larger scale features in the topographical system.

2 Methods

Observations of temperature profiles above and beside the road gave information about the height of the boundary layer above the road. The results were analyzed statistically in a Matlab environment.

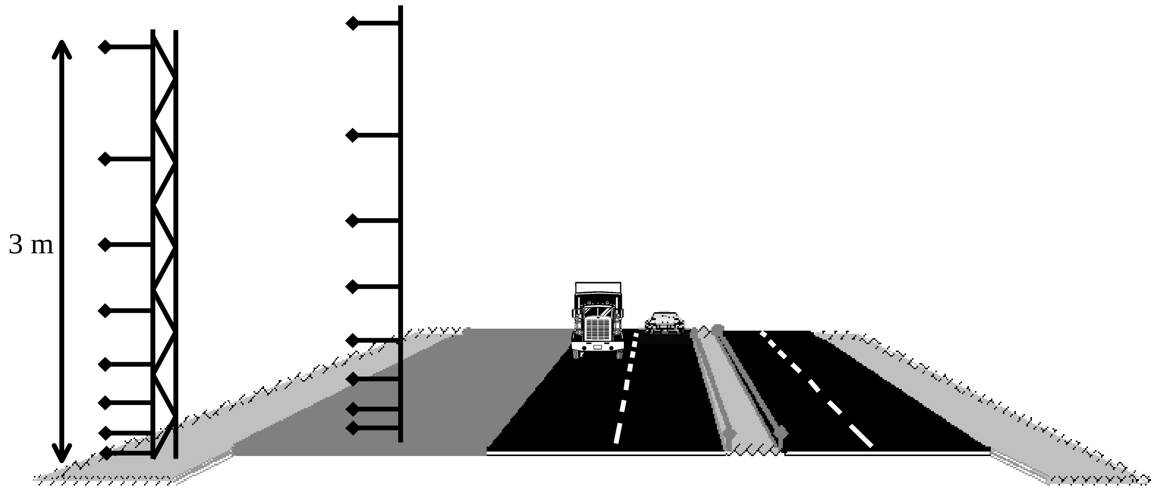

Figure 2-1. The site at Surte. The mast closest to the road is on an asphalt pocket. There is a RWIS-station placed in this area too. The mast in the vegetation is about 10 m from the road.

2.1 Measurements

Measurements of temperature were made at Surte 20 km north of Gothenburg from the 25/2-2000 to the 30/4-2000. The second part of the measurements was made at Strängsered, 120 km east of Gothenburg during the period 22/12-2000 to 30/4-2001. The Surte site is situated along a four lane highway running north in an approximately 1 km wide valley. The area is flat and the vegetation low. Influence from the topography is not an important factor. The temperature sensors were placed at eight levels above the road and vegetation as shown in figure 2-1. The sensors were placed in a logarithmical manner with more sensors closer to the ground. The instrument masts were constructed as shown in figure 2-3. The measurements were made every 10 minutes where each value represents the mean of the preceding ten-minute interval. The data was collected by a CR-10 Campbell Scientific Ltd. logger. The logger collecting the vegetation data was placed in a locker as shown in figure while the logger collecting the asphalt data was placed inside a workmen's cabin. The cabin was 8 m south of the asphalt mast and could influence the measurements by having a sheltering effect when the wind was southern. The shading from the cabin did not reach the sensors since the sun was at its highest when it was above the cabin. When the sun had sunk to cast long enough shadows it had already passed the cabin to the west.

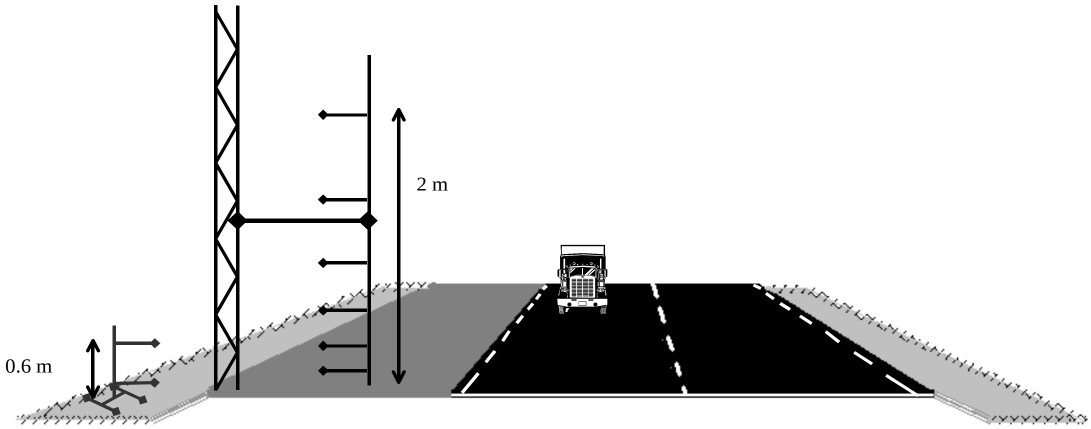

Figure 2-2. The Strängsered site. The instruments closest to the road are placed on a bus stop area. There is a RWIS-station at this site too. The sensors in the vegetation are about 7 m from the road and in altitude approximately 1 m below the road.

At Strängsered the measurements were made in an open area and in a forested area (pine trees), which was shaded during the day. The open area is situated, although at a high altitude (~300 m), in a topographical minimum. There is a lake to the north of the road. The shaded area is on the downward slope, 500 m to the west of the open area. In figure 2-2 one can see the placement of the instruments in the open area. There were 8 sensor of which 2 were placed in the vegetation and 6 above the road. The setup was similar in the shaded area. The two sensors in the vegetation were placed 6 m from the road within the forest. The collection of the data was done exactly as it had been done at Surte the previous year.

The temperature sensors consisted of thermocouples covered in an elastic rubber material to protect them from rain and dirt. This made them durable, but the response time was larger. However, since 10 minute means were used the response time was considered to be sufficient. The instruments were placed in a cylinder shaped radiation shield covered with a highly reflective aluminum film. The cylinders were tilted towards the sun so that no direct sunlight reached inside the cylinders. At Strängsered the instruments were tilted in such a manner that a lot of splash from the cars would reach inside the cylinders. To prevent this, CD:s were attached to the exposed end of the cylinder.

The station at Surte has more meteorological facilities than Strängsered. Strängsered has the normal output of an RWIS-station, i.e. surface and air temperature, humidity, wind and precipitation. The temperature measurements at Surte were compared to measurements of wind profile, humidity, pressure, cloudiness, ground temperature and other climatological measurements.

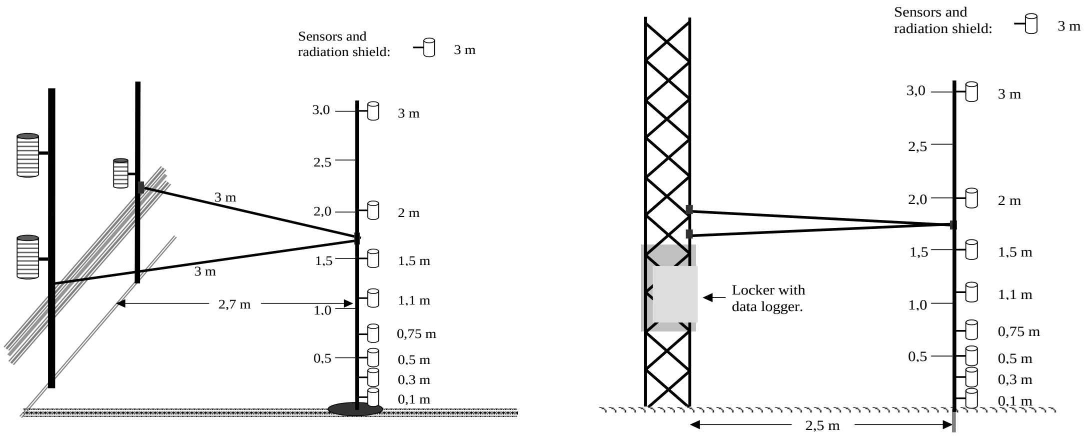

Figure 2-3. The distribution of the sensors at the Surte site. The figure to the left shows the sensors above the asphalt from the south. This means that the sensors are as close to the road as possible. In the right figure the sensors above the vegetation are viewed from the north. The sensors are turned from the road.

The Bulk Richardson number (in the following text referred to as just Richardson number or *Ri*), a convenient measure of stability in the lower boundary layer, was calculated using the wind and temperature gradient. The gradients were calculated using measurements of wind and temperature at 0.5 m, 1 m and 2 m height (For the temperature the height 1.1 m was used instead of 1 m both in the vegetation and over the road). The wind measurements were made by the side of the road, so the *Ri* for the vegetation was based on the same wind measurements as the *Ri* for the road. This will probably cause the *Ri* for the vegetation to be higher than if the wind measurements had been done in the vegetation. The *Ri* could only be calculated at Surte.

The temperature difference at different levels was analyzed and related to other climatological variables, such as wind, cloudiness and soil heat flux. For example the temperature difference at 10 cm was calculated in the following way: $\Delta T_{10}=T_{v10}-T_{a10}$, where ΔT_{10} is the temperature difference at 10 cm and T_{v10} and T_{a10} are the temperatures at 10 cm above the vegetation and asphalt respectively. The temperature difference at height x, ΔT_x was then compared to the climatological variables mentioned above. By using the climatological variables as predictors and ΔT_x as predictant a multiple regression analysis was made.

3 Results

The temperature of the air above the road is affected very much by the surroundings. When the temperature of the surface is higher than the air above, the air column becomes very unstable. The air above the road mixes efficiently with the air from the surroundings. The air above the vegetation at 1.5 - 3 m often has the same temperature as the air 0.3 – 3 m above the road. This is often the case in late winter since there is large heat storage in the road surface. The air from the surroundings of the road is often much more stable. If the cold air from the low level surroundings flows onto the road, the air temperature at about 10 cm will be lower than at the surface. This leads to a very complex temperature profile above the road. First the temperature will decrease just above the surface. At a certain height (10 - 20 cm) the temperature will start to increase again.

3.1 Results from Surte

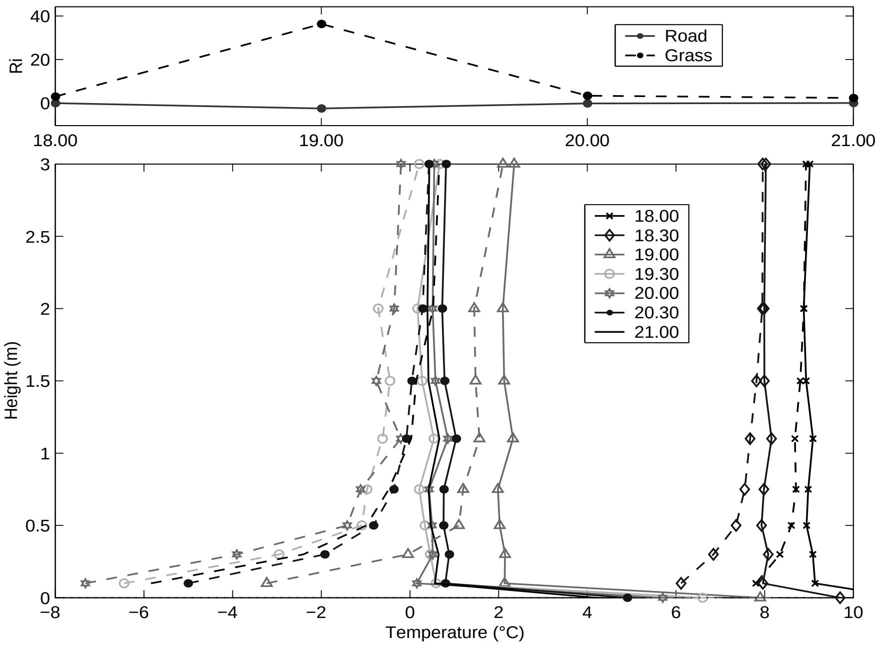

Figure 3-1. The data is from the 29/3 – 2000. The dashed and solid lines are temperature profiles above the vegetation and the road respectively. It is evident that the chilling of the air is much more efficient in the vegetation than over the road. It is also evident how the surface temperature of the road is maintained high during the chilling period. The Ri shows that the air is very stable above the vegetation, while it is unstable above the road.

Figure 3-1 shows that the difference in cooling in the vegetation and the road can lead to very large temperature differences. In this case the difference was almost 8 °C. One can see how the air above the road is influenced by the underlying surface. The stability of the air above the vegetation is much higher than of the air above the road, as shown in the top part of the figure. The Richardson number is extremely high over the vegetation while it is negative over the road. In figure 3-2, the temperature of the underlying road is shown. The surface temperature differs significantly from the temperature at 10 cm above the road.

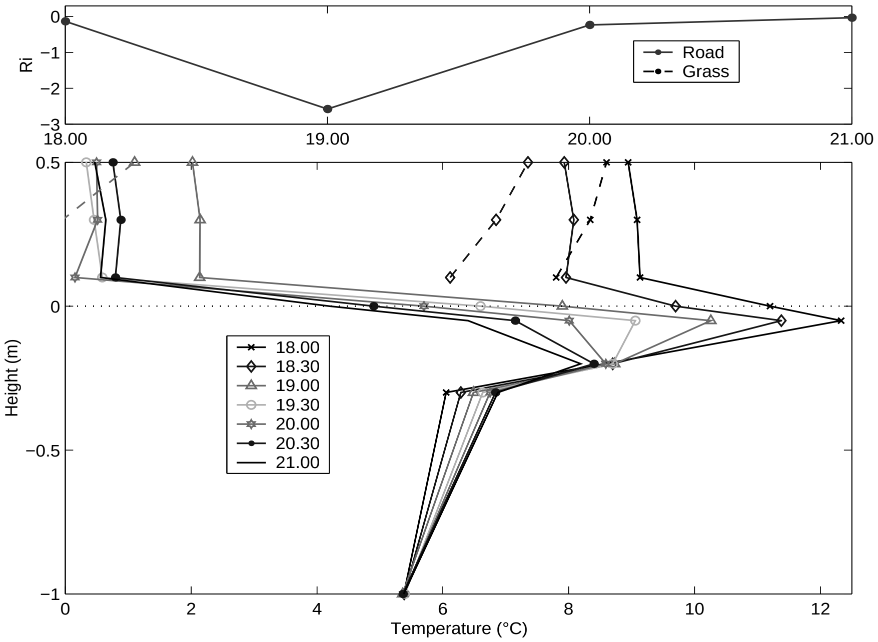

Figure 3-2. This plot is from the same time period as figure 3-1. When the ground temperature is plotted it is evident how the heat storage in the ground plays a significant role in the energy balance. The Ri for the road has been zoomed in to be better visualized.

Table 3-1. The elements in this table contains the coefficients to the regression equation $\Delta T_x = C_0 + C_1 \ln u + C_2 Cloud + C_3 Cloud \ln u$. The R^2-value shows how well the coefficients explain the variation of ΔT_x. All coefficients are significant on the 5 ‰ level except C_3 on 300 cm, which is significant on the 5 % level. The regression equation is based on nighttime measurements only.

Predictant	C_0	C_1	C_2	C_3	R^2
ΔT_{10}	-1.60	0.18	1.62	-0.17	84.5 %
ΔT_{30}	-0.60	0.083	0.72	-0.075	83.5 %
ΔT_{50}	-0.19	0.048	0.36	-0.034	80.9 %
ΔT_{75}	-0.13	0.033	0.27	-0.026	78.2 %
ΔT_{110}	0.04	0.020	0.18	-0.015	73.0 %
ΔT_{150}	0.16	0.012	0.15	-0.014	57.8 %
ΔT_{200}	0.38	0.010	0.08	-0.005	37.1 %
ΔT_{300}	0.33	0.006	0.04	-0.003**	15.0 %

Table 3-1 shows how well the temperature difference is explained by the wind and the cloudiness. Although the coefficients for this relationship are site-specific, it can be very useful for calculating the influence from the surroundings of the road. The value of the coefficients C_0-C_3 are larger for ΔT_x closer to the ground. This means that ΔT_x is influenced more by the wind and clouds, when measured closer to the ground.

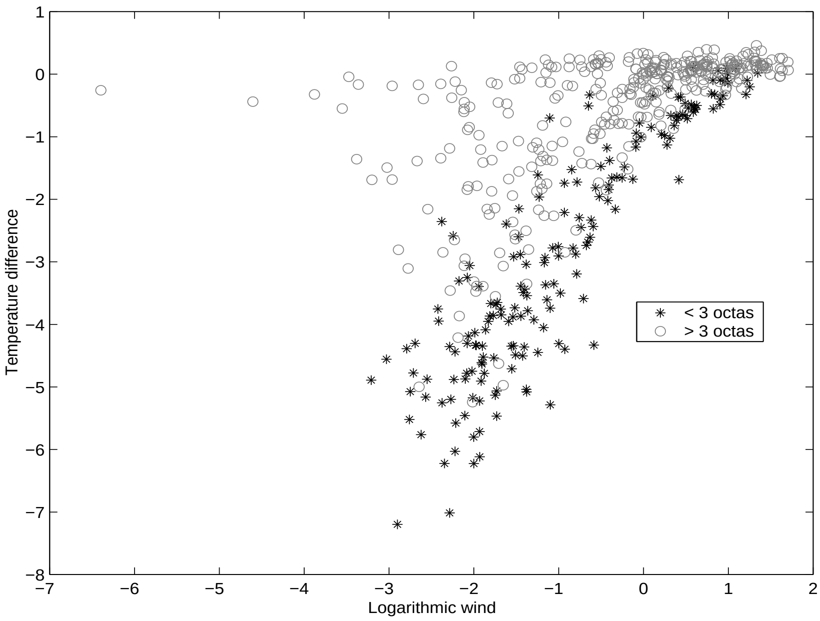

Figure 3-3. The temperature difference is plotted against the logarithmical wind. When there is large cloudiness the temperature difference decreases.

Figure 3-3 shows the influence from the cloudiness and the windiness on the temperature difference. A large cloud cover will lead to a small temperature difference. A high wind speed will also smoothen the differences.

3.2 Results from Strängsered

There is a warm front that arrives at 4 pm, as shown in figure 3-4. The road surface reacts slower than the air above, which can cause hazardous situations (Gustavsson and Bogren, 1990). The positive cooling rate, i.e. heating rate, shows the arrival of the warm front. The humidity in the air at 2 m was high at the time, so the risk for hoar frost formation was large. The open area reacts faster than the shaded area to the temperature change.

In figure 3-5 it is evident how the shaded area benefits from the decreased loss of radiation. The shaded area is almost 10 °C warmer than the open area in the vegetation at 22.30. The effect of topography is probably also present. The cold air pools in the open area and especially in the vegetation, which is situated about 1 m lower than the road. The 10 cm temperature above the road is not as low as the above air. This is caused by the snowfall during the morning. The road maintenance vehicles have probably cleared the roads and drowned the lowest sensor in snow.

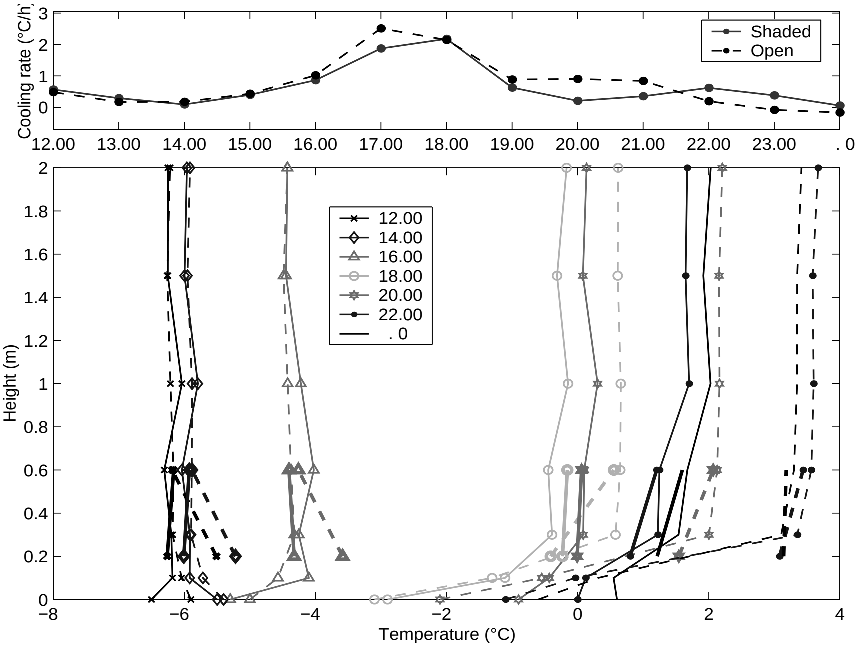

Figure 3-4. The data is from the 6/2 – 2001. The dashed and solid lines are temperature profiles in the open and shaded area respectively. The thick lines are from the temperature sensors in the vegetation. The top part of the figure shows the mean of the cooling rate.

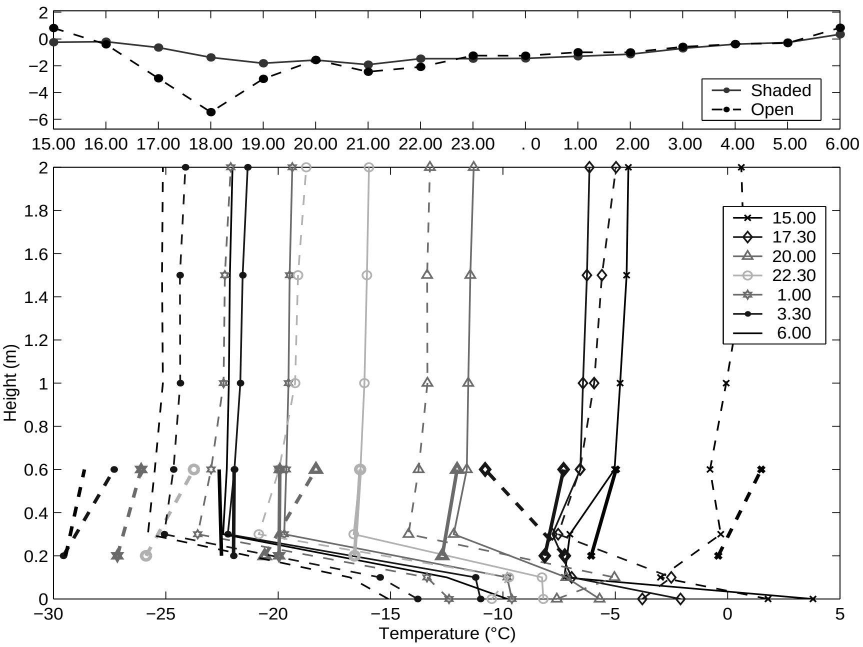

Figure 3-5. The data is from the 3/3 – 2001. The cooling is very rapid throughout the night. The temperature changes by almost 30 °C in less than 15 hours. In the early evening the air in the open area cools much more rapidly than in the shaded.

Table 3-2. The elements in this table contain the coefficients to the regression equation $\Delta T_x = C_0 + C_1 \ln u$. The R^2-value shows how well the coefficients explain the variation of ΔT_x. The cloudiness is not included. The regression equation is based on nighttime measurements in the open area.

Predictant	C_0	C_1	R^2
ΔT_{20}	0.66	-1.09	30.7 %
ΔT_{60}	0.34	-0.67	30.3 %

The wind only explains 30 % of the variation of the temperature difference, as shown in table 3-2. The cloudiness will probably explain part of the variation, but there are probably other processes that play a major role. Such processes could be topographical influences or just instrumental problems. The explanation of the variables is much better at the Surte station.

4 Discussion

4.1 The Surte station

The first thing that strikes you is the size of the temperature differences above the vegetation and the road. The explanation for this situation is mainly the large heat storage in the road. This is shown clearly in figure 3-1 and 3-2. The temperature is preserved high within the road all through the night. It is important to notice that this situation is valid only in late winter when the solar radiation is powerful enough to heat the road body sufficiently to cause the heat wave in the road. The intense cooling of the air in the vegetation close to the surface, causes an extremely stable air column. As shown in figure 3-1 and table 3-1, the stable layer reaches a height of about 1-1.5 m. The top of the boundary layer can be interpreted as where the R^2-value decreases, i.e. 1-1.5 m. Since the stable air reduces vertical movement, the cooling will continue close to the surface and enhance the stability of the air. The surface of the vegetated area consists of dried grass and other porous dead plant material. This keeps the heat storage in the soil low.

Previous studies of the difference between the vegetation and road at Surte (Karlsson, 1999) did not find the large temperature differences found in this study. Karlsson only used two sensors in the vegetation at 1 m and 2.5 m. This was insufficient to measure the cold air in the lower part of the vegetation.

The regression equation shown in table 3-1 can be very useful. In a site where the influence from the surroundings are larger than at Surte, it would be very important to know the approximate temperature in the surroundings. The coefficients of the equation would of course have to be adapted to the specific site.

4.2 The site at Strängsered

The shaded and open areas differ significantly. The open area reacts faster. The cooling is more intense and the heating is faster. More energy is transferred in the system. The difference between vegetation and road is much larger in the open area, as seen in figure 3-5. The radiation is sheltered in the shaded area, so the loss of energy is small. Therefore the temperature differences are smaller in the shaded area.

During the beginning of the winter the temperature differences between road and vegetation were smaller than towards the end of the winter. The energy input was smaller and therefore air flows caused by temperature differences were limited. When the energy input increases the system is more dynamic and there are occasions influenced by topographical features. The intense cooling shown in figure 3-5 is an example of this situation. The radiative cooling is not enough to cause the rapid cooling. There must be advection involved.

The relationship between the wind and the temperature difference is much weaker than at Surte. There must be other variables explaining this situation, such as topography and clouds. The wind instrument at Strängsered is probably not as reliable as the one used at Surte. This could explain the poor relationship.

5 References

Bogren, J., Gustavsson, T., Karlsson, I. M., and Postgård, U. (1999). The impact of screening on road surface temperature. *Submitted to Journal of Applied Meteorology*.

Gustavsson, T., and Bogren, J. (1990). Road Slipperiness During Warm-Air Advections. *Meteorological Magazine* **119,** 267-270.

Karlsson, I. M. (1999). Temperature differences in the air layer close to a road surface. *Submitted to Meteorological applications*.

Norrman, J., Karlsson, I. M., and Nunez, M. (1999). Intense nocturnal cooling in a valley - the relative importance of various heat fluxes. *Submitted to International Journal of Climatology*.