Road climatological studies with emphasis on temperature variations and road slipperiness

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INTRODUCTION

This paper is a short summary of the thesis - Local and micro climatological studies with emphasis on temperature variations and road slipperiness, by Maria Karlsson at the, Department of Earth Sciences, Physical Geography University of Göteborg, Sweden. The text in this summary is direct parts from the thesis by Maria Karlsson (1999).

This work has been funded by the Swedish National Road Administration and can be seen as a part of a long term strategic engagement for research and development in the field of road climatology. The benefits from research activities can be seen in several applications such as for example sensor locations, development of forecasts and modelling of climate.

The thesis – *Local and micro climatological studies with emphasis on temperature variations and road slipperiness* - focuses on temperature differences due to varying topography and land use both during day and night-time. The emphasis has been to analyse and determine the relative importance of factors in a local scale leading to a varying air and road surface temperature pattern. Another point in the thesis deals with the temperature and humidity variations above a road surface. These measurements focus on a physical description of the factors and circumstances leading to risk for road slipperiness.

The analyses of processes of interest have been performed with the help of data recorded with mobile measurements of road surface temperature, air temperature and humidity along road stretches. Field stations measuring air and road surface temperature, humidity, net radiation, wind speed and direction have been used in areas of special interest. Temperature and humidity profiles above and across the road have also been measured and hoar-frost has been observed manually. Data from the Road Weather information System (RWiS) and synoptic observations from the Swedish Meteorological and Hydrological Institute (SMHI) have also been used in the study. The measurements have been performed in south-west Sweden.

This thesis is based on articles on two themes: the spatial and temporal variations in the temperature pattern for roads in complex terrain and the microclimate and slipperiness at the road surface. The following articles are included in the thesis:

I. Gustavsson T., Karlsson M., Bogren J. and Lindqvist S., 1998*: Development of Temperature Pattern During Clear Nights*. Journal of Applied Meteorology, **37**, 559-571

II. Karlsson I. M., 1999: *Nocturnal Temperature Variations Between Forest and Open Areas*, Accepted for publication in Journal of Applied Meteorology

III. 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

IV. Bogren J., Gustavsson T., Karlsson M. and Postgård U., 1999: *The Impact of Screening on Road Surface Temperature.* Submitted to Meteorological Applications

V. Karlsson I. M., 1999: *Temperature Differences in the Air Layer Close to a Road Surface.* Submitted to Meteorological Applications

VI. Karlsson I. M., 1999: *Prediction of Hoar-frost by use of a Road Weather Information System.* Submitted to Meteorological Applications

The work in this thesis has been performed in close collaboration with my colleagues. My emphasis has been placed especially on air temperature variations in different terrain (Paper I –III), air temperature variations close to the road surface during the development of slippery conditions (Paper V and VI), the development of hoar-frost on the road surface (Paper VI) and the preservation of road surface temperature differences in screened areas after sunset (Paper IV).

CONCLUSIONS

The results of this study showed that the reoccurring temperature pattern during clear calm weather is largely due to different degrees of shelter (Paper I-III). Large temperature variations developed shortly after sunset with lowest temperatures in areas sheltered by topography or vegetation. Locations exposed to regional winds or slope winds will have less intense cooling than sheltered locations. The effect of cold air flow, which in many studies has been used to explain the temperature differences, was mainly to increase the turbulence on slopes and thereby enhance the temperature differences between valley bottoms and crests. The degree of shelter was more important than differences in topography since valleys of different size experienced the same amount of cooling. The sheltering effect is prevalent in forest as well and should be accounted for together with the screening effect of the forest.

The air temperature pattern with lowest temperature in valleys developed shortly after sunset whereas the road surface temperature reflected the temperature pattern caused by screening for several hours after sunset. The duration and magnitude of temperature differences were ruled by the solar elevation. The influence on road slipperiness is largest during early spring when the screening causes large temperature differences that are maintained for several hours after sunset and occasions with temperature below 0°C are still frequent.

Large temperature differences were also recorded in the air layer above the road surface (Paper V and VI). The measurements showed that large temperature differences were prevalent during occasions with slipperiness, i.e. hoar-frost, snow or ice on the road surface. The large temperature difference in the near surface air layer makes it difficult to estimate hoar-frost from the measurements at 2m in the RWiS. Measurements at lower levels will enhance the accuracy of road slipperiness forecasting. The conclusions drawn in this thesis are summarised below.

Cold air pooling:

- The temperature pattern with lower temperatures in areas sheltered by either topography or vegetation was established within half an hour after sunset.
- The fast establishment and the fact that the slope winds were warmer than the stable layer at the valley bottoms indicated that cold air flow were not the cause of the lower air temperatures in the valley bottom.

Sheltering effect:

- The lower temperatures were the result of stable conditions established earlier in sheltered locations.
- The sheltering effect was largest during clear calm weather but a sheltering effect could be recognised at regional wind speeds up to $5ms^{-1}$.

Influence from forest:

- The results showed that the approximately 4°C lower temperatures in the forest, during clear calm nights, were largely due to wind sheltering and reduced turbulence in the forest. In the forest the latent and sensible heat flux is small and the net radiation is governed by the sky view factor, which means that the lower temperatures are due to reduced turbulence inside the forest which could be compared with the reduced turbulence in a valley bottom.
- The temperature pattern with lower temperatures in the forest compared with open areas is valid only on a large scale. Clearings and small open areas within the forest are, as expected, colder than the forest due to greater cooling by radiation.

Screening effect:

- The solar elevation during the day determines the potential for the temperature pattern between sun-exposed and screened areas.
- The solar elevation also determines the duration after sunset of the temperature pattern created during the day.

Temperature differences close to the road surface:

- The statistical analyses of temperature gradients showed that large temperature differences, between 250cm and 10cm above the road, were most common during clear and partly cloudy weather with weak winds. Variations were from –0.5 to +1.7°C for night situations and from –1.2 to +1.4°C during daytime situations.
- The temperature difference between the road and its surroundings decreased with increasing cloudiness and wind speed. It also decreased with height above the surface.
- Temperature differences were not much influenced by differences in humidity and thermal capacity of the surrounding areas but rather by weather situations typical for certain wind directions.
- Situations when large temperature differences develop could be divided into three weather types: cooling situations during clear, calm weather, advection of warm air during front passages and situations with snow or ice on the road surface. That is, large temperature differences in the air layer close to the road surface occur during situations with high risk for slipperiness.

- The development of large temperature differences is associated with the exchange of temperature and humidity close to the road surface. At 10cm above the road the temperature and humidity changes are well correlated whereas at higher levels turbulence and advection have a large influence and temperature and humidity readings do not reflect the processes at the road surface.

Prediction of hoar-frost

- The amount of hoar-frost on the road surface is well correlated to: the duration of road surface temperatures below the dew point, the magnitude of temperature difference between dew point and road surface temperature and the minimum road surface temperature.
- The friction at the road surface is also well correlated to the duration and magnitude of the temperature difference between dew point and road surface temperature.
- The ability to estimate amount of hoar-frost with the help of measured weather parameters will increase if measurements are performed at lower levels.

Recommendations

Several of the above-mentioned results will increase the ability to accurately forecast slipperiness on the road surface. Early detection of the road surface status is necessary for maintenance activities to be able to prevent slipperiness before it occurs. The conclusions of this thesis have several applications within road weather climatology.

When temporal development of the spatial air temperature pattern, during clear, calm nights is modelled, the focus should be put upon turbulent mixing of the near surface air layers. Both the importance of SVF and sheltering have to be accounted for in forests since the sheltering effect varies in importance in different forests, depending on their structure and size.The temperature differences recorded in the air layer close to the road surface will also have to be accounted for in models based on the measurements at 2m. The ability to indicate road surface status from RWiS would be increased if the air temperature and humidity were measured at two levels with one level situated closer to the road surface than at present. The idea to measure at two levels has been suggested before, but it is only now that the improved accuracy of measuring instruments makes it relevant to measure at two levels. It might be possible to calculate the temperature gradient for different weather situations but it would require synoptic weather data and information on the thermal properties of the road as well as the surroundings.

The combined results of this thesis can increase the capacity of thermal mapping of frost-prone areas. Measurements at two levels would not only give information on the coldest location but also show where large air temperature differences are present in air layer close to the road surface. Together with humidity measurements this information will indicate where hoar-frost will develop. This thesis has also shown that it is important to perform repeated mobile measurements to receive the temporal development of temperature patterns.

REFERENCE

Karlsson I. M., 1999: *Local and micro climatological studies with emphasis on temperature variations and road slipperiness.* Earth sciences centre, Göteborg University report A42 199, Ph.D Thesis.