A Critical Review of Thermal Mapping Techniques

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Introduction

Micro and local climatological processes varies in relation to small scale features. Due to this fact measurements that aims at covering these variations must be properly designed. Most commonly in local climatological studies are to use a stationary network of field stations, like the RWIS, or to use mobile measurements equipped with temperature sensors. Mobile measurements have a long tradition. Schmidt (1927; 1930) and Peppler (1929) published some early work where mobile platforms were used to describe climate variations. The car has later on been used in a large number of studies concerned with topoclimatology as well as urban climate. An advantage of using a mobile platform is that a large area can be covered in a relatively short time period and that the same instruments are used. This results in a temperature pattern that can be analysed in relation to, for example, topographical factors and that differences that can be related to instrumental errors are avoided.

Mobile temperature measurements, of thermal mapping, have been used in applied road climatological studies since the middle of the 1970's. Lindqvist (1976) published an early report where methods for detecting road sections with a high frequency of ice formation were discussed. This technique has later on been developed, and is today a method which is used in most cases priore to an installation of a RWIS. Thornes (1991) published a paper where he describes the thermal mapping technique in great detail and also gives examples of how the temperature data varies according to weather as well as other important factors.

The new thing about using mobile platforms in road climatological studies was that surface temperature detectors were included in the instrumentation. By use of this type of sensor a coverage of all the important factors influencing the local risk of road icing could be measured. Traditionally thermal mapping is used as a method to detect areas which differs in temperature compared to neutral areas. These areas are further compared with field observations and analyses of topographical maps to rank the most suitable locations for field stations in a RWIS.

The present study emanates from a long tradition in using thermal mapping technique for climatological studies. A need for evaluation of the technique, both in respect of instrumentation and ways of analysing the recordings, has grown during the last years. It is very important that thermal mapping is performed in a correct way since the technique is very sensitive to errors. The result presented in this paper is part of an ongoing project where different aspects of thermal mapping is analysed. The result from the entire project will be suggestions of how the technique should be developed in order to give high quality data for analyses of road climate variations.

Measuring technique

Surface temperature is a very difficult parameter to measure. The surface is what one could characterise as the transition zone between two different mediums. Large temperature differences often occur in this zone owing to the change from turbulent to laminar flows. One way of performing measurement of the surface temperature is to register the energy flux and relate that to the temperature by use of Stefan-Boltzmann's law:

$$\mathbf{I = \varepsilon * \sigma * T^4}$$

where I is the energy flux, σ is the Stefan-Boltzmann constant, ε is the emissivity and T is the temperature of the surface given in Kelvin.

Infrared scanners are instruments which have sensors that are sensitive to a specific wavelength-band. 8 to 12 μm is most commonly used as that corresponding to the atmospheric window, i.e. where the atmosphere is transparent for energy flow, and also well to the temperatures most interesting to measure in the applied climatological studies.

However, using IR-technique is not trouble-free. Especially the emissivity factor can be difficult to handle, as a small variation can cause large variation in temperature calculations. In figure 1 the temperature variation is shown in relation to a calculation using 0.95 for emissivity. A change from 0.95 to 0.85 gives a surface temperature difference of approximately 8°C, given that I = 300 Wm^{-2}. The emissivity of a surface varies with type of material, texture etc. Another parameter of special importance in road climatology is if the surface is wet or dry, which will significantly determine the emissivity of the asphalt.

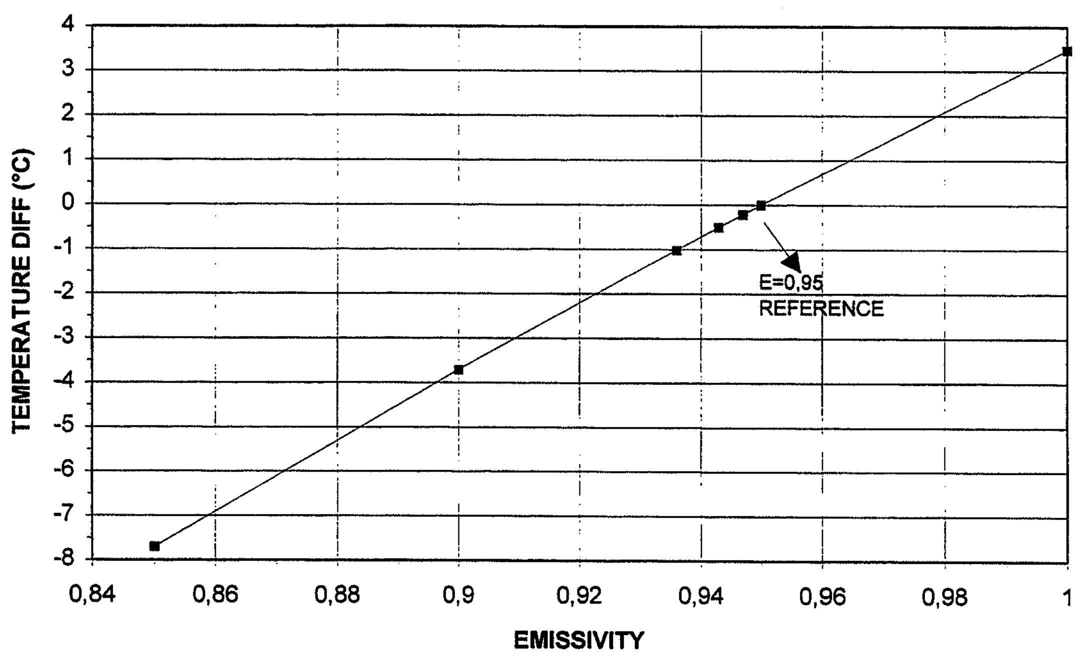

Figure 1. Variation in calculated temperature due to changes in emissivity.

The radiation received by the IR-sensor comes from mainly three different sources and the total radiance (I_{tot}) can be calculated using the following equation

$$\mathbf{I_{tot} = I_{t\text{-}objekt} * \tau * \varepsilon + I_{t\text{-}ambient} * \tau * (1 - \varepsilon) + I_{t\text{-}atmos} * \tau * (1 - \varepsilon)}$$

where $I_{t\text{-}objekt}$ = radiation from the road surface, $I_{t\text{-}ambient}$ is the reflected radiation from surrounding objects with the temperature ($t_{\text{-}ambient}$) $I_{t\text{-}atmos}$ is the radiation from the atmosphere, τ = transmission and ε = emissivity. A problem during thermal mapping measurements is to minimise the influence from the last two factors in the formula. One way of doing that is to have the scanner mounted in a nadir position and to install the sensor not too far from the surface. If the scanner is mounted with a view angle differing from nadir a number of problems occur. First of all the size of the measuring area increases, which in a way can be an advantage, but if the oblique angle view is used, the importance of radiation from the surroundings and the atmosphere increases. Furthermore the emissivity changes with view angle and thereby the risk of misinterpretation can increase. The intensity of the radiation also differs in relation to the view angle and if an oblique set up is used a recalculation must be made to be able to compare measurements carried out using different set-ups.

In figure 2 repeated temperature measurements along a specific road stretch is shown. Measurements were carried out 4 times during the same night in order to follow the temperature development of the road stretch, and also to be able to analyse the quality of the instruments used. If the instrument is of high quality and the measurements are carried out in a proper way, the correlation between the individual measurements should be high, which is the case for the example shown in the figure. The amplitude of the temperature differences changes through the night but the pattern is kept. Other factors that can influence the quality of the measurements are if the scanner is kept at constant temperature, if the lens of the scanner is cleaned and if the instruments are calibrated.

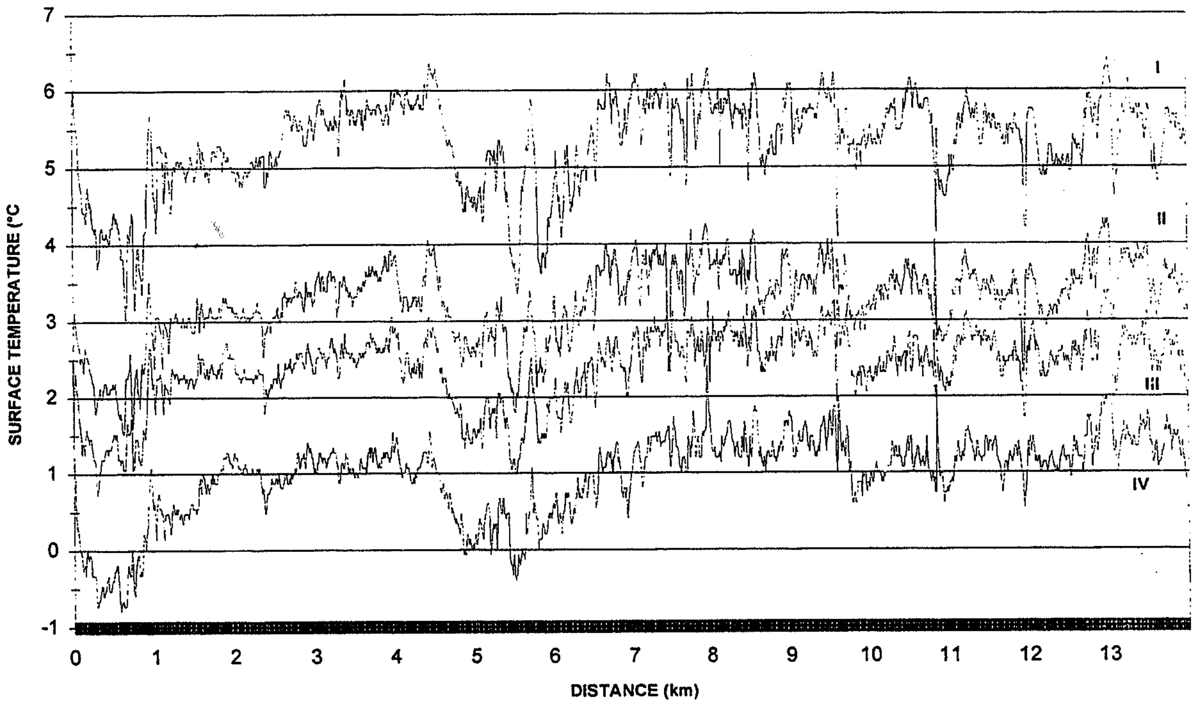

Figure 2. Surface temperature measured on 4 occasions (I to IV) during the same night in order to test if the IR-sensors have the capacity to detect the same pattern .

Analysis of thermal mapping recordings

Three main factors can be distinguished determining the road surface temperature,

1 road bed materials,2 radiation, 3 -advection. The heat flow in the road bed is determined by the thermal properties of the material used in the road construction. These factors influence the temperature reaction during cooling as well as during warming up. Information about the type of material used is not always available and therefore it is very important to perform the thermal mapping in such a way that this parameter is covered. An example of the large influence from the construction material is presented in figure 3. The measurement was carried out during a cloudy, windy night along a road stretch with no variation in altitude. The air temperature shows very little variation. The surface temperature gives a totally different signal - large variations occur and these can be attributed to the road bed material used. This

road stretch is a test road and the material is well documented which gives the possibility of a detailed analysis of material and temperature.

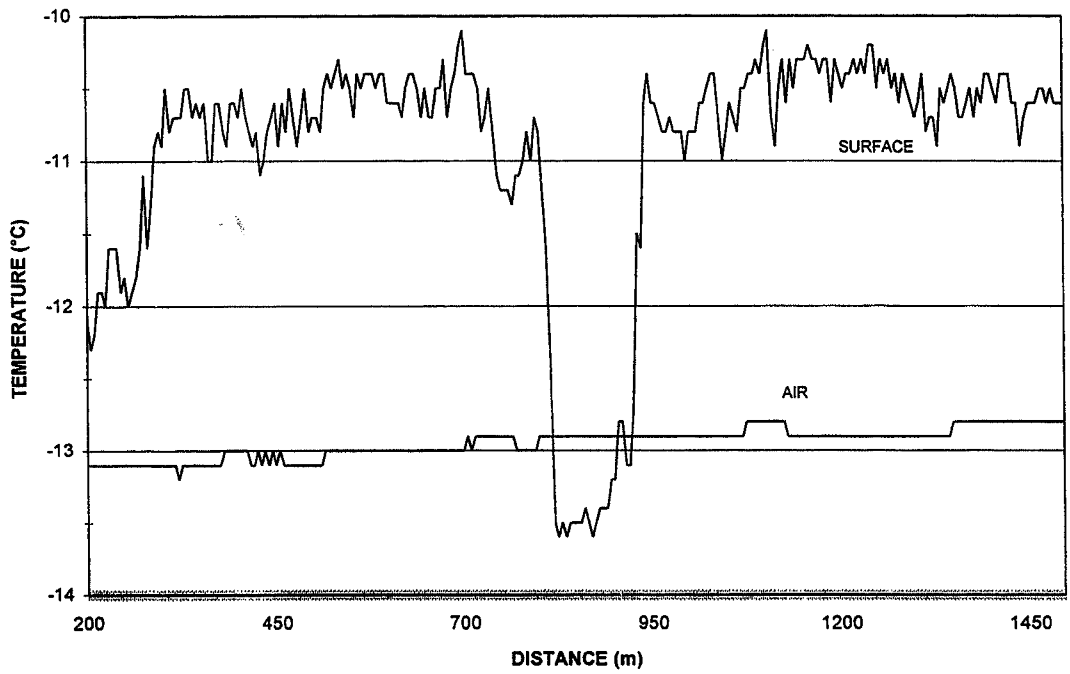

Figure 3. Air and surface temperature measurement along a test road with variation in road-bed material. A iron rich sand, a vast product from mining, is used between 800 to 950 m.

The radiation factor describes the local variation in obstruction of the short and long-wave radiation. Open areas have free inflow of short-wave radiation from the sun during the day. The cooling during evenings and nights can also take place without and disturbance. Day-time measurements give information about the screening effect and the resulting temperature variation between screened and sun exposed areas. The night-time situation can be determined from these types of registration as well, given that the mapping is carried out during late afternoon However, a better way is to measure the radiation by use of sensors.

Advection of air, especially cold air flows, could significantly influence the road surface temperature. By measuring the air temperature at several levels this parameter can be determined. This type of measurement also gives the possibility to analyse the potential risk of road slipperiness with better resolution as the slipperiness is often a combination of the surface and the air/dewpoint temperature.

Conclusions

Thermal mapping is a very useful technique in applied climatological studies. However special attention must be paid to a number of factors during the measurement. This specially holds for the measurement by use of IR-sensors. Especially important is the mounting of the IR-sensor and awareness of the factors controlling the radiation received by the sensor as well as the quality of the type of sensor used. Analysis of the recordings in order to select the most suitable locations for field stations in a RWIS is also an important task. It is very important that all parameters that controls the road surface temperature are measured in order to interpret the recordings.

Acknowledgment.

This study was supported by the Swedish National Road Adminstration.

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