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Influence of the accumulated screening effect on road surface temperature distribution

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ABSTRACT

In winter time, ice or snow is easily formed at road surface, especially at sites that are usually screened. During daytime, the effect of screening often causes extensive road surface temperature (RST) difference. Temperature of the screened sites is usually found to be much lower than the sun-exposed sites, which often leads to slippery conditions in winter time. The screening effect at a certain moment is often found to be influential. In this study, a new view of the influence of the screening effect, the accumulated screening effect from sunrise to a certain moment, has been adopted to understand the accumulated influence of the screening effect. With a 2m resolution LIDAR dataset and 11 thermal mapping measurements during day time, GIS based shadow approach has been used to generate the screening pattern for the roads every half hour and the influence of the accumulated screening effect on maximum RST difference has been analyzed. Results show that the calculated maximum RST difference is 92% correlated with result using previous empirical approach. GIS based shadow approach is found to be reliable in describing influence of the accumulated screening effect on maximum RST difference. The result of this study is expected to be used in the route-based prognosis of road surface temperature.

Keywords: road surface temperature, accumulated screening effect, shadow approach, GIS

1 INTRODUCTION

To plan winter road maintenance in an efficient way, high quality prognosis of road surface temperature (RST) and condition is demanded. With the help of reliable prognosis, the winter road maintenance engineers can make plan for salting or gritting road and work under less stress. In 2011, the Swedish Transport Administration started a project named as "Development of model for prognosis of temperature and slippery condition". The main aim of the project is to develop a RST forecast model which suits the Swedish weather condition. The model is a pre-existed model- Support System for Winter Maintenance (SSWM), which is based on an energy-balance model-METRo. RST is influenced by many different parameters, including meteorological, road construction and geographical parameters (White *et al.*, 2006). SSWM has been improved by including different geographical parameters that influences the distribution of RST. Of them, the screening effect is an important one. The screening effect influences the road surface temperature mainly by blocking the direct radiation to the road surface. Previous studies mainly focus on the influence of the screening effect at a certain moment or the lagged effect on RST after sunset. The current study takes another view to look at the screening effect- the accumulated screening effect from sunrise to a certain moment during daytime. By comparing with the previous empirical approach, the main aim of this study is to: (1) evaluate the GIS-based shadow approach in describing the screening effect; (2) evaluate the accumulated concept in modelling the maximum RST difference along the road.

2 Study area and data

The study was conducted in two areas, one is the country roads near city Borås, and another is the motorway to the north of city Uddevalla, Sweden. Both areas were chosen to cover different types of roads and environment.

In total 11 thermal mapping measurements were carried out to collect the RST along the experiment roads. The spatial resolution was 30m. During the measurement, different time and weather conditions were covered. Table 1 shows the detail description of all the measurements. Two measurements with high cloudiness amount were also included to cover the influence of different weather conditions.

Date	*time*	*weather*	*Cloud height*	*Cloudiness amount (okta)*	*Solar elevation*
2012-01-23	14:00	Partly cloudy	low	7	9.99
2012-02-01	10:00	Partly cloudy	high&middle	3	9.54
2012-02-09	10:00	Partly cloudy	high	6	11.76
2012-02-09	14:00	overcast	low	8	14.72
2012-03-02	10:00	clear	/	0	19.31
2012-03-02	14:00	clear	/	0	22.19
2012-03-06	10:00	Partly cloudy	high	4	20.83
2012-03-06	14:00	Partly cloudy	high	4	23.63
2012-03-06	17:00	Partly cloudy	middle	3	5.92
2013-03-11	12:02	clear	/	0	27.54
2013-03-11	13:55	clear	/	0	24.95

Table 1. Thermal mapping measurements used in this study.

Observation from road weather information system (RWIS) stations was used to remove the time trend of thermal mapping data.

To model the screening effect, it is important to obtain the land use environment and the corresponding height. With the development of Lidar technology, it is possible to get high resolution Digital Surface Model (DSM), which contains both land use and height information. In this study, Lidar data with 2m resolution was used to model the screening effect along the road. Figure 1 shows a map of the Lidar data in the study area and an example of the screening effect. Buildings, trees, roads and forest are easily identified in the Lidar data and the corresponding height is also recorded. Based on the Lidar data, the screening effect map clearly shows the shadow pattern of each object on the surface. Road stretches that are either screened or sun-exposed are easily identified.

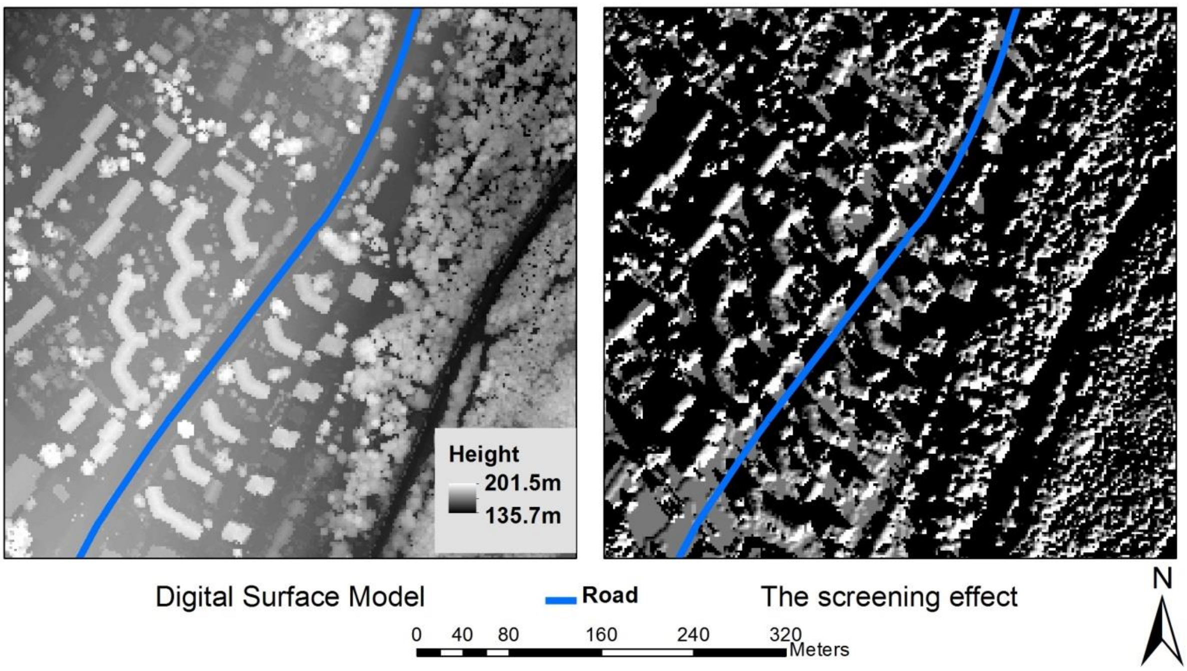

Figure 1. An example of the lidar data and the sreening effect.

3 Theoretical approach

3.1 Circumstance for observation of significant influence of the screening effect

Influence of the screening effect is important information for prognosis of RST, thus it is usually included in the models for RST. However, the influence of screening effect on RST is not always significant and is affected by both time and solar elevation (Bogren, 1991). It has been shown that the influence of the screening effect increases with increasing solar elevation. The presence of cloud will decrease the influence of the screening effect, instead influence of other parameters becomes more important, such as altitude. Previous study (Bogren, 1991) has shown that to observe slippery condition caused by the screening effect, the time need to be at least from late January in Sweden and the cloudiness amount should be less than 6 octas.

3.2 Empirical approach for calculation of the maximum RST difference

Previously, the influence of the screening effect on the maximum RST difference between sun-exposed and screened sites can be calculated by using an empirical formula by Bogren *et al.* (2000a). The relationship is expressed as:

$$RST_{diff} = -2.7 + 0.46\beta \tag{1}$$

Where RST_{diff} is the maximum RST difference and $\beta \geq 5.87$ is the maximum solar elevation during a day.
The empirical formula is first developed for calculation of the maximum RST difference between sun-exposed and screened sites during a clear day, when the solar elevation reaches the maximum value. Since solar elevation not only changes daily, but also annually, the formula can be also extended to any time of a day until sun reaches the maximum height. After noon time, RST starts to decrease and the influence of the screening effect is more complicate to model. Another circumstance for the application of the formula is that the sites for comparison should always be sun-exposed or screened from sunrise to the moment of interest.
Formula (1) is only valid during clear conditions. For partly cloudy conditions, the maximum RST difference between sun-exposed and screened sites is influenced by both solar elevation and the cloudiness amount (Bogren *et al.*, 2000b). The function is expressed as following:

$$RST_{diff} = \frac{-2.7+0.46(\beta)}{(1-0.75(N)^{3.4}} \tag{2}$$

Where N is the cloudiness amount.

3.3 GIS-based shadow approach for calculation of the maximum RST difference

Before, the influence of the screening effect at a certain moment is usually studied. In this study, the definition-the accumulated screening effect from sunrise to a certain moment during daytime is adopted. With the development of Geographical Information System (GIS), it is possible to model the screening effect at a certain moment in GIS environment using Lidar data (Figure 1). By automating the process, the shadow status of a site is generated in GIS, and thus the accumulated screening effect is calculated for each road stretch. Road segments that are always sun-exposed or screened are identified. Combining with thermal mapping measurements, the average anomaly of RST are calculated for sun-exposed segments and screened segments separately. Then, maximum RST difference between sun-exposed and screened sites caused by the accumulated screening effect is calculated. The study result is compared with the result by using the empirical approach. Since the thermal mapping measurements covers different time of a day, formula (1) and (2) are assumed to be suitable to use during a whole day time, under the condition that $\beta \geq 5.87$.

4 Result and discussion

Using the empirical approach and the GIS-based shadow approach, the maximum RST difference between sun-exposed and screened road stretches has been calculated separately and the relationship between them is shown in Figure 2. The results calculated by two methods are 92% correlated with each other and the mean absolute error is 1.3˚C. The high correlation between the results from two methods shows that the GIS-based shadow approach is a reliable method to model the screening effect along the road. The high resolution Lidar data is detail enough to be used for modelling of the screening effect. It is also implied that the accumulated screening effect is a significant parameter in describing the RST difference along the road. By using the accumulated shadow approach, the influence of the weather changes is also accounted. Thus, the influence of earlier clear condition on later overcast condition is possible to be calculated.
Comparing with the results using the accumulated screening approach, the empirical approach tends to overestimate the maximum RST difference between sun-exposed and screened sites. One possible reason is that it is difficult to find road stretches that are always sun-exposed or screened all day along.

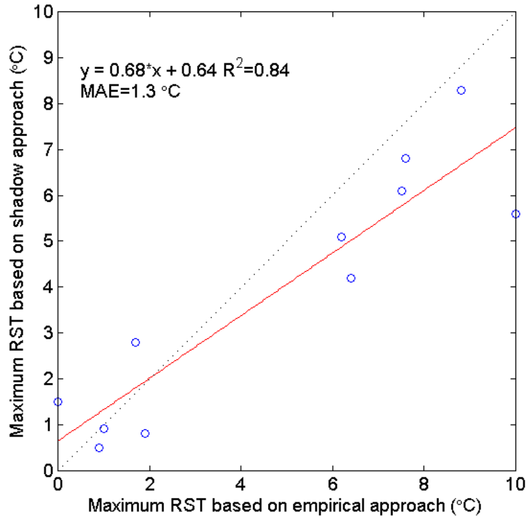

Figure 2. The relationship between the maximum RST difference based on empirical and shadow approach, MAE: mean absolute error.

5 Conclusion

When considering the influence of the screening effect on the distribution of RST, not only the effect at a certain moment is important, but also the accumulated effect. The accumulated screening effect is a significant parameter in describing the RST difference between the sun-exposed and screened sites. GIS-base shadow approach together with high resolution Lidar data is a reliable method to model the screening effect. The result of this study indicates that the accumulated screening effect can be used in the prognosis of the distribution of RST.

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