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REAL-TIME REGIONAL AUTOMATIC MAPPING OF NOCTURNAL WINTER ROAD TEMPERATURES : APPLICATION OF A METHODOLOGY OF ANALOGOUS SITUATIONS, THE CASE OF THE WALLOON REGION (BELGIUM)

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1. INTRODUCTION

The temperature of the road surface, as that of any other material object, varies in relation to the thermal conductivity of its upper layers. This temperature also depends on the relationship between the energy absorbed and the energy lost by that surface at any given time. For objects exposed to the vicissitudes of the atmosphere, this relationship may change seasonally, monthly or daily. The road surface temperature, therefore, varies not only in accordance with local topoclimatic variables and the environment near the road; it also varies in accordance with the radiative properties of the road, its texture and the roughness of the road surface. Furthermore, we must not neglect the influence of the physical characteristics of the foundations (thickness, nature, compactness, bedding and grain size of the materials used). (see bibliography)

Due to the very wide vertical and longitudinal variability of the road characteristics, one must know the exact temperature of the surface combined with the meteorological parameters. To these ends, it is necessary to turn to a spatial temperature model based on similar reactions, systematically catalogued for extreme nocturnal atmospheric situations in the second part of the night (for calm, radative weather on one hand, and overcast, windy weather on the other).

Great attention was paid in collecting precise yet comprehensive radiance temperatures along roads. Measurements were made using a mobile vehicle. They were taken at a frequency of 2 Hz, only when the vehicle was moving.

2. THE CASE OF THE WALLOON REGION

The climate of Wallonia (area 16,844 km^2) (Aexandre et al., 1992, Erpicum, 1986 and 1989 and Funcken et al., 1995), a region in the south of Belgium straddling the 50°N parallel and endowed with undulating relief (altitude varying from 20 m to 695 m), is a significant burden in winter, as far as maintaining the flow of roadway and highway traffic and security is concerned (Erpicum, 1998). The Walloon administration (Ministry for Equipment and Transport: MET – DG1 and DG4) responsible for organising the winter service and technical equipment infrastructures, invested in the setting up of a sophisticated and telemeasured road-meteorological surveillance system in 1993 (MET, 1997). Two years later, this network is endowed with a multi-user nocturnal thermal road surface mapping system that may be consulted in real time from October 15th until April 15th. The temperature of the entirety of the roadway and highway networks has therefore been mapped and, since then, the maps have been reviewed each year according to environmental changes in the vicinity of the roads or whether the road surface has been replaced (about 5% of the road network each year).

Frequent road temperature fluctuations are observed on either side of the 0°C isotherm in this region. These are combined with a high frequency of hydrometeors and a wide spatial and temporal variability of night-time cloud cover. It was therefore thought necessary to use a mapping system developed according to the average temperature obtained after 500 m to 1000 m sections had been generalised and georeferenced with the kilometre markers of the road network. Very cold temperatures (in other words road temperatures less than or equal to -5°C), temperatures close to 0°C (comprised of three classes: -3°C to -1°C,-1°C to +1°C and +1 to +3°C) and clearly positive temperatures (surface temperatures greater than or equal to 3°C) require different levels of vigilance from the winter service and make up the 5 temperature classes.

The mapping system in question covers 836 km of motorways and 512 km of express roads (in both traffic directions) and 6,777 km of regional

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roads, which shall soon be joined by provincial roads.

In short, the spatial resolution of the maps is in kilometres and is georeferenced with regard to the position of the official kilometre markers, accurate within a turn or two of the vehicle's wheel. The standard error of the road temperature mapped is to the order of one degree Celsius. Places whose localised temperature is 2°C below the average of the kilometre long segment being considered are determined within a wheels turn or two. A data base of thermal road surface information is made in steps of 500 m or 1000 m with five successive layers of information (the average value and the significant minimal value of "relative temperatures" for radiative type weather and windy, overcast type weather respectively; and the average temperature values for the intermediary types of weather).

3. METHODOLOGY AND RELEVANCE OF ROAD SURFACE THERMAL FINGERPRINTS

The mobile recording of radiance temperatures of the longitudinal road axis was carried out between the wheels of the vehicles, on the right hand lane of the road, using a programmable radiothermometer. Naturally, the simultaneous movements of the vehicle were also precisely measured, together with a series of complementary data: the radiative balance, the air temperature at 2 m and 20 cm from the road surface and the atmospheric pressure (altimeter).

3.1 *Reproducibility of thermal road surface fingerprints in similar types of weather*

The reproducibility of road surface radiance temperature measurements was verified for similar types of weather in order to support the use of thermal mapping based on analogous situations. Figure 1 consists of a 10 km road sample covered on two different occasions under similar atmospheric conditions. This double graph highlights how the thermal behaviour of the road surface may be reproduced in calm radiative weather between midnight and sunrise. This characteristic point is detected during the two mobile campaigns. Furthermore, a zone a little over 1 km long, between 4 and 5.2 km on the horizontal axis, is almost a degree colder than the average of the road section analysed. When the average temperature of a road is near freezing point, this road is more dangerous and should be closely monitored by winter service agents. The very wide variability of a longitudinal profile of thermal behaviour shows how there may be great road surface temperature differences from one place to another and how this behaviour should be modelled using the method of analogies in similar weather conditions.

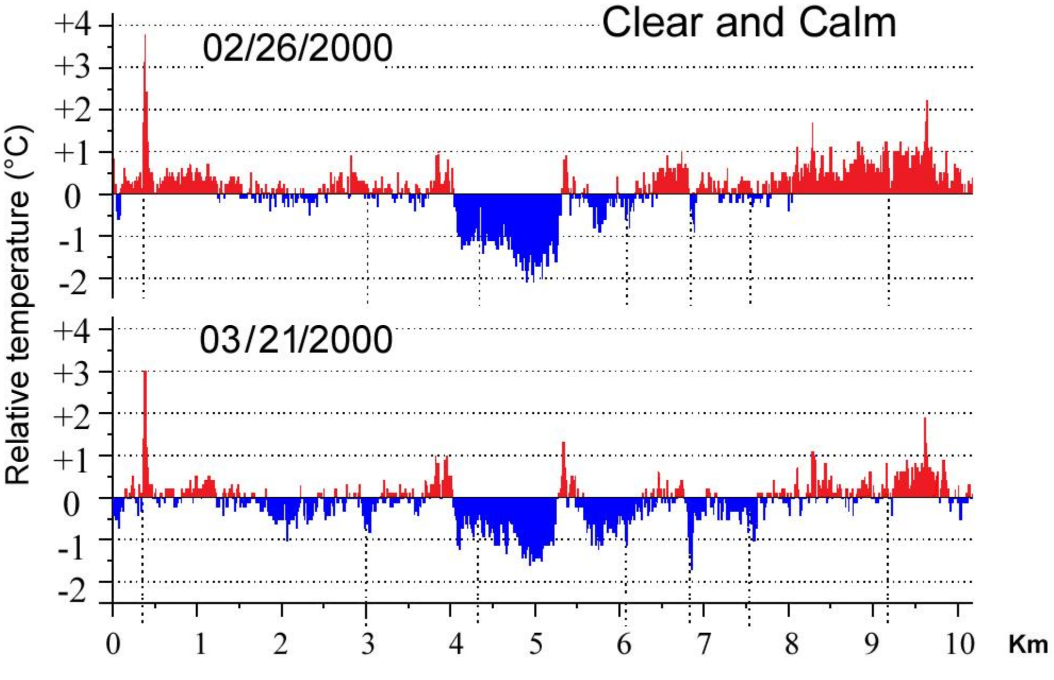


Figure 1 : Comparison of thermal fingerprints by radiative weather

3.2 *Thermal road behaviour and weather types*

Erpicum (2004) analysed the distinction between radiative and advective weather types. Furthermore, Erpicum et al. (2000) had previously shown how atmospheric conditions have a major effect on the thermal behaviour of the air and of roads. Figure 2 presents a sample of two thermal fingerprints of roads obtained for contrasting weather conditions: calm and radiative weather and overcast and windy weather (see the upper part of figure 2, drawn with the same conventions as figure 1). The central part of figure 2 illustrates the topographic profile of the road and documents the principal points of reference of the road environment. The lower part of this figure consists of the legend of road descriptions. The legend common to all road surveys conducted (that is to say over 9,000 km for each of the two types of extreme weather conditions) is much better documented.

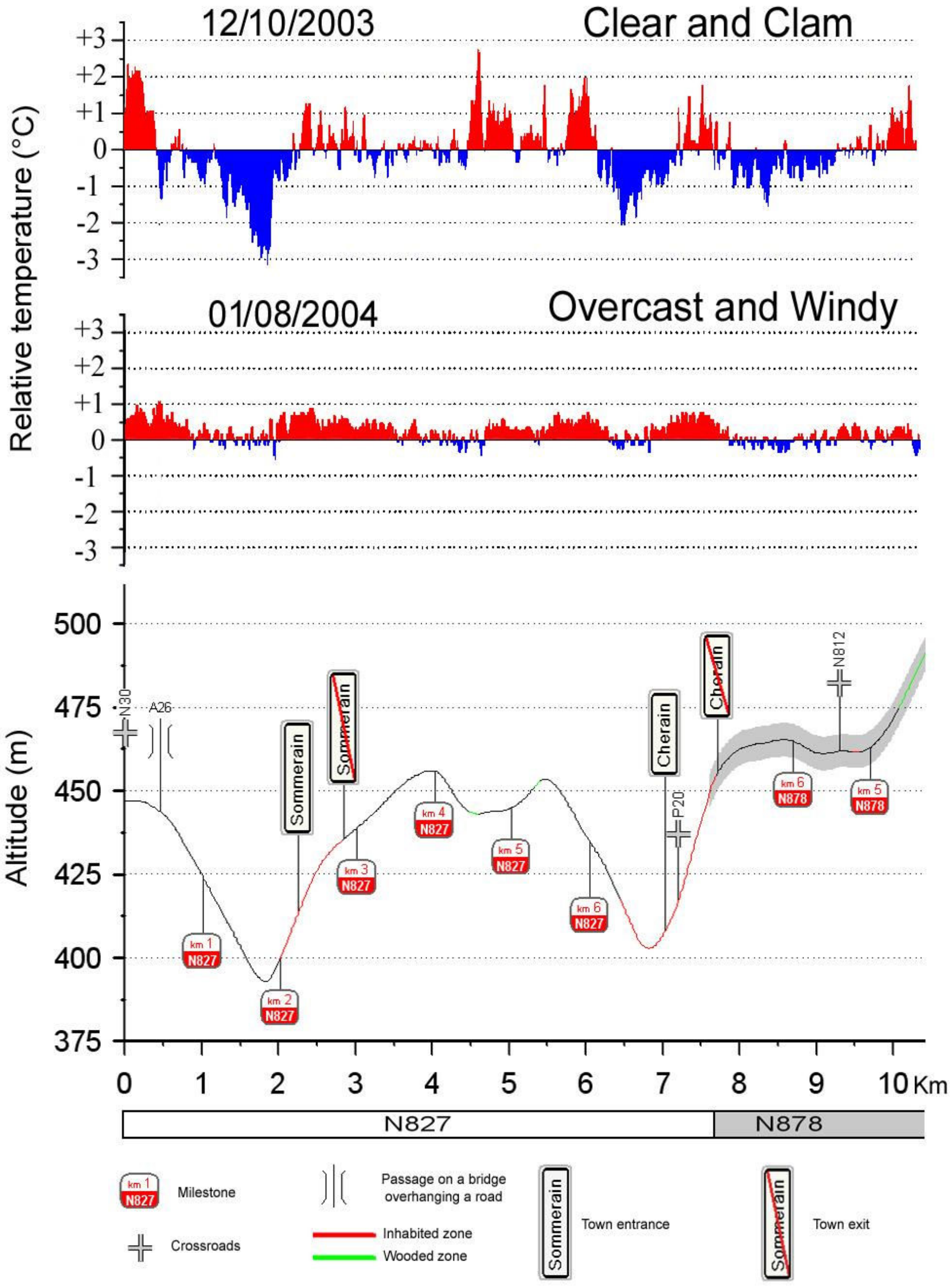


Figure 2: Comparison of thermal fingerprints by types of radiative and overcast weather

Figure 2 confirms that, in radiative weather conditions, thermal contrasts on the roadway and highway networks are much greater and sometimes even behave in the opposite fashion to those observed in overcast weather. It was therefore necessary to take account of the spatial variability of the cloud cover over the entire Walloon territory in order to successfully map the road surface temperatures in real time, both automatically and dynamically.

3.3 *Methodology and elaboration of thermal reference maps*

The thermal data for roads obtained for the purest types of extreme weather (radiative weather and overcast weather), undisturbed by synoptic advection were recorded on different dates throughout the course of successive winter periods (from November 15th to March 15th) and at different times throughout the night (from midnight until sunrise). This state of affairs therefore required one sole reference time (6 o' clock in the morning) for all of the thermal fingerprints collected, which could be transposed to the entire Walloon region.

To meet this requirement, night-time cooling curve recorded for the elaboration of thermal fingerprints (reference data for thermal reference maps) needed be as regular as possible. The temperature surveys for each elementary segment of the reference map were extrapolated to 6 o' clock in the morning. This was on condition that the coefficient of determination for the best adjustment to the parabolic equation applied to the series of road surface temperatures (made at 6 minute intervals throughout the night in question (Erpicum et al. 1998) at the level of the three M.E.T principal road-meteorological stations (PRMS) nearest the kilometre road marker which serves as a georeference) were greater or equal to 0.95. These extrapolations at 6 o' clock in the morning were weighted by applying the following weighting coefficients to the differences in temperature observed between the time that the temperature was recorded on each elementary road section and 6 o' clock in the morning:

$$p_i = \frac{\frac{1}{Di}}{\frac{1}{D1}+\frac{1}{D2}+\frac{1}{D3}} * 100$$

***pi** = weighting for the PRM station to the order of i*
***Di** = distance to the PRM station to the order i of proximity*
*For **i** varying successively from 1 to 3 (order of proximity)*

3.4 *Elaboration and verification of thermal mapping in real time*

Thermal maps in real time may be made at any period of the night in winter by taking account of the effective cloud cover in the preceding hour, which is estimated from the automated interpretation of thermal infrared radiance measurements from the sky and the road surface of the right-hand lane at PRM stations of the M.E.T. network. Three categories of effective nebulosity may be distinguished: clear skies or a veil of high altitude cirrus cloud (radiative weather), skies with medium level discontinuous cloud cover or thin cloud layers that are not in contact with the ground (intermediate type weather) and very overcast skies with low cloud or fog (non-radiative type weather).

The temperature of each elementary road segment is interpolated by applying the same weighting factor as in section 2-3, to the relative temperature values obtained at the three nearest PRMS whose zone of influence covers the elementary road segment in question.

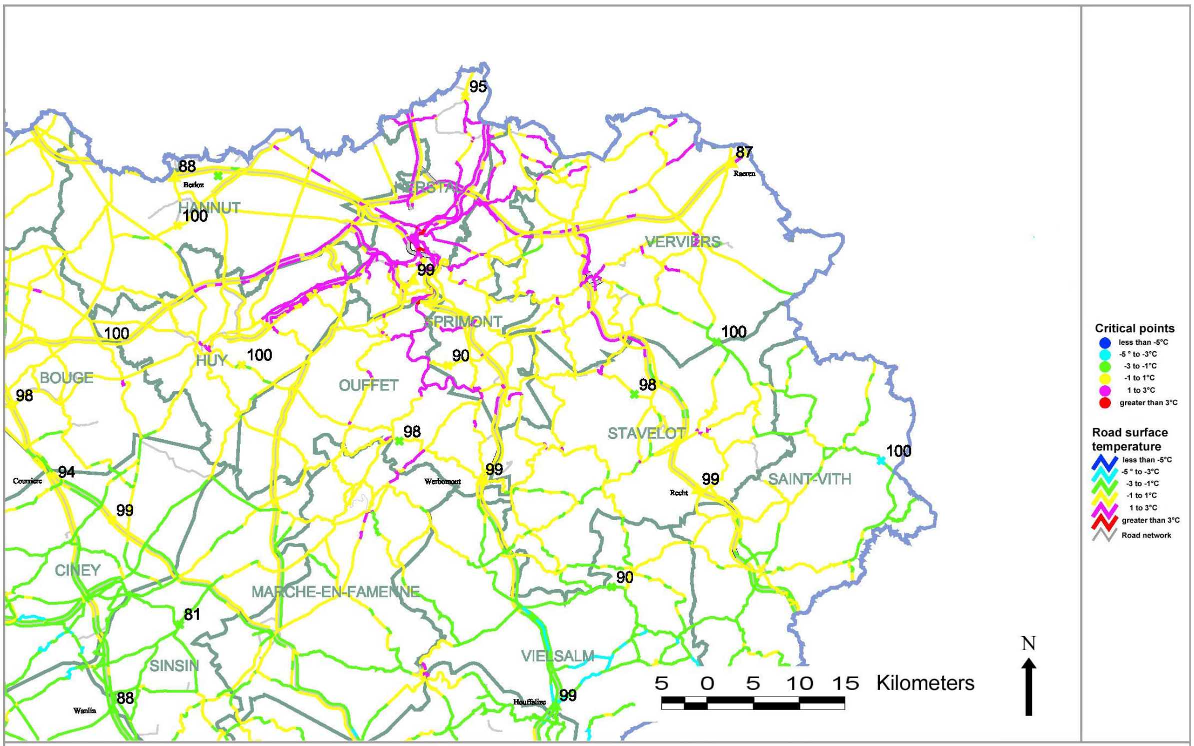
The quality of the maps is verified by comparing the localised road surface temperature values at the level of the 35 operational meteorological stations (OMS) (multiplication sign coloured in the shade representing the temperature class at the position of these stations on figure 3) to the temperature values modelled on the road sections of 500 m to 1000 m which correspond to these stations.

To recap, thermal road mapping, which is presented here (figure 4 and 5) is designed according to five temperature classes with a 2°C range and centred on 0°C. These temperature classes were adapted in the interest of being easily readable and in order to provide a synthesis of necessary thermal information for the criteria of the winter service, criteria which were established in collaboration with the accompanying committee of the project. However, quality control tests which were performed beforehand in a laboratory on the three reference maps were made using 1°C range temperature classes.

Instantaneous thermic cartography
Full road and motorway network
March 11th, 2004 at 05h48 am

Raeren	Intermediate	-3.6°C(S1)	Arlon	Intermediate	-0.7°C(S1)			
Recht	Intermediate	-2.1°C(S1)	Wanlin	Intermediate	0.2°C(S1)			
Houffalize	Clear and Calm	-3.9°C(S1)	Mariembourg	Intermediate	-0.2°C(S1)	Estaimpuis	Intermediate	2.5°C(S1)
Werbomont	Intermediate	-1.6°C(S1)	Courrière	Intermediate	0°C(S1)	Ittre	Intermediate	1.4°C(S1)
Berloz	Intermediate	0.4°C(S1)	Charleroi	Intermediate	0.8°C(S1)	Liège	Intermediate	0.3°C(S1)
Neufchateau	Intermediate	-1.5°C(S1)	Hautrage	Intermediate	1.6°C(S1)	Papignies	Intermediate	0.6°C(S1)

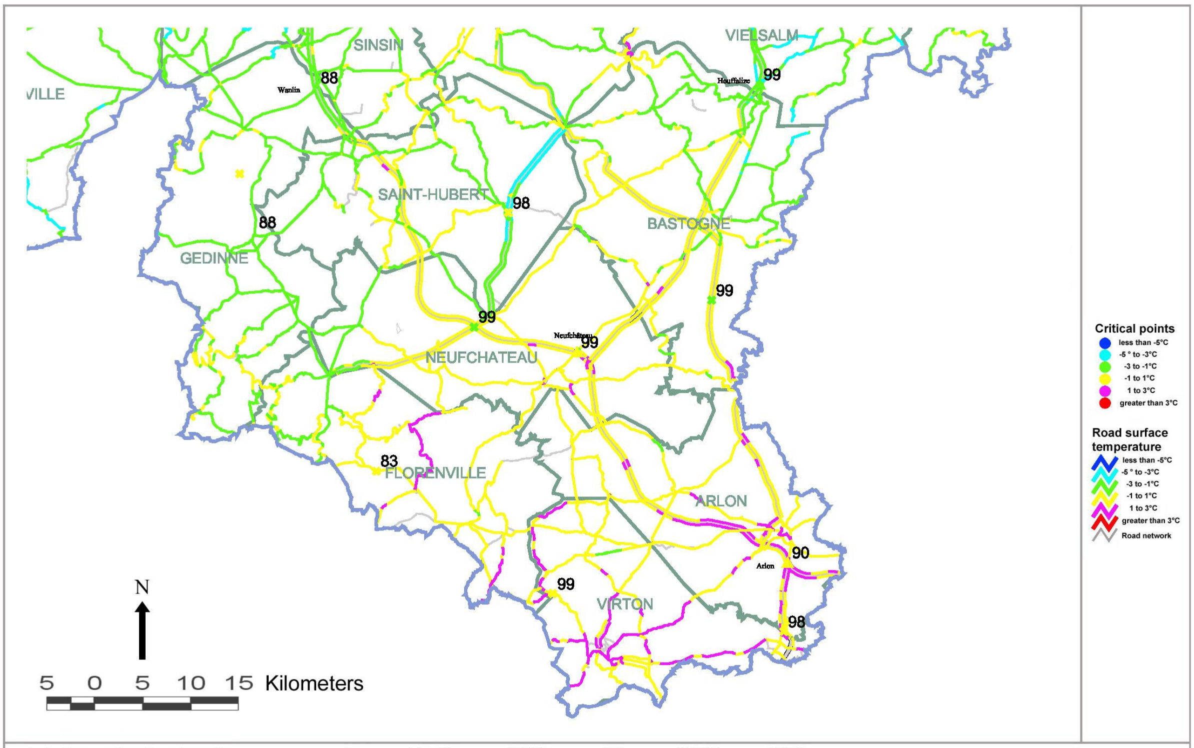
Figure 3 : Real time mapping, Walloon Region, march 11th, 2004 at 05h48 am



Instantaneous thermic cartography
Full road and motorway network
March 2nd, 2004 at 05h42 am

Raeren	Intermediate	0.9°C(S1)	Arlon	Intermediate	0.7°C(S1)			
Recht	Intermediate	-0.1°C(S1)	Wanlin	Intermediate	-1.4°C(S1)			
Houffalize	Intermediate	-1.4°C(S1)	Mariembourg	Intermediate	-2.5°C(S1)	Estaimpuis	Intermediate	-0.3°C(S1)
Werbomont	Intermediate	0°C(S1)	Courrière	Intermediate	-0.3°C(S1)	Ittre	Intermediate	-1.1°C(S1)
Berloz	Intermediate	-0.2°C(S1)	Charleroi	Intermediate	-0.9°C(S1)	Liège	Intermediate	0.3°C(S1)
Neufchateau	Intermediate	0°C(S1)	Hautrage	Intermediate	-1.1°C(S1)	Papignies	Clear and Calm	-0.9°C(S1)

Figure 4 : Real time mapping, zoom on the region of Liège , march 2nd, 2004 at 05h42 am



Instantaneous thermic cartography
Full road and motorway network
March 2nd, 2004 at 05h42 am

Raeren	Intermediate	0.9°C(S1)	Arlon	Intermediate	0.7°C(S1)			
Recht	Intermediate	-0.1°C(S1)	Wanlin	Intermediate	-1.4°C(S1)			
Houffalize	Intermediate	-1.4°C(S1)	Mariembourg	Intermediate	-2.5°C(S1)	Estaimpuis	Intermediate	-0.3°C(S1)
Werbomont	Intermediate	0°C(S1)	Courrière	Intermediate	-0.3°C(S1)	Ittre	Intermediate	-1.1°C(S1)
Berloz	Intermediate	-0.2°C(S1)	Charleroi	Intermediate	-0.9°C(S1)	Liège	Intermediate	0.3°C(S1)
Neufchateau	Intermediate	0°C(S1)	Hautrage	Intermediate	-1.1°C(S1)	Papignies	Clear and Calm	-0.9°C(S1)

Figure 5 : Real time mapping, zoom on the province of Luxembourg , march 2nd, 2004 at 05h42 am

4. CONCLUSIONS

The thermal mapping of roadway and highway networks is the result of much collaboration between the delegates of the M.E.T. administration, Cap Gemini (1998) and the authors. This project has proved highly satisfactory for the agents of the M.E.T. Furthermore, thermal mapping has allowed salt spreading to be reduced, while contributing to the improved organisation of the winter service operations.

One should keep in mind that spatial and temporal variations in effective cloud cover (holes in cloud layers, cloud layers at different levels, movement of cloud zones throughout the night...) have a significant influence on road surface temperatures. Nights with homogenous cloud cover over the entire Walloon territory are very rare. However, many nights require the availability of a dynamic thermal mapping system, such as that presented in this paper, which has dealt with the surface cooling rate of 9,000 km of road, mapped in real time throughout the course of the night.

Our research continues in the hope that the mapping system may be improved even further in the future.

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We would also like to thank the members of the accompanying committee who worked tirelessly in improving the road-meteorological system, especially the co-presidents R. Druart (†) and A. Prevot and the officials and numerous special agents (for their enlightened advice and perceptiveness), the directors of Road Data (D.114), Coordination of Road Information (D.115), Road Maintenance (D.121) and the Electrical, Electromechanical and Telecommunications Division of the M.E.T. (D.451, D.452, D.453, D.454, D.455, D.456).

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