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Thermal Mapping Data for Verification of the Overall Performance of the DMI-HIRLAM Road Weather Modelling System


Snerydning
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Alexander Mahura[1], Claus Petersen[1], Bent Sass[1], Peter Holm[2]

[1] *Danish Meteorological Institute (DMI), Lyngbyvej 100, DK-2100, Copenhagen O, Denmark*
[2] *Danish Road Directorate (DRD), Niels Juels Gade 13, DK-1059, Copenhagen K, Denmark*

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Author(s):
Alexander Mahura, Claus Petersen, Bent Hansen Sass, Peter Holm

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Abstract

In this study, the vehicles measurements of the road conditions (road surface and air temperatures - thermal mapping data) from the Ribe Amt Commune VA_4 road of the Jylland Peninsula (Denmark) have been used for verification of performance of the Danish Road Weather Model (RWM) system. During 2005-2006, in total 102 cases/dates with road salting activities have been identified and analyzed by comparing observed and forecasted road surface and air temperatures at 30 selected stretches (situated at distances of 2 km from each other) of the road.

It is found that the RWM system has a good predictive skill for the road surface temperature at the road stretches having a mean absolute error of 0.5-1ºC (bias - less than ±0.5ºC) for all stretches during November-March. For the air temperature, the mean absolute error is within 1ºC and higher (bias - always positive and higher than 0.5ºC). On a diurnal cycle, for the road surface temperature the nighttimes had the best quality of prediction and the score is the lowest during 12-14 h of local time, and vise versa for the air temperature. Only in 10 and 18% of the road activities for the road surface and air temperatures, respectively, the mean absolute error is higher than |±1.5ºC|.

Resumé

I denne rapport er målinger af vejforholdene (luft- og vejtemperatur) fra en vejstrækning i Ribe Amt betegnet VA_4 blevet anvendt til at verificere kvaliteten af DMI’s vejvejr system.

I løbet af glatføresæsonen 2005-2006 er der blevet foretaget saltning/målinger af denne rute i 102 tilfælde og disse er blevet analyseret og sammenlignet med prognoser og målinger fra vejstationer af vej og lufttemperatur. Vejstrækningen er opdelt i 30 dele af hver 2 km længde.

Forudsigelsen af vejtemperatur er velforudsagt med en absolut middel fejl på mellem 0.5-1°C for alle vejstrækninger i perioden november til marts. For lufttemperaturen er middelfejlen indenfor 1°C eller lidt højere (middelfejlen altid positiv og større end 0.5°C). På daglig basis er vejtemperaturen bedst forudsagt om natten og lavest i dagtimerne mellem klokken 12-14 lokal tid. Samme mønster ses også for lufttemperaturen. Kun i 10% og 18% af tilfældene for henholdsvis vej- og lufttemperaturen er den absolutte middelfejl større end 1.5°C.

1. Introduction

The continuous development of more refined numerical weather prediction (NWP) models and increased computer power allow an increasing model resolution and provide more local and accurate forecasts. There are several important issues which should be mentioned. Satellite data for cloud cover are now assimilated and routinely used for the road weather forecasting. Second, a high resolution model is already available, i.e. DMI is using the HIRLAM model of 5 km resolution for the operational daily runs. Also a research version of this model is available with a resolution of 1.4 km (covering territory of Denmark and surroundings). Third, in Denmark, the road services already have started to use observations from vehicles allowing to get additional information on road conditions which can also be used for forecasting purposes. During the winter season, such accurate information on spatial variation of road surface temperature is valuable and important for the road authorities who are making decisions on where and when to spread salt over the road surfaces. The process of recording and quantifying of temperature pattern variations is known as the thermal mapping (done by special infra-red thermometers mounted on vehicles).

This third item is a focus of our study. Such data might improve forecasts of detailed road conditions along road sections/stretches (located at short distances from each other), and especially temperature related, which is provided for the road authorities. This can allow optimizing of the amount of salt spreaded over the road surface to prevent the icing/freezing as well as better planning and timing of the schedule for such operations by the road authorities. And this is important for the safety of road traffic.

Moreover, the road conditions depend strongly on the cloud cover, shadows, precipitation, wind speed, air temperature, and humidity. However, some of these quantities have a large local variability and the road conditions can be affected by changes in these parameters on very short temporal and spatial scales. Because existing model systems do not provide sufficient accuracy for these parameters, it is expected that thermal mapping data can give more detailed information and can improve existing forecasts of road conditions at selected points along the Danish road station network. Therefore, evaluation, forecasting, and verification of road conditions at stretches along the road pathways of the Danish road network using observational data from the road vehicles (thermal mapping measurements) is a focus of our study (as a part of the joint DRD and DMI project entitled “Road Segment Forecasts”).

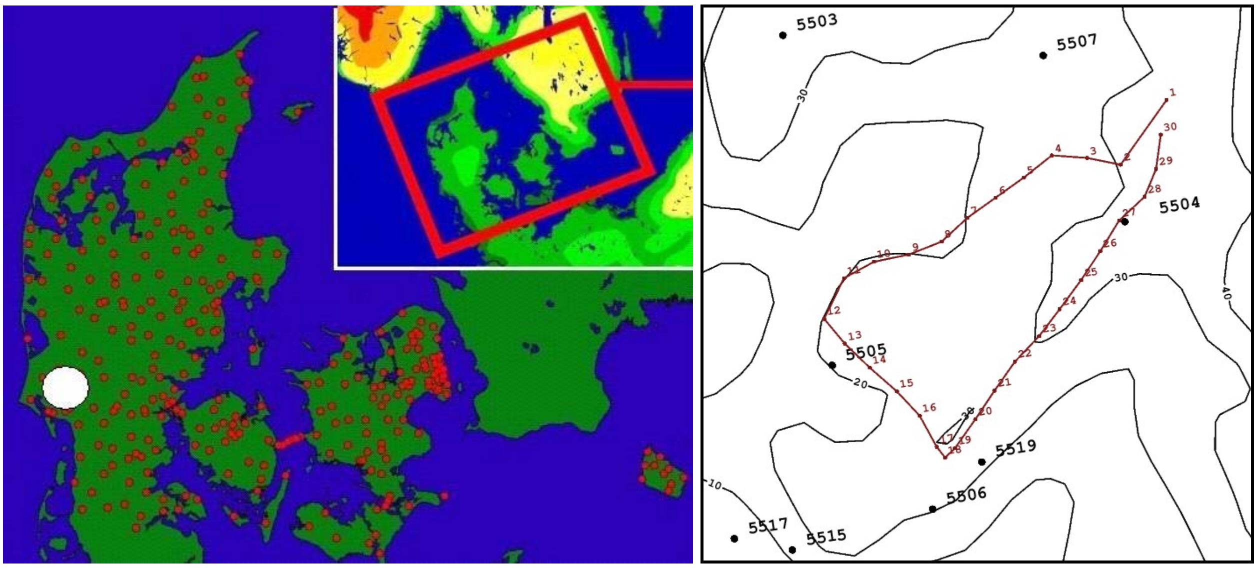
2. Methodology

2.1. Forecasting Using DMI-HIRLAM Road Weather Model System

During the last 15 years the Danish Meteorological Institute (DMI) in cooperation with the Danish Road Directorate (DRD) has developed and used the Road Weather Model (RWM) system. This system provides forecasts of main road conditions at selected locations of the Danish road station network. There are more than 300 stations, where the temperature of the road surface, air temperature and dew point at 2 meters are provided to the customers. These stations are not equally distributed within the road network. Forecasts of road conditions at these points are given every 30/60 minutes based on output from the DMI-HIRLAM NWP model.

The RWM system includes a web based user interface. The main idea is to use road observations from the Danish road stations as input into a numerical model which is designed to predict the road conditions. Essentially, this means the forecasting of the road surface temperature and the accumulated water/ice on the road surface. Data assimilation of road observations gives optimal initialization of the road surface temperature and temperature profile in the soil layer. The meteorological conditions are prescribed based on a 3D NWP model which is a version of the HIgh Resolution

Limited Area Model (HIRLAM). The road conditions model is a 1D model, and it uses meteorological output from the NWP model. The NWP model domain (called DMI-HIRLAM-R) and network of road stations are shown in **Figure 1a**. Detailed description of the road conditions model is given by *Sass (1992, 1997)* and documentation for the HIRLAM model used is provided by *Sass et al. (2002)*. A summary of recent research developments done for the RWM system is given in publications/presentations by *Sass & Petersen (2004); Petersen (2005); Petersen & Sass (2005); Sass et al. (2005, 2006); Petersen et al. (2006abcd).*



(a) (b)

Figure 1. a) DMI-HIRLAM-R RWM system modelling domain with the Danish network of the road stations and b) VA_4 road of the Ribe Amt Commune /located on Jylland Peninsula of Denmark/ with the marked road stretches and road stations.

2.2. Thermal Mapping Measurements

Thermal mapping is a process of measurement of spatial variation of road surface temperature under different weather conditions. The equipment used to make such kind of accurate measurements is an infrared thermometer of a high resolution. In particular, the RoadWatch Safety System (RWSS) temperature sensors are used to measure the road temperature (*RoadWatch SS, Owners Manual*). This device measures temperature within a range from -40ºC to +90ºC with an accuracy of 0.5ºC. The device is mounted on the vehicle at the height that sensor should have a clear sight to the road surface. The measurements are done continuously during the road salting activities at intervals of 100 meters and when the spreader changes settings.

Mostly such measurements are performed during road winter seasons with a focus on nighttimes. Because at this time, differences in temperature across the roads can vary up to several degrees, and hence, some parts of the road can be near or below the icing/freezing point and others - may be not. Note that this pattern and distribution of warm and cold sections is determined by local scale conditions as well as synoptic scale dominating weather conditions. The ice will occur on the surface of the road depending on a balance of energy which the road surface might receive and lose in conjunction with the available amount of moisture.

For each road such balance is affected by complex interactions between various factors including: dominating weather conditions; sky view factor or shadowing effects from, for example, trees, buildings, constructions; height of the road section; geographical location with respect to major water objects; effects of urban areas resulting in building up of so-called urban heat islands; road and traffic related peculiarities; etc. Combination of all these factors will create a unique "temperature fingerprint" for each road. So, thermal mapping procedure recreates a relationship between all these factors and how these interact with each other. A large number of continuous measurements can allow to build temperature profiles which will be unique for each road. From analysis of profiles the thermal maps can be constructed for each dominating weather conditions identifying variations in road surface temperature and underlying possible relative differences, for example, as colored temperature intervals.

2.3. Data Treatment

2.3.1. Original Thermal Mapping Data

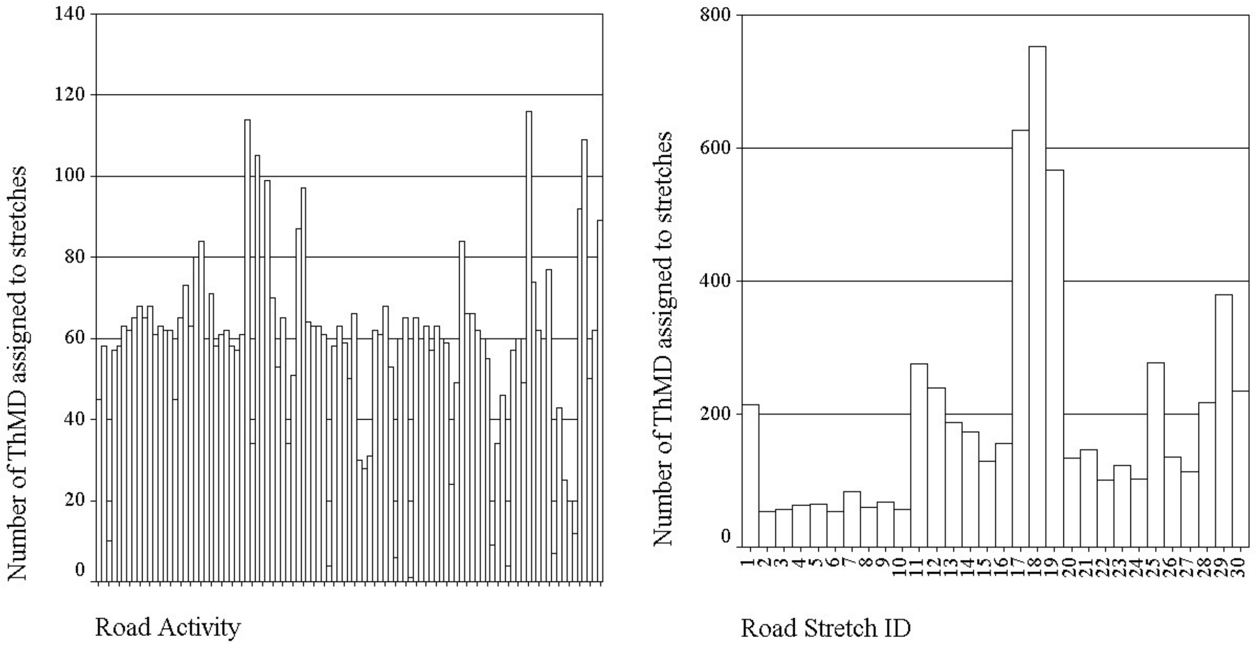
The thermal mapping data has been provided by the Danish Road Directorate (DRD) through the database access using the VINTERMAN software package. The database contains detailed information about number of the driving, measuring, and salting activities' parameters. The focus is on data/measurements of road surface temperature (Ts) and air temperature (Ta) (i.e. a set of so-called the thermal mapping data, ThMD) obtained from special instrumentally equipped vehicles. These measurements are mostly done during days when salt is spreaded along the roads to prevent icing conditions. Note, that these data are irregularly measured depending on the road authority programmes, and the measurements are done at discrete time and space intervals. In our study, the ThMD from the so-called "VA_4" road (**Figure 1b**; Ribe Amt Commune located on the Jylland Peninsula of Denmark) were extracted. For the winter season of 2005-2006, 102 specific cases/dates with the ThMD measurements were identified. The duration of such measurements varied from a few minutes up to 4 hours (with 27 cases having duration of more than 2 hours). The longest data count of ThMD contained 1144 measurements (date of 28 Dec 2005). The highest salted length was approximately 115 km (date of 27 Dec 2005). The average vehicle speed on the road was around 41±3 km per hour.

From these cases, dates with missing measurements of one of the temperatures and missing geographical position system (GPS) coordinates were excluded. Also data were rejected if relative humidity was not presented in the database. After screening, in total **90459** records containing a set of parameters (identificator of road activity; temporal - year, month, day, hour, minute, second; latitude and longitude based on the GPS values, and measurements of the road surface and air temperatures) were extracted from the DRD database.

2.3.2. Time Series of Forecasted vs. Thermal Mapping Data at Road Stretches

Since the thermal mapping measurements are done at non-equal discrete time intervals (due to different velocities of moving vehicle along parts of the road), the temperatures were recalculated by averaging at each 1 minute interval. For each interval the new values of temperatures were reassigned to new interpolated latitude vs. longitude position (which is located exactly in the middle of the road section passed by the vehicle during the same 1 minute interval). This procedure reduced the original dataset into **12611** records. Each new record contained a set of parameters including the same identificator of road activity; temporal - year, month, day, hour, minute; and new - values of averaged temperatures, latitude and longitude; overall changes (as sign) in positions corresponding to initial and final points of driving path; and number of ThMD measurements during each 1 minute time interval (reflecting driving vehicle velocities) used for averaging.

Because our interest is related to verification, at first, of the road surface temperature for the thermal mapping vs. forecasting data, the focus will be only on the road stretches (in total 30 stretches covering a distance of approximately 60 km, see **Figure 1b**; as seen, heights of the road stretches vary between 20-35 meters, i.e. the selected road path can be considered as a relatively flat angled surface). For that, the dataset was subsequently restructured by re-assigning pairs of measured (or observed) temperatures at exact local times when simultaneously measuring and forecasting are done for corresponding locations of the road stretches. In order to build such unified dataset, the DMI-HIRLAM-RWM system recalculated output was used (at each 2 minute interval for all mentioned specific cases). Although recalculations were also tested at 30 and 5 minute intervals, the smallest interval was selected in order to include all possible available thermal mapping data into the verification procedure. Moreover, it was also found to be the most useful for the road stretches situated at 2 km distances from each other. Hence, in total only **5844** records were corresponded to 30 road stretches. From these, 2654 were identified in the year of 2005, and 3190 – in 2006. In this final dataset each record contained the following set of parameters: identificator of road activity; temporal - year, month, day, hour, minute; identificator of the road stretch (1-30) with corresponding latitude and longitude as well as the forecasted and observed/measured road surface and air temperatures. The overall distribution of available records by the identificators of the road activities and road stretches is shown in **Figure 2ab**. Note, from 102 cases – 7 cases had less than 10 ThMD measurements assigned to the stretches; 4 cases were presented by more than 100 ThMD measurements assigned to the stretches. These cases are the road salting activities N-55001753, N-55001793, N-55003816, and N-55004154 carried out on 27 Dec 2005, 28 Dec 2005, 28 Feb 2006, and 6 Mar 2006, respectively. As seen, the largest number of ThMD was obtained at the stretches 17, 18, and 19, and hence, this part of the road, probably, represents the highest concern for the salting activities.



(a) (b)

Figure 2. Distribution of the thermal mapping measurements as a function of the road a) salting activities and b) stretches.

2.3.3. Time Series of Road Station Observations vs. Thermal Mapping Data at Road Stretches

For the same selected dates of the road conditions forecasting season of 2005-2006, the temperatures of the road surface and air measured at three Danish road stations have been also compared with the thermal mapping data from the road stretches. The corresponding stretches were selected based on the shortest distances from the road stations located near the VA_4 road. So, the stretch 13 is the closest to the road station 5505; and 18 and 27 are the closest to the road stations 5519 and 5504, respectively (**Figure 1b).**

In total, the original dataset for the road stations consisted of **40325** records containing measurements of the road surface and air temperatures for the same corresponding temporal intervals of 2 minute. The ThMD dataset contained **12611** records. From these both the corresponding time series has been constructed based on the ThMD measurements and road stations measurements. For the selected 3 road stations only **680** records were assigned as measurements' pairs of the ThMD vs. road station data: 59, 67, and 554 for the road stations 5504, 5505, and 5519, respectively. This time series has the same structure as in 2.3.2, except that the temperatures of the road surface and air are represented by interpolated measurements at three road stretches vs. road stations along the studied road.

2.3.4. Evaluated Parameters

For tasks of the road segment forecasting it is important to predict temperature conditions leading to salting activities organized by the road authorities. At the same time, the RWM system should be capable to predict common typical meteorological situations as well as relatively rare events, such as heavy rain/snow conditions. Evaluation of the DMI-HIRLAM-RWM system forecasting performance was done by analysis of the mean absolute error, *MAE* and bias, *BIAS* for both temperatures : the road surface temperature (*Ts*) and the air temperature (*Ta*). The MAE and BIAS have been estimated using the following equations:

$$MAE = \frac{1}{N}\sum_{i=1,N}\left|T_{f_i} - T_{o_i}\right|,$$

$$BIAS = \frac{1}{N}\sum_{i=1,N}\left(T_{f_i} - T_{o_i}\right),$$

where: *N* is the number of pairs (interpolated measured ThMD value and forecasted value at the road stretch) or total number of observations/measurements, *i* denotes the i^{th} observation/measurement, T_f and T_o are the forecasted and observed values for temperatures, respectively.

For bias, the positive difference sign shows over prediction (i.e. the forecasted value is higher compared with observed), and the negative – under prediction (i.e. the forecasted value is lower compared with observed) of temperatures compared with observed value.

For both observed/measured temperatures from the road stations and thermal mapping data the value of mean of deviation between observed temperatures was estimated using the following equation:

$$MD = \frac{1}{N}\sum_{i=1,N}\left|T_{Orst_i} - T_{Othmd_i}\right|,$$

where: *N* is the number of pairs (interpolated measured ThMD value at selected road stretch and measured at the road station) or total number of observations/measurements, *i* denotes the i^{th} observation/measurement, T_{Orst} and T_{Othmd} are the observed values for temperatures based on the ThMD and road station measurements, respectively. Note, that large consistent deviations may reflect instrumental errors.

Evaluations of these parameters were done as a function of the road stretch identificator, road activity, by month, by year, and on a diurnal cycle.

3. Results and Discussions

3.1. Spatial and Temporal Variability of Thermal Mapping vs. Forecasting Data

Evaluation of the RWM system forecasting performance (employing DMI-HIRLAM NWP model with a horizontal resolution of 15 km; note, 5 km – in 2007) was done by analysis of mean absolute error (**Figure 3 and 4**) and bias (**Appendix A**) for both *Ts* and *Ta* as difference between the forecasted and observed values. In terms of MAE and BIAS the overall *Ts* and *Ta* verification scores for the studied period were good. For the entire dataset: for *Ts* the MAE and BIAS were 0.82 and 0.05ºC, respectively; for *Ta* these were 1.03 and 0.75ºC, respectively.

Detailed analysis by road stretches (**Figure 3a, Figure A1a**) showed that the RWM overall performance to forecast *Ts* is good and the mean absolute error at 95% confidence interval is within a range of 0.5-1ºC (and the bias is less than ±0.5ºC) for all stretches. The part of the VA_4 road between the stretches 9 and 22 is characterized by the higher MAE (i.e. more than 0.8ºC, with a maximum of 1ºC for the road stretch 11) compared with other parts of this road. For *Ta*, it always showed over prediction: MAE was around 1ºC and higher (BIAS was around +0.5ºC and higher). On an interannual scale (**Figure 3b**), the MAE was 0.8-0.9ºC and 1-1.1ºC for *Ts* and *Ta*, respectively; and the BIAS was –0.2-0.1ºC and 0.7-0.8ºC for *Ts* and *Ta*, respectively

On a diurnal cycle (**Figure 4a**), in general the MAE for *Ts* is less than 1ºC, except during daytime. For *Ta*, it is within 1ºC and higher, except during 10-14 local standard time (LST) interval with the lowest of 0.45 (22 measurements) at 13 LST. The BIAS (**Figure A1c**) for *Ts* is the lowest during nighttime, and it is the highest (≈ –1ºC) during 12-14 LST interval. At the same interval, the BIAS for *Ta* is the lowest, although during the rest of the day it is above +0.5ºC, and the highest during 18-20 LST interval.

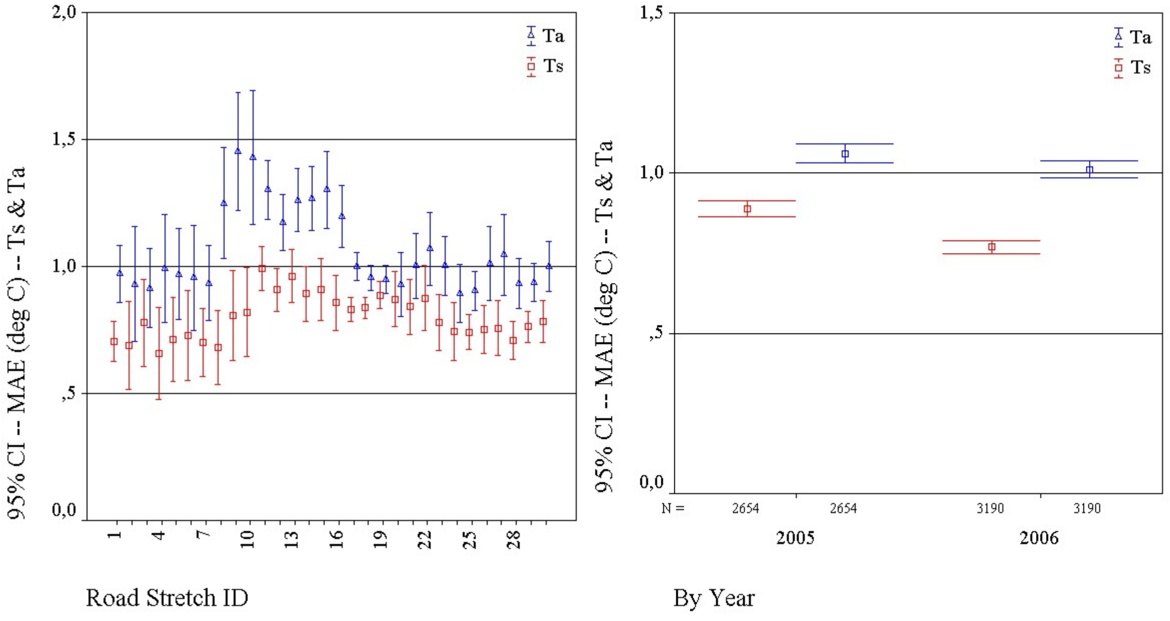
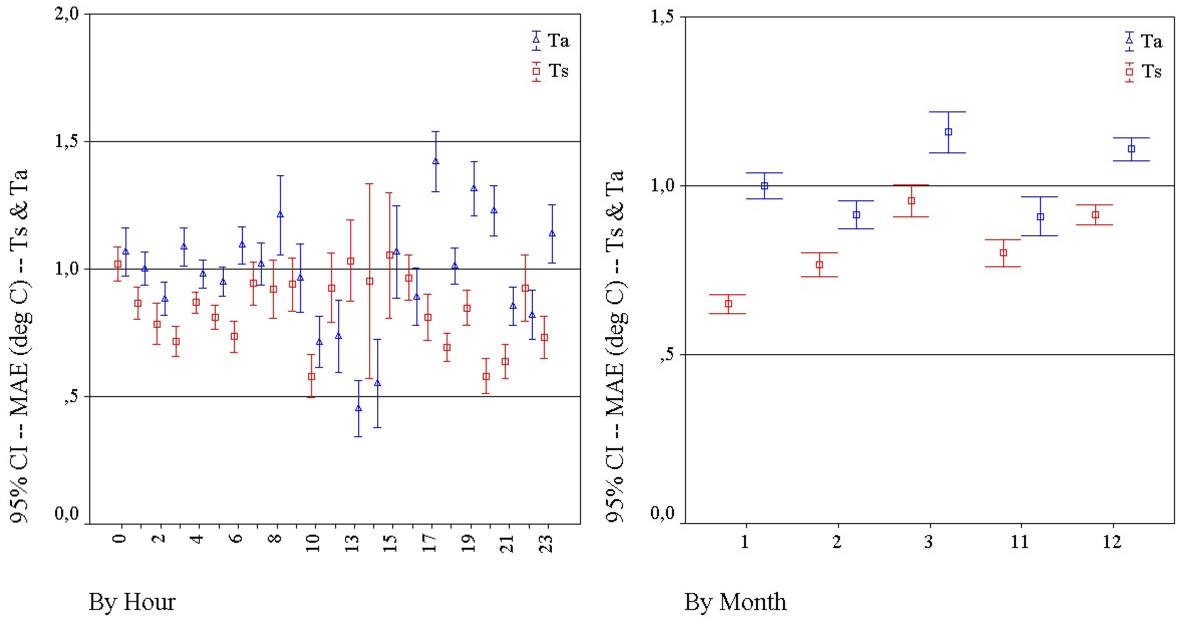


Figure 3. Mean absolute error, MAE (at 95% confidence interval) of the road surface temperature (*Ts*) and air temperature (*Ta*) a) by road stretches identificators and b) by years.



(a) (b)

Figure 4. Mean absolute error, MAE (at 95% confidence interval) of the road surface temperature (*Ts*) and air temperature (*Ta*) as a function of a) diurnal cycle and b) by months.

Month-to-month variability showed (**Figure 4b**) that MAE for *Ts* is less than 0.95ºC with the lowest value of 0.65ºC in January. The MAE for *Ta* is within a range of 1±0.1ºC with the highest value in March. For *Ts*, the BIAS (**Figure A1b**) is within a range of |±0.25|ºC, and as seen, the road surface temperature is over predicted in December. For *Ta*, it is always over predicated within a range of +0.5 ÷ +1ºC with the lowest mean value of +0.6ºC in February.

For clarity, analysis of a reduced dataset (which included only measurements of the road surface temperature within a range of –1 - +1ºC; i.e. **2307** records : 833 – in 2005 and 1474 – in 2006) has been also performed. This analysis showed a very similar pattern for MAE and BIAS of both temperatures (**Appendix B**) as a function of the road stretches, on diurnal cycle and by months. For this dataset: for *Ts* the MAE and BIAS were 0.81 and 0.02ºC, respectively; for *Ta* these were 1.03 and 0.77ºC, respectively.

The summary for 102 road activities of the MAE and BIAS for both temperatures is given in **Table 1** for different temperature intervals: 1) –0.5 ÷ +0.5ºC, 2) –1 ÷ –0.5ºC and +0.5 ÷ +1ºC, 3) –1.5 ÷ –1ºC and +1 ÷ +1.5ºC, and 4) >+1.5ºC and <–1.5ºC (note, MAE is always positive by definition). As seen, the MAE and BIAS of *Ts* were contained within a range of less than |±1ºC| in 70 and 75%, respectively, of the road salting activities; but they were higher than |±1.5ºC| in less than 10% of the activities. For *Ta*, the MAE and BIAS showed values of less than |±1.5ºC| in 82% of the performed road activities. A summary by different road activities (in total 102) for the MAE and BIAS of both temperatures at selected 95% confidence interval is given in **Appendix E**.

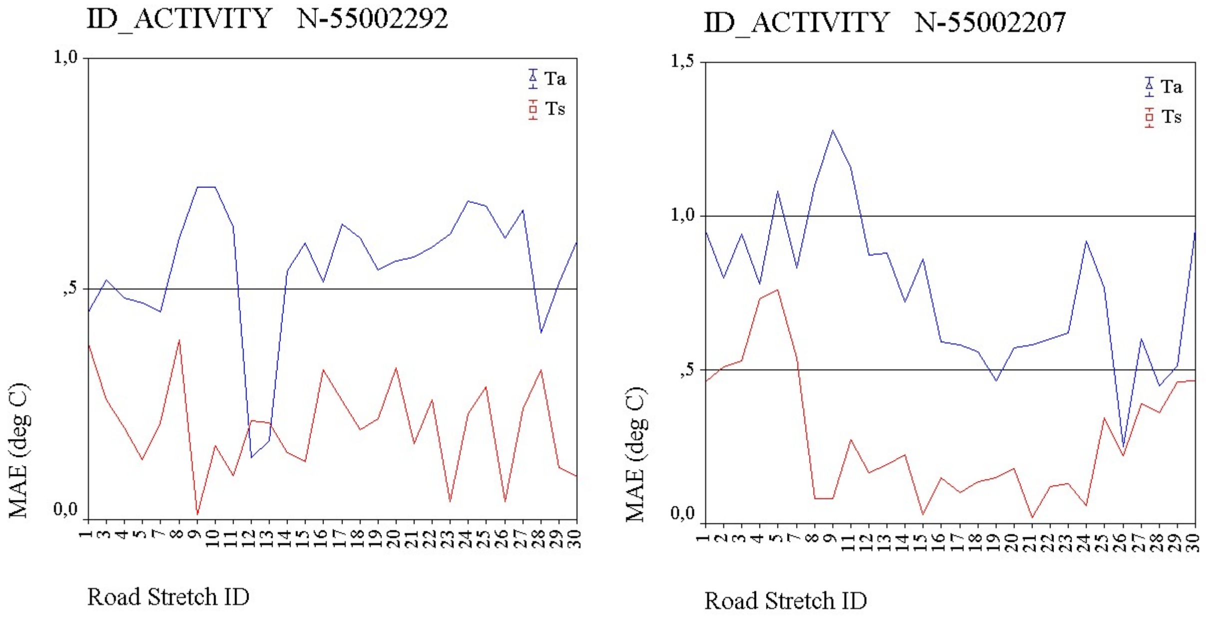
Temperature interval, ºC		**BIAS Ts**			**BIAS Ta**			**MAE Ts**			**MAE Ta**		
		N	**%**	**∑%**	**N**	**%**	**∑ %**	**N**	**%**	**∑ %**	**N**	**%**	**∑%**
–0.5 ÷ +0.5	**1**	**53**	**52**	***52***	**30**	**29**	***29***	**27**	**26**	***26***	**12**	**12**	***12***
–1 ÷ –0.5 & +0.5 ÷ +1	**2**	**24**	**23**	***75***	**30**	**29**	***58***	**45**	**44**	***70***	**42**	**41**	***53***
–1.5 ÷ –1 & +1 ÷ +1.5	**3**	**18**	**18**	***93***	**24**	**24**	***82***	**21**	**21**	***91***	**30**	**29**	***82***
<–1.5 and >+1.5	**4**	**7**	**7**	***100***	**18**	**18**	***100***	**9**	**9**	***100***	**18**	**18**	***100***

Table 1. Summary (for 102 road activities) of the mean absolute error, MAE and BIAS for the road surface temperature (*Ts*) and air temperature (*Ta*) for different temperature intervals /where: N – number of cases, % - percentage of cases from entire dataset, ∑% - cumulative percentage of cases).

3.2. Examples of Road Activities with Thermal Mapping vs. Forecasting Data

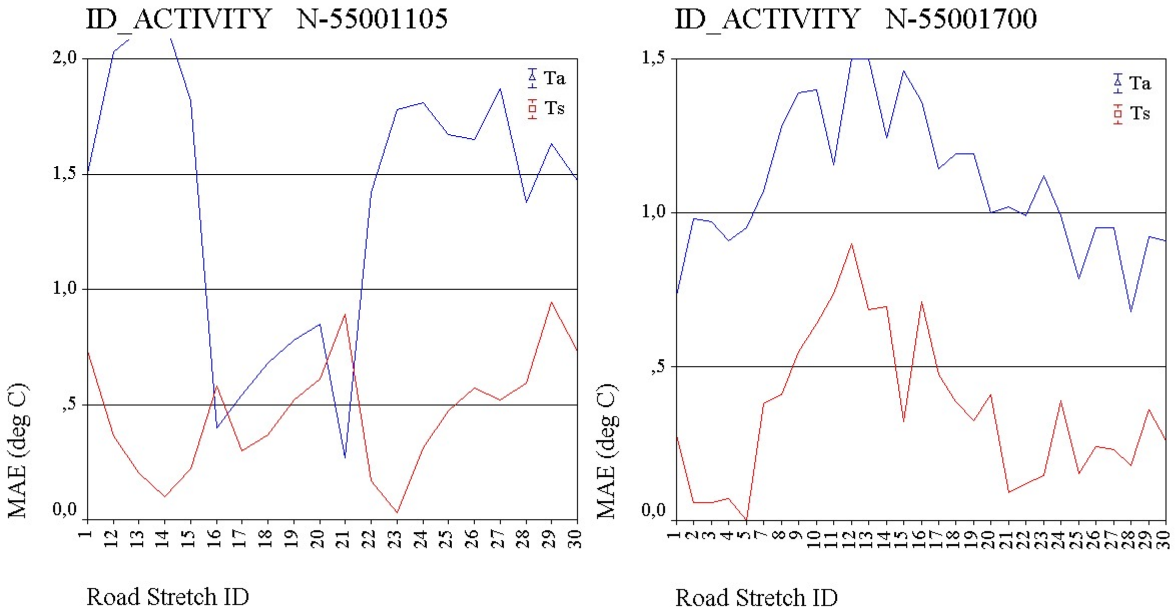
Several examples of a good RWM system performance in forecasting of the road surface temperature are shown with respect to MAE in **Figure 5-6 (**for BIAS - in **Appendix C**). A complex situation with a poor forecasting at some parts (stretches) of the road is given in **Figure 7a**. And a bad performance of the RWM forecast for all road stretches is presented in **Figure 7b**. The MAE for both the road surface and air temperatures for the 4 longest ThMD measurements corresponding to the road salting activities – N-55001753, N-55001793, N-55003816, and N-55004154 carried out during Dec 2005–Mar 2006 – is given in **Appendix D**. The summary of the MAE and BIAS for both temperatures for each road activity is shown in **Appendix E**.

As seen in **Figure 5a**, both temperatures were predicted with a high accuracy: MAE for *Ts* and *Ta* were 0.20ºC and 0.55ºC, respectively. On average, the MAE of *Ts* was 0.26ºC and for *Ta* it was 0.69ºC (with some less accurate prediction at several road stretches) as shown in **Figure 5b**. Although prediction of *Ts* was done good (i.e. MAEs of 0.48 and 0.39ºC for the road activities on 10 and 27 December 2005, respectively) as shown in **Figure 6ab**, for *Ta* the MAE mostly was more than 1ºC for the same road activities, except between the stretches 16 and 21 on 10 December 2005.



(a) (b)

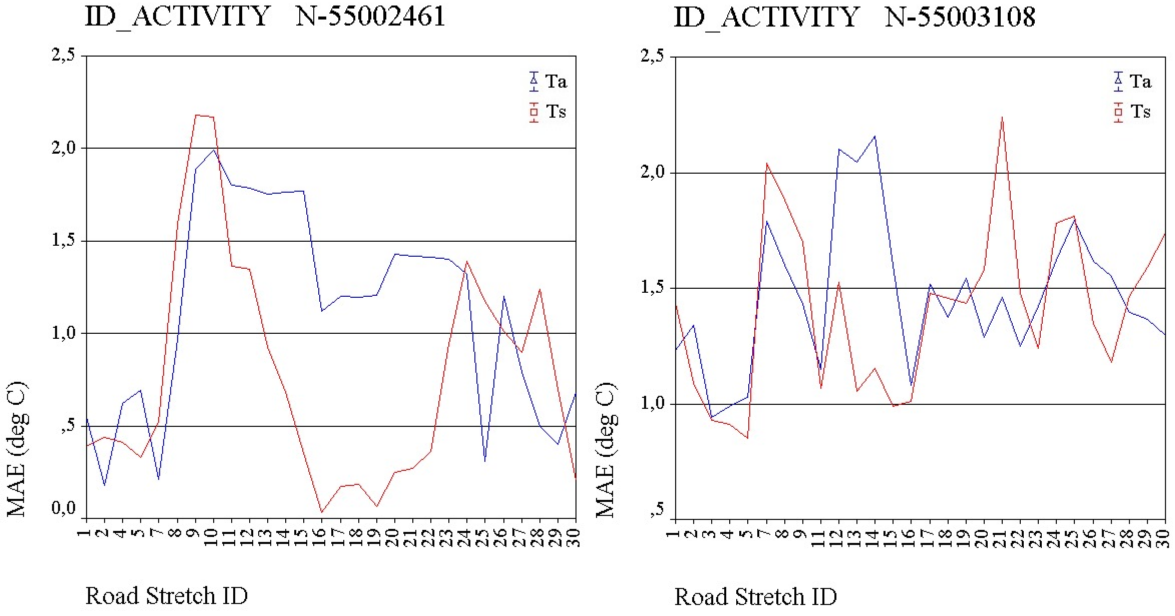
Figure 5. Mean absolute error, MAE of the road surface temperature (*Ts*) and air temperature (Ta) at the road stretches for the road salting activity: a) N-55002292 /ThMD from 06:16 to 08:00 on 07 Jan 2006/ and b) N-55002207 /ThMD from 20:50 to 22:40 on 03 Jan 2006/.



(a) (b)

Figure 6. Mean absolute error, MAE of the road surface temperature (*Ts*) and air temperature (*Ta*) at the road stretches for the road salting activity: a) N-55001105 /ThMD from 05:36 to 06:48 on 10 Dec 2005/ and b) N-55001700 /ThMD from 02:24 to 04:30 on 27 Dec 2005/.

As shown in **Figure 7b**, the MAE was more than 1ºC during the entire period of the road activity (on average/maximum, MAE was 1.43/2.24 and 1.49/2.37ºC for *Ts* and *Ta*, respectively). Such large errors can be caused by the dominated meteorological conditions. Based on a few synoptic meteorological stations located not far from the VA_4 road, the meteorological conditions during 01-05 LST on 30 January 2006 were characterized as the following. At the beginning of the road activity very low western winds and almost calm conditions were later observed. The air temperature ranged from +0.3ºC (01 LST) to +1.6ºC (05 LST) with a cloudy and then foggy conditions as well as high (98-100%) relative humidity. As it was shown in Table 1, only less than 10% of the road activities can be assigned to the low quality forecast done by the RWM system, these will be further investigated into more details.



(a) (b)

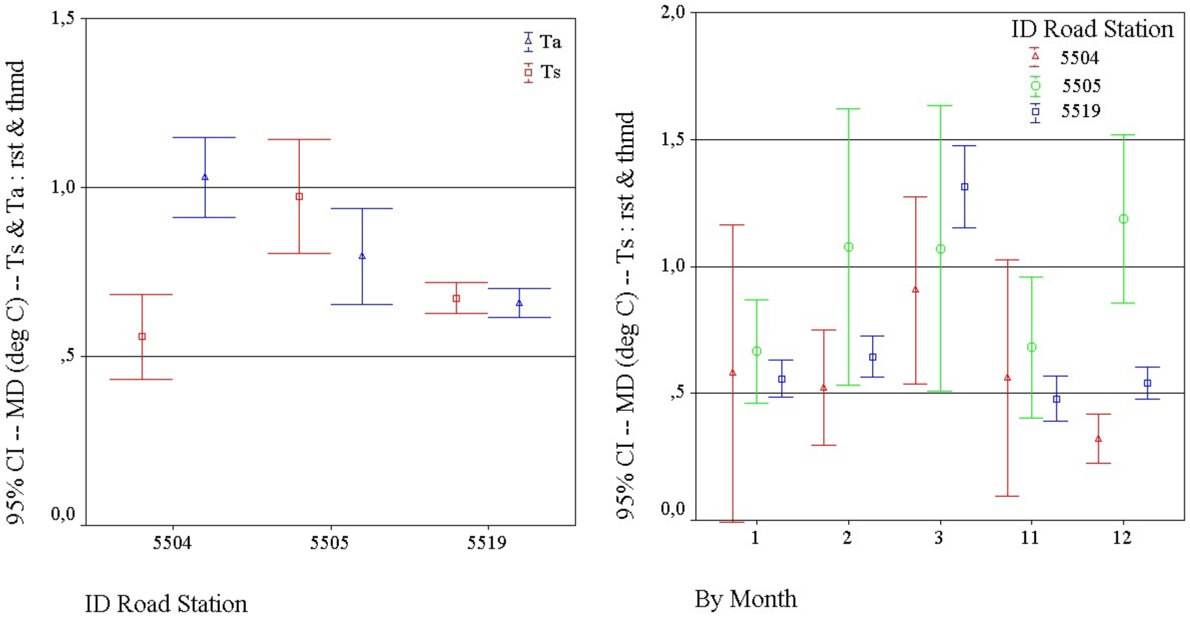
Figure 7. Mean absolute error, MAE of the road surface temperature (*Ts*) and air temperature (*Ta*) at the road stretches for the road salting activity: a) N-55002461 /ThMD from 17:48 to 19:42 on 14 Jan 2006/ and

b) N-55003108 /ThMD from 02:50 to 04:36 on 30 Jan 2006/.

3.3. Variability of Thermal Mapping vs. Selected Road Station Data

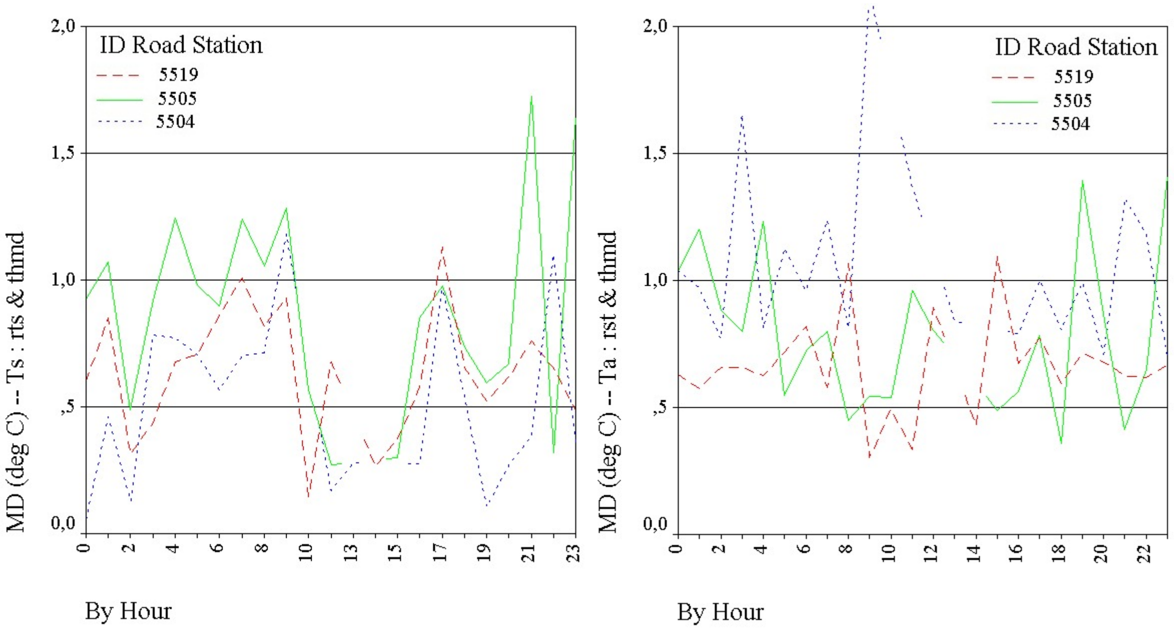
The summaries based on all available cases of the mean of deviation, MD (as difference between the observation at the road station vs. measurement at the road stretch with a corresponding thermal mapping data value) for 3 road stations are given in **Figure 8a**. As seen, for the entire dataset, the lowest (highest) value of MD for *Ts* is characteristic for the road station 5504 (5505) located along the VA_4 road and at the shortest (longest) distance from the road stretch 27 (13) (see stretches in **Figure 1b**). MD of *Ts* at the same road stations by months is given in **Figure 8b**, and MD for both temperatures on a diurnal cycle is shown in **Figure 9**. As seen the farther the road station is located from the road itself (or from the stretch) the higher will be values of deviation.

A relatively good fit between measurement of the ThMD at the road stretch and measurement at the road station 5519 (as well as 5504) was observed during most months (**Figure 8b**), except March. For *Ts* the lowest MD were 0.32ºC (December), 0.67ºC (January), and 0.48ºC (November) for the road stations 5504, 5505, and 5519, respectively; and the highest deviations were 0.91ºC (March), 1.19ºC (December), and 1.31ºC (March) for the same stations, respectively. For *Ta* the lowest MD were 0.85ºC (November), 0.66ºC (November), and 0.58ºC (February) for the road stations 5504, 5505, and 5519, respectively; and the highest deviations were 1.27ºC (March), 0.88ºC (February), and 0.80ºC (March) for the same stations, respectively. Note, that on a diurnal cycle, a larger variability of deviations was observed for the air temperature compared with the road surface temperature (**Figure 9**).



(a) (b)

Figure 8. Mean deviation, MD (at 95% confidence interval) of the road surface temperature (*Ts*) and air temperature (*Ta*) at 3 road stations for the a) entire dataset and b) by months.



(a) (b)

Figure 9. Mean of deviation for the a) road surface temperature (*Ts*) and b) air temperature (*Ta*) by hours at 3 road stations.

4. Conclusions

In our study, the vehicles measurements (so-called the thermal mapping data) of the road conditions including the road surface and air temperatures have been used for verification of the skills and performance of the Danish Road Weather Model (RWM) system. At the current moment this sytems is employing the DMI-HIRLAM NWP model with a horizontal resolution of 15 km (in 2007 – 5 km). During 2005-2006, in total 102 cases/dates with the road salting activities of the Ribe Amt Commune VA_4 road (Jylland Peninsula, Denmark) have been identified, extracted, and statistically analyzed. The comparison of the observed and forecasted the road surface and air temperatures was done at 30 selected road stretches of VA_4 road situated at distances of 2 km from each other.

It was found that the RWM system showed a good predictability of the road surface temperature at the road stretches. The mean absolute error was 0.5-1ºC for all stretches during the road winter season of November 2005 – March 2006. The bias was less than ±0.5ºC. For the air temperature, the mean absolute error was around 1ºC and higher. The bias was always positive and higher than +0.5ºC. On a diurnal cycle, for the road surface temperature the nighttimes had the best quality of prediction and its quality was lower during daytime (12-14 h of local time), and vise versa for the air temperature. Analysis of reduced dataset with the road surface temperature ranging from –1ºC to +1ºC showed similar pattern for the mean absolute error and bias of both temperatures. Moreover, note that the mean absolute error was higher than |±1.5ºC| in 10 and 18% of the road activities for the road surface and air temperatures, respectively.

Evaluation of the mean deviation for the thermal mapping data at the road stretches of the VA_4 road vs. 3 selected road stations showed a relatively good fit for the road surface temperature in all months studied, except March. The lowest mean deviation was 0.32ºC and the highest - 1.31ºC. Moreover, on a diurnal cycle, a larger variability of deviations was observed for the air temperature compared with the road surface temperature, which probably might be caused by cloudiness and shadowing effects.

It should be noted, that although ThMD data showed that they are very useful for verification of the performance of the RWM system, these are less useful and valuable for on-line assimilation into the system due to sparse and irregular measurements. But they can be used for possible correction of the road surface temperature forecasts by integration into the neural network based on the long-term road surface temperature dataset over the Danish road network domain which will be better investigated later in this project.

A few items of further extension of research into the year of 2007, in order to improve the RWM system forecasting performance and capability, should be mentioned.

- To study impact of finer horizontal resolutions of NWP model on the RWM scores : the evaluation of the ThMD and RWM system performance will be also done for the same road winter period of 2005-2006 based on the DMI-HIRLAM NWP model using resolution of 5 km.
- To demonstrate consistency of obtained road surface temperature patterns from one winter salting period to another : more consistent and longer time series of the thermal mapping measurements are needed; more weather types/situations need to be taken into account; another types of roads in more complex terrain need to be studied; etc.).

In addition:

- Other factors, such as shadowing effects, influencing accuracy of the road surface temperature forecasting will be also studied.
- The verification of road surface temperature for an “imaginary” road (i.e. a road represented by a sequence of road stations identified as stretches of the road passing by through these stations, and located on the Jylland Peninsula of Denmark) will be conducted over a longer time period (road winter season of Nov 2005 - Apr 2006) using different interpolation techniques.
- Moreover, verification of the RWM system based on assimilation of the high resolution MSG-1 satellite data will be extended over a 1 year period (including 2005-2006 road winter season) in order to study as the impact of cloud cover on road surface temperature.

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6. References

DMI-HIRLAM-RWM basic related:

Sass B.H., **1992**: A Numerical Model for Prediction of Road Temperature and Ice. *Journal of Applied Meteorology,* 31, pp. 1499-1506.

Sass B.H., **1997**: A Numerical Forecasting System for the Prediction of Slippery Roads. *Journal of Applied Meteorology,* 36, pp. 801-817.

Sass B.H., N.W. Woetmann, J.U. Jorgensen, B. Amstrup, M. Kmit, K.S. Mogensen, **2002**: The operational DMI-RIRLAM system 2002 - version. *DMI Technical Report* N 02-05, 60p.

RWM previous project related:

Sass B.H., Petersen C., **2004**: A Coupled Automatic Road Weather Forecasting System. *Extended abstracts of the 12th International Road Weather Conference, 16-18 June 2004, Bingen, Germany*. In "Forecast Methods and Accuracy", N TII-7, 8p.

Petersen C., B.H. Sass, **2005**: Improving of road weather forecasting by using high resolution satellite data. *Extended abstracts of the World Weather Research Programme International Symposium on Nowcasting and Very Short Range Forecasting (WSN05), 5-9 September 2005, Toulouse, France*, N 6.28, 12p.

Sass B.H., C. Petersen, A. Mahura, N.W. Nielsen, T.S. Pedersen, M. Lind, S. Andersen, **2005**: Improvement of Operational Danish Road Weather Forecasting using High Resolution Satellite Data. *DMI Scientific Report 06-01*, Jan 2006, 27p.

Petersen C., **2005**: Improving of road weather forecasting by using high resolution satellite data. *VIKING Best Practice Workshop*, 5-6 October 2005, Copenhagen, Denmark.

Petersen C., B. Sass, A. Mahura, N.W. Nielsen, T.S. Pedersen, M. Lind, S. Andersen, **2006a**: Assimilation and Validation of Satellite Cloud Cover for Road Weather Forecasting. *Proceedings of the International Conference on Mesoscale Processes in Atmosphere, Ocean and Environmental Systems*. 14-17 February 2006, Delhi, India, SVA-01, pp. 128-129.

Petersen C., B.H. Sass, A. Mahura, N.W. Nielsen, T.S. Pedersen, M. Lind, S. Andersen, **2006b**: Operational Danish Road Weather Forecasting using High Resolution Satellite Data. *Proceedings of the 13th International Road Weather Conference*, SIRWEC-2006, 25-27 March 2006, Torino, Italy, pp. 80-86.

Sass B.H., C. Petersen, A. Mahura, N.W. Nielsen, T.S Pedersen, M. Lind, S. Andersen, **2007**: Capabilities of Road Forecasting Modelling using Satellite Data. *Manuscript in Preparation for Journal of Meteorological Applications.*

RSF current project related:

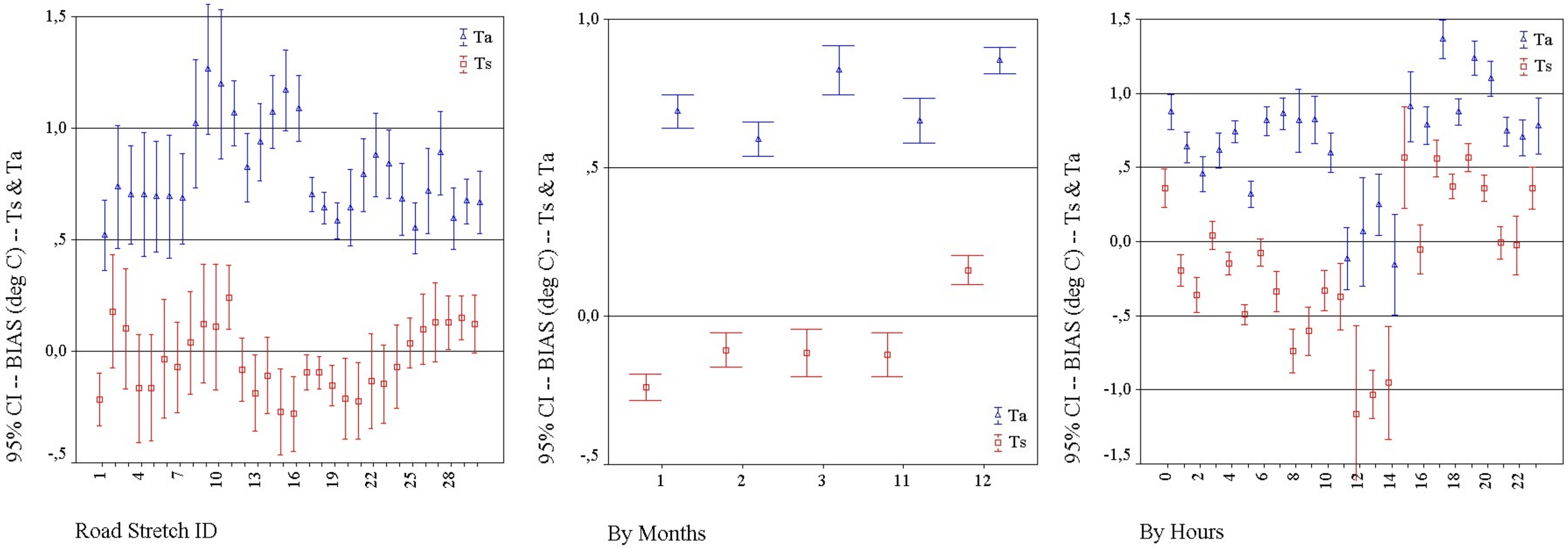
Petersen C., B.H. Sass, A. Mahura, **2006c**: Glatforemodellen – et kig tilbage og et lille kig frem. *Oral presentation at the Glatforebrugermode for seasonen 2005/2006*, 18 April 2006, Ingeniorforeningens Modecenter – Copenhagen, Denmark.

Petersen C., A. Mahura, B.H. Sass, T.S. Pedersen, N.K. Petersen, **2006d**: Road stretch forecasting. *Abstracts of the 6th Annual Meeting of the European Meteorological Society (EMS),* 3-7 September 2006, Ljubljana, Slovenia; Vol. 3, EMS2006-A-00485.

Pedersen T.S., Mahura A., C. Petersen, B.H. Sass, **2007**: Road segment forecasting: a tool for salt spreader control using GPS. *Viking Workshop*, 15 March 2007, Hamburg, Germany.

Mahura A., C. Petersen, B.H. Sass, T.S. Pedersen, **2007**: Applicability of interpolation methods in road weather modelling. *DMI Scientific Report, In Preparation.*

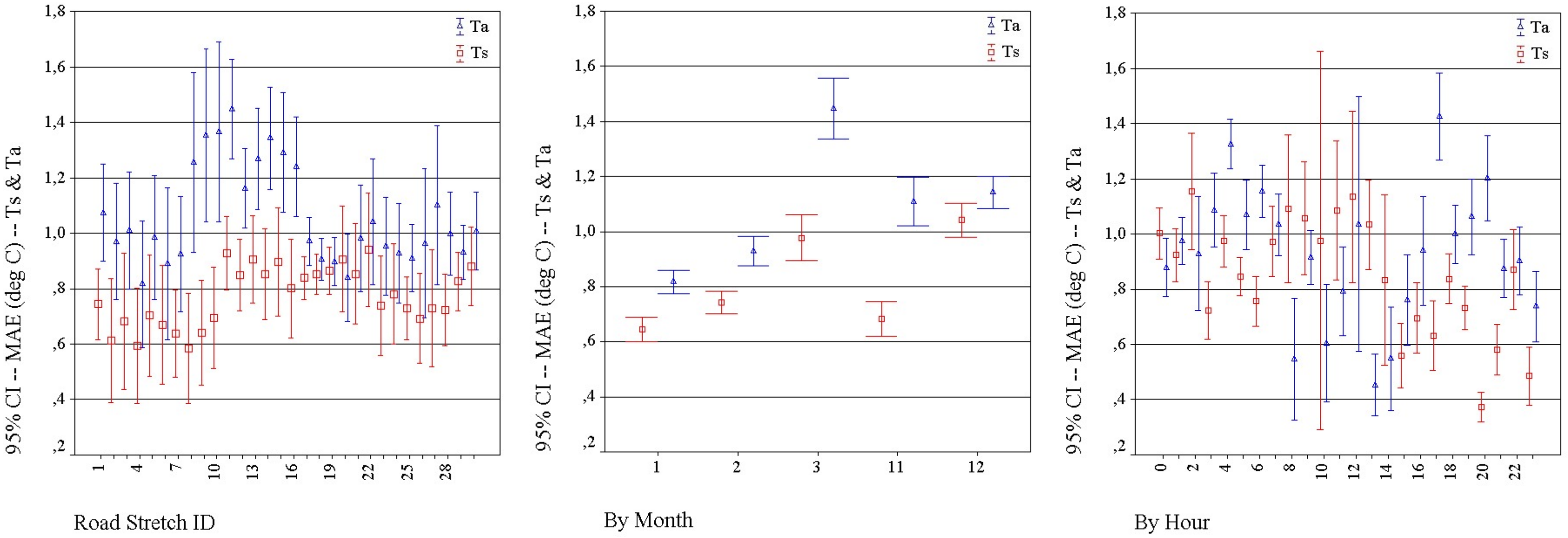
Appendix A : Bias of Road Surface and Air Temperatures for Entire Dataset Thermal Mapping Data



(a) (b) (c)

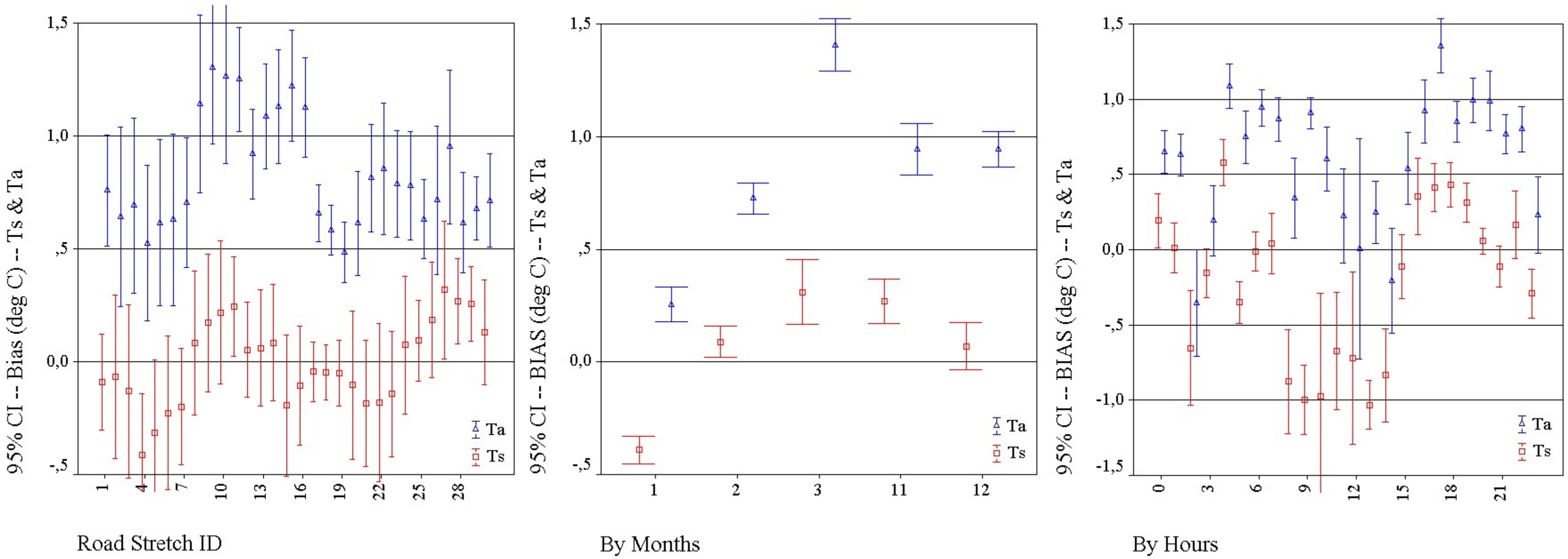
Figure A1. Bias (at 95% confidence interval) for the road surface temperature (*Ts*) and air temperature (*Ta*) as a function of a) road stretch number (or identificator), b) month and c) hour /local standard time/ based on the entire thermal mapping dataset.

Appendix B : Mean Absolute Error and Bias of Road Surface and Air Temperatures for Observed Interval of Ts=±1ºC Dataset



(a) (b) (c)

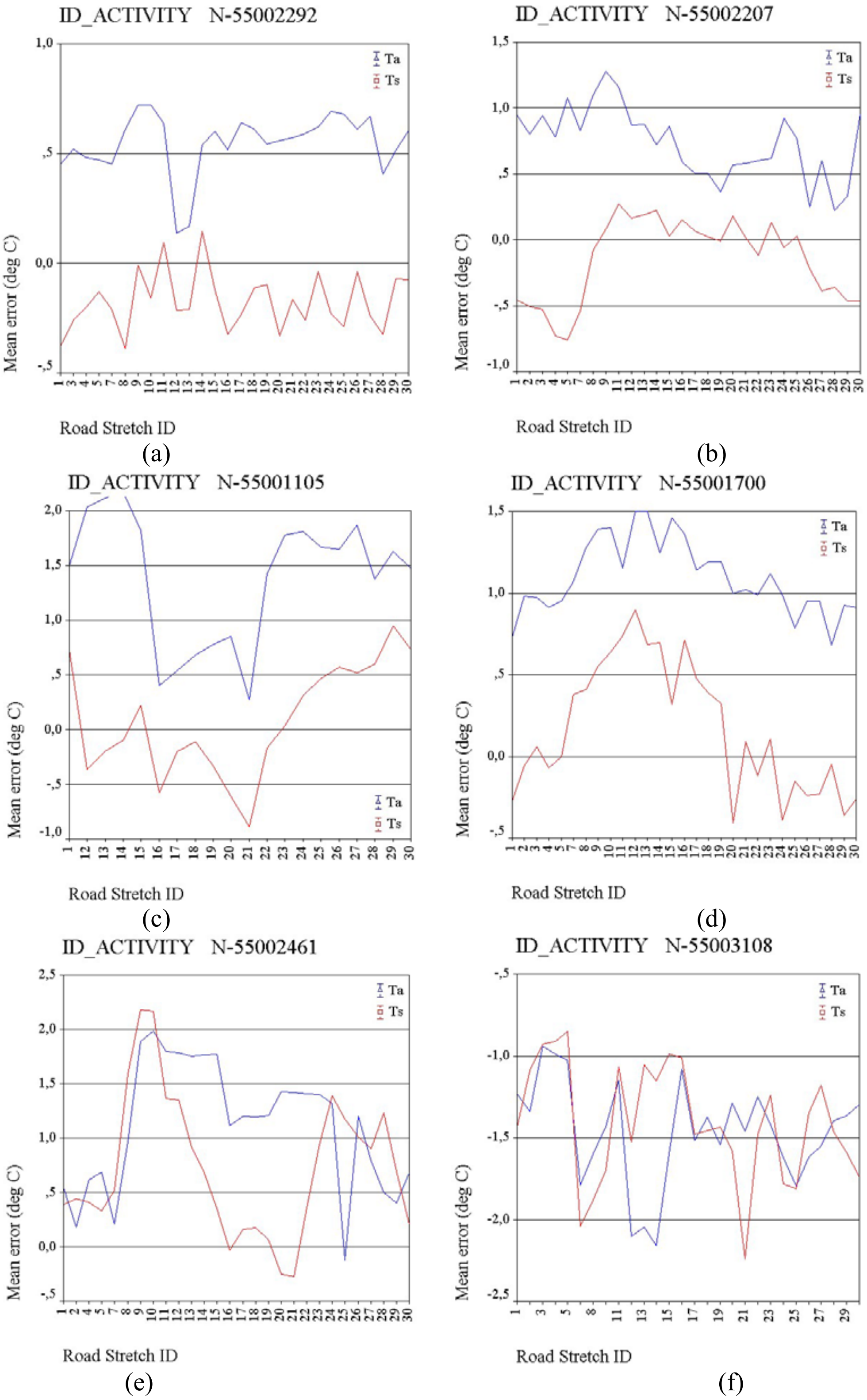
Figure B1. Mean absolute error, MAE (at 95% confidence interval) for the road surface temperature (*Ts*) and air temperature (*Ta*) as a function of a) road stretch number (or identificator), b) month and c) hour /local standard time/ based on dataset with observed interval of *Ts* = ±1ºC.



(a) (b) (c)

Figure B2. Bias (at 95% confidence interval) for the road surface temperature (*Ts*) and air temperature (*Ta*) as a function of a) road stretch number (or identificator), b) month and c) hour /local standard time/ based on dataset with observed interval of *Ts* = ±1ºC.

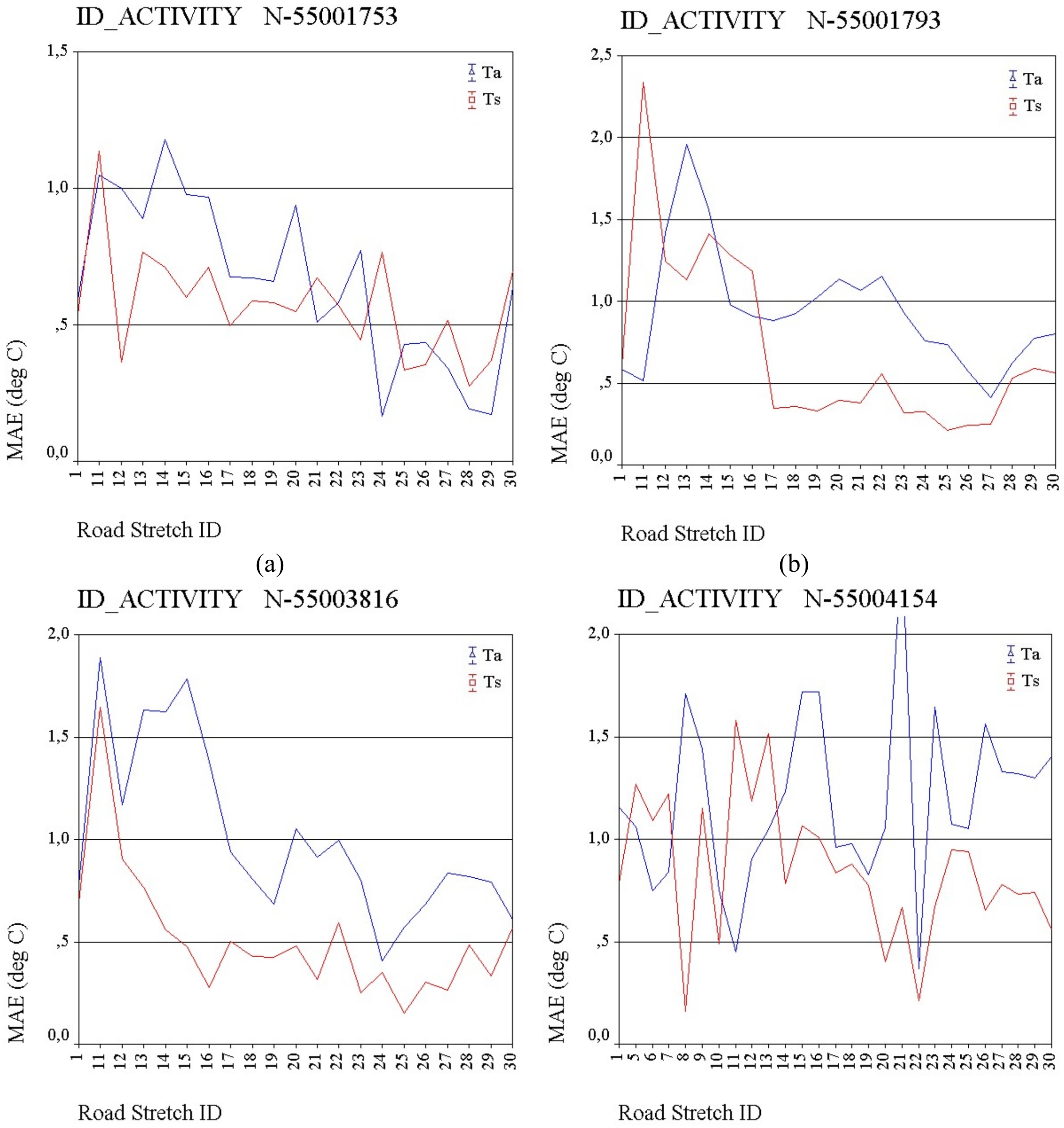
Appendix C : Mean Error of Road Surface and Air Temperatures for Road Activities



(a) (b) (c) (d) (e) (f)

Figure C1. Mean error /bias/of the road surface temperature (*Ts*) and air temperature (*Ta*) at the road stretches for the road salting activities: a) N-55002292 /ThMD from 06:16 to 08:00 on 07 Jan 2006/, b) N-55002207 /ThMD from 20:50 to 22:40 on 03 Jan 2006/, c) N-55001105 /ThMD from 05:36 to 06:48 on 10 Dec 2005/, d) N-55001700 /ThMD from 02:24 to 04:30 on 27 Dec 2005/, e) N-55002461 /ThMD from 17:48 to 19:42 on 14 Jan 2006/ and f) N-55003108 /ThMD from 02:50 to 04:36 on 30 Jan 2006/.

Appendix D : Mean Absolute Error of Road Surface and Air Temperatures for Road Activities with Longest Thermal Mapping Data Measurements

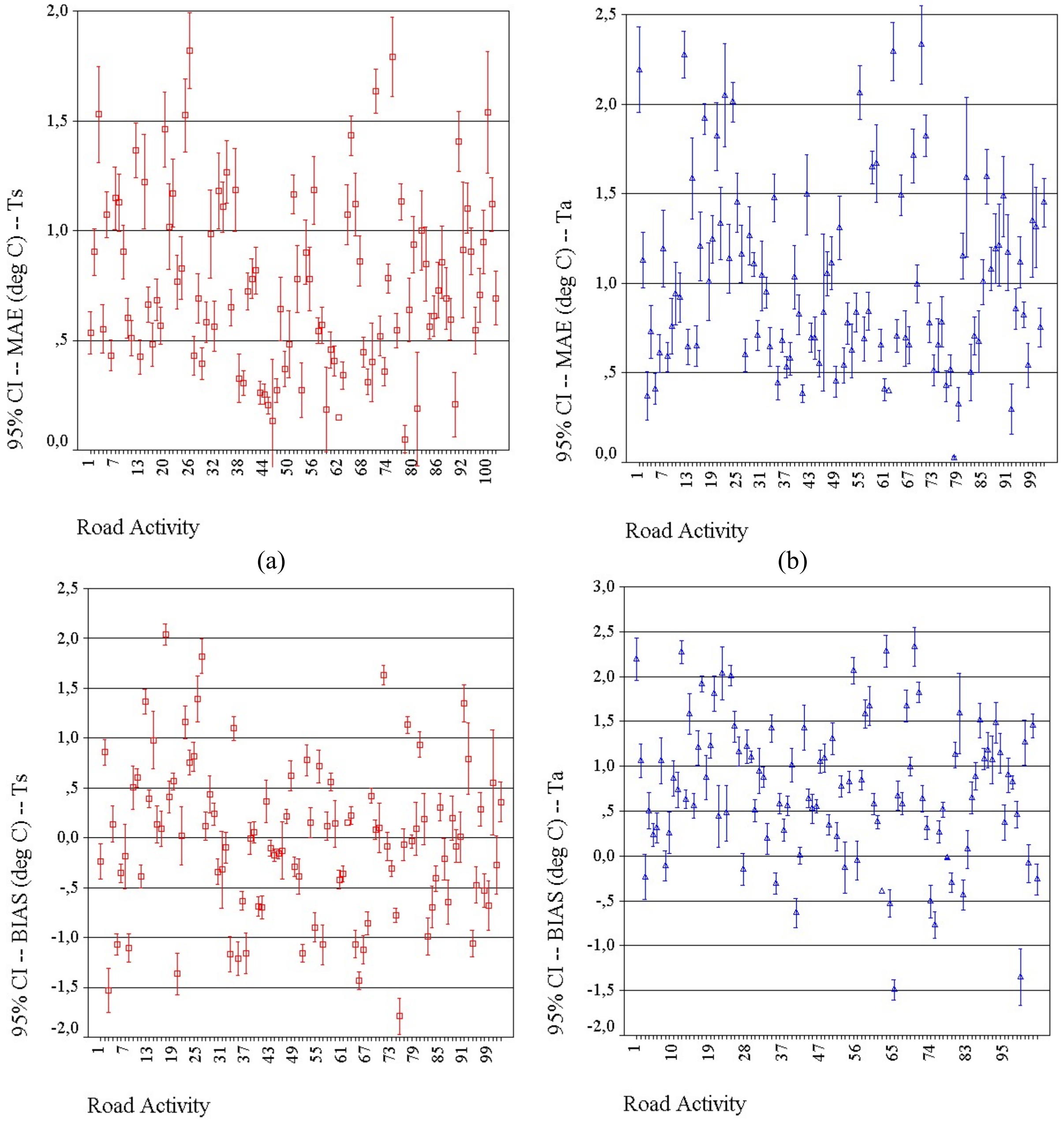


(a) (b)

(c) (d)

Figure D1. Mean absolute error, MAE for the road surface temperature (*Ts*) and air temperature (*Ta*) as a function of the road stretch identificator for the road salting activities: a) N-55001753 (18:32-21:52 on 27 Dec 2005; 114), b) N-55001793 (03:38-06:28 on 28 Dec 2005; 105), c) N-55003816 (02:48-06:00 on 28 Feb 2006; 116) and N-55004154 (06:08-09:30 on 06 Mar 2006; 109).

Appendix E : Mean Absolute Error and Bias of Road Surface and Air Temperatures as a Function of Road Activity



(a) (b)

(c) (d)

Figure E1. Mean absolute error (a,b) and bias (c,d) (at 95% confidence interval) for the road surface temperature (*Ts*) (a,c) and air temperature (*Ta*) (b,d) as a function of the road salting activity.

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