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Thermal Mapping Data Measurements: Road Weather Seasons 2008-2011

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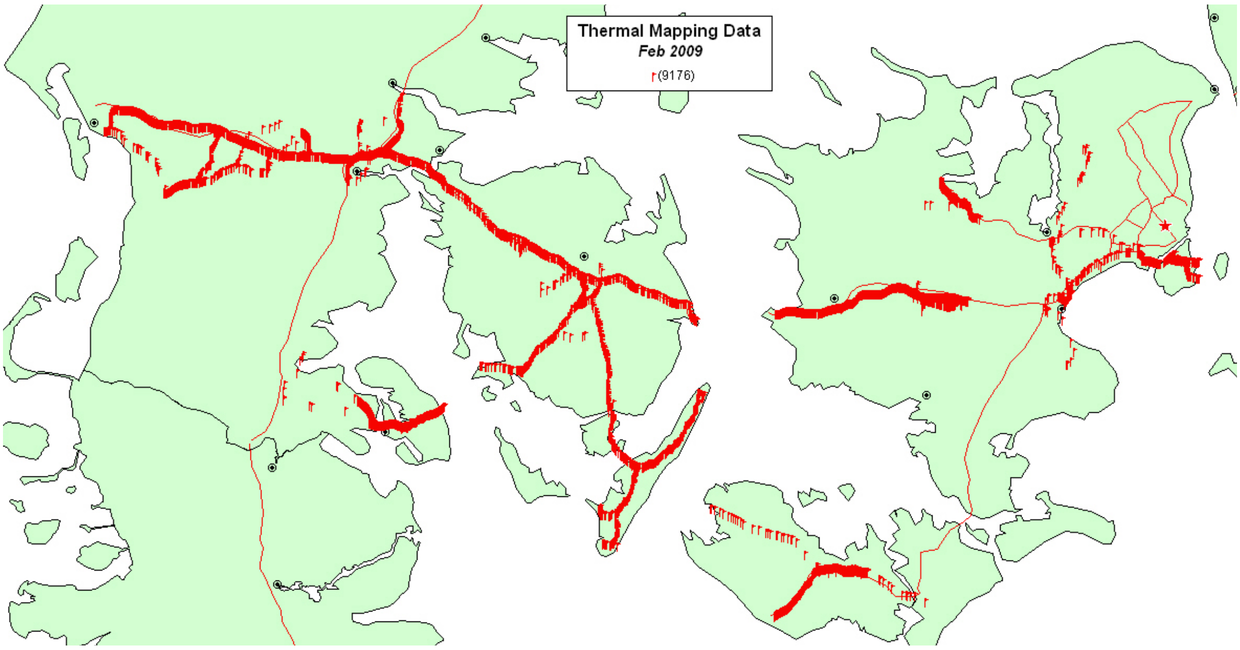

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Abstract

The vehicles measurements of the road conditions (so-called thermal mapping data, ThMD) have been used for verification of the performance of the Danish Road Weather Modelling System (RWMS) at road stretches of selected roads and compared with forecasts at selected road stations of the Danish road network. It was found that the RWMS system showed a comparable predictability for the road surface temperature for 3 hour forecasts at road stations vs. road stretches. Although ThMD data showed that they are very useful for verification, these are less applicable and valuable for on-line assimilation into the system due to limited spatial and temporal distribution and irregular measurements. But such ThMD can be used for possible correction of the road surface temperature forecasts based on detailed analysis and integration of such data, if the data are of sufficient quality and if long enough time-series is collected. Although quite a large number of ThMD observations were of a poor quality, and even some measurements were as much as 10 degrees colder (which might be due to accuracy of measurements, instrumental errors and in-time calibration issues of sensors mounted at the vehicles), but still these observations have important information about variation of the road surface temperature. Analysis showed an importance of further investigation of the road surface temperature forecasts as a function of different road and environmental characteristics.

Resumé

Mobile opmålinger af vejforholdene (thermal mapping data, ThMD) er blevet anvendt til verifikation det danske Road Weather Modelling System (RWMS) på udvalgte vejstrækninger og sammenlignet med prognoser for udvalgte danske stationer. Det blev konstateret at RWMS systemet havde en sammenlignelig forudsigelighed for vej temperaturen i 3 timers prognoser for vejstrækninger når disse blev sammenlignet med vejstationer. ThMD data viste sig meget nyttige til verifikation, men mindre relevante og værdifulde for on-line assimilation i systemet på grund af begrænsede geografiske og tidsmæssige fordeling og uregelmæssige målinger. Men ThMD kan bruges til korrektion af vejtemperaturprognoser baseret på en detaljeret analyse og integration af sådanne data. Under forudsætning af at data er af tilstrækkelige kvalitet og med lange tidsserier til rådighed. Selvom et ganske stort antal ThMD observationer var af dårlig kvalitet, og nogle målinger endda var så meget som 10 grader koldere (som kan være på grund af nøjagtigheden af målinger, tekniske fejl og dårligt kalibreriet sensorer), gav disse observationer stadigræk oplysninger om variation af vejtemperaturen. Analyse viste et behov for yderligere undersøgelse af vejtemperaturprognosernes afhængighed af omgivelserne.

1. Introduction

The road weather forecasts with a focus on prediction of the slippery road conditions are performed by the Road Weather Modelling System (RWMS) and it is an important operational product produced by DMI. In order to stimulate and continue further development of the existing system, annual verification of its performance is conducted at the end of each road season. The performance of the Road Conditions Model (RCM; *Sass, 1992; 1997*) is evaluated by estimating forecasts for key parameters such as mean absolute error and bias for the road surface temperature (*Ts*), 2m air temperature (*Ta*) and 2 m dew point temperature (*Td*), as well as scores reflecting a frequency of good/poor quality forecasts. For the recent road weather seasons (i.e. during 2005-2010; duration from October through April) the verification reports are given by *Petersen et al. (2007-2011).* In operational runs, the system uses continuous observations from synoptic weather stations and road stations (having now more than 490 sensors) of the Danish Road Network (DRN) along with the meteorological output from the DMI-HIRLAM (High Resolution Limited Area Model; *Sass et al., 2002; Yang et a., 2005*) numerical weather prediction (NWP) model as input to produce 24 hour forecasts every hour. The description of the RWMS operational system/ product is given in the manual *GlatTerm (2004).*

Recently the road weather forecasting system extended its applicability with focus on detailed road stretch forecasting at distances of 1 km and even down to 250 meters along the driving lanes (*Mahura et al., 2007; Petersen et al., 2012*), the information about spatial variability of observed icing conditions on roads or situations leading to such danger became needed.

Ice on road surfaces is one of the most serious and dangerous meteorological hazardous phenomenon, and it is well known that annually it causes serious injuries and even deaths in road accidents. Although slippery condition occurs under conditions which are generally well understood and often, with some degree of accuracy, possible to forecast, the reduction of the threat of the winter weather related accidents still remain the key issue for the national road authorities. In order for rime or frost to be formed on the road surface the following is required: temperatures near and below 0°C as well as presence of water (moisture) on the surface of the road. It is important to identify where local slippery road conditions occur, where complexities and failed predictions of road conditions in forecasting at short distances might be expected within the road network. Here the focus is on ice formed, because the rime, snow, and freezing melting water are not directly considered.

The continuous development of more refined numerical weather prediction (NWP) models and increased computer power allow an increasing model resolution which provides 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. Danish Meteorological Institute (DMI) is running the HIgh Resolution Limited Area Model (HIRLAM) with a resolution of 3 km for the operational daily runs. Third, in Denmark, the road services already have started to use observations from vehicles allowing getting additional information on road conditions which can also be used for forecasting purposes. During the winter season, 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 kind of data provide more details of the road conditions along road sections/stretches (located at short distances from each other), and can be used to improve the forecasts by providing more local information. This 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. This improves the safety of road traffic.

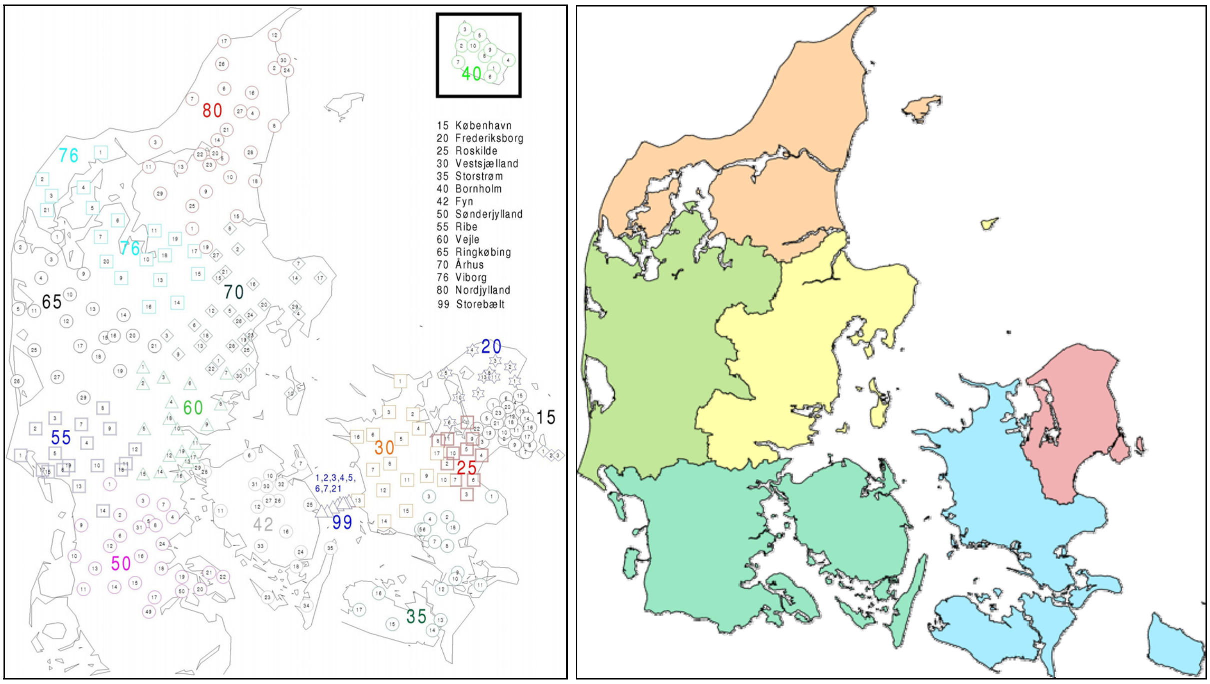
The road conditions depend strongly on the cloud cover, shadows, precipitation, wind speed, air temperature, and humidity. However, some of these quantities have a large local variability and the road conditions can be affected by changes in these parameters on very short temporal and spatial scales. Since existing model systems do not provide sufficient accuracy for these parameters, it is expected that thermal mapping data can give more detailed information and 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 Danish Road Directorate (DRD) and DMI project entitled “Fine-Scale Road Stretches Forecasting” (2009-2011) within framework of the VIKING Projects.

2. Methodology

2.1 Danish Roads Network

The Danish Roads Network is represented by more than 490 sensors (measuring continuously the road surface, air and dew point temperatures) at more 380 road stations (according to DRD, April 2011). At some stations there are two or more sensors placed along the driving lanes or on the opposite side of the road not far from each other. Note, that positions of the road stations are not equally spatially distributed within the network, but the stations are placed along most of the roads to cover as much as possible the entire territory of Denmark. Roughly, it can be estimated that for a length of approximately 10 km there is one road station placed in the network.

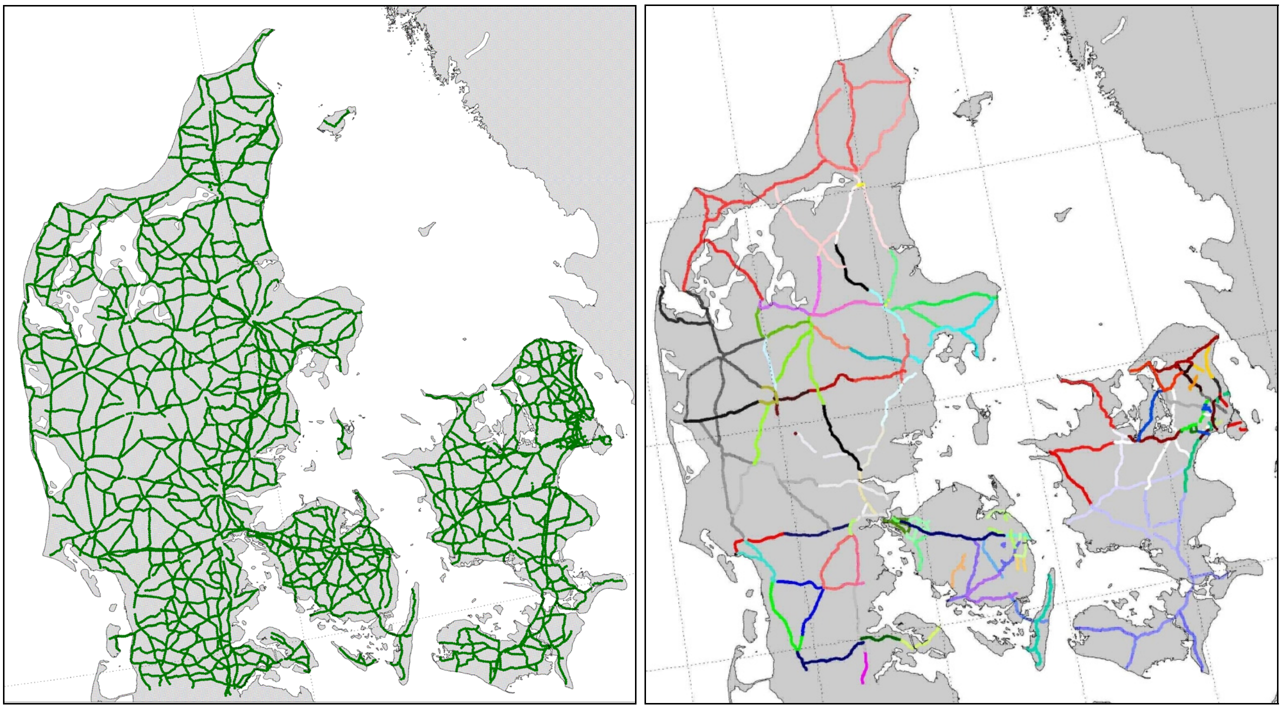


(a) *(b)*

Figure 2.1.1: *Division of the Danish road network into regions (a) until end of 2008 and (b) beginning of 2009 (Fig. 1b - source: see section Vejprojekter at http://www.vejdirektoratet.dk).*

Until the end of 2008, the network consisted of several regions shown in Figure 2.1.1a. These regions were the following. For the Zealand Island – regions of Copenhagen (N15), Frederiksborg (N20), Roskilde (N25), Vestsjelland (N30), and Storstrom (N35). For the Jutland Peninsula – regions of NordJylland (N80), Viborg (N76), Århus (N70), Ringkobing (N65), Vejle (N60), Ribe (N55), and SønderJylland (N50). There were also regions of the islands of Fyn (N42) and Bornholm (N40); and a region of Storebelt (N99) which is represented by a bridge connecting two islands of Zealand and Fyn. Starting 2009, the Danish territory was divided into 6 main regions (Nordjylland, Midt- og Vestjylland, Østjylland, Syddanmark, Sjælland, and Hovedstaden) and the road stations were re-numbered and re-assigned to these new regions (Figure 2.1.1b).

During 2006-2008, the forecasting of road weather conditions was performed at 16637 road stretches (located at distances of approximately 1 km from each other) covering 296 roads of the road network (Figure 2.1.2a). The geographical positions of road stretches were identified based on the detailed high-resolution GPS data (obtained from the DRD VINTERMAN database) for the driving lanes of the road network. Starting 2009, the focus was shifted to the major roads of the network (Figure 2.1.2b). There are 22840 stretches (located at shorter variable distances of 250 m from each other) covering 153 roads (where salting activities take place) of the network. The geographical positions of newly revised road stretches were provided by the DRD.



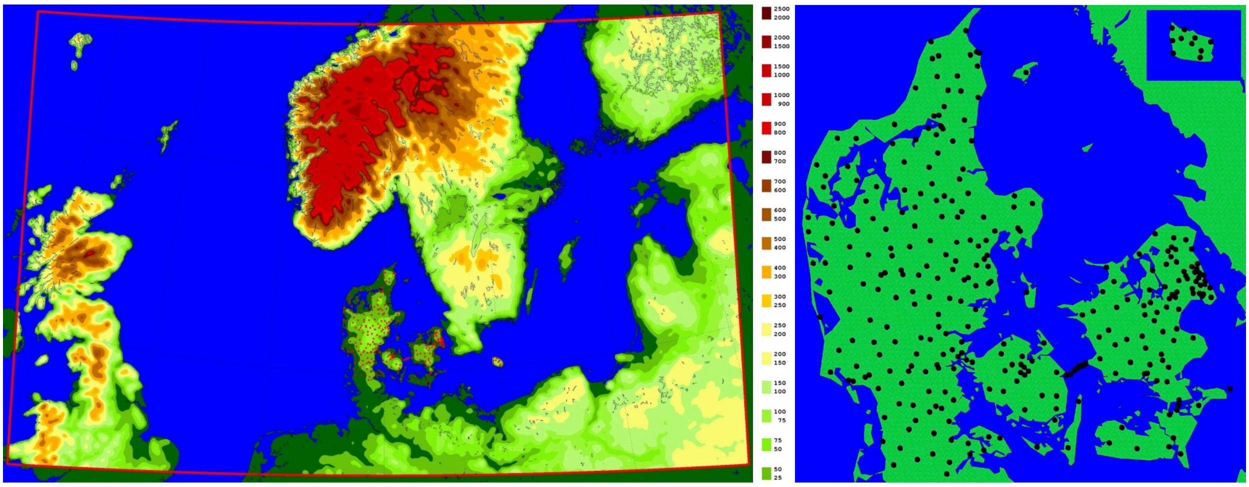
(a) (b)

Figure 2.1.2: *Danish road network covering (a) 296 roads with almost 17000 road stretches (2006-2008) and (b) 153 roads with almost 23000 road stretches (2009-present).*

2.2 Forecasting Using DMI-HIRLAM Road Weather Model System

During the last two decades the Danish Meteorological Institute (DMI) in cooperation with the Danish Road Directorate (DRD) has developed and used a Road Weather Model (RWM) system. This system provides monitoring and forecasting of road conditions at selected locations in Denmark. There are more than 380 stations and each station is equipped with different types of sensors with measurements of road surface temperature, air and dew point temperatures at 2 meters as the most important. 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 RWM model (*Sass, 1992; 1997; Sass et al., 2002*).

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 having a 15 km resolution; from Fall of 2007 – DMI-HIRLAM-R model at 5 km resolution, and currently – at 3 km resolution) and network of road stations are shown in Figure 2.2.1.



(a) *(b)*

Figure 2.2.1: *(a) Road weather modeling (RWM) system domain (-R05) having 5 km resolution; and (b) road stations of the Danish network (black dots).*

2.3 Influence of Surrounding Terrain and Land-Use

It is well known that cold air is more dense and heavier than warm air, and therefore, it will move down the slopes as well as it has a tendency to drain, so-called cold air pooling. That is reflected in influence of the local adjacent to roads terrain and land use on formation of the ice. In this case the valleys or bottoms of the hills tend to be cooler at night during calm and stable conditions compared with adjacent places of higher elevation, and moreover, the observed changes in temperature with height can be quite large. For example, in urban areas, the roads will be warmer during nighttimes due to pavement made of concrete/ asphalt which tends to accumulate heat during the daytime. This is both a heat from the sun as well as a heat from the buildings/constructions surrounding the roads. Moreover, during the winter at nighttimes the freezing will be less likely near lakes, ponds, rivers, etc. since the water surface is warmer than the land surface. Since variations in temperature due to almost unchangeable features of the local terrain are repeatable from night to night, these can be used for developing of suitable parameterizations which can lead to improvements of forecasts at selected nearby locations.

The influence of obstacles (such as trees, hills, and other objects) located near the roads is also very important. Shading of road surfaces by obstacles significantly influences the possibility of the ice formation. For example, during nighttime, the overhanging trees or other road covers will reduce such possibility due to decrease of the infrared heat loss. Shading due to trees or hills can delay also melting at late morning hours and it will allow ice to remain for the rest of the day. Parts of the road, which are located in the shadow of hills, can start to cool rapidly during hours before sunset, and this can also result in icing conditions at evening hours.

2.4 Background on 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. In particular, the RoadWatch Safety System (RWSS) temperature sensors are used to measure the road temperature. This device measures temperature within a range from -40ºC to +90ºC with an accuracy of 0.5ºC. The device is mounted on the vehicle in a way that sensor should have a clear sight to the road surface. The measurements are done continuously during the road salting activities at intervals of less than 100 meters and when the spreader changes settings. Mostly these measurements are performed during winter season with a focus on nighttimes since cooling of the roads is most common during night, because of nocturnal cooling which often is a very local phenomenon. Differences in temperature along 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 cooling of the road may lead to slippery road surfaces if roads are already wet, or as a consequence of a dew deposition. This also means that forecasting of precipitation and humidity should be of high resolution.
For each road the energy balance is affected by complex interactions between various factors including: weather conditions; sky view factor or shadowing effects from trees, buildings, constructions, etc.; height of the road section; geographical location with respect to water objects (lakes, ponds, rivers, etc.); 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. 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 building 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.

2.5 Thermal Mapping Activities during Road Weather Seasons

The thermal mapping data has been provided by the Danish Road Directorate (DRD) through a database, the so-called VINTERMAN software package. The database contains detailed information about number of the driving, measuring, and salting activities' parameters. The focus of this study 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 spread 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.

During the recent road winter seasons (2008-2009, 2009-2010, and 2010-2011) the thermal mapping data (ThMD) measurements have been conducted along many Danish roads/ driving lanes (see summary in Table 2.5.1, Figure 2.5.1). In total, the original raw data (time-series of measurements) obtained from the DRD database included 422697, 911277, and 562611 records for the three last seasons, respectively. During 2008-2009 season, the largest number of measurements (145003, or 34.3% of total) was performed in March 2009, and the lowest (4050) - in October 2008. During 2009-2010 season, the largest number of measurements (476504, or 52.3% of total) was performed in December 2009, and the lowest (601) - in November 2009. During 2010-2011 season, the largest number of measurements (139685, or 24.8% of total) was performed in March 2011, and the lowest (15946) - in October 2010. Almost 77% (2008-2009), 64% (2009-2010), and 82.4% (2010-2011) of these measurements were collected in the time interval 18-06 UTCs which corresponds to a higher likelihood of the icing conditions formation along the driving lanes. The distribution of ThMD measurements (raw data) by days (1-31) of the month and by hours (00-23) of the day during the months (Oct – Apr) of the road seasons is summarized in the Appendixes A-B.

	Road Weather Season					
Season	**2008-2009**		**2009-2010**		**2010-2011**	
Month	**N**	**%**	**N**	**%**	**N**	**%**
Oct	**4050**	0,96	4678	0,51	**15946**	2,83
Nov	21433	5,07	**601**	0,07	80830	14,37
Dec	53643	12,69	**476504**	52,29	84761	15,07
Jan	73531	17,40	232240	25,49	128899	22,91
Feb	72779	17,22	114835	12,60	93433	16,61
Mar	**145003**	34,30	59125	6,49	**139685**	24,83
Apr	52258	12,36	23294	2,56	19057	3,39
Total	***422697***	100,00	***911277***	100,00	***562611***	100,00

Table 2.5.1: *Summary of the thermal mapping measurements (number of measurements and monthly % with respect to the entire road season) taken during road weather seasons of 2008-2009, 2009-2010, and 2010-2011 by the DRD vehicles.*

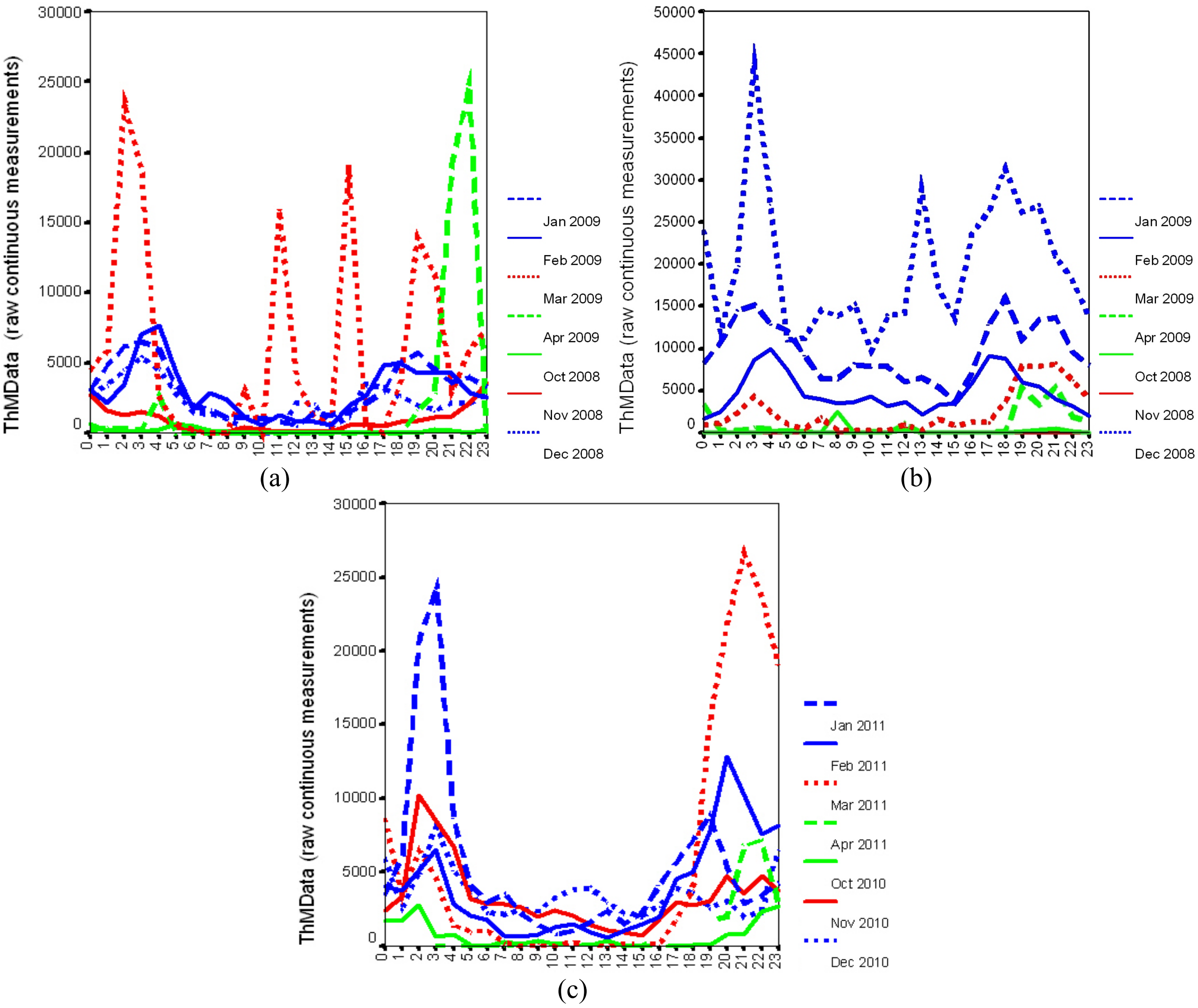


Figure 2.5.1*: Temporal (hours vs. months) distribution of the number of the raw thermal mapping data measurements during road weather season (a) 1 Oct 2008 – 30 Apr 2009, (b) 1 Oct 2009 – 30 Apr 2010, and (c) 1 Oct 2010 – 30 Apr 2011.*

Each record in the DRD database consisted of the following:

(i) identificator of the record in the database;
(ii) identificator of the road activity collecting thermal mapping data from a vehicle;
(iii) time corresponding to the actually taken measurement from a moving vehicle;
(iv) time corresponding to inclusion of the taken measurement into the database;
(v) latitude and longitude of the taken measurement applying GPS;
(vi) measured values of the road surface temperature (in deg C), air temperature (in deg C), and relative humidity (in %).

Note that time is represented by year, month, day, hour, minute, second; and is given in UTCs (universal coordinated time) units.

2.6 Thermal Mapping and Forecasted Data Treatment

For optimization of verification procedure and reduction of the CPU time required for the RCM model re-runs, at first, the number of the road stretches used for the model re-runs was reduced. Note, although the total number of the road stretches accounts for almost 23000 locations, the forecasts at stretches were done only for 12460 locations. These locations were chosen due to obtained spatial distribution of the ThMD vehicles measurements (see Figures 2.6.1-2.6.2) during 2008-2011. For example, the ThMD data were not available from the NordJylland region, and hence, the road stretches from this region were not used for verification.
Moreover, in order to use as much as possible available ThMD, the forecasts of the road surface temperature were performed by re-running the RCM every hour and providing forecasting output at 1 minute interval at all these selected locations. Although, the forecasting was performed for a six hour forecast length, the 3 hour forecasts have been extracted and further used for verification of the road surface temperature at road stretches. Considering that the total number of forecasts produced for 1 run was equal to 4124260, the selected 3h forecasts accounted for 747600.
Each record in forecast output included the following:

(i) identificators of region, road, and stretch;
(ii) time of forecast (year, month, day, hour, minute);
(iii) road surface, air and dew point temperatures (in deg C).

In addition, based on temporal distribution (i.e. days within the months, as well as for more details hours of measurements within the days) of taken ThMD it was possible also to minimize the number of the RCM re-runs required (i.e. RCM was run to produce the road stretches forecasts only for these specific days).

The ThMD measurements, which are closest to the minute within a range of ±5 sec, were extracted and interpolated from the original raw TMD data (see Table 2.6.1). It was done, because:

1) the thermal mapping measurements are done at a very short and non-equal discrete time intervals (due to different velocities of moving vehicles along different parts of the roads);
2) the road stretches are located relatively close to each other (at variable distances of approximately 250 m); and
3) the finest temporal resolution of the RCM forecasts is equal to 1 minute, and hence, ThMD need to be the closest to available forecasts' times.

As seen (Table 2.6.1) such treatment substantially reduced the number of available ThMD which are valuable for verification purposes, but such procedure is a necessary step. These data were also checked on possibility of assigning with geographical positions of selected (from 12460) road stretches and hence, the already revised dataset was again reduced (see Table 2.6.1). The examples of the spatial distribution of the thermal mapping data assigned to positions of road stretches for the road seasons 2008-2011 are shown in Figures 2.6.1-2.6.2. The summaries for other months are shown in Figure 2.6.3 and Appendix C.

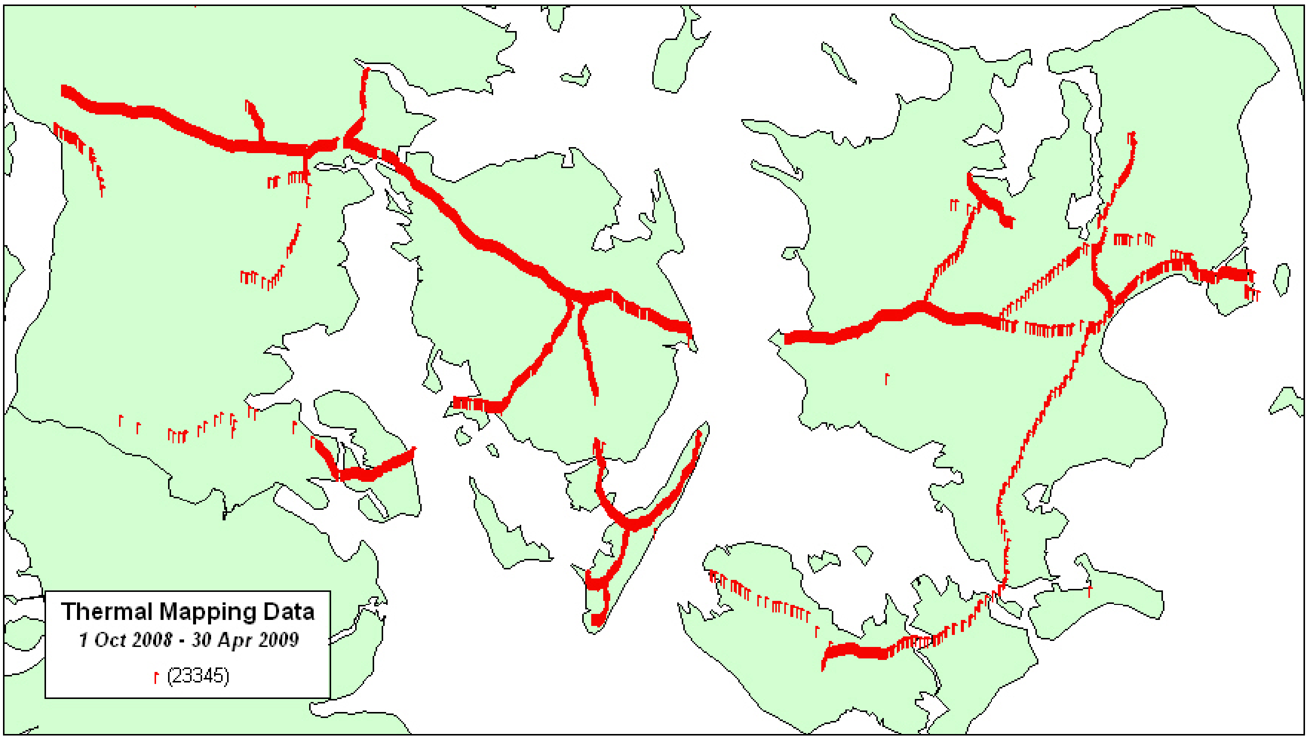
		Thermal Mapping Data, ThMD			
Month	*Year*	*Raw original data*	*Closest to minute within ±5 sec interval*	*Assigned to road stretches*	*Linked with corresponding RWM forecasts at ±3 deg C interval*
Road weather season 2008-2009					
Oct	2008	4050	719	408	<10
Nov	2008	21433	3575	2018	81
Dec	2008	53643	8958	5184	1497
Jan	2009	73531	12121	6889	409
Feb	2009	72779	12222	7080	1878
Mar	2009	145003	26486	1637	71
Apr	2009	52258	9239	129	20
Season		*422697*	*73320*	*23345*	3956
Road weather season 2009-2010					
Oct	2009	4678	885	158	<10
Nov	2009	601	110	4	<10
Dec	2009	476504	82828	49776	49500
Jan	2010	232240	43553	28231	28021
Feb	2010	114835	22913	14275	14067
Mar	2010	59125	10893	3063	2988
Apr	2010	23294	4265	236	191
Season		*911277*	165447	95743	94787
Road weather season 2010-2011					
Oct	2010	15946	2799	1448	1320
Nov	2010	80830	16539	10491	10057
Dec	2010	84761	16088	10186	9859
Jan	2011	128899	22684	9339	8872
Feb	2011	93433	16429	4770	4670
Mar	2011	139685	25183	3507	3301
Apr	2011	19057	3478	252	197
Season		*562611*	103200	39993	38276

Table 2.6.1: *Summary of thermal mapping data pre-screening, interpolating and assigning to road stretches for the road winter seasons of 2008-2011.*

Furthermore, by comparing the road surface temperature measured (from THMD) vs. modeled (forecasted by RCM) at the same road stretches (i.e. same region, same road, and same number of road stretch) geographical positions (latitude and longitude) at identical times (i.e. same year, month, day, hour, minute) a separate dataset was built. In this final dataset only the road surface temperatures within ±3°C interval (as the most important for the building up of icing conditions and further analysis) were selected. Therefore, the final dataset has contained a time series of forecasted (3 h forecast) vs. measured (from thermal mapping data) road surface temperature which was assigned to geographical positions of road stretches as well as linked with produced forecast times.
Each record in the final dataset consisted of the following parameters:

(iv) identificators of region, road, and stretch for the forecast;
(v) time (year, month, day, hour, minute) of forecast at the corresponding above road stretch at specific geographical position;
(vi) forecasted value of the road surface temperature at this stretch;
(vii) identificators of region, road, and stretch for the "observation" (ThMD);
(viii) time (year, month, day, hour, minute) of ThMD measurement at the corresponding above assigned road stretch at specific geographical position;

(ix) observed value of the road surface temperature at this stretch;
(vii) latitude and longitude of the road stretch;
(viii) name of the used input file with forecasts at road stretches.



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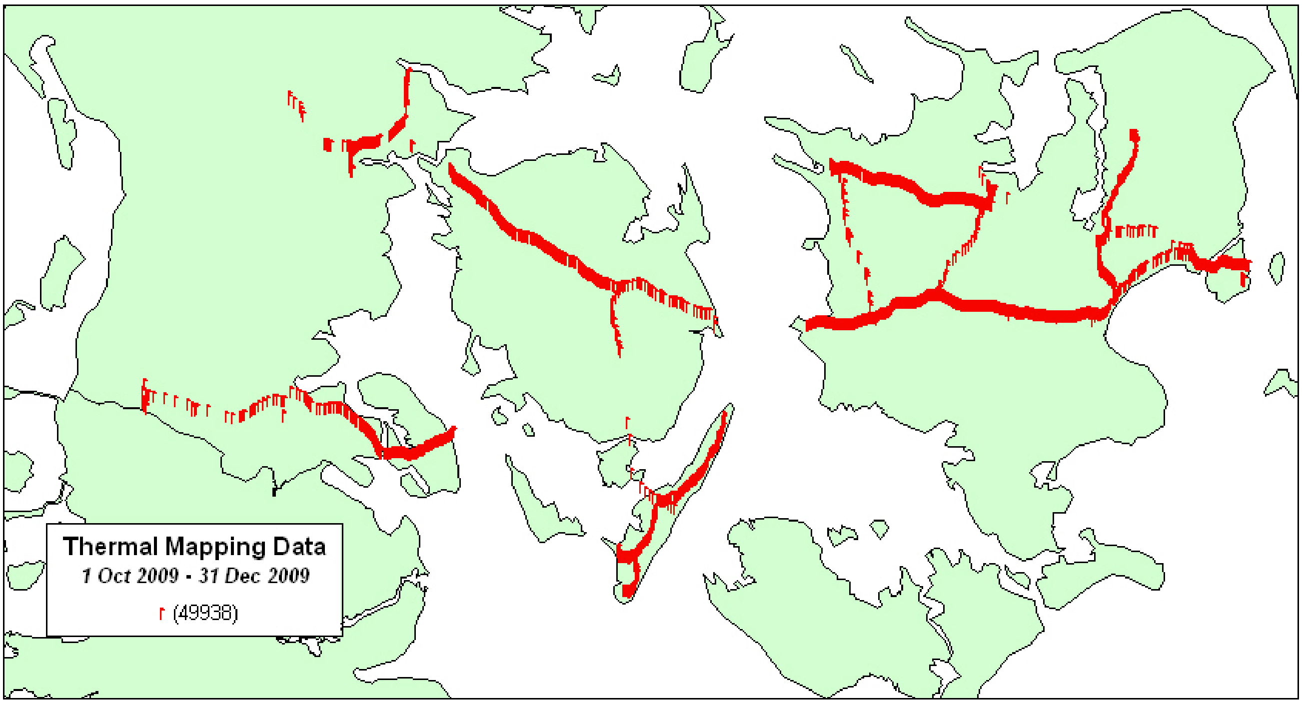
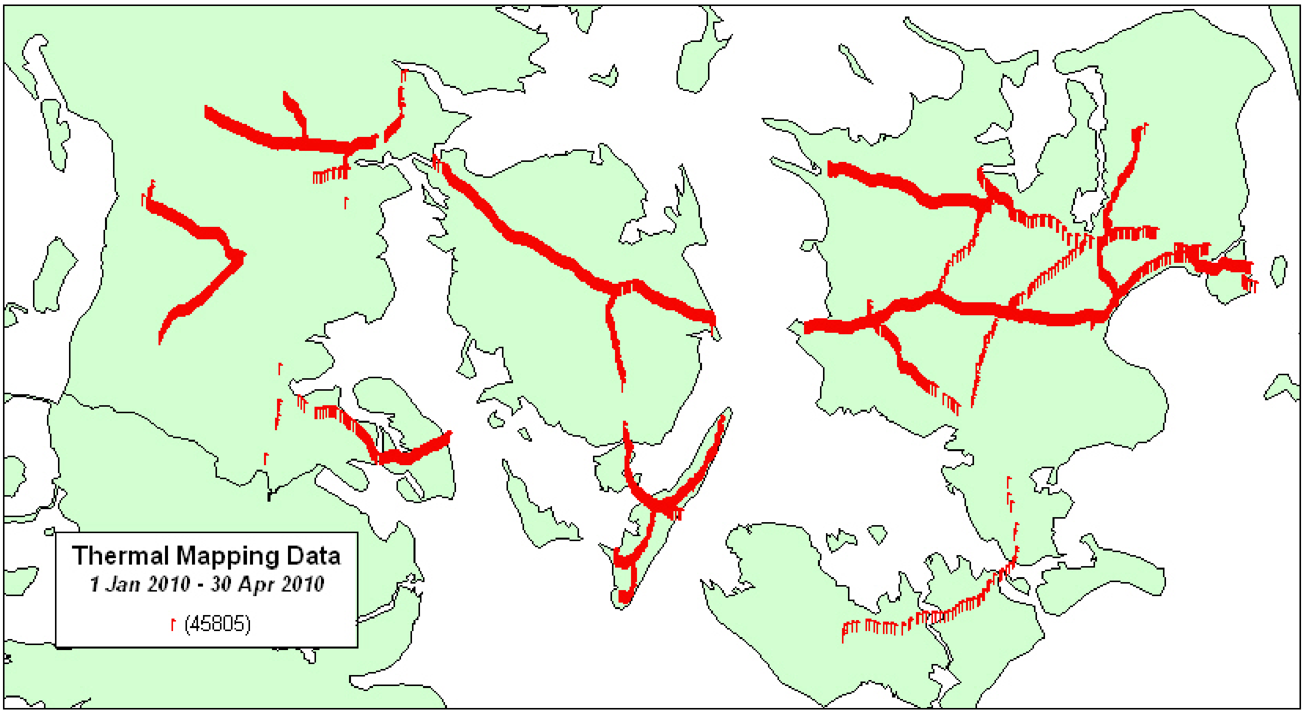


(b)

Figure 2.6.1: *Spatial distribution of thermal mapping data measurements (road surface temperature assigned to road stretches) for road weather season from (a) 1 Oct 2008 – 30 Apr 2009 and (b) 1 Oct – 31 Dec 2009.*



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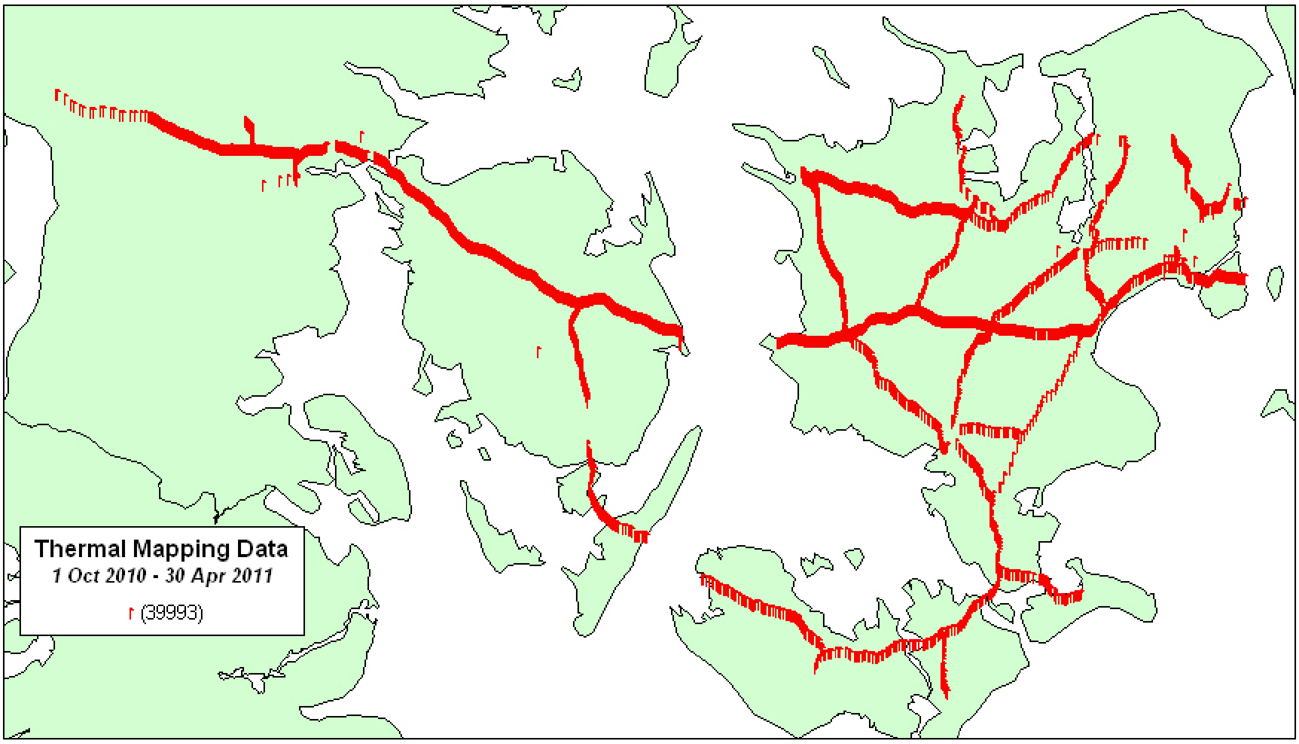
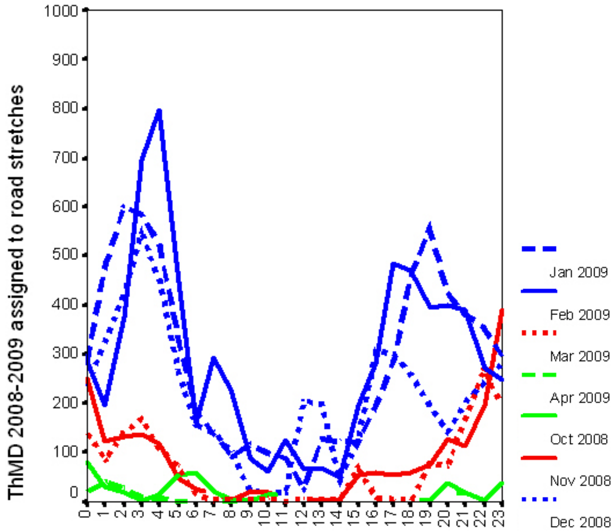


(b)

Figure 2.6.2: *Spatial distribution of thermal mapping data measurements (road surface temperature assigned to road stretches) for road weather season from (a) 1 Jan – 30 Apr 2010 and (b) 1 Oct 2010 – 30 Apr 2011.*



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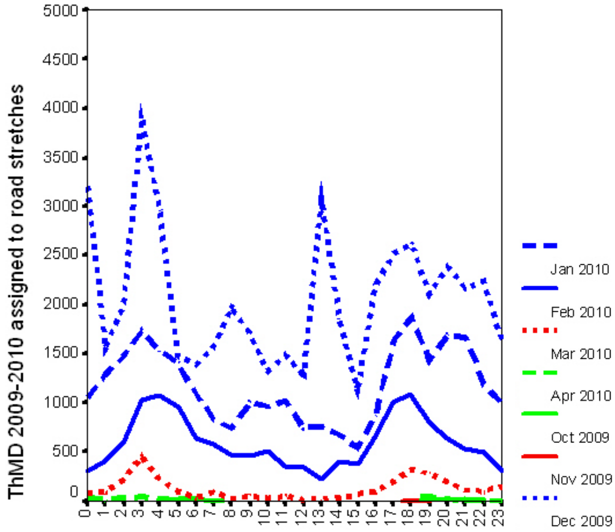

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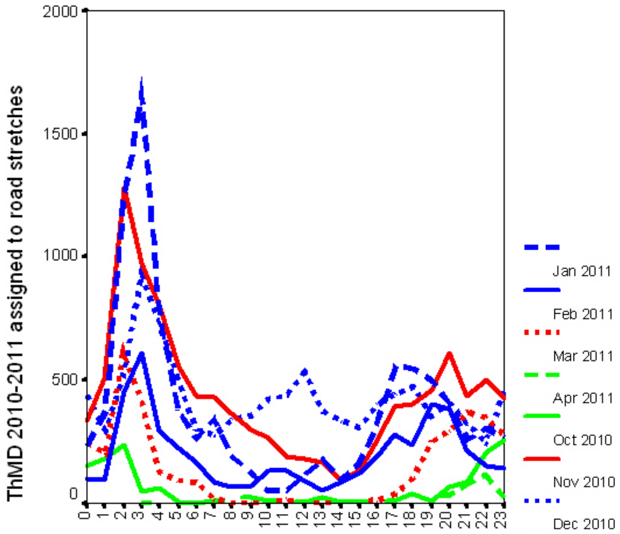


(c)

***Figure 2.6.3**: Temporal (hours vs. months) distribution of thermal mapping data measurements (road surface temperature assigned to road stretches) during road weather season (a) Oct 2008 – Apr 2009, (b) Oct 2009 – Apr 2010, and (c) Oct 2010 – Apr 2011.*

Season	***2008-2009***			***2009-2010***			***2010-2011***		
#	**Road**	**N**	**%**	**Road**	**N**	**%**	**Road**	**N**	**%**
1	123001	2623	11,24	123001	14633	15,28	120001	6829	17,08
2	39002	2416	10,35	39002	11470	11,98	18003	6687	16,72
3	15001	2160	9,25	119003	9698	10,13	41001	5782	14,46
4	132001	1336	5,72	125001	9132	9,54	123001	4118	10,30
5	51001	1328	5,69	15001	6206	6,48	119003	3069	7,67
6	44001	1287	5,51	39001	4787	5,00	44001	2959	7,40
7	291001	1076	4,61	17001	3835	4,01	17001	2186	5,47
8	1002	1020	4,37	291002	3809	3,98	47001	1783	4,46
9	41001	930	3,98	4003	3624	3,79	15001	863	2,16
10	18003	916	3,92	291001	3230	3,37	234010	654	1,64
Σ 1-10		**15092**	**64,65**		**70424**	**73,56**		**34930**	**87,34**
Σ rest of roads		8253	35.35		25319	26.44		5063	12.66
Total		23345	100		95743	100		39993	100

***Table 2.6.2:** Ten-top largest time-series of ThMD measurements for selected Danish roads /N – number of ThMD measurements assigned to positions of road stretches along the roads/.*

These listed parameters were included in order to have a scrutinized double check of both the forecasted and observed values of the road surface temperature to be sure that these are interlinked exactly in space (geographical position of stretch) and in time (same times for both forecast and assigned ThMD measurement at geographical position of stretch).
A summary on roads with largest time-series of ThMD measurements assigned to road stretches positions along the roads is given in Table 2.6.2. Examples of spatial distribution of assigned ThMD for selected roads are given in Figure 2.6.4.

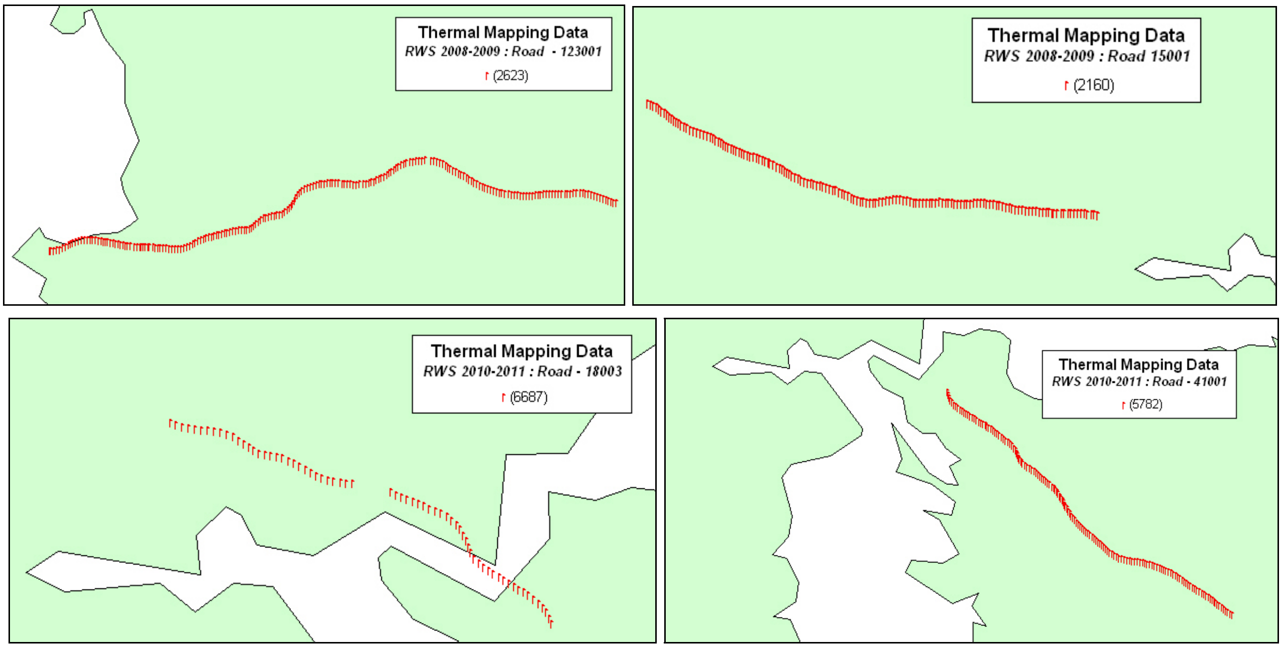


Figure 2.6.4: *Selected roads with largest time-series of ThMD measurements assigned to positions of road stretches along the roads.*

2.7 Evaluated Parameters

For tasks of the road stretches 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 RWM system forecasting performance was done by analysis of the mean absolute error, *MAE* and bias, *BIAS* for 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.

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

3 Results and Discussions

3.1 Summary of Verification for 2008-2011 Road Weather Season

For the three (2008-2009, 2009-2010, and 2010-2011) road seasons, the score for the 3 hour forecasts of the road surface temperature at road stations of the Danish road network with an error of less than ±1ºC was 80, 82.5, and 81.9% based on more than 519, 473, and 563 thousand corresponding forecasts (see details in *Petersen et al., 2009, 2010, 2011*).
The overall seasonal averages of the bias and mean absolute error were -0.11, +0.02, and +0.09ºC and 0.76, 0.69, and 0.70ºC, respectively for the last three subsequent seasons (see Table 3.1.1). It showed a better performance of the road conditions model compared with the previous seasons 2005-2006, 2006-2007, and 2007-2008, where the biases and mean absolute errors were +0.31, +0.22, and +0.18ºC and 0.78, 0.74, and 0.78ºC, respectively.

Road Season		2005-06	2006-07	2007-08	2008-09	2009-10	2010-11
BIAS	**Ts**	**0.31**	**0.22**	**0.18**	**-0.11**	**0.02**	**0.09**
	Ta	0.15	-0.02	-0.04	0.02	0.12	-0.15
	Td	0.27	0.33	0.31	0.24	0.44	0.12
MAE	**Ts**	**0.78**	**0.74**	**0.78**	**0.76**	**0.69**	**0.70**
	Ta	0.80	0.77	0.81	0.72	0.68	0.65
	Td	0.86	0.86	0.87	0.75	0.80	0.81
Score		**80**	**83**	**81**	**80**	**82.5**	**81.9**

Table 3.1.1 *: Summary of overall BIAS and MAE of the road surface temperature (Ts), air temperature (Ta), and dew point temperature (Td) for the road seasons of 2005-2011.*

3.2 Thermal Mapping Data (ThMD) vs. Road Stations Observations

3.2.1 Assignment of ThMD to Observations at Road Stations

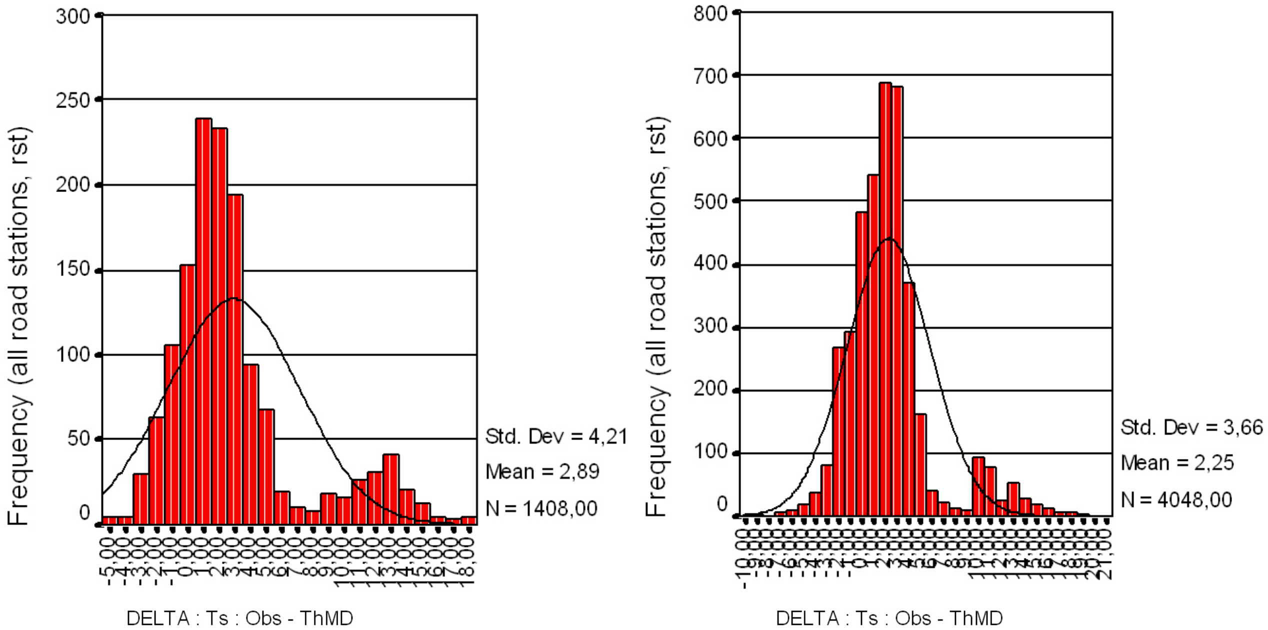
Thermal mapping data has been compared vs. observations at the road stations. For that the pretreatment of the ThMD measurements for the road weather seasons had been done. A summary is presented in Table 3.2.1. First of all, the original raw ThMD data has been assigned to times/ terms of measurements at road stations (every 10 minutes) within a ±3 second time interval. Second, these data has been assigned to positions of road stations within 3 different distance intervals (in meters) along the driving lanes from the road station. Three intervals have been considered: ±25, ±50 and ±75 meters from the position of the station. The estimation of distance between the GPS positions of the road stations and ThMD measurement points of the road surface is given in Appendix D. Note, that among these re-assigned the majority is represented only by one point on the road, and roughly half of these data are within ±3ºC interval. Finally, the averaged ThMD has been re-assigned to positions of road stations.

Table 3.2.1*: Statistics on pre-treatment of the ThMD measurements for road weather seasons of 2008-2010.*

Road weather season / ***ThMData***	***2008-2009***			***2009-2010***		
Original raw data from DRD database	422697	422697	422697	911277	911277	911277
Assigned to times of measurements (every 10 min) at RSTs within ±3 sec time interval	777	1904	3052	3681	7196	10498
Distance Interval from the RST to position of ThMD measurement	***±25 m***	***±50 m***	***±75 m***	***±25 m***	***±50 m***	***±75 m***
*Assigned to positions of RST with a distance intervals of ±25, 50, and 75 m	666	1571	2471	2255	4891	7061
From assigned, all available only at 1 point on the road	588	1387	2161	1844	3990	5502
From assigned, all available within ±3°C interval	464	1071	1696	1204	2444	3643
Averaged from (*) and re-assigned to positions of road stations	388	888	**1408**	1190	2830	**4048**

3.2.2 Deviations between ThMD and Observations at Road Stations

Frequency, as histograms of distributions of the road surface temperature deviations ($Ts_{obs} – Ts_{ThMD}$, in deg C) between observations at road stations vs. averaged thermal mapping data measurements assigned to positions of road stations - for all road stations for the road weather seasons of 2008-2010 as shown in Figure 3.2.1. Examples of such distributions for selected road stations are shown in Figure 3.2.2. Frequency of *Ts* deviations for a selected *Ts* interval (±3ºC) is shown in Figure 3.2.3. A summary of distribution of the road surface temperature deviations assigned to positions of road stations (within intervals of ±75, 50, 25 meters in distance from the position of the road station) during road weather season of 2008-2009 is given in Table 3.2.2 (only road stations having 10 and more values are included into the table).



(a) *(b)*

Figure 3.2.1*: Histograms of distributions of the road surface temperature deviations, in deg C (between observations at road stations vs. averaged thermal mapping data measurements assigned to positions of road stations) for all road stations for the road weather seasons (a) 2008-2009 and (b) 2009-2010.*

As seen from Figure 3.2.1, the distributions of *Ts* deviations have two modes, and hence, a possibility of included "poor quality" original ThMD should be investigated. For that an analysis of distributions a station-by-station has been done.

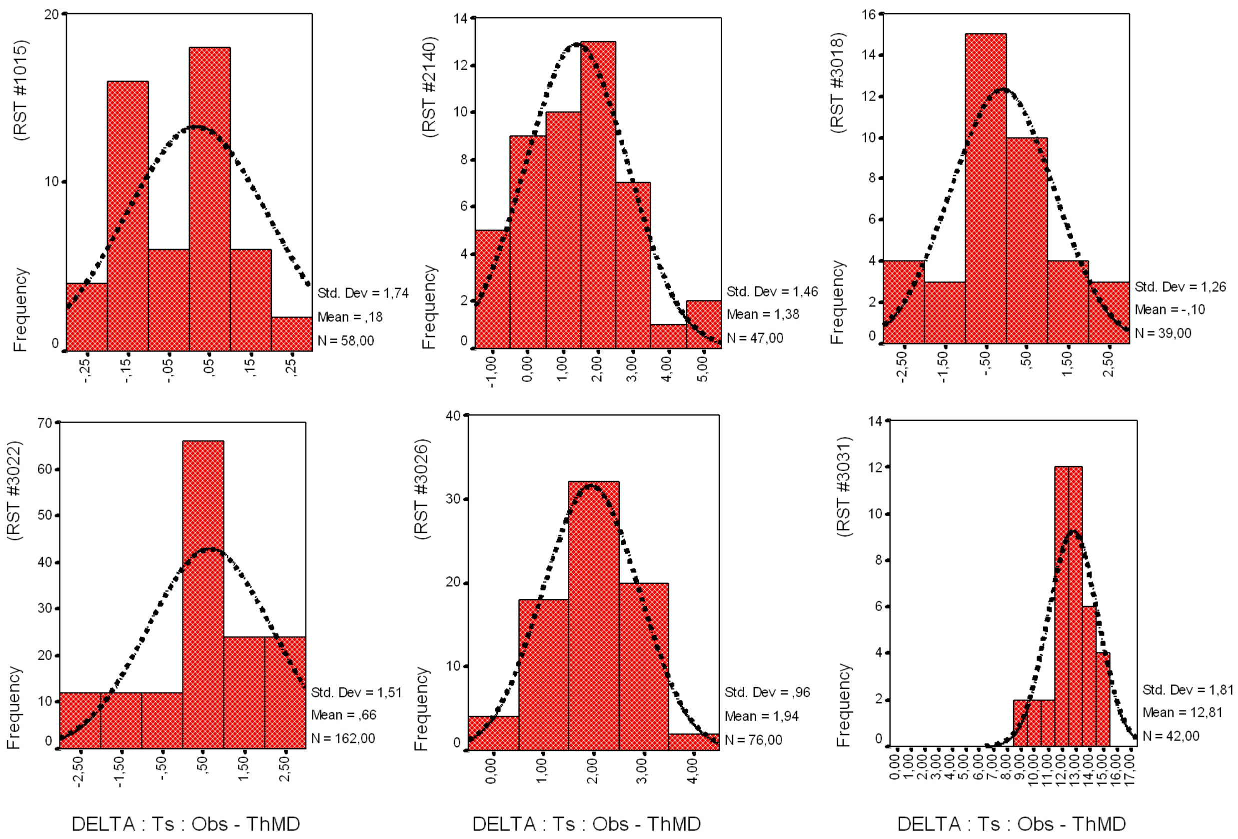


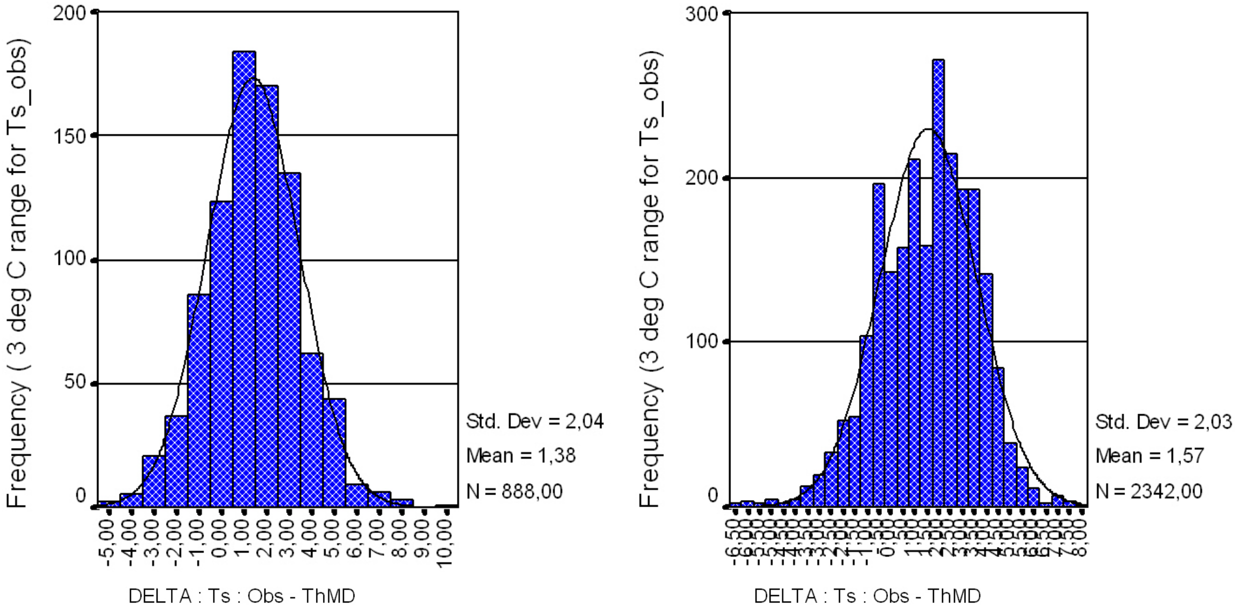
Figure 3.2.2*: Histograms of distributions of the road surface temperature deviations, in deg C (between observations at road stations and averaged ThMD) within a distance interval of ±75 meters from the positions of the selected road stations during the road season of 2008-2009.*

As seen in Table 3.2.2 (on example of road season 2008-2009) the mean *Ts* deviations at road stations for different distance intervals (±75, 50, and 25 meters from the position of the road station to the position of the ThMD measurement) vary substantially from station to station. Note, that in addition to listed in the table stations, the rest of other stations contributed a smaller number of such cases, i.e. having less than 10 cases per station. For example, a contribution of such cases for a distance interval of ±75 m is only 4.3%. Moreover, several road stations have shown large *Ts* deviations (for example, RST#3005, 3006, etc – stations marked in red). Such large deviations might be related to technical aspects of original calibration of the devises used for the ThMD measurements, showing always lower road surface temperatures measured by devices (see example on Figure 3.2.2 for the road station #3031; and for other similar stations in Section 3.2.3). Inclusion of such cases (as seen in Figure 3.2.1 as secondary maxima in histograms) into statistical analysis can degrade the overall evaluation of the *Ts* accuracy of measurements (i.e. spatially variable measurements along the driving lanes at different positions along the roads vs. local measurements at fixed positions of road stations). Therefore, such data should be treated more accurately, reasons for such large deviations should be investigated and/or such data should be excluded from analysis.
In order to keep as much as possible ThMD assigned to road stations positions the largest distance interval has been used (i.e. ±75 m). A summary of the mean *Ts* deviations for this distance interval during road weather seasons 2008-2010 is given in Table 3.2.3. As seen for the road season 2009-2010, all other road stations have contributed only 1.5% from total of 4048 cases analyzed. The mean Ts deviation was around 2.25ºC.
As seen in Figure 3.2.3, the distribution of frequencies of *Ts* deviations for a selected *Ts* interval

(±3ºC) is close to the normal distribution. For 2008-2009, the mean *Ts* deviation was about 1.38ºC with a standard deviation of 2.04 ºC. For 2009-2010, the mean *Ts* deviation was about 1.57 ºC with a standard deviation of 2.03 ºC.

Table 3.2.2*: The mean road surface temperature deviations (between observations at road stations, RST and averaged ThMD) assigned to positions of road stations (within intervals of ±75, 50, 25 meters in distance from the position of the road station) during road weather season of 2008-2009.*

Distance to RST	**±75 m**			**±50 m**			**±25 m**	
	Count	**Mean**		**Count**	**Mean**		**Count**	**Mean**
RST			***RST***			***RST***		
1015	58	0,18	*1015*	52	0,17	*1015*	32	-0,08
1016	44	0,23	*1016*	32	0,49	*1016*	20	0,29
1549	60	-0,45	*1549*	16	0,78	*1823*	11	-1,18
1822	14	-1,07	*1823*	19	-1,46	*2007*	20	1,98
1823	26	-1,31	*2007*	34	2,41	*2009*	18	1,85
1824	12	-0,68	*2008*	14	2,90	*2020*	14	2,50
2007	52	2,95	*2009*	42	2,06	*3005*	24	9,50
2008	22	2,96	*2020*	30	3,14	*3018*	14	-0,08
2009	60	2,22	*3002*	10	-0,03	*3022*	72	0,94
2020	48	3,48	*3003*	26	-0,08	*3023*	16	2,31
2140	47	1,38	*3004*	54	3,59	*3024*	10	3,16
3002	17	0,19	*3005*	54	8,55	*3025*	12	2,77
3003	44	-0,09	*3006*	27	7,68	*3026*	16	1,61
3004	75	3,34	*3018*	24	-0,32	*3461*	14	13,12
3005	88	7,95	*3022*	108	0,72	*5200*	16	1,20
3006	47	8,18	*3023*	48	1,97	***Other RST***	***79***	
3018	39	-0,10	*3024*	16	2,80	***All RST***	***388***	
3022	162	0,66	*3025*	84	2,58			
3023	66	2,05	*3026*	50	1,94			
3024	26	2,64	*3031*	28	12,76			
3025	112	2,48	*3360*	10	2,92			
3026	76	1,94	*3461*	30	12,52			
3030	10	12,17	*5200*	16	1,12			
3031	42	12,81	***Other RST***	***64***				
3360	10	2,92	***All RST***	***888***				
3460	13	12,65						
3461	43	12,43						
4011	18	0,97						
5200	16	1,06						
Other RST	***61***							
All RST	***1408***							



(a) *(b)*

Figure 3.2.3*: Histograms of distributions of the road surface temperature deviations, in deg C (between observations at road stations, Obs, vs. averaged thermal mapping data (ThMD) measurements assigned to positions of road stations) for all road stations for the Ts range of ±3 deg C for the road weather seasons (a) 2008-2009 and (b) 2009-2010.*

Road Season 2008-2009			Road Season 2009-2010		
RST	**Count**	**Mean**	***RST***	**Count**	**Mean**
1015	58	0,18	*1008*	19	-0,16
1016	44	0,23	*1015*	174	-0,46
1549	60	-0,45	*1016*	88	-0,57
1822	14	-1,07	*1017*	33	-0,53
1823	26	-1,31	*1018*	74	0,25
1824	12	-0,68	*1020*	20	0,16
2007	52	2,95	*1549*	184	-0,72
2008	22	2,96	*1620*	16	0,39
2009	60	2,22	*1822*	43	-2,65
2020	48	3,48	*1823*	57	-2,41
2140	47	1,38	*1824*	27	-1,84
3002	17	0,19	*2003*	180	3,1
3003	44	-0,09	*2005*	199	3,36
3004	75	3,34	*2007*	446	1,12
3005	88	7,95	*2008*	63	0,84
3006	47	8,18	*2009*	280	0,92
3018	39	-0,1	*2140*	117	2,83
3022	162	0,66	*3004*	333	2,8
3023	66	2,05	*3005*	292	3,18
3024	26	2,64	*3006*	269	7,24
3025	112	2,48	*3009*	63	3,03
3026	76	1,94	*3010*	120	3,18
3030	10	12,17	*3014*	80	2,94
3031	42	12,81	*3015*	71	2,72
3360	10	2,92	*3017*	107	-1,45
3460	13	12,65	*3018*	104	-0,38
3461	43	12,43	*3023*	26	1,35

4011	18	0,97	*3024*	12	2,1
5200	16	1,06	*3025*	76	2,55
Other RST	***61***		*3026*	86	2,07
All RST	***1408***	**2,89**	*3031*	10	11,48
			3032	14	13,36
			3033	154	-0,23
			3460	22	12,64
			3461	114	13,74
			4001	14	1,76
			Other RST	**61**	
			All RST	**4048**	**2,25**

Table 3.2.3: *Distribution of the road surface temperature deviations (between observations at road stations, RST and averaged ThMD) assigned to positions of road stations (within intervals of ±75 meters in distance from the position of the road station) during road weather seasons 2008-2010.*

3.2.3 Largest Deviations between ThMD and Road Stations Observations

Among all road stations considered, several have shown the largest deviations between the ThMD measurements and measurements of the road surface temperature at the road stations (see Tables 3.2.2 and 3.2.3). All road stations having the largest *Ts* deviations are shown in Figure 3.2.4.
The geographical positions of the ThMD measurements assigned to locations of selected road stations (#3461 and #3006) within a distance interval of ±75 meters from the positions of the road stations are shown in Figure 3.2.5. The histograms of *Ts* deviations for the same locations as the road stations are shown in Figure 3.2.6, where it can be seen that ThMD always show lower values compared with road stations observations.

Figure 3.2.4: *Spatial locations of the road stations having the largest Ts deviations (difference in deg C between the road station and ThMD observations of the road surface temperature) during road seasons 2008-2010.*

Possible reason for such large deviations can be linked with an instrumental error or issues of calibration of measuring devices. Here, re-evaluation of *Ts* deviations has been done assuming that such ThMD measurements can be erroneous and hence, such data should be, in principle, excluded during screening procedure and should not be further used for purposes of verification. For that, evaluation for datasets with including and excluding locations having the largest values of deviations compared with closest road stations was performed, and results are summarized in Table 3.2.4. As seen, during the road weather season 2008-2009, at locations of 7 road stations the largest deviations contributed 248 cases (17.6%) in the total of 1408. If measurements at road stretches (always showing larger deviations compared with the road station observations) corresponding to these 7 locations are accounted in analysis than the mean *Ts* deviation is about 2.89ºC, if these are excluded – it is 1.36ºC. As seen, it will be almost 50% improvement in differences between measurements at road stations and at vehicle devices (i.e. ThMD). The differences became substantially smaller.

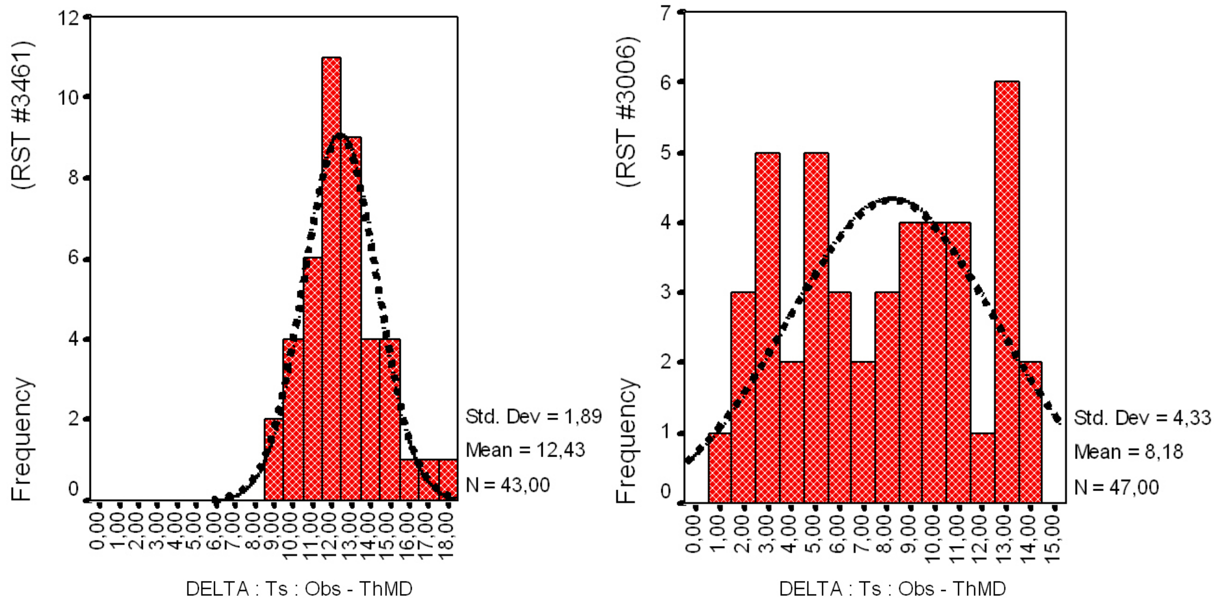
Similarly, for the road season 2009-2010, practically at the same locations (except along some roads, where the road stations are located, but ThMD measurements were not carried out compared with the previous road season) the largest *Ts* deviations were again observed. So, again if these locations are included than the mean *Ts* deviation is about 2.25ºC, and if these are excluded – it is lower, i.e. 1.39ºC. Moreover, after exclusion of such measurements the frequency distribution of *Ts* deviations became closer to the normal distribution as seen in Figure 3.2.7.

(a) (b)

Figure 3.2.5: *Positions of the ThMD measurements (with highest deviations from the road station measurements) assigned to locations of road stations (a) #3461 and (b) #3006 within a distance interval of ±75 meters from the positions of stations (during road season of 2008-2009) /extracted from Google/.*

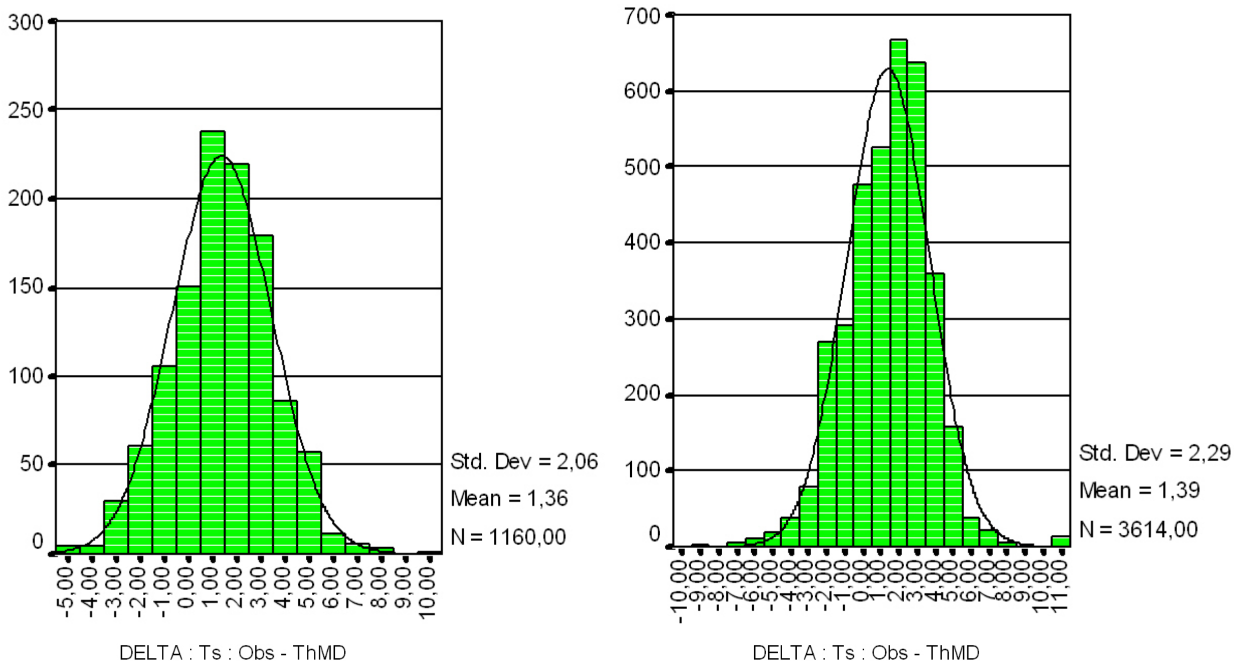
Table 3.2.4: *List of road stations for which the ThMD measurements showed the largest Ts deviations between the ThMD and road station observations (within interval of ±75 meters in distance from the position of the road station) and summary statistics for the mean Ts deviation with included & excluded list of stations.*

Road season 2008-2009				**Road season 2009-2010**			
	RST	**Count**	**Mean**		**RST**	**Count**	**Mean**
	3005	88	7,95			-	-
	3006	47	8,18		*3006*	269	7,24
	3030	10	12,17		*3030*	2	13,65
	3031	42	12,81		*3031*	10	11,48
		-	-		*3032*	14	13,36
	3140	5	9,98			-	-
	3460	13	12,65		*3460*	22	12,64
	3461	43	12,43		*3461*	114	13,74
Σ		248		**Σ**		434	
Incl		**1408**	**2,89**	**Incl**		**4048**	**2,25**
Excl		**1160**	**1,36**	**Excl**		**3614**	**1,39**



(a) *(b)*

Figure 3.2.6*: Histograms of distributions of deviations (difference in deg C between the road station and ThMD observations of the road surface temperature) within a distance interval of ±75 meters from the positions of the road stations (left) #3461 and (right) #3006 (during the road season of 2008-2009).*



(a) *(b)*

Figure 3.2.7*: Histograms of distributions (frequency – vertical axis) of the road surface temperature deviations, in deg C (between observations at road stations, Obs, vs. averaged thermal mapping data (ThMD) measurements assigned to positions of road stations) excluding road station with poorly-calibrated ThMD devices for the road weather seasons (a) 2008-2009 and (b) 2009-2010.*

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

3.3.1 Diurnal Cycle and Monthly Variability

Evaluation of the RWM system forecasting performance (employing DMI-HIRLAM NWP model with a horizontal resolution of 0.03 deg in a rotated system of coordinates) was done by analysis of the mean absolute error, MAE and mean error, BIAS for *Ts* as a difference between the 3 hour forecasted and observed values (based on ThMD). For road stretches, in terms of MAE and BIAS the overall *Ts* verification scores for the studied period were comparable with forecasts at road stations.

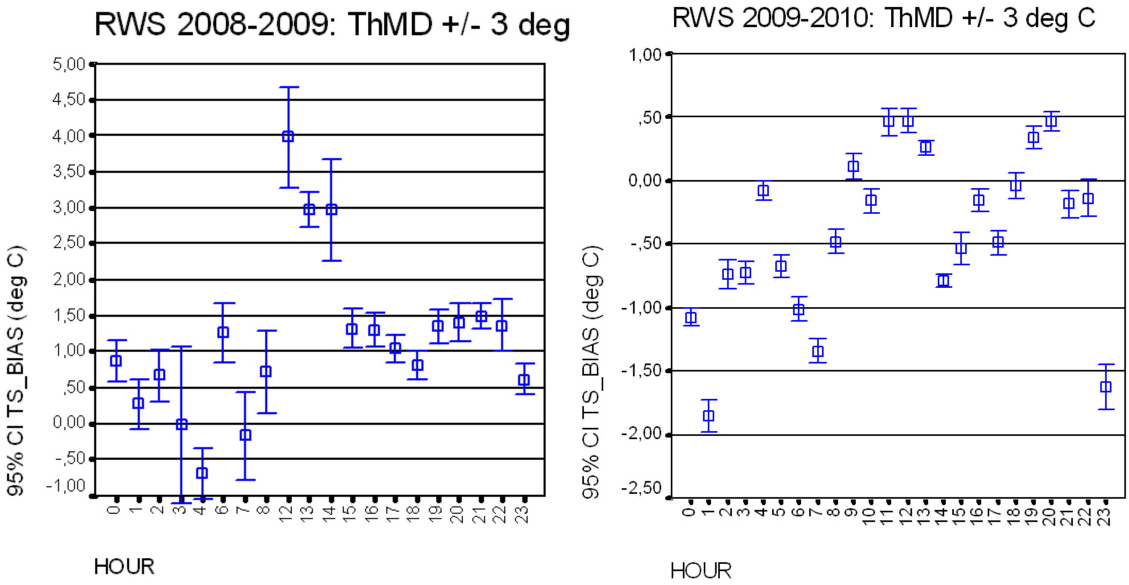
Although, the RCM forecasting is done on a 24 hour time scale, the salting activities along the roads are conducted mostly during evening-nighttime hours (from 18 till 06 hours), and hence, the ThMD available during these hours are of major interest in forecasting occurrences of icing conditions at road stretches.

For road seasons 2008-2010, the diurnal cycle variability of Ts bias and mae is summarized in Table 3.3.1 (where N is a number of cases used in calculation of statistics). The variability of Ts bias on a diurnal cycle for three recent road weather seasons is shown in Figure 3.3.1.

On average, on a diurnal cycle, the bias was +1.10 and -0.37°C and the mae was 1.71 and 1.57°C, for the three seasons, respectively. During 2008-2009, the bias was better during nighttime hours, and it has bee the largest during daytime hours (i.e. 12-14). Although on a diurnal cycle, the bias was mostly positive, it had a negative sign during 03-07 hours. For 2009-2010 season, the bias had improved reaching -0.37°C. It became negative during late evening – nighttime – early morning hours. The best (lowest) bias was -0.1°C at 04 hours.

Table 3.3.1: *BIAS and MAE (deg C) of the road surface temperature (Ts) on a diurnal cycle for all stretches of all roads for the road weather seasons 2008-2010.*

	RWS 2008-2009			**RWS 2009-2010**		
Hour	**BIAS**	**MAE**	**N**	**BIAS**	**MAE**	**N**
0	0,88	1,44	139	-1,08	1,37	2715
1	0,28	1,70	163	-1,85	2,13	1540
2	0,67	1,73	114	-0,74	1,78	1751
3	-0,01	1,91	19	-0,73	1,44	2446
4	-0,70	0,70	6	-0,08	1,21	2304
5				-0,67	1,39	1825
6	1,27	1,27	13	-1,01	1,51	1541
7	-0,17	1,43	29	-1,34	1,69	1393
8	0,72	0,72	5	-0,48	1,90	2116
9				0,11	1,63	2011
10				-0,16	1,34	1702
11				0,47	1,75	1808
12	3,98	3,98	21	0,47	1,47	1403
13	2,97	2,97	36	0,26	1,03	2736
14	2,96	2,96	4	-0,79	1,29	3242
15	1,32	1,87	169	-0,53	1,73	1007
16	1,30	1,82	250	-0,15	1,41	1500
17	1,04	1,64	326	-0,49	1,73	2121
18	0,81	1,62	282	-0,05	1,80	2117
19	1,35	1,74	199	0,34	1,70	2044
20	1,40	1,94	205	0,46	1,56	2444
21	1,50	1,67	232	-0,19	1,56	1590
22	1,37	1,73	91	-0,14	2,20	1552
23	0,62	1,05	135	-1,63	2,28	885
Total	**1,10**	**1,71**	**2438**	**-0,37**	**1,57**	**45793**



(a) *(b)*

***Figure 3.3.1:** Diurnal cycle of the mean error, BIAS, at 95% confidence interval of the road surface temperature (Ts) during road weather seasons (RWS) (a) 2008-2009, and (b) 2009-2010.*

The month-to-month variability of the diurnal cycle is presented in Appendix E. Mention, that for some months, for example, April 2010 only relatively small number (124 in total) of measurements was available within a Ts range of ±3°C and only at a few terms (hours); hence, these have been excluded from a summary Table E2 in Appendix E.
During 2008-2009 season, the best (lowest) Ts bias of +0.92°C has been in February 2009 with mae of 1.60°C. Averaged other the season, the bias was always positive (+1.10°C).
During 2009-2010 season, the best (lowest) Ts bias of -0.15°C has been in December 2009 with mae of 1.23°C. Averaged other the season, the bias was negative (-0.37°C). Although bias had also a negative sign during winter months (Dec-Jan-Feb), but it was positive in March and April 2010.

3.3.2 Roads and Road Stretches

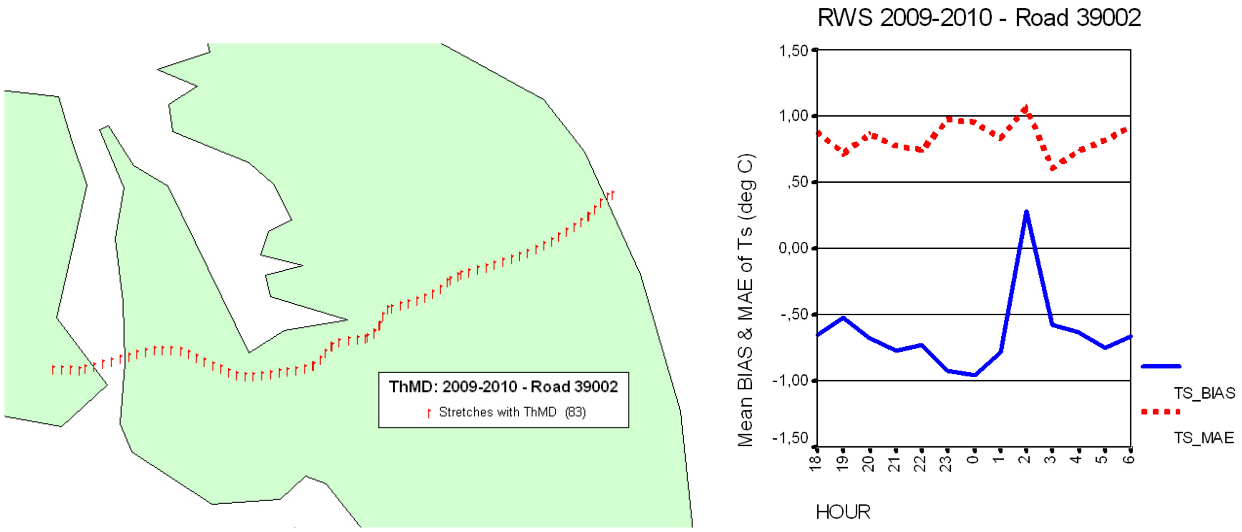
Analyses of Ts bias and mae by individual Danish roads for road seasons 2008-2011are summarized in Appendix F (Tables F1, F2, and F3).

During 2008-2009 the ThMD measurements at road stretches had been carried out along 49 Danish roads, although at almost 20 of these roads the number of measurements was limited to less than 10 per road. From these 49 roads, 26 roads are situated in region 1, 9 – in region 6, 12 – in region 5, and only one road in region 3 (road 23003) and 4 (road 88005). Considering all temperature intervals for Ts, the region 1 has the largest number (2896) of ThMD measurements assigned to positions of road stretches; the second largest number (749) has the region 5. When only a Ts range of ±3°C is considered for icing conditions, the number is reduced to 1868 and 596 for the 1st and 5th regions, respectively.
During 2009-2010 the ThMD measurements at road stretches had been carried out along 56 Danish roads, although at almost 20 of these roads the number of measurements was limited to less than 10 per road. From these 56 roads, 23 roads are situated in region 1, 21 – in region 6, 11 – in region 5, and only 1 road (23003) in region 3. Considering all temperature intervals for Ts, the region 1 has the largest number (39982) of ThMD measurements assigned to positions of road stretches; the second largest number (34148) has the region 5. When only a Ts range of ±3°C is considered for icing conditions, the number is reduced to 21352 and 20713 for the 1st and 5th regions, respectively.

For 2008-2009 season, in total, from 23345 averaged ThMD measurements 2438 were within a range of ±3°C. A summary of bias and mae for the road surface temperature (based on ThMD) for Danish roads is shown in Table F2 (Appendix F). It should be noted that only roads, where the ThMD measurements were carried out, were studied. Note that these roads have multiple number of road stretches, varying in number and positioning from road to road. Statistics on bias and mae with corresponding number/ counts used for evaluation of these parameters is shown for each road where the ThMD measurements were carried out (note, if a few measurements are available for the road then the statistical output is in a question). Two periods were considered: the evening-nighttime period (from 18 till 06 hours) and the morning-daytime period (from 06 till 18 hours). Although there is large variability between the roads, on average, for all roads considered, the bias and mae were +1.10°C and 1.71°C, respectively. On average, both the bias and mae were slightly higher for the morning-daytime period, i.e. +1.30°C and 1.85°C, compared with the evening-nighttime: +1.00°C and 1.64°C, respectively.
For 2009-2010 season, in total, from 95494 averaged ThMD measurements 45793 were within a range of ±3°C. A summary of bias and mae for the road surface temperature (based on ThMD) for Danish roads is shown in Table F2 (Appendix F). Although there is large variability between the roads, on average, for all roads considered, the bias and mae were -0.37°C and 1.57°C, respectively, which was an improvement by more than half of degree in bias compared with 2008-2009 season. On average, both the bias and mae were slightly higher for the morning-daytime period, i.e. -0.24°C and 1.51°C, compared with the evening-nighttime: -0.49°C and 1.63°C, respectively.

3.3.3 Roads with Longest Time-Series of Measurements: 39002 and 123001

During road weather season (RWS) 2009-2010, the largest number of the ThMD measurements was carried out along the two roads – 39002 (situated in the south-eastern part of the Jutland Peninsula) and 123001 (situated in the western central part of the Zealand Island). Results of comparison of the ThMD measurements (averaged and assigned to road stretches positions of these two roads) vs. road conditions model forecasts are summarized here.
In total, 11653 averaged ThMD measurements (covering all Ts temperature ranges) of the road surface were assigned to road stretches positions of the road 39002. For these, on average, the bias and mae were -0.57°C and 0.88°C, respectively.



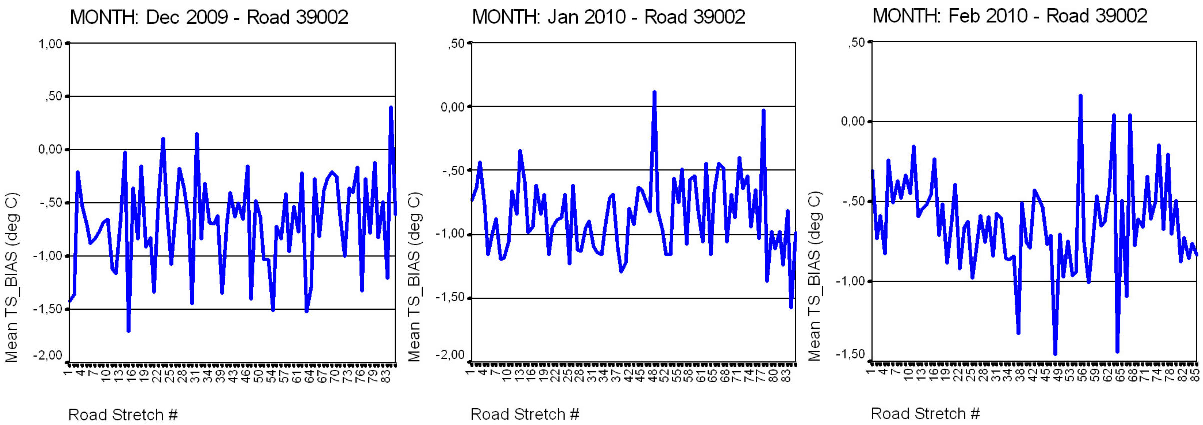
(a) *(b)*

***Figure 3.3.2**: (a) ThMD measurements assigned to positions of road stretches (road 39002), and (b) mean bias and mae of Ts (based on ThMD) during evening-nighttime hours for the road weather season (RWS) 2009-2010.*

From these 11653, in total only 9809 ThMD were within a range of ±3°C (see Figure 3.3.2a). Among these, the 5094 are linked with 18-06 hour period and 4715 - from 06 till 18 h. On average, on a diurnal cycle, the bias (mae) was -0.68°C (0.89°C). For evening-nighttime hours the bias (mae) was -0.55°C (0.85°C); and for morning-daytime hours the bias and mae were larger (-0.82°C and 0.93°C, respectively) compared with evening-nighttime period.

***Table 3.3.2**: Diurnal cycle of the mean bias and mae of Ts (based on ThMD) for roads 39002 and 123001 for the road weather season 2009-2010.*

Road	39002			123001		
Hour	**BIAS**	**MAE**	**Count**	**BIAS**	**MAE**	**Count**
0	-0,95	0,95	231	-1,63	2,28	264
1	-0,78	0,83	601	-0,06	1,68	124
2	0,28	1,06	787	-0,54	1,93	143
3	-0,57	0,61	547	-0,38	0,91	652
4	-0,63	0,74	233	0,53	0,78	968
5	-0,75	0,81	474	0,04	0,90	812
6	-0,66	0,93	626	-0,41	1,26	472
7	-1,13	1,23	541	-0,43	1,74	178
8	-1,44	1,44	616	1,24	2,11	748
9	-0,80	0,85	348	0,69	1,36	923
10	-0,48	0,73	109	0,18	0,63	679
11	-0,61	0,80	86	-0,35	1,48	183
12	-0,55	0,91	90	0,93	1,50	402
13	-0,23	0,48	1045	1,33	1,46	885
14	-0,81	0,82	1307	-0,48	1,21	200
15	-1,12	1,37	92	0,50	1,62	134
16	-1,34	1,47	237	0,03	1,22	141
17	-0,80	1,07	244	-0,58	1,78	216
18	-0,65	0,88	249	0,24	1,36	221
19	-0,52	0,72	200	1,23	1,83	298
20	-0,67	0,86	455	1,51	2,18	446
21	-0,77	0,77	242	0,60	1,45	318
22	-0,73	0,74	277	1,29	2,55	391
23	-0,92	0,98	172	-0,08	2,01	128
Total	**-0,68**	**0,89**	**9809**	**0,44**	**1,42**	**9926**

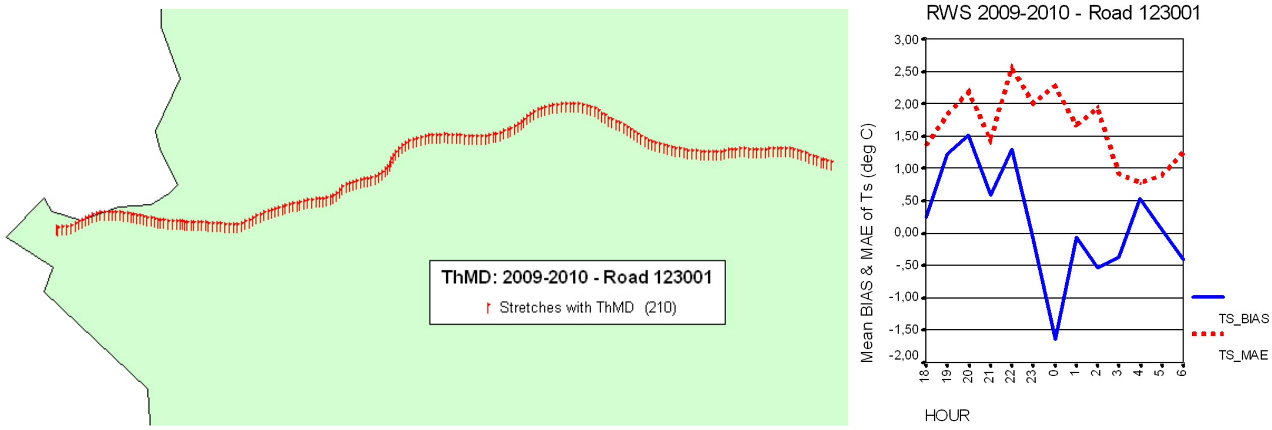


(a) (b) (c)

***Figure 3.3.3**: Mean bias of Ts (based on ThMD) at road stretches of the road 39002 for the road weather season 2009-2010 in (a) December 2009, (b) January 2010, and (c) February 2010.*

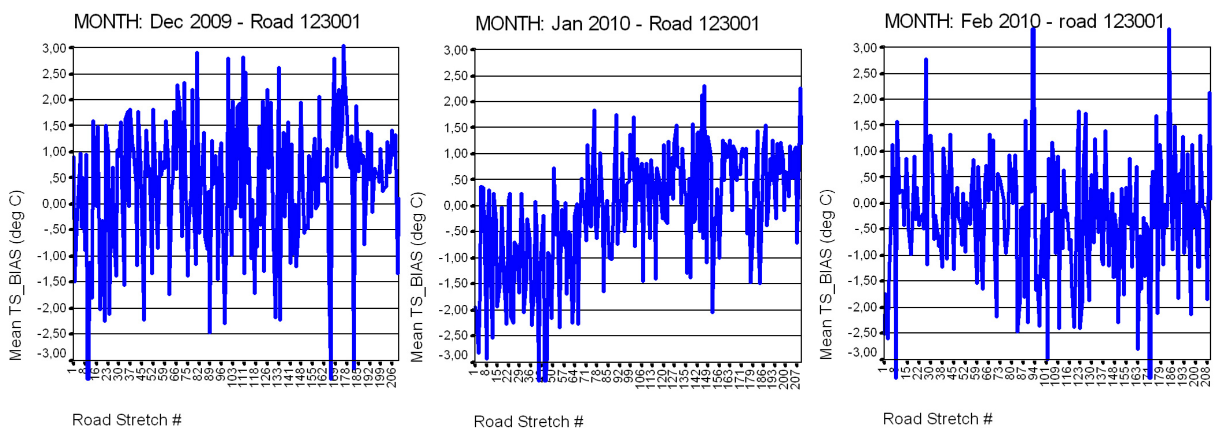
A summary on a diurnal cycle for bias and mae is given in Table 3.3.2 and Figure 3.3.2b (for the evening-nighttime hours). On a month-by-month basis, the bias (mae) were -0.65 (0.88), -0.88 (0.99), and -0.65°C (0.84°C) for December 2009, January and February 2010, respectively. Mean bias of Ts (based on ThMD) at 83 road stretches along the road 39002 for these 3 months is shown in Figure 3.3.3.

In total, 14514 averaged ThMD measurements (covering all Ts temperature ranges) of the road surface were assigned to road stretches positions of the road 123001. For these, on average, the bias and mae were +0.48°C and 1.62°C, respectively.
From these 14514, in total only 9926 ThMD were within a range of ±3°C (see Figure 3.3.4a). Among these, the 5237 are linked with 18-06 hour period and 4689 - from 06 till 18 h. On average, on a diurnal cycle, the bias (mae) was +0.44°C (1.42°C). For evening-nighttime hours the bias (mae) was +0.26°C (1.39°C); and for morning-daytime hours the bias and mae were larger (+0.63°C and 1.44°C, respectively) compared with evening-nighttime period. A summary on a diurnal cycle for bias and mae is given in Table 3.3.2 and Figure 3.3.4b (for the evening-nighttime hours). On a month-by-month basis, the bias (mae) were +0.65 (1.35), -0.44 (1.58), and -0.41°C (1.61°C) for December 2009, January and February 2010, respectively. Mean bias of Ts (based on ThMD) at 210 road stretches along the road 123001 for these 3 months is shown in Figure 3.3.5.



(a) (b)

Figure 3.3.4: *(a) ThMD measurements assigned to positions of road stretches (road 123001), and (b) mean bias and mae of Ts (based on ThMD) during evening-nighttime hours for the road weather season (RWS) 2009-2010.*



(a) (b) (c)

Figure 3.3.5: *Mean bias of Ts (based on ThMD) at road stretches of the road 123001 for the road weather season 2009-2010 in (a) December 2009, (b) January 2010, and (c) February 2010.*

4 Conclusions

In this study, the DRD vehicles measurements (the so-called thermal mapping data, ThMD) of the road conditions including the road surface temperature have been used for verification of the performance of the Danish Road Weather Modelling System (RWMS) at road stretches of selected Danish roads, as well as compared with forecasts done at Danish road stations.

It was found that the RWM system showed a comparable predictability for the road surface temperature for 3 hour forecasts at road stations and at road stretches.
Although ThMD data showed that they are very useful for verification of the performance of the RWM system, these are less applicable and valuable for on-line assimilation into the system due to limited spatial and temporal distribution and irregular measurements.

It should be noted that quite a large number of ThMD observations were of a poor quality, and even some measurements were as much as 10 degrees colder (which might be due to accuracy of measurements, instrumental errors and in-time calibration issues of sensors mounted at the vehicles). Still these observations have important information about variation of the road surface temperature. Although such measurements are relative simple to exclude, but more complex is to identify those having a smaller bias and at the same time being identified as erroneous. The ThMD used in verification have been required to be reasonably good at fitting to observations of the road surface temperature at road stations, and still allowing colder and warmer extremes compared with observed at road stations.

Analysis showed an importance of further investigation of the road surface temperature forecasts as a function of different road and environmental characteristics.

The results of this study are applicable for improvement of quality of detailed forecasts at road stations and stretches. This will facilitate the use of data from the road stretch forecasting to automatic adjustment of control of the dosage spread by salting spreaders (i.e. for optimization of the salt amount spread in order to prevent the icing/freezing and better timing of salting schedule). It will lead to improvement of the overall safety of the winter road traffic. It will contribute to further development and improvement of the visualization tools for the road stretches forecasting. And it may reduce the environmental impact in the road surroundings due to an optimized spreading of the salt.

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6 References

Road Weather Modelling System (RWMS) 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.

Yang X., Petersen C., Amstrup B., Andersen B., Feddersen H., Kmit M., Korsholm U., Lindberg K., Mogensen K., Sass B., Sattler K., Nielsen W. **2005**: The DMI–HIRLAM upgrade in June 2004. *DMI Technical Report*, 05-09, 35 p.

GlatTerm, **2004**: Brugervejledning til GlatTerm version 2.73. *Technical Documentation for the DMI Road Weather Modelling system*, 31p, September 2004.

Project (2004-2005) - *Improvement of Operational Danish Road Weather Forecasting using High Resolution Satellite Data*

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 (**2006**): 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, (**2006**): 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.

Project (2006-2008) - *Road Segments Forecasting*"

2006:

Petersen C., B.H. Sass, A. Mahura, (**2006**): 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, (**2006**): 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.

Mahura A. C. Petersen, B. Sass, P. Holm, (**2006**): Thermal Mapping Data for Verification of the Overall Performance of the DMI-HIRLAM Road Weather Model System. *DMI Technical Report*, 06-16, 24 p.

2007:

Pedersen T.S., Mahura A., C. Petersen, B.H. Sass, (**2007**): Road segment forecasting: a tool for salt spreader control using GPS. *Viking Workshop – Best Practices in Monitoring Deployment, 15-16 March 2007, Hamburg, Germany* (oral presentation).

Petersen C., Sass B., Mahura A., T.S. Pedersen, (**2007**): Road Weather Model System : Verification for 2005-2007 Road Weather Seasons. *DMI Technical Report*, *07-11, 19 p*, www.dmi.dk/dmi/tr07-11.pdf

Pedersen T.S., (**2007**): Decision Support or Winter Road Management. *Abstract submitted to the I2TERN "Easy Way towards sustainable mobility" Euro-Regional Conference*, 20-21 June 2007, Alborg, Denmark.

Petersen C., B.H. Sass, A. Mahura, T. Pedersen, (**2007**): DMI Road Weather Modelling System : Evaluation of Slippery Road Seasons. *Abstract submitted to the 7th Annual Meeting of the European Meteorological Society and EU Conference on Applications of Meteorology, 1-5 October 2007, San Lorenzo, Spain,* EMS2007-A-00012.

Mahura A., C. Petersen, B.H. Sass, P. Holm, T. Pedersen, (**2007**): Thermal Mapping Data in Verification of Road Weather Modelling. *Abstract submitted to the 7th Annual Meeting of the European Meteorological Society and EU Conference on Applications of Meteorology, 1-5 October 2007, San Lorenzo, Spain,* EMS2007-A-00013.

Petersen C., Mahura A., Sass B., (**2007**): Strækningsvejr – fremtidens glatføreprognoser. *Dansk Vejtidsskrift journal*, Vol. 10, pp. 15-17 (*in Danish*).

Mahura A., C. Petersen, B.H. Sass, P. Holm, T.S. Pedersen, (**2007**): Road Stretch Weather Forecasting: Thermal Mapping Data Applicability. *DMI Scientific Report, 07-06, 33 p,* www.dmi.dk/dmi/sr07-06.pdf

Mahura A., C. Petersen, B.H. Sass, P. Holm, T.S. Pedersen, (**2007**): Road Stretch Forecasting and Thermal Mapping Data. *Manuscript to be submitted to Meteorological Applications, 10 p.*

2008:

Petersen C., Mahura A., Sass B., Pedersen T., (**2008**): Road Weather Modelling System: Verification for 2007-2008 Road Weather Season. *DMI Technical Report 08-09, 14 p.*, www.dmi.dk/dmi/tr08-09.pdf

Mahura A., Petersen C., Sass B., (**2008**): Road Icing Conditions in Denmark. *DMI Scientific Report 08-03, 25 p., 978-87-7478-567-5,* www.dmi.dk/dmi/sr08-03.pdf

Petersen C., Mahura A., B.H. Sass, (**2008**): A new step towards a road stretch forecasting system. *Abstract Proceedings of the 14th International Road Weather Conference - SIRWEC (Standing International Road Weather Commission), 14-16 May 2008, Prague, Czech Republic, pp. 9-10; ID-03, 6p.*

Petersen C. (**2008**): Slippery Roads (practical exercise). *Nordisk Meteorologisk Kompetensutbildning (NOMEK) Course,* 21-25 April 2008, SMHI, Norrköping, Sweden, http://www.eumetcal.org/courses/course

Mahura A., C. Petersen, B.H. Sass, (**2008**): Road Weather Model Verification: Revised Approach. *Abstracts of the 8th Annual Meeting of the European Meteorological Society and European Conference on Applied Climatology, 29 Sep – 3 Oct 2008, Amsterdam, The Netherlands; Vol. 5, EMS2008-A-00456.*

Project (2009-2011) - "*Fine-Scale Road Stretches Forecasting*"

2009:

Petersen C., Mahura A., Sattler K., Sass B., (**2009**): Strækningsvejr - modeludvikling. *Annual National Danish Road Directorate Conference,* 12 Apr 2009, Middelfart, Denmark (oral presentation)

Petersen C., Mahura A., B. Sass, (**2009**): Road Weather Modelling System: Verification for 2008-2009 Road Weather Season. *DMI Technical Report 09-10, 20p.,* www.dmi.dk/dmi/tr09-10.pdf

Mahura A., C. Petersen, B. Sass, K. Sattler (**2009**): Fine-Scale Road Stretch Forecasting. *Proceedings of the International Symposium on Nowcasting and Very Short Range Forecasting, 30 Aug – 4 Sep 2009, Whistler, British Columbia, Canada, P1.10L.*

Petersen C. (**2009**): Slippery Roads (practical exercise). *Nordisk Meteorologisk Kompetensutbildning (NOMEK) Course,* 11-15 May 2009, IMO, Reykjavik, Iceland, http://www.eumetcal.org/courses/course

Petersen C., Kai S., Mahura A. (**2009**): Strækningsvejr – detaljer tæller. *Dansk Vejtidsskrift journal*, Vol. 10, pp. 46-48 (*in Danish*).

Mahura A., C. Petersen, K. Sattler, B. Sass (**2009**): Fine-Scale Road Stretch Forecasting along Main Danish Roads. *Abstracts of the European Meteorological Society (EMS) Annual Meeting, 28 Sep - 2 Oct 2009, Toulouse, France, Vol. 6, EMS2009-71.*

Mahura A., K. Sattler, C. Petersen, B. Sass (**2009**): Improvement of Road Forecasting using Effects of Shadowing due to Terrain and Distance to Seashore. *Abstracts of the 9th European Meteorological Society (EMS) Annual Meeting, 28 Sep - 2 Oct 2009, Toulouse, France, Vol. 6, EMS2009-81.*

Mahura A., Petersen C., Sass B.H. (**2009**): Road Weather Modelling: Revised Approach and Formulations, *DMI Sci. Report 09-02, ISBN: 978-87-7478-587-3, 30p,* www.dmi.dk/dmi/sr09-02.pdf

2010:

Pedersen T.S., Petersen C., Sattler K., Mahura A., Sass B.H., (**2010**): Physiographic Data for Road Stretch Forecasting. *Abstracts of the 15th International Road Weather Conference, SIRWEC, 5-7 Feb 2010, Quebec, Canada, T5.18, 5 p.*

Petersen C., Mahura A., Sattler K., Sass B., (**2010**): Strækningsvejr og andre modeltiltag. *Annual National Danish Road Directorate Conference,* 15 Apr 2010, Middelfart, Denmark (oral presentation)

Sattler K., Petersen C., Mahura A., Sass B., Pedersen T.S. (**2010**): Road Weather Forecast using High Resolution Data from the Danish Height Model Database. *HIRLAM All Staff – ALADIN workshop, 13 – 16 Apr 2010, Krakow, Poland* (poster presentation)

Petersen C., Mahura A., B. Sass, (**2010**): Road Weather Modelling System: Verification for 2009-2010 Road Weather Season. *DMI Technical Report 10-12, 20 p.,* www.dmi.dk/dmi/tr10-12.pdf

Mahura A., Petersen C., Sattler K., Sass B.H., Pedersen T. (**2010**): High Resolution Physiographic Data for Fine-Scale Road Weather Forecasting, *DMI Sci. Report 10-05, ISBN: 978-87-7478-605-4, 30p,* www.dmi.dk/dmi/sr10-05.pdf

2011:

Sattler K., Sass B., Petersen C., Mahura A., Pedersen S. (**2011**): Om brugen af data fra DHM (DTM/DSM) i Glatføremodellen ved DMI. *Kort & Matrikelstyrelsen Statslige DHM Samarbejdsforum, 4 Apr 2011, Ballerup, Denmark*

Petersen C., Mahura A., Sattler K. (**2011**): Strækningsvejr Model Udvikling. *Annual National Danish Road Directorate Conference "Glatførebrugermøde for sæsonen 2010/2011",* 12 Apr 2011, Taulov, Denmark (oral presentation)

Mahura A., C. Petersen, K. Sattler, B.H. Sass (**2011**): Fine-Scale Road Stretch Forecasting: Improvements due to Applications of High Resolution Databases. *Abstracts of the International Conference on Computational Information Technologies for Environmental Sciences (CITES-2011), 3-13 Jul 2011, Tomsk, Russia, pp. 67-68*

Petersen C., Mahura A., B. Sass, (**2011**): Road Weather Modelling System: Verification for 2010-2011 Road Weather Season. *DMI Technical Report 11-19, 28p;* www.dmi.dk/dmi/tr11-19.pdf

Mahura A., Petersen C., Sass B.H., Holm P., Pedersen T.S. (**2011**): Thermal Mapping Data Measurements: Road Weather Seasons 2008-2011. *DMI Sci. Report 11-03, 49p, ISBN: 978-87-7478-602-3,* www.dmi.dk/dmi/sr11-03.pdf

Appendix A: Daily vs. Months Distribution of Raw Thermal Mapping Measurements

Month Year	Oct 2008	Nov 2008	Dec 2008	Jan 2009	Feb 2009	Mar 2009	Apr 2009	Season
Day								*Count*
1		165	2858	2225	3549		1622	10419
2			2055	2166	499	53	1158	5931
3			5583	5727	76		4299	15685
4			2973	7326	237	197		10733
5				4613	2435		42572	49620
6			680	5357	1477	26		7540
7			2011	4628	3246	431		10316
8	33		93	2523	5959	3574		12182
9			905	1711	4661	206		7483
10			3992	2845	5795			12632
11			2885	581	5426	1026		9918
12			3864	6	2187	166		6223
13			1		6803			6804
14			455	747	1	2		1205
15	1			2285	8097			10383
16		732		1012	4158			5902
17		1168	2023	927	2259	65540		71917
18		700	55	1414	1716	575		4460
19		157	383	1362	4121	13343	1575	20941
20		1750		3433	2724	39470	954	48331
21		2220	381	3429	2069			8099
22		2752		1489	282			4523
23		2041	3141	3820	2746	1419		13167
24		4614	2539	2686	1016	289		11144
25		3133	2828	2763		2327		11051
26		813	2683	361	204	15814		19875
27	23	56	2183	2866	1036	203		6367
28	33	88	1624	440		64		2249
29	1464	1031	3209	3027		153	78	8962
30	1911	13	410	1035		125		3494
31	585		3829	727				5141
Total	***4050***	***21433***	***53643***	***73531***	***72779***	***145003***	***52258***	***422697***
%	***0,96***	***5,07***	***12,69***	***17,40***	***17,22***	***34,30***	***12,36***	***100,00***

Table A1: *Summary on daily thermal mapping measurements (counts and perecentage) taken by DRD vehicles vs. months during the road weather season of 2008-2009.*

Month Year	Oct 2009	Nov 2009	Dec 2009	Jan 2010	Feb 2010	Mar 2010	Apr 2010	Season
Day								*Count*
1			7006	1254	4654	13057		25971
2			6232	22319	7292	10104	5101	51048
3			33	3195	5668	904		9800
4				14883	4301	7237		26421
5				14202	3466	2649		20317
6	7	1		7774	2627	131		10540
7	137			7034	695	5998		13864
8	693		381	6635	341	4410	1040	13500
9				12675	4647	1081		18403
10		15	8	8031	5016	1438		14508
11		27	2237	5565	1784	173		9786
12	3		1343	7236	4303	1518	4412	18815
13			16527	6395	7528	657	4667	35774
14	974		3925	2228	5110	2106	4325	18668
15	12		18328	2674	4553	660	3481	29708
16	10		48896	3398	2308	1777		56389
17			54276	12041	3813			70130
18			44156	9864	5848	12		59880
19	577		32489	4213	5983			43262
20			26844	8517	6518		145	42024
21			48641	4571	6244			59456
22			62250	1826	5633		118	69827
23			9685	6280	7605	4551		28121
24			17577	12826	6088	662	5	37158
25			10812	1424	148			12384
26			22649	2698	325			25672
27			185	12839	1148			14172
28	265		22002	7605	1189			31061
29	1275		10770	7001				19046
30	725	558	5477	7631				14391
31			3775	7406				11181
Total	***4678***	***601***	***476504***	***232240***	***114835***	***59125***	***23294***	***911277***
%	***0,51***	***0,07***	***52,29***	***25,49***	***12,60***	***6,49***	***2,56***	***100,00***

Table A2: *Summary on daily thermal mapping measurements (counts and perecentage) taken by DRD vehicles vs. months during the road weather season of 2009-2010.*

Month Year	Oct 2010	Nov 2010	Dec 2010	Jan 2011	Feb 2011	Mar 2011	Apr 2011	Season
Day								*Count*
1			4925	5703	3061	1483		15172
2			7128	4224	1755	188		13295
3		4	1672	4459	1928	2939		11002
4			2769	15792	401	1823	9435	30220
5		4	4292	9958		416	59	14729
6			3088	8795		2412		14295
7		5740	3009	7070		29432		45251
8		570	1240	3185	12236	33880		51111
9		518	1641	7313	1814	2539		13825
10		3844	2073	8010	403	1542		15872
11		576	101	7067	1717	2165	75	11701
12		3	1667	2679		1316		5665
13			2801	5654	3904	428		12787
14	2		1081	4037	489		9482	15091
15		2263	6100	231	7248	21548		37390
16	530	3014	7157		8531	3285		22517
17	2176	3380	2332	347	3586	404		12225
18	1184	149	2688	1545		464	6	6036
19	362	2663	1043	1873		820		6761
20	3486	1081	3023	4308	1150	394		13442
21	775		3230	5135	163	1159		10462
22	1703	149	1539	3604	2864	12723		22582
23		7544	5748	1336	1668	5066		21362
24	412	5871	2331	1876	15783			26273
25	4594	8135	1666	1003	7658			23056
26	622	8298	1732	2526	399			13577
27	100	7660	1284	2001	1717			12762
28		5538	841	2038	14958	13242		36617
29		8770	1026	2745		17		12558
30		5056	986	2385				8427
31			4548	2000				6548
Total	***15946***	***80830***	***84761***	***128899***	***93433***	***139685***	***19057***	***562611***
%	***2,83***	***14,37***	***15,07***	***22,91***	***16,61***	***24,83***	***3,39***	***100,00***

Table A3*: Summary on daily thermal mapping measurements (counts and perecentage) taken by DRD vehicles vs. months during the road weather season of 2010-2011.*

Appendix B: Hourly vs. Months Distribution of Raw Thermal Mapping Measurements

Month Year	Oct 2008	Nov 2008	Dec 2008	Jan 2009	Feb 2009	Mar 2009	Apr 2009	Season	
Hour								*Count*	*%*
0	682	2644	2680	3029	3090	4511	241	16877	3,99
1	181	1624	3442	4834	2224	5862	395	18562	4,39
2	156	1256	4444	6177	3517	23491	331	39372	9,31
3	118	1538	5377	6526	7080	18509	229	39377	9,32
4	307	1198	4506	5968	7635	2555	2649	24818	5,87
5	682	384	2818	3282	4310	661	9	12146	2,87
6	512	200	1487	1963	1737	177		6076	1,44
7	233	21	1336	1649	2871	33		6143	1,45
8	58	110	1052	1078	2377	91	73	4839	1,14
9	12	431	258	1167	1093	3034	8	6003	1,42
10	127	268	32	1028	617	25		2097	0,50
11	21	77	190	867	1295	15854		18304	4,33
12	1	61	2167	550	766	3695		7240	1,71
13		110	2058	1450	758	1233		5609	1,33
14		95	519	1246	571	569		3000	0,71
15	1	552	1162	1482	2014	19023		24234	5,73
16	33	680	3533	2151	2722	517		9636	2,28
17		473	3199	2950	4865	17		11504	2,72
18		751	2603	5052	4931	3563		16900	4,00
19	41	857	1984	5723	4301	13970	1556	28432	6,73
20	322	1102	1610	4517	4240	11326	2876	25993	6,15
21	193	1215	2109	3593	4245	2982	19087	33424	7,91
22	29	2178	2129	3978	2892	5868	24768	41842	9,90
23	341	3608	2948	3271	2628	7437	36	20269	4,80
Total	***4050***	***21433***	***53643***	***73531***	***72779***	***145003***	***52258***	***422697***	***100,00***

Table B1: *Summary on hourly thermal mapping measurements (counts and perecentage) taken by DRD vehicles vs. months during the road weather season of 2008-2009.*

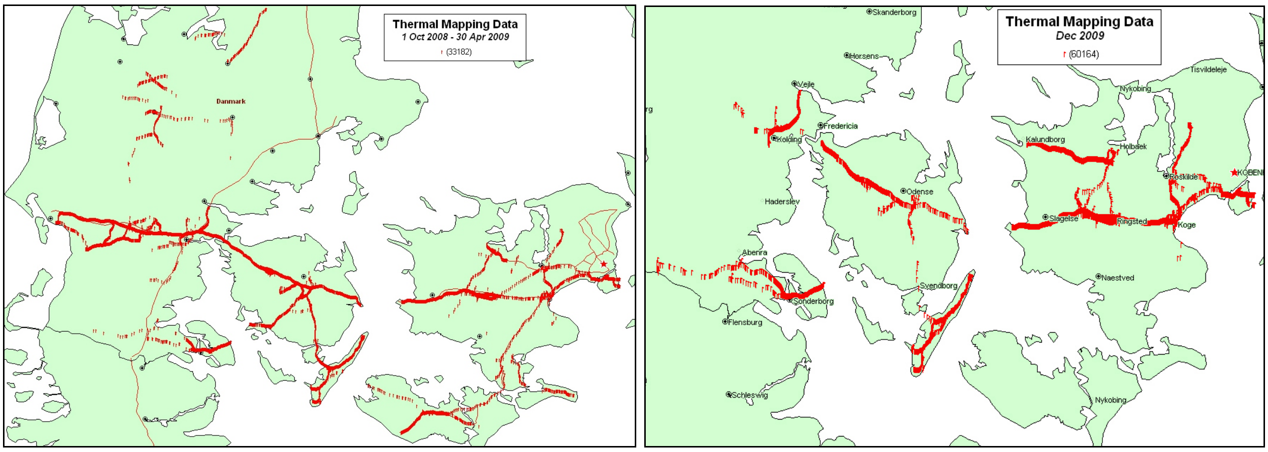
Month Year	Oct 2009	Nov 2009	Dec 2009	Jan 2010	Feb 2010	Mar 2010	Apr 2010	Season	
Hour								***Count***	***%***
0	12		24047	8220	1735	891	3317	38222	4,19
1			11730	10734	2531	1114	235	26344	2,89
2			19799	14400	4762	2345	248	41554	4,56
3			43803	15152	8570	4267	560	72352	7,94
4	170		27108	12928	9854	2366	370	52796	5,79
5	404	6	10973	12086	7430	997	21	31917	3,50
6	146	10	11236	9171	4265	506		25334	2,78
7	8	12	14566	6396	3958	1701		26641	2,92
8	2547	1	13824	6365	3404	320		26461	2,90
9	7		15126	8098	3627	316		27174	2,98
10	7		9677	7848	4280	198	101	22111	2,43
11	1		13818	7836	3192	215		25062	2,75
12	311	560	14215	5999	3646	932	1040	26703	2,93
13	82		28984	6575	2101	260		38002	4,17
14	9		17105	5386	3388	1560		27448	3,01
15			13491	3598	3499	856		21444	2,35
16			23652	7032	5959	1264		37907	4,16
17			26261	12688	9101	1267		49317	5,41
18		10	31379	16054	8838	3706	156	60143	6,60
19	134	2	26204	11016	5999	7932	5321	56608	6,21
20	270		26903	13397	5545	7879	3259	57253	6,28
21	474		20860	13701	3947	8132	5381	52495	5,76
22	91		18126	9556	3216	6159	1970	39118	4,29
23	5		13617	8004	1988	3942	1315	28871	3,17
Total	***4678***	***601***	***476504***	***232240***	***114835***	***59125***	***23294***	***911277***	***100,00***

Table B2*: Summary on hourly thermal mapping measurements (counts and perecentage) taken by DRD vehicles vs. months during the road weather season of 2009-2010.*

Month Year	Oct 2010	Nov 2010	Dec 2010	Jan 2011	Feb 2011	Mar 2011	Apr 2011	Season	
Hour								***Count***	***%***
0	1664	2421	5970	3459	3991	8685		26190	4,66
1	1740	3319	2592	6145	3751	3397		20944	3,72
2	2733	10251	5001	20815	5132	6477		50409	8,96
3	604	8538	8155	24264	6538	4554	6	52659	9,36
4	799	6706	5185	8708	2909	1390		25697	4,57
5	128	3182	3602	4134	2058	976	59	14139	2,51
6	4	2840	2294	2998	1827	1008	65	11036	1,96
7	305	2902	2135	3494	761	240	10	9847	1,75
8	163	2618	2516	2183	649	39		8168	1,45
9	363	1992	2380	1375	843	74		7027	1,25
10	198	2384	3324	867	1293	80		8146	1,45
11		2022	3804	1002	1523	255		8606	1,53
12	53	1439	3941	1648	925			8006	1,42
13	326	1072	2982	2394	547	12		7333	1,30
14	35	870	2233	1484	1044	123		5789	1,03
15	23	672	2050	2245	1482		40	6512	1,16
16		1882	2690	4081	1945	96		10694	1,90
17	24	2955	3925	5642	4578	1754		18878	3,36
18	47	2786	3563	7193	4980	3803		22372	3,98
19	120	3052	2592	8847	7803	15271		37685	6,70
20	766	4765	3072	5326	12785	21883	2021	50618	9,00
21	804	3592	1975	2912	10286	26646	6825	53040	9,43
22	2327	4790	2276	3398	7606	23904	7169	51470	9,15
23	2720	3780	6504	4285	8177	19018	2862	47346	8,42
Total	***15946***	***80830***	***84761***	***128899***	***93433***	***139685***	***19057***	***562611***	***100,00***

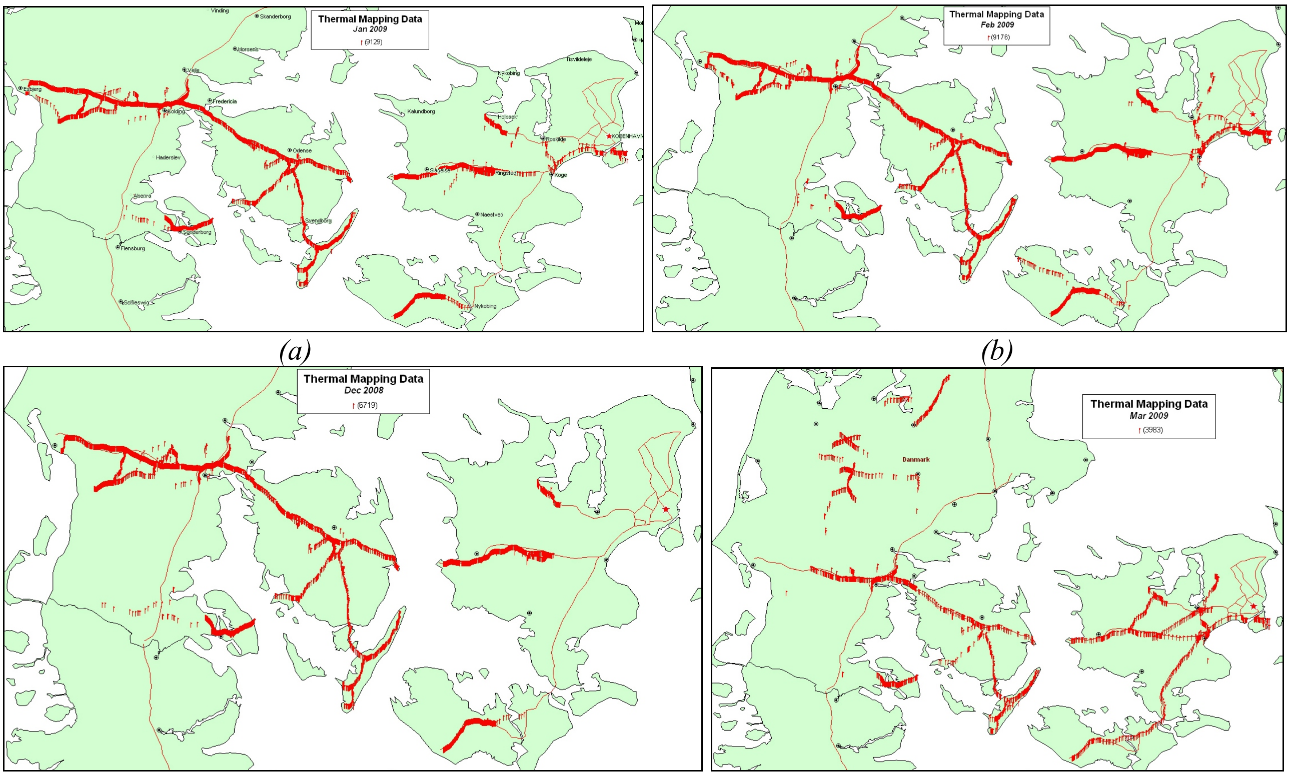
Table B3*: Summary on hourly thermal mapping measurements (counts and perecentage) taken by DRD vehicles vs. months during the road weather season of 2010-2011.*

Appendix C: Spatial Distribution of Thermal Mapping Data Assigned to Road Stretches Positions



(a) (b)

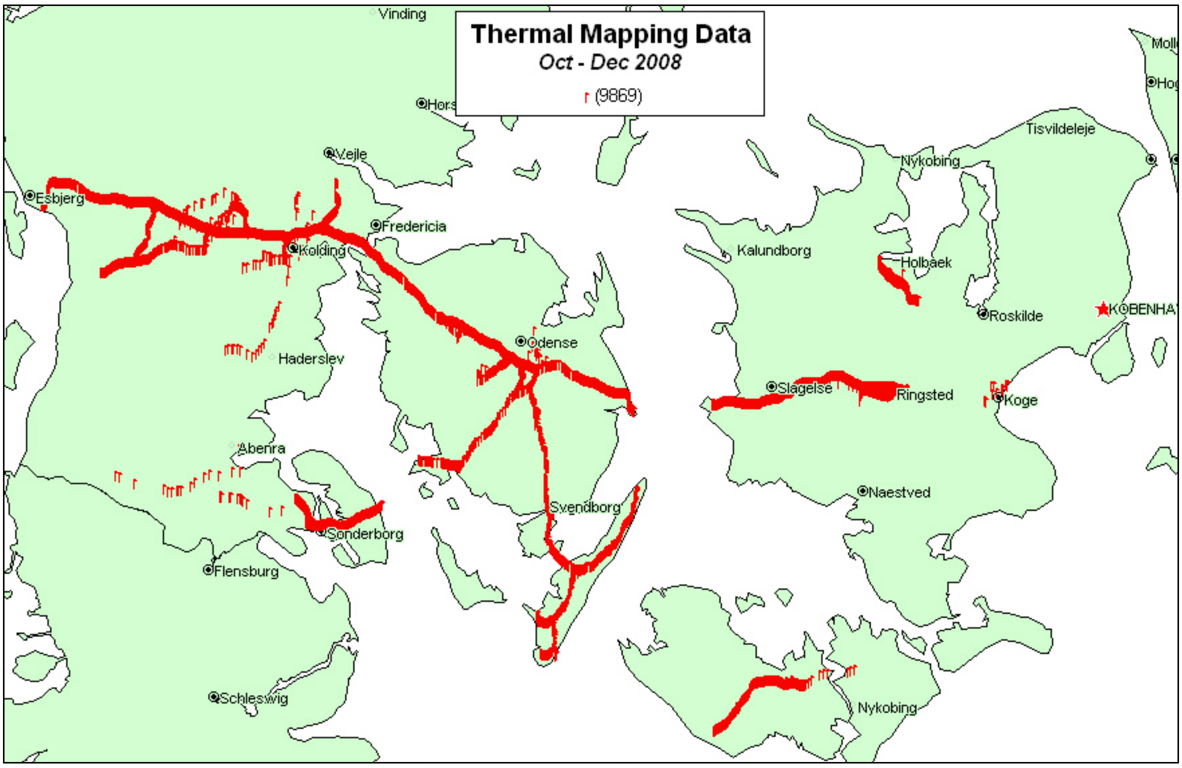
Figure C1: *Spatial distribution of the thermal mapping data measurements (road surface temperature assigned to road stretches positions) for (a) October 2008 – April 2009, and (b) December 2009.*



(a) (b)

(c) (d)

Figure C2: *Spatial distribution of thermal mapping data measurements (road surface temperature assigned to road stretches) during Jan 2009, (b) Feb 2009, (c) Dec 2008, and (d) Mar 2009 for road weather season from 1 Oct 2008 – 30 Apr 2009.*



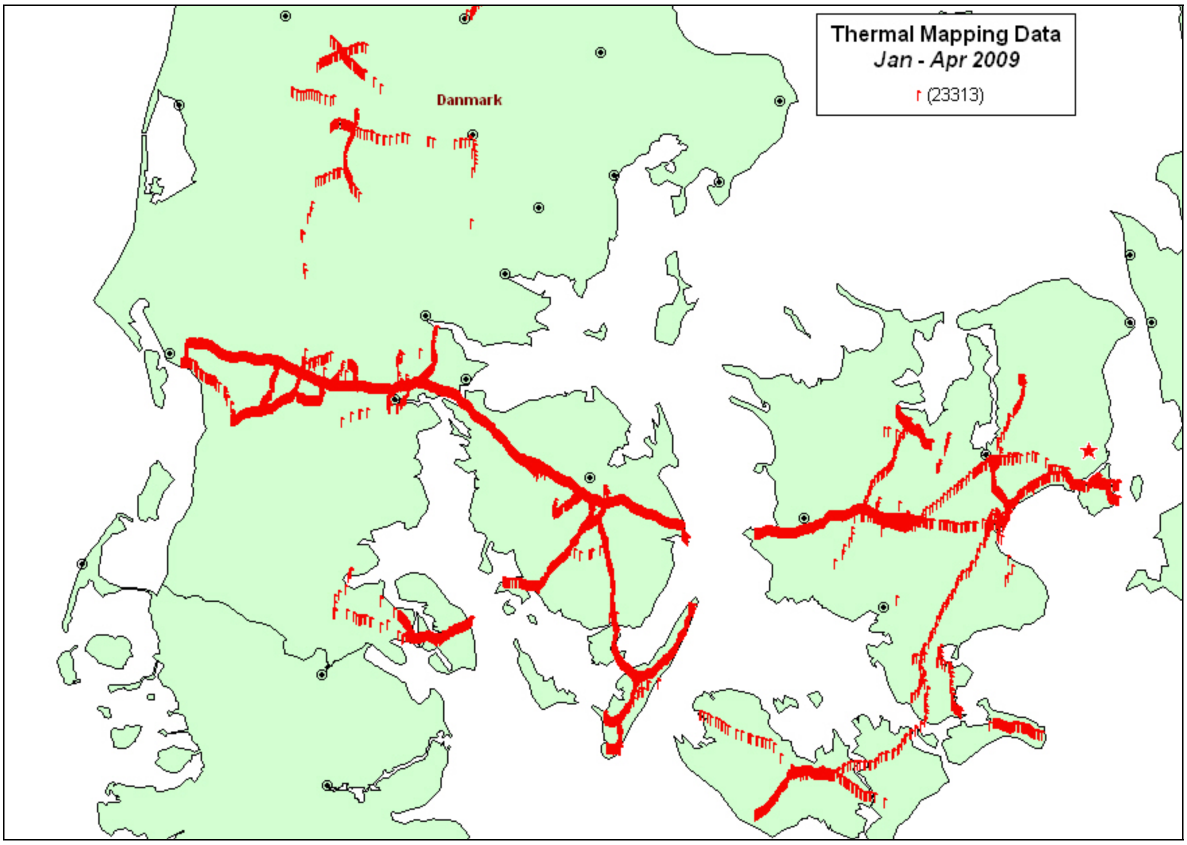


Figure C3: *Spatial distribution of the thermal mapping data assigned to road stretches positions for (top) October-December 2008 and (bottom) January-April 2009.*

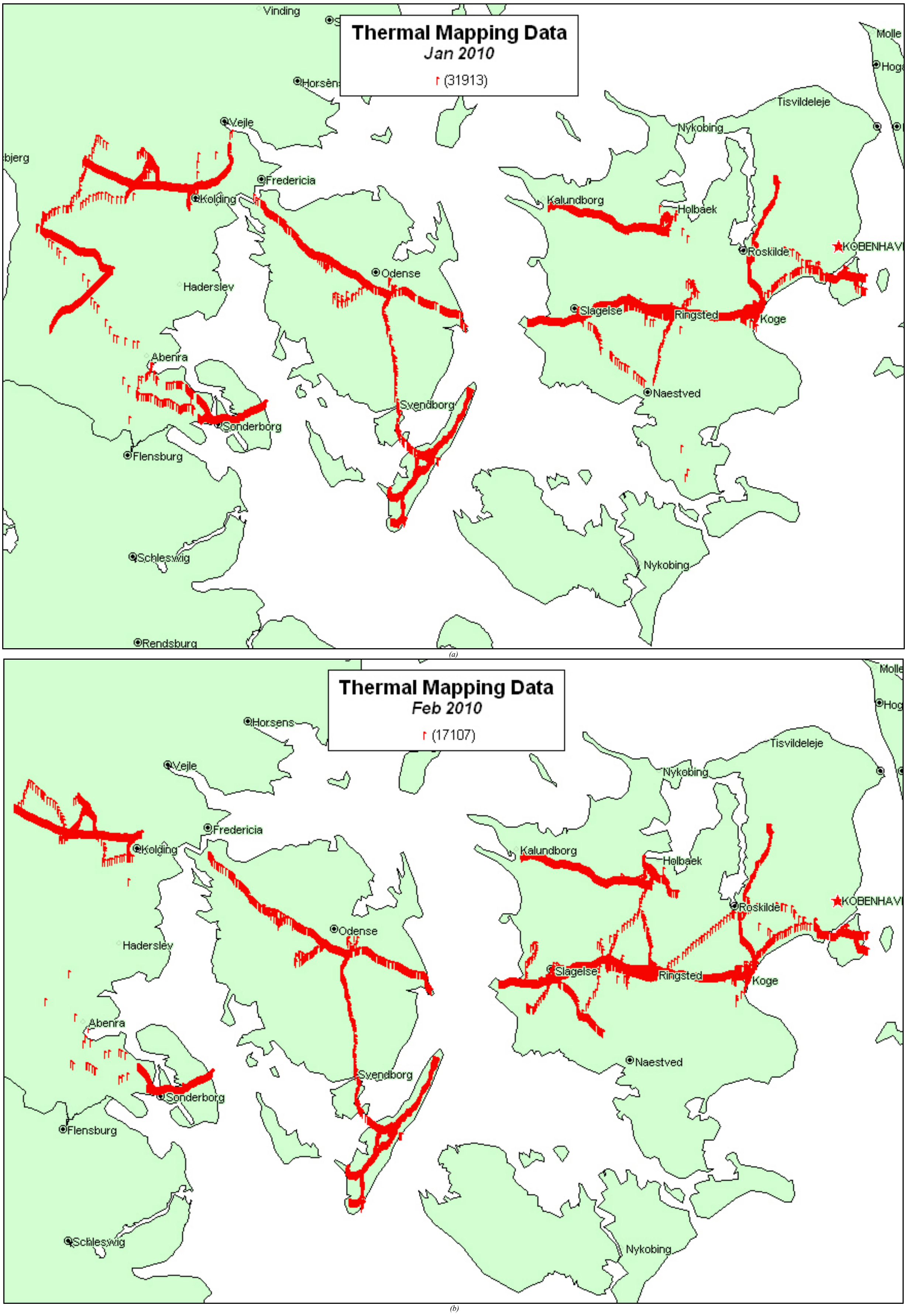


Figure C4: *Spatial distribution of the thermal mapping data assigned to road stretches positions for (top) January 2010, and (bottom) February 2010.*

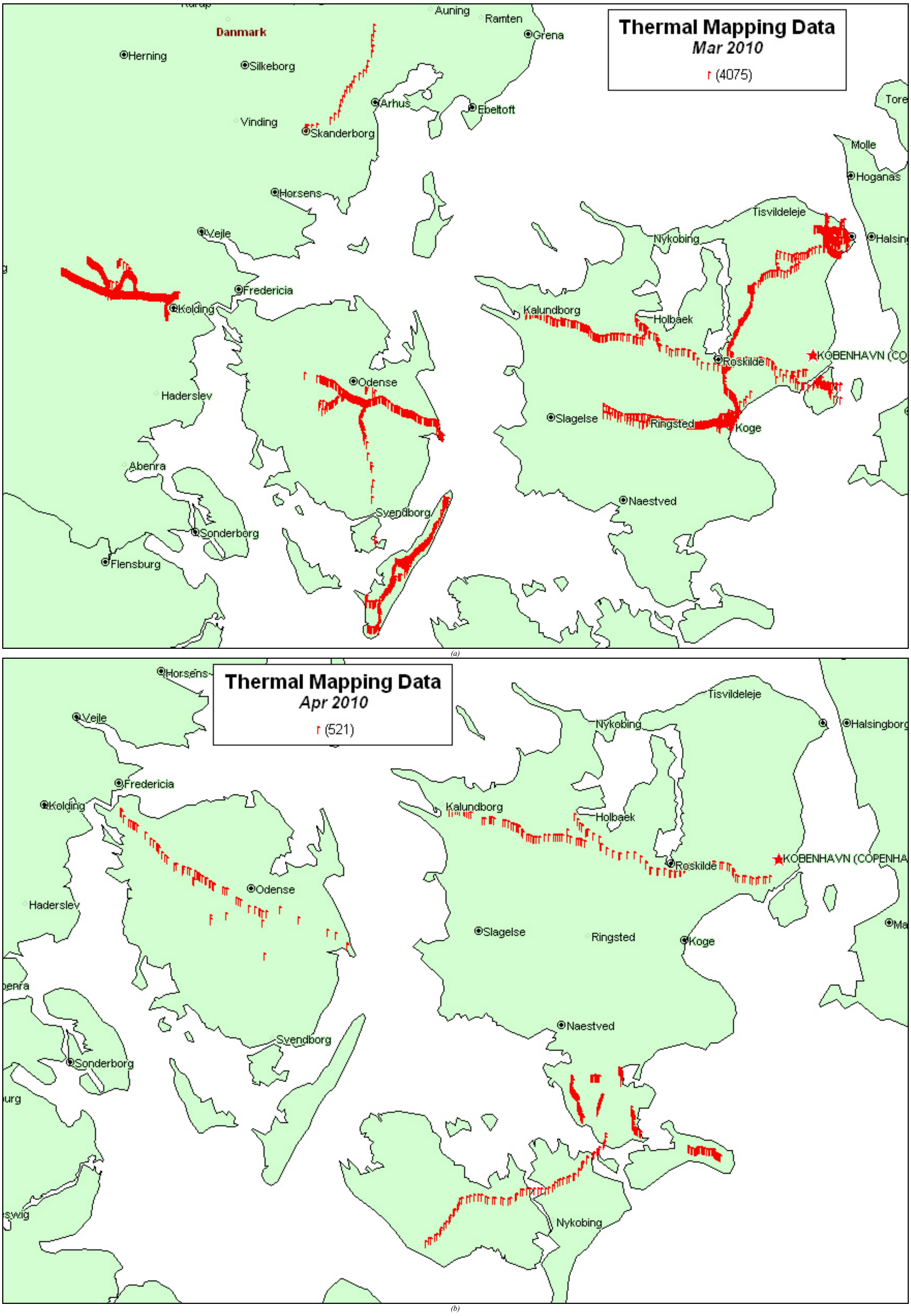


Figure C5: *Spatial distribution of the thermal mapping data assigned to road stretches positions for (top) March 2010, and (bottom) April 2010.*

Appendix D: Estimation of Distance between Positions of the Road Stations and Thermal Mapping Data Measurement Points

An estimation of distance between the GPS positions of the road stations and thermal mapping data measurement points on the road surface is given here. The distance ($L_{ThMD-RST}$, see Figure D1) between the point on the road (where the thermal mapping data, ThMD measurement was taken from the moving equipped vehicle) and the position of the road station / sensor (where the measurement of the road surface temperature was taken) has been calculated taking into account the GPS positioning of both the road station and point with ThMD on the road surface.

***Figure D1**: Evaluation of distance between the 2 points (road station #2012 and point on the road corresponding to thermal mapping data measurement) /extracted from Google/.*

Considering that on a spherical surface at the sea level 1 degree of latitude (ΔLAT_{1deg}) is equal to 110900 m. The width of 1° of latitude (ΔLON_{1deg}) is a function of the latitude, and the following approximation can be used:

$$\Delta LON_{1\deg} = \cos(\varphi \frac{\pi}{180^\circ}) \sqrt{\frac{a^4 \cos(\varphi \frac{\pi}{180^\circ})^2 + b^4 \sin(\varphi \frac{\pi}{180^\circ})^2}{(a\cos(\varphi \frac{\pi}{180^\circ}))^2 + (b\sin(\varphi \frac{\pi}{180^\circ}))^2}} \frac{\pi}{180^\circ},$$

where: φ - latitude in degrees; a = 6378137 m is the Earth's equatorial radius, and b = 6356752.3 m is the Earth's polar radius.

The latitudinal ($\Delta\varphi$) and longitudinal ($\Delta\lambda$) differences in degrees between locations with GPS positions are calculated:

$\Delta\lambda = \lambda_{ThMD} - \lambda_{RST}$;

$\Delta\varphi = \varphi_{ThMD} - \varphi_{RST}$;

$\lambda_{ThMD}, \varphi_{ThMD}$ - longitude and latitude of the thermal mapping data measurement on the road surface (using GPS); and $\lambda_{RST}, \varphi_{RST}$ - longitude and latitude of the road station/ sensor (using GPS);

and then converted into differences/ distances (ΔX, ΔY) in meters taking into account the length of 1 degree of longitude corresponding to latitude where the road station is located:

$\Delta X = \Delta\lambda \cdot \Delta LON_{1\deg}$;

$\Delta Y = \Delta\varphi \cdot \Delta LAT_{1\deg}$;

finally, the distance ($L_{ThMD-RST}$) in meters between 2 points is calculated: $L_{ThMD-RST} = \sqrt{\Delta X^2 + \Delta Y^2}$.

Appendix E: Diurnal Cycle and Month-to-Month Variability

Month	Dec 2008			Jan 2009			Feb 2009		
Hour	**BIAS**	**MAE**	**Count**	**BIAS**	**MAE**	**Count**	**BIAS**	**MAE**	**Count**
0	0,81	1,21	78				0,96	1,74	61
1	0,50	1,82	122				-0,39	1,36	41
2	0,67	1,73	114						
3				-0,01	1,91	19			
4				-0,70	0,70	6			
5									
6				1,27	1,27	13			
7				-0,17	1,43	29			
8				0,72	0,72	5			
9									
10									
11									
12	3,98	3,98	21						
13	2,97	2,97	36						
14	2,96	2,96	4						
15	1,44	1,60	26				1,29	1,92	143
16	1,36	1,86	123	2,17	2,26	20	1,06	1,69	107
17	0,36	1,34	107	2,18	2,26	85	0,87	1,49	134
18	1,35	1,83	82	0,89	1,42	47	0,50	1,57	153
19	1,19	1,36	72	3,57	3,57	9	1,28	1,83	118
20	2,73	2,75	70	1,25	1,48	19	0,63	1,52	116
21	1,70	1,78	52	2,64	2,69	19	1,30	1,51	161
22	2,37	2,37	16	2,05	2,05	11	1,01	1,52	64
23	0,56	0,92	69	2,36	2,36	1	0,66	1,17	65
Total	**1,21**	**1,78**	**992**	**1,46**	**1,92**	**283**	**0,92**	**1,60**	**1163**

Table E1: *BIAS and MAE (deg C) of the road surface temperature (Ts) on a diurnal cycle for all stretches of all roads for the road weather season of 2008-2009 (Dec 2008, Jan-Feb 2009).*

Month	Dec 2009			Jan 2010			Feb 2010			Mar 2010		
Hour	**BIAS**	**MAE**	**Count**	**BIAS**	**MAE**	**Count**	**BIAS**	**MAE**	**Count**	**BIAS**	**MAE**	**Count**
0	-0,80	0,91	2192	-3,11	3,76	288	-2,45	2,70	173	2,99	2,99	28
1	-1,35	1,58	991	-2,79	3,18	369	-2,89	3,04	171	1,68	1,68	7
2	0,06	1,31	1139	-2,30	2,76	350	-2,36	2,61	238	0,32	1,21	24
3	-0,63	0,98	1485	-1,25	2,13	474	-1,74	2,37	309	1,46	1,71	128
4	0,14	0,80	1466	-1,05	2,10	411	-0,35	1,77	332	1,86	2,03	71
5	-0,16	0,86	1159	-1,78	2,36	328	-1,76	2,36	293	1,21	1,46	45
6	-0,39	0,98	1031	-1,43	1,83	262	-3,33	3,45	238	1,20	1,24	10
7	-0,84	1,24	819	-1,52	1,85	299	-2,66	2,89	274	0,34	0,34	1
8	-0,09	1,82	1567	-1,39	1,80	286	-1,86	2,50	261	4,00	4,00	2
9	0,30	1,26	1322	-1,11	2,09	393	-0,51	1,55	250	8,41	8,41	46
10	-0,05	0,66	953	-0,77	2,01	433	0,10	2,29	304	6,44	6,44	12
11	0,85	1,46	1040	-0,57	1,48	495	0,01	2,94	231	5,61	5,61	42
12	0,85	1,32	796	-0,42	1,49	373	0,40	1,76	223	5,00	5,00	11
13	0,34	0,86	2326	-0,66	2,02	282	0,53	1,81	118	4,30	4,30	10
14	-0,99	1,05	2656	-1,72	2,43	282	1,11	1,71	273	7,91	7,91	31
15	-0,96	1,30	468	-2,26	2,40	241	1,11	1,51	242	3,33	3,37	56
16	-0,65	1,16	613	-0,32	1,73	369	0,38	1,29	442	1,54	2,49	76
17	-1,10	1,57	863	-0,87	2,03	617	0,48	1,44	527	1,69	2,59	114
18	-0,69	1,60	654	-0,64	2,02	604	0,44	1,44	634	2,06	2,84	225
19	0,93	1,75	914	-0,52	1,56	613	0,07	1,63	387	1,04	2,10	129
20	0,80	1,62	1465	-0,53	1,42	434	0,58	1,57	389	-0,37	1,40	146
21	0,57	1,28	736	-0,78	1,54	433	-1,06	2,10	349	-0,07	1,84	72
22	1,13	2,13	855	-1,91	2,24	381	-1,63	2,47	271	-0,04	1,73	45
23	-0,60	1,34	388	-2,28	2,46	254	-3,71	3,90	188	1,22	2,53	52
Total	**-0,15**	**1,23**	**27898**	**-1,21**	**2,06**	**9271**	**-0,64**	**2,07**	**7117**	**1,91**	**2,71**	**1383**

Table E2: *BIAS and MAE (deg C) of the road surface temperature (Ts) on a diurnal cycle for all stretches of all roads for the road weather season of 2009-2010 (Dec 2009, Jan-Feb-Mar 2010).*

Appendix F: Bias and MAE for Danish Roads during Evening-Nighttime vs. Morning-Daytime Periods

***Table F1:** BIAS and MAE (deg C) of the road surface temperature (Ts based on ThMD; range of icing conditions considered is ±3°C) for selected Danish roads for all day period, evening-nighttime hours, and morning-daytime hours during road weather season 2008-2009.*

All day period				18-06 h – evening-nighttime				06-18 h – morning-daytime			
RST	BIAS	MAE	Count	RST	BIAS	MAE	Count	RST	BIAS	MAE	Count
1002	-0,34	1,03	177	1002	-0,40	0,97	117	1002	-0,23	1,15	60
5002	-0,47	0,77	3	5002	-0,38	0,83	2	5002	-0,65	0,65	1
10001	-0,78	0,78	3	10001	-0,62	0,62	2	10001	-1,09	1,09	1
15001	1,82	2,17	294	15001	1,84	2,24	188	15001	1,78	2,03	106
18003	0,51	1,10	156	18003	0,50	1,11	84	18003	0,52	1,09	72
23003	2,53	2,59	31	23003	2,71	2,81	18	23003	2,29	2,29	13
39001	-0,50	0,83	125	39001	-0,41	0,69	83	39001	-0,69	1,10	42
39002	-0,56	0,81	366	39002	-0,50	0,73	243	39002	-0,69	0,96	123
41001	2,08	2,33	139	41001	1,53	2,02	69	41001	2,63	2,65	70
44001	1,65	1,77	196	44001	1,53	1,69	119	44001	1,84	1,89	77
51001	2,68	2,72	194	51001	2,59	2,60	102	51001	2,77	2,85	92
51002	2,14	2,20	55	51002	2,11	2,11	35	51002	2,20	2,36	20
52002	2,44	2,44	5	52002	1,90	1,90	2	52002	2,81	2,81	3
56001	1,04	1,10	6	56001	1,88	1,88	3	56001	0,19	0,31	3
58001	-0,21	1,89	13	58001	-0,41	1,86	12	58001	2,29	2,29	1
62008	1,63	1,63	1					62008	1,63	1,63	1
68006	1,88	2,74	2	68006	-0,86	0,86	1	68006	4,61	4,61	1
118001	-0,07	0,36	2	118001	-0,07	0,36	2				
119003	-0,38	0,38	2	119003	-0,38	0,38	2				
121004	-0,47	0,91	84	121004	-0,91	1,04	55	121004	0,38	0,67	29
122001	0,20	1,53	5	122001	0,20	1,53	5				
123001	1,92	1,98	290	123001	1,82	1,89	239	123001	2,40	2,40	51
125001	1,62	1,99	17	125001	1,48	1,93	14	125001	2,30	2,30	3
126001	2,79	2,79	2	126001	2,79	2,79	2				
131001	2,99	2,99	20	131001	2,73	2,73	13	131001	3,48	3,48	7
132001	2,87	2,87	173	132001	2,73	2,73	125	132001	3,24	3,24	48
133001	2,90	2,90	1	133001	2,90	2,90	1				
194000	-0,24	0,46	2	194000	-0,24	0,46	2				
203010	-0,23	0,65	12	203010	-0,65	0,89	5	203010	0,07	0,49	7
206010	-0,56	0,70	8	206010	-0,57	0,80	5	206010	-0,54	0,54	3
246010	-0,49	0,62	10	246010	-0,72	0,72	7	246010	0,06	0,38	3
246020	-0,65	0,66	9	246020	-0,87	0,89	6	246020	-0,20	0,20	3
259010	-1,25	1,30	33	259010	-1,25	1,30	33				
259050	-0,01	0,18	2	259050	-0,01	0,18	2				
All	**1,10**	**1,71**	**2438**	**All**	**1,00**	**1,64**	**1598**	**All**	**1,30**	**1,85**	**840**

***Table F2:** BIAS and MAE (deg C) of the road surface temperature (Ts based on ThMD; range of icing conditions considered is ±3°C) for selected Danish roads for all day period, evening-nighttime hours, and morning-daytime hours during road weather season 2009-2010.*

All day period				18-06 h – evening-nighttime				06-18 h – morning-daytime			
RST	**BIAS**	**MAE**	**Count**	**RST**	**BIAS**	**MAE**	**Count**	**RST**	**BIAS**	**MAE**	**Count**
1002	1,51	1,62	50	1002	1,37	1,54	32	1002	1,75	1,75	18
3001	3,05	3,05	1					3001	3,05	3,05	1
3003	1,81	1,81	5	3003	1,80	1,80	3	3003	1,83	1,83	2
4001	1,27	1,37	108	4001	0,97	1,11	73	4001	1,91	1,91	35
4002	1,35	1,42	178	4002	1,30	1,32	94	4002	1,40	1,53	84
4003	1,59	1,59	412	4003	1,33	1,33	212	4003	1,87	1,87	200
5002	2,24	2,24	3	5002	1,59	1,59	1	5002	2,56	2,56	2
5003	1,06	1,75	5	5003	1,52	1,52	1	5003	0,95	1,81	4
6001	-1,17	1,17	1	6001	-1,17	1,17	1				
7001	-0,09	0,27	81	7001	-0,91	0,91	7	7001	-0,01	0,21	74
9001	-0,63	0,87	738	9001	-0,52	0,52	1	9001	-0,63	0,87	737
9002	0,14	0,50	590					9002	0,14	0,50	590
9003	0,54	0,55	368					9003	0,54	0,55	368
10001	-0,63	0,71	1818	10001	-0,57	0,63	1594	10001	-1,04	1,30	224
15001	2,07	2,12	1625	15001	2,00	2,07	1077	15001	2,19	2,22	548
18003	1,76	1,76	29	18003	1,83	1,85	7	18003	1,74	1,74	22
23003	1,93	1,95	188	23003	1,69	1,73	120	23003	2,35	2,35	68
39001	-0,75	0,91	4601	39001	-0,43	0,70	2306	39001	-1,08	1,12	2295
39002	-0,68	0,89	9809	39002	-0,55	0,85	5094	39002	-0,82	0,93	4715
41001	1,57	1,76	404	41001	1,39	1,81	168	41001	1,70	1,72	236
44001	1,48	1,63	468	44001	1,36	1,52	301	44001	1,70	1,82	167
58001	1,78	2,07	51	58001	1,56	1,91	33	58001	2,18	2,36	18
68006	1,05	1,79	5	68006	0,14	2,00	2	68006	1,66	1,66	3
68009	2,99	2,99	2	68009	2,99	2,99	2				
118001	-1,23	1,30	10	118001	-1,54	1,54	4	118001	-1,02	1,13	6
119003	2,14	2,38	2969	119003	1,94	2,27	1792	119003	2,45	2,53	1177
120001	-0,47	2,63	9	120001	-2,27	2,27	6	120001	3,11	3,34	3
121004	-0,57	0,98	101	121004	-0,87	1,00	38	121004	-0,39	0,96	63
122001	-1,01	2,75	266	122001	-1,71	3,78	161	122001	0,05	1,16	105
123001	0,44	1,42	9926	123001	0,26	1,39	5237	123001	0,63	1,44	4689
125001	-2,35	3,00	7313	125001	-2,90	3,26	4204	125001	-1,61	2,66	3109
126001	-1,73	2,42	77	126001	-1,60	2,44	63	126001	-2,32	2,32	14
129001	1,51	1,51	8	129001	1,97	1,97	5	129001	0,74	0,74	3
131001	1,68	1,68	23	131001	1,68	1,68	23				
132001	3,01	3,01	11	132001	3,01	3,01	11				
194000	-1,31	1,46	729	194000	-1,36	1,50	391	194000	-1,24	1,42	338
194010	-1,31	1,41	896	194010	-1,38	1,45	526	194010	-1,20	1,34	370
194020	-1,67	1,78	64	194020	-1,78	1,91	31	194020	-1,57	1,66	33
199020	-1,47	1,68	271	199020	-1,74	1,87	148	199020	-1,15	1,44	123
199031	0,80	0,80	1	199031	0,80	0,80	1				
199040	2,11	2,11	4	199040	2,04	2,04	2	199040	2,19	2,19	2
203010	-0,61	1,15	22	203010	-0,83	1,37	14	203010	-0,21	0,77	8
206010	-2,01	2,44	598	206010	-2,23	2,47	357	206010	-1,68	2,39	241
206020	-1,05	1,25	40	206020	-1,04	1,20	22	206020	-1,05	1,31	18
206040	-0,63	0,90	8	206040	-0,83	0,91	7	206040	0,78	0,78	1
210010	-1,69	1,69	5	210010	-1,37	1,37	3	210010	-2,18	2,18	2
218020	-2,90	2,90	1	218020	-2,90	2,90	1				
222020	-0,75	1,66	19	222020	-0,76	1,91	11	222020	-0,73	1,32	8
222050	-0,89	1,39	8	222050	0,38	1,64	2	222050	-1,31	1,31	6
226035	-0,16	1,62	7	226035	1,23	2,18	3	226035	-1,20	1,20	4

246010	-1,31	1,42	167	246010	-1,32	1,49	101	246010	-1,30	1,32	66
246020	-1,30	1,65	56	246020	-1,33	1,77	45	246020	-1,15	1,16	11
250010	-1,16	1,19	3	250010	-2,19	2,19	1	250010	-0,65	0,70	2
259010	-1,34	1,47	533	259010	-1,46	1,57	343	259010	-1,13	1,29	190
259050	-1,22	1,34	37	259050	-1,50	1,68	20	259050	-0,90	0,95	17
279040	-1,18	1,40	71	279040	-1,32	1,35	52	279040	-0,80	1,52	19
All	**-0,37**	**1,57**	**45793**	**All**	**-0,49**	**1,63**	**24754**	**All**	**-0,24**	**1,51**	**21039**

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