Ministry of Climate and Energy

Scientific Report 09-02

Road Weather Verification: Revised Approach

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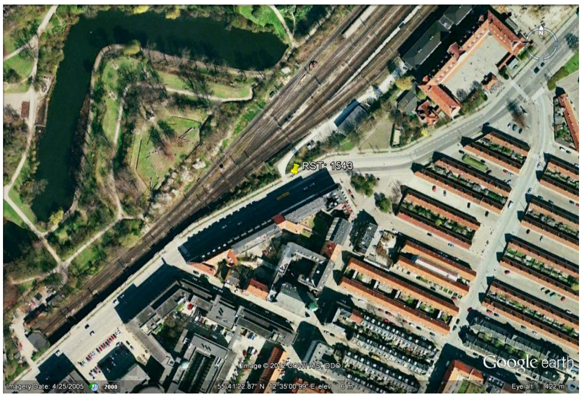

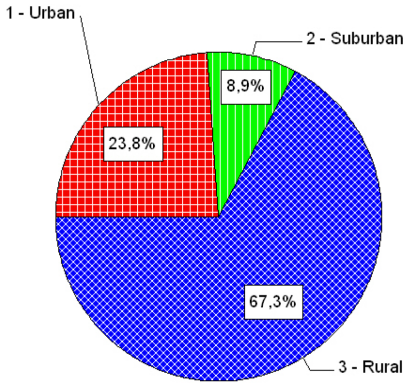

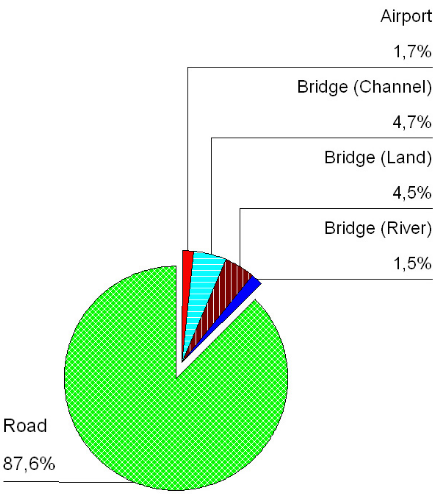

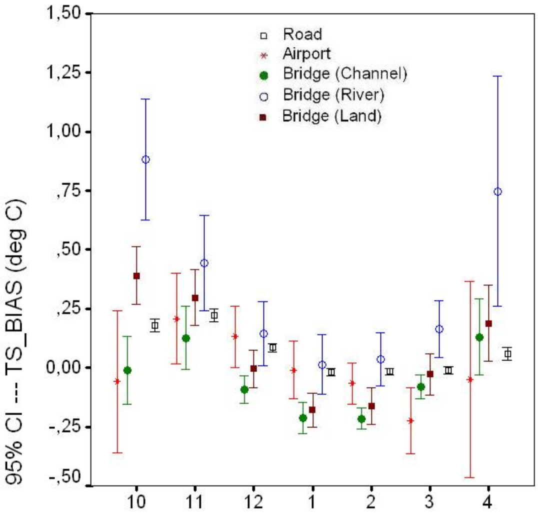

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Copenhagen 2009

Colophon

Serial title:
Scientific Report **09-02**

Title:
Road Weather Verification: Revised Approach

Subtitle:

Author(s):
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Other contributors:

Responsible institution:
Danish Meteorological Institute

Language:
English

Keywords:
Road weather modelling, verification, road station, urban related classification, proximity (minimum distance and azimuth) to seashore, surroundings, BIAS, mean absolute error, monthly and road weather season variability

Url:
www.dmi.dk/dmi/sr09-02.pdf

Digital ISBN:
978-87-7478-587-3 (on-line)

ISSN:
1399-1949 (on-line)

Version:

Website:
www.dmi.dk

Content:

Abstract

The variability of the road surface temperature (*Ts*) BIAS and MAE on a scale of the road weather season and on a monthly scale was analyzed applying various classifications of the road stations. These were based on: (i) positioning or placement near/at the driving lanes (in airport areas, on bridges and near the roads); (ii) urban related environment (urban, suburban, and rural); (iii) surroundings (fields, forests, water surfaces, trees) near the station; (iv) geographical position and proximity to the seashore (minimum distance and corresponding azimuth); (v) height of the station above sea level; (vi) properties of the driving lanes (pavement) of the roads.

Classification of road station (in total 404) showed that the majority (88%) of the stations is placed near/at the roads, and the rest are stations located within airport areas and stations on bridges over channels, rivers and land. Most of the stations (67%) are situated in the rural environment. More than 60 stations are placed at the sea level, and only a few – at height above 100 meters. More than 60 stations (including those placed on the bridges over channels) are in a close proximity to the sea and about 30 of them are at distances more than 30 km inland. For about 71, 30, 21, and 31% of the stations the surroundings include the presence of fields (agricultural and artificial such as airfield and industrial grounds), forest, water (sea, channels, rivers, lakes), and trees (independent and alley of trees along the roads), respectively. The most frequent categories (in a sum - about 46%) of surroundings around the station includes “*fields*”, “*trees*”, and “*fields-forests*”, and all of these are located in the rural areas.

It was found that both the largest *Ts* BIAS (with a higher variability) and MAE are characteristic for road stations located on bridges over the rivers. The BIAS is larger for the urban stations, but the MAE is better (i.e. lower magnitude values) during December-March compared with the suburban and rural stations. Over the season the BIAS is positive and larger for stations placed at low heights, and it is improving with the height increasing (on monthly scale: it is mostly negative during January-February). Over the season the BIAS is positive and larger at shorter distances from the seashore (on monthly scale: BIAS is the highest during October-November, but during January-March it became negative at distances more than 5 km away from the sea). Over the season the BIAS is positive and larger by magnitude for all stations, except those assigned to the southern sector (on monthly scale: the positive BIAS dominates for all azimuth directions during October-December and in April; and it is mostly negative during January-March in the east-northeast – south-southwest sector). On a monthly scale, positive BIAS dominates for 19 categories (most linked to suburban; 10 out of 13) vs. the negative BIAS dominates for 12 categories (most linked to urban; 7 out of 11). The absolute largest negative BIAS is associated with the urban station. The *Ts* MAE larger than 1°C was identified for two categories (”*urban: forest-water*” and “*urban: field-forest*”) both associated with urban areas.

Resumé

Variabiliteten af middelfejl og middel absolut fejl for vejtemperaturen (*Ts*) i løbet af vintersæsonen og på månedsbasis er blevet analyseret ved anvendelse af forskellige klassifikationer for vejtemperaturen ved målestationerne. Klassifikationerne er baseret på (i) placering af målestationen (i lufthavnsområder, på broer, og nær ved vejene); (ii) urbane omgivelser (urbane, sub-urbane og landlige forhold); (iii) andre omgivelser (marker, skov, søer, træer) nær vejstationen; (iv) geografisk position og afstand til havet (minimum afstand og tilhørende azimutvinkel); (v) højden af stationen over havniveau; (vi) egenskaber af kørebanerne (overfladetype).

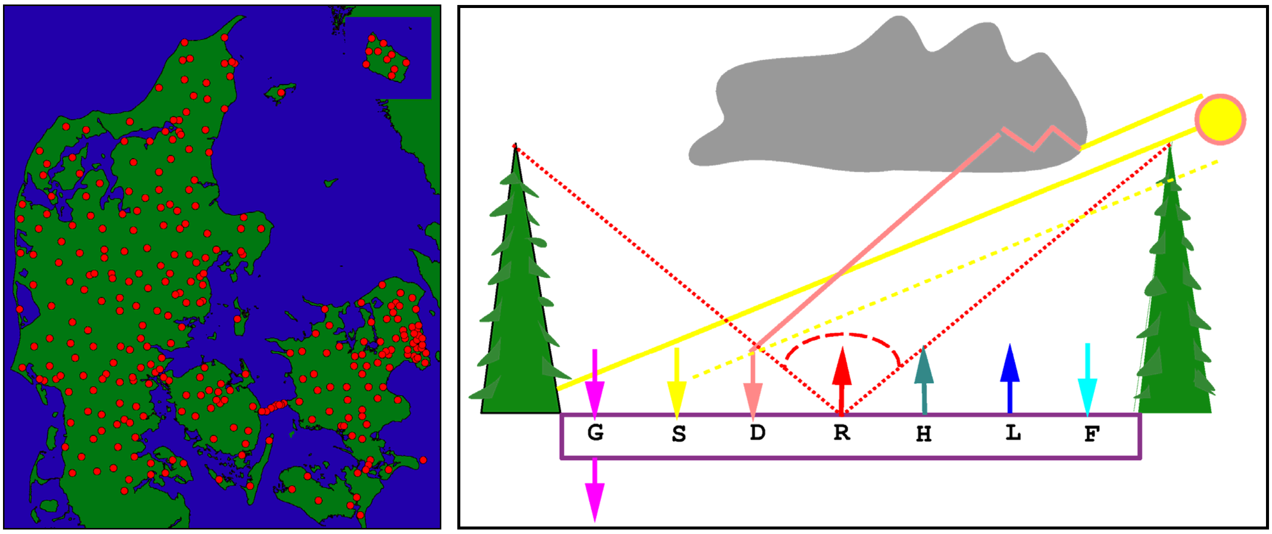
Klassifikationen viser (total =404 stationer) at hovedparten (88%) er placeret nær vejene, og resten er stationer anbragt enten i lufthavnsområder, eller på broer over enten vandløb eller landområder. De fleste stationer findes i landlige omgivelser. Mere end 60 stationer befinder sig ved havniveau, og kun få ligger over en højde på 100 m. Ligeledes mere end 60 stationer, der inkluderer stationer placeret på broer over vandløb, er beliggende tæt ved havet. For 71, 30, 21 og 31 % af stationerne inkluderer omgivelserne henholdsvis marker (eller åbne områder), skov, hav eller vandområder, og træer. De mest hyppige omgivelser omkring en målestation (totalt omkring 46 %) inkluderer `marker`, `træer` eller en blanding af marker og træer, der befinder sig i landlige omgivelser.

De største middelfejl for *Ts* (med stor variabilitet) og middel absolut fejl er karakteristisk for vejstationer beliggende på broer over vandløb. Middelfejlen er større for de urbane områder. Middel absolut fejl er lavere for perioden december – marts, sammenlignet med stationer i sub-urbane eller landlige omgivelser. Igennem vintersæsonen er middelfejlen positiv og større for stationer i lav højde. Mindre fejl fås for stationer i større højde. Igennem hele sæsonen er BIAS positiv og større tættere ved kysten (middelfejl størst i oktober – november, og negativ fra januar til marts længere fra kysten end 5 km). Positiv middelfejl dominerer for alle azimutretninger fra oktober – december og i april; men middelfejlen er mest negativ fra januar –marts i sektor fra retning østnordøst til sydsydvest. Positiv middelfejl dominerer for 19 kategorier (mest knyttet til sub-urbant, 10 ud af 13). Den negative middelfejl dominerer for 12 kategorier (mest knyttet til urbant miljø, 7 ud af 11). De største negative middelfejl findes for nogle stationer i urbane omgivelser. En middel absolut fejl større end 1 °C er blevet identificeret for 2 kategorier , der begge er knyttet til urbane områder.

1. Introduction

For almost two decades the DMI has in collaboration with the Danish Road Directorate (DRD) used the Road Weather Modelling System (RWMS) to provide operational forecasts of the slippery road conditions at multiple points (road stations) along the roads of the Danish road network. The road weather 24 hour forecasts done by this system is an important operational product produced by DMI. The system includes the dense network of road observations (about 400 road stations; see Figure 1.1a), some of which are equipped with more than one sensor measuring road surface, air and dew point temperatures), the Road Condition Model (RCM; *Sass, 1992; 1997*) and the numerical weather prediction (NWP) model - HIgh Resolution Limited Area Model, HIRLAM; *Yang et al., 2005*). For a description of the operational RWMS see the manual *GlatTerm (2004).*

After each season, it is relevant to evaluate the performance of the Road Conditions Model (see schematic view over fluxes in the model in Figure 1.1b) in order to continue further development and improvement of the RWMS. The performance of the system is evaluated by verifying forecasts for key parameters such as mean absolute error and BIAS for the road surface temperature (*Ts*), 2 m air temperature (*Ta*) and 2 m dew point temperature (*Td*), as well as scores reflecting a frequency of good/poor quality forecasts are calculated. The verification of the road slippery conditions for the road weather seasons is carried out annually. In addition, users of the RWMS might have also an interest in gaining free access to verification reports after each season.



(a) (b)

Figure 1.1: *(a) Geographical locations of the Danish road stations (in the right top corner of this figure the Island of Bornholm is presented), and (b) Schematic view over fluxes in the one dimensional road model, where : G - ground heat flux, S - direct insolation, D - diffuse insolation, R - infrared radiation, H - sensible heat flux, L - latent heat flux, and F - flux correction.*

2. Road Weather Model Verification

2.1. Standard Approach to Verification

The road weather season is run from October till April. The reason for such duration is based on a potential possibility that slippery road situations can occur in all these months. The verification of the RWMS performance is conducted based on evaluation of the DMI-HIRLAM model (see corresponding quarterly reports at the DMI web-site) and RCM forecasts for *Ts*, *Ta* and *Td* as well as scores. To make verification two conditions are required, i.e. both the observational data and modeled forecasts have to be available at exact times of observation vs. forecast. If one of these is missing then both are excluded from verification. Note, that usually the missing forecasts account for 1-2%. In almost all cases the missing forecasts are related to computer processing and archiving problems (or missing input meteorological data from the DMI-HIRLAM model).

Such verification includes analysis of all times forecasts (i.e. from 01 to 24 hours); however, only forecasts, where both the observed and forecasted *Ts* are within a range of ±3ºC, are included. Moreover, the major interest is represented by the first six hour forecasts (i.e. the responsible time for the road authorities and representing the time period on a diurnal cycle when the probability of the slippery road conditions is the highest). Note, all road stations of the Danish road network are included in verification. In general, the RCM shows a good performance compared with a simple linear trend forecast (assuming that the temperature tendency that existed an hour ago also holds for the remainder of the forecast). The verification of RCM for *Ts, Ta,* and *Td* for the road seasons is given by the mean absolute error (MAE), mean error (BIAS), and error frequencies (%) of *Ts* for 3 hour RCM forecasted values.

Annually the DMI performs standard verification of the RWMS performance and provide results at the DMI public website in the corresponding section of the Technical Reports (see corresponding links at: http://www.dmi.dk/dmi/index/viden/dmi-publikationer/tekniskerapporter.htm). Such annual reports are called: "*Road Weather Modelling System: Verification for Year-Year Road Weather Season*". Each report includes summary results of verification for BIAS and MAE of mentioned above parameters on an overall road weather season and monthly scales. Additionally, information on changes in the RWM setup and operational irregularities are also included. After *Mahura et al. (2008)* the additional information on spatial distribution of the road icing conditions at road stations within the Danish road network was added to such annual reports. Moreover, it is planned that in a future the results on verification of *Ts* based on the thermal mapping measurements will be also included following *Mahura et al. (2011).*

There are several factors influencing the verification scores for the road surface temperature prediction between seasons. For example, there is a natural variability of the weather conditions from year to year. For individual road stations there can be a large difference in verification score even though they are situated close to each other, and this difference can also be large from one county to another. Also the climatology in DMI-HIRLAM data, and especially from the road stations located in close proximity to the seashore can affect the result. An insight on possible improvement can be obtained through a better detailed analysis and representation of variability of simulated meteorological parameters, and first of all, the road surface temperature. The main goal of this study is to re-evaluate verification results and an overall performance of the RCM model considering different re-classifications of road stations following different approaches and using available data for groups of road stations.

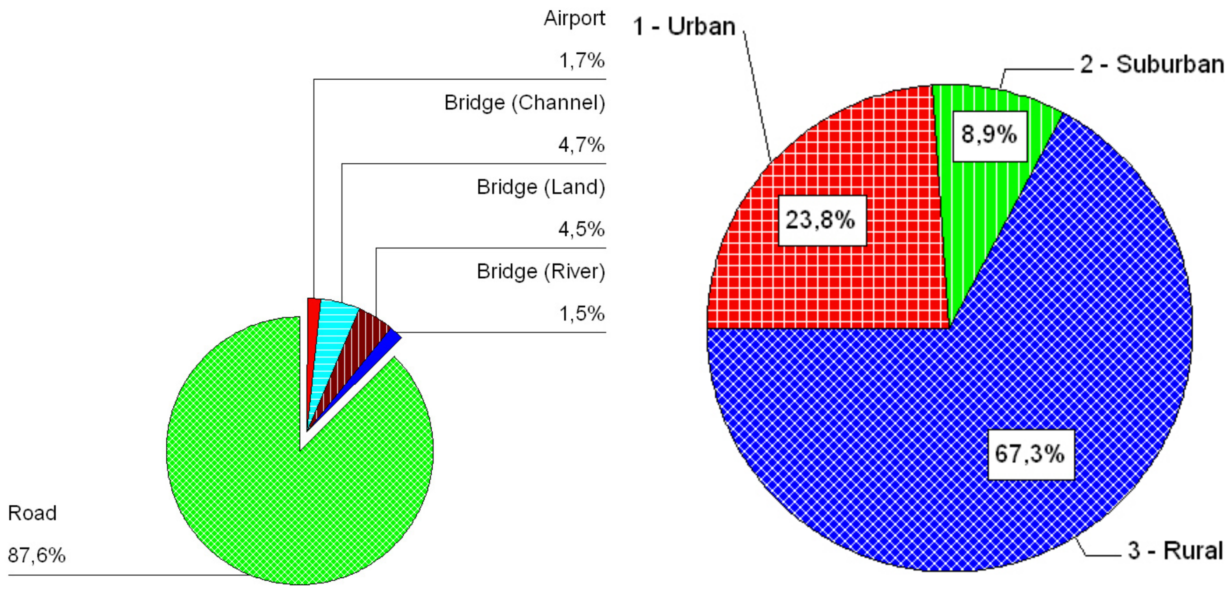
2.2. Revised Classifications for Road Stations

The Danish road network has about 400 road stations carrying out continuous measurements of road conditions. Each station is equipped with one or more sensors to measure the road surface temperature. The station is installed on one of the sides of the road, and the sensors are placed on the driving lanes in the pavement (asphalt). Road stations are situated in different environmental conditions, different geographical locations and at different heights above sea level, proximity to the sea, dominating or combined type (when several types of land use/ land-cover are presented near the road station) of surroundings. Hence, all listed above parameters (separately or in different combinations) can influence the forecasting of the slippery road conditions, and first of all, the road surface temperature.

2.2.1. Position on the Road

Road stations are placed at different positions near the driving lanes of the roads. In particular, analysis showed (Figure 2.1a) that about 1.7% of the road stations are placed in the airport areas, 4.7% are located on bridges over the channels, 4.5% are situated on bridges over the land (or over crossing roads), and 1.5% are situated on bridges over rivers. The rest, i.e. majority of 87.6% are placed near ordinary roads itself. Taking into account, for example, that bridges over the land/water surfaces will have different characteristics of cooling/ heating compared with asphalt roads situated in terrain, an analysis of the road surface temperature as a function of the type of the road station positioning could be also important.

Depending on the surrounding environment the road stations could be also divided on those situated in the urban, suburban, and rural areas. As seen in Figure 2.1b, about 24% of road stations are situated in the urban areas, about 9% – in suburban areas, and about 67% – in rural areas. Each of such areas has specific variability on a diurnal cycle for main meteorological variables such as air temperature, wind characteristics, and humidity regime. For example, for the Copenhagen metropolitan area, the analysis of short- and long-term episodes with the urbanized DMI-HIRLAM model showed significant differences in temperature, wind and humidity regimes when compared with the control run (*Mahura et al., 2008; 2009*). These differences are more visible for cases with dominating low wind conditions. So, analysis of the road surface temperature as a function of the urban related classification of the road stations could be also important.



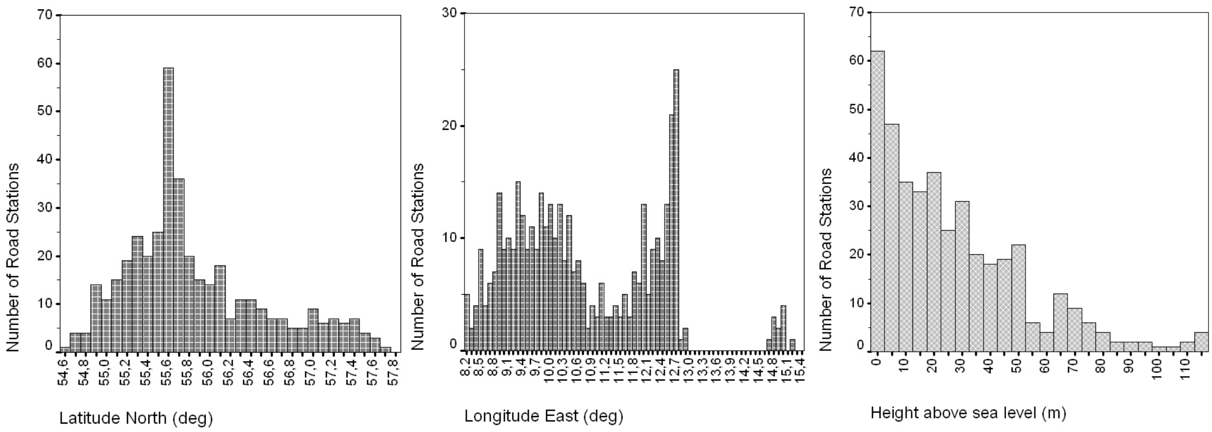
(a) *(b)*

Figure 2.1: *Classification of the road stations by (a) positioning on the road and (b) placing in urban related environment.*

2.2.2. Geographical Location, Height, and Proximity to Seashore

The total area of the country is about 43075 km^2, then on average, one such road station is placed within an area of 100 km^2 (or 10 x 10 km). This should be considered as a good coverage of the territory; and hence, there is sufficient information to be used for both purposes: measurements for assimilation into the model and verification of delivered forecasts at positions of road stations. Figure 2.2 shows distribution of road stations as a function of the latitude, longitude, and height above sea level. As seen in Figure 2.2ab, the largest number of stations is placed along latitude of 55.6 deg N and along longitude of 12.7 deg E. Note, that about 10 road stations are placed (within 14.7-15.2 deg E; Figure 2.2b) on Bornholm Island. Such output provides just general information on geographical distribution of road stations within the road network.

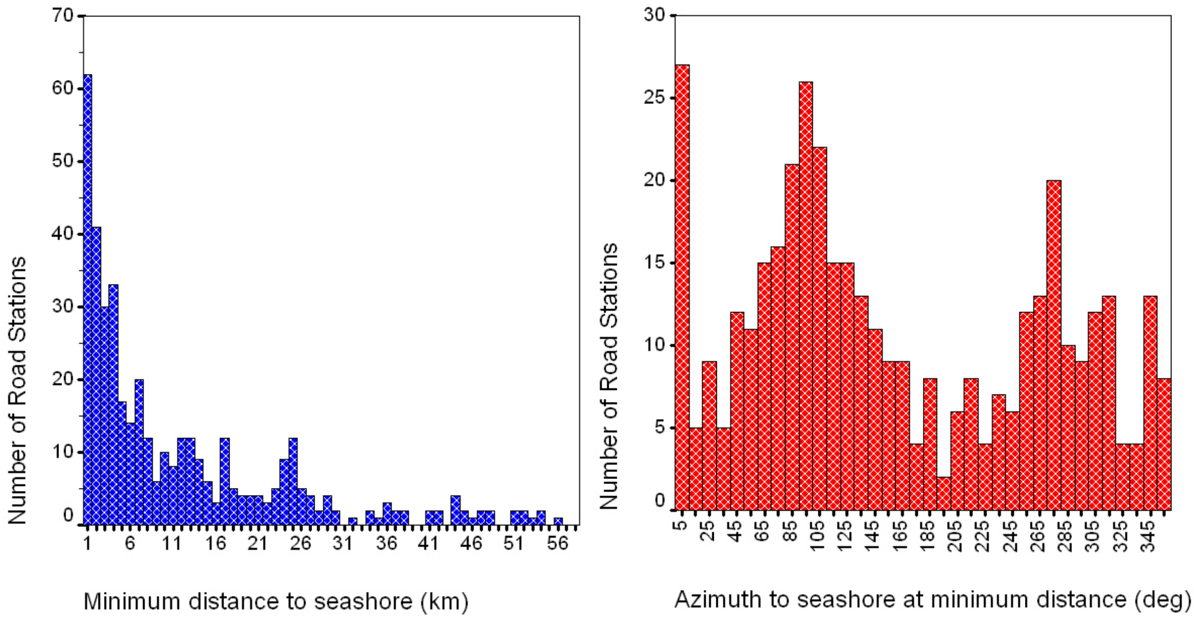
Denmark should be considered as a country with a flat terrain. An average height above sea level (asl) is about 31 m. The highest point called the "Møllehøj" is about 171 m. As seen in Figure 2.2c, the large number of stations is situated at low heights asl (for more than 60 stations it is at the sea level), and only a few are located above 100 m. Taking into account that there is known dependence and variability in air temperature with the height, the similar can be assumed and valid for the road surface temperature. So, analysis of the road surface temperature forecasts as a function of the height-parameter could be important.



(a) *(b)* *(c)*

***Figure 2.2:** Distribution of the road stations by (a) latitude, (b) longitude, and (c) height above sea level.*

The Danish coastline in total has a length of more than 7300 km including small bays and inlets; and hence, some road stations are located not far from the sea. Specific meteorological conditions are dominating at such stations. Therefore, the accurate forecasting of road conditions could also depend on proximity of the road station toward the seashore.



(a) *(b)*

***Figure 2.3:** Distribution of the road stations by (a) minimum distance to seashore, and (b) corresponding azimuth to seashore at minimum distance.*

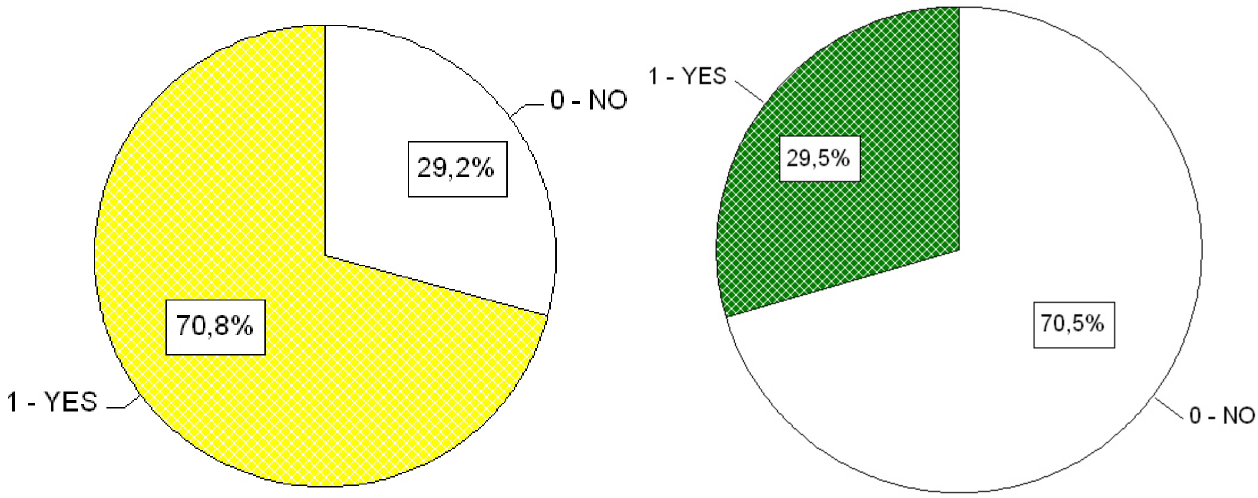
As seen in Figure 2.3a, considering the minimum distance to seashore, the largest number of road stations (including those - 19 - placed on the bridges over channels connecting large parts of Denmark) is in a close proximity to the sea. About 30 of them are situated at distances more than 30 km away from the sea, i.e. practically inland and hence, the sea influence on such stations will be less pronounced.

As seen in Figure 2.3b, for majority of the stations, the azimuth (or direction) toward the sea at minimum distance is within the eastern and western sectors (i.e. within about 90±30 and 280±30 deg), and hence, moist air masses passing over the large water surfaces could be transported from these directions. Note that all road stations (in total 19) placed on bridges over the channels were also assigned to the northern sector. Parameter - azimuth at minimum distance to seashore – is not applicable for such stations surrounded by water from all directions; hence, the value at the first column of Figure 2.3b could be adapted to show that less than 10 stations are placed on land within the northern direction in proximity to the sea.

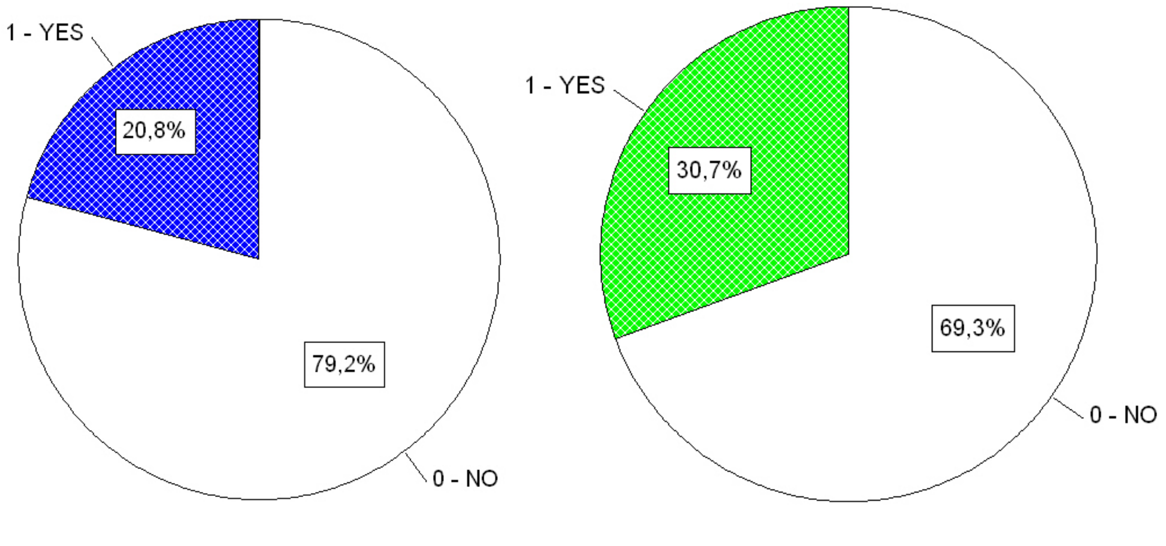
Moreover, additional information on distance to seashore under different azimuthal angles (considering entire 0-360 degrees) will be useful information for forecasting of road conditions and for evaluating influence on atmospheric transport of cool/warm, most/dry air masses toward the positions of road stations. So, specific datasets having such information could be used to calculate distances with corresponding azimuthal angles at different geographical positions of road stations. For example, the Global Self-consistent Hierarchical High-resolution Shorelines (GSHHS; *Wessel and Smith, 1996*) dataset could be applied for such calculations.

2.2.3. Characteristics of Roads' Surroundings

The surroundings of the road stations are important information for accurate prediction of the road surface temperature. The station can have one or several types of surrounding environments. For example, almost 71% of the stations are surrounded by fields and open areas (Figure 2.4a). Both agricultural fields mostly in the rural areas and open artificial (airfields or industrial) fields in the urban areas are included in this type. For near 31% of the stations water (as sea, channels, rivers, lakes) is a part of the surrounding environment (Figure 2.4c).



(a) *(b)*



(c) (d)

Figure 2.4: *Distribution of the road stations by presence of surroundings such as (a) fields, (b) forests, (c) water surfaces, and (d) trees.*

For such stations, the changing moisture content represents higher possible influence compared with open fields. For almost 30% of the road stations the forest (expanded far in distance and around the station) as a type of surrounding is presented near the station (Figure 2.4b). For about 31% of the stations, independently growing trees or alleys of tress along the roads are observed (Figure 2.4d). The two latter are especially important for taking into account the shadowing effects due to obstacles. Hence, these will influence shape and amplitude of the *Ts* diurnal cycle variability.

At one station several types of surrounding environment can be presented. I.e. the combined effects should be taken into consideration when the forecasting is performed. A summary on surroundings near the Danish road stations is given in Table 2.1. It includes number (and percentage) of the road stations linked with one of the possible combined categories based on urban related classification (urban, suburban, and rural classes) and surrounding environment ("*field*", "*forest*", "*water*", and "*tree*").

For the **urban** class of road stations, 11 categories were identified. The largest number of stations (28, or about 7% from all analyzed) was assigned to combined "*urban: field-water*" environment. The second largest are urban stations located near "*urban: fields*" and surrounded by "*urban: trees*" sharing about 4% each of the categories. None of the urban stations showed more than two combined environments.

For the **suburban** class of road stations, 7 categories were identified. The largest number of the suburban stations (14, or about 3.5%) was assigned to "*suburban: field*" environment. The second largest (but only less than 2%) is suburban road stations located in "*suburban: field-tree*". Similarly to urban stations, none of the suburban stations showed more than two combined environments.

For the **rural** class of road stations, 13 categories were identified. The largest number of the rural stations (71, or about 17.7%) was assigned to "*rural: field*" environment. The second largest (60, or 14.9%) category is the rural road stations located in "*rural: field-tree*"; followed by stations (54, or 13.4%) located in "*rural: field-forest"* environment. For rural stations, several three combined environments were observed: "*rural: field-water-tree*", "*rural: field-forest-tree*", and "*rural: field-forest-water*". These three accounted together in total 4.2% (or 17 stations). It should be mentioned that for these stations the influence on road surface temperature could be complex due to contribution of several environments or factors.

Table 2.1: *Classification of the road stations into categories as a function of surroundings (field, forest, water, tree) for 3 classes (urban, suburban, and rural) of the road stations /0 – not presented, 1 – presented/*

Type Category	Surroundings of Road Stations						
Urban (1)	*Class*	*Field*	*Forest*	*Water*	*Tree*	N	%
10000	1	0	0	0	0	13	3,22
10001	1	0	0	0	1	16	3,96
10010	1	0	0	1	0	8	1,98
10011	1	0	0	1	1	1	0,25
10100	1	0	1	0	0	2	0,50
10101	1	0	1	0	1	3	0,74
10110	1	0	1	1	0	2	0,50
11000	1	1	0	0	0	16	3,96
11001	1	1	0	0	1	6	1,49
11010	1	1	0	1	0	28	6,93
11100	1	1	1	0	0	1	0,25
Suburban (2)							
20001	2	0	0	0	1	4	0,99
20100	2	0	1	0	0	3	0,74
20101	2	0	1	0	1	2	0,50
20110	2	0	1	1	0	2	0,50
21000	2	1	0	0	0	14	3,47
21001	2	1	0	0	1	7	1,73
21100	2	1	1	0	0	4	0,99
Rural (3)							
30001	3	0	0	0	1	11	2,72
30010	3	0	0	1	0	15	3,71
30011	3	0	0	1	1	2	0,50
30100	3	0	1	0	0	26	6,44
30101	3	0	1	0	1	1	0,25
30110	3	0	1	1	0	7	1,73
31000	3	1	0	0	0	71	17,57
31001	3	1	0	0	1	60	14,85
31010	3	1	0	1	0	8	1,98
31011	3	1	0	1	1	5	1,24
31100	3	1	1	0	0	54	13,37
31101	3	1	1	0	1	6	1,49
31110	3	1	1	1	0	6	1,49
					All	404	100

The operationally numerical weather prediction model HIRLAM is using only dominating types of the land-use (so-called, tiles) over the grid-cells of model domain. Hence, the calculated temperature, wind, humidity, etc. fields do not take into account specifics of the exact point/ location. The RCM model is running at selected points (geographical locations of road stations), and peculiarities of local surroundings are playing important role.
So, at least, the following important factors of surroundings should be taken into account for the road conditions modelling:

1) Changes in shadowing and skyview during the day are taking place because the presence of obstacles (forest, different types of buildings/constructions, alleys of trees along the roads, and individual trees, etc.) located in proximity of the road station;

2) Presence of water surfaces (such as lakes, rivers, channels, sea) which influences the moisture budget;
3) Observed types of land-use/ land-cover (where it could only one of several types presented near the station) which influence interactions between soil-atmosphere-biosphere.

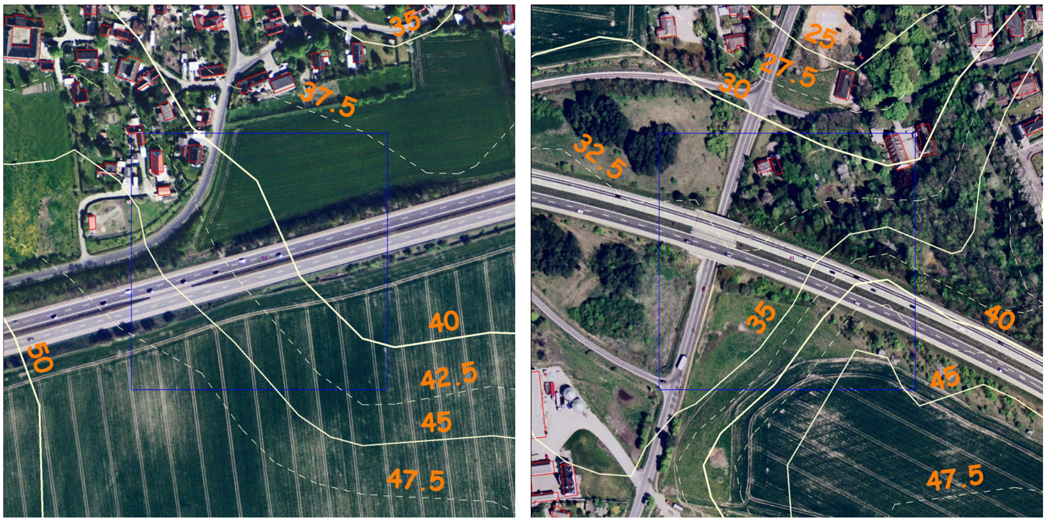
In order to obtain reliable information on surroundings, at first, the accurate and exact geographical position of each road station should be available; for example, using Geographic Positioning System (GPS). In particular, in spring 2009 using available Google resources the positions of road stations were checked, and about 20% of the stations were found to be misplaced with respect to positioning near/at the road's driving lanes. Following a request, the DRD had performed re-evaluation of GPS positions of stations including making 360 degree panoramic photos (an example is shown in Figure 2.5) to view and analyze currently existing shadowing and skyview effects.

Figure 2.5*: A 360 degree panoramic photo of surroundings near the road station N-3027 /provided by DRD/.*

Several datasets could be applied to extract for the RCM model necessary information on surroundings. First of all, it is high resolution database from the Kort og Matrikel Styrelsen (so-called Danish Height Model – Danmarks HøjdeModel, DHM). This database has very detailed terrain topography and surrounding obstacles (horizontal resolution – 1.6 m, and vertical precision – 20 cm). Second, the COoRdinate INformation on the Environment (CORINE) dataset has detailed information on spatial distribution (horizontal resolution of 250 meters) of different land-use/ land-cover classes. So, these can be used to identify surroundings of the road stations, and especially at the local scale. The Google-Earth has very good potential to be used for visualization of road stations positions and surroundings, as well as integrating the results of modelling.

2.2.3. Road Pavement Properties

The Danish Road Directorate (DRD) database about detailed properties of the roads has been also analysed on example of the road N-21 in the Roskilde Commune. Available information includes the following: type of pavement (as a weight in kg/cm^2); width of the road; density of material used in construction; heat conductivity and heat value; and year of construction. All data are given for each section of the road (examples of road sections are shown in Figure 2.6). A summary is given in Table 2.2 on example of the road N-21 (note, coordinates with respect to road are not included in the table, although these are available). The local conditions and surroundings including elevation/ height above sea level at two selected road sections (N-36 and N-41) are shown in Figure 2.6. As seen in Table, even at one section (on different sides of the road – left and right) two types of pavement can be used and parts of the road can be constructed /repaired in different years. The width of the road can also vary along the driving lanes. Moreover, depending on a construction procedure the density, heat conductivity and heat value can also vary.



(a) (b)

Figure 2.6: *Detailed characteristics of surroundings near road sections (a) N-36 and (b) N-41 along the road N-21 in the Roskilde Commune /provided by DRD/.*

Table 2.2: *Detailed properties for the road sections N-36 and N-41 along the road N-21 in the Roskilde Commune /provided by DRD/.*

Section **Right road side**	35	36	37	38	39	40	41	42	43
Pavement type	45PAST	45PAST	45PAST	45PAST	90ABS	90ABS	90ABS	90ABS	90ABS
Road width (m)	12	11,5	11,5	11,5	11,5	11,5	11,5	11,5	15,5
Density (g/cm^3)	2,3-2,4	2,3-2,4	2,3-2,4	2,3-2,4	2,3-2,4	2,3-2,4	2,3-2,4	2,3-2,4	2,3-2,4
Heat conductivity (W/m °C)	0,8	0,8	0,8	0,8	0,8	0,8	0,8	0,8	0,8
Heat value (MJ/Kg)	40	40	40	40	40	40	40	40	40
Built-date	1992	1992	1992	1992	1983	1983	1983	1983	1983
Section **Left road side**	35	36	37	38	39	40	41	42	43
Pavement type	40TB	40TB	40TB	40TB	50TB	50TB	50TB	50TB	50TB
Road width (m)	12	11,5	11,5	11,5	8,5	11,5	8,5	11,5	12
Density (g/cm^3)	2,3-2,4	2,3-2,4	2,3-2,4	2,3-2,4	2,3-2,4	2,3-2,4	2,3-2,4	2,3-2,4	2,3-2,4
Heat conductivity (W/m °C)	0,8	0,8	0,8	0,8	0,8	0,8	0,8	0,8	0,8
Heat value (MJ/Kg)	40	40	40	40	40	40	40	40	40
Built-date	2001	2001	2001	2001	2002	2002	2002	2002	2002

As for roads the natural wearing is continuously taking place due to traffic, exposure to sunlight and various precipitations. The continuous from time-to-time repairment and replacements of the parts or sections of the roads with new-fresh asphalt (or any other material) are changing specific characteristics of the road surface at exact locations. These are more difficult to incorporate as temporally and spatially variable parameters into the RCM model compared with almost unchangeable distance to seashore, height above sea level, and less variable shadowing effects and skyview due to obstacles and land-use/land-cover. Therefore, as for now, the averaged characteristics for albedo, density, heat conductivity, heat capacity, etc. are used in the model.

In principle, using such detailed road properties for sections of the roads, where the road stations (about 400) are placed, will be desirable, although it will require updates (at least, once per road weather season). For a limited number of locations (such as road stations) it could be done manually. For more frequent updates, an automatic procedure needs to be developed. It will become critical when such data will be needed for road stretches forecasting, i.e. when number of locations where the forecasts should be produced will be increased up to several thousand and more.

Finally, for practical application and in order to identify possible reasons for large deviations between forecasts and observations, the analyses of both the NWP model forecast and information about local peculiarities and conditions at the location of the forecast might be necessary.
For that, the **cataloguing of individual characteristics of each road station** is planned to be carried out. Such catalogue can include: (i) position of the road station using geographic position system; (ii) height; (iii) horizon angle by sectors for shadowing effects due to surrounding terrain and obstacles; (iv) distance to seashore by sectors; (v) classification of stations based on proximity to seashore; (vi) classification of surroundings of stations taking into account types of land-use /land-cover, and especially with respect to forest, open agricultural/ artificial fields, urban/ suburban/ rural areas, closest water bodies (such as sea, channel, river, lake).

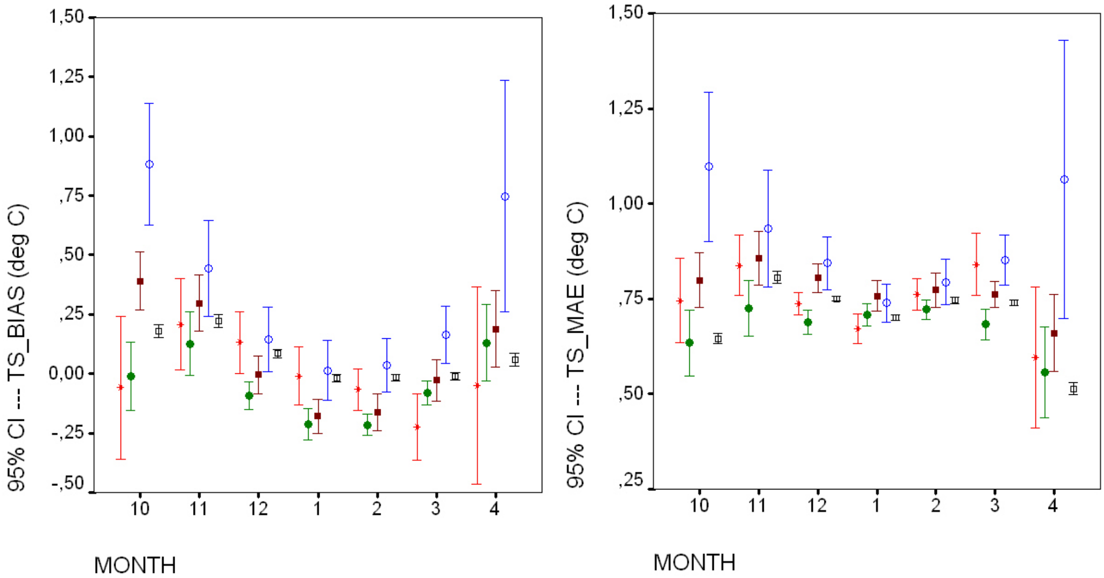
3. Results and Discussions: Revised Verification for Road Stations

3.1. Based on positioning of road station

Figure 3.1 shows monthly variability of the road surface temperature (*Ts*) BIAS and mean absolute error (MAE) depending on the positioning/ placement of road stations along the driving lanes of the roads. As seen in Figure 3.1a, on average the BIAS is the largest for road stations located on **bridges over rivers**. Especially, it occurs at the beginning (October) and the end (April) of the road weather season (*thereafter, season*), when it reaches up to 0.88 and 0.75°C, respectively. It is the lowest in January. On average, a positive BIAS is dominating for this type of the road stations throughout the season, although a large variability in BIAS is also observed. In particular, variability is one of the largest among other types of stations, followed by the **airport stations** located within airport area mostly on open fields. For this type of stations, the BIAS is negative expect November-December. Throughout the season, the minimum value of BIAS (-0.22°C) is observed in March, and the maximum value (+0.21°C) – in November. In general, for **stations near the roads** the value of BIAS is relatively small. It is positive during October-December and negative during January-March. Note that for this type of stations the variability in BIAS is the lowest compared with other types. For the road stations on **bridges over land** similarly to stations near the roads, the BIAS is also negative during January-March, and it is positive in other months. It has the largest positive value (+0.39°C) in October and the negative (-0.18°C) – in January. For stations located on the **bridges over channels**, mostly the negative BIAS is observed, except in November and April (+0.13°C in both months). Its absolute value is higher almost twice in January-February (reaching -0.22°C) compared with other months.

The analysis of MAE (see Figure 3.1b) underlined that during beginning and end of the season, there is larger variability in MAE for all types of stations, except the stations located near the roads. The largest MAE as well as its highest variability (i.e. worst for predicted *Ts*) is characteristic for the road stations located on the bridges over rivers. Averaged over the season, MAE is about 0.9°C, with the highest of 1.1°C - in October and April. The MAE is the best (about 0.7°C) for stations located near the roads and on the bridges over channels. For the airport areas and bridges over the land surface, it is about 0.75 and 0.78°C, respectively.

Analysis showed that, the RCM forecasts of the road surface temperature have lower quality MAEs for the road stations located on the bridges over the rivers. Hence, more attention should be paid for improvement of the forecasts at these locations because a small percentage of road stations can contribute to degrading the overall RCM model performance and scores. It is especially seen in the beginning and end of the road weather seasons.



(a) *(b)*

Figure 3.1: *Monthly variability (at 95% confidence interval, CI, for the mean) of the road surface temperature (a) Ts BIAS and (b) Ts MAE as a function of different positioning/ placement of the road stations /▫ - road, * - airport, ● - bridge over channel, ○ - bridge over river, ▪ - bridge over land/.*

Table 3.1: *Monthly variability of the road surface temperature Ts BIAS and Ts MAE for the road stations located on the bridges over rivers.*

Ts MAE (°C)

Month Station	Oct	Nov	Dec	Jan	Feb	Mar	Apr	Season
1006	0,86	0,81	0,83	0,83	0,78	0,79	0,54	**0,79**
2015	1,63	1,04	0,76	0,72	0,74	0,92	1,89	**1,08**
5013	0,83	0,93	0,87	0,79	0,82	0,87	0,88	**0,85**
6016	0,70	0,83	0,83	0,68	0,81	0,73	0,55	**0,74**
6018	0,82	1,22	1,09	0,75	0,86	0,87	0,89	**0,92**
6122	1,44	0,98	0,81	0,67	0,80	0,94	1,46	**1,00**
All	**1,10**	**0,94**	**0,84**	**0,74**	**0,79**	**0,85**	**1,06**	**0,89**

Ts BIAS (°C)

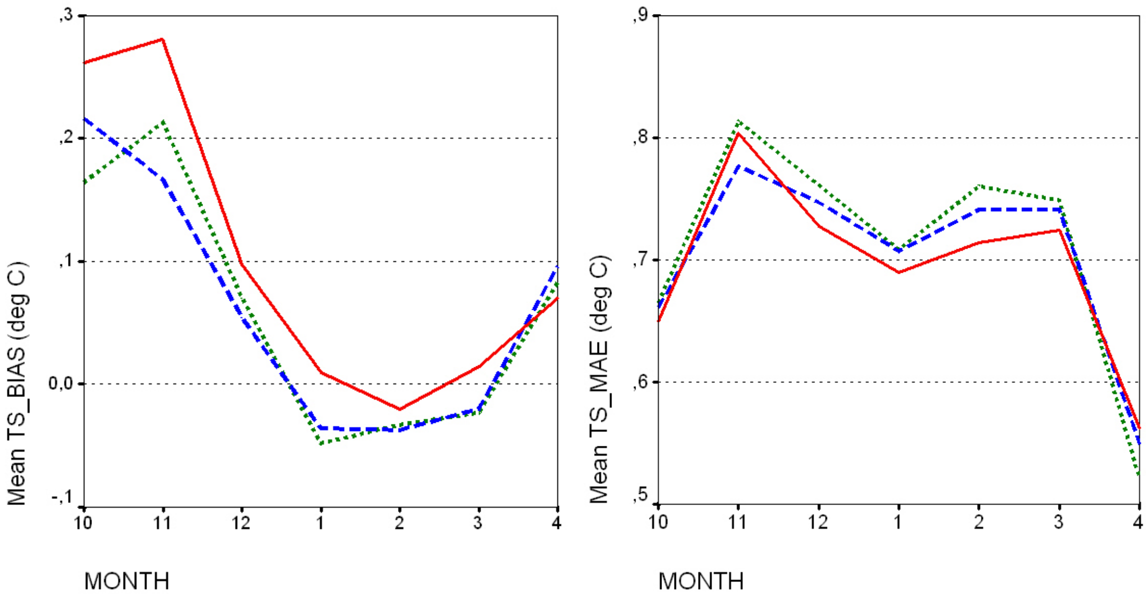
Month Station	Oct	Nov	Dec	Jan	Feb	Mar	Apr	Season
1006	0,47	0,16	-0,23	-0,36	-0,26	-0,15	0,18	**-0,03**
2015	1,58	0,51	0,12	-0,02	-0,01	0,37	1,75	**0,58**
5013	0,69	0,39	0,35	0,11	0,07	0,23	-0,28	**0,26**
6016	0,32	0,50	0,28	0,16	0,28	0,10	0,41	**0,29**
6018	0,56	0,74	-0,10	-0,06	-0,11	0,04	0,73	**0,15**
6122	1,30	0,59	0,34	0,21	0,19	0,32	1,34	**0,60**
All	**0,88**	**0,44**	**0,15**	**0,01**	**0,04**	**0,17**	**0,75**	**0,33**

For individual road stations placed on the bridges over the rivers (see Figure 3.2), a summary of BIASes and MAEs is given in Table 3.1. As seen, there are stations where the MAE and BIAS are larger than 1°C.

Figure 3.2: Road stations assigned to category "bridges over rivers"/ extracted from Google-Earth/.

3.2. Based on urban related classification

Figure 3.3 shows monthly variability of the *Ts* BIAS and MAE for different types of **road stations assigned to urban, suburban and rural environments**. As seen in Figure 3.3a and Table 3.2, on average, the BIAS is larger for urban compared with suburban and rural stations. This tendency is observed during all months, except April. During the season, for the urban stations the BIAS is positive, except in February. For the suburban and rural stations it is negative during January-March period, and positive in other months. For urban stations the largest BIAS of +0.28°C is in November. Averaged over the season, the MAE is a slightly better for the urban type of stations; in particular, during December-March it is better compared with two other types of road stations (Figure 3.3b).



(a) *(b)*

***Figure 3.3:** Monthly variability of the road surface temperature (a) Ts BIAS and (b) Ts MAE as a function of the urban related classification for the road stations (—— - urban, - - - - suburban, ······ - rural).*

Ts MAE (°C)								
Month ***Class***	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**Season**
Urban	0,65	0,80	0,73	0,69	0,71	0,72	0,56	**0,70**
Suburban	0,66	0,78	0,75	0,71	0,74	0,74	0,55	**0,71**
Rural	0,67	0,81	0,76	0,71	0,76	0,75	0,52	**0,72**
All	**0,66**	**0,81**	**0,75**	**0,70**	**0,75**	**0,74**	**0,53**	**0,72**
Ts BIAS (°C)								
Month ***Class***	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**Season**
Urban	0,26	0,28	0,10	0,01	-0,02	0,01	0,07	**0,10**
Suburban	0,22	0,17	0,05	-0,04	-0,04	-0,02	0,10	**0,06**
Rural	0,16	0,21	0,07	-0,05	-0,03	-0,02	0,08	**0,06**
All	**0,19**	**0,22**	**0,08**	**-0,03**	**-0,03**	**-0,01**	**0,08**	**0,07**

Table 3.2: *Monthly variability of the road surface temperature Ts MAE and Ts BIAS for the road stations located in different urban related environments (urban, suburban, and rural).*

Examples of road stations placed in different urban related environments are shown in Figure 3.4. The large changes in surroundings are especially seen for urban vs. rural station. Summary for *Ts* MAE is given in table, where the better MAE values (lower in magnitude) correspond to better quality of *Ts* forecasts. As seen, on a season scale, the road surface temperature was better predicted for the urban compared with the rural station.

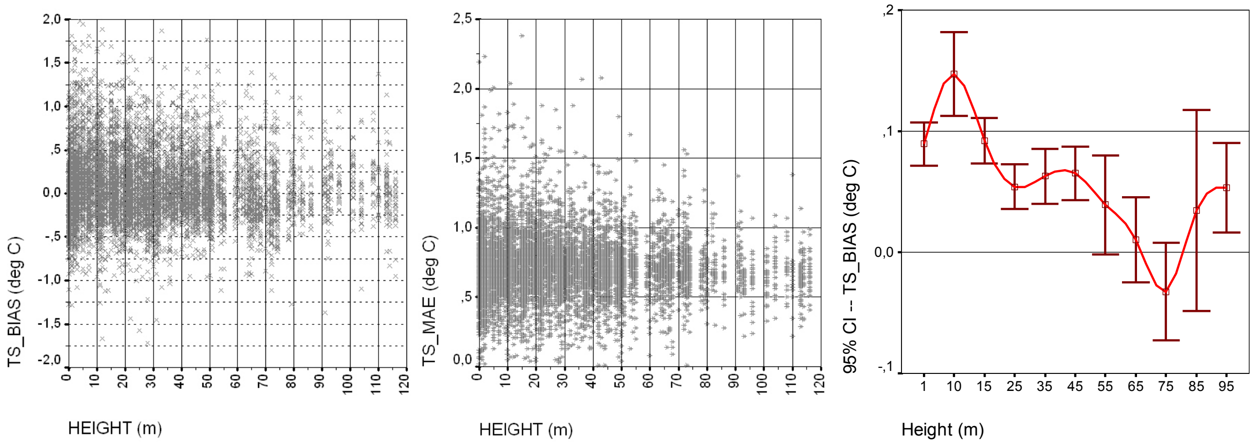
(a) *(b)* *(c)*

Ts MAE (°C)									
Station	**Month** ***Class***	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**Season**
1543	***Urban***	0,39	0,71	0,69	0,64	0,72	0,68	0,69	**0,64**
2161	***Suburban***	0,51	0,79	0,66	0,63	0,69	0,79	0,52	**0,66**
2013	***Rural***	0,65	0,73	0,64	0,66	0,66	0,78	0,59	**0,67**

Figure 3.4: *Examples of the road stations classified into urban related classes: (a) urban N-1543, (b) suburban N-2161 and (c) rural N-2013 /extracted from Google-Earth/; and Table with monthly variability of Ts MAE at these stations.*

3.3. Based on height

Figure 3.5ab shows scatter plots of the *Ts* BIAS and MAE as a function of the **height** of the road stations above sea level (asl). Figure 3.5c shows *Ts* BIAS at 95% confidence interval for the mean. As seen, in general, the BIAS is negative for the road stations located at the sea level (0 meters). At heights up to 70 meters the BIAS is positive. For this interval of heights the overall tendency is that the BIAS is improving (i.e. decreasing toward zero) with the height increasing. Then, it become negative (at 75 m), and afterwards it become positive in sign again and it continues to increase with the height.



(a) *(b)* *(c)*

Figure 3.5: *Scatter plot of the road surface temperature (a) Ts BIAS and (b)Ts MAE; and (c) Ts BIAS at 95% confidence interval for the mean vs. height of the road stations above sea level.*

It was found that *Ts* BIAS is weakly negatively correlated ($-0.2 \leq R \leq -0.1$) with the height and during all months the correlation coefficient is negative, except February ($R = +0.1$). There is a pattern on a month-to-month scale for *Ts* BIAS, (see Appendix 1; Figures 1A-1B), except October and April. The BIAS is positive and the largest (+0.36°C) in November. It decreases by a factor more than two in December. During January-March, the BIAS become smaller compared with previous months and mostly it is negative in sign. The largest negative BIAS (-0.18°C) is in March. As seen, for the monthly curves a representative fit to data could be done through applying a linear regression method. As seen, the absolute value of *Ts* BIAS has a tendency of decreasing with the height, and a slope of such decrease has also a month-to-month variability. Summary of monthly and season variability for the *Ts* BIAS and MAE as a function of the height of the road station above sea level are given in Tables 3.3-3.4. Note, that heights starting from 10 m asl have been assigned to intervals of 10 meters each.

Table 3.3: *Monthly variability of the road surface temperature Ts BIAS as a function of the height of the road station above sea level.*

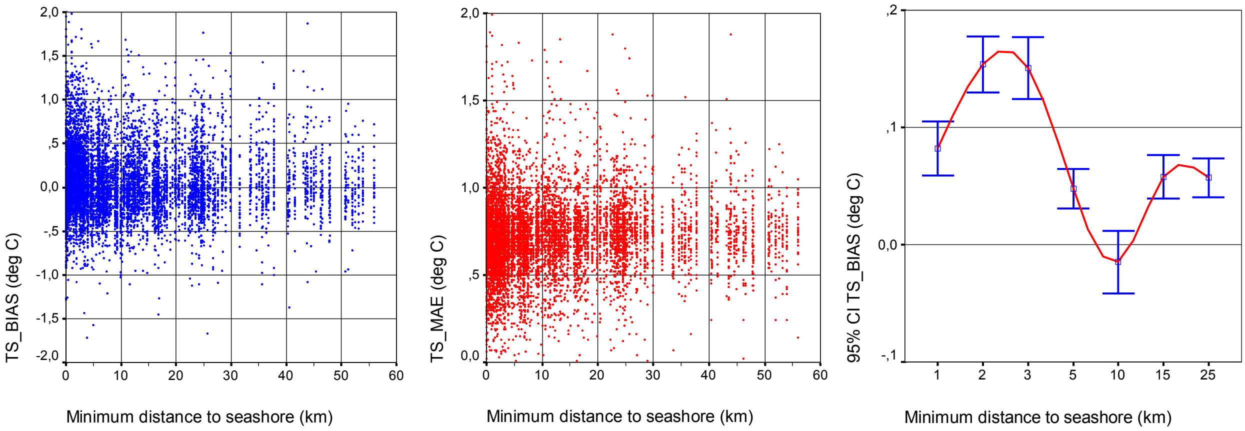
Ts BIAS (°C)								
Month ***Height (m)***	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**Season**
0-5	0,28	0,28	0,09	-0,04	-0,08	0,00	0,16	**0,09**
5-10	0,36	0,31	0,15	0,02	0,01	0,04	0,13	**0,15**
10-20	0,22	0,24	0,11	0,00	-0,02	0,00	0,10	**0,09**
20-30	0,15	0,19	0,04	-0,05	-0,01	-0,01	0,07	**0,05**
30-40	0,13	0,22	0,07	-0,02	-0,02	-0,03	0,07	**0,06**
40-50	0,18	0,20	0,06	-0,04	0,00	0,00	0,03	**0,07**
50-60	0,17	0,14	0,03	-0,09	-0,06	-0,08	0,20	**0,04**
60-70	0,05	0,19	0,05	-0,09	-0,04	-0,07	-0,06	**0,01**
70-80	-0,04	0,15	0,05	-0,11	-0,07	-0,18	-0,12	**-0,03**
80-90	0,25	0,21	0,01	-0,17	-0,12	-0,10	0,16	**0,03**
>90	0,16	0,14	0,05	0,02	0,07	0,03	-0,14	**0,05**
All	**0,19**	**0,22**	**0,08**	**-0,03**	**-0,03**	**-0,01**	**0,08**	**0,07**

Table 3.4: *Monthly variability of the road surface temperature Ts MAE as a function of the height of the road station above sea level.*

Ts MAE (°C)								
Month ***Height (m)***	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**Season**
0-5	0,67	0,81	0,72	0,71	0,72	0,72	0,56	**0,71**
5-10	0,71	0,80	0,76	0,69	0,74	0,75	0,59	**0,73**
10-20	0,67	0,85	0,78	0,71	0,77	0,74	0,53	**0,73**
20-30	0,65	0,81	0,77	0,72	0,77	0,75	0,52	**0,73**
30-40	0,66	0,82	0,75	0,70	0,76	0,75	0,48	**0,71**
40-50	0,63	0,77	0,75	0,70	0,75	0,75	0,50	**0,70**
50-60	0,70	0,77	0,74	0,69	0,74	0,74	0,57	**0,71**
60-70	0,64	0,79	0,77	0,71	0,77	0,77	0,54	**0,72**
70-80	0,67	0,79	0,75	0,70	0,73	0,78	0,55	**0,72**
80-90	0,69	0,81	0,75	0,67	0,73	0,75	0,61	**0,72**
>90	0,64	0,72	0,69	0,65	0,70	0,73	0,56	**0,67**
All	**0,66**	**0,81**	**0,75**	**0,70**	**0,75**	**0,74**	**0,53**	**0,72**

3.4. Based on minimum distance to seashore

Figure 3.6ab shows scatter plots of the *Ts* BIAS and MAE as a function of the **minimum distance from the road station to seashore.** Figure 3.6c shows *Ts* BIAS at 95% confidence interval for the mean. As seen, on a season scale, the BIAS is positive and larger by value (up to +0.15°C) at shorter distances from the seashore, and it is smaller (+0.06°C) at larger distances, i.e. for road stations located far inland, where less influence from the sea could be observed. The BIAS is slightly negative (-0.01°C) at distances of about 10 km.
A similar shape of the pattern is observed on a month-to-month scale (see Appendix 2; Figures 2A-2B). At shorter distances (less than 3 km), on average, the BIAS is positive, except in January and February. The largest positive BIASes are in October (+0.28°C) and November (+0.33°C). At distances of about 10 km the BIAS was smaller (by an absolute value), and then it is slightly increasing. During January-March, at distances more than 5 km the BIAS became negative. It is the largest negative (-0.1°C) in January.



(a) *(b)* *(c)*

Figure 3.6: *Scatter plot of the road surface temperature (a) Ts BIAS and (b) Ts MAE; and (c) Ts BIAS at 95% confidence interval for the mean vs. minimum distance from the road station to seashore.*

Summary of monthly and season variability for the *Ts* BIAS and MAE as a function of the minimum distance from the road station to the seashore are given in Tables 3.5-3.6 for intervals between 0-1, 1-2, 2-3, 3-7, 7-10, 10-20, and more than 20 km (shown in Figure 3.6 on the horizontal axis as 1, 2, 3, 5, 10, 15, and 25 km, respectively).

Table 3.5: Monthly variability of the road surface temperature Ts BIAS as a function of the minimum distance from the road station to the seashore.

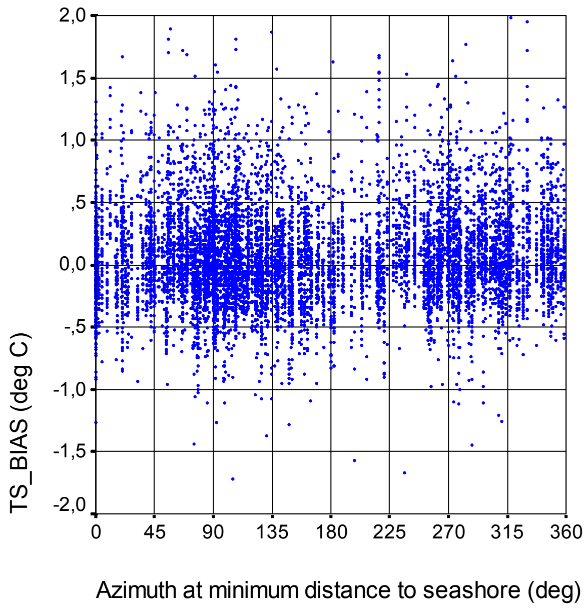
Ts BIAS (°C)								
Month ***Distance (km)***	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**Season**
0-1	0,27	0,25	0,08	-0,04	-0,07	0,00	0,16	**0,08**
1-2	0,28	0,33	0,18	0,08	0,03	0,04	0,11	**0,15**
2-3	0,29	0,32	0,15	0,07	0,01	0,07	0,13	**0,15**
3-7	0,18	0,19	0,03	-0,05	-0,05	-0,01	0,05	**0,05**
10-20	0,08	0,12	-0,02	-0,10	-0,08	-0,07	-0,05	**-0,01**
> 20	0,17	0,19	0,05	-0,05	-0,03	-0,02	0,10	**0,06**

Table 3.6: Monthly variability of the road surface temperature Ts MAE as a function of the minimum distance from the road station to the seashore.

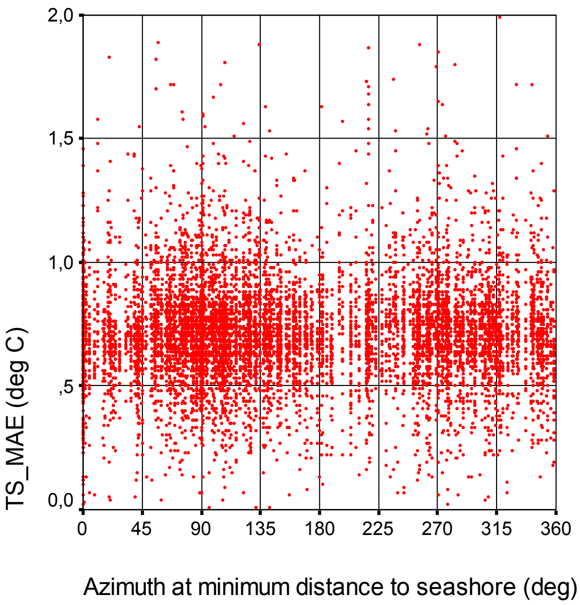
Ts MAE (°C)								
Month ***Distance (km)***	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**Season**
0-1	0,70	0,72	0,71	0,57	0,70	0,80	0,72	**0,71**
1-2	0,68	0,71	0,72	0,51	0,61	0,79	0,73	**0,69**
2-3	0,68	0,73	0,74	0,56	0,67	0,82	0,74	**0,71**
3-7	0,70	0,74	0,74	0,51	0,62	0,79	0,75	**0,70**
10-20	0,70	0,74	0,74	0,49	0,65	0,77	0,73	**0,70**
> 20	0,72	0,77	0,75	0,54	0,67	0,84	0,77	**0,73**

3.5. Based on azimuth to seashore

Figure 3.7ab shows scatter plots of the *Ts* BIAS and MAE as a function of the **azimuth at minimum distance from the road station to seashore**. Figure 3.8ab shows *Ts* BIAS and MAE at 95% confidence interval for the mean.



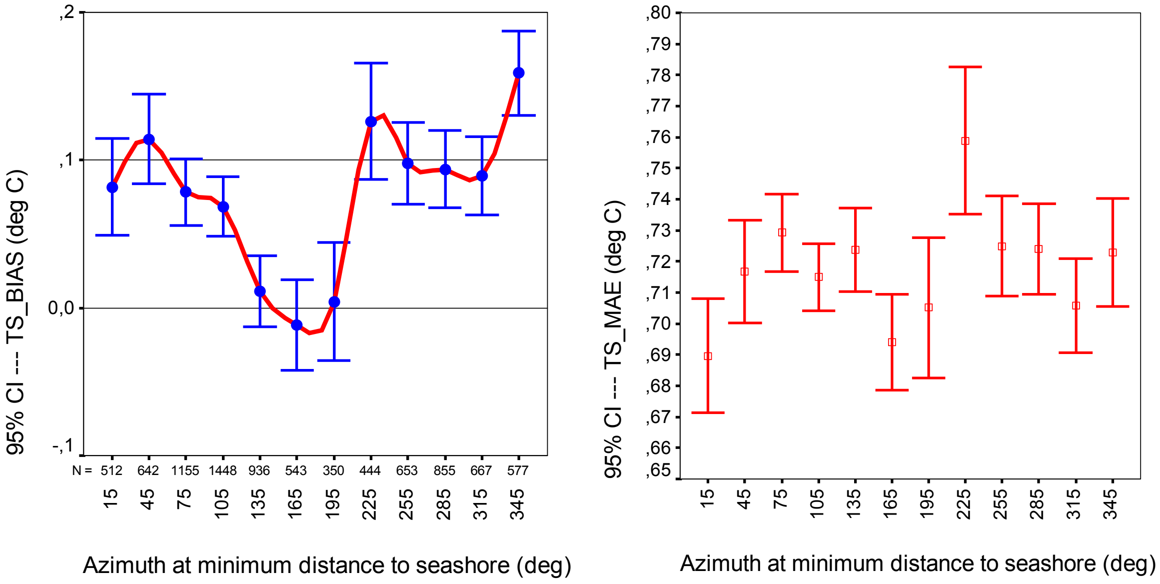
(a)



(b)

Figure 3.7: *Scatter plots of the road surface temperature (a) Ts BIAS and (b) Ts MAE vs. azimuth corresponding to minimum distance from the road station to seashore /intervals: azimuth value ± 22.5 deg; for example: 90 deg corresponds to interval 67.5 - 112.5 deg /.*

As seen, on a season scale, on average, the BIAS is positive and larger by magnitude for all stations, except those assigned to the southern sector (Figure 3.7a). For the southern sector, the BIAS is the smallest and can be even negative. The BIAS is largest (+0.16°C) for stations assigned to the northern sector. The *Ts* MAE is worst (0.76°C) for stations assigned to 225 deg (around SW; see Figure 3.7b) with the second largest positive BIAS (+0.13°C) after those stations assigned to the 345 deg (around NNE).



(a) *(b)*

Figure 3.8: *Road surface temperature (a) Ts BIAS and (b) Ts MAE at 95% confidence interval for the mean vs. azimuth corresponding to minimum distance from the road station to seashore /intervals: azimuth value ± 22.5 deg; for example: 90 deg corresponds to interval 67.5 - 112.5 deg /*

Table 3.7: *Monthly variability of the road surface temperature Ts BIAS as a function of the azimuth at minimum distance from the road station toward the seashore.*

Ts BIAS (°C)								
Month ***Azimuth (deg)***	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**Season**
15	0,22	0,18	0,11	-0,01	-0,01	-0,01	0,11	**0,08**
45	**0,29**	0,26	0,09	-0,01	0,01	0,02	0,13	**0,11**
75	**0,29**	0,22	0,05	-0,07	-0,06	-0,01	0,13	**0,08**
105	0,16	0,26	0,08	-0,01	-0,03	-0,05	0,03	**0,07**
135	0,15	0,21	0,04	-0,10	-0,10	-0,10	-0,06	**0,01**
165	0,08	0,15	0,01	**-0,12**	**-0,12**	-0,07	0,01	**-0,01**
195	0,17	0,12	0,00	-0,11	-0,11	-0,04	0,02	**0,00**
225	**0,29**	0,27	0,11	-0,01	-0,04	0,02	0,29	**0,13**
255	0,16	0,26	0,10	0,00	0,04	0,03	0,09	**0,10**
285	0,10	0,23	0,13	0,04	0,05	0,03	0,05	**0,09**
315	0,17	0,19	0,11	0,01	0,03	0,00	0,13	**0,09**
345	0,27	**0,30**	0,16	0,04	0,06	0,10	0,19	**0,16**

On a monthly scale, the positive BIAS dominates for all azimuth directions during October-December and in April (see Appendix 3; Figures 3A-3B). For all directions, the larger magnitude values of positive BIAS more than +0.2°C (up to 0.29-0.30°C) are seen during October-November compared with other months. The BIAS is negative during January-March for the azimuths between 52.5 - 217.5 deg (ENE – SSW), with the largest value of -0.12°C at around 165 deg. The general

tendency in *Ts* monthly variability that BIAS is gradually decreasing from the beginning of the season, and become mostly negative during January-March (in ENE – SSW sector) with returning to positive values in April.
Summary of monthly and season variability for the *Ts* BIAS and MAE as a function of the azimuth at minimum distance from the road station to the seashore are given in Tables 3.7-3.8 for azimuth intervals (see explanation in Figure 3.7).

Table 3.8: *Monthly variability of the road surface temperature Ts MAE as a function of the azimuth at minimum distance from the road station toward the seashore.*

Ts MAE (°C)								
Month ***Azimuth (deg)***	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**Season**
15	0,66	0,76	0,73	0,69	0,73	0,71	0,46	**0,69**
45	0,70	0,78	0,74	0,70	0,73	0,74	0,59	**0,72**
75	0,71	0,80	0,75	0,71	0,76	0,76	0,56	**0,73**
105	0,67	0,82	0,75	0,69	0,73	0,75	0,53	**0,71**
135	0,65	0,81	0,77	0,73	0,75	0,76	0,55	**0,72**
165	0,60	0,79	0,73	0,69	0,73	0,74	0,52	**0,69**
195	0,65	0,76	0,75	0,70	0,74	0,74	0,53	**0,71**
225	0,70	0,88	0,79	0,73	0,79	0,75	0,61	**0,76**
255	0,62	0,84	0,77	0,72	0,78	0,74	0,48	**0,72**
285	0,67	0,84	0,76	0,70	0,75	0,72	0,51	**0,72**
315	0,62	0,79	0,76	0,69	0,74	0,75	0,49	**0,71**
345	0,65	0,83	0,76	0,70	0,76	0,77	0,54	**0,72**

3.6. Based on surroundings

Month-to-month variability of the *Ts* BIAS and MAE for different **categories of road stations as a function of surroundings** is summarized in Tables 3.9-3.10 and in Appendix 4. As seen in Table 3.9 and Figure 4A (see Appendix 4), on a monthly scale, on average, the *Ts* positive BIAS dominates for 19 categories (most of these categories are linked the suburban type of road stations; 10 out of 13 categories) vs. the negative BIAS dominates for 12 categories (most of these categories are linked with the urban type of road stations; 7 out of 11 categories). The domination of positive vs. negative BIASes for categories within the three classes (urban, suburban, and rural) of road stations is given by percentage (see last two columns in Table 3.9). For some categories such as "*urban: field-water*" (11010) in urban area and "*rural: forest*" (30100) in rural area, only the positive BIAS is dominating. On average, the positive BIAS is observed for all types of stations in November, with the largest (+0.52°C) for the 11010 category. For two other urban related categories (both in urban areas – "*urban: water-tree*" (10011) and "*urban: field-forest*" (11100)) the BIAS is also above +0.40°C. In general, among all categories the positive BIAS dominates during October–December and in April, and the negative BIAS dominates during January-March. The largest negative BIASes are both associated with urban type of stations: -0.30°C in January for "*forest-water*" (10110) category, and -0.32°C in February for "*urban: forest*" (10100) category.
In January, the negative BIAS is observed for all categories in rural environment, and for majority in urban and suburban areas (except a few such as "*urban: tree*" (10001), "*urban: water-tree*" (10011), "*suburban: forest*" (20101) and "*suburban: field-tree*" (21001), respectively). In April, for majority of the rural categories the BIAS is positive; except, "*rural: tree*" (30001) and "*rural: field-water*" (31010).
As seen in Table 3.10 and Figure 4B (see Appendix 4), the *Ts* MAE higher than 1°C was identified for two categories of the urban stations – "*urban: forest-water*" (10110) in October and "*urban: field-forest*" (11100) in November. In November for 7 and 9 categories of urban and rural station,

the MAE was higher than 0.8°C. For the 20001 category of the suburban station the MAE above 0.8°C dominated for more than half of the season.

Table 3.9: *Monthly variability of the road surface temperature Ts BIAS as a function of the categories of the road stations assigned to urban, suburban, and rural classes.*

Ts BIAS (°C)										
Month / ***Category***	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**Season**	**Pos BIAS %**	**Neg BIAS %**
Urban stations										
10000	0,24	0,13	-0,07	-0,17	-0,13	-0,12	-0,08	**-0,04**	28,6	71,4
10001	0,14	0,22	0,14	0,03	0,05	-0,01	0,03	**0,09**	85,7	14,3
10010	0,04	0,10	-0,04	-0,06	-0,10	-0,11	-0,20	**-0,05**	28,6	71,4
10011	-0,08	0,40	0,30	0,09	-0,08	0,19	-0,11	**0,10**	57,1	42,9
10100	0,28	0,19	-0,13	-0,23	-0,32	-0,12	0,15	**-0,09**	42,9	57,1
10101	-0,12	0,19	0,09	-0,08	-0,02	-0,04	0,14	**0,02**	42,9	57,1
10110	0,41	0,01	-0,21	-0,30	-0,20	-0,01	0,50	**0,02**	42,9	57,1
11000	0,38	0,26	0,08	-0,01	-0,03	0,04	0,22	**0,13**	71,4	28,6
11001	0,12	0,14	0,01	-0,03	-0,05	-0,05	-0,13	**0,01**	42,9	57,1
11010	0,46	0,52	0,26	0,18	0,06	0,15	0,18	**0,26**	100,0	0,0
11100	0,19	0,47	-0,05	-0,12	-0,11	-0,09	0,07	**0,06**	42,9	57,1
Suburban stations										
20001	0,25	0,18	-0,08	-0,22	-0,19	-0,12	0,19	**-0,01**	42,9	57,1
20100	0,18	0,14	0,02	-0,10	-0,06	-0,08	-0,13	**0,01**	42,9	57,1
20101	0,40	0,21	0,21	0,07	-0,06	0,00	0,30	**0,16**	85,7	14,3
20110	0,30	0,24	0,02	-0,18	-0,12	0,09	-0,02	**0,06**	57,1	42,9
21000	0,21	0,19	0,04	-0,01	0,00	0,01	0,22	**0,09**	85,7	14,3
21001	0,12	0,15	0,12	0,05	-0,01	0,00	-0,13	**0,05**	71,4	28,6
21100	0,24	0,07	0,10	-0,01	0,02	-0,07	0,09	**0,06**	71,4	28,6
Rural stations										
30001	-0,03	0,14	0,01	-0,12	-0,06	-0,11	-0,02	**-0,03**	28,6	71,4
30010	0,02	0,14	-0,06	-0,21	-0,22	-0,04	0,17	**-0,05**	42,9	57,1
30011	0,20	0,23	0,04	-0,07	-0,09	-0,02	0,49	**0,08**	57,1	42,9
30100	0,21	0,28	0,17	0,05	0,12	0,07	0,12	**0,15**	100,0	0,0
30101	0,40	0,34	0,05	-0,01	0,09	0,04	0,40	**0,18**	85,7	14,3
30110	0,17	0,21	0,11	-0,07	-0,03	-0,02	0,10	**0,07**	57,1	42,9
31000	0,17	0,19	0,00	-0,10	-0,11	-0,08	0,09	**0,02**	57,1	42,9
31001	0,20	0,23	0,11	-0,01	0,00	0,00	0,07	**0,09**	71,4	28,6
31010	0,21	0,01	-0,07	-0,24	-0,21	-0,18	-0,05	**-0,10**	28,6	71,4
31011	0,35	0,24	0,13	-0,01	-0,04	0,02	0,03	**0,11**	71,4	28,6
31100	0,12	0,24	0,10	-0,02	0,01	0,00	0,04	**0,07**	71,4	28,6
31101	0,15	0,16	0,10	-0,03	0,02	-0,02	0,06	**0,07**	71,4	28,6
31110	0,26	0,31	0,06	-0,05	-0,13	0,03	0,28	**0,10**	71,4	28,6
									19 ca	**12 ca**

Table 3.10: *Monthly variability of the road surface temperature Ts MAE as a function of the categories of the road stations assigned to urban, suburban, and rural classes.*

Ts MAE (°C)								
Month / ***Category***	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**Season**
Urban stations								
10000	0,64	0,80	0,78	0,74	0,75	0,74	0,62	**0,73**
10001	0,63	0,80	0,75	0,69	0,75	0,73	0,53	**0,71**
10010	0,58	0,75	0,73	0,72	0,71	0,73	0,50	**0,68**
10011	0,47	0,89	0,78	0,69	0,69	0,73	0,40	**0,67**
10100	0,73	0,85	0,72	0,62	0,78	0,78	0,46	**0,73**
10101	0,74	0,77	0,70	0,66	0,69	0,71	0,66	**0,70**
10110	**1,05**	0,72	0,78	0,78	0,77	0,79	**0,90**	**0,83**
11000	0,69	0,80	0,74	0,69	0,71	0,74	0,60	**0,71**
11001	0,62	0,78	0,71	0,69	0,71	0,70	0,44	**0,67**
11010	0,63	0,83	0,68	0,66	0,67	0,70	0,56	**0,68**
11100	0,59	**1,14**	0,72	0,70	0,80	0,71	0,45	**0,75**
Suburban stations								
20001	0,74	**0,92**	0,82	0,79	0,84	0,81	0,47	**0,78**
20100	0,61	0,78	0,81	0,72	0,73	0,78	0,67	**0,73**
20101	0,63	0,71	0,75	0,68	0,74	0,76	0,51	**0,69**
20110	0,78	0,82	0,72	0,71	0,69	0,79	0,48	**0,72**
21000	0,68	0,77	0,71	0,69	0,72	0,72	0,60	**0,70**
21001	0,61	0,76	0,75	0,70	0,74	0,71	0,58	**0,70**
21100	0,63	0,71	0,75	0,71	0,74	0,74	0,40	**0,68**
Rural stations								
30001	0,60	0,76	0,73	0,72	0,77	0,76	0,47	**0,70**
30010	0,55	0,75	0,66	0,68	0,71	0,65	0,49	**0,65**
30011	0,65	0,81	0,69	0,67	0,68	0,67	0,73	**0,70**
30100	0,67	0,84	0,78	0,72	0,76	0,76	0,53	**0,74**
30101	**0,92**	**0,90**	0,73	0,71	0,80	0,76	0,53	**0,77**
30110	0,67	0,81	0,77	0,69	0,75	0,77	0,60	**0,73**
31000	0,66	0,83	0,77	0,72	0,75	0,76	0,55	**0,73**
31001	0,67	0,82	0,75	0,69	0,76	0,75	0,52	**0,72**
31010	0,67	0,78	0,72	0,76	0,81	0,72	0,45	**0,72**
31011	0,73	0,84	0,77	0,71	0,73	0,78	0,53	**0,74**
31100	0,67	0,81	0,78	0,71	0,77	0,75	0,49	**0,73**
31101	0,59	0,70	0,74	0,70	0,73	0,75	0,42	**0,68**
31110	0,73	0,83	0,79	0,73	0,82	0,80	0,64	**0,77**

4. Conclusion

In this study, various classifications of the road stations based on: (i) positioning or placement near/at the driving lanes (in airport areas; on bridges and near the roads); (ii) urban related environment (urban, suburban, and rural); (iii) surroundings (fields, forests, water surfaces, trees) near the station; (iv) geographical position and proximity to the seashore (minimum distance and corresponding azimuth); (v) height of the station above sea level; (vi) properties of the driving lanes (pavement) of the roads – were established and analyzed. For these classifications, a comparative analysis of the road surface temperature BIAS and MAE on the road weather season (from October through April) and monthly scales was performed.

Classification of road stations (in total 404) showed that the majority (88%) of the stations is placed near/at roads, and the rest are stations located within airport areas and stations on bridges over channels, rivers and land. Most of the stations are situated in the rural environment (67%), followed by urban (24%) and suburban (9%). More than 60 stations are placed at the sea level, and only a few – at height above 100 meters. More than 60 stations (including those placed on the bridges over channels (19) connecting large parts of Denmark) are in a close proximity to the sea and about 30 of them are situated inland at distances more than 30 km away from the sea. For about 71, 30, 21, and 31% of the stations the surroundings include the presence of fields (agricultural and artificial such as airfield and industrial grounds), forest, water (sea, channels, rivers, lakes), and trees (independent and alley of trees along the roads), respectively. The most frequent categories (in a sum - about 46%) of surroundings around the stations includes "*fields*" (17.6%), "*trees*" (14.9%), and "*fields-forests*" (13.4%), and all of these categories are located in the rural areas. Analysis pavement properties showed that even at the same section of the road different types of pavement can be used on adjacent driving lanes with different characteristics which are being input into the RCM model.

The variability of the road surface temperature *Ts* BIAS and MAE on a scale of the road weather season and on a monthly scale showed that for the road stations analyzed by:

- **Position**: both the largest BIAS (with a higher variability) and MAE are characteristic for the road stations located on the bridges over the rivers;
- **Urban environment**: the BIAS is larger for the urban stations, the MAE is better (i.e. lower magnitude values) during December-March compared with the suburban and rural stations;
- **Height**: although, on a season scale, the BIAS is positive and larger for the road stations placed at low heights, and it is improving with the height increasing; but on a monthly scale, it is mostly negative during January-February;
- **Distance to seashore**: on a season scale, the BIAS is positive and larger at shorter distances from the seashore; on a monthly scale, it is the highest during October-November, but during January-March the BIAS became negative at distances more than 5 km away from the sea;
- **Azimuth to seashore**: on a season scale, the BIAS is positive and larger by magnitude for all stations, except those assigned to the southern sector. The BIAS is largest for the northern sector. On a monthly scale, the positive BIAS dominates for all azimuth directions during October-December and in April; and it is mostly negative during January-March (in ENE – SSW sector);
- **Surroundings**: on a monthly scale, positive BIAS dominates for 19 categories (most linked with the suburban stations; 10 out of 13 categories assigned) vs. the negative BIAS dominates for 12 categories (most linked with the urban stations; 7 out of 11 categories). It is positive for all categories in November. Among all categories the positive BIAS dominates during October–December and in April, and the negative BIAS dominates during January-March. The absolute largest negative BIASes are both associated with the urban stations. In

January, the negative BIAS is observed for all categories in rural environment and majority in urban and suburban areas. In April, for majority of the rural categories the BIAS is positive. The *Ts* MAE larger than 1°C was identified for two categories ("*forest-water*" and "*field-forest*") both associated with urban areas.

The results of this study are applicable for further improvement of the road conditions model forecasts. In particular, these findings are useful for elaboration of the statistical correction to the road surface temperature taking into account spatial variability of the analyzed factors related to local conditions at the station, some of which could be considered unchangeable (height, proximity to sea as distance and azimuth, positioning at/near the driving lanes) and some of which could more variable with time (surroundings of road stations influencing shadowing effects). Although priority for improvements needs to be given to road stations where in general the MAEs are the highest (i.e. above 1°C) over a long period of time (i.e. during several road weather seasons), but the improvement of *Ts* forecasts should be also done selected categories where more similar process of the local nature are taking place depending on the surroundings near the road stations. A special attention should be paid to forecasting of road conditions on bridges over rivers, because other specific properties of such roads' pavement should be also taken into consideration.

Acknowledgments

The authors are grateful to the DMI FM colleagues for constructive discussions and comments. The computer facilities at the Danish Meteorological Institute (DMI) have been employed extensively. The data on properties of selected roads (route N-21) in the Roskilde Commune were provided by the Danish Road Directorate (DRD). Especially thanks to Michel M. Eram (DRD) for discussions and comments.
The authors are thankful for collaboration to the DRD and DMI Computer Support.
The funding was provided within the frameworks of the joint DMI and DRD projects entitled "*Road Segment Forecasts*" (2006-2008) and "*Fine-Scale Road Stretch Forecasting*" (2009-2011) within framework of the VIKING Projects.
The Google-Earth (http://earth.google.com) has been used to visualize information for road stations.

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Appendix 1. Monthly *Ts* BIAS and MAE variability as a function of the height of the road station

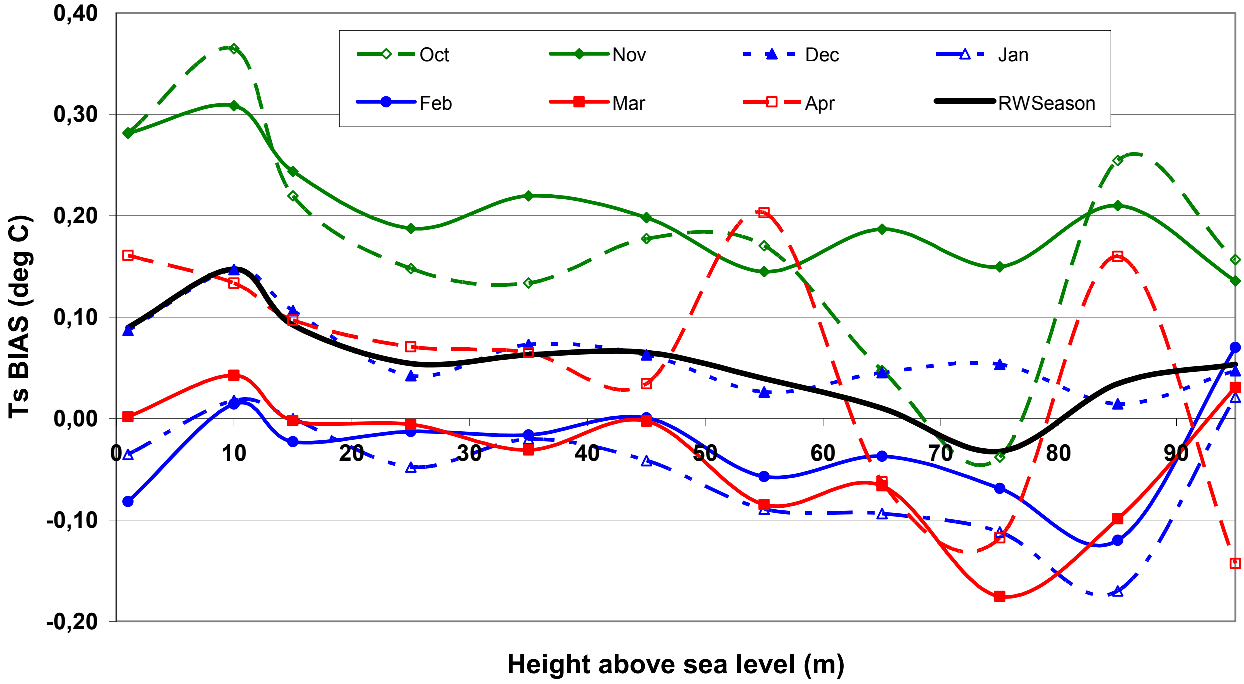

Figure 1A: *Monthly variability of the mean Ts BIAS as a function of a height of the road station above the sea level.*

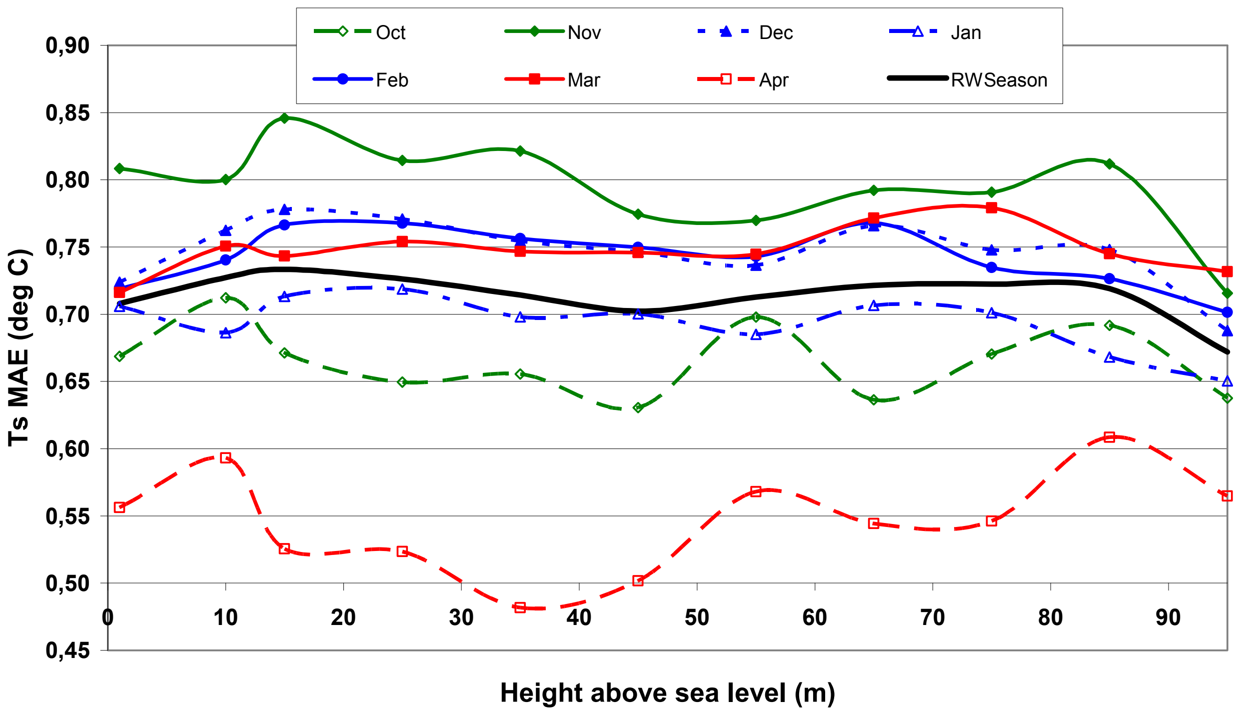

Figure 1B: *Monthly variability of the mean Ts MAE as a function of a height of the road station above the sea level.*

Appendix 2. Monthly *Ts* BIAS and MAE variability as a function of the minimum distance from the road station to seashore

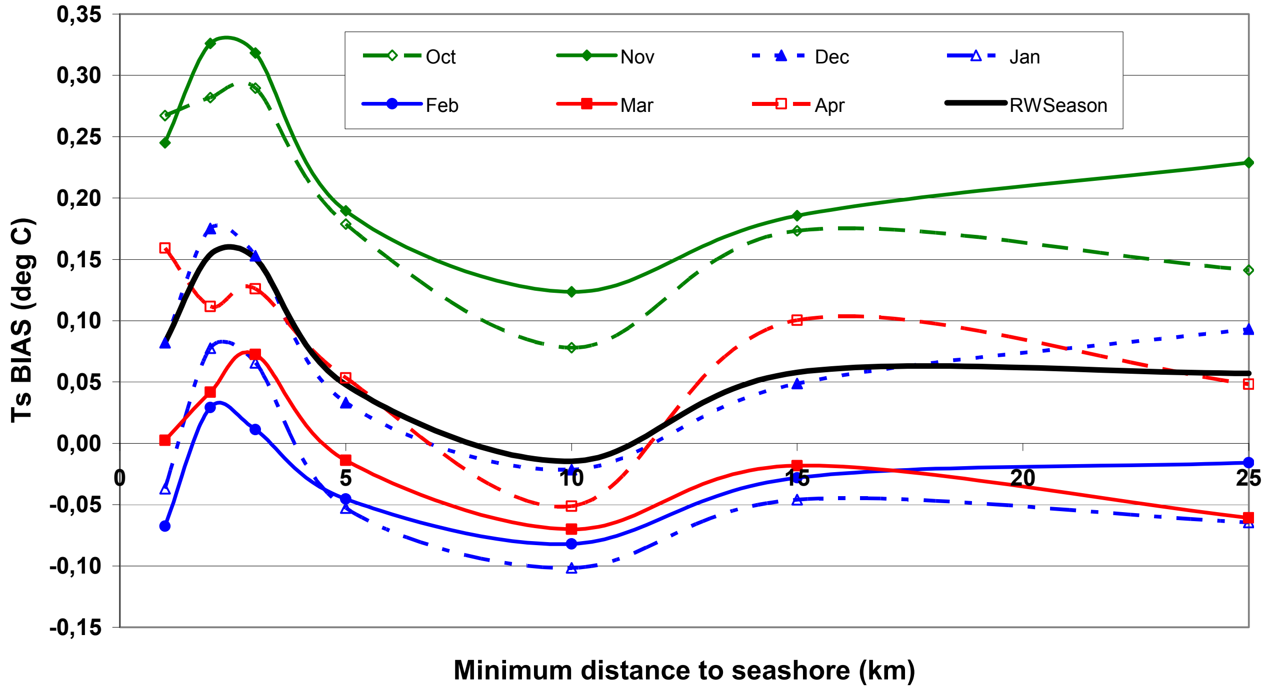

Figure 2A: *Monthly variability of the mean Ts BIAS as a function of a minimum distance from the road station to seashore.*

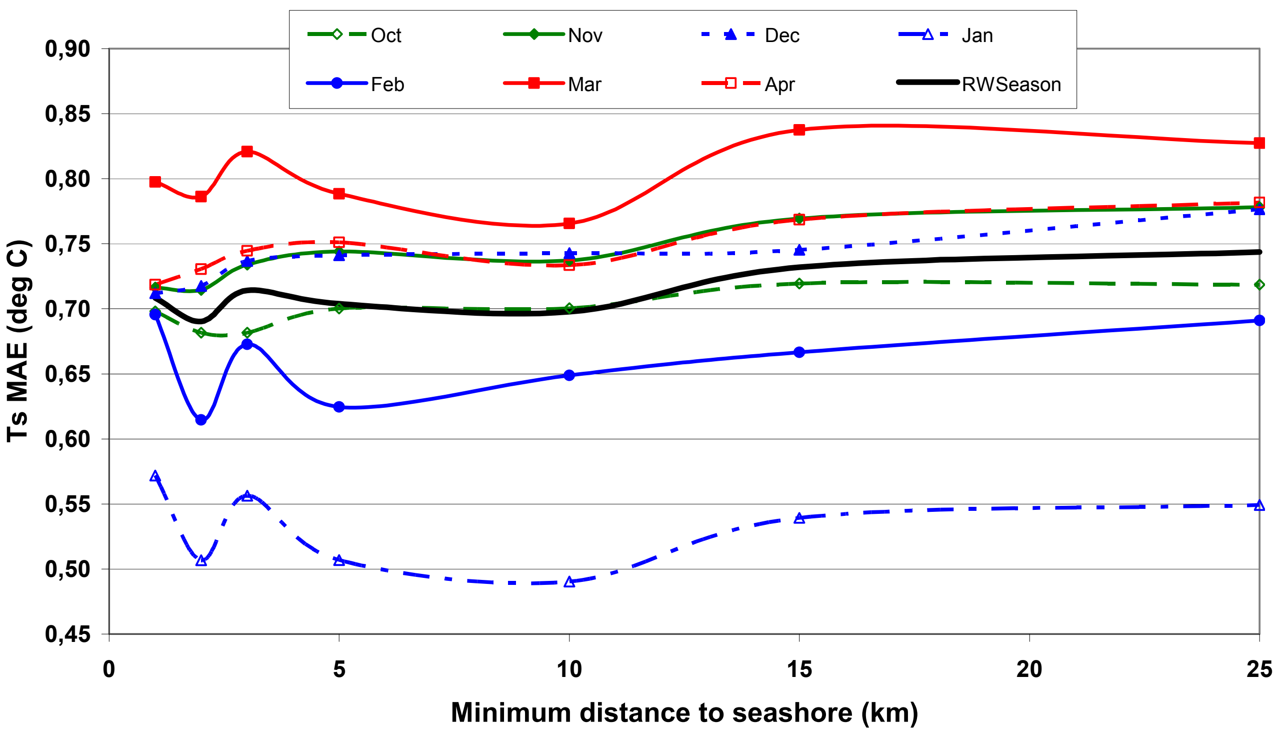

Figure 2B: *Monthly variability of the mean Ts MAE as a function of a minimum distance from the road station to seashore.*

Appendix 3. Monthly *Ts* BIAS and MAE variability as a function of the azimuth at minimum distance from the road station to seashore

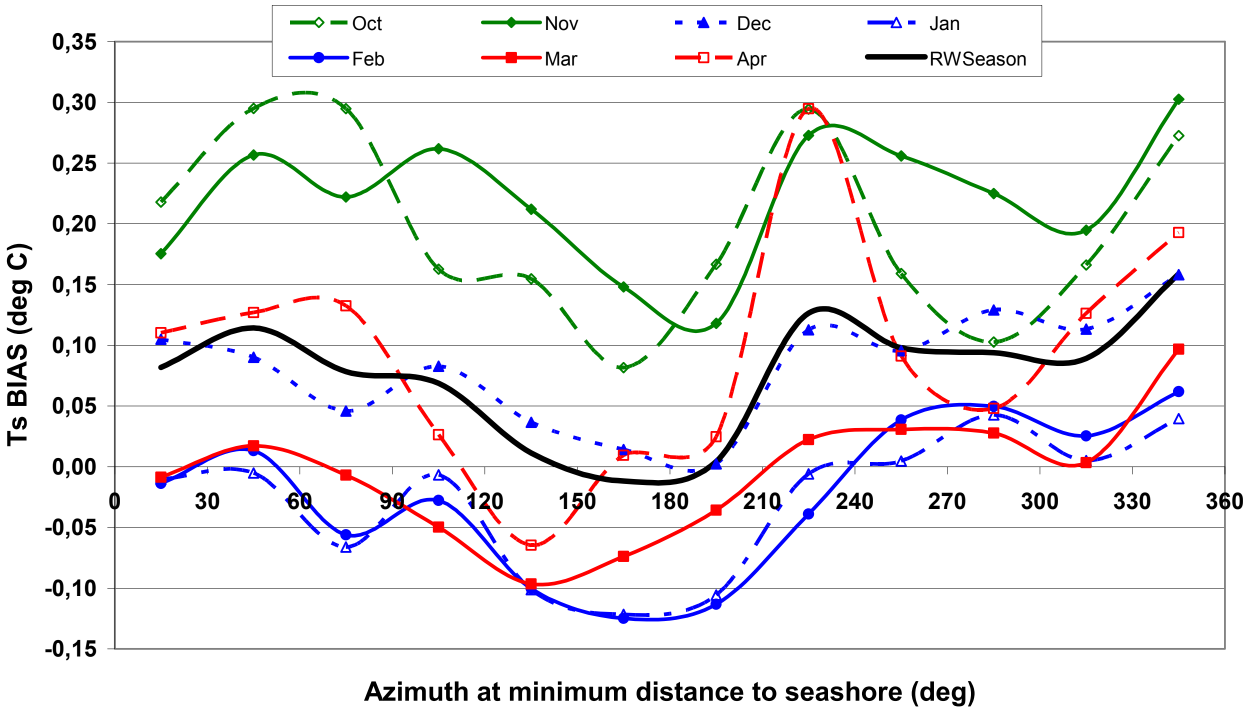

Figure 3A: *Monthly variability of the mean Ts BIAS as a function of the azimuth at minimum distance from the road station to seashore.*

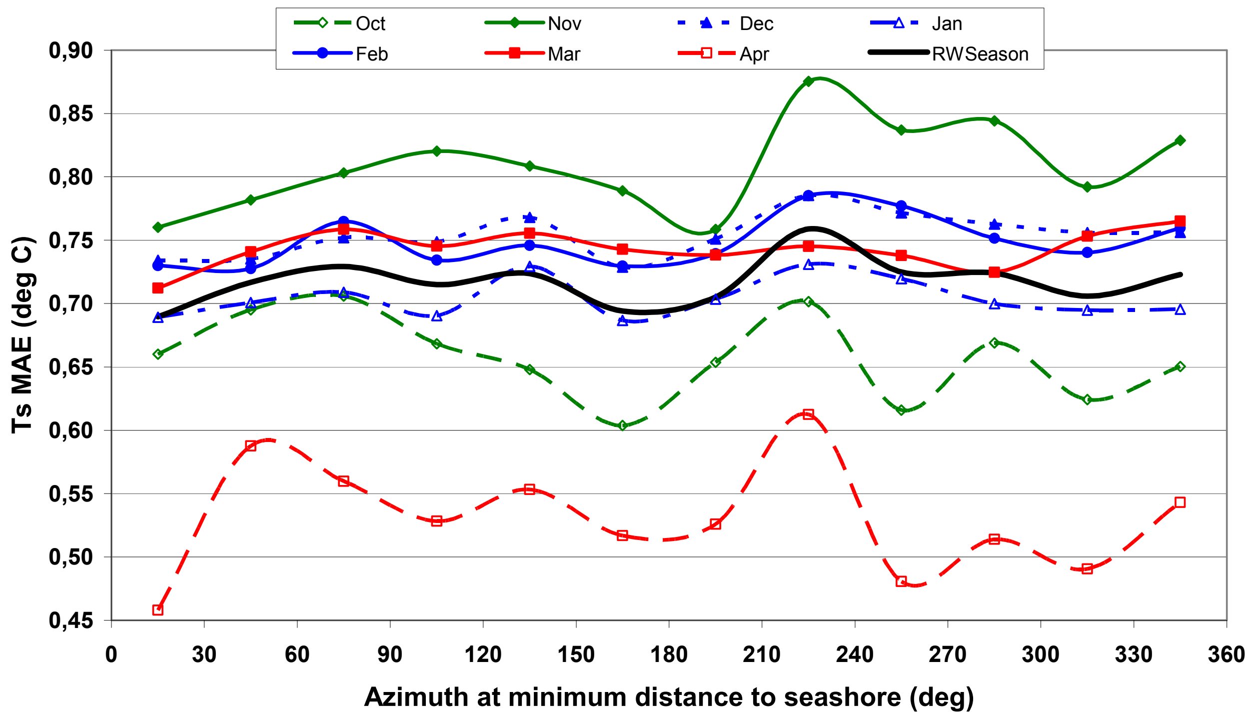

Figure 3B: *Monthly variability of the mean Ts MAE as a function of the azimuth at minimum distance from the road station to seashore.*

Appendix 4. Monthly *Ts* BIAS and MAE variability as a function of the category of the road station depending on surroundings

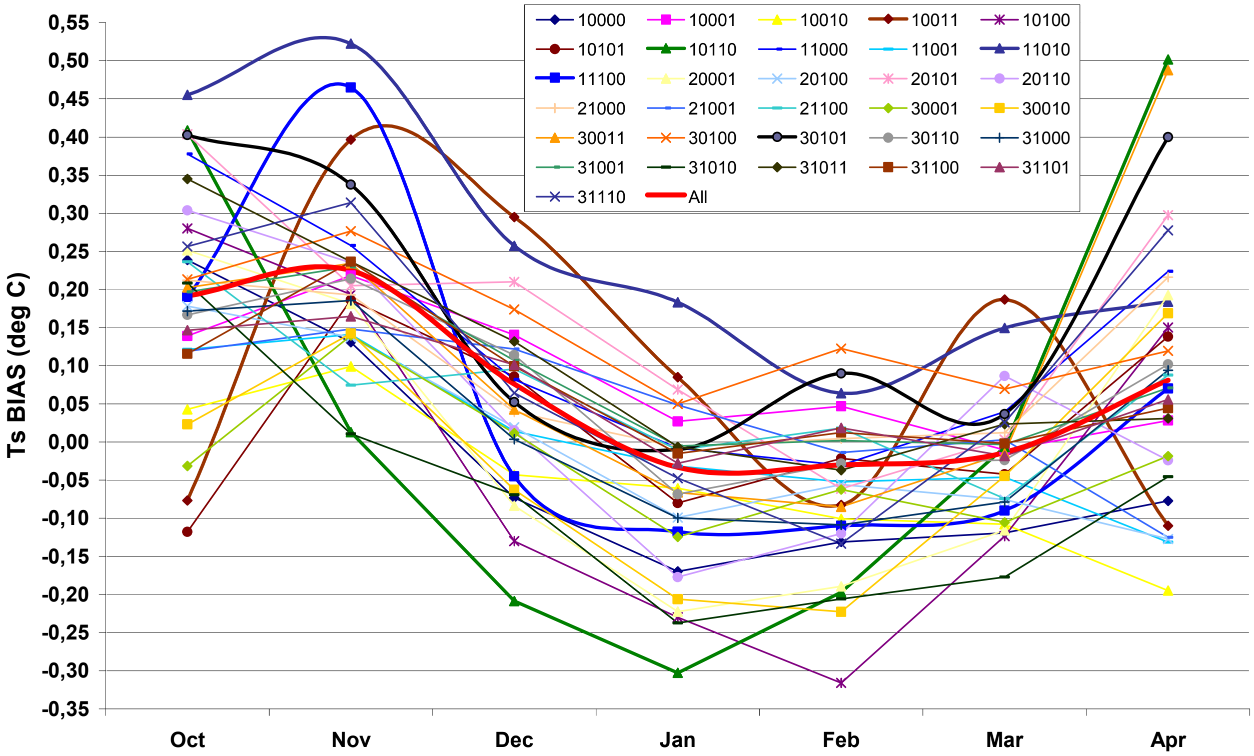

Figure 4A: *Monthly variability of the mean Ts BIAS as a function of the category of the road station depending on surroundings.*

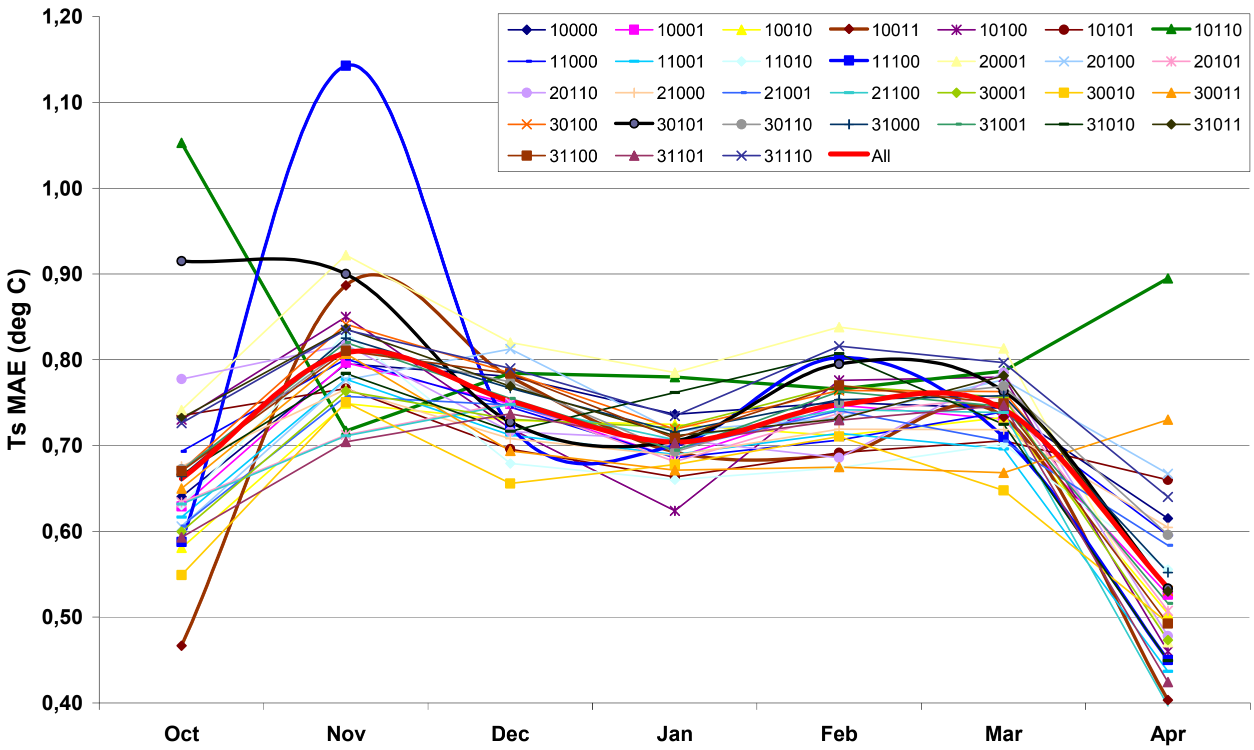

Figure 4B: *Monthly variability of the mean Ts MAE as a function of the category of the road station depending on surroundings.*