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Road Weather Modelling System:
Verification for 2010-2011 Road Weather Season

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Abstract

For the road weather season (1 October – 1 May) 2010/2011, the scores for the 3 hour forecasts of the road surface temperature with an error of less than ±1ºC is almost 82% (78% - new verification approach; where the interval of the forecasted road surface temperature is extended from ±3ºC to ±12ºC and the observational interval is kept at ±3ºC). These scores are based on more than 563 (634) thousand corresponding forecasts. The overall seasonal averages of the bias and mean absolute error are +0.09ºC (+0.12ºC) and 0.70ºC (0.79 ºC). It is closely comparable with season 2009-2010, where the bias and mean absolute error were +0.02ºC and 0.69ºC, respectively.

Resumé

For vejsæsonen (1. October – 1. May) 2010/2011 er scoren for forudsagt vejtemperatur 82% (72% med ny metode hvor intervallet at de forudsagte vej temperature er udvidet til maximum +12ºC og minimum -12ºC; observations intervallet er lostholdt pa ±3ºC), hvor scoren er defineret som det procentvise antal af 3 timers prognoser for vejtemperatur der har en fejl mindre end ±1ºC. Der indgår ca. 563 (634) tusinde prognoser i beregningen af scoren. For hele sæsonen er bias og middelfejlen henholdsvis +0.09ºC (+0.12ºC) og 0.70ºC (0.79 ºC).. Dette er sammenligneligt i forhold til sæsonen 2009-2010, hvor bias og middelfejlen var henholdsvis +0.02ºC og 0.69ºC.

1. Introduction

The road weather forecasts done by the Road Weather Model (RWM) system is an important operational product produced by DMI. It is, therefore, relevant after each season to evaluate the performance of the Road Conditions Model (RCM: *Sass, 1992; 1997*) in order to continue further development and improvement of the system. In addition, users of the RWM system might have an interest in gaining access to verification report after each season. Briefly, the RWM system uses the continuous observations from the Danish road stations as well as standard meteorological and satellite based observations and meteorological output from the DMI-HIRLAM (High Resolution Limited Area Model; *Sass et al., 2002; Yang et al., 2005*) numerical weather prediction (NWP) model as input to produce 24 h forecasts every hour. For a description of the RWM operational system see the manual *GlatTerm (2004)*. For some previous road seasons the verification reports are given by *Kmit & Sass (1999)*; *Sass & Petersen (2000)*; *Petersen & Nielsen (2000; 2003), Petersen et al., (2007, 2008, 2009, 2010)*. Operational irregularities for the 2005-2011 road seasons are listed in Appendix 1 showing changes and modifications made in the DMI-HIRLAM RWM system, and RCM model.

2. Road Weather Model Verification

2.1. General (Old) and New Approach

A road weather season is considered to run from October to April. The reason for selection of this period is based on a potential risk of slippery road in these months. Although during the last years the warmer winters have reduced the number of slippery road cases, the two recent winters of 2009-2010 and 2010-2011 were characterized by lower air temperatures than usual and snow fall starting from the middle of November 2010 and extended further for more than 2 months. In fact December 2010 was the second coldest month ever recorded. Note that a very low number of forecasts had been verified for April 2011 (this month had been identified as the warmest April in the observational records of Denmark).

The verification of the RWM system performance is based on evaluation of the DMI-HIRLAM model used for road forecasts, which is a special version of the DMI-HIRLAM where key parameters are calculated in 380 (by April 2011, according to the Danish Road Directorate, DRD) observational points (i.e. road stations). In these points the verification is performed. The verification of the RCM forecasts for key parameters is done 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. To make verification two conditions are required, i.e. both the observational data and modelled forecasts have to be available at exact times of observation vs. forecast. If one of these is missing then both are not used in verification. Note, that usually the missing forecasts account for less than 0.5%. In almost all cases the missing forecasts are related to computer processing, missing observations and archiving problems (or missing input meteorological data from the DMI-HIRLAM model).

This verification includes analysis of all forecasts (i.e. from 01 to 24 hours). Prior the 2010-2011 season, for verification only forecasts, where both the observed and forecasted *Ts* are within a range of ±3ºC, were included (old approach). However, for this season, for the new verification approach only forecasts, where the observed *Ts* is within a range of ±3ºC and the forecasted *Ts* is within a range of ±12ºC, are included. This insures that very large errors in observations are excluded. Still minor systematic errors are included and therefore, this verification should be considered as an absolute minimum performance of the model. Moreover, the major interest is on the first six hour forecasts. Note, all road stations of the Danish road network are included. Spatial distribution of occurrences of the conditions leading to icing on the roads for the red alert situations (i.e. when Ts < 0 and Ts < Td) observed during the 2010-2011 season is shown in Chapter 3 of this report as well as a month-to-month variability in Appendix 5.

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.

2.2. Road Weather Season 2010-2011

MAE and BIAS for Ts

The Figures 1-2 show the bias and mean absolute error for road surface temperature (*Ts*) during the first six hour RCM forecasts. Results for both the old and new verification approaches are presented. For the old verification approach, as seen at 5 hour RCM forecasts: the highest bias is +0.23ºC (December 2010), and the lowest is –0.01ºC (February 2011). During the road season, on average, it was +0.09C. The highest MAE of 0.72ºC is observed in January 2011 and the lowest (0.64ºC) - in November 2010. During the season, on average, it was 0.70ºC.

For the new verification approach, as seen at 5 hour RCM forecasts: the highest bias is +0.72ºC (April 2011), and the lowest is +0.01ºC (November 2010 and February 2011). During the road season, on average, it was +0.12C. The highest MAE of 1.02ºC is observed in April 2011 and the lowest (0.71ºC) - in November 2010. During the season, on average, it was 0.79ºC.

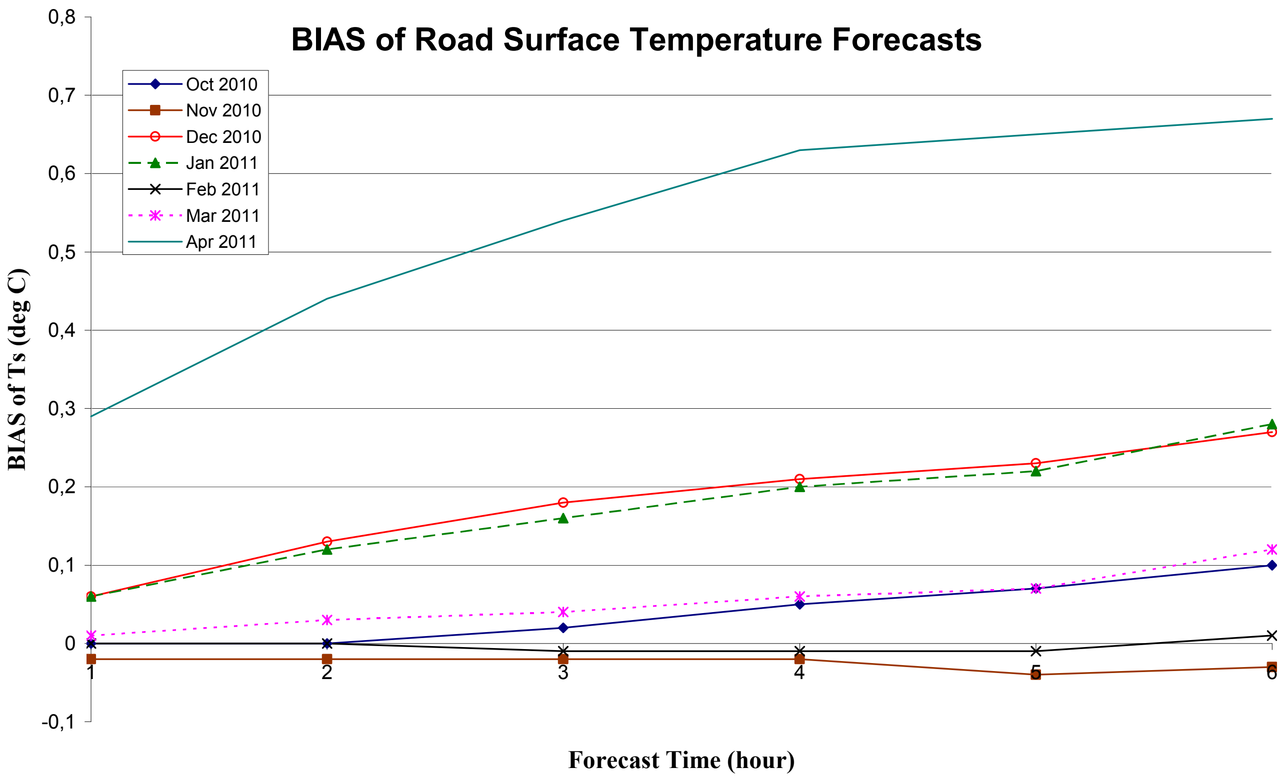
Although during the 2010-2011 season, on average, based on old vs. new verification both the BIAS (+0.09 vs. +0.12 ºC) and MAE (0.70 vs. 0.79ºC) are not substantially different, the April 2011 had larger values than usual. This might be due to lower number of icing conditions observed (the statistics was based on a small number of cases) and because this month was the warmest April in the observational records of Denmark (and it has been related to DMI-HIRLAM model performance). Note, the larger errors in Ts in the beginning and end of the seasons are mostly related to greater sensitivity in shadows as the shortwave radiation heating of the road surfaces has more impact in October, March, April compared with November-February period.

The bias and mean absolute error for the *Ta* and *Td* temperatures at the height of 2 meters above the ground are given in Appendixes 2-3.

The summary of monthly variability for MAEs and BIASes of the *Ts, Ta,* and *Td* temperatures at 5 hour forecasts for the road season 2010-2011 with the corresponding number of the RCM forecasts is given in Table 1).

Month Year			Oct 2010	Nov 2010	Dec 2010	Jan 2011	Feb 2011	Mar 2011	Apr 2011
BIAS	**Ts**	*old*	0.07	-0.04	0.23	0.22	-0.01	0.07	0.12
		new	0.34	0.01	0.04	0.20	0.01	0.25	0.72
	Ta	*old*	0.04	-0.02	0.02	-0.02	-0.39	-0.28	-1.13
		new	0.22	0.01	-0.05	-0.02	-0.37	-0.24	-0.76
	Td	*old*	-0.09	-0.27	0.06	0.12	0.48	0.10	-0.53
		new	0.05	-0.21	0.01	0.11	0.49	0.13	-0.23
MAE	**Ts**	*old*	0.67	0.64	0.70	0.72	0.70	0.71	0.65
		new	0.83	0.71	0.81	0.80	0.78	0.87	1.02
	Ta	*old*	1.04	0.65	0.66	0.59	0.63	0.71	1.36
		new	1.09	0.67	0.69	0.62	0.65	0.73	1.23
	Td	*old*	1.04	0.84	0.79	0.68	0.90	0.83	1.10
		new	1.08	0.86	0.82	0.71	0.90	0.84	1.09
RCM *Ts* forecasts		*old*	17091	94272	66037	150565	127054	94616	1040
		new	21128	105026	80075	168579	146208	109118	1868
% of Ts_{for} > ±2ºC		*old*	1.45	1.92	1.66	2.67	2.71	2.52	2.49
		new	4.10	2.85	3.04	3.64	3.85	5.65	7.01

Table 1. *Summary of monthly MAEs and BIASes of the road surface temperature (Ts), air temperature (Ta), and dew point temperature (Td) at 5 hour forecasts for the road season 2010-2011 with the corresponding number of the RCM forecasts for Ts, and percentage of the Ts forecasts with MAE higher than ±2ºC.*



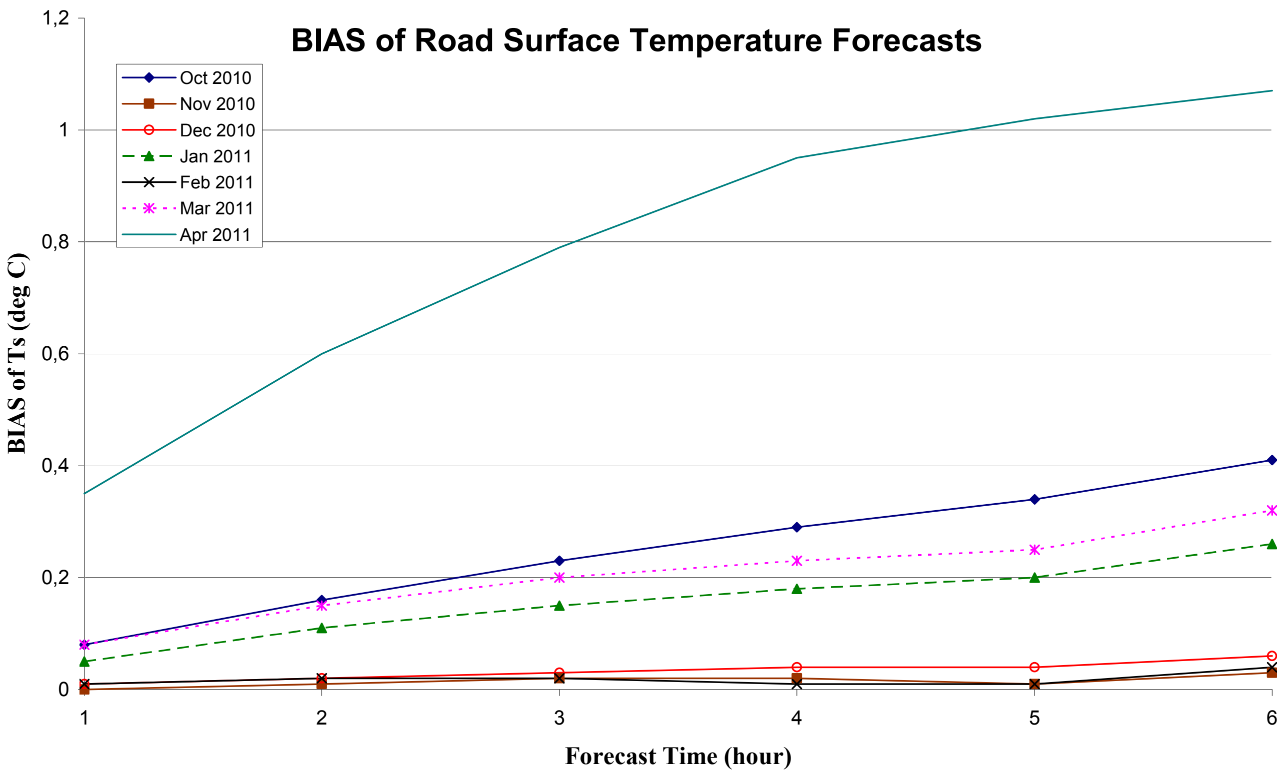


Figure 1. *Monthly variability of the mean error (BIAS) of the road surface temperature (Ts) vs. forecast time for the road weather season 2010-2011 /evaluation based on (top) old and (bottom) new approach for verification/.*

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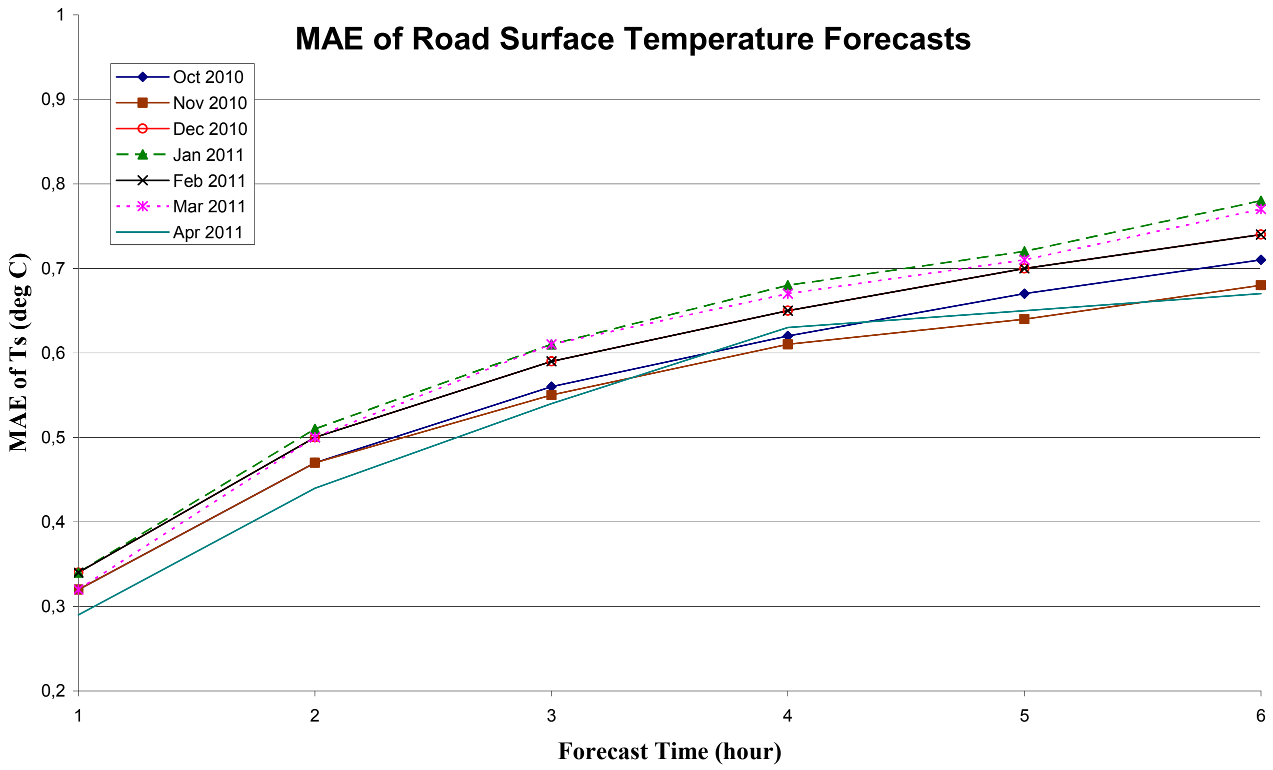

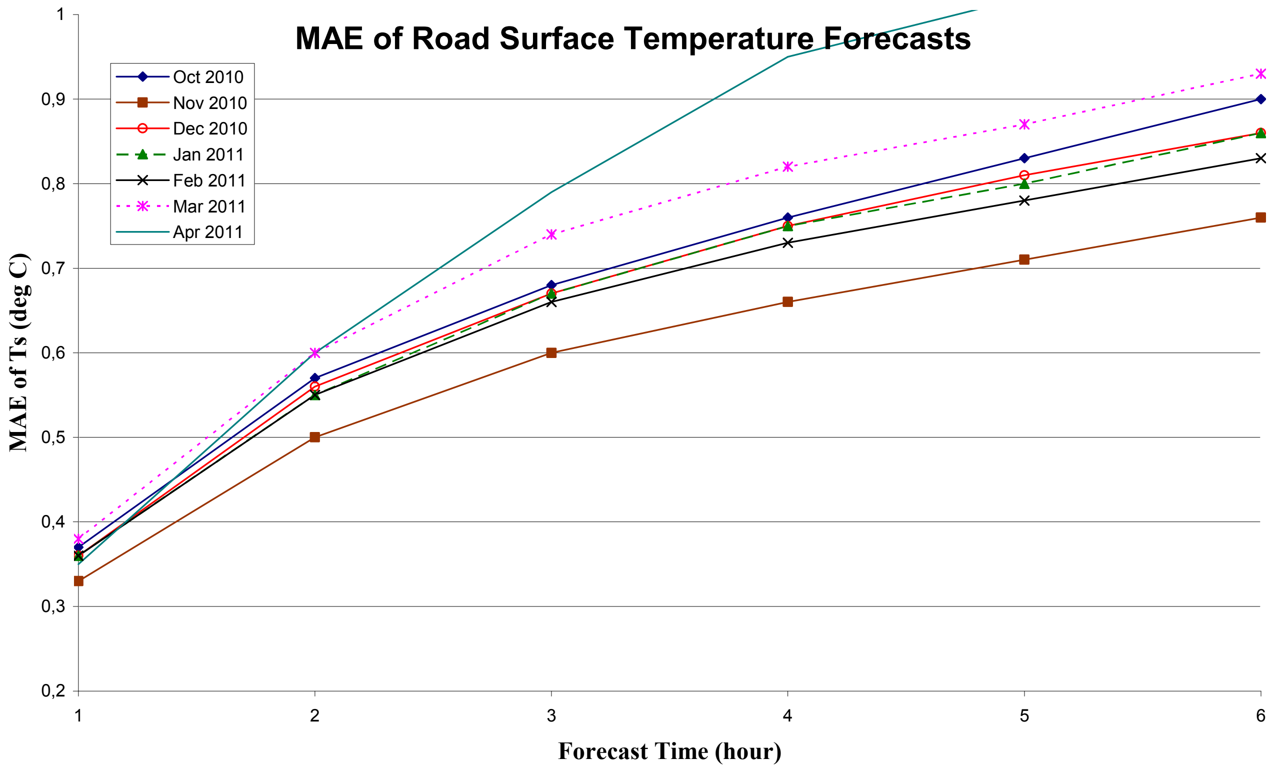

Figure 2. *Monthly variability of the mean absolute error (MAE) of the road surface temperature (Ts) vs. forecast time for the road weather season 2010-2011 /evaluation based on (top) old and (bottom) new approach for verification/.*

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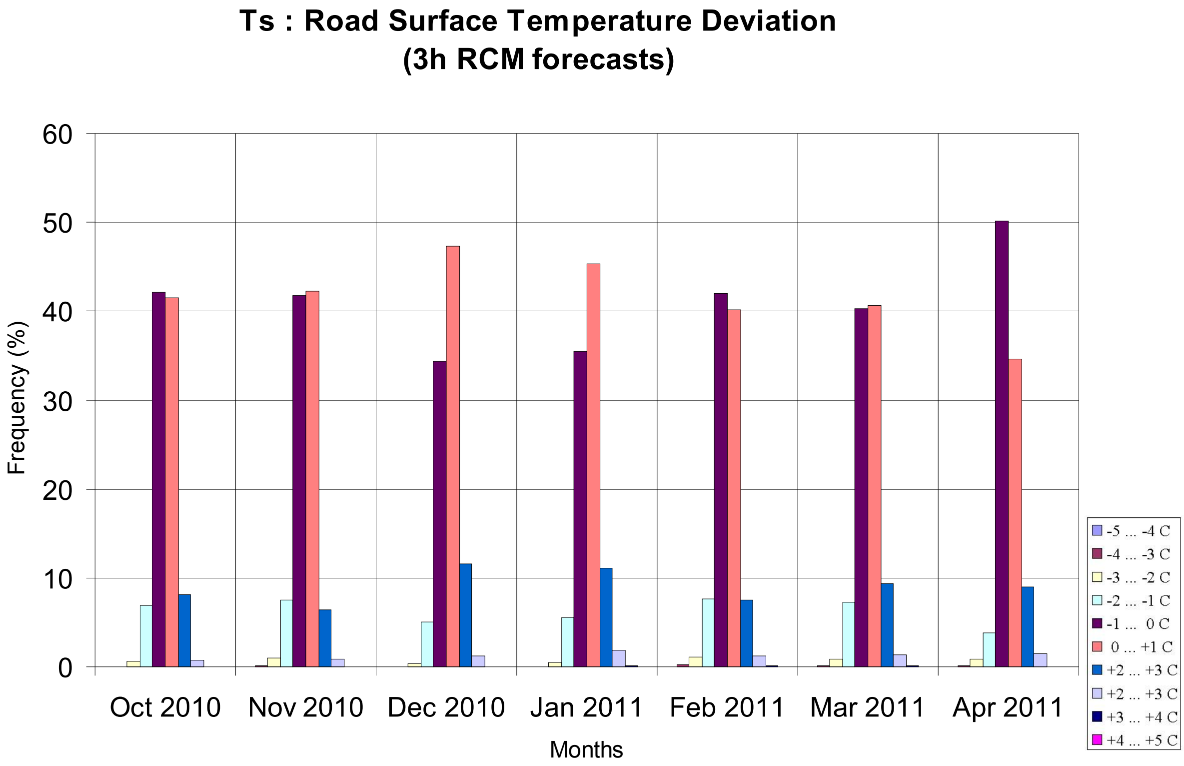
The percentage of the *Ts* forecasts higher than ±2ºC is low (based on old verification approach), on average it is 2.20%, compared with previous season (2009-2010) - 2.68%. For the new approach it is on average 4.31%. It ranges from 1.45% (new - 2.85%) in October 2010 (November 2010) to 2.71% (7.01%) in February 2011 (April 2011). As seen the relative number of RCM forecasts (more cases) used in new verification is higher compared with the old verification approach ranging from 11% (November 2010) up to 80% (April 2011).

Scores for Ts

The monthly variability of the road surface temperature (*Ts*) deviations as error frequencies (%) for the Danish road stations based on 3 hour RCM forecasts is shown in Figure 3. Note that for the old verification approach (used prior the road season 2010-2011) the number of the forecasts is 563467, but for new – 634176 – is higher. For the air temperature (*Ta*) and dew point temperature (*Td*) - see Appendix 4. For this figure all analysis times are included, and the frequencies are divided into one degree intervals, with the highest frequencies corresponding to the temperature intervals: from -1ºC to 0ºC and from 0ºC to +1ºC. Note, all other intervals have substantially lower frequencies. For this road season, 78.01% (81.88% - old approach) of the forecasts are within ±1ºC of the observed values (Table 2).

Road Season	**2010-2011**			
Verification Approach	***old***		***new***	
Month	**scores**	**N**	**scores**	**N**
October	83.62	17605	76.59	21135
November	84.06	95599	81.50	105062
December	81.73	68307	77.16	80127
January	80.74	153886	77.57	169316
February	82.19	130159	78.42	146735
March	80.85	96705	75.86	109933
April	84.66	1206	68.36	1868
Season	**81.88**	**563467**	**78.01**	**634176**

Table 2. *Summary of monthly scores for the RCM forecasts within a range of ±1ºC with the corresponding number of forecasts and observations during road weather season 2010-2011 /evaluation based on old and new approach for verification/..*



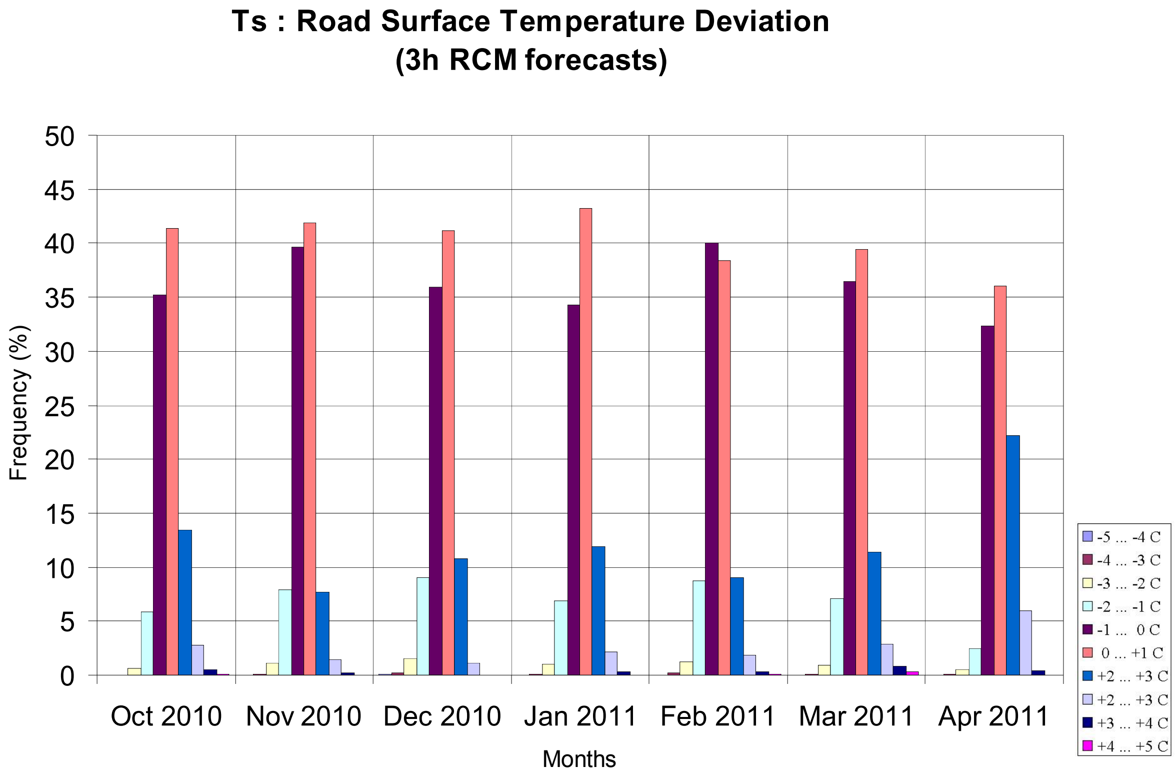


Figure 3. *Monthly variability of the road surface temperature (Ts) deviations as error frequencies (%) for the Danish road stations based on 3 hour RCM forecasts for season 2010-2011 /evaluation based on (top) old and (bottom) new approach for verification/.*

3. Road Icing Conditions in 2010-2011

For this season the road icing conditions have been measured at 380 road stations (using 493 sensors; according to DRD, April 2011). The spatial distribution of occurrences of the conditions leading to icing on the roads for the red alert situations (RA1: i.e. when *Ts* < 0 and *Ts* < *Td*) observed at the Danish road stations during October 2010 – April 2011 is shown in Figure 4 (and separately in Figure 5 – for the Northern Jutland, Fyn and Zealand). The total number of such cases at all road stations was equal to 267367, with a smallest number – 21 – in April 2011, and a largest number – 127234 – in January 2011.

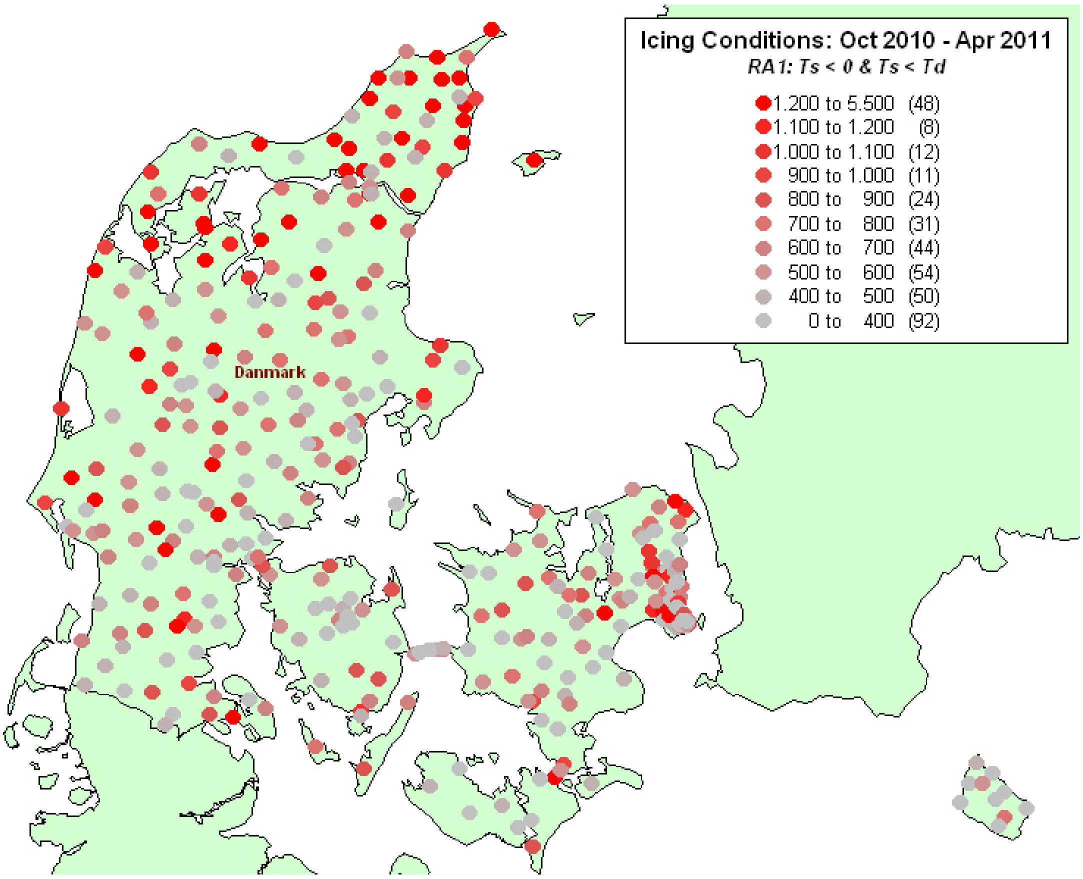


Figure 4. *Spatial distribution of occurrences of the conditions leading to icing on the roads for the red alert situations (RA1) observed at the Danish road stations during October 2010 – April 2011 /number in brackets corresponds to number of the road stations with similar conditions, and intensity of the colored symbol corresponds to higher likelihood of icing/.*

The top 10 "coldest" (having the highest number of occurrences of the conditions leading to icing on the roads) and "warmest" (having the lowest number of such occurrences) road stations were identified for the season. The month-to-month variability of icing conditions at these coldest and warmest road stations is summarized in Tables 3 (and their location is shown in Figures 6-7. The majority of the coldest stations is situated in the Northern Jutland (Figure 6). The majority of the warmest stations is situated in the Zealand (Figure 7), including 4 such stations (1817, 1818, 1819, and 1820) located on the territory of the Copenhagen airport, and stations 1804 and 1802 which are situated in a close proximity to the airport area.

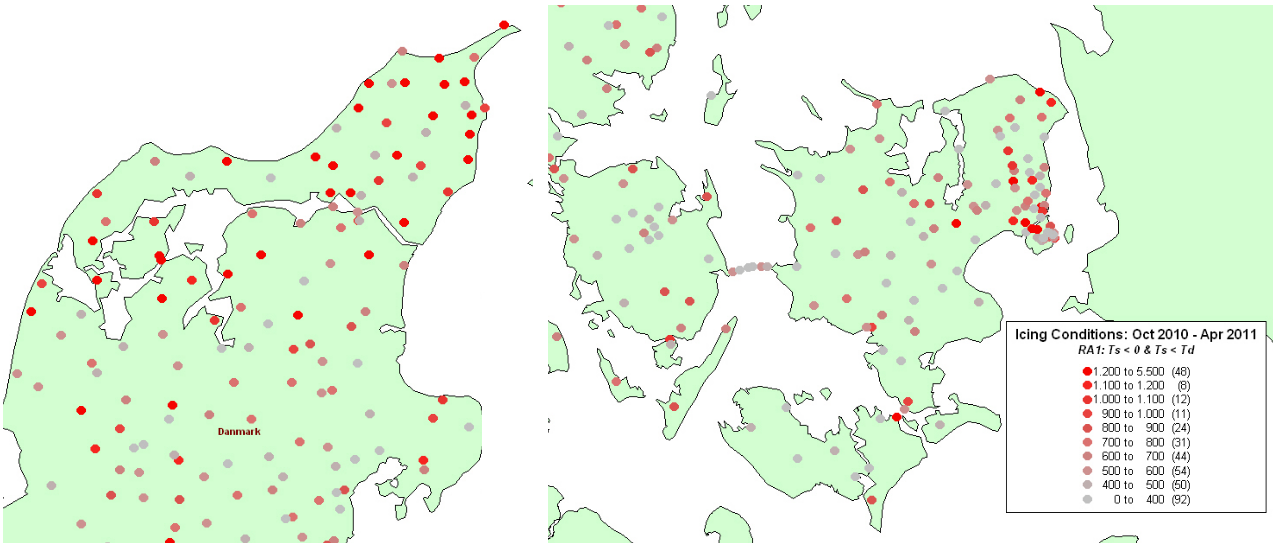


Figure 5. *Spatial distribution of occurrences of the conditions leading to icing on the roads for the red alert situations (RA1) observed at the Danish road stations during Oct 2010-Apr 2011 (left) in the Northern Jutland and (right) in the Fyn and Zealand /number in brackets corresponds to number of the road stations with similar conditions, and intensity of the colored symbol corresponds to higher likelihood of icing/.*

Road Station	***Oct 2010***	***Nov 2010***	***Dec 2010***	***Jan 2011***	***Feb 2011***	***Mar 2011***	***Apr 2011***	***Season 2010-2011***
Coldest Road Stations (Highest Number of Occurrences)								
5800	64	230	2818	2085	110	128		5435
6800	78	265	1661	2073	239	84		4400
6181	35	208	909	1124	192	226	1	2695
1550	13	73	855	1258	136	144		2479
6160	13	203	704	1013	189	141		2263
6182	26	113	683	1016	196	86		2120
6124	31	155	507	987	225	145		2050
6123	17	217	636	831	217	115		2033
6104	27	142	638	946	171	100		2024
6016	31	174	682	867	137	104		1995
Warmest Road Stations (Lowest Number of Occurrences)								
1817					7	4		11
1818					7	4		11
1820					2	14		16
1819					3	15		18
1802			9	10				19
1420			32	10				42
1262				21	18	23		62
2345			12	32	2	27		73
3034				81		4		85
1804			25	63	1	6		95

Table 3. *Top 10 road stations with highest and lowest number of occurrences of the conditions leading to icing on the roads for the red alert situations (RA1: Ts < 0 and Ts < Td) observed at the Danish road stations during road weather season 2010-2011).*

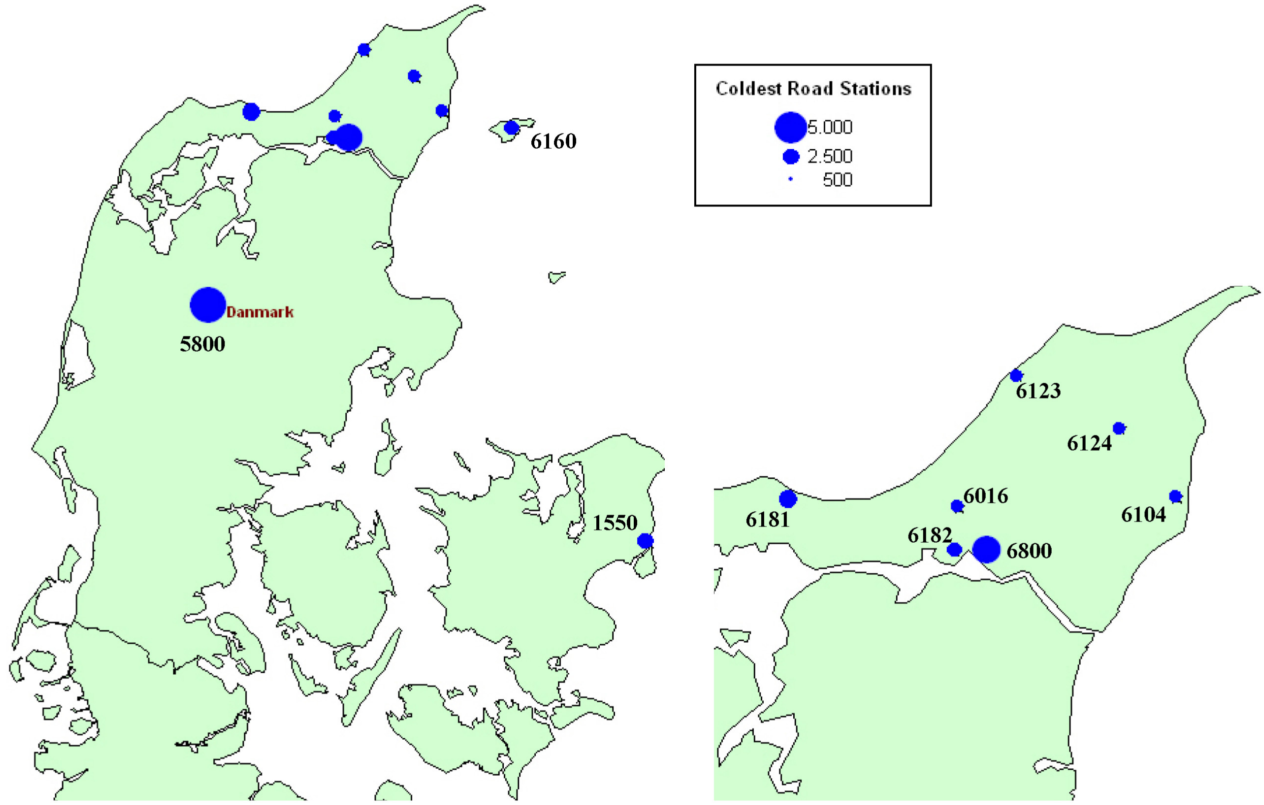


Figure 6. *Spatial location of 10 coldest Danish road stations, i.e. having the highest number of occurrences of the conditions leading to icing on the roads for the red alert situations (RA1) observed during Oct 2010-Apr 2011 /numbers – are road station identificators; and size of the colored symbol corresponds to number of icing conditions observed/.*

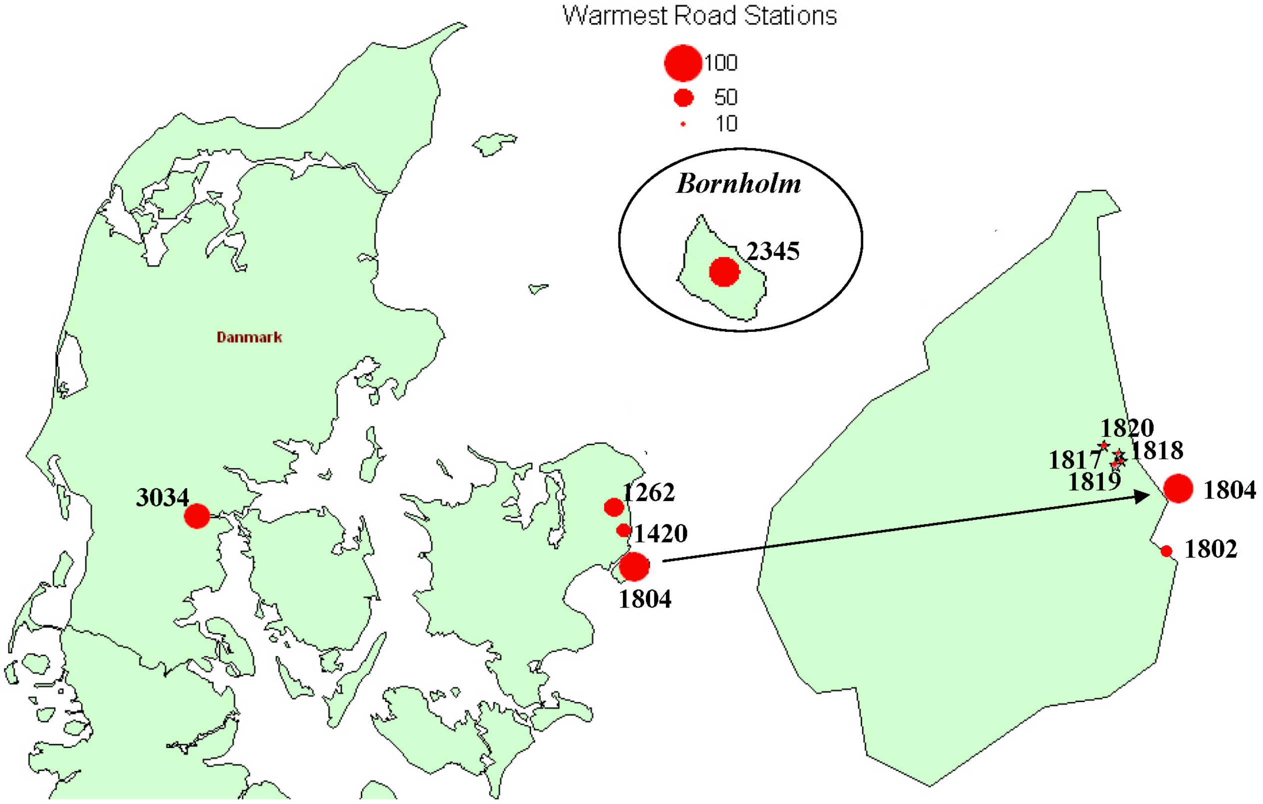


Figure 7. *Spatial location of 10 warmest Danish road stations, i.e. having the lowest number of occurrences of the conditions leading to icing on the roads for the red alert situations (RA1) observed during Oct 2010-Apr 2011 /numbers – are road station identificators; and size of the colored symbol corresponds to number of icing conditions observed/.*

4. Concluding Remarks

For this season the *Ts* verification based on the old approach has almost similar scores (81.88 vs. 82.44) compared with the previous season 2009-2010 (see Table 4). The new approach gives score of 78.01, which is slightly lower than one based on the old verification approach. But it should be noted that for the new approach the larger number of forecasts have been used (i.e. 634176 vs. 563467) for verification. Based on old approach, for the last season there is a weak tendency to higher verification scores of the road surface and air temperatures in November-December and February-March (see Table 4). For the last six road seasons (from October 2005 till April 2011) the scores for 3 hour *Ts* forecasts (in the interval ±3ºC) with an error of less than ±1ºC were always above 80%. For each month of these seasons the scores (with corresponding number of forecasts) are summarized in Table 4.

Month	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**Season**
Road Season - 2005-2006								
Scores	88.5	73.5	80.9	83.2	81.5	71.7	-	**80**
N	4273	71760	137505	173149	152042	96479	-	**635208**
Road Season - 2006-2007								
Scores	97.1	79.7	75.0	76.5	84.4	84.2	-	**83**
N	35	21644	24106	55189	127007	31546	-	**259527**
Road Season - 2007-2008								
Scores	82.7	76.3	80.9	83.1	79.8	75.9	85.5	**81**
N	12369	78434	63487	122915	67884	80306	16873	**442268**
Road Season - 2008-2009								
Scores	79.72	74.03	78.67	79.63	80.78	82.49	91.43	**80**
N	9420	54275	122747	164389	134052	30627	3560	**519070**
Road Season - 2009-2010								
Scores	86.28	80.40	80.24	87.63	81.98	76.12	88.09	**82.44**
N	13169	5843	116307	120423	138204	66203	13479	**473628**
Road Season - 2010-2011 old (new) approach								
Scores	83.62	84.06	81.73	80.74	82.19	80.85	84.66	**81.88**
	(76.59)	(81.50)	(77.16)	(77.57)	(78.42)	(75.86)	(68.36)	**(78.01)**
N	17605	95599	68307	153886	130159	96705	1206	**563467**
	(21135)	(105062)	(80127)	(169316)	(146735)	(109933)	(1868)	**(634176)**

Table 4. *Summary of monthly and overall season scores for the RCM forecasts within a range of ±1ºC (with corresponding number of forecasts, N) during recent road weather seasons 2005-2011.*

The summary for averaged seasonal values of the mean error, BIAS and mean absolute error, MAE for the Danish road seasons of 2005-2011 is given in the Table 5.

As seen, for the road season of 2010-2011, based on old verification approach, for the road surface temperature, *Ts,* the bias has changed from +0.02ºC to +0.09ºC (+0.12ºC – in new approach). The mean absolute error has been changed from 0.69ºC to 0.70ºC (0.79 ºC – in new approach).

For the air temperature, *Ta,* the bias has been changed from +0.12ºC to -0.15ºC compared with the previous season; and the mean absolute error has been slightly improved from 0.68ºC to 0.65ºC (and remained 0.68 ºC – in new approach). For the dew point temperature, *Td,* the bias has been improved from +0.44ºC to +0.12ºC (+0.13ºC – in new approach); and the mean absolute error almost unchanged – i.e. from 0.80ºC to 0.81ºC (0.83ºC – in new approach).

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 (0.12)
	Ta	0.15	-0.02	-0.04	0.02	0.12	-0.15 (-0.13)
	Td	0.27	0.33	0.31	0.24	0.44	0.12 (0.13)
MAE	**Ts**	0.78	0.74	0.78	0.76	0.69	0.70 (0.79)
	Ta	0.80	0.77	0.81	0.72	0.68	0.65 (0.68)
	Td	0.86	0.86	0.87	0.75	0.80	0.81 (0.83)
Score		80	83	81	80	82.5	81.9 (78)

Table 5. *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.*

There may be several factors influencing the verification scores for the road surface temperature prediction in the current season compared with the previous seasons and first of all, the natural variability of the weather conditions is considerable from year to year. The two last seasons have been the coldest for the last 15 years in the Danish observations records, although April 2011 was the warmest April in the Danish observational records.

There are a number of factors which may have influenced the performance of the RCM during the recent seasons. This has been described in Appendix 1. Note, 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 close to the coast, can affect the result. However, the most needed improvement is a better representation of spatial variability of simulated meteorological parameters used in the RCM as input. This can be done by changing of the horizontal resolution of the DMI-HIRLAM NWP model (i.e. from 15 km to 5 km, and further downscaling to 2.5 km), and this is one of the tasks of the "Fine-Scale Road Stretches Forecasting" (RSF) project (2008-2011). In the future it seems useful to consider "problematic" cases showing poor forecasting of *Ts*, e.g. with difficult atmospheric conditions. This needs to be done in order to estimate more clear impact of modifications in the RWM system. Several such cases should be considered when testing new methods for predicting the critical weather parameters such as cloud cover and precipitation, improved shadow measurements.

Acknowledgments

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Petersen C., Mahura A., Sass B., **2010**: Road Weather Modelling System: Verification for 2009-2010 Road Weather Season. *DMI Technical Report* N 10-12, 20 p.

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Appendix 1. Changes in RWM Setup during Road Seasons

During the road weather seasons 2005-2011 several modifications and up-grades of both the DMI-HIRLAM and RWM systems, and RCM model have been done:

- **2005/2006:** On average about 99.7 % of the forecasts are performed without problems. Most errors have been caused by network or computer hardware errors. However, in October 2005 some model runs crashed as a result of numerical instabilities in the model. On average about 1 model run each month crashes due to numerical instabilities. The model setup was changed to perform 24 forecasts for road stations. Still the model deliver 5 hours forecast in a separate file and the 24 hour forecast in a separate file; the latter - with a delay of about 20 minutes.

- **2006/2007:** On average about 99.7 % of the forecasts are performed without problems. Most errors have been caused by network or computer hardware errors. On average about 1 model run each month crashes due to numerical instabilities. On January 29 2007, the heat conductivity constant for road was changed from 2.0 to 1.5. From experimental data this coefficient should be about 1.5 for concrete and 0.8 for asphalt.

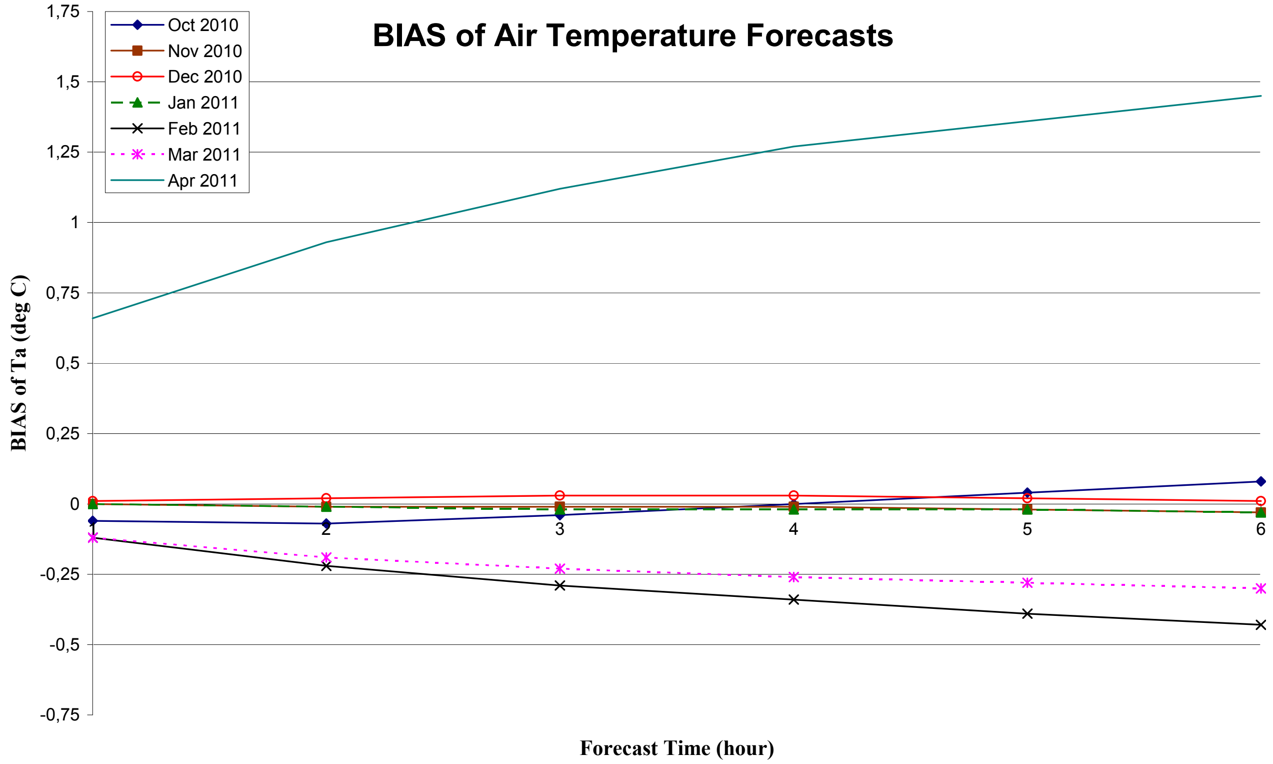
- **2007/2008:** On average about 99.7 % of the forecasts are performed without problems. Most errors have been caused by network or computer hardware errors. On average about 1 model run each month crashes due to numerical instabilities. The heat capacity for the surface scheme in HIRLAM was slightly modified to a lower value to get higher daily amplitude on temperature. A bug was identified which did not set the temperature for the lowest soil layer correctly to a climatic value. Instead a constant value for the year was used which is too high for the winter months.

- **2008/2009:** The use of satellite data was changed in Jan 2009. High thin cirrus clouds are now interpreted as cloud free to avoid too high temperature. There have been only few irregularities in the forecasting.

- **2009/2010:** There have been changes in the snow melting in HIRLAM. Precipitation in the road model is now using HIRLAM snow and rain intensity rather than post-processing of total precipitation. 100% of all forecasts have been performed. However, some might be delayed due to error in the distribution. Few forecasts in October 2009 were delayed for this reason.

- **2010/2011:** The HIRLAM system has been revised to version 7.2. Most aspects of the model have changed. *Yang et al., 2005* describes in more details a similar upgrade. This upgrade includes more features connected to the road weather model such as data assimilation of clouds and additional observations from road stations. 100% of all forecasts have been performed. However, some might be delayed due to error in the distribution.

Appendix 2. Verification of 2 m Air Temperature for Road Season 2010-2011



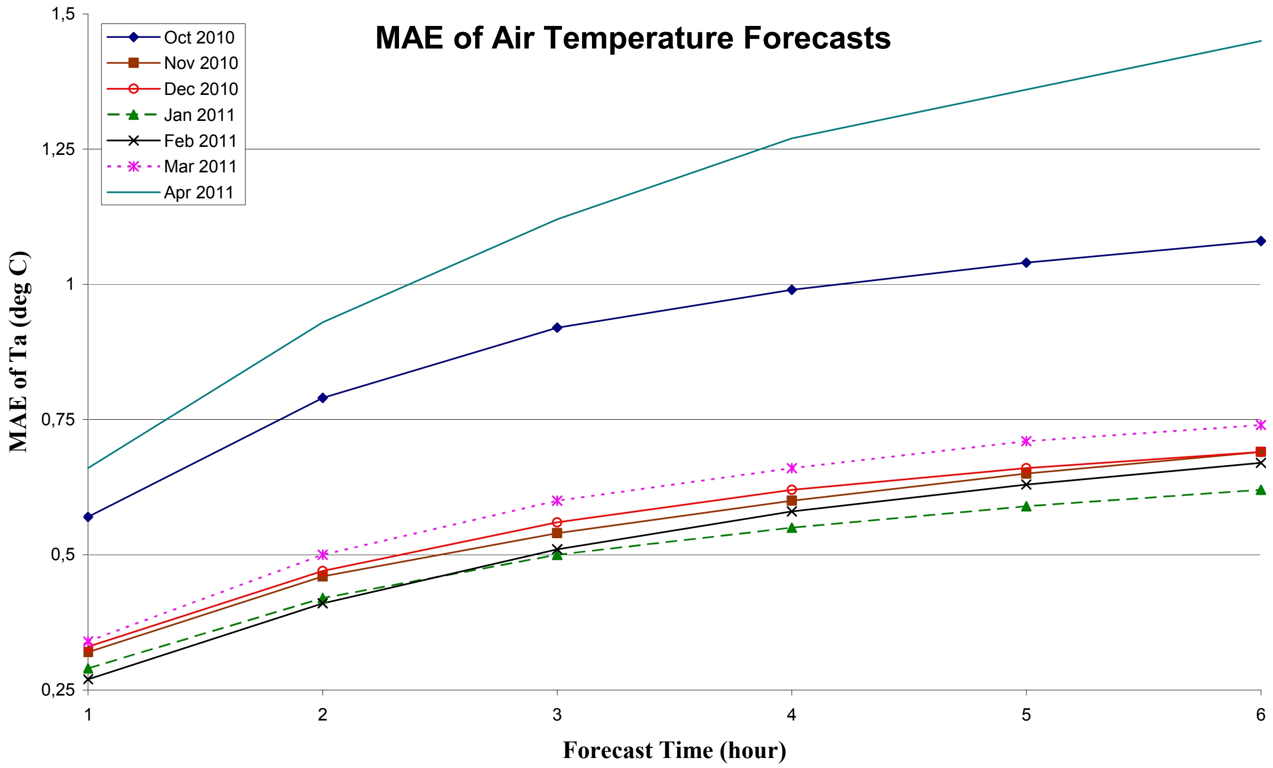
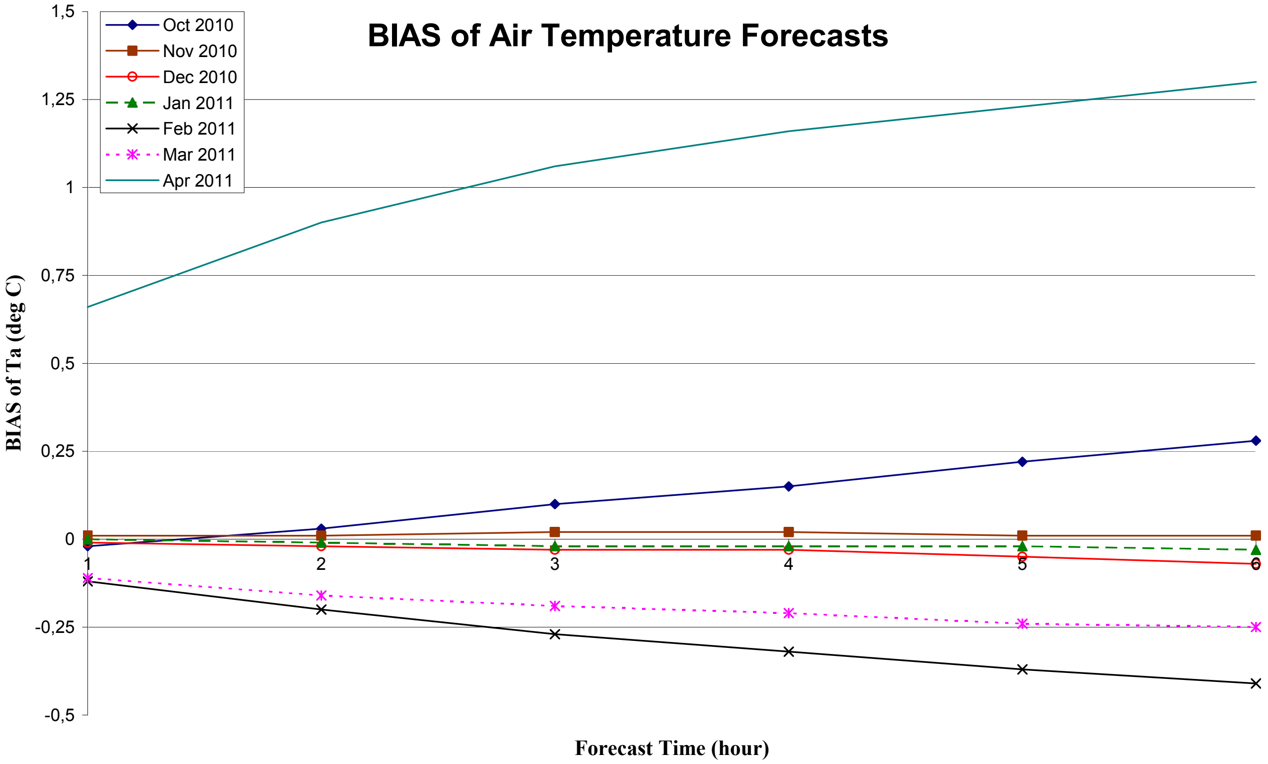


Figure 2A. *Monthly variability of the mean error, BIAS (top) and mean absolute error, MAE (bottom) of the air temperature (Ta) vs. forecast time for the road weather season 2010-2011 /evaluation based on old approach for verification/.*



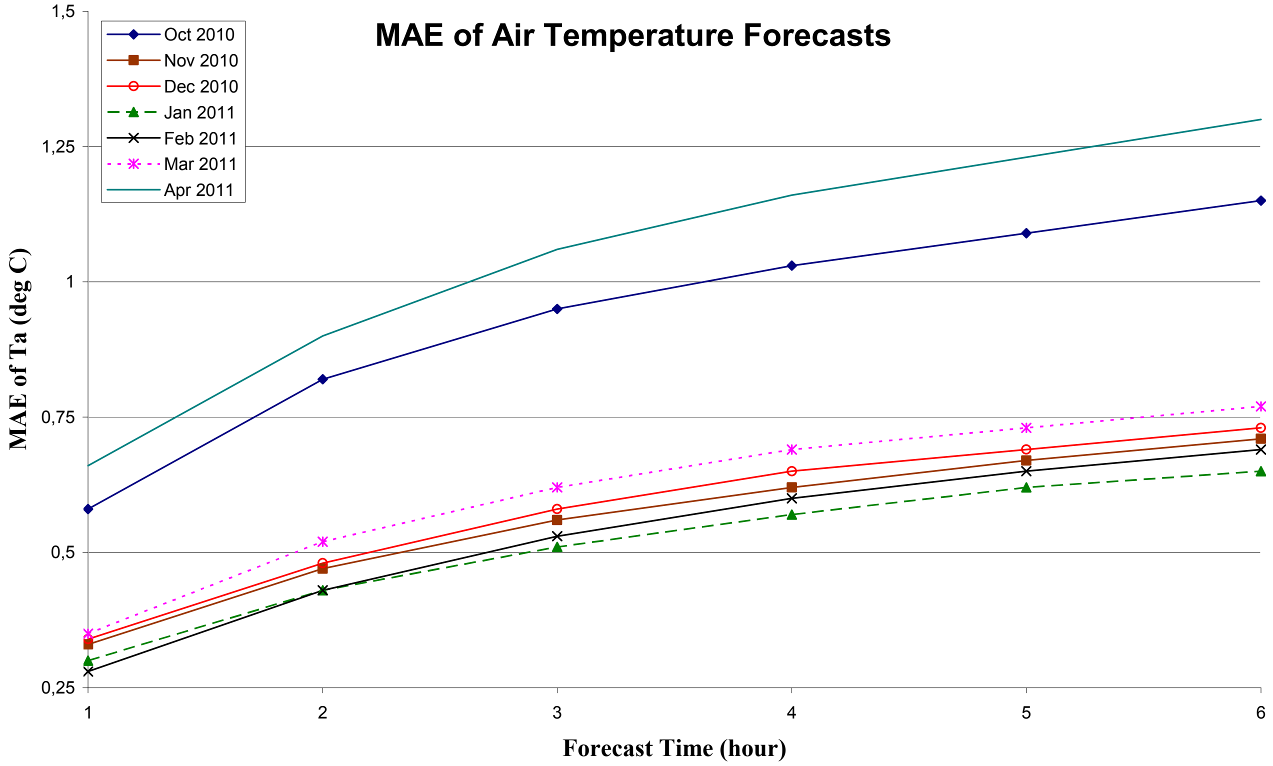


Figure 2B. *Monthly variability of the mean error, BIAS (top) and mean absolute error, MAE (bottom) of the air temperature (Ta) vs. forecast time for the road weather season 2010-2011 /evaluation based on new approach for verification/.*

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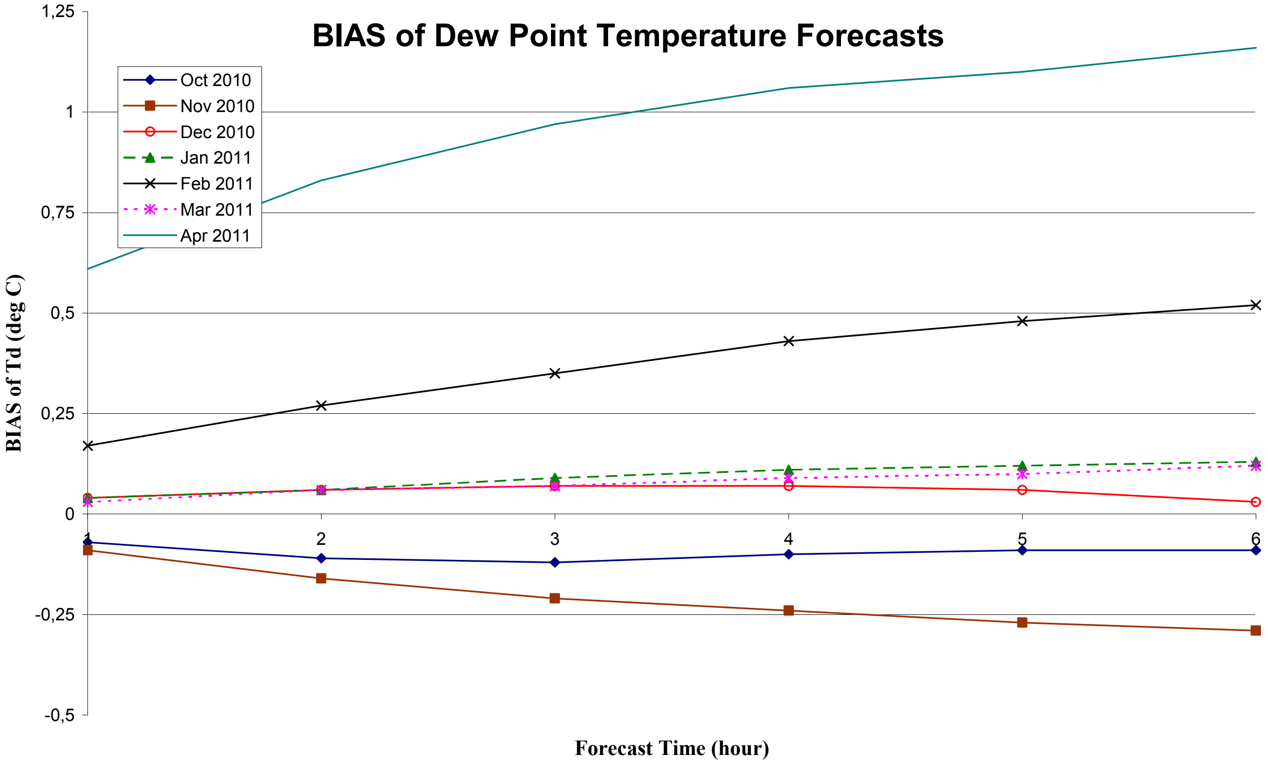
Appendix 3. Verification of 2 m Dew Point Temperature for Road Season 2010-2011



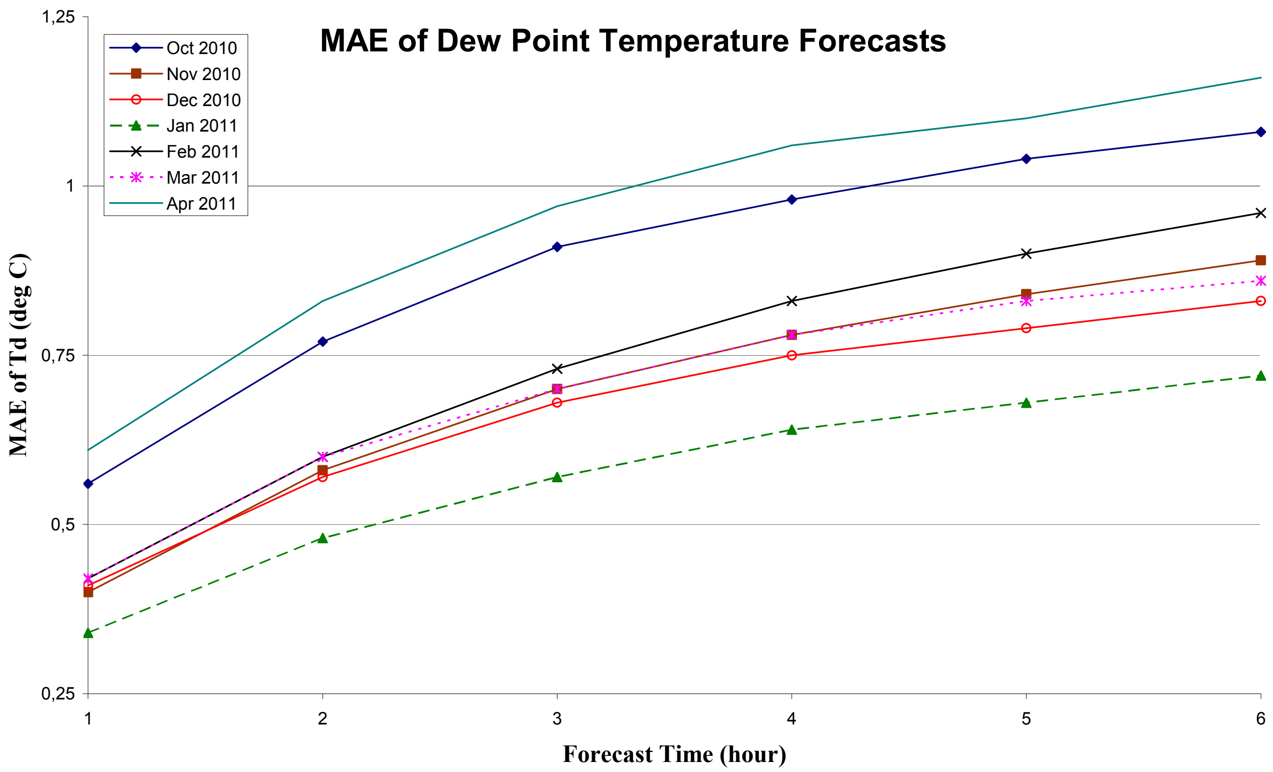
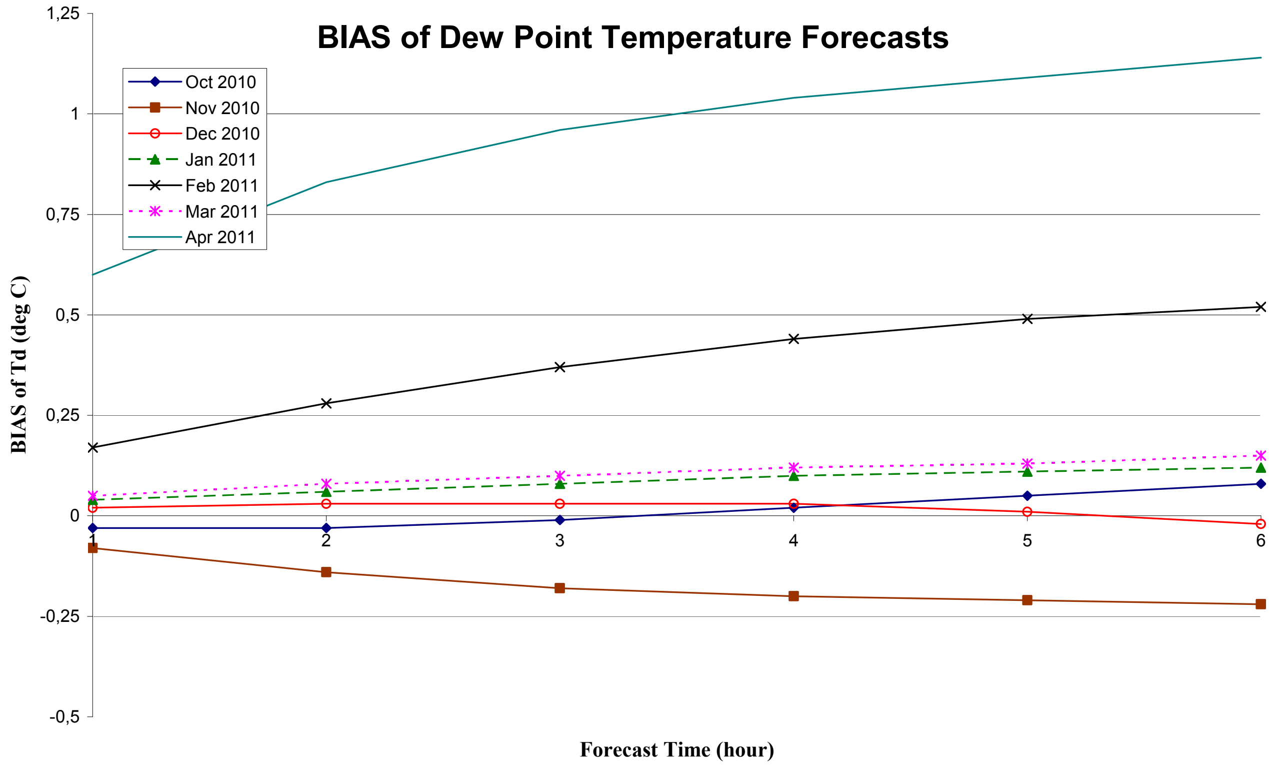


Figure 3A. *Monthly variability of the mean error, BIAS (top) and mean absolute error, MAE (bottom) of the dew point temperature (Td) vs. forecast time for the road weather season 2010-2011 /evaluation based on old approach for verification/.*



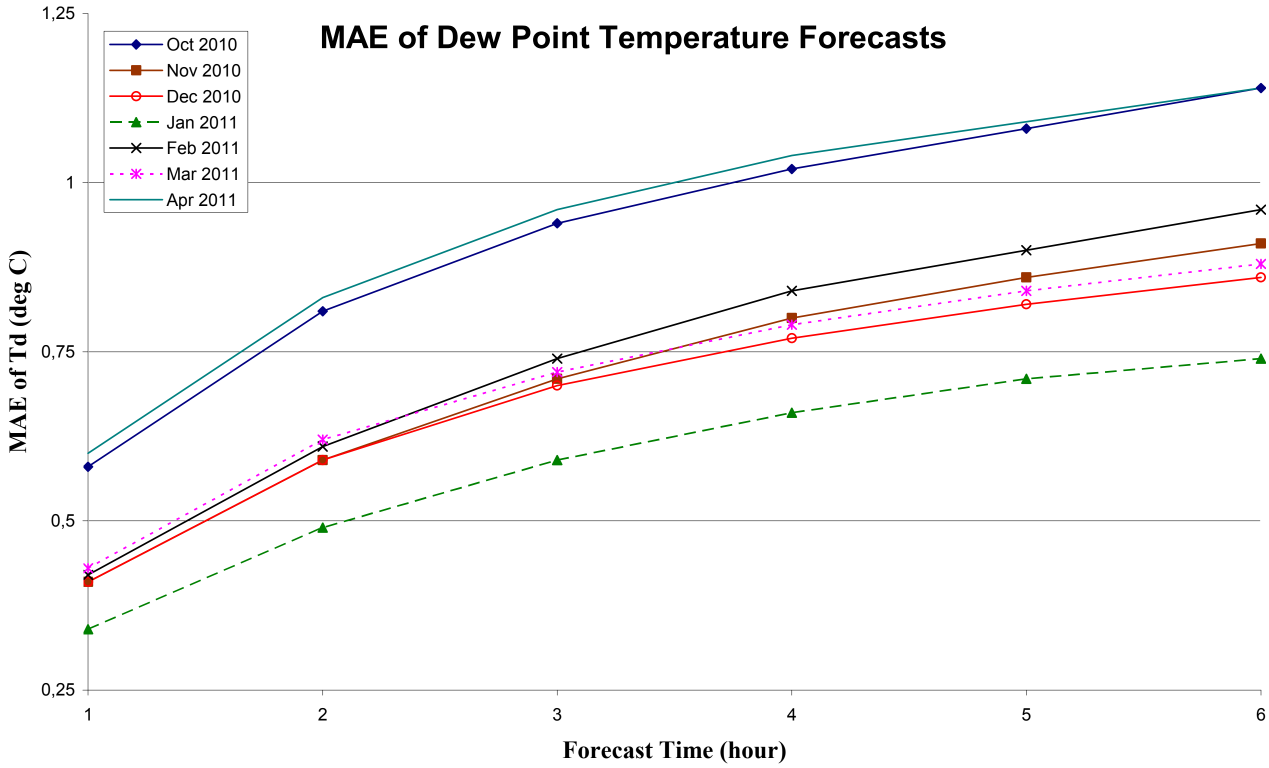


Figure 3B. *Monthly variability of the mean error, BIAS (top) and mean absolute error, MAE (bottom) of the dew point temperature (Td) vs. forecast time for the road weather season 2010-2011 /evaluation based on new approach for verification/.*

Appendix 4. Monthly Variability of Air and Dew Point Temperatures Deviations as Error Frequencies for Road Season 2010-2011

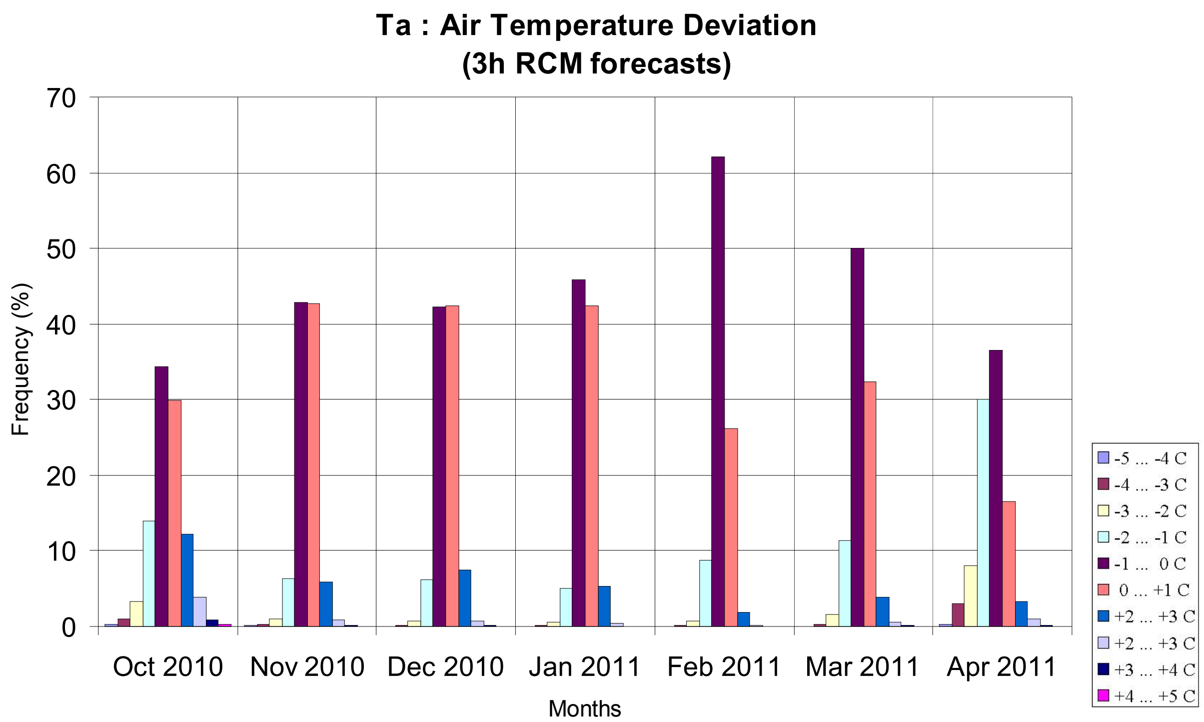


Figure 4A. *Monthly variability of the air temperature (Ta) deviations as error frequencies (%) for the Danish road stations based on 3 hour RCM forecasts for season 2010-2011 /based on old verification approach/.*

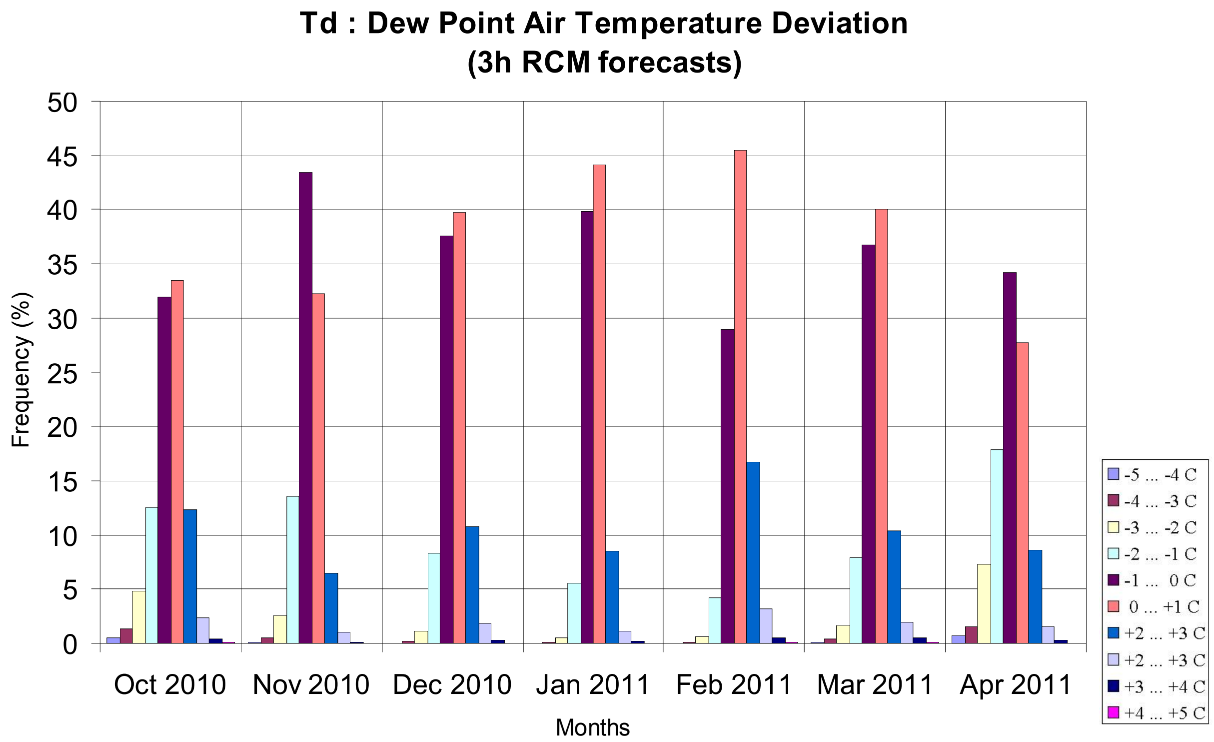


Figure 4B. *Monthly variability of the dew point temperature (Ta) deviations as error frequencies (%) for the Danish road stations based on 3 hour RCM forecasts for season 2010-2011 /based on old verification approach/.*

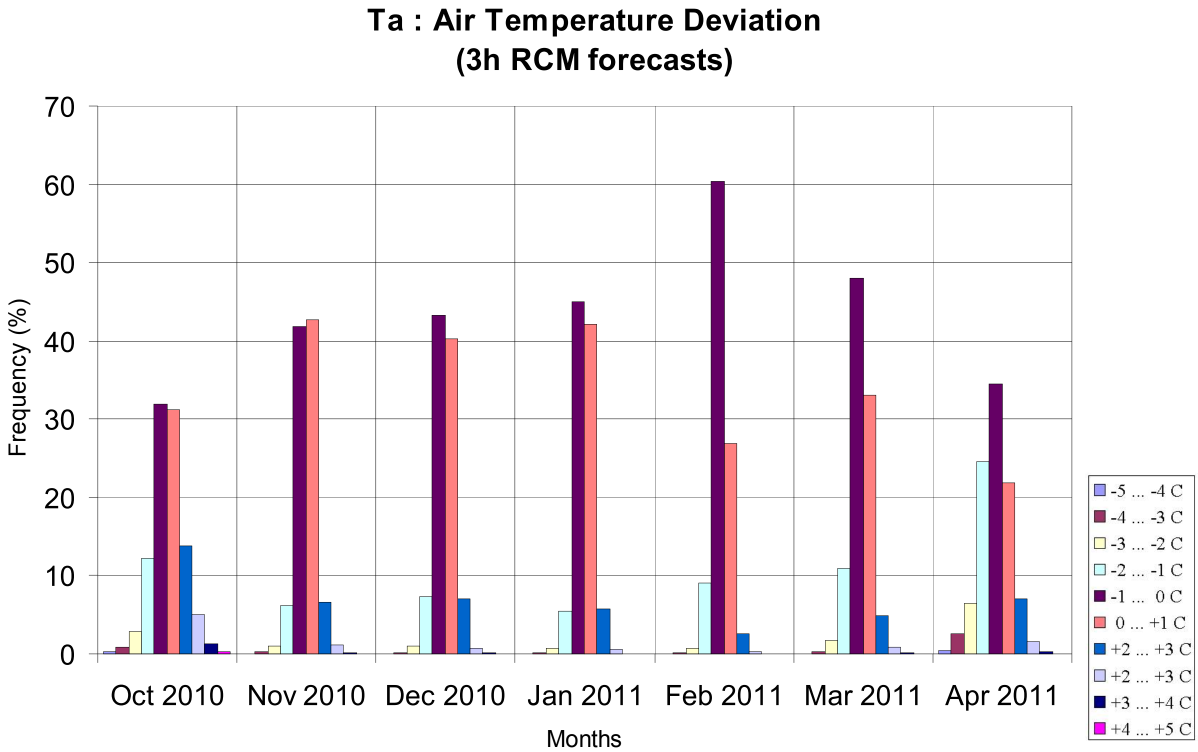


Figure 4C. *Monthly variability of the air temperature (Ta) deviations as error frequencies (%) for the Danish road stations based on 3 hour RCM forecasts for season 2010-2011 /based on new verification approach/.*

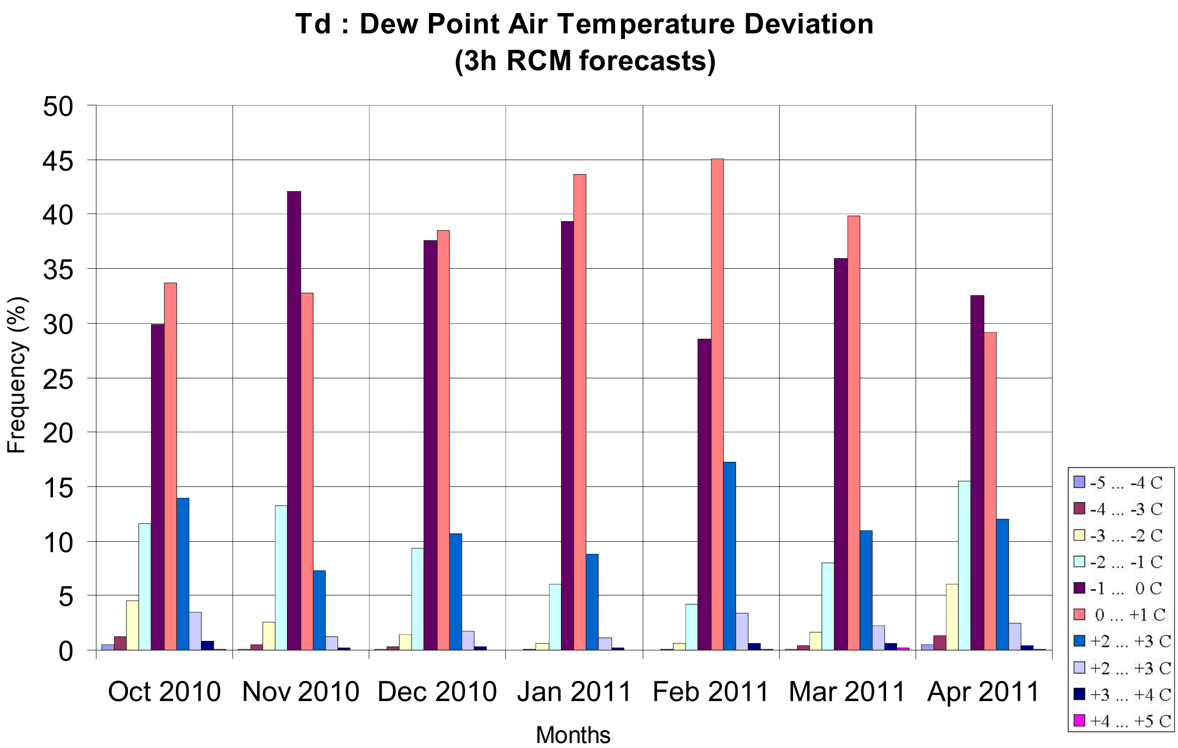
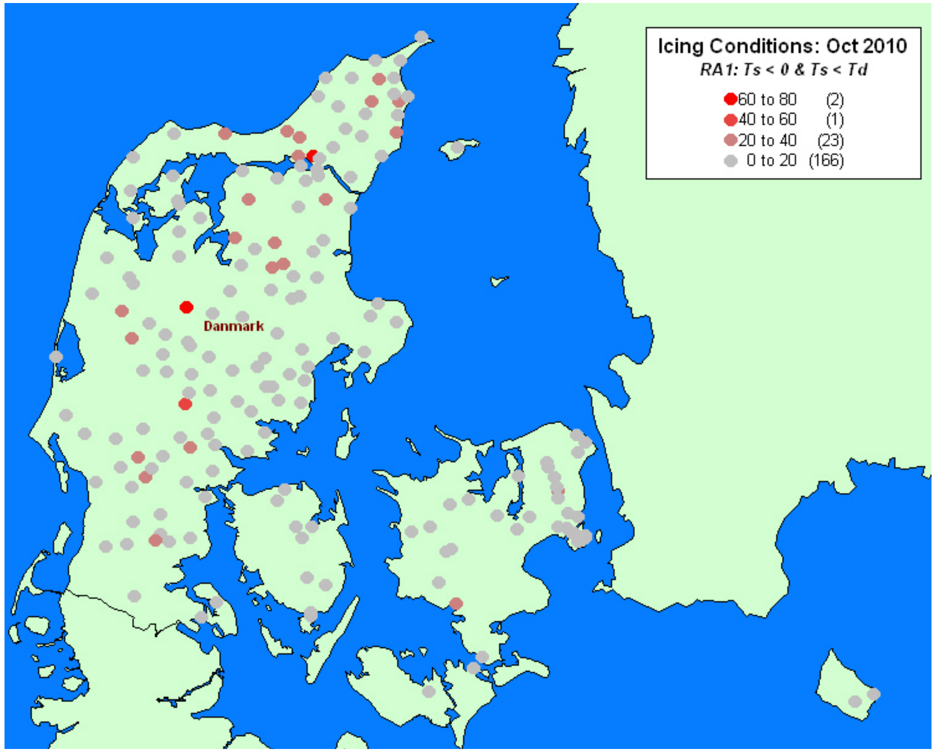


Figure 4D. *Monthly variability of the dew point temperature (Ta) deviations as error frequencies (%) for the Danish road stations based on 3 hour RCM forecasts for season 2010-2011 /based on new verification approach/.*

Appendix 5. Monthly Variability of Road Icing Conditions in Denmark for Road Season 2010-2011



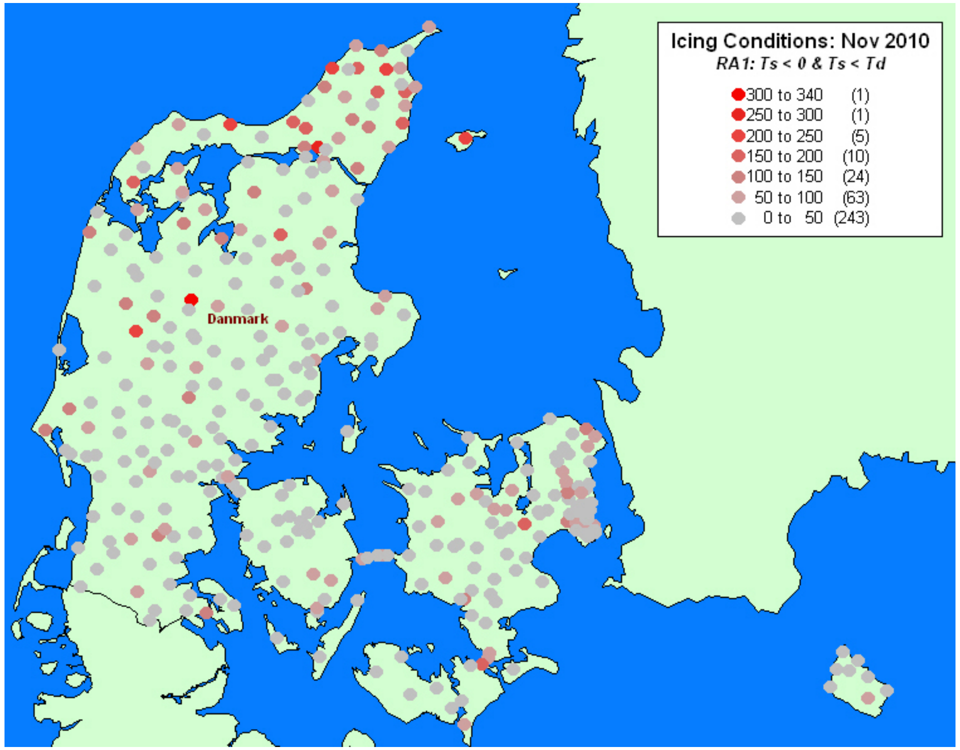


Figure 5A. *Spatial distribution of occurrences of the conditions leading to icing on the roads for the red alert situations (RA1) observed at the Danish road stations during (left) October 2010 and (right) November 2010 /number in brackets corresponds to number of the road stations with similar conditions, and intensity of the colored symbol corresponds to higher likelihood of icing/.*

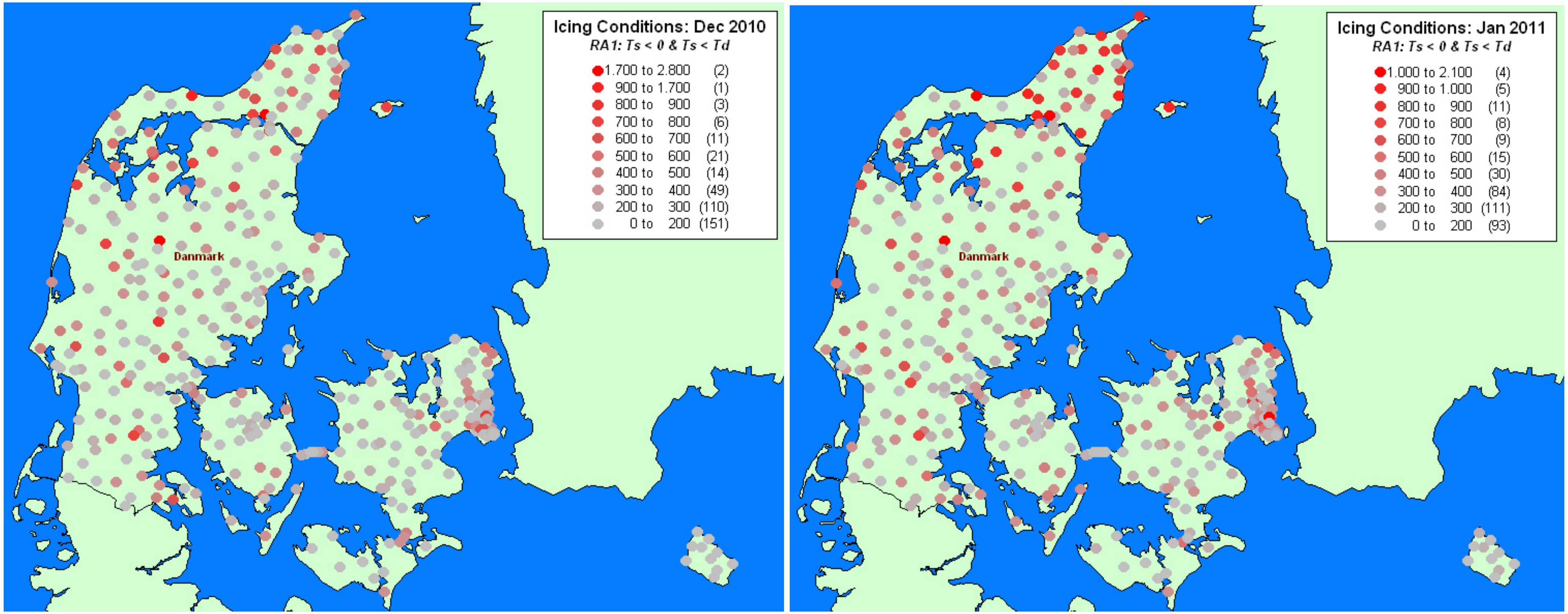


Figure 5B. *Spatial distribution of occurrences of the conditions leading to icing on the roads for the red alert situations (RA1) observed at the Danish road stations during (left) December 2010 and (right) January 2011 /number in brackets corresponds to number of the road stations with similar conditions, and intensity of the colored symbol corresponds to higher likelihood of icing/.*

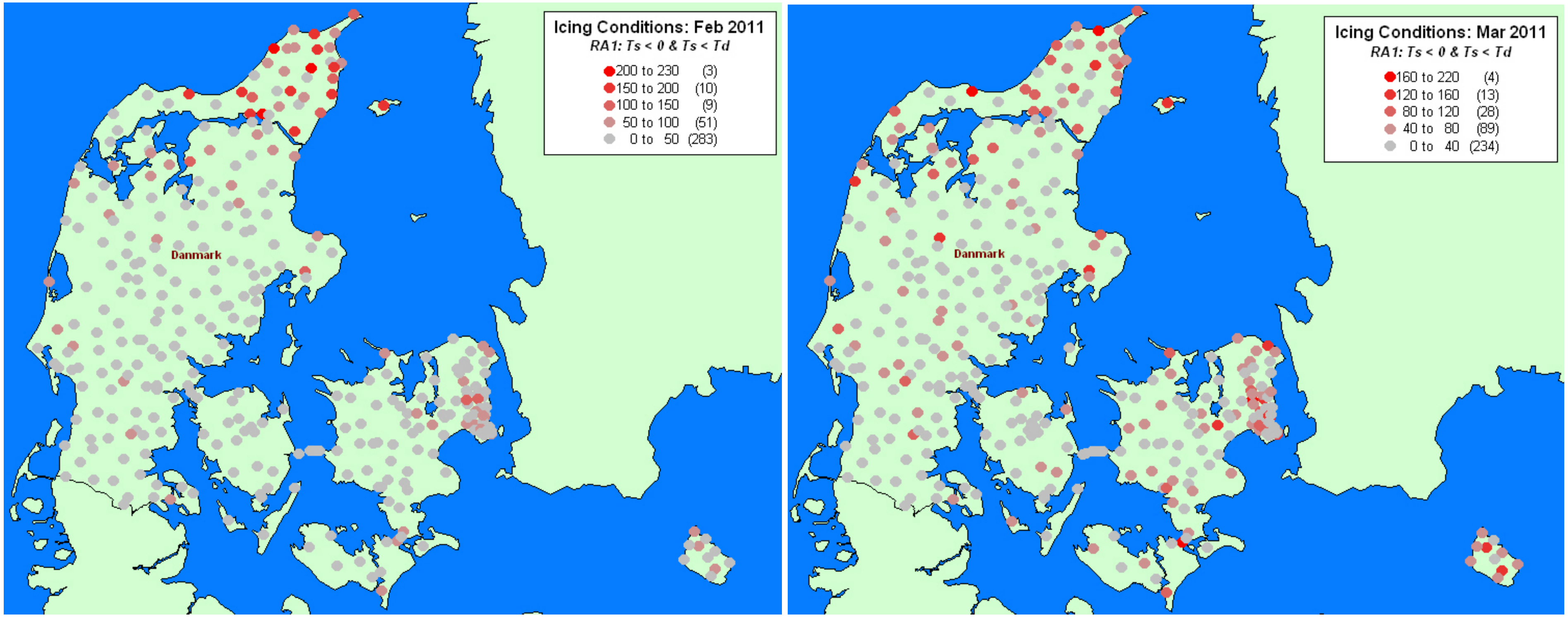


Figure 5C. *Spatial distribution of occurrences of the conditions leading to icing on the roads for the red alert situations (RA1) observed at the Danish road stations during (left) February 2011 and (right) March 2011 /number in brackets corresponds to number of the road stations with similar conditions, and intensity of the colored symbol corresponds to higher likelihood of icing/.*

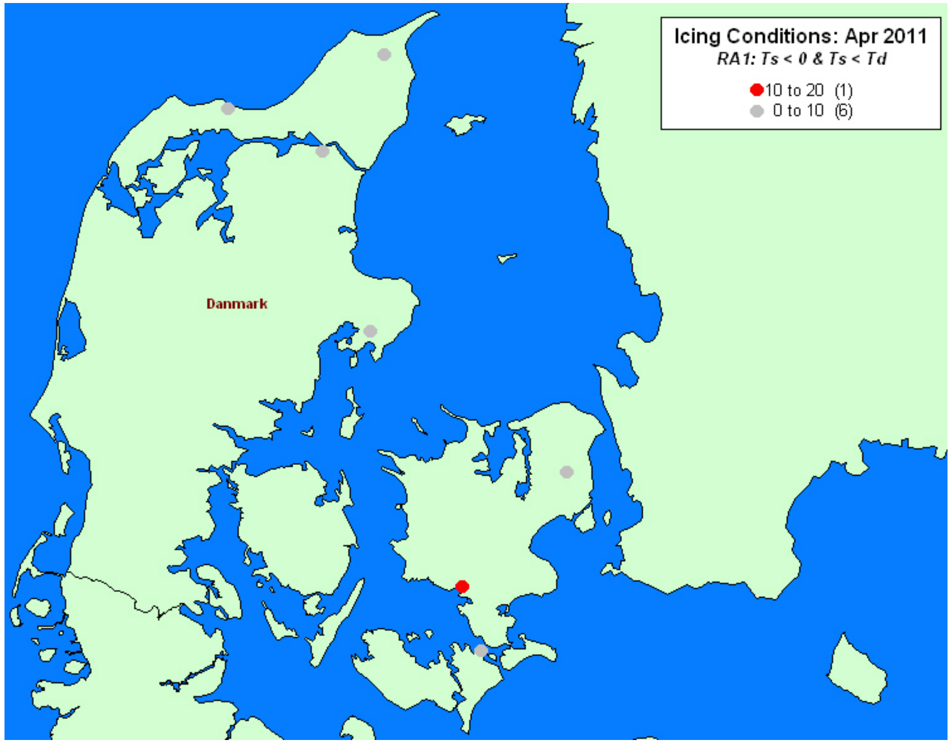


Figure 5D. *Spatial distribution of occurrences of the conditions leading to icing on the roads for the red alert situations (RA1) observed at the Danish road stations during April 2011 /number in brackets corresponds to number of the road stations with similar conditions, and intensity of the colored symbol corresponds to higher likelihood of icing/.*