A New Step Towards a Road Stretch Forecasting System

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ABSTRACT

It is an ultimate goal to deliver accurate forecasts for every locations. At the moment DMI is able to deliver accurate point forecasts for a limited number of places along the Danish road network. All these locations are equipped with measuring instruments which provide a numerical model with initial conditions for the road surface. A project at DMI aims to develop such system in a way that it can make forecasts not only for these selected points but for the whole road network. In numbers this means that instead of deliver forecasts for about 300 points this is increased to about 17000 for Denmark. The motivation to build the system is a vision of a fully automatic forecast system which in combination with GPS (Global Position System) technology mounted on vehicles can control the salt spreaders so it will reduce or increase the salt dose to be spreaded after the forecasted conditions for specific road stretches. The challenge in the project is to provide the same high accuracy of the forecasts to all the 17000 points as in the existing system. A rough description of the new system will be presented and preliminary results of simple road stretch forecasts will be compared with observations of road surface temperature along selected road stretches. These measurements have been done from moving vehicles equipped with GPS and inferred road surface temperature sensors. This also introduces the concept called thermal mapping data which is a technique to provide additional very local information to high resolution forecasts. Verification of the first simple road stretch forecasts shows a good agreement between observations and forecasts which at the same time also shows that the quality of the observations from moving vehicles are almost comparable to traditional observations at road stations.

Keywords: road stretch forecast, GPS, high resolution, NWP model, thermal mapping data

1. INTRODUCTION

Danish Meteorological Institute (DMI) has for the last 15 years produced road forecasts for selected point along the Danish road network. At each at these points the road surface temperature, 2 m temperature, 2 m dew point temperature have been measured typically with an interval of 10 minutes and by time more advanced sensors have been developed which can also measure other meteorological variables. In itself these observations are a part of a monitoring system of the road conditions but at the same time the observations are used to initialize a road condition model [1,2] which then can produce precise, unbiased short range forecasts.

New technology and more computer power have opened new possibilities for improving road forecasts. This is primary driven by a wish of more accurate forecasts and new technology emerged - GPS (Global Position System) which now is cheap and well working. Mounting GPS equipment and intelligent salt spreaders on vehicles enable the possibility to accurate monitoring the amount of salt which have been spread on individual road stretches. Measurements of road surface temperature, air temperature and other additional meteorological variables from vehicles mounted with GPS can at the same time provide insight to the meteorological conditions along individual road stretches. Most important of all is the road surface temperature.

The long term vision is detailed and accurate road stretch forecasts which can be used to a more selective and automatic dosing of salt. As a first approach a road stretch is defined as a 1 kilometre long part of a road (driving lane). This length has been chosen for practical reasons taking in to account the number of data and also as a limit where present numerical weather prediction (NWP) models can give information. For Denmark this corresponds to about 17000 road stretches which should be compared to the about 300 spots (road stations)

where forecasts are delivered at the moment. Figure 1a shows the locations of the road stations with red dots and green dots indicate road stretches all together forming the roads. The road stretch forecasts will, first of all, give a more detailed picture of the road conditions and it is expected that especially for marginal situations the road stretch forecast can provide more information to the decision makers about optimized preventive salting. The next step from this point is to use road stretch forecasts directly to control salt spreaders on vehicles mounted with GPS and GPS controlled salt spreaders. These kinds of spreaders are already on a market and can also change dose depending on the vehicle speed and the shape of the driving lane if provided with the right and detailed data. In a case that a part of a salting route has forecasted road surface temperature above 0 ºC or the road is predicted to be dry the salt spreader will turn off or reduce the amount of salt to be spreaded. Of course, some security limits will be set depending on the forecast accuracy and most likely a worst case scenario will be chosen to be on a safe side.

2. METHODOLOGY

2.1 Road Stretch Forecasting System

Using a high resolution NWP model will give a detailed picture of the variations of several meteorological key parameters. For road forecasting the most important parameters are near surface temperature, near surface wind speed, near surface wind direction, precipitation intensity, precipitation type and the 3D cloud structure. For this reason high resolution data-assimilation is necessary in order to provide the NWP model with sufficiently good enough initial conditions. However, it is well known that data-assimilation and NWP models at present stage can not provide sufficiently detailed analysis. The traditional observations network is very sparse but has been improved with satellite observations. Additionally for Denmark the network of road stations is very dense but still not enough when the forecast should show details about a road stretch with a length of 1 kilometre or less. Figure 1b shows the present NWP model domain (R15) and the domain (R05) which will be used as NWP model input to the road stretch forecasts. Essentially the difference is the horizontal resolution which is shifted from 0.15°x0.15° to 0.05°x0.05° of latitude vs. longitude to provide more detailed local meteorological information to the road stretch forecasts. The NWP model is based on the HIRLAM (High Resolution Limited Area Model) which is a hydrostatic model [3,4]. The model is running with 40 vertical levels and using initial and boundary conditions from a HIRLAM model covering the North Atlantic, Arctic and Europe.
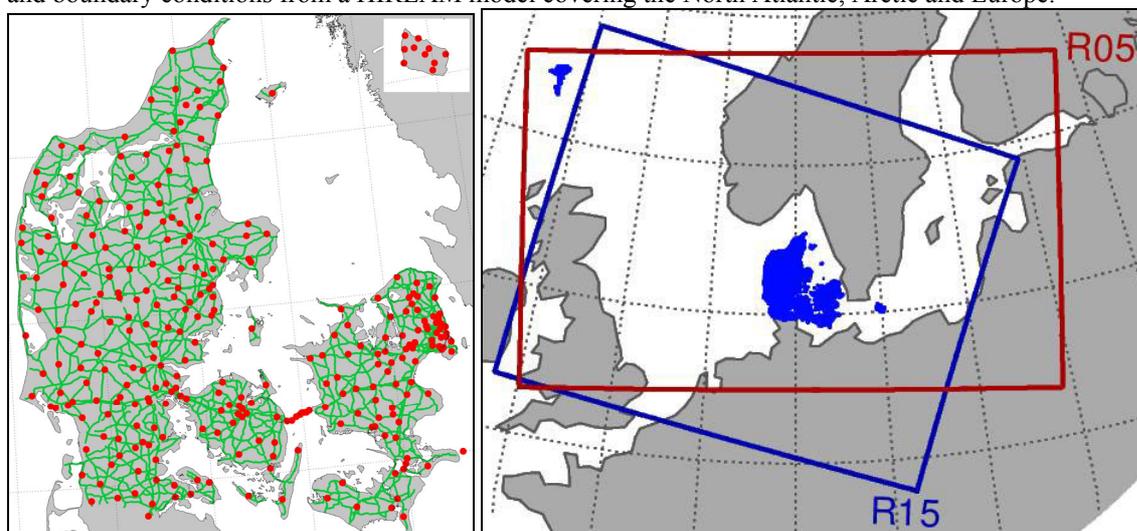

Figure 1. (a) Road stretches (green) of the driving lanes and road stations (red) of the Danish road network and (b) Model domains of the DMI-HIRLAM RWM system having 15 (R15) and 5 (R05) km resolutions.

The road stretch forecast model will run every hour and therefore the NWP model will run every hour to provide the changing atmospheric state to the road conditions model. The NWP model will make data-assimilation of the observations which have arrived during the last hour. In reality there are only three sources of detailed information available for each road stretch:

1) Very high resolution detailed meteorological output of the NWP model;
2) Specific characteristics of the roads: types, pavements, conductivity, albedo, etc., as well as shadowing effects along the roads and high resolution land-use classification datasets for the road surroundings;
3) Thermal mapping data measurements conducted along the road pathways.

Additionally there are other sources of information which are less local like road stations. The concept of how to make the road stretch forecast for these data is shown in Figure 2.

Figure 2a shows the northern part of Denmark and the network of road stations for this area (marked with red dots). The grey line in the middle of the figure shows a selected part of the road. Figure 2b shows a zoom into the road stretches. The figure shows the model points (marked with black dots) from a NWP model with a horizontal resolution of about 2.5 kilometre between the grid points. This part of the road has been decomposed into points (marked in grey color) with a distance of about 1 kilometre. It is clear that several approaches can be applied to predict the road surface temperature for each individual road stretch. Basically the state of the free atmospheric can only be obtained from the NWP model and the most obvious method is to use the nearest model point or bilinear interpolation from the neighbour points. Observations of road surface temperature, the near surface air temperature and humidity can be obtained from nearby located road stations. These observations are essential to ensure unbiased initial conditions. The underlying assumption is that the model error at each road stretch is comparable to the error at nearby road station points. Observations from moving vehicle at individual road stretches can additionally be used to obtain statistical information about the model error or deviation from nearest road stations for individual road stretches. Ultimately these data can be used to estimate a so-called background error. However, it is expected that the background error will highly depend on the individual weather situation. A good formulation of how to solve this problem is still needed and it will also be necessary to have a large data base with observations. The concept of thermal mapping data will be further explained in next sections. The road stretch forecasts presented here is in reality the interpolation of forecasts from the nearest road station points. This corresponds to a situation with a coarse NWP model resolution and ignoring the background error.
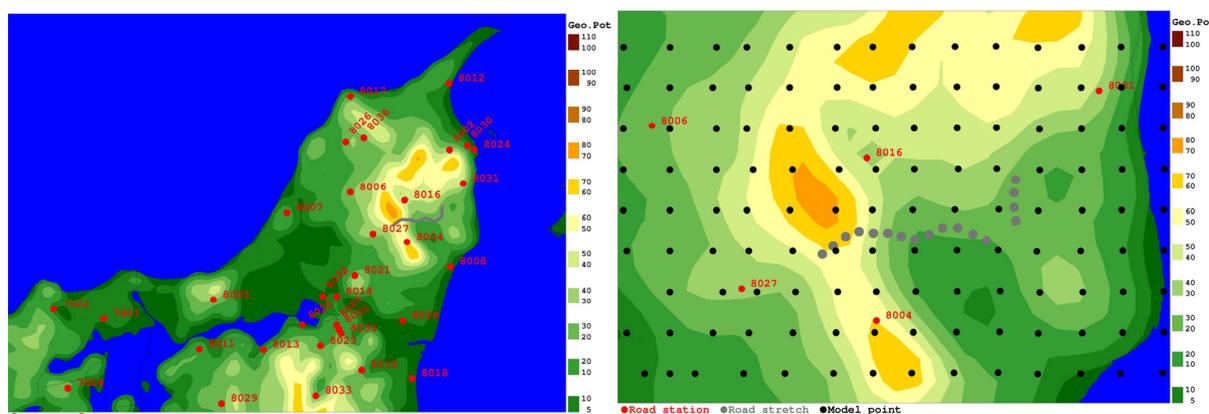

Figure 2. (a) Northern Jutland of Denmark (red dots -positions of road stations; grey line - part of the road); (b) A zoom into the road (a distance between grey dots - corresponds to a length of about 1 kilometre, called the road stretch; black dots - grids from the NWP model).

2.2 Thermal Mapping Measurements and Their Treatment

Thermal mapping is a process of measurement of spatial variation of road surface temperature under different weather conditions. The equipment used to make such kind of accurate measurements is an infrared thermometer of a high resolution. The device is mounted on the vehicle at the height that sensor should have a clear sight to the road surface. Mostly such measurements are performed during road winter seasons with a focus on nighttimes. Because at this time, differences in temperature across the roads can vary up to several degrees, and hence, some parts of the road can be near or below the icing/freezing point and others - may be not. Note that this pattern and distribution of warm and cold sections is determined by local scale conditions as well as synoptic scale dominating weather conditions. The ice will occur on the surface of the road depending on a balance of energy which the road surface might receive and lose in conjunction with the available amount of moisture. For each road such balance is affected by complex interactions between various factors including: dominating weather conditions; sky view factor or shadowing effects from, for example, trees, buildings, constructions; height of the road section; geographical location with respect to major water objects; effects of urban areas resulting in building up of so-called urban heat islands; road and traffic related peculiarities; etc. Combination of all these factors will create a unique "temperature fingerprint" for each road. So, thermal mapping procedure recreates a relationship between all these factors and how these interact with each other. A large number of continuous measurements can allow building temperature profiles which will be unique for each road.

2.3 Original Data and Time Series of Forecasted vs. Thermal Mapping Data at Road Stretches

The thermal mapping data has been provided by the Danish Road Directorate (DRD) through the on-line database access using the VINTERMAN software package. The database contains detailed information about

number of the driving, measuring, and salting activities' parameters. The focus is on data/measurements of road surface temperature (Ts) and air temperature (Ta) (i.e. a set of so-called the thermal mapping data, ThMD). Note, that these data are irregularly measured depending on the road authority programmes, and the measurements are done at discrete time and space intervals. In our study, for the winter seasons of 2005-2007 almost 290 road salting activities with the ThMD measurements for selected roads were identified, respectively. The duration of such measurements varied from a few minutes up to several hours. From these cases, dates with missing measurements of one of the temperatures and missing GPS coordinates were excluded. After screening, in total almost 168000 records containing a set of parameters (identificator of road activity; temporal - year, month, day, hour, minute, second; latitude and longitude based on the GPS values, and measurements of the road surface and air temperatures) were extracted from the DRD database [5,6].

Since the thermal mapping measurements are done at non-equal discrete time intervals (due to different velocities of moving vehicle along parts of the road), the temperatures were recalculated by averaging at each 1 minute interval, which reduced the original datasets into almost 24000 records having similar parameters. Since the focus is on the road stretches, therefore, the datasets were restructured by re-assigning pairs of measured (or observed) temperatures at exact local times when simultaneously measuring and forecasting are done for corresponding locations of the road stretches. In order to build such unified dataset, the NWP+RWM system recalculated output was used (at each 2 minute interval for all mentioned specific cases). It was found to be the most useful for the road stretches situated at 1 km distances from each other. Hence, in total more than 11000 records were corresponded to road stretches. In this final dataset each record contained the following set of parameters: identificator of road activity; temporal - year, month, day, hour, minute; identificator of the road stretch with corresponding latitude and longitude as well as the forecasted and observed/measured road surface and air temperatures.

3. RESULTS AND DISCUSSIONS

3.1 Overall Verification for Recent Road Weather Seasons

Evaluation of the RWM system forecasting performance was done by analysis of the mean absolute error, MAE and mean error, BIAS for both Ts and Ta as a difference between the 3 hour forecasted and observed values [7,8]. During season of 2006-2007, the score for the 3 hour RWM forecasts of the road surface temperature with an error of less than ±1ºC was 83% (with the highest score in October – 97%) based on more than 259 thousand corresponding forecasts. The scores have improved during spring months of 2007 due to changes of the roads heat conductivity. The overall seasonal averages of the bias and mean absolute error were 0.22ºC and 0.74ºC, which showed a slightly better performance of the model compared with the previous season 2005-2006 (Figure 3), where the bias and mean absolute error were 0.31ºC and 0.78ºC, respectively. For the air temperature, Ta, the bias has been improved from 0.15ºC to –0.02ºC, and the mean absolute error changed from 0.80ºC to 0.77ºC. For the dew point temperature, Td, the bias has changed from 0.27ºC to 0.33ºC, and the mean absolute error remained the same of 0.86ºC.

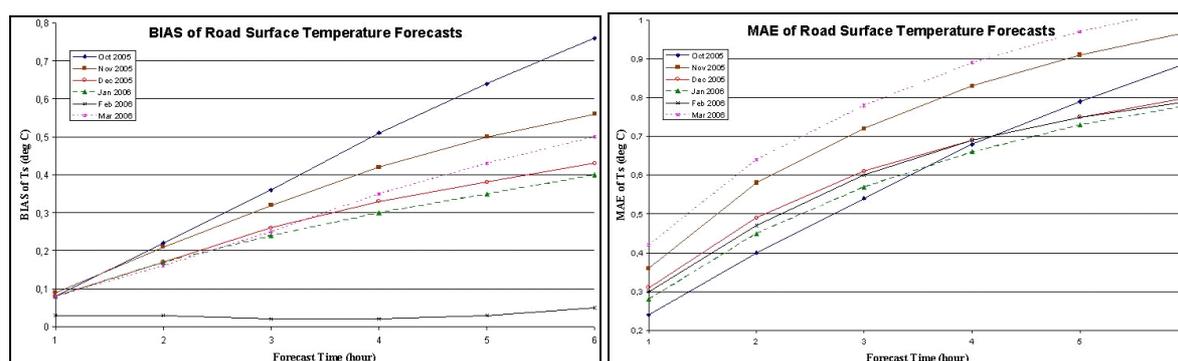Figure 3. Example of the monthly variability of the mean error, BIAS (a) and mean absolute error, MAE (b) of the road surface temperature (Td) vs. forecast time for the road weather season 2005-2006.

3.2 Monthly Variability of Thermal Mapping vs. Forecasting Data

In terms of MAE and BIAS the overall Ts verification scores for the studied road weather season of 2006-2007 were relatively good. For all road stretches considered (Figure 4), on average, for Ts the BIAS and MAE were 0.34 and 0.90ºC, respectively; and for Ta these were 1.30 and 1.44ºC, respectively.

Figure 4. Ribe Amt region selected roads - VA4 (blue), GR2 (red), and RI1 (green) – with corresponding road stretches.

For this road, the lowest BIAS (0.02ºC) and MAE (0.38ºC) were in December 2006. For VA-4 road, the lowest BIAS (-0.13ºC) and MAE (0.67ºC) were in January and March of 2007, respectively. In general the BIAS is always negative, except for December. For the GR-2 road, during this season both BIAS and MAE were more than 1ºC. It could be due to the fact that the stretches (i.e. 18 from 30 stretches are situated at more than 30 meters asl) of this road are situated at higher altitudes compared with other roads. I.e. for the RI-1 road there is only 1 of 23 stretches, and for the VA-4 road there are 10 of 30 stretches. For Ta, in general, the month-to-month variability showed overpredicted values which were more than +1ºC. Although in March, for the VA-4 road, the BIAS and MAE were 0.82 and 0.93ºC, respectively. Month-to-month variability of Ts showed that the lowest/best values are observed for the RI-1 road.

For Ts, 3 hour forecasts were contained within a range of less than |±1ºC| in more than 60% (with the highest – 81% for the RI-1 road, and the lowest – 34% for the GR-2 road) of the road salting activities. They were higher than |±1.5ºC| in less than 17% (with the highest – 34% for the GR-2 road, and the lowest – 5% for the RI-1 road) of the activities. For Ta, the MAE and BIAS showed values of less than |±1.5ºC| in 62% of the performed road activities.

3.3 Road Stretches Forecasts and Need of New Improvements

The Danish road network is represented by a large number of the roads/driving lanes in various communes (so-called communes/regions numbered from 15 to 80). In order to perform the road stretches forecasting the coordinates of the road stretches along the roads are needed. The GPS coordinates from the VINTERMAN database were extracted and recalculated at 1 km driving distances along the roads. In total, more than 17 thousand road stretches were identified covering the entire Danish road network (except, Island of Bornholm) as it was shown in Figure 1a.
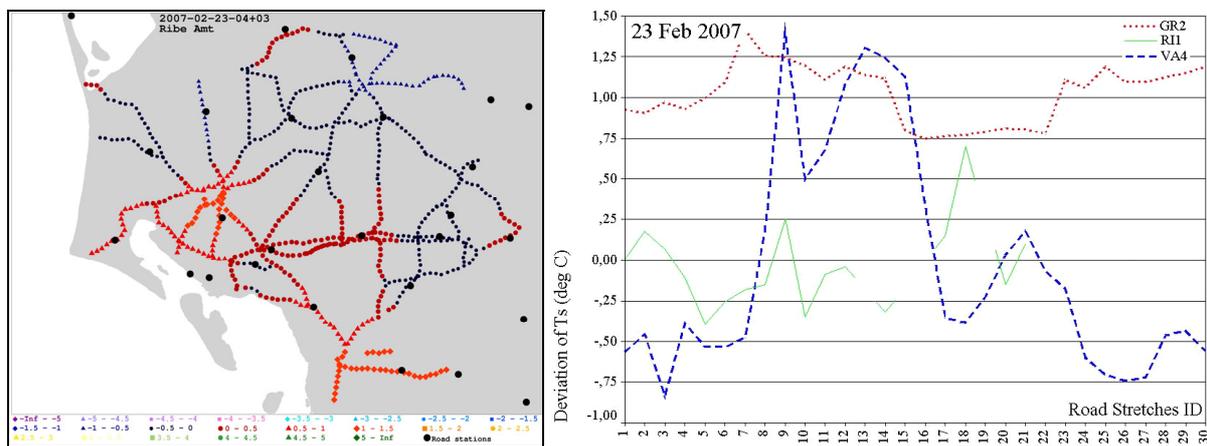

Figure 5. (a) Three hour forecasts of the road surface temperature at the road stretches in the Ribe Amt region on 23 Feb 2007 at 07 h and (b) Difference between the forecasted and thermal mapping measurements of the of road surface temperature along stretches of the three – GR2, RI1, and VA4 – roads in the Ribe Amt region during 23 Feb 2007.

During the last season the thermal mapping measurements were done mostly in the former Ribe Amt commune/region for 3 selected roads. These roads – VA-4 (57 km), GR-2 (66 km), and RI-1 (46 km) – are located on the Jylland Peninsula and are represented by 84 road stretches from total of 714 and by 10 closely located road stations (Figure 5a).

On 23 February 2007, similarly to the previous case, the salting activities were performed for the entire paths of the VA4 and GR2 roads, but not completely along the RI1 road (Figure 5b). For the GR2 road, the deviations

were mostly around 1±0.25ºC showing oveprediction of Ts. For two other roads these were lower, except for a part of the VA4 road. The examples of Ts 3 hour forecasts at the road stretches within the Ribe Amt region are shown in Figure 5a. The quality of the Ts forecasts show significant variability along the roads. As seen some parts of the roads are warmer or colder than forecasted because of very local features either at the road stretch which are not forecasted well or the forecast was affected by observations from a near by road stations which differed to much for the road stretch. This clearly shows that salting based on road stretch forecasts can influence the decision making process and allow a driver, having operational on-line access to these forecasts, to optimize where and when exactly the salting activities should be performed and hence, reduce the amount of salt spreaded during the road weather seasons. Moreover, consequently, it will positively influence the environmental conditions of the surrounding area. Detailed analysis of this and other cases is summarized in [9].

4. CONCLUSION

It has been seen that road stretch forecasts are useful and a new step in road conditions forecasting . Even with application of a simple approach the results obtained are promising. The direct verification of the road stretch forecasts vs. observations show a high quality which is not far from the quality of existing of point forecasts. It is clear that the quality of the used NWP model is essential for a detailed road stretch forecasts and that the horizontal resolution of the NWP model should be comparable to the length of the individual road stretch. At DMI it is planed to run such model with a resolution of 0.05°x0.05° for the winter 2008/2009 and increase the horizontal resolution in the NWP model to 0.025°x0.025° for the following winter 2009/2010.

It is expected that this improvement will add considerably more information to the operational road stretch forecasts. Moreover, it will be possible to see more spatial and temporal variations in the road surface temperature patterns than in traditional point forecasts.

It can also be concluded that the measuring quality of thermal mapping data seems to be high and comparable to conventional temperature measurements at road stations.

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