Operational Danish Road Weather Forecasting using High Resolution Satellite Data

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ABSTRACT

Improvements in performance of the Danish Road Weather Model system due to incorporation and assimilation of cloud observations from satellites and conventional data are discussed. Both conventional observations and NOAA and MSG-1 satellite data were assimilated using a nudging technique and the results were verified for a two weeks period. Additionally the derived cloud mask from the NOAA satellite was compared with conventional observations. The results indicate that use of cloud data can be used to improve forecasts of the road surface temperature in particularly for short term forecasts. It is also emphasized that NOAA data for some days differ from conventional data and should be used with care in certain situations.

Keywords: road, surface, temperature, cloud, satellite

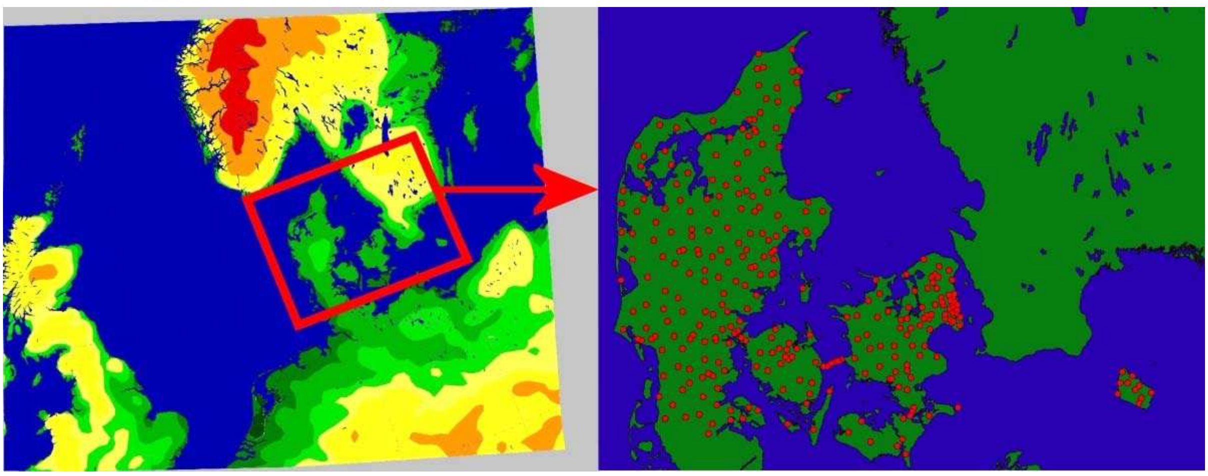
1. INTRODUCTION

During the last 15 years the Danish Meteorological Institute in cooperation with the Danish Road Authorities has developed the Road Weather Model (RWM) system. This includes a web based user interface with additional facilities. The main idea is to use road observations along the Danish roads as input into a numerical model which is designed to predict the road conditions. Essentially, this means forecasting of the road surface temperature and the accumulated water/ice on the road. Data assimilation of road observations gives optimal initialization of the road surface temperature and temperature profile in the soil layer. The atmospheric state is prescribed from a 3D (dimensional) numerical weather prediction model (NWP) which is a special designed version of the HIRLAM model (HIgh Resolution Limited Area Model). The road condition model itself is a one dimensional model. It obtains the future atmospheric state from the NWP model. The NWP model domain (DMI-HIRLAM-R) and network of road stations are shown in Fig. 1.

Detailed description of the road condition model is given by *Sass, 1997* and documentation for HIRLAM is provided by *Sass, 2002.* In order to improve road forecasts and, in particular, the short-term range forecast it

Figure 1. (a) DMI-HIRLAM-R NWP modelling domain and (b) locations of the Danish road stations.

(a) (b)



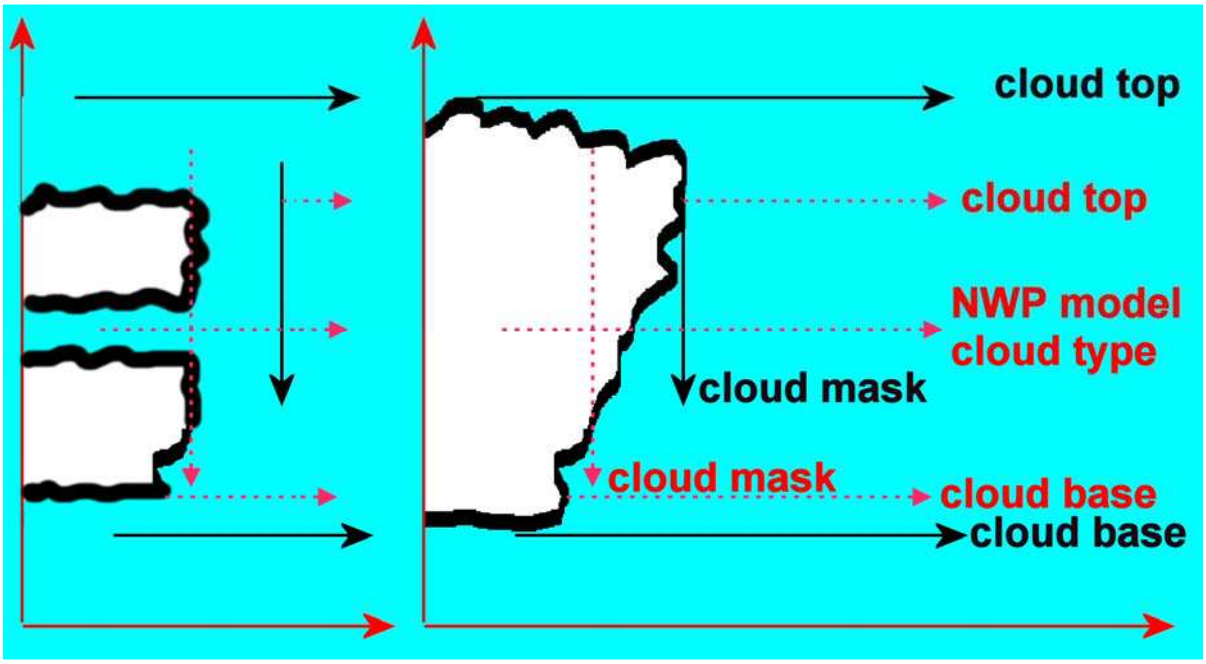


Figure 2. Scheme of the three dimensional cloud structure. The right figure shows the initial guess of the cloud structure. The red color indicates observations and numerical data which are used in the analysis. The left figure shows the cloud structure after applying observation.

was realized that the initial conditions of the NWP model has to be consistent with observations at the road stations. Note, the road conditions depend strongly on the cloud cover, shadows, precipitation, wind speed, air temperature and humidity. However, some of these quantities have a large local variability and the road conditions can be affected by changes in these parameters on a very short time scale. It is known that local weather conditions can be forecasted with a high accuracy only for a limited time period depending on a weather situation. For these reasons it was decided to develop methods to assimilate high resolution observations of cloud cover into the NWP model. This paper describes the methods and results of data assimilation of cloud cover from satellites and conventional observations into the HIRLAM NWP model. Note, a summary of the recent DMI-RWM system research activities is given by *Sass & Petersen, 2004; Petersen & Sass, 2005; Sass et al., 2005*.

2. METHOD

A general method for NWP models based on nudging has been developed. It is assumed that cloud cover only depends of specific water vapor and specific cloud water contents. However, these quantities are not well observed. Instead observations of cloud cover, the height of cloud base, temperature of cloud top and cloud type are combined with model data and used to make an analysis of 3D cloud structure. A simple relationship between cloud cover and other quantities does not exist. The equations are highly non-linear and observed cloud cover at any time depends on the state of the atmosphere. Different methods have been applied to parameterize the convection and condensation leading to a variety of parameterization schemes that have been tested and run operationally. Many different approaches have been tested during the last decades. This has the consequences that assimilation of cloud cover should lead to the same value of cloud cover for different models, but the resulting analysis of cloud water and specific water vapor content will not be necessary identical. The so called STRACO scheme has been used. This condensation and convection module was specifically developed for use with the HIRLAM model. At the moment this scheme does not contain explicit equations for rain water or any advanced treatment of hydrometeors. The analyzed cloud cover is nudged into the model as tendencies of specific water vapor and cloud water contents. The tendencies are calculated as a part of the physics package of the NWP model in a 3 hour long data assimilation cycle and are restricted by other constrains to avoid instability and unrealistic high precipitation amounts. It was also necessary to develop an analysis of precipitation which is used to switch off the nudging module if the analyzed cloud cover cannot be achieved without producing unrealistic atmospheric features.

Figure 2 shows schematically how the analyzed 3D cloud structure is obtained from different data sources. Note, that NWP data is necessary to use as a kind of a first guess or background field to estimate the cloud structure. The applied observations do only contain limited information of the 3 dimensional structures. The philosophy of this method is that intensive use of high resolution satellite data and frequent forecasts will keep the first guess field from the previous forecast close to the observed cloud cover which means that only small modifications are needed. However, the method is general and will also adjust in cases where the background cloud cover and observations are very different. The method is primary designed for stratiform clouds and shallow convection, whereas the way deep convection is parameterized makes it more problematic to correct errors in cloud cover or the correction may only have a relative short lifetime. In certain cases the nudging can trigger convection correctly and it is also effective to suppress any kind of precipitation during the data-assimilation cycle.

3. DATA USED

All kinds of cloud related observations of cloud cover can be used in the data-assimilation. Satellite data is processed in to gridded data with a resolution comparable to the NWP model. Recently it has become possible to use both NOAA and MSG-1 data. Compared to the polar orbiting NOAA satellites the geostationary MSG-1 satellite provides data every 15 minutes and covers the entire DMI-HIRLAM-R model domain. These data is also received with a very short delay of about 10 minutes. Regarding the NOAA data these are only available about 8 times per day and some of the satellite passages only partially cover the DMI-HIRLAM-R model domain. Even though NOAA data has a higher spatial resolution, it is experienced that MSG-1 data is of higher quality probably due to better post processing of data and more spectral channels. The NOAA output was compared with observations of cloud cover from Danish SYNOP stations. Because the MSG-1 data has only been available for a short period these are not considered in the verification in section 4.

4. COMPARISON OF OBSERVATIONAL VS. NOAA SATELLITE DATA

In order the verify quality and accuracy of the road weather forecasting a statistical analyses of ground vs. satellite observations of cloud cover were done. The NOAA satellite data (resolution of 1 km) and ground observations for cloud cover were evaluated and inter-compared for the period September 2004 – May 2005 (i.e. 9 month) Note, the satellite data were not available at each UTC term, and due to difference in the time and space span of the NOAA satellite. These are not given every hour and often they do not cover the entire selected DMI-RFM model domain.

The cloud cover values were extracted at geographical locations of stations (combined of the land, coastal, and sea located sites) located in the DMI-RWF model domain and re-recorded separately for each available term as time series. To unify analysis the cloud cover from both the satellite and ground observations were converted from scales of fractions from 0 to 1 and points of 0 to 8, respectively, to a scale ranging from 0 to 100%.

Both types of data – satellite and ground meteorological observations – were combined into one dataset and re-arranged as time series records including: year, month, day, hour (UTC term), cloud cover (in %), type of observations (satellite vs. ground), station type, station's identification number. Statistical analysis of cloud cover was performed on a basis of: a) data type analyzed, i.e. satellite vs. ground meteorological observations; 2) separation into Danish land vs. Danish coastal stations; 3) month-to-month variability; 4) diurnal cycle variability. The monthly variability of the cloud cover observed from ground vs. satellite observations for three groups of stations is shown in Fig. 3

. For Danish coastal stations, on average, the satellite cloud cover is about 6% higher compared with the ground observations. During May, this difference is the highest (12%), and moreover, only during December, in opposite, the ground observations are higher by 4% compared with satellite ones. For the Danish land station the situation is more complex. During November-March, satellite observations showed lower (max of 15% in

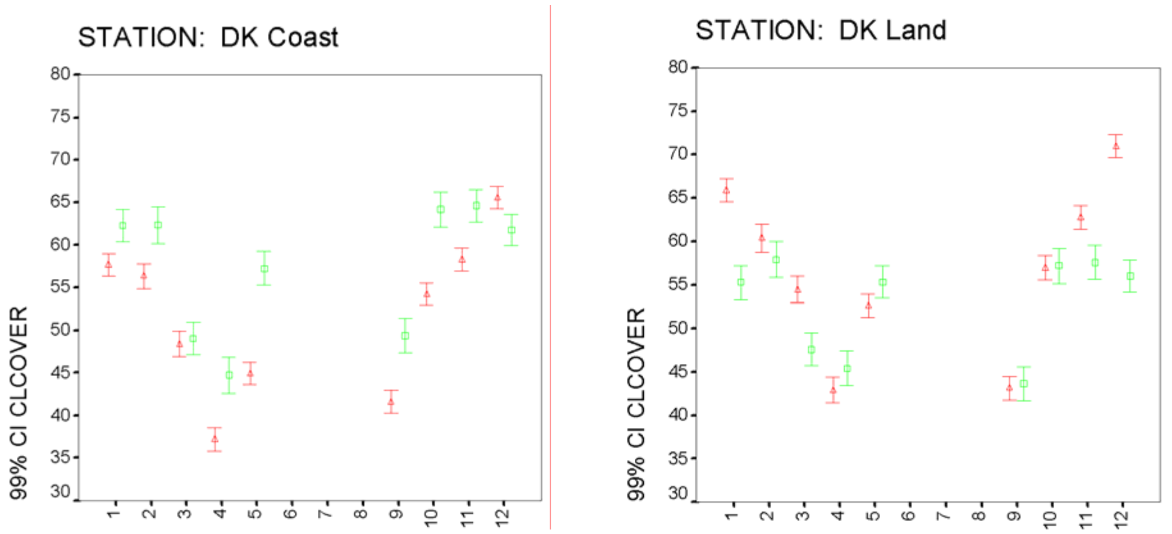


Figure 3. Summary of monthly variability (at UTC terms) of cloud cover (in %) at 99% of confidence level for two types of observations (red triangles – for metobs – ground meteorological stations' observations, and green squares – for satobs – NOAA satellite observations) for three groups of stations: (a) DK Coast – coastal Danish stations, (b) DK Land – land Danish stations. (Note: June-July-August months are excluded since these did not have full months of satellite data).

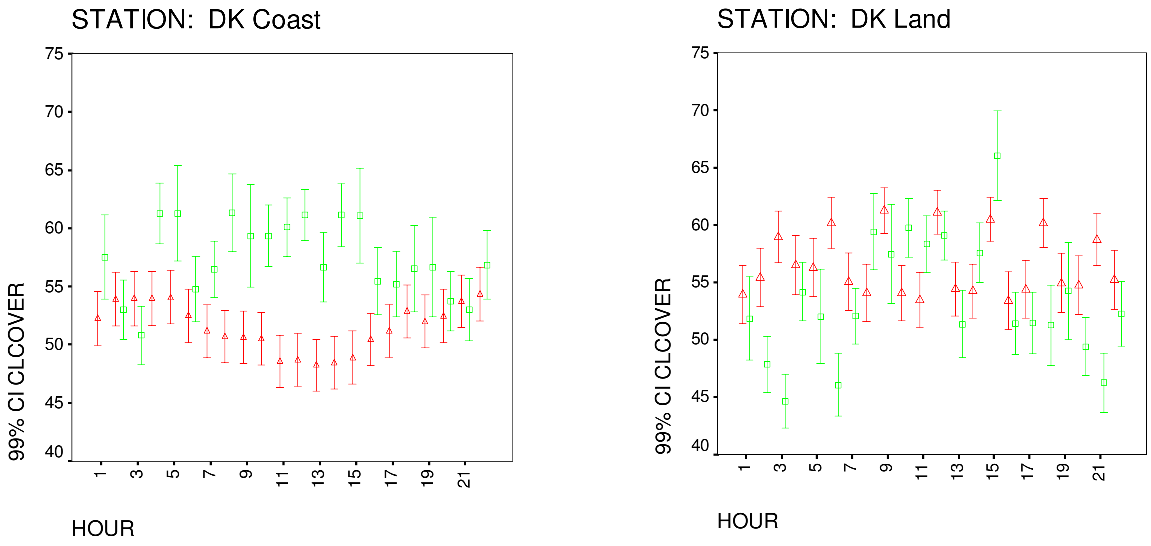


Figure 4. Summary of diurnal variability (at UTC terms) of cloud cover (in %) at 99% of confidence level for two types of observations (red triangles – for metobs – ground meteorological stations' observations, and green squares – for satobs – NOAA satellite observations) for three groups of stations: (a) DK Coast – coastal Danish stations, (b) DK Land – land Danish stations. (Note: 00 and 23 UTC were excluded since no satellite data were available for analysis from Danish stations).

December) values compared with the ground, although in other months there is an opposite situation (but difference does not exceed 3%). Throughout the year, on average, the ground observations are higher by 4% compared with the satellite.

The diurnal variability of the cloud cover observed from the ground vs. satellite observations for two groups of stations is shown in Fig. 4. On a diurnal cycle, the ground observations showed higher values compared with the satellite observations. The difference is higher during 16-08 UTCs with a maximum of 21% at 03 UTC. During other time (9-15 UTCs) it is significantly lower – less twice and even more than in other hours. For Danish land stations, the difference is small, except during night time (with a maximum of 14% at 03 UTC). For the Danish coastal stations, the difference in cloud cover is more visible and underlined, especially between 07-16 UTCs (with a maximum of 13% at 14 UTC), and moreover, mostly satellite showed higher values compared with ground observations.

Detailed analysis of monthly diurnal cycles showed that for Danish coastal stations, during all months (except September and March) the values of satellite observations are mostly higher than those of the ground observations. The highest number of UTC terms (i.e. 15 terms), when the difference is more than 1 point (or 12.5%), was observed in January, and then followed (10 terms) in May. On a diurnal cycle, the highest difference is observed during May (-21% at 15 UTC). For the Danish land stations, throughout the day during all months, except March, the ground observation's values are higher compared with satellite. Note, during February and March, between 10-14 UTC this difference is negative. On a diurnal cycle, the highest number of UTC terms (i.e. 13 terms), when the difference is more than 1 point, was observed in April, and then followed (12 terms) in December and January. Moreover, the difference became larger than 25% during September-October and December-January at 14-16 UTCs as well as during some night time hours, especially in September. The absolute maximum of 41% was observed at 15 UTC in September too.

5. EXAMPLE

Fig. 5 shows an example of observed and forecasted cloud cover by the DMI-RWM system. Left panel in Fig. 5 shows the post-processed observed cloud cover as viewed from the MSG-1 satellite. Middle panel in Fig. 5 shows the forecasted cloud cover where data-assimilation of cloud cover has been introduced into the road condition model. Right panel in Fig. 5 shows the forecast without data-assimilation of cloud cover. The shown forecast lengths are respectively 1, 6, and 21 hours for the two panels and both forecasts were initiated on 20 September 2005 at 6 UTC. It is evident that 1 hour cloud cover forecast resembles more closely the observed

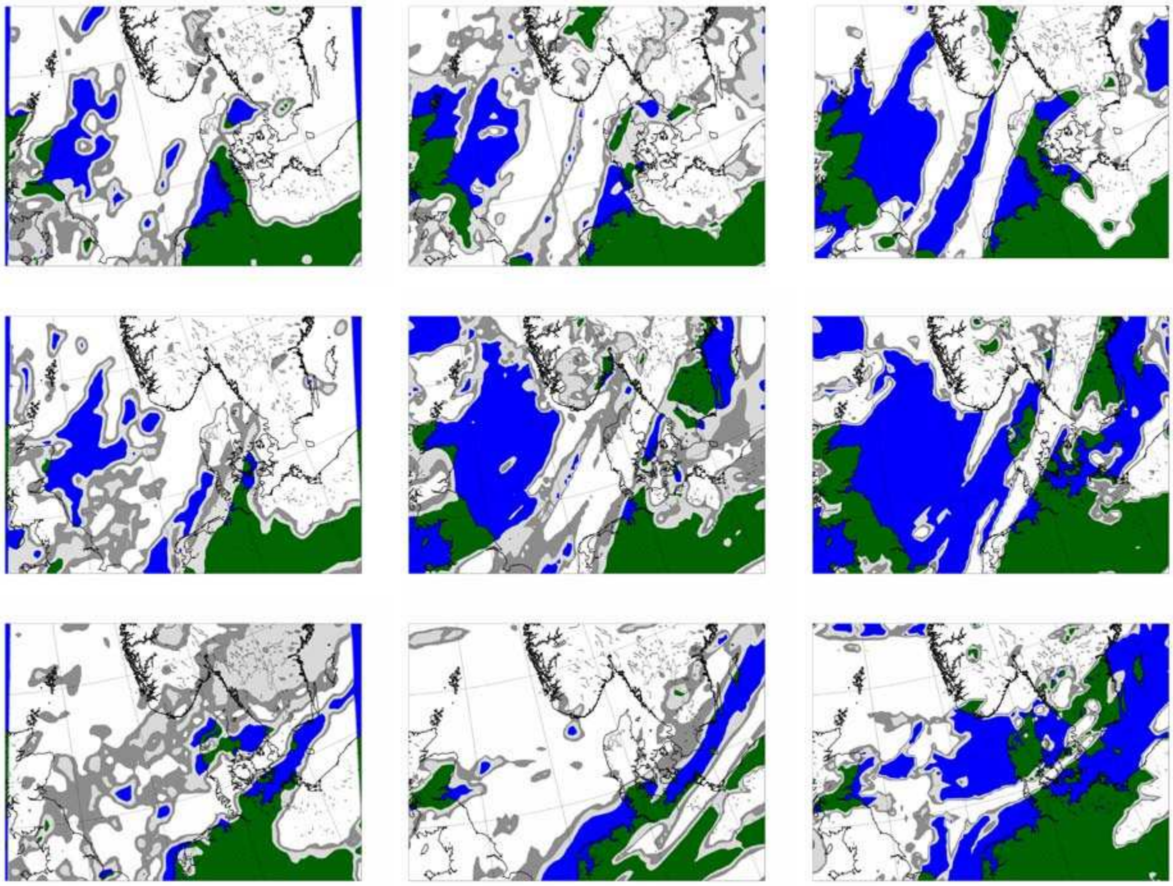


Figure 5. The observed cloud cover as viewed from the MSG-1 satellite (left panel). The forecasts for 1, 6, and 21 hours using observed cloud cover from satellite (middle panel).
The forecasts for 1, 6, and 21 hours without using observed cloud cover (right panel). The forecast was initiated on 20 September 2005 at 6 UTC.

cloud cover compared with the run without data-assimilation of cloud cover. It is also clear that the difference can be seen for both 6 and 21 hour forecasts. However, the benefit of cloud cover data assimilation decline with time. In this particular case most of the clouds are not a result of strong dynamic forcing and most of the clouds were non precipitating. In these situations the benefit of the data-assimilation is more pronounced

because of the more slowly development of the cloud cover. Moreover, for shallow, low clouds the parameterization of turbulence and vertical diffusion are important for dissipation and creation and destruction of these clouds. In situations with strong dynamic forcing or deep convection the benefit of data-assimilation of cloud cover has a shorter lasting effect. This is because the life cycle of a typical convective cloud is of the order of one hour and that the cloud dynamic of the individual cloud is on a much smaller scale than the resolution of the dynamics in the NWP model. For more stratiform clouds with weak dynamic forcing the data-assimilation of cloud cover can have a long lasting effect, but especially the dissipation of low stratus or fog in the NWP model is very sensitive to the parameterization of these processes. Prediction of the road surface temperature is very sensitive to both the solar radiation and cloud cover. In this particularly shown case the clouds were mostly stratiform and none precipitating.Fig. 6 shows an example of the DMI-RWM system output (screen snapshot) for a selected road station for end-users. A set of important forecasted parameters is shown including the road surface temperature, temperature and dew point temperature at 2 meter. The prediction of other parameters such as cloud cover, precipitation intensity, and wind characteristics is also shown. The road station (Fiskebæk) is situated in the Copenhagen area and the forecast period correspond to the shown forecasts of cloud cover in previous Fig. 5. It is seen that changes in road surface temperature are well correlated with cloud cover. Note, that sudden changes in road surface temperature can be caused by shadows from the surroundings and that melting/freezing of ice/water may result in similar changes.

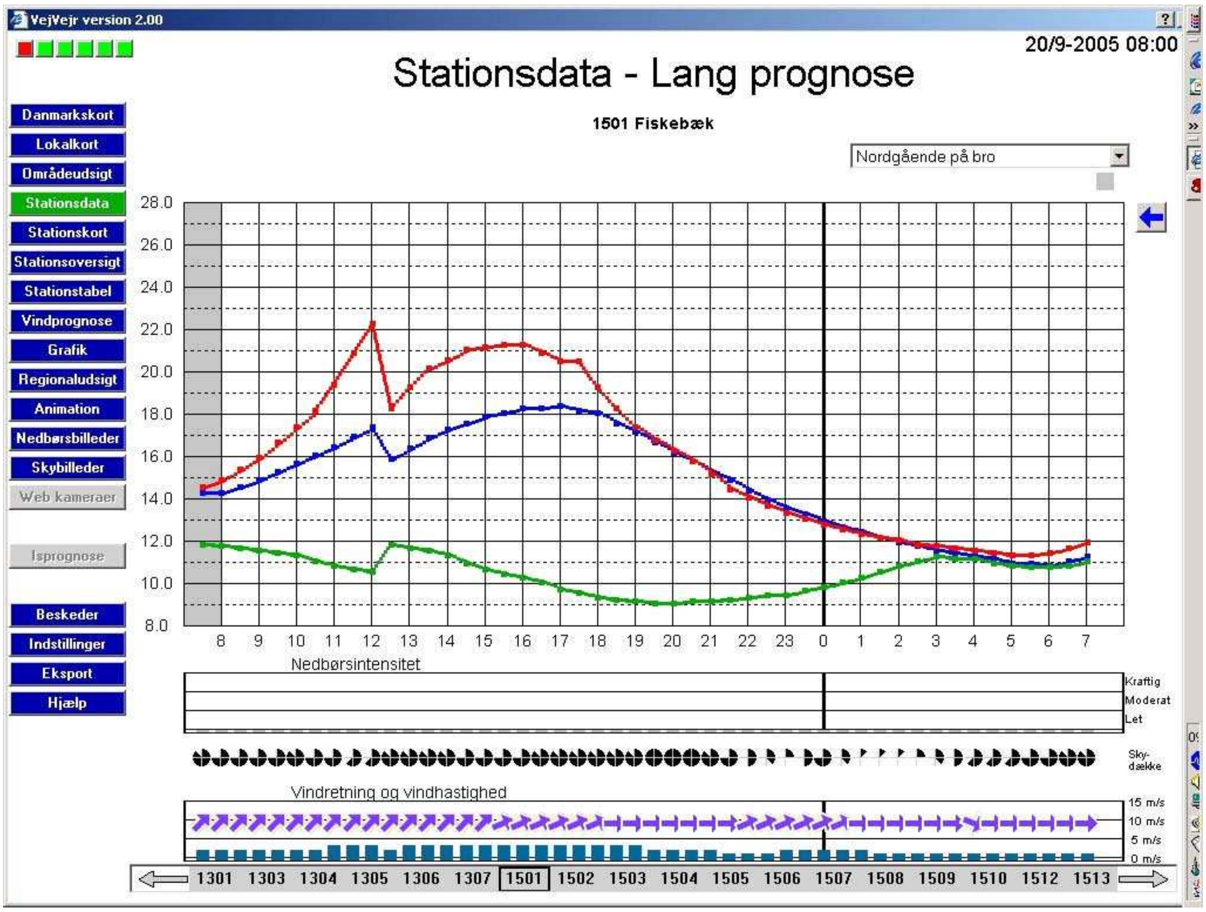


Figure 6. DMI - Road Weather Model system user interface on example of the Fiskebæk Danish road station (Lines: red - forecasted road surface temperature; blue – temperature at 2 m; green - dew point temperature at 2 m;) The graphics in the lower panel show precipitation intensity, cloud cover, wind speed and direction.

6. CLOUD COVER VERIFICATION

To verify that the impact of cloud cover data-assimilation on forecasted cloud cover the RWM system was tested on a two weeks period in March 2005. A 5 hour forecast was produced every hour and forecasted cloud cover was compared with Danish SYNOP observations. The cloud cover data from the MSG-1 satellite was also used. However, at that time this dataset was limited to cover only a fraction of the model domain. This was seen in verification of forecasted values outside of domain, which did not show any improvement. Fig. 7 shows the bias and mean absolute error (MAE) in cloud cover in a forecast range of up to 5 hours. It is clearly seen that there is a significantly reduction in MAE in the first hours of the forecast and that the improvement declines with time. A similar result has been achieved in other experiments, where cloud cover and radar observations have been used in data-assimilation. The fast decline is a result of a typical life time of individual clouds. However, it must be emphasized that in some individual cases the data-assimilation of clouds may have a longer lasting effect.

7. CONCLUSIONS

Data-assimilation of moist variables into NWP models has been troublesome and has been poorly investigated. At present, there are no direct observations of cloud water, and observations of humidity are sparse. However, recently humidity derived from satellites has been available to some extent. DMI has gone one step further and tried to assimilate information of cloud water and humidity by using information of cloud cover and other related cloud characteristics. It has been demonstrated that it can result in large differences in predicted values of cloud cover compared to model runs without use of data-assimilation of cloud cover. Verification for a period of two weeks in March 2005 showed that there was a reduction in mean absolute error for model runs when data-assimilation of cloud cover is used. The effect was most clear for short range forecasts. Analysis of cloud cover from ground vs. satellite observations, performed on a month-to-month and diurnal scales for Danish land

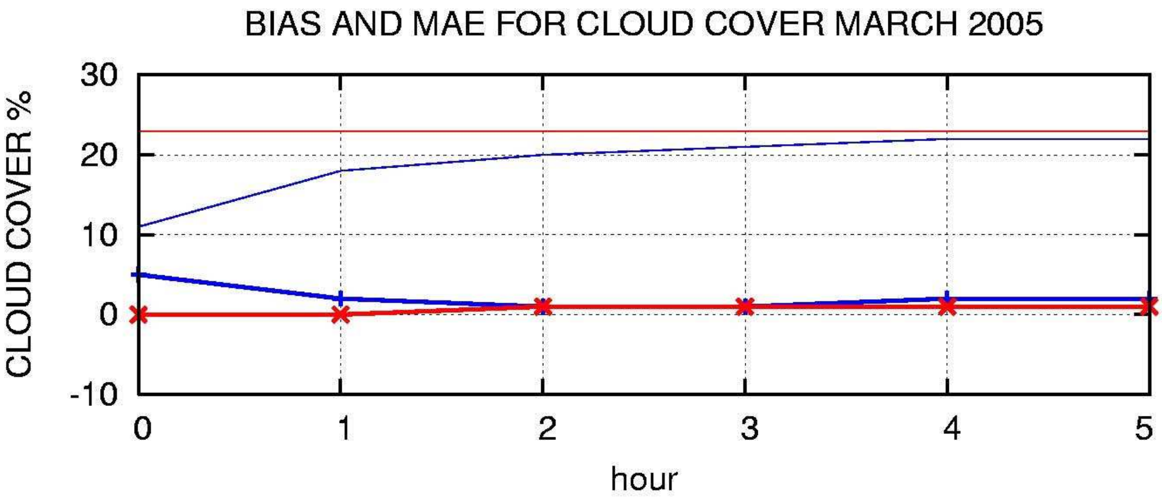


Figure 7. Values of the bias, BIAS (thick lines) and mean absolute error, MAE (thin lines) of forecasted cloud cover (Line: blue - data-assimilation of cloud cover was used; red - data assimilation of cloud cover was not used).

and coastal stations, showed that although on average the annual difference is not high, for some months it might be more than 21%; and moreover, in some situations it can be even higher than 40%. Still it must be emphasized that the experienced benefit obtained with the supplied satellite data is modest and that more verification and more case and long-term studies are needed. These are important to improve the used approaches of the analysis and nudging technique. However limited studies not shown here indicates that data from newer satellite with more spectral channels can provide more reliable data.

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