6.28 Improving of road weather forecasting by using high resolution satellite data

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1. INTRODUCTION

Observations of high resolution satellite data and unconventional data types such as cloud cover, cloud top temperature, precipitation and other non-standard data are only used very limited in present numerical weather prediction (NWP) models. In most cases, the data-assimilation system associated with the NWP model is limited to use conventional data such as SYNOP, SHIP, TEMP, AIREP, BOUY and processed data from satellites providing the analysis with temperature, humidity and wind profiles primary from the upper levels of the atmosphere and only for limited areas. Analyses of cloud cover, cloud water, precipitation are neglected in most models and there exists no standard method to adopt these data in NWP models. A common feature for these data is that they are available with high resolution in time and space and that the data is mostly used for short range forecasting in a subjective manner directly by the weather service.

In recent years, it has become standard to have a surface analysis as a part of the forecasting system. In contrary to the upper air analysis the amount of surface data tends to be available with higher frequency and of higher resolution. For the Danish area surface observations from road stations and conventional meteorological data have an average distance of about 10 kilometres distance between each observation point. This can provide the NWP model with a very detailed surface analysis of both the temperature and dew point temperature at 2 m. However, these quantities are very depending of the actual weather such as precipitation and cloud cover. In many cases inconsistency between the upper atmosphere and the surface analysis can spoil the benefit of the detailed surface analysis and give a high growth in the error statistics of the surface predicted parameters. For short range forecasting this can have the consequence that a simple bias correction of the surface quantities can be superior to the more physical correct surface analysis which very fast will drift away from its initial condition and adjust to a state which is in balance with the upper atmosphere. For road forecasting it has been recognized that unpredicted cloud cover and precipitation in most cases both are responsible to large errors in prediction of road surface temperature. Shadows from the surroundings are another factor which can contribute to a large error in the error growth of the road surface temperature during daytime. This type of error can be minimized by careful measurement of the shadowing objects at the observation point. In this report it will be showed how DMRWS (Danish Meteorological Institute Road Weather system) uses cloud cover observations to improve the prediction of surface quantities. Instead of using advanced data-assimilation methods a more simple nudging technique is applied.

At the same time, the high resolution data of surface quantities are used in the surface analysis to obtain initial surface conditions. The improved cloud cover prediction will ensure that the surface analysis is more consistent with the upper atmosphere and that the NWP model provides the DMRWS with improved data for the future state of the upper atmosphere. The DMRWS will be briefly described in the next section.

2. MODEL

2.1 DMRWS

DMRWS was originally a 1-d model which predicted the meteorological and the road conditions at selected locations along Danish roads, Sass (1997). At these locations measurements of meteorological parameters and specific measurements of the road conditions are used to

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initialize the surface and soil condition of the road in the model. Figure shows the location of Danish road stations. The 1-d model calculates all fluxes at the road surface and solves the heat equation for the soil layers which are subdivided into 16 layers. Furthermore, freezing and melting of water/ice on the road as well as deposition of frost and dew are all considered. The model includes a data-assimilation of road surface temperature. Observations for the last 3 hours are used to initialize the temperature in the soil layers. In this mode the model runs with observations as upper boundary conditions, and the first guess field is obtained from previous forecast. For the last 20 minutes of this period the model runs with forcing from the upper atmosphere and a flux correction (labelled F in figure 2) is estimated. The flux represents all uncertainties in the model but in practice it will compensate for incorrect cloud cover or shadow measurements. It is assumed that the flux correction decays to 0 as a function of time and change in short wave radiation. In most cases, the flux correction is largest during daytime. The details are summarized in figure 2.

The state of the upper atmosphere is passed to DMIRWS for every time step. In the original 1-d model, bias corrections of temperature and dew point temperature at 2 m and cloud cover ensured that large errors in the observed values compared to the derived values from the NWP model at initial time, only were allowed to slowly approach the predicted values from the NWP model, depending on the initial error and empirical determined decay coefficients. It has been recognized that in order to improve sort range forecasting of the road condition and especially to capture fast changes in road conditions, it is necessary that the NWP model can predict weather specific parameters with high precision. These are primary temperature and humidity at 2 m, precipitation and cloud cover. The first step was to integrate the DMIRWS in the NWP model and use road and cloud cover observations to ensure that the NWP model’s initial state is consistent with the observed conditions at the road stations.

### 2.2 NWP model

The NWP model associated with the DMIRWS is a modified version of HIRLAM (High Resolution Limited Area Model). It is a hydrostatic model including a 3-d variational (3d-var) data-assimilation system and a surface analysis module. At the present state the NWP model used in connection with DMIRWS derivates on numerous ways from the latest release of HIRLAM. It is an earlier version of HIRLAM which was modified at DMI and new features from the HIRLAM project were implemented in to the model. This model is still used for road forecasting. This version was the operational NWP model at Danish Meteorological Institute (DMI) until June 2004. The details of the model are described in Sass (2000). Boundaries and large scale analysis are supplied through a nested system of models to the DMIRWS. The main model (not DMIRWS) is running 4 times every day with 2 additional data re-assimilations cycles and is supplied with boundaries from ECMWF’s global model. The host models cover North America,

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**Figure 1** Positions of road stations in Denmark.

**Figure 2** Schematic view over fluxes in the one dimensional road model.
Europe, the North Pole, the North Atlantic and the Mediterranean Ocean. The horizontal and vertical resolution of the host model is identical to DMIRWS. On contrary to the DMIRWS, the outer most model in the nested system is based on the newest release of HIRLAM as described by Unden et al. (2002). The model domain for DMIRWS can be seen in figure 3 and model characteristics are summarized in table 1.

In order to improve short range forecasting for the DMIRWS, additional modules to assimilate cloud observations and road observations in to the NWP model were developed. Primary the modules makes analysis of the 3-d cloud structure, temperature and dew point temperature at 2 m by using observations and model data which are obtained from the first guess field. Originally, this was developed for the 1-d DMIRWS, Sass (2002a), where analysis of cloud cover was used to predict cloud cover at the road stations assuming that the analysed cloud structure at initial time is decayed towards the predicted cloud structure obtained from the NWP model as a function of time and empirically determined decaying coefficient. A similar approach for temperature and dew point temperature at 2 m is also used in the DMIRWS. In order to eliminate this empirical method which tends to fail in cases with large initial errors and fast changes in weather conditions Sass (2002b) extended the data analysis of cloud cover and the surface quantities to cover the entire model domain in the NWP model. The analysed parameters are assimilated in to the model using a nudging technique which will force the NWP model towards the analysed value. This is more carefully described in next section and in Sass (2002b).

### Table 1

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Characteristics</th>
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</thead>
<tbody>
<tr>
<td>Horizontal resolution</td>
<td>0.15x0.15 (degree)</td>
</tr>
<tr>
<td>Vertical levels</td>
<td>40</td>
</tr>
<tr>
<td>Rotation of south pole</td>
<td>Lon.=80  Lat.=0 (degree)</td>
</tr>
<tr>
<td>Number of grid points</td>
<td>82x98=8036</td>
</tr>
<tr>
<td>Dynamic time step</td>
<td>50 (s)</td>
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<tr>
<td>Physical time step</td>
<td>400 (s)</td>
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<tr>
<td>Boundary update</td>
<td>Every hour</td>
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<td>Boundary age</td>
<td>0-5 hours</td>
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<tr>
<td>First guess age</td>
<td>0 or 1 hour</td>
</tr>
<tr>
<td>Forecast frequency</td>
<td>Every hour</td>
</tr>
<tr>
<td>Forecast length</td>
<td>3 or 3 + 5 hours</td>
</tr>
<tr>
<td>Data-assimilation period</td>
<td>3 hours</td>
</tr>
</tbody>
</table>

Table 1 Model characteristics for the DMIRWS. For the short reference forecast the forecast length is 3 hours. For the long forecast the data-assimilation cycle is 3 hours and continues with an additional 5 hours forecast. See text for further explanation.

#### 2.3 DATA-ASSIMILATION

Different data assimilation techniques are already used and combined. Most large scale NWP models have data assimilation modules. In recent years 3-d and 4-d variational (4d-var) data assimilation have replaced the traditionally optimal interpolation (OI) analysis. However these are based on some tight constrains which primary are linked to the dynamic of the equations. With 4d-var the parameterized part of the equations such as convection are beginning to be considered but only in very simplified linear versions. It should be noted that especially 4d-var is extremely computationally expensive.

The nudging technique is not widely used in NWP models but in situations where traditionally assimilation schemes are to complicated, the nudging technique can be used. Stauffer (1990, 1991) used nudging to assimilate data into a NWP model. Essentially they used the technique with traditionally data such as rawinsonde data (TEMP). The basic initial conditions (background fields) were interpolated to the grid from a host model. It was shown that nudging rawinsonde data in to the model, the results

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**Figure 3** Orographic map of the model domain. The road stations as viewed in figure 1 are approximately in the middle of the model domain.
were improved even though it must be assumed that these data already was used in the data-assimilation in the host model. Modern assimilation system can now assimilate these data types very well. However many data are not used such as and 10 m wind and radar data. Data may even be thinned to fit the resolution of the analysis or reduce the computationally cost. Typical, the analysis is done at a lower resolution. This is the case with HIRLAM running at DMI where the resolution of the analysis is 0.5 degree whereas the model is running at a resolution of 0.15 degree. The large scale waves of the analysis are blended with the smaller scales from the first guess field. Compared to the nudging technique this gives a better control of the noise level in the initialization of the model and many resources have been used to improve the technique so the theory and mathematical concept now is very documented and tested. Despite this fact, nudging seems to provide a method to assimilate high resolution data and inadequate model parameters for limited area models on a small domain where 3d or 4d-var is not suitable. Cloud cover, precipitation and humidity have a much higher variability than traditionally analysed parameters such as mean sea level pressure, upper air temperature and wind. This means that prediction of the small scale variability solely depends on the model’s capability to simulate the smaller scales. The surface quantities are typical analysed with a higher resolution in areas with a dense network of observations. Already now, both 3d-var and 4d-var are used for the upper air analysis but at the same time it is accepted to use OI analysis for the surface quantities. This combination of methods can be justified if the processes which are responsible for the large variation in the surface parameters are coursed by the parameterized part of the equations rather than as a consequence of advection. However certain surface parameters such as the surface temperature and surface wetness are very depended on the cloud cover and the history of past and present weather. The lack of smaller scales of the upper air analysis will in many cases rapidly destroy the small scale features of the surface analysis because of inconsistency between the two different analysis systems. Even though, the detailed surface analysis will improve the prediction of the surface parameters for short range forecasts, it is not guarantied that it would be better than a simple bias correction for short range forecasts. Bayler (2000) used satellite data to initialize the cloud structure in a NWP model. The cloud water and relative humidity were adjusted by following some rules where the background fields and derived parameters from satellite data were used to initialize cloud water and humidity. In general the best results were obtained with satellite data but a large part of the improvement was a consequence of change of condensation scheme. It was also clear that nudging data gradually in to the model during a data-assimilation gave better results compared to simulations where the moist variables only were adjusted at initial time of the forecast. Yucel (2003) assimilated satellite data into a version of MM5 in a similar fashion. In this case the model domain was smaller but with higher horizontal resolution. The adjustment of the moist variables was only done at the initialization step of the model. Even though, this gave a better prediction of cloud cover and precipitation, the benefit of the satellite data was only significantly for very short forecast ranges, most likely because of inconsistence between the mass field and the ingested cloud cover.

2.4 Data types

The SAF (Satellite Application Facilities, www.eumetsat.com) project has made it simple to access high resolution satellite data. At the present stage, the SAF derived data from NOAA-16, NOAA-17 and MSG1 (meteosat) are operationally available at Danish Meteorological Institute (DMI). Data are processed into gridded data which easily can be interpolated to the NWP model domain. The high horizontal resolution of cloud cover in these data is used to calculate fractional cloud cover. The SAF module derives many fields such as cloud cover, cloud top temperature, cloud type and precipitation intensity. Altogether this does not give the total 3-d structure of the cloud cover. However, it gives some constraints about the cloud structure. Conventional ground based observations of cloud cover and height of cloud base are also included in the available data types. Even though, the frequency and the area coverage of these data are much smaller than satellite data they are in most cases of higher
reliability. Especially during night time, surface observations are particularly important over land area where it is difficult to distinguish cold surfaces from low thin clouds. The information about height of cloud base does also give additional constrains to the 3-d cloud structure. The NWP model will provide a first guess field to the 3 dimensional cloud structures.

2.5 Nudging method

In most cases the NWP model will simulate the cloud structure very well in situations with large scale precipitation bearing weather systems with large dynamic forcing. However, NWP models often have problems to simulate the extension of the cloudy area associated with these large systems. None precipitation clouds can appear too soon or late in the NWP model. These areas are not necessary dominated by strong dynamic forcing, and it is possible to adjust the moisture and cloud water field by applying a nudging technique and force the model towards the observed cloud cover. It is clear that in cases where large errors in the wind field or surface pressure courses large errors in the cloud cover it will be difficult to correct the NWP model cloud cover towards observations and the correction may only have a limited effect. The used nudging technique allows some freedom for the model to adjust those layers of the model which most easily can be forced towards the observed cloud cover within some limits. This ensures in many cases that only rather small corrections of the moisture and cloud water field are necessary. The nudging technique can have some difficulties in situations with strong convection. It is possible to suppress convection during the data-assimilation and to develop to correct amount of precipitation. At the present stage there is no difference in the treatment of stratiform or convective clouds in the nudging module. Suppressed or enhanced precipitation may reappear/disappear in the model after the nudging module has been switched off depending on the strength of the dynamic forcing. For the DMIRWS convection plays a minor role. The model output is only used in winter time where convection only contributes little to the observed cloud cover and accumulated precipitation. The purpose of the model is to predict the road surface temperature and the deposition of frost on the road. In critical situations it is crucial to predict the cloud cover and temporal clearances. During the winter the dominating clouds are low clouds or a massive layer of stratus clouds which can cover a large area. The precipitation form is most of a stratiform type. For the prediction of the road surface temperature it is also important to know that the height of the cloud base and the thickness of the cloud are correct. Especially, short term clearances are important to predict and clearance after cold front passage during the night which in many cases leaves a wet road with potential risk for slippery roads. It is common that the clearance is of very short duration before a new weather system with clouds and rising temperature will arrive and reduce the risk for slippery roads. The nudging technique can in these cases effective to force the NWP model cloud cover towards observed cloud cover if the timing of the system is well predicted. Technically the nudging module adds tendencies of specific water vapour content and specific cloud water content. During the data-assimilation, the nudging module is called as a part of the physical package of the NWP model just after the vertical diffusion scheme and before the condensation scheme. The equations are given by

\[
\frac{\partial q}{\partial t}_{\text{nud}} = \left(\frac{\partial q}{\partial t}\right)_s + K_{q1} \cdot q \cdot (f_a - f_p) \quad (1)
\]

\[
\frac{\partial w}{\partial t}_{\text{nud}} = \left(\frac{\partial w}{\partial t}\right)_s + K_{w1} \cdot w \cdot (f_a - f_p) \quad (2)
\]

where \( q \) is specific water vapour content and \( w \) is specific cloud water content. The asterisk at the rhs of the equations represents the preliminary tendencies from other physical processes e.g. vertical diffusion and the tendencies from the dynamics. For both equations, the additional tendencies from the nudging depend of the difference in analysed cloud cover at the individually model levels \((f_a)\) and the predicted value of the cloud fraction at each level from previous time step \((f_p)\). \( K_{q1} \) and \( K_{w1} \) are empirical coefficients to be determined by experiments, Sass (2002a). Compared to the equations as described in Sass...
only the most significant part of the nudging terms are presented here. Additionally constrains have been added to avoid spurious precipitation and very large tendencies and the reader is referred to Sass (2002b) for the details.

It is important to note that the final state of $w$ and $q$ after nudging depends on the actual formulation of the parameterization of the condensation scheme. Changing the condensation scheme would most likely lead to another result for these two parameters but the resulting cloud cover should converge towards the same structure. Similar nudging equations are developed for predicting the temperature and 2 m dew point temperature. Tendencies for soil water, surface temperature, temperature and humidity of the lowest model level are calculated. Relative to equations 3 and 4, analysed temperature and dew point temperature at 2 m are used in the equations instead of analysed cloud cover.

### 2.4 Setup

The DMRWS has been run for the first two week of March 2005 for the domain and setup as indicated in figure 3 and table 1. First, the model runs a 3 hour forecast using the 1 hour forecast from last run as first guess input. Afterwards it is running a forecast with the same initial start date with the nudging module switch on for the first 3 hours and continues to produce forecasts for additional 5 hours. This means that the maximum forecast length is 5 hours. This 2 steps procedure has been done in order to use the newest data and to have a reference run which is
used as NWP model data in the cloud cover and surface analysis modules. The model output for this run is also used in the analysis of precipitation intensity and ensures that the cloud cover nudging is switched off if the precipitation intensity is increased beyond a certain limit as a consequence of the nudging terms. In the precipitation analysis only SYNOP and SHIP observations of present weather and accumulated precipitation are used. The specific road model is only called in the last 5 hours after the nudging module has been switched off.

Several model versions and setups were tested for the period and will be presented in the next section. In this context three different runs will be compared:

1) Reference run with all nudging modules switched off (REF).
2) Run with only cloud nudging switched on (CLOUD).
3) Run with both cloud nudging and surface nudging switched on (ALL).

All 3 setups call the road condition model module and produces 5 hours forecast. All features of the road model are switched on for every model runs. This includes bias correction of temperature and dew point temperature at 2 m and flux correction in the road surface energy budget.

3. Results
3.1 TEST PERIOD

The first 2 weeks of March 2005 was in general colder than normal and several events of snowfall occurred in this period. It is also a relatively difficult to predict the road surface temperature in March. This has to do

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**Figure 6** MAE for 3 hours forecasts for 2 m temperature. In the plot red colour refer to REF, green colour to CLOUD and blue colour to ALL. The time indicated is valid time for the forecast.

**Figure 7** BIAS for 3 hours forecasts for 2 m temperature. In the plot red colour refer to REF, green colour to CLOUD and blue colour to ALL. The time indicated is valid time for the forecast.
with the fact that the daily variability is higher for this month than the other winter months. Figure 4-9 shows the day to day variation in MAE (mean absolute error) for 3 hours forecasts averaged over all road stations (384) and the corresponding variation in BIAS (bias). In next section the definition of MAE and BIAS is defined. The figures show the variation for the 3 parameters: surface temperature, temperature and dew point temperature at 2 m. In all figures red lines are associated with the reference experiment (REF), green with only cloud nudging switched on (CLOUD) and blue with both cloud and surface nudging switched on (ALL). The largest difference between the 3 experiments can be seen in the interval from the 3\textsuperscript{rd} to the 5\textsuperscript{th} March. The signal is most pronounced in temperature and dew point temperature at 2 m whereas only small differences in MAE and BIAS can be seen in road surface temperature for the 3 experiments. The daily variation seen in MAE and BIAS for road surface temperature is a consequence of larger uncertainties in the radiation budget and shadows from the environment during daytime in situations which are dominated by clear weather.

The 3\textsuperscript{rd} to the 5\textsuperscript{th} March were dominated of relative clear weather and low temperatures. The large error in MAE during night time is a result of ceasing wind followed by fast cooling over snow covered areas. The reduced MAE in 2 m temperature is mainly achieved when the surface nudging module is switched on. However, it can be seen that the CLOUD experiment also performs slightly better than the REF experiment.

**Figure 8** MAE for 3 hours forecasts for 2 m dew point temperature. In the plot red colour refer to REF, green colour to CLOUD and blue colour to ALL. The time indicated is valid time for the forecast.

**Figure 9** BIAS for 3 hours forecasts for 2 m dew point temperature. In the plot red colour refer to REF, green colour to CLOUD and blue colour to ALL. The time indicated is valid time for the forecast.
Figure 10 illustrates an example of difference in cloud cover for the mentioned period. The upper panel shows observed cloud cover at 3rd March 2005 22 UTC (left panel) and 3 hours later (right panel) as viewed from MSG1. The middle panel shows the initial conditions for the ALL experiment (left) and the forecasted cloud cover 3 hours later. The lower panel shows the initial conditions for the REF experiment (left) and the forecasted cloud cover 3 hours later.

Figure 10 shows total cloud cover. Cloud fractions are in the intervals: 0.0-0.20, 0.20-0.40, 0.40-0.60, 0.60-0.80, 0.80-1.00. The upper panel shows observed cloud cover at 3rd March 2005 22 UTC (left) and 4th March 2005 01 UTC (right). The middle panel shows the initial conditions for the ALL experiment (left) and the forecasted cloud cover 3 hours later. The lower panel shows the initial conditions for the REF experiment (left) and the forecasted cloud cover 3 hours later.

### 3.2 Verification

Verification can be done in many ways. For road forecasting it is of particularly importance to predict relative rare incidents such as heavy snow storm but at the same time the system must be robust and stable and also predict more normal situations and avoid a large number of false alarms. In this section the model will be compared in terms of mean absolute error (MAE) and bias (BIAS) as defined by equations 3 and 4.

\[
MAE = \frac{1}{N} \sum_i (T_{f,i} - T_{o,i}) 
\]

\[
BIAS = \frac{1}{N} \sum_i |T_{f,i} - T_{o,i}|
\]

In equation 3 and 4 N is the number of road stations or total number of observations, \(i\) denotes the \(i^{th}\) observations, \(T_f\) and \(T_o\) are respectively the forecasted and the observed value. The overall verification score for the whole period is depicted in figure 11 in terms of MAE and BIAS averaged over all road stations and all forecasts. The benefit of the additional data-assimilation of cloud cover and surface analysis affects the temperature and dew point temperature at 2 m to a higher degree than the road surface temperature. As it can be seen in the daily variation in MAE for 2 m dew point temperature in figure 9 the improvement is significant during daytime for some certain days. The reason to the very little impact on the road surface temperature is most likely a consequence of high uncertainties in shadows from the surroundings and to the existing flux correction in the road model. The flux correction will at initial time total compensates from errors in the road surface temperature. The biggest impact is seen in the 2 m dew point temperature. The processes which control 2 m dew point temperature depend on the specific water vapour content which is affected by advection, mixing of air masses and evaporation of water vapour from the surface. This is in contrast to the 2 m temperature which also depends on radiation which very fast will adjust towards the surface temperature towards an equilibrium state with the upper atmosphere. The larger improvement in 2 m dew point temperature is most likely a result of to little ventilation of the surface layer in the model during daytime. The nudging in the surface layer is in these cases effective in reducing the error.
An additional verification was made for approximately 50 Danish SYNOP stations. The forecasts for these points are not bias corrected and are interpolated from the output of the NWP model to the location of the SYNOP stations. Only the reference run (REF) and the run with all nudging switched on (ALL) have been verified. Figure 12 shows MAE and BIAS for temperature and dew point temperature at 2 m. For these points also the total cloud cover is verified instead of road surface temperature. The first 3 hours forecasts are not verified for these points. This has to do with the fact that the data-assimilation takes places in the first 3 hours and that the forecast first will be available after this time. The picture here is quiet similar to the verification at the road stations. The most significant improvement is seen in 2 m dew point temperature. There is also a clear signal in the cloud cover verification but the improvement declines faster than for 2 m dew point temperature. This also corresponds to the spin up time of the model where

Figure 11 Development in BIAS and MAE for the forecast range of to 5 hours averaged for all road stations and all forecasts. In the plot red colour refer to REF, green colour to CLOUD and blue colour to ALL. The time indicated is valid time for the forecast. Thin lines are associated with MAE and thick lines with BIAS.
Figure 12 Development in BIAS and MAE for the forecast range of to 5 hours averaged for all SYNOP stations and all forecasts. In the plot red colour refer to CLOUD and blue colour to ALL. The time indicated is valid time for the forecast. Thin lines are associated with MAE and thick lines with BIAS.

From the reference run (REF) it has been seen that the performance of the NWP model in general is good. Compared to the 2 other runs with the nudging modules switch on, the reference run (REF) can almost produce a forecast of the same quality for the road surface temperature. This has to do with the fact that the physics and dynamics of the model are able to produce the fine scale structure and that the traditional data-assimilation can incorporate observations on larger scales with out destroying the smaller scales from the first guess fields. At the same time the dynamic will remove inconsistency between the mass field and the nudged cloud cover. This is also observed after a conventional data-assimilation. Here it is often seen that there is an underestimation of precipitation for the first hours of the forecast and that the model tends to be too dry. For HIRLAM the spin up time is typical up to 6 hours but the spin up time is reduced with increased horizontal resolution.

6. Conclusion
time the built-in bias and flux correction is also able to correct larger errors except for 2 m dew point temperature where large improvement are achieved for some days.

The verification of the test period indicates clearly that the data-assimilation of cloud cover is most important for short range forecasting. The spin up time of the moist variables in NWP models is typically seen the first 6 hours of the forecast. This corresponds approximately to the time range where improvement in the cloud cover is seen for Danish SYNOP stations. This also emphasizes the importance of consistency between the wind and mass field and the moist variables.

In situations with large dynamic forcing, the data-assimilation of moist variables into the model will only have limited effect and can even course undesirable precipitation in the initial phase of the forecast after the data-assimilation adjustment.

REFERENCES


Sass, B. H. and Petersen C., 2002a: Short range atmospheric forecasts using a nudging procedure to combine analysis of cloud and precipitation with a numerical forecast model. Danish Meteorological Institute, no. 02-01 (www.dmi.dk).

Sass, B. H. and Claus Petersen, 2002b: Analysis and short range forecasts of cloud cover. Danish Meteorological Institute, no. 02-09 (www.dmi.dk).


