The development of accurate automatic road-weather forecasts

Bent H. Sass and Claus Petersen

Danish Meteorological Institute

1. Introduction

The prediction of road weather conditions requires the production of accurate forecasts of temperature, humidity and precipitation at the road surface. It is a big challenge to obtain sufficient forecast accuracy of the road weather in order to produce correct warnings on slippery road conditions.

During the last two decades a system of road-weather stations has been established in Denmark. At each station some relevant weather parameters are measured, e.g., the road surface temperature, and the temperature and relative humidity at 2 metres above the surface. This network of stations has been necessary in order to monitor the road-weather conditions in Denmark. A manual now-casting system was established in the 1980s to provide guidance for the road-weather authorities on the road maintenance. A weather forecaster at the Danish Meteorological Institute (DMI) issued warnings of slippery road conditions 3 hours ahead for different regions of Denmark, based on data from the road station network and from other more traditional meteorological sources including numerical weather prediction products. Due to the rapidly increasing number of road stations, to nearly 300 stations during the 1990s, the work load on the forecaster grew excessively.

It was therefore decided in 1992 to develop an automatic road weather forecasting system with the goal of predicting as accurately as possible the relevant meteorological parameters such as road surface temperature, precipitation and dew point temperature 5 hours ahead.

It has been decided to construct a numerical forecast model which is physically based on the computation of the heat budget components at the road surface. The model requires input from an atmospheric numerical forecast model `DMI-HIRLAM' run operationally at DMI. The road conditions forecasting system, which has been operational in recent years, is briefly outlined in section 2. The operational experience gathered from this prediction system over the years showed indeed a predictive skill by the system. However, the demands on high accuracy in the temperature and precipitation prediction has been difficult to achieve unless a new effort was undertaken to increase the accuracy.

A new 3-year development project has been established in 2000 in corporation with the road authorities, based on new potential possibilities to improve cloud cover and precipitation prediction which turn out to be critically important. Section 2 also provides a brief introduction to the model upgrades established during the first year of the new project.

Section 3 provides a description of two forecast examples in Denmark where the special problems associated with clouds and accurate road surface temperature forecasts are illustrated. Finally, some concluding remarks are provided in section 4.

2. The road condition model

The numerical model is physically based and attempts to describe the relevant heat- and moisture fluxes affecting the energy budget of the road. These fluxes are illustrated in Fig.1. The forecast model, outlined below, has been operational until the autumn 2001 and has been described by Sass (1997).

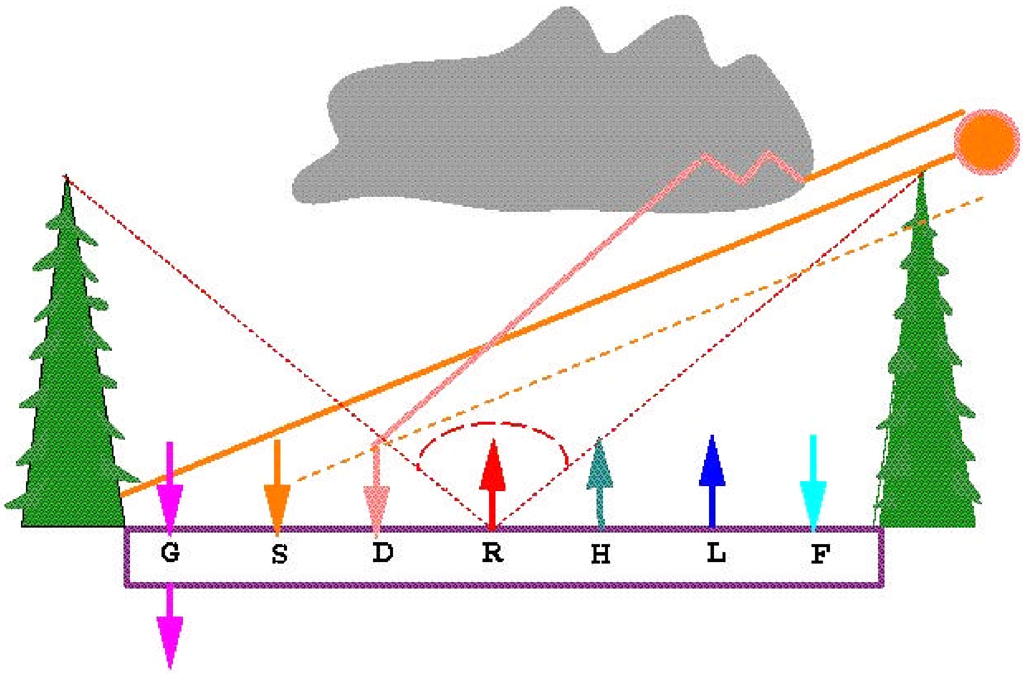

Figure 1. Contributions to the energy budget at the road surface. See text for explanation.

The heat flux G into the road as a result of conduction is computed by solving the equation of heat conduction for a road surface, using 15 model levels below the surface and physical properties typical of asphalt. New forecasts 5 hours ahead are computed for all station sites on an hourly basis from October through April. In order to compute the surface ground heat flux in a realistic way, observations of surface temperature are assimilated during a 3 hour data assimilation period using observed surface temperatures, approximately every 10 minutes, as a boundary condition for the heat conduction.

For the real forecast, the surface temperature cannot be prescribed but evolves under the influence of predicted atmospheric fluxes using hourly forecast information on the atmospheric state from the weather model `DMI-HIRLAM'.

A special feature of the road model system is a station dependent heat flux correction at the forecast initial time. This flux (included in flux contribution F of figure 1) is intended to represent local effects not otherwise accounted for, e.g. a different energy heat balance due to an inadequate model description of cloud cover at the specific time, or effects from traffic. This flux correction is determined from short simulations during the last 20 minutes before the start of the forecast. The flux correction giving the best agreement with observed temperatures during this period is chosen as the flux correction to be used. The current strategy is to assume that the flux correction declines during the 5 hour forecast period.

The computation of heat fluxes due to radiation, sensible heat and latent heat (evaporation) requires information from the atmospheric prediction model. The computational method involves the use of the atmospheric vertical profiles of temperature, humidity, cloud cover and wind (Sass 1997). This raw atmospheric forecast data from DMI-HIRLAM is improved by taking into account the total cloud cover observed and the lowest cloud base height from Danish synoptic stations. The cloud cover correction (Sass 1997) is however quite simple and does not adequately describe the time evolution of different cloud types (see examples of section 3).

The sensible heat flux (H) and the latent heat flux (L) related to evaporation or sublimation is also improved by correcting forecast information from DMI-HIRLAM by local temperature and relative humidity observations from the road stations.

It is a special challenge to compute radiation accurately at a given road station. Special information about shading effects is needed to compute direct solar radiation (S) reaching the road surface. A data base describing the height of shading objects in different directions is used for this purpose. The diffuse solar radiation (D) as well as the infrared radiation (R) are also affected by the shading objects through a sky-view factor.

The effect of freezing or melting of precipitation and of water/ice on the road is also taken into account (figure 1).

An enhanced model system is under development (see section 4). The main goals are to substantially improve the quality of the cloud cover and precipitation forecast. The work has led to an operational model upgrade in October 2001, with the following new features.

A revised 3-dimensional cloud analysis has been developed based on raw HIRLAM cloud forecast information and the utilization of more synoptic cloud observational data. This data can be provided on an hourly basis (previously every 3 hours) utilizing additional data from automatic cloud sensors (ceilometers).

The new and more advanced statistical cloud algorithm makes specific use of observations of low level, medium level and high level cloud amount in combination with the associated cloud base heights. This enables that a more realistic vertical structure of the cloud correction can be established. The time evolution of clouds is a combination of the 3-dimensional cloud analysis and the cloud cover information from DMI-HIRLAM using a more advanced scheme than previously.

In addition, some model improvements have been implemented, mainly related to the description of the transmission of solar radiation through various cloud types in the atmosphere. A DMI Technical Report describing the new model version in detail is in progress (September 2001) and will be published in early 2002.

3. Forecast examples

The problem of producing accurate road surface temperature forecasts is illustrated by two rather extreme forecast examples where different model predictions are compared with an observed temperature development. The model version operational until October 2001 is referred to as REF while the new operational model version is referred to as NEW.

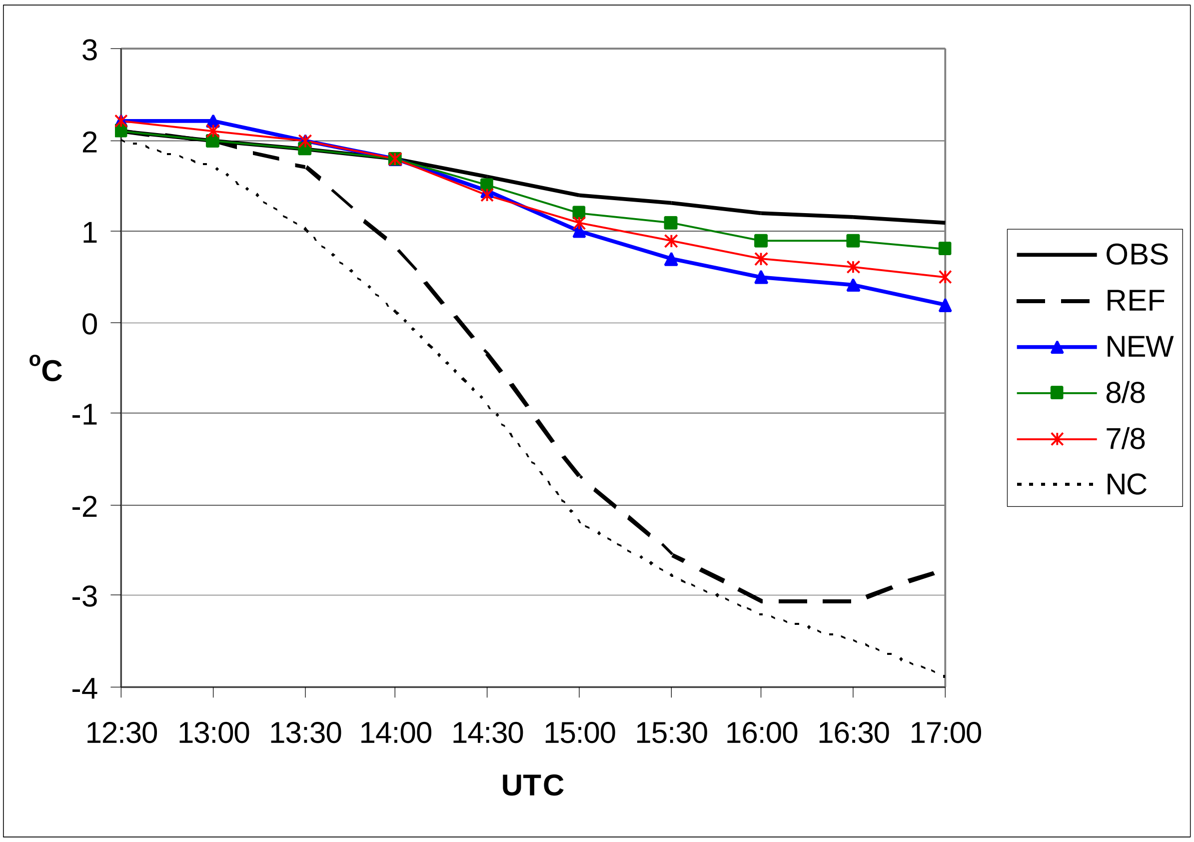

Figure 2. Observed and simulated road surface temperature example 1. See text for details

The first weather situation is from 13 January 2000. The temperature prediction in the afternoon is examined for a road station in the southern part of Denmark. Overcast skies were reported during the period from noon and 5 hours ahead. The cloud base was below 1000 metres. No precipitation was reported. The wind was light from a southerly direction, and the temperature at two metres height was between 0 °C and +1 °C. The observed road surface temperature in this period dropped only slightly from +2.1 °C to +1.1 °C. Figure 2 shows the observed surface temperature for this case (OBS). In addition, the results of various model simulations are shown for the same location. A simulation with a cloud free atmosphere provides a significant cooling due to a large net radiative energy loss (curve "NC"). The temperature drops to almost -4 °C during the forecast. The operational forecast at that time (curve "REF") was also of a poor quality. It turns out that the cloud prediction did not preserve the low cloud cover. Instead the sky become partly covered with high level cloud which cannot prevent a significant cooling at the surface because of the low cloud radiation temperature.

The forecast produced with the new model version (curve "NEW") is much more realistic due to a better cloud correction procedure which is able to retain a better cloud structure. The temperature is slightly above the observed temperature in the beginning of the forecast but becomes 0.9 °C too low at the end. The temperature, however stays above the freezing point.

Finally, the curves "7/8" and "8/8" represent experiments where the cloud cover is artificially fixed to be 7/8 and 8/8 respectively with a cloud base around 400 m. It is seen that with this type of modification the model approaches quite closely the observed temperature.

The second example is taken from 20 February 2001. In this situation the problem of producing an accurate temperature rise in the morning hours is examined for another road station which is not fully exposed to solar radiation. On the given day the site is not exposed to direct solar radiation between approximately 9:30 UTC and 12:00 UTC. There is however still a significant energy transfer to the road from diffuse solar radiation. The weather situation is characterized by dry conditions with practically no low clouds, but areas of cirrus clouds are crossing Denmark. The results of different simulations are shown in figure 3.

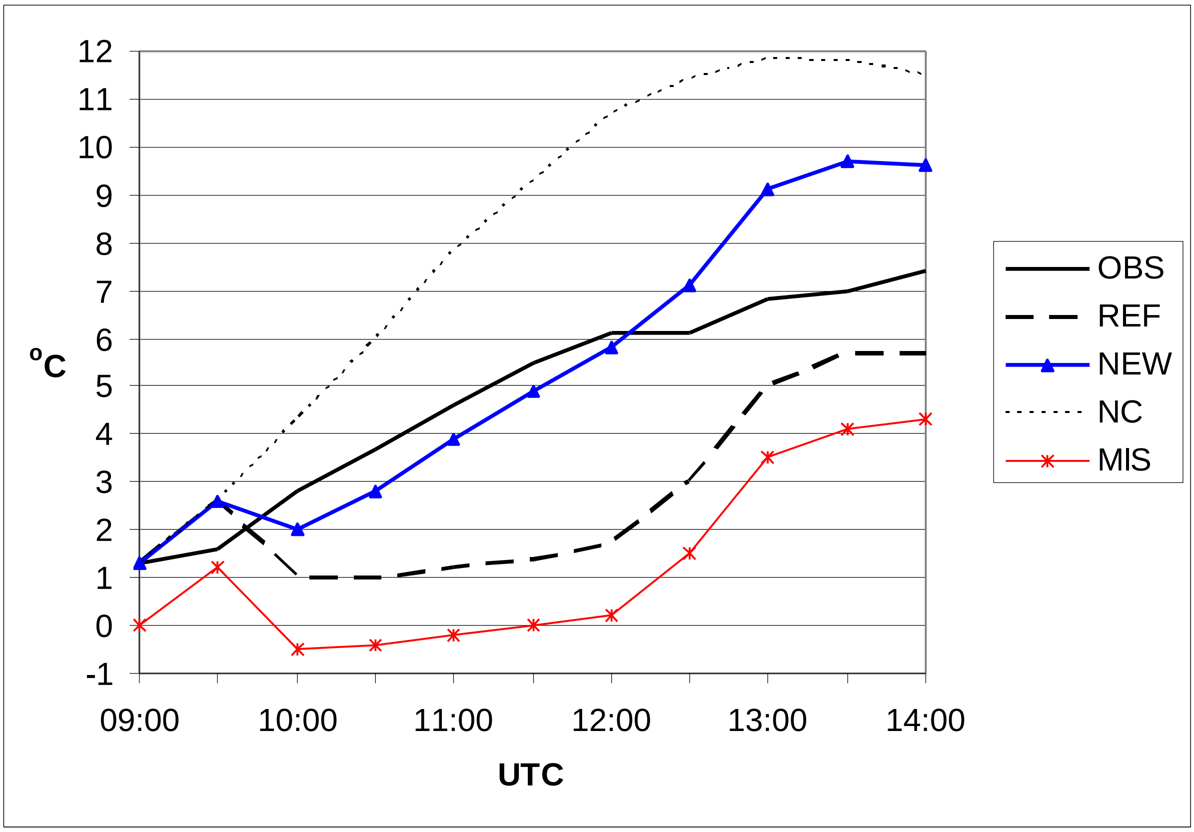

Figure 2. Observed and simulated road surface temperature example 2. See text for details

A model simulation with no clouds and no shading objects is shown in curve "NC". As expected, the temperature rise becomes larger than observed. Moreover the shape of the temperature curve does not show the kink which is apparent in the curves "REF", "NEW" and "MIS". The regular shape of the heating reflects full solar radiation without reduction due to shading and clouds.

It is noted that all simulations except "MIS" start with practically the same temperature evolution for the first 20 min. after the initial forecast time. This is because the actual forecast starts with some delay in order to wait for synoptic cloud observations to be used in the forecast. The latest observed surface temperatures after the formal start of the forecast can then be used as `observations' into the very early part of the forecast.

The curves "REF" and "NEW" have the common feature that the forecasted temperature drop between 9:30 and 10:00 UTC is excessive indicates and that the model description of shading is somewhat inaccurate, providing too much shading during this time interval.

The smaller upward temperature trend of (REF) compared with (NEW) is mainly caused by a better transmission of solar radiation through a partial cirrus cloud cover. After 12:00 UTC the model heating rate is increased in both REF and NEW due to a lack of shading effects. It is seen that the temperature forecast using NEW is on the average substantially better than the corresponding forecast of REF. However none of the forecasts have a correct description of a more dense high level cirrus cloud deck which seems to occur around 12:00 UTC. The effect on the temperature observations is clearly seen in the curve "OBS". Apparently this detail requires additional accuracy of the 3-dimensional cloud cover inside the atmospheric DMI-HIRLAM model. Advection of clouds over the area where the road station is situated needs to be forecasted better.

Finally, the curve "MIS" illustrates an imagined situation that there has been a data gap of one hour between 8:00 and 9:00 UTC without surface temperature observations. This will have serious consequences for the quality of the forecast. The flux correction procedure yields a negative flux correction to reproduce the low temperatures observed at 8.00 UTC (not shown). A correct observation received at 9:20 will not help much because the effect of the negative flux correction will appear as a temperature drop shortly after when the shading conditions are established. This emphasizes the importance of a stable observational data supply to obtain optimal forecasts.

The expected improvements of the new operational model has been further investigated in a month long parallel test for February 2001. The experimental conditions are comparable to those for the operational model (REF) during that period. The improved performance of the new system has been confirmed. For example, the occurrence of road temperature errors exceeding 1.0 C in 3 hour forecasts is reduced by 14 percent.

4. Concluding remarks:

The present report has emphasized the importance of a careful data processing in connection with high accuracy numerical road temperature forecasts. It is also of importance to describe the vertical distribution of cloud cover with a reasonable accuracy. This goal is a difficult one to reach. A framework for further improvements of the new model system has already been established, because the road conditions model has been built into the DMI-HIRLAM system as an integrated part. This provides the possibility to provide a two-way interaction between the two systems. The combined system can then profit from new observational data, e.g., related to a better cloud analysis. Improved cloud prediction is then likely to depend on a detailed cloud cover assimilation in the atmospheric model.

Reference:

Sass, B.H., 1997: A Numerical Forecasting System for the Prediction of Slippery Roads. J. Appl. Meteor., 36, 801-817.