On the Prediction of Road Conditions by a Combined Road Layer–Atmospheric Model in Winter

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An effective forecasting system for slippery road warnings has been operational in Denmark for some years and was recently extended to the whole country except for the island Bornholm. The system is based on a network of road-weather stations throughout the country that submit a continual flow of data, every 10 min, to the road master; the data are the current values of road-surface temperature, air temperature, and humidity. An instrument to measure the amount of resting salt is also installed in connection with most stations. Before making any decisions, the road master also has access to very short range weather forecasts that are issued every other hour and are valid for 3 hr. Each forecast is limited to a specific county. So far the forecasts have been worked out manually, but an automatic forecasting system based on a combined model for the prediction of atmospheric and road surface changes has been developed and tested to some extent. The atmospheric model is called the HIRLAM (High Resolution Limited Area Model). The model results are continually adjusted by observations from nearby weather stations so that the predicted parameters can be corrected before they are entered in the combined model. The purpose is to produce a short-range forecast of air temperature, humidity, and road-surface temperature for each of the more than 200 road-weather stations in Denmark. The combined model was tested last winter in five locations in Denmark. Some results of this test will be presented.

Fifteen years have passed since the first modest steps toward forecasting slippery roads took place in Denmark. Two stations were established for measuring road-surface temperatures: one on the high road passing the Danish Meteorological Institute (DMI) and another near the road master's headquarters in a suburb of Copenhagen. The road master and the forecaster exchanged data by telephone twice a day (at 4:00 a.m. and 1:00 p.m.) and discussed what could happen during the coming rush hour in view of the risk that the roads would become slippery or the weather would cause any other traffic difficulties.

About 10 years ago some action was taken toward establishing a nationwide warning system for slippery roads, designed for use by the road masters in the different counties. During the 1985–1986 winter, Roskilde county (west of Copenhagen) was the first to act on the basis of direct measurements, but it still stuck with the old system, that based on human observations by patrol drivers. Since then the system has increased to cover nearly all of Denmark (13 of 14 counties), and now all road masters base their decisions on a

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combination of information from man and machine, excluding patrol driving (Figure 1).

Each county has direct access to data from its own road-weather measuring stations (5 to 25, according to the size of the county), and the data are presented to the road master by various PC-screen images (Figure 2). Moreover, forecasts of relevant weather parameters for the next 3 hr are issued by the forecaster on duty at DMI every other hour and made available to the road master directly on the computer screen. Some counties also receive radar images of precipitation.

The predicted air- and road-surface temperatures, dew-point, cloudiness, precipitation (especially frozen precipitation), and wind velocity are all expressed as intervals valid for the entire county (Figure 3).

This operational system works quite well, and it has been developed further during the past 7 years. Both the road masters and the meteorological forecasters have learned much about what is going on in the foot level, so to speak, of the atmosphere. Today the road masters generally make their decisions on the basis of all this information. Doing so is not at all easier, but it is hoped to be better.

From the forecaster's point of view, sometimes (such as during mild winter conditions) it might be very easy to work out this type of "nowcasting," but when temperatures vary near freezing, as they often do during the Danish winter, it can be a hard task to produce detailed forecasts for 13 counties every other hour, day and night. That is one of the reasons for the development of a combined prediction model for road traffic conditions; the model is intended to issue a 6-hr forecast every hour for every observation site in Denmark (more than 200).

DESCRIPTION OF MODEL

The prediction model, developed by Sass of DMI (1), consists of two main components: a purely atmospheric prediction model, and a model treating the heat transfers in the layer just under the road surface, down to a certain depth. The change of road-surface temperature is determined at any time as a result of either net heat gain (leading to rising temperature) or net heat loss (leading to falling temperature). This net heat gain or loss, however, depends on many factors. Heat exchange between the road surface and the atmosphere (or partly direct loss to space) goes on in several ways:

- Sensible heat flux due to temperature difference between the air and the road surface (H),
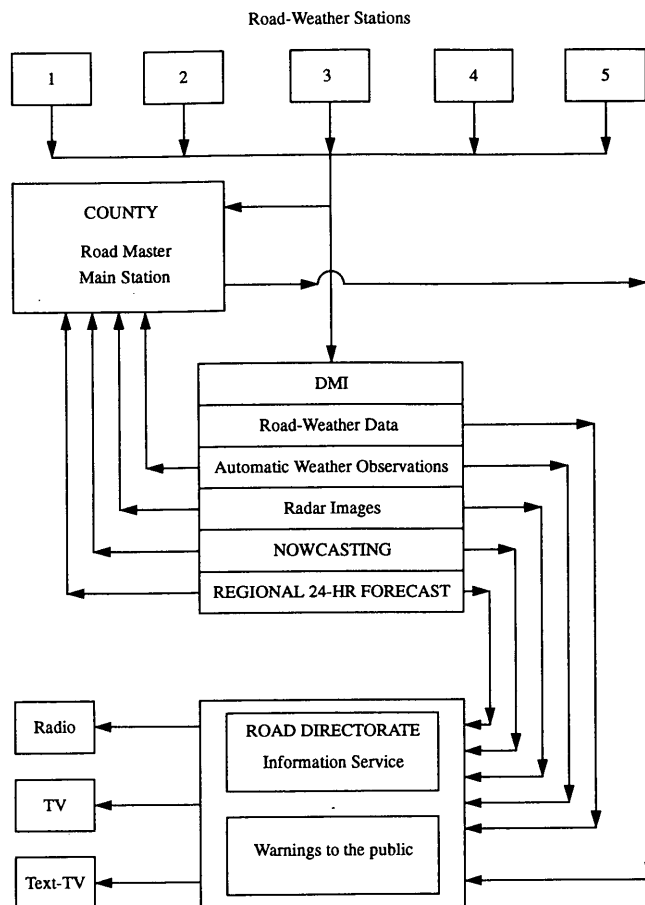
Road-Weather Stations

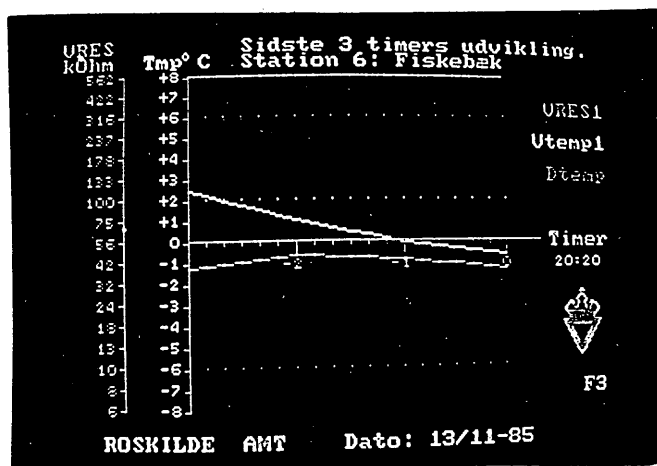**FIGURE 1   Flow chart for the integrated traffic warning system.**

FIGURE 2   Evolution during the last 3 hr of road temperature and dewpoint. VRES-KOhm expresses the road surface condition by a resistance of electric current between two electrodes in road surface, but it remains at maximum value (562 KOhm).

● Latent heat flux by evaporation or condensation and sublimation (Q),
● Latent heat flux by melting or freezing (R), and
● Net radiation flux (balance between incoming and outgoing radiation (S).

The second component of the model (beneath the road surface) consists of only one item: heat conduction in the solid road layer (G).

Figure 4 shows qualitatively the sign and magnitude of these quantities during a calm, clear night.

The final result of the combined model is then to work out a prediction of road-surface temperature, as well as water, ice, or snow on the road, by the following calculations:

● S, H, Q, and R based on predicted atmospheric data.
● Water, ice, or snow as a function of predicted precipitation in relation to eventual evaporation, condensation or sublimation, melting or freezing, and runoff from the road.

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VEJDIREKTORATET / DANMARKS METEOROLOGISKE INSTITUT
Weather forecast for County FUENEN
Issued Monday 15. April 1990 at 09:00 a.m.,valid until 12:00 a.m.
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	GENERAL TENDENCY			Expected STATUS 12:00 a.m.
	Falling/decreasing	Unchanged/variable	Rising/increasing	−20 −15 −10 −5 0 5
Air temp.	******			
Road temp.		******		
Dew-point			******	
Cloudiness			******	Cloudy/overcast
Precip.			******	4 − 6 cm snow
Wind veloc		******		SE 5-7 m/sec

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Further remarks: Snowfall starts at 10 - 11 a.m. First in the Eastern
                 districts.
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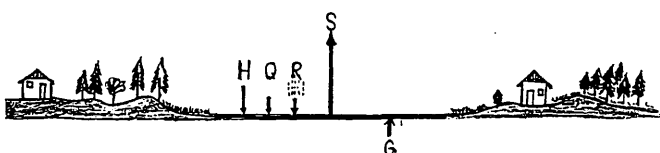**FIGURE 3   Copy of weather forecast issued for Fuenen county.**

FIGURE 4   Energy budget during a calm, clear night.

DOMINANT FEATURE

All of this appears very complicated, and it is; however, one quantity often dominates everything: radiation. The net radiation is largely dependent on cloudiness. If it is overcast with thick, low clouds, very little short-wave radiation (sunlight) reaches the ground, but at the same time the net long-wave radiation is also very small. The result is little or no change in road-surface temperature. On the contrary, when skies are clear, the net outgoing long-wave radiation is large and, during winter, the ingoing short-wave radiation is usually small during the day and equals zero during the long winter night. Result: large heat loss to space by radiation, leading to rapid decline in road-surface temperature.

This fact is well known to all people who work in this field, but it is mentioned here to illustrate what is needed most of all: exact predictions of cloudiness, both amount and height. Unfortunately, cloudiness is one of the most difficult parameters to predict by models on such short time scales. Therefore, running corrections of the model output must be carried out by means of observed values from nearby synoptic stations.

HIRLAM

The atmospheric model used for the experiments is called HIRLAM (High Resolution Limited Area Model); it is a three-dimensional operational model run twice a day at the DMI up to 36 hr ahead. The model was developed in a Nordic research project.

Any detailed description of this model is beyond the scope of the paper; all that will be said is that the road-surface model is fed constantly by predicted data with some time frequency, such as 1 hr. Predicted parameters used are temperature and

specific humidity at various levels, including 2 m. Furthermore, fractional cloud cover, accumulated precipitation, surface pressure, and horizontal wind components at a level of 10 m are used. The initial values of road water, ice, and snow are zero, unless additional information is available.

MODEL EXPERIMENTS

The first experiment with the combined road layer–atmospheric model was carried out from February 14 to 28, 1991, for one road-weather station, VOJENS, in southern Jutland. Data from the nearby synoptic station SKRYDSTRUP were used to make current corrections of the predicted HIRLAM parameters. The result looked very promising (Figure 5), and all were optimistic. However, some of the success was apparently due to the location of VOJENS—on a bridge without shadow—whereas most other stations in Denmark are situated in the coldest places, the so-called "white spots" on the road network, which are characterized by maximal shadow. So, it
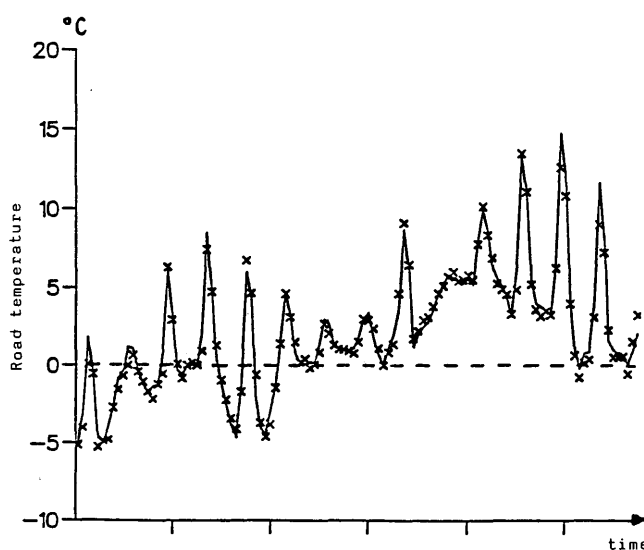

FIGURE 5   Observed road temperature (solid line) versus forecasted temperature (x) at VOJENS February 14 to 28, 1991.
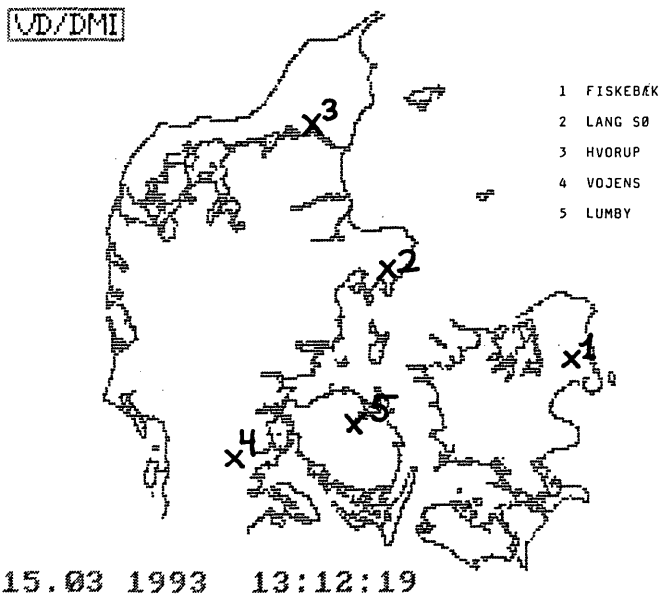
1	FISKEBÆK
2	LANG SØ
3	HVORUP
4	VOJENS
5	LUMBY

15.03 1993   13:12:19

FIGURE 6 Stations used for experiment from February 10 to March 10, 1992 (Numbers 1 through 5).

parentheses apply to experiments not using additional data from the nearest synoptic station.) The largest bias, expressed by the mean error, shows up at Station LA, which is situated at a wind-protected place with no sunshine at all.

FUTURE PROSPECTS

A joint experiment is planned for the coming winter: it will be the first real operational experiment, involving 20 stations throughout the country. The verification will not only consist of calculation of mean errors and such, but also include the road masters' views of the practicability of the system. Various layouts will be presented in order to fulfill the users' desires (Figure 7).

Next spring the results will be discussed in the so-called winter council, and it is hoped that during the 1993–1994 winter the new automatic forecast system can replace the "manual" forecasts.

became necessary to incorporate some kind of station characteristics if the model was to be used for other locations.

The next experiment took place from February 10 to March 10, 1992, at five locations in Denmark (Figure 6). Some results are given in Tables 1 and 2. (In the table, the results in

CONCLUSIONS

The preliminary experiments with the combined road layer–atmospheric model were promising. Some alterations, however, have become clearly necessary:

1. Station characteristics, such as duration of shadow, must be incorporated.

TABLE 1 DMI Road Temperature Forecasts, February 10 to March 10, 1992: Mean Error

Forecast Projection (hr)	N	Mean Error (°C) FI	LA	HV	VO
1	580	-0.0(-0.6)	0.3(-0.2)	-0.0(-0.6)	-0.1(-0.6)
2	568	-0.1(-0.8)	0.2(-0.3)	-0.1(-0.7)	-0.2(-0.8)
3	559	-0.1(-0.8)	0.3(-0.3)	-0.1(-0.8)	-0.2(-0.9)
4	550	-0.1(-0.9)	0.3(-0.4)	-0.1(-0.9)	-0.3(-1.0)
5	542	-0.1(-1.0)	0.3(-0.4)	-0.2(-1.0)	-0.4(-1.1)

NOTE: FI = Station FISKEBÆK, LA = Station LANG SO, HV = Station HVORUP, VO = Station VOJENS

TABLE 2 DMI Road Temperature Forecasts, February 10 to March 10, 1992: Mean Absolute Error

Forecast Projection (hr)	N	Mean Absolute Error (°C) FI	LA	HV	VO
1	580	0.7 (1.1)	0.7 (1.0)	0.6 (1.0)	0.5 (0.9)
2	568	0.9 (1.3)	0.9 (1.3)	0.8 (1.2)	0.7 (1.1)
3	559	1.1 (1.5)	1.0 (1.4)	0.9 (1.3)	0.9 (1.3)
4	550	1.2 (1.7)	1.1 (1.5)	1.0 (1.4)	0.9 (1.4)
5	542	1.3 (1.8)	1.2 (1.6)	1.1 (1.5)	1.0 (1.5)

NOTE: FI = Station FISKEBÆK, LA = Station LANG SO, HV = Station HVORUP, VO = Station VOJENS
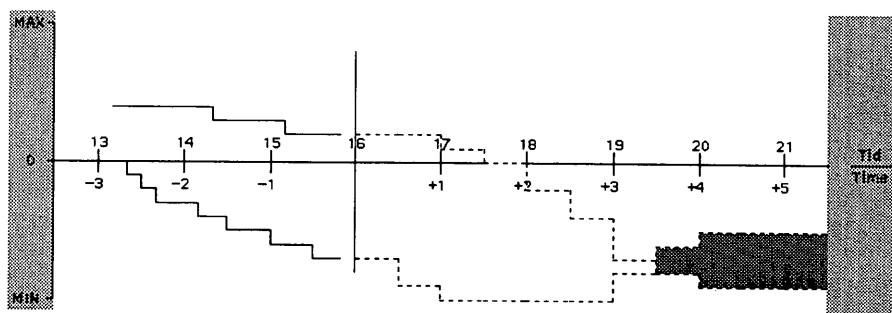
FIGURE 7 Last 3 hr of road temperature and dewpoint and forecast up to 6 hr ahead. Solid line is observed road temperature, and broken line is forecast road temperature; shaded area is danger: road temperature is below zero and the dewpoint.

2. The correction of atmospheric model outputs by observed values from one or more synoptic stations is indispensable.

3. The determination of the initial road surface condition (wet or dry, etc.) must be more accurate.

4. A higher time frequency for observations is desirable.

5. The model output presentation, especially in graphical form, should be redesigned to present large amounts of data to the road masters and to the meteorologists.

It is hoped to implement the first three items by next winter and the rest the following winter and, at the same time, extend the automatic winter warning system to all of Denmark.

REFERENCE

1. B. H. Sass. A Numerical Model for Prediction of Road Temperature and Ice. *Journal of Applied Meteorology*, Vol. 31, No. 12, Dec. 1992.