SOME NEW PARAMETERS IN THE FIELD OF ROAD WEATHER FORECASTING

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Abstract

The road weather forecasts provided by the Danish Meteorological Institute for the road authorities has been extended with 36 hour forecasts of wind and in-cloud icing. The forecasts are of primary use for the Great Belt Bridge where ice-aggregation due to in-cloud icing on the structures can be of such magnitude that it poses a danger to the traffic when it falls down. The wind forecasts are used to regulate the traffic on the bridge as high winds may problems for light vehicles, however, experience shows that the wind forecasts has a general applicability for ordinary roads at times with drifting snow.

Introduction

The Danish system for road weather information is primarily focused on the winter season, i.e. forecasting slippery roads. The system has been developed over the last decade by close collaboration between the Danish Meteorological Institute (DMI) and the Danish Road Authorities (DRA) both on the state and county level.

One of the corner stones is a Road Condition Model (RCM) which based on observations and atmospheric forcing from a limited area numerical model (HIRLAM) solves the energy balance at the road surface. The primary task of the model is to forecast rime formation or the freezing of wet roads as these conditions are the most frequent course for the risk of slippery roads in Denmark. A detailed description of the model is given in Sass (1999). Five hour forecasts are made every hour for the more than 275 road stations in Denmark and disseminated to the road authorities together with derived products such as alarm status, area (typically a county) forecasts with additional comments from a meteorologist.

The meteorological information is presented to the end user via a PC-program developed by the DMI for the DRA. A detailed description of operational set up and the PC-program is given in Pedersen (1999).

In connection with the opening of the Great Belt Bridge, a 22 km long bridge connecting two Danish islands, the system has been extended with two new types of forecasts - 36 hour forecasts of wind and in-cloud icing of the cables supporting the high bridge. This paper concentrates on these new features.

Wind forecasts

Previously wind forecasts has been included for the road stations but only for the five hour period which the RCM covers, further, the wind forecasts was based on the direct model output from the HIRLAM as only relatively few of the road stations are equipped with ane-

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mometers. However, for the Great Belt Bridge accurate wind forecasts are necessary all year round as strong wind, especially across the bridge, is dangerous in the way that it can course cars to turn over.

Based on 20 years of wind measurements from a meteorological mast placed on an island in the middle of the strait Sound &Belt - the company operating the bridge - has specified actions to be taken due to wind as given in Table 1.

The purpose of having 36 hour forecasts is to be able to give advance notice to the users of the bridge with respect to when and for how long adverse conditions are expected. New forecasts are issued every hour.

Step	Wind speed (10 min. mean)	Action	Expected frequency (hours / year)
1	Cross wind > 10 m/s or wind > 18 m/s	Max 50 km/h for light vehicles	1350
2	Cross wind > 15 m/s	No access for light vehicles Max. 80 km/h for other vehicles	200
3	Cross wind > 20 m/s	No access for light vehicles Max. 50 km/h for other vehicles	10
4	Wind > 25 m/s	Bridge is closed to traffic	1

Table 1. Actions to be taken due to strong winds. Light vehicles are cars with campers, trucks with light load and the like.

As there are two anemometers on the high bridge it is possible to improve the direct model output from the HIRLAM applying a statistical technique called Kalman Filtering (Kalman and Bucy, 1961). Basically it is assumed that a linear relation exists between the predictand, i.e. the wind h hours ahead, $V(h)$, and the predictors which in this system is the direct model output from the HIRLAM valid h hours ahead, $V_{hir}(h)$, and the latest observation from the road station, V_{obs}, given as:

$$V(h) = a + b * V_{hir}(h) + c * V_{obs} \tag{1}$$

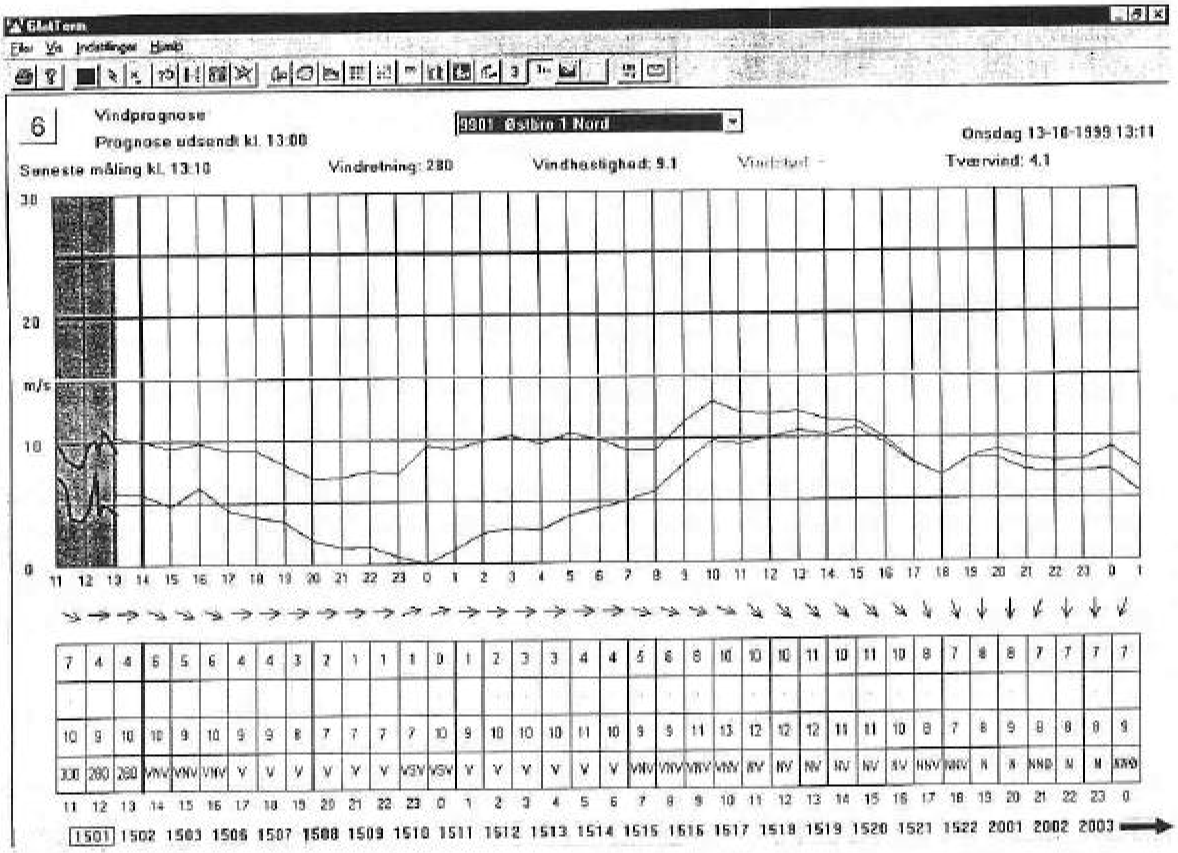
Based on the deviation between the forecast given by (1) and the subsequent observation the Kalman Filtering adjusts the coefficients (a, b and c) so as to reduce the error. The method cannot eliminate the errors totally but it will remove systematic biases and a further advantage of the method is that it will automatically react to external changes such as seasonal variations and improvements in the HIRLAM.

Given a reasonable first guess for the coefficients, e.g. a=0, b=1 and c=0 corresponding to complete confidence in the HIRLAM forecasts, the coefficients will typically be tuned well in 2 to 3 weeks. In practise the coefficient c will only differ from zero for the first 6 hours of forecast. The filtering technique is only applied to the wind speed where as the direct model output is used for the direction.

Figure 1 shows how the forecast is presented to the end users - the traffic guard at Sound & Belt and the police. To the left is shown observations for the last 3 hours and to the right the 36 hour forecast of wind, cross wind and direction is shown in graphic as well as tabular form.

The experience from 1999 shows that the traffic guard and police using the forecasts have been able to administer the actions given in Table 1 smoothly and without erratic decisions.

The Kalman Filtering of the wind forecasts is now applied to all the road stations equipped with anemometers a few of which is placed on other bridges and the experience from the last winter season shows that the users value these especially in cases with drifting snow.



Vindprognose
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Onsdag 13-10-1999 13:11
Seneste måling kl. 13:10
Vindretning: 280
Vindhastighed: 9.1
Vindstød -
Tværvind: 4.1

11	12	13	14	15	16	17	18	19	20	21	22	23	0	1	2	3	4	5
7	4	4	5	5	6	4	4	3	2	1	1	1	0	1	2	3	3	4
10	9	10	10	9	10	9	9	8	7	7	7	7	10	9	10	10	10	11
300	280	280	VNV	VNV	VNV	V	V	V	V	V	V	VSV	VSV	V	V	V	V	V

6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	0
4	5	6	8	10	10	10	11	10	11	10	8	7	8	8	7	7	7	7
10	9	9	11	13	12	12	12	11	11	10	8	7	8	9	8	8	8	9
V	VNV	VNV	VNV	VNV	NV	NV	NV	NV	NV	NV	NNV	NNV	N	N	NNØ	N	N	NNØ

Figure 1. Wind observations and prognoses as they are presented to the user.

In-cloud icing

The pylons suspending the east bridge reaches 256 m above the sea surface and during the construction of the high bridge heavy icing due to in-cloud icing was observed. This type of icing occurs when supercooled water droplets in a cloud hits the structure at subfreezing temperatures. Supercooled droplets coexists with ice crystals and snow in clouds from the freezing point to about minus 23 °C. The more liquid water a cloud contains and the stronger the wind the heavier the deposit of ice on the structure will be. Also the shape of the structure plays a role.

The aggregation of ice on a cable with a subfreezing surface temperature is well described by

$$dM/dt = C * v * q_w \tag{2}$$

where the left side describes the increase of ice (mass per meter) per time unit as a function of a shape dependent constant, C, the wind speed, v, and the specific water content of the cloud, q_w. q_w is the mass of liquid water per mass of air in the cloud.

For the Great Belt Bridge the problem is not that ice will accumulate on the structure as it is dimensioned to carry the extra load. The danger arises when thaw sets in and large pieces of ice may fall from the vertical cables suspending the bridge coursing severe danger to the traffic on the bridge.

Based on 21 years of data from a near by light tower it is estimated that up to 8 kg of ice per meter can be aggregated on the cables, however, during most winters serious icing (more than 0.5 kg / m at 200 m) will not occur or at most once. The statistics show that during severe winters (when the sea below the bridge is frozen) it may happen from 4 to 8 times. In-cloud icing of the cables is not a rapid process, to get an aggregation of 0.5 kg / m on a cable at least 10 hours with wind speeds above 10 m/s and the cloud base below 200 m is needed.

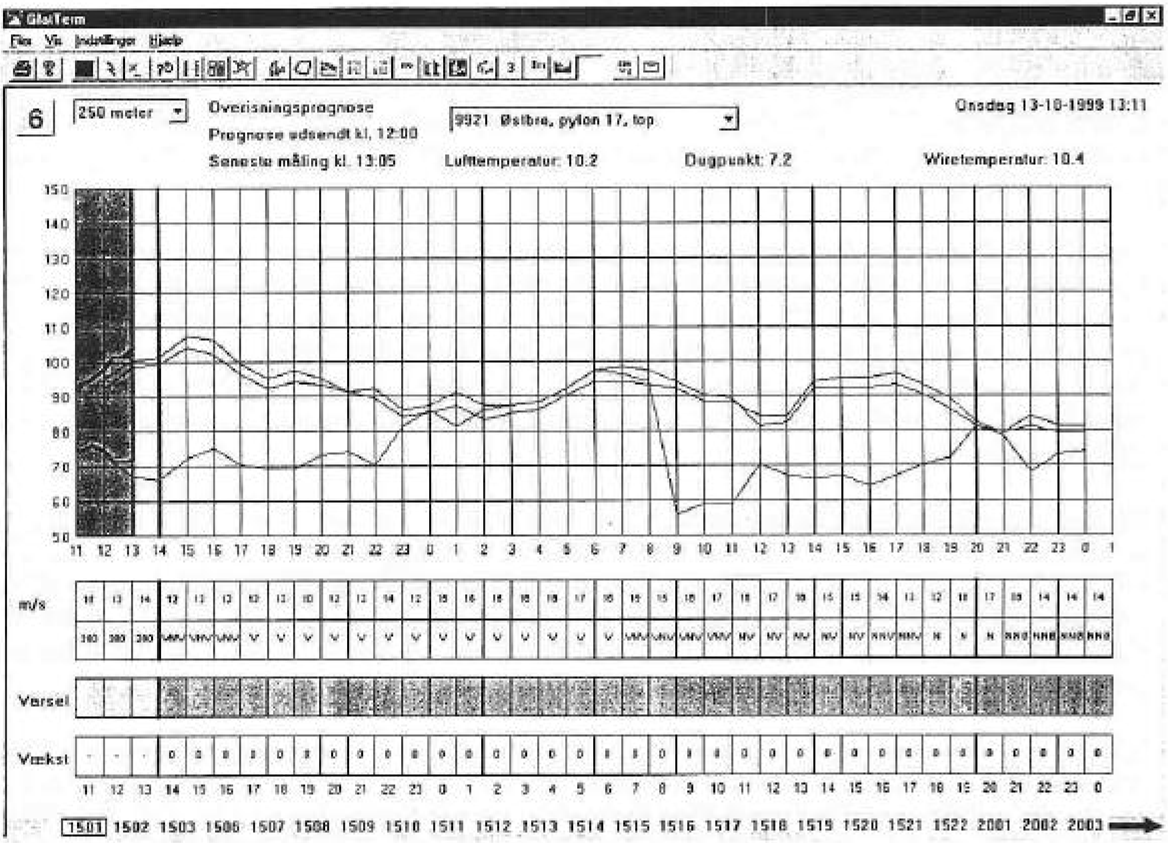
The model forecasting the aggregation of ice predicts air- and dew point temperature, wind speed, temperature of the cable surface and the aggregation rate of ice at 70, 100, 150, 200 and 250 m. Forecasts are made every hour for 36 hours ahead. The model cannot predict melting or dropping of ice and consequently neither the amount of ice at a given time, however, a warning for the risk of ice falling off the cable is given if thaw is predicted after ice has been aggregating.

Instruments are placed at the top of the pylon (250 m) and at highest point of the driving lanes (70 m). The measurements available are wind, air- and dew point temperature as well as the cable- and road surface temperature respectively. These parameters together with the HIRLAM forecasts of liquid cloud water, water vapour, air temperature and wind constitutes the bases for the ice-aggregation model.

Also in this connection Kalman Filtering is applied to some of the parameters using filters analogue to (1). Besides the wind speed the air temperature, the cable / road surface temperature and a generalised dew point difference is filtered. In a cloud the generalised dew point difference is a measure of the amount of condensed water and thus the amount of liquid water which can be aggregated as ice. Outside clouds it corresponds to the difference between the air- and dew point temperature.

The filtered parameters are used in (2) to forecast the aggregation of ice at the two measuring sites (at 70 m the lowest of the air- and the road surface temperature is assumed for the cable surface temperature). For the three intermediate levels (2) is also applied using values interpolated directly or as corrections to the HIRLAM direct model output.

Figure 2 shows how the forecasts are presented to the traffic guard at Sound & Belt. To the left is shown observations for the last three hours and to the right the forecast. The curves show air-, dew point- and cable surface temperature while wind, alarm level and ice aggregation rate is given in tabular form at the bottom. There are three alarm levels corresponding to no aggregation (green), ice is aggregated (yellow) and thaw is forecast after aggregation has occurred (red).



250 meter
Overisningsprognose
Prognose udsendt kl. 12:00
Seneste måling kl. 13:05
9921 Østbro, pylon 17, top
Onsdag 13-10-1999 13:11
Lufttemperatur: 10.2
Dugpunkt: 7.2
Wiretemperatur: 10.4

Figure 2. Presentation of ice-aggregation rate and associated parameters at 200 m as presented to the end user.

The ice-aggregation model will be used operationally from the 1999 / 2000 season. Also during this season the Sound & Belt plans to test a Canadian method applying strong electromagnetic pulses through a conductor twisted around a cable which should make the ice blow off the cable. In this way the ice can be removed before it poses a danger to the traffic or at least be removed in a controlled manner. Only a few cables will be included in the test, but if it yields a satisfying result it is planned to equip all the cables with the system.

Concluding remarks

Two new parameters have been included in the road weather forecasts made by the Danish Meteorological Institute specifically for the road authorities. The presentation of the forecasts to the end users have been integrated in the general road weather system used by the road authorities in Denmark.

The experience from 1999 shows that the 36 hour wind forecasts are valuable for the traffic controller at the Great Belt Bridge and the police when high winds necessitate regulation of the traffic on the bridge, both in giving advance notice of high winds as well as making it possible to notify the public as to when regulations will be lifted. The wind forecasts have also proven helpful in giving guidance with respect to snow drift on ordinary roads.

The forecasts of ice-aggregation and the potential for the falling down of previously aggregated ice from the cables supporting the Great Belt Bridge will be operational from the 1999 / 2000 winter season. It is expected that these forecasts in line with the wind forecasts will provide the traffic controllers with useful guidance in cases where in-cloud icing may course hazards for the traffic, both for warnings as well as for the planning of controlled removal of aggregated ice if the cables are equipped for this purpose in the future.

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