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An overview of road surface conditions forecasting in Météo-France

L. Bouilloud [1], O. Coudert [1] and A. Foidart [1]

[1] Météo-France/DPrévi/GCRI,
Toulouse, France

Corresponding author's E-mail: ludovic.bouilloud@meteo.fr

ABSTRACT

During winter, ice or snow presence on the roads might have serious consequences on road traffic and security. So Météo-France had developed decision-making tools for road management in winter using a specific model, ISBA-Route, which permits to simulate the behaviour (temperature, liquid and ice content) within the road and the natural soil under the influence of atmospheric conditions. To improve this model, it was coupled with the detailed snow model CROCUS in aim to simulate the behaviour of a snow layer deposited on a road. These models are the basis of the road surface condition forecasting and they are briefly presented in the first part of the manuscript. Then, in the second part, all the operational road prediction products are presented with associated results. Among these products, a focus is given on the AROME/ISBA-Route system, resulting from the coupling of the ISBA-Route model with the high-resolution atmospheric AROME model, which is the major forecast product of Météo-France. This coupling permitted to improve the accuracy of the forecast. So, at this step, to continue to progress in accuracy and to deliver a complete and coherent information. Météo-France plans to use the human forecasters expertise. These researches in road meteorology are presented in the last part of the paper, and will lead to an improvement of the quality of road conditions prediction during future years.

Keywords: Winter maintenance/ Road surface conditions/ Forecasting.

1 INTRODUCTION

A winter maintenance strategy depends on a number of factors, including climatic and demographic conditions as well as the road network density and traffic. Most countries use road-weather forecasting systems to predict road conditions, organize maintenance, and reduce the risk of accidents. Numerical models are used to predict road surface condition and these models perform a resolution of the energy budget of a road, in a more or less complex way (surface energy budget, diffusion model, with or without water and ice budget…). For this purpose, a specific model was developed in France: the ISBA-Route/CROCUS model. This model permits to describe with accuracy the road surface temperature evolution, the water and ice road content and the behaviour of a snow layer deposited on a road. The model is presented in the first part of the paper. In a second time, the results of the operational forecast road conditions systems used by Météo-France are discussed. The last part of the paper presents the main research results which will lead to an improvement of operational prediction.

2 BRIEF DESCRIPTION OF THE MODELS

The ISBA-Route/CROCUS coupled model consists in two coupled one-dimensional models : the soil model ISBA [1-2] and the snow model CROCUS [3-4]. ISBA-Route is the road adaptation of ISBA used in its multi-layer diffusion scheme version [5]. CROCUS is the detailed snow process model which originally was used for avalanche forecasting at Météo-France [6]. The validation of the model was done using data from a comprehensive experimental field campaign during the 1997/1998, 1998/1999 and 1999/2000 winters at the Météo-France Col de Porte (1320m, Chartreuse mountain range, French Alps) experimental site. The model evaluation consisted in the comparison of simulated and measured road surface temperature, 0.6 m deep temperature, snow depth and road/snow interface conditions for 60 snowfall on experimental road events. The model validation was done using a pavement type corresponding to a relatively thick highway structure, for which the surface layer is constituted of semi-grainy bituminous concrete. This type of road composition was then used for the forecast over all of France. The physical and thermal properties of the pavement are listed in Table 1. The surface properties were prescribed using an albedo of 0.1, an emissivity of 1 and a roughness length of 0.001 m.

Material	Δz (m)	ρ (kg m^{-3})	k_{dry} (W m^{-1} K^{-1})	Wsat (%)
Semi-grainy bituminous concrete	0.005	2000	2.1	6.35
Semi-grainy bituminous concrete	0.077	2000	2.1	2.35
Sand gravel cement mix	0.512	2400	2.0	7.2
Unbound gravel	0.174	2200	2.0	8.8
Natural soil	8.5	1700	3.0	42.5

Table 1. Physical and thermal properties of the road structure and the underlying soil. Δz is the total layer thickness, ρ the dry density, k_{dry} the dry thermal conductivity and *Wsat* the volume porosity.

The ISBA-Route/CROCUS coupled model accurately simulated the road surface temperature, and the occurrence of the snow on the road. However, some discrepancies in term of the simulated snow height occurred. The simulation errors were mainly caused by uncertainties of the precipitation phase, difficulties in predicting the snow density or phenomena not accounted for by the model (e.g. snow transport by the wind). In addition, snowmelt was a bit too slow. On the roads, the snow coverage was actually spatially inhomogenous, and lateral heat transfers enhanced the melting, especially when the underlying dark road surface began to appear. However, these discrepancies (late melting and snow depth uncertainty) where determined not to be critical for the projected application over all of France, which concerns primarily determination of the occurrence of snow on the road and the beginning of the snow coverage. More details concerning the experiments, the model and the validation can be found in [7].

3 OPERATIONAL ROAD SURFACE CONDITION FORECASTING

3.1 Road surface temperature forecast at the France scale

At this moment, the ISBA-Route/CROCUS model for snow conditions of the road network is not used for the whole French territory, it is used only for several locations (airports, road weather stations). A use at the France scale will probably be available for the next 2012/2013 winter. So, the main operational model is only the ISBA-Route model, for the forecast of temperature, liquid and ice content within and at the surface of French roads, used operationally since 2004. The last major improvement of the system was the coupling of the ISBA-Route model with the high-resolution (2.5 km) AROME model [8] during 2010. The AROME model was operationally used by Météo-France since the end of 2008. The main characteristics are the nonhydrostatic dynamical model core, detailed moist physics, and the associated three-dimensional variational data assimilation (3D-Var) scheme with some mesoscale specific data such as Doppler radar. Concerning road conditions forecasting, main improvements due to the coupling with this high-resolution model were:

- a better resolution (2.5km instead of 8km) and better orography representation
- no more downscaling is now necessary
- a better representation of hydrometeors (essential for snow prediction)
- improvement of representation of the boundary layer

The resulting system was called AROME-ISBA-Route (AIR). Previously, the ISBA-Route model was used with the SAFRAN model in its forecast mode [9-10], which is a downscaling on a 8 km resolution grid of the numerical weather prediction model ARPEGE [11]. The whole SAFRAN-ISBA-Route (SIR) system was described more precisely in [12].

The originality of the systems used at Météo-France are their availability for all the road network, only with the need of atmospheric forecasting data (i.e. no additional data is required, for example road weather stations observations). The SIR forecast system is used once a day, at 6h UTC to produce 96h forecast, and the AIR system run 4 times per day, to produce 30h forecast. The SIR system is still used for long range forecast, but the main product for Météo-France concerning road conditions forecasting is AIR. The initial profile of temperature, water and ice results for an analysis run of the previous day with the SAFRAN analysis at 6h UTC, or for the 6 hour forecast of the previous run for the 12h, 18h and 0h UTC run. The objective of the “analysis” mode of the SAFRAN model is to produce the most accurate estimation of the atmospheric variables and downward fluxes needed to force the ISBA-Route/CROCUS model. SAFRAN uses an optimal interpolation method to analyse most of the parameters, and combining data from numerical model and all available observations (soil, satellite, radar…). The analysis is done over climatically homogeneous zones, which are areas of irregular shapes where the horizontal climatic gradients are weak. SAFRAN estimates one value of each parameter for each zone at several altitudes. Within the zone, analysed parameters depend only on elevation and aspect. The zones are not isolated, i.e. observations from neighbouring zones can be used. Then an interpolation on the 2.5km grid is done. The AIR forecast system is described in figure 1 for the 6 UTC run.

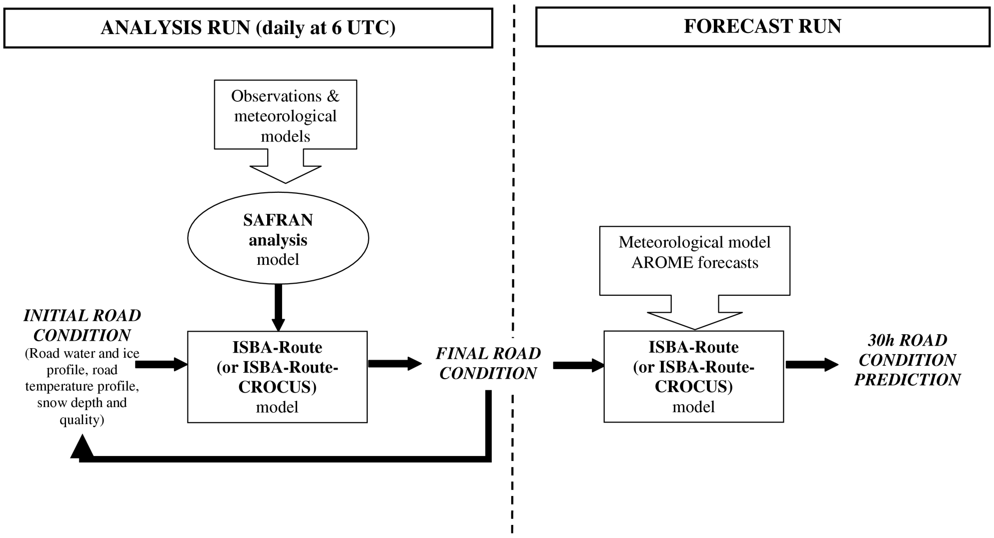

Figure 1. Simplified diagram of the AROME-ISBA-Route (AIR) road condition prediction system for the 6h UTC run with daily analysis.

3.2 Forecast for specific locations

Supplementary to the whole France systems described in the previous section, some other operational forecast are available. The main interest of these secondary predictions was to improve the forecasts of road surface temperature thanks to the use of the road weather stations measurements (and for the moment to forecast snow height and type on the road which is still not existing at the France scale). Indeed, for some road weather stations of the road network (approximately 150), the measurement of these stations are integrated in real-time in the Météo-France database. So, for these locations, the initial profile within the road extracted from the France scale profile is corrected for each run with measurements. For some stations, with a long enough archive measurement period (at least 2 years of measurement), statistical adaptations were performed to improve the quality of the forecast.

3.3 Control and quality of the road surface temperature forecast

To judge the quality of the forecast and the improvement due to the coupling with the high-resolution AROME model, typical scores were computed for the previous winter maintenance period (winter 2010/2011). These scores are the mean error and the root mean square error, and the probabilities of false alarm and detection for the prediction of the event “negative road surface temperature”. To compare the two systems SIR and AIR, scores were computed on the ranges corresponding to the 30h forecast of the AIR system for the 4 production networks (0,6,12 and 18 UTC), and for a sample of 102 road weather stations located in the whole French territory, from 1 November 2010 to 31 March 2011. The scores are summarized in Table 2.

System	Mean Error (°C)	Root Mean Square Error (°C)	Probabilty Of Detection (%)	Probability of False Alarm (%)
SIR	1.27	3.3	95	44
AIR	1.14	2.75	95	38

Table 2. Comparison of the scores of the two Météo-France operational road surface temperature forecast systems : AROME-ISBA-Route (AIR) and SAFRAN-ISBA-Route (SIR).

It might be observed in Table 2 that the coupling with the AROME model led to a significant improvement of quality of the forecast (with a gain of approximately 0.5 °C concerning the root mean square error). However, for the two systems it could be observed a positive mean error (equivalent to a cold bias). This cold bias was responsible to the poor quality of the forecast of the event “negative road surface temperature” with a very satisfactory probability of detection but with a quite high probability of false alarm for the SIR and AIR systems (with respectively 44% and 38%). So, in spite of an improvement due to the coupling with AROME, these results need to be improved. The main source of large errors in prediction was a wrong prediction of atmospheric radiation (due to a wrong prediction of nebulosity). A way of improvement was envisaged, it consisted in using the expertise of human forecasters of Météo-France. This method is presented in the section 4, relative to the current research performed in Météo-France concerning road weather.

The results obtained at the France scale were locally improved with the local system using the road temperature measurements or with statistical adaptations. With the use of measurements, the gain in root mean square error compared to France results of the AIR system, was 0.25°C for the 30 hour prediction and reached 0.6 °C for the 6 hour prediction. However, it could be noticed that the results were significant essentially for the road weather stations with deep temperature measurement (several centimetres below the road surface). This system will be probably be more interesting during future years for nowcasting application. Indeed, a nowcasting application (6 hour range and hourly run) of the AROME model is under development in Météo-France and will be available in next years. A coupling with the local system using real-time temperature will probably be very interesting in this context. The statistical adaptations computed on the AIR system permitted to improve the results, with a bias close to 0°C and a gain of 1°C concerning root mean square error. However, the amount of stations concerned (where measurement archive length was sufficient) is not very important (approximately 50 stations at this date).

4 CURRENT RESEARCHES IN ROAD WEATHER

4.1 The expertised road surface temperature prediction system PrevExp-IR

As it was described in section 3.3, the use of high-resolution forecast model permitted to improve significantly the results in comparison with the older SIR system, however some improvements need to be done in aim to reduce the cold bias of the forecast and consequently improve the prediction of negative road surface temperatures, which is a fundamental parameter for road mangers. For this purpose, the human appraisal of the national and local forecasters of Météo-France is an important source of improvement. Indeed, human forecasters permit to obtain a best prediction in comparison with the raw AROME atmospheric prediction. Their role is to synthesize all the available informations (predictions of an important amount of atmospheric models, observations, ensemble forecasts, local expertise…) and to perform the best prediction in aim to elaborate a coherent and a-priori best forecast for all the French cities and some others specific locations (beach, winter sports resort, mountain places…). So, it was decided to elaborate a new road surface temperature forecast system (PrevExp-IR) based on this atmospheric expertised predictions and to test this system in real-time for the 2011/2012 winter. A difference with numerical weather prediction models is the unavailability of some parameters which are not expertised. These parameters are radiation parameters: solar and atmospheric radiation. So, as it was said previously, the atmospheric radiation is the main parameter responsible to the temperature amplitude decrease of the road during the night. As opposite, the solar radiation is not fundamental for winter road maintenance, its effect occurring essentially for the diurnal maximum temperature. So, for this test the solar radiation used was raw model solar radiation and the atmospheric radiation was computed using 3 expertised parameters : the 2m air temperature, the nebulosity and the humidity using Eq. (1) [13]:

$$R_{atm} = \varepsilon\,\sigma T_a^{\ 4} \text{ with } \varepsilon = \left\{ N + (1-N).\left[0.67\,(1670\,q)^{0.08}\right]\right\} \quad (1)$$

where R_{atm} is the atmospheric radiation, ε is the atmospheric emissivity, σ is the Stefan constant, T_a is the 2m air temperature, N is the nebulosity and q is the specific humidity.

For the current test, this system runs every day at 14h UTC, to provide a forecast available during the afternoon. The comparison with the AIR system is given in Table 3, for the period from 1 November 2011 to 15 February 2012. The forecasting range of the PrevExp-IR forecast is 3 day. So for this test, the daily solar radiation was extracted from the lower resolution ARPEGE (approximately 10km) model. Benefits during daily period is less significant than nocturnal period. So, and in order to compare with the 30 hour forecast of AIR, the scores were computed only for the first nocturnal prediction (from 18h UTC to 6h UTC). For a future operational use, the first day solar radiation will be extracted from the high-resolution model AROME, so first daily period results will be improved in comparison of the test period.

System	Mean Error (°C)	Root Mean Square Error (°C)	Probabilty Of Detection (%)	Probability of False Alarm (%)
AIR	1.23	2.13	94	30
PrevExp-IR	-0.27	1.76	82	14

Table 3. Comparison of the nocturnal scores for the AROME-ISBA-Route (AIR) and PrevExp-IR road surface temperature forecast systems.

It might be observed in table 3 that the improvement due to the use of expertised atmospheric forecast is significant with an important decrease of root mean square error or mean error and above all a decrease of the probability of false alarm (14% instead of 30% for the AIR system) which is fundamental for road managers, because of the cost of an useless road treatment.

4.2 Snow presence on road prediction

Following the same principle of the PrevExp-IR system, a new system will be available during the winter 2012/2013 in Météo-France for the forecast of snow presence on the French road network. This system will use expertised atmospheric forecast and the ISBA-Route/CROCUS model to perform a forecast of snow type on the road (height, density, snow water content, grain type, snow/road interface configuration…) in aim to serve decision-makers for snow treatments. An example of results of this prediction system is given here for a snow event which occurred during 5 February 2012. This event was relatively interesting because of its high geographical extension and because of the concerned areas, which were plain areas not frequently concerned with snow events.

To compare with available observations, the forecast was done from the period of 5 February 2012 at 6h UTC to 6 February at 6h UTC. In figure 2 are given the forecast of the snow height, the contingency of the observed snow height during the 24 hour period versus the prediction, and the scatterplot of the comparison of predicted and observed snow height. Two important points need to be noticed here. First, the prediction consists in a 24 hour forecast of snow height on the road in natural conditions (e.g. without accounting for road de-icing, snow removals by road managers or traffic). Secondly, the compared parameter are not the same. Indeed, the observed snow height is measured on natural soils while the predicted parameter is the snow height on roads, with higher conduction fluxes than for natural soils. However, this event occurred during a very cold period in France and consequently conduction fluxes between road and snow were probably not very high, so the parameters might be considered relatively close for this event.

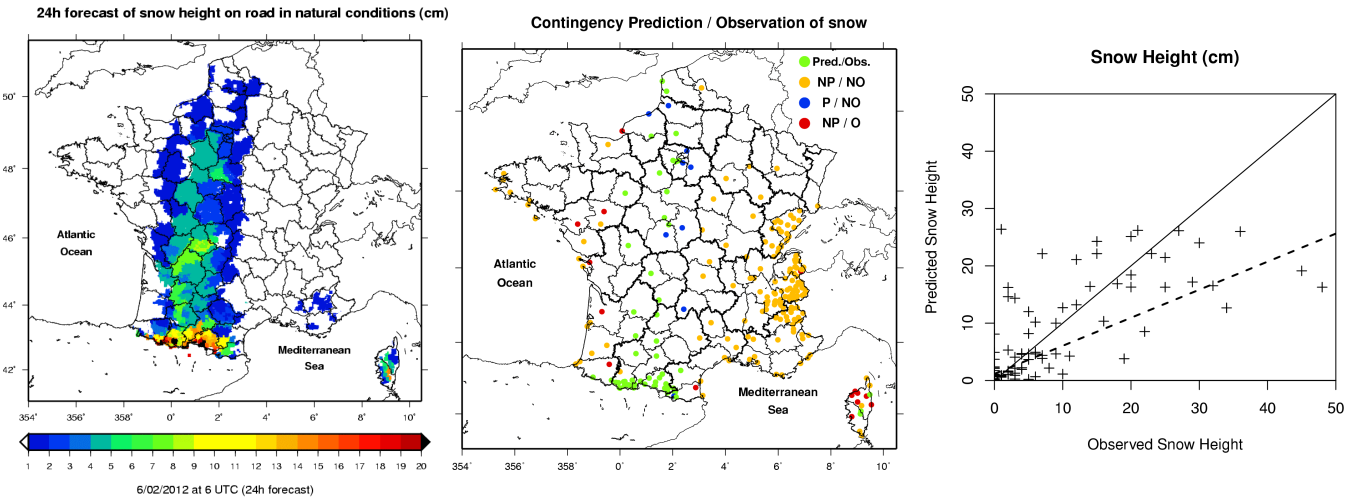

Figure 2. Results of the snow on road forecast for the 5 February 2012 event: 24h predicted snow height on the roads (in natural conditions without traffic or road treatments) (left), contingency with observations (centre) and comparison of predicted snow height on road with observed snow height on natural soils (right).

It might be observed in figure 2 that this event was a significant event with snow height on roads exceeding locally 10 cm in plain areas and with very important 24h snow quantities in the Pyrenees mountains (50cm). The contingency between observations and predictions showed that the prediction was relatively accurate concerning the spatial coverage of the event, with few false alarms or non detections. The corresponding scores were a probability of detection of 79% and a probability of false alarm of 17%. Concerning the non detection of the event (red circles on the map), it might be observed that it happened on the boundaries of the event, where observed snow heights were relatively low, and it is impossible to conclude with certainty. Indeed, it might be cases were the low snow amount had melted on road surface and had holded on natural areas with lower conduction fluxes. This discrepancy might explain a part of the underestimation of predicted snow height on the scatterplot. Some discrepancies might have been due to difference between observed and simulated snow type. However, even if some discrepancies or uncertainties due to the difference in observed and predicted parameters were associated, it might be concluded that the forecast was relatively informative, with a respect of the order of magnitude of snow heights for this event. These results were observed for other events, and consequently an operational use of this forecast system will be very usefull.

5 CONCLUSION

After the historical SAFRAN-ISBA-Route 8 km resolution system and available since 2004, the first improvement was the coupling of the ISBA-Route road model with the high-resolution and nonhydrostatic mesoscale model AROME. This AROME-ISBA-Route system led to an important improvement of the quality of road surface temperature prediction. However, it had be shown that this improvement was not sufficient because of a too high probability of false alarm for negative road surface temperature predictions, which was problematic for road managers. So, a way of improvement using human expertised atmospheric forecast was tested during the 2011/2012 winter. The results of this system called PrevExp-IR were relatively improved compared to the raw model prediction. A significant decrease of the cold bias, and consequently a decrease of false alarm amount, was observed. So it was decided to use this system operationally from the next 2012/2013 winter. With this perspective all the winter productions, dedicated for the road maintenance, will be coherent and stem from a unique expertise, the forecaster's one.

The ISBA-Route/CROCUS coupled model was developed with the primary goal of predicting the road surface conditions in winter. The model was able to accurately simulate the behaviour of a snow layer deposited on a road using observed meteorological data providing from an experimental site. Some tests were done at the France scale to evaluate the behaviour of the model with the expertised atmospheric forecast. It had been observed that these predictions will probably be very useful in an operational way. So consequently this system will be used operationally too.

Next steps concerning this topic will be dedicated to improve the model. Indeed, the model didn't consider real conditions as traffic or road de-icing. Some parameterizations will be introduced during following years to take into account these real conditions. Another point of interest is the account of specific points of the road network as cold spot or bridges. Studies were undertaken to develop specific forecasts to these particular points. One of them is to develop specific model for bridges in aim to improve ice, frost or snow presence on bridges prediction. Concerning cold spots, a study will be done during following months, in collaboration with Vaisala, about using thermal mapping for improving the quality of forecast for specific points of the network.

All presented products and future developments are available over the French road network through the Météo-France OPTIMA decision-making tool [14], which presents all the pertinent road weather information for every kilometric road sections.

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