IMPROVEMENTS IN ROAD FORECASTING TECHNIQUES & THEIR APPLICATIONS.

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Background

The Met Office has been providing guidance to local administrative bodies within the UK on winter road conditions through its OpenRoad service for about 15 years. Ice and snow on roads is considered a particular concern as a risk to driver safety and general traffic flow. The Met Office currently provides forecasts via its distributed local forecast offices. These are normally delivered to customers at around midday for the night ahead based upon the latest Numerical Weather Prediction (NWP) guidance available to meet this delivery time (06Z). After delivery of this initial forecast the performance of the forecast is monitored against the observed evolution combined with later NWP guidance and, where divergent, a warning and an amended forecast are delivered to customers. This is done for the nationwide network of about 600 road sites many of which have automated observations available that allow real time monitoring and post-event verification.

The forecasts of road ice are generated by coupling the NWP guidance to a local road ice prediction model that outputs a forecast of road surface temperature and road state. The quality of the product generated by this arrangement has two sources of degradation or error: the error in the NWP guidance for synoptic scale evolution; e.g. the passage of a front is mis-timed; and the error in the prediction of local road conditions by the local road ice model due to, for example, inadequate description of the surface physics. Forecasters therefore occupy a role of quality control and error mitigation to add value to a raw product.

Until the winter of 2000-01, forecasters at the distributed forecast offices ran the road ice model by-hand using the NWP guidance as input together with their own local knowledge. Hence the quality control was implied as inherent within the model process. From the winter of 2001-02, following development of an enhanced road ice model, the running of the road ice model was centralised with the NWP, to Met Office HQ to generate a forecast 1st guess product. Consequently, the role of the forecaster in the distributed forecast offices changed from one of forecast creation to one of quality control, amendment and subsequent monitoring.

Although the NWP capability of Met services has improved steadily over the past decade, the rationale behind this fundamental change in forecaster involvement was the much more rapid progress made in the performance of road ice prediction models. This is because road ice prediction models are relatively simple surface exchange models and the identification & correction of errors and deficiencies is more tractable. In 2000 this development coincided with a need to streamline the production of Met Office road ice forecasts to make the service to customers more cost effective. A by-product of this change in the road ice forecast process was that the value added by forecasters to the raw "automated" product could be measured and therefore the impact of improvements in the NWP or road ice modelling better quantified.

Forecaster Added Value

The main variable used to assess the quality of the OpenRoad service is the minimum road surface temperature, as this is indicative of the worst road state during the night. Figure 1 shows mean and RMS errors for the minimum road surface temperatures over the whole OpenRoad network since 1996-7, comparing initial model forecasts with forecaster intervened forecasts.

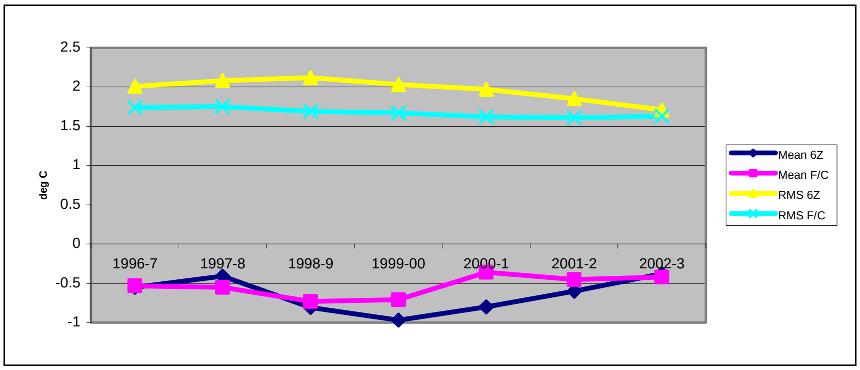
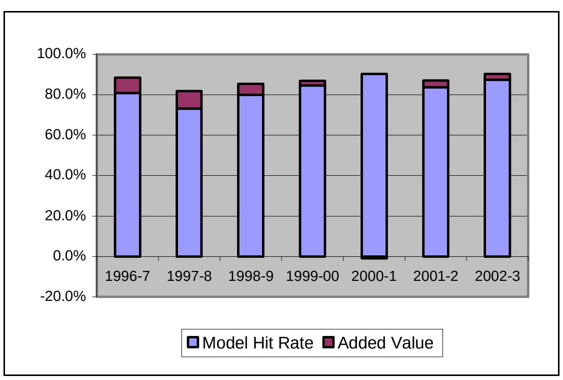
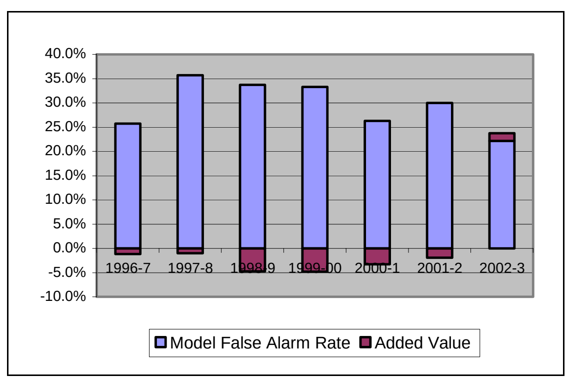


Figure 1 - Mean and RMS error for minimum road surface temperatures since 1996-97.

Over the whole period, the RMS error for forecaster issued forecasts has improved slightly from ~1.75°C to 1.6°C. Since 1998-9, the RMS error in the automated 1st guess has fallen from 2.1°C to 1.7°C. Similar improvements can be seen in the ability to forecast ground frosts (i.e. RST ≤ 0°C), as measured by Hit rate and False Alarm rate skill scores as seen in Figures 2 & 3.





Figures 2, 3 - First guess hit rate and false alarm rate, and improvements made by forecasters (target HR is >87%, target FAR is <30%). Note that forecasters generally able to improve hit rate and reduce false alarms, though could only increase hit rate last year at expense of FAR.

A number of developments have lead to these improvements, the more important of which are:

- In 1999-2000, the Site Specific Forecast Model (SSFM), rather than UK Mesoscale model was used to drive the road ice prediction model. This local NWP model provides descriptions of non-linear local physics particularly that of sub-gridscale heterogeneous landuse and orography enabling the site-specific impacts on the lower boundary evolution to be better estimated. The capturing of the effects of complex terrain has particular benefit to road ice forecasting as forecast sites tend to be at locations significantly affected by small scale orographic processes, e.g. frost hollows.
- In 2000-01, the centralisation of the 1st guess production system was brought in. This included the introduction of a new road ice prediction model, MORST, that addressed many of the known deficiencies in the road ice prediction model, e.g. an improved surface exchange scheme that significantly reduced general cold bias; better representation of surface water/snow budget. A basic Kalman Filter correction was also introduced to downscale to local processes further.
- In 2001-02, the utilisation of the sophisticated two-stream, multi-band Edwards-Slingo radiation scheme within the road ice modelling package. The main benefit of this scheme is the inclusion of cloud radiative interactions in both the long and short wave regions.
- In 2001-02, an upgrade to MORST was introduced, that included parametrizations of the turbulent, heating and water-removing effects of traffic and 'urban warming'. This addressed a cold bias seen at many city-centre locations. Also adaptive site-specific sub-surface diffusion coefficients, derived from the automated roadside observations, were introduced to take account of differing road constructions.
- In 2002-03, a revised and more sophisticated "adaptive" Kalman Filter correction was introduced to correct for systematic biases in forecast temperature.

Areas Where Forecasters Add Value.

Road-side forecast sites are not as well sited as standard synoptic observing sites in that, as mentioned previously, the terrain is often not flat, can be surrounded by buildings or trees, and the roads they are adjacent to have cars running up and down them for example. Unless these are accounted for, there will be systematic errors in any forecast. Accommodation for this can be done intuitively by forecasters, modelled explicitly or some combination of the two. The use of the SSFM data to drive the ice prediction model takes some account of the local terrain and land-use. The introduction of traffic and urban parametrizations has addressed missing physical processes in the ice prediction model, i.e. the extra turbulence generated by moving traffic, the heat emitted from car engines, the removal of road water and snow by tyres and the downward LW heat flux emitted by buildings. The Kalman Filter has been used as a further downscaling tool so that other systematic biases caused by very local effects (e.g. local shading, sites on bridges, traffic jams, proximity to lakes) which are either poorly represented, not represented at all or we don't know how to represent in the ice prediction model can be mitigated.

Due to improvements in the quality of the road ice prediction modelling described above, forecasters are only realistically still able to enhance the site-specific products when there is a systematic bias, or an error (temporal or magnitude) in the large-scale forecast, i.e. the data that used to drive the road ice prediction model. This is because surface temperatures are sensitive to cloud cover, so timings of synoptic scale systems and in particular frontal zones are important. Consequently they are an area where forecasters can significantly improve the automated forecasts. However ongoing long term improvements in NWP capability (e.g. 3D-

VAR, New non-hydrostatic dynamics scheme) mean that this is becoming less frequent and further improvement is expected to filter into the NWP modelling system with future enhancements such as the introduction of 4D-VAR data assimilation.

Forecaster benefit can also be made by ensuring that the product is physically consistent and appears realistic such as adding value at sites that are particularly poorly sited. For example there is one UK prediction site that is shaded from direct sunlight by a number of large trees, so daytime temperatures are often much lower than forecast centrally, especially on cloud-free days. The Kalman Filter "learns" about this bias and reduces the daytime temperatures accordingly. Unfortunately it even corrects this bias on cloudy days when the shading of the trees has little effect (there being little direct sunshine). Through experience forecasters have learned that on cloud-free days, the bias-corrected forecasts are better at that site, but that the uncorrected forecast is better when it is cloudy or overcast.

Forecasters can sometimes add value in marginal cases, where the forecast minimum temperature is close to 0^{o}C. It generally costs more not to salt an icy road (as there are more accidents, disruption etc) than to salt unnecessarily, so forecasters will tend to have a pessimistic bias at the expense of a few extra false alarms. In past years, forecasters have been able to off-set these extra false alarms against others where the 1^{st} guess was overly pessimistic, and delivered a lower overall FAR than the raw forecast. Last year, there were sufficiently few of these 1^{st} guess false alarms that forecasters were not able to do this.

Can We Predict When Forecasters Won't Add Any More Value?

The above results suggest that the limit of capability with the road ice prediction model is very close to being reached because the errors, as demonstrated by perfect prognosis statistics, are dominated not by processes that are not captured or understood but by ancillary information that is either not available or highly complex to interpret and validate. Furthermore it is very costly to collect and maintain. For example, the vector positioning of obstacles that impact on the radiation budget through shadowing and/or the turbulence budget through wake dynamics that also requires detailed knowledge of obstacle shape. Hence development focus in more cost effectively spent on reducing the error in the large scale forecast data used to drive any road ice prediction model. Three ways of achieving this present themselves:

- Improve the large scale NWP system through better data assimilation techniques, such as 4D-VAR assimilation, as well as increased horizontal and vertical resolution in order to resolve the local physical processes that are currently sub-gridscale. This assumes that processes that remain sub-gridscale continue to be adequately parametrized.
- Use the known errors in the large scale NWP system to infer extra useful information. This can be done by running ensembles of the NWP forecast model to test how sensitive an individual forecast is to errors in variables that are important to road ice prediction, such as cloud impacts on the surface radiation budget.
- Central forecaster modification of the large scale NWP fields in a meteorologically consistent way prior to input into the road ice prediction model.

1) Improvement of the large scale NWP system – continual and long term research & development.

The Met Office intends for the UK domain to have an operational 4km NWP Mesoscale model that should outperform the local schemes within the current SSFM by 2005 and an operational 1km Mesoscale model by 2007-08. For the European domain an operational 12km Mesoscale model is intended by summer 2004.

2) Ensembles and Confidence Estimation.

The use of ensembles is attractive because it enables confidence limits in the forecast to be estimated in order to target forecaster intervention. In the example below, for an eight member ensemble of SSFM simulations there is a reasonable spread in minimum temperatures between the ensemble members, but since the worst case ensemble member stays well above freezing, it is unlikely that a forecaster will add much to the decision on whether to salt or not. If this case had happened slightly later in the winter and temperatures were ~4C cooler, then a forecaster may well be able to have some impact.

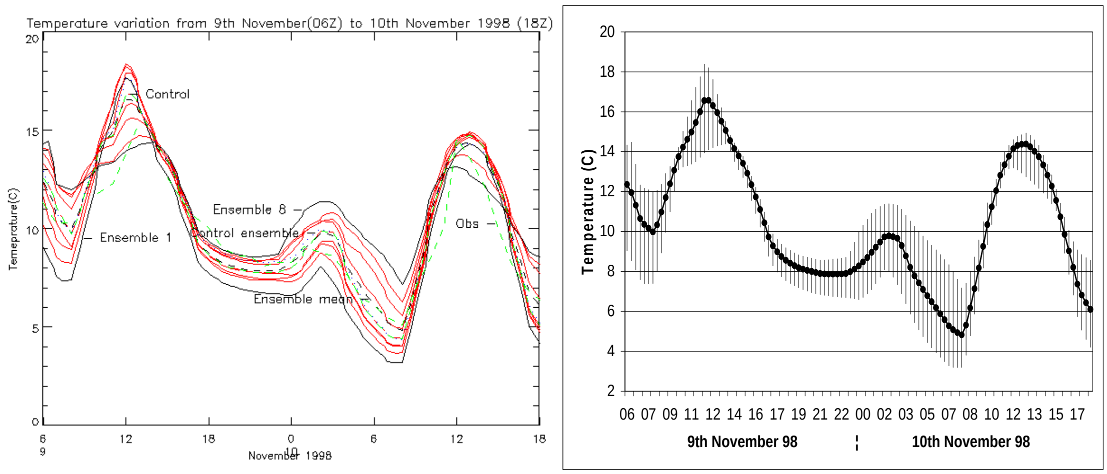


Figure 4 - MORST forecasts from an ensemble of SSFM runs, and an indication of forecast 'confidence'.

Despite these attractions the technique is computationally expensive and to provide and improve disseminated forecasts it needs a reliable mechanism to choose the likely evolution to drive any road ice prediction model.

3) Central Forecaster Modification.

The use of central forecaster modification of the large scale NWP fields in a meteorologically consistent way provides the most tractable short-term way of reducing the error in the large scale forecast prior to input into the road ice prediction model. It also provides a mechanism for reducing or eliminating downstream forecaster intervention on the road ice prediction forecasts. The Met Office has developed an application that allows forecasters, centrally within the Met Office National Meteorological Centre, to reposition and change the intensity of synoptic features such as fronts and depressions as well as clouds and precipitation. Called "on-screen field modification "(OSFM) it allows NWP model fields to be altered, via potential vorticity inversion, in a meteorologically consistent way. A number of modification

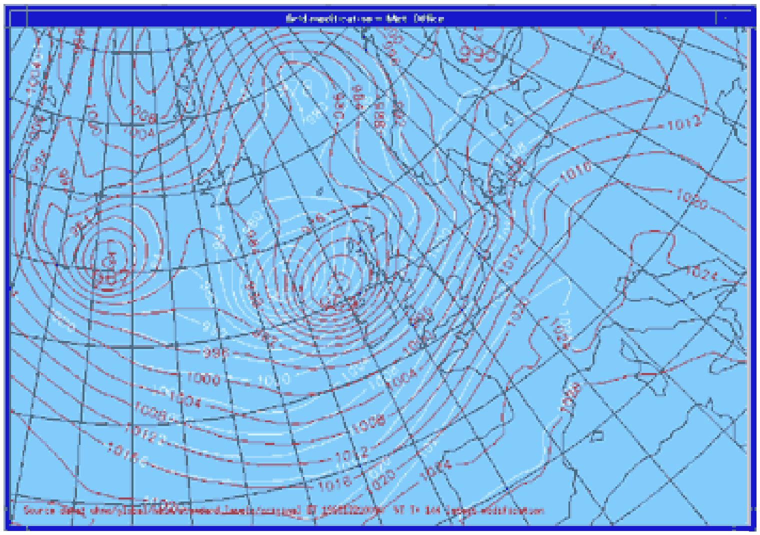


Figure 5 - Surface pressure field, showing original (white) and modified (red) surface pressure pattern

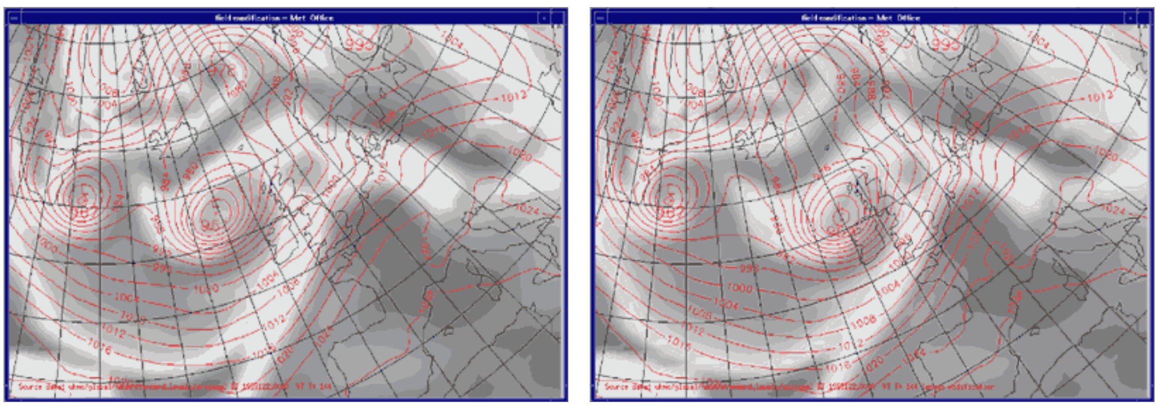


Figure 6 - 700 hPa relative humidity field, showing the effect before (left) and after field

methods allow the forecaster to ensure the changes proposed are meteorologically consistent throughout the atmosphere. A “time-link” feature enables modified fields to be propagated in time, allowing an optimised method of modifying a number of forecast periods at once. Modification to the precipitation and humidity (surrogate cloud) fields are moved along with the dynamic fields, so a coherent structure is retained. In addition, a decoupled editing option is available whereby areas of precipitation (rain and snow) can be moved, pasted in or cut out, or the rain/snow divide in existing areas of precipitation can be moved. This allows the forecaster to override the NWP output, increasing orographically enhanced rain or reducing precipitation in the light of experience with the model. Also when the dynamical fields are modified via potential vorticity, a new consistent wind field is generated automatically. Examples are shown in Figures 5 & 6.

The OSFM methodology, as it is inverting the potential vorticity field, is limited to changes to synoptic scale features. Applying it to Mesoscale and local scale phenomenon such as cloud introduces an imbalance into the boundary layer. This can be brought back into equilibrium and continue to propagate the changes made by the OSFM system by coupling the output to the SSFM. As an added benefit this coupling takes advantage of the local physical schemes encompassed within the SSFM. To take full advantage of this methodology requires the subsequent downstream coupling of the field modified SSFM output to the centralised ice prediction model. This is currently under development and is expected to become operational in 2004 in preparation for the 2004-05 northern hemisphere winter.

Conclusions

The conclusions are summarised below:

a) Accuracy of ice predictions is dominated by two errors: the error in the large scale synoptic evolution (NWP) and the error in the local diagnosis of road ice (ice prediction model) from the large scale synoptic evolution.

b) The performance of ice prediction models, though easier to improve, have reached the limit of cost-effective technology.

c) Further, due to the recent improvement in ice prediction models, forecasters mainly add value to road ice forecasts by correcting errors in the large scale synoptic evolution.

d) Hence to make further improvements and fully open the possibility of semi or full automation the focus of work needs to turn to methods of either correcting or mitigating the occasional errors in the large scale evolution (NWP).

e) Improvement in NWP to reduce the occurrence of errors in the large scale synoptic evolution is a long term incremental process unlikely to deliver benefits in the next five to ten years. This is because although we have the capability to use high resolution 3D models we do not yet know enough about modelling the newly resolved processes and the data assimilation methodology required to optimise performance.

f) The use of ensemble techniques to gain forecast confidence information in order to target forecaster intervention, though scientifically tractable, is too computationally expensive. Central forecaster field modification provides an alternative short to medium term way forward.

g) Although this appears to predict the end for forecaster involvement the reality is that the forecaster role may change to become more of a consultant offering interpretation specific to particular customers. For example focussing on the outcomes of the ice prediction service and helping customers decide how to deploy their salting vehicles and where and at what time is the most optimum to salt.