Impact of High Resolution Site Specific Modelling on Road Surface Temperature Forecasts

P.E. Maisey, W.P. Hopwood & I.J. Pearman

Local Forecasting R&D,
UK Meteorological Office
London Road, Bracknell
Berkshire RG12 2SZ

Abstract

The use of a Site Specific Forecast Model (SSFM), a high resolution 1D local forecasting model forced from either 3D global or mesoscale NWP output, in road weather forecasting is demonstrated. This brings with it the potential for improvements in the atmospheric forecast data used to drive a Road Surface Temperature model. Furthermore, this allows the automation of labour in the production of the large number of road weather forecasts currently provided. The SSFM takes account of the local environment surrounding the site and models the boundary layer evolution in more detail. Results from two winter trials are presented and show significant improvements in forecast accuracy. A much more extensive trial is now under way.

Introduction

The UK Meteorological Office's Site Specific Forecast Model (SSFM) is a 1D model that has been under development for the past four years. It is designed to improve local forecasting at specific locations through the use of higher resolution modelling and better representation of the surroundings of a site, yet maintain overall consistency via coupling to either global or mesoscale NWP output.

The UK OpenRoad system provides road weather forecasts for over 400 sites in the United Kingdom through the use of a Road Surface Temperature (RST) model (Rayer 1987). Currently, the UK Met Office's Mesoscale Model (MES) is used to derive atmospheric variables which drive the RST model, but since the horizontal resolution of the MES is currently around 11km, interpolation of this data for forcing the RST model leads to errors in representivity. The SSFM is ideally suited to provide much better forcing data to the RST model.

Site Specific Forecast Model (SSFM)

The SSFM is run four times a day out to a forecast time of 36 hours. Coupling to the relevant 3D model - the MES for UK sites or the Unified Model (UM) globally - provides the method by which large-scale flow is incorporated. Profiles of the basic atmospheric variables - temperature, wind, etc - are interpolated from the nearest gridpoints in the 3D model. These are then relaxed onto the SSFM profiles from the previous model run such that the large scale flow dominates above the boundary layer and the influence of the surface increases through the dominant influence of the SSFM profiles in the lower model levels. The SSFM is a high resolution 1D version of the UM with a four-fold increase in vertical resolution over the MES, with much of this increase concentrated in the boundary layer (53 levels below ~2.2km) primarily to improve the treatment of fog and vegetation canopy transports.

The SSFM uses much of the UM physics routines, such as precipitation, cloud and convection schemes, to maintain compatibility with the driving model and reduce development and maintenance costs. However, there are several additional schemes which are used to improve representation of the surface exchange.

Turbulent exchange at a particular location is dependent not only on the fluxes at that point but also on the fluxes within the upwind fetch. The SSFM takes this into account through the use of high resolution (25 metre horizontal resolution) land use data, a tiling approach to surface exchange and a source area model (SAM) methodology. The tile scheme calculates fluxes over each surface type (i.e. grass, trees, urban) individually and then estimates the aggregate surface fluxes rather than using effective parameters. The SAM derives an upwind *fetch footprint* within which the contribution of each surface flux to the aggregate is determined based on distance from the site and atmospheric stability. A further improvement to the treatment of surface exchange is provided by the use of a vegetation canopy scheme which decouples the ground flux from fluxes in the bottom model level by representing the canopy layer as a purely radiative link between the two. High resolution (100 metre horizontal resolution) orography data is used to calculate orographic roughness parameters to account for the effects of sub-grid scale orography. It is also used in an orographic correction scheme to determine possible flow cut-off due to orography, based on boundary layer stability. Model profiles are adjusted by using the first model level for which flow cut-off does not occur as the new *effective surface*.

The SSFM has been running since 1996 and has already shown significant improvements over the MES for site-specific forecasting. Currently, around 600 sites are run operationally over the UK. These are made up of around 200 standard UK observing sites (Weather Centres, military and civilian airfields) and over 400 OpenRoad sites. In addition, there are now a small but rapidly expanding selection of International OpenRoad sites in Sweden, Canada and the USA for which road weather forecasts are being provided on a trial operational basis.

Road Surface Temperature model (RST)

The RST model is a 20-layer soil temperature model, with a fixed bottom level temperature which is set to a monthly climatological value and a surface temperature which is determined from an energy balance at the surface. The soil temperature profile is initialised either using output from the previous model run or by using an idealised linear profile. Observations of screen temperature and dewpoint, 10m wind speed and 30cm soil temperature taken from the OpenRoad location can be used to constrain the model bias in the longer term, but are not essential. The surface energy balance is calculated using forecast values of screen temperature and dewpoint, 10m wind speed, cloud and precipitation supplied by the SSFM at hourly intervals. Simple empirical schemes are then used to estimate the longwave and shortwave radiative fluxes.
The RST model simulation runs for 30 hours forced from the 06Z SSFM run to cover the following nocturnal period. It models the evolution of the vertical soil temperature profile using the heat flux into the roadbed and the layers below (to a depth of 1.15m) with an explicit finite difference scheme.

UK OpenRoad forecasts - winter 1997/98 trial results

An initial trial of the SSFM coupled to the RST model was carried out during the 1997/98 OpenRoad season, from November to January inclusive. This was for a selection of five UK sites (Table 1) chosen to cover a variety of environments, such as hill tops and frost-prone valleys, along with several standard meteorological observing sites. Forecast road surface temperature minima and occurrences of road surface temperature below 0°C were verified. Table 2 summarises results from the winter 1997/98 trial, comparing the number of occasions

Site ID	Site name	Latitude	Longitude
BU004	Astwood	52.12 N	0.60 W
WM006	Sedgley Ridge	52.54 N	2.13 W
ST007	Smestow Gate	52.53 N	2.22 W
LA002	Mere Brow	53.66 N	2.88 W
ME008	Catchdale Moss	53.47 N	2.80 W

Table 1 : Names and locations of the UK sites used during the winter 1997/98 trial

% - out of 390 cases		Observed		Hit Rate	False Alarm Rate	% correct	CSI	ETS	HK Skill Score
		T≤0°C	T>0°C						
MES	T≤0°C	14.1	10.5	75.34	42.71	84.87	48.25	38.56	60.49
	T>0°C	4.6	70.8						
IFC	T≤0°C	15.6	11.8	83.56	42.99	85.13	51.26	41.40	66.59
	T>0°C	3.1	69.5						
AFC	T≤0°C	15.4	7.7	82.19	33.33	88.97	58.25	50.09	71.74
	T>0°C	3.3	73.6						
SSFM	T≤0°C	15.9	11.0	84.93	40.95	86.15	53.45	43.95	69.24
	T>0°C	2.8	70.3						

Table 2 : Winter 1997/98 trial results

when the observed road surface temperature during a model integration period fell to or below 0°C against forecast data for the same period. Four forecasts are considered, the MES-driven RST model (MES), output from the MES with initial manual forecaster adjustment (IFC), forecaster-adjusted output amended to take account of more up-to-date data (AFC) and the SSFM-driven RST model. Overall, the SSFM-driven RST model outperforms both the MES and the initial forecaster output. Whilst the number of correct non-freezing event forecasts is

Site ID	Site name	Latitude	Longitude
Montana, USA			
S00300428	Macdonald Pass	46.59 N	112.30 W
S00300429	Gary Cooper Bridge	47.18 N	111.83 W
S00300430	Reedpoint I90	45.73 N	109.63 W
Ontario, Canada			
S00300431	Vespra	44.39 N	79.76 W
S00300432	Putnam	43.06 N	81.00 W
Idaho, USA			
S00300434	Cotterell	42.50 N	113.41 W
S00300435	Isaacs Canyon	43.51 N	116.15 W
S00300436	Black Canyon	43.87 N	116.78 W
Sweden			
S00300437	Lekhyttan	59.26 N	14.81 E
S00300438	Stockholm (Soderhall)	59.69 N	18.42 E
S00300439	Stockholm (Frosundavik)	59.39 N	18.01 E

Table 3 : International OpenRoad site names and locations for winter 1998/99 trial

Site name	Mean error	KF mean	RMS error	KF RMS	% accuracy	KF % accuracy
Macdonald Pass	1.69	0.23	7.0	2.1	79.8	81.9
Gary Cooper Bridge	3.13	0.13	4.8	2.0	71.3	94.1
Reedpoint I90	-0.92	-0.31	4.5	2.2	75.4	79.6
Cotterell	-0.03	0.10	4.1	2.1	88.1	94.5
Isaacs Canyon	1.04	-0.08	4.6	1.9	80.2	90.5
Black Canyon	1.62	0.01	4.2	1.9	85.4	92.7
Vespra	2.2	0.0	3.9	1.7	87.9	92.8
Putnam	3.8	0.0	4.9	1.4	81.3	93.1

Table 4 : International OpenRoad winter 1998/99 trial results

similar in all three, the SSFM missed far fewer sub-zero events. For the individual sites (results not shown), the SSFM outperformed the MES on all the skill scores although the results at a couple of the sites lack sufficient data to be considered representative due to the exceptionally mild, frost-free conditions during much of the study period.

International OpenRoad forecasts - winter 1998/99 trial results

The use of the RST model driven from the SSFM was extended to eleven foreign locations for a trial during the winter of 1998/99. The sites were all used by the relevant state or national transportation authorities in their own road weather networks and covered the US states of Montana and Idaho, Ontario in Canada and three sites in Sweden (Table 3).
Some degradation of the SSFM performance was expected relative to the UK sites, because of the use of UM global forcing data (with a horizontal resolution of 60km), the AVHRR-derived land use data (with a horizontal resolution of 1km) and 1km horizontal resolution orography data.
Table 4 shows the results for January to March 1999 inclusive. Apart from the degradation in accuracy already attributed to the reduced resolution of the forcing and site environment data, possible source of error resulted from the incorrect specification of the road bed characteristics (the site data being based on UK road construction), traffic volume effects and non-standard exposure of the sensors. Since these are all in some part systematic errors they can be accounted for in this instance by using a Kalman filter technique.
Results show a percentage accuracy comparable with the UK OpenRoad sites and recipients of the products have commented on the high accuracy.

Conclusions

The combination of the SSFM and the RST model has shown significant improvements in skill in forecasting road surface temperatures for a fraction of the cost of manual forecasting for such a large number of sites. This benefit has been demonstrated for UK sites and abroad despite an absence of the high resolution data required as input.

Future developments

Further improvements in the SSFM are under way. These include applying linear flow modelling to modify the wind field around a site based on the local orography and improve wind speed and direction forecasts, especially for sites in areas of complex terrain. The use of local observational data within the model is also being studied. Adjustments to the RST system are being considered, making product delivery more efficient and allowing application of the model to a wider variety of sites.

References

Rayer, P.J. 1987: The Meteorological Office forecast road surface temperature model, **Meteorological Magazine 116**, 180-191