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THE IMPLEMENTATION AND PERFORMANCE OF A 1D MODEL COUPLED TO NWP FORCING FOR LOW-COST SITE-SPECIFIC FORECASTING.

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1. INTRODUCTION

The resolution of operational Numerical Weather Prediction models has improved steadily over time, to the extent that horizontal resolution of about 10x10 km is now achievable. However, neither this or the next generation (which may improve resolution by a factor or 2 or 3) is sufficient to resolve small urban areas or, in practice, the variations that tend to occur within large urban areas. Until sufficient computer power becomes available, alternative methods are required for operational urban forecasting. Furthermore, for some applications, such as forecasting road surface conditions, it is questionable whether full 3D modelling will ever be appropriate, since the very local environment can be very dominant.

While some features of urban meteorology require solution of the 3D problem, the broader features of the urban boundary layer can be described using a 1D model; indeed, many routinely applied air quality models require only 1D information, as they assume local homogeneity. With this in mind, the U.K. Meteorological Office (UKMO) has developed a forecasting model based upon a 1D version of its NWP model (the Unified Model), dynamically forced from 3D NWP data modified in a simple way to take some account of local orography. Extensive modifications have been made to the surface exchange scheme to provide better urban (and rural) simulations, based upon a multiple tile approach driven by detailed land-use and orography data. Care has been taken to represent the 'urban' tile component realistically, both in terms of drag and surface heat and moisture exchange.

This paper describes the formulation of this 'Site-Specific Forecast Model' (SSFM), together with results from trials.

2. MODEL FORMULATION

The model is based upon the 'single column' version of the UKMO Unified Model; it includes parametrizations of the full range of diabatic processes, including a full long-wave and shortwave radiation scheme, layer and convective cloud and precipitation processes, boundary layer transport and surface exchange. In practice the convection scheme has been used in a 'diagnostic' mode, to provide input to the radiation and hydrology schemes, but not allowed to impact the prognostic variables as convection is regarded as a process occurring on a scale larger than the model. The boundary layer is treated using a purely local scheme, though a new non-local scheme has been developed and will be tested in future versions of the model. The boundary layer scheme is run with four times the vertical resolution of the operational NWP models (i.e. 53 levels below about 2.2 km), primarily to improve treatment of fog and cloud processes. The UM surface scheme is typical of NWP and GCM models and is relatively simple. It uses a Louis type explicit surface exchange parametrization, the surface being represented by a fixed roughness, vegetation fraction, surface resistance to evaporation, albedo etc.. The sub-surface is represented using a 4 layer heat transport scheme and single layer hydrology. This surface and sub-surface scheme has been completely replaced as described below.

The UM physics have been used to minimize development and maintenance costs and maintain compatibility with the driving model. In this respect the approach is very similar to that of Gollvik and Olsson (1995), who use a high vertical resolution 1D version of HIRLAM. However, our approach to forcing the model and surface exchange is somewhat different. We have argued that, in practice, local meteorology is generally dominated by two factors - local orography and the surface characteristics of the upwind fetch. It is very difficult to correct a great deal for local orography in a 1D model. We have implemented a simple system which assumes that the 'zeroth' order impact of orography is through surface pressure perturbations.

To force the model, we extract surface pressure and height and vertical profiles of wind, temperature and total water from NWP output, together with their horizontal gradients. From these we derive the hydrostatic pressure gradient and large scale vertical velocity. The NWP model levels are assumed to be perturbed by local orography as follows. First, the maximum upwind elevation (out to a range of 10 km) relative to the orography in the forcing model is used

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to estimate whether any flow blocking is likely. A (conservative) estimate of a ’dividing streamline height’, H, is derived from U/N where U is the average wind speed in the layer and N the average buoyancy frequency. (These are defined using strict energy considerations but space does not permit further detail). If above the surface, the forcing profile below this is discarded, the position of the maximum upwind elevation used to define the model fetch. Whether or not such blocking occurs, the remaining ’connected’ levels in the forcing data are perturbed an amount based upon a simple linear perturbation model, viz:

$$h(z) = h(0)e^{-M(z)} \tag{1}$$

where

$$M(z) = k\int_0^z \left(1 - \frac{N^2}{U_0^2 k^2}\right)^{\frac{1}{2}} dz' \tag{2}$$

and the buoyancy frequency, N, is defined as usual.

The ’representative’ wavenumber, k, represents the ’typical’ slope of the local orography and is derived from the ratio of the typical peak to trough height (derived from the standard deviation of local orography) to the ’silhouette cross sectional area per unit surface area’. These parameters are used in the orographic roughness scheme, which represents drag due to unresolved orography. They are derived from the local orography out to a fetch of 5 km, a distance typical of that required to deal with local surface heterogeneity (see below). Once the level perturbations are derived, it is straightforward to derive the new surface pressure and perturbed profile. In principle, a correction to the wind could also be made, and results suggest that this may be worthwhile, but remains as future work.

This modified forcing data is used straightforwardly, using pressure gradient, Coriolis and advection terms in the momentum budget and advection terms in the temperature and moisture budgets. An additional term is used to represent ’local’ advection: if we denote the ’large scale’ forcing data with the subscript L, then we can break down advection in some quantity c according to:

$$\boldsymbol{u}.\nabla c = \boldsymbol{u}.\nabla c_L + \boldsymbol{u}.\nabla(c - c_L) \tag{3}$$

The first term is supplied by the forcing data. The second represents advection of local perturbations. We parametrize this by:

$$\boldsymbol{u}.\nabla(c - c_L) \approx |\boldsymbol{u}|\frac{(c - c_L)}{L_F} \tag{4}$$

where L_F is the fetch length, defined by the shorter of the orographic cutoff fetch defined above or the grid box size of the forcing NWP data. This relaxation term also ensures that the simulation does not stray unrealistically from the forcing model.

The orographic corrections are extremely crude. It is possible to treat surface exchange rather more accurately in a 1D model. In principle, it is evident that the nature of the immediate upwind surface is crucial in determining the thermodynamic and turbulent structure of the lower boundary layer. We treat heterogeneous surface exchange using a tile scheme, where surface exchange over each separate land-use category is treated assuming homogeneous equilibrium (using Monin-Obukhov theory), the separate fluxes being calculated and combined at an appropriate blending height. The amount of each surface contributing is calculated using a Source Area Model(SAM), which effectively calculates the weight given to each upwind surface element on the basis of its contribution to the flux at the ’diffusion’ height (at which the surface appears homogeneous). Diagnostics at other heights (such as screen temperature) are computed from weighted averages of equilibrium values using weights derived with a similar SAM appropriate for that height. Validation of the scheme is discussed further by Hopwood (1998a and b).

Over the UK we use LANDSAT derived land-use data with 25m resolution (supplied by the Institute of Terrestrial Ecology). At present this is reduced to 7 effective classes, deciduous trees, coniferous trees, C3 grass (including crops) C4 grass (generally not applicable to UK), bare soil, urban and open water. Over each surface, a surface exchange scheme which simulates plant physiology to derive surface resistance to evaporation, is used (Cox *et al*). This has been modified to include a radiative canopy over the vegetative and urban tile. The urban canopy is of particular interest and is discussed by Best (1998).

3. MODEL EVALUATION.

The model was developed over a two year period, during which various versions were run on a daily basis for a number of sites, including the Meteorological Research Unit, Cardington, where detailed surface flux measurements were collected for comparison, and several synoptic observation stations. The final version of the model was trialled for a 3 month period, November 1997 to January 1998, at 14 synoptic stations (mainly airfields) and 5 sites which are used as part of the UKMO OpenRoad service.

This service uses a Road Surface Temperature model (RST) to forecast road surface conditions. This is driven by atmospheric data (screen temperature and humidity, cloud cover and 10 m wind speed). A first guess is provided by output from the mesoscale forecast model, which may be manually modified by forecasters. The SSFM is intended as a means of providing an improved first guess. The 5 sites were chosen as a challenge to the model, so verification statistics should not be regarded as representative of the service. Service targets are based on forecasts of surface frost, so this has been used to illustrate the SSFM performance. Scores for three systems are given below: the RST driven by mesoscale NWP forcing data (MES), driven by mesoscale NWP forcing data modified at the weather centre by human forecaster (WC) and driven by SSFM output. Overall hit rate (HR), false alarm rate (FAR), Equitable Threat Score (ETS) and Hanssen-Kuiper skill score (HK) are given in Table 1.

Table I - Open Road Performance

Config.	Score (%)			
	HR	FAR	ETS	HK
MES	75.3	42.7	38.6	60.5
WC	83.6	43.0	41.4	66.6
SSFM	84.9	41.0	44.0	69.6

These results show an overall performance slightly superior to the human forecaster. When the 5 sites are considered separately, performance greatly exceeds the mesoscale first guess at all, but it exceeds that of the forecaster at only 3 out of 5.

These results might, of course, simply represent the impact of improved physics. The ’site-specific’ skill can be judged by considering two sites close enough together to see essentially the same mesoscale forcing. Heathrow Airport and Beaufort Park were chosen, being about 25 km apart but having very different environments. The average fetch land use fractions of urban and grass are show in Fig. 1 for the two sites: clearly Beaufort Park is much more rural.

The degree to which the site characteristics have been taken into account may be judged by comparing the forecast difference in a parameter with the observed difference. The mean and standard deviation of this population for screen temperature for the November ’97 to January 98 3 month trial is shown in Fig. 2 as a function of forecast time for the forecast initiated at 12Z. This confirms that the forcing mesoscale model is incapable of resolving significant differences, while the SSFM clearly captures some, but not all of the difference. Interestingly, both the model and observations show the greatest difference during the evening transition period. A similar plot for RH (Fig. 3) shows some, but rather less capability. This plot includes the short

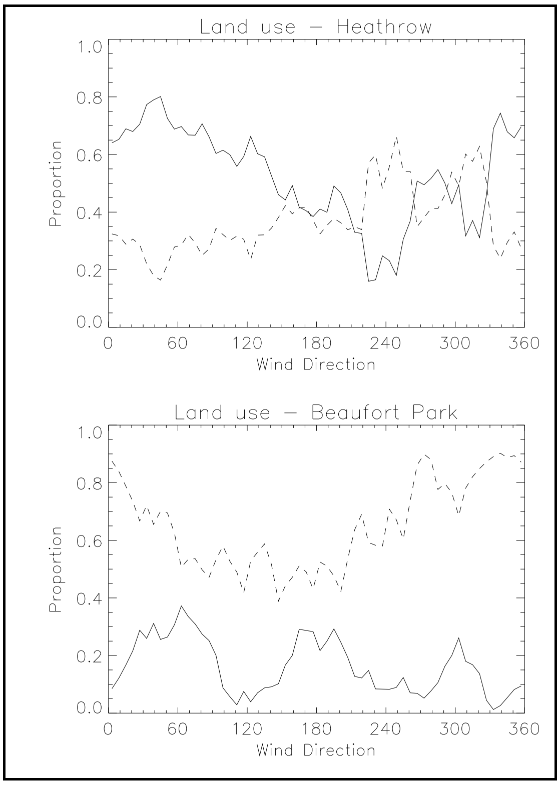

Figure 1 Average fetch proportion of urban and grass (dotted) for Heathrow and Beaufort Park.

range forecast where data assimilation ensures that the mesoscale contains some local site data, though clearly this has largely been discarded in the assimilation process.

Similar diurnal cycles are exhibited by runs initiated at other times of day, except for the period close to the run start. To show the ’average’ response, data from the 06Z run, which extends to T+30, have been extracted from T+6 to T+30 and averaged. Fig. 4 shows the average temperature difference as a function of observed difference. The frequency of extreme differences was small, and the error bars denote two standard errors about the mean. Nevertheless, these confirm roughly a factor of two difference between forecast and observed urban warming in the SSFM, while no urban warming is evident in the mesoscale forecast.

4. CONCLUSIONS.

Space does not permit a full analysis of the system, but results clearly demonstrate that a relatively simple 1D model can add significant local skill to mesoscale NWP forecasts, and in some applications match that of the human forecaster. Some, but not all of the autumn urban/rural contrast can be captured simply by more accurate treatment of the upwind surface exchange, taking proper account of the impact of inhomogeneous terrain.

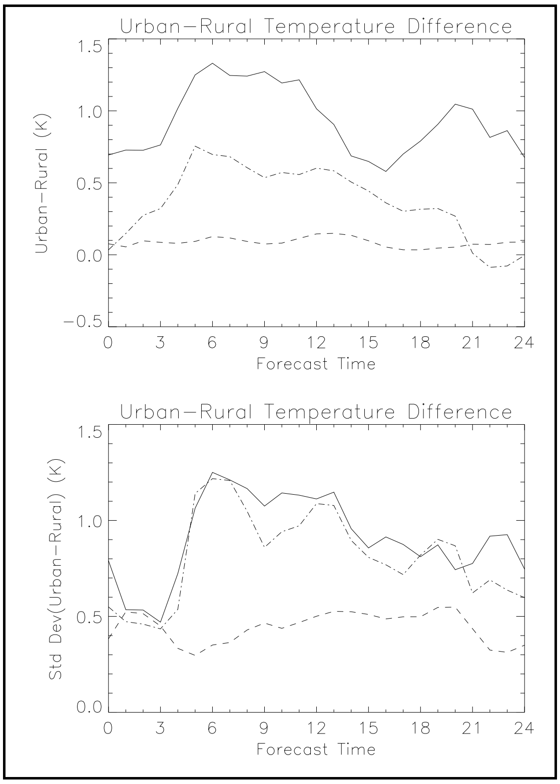

Figure 2 Mean and standard deviation of temperature difference between Heathrow and Beaufort Park. Obs (solid), Mes (dashed), SSFM (dot-dashed).

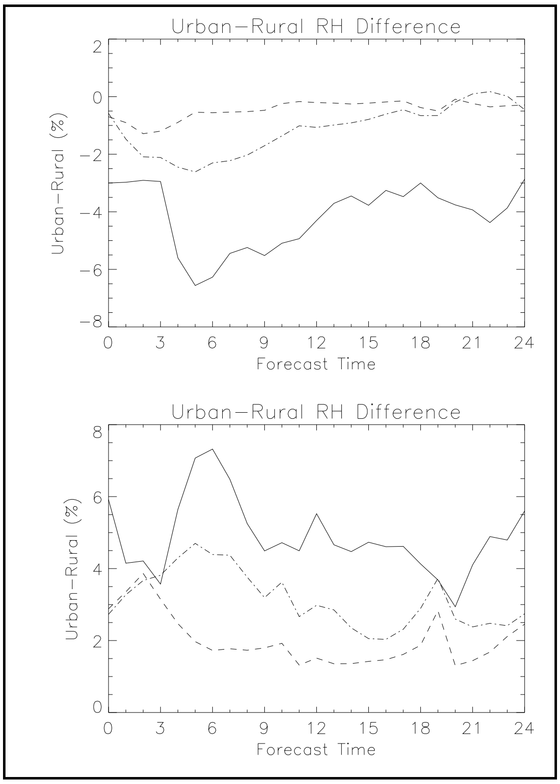

Figure 3 Mean and standard deviation of Relative humidity difference between Heathrow and Beaufort Park. Obs (solid), Mes (dashed), SSFM (dot-dashed).

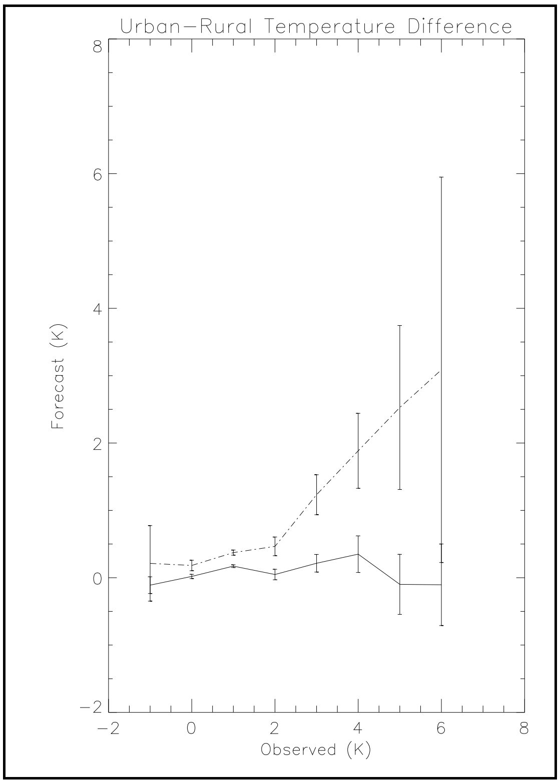

Figure 4 Average forecast temperature difference between Heathrow and Beaufort Park from T+7 to T+24 from the 06Z forecast. Mesoscale solid, SSFM dashed.

5. References.

Best, M.J., 1998, Representing urban areas in numerical weather prediction models. Proceedings Second Symposium on Urban Environment, Albuquerque, New Mexico

Cox, P.M., Betts, R.A., Bunton, C.B., Essery, R.L.H., Rowntree, P.R. and Smith, J. 1998 The impact of new land surface physics on the GCM simulation of climate and climate sensitivity. Submitted to *Climate Dynamics*.

Gollvik,S. and Olsson,E.,1995, A one-dimensional interpretation model for detailed short-range forecasting. *Met. Apps* 2,209-216

Hopwood, W.P., 1998a, The implementation and validation of a tile surface exchange scheme within a site-specific model over partly forested areas. Proceedings 23rd Conference on Agricultural and Forest Meteorology, Albuquerque, New Mexico.

Hopwood, W.P., 1998b, The coupling of a source area model to a site-specific model for Diagnosis of land surface characteristics within partly forested areas. Proceedings 23rd Conference on Agricultural and Forest Meteorology, Albuquerque, New Mexico.