Modelling the Stable Boundary Layer in Operati

J. M. Edwards and A. P. Lock

Summary

It is a commonplace in boundary-layer research that operational NWP models must be run with enhanced mixing in the SBL to produce acceptable forecasts. Over the past decade, the degree of enhancement employed in forecasting configurations of the Met Office Unified Model (MetUM) has gradually been reduced, to the extent that sharp-tailed stability functions are now used in short-range high-resolution forecasts for the UK. We review the current position in global and high-resolution models, indicating how improvements in parametrizations and vertical resolution have made this possible, and offer a perspective on current issues.

Parametrization of Turbulent Mixing in Stable conditions

Turbulent mixing in the MetUM is represented using a typical first-order closure. The reduction of the diffusivity as the stability of the atmosphere increases is represented by a Richardson number-dependent tail, $f_{m,h}$. Various different forms of tail are in use.

$$K_{m,h} = l_m l_{m,h} \left|\frac{\partial \mathbf{u}}{\partial z}\right| f_{m,h}(Ri), \qquad \text{with} \quad f(Ri) = \begin{cases} 1/(1+10Ri) & \textbf{Long} \\ 1/(1+5Ri)^2 & \textbf{Louis} \\ \begin{cases} (1-5Ri)^2 & \text{if } Ri < 0.1 \\ 1/(20Ri)^2 & \text{if } Ri > 0.1. \end{cases} & \textbf{Sharp} \end{cases}$$

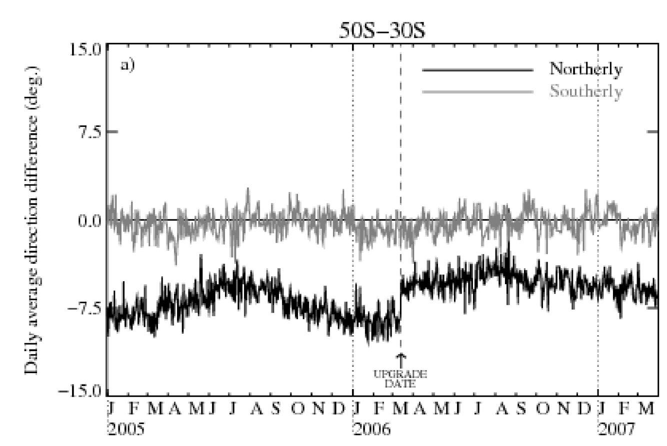
Additionally some configurations use "Mesoscale" tails that are equivalent to Louis tails at the surface, but are interpolated linearly in height to Sharp at 200 m. Mixing is reduced through the sequence, Long, Louis, Mesoscale and Sharp. The neutral mixing lengths for momentum and scalars are set using Blackadar's formula and the asymptotic mixing lengths are defined as fractions of the boundary layer depth, h_{BL},

$$l_{m,h}^{-1} = (kz)^{-1} + l_{\infty m,h}^{-1} \quad \text{and} \quad l_{\infty m,h} = \max(40\text{m}, \alpha_{m,h} h_{BL}),$$

where $\alpha_{m,h} = 0.15$, except in the global model, where, currently, $\alpha_m = 0.3$.

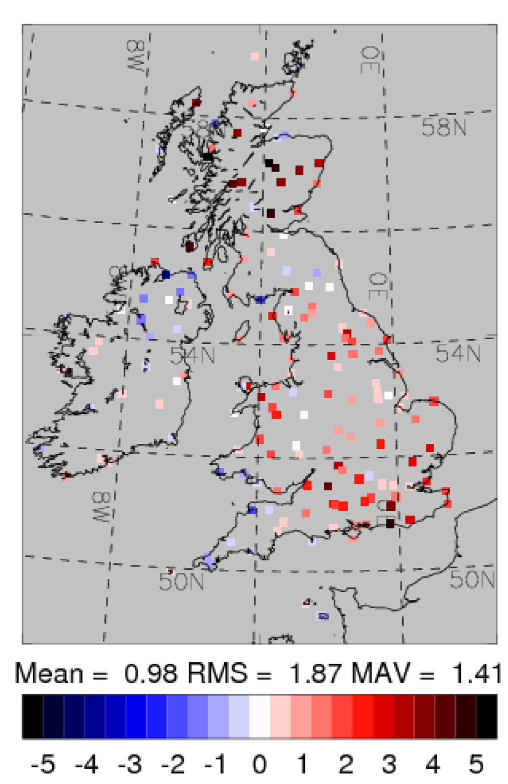
The Global Configuration

Long tails have been used in global NWP since the introduction of the MetUM. In March 2006, sharp tails were introduced over the sea, resulting in a reduction in errors in wind direction during warm advection (Brown et al. 2008). However, long tails were retained over land to avoid pronounced cold biases developing over 5-day forecasts.
This summer we plan to implement a new configuration of the model that will introduce mesoscale tails over land and reduce α_m to 0.15, in line with other configurations.

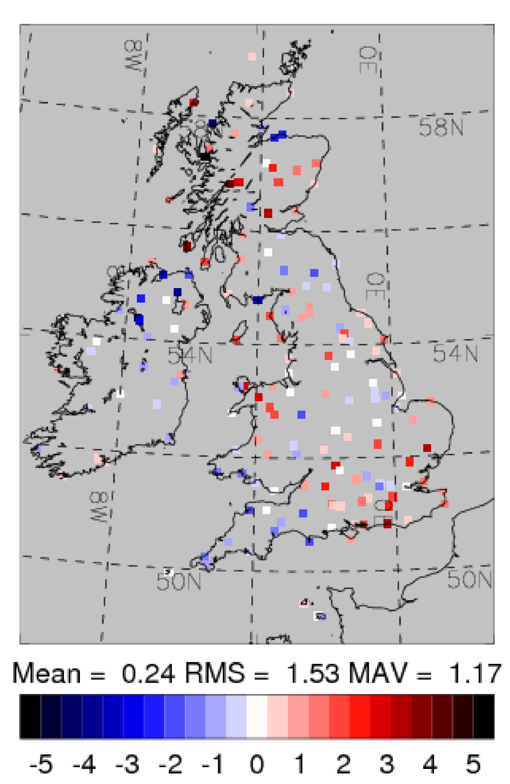


The High-resolution Configuration

Short-range forecasts for the UK are produced using a 1.5 km model that is run to T+36. This superseded an earlier 4 km model in 2009.
At the beginning of 2007, the 4 km model, with mesoscale tails, showed a consistent cold bias of about 0.2 K in winter. By early 2012, following various upgrades, a warm bias in the 1.5 km model, also with mesoscale tails, had become apparent on clear nights with light winds. In December 2012 we implemented a new physics package that introduced sharp tails. This significantly reduced the warm bias in such cases, as shown by the reduced errors in 1.5 m temperature at 06 UTC on 12 Decemeber 2012 with the new package. (Crucially, the overall performance of the package over an extended period was also beneficial.)



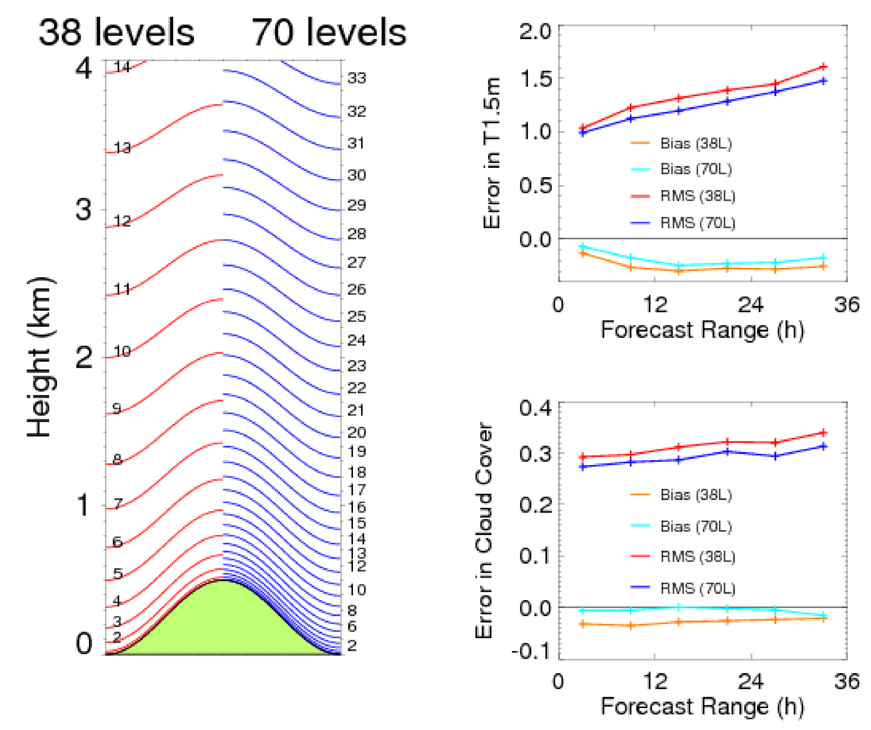
Operational Model: Error in T1.5m



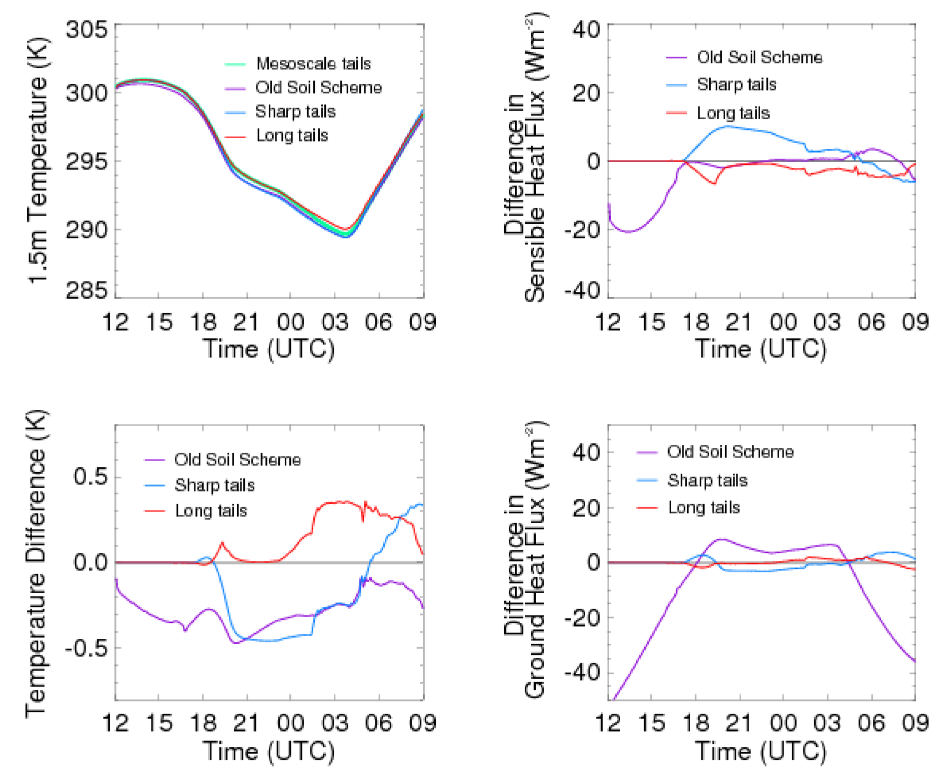
Reduced Mixing: Error in T1.5m

Many individual changes contributed to counteracting the model's original cold bias, but finer vertical resolution and improved representation of clouds and soil properties were significant.

- In December 2007, the vertical resolution of the then 4 km UK model was increased from 38 to 70 levels, with the lowest model level at 5 m instead of 20 m. This reduced the model's cold bias in 1.5 m temperature by 30% and the rms error by 10%. The increased resolution allowed better representation of cloud, essentially removing a low bias of 3% in the cloud fraction, thus reducing LW cooling of the surface. Improvements in the assimilation of cloud have also contributed.

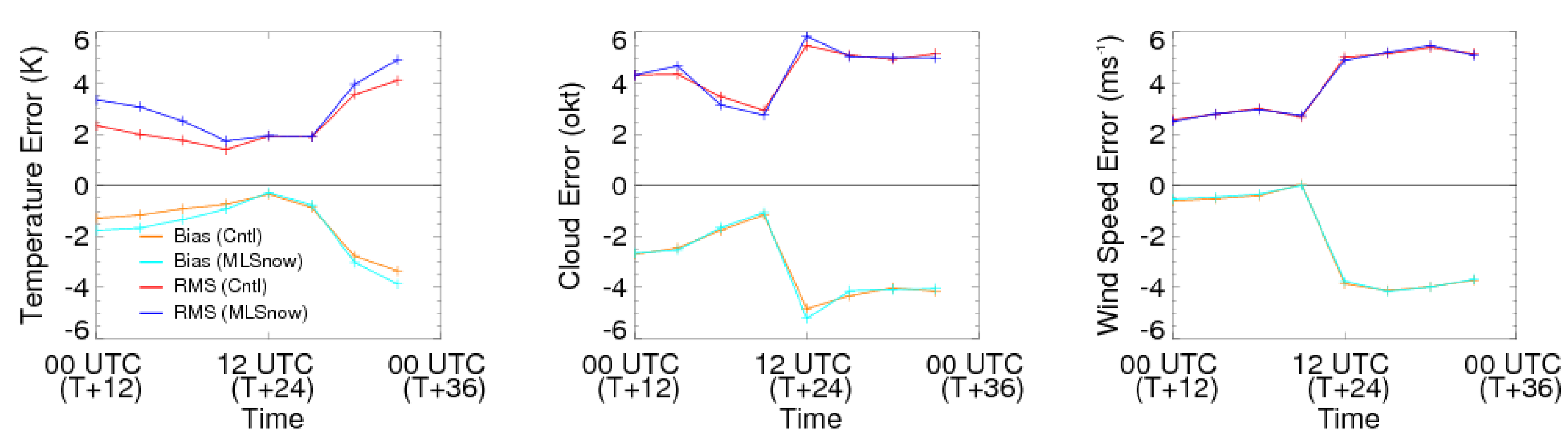


- Revised soil hydraulic and thermal properties were introduced in 2008. These reduced evaporation and increased heat storage in the ground. We illustrate their impact by running the GABLS3 SCM case (a diurnal cycle starting at noon, including an interactive surface scheme) with various stability functions and also with mesoscale tails, as were then operational, but with the old soil scheme.
The nocturnal cooling due to introducing sharp stability functions is very similar to that due to reverting to the old soil properties, while changes in the ground heat flux and the sensible heat flux are of a roughly equal magnitude.



Current Developments bearing on the SBL

- Snow: Currently snow is treated as part of the top soil layer. This overestimates the thermal inertia of the snowpack and can lead to warm biases when the temperature falls rapidly. We aim to implement a multilayer snow scheme with less thermal inertia, but this makes the model more sensitive to errors in other schemes. In this example forecast, both the operational configuration and the multilayer snow scheme exhibit cold biases resulting from very similar errors in cloud and wind speed, but the multilayer snow scheme is more sensitive to these errors, yielding larger RMS errors in temperature.



- Coupling to the canopy: Evidence from the DICE project (See presentation 46.B) suggests that the canopy is too closely coupled to the surface and that fraction of bare soil is too high.

Conclusion

Gradual progress is being made in reducing enhanced mixing in the SBL in operational NWP by the elimination of compensating errors in associated schemes, but parametrizations which produce less damping, even if physically better based, may lead to increased RMS errors.
We have emphasised near-surface temperatures here, but parametrization of the SBL is also important in the forecasting of wind speeds, which are still overestimated at night.

References

Brown AR, Beare RJ, Edwards JM, Lock AP, Keogh SJ, Milton SF, Walters DN (2008) Upgrades to the Boundary-Layer Scheme in the Met. Office Numerical Weather Prediction Model. Boundary-Layer Meterol 128:117–132.

Met Office FitzRoy Road, Exeter, Devon, EX1 3PB United Kingdom
Tel: 01392 885680 Fax: 01392 885681
Email: john.m.edwards@metoffice.gov.uk