Understanding cold valleys in convective scale models

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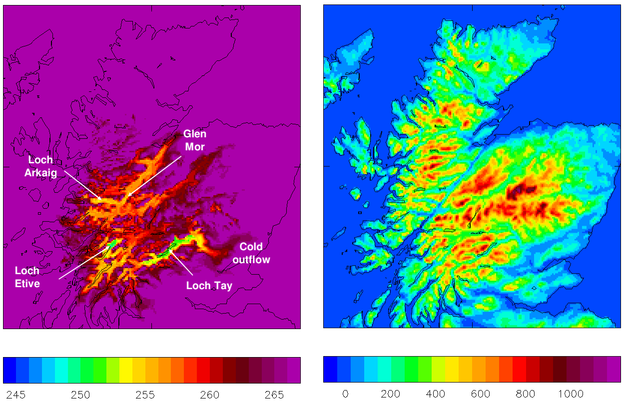
The Met Office has been using a convective scale NWP system for the last three years, first in small sub-domains and then for the whole of the UK spinning up from the 12 km resolution NAE model. In November 2009, continuous DA was implemented, allowing the model to develop to its own climatology in which resolved deep valleys undergo severe cooling due to insufficient turbulent mixing in stable conditions. The same problem has been recorded in configurations of the Met Unified Model (UM) at 4 km over the Alps and 12 km over the Himalayas. This poster relates the diagnostics and solutions on the UK convective scale configuration (UKV).

In the UKV model, during episodes of stable weather in winter, some of the Scottish glens develop a cooling trend that brings screen temperatures to the order of 248 K, while observations from nearby stations read 268 K. The situation takes a few days to develop with Data Assimilation being unable to control it, due initially to the small scales of the features in a stations sparse area and later the observations being rejected by QC as their values are significantly different from the model background. The cooling trend stops once the temperature reaches a minimum and the model remains stable, although the cold air spills out of the glens and the forecast of near surface variables of locations in its reach is severely damaged.

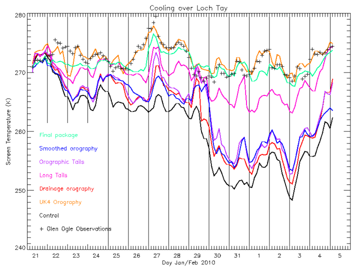
To diagnose the problem an experiment was performed, starting from interpolated 12 km data, and allowing the model to run freely for several days with no external input other than regular update of lateral boundary conditions; different options were tested against this settings. The figure below shows screen temperatures colder than 265 K after 12 days and 18 hours (VT 00:00 UTC 03/02/2010) with the location of the coldest points; comparison with the model orography on the right reveals these as closed valleys. The cold outflow from Loch Tay into the lowlands is also noticeable.



With the same experimental setup we performed several trials in order to understand the problem and develop potential solutions:

- Use of 4 km interpolated orography: this removed closed valleys and reduced sharp orographic gradients. In this configuration no cooling develops.
- Increase length of tails in stability functions as in the global (40 km gridlength) model: this option is not suitable for convective scale modelling; it reduced the cooling significantly, indicating that lack of mixing in stable conditions was a cause of the problem.
- Modified orography by opening drainage channels for closed valleys: reduced the symptoms and made the recovery faster, but didn't eliminate the cooling; hence, closed valleys exacerbate the problem but don't cause it.
- Change properties of the inland water surface type to make it closer to deep lakes, rather than wetlands, increasing thermal inertia: is a more accurate representation of reality as we are resolving lakes (inland water fraction > 0.8), as expected it slightly mitigated the cooling.
- Don't allow the inland water surface albedo to increase with snow cover: represents snow not settling in deep lakes, the cooling was slightly reduced.
- Increase the mixing over unresolved orography by enlarging locally the tail of stability functions: Is a pragmatic approach to apply extra mixing where we know it is lacking, it partly resolved the problem, although not to the desired extent.
- Smoothed orography (Epsilon = 1): significantly resolved the problem in most valleys, although some others, particularly Loch Tay, remained cold.
- Subgrid drainage shear: is a parametrization of a process not represented previously. A detailed description of the parametrization is provided on the top right of the poster. In combination with smooth orography this completely resolves the cooling issue.

The time series of screen temperature on a gridbox over Loch Tay shows the effect of the different trials in alleviating the cooling in the valley. The vertical lines mark midnight, and the crosses indicate the temperature observed at Glen Ogle, the closest station; although non co-located with the gridbox and hence not valid for a direct comparison, they give an accurate idea of the range of values that happened in reality. The package implemented operationally included Subgrid Drainage Shear, smoothed orography and changes to the lakes albedo and thermal properties.



Description of the Subgrid drainage shear solution

Previous research at the Met Office (McCabe and Brown, 2007) had demonstrated that area-averaging high resolution simulations of stable boundary layers in complex terrain can imply vertical mixing that is enhanced over what would be expected over a flat surface. Qualitatively this was attributed to the enhanced shear arising from small scale drainage flows but no quantitative parametrization was developed in that study.

Here, following Derbyshire and Wood (1994), we consider an idealised two-dimensional regime where uniform surface cooling under light winds leads to the generation of static stability (with buoyancy parameter N^2) over a slope of gradient *α*. After a time *t*, the hydrostatic imbalance will generate a drainage flow with associated wind shear, S_d, given by:

$$S_d = N^2 \alpha t$$

In this initial implementation, *t* has been taken as a fixed timescale of 30 minutes, for simplicity. So, for example, taking typical values for the Scottish Glens of $N^2 \sim 1\text{K}/100\text{m}$ and $\alpha=0.15$ gives $S_d \sim 0.1\text{s}^{-1}$, or a drainage flow of 2ms^{-1} at 20m.

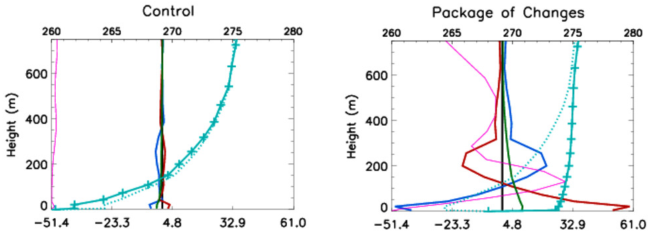
For scales where the model does not explicitly resolve these flows, this wind shear should then appear in the turbulent mixing parametrization, as an enhancement to the resolved scale vertical shear, *S,* of the horizontal wind components. In addition, sensitivity to the surface slope will decrease with height so S_d is scaled by factor that reduces smoothly from 1 near the surface to zero by 1.5 standard deviations of the subgrid orographic height. Thus, the UM's 1st order closure for the turbulent diffusion coefficient becomes:

$$K = \lambda^2 \left(S + S_d\right) f\left(Ri\right) \quad \text{with} \quad Ri = {N^2}\Big/{\left(S+S_d\right)^2}$$

where *λ* is the mixing length and *f* the stability function. Importantly, the scales over which the model is known to underestimate the magnitude of local flows is of the order of six times the grid spacing. Hence in the UKV implementation, the slope is taken as the average slope over the surrounding 12km.

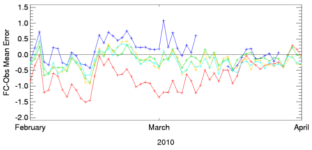
Derbyshire, S.H. and Wood, N. (1994): The sensitivity of stable boundary layers to small slopes and other influences. Pp.105-118, *Proc. 4th IMA Conf. Waves and Stably-stratified Turbulence*, ed. N.Rockliff and I.P.Castro. Clarendon Press, Oxford

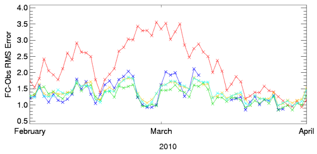
McCabe, A. and Brown, A.R. (2007): The role of surface heterogeneity in modelling the stable boundary layer. *Boundary-Layer Meteorol.*, **122**, 517-534



The graphs above shows thermodynamic budget diagnostics computed over six hours for the lowest 750 m of the atmosphere for a gridbox over Loch Tay. The left panel shows the original setup and the right the final package. The cyan lines are profiles of potential temperature (in Kelvin), dotted initial and solid final, with the values labelled on the top x-axis. The increments (in Kelvin with values labelled on the bottom x-axis) for most processes are negligible and omitted from the plots for clarity, with the only significant contributions being near surface warming with cooling above from the boundary layer which is almost balanced by advection (dark blue). However, the balance is not exact and so the net increment (green) is negative in the control and significantly positive in the trial. Note that the large increments in the boundary layer scheme with the package are caused by the simulation starting in a cold state, and once a balance is reached the values become much smaller. The turbulent mixing coefficient for scalar quantities Kh, plotted in pink with x-axis ranging from 0 to 50 (m^2s^{-1}), shows the extent of the increase in mixing.

The solution was implemented operationally on 14 July. To assess the performance of the package in an operational setup during the winter months, a rerun of the operational suite was performed from 20 January to 31 March. Results are very encouraging towards next winter, with temperature verification scores (shown below) matching or improving the other operational models. In the figures, at forecast range T+12, red is the operational forecast, blue the winter trial, green the operational UK4 model and yellow and cyan the two nearest forecast of the NAE (T+09 and T+15).





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