SENSITIVITY OF TOTAL MOUNTAIN DRAG TO MODEL RESOLUTION FOR MAP Case Studies

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1. INTRODUCTION

A fundamental requirement of any parametrization of sub-gridscale orography (SSO) is that the total (resolved plus parametrized) drag on a mountain range should be independent of the model horizontal resolution. However, parametrizations are typically developed and tested (and inevitably tuned) for a single model resolution and so this issue tends not to be addressed.

In this study, this issue is addressed by investigating the behaviour of the Met Office Unified Model (UM) flow-blocking and gravity-wave drag scheme (hereafter the SSO drag scheme) and boundary layer scheme (incorporating an orographic roughness scheme, hereafter the OR scheme) in UM simulations at horizontal resolutions ranging between 60 km and 2 km. At 60 km resolution most of the total orographic drag must be parametrized, whilst at 2 km resolution most of the total drag should be resolved.

This paper builds on the Smith *et al.* (paper A.9, these proceedings) resolved drag convergence study, with the primary focus here being to assess the degree to which the total mountain drag is independent of the model resolution. Thus, as in the Smith *et al.* study, the UM has been used to simulate seven different MAP case, although here we concentrate on the 8/11/99 IOP15 case. The two main questions we aim to answer are:-

- how does the mountain drag vary as a function of the model resolution?
- can we improve on the specification of the SSO currently used in the operational UM?

2. EXPERIMENTAL SET UP

For each of the four experiments to be described below, a suite of UM simulations was performed. In each experiment the UM operational 00z analysis for 8/11/99 is used as the initial condition for the driving global forecast model.

The global forecast was run for 24 hours and hourly lateral boundary conditions (LBCs) were output for the limited area models (LAMs) of resolutions 60 km, 40 km, 20 km and 12 km. Each of these LAMs used the reconfigured global analysis as their initial conditions. The 12 km LAM generated both the initial conditions (an output dump at T+2) and half-hourly LBCs for the 4 km LAM. The 4 km LAM produced the initial conditions (again T+2, i.e. 04z) and half-hourly LBCs for the 2 km simulation.

We now briefly outline the SSO drag calculation so that we can motivate the four experiments performed. Following Webster *et al.* (2003), the surface pressure drag diagnosed by the SSO scheme is given by

$$\tau_{sx} = \rho U N \hat{K}^{-1}(\sigma_{xx}\cos\chi + \sigma_{xy}\sin\chi) \quad (1)$$

$$\tau_{sy} = \rho U N \hat{K}^{-1}(\sigma_{xy}\cos\chi + \sigma_{yy}\sin\chi) \quad (2)$$

Experiment	Source filter length scale	$\hat{K}^{-1}$
KM6	6 km	3.3×10^3 m
KM40_1	40 km	$1. \times 10^5$ m
KM40_0.5	40 km	0.5×10^5 m
KM0	Unfiltered	1.6×10^3 m

Table 1: The naming and configuration of the various experiments.

where τ_{sx} and τ_{sy} are the zonal and meridional components of the surface stress respectively, ρ is the low-level density, U is the low-level wind speed, N is the low-level buoyancy frequency, χ is the direction of the low-level wind relative to westerly, $\hat{K}^{-1}$ is a "tuneable" wavenumber constant, and the σ_{ij} are the squared grid-box-average gradients of the source dataset.

The σ_{ij} terms are the ones that contain the key "summary" information about the SSO within a model grid box. It is the specification of these terms that we aim to improve in this study. The orography which is represented by these terms will depend on both the model grid resolution (which determines the longest orographic sub-grid length scale) and also on the resolution of the real (source) orography dataset (which determines the shortest sub-grid length scale).

When the SSO drag scheme was originally implemented in the global UM the SSO was derived from a 20 km source orography dataset. Optimum performance (in a global mean root mean square error sense) was achieved by tuning $\hat{K}^{-1}$. In the present implementation, the source dataset resolution is 2 km. However, for pragmatic rather than scientific reasons, the present implementation uses the same $\hat{K}^{-1}$ as used in the original implementation. This was only possible by strongly filtering the 2 km source dataset to remove small scale structure. The scale selective filter described in Raymond (1987) was used and the filtering was chosen so that 40 km length scale features were damped by 50%. With this filtering, the effective resolution of the 2 km resolution dataset is close to the 20 km resolution of the original dataset. Thus the current implementation makes little use of the additional information in the 2 km resolution dataset. This is not a major issue for global forecast models (with resolutions of 50 km or greater), but is obviously much more of an issue in LAMs where the model resolution will be comparable to or in excess of the effective source data resolution.

In this study, four experiments have been performed to assess the sensitivity of the total drag to the SSO specification. The details of these experiments are summarised in Table 1. In each case, the mean and sub-gridscale orography are derived from the 2 km source dataset. In the first experiment (KM40_1, our current operational set up), the source orography is derived using the current 40 km scale source orography filtering, together with the optimised value $\hat{K}^{-1}$. In the second experiment (KM40_0.5) the value of $\hat{K}^{-1}$ is halved, i.e. set to a value that is sub-optimum for global forecast model performance.

In the third experiment (KM0), no filtering is applied to the 2 km source dataset, i.e. we make use of all the information in the dataset when deriving the SSO. In the final experiment (KM6), we filter the source orography so that 6 km scale features are damped by 50%. This 6 km filter scale is physically based, being the shortest scale at which buoyancy (N) effects will be important (for typical U/N), and hence it is the shortest physical scale that should be represented by the parametization (shorter scales should be left to the OR scheme). In both these final two experiments, $\hat{K}^{-1}$ is specified so that the average value of $\hat{K}^{-1}\sigma_{ij}$ over the Alps is approximately the same as for the current operational set up. Referring back to Eqs. 1 and 2, it can be seen that with this choice of $\hat{K}^{-1}$ these final two experiments, if ρ, U and N are unchanged, should yield the same SSO drag as in the current operational experiment.

It is worth noting how incredibly sensitive the SSO specification is to the scales retained in the source dataset. Thus, as evident in Table 1, to keep the SSO drag unchanged in the 60 km model in each experiment, the value of $\hat{K}^{-1}$ must change by a factor of 60, i.e. the amplitude of the σ_{ij} terms varies by a factor of 60 in the four experiments.

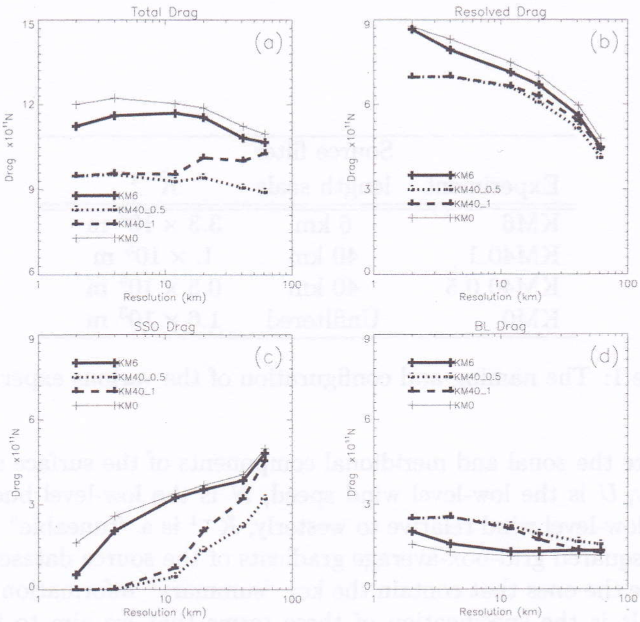

Figure 1: Area and time averaged drag magnitude as a function of model resolution for all the simulations performed. The area-averaging region is the latitude-longitude box stretching from 5°E to 17°E and from 43°N to 49°N. The time average is taken between 06z and 15z. (a) The total drag. (b), (c) and (d) show the three components (resolved, SSO and boundary layer) of the total drag respectively. **N.B.** the range on the y (drag) axis is different in (a) to that in the other panels.

3. RESULTS

3.1 Overall Drag Behaviour

Figure 1 shows all the main results of this study. It shows the time averaged (06z-15z), area averaged (over the whole Alps) drags as a function of model resolution for the all the experiments performed.

The first and most important feature to note is seen in Fig. 1(a) where the total drag, perhaps surprisingly, is seen to be remarkably insensitive to the model resolution. In all four experiments, in fact, the total drag varies by less than 10% as the resolution is varied between 60 km and 2 km. The individual components of the total drag, shown in Figs. 1(b)-(d), vary much more as a function of resolution. The resolved drag (Fig. 1(b)), approximately doubles in amplitude from the lowest to the highest resolution. An approximately equal and opposite change in drag is seen in the SSO drag (Fig. 1(c)). At 60 km resolution, the SSO drag is comparable to the resolved drag whilst at 2 km resolution the SSO drag is close to zero. The magnitudes of the changes in the boundary layer (BL) drag (which includes the OR drag, Fig. 2(d)) with horizontal resolution are much smaller than those of the other two components. The 30% to 50% changes between the 60 km and the 2 km BL drags are mostly due to the response of the OR scheme to the changes in low level winds associated with the changes in drag applied by the SSO scheme.

3.2 Current Operational Source Dataset Filtering

The behaviour of the simulations with the 40 km source filtering is now discussed. With 60 km model resolution, KM40_1 and KM40_0.5 give resolved drags very close to those from the experiments with less or no filtering (as the resolved orography at this resolution will be almost identical in all cases). The SSO drags in KM40_1 are also similar to those in the other simulations (by design). However, the behaviour of the drags as the model resolution is increased does differ significantly from that in the other simulations.

The resolved orographic drag in KM40_1 (and KM40_0.5) increases as the resolution gets finer, but can be seen to have largely converged at O(10km) resolution (Fig. 1b). This is consistent with the effective resolution of the source dataset in these experiments; with the 40 km filter scale almost no structure remains at grid-lengths less than 10km. In other words, the resolved drag is forced to converge at O(10km) resolution because all finer scales have been removed from the source dataset.

The SSO drag (Fig. 1(c)) decreases as expected as the resolution is made finer, but the reduction is more rapid than that in the experiments with less filtering of the source dataset. This is because this degree of smoothing of the source dataset means there is essentially no SSO for model resolutions finer than around 10 km, and the SSO drags must then be zero. The combined effect of the resolved and SSO drag changes is that the total drag in experiment KM40_1 decreases as the resolution is increased. While it would be possible to choose a value of $\hat{K}^{-1}$ that made the total drag more independent of resolution (e.g. Fig 1(a) suggests a value intermediate between those used in KM40_1 and KM40_0.5 might achieve this), this would be achieved by undesirably reducing the drag at coarse resolution, i.e. with the current source dataset filtering, it seems unlikely that the total drag could be made independent of resolution **and** be correct at the global resolution simultaneously.

3.2 6km scale filtering and no filtering

Fig. 1(b) shows that the resolved drags in the 6 km filtering and no filtering experiments do not appear to have converged even at 2 km resolution. This issue of a lack of convergence for this case is dicussed in more detail in the Smith *et al.* study. If, as seems reasonable, we assume that the converged resolved drag will not be much higher than that reached at 2 km, then the fact that both KM6 and KM0 show relatively little change in total drag with resolution suggests that the parametrization is giving approximately the correct amount of drag at 60 km resolution.

4. CONCLUSIONS

Although only a single MAP case study has been illustrated here, 6 other cases have also been run, and the conclusions we are able to draw from the 8/11/99 case appear to hold more generally. Our main conclusions are as follows:-

- Perhaps somewhat surprisingly, the total drag varies by only a relatively small amount as the model resolution is varied by a large amount. For the 8/11/99 case the variation is about 10% and, for the full seven cases variation is never more than 25%.

- The current 40 km length-scale source data filtering appears to be excessive, and so either the SSO drag scheme can be tuned to give the correct drag at the global resolution, or it can be tuned to make the total drag independent of the model resolution, but it cannot be tuned to do both at the same time.

- From the results presented here, the filtering applied to the source dataset should be reduced to either the 6 km scale or no filtering should be applied at all. In three of the seven cases the SSO drag is larger in the 2 km model than in the 4 km model when no filtering is used, and this unphysical behaviour indicates that the physically based 6 km filter scale is the best of the choices investigated here.

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