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Physical processes in present and future large-scale models

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Summary

Representation of sub-grid orography in models - Steve Derbyshire (Met office)

Representation of “subgrid orography” in models on various scales is again coming to the forefront as a parametrization issue.

NWP and climate models represent orography (i.e. mountains and to some extent also smaller hills) both explicitly and via “subgrid” parameterizations. More precisely the parametrizations should be considered as representing the systematic effects of the “unresolved” part of atmospheric processes, where the resolution depends not just on grid-length but on other aspects of the model. Such effects include for instance orographic precipitation and potentially also the downscaling to add local weather detail, but here we shall concentrate on the major issue of orographic drag.

Orographic characteristics vary widely across the world according to geology. Relevant orographic parameters include steepness (e.g. cliffs on any scale) and also mountain height (e.g. the Himalayas). Globally the most significant orography for meteorological purposes might be the barrier ranges (Rockies or Andes) or the Himalayas.

In a stably-stratified atmosphere the dynamic scale U/N (flow speed over Brunt-Vaisala frequency) provides a key scaling for both mountain width and mountain height, especially in their capacity to generate gravity-wave drag. Mountains on smaller horizontal scales than ~U/N (typically a few km) provide too “fast” a wavemaker to excite propagating gravity-waves. Mountains taller than ~U/N tend to generate flow-blocking at low levels, where the flow has insufficient kinetic energy to go over the mountain.

Classic papers in orographic drag parametrization include Palmer et al. (1986) and McFarlane (1987). Palmer et al. showed how a simple model of gravity-wave drag GWD could explain and correct much of the overspeeding bias in westerly midlatitude circulations found in models at that time. McFarlane broadly confirmed this result in a different model and with different choices in the detailed algorithm. These GWD schemes are effectively composed of (i) a low-level wave-generation algorithm tied to the orography (ii) a model of gravity-wave amplitude variation with height due to wind, stability and density variations (iii) a model of wave-breaking and dissipation when the amplitude reaches a given threshold.

Lott and Miller (1997) made an important extension to the GWD paradigm through the introduction of flow-blocking based on results from the PYREX field campaign.
Many major modelling centres now use schemes based essentially on the Lott and Miller framework of GWD plus flow-blocking. For instance, the Met Office Unified Model now uses a scheme of this type, with a wave-breaking algorithm based on the overturning arguments of McFarlane.

Despite this broad conceptual convergence, recent work under the WGNE Drag project (Zadra 2015) has shown that leading NWP models partition the land-drag very differently between orographic and boundary-layer components.

Motivated partly by this large-scale modelling uncertainty, we are involved in high-resolution model comparisons in observational campaigns in South Georgia (SG-WEX) and New Zealand (DEEPWAVE).

Preliminary results indicate that with some tuning to the orography in question, orographic parametrizations of the type discussed can represent the low-level drag and momentum flux reasonably well, with total (resolved plus parametrized) drag approximately invariant across resolutions in the range 1-20km. However, there are indications that the tuning to South Georgia may not be optimal for New Zealand or perhaps also more complex continental or coastal mountain ranges.

Given the sensitivity of major large-scale circulations to these parametrizations, there is a clear need for further research in this area to strengthen the underpinning basis for the representation of subgrid orography in models.

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