The circulation response to resolved versus parametrized orographic drag over complex mountain terrains

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The accurate representation of orographic drag, resolved and parametrized, has been shown to be important for capturing key aspects of the large-scale circulation in both numerical weather forecasts and climate projections. The representation of parametrized orographic drag remains, however, extremely uncertain. With the increased computational power and numerical stability now available, realistic km scale resolution simulations of flow over complex terrain is now possible. In this work, we perform high and low resolution short-range forecast simulations over some of the Earth's most complex mountain regions, namely the Himalayas, the Caucasus and the Andes, to understand the dynamic impacts of resolved orography on the atmospheric flow and to validate existing parametrizations of orographic drag. The impact of resolved orography on the flow is deduced by taking the difference between regional high resolution simulations (4km) with a high (4km) and low resolution orography (150 km), performed using the Met Office Unified Model (MetUM). This impact is then compared with the impact of parametrized orographic drag, which is deduced by comparing global low resolution experiments (150km) with and without parametrized orographic drag. The expectation is that the orographic drag parametrization should mimic the impact of resolved orography on the flow. However, we find that impacts of the resolved and parametrized orographic drag differ substantially in both magnitude and spatial distribution in the MetUM. Similar conclusions can be drawn for the European Centre for Medium Range Weather Forecasts Integrated Forecasting System (ECMWF IFS) where, instead of using regional 4km simulations to diagnose the impact of resolved orography, we use global 9 km simulations (with high and low resolution orography) and compare these with global 125km simulations (with and without parametrized orographic drag). At low horizontal resolutions, both the MetUM and ECMWF IFS exhibit too strong zonal winds (relative to analysis) in the lower stratosphere, in the region of maximum resolved orographic gravity wave breaking. Diagnosis of the physics and dynamics tendencies reveal that this is partly due to the manner in which the dynamics responds to parametrized orographic drag. This work introduces a method to quantify the impacts of resolved versus parametrized orographic drag in global NWP and climate models and demonstrates the importance of understanding the coupling between model physics and dynamics.

Key words: orographic drag, gravity waves, high resolution modelling, physics-dynamics coupling