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Circulation response to resolved versus parametrized orographic drag over complex mountain regions

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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 orographic drag remains, however, extremely uncertain. Due to the inherent difficulties in deriving analytical expressions, directly measuring orographic drag over large regions and simulating complex flows over complex orography, the development of orographic drag parameterizations has mostly relied, so far, on studies of idealised mountains in idealised flow. With the increased computational power now available, realistic km scale resolution simulations of flow over complex terrain are now becoming possible. In this work, we perform high and low resolution simulations over some of the 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 parametrizations should mimic the impact of resolved orography on the flow. However, we find that impacts of the resolved and parametrized orographic drag substantially differ in both magnitude and spatial distribution in the MetUM. Diagnosis of the physics and dynamics tendencies reveal that this disagreement is partly due to the manner in which the dynamics responds to parametrized orographic drag. Importantly, similar conclusions can be drawn if, instead of using regional 4km simulations to diagnose the impact of resolved orography, we use global 16 km simulations (with high and low resolution orography). This means that this exercise can be repeated for any global NWP model. To demonstrate this, a similar analysis is performed for runs done with the European Centre for Medium Range Weather Forecasts Integrated Forecasting System (ECMWF IFS). We find that in the IFS, the impact of parametrized orographic drag on the flow is comparable to that of the resolved orography, and that the response of the dynamics to parametrized orographic drag is weaker than in the MetUM. This work introduces a method to quantify the impacts of resolved and parametrized orographic drag in global NWP and climate models and demonstrates the importance of understanding the coupling between the physics and dynamics.