

Title: Quantifying the uncertainty in parametrized orographic drag and its impact on the large scale atmospheric circulation.

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The relative contributions of resolved and parametrized orographic drag towards balancing the atmospheric angular momentum flux convergence (AMFC) and their sensitivity to horizontal resolution are diagnosed in an atmospheric model. This sensitivity can be difficult to elucidate in free-running climate models, in which the AMFC varies with changing climatologies and, as a result, the relative contributions of surface terms balancing the AMFC also vary. We demonstrate that a nudging framework is an effective method for constraining the AMFC. The Met Office Unified Model is integrated at three horizontal resolutions ranging from 130 to 25km, while relaxing the models wind and temperature fields towards the ERA-Interim reanalysis within the altitude regions of maximum AMFC. These experiments are then used to assess the fidelity of the exchange between parametrized and resolved orographic torques with changes in horizontal resolution. The tendencies produced by the nudging routine indicate that the additional drag at lower horizontal resolution is excessive over the Northern Hemisphere mid-latitudes. This work illustrates how the large uncertainties in the formulation of parametrized orographic drag can lead to systematic model biases at climate model resolutions. The impact of this uncertainty on the circulation response to climate change is then investigated in a systematic way by altering the low-level parametrized orographic drag within the Canadian Atmospheric Global Climate Model (CanAM4.1). The parametrized orographic drag is shown to mediate the strength of the Northern Hemisphere winter-time stationary waves and a strong relationship between the climatological stationary wave amplitudes and their response to climate change is found.