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Orographic gravity wave drag amplification by parametric resonance

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One of the mechanisms identified by Wells and Vosper (2010) for the amplification of gravity wave drag produced in flow over mountains, which makes this force substantially exceed its linear estimate even for very low mountain heights, requires a Scorer parameter profile that oscillates with height with a wavelength half that of the primary waves generated by the vertically-averaged Scorer parameter. This mechanism, first mentioned by Phillips (1968) in an oceanic context, relies on a resonance process, and Wells and Vosper claim that this resonance is intrinsically nonlinear.

In the present study (see Teixeira et al. 2012), we examine this mechanism in more detail, considering flow over an isolated mountain with a Scorer parameter that is constant in the vertical apart from a superposed small-amplitude sinusoidal oscillation. This problem is treated both using an analytical perturbation method and numerical simulations with a mesoscale model. It is shown that the processes leading to drag enhancement (or reduction) are linear, since they result from the interaction between the primary wave and the Scorer parameter oscillation. These processes may therefore be captured in a linear framework, by expanding the solution to the Taylor-Goldstein equation in powers of a small parameter proportional to the amplitude of the Scorer parameter oscillation.

A semi-analytical model based on this approach produces results that are qualitatively similar to those obtained in the numerical simulations. The drag normalized by its value for a constant Scorer parameter is studied as a function of the wavelength and phase of the Scorer parameter oscillation. Only higher-order effects may be attributed to nonlinearity. However, it is shown that the results are quite sensitive to friction, in particular no drag enhancement is produced for some values of the phase of the Scorer parameter oscillation unless friction is included in some form. This implies that, in numerical simulations, the drag behaviour should be sensitive to the numerical diffusion inherent to the discretization schemes and to the type of turbulence closure employed in the numerical model. In our study, the semi-analytical model uses a simple Rayleigh damping coefficient to represent friction, and the value of this parameter is estimated from the numerical simulations.

While most of the numerical simulations are nominally inviscid, a first assessment of the effect of physical friction, using simulations with turbulence closures, is also carried out. Additionally, non-hydrostatic effects are assessed, and found to have an important impact on the drag amplification, weakening the resonance process due to wave dispersion.