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The momentum fluxes in gravity waves generated by sheared flows over axisymmetric mountains

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The momentum fluxes associated with internal gravity waves generated by directionally sheared winds flowing over axisymmetric mountains are calculated in the inviscid, hydrostatic, non-rotating limit. Through the use of a WKB approximation, generic wind profiles may be treated, provided that they vary sufficiently slowly in the vertical. The WKB approximation must be extended to third order in the small perturbation parameter to capture two effects that have been neglected by previous authors: 1. the impact of the wind variation with height on the surface drag and 2. the impact of partial wave absorption (i.e. wave filtering) at critical levels. The momentum fluxes are obtained as 1D integrals and, for this particular type of orography, do not depend on the detailed shape of the mountains. The momentum flux divergence (which corresponds to the force on the atmosphere that must be parameterized in large-scale numerical models) has a closed analytical form. Unlike previous studies, now both the surface drag (which coincides with the surface value of the momentum flux) and the amount of wave attenuation at critical levels depend on the Richardson number of the basic flow, Ri. The momentum flux profiles are tested for three idealized wind profiles, in linear and weakly nonlinear conditions. The theoretical model developed here is seen to be in good agreement with the linear numerical simulations. Even in nonlinear conditions, the model provides a considerable improvement upon existing theory, developed for very high Ri. The case of a wind that turns with height at a constant rate maintaining its magnitude provides a good test case for the filtering effect of critical levels, because all the components in the wave spectrum generated by the mountain have critical levels. The value of the momentum flux at the height where the whole wave spectrum has been filtered (i.e. where the wind has turned by 180 degrees) is seen to be predicted with very good accuracy in linear conditions for values of Ri down to 1/3.