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An extension of Phillips' GWD model for flow over elliptical mountains to slowly varying wind profiles

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Gravity wave drag (GWD) produced by mesoscale mountains remains a subgrid process in most large-scale meteorological models, and therefore must be parameterized. For this purpose, knowledge about the dependence of the drag on the parameters of the orography and large-scale flow is required. One of the most influential theories that provide this dependence in rather idealized conditions is that of Phillips (1984), where hydrostatic, non-rotating flow over mountains with an elliptical horizontal cross section is considered. In this model, which is employed to calculate the linear part of the drag in some parameterizations used operationally, both the wind and static stability are assumed to be constant with height. In the present study, Phillips' model is extended to consider wind profiles that vary relatively slowly with height, by using the WKB approximation to solve the Taylor-Goldstein equation. The present model may also be viewed as an extension of those presented by Teixeira et al. (2004) and Teixeira and Miranda (2004) to elliptical mountains. The WKB approximation must be extended to 2nd order for the wind variation with height to have an impact on the surface drag. The drag normalized by its value for a constant wind (i.e., Phillips' value) depends on the first and second derivatives of the wind velocity at the surface, and on the aspect ratio of the mountain. The model is tested for simple wind profiles, and various wind incidence angles. For a linear wind profile, the drag is predicted to decrease as the Richardson number Ri decreases, more rapidly for a wind perpendicular to the axis of the mountain than for a wind parallel to it. For an oblique wind, the component of the drag that varies most rapidly with Ri, surprisingly, is that parallel to the axis of the mountain. For a wind that turns with height maintaining its magnitude, the drag is generally predicted to increase as Ri decreases. These predictions are compared with results from a mesoscale numerical model and found to be asymptotically correct in the limit of large Ri, and sometimes quantitatively correct for Ri of order one.