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Wind profile effects on the surface drag and vertical momentum fluxes associated with mountain waves

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Parametrizations of gravity wave drag in numerical weather prediction and climate models generally do not consider the detailed effects of wind variations with height on the value of the surface drag and on the momentum flux profiles associated with mountain waves. However, this subject has generated considerable interest in recent years, with the appearance of a number of idealized studies. These studies have focused on shear effects on the surface drag for simple types of wind profiles, and on wave momentum absorption at critical levels at very high Richardson numbers, Ri.
More recently, the present authors calculated the surface drag produced by axisymmetric, 2D mountains, and mountains with an elliptical horizontal cross section using linear theory, for generic wind profiles with relatively low Ri. More recently still, we tested the impact of these effects on the surface drag at the global scale, using orography representative of the real mountain ranges and reanalysis meteorological data. We also extended the theory of the momentum fluxes to atmospheres with lower Ri, where the wave momentum absorption at critical levels is not total.
In all of these recent developments, the WKB approximation was employed to solve the Taylor-Goldstein equation, for generic, non-constant, wind profiles varying sufficiently slowly in the vertical. These results are reviewed here. It was found that the impact of wind profile variations on the surface drag at the global scale is generally in the sense of increasing the magnitude of this force. This happens because wind profile curvature effects (present, for example, when the wind turns), dominate over the effects of shear. The region most affected by this drag enhancement is Antarctica, due to the strong katabatic winds with large directional shear that occur there. The contribution of these corrections to the global gravity wave torque is relatively small, but in the right direction, considering the imbalance that currently is known to exist.
These results suggest that an inclusion of wind profile effects on the drag may be worthwhile in numerical models. However, in order to do this, it is also necessary to determine the actual reaction force of the orography on the atmosphere, which is distributed vertically as the divergence of the wave momentum flux. A first step in this direction was taken recently, with the calculation of momentum flux profiles for flow over axisymmetric mountains. The surface momentum flux (which is equivalent to the surface drag) depends on the vertical derivatives of the wind velocity, but the wave attenuation at critical levels (which have a continuous distribution in directional shear flows) is also dependent on the characteristics of the wind profile. We have explicitly obtained these dependencies for generic wind profiles at relatively low Ri.