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The effects of the tropopause on nonlinear hydrostatic mountain waves

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A two-dimensional, semi-infinite, two-layer stratified airflow over a mountain of arbitrary shape is considered on the assumptions that upstream wind velocity and static stability within each layer are constant (Long's model). The stratosphere is simulated by infinitely deep upper layer with enhanced static stability. On the dividing streamline (tropopause), the kinematic condition and dynamic requirement for the lower and upper flows are formulated exactly without usual assumption of small disturbances.

The exact solutions for the wave drag and stream function are obtained as well as first (linear) and second order approximations in hydrostatic limit $N_1 L/U_0 \rightarrow \infty$, where N_1 is Brent-Väsälä frequency in the troposphere, L is a characteristic length of the obstacle, and U_0 is upstream velocity. According to calculations, the process of wave amplification due to partial wave reflection from the tropopause is controlled significantly by the nonlinear effects associated to finite height as well as shape of the mountain. The tropopause displacement from its background (equilibrium) level produces generally the stabilizing effect preventing the development of exceptionally strong disturbances as predicted by linear models. Consequently, the flow remains dynamically stable throughout the troposphere for substantially wider range of the flow parameters compared to that one predicted from linear theory. The combined effects of topography and vertical variations of static stability for some well documented atmospheric events are investigated. The results testify for important role of the dynamical interaction between the troposphere and upper layers for some atmospheric conditions, which must be taken into account when interpreting the results of numerical modeling of the overflow process as well as observational data.