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Wave drag on mesoscale mountains

K. Moiseenko

A.M. Obukhov Institute of Atmospheric Physics, Moscow, Russia (konst.dvina@mail.ru)

A two-dimensional 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. The analytical solution for stream function as well as first (linear) and second order approximations to the wave drag are obtained in hydrostatic limit $N_1 L/U_0 \to \infty$, where N_1 is Brent-Väsälä frequency in the troposphere, L is a characteristic length of the obstacle, and U_0 is upstream velocity. The results of numerical computations show the principal role of long waves in the process of interaction between the model layers for a typical mesoscale mountains for which the hydrostatic approximation proves valid in wide range of flow parameters, in accordance with earlier conclusions of Klemp and Lilly. Partial reflection of wave energy from tropopause produces strong influence on the value of wave drag for typical middle and upper tropospheric lapse rates, leading to quasi-periodic dependence of wave drag on a reduced frequency $k = N_1 H/\pi U_0$ (where H is tropopause height) in the troposphere. The flow seems to be statically unstable for $k \geq 2$ for sufficiently large obstacles (whose height exceeds 1 km). In this case, vast regions of rotor motions and strong turbulence are predicted from model calculations in middle troposphere and lower stratosphere. The model calculations also testify for possible important role of non-linear effects associated with finite height of the mountain on the conditions of wave drag amplification in the process of overflow of real mountains.