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A linear model for rotors produced by trapped lee waves with a simple representation of boundary layer friction

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A linear model is used to diagnose the onset of rotors in flow over 2D ridges, for atmospheres that are neutrally stratified near the surface and stably stratified aloft, with a sharp temperature inversion in between, where trapped lee waves may propagate. This is achieved by coupling an inviscid two-layer mountain-wave model with a bulk boundary-layer model. The full model shows some ability to detect flow stagnation as a function of key input parameters, such as the Froude number and the height of the inversion, by comparison with results from numerical simulations and laboratory experiments carried out by previous authors. The effect of a boundary layer is essential to correctly predict flow stagnation, as the inviscid version of the model severely overestimates the dimensionless critical mountain height necessary for stagnation to occur. An improved model that includes only the effects of mean flow deceleration and amplification of the velocity perturbation within the boundary layer predicts flow stagnation much better in the most non-hydrostatic cases treated here, where waves appear to be directly forced by the orography. However, in the most hydrostatic case, only the full model, taking into account the feedback of the boundary layer on the inviscid flow, satisfactorily predicts flow stagnation, although the corresponding stagnation condition is unable to discriminate between rotors and hydraulic jumps. This is due to the fact that the trapped lee waves associated with the rotors are not forced directly by the orography in this case, but rather seem to be generated indirectly by nonlinear processes. This mechanism is, to a certain extent, mimicked by the modified surface boundary condition adopted in the full model, where an "effective orography" that differs from the real one forces the trapped lee waves. Versions of the model not including this feedback severely underestimate the amplitude of the trapped lee waves in the most hydrostatic case, partly because the Fourier transform of the orography has zeros, which unrealistically weaken the wave response. Concerning the inability of even the full model to discriminate between rotors and hydraulic jumps, this may be attributed to the fact that the flow perturbations associated with stagnation in the model differ from those seen in the numerical simulations, especially for the most hydrostatic rotors, where the waves are generated indirectly. This suggests that flow stagnation may not be occurring for the right reasons in those cases.