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Dynamics of mountain-wave induced rotors and sub-rotors

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The study of stratified flow over and around topography is one of the classical theoretical problems in atmospheric and oceanic dynamics. Mountain waves generated by stably stratified flow over topography may be accompanied by severe downslope winds and intense circulations in the lee, known as rotors, that are characterized by boundary layer separation and return flow toward the mountain. Mountain-induced rotors still remain poorly understood, particularly with respect to three-dimensional aspects of the flow.

The dynamics of rotors forced by three-dimensional topography are investigated through a series of ultra high-resolution (isotropic resolution of 60 m) idealized simulations with the non-hydrostatic COAMPS model. The focus of this investigation is on the internal structure of rotors and in particular on the dynamics of small-scale intense circulations within rotors that we refer to as "sub-rotors". Simulations are conducted using an upstream reference state representative of the conditions under which rotors form. The topography is specified as a 1000-m high elongated ridge, with a 500-m circular peak that is used in several experiments to investigate the sensitivity of the rotor dynamics to topographic variations in the cross-flow direction.

The simulation results indicate a thin sheet of high-vorticity fluid develops adjacent to the ground along the lee slope and then ascends abruptly as it is advected into the updraft at the leading edge of the first trapped lee wave. This vortex sheet is primarily forced by mechanical shear associated with frictional processes at the surface. Sub-rotor circulations develop along the leading edge of the "parent" rotor due to parallel-shear instability. These sub-rotors are advected downstream or back toward the mountain within the parent rotor and occasionally intensify as exhibited by a several fold

enhancement of horizontal vorticity. A vorticity budget indicates that horizontal vorticity generation due to the stretching of vorticity is significantly larger than tilting and baroclinic generation. The results suggest that preferred regions of intense sub-rotors may exist near topographic features that enhance vortex stretching.