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Wave-Induced Boundary-Layer Separation and Turbulence

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The wave-induced boundary-layer separation in flow over orography has received significant attention in recent years, especially in relation to formation of atmospheric rotors. Rotors–traditionally depicted as horizontal eddies in the lee of mountain ranges–are characterized by intense turbulence and as such pose a known threat to aviation. This study focuses on the first observationally documented case of wave-induced boundary-layer separation. On Jan 26 2006, the University of Wyoming King Air (UWKA) aircraft, highly instrumented for collecting both in situ and remote sensing measurements, the latter with the airborne Wyoming Cloud Radar (WCR), flew repeated passes over the Medicine Bow Mountains in SE Wyoming at a range of altitudes as low as 700 m above the highest terrain. The Dual-Doppler synthesis of WCR data and the corresponding retrieval of the two-dimensional flow field in the vertical plane beneath the aircraft indicate strong wave activity, downslope winds in excess of 30 m s^{-1} within 200 m above the ground and severe turbulence in the lee of the mountains.

High-resolution numerical simulations of this event with the NRL COAMPS model, using multiple nested domains to achieve a horizontal resolution of $\sim$300 m over the area of observations, show presence of rapidly evolving terrain-generated lee waves and boundary-layer separation occurring over the lee slopes. At this horizontal resolution the simulated flow is in good agreement with the overall features of the retrieved flow from the dual-Doppler analysis. However, the much finer resolution of WCR data (of the order of 40x40 m^2 for two-dimensional velocity fields), allows one to discern fine-scale coherent vortical structures within the rotor zone, where more turbulent dynamics and smaller-scale vortices appear to be prevalent. These flow features cannot be explicitly resolved by a mesoscale numerical model; their simulation requires a higher-resolution grid and the use of a large-eddy simulation (LES) approach. Presented herein will be the results of LES simulations of wave-induced boundary-layer separation and breakdown of flow into turbulence at the leading edge of the rotor. The simulation results are discussed within the context of the WCR observations and other recent related studies.