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Turbulence generation by mountain wave breaking in flows with directional wind shear

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In this study, wave breaking, and the potential for the generation of turbulence in the atmosphere, is investigated using high-resolution numerical simulations of idealized atmospheric flows with directional wind shear over a three-dimensional isolated mountain. These simulations, which use the WRF-ARW model, differ in degree of flow non-linearity and directional wind shear intensity, quantified through the dimensionless mountain height and the Richardson number of the incoming flow. The aim is to predict wave breaking occurrence based on large-scale variables. The simulation results have been used to produce a regime diagram representing a description of wave breaking behavior in parameter space. By selecting flow overturning occurrence as a discriminating factor, it was possible to split the regime diagram in two sub-regions representing: a non-wave breaking regime and a wave breaking regime. The regime diagram shows that in the presence of directional shear wave breaking may occur over lower mountains that in a constant-wind case.

When mountain waves break, the associated convective instability can lead to turbulence generation (known as Clear Air Turbulence or CAT in a non-cloudy atmosphere), thus, regions within the simulation domain where wave breaking and potential development of CAT are expected have been identified. The extent of these regions is variable and increases with the background shear intensity. In contrast with constant-wind flows, where wave breaking occurs in the stream-wise direction aligned with the mountain, for the helical wind profiles considered in this study as prototypes of flows with directional wind shear, flow overturning regions have a more three-dimensional geometry.

The analysis of the model outputs, supported by theoretical arguments, suggest the existence of a link between wave breaking and the relative orientation of the incoming wind vector and the horizontal velocity perturbation vector. In particular, in a wave breaking event, due to the effect of critical levels, the background wind vector and the wave-number vector of the dominant mountain waves are perpendicular. It is shown that, for the wind profile employed in this study, this corresponds to a situation where the background wind vector and the velocity perturbation vector are also perpendicular. This latter condition seems more convenient, as it may be expressed totally in physical space.