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High-resolution numerical simulation of breaking gravity waves due to winds over the southern Andes mountains

Thomas Lund (1), David Fritts (2), Brian Laughman (2), and Hanli Liu (3)

(1) NorthWest Research Associates, Boulder Office, United States (lund@cora.nwra.com), (2) GATS Incorporated, Boulder Office, United States, (3) National Center for Atmospheric Research, United States

Gravity wave generation by winds blowing over the Southern Andes Range is studied numerically via a high-resolution fully-compressible numerical model. Realistic wind and temperature profiles for winter conditions are taken from a mesoscale model run and the mountainous terrain is resolved directly in the high-resolution simulation. The chosen winds at lower elevation are nearly perpendicular to the range and these produce strong waves that become unstable and break in the mesosphere. The instability processes as well as the energy-containing portion of the turbulent spectrum are reasonably well resolved on the mesh with isotropic resolution of 500 m. Unresolved turbulent motions are treated with a dynamic Smagorinsky subgrid-scale model. Grid stretching in all three directions allows us to achieve the 500 m resolution in the breaking region while using a computational box that extends 35 degrees in longitude, 18 degrees in latitude, and to an altitude of 200 km. The simulation is run on a massively parallel supercomputer and makes use of 530 million mesh points.

The simulation is started from rest and then the winds are ramped up to the desired profile over a period of 40 minutes. Instability is noted at a total elapsed time of 65 minutes and turbulence is formed shortly thereafter. The waves are found to break within two distinct regions of high wind shear (located at 75 and 110 km) where the zonal wind decreases with altitude. The decreasing wind refracts the waves to shorter vertical scale, thereby increasing the perturbation potential temperature gradients. This effect, together with the wind shear itself set the stage for a Kelvin-Helmholtz type instability.

The initial overturning structures are found to launch fast-running acoustic-gravity waves. As the turbulence becomes more homogeneous a mixture of both ordinary and acoustic-gravity secondary waves are generated. The secondary waves propagate freely to higher altitudes and induce perturbations in excess of 100 m/s at and altitude of 175 km.

Both viscous and turbulent transfer of wave momentum to the mean flow produce significant localized changes to the mean winds. These effects are most pronounced within the breaking zone and at altitudes above 150 km.