Geophysical Research Abstracts
Vol. 20, EGU2018-9560, 2018
EGU General Assembly 2018

Dynamics of large-amplitude mountain waves in the mesosphere due to weak orographic forcing during DEEPWAVE research flight RF22

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In-situ, lidar, and imaging instruments aboard the NSF/NCAR Gulfstream V (GV) observed a dramatic mountain wave event in the stratosphere and mesosphere on DEEPWAVE Research Flight 22 under conditions of weak and decreasing flow over the Southern Alps. Four east-west flight segments over Mt. Cook exhibited mountain wave (MW) zonal wavelengths of $\lambda x \sim 30$-300 km extending from the GV flight altitude (12 km) to $\sim$87 km. Large MW amplitudes were enabled by largely linear propagation from the tropopause into the mesosphere due to zonal winds increasing to $\sim$130 m/s at 55 km. Decreasing zonal winds above, with a critical level at $\sim$90 km, caused MW breaking and decreasing amplitudes beginning at $\sim$75 km. Peak-to-peak displacements of the superposed MWs were as large as 10-12 km on each flight segment, and as large as 5-7 km for individual MWs. The largest MW amplitudes occurred at $\lambda x \sim 60$-80 km and their momentum fluxes were among the largest ever measured. The strong MW response in the mesosphere also extended over a substantially larger region than the forcing terrain. A UK Met Office simulation of this event captured many aspects of the observed MW field and provided insights into model resolution needs. Important results from the RF22 event from a gravity wave dynamics and parameterization perspective include the following:

1) orographic forcing often yields multiple MW scales and orientations, and the dominant responses often having primary orientations along the cross-mountain flow,

2) horizontal dispersion leads to extended horizontal responses in the stratosphere and mesosphere that violate the typical GCM single-column approximation,

3) small vertical wavelengths, λz, and vertical group velocities, cgz, where (c-Uh) is small can delay high altitude responses by many hours,

4) the linear view of GW breaking is wrong: breaking is intermittent, it significantly reduces GW amplitudes, but the GWs can again achieve large amplitudes at higher altitudes,

5) intermittent GW breaking yields local, stochastic forcing and generation of secondary GWs spanning a wide range of spatial and temporal scales and propagation directions,

6) secondary GWs having large scales and cgz can readily penetrate to much higher altitudes,

7) even when larger-scale ($\lambda h \sim 100$-300 km) MWs are observed, the major momentum fluxes are typically associated with $\lambda h < 100$ km, and can be very large.