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Interactions between gravity waves and turbulence in unbalanced jets

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The cascade of energy from gravity-inertia waves generated by unbalanced jet streak dynamics to turbulent eddies has been simulated with numerical weather prediction models and observed with high-resolution dropwindsonde and 25-Hz in-situ measurements collected by a Gulfstream-IV research aircraft. The observed clear-air turbulence event was simulated with the 20-km hydrostatic Rapid Update Cycle (RUC) model and a nested 1-km version of the nonhydrostatic Clark-Hall (CH) cloud-scale model.

Analyses of the RUC and CH model simulations and the G-IV observations reveal that turbulence occurred in association with a broad spectrum of gravity waves above the jet core along the upstream side of the trough. Inertia-gravity waves were generated within a region of unbalanced frontogenesis in the vicinity of a complex tropopause fold. Turbulent kinetic energy fields forecast by the models displayed a strongly banded appearance associated with these gravity waves. Perturbations produced by embedded smaller-scale waves created bands of reduced Richardson number conducive to the generation of turbulence.

Spectra computed from the G-IV observations indicating the presence of gravity waves do not permit recovery of rapid changes in wave amplitudes and phase and frequency shifts. By combining cross-spectral and wavelet analysis methods, we are able to show that intermittent episodes of high turbulent energy were closely associated with gravity wave occurrences. Introduction of the wavelet cross-spectrum technique into the Stokes parameter methodology reveals 1) small-scale gravity waves possess distinctive polarization signatures, 2) the turbulence production is closely related to an enhanced level of polarization and coherency in the two components of the horizontal wind in the gravity waves, and 3) turbulence surges are accompanied by an

instantaneous reduction of polarization of the progenitor gravity waves. Third-order structure function analysis provides evidence that turbulence was most strongly forced at a horizontal scale of 700 m. In summary, the picture that emerges is one of forcing of gravity-inertia waves at the jet streak scale, the continuous generation of gravity waves over a broad spectrum of smaller scales, reduction of the Richardson number by sharpening of the wave fronts at the smallest (kilometer-scale) end of the wave spectrum, and generation of turbulent kinetic energy by wave breaking.