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Gravity waves emitted from jets: lessons from idealized simulations

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A longstanding problem in the description of gravity wave sources concerns waves emitted from jets and fronts. Theoretical studies of mechanisms of spontaneous generation suggest that the emission is expected to be exponentially weak in Rossby number, yet the mechanisms described (e.g. mixed instabilities involving balanced and unbalanced motions) do not seem to explain the emission observed and simulated near jets.

From observations, it has been known for some time that jet exit regions often exhibit intense inertia-gravity wave activity, suggesting generation there. Numerical simulations of idealized baroclinic life cycles have confirmed the specific role of these jet exit regions and shown that specific processes for propagation (i.e. 'wave capture') play an important role there. The generation and subsequent propagation of waves at the front of upper-tropospheric jet streaks has been shown to be analogous to what happens in a dipole, yet the latter case is, attractively, much simpler. Simulations of dipoles allow a detailled understanding of the generation mechanism. We will focus on recent advances on wave excitation in a dipole and in different baroclinic life cycles.

The generation of inertia-gravity waves in the front of a dipole has been explained as the linear response, within a balanced background dipole flow, to the small discrepancies between the balanced and the full tendencies for wind and potential temperature. It is worth emphasizing that it is crucial to linearize around a background dipole flow, as the structure of the waves that are generated (i.e. concentration in the jet exit region, phase lines transverse to the flow there, small horizontal scales) comes almost entirely from the resulting non-trivial, non-constant coefficient linear operator.

Past studies have seeked to isolate a diagnostic from the large-scale flow that could be indicative of the location and intensity with which gravity waves are generated (e.g. Lagrangian Rossby numbers, residual of the Nonlinear Balance Equation). The relevance of these diagnostics is tested in both dipole and idealized baroclinic wave simulations. Regarding location, they are not always found to indicate the dynamically significant regions of the flow. An indicator such as the Okubo-Weiss parameter, which highlights regions of strong strain without vorticity, is found to better isolate jet exit regions where waves tend to be captured. Regarding amplitudes, such indicators are by construction linear or quadratic in the dipole strength or as the square of the dipole strength. The emission was not found to follow such a simple scaling law. On the contrary, it rather seems to 'turn on' at a certain finite Rossby number, as could appear if waves are exponentially small in Rossby number. This behavior can be explained if we take into account the advection by the flow past the forcing term. As the dipole strength increases, it is not only the intensity of the forcing which increases, but also the advection past this forcing. As a result, a larger part of the spectrum contributes to wave generation. A nonlinear dependence of wave amplitude on the intensity of the dipole is thus obtained, qualitatively similar to what was found in simulations.