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Secondary instabilities in breaking inertia gravity waves

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The breaking of inertia-gravity waves is an important process in the control of the structure and variability of the circulation in the middle atmosphere as well as contributing to mixing of atmospheric constituents. Since inertia-gravity waves involve such a wide range of temporal and spatial scales, their effects must inevitably be parameterized in large-scale models. It is therefore critical that the conditions for breaking and the dynamics of the ensuing turbulence be well understood.

In this talk, the three-dimensionalization of turbulence in the breaking of vertically propagating inertia-gravity waves is investigated using singular vector analysis, whereby the initial perturbations whose energy grows by the largest factor in a given optimization time are found. It builds on earlier work in which the development of turbulence in a breaking inertia-gravity wave was investigated using a high-resolution nonlinear two-dimensional Boussinesq model initialized with a single inertia-gravity wave and one of its leading singular vectors or fastest growing normal modes. In practice, however, the flow becomes strongly three-dimensional. A tangent-linear model is used to find the leading singular vectors orthogonal to the plane containing the wave vectors of the breaking wave and primary perturbation and thus shed light on the dynamics of the initial three-dimensionalization of the flow.

The talk will focus on two cases: a statically stable wave perturbed by its leading singular vector and a statically unstable wave perturbed by its leading normal mode. In both cases, the secondary instabilities grow through interaction with the buoyancy gradient and velocity shear in the basic state. Which growth mechanism predominates depends on the time dependent structure of the basic state and the wavelength of the secondary perturbation. The singular vectors are compared to integrations of the tangent-linear model using random initial conditions, and the leading few singular vectors are found to be representative of the structures that emerge in the random integrations. A main result is that the length scales of the leading secondary instabilities are an order of magnitude smaller than the wavelengths of both the initial wave and primary perturbation, suggesting the essential dynamics of the breaking might be captured by tractable nonlinear three-dimensional simulations in a relatively small triply-periodic domain.