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3D DNS and LES of Breaking Inertia-Gravity Waves

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As inertia-gravity waves we refer to gravity waves that have a sufficiently low frequency and correspondingly large horizontal wavelength to be strongly influenced by the Coriolis force. Inertia-gravity waves are very active in the middle atmosphere and their breaking is potentially an important influence on the circulation in this region. The parametrization of this process requires a good theoretical understanding, which we want to enhance with the present study.

Primary linear instabilities of an inertia-gravity wave and "2.5-dimensional" nonlinear simulations (where the spatial dependence is two dimensional but the velocity and vorticity fields are three-dimensional) with the wave perturbed by its leading primary instabilities by Achatz [1] have shown that the breaking differs significantly from that of high-frequency gravity waves due to the strongly sheared component of velocity perpendicular to the plane of wave-propagation. Fruman & Achatz [2] investigated the three-dimensionalization of the breaking by computing the secondary linear instabilities of the same waves using singular vector analysis. These secondary instabilities are variations perpendicular to the direction of the primary perturbation and the wave itself, and their wavelengths are an order of magnitude shorter than both. In continuation of this work, we carried out fully three-dimensional nonlinear simulations of inertia-gravity waves perturbed by their leading primary and secondary instabilities. The direct numerical simulation (DNS) was made tractable by restricting the domain size to the dominant scales selected by the linear analyses. The study includes both convectively stable and unstable waves.

To the best of our knowledge, this is the first fully three-dimensional nonlinear direct numerical simulation of inertia-gravity waves at realistic Reynolds numbers with complete resolution of the smallest turbulence scales. Previous simulations either were restricted to high frequency gravity waves (e. g. Fritts et al. [3]), or the ratio N/f was artificially reduced (e. g. Lelong & Dunkerton [4]). The present simulations give us insight into the three-dimensional breaking process as well as the emerging turbulence. We assess the possibility of reducing the computational costs of three-dimensional simulations by using an implicit turbulence subgrid-scale parametrization based on the Adaptive Local Deconvolution Method (ALDM) for stratified turbulence [5].

In addition, we have performed ensembles of nonlinear 2.5-dimensional DNS, like those in Achatz [1] but with a small amount of noise superposed to the initial state, and compared the results with coarse-resolution simulations using either ALDM as well as with standard LES schemes. We found that the results of the models with parametrized turbulence, which are orders of magnitude more computationally economical than the DNS, compare favorably with the DNS in terms of the decay of the wave amplitude with time (the quantity most important for application to gravity-wave drag parametrization) suggesting that they may be trusted in future simulations of gravity wave breaking.

References

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