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Modal and nonmodal perturbations of monochromatic high-frequency gravity waves: Primary nonlinear dynamics

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The primary nonlinear dynamics of high-frequency gravity waves (HGWs) perturbed by their most prominent normal modes (NMs) or singular vectors (SVs) in a rotating Boussinesq fluid have been studied by direct numerical simulations (DNS), with wave scales and values of viscosity and diffusivity characteristic for the upper mesosphere. The DNS is 2.5D in that it has only two spatial dimensions, defined by the direction of propagation of the HGW and the direction of propagation of the perturbation in the plane orthogonal to the HGW phase direction, but describes a fully 3D velocity field. Many results of the more comprehensive fully 3D simulations in the literature are reproduced. So it is found that statically unstable HGWs are subject to wave breaking ending in a wave amplitude with respect to the overturning threshold near 0.3. It is shown that this is a result of a perturbation of the HGW by its leading transverse NM. For statically stable HGWs a parallel NM has the strongest effect, quite in line with previous results on the predominantly 2D instability of such HGWs. This parallel mode is, however, not the leading NM but a larger-scale pattern, seemingly driven by resonant wave-wave interactions, leading eventually to energy transfer from the HGW into another gravity wave with steeper phase propagation. SVs turn out to be less effective in triggering HGW decay but they can produce turbulence of a strength which is, as that from the NMs, within the range of measured values, however with a more pronounced spatial confinement.