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Interactions between Meso- and Sub-Mesoscale Gravity Waves and their Efficient Representation in Mesoscale-Resolving Models

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As present weather-forecast codes and increasingly many atmospheric climate models resolve at least part of the mesoscale flow, and hence also internal gravity waves (GWs), it is natural to ask whether even in such configurations sub-gridscale GWs might impact the resolved flow, and how their effect could be taken into account. This motivates a theoretical and numerical investigation of the interaction between unresolved sub-mesoscale and resolved mesoscale GWs, using Boussinesq dynamics for simplicity. By scaling arguments, first a subset of sub-mesoscale GWs is identified that can indeed influence the dynamics of mesoscale GWs. Therein, hydrostatic GWs with wavelengths corresponding to the largest unresolved scales of present-day limited-area weather forecast models are an interesting example. A large-amplitude WKB theory, allowing for a mesoscale unbalanced flow, is then formulated, based on multi-scale asymptotic analysis utilizing a proper scale-separation parameter. Purely vertical propagation of sub-mesoscale GWs is found to be most important, implying inter alia that the resolved flow is only affected by the vertical flux convergence of sub-mesoscale horizontal momentum at leading order. In turn, sub-mesoscale GWs are refracted by mesoscale vertical wind shear while conserving their wave-action density. An efficient numerical implementation of the theory uses a phase-space ray tracer, thus handling the frequent appearance of caustics. The WKB approach and its numerical implementation are validated successfully against sub-mesoscale resolving simulations of the resonant radiation of mesoscale inertia GWs by a horizontally as well as vertically confined sub-mesoscale GW packet.