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The interaction between atmospheric gravity waves and large-scale flows: an efficient description beyond the non-acceleration paradigm

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With the aim of contributing to the improvement of subgrid-scale gravity wave (GW) parameterizations in numerical-weather-prediction and climate models, the comparative relevance in GW drag of direct GW-mean-flow interactions and turbulent wave breakdown are investigated. Of equal interest is how well Wentzel-Kramer-Brillouin (WKB) theory can capture direct wave-mean-flow interactions, that are excluded by applying the steady-state approximation. WKB is implemented in a very efficient Lagrangian ray-tracing approach that considers wave action density in phase-space, thereby avoiding numerical instabilities due to caustics (Muraschko et al., 2015, *Quart. J. Roy. Meteor. Soc.*, **141**, 676–697). It is supplemented by a simple wave-breaking scheme based on a static-instability saturation criterion. Idealized test cases of horizontally homogeneous GW packets are considered where wave-resolving Large-Eddy Simulations (LES) provide the reference. In all of theses cases the WKB simulations including direct GW-mean-flow interactions reproduce the LES data, to a good accuracy, already without wave-breaking scheme. The latter provides a next-order correction that is useful for fully capturing the total-energy balance between wave and mean flow. Moreover, a steady-state WKB implementation, as used in present GW parameterizations, and where turbulence provides, by the non-interaction paradigm, the only possibility to affect the mean flow, is much less able to yield reliable results. The GW energy is damped too strongly and induces an over-simplified mean flow. This argues for WKB approaches to GW parameterization that take wave transience into account (Bölöni et al., 2016 *J. Atmos. Sci.*, **73**, 4833–4852).