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The Interaction between Meso- and Sub-mesoscale Gravity Waves in Boussinesq Dynamics

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Nowadays, high-resolution numerical weather prediction (NWP) models are resolving the mesoscale part of the gravity wave (GW) spectrum, while the effect of small sub-gridscale GWs is not taken into account, although there are indications that the GW momentum flux associated with the small-scale waves might have relevant contributions to the energy budget. In contrast to the situation when GW parameterisations were developed for interactions of (mesoscale) GWs with a synoptic-scale flow, unresolved GWs propagate now in a background which includes resolved mesoscale GWs. Consequently, it is necessary to reconsider the basic theory, which GW parameterisations are based on, and study the interaction between meso- and sub-mesoscale GWs theoretically and numerically.

A multi-scale asymptotic analysis is applied in Boussinesq dynamics in order to identify regimes for this interaction, characterised by the amplitude and aspect ratio of small-scale waves, and the ratio of Coriolis parameter and Brunt-Väisälä frequency, where powers of the latter are acting as the scale separation parameter [1]. It is found that mesoscale waves are mainly influenced by the vertical flux of horizontal momentum associated with the sub-mesoscale waves. Moreover, the sub-mesoscale GW field is able to produce mesoscale wind patterns far away from itself, connected to a resonance phenomenon known from wave-wave interaction theory [2]. As variations of background stratification and mesoscale wind patterns also impact the characteristics of the sub-mesoscale wave field, a two-way coupling occurs that can be studied by a WKB ray tracer as a transient GW parameterisation. Indeed, it has recently been shown that a weakly nonlinear coupling can be described very well by a phase space Lagrangian WKB ray tracer [3]. Beyond that, the role of wave breaking in the wave-mean flow interaction has been found to only be of secondary importance [4].

Fully nonlinear Large Eddy Simulations (LES), resolving also sub-mesoscale wave structures, confirm our theoretical findings and validate the phase space approach of the Lagrangian WKB ray tracer for vertically as well as horizontally confined (2D) wave fields. The theory and the corresponding ray tracer will be described, and validating numerical simulations will be shown. Several cases will be discussed, exhibiting e.g. the radiation of a mesoscale GW by a sub-mesoscale GW packet.

References

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