Atmospheric Dynamics

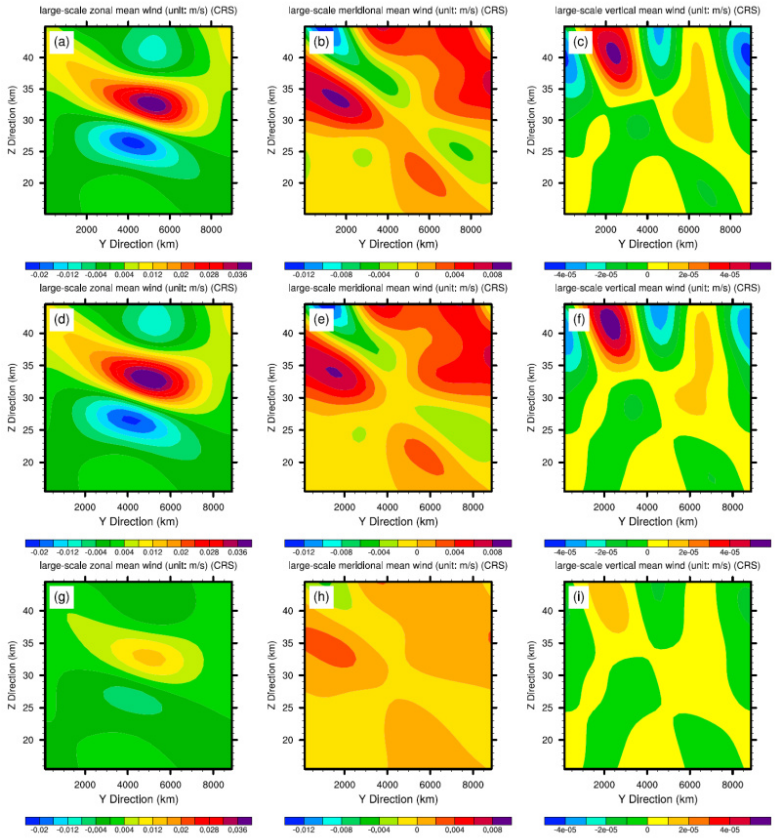


Fig. 1: The two horizontal wind components (left and middle column) and the vertical wind (right), all in m/s, induced by a GW packet, as simulated by PincFloit LES (top row), the WKB MS-GWaM according to Achatz et al (2017, middle), and the conventional WKB approach (bottom), taken from [9].

Introduction

Atmospheric gravity waves (GWs) are rather short in wavelength (1km – 100km in the horizontal, 100m – 10km in the vertical). Excited mostly below 10km altitude, through processes such as flow over mountains, thunderstorms, and other heavy weather, they transport momentum and energy to higher atmospheric layers, where they deposit their momentum and affect the thermodynamic energy balance, e.g. via turbulent frictional heating. This impact is crucial for the large-scale circulation in the atmosphere and potentially also has significant impacts on tropospheric weather and climate. A large fraction of the GW spectrum cannot be resolved by atmospheric codes, yet their effect is important, so that it must be described in so-called parameterizations.

Methods

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Institute
Geosciences/Geography Department

University
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Partners
BTU Cottbus - Senftenberg , Deutscher Wetterdienst, Freie Universität Berlin, Forschungszentrum Jülich, Leibniz-Institut für Atmosphärenphysik, Massachusetts Institute of Technology, Max-Planck-Institut für Meteorologie, YONSEI University, Seoul, Korea

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In this project, GWs and their dynamics are studied by a hierarchy of codes with different costliness and complexity. Idealized Large-Eddy simulations using the group's massively parallel code PincFloit [7] are done in wave and partially also turbulence resolving mode to provide reference data. These provide benchmark test of the group's WKB GW code MS-GWaM [2, 4, 8, 9], coupled to a low-resolution variant of PincFloit. Lessons learned from these studies help in the implementation of MS-GWaM into the operational weather-forecast and climate-simulation code ICON of the German weather service (DWD, in Offenbach) and the Max-Planck-Institute for Meteorology (MPI-M, in Hamburg). Another branch of research investigates the dynamics of related laboratory experiments, with PincFloit adjusted in its geometry to a corresponding experiment [3].

Results

Wentzel-Kramer-Brillouin (WKB) theory is the basis of most GW parameterizations. There is, however, an increasing appreciation that the present handling of this technique needs improvements [1]: a simplification typically used is (1) the neglect of horizontal GW propagation (single-column approximation) and (2) the assumption that GWs propagate instantaneously from their sources to the model top (steady-state approximation). Using a spectral-Lagrangian technique that first made it possible to solve the WKB equations without these approximations [4], the single column approximation has been shown to be an important weakness of state-of-the-art parameterizations by [5, 6], while [2] and [8] demonstrate the weaknesses of the steady-state assumption by numerical solutions of the general WKB theory and comparisons to conventional parameterizations. Another drawback of GW parameterizations in current climate and weather codes is that they assume approximately balanced resolved flows. With the increasing spatial resolutions applied nowadays, this is no good assumption anymore. If the resolved flow is not balanced additional forcing terms due to the GW dynamics appear both in the momentum and the entropy equation representing e.g. elastic effects [1]. [9] have investigated the relevance of these considerations. They show that a more general approach is much better able to simulate the atmospheric GW field.

Outlook

These studies have brought us appreciably closer to a realistic description of GWs in global atmospheric models. Much remains to be done, however. The implementation of MS-GWaM into ICON will be accompanied by studies of the most important GW-source processes and their representation in WKB theory and modelling, as well as the relevance of nonlinear GW-GW interactions. These activities will be further funded by DFG (e.g. FOR MS-GWaves, funded into 2021) and BMBF (framework ROMIC-II, until fall 2021), and possibly additional funding sources.

Publications

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