Project: **1097**

Project title: **Multiscale Dynamics of Atmospheric Gravity Waves**

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The overall goal of the project is to improve the representation of subgrid-scale gravity wave (GW) effects on the resolved flow in atmospheric models and to validate and utilize it to study atmospheric dynamics associated with GWs. The transient GW parameterization MS-GWaM (Multi-Scale Gravity Wave Model) has been developed for this purpose, and implemented into a high-top global model (UA-ICON) and a Pseudo-Incompressible Flow solver (PincFlow). Early this year two manuscripts documenting its implementation into UA-ICON and its impact on the global circulation and GW intermittency (reported to DKRZ last year) have been published (Bölöni et al. 2021, JAS; Kim et al. 2021, JAS). Later on, the computational resources of this project have been used to the largest part for (1) quasi-biennial-oscillation (QBO) simulations and (2) the implementation of a 3D mode of MS-GWaM (allowing lateral propagation of GWs, among other effects).

(1) Presently, tropical stratospheric dynamics associated with the QBO is studied using UA-ICON with MS-GWaM. The same configuration of UA-ICON/MS-GWaM as that in Kim et al. (2021) has been used initially, with a vertical resolution of 700 m in the stratosphere. In the first four months of corresponding simulations one observes an interesting interaction between stratospheric Kelvin waves and parameterized GWs. Figure 1(a-c) shows the Kelvin-wave perturbations (contours) propagating eastward and the GW drag (shaded) coupled to the these perturbations. Further investigation of this feature using additional simulations (not shown) reveal that this coupling of the GW drag occurs due to the modulation of the local wind shear by Kelvin waves while the coupled GW drag again has a feedback on the Kelvin waves, enhancing their amplitudes. This interaction, unknown up to now, is of relevance for QBO dynamics since these two types of waves are known to be the most important contributors to QBO driving. A corresponding paper has been submitted to the Geophysical Research Letters.

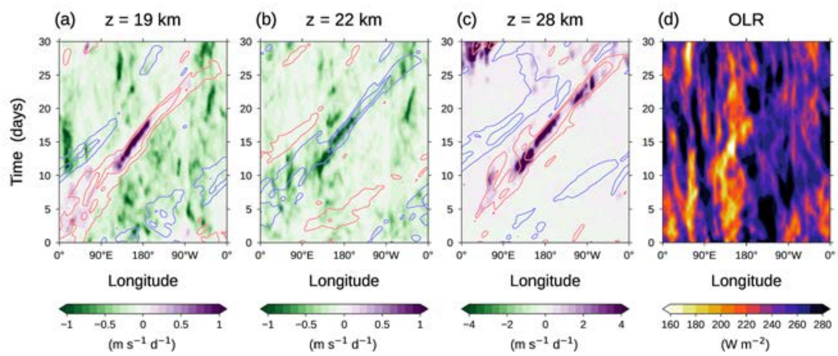

Figure 1: Hovmöller diagrams of (a,b,c) Kelvin wave temperatures (red and blue contours for positive and negative, respectively) and zonal GW drag (shading) at 19, 22, and 28 km (from left to right) and (d) daily averaged OLR in the simulation.

In the aforementioned configuration of UA-ICON/MS-GWaM, however, the QBO could not be maintained over a longer period. The tropical zonal-wind time series for a 5-year integration is shown in Fig. 2 (upper panel). One sees a combined annual and semiannual oscillation, extending from above in an unrealistic manner into the lower stratosphere, while the QBO signals are absent. Therefore, the configuration of UA-ICON/MS-GWaM has been modified, by (1) changing the numerical treatment of the model dynamics (e.g. vertical resolution and diffusion) and (2) improving the relevant physics (GW and convection parameterization). This has required a large number of sensitivity tests that have consumed the major part of the allocated computational resources. A reasonable setup has finally been obtained, among others with (a) a vertical grid spacing of 400 m in the stratosphere (cf. 700 m, previously) and (b) a significantly (by 90%) reduced minimum vertical-diffusion coefficient in the stratosphere. Already just increasing the vertical resolution (180 levels) leads to an an improvement by extending the QBO period to about 1.5 years (not shown). Reducing in addition the minimum vertical diffusion (and adjusting a parameter in the subgrid convection scheme) results in further improvements in oscillation in the stratosphere. The

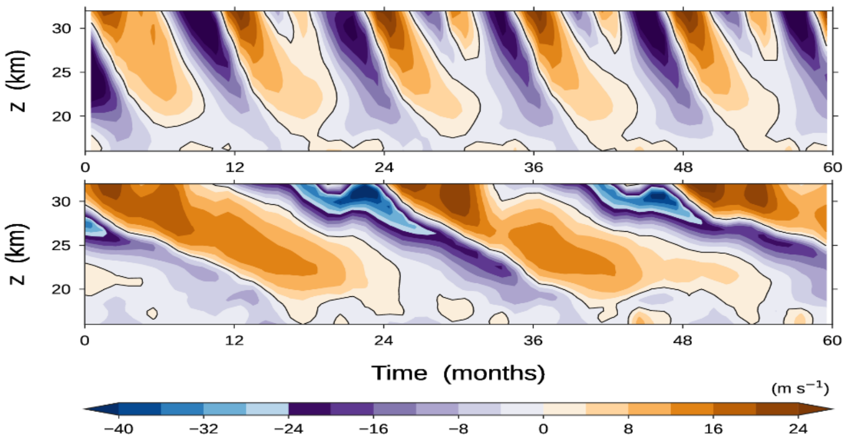

Figure 2: Tropical monthly zonal-mean zonal winds averaged over 5°N-5°S simulated by UA-ICON/MS-GWaM: (top panel) with the previously published configuration and (bottom) with reduced vertical grid spacing and adjusted model dynamics (especially reduced vertical diffusion). The GW parametrization remains to be improved further.

simulation result using this configuration is shown in the bottom panel of Fig. 2. The QBO period is longer (about 2 years) and the easterly-phase amplitudes are stronger. The easterlies in the oscillation at z = 19-28 km tend to be still weaker than those in the real atmosphere, which is indeed a common bias of the current generation of GCMs that are capable of simulating the QBO qualitatively.

We note that all the changes made in the above sensitivity runs have left MS-GWaM untouched. Current work regarding this topic, to be continued also next year, addresses a better representation of the convective source of GWs (through the subproject QUBICC within ROMIC 2) and the implementation of a 3D mode of MS-GWaM (subprojects W1 and S2 in the DFG CRC-181), both of which are currently being carried out. The simulation results will also be submitted to the SPARC/QBOi intercomparison activity.

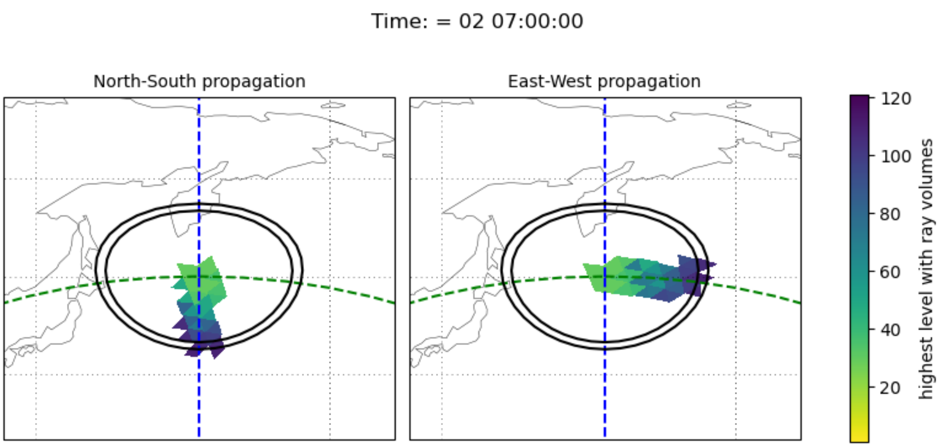

Figure 3: Testing the horizontal and vertical propagation of ray volumes with MS-GWaM in UA-ICON. Dashed lines are great circles showing the theoretically predicted horizontal direction of propagation and the black rings are predictions of the horizontal positions at which the ray volumes are expected to hit the model top.

(2) As for the 3D-propagation of GWs in MS-GWaM in UA-ICON, we have completed the implementation and started testing the code by comparing to previously reported results. In particular we have carried out propagation and parallelization tests to ensure the correctness and performance of the parametrization (Fig. 3). Currently we are performing comparisons with results from idealized simulations using PincFlow in order to validate the implementation of the directly computed 3D momentum and heat fluxes. At the same time, we are introducing a ray splitting and merging algorithm to further increase the performance of MS-GWaM. While these first steps have been relatively low in computational costs we expect an increased computational need for the rest of the year in order to perform production runs once we have completed the testing stage. It is then planned to produce composite runs as in Bölöni et al. (2021) to isolate the effects of the 3D propagation and the modified fluxes. Results are planned to be reported in two separate publications early next year.