Project: **951**

Project title: **Gravity Wave Interactions in the Global Atmosphere (GWING)**

Project lead: **Hauke Schmidt**

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Since its start on September 15, 2015, the project has extended the ICON model to the upper atmosphere (UA-ICON) and is progressing towards the analysis of resolved gravity waves (GWs) in 150km-top UA-ICON simulations at 20km resolution and in standard-top ICON simulations at even higher ("storm-resolving", up to 2.5km horizontal) resolution.

Summary of achievements (in 2019)

1. Evaluation of UA-ICON with GW-permitting resolution

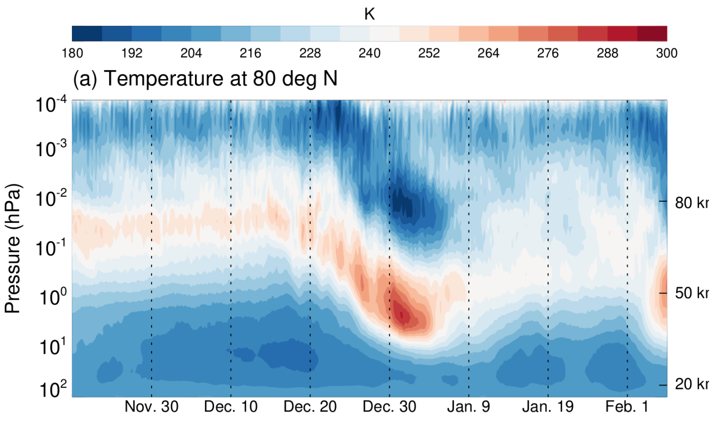
The model description paper for UA-ICON, where the R2B04 grid was used, has been published (Borchert et al., 2019). After testing a version of UA-ICON at horizontal resolutions of roughly 20 km (R02B07), simulations were performed encompassing 6 months of extended winter seasons starting in October until March of the following year. The large-scale circulation has been evaluated. One of the most important aspects of these simulations is that they are run with both gravity wave parameterization schemes (orographic as well as non-orographic) switched off. Additionally, in one out of six simulations the vertical resolution is doubled (360 vertical levels instead of 180) in order to understand the sensitivity of gravity wave representations and responses to different vertical resolutions. The major focus lie on i) GW propagation in case of a minor stratospheric sudden warming and ii) GW differences in summer easterlies in the middle atmosphere.

In general, the stratospheric polar vortex of the winter hemisphere remains too strong and cold in all simulations which is visible in comparison with URAP reference atmosphere. Due to the cold bias, major sudden stratospheric warmings are not occurring in the six winters simulated with UA-ICON at R02B07. However, the model is capable to simulate minor stratospheric sudden warmings. Major findings of the case of the minor stratospheric sudden warming (SSW) are (Fig. 1):

- The abrupt changes of a minor SSW is accompanied by an altitude change of the stratopause and a cooling of the mesosphere. After the onset of the warming the stratopause reestablishes at a different altitude (such events are sometimes called elevated stratopause events).

- These events reflect the coupling between stratosphere and mesosphere. An analysis of observational data of the MLS (Microwave Limb Sounder) of the Aura satellite for two selected major warmings corroborate the realistic behaviour of the simulated result.

- Based on the simulations, the analysis shows that oblique GW propagation [Stephan et al., 2019c, submitted] can occur and give a hint for rethinking the GW parameterization schemes, which assume purely vertical propagation and breaking/dissipation of GWs.



- The cold bias remains in the higher resolution run of UA-ICON. It is hypothesized that due to a cold bias in the high-latitude winter stratosphere the tropospheric forcing is not able to disturb the stratospheric polar vortex in the sense of representing a major warming. The question remains which parameters have to be adjusted in order to simulate a more realistic state of the middle atmosphere.

2. Evaluation of UA-ICON with different vertical layering

One out of six extended winter simulations was performed with a doubling of the standard vertical resolution for UA-ICON (R02B07L360). Using the TEM framework in order to understand the eddy-mean flow interactions, the divergence of the Eliassen-Palm Flux (E-P Flux) and the components of the residual circulation were evaluated. In this framework the E-P flux can be understood as an internal forcing driving the mean state. A harmonic analysis separates contributions due to planetary, synoptic and gravity waves (GW). Considering the contributions of GWs (here defined as horizontal wave lengths below 1800 km), distinct differences of the divergence of the E-P Flux occur in the summer middle atmosphere at altitudes above 0.1 hPa (Fig. 2). These changed GW effects indicate that the model reacts sensitively to the choice of vertical layers, especially in the middle atmosphere where dynamics are dominated by GWs.

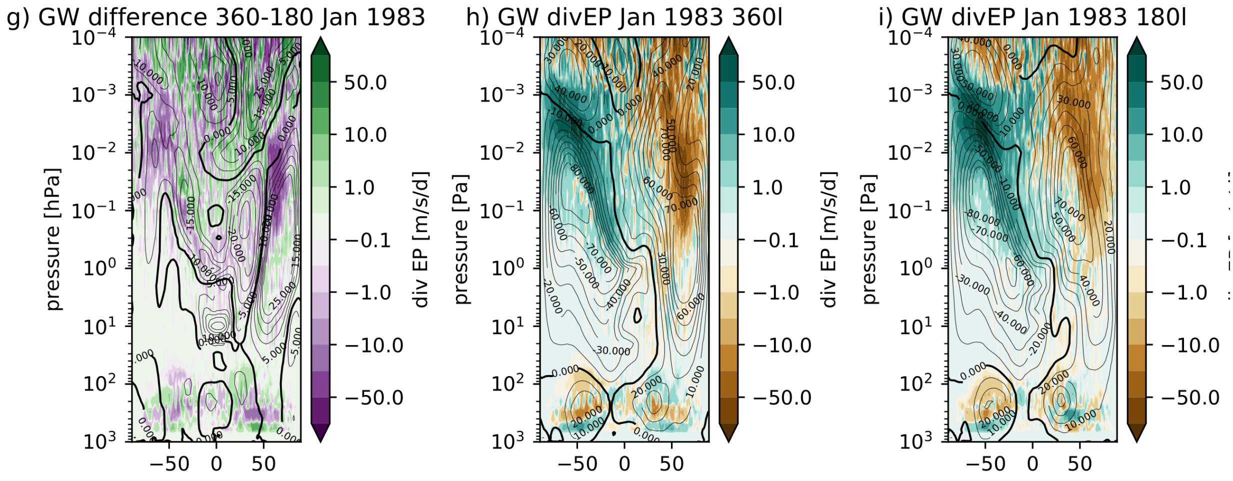


Figure 2: Divergence of the E-P Flux (shading) and zonal mean zonal wind (contours) for January 1983 simulated

3. Analysis of GWs in DYAMOND ("storm resolving") simulations

We analyzed gravity waves in the so-called DYAMOND simulations performed with ICON and other models at horizontal resolutions between 2.5 and 9 km. While the simulations have been performed in other projects and at other computer centers, also the post-processing is computationally expensive and has been performed partly within this project. A first study analyzes the effects of switching on or off convection parameterizations on the simulation of gravity waves in ICON simulations at 5 km horizontal resolution [Stephan et al., 2019a]. One result is that the simulation without convection parameterization shows larger variability of precipitation and subsequently higher gravity wave momentum flux (increased e.g. by 30-50% where convection ist the dominant GW source. In a 2nd study [Stephan et al., 2019b] we have compared simulations with 3 different models at 2 horizontal resolutions each (e.g. ICON at 2.5 and 5 km). While the patterns of GW momentum fluxes agree well among models and observations, quantitatively the zonal momentum fluxes can differ even in the zonal mean by up to a factor of about 3 between models.

Review of the plan proposed last year

Due to a change of staff the plan proposed last year is postponed in some parts to the next year. The following points are in line with the plan proposed last year:

"… develop and evaluate the GW-permitting configuration of UA-ICON (R02B07) …. in terms of large-scale circulation ..." -

This has been achieved.

" 7 years of UA_ICON R02B07 with and without GW parameterizations ..." -

One part of the simulations (without GW parameterizations, extended winter, UA-ICON R02B07L180) were simulated. Simulations with additional GW parameterizations will be performed by the end of 2019.

Some part of the computing time was used for post-processing of the UA-ICON R02B07 extended winter simulations as well as of DYAMOND simulations (see Sections 2 and 3, above). The DYAMOND simulations based on the explicit turn-off of the convection parameterization as well as the gravity wave parameterizations were done for a full range of different resolutions spanning from 80 km up to 2.5 km horizontal grid spacing. This comprehensive set of different resolutions give the possibility for a detailed analysis of GW responses with changing resolutions, focussing here onto the momentum budget.

Publications

Borchert, S., Zhou, G., Baldauf, M., Schmidt, H., Zängl, G., & Reinert, D.: The upper-atmosphere extension of the ICON general circulation model (version: ua-icon-1.0). Geoscientific Model Development, 12, 3541-3569, 2019.

Stephan, C. C., Strube, C., Klocke, D., Ern, M., Hoffmann, L., Preusse, P., & Schmidt, H.: Gravity waves in global high-resolution simulations with explicit and parameterized convection. J. Geophys. Res., 124, 4446–4459, 2019a.

Stephan, C. C., Strube, C., Klocke, D., Ern, M., Hoffmann, L., Preusse, P., & Schmidt, H.: Intercomparison of Gravity Waves in Global Convection-Permitting Models, J. Climate, in press, 2019b.

Stephan, C.C., Schmidt, H., Zülicke, C., and Matthias, V.: Oblique Gravity Wave Propagation during Sudden Stratospheric Warmings; J. Geophys., Res., submitted, 2019c.