Project: 951 Project title: Gravity Wave Interactions in the Global Atmosphere (GWING) Project lead: Hauke Schmidt Report period: 1.1.2018 – 31.12.2018

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 75km-top high-resolution ICON simulations, and UA-ICON simulations at 20km resolution.

Summary of achievements (in 2018)

1. Evaluation of the coarse resolution UA-ICON configuration

As mentioned in last year's report, the evaluation of the coarse UA-ICON configuration, which was originally planned for 2017, had to be postponed to 2018 as we had to wait for the correction of input SSO parameters. The performance of the dynamical core and the large-scale circulation in UA-ICON have now been evaluated. In collaboration with colleagues from the DWD the results have been written up in a publication titled 'The upper-atmosphere extension of the ICON general circulation model' [Borchert et al., to be submitted in November 2018]. As detailed in this manuscript, UA-ICON is capable of

- satisfactorily reproducing the analytical solution to an idealized sound-wave propagation test case, which shows that the spherical geometry of the model is correctly implemented with regard to the metric terms and the complete Coriolis acceleration terms that enter the momentum equation.

- passing the Jablonowski-Williamson baroclinic instability test case, i.e., UA-ICON is able to maintain an initial hydrostatic and geostrophic equilibrium for several days and reproduces the amplitude and shape of a baroclinic wave when compared to a benchmark solution.

- simulating well the zonal mean temperatures in comparison to SABER observations and an ICON simulation with a standard 80-km lid, albeit with a winter mesopause that is characterized by a vertically extended region of similar low temperatures, missing the observed distinct temperature minimum near 100 km.



Figure 1: Climatological zonal-mean temperature for (top) January and (bottom) July averages from (left) UA-ICON, middle (ICON) and (right) SABER satellite (Fig. 5 form Borchert et al.).

- simulating similar zonal mean winds as observed by URAP but with lower-thermospheric jets that are too strong, and occur somewhat too low in the atmosphere.



Figure 2: Climatological zonal-mean zonal wind for (top) January and (bottom) July averages from (left) UA-ICON, middle (ICON) and (right) URAP (Fig. 7 from Borchert et al.).

2. Development of UA-ICON at R2B7 resolution (20 km horizontal resolution).

After merging the UA-ICON code with the most recent version of the ICON branch in May 2018, we set up a UA-ICON simulation at R2B7. Before the model ran for longer than a few seconds and eventually longer than a few days, it was necessary to modify several namelist parameters in a trial and error approach. Eventually, a stable simulation was achieved in June 2018. The main modifications compared to R2B7 include:

- increasing the number of vertical levels from 120 to 180
- reducing the model time step from 4min to 30s
- reducing the number of numerical substeps from 5 to 2
- reducing the start of the damping layer from 120 to 100 km
- several changes to the divergence damping and diffusion settings

The simulation was performed for one January to allow for a basic first evaluation.

Preliminary results indicate that our first attempt at running UA-ICON at R2B7 resolution without orographic and



nonorographic GW parameterizations is successful at reproducing the R2B4 zonal mean zonal wind and temperatures.

One may even argue that the lower thermospheric jets have improved. However, both versions have a poor representation of the winter mesopause.

We are satisfied to have achieved a stable simulation at R2B7 after only 1 month of model development. We postponed further developments of UA-ICON until the beginning of 2019 to take advantage of the

Figure 3: Zonal mean temperature (left) and zonal wind (right) averaged from one January simulated with UA-ICON at R2B7 resolution.

opportunity to study explicitly resolved GWs in global high-resolution climate models (next point).

3. Evaluation of explicitly resolved GWs in climate models participating in the DYAMOND project.



Two manuscripts are in preparation. One compares GWs in 5 different simulations that are part of the DYAMOND suite, namely ICON-5km, ICON-2.5km, SAM-4km, FV3-3.25km and NICAM-7km (Figure to the left). GWs in these models were evaluated and compared to HIRDLS, SABER and AIRS satellite observations using the small-volume few-wave decomposition method S3D and computations based on local temperature and wind amplitude perturbations (LPA). This is the first intercomparison of GWs in cloud-resolving simulations and this analysis fits well within the scope of our project to understand processes from GW generation via propagation to dissipation in numerical weather prediction and climate models.

(a) August-mean zonal-mean absolute GWMF at 30km for all simulations and observed by HIRDLS and SABER. Simulated GWMF was computed by applying S3D (colored lines) and LPA (colored lines with gray background).

(b) Simulated net meridional and zonal, respectively, GWMF from S3D.

Figure 4: Simulated absolute (top), zonal (middle), and meridional (bottom) gravity wave momentum fluxes from DYAMOND simulations with models as indicated in the legend.

The second manuscript in preparation is an intercomparison of GWs in 5km ICON simulations with and without a

convective parameterization and it allows us to determine the effects that turning on a convective parameterization in models with fine resolution has on GWs.

Review of the plan proposed last year

Our work is generally progressing in line with the plan proposed last year:

"The evaluation of the coarse resolution configuration is planned to be done by early summer 2018."

This goal has been achieved.

"Next, the GW-permitting configuration of UA-ICON is planned to be developed and evaluated, again in terms of large-scale circulation [...]. The planned finishing time is winter 2018."

During summer and autumn of 2018 we focused on the DYAMOND simulations and decided to delay further developments of UA-ICON until 2019. This departure from our original plan is beneficial for the development of UA-ICON for several reasons: (i) we had to adapt wave fitting and wave tracing code to work on ICON model output and these tools can equally well be applied to UA-ICON. (ii) we now have got satellite climatologies against which we can evaluate GWs in UA-ICON (iii) we can evaluate which fraction of the UA-ICON GW spectrum is resolved by comparing GWs below 40km to the results obtained for ICON-5km and ICON-2.5km.