Project: **951**

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

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Started on September 15, 2015, the project is progressing properly towards extending the ICON model to the upper atmosphere (UA-ICON).

Summary of achievements

1. Implementation of the interface of upper atmospheric (UA) physics into the numerical weather prediction (NWP) physics package

In the report last year, we already largely finished implementing the UA physics package, and the interface of the UA package to the ECHAM package in standard ICON. Together with colleagues from Germen Weather Service (DWD), we have already implemented the interface also to the Numerical Weather Prediction (NWP) physics.

2. Debugging and stabilizing the model

We have spent much time detecting and fixing a number of various bugs in our code, including the ones denoted in the last report. The bugs rose from diverse sources, including typos, pure software engineering mistakes, and mistreatment of the transition into a non-hydrostatic code base. The model is currently believed to be very mature.

We also devoted considerable effort into stabilizing the model. After a long period fumbling around the pool of namelist parameters, it is now known that for a model top as high as 150 km and a sponge layer not too thick, so that the region of interest (up to 120 km) is properly simulated, the gravity wave parameterization is chiefly responsible for the stability of the model. Particularly, the cut-off vertical wavenumber of gravity waves is crucial. The default value of this parameter, which effectively poses no limit on the vertical wavenumber, would allow long waves to propagate into the upper atmosphere. This is both numerically unstable and physically unreasonable, but does not play a noticeable role if the model does not cover the upper atmosphere.

3. Increase of the computational efficiency of the UA package

Since effects of much of the UA physical processes are extremely small in the lower atmosphere, it is a waste of computing time to calculate those below a certain altitude (usually ~80 km). Therefore, we introduced a new approach starting the computation only in the upper part of the atmosphere. With this, we achieved a performance boost of more than 150%.

4. Adoption of the corrected sub-grid scale orographic (SSO) parameters from the standard ICON, update of code structure in accordance to standard ICON, and preparing for back-merge of UA-ICON into the ICON code base

It was revealed late last year that the SSO parameters in the input files of standard ICON contain errors, which has been keeping developers of the standard ICON busy since. As the SSO parameters largely control the SSO gravity wave drag which then greatly modulate the circulation of the whole atmosphere, UA-ICON also needed to wait for the corrected input files to enable credible simulation of the upper atmosphere. While waiting, we updated the code structure of UA-ICON in accordance to the change of code structure in standard ICON, which must be done in order to merge in the fixes of ICON. At the time of writing this report (Oct. 2017), preliminary versions of the corrected input files have been released, and we already made use of them in our test simulations.

5. Adoption and investigation of the new tuning parameters related to the SSO gravity wave drag

Following the correction of the input SSO parameters, the tuning parameters of the SSO drag parameterization also have to be changed. This is currently under active development in standard ICON. We started adopting the preliminary results of the new tuning parameters, but noticed that while these parameters may be suitable for the lower atmosphere, they may not be ideal for the upper atmosphere. We have started inspecting their effects and trying to find a better tuning for the upper atmosphere.

Review of the plan proposed last year

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

> "As a first and essential step, we plan to fix the known bugs and try to find configurations that stabilizes the model on coarse resolution (R2B4)."

We have finished the debugging and stabilizing of the model, and, in view of the heavy computational workload, additionally implemented the mechanism for computing only in the necessary parts of the atmosphere. This work has been finished in early summer 2017.

> "It is planned to evaluate the result of the UA-ICON simulations in terms of large-scale circulation. … The evaluation of the coarse resolution configuration is planned to be done by summer 2017. … Next, the GW-permitting configuration of UA-ICON is planned to be developed and evaluated. … The planned finishing time is end of 2017."

Due to the unexpected problem with the SSO parameters in the standard ICON, the focus of our development work had to turn to the preparation for adopting the corrected parameters in a new code structure. The choice of new tuning parameters is currently being done. Therefore, the planned evaluation of the UA-ICON on coarse and GW-permitting resolutions are delayed. However, we are fully confident that the evaluation will soon become possible. Moreover, we started processing satellite data in the meantime, which is a necessary step for evaluating the model.

Preliminary results

The following figures are zonal mean plots of temperature, zonal wind, and gravity wave drag, averaged over January in an 8-year AMIP simulation for 1979-1986, with qualitative comparison with the results of HAMMONIA in a 30-year simulation. It could be concluded that in the sense of climatology, the results of UA-ICON are generally reasonable.