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 upper atmospheric (UA) physics

We have implemented the new UA physics packaged into ICON. This involves

1) Infrastructure: new data structures holding additional data fields and tendencies; subroutines initializing and cleaning up memory; subroutines reading gas mixing ratios from external NetCDF files of various types and converting the unit; subroutines performing vertical and temporal interpolation of gas mixing ratios and calculating column density; new namelist controlling the on/off status and behavior of the new UA physics; framework and interface for the new UA physics parameterizations; additional timers for the individual UA physics parameterizations.

2) Radiation: shortwave radiative heating in the Schumann-Runge Bands and Continuum (SRBC), and in the extreme ultra-violet and X-ray (EUV); infrared heating/cooling due to absorption by NO, and by CO_2 and O_3 under non-local-thermodynamical-equilibrium (non-LTE) conditions.

3) UA-specific physics: ion drag and Joule heating; molecular diffusion of heat and momentum; frictional heating, i.e. heating due to molecular diffusion of momentum; chemical heating.

All parameterizations, except for chemical heating, are imported from HAMMONIA and adjusted for ICON. Chemical heating is implemented from scratch based on climatological heating rates from a HAMMONIA simulation. All parameterizations are currently only implemented in the ECHAM physics package of ICON. Colleagues from Germen Weather Service (DWD) are porting the new physics package also to the Numerical Weather Prediction (NWP) physics.

2. Merging the UA physics with the deep atmospheric (DA) dynamics

The DA dynamical core being developed in parallel by colleagues from DWD has been successfully merged with our newly developed physics package. In the DA dynamical core, the shallow water equations are relaxed to deep water equations, and several metrical and other correction terms are introduced to better suit the needs in the UA. After merging, we are able to use both an UA-suitable dynamical core and parameterization package along with the ECHAM physics for UA simulations.

3. Debugging and testing

Vigorous effort has been spent on debugging. A number of compile time, run time and logical errors have been detected and fixed. Currently there is still a known bug in the non-LTE radiation subroutine causing zero heating rates over every level at some areas of the globe. This bug is under active inspection.

We have performed a series of AMIP-type test simulations with the ICON model both with and without the newly developed UA physics and/or the DA dynamical core. The goal of the tests is focused on the stability of the model. It can be generally concluded that the stability is very much sensitive to the configuration of the model top, the starting height of the sponge layer, and horizontal, vertical and Rayleigh damping. At the time of writing this report (late October 2016), we are able to stably run the model with a top height of 120 km using a somewhat too large, unphysical Rayleigh damping coefficient (see the row in bold font in the following table). More effort is being spent on increasing the model top and reducing the Rayleigh coefficient.

Table 1. Results of selected AMIP test cases. Resolution: R2B4 (~160 km); Timestep: 2 min.

Top height (km)	Damp height (km)	Number of levels	Rayleigh coefficient	UA physics	DA dynamics	Integration length
80	50	50	0.4	Off	Off	>3 mon
80	50	50	0.4	On	Off	>3 mon

120	65	120	0.4	On	On	~3 day
120	65	120	4	On	On	~3 day
120	65	120	10	On	On	~4 day
120	**65**	**120**	**15**	**On**	**On**	**>3mon**
120	65	120	50	Off	Off	>1 yr
130	70	120	50	Off	Off	<1 day
140	75	120	50	Off	Off	<1 day
150	80	120	50	Off	Off	<1 day
150	80	120	50	On	Off	<1 day
150	80	120	50	On	On	<1 day
150	65	120	50	On	On	intended

Review of the plan proposed last year

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

> "Within the first year of the project (September 2015 – September 2016) the work will focus on the upward extension of the ICON model by implementing physical processes of importance to the upper atmosphere."

We have basically finished the development phase and entered the debugging and testing phase since ca August 2016.

> "The vertically extended dynamical core being developed in parallel by the DWD will be introduced in the last few months of the first project year."

This has been successfully done by ca August 2016.

> "This work will be performed with a coarse version of the ICON model."

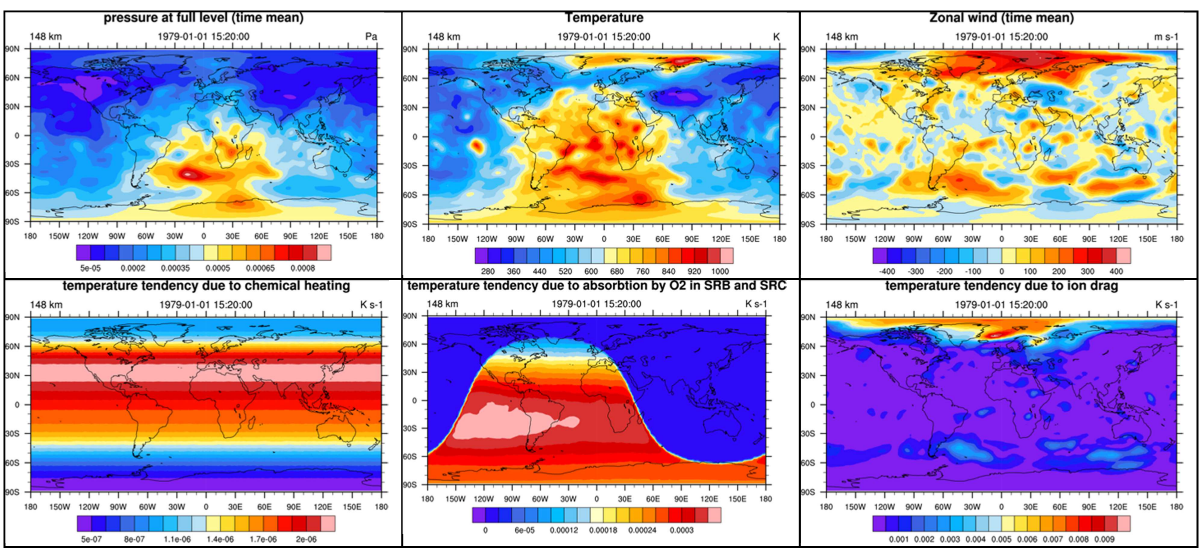
Coarse resolution (R2B4, ~160km) test cases have been performed.

> "Starting in October 2016, the GW-permitting configuration of MA-ICON is planned to be developed and evaluated."

The debugging and testing processes are more difficult and time consuming than imagined, thus the model is not yet ready for evaluation. However, this is absolutely normal in complex software development. Given the great number of tests and diagnosis we have performed and the considerable experience we have accumulated thereby, we fully expect to have a reasonable and stable version of the model in the very near future.

Preliminary results

The following figures are snapshots at the upmost level showing pressure, temperature, zonal wind, and heating rates due to chemical heating, SRBC radiation, and ion drag. It can be inferred that the atmospheric state is reasonably simulated, although the day-night temperature difference seems too large. The displayed heating rates are reasonable too.



The following figure shows the globally averaged profiles of different heating rates at the same time step as above. Most of the newly-add heating rates are effective above 110 km, with the molecular diffusion, EUV heating, and frictional heating being the most dominant heating/cooling sources, whose magnitudes are too large compared to literature results. The non-LTE and the standard long-wave heating rates are merged so that below ~70 km only the standard long-wave radiation is used while the non-LTE heating is effective higher up. It has to be noted that this timestep is immediately before the model crashes with lookup table overflow, thus the heating rates might well be erroneous. The reason for the crash remains to be uncovered.