ICON – Developing a New Generation of Climate and Weather Forecasting Models

Within the ICON project, the Max Planck Institute for Meteorology (MPI-M) and the German Meteorological Service (DWD) are developing a new generation of climate and weather forecasting models whose grids are derived from icosahedrons. Both, atmosphere and ocean models are being developed which can be run as stand-alone or coupled models. For the first time the model components atmosphere and ocean now share a common grid. For weather forecasting a new method has been developed which allows for computing one or even more high-resolution regions that are embedded in a global model. This coordinated approach of combining atmosphere and ocean models into one single system – for the purpose of climate research as well as weather forecasting – is unique in the world.

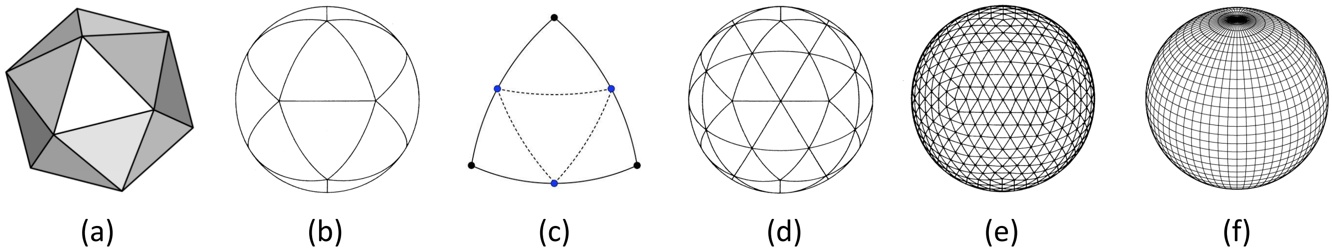


Figure 1 describes the construction of the grids. The icosahedron (a) is projected onto a sphere (b). The edges of each triangle are bisected into equal halves or more generally into *n* equal sections. The new edge points are connected by great circle arcs to yield 4 (or more generally n^2) spherical triangles within the original triangle (c). After refining the first spherical icosahedrons (d), this method can be extended in the same way. After two more steps the grid is reached (e). Such grids avoid polar singularities of latitude-longitude grids and allow a high uniformity in resolution over the whole sphere (f).

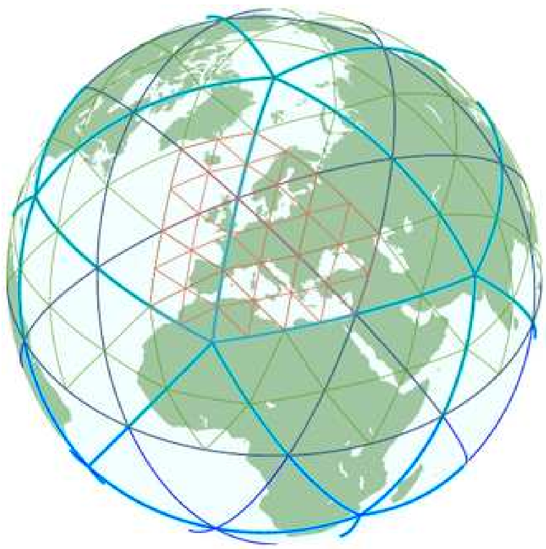


Figure 2: Example for a regionally refined grid. The spherical icosahedron (light blue) was globally and regionally refined within three steps: 1. globally (dark blue), 2. on the Northern hemisphere (green), 3. in a region over Europe (red).

Why do the project partners need new models? Both institutions successfully work with their current respective models – which is MPI-M's ESM (comprised of ECHAM for the atmosphere and MPIOM for the ocean) and DWD's GME and COSMO weather forecasting models. At the same time, the evolving needs of climate research and operational weather forecasting, as well as the general evolution of high-performance computing, place new demands on models. So what are the advantages of ICON in comparison to the present models ECHAM or GME?

To put it briefly:

- **System of equations:** by solving the non-hydrostatic atmospheric equation of motion, the circulation can be simulated at a much higher resolution.
- **Numerics:** The newly developed numerics allow for consistently solving the equation of continuity and transport.
- **Grid:** the icosahedron grid is a new approach in climate modeling. It allows for diverse and complex configurations: global or regional grids, consistently or regionally refined grids. The atmosphere and ocean model can use a common grid infrastructure.
- **Parameterization packages:** the parameterization of physical processes occurring in the atmosphere and ocean can be used and developed for varying scales within the same system: for scales from ~100 km for long-term coupled climate simulations to ~1 km for short-term weather forecasts.
- **Infrastructure:** both, atmosphere and ocean models share the same infrastructure for data I/O, parallelization, time-keeping and model control, etc. This unified software structure significantly reduces the efforts in terms of technical development.
- **Scalability:** ICON permits scalability at a high range to be run on future massive parallel computing systems.
- **Portability:** the ICON model runs on different computing systems, ranging from simple laptops to high-performance computers operated at the German Climate Computing Center (DKRZ) or at DWD.

From the development of a joint model system by MPI-M and DWD, some concrete advantages accrue: while MPI-M's area of expertise lies in climate simulations performed by coupled Earth system models running for only a few years to several centuries, the DWD's expert knowledge is high-resolution atmospheric modeling and quantifying errors in daily weather forecasting. This joint expertise is an asset for developing high-resolution models. These kinds of models are needed for studying the role of small-scale processes in the climate system as well as for operational weather forecasting with coupled atmosphere-ocean models over several months and perhaps over a few years in the future.

So far the ICON project has reached different intermediate goals on its way to a coupled climate model and the first operational weather forecasts, which are planned for 2013. In 2011, the focus was and has been on completing the dynamical cores by parameterization packages for weather forecasting and climate simulations. For the area of forecasting, first tests initialized with weather analyses have been carried out already.

In terms of climate modeling, MPI-M is currently working on the Aqua-Planet experiments: both, atmosphere and ocean model coupled by temperature and wind at the sea surface are run on a land-free planet on the same horizontal grid with a resolution of ~140 km. The atmosphere is vertically resolved by 47 layers reaching heights of 80 km (0.01 hPa), while the global ocean is resolved by 10 layers up to the 5 km deep flat lower boundary. The atmospheric processes are parameterized through the ECHAM physics package. At every ocean time step, that is every half hour, the coupling fields are exchanged.

Figure 3 shows a snapshot of the sea surface temperature and in vertical north-south cross sections through the atmosphere and ocean at 0° longitude. This figure shows the state after an integration time of around 2 years – taken from a test that serves as preparation for a forthcoming multi-decadal simulation.

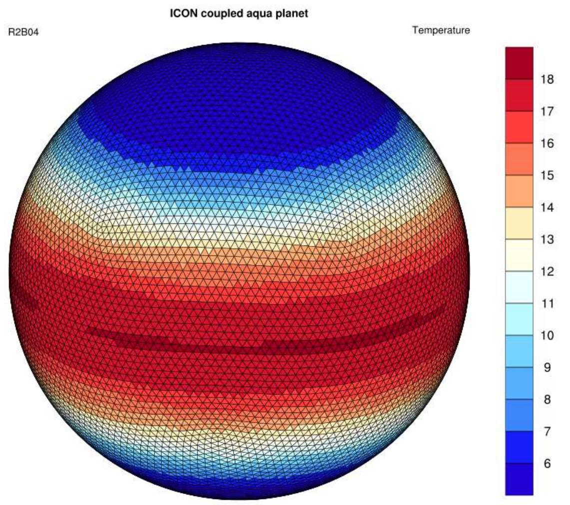
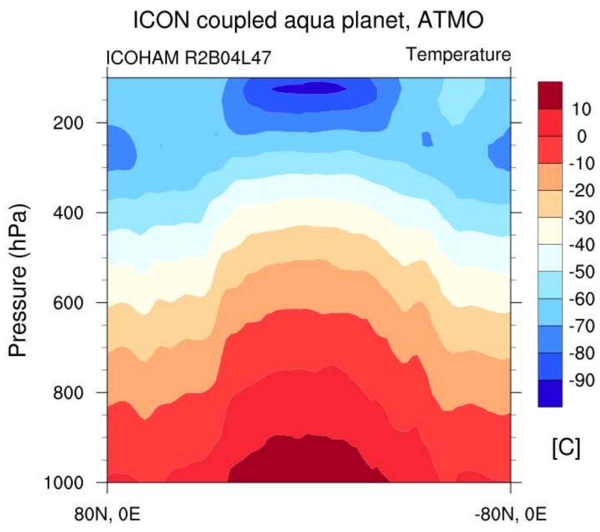
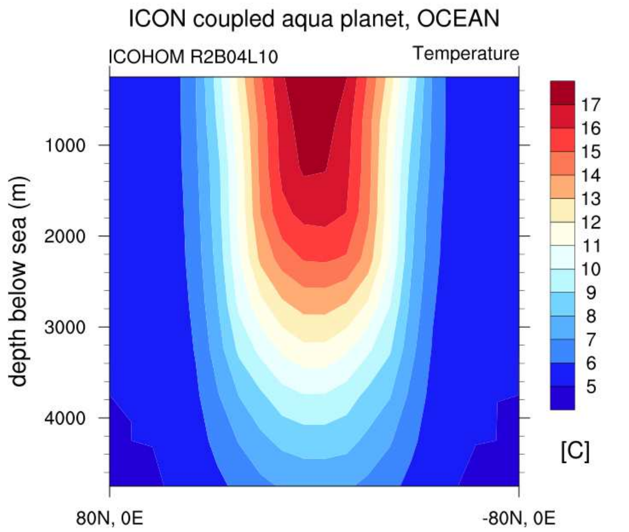


Figure 3. On top: sea surface temperature in °C. Snapshot after two years of simulation time. At bottom (left and right): temperature in °C in the atmosphere and ocean in a north-south cross section at 0° longitude





Contact:

Dr. Marco Giorgetta
Max Planck Institute for Meteorology
Phone: +49 (0)40 41173 358
Email: marco.giorgetta@zmaw.de

Dr. Peter Korn
Max Planck Institute for Meteorology
Phone: +49 (0)40 41173 470
Email: peter.korn@zmaw.de

Dr. Günther Zängl
German Meteorological Service
Phone: +49 (0)69 8062 2728
Email: guenther.zaengl@dwd.de