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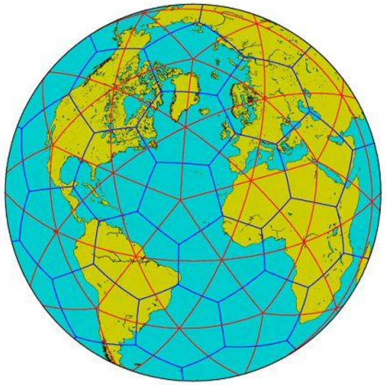
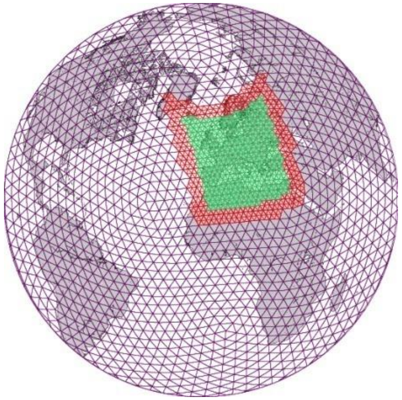
Deutscher Wetterdienst
Wetter und Klima aus einer Hand



ICON



The Icosahedral Nonhydrostatic modelling framework

Basic formulation, NWP and high-performance computing aspects, and its perspective towards a unified model for seamless prediction

Günther Zängl, Daniel Reinert, Florian Prill, Martin Köhler, Slavko Brdar, Marco Giorgetta, Leonidas Linardakis, Luis Kornblueh

PDEs on the sphere, 10.04.2014

Outline

- Introduction: Main goals of the ICON project
- Dynamical core and numerical implementation
- Model applications: global, nested, and limited-area mode
- Scalability
- Conclusions

Primary development goals

- Unified modeling system for NWP and climate prediction in order to bundle knowledge and to maximize synergy effects between DWD and Max Planck Institute for Meteorology
- Better conservation properties
- Nonhydrostatic dynamical core for capability of seamless prediction
- Scalability and efficiency on O(10^4+) cores
- Flexible grid nesting in order to replace both GME (global, 20 km) and COSMO-EU (regional, 7 km) in the operational suite of DWD
- Limited-area mode to achieve a unified modelling system for operational forecasting in the mid-term future

Model equations, dry dynamical core

(see Zängl, G., D. Reinert, P. Ripodas, and M. Baldauf, 2014, QJRMS, in press)

$$\frac{\partial v_n}{\partial t} + (\zeta + f)v_t + \frac{\partial K}{\partial n} + w\frac{\partial v_n}{\partial z} = -c_{pd}\theta_v \frac{\partial \pi}{\partial n}$$

$$\frac{\partial w}{\partial t} + \vec{v}_h \cdot \nabla w + w\frac{\partial w}{\partial z} = -c_{pd}\theta_v \frac{\partial \pi}{\partial z} - g$$

$$\frac{\partial \rho}{\partial t} + \nabla \cdot (\vec{v}\rho) = 0$$

$$\frac{\partial \rho\theta_v}{\partial t} + \nabla \cdot (\vec{v}\rho\theta_v) = 0$$

v_n,w: normal/vertical velocity component

ρ: density

θ_v: Virtual potential temperature

K: horizontal kinetic energy

ζ: vertical vorticity component

π: Exner function

blue: independent prognostic variables

Numerical implementation

- Discretization on icosahedral-triangular C-grid
- Two-time-level predictor-corrector time stepping scheme
- For thermodynamic variables: Miura 2nd-order upwind scheme for horizontal and vertical flux reconstruction; 5-point averaged velocity to achieve (nearly) second-order accuracy for divergence
- Horizontally explicit-vertically implicit scheme; larger time steps (default 5x) for tracer advection / physics parameterizations
- Numerical filter: fourth-order divergence damping
- Tracer advection with 2nd-order and 3rd-order accurate finite-volume schemes with optional positive definite or monotonous flux limiters; index-list based extensions for large CFL numbers

Main features of grid nesting

- Similar to classical two-way nesting (with option for one-way nesting), coupling at physics time step, feedback with Newtonian relaxation
- Option for vertical nesting: nested domain may have lower top than parent domain
- One-way and two-way nested domains can be combined; processor splitting possible for reduced communication overhead
- Nested domains do not have to be contiguous, i.e. a logical nested domain (from a flow-control point of view) can consist of several physical nested domains
- Flow control also allows running the model in limited-area mode

Model application I

Simulation of „monster-typhoon“ Haiyan

- **Three-domain nested configuration with 10/5/2.5 mesh size, 90/60/54 model levels (4.1M grid points in the 2.5 km domain)**
- **NWP physics package, convection scheme turned off in 5 and 2.5 km domains**
- **Initialization from operational IFS analysis on 2013-11-05, 00 UTC, 168-hour forecast**
- **Thanks to Bodo Ritter for preparing the animations!**

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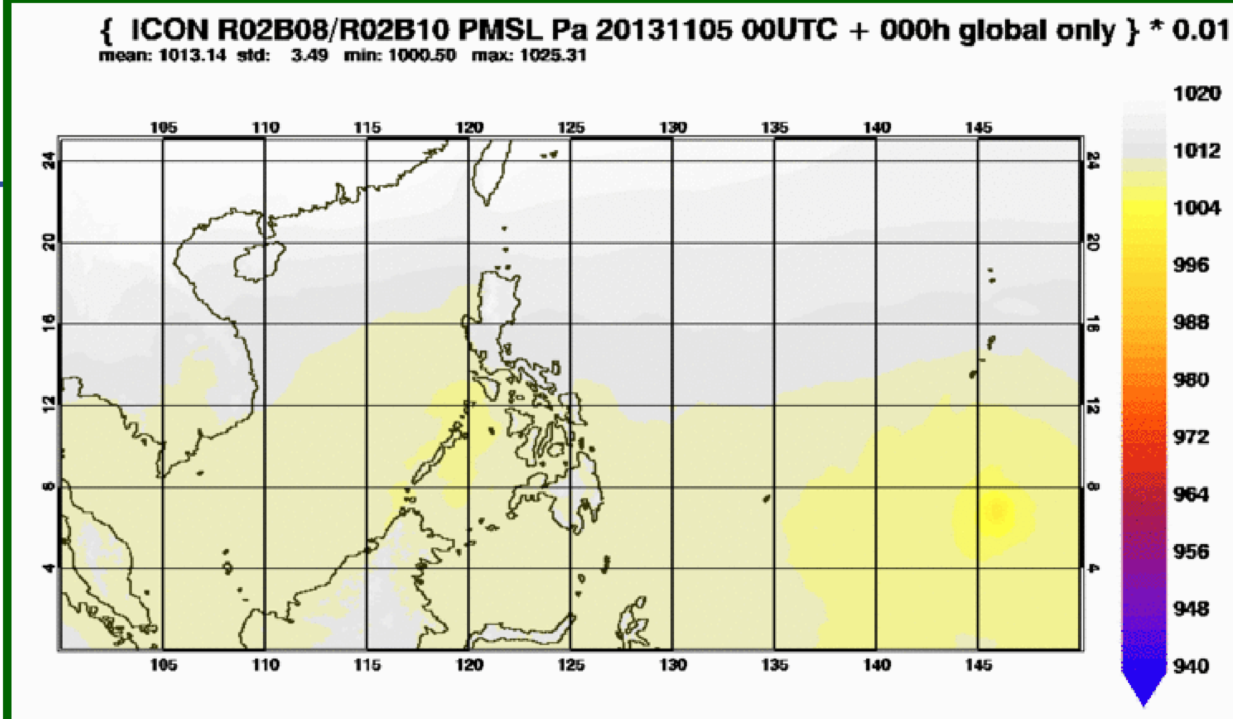
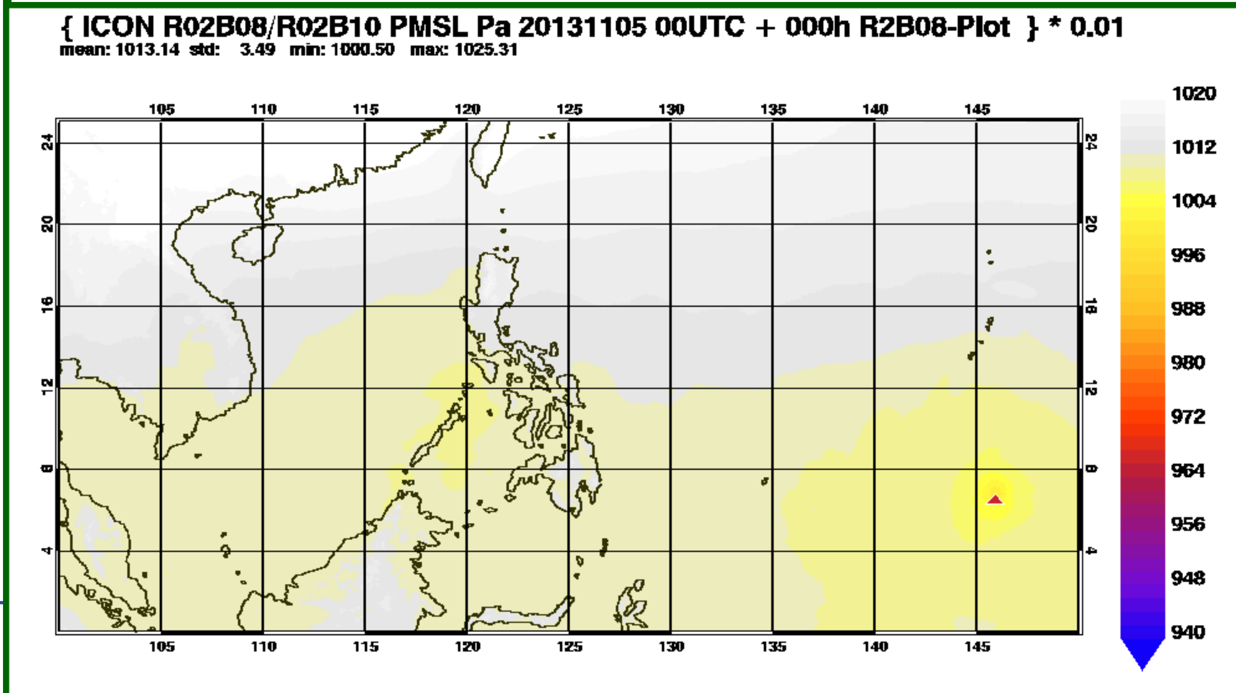
Sea-level pressure (hPa)

Top: 10-km domain

Bottom: 2.5-km domain, including observed track





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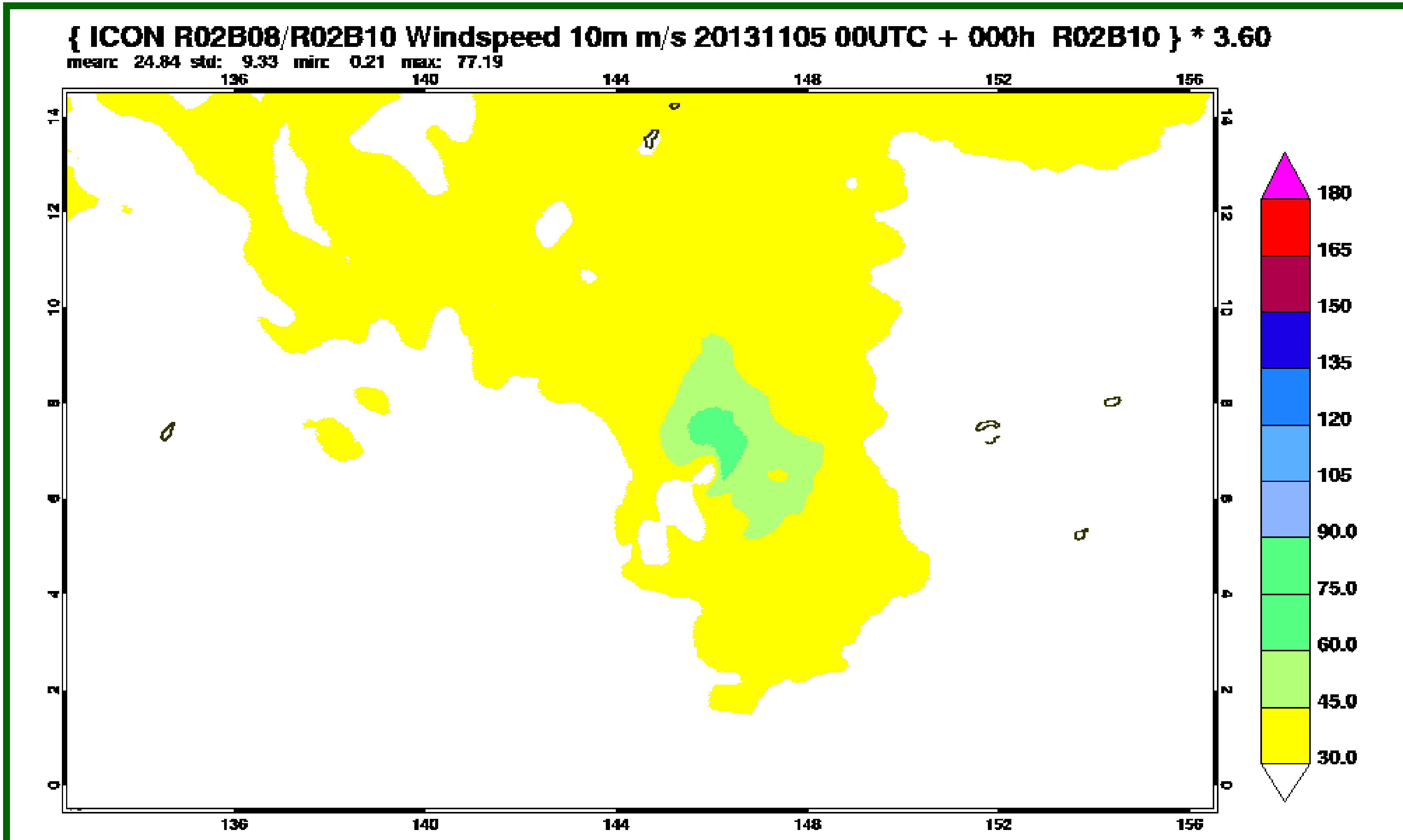
10-m wind speed (km/h), 2.5-km domain



Model application II

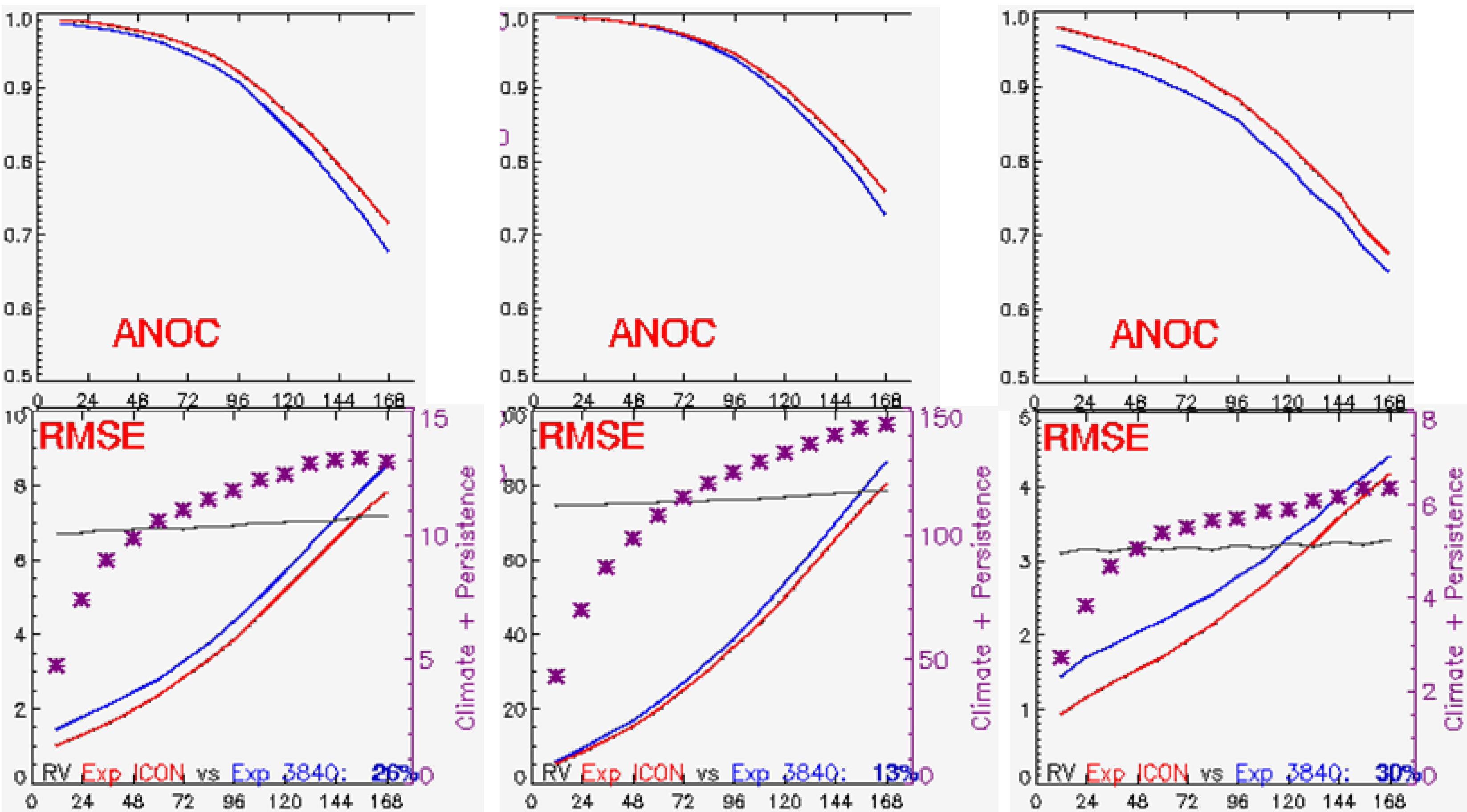
NWP test suite

- Real-case tests with interpolated IFS analysis data
- 7-day forecasts starting at 00 UTC of each day in January and June 2012
- Model resolution 40 km / 90 levels up to 75 km (no nesting applied in the experiment shown here)
- Reference experiment with GME40L60 with interpolated IFS data
- WMO standard verification on 1.5° lat-lon grid against IFS analyses (thanks to Uli Damrath!)

WMO standard verification against IFS analysis: **NH, January 2012**

blue: GME 40 km with IFS analysis, red: ICON 40 km with IFS analysis

Sea-level pressure (hPa) **500-hPa geopotential (m)** **850-hPa temperature (K)**



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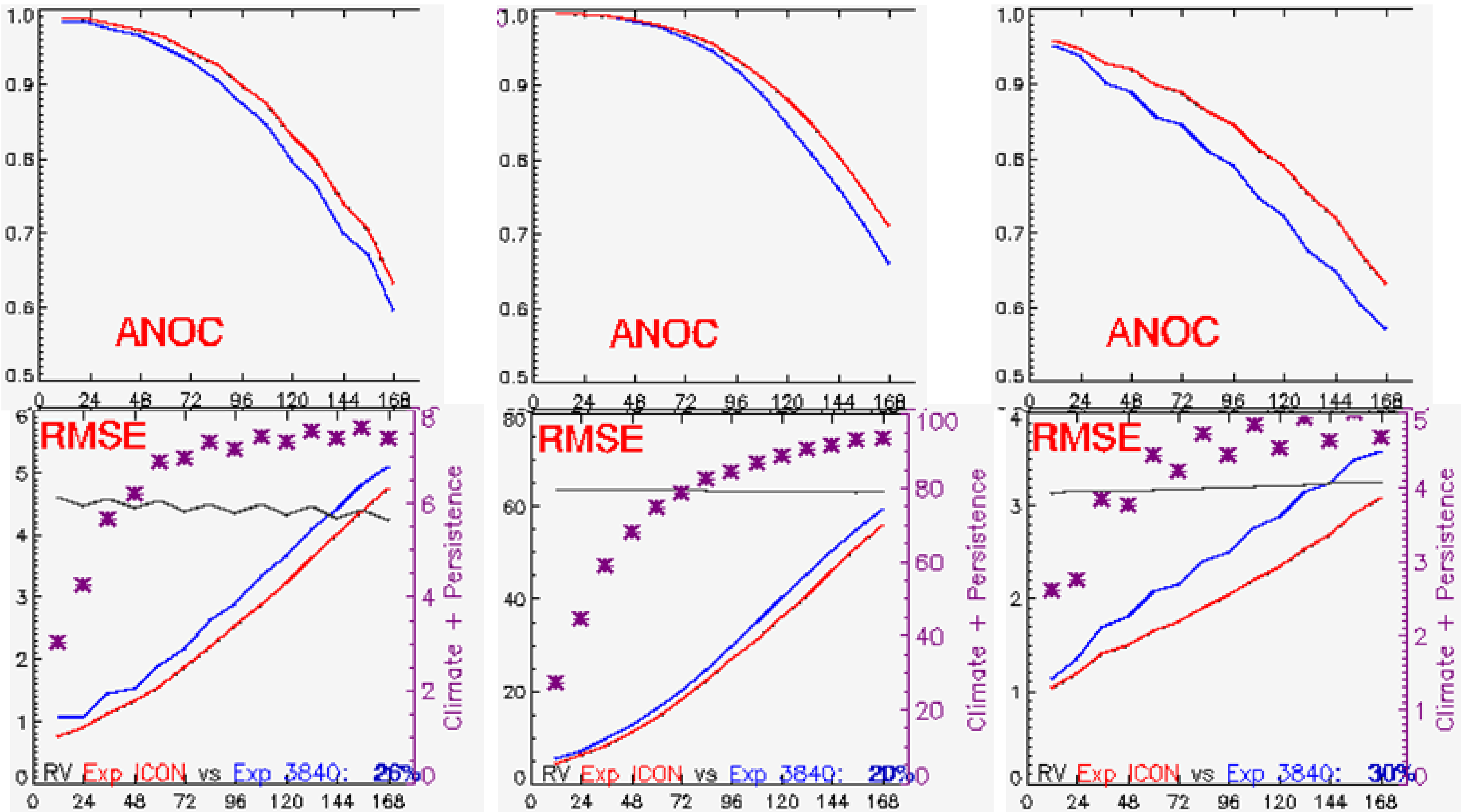

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Kinetic energy spectra

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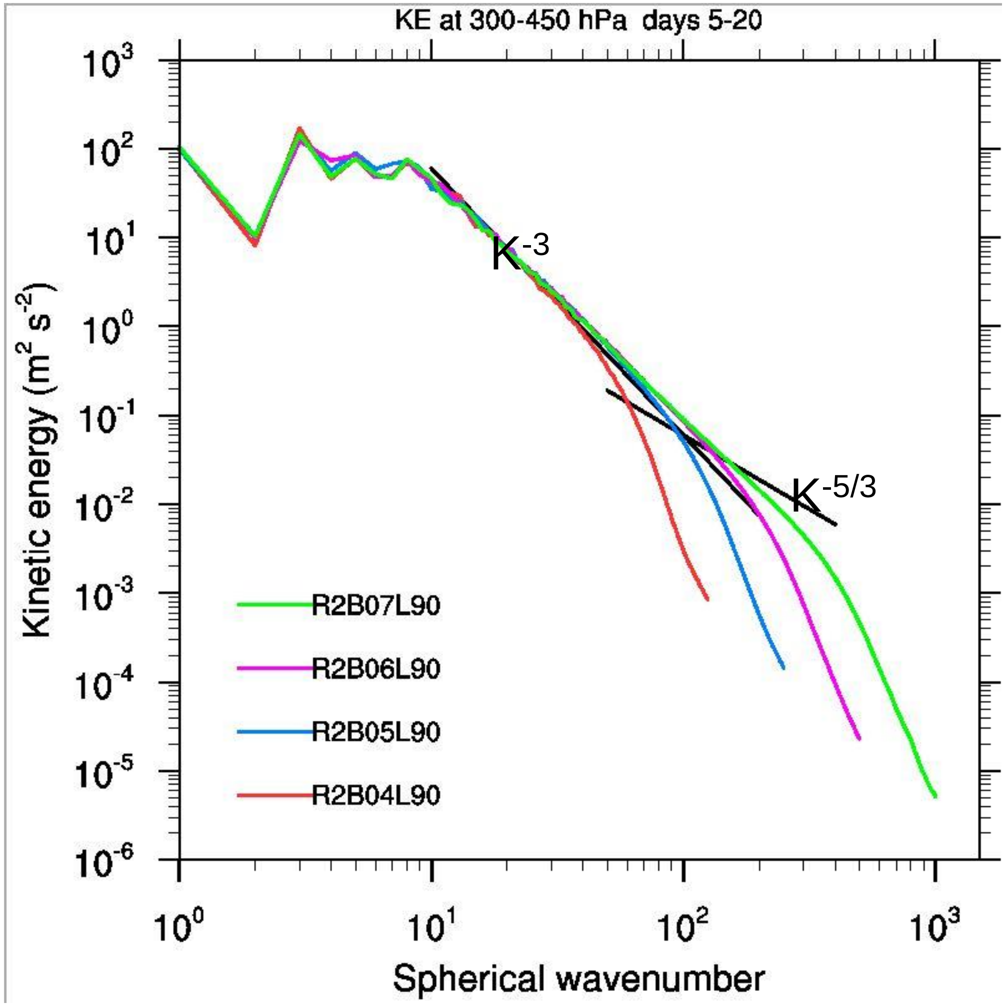

Kinetic energy spectra between 300 and 450 hPa for ICON at a grid spacing of

158 km (red)
79 km (blue)
40 km (magenta)
20 km (green)

Effective model resolution about 6-8 x grid spacing!

Model application III

Limited-area experiments with time-dependent boundary conditions

- Developments within HD(CP)² project (Slavko Brdar, Daniel Klocke, Mukund Pondkule)
- Ultimate project goal: shallow-convection-resolving LES (~100 m) over (almost) the whole of Germany
- a) Coarse-resolution (20 km) limited-area experiment over Europe, comparison against global one-way nested (40-20 km) run
- b) High-resolution (625 m) limited-area experiments over Germany, driven by COSMO-DE analyses, comparison of precipitation / radar reflectivity against observations and COSMO-DE (i.e. DWD's 2.8-km convection-permitting operational model)

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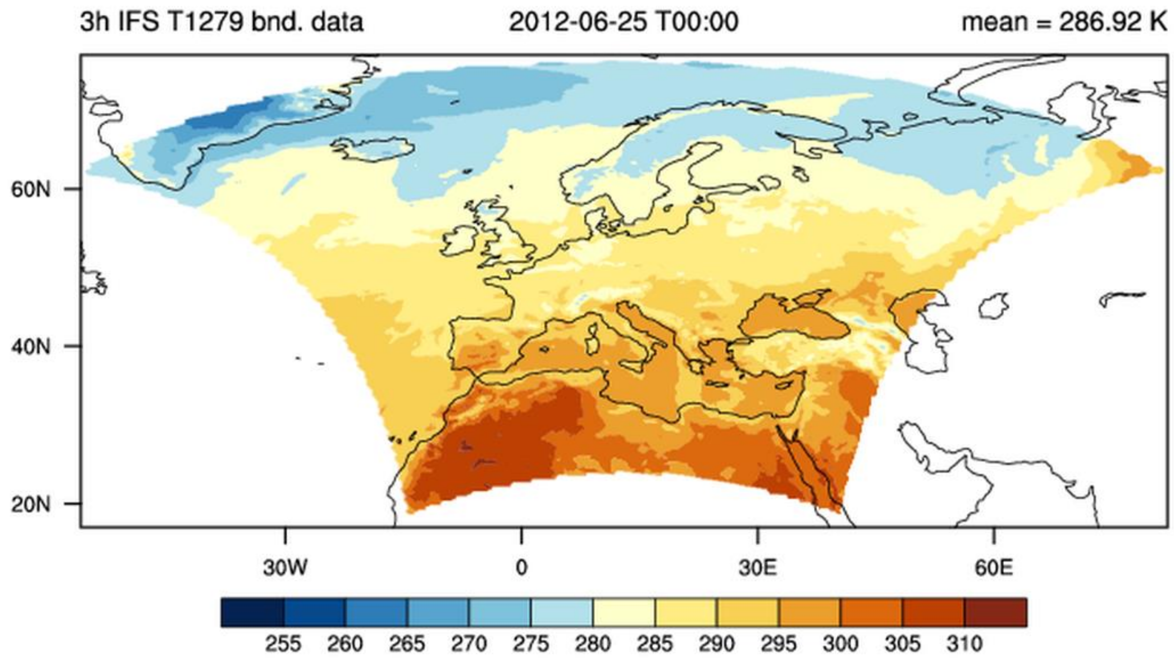
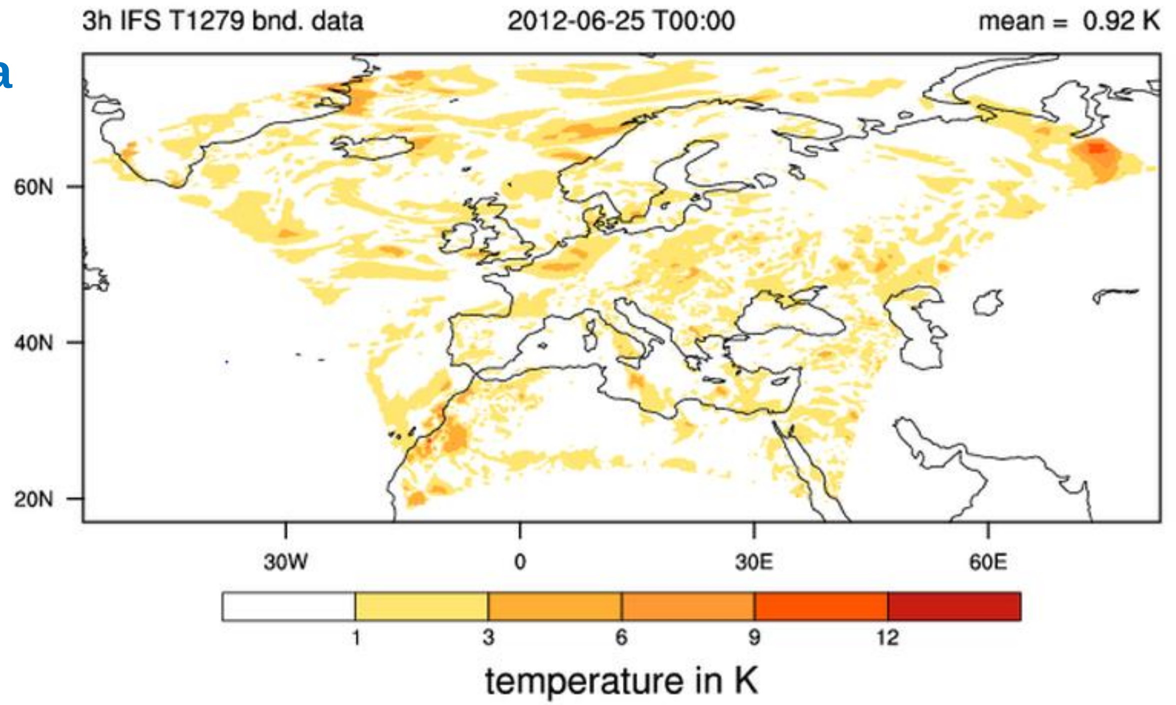
Temperature at lowest model level (10 m AGL), four-day forecast

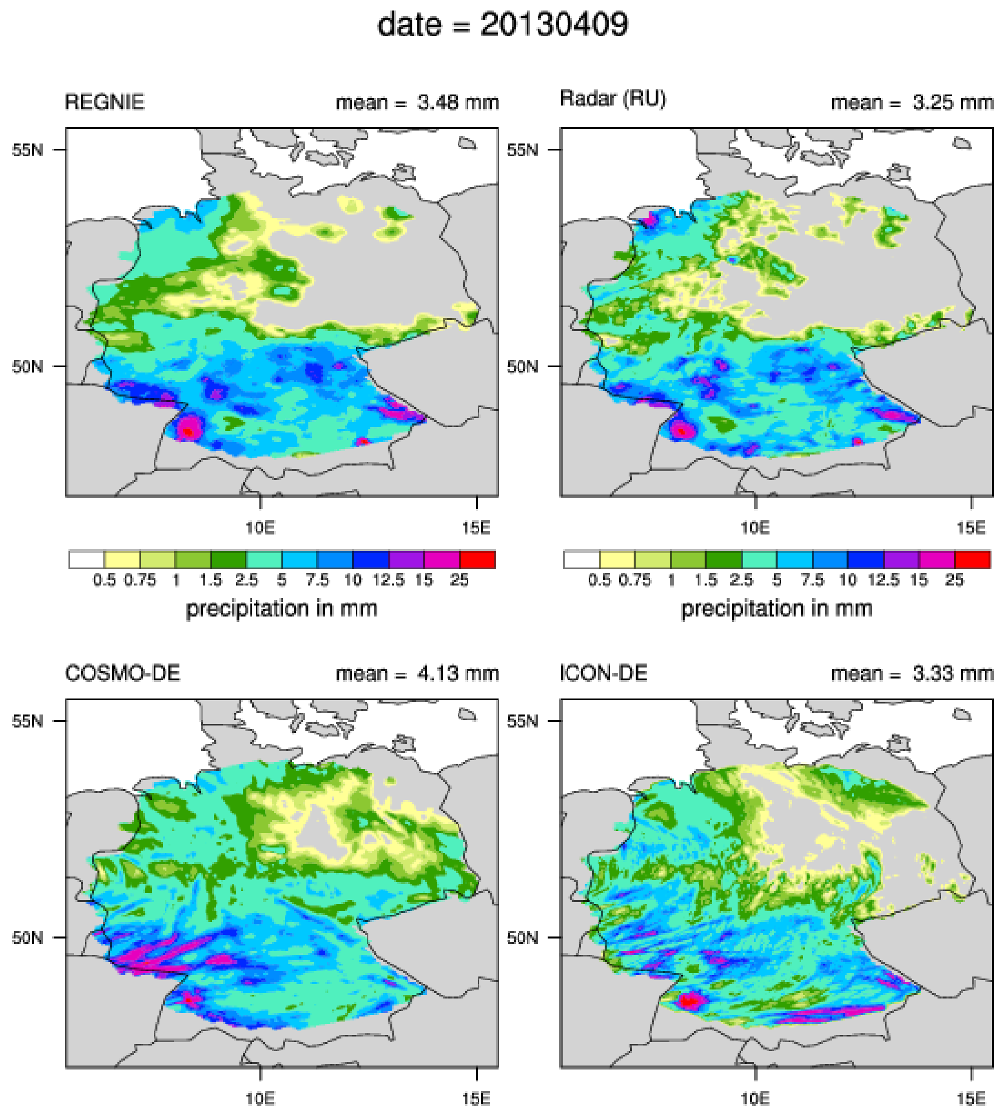
top: coarse-resolution (20 km) limited-area run, lateral boundary conditions from 3-hourly IFS analysis data

bottom: absolute difference to one-way-nested (40-20 km) reference





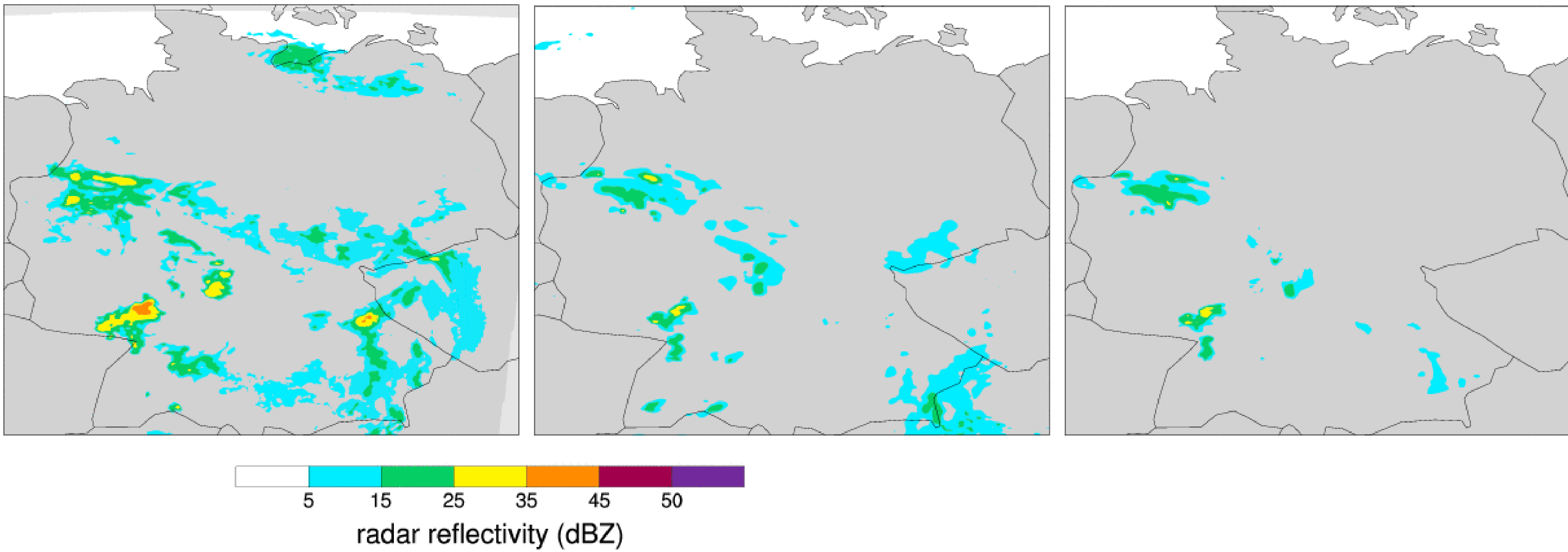
24-hour accumulated precipitation (mm)



Animation of 15-min radar reflectivity

Measurements | COSMO-DE | ICON

20130409, 00:00 | 20130409, 00 UTC + 0.25 h | 20130409, 00 UTC + 0.25 h



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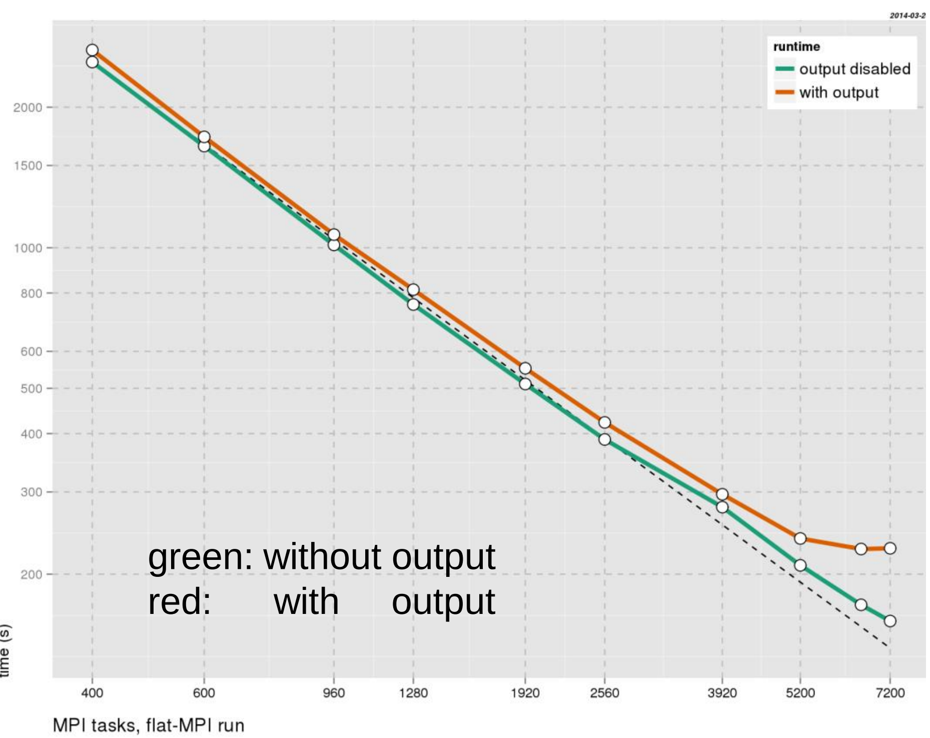
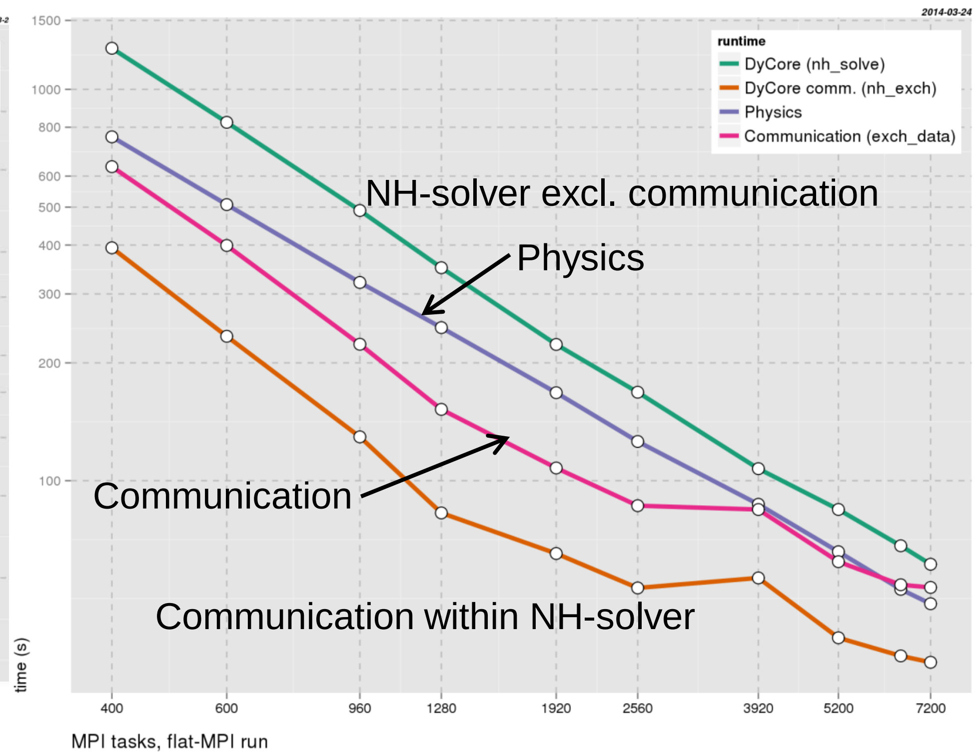
Scaling test

- **Mesh size 13 km (R3B07), 90 levels, 1-day forecast (3600 time steps)**
- **Full NWP physics, asynchronous output (if active) on 42 tasks**
- **Range: 20–360 nodes Cray XC 30, 20 cores/node, flat MPI run**

total runtime



sub-timers



Thanks to Florian Prill!

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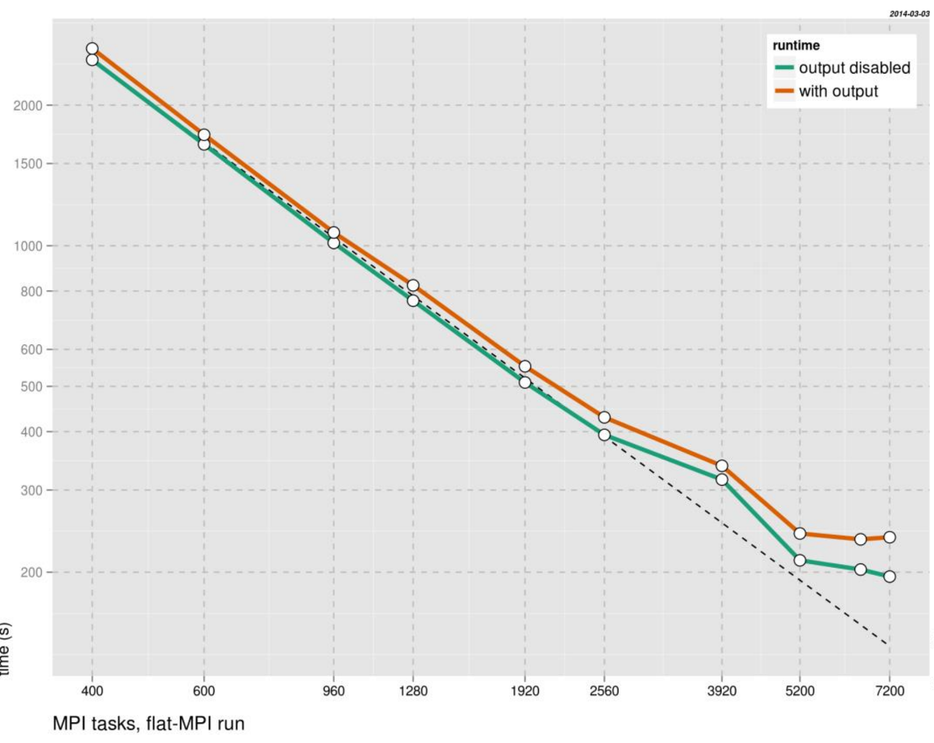
Result of first try – before Cray fixed some hardware issues …

total runtime



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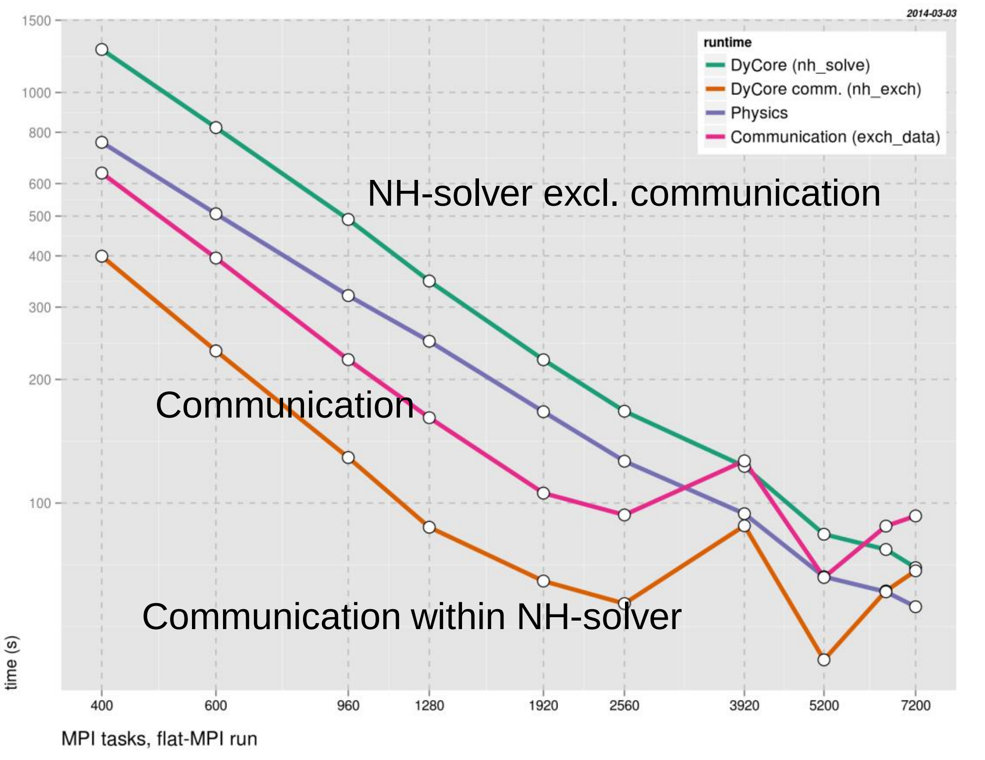

Conclusions

- **We are on a good way towards getting ICON operational by the end of 2014**
- **Significant improvement over the current hydrostatic global model GME with respect of forecast accuracy (and also in terms of efficiency and scalability)**
- **Grid nesting allows for flexible refinement of regional domains; related flow control includes a limited-area functionality**

See poster by Michael Baldauf for results from an idealized sound-wave gravity-wave test (convergence against analytical solution)

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Hybrid parallelization:
4/10 threads with hyperthreading

total runtime