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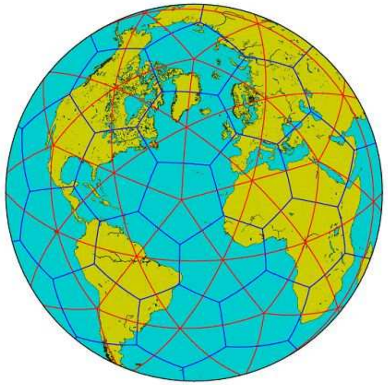
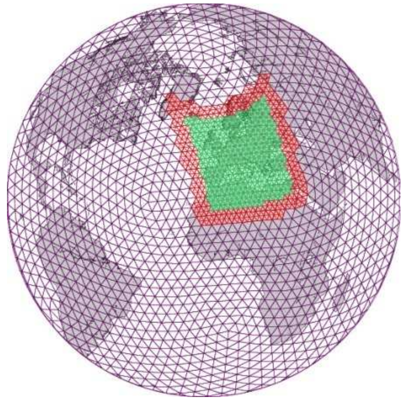
für Meteorologie

DWD
Deutscher Wetterdienst
Wetter und Klima aus einer Hand





ICON

Its way towards operational numerical weather prediction

Günther Zängl, on behalf of the ICON development team

COSMO User Seminar, 19.03.2014

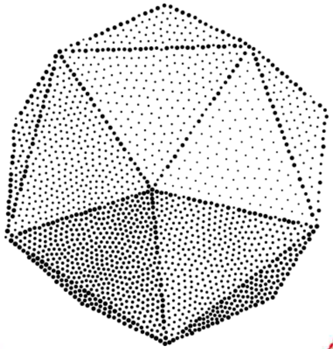
Outline

- Introduction: Main goals of the ICON project
- Grid structure, dynamical core and physics parameterizations
- Model applications: from idealized tests to NWP
- Time plan towards operational use

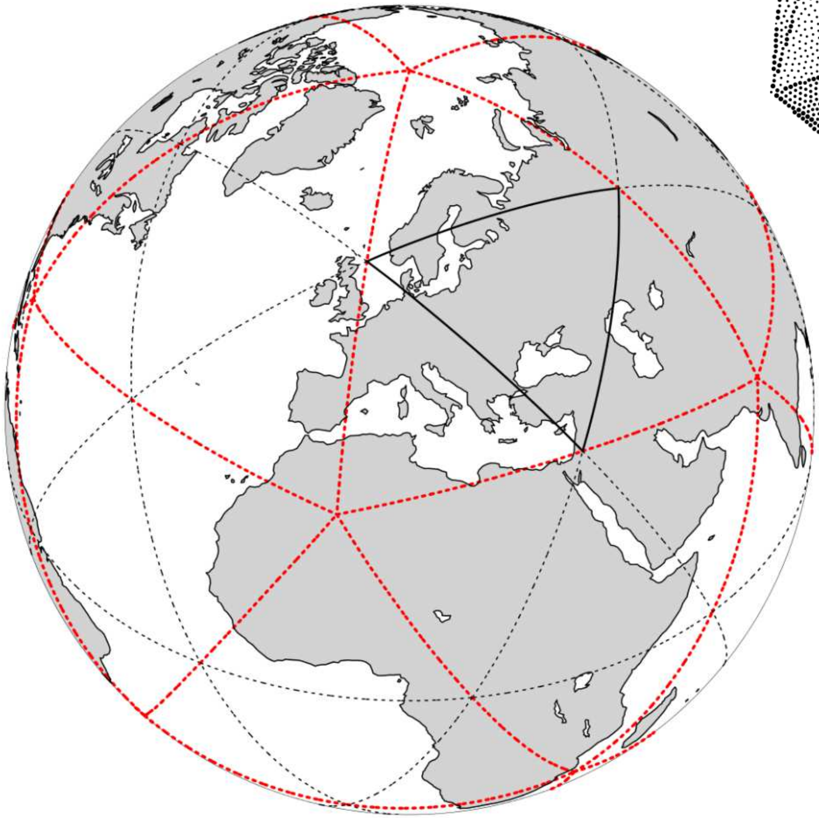
Primary development goals

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

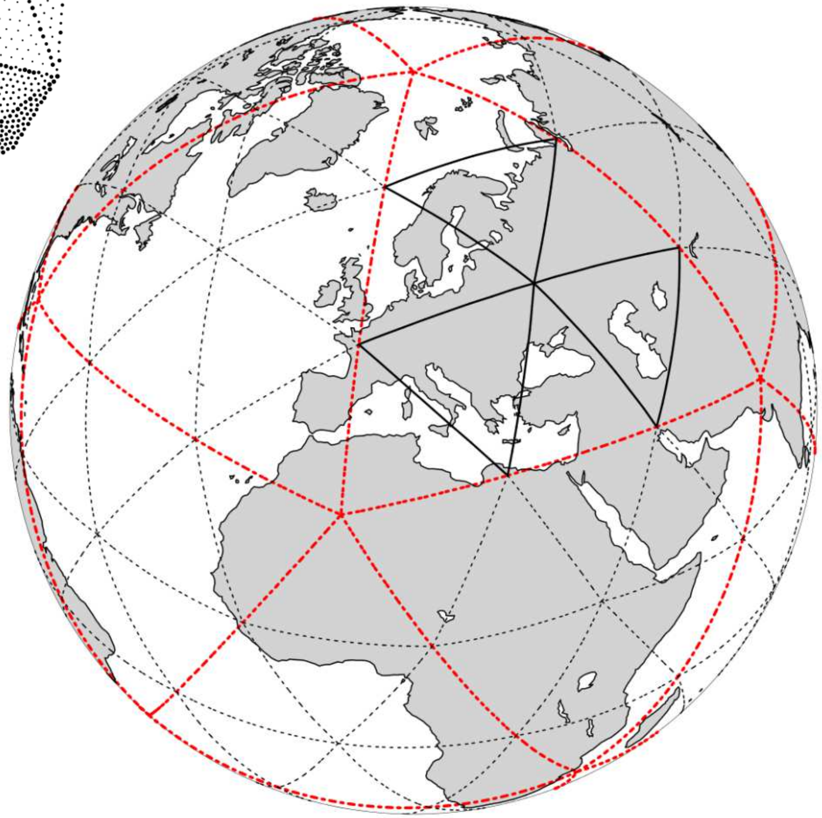
Grid generation is based on the icosahedron



R2B00



R3B00



Grid structure in the presence of nesting

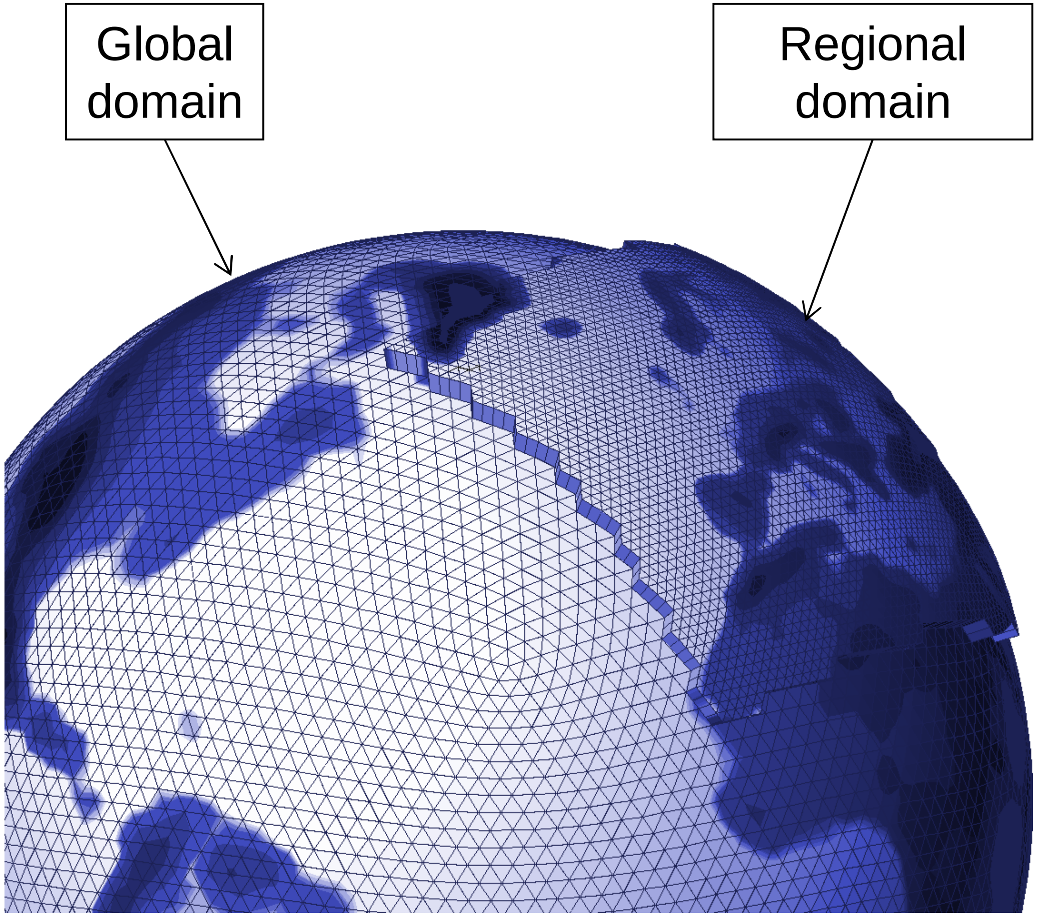
Effective grid spacing
(distance between points):
$\Delta x \approx 5050 / (n\, 2^k)$ [km]

Example:
R2B7: n = 2, k = 7

Grid spacing: 20 km

Global grid consists of
1.3 million spherical
triangles.

Regional domain with higher
horizontal resolution.



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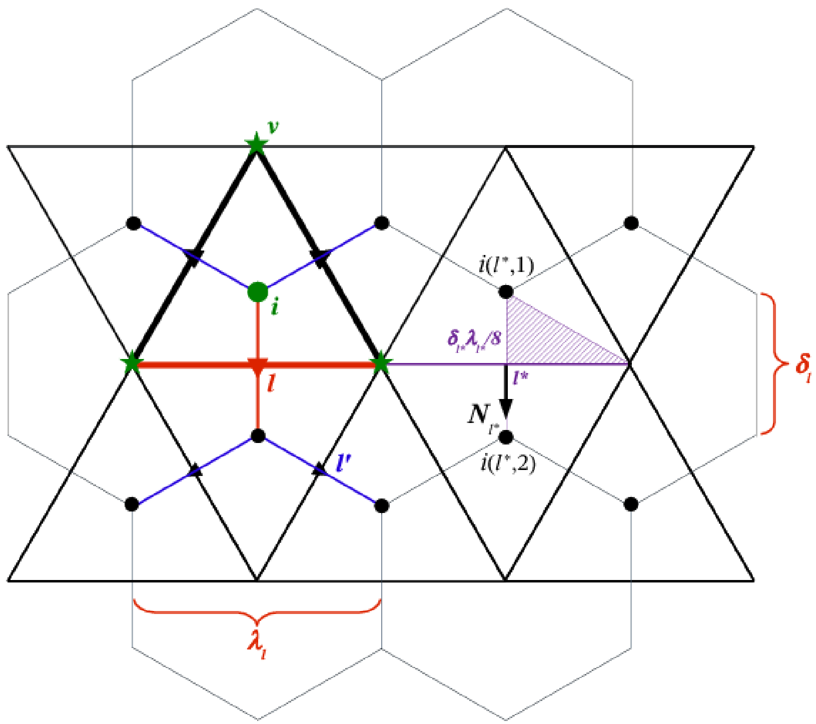
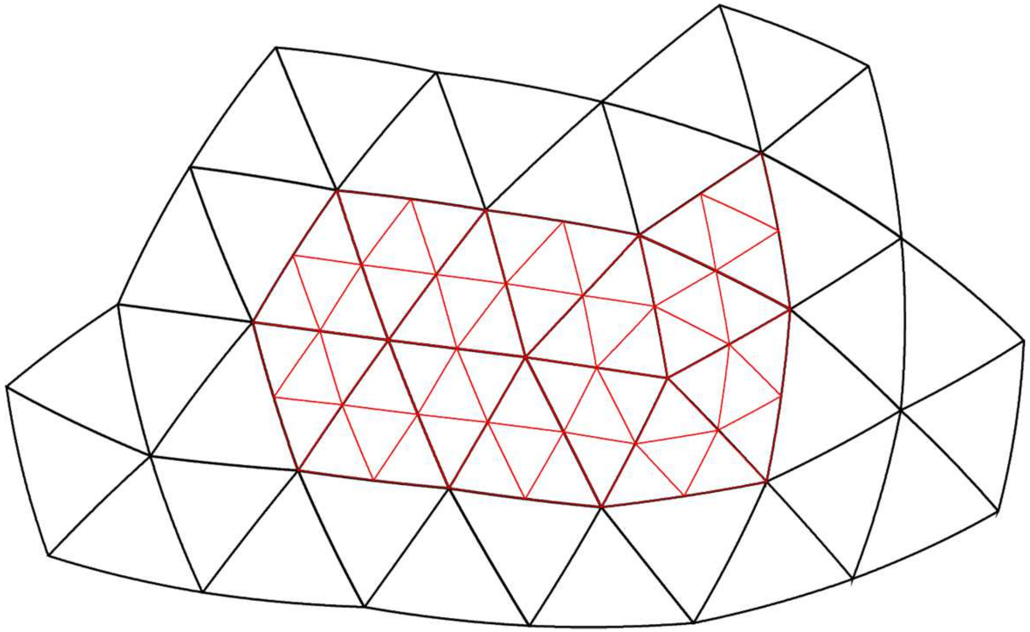
Staggering of variables and structure of nest interface





- Triangles are used as primal cells
- Mass points are in the circumcenter
- Velocity is defined at the edge midpoints

- Red cells refer to refined domain
- Boundary interpolation is needed from parent to child mass points and velocity points

Model equations, dry dynamical core

(see Zängl, G., D. Reinert, P. Ripodas, and M. Baldauf, 2014, QJRMS, revised version submitted)

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

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

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

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

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

- 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

Implementation of grid nesting

- Basic flow sequence: 1 complete physics time step in parent domain, interpolation of lateral boundary fields/tendencies, 2 complete physics time steps in refined domain, feedback (in the case of two-way nesting)
- Difference between one-way and two-way nesting: feedback is turned off, nudging near the lateral boundaries of the nested domains is activated
- Vertical nesting: boundary condition for nest interface level is provided in addition by parent-to-child interpolation
- One-way and two-way nested domains can be combined
- 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

Physics parameterizations

Process	Authors	Scheme	Origin
Radiation	Mlawer et al. (1997) Barker et al. (2002)	RRTM (later with McICA & McSI)	ECHAM6/IFS
	Ritter and Geleyn (1992)	δ two-stream	GME/COSMO
Non-orographic gravity wave drag	Scinocca (2003) Orr, Bechtold et al. (2010)	wave dissipation at critical level	IFS
Sub-grid scale orographic drag	Lott and Miller (1997)	blocking, GWD	IFS
Cloud cover	Doms and Schättler (2004)	sub-grid diagnostic	GME/COSMO
	Köhler et al. (new development)	diagnostic (later prognostic) PDF	ICON
Microphysics	Doms and Schättler (2004) Seifert (2010)	prognostic: water vapor, cloud water,cloud ice, rain and snow	GME/COSMO
Convection	Tiedtke (1989) Bechthold et al. (2008)	mass-flux shallow and deep	IFS
Turbulent transfer	Raschendorfer (2001)	prognostic TKE	COSMO
	Brinkop and Roeckner (1995)	prognostic TKE	ECHAM6/IFS
	Neggers, Köhler, Beljaars (2010)	EDMF-DUALM	IFS
Land	Heise and Schrodin (2002), Helmert, Mironov (2008, lake)	tiled TERRA + FLAKE + multi-layer snow	GME/COSMO
	Raddatz, Knorr	JSBACH	ECHAM6

Related projects

ICON-ART (KIT Karlsruhe):

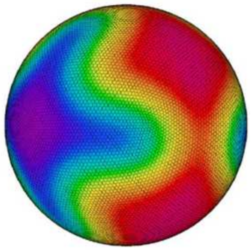
aerosols and reactive trace gases

(B. Vogel, H. Vogel, K. Lundgren, D. Rieger, M. Bangert)

HD(CP)² (led by MPI-M, Hamburg):

High-definition clouds and precipitation for advancing climate prediction

(S. Brdar, M. Pondkule, D. Klocke, T. Göcke; T. Jahns, M. Hanke)

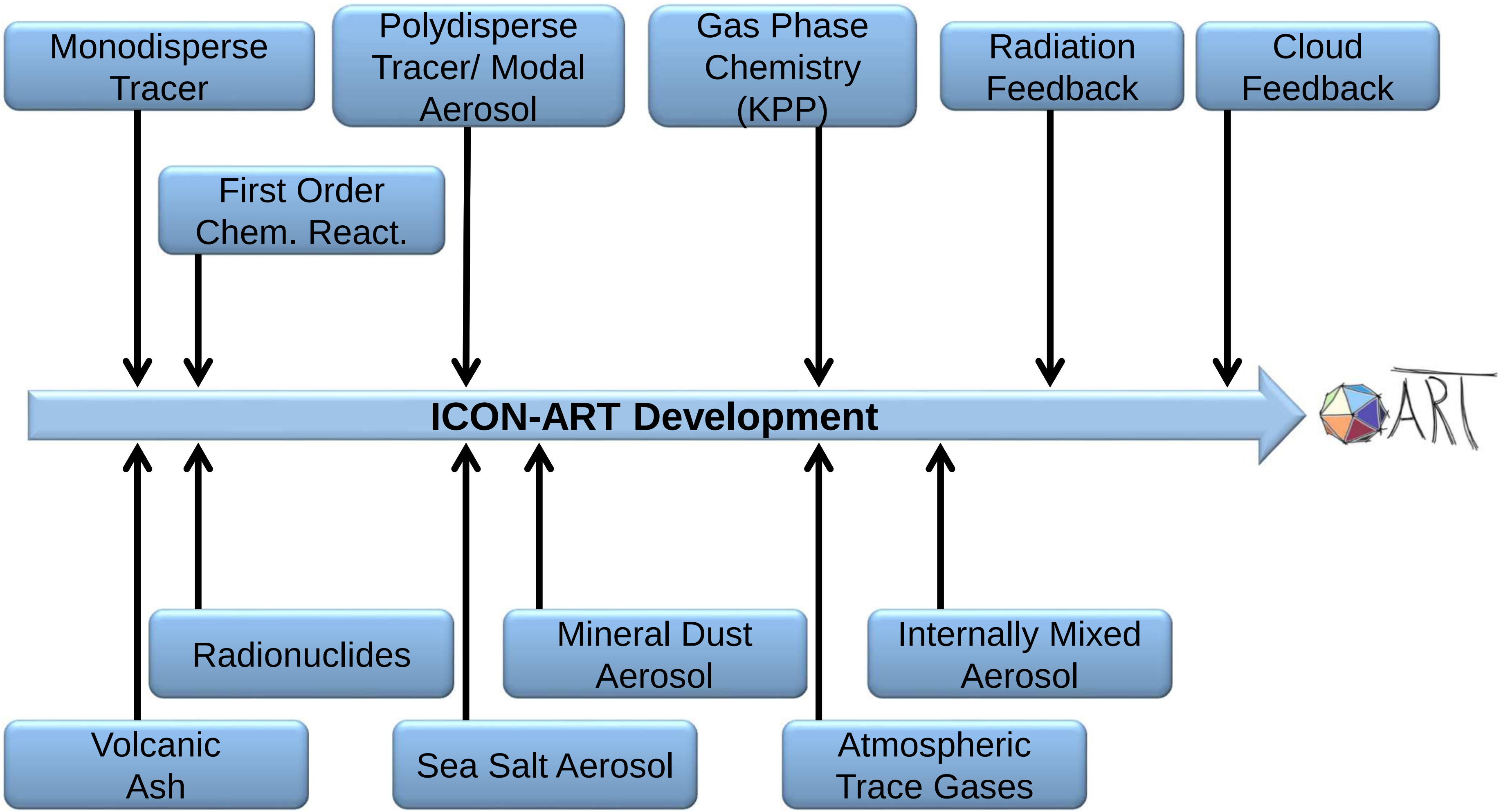


ICOMEX (led by DWD):

ICOsahedral-grid models for Exascale Earth-system simulations

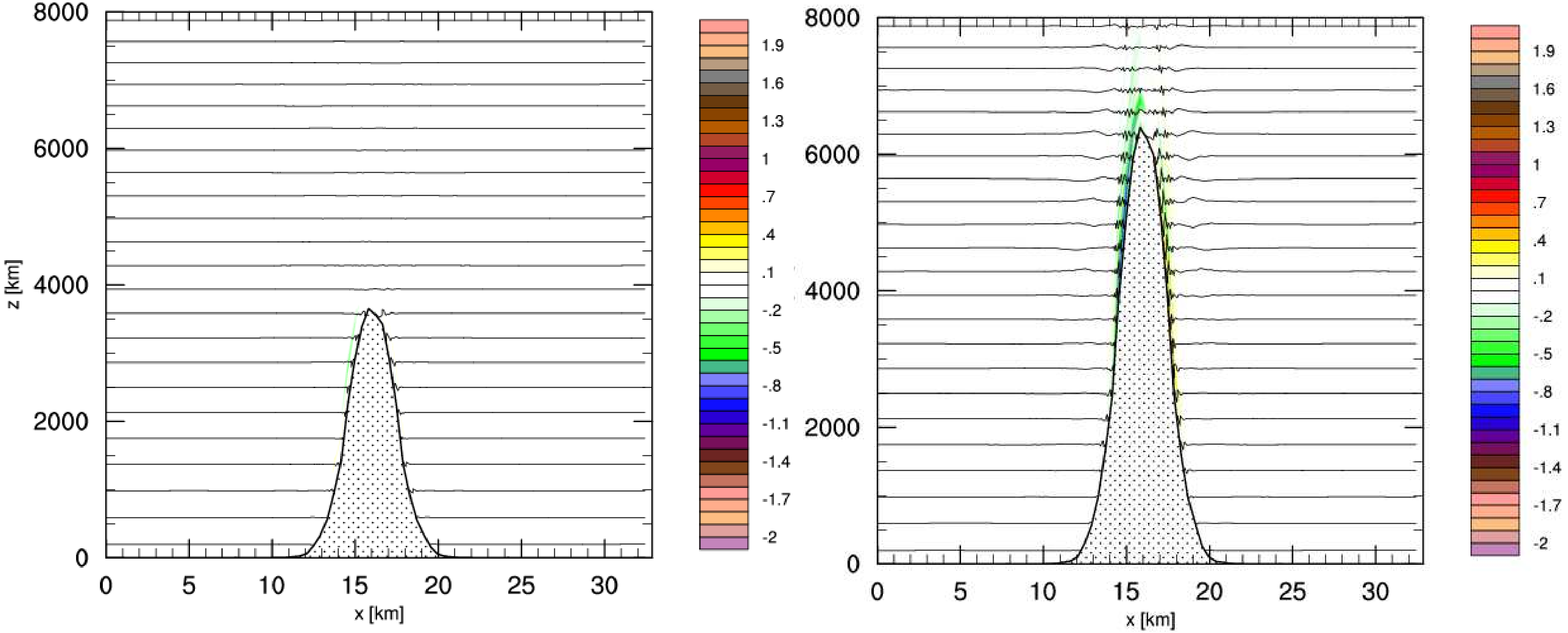
(R. Torres, L. Linardakis)

Structure of the ART module



Model application I

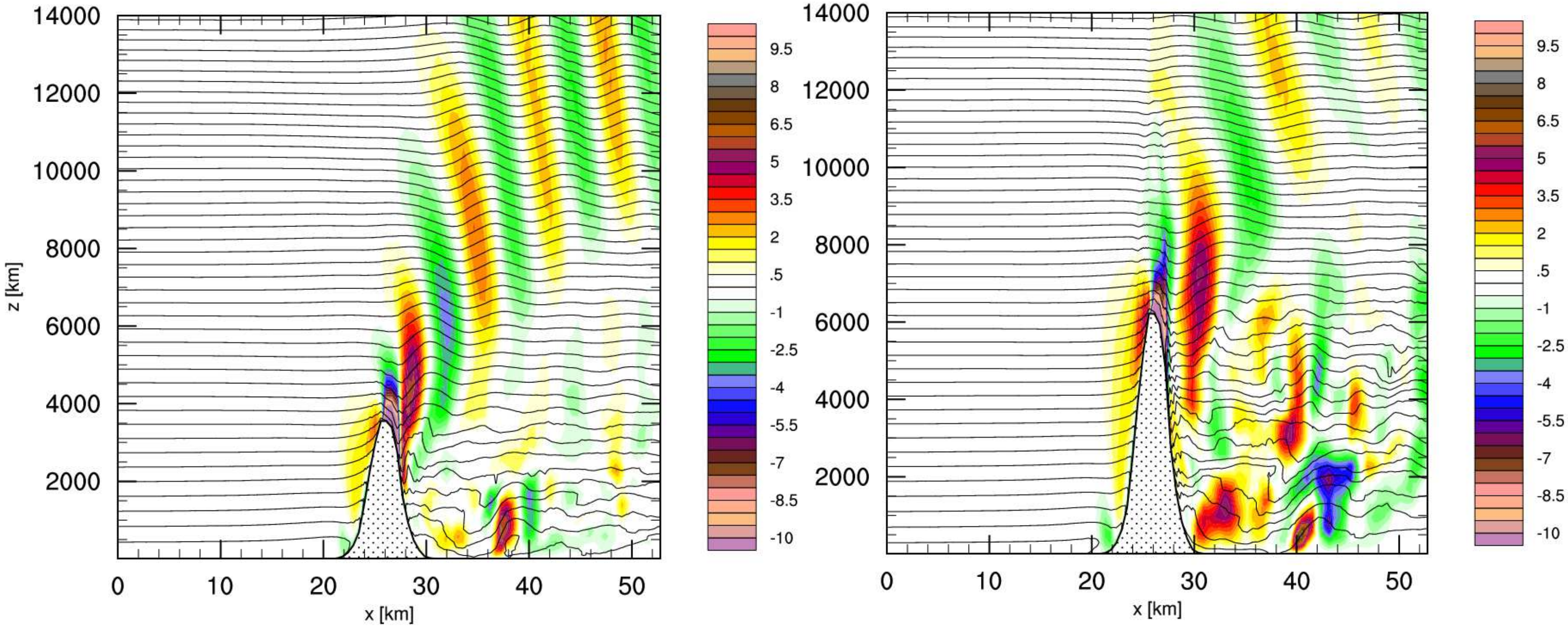
Atmosphere-at-rest test, isothermal atmosphere, limited-area mode, mesh size 300 m



colours: vertical wind speed (m/s)   contours: potential temperature (c.i. 4 K)

mountain height: 4.0 km / 7.0 km, maximum slope 59° / 71°

Constant wind speed 20 m/s, isothermal atmosphere, limited-area mode, mesh size 300 m

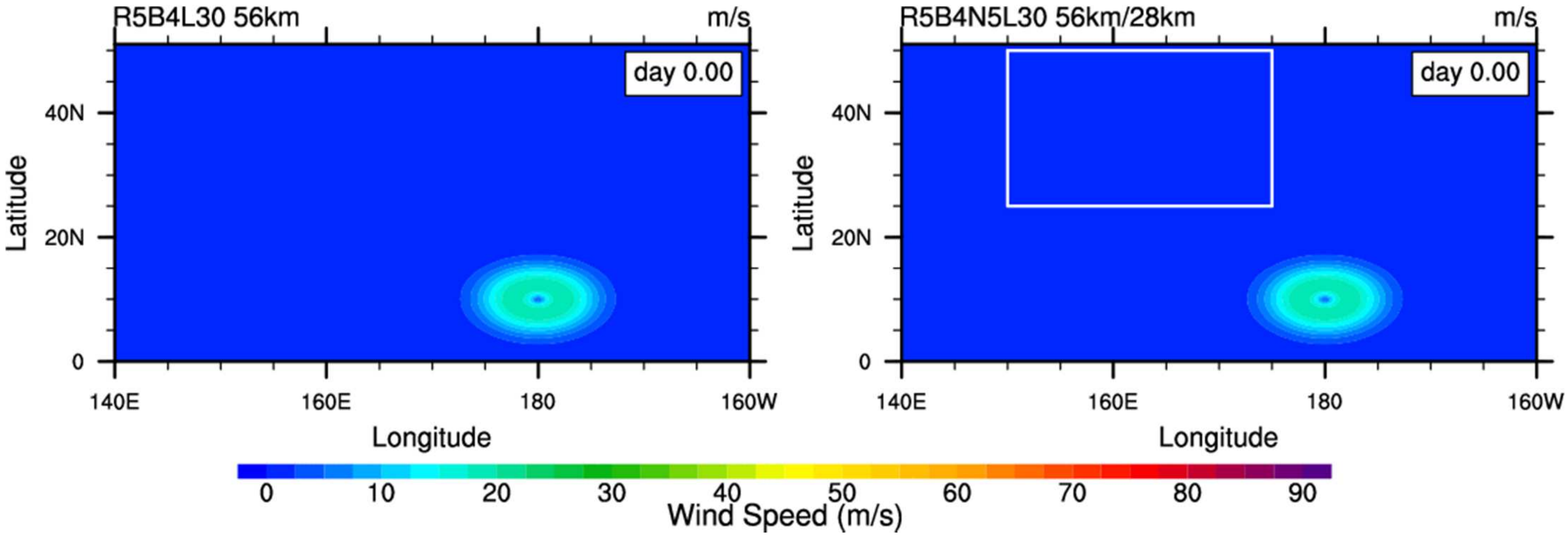


colours: vertical wind speed (m/s) contours: potential temperature (c.i. 4 K)

mountain height: 4.0 km / 7.0 km, maximum slope 59° / 71°

Model application II

DCMIP-Test: Idealized tropical cyclone, 12-day-simulation



Horizontal wind speed (m/s)

Left: Global domain, $\Delta x \approx 56$ km; right: 2-Way-Nesting, $\Delta x \approx 56$ km / 28 km

Thanks to Daniel Reinert!

Simulation of „super-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 Martin Köhler and Bodo Ritter!

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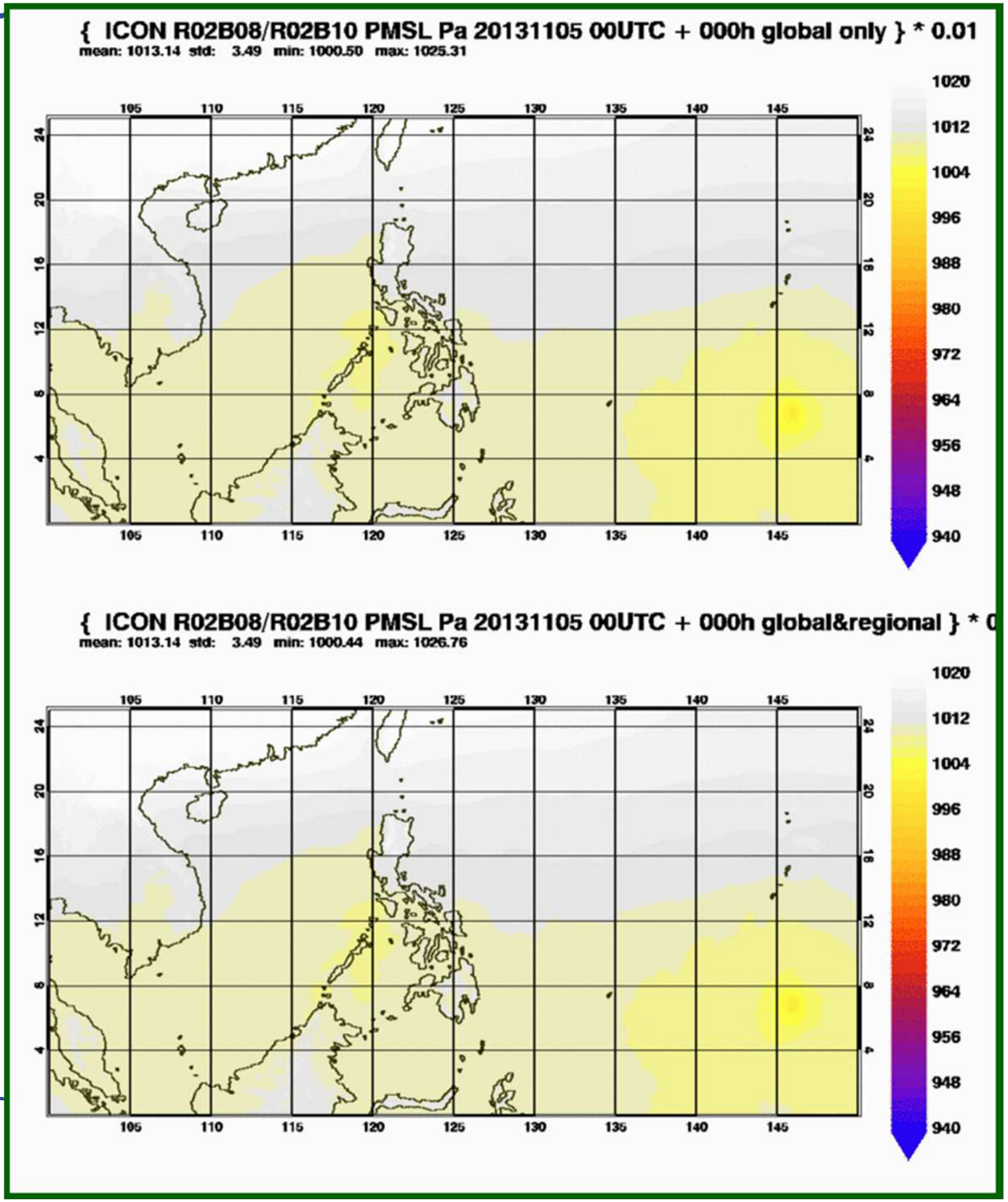
Sea-level pressure (hPa)

Top: 10-km domain

Bottom: 2.5-km domain



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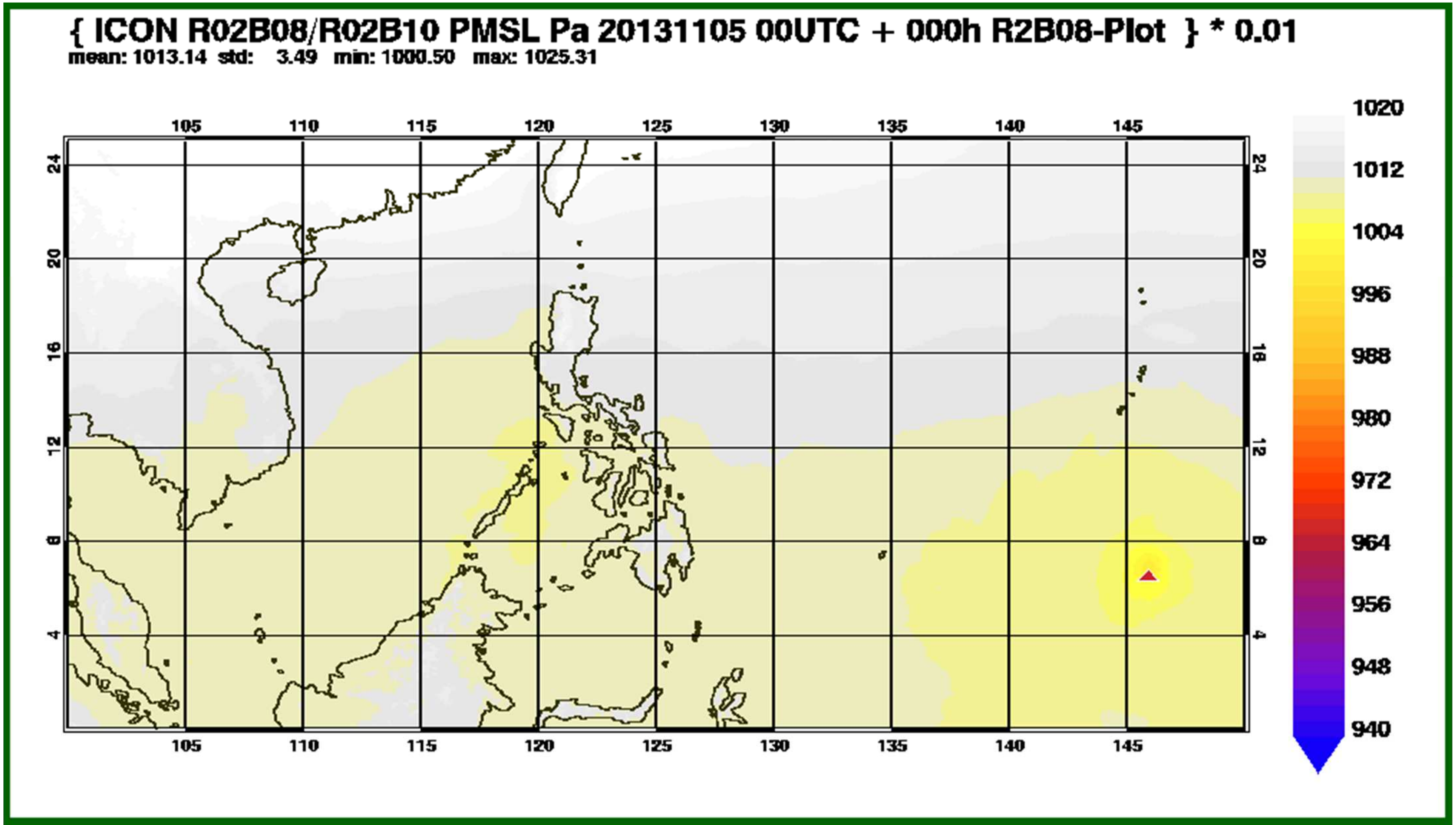
Comparison with observed track



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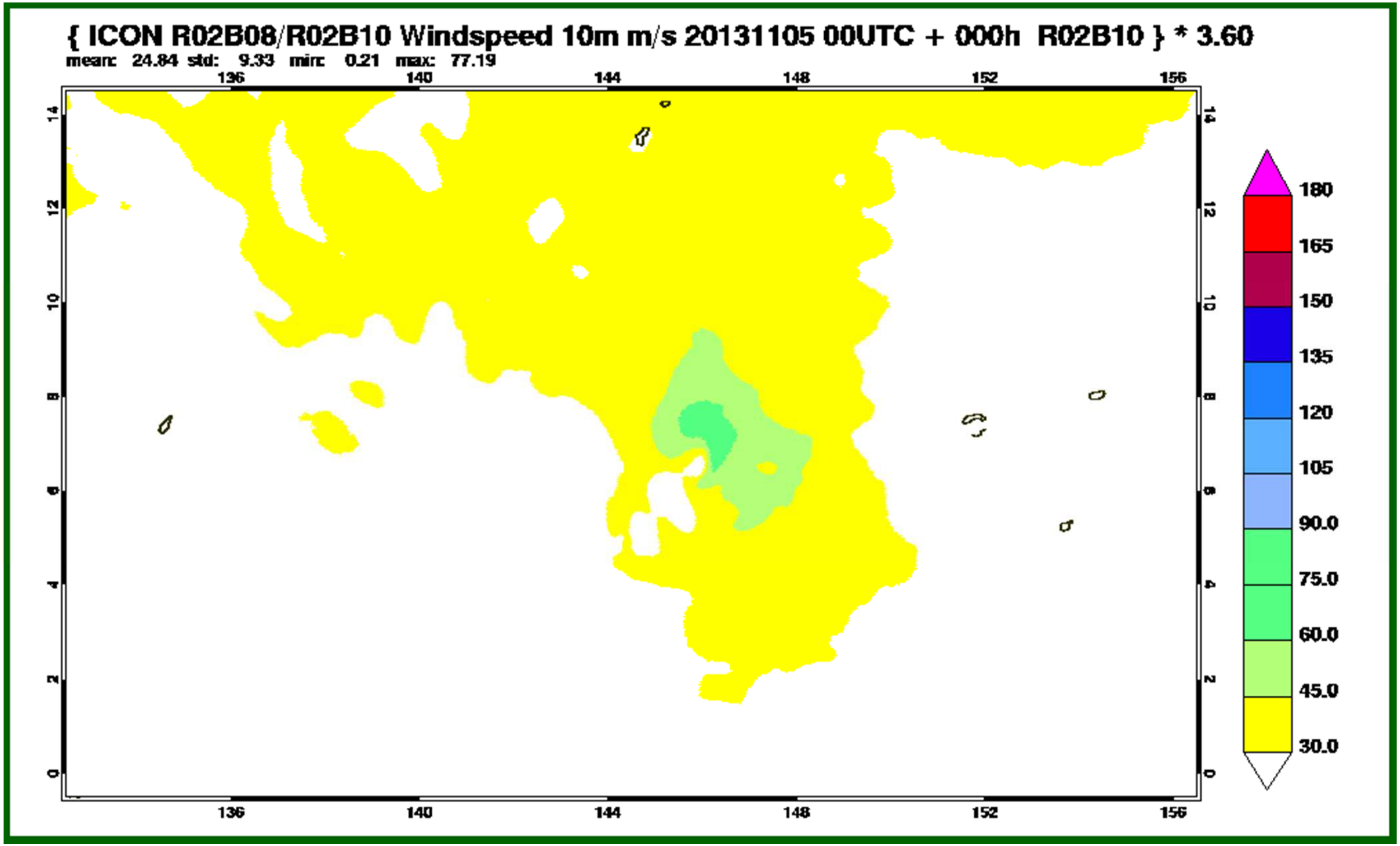
10-m wind speed (m/s), 2.5-km domain



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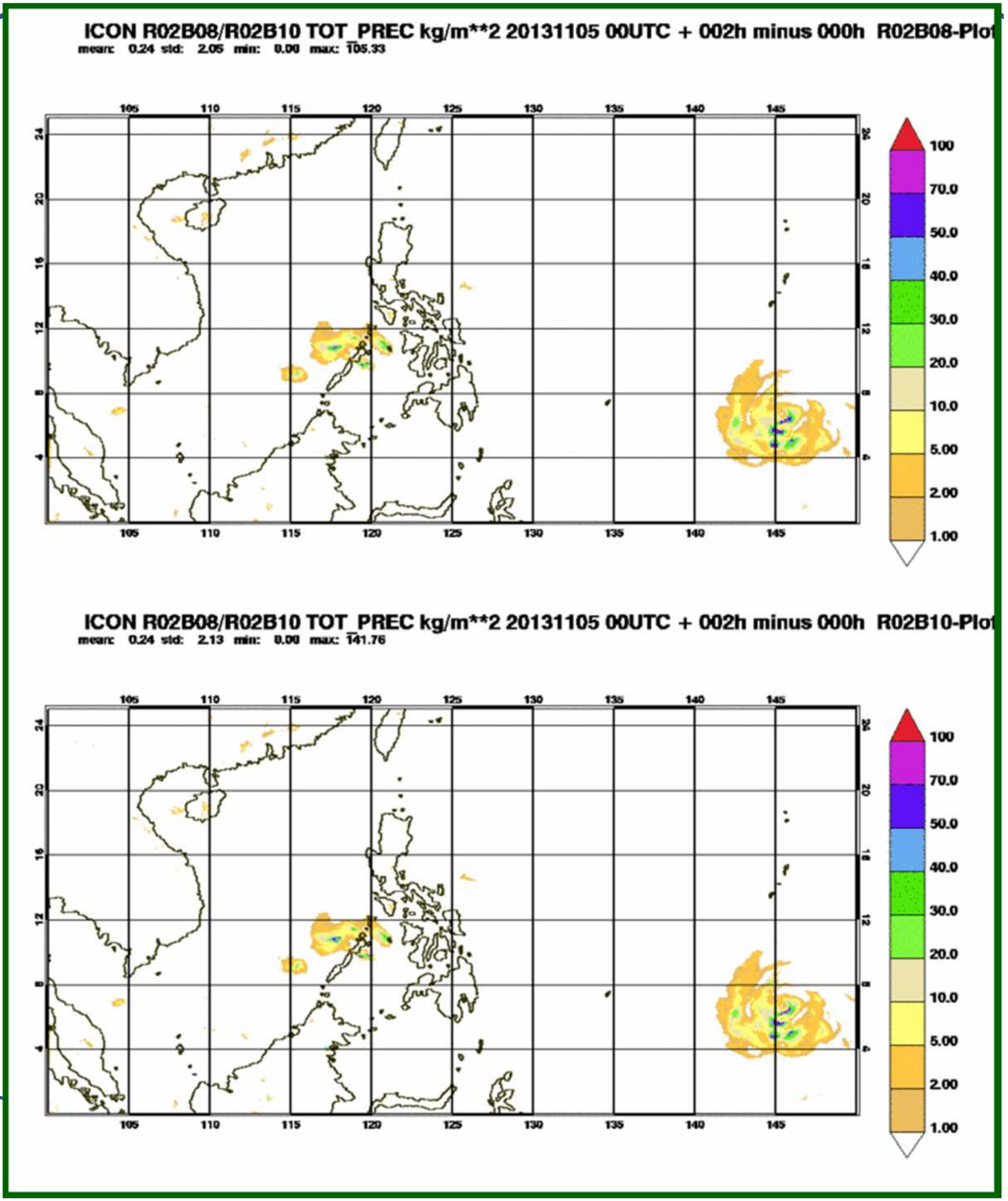
Two-hourly rainfall accumulation (mm)

Top: 10-km domain

Bottom: 2.5-km domain

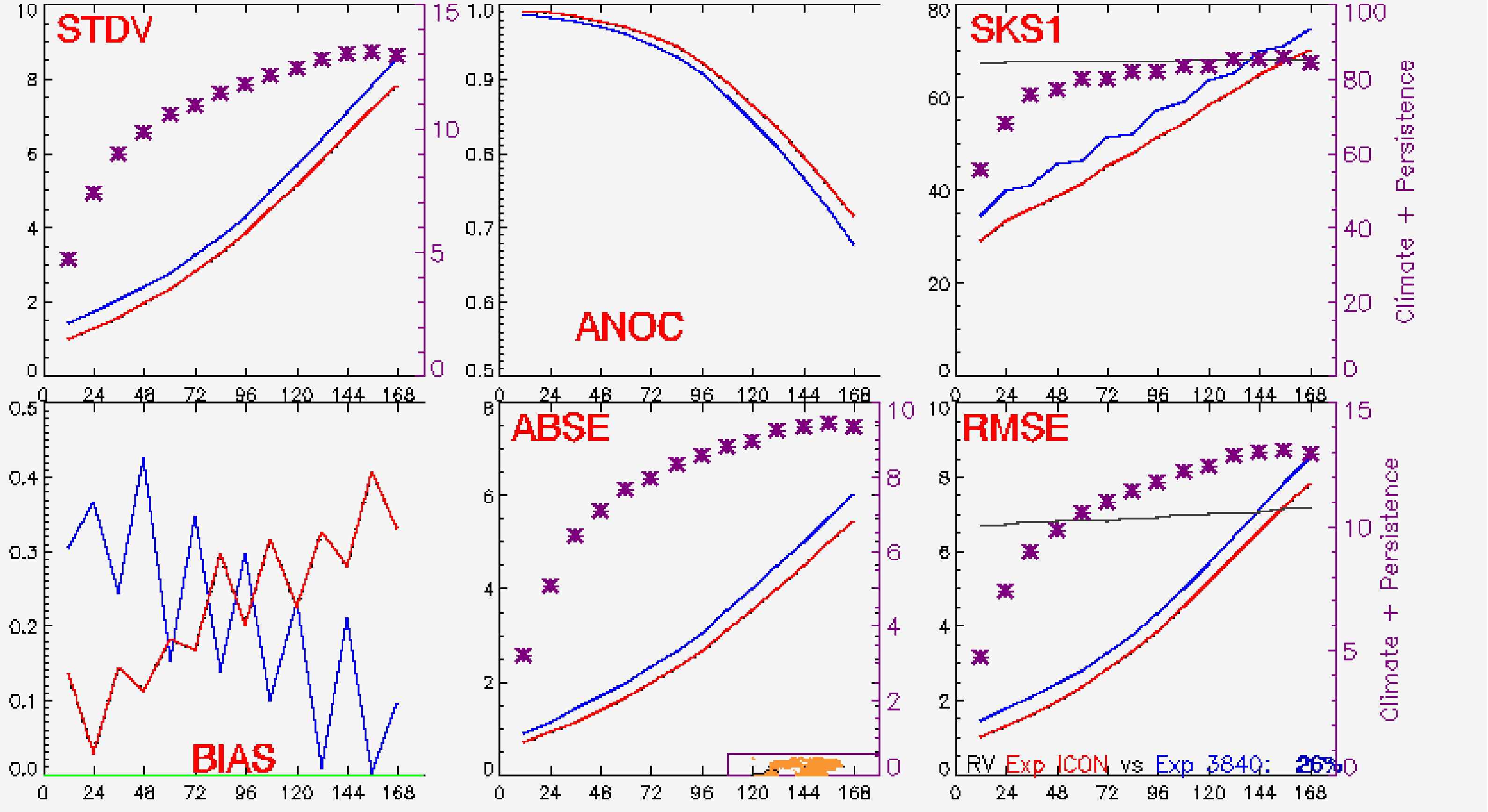


NWP test suite

- 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: sea-level pressure, NH

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



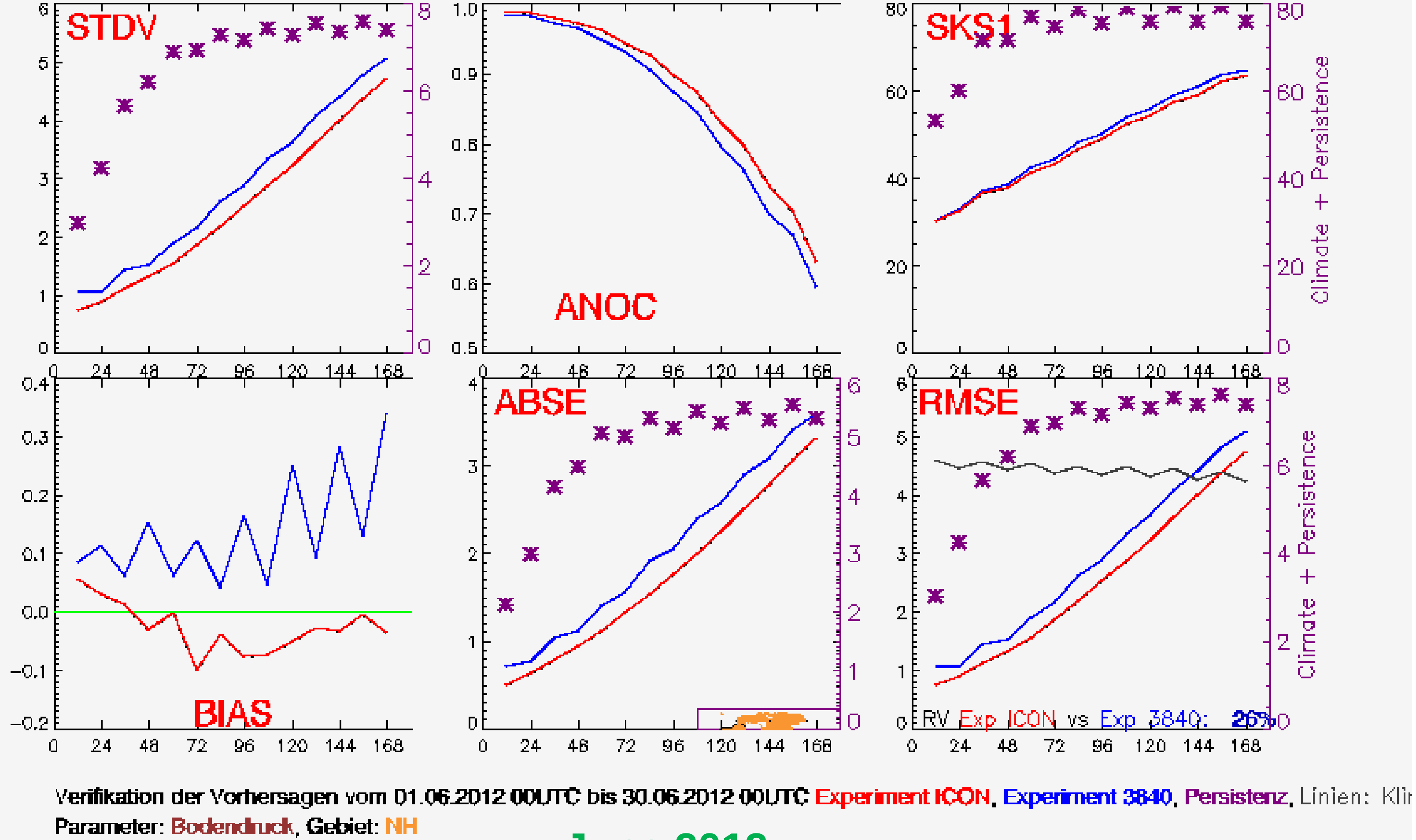
Verifikation der Vorhersagen vom 01.01.2012 00UTC bis 31.01.2012 00UTC Experiment ICON, Experiment 3840, Persistenz, Linien: Kli

Parameter: Bodendruck, Gebiet: NH

January 2012

WMO standard verification against IFS analysis: sea-level pressure, NH

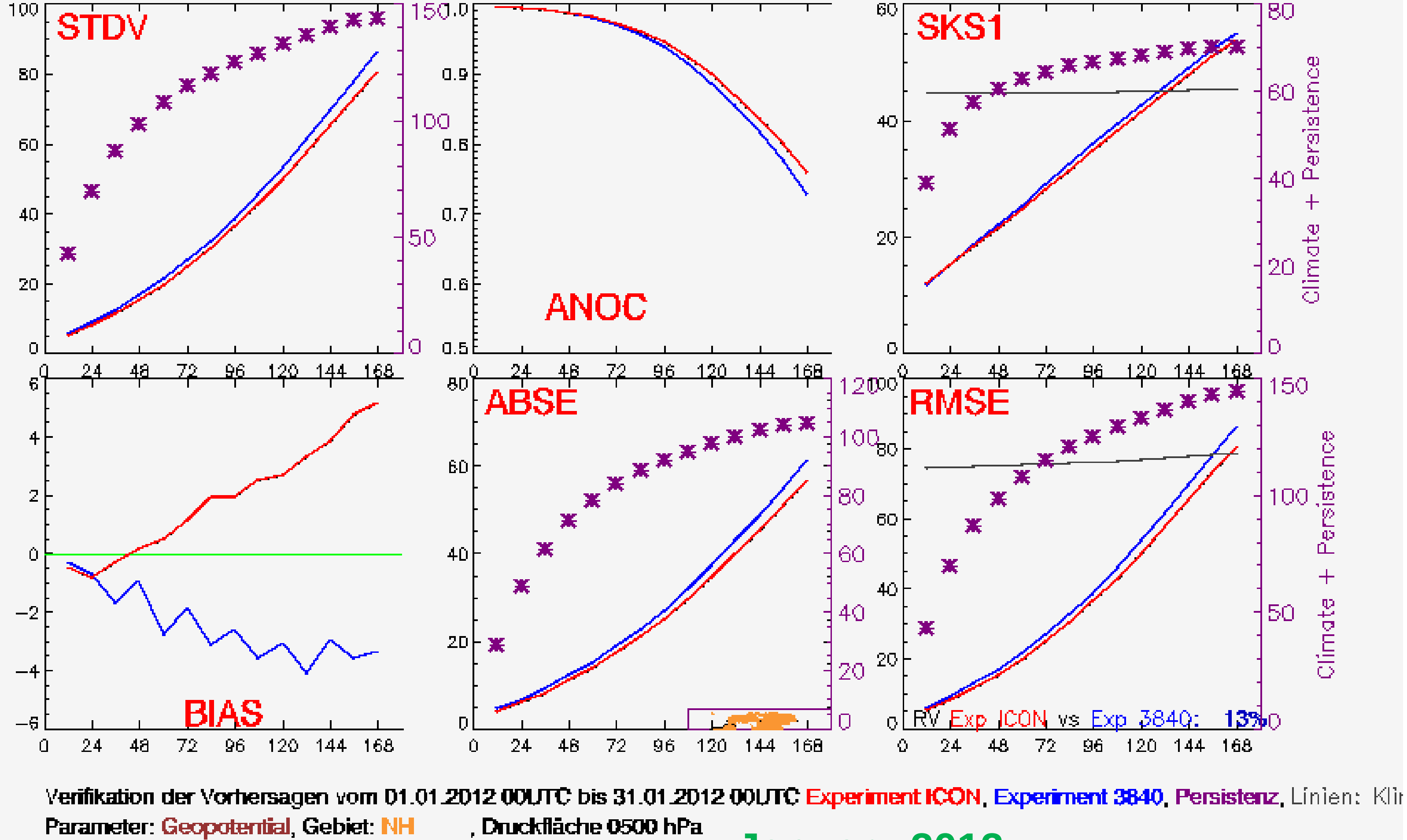
blue: GME 40 km with IFS analysis, red: ICON 40 km with IFS analysis



June 2012

WMO standard verification against IFS analysis: 500 hPa geopotential, NH

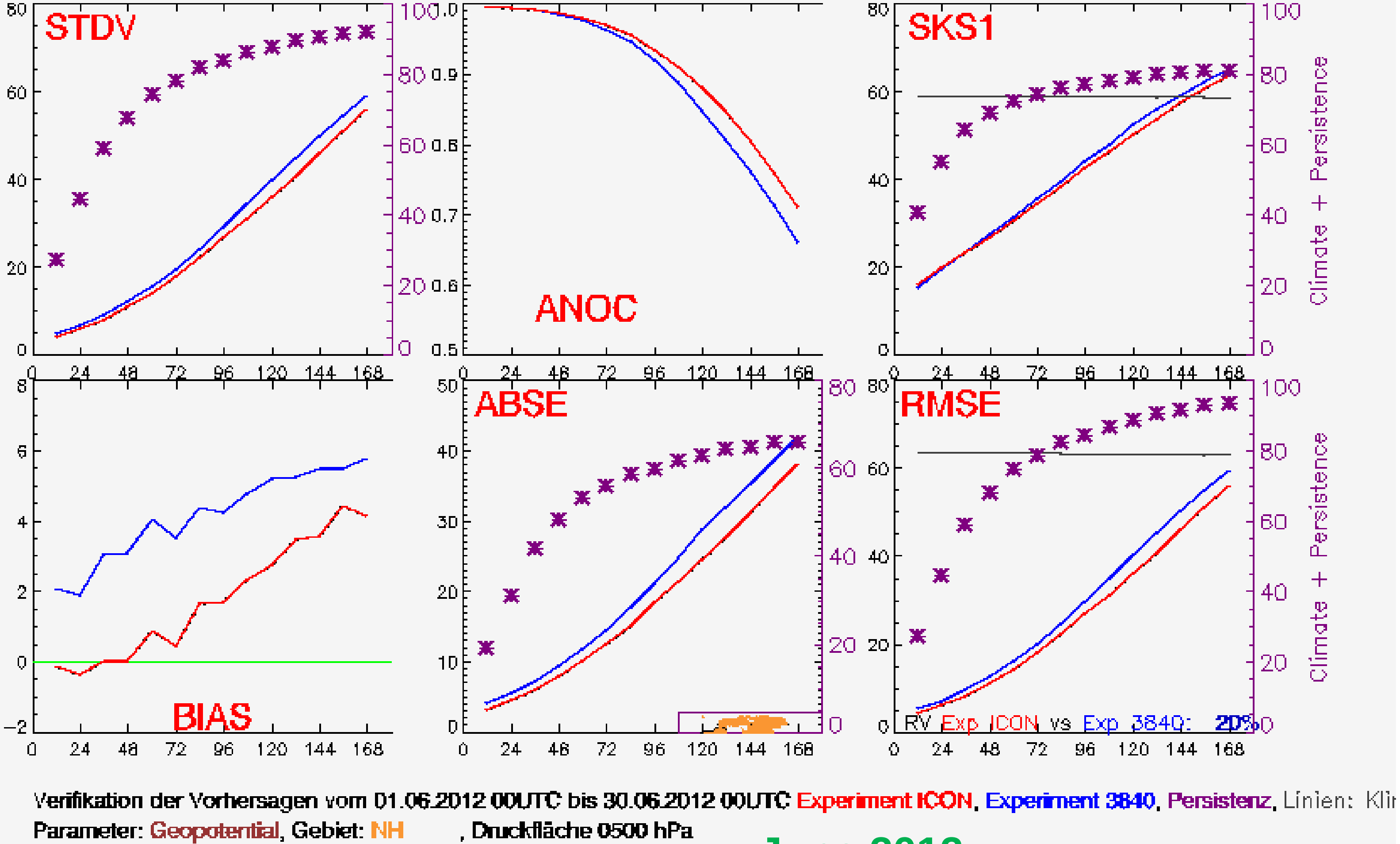
blue: GME 40 km with IFS analysis, red: ICON 40 km with IFS analysis



January 2012

WMO standard verification against IFS analysis: 500 hPa geopotential, NH

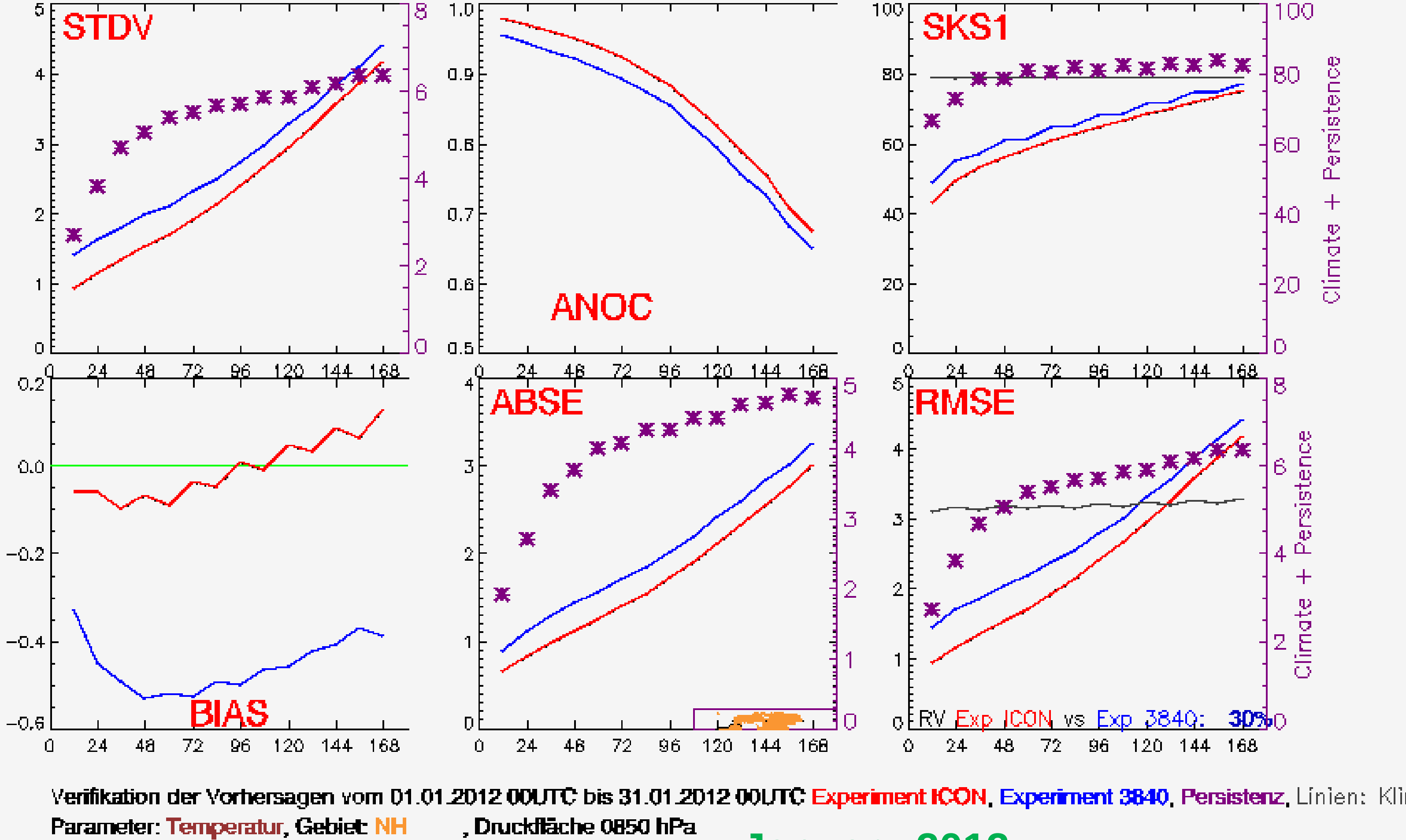
blue: GME 40 km with IFS analysis, red: ICON 40 km with IFS analysis



June 2012

WMO standard verification against IFS analysis: 850 hPa temperature, NH

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



January 2012

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WMO standard verification against IFS analysis: 850 hPa temperature, NH

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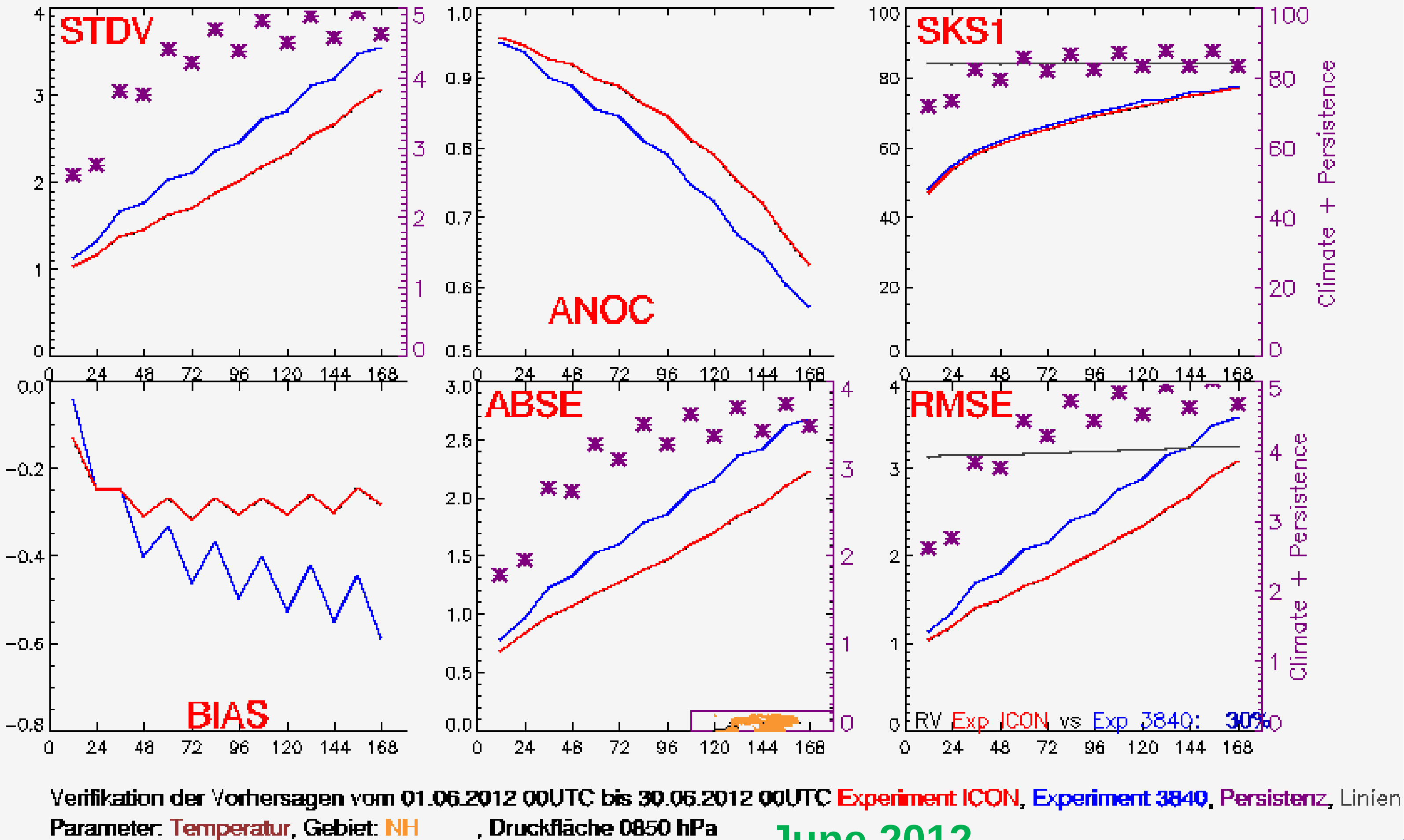
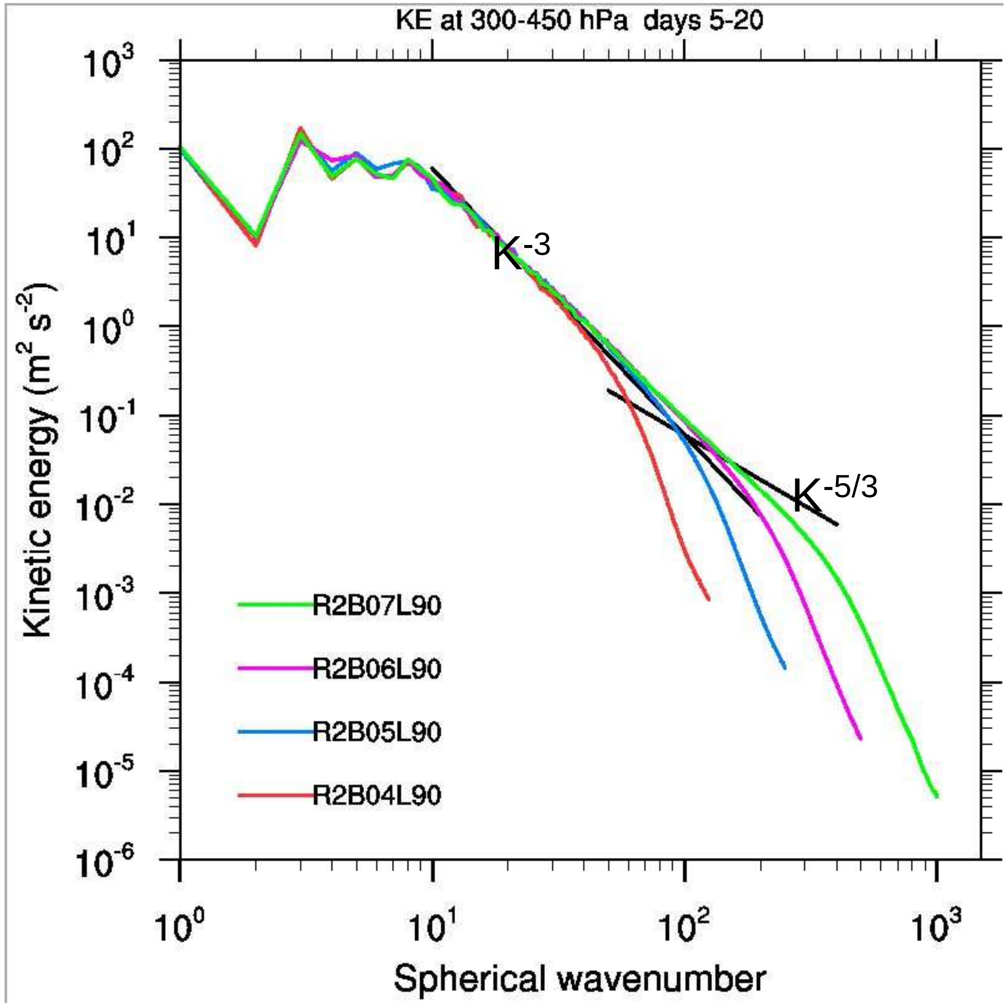


June 2012

Kinetic energy spectra



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!

Limited-area experiments with time-dependent boundary conditions

- **Developments within HD(CP)² project (Slavko Brdar, Daniel Klocke, Mukund Pondkule)**
- **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**

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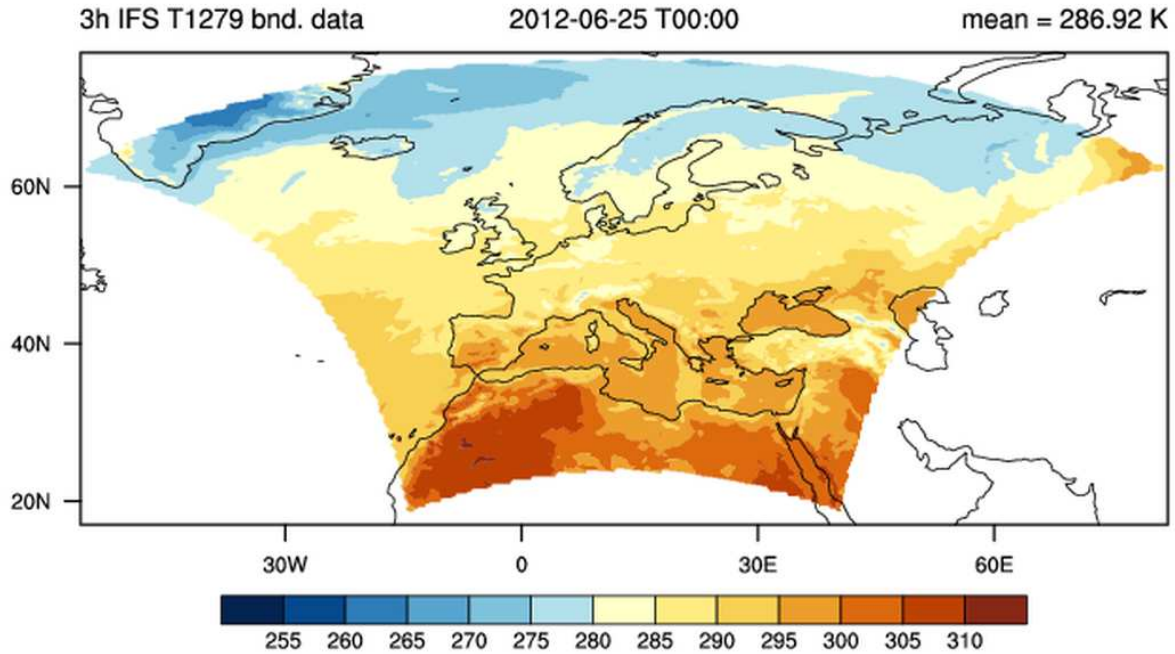
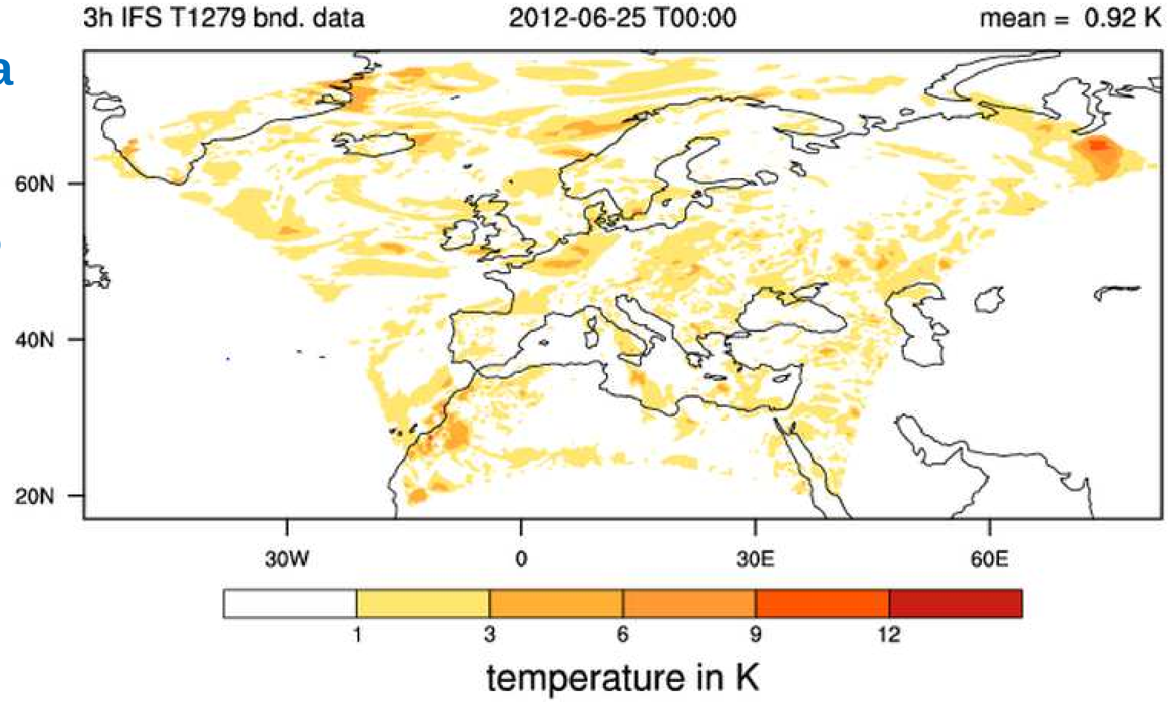
Temperature at lowest model level (10 m AGL), four-day forecast

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





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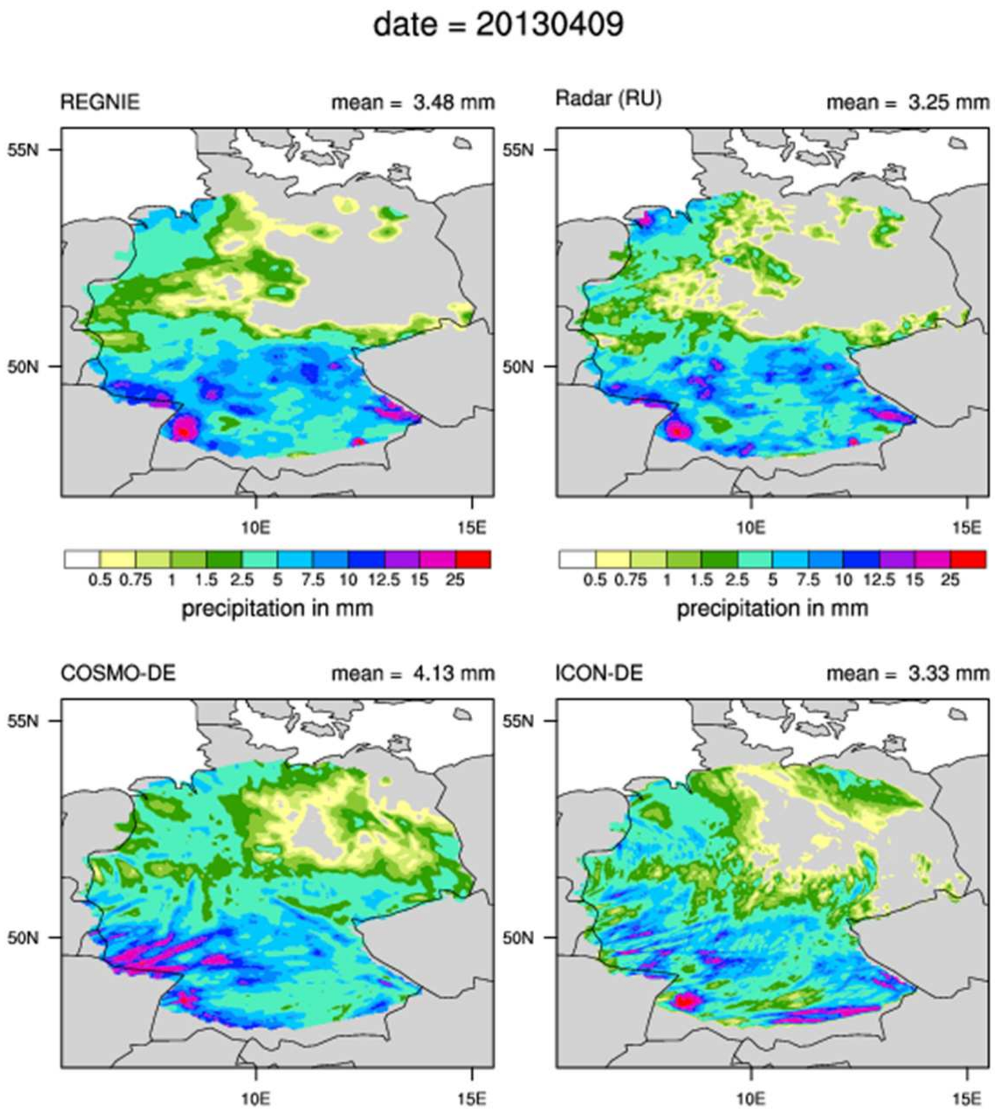
24-hour accumulated precipitation (mm)

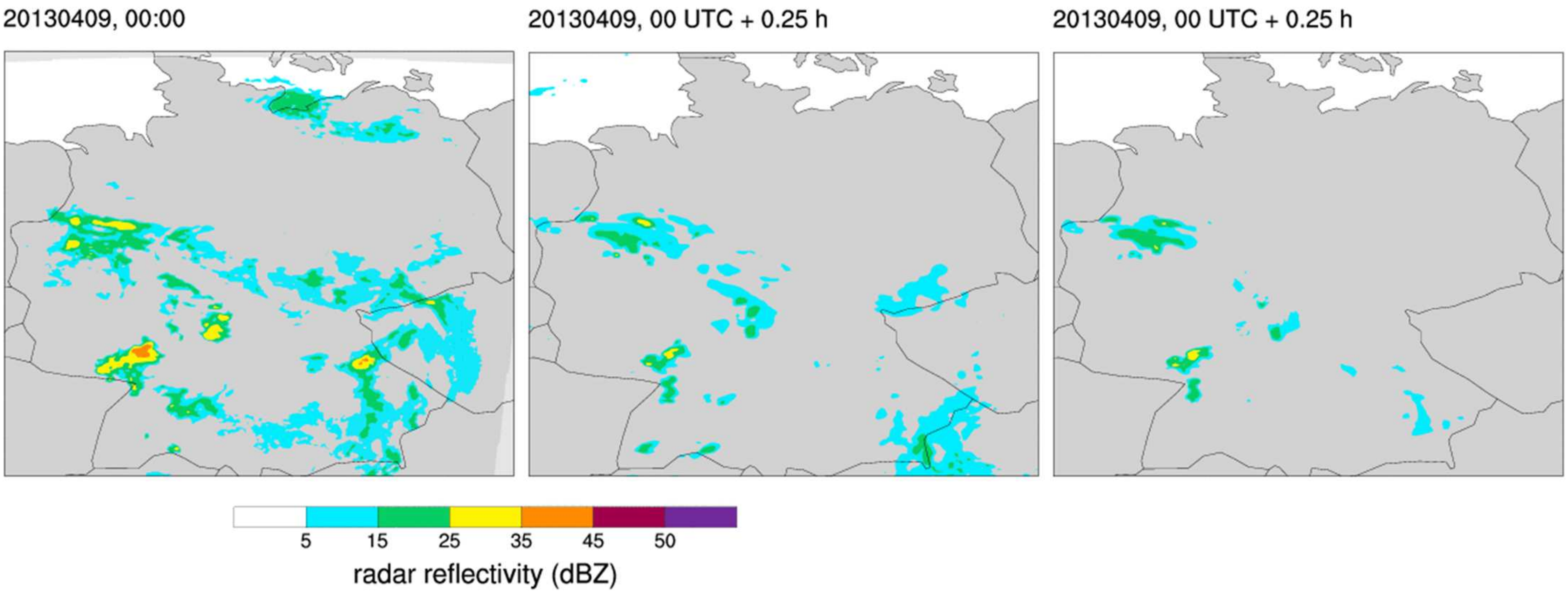


Animation of 15-min radar reflectivity

Measurements

COSMO-DE

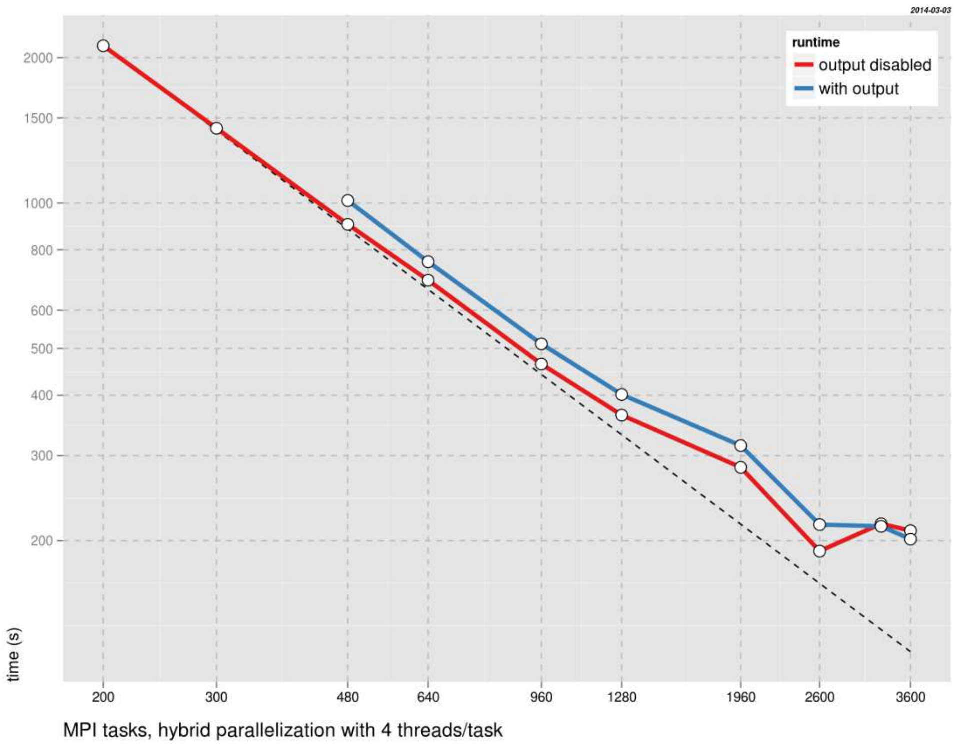
ICON



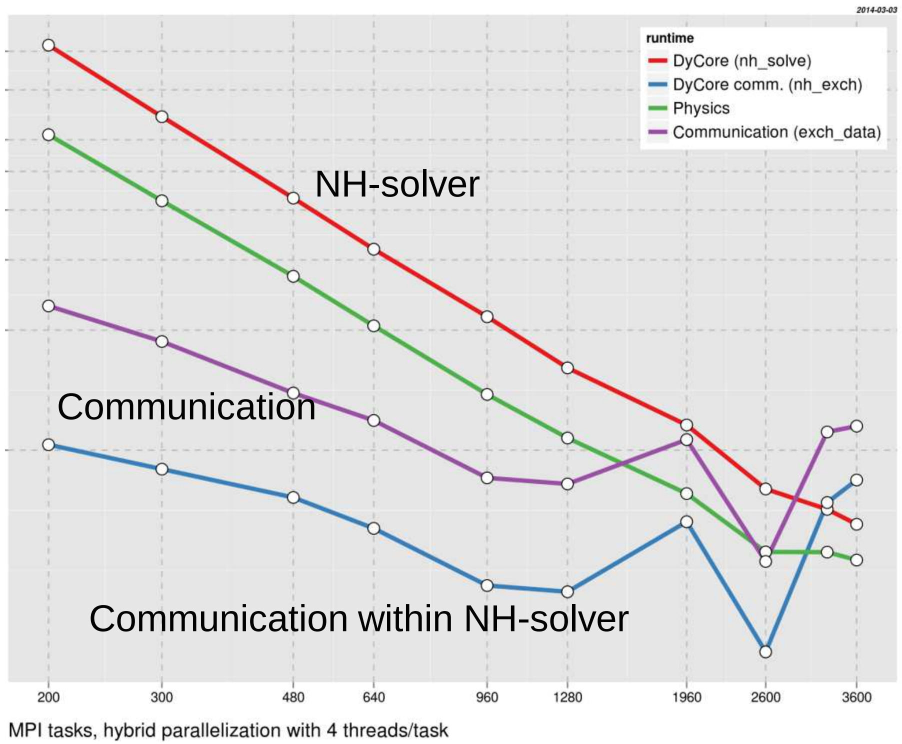
Scaling test

- **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, 10 MPI-tasks/node**

total runtime

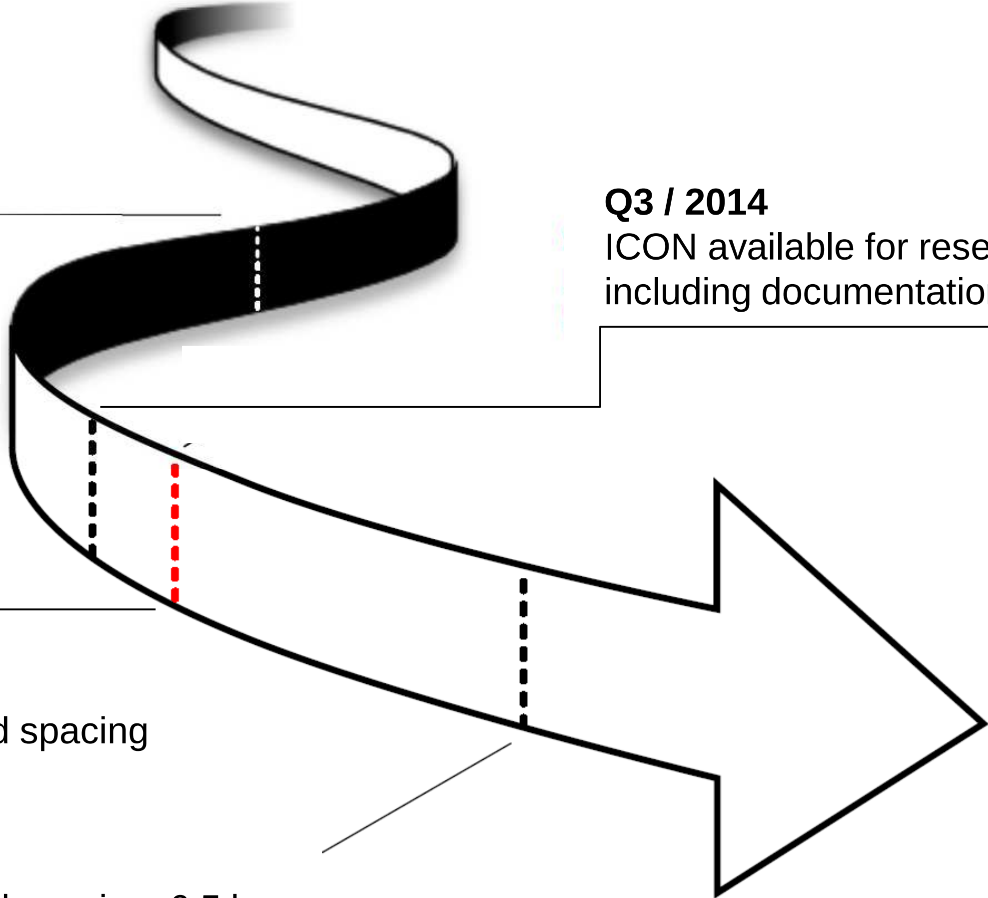


sub-timers



Thanks to Florian Prill!

Time schedule



Q1 / 2014
Start of pre-operational phase with full data assimilation (only global)

Q3 / 2014
ICON available for research including documentation / training

Q4 / 2014
Start of operational phase with grid spacing 13 km L90; replacement of GME

Q2-Q4 / 2015
Start of operational phase with grid spacing 6.5 km over Europe; replacement of COSMO-EU

Q4 / 2015
Test version of limited-area mode will be provided to COSMO partners


Thank you for your attention!
Any questions?