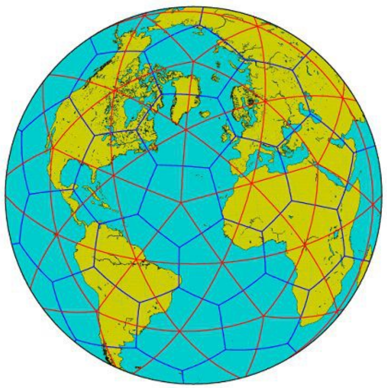
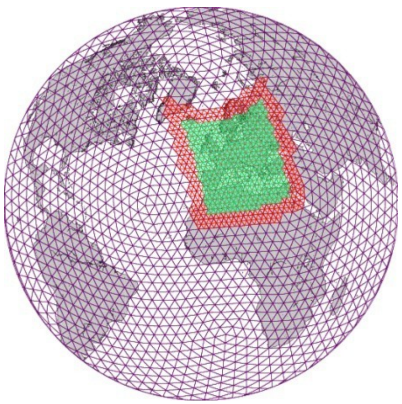


ICON



The new global nonhydrostatic model of DWD and MPI-M

Günther Zängl

(on behalf of the ICON development team)

10th SRNWP Workshop

13.05.2013

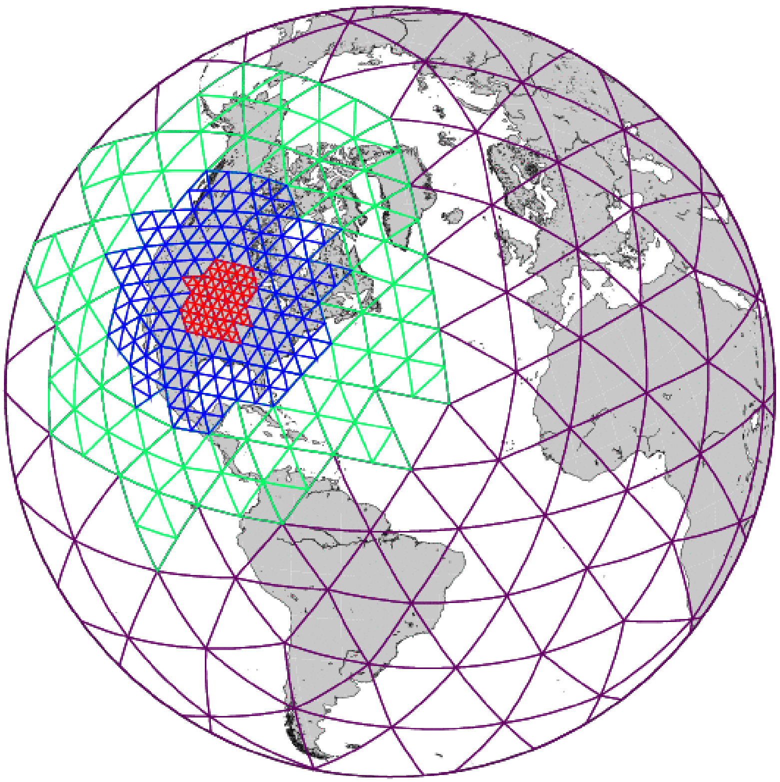
Outline

- ➔ **Introduction: Main features of ICON**
- ➔ **Selected results: from idealized tests to NWP applications**
- ➔ **Time plans towards operational use of ICON**

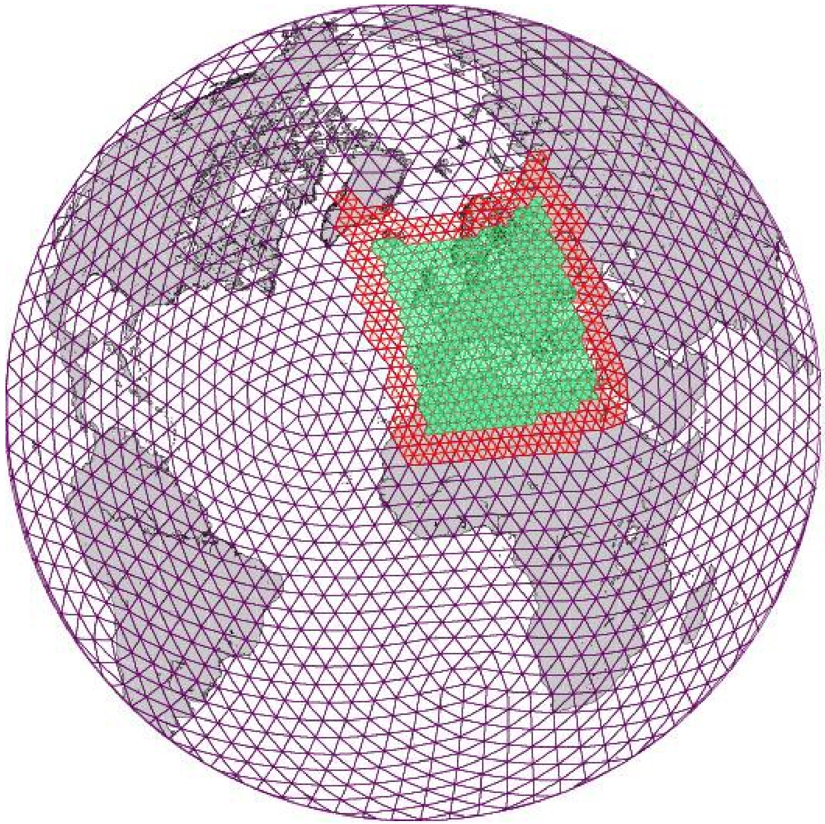
ICON = ICOsahedral Nonhydrostatic model

- Joint development project of DWD and Max-Planck-Institute for Meteorology for the next-generation global NWP and climate modeling system
- Nonhydrostatic dynamical core on an icosahedral-triangular C-grid; coupled with full set of physics parameterizations
- Two-way nesting with capability for multiple nests per nesting level; vertical nesting, one-way nesting mode and limited-area mode are also available
- Local mass conservation and tracer mass continuity
- Substantially higher computational efficiency and scalability than GME

Grid structure with nested domains (schematically)



circular nests



latitude-longitude nests

Nonhydrostatic equation system (dry adiabatic limit)

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

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

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

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

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

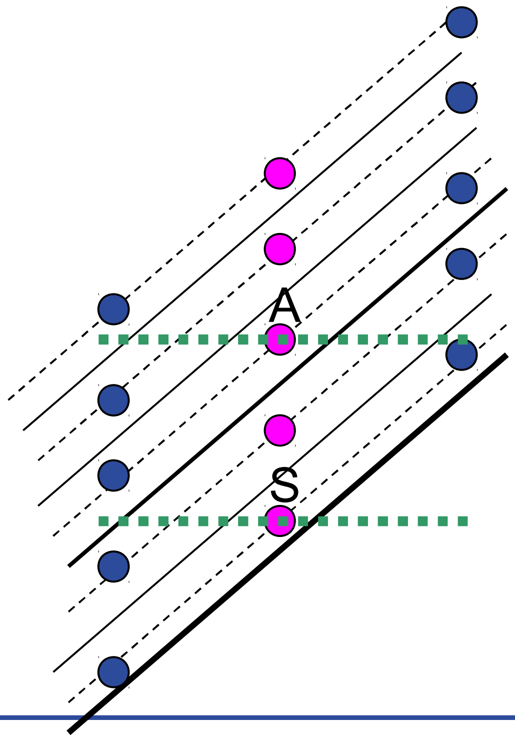
Numerical implementation

- Two-time-level predictor-corrector time stepping scheme
- implicit treatment of vertically propagating sound waves, but explicit time-integration in the horizontal (at sound wave time step; not split-explicit); larger time step (usually 4x or 5x) for tracer advection / fast physics
- Finite-volume tracer advection scheme (Miura) with 2nd-order and 3rd-order accuracy for horizontal tracer advection; extension for CFL values slightly larger than 1 available
- 2nd-order and 3rd-order (PPM) for vertical advection with extension to CFL values much larger than 1 (partial-flux method)
- Monotonous and positive-definite flux limiters

Special discretization of horizontal pressure gradient

(apart from conventional method; Zängl 2012, MWR)

- **Precompute for each edge (velocity) point at level the grid layers into which the edge point would fall in the two adjacent cells**



dashed lines: main levels
pink: edge (velocity) points
blue: cell (mass) points

Discretization of horizontal pressure gradient

- Reconstruct the Exner function at the mass points using a quadratic Taylor expansion, starting from the point lying in the model layer closest to the edge point

$$\tilde{\pi}_c = \pi_c + \frac{\partial \pi_c}{\partial z}(z_e - z_c) + \frac{1}{2}\frac{g}{c_p \theta_v^2}\frac{\partial \theta_v}{\partial z}(z_e - z_c)^2$$

- Note: the quadratic term has been approximated using the hydrostatic equation to avoid computing a second derivative
- Treatment at slope points where the surface is intersected:

$$\frac{\partial \pi}{\partial x}\Big|_S = \frac{\partial \pi}{\partial x}\Big|_A + \frac{g}{c_p \theta_v^2}\frac{\partial \theta_v}{\partial x}\Big|_A (z_S - z_A)$$

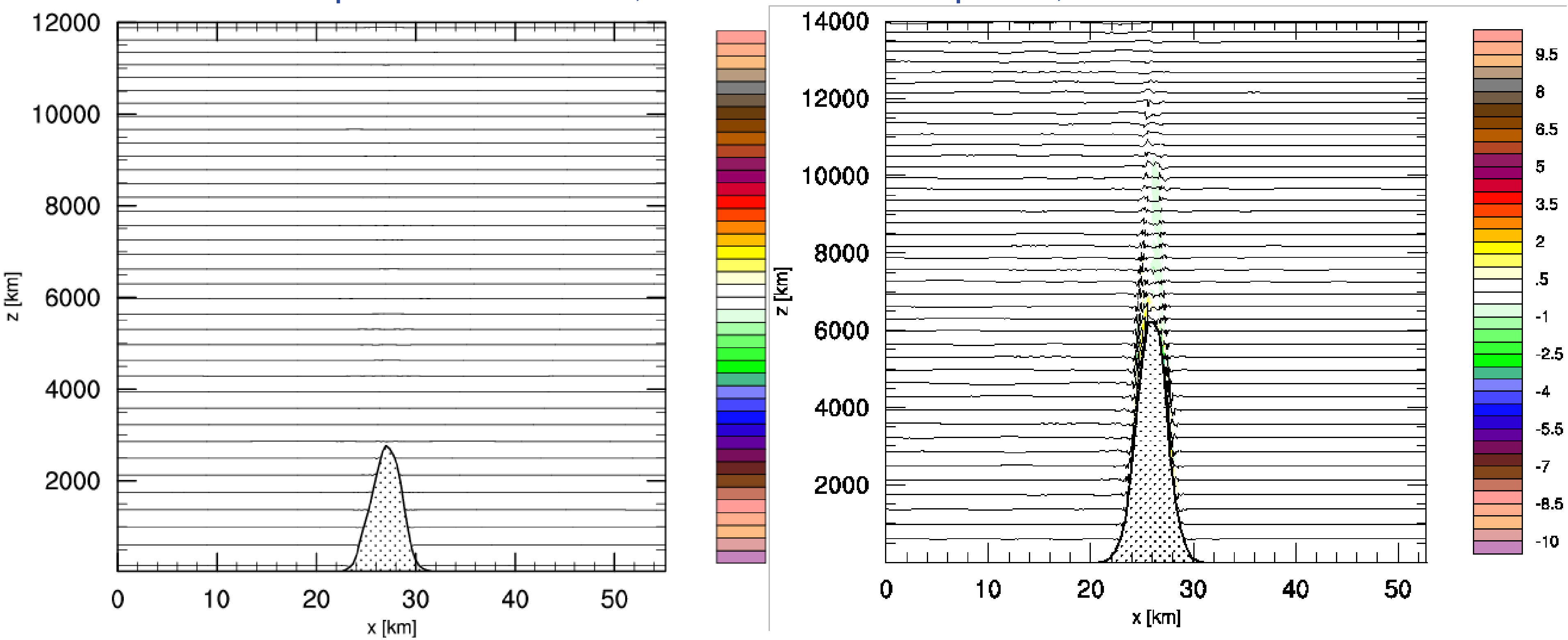
Physics-dynamics coupling

- Fast-physics processes: incremental update in the sequence: saturation adjustment, transfer scheme, surface coupling, turbulence, cloud microphysics, saturation adjustment
- Slow-physics processes (convection, cloud cover diagnosis, radiation, orographic blocking, sub-grid-scale gravity waves): tendencies are added to the right-hand side of the velocity and Exner pressure equation
- Diabatic heating rates related to phase changes and radiation are consistently treated at constant volume
- Option for reduced radiation grid with special domain decomposition to minimize day/night load imbalance

Selected experiments and results

- Idealized tests with an isolated steep mountain, mesh size ~300 m: atmosphere-at-rest and generation of nonhydrostatic gravity waves
- Quasi-linear Schär mountain test, mesh size 625 m
- DCMIP tropical cyclone test with/without grid nesting
- Real-case tests with interpolated IFS analysis data

atmosphere-at-rest test, isothermal atmosphere, results at t = 6h

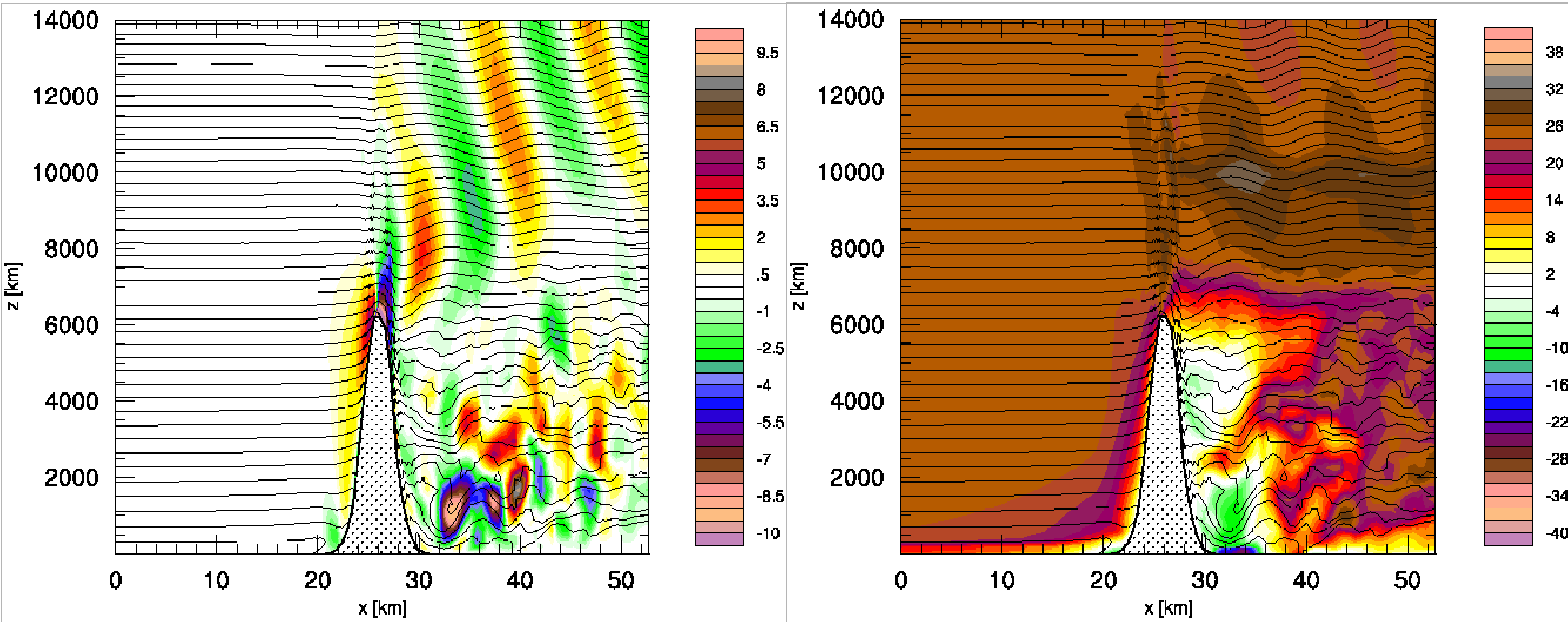


vertical wind speed (m/s), potential temperature (contour interval 4 K)

circular Gaussian mountain, e-folding width 2 km, height: 3.0 km (left), 7.0 km (right)

maximum slope: 1.27 (52°) / 2.97 (71°)

ambient wind speed 25 m/s, isothermal atmosphere, results at t = 6h

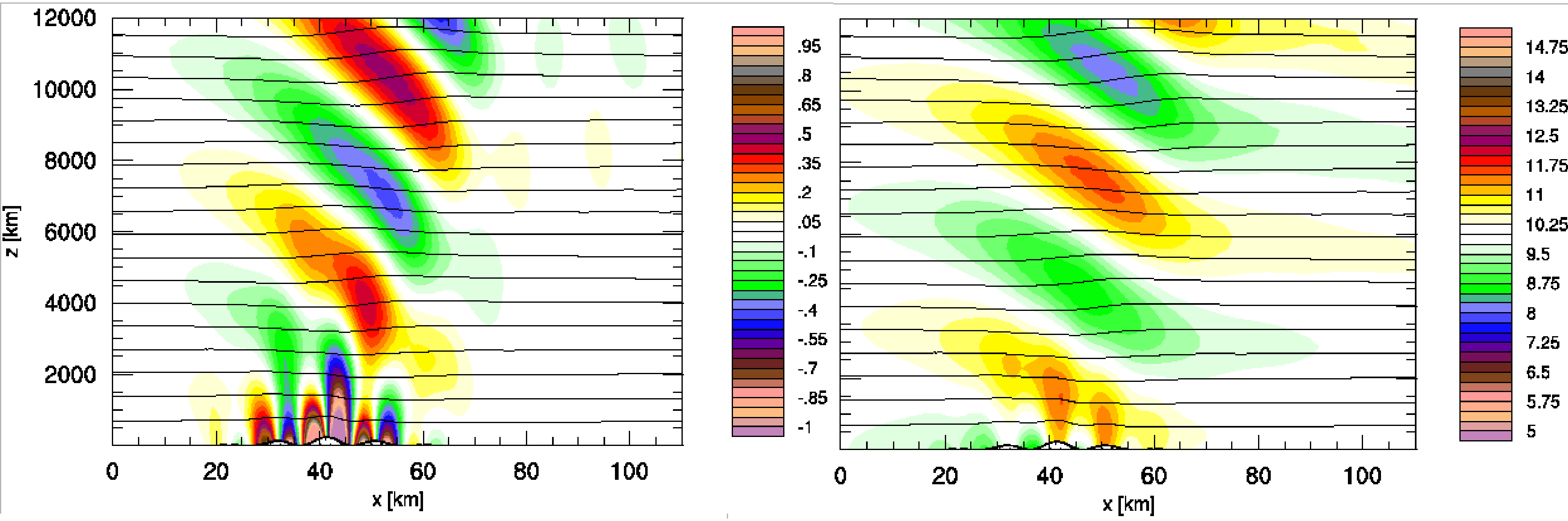


vertical (left) / horizontal (right) wind speed (m/s), potential temperature (contour interval 4 K)

circular Gaussian mountain, e-folding width 2 km, height: 7.0 km

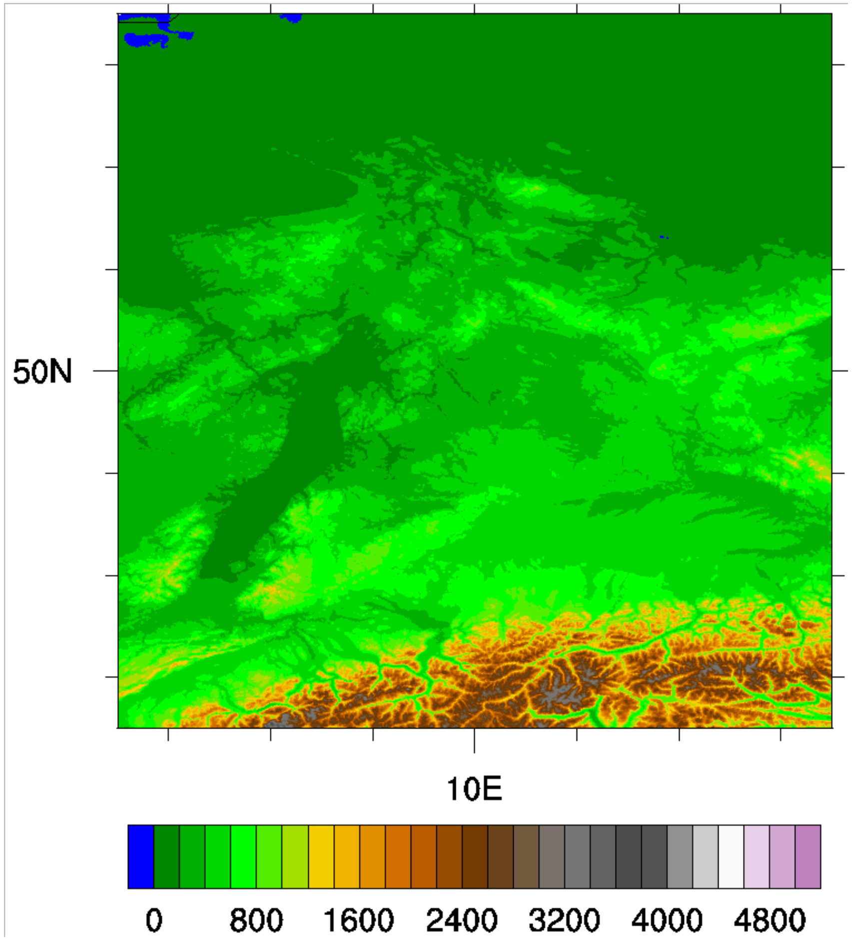
maximum slope: 2.97 (71°)

Quasi-linear Schär mountain test, mountain height 250 m, results at t = 6h, mesh size 625 m

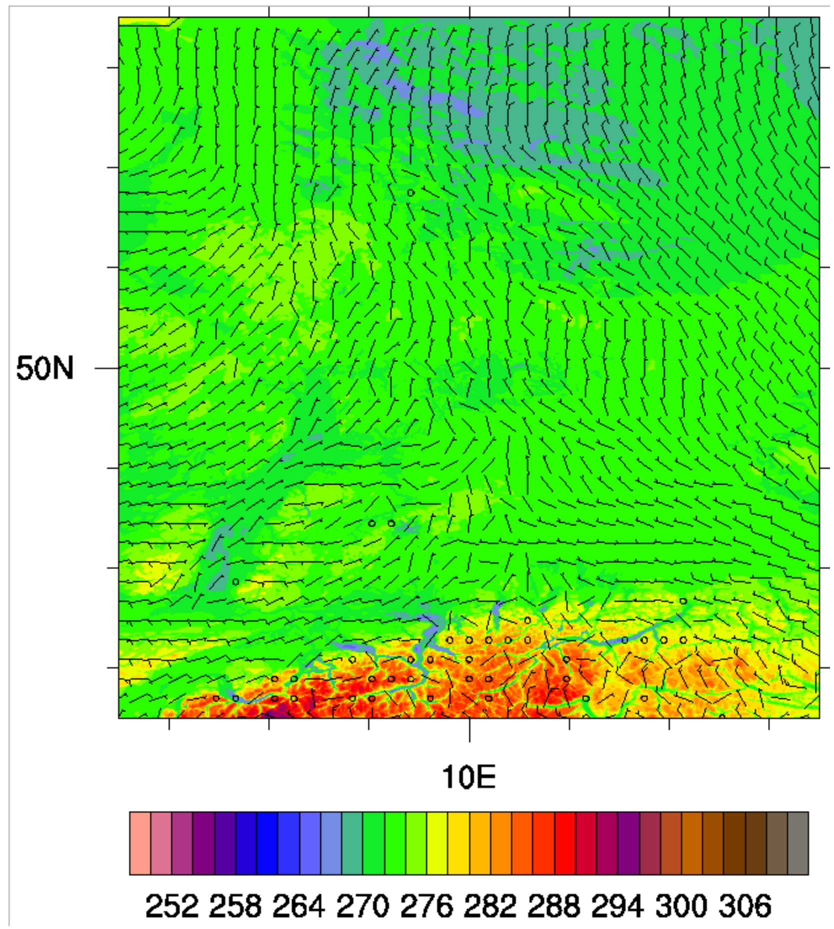


vertical (left) / horizontal (right) wind speed (m/s), potential temperature (contour interval 2 K)

7-step two-way nested real-case experiment, mesh sizes 20 km (global) – 312 m: initialized with IFS analysis data at 15.01.2012 00 UTC, 6h-hour forecast, 625m-domain

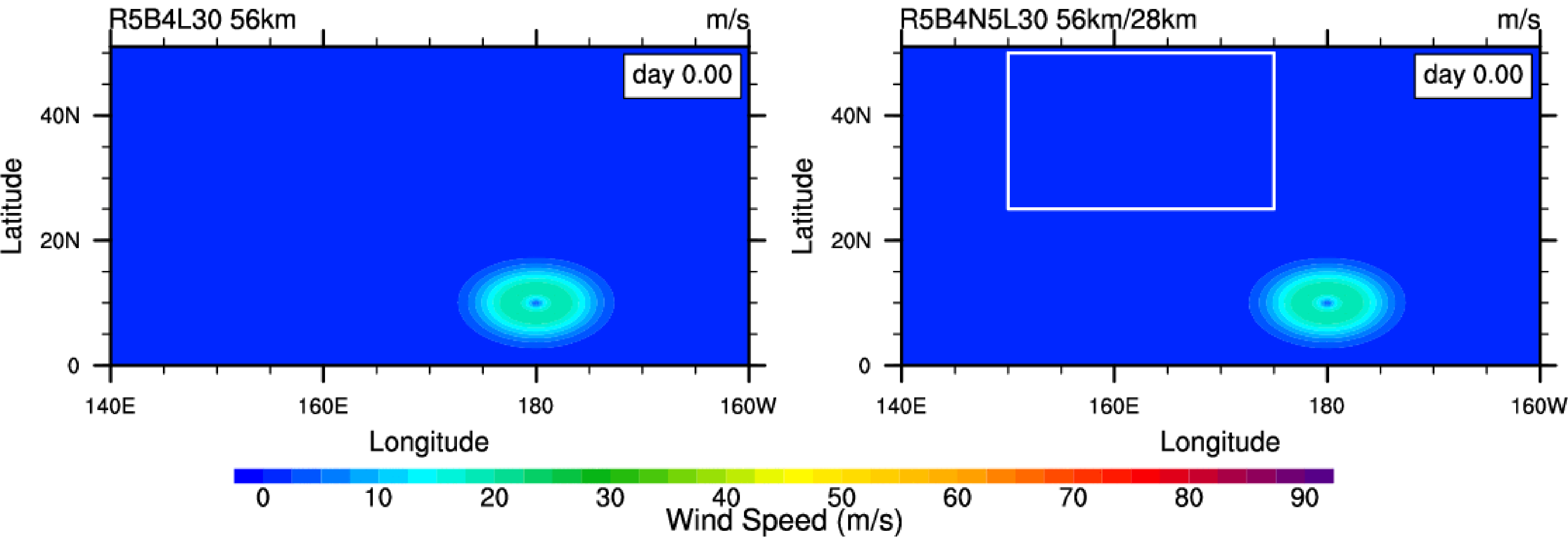


model orography (m)



potential temperature (K), wind barbs at 10 m AGL

DCMIP tropical cyclone test with NWP physics schemes, evolution over 12 days



Absolute horizontal wind speed (m/s)

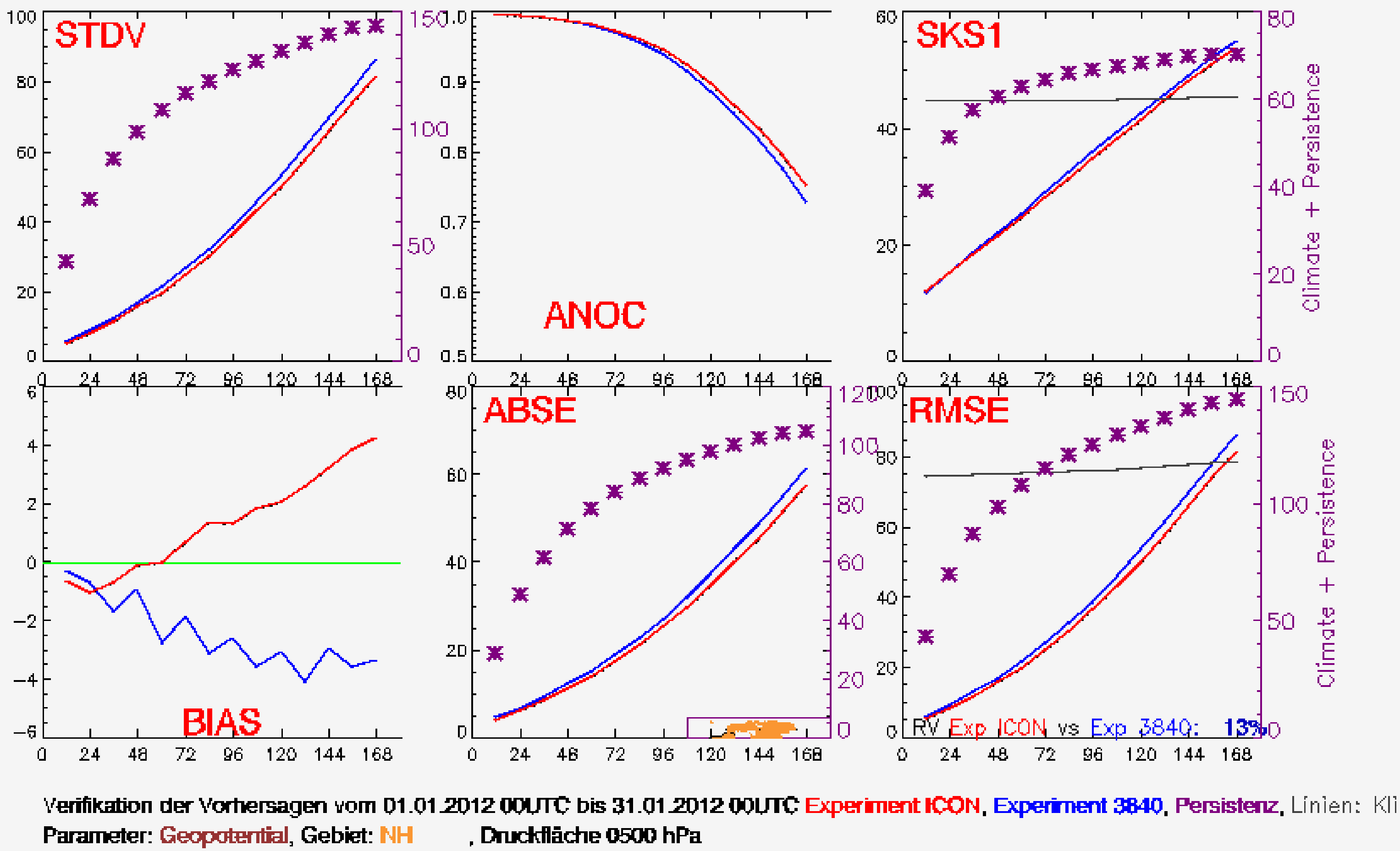
Left: single domain, 56 km; right: two-way nesting, 56 km / 28 km

Selected results of 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; separately for January and June
- Full NWP Physics package

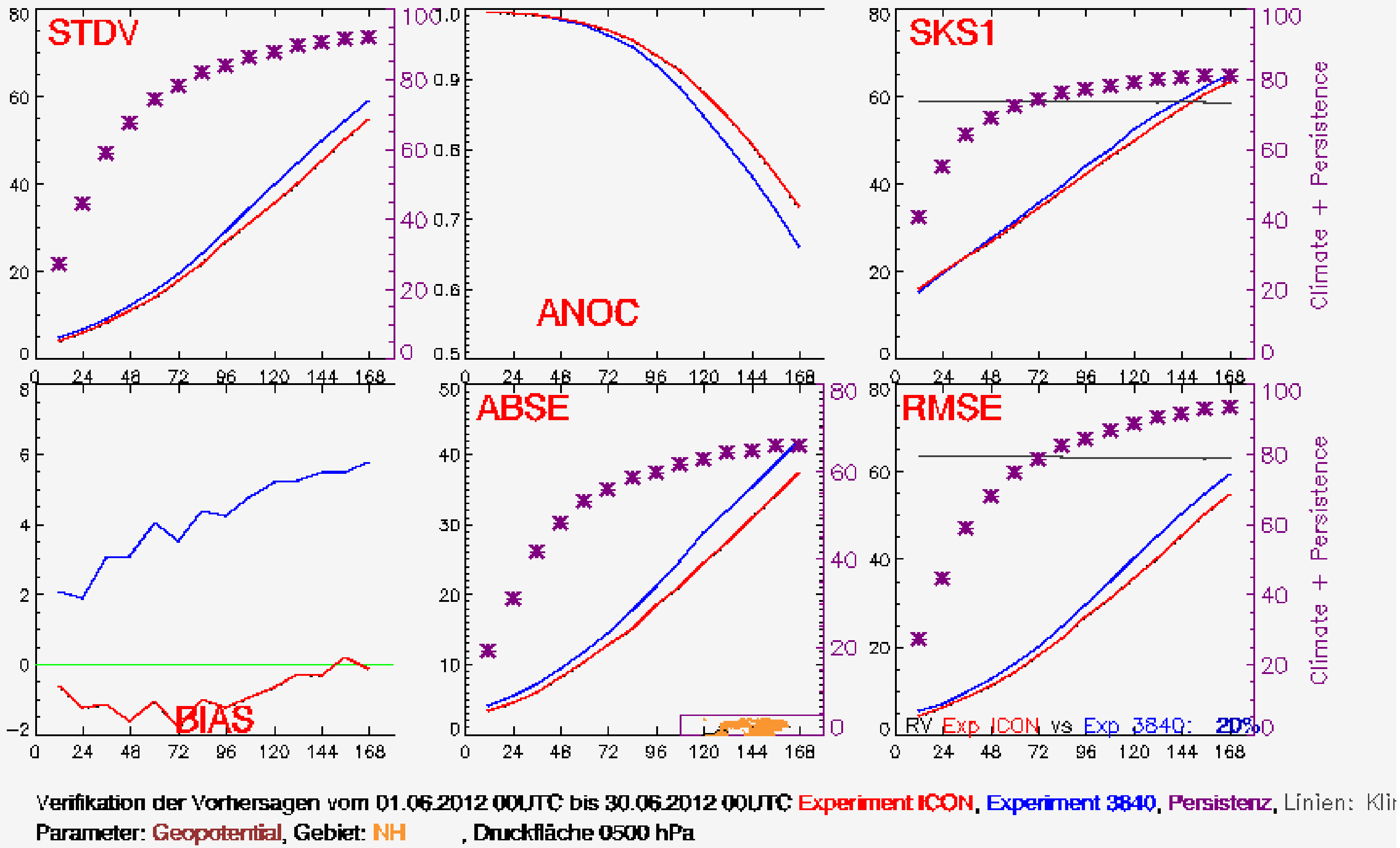
WMO standard verification against IFS analysis: 500 hPa geopotential, NH

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



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

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



Time planning towards operational use

- **Ongoing: systematic analysis and optimization of forecast quality of ICON using test series with interpolated IFS analyses**
- **Ongoing: Coupling with data assimilation**
- **Q3/2013: Start of preoperational tests with data assimilation**
- **Q2/2014: First step of operational use of ICON: replacement of GME with 13-km ICON without nesting**
- **Q4/2014: Second step: Replacement of COSMO-EU by nested ICON domain (13-6.5 km)**
- **2015: Additional one-way nested domains for MetBw**
- **Main risks: technical difficulties with GRIB2 I/O via cdi library, extensions of GRIB2 standard needed for unstructured grid, generalized vertical coordinate, tile approach for surface scheme; slow progress of experiments due to database performance issues**