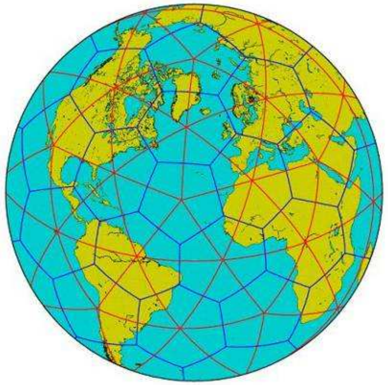
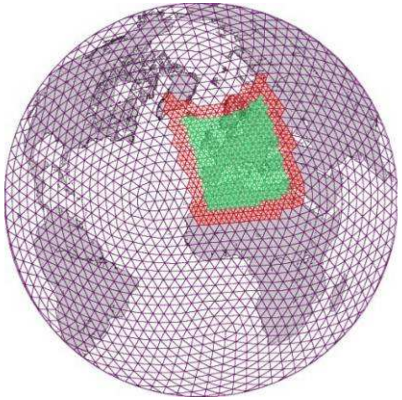


ICON



The new global model for numerical weather prediction and climate modelling of DWD and MPI-M

Günther Zängl

CONSORTIUM FOR SMALL SCALE MODELING
COSMO User Seminar

07.03.2013

Outline

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

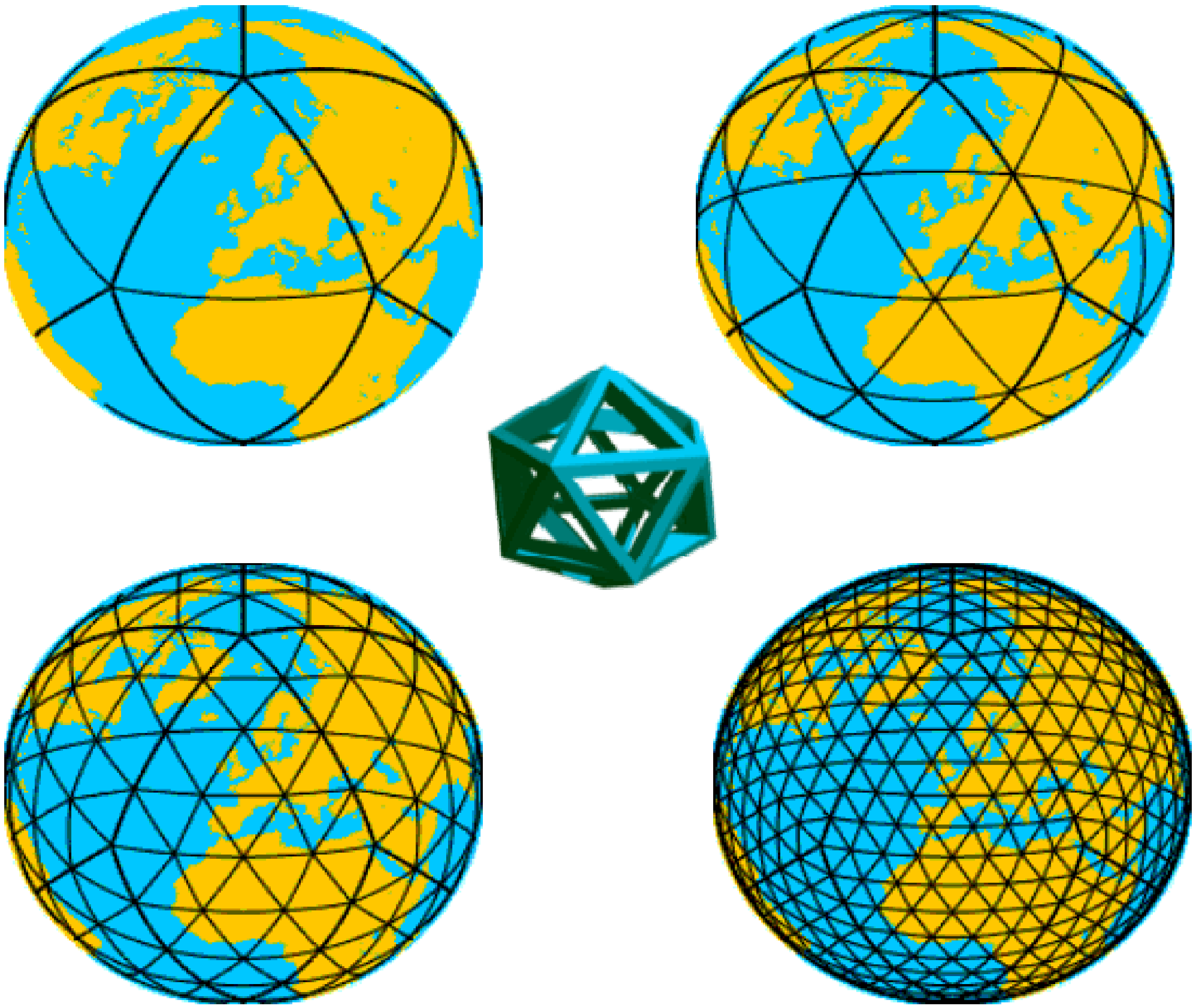
ICON = ICOsahedral Nonhydrostatic model

- 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

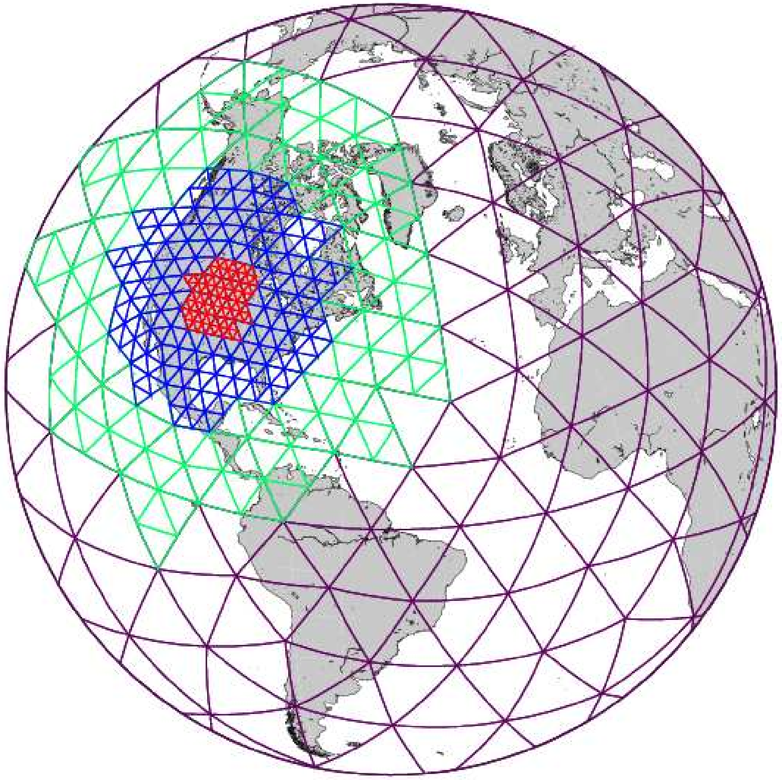
Primary development goals

- ➔ Better conservation properties (air mass, mass of trace gases and moisture, consistent transport of tracers)
- ➔ Grid nesting in order to replace both GME (global forecast model, mesh size 20 km) and COSMO-EU (regional model, mesh size 7 km) in the operational suite of DWD
- ➔ Applicability on a wide range of scales in space and time down to mesh sizes that require a nonhydrostatic dynamical core
- ➔ Scalability and efficiency on massively parallel computer architectures with $O(10^4+)$ cores
- ➔ At MPI-M: Develop an ocean model based on ICON grid structures and operators; Use limited-area mode of ICON to replace regional climate model REMO.
- ➔ By the end of this decade: participate in the seasonal prediction project EURO-SIP with coupled atmosphere-ocean ICON

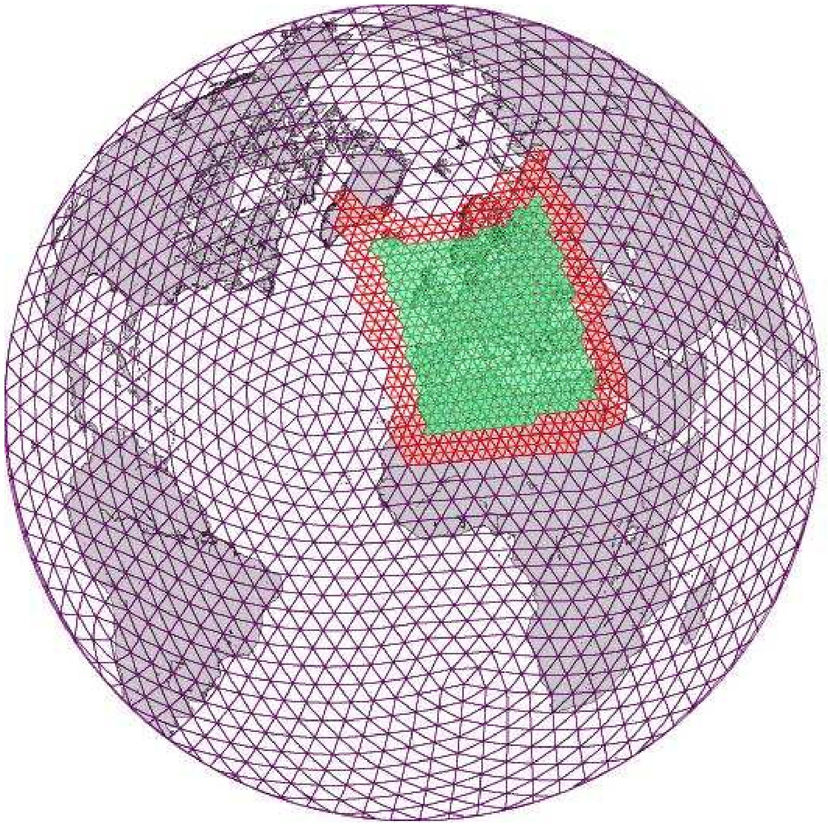
The horizontal grid



Grid structure with nested domains



circular nests



latitude-longitude nests

Nonhydrostatic equation system (dry adiabatic)

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

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

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

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

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

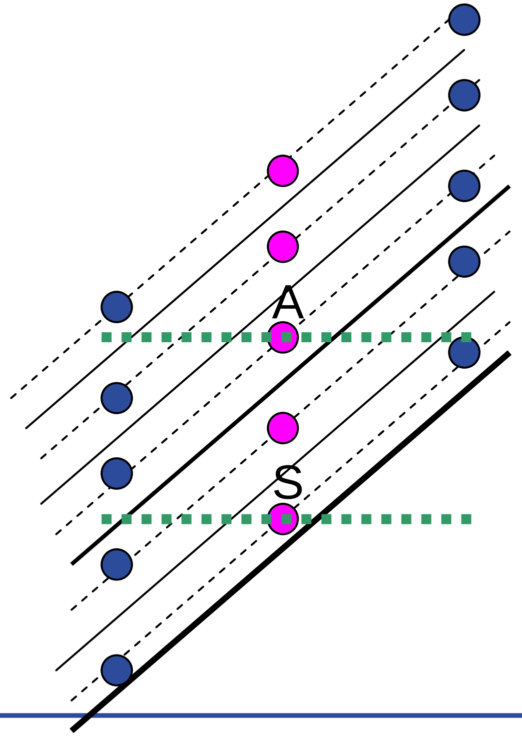
Numerical implementation

- **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:**

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

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
	Louis (1979)	1st-order closure	GME
	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

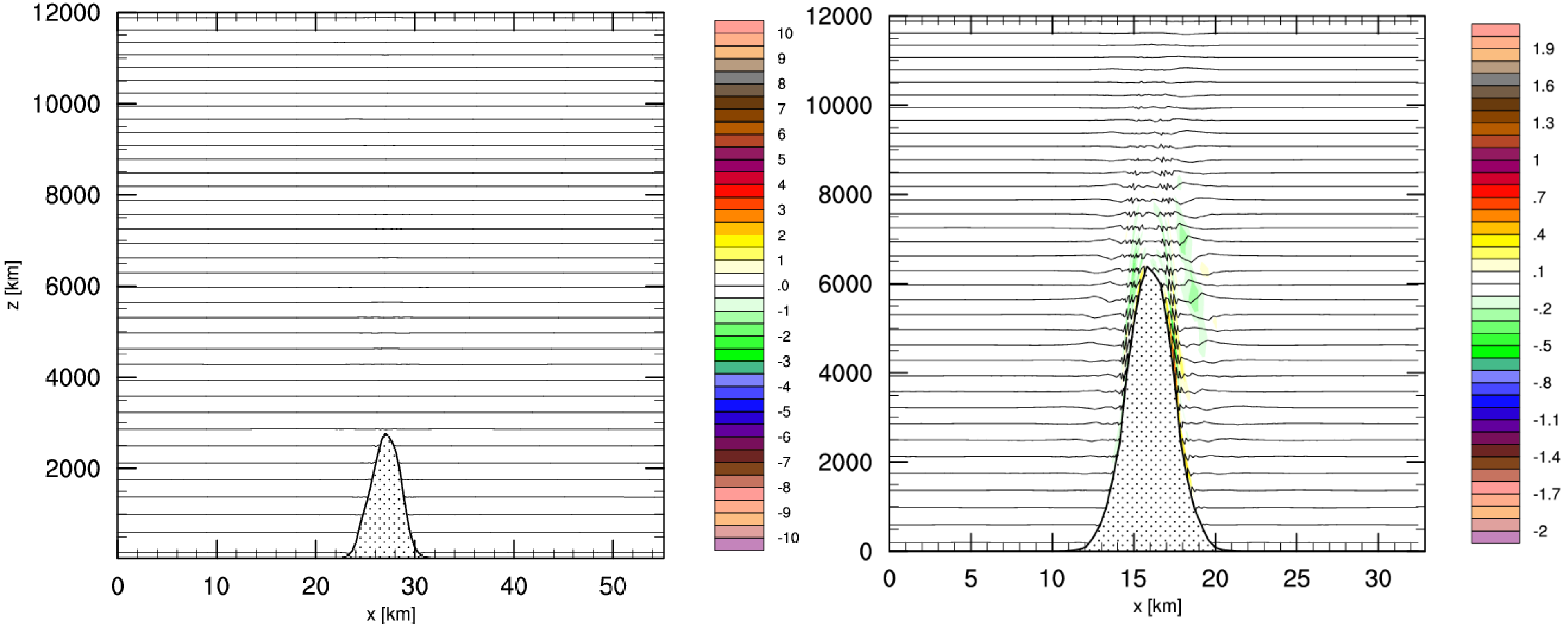
Physics-dynamics coupling

- **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**
- **Jablonowski-Williamson baroclinic wave test with/without grid nesting**
- **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

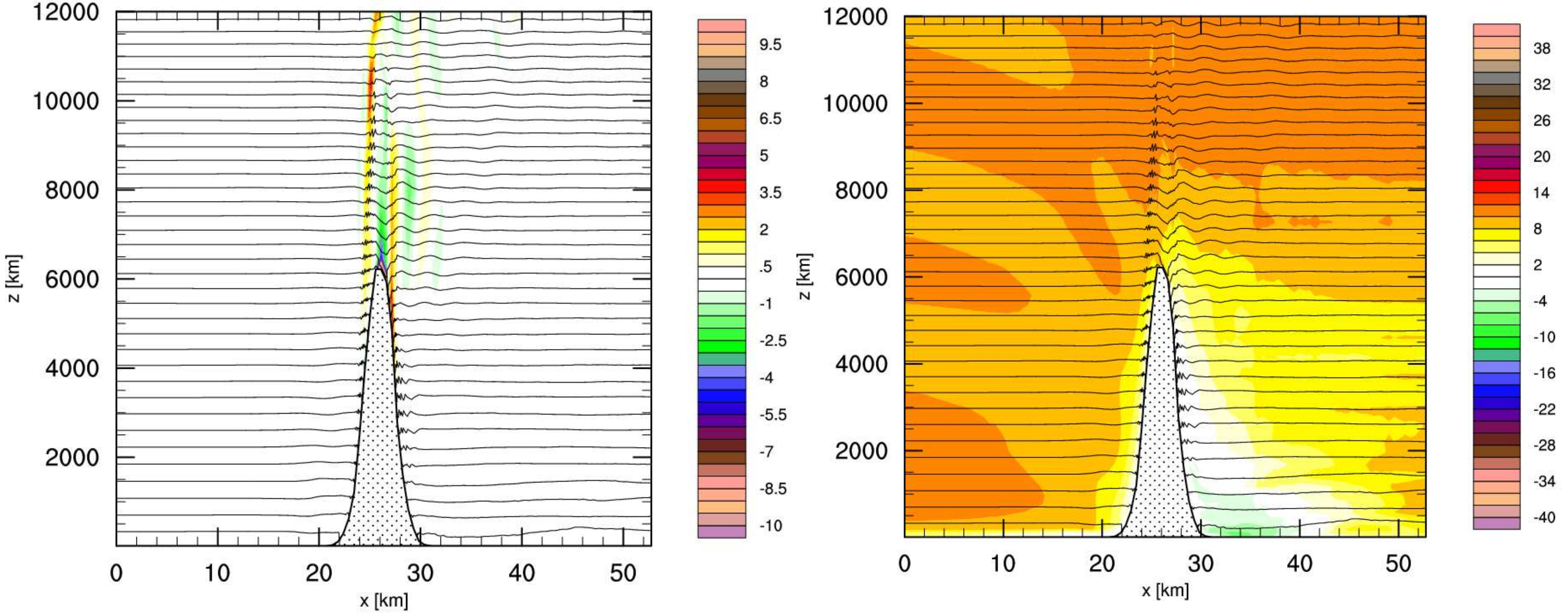


vertical wind speed (m/s), potential temperature (contour interval 4 K)

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 10 m/s, isothermal atmosphere, results at t = 6h

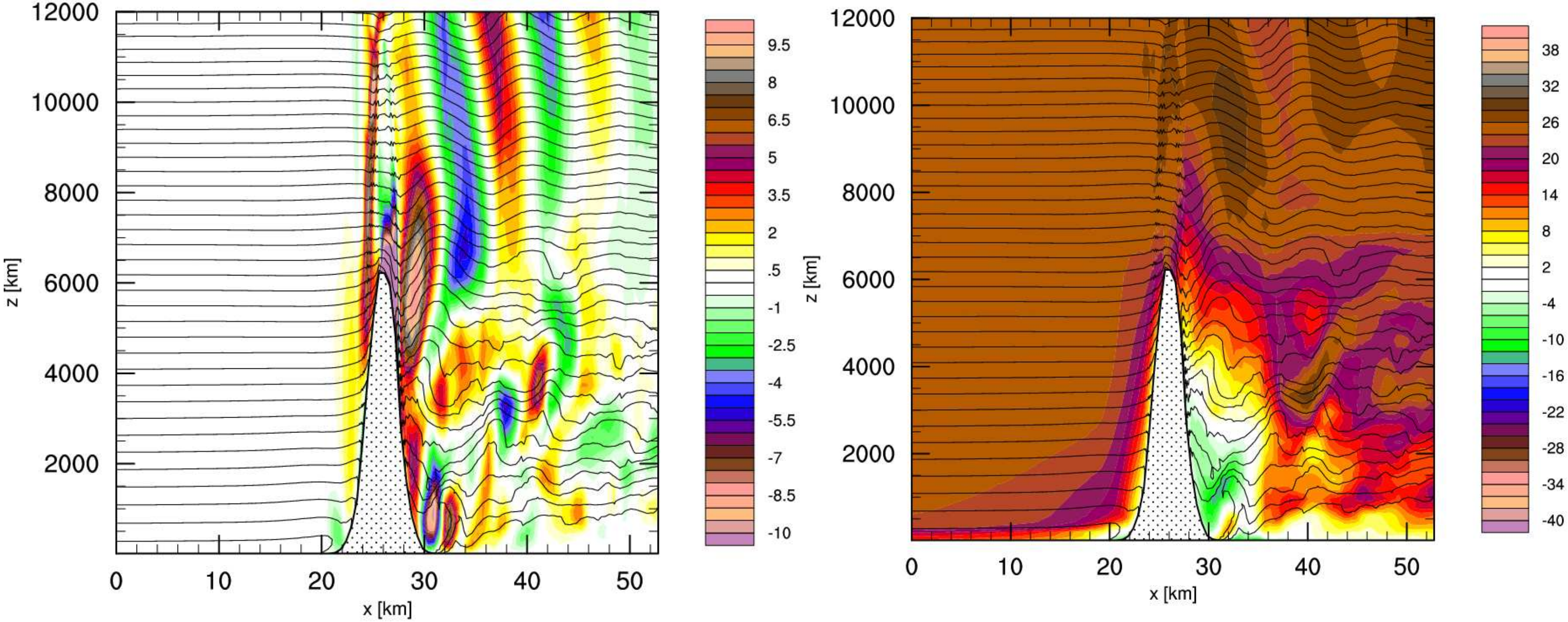


vertical (left) / horizontal (right) wind speed (m/s), potential temperature (contour interval 4 K)

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

maximum slope: 2.97 (71°)

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

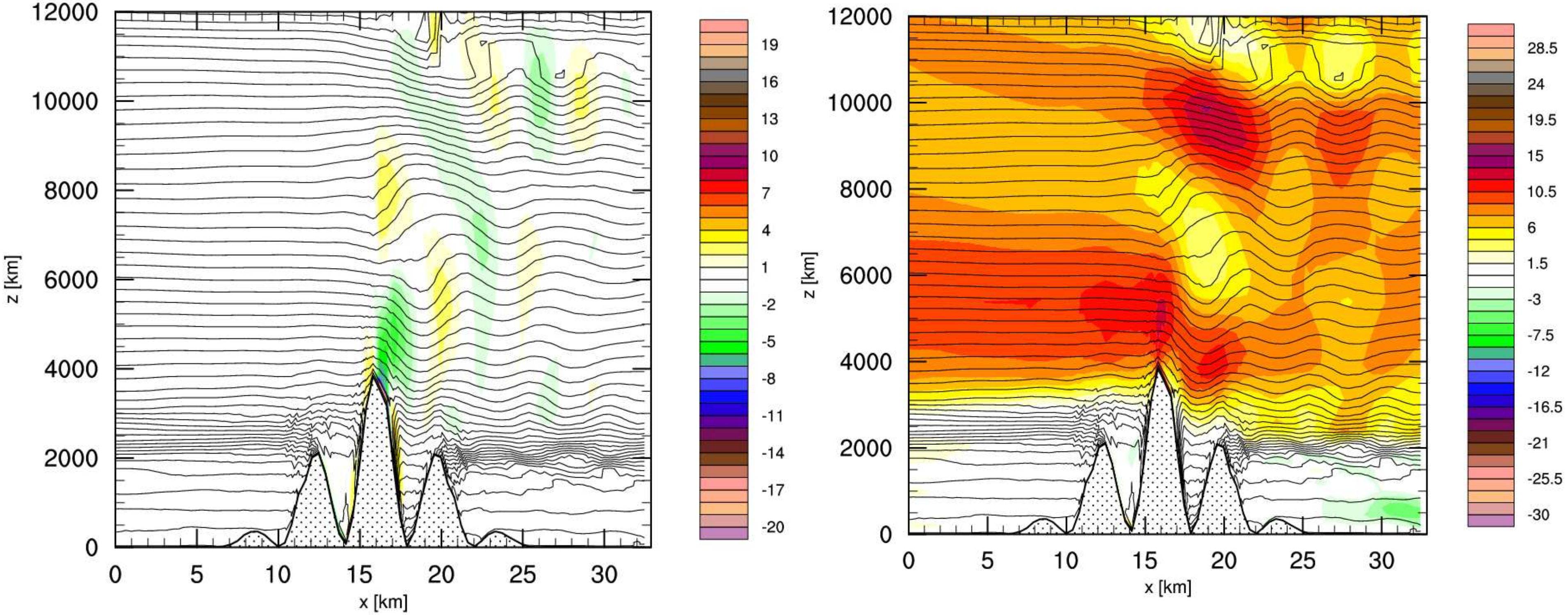


vertical (left) / horizontal (right) wind speed (m/s), potential temperature (contour interval 4 K)

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

maximum slope: 2.97 (71°)

ambient wind speed 7.5 m/s, multi-layer atmosphere, results at t = 6h

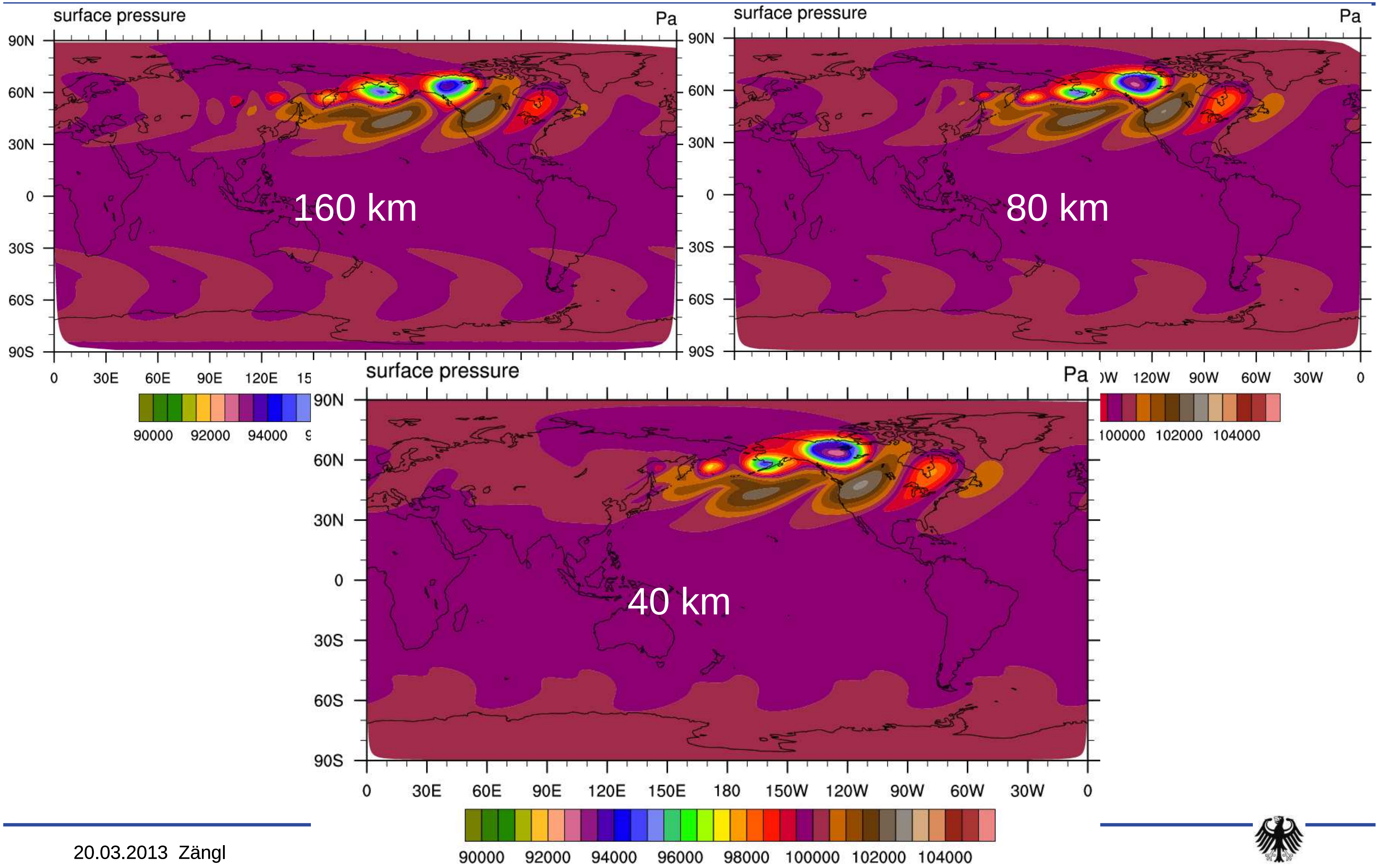


vertical (left) / horizontal (right) wind speed (m/s), potential temperature (contour interval 2 K)

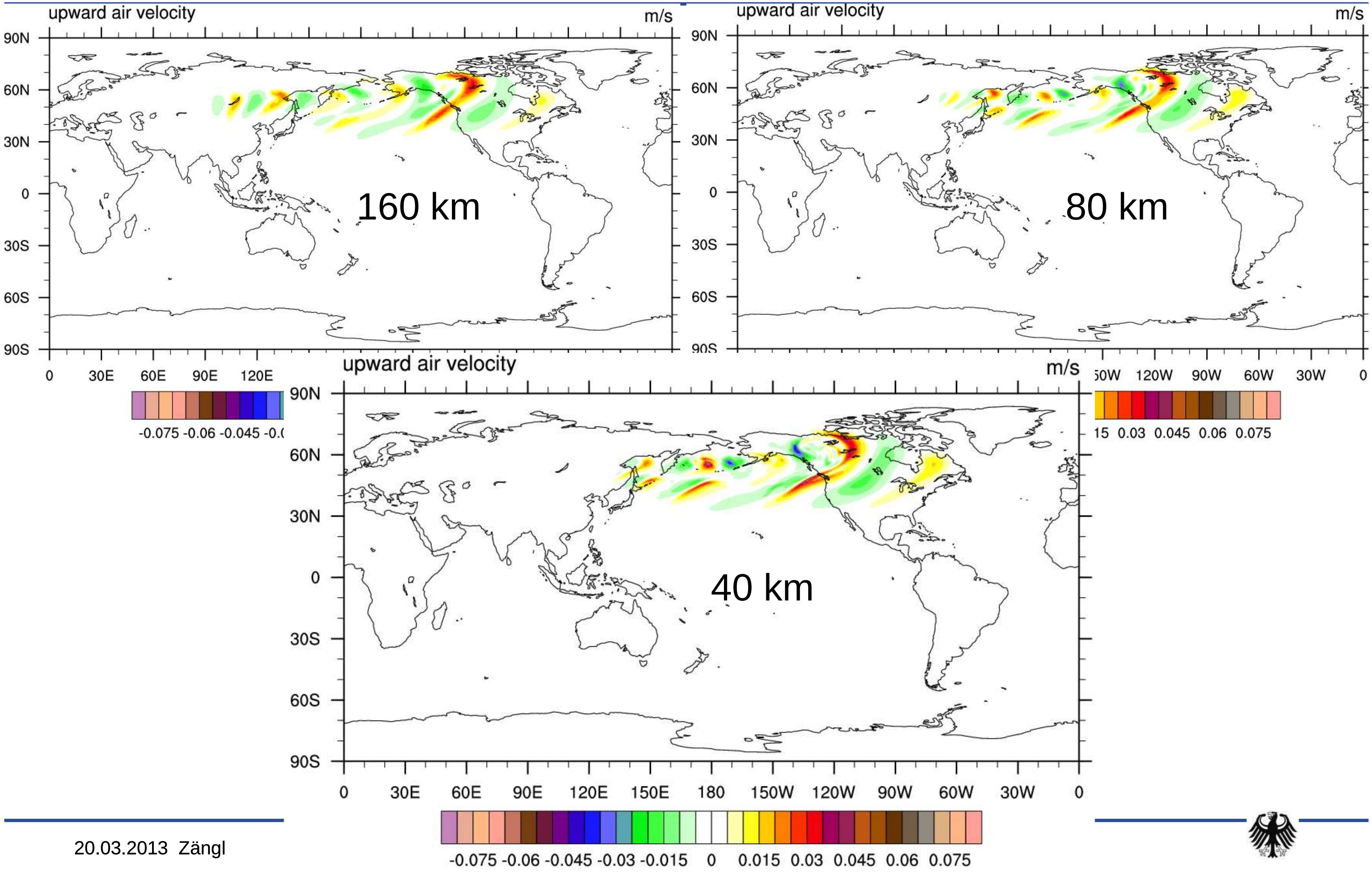
3D Schär mountain, height: 4.0 km, peak-to-peak distance 4.0 km

maximum slope: 2.73 (70°)

Jablonowski-Wiliamson test, surface pressure (Pa) after 10 days



Jablonowski-Wiliamson test, vertical wind at 1.5 km AGL (m/s) after 10 days



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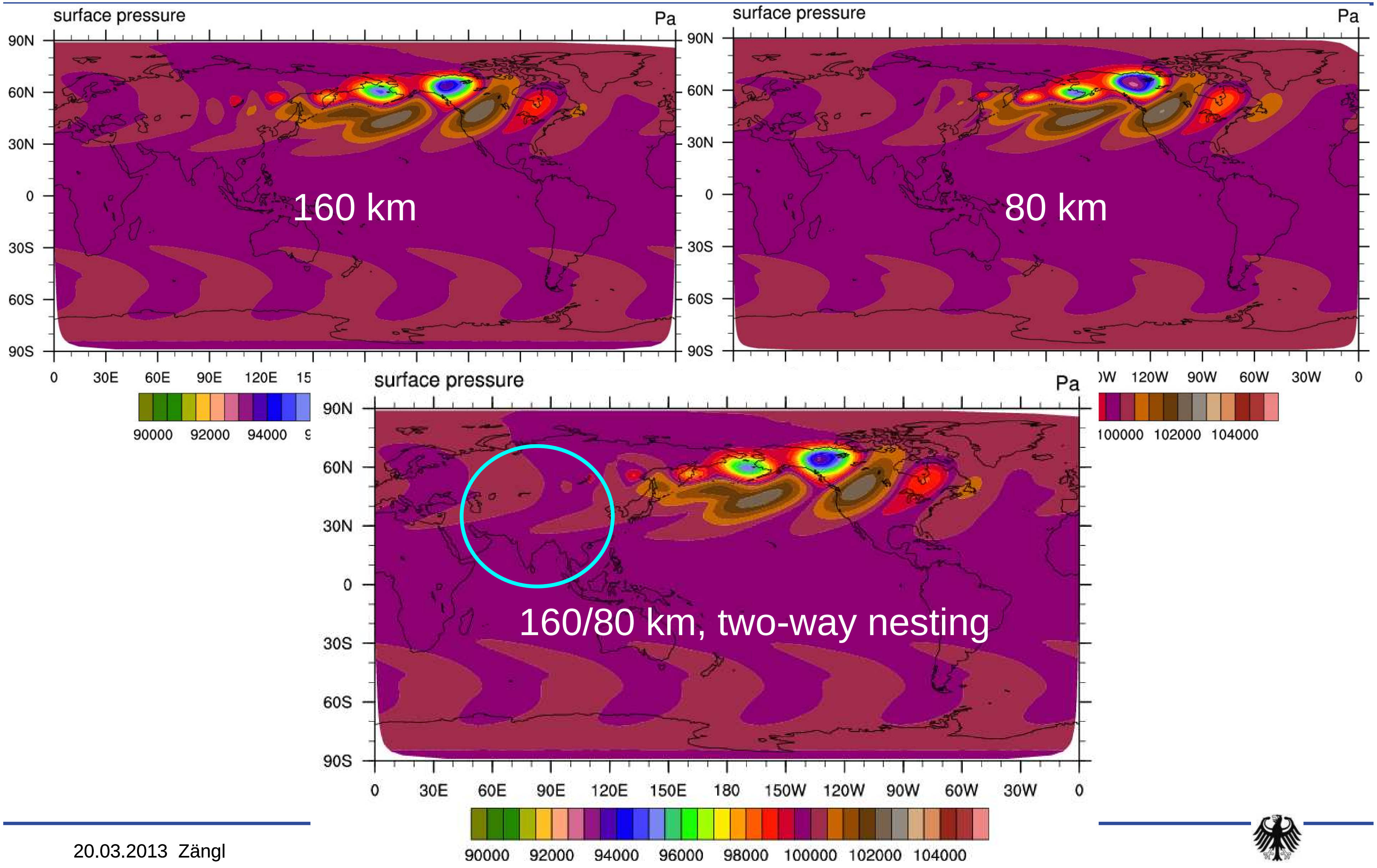
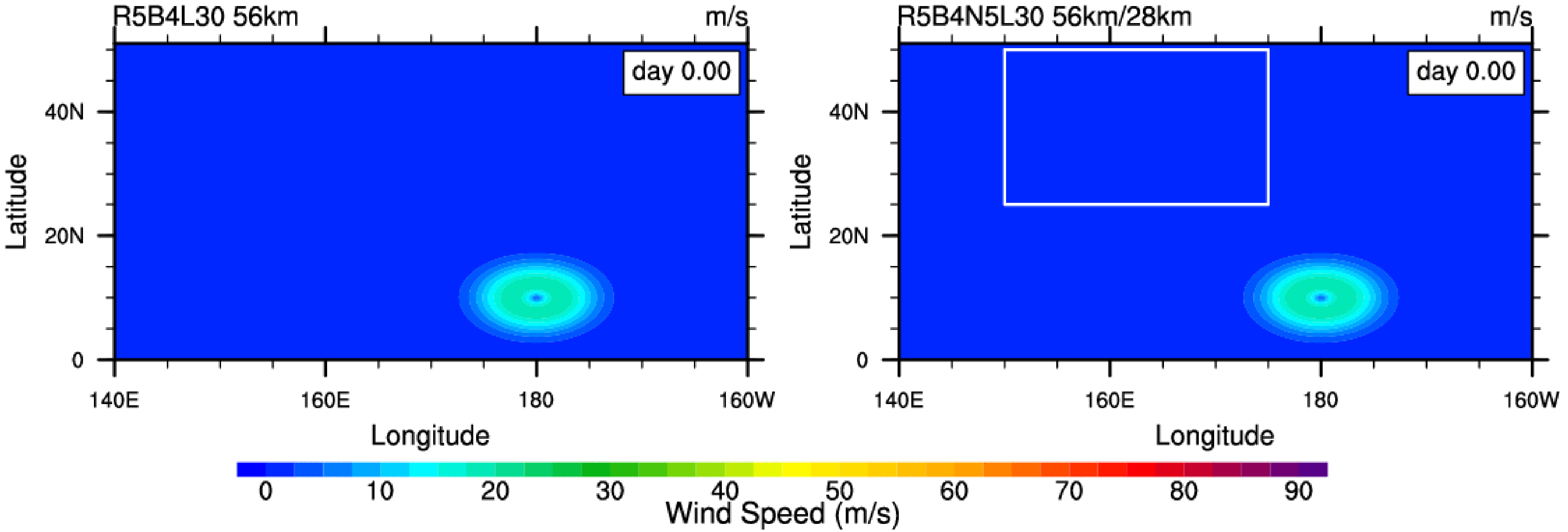
Jablonowski-Wiliamson test, surface pressure (Pa) after 10 days

Deutscher Wetterdienst
Wetter und Klima aus einer Hand



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



Absolute horizontal wind speed (m/s)

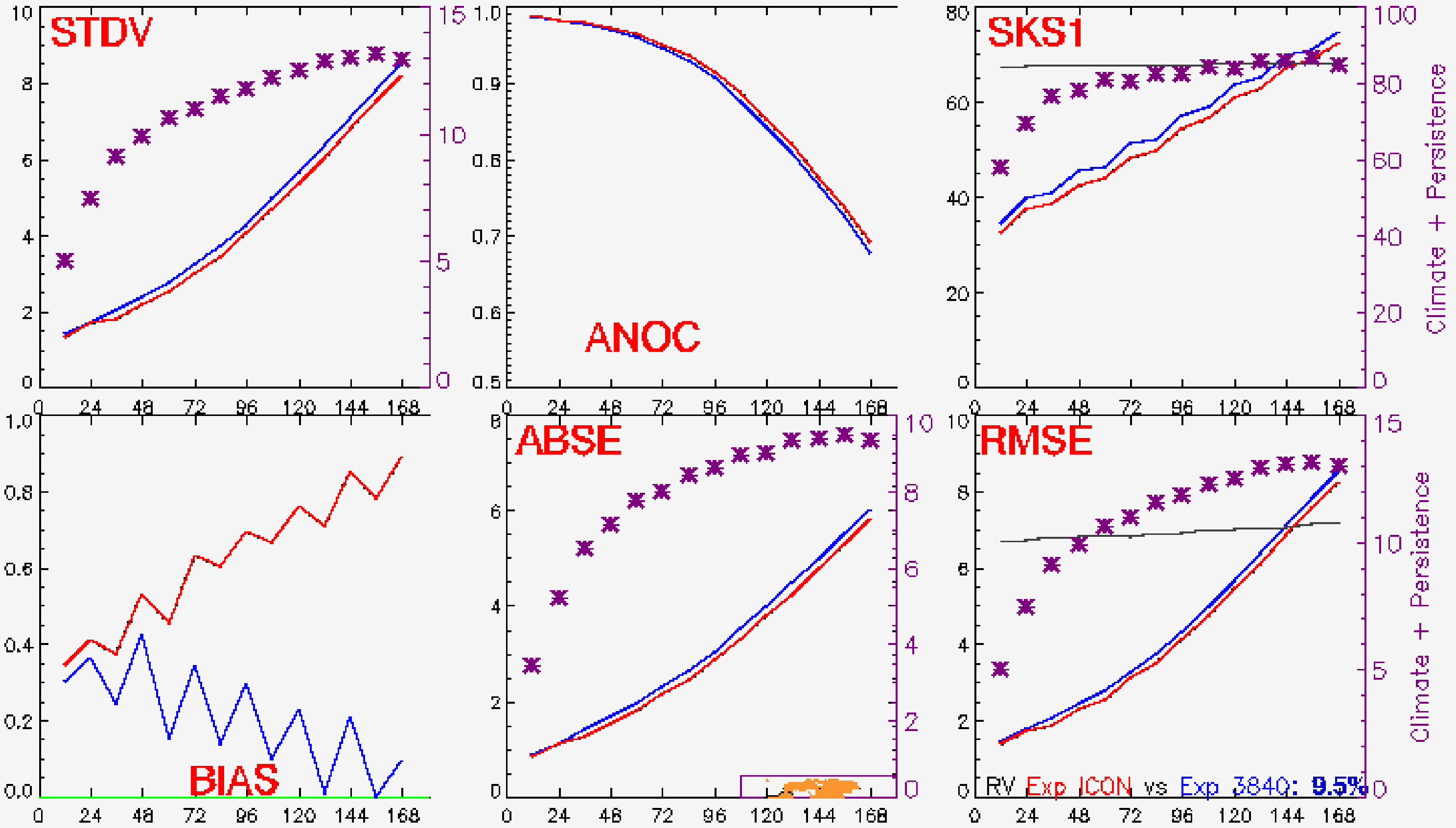
Left: single domain, 56 km; right: two-way nesting, 56 km / 28 km

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**
- **Physics package: RRTM with Köhler cloud cover scheme, COSMO-EU microphysics of v4.24, Tiedtke-Bechtold convection, COSMO-EU turbulence scheme with minimum vertical diffusion coefficient of 0.2 m²/s, retuning of SSO scheme with respect to GME settings**

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

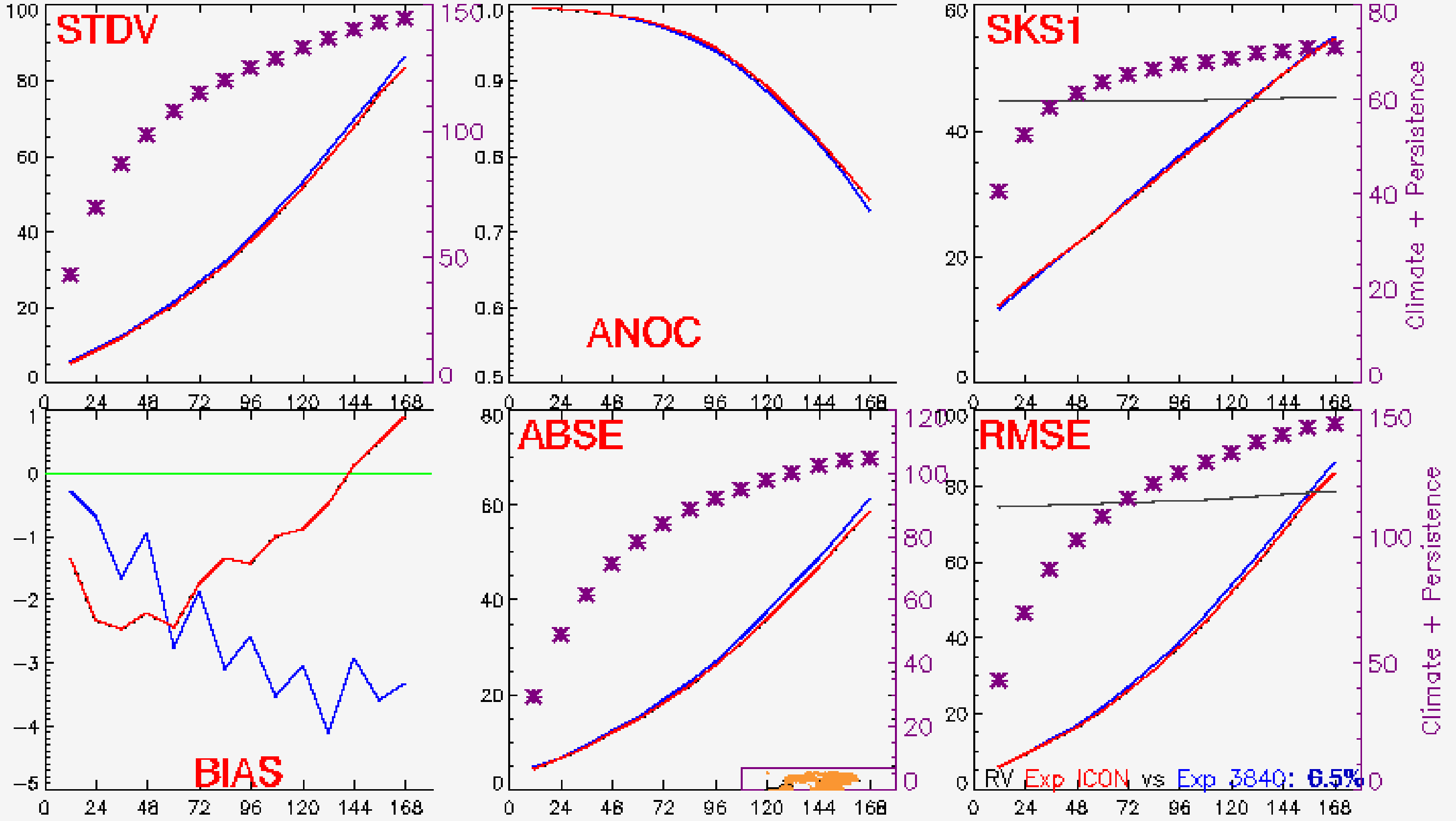
blue: GME 40 km with IFS analysis, red: ICON 40 km with IFS analysis



Verifikation der Vorhersagen vom 01.01.2012 00UTC bis 31.01.2012 00UTC Experiment ICON, Experiment 3840, Persistenz, Linien
Parameter: Bodendruck, Gebiet: NH

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

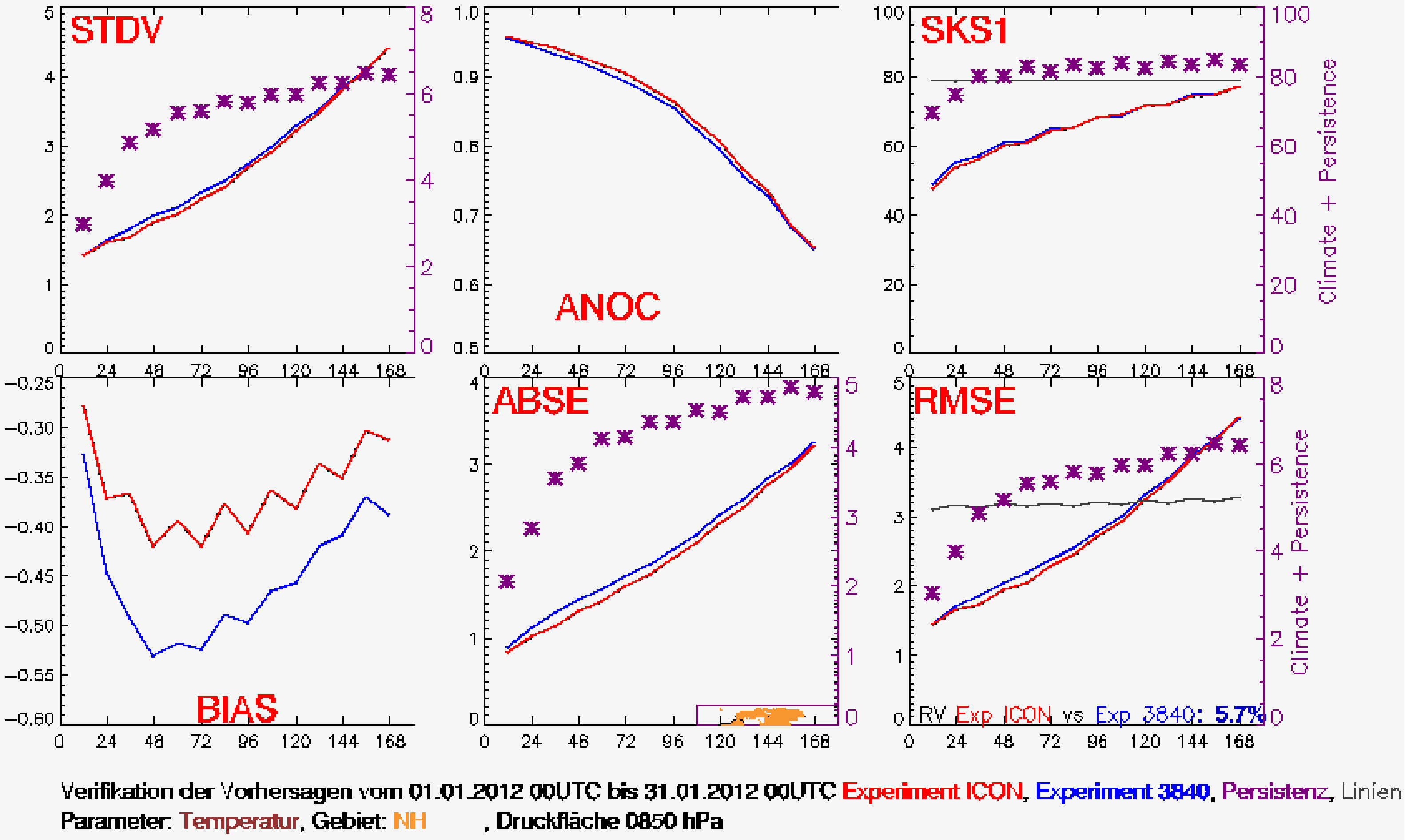
blue: GME 40 km with IFS analysis, red: ICON 40 km with IFS analysis



Verifikation der Vorhersagen vom 01.01.2012 00UTC bis 31.01.2012 00UTC Experiment ICON, Experiment 3840, Persistenz, Linien
Parameter: Geopotential, Gebiet: NH , Druckfläche 0500 hPa

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

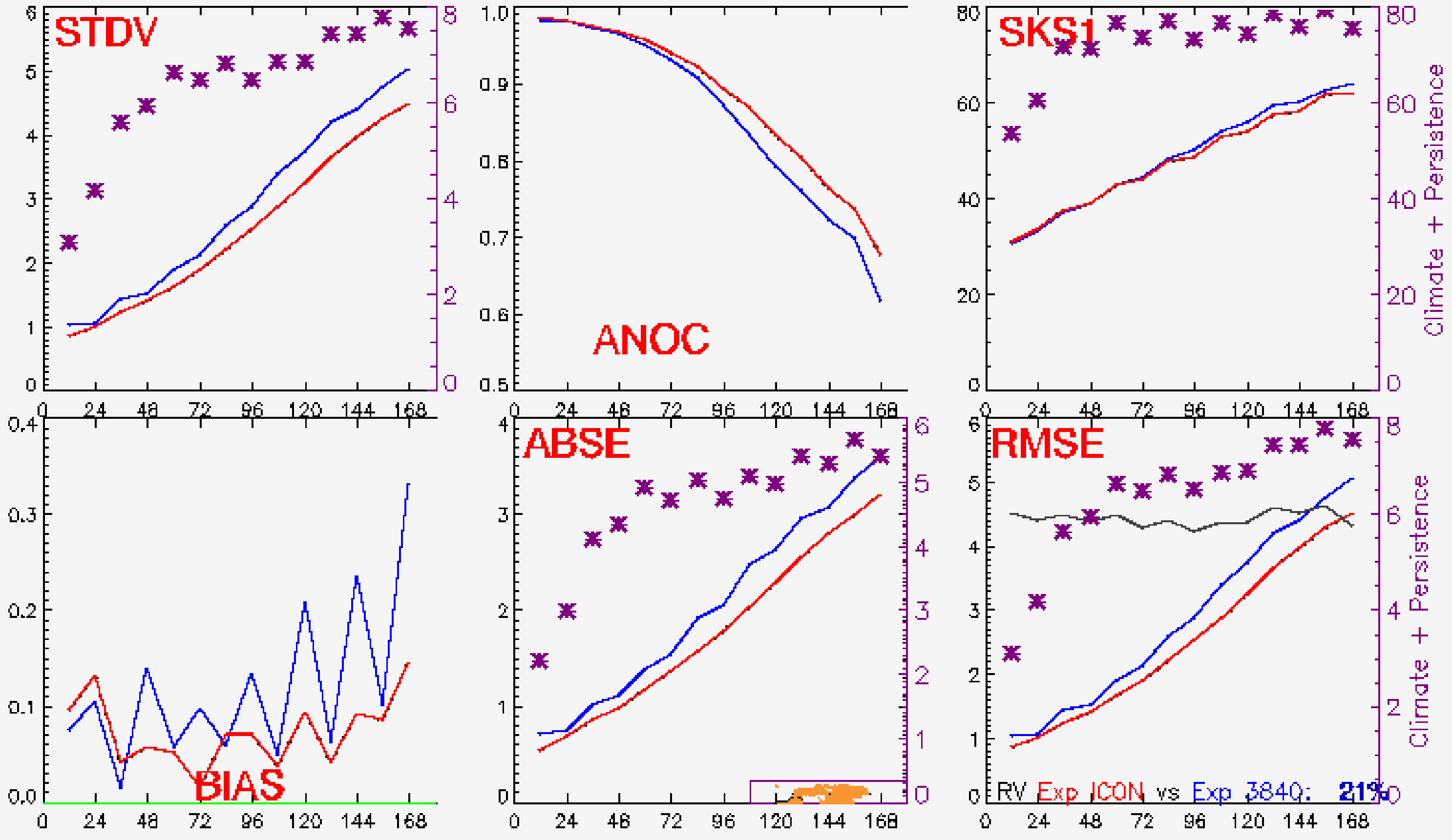
blue: GME 40 km with IFS analysis, red: ICON 40 km with IFS analysis



Verifikation der Vorhersagen vom 01.01.2012 00UTC bis 31.01.2012 00UTC **Experiment ICON**, **Experiment 3840**, **Persistenz**, Linien
Parameter: Temperatur, Gebiet: NH , Druckfläche 0850 hPa

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

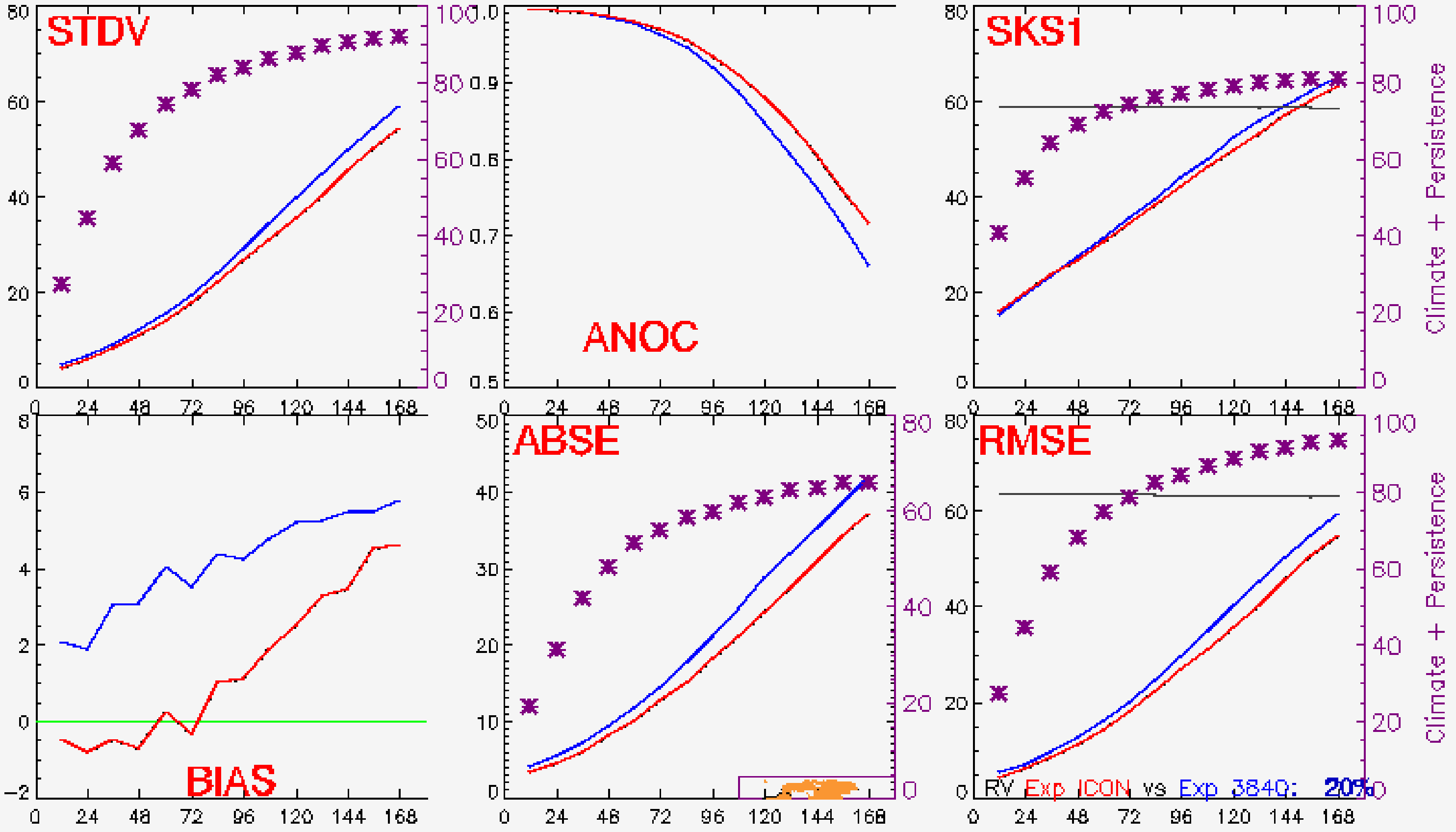
blue: GME 40 km with IFS analysis, red: ICON 40 km with IFS analysis



Verifikation der Vorhersagen vom 01.06.2012 00UTC bis 30.06.2012 00UTC Experiment ICON, Experiment 3840, Persistenz, Linien
Parameter: Bodendruck, Gebiet: NH

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

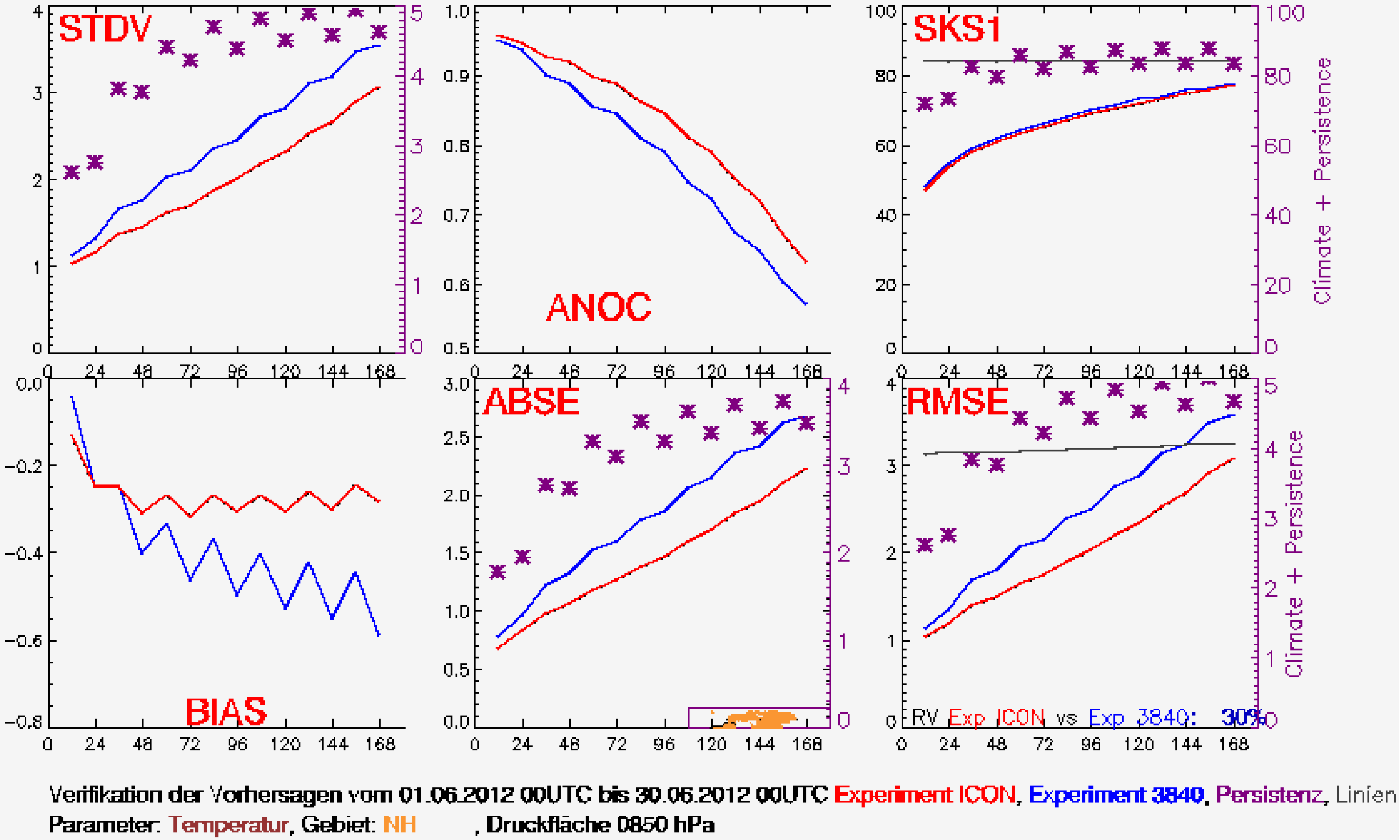
blue: GME 40 km with IFS analysis, red: ICON 40 km with IFS analysis



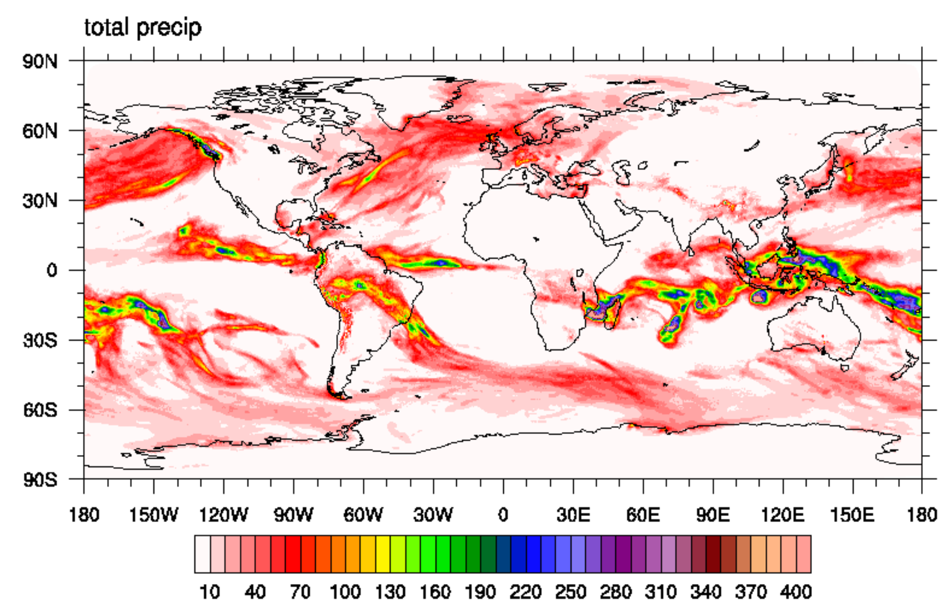
Verifikation der Vorhersagen vom 01.06.2012 00UTC bis 30.06.2012 00UTC **Experiment ICON**, **Experiment 3840**, **Persistenz**, Linien
Parameter: **Geopotential**, Gebiet: **NH** , Druckfläche 0500 hPa

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

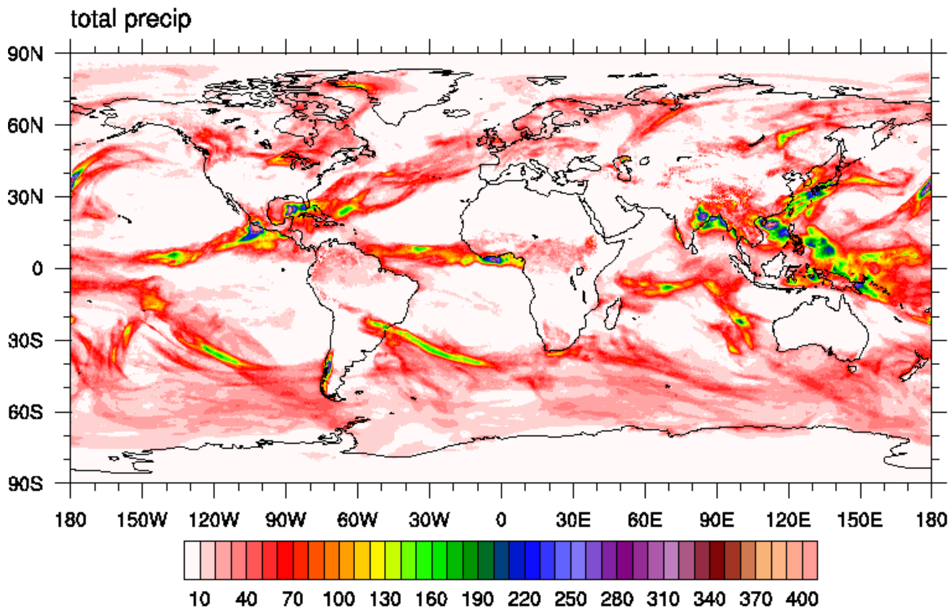
blue: GME 40 km with IFS analysis, red: ICON 40 km with IFS analysis



Two (arbitrarily chosen) examples of 7-day accumulated precipitation



2 Jan 2012, 00 UTC + 168 h



18 Jun 2012, 00 UTC + 168 h

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**
- **Q1/2014-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 risk: 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, …**