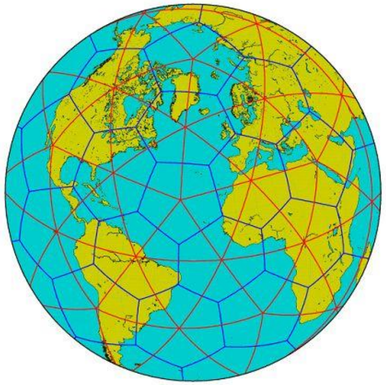
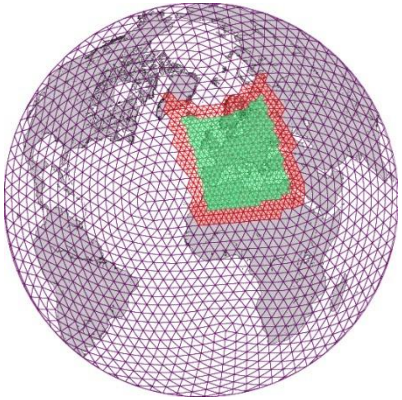


ICON



The next-generation global model for weather prediction and climate modeling of DWD and MPI-M

2nd IS-ENES workshop on HPC for climate models

Günther Zängl

31.01.2013

Outline

- Introduction: Main goals of the ICON project
- The dynamical core and physics-dynamics coupling
- Selected results: from idealized tests to NWP applications
- Summary

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.
- Later in this decade: participate in the seasonal prediction project EURO-SIP

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

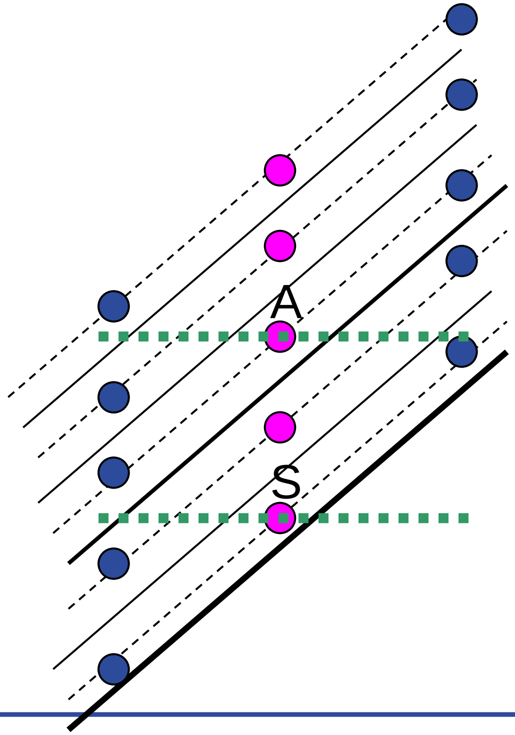
Numerical implementation

- **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-dynamics coupling

- **Fast-physics processes: incremental update in the sequence: saturation adjustment, turbulence, cloud microphysics, saturation adjustment, surface coupling**
- **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**

Physics parameterizations

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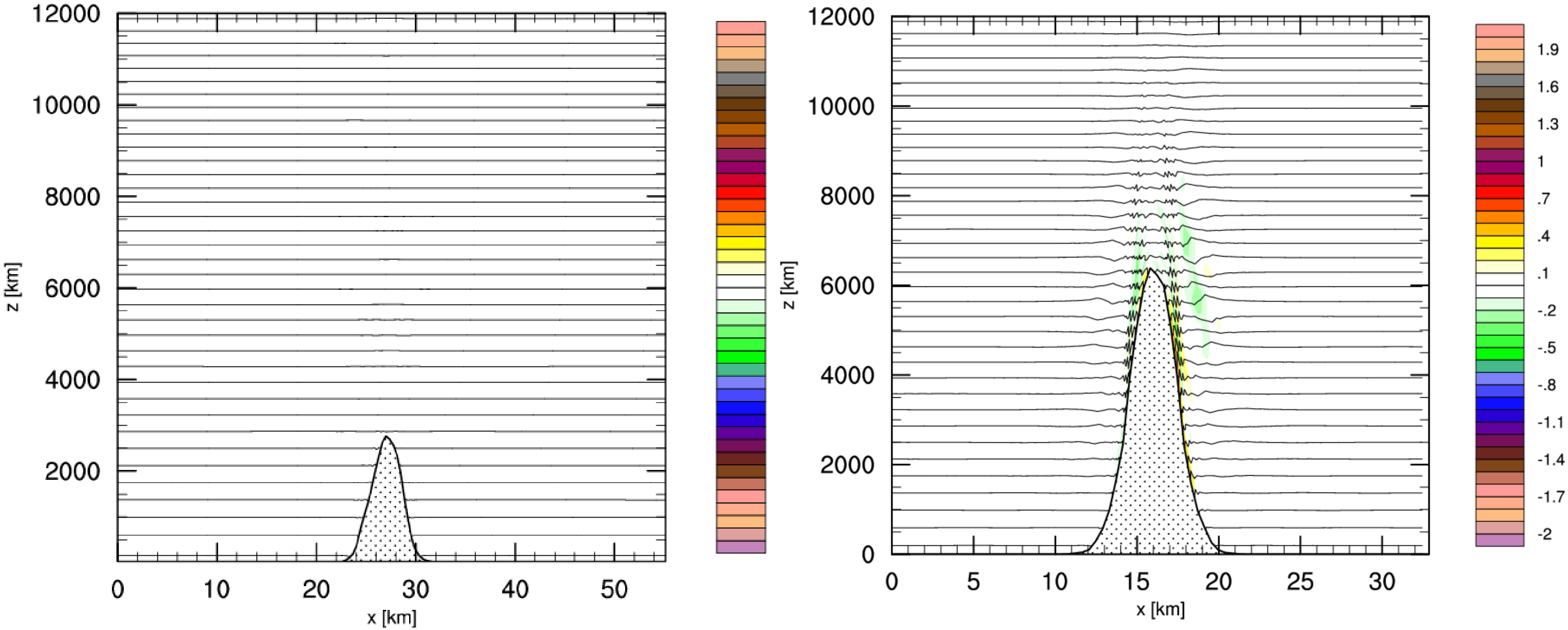
Deutscher Wetterdienst
Wetter und Klima aus einer Hand

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

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

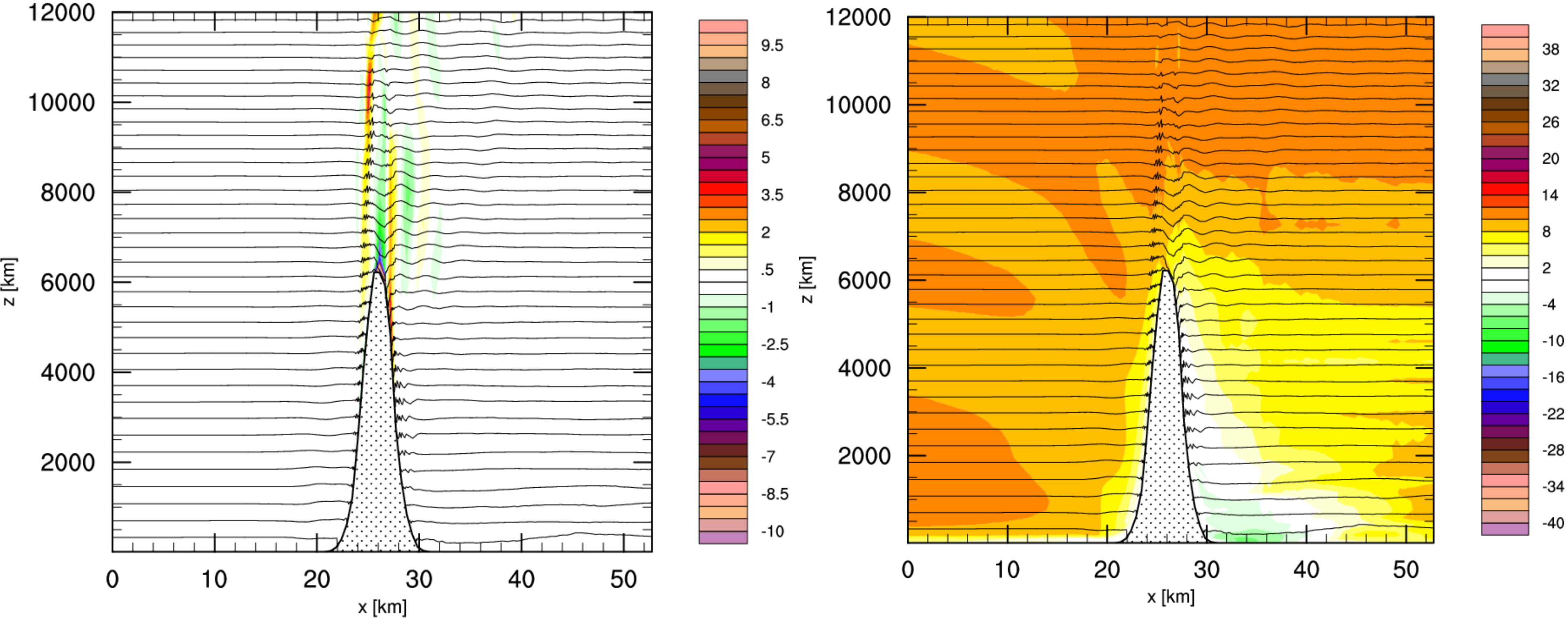


vertical wind speed (m/s), potential temperature (contour interval 4 K)

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

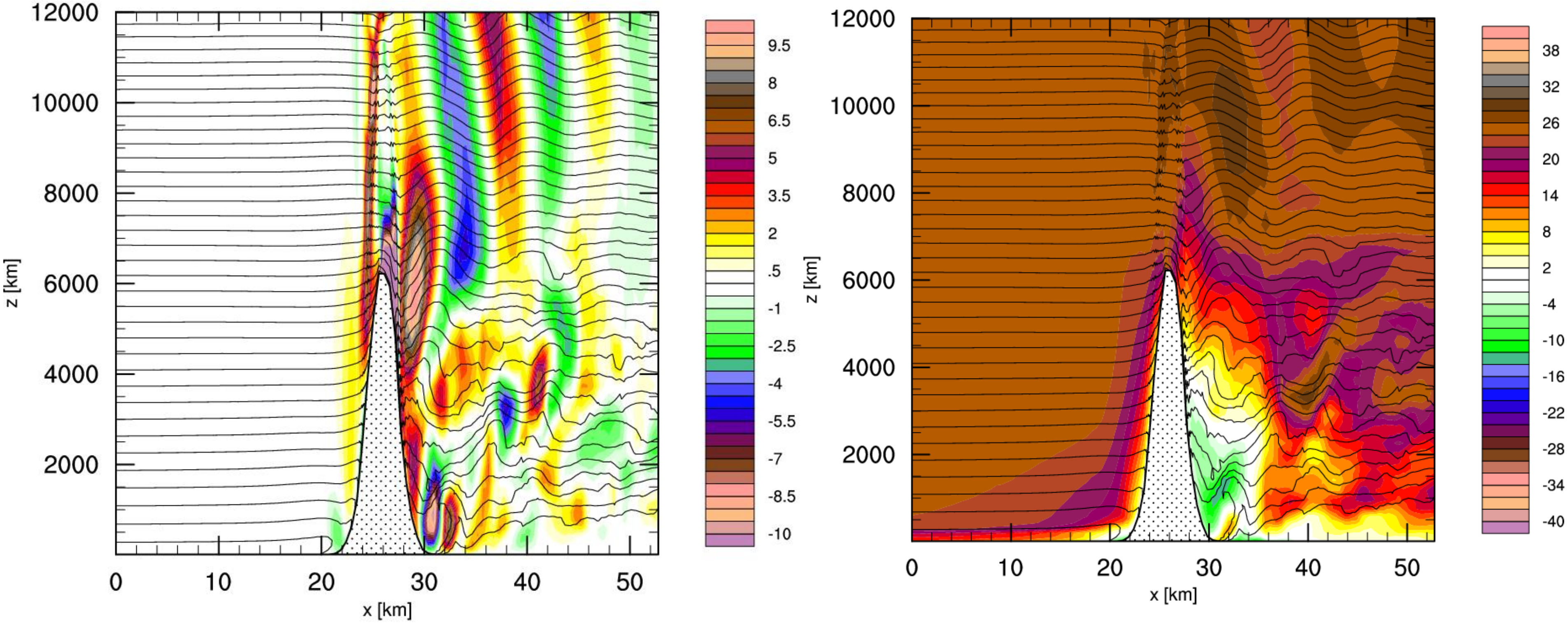


vertical (left) / horizontal (right) wind speed (m/s), potential temperature (contour interval 4 K)

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°)

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

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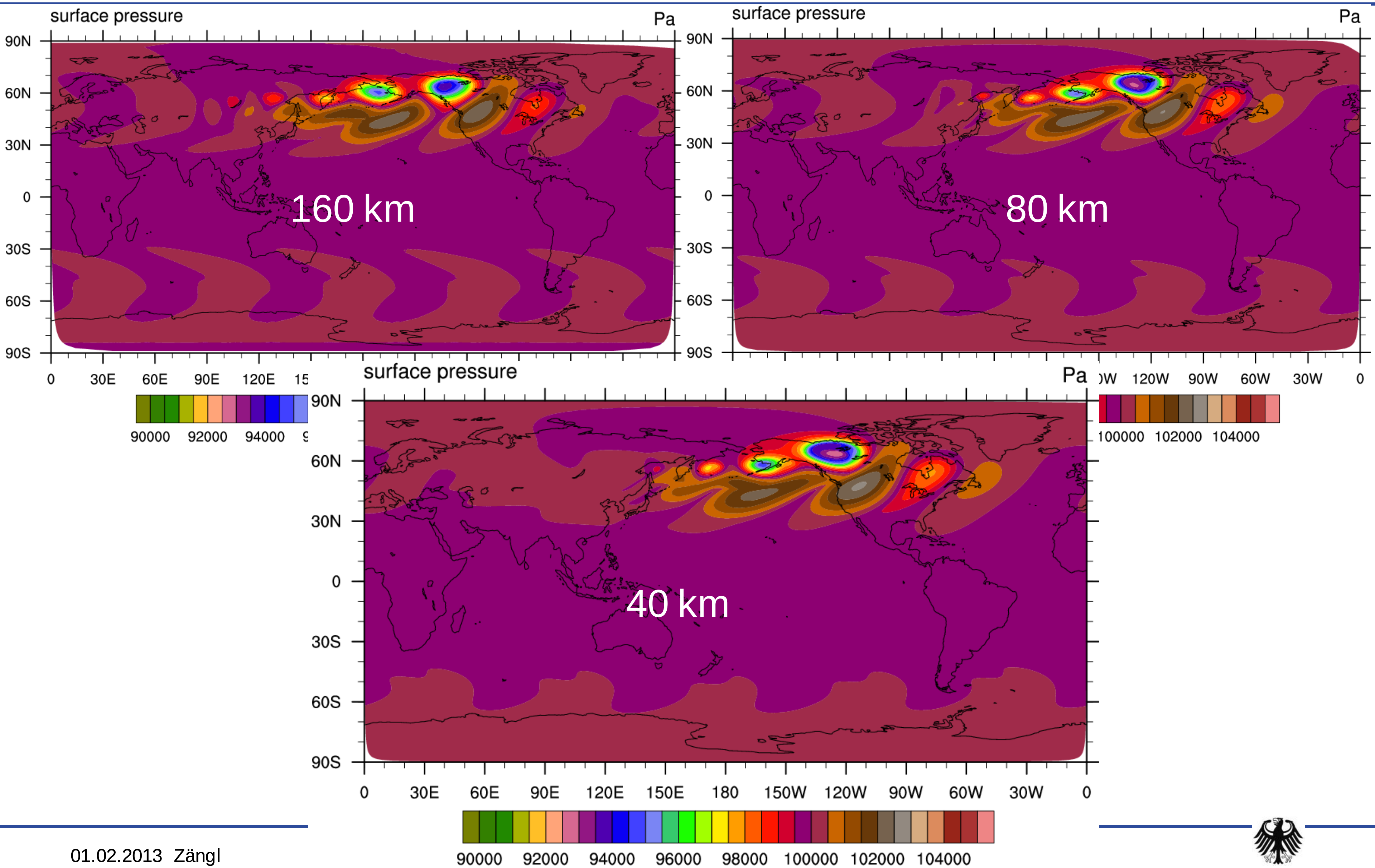

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Jablonowski-Wiliamson test, surface pressure (Pa) after 10 days

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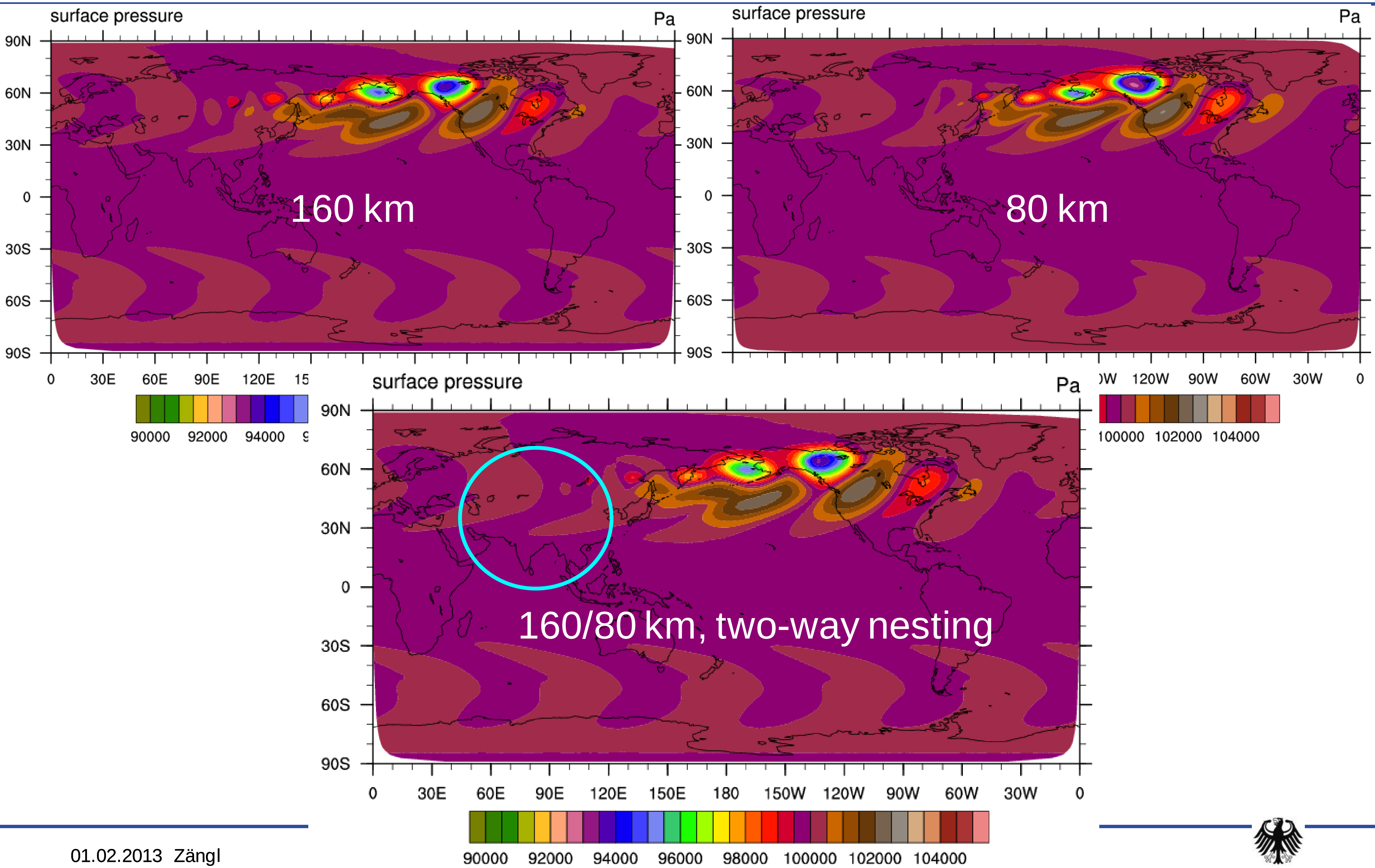
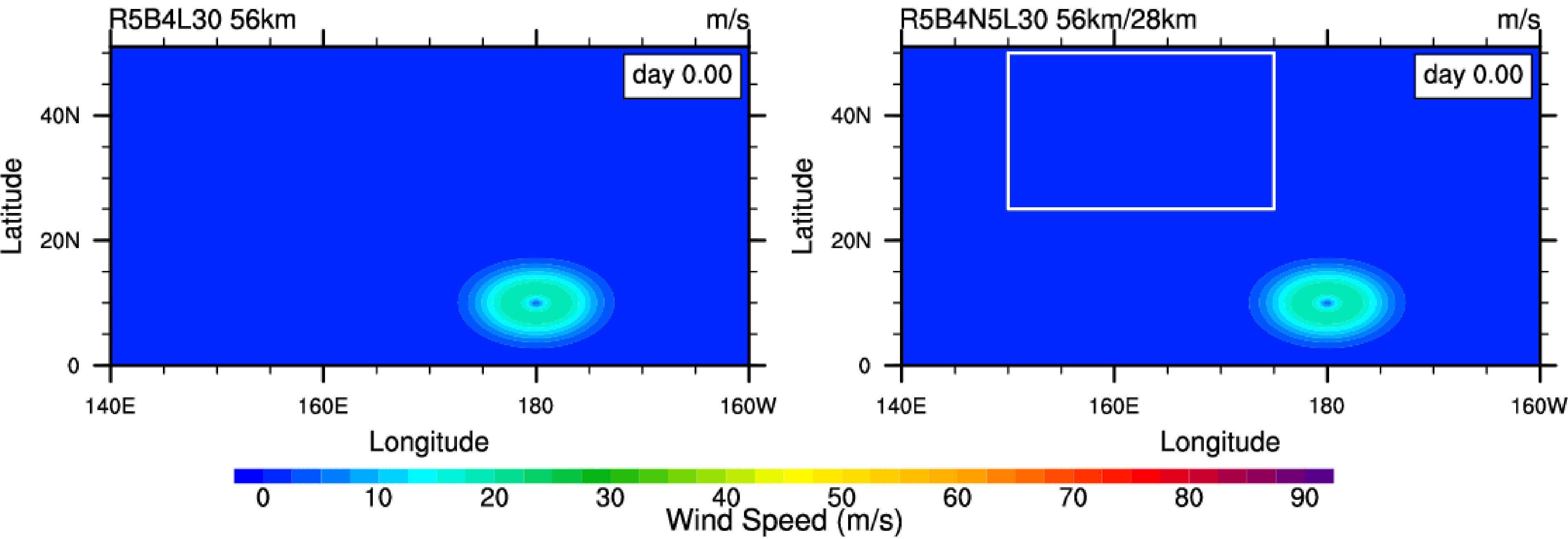


DCMIP tropical cyclone test with NWP physics schemes, evolution over 12 days



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**

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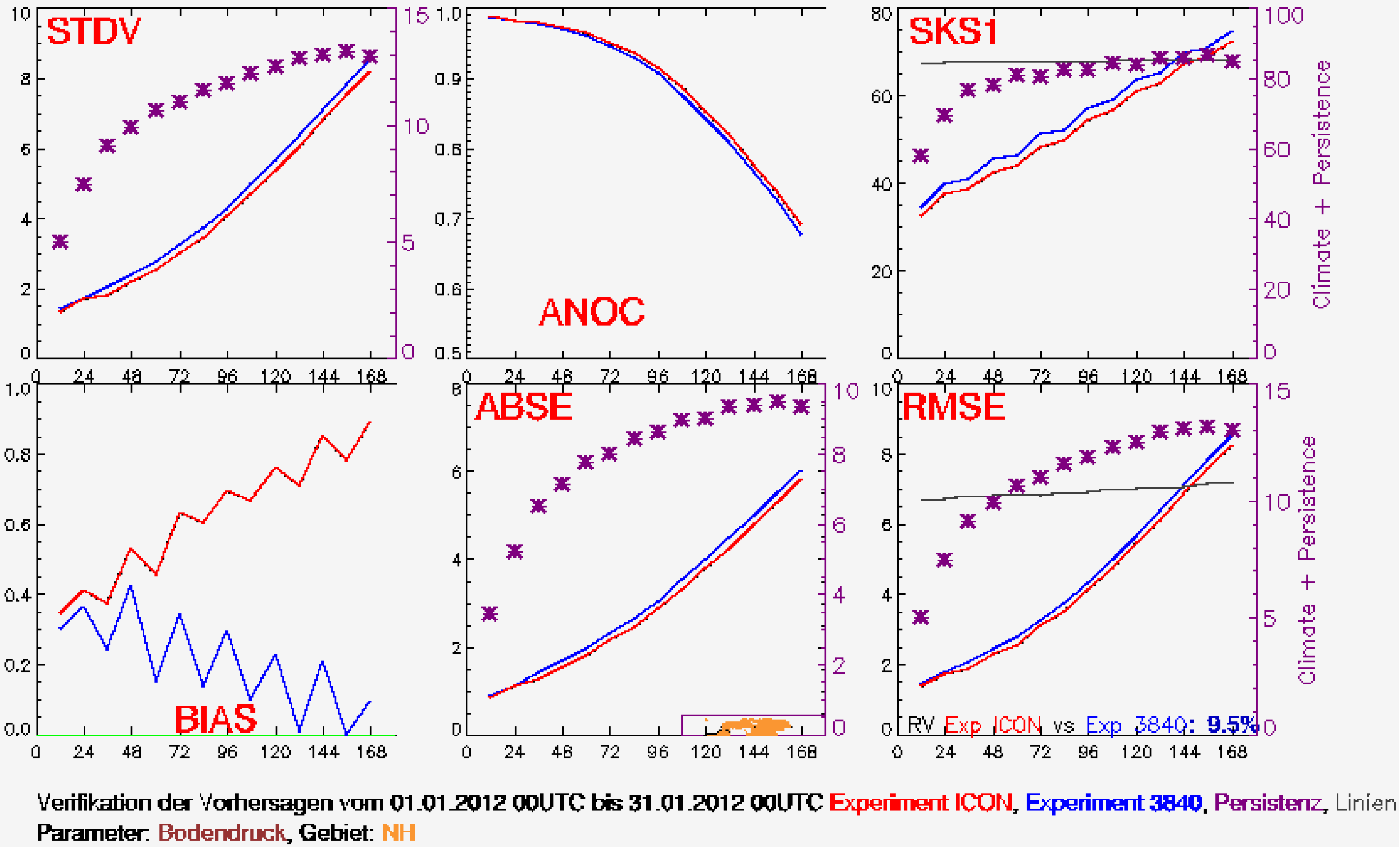
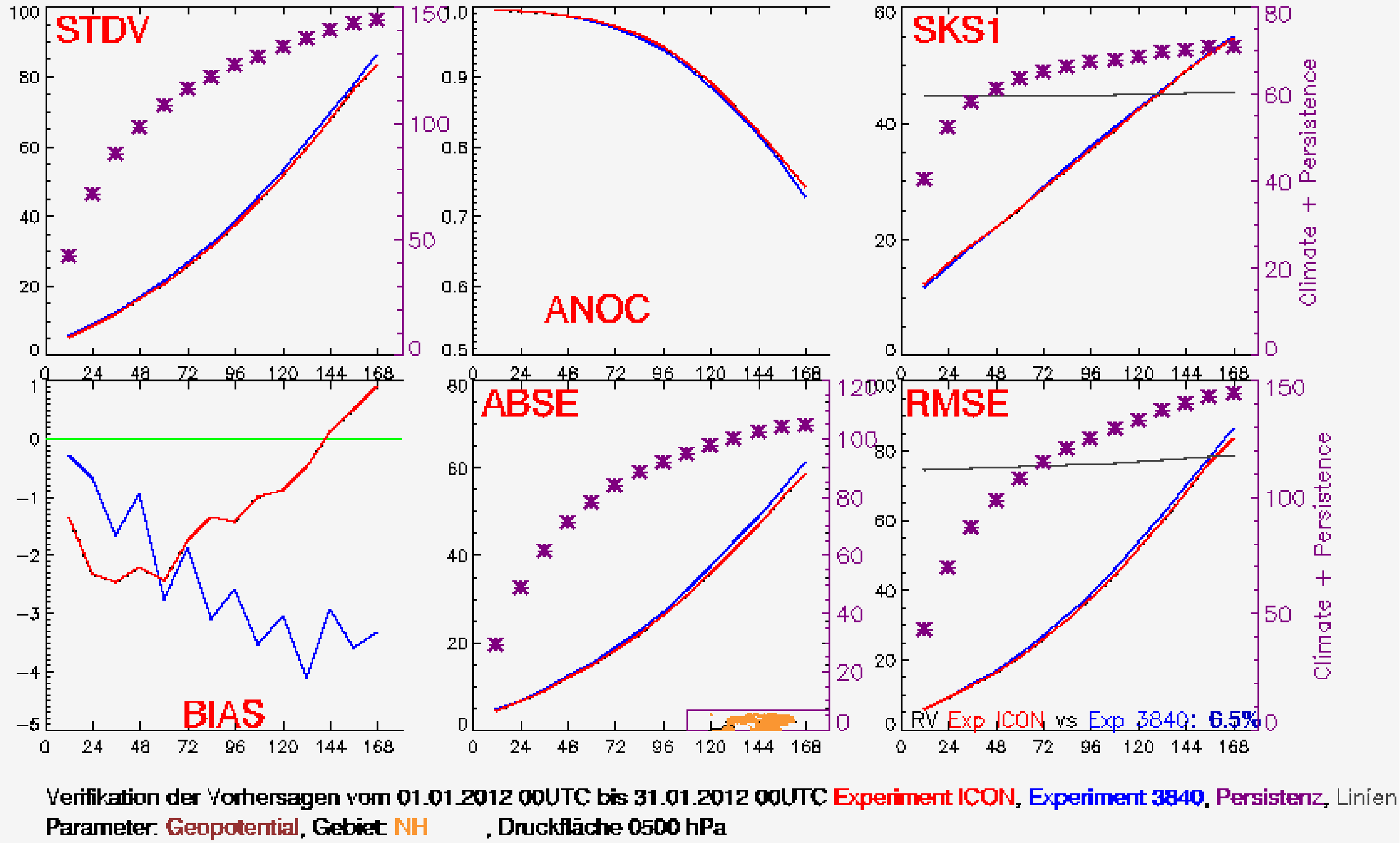
WMO standard verification against IFS analysis: sea-level pressure, NH

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



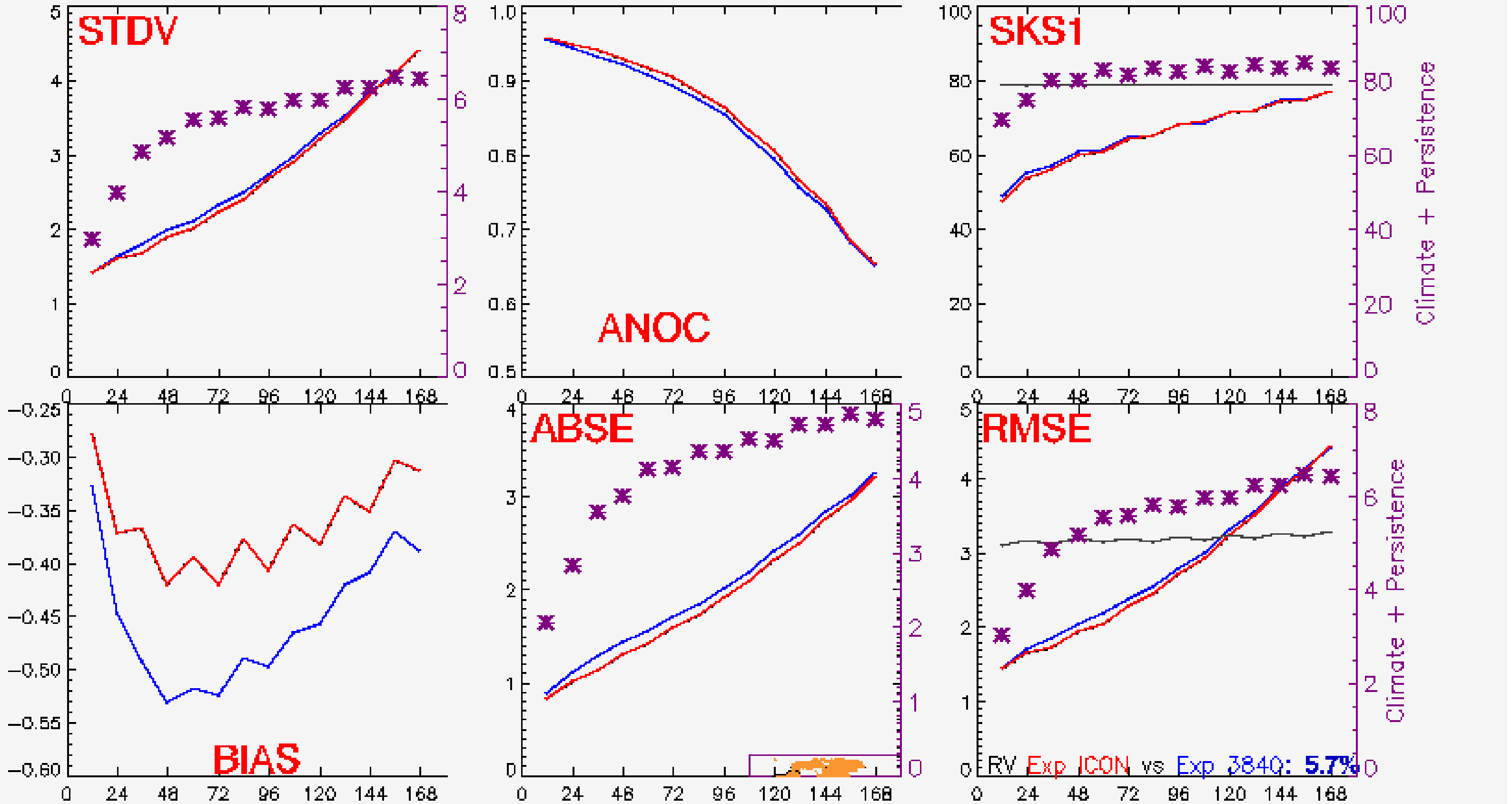
WMO standard verification against IFS analysis: 500 hPa geopotential, NH

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



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

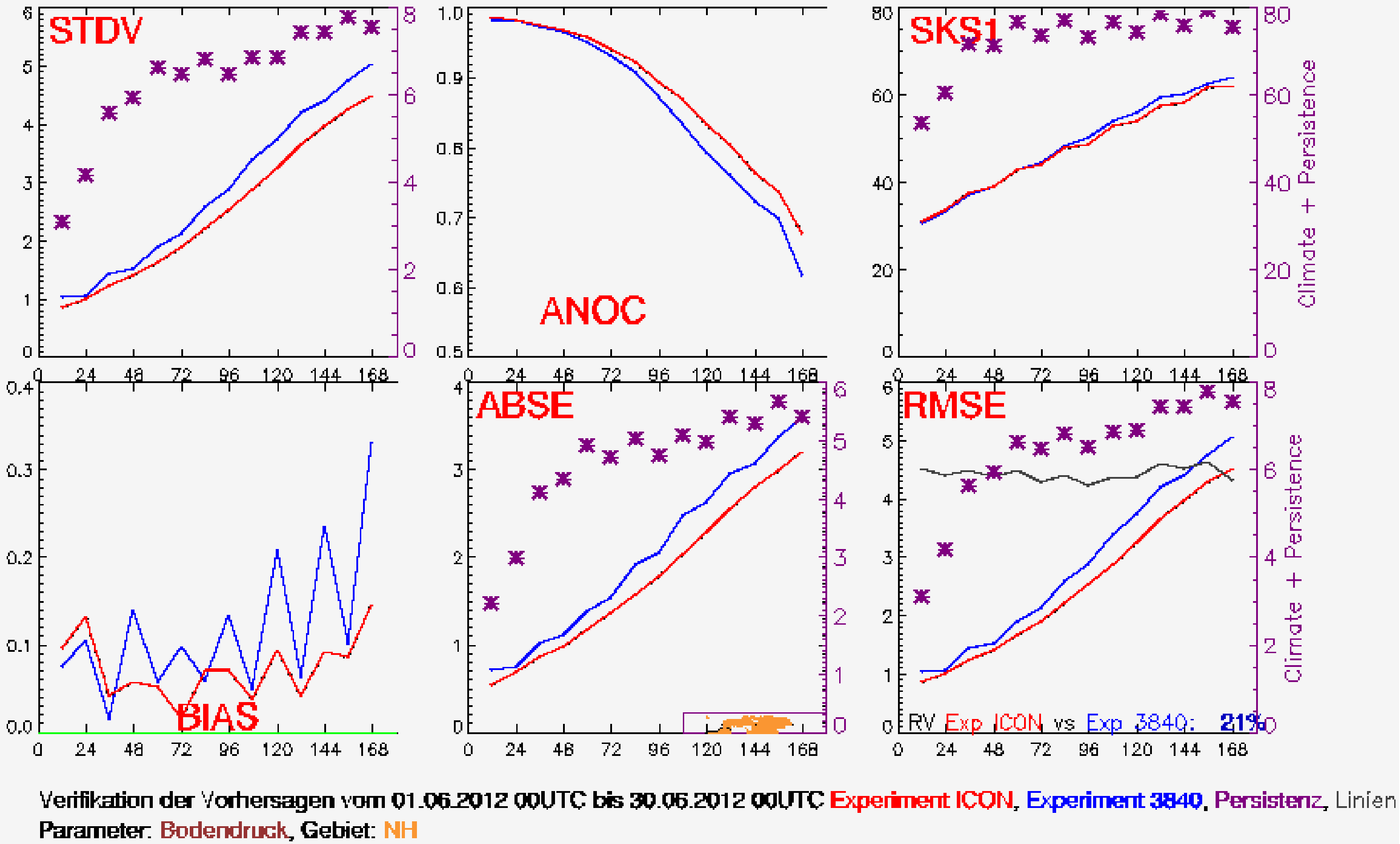
blue: GME 40 km with IFS analysis, red: ICON 40 km with IFS analysis



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



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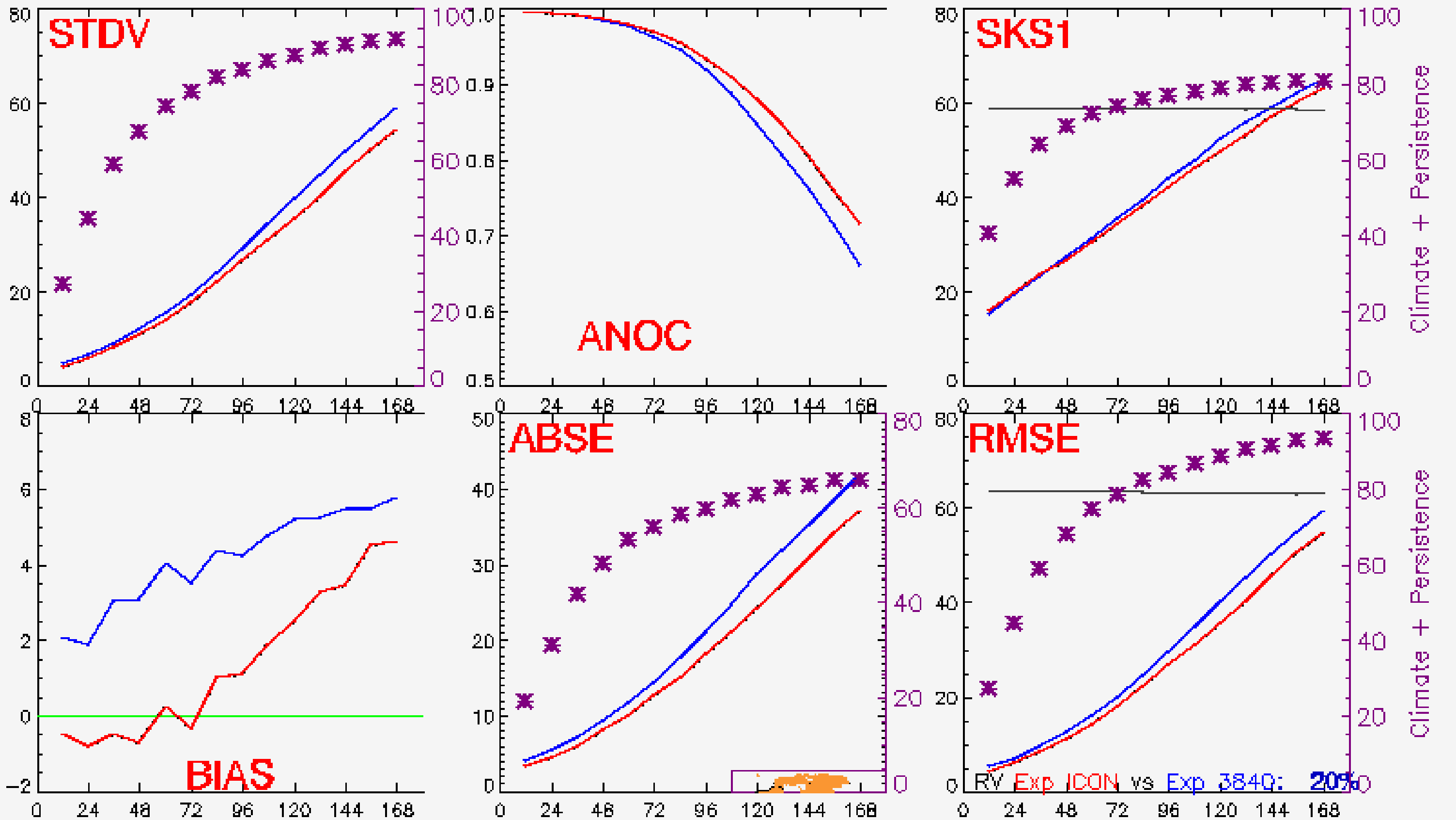
Wetter und Klima aus einer Hand

DWD

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

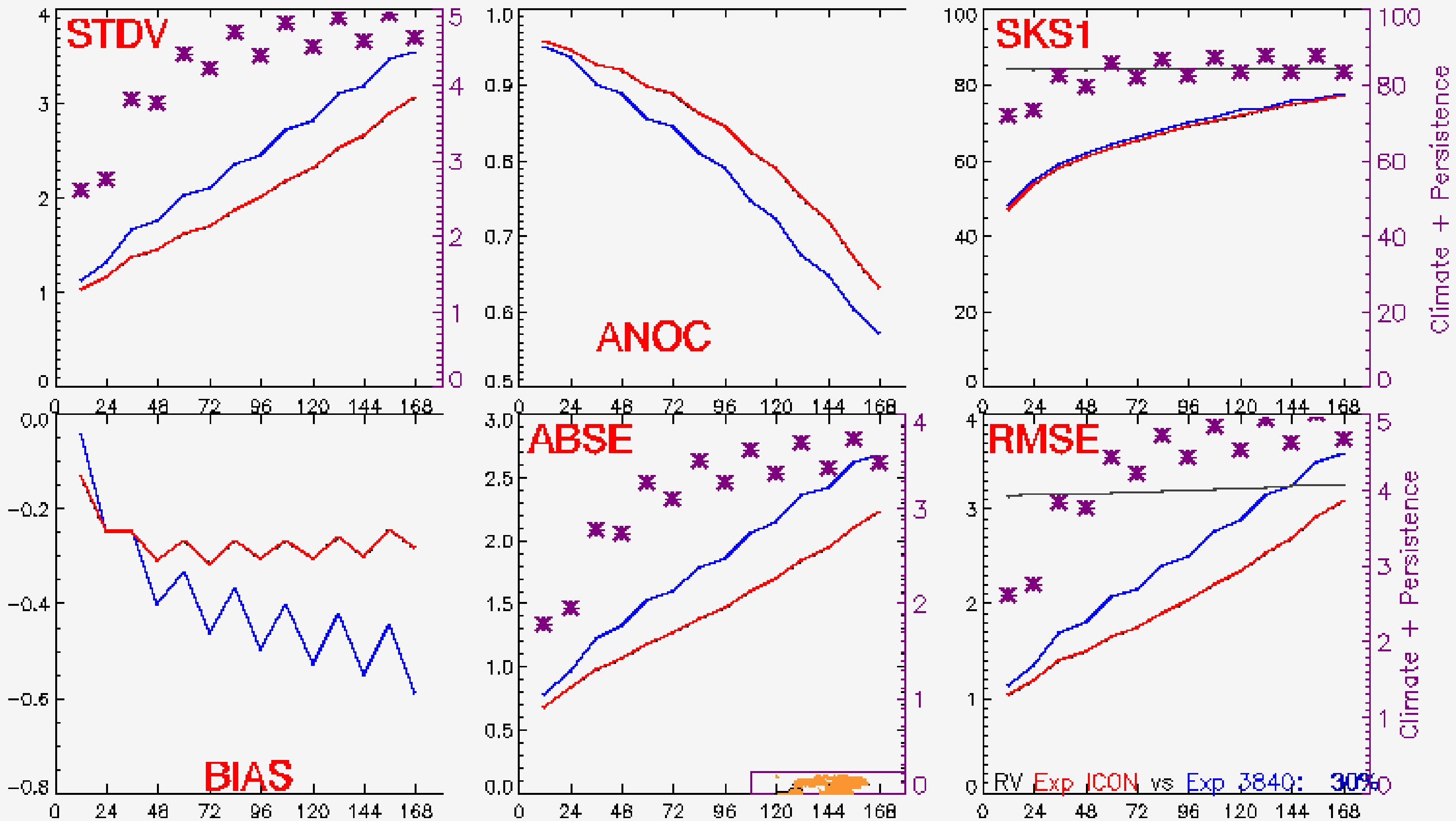
blue: GME 40 km with IFS analysis, red: ICON 40 km with IFS analysis



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



Verifikation der Vorhersagen vom 01.06.2012 00UTC bis 30.06.2012 00UTC Experiment ICON, Experiment 3840, Persistenz, Linien
Parameter: Temperatur, Gebiet: NH , Druckfläche 0850 hPa

Summary

- **ICON is prepared for applications at a wide range of complexity, reaching from idealized dynamical core tests to real-case (NWP or climate prediction) applications**
- **The dynamical core of ICON combines efficiency, high numerical stability and improved conservation properties and has been tested for a scale range of three orders of magnitude**
- **The two-way nesting offers high flexibility, supports vertical nesting and a limited-area mode, and induces very weak numerical disturbances**