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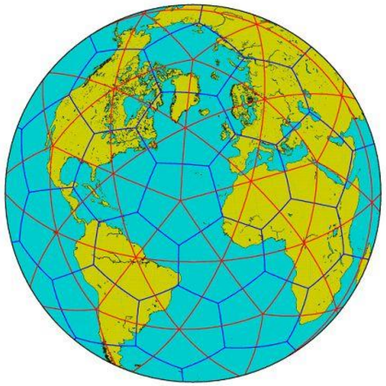
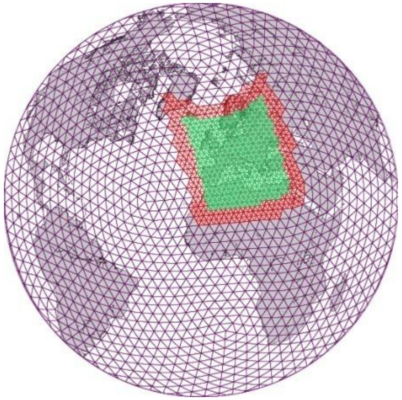
Deutscher Wetterdienst
Wetter und Klima aus einer Hand



ICON



The Icosahedral Nonhydrostatic model on its way towards operational NWP

Günther Zängl, on behalf of the ICON development team

COSMO General Meeting, Eretria, 09.09.2014

Outline

- Introduction: Main goals of the ICON project
- Overview of the preoperational NWP system based on ICON
- Model scores in various forecasting configurations
- Scalability
- Conclusions

Joint development project between DWD and MPI-M (Hamburg); recently, KIT (Karlsruhe) joined for contributing the ART module

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 (global, 20 km) and COSMO-EU (regional, 7 km) 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

Model equations, dry dynamical core

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

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

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

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

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

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

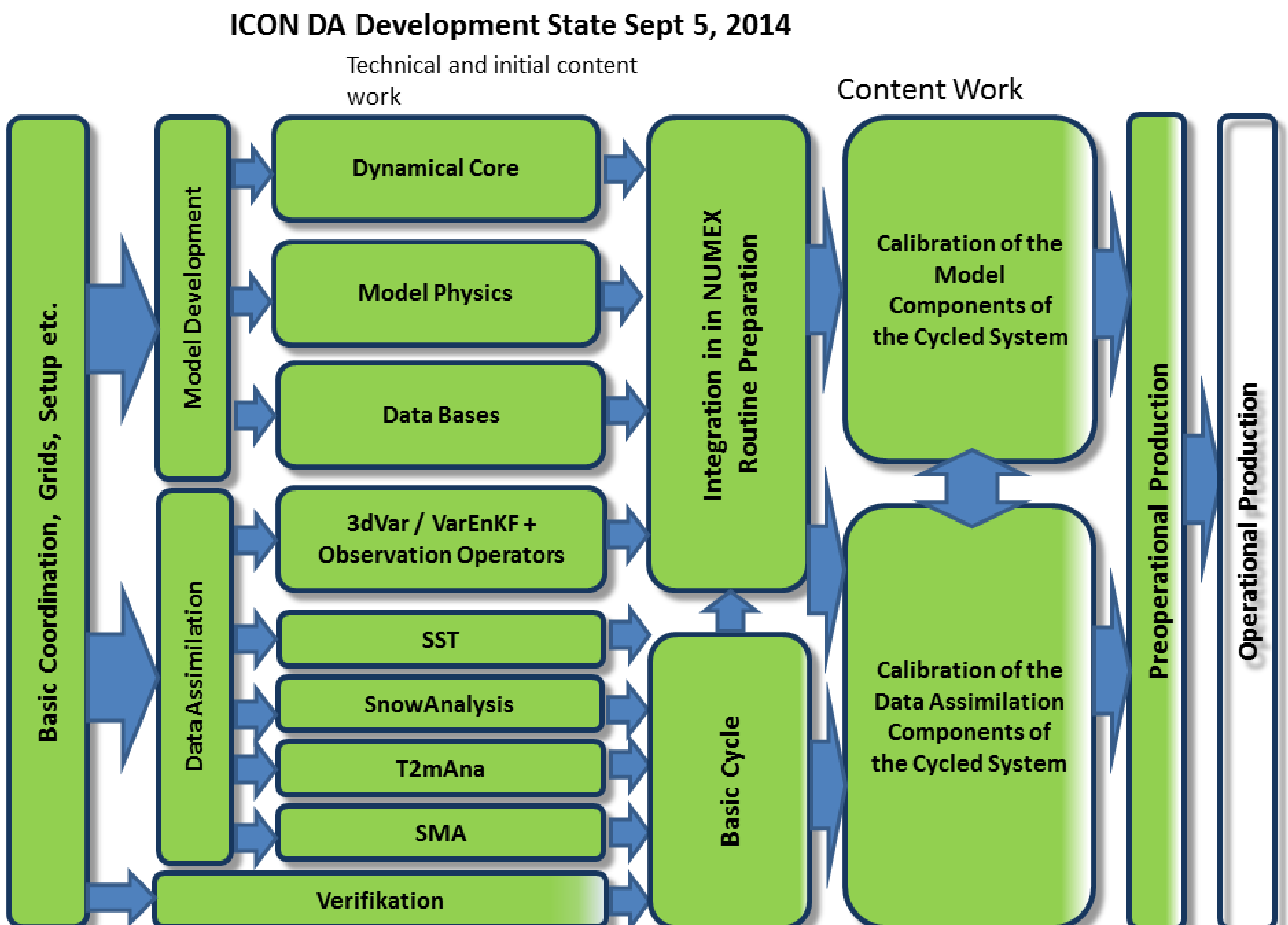
Numerical implementation

- 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
- 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
- Speedup w.r.t. GME: between ~ 2.3 (Cray XC30) and ~ 4 (NEC SX9)

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

The coupled ICON – 3D-Var forecasting system



thanks to Roland Potthast!

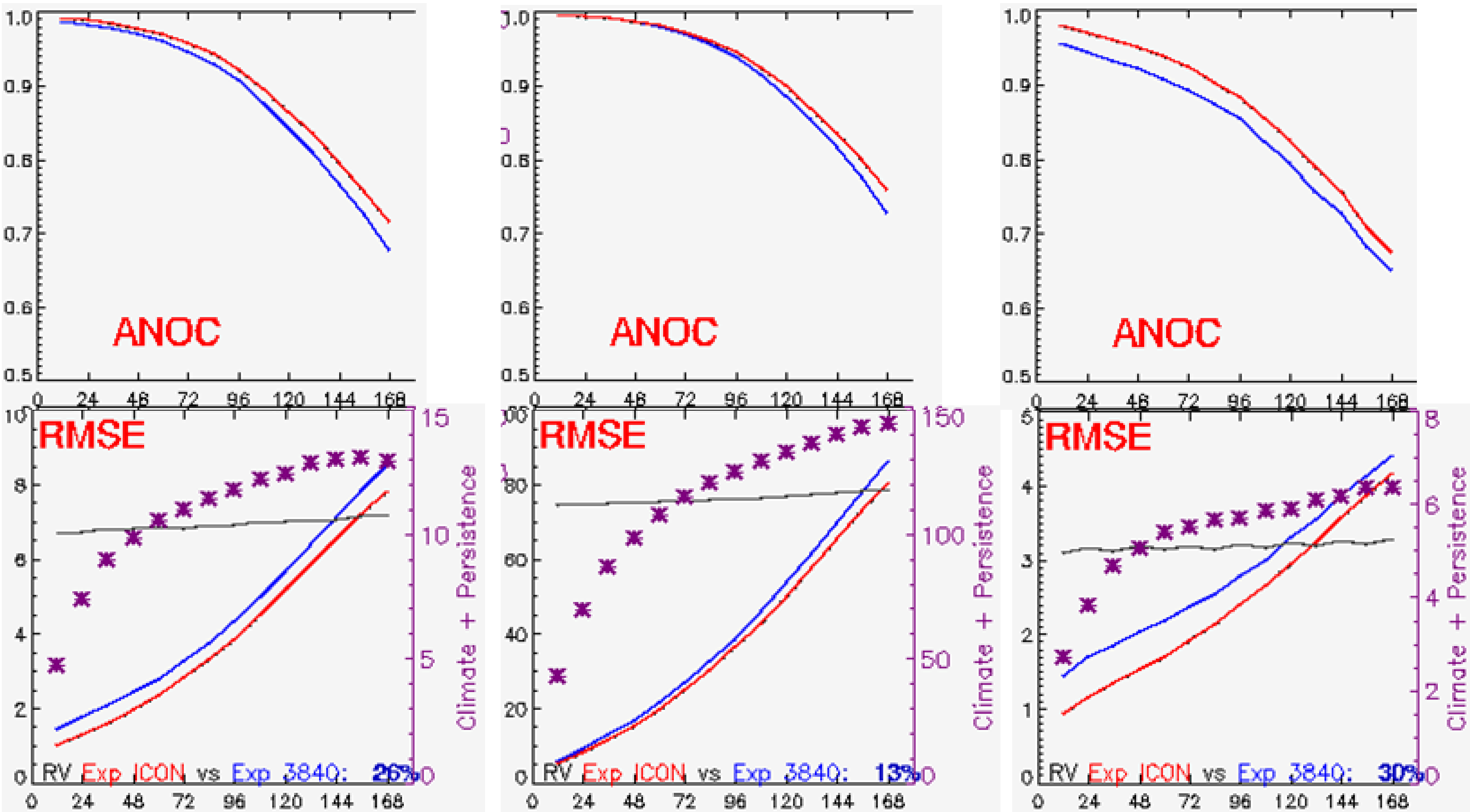
Verification results

- **Comparison 1: ICON 40 km / 90 levels with GME 40 km / 60 levels initialized with interpolated IFS analyses; WMO standard verification (1.5° lat-lon grid) against IFS analyses; January and June 2012**
- **Comparison 2: ICON 40 km / 90 levels with 3D-Var data assimilation against operational GME 20 km / 60 levels; verification against own analyses; July 2013**
- **Comparison 3: ICON parallel routine (since 12.08.2014) 13 km / 90 levels against operational GME 20 km / 60 levels; verification against radiosondes**
- **Thanks to Harald Anlauf, Uli Pflüger, 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

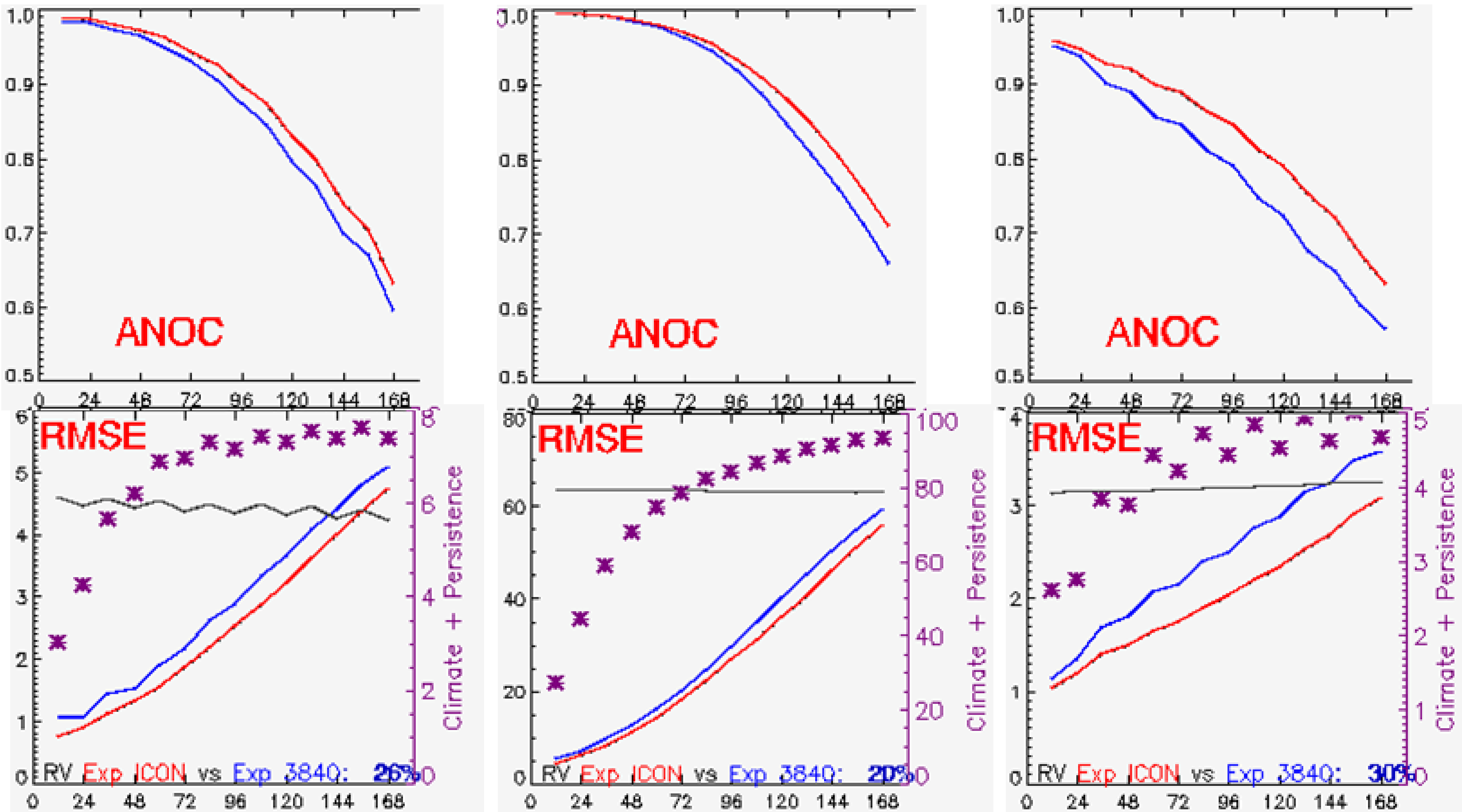
Sea-level pressure (hPa) **500-hPa geopotential (m)** **850-hPa temperature (K)**



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

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

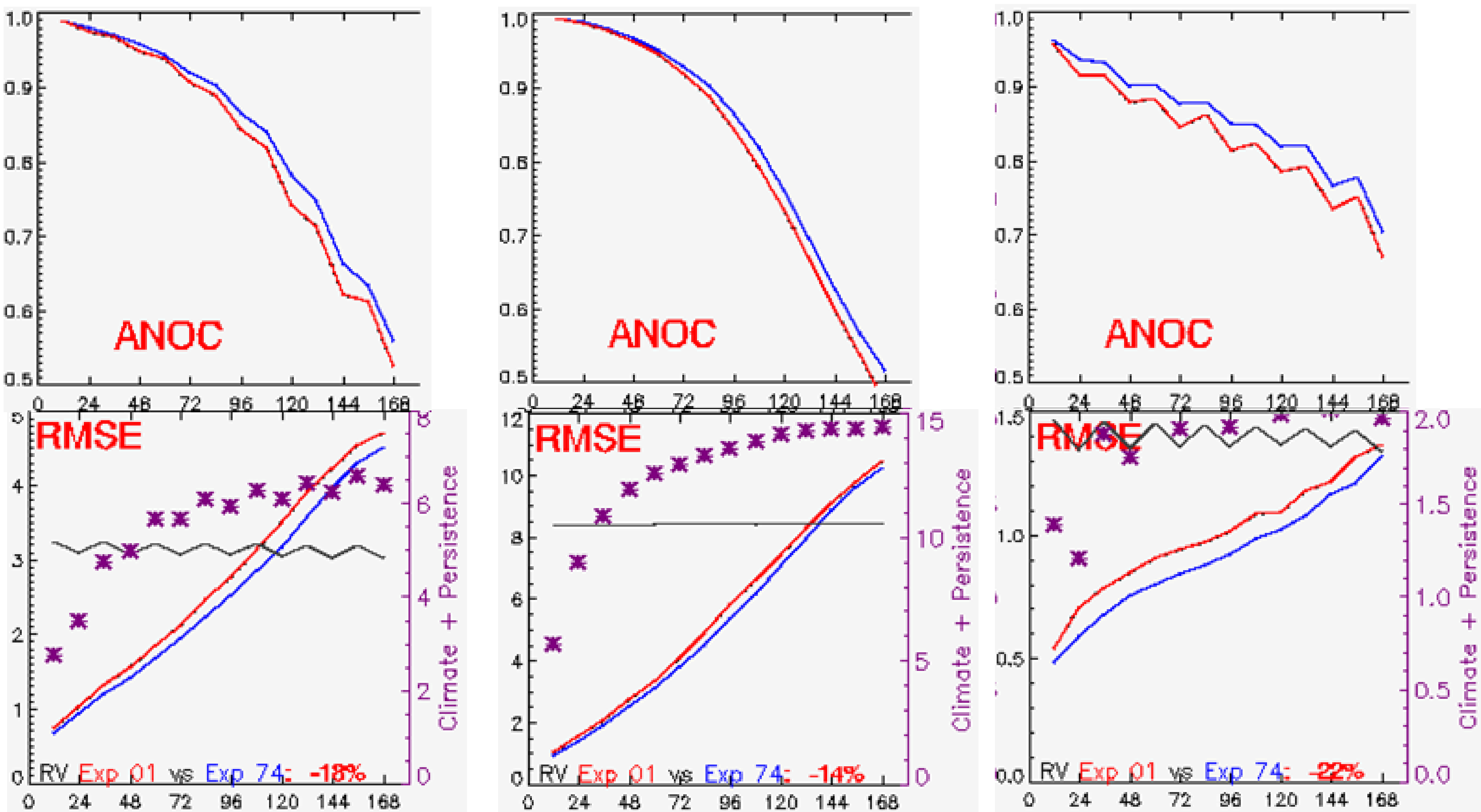
Sea-level pressure (hPa) | **500-hPa geopotential (m)** | **850-hPa temperature (K)**



WMO standard verif. against own analysis: **sea-level pressure, July 2013**

blue: ICON 40 km with 3D-Var DA, red: GME 20 km operational (3D-Var DA)

Northern hemisphere | **Southern hemisphere** | **Tropics**



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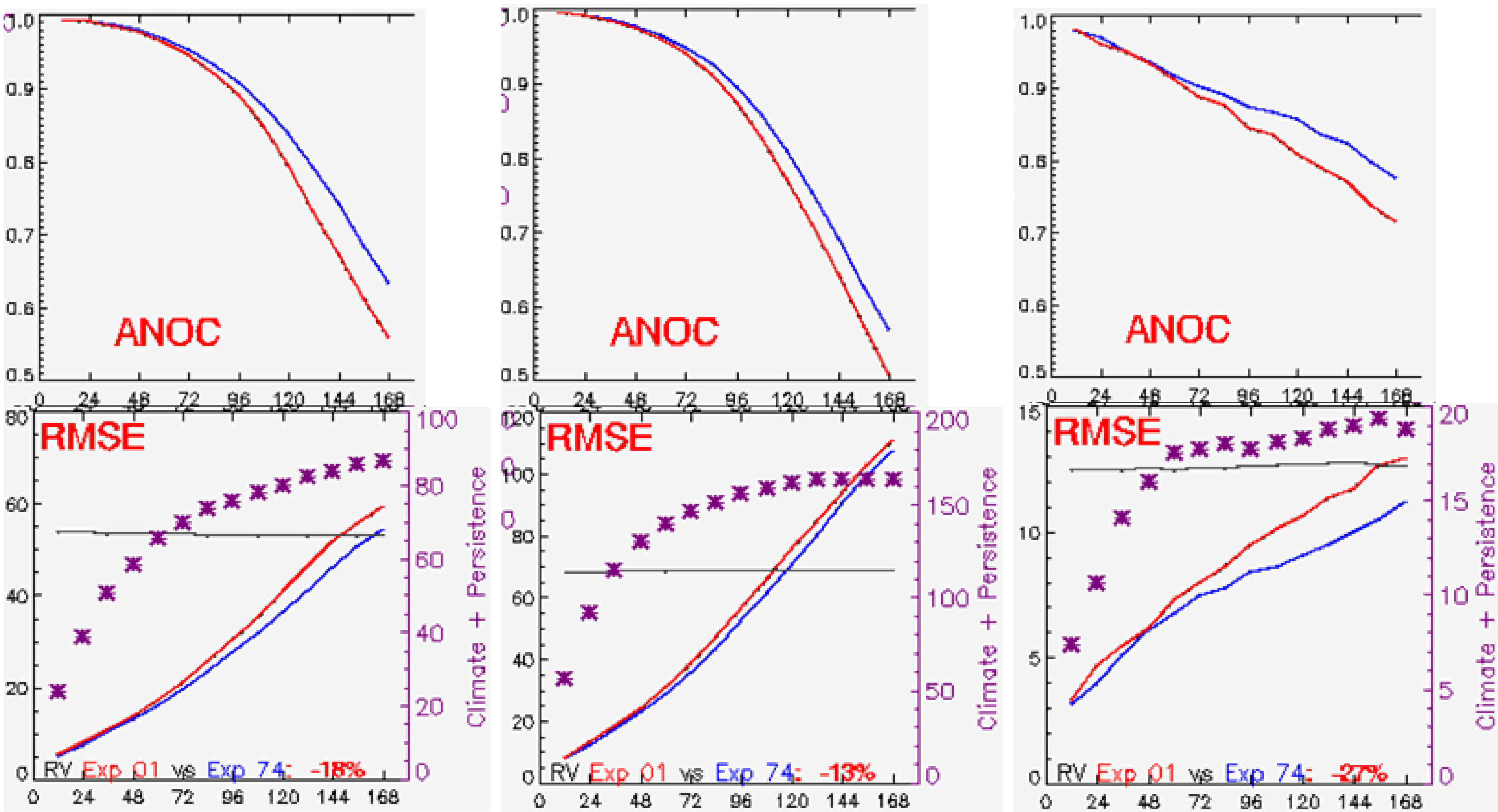
WMO standard verif. against own analysis: **500-hPa geopotential, July 2013**

blue: ICON 40 km with 3D-Var DA, red: GME 20 km operational (3D-Var DA)

Northern hemisphere **Southern hemisphere** **Tropics**



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Deutscher Wetterdienst DWD
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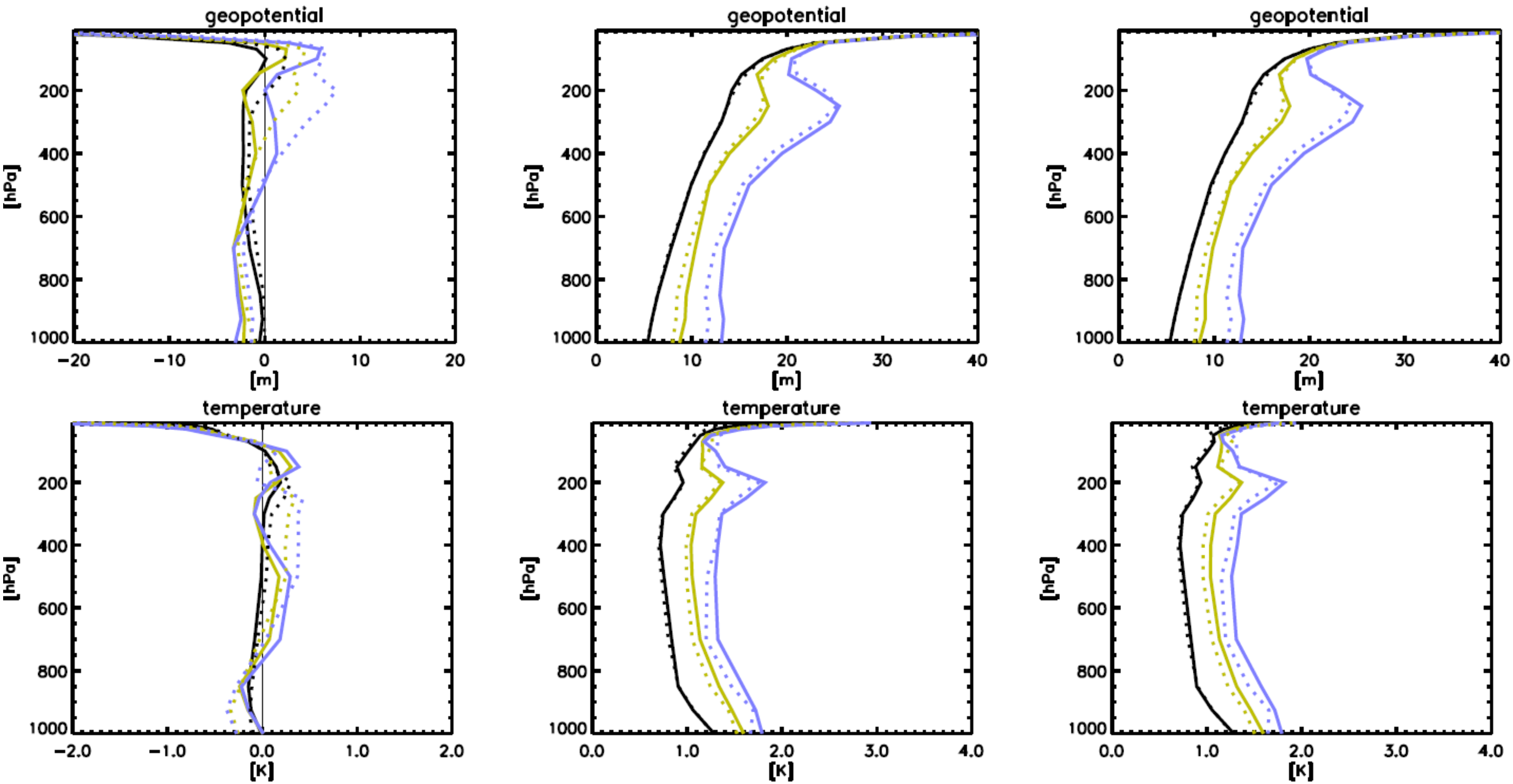
Verification against radiosondes 18.08.2014 – 31.08.2014, 00 UTC runs

solid - GME, dotted – ICON; colours: analysis, 24h-forecast, 48h-forecast; NH extratropics



Bias RMSE stdev

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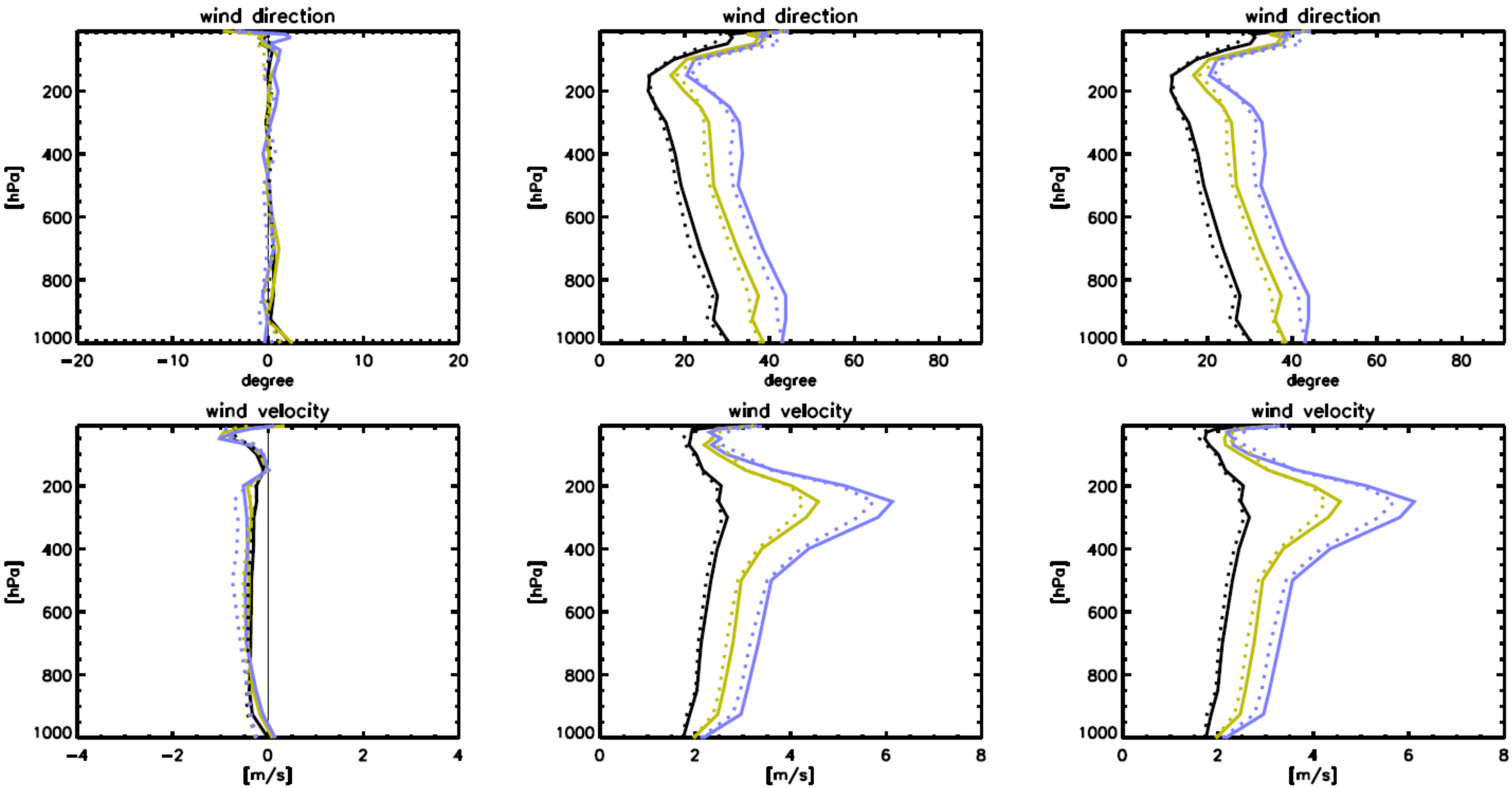
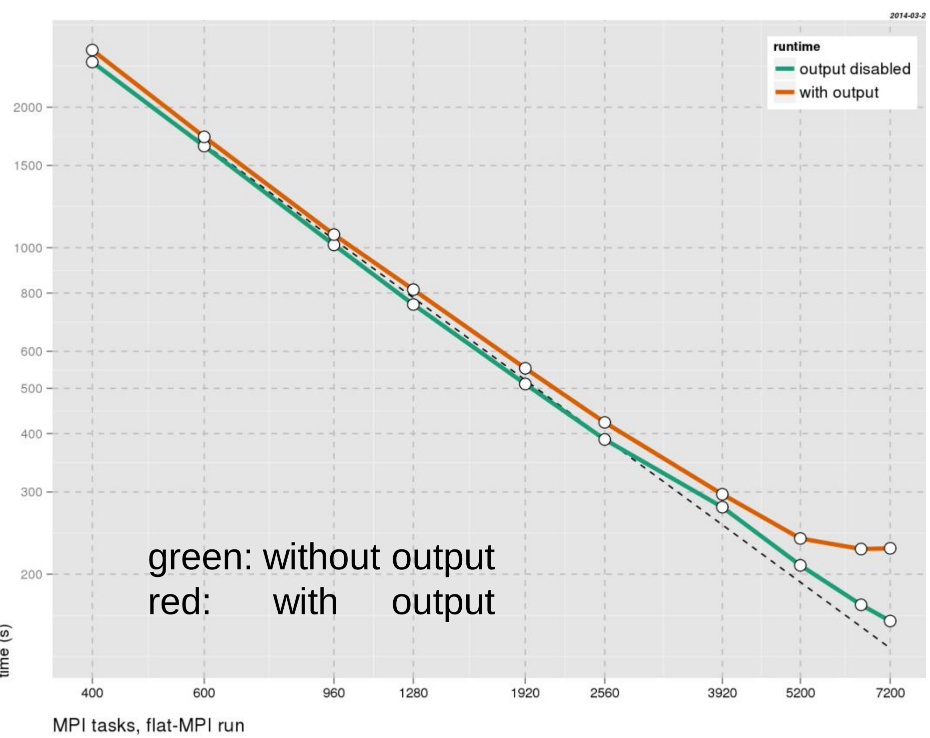


Bias RMSE stdev

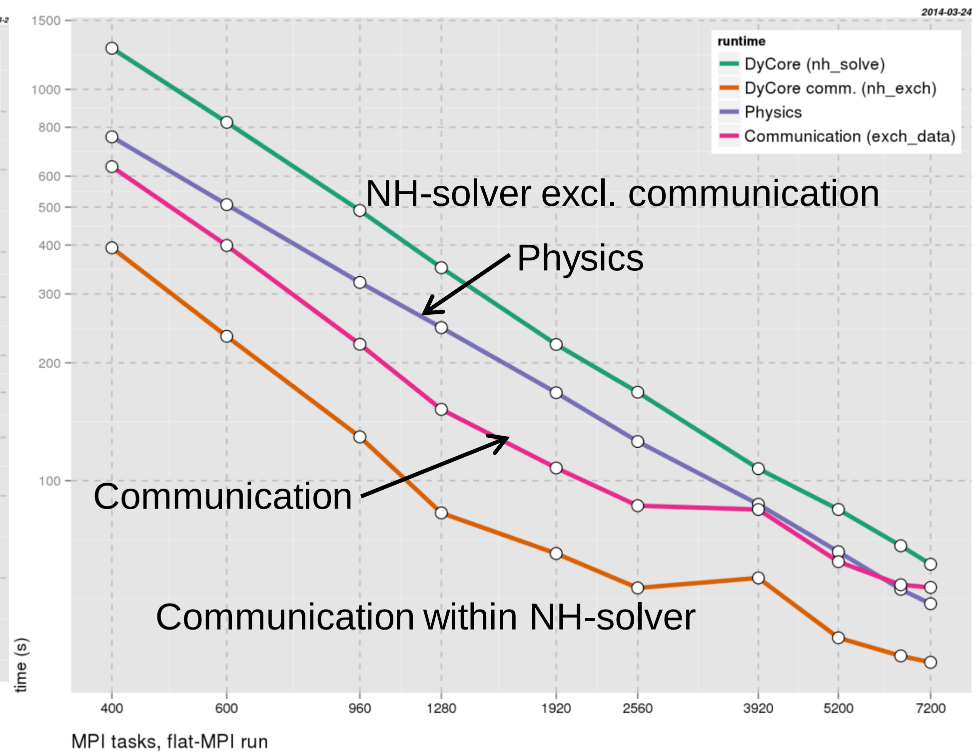
Scaling test

- **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



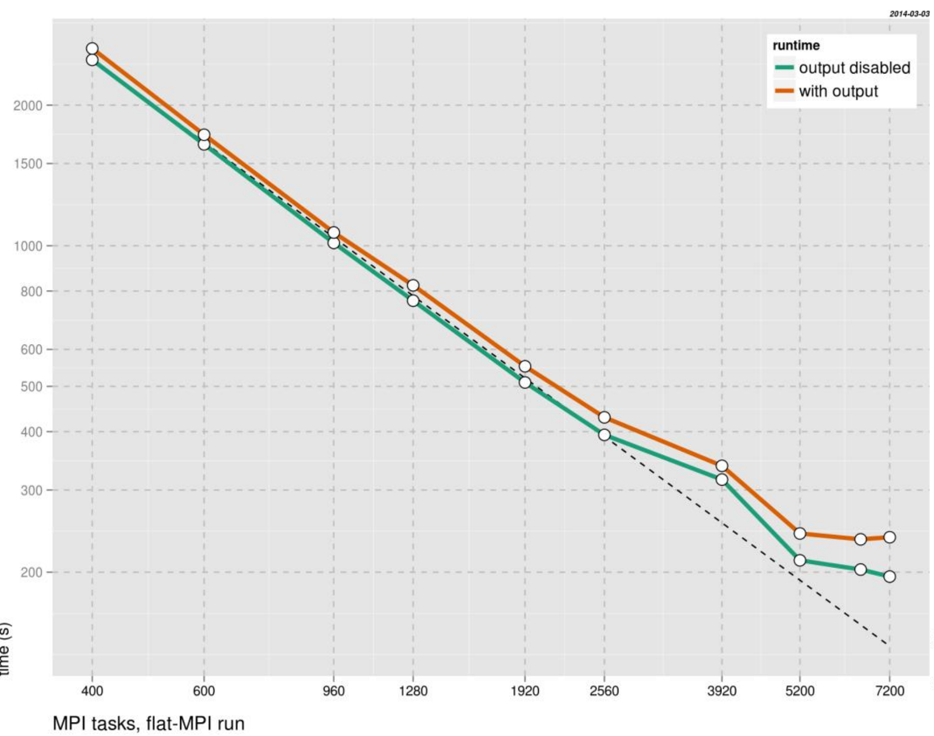
sub-timers



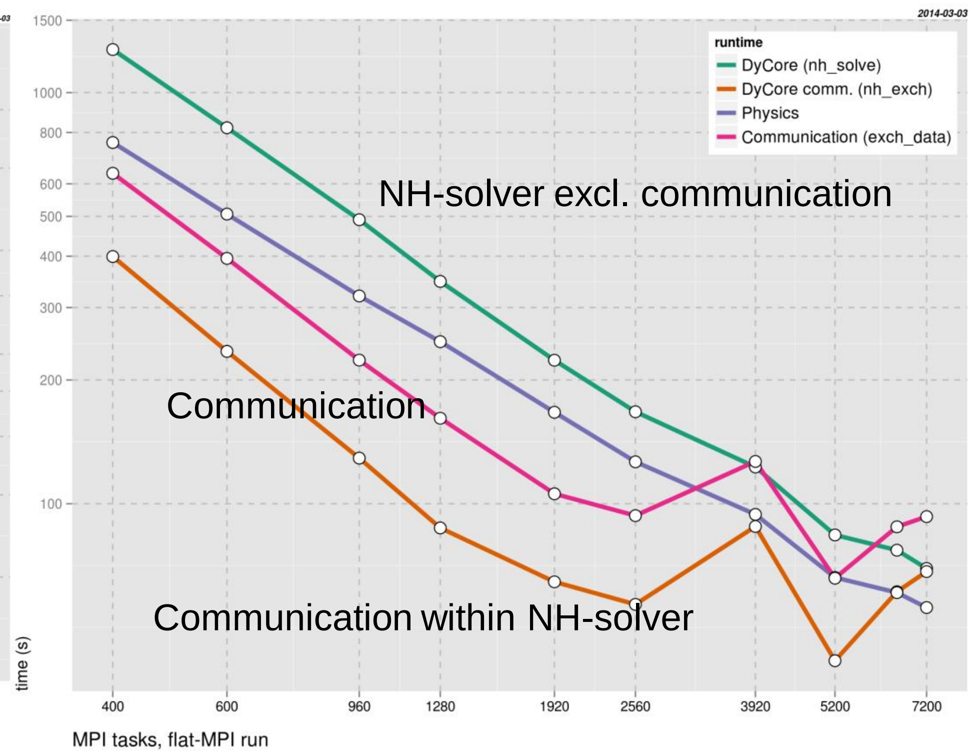
Thanks to Florian Prill!

Result of first try – before fixing some hardware issues …

total runtime



sub-timers



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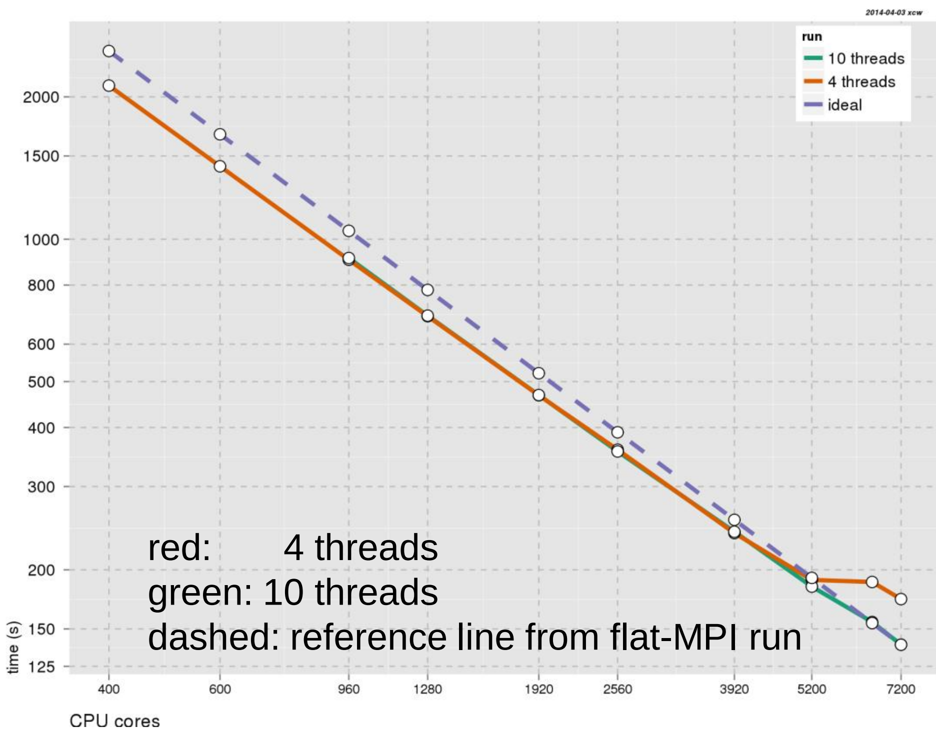
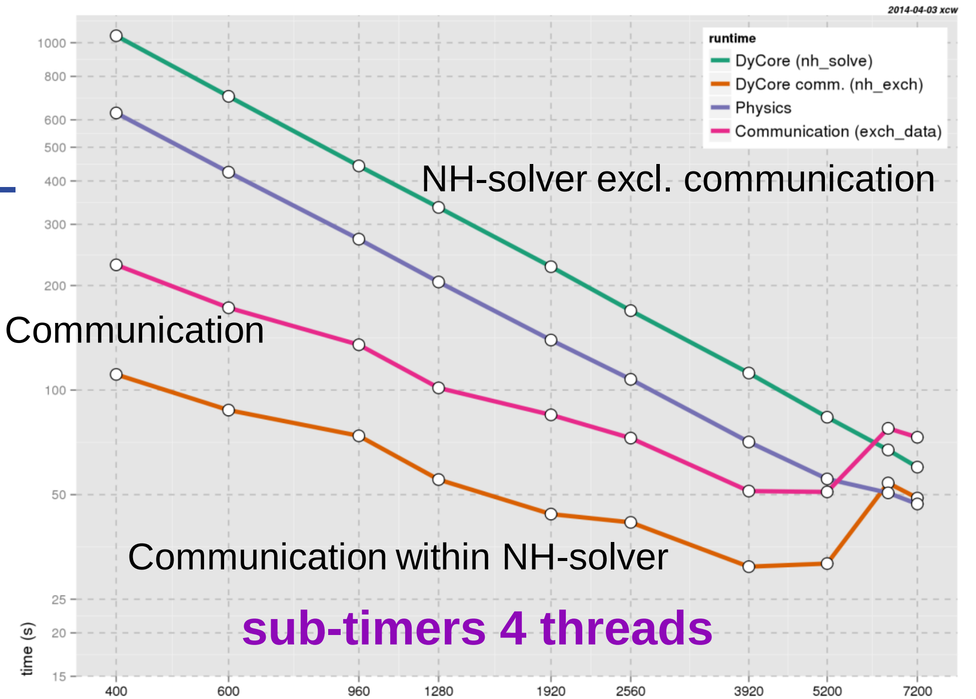
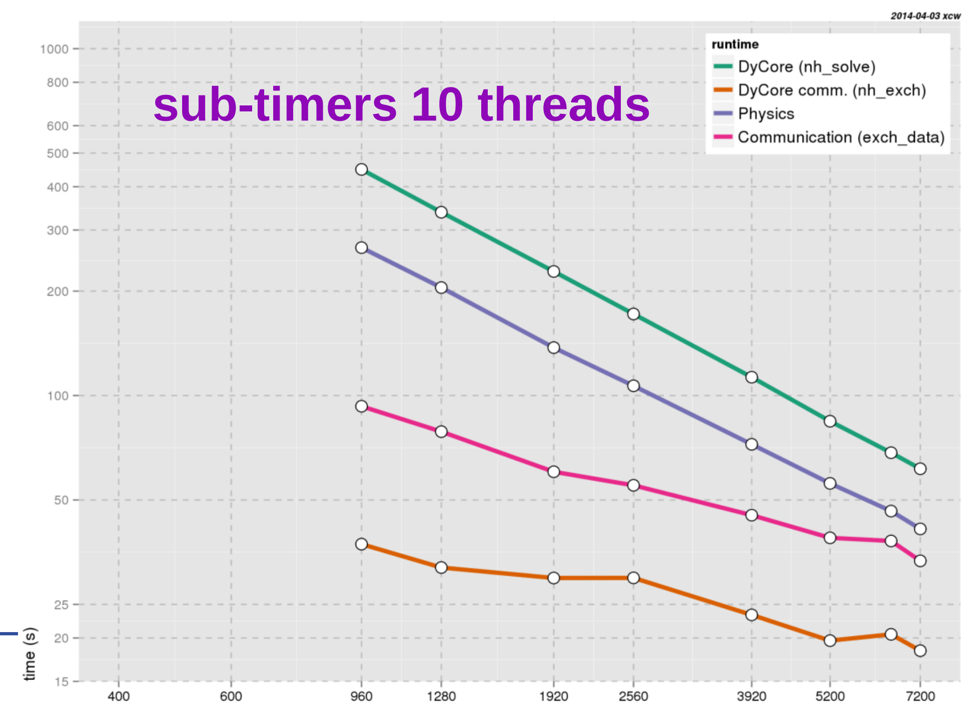
Hybrid parallelization:

4/10 threads with hyperthreading

total runtime







Summary

- **ICON will constitute a unified modeling system for NWP and climate prediction in order to bundle knowledge and to maximize synergy effects**
- **Better conservation properties than GME, ECHAM and COSMO-Model**
- **Better NWP scores than GME**
- **Substantially better scalability and efficiency than GME**
- **Target date for start of operational production: 09.12.2014**