Max-Planck-Institut
für Meteorologie

DWD
Deutscher Wetterdienst
Wetter und Klima aus einer Hand

# ICON

## First experiences in operational forecasting and further plans

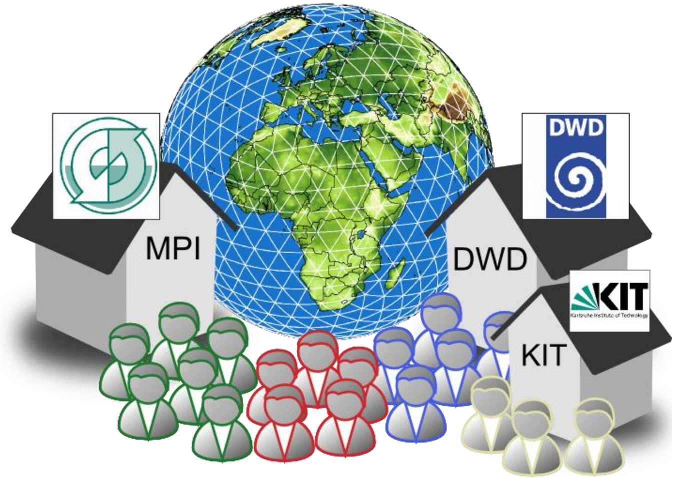
**Günther Zängl**

**COSMO User Seminar, 03.03.15**

# ICON – ICOsahedral Nonhydrostatic Model

- Joint development of **DWD** and **MPI-M** (Hamburg) for NWP **and** climate modelling

- 2012, **KIT** (Karlsruhe) joined to implement the chemistry module ART (Aerosols and Reactive Trace Gases).



- About 40 active developers from atmospheric and computational sciences

- ~ 600000 lines of Fortran code

# Outline

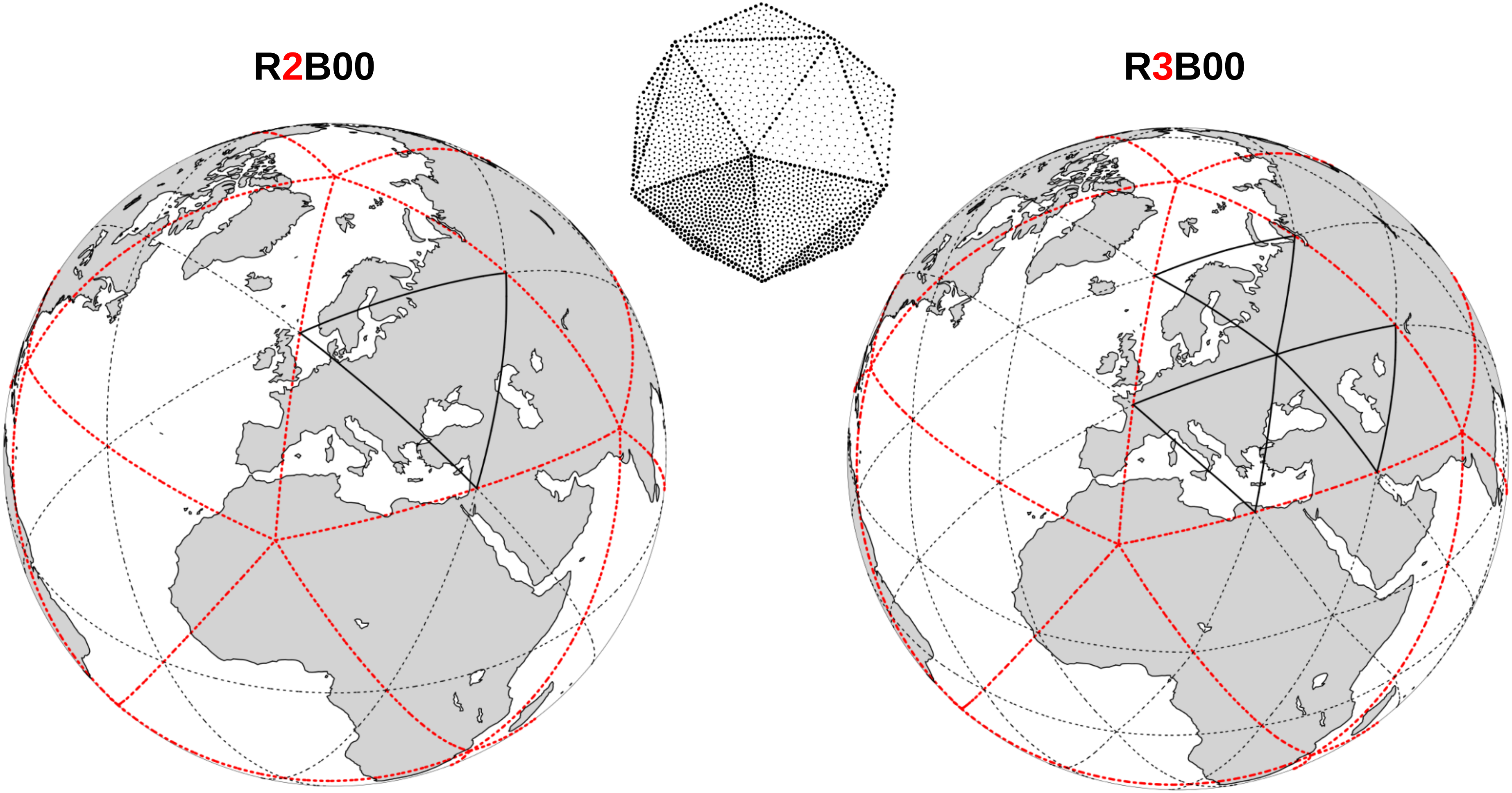
- Introduction: Main goals of the ICON project
- Grid structure, dynamical core and physics schemes
- Comparison of forecast skills with GME
- Scalability
- Selected applications of ART module
- Outlook

# Primary development goals

- Joint project between DWD and MPI-M (Max Planck Institute for Meteorology, Hamburg)
- 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

# Grid structure

## Icosahedral grid similar to GME, but unstructured



**R2B00**

**R3B00**

# Grid structure with refinement

Rule-of-thumb for average mesh size:

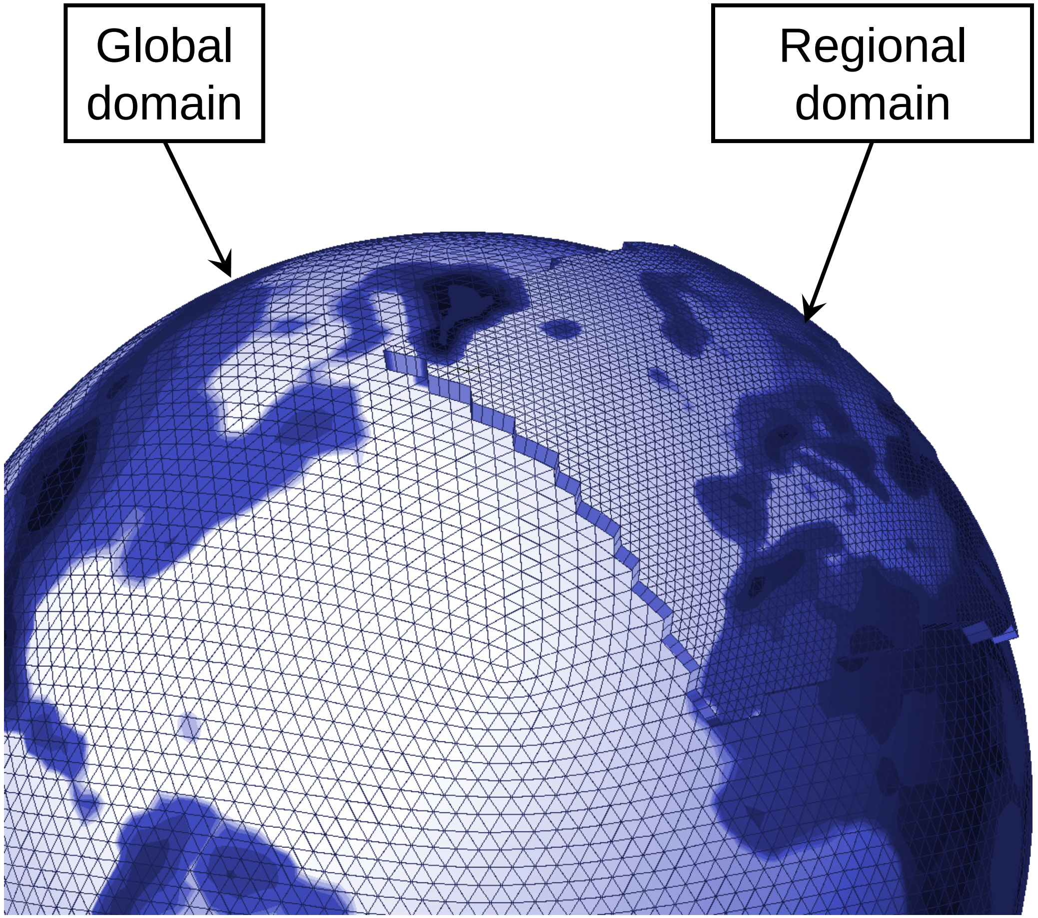
$\Delta x \approx 5050 / ( n\, 2^k )$ [ km ]

**Example:**

R3B7: n = 3, k = 7

Mesh size: 13 km;2.95 Mio grid points in global domain

The nested domain over Europe (replacing COSMO-EU) will have a mesh size of 6.5 km



# Model equations, dry dynamical core

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

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

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

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

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

$v_n$,w: normal/vertical velocity component

$\rho$: density

$\theta_v$: Virtual potential temperature

K: horizontal kinetic energy

$\zeta$: vertical vorticity component

$\pi$: Exner function

blue: independent prognostic variables

# Physics parameterizations

| Process | Authors | Scheme | Origin |
|---|---|---|---|
| **Radiation** | Mlawer et al. (1997)<br>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)<br>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)<br>Seifert (2010) | prognostic: water vapor, cloud water,cloud ice, rain and snow | GME/COSMO |
| **Convection** | Tiedtke (1989)<br>Bechthold et al. (2008) | mass-flux shallow and deep | IFS |
| **Turbulent transfer** | Raschendorfer (2001) | prognostic TKE | COSMO |
| | Louis (1979) | 1$^{st}$ order closure | GME |
| | Neggers, Köhler, Beljaars (2010) | EDMF-DUALM | IFS |
| **Land** | Heise and Schrodin (2002), Machulskaya, Helmert, Mironov (2008, lake) | tiled TERRA + FLAKE + multi-layer snow | GME/COSMO |
| | Raddatz, Knorr | JSBACH | ECHAM6 |

Operational at DWD

# First operational configuration of ICON for NWP

- Mesh size 13 km (R3B07), 90 levels, model top at 75 km
- 3D-Var data assimilation system taken over from GME
- Preoperational production since 12 Aug 2014
- Operational production since 20 Jan 2015
- Forecast range: 180 h (00+12 UTC), 120 h (06+18 UTC)
- Output on native model grid and on 0.25°x 0.25° lat-lon grid

# Verification results

## a) analysis verification

- **WMO standard verification against own analyses on 1.5°x1.5° lat-lon grid, December 2014, 12 UTC runs**

## b) radiosonde verification

- **Verification against radiosondes (that passed the quality check of the data assimilation scheme), December 2014, 00 UTC runs**

## c) surface verification

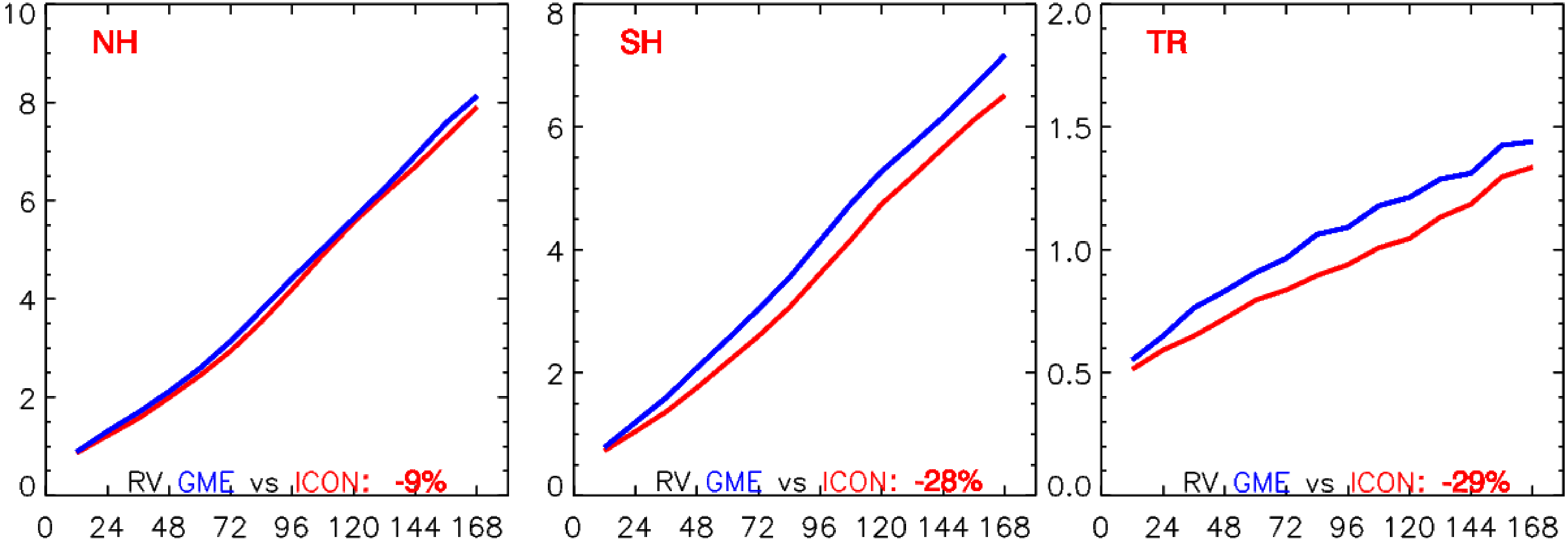
- **Verification against SYNOP observations, 16 Dec 2014 – 16 Jan 2015, 00 UTC runs**

**Many thanks to Uli Damrath and Uli Pflüger!**

# Analysis verification

## Mean sea-level pressure, RMSE in hPa

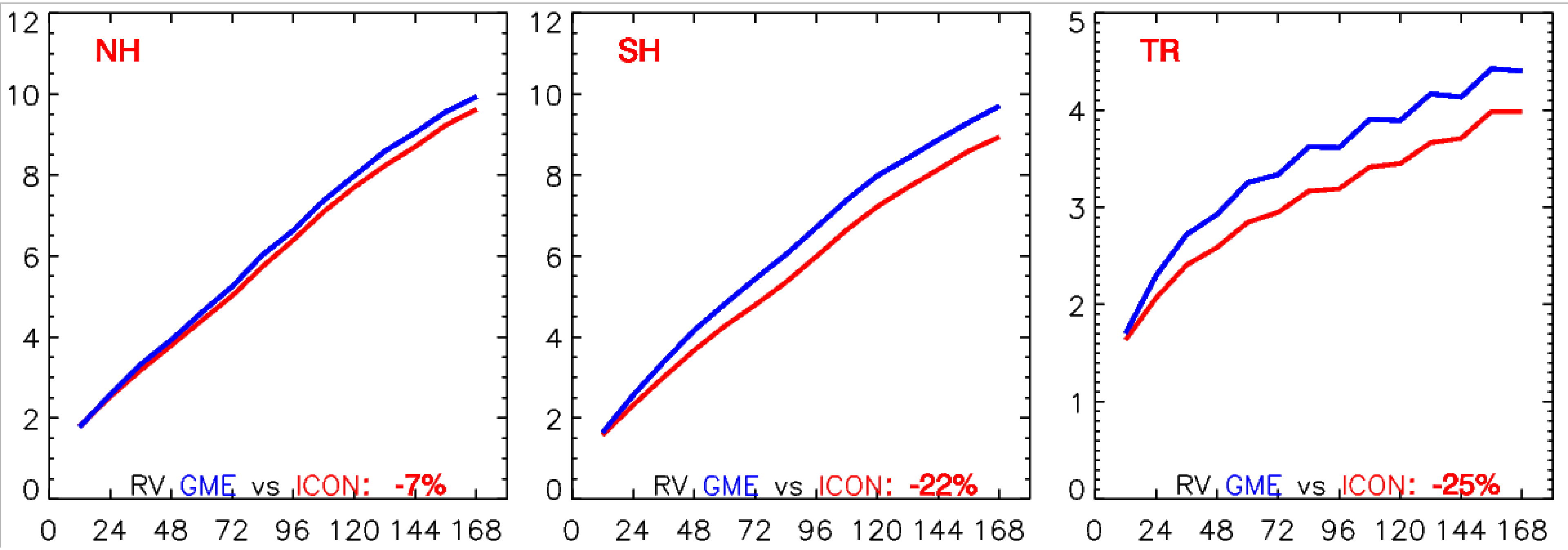
**blue: GME**, **red: ICON**; **RV: reduction of variance**



# Analysis verification

## Wind at 925 hPa, vector-RMSE in m/s

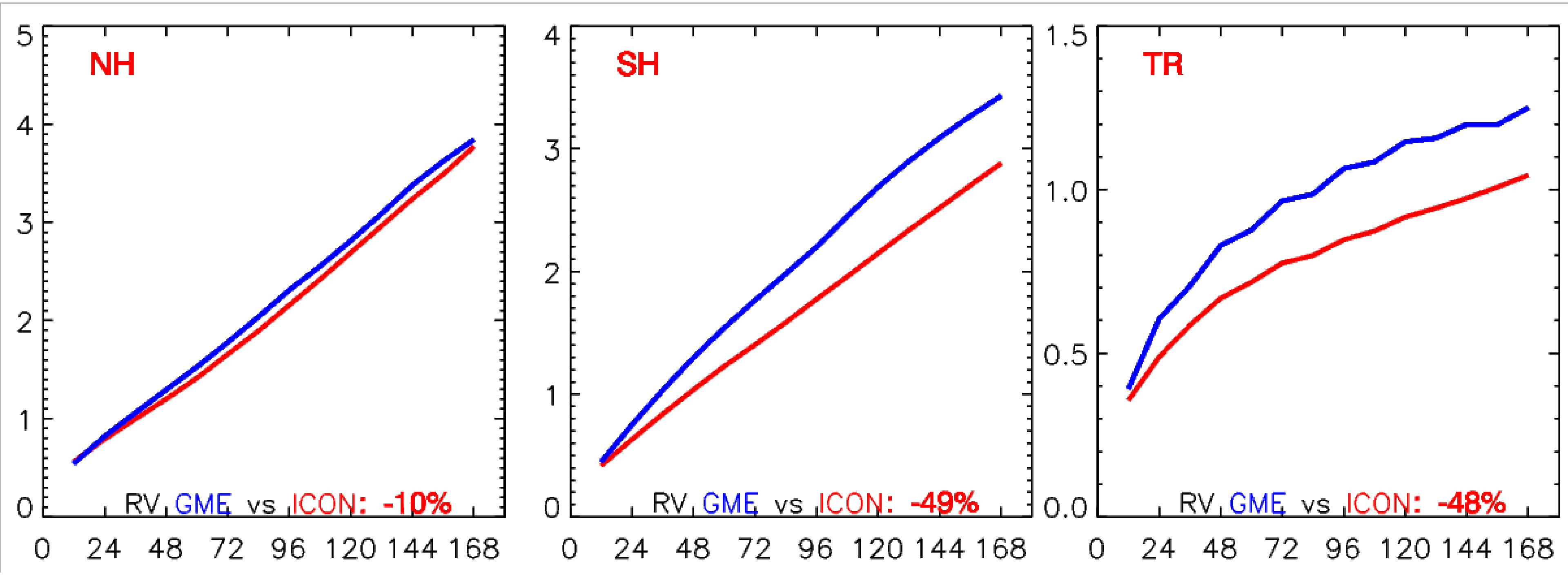
blue: GME, red: ICON; RV: reduction of variance



# Analysis verification

## Temperature at 700 hPa, RMSE in K

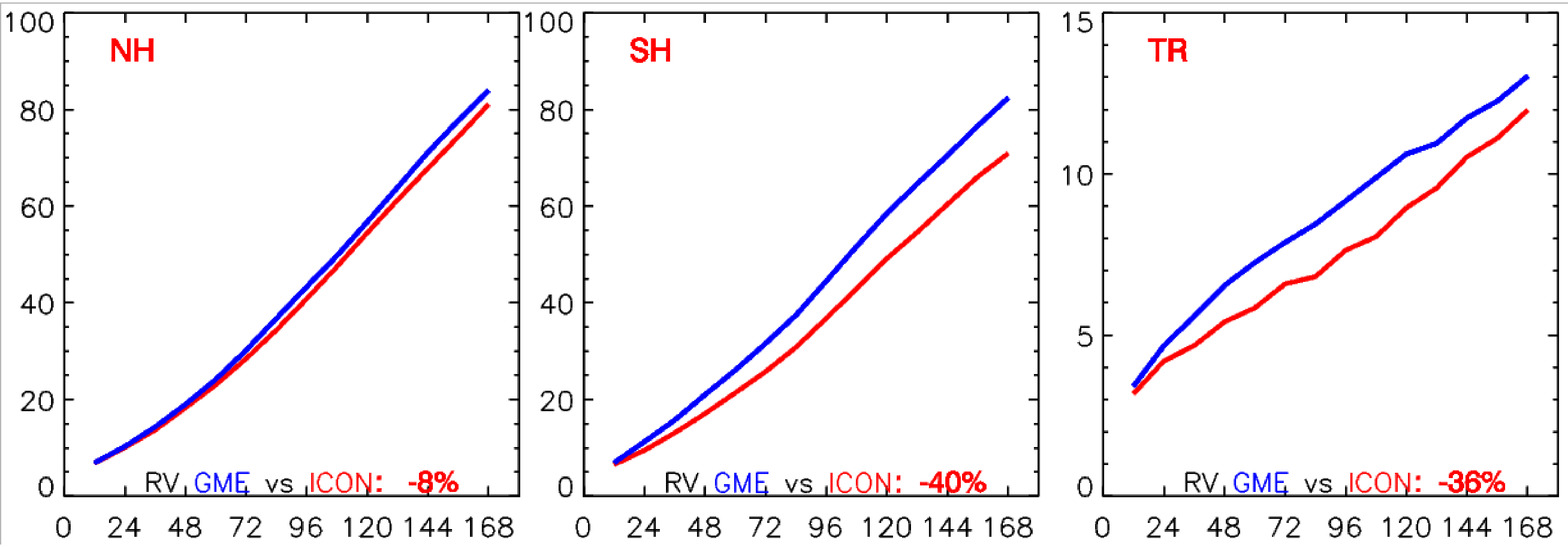
**blue: GME, red: ICON; RV: reduction of variance**



# Analysis verification

## Geopotential height at 500 hPa, RMSE in m

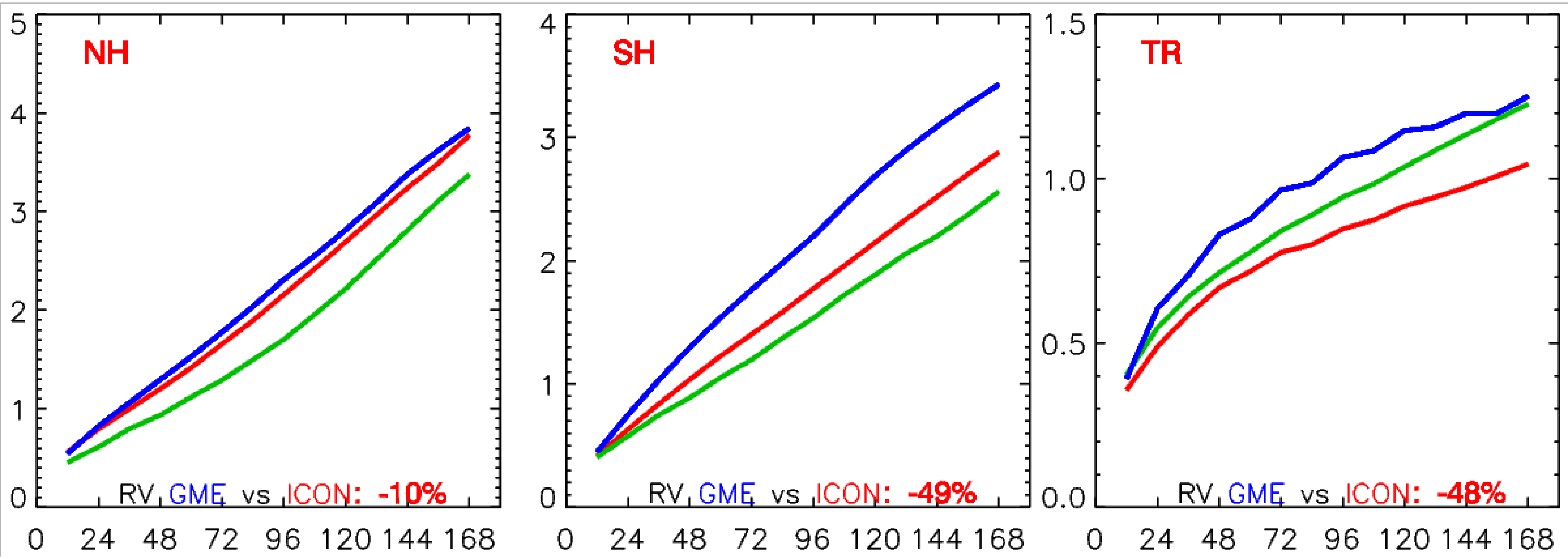
**blue: GME, red: ICON; RV: reduction of variance**



## Analysis verification

# Temperature at 700 hPa, RMSE in K

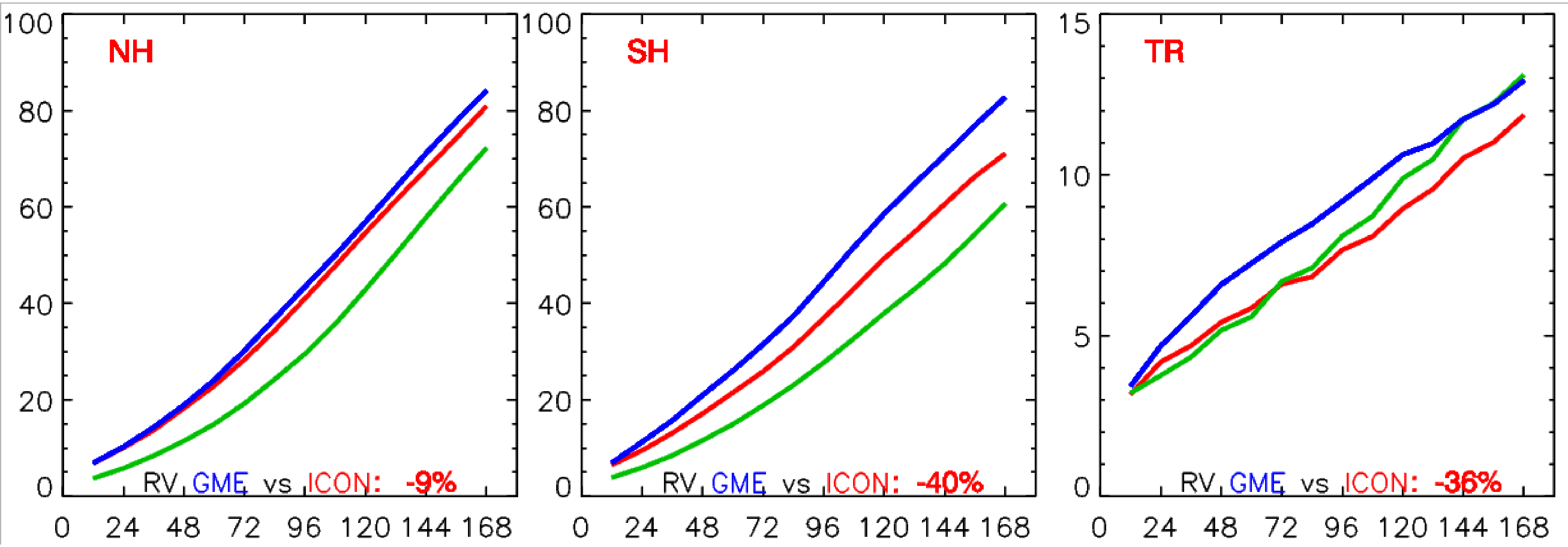
**blue: GME, red: ICON, green: IFS; RV: reduction of variance**



# Analysis verification

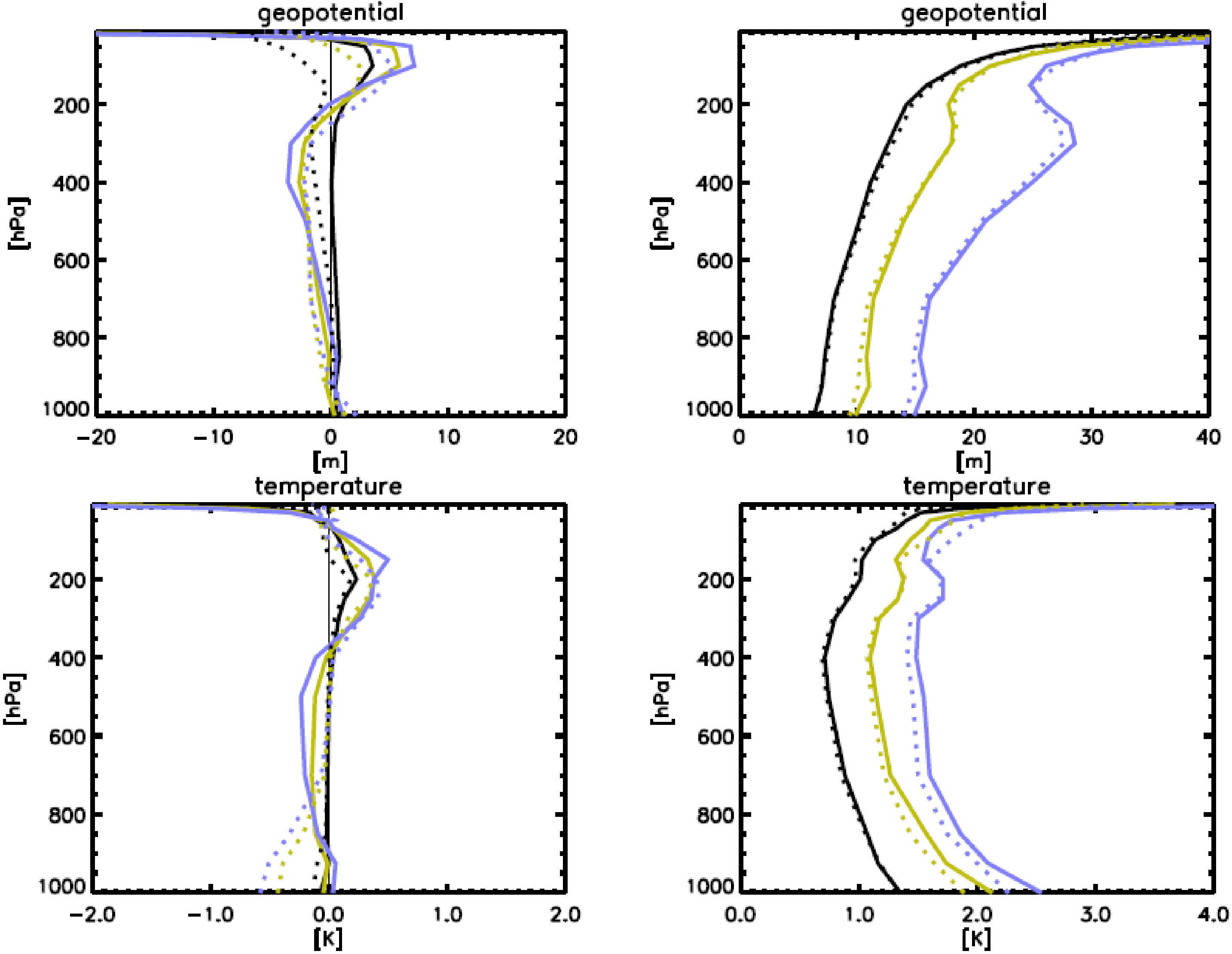
## Geopotential height at 500 hPa, RMSE in m

**blue: GME, red: ICON, green: IFS; RV: reduction of variance**



# Radiosonde verification northern hemisphere

## Geopotential and temperature

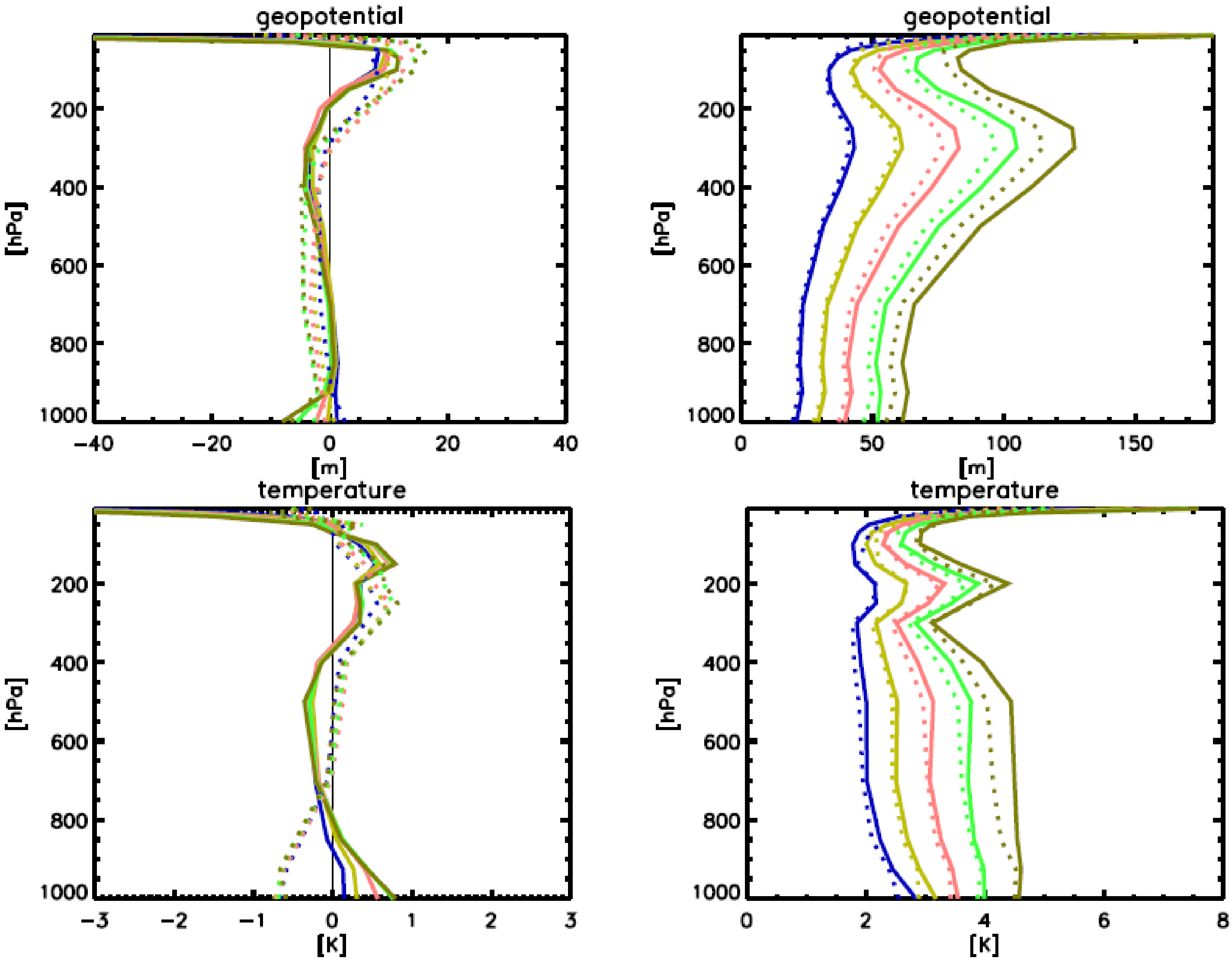


**dashed: ICON 13L90**
**solid: GME 20L60**

**Bias, 0-48 h** **RMSE, 0-48 h**

# Radiosonde verification northern hemisphere

## Geopotential and temperature



**dashed: ICON 13L90**
**solid: GME 20L60**

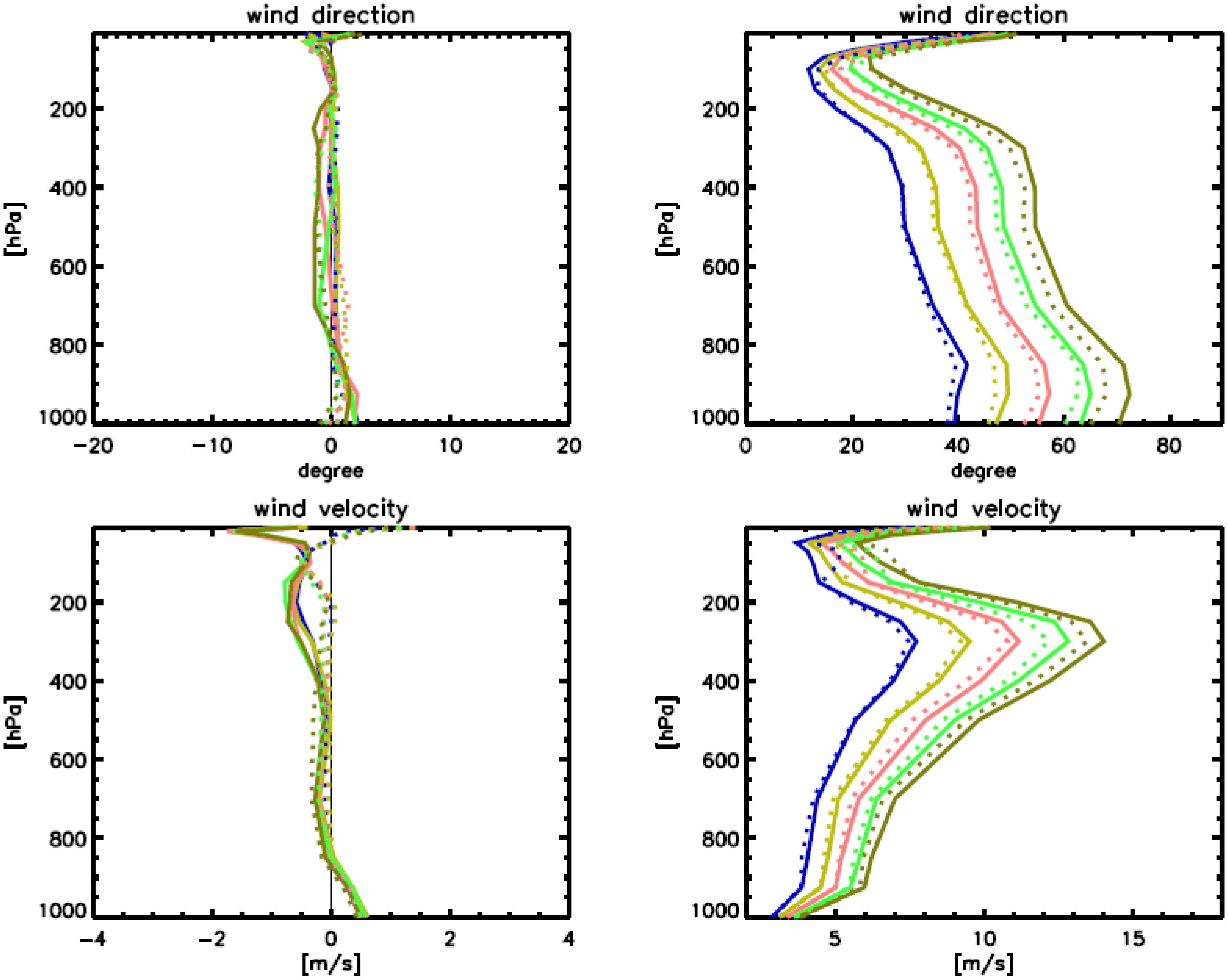
**Bias, 72-168 h**

**RMSE, 72-168 h**

# Radiosonde verification northern hemisphere

## Wind direction and speed

**dashed: ICON 13L90**
**solid: GME 20L60**

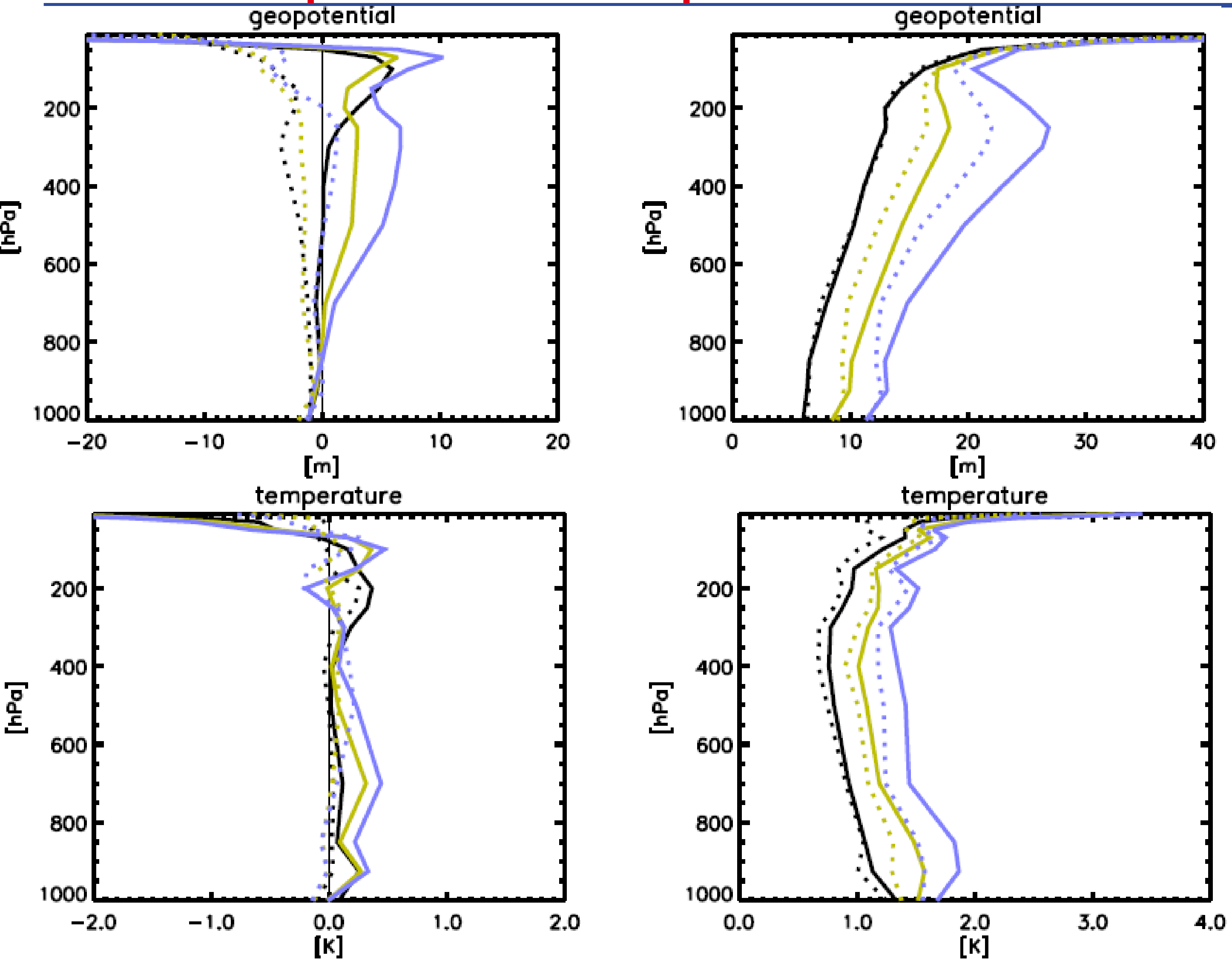


**Bias, 72-168 h**

**RMSE, 72-168 h**

# Radiosonde verification southern hemisphere

## Geopotential and temperature

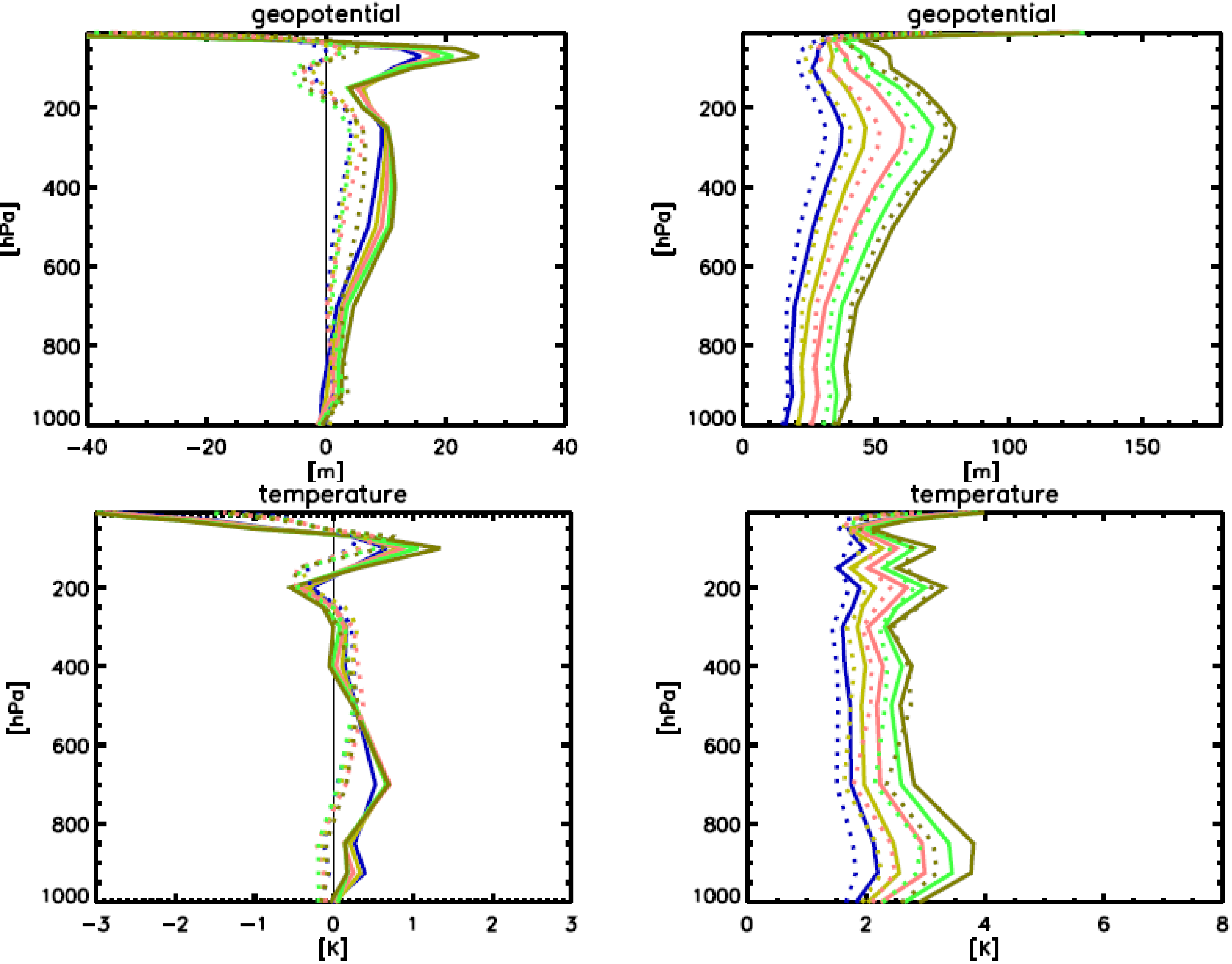


**dashed: ICON 13L90**
**solid: GME 20L60**

**Bias, 0-48 h** **RMSE, 0-48 h**

# Radiosonde verification southern hemisphere

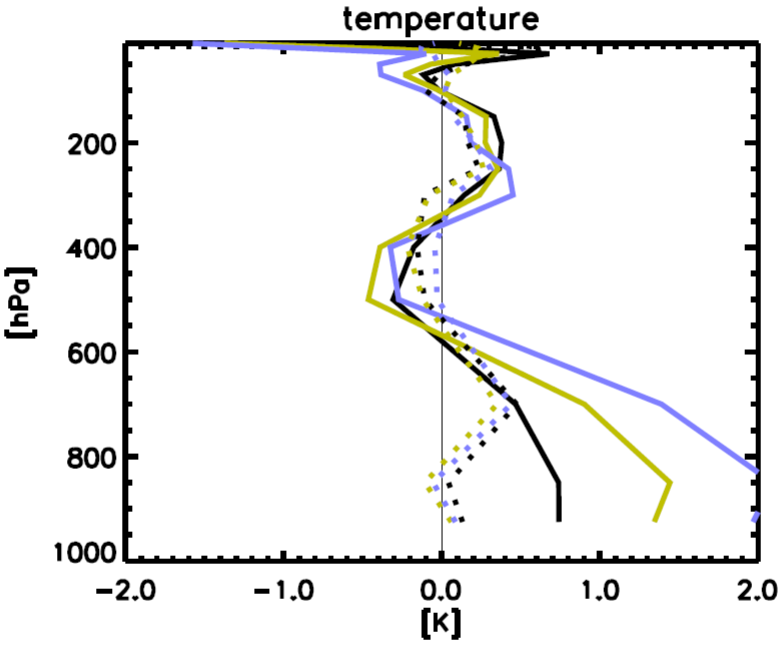
## Geopotential and temperature



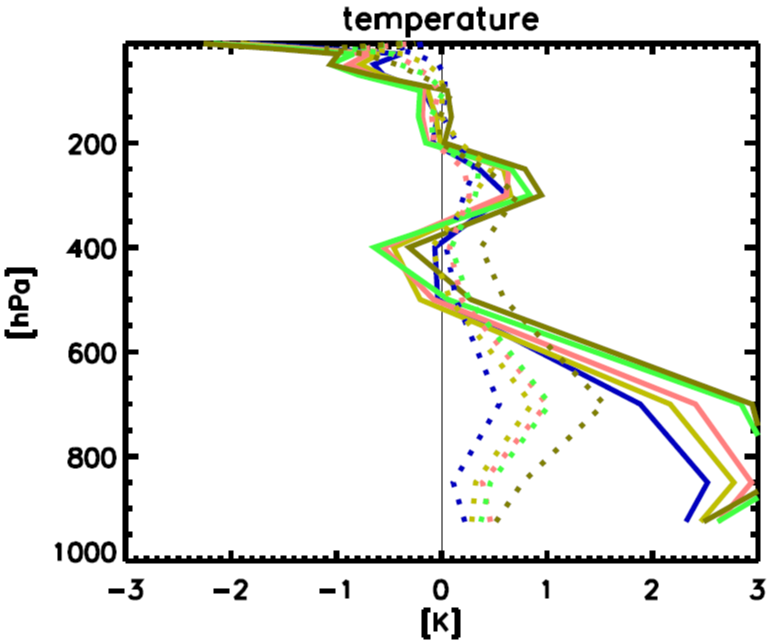
**dashed: ICON 13L90**
**solid: GME 20L60**

**Bias, 72-168 h** **RMSE, 72-168 h**

# Close-up view for Antarctica



**Bias, 0-48 h**



**Bias, 72-168 h**

# Surface verification Europe; blue: GME, red: ICON

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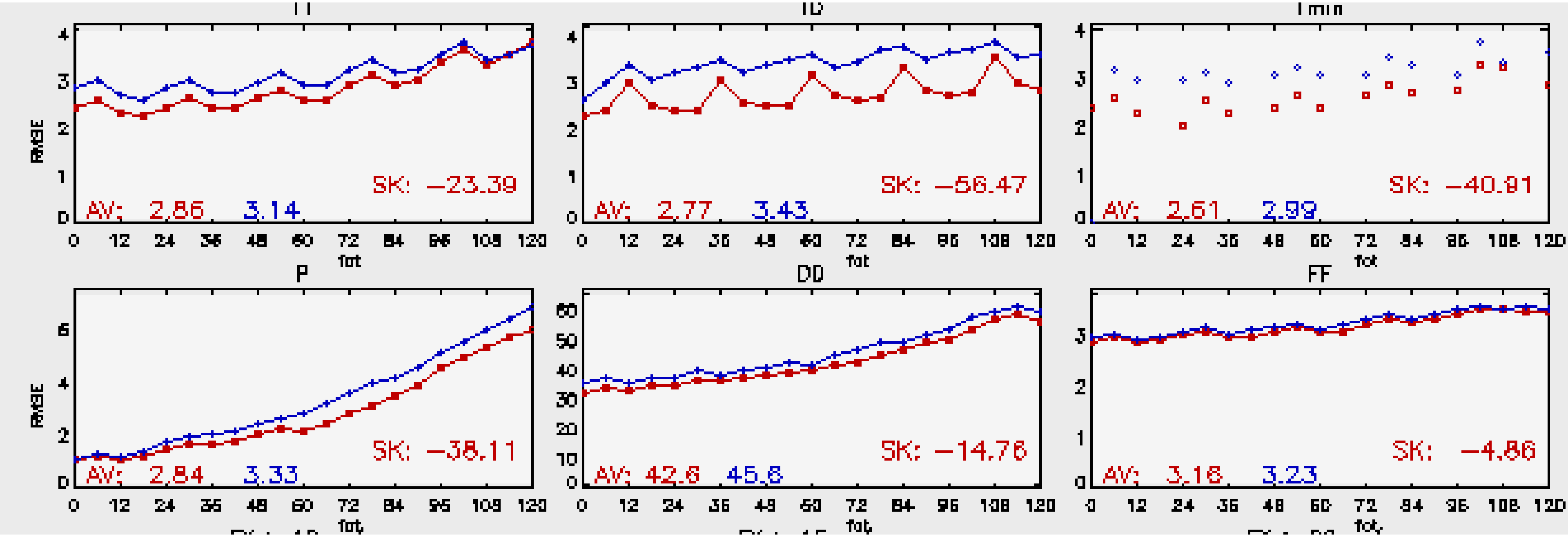
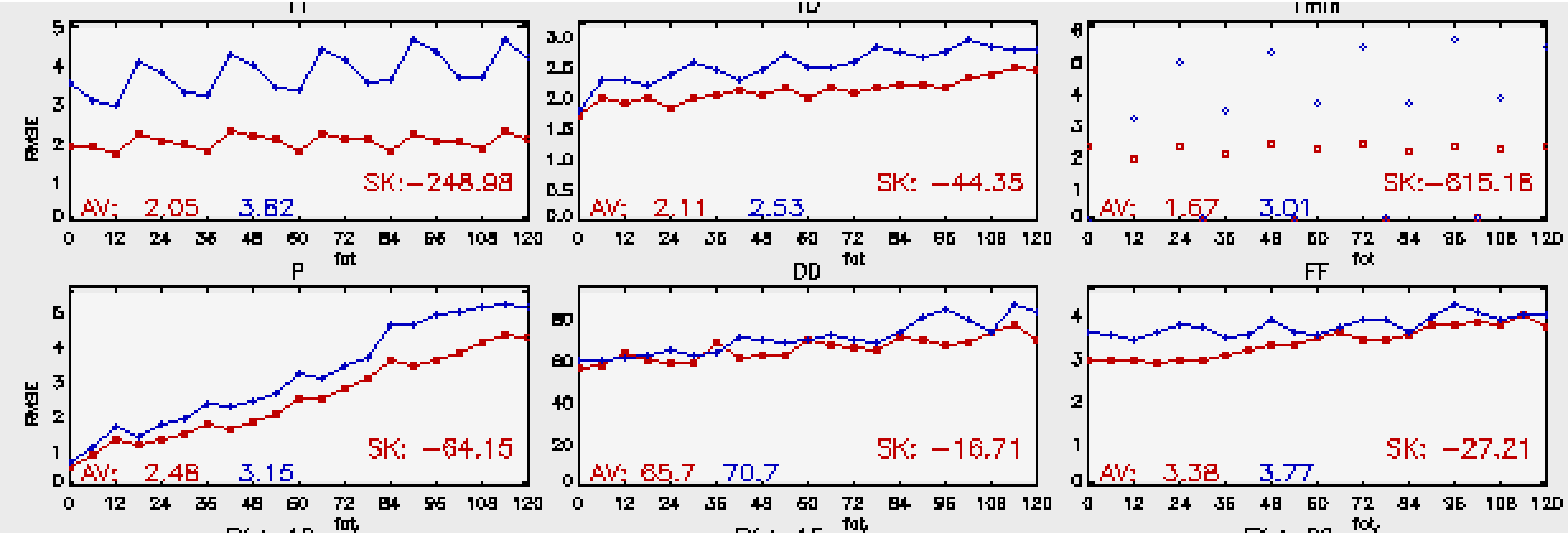
temperature dew point depression minimum temperature



pressure wind direction wind speed

# Surface verification Antarctica; blue: GME, red: ICON

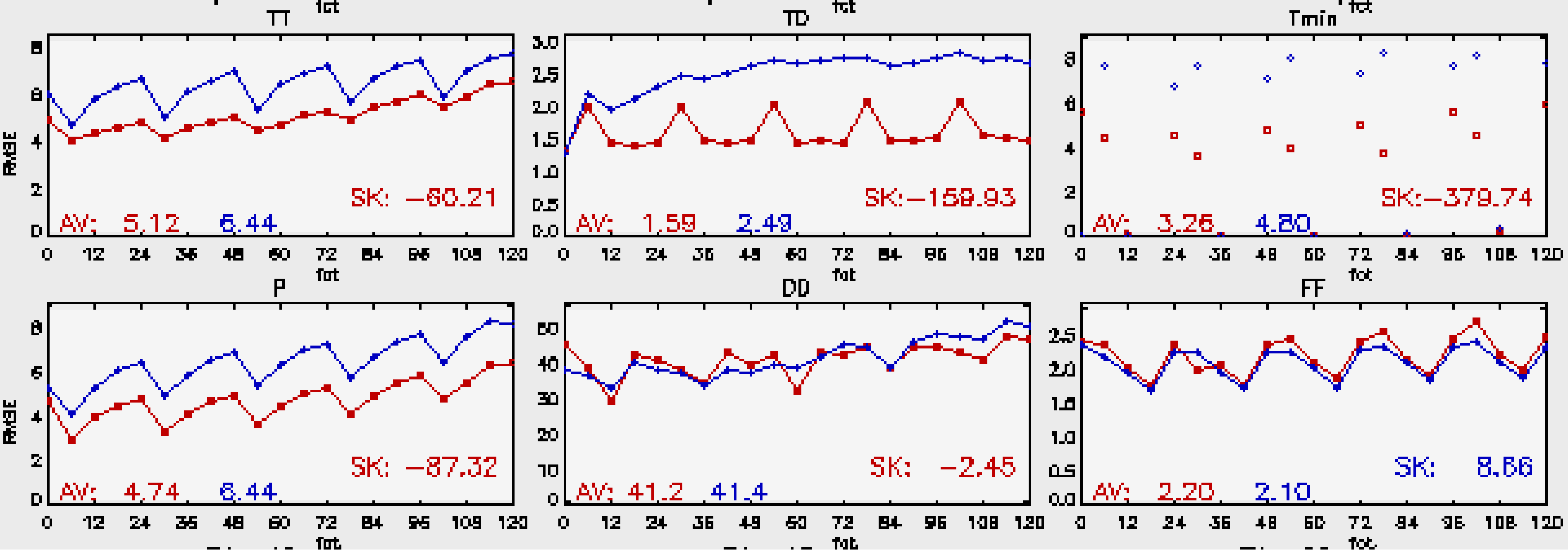
temperature dew point depression minimum temperature



pressure wind direction wind speed

# Surface verification eastern Siberia

temperature dew point depression minimum temperature



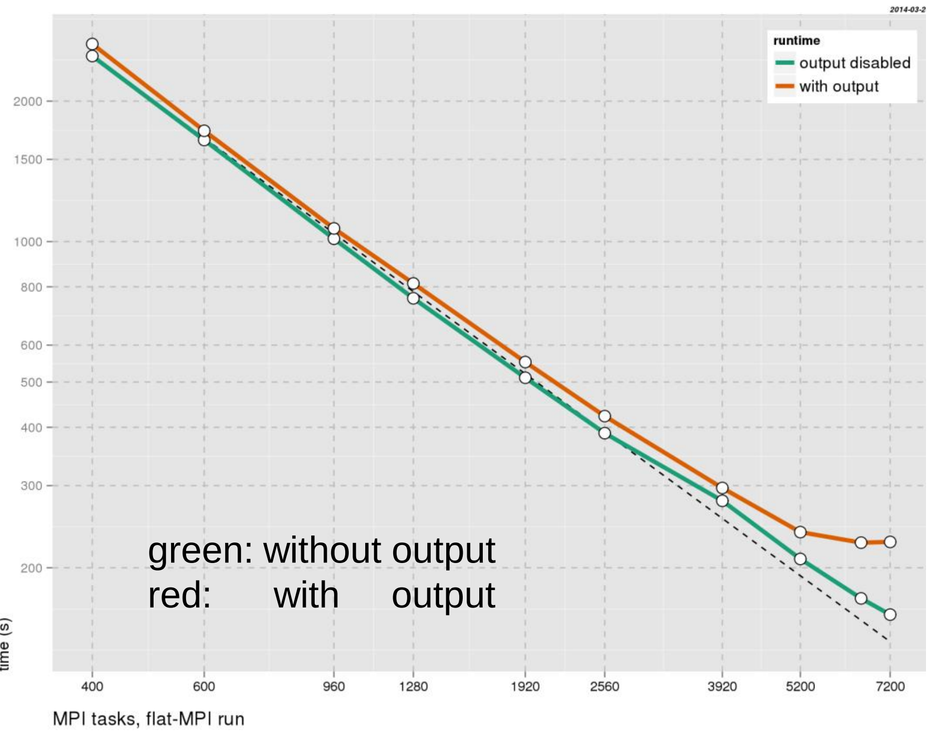
pressure wind direction wind speed

# Scaling test

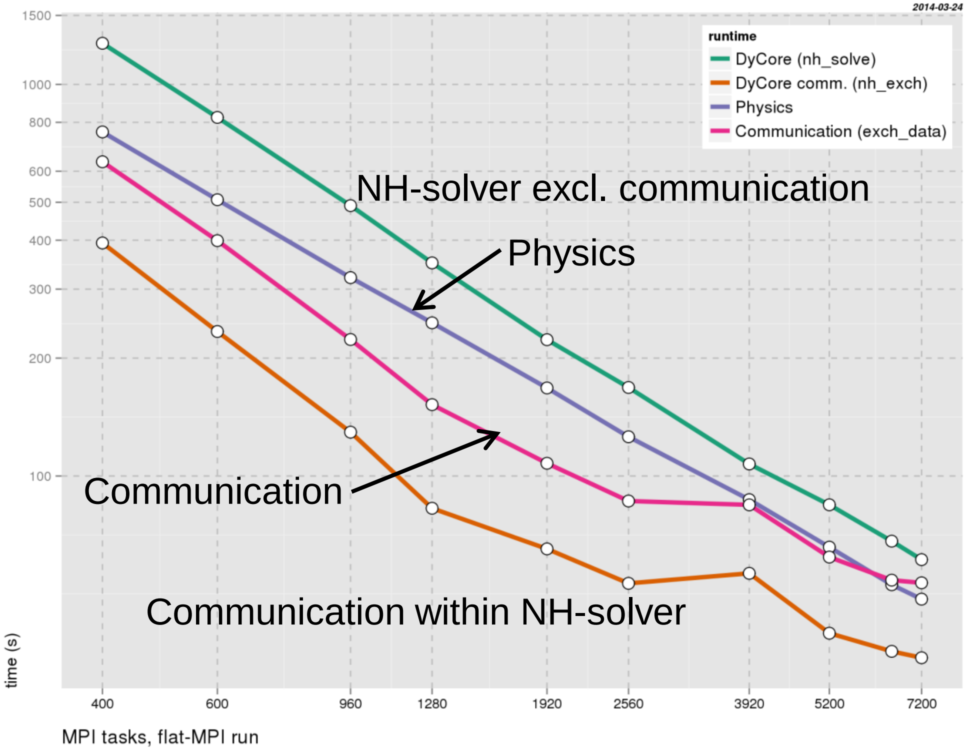
- Mesh size 13 km (R3B07), 90 levels, 1-day forecast (3600 time steps)
- Full NWP physics, asynchronous output (if active) on 42 tasks
- Range: 20–360 nodes Cray XC 30, 20 cores/node, flat MPI run

## total runtime

## sub-timers



green: without output
red: with output



NH-solver excl. communication

Physics

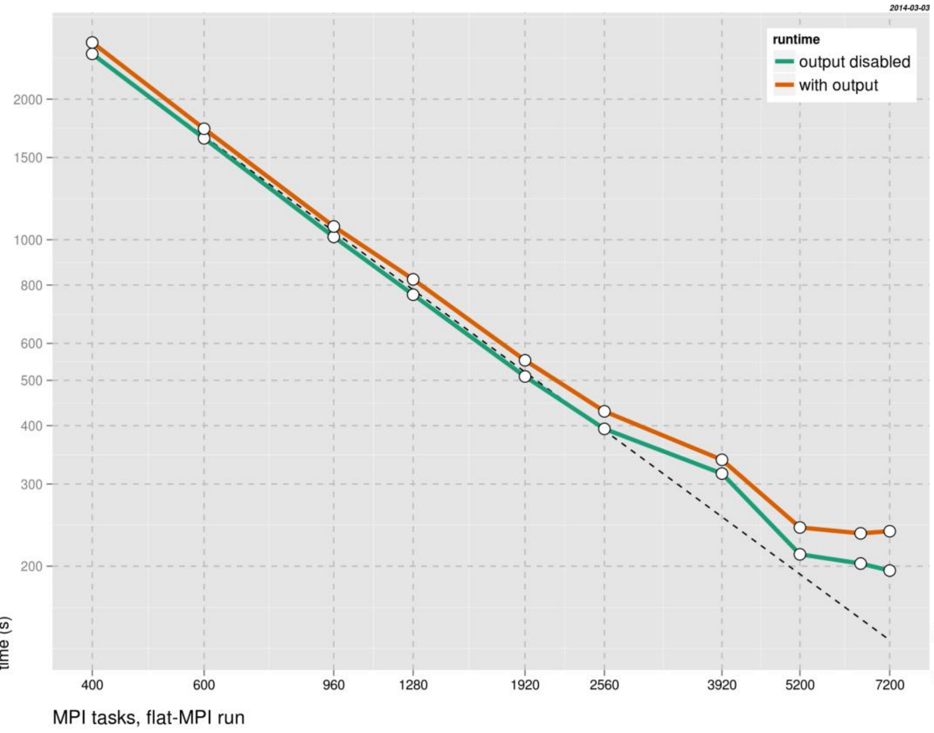
Communication

Communication within NH-solver

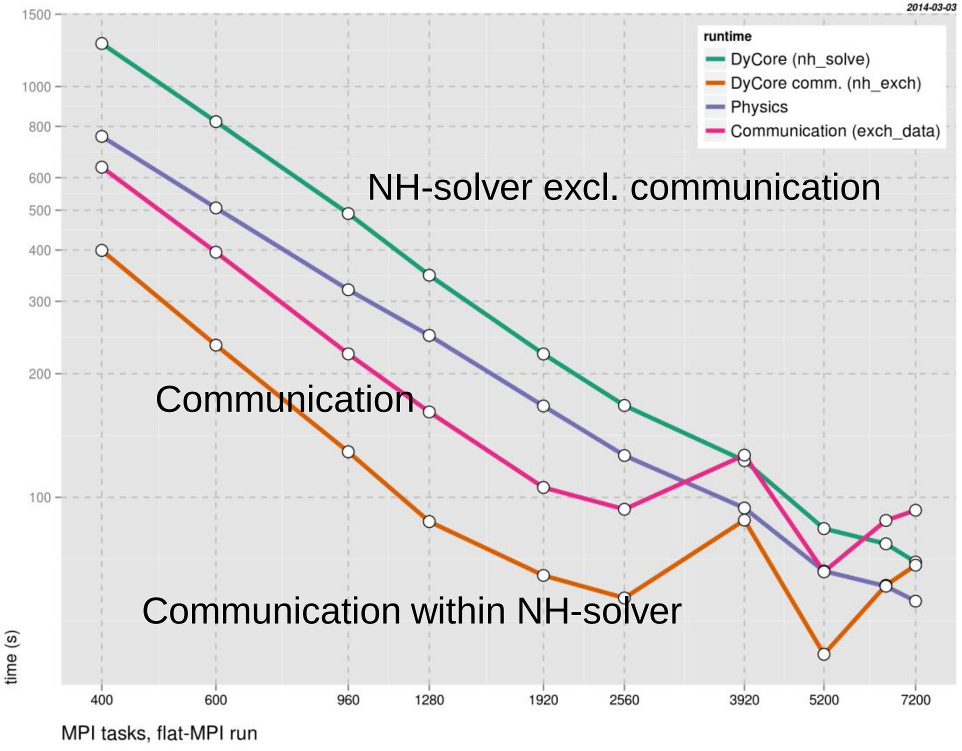
**Thanks to Florian Prill!**

# Result of first try – before fixing some hardware issues …

## total runtime



## sub-timers



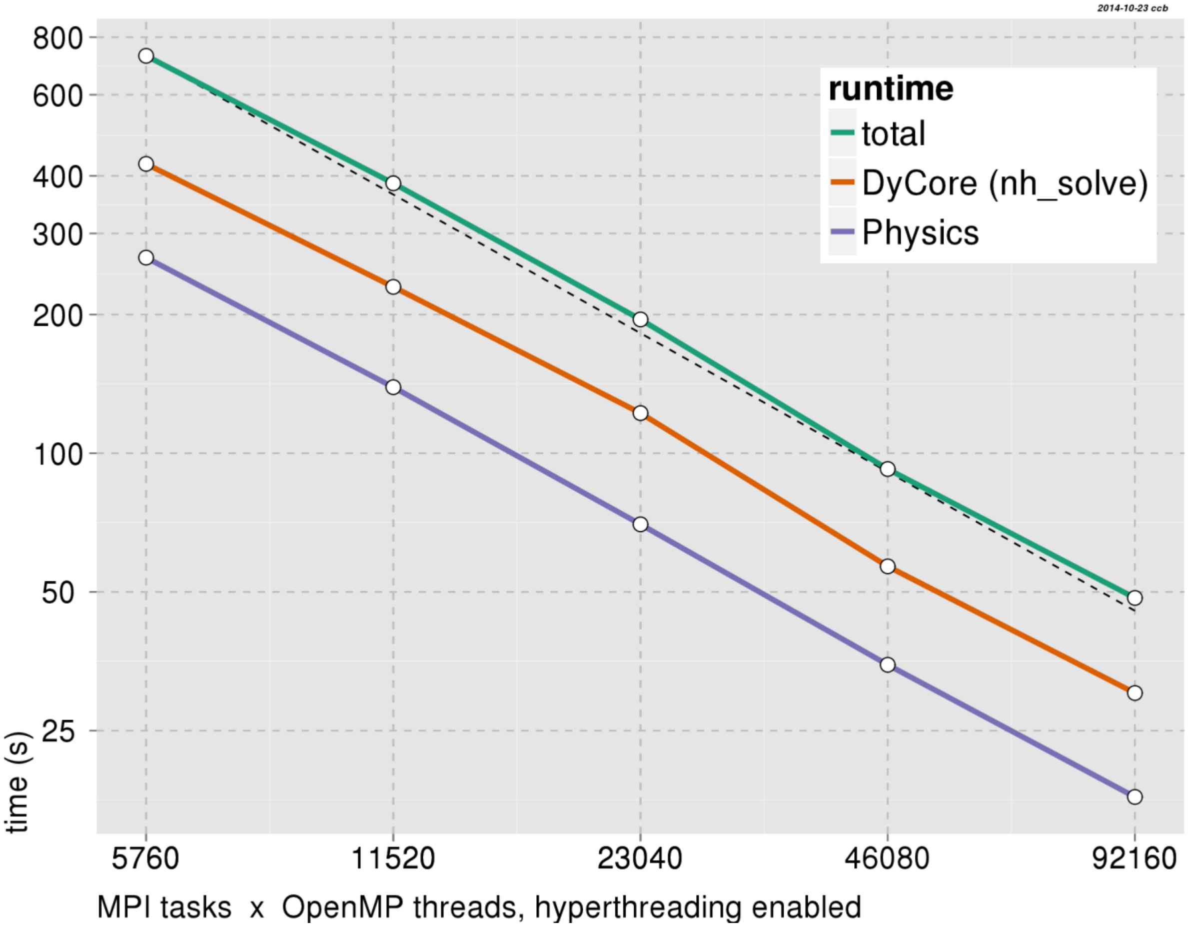
NH-solver excl. communication

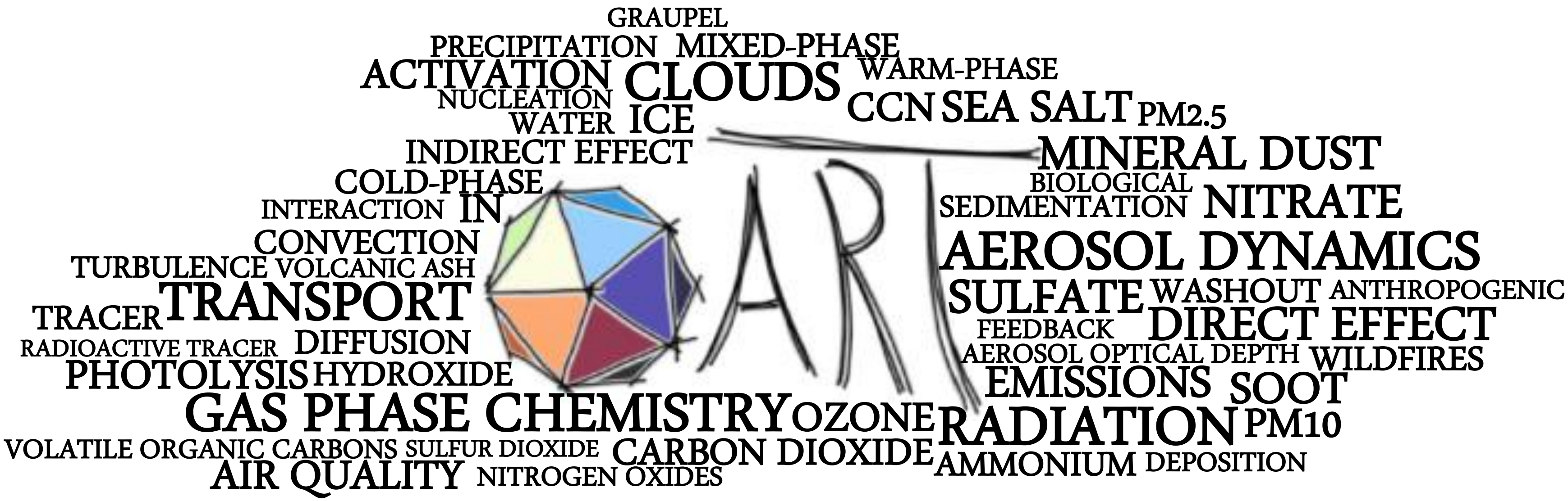
Communication

Communication within NH-solver

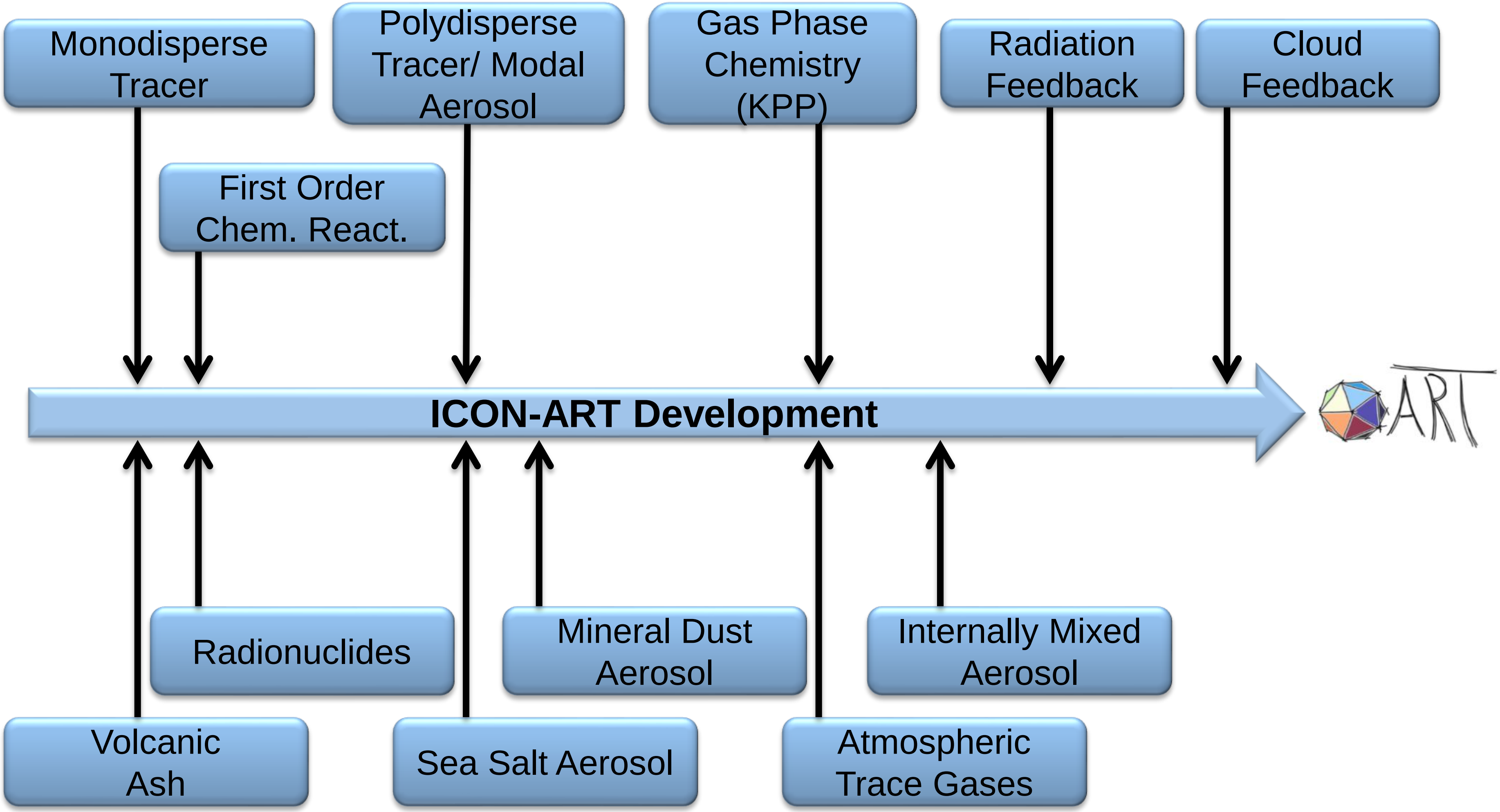
# XXL test (computed at ECMWF)

- **Mesh size 5 km (~21M grid points), 90 levels, 1000 time steps**
- **No output (field size too large for NetCDF3, technical issues with NetCDF4)**




GRAUPEL
PRECIPITATION MIXED-PHASE
ACTIVATION CLOUDS WARM-PHASE
NUCLEATION
CCN SEA SALT PM2.5
WATER ICE
INDIRECT EFFECT
MINERAL DUST
COLD-PHASE
BIOLOGICAL
INTERACTION IN
SEDIMENTATION NITRATE
ART
CONVECTION
AEROSOL DYNAMICS
TURBULENCE VOLCANIC ASH
SULFATE WASHOUT ANTHROPOGENIC
TRACER TRANSPORT
FEEDBACK DIRECT EFFECT
RADIOACTIVE TRACER DIFFUSION
AEROSOL OPTICAL DEPTH WILDFIRES
PHOTOLYSIS HYDROXIDE
EMISSIONS SOOT
GAS PHASE CHEMISTRY OZONE RADIATION PM10
VOLATILE ORGANIC CARBONS SULFUR DIOXIDE CARBON DIOXIDE
AMMONIUM DEPOSITION
AIR QUALITY NITROGEN OXIDES

# ICON-ART



Monodisperse Tracer

Polydisperse Tracer/ Modal Aerosol

Gas Phase Chemistry (KPP)

Radiation Feedback

Cloud Feedback

First Order Chem. React.

**ICON-ART Development**

Radionuclides

Mineral Dust Aerosol

Internally Mixed Aerosol

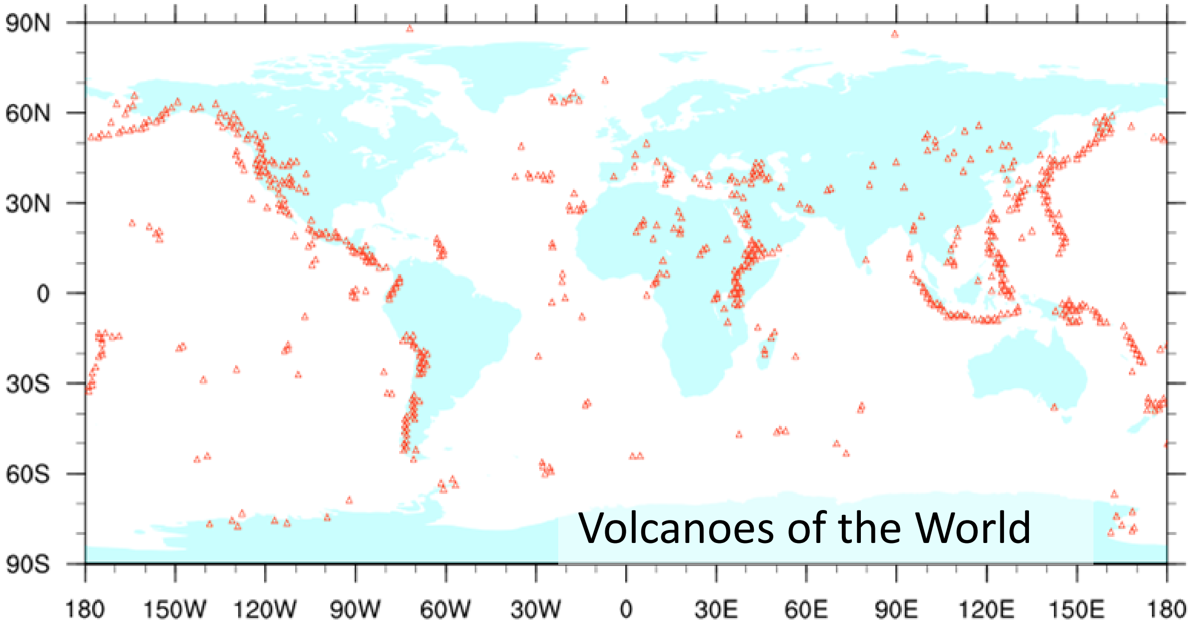
Volcanic Ash

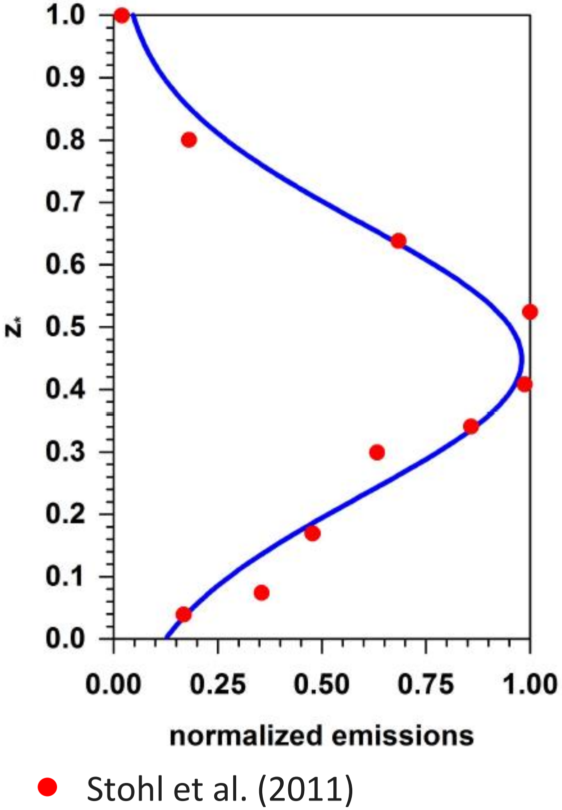
Sea Salt Aerosol

Atmospheric Trace Gases

# Emission of Volcanic Ash

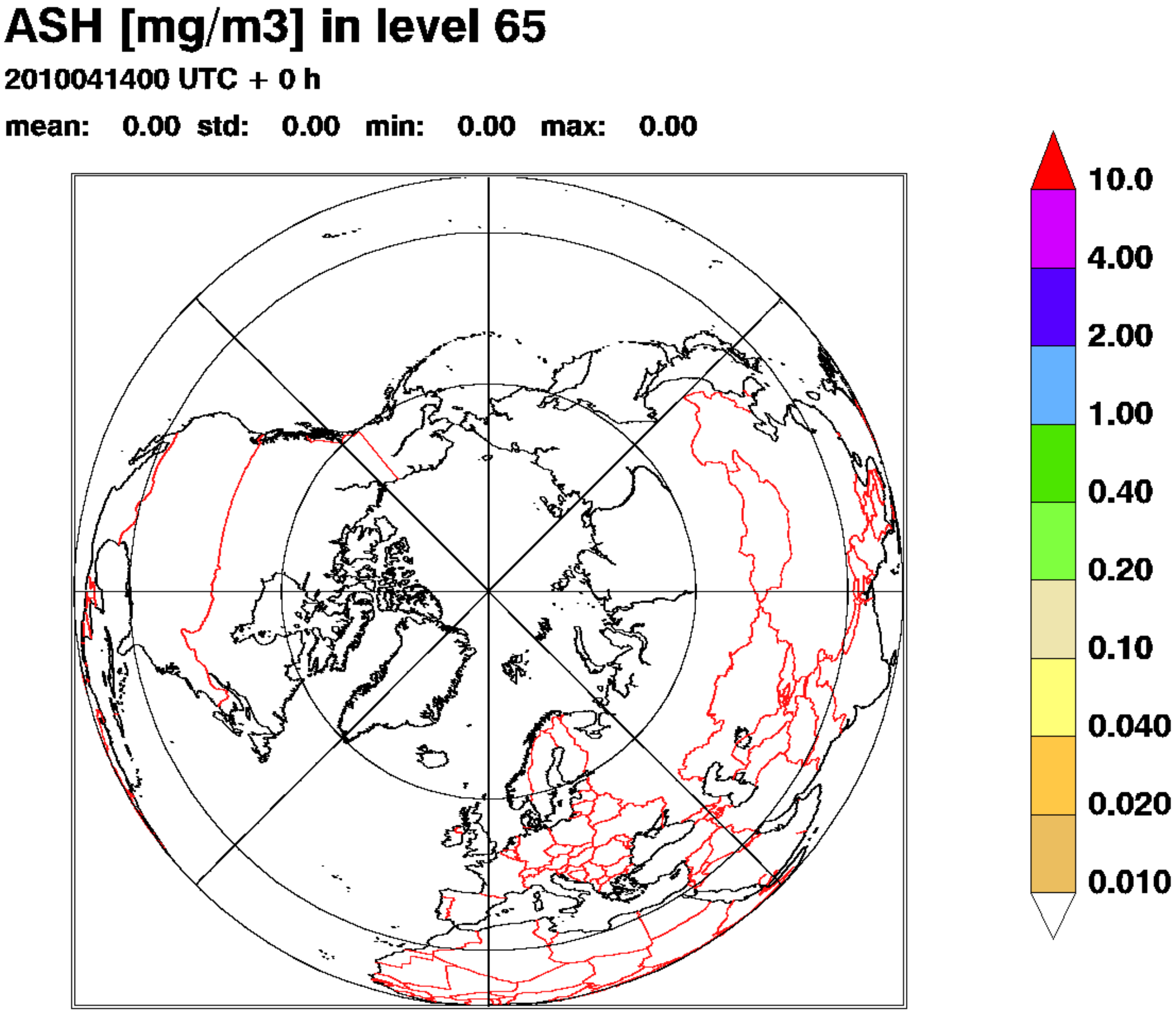
- Source strength, source height, temporal development
- Updated at every advection time step before the tracer advection
- Input file: „name“ „lon(°N)“ „lat(°E)“ „active“ „source strength“ „source height“
- **Gaussian distribution of source strength…**
  **as a function of plume height (Mastin et al. 2009),**
  **measured size distribution (Schumann et al. 2011)**





B. Vogel, KIT

# ICON-ART simulation of two (artificial) volcanic eruptions



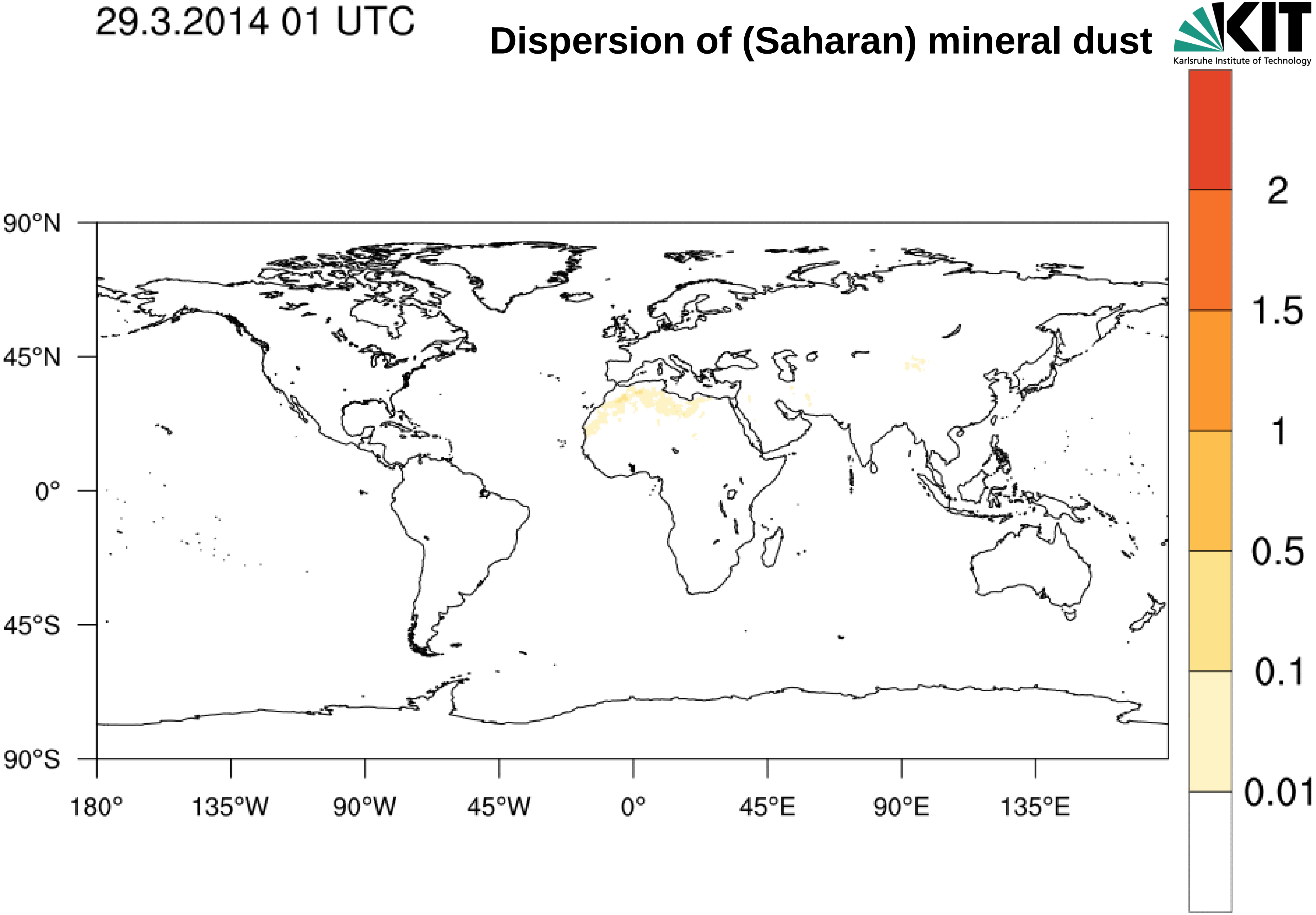
**ASH [mg/m3] in level 65**

2010041400 UTC + 0 h

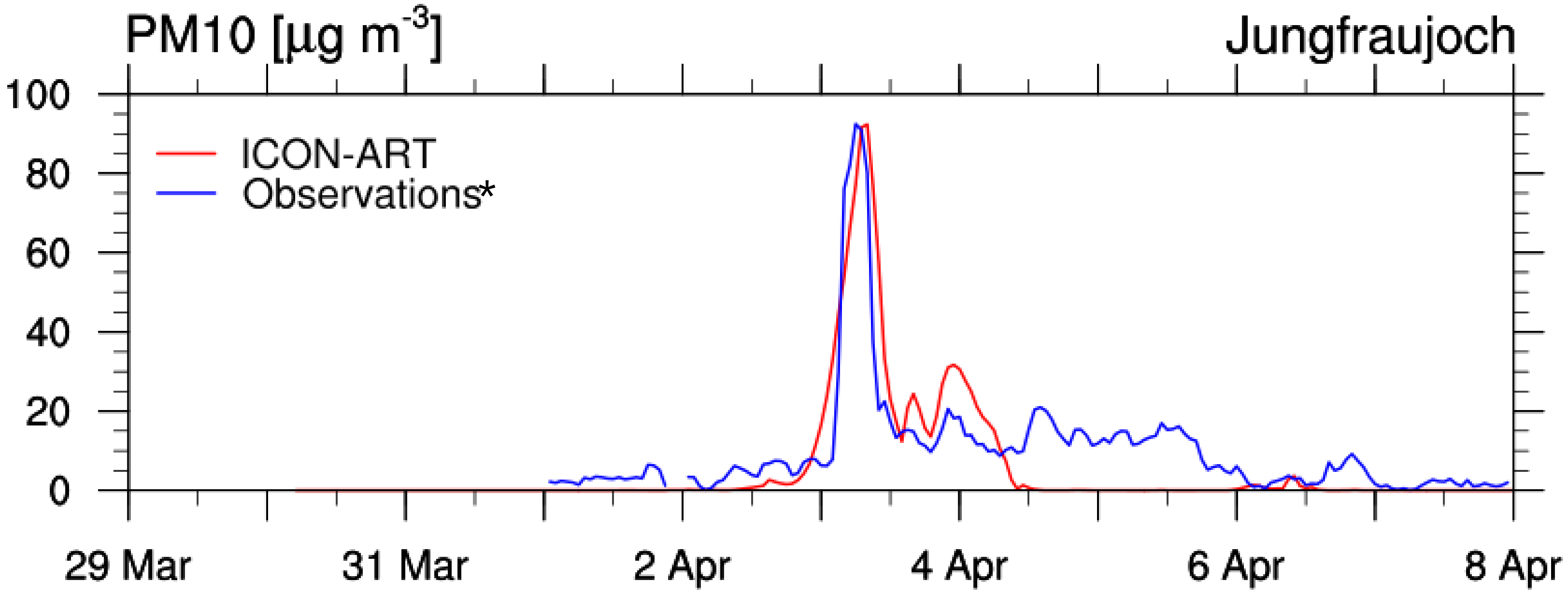
mean: 0.00 std: 0.00 min: 0.00 max: 0.00

B. Vogel, KIT

# Dispersion of (Saharan) mineral dust



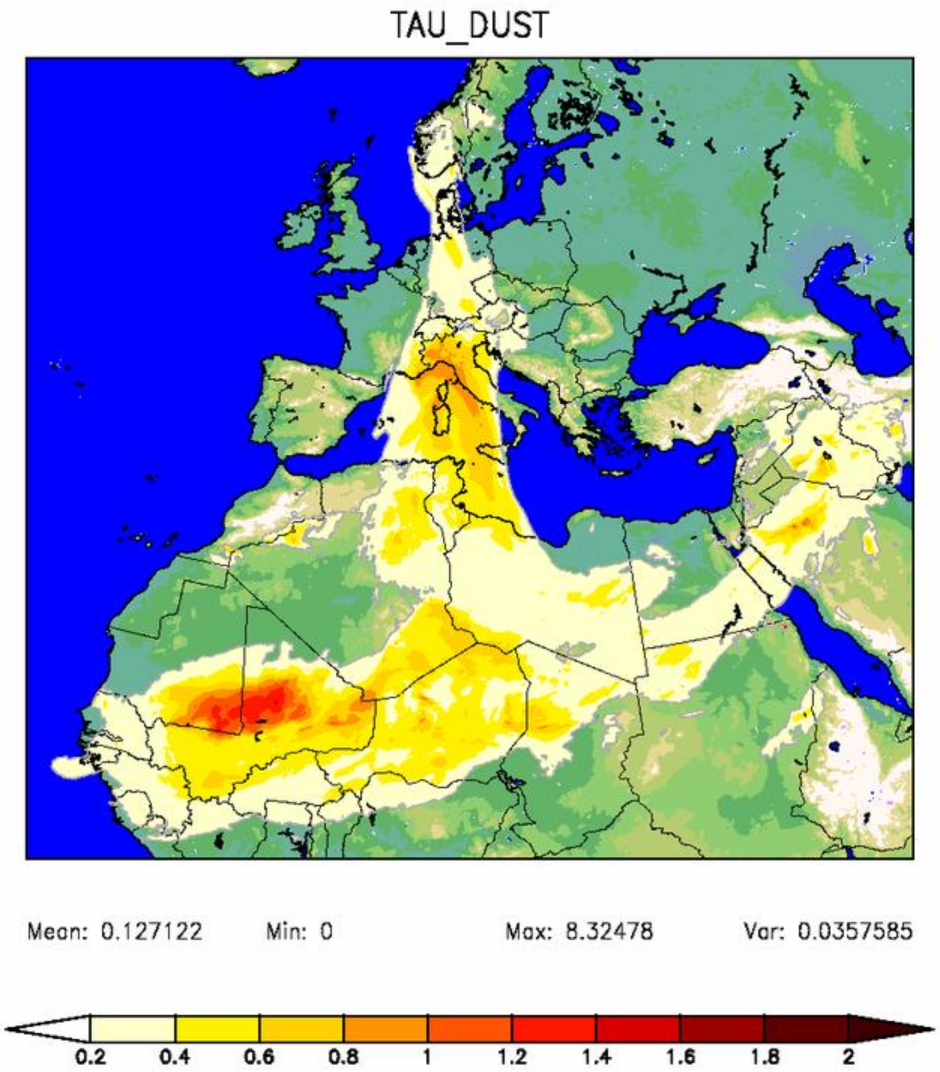
**B. Vogel, KIT**

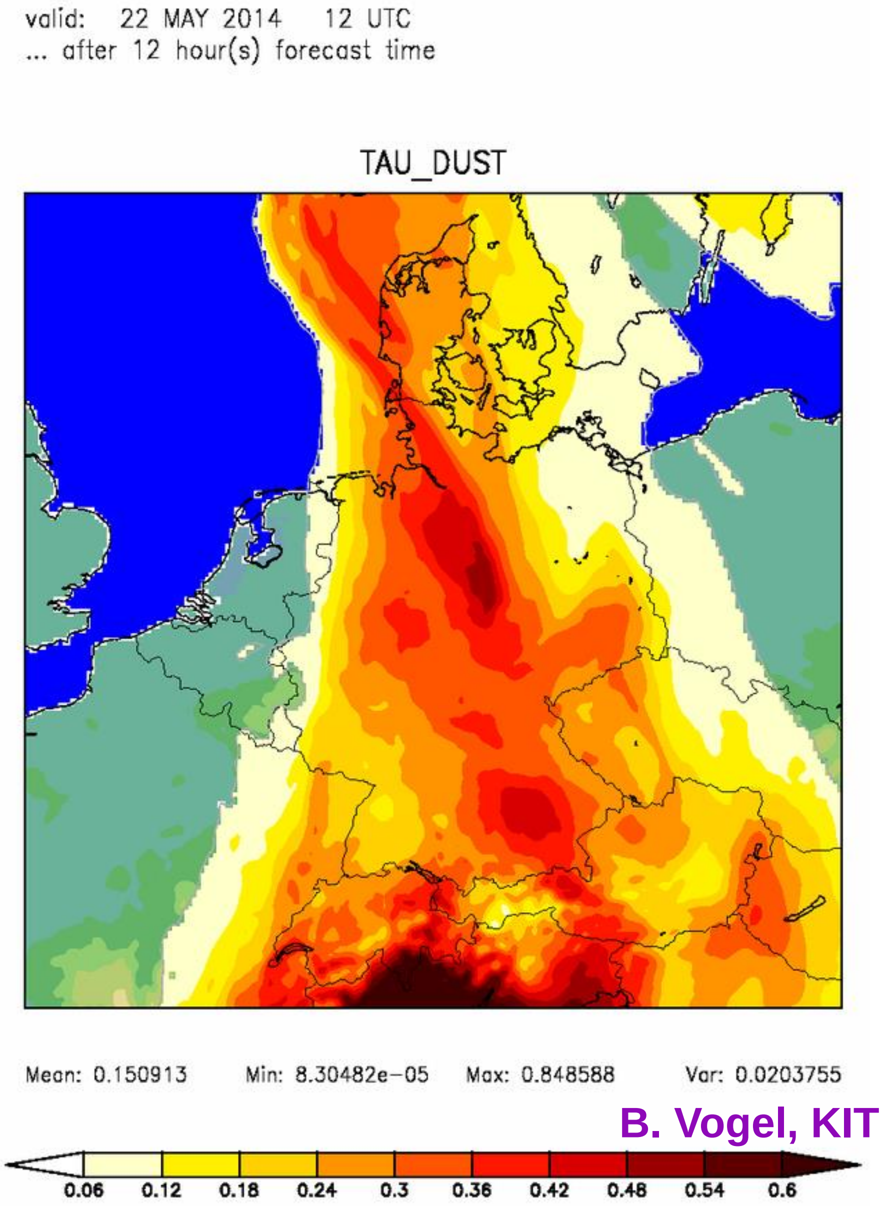


*Volkswirtschaftsdirektion des Kantons Bern, 2015

# Forecast of a Saharan dust outbreak

$$I(\lambda) = I_0 e^{-\tau(\lambda)} \quad \text{for } \lambda = 550 \text{ nm}$$





**B. Vogel, KIT**

# Summary

- **Significant improvement of forecast skill over GME**
- **Higher flexibility thanks to grid nesting capability**
- **Higher efficiency than GME on massively parallel computer architectures**
- **Large range of applications in environmental modelling thanks to ART module**

## Upcoming upgrades at DWD:

- **Q1-Q3: Tile approach for TERRA**
- **Q2/Q3: Activation of nested domain over Europe (“ICON-EU”)**
- **Q4: First step towards ensemble data assimilation**