DWD report

30th WGNE-meeting
23-26 March 2015, NCEP, Washington

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Roland Potthast

Supercomputing environment at DWD (Dec. 2014)

One **production** and one **research** computer **Cray XC.., each** with

- 2 Cabinets with 364 compute nodes (Cray XC30)
  each node: 2 * Intel Xeon (Ivy Bridge, 2.5 GHz, 10 cores), 64 Gbyte
  → 7280 cores, 22.75 Tbyte
  Linpack R_{max}=133.7 Tflop/s
- 3 Cabinets with 432 compute nodes (Cray XC40)
  each node: 2 * Intel Xeon (Haswell, 2.5 GHz, 12 cores), 128 Gbyte
  → 10368 cores, 54 Tbyte
  Linpack R_{max}=390.6 Tflop/s

Rank 128 & 129 in Top500-list from Nov. 2014

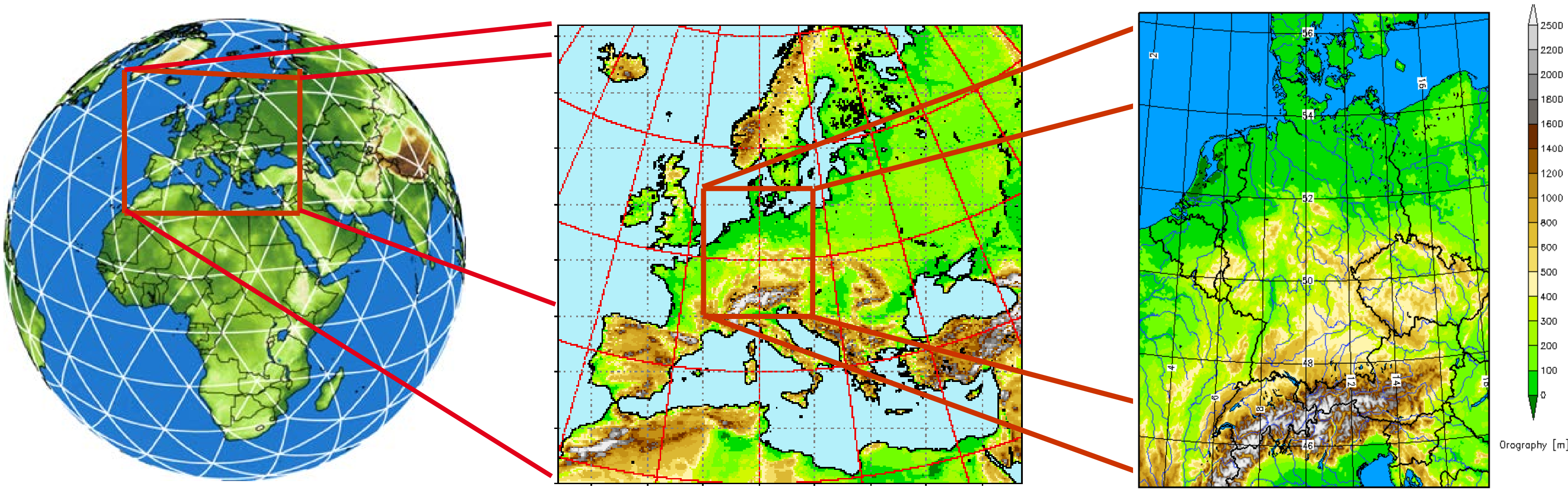
Login nodes:
2 * (prod./research) login nodes:
12 (14) nodes
each node: 2x Intel Xeon (Ivy Bridge, 10 cores), 128/512 GByte

The operational Model Chain of DWD

ICON
(has replaced GME)

COSMO-EU

COSMO-DE
and **–EPS** (20 members)



non-hydrostatic
parameterised convection
Δx ≈ 13 km, Δt = 120 (24) sec.,
2.95 Mio. * 90 GP
T = 180h (00, 12 UTC runs)
120h (06, 18 UTC runs)

non-hydrostatic
parameterised convection
Δx = 7 km, Δt = 66 sec.,
665 * 657 * 40 GP
T = 78 h (00, 06, 12, 18 UTC runs)

non-hydrostatic
convection-permitting
Δx = 2.8 km, Δt = 25 sec.,
421 * 461 * 50 GP
T = 27 h (every 3 hrs)

Future NWP system at DWD at end of 2015

Deutscher Wetterdienst
Wetter und Klima aus einer Hand

Global model ICON

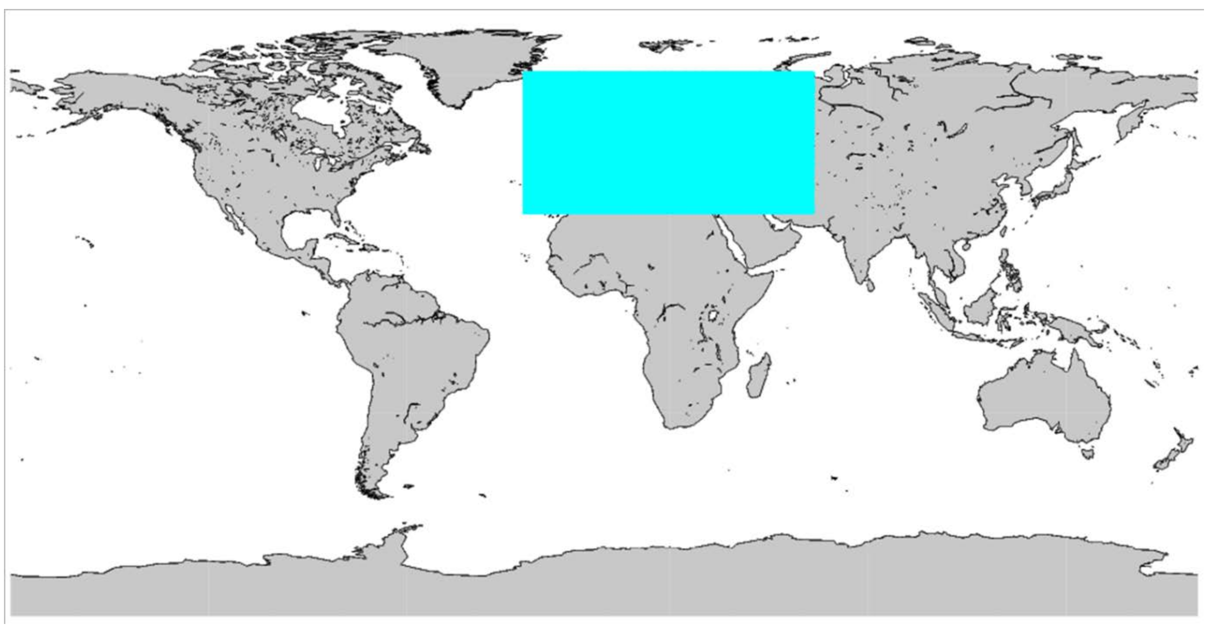
(oper. since 20 Jan. 2015)
$\Delta x \approx 13$ km, $\Delta t = 120$ (24) sec.,
2.95 Mio. * 90 GP
180 h (00, 12 UTC runs)
120 h (06, 18 UTC runs)
grid area: 173 km^2
H = 75 km

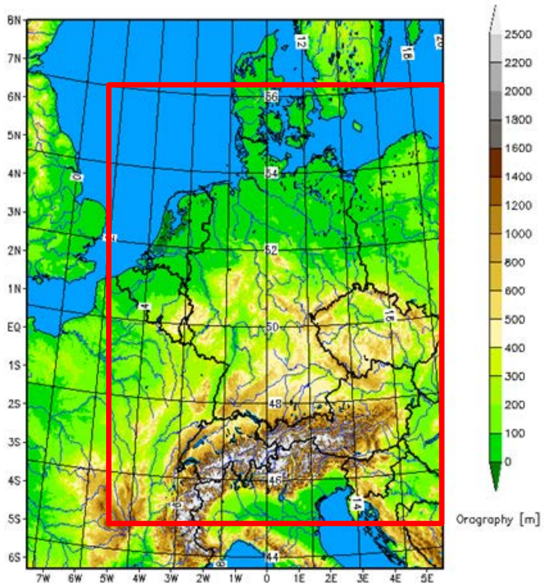
ICON (zooming area Europe)

$\Delta x \sim 6.5$ km
levels: 60
120 h (00, 06, 12, 18 UTC runs)
grid area: 43 km^2
H = 22.5 km

COSMO-DE (-EPS)

$\Delta x \sim 2.2$ km, $\Delta t = 20$ sec.
levels: 65
27 h (00,03, …,18,21 UTC run)
grid area: 5 km^2
H = 22 km
EPS with 40 members





Global model ICON

(replaced the former GME)

Model equations (dry dynamical core)

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

$$\partial_t v_n + (\zeta + f)\, v_t + \partial_n K + w\, \partial_z v_n = -\, c_{pd}\theta_v \partial_n \pi$$

$$\partial_t w + \vec{v}_h \cdot \nabla w + w\, \partial_z w = -\, c_{pd}\theta_v \partial_z \pi - g$$

$$\partial_t \rho + \nabla \cdot (\vec{v}\rho) = 0$$

$$\partial_t(\rho\theta_v) + \nabla \cdot (\vec{v}\rho\theta_v) = 0$$

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

red: independent prognostic variables

Parameterisations of physical processes

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), Machulskaya, Helmert, Mironov (2008, lake)	tiled TERRA + FLAKE + multi-layer snow	GME/COSMO
	Raddatz, Knorr	JSBACH	ECHAM6

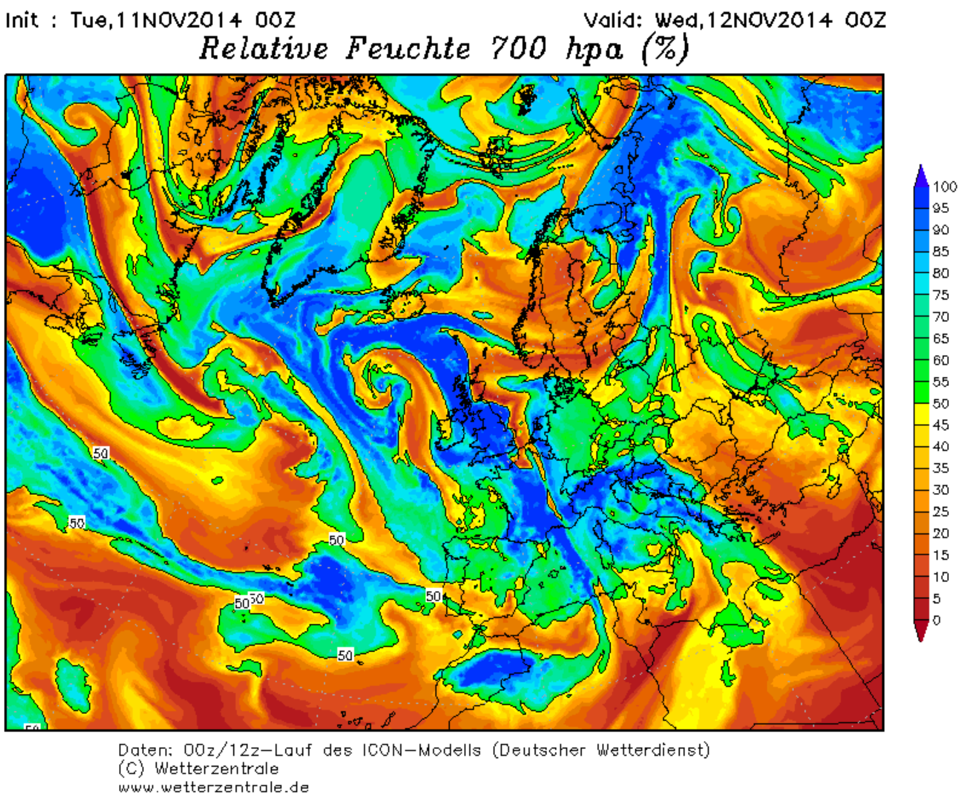
Operational at DWD

Systematic changes compared to GME

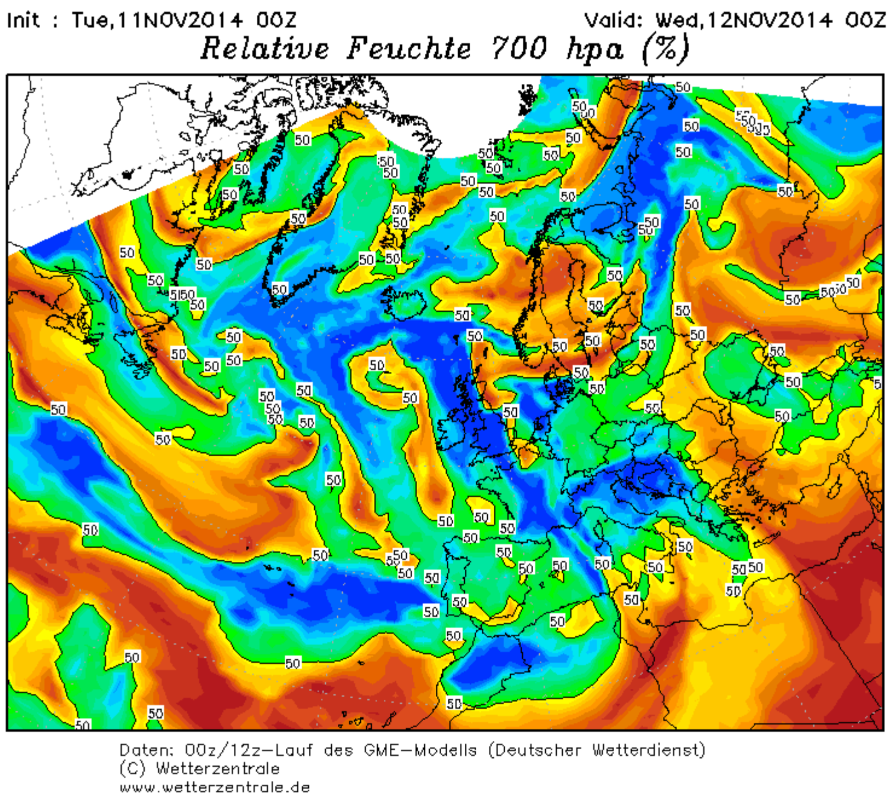
- **less diffusive numerics → more fine scale structures**

Illustration 1: RH700

ICON



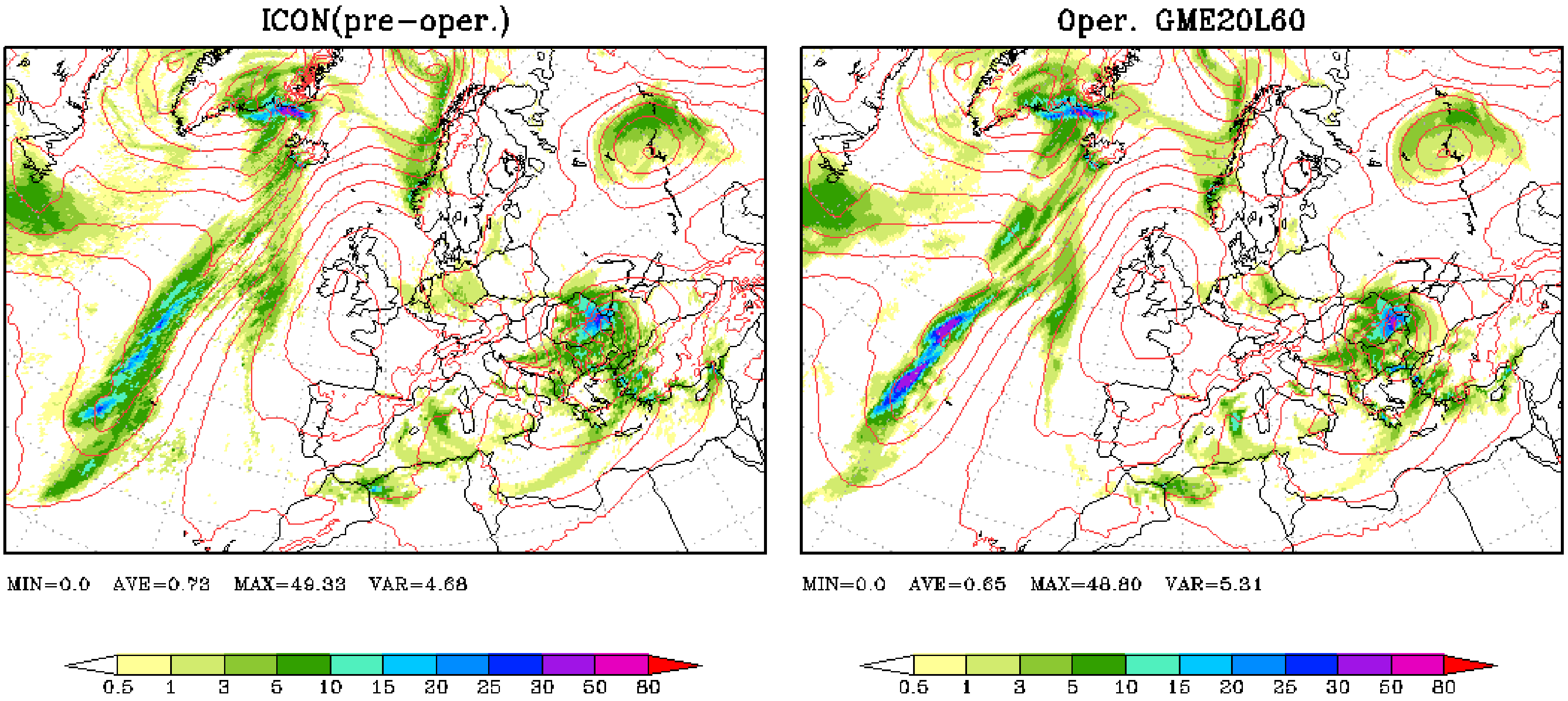
GME



Systematic changes compared to GME

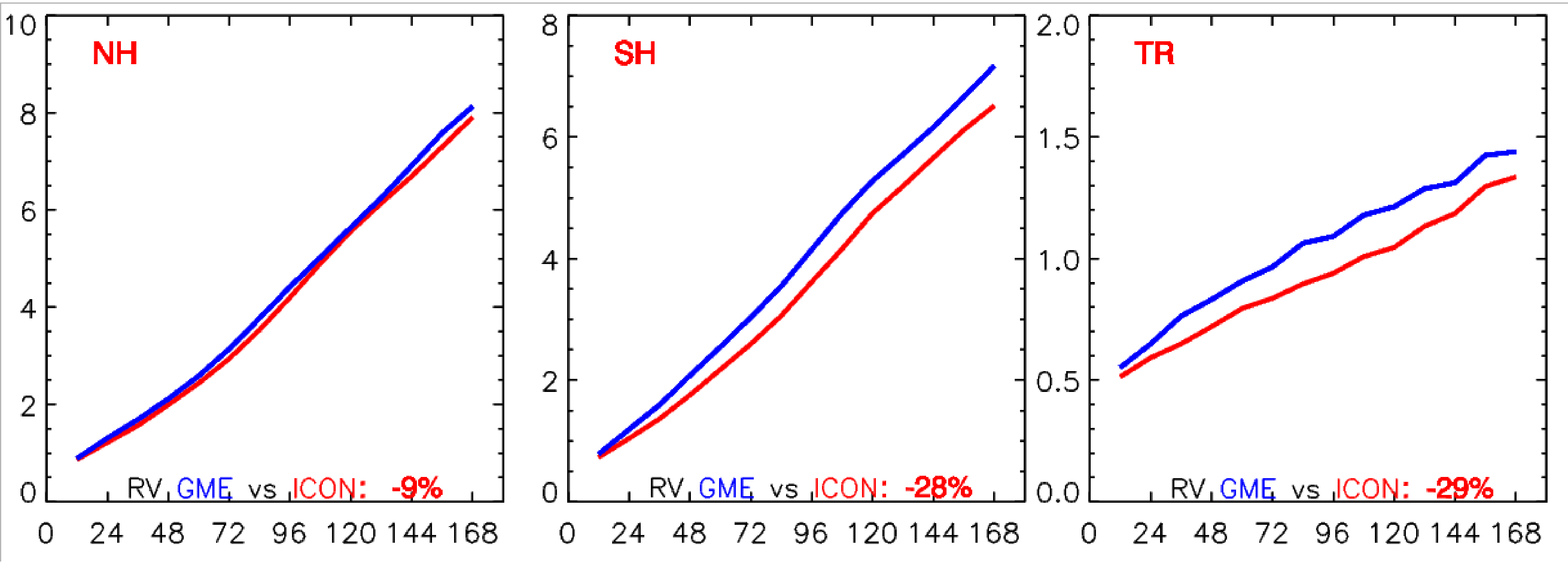
- less diffusive numerics → more fine scale structures
- changed diagnostics of temperature and geopotential / reduced bottom pressure for extrapolation beneath the ground
- **changed convection parameterisation (Bechthold et al.-scheme) → more uniform distribution of precipitation**

Illustration 3: 6-hourly precipitation, 28.12.2014, vv=12h until vv=18h



Mean sea-level pressure, RMSE in hPa

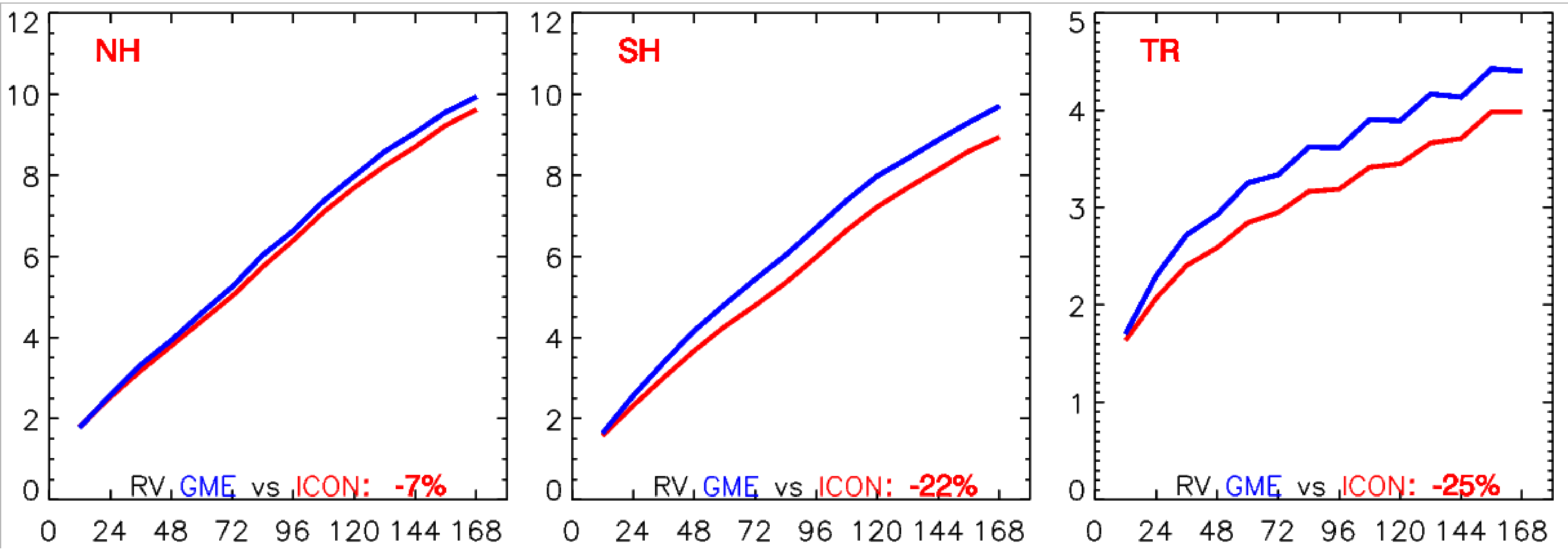
blue: GME, red: ICON



RV = reduction of variance

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

blue: GME, red: ICON



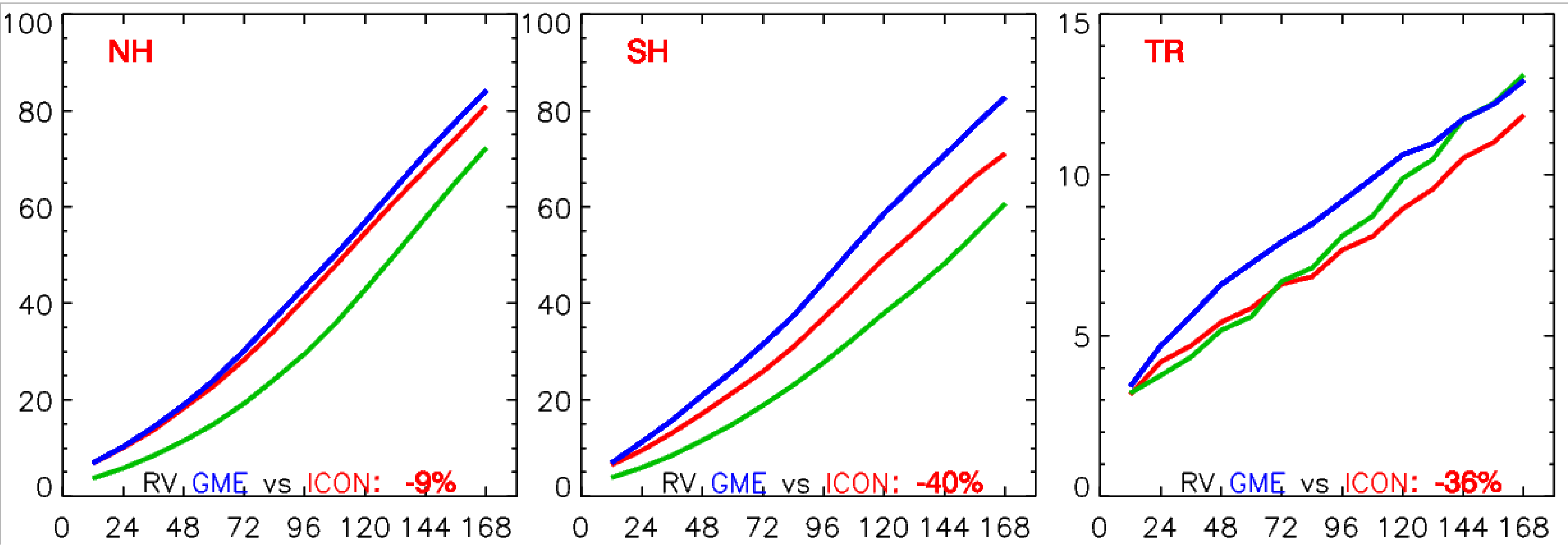
RV = reduction of variance

Analysis verification

Deutscher Wetterdienst
Wetter und Klima aus einer Hand

Geopotential height at 500 hPa, RMSE in m

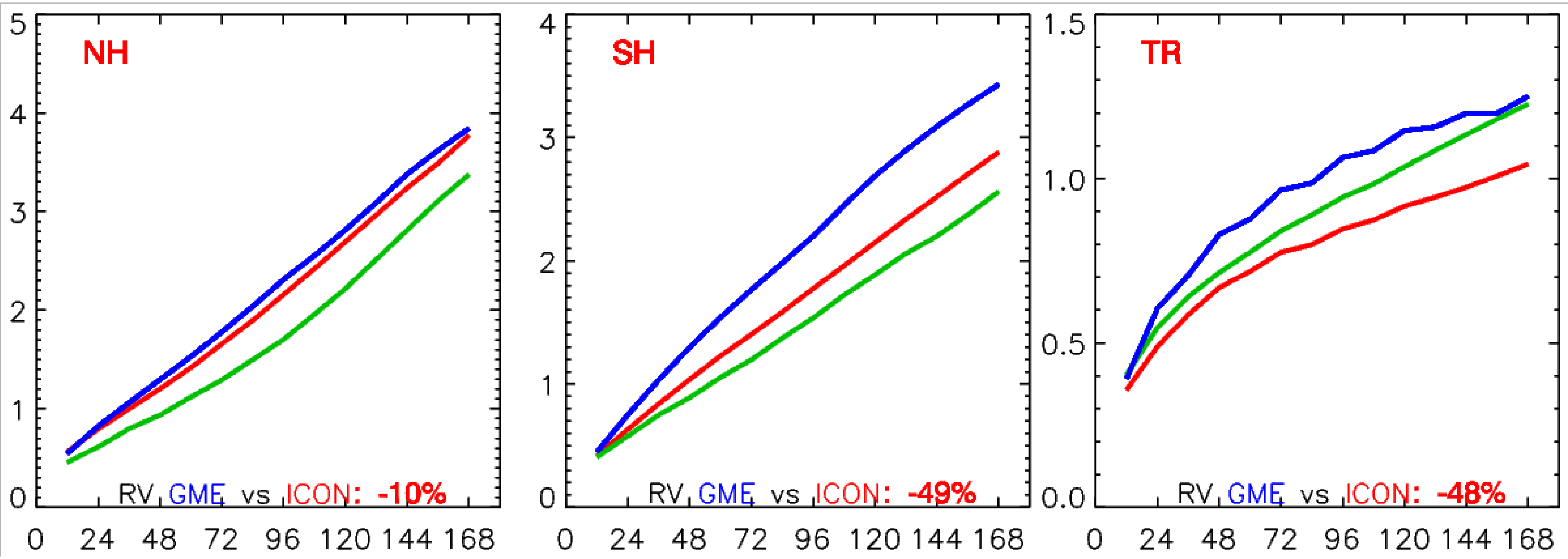
blue: GME, red: ICON, green: IFS



RV = reduction of variance

Temperature at 700 hPa, RMSE in K

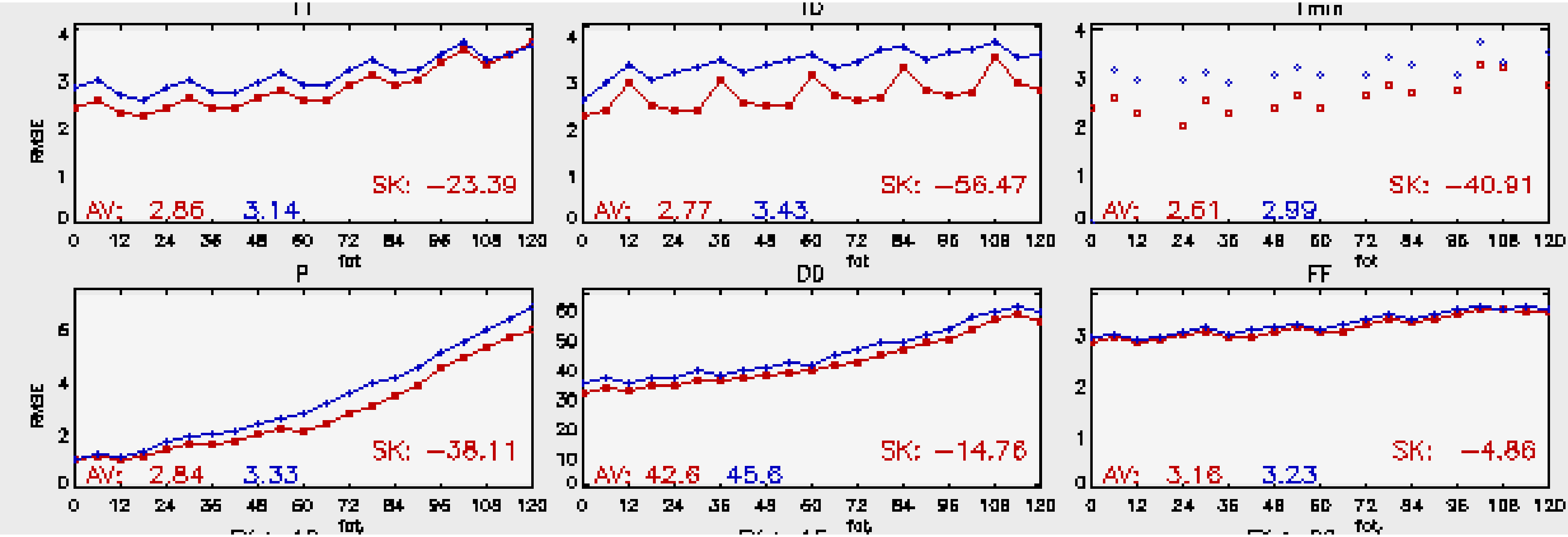
blue: GME, red: ICON, green: IFS



RV = reduction of variance

Surface verification Europe; blue: GME, red: ICON

temperature | dew point depression | minimum temperature



pressure | wind direction | wind speed

XXL scalability test (computed at ECMWF)

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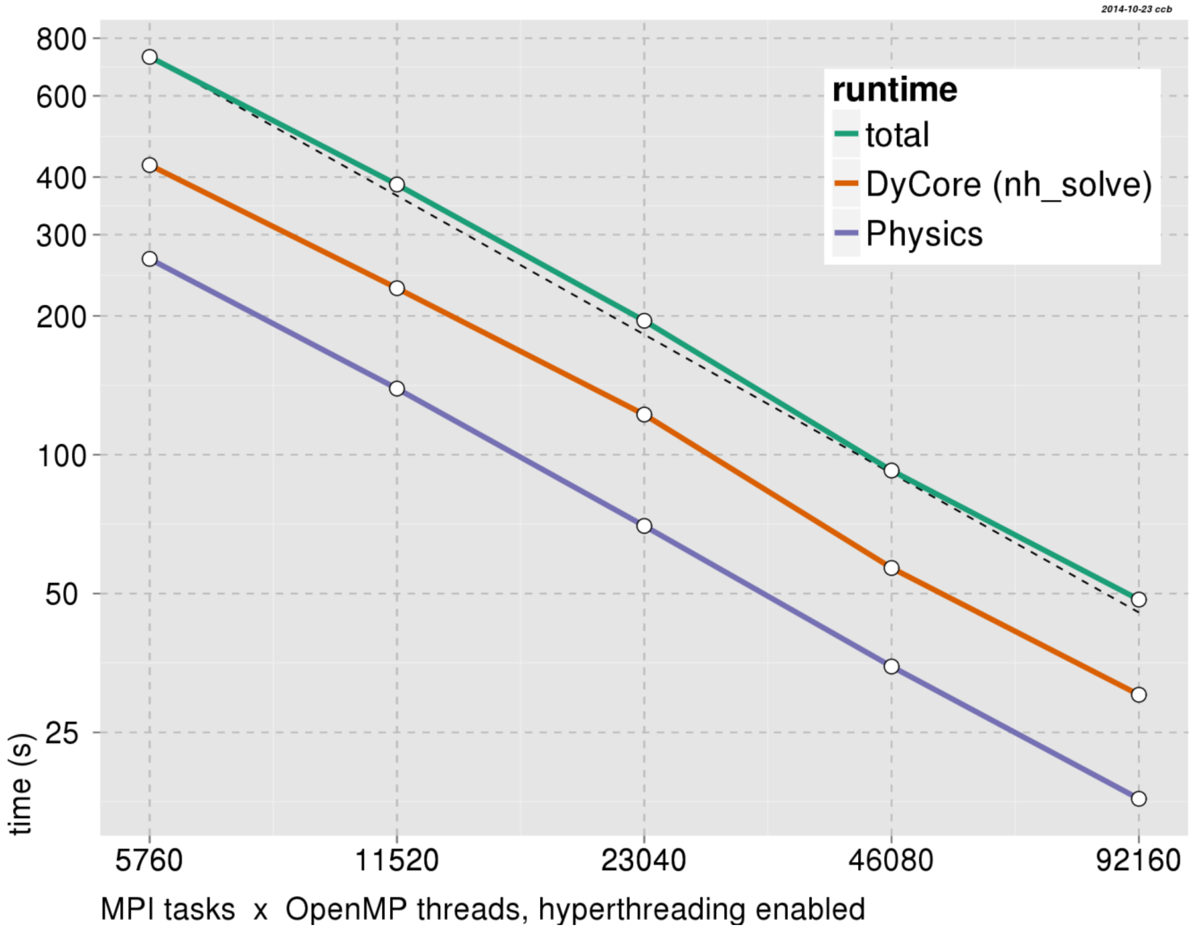
- **Mesh size 5 km (~21M grid points), 90 levels, 1000 time steps**
- **No output (field size too large for NetCDF3, technical issues with NetCDF4)**

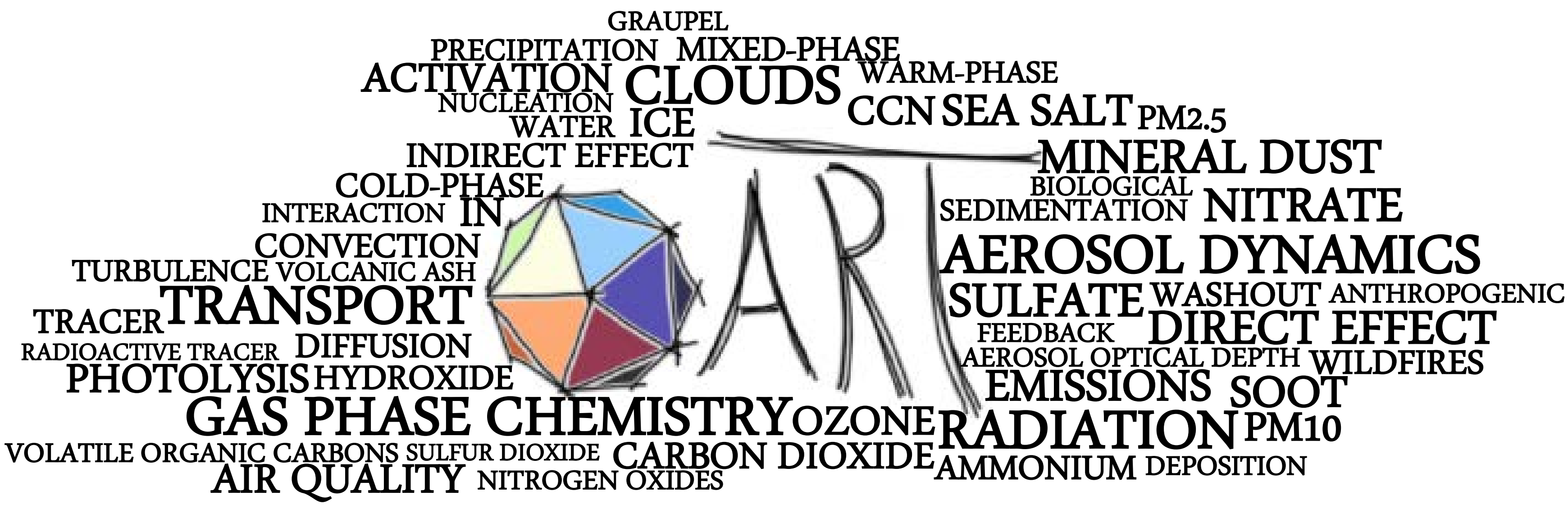


Summary

- Significant improvement of forecast skill compared to 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



ICON-ART

ART = Aerosol and Reactive Trace gases

Emission of Volcanic Ash

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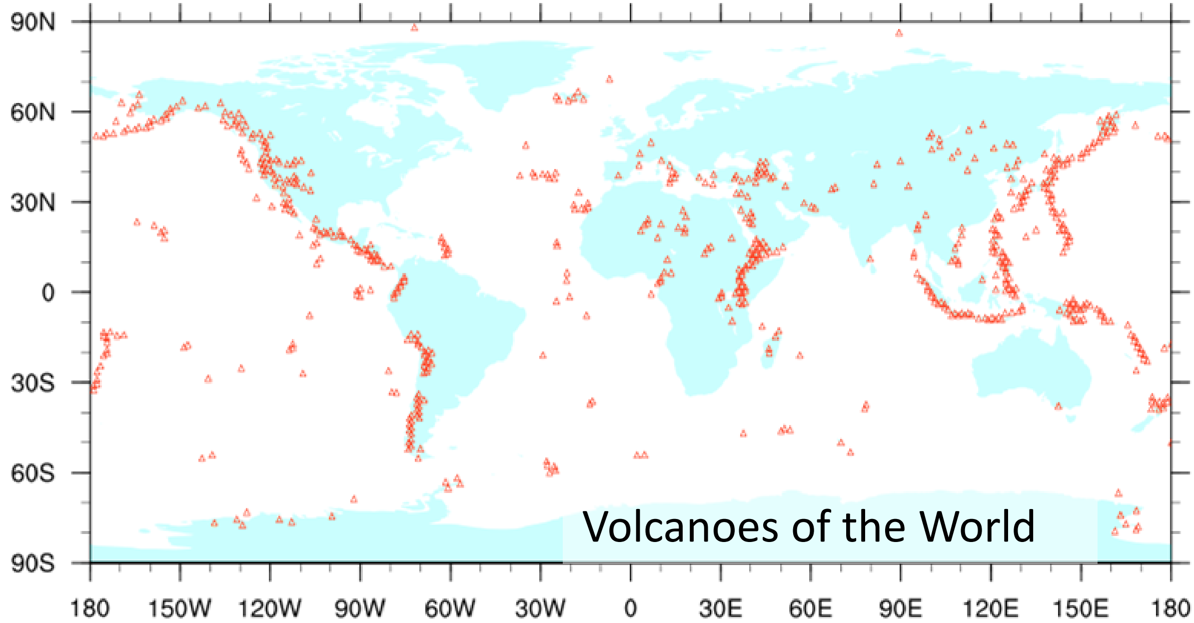
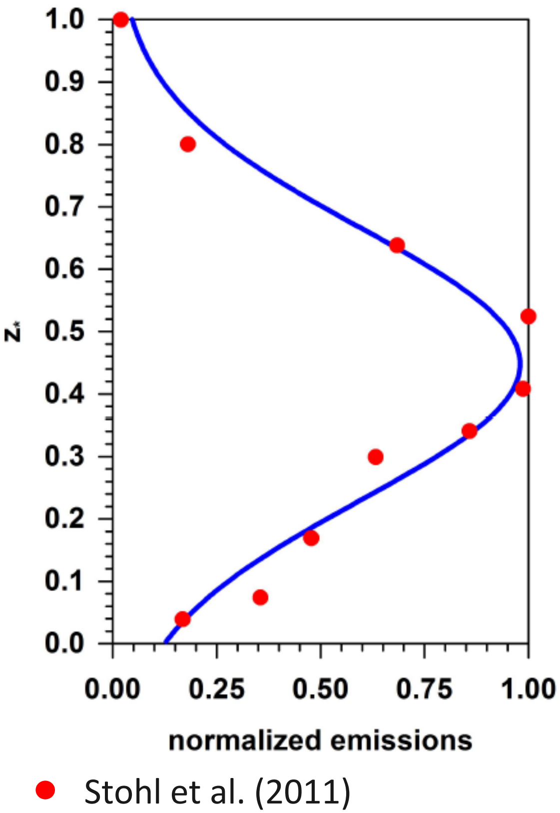
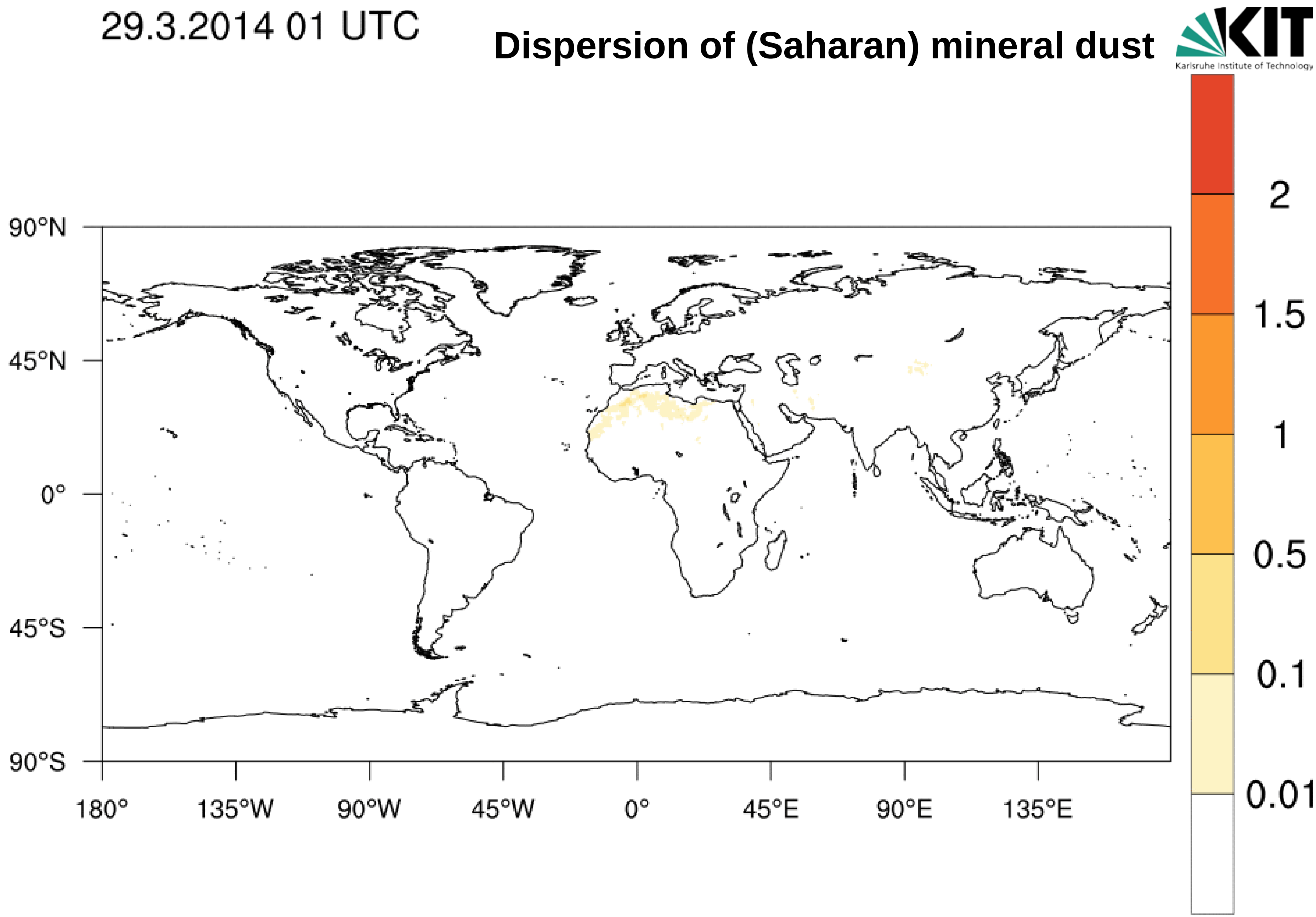
volcanic ash forecast is used as an alert system at DWD

- 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)**





Dispersion of (Saharan) mineral dust



B. Vogel, KIT

Forecast of a Saharan dust outbreak

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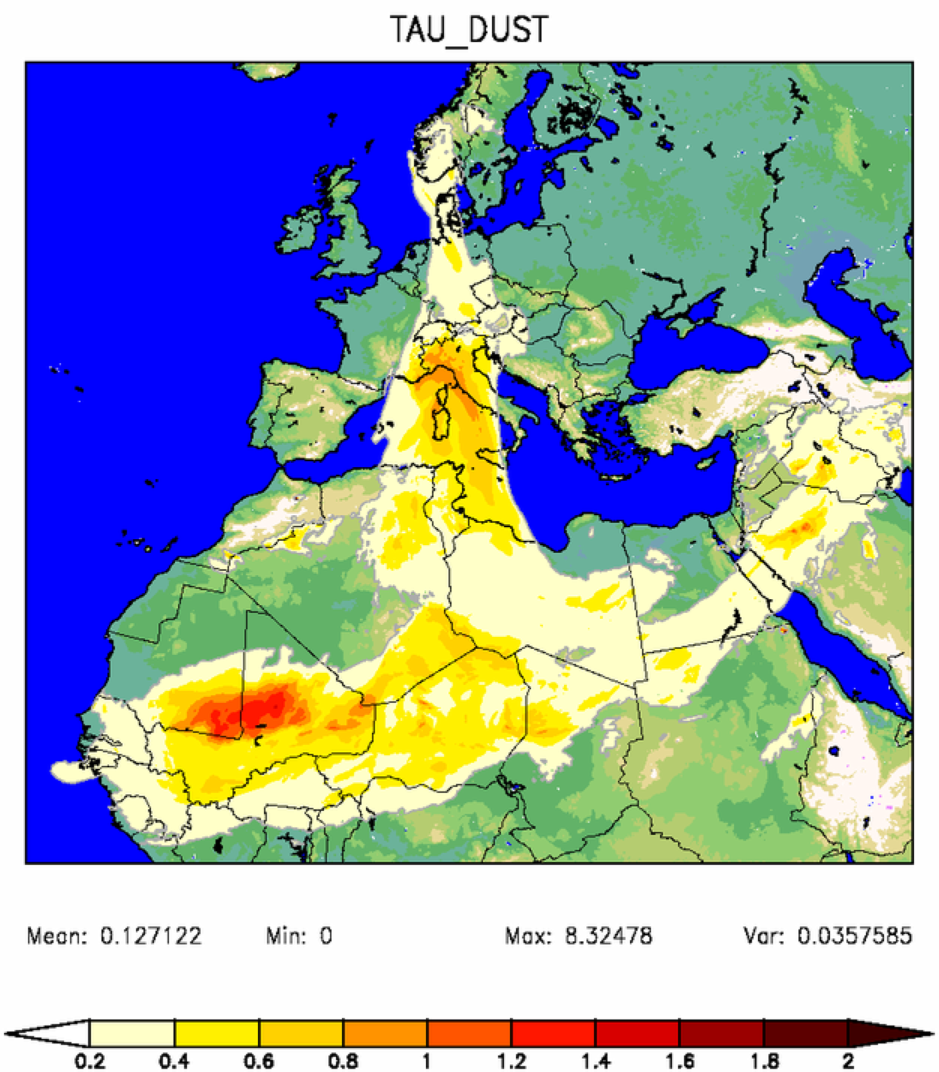
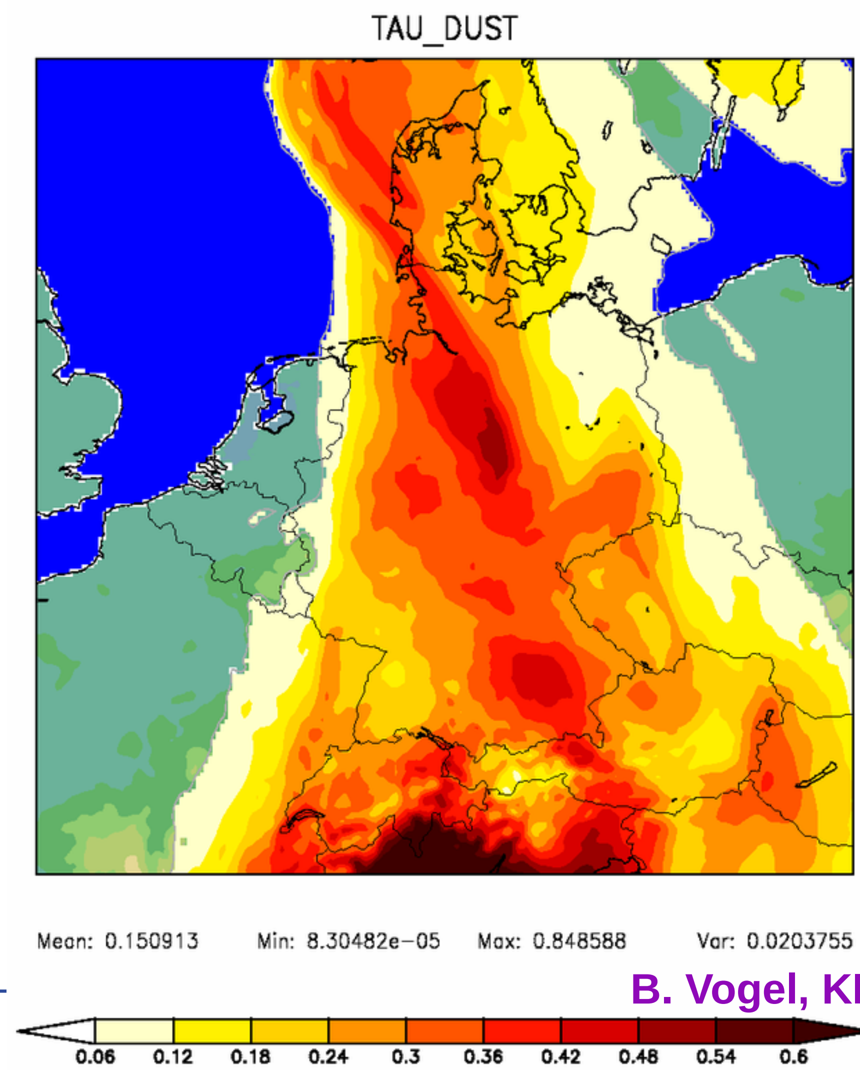
optical thickness τ of interest for solar energy forecast!

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

valid: 22 MAY 2014 12 UTC
... after 12 hour(s) forecast time





B. Vogel, KIT

Global
Ensemble Data Assimilation (EDA)

- VarEnKF
- 40 Members
- 1 Deterministic

from Roland Potthast

Global EDA (VarEnKF) Development

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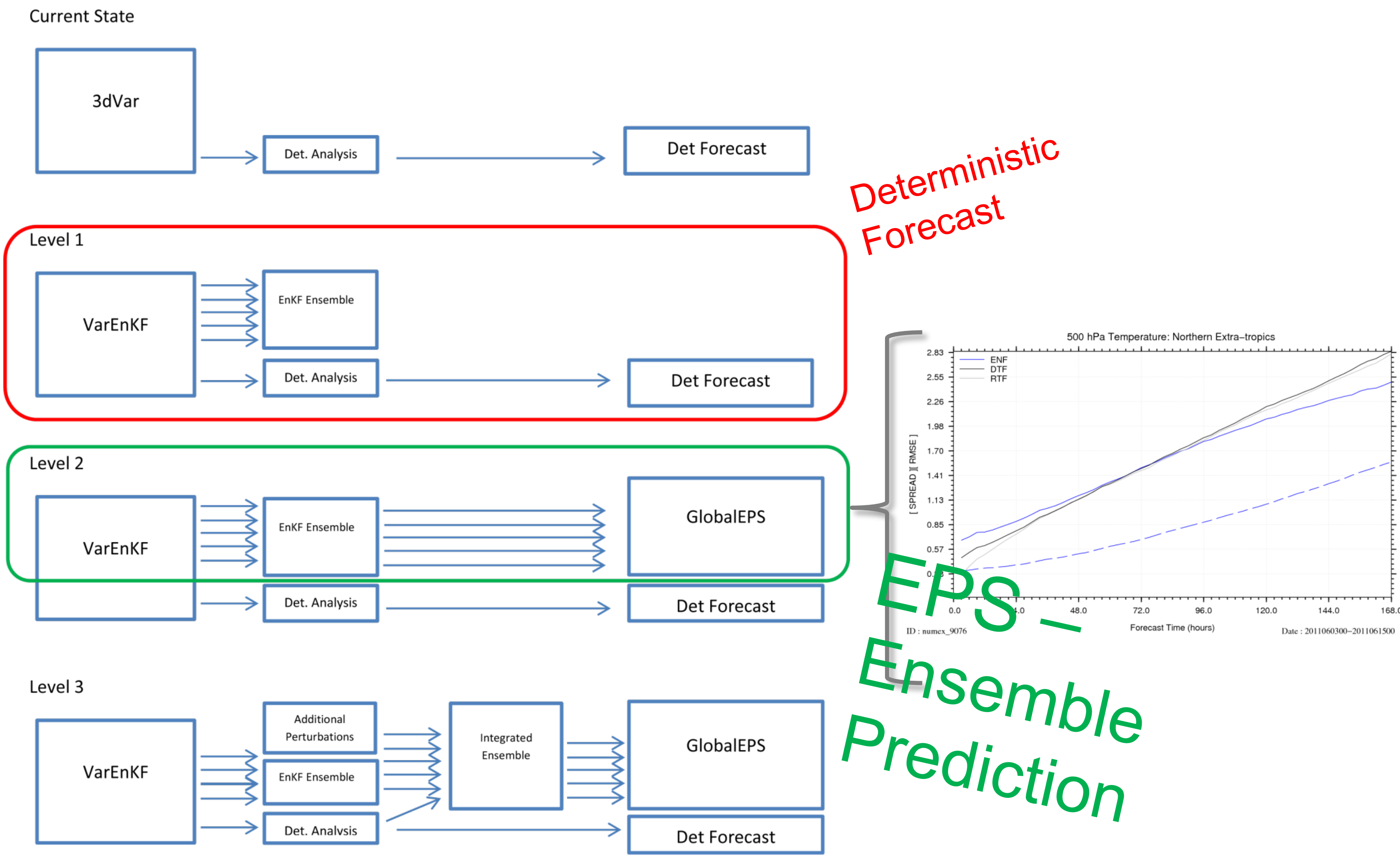
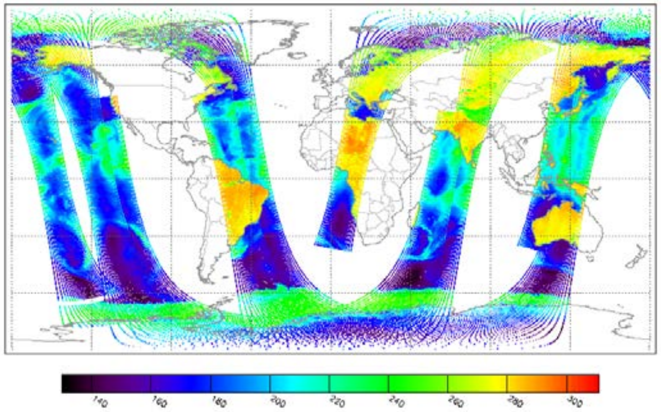
Wetter und Klima aus einer Hand

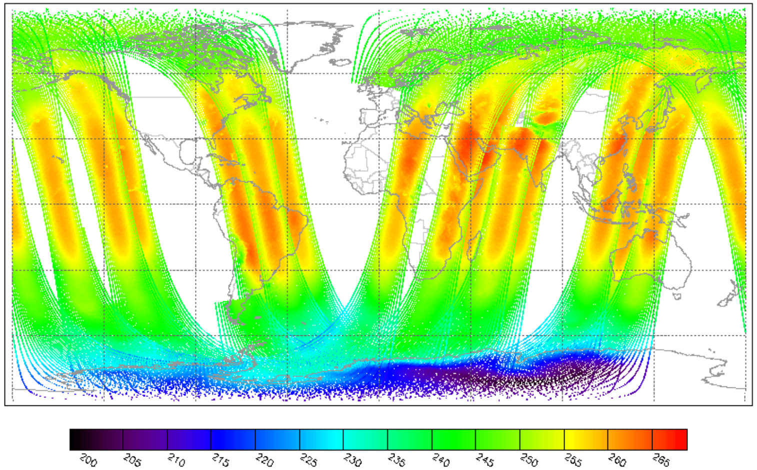


from Roland Potthast

Global EnKF + EPS for ICON

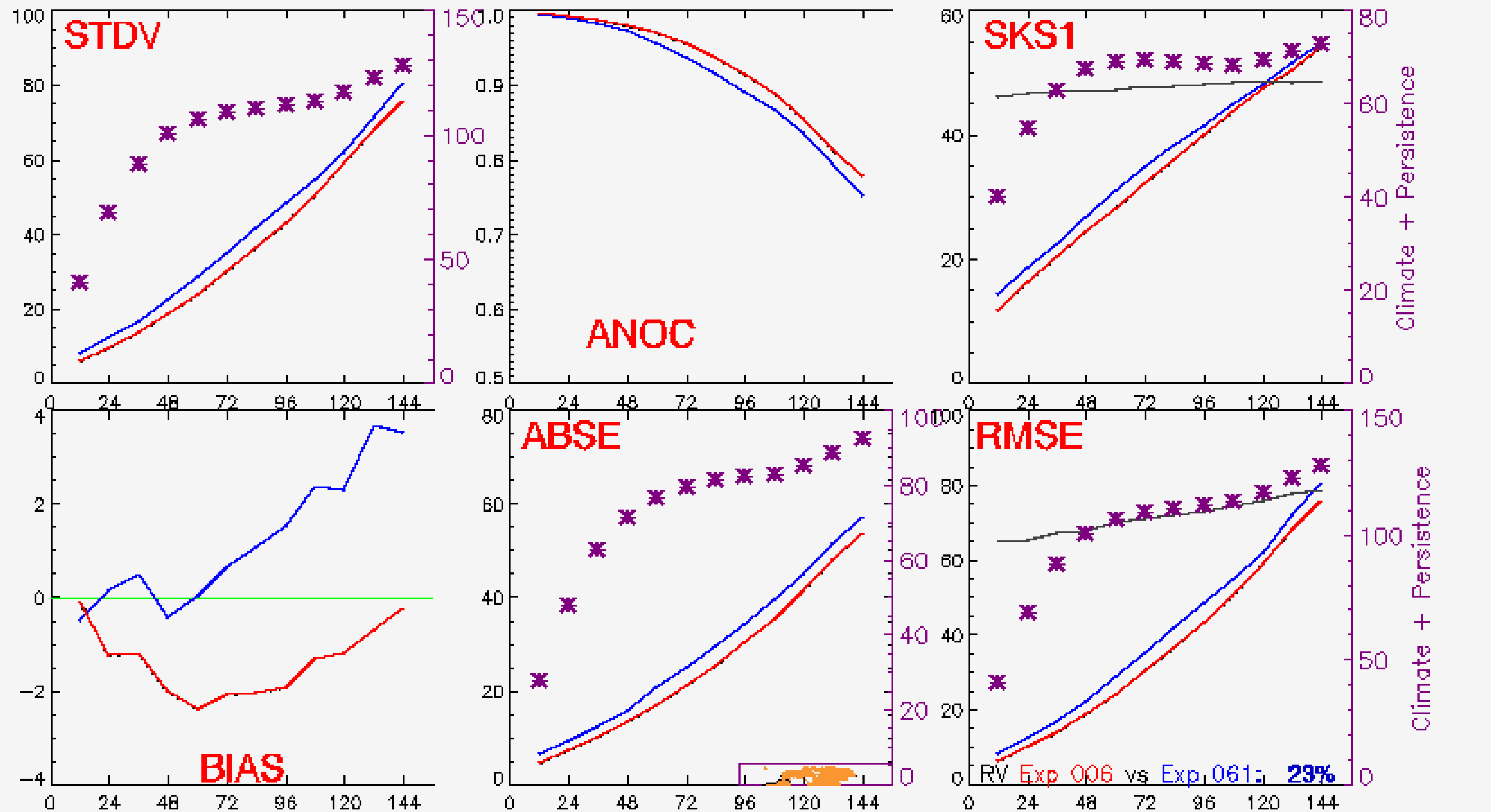


1. **Full System** with all current observation systems *running in BACY experiments (80/40km)*
2. Currently: verification against own analysis **better or comparable** to current 3DVAR system
3. Work in progress on **spread** in different regions (upper troposphere, Europe, …)
4. Adaptive localization **calibration** is ongoing
5. Technical work on speed (ICON 13km) ongoing (02/2015 to be finished)
6. **Archive/Storage** challenges remain severe



from Roland Potthast

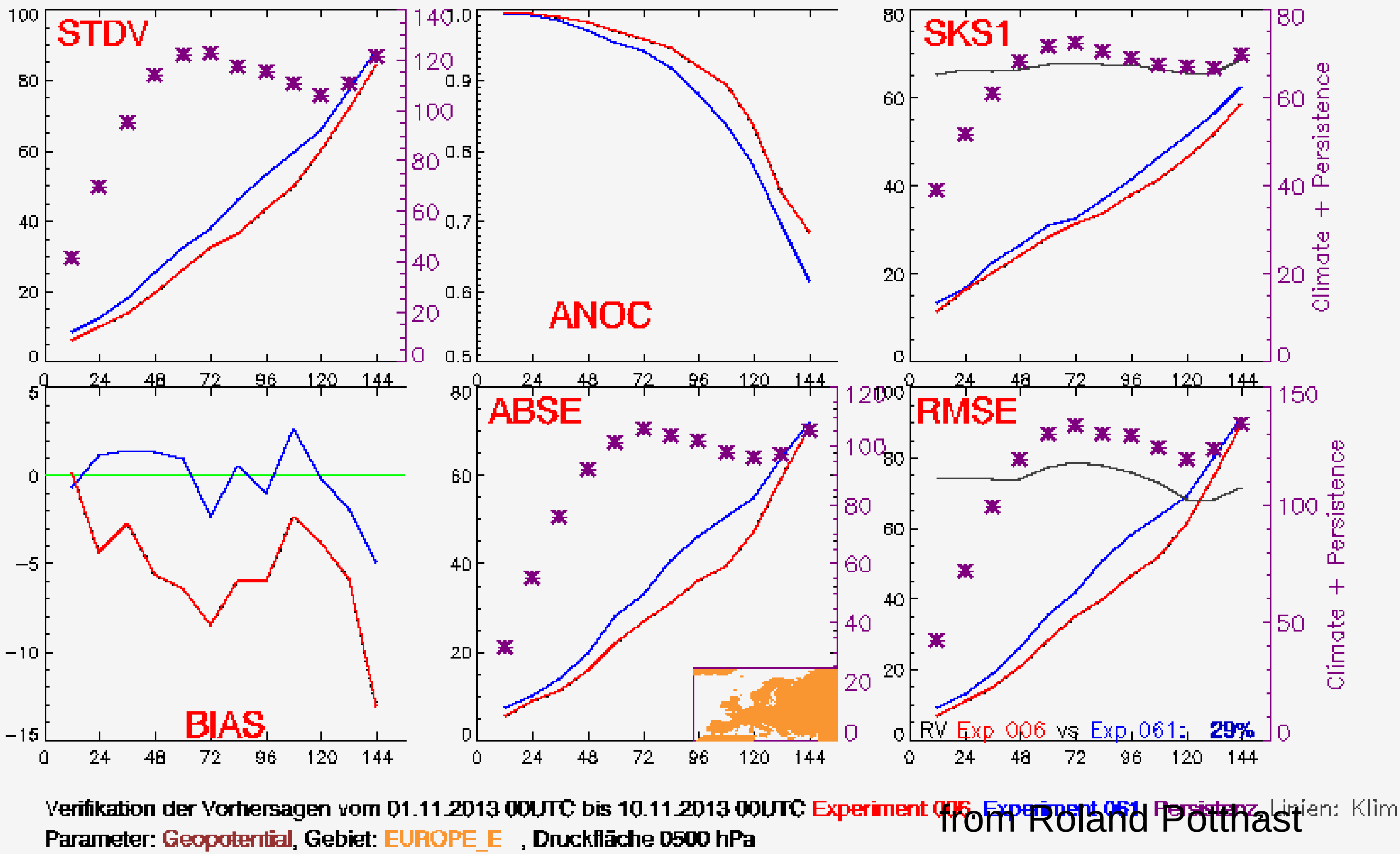
NH, 500hPa Geopotential, rot ICON EDA, blau 3DVAR



Verifikation der Vorhersagen vom 01.11.2013 00UTC bis 10.11.2013 00UTC Experiment 006 Experiment 061 Persistenz Linien: Klima
Parameter: Geopotential, Gebiet: NH , Druckfläche 0500 hPa

from Roland Potthast

Europa, 500hPa Geopotential, rot ICON EDA, blau 3DVAR

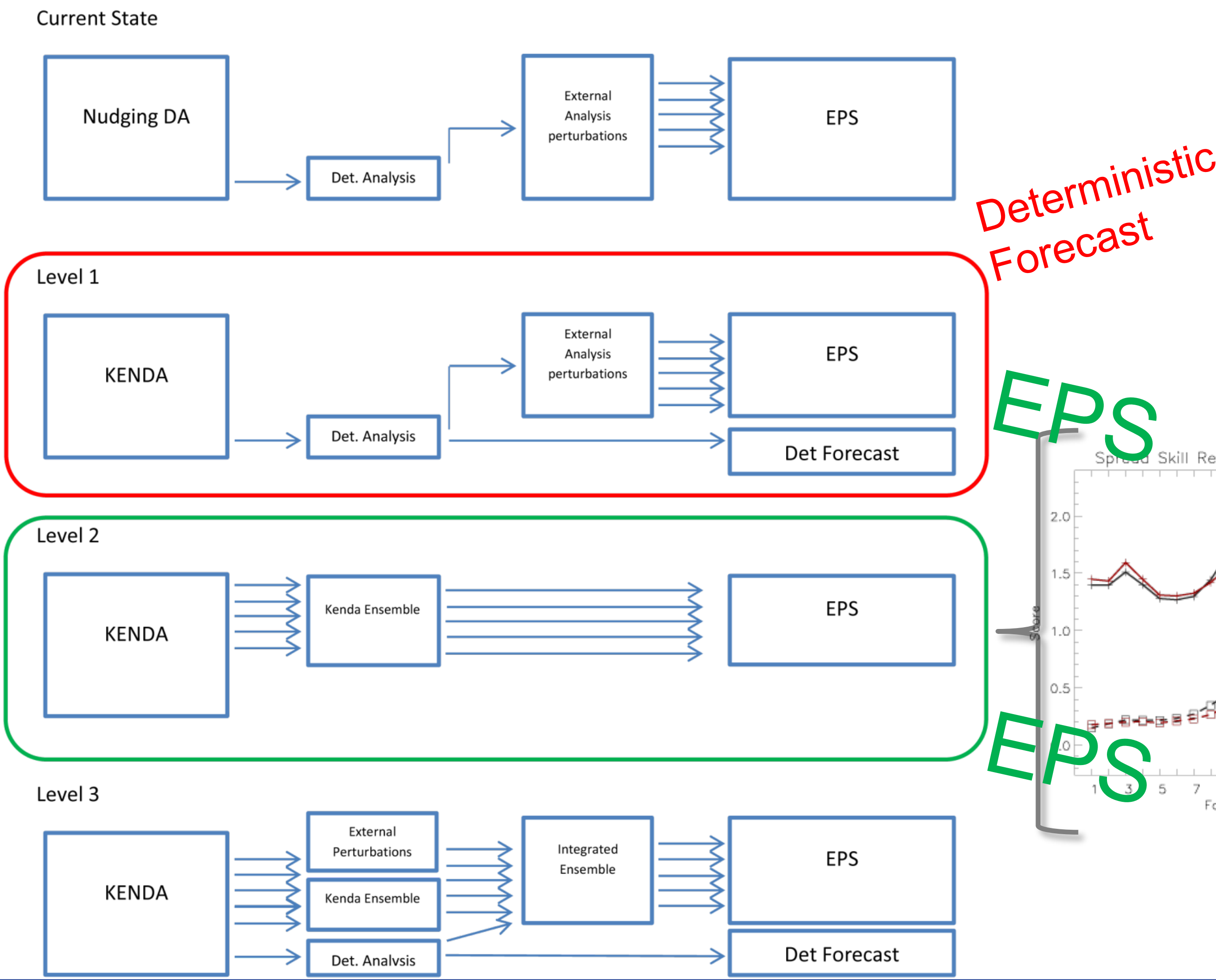


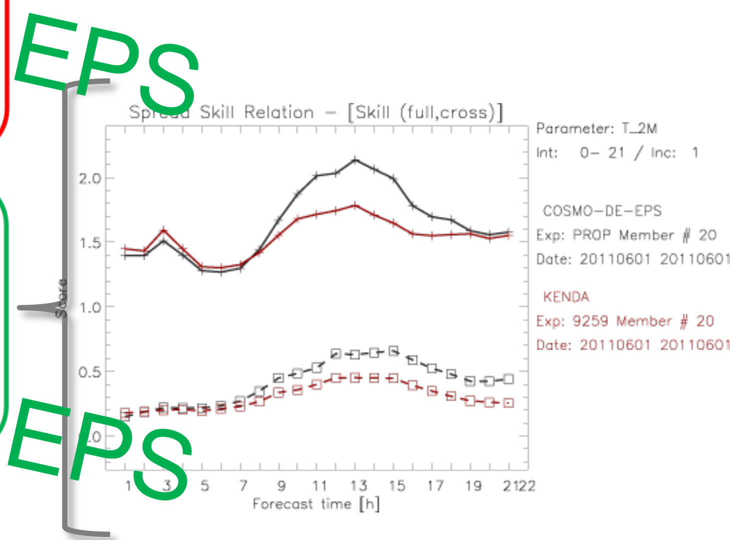
from Roland Potthast

Kilometer Scale Ensemble Data Assimilation (KENDA)

- **LETKF + DetAnalysis**

KENDA and EPS Development





KENDA for COSMO

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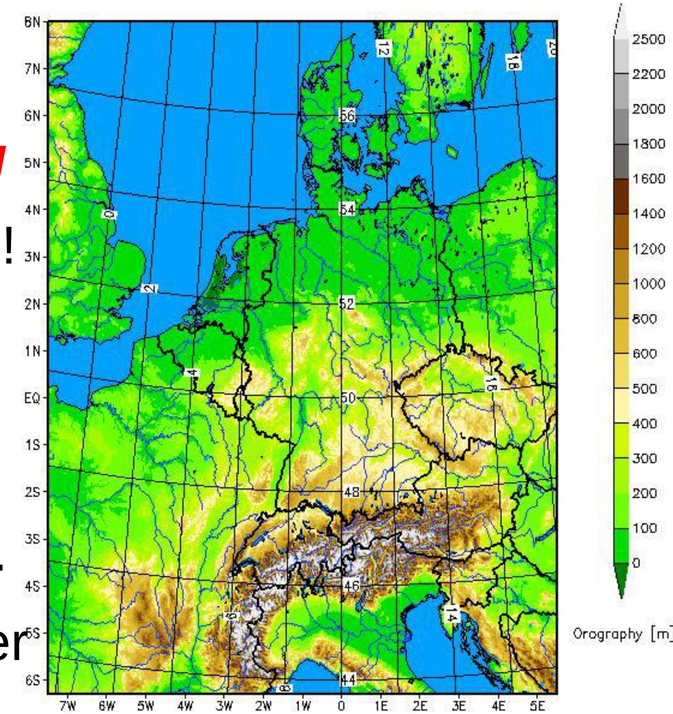


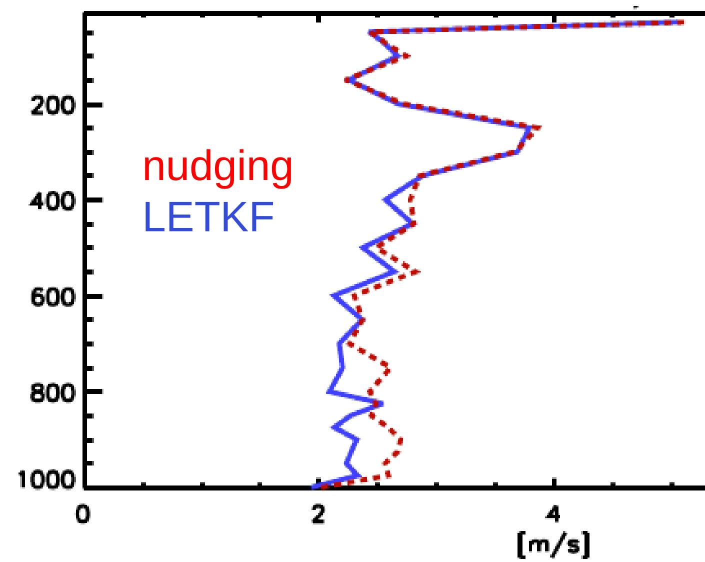
1. **Full System** with **conventional data** ***running***
2. Work **Latent Heat Nudging**, done, works well!
3. Further **Observation Systems** under development (e.g. **SEVIRI, GPS/GNSS**, Lidar, …)
4. **Longer Periods/Winter Periods** to be tested.
5. **Technical work** on operational setup (member loss) ongoing
6. **Archive/Storage** challenges remain severe
7. **Pattern Generator** and further **Refinements** (Localization, Covariance Inflation, …)

from Roland Potthast

LETKF vs. Nudging (using COSMO-DE soil): KENDA score chart

	LETKF vs. **Nudging**		
	Variable	RMSE	bias
upper air	geopotential	=	=
	temperature	=	=
	(relative humidity)	+	=
	wind speed	+	=
	wind direction	(+)	=
surface	2-m temperature	(+)	=
	2-m dew point temp.	=	=
	10-m wind	=	=
	surface pressure	-	=
	total cloud	=	=
	low cloud	(+)	(+)
	mid-level cloud	+	(+)
	high cloud	(-)	(-)

RMSE wind speed, + 6 h



LETKF used fewer RH obs than nudging, due to stricter QC !!

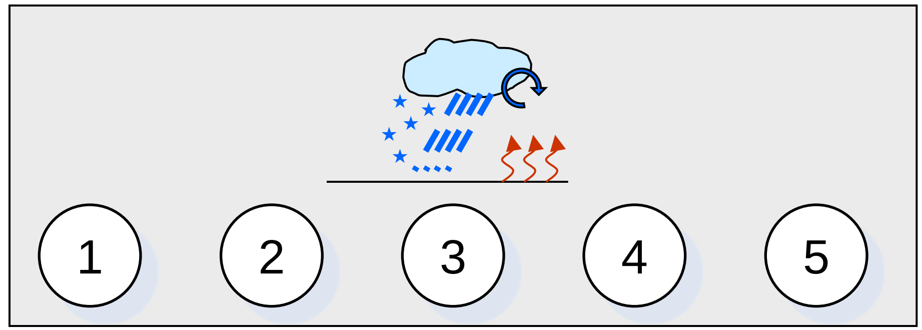
from Roland Potthast

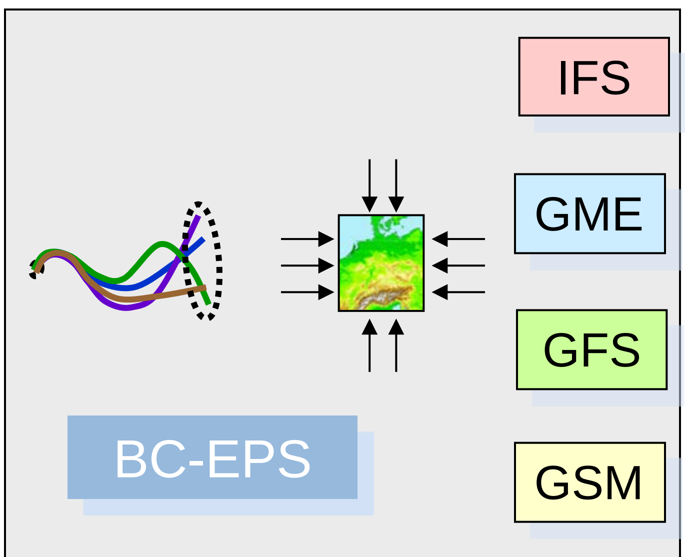
DWD’s Ensemble Prediction System
COSMO-DE-EPS

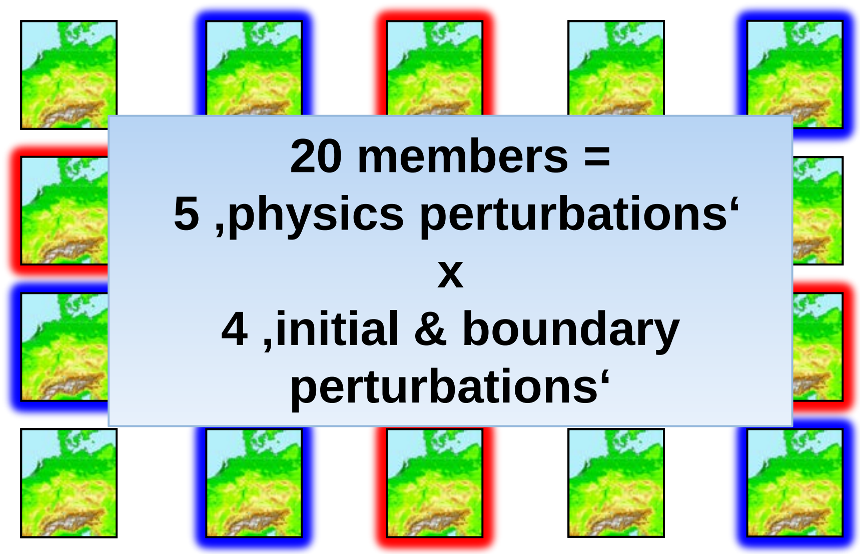
Members 1 - 20 (operational setup)

„+" soil moisture anomaly

„-" soil moisture anomaly







DWD's Ensemble Prediction System

Current Research:
Extension to 40 Members

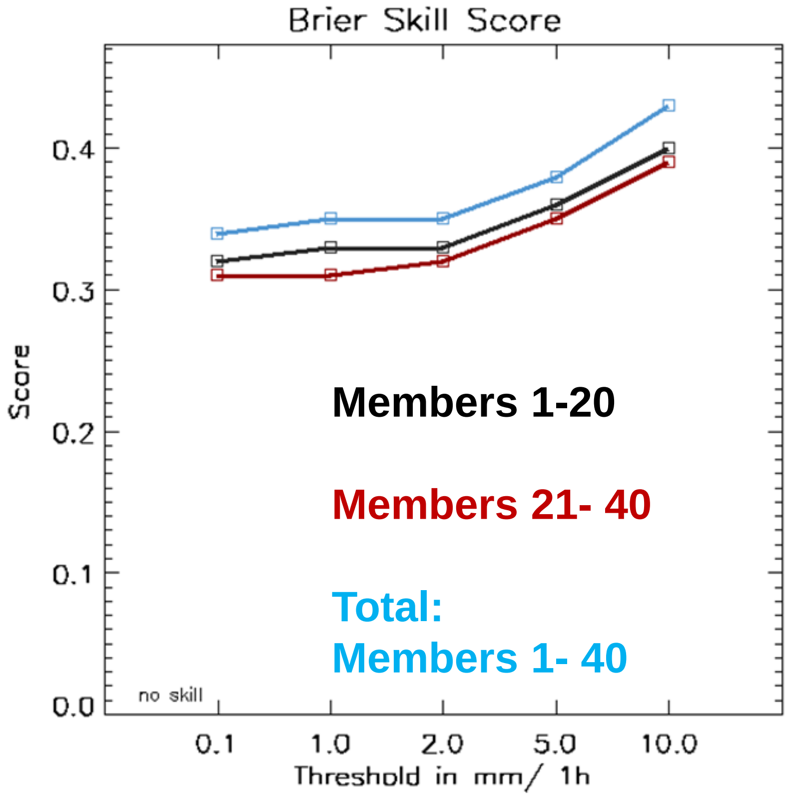
➔ **increase number of boundary forecasts**

current setup: **4** x 5 = 20 members

future setup: **8** x 5 = 40 members

➔ **the 4 additional boundary forecasts:**
selected members from COSMO-LEPS ensemble
(driven by the global ECMWF ENS)

Verification Results (precipitation)



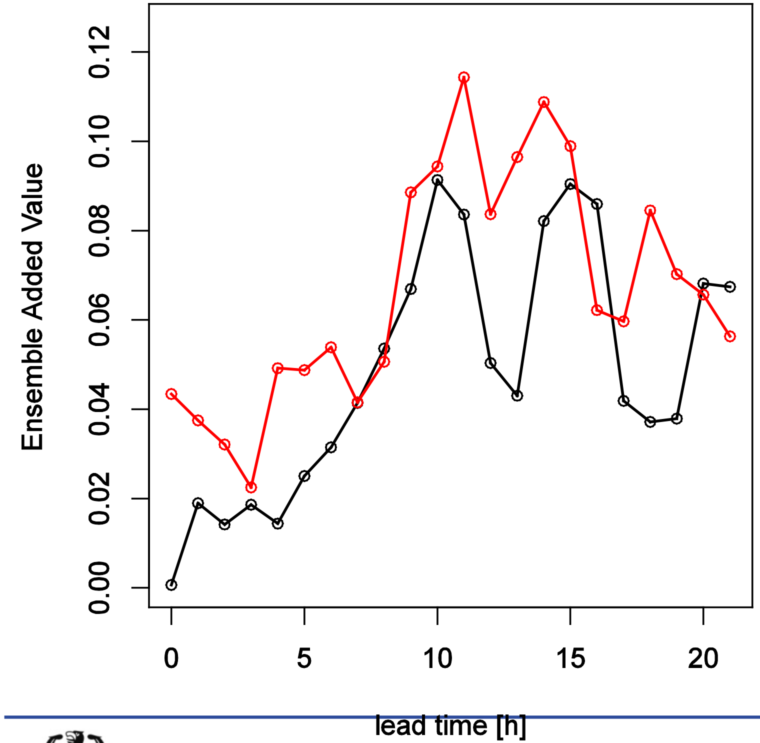
DWD's Ensemble Prediction System

Current Research:

Use of IC from the Kilometer scale ENsemble Data Assimilation (KENDA) based on the LETKF scheme (Hunt et al., 2007)

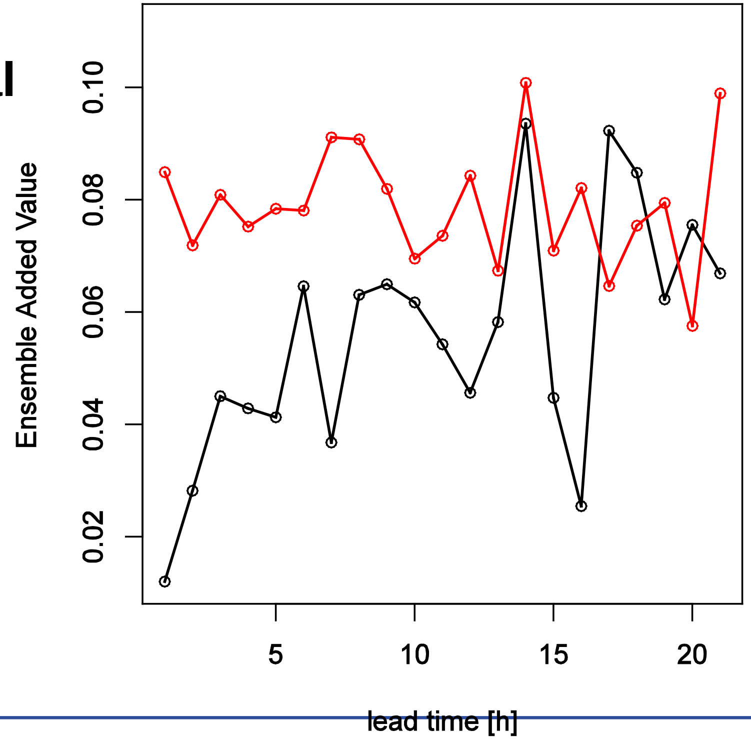
Results: **Ensemble Added Value**

2m temperature



operational
KENDA IC

10m wind gusts



Future plans

➔ operational use of KENDA for IC perturbations

➔ add new physics perturbations or alternative perturbation methods (e.g. stochastic physics)

➔ use of global ICON EPS for BC perturbations

Stochastic physics - Outline of the method

The main idea to simulate the model error is

- to approximate the empirically determined error of the model tendencies from physical parameterizations by a random process with the same statistical properties;
- to add this estimate of the model tendency error to the right-hand side of the governing equations, e.g.

$$\frac{\partial T}{\partial t} = \left[\frac{\partial T}{\partial t}\right]_{det} + \eta(t)$$

Disadvantage: lack of understanding of essential physics of model error

Advantages:

- the entire model error is represented (important for data assimilation);
- properties of the simulated model error η (noise amplitude, time and space correlations) are not taken arbitrary

The model error is estimated as "3h forecast – analysis" differences

from Ekaterina Machulskaya (DWD)

Stochastic physics - A model for the model error

The model error is assumed to obey a stochastic differential equation

$$\frac{\partial \eta(x,t)}{\partial t} = -\gamma\eta + \gamma\lambda^2\nabla^2\eta + \sigma\xi(x,t)$$

persistence in time,
$\frac{1}{\gamma}$ – correlation time scale

diffusion measures spatial influence
(spatial correlations)

random component,
$\xi(x, t) \sim N(0,1)$

σ, γ, and λ are determined from the available statistics (time series of “3h forecast – analysis”).

σ, γ, and λ are made flow-dependent: if there is a clear dependence of σ, γ, and λ on some model fields (e.g. temperature, humidity, wind speed, temperature tendency, etc.) → those quantities are chosen to be predictors for σ, γ, and λ.

from Ekaterina Machulskaya (DWD)

Revised Infiltration in TERRA (SVAT-model)

- COSMO-DE changed land-use data set at 18/04/2014 from the old **GLC2000** to the new **GlobCover2009**
- Enhanced LAI in GlobCover increased evapotranspiration
- Problem:
  → dry out of root zone of soil possible
  → plants achieve their wilting point
  → shutdown of latent heat flux
- Solution: enhanced infiltration parameterization (→ reduce runoff!)
- Experiment start 2013040100 – 5 months assimilation
- Full experiment start 2014051000 for summer 2014 V5.0.1.1

from Jürgen Helmert (DWD)

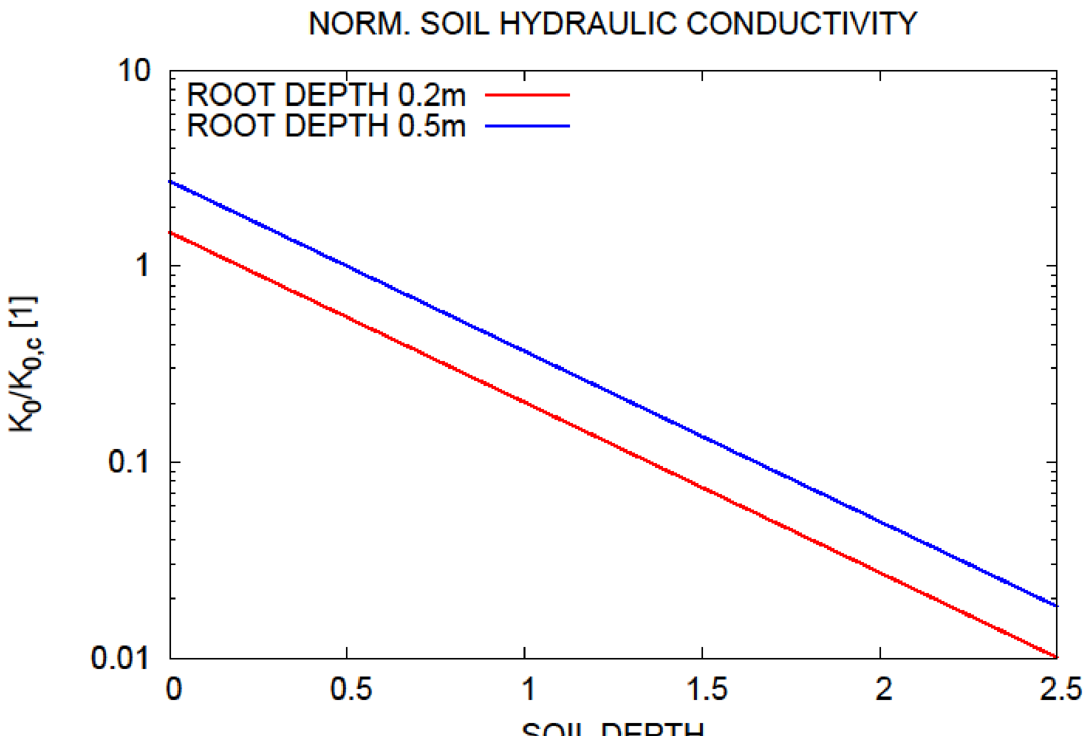
Revised infiltration

$$I'_{max} = \begin{cases} 0 & : T_{sfc} \leq T_0 \\ f_r\, S_{orc}\, \rho_w K_0(z) & : T_{sfc} > T_0 \end{cases} \quad (10.3$$

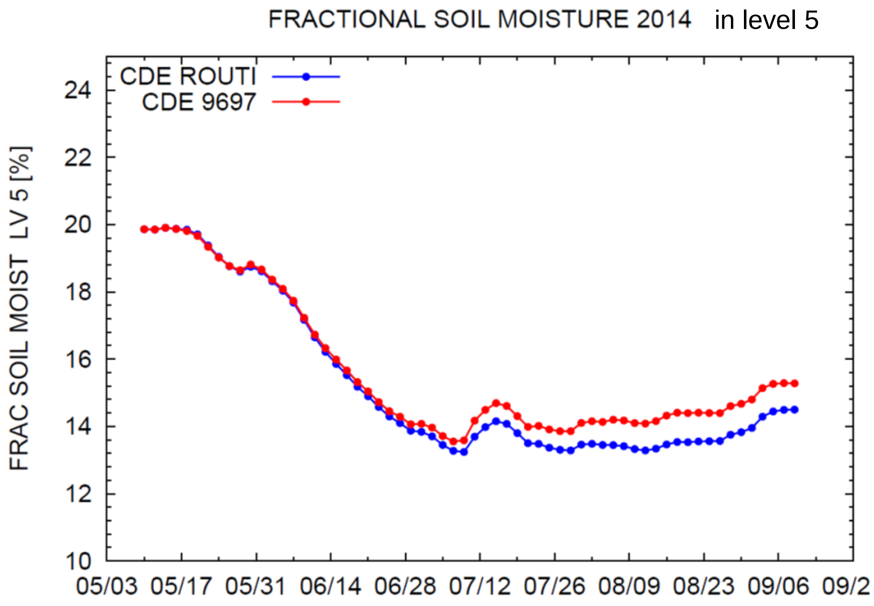
$$K_w(w_l) = K_0(z)\, exp\left[K_1 (w_{PV} - \bar{w}_l)/(w_{PV} - w_{ADP})\right]$$

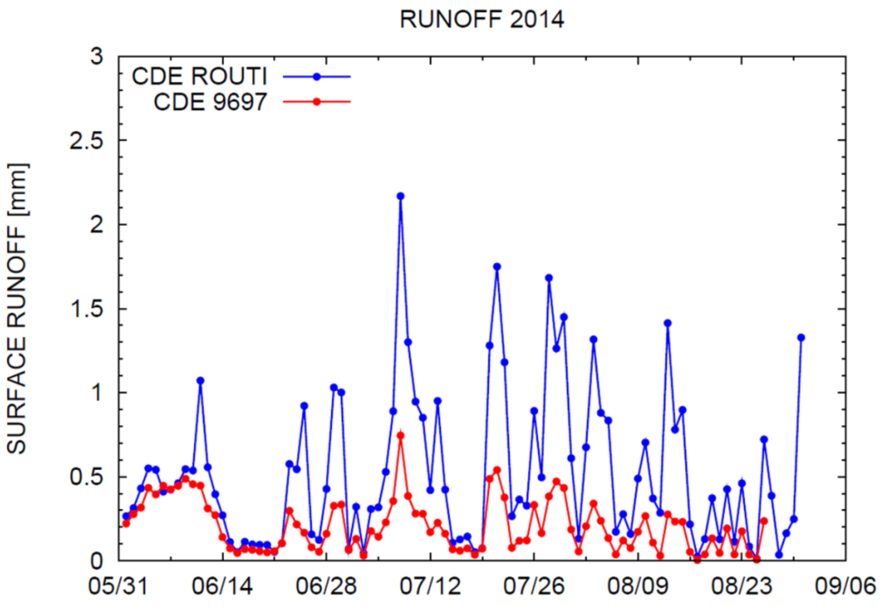
$$K_0(z) = K_{0,c}\, e^{-f(z-d_c)}$$

Profile of sat. hydr. conductivity, Decharme (2006)



Revised infiltration CDE- domain average

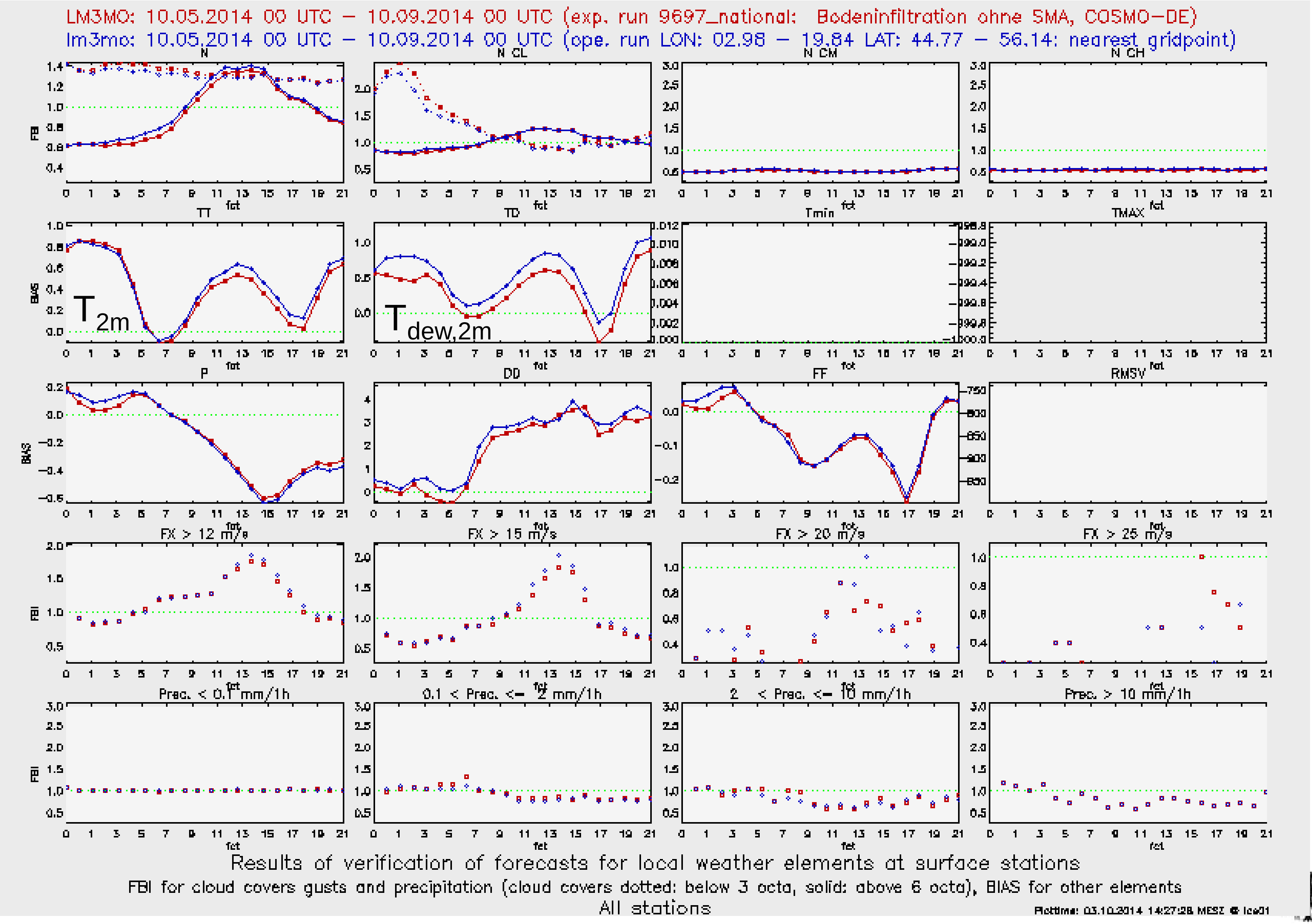




effect: soil moisture at root level increased; runoff reduced

Revised infiltration
CDE- Verification

CONSORTIUM FOR SMALL SCALE MODELING COSMO
Deutscher Wetterdienst
Wetter und Klima aus einer Hand
DWD



Renewable Energy Meteorology Projects at

Gefördert durch: Bundesministerium für Wirtschaft und Energie

aufgrund eines Beschlusses des Deutschen Bundestages

EWeLiNE 12/2012-11/2016

23 Researchers (10 IWES + 13 DWD)

➔ **Focus: improved day ahead forecasts** for renewable energies

➔ **Research topics:**

- **Improved initial conditions** by applying new data types (data assimilation)
- More accurate forecasts by **optimizing** the **model physics**
- More reliable predictions through **optimized ensemble forecasts** and **new probabilistic products**
- **Optimized Model Output Statistics**

➔ **Integration** of **new products** in **desicion making processes!**

ORKA 8/2012-12/2015

4 Researchers (2 emsys + 2 DWD)

➔ **Focus: improved short-term forecasts** (12h) for renewable energies

➔ **Research Topics:**

- **Optimized ensemble forecasts** for renewable energies
- Development of **ensemble products** for **grid security aspects**; „worst-case“ scenarios, risk management,..

➔ **Iterative cycle** of **evaluation** and **test results**

from Kristina Lundgren (DWD)

New challenges to NWP

➔ Availability of suitable observation data sets for renewables is restricted

A few critical weather situations in day-to-day business:

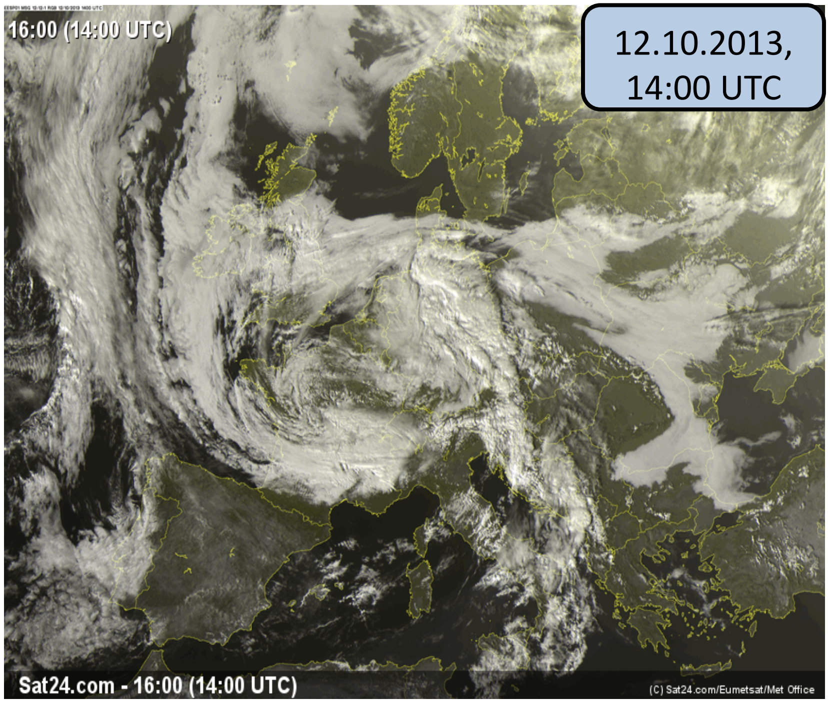
➔ Frontal passages (ramps)
– Intensity, location (timing)

➔ (Small-scale) low-pressure systems
– Intensity, location (timing)

➔ Pronounced diurnal cycle of the Planetary Boundary Layer (PBL)

➔ Convective events

➔ Fog/Low stratus clouds

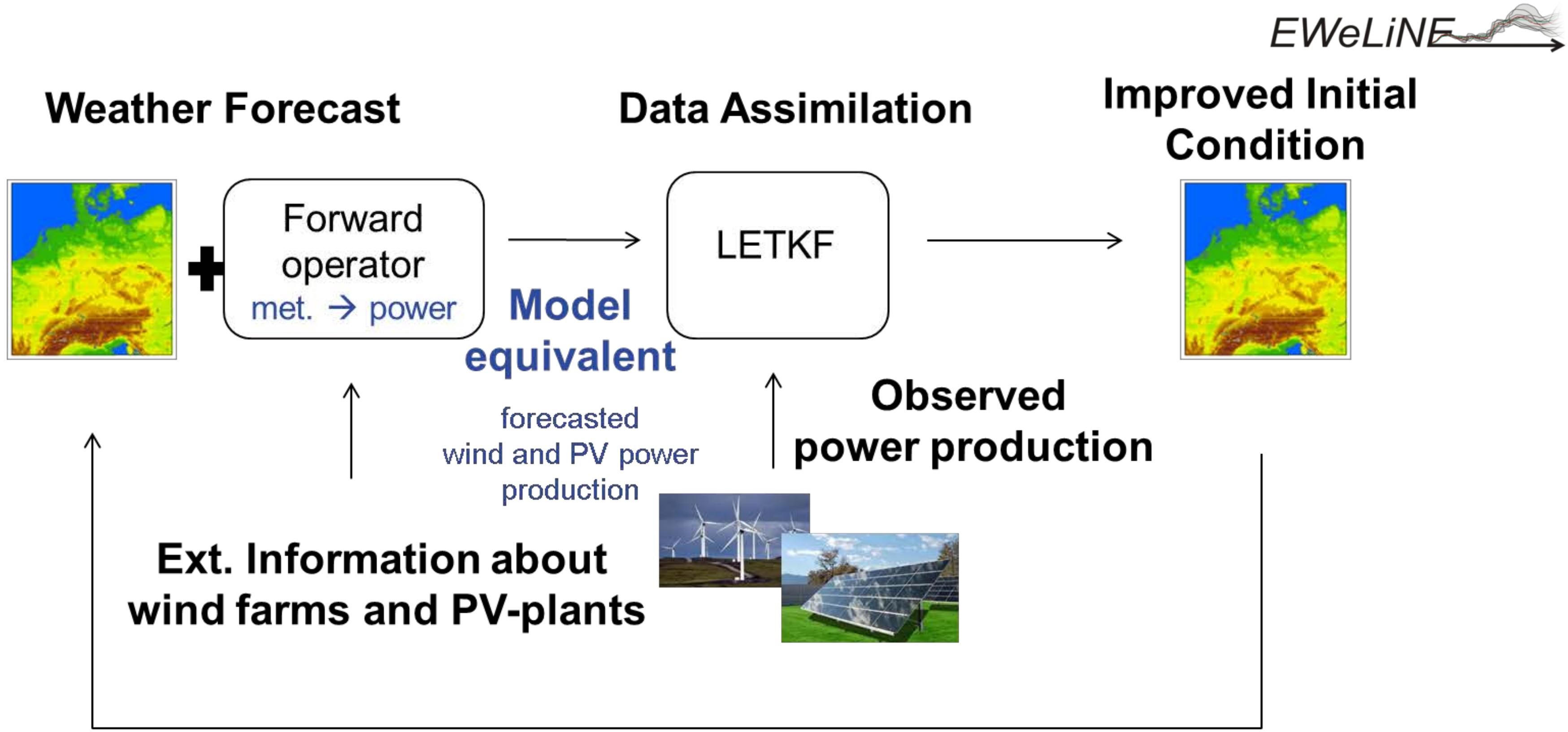


Source: http://www.sat24.com/history.aspx

➔ Most critical when both wind and radiation are difficult to predict (example: October 12, 2013)

from Kristina Lundgren (DWD)

Assimilation of power data



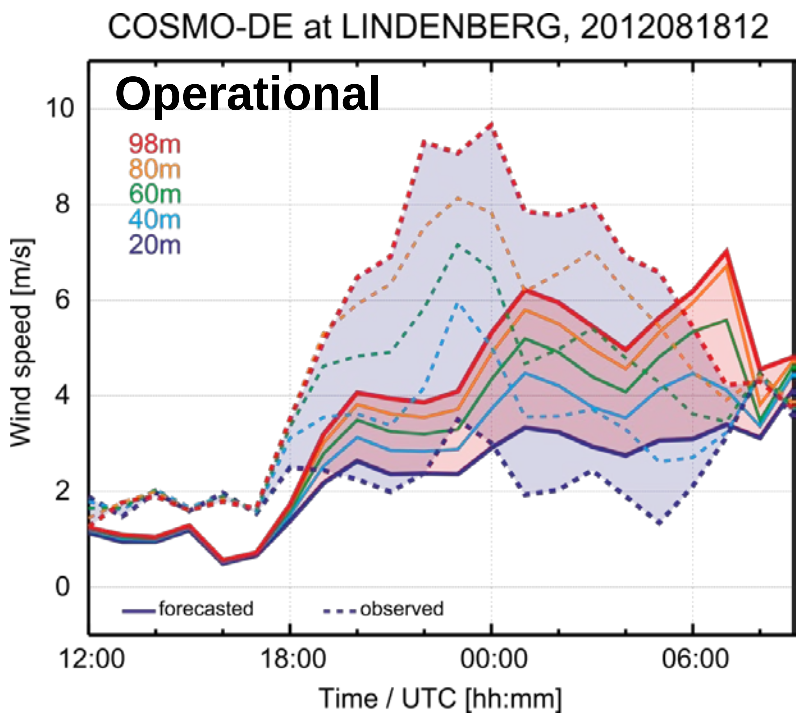
LETKF=Local Ensemble Transform Kalman Filter (Hunt et al., 2007)

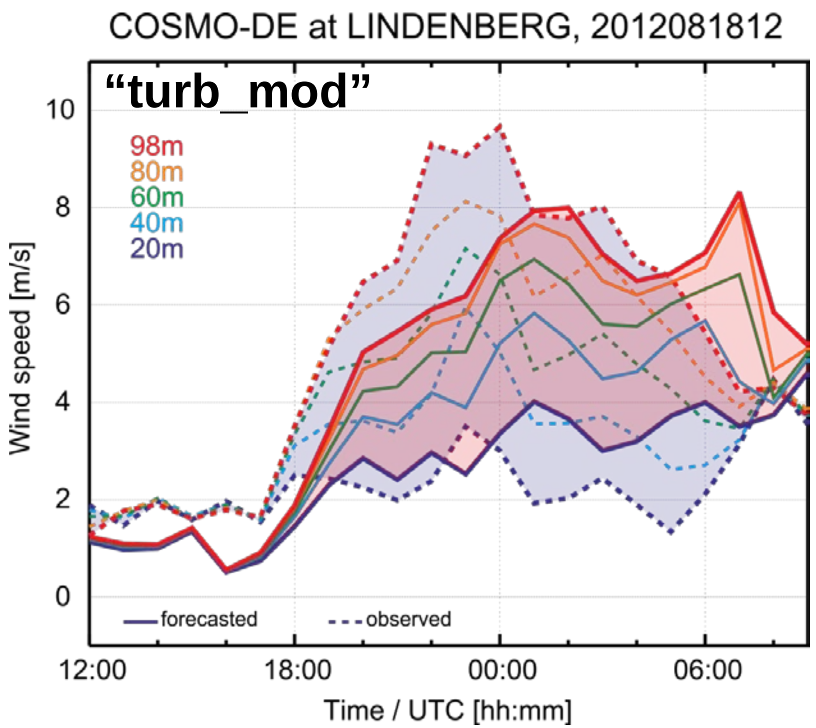
Diurnal cycle in wind speed

Deutscher Wetterdienst
Wetter und Klima aus einer Hand

EWeLiNE

- Sensitivity study August 18-19, 2012
- Low Level Jet is not captured in the forecast:





patlen=200, rlammom=0.7, tkh/min=0.1,turlen=150, astab=1

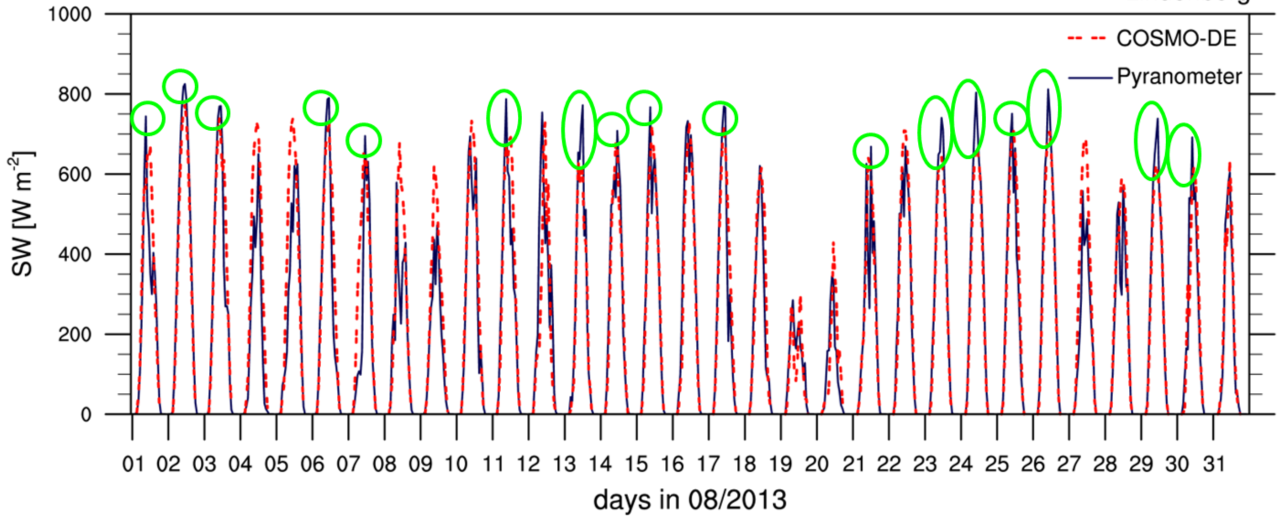
- Modified turbulence parameters allow for higher nocturnal wind speeds

Observations operated by Meteorologisches Observatorium Lindenberg

Improved radiation forecasts

Deutscher Wetterdienst
Wetter und Klima aus einer Hand
Lindenberg

- Underprediction of shortwave radiation on cloud free days: Exampel for COSMO-DE forecasts August, 2013



- Modified aerosol climatology shows an improvement due to reduced optical thickness of the atmosphere

- Example: Hourly averaged SW for clear sky day