The NWP system at DWD

12th Workshop on Meteorological Operational Systems

ECMWF

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Outline

Infrastructure

New Headquarter and computer system
Migration of NWP model suite

NWP models

GME / COSMO-EU / COSMO-DE
Operational Schedule
Operational changes 2007-2009

Recent developments

GME30L60
GME-SMA
COSMO-DE EPS
ICON

New DWD Headquarters by June 2008

New computer system at DWD

NEC SX-9

Two identical systems: Operations and research, each

- 14 x 16 = 224 vector processors
- 23 Teraflop/s peak performance
- 4.5 Teraflop/s sustained performance
- 7168 GByte main memory

New computer system at DWD

SUN Login nodes

Two SUN Fire x4600 clusters: Operations and research

- 11 nodes with 8 AMD Opteron QuadCore 2.3 GHz CPUs
- SuSE Linux SLES 10 SP 2
- 128 GByte RAM per node
- 300 Gigaflop/s peak
- Used as frontend system of NEC SX-9 and for pre- and post-processing

New computer system at DWD

SGI database server

- SGI Altix 4700, 2 nodes each with
- 92 x Intel Itanium dual core 1.6 GHz CPUs
- 1104 GByte RAM
- SuSE Linux SLES 10 SP 2
- Runs Oracle database for observations and model fields

Silo Storage

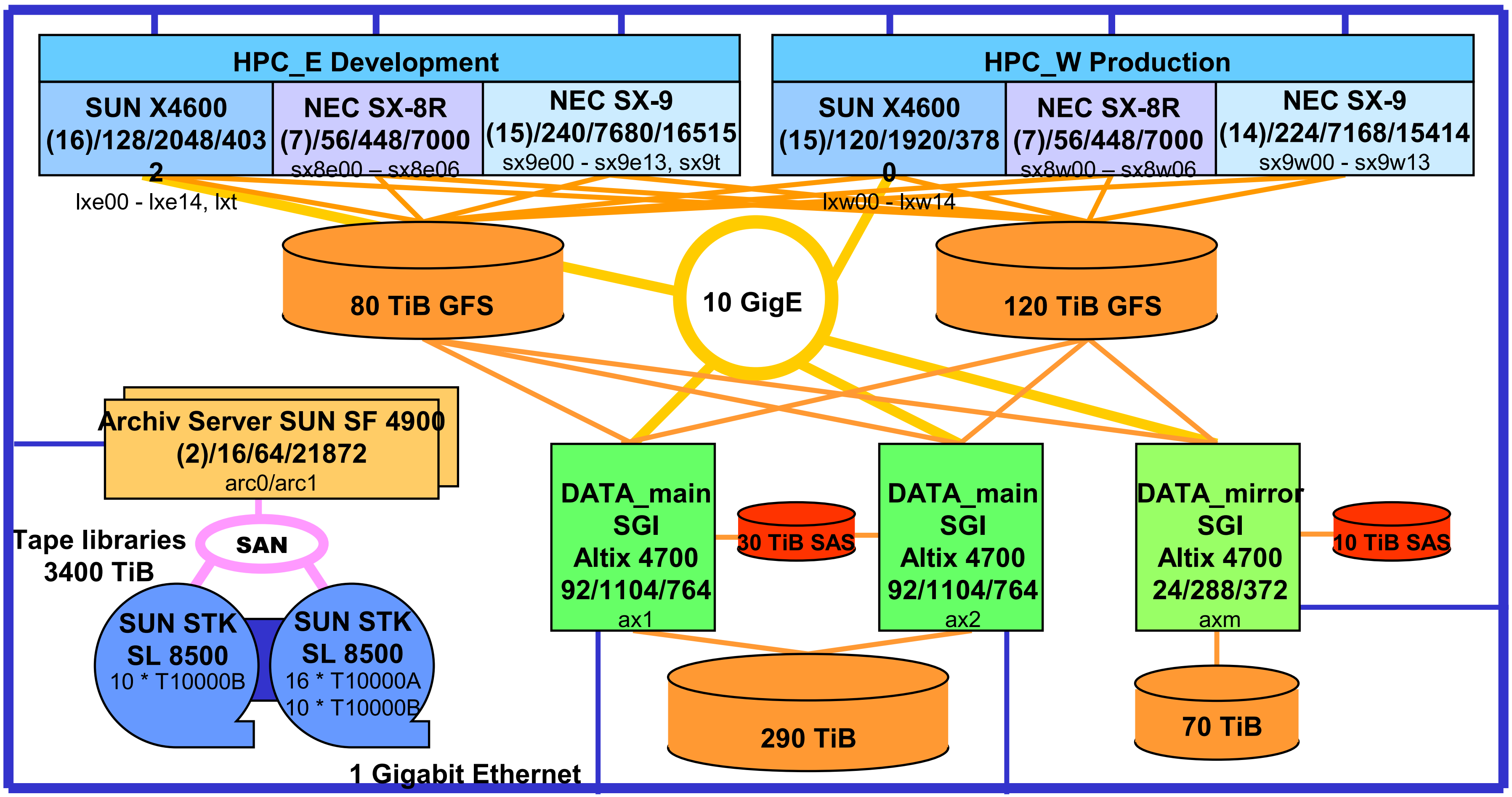
Two Sun/Storage SL8500 Silos

- 10.000 tape cassettes each
- 50 tape units and 16 robot arms
- Storage capacity: up to 40 Petabyte in 2012

New computer system at DWD

DMRZ (OF) – Configuration HPC Systems 2009

Status: October 2009   Keys: (number systems)/number processors/memory in GiB/disk space in GiB



New computer system: migrations (3+)

IBM P5 / AIX / MPI ➤ NEC SX-9 / Super UX / MPI (via NEC SX-8R)

- NWP-models (GME, COSMO-EU, COSMO-DE, WAVE, LPDM)

IBM P5 / AIX / MPI ➤ SUN Fire / Linux / MPI

- non-vectorizing parallel programs (1Dvar, probabilities, statistics, ...)
- serial programs (surface analysis, postprocessing, …)
- parallel execution of serial commands and shell-scripts via MPI
- data transfer to databases (grib, bufr, ..)

IBM P4 / AIX ➤ SGI Altix / Linux

- Oracle databases, database interfaces, archive software

New computer system: lessons learnt

- Sun servers initially quite unstable; Bug in Kernel of Novell SLES10; upgrade to service pack 2 solved the problem.
- Slow meta data retrieval on SGI data base server (millions of files); new configuration of disks necessary.
- Several MPI-bugs on NEC SX-9; latest MPI library (Sept. 2009) solved the problems.
- It took almost one year to fully migrate the operational NWP suite to the new computer system!
- Since 29 Sept. 2009 the operational NWP system is smoothly running on NEC SX-9.
- Significant delay of some essential projects.

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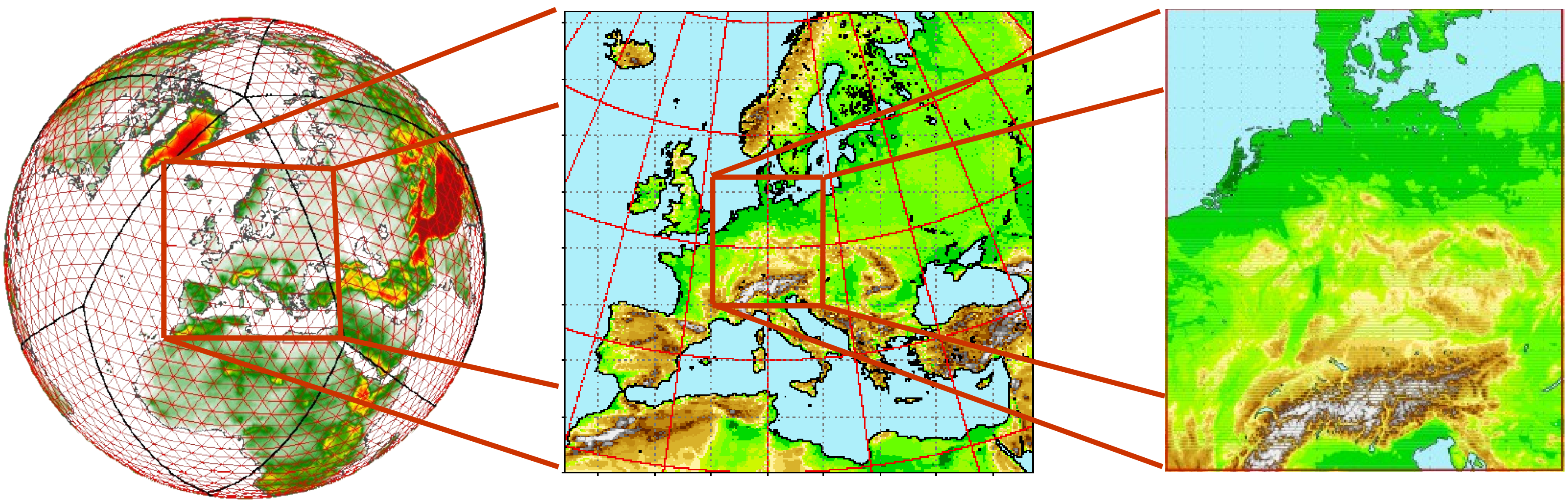
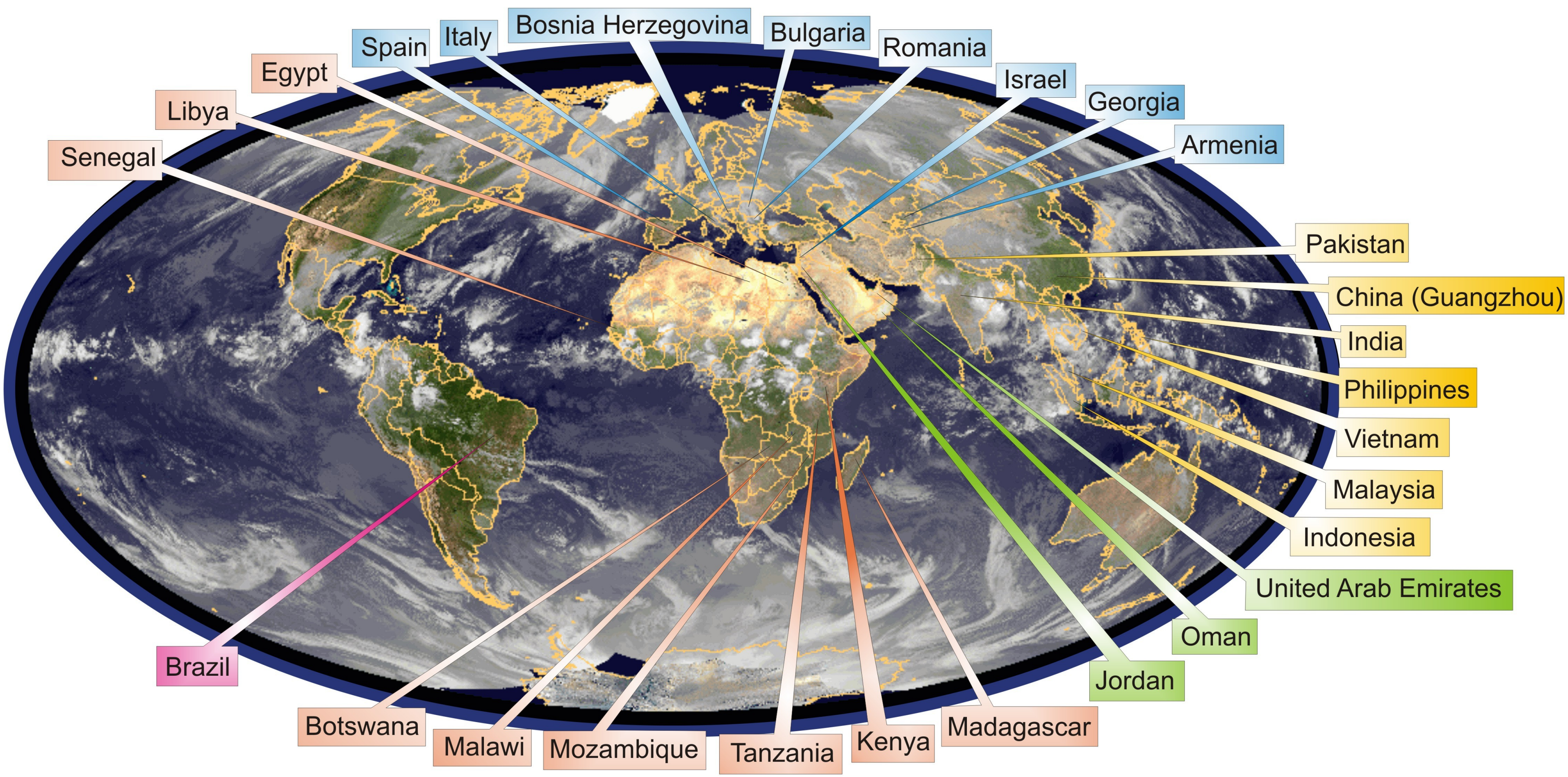
The operational model chain of DWD

GME	COSMO-EU (LME)	COSMO-DE (LMK)



hydrostatic	non-hydrostatic	non-hydrostatic
parameterised convection	parameterised convection	resolved convection
$\Delta x \approx$ 40 km	Δx = 7 km	Δx = 2.8 km
368642 * 40 GP	665 * 657 * 40 GP	421 * 461 * 50 GP
Δt = 133 sec., T = 7 days	Δt = 40 sec., T= 78 h	Δt = 25 sec., T = 21 h

Supporting Regional NWP Worldwide



Countries running DWD's regional NWP model HRM based on GME data

Global Model GME

Operational since 27.09.2004

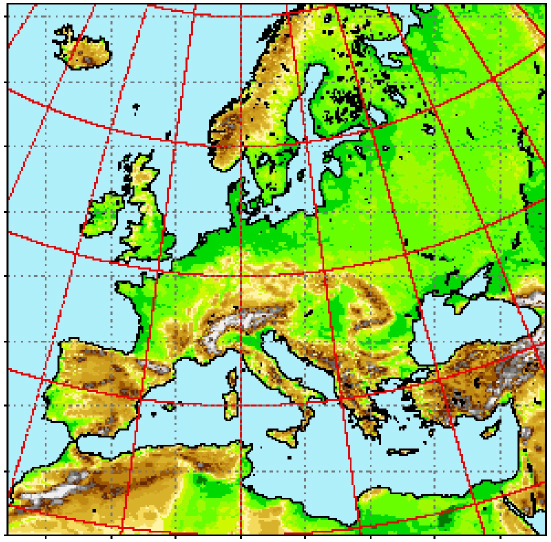
triangular grid

- horizontal resolution: 40 km (NI=192)
- vertical levels: 40
- grid cell area: 1384 km²

- hydrostatic
- 7-layer soil model including freezing/melting of soil water
- sea ice model
- seasonal variation of plant cover based on NDVI data
- aerosol climatology

COSMO-EU

Operational since 28.09.2005



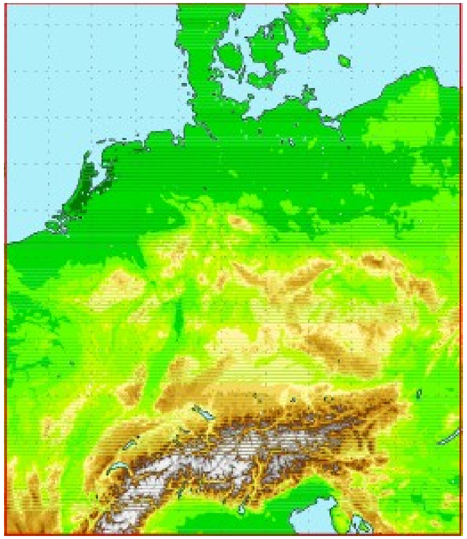
horizontal resolution: 7 km

- vertical levels: 40
- grid cell area: 49 km²
- forecast area: Europe

- non-hydrostatic
- parametrized convection
- 7-layer soil model including freezing/melting of soil water
- during forecast observation nudging
- prognostic variables: p, u, v, w, T, q_v, q_c, q_i, q_r, q_s, TKE
- SSO scheme
- boundary data from GME hourly

COSMO-DE

Operational since 16.04.2007



- horizontal resolution: 2,8 km
- vertical levels: 50
- grid cell area: 7,84 km²
- forecast area: Germany

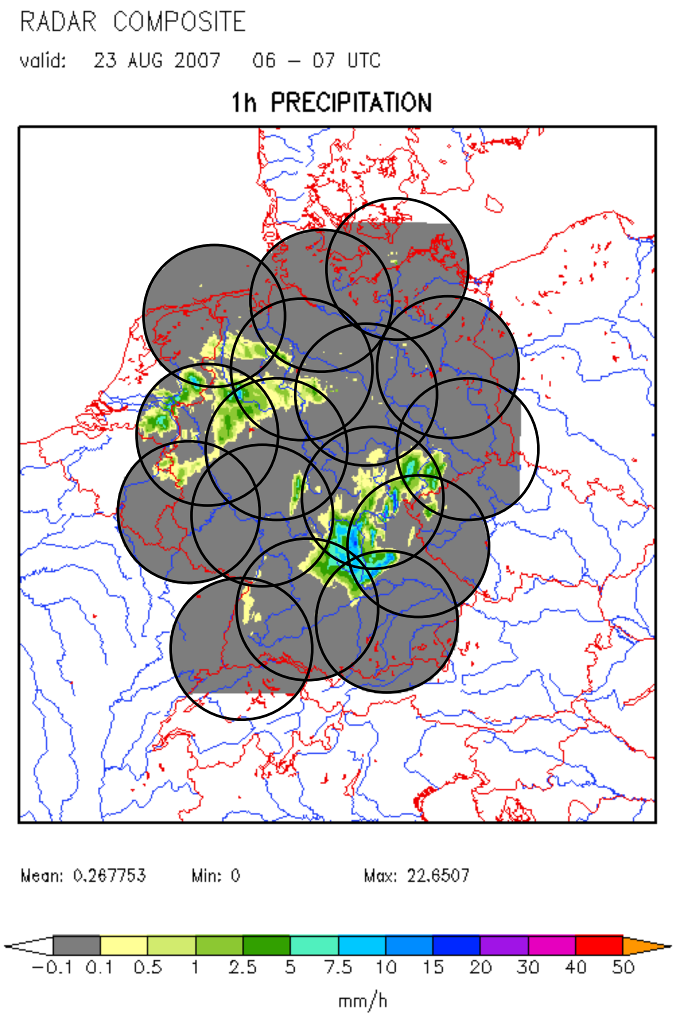
- non-hydrostatic
- resolved convection
- 7-layer soil model including freezing/melting of soil water
- during forecast observation nudging
- prognostic variables: p, u, v, w, T, q_v, q_c, q_i, q_r, q_s, q_g, TKE
- latent heat nudging (LHN) of radar data
- boundary data from COSMO-EU hourly
- output sequence: 15 min

COSMO-DE: LHN

Radar Data

Composite of 16 stations (reflectivity)

- terrain following scan, elevations: 0.5°-1.8°
- spatial resolution: 1km x 1km
- timeliness: 5 minutes
- quality check of spurious data
- variable Z-R relation (radar reflectivity – rainfall rate) to derive rain rates



COSMO-DE: LHN

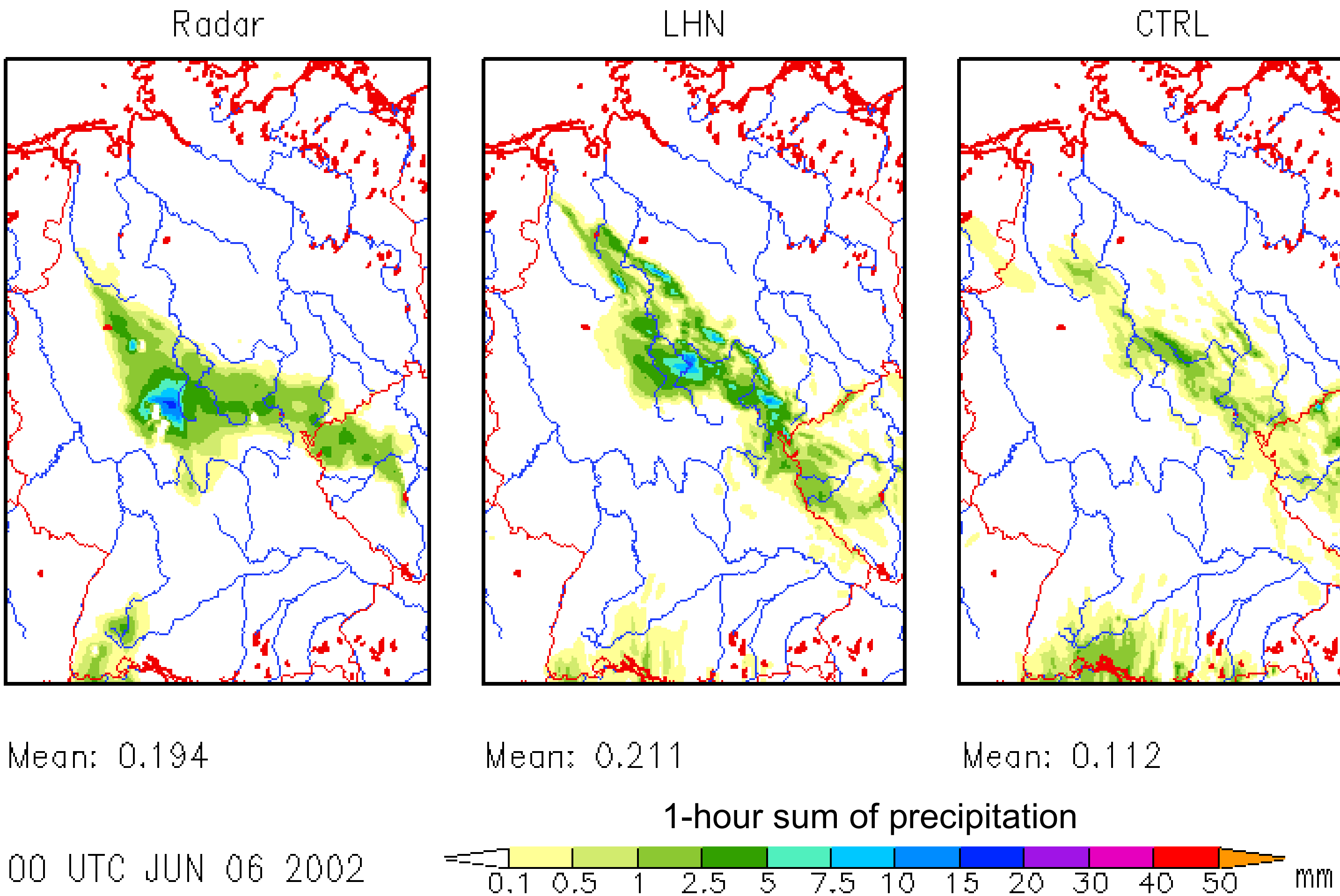
Latent Heat Nudging

- Special nudging technique to assimilated radar derived precipitation
- Goal: Trigger the model’s dynamic that it is able to produce the observed precipitation by its own
- Precipitation will have only little influence of thermodynamic
- Therefore temperature is used as it is strongly connected with precipitation formation

COSMO-DE: LHN – Impact Study

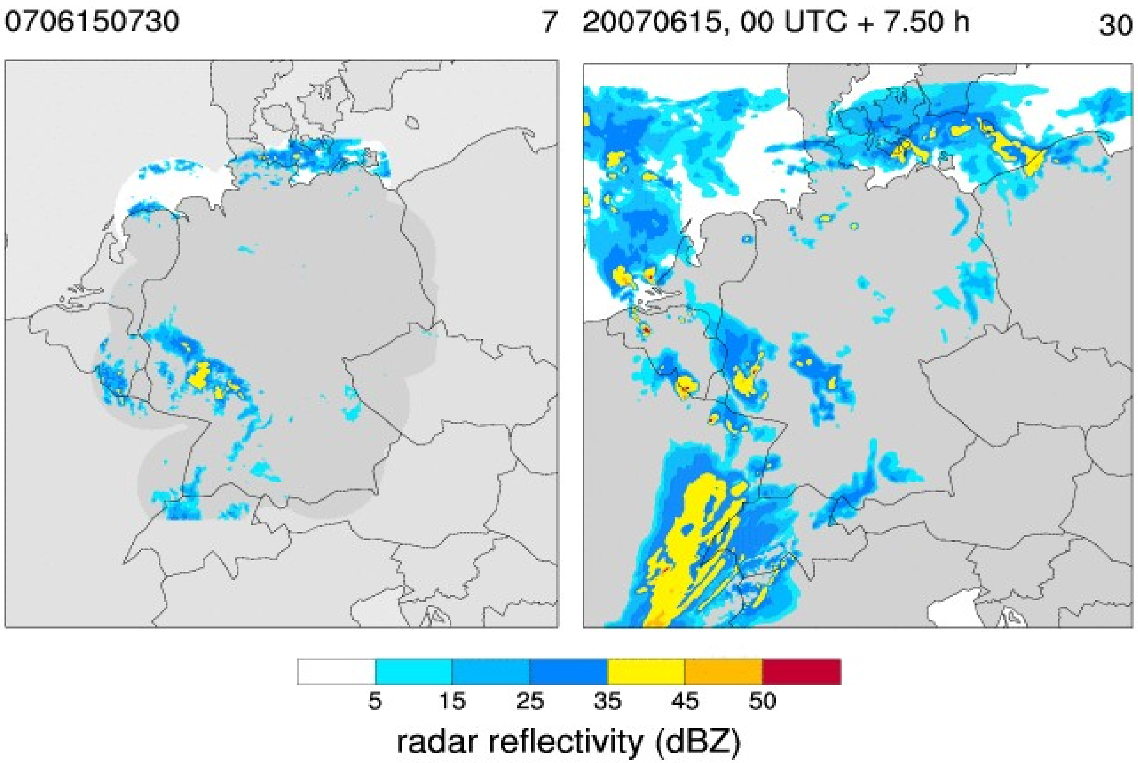
Δx = 2.8 km , no convection parametrisation , LHN with humidity adjustment

+ 6 h



COSMO-DE: Case study

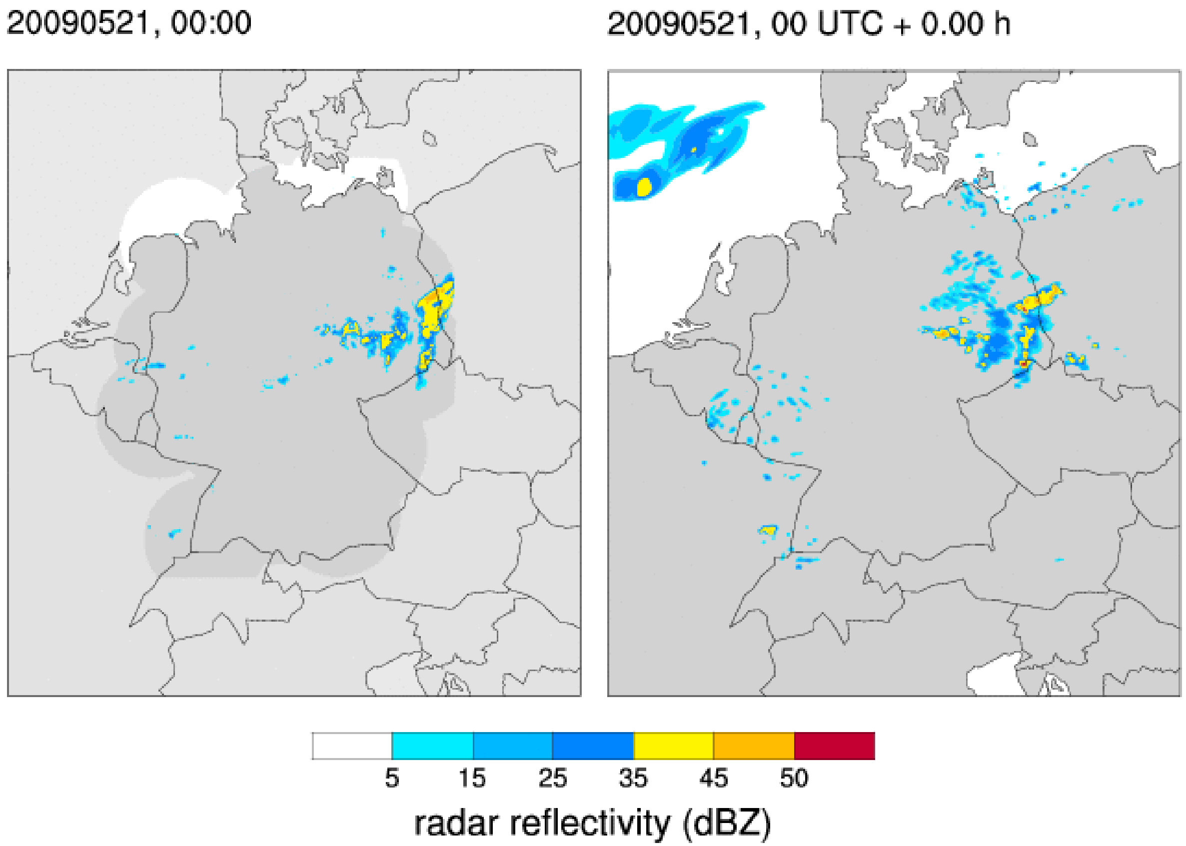
Radar composite / Model reflectivity   15 June 2007



- The COSMO-DE forecasts provide a good guidance where and when strong convection might develop.
- Exact deterministic forecasts cannot be expected on the convective scale

COSMO-DE: Forecasting of Supercells

Radar composite / Model reflectivity 21 May 2009



rotating updrafts (supercells)

- Many supercells in the COSMO-DE simulations, especially in Northern Germany
- An F2 tornado was indeed observed and confirmed near Plate/Schwerin

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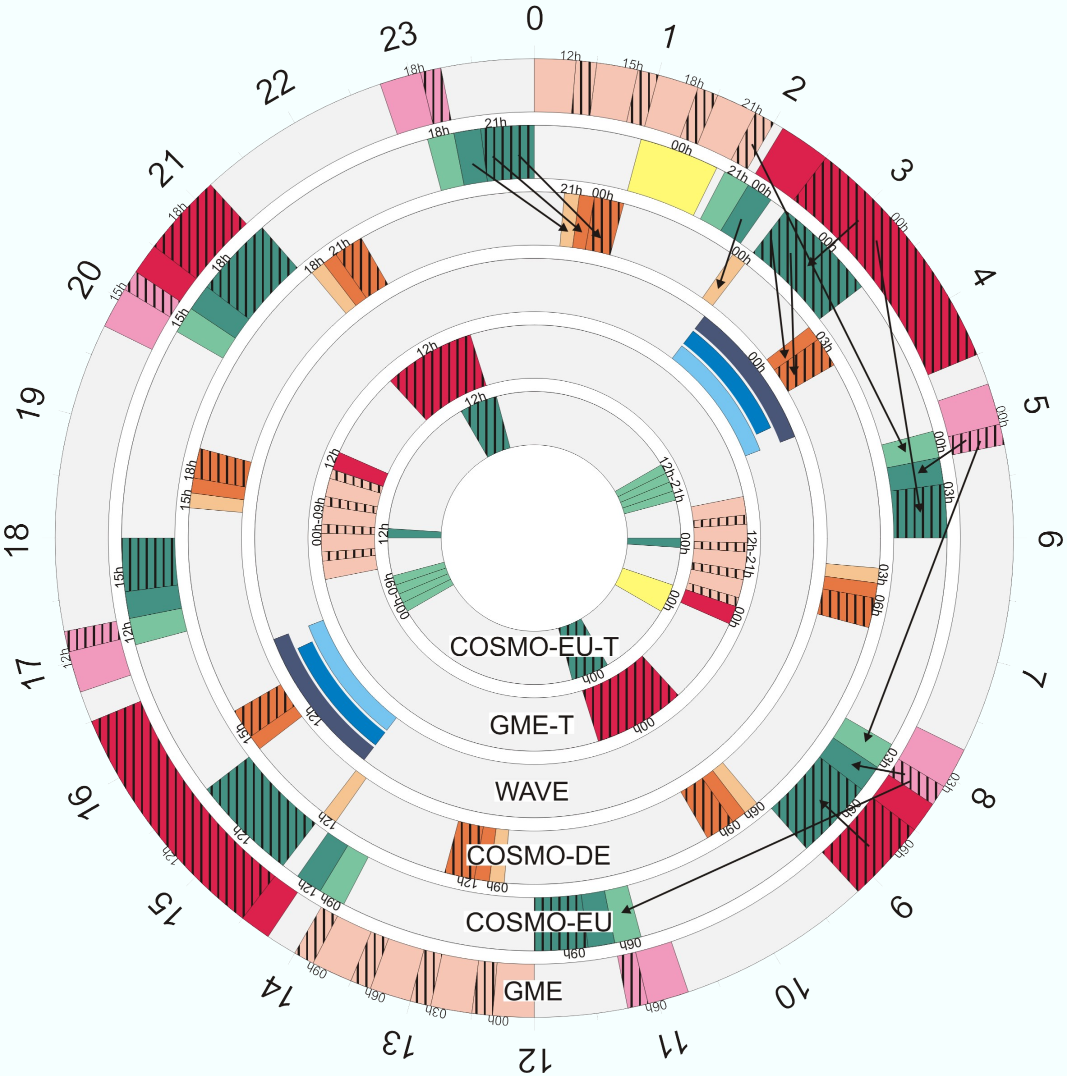
Operational schedule



Operational timetable
of the
DWD model suite
GME, COSMO-EU, COSMO-DE
and WAVE

GME, COSMO: Analysis / Nudging

GME, COSMO: Forecast

WAVE (GSM, LSM, MSM)

COSMO-EU: Surface moisture analysis

T Testsuite

Main run

Pre-Assimilation

Assimilation

00..23 real time [UTC]

00h, 03h, .. model time

Data assimilation scheme

Modell	GME	COSMO-EU	COSMO-DE
assimilation interval	3 hourly	3 hourly	3 hourly
assimilation type	3+1DVar + 3 hour forecast	cont. data assimilation (nudging)	cont. data assimilation (nudging)
sea surface temperatur	00 UTC	00 UTC	00 UTC
snow (density, depth, temperatur)	3 hourly	6 hourly	6 hourly
surface moisture	- (planed)	00 UTC	-
additional data	-	-	LHN (radar data)

Operational schedule

	type	time [UTC] / interval	forecast time [h]	cut off time X + ??	ready time X + ??
GME	main forecast	00, 12 06, 18	174 48	+ 2:14 + 2:15	+ 4:20 + 3:05
	pre-assimilation	3 hourly	3	+ 4:45	+ 5:15
	assimilation	00, 12 03, 15 06, 18 09, 21	3 3 3 3	+ 12:00 + 9:30 + 7:00 + 4:30	+ 12:30 + 10:00 + 7:30 + 5:00
COSMO-EU	main forecast	00, 12 06, 18 03, 09, 15, 21	78 48 24	+ 2:30 + 2:30 + 2:30	+ 3:30 + 3:10 + 2:50
	assimilation	3 hourly	3 (cont.)	+ 4:50 (.. 7:50)	+ 5:00
COSMO-DE	main forecast	3 hourly	21	+ 0:40	+ 1:00
	assimilation	3 hourly	3 (cont.)	+ 3:20 (.. 6:20)	+ 3:30

Operational changes: GME

05.12.2007	modified diagnostic determination of T2M (significant reduction of RMSE and BIAS)
12.03.2008	“Targeted Smoothing of vater vapor fields (avoid “Grid point storms” with extreme precipitation)
17.09.2008	implemention of a 3-dimensional variational data assimilation scheme (no more “pseudotemps”)
18.05.2009	implementation of an aerosol climatology (adaptation of aerosol properties within radiation scheme)
satellite usage	AMV-winds from MTSAT-1R polar vector winds from AVHRR AMSU-A of NOAA 19 “direct broadcast” MODIS winds ...

Operational changes: COSMO-EU

12.12.2007	revision of turbulent gust diagnostics (avoid overestimation of wind gusts)
12.03.2008	modified diagnostic determination of T2M (significant reduction of RMSE and BIAS)
23.07.2008	modified cumulus convection scheme (Tiedke) (improved forecast of heavy precipitation – decrease)
12.11.2008	sub-grid scale orography (SSO) scheme (Lott and Miller 1997) (improve of speed and direction of near surface wind, reduction of RMSE and BIAS of surface pressure)

Operational changes: COSMO-DE

12.12.2007	revision of turbulent gust diagnostics (avoid overestimation of wind gusts)
12.12.2007	modified broad band diagnostics of radar data (allows usage of radar data within LHN in winter)
16.01.2008	output of SDI (supercell detection index) and ceiling (experimental diagnostic feature)
12.03.2008	modified diagnostic determination of T2M (significant reduction of RMSE and BIAS)
08.04.2008	probabilities of severe events (1 and 6 hourly)
02.11.2008	semi-langrange advection of humidity variables and TKE (instability of Bott-advection at lower boundary in winter)
29.04.2009	Bott-advection of humidity variables and TKE (unrealistic precipitation maxima of semi-langrange adv. sch.)

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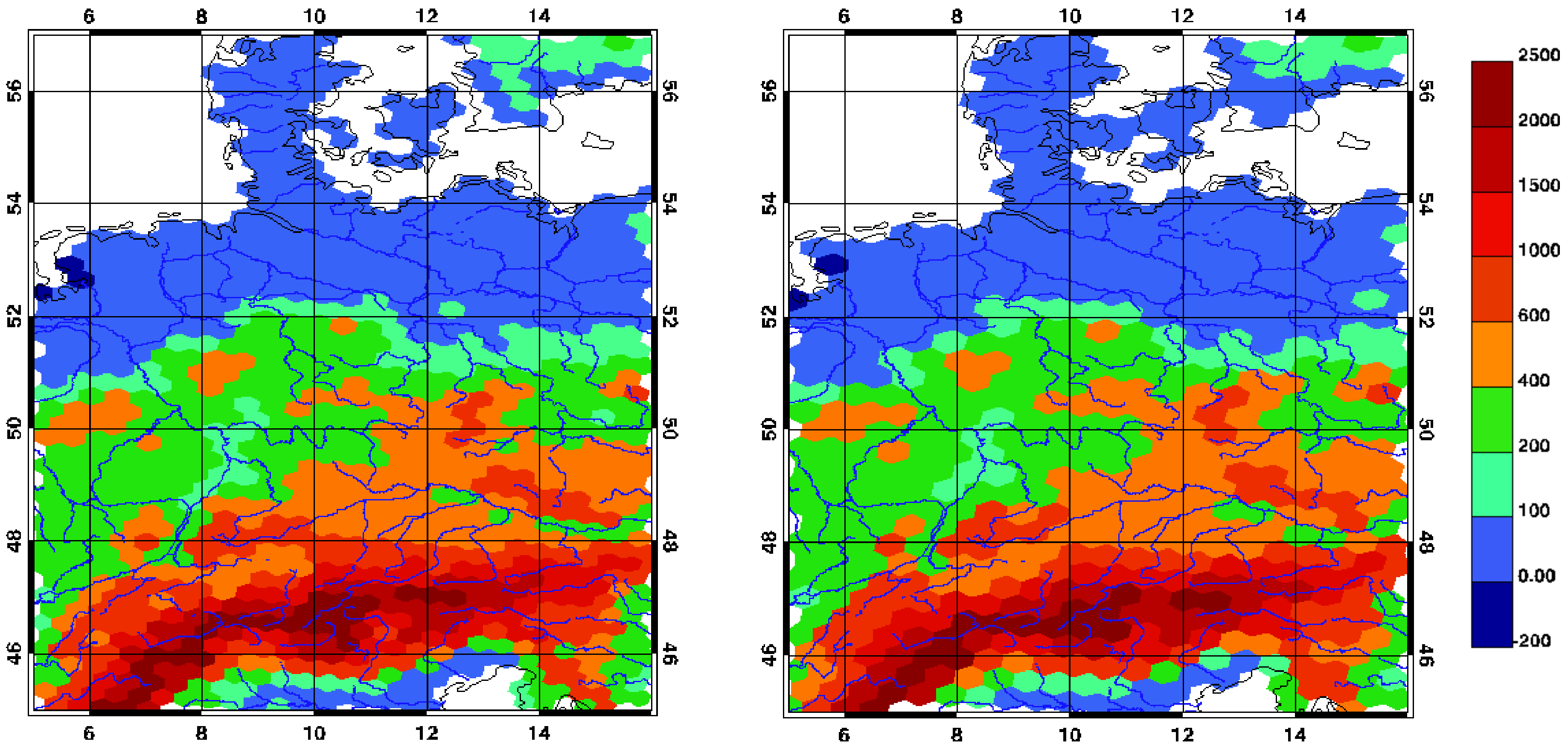
GME30L60 vs. GME40L40

fully operational: february 2010

	GME40L40 (oper.)	GME30L60
mesh width	40 km (NI=192)	30 km (NI=256)
vertical levels	40	60
top model level	10 hPa	5 hPa
prognostic precipitation	-	QR, QS
convection scheme	Tiedke	Bechthold
surface moisture analysis	-	- (planed)
number of gridpoints	14.7 Mio	39.3 Mio
Time step	133.33	100.00

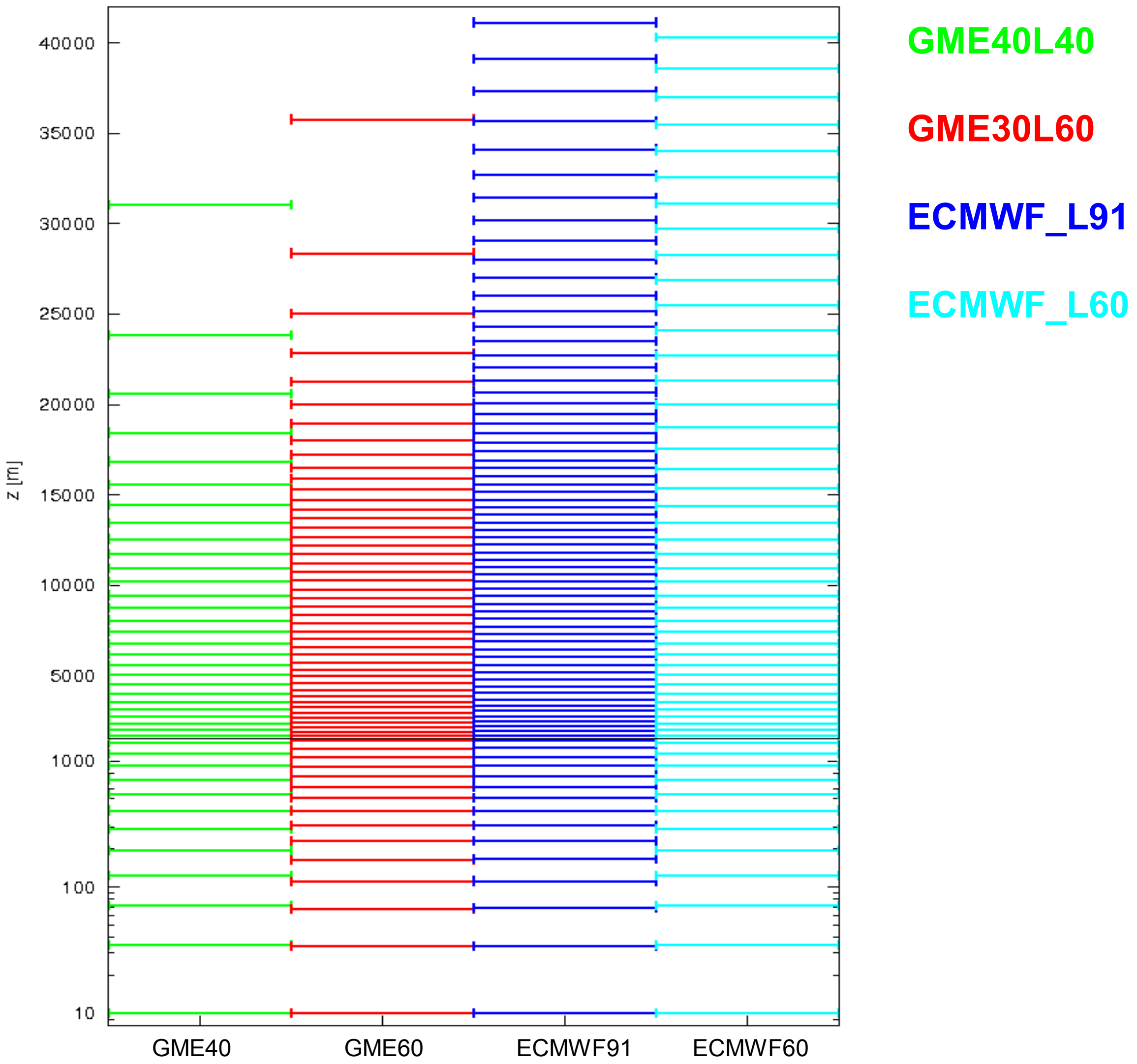
GME30L60: Orography

GME30L60	GME40L40
max. height 2672m	max. height 2551m

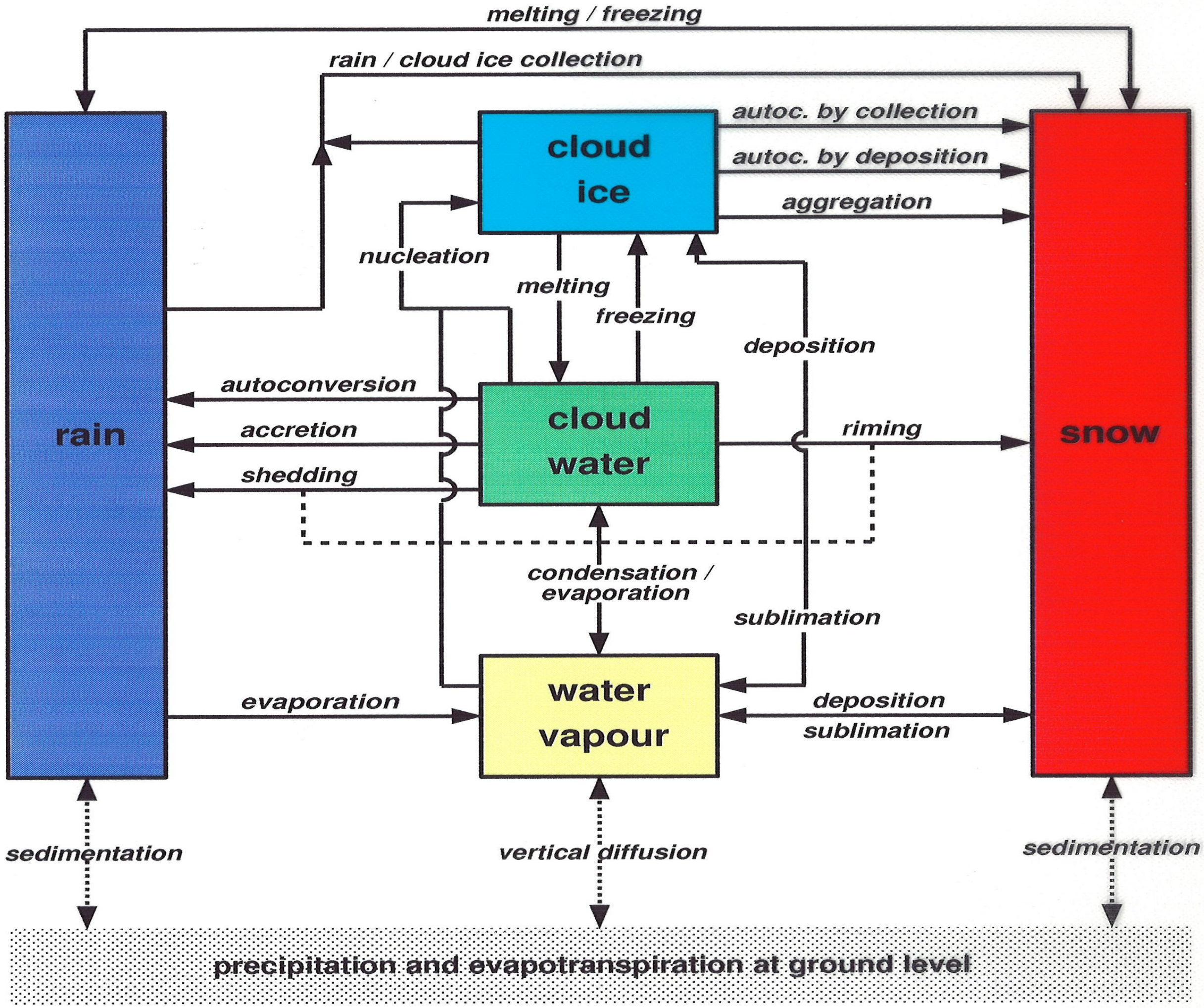


GME30L60: height of vertical levels

Reference: US standard atmosphere, 1013 hPa surface pressure



GME30L60: Prognostic precipitation

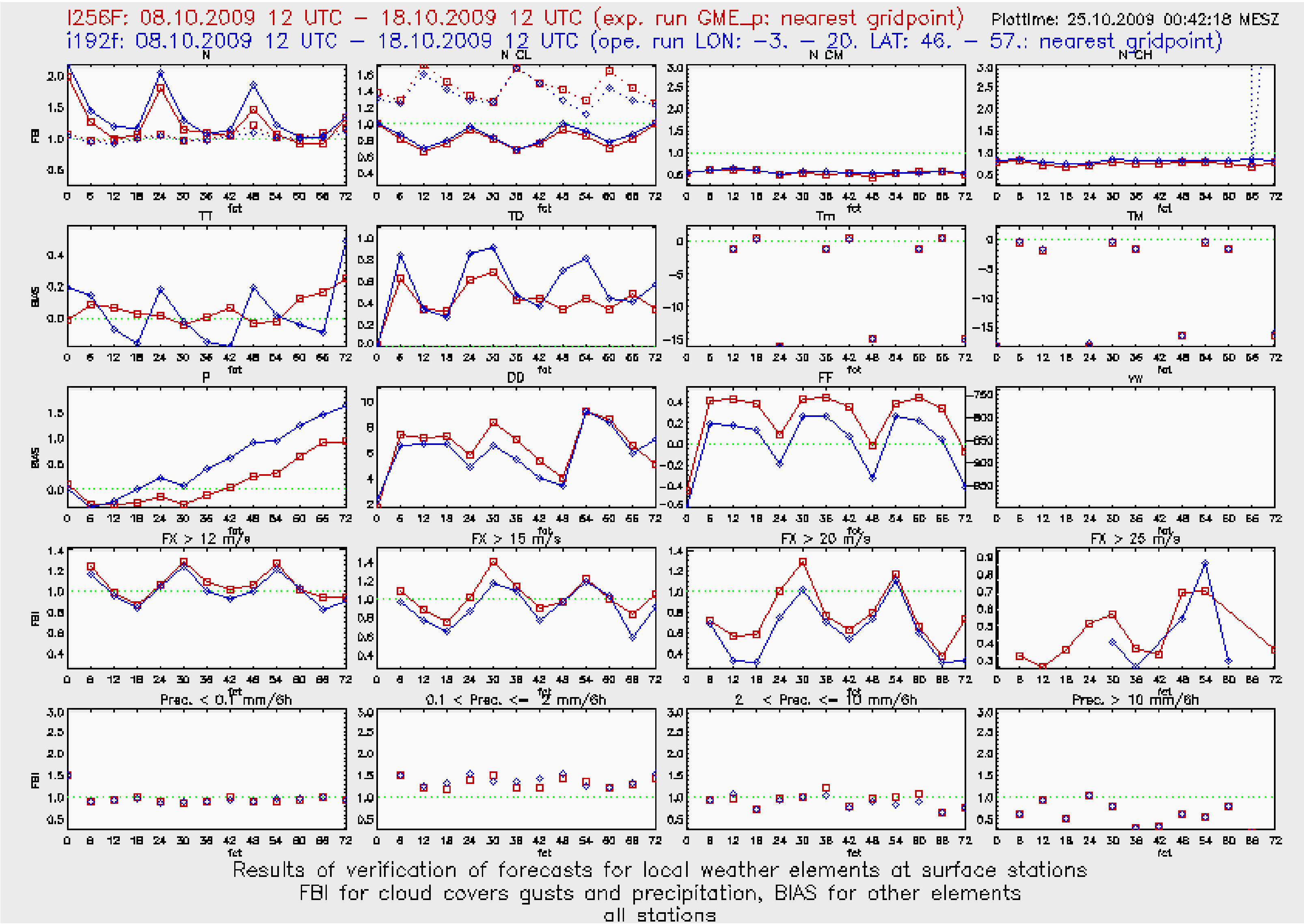


Processes considered in the grid-scale precipitation scheme.

Currently, rain and snow are treated diagnostically.

Prognostic treatment of rain and snow (with/without advection) is now being tested.

GME30L60 vs. GME40L40



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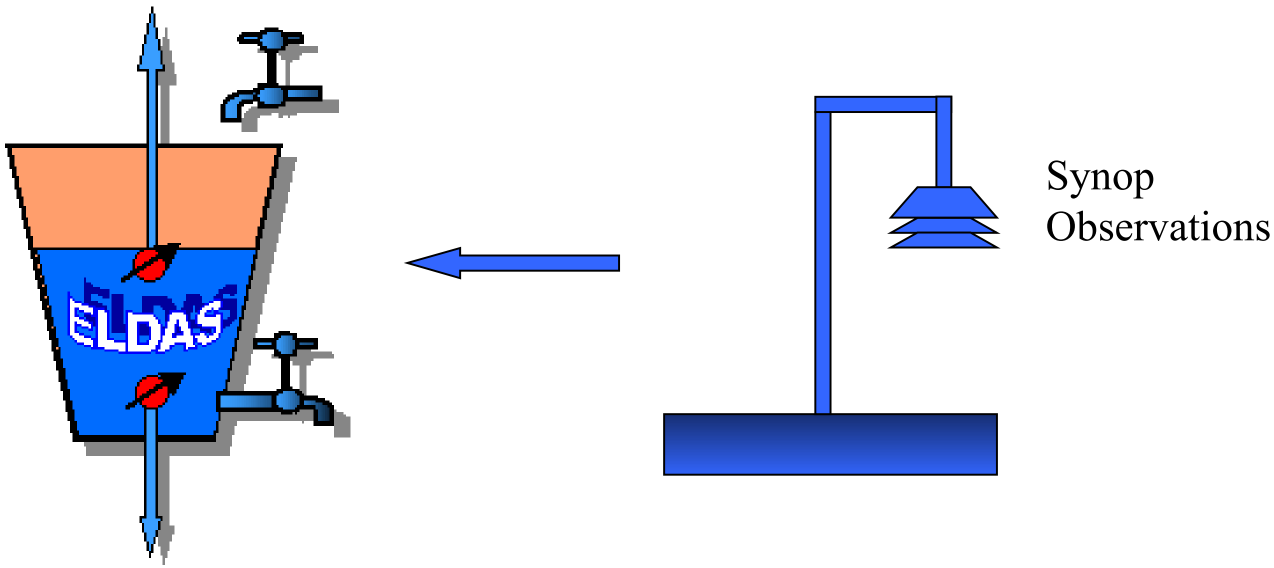
Why do we need a soil moisture assimilation ?

- Soil moisture determines on clear/partially cloudy days the maximum temperature, ABL depth, low level clouds as well as the initiation of convection to a large extend.
- If the soil moisture is too high, the model will develop a cold bias. If it is too low, a warm bias will result.
- Soil moisture has a long “memory“.

2d Var (z,t) SMA



Cost function considers deviations from initial soil moisture and screen level observations.

$$J = (w - w_b)^T B^{-1} (w - w_b) + (T_{2m} - T_{2m}{}^{obs})^T O^{-1} (T_{2m} - T_{2m}{}^{obs})$$

Goal: Minimisation of screen level forecast error

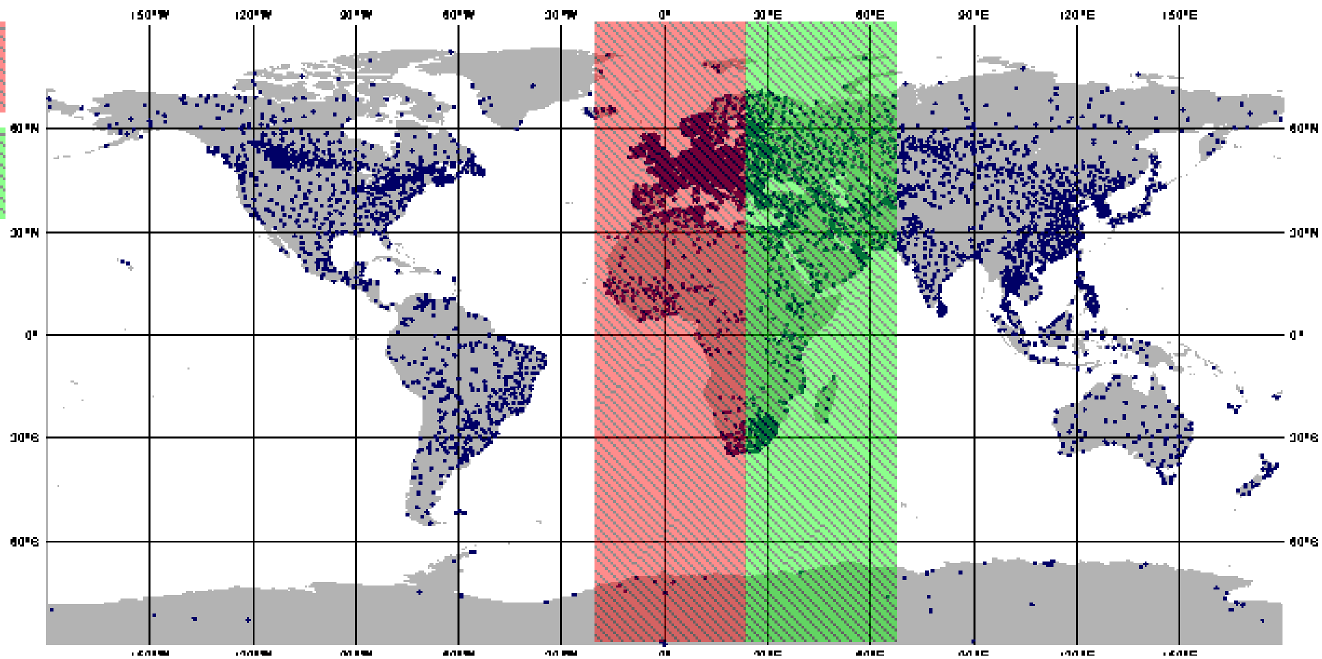
GME-SMA

Analyses in different time zones need background field with different forecast lead time

Analysis for main run at 0:00 UTC,
Observations at 12:00, 15:00 LT

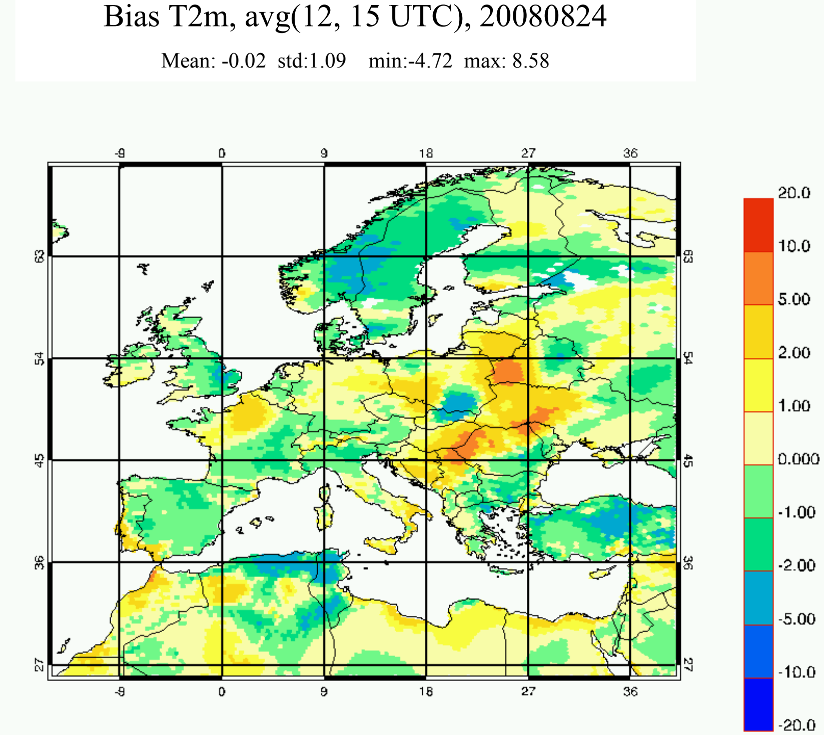
T0=0:00 LT,
vv=12, 15 hrs

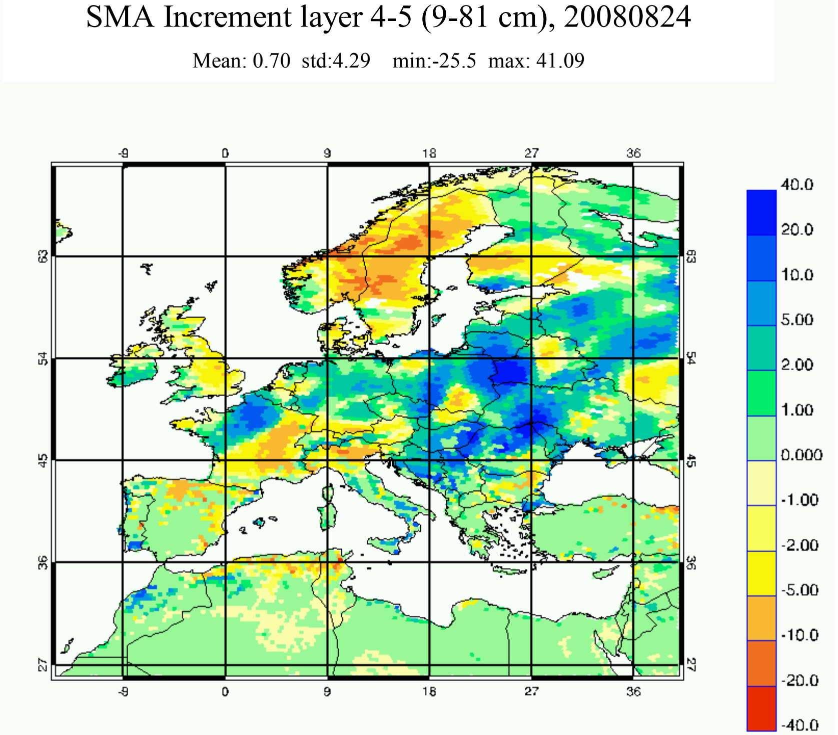
T0=3:00 LT,
vv=9, 12 hrs



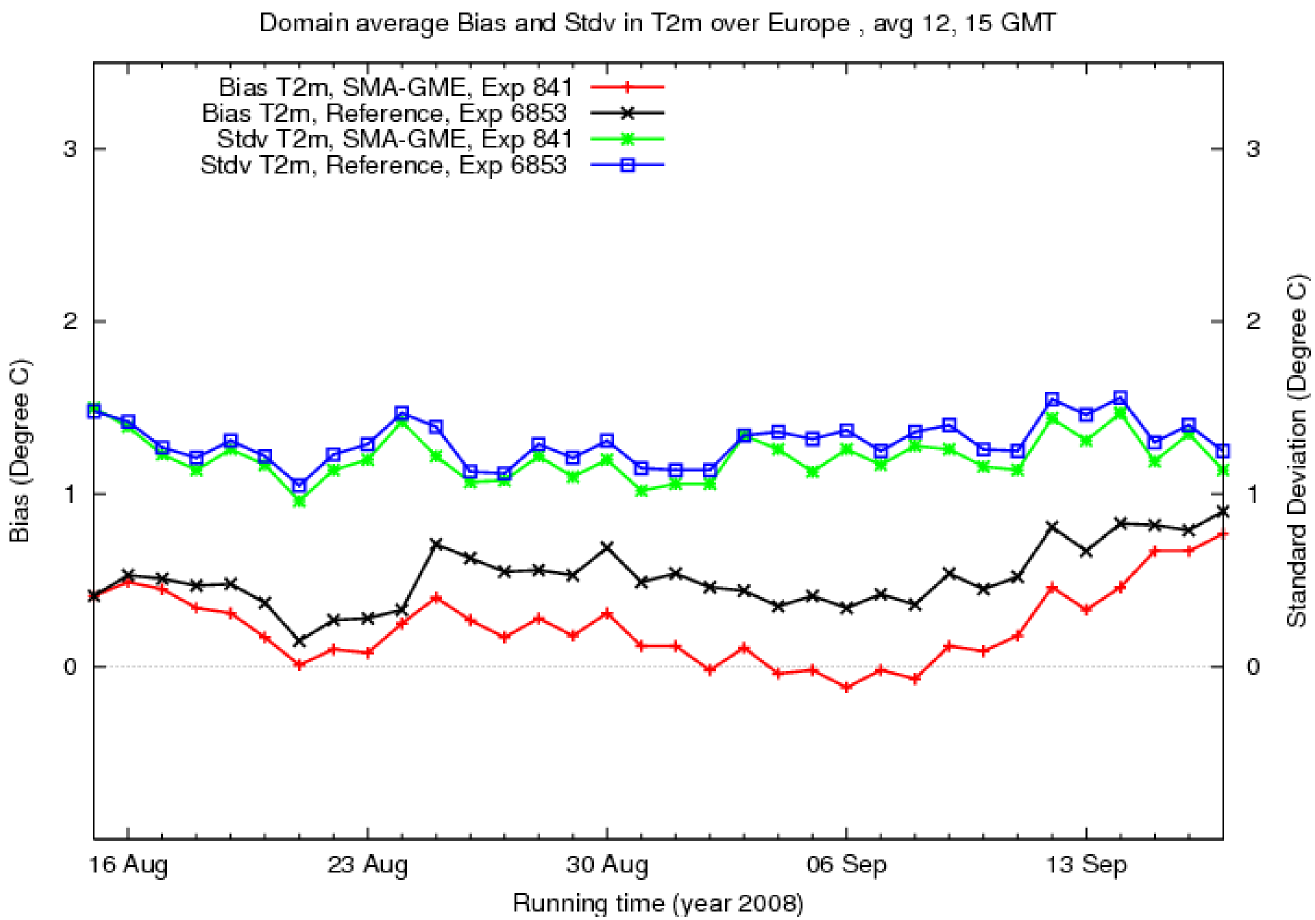
Data coverage active synops over land, 2007/10/07,12:00 UTC

Soil moisture increments based on T2m fc-error





Effective reduction in Bias and Rmse of T2m



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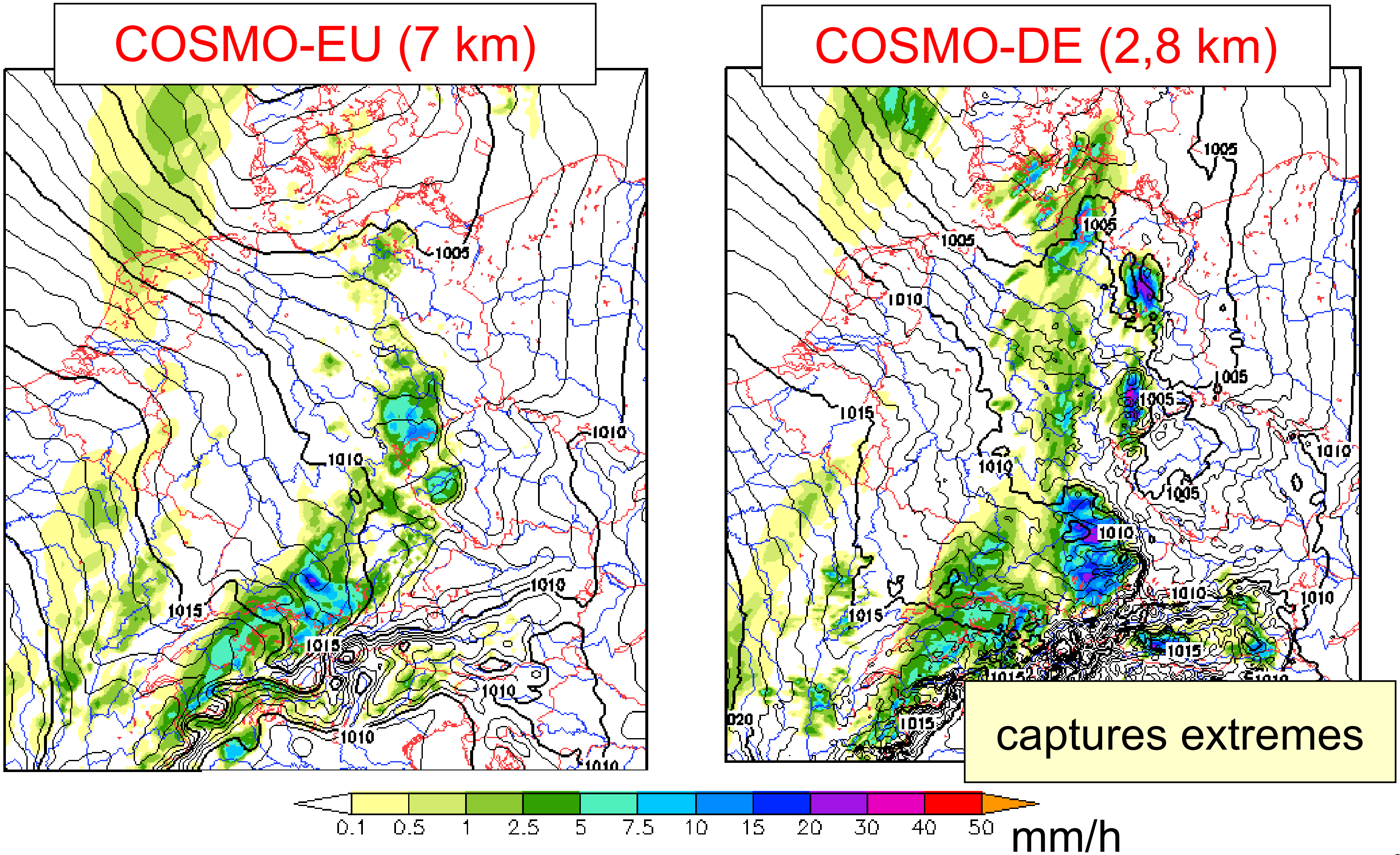
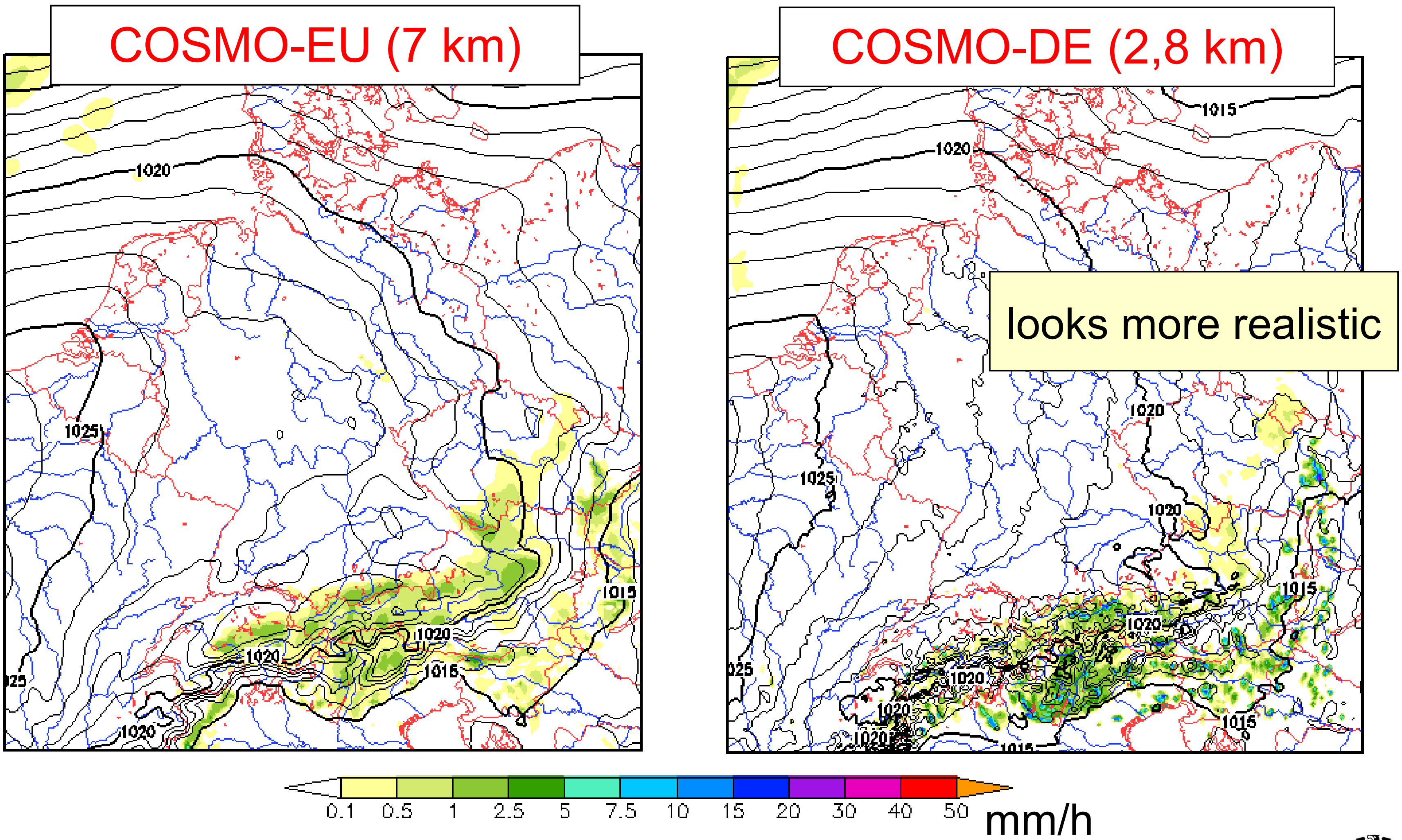
DWD

Benefits of COSMO-DE



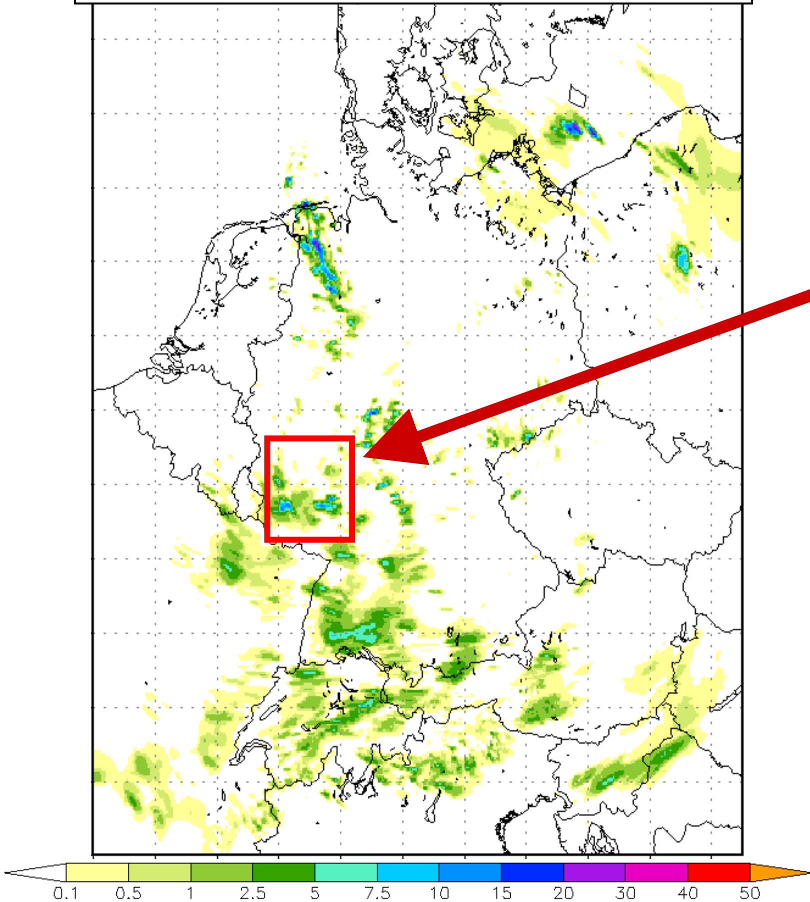
COSMO-DE Ensemble Prediction System

Benefits of COSMO-DE

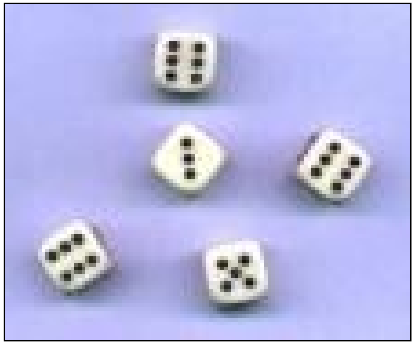


COSMO-DE EPS

COSMO-DE (2,8 km)



mm/h



need for probabilistic approach

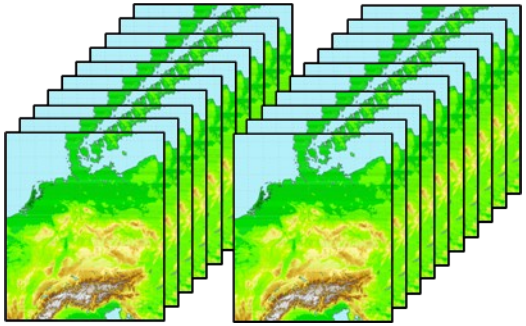
→ so that user really gets benefit

COSMO-DE EPS

The predictability of convective systems is rather limited.

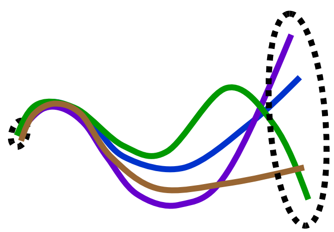
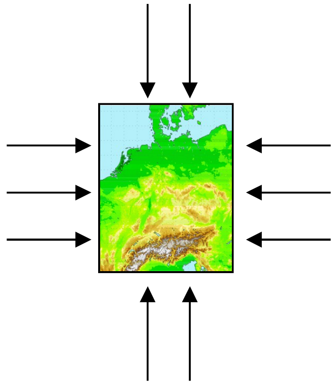
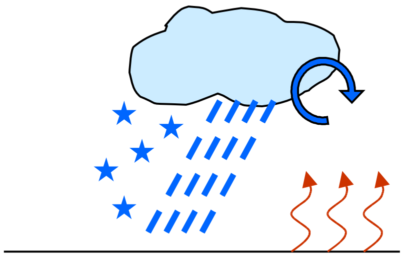
Evaluation of COSMO-DE forecasts show that single deep moist convective cells are hardly predictable, i.e. the spatial-temporal localization is extremely difficult.

On the convective scale ensemble prediction systems (EPS) are really necessary. At DWD, first pre-operational runs of COSMO-DE-EPS with 20 members are planned for Q1 2010.



COSMO-DE EPS: Ensemble setup

Uncertainity of forecasts is due to

initial conditions		boundary conditions		model physics
	X		X	

Currently perturbed nudging system and anomaly fields, later EnTKF data assimilation.

Multi-model boundary condition using different global models

SREPS

GME	IFS	UM	NCEP

Perturbed parameters in physical parameterizations.

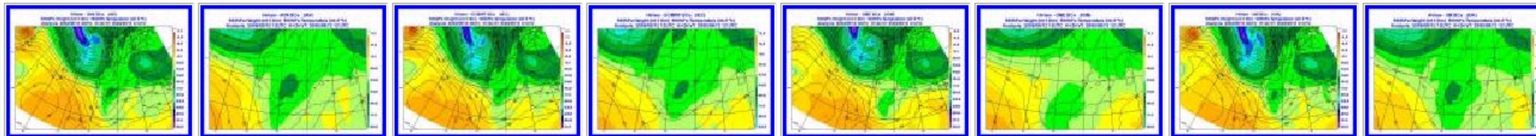
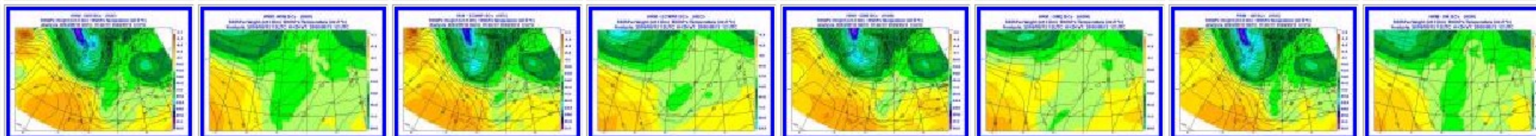
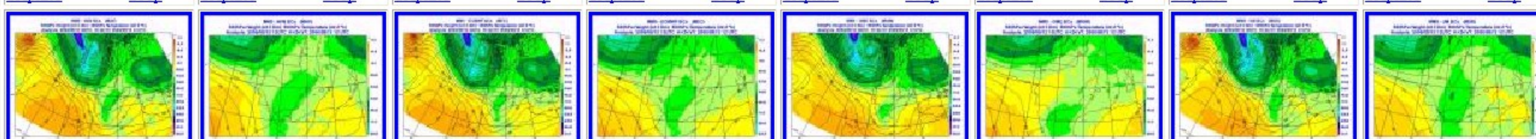
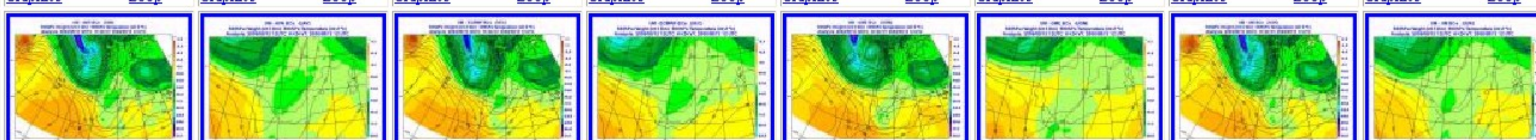
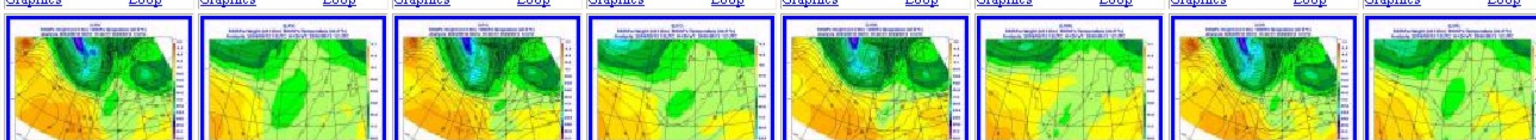
Possible alternative: Stochastic physics

SREPS – Multimodel-Multiboundaries

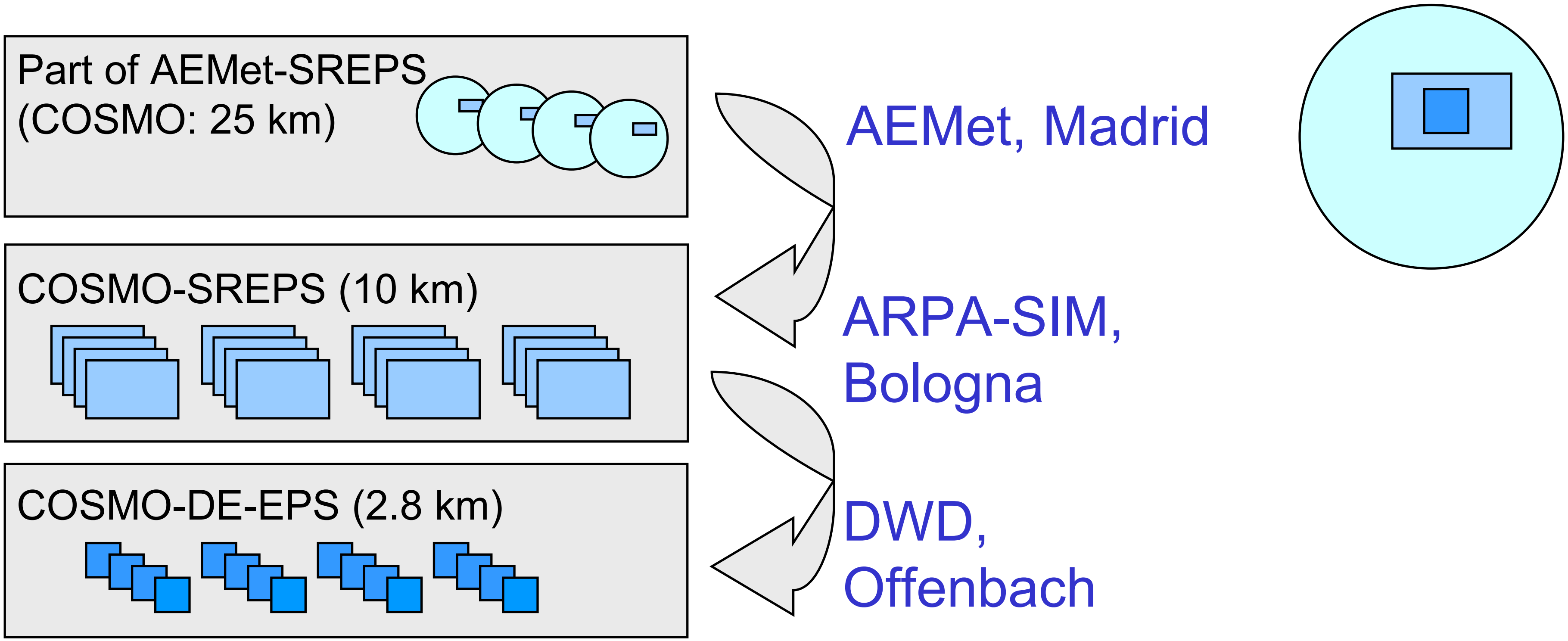
Run: D-3, 12UTC , H+00 , H+06 , H+12 , H+18 , **H+24** , H+30 , H+36 , H+42 , H+48 , H+54 , H+60 , H+66 , H+72

500hPa Height & Temperature

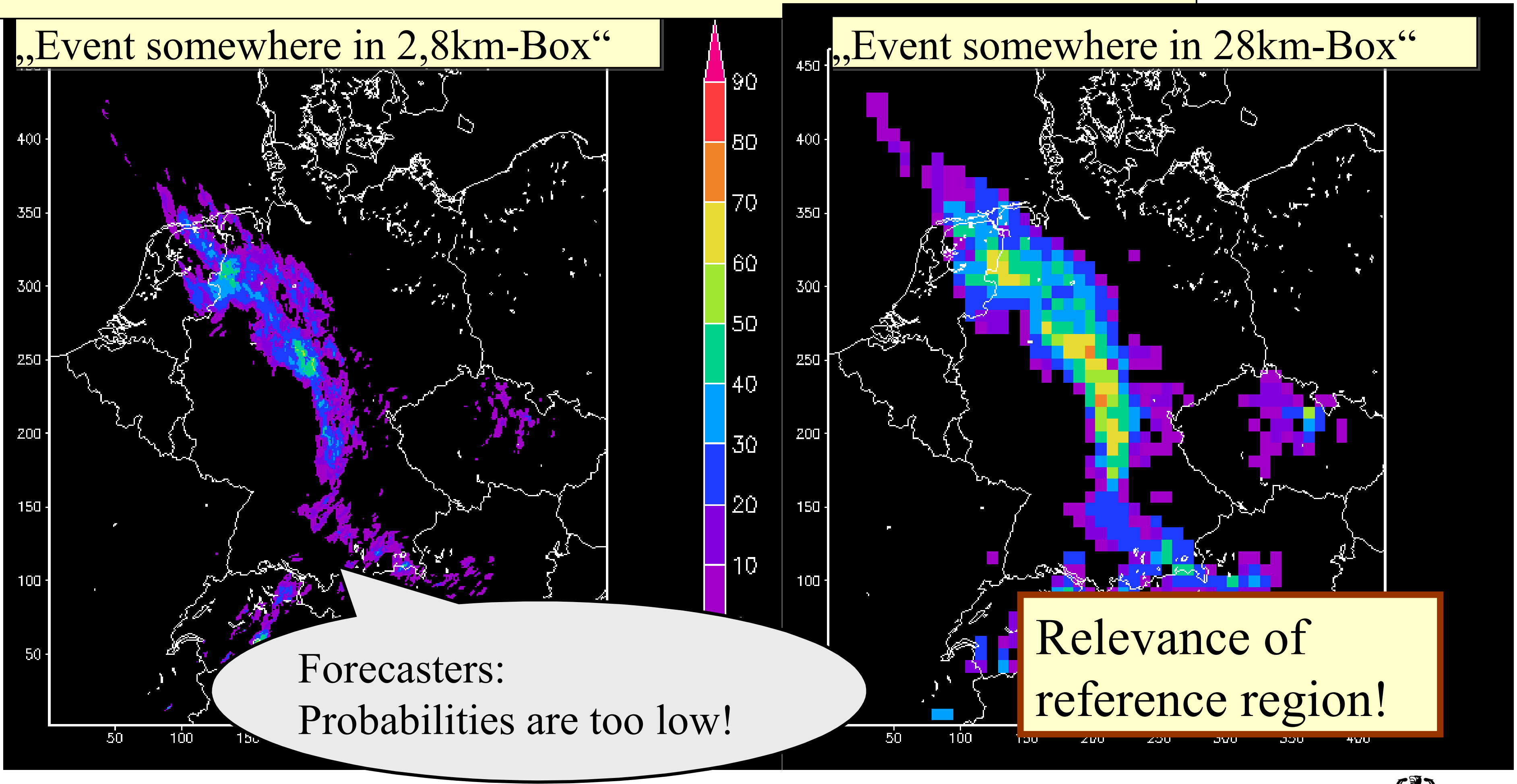
Models X Boundaries

Models / Boundaries	AVN-BCs		ECMWF-BCs		GME-BCs		UM-BCs	
Hirlam	 HH+24 Graphics Loop	HH+24 Graphics Loop	HH+24 Graphics Loop	HH+24 Graphics Loop	HH+24 Graphics Loop	HH+24 Graphics Loop	HH+24 Graphics Loop	HH+24 Graphics Loop
HRM	 HH+24 Graphics Loop	HH+24 Graphics Loop	HH+24 Graphics Loop	HH+24 Graphics Loop	HH+24 Graphics Loop	HH+24 Graphics Loop	HH+24 Graphics Loop	HH+24 Graphics Loop
MM5	 HH+24 Graphics Loop	HH+24 Graphics Loop	HH+24 Graphics Loop	HH+24 Graphics Loop	HH+24 Graphics Loop	HH+24 Graphics Loop	HH+24 Graphics Loop	HH+24 Graphics Loop
UM	 HH+24 Graphics Loop	HH+24 Graphics Loop	HH+24 Graphics Loop	HH+24 Graphics Loop	HH+24 Graphics Loop	HH+24 Graphics Loop	HH+24 Graphics Loop	HH+24 Graphics Loop
LM	 HH+24 Graphics Loop	HH+24 Graphics Loop	HH+24 Graphics Loop	HH+24 Graphics Loop	HH+24 Graphics Loop	HH+24 Graphics Loop	HH+24 Graphics Loop	HH+24 Graphics Loop

Pertubation strategy of boundary data



EPS Product Example: Probability Maps



COSMO-DE EPS: A Challenge

Pre-operational: Q1 2010

- EPS runs per day: 8
- number of ensemble members: 20
- forecast time: 21h
- observation cut off time: X + 0:45 h
- ready time of model run: X + 1:15 h
- data amount per ensemble run (full / red.): ca. 766 / 300 Gbyte
- data transfer rate into database (full / red.): ca. 3.4 / 1.3 Gbit/s

Outline

Infrastructure

- New Headquarter and computer system
- Migration of NWP model suite

NWP models

- GME / COSMO-EU / COSMO-DE
- Operational Schedule
- Operational changes 2007-2009

Recent developments

- GME30L60
- GME-SMA
- COSMO-DE EPS
- ICON

ICON – *ICO*sahedral *N*onhydrostatic Model

The next generation global model at DWD and MPI-M

http://www.icon.enes.org

Main goals of the ICON-Project

- Centralize Know-how in the field of *global modelling* at DWD and the Max-Planck-Institute (MPI-M) in Hamburg.
- Develop a ***nonhydrostatic global model with static local zooming option***
- At DWD: Replace global model GME and regional model COSMO-EU by ICON with a high-resolution window over Europe

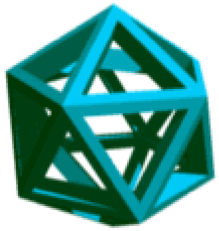
  Establish a library of scale-adaptive physical parameterization schemes (to be used in ICON and COSMO-DE).
- At MPI-M: Use ICON as dynamical core of an Earth System Model (COSMOS)

  replace regional climate model REMO

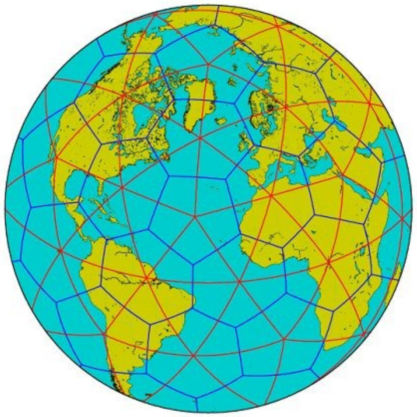
  Develop an ocean model based on ICON grid structures and operators.
- DWD and MPI-M: Contribute to operational seasonal prediction in the framework of the Multi-Model Seasonal Prediction System EURO-SIP at ECMWF

ICON

Grid topology and geometry



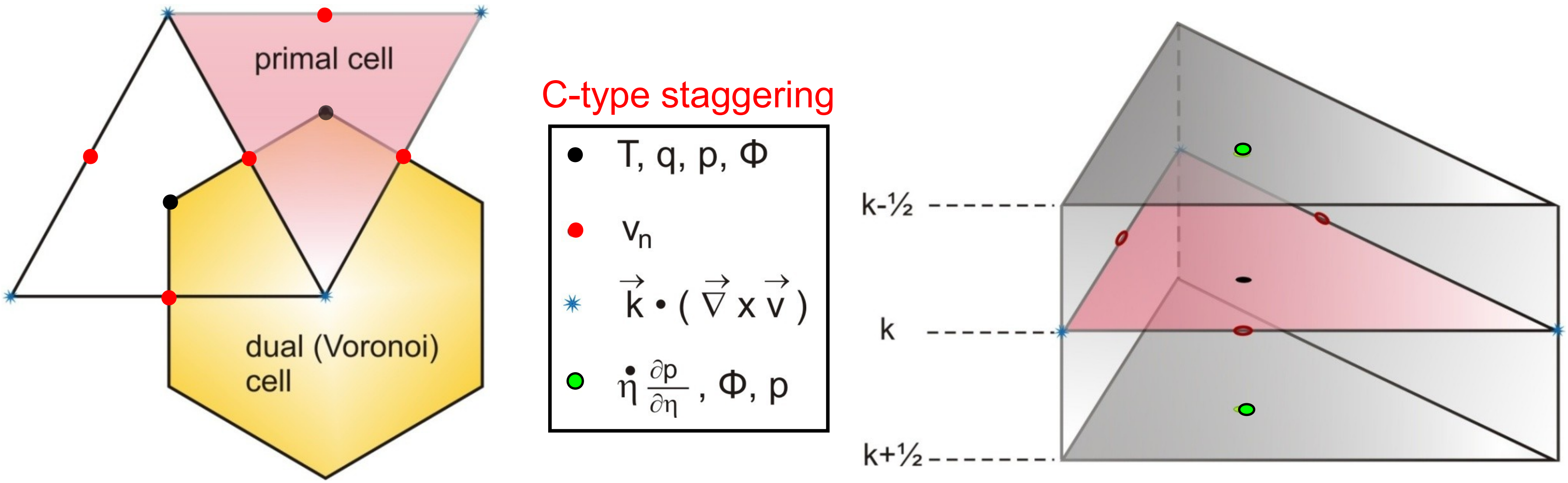
- Inscribe icosahedron inside the unit sphere
- The 12 vertices touching the surface define the basic mesh consisting of 20 spherical triangles.
- Further mesh refinement by one „root division“ followed by successive bisections (connect midpoints of the edges for each triangle by great circle arcs)



- Primal (Delaunay) grid: triangles
- Dual (Voronoi) grid: hexagons

  (+ 12 pentagons at the icosahedron vertices)

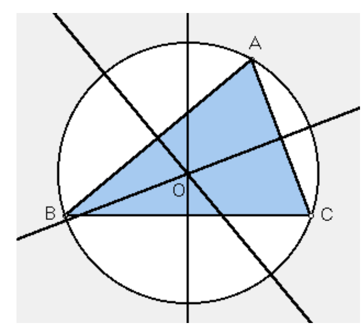
3D arrangement of the discrete variables



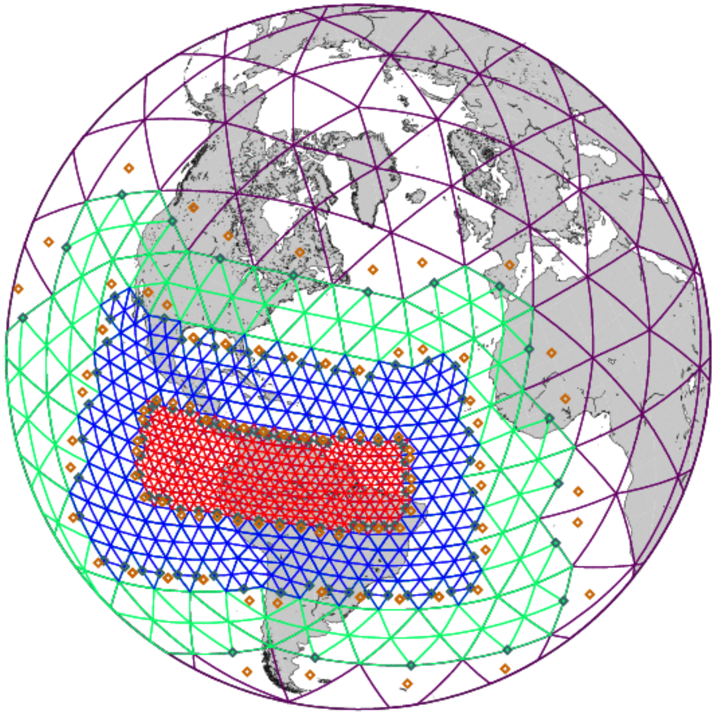
horizontal **vertical**

- Cell center: center of triangle circumcircle

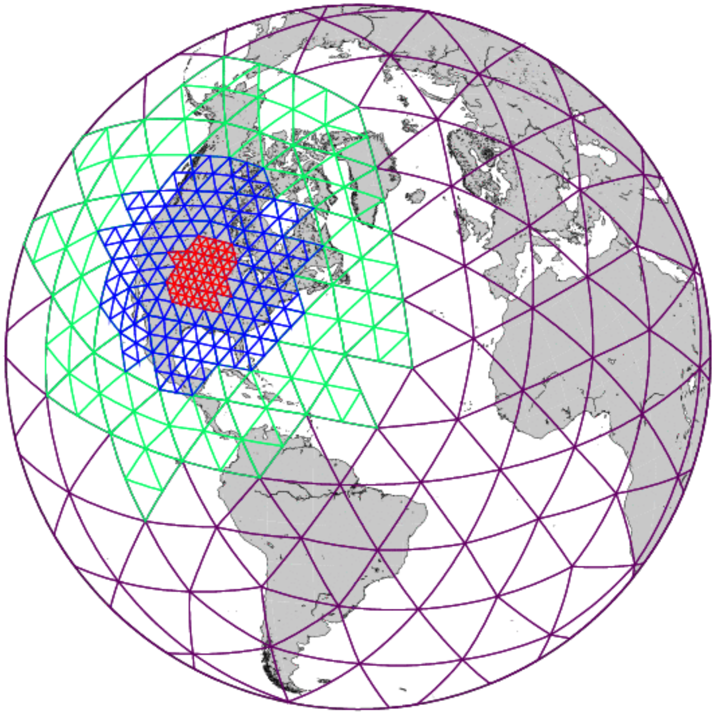
  ⇒ Arc connecting two mass points is orthogonal to and bisects triangle edge



Higher resolution windows at three refinement levels
(one-way or two-way nesting)



Latitude-Longitude window



Circular window

ICON – Conclusions and outlook

- In the ICON project DWD and the German Climate Research Centre MPI-M jointly develop the next generation global weather forecast and climate simulation model.
- A shallow water and a hydrostatic 3D dynamical core have been developed and evaluated in the past three years.
- The grid refinement allows for locally resolving finer-scale structures while properly interacting with the larger-scale flow.
- In 2009 the nonhydrostatic core will be developed.
- A first operational NWP model version will be ready by 2011.

END

Thank You

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