Review about the current dynamical core developments in the COSMO model

36th EWGLAM / 21th SRNWP meeting
29 Sept. – 02 Oct. 2014, Offenbach, DWD

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(IMGW, Poland)

Dynamical core (Euler solver) developments in COSMO

- Current Runge-Kutta dynamical core
  (*Wicker, Skamarock (2002) MWR, Baldauf (2010) MWR*)
  - further maintenance (DWD) (~0.5 FTE)
  - higher order discretizations (Univ. Cottbus) (~1 FTE)
  - code rewrite in particular for GPU's (→ COSMO WG6 ‚system aspects')

- EULAG (anelastic) as a candidate for the future COSMO dyn. core
  COSMO PP ‚Conservative dynamical core' (2008-2012):
  (Baldauf et al. (2013) COSMO Tech. Rep. no.23, Ziemiański et al. (2011) Acta Geophysica, Rosa et al. (2011) Acta Geophysica, Kurowski et al. (2011) Acta Geophysica)
  PP ‚COSMO-EULAG operationalization' (2012-2016) (IMGW, Poland) (~3 FTE)

- fully implicit FV solver ‚CONSOL' (CIRA, Italy) (~0.2 FTE)
  Jameson (1991) AIAA

Project in the framework of the German research community (DFG) MetStröm

- Dynamical core based on Discontinuous Galerkin methods
  (DWD, Univ. Freiburg, 2010-2014, ~1 FTE)

1 FTE (full time equivalent) = 1 person/year

CONSORTIUM FOR SMALL SCALE MODELING COSMO

Deutscher Wetterdienst
Wetter und Klima aus einer Hand

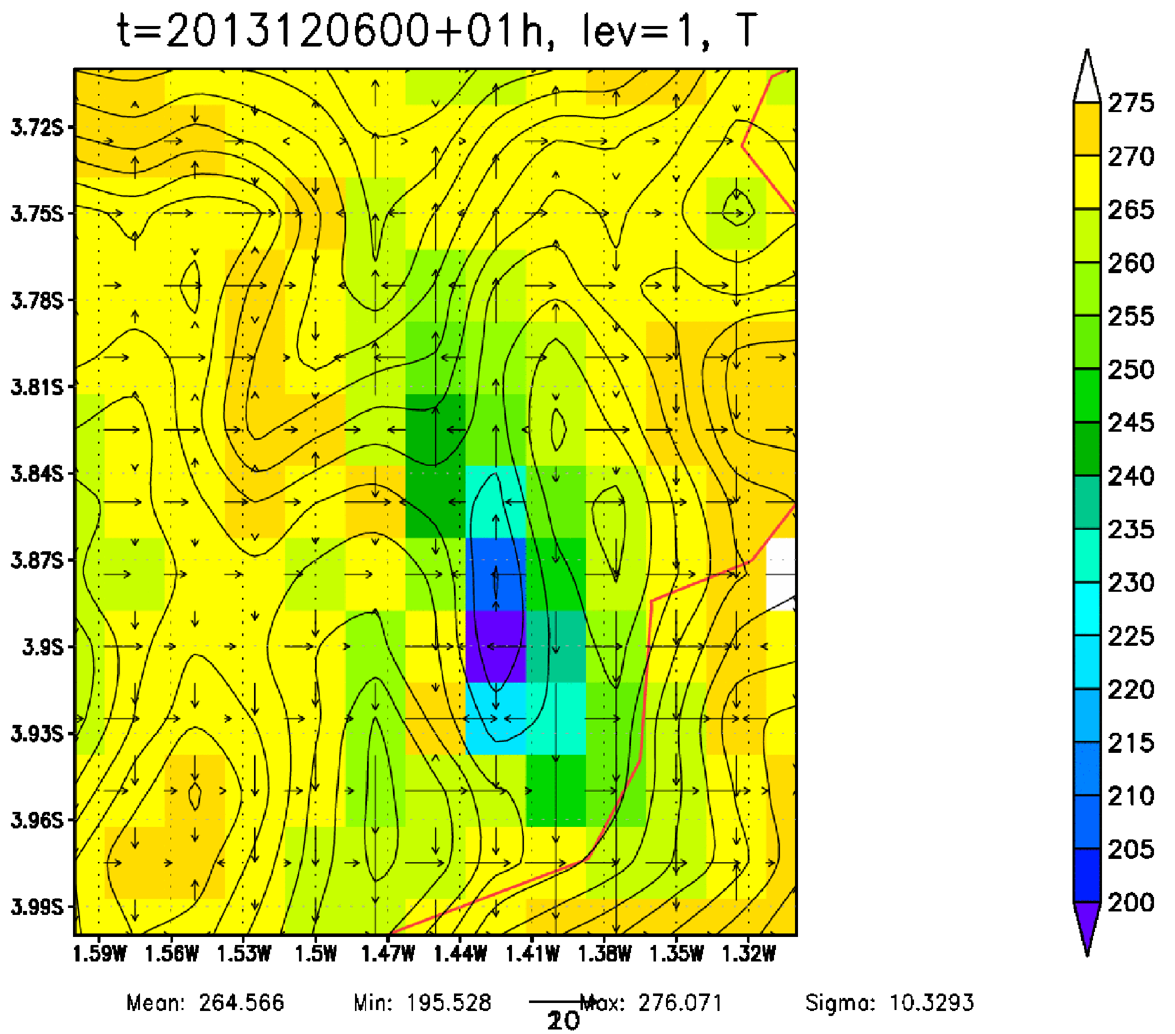
DWD

‘Targeted diffusion’ to avoid cold pools in narrow valleys

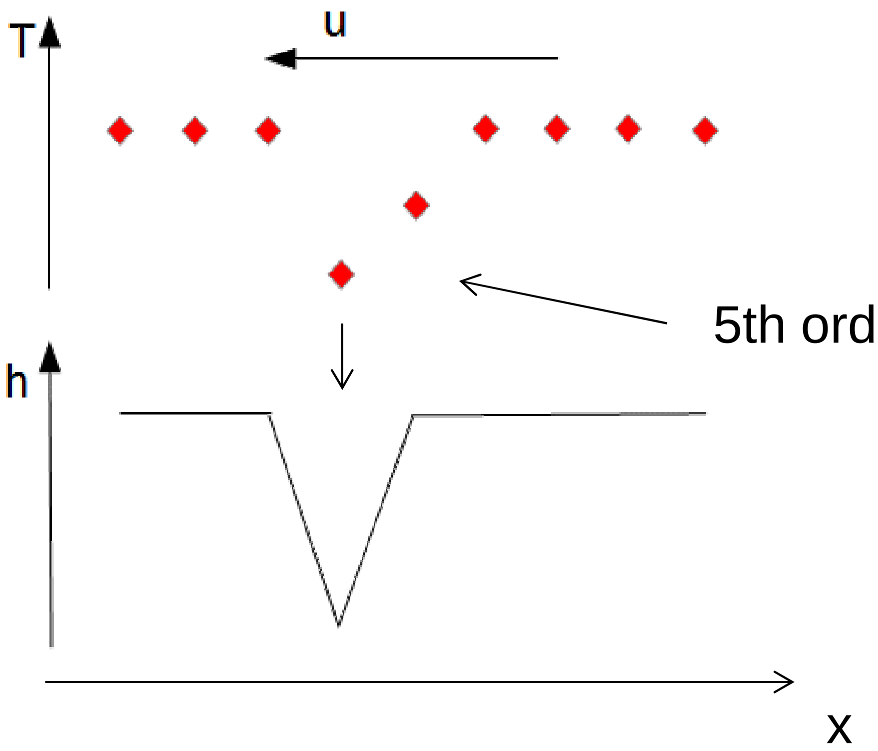
M. Baldauf (DWD)

… occured in a few COSMO-DE-runs around 06 Dec. 2013 in a narrow Alpine valley and even led to a model crash in 2 EPS-members (parallel routine).

Similar ‚cold pools‘ have been reported by MeteoCH.



Main contributor to the cooling is the horizontal advection:



5th order advection intensifies the ‚ramp‘

Linear advection equation (1-dim.) $\frac{\partial q}{\partial t} + u \frac{\partial q}{\partial x} = 0$ discretized: $\frac{q_j^{n+1} - q_j^n}{\Delta t} = f_j(q^n)$

$$f_j^{(5)}(q) \quad := \quad -u \frac{-3q_{j+2} + 30q_{j+1} + 20q_j - 60q_{j-1} + 15q_{j-2} - 2q_{j-3}}{60\,\Delta x}$$

`iadv_order=5 !`

‘Targeted diffusion’ to avoid cold pools in narrow valleys

these cold pools are a numerical artefact of the upwind 5th order advection scheme.

‚Targeted diffusion‘ (analogous to G. Zängl in ICON)

criteria: diffusion in a (near bottom) grid point, if

$$T' < \langle T'_{environment} \rangle - 10K$$

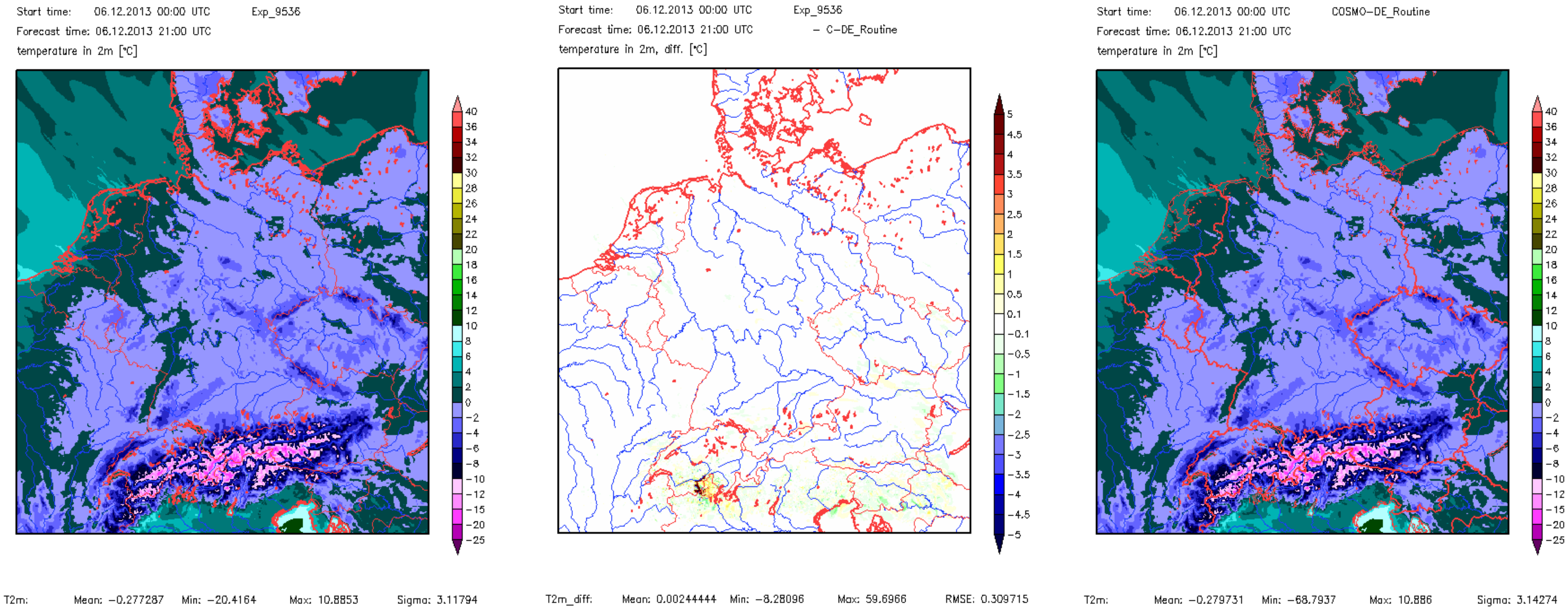
is applied only in these grid points;
reduces a cold pool very quickly and is not active later on

computation time consumption ~ 0.05%

implemented in **COSMO 5.0.2**

documentation: a short section will be included in the COSMO Sci. Doc. Part I

Example for the influence of ‚targeted diffusion' and ‚reform. div. damping coeff'
06. Dec. 2013, 21 h forecast, T2m



Additionally: both actions do not significantly change the verification scores

Other work in the dynamics 2014 … finished:

- Revision of the Davies-lateral boundary relaxation (Arteaga, Baldauf, Fuhrer, Schneider)
- Reformulation of the divergence damping coefficient in steep terrain (Baldauf)
- Advection and horizontal diffusion of TKE (Blahak)
- Removal of inconsistencies (‚hacks') in the tracer module (Roches, Fuhrer)
- Cache optimizations for new fast waves solver (Baldauf)
- Code rewrite of the new fast waves solver (in particular for GPUs) using the stencil library STELLA (Baldauf, Arteaga)

… currently running:

- Revised Bott (2010)-scheme with deformational correction for tracer advection (Schneider, Bott (Univ. Bonn), Blahak (DWD))
- Adaptive time step (Smalla, Reinhard (DWD))

Status of the priority project CELO (COSMO-EULAG operationalization)

= implementation of the EULAG dynamical core (anelastic equations) into COSMO

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Institute of Meteorology and Water Management
National Research Institute

Rough comparison of dynamical cores (Euler solvers)

	COSMO-RK	COSMO-EULAG
Equation system	compressible	anelastic (Lipps, Hemler, 1982)
Spatial discret.	Finite-difference mix. 2nd / 5th order	Finite-volume, 2nd order
Temporal discret.	Time-splitting vertically implicit Runge-Kutta	semi-implicit ‚nonlinear forward in time‘
Grid	Arakawa-C Lorenz	unstaggered (collocated)

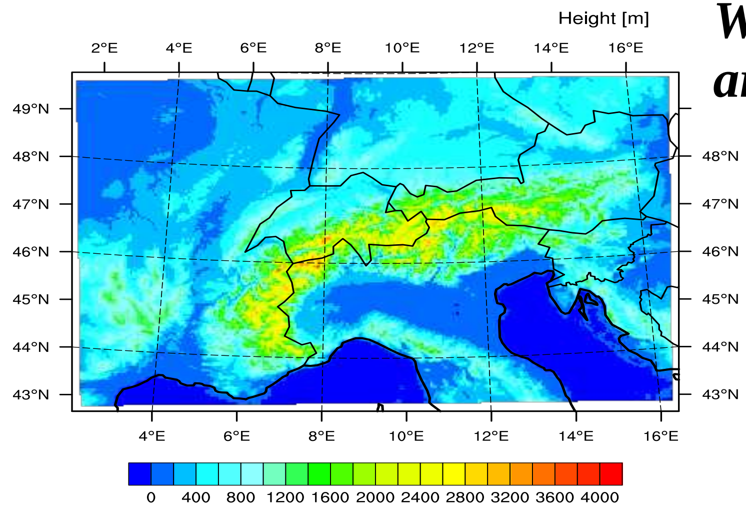
Preliminary results of verification (June and November 2013)

Computational domain :

- WE x NS = 520 x 350 gridpoints, 2.2km resolution
- standard operational COSMO-2 model of Meteo-Swiss vertical distribution of levels (61), Gal-Chen coordinate system with the top at 23588.50m.a.s.l.
- Orography as in the COSMO-2 model of Meteo-Swiss configuration
- Lateral absorber width = 40km
- Top sponge base height = 15km

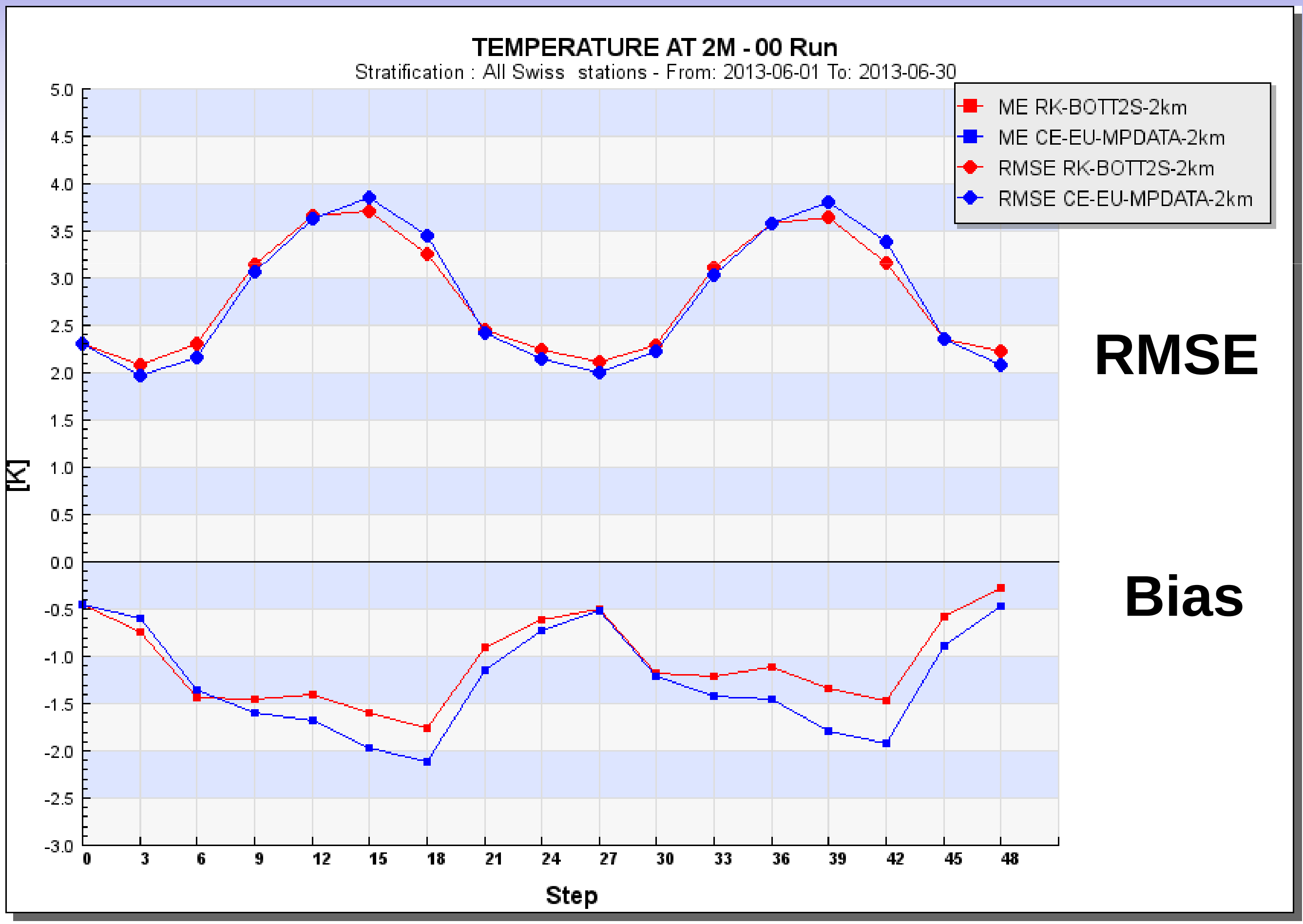
Initial and boundary data for all simulations are interpolated from COSMO – 7 forecast of Meteo Swiss (using Int2lm 1.22).

- **Shallow convection parameterization is turned off (*lconv=F*)**
- **Topographical corrections to radiation are turned off (*lradtopo=F*)**
- **Old fast waves solver (*irunge_kutta=1* and *itype_fast_waves=1*)**



Weather forecasts are 48 hours long

Temperature (June 2013)



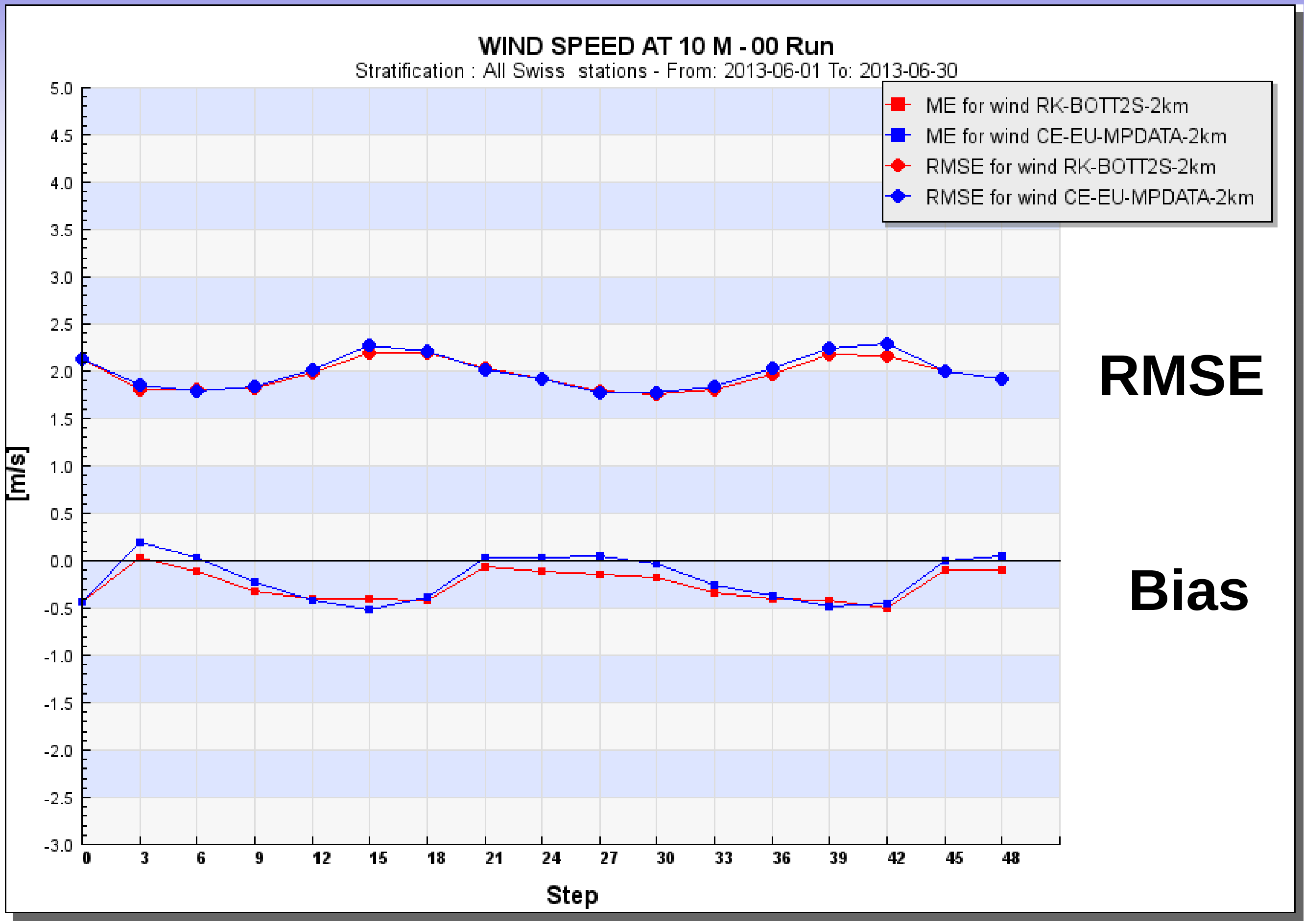
Cosmo Runge-Kutta

Cosmo-Eulag

see also Poster Poland (COSMO)

- **The RMSE of C-RK and C-E are very similar**
- **The bias of C-RK is better, both models underestimate T by ~1.0°**
- **Visible diurnal cycle**

Wind (June 2013)



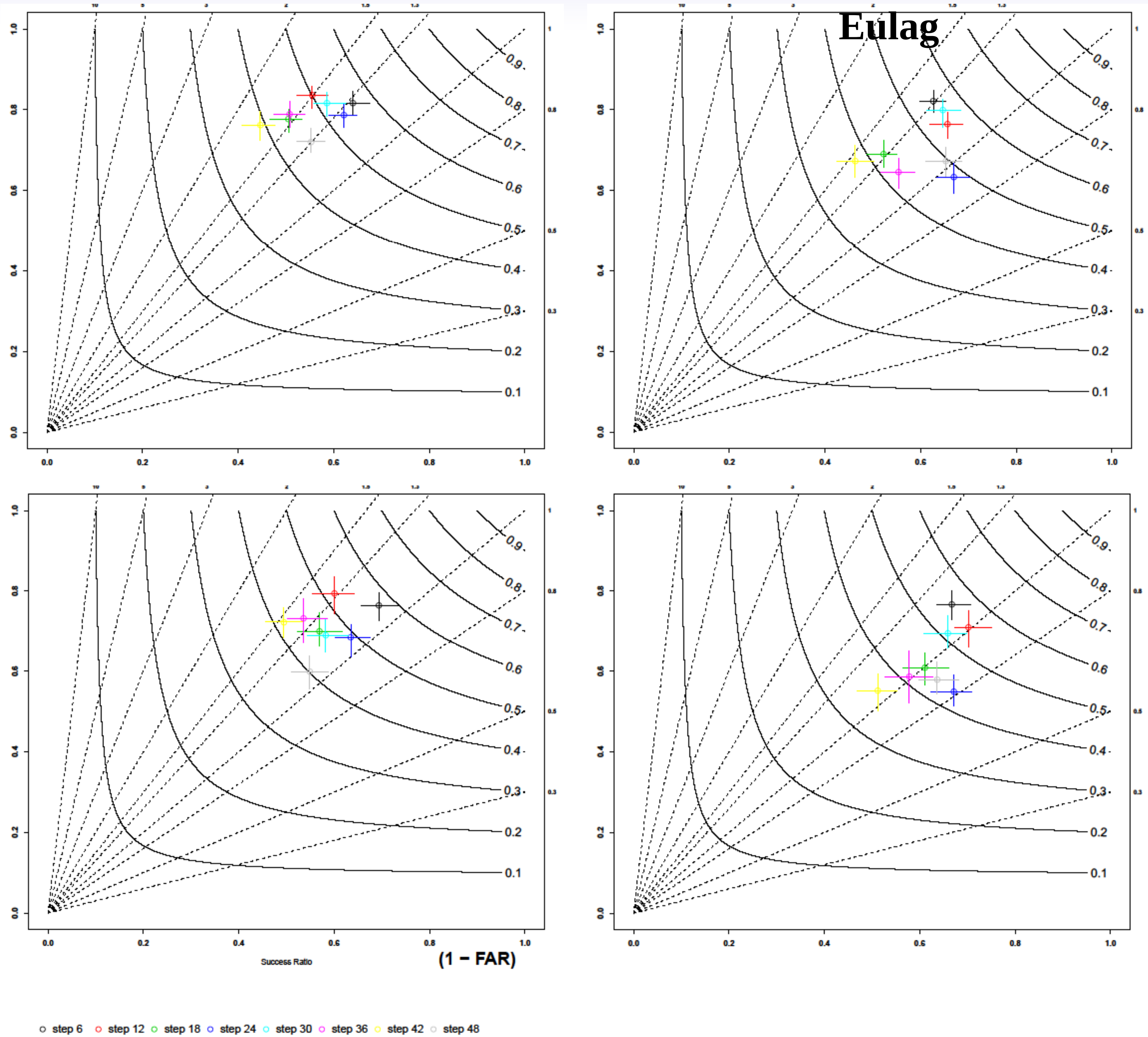
Cosmo Runge-Kutta

Cosmo-Eulag

- **The both scores are very similar**
- **The RMSE of Cosmo R-K is lower around 3pm**
- **The bias of Cosmo-Eulag is lower during night and morning hours**

Precipitation (June 2013)

Cosmo R-K **Cosmo-Eulag**



X axis: Success Ratio
Y axis: Probability of Detection

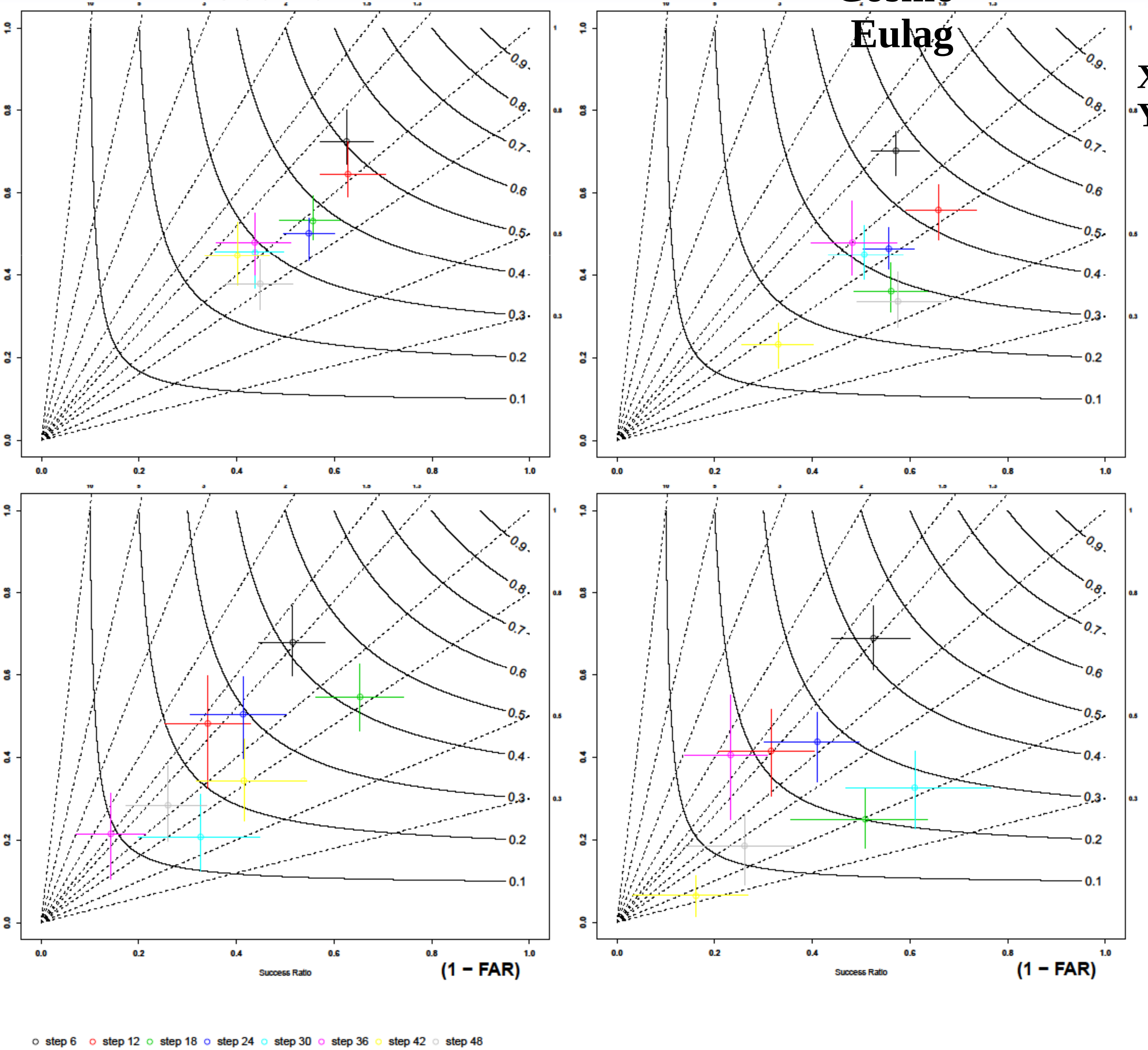
+0.2 mm

For these rainfall ranges Probability of Detection is higher for Cosmo R-K
The Success Ratio is higher for Cosmo-Eulag (but not in all timesteps)

+0.8 mm

Precipitation (June 2013)

Cosmo R-K | Cosmo-Eulag



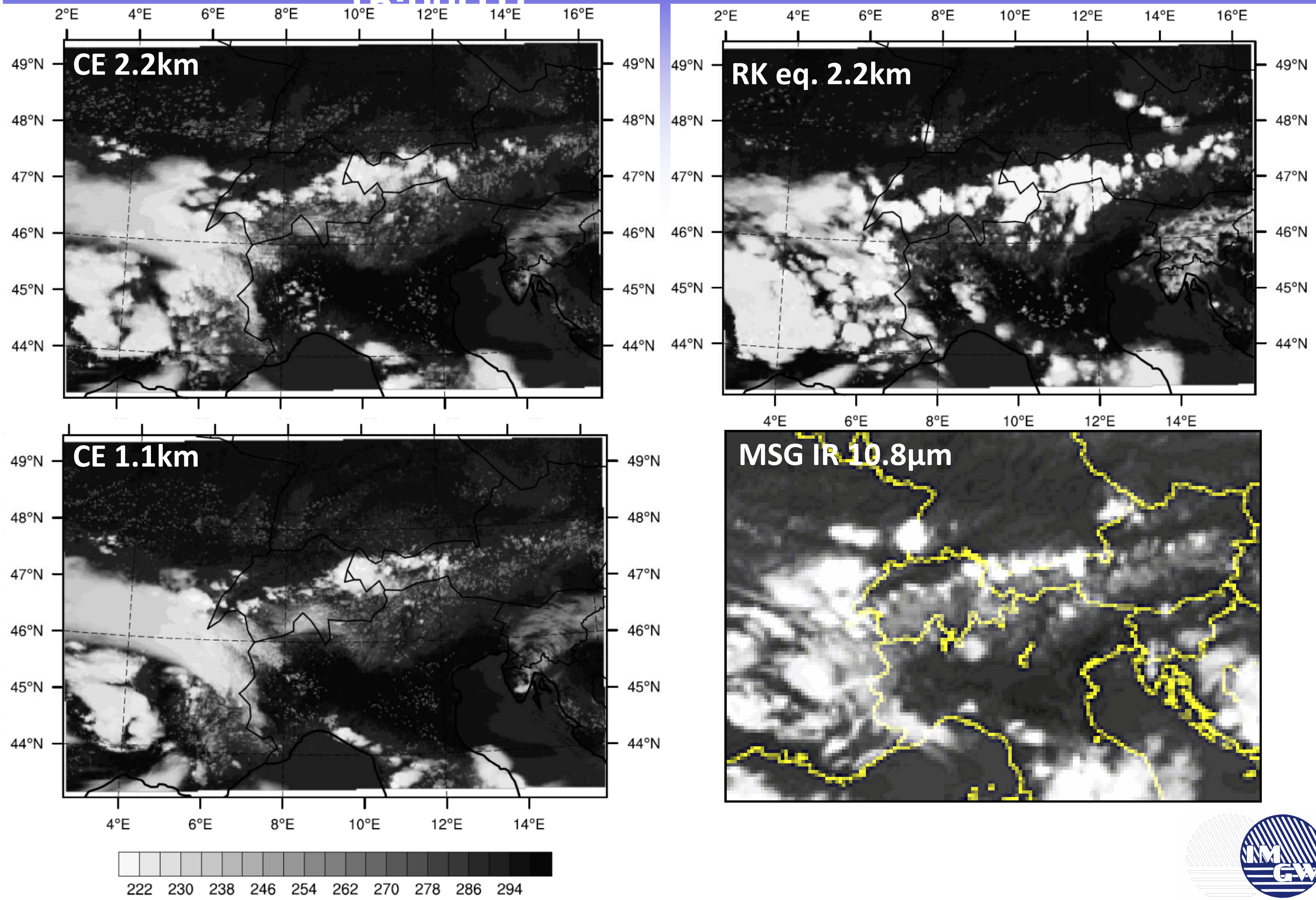
X axis: Success Ratio
Y axis: Probability of Detection

+4.0 mm

For these rainfall ranges Probability of Detection is higher for Cosmo R-K
The Success Ratio is higher for Cosmo-Eulag (but not in all timesteps)

+8.0 mm

Brightness temperature, IR 10.8µm channel, 19 July 2013 15:00UTC



Summary (Verification)

- Now, in COSMO two quite different dynamical cores available with a similar behaviour concerning scores
- Verification scores of dynamical variables (Temperature, Wind) are very similar for Cosmo-Eulag and Cosmo Runge-Kutta (in the equivalent setup)
- Verification scores of moist variables (Total Cloud Cover, Dew-Point Temperature) are slightly better for the Cosmo Runge-Kutta (in the equivalent setup)
- Verification scores of Precipitation are usually better for the Cosmo Runge-Kutta (precipitation events with 0.8 mm and higher rainfall)
- Scores of dynamical and moist variables contain clear diurnal cycle component (June 2013)
- Biases of dynamical and moist variables have usually the same sign for Cosmo-Eulag and Cosmo Runge-Kutta
- Tuning is needed to improve the precipitation scores

A new dynamical core based on Discontinuous Galerkin methods

Project ‘Adaptive numerics for multi-scale flow’, DFG priority program ‘Metström’

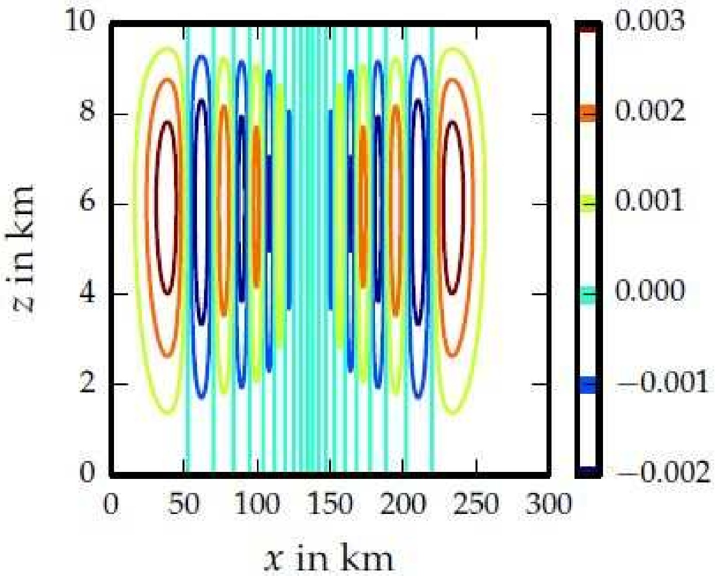
D. Schuster, M. Baldauf (DWD)

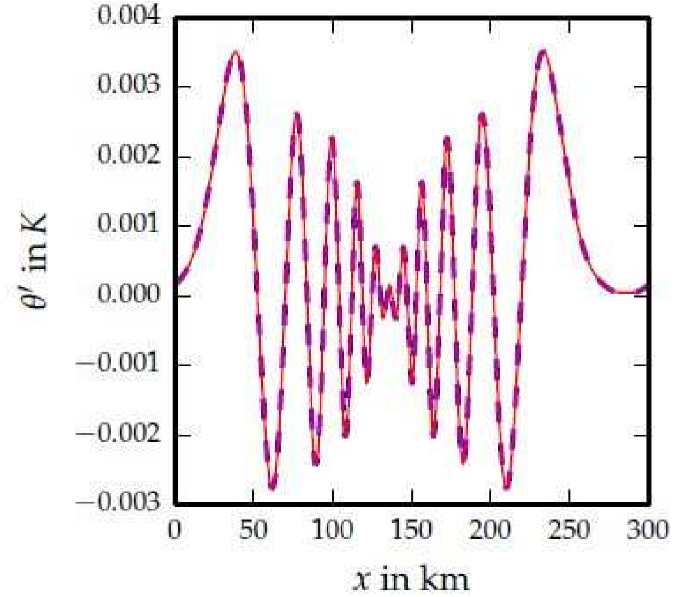
- cooperation between DWD, Univ. Freiburg, Univ. Warwick (6-year program)
  - one PhD position (2010-2014) at DWD
- goals for the DWD: new (prototype) dynamical core for COSMO with
  - high order accuracy
  - conservation of mass, momentum and energy / potential temperature
  - scalability to thousands of CPUs
  - (high grid flexibility)

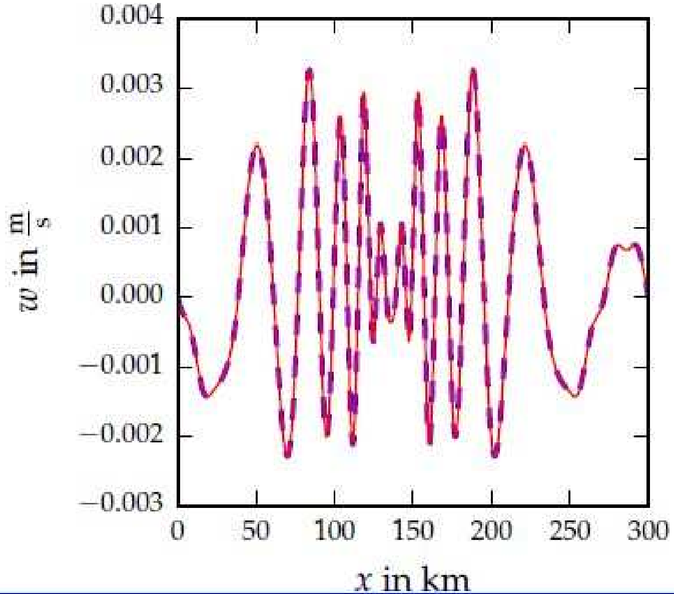
➥ **use of discontinuous Galerkin methods**

- explicit time integration (Runge-Kutta) (not efficient, of course)
- terrain following coordinates
- coupling of physical parameterisations

$\theta'(t = 30\,\text{min})$

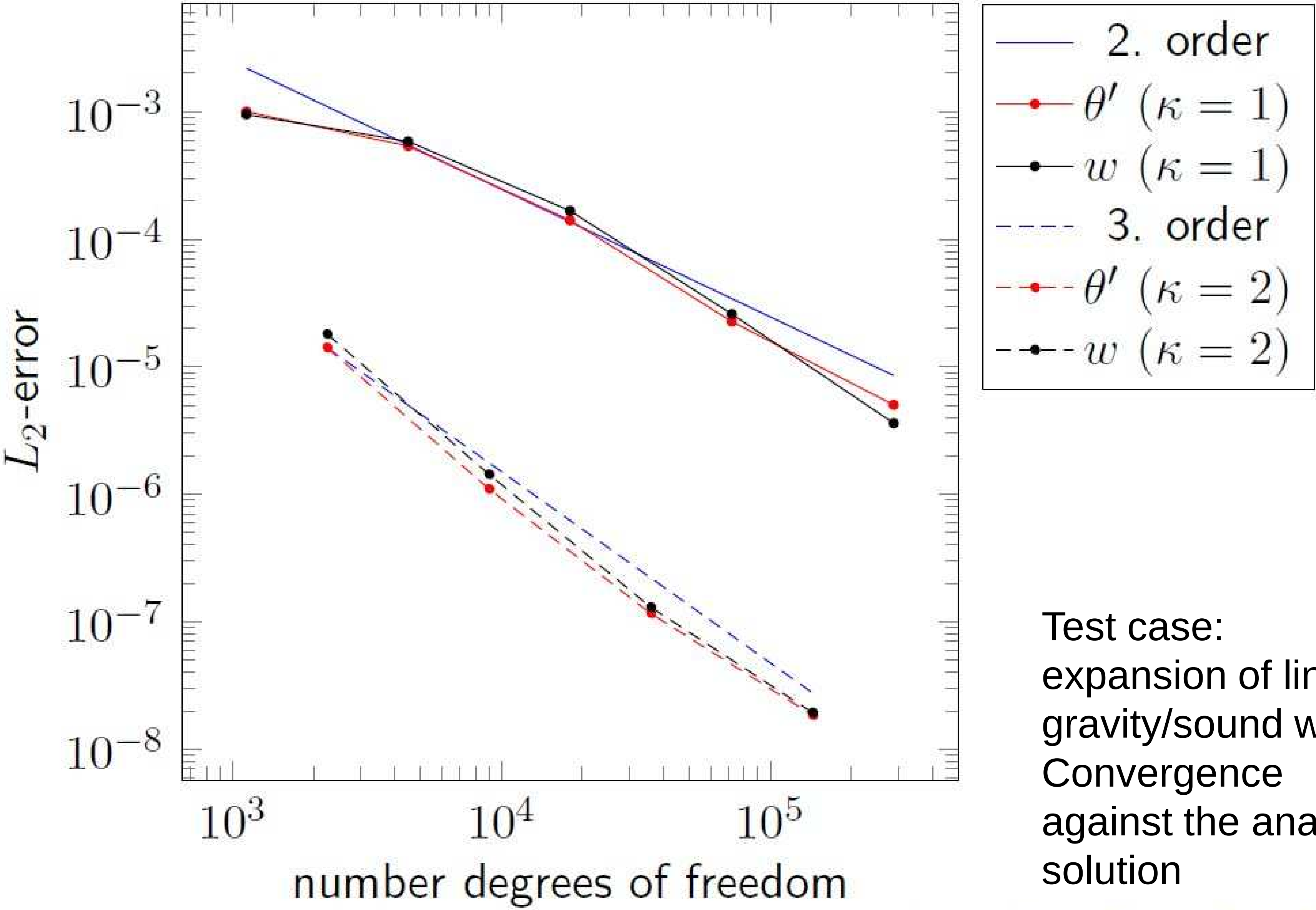






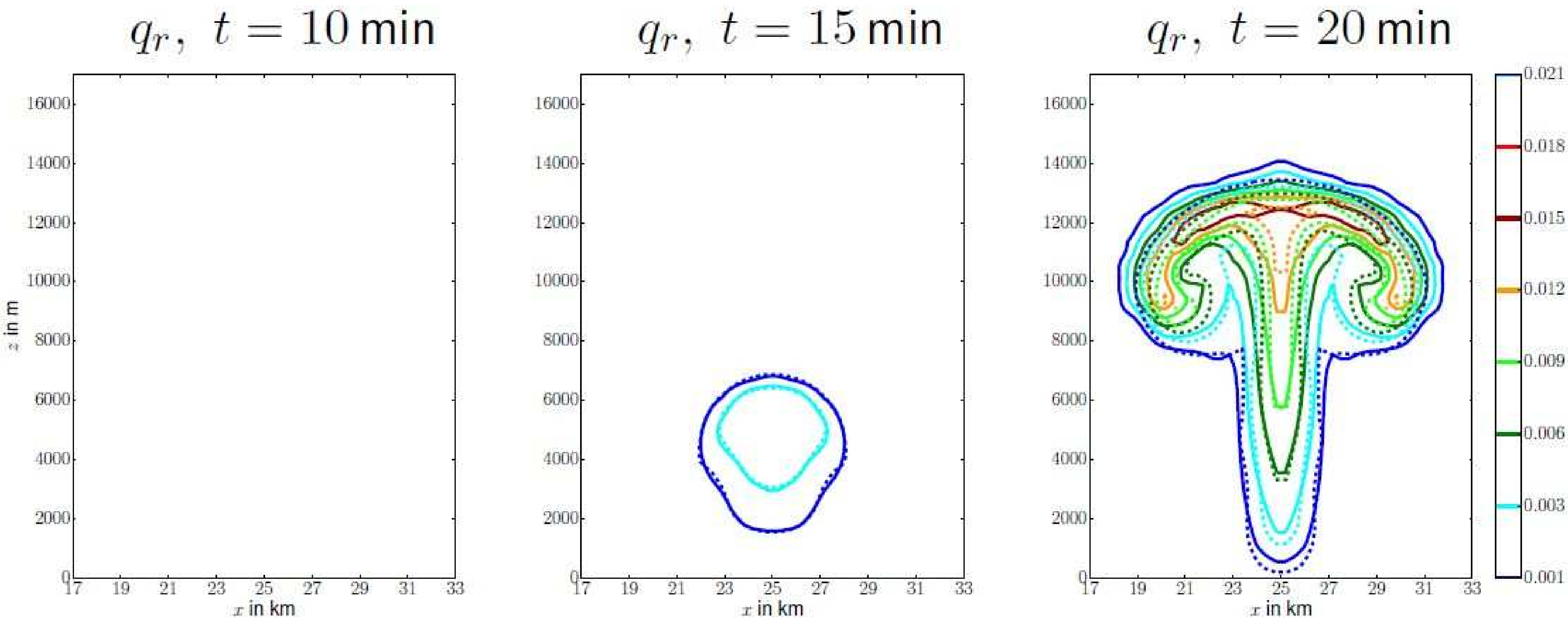
Test case:
expansion of linear gravity/sound waves
(*Baldauf, Brdar (2013) QJRMS*)

linearised solution dashed blue lines
DG-COSMO $\kappa = 3$, $\Delta x = 500\,\text{m}$, red line



Test case:
expansion of linear gravity/sound waves
Convergence against the analytic solution

Test case: warm bubble (*Weisman, Klemp (1982) MWR*)



COSMO dashed lines, DGCOSMO solid lines

Summary

- Discontinuous Galerkin discretization for different polynomial degrees (p=1,2,3) and RK-schemes has been implemented into COSMO
- coupling with Kessler microphysics scheme and an LES turbulence scheme (Smagorinski) has been done.
  However, physics coupling is technically more difficult than expected (physics package calls on quadrature points instead of grid points)
  By the way, similar technical problems for I/O …
- idealized tests (mountain flows, wave expansion, moist convection, …) have been performed successfully
- At least to do:
  - vertically implicit time integration scheme (strong efficiency increase needed)
  - continue physics coupling
- After finishing his PhD work, D. Schuster has found a permanent position outside of DWD → continuation of the project unclear

References

S. Brdar, M. Baldauf, A. Dedner, R. Klöfkorn (2012): *Comparison of dynamical cores for NWP models: comparison of COSMO and Dune*, Theor. Comput. Fluid Dyn., 27, 453-472

M. Baldauf, S. Brdar (2013): *An analytic solution for linear gravity waves in a channel as a test for numerical models using the non-hydrostatic, compressible Euler equations*, QJRMS, 139, 1977-1989

D. Schuster, S. Brdar, M. Baldauf, A. Dedner, R. Klöfkorn, D. Kröner: *On discontinuous Galerkin approach for atmospheric flow in the mesoscale with and without moisture*, accepted by Met. Z.

D. Schuster (2014): *Diskontinuierliche Galerkin-Verfahren für die operationelle Wettervorhersage*, PhD thesis, Univ. Mainz

Thank you for your attention!