Recent numerics developments in the COSMO model

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COSMO Science Plan (2015-2020)

main topics for COSMO dynamics

- for current 'Runge-Kutta' split-explicit dynamical core (*Wicker, Skamarock (2002), Baldauf (2010), …*)
  - New *Bott (2010)* advection scheme for tracer transport
  - Higher order, symmetric scheme for the horizontal discretizations (*Morinishi et al. (1998) JCP, Ogaja, Will (2014) MetZ*)
  - …
- Eulag dynamical core (*Smolarkiewicz et al. …*) as an alternative option
  Priority Projects 'CELO', 'EX-CELO', 'CELO-ACCEL'
- **transition from COSMO model → ICON (LAM) model (~2020+)**
  preparation by COSMO Priority Projects; currently
  PP 'Comparison of the dynamical cores of ICON and COSMO' (CDIC)
  (see dynamics talk last year)

The new Bott (2010) advection scheme

… as an *optional* candidate for tracer advection

Werner Schneider (Univ Bonn)
Uli Blahak (DWD)

currently used scheme:

- *Bott (1989) MWR*
  - A 1-dim. finite volume advection scheme using the polynomial reconstr. idea of *Tremback et al. (1987)* (default: polynomial degree 2)
  - positive definite flux limitation
  - direction- (or time-) splitting for 3D flows
- *Skamarock (2006) MWR*:
  - *mass consistency* by parallel comput. of an additional continuity equation
  - CFL>1: use of 'integer/fractional fluxes'
- possible instabilities are reduced by 'full' Strang-splitting ('*½z-½y-x-½y-½z*')

experience: (nearly) tracer mass conservation is beneficial in convection-permitting models (compared to a classical Semi-Lagrangian scheme)

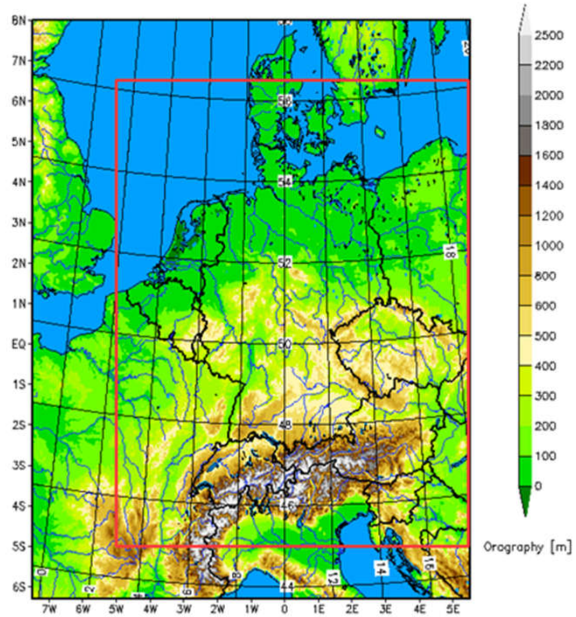
New development: *Bott (2010) AtmRes*:

- combines a 1D advection scheme (e.g. *Bott, 1989)* to a 3D scheme
- polynomial degree 4 proposed
- retains $q\rho$=const. for non-divergent flow
  without parallel computation of a continuity equation,
  but with an add./substr. of the divergence in the direction-splitting scheme
  → increase in stability
- without 'full' Strang-splitting
  → efficiency gain: total model costs reduced by 5%
  however still x-y-z / z-y-x for odd/even time steps
- for CFL > 1: sub-stepping in the grid row

Following slides:
Verification results for the comparison of the new Bott scheme with the current one.

setup:

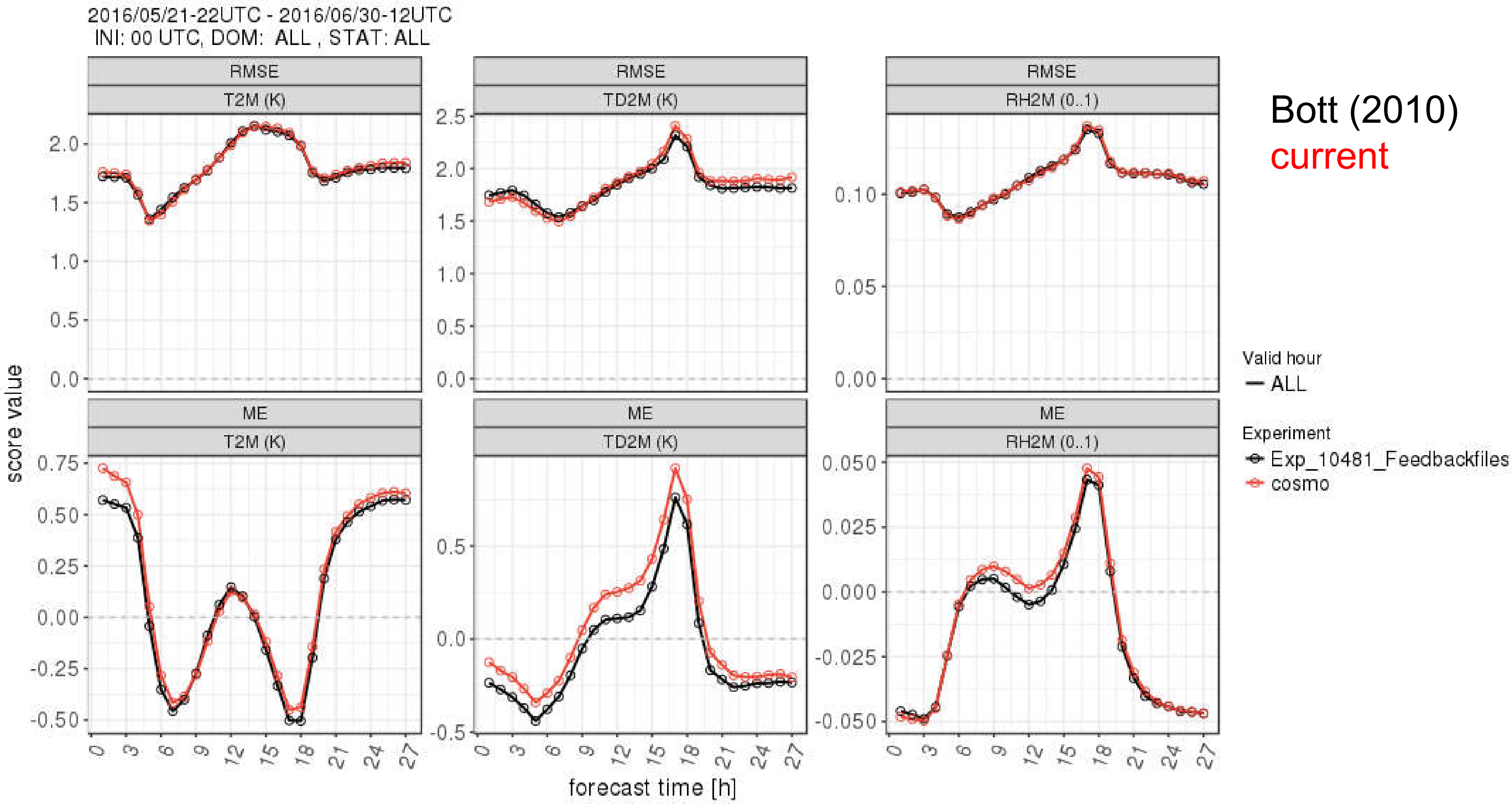
- operational COSMO-DE: 2.8 km L50, dt = 25 sec.
- area: red rectangle, 421 * 461 * 50 GPs
- convection permitting
  (graupel microphysics scheme,
  only shallow Tiedtke convection, …)
- nudging analysis



side remark: full region marks the
new COSMO-D2 area, 2.2 km L65
planned for operational use at DWD: Q2/2018

Synop verification

Deutscher Wetterdienst
Wetter und Klima aus einer Hand



Bott (2010)
current

Synop verification

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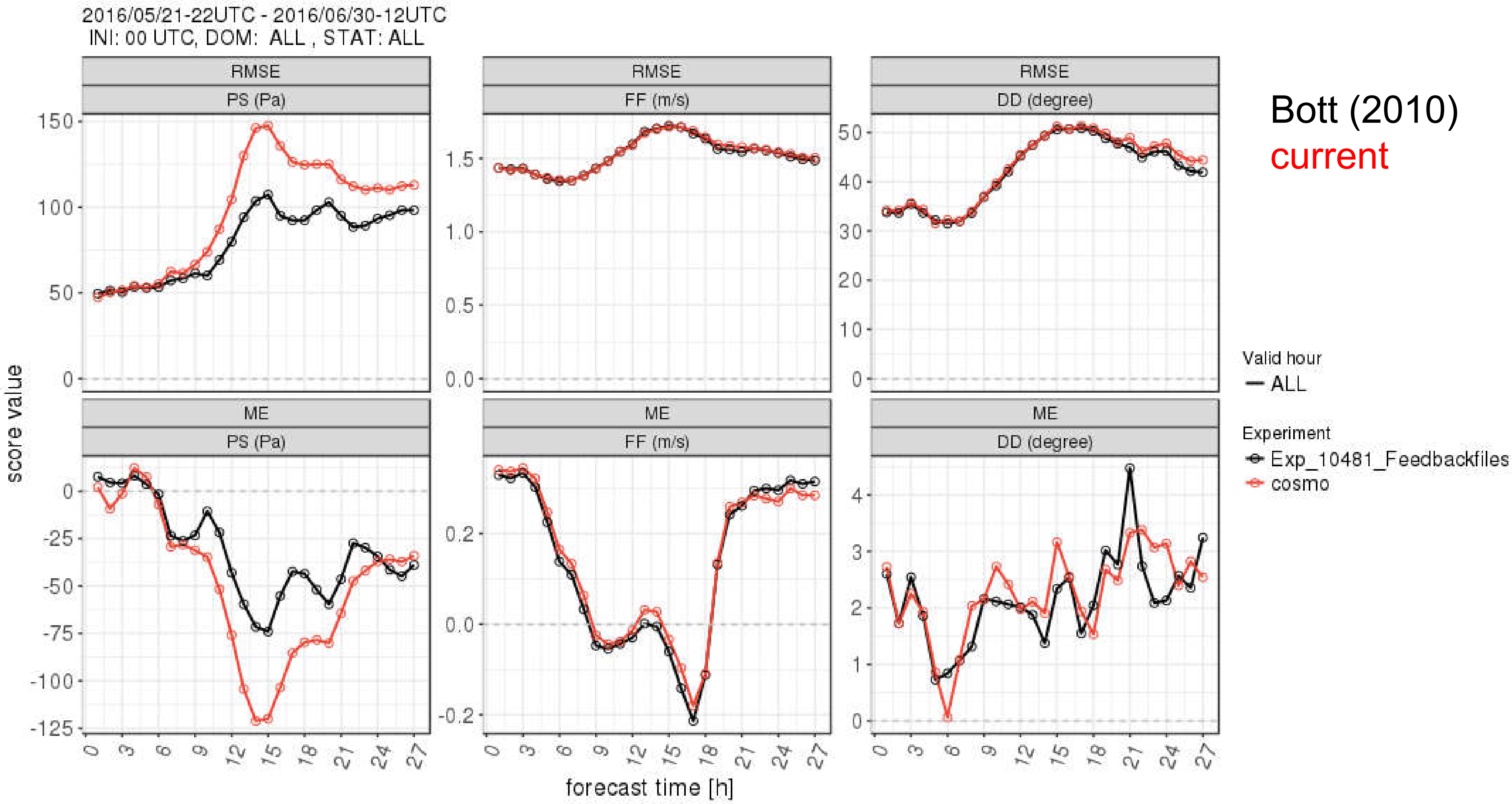
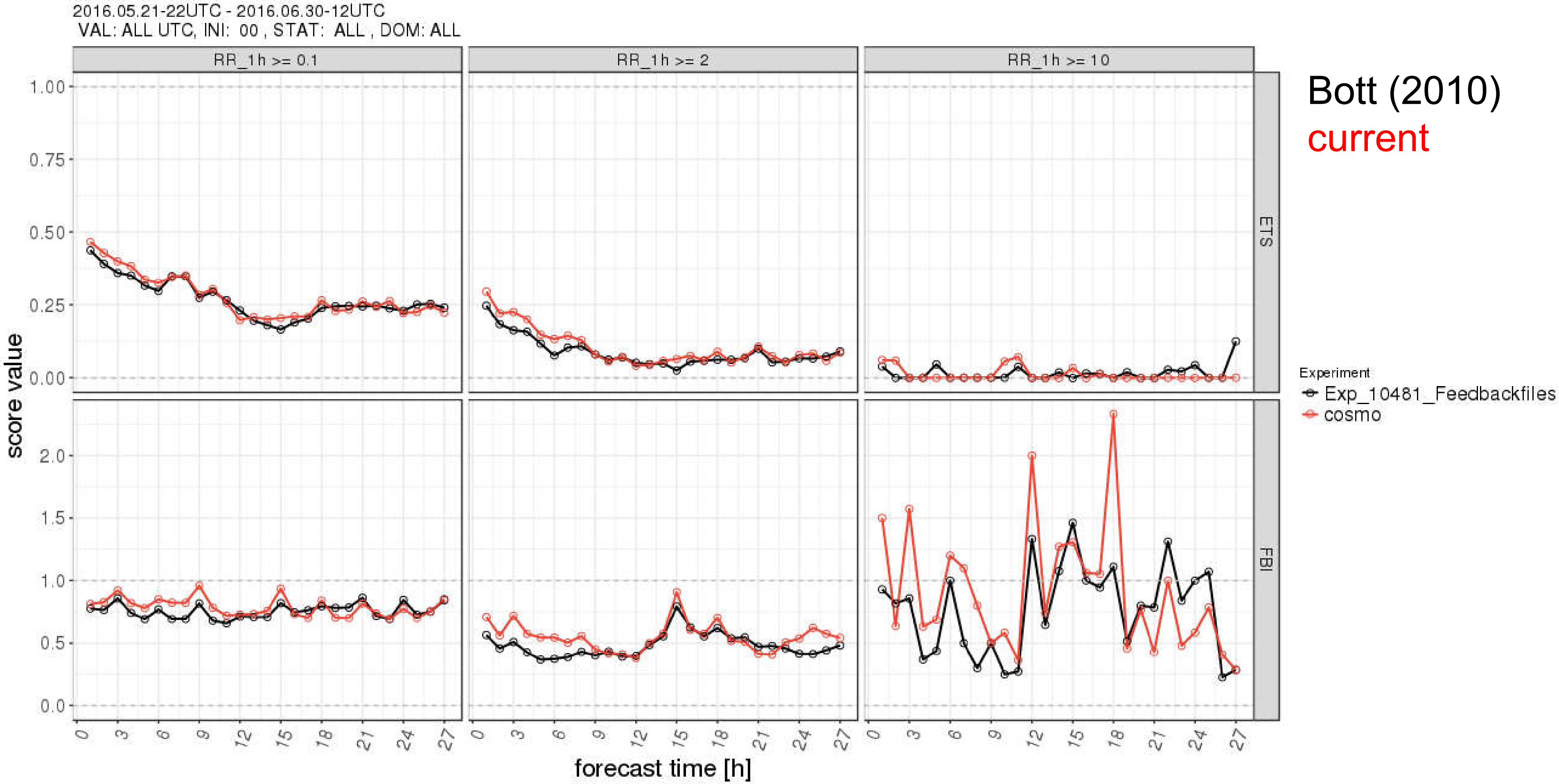


Bott (2010)
current

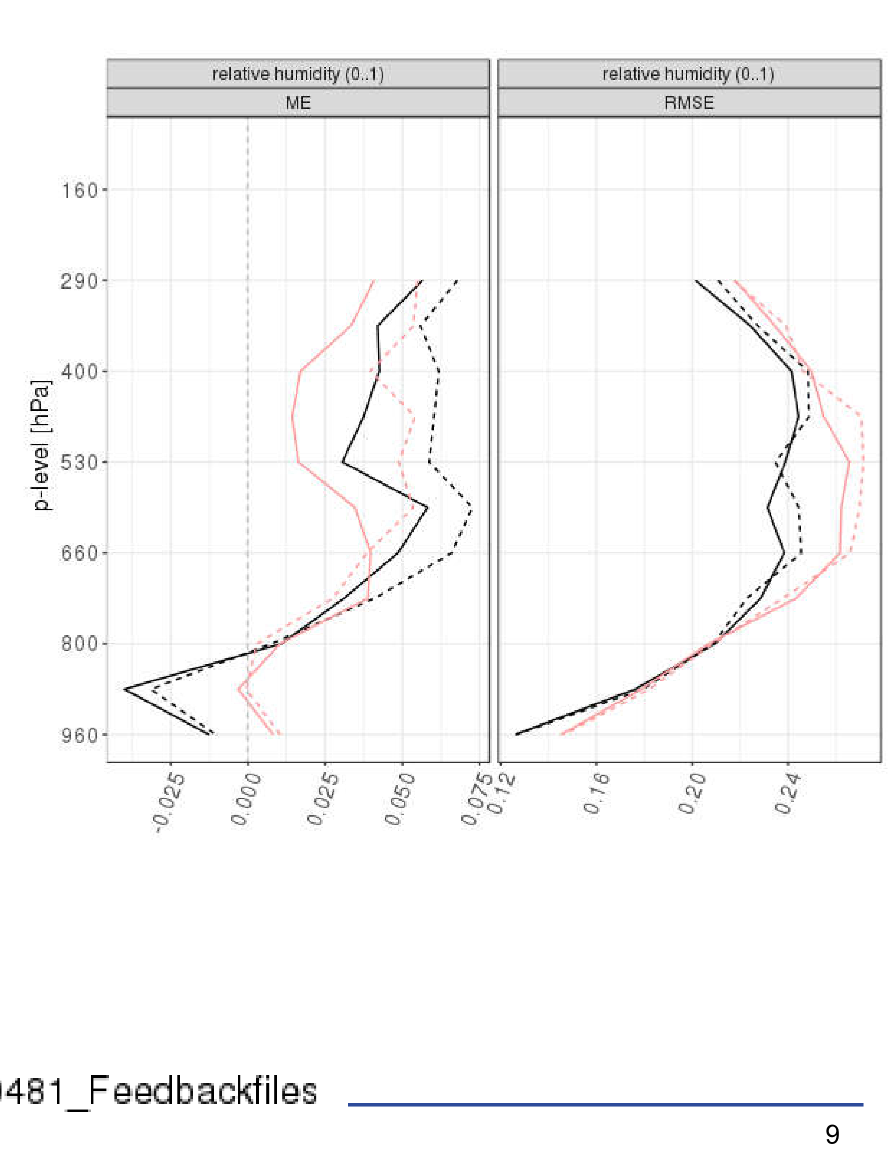
Synop verification



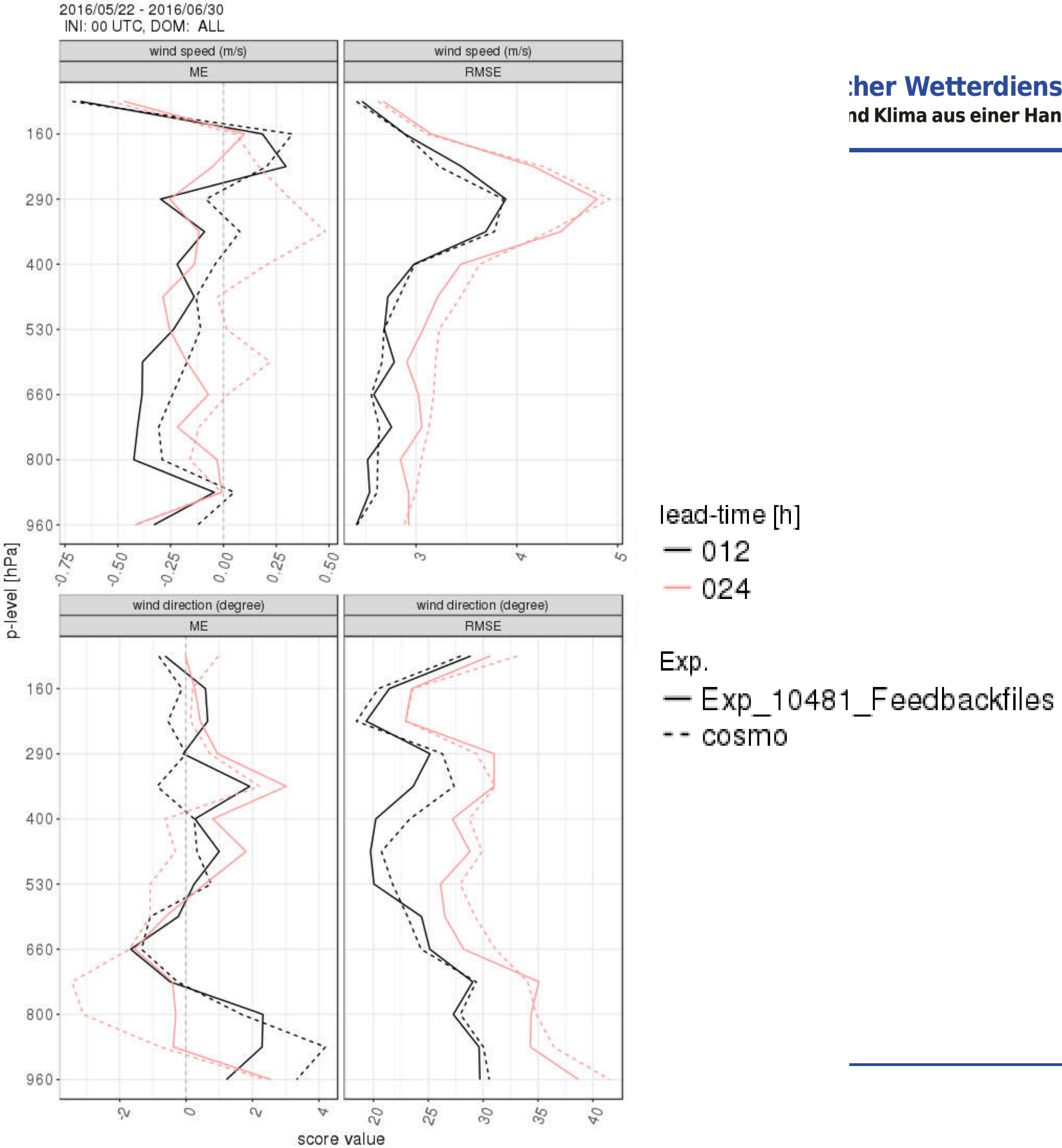
Bott (2010)

current

Upper air verification



Upper air verification



Summary for the verification results of the new Bott-scheme

- Synop-Verif. of T_{2m} and v_{10m} is slightly positive, neutral for TD_{2m}, RH_{2m}
- Synop-Verif. of categorical measures for rain and gusts is negative, cloudiness is neutral
- Temp-Verif. is very positive

→ Proposal:

the results are not entirely satisfying, however good enough

to bring the new Bott-scheme as an option (!) into the official code (v5.6)

(fulfil COSMO science plan, sec. 5.2.4)

Outlook:

- further code optimization possible
- extension for TKE advection necessary (TKE lives at w position)
- further tests …

The Eulag dynamical core as an alternative for the COSMO model

Bogdan Rosa, Zbigniew Piotrowski, Damian Wojcik, Michal Ziemianski (IMGW)
Piotr Smolarkiewicz (ECMWF)

Priority projects:

- COSMO-EULAG Operationalization (CELO)
- EXtension of COSMO-EULAG Operationalization (EX-CELO)

Task 5: Integration and consolidation of the EULAG compressible DC with COSMO framework

- Optimal formulation for the flows with the open boundary conditions: pressure bias diagnostics

Semi-realistic simulations: setup

Semi-realistic simulations using COSMO Runge-Kutta (RK) and compressible COSMO-EULAG (CE) were performed to diagnose for the problem of pressure bias development.

Configuration:

- Turbulence parameterization is turned on
- Moist microphysics and saturation adjustment are turned off
- Soil (sea) processes are turned off
- Water vapour enters buoyancy and there are no sources / sinks of water vapour
- dt = 15 s

Computational domain:

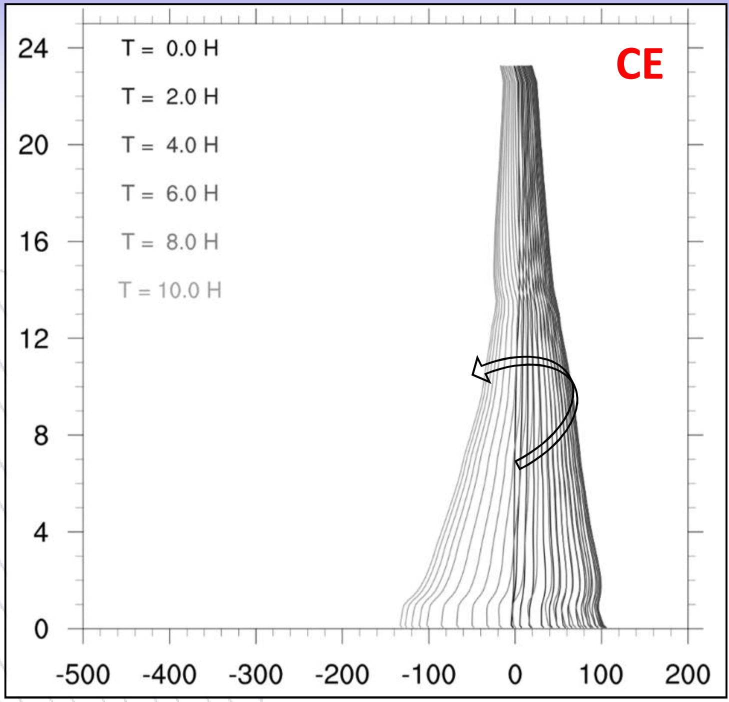
- Bay of Biscay (flat)
- dx = 2.2 km

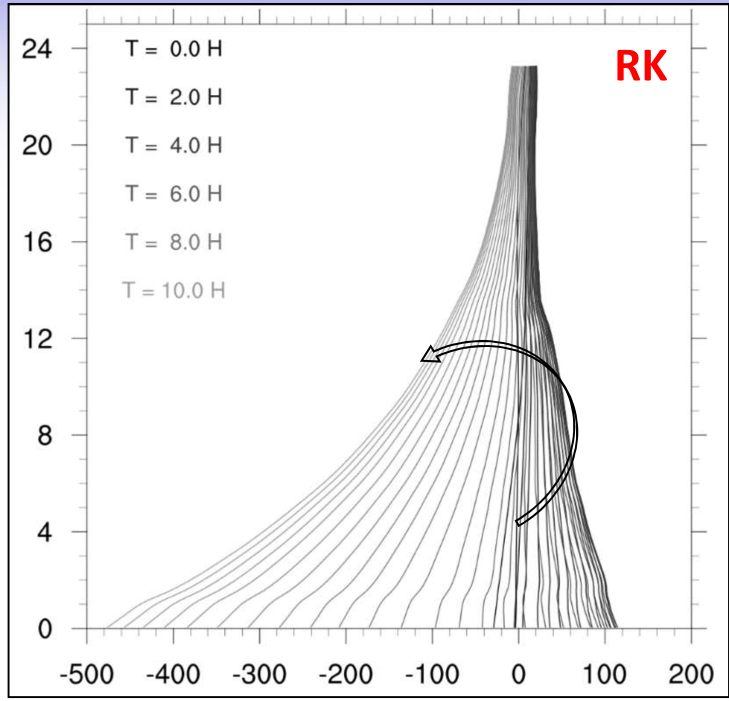
Test case:

- 15 November 2013 (Azoren High)

Figures in following slides show time evolution of horizontally averaged pressure perturbations. The perturbations are calculated with respect to the time-evolving pressure from the driving COSMO-7 simulation.

time evolution of horizontally averaged pressure perturbations





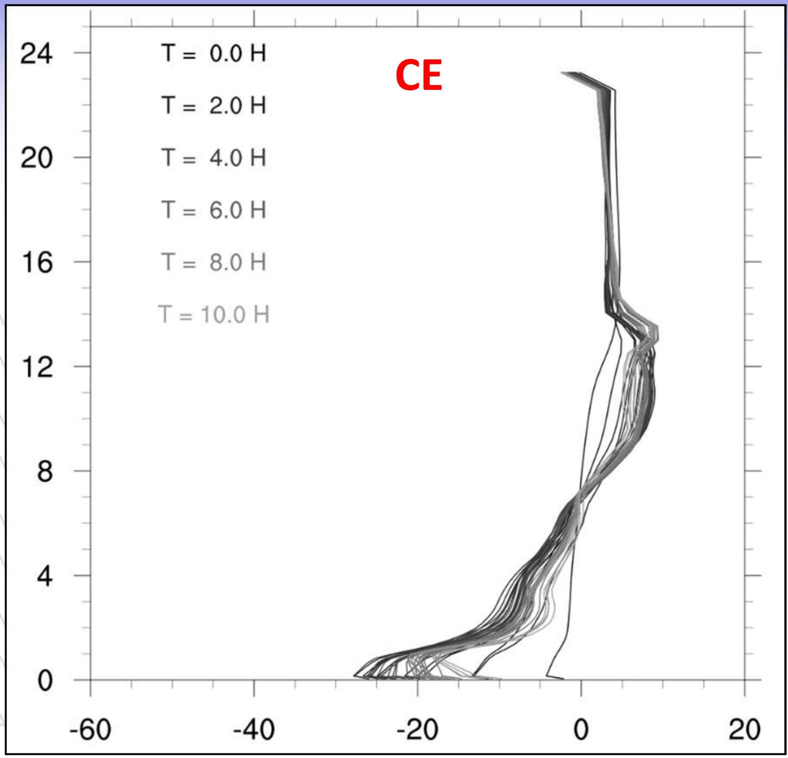
The compressible implicit EULAG solver employs absorbers only for:

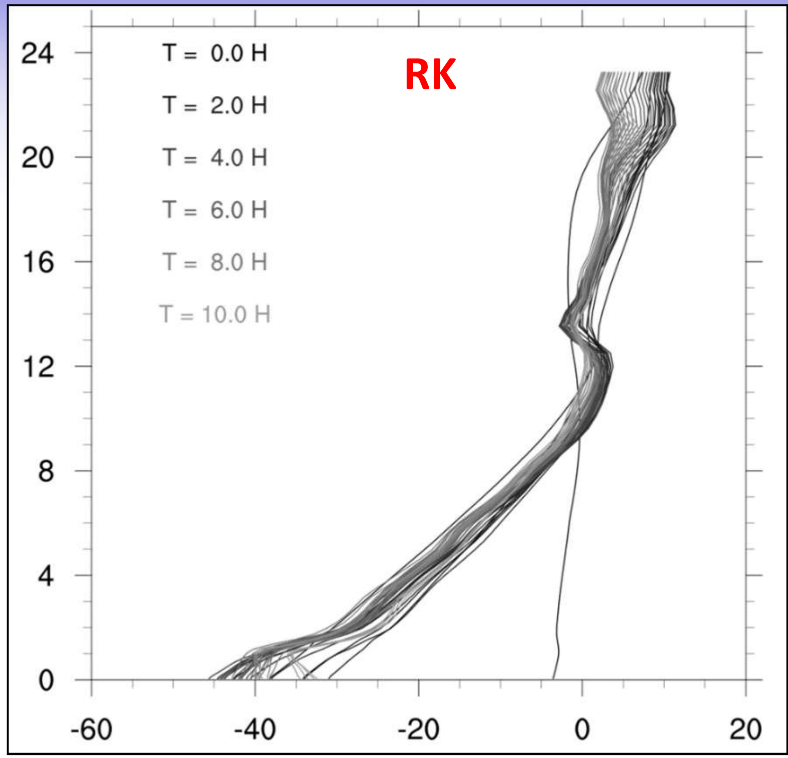
- **U- and V-velocity components**
- **W (towards 0)**
- **Potential temperature**

Default version of COSMO Runge-Kutta dynamical core uses absorbers for:

- **U- and V-velocity components**
- **W (towards 0)**
- **Temperature**
- **Pressure**

Semi-realistic simulations: **results with absorber for pressure**





Disabling the pressure absorber in RK results in the development of a pressure bias similar to that observed in CE results.

Conversely, adding of a simple linear absorber to the compressible implicit CE results in significant reduction of the pressure bias for CE.

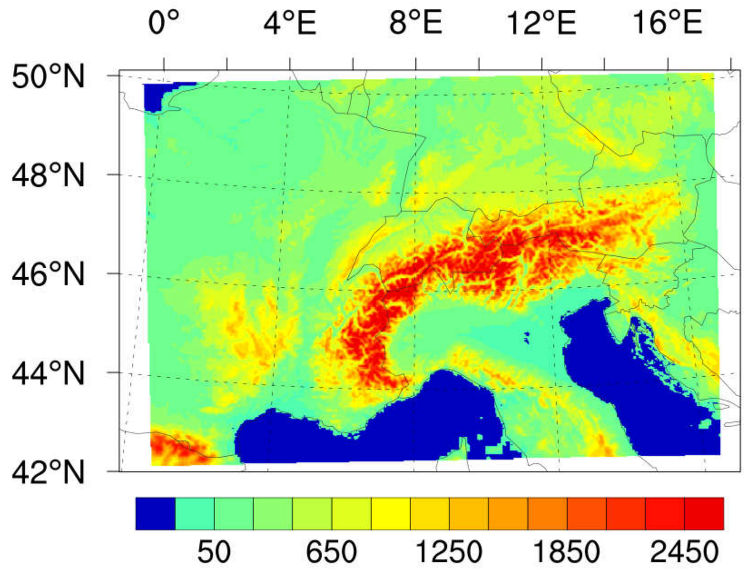
A 72 hour realistic simulation with the linear pressure absorber

Realistic simulation using COSMO Runge-Kutta (RK) and compressible COSMO-EULAG (CE) was run for 72 hours in order to check pressure fluctuations in a long-term simulation.

Configuration:
- Turbulence parameterization is turned on
- Moist microphysics and saturation adjustment are turned on
- Soil processes are turned on
- dt = 15 s (RK), dt = 10 s (CE)

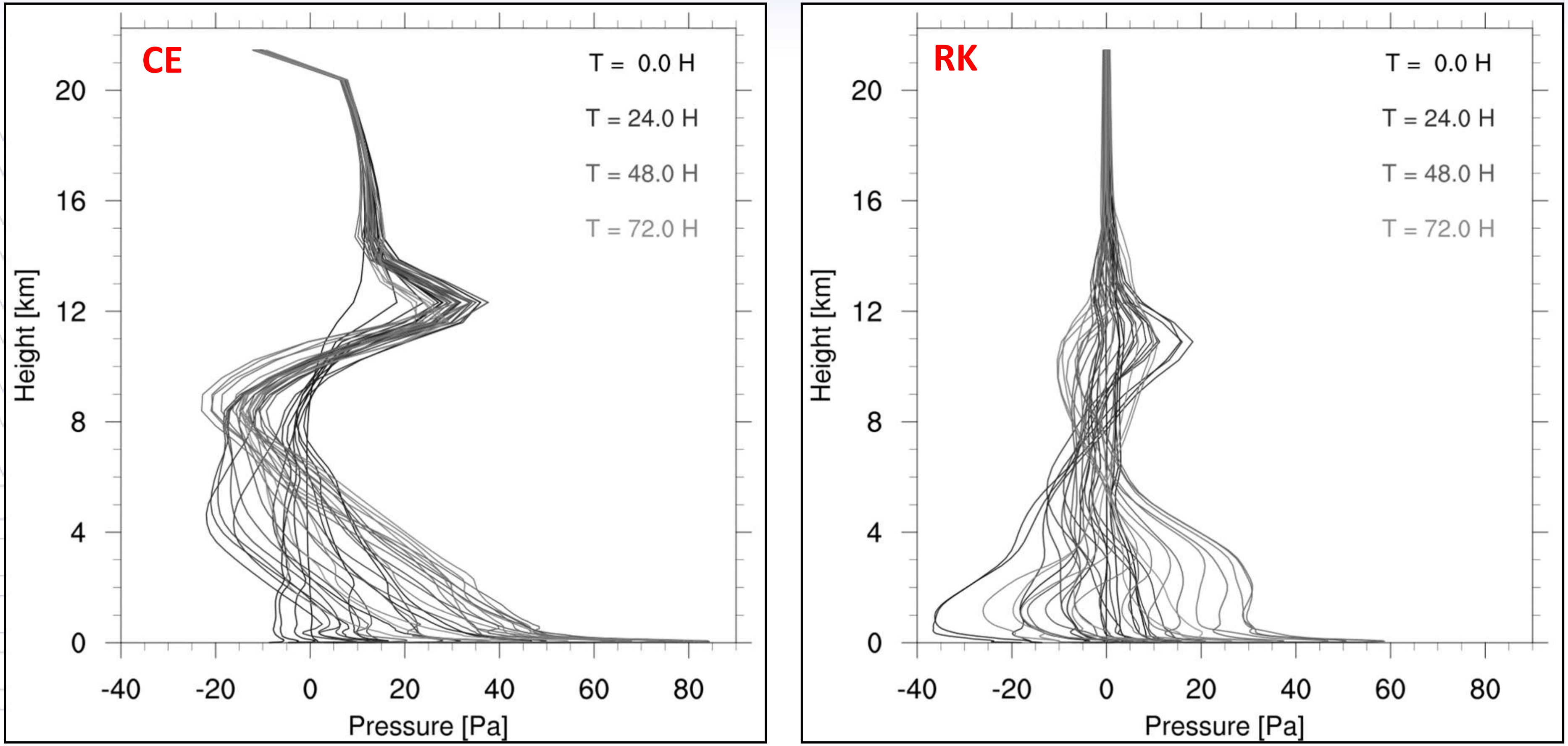
Computational domain:
- COSMO-2 domain of MeteoSwiss
- dx = 2.2 km,
- ie_tot – 582, je_tot = 390, ke_tot = 60

Test case :
- 21 July 2017



A 72 hour simulation with compressible CE at 2.2 km grid resolution

Time evolution of horizontally averaged pressure perturbations. The perturbations were computed with respect to the time-evolving boundary data pressure from the simulations-driving COSMO-7 simulation. Now also absorber for pressure switched on.

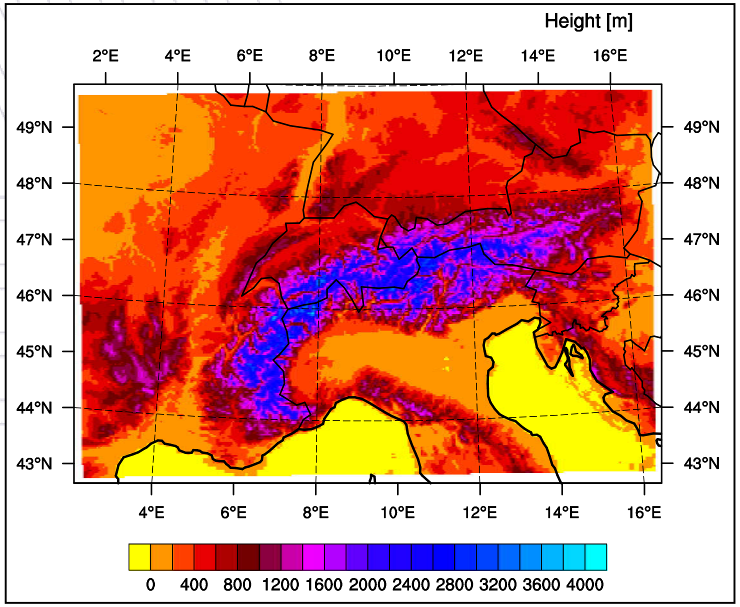


Pressure perturbations within the both models have a similar magnitude also after 72 hours long integration time.

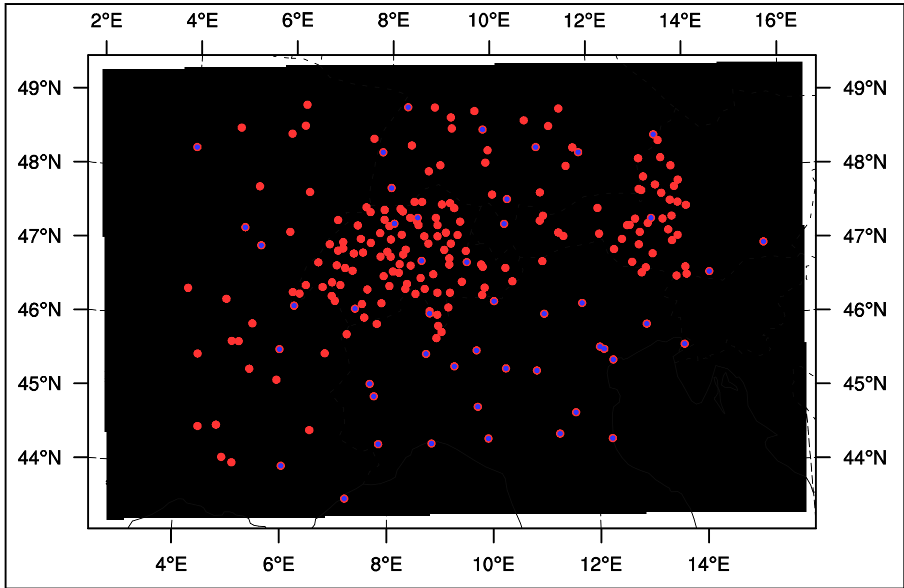
Verification of CE forecasts computed for Nov 2013 (24h forecast)

- Verification of the CE forecast for November 2013
- Realistic simulations were performed for each day separately (24h forecast)
- 2.2 km
- Domain corresponds to the standard operational COSMO-2 domain of Meteo-Swiss.
- The simulations were performed using both CE and RK
- Sensitivity of the results to different values of mixing length (150m and 500m), vertical smoothing factor for explicit vertical diffusion (*wichfakt*) and diffusion coefficient for momentum (*tkmmin*) is also analyzed

Topographical map of the domain



Station network for surface verification



Experiment settings

Dynamics:

- Numerical and Smagorinsky diffusion are *turned off* for Cosmo-Eulag and *on* for Cosmo Runge-Kutta
- In Cosmo Runge-Kutta setup moist quantities are advected using the „Bott2Strang" scheme
- In Cosmo-Eulag setup moist quantities are advected using the MPDATA A scheme
- For Cosmo Runge-Kutta *irunge_kutta=1* and *itype_fast_waves=2*
- dt = 10 s (RK), dt = 10 s (CE)

Microphysics:

- Standard one-moment COSMO microphysics parameterization including ice, rain, snow and graupel precipitation (*igsp=4*)

Radiation:

- Calculated every 6 minutes
- Topographical corrections to radiation are turned off (*lradtopo=F*)

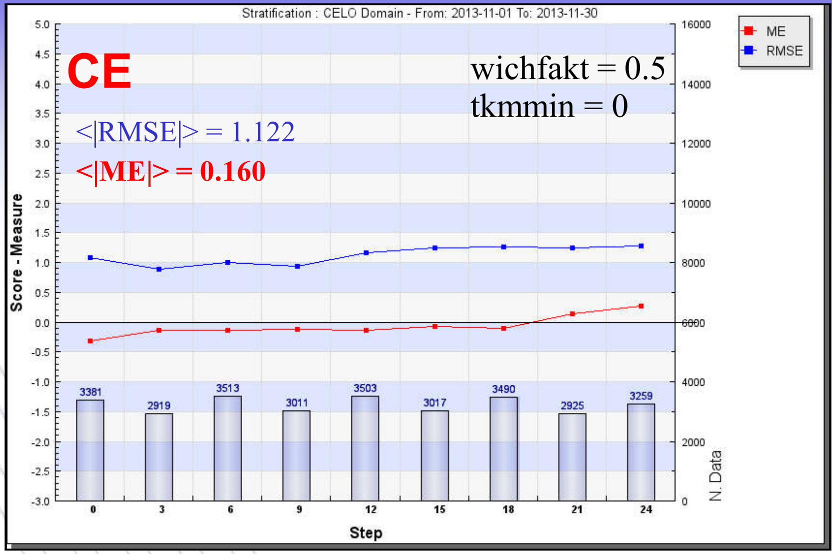
Turbulence and convection scheme :

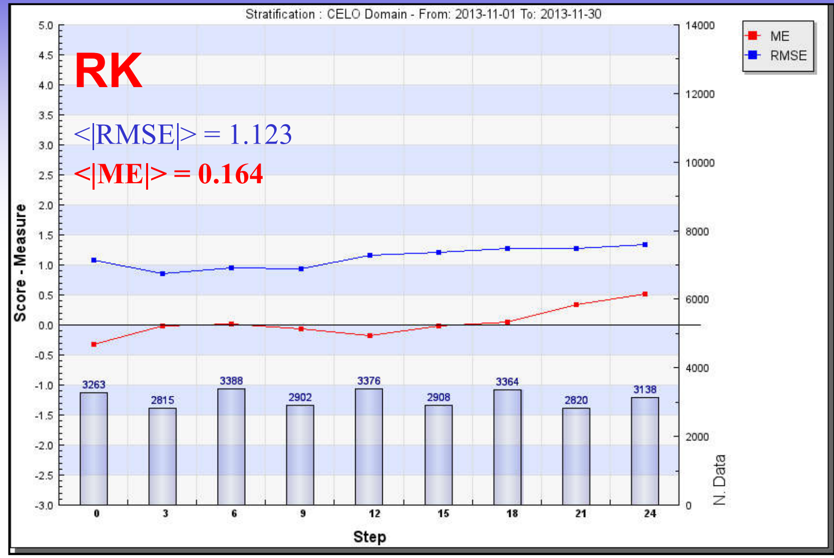
- Default turbulence setup for high-resolution NWP (*itype_turb=3, limpltkediff=T)*
- Shallow convection parameterization is turned off (*lconv=F)*

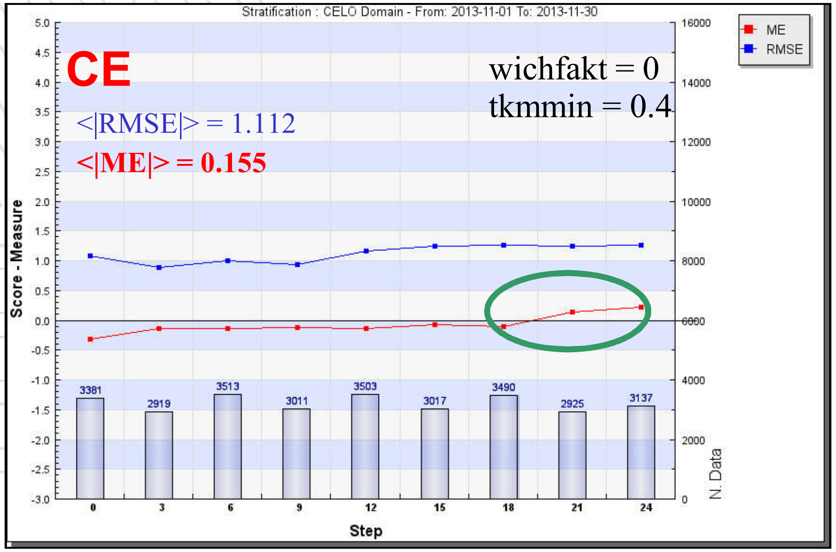
Soil model:

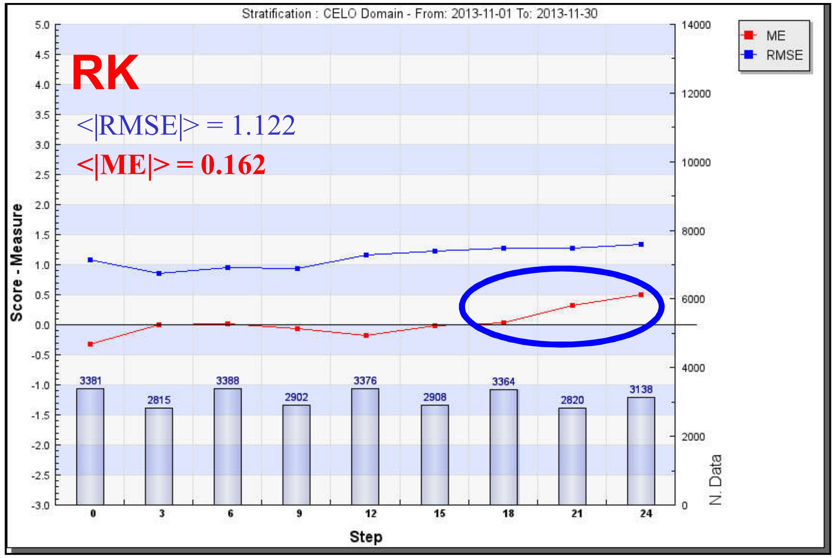
- Multi-layer soil model is used *(lsoil= T, lmulti_layer=T,* lforest=T)

Pressure (hPa) – forecast verification with pressure absorber





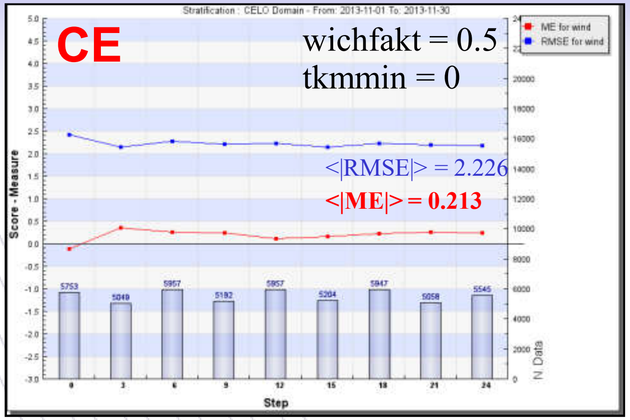


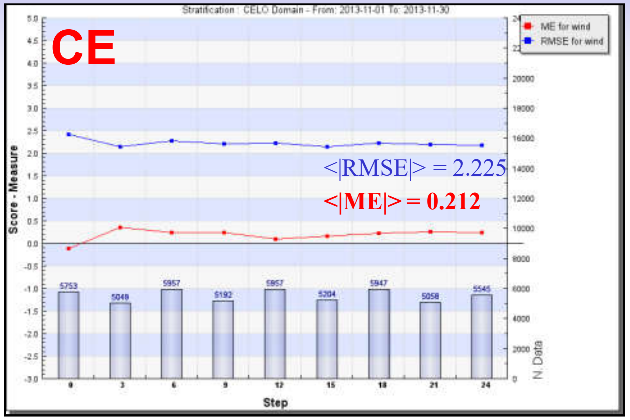


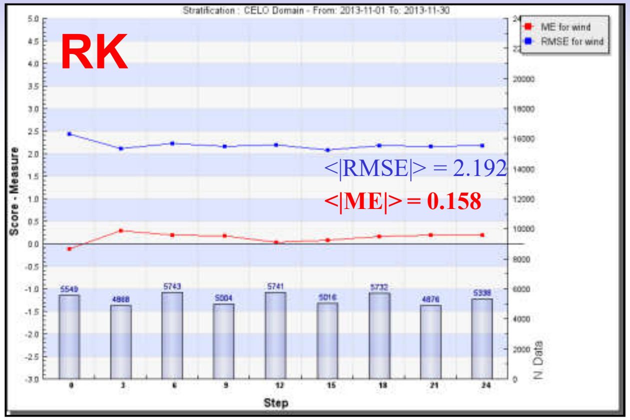
Mean error is relatively small for both CE and RK. Before 18:00 simulations performed with RK are slightly more in line with observations than those performed with CE. After 18:00, the forecast computed using CE is in better agreement with observations.

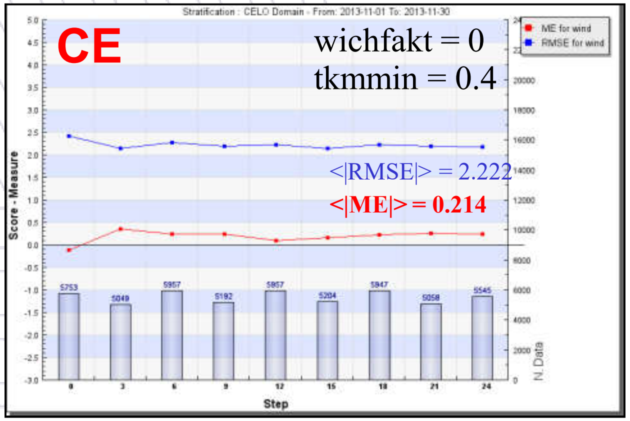
Horizontal wind (m/s) at 10 m (with pressure absorber)

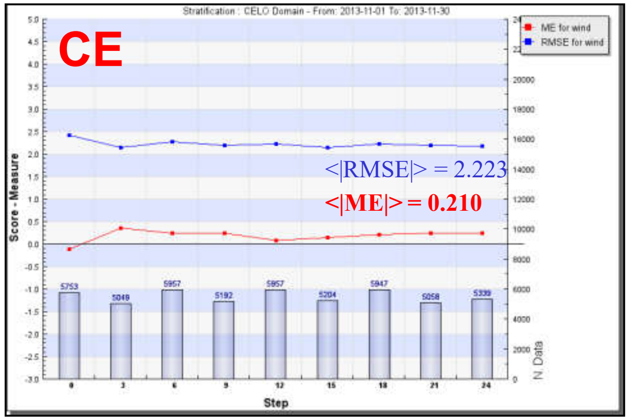
Before pressure correction | **With pressure absorber**

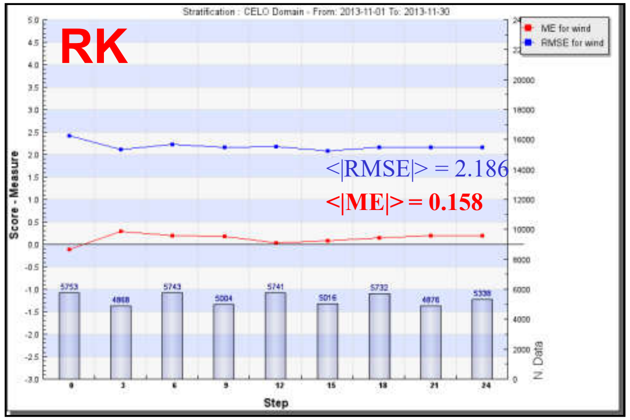






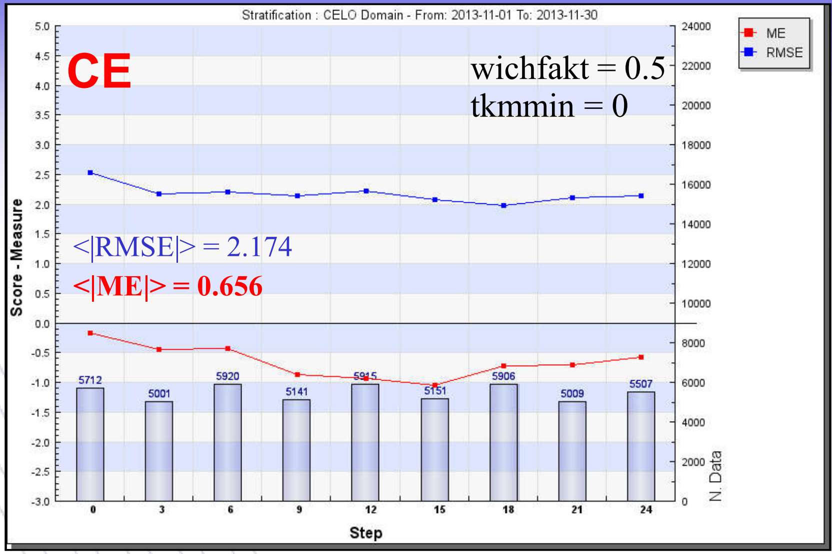


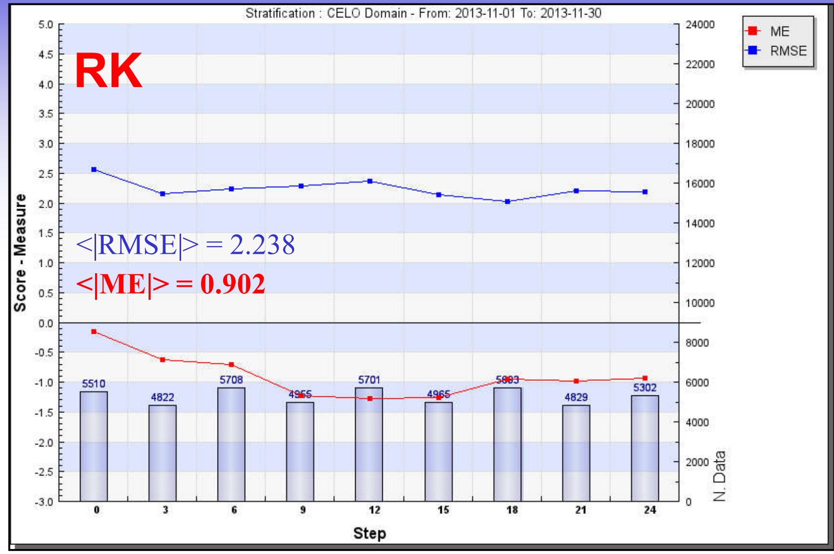


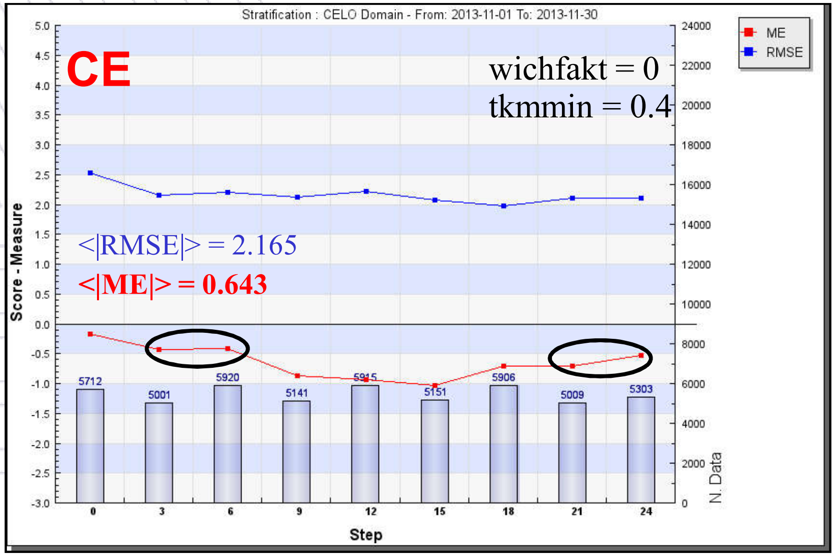


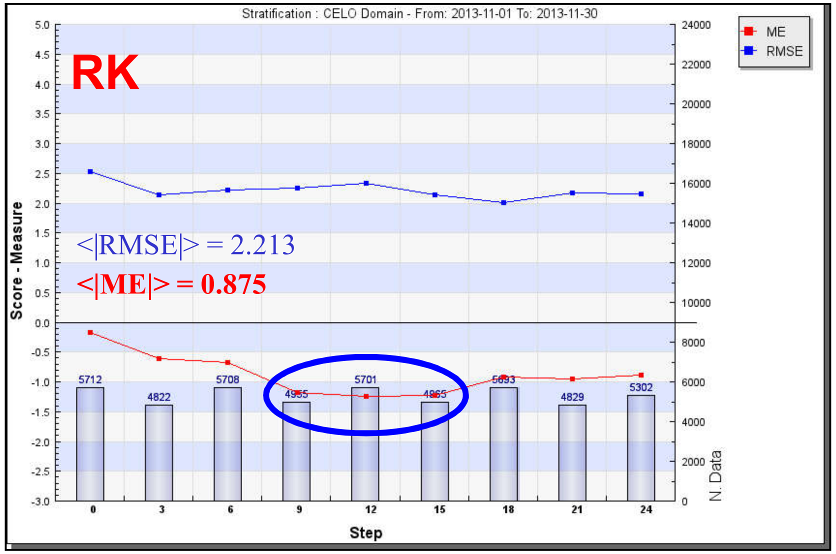
Little effect of pressure absorber on horizontal wind.

Temperature at 2 m – forecast verification with pressure absorber



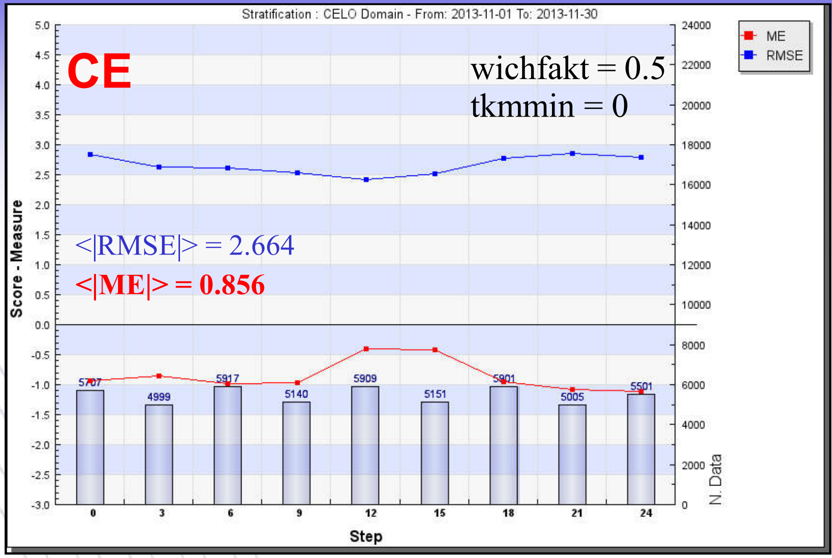


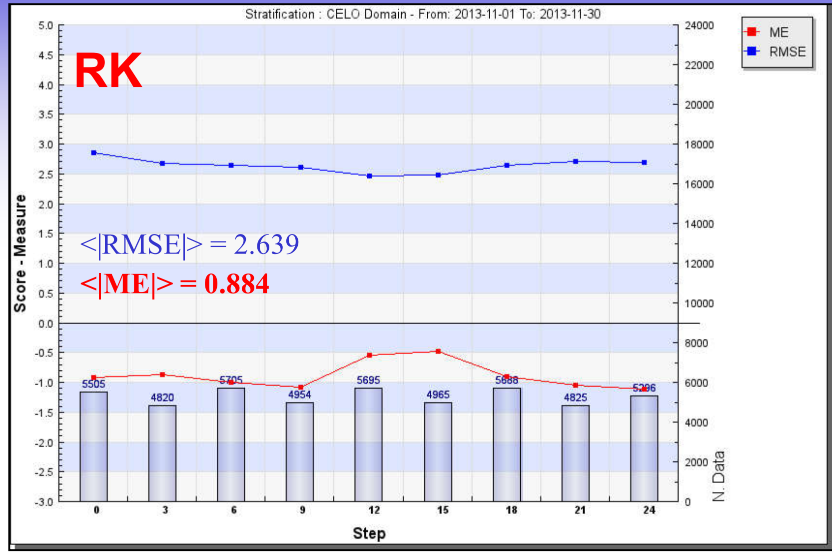


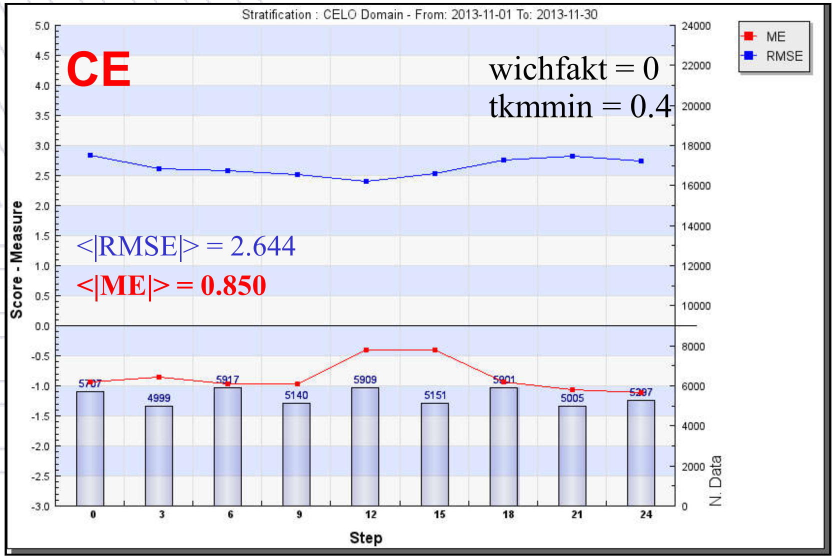


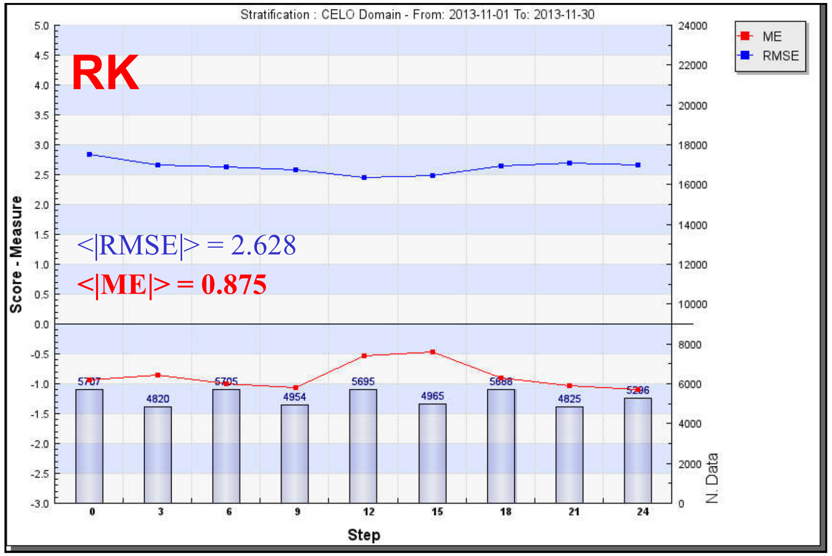
Results computed using CE are closer to observations than those computed with RK. No effect resulting from different values of parameters *wichfakt* and *tkmmin*.

Dew point temperature at 2 m – verification with pressure absorber



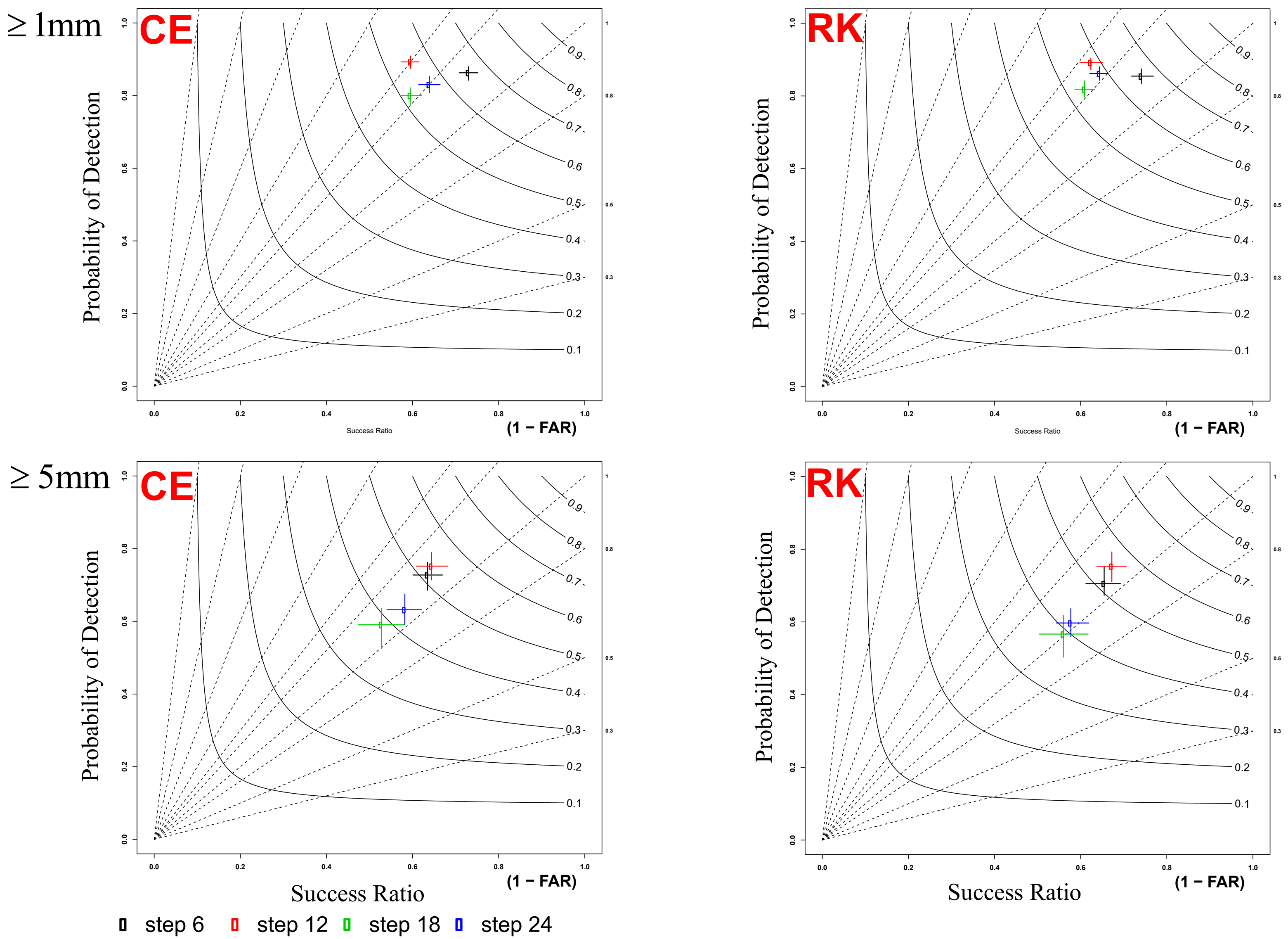






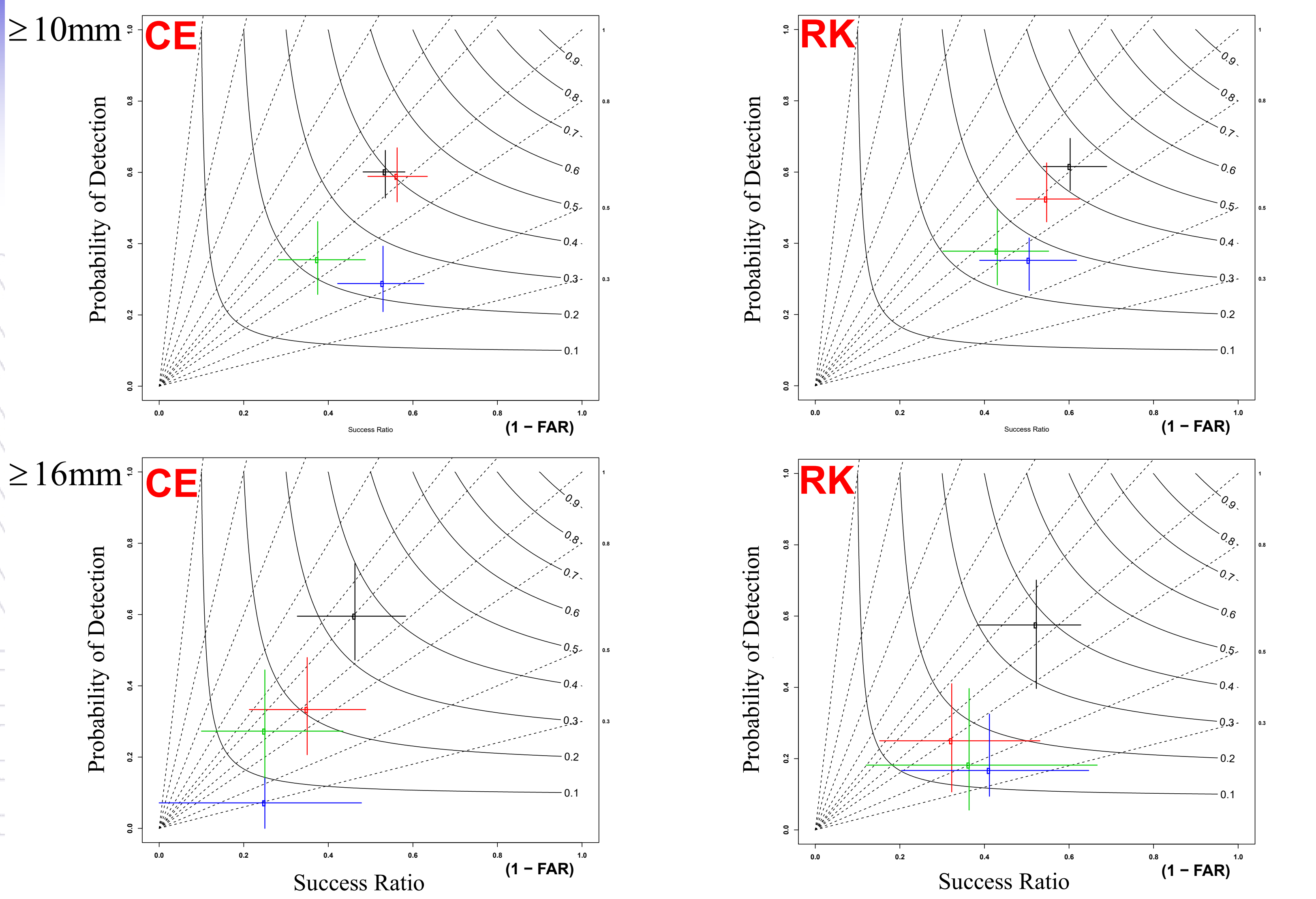
Results from both models are in good quantitative agreement. Low sensitivity to different settings of vertical smoothing factor and minimal diffusion coefficients.

Precipitation – forecast verification (wichfakt = 0.5, tkmmin = 0)



Numerical results computed using CE and RK (with pressure absorber) are in good quantitative agreement. The differences are in the range of statistical uncertainty.

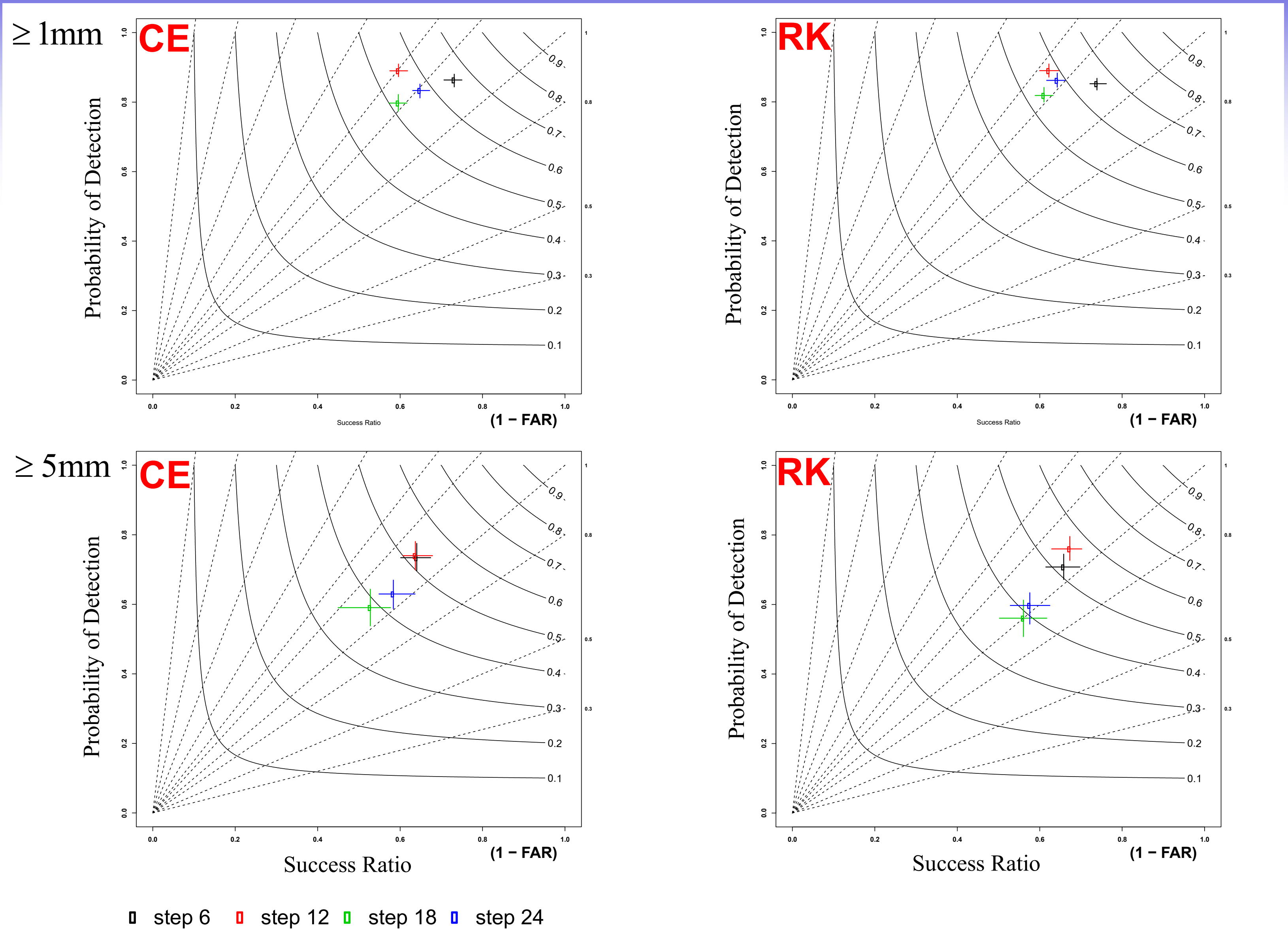
Precipitation cntd. – forecast verification (wichfakt = 0.5, tkmmin = 0)



step 6 step 12 step 18 step 24

Also for larger precipitation the differences are in the range of statistical uncertainty.

Precipitation – forecast verification (wichfakt = 0, tkmmin = 0.4)

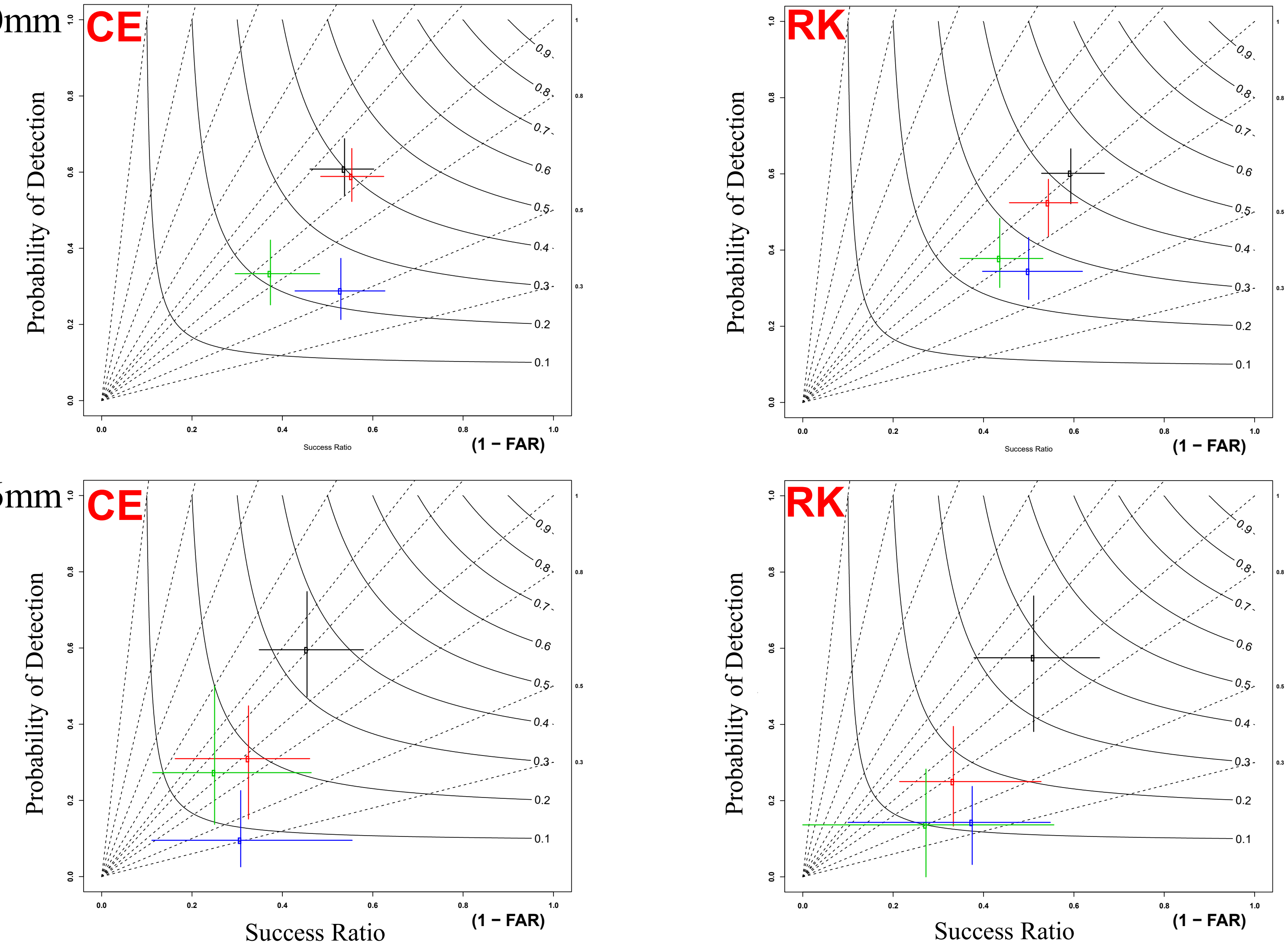


w sensitivity to different numerical parameters. Simulations performed with pressure absorber.

Precipitation cntd. – forecast verification (wichfakt = 0, tkmmin = 0.4)

≥10mm

≥16mm



step 6 step 12 step 18 step 24

Precipitation statistics evolve (in time) in a similar manner. For precipitation 16 mm and more results CE and RK are in qualitative agreement.

Summary for COSMO-EULAG

- the problem of the pressure bias is solved (lateral boundary relaxation for p) →
- The compressible Eulag dyn. core implementation into COSMO now shows comparable verification results with the RK solver
- next steps: make ready for operationalisation
  - transfer code into the official COSMO code version (v 5.6?)
  - coupling with Data Assim. (KENDA)
  - make code ready for running on GPUs
  - …