Status report of

WG 2 – Numerical aspects

COSMO General meeting, St. Petersburg, Russia
03-06 Sept. 2018

Michael Baldauf, Andreas Will, Jack Ogaja (Univ. Cottbus),
Werner Schneider (Univ. Bonn)

Outlook

- Extension of the new Bott (2010) advection scheme
- Higher order scheme (horizontal)
- Science plan check

- PP CDIC final report
- PP CELO final report → Bogdan Rosa
- PP EX-CELO → Zbigniew Piotrowski

The new Bott advection scheme

… as an *optional* candidate for tracer advection

Andreas Bott,
Werner Schneider (Univ Bonn),
Uli Blahak,
Michael Baldauf (DWD)

$$\frac{\partial \rho q}{\partial t} + \nabla \cdot (\mathbf{v} \rho q) = \rho S$$

COSMO-…: $q = q_v, q_c, q_i, q_r, q_s, q_g, (TKE)$

Original COSMO-implementation (by W. Schneider, modif. by U. Blahak):
verification results see COSMO-GM 2017

in the meanwhile: problems found with
reproducibility under domain decomposition, accuracy → …

CONSORTIUM FOR SMALL SCALE MODELING COSMO

Deutscher Wetterdienst
Wetter und Klima aus einer Hand

Bott (2010) Atm. Res.

to reduce splitting errors in strongly deformational fields,
add and subtract the divergence term (‚deformational correction'):

$$\begin{aligned}
\phi' &= \phi^n - \Delta t \, \frac{f_x^+(\phi^n) - f_x^-(\phi^n)}{\Delta x} + \Delta t \, \phi^n \frac{\partial u}{\partial x}, \\
\phi'' &= \phi' - \Delta t \, \frac{f_y^+(\phi') - f_y^-(\phi')}{\Delta y} + \Delta t \, \phi^n \frac{\partial v}{\partial y}, \\
\phi^{n+1} &= \phi'' - \Delta t \, \frac{f_z^+(\phi'') - f_z^-(\phi'')}{\Delta z} + \Delta t \, \phi^n \frac{\partial w}{\partial z} - \Delta t \, \phi^n \nabla \cdot \mathbf{v},
\end{aligned}$$

- scheme is (still) locally mass conserving
- scheme can be formulated positive-definite
- ϕ=const. remains constant in arbitrary divergence free wind fields (*Bott (2010)* calls this ‚mass-consistent')
- use e.g. *Bott (1989) MWR* to calculate fluxes f_x, f_y, f_z.

Additionally: development of a **local time-stepping** that maintains these properties (*M. Baldauf*)
→ simple Strang-splitting is possible → **larger saving of computation time!**

W. Schneider, A. Bott (Uni. Bonn):

Implementierung des *Bott (2010)*-Schemas in COSMO

- falls CFL>1: ‚row-oriented' time-stepping
- verletzt allerdings numerische Reproduzierbarkeit unter domain decomp. (oder würde ineffiziente globale Kommunikation verlangen)

MB:

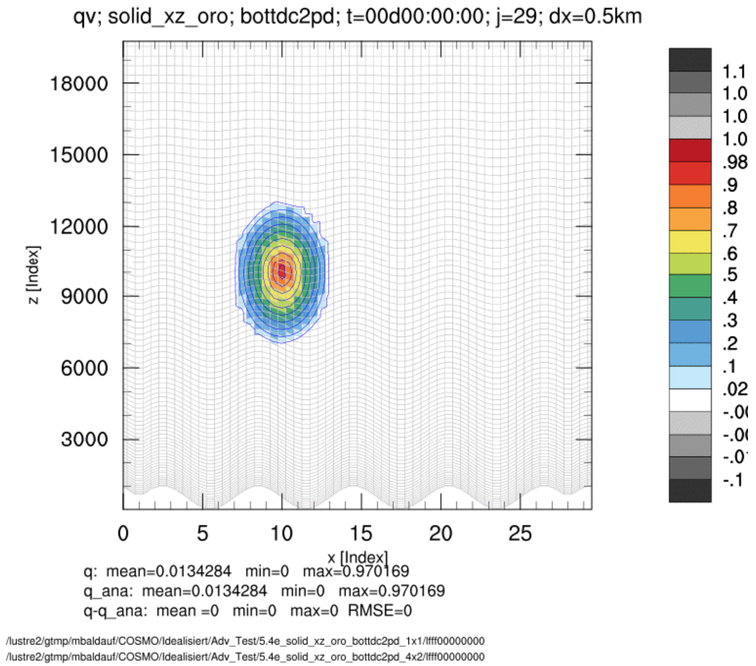
Entwicklung eines ‚**local time stepping**' (für CFL>1) mit den Eigenschaften:

- Erhaltung gewährleistet
- positiv definit
- deformational correction von *Bott (2010)* funktioniert weiterhin
- num. Reproduzierbarkeit unter domain decomposition
- → ‚einfaches' Strang-splitting (alternierend ‚x-y-z' und ‚z-y-x') reicht aus
  → spart idealerweise ~40% Rechenzeit gegenüber ‚vollem' Strang-Splitting

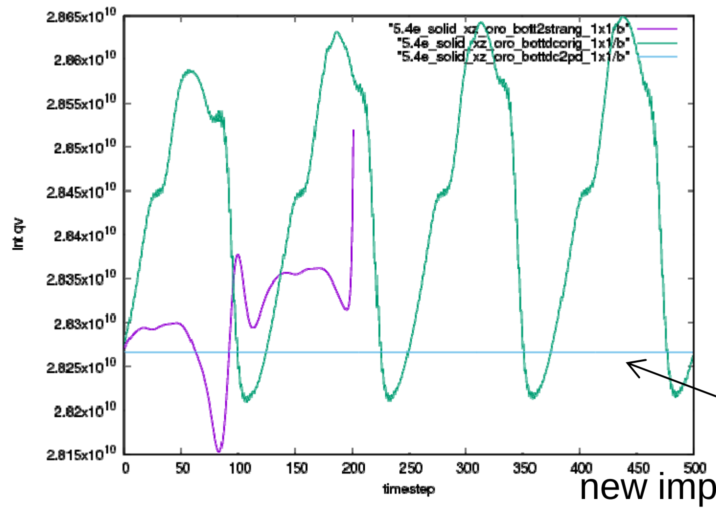
(Publikation als ‚notes&corresp.' geplant in QJRMS)

Idealized advection tests performed
(this is at the same time a contribution to the PP CDIC Task 1, advection tests)

1.) solid body rotation in x-y- and x-z- plane, with/without orography



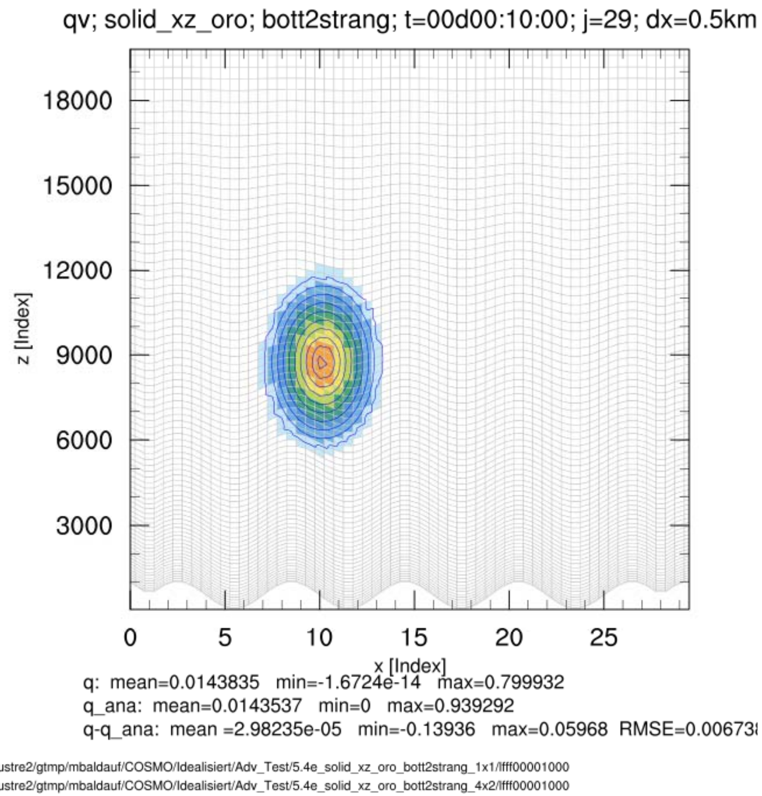
total mass:

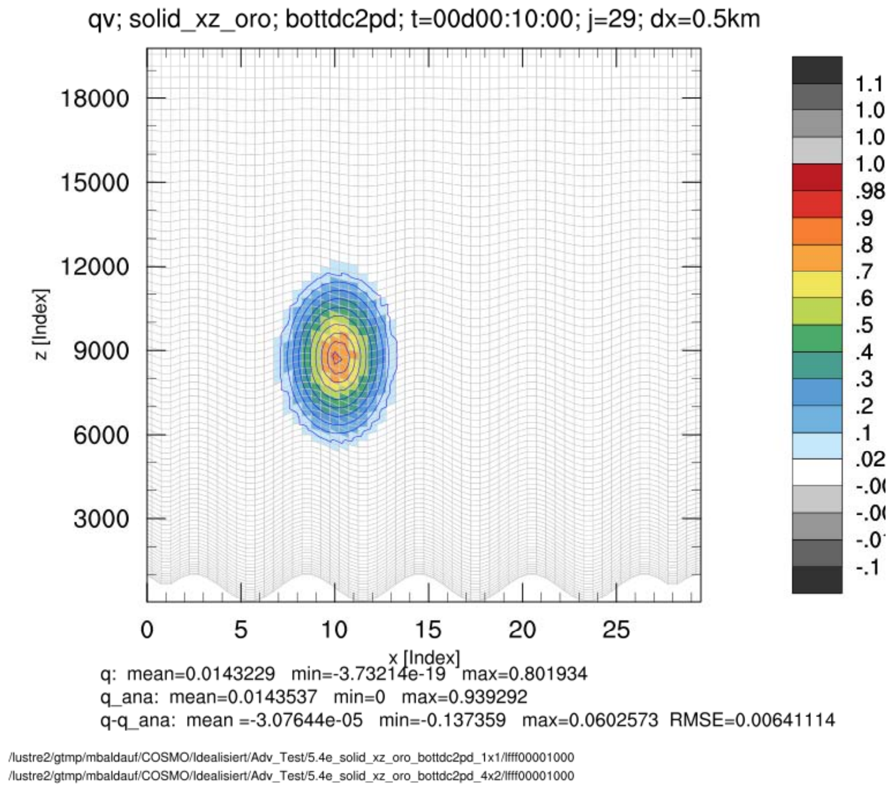


new implementation
is exactly
mass conserving

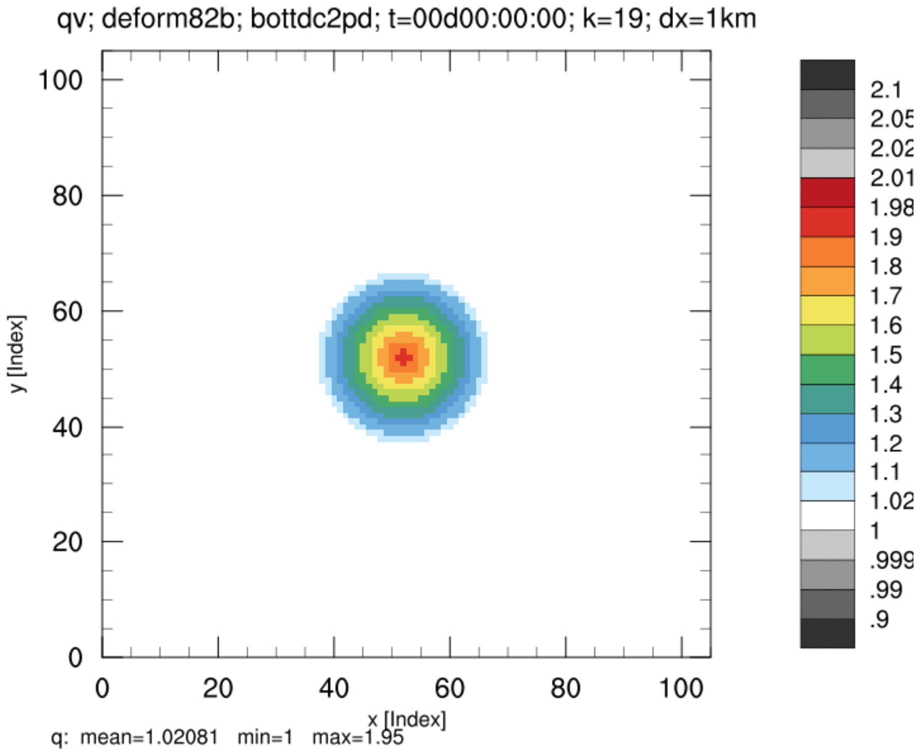
1.) solid body rotation in x-z- plane, with orography

solution after one rotation:

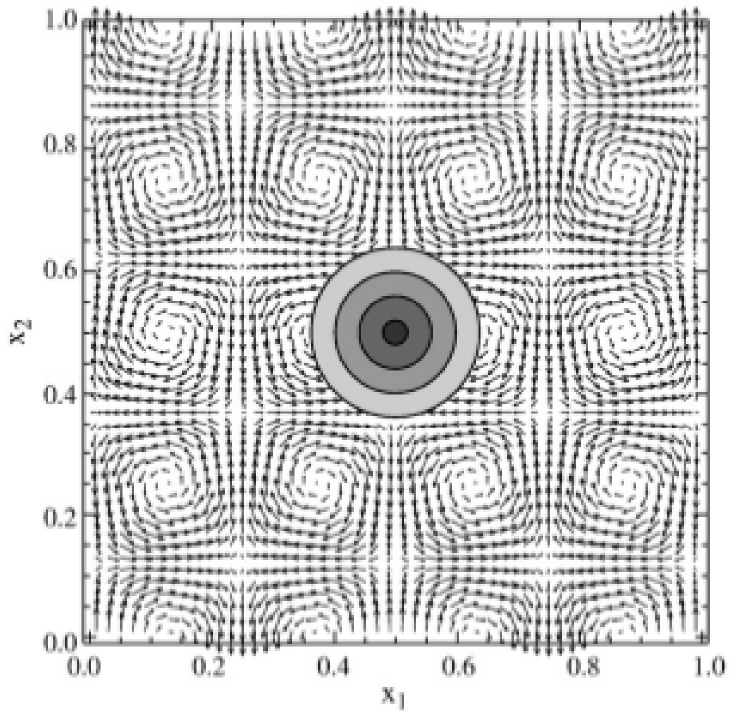




Strongly deformational flow test (*Smolarkiewicz, 1982*)



/lustre2/gtmp/mbaldauf/COSMO/Idealisiert/Adv_Test/5.4e_deform82b_bottdc2pd_1x1/lfff00000000.nc

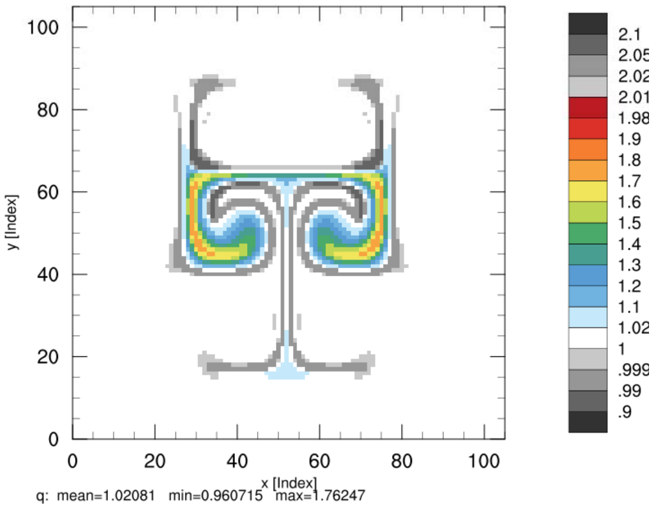


from Bott (2010)

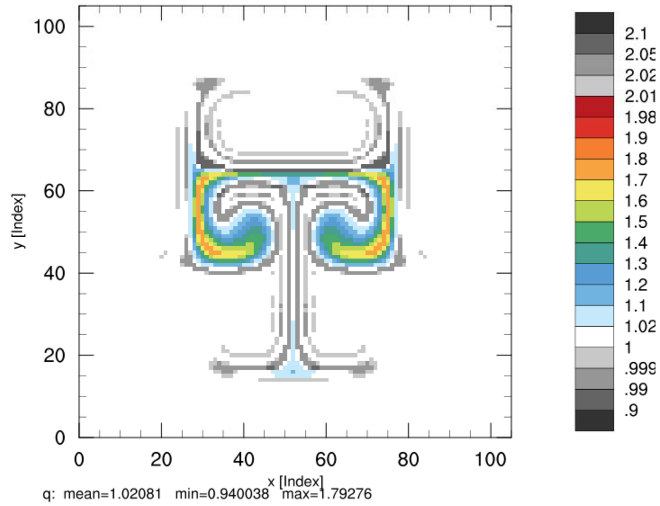
velocity field with $du/dx + dv/dy = 0$
but the two terms are strongly non-zero.
→ can lead to splitting errors

Strongly deformational flow test (Smolark. 1982), after t=5 min

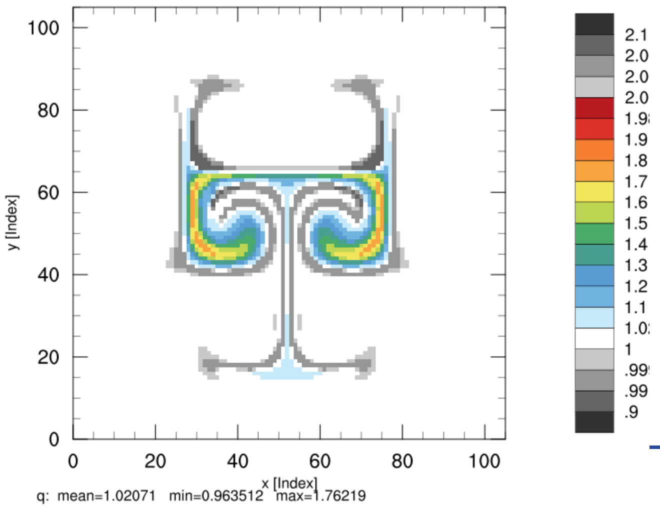
new version: `BottDC2`



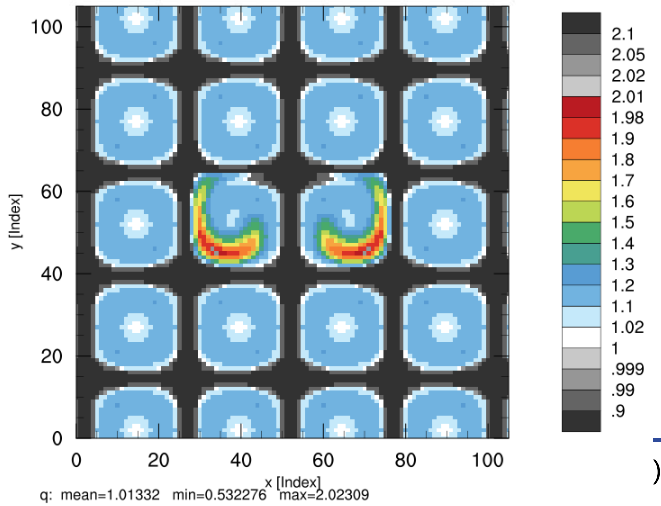
Bott (2010) Univ. Bonn version



current version: `Bott2_Strang`



Bott (1989)

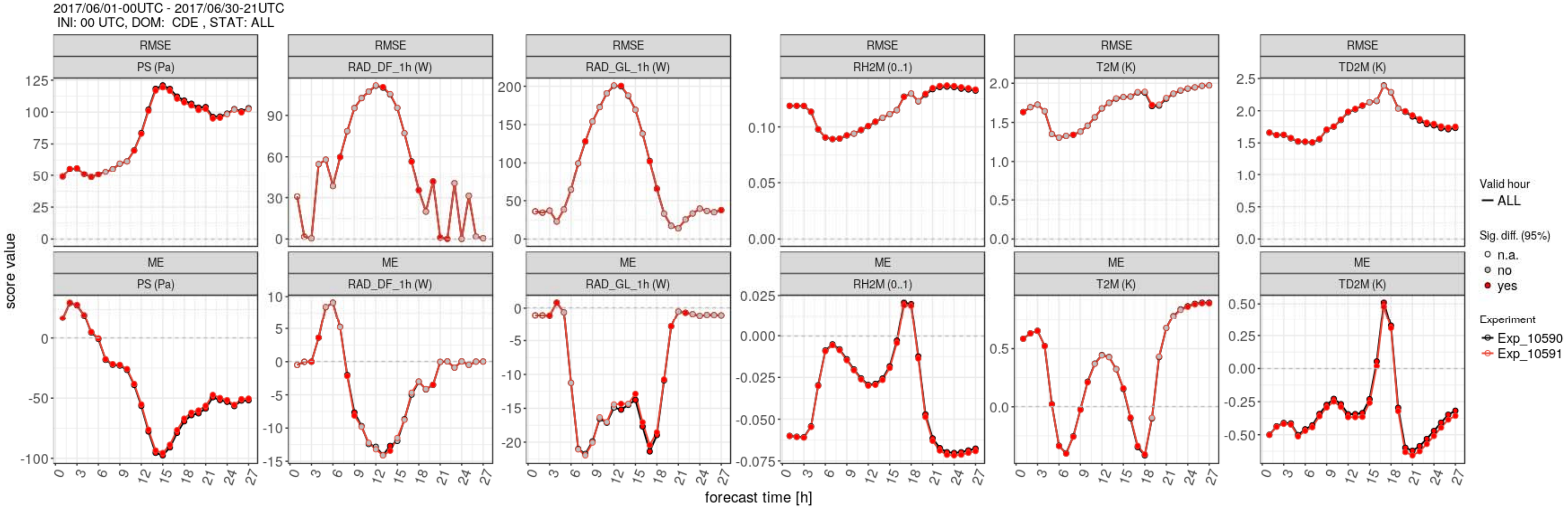


Comparison of advection schemes in NUMEX-Exp.

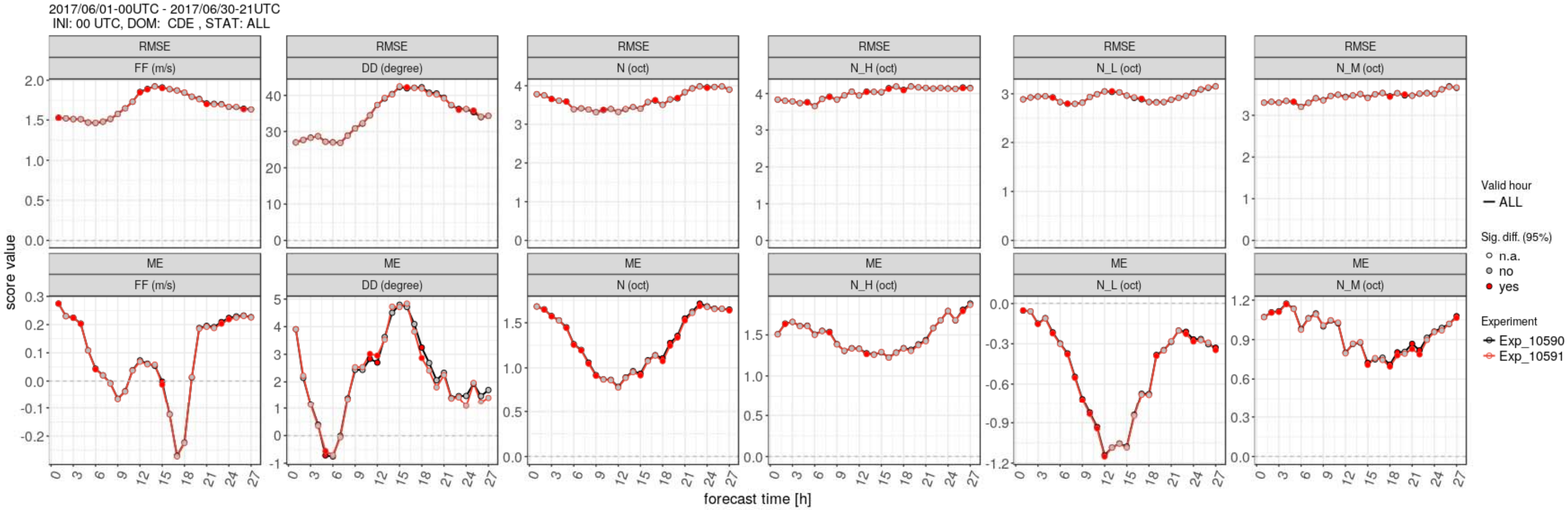
Exp. 10590: y_scalar_advect=„BOTT2_Strang" (current scheme)
Exp. 10591: y_scalar_advect=„BOTTDC2" (new scheme)

based on COSMO 5.4h1
time range: ‚June 2017'
only COSMO-D2 forecast runs; every run is initialized by analyses of NUMEX-Exp. 10535 (‚COSMO-D2 reforecasts').

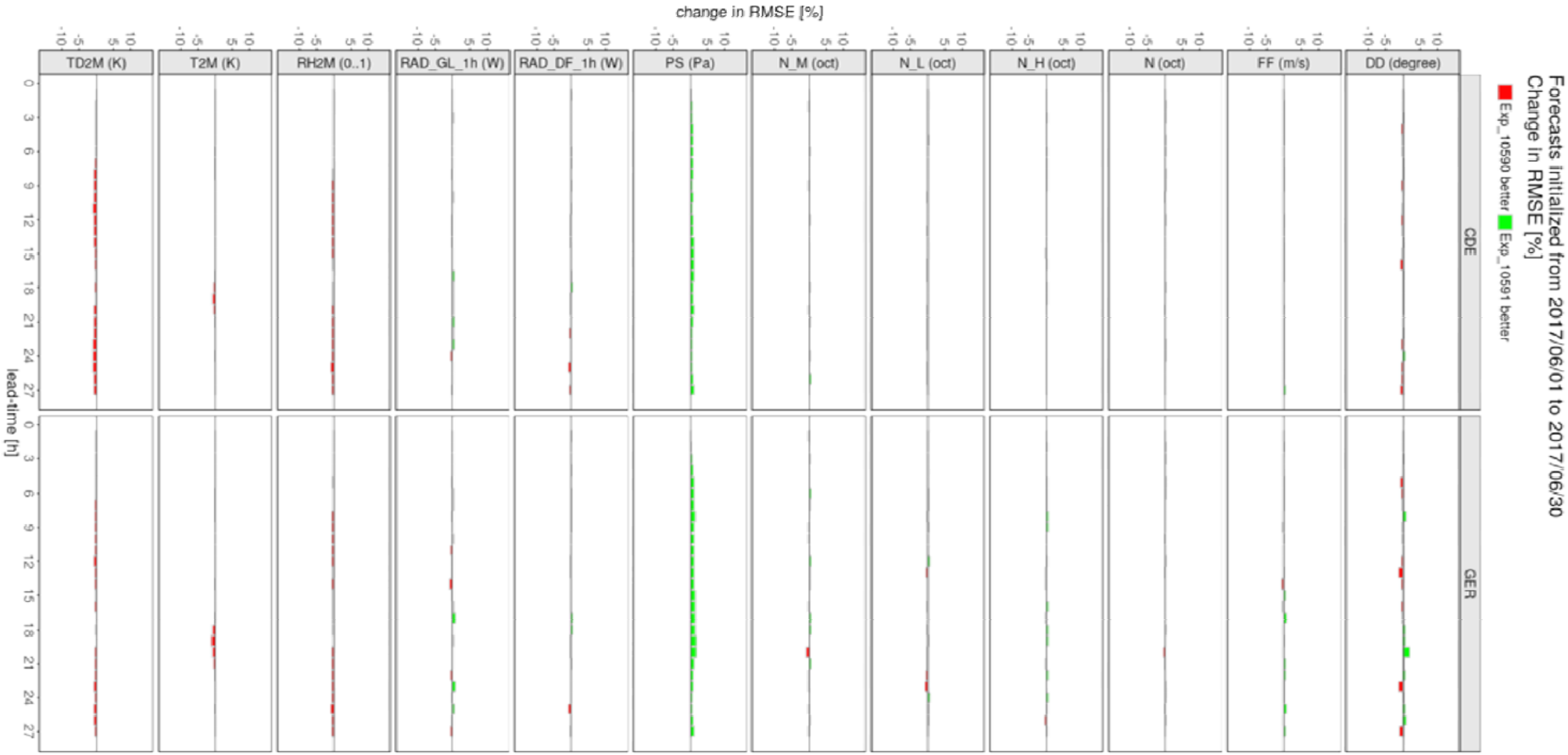
Synop-Verification, cont., Juni 2017



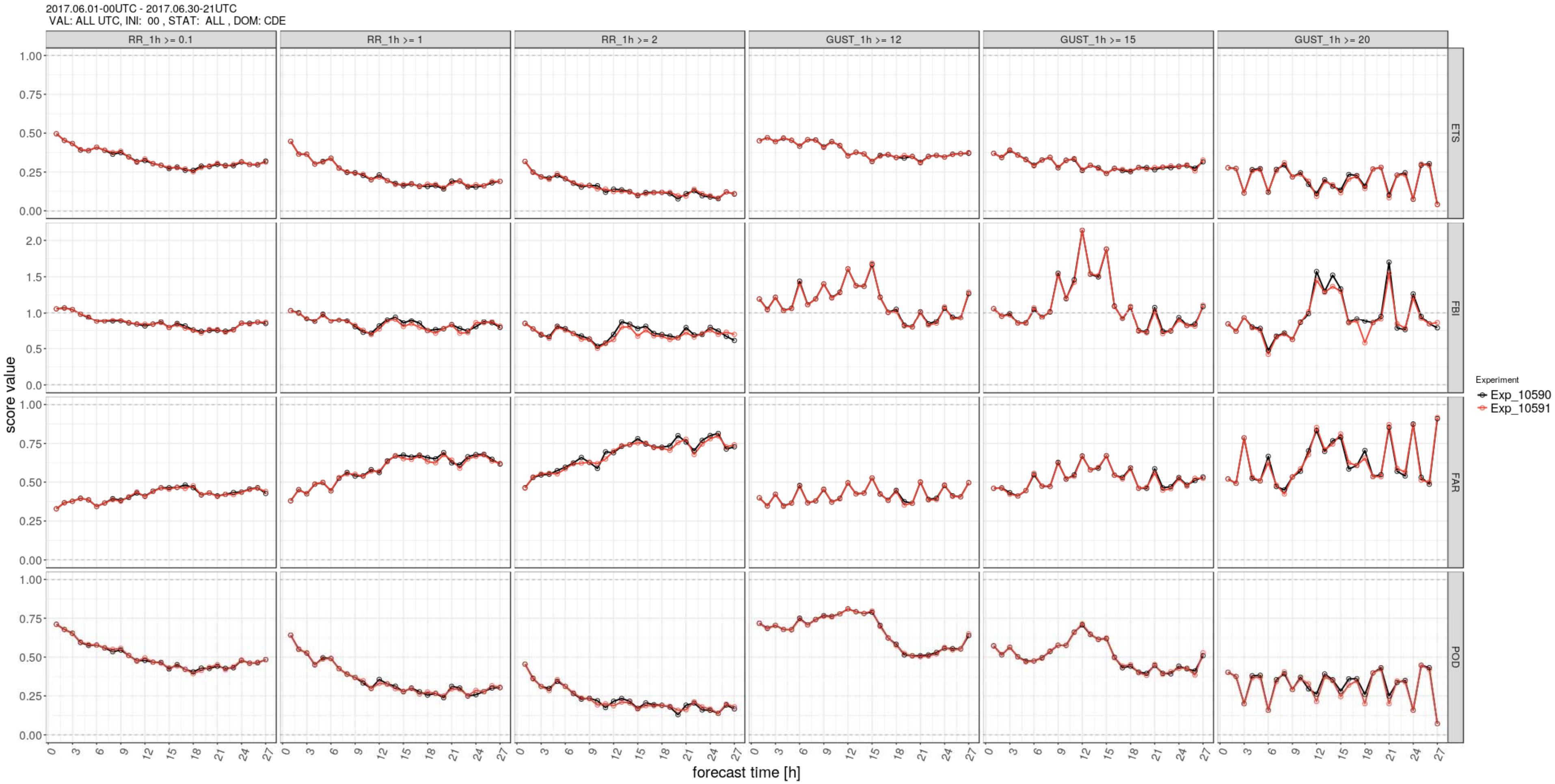
Synop-Verification, cont., Juni 2017



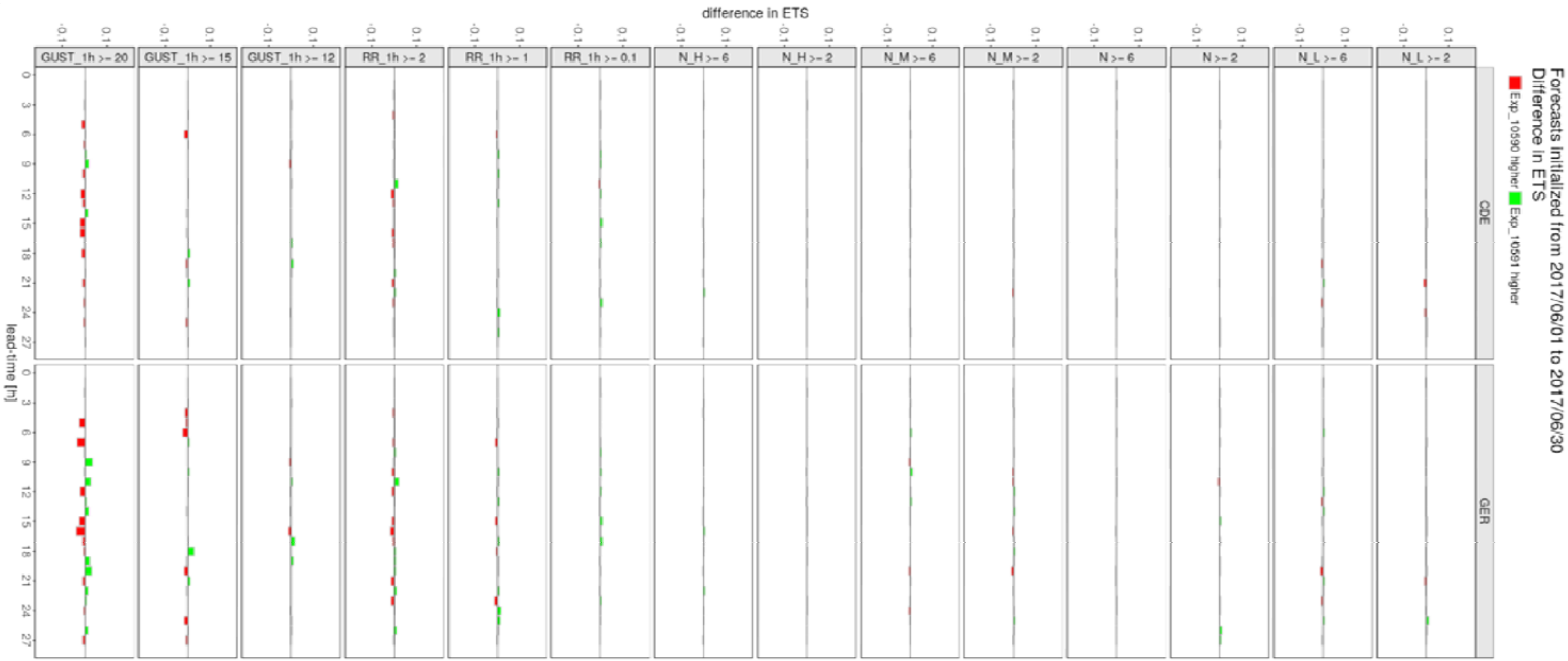
Synop-Verification, cont., Juni 2017

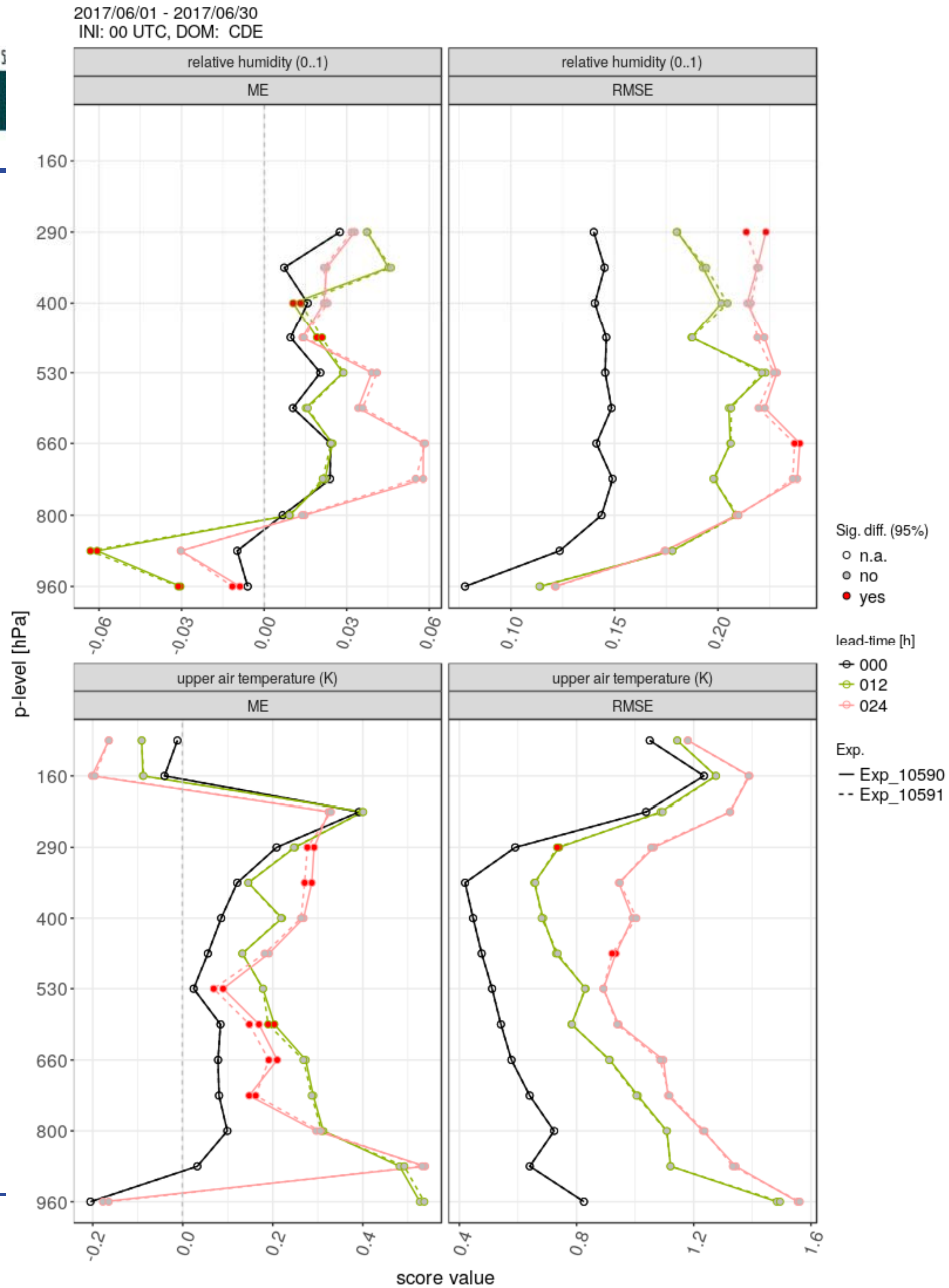


Synop-Verification, categ., Juni 2017



Synop-Verification, categ., Juni 2017




2017/06/01 - 2017/06/30
INI: 00 UTC, DOM: CDE
relative humidity (0..1)
ME
relative humidity (0..1)
RMSE
upper air temperature (K)
ME
upper air temperature (K)
RMSE
p-level [hPa]
score value
Sig. diff. (95%)
n.a.
no
yes
lead-time [h]
000
012
024
Exp.
Exp_10590
Exp_10591

Summary

- Both idealized tests and hindcast-/Numex-experiments show that the transport properties of the new version (`y_scalar_advect`=‚`BOTTDC2`‘) and the current (‚`BOTT2_Strang`‘) are quite similar
(reason: same flux formulation by *Bott (1989)*)
- The new scheme was tested with several other periods (also in full ensemble mode) and always kept stable
- The ‚deformation correction‘ (*Bott, 2010*) allows ‚simple Strang-splitting‘ and together with the (reproducible!) ‚local time stepping‘ results in a **reduction of computation time**
  - for the tracer advection alone of about 30%
  - and for a whole COSMO-D2 run by **about 5%.**
- Scheme is available with COSMO version 5.5a
- runs pre-operationally at DWD since 11.07.2018
- publication: *M. Baldauf: Local time stepping for a mass-consistent … (accepted by QJRMS)*

Higher Order Spatial Schemes for the COSMO Model

Andreas Will, Jack Ogaja (BTU Cottbus)

New (symmetric!) discretization of the advection operator:

$$AdvS4 := \quad (\mathbf{v_h} \cdot \nabla_h u)_{i+\frac{1}{2},j} := \quad \frac{9}{8}\overline{\overline{u}^{O4,\lambda}\delta_\lambda u}^{\lambda} - \frac{1}{8}\overline{\overline{u}^{O4,\lambda}\delta_{3\lambda} u}^{3\lambda} + \frac{9}{8}\overline{\overline{v}^{O4,\lambda}\delta_\phi u}^{\phi} - \frac{1}{8}\overline{\overline{v}^{O4,\lambda}\delta_{3\phi} u}^{3\phi}$$

kinetic energy conserving discretization (*Morinishi et al., 1998*)

Additionally one can use 4th order discretizations of horizontal derivatives
in the fast waves solver.

In the following:
CDE011: COSMO-DE (2.8km) with original COSMO RK-scheme (C3p2d0.25Ct)
CDE012: COSMO-DE (2.8km) with symmetric discretization (S4p4d0.0Cs)

, :

List of simulations 2000-2014

EXPID	IBC	HR	DOM	CONF
C3p2d0.25Ct-dynamics (standard COSMO-RK)				
TEU006	ERAINT	50 km	EUL	CCLM
CEU011	TEU006	7 km	EU	COSMO-EU
CDE011	CEU011	2.8km	DE	COSMO-DE
S4p4d0.0Cs-dynamics (symmetric dynamic)				
TEU007	ERAINT	50 km	EUL	CCLM
CEU012	TEU007	7 km	EU	COSMO-EU
CDE014	CEU012	4.5km	DE	COSMO-DE
CDE012	CEU012	2.8km	DE	COSMO-DE, tkhmin=tkmmin=0.01

IBC: Initial and Boundary Conditions
HR: Horizontal model resolutions
DOM: Domain simulated
CONF Model configuration used

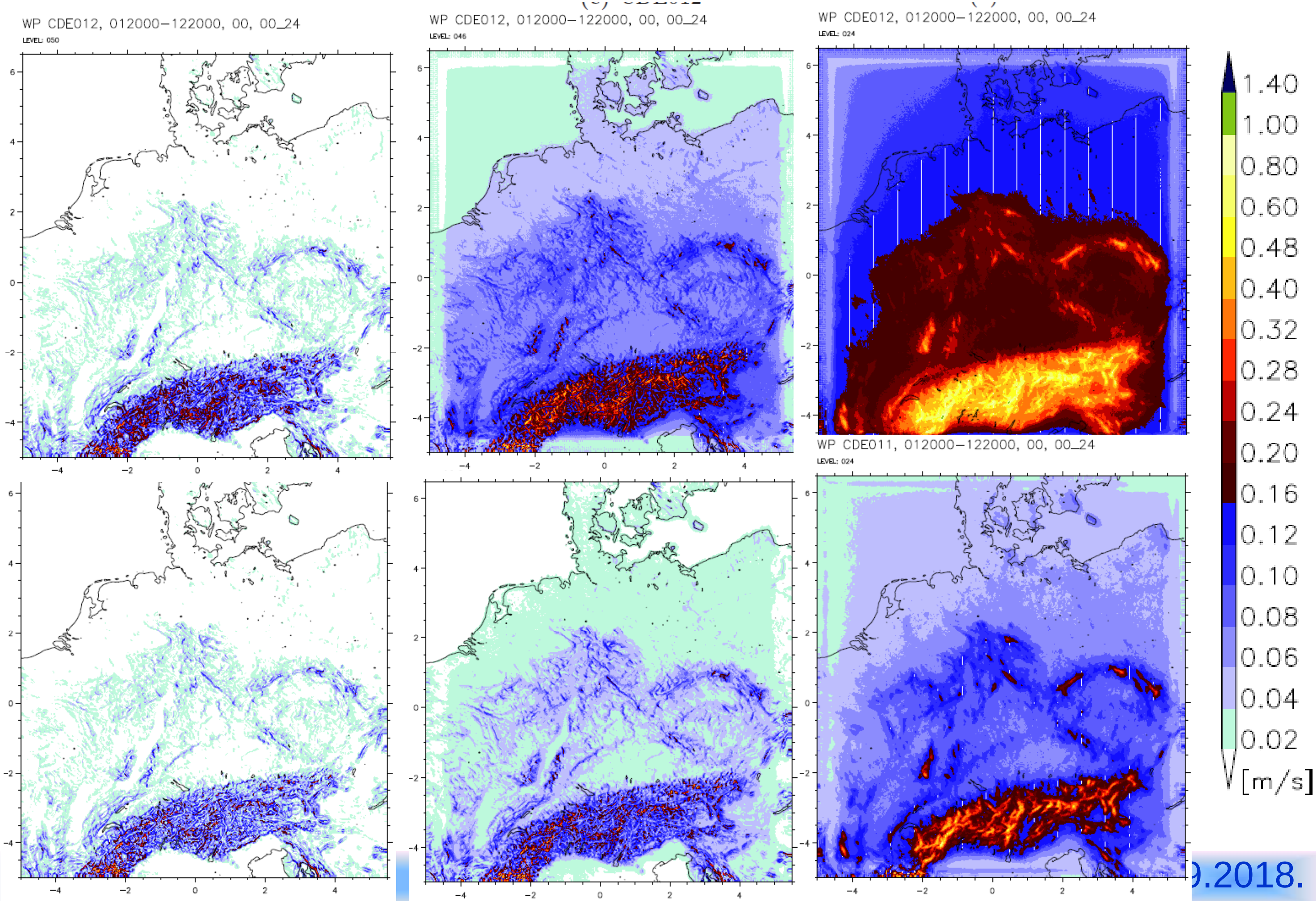
RESULTS for WP (W>0)
mean 2000

Brandenburgische Technische Universität Cottbus

P= **998 hPa** **975 hPa** **500 hPa**

CDE012 (symm)

CDE011

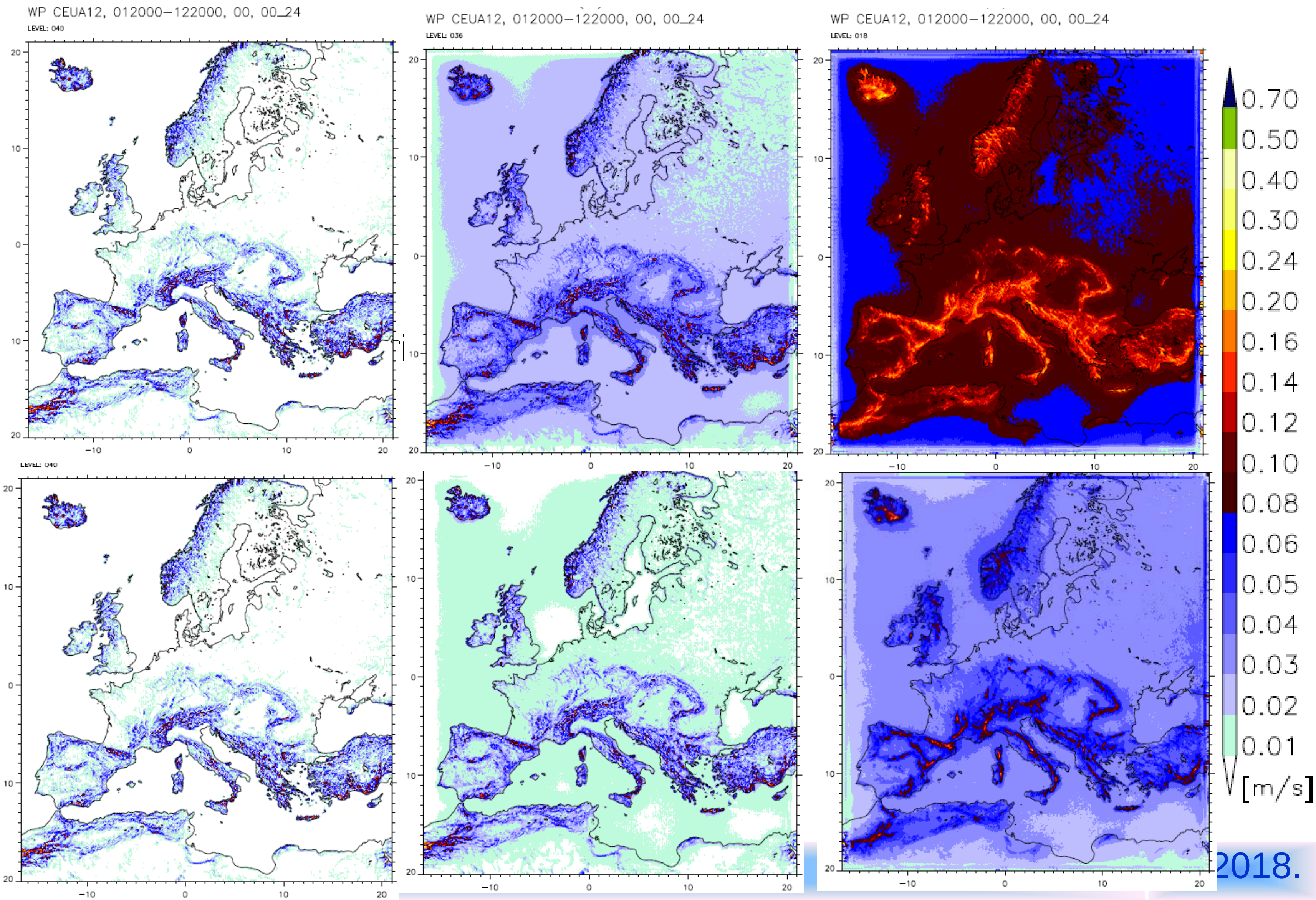


RESULTS for WP = W>0

Mean 2000

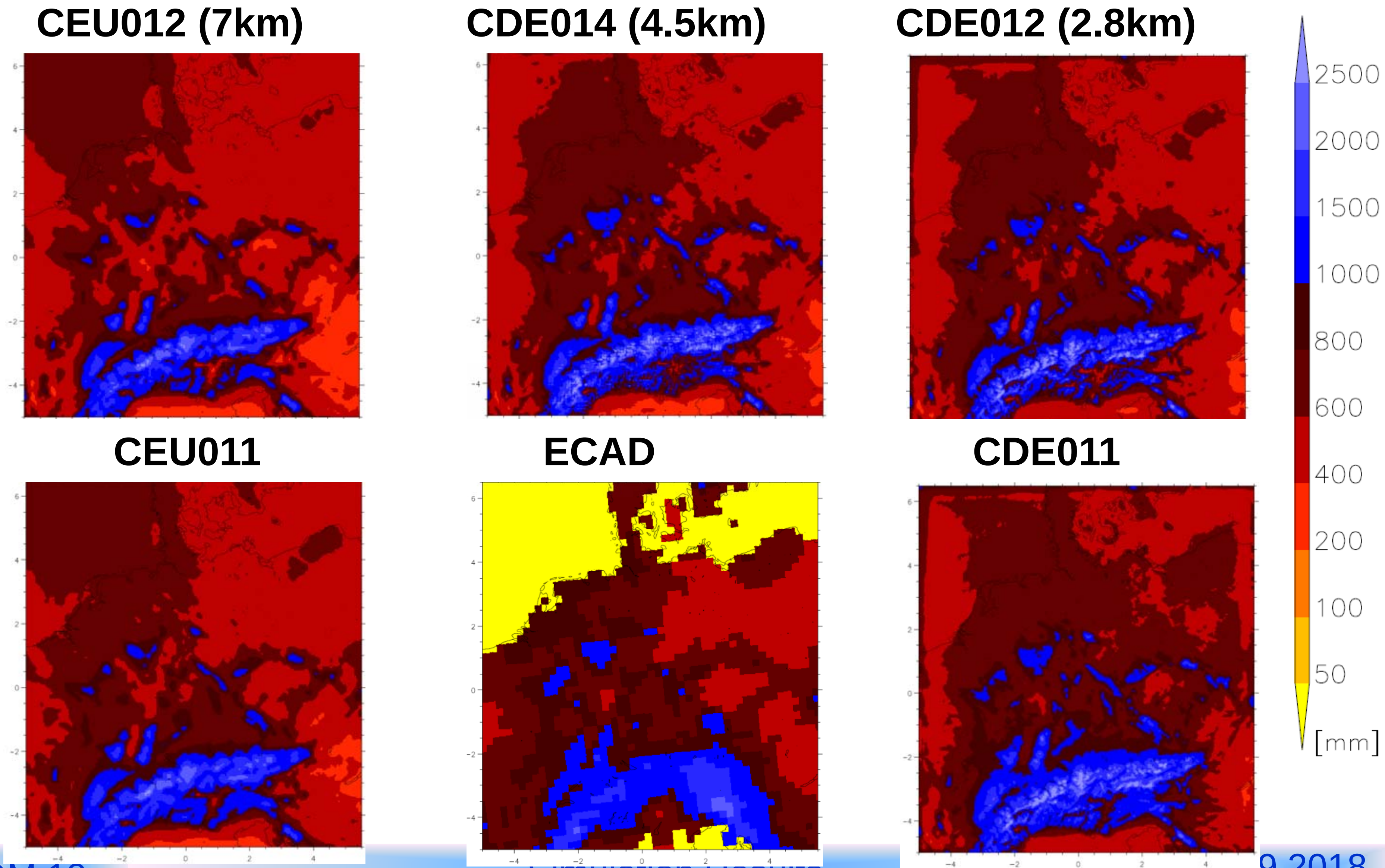
Brandenburgische Technische Universität Cottbus

P=	998 hPa	975 hPa	500 hPa
CEU012 (symm)			
CEU011			



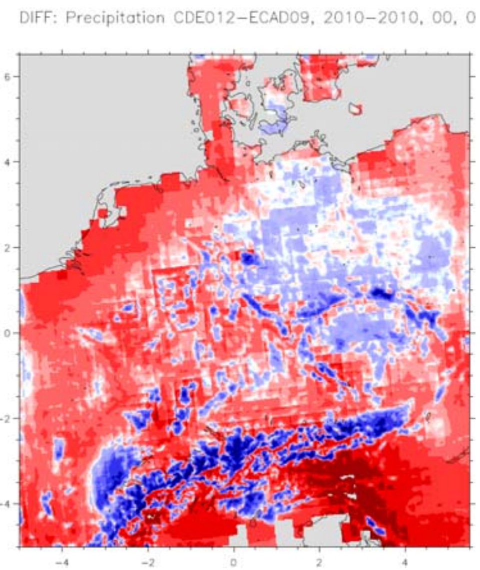
3.1 TOT_PREC
mean annual sum 2000-2010

Brandenburgische Technische Universität Cottbus

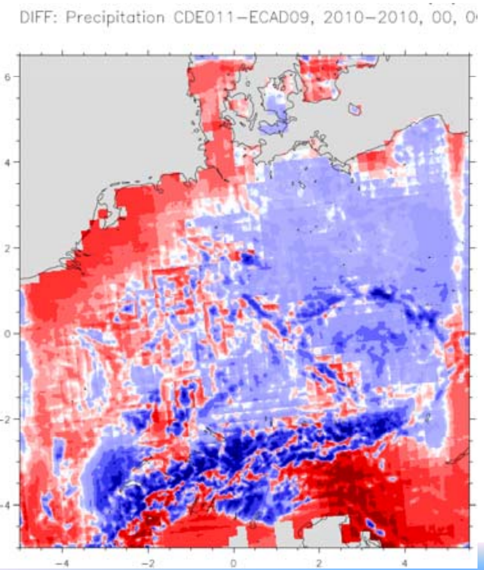


4. RESULTS for TOT_PREC 2000-2014

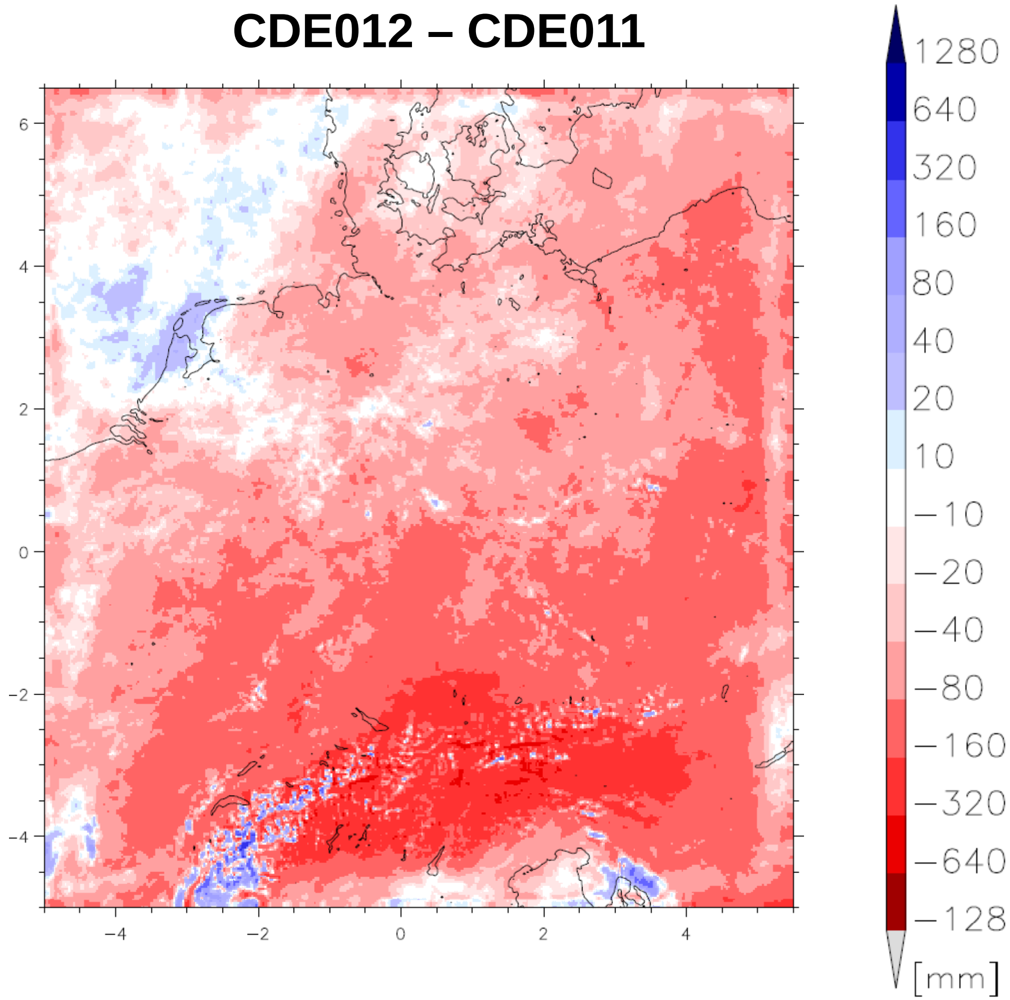
CDE012-ECAD



CDE011-ECAD



CDE012 – CDE011



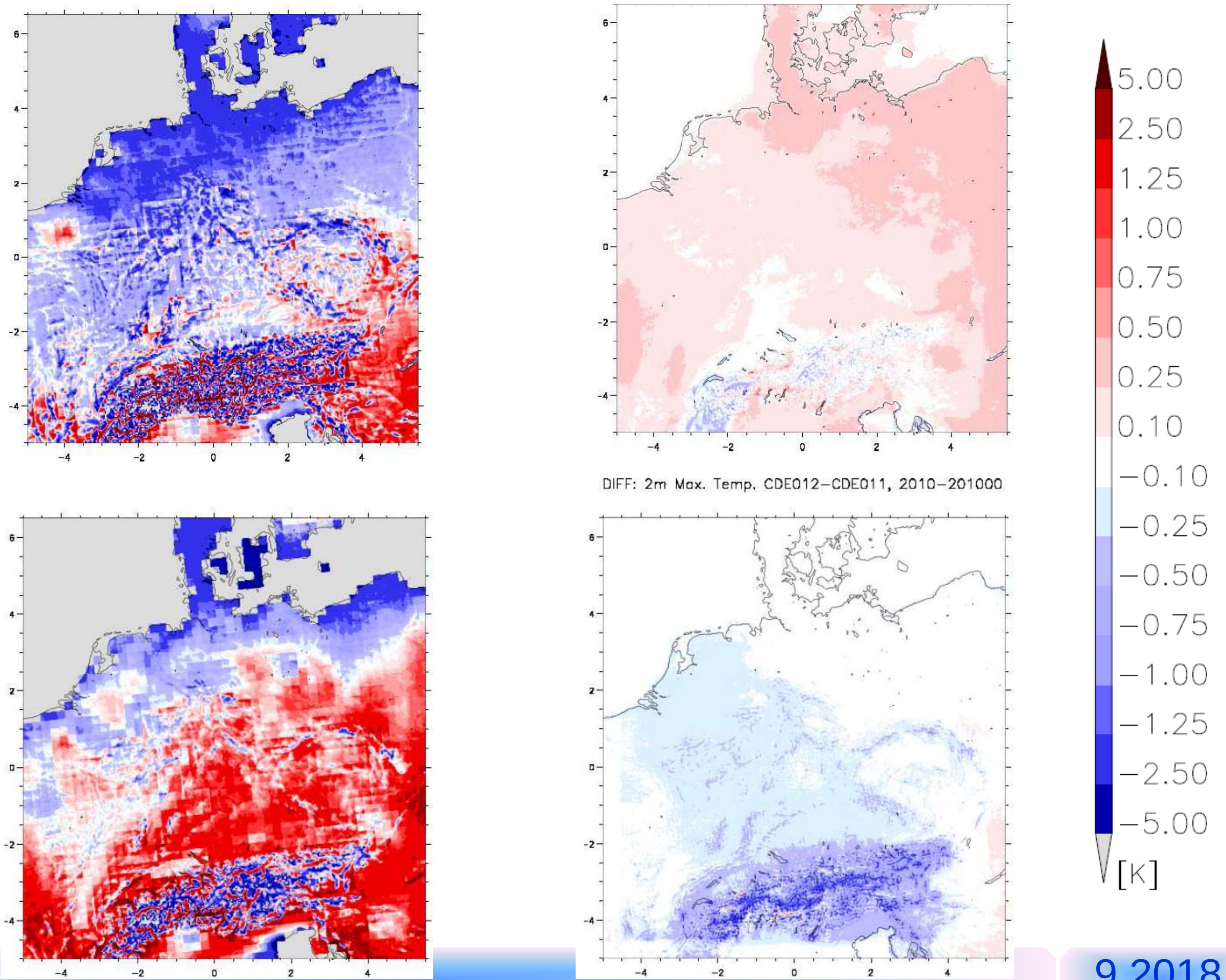
b-tu Brandenburgische Technische Universität Cottbus

4. RESULTS for TMIN/TMAX_2M 2000-2014

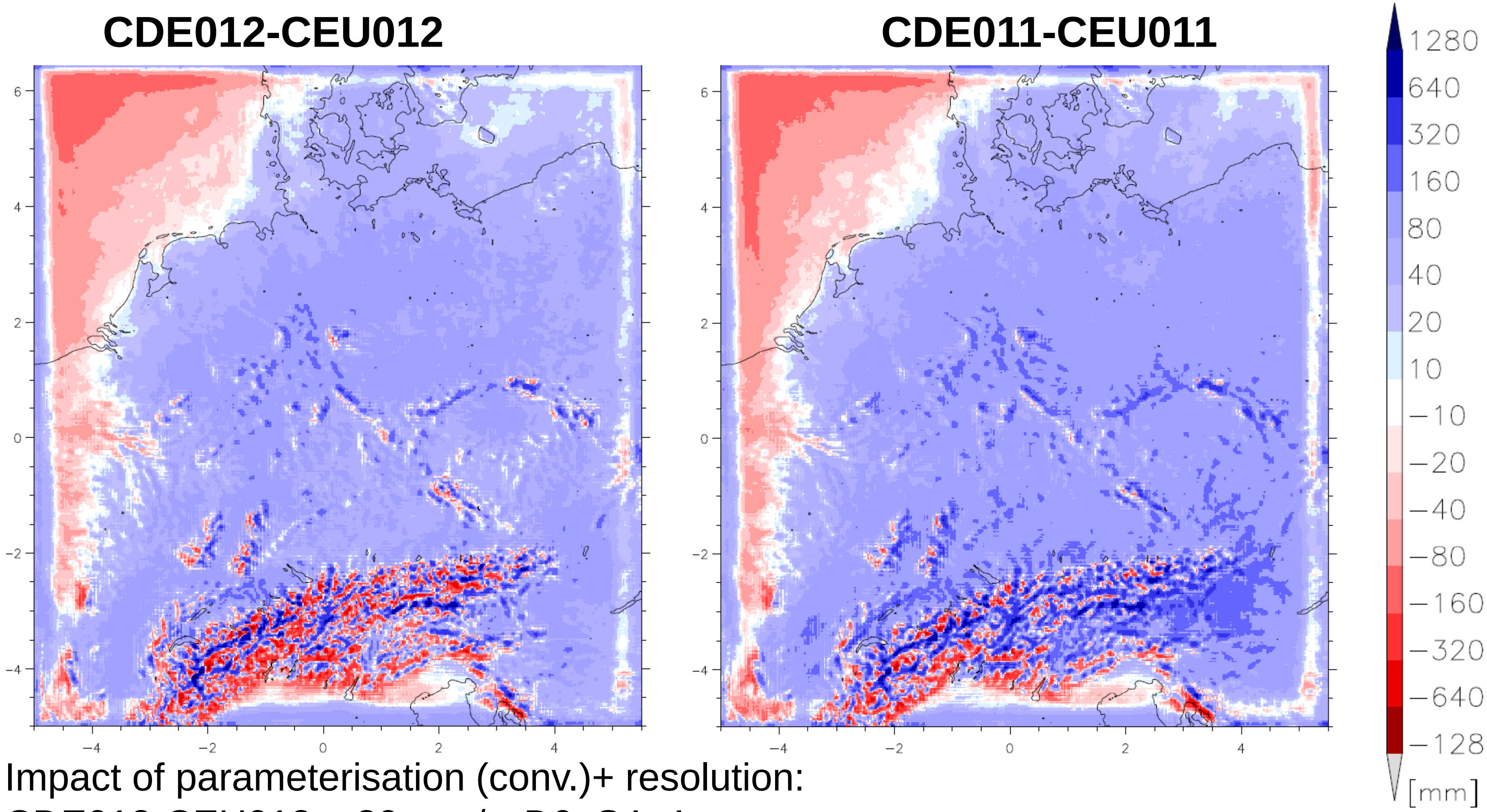
CDE012 - ECAD | CDE012 – CDE011

TMAX_2M

TMIN_2M



3.1 TOT_PREC, 2000-2014



Impact of parameterisation (conv.)+ resolution:
CDE012-CEU012: +80 mm/y, D0, S4p4
CDE011-CEU011: +40 mm/y, D0.25, C3p2

3.1 Impact of resolution, numerics and model physics

Precipitation is

- **reduced by higher model resolution (factor 2 reduces by 5%)**
- **increased by Numerical Diffusion is increasing precipitation and**
- **reduced by deep Convection parameterisation by 10 to 20 %**

Daily temperature range increased by HOS (1 K)

Clouds: More high, less low clouds (5-10%) (not shown)

HPBL: no significant differences

•INTERPRETATION:

- Convection parameterisation has an infinite speed. The potential energy is transported vertically immediately when buoyancy is positive. The physical convection has a finite speed. The convective motion is suppressed as long as the convection parameterisation is used.

- Parameterised convection is tuned to produce the correct amount with numerical diffusion.

- Numerical Diffusion is a disturbance of dynamics. This increases the precipitation since the atmosphere has to balance this disturbance

- An Increase of horizontal resolution is reducing the size of the air parcels. Smaller air parcels have higher vertical velocity and thus the system is faster in aequilibrium. This is reducing the precipitation because precipitation occurs if the system is out of aequilibrium.

- Retuning of precipitation is necessary without numerical diffusion.

Status of implementation of HOS in cosmo_5.5

Routine	implementation	TTS	4 eye	CLM test	NWP test
- organize_dynamics.f90	finished		tbd		
- fast_waves_sc.f90	finished	tbd	tbd		
- src_runge_kutta.f90	finished		tbd		
- src_advection_rk.f90	finished	tbd	tbd		
- numeric_utilities.f90	tbd		tbd		
- grid_metrics_utilities.f90	tbd		tbd		
- all		tbd		10.2018	??

CLM test: COSMO-DE, COSMO-DE2, COSMO-BRB1

-Quantities/Cases of interest

- boundary layer meterorology in mountaineous region
  Wallis
- boundary layer meteorology in flat terrain
  Brandenburg, Harz mountains

Other WG2 stuff …

- At DWD, **COSMO-D2** (2.2km, L65, enhanced domain) became operational at **15 May 2018**
- COSMO Sci. Doc Part I (‚Dyn & Num.‘) has been updated
  - new section about ‚spectral nudging‘
  - new section about the new Bott (2010) + LTS scheme

COSMO science plan 2015-2020, chapter 5: ‚Dynamics and Numerics'

- 5.2.1 Further maintenance of RK dyn. core
  - higher order discretization (Univ. Cottbus) (✓)
  - further work on Mahrer-option in steep terrain → Univ.Cottbus 🛠
  - variable time step ✕
  - horizontal grid stretching ✕
- 5.2.2 COSMO-EULAG operationalization
  - is currently done at IMGW; PPs: CELO, EX-CELO, (CCE?) ✓
- 5.2.3 Investigation in new Euler solvers based on Finite volume schemes
  - stopped for COSMO ✕
- 5.2.4 Tracer advection schemes
  - New Bott (2010) scheme with LTS is implemented ✓
- 5.2.5 Other tasks
  - numerical stability of 3D turbulence in terrain-following coord. ✓
- 5.2.6 Transition to the new model ICON
  - done in PP CDIC ✓
  - new PP C2I 🛠

Final report of the Priority Project
‚Comparison between the dynamical cores of COSMO and ICON‘ (CDIC)

COSMO General meeting, St. Petersburg, Russia
03-07 September 2018

Project team (current):
Michael Baldauf, Florian Prill (DWD), Rodica Dumitrache, Amalia Iriza (NMA), Damian Wojcik (IMGW), Guy de Morsier (MeteoCH), Marina Shatunova, Denis Blinov, Alexandr Kirsanov (Roshydromet)

with strong support from
Günther Zängl, Daniel Reinert, Uli Schättler (DWD)

Aim of the COSMO priority project
‚Comparison of the dynamical cores of COSMO and ICON' (CDIC):

deliver an as objective as possible **comparison** of the **dynamical cores** of COSMO and ICON with the emphasis on **limited area modelling**.

- Task 1: idealised tests (main focus)
- Task 2: semi-realistic tests
- Task 3: scalability/performance
- Task 4: Principal properties of the numerical formulation
- Task 5: Suitability for other applications (climate/chemistry)

Task 1. Good performance on a standard set of idealized test cases

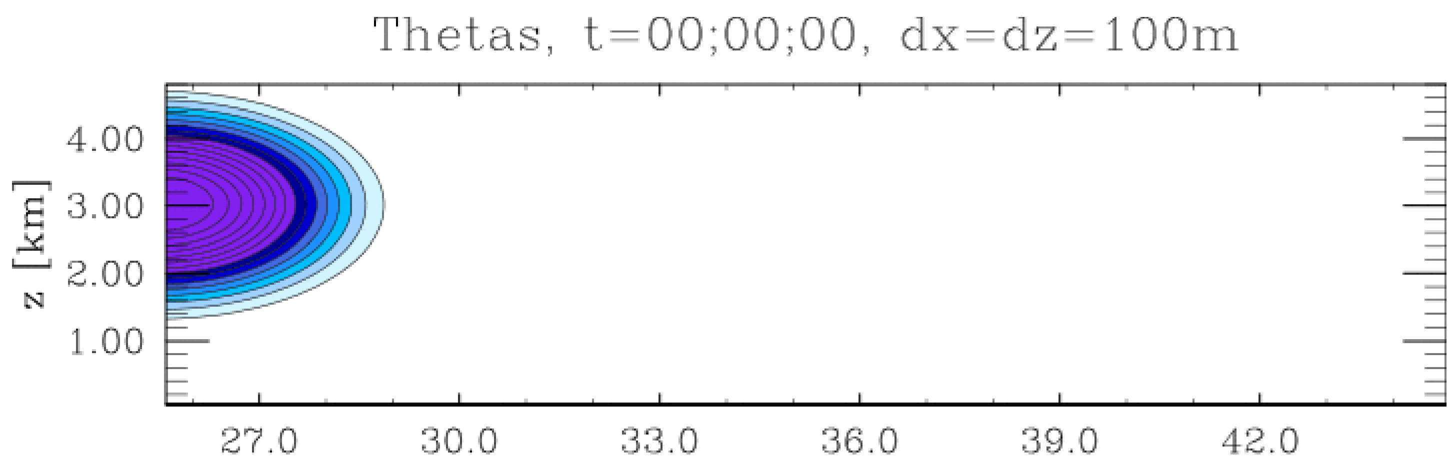
Defined test cases:

1. Advection test with nonlinear dynamics *(Schär et al., 2002)* -
2. Atmosphere at rest *(Zängl et. al (2004) MetZ)* ✓
3. Cold bubble →unstationary density flow *(Straka et al., 1993)* ✓ / 🛠
4. Mountain flow tests (stationary, orographic flows)
   - 4.1 *Schär et al. (2002), section 5b* ✓
   - 4.2 *Bonaventura (2000) JCP (selection)* ✓
   - 4.3 3D-case (dry) ✓
5. Linear Gravity waves *(Baldauf, Brdar, 2013)* ✓
6. Warm bubble *(Robert (1993), Giraldo (2008))* -
7. Moist, warm bubble *(Weisman, Klemp, 1982)* ✓
8. Advection tests for tracer schemes (solid body rotation, …) 🛠

Test case 3: cold bubble

R. Dumitrache, A. Iriza (NMA), M. Baldauf (DWD)

Testsetup by *Straka et al (1993)*

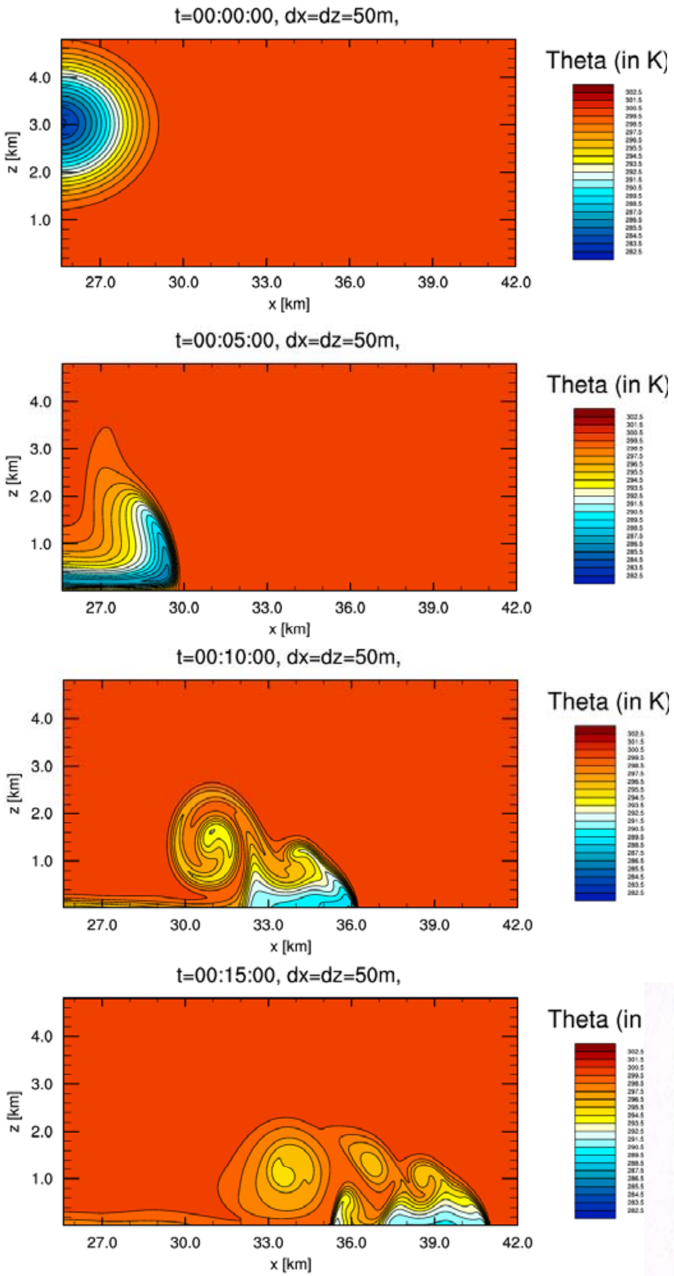


Test properties:

- test of dry Euler equations (without Coriolis force)
- unstationary
- strongly nonlinear
- comparison with reference solution from paper

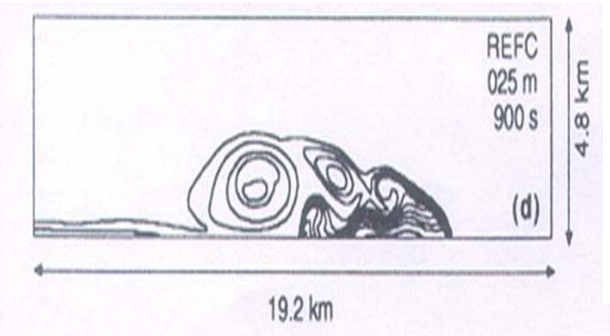
Test case 3: cold bubble

COSMO (dx=50m)

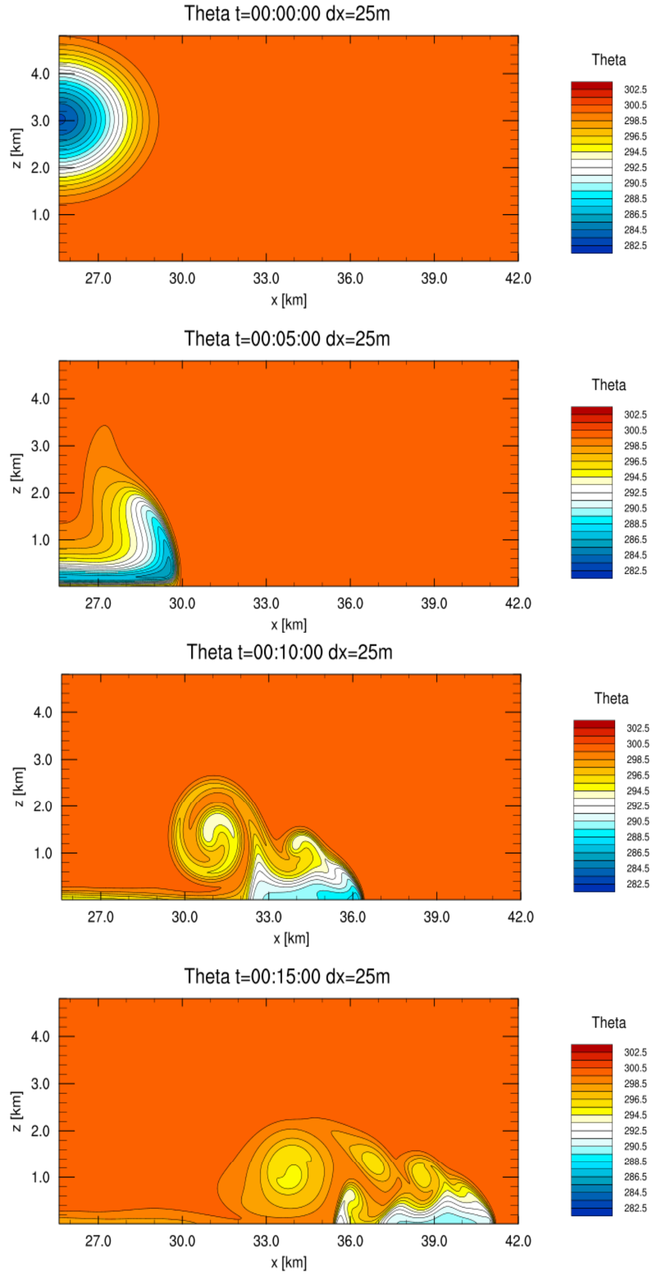


θ at t=0, 5, 10, 15 min.

Reference solution from Straka et al.:

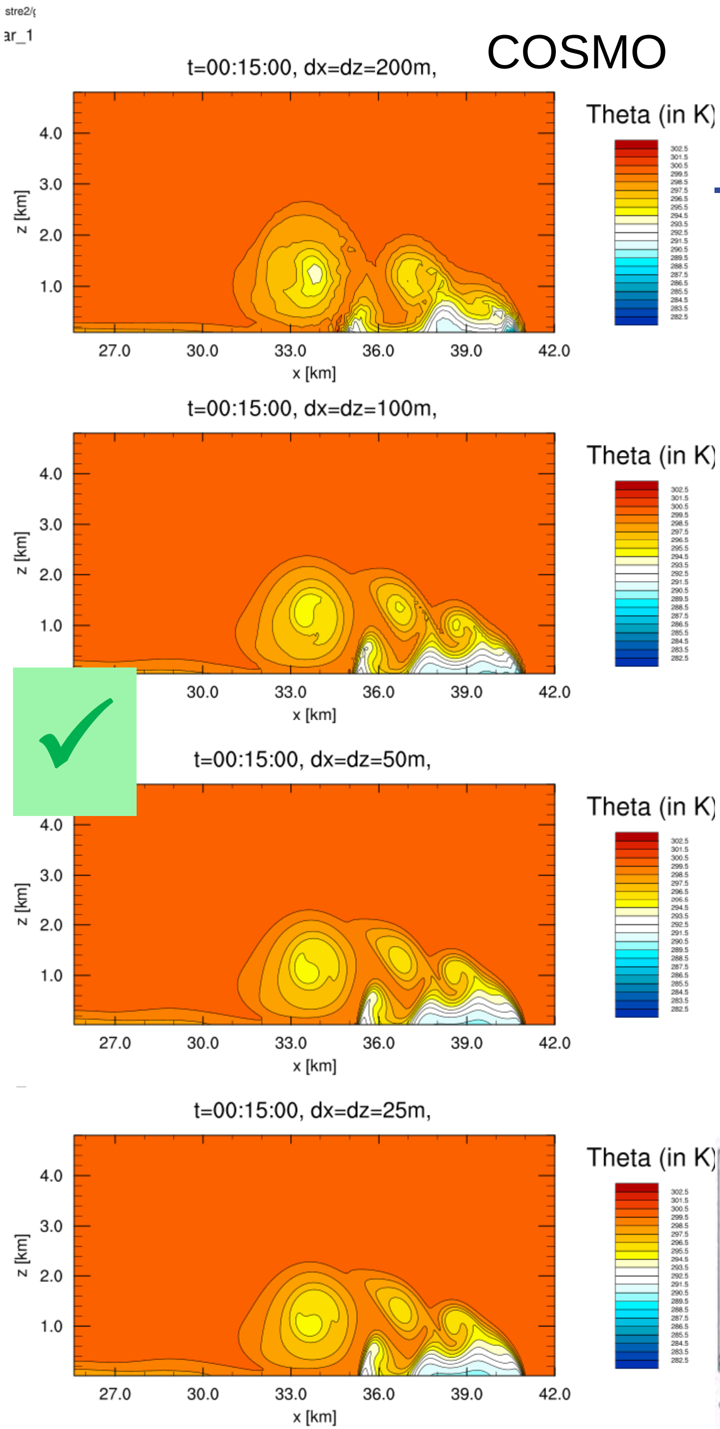


ICON (dx=25m)



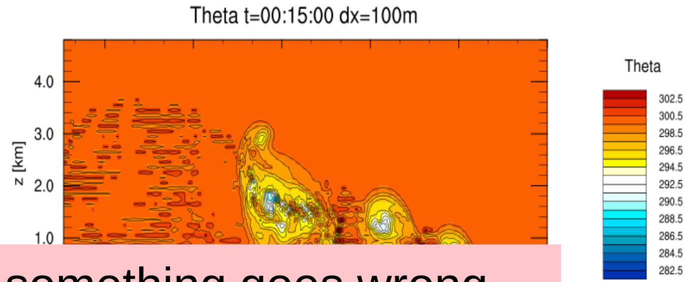
Test case 3: cold bubble

COSMO



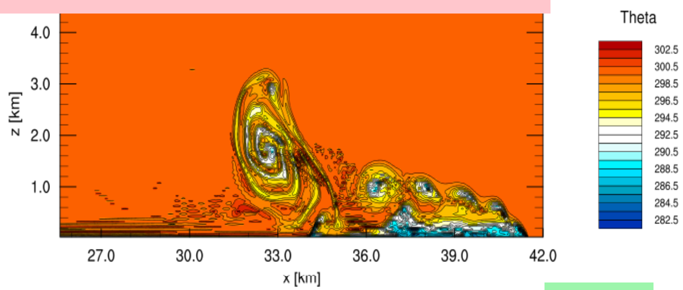
θ at t=15 min.
for Δx= 200, 100, 50, 25m

ICON

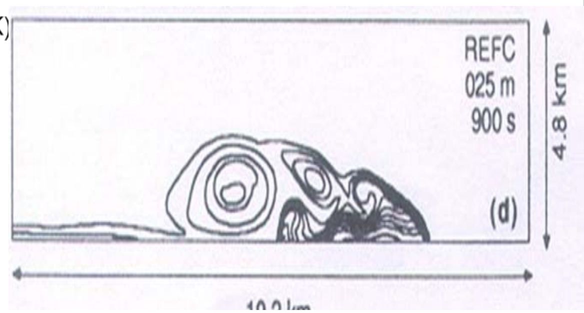


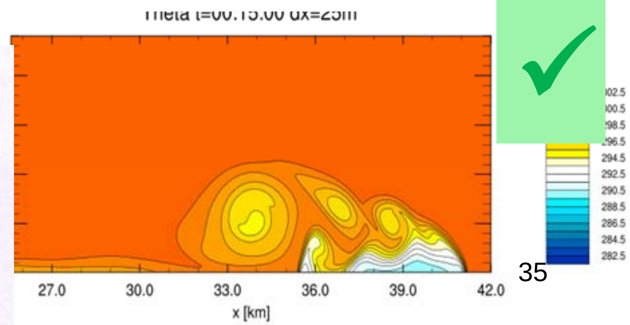
something goes wrong…
diffusion?
still to be done…

?



Reference solution
from Straka et al.:





Test case 7: Weisman, Klemp (1982) test setup

D. Wojcik (IMGW)

- Idealized **moist convection** experiment designed to reproduce the development and subsequent evolution of a convective cloud

- Test basic consistency of the **coupling** between dry model equations and moist microphysics and turbulence parameterization

horizontal resolution: 2km
COSMO, ICON: microphysics with 3-cat. ice ←→ WK82: Kessler

Following plots show:

- Vertical wind: on 4150 m height (contours, negative values dashed)
- Horizontal wind: on 87 m height (arrows)
- Gust front: on 10 m height (thick blue line, - 0.5 K temperature perturbation)
- Precipitation: on 10 m height (dashed, for QR values exceeding 1 and 4 g / kg)

Experimental setup

Experimental setup:

- Computational domain 200 km x 200 km x 40 km
- 90 vertical levels with stretching (ICON)
- 74 vertical levels with the same stretching spanning up to 25 km (COSMO R-K)
- Periodic domain in horizontal direction
- qv_0 = 14 g / kg
- U_s = 15, 25 and 35 m/s

Convection initiation:

- Warm bubble radius: r_h = 10 km, r_v = 1.4 km
- ΔT_{bubble} = +6 K

Parameterizations :

- 'COSMO' microphysics with 3-cat ice (inwp_gscp = 2)
- 'COSMO' diffusion scheme (inwp_turb = 1)
- Surface fluxes are turned off

Data visualization based on ICON native-output data. Since data are plotted with NCL the Earth System Modeling Framework (ESMF) tools are used to re-grid data to a regular grid:

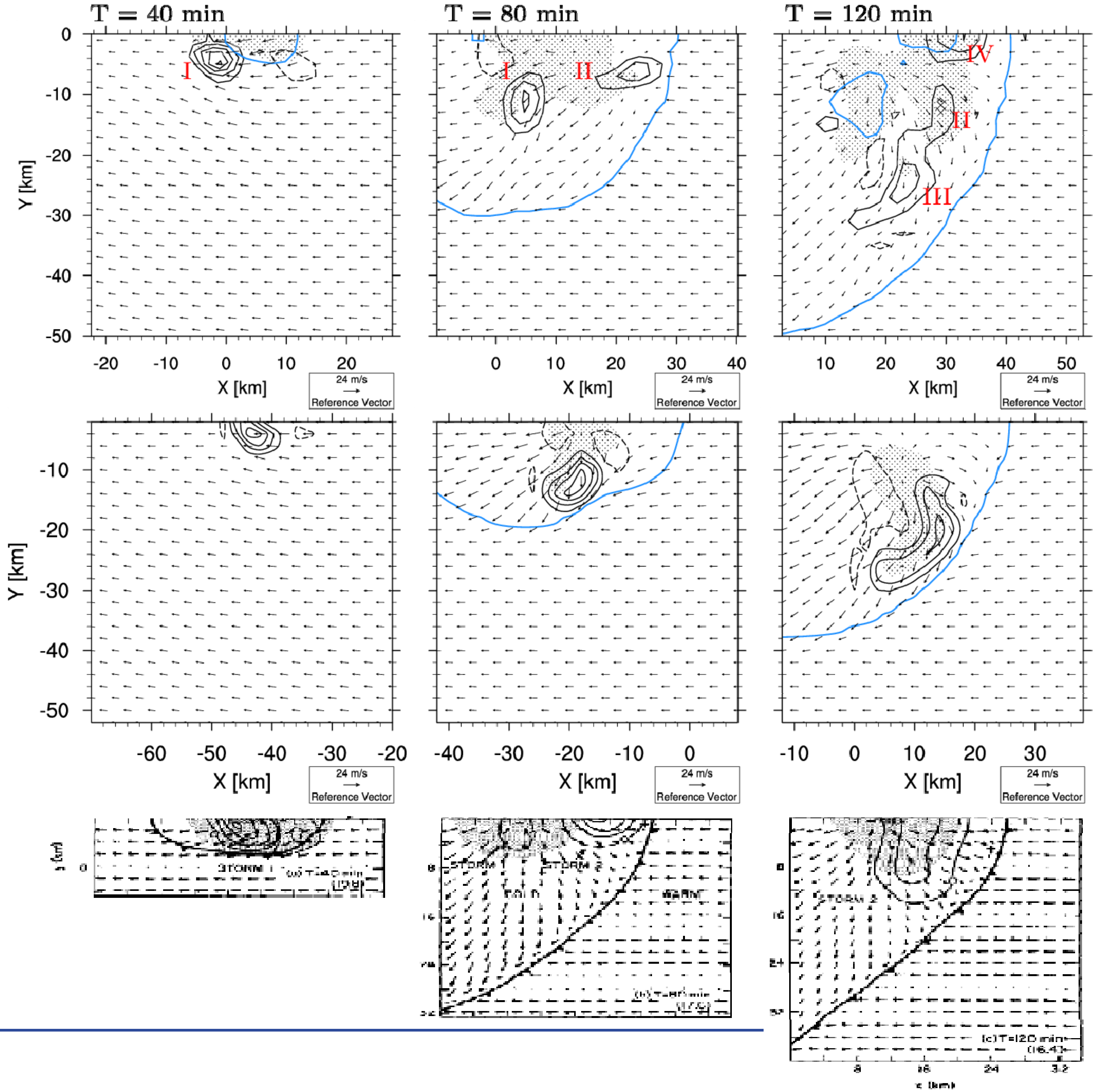
- Vertical wind: on 4150 m height (contours for: -8.,-6.,-4.,-2.,5.,10.,15.,20.,25.,30. and 35. m/s, negative values dashed)
- Horizontal wind: on 87 m height (arrows)
- Gust front: on 10 m height (thick blue line, - 0.5 K temperature perturbation)
- Precipitation: on 10 m height (dashed, for QR values exceeding 1 and 4 g / kg)

U=15 m/s

ICON

COSMO

Reference
(from WK82)

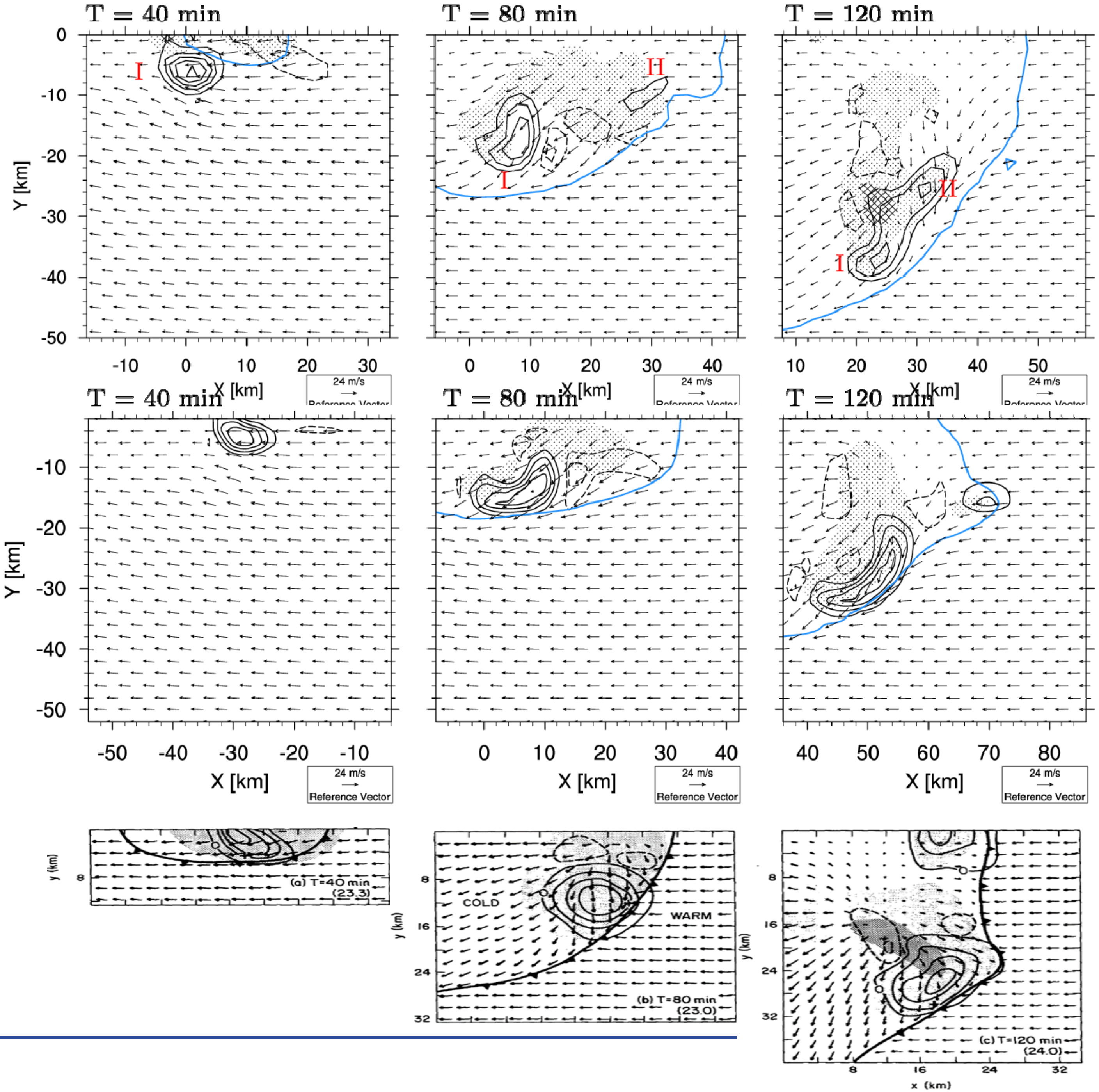


U=25 m/s

ICON

COSMO

Reference
(from WK82)

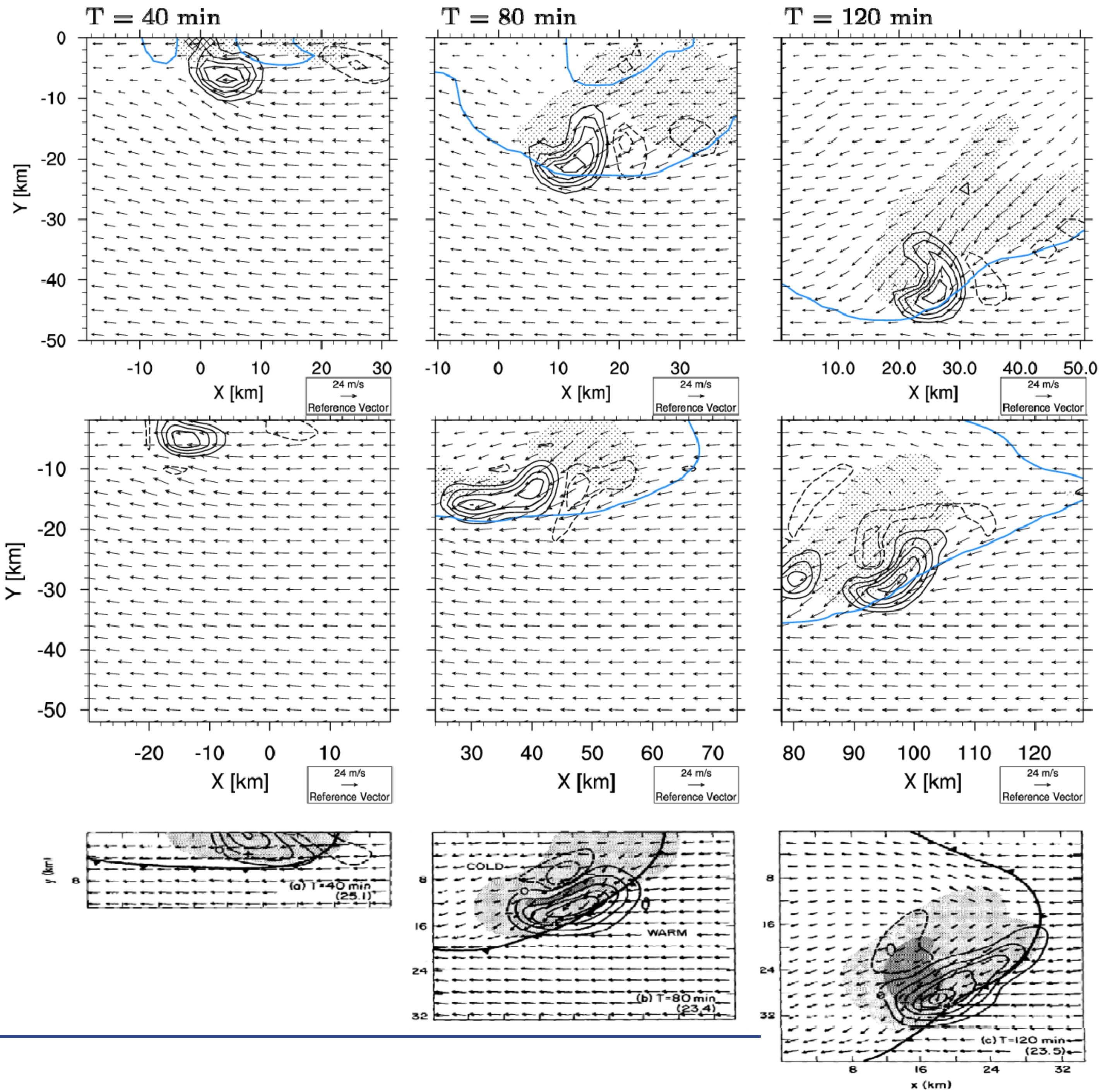


U=35 m/s

ICON

COSMO

Reference
(from WK82)



Summary

1. In this experiment ICON model demonstrates capability to reproduce realistic convective nonhydrostatic flows

2. There is no indication of basic errors in the coupling between dry ICON dynamical core and moist microphysics and turbulence parameterizations

3. When rather little horizontal environmental vorticity in present (U_s = 15 m/s) the ICON model reproduces basic convective structures (gust front, convective updraft, precipitation region and surface outflow). The convective updraft tends to get more 'blurred', but that probably results from different effective diffusivity of the two models

4. In the middle case (U_s = 25 m/s) the convective updraft for the ICON model is more compact (comparing to U_s = 15 m/s) bus still less compact in comparison with COSMO R-K

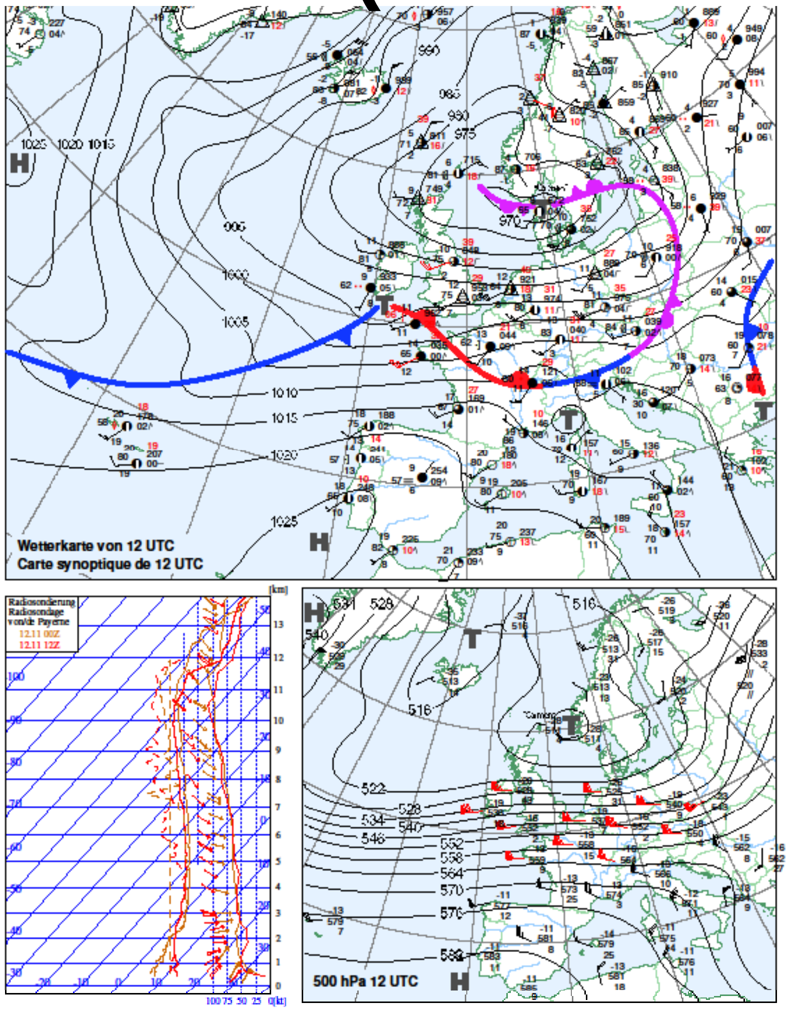
5. In the case with high env. vorticity (U_s = 35 m/s) the ICON model updraft is more compact comparing with COSMO R-K and more similar to the benchmark solution. Also the lateral drift of the convective cell is more similar to the benchmark solution

Task 2: Semi-realistic test cases

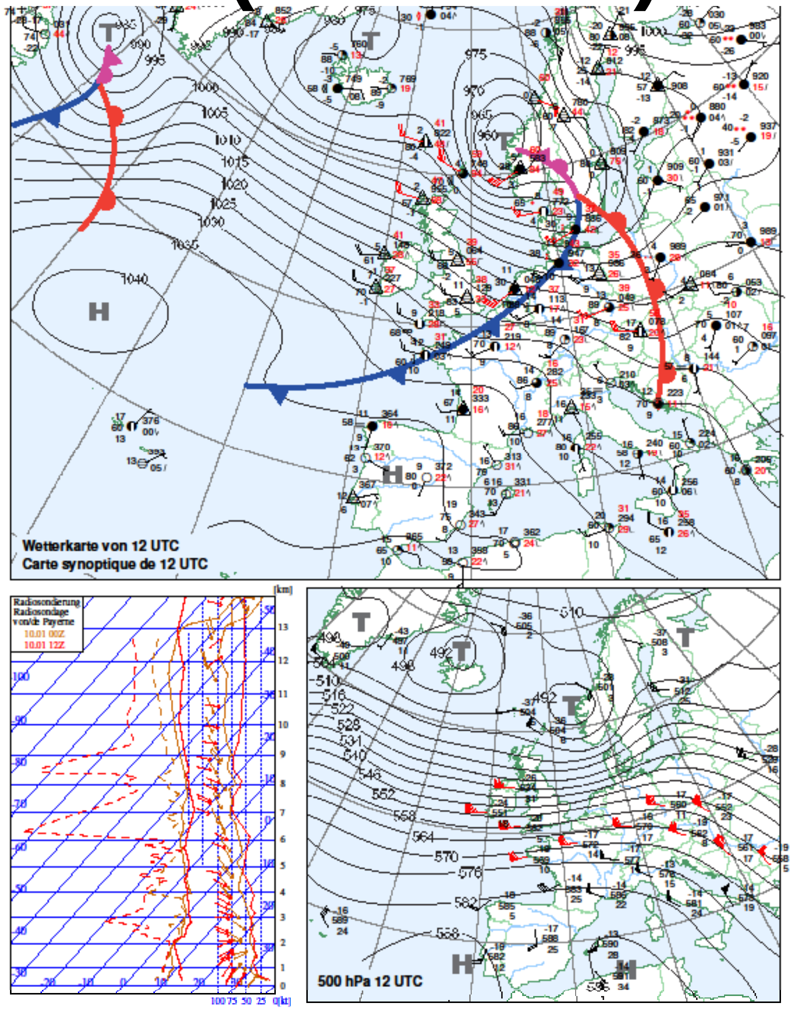
Guy de Morsier (MeteoCH)

- **goal: test COSMO and ICON with only vertical diffusion (no other physics packages)**
- Characteristics of storms
- **Results (only COSMO so far)**
- Summary & Outlook

Synoptic of Storms
Carmen (12.11.2010) Elon (10.1.2015)



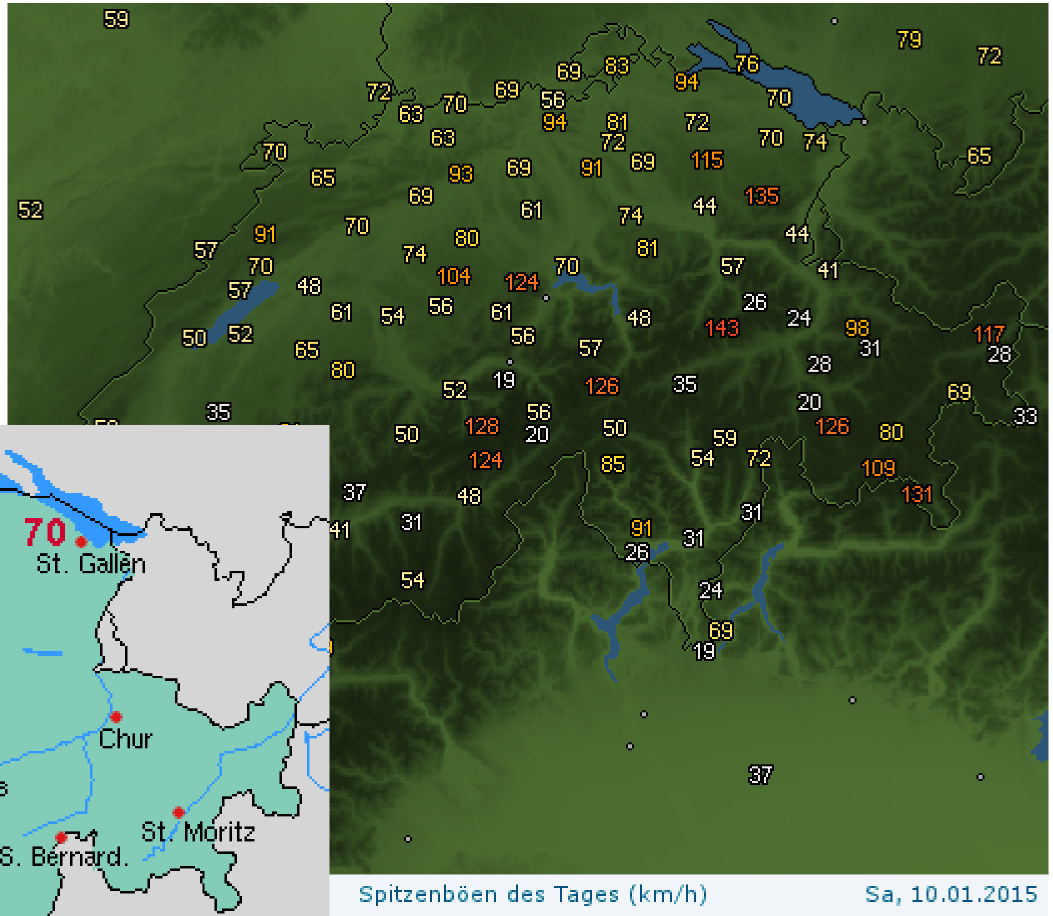
Wetterübersicht mit Karten + Daten ab Telefax Polling / Bulletin météorologique (cartes et données) par téléfax polling (Fr. 1.50 / Min.) 0900 162 244
Abonnement: MeteoSchweiz, F. Schacher, Postfach 514, 8044 Zürich



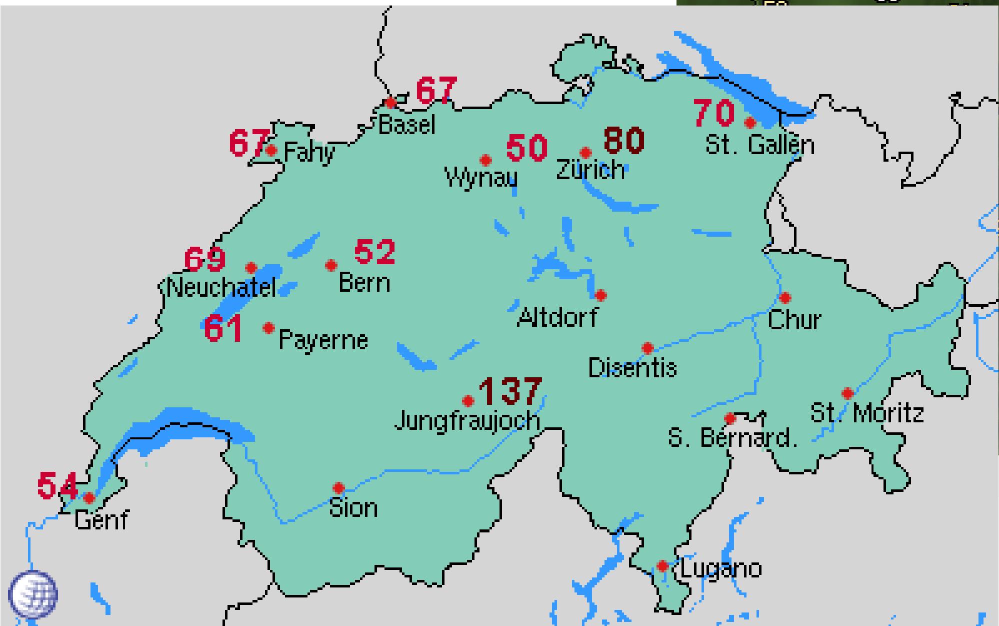
Wetterübersicht mit Karten + Daten ab Telefax Polling / Bulletin météorologique (cartes et données) par téléfax polling (Fr. 1.50 / Min.) 0900 162 244
Abonnement: MeteoSchweiz, F. Schacher, Postfach 514, 8044 Zürich

Observed wind gusts in km/h

for Elon =>

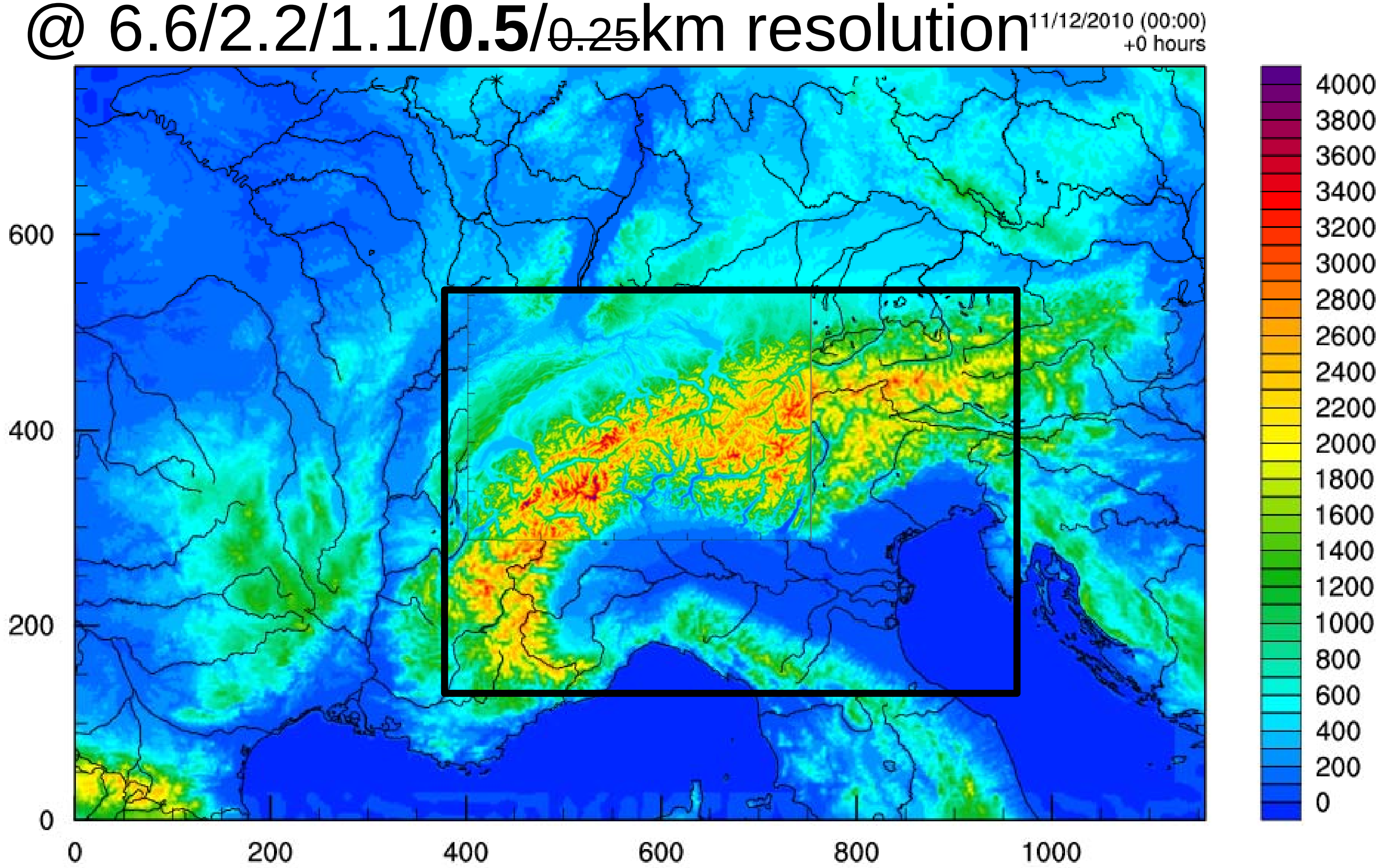


for Carmen 12.11.2010

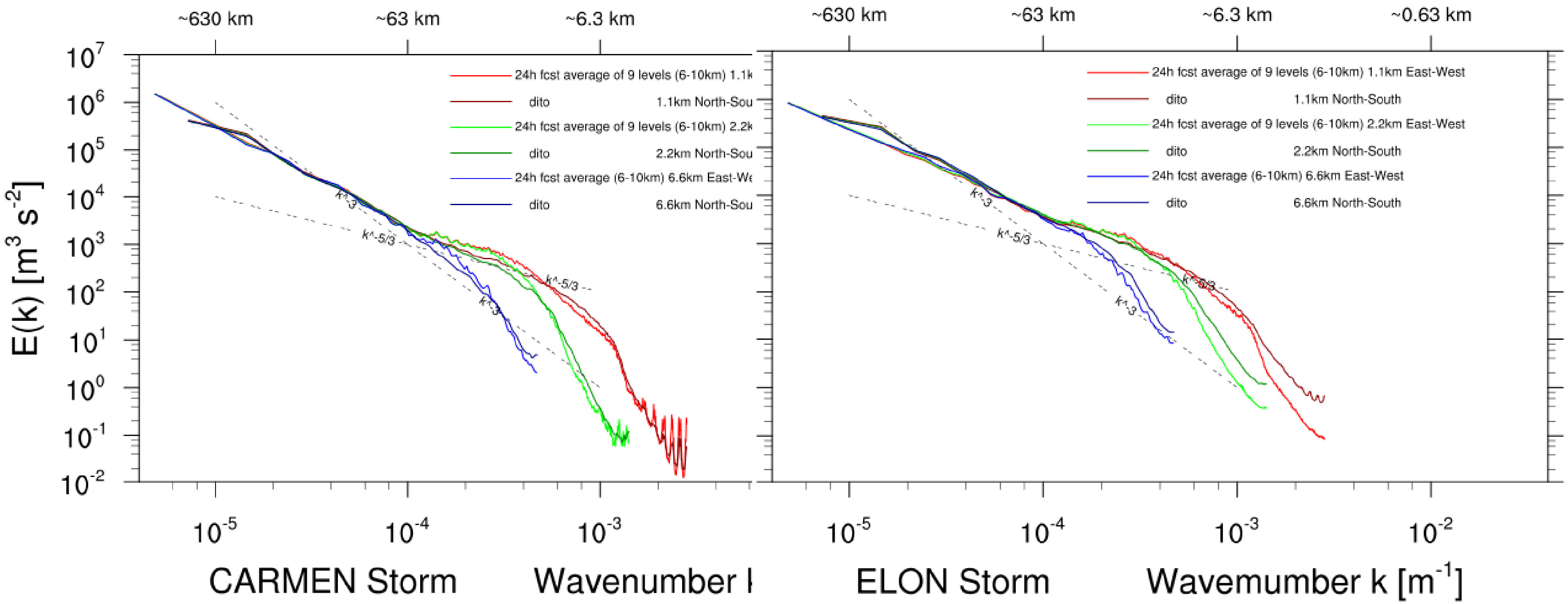


… similar !

COSMO-1 domain (topography)
@ 6.6/2.2/1.1/**0.5**/~~0.25~~km resolution



Power spectra of kinetic energy



ICON

- icon-training-2018 code release v2.3.00
- extract IFS data with preprocessing script mars4icon_smi
- icon remapping with icontools (not possible for SST)
  - no tests !
  - in contact since June with Daniel Reinert and Florian Prill
- aimed resolutions: 6.5, 2.2,1.1, 0.5 and 0.25km

Summary & Outlook

- With no horizontal diffusion **COSMO is OK @ 6.6 and 2.2km**
- @ **1.1km** the model CFL $\in$ [0.6,0.9] and the kinetic energy spectra shows some **noise** in the CARMEN case.
  → artificial horizontal diffusion is necessary
- @ **0.5km** COSMO is **unstable**; probably needs a spin-up to get a balanced initial conditions. Same for 0.25km resolution.

- Need some help to setup ICON with the same LBC's as COSMO
- Or use ICON-EU to start COSMO (OK) and ICON
- Hope that the DWD-ICON-LAM course in Oct. can help (C2I PP)

Towards operationalization of ICON-D2

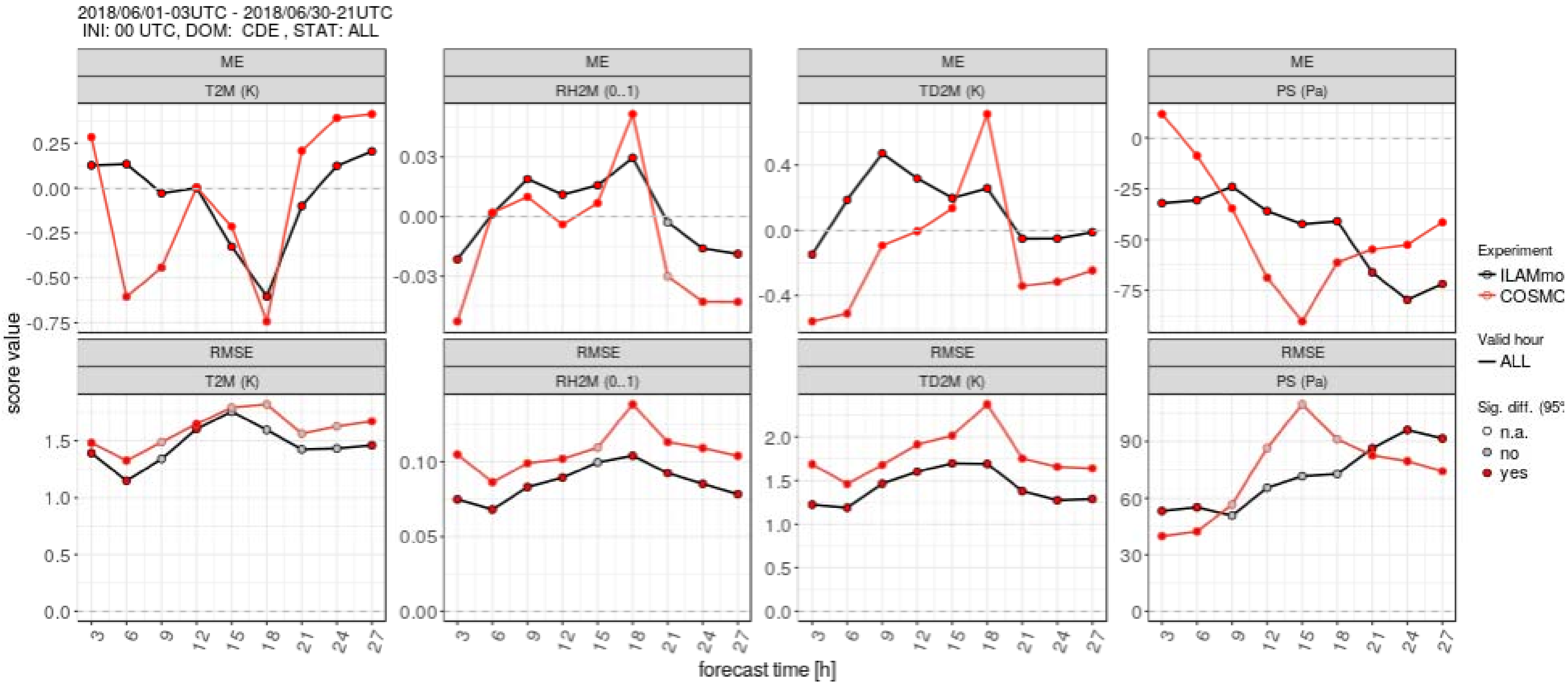
G. Zängl (DWD)

- Since June 2018, **ICON-D2** is run on a regularly basis at DWD, initialized by ICON-EU-Analyses
(only 0 UTC and 12 UTC runs, no EPS yet)
- Comparison between operational COSMO-D2 (KENDA-DA!) and these ICON-D2 runs.

Results:

- For the most variables ICON-D2 shows better scores than COSMO-D2
- exception: precipitation scores during the first ~ 6 h forecast, since ICON-D2 is started from interpolated analyses.

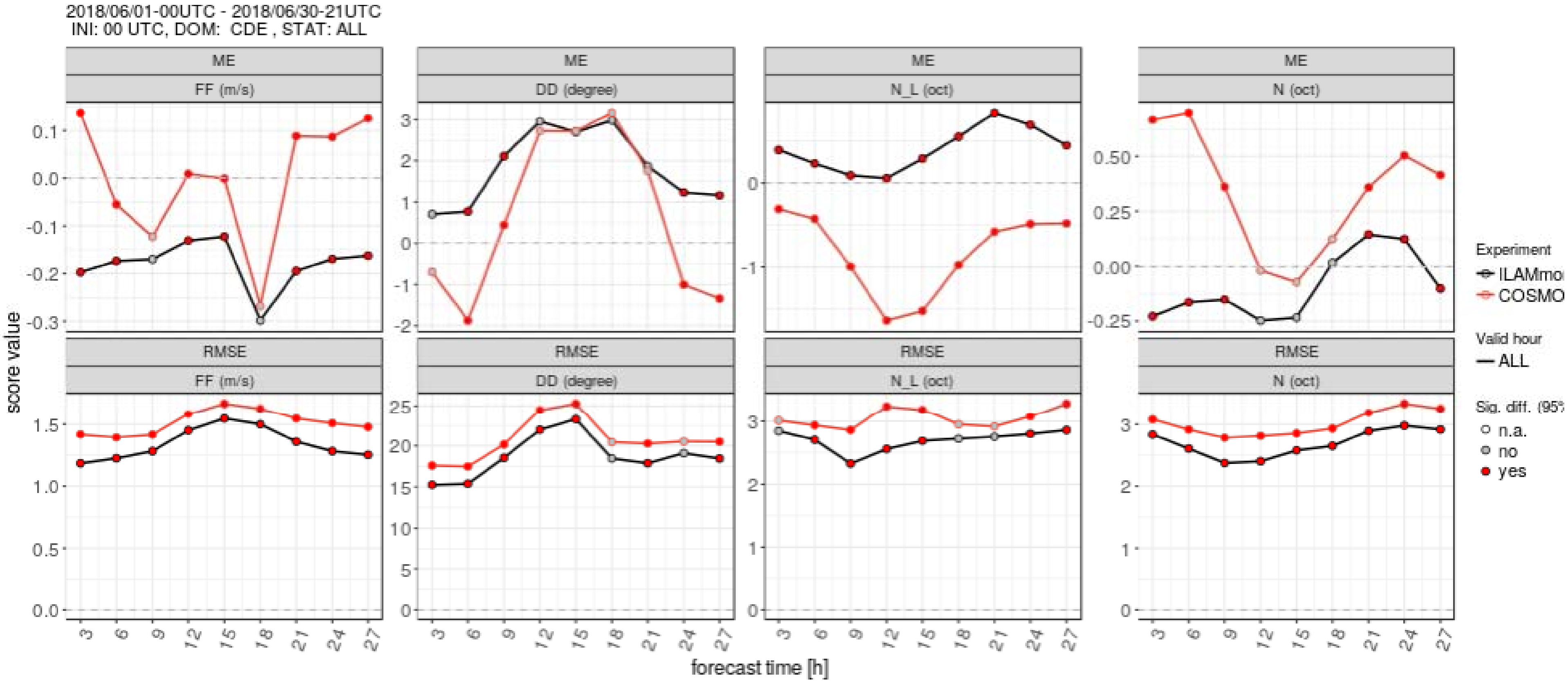
ICON-D2, init. by ICON-EU ←→ **COSMO-D2**, init. by KENDA *G. Zängl (DWD)*
June 2018, 00-UTC forecasts



2m temperature 2m humidity 2m dewpoint surface pressure

ICON-D2, init. by ICON-EU ←→ **COSMO-D2**, init. by KENDA June 2018, 00-UTC forecasts

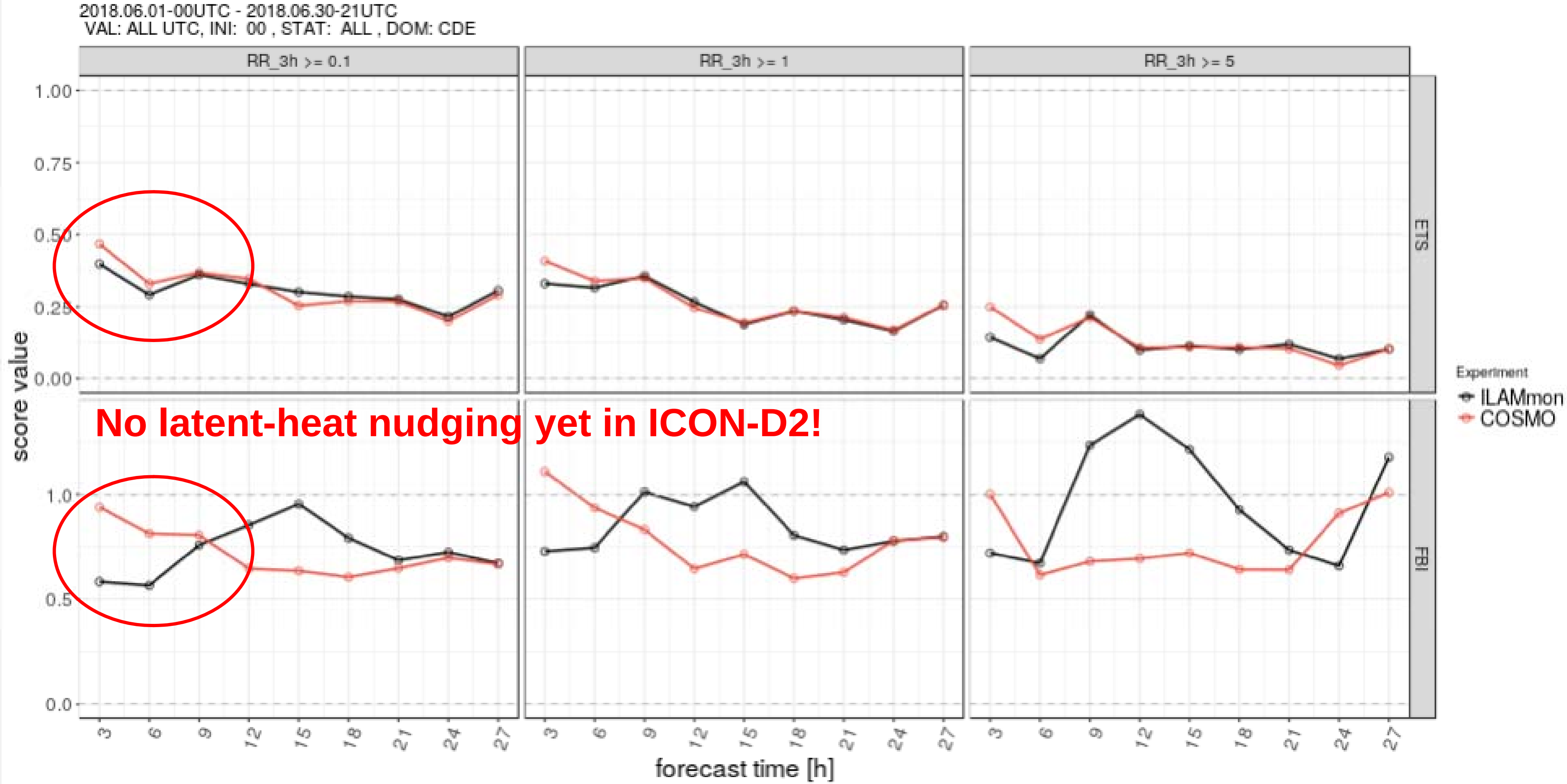
G. Zängl (DWD)



10m wind speed 10m wind dir. low cloud cover total cloud cover

ICON-D2, init. by ICON-EU ←→ **COSMO-D2**, init. by KENDA
June 2018, 00-UTC forecasts

G. Zängl (DWD)



RR > 0.1 mm/3h | RR > 1 mm/3h | RR > 5 mm/3h

Task 5: suitability for other applications

- Several projects with ICON-ART are running:
  - mineral dust for renewable energy forecast
  - volcanic ash forecast
- List of shortcomings for climate runs:

Issues	Status
Read in LBC Data from frame grid for ICON-LAM does not work yet with NCDF files.	Daniel Reinert and Guenther Zängl were already informed.
After restarting, ICON still read the LBC data from the first month	Already solved in new version
ICON creates itself a symbolic link to the restart file	This does not hurt. But just does not look nice and not necessary for us because we have different directories to store data and run the model. One can create the link by a run script and link to wherever…
Need to decide a standard input data that iconremap can treat. All GCM data should be transformed to this format	Task for CLM community
Soil must be deep enough (>12m) that the temperature at the bottom is constant throughout the year (should be the case in Terra)	Will be checked in our long simulation
Less frequently updated SST	
Top of the model is now open or will be prescribed by climatology	Must check prescribing by climatology is good enough, else need to implement something else.

Summary

- **task1:**
  - most of the idealized tests have been performed.
    ICON is in most cases as good as or even a bit better than COSMO
    (exception: Straka et al. test for coarser resolutions (??))
  - Test cases 2, 3, 4.x, 5, 7 are currently transferred to
    the `icon_nwp_dev` branch.
  - Additional advection tests (case 8) are available since COSMO 5.5a.
- **task 2:**
  despite the PP prolongation, only little work has been done.
  Taking into account the rapid progress in ICON-LAM operationalization
  at DWD/ installation in PP C2I, further effort does not seem appropriate.
- **task 3:**
  weak scalability of ICON is limited by BCs in comparison with global ICON.
  Nevertheless, still better than in COSMO.
- **task 4:**
  stability analysis has been done.
- **task 5:**
  list of todo‘s for climate runs is available.

Some admin. statistics:

FTEs used:	
2015-2016:	0.695 FTE
2016-2017:	0.87 FTE
2017-2018:	0.45 FTE (one year prolongation)

NMA:	0.75 FTE
MeteoCH:	0.22 FTE
IMGW:	0.3 FTE
DWD:	0.745 FTE
total:	**2.015 FTE**

Many thanks especially to

Damian Wojcik (IMGW)

Guy de Morsier (MeteoCH)

Rodica Dumitrache (NMA)

Amalia Iriza (NMA)

Floran Prill (DWD)

Günther Zängl (DWD)

Daniel Reinert (DWD)

Uli Schättler (DWD)

Christian Steger (DWD)