ICON

NWP model tuning for the convective greyzone: operational experience at DWD and possible pathways towards the convection-resolving scale

ECMWF greyzone workshop, 13.11.2017

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Overview

- Introduction: the ICON modelling system and its configuration for operational NWP at DWD
- Tuning of the Tiedtke-Bechtold convection scheme for the greyzone
- Preparatory tests for convection-permitting applications
- Summary

Grid structure and operational configuration

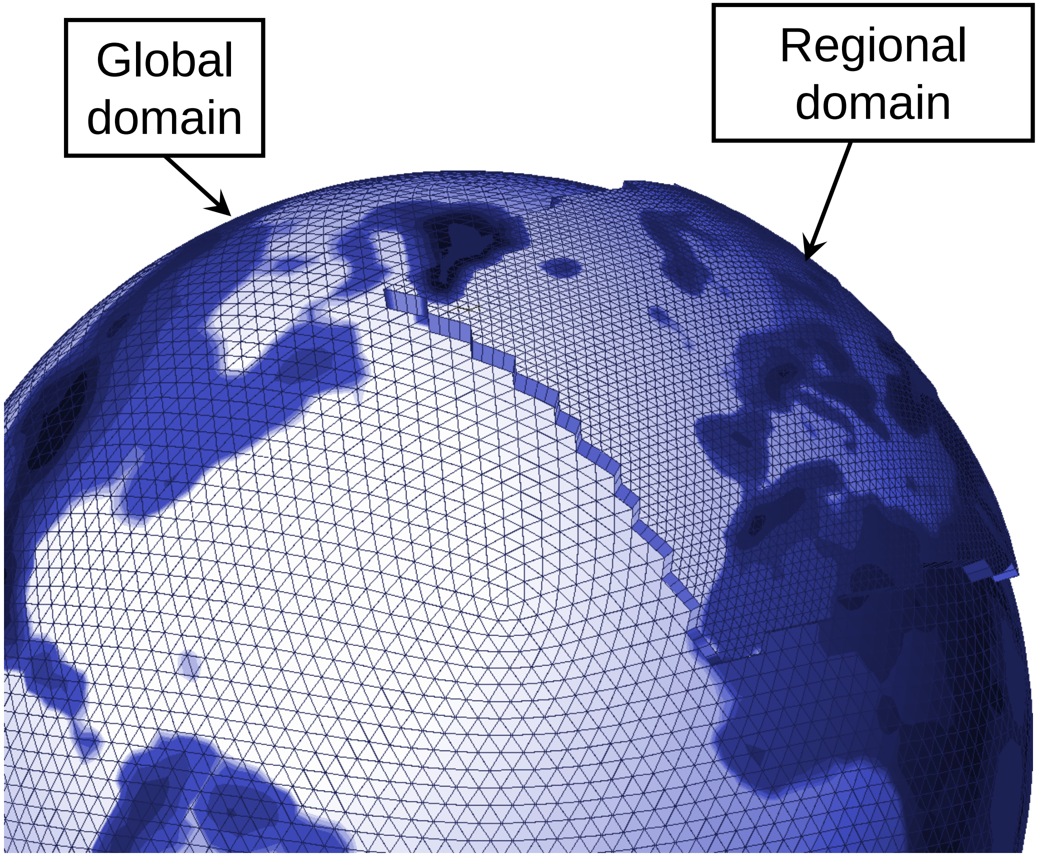
Icosahedral-triangular grid with two-way nesting capability

Grid generation starts with ‚root division' of the basic icosahedron by a choosable factor, followed by an arbitrary number of bisections

Operational configuration:
R3B7: root division n = 3, number of bisections k = 7

Mesh size: 13 km; 2.95 Mio grid points in global domain, 90 levels up to 75 km

The nested domain over Europe has a mesh size of 6.5 km (R3B8) and 60 levels up to 23 km



ICON: nonhydrostatic dynamical core

- **Fully compressible nonhydrostatic vector invariant form, shallow atmosphere approximation**

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

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

$$\partial_t \rho + \nabla \cdot (\vec{v}\rho) = 0$$ **Full air density**

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

$(v_n,\ w,\ \rho,\ \theta_v\ :\ \text{prognostic variables})$

Additional prognostic variables for q_v, q_c, q_i, q_r, q_s and TKE)

Solver:

- **Finite volume/finite difference discretization (mostly 2nd order)**
- **Two-time level predictor-corrector time integration**
- **Vertically implicit (vertical sound-wave propagation)**
- **Fully explicit time integration in the horizontal (at sound wave time step; not split explicit!)**
- **Mass conserving**

Zängl, G., D. Reinert, P. Ripodas, and M. Baldauf, 2015, QJRMS

NWP Physics in ICON

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Wetter und Klima aus einer Hand

Process	Scheme	Origin	Authors
Radiation	RRTM	ECHAM6/IFS	Mlawer et al. (1997) Barker et al. (2002)
	δ two-stream	GME/COSMO	Ritter and Geleyn (1992)
Non-orographic gravity wave drag	wave dissipation at critical level	IFS	Scinocca (2003) Orr, Bechtold et al. (2010)
Sub-grid scale orographic drag	blocking, GWD	IFS	Lott and Miller (1997)
Cloud cover	diagnostic PDF	ICON	Köhler et al. (new)
	sub-grid diagnostic	GME/COSMO	Doms et al. (2011)
Microphysics	prognostic: water vapor, cloud water,cloud ice, rain and snow	GME/COSMO	Doms et al. (2011) Seifert (2010)
	two-moment incl. graupel and hail	COSMO	Seifert and Beheng (2006)
Convection	mass-flux shallow and deep	IFS	Bechtold et al. (2008)
Turbulent transfer	prognostic TKE	COSMO	Raschendorfer (2001)
	prognostic TKE and scalar variances	COSMO	Machulskaya, Mironov (2013)
	EDMF-DUALM	IFS	Neggers, Köhler, Beljaars (2010)
Surface Processes	tiled TERRA + FLAKE + multi-layer snow + sea ice	GME/COSMO	Heise and Schrodin (2002), Helmert, Schulz et al. (2016), Mironov (2008) Machulskaya (2015)

Convection tuning for applications in the greyzone

Primary goals

- Gradual shift of partitioning from (parameterized) convective to gridscale precipitation when refining the model resolution
- Approach realistic spectrum of precipitation intensity when refining the model resolution (e.g. no drizzle bias)
- Two-way nesting approach adopted at DWD requires (as far as possible) resolution-independent ‘precipitation efficiency’

Resolution-dependent tuning parameters in ICON

- Convective adjustment time scale (reaches minimum near dx = 10 km and increases for coarser and finer resolution; also resolution-dependent in IFS)
- Scaling parameter for entrainment in organized convection (not restricted to greyzone)
- RH thresholds for evaporation below cloud base and convective area fraction (for dx < 20 km)
- Perturbation values for QV and T in test parcel ascent (for dx < 20 km)

Modifications adopted to reduce drizzle bias (not restricted to greyzone resolutions)

- QC and cloud depth thresholds for formation of convective precipitation depend on cloud-top temperature (warm clouds vs. mixed-phase clouds) and aerosol-derived droplet concentrations
- Enhanced entrainment in test parcel ascent, particularly over land
- Perturbation values for QV and T in test parcel ascent reduced w.r.t. default in IFS, and QV perturbation specified as a fraction of grid-scale QV rather than fixed value

In addition …

- **PBL CAPE correction for improved diurnal cycle of convection needed to be adapted**
- **Limits for convective mass flux were reduced, particularly for shallow convection, in order to suppress high-frequency surface pressure fluctuations and noisy appearance of convective precipitation**

Impact of anti-drizzle modifications

- Case study for June 27, 2017
- Synoptically forced severe convection over central Europe
- Results are shown for ICON-EU forecasts started at 00 UTC with / without the above-mentioned changes

6h-precipitation (mm), 27 June 2017, 06-12 UTC

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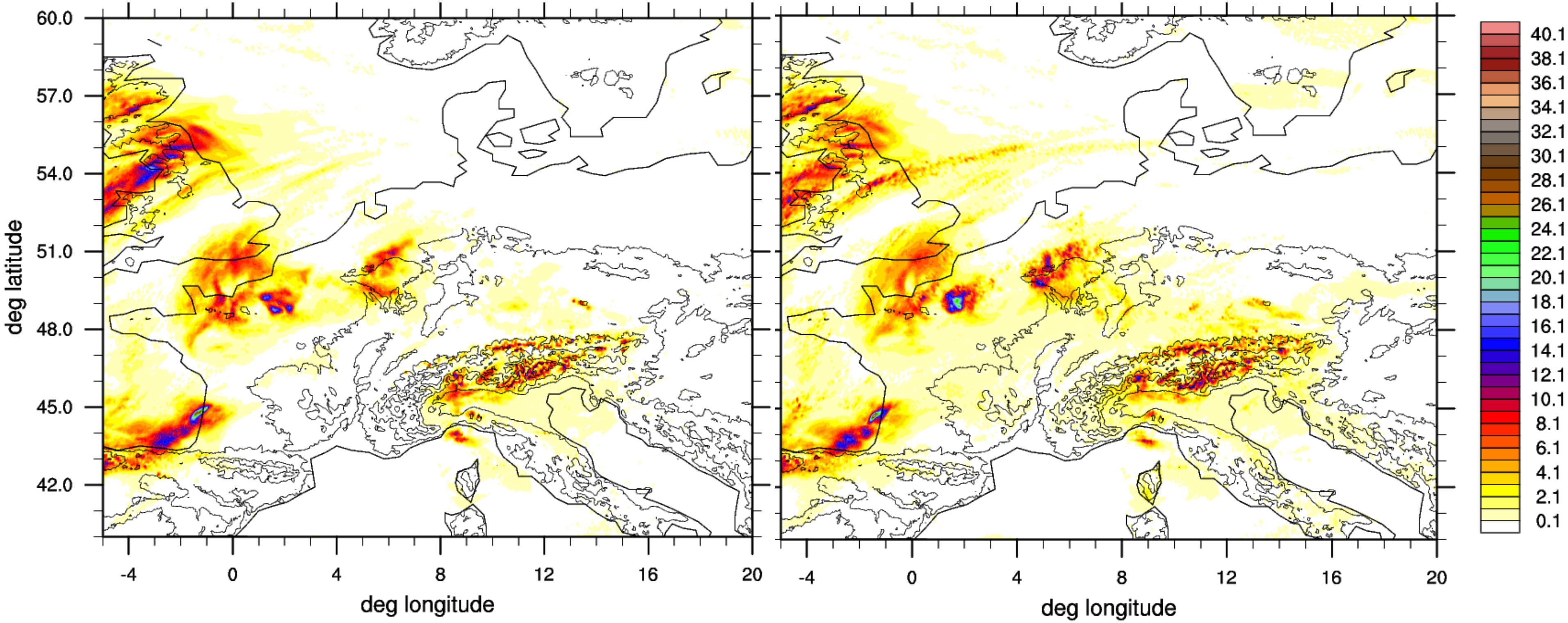
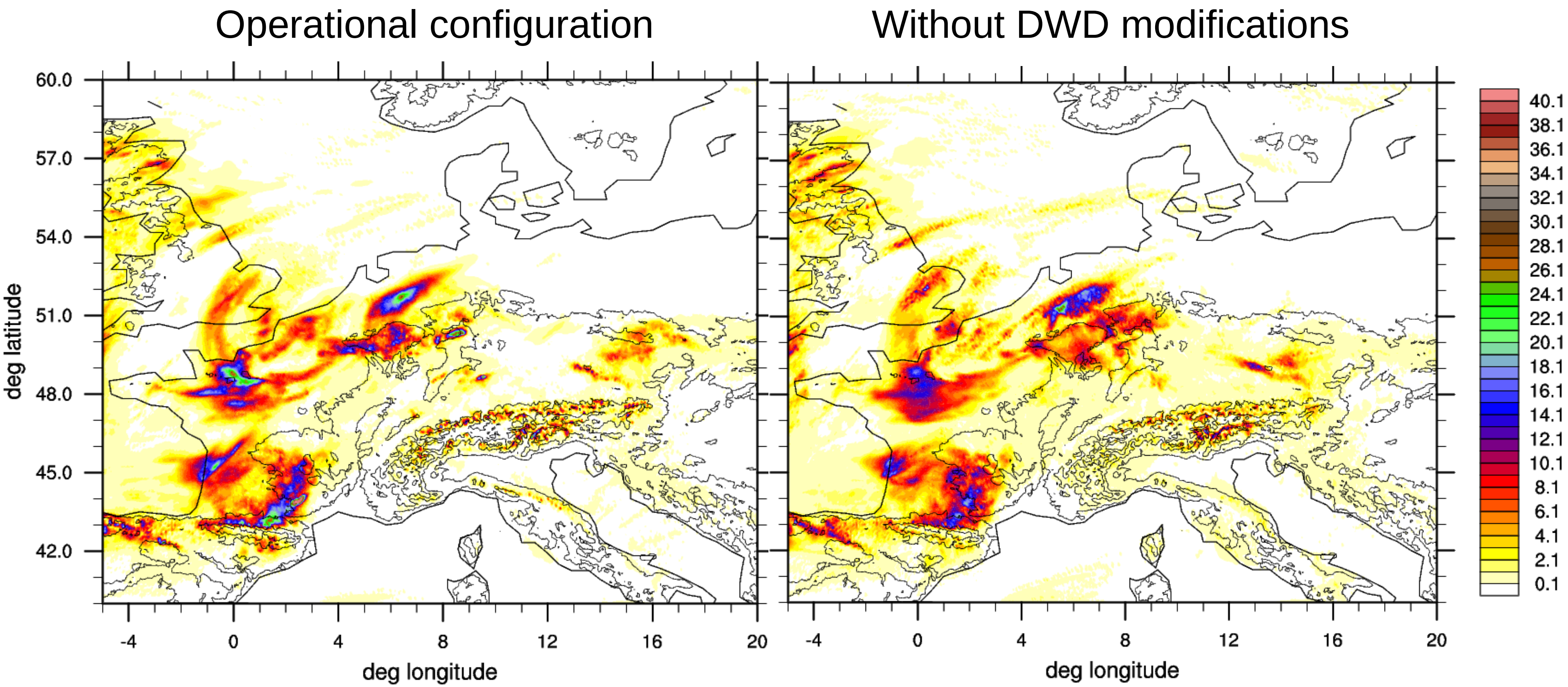
Operational configuration | Without DWD modifications

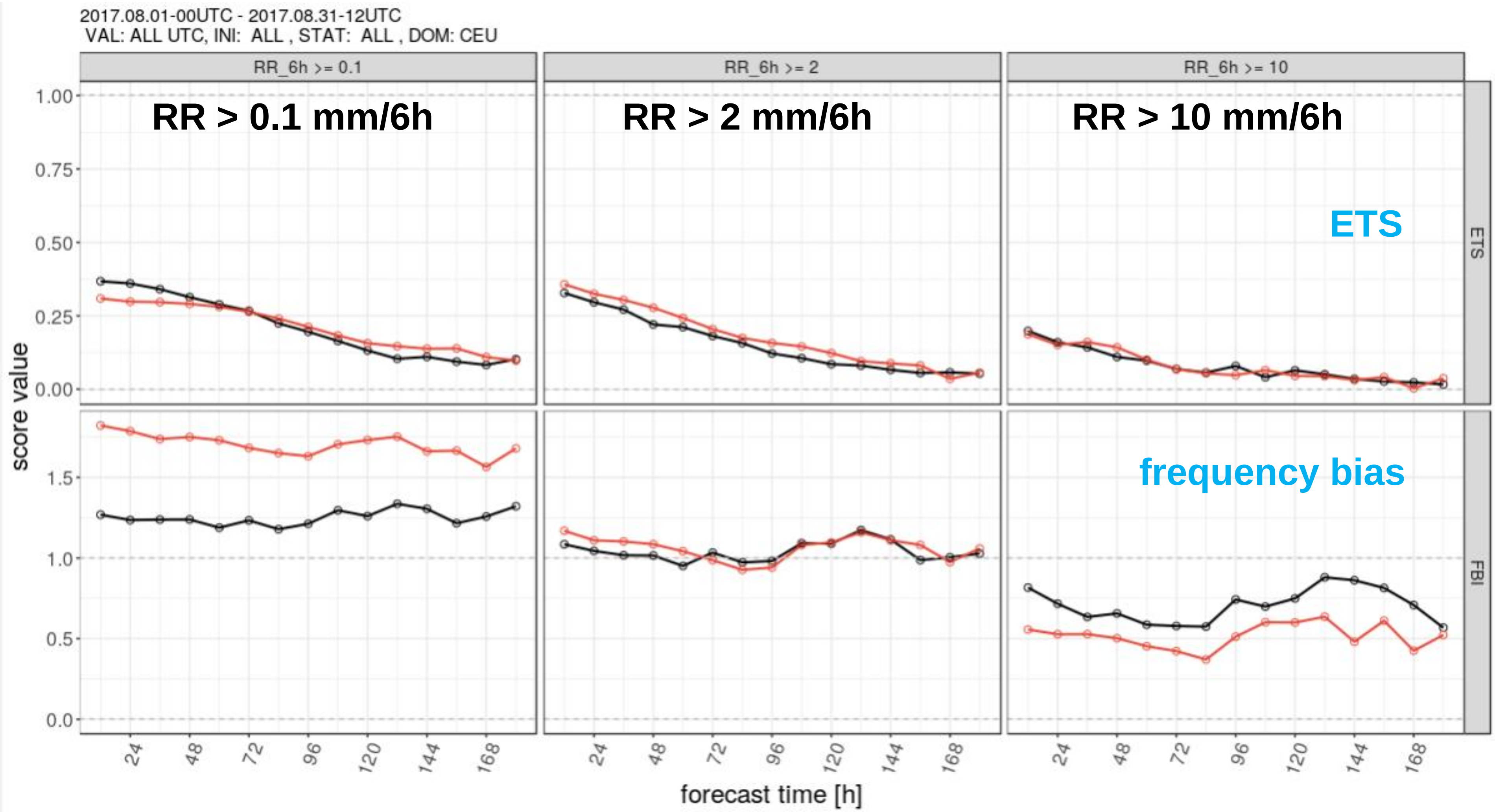


6h-precipitation (mm), 27 June 2017, 12-18 UTC



Precipitation verification against SYNOP stations, August 2017, Europe

red: IFS; black: ICON (global)



Precipitation verification against SYNOP stations, August 2017, Europe

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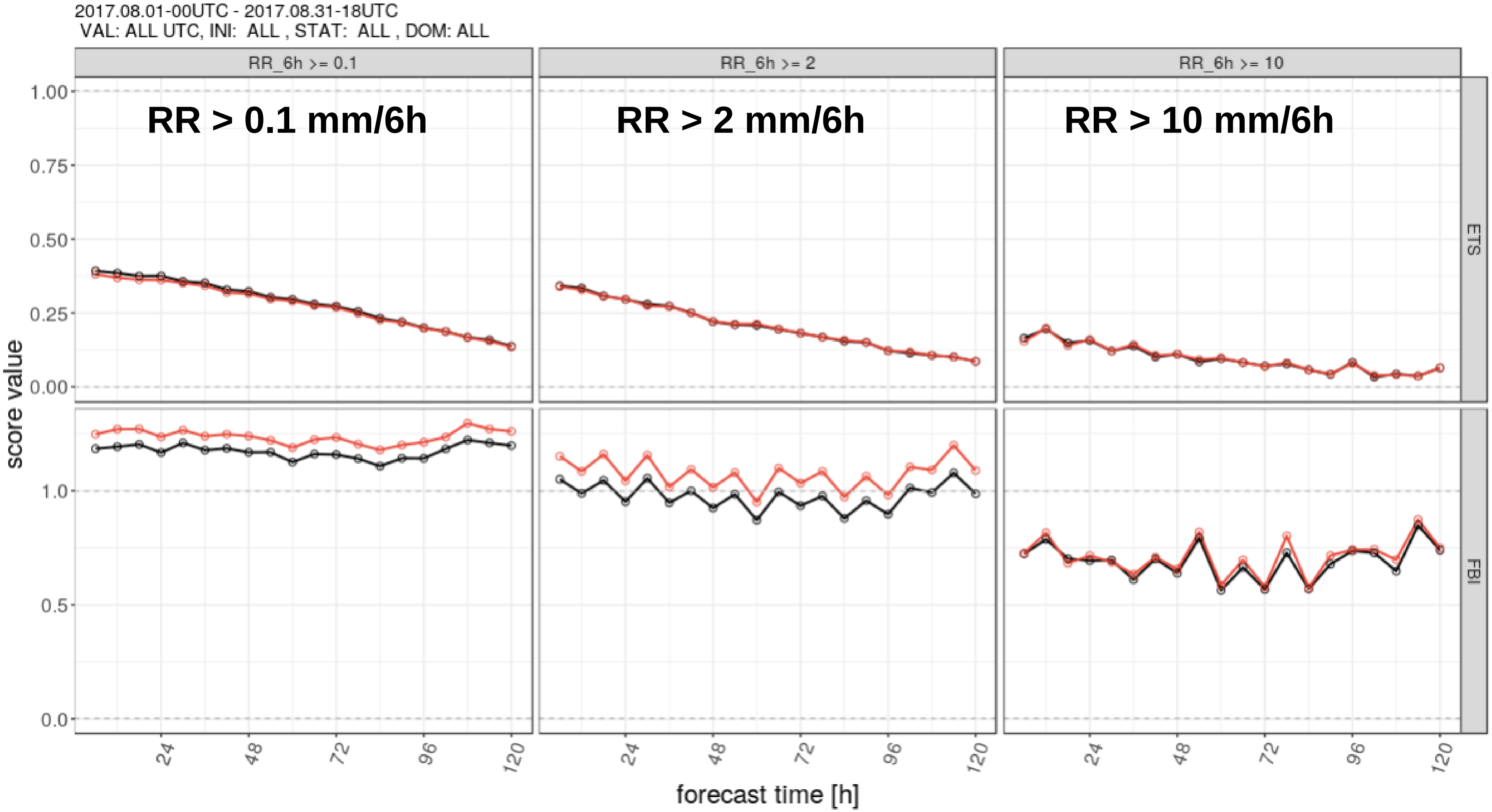
red: ICON (global); black: ICON-EU (6.5 km nest)



Another source of unrealistic drizzle: convection-microphysics coupling

- Case study for February 12, 2015
- Wintertime anticyclonic conditions over central Europe with widespread stratus clouds over low areas and sunny conditions in the mountains
- Observations showed small amounts of drizzle / snow grains at some spots
- Precipitation in the operational ICON forecast was too much and too widespread

24h-precipitation, 12 Feb. 15, 12 UTC

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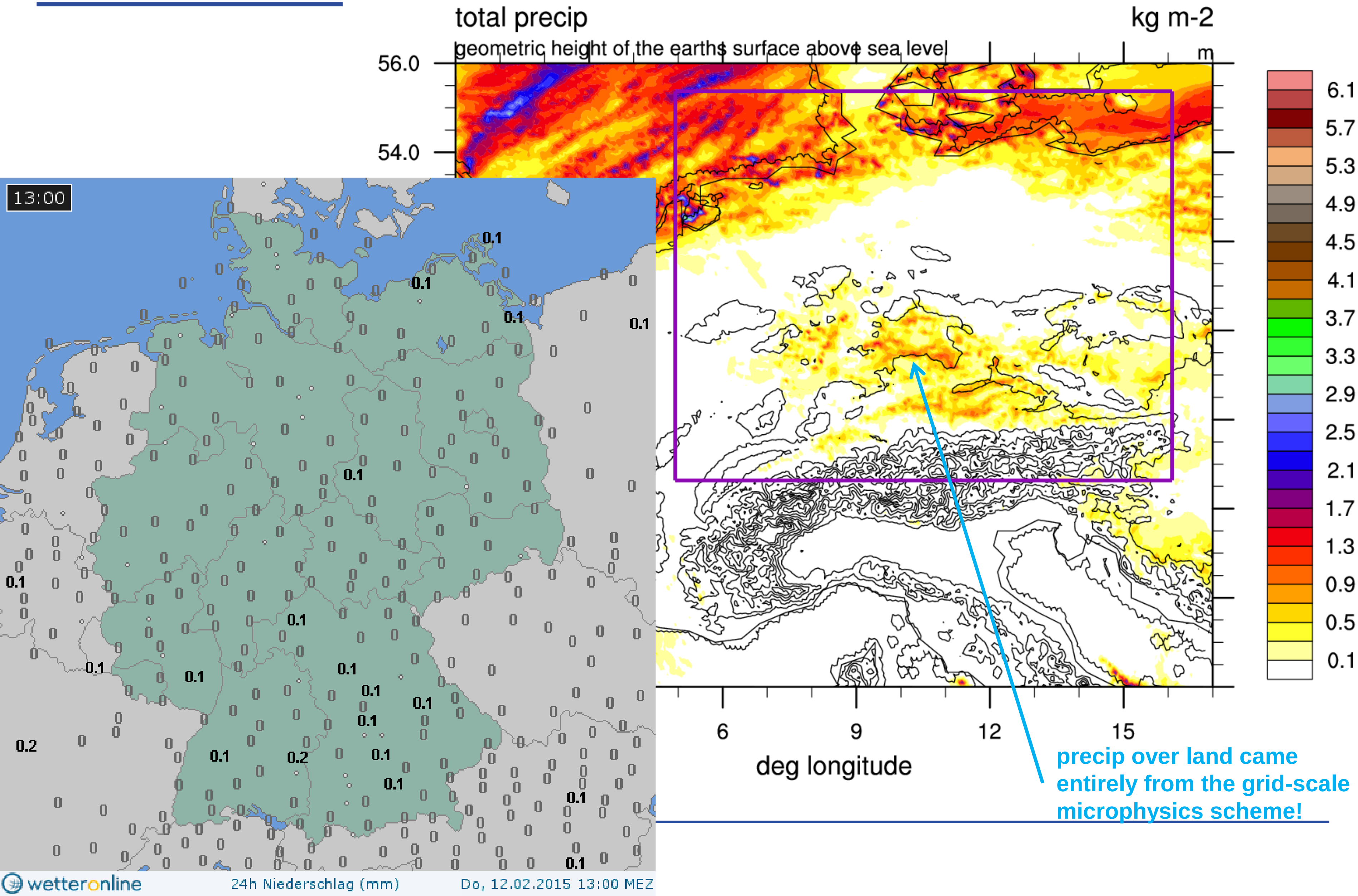
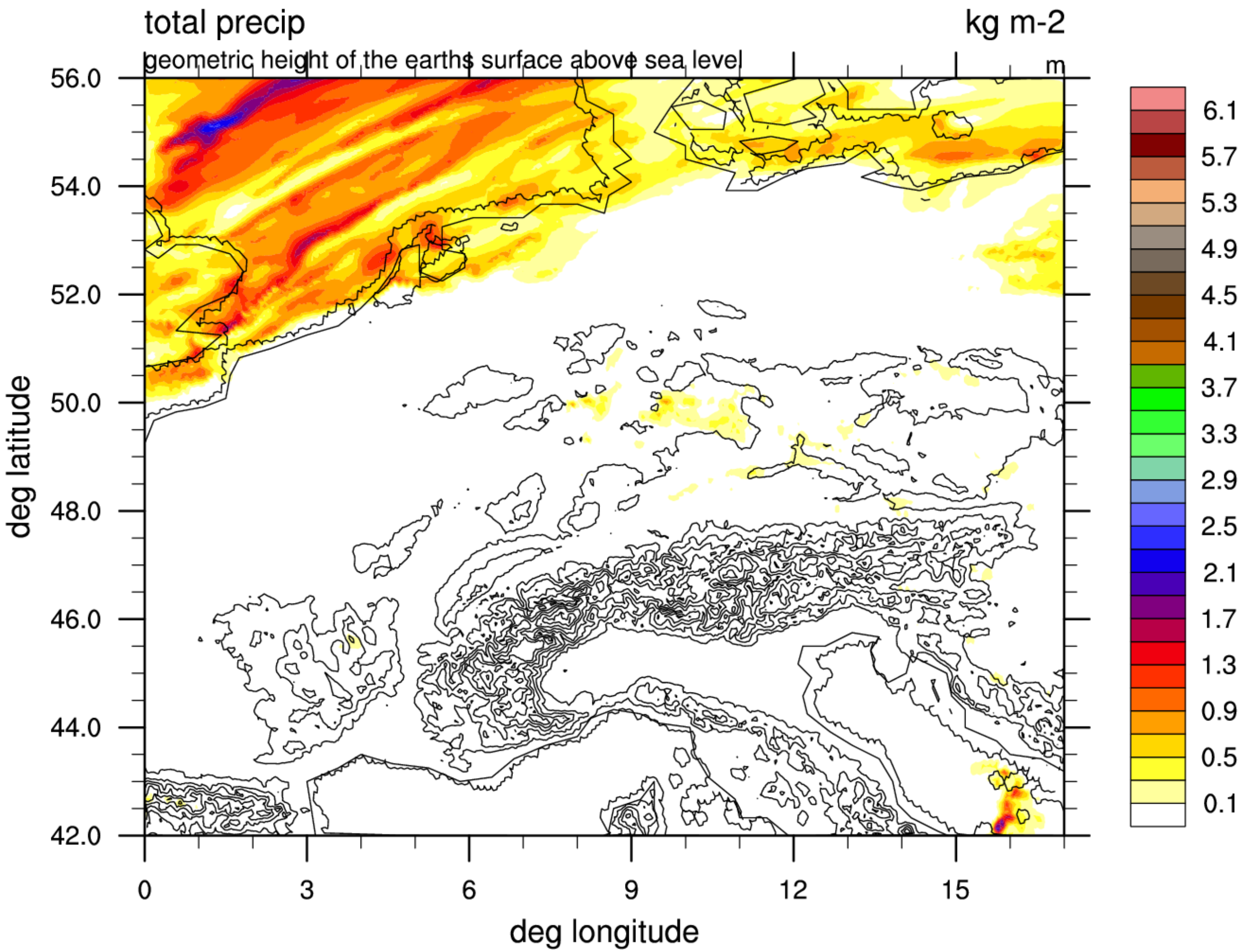


precip over land came entirely from the grid-scale microphysics scheme!

24h-precipitation, 12 Feb. 15, 12 UTC

no convection scheme in 6.5 km nest over Europe



What happens?

- The convection scheme gets triggered in the unstable upper part of the stratus cloud deck but does not generate precipitation because of insufficient convection depth
- Instead, it detrains condensate to the grid-scale scheme
- The water/ice-partitioning follows a universal function used throughout the convection scheme. At -3°C, already 25% of the condensate are diagnosed as cloud ice, which is completely unrealistic in this context
- The detrained cloud ice then triggers the Bergeron-Findeisen process in the microphysics scheme

- Workaround: change water/ice partitioning in the convective QC/QI tendencies depending on local temperature and (convective) cloud top temperature

24h-precipitation, 12 Feb. 15, 12 UTC

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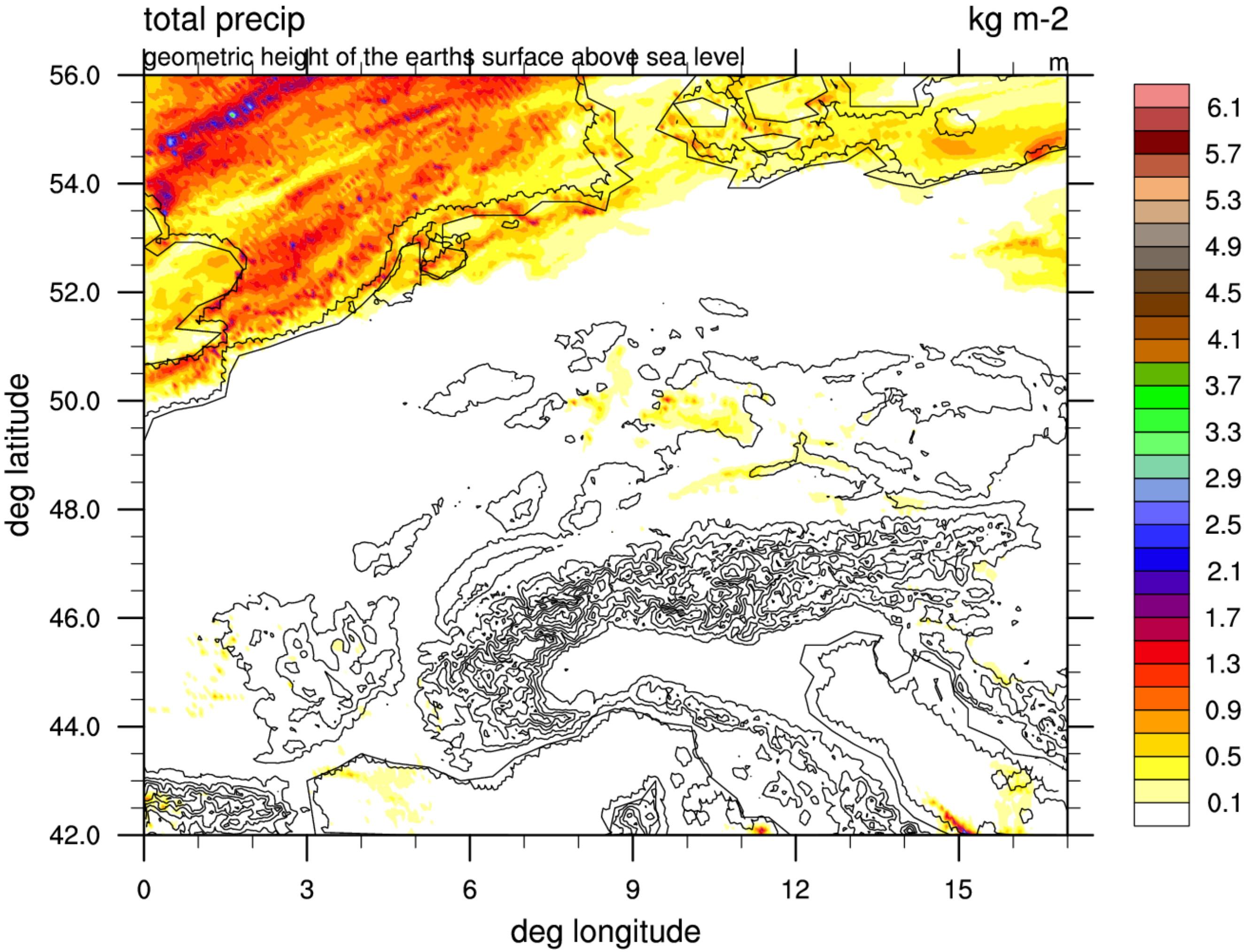
with modified water/ice partitioning in convection tendencies



Noise in surface pressure field

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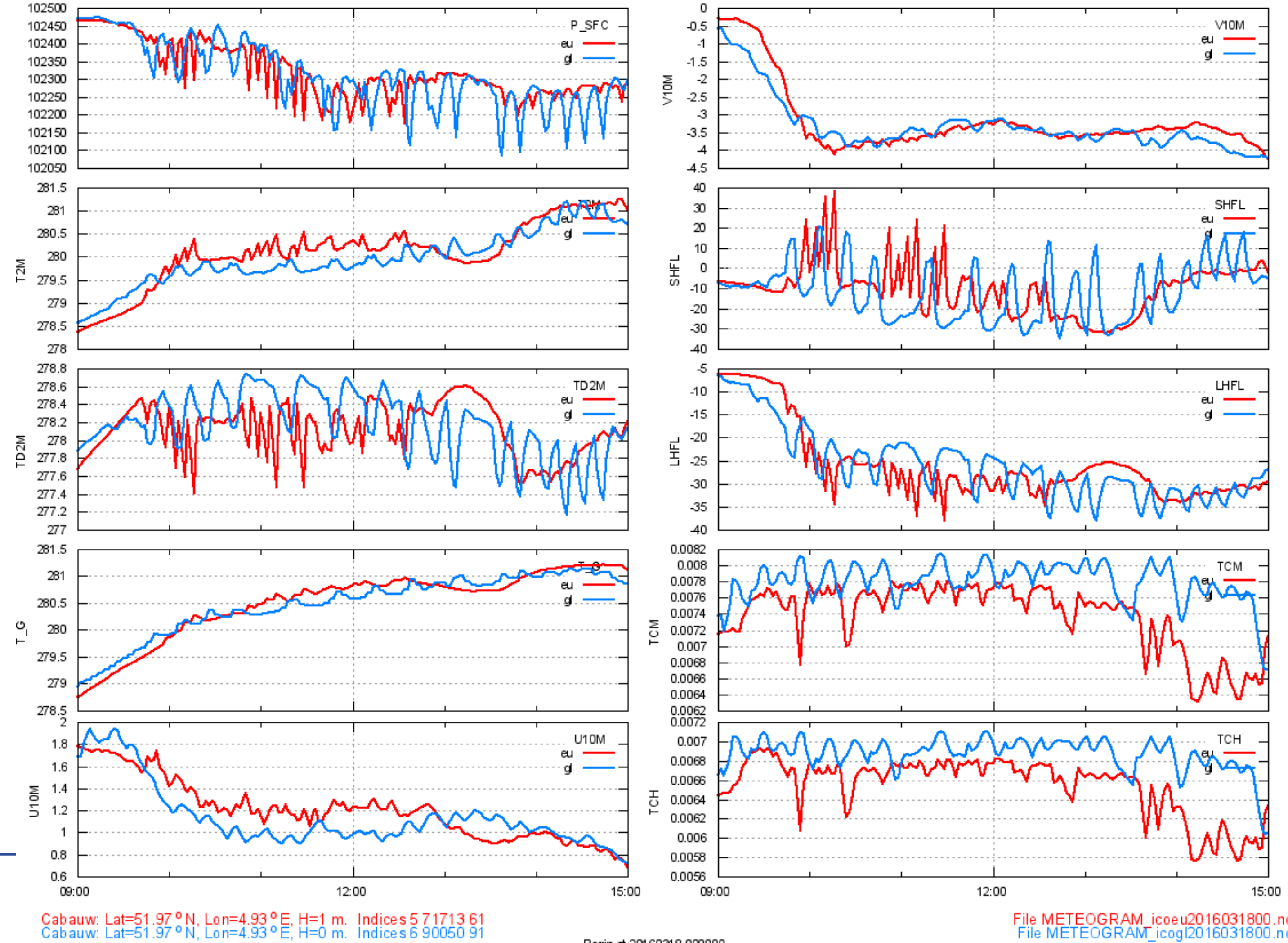
Meteogram output (every 2 min for ICON (global) and 1 min for ICON-EU) for Cabauw, 18.03.16, routine forecast

PMSL

T2M

TD2M



Result with more restrictive CFL stability limits for convective mass fluxes

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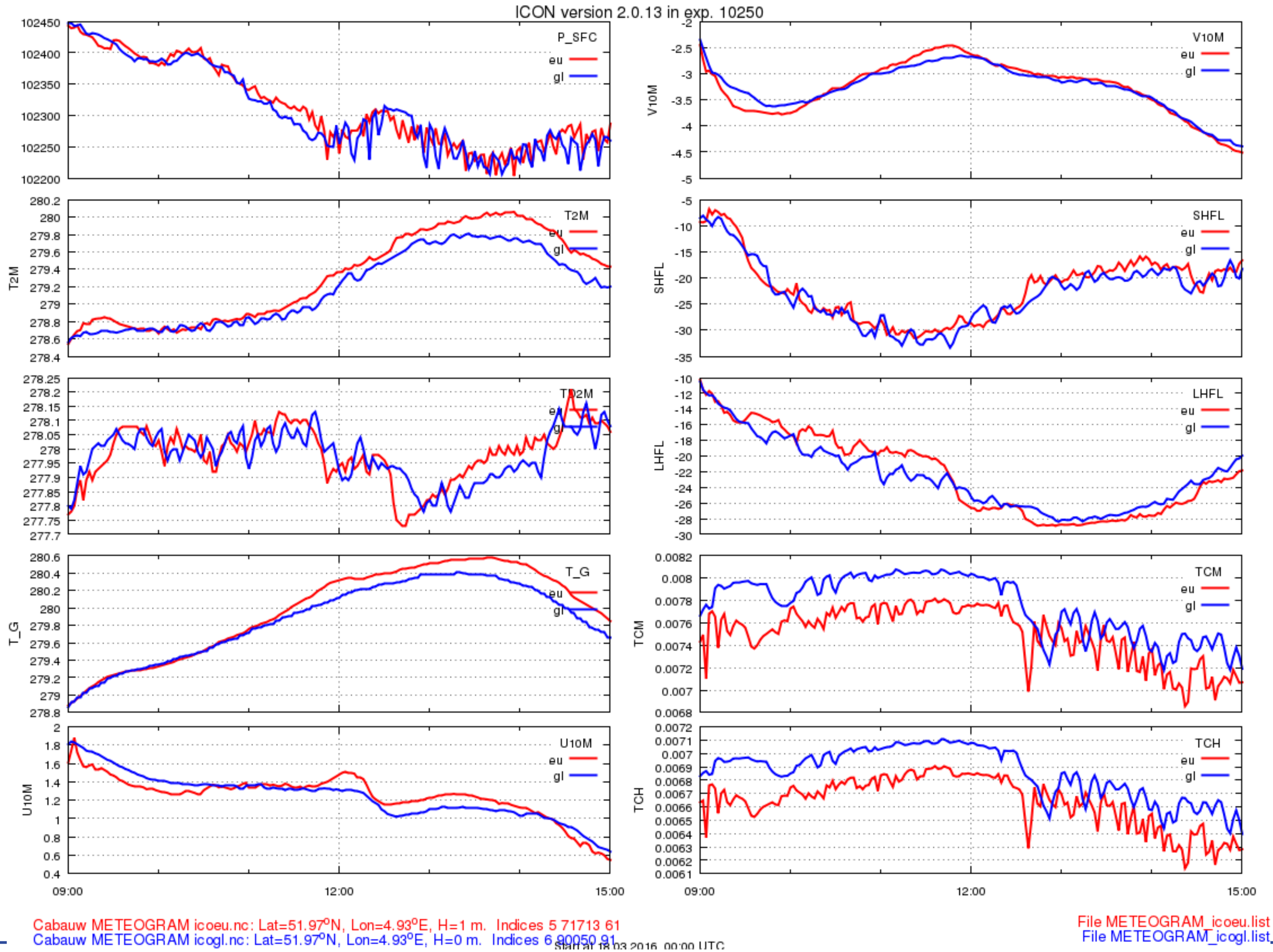
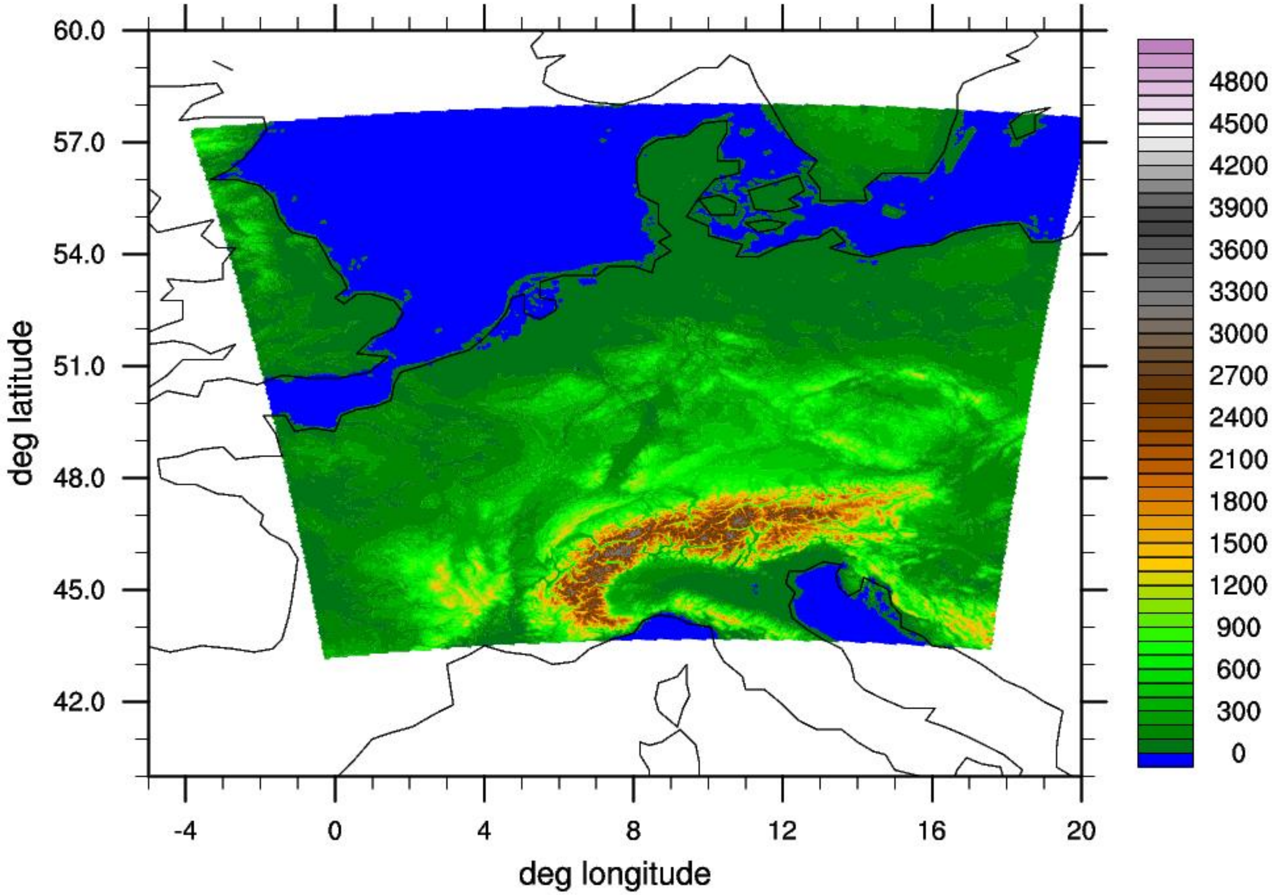


Experiment with limited-area configuration (dx = 2 km), driven with ICON-EU lateral boundary conditions
(27 June 2017, same case as before)



6h-precipitation (mm), 27 June 2017, 12-18 UTC

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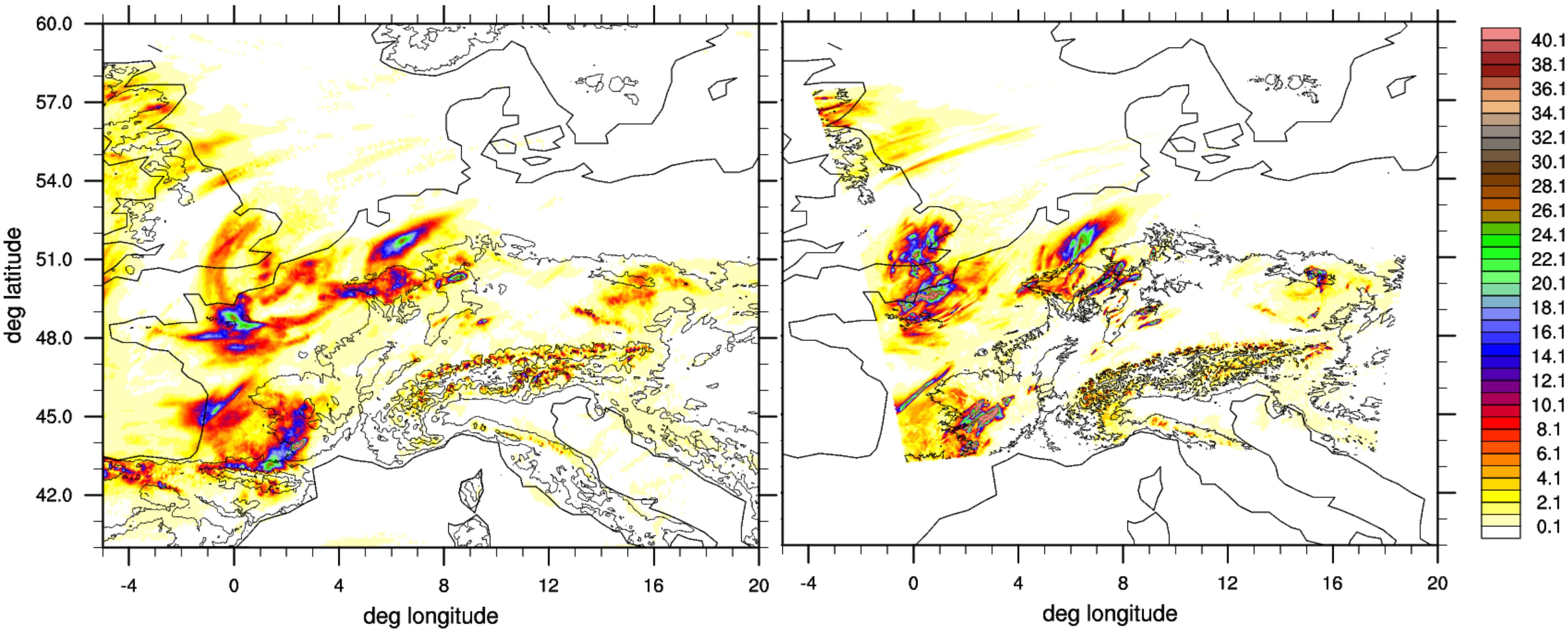
6.5 km (ICON-EU), full convection scheme | 2 km, full convection scheme



6h-precipitation (mm), 27 June 2017, 12-18 UTC

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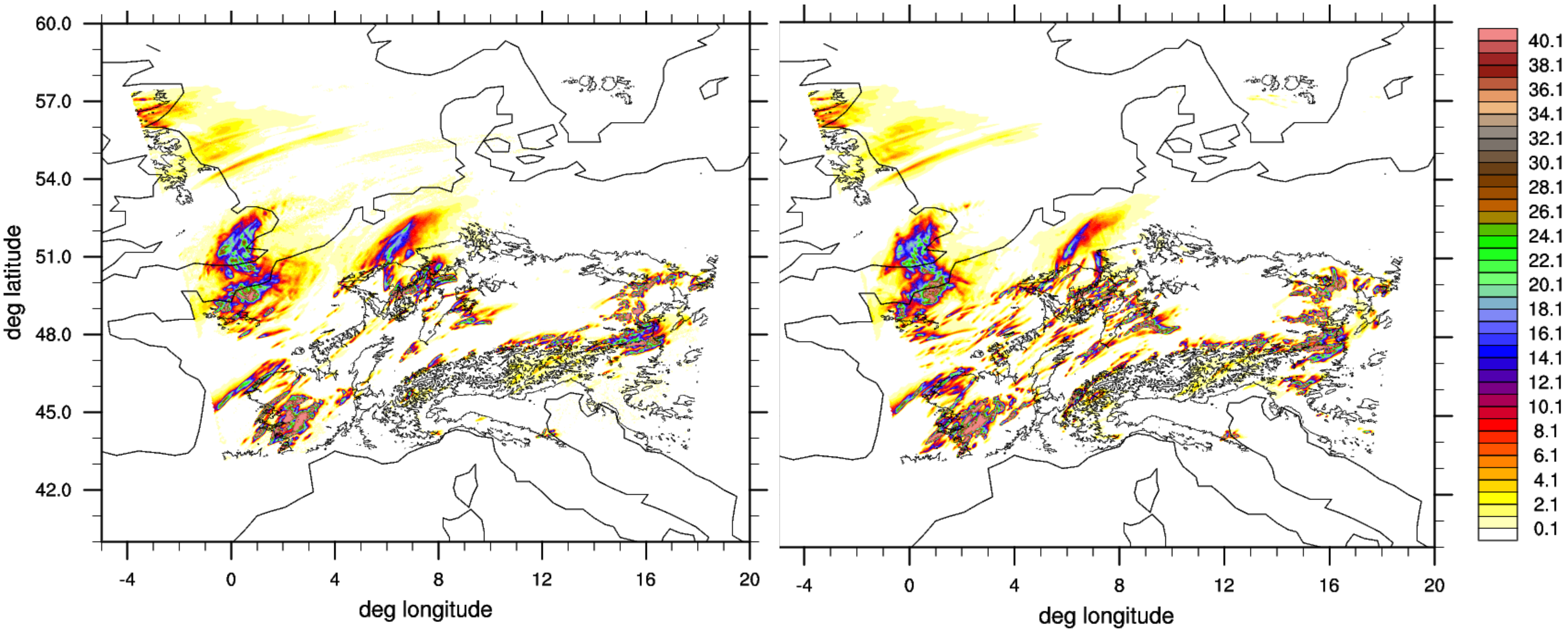
2 km, shallow convection only

2 km, no convection scheme



Hindcast experiment for June 2017

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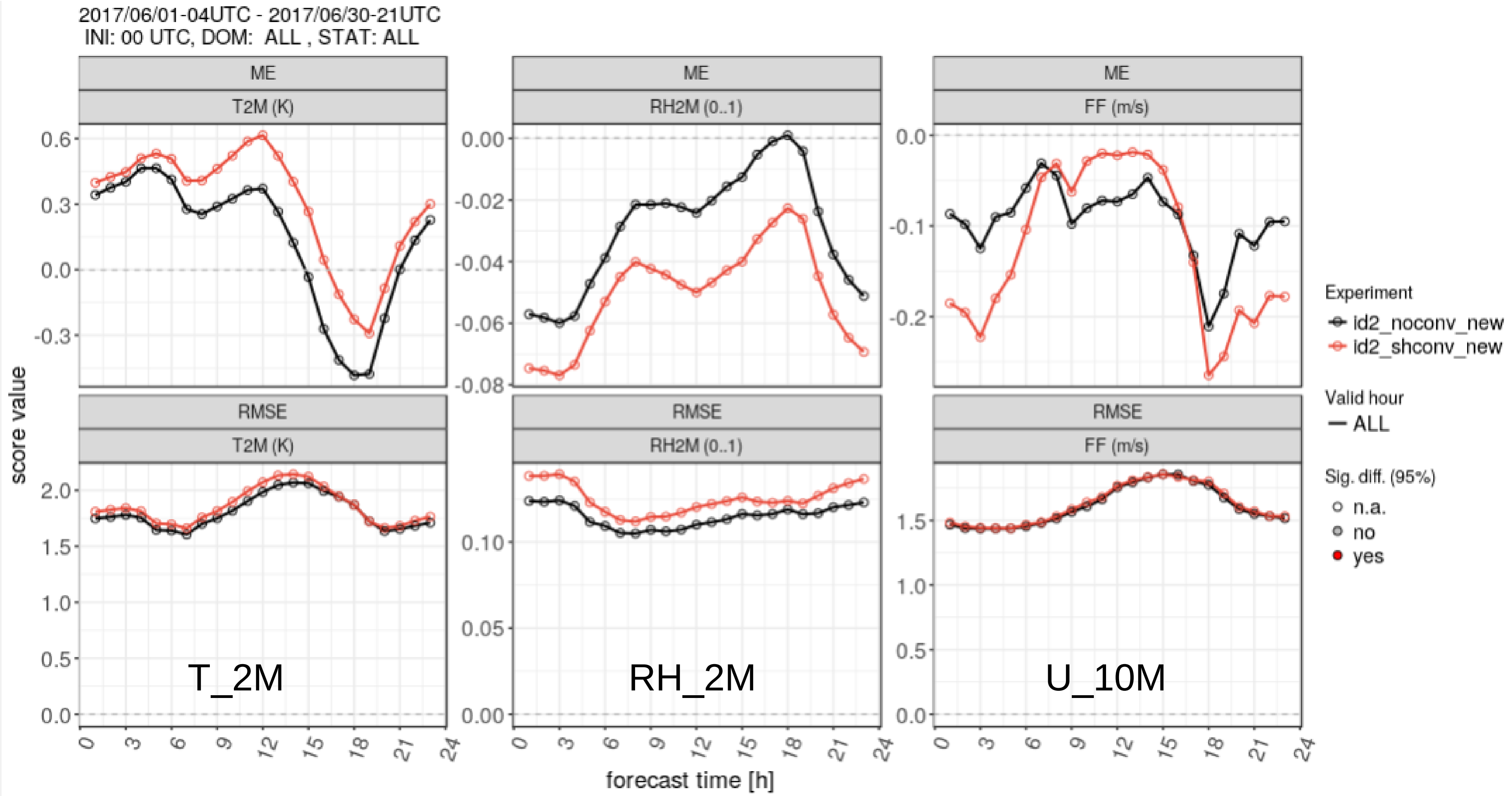
Continuous forecast driven with lateral boundary conditions from ICON-EU assimilation cycle

no convection scheme / shallow convection



Tests at convection-permitting scale: current status

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- Shallow-convection scheme appears to be needed to suppress excessive precipitation in weakly forced situations (airmass convection)
- However, boundary-layer mixing produced by shallow-convection scheme appears too strong (further tuning needed?)
- Way of treating sub-grid orography under investigation
- Benefit of 2-moment vs. 1-moment microphysics needs to be evaluated
- Two-way nesting across convective greyzone has already been discarded because precipitation characteristics with / without deep convection scheme are too different in some situations

Summary and outlook

- **Greyzone tuning of Tiedtke-Bechtold convection scheme was successful w.r.t flattening the frequency bias spectrum**
- **A gradual shift from convective to gridscale precipitation while maintaining the total ‘precipitation efficiency’ is difficult to achieve**
- **Considering the coupling between physics parameterizations is at least as important as tuning individual parameterizations**

- **Our next major step will be to use ICON at the convection-permitting/-resolving scale as well**
- **The model setup will likely be nested, but within the convection-permitting resolution range (2 km – 1 km)**