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COSMO-E update

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with contributions from Christina Klasa, Seraina Klaus, Mathias Aschwanden, and Marco Arpagaus
MeteoSwiss

COSMO General Meeting, 3.– 7. September 2018

Outline

- COSMO-E setup
- COSMO-E forecast quality vs. IFS-ENS
- Learnings and results from SPRED
- How to go on in APSU?
- ModInterim project: COSMO-E in 2020

COSMO-E operational setup

- 21 members (control and 20 perturbed runs)
- 2.2 km horizontal mesh-size, 60 vertical levels
- two forecasts per day (00 and 12 UTC) up to +120h
- initial condition (perturbations): KENDA assimilation cycle
  - KENDA ensemble mean for control
  - KENDA members 1-20 (out of 40)
- lateral boundary condition (perturbations): ECMWF IFS-ENS (18 & 06 UTC, i.e., 6h older LBCs)
  - ENS control for control
  - ENS members 1-20 (out of 50; member selection in e-suite)
- model uncertainty: SPPT
- COSMO version 5.0+/GPU, single precision

COSMO-E verification setup

- last seasons: SON 2017 to MAM 2018 (JJA not yet available) for all SYNOP stations over full domain
- precipitation; T2m, Td2m, FF10m
- Ensemble scores: RPSS; spread-skill, rank histogramm, outliers
- comparison against the driving model IFS-ENS

COSMO-E vs. ENS

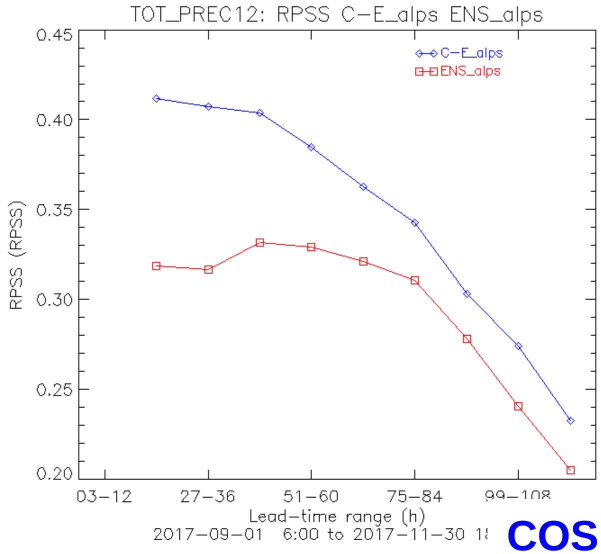
	COSMO-E	ECMWF IFS-ENS
grid-spacing	2.2 km (0.02°)	~20 km
domain	Alps	Global
forecast range	+120h	+360h
deep convection	explicit	Tiedtke-Bechtold convection scheme
subgrid-scale orographic drag	roughness length	SSO scheme & roughness length
initial conditions	KENDA (LETKF)	4D-Var + SVs & EDA
boundary conditions	ENS -6h	-
physics perturbations	SPPT	SPPT & SKEBS
availability (+120h)	3:45h after analysis time	7:20h after analysis time

COSMO-E forecast quality summary

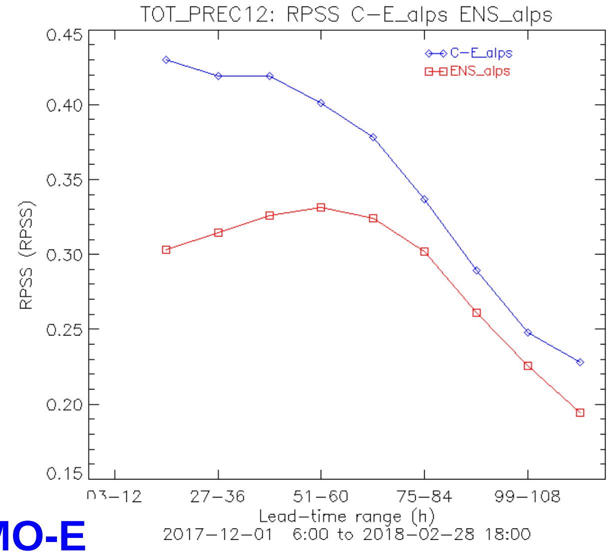
- COSMO-E **outperforms** ENS for the full Alpine domain for most variables and most seasons (despite 6h older LBCs)
- Particularly true for precipitation
- Benefit larger for earlier forecast range
- Both models are **underdispersive** in the PBL, most severely in the short-range (caveat: no obs error included)

12h precipitation; RPSS

SON



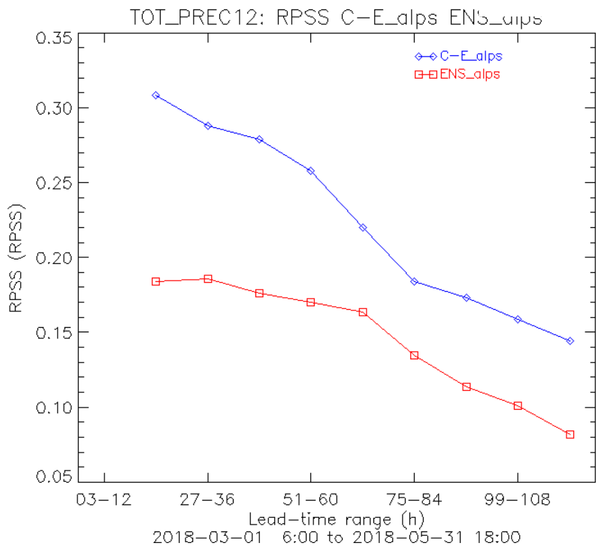
DJF



COSMO-E

ENS

MAM

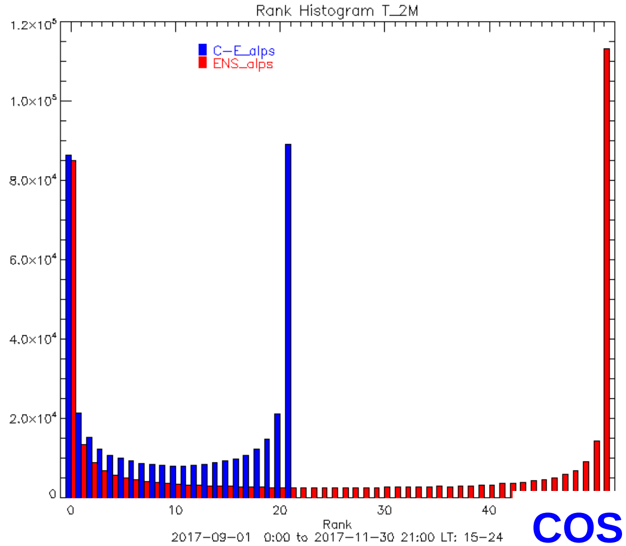


- skill until end of forecast range
- COSMO-E clearly outperforms ENS

Thresholds: 0.1, 0.2, 0.5, 1, 2, 5, 10, 20, 30, 50 mm/12h

T2m; rank histogram

SON



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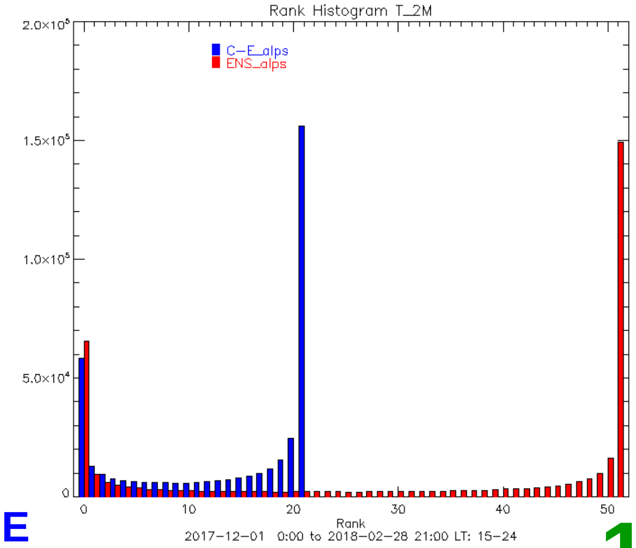
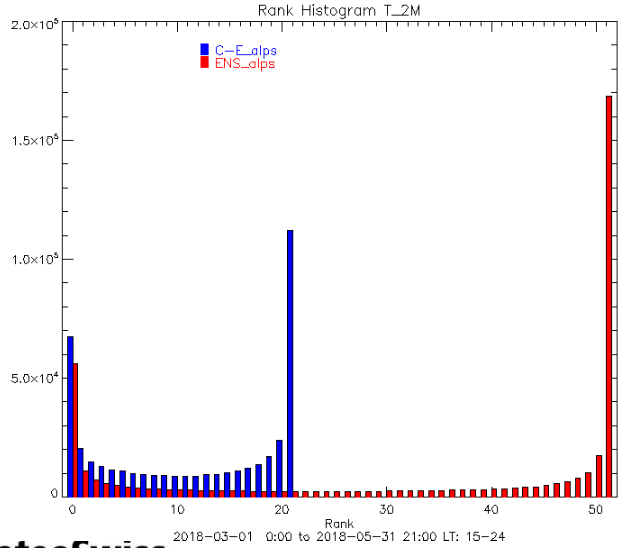


COSMO-E
ENS

15-24

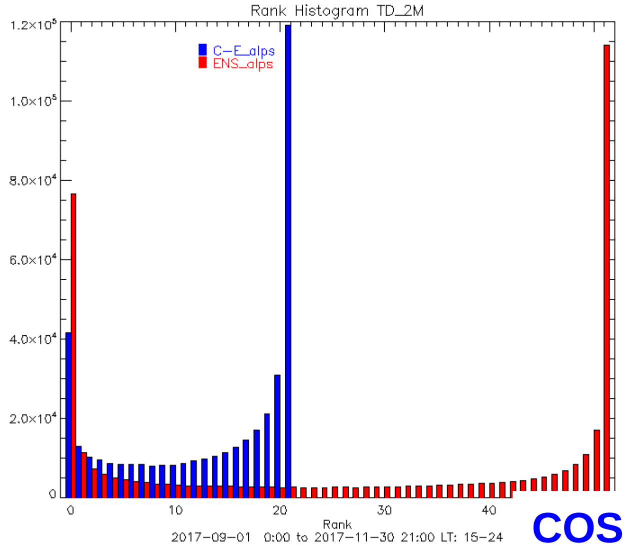
MAM



JJA

Td2m; rank histogram

SON



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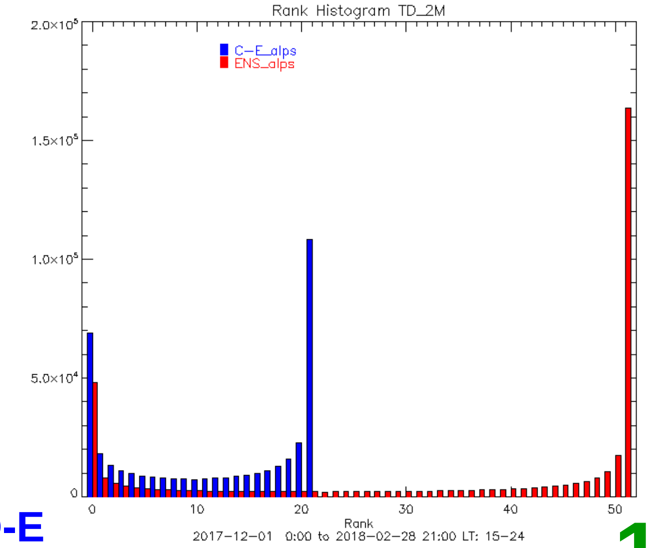
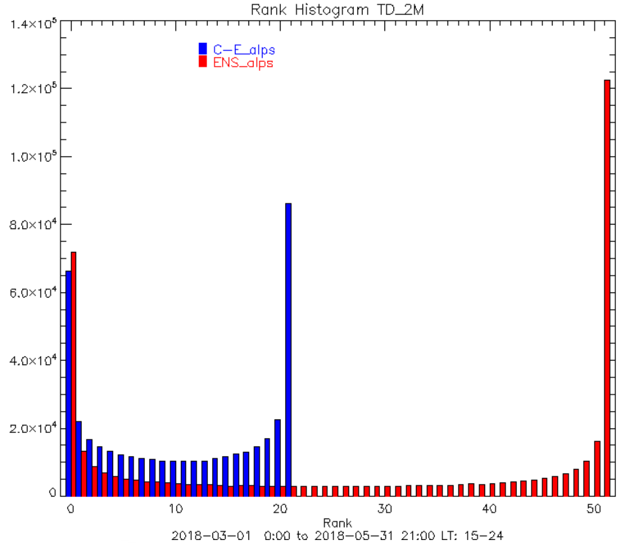


COSMO-E

ENS

15-24

MAM



JJA

MeteoSwiss

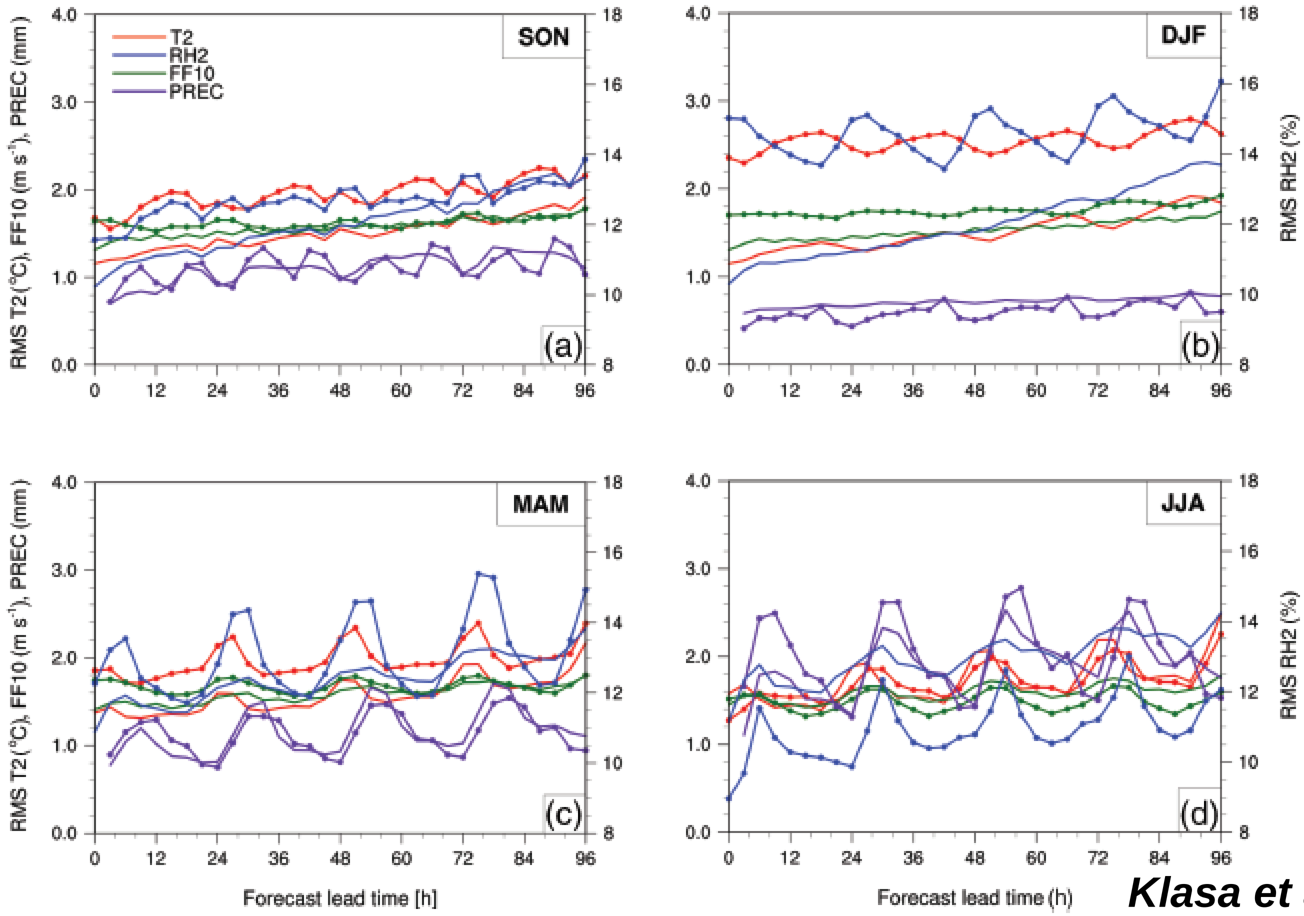
Learnings from SPRED

Spread vs error (task 1)

spread vs error
considering observation errors

Christina Klasa, Marco Arpagaus, André Walser, and Heini Wernli:
«An evaluation of the convection-permitting ensemble COSMO-E for three contrasting precipitation events in Switzerland», Quarterly Journal of the Royal Meteorological Society, 2018, 1-21. https://doi.org/10.1002/qj.3245

COSMO-E opr 2016/2017



Klasa et at. (2017)

- Lack of spread most of all in winter, in particular for T2m & RH2m
- Rather well dispersed in summer except for RH2m (overdispersive!)

Accounting for observation errors

Following Saetra et al. (2004), Klasa et al. (2017) added the squared observation error estimate (Table 1) r_o^2 to the ensemble variance s^2. The total spread s_t is then derived as:

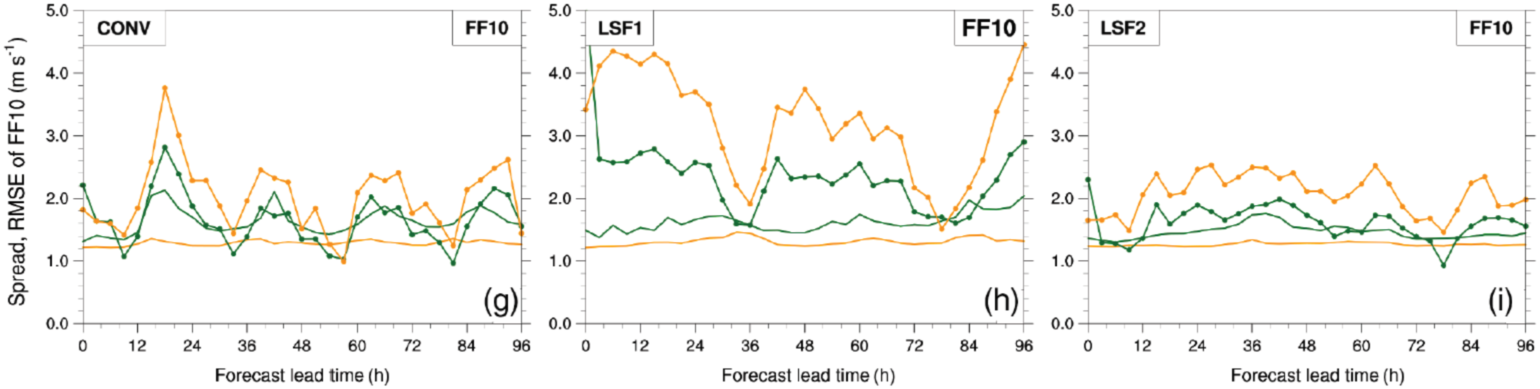
$$s_t = \sqrt{s^2 + r_o^2}$$

TABLE 1 Observation-error estimates for near-surface temperature (T2), relative humidity (RH2), wind speed (FF10), and 3 hr accumulated precipitation (PREC3), taken from Bouttier et al. (2012)

Variable	T2 (K)	RH2 (%)	FF10 (m/s)	PREC3 (mm)
Obs error	1.1	10	1.2	$0.5+0.3\mathrm{PREC3}_{obs}$

- r_o has a large impact on spread/skill results
- available values are only rough estimates for observation and representativeness errors
- should we work towards more appropriate estimates? From our KENDA cycles as soon as we assimilate near surface obs?
- or should we all work with these/the same numbers to get comparable results?

COSMO-E vs ENS for FF@10m Case studies



- convective (CONV) & 2 large-scale flow (LSF1/LSF2) cases
- COSMO-E shows smaller error and larger spread than ENS
- ENS misses the diurnal cycle of the spread for CONV

Klasa et at. (2017)

COSMO-E vs ENS
Case studies T and RH upper air

@ soundings

@ grid points (RMSE vs HRES ANA)

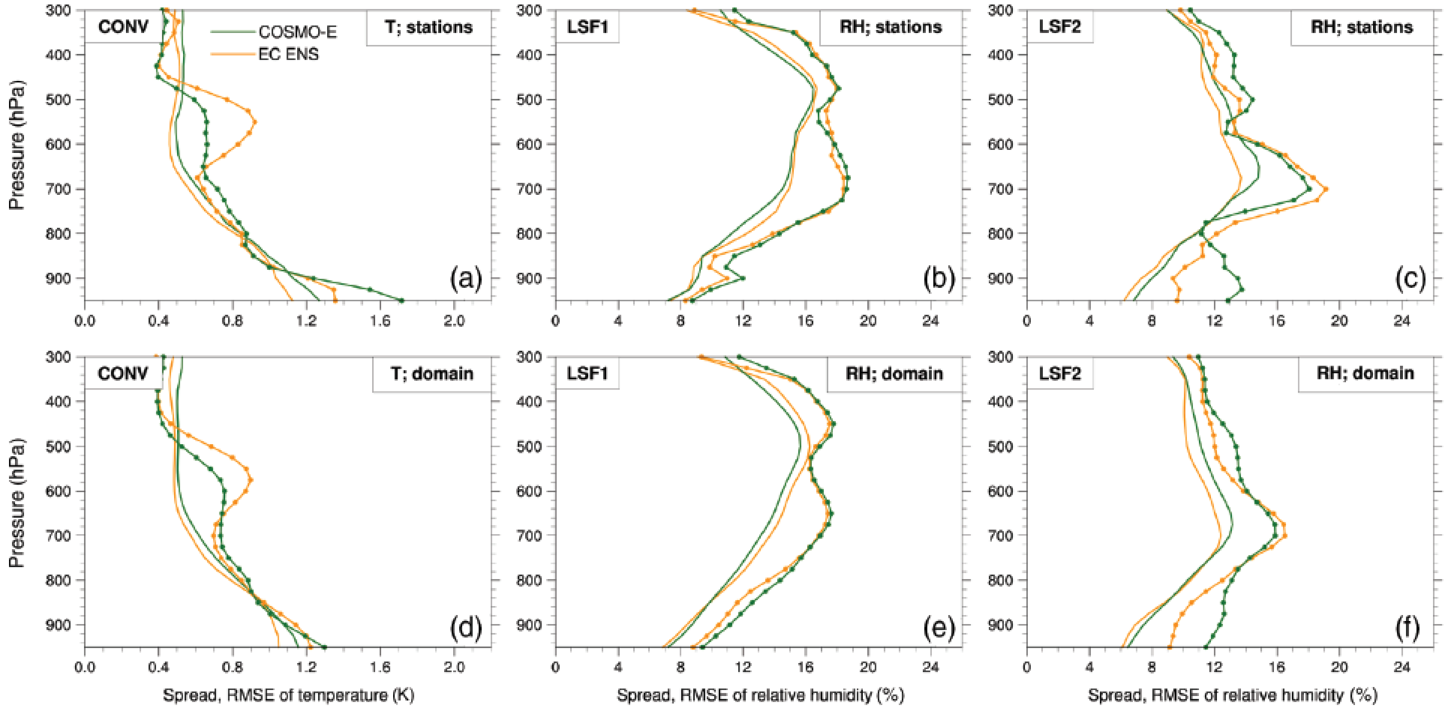


FIGURE 10 Vertical profiles of spread of (a,d) temperature and (b,c,e,f) relative humidity and RMSE of these variables (lines with symbols), averaged over all forecast lead times for the cases (a,d) CONV, (b,e) LSF1, and (c,f) LSF2. The RMSE is calculated against EC HRES-A. (a–c) are averaged only over the grid points closest to the ten radiosounding stations (Figure 1b), while (d–f) are averaged over the entire model domain. Values for COSMO-E are in green and for EC ENS in orange

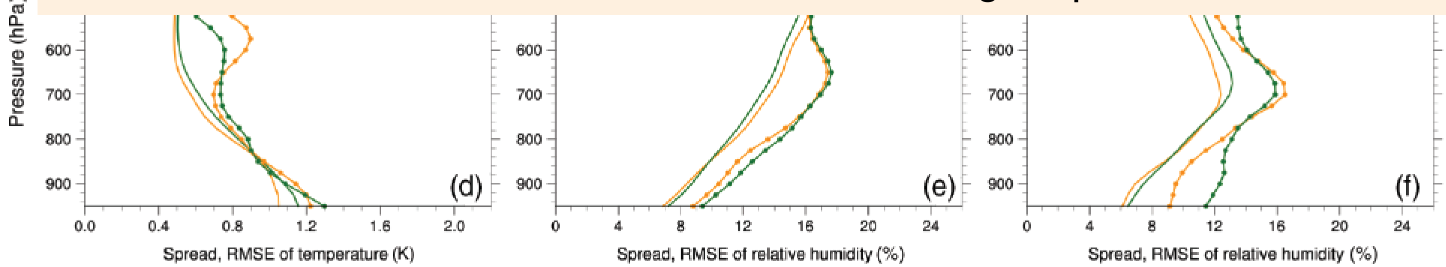
Klasa et at. (2017)

COSMO-E vs ENS
Case studies T and RH upper air

@ soundings

- for both events with large-scale advection, underdispersion occurs for mid-tropospheric relative humidity near fronts
- because frontal propagation is largely determined by LBCs, the underdispersion also occurs for COSMO-E
- for the convective event COSMO-E shows larger spread than ENS

@ grid points (RMSE vs HRES ANA)



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Klasa et at. (2017)

Model perturbations (task 2)

Learnings from model perturbations used and tested in COSMO-E:

- Stochastic Perturbation of Physical Tendencies (SPPT)
- Stochastic boundary layer perturbation scheme of Kober and Craig, 2016 (BLPERT)

Kober, K., and C. Craig, 2016*: Physically Based Stochastic Perturbations (PSP) in the Boundary Layer to Represent Uncertainty in Convective Initiation*, J. Atmos. Sci., **73**, 2893-2911.

Learnings from SPPT in COSMO-E

- Sum of parameterization tendencies for T and QV is largest in summer and dominated by those from the turbulence scheme
- Hence, SPPT is able to significantly increase spread in T/QV near surface in summer, but hardly in winter
- SPPT has only significant impact with large correlation lengths in space and time in the random pattern (we thus use 5deg and 6h)
- higher chance for unphysical temperature anomalies caused by advection scheme when physics tendencies are significantly reduced by SPPT (switched off locally in such cases)
- opr SPPT setup of COSMO-E leads to model crashes in 1.1 km runs

COSMO-E tests with Kober and Craig BLPERT scheme

Generation of perturbation fields:

- stochastic pert. of T, qv and w in the PBL only, coupled to the variances of these quantities as derived in the turbulence scheme:

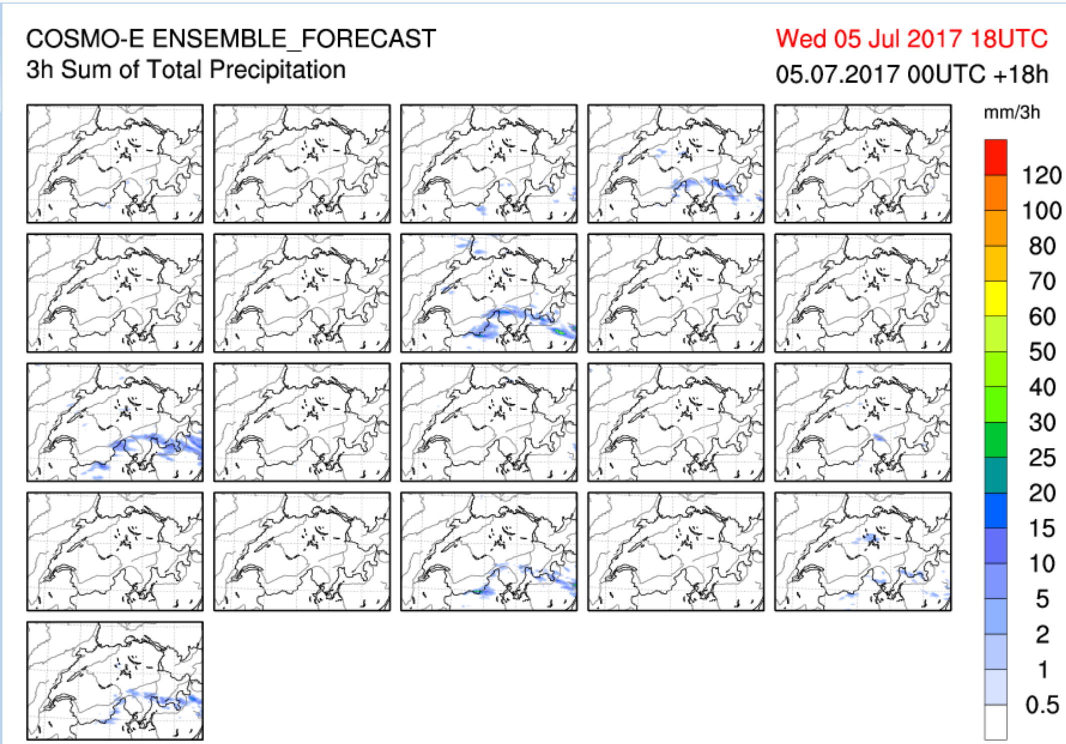
$$\left(\frac{\partial \Phi(z,t)}{\partial t}\right)^{pert} = \left(\frac{\partial \Phi(z,t)}{\partial t}\right)^{phys} + \alpha_{sh}\,\eta_{sh}\,\langle \Phi'^2(z,t)\rangle^{1/2}$$

$$\alpha_{sh} = \alpha_{sh,\Phi} \cdot \frac{\ell_\infty}{5 \cdot dx} \cdot \frac{1}{dt}$$

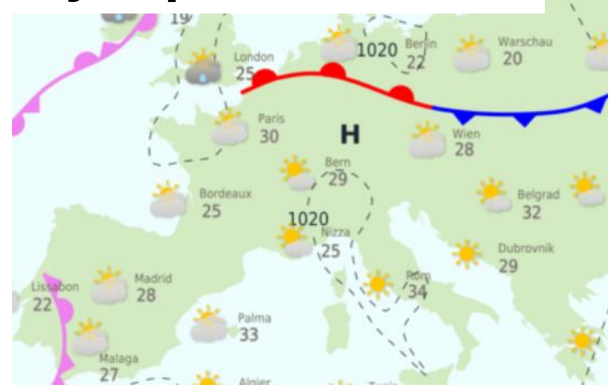
- Φ = {T, qv, w}
- Stddev(Φ) diagnosed from turbulence scheme (only itype_turb=3)
- choose space- and time-coherence scales for random number field below effective model resolution of these two quantities
- $\alpha_{sh,\Phi}$ = namelist (tuning) parameter *blpert_const*
- η_{sh} = 2D random number field, smoothed by Gaussian kernel to generate coherent structures. Held constant for typical eddy turnover times (~10‘; namelist parameter *blpert_fixedtime*)

copied and adapted from Uli Blahak

Weak forcing case: 5th of July 2017

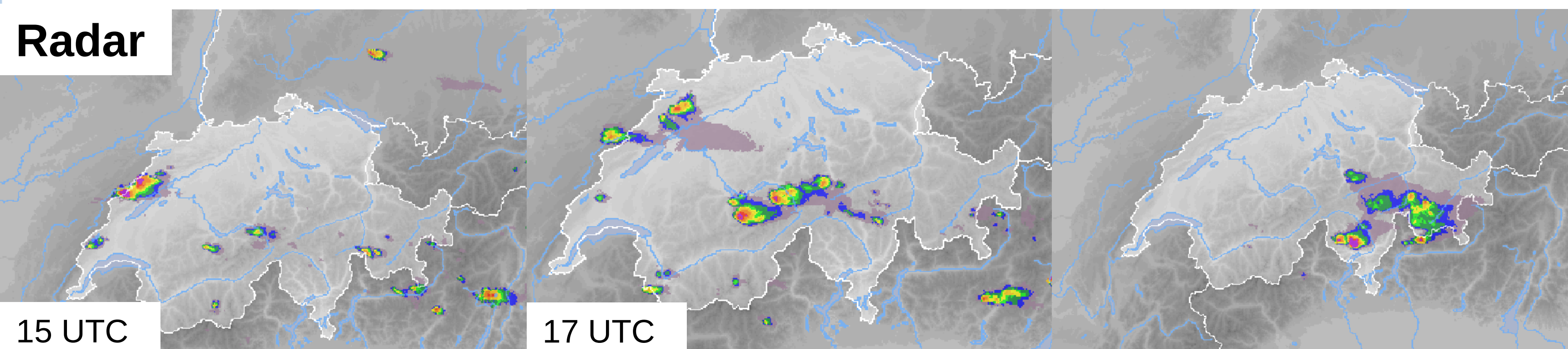


Synoptic Situation



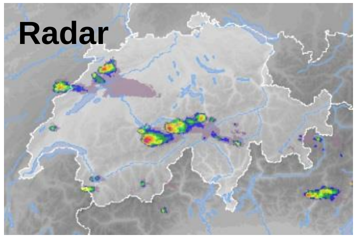
- sunny
- Tmax 34 degrees
- convective clouds in the afternoon
- showers and thunderstorms (Jura, Alps, Black Forest)

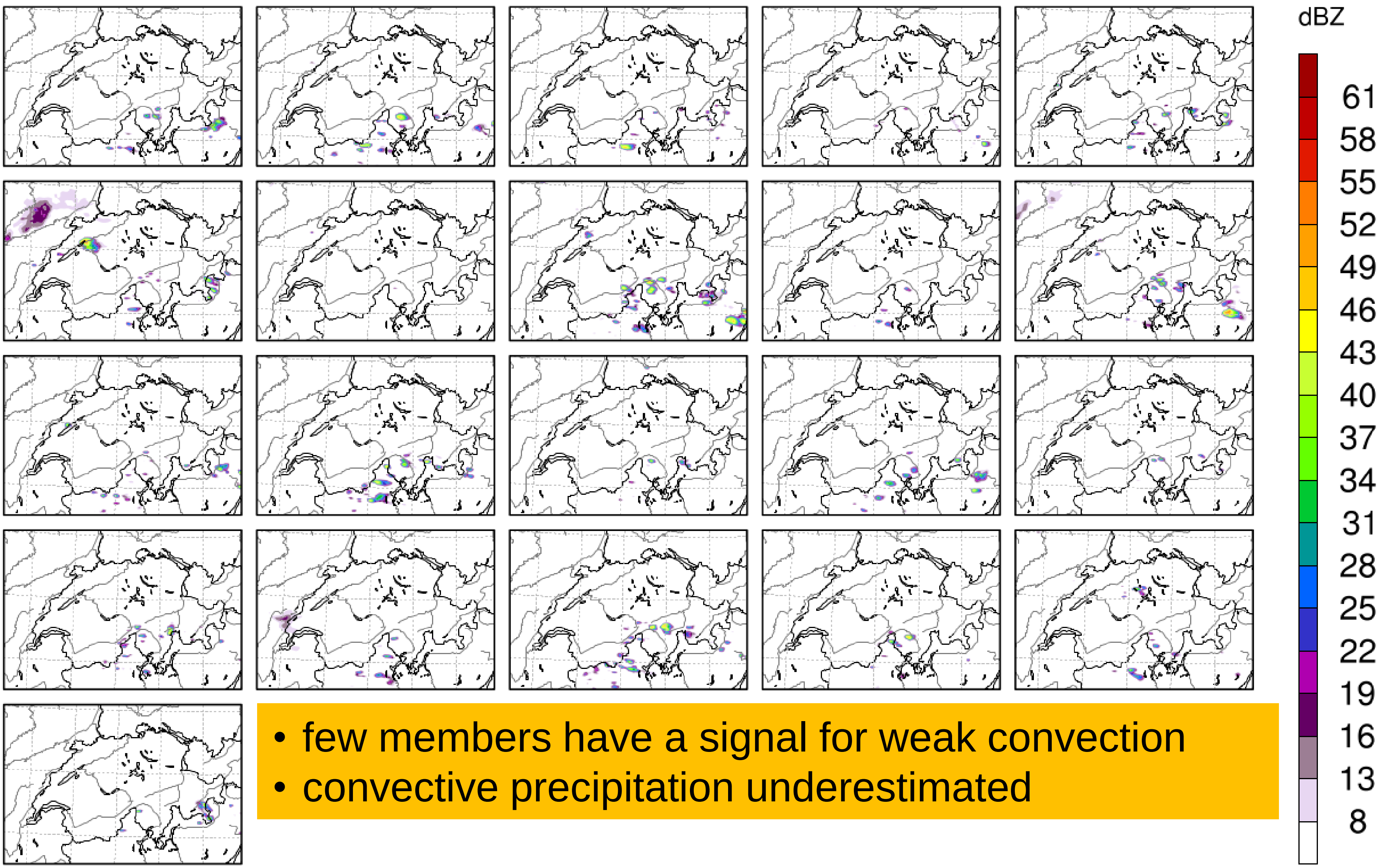
Radar



Reference: dBZ, +17h / 17 UTC

2.2 km, without SPPT

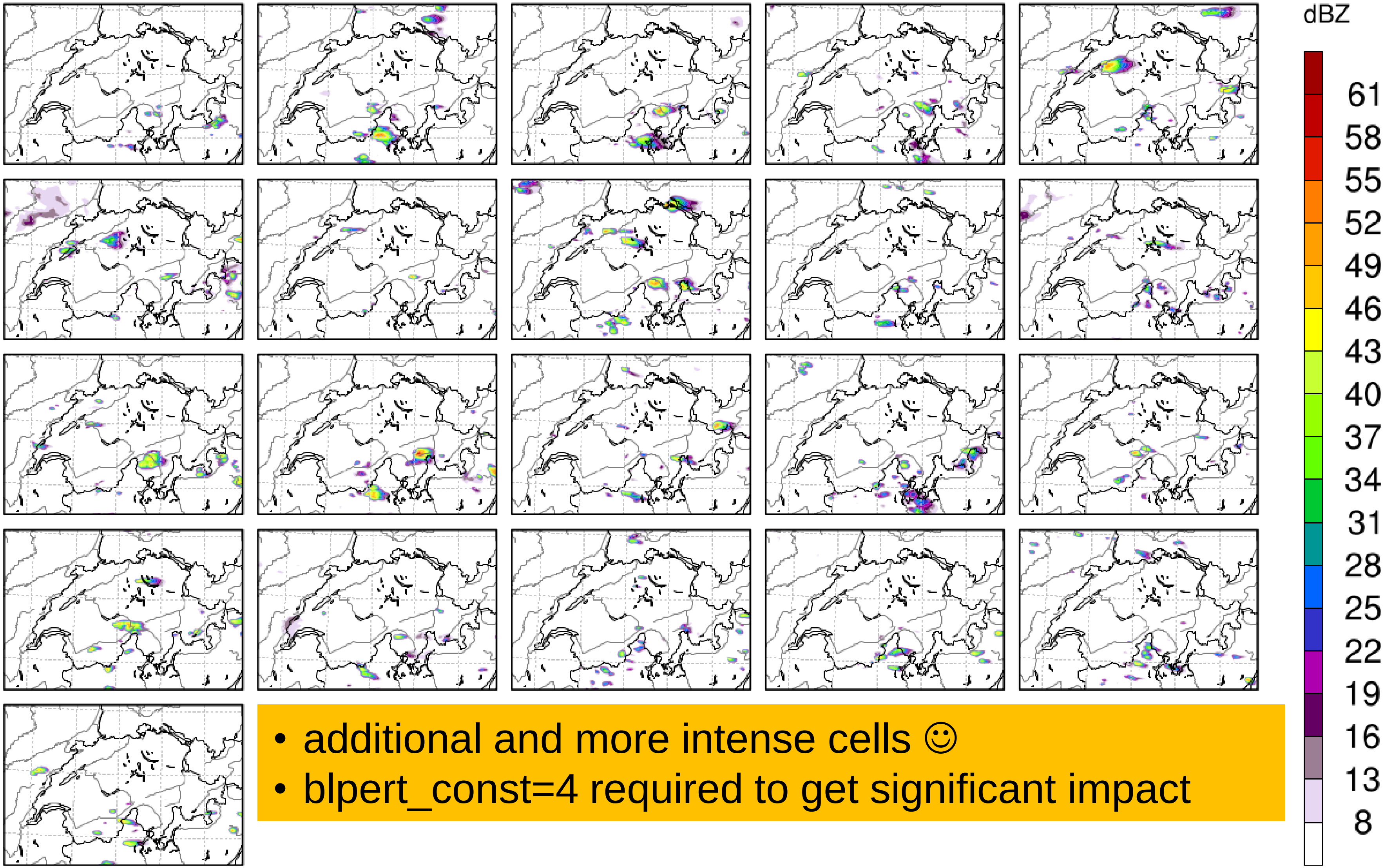




- few members have a signal for weak convection
- convective precipitation underestimated

BLPERT (285): dBZ, +17h / 17 UTC

2.2 km, without SPPT, with BLPERT, blpert_const = 4.0

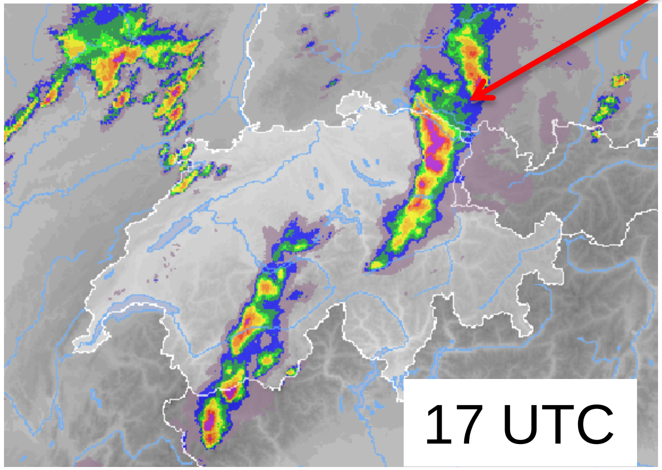


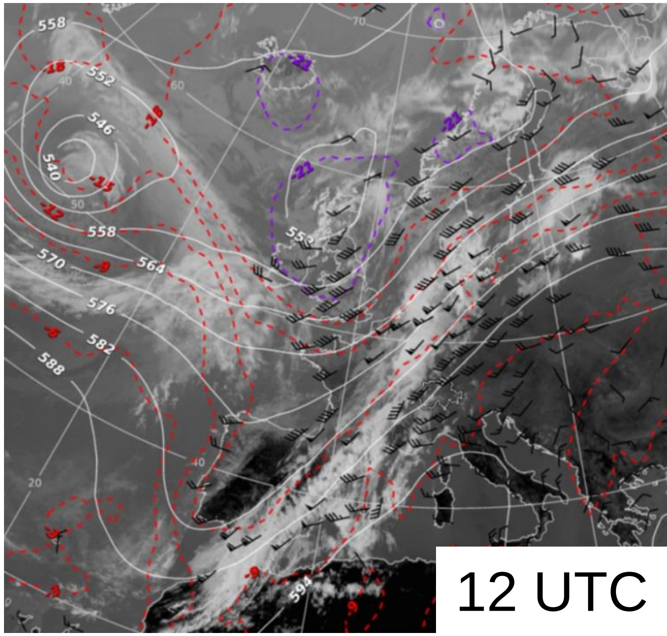
- additional and more intense cells ☺
- blpert_const=4 required to get significant impact

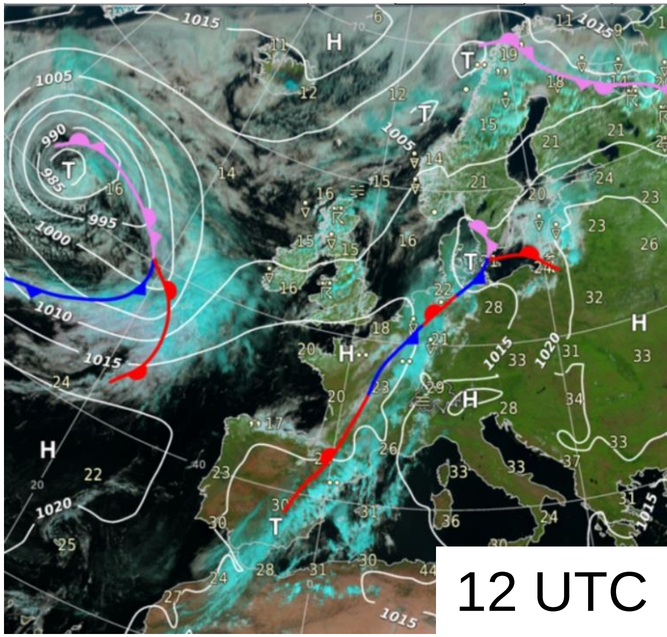
Weather situation: 1st of August 2017

Synoptic View:
Trough over West Europe, which is slowly approaching, prefrontal weather situation (SW), thunderstorms starting in the afternoon → strong forcing

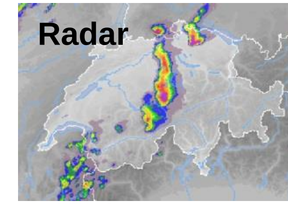
Thunderstorms:
Heavy precipitation (Engelberg 25mm in 10 min) and strong gusts (Lindau at Bodensee 133 km/h)


17 UTC

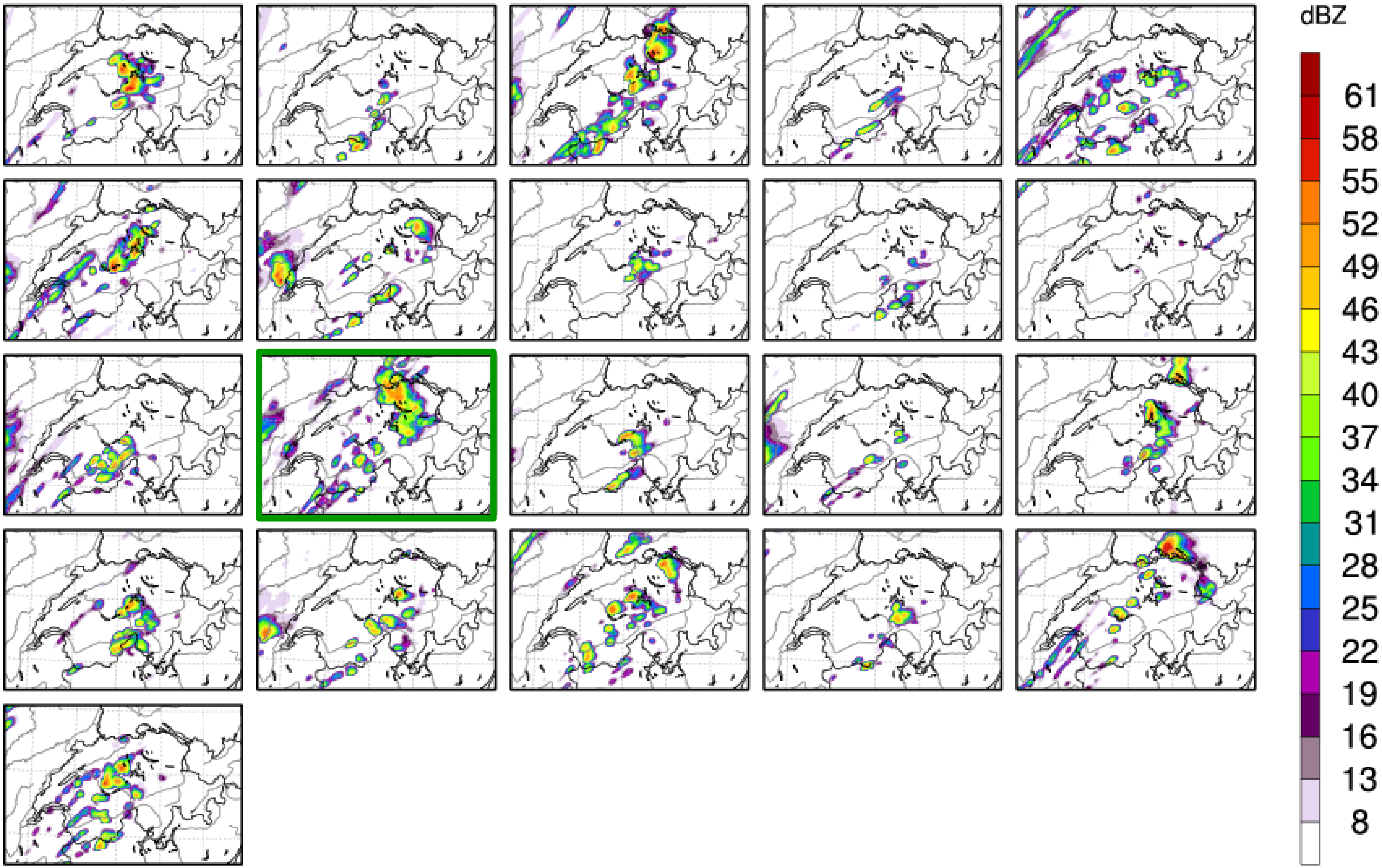

12 UTC

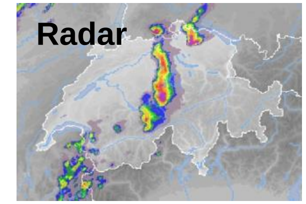

12 UTC

Reference (220): dBZ, +16h / 16 UTC



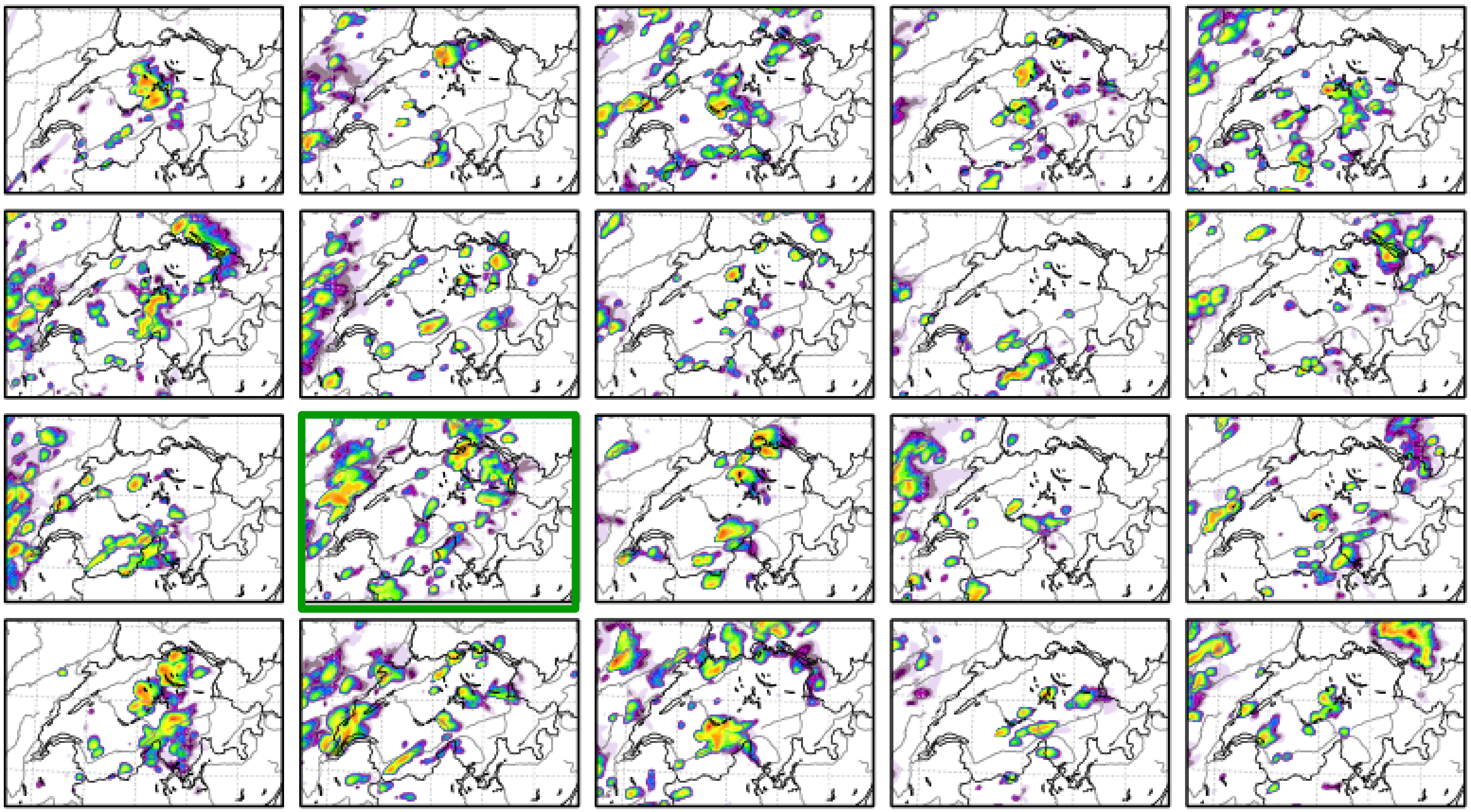
2.2 km, without SPPT, without BLPERT

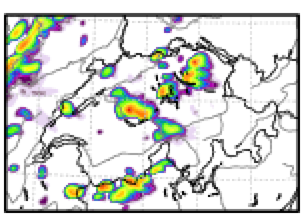


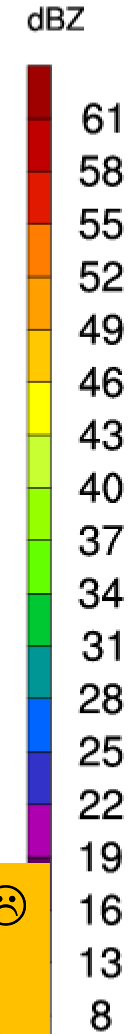


BLPERT (291): dBZ, +16h / 16 UTC

2.2 km, without SPPT, with BLPERT, blpert_const = 4.0



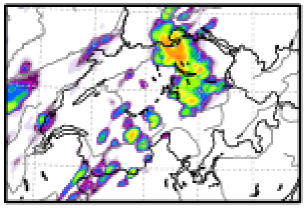


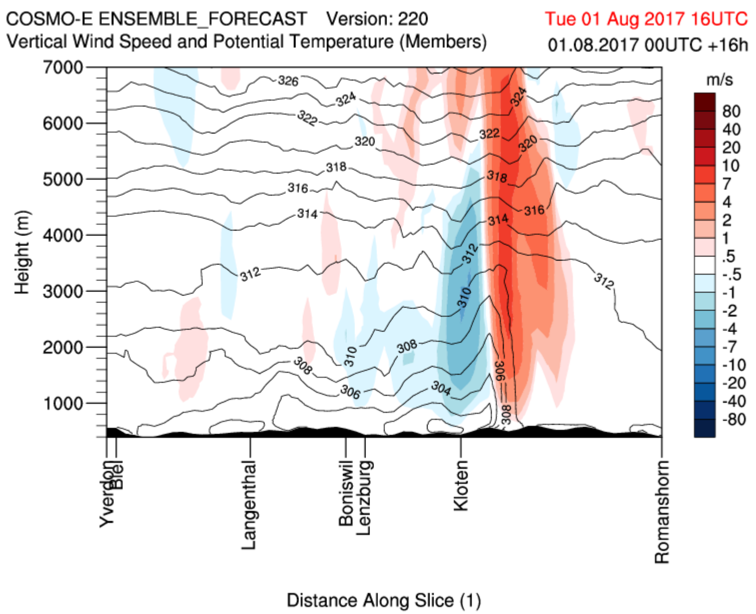


- best member worse (less intense, less organized) ☹
- more small-scale cells in general ☹
- new cells rather triggered in western Switzerland ☹

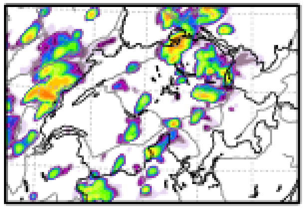
Cross-sections for W member 11

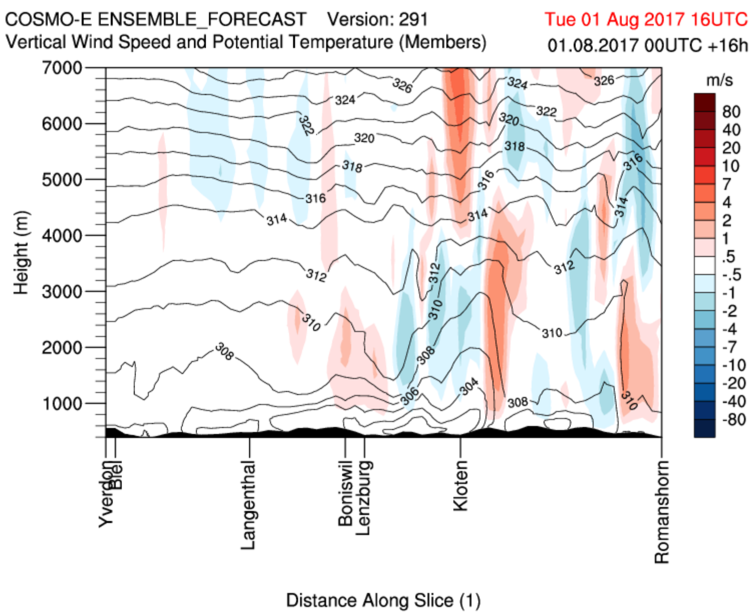
REF



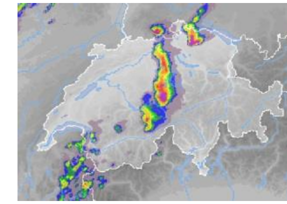


BLPERT

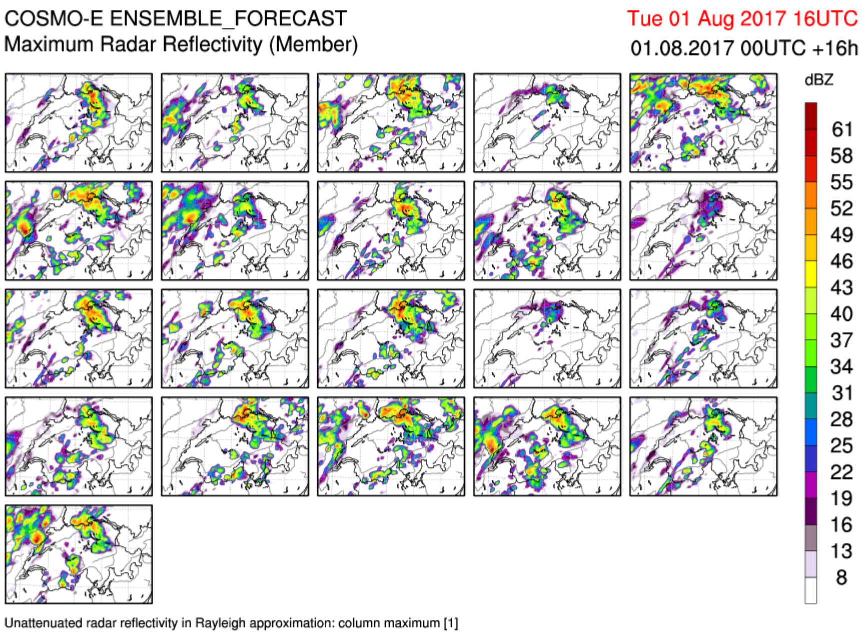




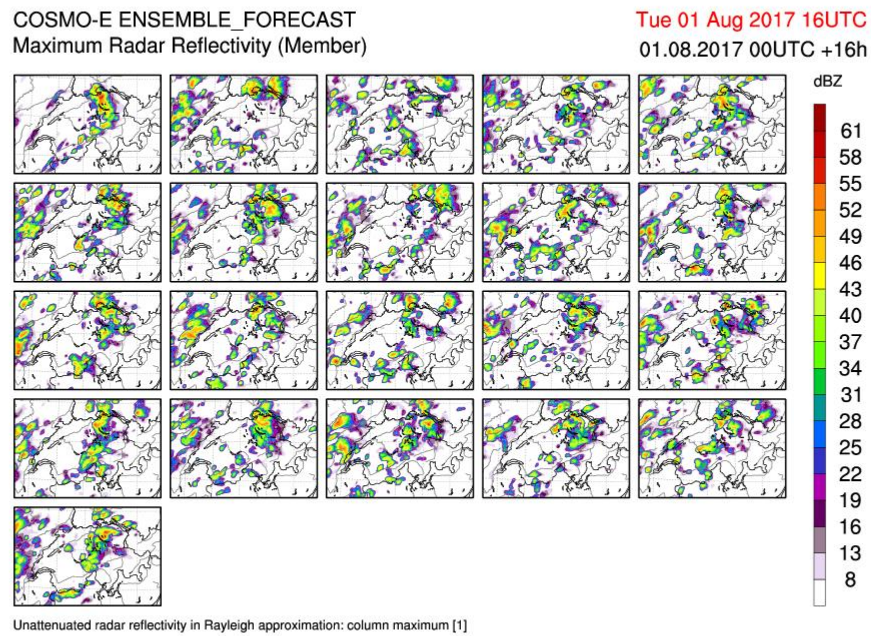
ICs and LBCs of member 11 for all members



SPPT



BLPERT (blpert_const = 2)



- SPPT has larger impact → larger variability
- SPPT exp shows more members that resembles the radar image

Thoughts about model perturbations

- model perturbations with BLPERT and SPPT have an impact on the physical processes that keep a convective system alive and they can be disruptive
- chance that perturbations are disruptive are particularly high with BLPERT with new random numbers every 10 minutes
- an issue of all our stochastic model perturbations schemes in convection-resolving ensembles (?)
- probably less an issue with parameter perturbations (?)
- process-level uncertainty representation by stochastic perturbed parameterizations (SPP) the long-term goal for our ensembles…?

Member selection (task 5)

no news

- sophisticated member selection like clustering for LBCs can improve COSMO-E forecasts significantly
- clustering is able to increase the spread for near-surface variables (most welcome!) → probably main reason for better scores
- random member choice can result in significantly worse forecasts with bad luck, can be at least as worse than ‘closest’ in specific case
- benefit of better IC selection limited, at least for scores averaged over day 1 (may be different for the very short range)

How to go on in APSU?

iSPPT: independent SPPT

- SPPT does not distinguish between different parameterization schemes
- but they do not necessarily have the same error characteristics
- Christensen et al. (2017) suggest independent random pattern for each parametrization scheme
- improves ENS forecasts (but mainly in the Tropics)

Christensen, H. M., Lock, S.-J., Moroz, I. M., and Palmer, T. N., 2017, Introducing Independent Patterns into the Stochastically Perturbed Parametrisation Tendencies (SPPT) scheme. Q. J. Roy Meteor Soc., 143(706), 2168–2181. DOI: 10.1002/qj.3075

iSPPT: independent SPPT

$$\frac{\partial X}{\partial t} = D^X + K^X + \sum_{i=1}^{N} (1 + rand_i) P_i{}^X$$

dynamics

local tendency | horizontal diffusion | physics

X prognostic variable (u, v, T, q_v, q_c, q_i, q_r, q_s, q_g)

$P_i{}^X$ physical parameterisation scheme *i*

(turbulence, radiation, microphysics, shallow convection, …)

- our focus would rather be on induvial amplitudes for the random patterns for the different tendencies P_i than on uncorrelated patterns

Christensen, H. M., Lock, S.-J., Moroz, I. M., and Palmer, T. N., 2017, Introducing Independent Patterns into the Stochastically Perturbed Parametrisation Tendencies (SPPT) scheme. Q. J. Roy Meteor Soc., 143(706), 2168–2181. DOI: 10.1002/qj.3075

Model perturbations based on analysis increments (Piccolo et al. 2018)

- motivation: analysis increments (i.e. difference between analysis and first guess) can take into account more possible sources of model errors than SPPT
- random forcing terms are derived by sampling a dataset of historic analysis increments (same resolution and time of year)
- assumes that model error statistics are stationary (i.e., no dependence on current model state)
- applied for global ensemble forecasts so far
- promising approach for our ensembles…?

Piccolo, C., and M. Cullen, W. Tennant, A. Semple, 2018: Comparison of different representations of model error in ensemble forecasts. Quart. J. Roy. Meteor. Soc., accepted. doi: 10.1002/qj.3348

ACI in KENDA instead of IC perturbation scaling?

- In APSU we planed to increase initial condition (IC) perturbations for COSMO-E by scaling those from the KENDA ensemble with a constant factor a in time:

$$IC_{pert\_CE} = a(z) * IC_{pert\_KENDA}$$

- However, improving the perturbations by a more ‘suitable’ additive covariance inflation (ACI) seems to be more promising (→ talk this morning by M. Arpagaus et al.)

➢ Focus on development of B-matrix for COSMO (WP in KENDA-O)

COSMO-E in 2020

Next MeteoSwiss NWP system: ‘Merge’ of COSMO-1 and COSMO-E

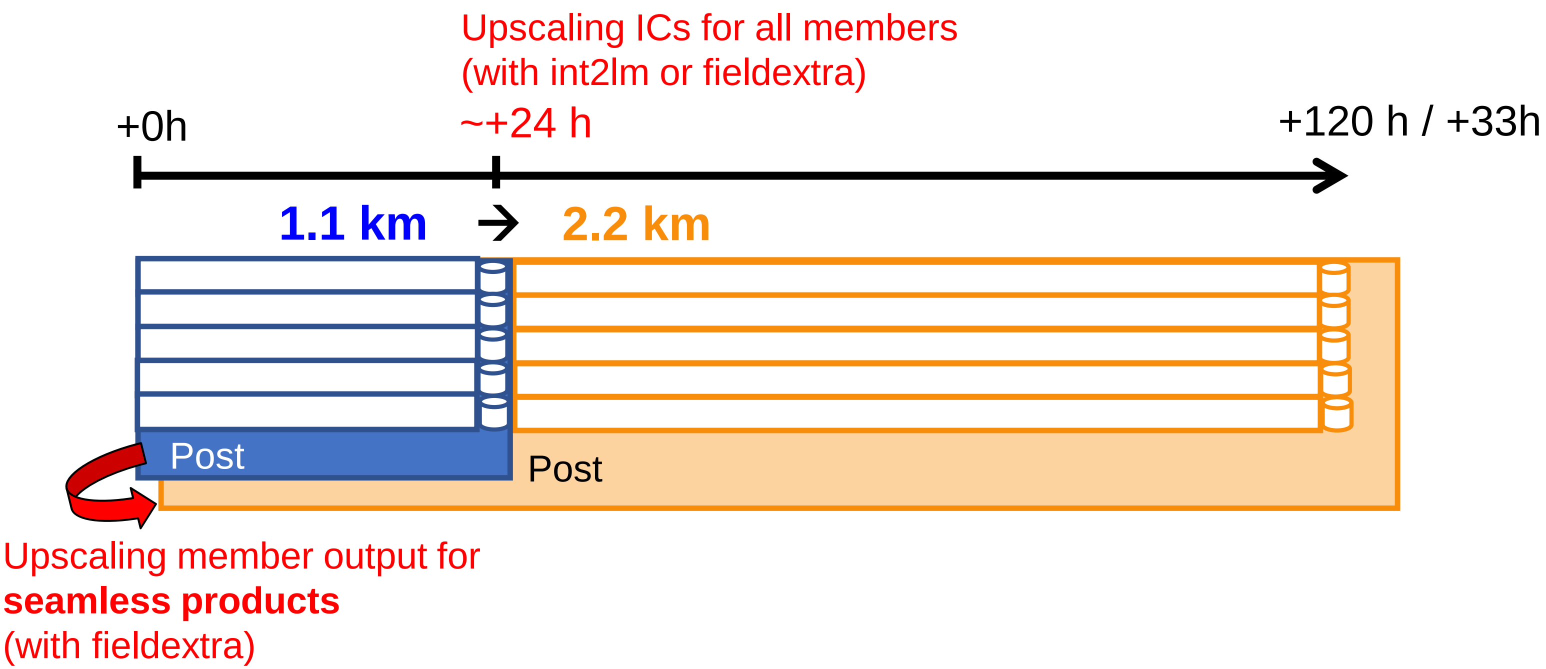
Main advantages of COSMO-1 (1.1 km) vs. COSMO-E members (2.2 km):

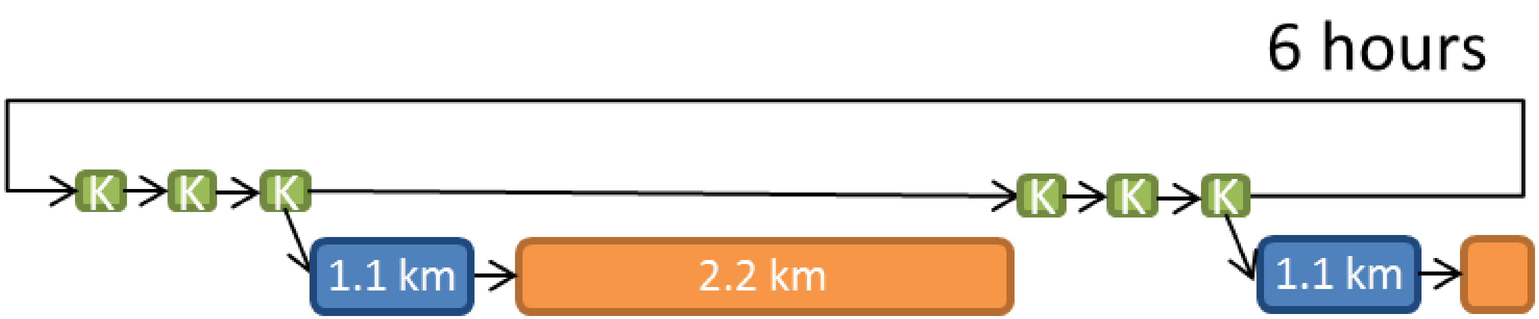
- valley winds
- high fog (winter)
- convection (characteristics, intensity, endurance of cells)

Project ModInterim: COSMO-E 2020

- KENDA @ 1.1 km (40 members) providing ICs for forecasts
- COSMO ensemble forecasts (tentative):
  - RUC: every 3h up to >= +33h
  - 4 x per day up to 120h
  - 1.1 km → 2.2 km after ~24h (1.1km too expensive for 120h forecast range)
  - 80 levels
  - at least 15 members (hopefully more)
  - short-range products based on 1.1 km output
  - medium-range products based on 2.2 km (upscaled for short-range) data

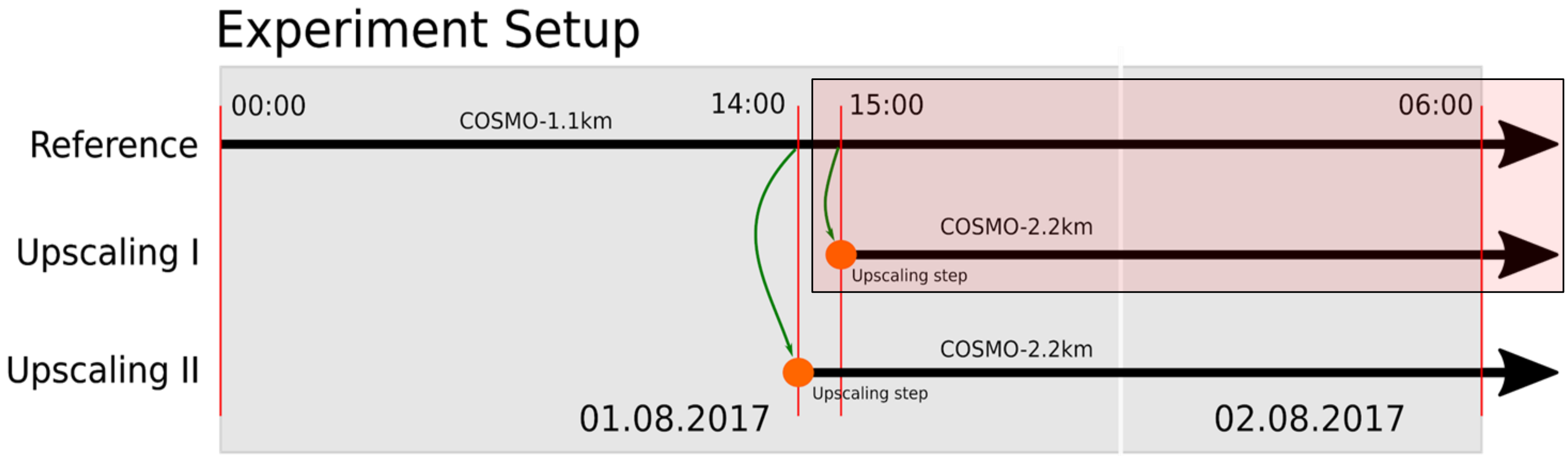
COSMO-E 2020 workflow





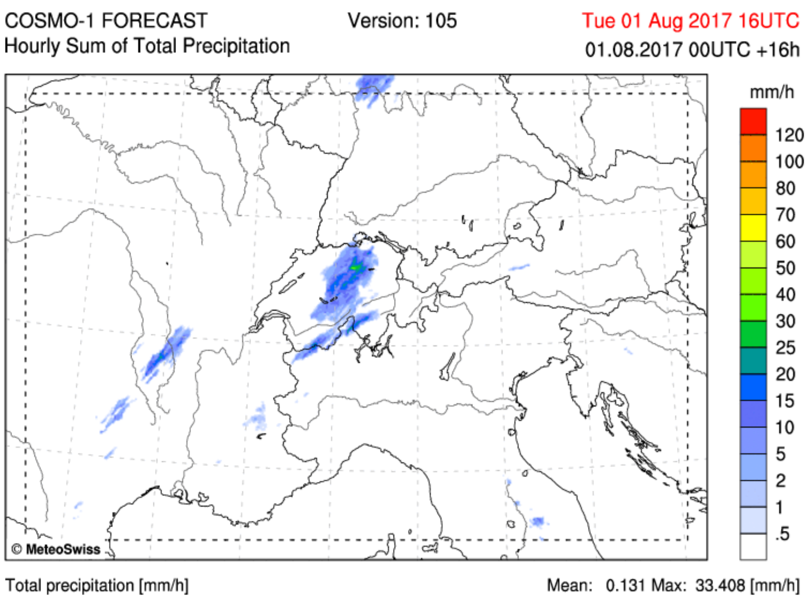
Upscaling COSMO fields

- started with deterministic experiments
- case studies

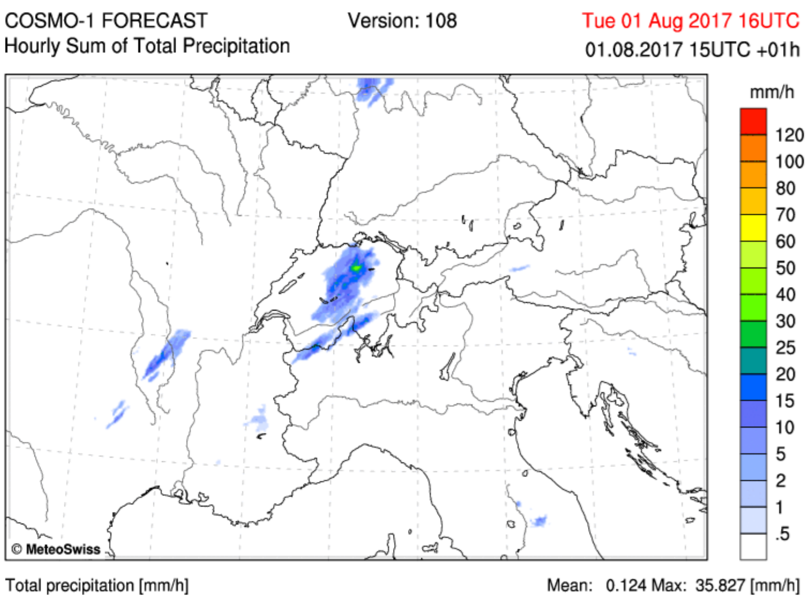


Convective case: hourly precipitation sums

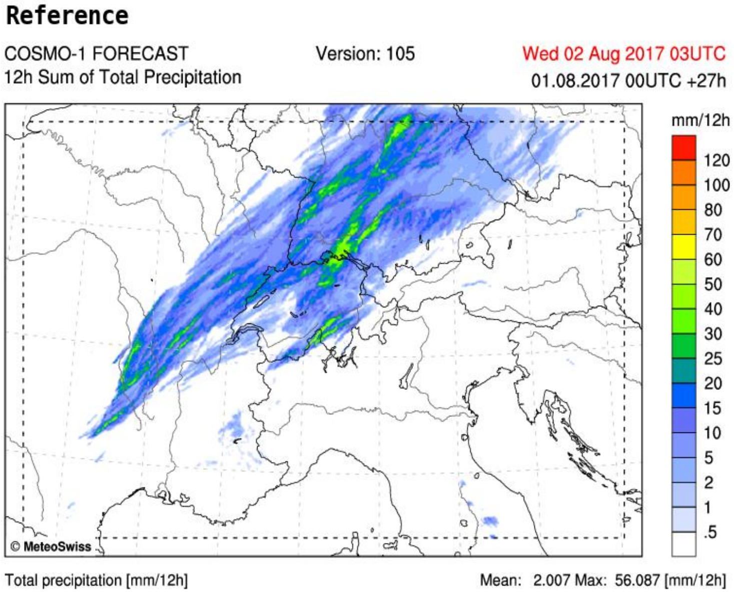
Reference

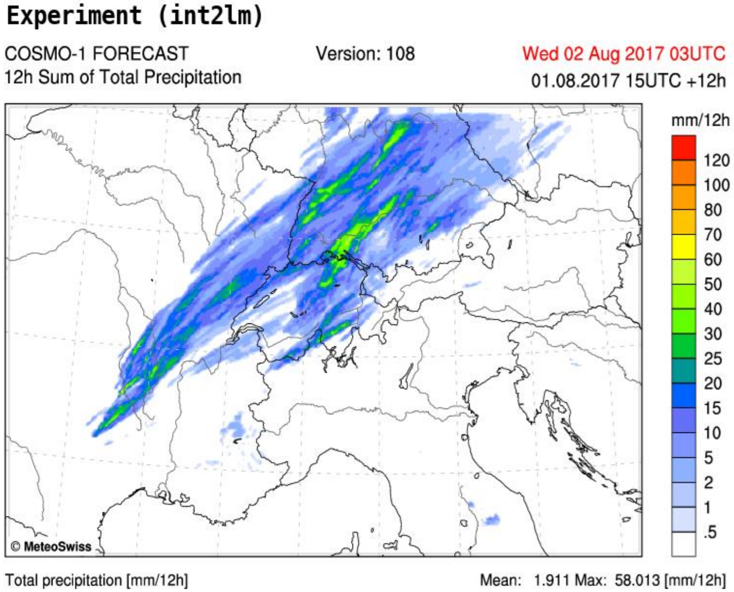


Experiment (int2lm)



Convective case:
12h precipitation sum

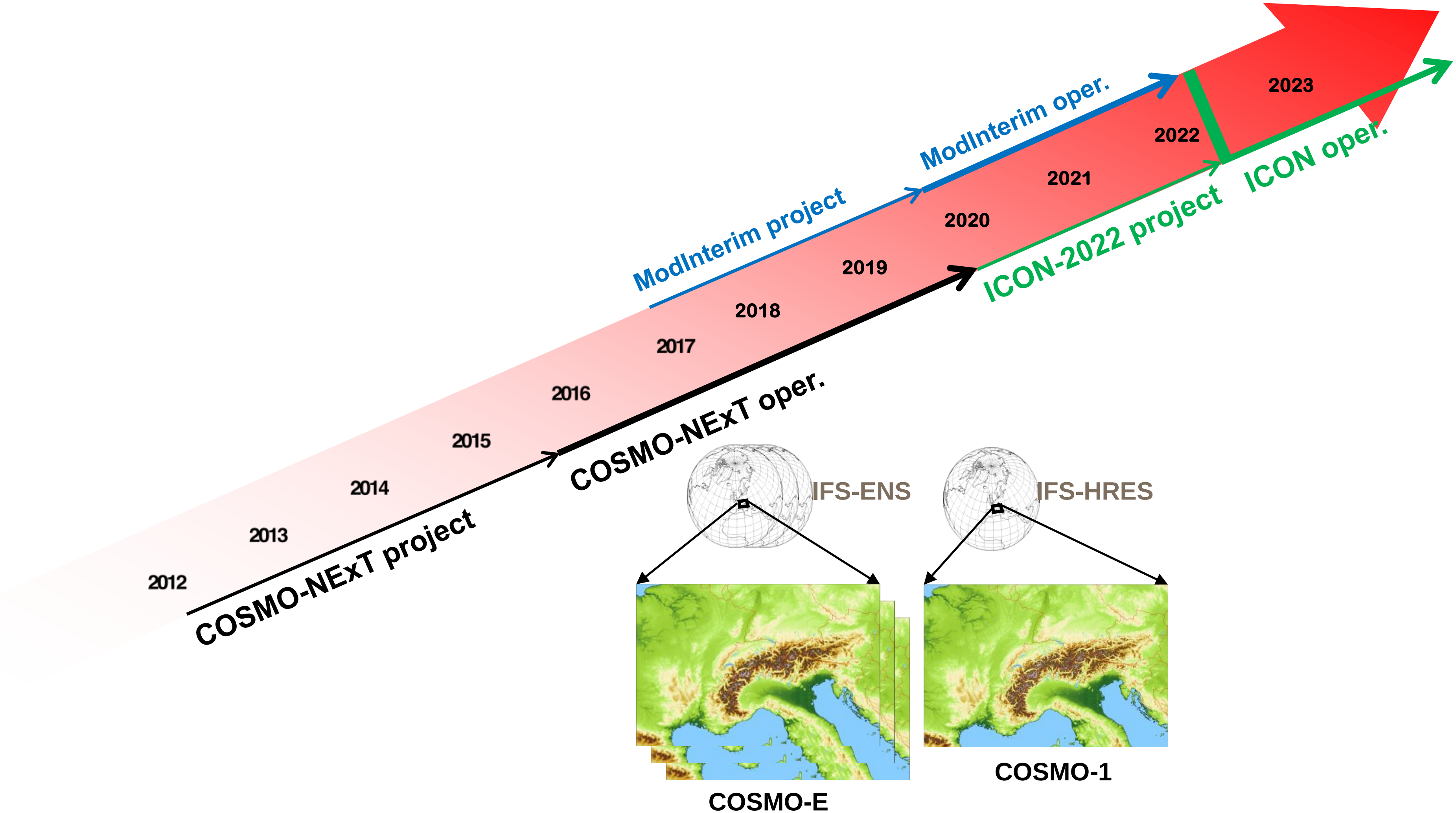




ModInterim next steps

- Case studies for six weather types
- decision whether fieldextra or int2lm is used as upscaling tool for generating the ICs for the 2.2 km members
- run ensembles and verification vs. opr COSMO-E

ModInterim: between COSMO-NExT and ICON-2022 projects



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