Boundary layer perturbations for convection triggering in COSMO-DE

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[1] Original inventors
[2] Implementation and testing at DWD

Literature

➔ 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.

Random perturbations

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Wetter und Klima aus einer Hand

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 (Kober et al, 2015)
- original: $\left(\frac{\partial \Phi(z,t)}{\partial t}\right)^{pert} = \left(\frac{\partial \Phi(z,t)}{\partial t}\right)^{phys} + \alpha_{sh} \eta_{sh} \langle \Phi'^2(z,t) \rangle^{1/2}$ $\qquad \alpha_{sh} = \alpha_{sh,\Phi} \cdot \frac{\ell_\infty}{5 \cdot dx} \cdot \frac{1}{dt}$

  (Kober et al., 2015)
- modified: $\left(\frac{\partial \Phi(z,t)}{\partial t}\right)^{pert} = \left(\frac{\partial \Phi(z,t)}{\partial t}\right)^{phys} + \alpha_{sh} \eta_{sh} \begin{cases} \max\limits_{[0,z]} \left[\langle \Phi'^2(z,t) \rangle^{1/2} \right] & , z_{k_e-1} \le z \le z_{pbl} \\ 0 & , z < z_{k_e} \wedge z > z_{pbl} \end{cases}$

  (devel options by U. Blahak)

  $$z_{pbl} = \min \left[\max \left[\left\{ z \,\middle|\, \frac{\partial \theta_v(z,t)}{\partial z} < 0.001\,\mathrm{K} \right\} \right], 1500\,\mathrm{m\ AGL} \right]$$
- 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
- α_{sh} = namelist parameter (<= 5, otherwise danger of crashes!)
- η_{sh} = 2D random number field, smoothed by Gaussian kernel to generate coherent structures. Held constant for typical eddy turnover times (~10‘)

Random perturbations (cont.)

Generation of random number field η_{sh} :

- ➔ 2D horizontal field of Gaussian random numbers (method „gasdev“ from „Numerical Recipes“)
- ➔ Smoothing (convolution) of this field with a Gaussian kernel with namelist-specified standard deviation results in smoothed structures with random variations on scales larger than the kernel standard deviation
- ➔ Perturbations held constant for some minutes (~eddy turnover time in shallow convection, 10 minutes by default), then new perturbations are computed with a new random seed
- ➔ Random number seed: initial seed by user or from model start date (only one integer), then change this seed with model forecast time in a deterministic way. Also, modify seed with the ensemble member ID in a deterministic way.
- ➔ 2 options for initial random number seed:
  - ➔ specify initial seed explicitly via namelist
  - ➔ if namelist value = -999, then construct initial seed from model starttime ydate_ini (alternatively from system time) and ensemble member number in a reproducible way

Random numbers η for perturbations

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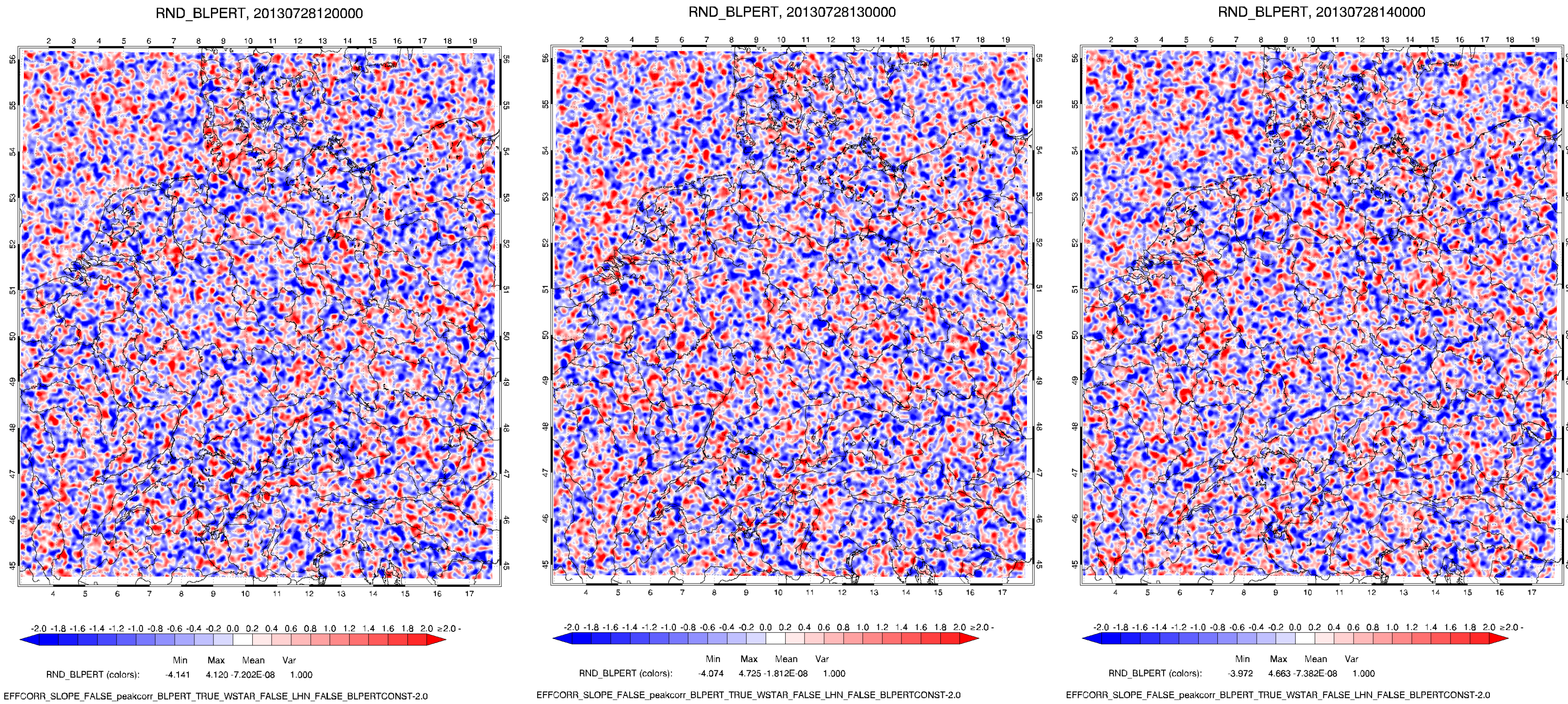
Hourly snapshots from a forecast run (η stays constant for a specified amount of time, e.g., 10 min)



Random number seeding such that random numbers are „deterministic“:

The seed depends uniquely on the model start time (ydate_ini), ntstep, nstop and ensemble member.

Alternatively, the ydate_ini-component can be replaced by seed from namelist parameter or the system time.

New namelist parameters (/RUNCTL/)

PARAMETER	DEFAULT	TYPE	MEANING
luseblpert	.FALSE.	L	Master switch
itype_blpert	1 *	INT	1 = original implementation 2…8 = modified options from devel
ladvect_blpert	.FALSE. *	L	If .TRUE. the random numbers η_{sh} are advected with the windspeed at level ke-10
blpert_sigma	2.5 *	REAL	STDDEV of Gaussian smoother for random numbers in units of grid points
blpert_const	2.0 *	REAL	$\alpha_{sh,\Phi}$
blpert_fixedtime	600.0 *	REAL	Time increment [s] of random number update (~eddy turnover time)
seed_val	-999	INT	If -999, use either model start time or system time for the initial random number seed
lseed_use_starttime	.TRUE.	L	If seed_val = -999: if .TRUE. ‚ydate_ini' determines seed, otherwise system time ‚DATE_AND_TIME()'

* If luseblpert=.TRUE., these defaults reproduce the orignial Kober (2010) settings, aside from the random seeding

Results case study 28.7.2013 12 UTC + 08h (Buggy version with only positive pert.!)

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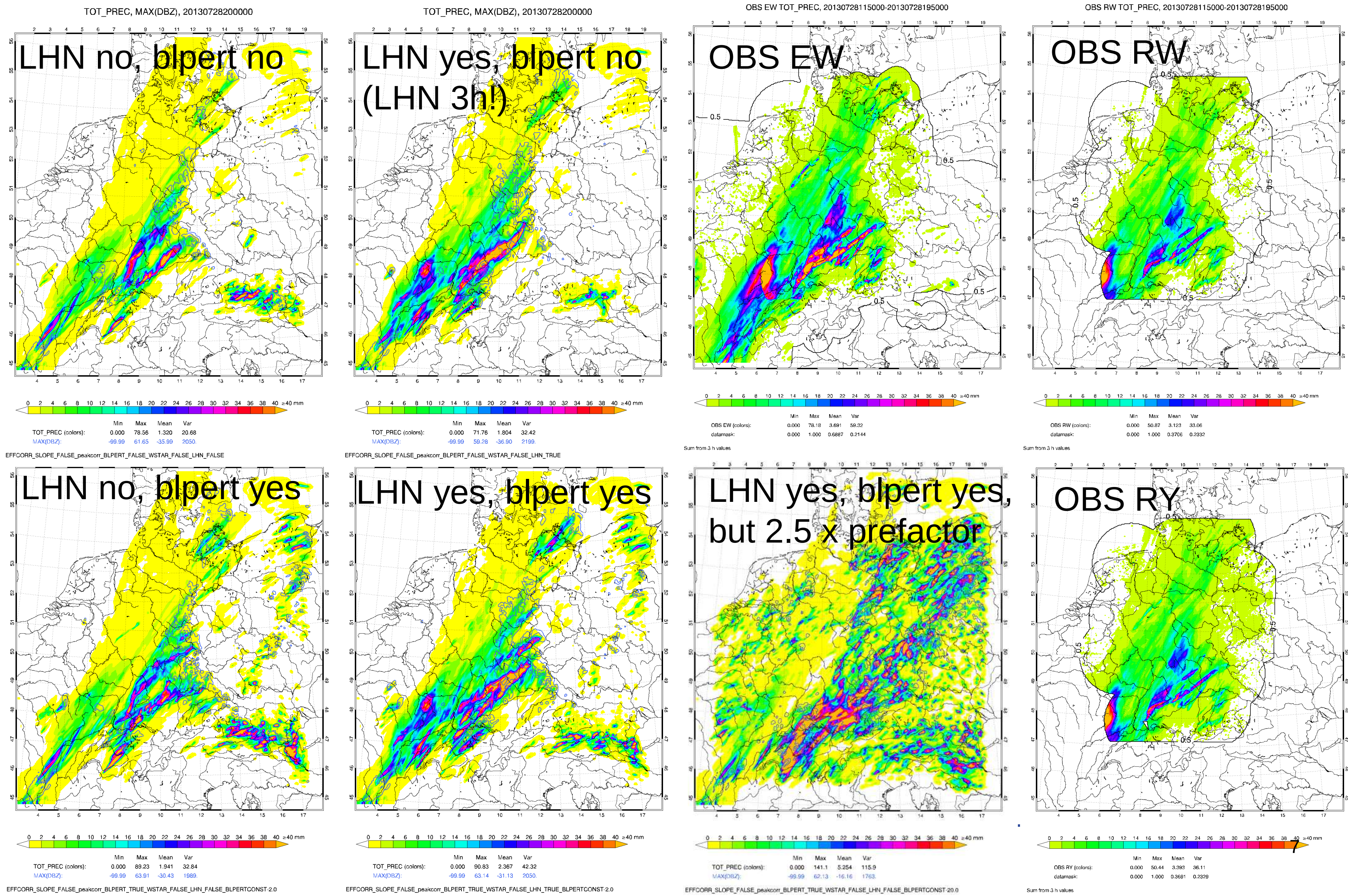

Results case study 28.7.2013 12 UTC + 08h (positive and negative pert., -> weak effect)

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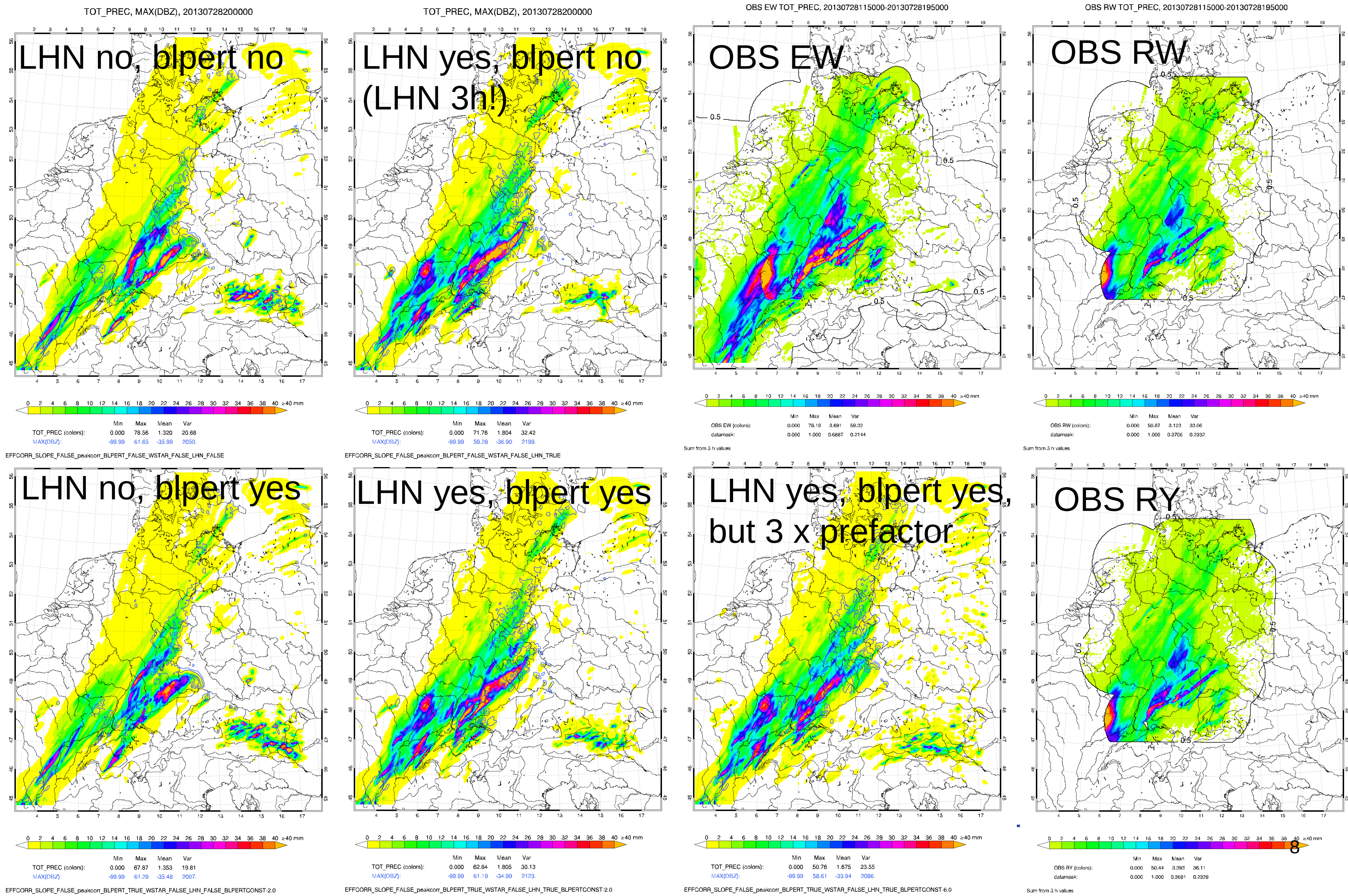

Results case study 28.7.2013 12 UTC + 08h (positive and negative pert., -> weak effect)

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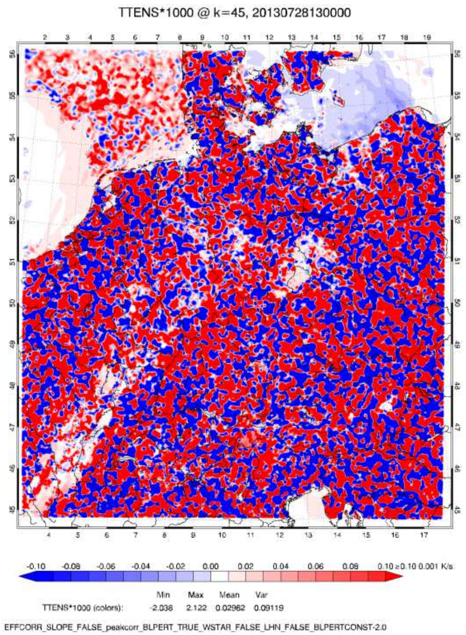
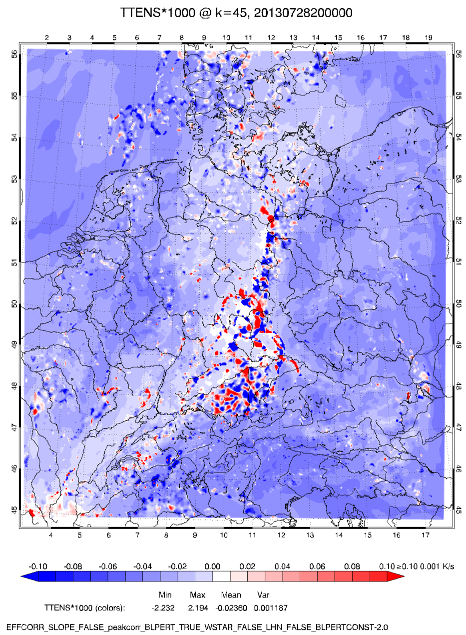
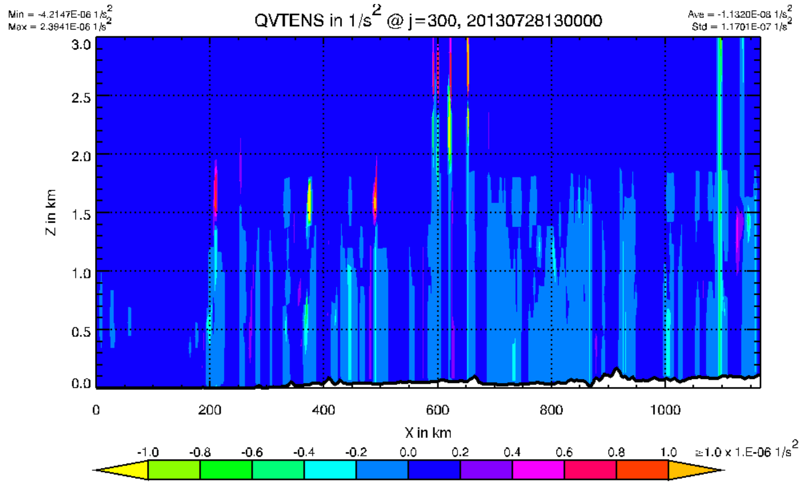
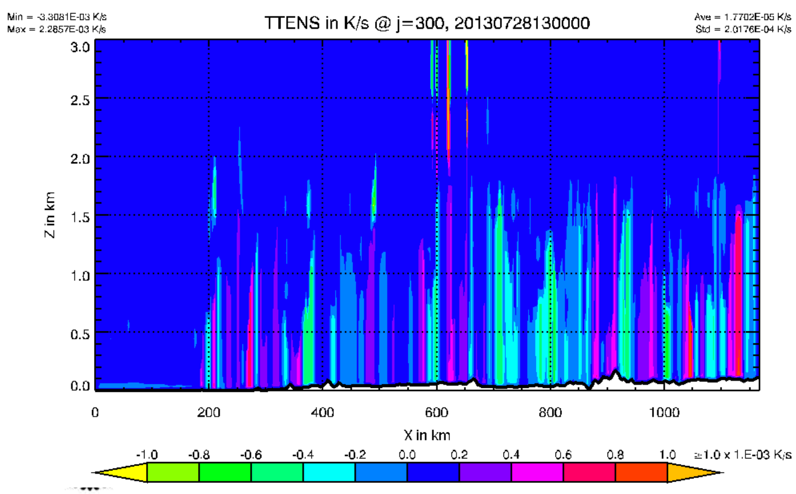
TTENS @ k=45 13:00 20:00

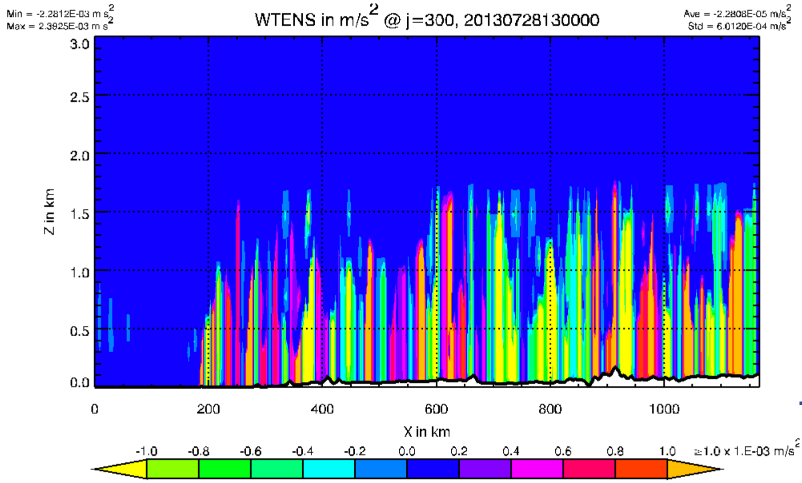




Tendencies @ j=300 13:00







Results case study 28.7.2013 12 UTC + 08h (positive and negative pert., -> weak effect)

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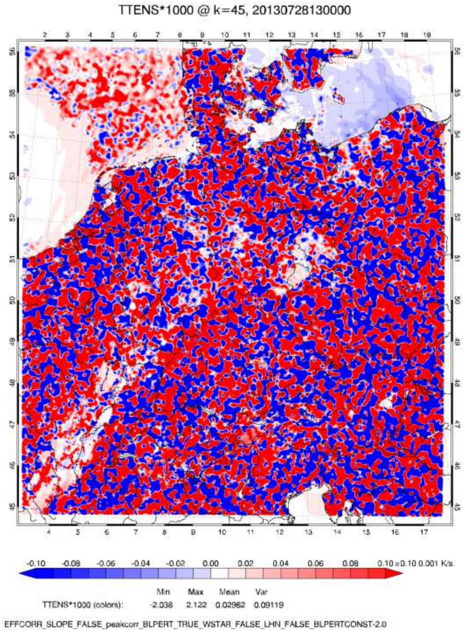
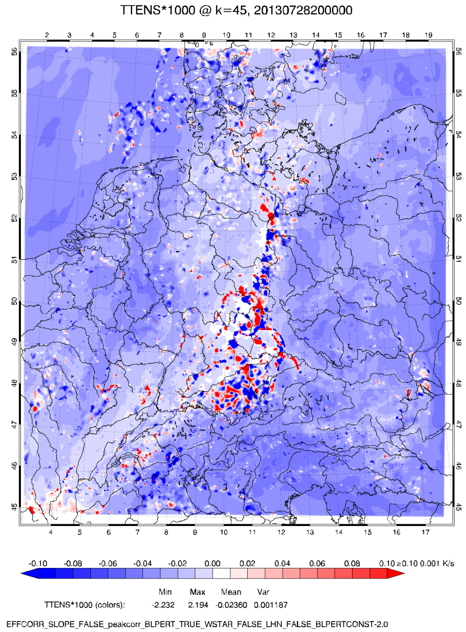
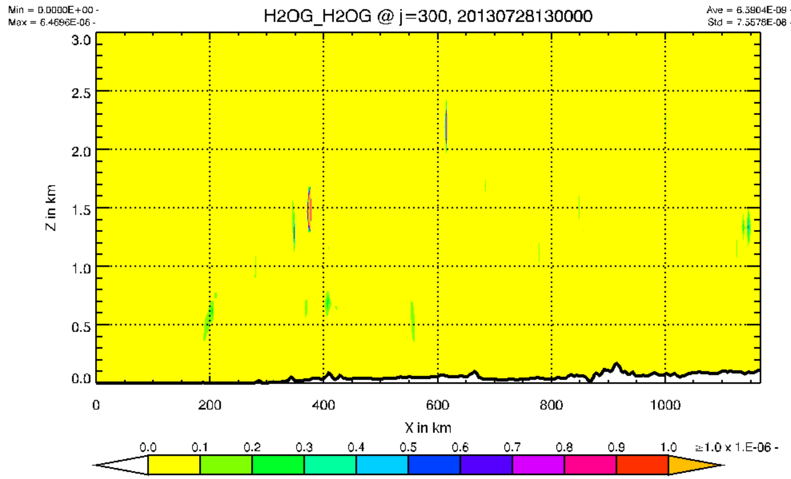
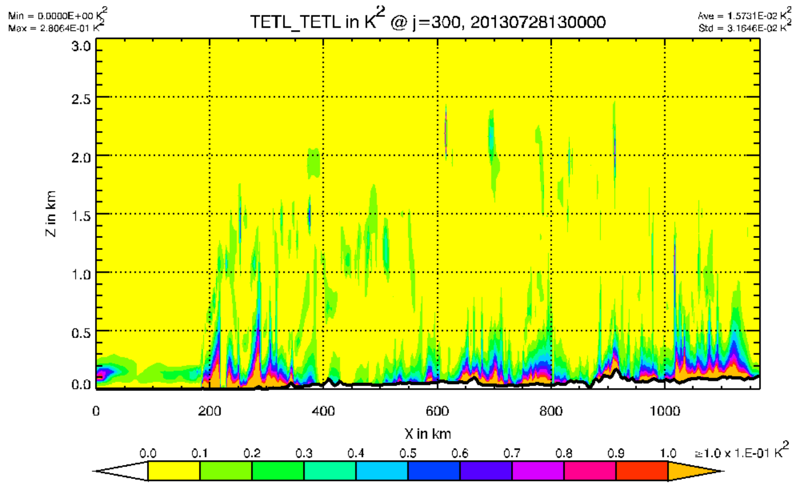
TTENS @ k=45 13:00   20:00

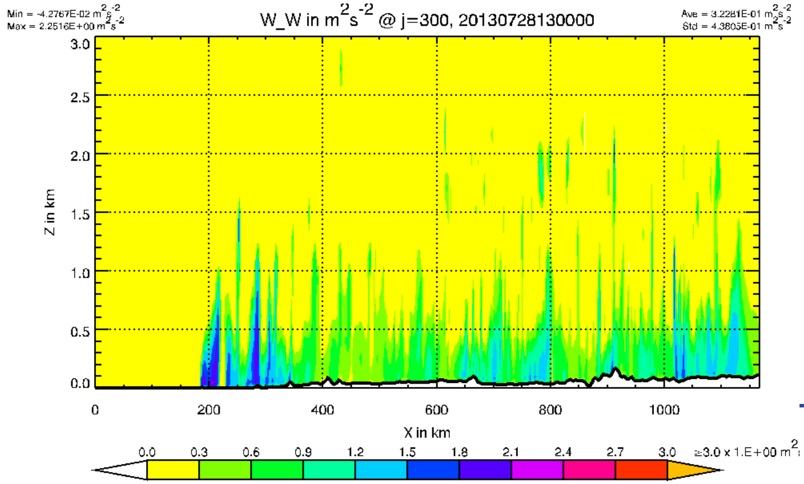




Variances @ j=300 13:00







Summary of case study

The small sensitivity study (only one case) suggests:

- ➔ The accidentially wrong experiment with only positive perturb. increases convective precipitation significantly.
- ➔ After fixing the bug, the effect of perturbations is more or less neutral in this case.
- ➔ Using the modified schemes (itype_blpert=2…8) does not improve the situation. Also, horizontal advection of random numbers does not have a notable effect.
- ➔ Hypothethis: This case is probably not sensitive to PBL triggering mechanisms.
- ➔ From another case study (25.6.2013) I have the impression that the original formulation of the perturbation is somewhat more effective in enhancing the convection triggering compared to my modified versions. This is maybe due to the fact that the modified version has „higher reaching“ warm perturbations, but also „higher reaching“ cold perturbations in the neighbourhood.

Experiment 10223 COSMO-DE driven by ICONEU with EDA for August 2015, comparison to 10168

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Verification against SYNOP available, no FUZZY and no TEMP at the moment:

➔ http://oflxs04.dwd.de/~for3dam/verifikation/Experimentverifikation/list_of_all_experiments_unix.html#10223_national_lm3mo_10168

➔ Setup: COSMO 5.3, but without the change in the infiltration param., so as to be as close as possible to 10168, where COSMO 5.2 was used.

PARAMETER	SETTING	DEFAUT	TYPE
luseblpert	T	F	L
itype_blpert	1	3	I
ladvect_blpert	F	F	L
lseed_use_starttime	T	T	L
blpert_sigma	2.0000	2.5000	R
blpert_const	3.0000	2.0000	R
blpert_fixedtime	900.0000	600.0000	R
seed_val	-999	-999	I

➔ Result: Verification mostly negative, there seems to be a dry bias (increased dew point depression) coming from the assimilation cycle, both for 00 UTC and 12 UTC, and at the same time no bias in the temperature. Hypothesis: more precip in the assimilation cycle dries out the model there, so convection is negatively affected in the forecast. (Todo: Look at precip in the assimilation cycle!)

➔ Other problem: The COSMO-DE routine (5.2 version) was used as the reference, but the test code is 5.3. Not sure how this influenced the assimilation.

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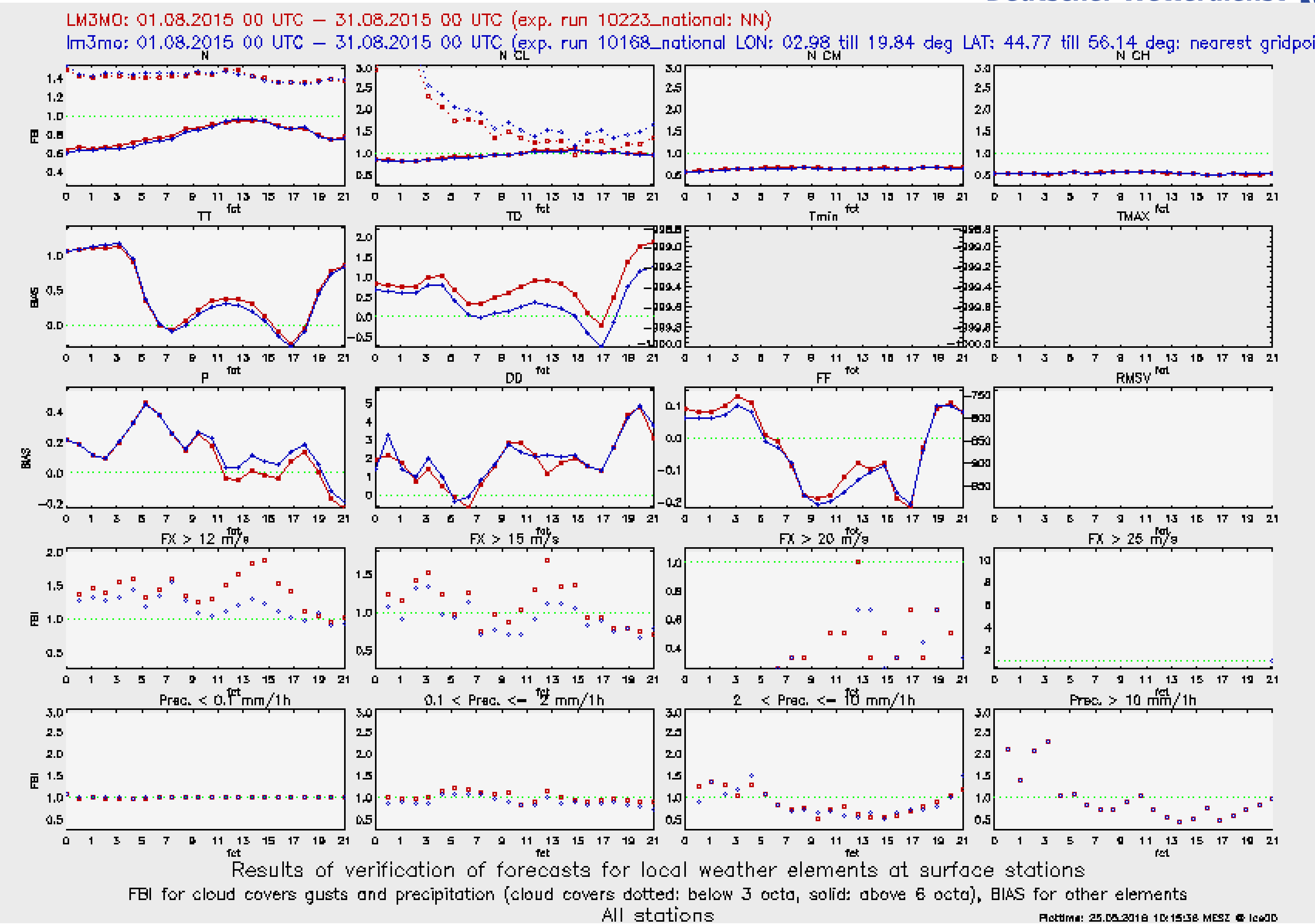

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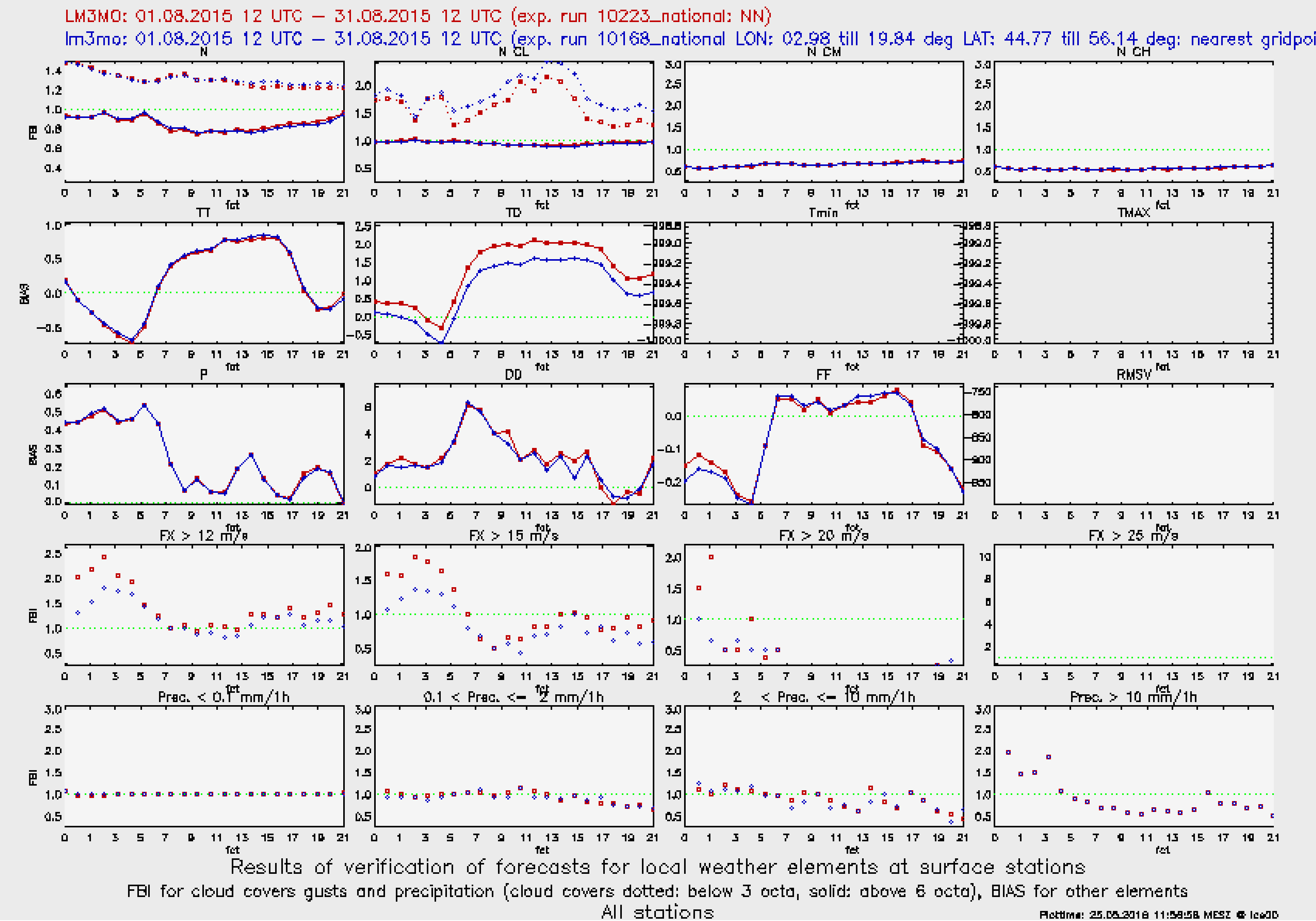
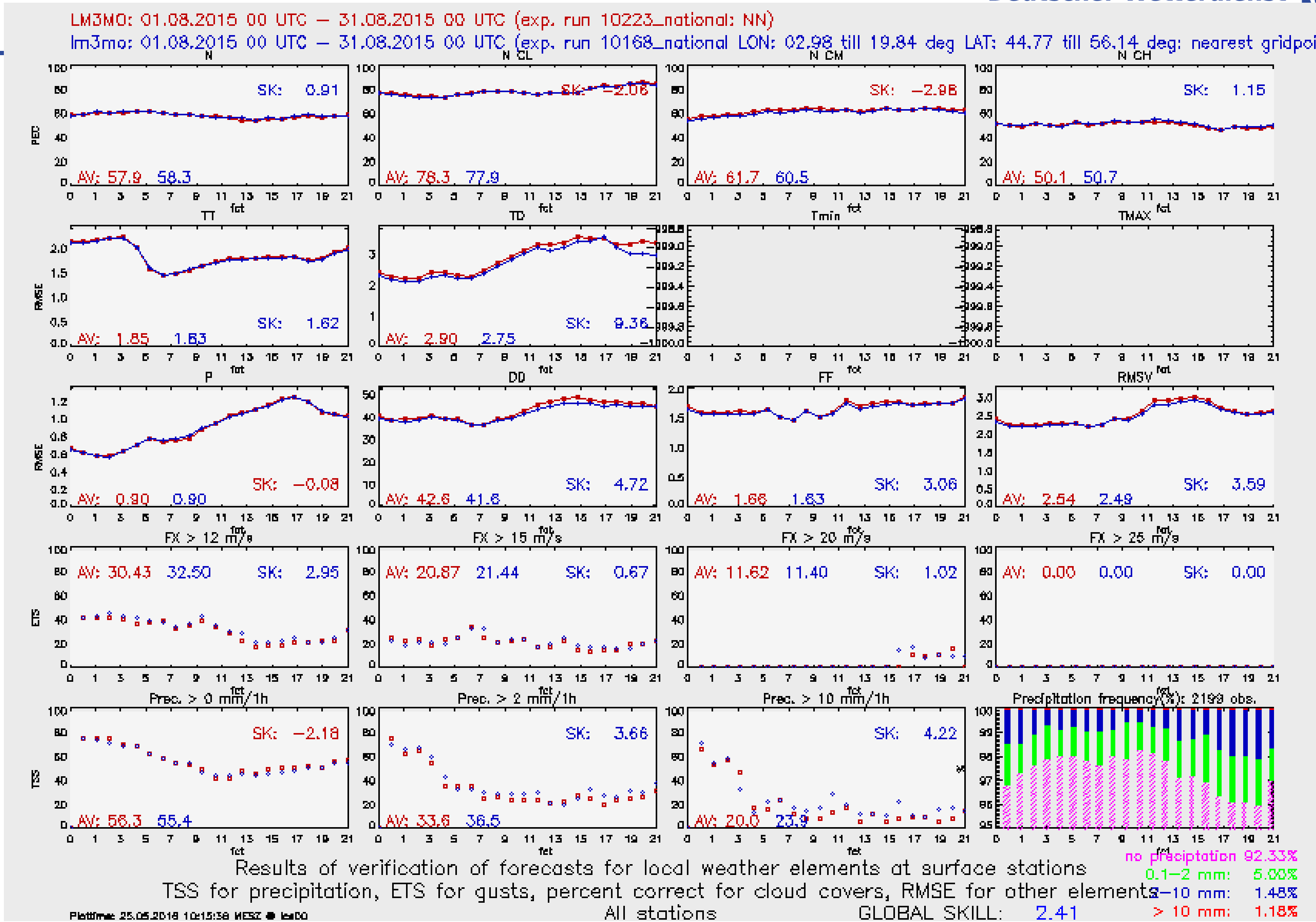
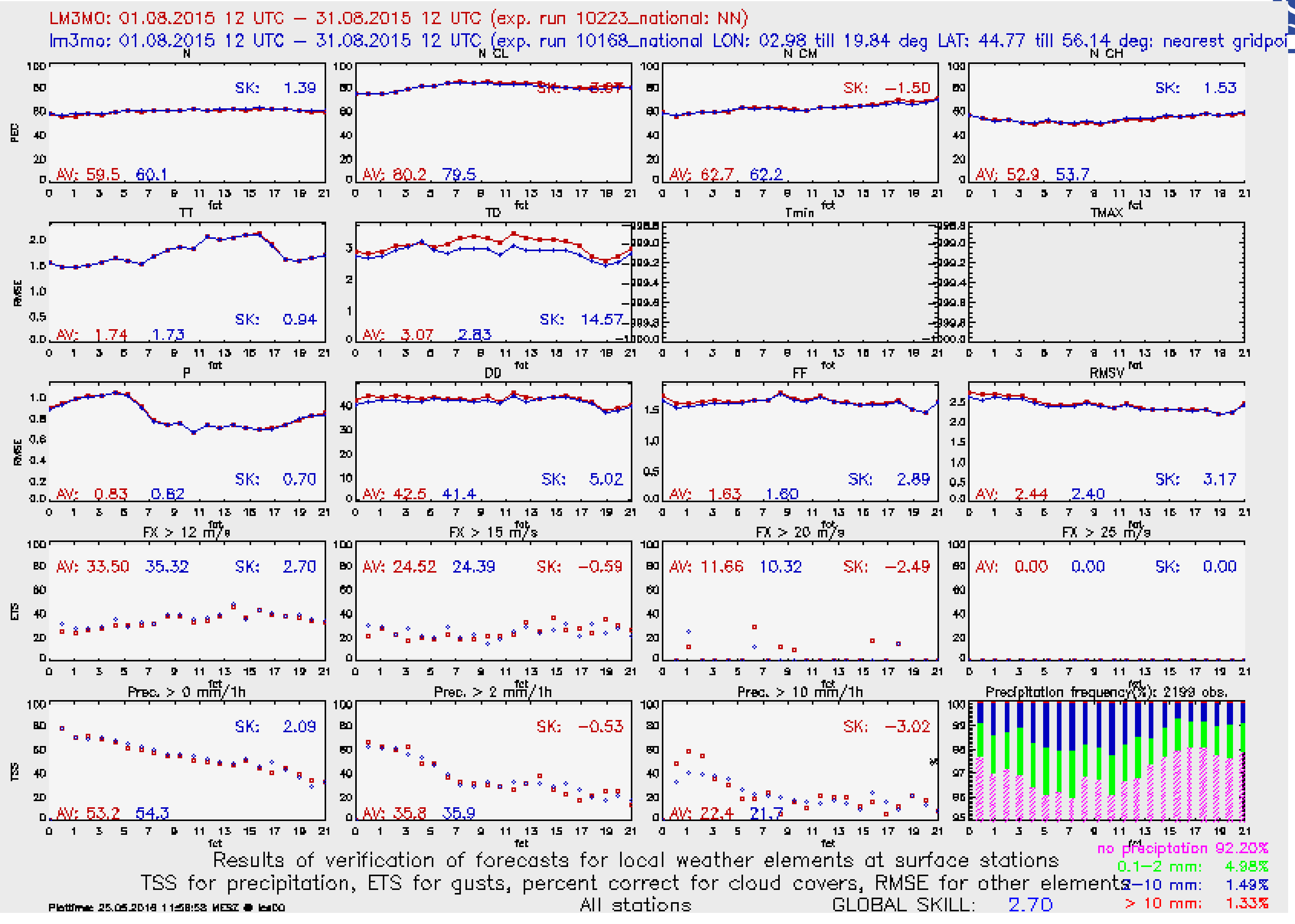



LM3MO: 01.08.2015 00 UTC – 31.08.2015 00 UTC (exp. run 10223_national: NN)
lm3mo: 01.08.2015 00 UTC – 31.08.2015 00 UTC (exp. run 10168_national LON: 02.98 till 19.84 deg LAT: 44.77 till 56.14 deg: nearest gridpoi
N SK: 0.91 AV: 57.9 58.3
N CL SK: –2.06 AV: 78.3 77.9
N CM SK: –2.98 AV: 61.7 60.5
N CH SK: 1.15 AV: 50.1 50.7
TT SK: 1.62 AV: 1.85 1.83
TD SK: 9.36 AV: 2.90 2.75
Tmin
TMAX
P SK: –0.08 AV: 0.90 0.90
DD SK: 4.72 AV: 42.6 41.6
FF SK: 3.06 AV: 1.66 1.63
RMSV SK: 3.59 AV: 2.54 2.49
FX > 12 m/s AV: 30.43 32.50 SK: 2.95
FX > 15 m/s AV: 20.87 21.44 SK: 0.67
FX > 20 m/s AV: 11.62 11.40 SK: 1.02
FX > 25 m/s AV: 0.00 0.00 SK: 0.00
Prec. > 0 mm/1h SK: –2.18 AV: 56.3 55.4
Prec. > 2 mm/1h SK: 3.66 AV: 33.6 36.5
Prec. > 10 mm/1h SK: 4.22 AV: 20.0 23.9
Precipitation frequency(%): 2199 obs.
PEC
RMSE
ETS
TSS
fct
no preciptation 92.33%
0.1–2 mm: 5.00%
2–10 mm: 1.48%
> 10 mm: 1.18%
Results of verification of forecasts for local weather elements at surface stations
TSS for precipitation, ETS for gusts, percent correct for cloud covers, RMSE for other elements
All stations GLOBAL SKILL: 2.41
Plottime: 25.05.2016 10:15:38 MESZ

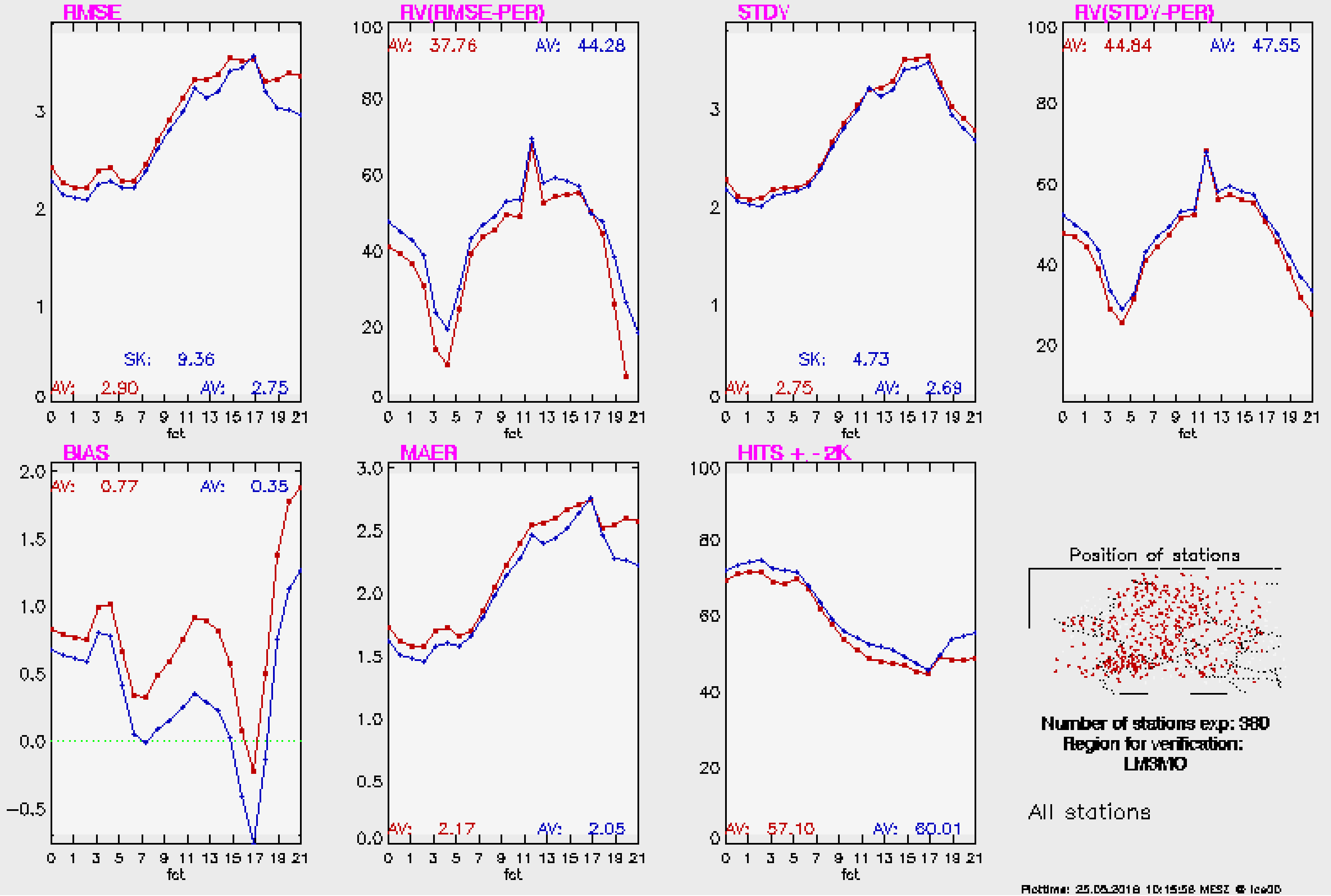

LM3MO: 01.08.2015 12 UTC – 31.08.2015 12 UTC (exp. run 10223_national: NN)
lm3mo: 01.08.2015 12 UTC – 31.08.2015 12 UTC (exp. run 10168_national LON: 02.98 till 19.84 deg LAT: 44.77 till 56.14 deg: nearest gridpoi
N
N CL
N CM
N CH
TT
TD
Tmin
TMAX
P
DD
FF
RMSV
FX > 12 m/s
FX > 15 m/s
FX > 20 m/s
FX > 25 m/s
Prec. > 0 mm/1h
Prec. > 2 mm/1h
Prec. > 10 mm/1h
Precipitation frequency(%): 2199 obs.
no preciptation 92.20%
0.1–2 mm: 4.98%
2–10 mm: 1.49%
> 10 mm: 1.33%
Results of verification of forecasts for local weather elements at surface stations
TSS for precipitation, ETS for gusts, percent correct for cloud covers, RMSE for other elements
All stations
GLOBAL SKILL: 2.70
Plottime: 25.05.2016 11:58:58 MESZ

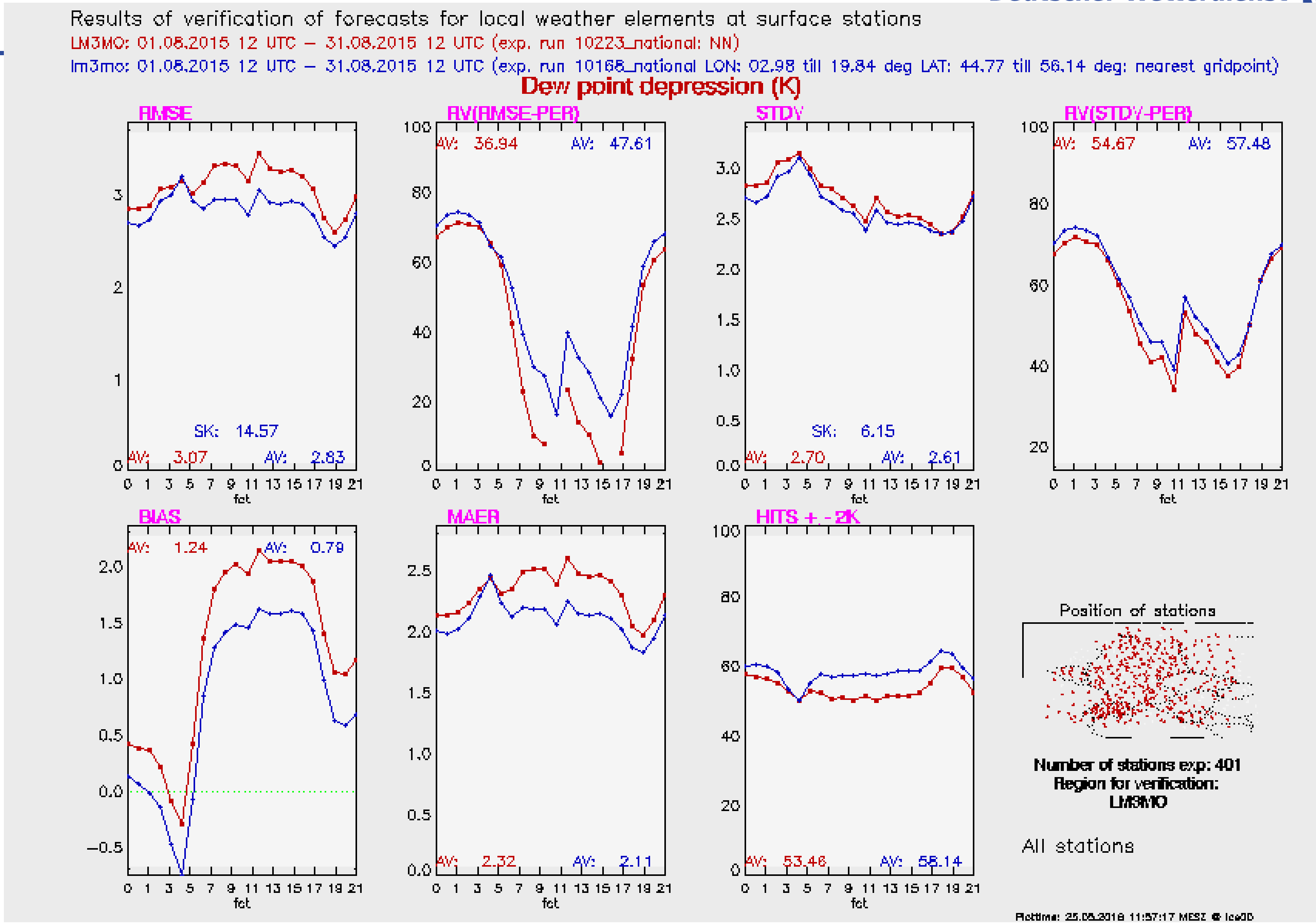
Results of verification of forecasts for local weather elements at surface stations

LM3MO: 01.08.2015 00 UTC – 31.08.2015 00 UTC (exp. run 10223_national: NN)

lm3mo: 01.08.2015 00 UTC – 31.08.2015 00 UTC (exp. run 10168_national LON: 02.98 till 19.84 deg LAT: 44.77 till 56.14 deg: nearest gridpoint)

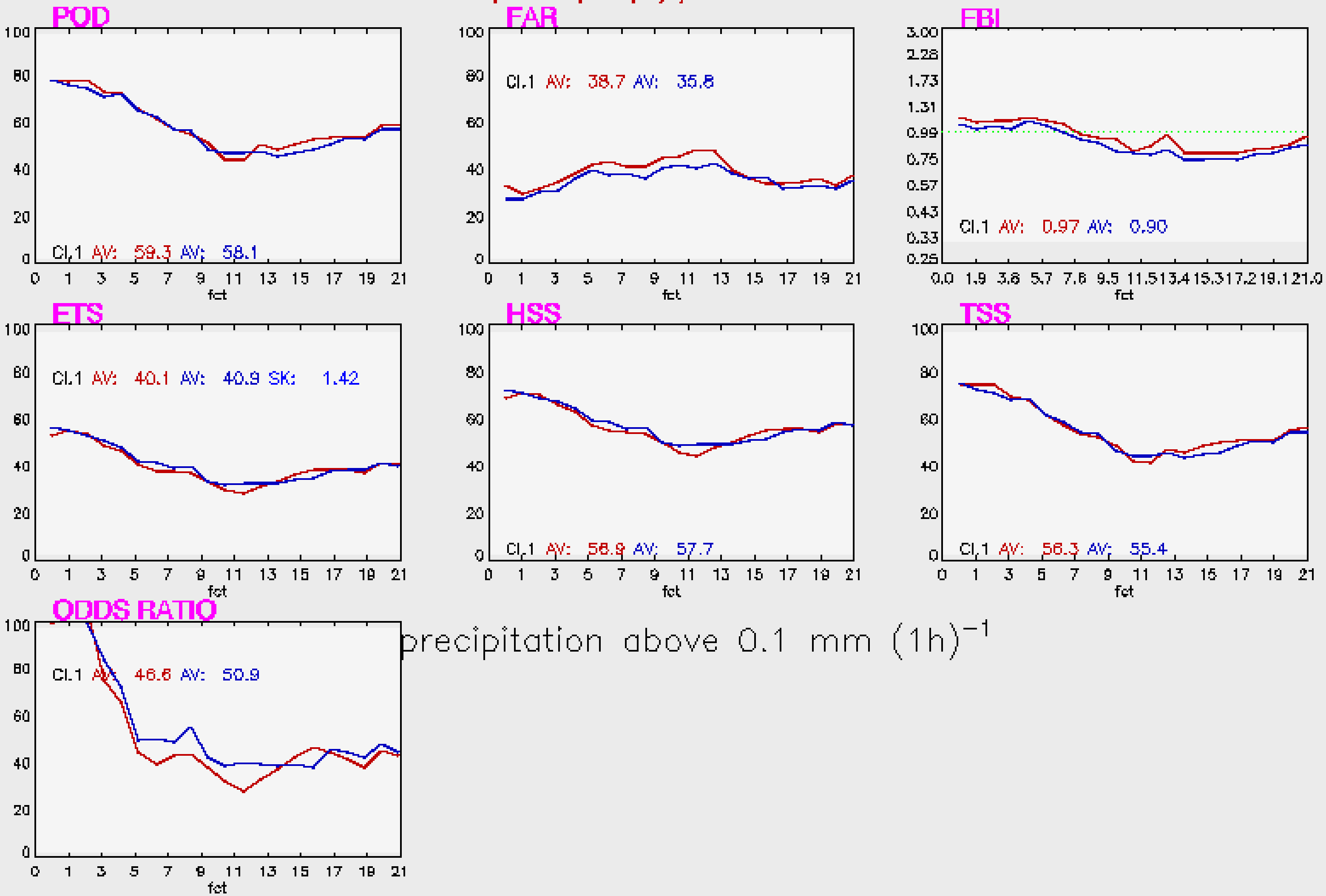
Dew point depression (K)




Results of verification of forecasts for local weather elements at surface stations
LM3MO: 01.08.2015 12 UTC – 31.08.2015 12 UTC (exp. run 10223_national: NN)
lm3mo: 01.08.2015 12 UTC – 31.08.2015 12 UTC (exp. run 10168_national LON: 02.98 till 19.84 deg LAT: 44.77 till 56.14 deg: nearest gridpoint)
Dew point depression (K)
RMSE
SK: 14.57
AV: 3.07 AV: 2.83
RV(RMSE-PER)
AV: 36.94 AV: 47.61
STDV
SK: 6.15
AV: 2.70 AV: 2.61
RV(STDV-PER)
AV: 54.67 AV: 57.48
BIAS
AV: 1.24 AV: 0.79
MAER
AV: 2.32 AV: 2.11
HITS +-2K
AV: 53.46 AV: 58.14
fct
Position of stations
Number of stations exp: 401
Region for verification:
LM3MO
All stations

Results of verification of forecasts for local weather elements at surface stations

Element: Precipitation (mm (1h)$^{-1}$) All stations

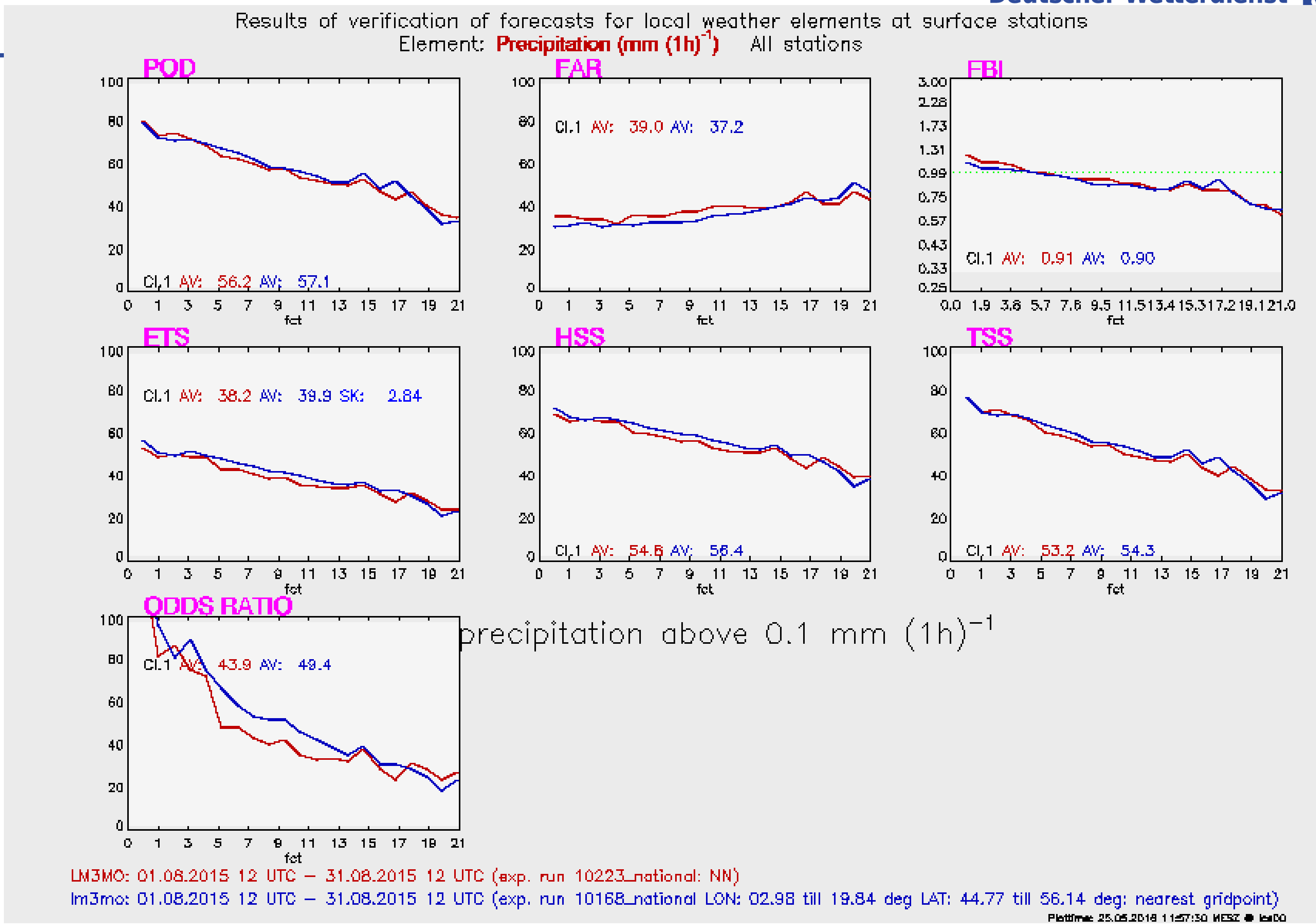


precipitation above 0.1 mm (1h)$^{-1}$

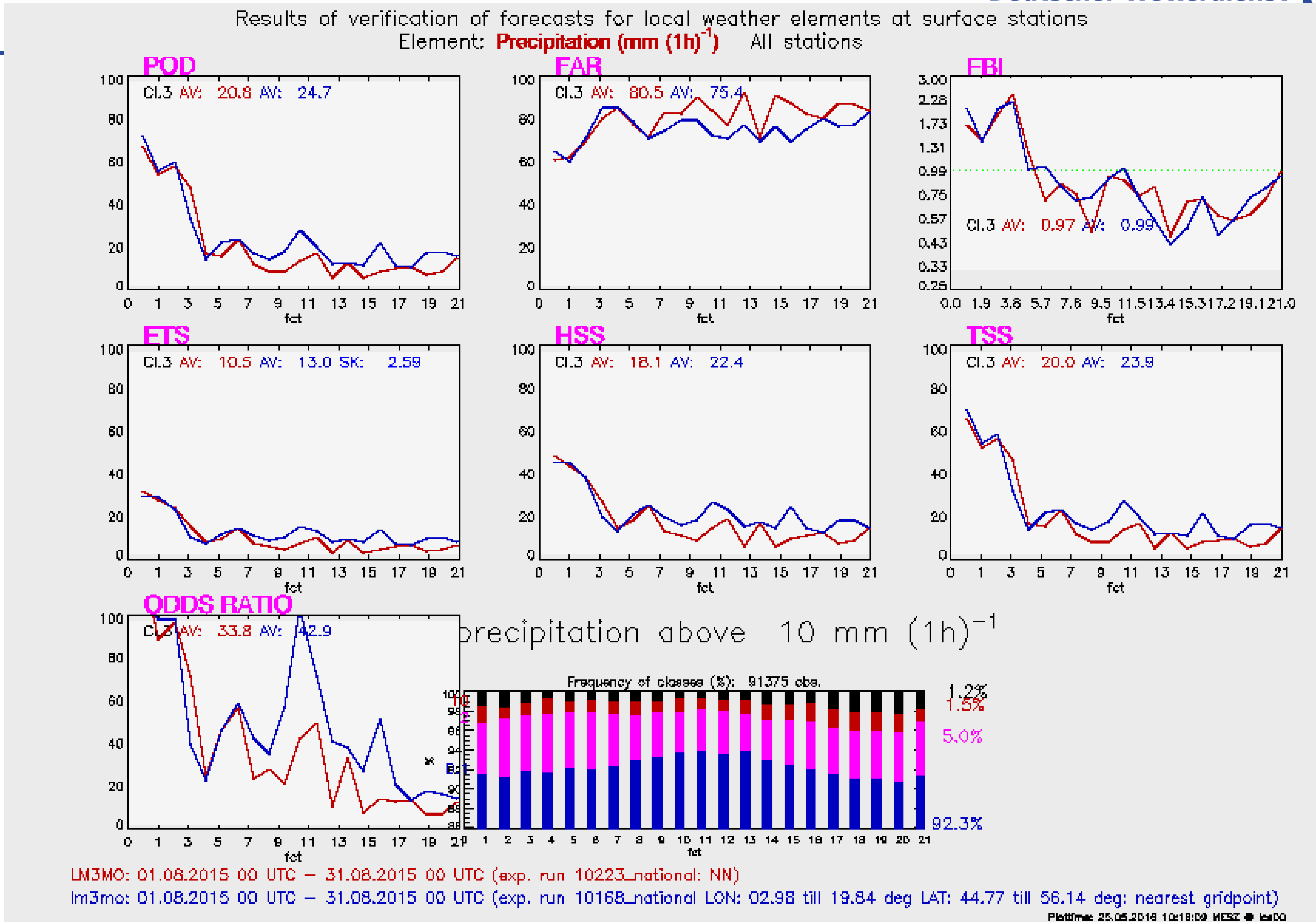
LM3MO: 01.08.2015 00 UTC – 31.08.2015 00 UTC (exp. run 10223_national: NN)

lm3mo: 01.08.2015 00 UTC – 31.08.2015 00 UTC (exp. run 10168_national LON: 02.98 till 19.84 deg LAT: 44.77 till 56.14 deg: nearest gridpoint)

Plottime: 25.05.2016 10:18:08 MESZ



precipitation above 0.1 mm $(1h)^{-1}$


Results of verification of forecasts for local weather elements at surface stations
Element: Precipitation (mm (1h)$^{-1}$) All stations
POD
Cl.3 AV: 20.8 AV: 24.7
FAR
Cl.3 AV: 80.5 AV: 75.4
FBI
Cl.3 AV: 0.97 AV: 0.99
ETS
Cl.3 AV: 10.5 AV: 13.0 SK: 2.59
HSS
Cl.3 AV: 18.1 AV: 22.4
TSS
Cl.3 AV: 20.0 AV: 23.9
ODDS RATIO
Cl.3 AV: 33.8 AV: 42.9
fct
precipitation above 10 mm (1h)$^{-1}$
Frequency of classes (%): 91375 obs.
1.2%
1.5%
5.0%
92.3%
LM3MO: 01.08.2015 00 UTC – 31.08.2015 00 UTC (exp. run 10223_national: NN)
lm3mo: 01.08.2015 00 UTC – 31.08.2015 00 UTC (exp. run 10168_national LON: 02.98 till 19.84 deg LAT: 44.77 till 56.14 deg: nearest gridpoint)

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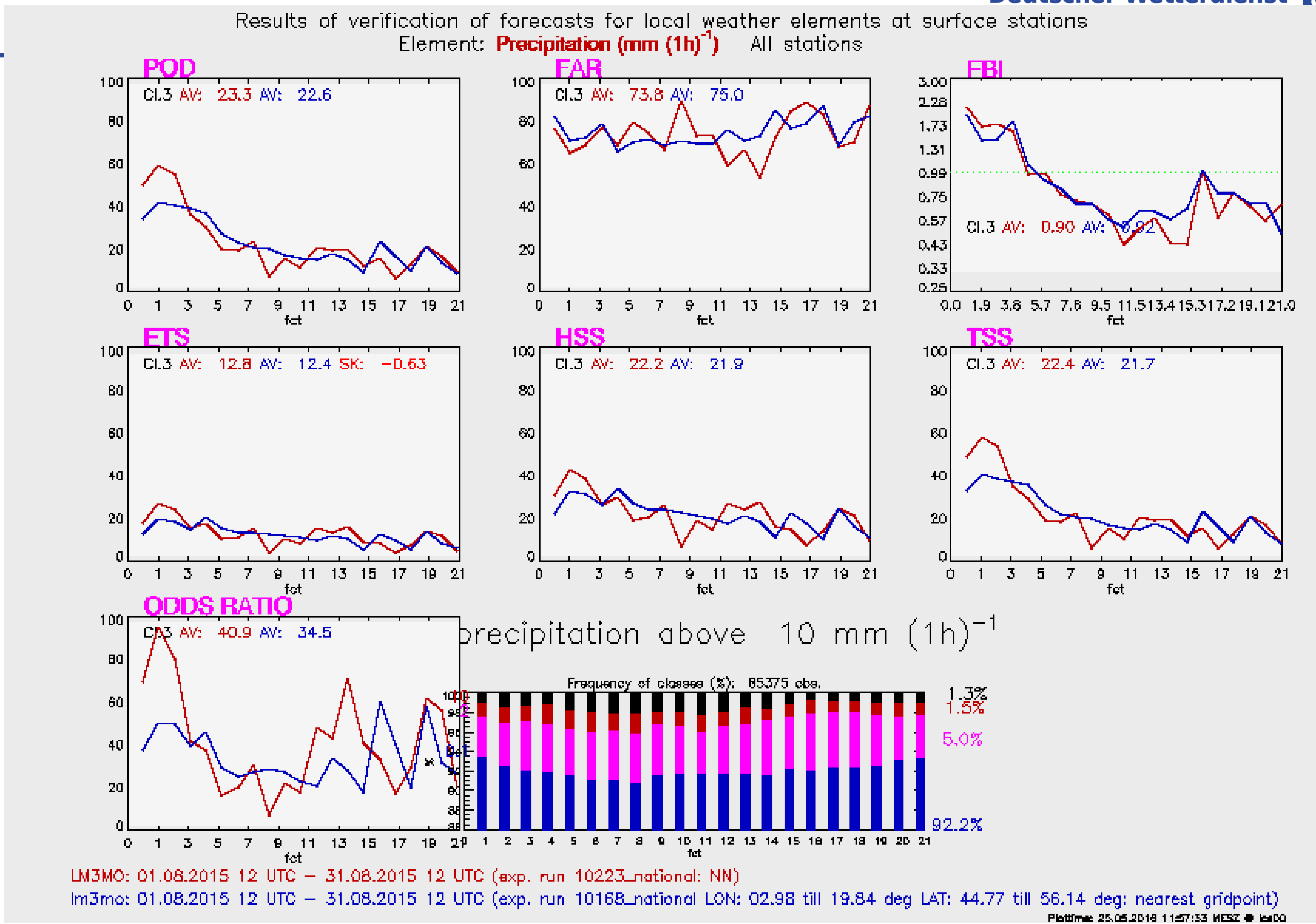
DWD



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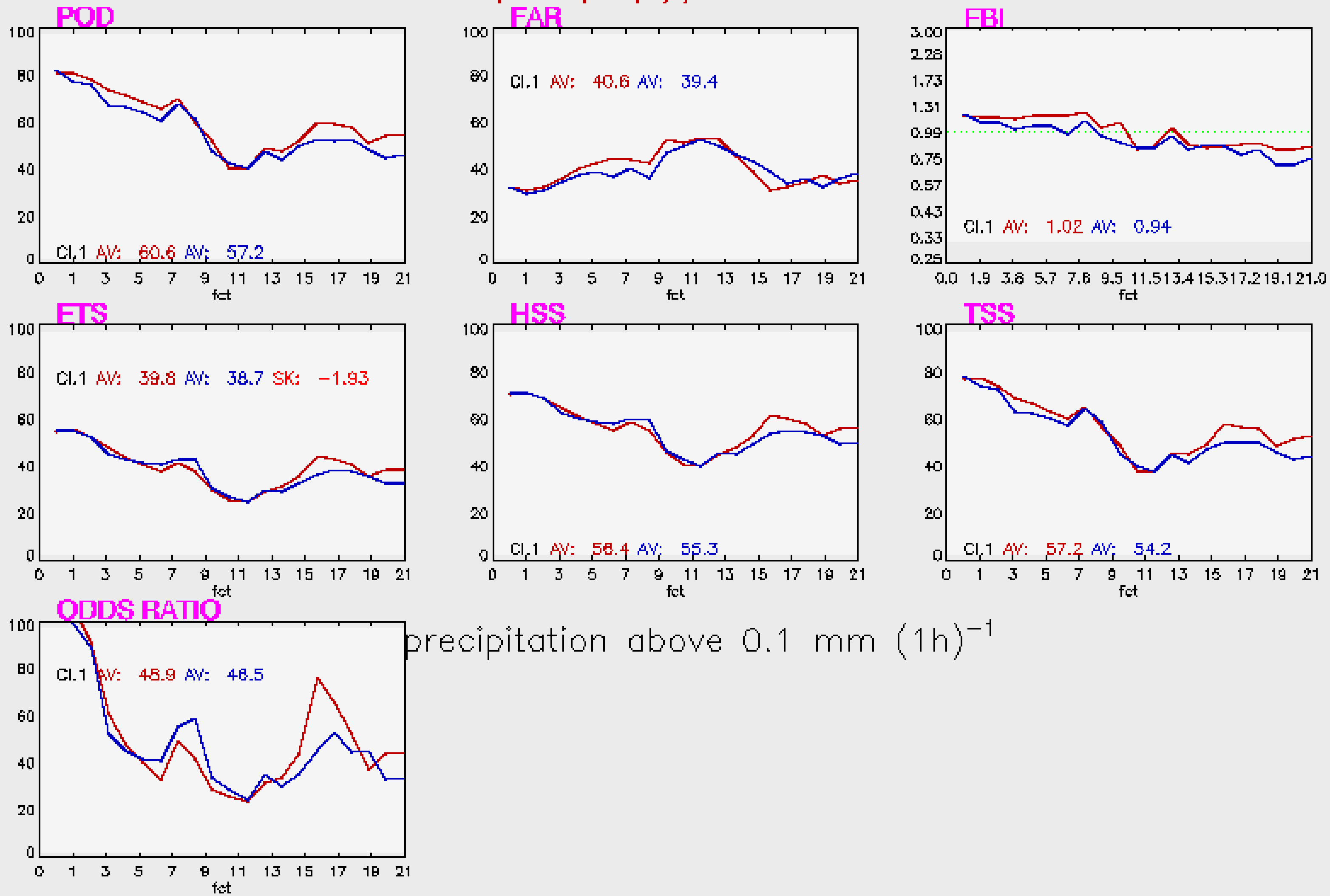
Results of verification of forecasts for local weather elements at surface stations

Element: **Precipitation (mm (1h)$^{-1}$)** Stations below 100 m



precipitation above 0.1 mm (1h)$^{-1}$

LM3MO: 01.08.2015 00 UTC – 31.08.2015 00 UTC (exp. run 10223_national: NN)

lm3mo: 01.08.2015 00 UTC – 31.08.2015 00 UTC (exp. run 10168_national LON: 02.98 till 19.84 deg LAT: 44.77 till 56.14 deg: nearest gridpoint)

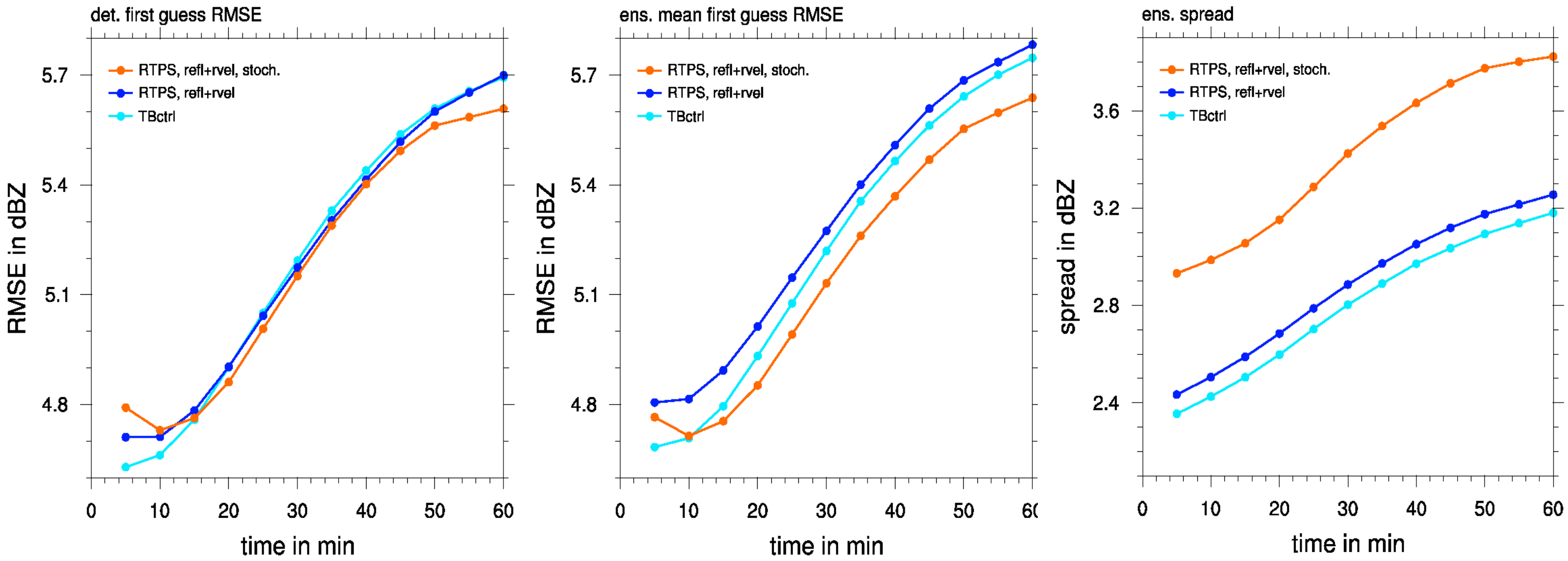
Plottime: 25.05.2016 10:18:25 MESZ ● lex00

First COSMO-DE-KENDA experiment

- Done by Axel Seifert
- COSMO-DE-KENDA incl. Radar (dBZ and v_r), 1-moment graupel scheme
- 22. – 28.7.2014 (same as in Bick et al., 2016)
- KENDA 1h assimilation cycle + deterministic 24 h forecast
- adaptive localization for conventional data
- fixed localization for radar data
- Return to prior spread
- blpert_sigma=1.5, blpert_const=2.0 itype_blpert = 1 ladvect_blpert = .FALSE. blpert_fixedtime=1200.0
- **Result: spread increases and RMS decreases in the analysis, but this positive signal is not preserved for very long in the determ. forecast (see next 2 slides)**
- Needs more experimentation:
  - Forecast with or without perturbations?
  - Re-tuning of other parameters to compensate the precipitation underestimation in the forecast?

First COSMO-DE-KENDA experiment

➔ Spread and RMSE in the 1 h assimilation cycle:



TBctrl = setup of Bick et al (2016) for reference
(no radial winds, fixed localization for conv. data)

First COSMO-DE-KENDA experiment

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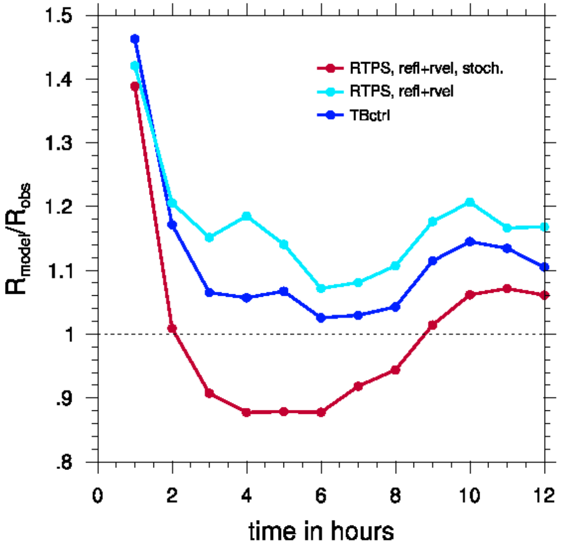
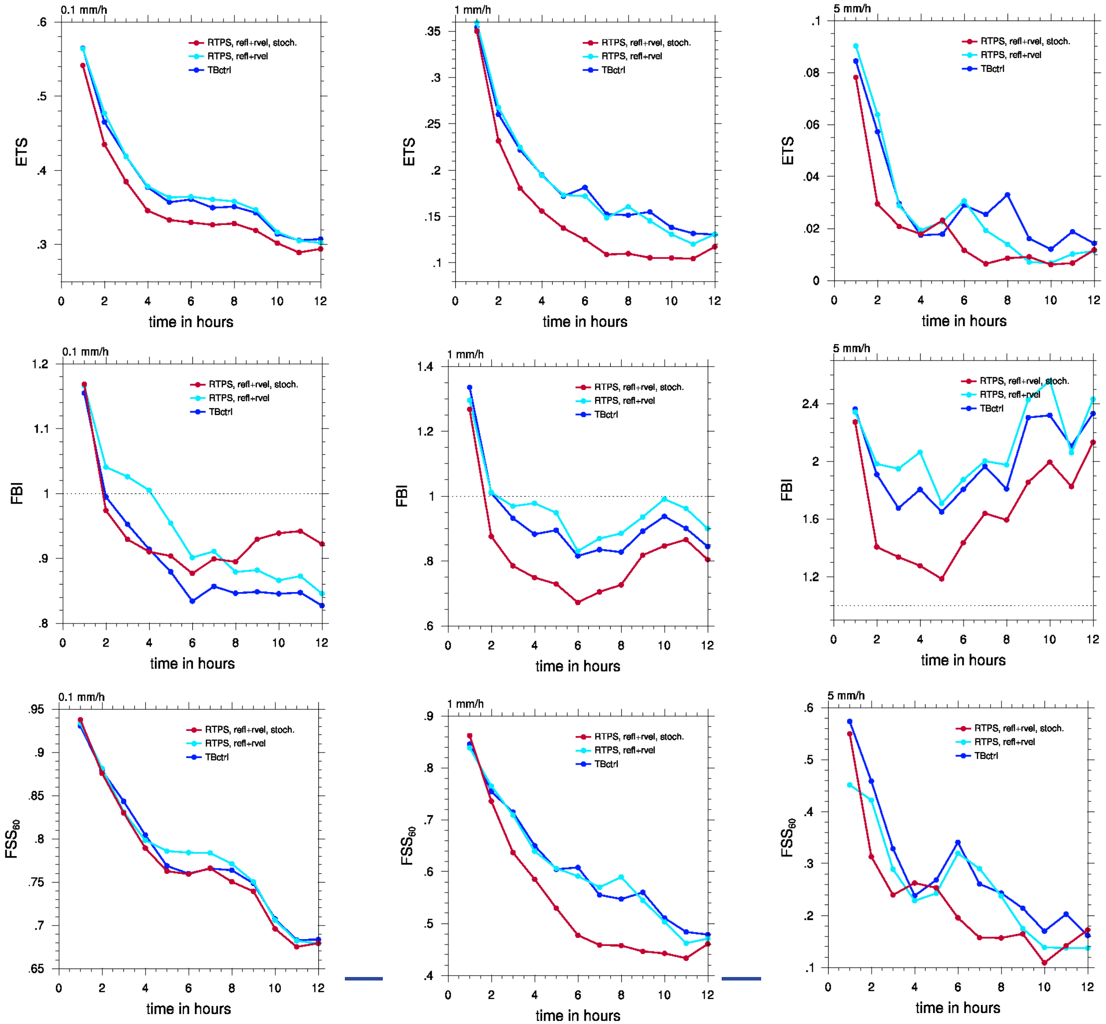
➔ ETS, FBI and FSS_{21x21} (~60 km scale) of deterministic precipitation forecast for thresholds 0.1, 1, 5 mm/h:

Domain average precipitation rate vs. obs.





Summary up to now

- ➔ Method works technically.
- ➔ Perturbations are introduced in the PBL when the PBL is „convectively active“ according to the turbulence parameterization. Perturbations are proportional to SGS standard deviations (second moments) of the perturbed quantities (T, QV, W). Conversely, no perturbations in stable situations.
- ➔ Depending on the weather situation, this can alter the triggering of convection by PBL processes in a physically plausible way.
- ➔ Sensitivities to the namelist parameters have been explored by 2 case studies
- ➔ First COSMO-DE-KENDA experiment is promising in the assimilation cycle. Some obvious problems in the deterministic forecast, started from the KENDA analysis remain to be solved.