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Running COSMO with single precision

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COSMO General Meeting
3 September 2013, Sibiu

Motivation & Goal

- The advantages of single precision computing:
  - `real(kind=8) :: a  ! I am 8 Bytes`
  - `real(kind=4) :: b  ! I am 4 Bytes`

  - Move less information
  - Keep more numbers in cache
  - Lower precision arithmetic is faster

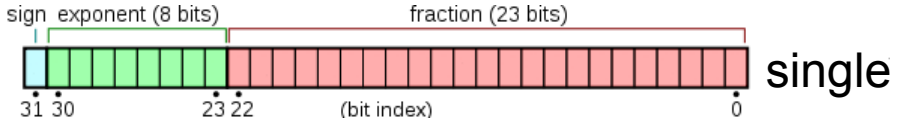
- Goal: one single place in code to define working precision

Floating point numbers

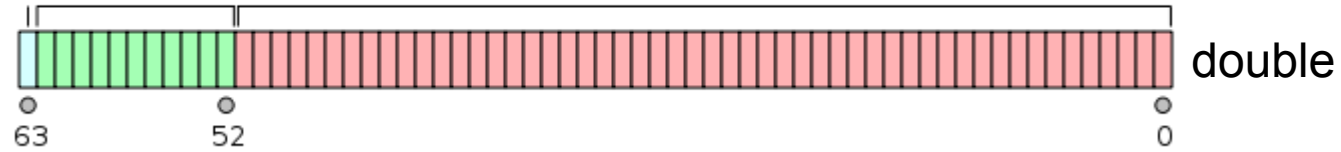
- Most computers follow the IEEE 754 standard

$$x = (-1)^s \cdot c \cdot b^q$$

s	sign
c	significand (coefficient)
b	base
q	exponent



single



double

- range and precision

	max	min	digits	precision
single	10^{38}	10^{-38}	7.2	10^{-7}
double	10^{308}	10^{-308}	16.0	10^{-16}

What happened so far…

- **Bachelor thesis Katharina Riedinger (2011)**
  - showed that using single precision in the fast wave solver of COSMO provides sufficient accuracy for meteorologically relevant situations

- **Internship Jérémie Despraz (2012)**
  - showed single precision provides sufficient accuracy for COSMO physics with minimal code changes except for radiation
  - developed a single precision prototype of COSMO

- **Internship Stefan Rüdisühli (2013 ongoing)**
  - clean implementation of single precision in current COSMO version with extensive validation

Errors Sources

- Cancellation error (e.g. finite differences)

$$\partial T/\partial x \quad \Delta x \approx T\downarrow 1 - T\downarrow 2 = 293.1876 - 292.9056 = 0.2820??$$

- Arithmetic overflow (e.g. due to large number)

  $a\uparrow 4 \,/\, b\uparrow 3$

- Code branches

  if (x-y < 10^{-9}) then

Code changes

- declaration of all reals with *_ireals* (globally)
- introduction of ireals8 to use doubles where required
- mixed precision in radiation
- re-formulation of “SP-unfriendly” calculations, e.g.
  $a\uparrow 4 / b\uparrow 3 = a\,(\,a/b\,)\uparrow 3$
- new global variables: rprecision, repsilon
- rprecision as abortion criterion (currently not used)
- replace hardcoded local epsilons (e.g. 10^{-30}) by repsilon

repsilon usage

- global variable allows precision-dependent definition
- very small number above zero
  - set to 1e6*TINY = 1E-32 (SP) / 2E-302 (DP)
- mainly used in divisions to avoid division-by-zero, e.g.
  - zr = zdqr / (zdql + repsilon)
  - zsdau = zsvidep / MAX(zztau, repsilon)
- further used in IF-statements, e.g.
  - IF (rho > c1+epsy) THEN ...

repsilon usage

- so far, all epsilons in divisions replaced by *repsilon*
  - obvious purpose: avoid division by zero
- remaining epsilons mostly *epsy* (in assimilation)
  - all other local epsilons (often only used once of twice per definition) also replaced by *repsilon*
- option: non-global, but not-too-local epsilons (module variables)
  - *epsy* already is such a variable for data assimilation (data_obs_lib_cosmo)

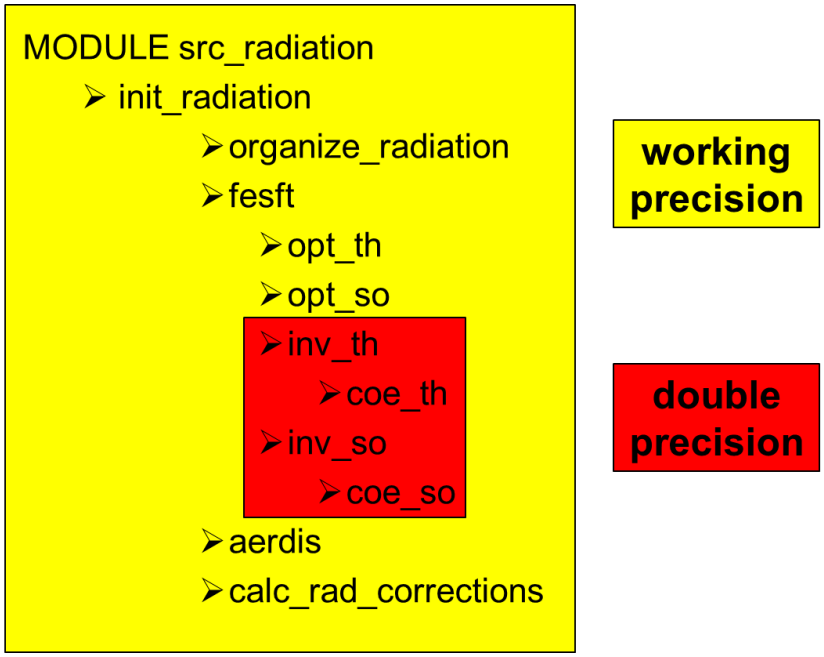
repsilon occurrence

file (~.f90)	variable	value	#
near_surface	zepsi	1.0E-06	1
numeric_utilities	zeps	1.0E-15	7
numeric_utilities_rk	zeps	1.0E-15	17
numeric_utilities_rk	eps	1.0E-06	6
pp_utilities	eps	1.0E-15	12
src_correl_cutoff	epsy	1.0E-08	3
src_gscp	zeps	1.0E-15	3
src_lheat_nudge	epsilon	1.0E-35	2
src_mult_local	epsy	1.0E-08	2
src_mult_spread	epsy	1.0E-08	33
src_obs_proc_air	epsy	1.0E-08	1
src_obs_processing	epsy	1.0E-08	1
src_sing_local	epsy	1.0E-08	1
src_sing_spread	epsy	1.0E-08	8
src_soil	zepsi	1.0E-06	6
src_soil_multlay	zepsi	1.0E-06	12
src_soil_multlay	epsi	1.0E-06	4

Mixed-precision radiation

Problem: radiation doesn't work in SP (so far)

- becomes unstable after ~ +8h (in our setup)
- rather a technical (not physical) problem
- work-around: run critical parts in DP
- critical parts: inversion and coefficients



Sensitivity experiments

- Validation of code changes
- Setup of COSMO-7 with +72h lead time
- COSMO version 4.26
- Experiments
  - original version (OR)
  - modified version with reals as doubles (DP)
  - original version with random perturbations (PR)

Random perturbations

- Addition of missing _ireals removes random digits in DP
  - Hypothesis: main reason for deviations of DP from OR

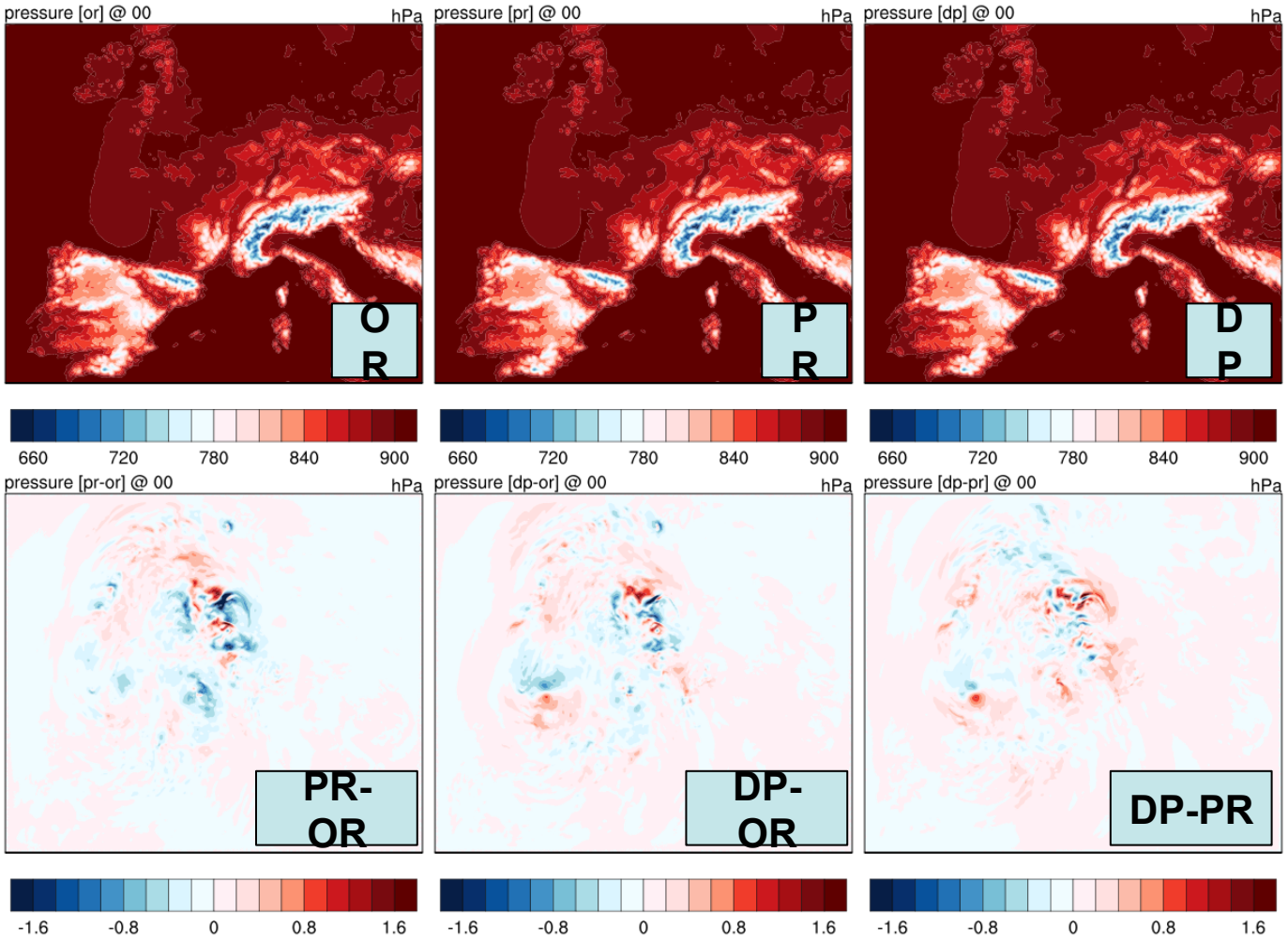
2.0	2.0_ireals
2.000000437165203	2.000000000000000

- Simulate this effect by adding random fields => PR
  - Magnitude O(1.0E-7) , added every time step
  - Fields: PP, T, U, V, W, QV, QC, QI, QR, QS, QG

- Compare deviations PR-OR to DP-OR

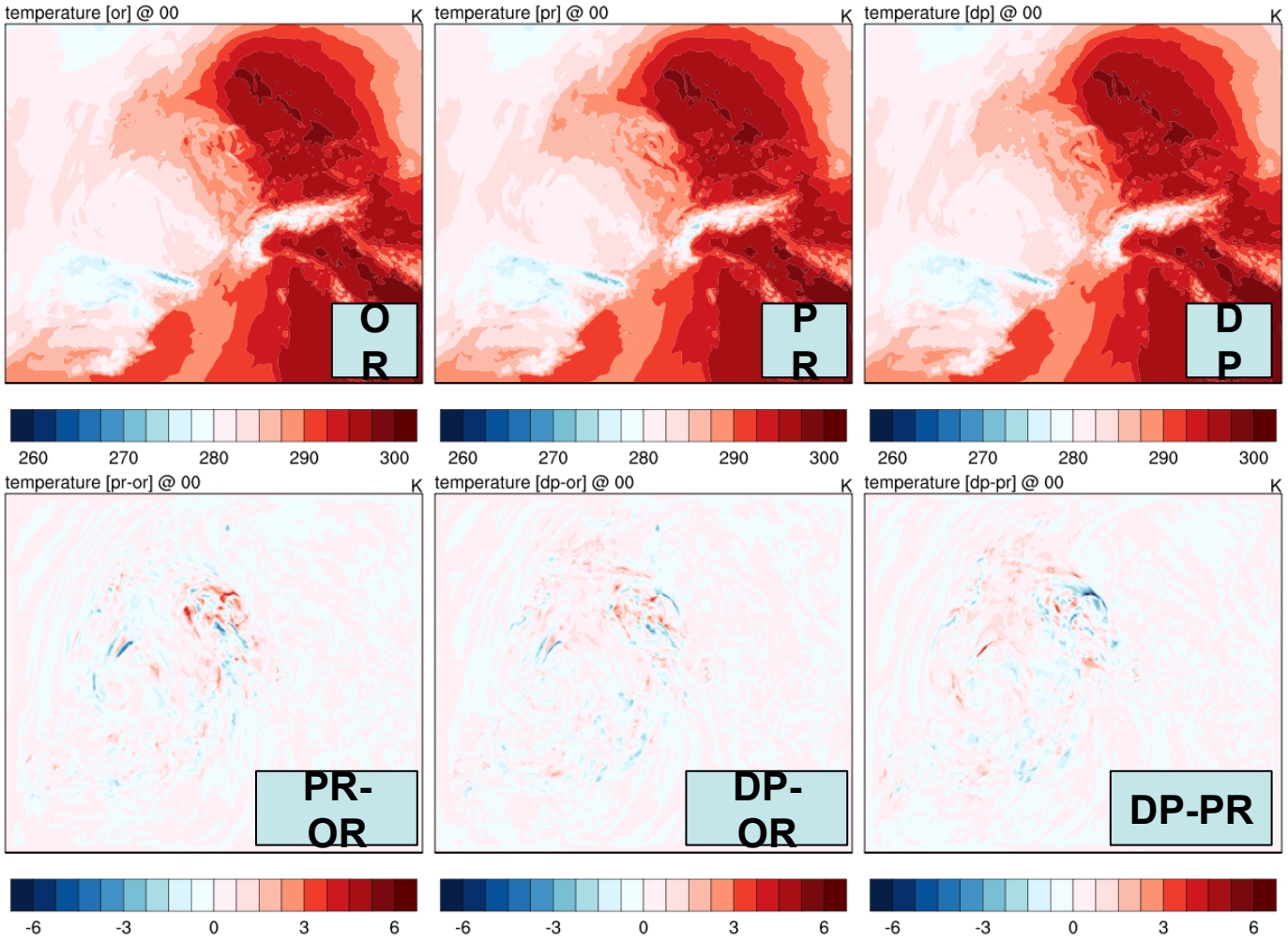
OR vs. DP and PR (+72h)

pressure @ surface



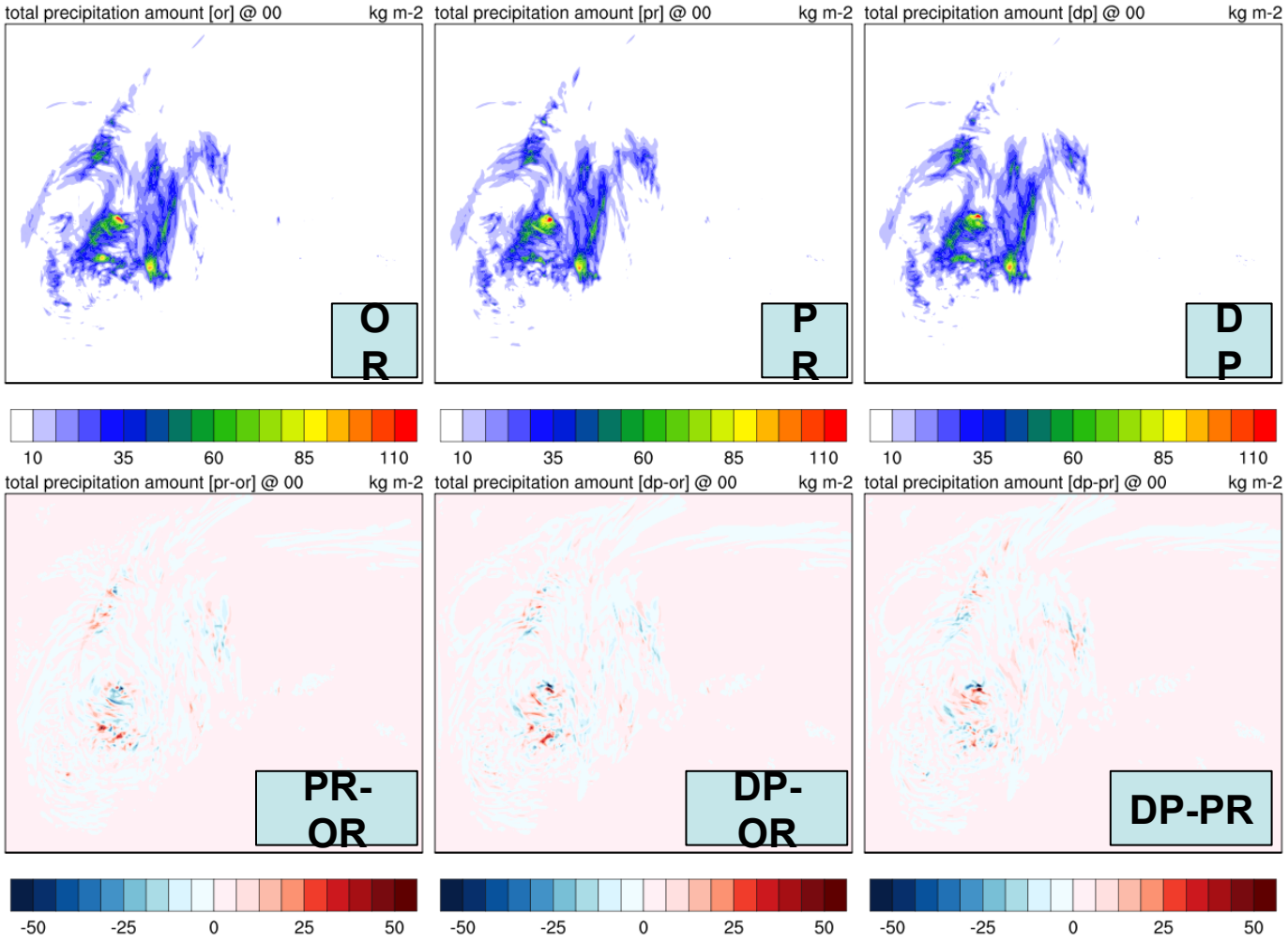
OR vs. DP and PR (+72h)

temperature @ surface



OR vs. DP and PR (+72h)

accumulated precipitation @ surface

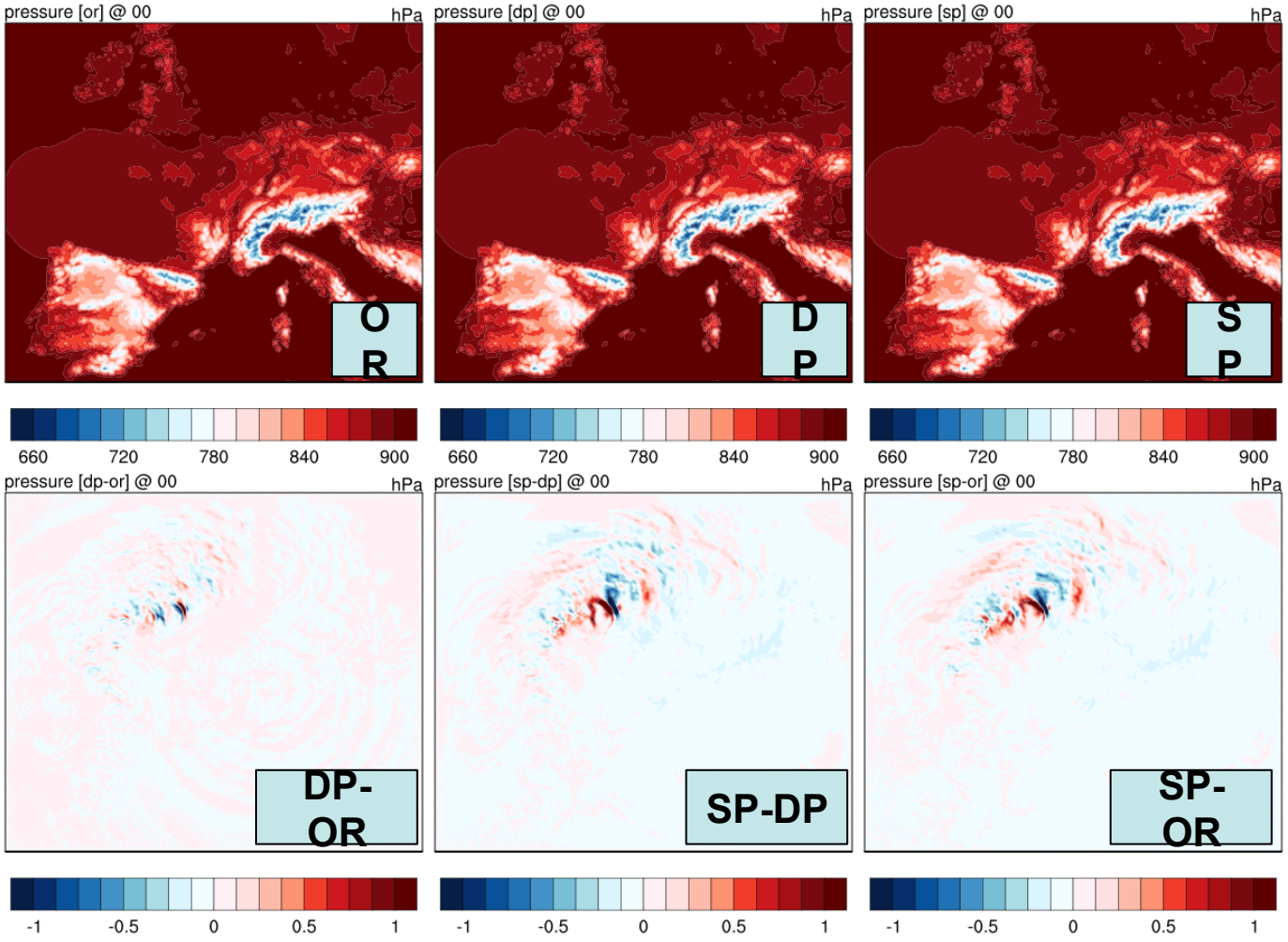


Summary OR vs. double precision

- Deviations of PR and DP from OR of same magnitude
- Reasonable assumption: deviations of DP from OR due to additional _ireals (elimination of random digits beyond 1.0E-7)

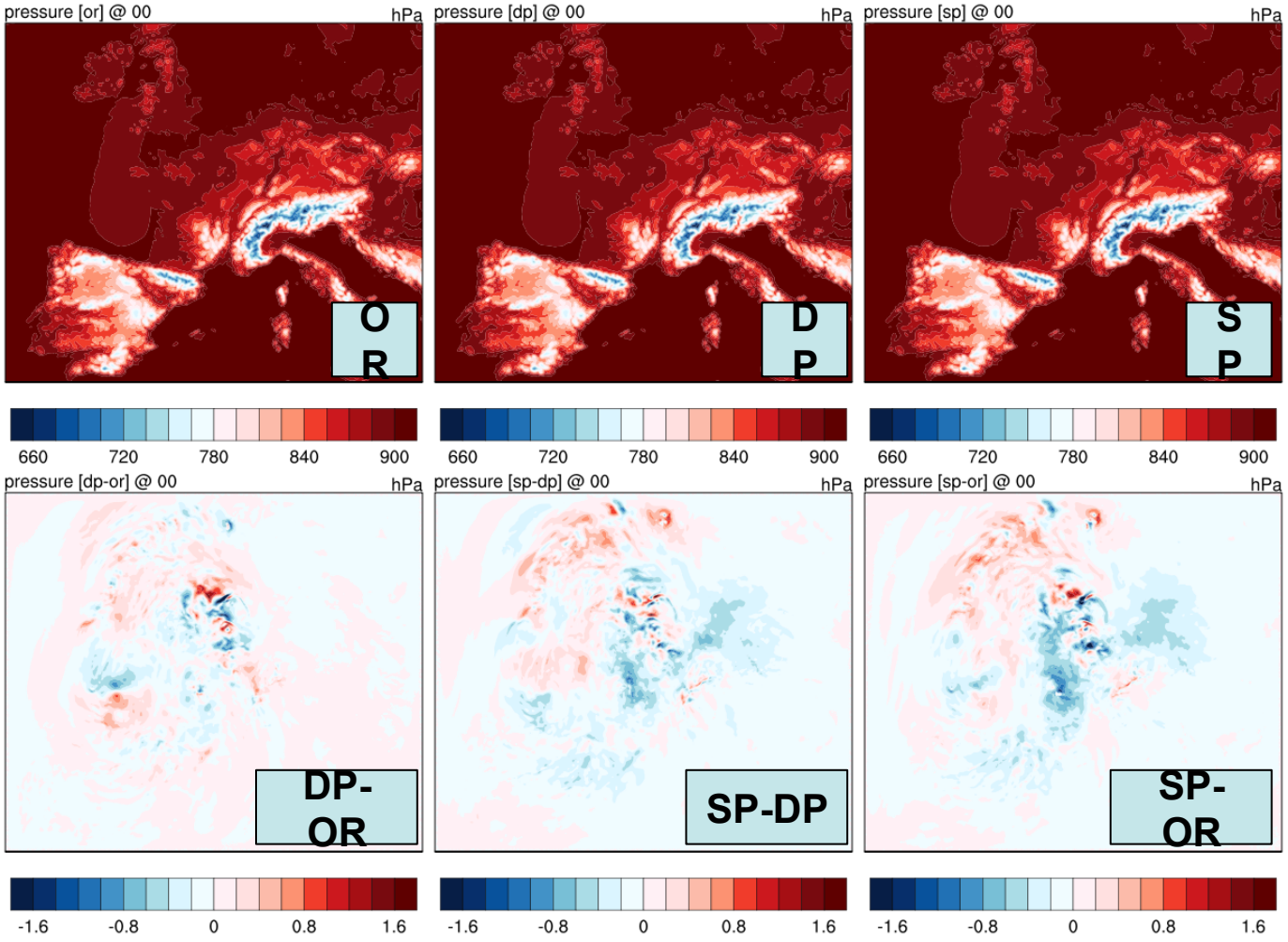
Single vs. double precision (+12h)

pressure @ surface



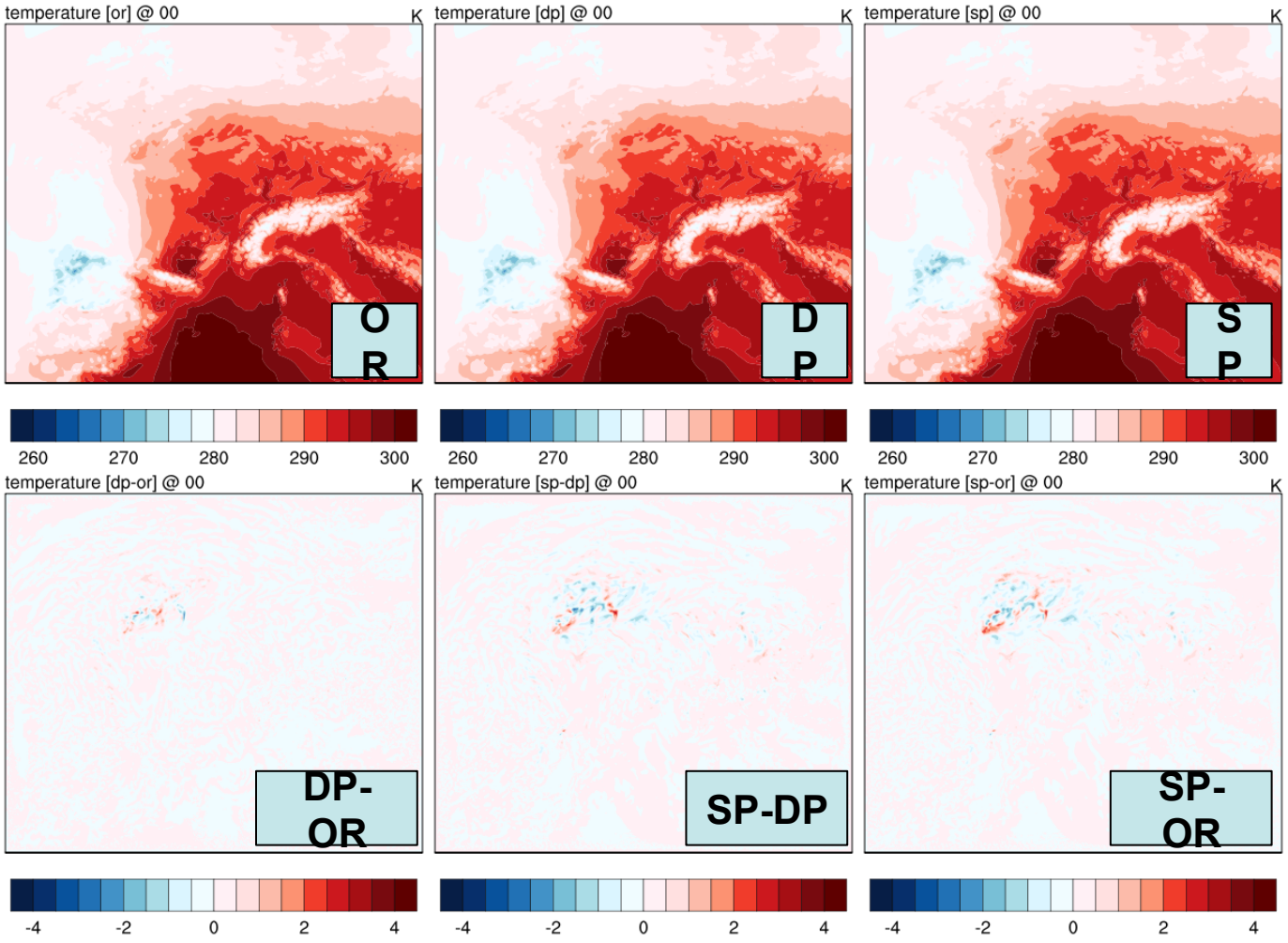
Single vs. double precision (+72h)

pressure @ surface



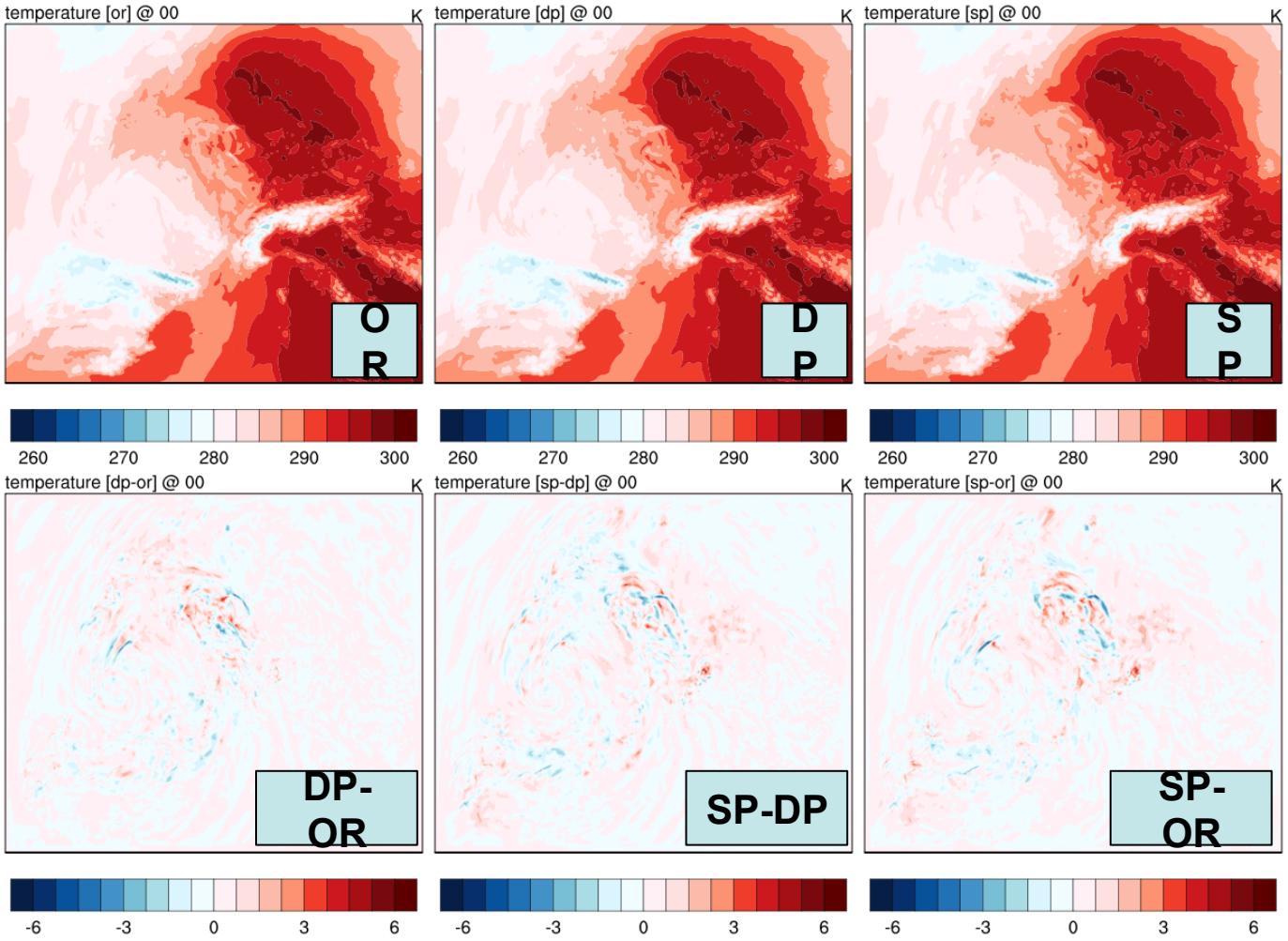
Single vs. double precision (+12h)

temperature @ surface



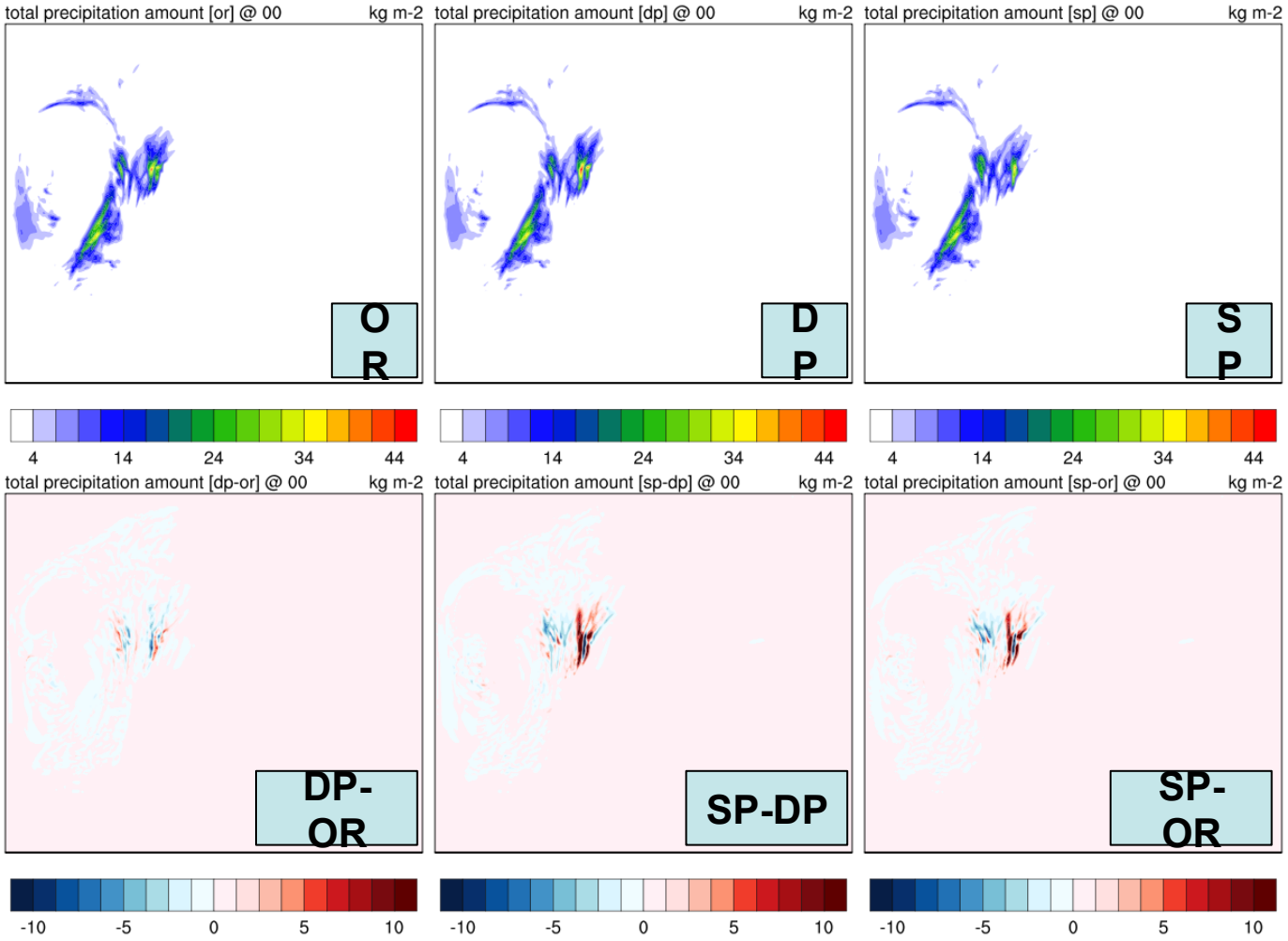
Single vs. double precision (+72h)

temperature @ surface



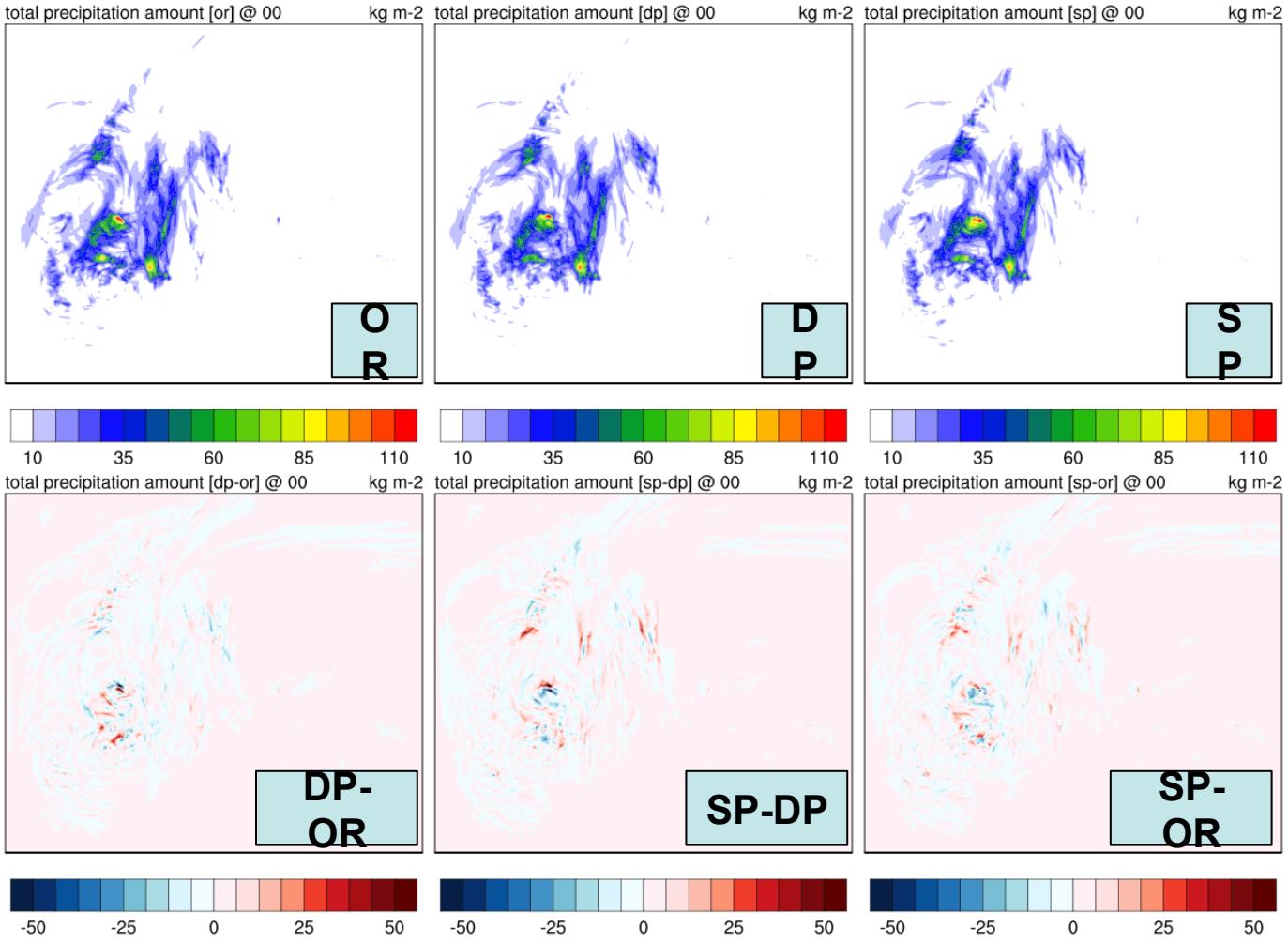
Single vs. double precision (+12h)

accumulated precipitation @ surface



Single vs. double precision (+72hr)

accumulated precipitation @ surface



Single vs. double precision

- Deviation growth in first +12h clearly larger with SP than with DP vs. original code (OR)
- After +72h deviations with SP still somewhat larger but comparable
- Ready for test suite and verification against observations!

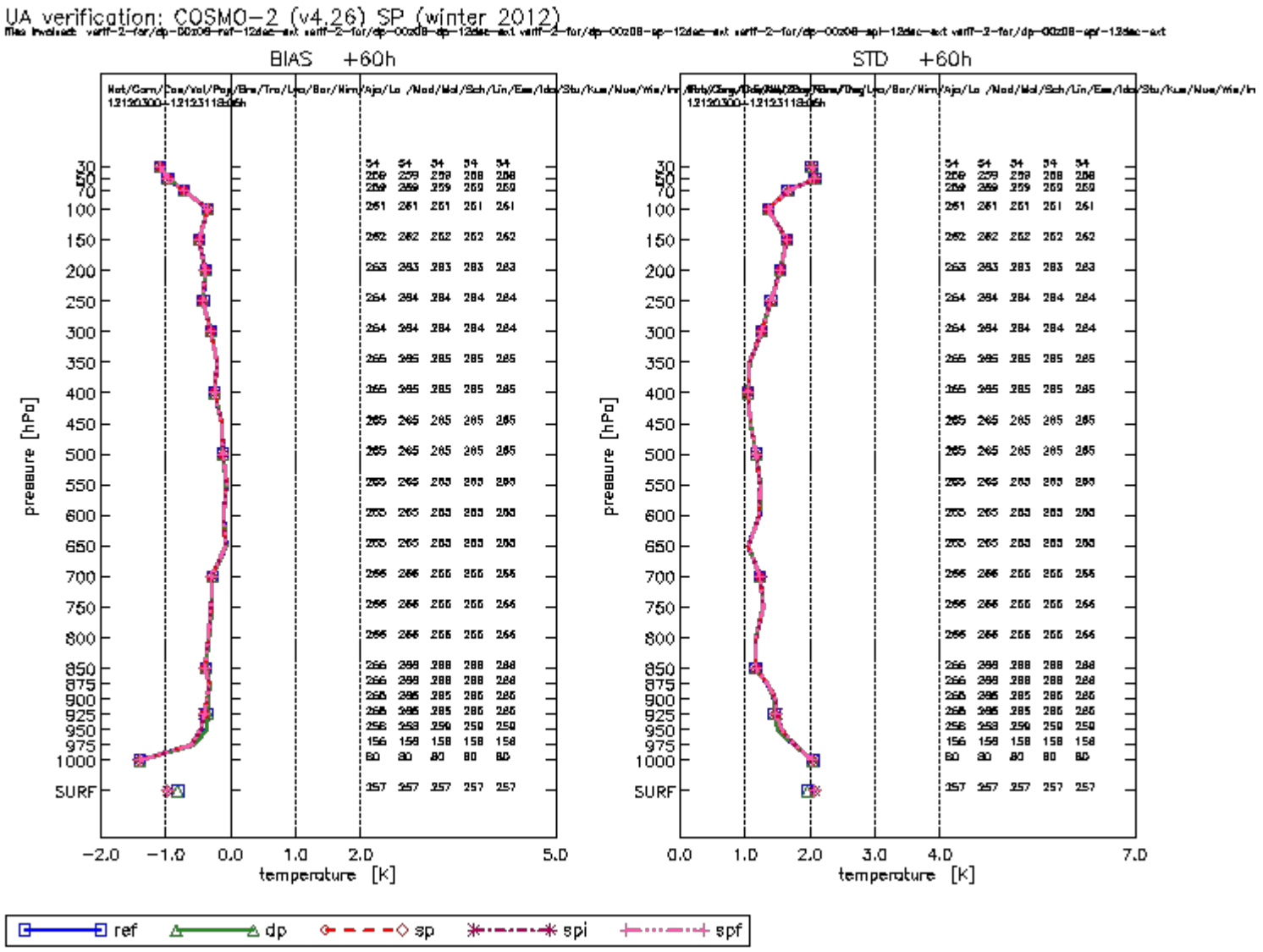
Test suite

- COSMO-2 setup with experiments up to +120h
- 4 weeks in summer and winter
- Experiments with
  - COSMO 4.26 (ref)
  - double precision (dp)
  - single precision (sp)
  - sp without –Kieee (spi)
    - turn off strict IEEE conformance for floating point operations (e.g., sin, cos, exp, log,…)
  - spi with –Mfprelaxed (spf)
    - Mfprelaxed: relaxed precision in the calculation of some intrinsic functions

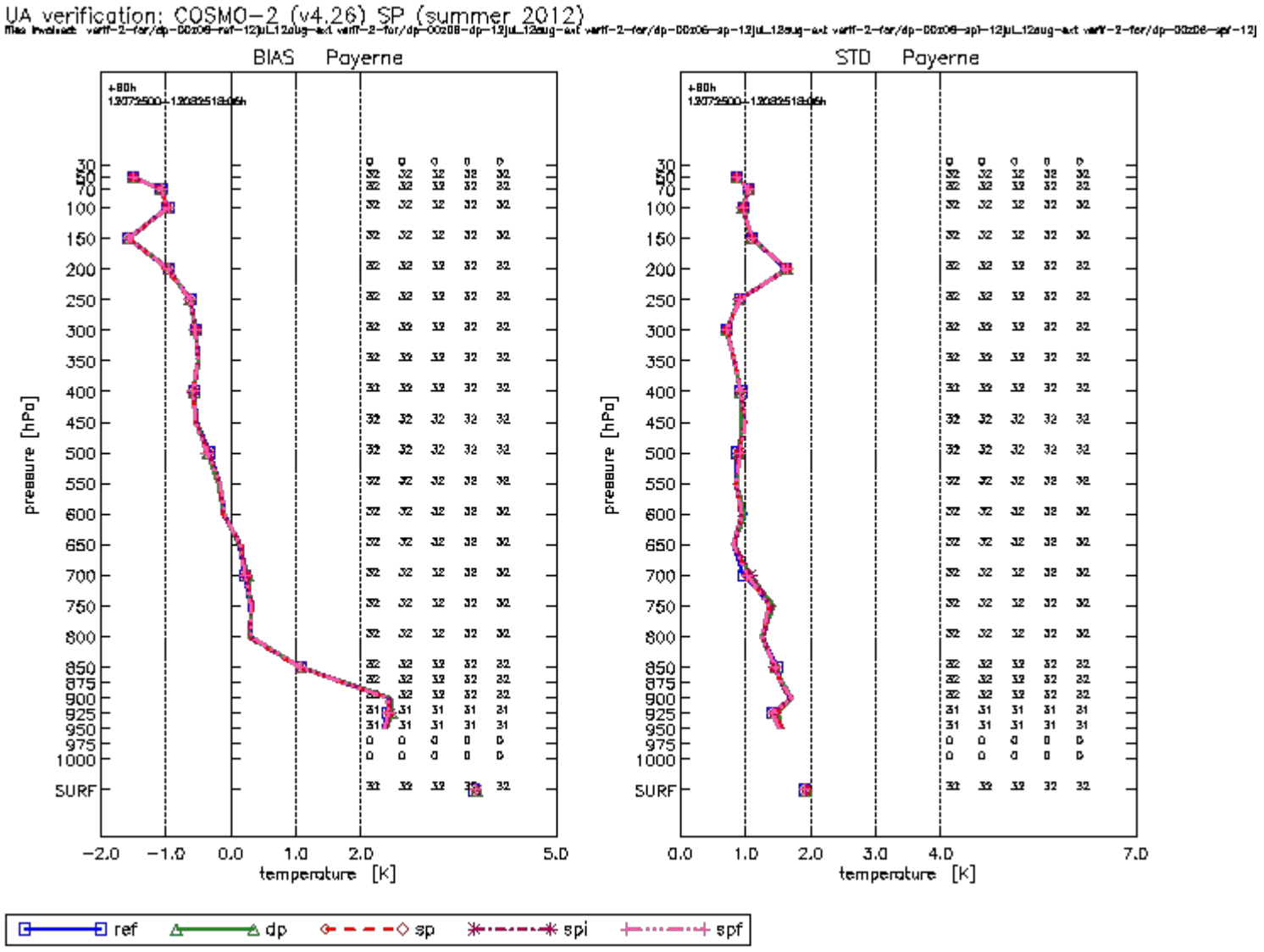
Verification with soundings

- Verification for summer and winter period (tool supports only up to +72h)
- Bias and std for RH, T, FF, DD, Z on 25 pressure levels
- Experiments show same results for both periods average over all stations
- Even station based verification shows no are only small differences

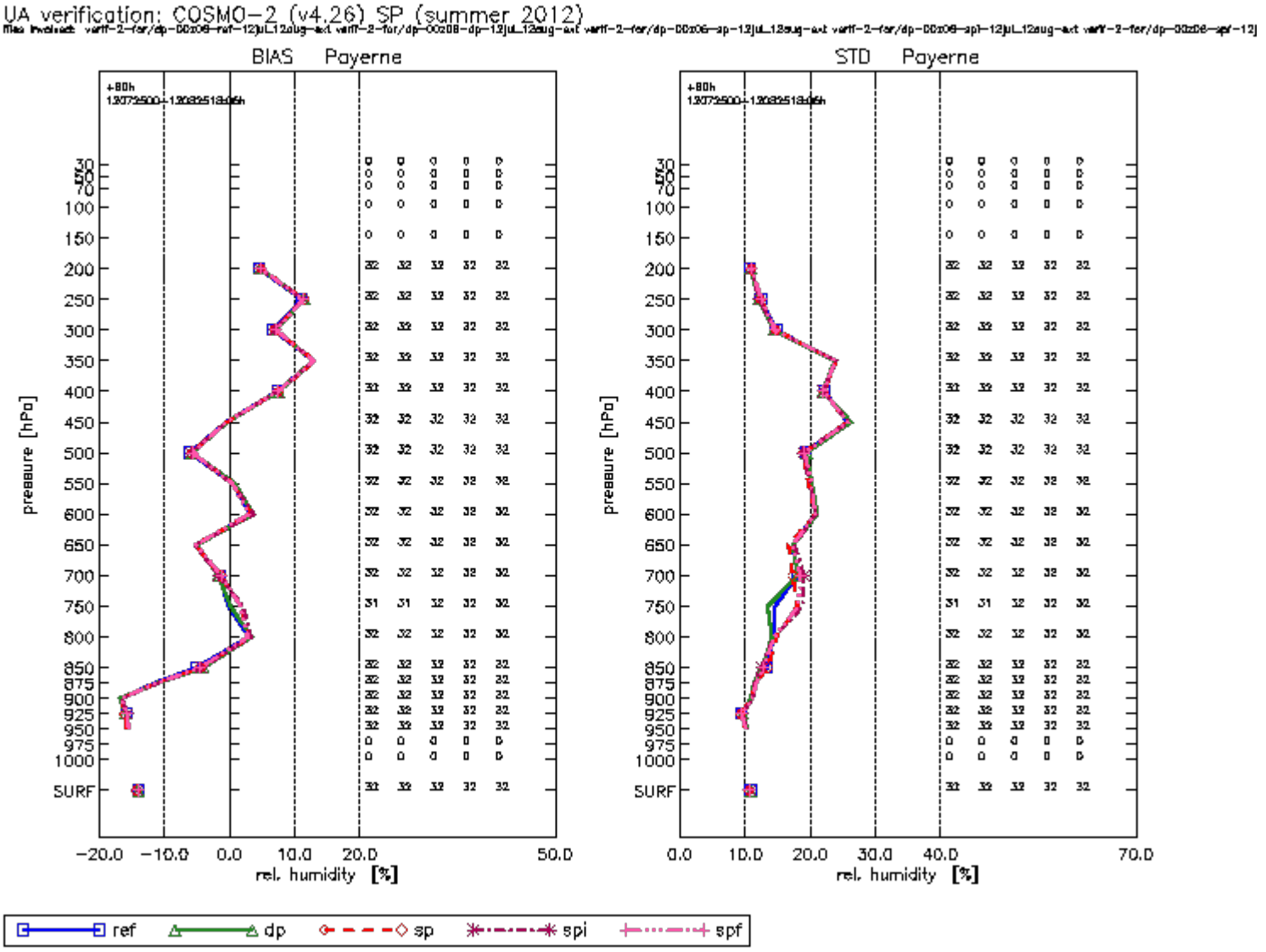
Example: T winter all soundings (+60h)



Example: T summer at Payerne (+60h)



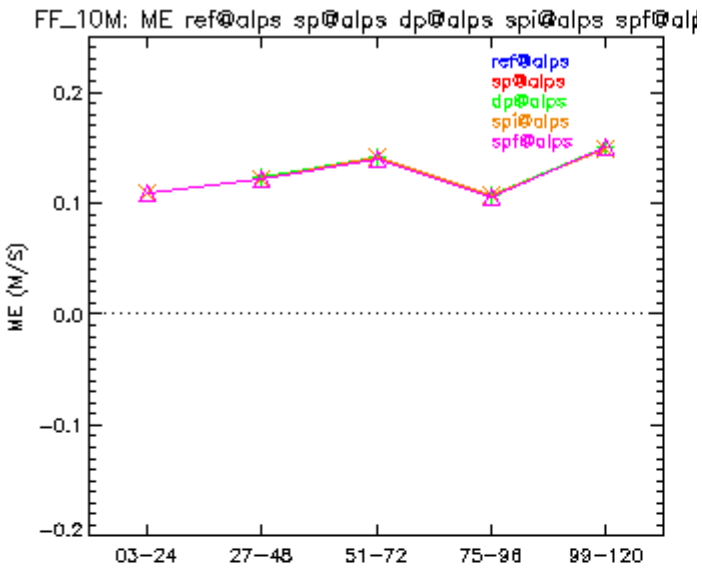
Example: RH summer at Payerne (+60h)

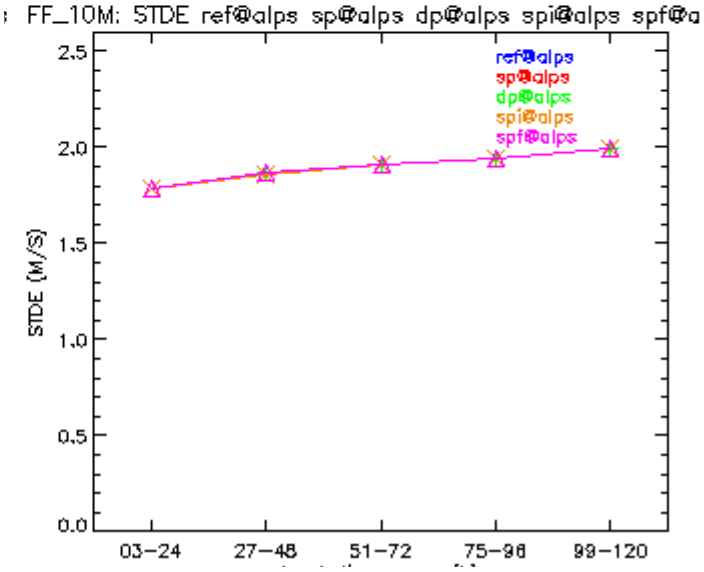


SYNOP Verification

- Verification with all available SYNOP station in COSMO-2 domain
- Standard scores
- Experiments shows same results for summer period

Example: 10m wind speed summer



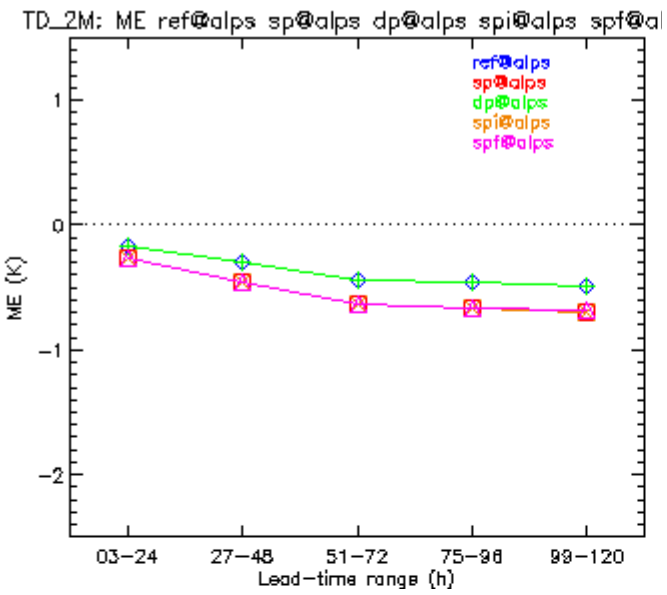


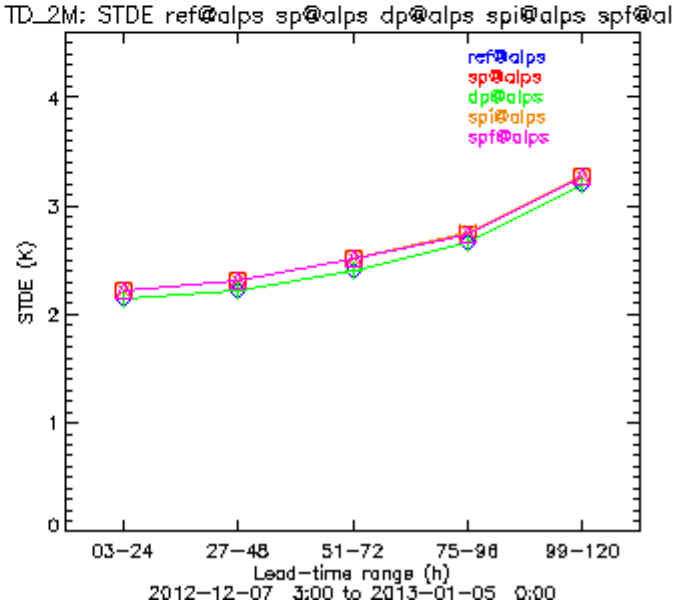
Same results for all 5 experiments

SYNOP Verification

- Verification with all available SYNOP station in COSMO-2 domain
- Standard scores
- Experiments shows same results for summer period
- …but winter period show differences between SP experiments and REF/DP experiments for 2m temp. and 2m dew point temp.

Example: dew point temp winter



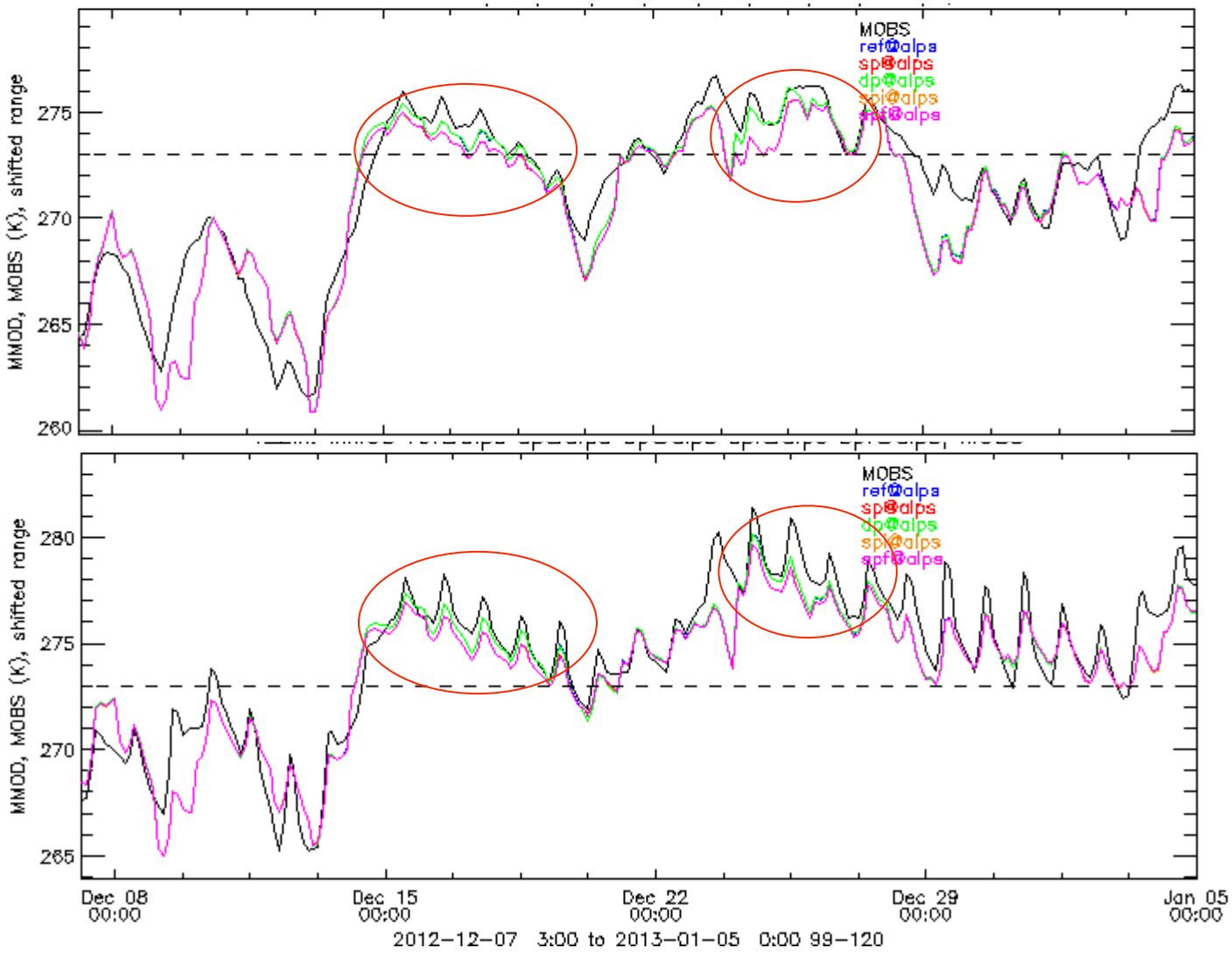


- significant difference between experiments
- REF/DP better than SP's

Time-series TD_2M & T_2M +(99-120h)

TD_2M

T_2M



Timings

	ref	dp%	sp%	spi%	spf%
Dyn. Computations	47.9	100%	52%	51%	51%
Add. Tend+Moist	13.5	102%	51%	52%	51%
Fast Waves	23.2	100%	51%	51%	51%
Communications Dyn	2.4	101%	55%	55%	55%
Barrier Waiting Dyn	4.7	101%	72%	54%	54%
Phy. Computations	10.8	110%	82%	69%	68%
Precipitation	3.0	100%	64%	57%	56%
Radiation	2.0	155%	150%	120%	119%
Turbulence	3.9	99%	63%	50%	49%
Others	9.5	101%	72%	68%	68%
Total	**75.2**	**102%**	**60%**	**56%**	**56%**

with ltime_barrier = .true.

Caveats

- Data assimilation not yet tested
- COSMO crashes with SP & luse_rttov = .true. (technical issue only)

Summary & conclusions

- COSMO version 4.26 with support for user-defined working precision ready for test purposes
- new code shows same skill with double precision as original code
- marginal degradation in skill found with single precision during a limited period, will be investigated
- reduction of elapsed time to 60% with single precision (COSMO-2 setup)!
- performance penalty in radiation noticed, should be minimized