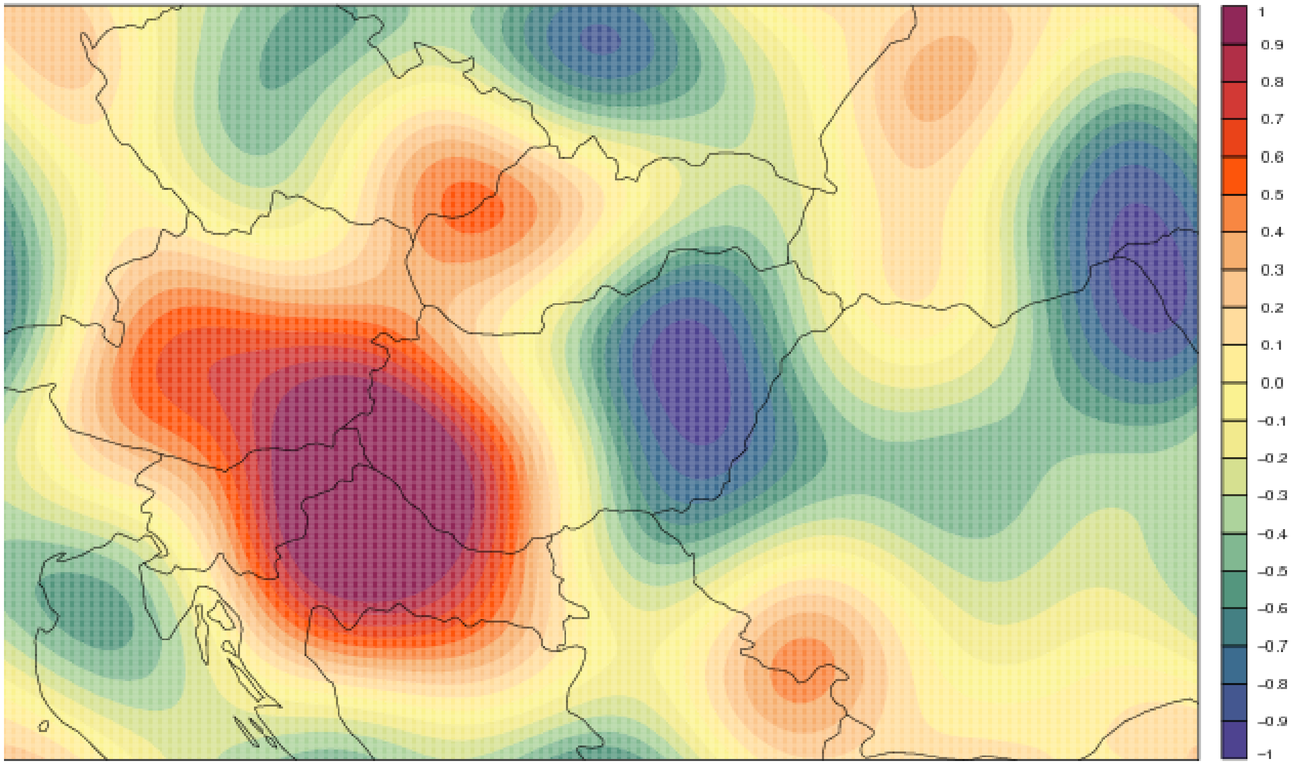
SPPT experiments in AROME-EPS

Stochastically Perturbed Parameterized Tendencies



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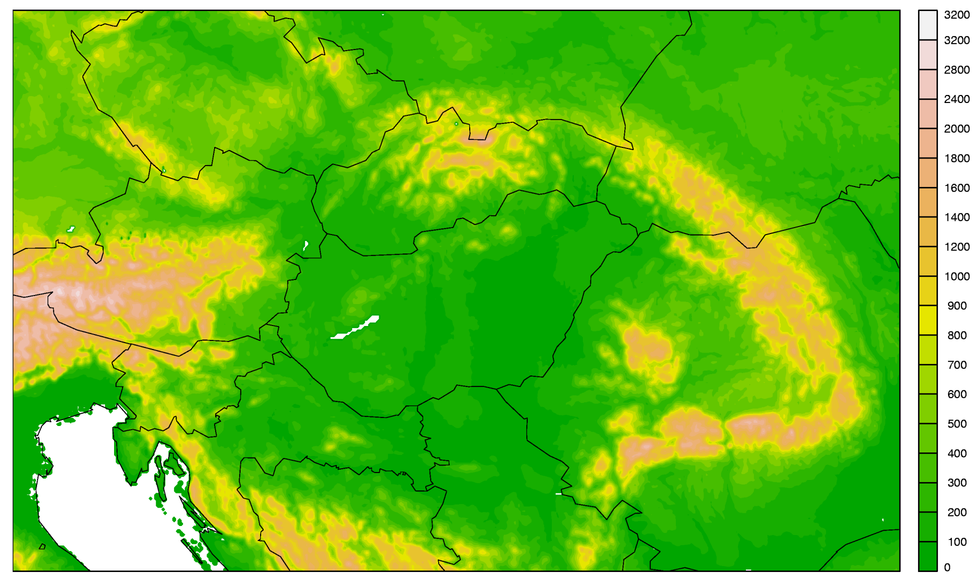
SPPT experiments in AROME-EPS
Content

- Hungarian AROME-EPS configuration
- Generalities about the SPPT scheme
  - Concept of the original stochastic physics scheme
  - The SPPT scheme on global scale
  - SPPT representation in AROME
- Settings of the random pattern generator in AROME
  - Sensitivity of the pattern on its control parameters
  - Comparison of different settings and their impact on the ensemble forecast
- Two possible modification in SPPT scheme
  - SPPT with four independent random pattern: 4D-SPPT
  - SPPT with four joint random pattern: 4D-elliptic-SPPT

The Hungarian test AROME-EPS

- The same model settings than in Hungarian operational AROME runs.
- We tested more coupling strategies but following results was carried out by PEARP dynamical downscaling.
- Tests took place on cca machine of ECMWF. We used quota of 'spfrbout' special project, where MeteoFrance and Hungarian Meteorological Service participate together and which is led by Francois Bouttier.

Grid-points	500*320
Timestep	60s
Resolution	2.5km
Time	18UTC + 36hours
Number of members	11



Generalities about the SPPT
The main concept of stochastic physics scheme

- The main concept was described by *Buizza et al., 1999*:
  - Following their original formalism the state of the j-th member can be written as:

    $$e_j(T)=\int \{A(e_j;t)+P'(e_j;t)\}dt$$

  - Which is the integral of the following model equation:

    $$\frac{\partial e_j}{\partial t}=A(e_j;t)+P'(e_j;t)$$
    $$e_j(t=0)=e_0(t=0)+\delta e_j(t=0)$$

    - **A** – the non-perturbed contribution of the non-parameterized processes (dynamics)
    - **P'** – the perturbed contribution of the parameterized processes (physics)
    - **δe** – initial condition perturbation (not the topic of this presentation)
- Physics tendencies are perturbed by a random number:

  $$P'(e_j;t)=(1+\langle r_j(\lambda;\phi;t)\rangle_{D;T})*P(e_j;t)$$

  - **r** was a uniformly sampled random number from a symmetric interval around 0 (eg. [-0.5; 0.5]) and constant over a given area (set by **D**) and over a given time (set by **T**)

Buizza, R., M. Miller, and T. N. Palmer (1999), Stochastic representation of model uncertainties in the ECMWF Ensemble Prediction System, Quart. J. Roy. Meteorol. Soc., 125, 2887–2908.

Generalities about the SPPT
The revised SPPT scheme on global scale

- The revised scheme was described by *Palmer et al., 2009*:
  - They changed the way how random numbers are defined:

$$P'(e_j;t)=(1+\alpha r_j)*P(e_j;t)$$

  - r is not defined as an independent value in grid-boxes but as a global field with spectral coefficients and spherical harmonics:

$$r=\sum_{mn} \hat{r}_{mn} * Y_{mn}$$

  - Spectral coefficients evolve according to an AR(1) process:

$$\hat{r}_{mn}(t+\Delta t)=\Phi \hat{r}_{mn}(t)+\sigma_n \eta_{mn}$$

  - Where temporal correlation is controlled by **τ** decorrelation timescale which is one important control parameter of the scheme:

$$\Phi=\exp(-\Delta t/\tau)$$

  - And where η values are independent, white in time and picked from a 0-mean, unit variance Gaussian distribution.

Palmer, T., R. Buizza, F. Doblas-Reyes, T. Jung, M. Leutbecher, G. Shutts, M. Steinheimer, and A. Weisheimer, 2009: Stochastic parametrization and model uncertainty. Tech. Rep., ECMWF Tech. Memo. 598, 42 pp. [Available online at http://www.ecmwf.int/publications/.]

Generalities about the SPPT
The revised SPPT scheme on global scale

- The revised scheme was described by *Palmer et al., 2009*:
  - **σ_n** is the standard deviation of the noise in the AR(1) process of the different spectral coefficients which is defined as:

$$\sigma_n = F_0 \exp(-\kappa T n(n+1)/2)$$

$$F_0 = \left(\frac{\sigma(1-\Phi^2)}{2\sum_{n=1}^{N}(2n+1)\exp(-\kappa T n(n+1))} \right)^{1/2} \qquad \kappa T = \frac{1}{2}\left(\frac{l}{R_E}\right)^2$$

  - **σ** is the standard deviation which can control the amplitude of the perturbation.
    - Note that this is non-trivially equal with the spread of the **r** values what we get in grid-point space.
    - At the end r values are bounded to a [-cσ;cσ] interval where c is the clipping ratio set to 2.0 as a default in the code
  - ***l*** is the horizontal correlation length which is also a control parameter of the scheme set from the namelist.

Palmer, T., R. Buizza, F. Doblas-Reyes, T. Jung, M. Leutbecher, G. Shutts, M. Steinheimer, and A. Weisheimer, 2009: Stochastic parametrization and model uncertainty. Tech. Rep., ECMWF Tech. Memo. 598, 42 pp. [Available online at http://www.ecmwf.int/publications/.]

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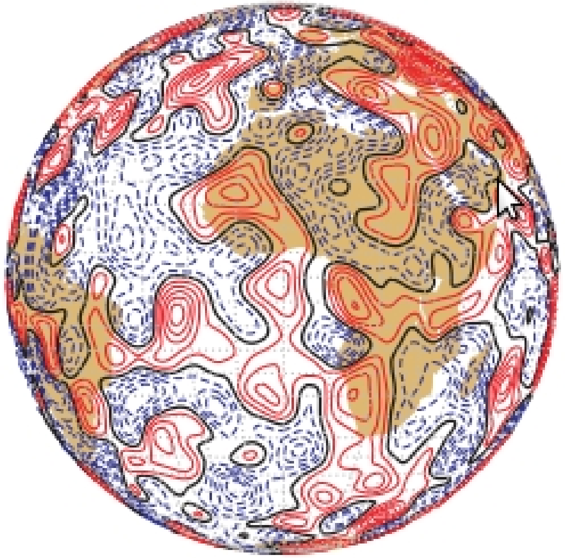
  - ECMWF uses the combination of more pattern. The one which takes into account the uncertainty of synoptic scales is set and visualized as:
    - **σ=0.5**
    - **l=500km**
    - **τ=6h**



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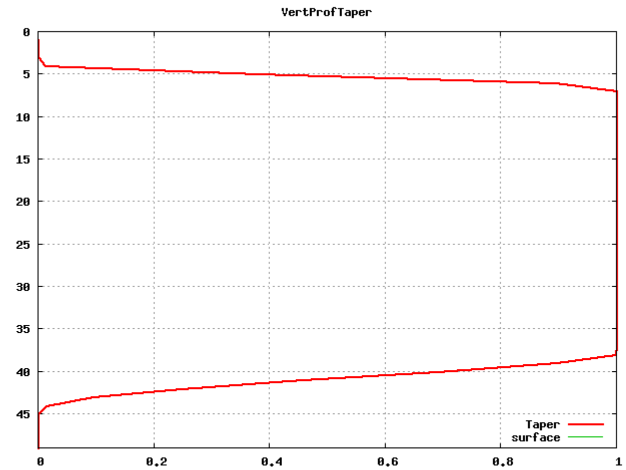
SPPT scheme in AROME
General representation

- SPPT is available over cycle38 and MeteoFrance's test results described by *Bouttier et al., 2012*:
  - Basic equations are the same than on global scale:



$$P'_X(e_j;t) = \left(1 + \boxed{\alpha(h)}\, r_j\right) * P_X(e_j;t)$$

$$X = \{u; v; T; q\}$$

  - α is a height dependent function which helps to avoid numerical instabilities at the bottom and at the top of the atmosphere.
    - (Could we modify it in the future?)
  - Instead of spherical harmonics there are biFourier functions but $\boldsymbol{\sigma}_n$ is defined on the same way:

$$\sigma_n = F_0 \exp(-\kappa T n(n+1)/2)$$

$$F_0 = \left(\frac{\sigma(1-\Phi^2)}{2 \sum_{n=1}^{N} (2n+1) \exp(-\kappa T n(n+1))} \right)^{1/2} \qquad \kappa T = \frac{1}{2} \left(\frac{l}{R_E} \right)^2$$

Bouttier, François, Benoît Vié, Olivier Nuissier, Laure Raynaud, 2012: Impact of Stochastic Physics in a Convection-Permitting Ensemble. Mon. Wea. Rev., 140, 3706–3721.

SPPT scheme in AROME
Random pattern generator

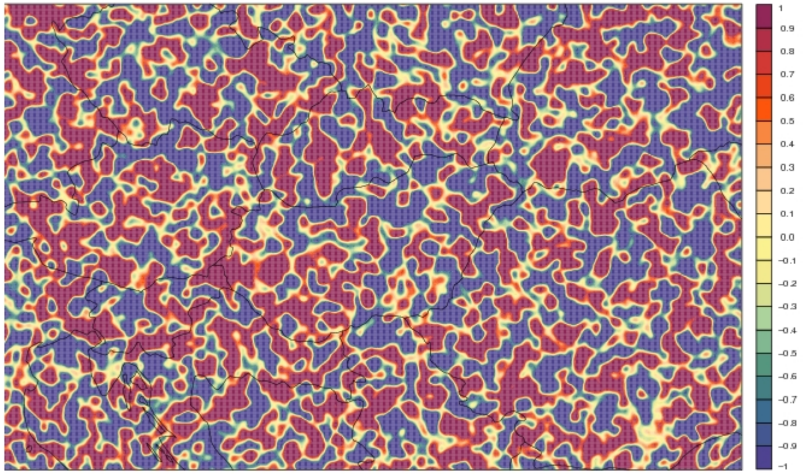
- Examination of random pattern on the Hungarian domain:
  - σ_n is defined on the same way than in global model: $$\sigma_n = F_0 \exp(-\kappa T n(n+1)/2)$$

$$F_0 = \left(\frac{\sigma(1-\Phi^2)}{2\sum_{n=1}^{N}(2n+1)\exp(-\kappa T n(n+1))} \right)^{1/2}$$

$$\kappa T = \frac{1}{2}\left(\frac{l}{R_E}\right)^2$$

  - It is possible to use the default values which are identical with the ones described by ECMWF's reference:

	SPPT default
σ	0.5
c	2.0
τ(h)	6
l(km)	500



  - The actual horizontal correlation looks smaller than **l**.
  - Pattern generator counts with the Earth's radius (R_E) as defining the standard deviation of spectral coefficients.
  - Random pattern is made for the whole globe, but it is compressed just over a small domain.

SPPT scheme in AROME
Random pattern generator

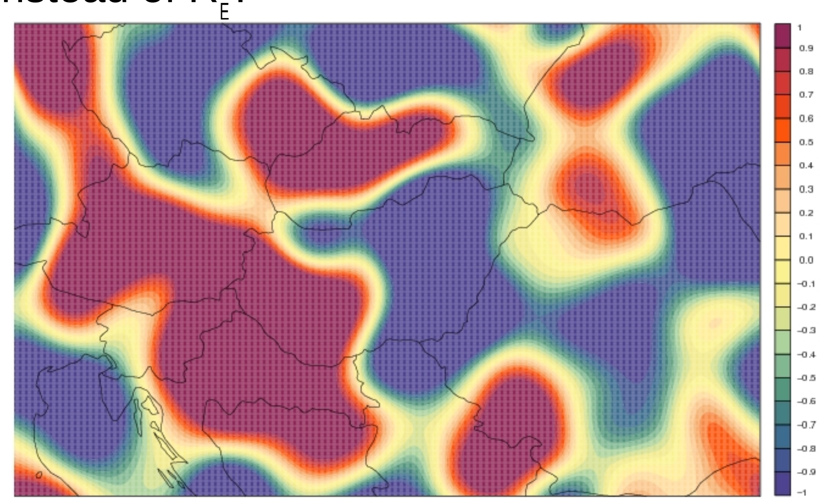
- Examination of random pattern on the Hungarian domain:

$$\kappa T = \frac{1}{2}\left(\frac{l}{R_E}\right)^2$$

  – Domain size dependent variable should be defined instead of R_E?

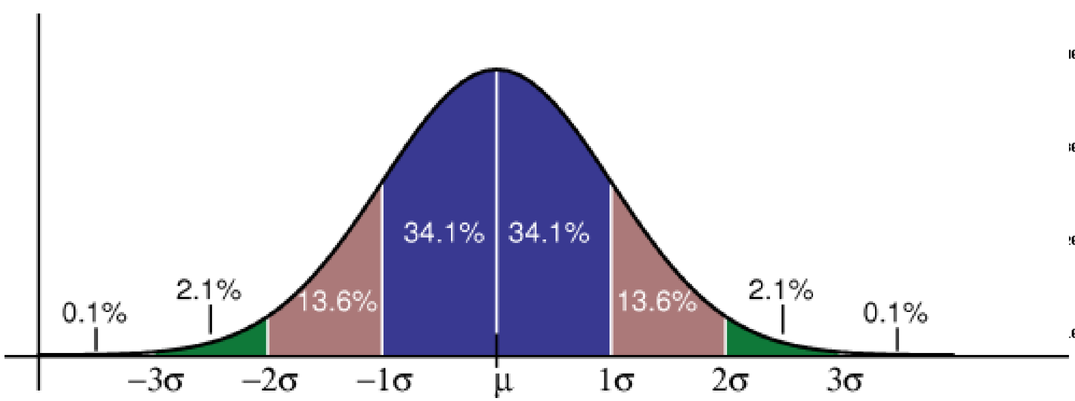
    - Bigger **l** is an equivalent solution (SPPT-big):

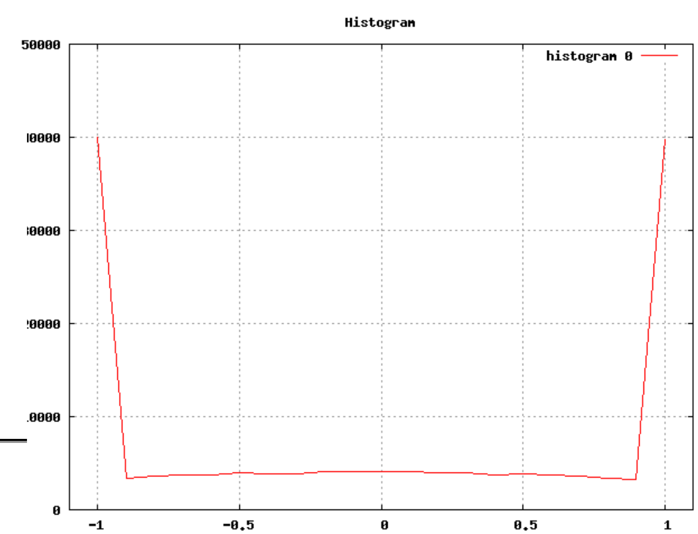
	SPPT-default	SPPT-big
σ	0.5	0.5
c	2.0	2.0
τ(h)	6	8
l(km)	**500**	**4000**



  – It looks that map is full of points from the edge of the interval where distribution is bounded (-1 or +1)

  – Random numbers do not necessarily form exact normal distribution with **σ** standard deviation, but how far they are from that?

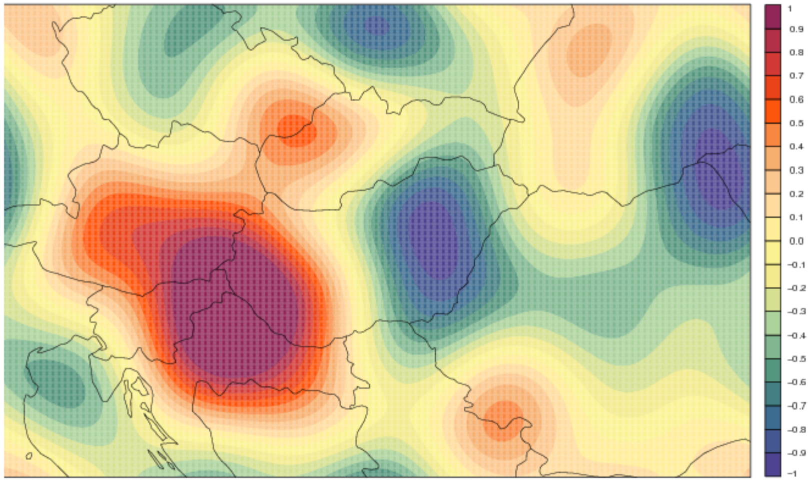




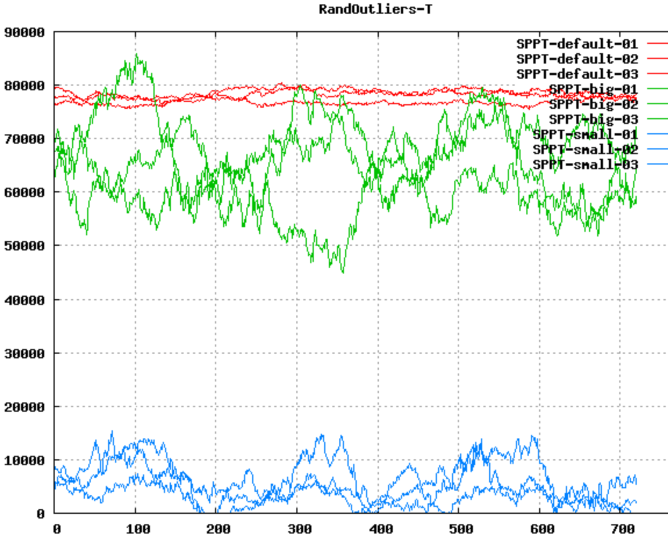
SPPT scheme in AROME
Random pattern generator

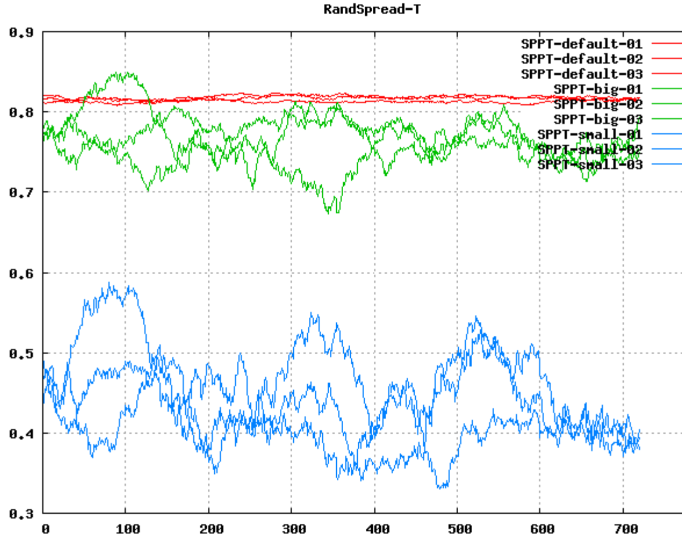
- Moderated perturbations (SPPT-small):
  - In this version r numbers have smaller spread but also bounded into [-1;1] interval
    - Clipping ration is in accordance with σ

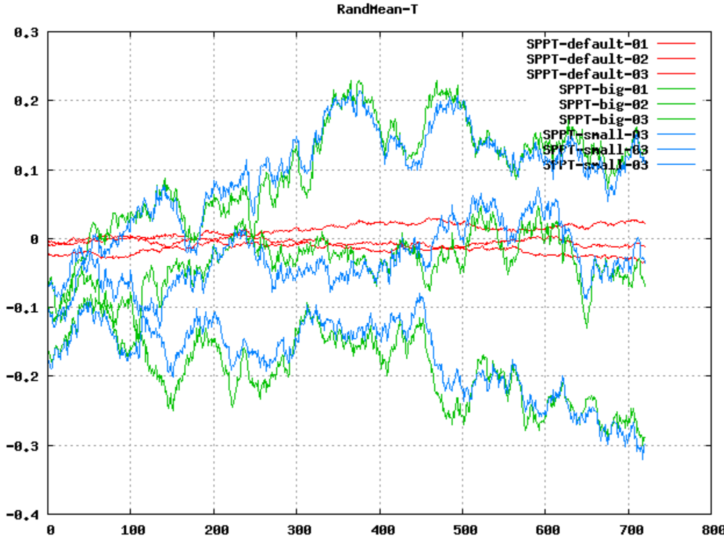
	SPPT default	SPPT big	SPPT small
σ	0.5	**0.5**	**0.2**
c	2.0	**2.0**	**5.0**
τ(h)	6	8	8
l(km)	500	4000	4000



- Number of points on the edge of the interval, spread and mean as function of time:

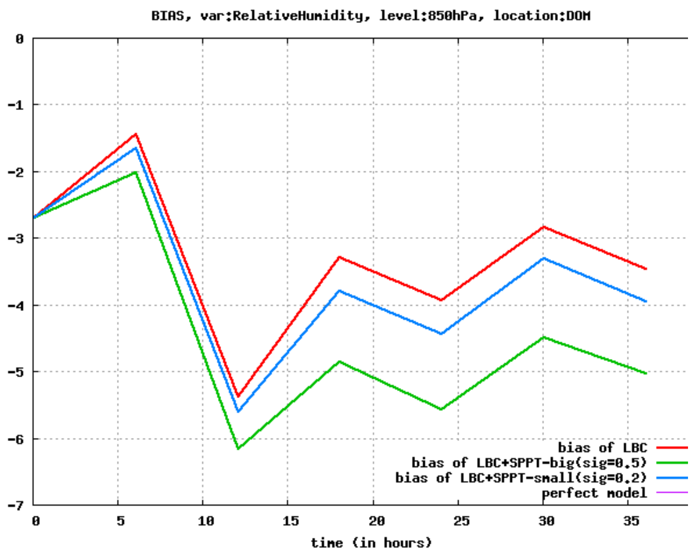


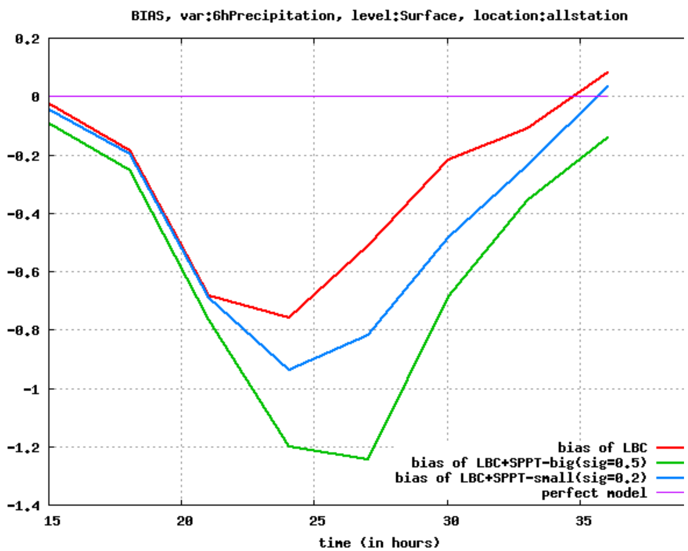


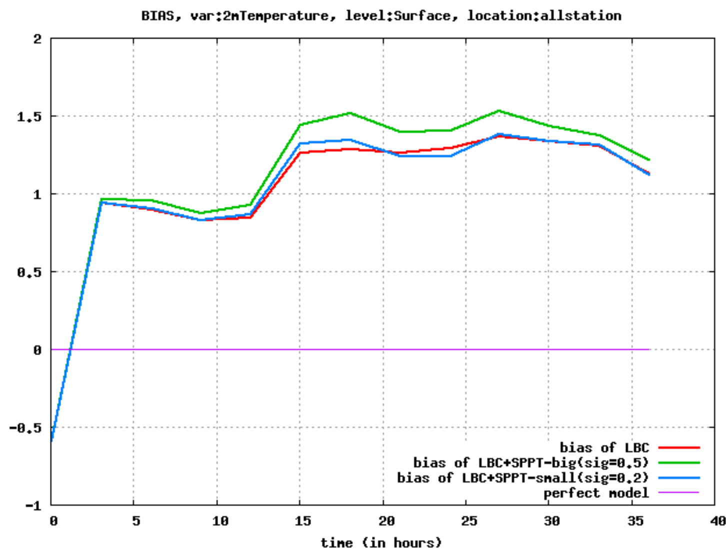


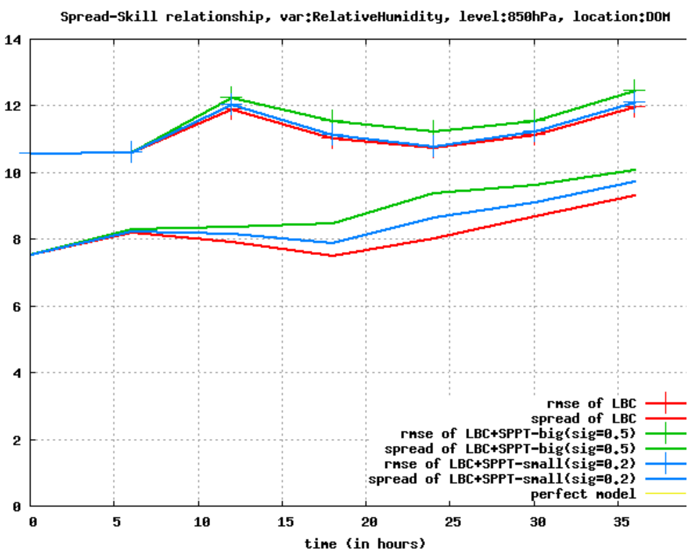
SPPT scheme in AROME

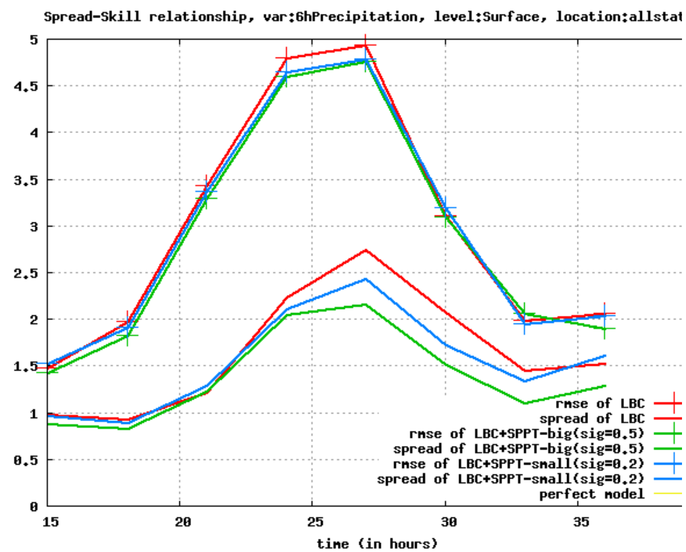
- Impact of moderated perturbations (SPPT-small vs SPPT-big):
  - “Verification” was done on 10 active cases between April and August 2015.
  - Smaller bias drift and rmse values but also smaller spread values (not efficient enough)

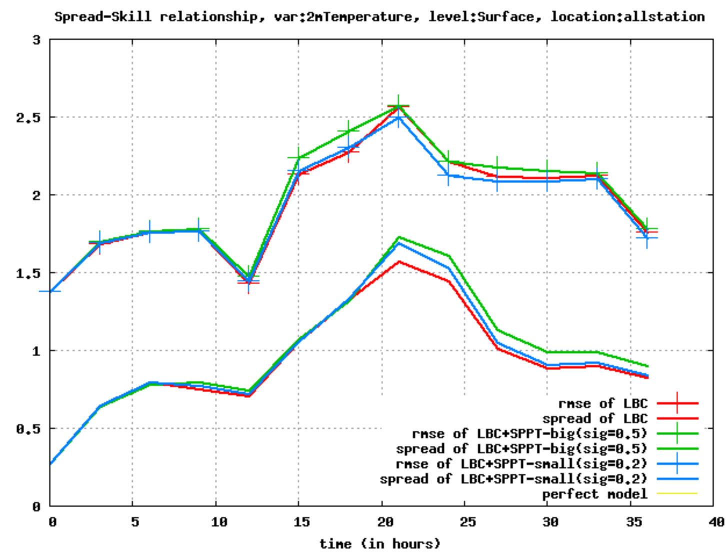










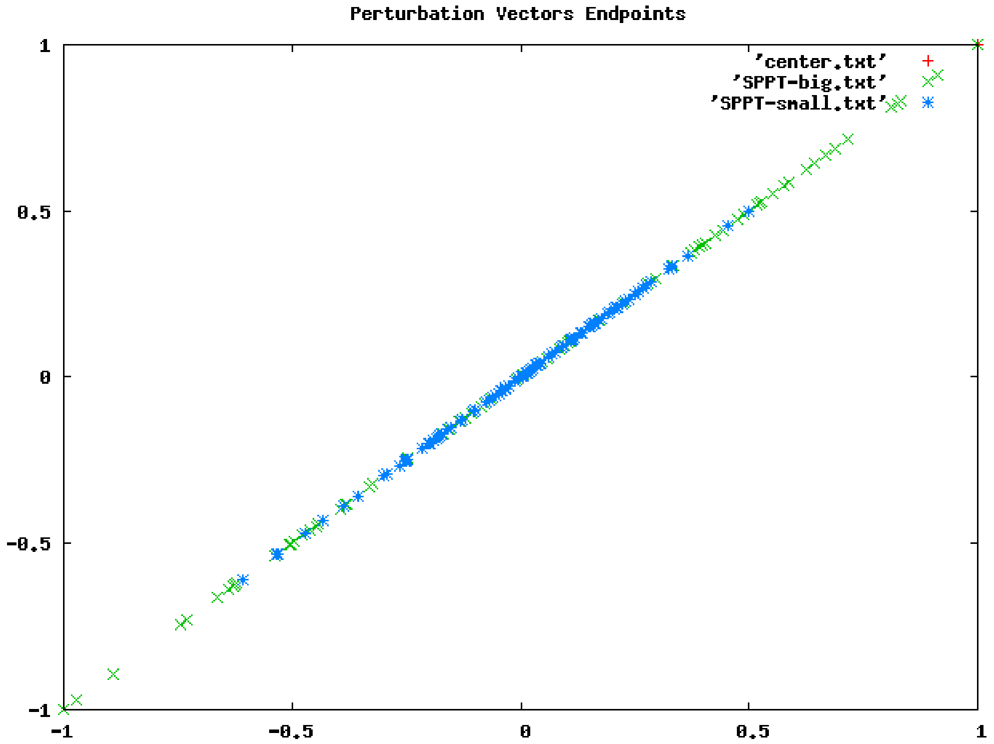


SPPT scheme in AROME

- The above-mentioned versions can not ensure sufficient spread
  - All the tendencies of prognostic variables are multiplied with the same number.
  - E.g. in case of wind it means that the size of the tendency is perturbed but the direction stays untouched.

$$P'_X(e_j;t) = (1+\alpha(h) r_j) * P_X(e_j;t)$$

$$X = \{u; v; T; q\}$$



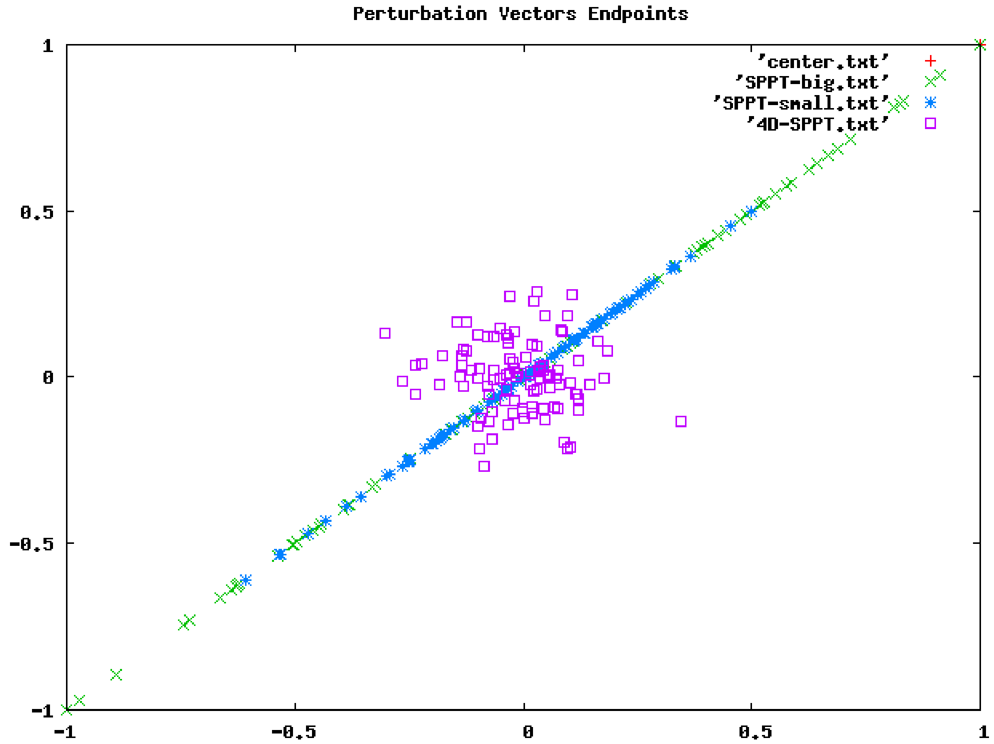
  - Is it true that the size of the tendency is very uncertain and we can perturb it very much while its direction is absolutely certain and we can not touch?

4D-SPPT

- Tendencies of variables can be perturbed independently:
  - 4 independent random patterns can be evolved and used:

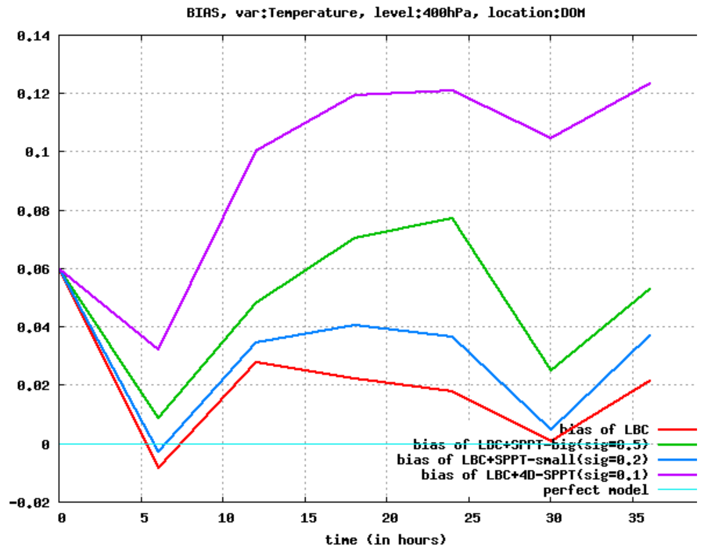
$$P'_{u_j}(e_j;t)=(1+r_{1_j})*P_{u_j}(e_j;t)$$
$$P'_{v_j}(e_j;t)=(1+r_{2_j})*P_{v_j}(e_j;t)$$
$$P'_{T_j}(e_j;t)=(1+r_{3_j})*P_{T_j}(e_j;t)$$
$$P'_{q_j}(e_j;t)=(1+r_{4_j})*P_{q_j}(e_j;t)$$

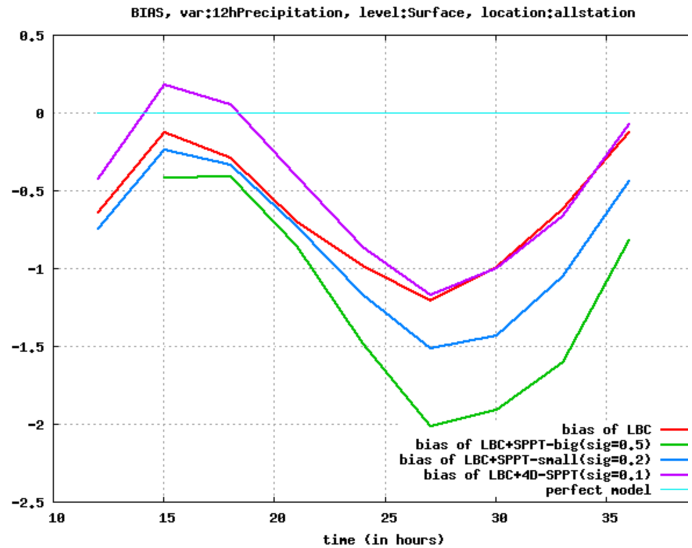
	SPPT big	**SPPT small**	**4D-SPPT**
σ	0.5	**0.2**	**0.1**
c	2.0	5.0	5.0
τ(h)	8	8	8
l(km)	4000	4000	4000

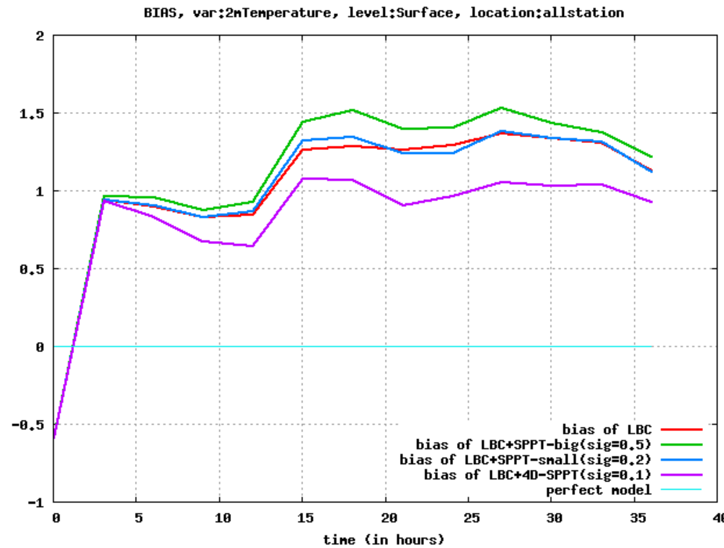


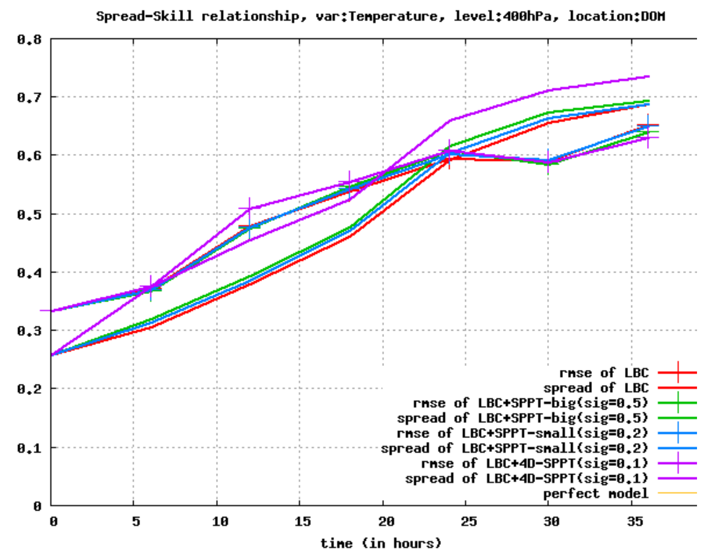
4D-SPPT

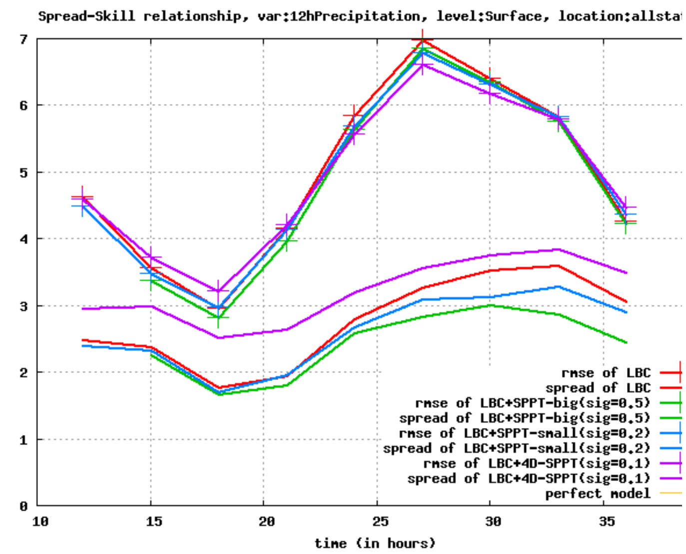
- Performance against original SPPT (4D-SPPT vs SPPT-small vs SPPT-big):
  - There are also bias drifts but on higher-levels.
  - Usually it has a good effect on error and spread, as well.

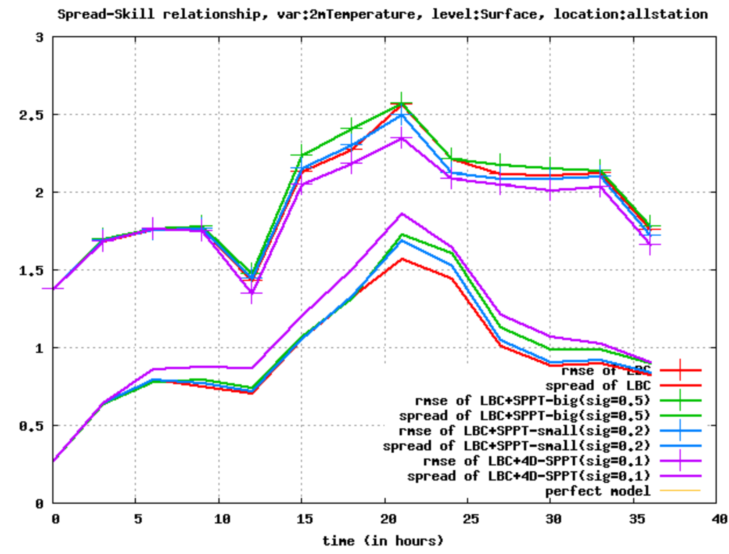












4D-elliptic-SPPT

- 4 dimensional extension of the scheme but with a trust of the original direction:
  - 4 independent patterns can be combined to form new joint patterns for all prognostic variables:

$$P'_{u_j}(e_j;t)=(1+r_{u_j})*P_{u_j}(e_j;t) \qquad r_{u_j}=r_{1_j}(0;\sigma_1)+r_{2_j}(0;\sigma_2)+r_{3_j}(0;\sigma_3)+r_{4_j}(0;\sigma_4)$$

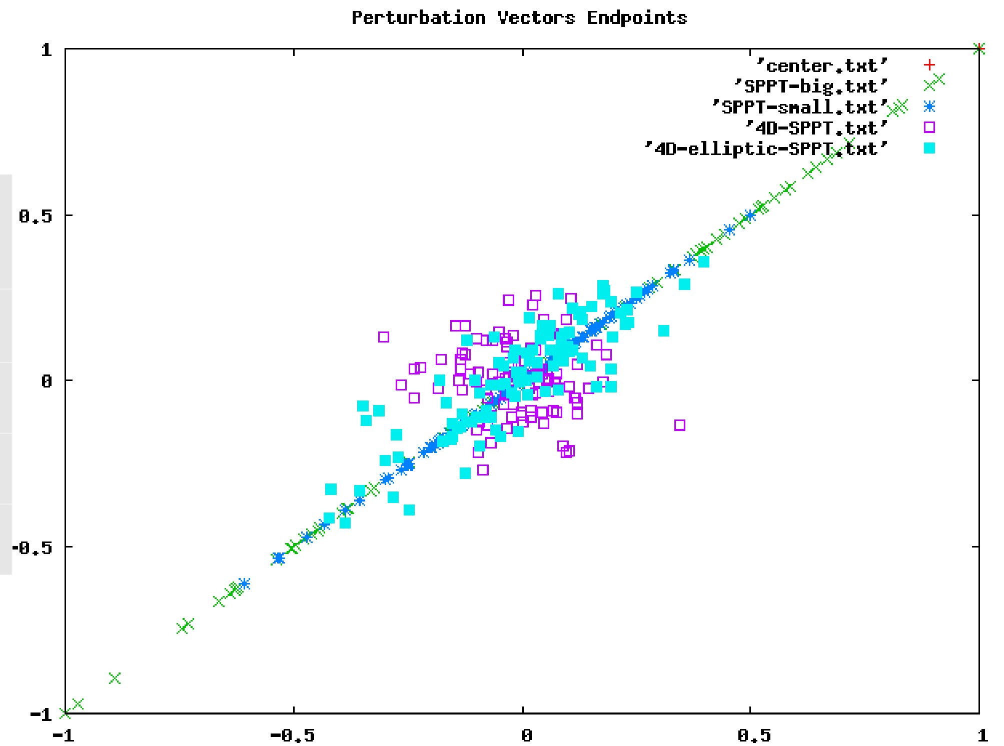
$$P'_{v_j}(e_j;t)=(1+r_{v_j})*P_{v_j}(e_j;t) \qquad r_{v_j}=r_{1_j}(0;\sigma_1)-r_{2_j}(0;\sigma_2)+r_{3_j}(0;\sigma_3)+r_{4_j}(0;\sigma_4)$$

$$P'_{T_j}(e_j;t)=(1+r_{T_j})*P_{T_j}(e_j;t) \qquad r_{T_j}=r_{1_j}(0;\sigma_1)+r_{2_j}(0;\sigma_2)-r_{3_j}(0;\sigma_3)+r_{4_j}(0;\sigma_4)$$

$$P'_{q_j}(e_j;t)=(1+r_{q_j})*P_{q_j}(e_j;t) \qquad r_{q_j}=r_{1_j}(0;\sigma_1)+r_{2_j}(0;\sigma_2)+r_{3_j}(0;\sigma_3)-r_{4_j}(0;\sigma_4)$$

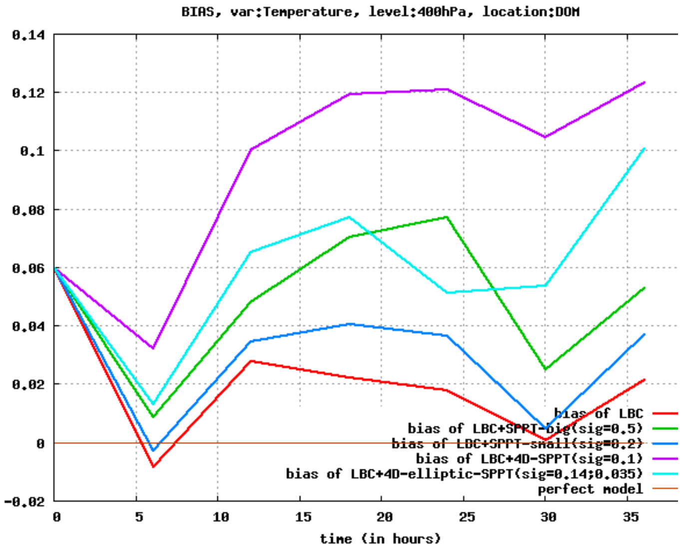
$$\sigma_1=N*\sigma_2$$
$$\sigma_2=\sigma_3=\sigma_4$$

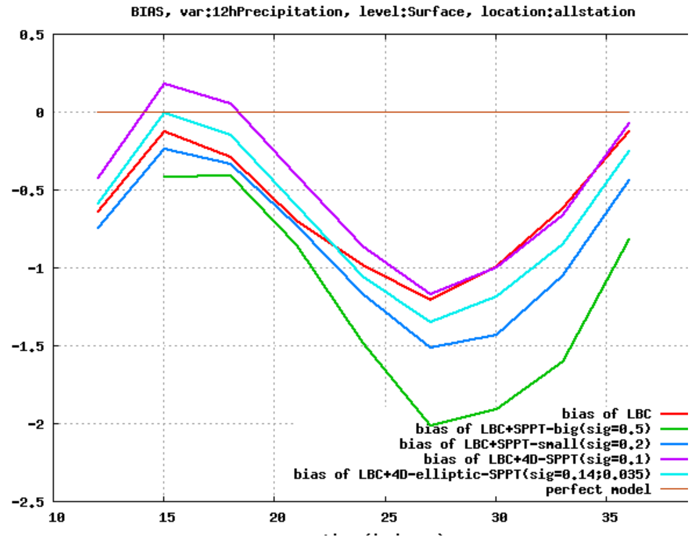
	SPPT big	SPPT small	4D-SPPT	4D-elliptic-SPPT
σ	0.5	**0.2**	**0.1**	**0.14; 0.035**
c	2.0	5.0	5.0	5.0
τ(h)	8	8	8	8
l(km)	4000	4000	4000	4000

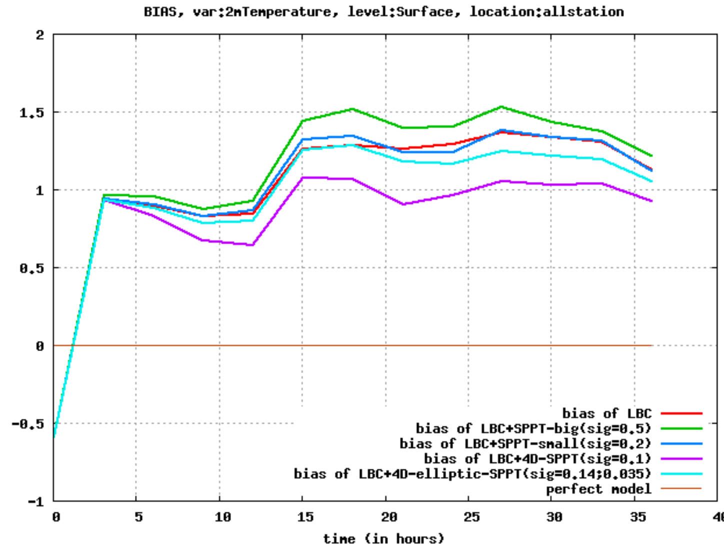


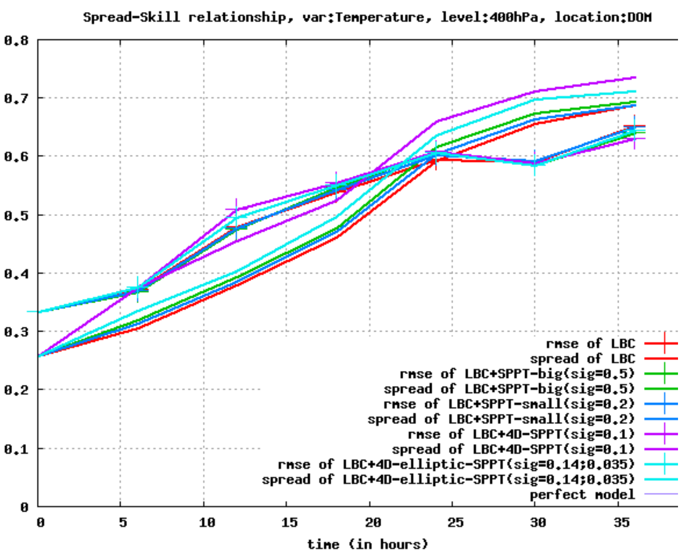
4D-elliptic-SPPT

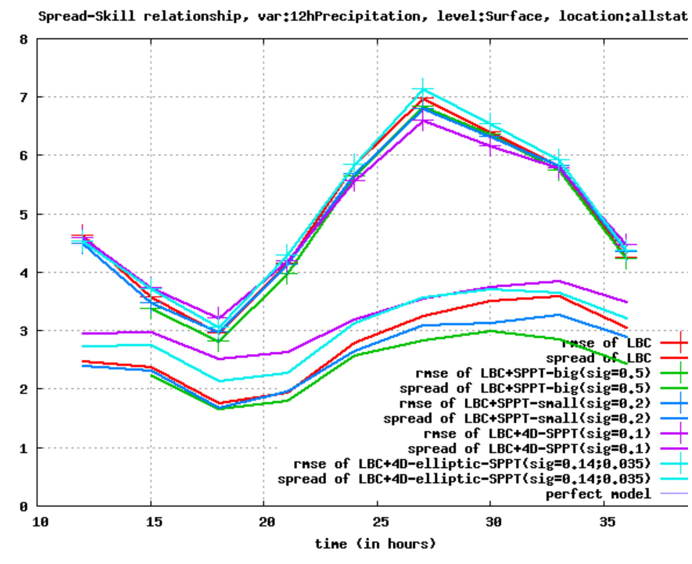
- Performance against other versions (4D-elliptic-SPPT vs 4D-SPPT vs SPPT-small vs SPPT-big):
  - Model drifts can be decreased on higher levels
  - Smaller spread

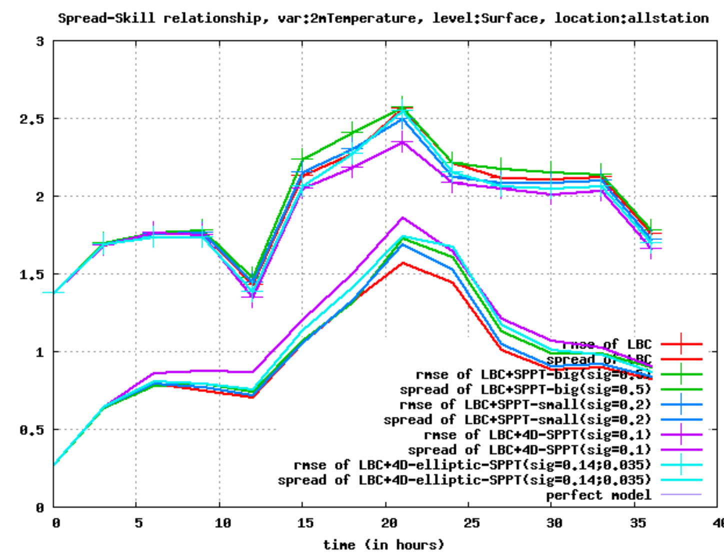




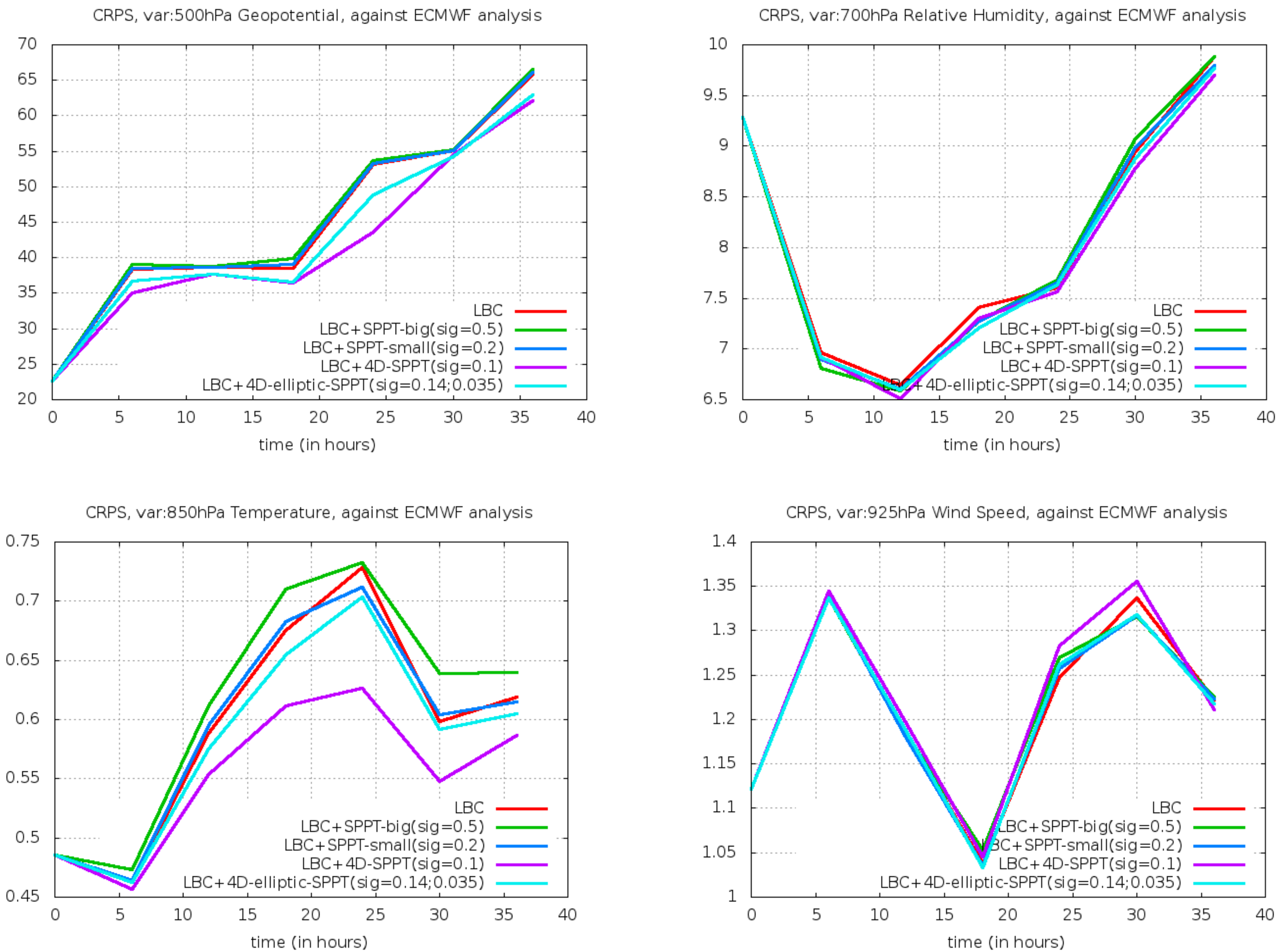




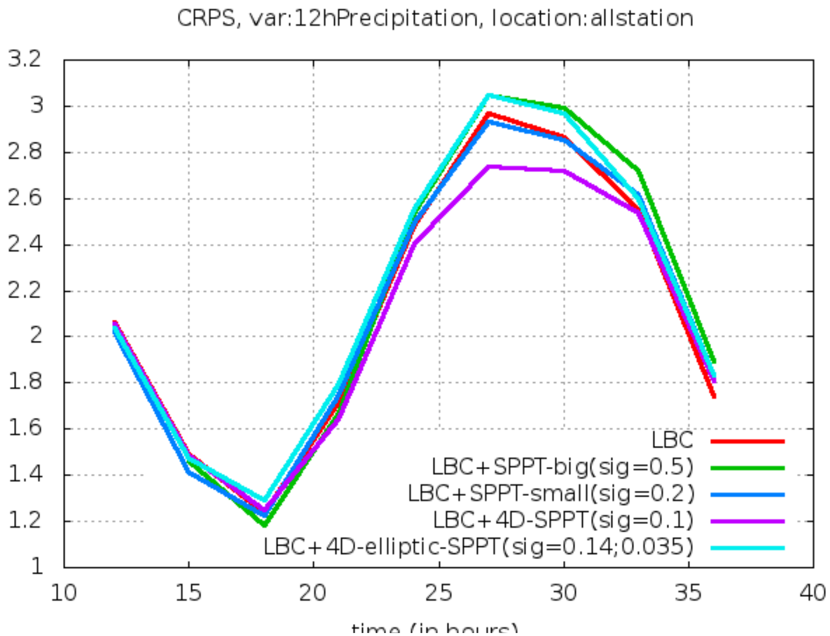


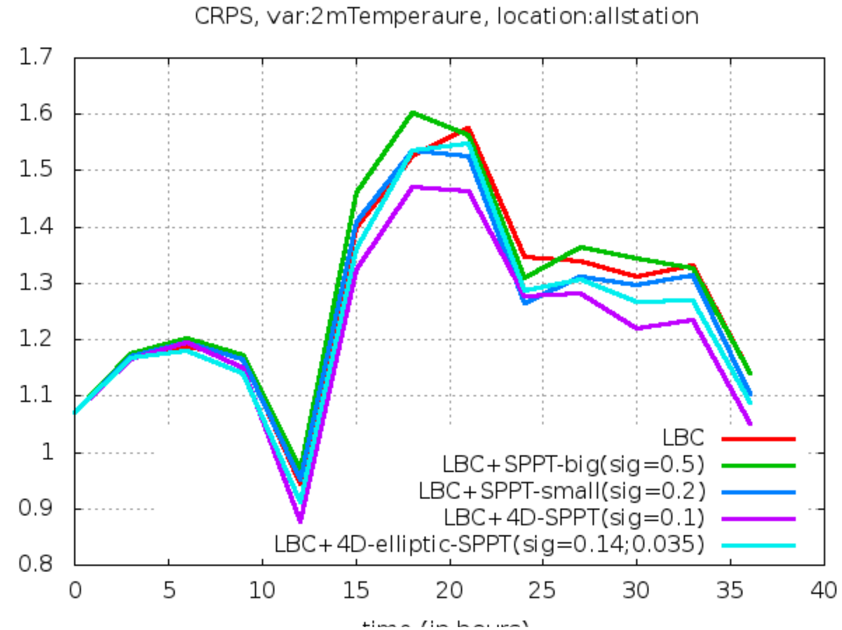


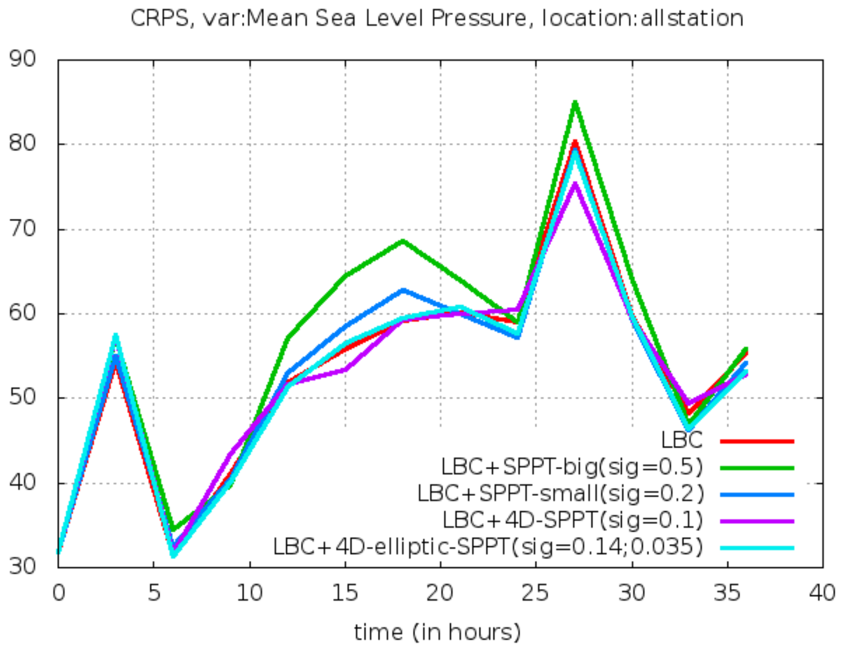
Some probabilistic score

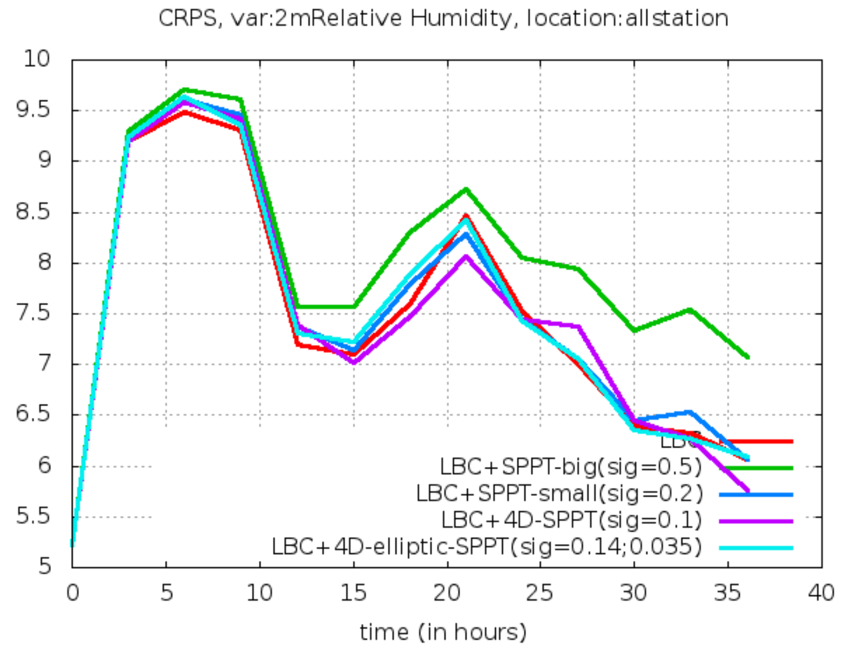


Some probabilistic score









SPPT experiments in AROME-EPS
Conclusions

- It is hard to find the ideal settings of spectral random pattern generator:
  - what is scientifically reasonable,
  - what does not make model drifts,
  - what is efficient enough (ensures additional spread).
- Two possible extension of application of random patterns was proposed:
  - what did not make SPPT scheme “smarter” or “more scientific”,
  - but probably can help to work better within its limitation.

SPPT experiments in AROME-EPS

Thank you for your attention!

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