Regional Cooperation for
Limited Area Modeling in Central Europe

LACE
nwp central europe

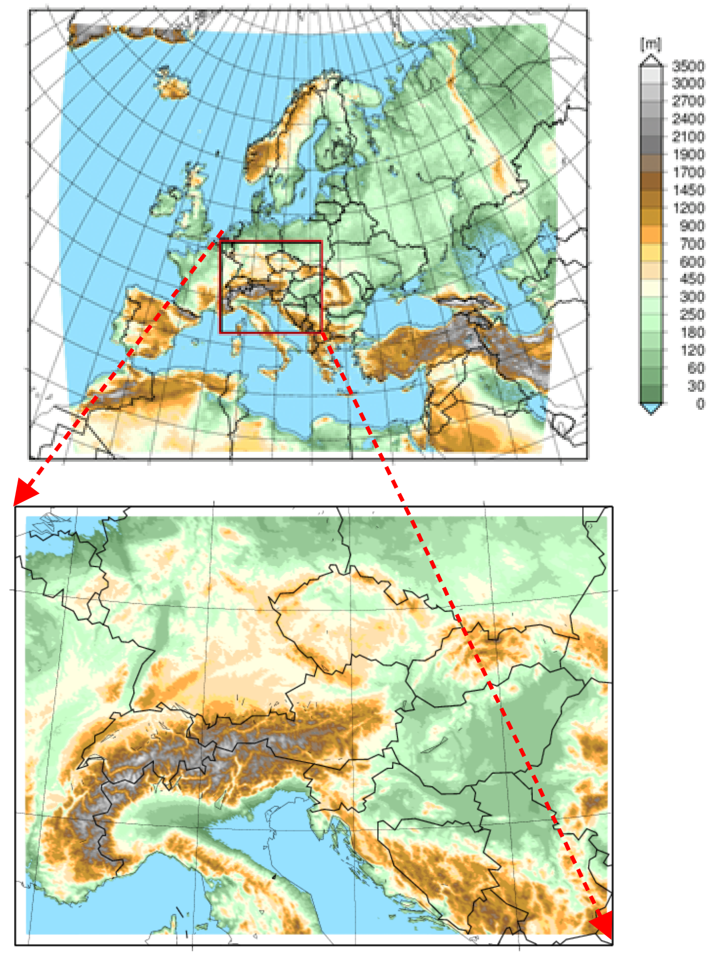
Stochastic perturbations of model tendencies in AROME-EPS

Clemens Wastl, Yong Wang, ZAMG

AROME-EPS at ZAMG

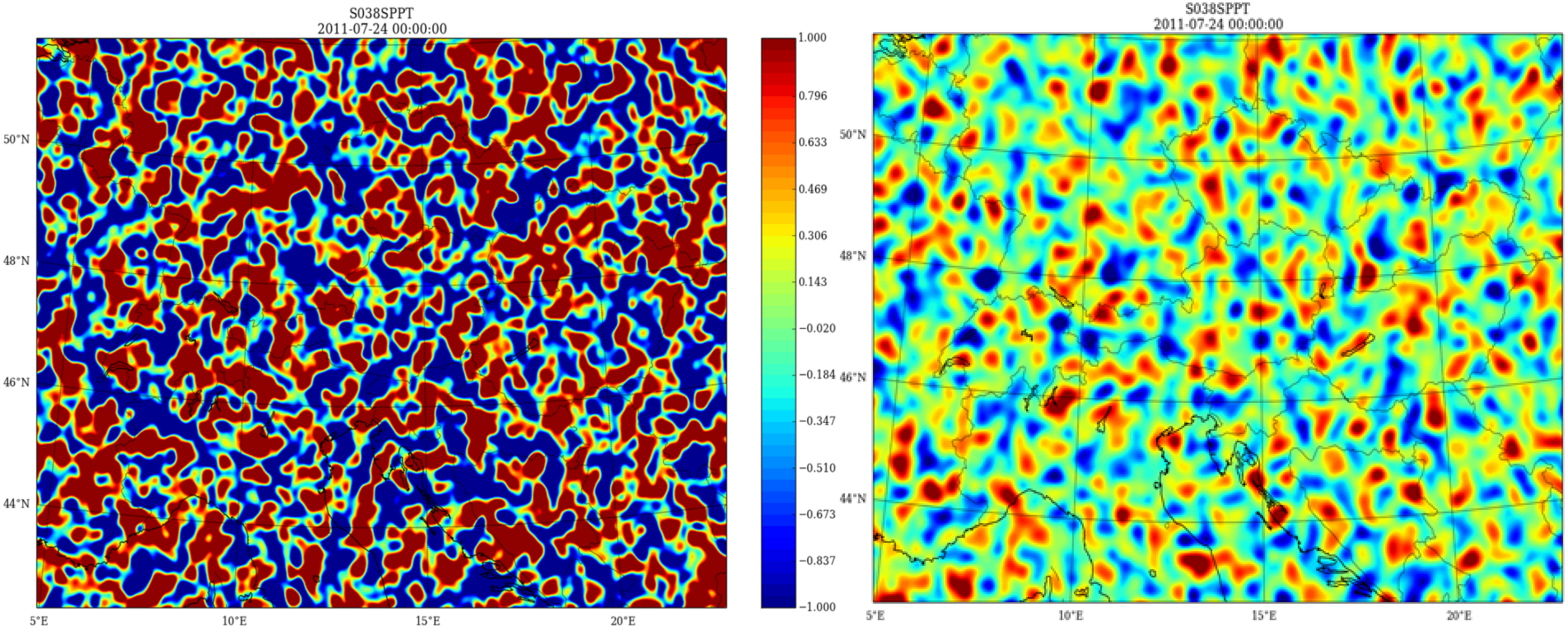
- not yet operational
- test phase - wait for new HPC at ZAMG

AROME-EPS	
ensemble size	16 + 1
Δx / vertical levels	2.5 km / 90
coupling	ECMWF EPS
runs per day	2 / 4 runs (+ 30 h forecast)
IC perturbation	EDA + EnJk + sEDA
model perturbation	SPPT / iSPPT / pSPPT / ipSPPT: ● total tendencies (SPPT) ● independent total tendencies (iSPPT) ● partial tendencies (pSPPT) ● independent partial tendencies (ipSPPT)



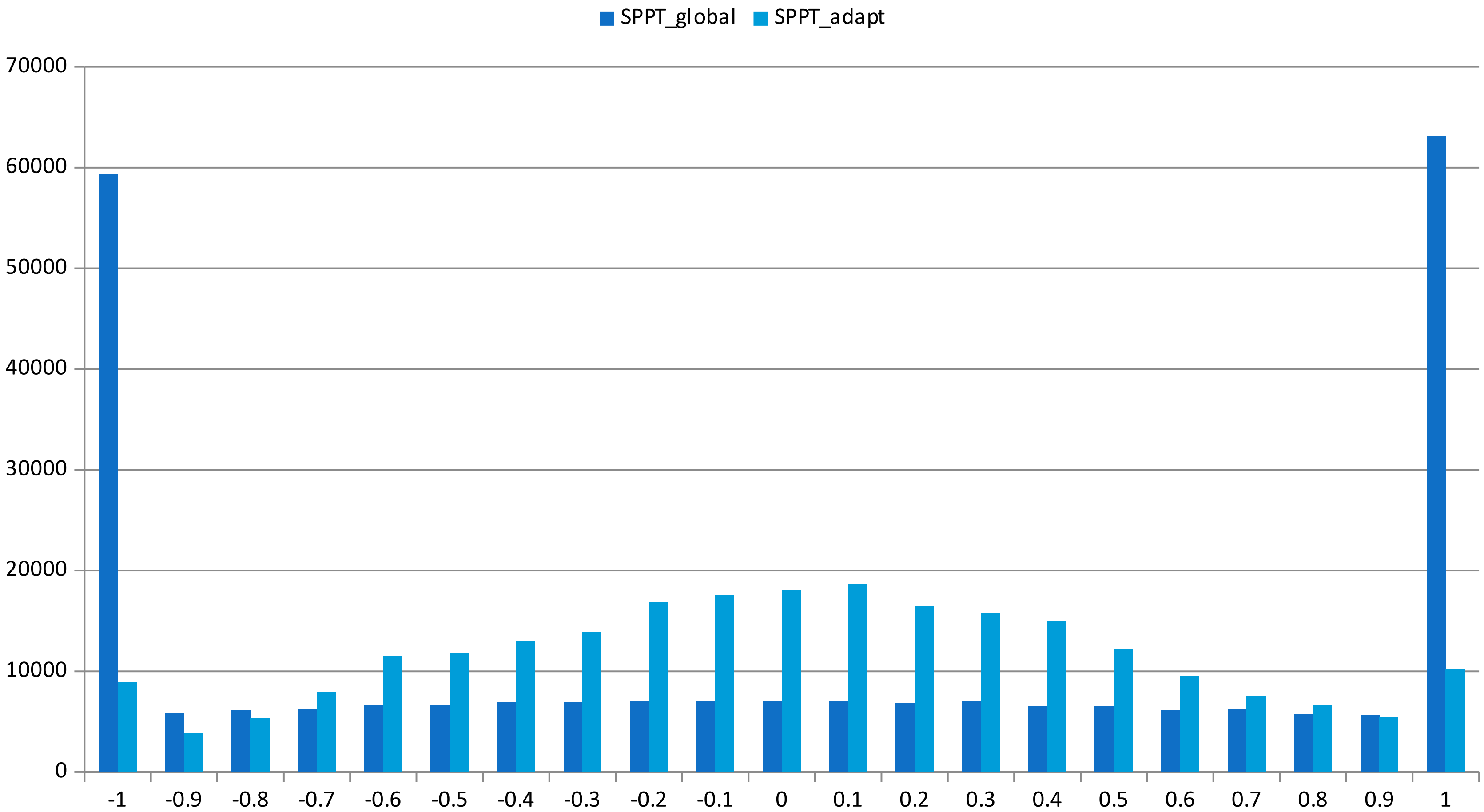
Domain of AROME-EPS at ZAMG

Adaptation of spectral pattern generator



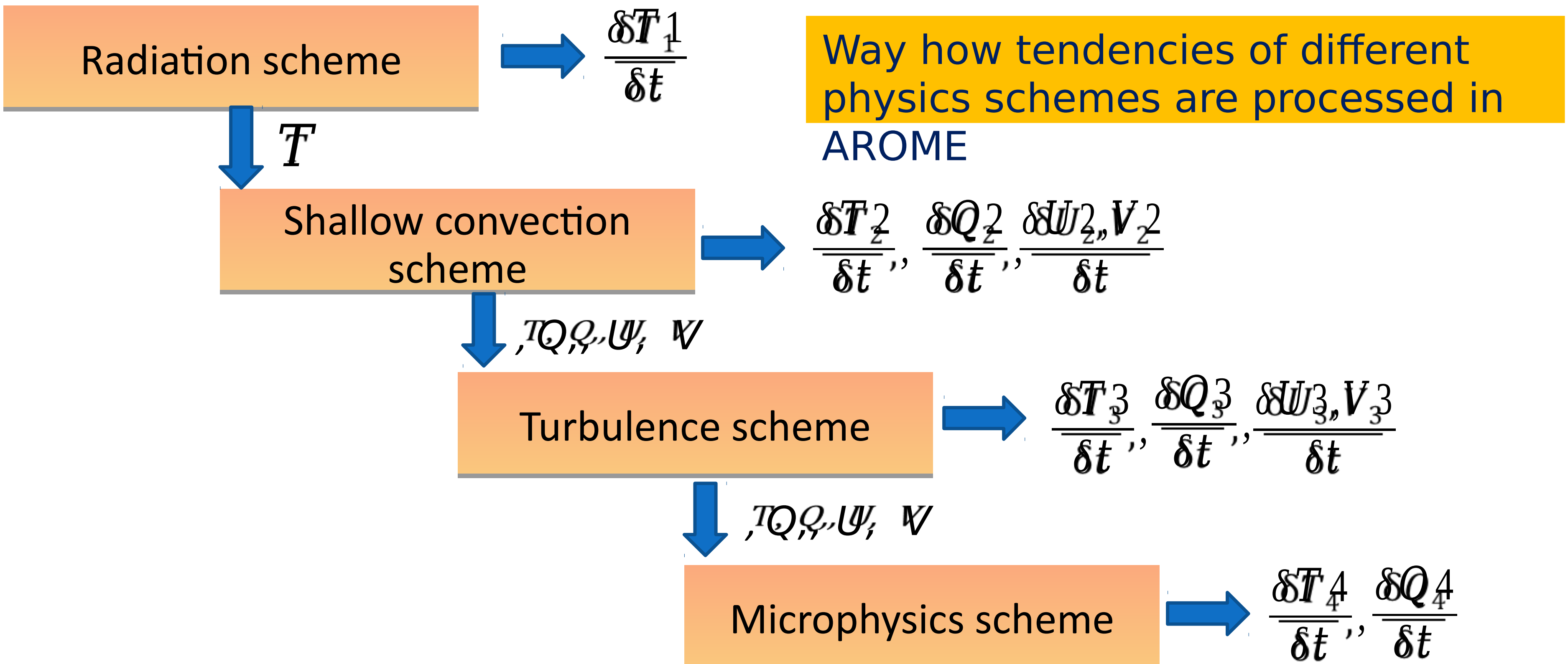
Stochastic patterns created with default (left) and adapted (right) spectral pattern generator

Adaptation of spectral pattern generator



Absolute frequency of stochastic perturbations (number of gridpoints)

Stochastic perturbations of total model tendencies: SPPT (ECMWF)

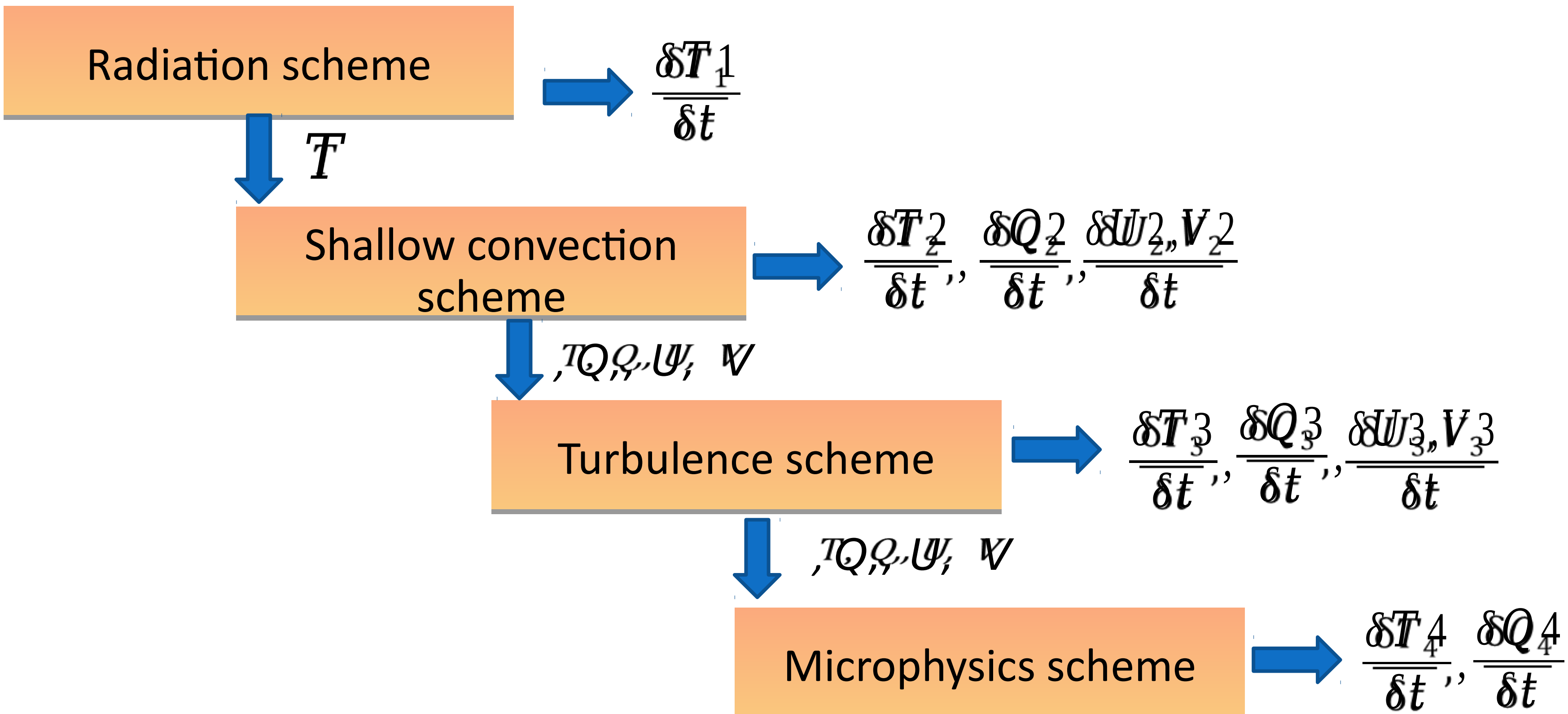


Standard SPPT: Perturbation of total tendencies

$$\frac{dT}{dt} = \sum_{i=1}^{4} \frac{\delta T_i}{\delta t} \qquad \frac{dT'}{dt} = \frac{dT}{dt} * (1 + P) \qquad \frac{dQ}{dt} = \sum_{i=1}^{4} \frac{\delta Q_i}{\delta t} \qquad \frac{dU}{dt} = \ldots$$

P …. stochastic pattern

Independent perturbations of total tendencies: iSPPT (Christensen et al.)



iSPPT: Perturbation of total tendencies - 4 different patterns

$$\frac{dT}{dt} = \sum_{i=1}^{4} \frac{\delta T_i}{\delta t} \qquad \frac{dT'}{dt} = \sum_{i=1}^{4} \frac{\delta T_i}{\delta t} * (1 + P_i) \qquad \frac{dQ}{dt} = \sum_{i=1}^{4} \frac{\delta Q_i}{\delta t}$$

Pi .... stochastic patterns

Stochastic perturbation of partial tendencies: pSPPT (ZAMG)

Radiation scheme

$$\frac{\delta T_1}{\delta t} * (1+P)$$

Shallow convection scheme

$$\frac{\delta T_2}{\delta t} * (1+P), \frac{\delta Q_2}{\delta t} * (1+P), etc.$$

Turbulence scheme

$$\frac{\delta T_3}{\delta t} * (1+P), \frac{\delta Q_3}{\delta t} * (1+P), etc.$$

Microphysics scheme

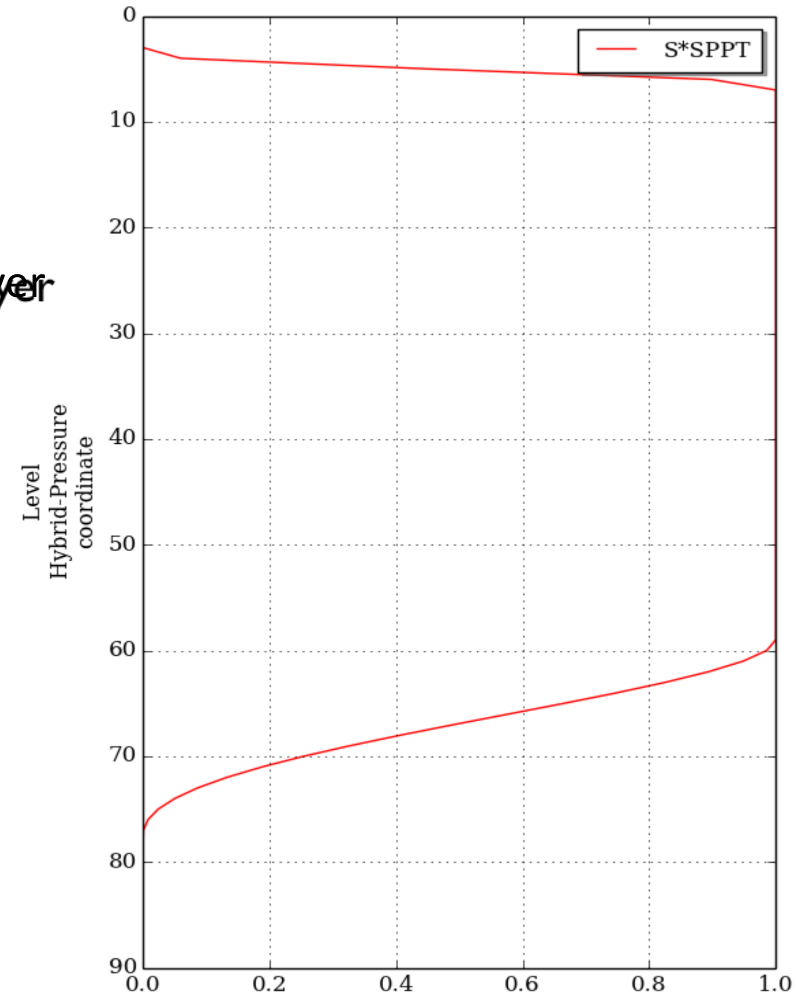
$$\frac{\delta T_4}{\delta t} * (1+P), \frac{\delta Q_4}{\delta t} * (1+P), etc.$$

- pSPPT: stochastically perturbed partial tendencies
- partial T, Q, U and V tendencies of e.g. shallow convection scheme are directly perturbed
- perturbed partial tendencies influence the subsequent turbulence scheme
- partial T, Q, U and V tendencies of turbulence scheme are perturbed and passed to microphysics scheme
- etc.

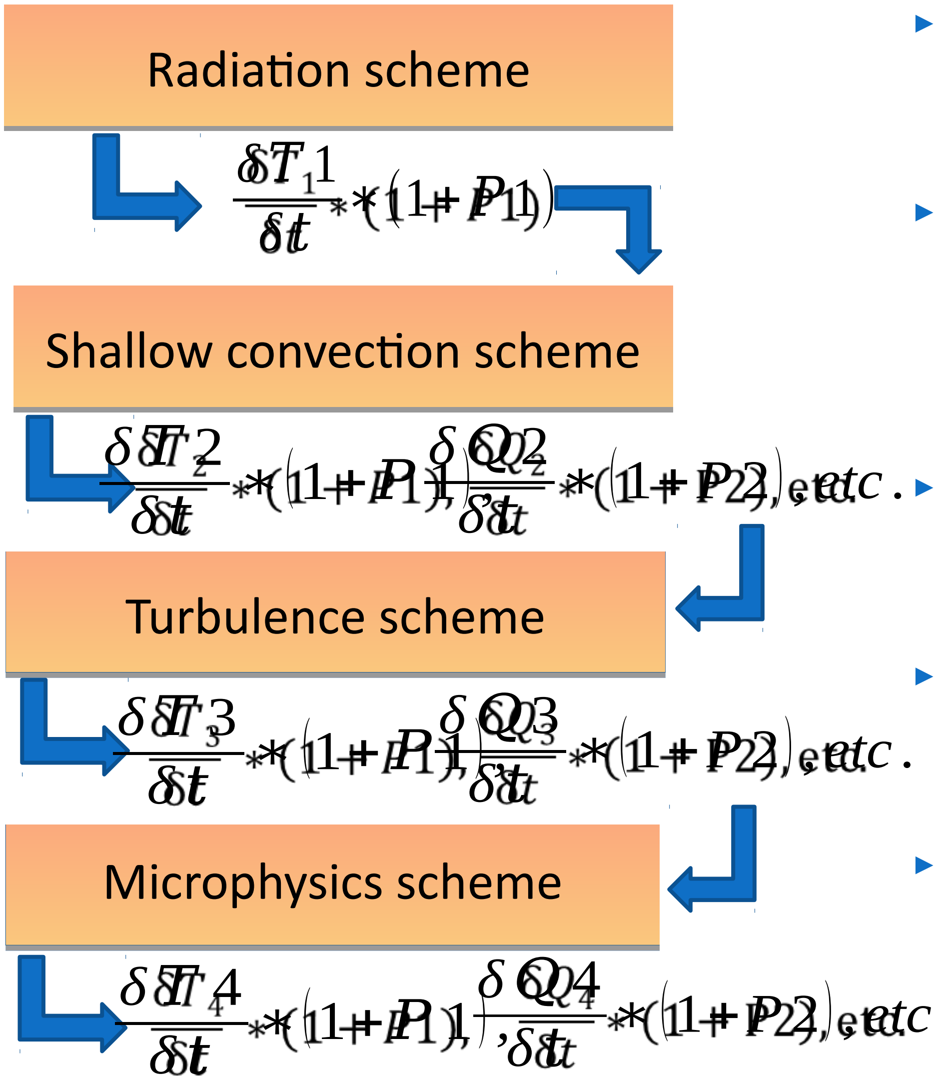
Tapering function

$$\frac{dT'}{dt} = \frac{dT}{dt} * (1 + \mathrm{P}) \qquad \mathrm{P} = \mathrm{P} * \alpha$$

- Tapering function α introduced in SPPT because of numerical instabilities
- Reduces the perturbations to 0 in the boundary layer (< 1300m) and in the stratosphere (> 100hPa)
- Physically not acceptable (assumes different error statistics in the atmosphere)
- Tests with SPPT and tapering off in July 2016 revealed 10% model crashes (too strong wind)
- pSPPT approach is much more stable (< 3% model crashes) and flexible
- Tapering can be switched on/off separately for different physics schemes
- Setting with tapering off, except for turbulence revealed best results and is stable



Independent perturbation of partial tendencies: ipSPPT (ZAMG)



- ipSPPT: independent perturbation of partial tendencies
- Assumption in SPPT that all parameters (T, Q, U, V) in one physics scheme have the same error characteristic(same pert.)
- Wind direction is never changed in that way (U, V – same pert. pattern)
- In ipSPPT different perturbations are applied to the parameters T, Q, U, V
- We need 4 different perturbation patterns – pattern generator has to be run 4 times with different seeds

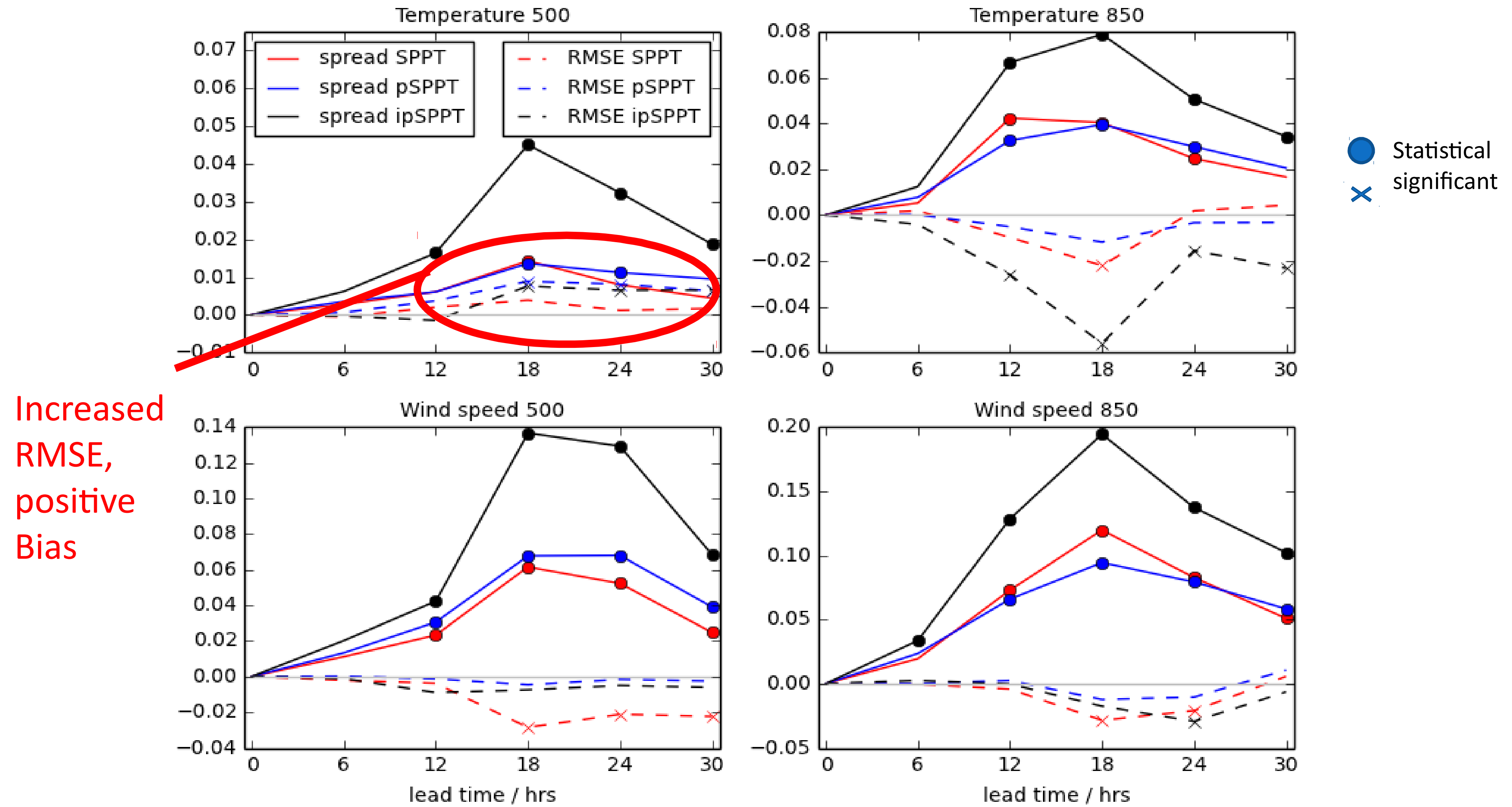
Set-up for verification

- 2 test periods of 1 month: July 2016 and January 2017
- 16 members, 00 UTC run, 30 h lead time
- No data assimilation, no initial perturbations

  only interested in effect of stochastic physics
- 4 experiments: Ref, SPPT, pSPPT, ipSPPT
- Verification of upper air variables (500 h Pa and 850 hPa): ECMWF analysis
- Verification of surface variables: point verification; 1200 synop stations in operational domain
- Classical scores (RMSE, bias, spread)

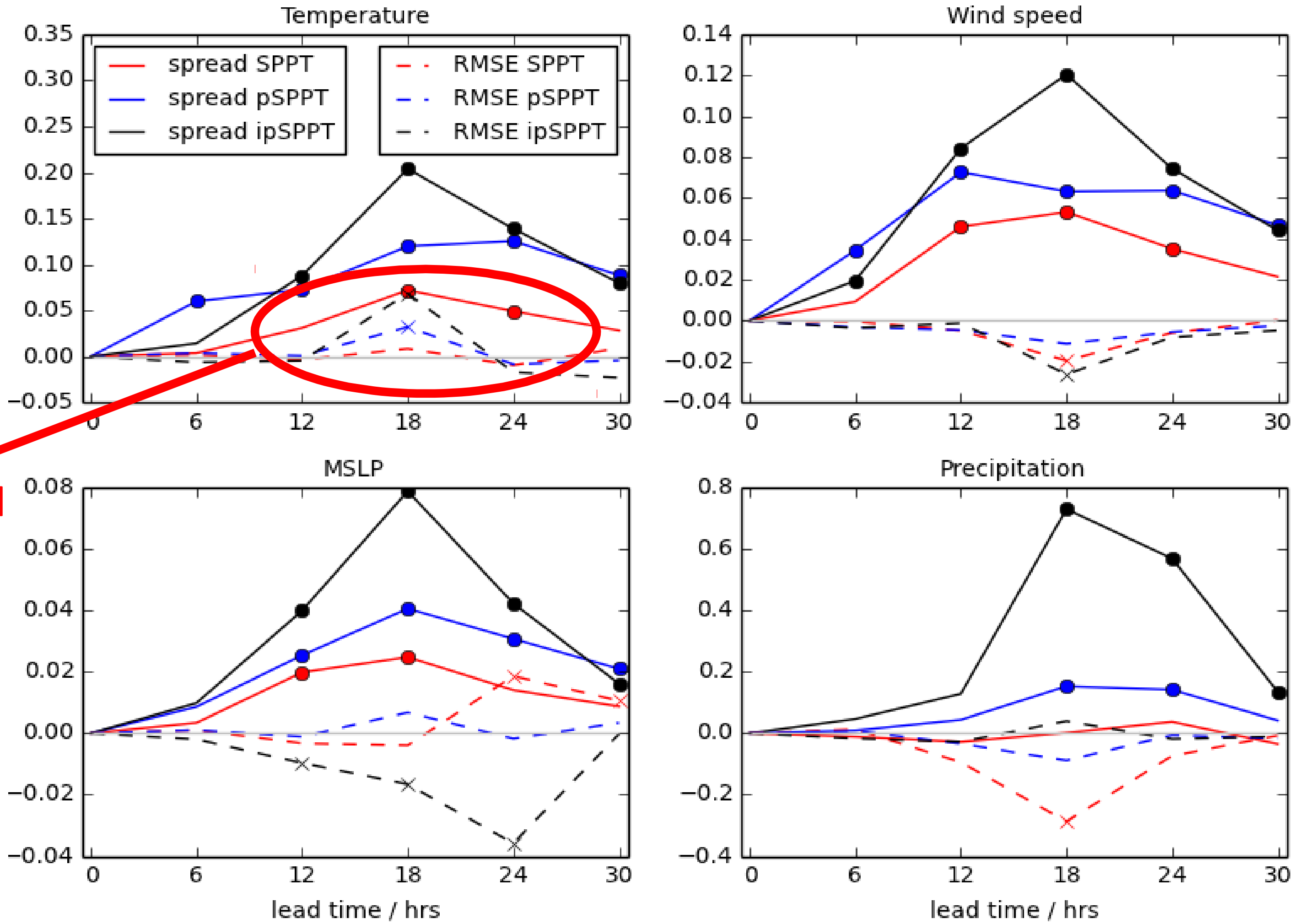
  probabilistic scores (CRPS, Brier Score, Talagrand, etc.)
- All scores are relative to AROME-Ref without any stochastic physics

Results – July 2016



Ensemble spread and RMSE of temperature and wind speed at 500/850 hPa for July 2016

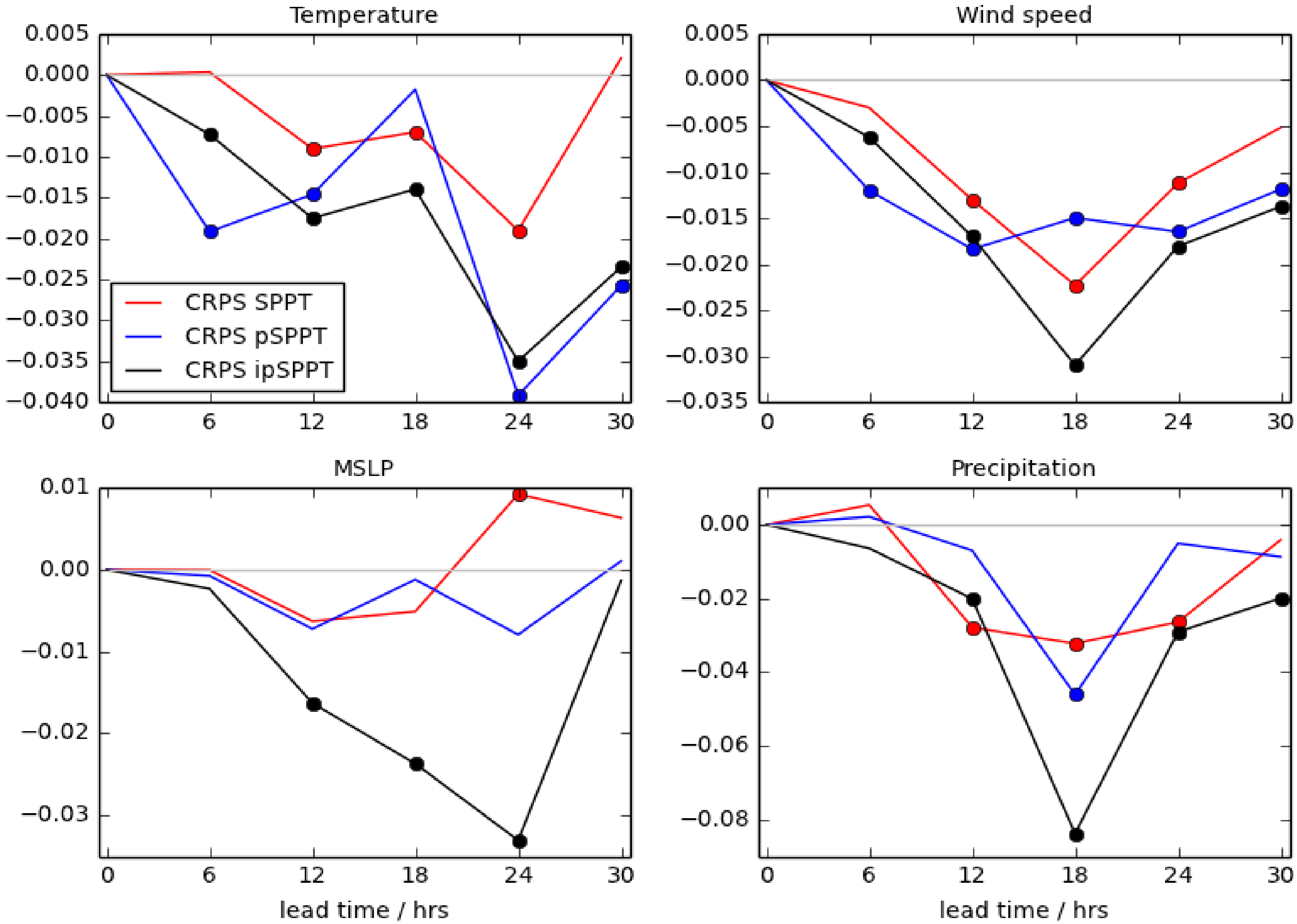
Results – July 2016



Increased RMSE, negative Bias

Ensemble spread and RMSE of 2m-T, 10m-wind speed, MSLP and precipitation for July 2016

Results – July 2016

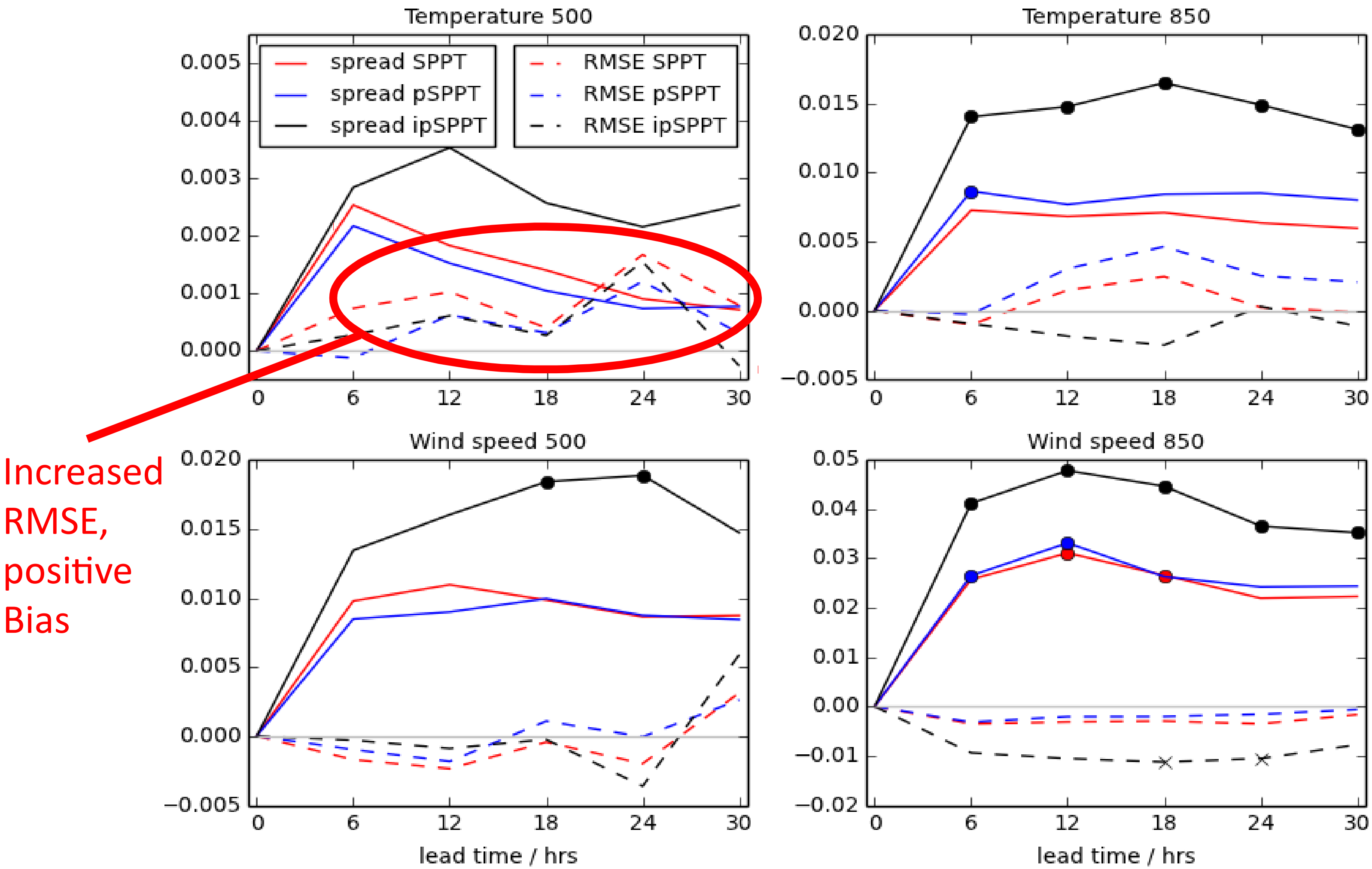


CRPS of 2m-temperature, 10m-wind speed, MSLP and precipitation for July 2016

Supersaturation adjustment

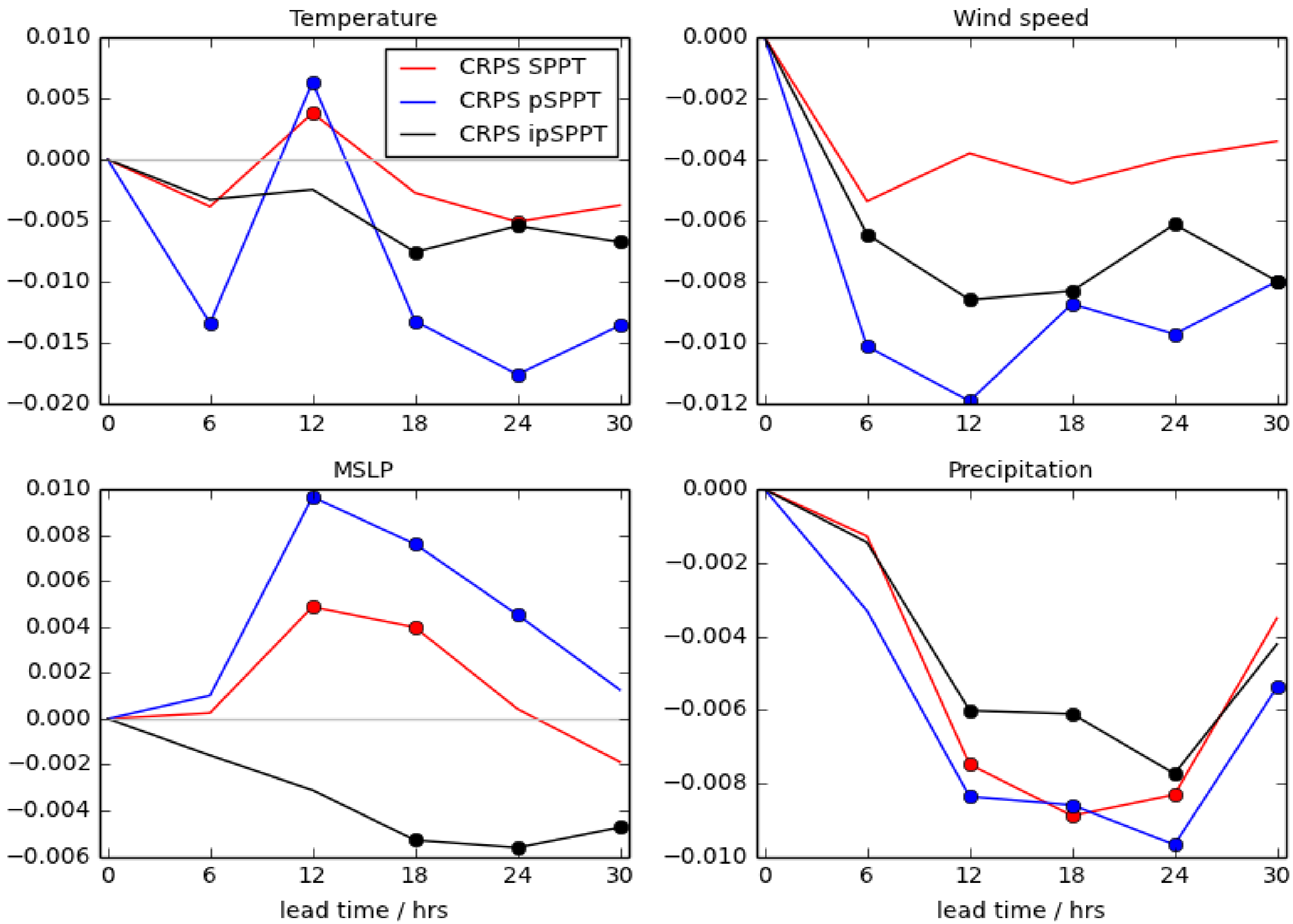
- T increase in the upper levels; decrease near the surface; drying of the atmosphere
- Perturbations are between -1 and +1, on average 0
- We use the very simple supersaturation adjustment:
  no perturbations are added if air is saturated (T and Q perturbations)
- On average we get a small negative bias of water vapor content (drying of atmosphere) and a slight positive bias of temperature
- Near the surface we experienced a slight temperature decrease – increased evaporation due to dryer air
- In SPPT this effect is reduced near the surface (tapering)

Results – January 2017



Ensemble spread and RMSE of temperature and wind speed at 500/850 hPa for January 2017

Results – January 2017



CRPS of 2m-temperature, 10m-wind speed, MSLP and precipitation for January 2017

Conclusions

- Spectral pattern generator has to be adapted to domain; bug removed
- SPPT significantly increases spread and reduces RMSE in many cases (after adaptation of pattern generator)
- Effect of stochastic physics is generally higher in summer (more sensible because of convection)
- Perturbing partial tendencies of physics schemes increases stability of the model – tapering can be switched off, except for turbulence
- Seperately perturbing the parameters T, U, V, Q provides best results, especially for spread
- Some shortcomings can be reduced to the simple supersaturation adjustment – adaptations necessary