# Stochastic perturbation of parameters in SL-AV model

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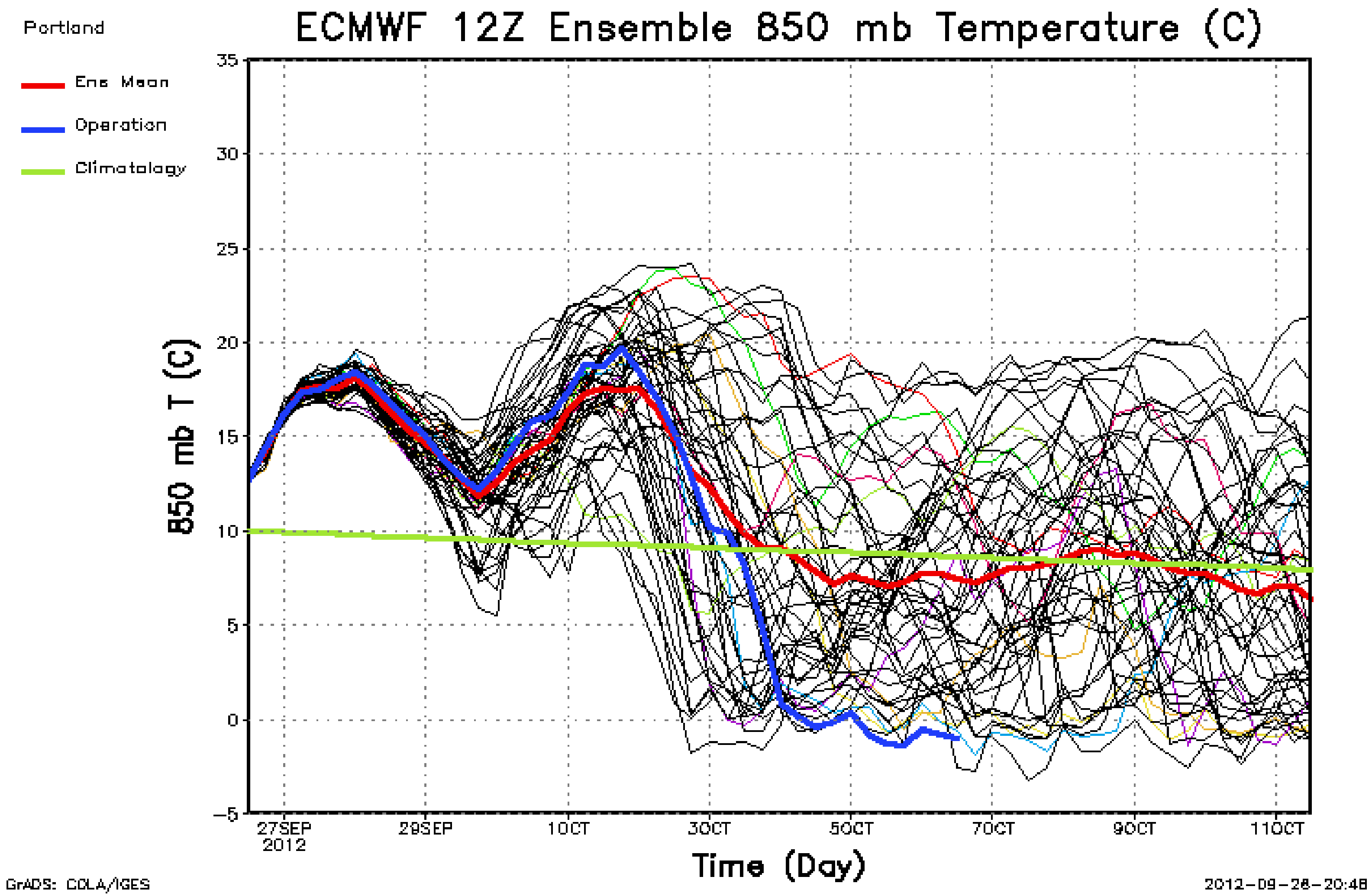
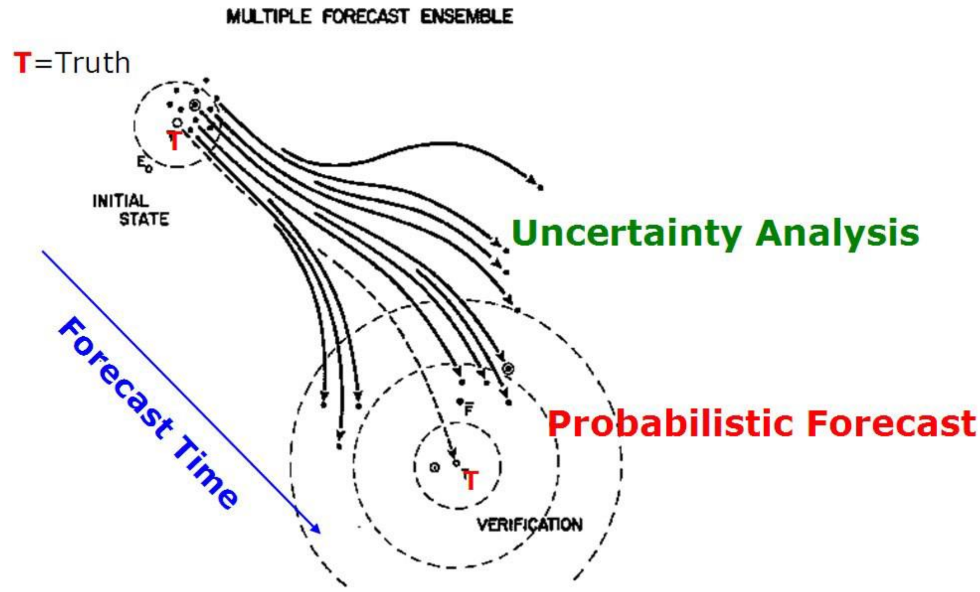
# Actuality

- medium-range ensemble forecasting
- severe weather prediction

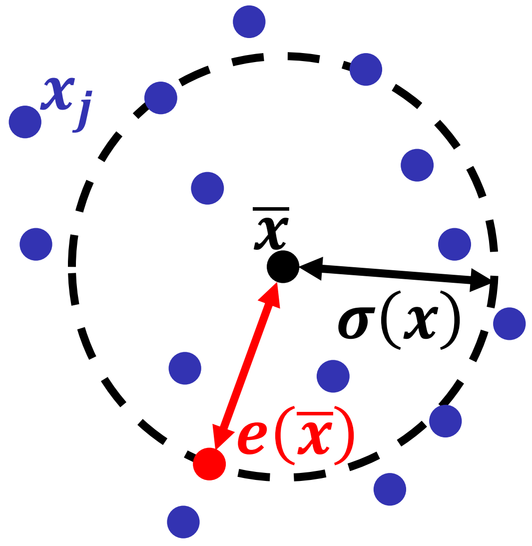


# Sources of uncertainty in atmospheric modelling

- initial data uncertainty
- model uncertainty:
  - scale interactions in the atmosphere
  - dynamics (Semi-Lagrangian advection)
  - physics parametrizations




Good ensemble:
$\sigma(x) \approx |e(\overline{x})|$




- ensemble member
- ensemble mean
- observation

# Representation of model uncertainties in atmospheric modelling

- **initial data uncertainty:**
  - Lagged average forecast (R. Hoffman)
  - Singular vector decomposition (R. Buizza)
  - Breeding (Z. Toth, E. Kalnay)
  - Ensemble Kalman filters (P. Houtekamer, H. Mitchell)

**Implemented by A. Shlyaeva, M. Tolstykh V. Mizyak, V. Rogutov [1]**

- **model uncertainty:**
  - SKEB (G. Shutts)
  - SL departure point perturbation (M. Diamantakis)
  - Tendency/parameter perturbation – SPPT, SPP (R. Buizza, P. Ollinaho)

**Need to implement!**

[1] A. Shlyaeva, M. Tolstykh, V. Mizyak, V. Rogutov, Local ensemble transform Kalman filter data assimilation system for the global semi-Lagrangian atmospheric model // Russ. J. Numer. Anal. Math. Modelling. 2013. V. 28. No. 4. P. 419-441.

# SPPT (R. Buizza, 1999)

Stochastically perturbed parametrization tendencies:

$$X_p = (1 + r\mu)X_c,$$

$X_c$ - unperturbed tendency,

$X_p$ - perturbed tendency,

$r$ - normally distributed random variable,

$\mu \in [0,1]$ - tunable parameter.

- Method is proposed for perturbing temperature, humidity and wind tendencies

- Conservation problems

# SPP (P. Ollinaho, 2017)

Stochastically perturbed parametrizations:

$$\xi_j = e^{\psi_j}\tilde{\xi}_j, \qquad \psi_j \sim \mathcal{N}\left(\mu_j, \sigma_j^2\right),$$

$\xi_j$ - perturbed parameter,

$\tilde{\xi}_j$ - unperturbed parameter,

$\psi_j$ - normally distributed random variable with a mean $\mu_j$ and a standard deviation $\sigma_j$.

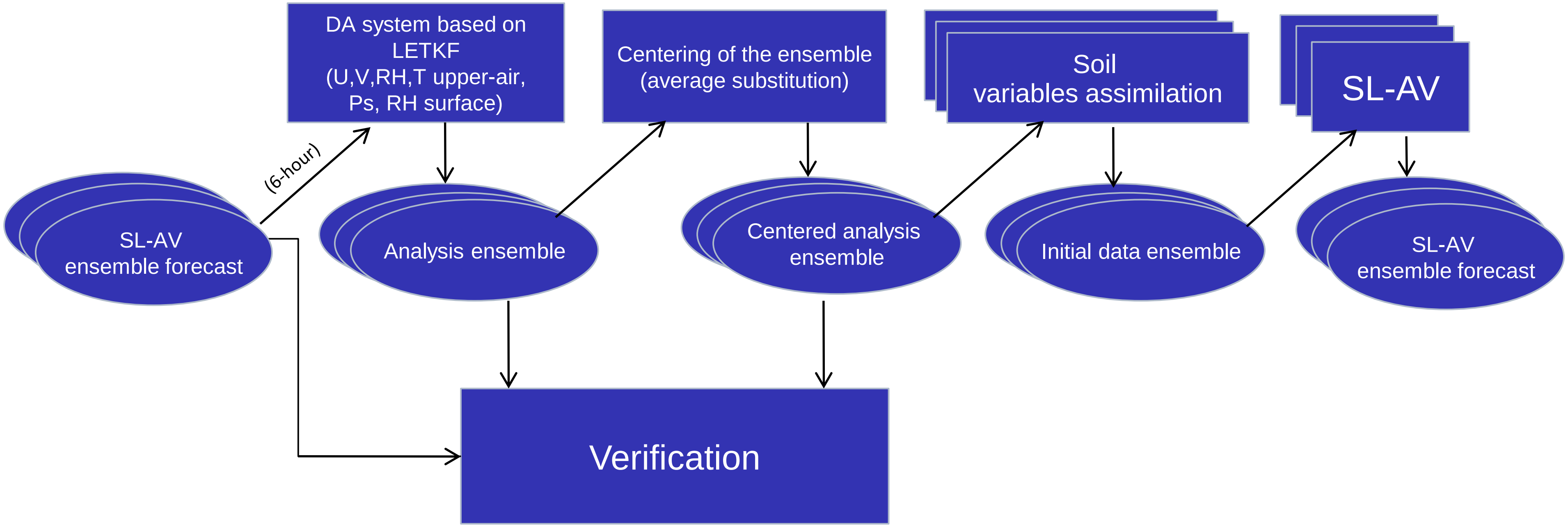
- $\mu_j = -\frac{1}{2}\sigma_j^2$ or $\mu_j = 0$
- Adding perturbations directly to poorly constrained parameters and variables within the parametrization schemes
- “Conservative” method

# Ensemble prediction system

- Local Ensemble Transform Kalman Filter (LETKF) is used to generate perturbations in the ensemble of initial data
- Ensemble is centered to the HMC operational analysis
- SL-AV global Semi-Lagrangian atmospheric model

(0,9°x0,72°, finite-difference grid, 96 hybrid vertical levels)

- Ensemble of 60 members



# Stochastic physics in SL-AV model

2D log-normally distributed stochastic patterns

- spatial correlation (biharmonic filtration)
- time correlation (AR(1)-process)

Tunable parameters:

- amplitude
- spatial auto-correlation scale
- time decorrelation scale

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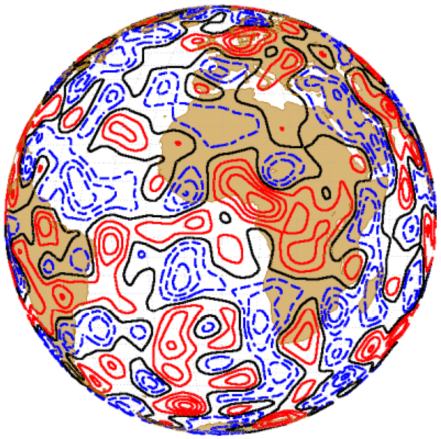
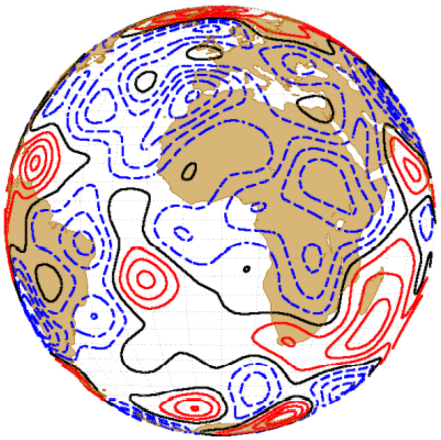
- Stochastic perturbation of uncertain parameters and variables

- Mean / median of perturbed parameter equals to unperturbed value

- Description of uncertainty in the entire atmosphere from boundary layer and free troposphere to the stratosphere

- Tendencies are not perturbed near the Earth' surface and in the stratosphere





# Stochastic physics in SL-AV model

27 stochastically perturbed parameters and variables in parametrizations of

- cloud processes
- radiation
- convection
- condensation and precipitation
- microphysics
- subgrid orography
- turbulence

2 stochastically perturbed tendencies:

- vorticity
- temperature

Humidity is not perturbed due to conservation problems

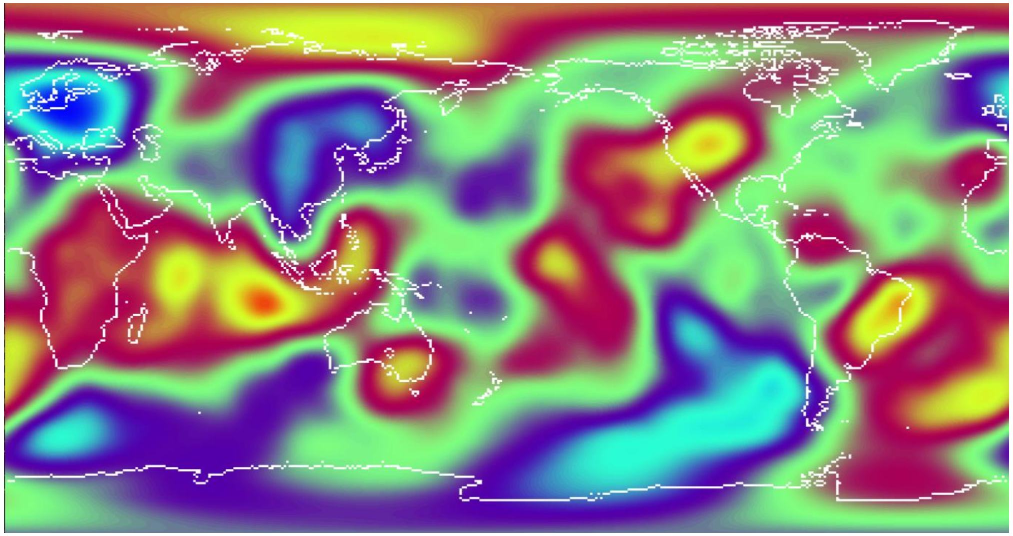


Fig.: Example of a stochastic pattern

# Stochastic patterns generation (G. S. Goyman)

2D patterns: $\xi_j = e^{\psi_j}\tilde{\xi}_j, \quad \psi_j \sim \mathcal{N}\left(-\frac{1}{2}\sigma_j^2, \sigma_j^2\right),$

$\xi_j$ - perturbed parameter,

$\tilde{\xi}_j$ - unperturbed parameter,

$\psi_j$ - random field.

- Biharmonic filtration for spatial correlation:

$$\psi_{j(f)} = \psi_j - \nu\Delta^2\psi_{j(f)},$$

$\nu$ - spatial auto-correlation scale.

- AR(1)-process for time correlation:

$$\psi_j^{n+1} = \frac{1}{2}\sigma_j^2\frac{\Delta t}{\tau_j} + \left(1 - \frac{\Delta t}{\tau_j}\right)\psi_j^{n+1} + \left[\frac{\Delta t}{\tau_j}\left(2 - \frac{\Delta t}{\tau_j}\right)\right]^{\frac{1}{2}}\varepsilon_j^n$$

$\Delta t$ - model time step,

$\tau_j$ - time decorrelation scale,

$\varepsilon_j^n$ - 2D filtered random field with distribution $\mathcal{N}\left(-\frac{1}{2}\sigma_j^2, \sigma_j^2\right)$

# Forecast RMSE vs ensemble spread, Jan 2021

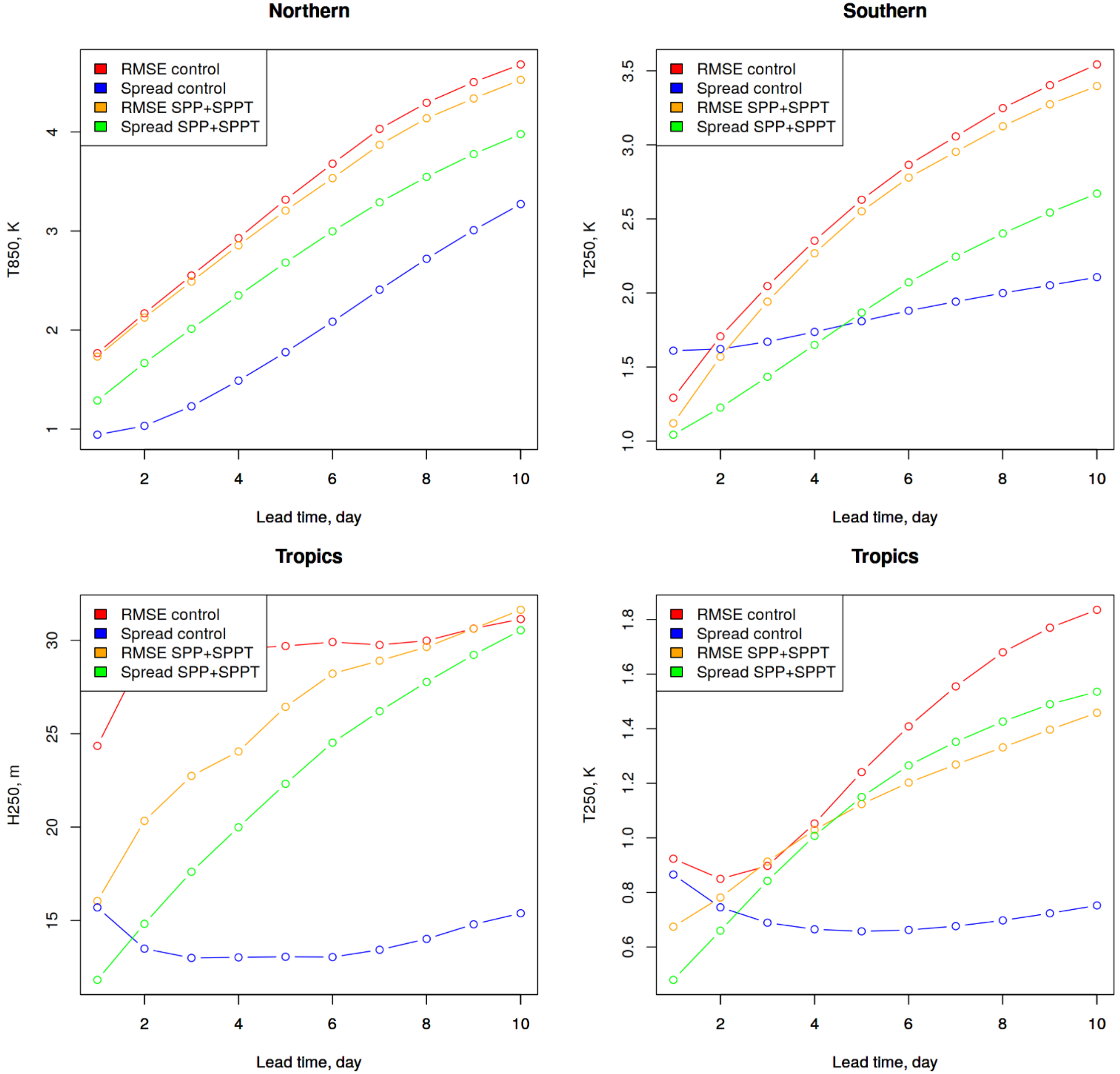
Red – forecast RMSE in control experiment

Blue – ensemble spread in control experiment

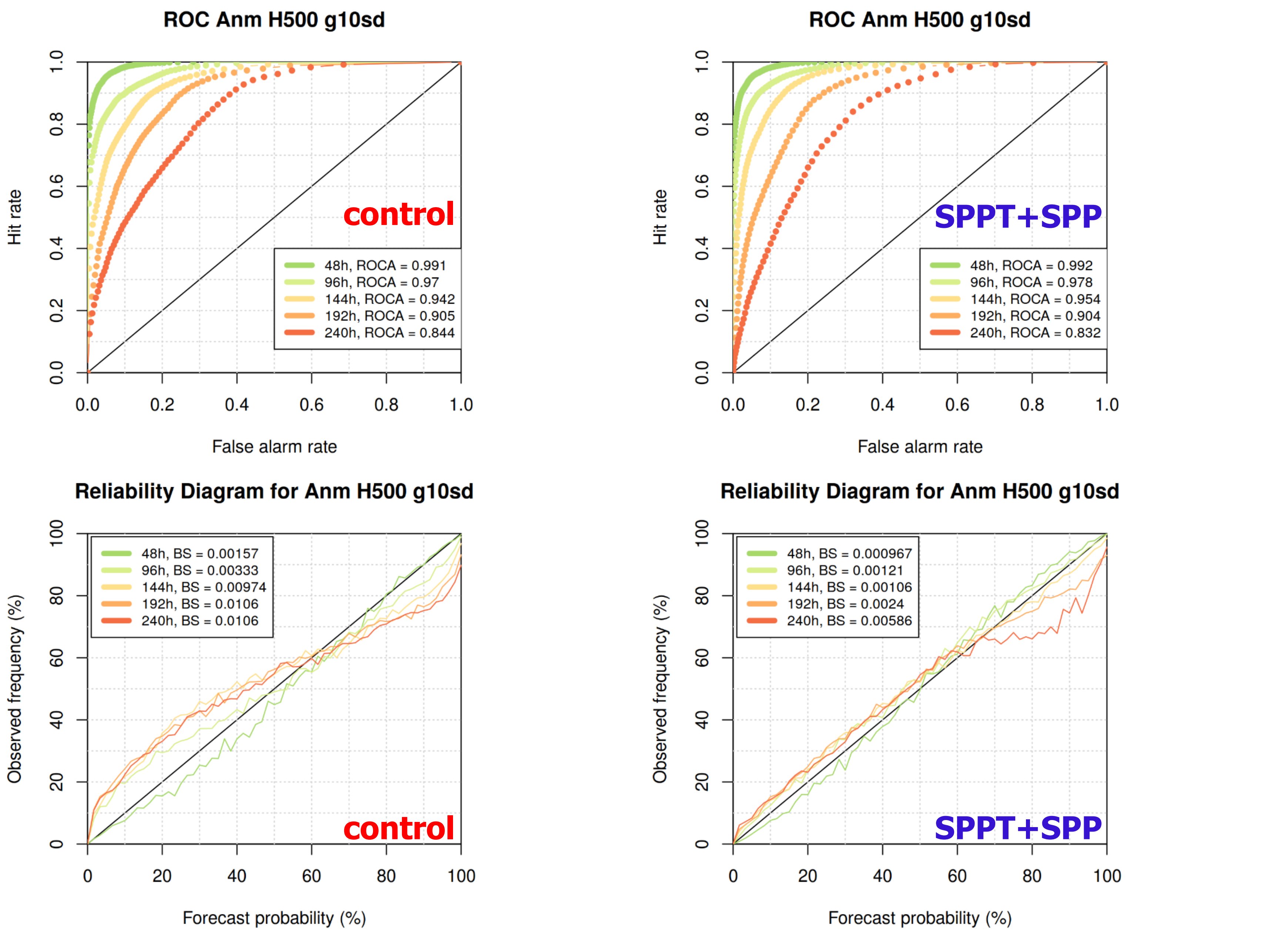
Yellow – forecast RMSE with SPPT+SPP

Green – ensemble spread with SPPT+SPP

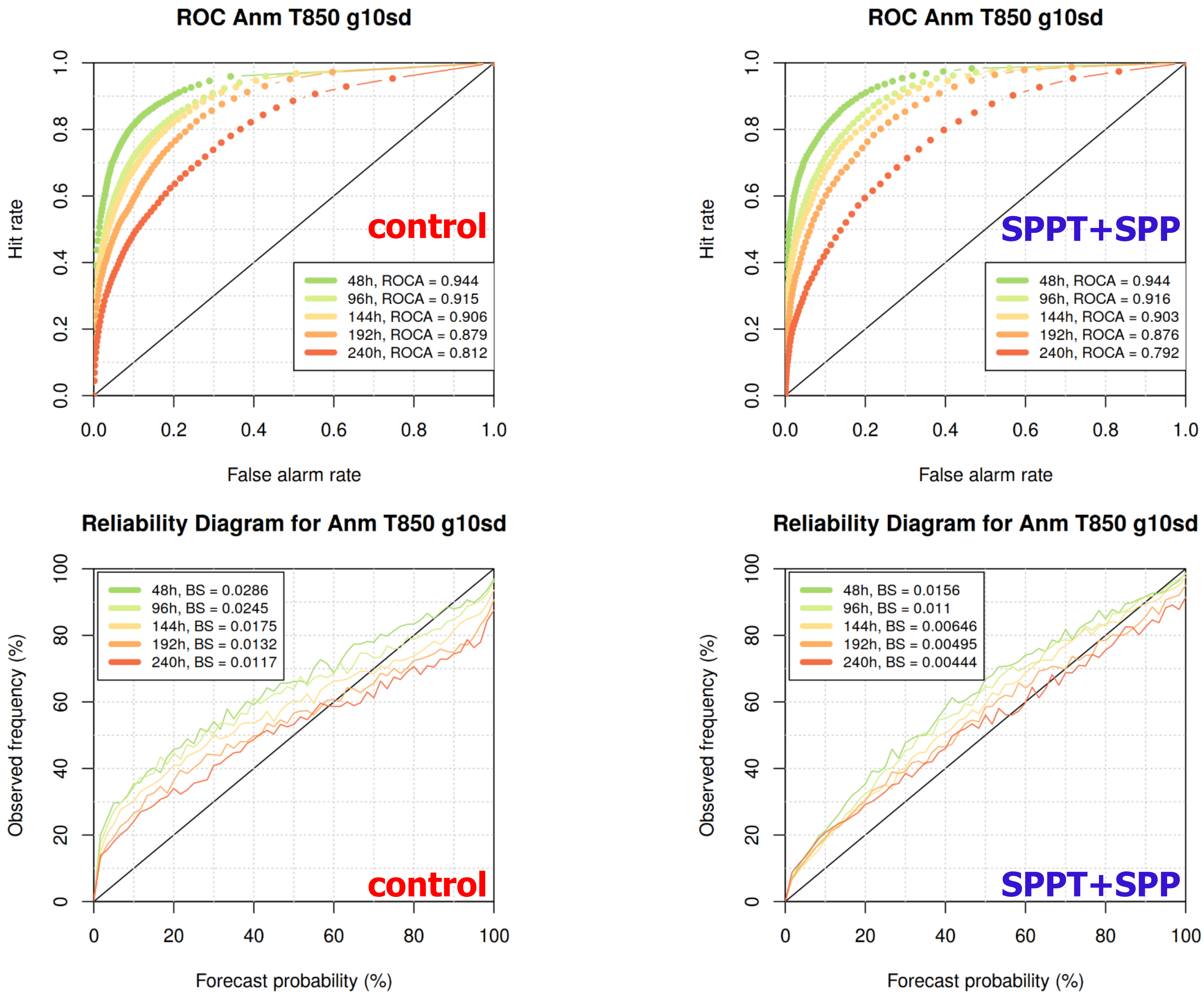
Control experiment: different parameters for different ensemble members in model namelist, do not vary in time



# ROCs and reliability diagrams, Jan 2021



# ROCs and reliability diagrams, Jan 2021



# Summary

Results:

- Stochastic perturbations of tendencies and parameters were implemented in SL-AV model
- Stochastic physics increased the ensemble spread for all variables
- The reliability of probabilistic ensemble weather forecasts was improved for some variables
- Brier score became smaller for T850 and H500

Future plans:

- Optimization of the combination of additive inflation in the initial data ensemble and SPPT + SPP in the model
- Stochastic perturbations of Semi-Lagrangian departure points iterations

# Thank you for your attention!

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