AMPT: Additive Model-error perturbations scaled by Physical Tendencies

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Outline

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    3. Perturbations-induced biases
    4. Ensemble prediction scores

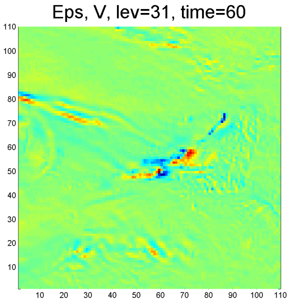
AMPT: motivation

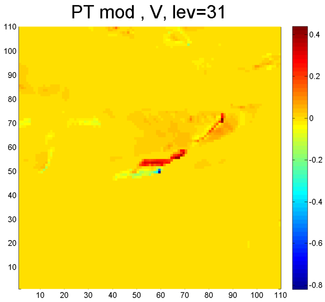
Drawbacks of SPPT

1. SPPT produces a small perturbation at some point in space and time whenever the physical tendency is small there. But small physical tendency doesn't necessarily imply small *error*.
   E.g., a convective cell starts to develop in the true model whilst the convective parameterization fails to be activated.
   $\Rightarrow$ An **additive** model-error component would resolve the problem.

2. SPPT perturbs only the magnitude of the **multivariate** physical tendency $\mathcal{P}$: $\mathcal{P}^* = (1 + \xi) \cdot \mathcal{P}$
   tacitly assuming that the error is only in the *magnitude* of the vector $\mathcal{P}$, whilst the *relationships* between the physical tendencies of different variables are *error-free*, which is highly unlikely.
   $\Rightarrow$ Introducing **uncorrelated additive** perturbations in different variables would mitigate the problem.

Model error (left) and physical tendency (right)





- Physical tendency is informative but not everywhere. Hence, a physical-tendency-independent model-error term is needed.

Proposal

Our empirical study of model error structures (by using a more sophisticated and hi-res version of COSMO as the truth) suggests that both an additive and a multiplicative error components should be present.

AMPT is the additive model-error-model component. It relies on the Stochastic Pattern Generator (SPG, Tsyrulnikov and Gayfulin 2017) as the spatio-temporal stochastic source.

The final model-error-model is a linear combination of AMPT and SPPT.

AMPT: description

General

The **AMPT** model error perturbations:

1. are mutually uncorrelated spatio-temporal (SPG-generated) random fields.
2. are scaled as the *area averaged* (in the horizontal) $|\mathcal{P}|$.

AMPT perturbations: (1) **"Gaussian distributed" variables** T, u, v

The idea is to scale the additive perturbation (say, of T) by the **horizontal domain average of the modulus of the Physical Tendency** P_T:

$$\bar{\mathcal{P}}_T(\mu, t) = \langle |P_T(x, y, \mu, t)| \rangle,$$

where μ is the vertical coordinate and $\langle . \rangle$ is the horizontal averaging operator on the model grid. Then, the perturbation is

$$\Delta T(x, y, \mu, t) = \epsilon_T \cdot \bar{\mathcal{P}}_T(\mu, t) \cdot \xi_T(x, y, \mu, t),$$

where ϵ_T is the external parameter that determines the overall magnitude of the perturbation and $\xi_T(x, y, \mu, t)$ is the SPG generated pseudo-random field with zero mean and unity variance.

AMPT perturbations: (2) **humidity** q_v

Similar to T, u, v except

1. Gaussian SPG-generated perturbations are added to *pseudo-relative humidity* $\rho = q_v / q_{\rm sat}^{\rm fixed}$ (assumed to be more Gaussian than q_v).
2. Perturbations are truncated at $\rho = 0$.
3. No truncation of perturbations at the saturation limit is applied.
4. No changes in temperature perturbations are made.

AMPT perturbations: (3) **cloud fields** q_c, q_i

Similar to humidity except

- The **horizontal averaging** of the modulus of the Physical Tendency for these variables is performed over grid points where the Physical Tendency is non-zero.
- Perturbations of q_c and q_i are generated only at grid points with non-zero q_c and q_i, respectively.

A hybrid: AMPT + SPPT

$$\varepsilon = \boxed{w_{\mathrm{add}} \cdot \varepsilon_{AMPT} + w_{\mathrm{mult}} \cdot \varepsilon_{SPPT}}$$

w_{add} and w_{mult} can be level-dependent (at the moment these are constants).

Numerical experiments

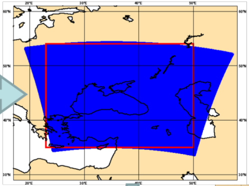
Domain and cases

- Roughly 300*400 km area centered at Sochi (latitude 44N). Half of the domain is Black sea, another half is land with mountains.
- Model configuration: 2.2 km, 50 levels.
- Initial and lateral boundary conditions for ensemble members are taken for COSMO-LEPS adapted for a larger Sochi region (resolution 7 km) – made by the Italian colleagues.
- Cases: 1-11 February 2014 and 1–12 May 2014.

EPS setup

ECMWF-EPS
Globe
T779L61 (Δx~30 km)
M51, fc+14d
ECMWF computer

Clustering
Nesting



COSMO-S14-EPS
SOCHI DOMain
Δx~7km, L40
M10, fc+72h
ECMWF computer

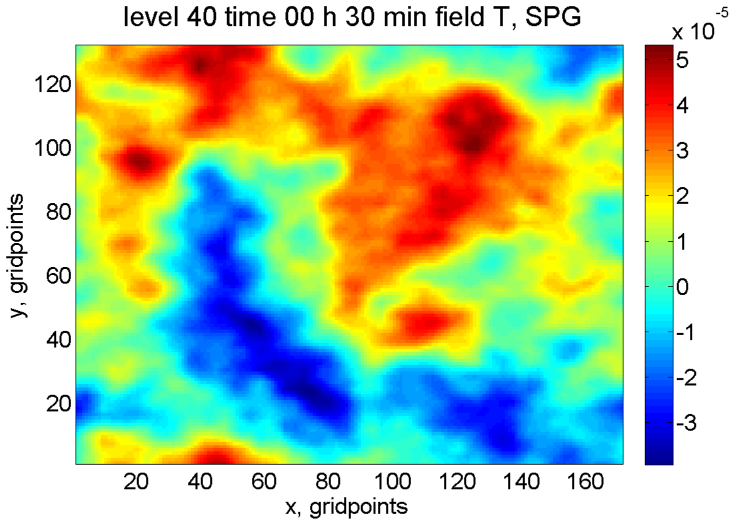
Nesting

COSMO-Ru2-EPS
Sochi region
Δx~2.2 km, L51
M10, fc+48h
RHMC computer

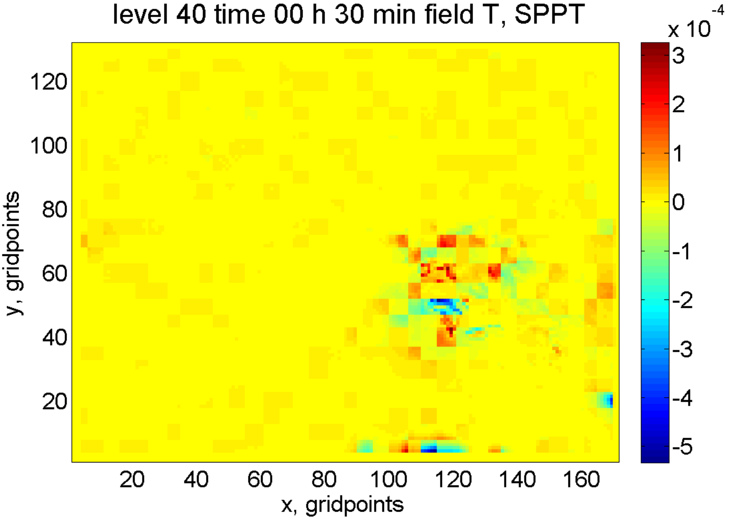
Model error perturbation fields.

AMPT, SPPT, and AMPT+SPPT

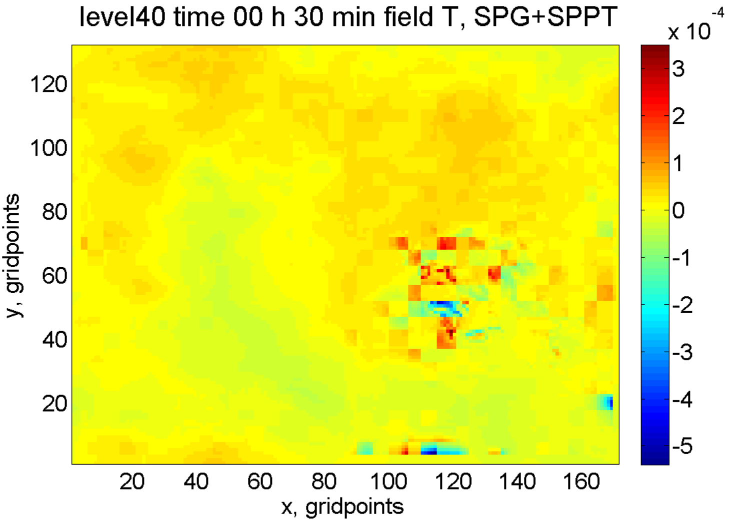
T model error perturbation: AMPT (level 40)



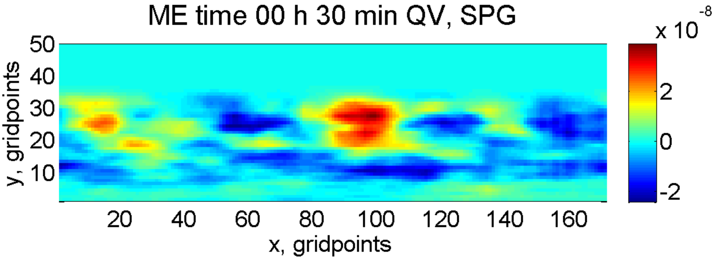
T model error perturbation: SPPT (level 40)



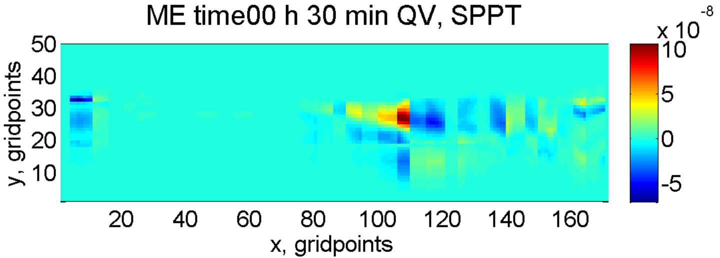
T model error perturbation: AMPT+SPPT (level 40)



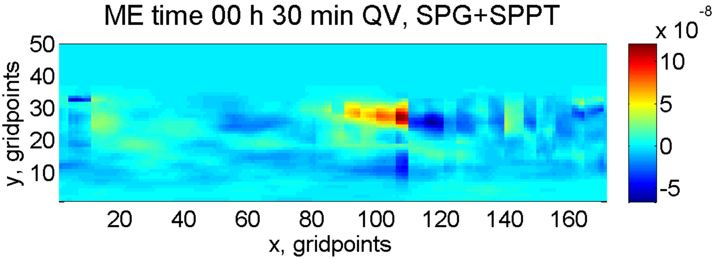
q_v model error perturbation (vertical cross-section): AMPT



q_v model error perturbation: SPPT



q_v model error perturbation: AMPT+SPPT

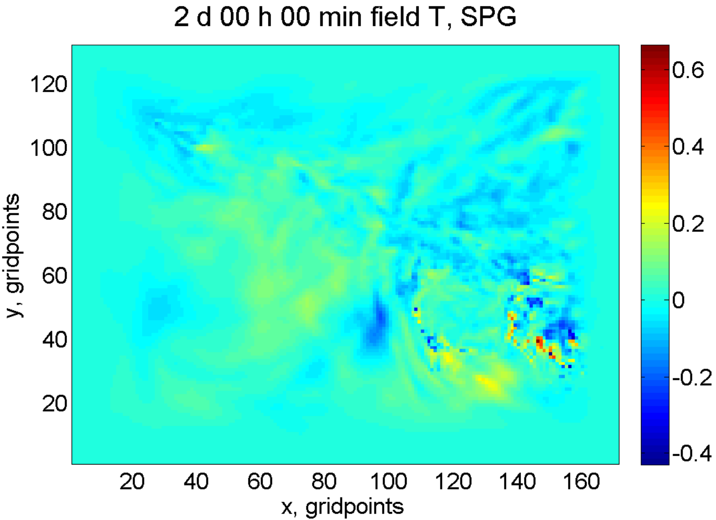


Forecast error perturbation fields.

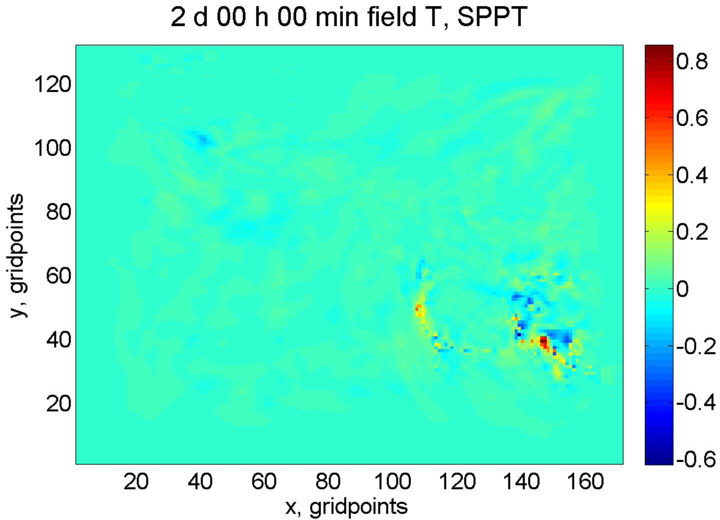
(Only model-error perturbations imposed. 3h and 48h forecasts)

AMPT v SPPT

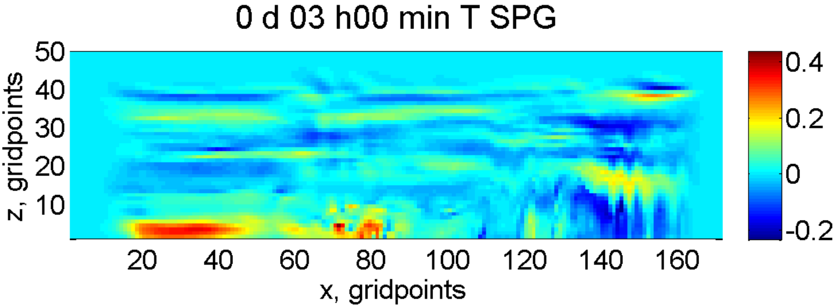
Level 35, 48h. AMPT



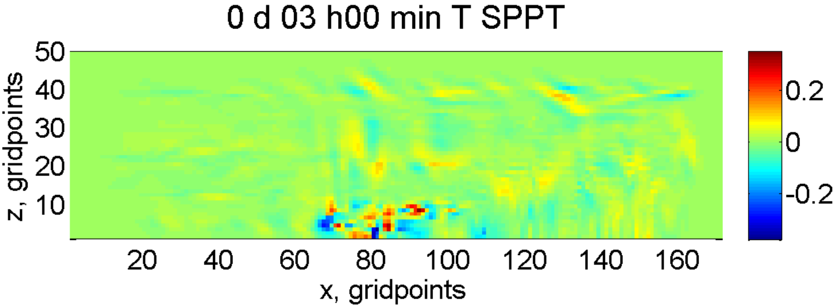
Level 35, 48h. SPPT



Vertical cross-section, AMPT, 3h

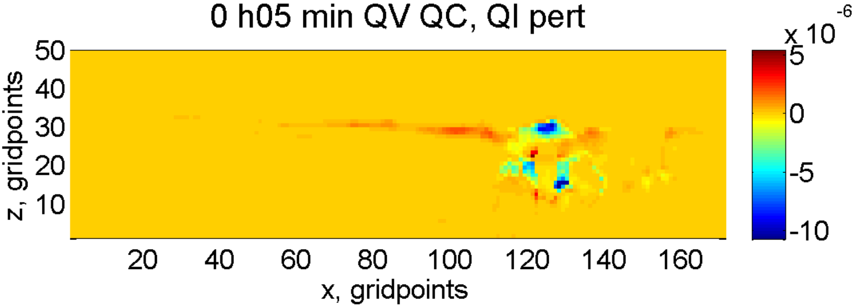


Vertical cross-section, SPPT, 3h



Forecast perturbations of q_v (vertical cross-section) in response to q_c, q_i AMPT model-error perturbations.

Animation 0–6 h every 5 min



Conclusion on model-error and forecast-error perturbations

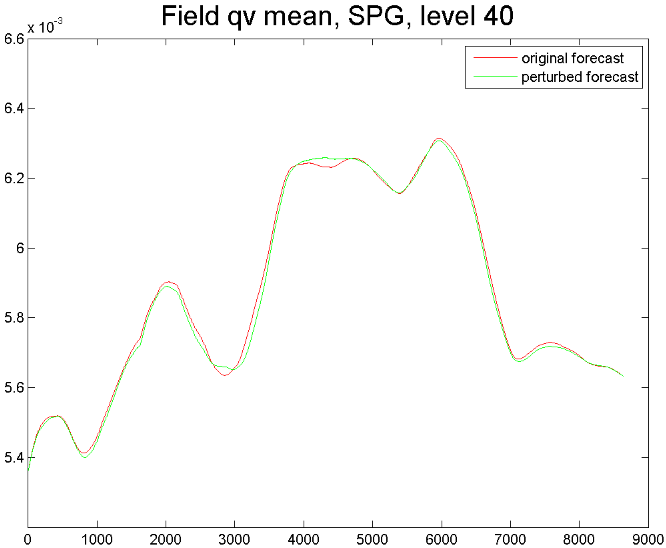
Model error perturbations:

- AMPT model-error perturbations are less localized (with a more spatially uniform magnitude) than SPPT perturbations.
- The magnitudes of the model-error perturbations in AMPT and SPPT are comparable (maxima are greater in SPPT, rms values are greater in AMPT).

Forecast perturbations: largely inherit the above properties of the model error perturbations.

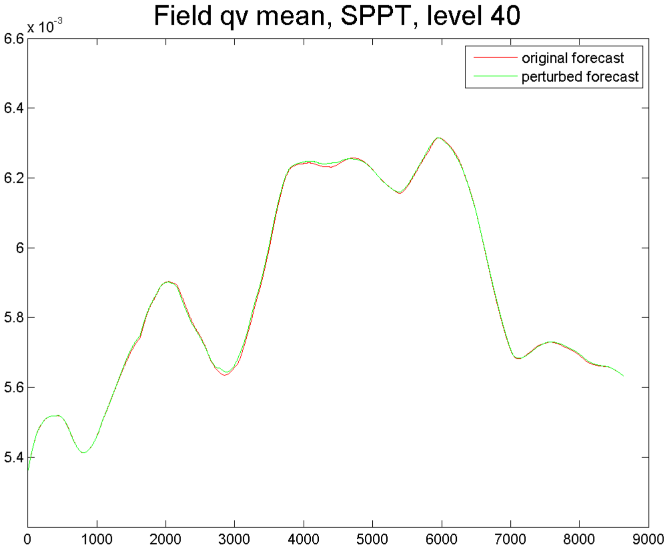
Perturbations-induced biases. **AMPT**.

Bias in q_v forecast perturbations



Perturbations-induced biases. **SPPT**.

Bias in q_v forecast perturbations



Perturbations-induced biases. **AMPT v SPPT**.

4D-averaged (48h) forecast biases

Scheme\Field	T	q_v	q_c	q_i
SPPT	$4 \cdot 10^{-4}$	$1 \cdot 10^{-6}$	$1 \cdot 10^{-8}$	$1 \cdot 10^{-9}$
AMPT	$4 \cdot 10^{-4}$	$9 \cdot 10^{-7}$	$2 \cdot 10^{-8}$	$9 \cdot 10^{-8}$

The global biases are seen to be small enough for both AMPT and SPPT.

Ensemble prediction scores.

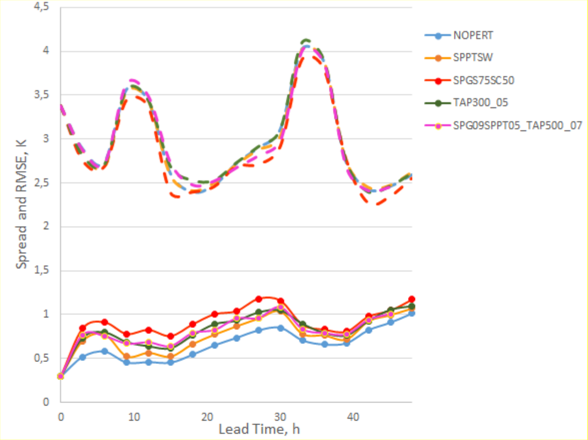
AMPT v SPPT

Setup

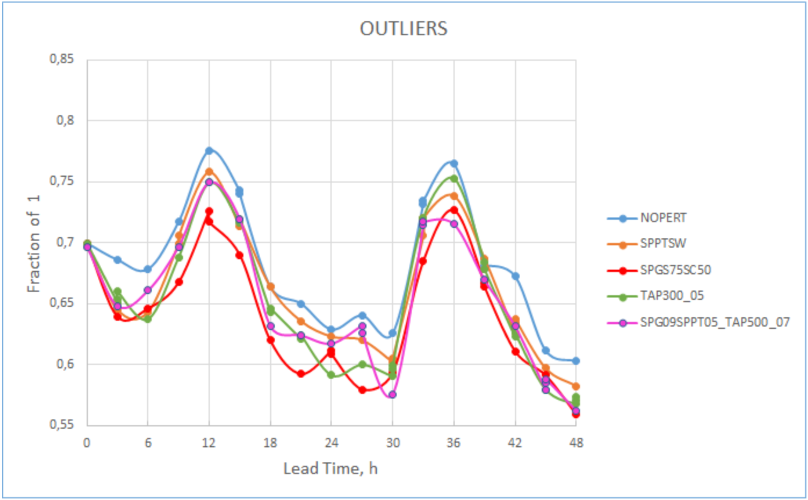
- Ensemble size 10, forecast lead time 48 h.
- SPPT's setup borrowed from the Meteo-Swiss colleagues (w/o tapering).
- Results for 1–11 February are shown (May results are similar but less conclusive).
- Verification against ($\sim$ 40) meteorological stations.
- T_{2m} verification results are shown.

RMSE (the smaller the better) and **spread** (the closer to the RMSE the better).

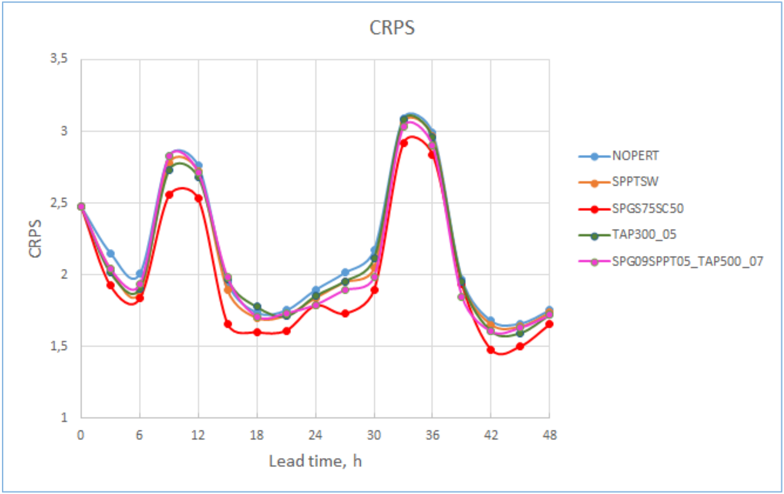
The "red version" of the AMPT (no tapering, no q_x perturbations, no SPPT added) is the overall winner in these experiments.



Outliers (the fewer the better)



CRPS (the lower the better)



Conclusions

- An Additive Model-error generation technique in which perturbations are scaled by Physical Tendencies (**AMPT**) is proposed and tested. In the AMPT:
  - The magnitude of the imposed perturbation is proportional to the horizontally averaged magnitude of the physical tendency.
  - The fields $T, u, v, p, q_v, q_c, q_i$ are perturbed.
  - Perturbations in different variables are independent.
  - The **SPG** is used as the 4D pattern generator.
- A mixed additive-multiplicative model-error generation scheme is motivated and tested.
- First results show that in ensemble forecasts, the new schemes can outperform SPPT.

Thank you!

Appendix: SPG

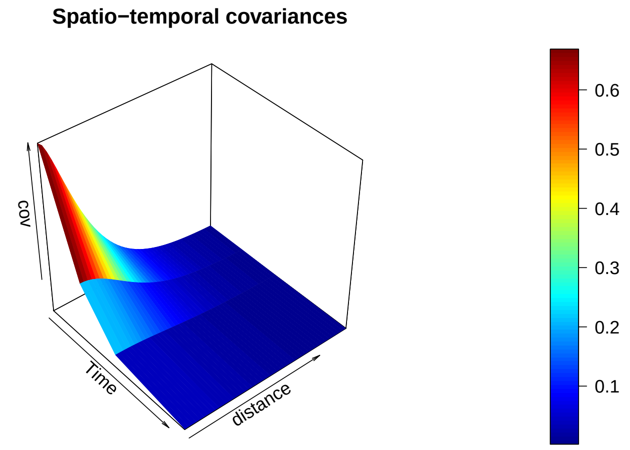
SPG

$$\left(\frac{\partial}{\partial t} + \frac{U}{\lambda}\sqrt{1-\lambda^2\Delta}\right)^3 \xi(t,\mathbf{s}) = \sigma\,\alpha(t,\mathbf{s})$$

– α is the white driving noise
– ξ is the output random field
– $\sqrt{1-\lambda^2\Delta}$ is the *pseudo-differential* operator needed to enforce the "proportionality of scales" property
– the 3rd order in time is needed to make the spatial variance spectra of ξ realistic

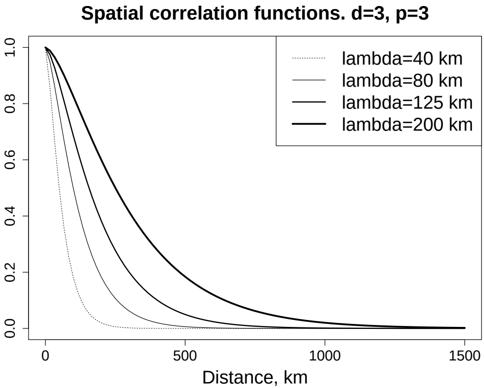
- σ controls the variance
- λ controls the spatial scale
- U controls the temporal scale

M.Tsyrulnikov and D. Gayfulin. A limited-area spatio-temporal stochastic pattern generator for simulation of uncertainties in ensemble applications. Meteorologische Zeitschrift (2017): 549-566.



Ranges: t=0...12 h, r=0...750 km

Spatial correlation functions



Temporal correlation functions