AMPT: Additive Model perturbations scaled by Physical Tendency

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Outline

1. How model perturbations are generated in DA and EPS?
2. Outline of the new scheme termed AMPT: Additive Model perturbations scaled by Physical Tendency
3. Testing AMPT in an EPS.

How model perturbations are generated in DA and EPS?

DA-specific ways to represent model errors

The most common techniques are:

1. Multiplicative inflation.
   Relaxation of analysis perturbations to the prior ensemble.
2. Additive inflation.

Disadvantages of these pragmatic approaches:

- Techniques of category (1) provide no additional stochasticity (whereas actual model errors do so).
- Techniques of category (2) are flow independent.
- Both (1) and (2) add perturbations not at *sources* of model uncertainties.

Sources of model errors

- simplifications of model equations
- missing processes
- subgrid-scale processes.
  Tackled by physical parameterization schemes $\Rightarrow$ uncertainty/error in physical tendency

EPS (and, increasingly, DA): Modeling uncertainties in physical parameterizations

Common approaches:

- Multi-physics (ad-hoc, non-stochastic).
- PP (Parameter Perturbations) (ad-hoc, a flavor of multi-physics).
- SPP (Stochastic Parameter Perturbations) (ad-hoc).
- SPPT (Stochastic Perturbations of Physical Tendency) (ad-hoc).
- Intrinsically stochastic physical parameterizations (better justified, promising, but still in their infancy).

SPP or SPPT?

We opted for SPPT because it attempts to do exactly what is needed to represent uncertainty in physical parameterizations: it perturbs the physical tendency.

SPP:

1. It accounts only for *parametric* uncertainty (inadequacies in modeling assumptions are not accounted for).
2. The *parameters* may have no counterparts in nature (no objective way to justify the perturbation statistics).

SPPT: formulation

The SPPT perturbation of the physical tendency in the i-th model variable P_i is

$$\Delta P_i(x, y, \zeta, t) = \epsilon\,\xi(x, y, t) \cdot P_i(x, y, \zeta, t)$$

(ξ is the zero-mean, unit-variance random field, ϵ is the magnitude parameter)

NB:
The random multiplier $\epsilon\,\xi(x, y, t)$ is the same for all model variables and all vertical levels.

SPPT: critique

1. If at some point $P_i = 0$, then the perturbation $\Delta P_i \propto P_i = 0$ (i.e. the assumed model error $=0$ there). Can be wrong if, say, in some grid cell, convection is initiated in nature whilst a convective parameterization fails to be activated.
2. The *relative* physical tendency $\frac{\Delta P_i(x,y,\zeta,t)}{P_i(x,y,\zeta,t)}$ is the same for all model variables at a grid point $\Rightarrow$ the relative model error is the same for all model variables i.
3. Similarly, as ξ is constant in the vertical in SPPT, the relative model error is the same for all grid points in the column.
4. Moreover, this approximately holds for huge 4D volumes: L=500km (!) and T=6h for SPPT in COSMO.

The SPPT's tacit assumption that errors in different variables everywhere in a LAM domain during hours of forecast time are almost 100% correlated is not realistic.

Outline of AMPT

AMPT: formulation

From SPPT,

$$\Delta P_i(x, y, \zeta, t) = \epsilon\, \xi(x, y, t) \cdot P_i(x, y, \zeta, t)$$

to

$$\boxed{\Delta P_i(x, y, \zeta, t) = \epsilon\, \xi_i(x, y, \zeta, t) \cdot \mathcal{P}_i(x, y, \zeta, t)}$$

Differences with SPPT:

1. Switch from pointwise physical tendency P_i to an area-averaged physical tendency $\mathcal{P}_i$.
2. Specify independent random fields for different model variables ξ_i.
3. Make ξ_i depend on the vertical coordinate.
4. Make space and time scales of ξ_i more realistic for a high-resolution model.

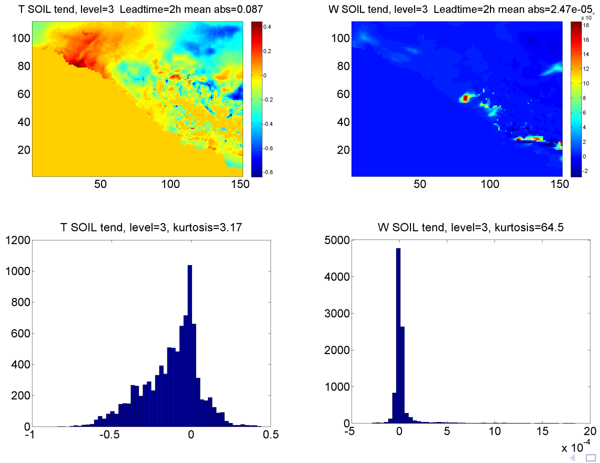
AMPT in COSMO

1. The 4D random pattern ξ is generated by the Stochastic Pattern Generator (SPG, *Tsyrulnikov and Gayfulin, Meteorol. Zeitschrift, 2017*).
2. Perturbed fields:
   - *Atmosphere*: T, u, v, q_v, q_c, q_i and hydrostatically balanced p.
   - *Soil*: $T_{\rm so}, W_{\rm so}$ (multi-layer, 2D random field ξ).

“Gaussian” and “non-Gaussian” fields

Example of two unperturbed T_{soil} (left panel) and W_{soil} (right panel) tendency fields

Gaussian non-Gaussian



Treatment of different model fields

In the soil:

1. $T_{\rm so}$: the area-averaged (scaling) physical tendency $\mathcal{P}_i$ is computed over the whole LAM domain.
2. $W_{\rm so}$: the scaling physical tendency $\mathcal{P}_i$ is computed over a small 2D moving window centered at the grid point in question.

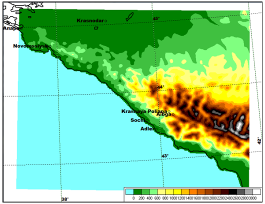
In the atmosphere:

1. T, u, v are treated like $T_{\rm so}$
2. q_v, q_c, q_i are treated like $W_{\rm so}$.

Testing AMPT in an EPS

Experimental setup

•Domain 290*380 km, centered at Sochi (44N 40E).



•Model: COSMO (version 5.01, single precision), grid spacing 2.2 km, 50 levels.

•Ensemble size 10.

•Initial and lateral boundary conditions for ensemble members are taken from COSMO-LEPS adapted for a larger Sochi region (resolution 7 km) — made by the Italian colleagues *(special thanks to Andrea Montani)*.

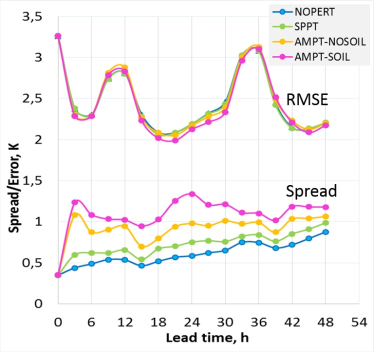
•Time period: February – March 2014.

•Verification against synoptic stations.

•SPG space and time scales: $L_\xi = 50$ km, $T_\xi = 1$ h

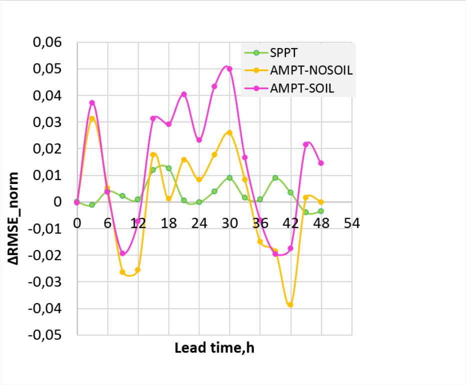
T_{2m}: RMSE of ensemble mean and ensemble spread

Experiment	Model perturbations
NOPERT	None
SPPT	SPPT: atmosphere
AMPT-NOSOIL	AMPT: atmosphere
AMPT-SOIL	AMPT: atmosphere + soil



⇒ Spread: big improvement (in *reliability*)

Normalized T_{2m} ensemble-mean RMSE *reduction*



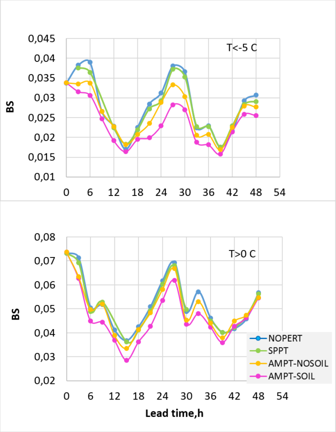
$(RMSE_{NOPERT} - RMSE)/RMSE_{NOPERT}$

The higher the better.

Deterministic verification.

⇒ somewhat better

T_{2m}: Brier score



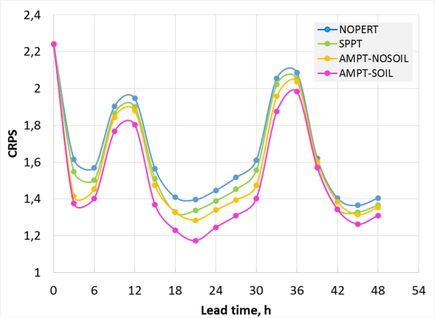
The lower the better.

Measures the combined effect of reliability and resolution for the selected threshold.

⇒ much better.

T_{2m}: CRPS

Experiment	Model perturbations
NOPERT	None
SPPT	SPPT: atmosphere
AMPT-NOSOIL	AMPT: atmosphere
AMPT-SOIL	AMPT: atmosphere + soil

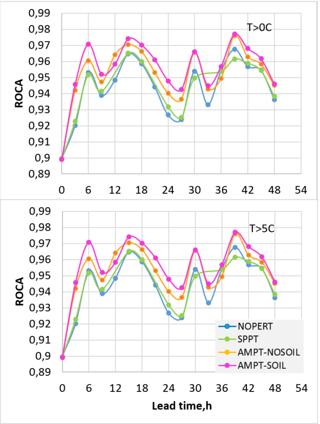


The lower the better.

Measures the combined effect of reliability and resolution. Integrated over all thresholds.

⇒ much better

T_{2m}: ROC area

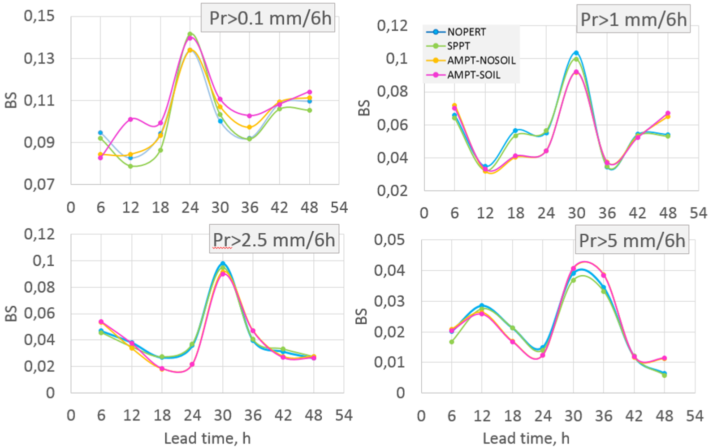


The higher the better.

Measures discrimination.

⇒ much better

Precipitation: Brier score



The lower the better

⇒ Mixed results

Conclusions

- A new model perturbation technique termed AMPT has been developed.
- AMPT aims to address some of the deficiencies of SPPT.
- AMPT generates additive perturbations with the magnitude determined by an area averaged physical tendency.
- AMPT relies on the previously developed 4D Stochastic Pattern Generator (SPG).
- In ensemble prediction experiments:
  - $T, u, v, p_\mathrm{s}, q_v, q_c, q_i, T_\mathrm{so}, W_\mathrm{so}$ were perturbed.
  - A positive effect from perturbing $T, u, v, T_\mathrm{so}, W_\mathrm{so}$, mixed effect from perturbing q_v, q_c, q_i.
  - AMPT significantly outperformed SPPT for T_2m, with nearly the same results for precipitation and near-surface wind.