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.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grid-points</td>
<td>500*320</td>
</tr>
<tr>
<td>Timestep</td>
<td>60s</td>
</tr>
<tr>
<td>Resolution</td>
<td>2.5km</td>
</tr>
<tr>
<td>Time</td>
<td>18UTC + 36hours</td>
</tr>
<tr>
<td>Number of members</td>
<td>11</td>
</tr>
</tbody>
</table>
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)
    - \( \delta e \) – 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)

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:
    \[ P'(e_j; t) = (1 + \alpha r_j) \cdot P(e_j; t) \]
  - \( r \) is not defined as an independent value in grid-boxes but as a global field with spectral coefficients and spherical harmonics:
    \[ r = \sum_{mn} r_{mn} * Y_{mn} \]
  - Spectral coefficients evolve according to an AR(1) process:
    \[ r_{mn}(t + \Delta t) = \Phi r_{mn}(t) + \sigma_n \eta_{mn} \]
    \[ \Phi = \exp \left( -\Delta t / \tau \right) \]
  - Where temporal correlation is controlled by \( \tau \) decorrelation timescale which is one important control parameter of the scheme:
  - And where \( \eta \) values are independent, white in time and picked from a 0-mean, unit variance Gaussian distribution.

Generalities about the SPPT
The revised SPPT scheme on global scale

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

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

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

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

- $\sigma$ 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 $[-c\sigma;c\sigma]$ 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.

Generalities about the SPPT
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    \[ \kappa T = \frac{1}{2} \left( \frac{l}{R_E} \right)^2 \]

- ECMWF uses the combination of more pattern. The one which takes into account the uncertainty of synoptic scales is set and visualized as:
  - $\sigma=0.5$
  - $l=500\text{km}$
  - $\tau=6\text{h}$

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:
    \[ P'_X(e_j; t) = (1 + \alpha(h) r_j) \times P_X(e_j; t) \]
    \[ X = \{ u, v, T, q \} \]
  - \( \alpha \) 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 \( \sigma_n \) is defined on the same way:
    \[ \sigma_n = F_0 \exp(-\kappa T n (n+1)/2) \]
    \[ F_0 = \left( \frac{\sigma(1-\Phi^2)}{2 \sum_{n=1}^{N} (2n+1) \exp(-\kappa T n (n+1))} \right)^{1/2} \]
    \[ \kappa T = \frac{1}{2} \left( \frac{l}{R_E} \right)^2 \]

SPPT scheme in AROME
Random pattern generator

- Examination of random pattern on the Hungarian domain:
  - $\sigma_n$ 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 | $\sigma$ | 0.5 |
    | | $c$ | 2.0 |
    | | $\tau(h)$ | 6 |
    | | $I(km)$ | 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:
  - Domain size dependent variable should be defined instead of $R_E$?
  - Bigger $I$ is an equivalent solution (SPPT-big):

<table>
<thead>
<tr>
<th></th>
<th>SPPT-default</th>
<th>SPPT-big</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\sigma$</td>
<td>0.5</td>
<td>0.5</td>
</tr>
<tr>
<td>$c$</td>
<td>2.0</td>
<td>2.0</td>
</tr>
<tr>
<td>$\tau(h)$</td>
<td>6</td>
<td>8</td>
</tr>
<tr>
<td>$l(km)$</td>
<td>500</td>
<td>4000</td>
</tr>
</tbody>
</table>

- 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 $\sigma$ standard deviation, but how far they are from that?

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

<table>
<thead>
<tr>
<th></th>
<th>SPPT default</th>
<th>SPPT big</th>
<th>SPPT small</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\sigma$</td>
<td>0.5</td>
<td>0.5</td>
<td>0.2</td>
</tr>
<tr>
<td>$c$</td>
<td>2.0</td>
<td>2.0</td>
<td>5.0</td>
</tr>
<tr>
<td>$\tau(h)$</td>
<td>6</td>
<td>8</td>
<td>8</td>
</tr>
<tr>
<td>$l(km)$</td>
<td>500</td>
<td>4000</td>
<td>4000</td>
</tr>
</tbody>
</table>

- 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.

\[ P'_X(e_j; t) = (1 + \alpha(h)r_j) \times P_X(e_j; t) \]

\[ X = \{u; v; T; q\} \]

- 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:

\[
\begin{align*}
P'_{u_j}(e_j; t) &= (1 + r_1) \cdot P_{u_j}(e_j; t) \\
P'_{v_j}(e_j; t) &= (1 + r_2) \cdot P_{v_j}(e_j; t) \\
P'_{T_j}(e_j; t) &= (1 + r_3) \cdot P_{T_j}(e_j; t) \\
P'_{q_j}(e_j; t) &= (1 + r_4) \cdot P_{q_j}(e_j; t)
\end{align*}
\]

<table>
<thead>
<tr>
<th></th>
<th>SPPT big</th>
<th>SPPT small</th>
<th>4D-SPPT</th>
</tr>
</thead>
<tbody>
<tr>
<td>(\sigma)</td>
<td>0.5</td>
<td>0.2</td>
<td>0.1</td>
</tr>
<tr>
<td>(c)</td>
<td>2.0</td>
<td>5.0</td>
<td>5.0</td>
</tr>
<tr>
<td>(\tau(h))</td>
<td>8</td>
<td>8</td>
<td>8</td>
</tr>
<tr>
<td>(l(km))</td>
<td>4000</td>
<td>4000</td>
<td>4000</td>
</tr>
</tbody>
</table>

Perturbation Vectors Endpoints

![Perturbation Vectors Endpoints](image)
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:

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

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

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

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

\[
\sigma_1 = N * \sigma_2 \\
\sigma_2 = \sigma_3 = \sigma_4
\]

<table>
<thead>
<tr>
<th>SPPT</th>
<th>SPPT</th>
<th>4D-SPPT</th>
<th>4D-elliptic-SPPT</th>
</tr>
</thead>
<tbody>
<tr>
<td>big</td>
<td>0.5</td>
<td>0.1</td>
<td>0.14; 0.035</td>
</tr>
<tr>
<td>small</td>
<td>0.2</td>
<td>0.1</td>
<td></td>
</tr>
<tr>
<td>σ</td>
<td>c</td>
<td>τ(h)</td>
<td>l(km)</td>
</tr>
<tr>
<td>0.2</td>
<td>5.0</td>
<td>8</td>
<td>4000</td>
</tr>
<tr>
<td>0.1</td>
<td>5.0</td>
<td>8</td>
<td>4000</td>
</tr>
<tr>
<td>0.14</td>
<td>5.0</td>
<td>8</td>
<td>4000</td>
</tr>
<tr>
<td>0.035</td>
<td>5.0</td>
<td>8</td>
<td>4000</td>
</tr>
</tbody>
</table>

Perturbation Vectors Endpoints

- 'center.txt'
- 'SPPT-big.txt'
- 'SPPT-small.txt'
- '4D-SPPT.txt'
- '4D-elliptic-SPPT.txt'
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

CRPS, var: 500hPa Geopotential, against ECMWF analysis

CRPS, var: 700hPa Relative Humidity, against ECMWF analysis

CRPS, var: 850hPa Temperature, against ECMWF analysis

CRPS, var: 925hPa Wind Speed, against ECMWF analysis
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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