Technical implementation of SPP in HarmonEPS: Single precision and other aspects

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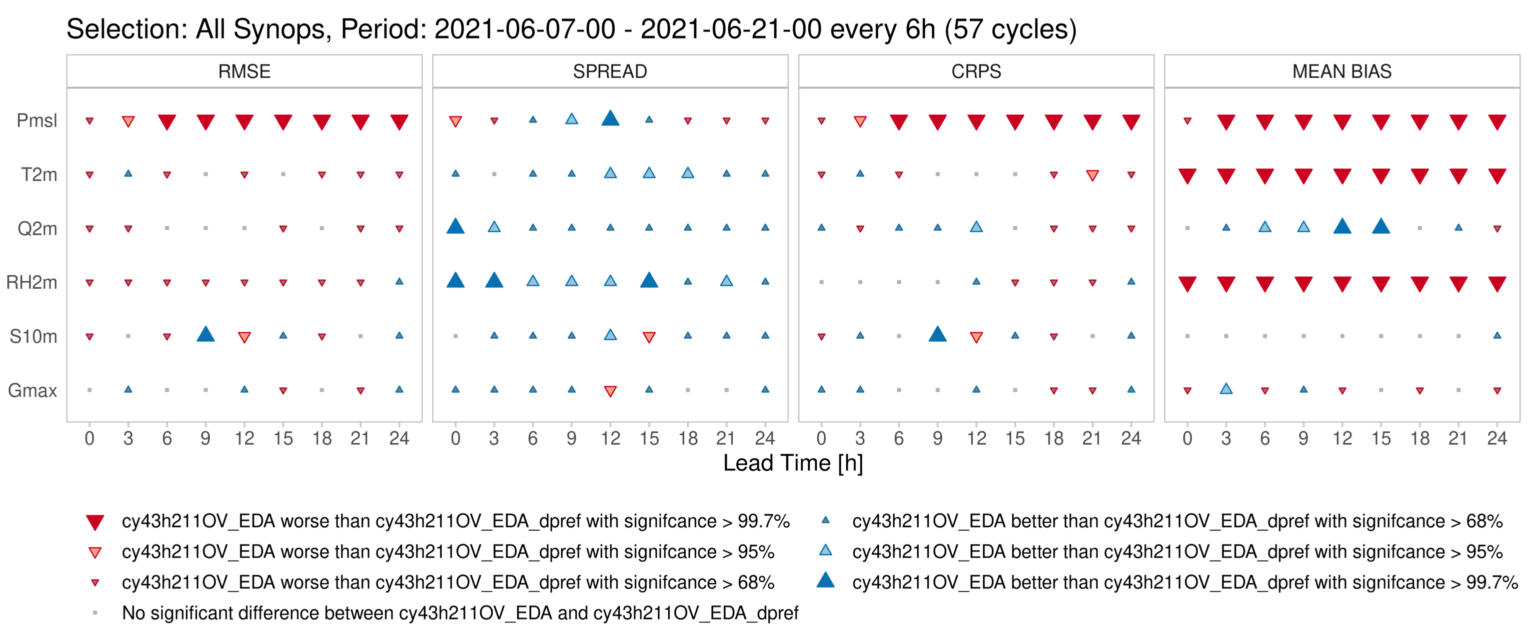
High Resolution Hirlam Limited Area Model

Single precision in HARMONIE-AROME

The option to run HARMONIE-AROME in single precision (SP) was originally made available as part of Cycle 43h2.1, and can be utilised through the FP_PRECISION=dual option from Cycle 43h2.2. This option builds the single and double precision (DP) binaries simultaneously and runs the forecast model alone in SP. All references to "SP forecasts" in this document imply the use of this dual precision option.

- Several HIRLAM institutes have investigated the use of SP forecasts in pre-operational testing of HarmonEPS (the ensemble realisation of HARMONIE-AROME). A sample comparison of SP vs DP performance for a pseudo-operational configuration is given in the scorecard below (experiment configuration detailed in the table on the right).
- Results typically indicate a relatively neutral impact on surface scores, with the exception of a positive MSLP bias, while small differences in upper-air humidity profiles have also been observed. Runtime savings of ∼30% are typically achieved by using the dual precision option.

Component	Description
Version	Cycle 43h2.1.1
Resolution	2.5 km horizontal, 65 levels (dt = 75 s)
DA	3DVAR (conv only), CANARI
Members	1+3, 3 h cycling, 24 h at 00, 06, 12, 18 UTC
EPS	EDA, SLAF, surface, multi-physics
Period	June 7th - 21st 2021



Scorecard for various surface parameters and ensemble scores. Red indicates a degradation in the SP ensemble performance, with symbol size indicating statistical significance. The difference in MSLP, T2m, and RH2m biases are ∼ 0.015 hPa, 0.015 K, and 0.1 % respectively. Model domain considered is illustrated in the SPG pattern map below.

Stochastically Perturbed Parameterizations (SPP) in SP

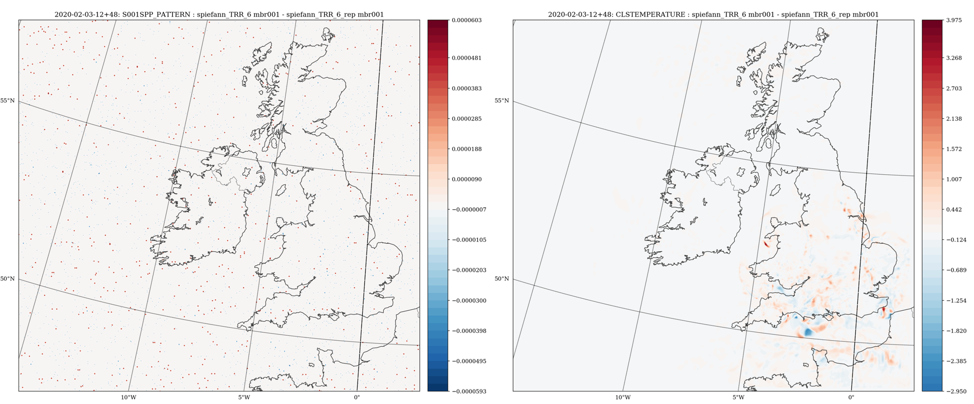
While efforts are ongoing to assess the viability of operational SP forecasts at HIRLAM institutes, a number of issues remain to be resolved. One such issue is the stability and performance of SP SPP. Initial investigations with Cycle 43h2.2 have encountered a number of technical difficulties, as summarised in the table below.

Component	Issue
Forecast	Crashes with SP SPP in various routines, primarily due to roundoff errors resulting in floating point overflow or invalid calculations in the forecast model. These have since been addressed, either using relatively simple workarounds or converting relevant calculations to DP.
SPG	Precision-dependence and reproduciblity of SPP perturbation patterns.
SPG	Roundoff error resulting in "static" perturbation patterns.

Additional details regarding the Stochastic Pattern Generator (SPG) issues are given below.

SPP perturbation pattern reproduciblity

- SPG perturbation patterns are precision-dependent, i. e. patterns used in the SP and DP forecasts are uncorrelated, although they are generated using the same underlying properties. This evidently complicates technical comparisons of SP and DP performance, and investigations into this issue are ongoing.
- On some platforms (e. g. cca with GNU Fortran), issues regarding the SPG pattern reproduciblity in DP have also been observed. The differences in the raw SPG patterns are typically $\sim 10^{-6}$, and thus the impact on the resulting forecasts appears to be minimal. The figure on the right illustrates the differences in a sample SPG perturbation pattern and T2m forecast for two identical experiments.



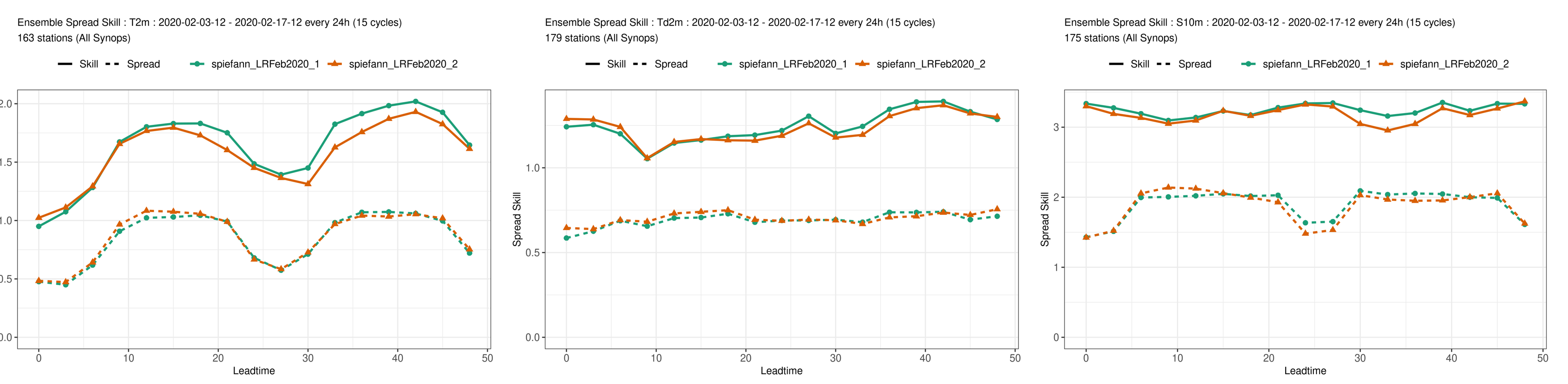
Difference in (left) sample raw SPG pattern and (right) T2m forecast for identical experiments (after 48 h). Forecast model run in DP.

"Static" patterns

- A two-week cycling experiment with SP SPP was carried out to test for additional SP-related instabilities and to generate initial verification statistics on SP ensemble performance. Configuration details are given on the right. No model crashes were encountered during this experiment.

Component	Description
Version	harmonEPS-43h2.2
Resolution	2.5 km horizontal, 65 levels (dt = 75 s)
DA	3DVAR (conv only), CANARI
Members	1+6, 3 h cycling, 48 h at 12 UTC
EPS	SPP only
Period	Feb 3rd - 17th 2020

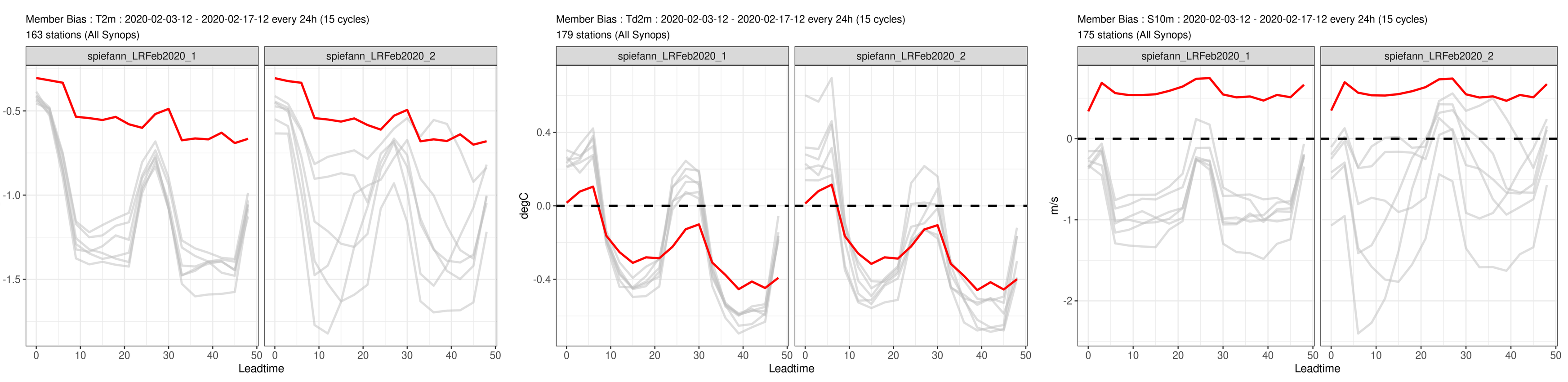
- Sample spread-skill scores for T2m, Td2m, and 10 m wind speed are given below. Overall the averaged ensemble scores appear to suggest no significant degradation in SP SPP performance relative to DP.



Spread-skill over all available synoptic stations for T2m (left), Td2m (middle), and 10 m wind speed (right). Experiment configuration given in the table, with the DP and SP ensembles in green and orange respectively. Model domain considered is illustrated in the SPG pattern map above.

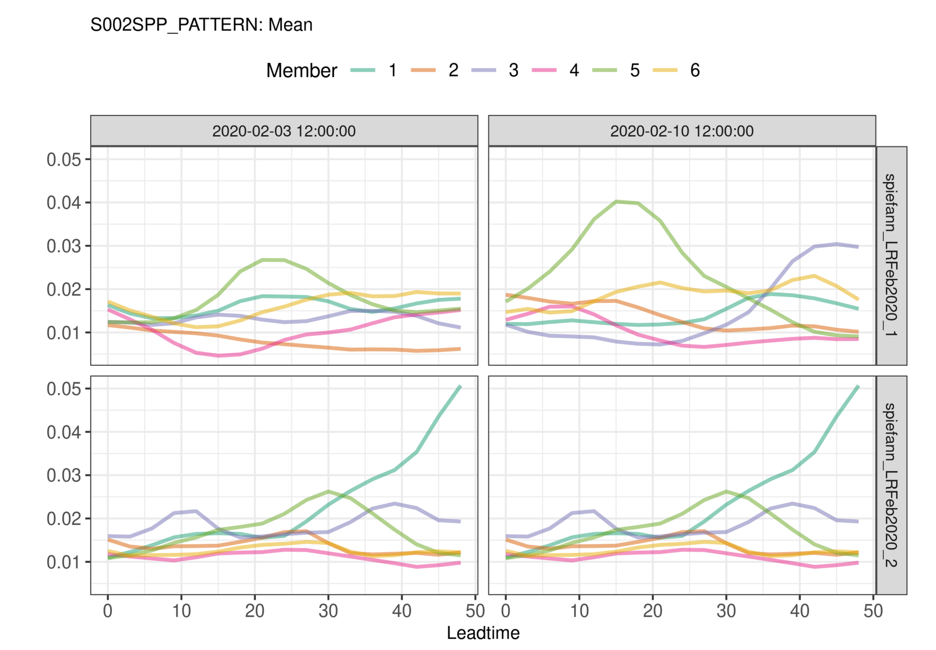
- However, the individual ensemble member biases indicate a notable change in the behaviour of the SP members relative to DP, e. g. the diurnal variation in the SP members is much less pronounced and there is rapid error growth immediately after initialisation in SP members.

Stochastically Perturbed Parameterizations (SPP) in SP (continued)



Corresponding member bias for T2m (left), Td2m (middle), and 10 m wind speed (right). In each subfigure the DP and SP ensembles are on the left and right, respectively. Control members are highlighted in red.

- Analysis of the SPP parameter patterns reveals that, in contrast to the standard behaviour in DP, the SP patterns do not update with increasing DTG.
- This behaviour is illustrated on the right for the mean value of the scaled PSIGQSAT perturbation pattern; the SP patterns evolve with lead time but are reproduced for each cycle. This likely contributed to the marked difference in individual member behaviour.
- This issue was traced to the pattern initialisation routine in which the DTG-dependence was lost in SP due to roundoff error, and is now resolved.



Columns on the left and right correspond to the 12Z cycles on February 3rd and 10th, respectively. The DP ensemble is given on the top row, SP on the bottom.

Uniform Distributions in SPP

The use of log-normal distributions and large uncertainty ranges for some SPP parameters have caused issues regarding systematic bias in the ensemble members. To overcome this limitation, we have introduced the option for uniform distributions in the SPP scheme. To generate the uniform perturbations, the cumulative distribution function of a random SPG field, denoted as Φ_j, of the j-th parameter is calculated as:

$$\mathrm{CDF}_j = \frac{1}{2}\left[1 + \mathrm{erf}\left(\frac{x - m_j}{\mathrm{SDEV} * \sqrt{2}}\right)\right], \quad (1)$$

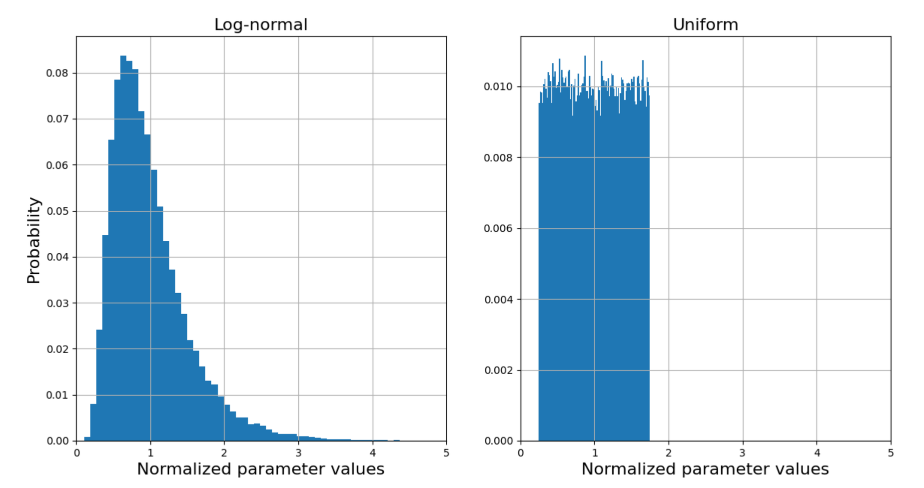
where $\mathrm{erf}\left[(x - m_j) / (\mathrm{SDEV} * \sqrt{2})\right]$ is the error function of the normal distribution Φ_j with mean value of m_j and standard deviation SDEV. A uniform temporally and spatially correlated SPG noise field is generated as:

$$U_j = \mathrm{CDF}_j - \beta, \quad (2)$$

where β is a parameter used to offset the centre of the uniform distribution. Finally, the perturbations for the j-th SPP parameter are generated as:

$$X_j = \widehat{X}_j + \widehat{X}_j \ \mathrm{CMPERT}_j \ U_j. \quad (3)$$

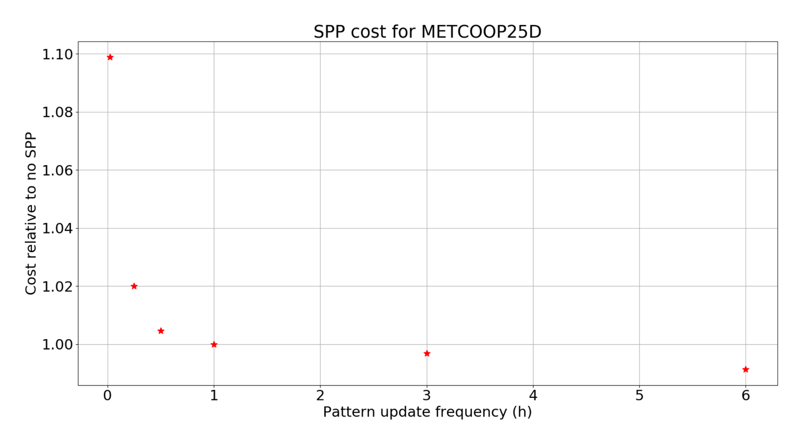
- SPP parameters using uniform distributions require substantially smaller, more realistic uncertainty ranges to achieve a similar effect on ensemble spread compared to log-normal distributions.
- Similar to the log-normal distributions, the uniform distributions retain the spatial and temporal correlation scales applied by the SPG noise.
- The addition of an offset parameter (β) allows for shifted distribution to counter any systematic bias problems.



Examples of log-normal and uniform distributions for a parameter in the SPP scheme of HarmonEPS. Perturbed parameter values are normalized by the reference value.

Reducing the cost of SPP

In SPP the stochastic pattern evolves in time with a typical timescale of 12 h. Updating the pattern every timestep adds an additional cost of 10-15 % to the forecast depending on the platform, which is far too much for operational usage. To reduce this cost we have implemented a solution where the pattern is propagated with the SPG solver for an arbitrary interval and with a linear interpolation in time within this interval.



The cost of a 48 h forecast with SPP relative to a no-SPP run as a function of pattern update frequency.

- The figure to the left demonstrates how the cost reduces as a function of increasing pattern update interval.
- At an update interval of approximately 1h, the difference in cost to the reference run is dominated by other factors like disk response speed.
- The SPG pattern is not reproducible when changing the update frequency but it retains its statistical properties.

Future plans

- Continue to investigate issues regarding SPG pattern reproduciblity, in particular DP versus SP pattern differences.
- Further testing of SP SPP in HarmonEPS on the new Atos HPCF in Bologna in order to identify additional stability and model performance issues in SP.
- Preparations are ongoing for the release of a first operational SPP setup using a reduced set of parameters (initially restricted to DP forecasts). Pre-operational testing to be carried out at several HIRLAM institutes, as well as within the United Weather Centres (UWC) West consortium.