Model Uncertainty Representation in a Convection-Permitting Ensemble - SPP and SPPT in HarmonEPS

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What is HarmonEPS?

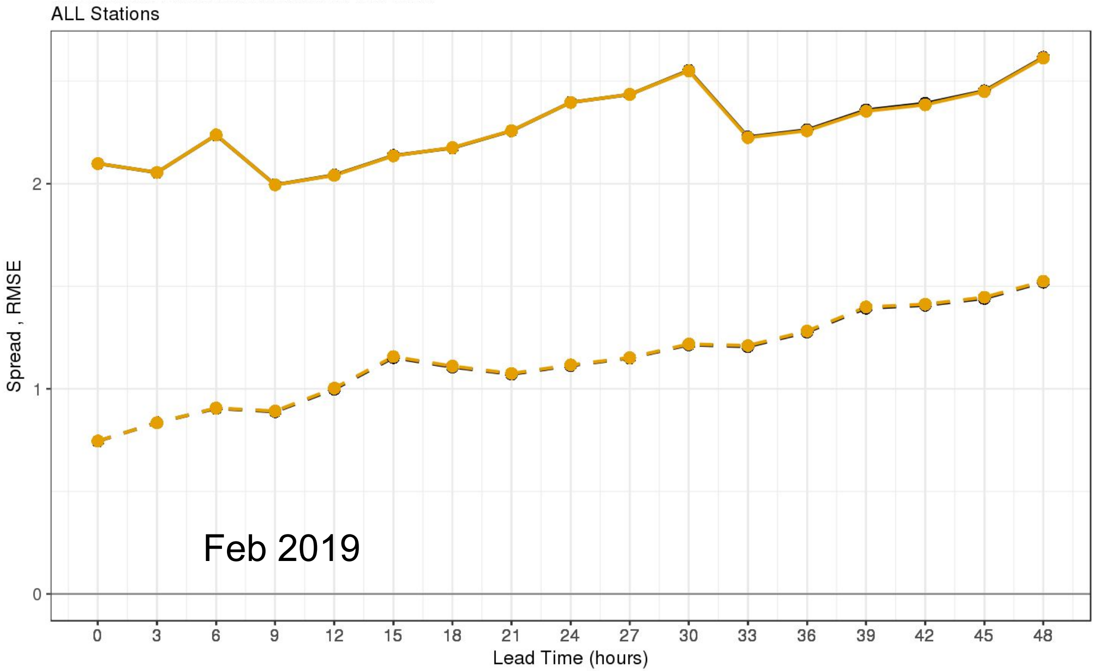
- A convection permitting, limited area ensemble system at 2.5 km
- Based on the HARMONIE-AROME model
- Serves as the operational forecasting tool in a number of countries in Europe
- In HarmonEPS you have the possibility to perturb (used in experiments presented here in blue):
  - Initial conditions using nesting model (usually IFS ENS) and/or observation perturbations (EDA) - both used operationally
  - Surface initial conditions and/or EDA - surface initial condition pert. used operationally
  - LBCs using nesting model (usually IFS ENS) - used operationally

For representing model uncertainty we have:

- multi-physics - used operationally by one institute
- SPPT (The Stochastically Perturbed Parameterization Tendencies) - not used operationally due to low impact on ensemble skill
- SPP (The Stochastically Perturbed parameterizations) - used operationally since 30 August 2022 by MetCoOp (Sweden, Finland, Norway and Estonia)

Does applying the model uncertainty schemes SPPT and SPP improve the ensemble?

Effect of adding SPPT in HarmonEPS



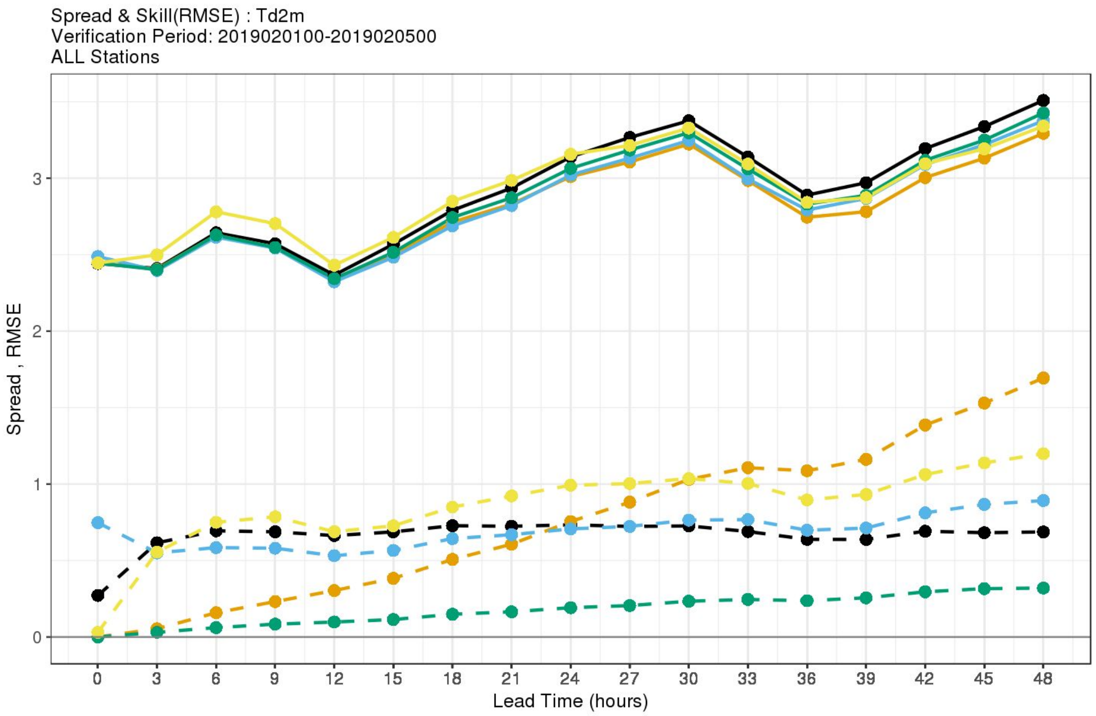
Spread/Skill
Td2m

no SPPT
with SPPT

No additional spread by SPPT. Note: one month period!

Let’s take a closer look at SPPT and the interactions with the other perturbations

First: one perturbation type at a time:

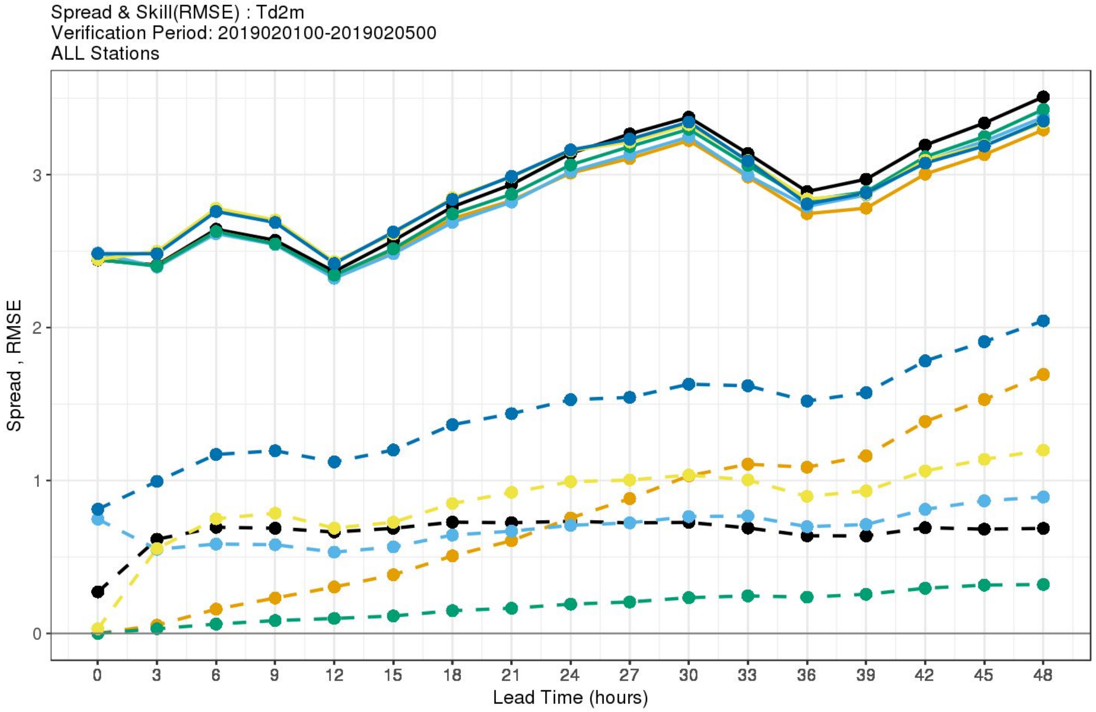


Spread/Skill
Td2m

SPPT
Boundary perturbations
Initial perturbations
Surface perturbations
SPP

All perturbations give spread to the ensemble when acting alone, also SPPT

- and the combination of all:

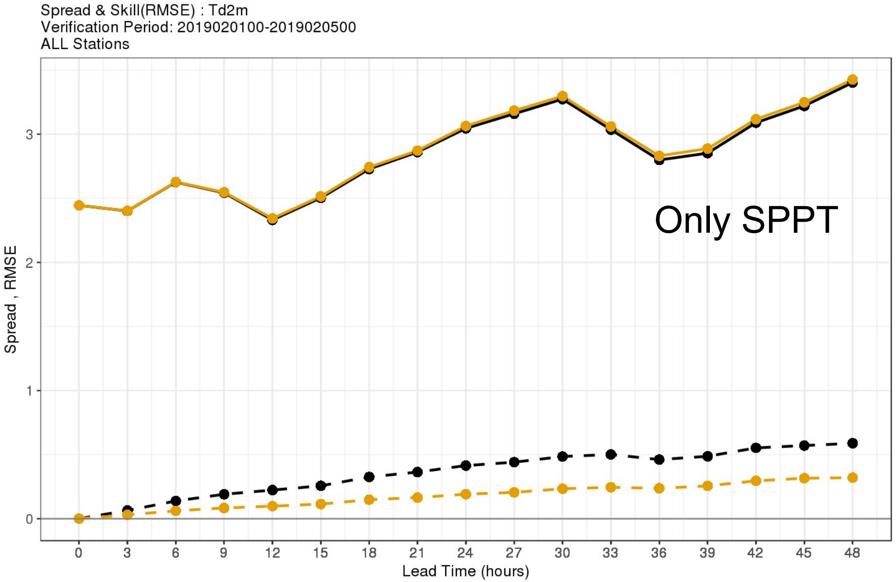


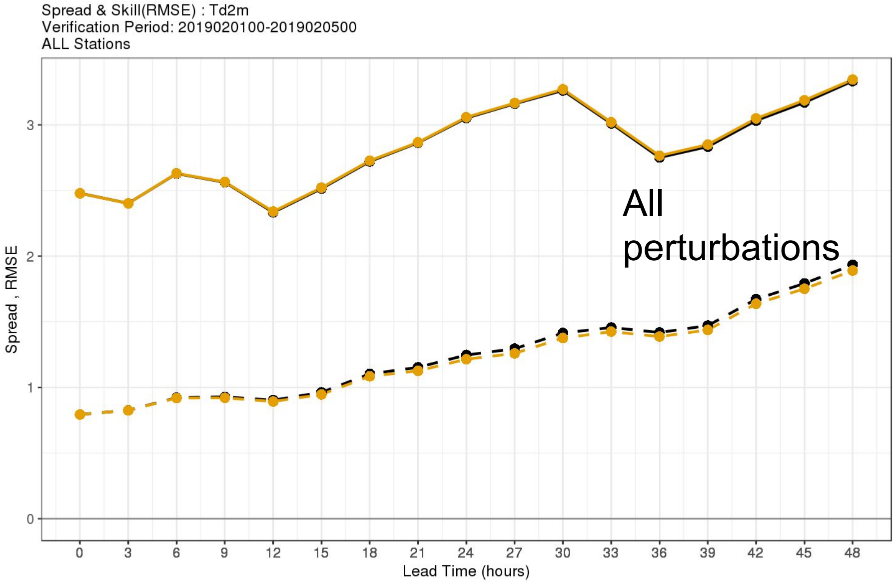
Spread/Skill
Td2m

SPPT
Boundary perturbations
Initial perturbations
Surface perturbations
SPP
All combined

The combination of all gives the highest spread

Was the SPPT perturbations simply too small?



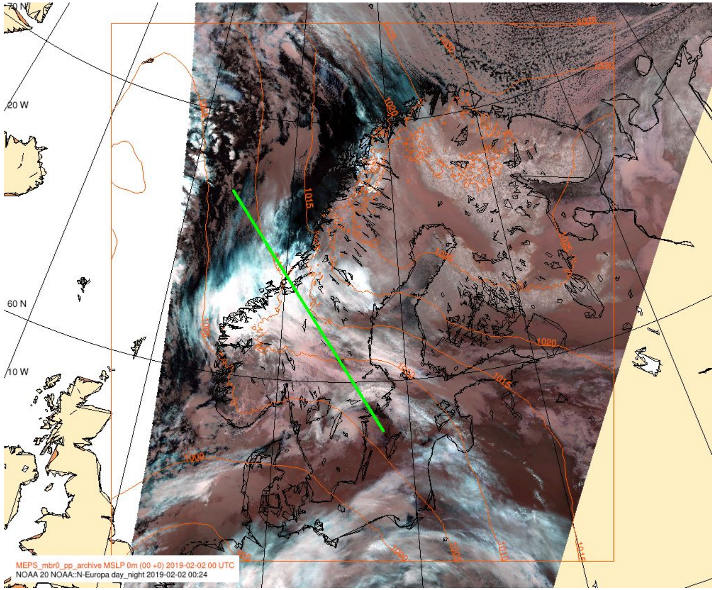


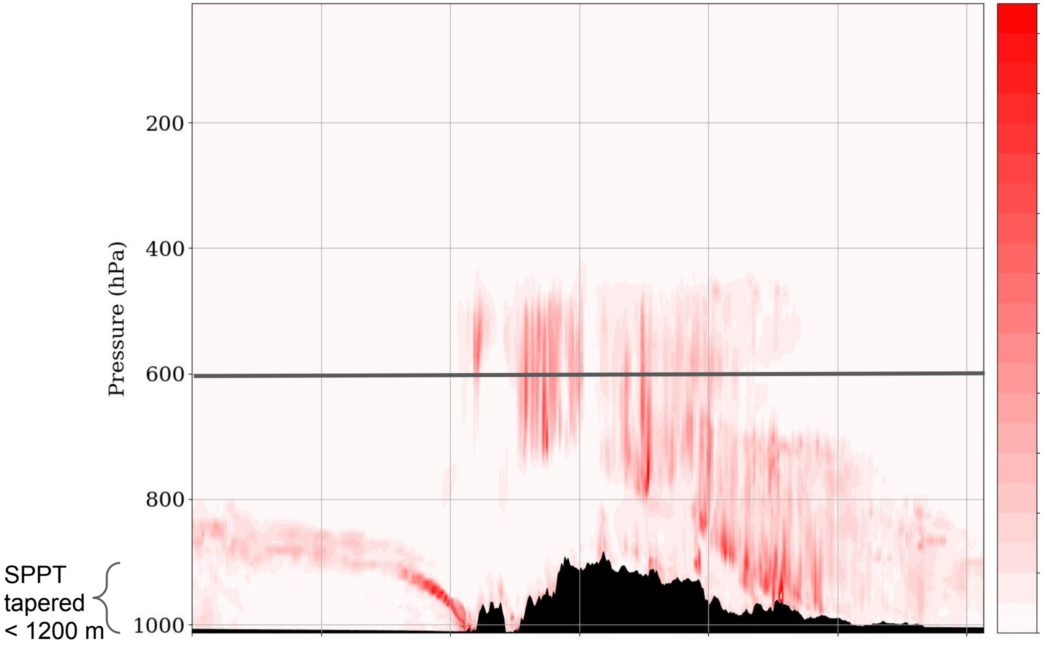
Default standard deviation for SPPT (0.3)
Increased standard deviation for SPPT (0.9)

We see clear effect on the spread of increasing the SDEV when SPPT acts alone.
This effect is almost completely wiped out when combined with the other perturbations

What's happening? Looking at tendencies

In the following looking at 3h accumulated humidity tendencies for the cross section shown and two levels 61 (~1000 hPa) and 28 (~600 hPa). Levels and cross sections chosen based on where the accumulated tendencies are "large".

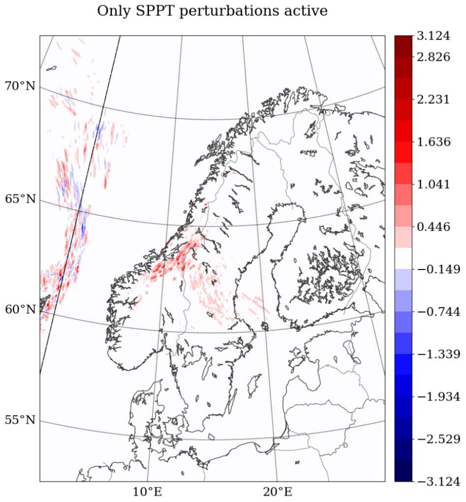




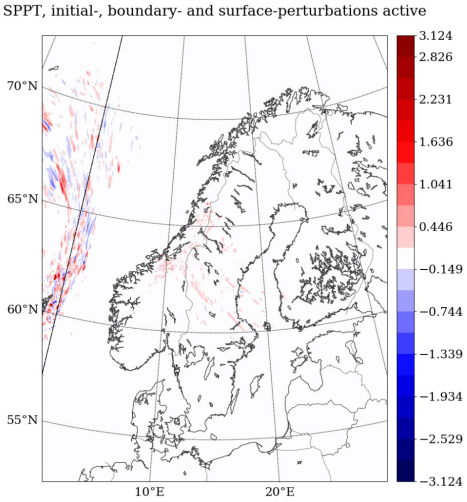
<u>Difference in ensemble standard deviation</u> for two experiments where SPPT standard deviation is 0.9 and 0.3

Effect of SPPT SDEV level 28

SDEV for 3h acc. humidity tendencies for 2019020100 +24h



Only SPPT



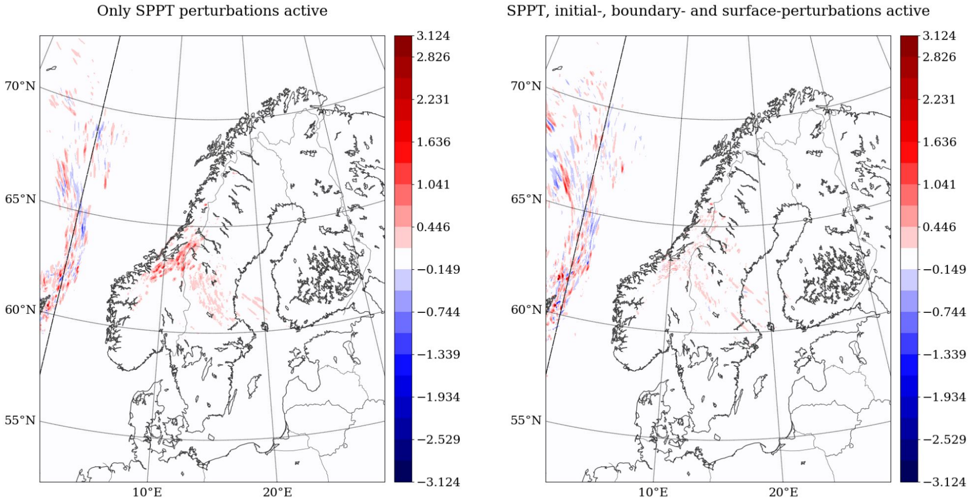
all other perturbations on in addition to SPPT

In line with the spread curves shown previously, we clearly see the effect of the increased SPPT standard deviation when SPPT is the only perturbation (left). The effect seen from increasing the size of the SPPT perturbations is much smaller over the main active area in the middle part of Norway when all other perturbations are also applied (right)

Effect of SPPT SDEV level 28

SDEV for 3h acc. humidity tendencies for 2019020100 +24h

Difference in ensemble standard deviation for two experiments where SPPT standard deviation is 0.9 and 0.3



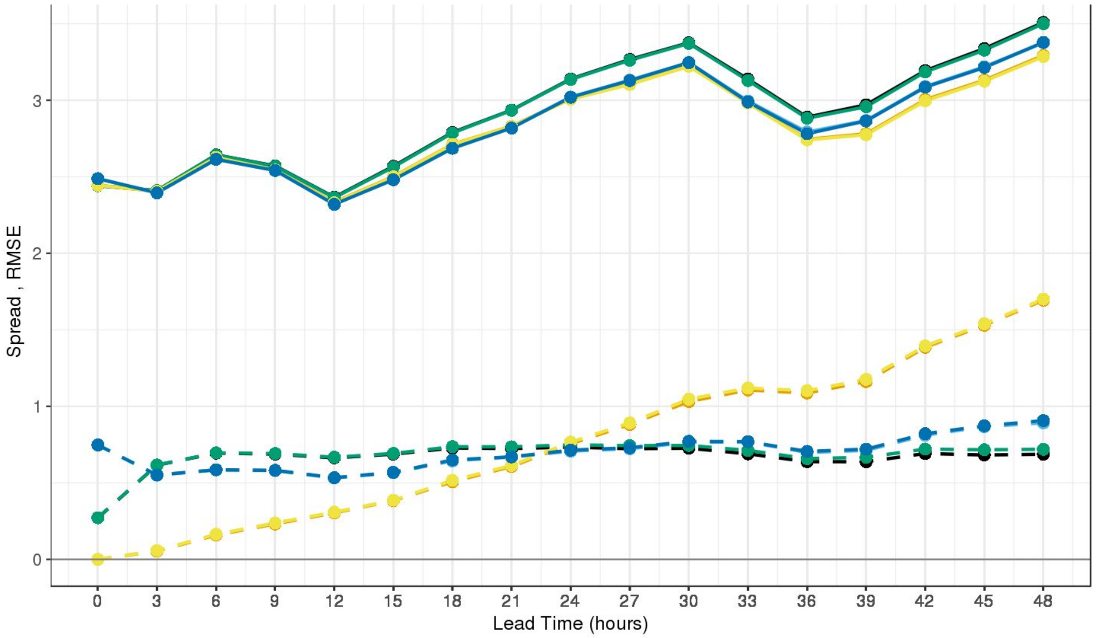
Only SPPT

all other perturbations on in addition to SPPT

Which perturbations mask the effect of SPPT?

In line with the spread curves shown previously, we clearly see the effect of the increased SPPT standard deviation when SPPT is the only perturbation (left). The effect seen from increasing the size of the SPPT perturbations is much smaller over the main active area in the middle part of Norway when all other perturbations are also applied (right)

Effect of SPPT combined with other perturbations separately



Spread/Skill
Td2m

Initial perturbations
Initial perturbations + SPPT
Lateral bnd perturbations
Lateral bnd perturbations + SPPT
Surface perturbations
Surface perturbations + SPPT

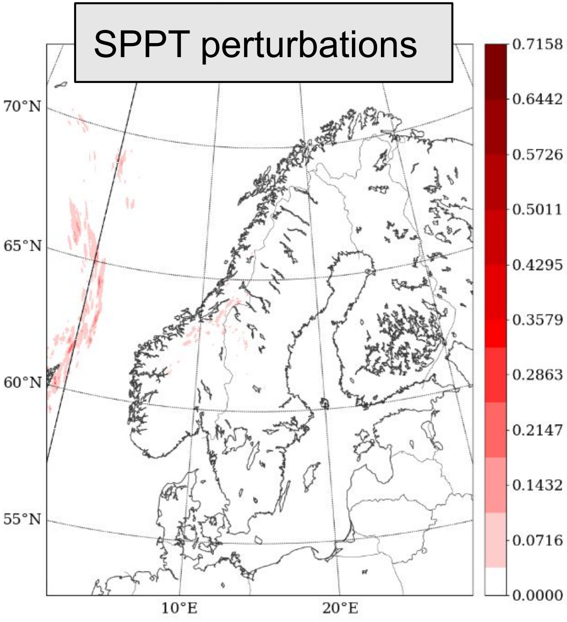
Somewhat extra spread on top of the surface perturbations, otherwise close to nothing

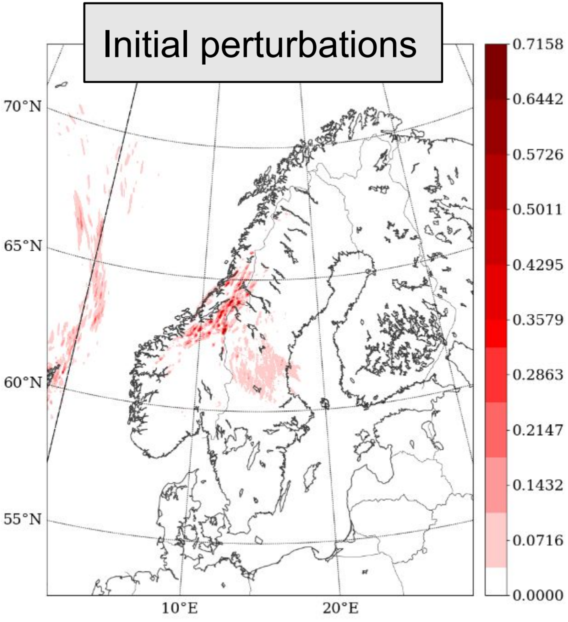
SPPT gives variability in the tendencies in the same places as the initial perturbations

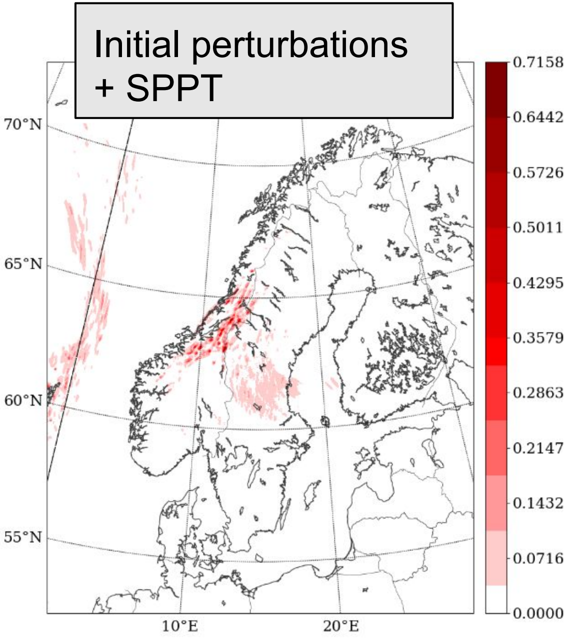
The areas where SPPT adds variability are in the same locations as the variability generated by the initial condition perturbations, and very little extra is introduced by SPPT

initial pert. + SPPT - level 28

SDEV for 3h acc. humidity tendencies for 2019020100 +24h





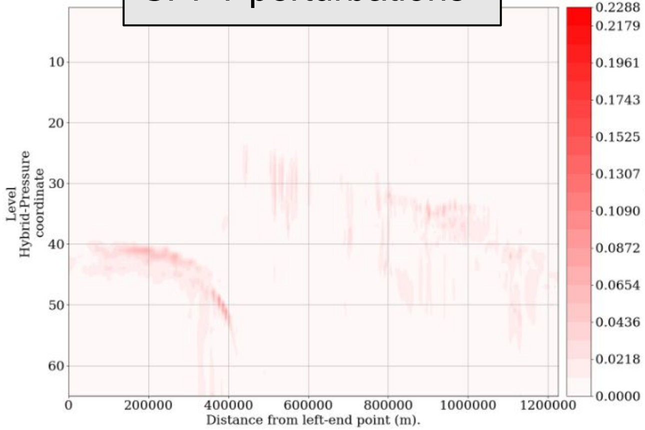


As for the initial perturbations, SPPT perturbations are also clearly masked by the lateral boundary perturbations - throughout the atmospheric column

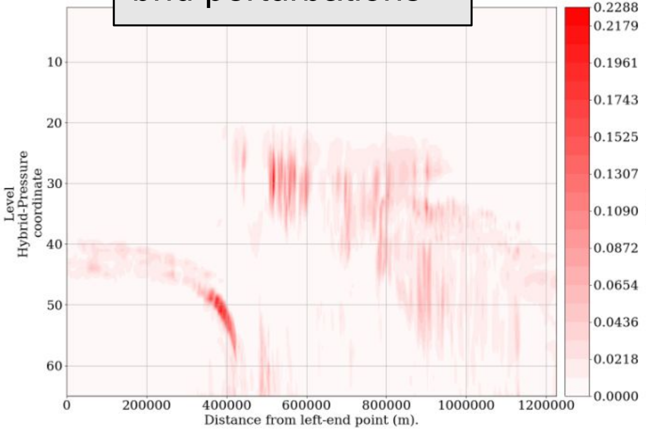
boundary pert. + SPPT -

SDEV for 3h acc. humidity tendencies for 2019020100 +24h

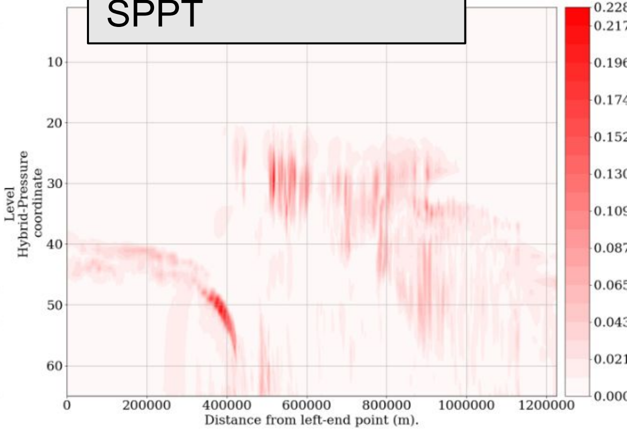
SPPT perturbations



bnd perturbations



bnd perturbations + SPPT

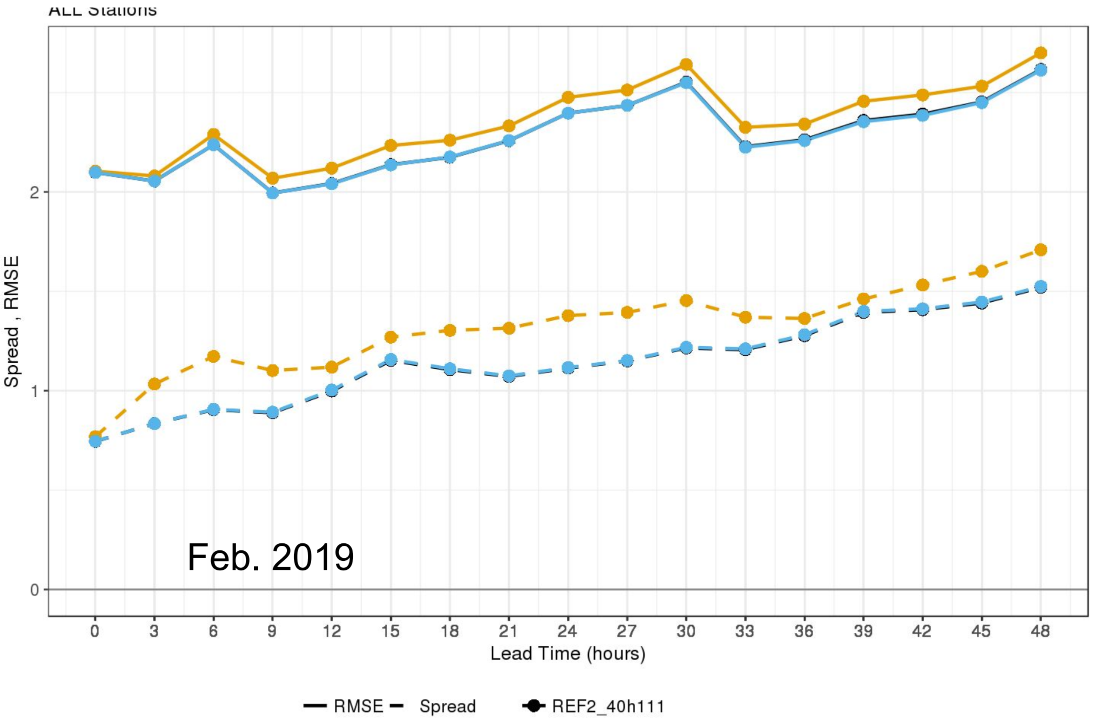


SPPT in (current setup) does not give much benefit in HarmonEPS, despite a big effort to find optimal settings (time scale, length scale, standard deviation and pattern generator work)

What about SPP, does it have the same problem?

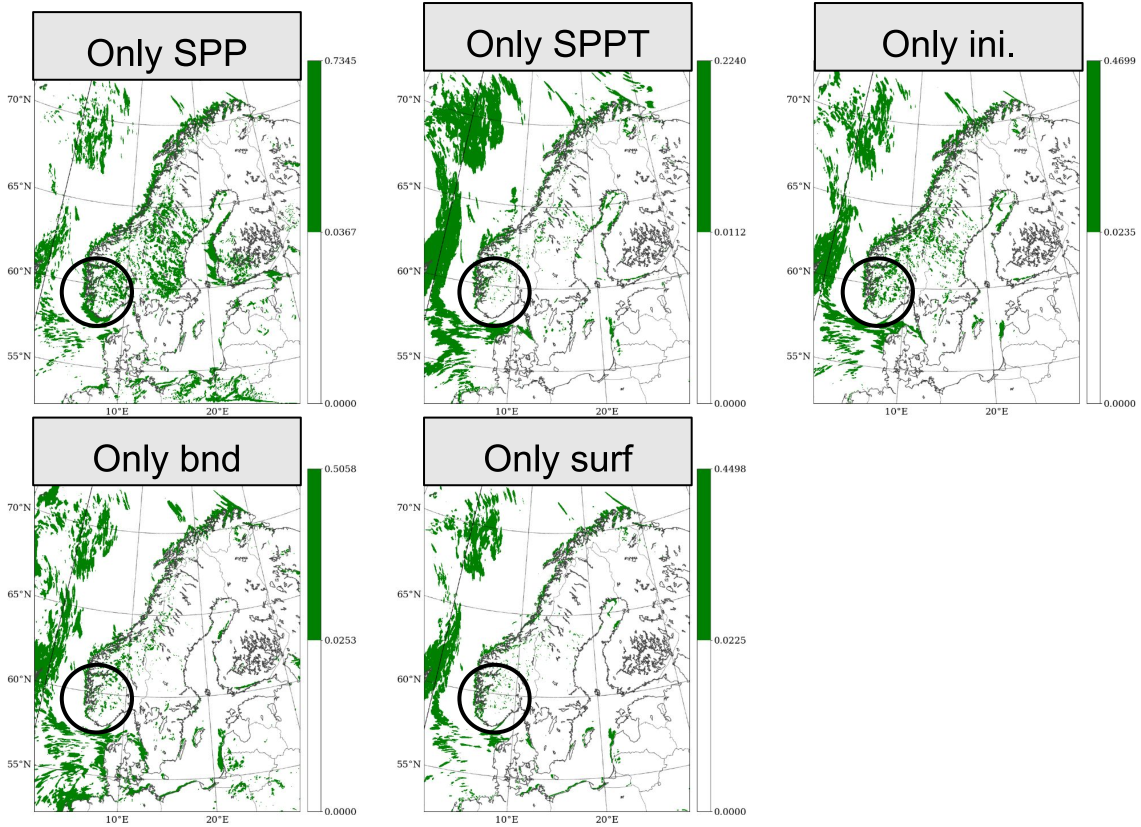
No, SPP adds spread!
(also increased RMSE here, will come back to this later)

Is it due to perturbations being introduced in other geographical areas (or in other weather situations), is it due to an amplification of the spread already created by the other perturbations, or a combination?



- Default pert.
+ SPPT
+ SPP

How does the tendencies look for SPP compared to the other perturbations?



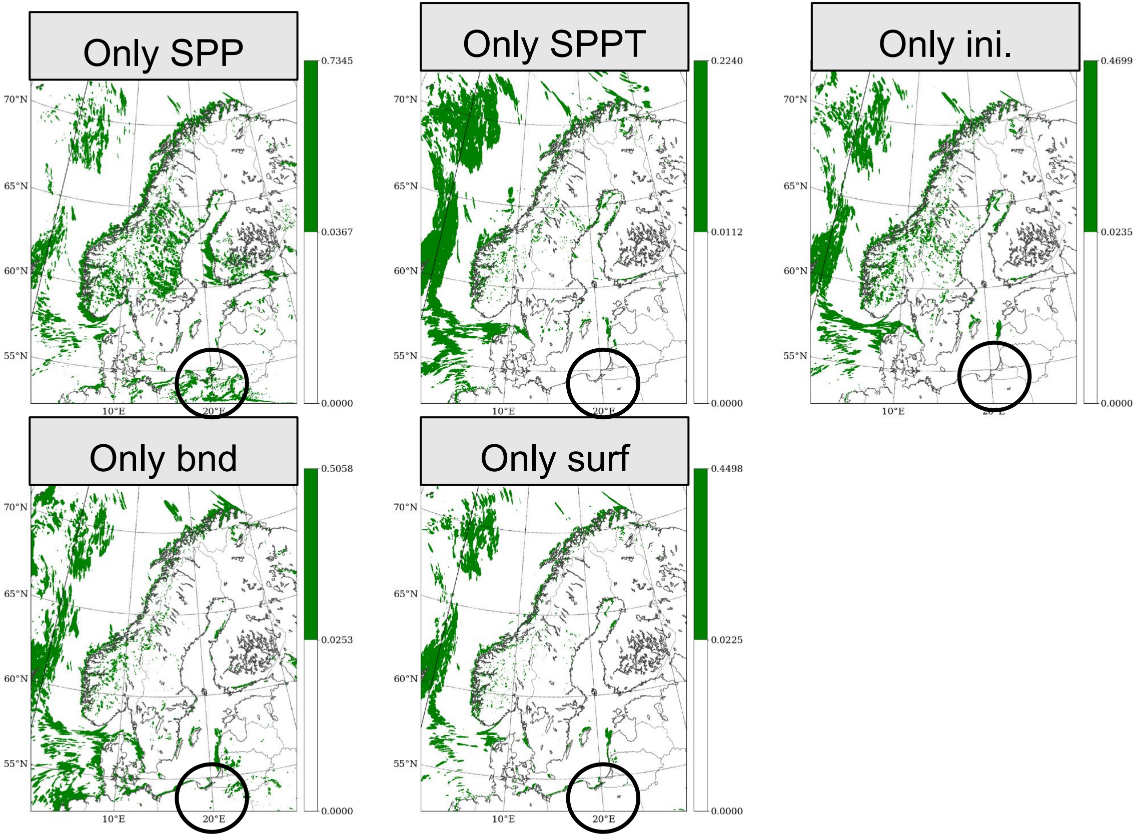
level 61

SDEV for 3h acc. humidity tendencies for 2019020100 +24h

The scaling in the plots are constructed to highlight the areas where the different perturbations add variability, with the transition from white to green equaling the maximum value in each plot divided by 20 (favourising SPPT)

SPP shows active areas where the other perturbations do not

How does the tendencies look for SPP compared to the other perturbations?



level 61

SDEV for 3h acc. humidity tendencies for 2019020100 +24h

The scaling in the plots are constructed to highlight the areas where the different perturbations add variability, with the transition from white to green equaling the maximum value in each plot divided by 20 (favourising SPPT)

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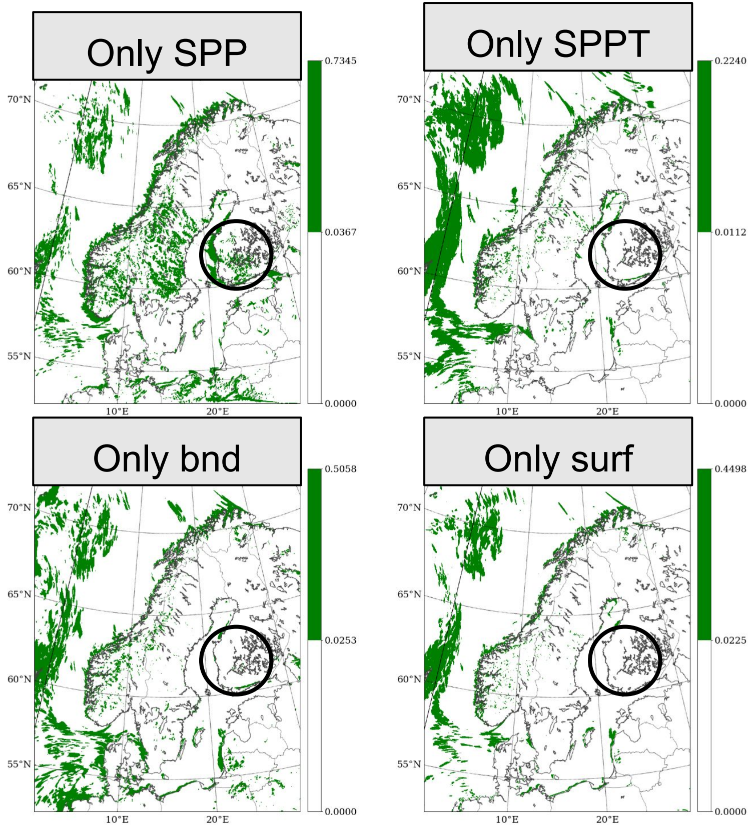


level 61

SDEV for 3h acc. humidity tendencies for 2019020100 +24h

The scaling in the plots are constructed to highlight the areas where the different perturbations add variability, with the transition from white to green equaling the maximum value in each plot divided by 20 (favourising SPPT)

SPP shows active areas where the other perturbations do not

SPP in HarmonEPS - currently 18 parameters implemented - 5 in first operational setup

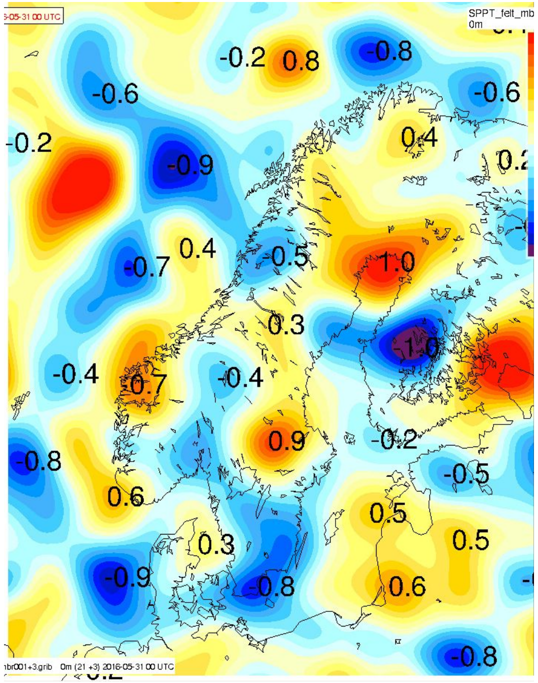
3 for clouds and microphysic

2 for turbulence

The perturbation characteristics - the pattern

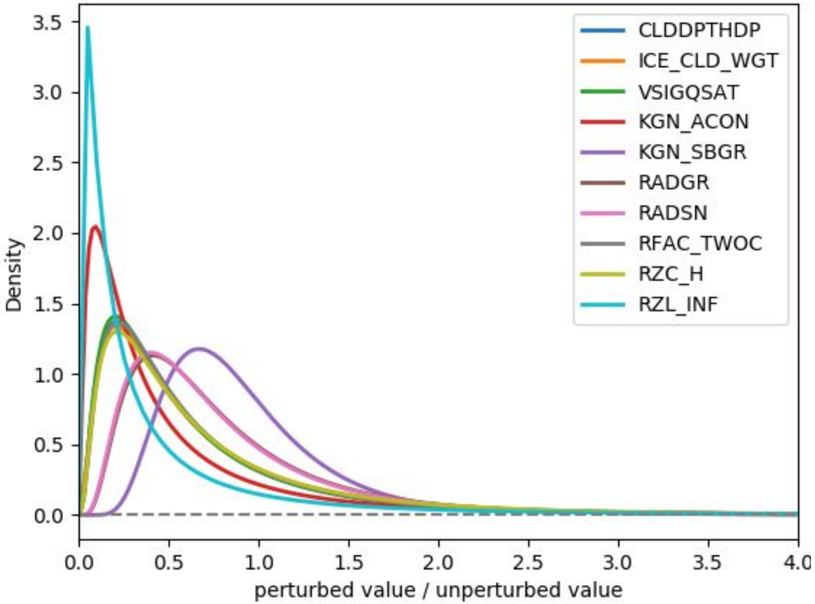
The pattern generator accounts for the proportionality of scales (Tsyrulnikov and Gayfulin 2017)

All parameters perturbed using the same spatial and temporal scales, but with a unique random seed

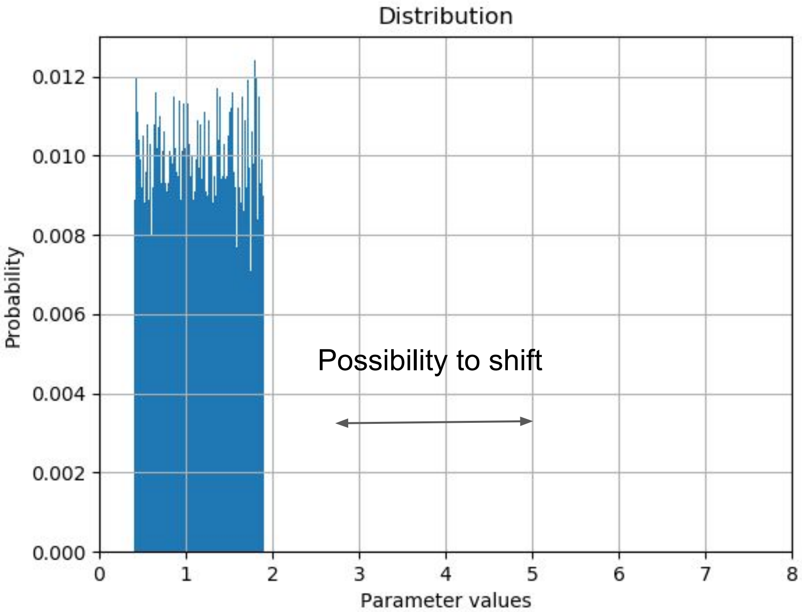


Spatial scale: 200km
Temporal scale: 12h

The perturbation characteristics - the probability distributions



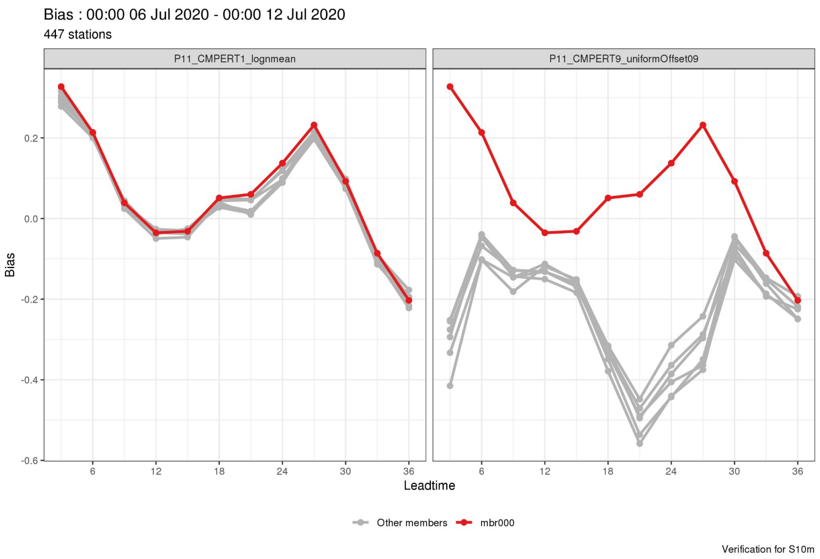
Lognormal distributions:
The mean is correlated with the unperturbed value



Uniform distributions:
The mean is correlated with the unperturbed value but the whole distribution can be shifted in both directions

Bias when changing the pdf of a parameter in SPP:

Example for 10 m wind speed
using two different pdfs:



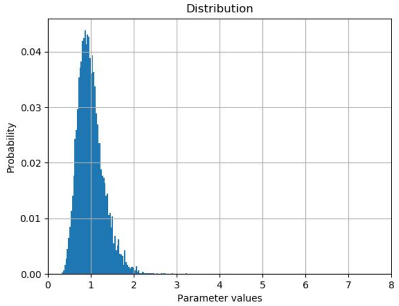
BIAS
Control member
All other members

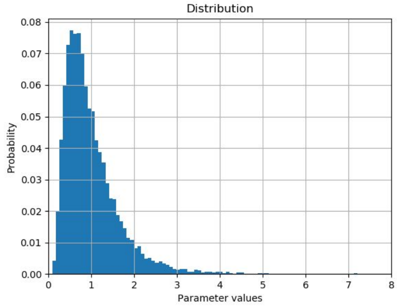
SPP is sensitive to bias change of members vs. control

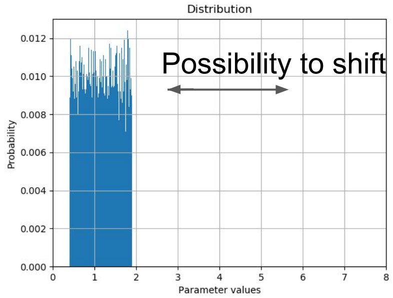
Should not push the ensemble members in one direction (always warmer, always drier etc.)

Care should be taken when deciding on the pdfs

The perturbation characteristics - the probability distributions







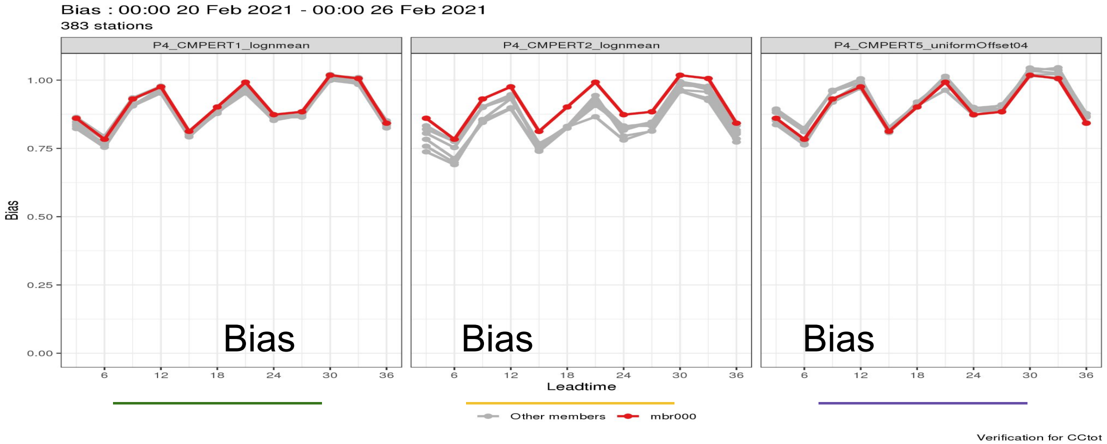
Lognormal distribution (initial SDEV) Lognormal distribution with double SDEV Uniform distribution

Changing the distribution

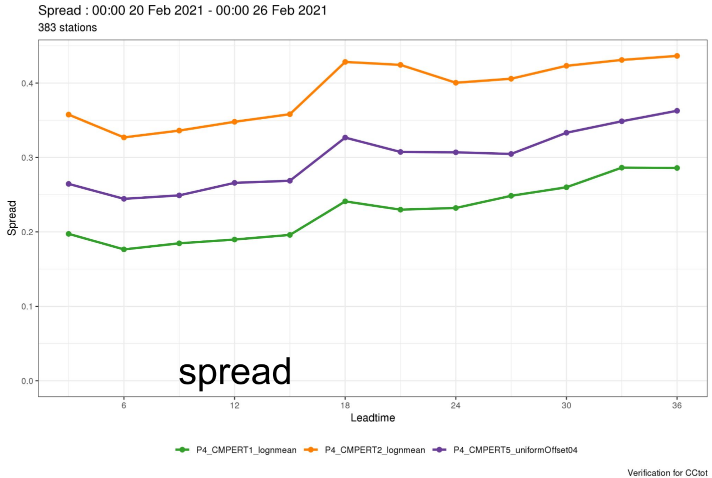
Example from parameter ICE_CLD_WGT (Cloud ice content impact on cloud thickness)

Lognormal distribution leads to less clouds in the members compared to the control when SDEV is increased to get higher spread

Using a uniform distribution increases the spread (compared to SDEV=1) and bias is OK

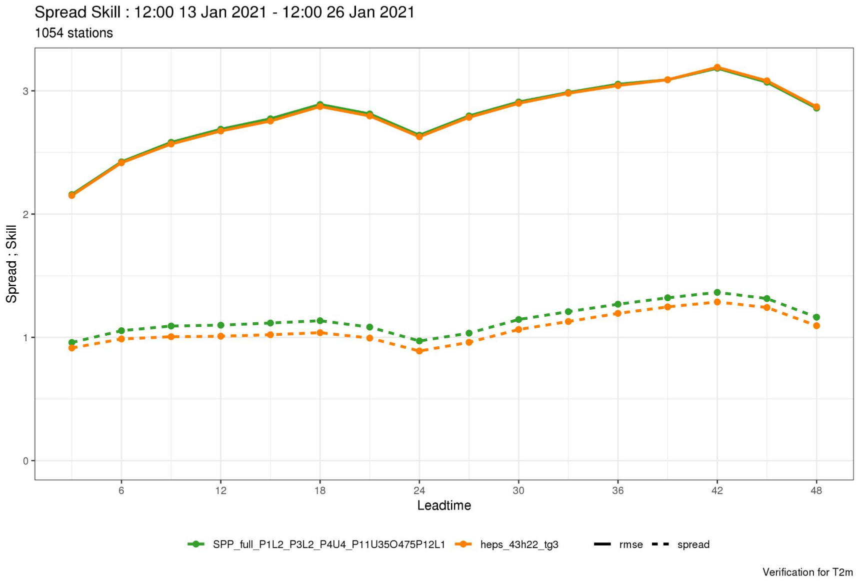


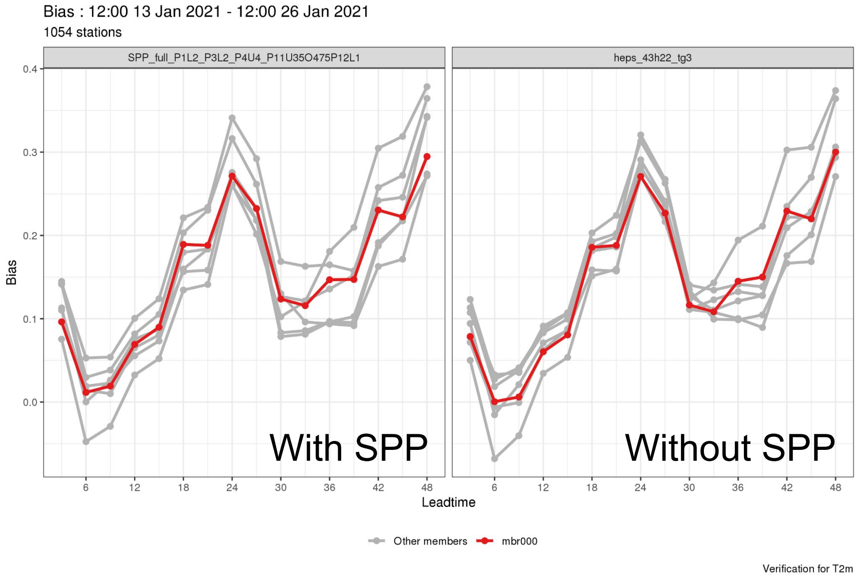
Bias for total cloud cover, control in red, members in grey



T2m

With SPP
Without SPP





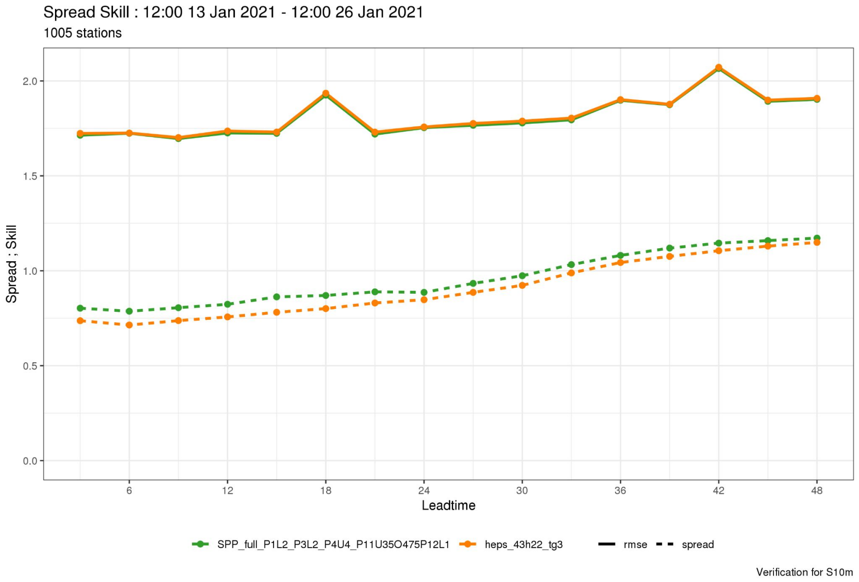
Spread (- - -) and Skill (——)

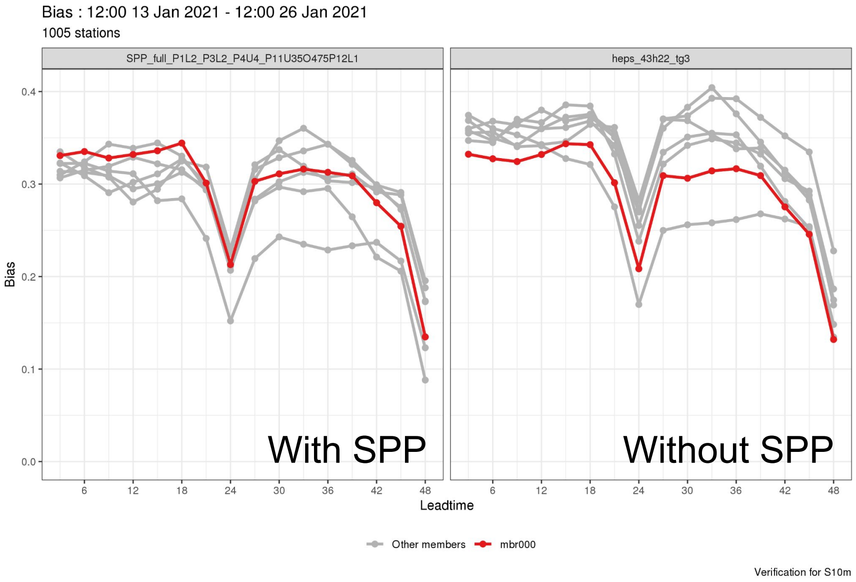
Bias (control / members)

Slightly higher spread leading to somewhat better spread/skill relationship.
Bias of the members with respect to the control ~neutral to SPP

S10m

With SPP
Without SPP





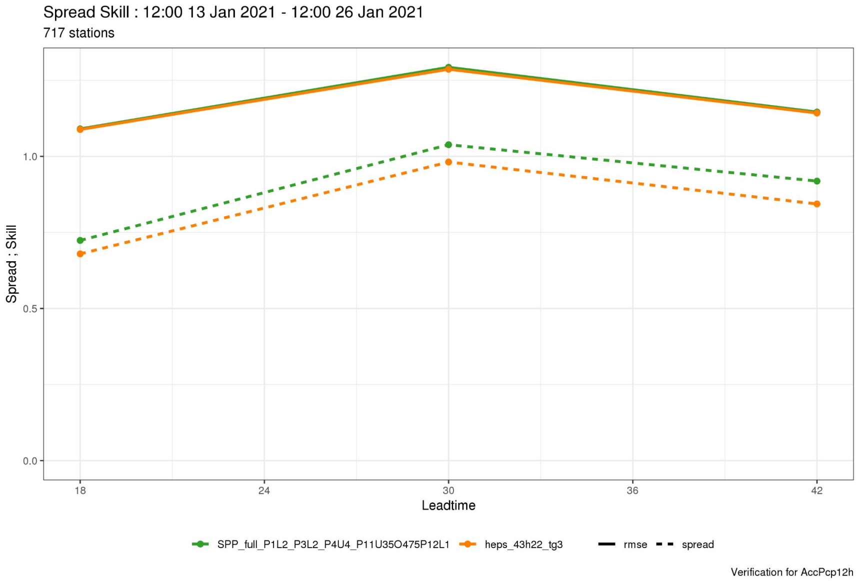
Spread (- - -) and Skill (___)

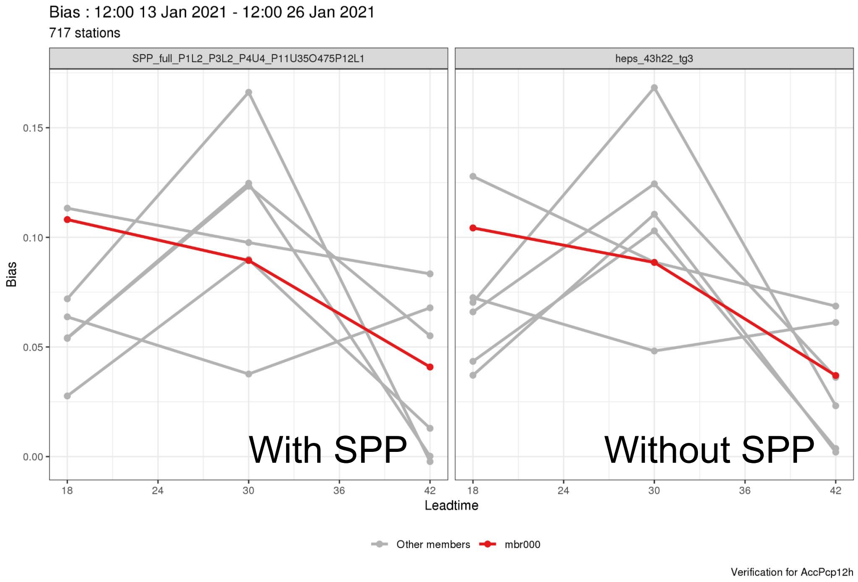
Bias (control / members)

Slightly higher spread leading to somewhat better spread/skill relationship.
Bias of the members with respect to the control ~neutral to SPP

Pcp12h

With SPP
Without SPP





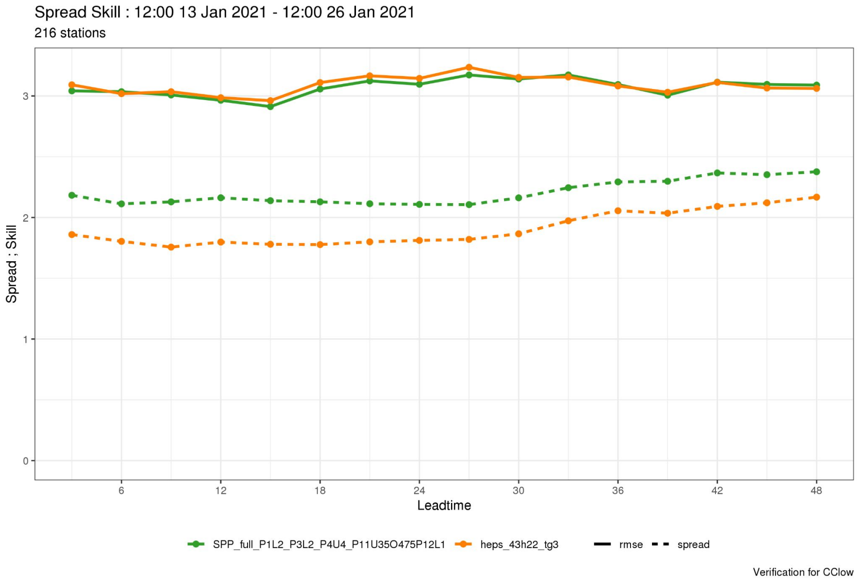
Spread (- - -) and Skill (___)

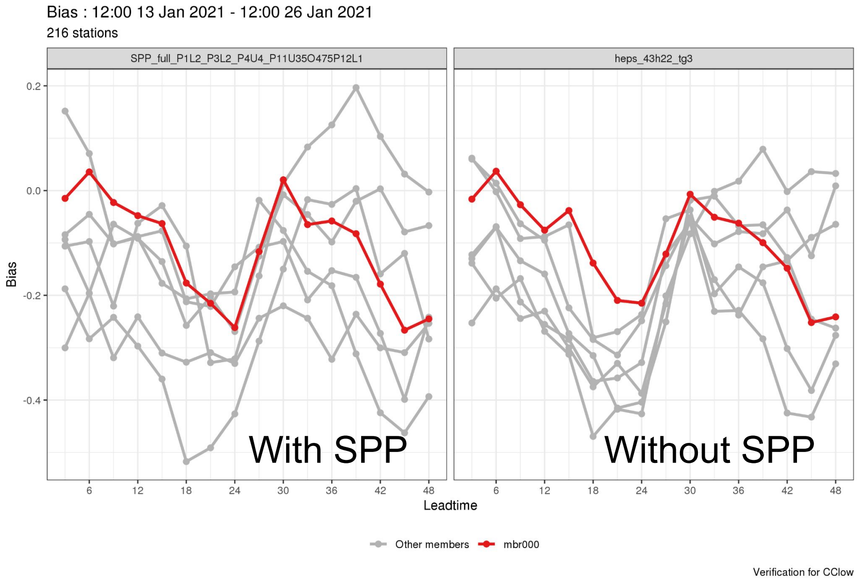
Bias (control / members)

Higher spread leading to better spread/skill relationship.
Bias of the members with respect to the control ~neutral to SPP

Low clouds

With SPP
Without SPP





Spread (- - -) and Skill (___)

Bias (control / members)

Higher spread leading to better spread/skill relationship.
Bias of the members with respect to the control ~neutral to SPP

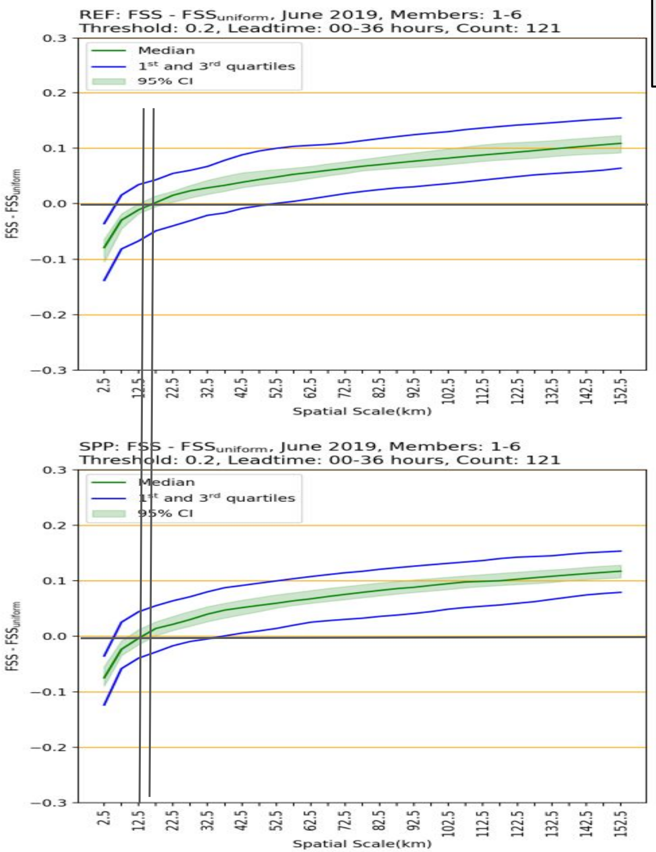
Fractions Skill Score (FSS) for total cloud cover - assessed against satellite-observed cloud mask

More than 50% of the model's domain was covered by clouds in the satellite data -> the model performance is assessed by forecasting clear areas instead of clouds

Threshold = 0.2, a low threshold means more clouds and less cloud-free grid cells. Mimics the cloud mask generation algorithm which describes a cell as being cloudy even when only thin cirrus clouds are present

Skillful forecast for scales FSS > FSS_uniform,
FSS_uniform = 0.5 + f
f is the fraction of cloud-free grid cells, calculated from satellite observations.

The median crosses the zero-line at ~12.5 km for SPP and ~17.5 km for REF -> SPP gives a forecast which has value at somewhat smaller scale



FSS - FSS_uniform

REF

REF + SPP

June 2019

Conclusions

- SPPT in HarmonEPS adds very little
  - SPPT was only able to create variability in the same geographical areas as the other perturbations, for the cases looked at
- SPP
  - SPP is able to add variability in geographical areas where the other perturbations are not active
    - Care needs to be taken to avoid bias change
  - SPP works well for the convection-permitting ensemble tested here, even when perturbing so few parameters involved in a rather limited set of physical parameterizations and processes within them

Further work and prospects for SPP

- Add more parameters to the scheme, extend to surface
- Continue the work on the parameter pdfs and correlations
- Test more distributions - if needed
- Need for more automatic tuning - utilize the one column model? URANIE?
- Play with the temporal and spatial scales - different for different parameters?

- SPP in operational Harmonie suites:
  - August 2022 in the MetCoOp ensemble (Norway, Sweden, Finland, Estonia)
    - Cost: an increase of 0.3%
  - Q3 2022 in the UWC-W ensemble (The Netherlands, Denmark, Ireland and Iceland)
  - The Netherlands (KNMI) ensemble during 2022

Model Uncertainty Representation in a Convection-Permitting Ensemble—SPP and SPPT in HarmonEPS

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Thank you for your attention!

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Extra

SPP - 11 parameter setup

SPP gives statistically indistinguishable ensemble members
The conservation properties and internal consistency are preserved

No.	Description	PAR.	Det.	STD#1	STD#2	95 perc.	Type
1)	Threshold for cloud thickness used in shallow/deep convection decision	CLDDPTHDP	4000	0.1	0.4	2.21	CONV
2)	Cloud ice content impact on cloud thickness	ICE_CLD_WGT	1	0.1	0.4	2.23	IM
3)	Ice nuclei concentration	ICENU	1	0.35	0.7	13.48	IM
4)	Saturation limit sensitivity for condensation	VSIGQSAT	0.03	0.1	0.4	2.17	LM
5)	Kogan autoconverltsion speed	KGN_ACON	10	0.25	0.5	2.06	LM
6)	Kogan subgrid scale (cloud fraction) sensitivity	KGN_SBGR	0.5	0.1	0.2	1.77	LM
7)	Graupel impact on radiation	RADGR	0.5	0.15	0.3	1.99	RAD
8)	Snow impact on radiation	RADSN	0.5	0.15	0.3	2.03	RAD
9)	Top entrainment efficiency	RFAC_TWO_COEF	2	0.1	0.4	2.07	TURB
10)	Stable conditions length scale	RZC_H	0.15	0.1	0.4	2.38	TURB
11)	Asymptotic free atmospheric length scale	RZL_INF	100	0.15	0.6	1.87	TURB

- Det. is the deterministic value of the parameter
- STD#1 is the original standard deviation
- STD#2 is the standard deviation we ended up with
- 95 perc. is the 95 percentile of the resulting pdf for STD#2, scaled by the deterministic value
- LM = liquid micro-physics
- IM = ice micro-physics
- RAD = radiation
- CONV = convection
- TURB = turbulence

the threshold for cloud thickness for stratocumulus/cumulus transition not in use

The following parameters are perturbed in MEPS:

Description	Parameter	Type
Threshold for cloud thickness used in shallow/deep convection decision	CLDDPTHDP	convection
Saturation limit sensitivity for condensation	VSIGQSAT	liquid microphysics
Cloud ice content impact on cloud thickness	ICE_CLD_WGT	ice microphysics
Stable conditions length scale	RZC_H	turbulence
Asymptotic free atmospheric length scale	RZL_INF	turbulence

SPG

Stochastic pattern generator (SPG; Tsyrulnikov and Gayfulin 2017) is employed for the generation of the random perturbation fields.

This pattern generator has the advantage of accounting for ‘proportionality of scales’, meaning it takes into account the fact that longer spatial scales live longer than shorter spatial scales, which die out quicker, a widespread feature in geophysics.

In SPG, the perturbations vary spatially and temporally, and are correlated through a third-order in time stochastic differential equation with a pseudo-differential spatial operator defined on a limited area.

The implementation in HarmonEPS interfaces the code provided by Tsyrulnikov and Gayfulin (2017) and is solely defined by the spatial (XLCOR) and temporal (TAU) correlation length scales, and the standard deviation, SDEV

FSS:

In order to undertake the model evaluation, a forecast cloud mask, M_f, is extracted from the predicted total cloud cover by defining a threshold q in the following way:

$$M_x = \begin{cases} 1 & \text{if} \quad C_x \leq q \\ 0 & otherwise \end{cases} \qquad (1)$$

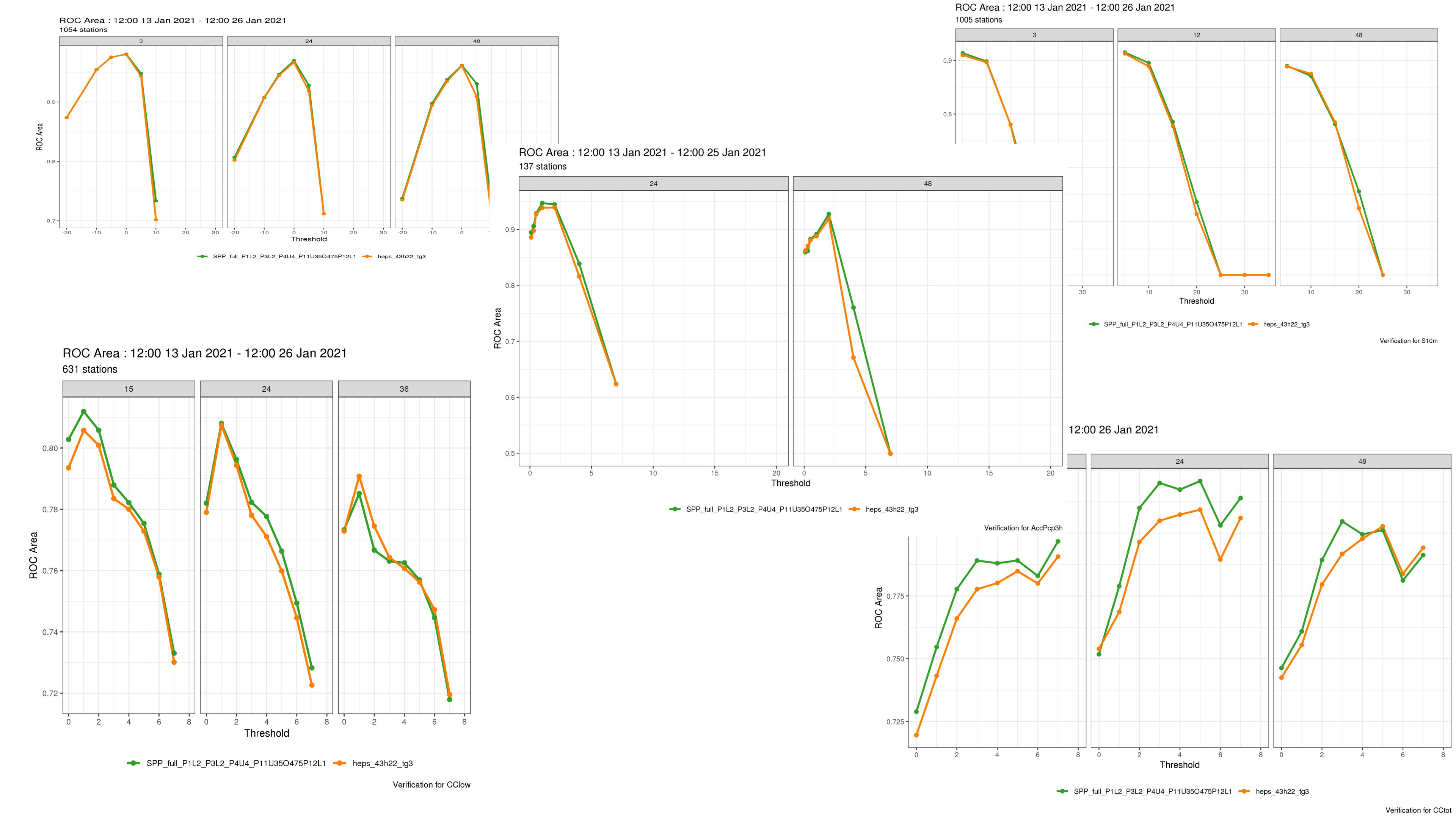
where M_x is the masked field, C_x is the cloud fraction and subscript x is o for observations and f for forecast fields.

$$\text{FSS} = 1 - \frac{\sum (PF_{ij} - OF_{ij})^2}{\sum (PF_{ij}^2 + OF_{ij}^2)} \qquad (2)$$

where PF_{ij} and OF_{ij} are the forecast and observed event fractions at grid cell ij, respectively, and following (Schwartz et al. 2010)

$$PF_{ij} = \frac{1}{N} \sum_{k=1}^{N} PF_{ijk} \qquad (3)$$

where PF_{ijk} is the forecast event fraction (here, being cloud-free) for grid cell ij and member k.



ROC Area : 12:00 13 Jan 2021 - 12:00 26 Jan 2021
1054 stations
ROC Area
Threshold
SPP_full_P1L2_P3L2_P4U4_P11U35O475P12L1
heps_43h22_tg3
ROC Area : 12:00 13 Jan 2021 - 12:00 26 Jan 2021
1005 stations
Threshold
SPP_full_P1L2_P3L2_P4U4_P11U35O475P12L1
heps_43h22_tg3
Verification for S10m
ROC Area : 12:00 13 Jan 2021 - 12:00 25 Jan 2021
137 stations
ROC Area
Threshold
SPP_full_P1L2_P3L2_P4U4_P11U35O475P12L1
heps_43h22_tg3
Verification for AccPcp3h
ROC Area : 12:00 13 Jan 2021 - 12:00 26 Jan 2021
631 stations
ROC Area
Threshold
SPP_full_P1L2_P3L2_P4U4_P11U35O475P12L1
heps_43h22_tg3
Verification for CClow
12:00 26 Jan 2021
ROC Area
Threshold
SPP_full_P1L2_P3L2_P4U4_P11U35O475P12L1
heps_43h22_tg3
Verification for CCtot

pSPPT

Other systems such as the Austrian C-LAEF use a partially perturbed parameterization tendency technique or pSPPT, based on the work of Wastl et al. (2019). In this approach, the partial tendencies of the physics parameterization schemes are perturbed separately which is in contrast to the traditional SPPT approach implemented in HarmonEPS. This approach allows the boundary layer tapering to be switched off and thus tendency style perturbations can play an enhanced role (Wastl et al. 2019).

Surface perturbations

Surface perturbations are applied to account for uncertainties in the turbulent fluxes emanating from interactions between the surface and the atmosphere. These uncertainties may come from both the specification of static physiographic fields and the analysis of prognostic surface parameters in the initial conditions. The method used to apply the surface perturbations is taken from Bouttier et al. (2016). The perturbations are applied to parameters in the SURFEX analysis after the surface data assimilation is completed and remain fixed throughout the forecast for static parameters. For prognostic parameters (i.e., soil temperature and soil moistures), the forecasts begin from the perturbed state and are then allowed to adjust dynamically to the model atmospheric forcing.

Parameter	Standard deviation	Type
Vegetation fraction	0.1	×
Leaf area index	0.1	×
Thermal coefficient of vegetation	0.1	×
Surface roughness length over land	0.2	×
Albedo	0.1	×
Sea surface temperature	0.25	+
Soil temperature	1.5	+
Soil moisture	0.1	×
Snow depth	0.5	×
Surface fluxes over sea	0.2	×