Progress towards a locally conserving representation of model uncertainties in the IFS

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Introduction

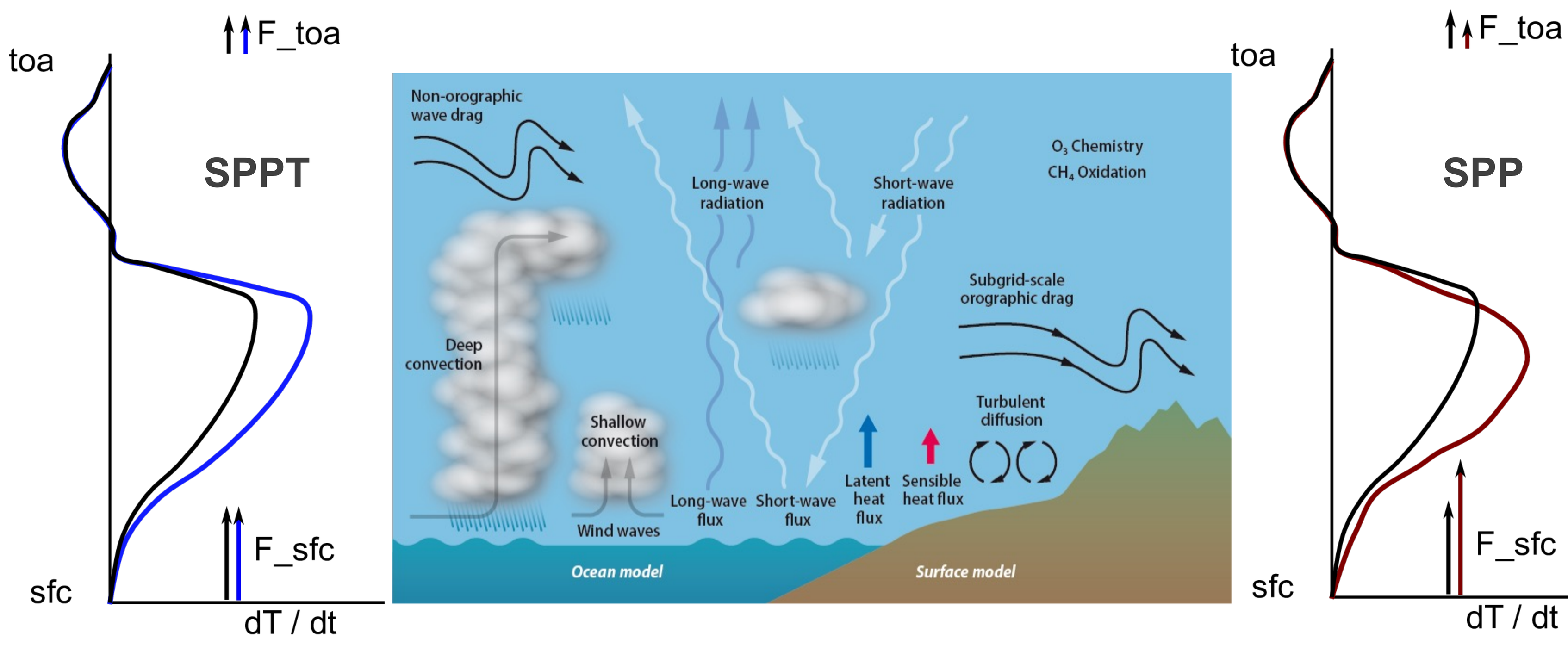
ECMWF uses SPPT (Stochastically Perturbed Parametrization Tendencies) to represent model uncertainties in the Integrated Forecasting System (IFS). SPPT is used at all lead times from the ensemble of data assimilations (EDA) to seasonal forecasts. SPPT in the IFS perturbs the sum of parametrized tendencies without perturbing fluxes at the surface or the top of the atmosphere. In consequence, there is an implied lack of local conservation of energy and moisture introduced by the perturbations. This leads to undesirable imbalances that are evident for instance in longer climate integrations as reported by Davini et al. (2017), who propose a fix that constrains the global integral of the perturbations. This fix addresses global conservation but not local conservation.

Maintaining local conservation in the perturbed IFS to a similar level as in the unperturbed model has strongly motivated work to develop an alternative model uncertainty representation at ECMWF (Leutbecher et al, 2017). The initial version of SPP (Stochastically Perturbed Parametrizations) has been documented by Ollinaho et al (2017). The results obtained with this version of SPP were promising but not good enough to use the scheme operationally. Over the last five years significant progress has been made (see 'The big step', Lang et al.,2021). In 2022, extensive testing of the SPP scheme took place at ECMWF covering all lead times and various horizontal resolutions up to 9 km. Most of the testing was based on the IFS version that became operational in October 2021 and is known as Cycle 47r3. That cycle contained a major upgrade of the moist physics parametrisations (Bechtold et al 2020). This poster summarises results from recent tests with Cycle 47r3 and reports remaining outstanding issues with SPP that are currently being worked on.

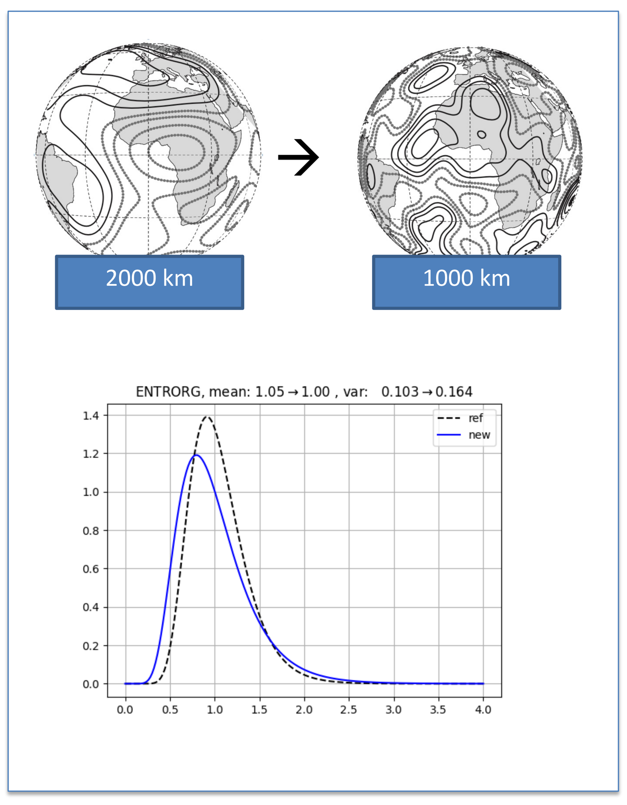
ECMWF plans to replace SPPT by SPP in cycle 49r1 (to be implemented in 2024) in all operational ensembles.

Key differences between SPPT and SPP

- representation of model uncertainties close to the assumed sources of the errors
- physical consistency: e.g. local budgets and flux perturbations
- SPPT only represents amplitude errors while SPP can also represent errors in the shape of a heating profile



The big step

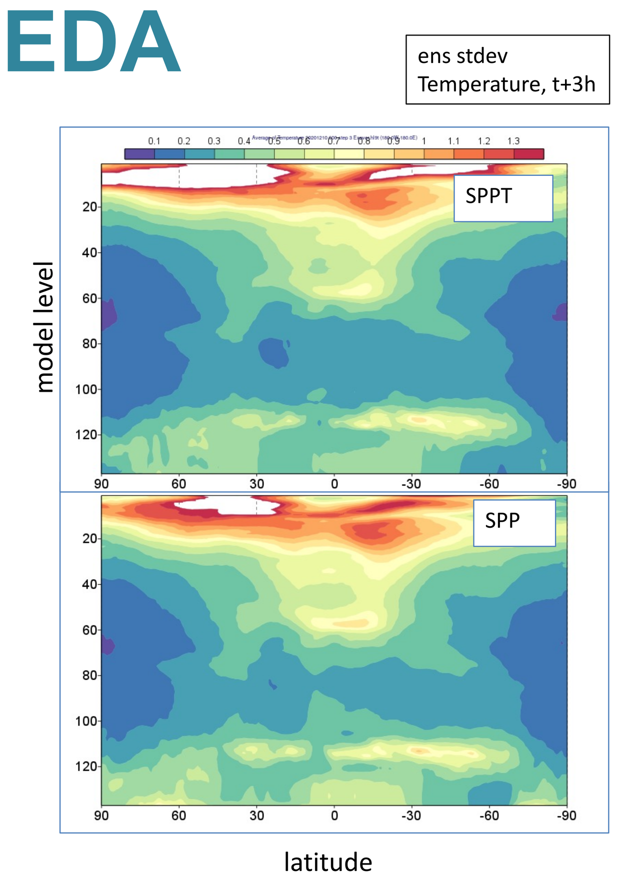


SPP has progressed considerably from Ollinaho et al. (2017) to Lang et al. (2021)

- Horizontal correlation length scale reduced
- Number of perturbation elements increased from 19 to 27
- Changes to mean and variance of probability distributions that define the version of SPP
- Reduced biases and improved medium-range ensemble spread leads to similar skill as SPPT
- What about shorter and longer lead times and the upcoming medium-range horizontal resolution upgrade?

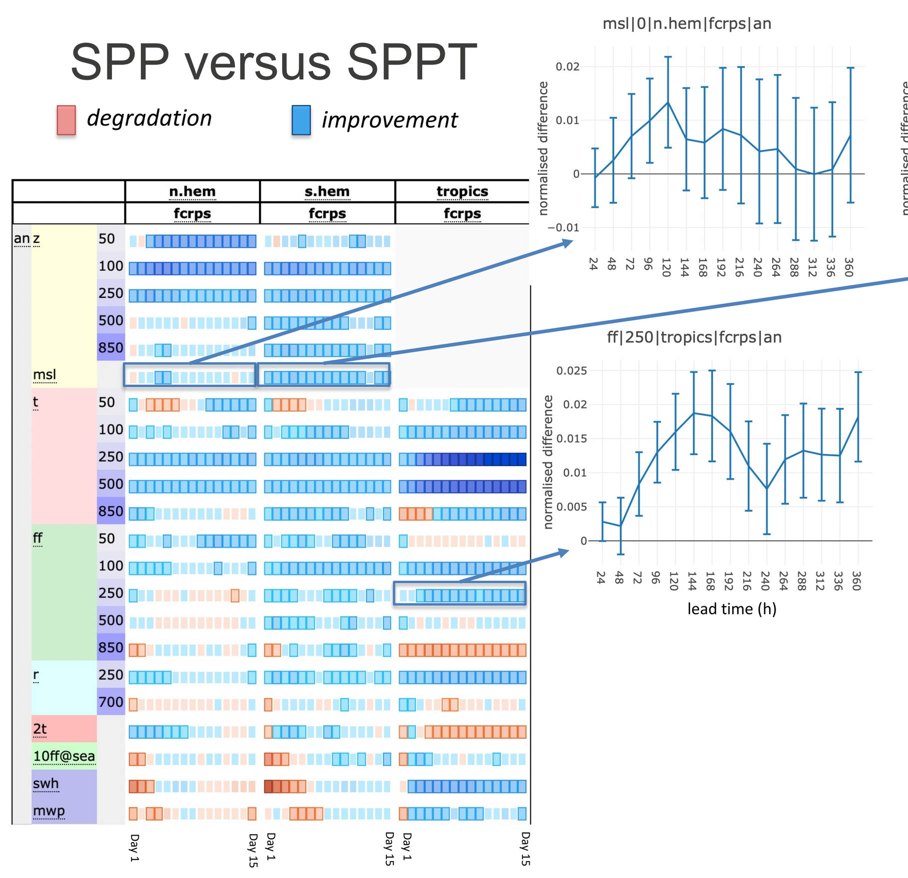
EDA

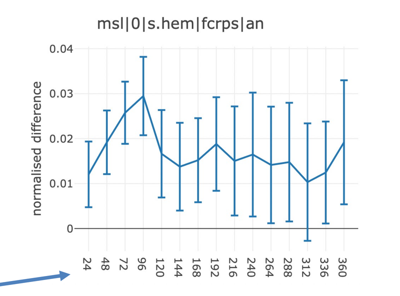
ens stdev
Temperature, t+3h



- Model uncertainty representation have considerable impact on EDA spread
- Overall, similar spread in the ensemble of 4D-Vars with the two alternative model uncertainty representations
- Increased spread near surface (level>125) with SPP — no tapering in BL and consistent perturbation of surface fluxes are assumed to be a factor in achieving this

Medium-range at Δx=9 km



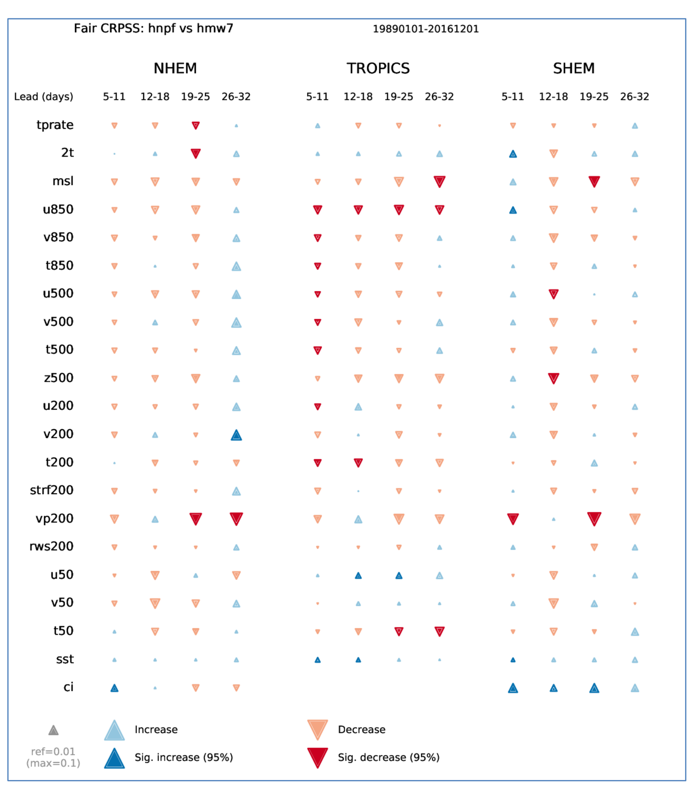


Experiments:

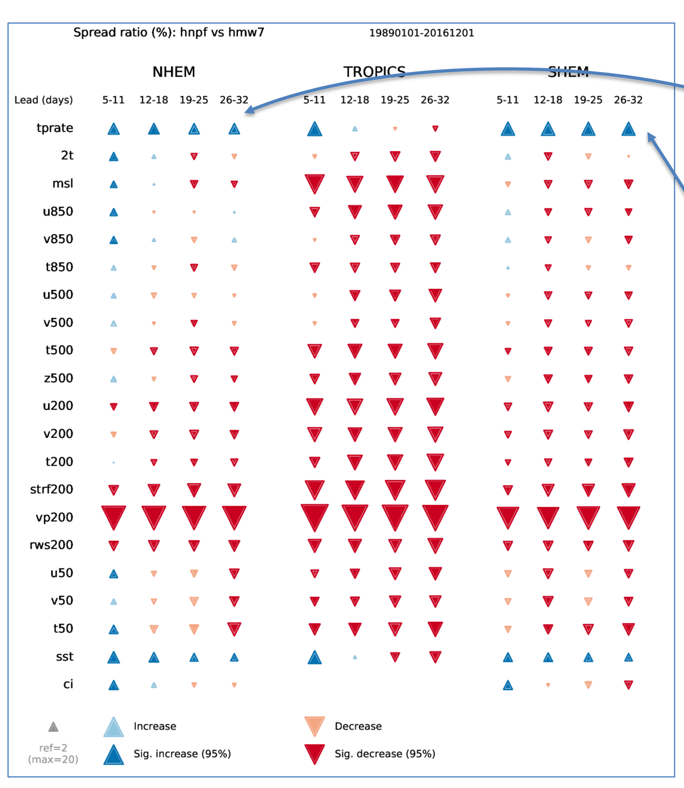
- CY47R3
- 9km ENS (TCo1279)
- 8+1 members
- fair CRPS (fcrps)
- Starts: every day, Jun+Jul+Dec+Jan 2020/21 at 00/12 UTC
- Forecast period: 15 days
- IC perturbations: EDA, SVs, ocean ICs

Extended-range forecasts

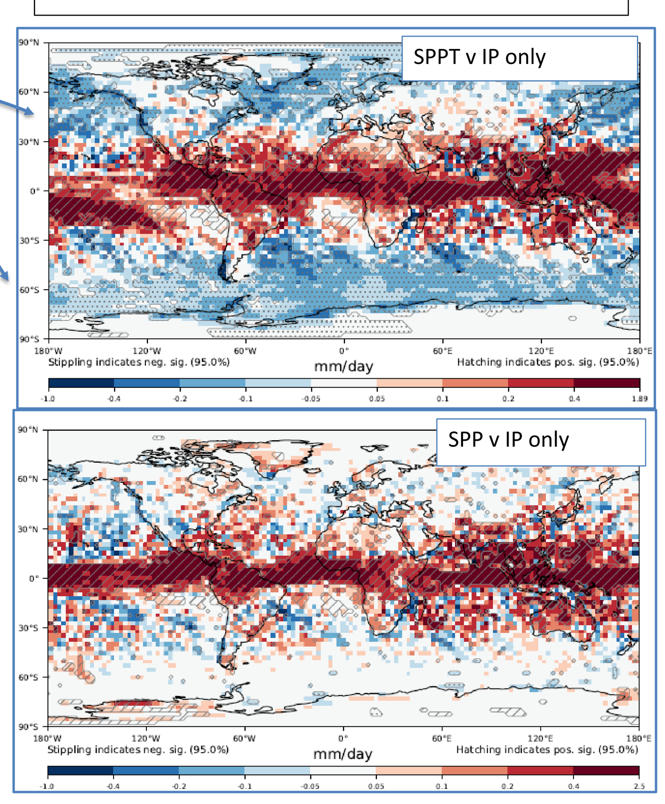
SPP v SPPT: Δ fCRPSS



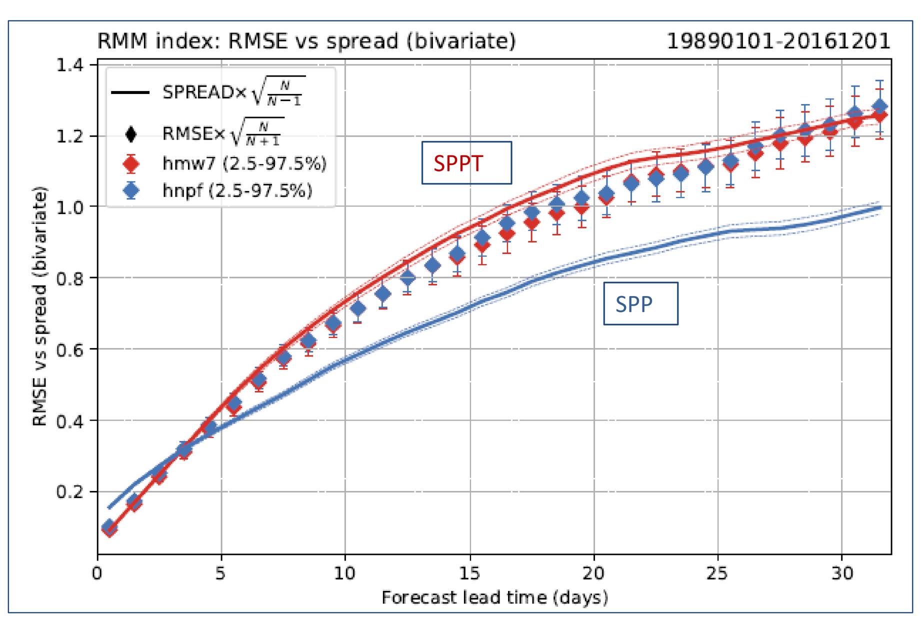
SPP v SPPT: Δ spread



Δ spread relative to initial perturbations only, "IP only"
total precipitation, t+600--768h



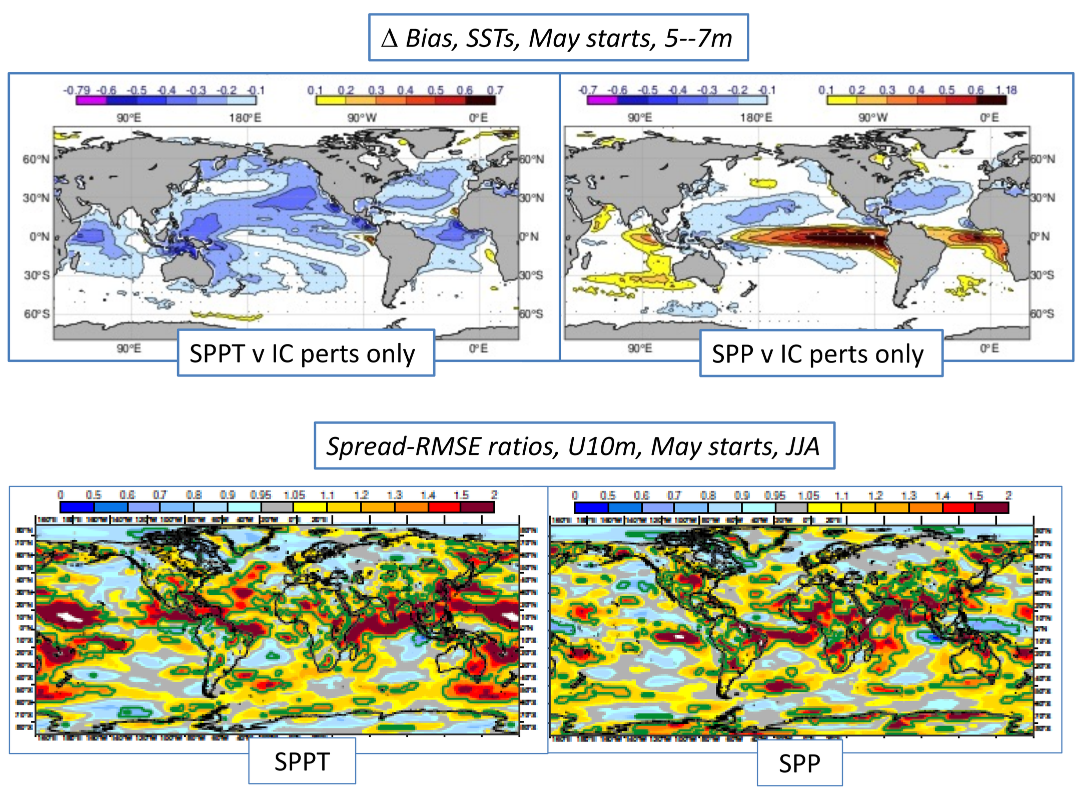
MJO index



- Overall, less ensemble spread with SPP than with SPPT for weekly anomalies and for bivariate MJO index
- Peculiar reduction of extended-range precipitation spread in extra-tropics and enhanced spread in tropics compared to initial perturbations only — a sign of lacking local conservation of moisture?

Experiments:
CY47R3
TCo199L137,ORCA1_Z75
9+1 members
Starts: 1st of each month during 2017; hindcasts: 1989..2016 (28 years)
IC perts: EDA, SVs, ocean ICs
Forecast period: 768h (32d)

Long-range forecasts



Change in bias due to model uncertainty representations

- Changes in model biases are not an aspect that is targeted in the development process of the stochastic parametrisations
- SPPT tends to generally cool the SSTs
- SPP cools and warms

Spread-RMSE ratios

- should asymptote to 1 in large sample
- long-range spread is linked to model activity
- SPPT (since cycle 45r1) leads to overdispersion of lower tropospheric tropical winds, this is improved with SPP

Experiments

CY47R3
TCo319L137, ORCA025_Z75
15 members
Starts: 01 May & 01 Nov, 1993..2020 (28 years)
IC perturbations: EDA, SVs, ocean ICs
Forecast period: 7 months

Summary and outlook

The recent revision of SPP produced a model uncertainty scheme that is competitive with SPPT for global medium-range ensemble forecasts with the IFS. These modifications of SPP were developed prior to the major moist physics upgrade in cycle 47R3. Nevertheless, SPP performs exceptionally well when compared to SPPT in cycle 47r3 — in particular at 9 km horizontal resolution, which is becoming operational in 2023. Testing SPP in the EDA has shown overall similar impact on ensemble spread as when using SPPT except for larger near-surface spread. This may have a beneficial impact on the assimilation of near-surface observations such as 2-metre temperature. Future work will assess how the replacement of SPPT by SPP in the EDA impacts the ensemble skill via changes to the deterministic analysis and changes to the initial perturbations obtained from the EDA.

In extended-range testing, it was observed that both SPP and SPPT positively contribute to probabilistic skill and the difference in skill of weekly anomalies between the schemes are small compared to their overall positive impact. However, SPP generates overall less spread than SPPT — in particular in the tropics. The spread-error relationship for the bi-variate MJO index is less good with SPP than with SPPT. This used to be the other way round prior to the revision of SPPT in Cycle 45r1 (Lock et al., 2019). Ongoing work focusses on modifications and extensions of SPP that will improve the ensemble dispersion for the MJO without adversely affecting other forecast aspects.

While SPPT generates about the right level of ensemble spread in the extended-range forecasts, it shows signs of significant overdispersion in long-range forecasts for near-surface winds. Ensembles using SPP are considerably less overdispersive for near-surface winds in seasonal forecasts than ensembles using SPPT. Both SPPT and SPP alter SST biases found in the unperturbed model. This is of particular interest in long-range forecasts where the magnitude of the bias and the signal can have similar magnitudes. An area that is monitored particularly closely is the tropical Pacific where the sign of the SST bias changes from one scheme to the other. The primary purpose of the stochastic model uncertainty schemes presented here is to generate a realistic level of ensemble dispersion that matches the error growth — it is not to alter the bias with respect to the unperturbed model. Ongoing work explores whether modifications of SPP can be identified that have a smaller impact on SST biases in the long-range forecasts.