Stochastic representations of model uncertainties in the IFS

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Model uncertainty representations in the IFS

- Operational in medium/extended-range and seasonal ensembles (ENS, SEAS)
  - SPPT (Stochastically Perturbed Parametrisation Tendencies) with 3-scales
  - SKEB (Stochastic Kinetic Energy Backscatter)
- Operational in ensemble of data assimilations (EDA)
  - SPPT with 1-scale (fast & small-scale)

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- Operational in ensemble of data assimilations (EDA)
  - SPPT with 1-scale (fast & small-scale)
- Research
  - modifications of SPPT (cf. talks by Weisheimer and Christensen)
  - Development of a new scheme "SPP": Stochastically Perturbed Parameterisations
  - ENS with SPP versus ENS with SPPT
  - EDA with SPP
  - EDA with 3-scale SPPT

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Stochastic Kinetic Energy Backscatter (SKEB)

- Rationale: A fraction of the dissipated energy is backscattered upscale and acts as streamfunction forcing for the resolved-scale flow (Shutts and Palmer 2004, Shutts 2005, Berner et al. 2009)
- Streamfunction forcing $= [bD]^{1/2}\ F(\lambda, \phi, \sigma, t)$,
  where b, D, F denote the backscatter ratio, the (smoothed) total dissipation rate and the 3-dim evolving pattern, respectively

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  where b, D, F denote the backscatter ratio, the (smoothed) total dissipation rate and the 3-dim evolving pattern, respectively
- Total dissipation rate: sum of
  - "Numerical" dissipation: Loss of KE by numerical diffusion + interpolation in semi-Lagrangian advection; estimated from biharmonic diffusion
  - an estimate of the deep convective KE production
- Resolution upgrade ($32 \rightarrow 19$ km) in March 2016:
  Spectral viscosity approach for cubic octahedral grid is inconsist with biharmonic diffusion assumed by SKEB and used previously with the linear grid ($\Rightarrow$ contribution from numerical dissipation deactivated, i.e. SKEB $\rightarrow$ SCB $\Rightarrow$ SKEB is less active)

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Stochastically Perturbed Parameterization Tendencies (SPPT)

- Total physics tendencies P perturbed by $\Delta P = \mu r P$, with r a random pattern and μ a tapering profile (0 in BL and stratosphere, 1 in free troposphere)
- Improved version of the original SPPT scheme (stochastic physics, Buizza, Miller & Palmer, 1999)

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- Improved version of the original SPPT scheme (stochastic physics, Buizza, Miller & Palmer, 1999)
- Random pattern $r(\mathrm{lat}, \mathrm{lon}, t)$ uses AR-1 processes in spectral space and is "continuous" in space and time
- Multi-scale pattern with three components:
  τ =6 h, 3 d, 30 d and L =500 km, 1000 km, 2000 km with standard deviations of σ =0.52, 0.18, 0.06, respectively
- Gaussian distribution (limited to range $[-1, 1]$)
- Same pattern r for T, q, u, v
- see Tech Memo 598, Palmer et al. (2009) and Shutts et al (2011), ECMWF Newsletter 129

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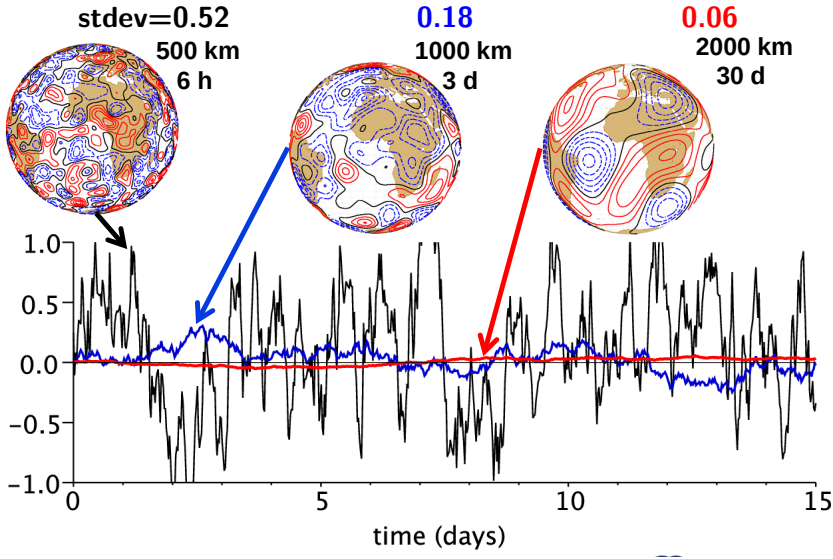
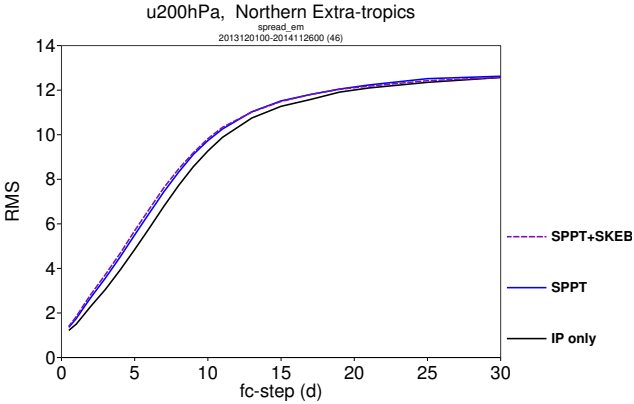
SPPT pattern

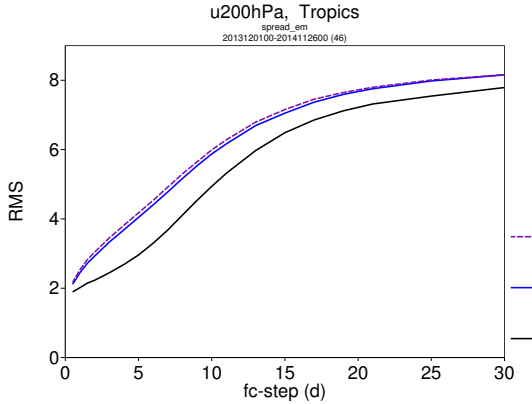
composed of 3 random fields



What happens without representation of model uncertainties?

Ensemble standard deviation

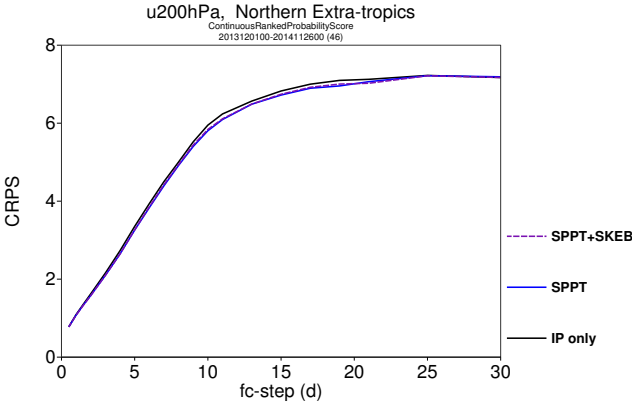


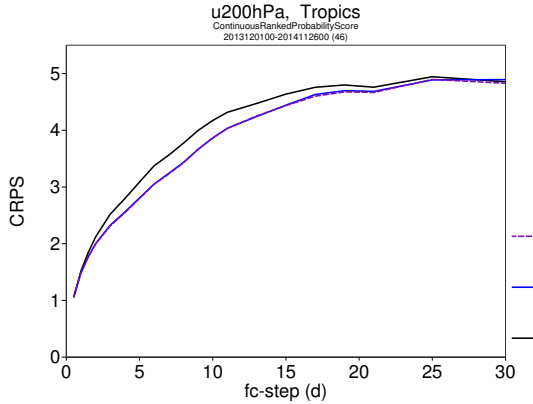


TL399/255, resolution change at D15, 20 members

What happens without representation of model uncertainties?

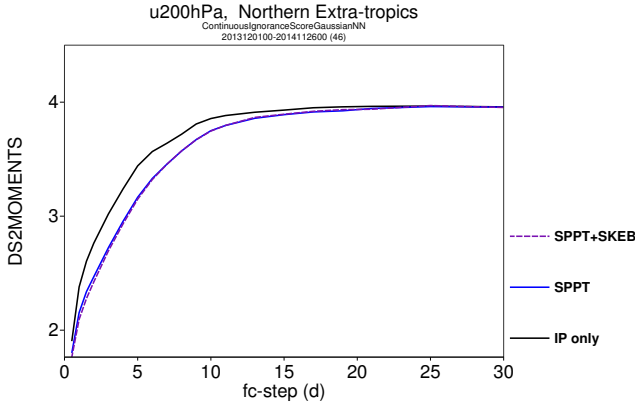
Probabilistic skill (I)

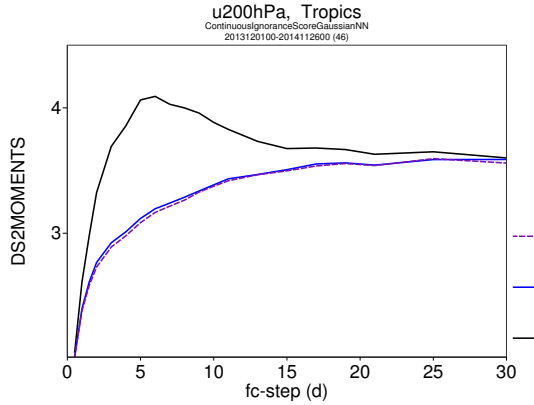




What happens without representation of model uncertainties?

Probabilistic skill (II)





Proper two-moment score of Dawid and Sebastiani (1999) $\equiv$ log-score of Gaussian distribution with the two moments given by ensemble mean and ensemble variance

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Planned and potential upgrades of SPPT

- fix global integral of perturbed tendency to the value of the unperturbed tendency to address lack of conservation (Antje Weisheimer, Simon Lang and Jost von Hardenberg)
- independent patterns for different processes / groups of processes (iSPPT: Hannah Christensen and Sarah-Jane Lock)
- re-assessment of supersaturation limiter (Sarah-Jane Lock)

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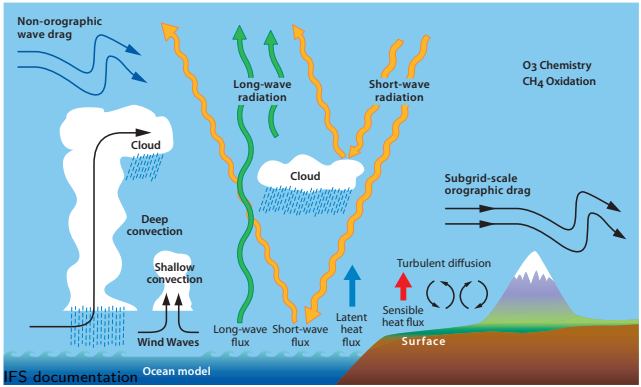
Towards process-level specification of uncertainties

Aim: Improve physical consistency of model uncertainty representation



- Flux perturbations at TOA and sfc that are consistent with tendency perturbation in atmospheric column
- Conservation of water
- No ad hoc tapering in BL and stratosphere
- Include multi-variate aspects of uncertainties

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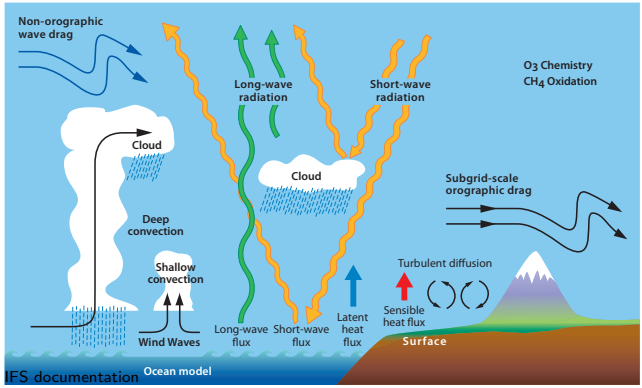

- Flux perturbations at TOA and sfc that are consistent with tendency perturbation in atmospheric column
- Conservation of water
- No ad hoc tapering in BL and stratosphere
- Include multi-variate aspects of uncertainties

- Embed stochasticity within IFS physics
- Local stochastic perturbations to parameters and variables with specified spatial and temporal correlations

- Target uncertainties that matter
- Stochastic parameterisation converges to deterministic IFS physics in limit of vanishing variance

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Stochastically Perturbed Parametrisations (SPP)

The distributions sampled by SPP

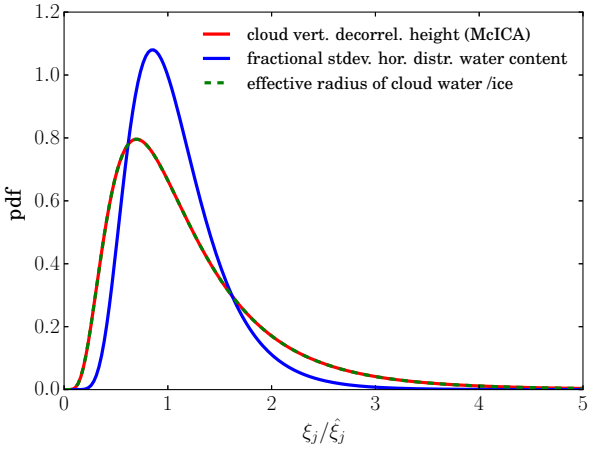
Stochastic parameterisation samples parameter ξ_j by a log-normal distribution

$$\xi_j = \hat{\xi}_j \exp(\Psi_j)$$

with unperturbed parameter $\hat{\xi}_j$

$$\Psi_j \sim \mathcal{N}(\mu_j, \sigma_j^2)$$

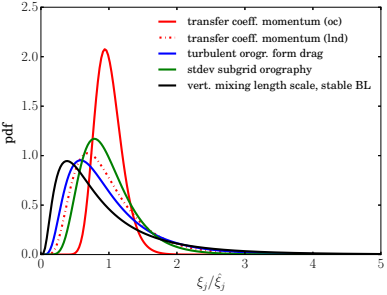
$\mu = 0 \Rightarrow$ median of ξ_j is equal to $\hat{\xi}_j$



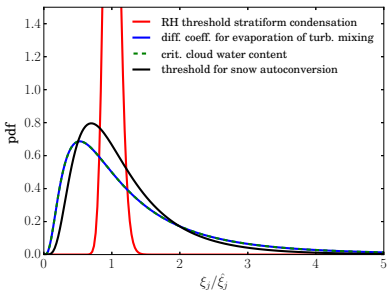
Development started with parameter perturbations that target the cloud-radiation interaction

The distributions sampled by SPP

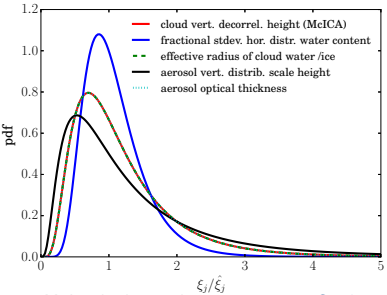
turbulent diffusion and subgrid oro.



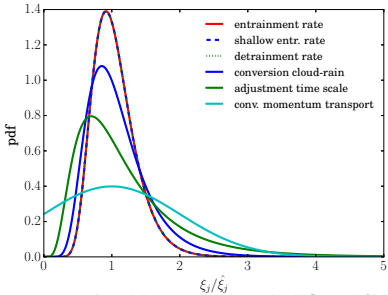
cloud and large-scale precipitation



radiation

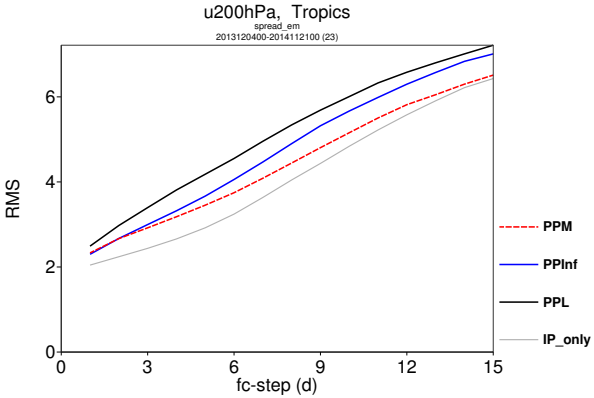


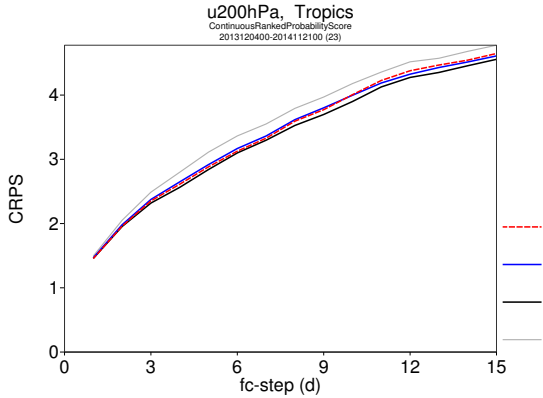
convection



Correlation scales matter

Ensemble standard deviation and CRPS





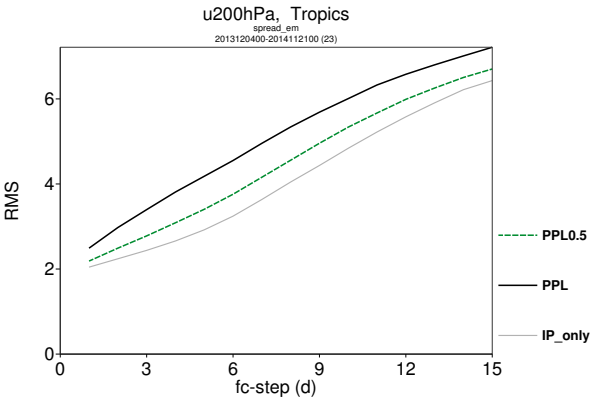
Exp	L (km)	τ (h)
PPM	500	6
PPL	2000	72
PPInf	∞	∞

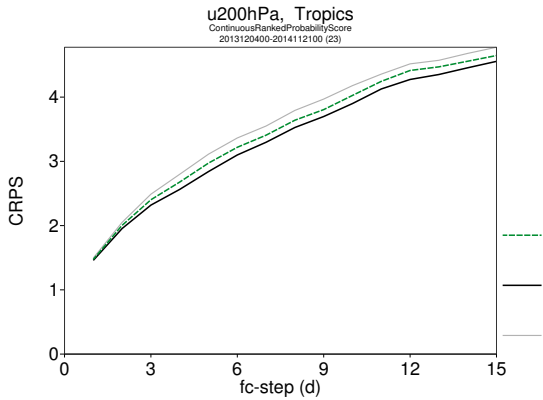
horizontal correlation length scale L
correlation time τ
for pattern Ψ

Ollinaho et al. (2016, submitted to QJ)

Amplitude matters too

Ensemble standard deviation and CRPS



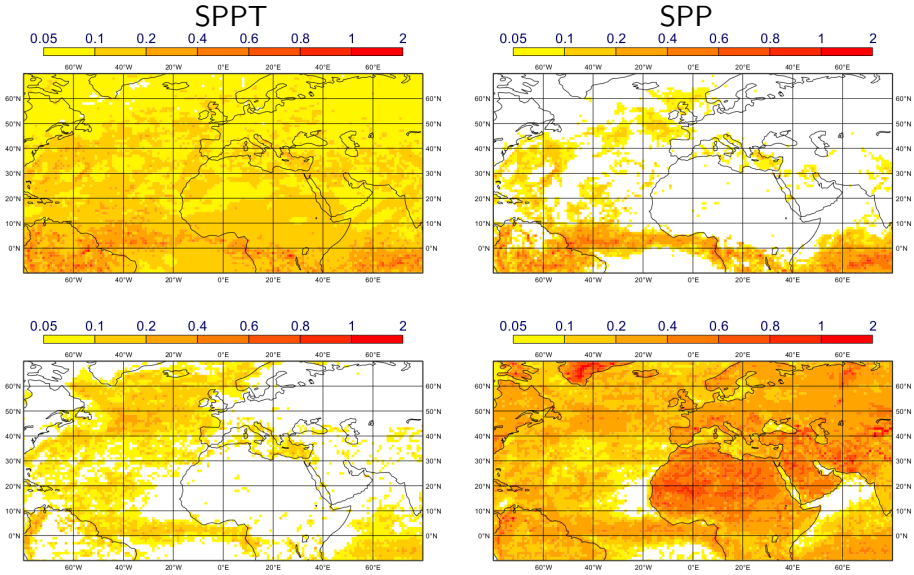


PPL0.5 has all standard deviations σ_j halved compared to PPL.
The correlation scales are 2000 km and 72 h in both experiments.

Ollinaho et al. (2016, submitted to QJ)

Intercomparison of SPP and SPPT

Ensemble stdev of 0–3 h temperature tendencies (K[3 h]$^{-1}$)



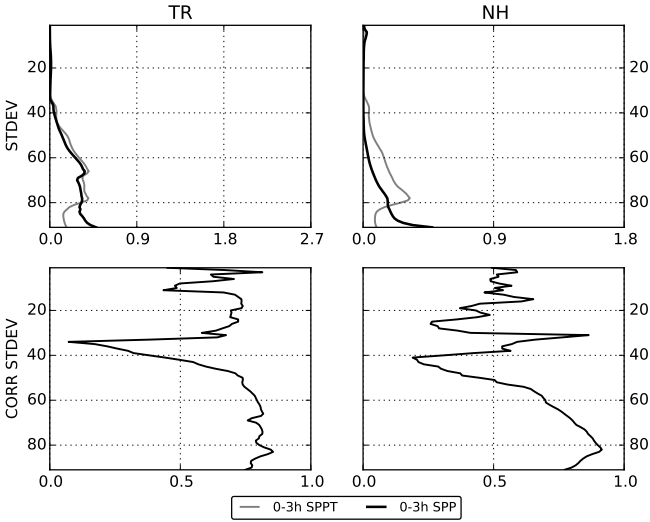
no initial pertns. TL255, 20 member

← level 64 ∼ 500 hPa

← level 91 10 m above surface

Comparing ensembles of temperature tendencies

SPP versus SPPT (no initial perturbations)



- Stdev of 0–3 h tendency
- SPP induces larger (smaller) tendency perturbations in (above) BL than SPPT
- regions where tendencies are most uncertain become more similar with increasing lead time (bottom: corr stdev)
- 6 boreal winter cases; Unit (top panels): K/(3 h)

Ollinaho et al. (2016, submitted to QJ)

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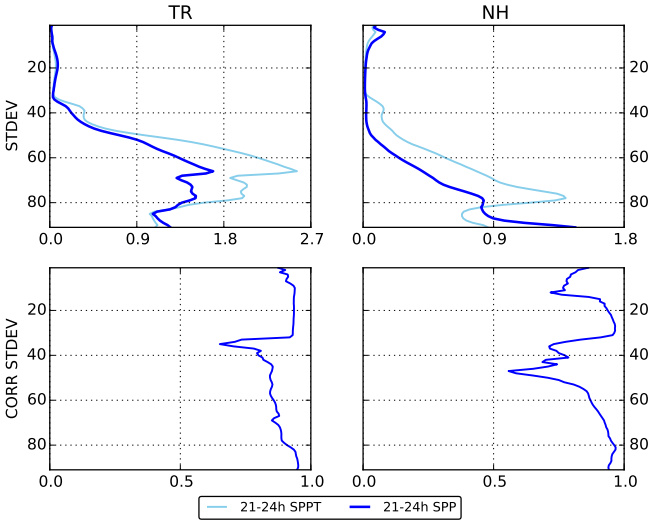
Comparing ensembles of temperature tendencies

SPP versus SPPT (no initial perturbations)



- Stdev of 21–24 h tendency
- SPP induces larger (smaller) tendency perturbations in (above) BL than SPPT
- regions where tendencies are most uncertain become more similar with increasing lead time (bottom: corr stdev)
- 6 boreal winter cases; Unit (top panels): K/(3 h)

Ollinaho et al. (2016, submitted to QJ)

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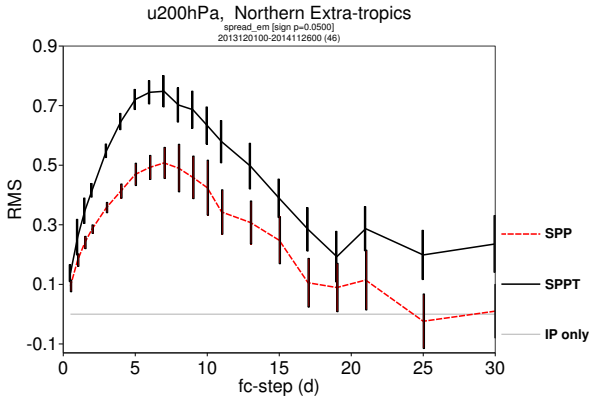
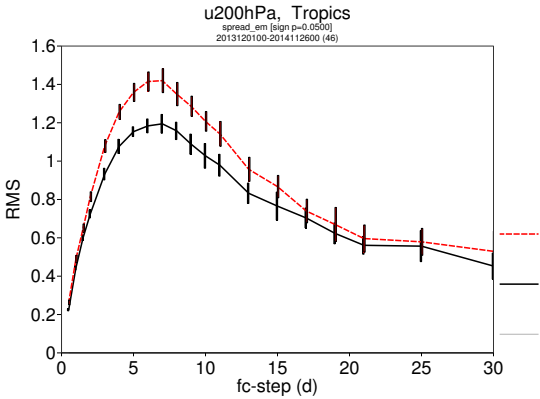
Change of ensemble stdev: 200 hPa zonal wind

SPP versus SPPT relative to initial perturbation only



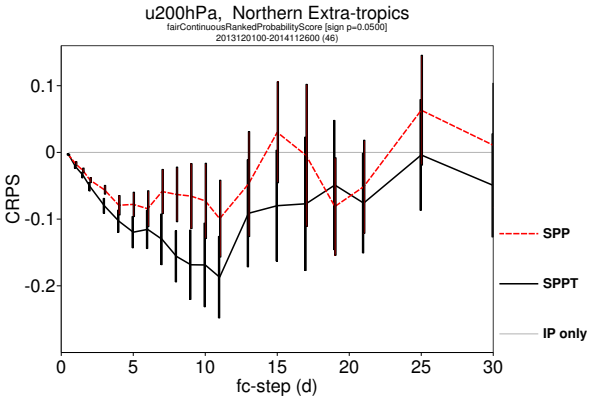


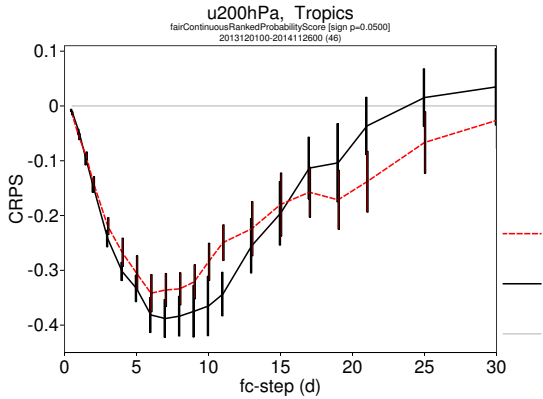
TCo255/159, resolution change at D15, 20 member

Exp	L (km)	τ (h)
SPP	2000	72
SPPT	3-scale	3-scale

Change of CRPS: 200 hPa zonal wind

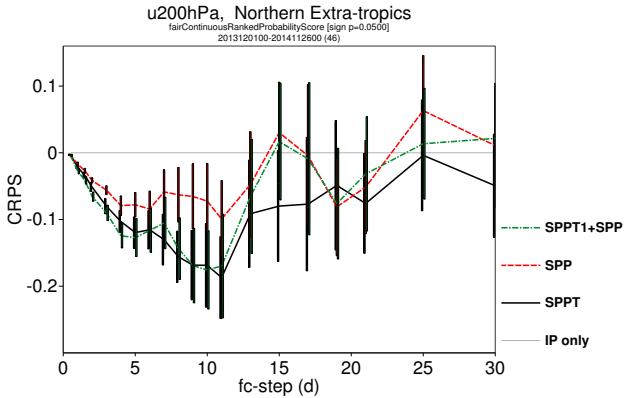
SPP versus SPPT relative to initial perturbation only

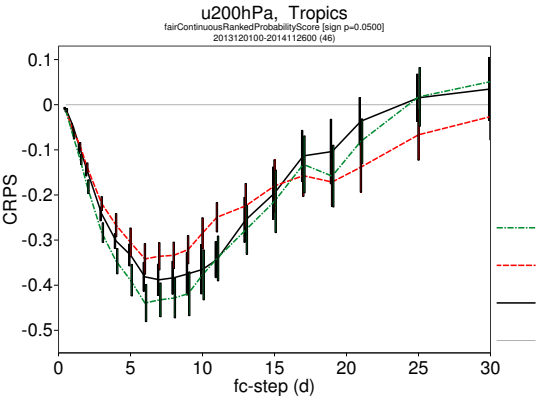




Change of CRPS: 200 hPa zonal wind

SPP+SPPT1 and . . . relative to initial perturbation only





Exp	L (km)	τ (h)
SPP	2000	72
SPPT1	500	6

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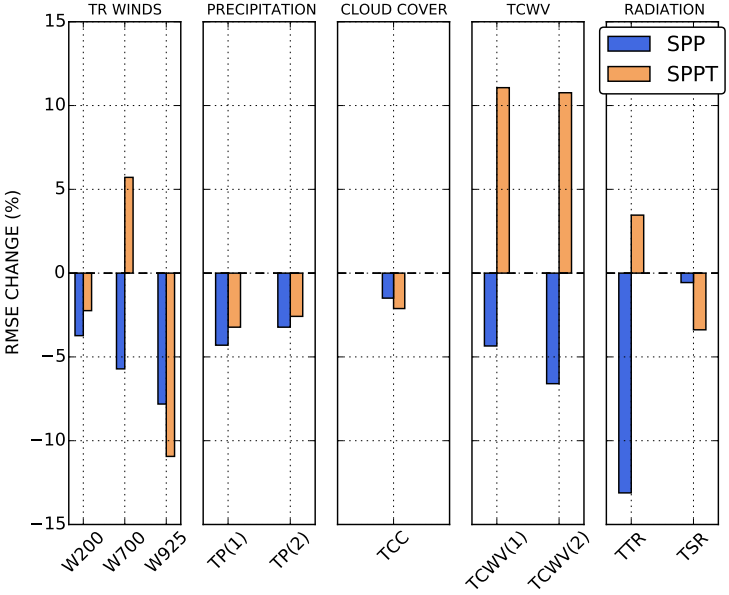
Impact on model climate



Relative change of RMS error of annual mean fields with respect to unperturbed forecasts.

ERA-Interim (tropical winds) and satellite obs. are used as reference.

Model configuration: uncoupled TL255, 4 start dates, initial month omitted.

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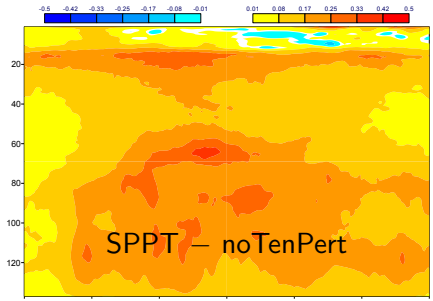
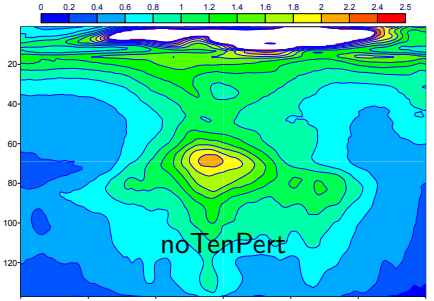
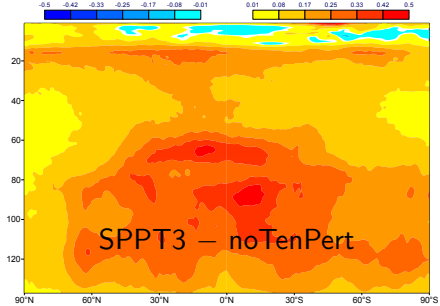
EDA first guess (3 h) stdev: Meridional wind ($m\,s^{-1}$)

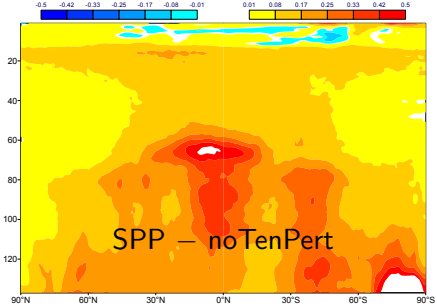




SPPT: oper. 1-scale

SPPT3 and SPP propagate random fields across cycles





mean over 16 12-hour assimilation cycles in June 2015

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Summary

- The operational schemes SPPT (+SKEB) contribute significantly to the probabilistic skill in medium range and extended range
- A new stochastic scheme has been developed for representing model uncertainties at the process level in IFS: The SPP scheme provides a framework to build stochastic parameterisations that are guided by existing deterministic parameterisations
  - A first attempt to represent model uncertainties in the main physical processes in a physically consistent way.
  - Further extensions of SPP are envisaged and ideas are welcome
- Proximity to processes implies a scheme that is less parsimonious than SPPT.
- Further development could benefit from validating the ensemble for variables that are close to the processes.
- Initial operational implementation could consider a combination of SPPT and SPP

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Current ECMWF ideas on future plans

For working group discussions

- Move towards consistent approach to represent model uncertainties in assimilations and forecasts at all lead times
- Process-oriented diagnostics of ensembles
  (e.g. radiative fluxes, precipitation, skin temperature)
- Ideas for extending scope of SPP:
  - thermodynamic coupling between surface and atmosphere
  - vertical mixing above boundary layer
  - atmospheric composition: trace gas sources/sinks
- How to evolve from current SKEB?
  Stochastic Convective Backscatter (SCB, Shutts 2015)
  and/or stochastic dynamical core

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Vacancy VN16-13 at ECMWF for Scientist to work on specification of global surface characteristics for land, ocean, biosphere and cryosphere and model uncertainty, see `http://www.ecmwf.int/en/about/jobs/jobs-ecmwf`

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extra slides . . .

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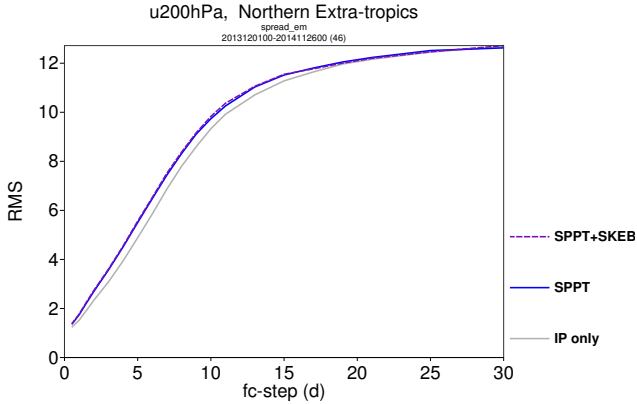

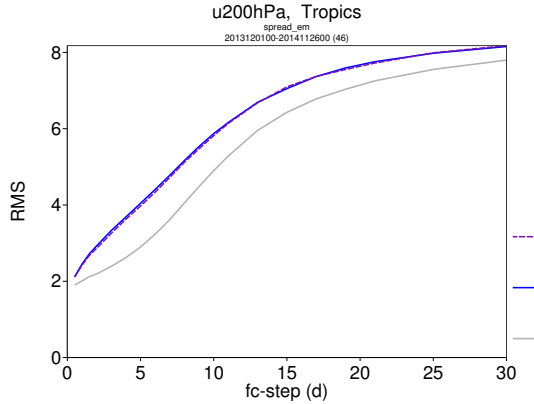

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