Stochastic representation of model uncertainties at ECMWF

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Status quo

- Model uncertainties represented by SPPT (Stochastically Perturbed Parametrisation Tendency scheme, a.k.a. “stochastic physics”)
- In medium-range ensemble since 1998, updated a couple of times
- Perturbs total tendencies from physics parametrisations:
  tendency perturbation = <2D random field> x <unperturbed tendency>
- Most recent configuration is described in Lock et al (2019, https://doi.org/10.1002/qj.3570)

Why seek an alternative to SPPT?

- Lack of physical consistency of perturbations
- Local conservation of energy, moisture and momentum is violated
  - fluxes at surface and top of the atmosphere are not consistent with perturbed tendency in column
  - SPPT is run with a global fix to address conservation in a globally integrated sense
  - Fix implies non-physical transport in the atmosphere
- Would like to represent uncertainty close to the sources of the errors
  - SPPT uses the same amplitude for all processes and weather situations
  - process-oriented representation of model uncertainty can offer greater flexibility

Stochastically Perturbed Parametrisation scheme (SPP)

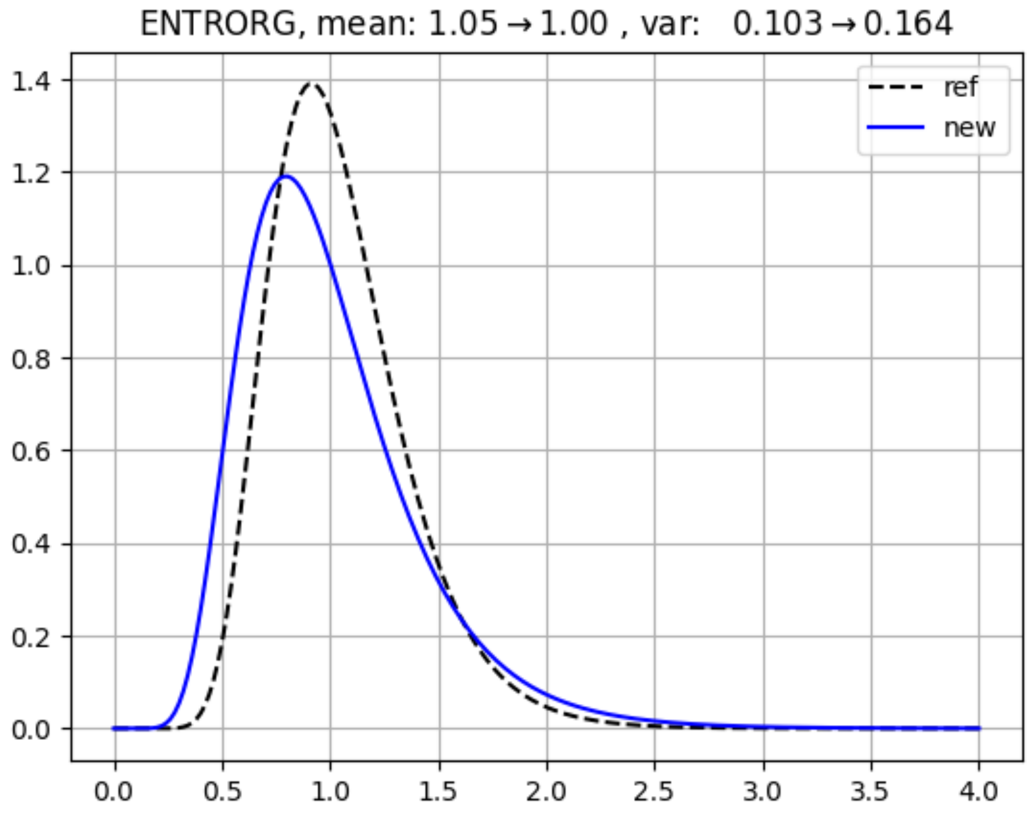
- process-oriented representation of uncertainties inside the IFS physics parametrisations
  - radiation,
  - vertical mixing,
  - cloud scheme and
  - convection scheme
- original version documented in Ollinaho et al (2017) https://doi.org/10.1002/qj.2931
- 19 (20) quantities perturbed, 2000 km correlation scale for random fields
- works well, medium-range ensemble skill significantly improved compared to ensemble that uses initial perturbations only
- However, the original version produces overall less spread than SPPT and the probabilistic skill is lower than with SPPT
- Is this a fundamental limitation of SPP or due to the specific configuration developed by Ollinaho et al (2017)?

A revision of SPP

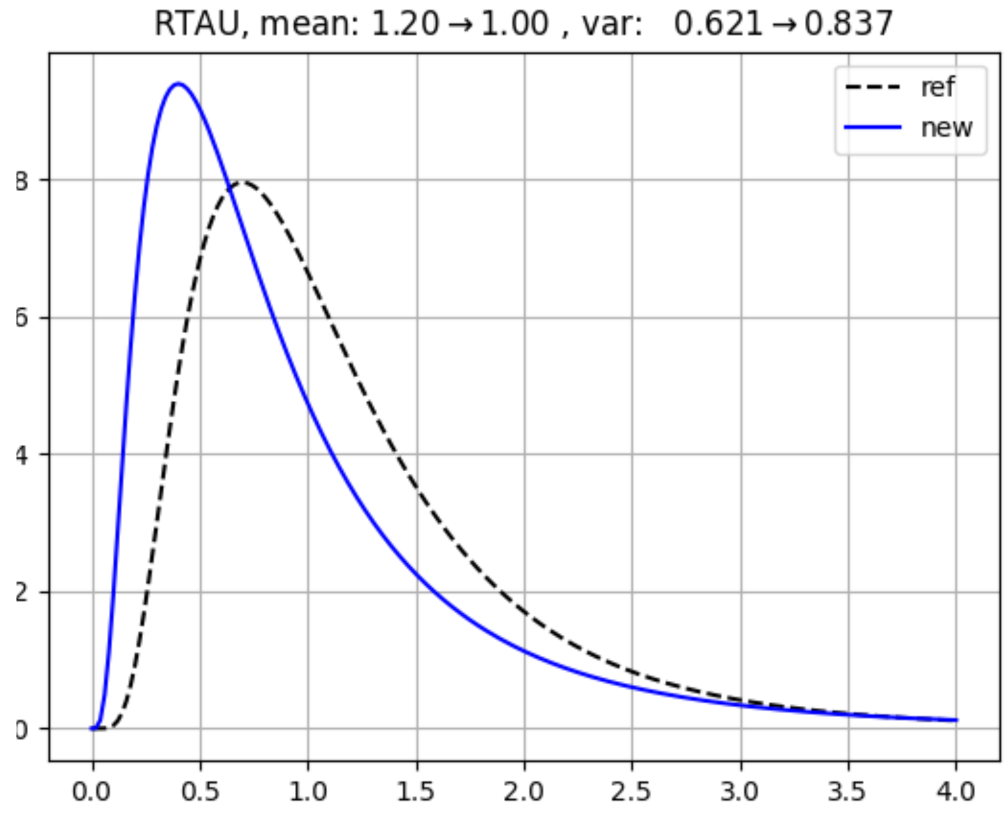
- Work on a revision of SPP completed: Lang et al (2021), https://doi.org/10.1002/qj.3978
- Will refer to original version of SPP as **ref** and to the revised SPP version as **new.**
- Summary of changes
  - probability distributions
  - correlation scale
  - perturbed quantities

Changed pdfs in convection perturbations

entrainment rate

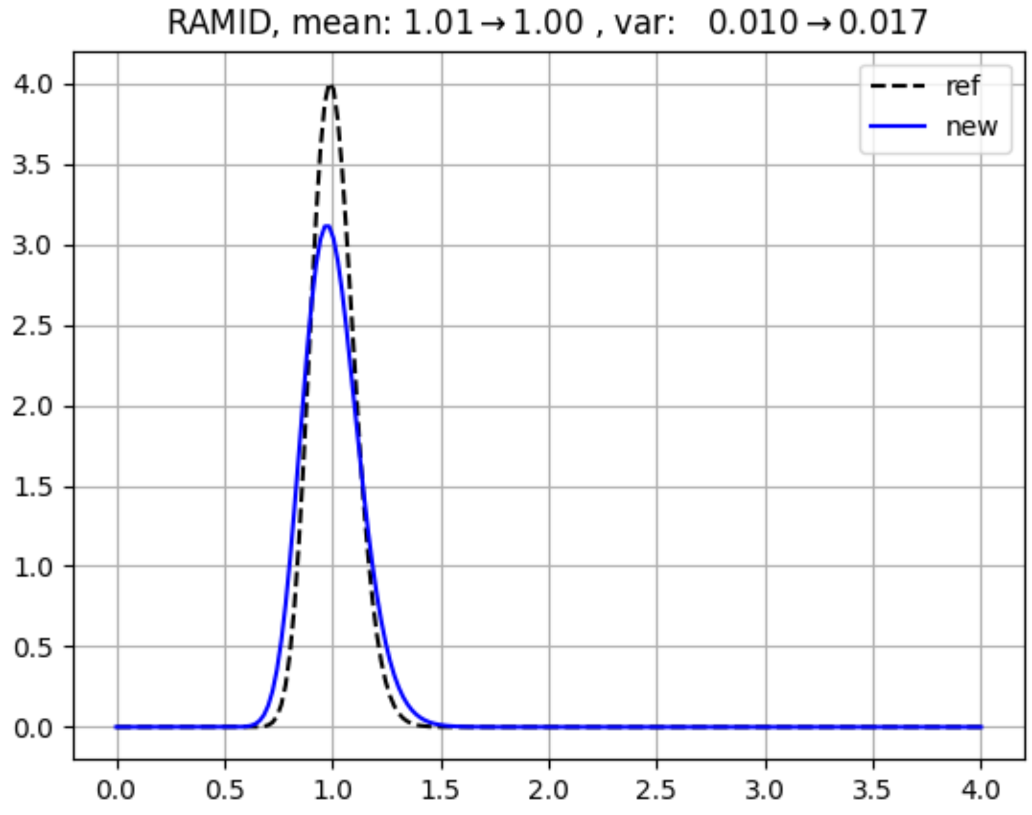


adjustment timescale in CAPE closure

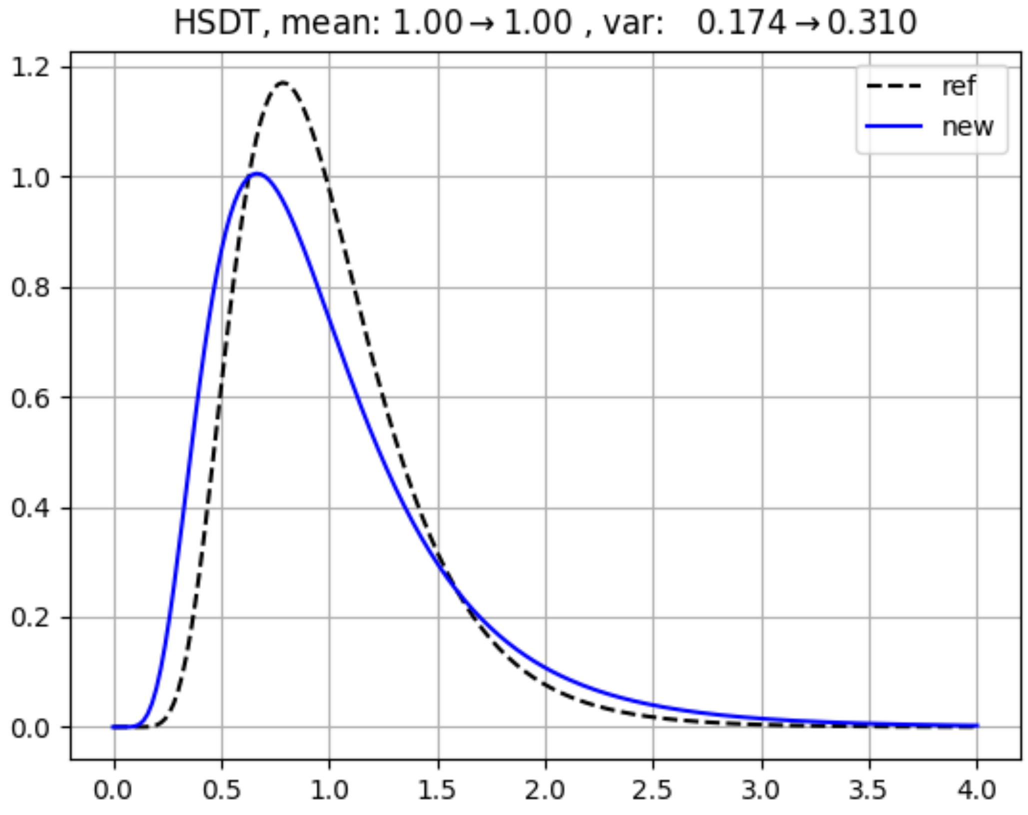


Changed pdfs (continued)

Rel. humidity threshold for onset of stratiform cond.

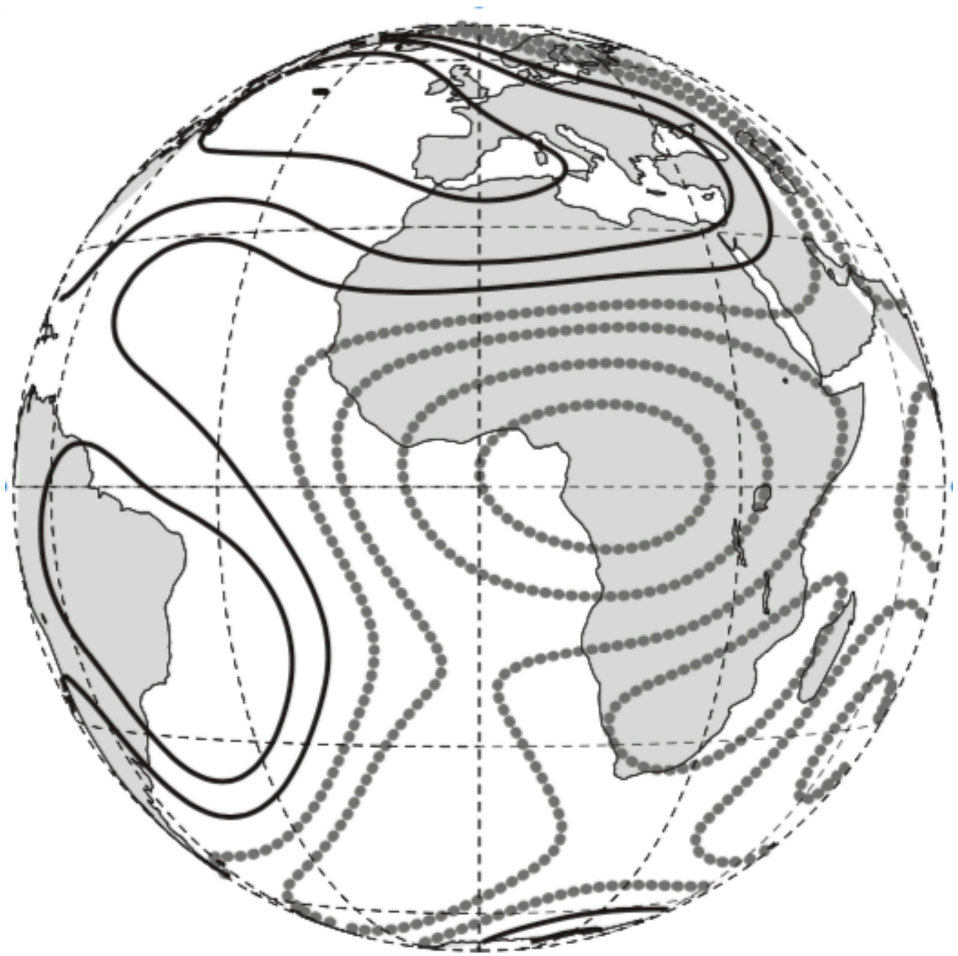


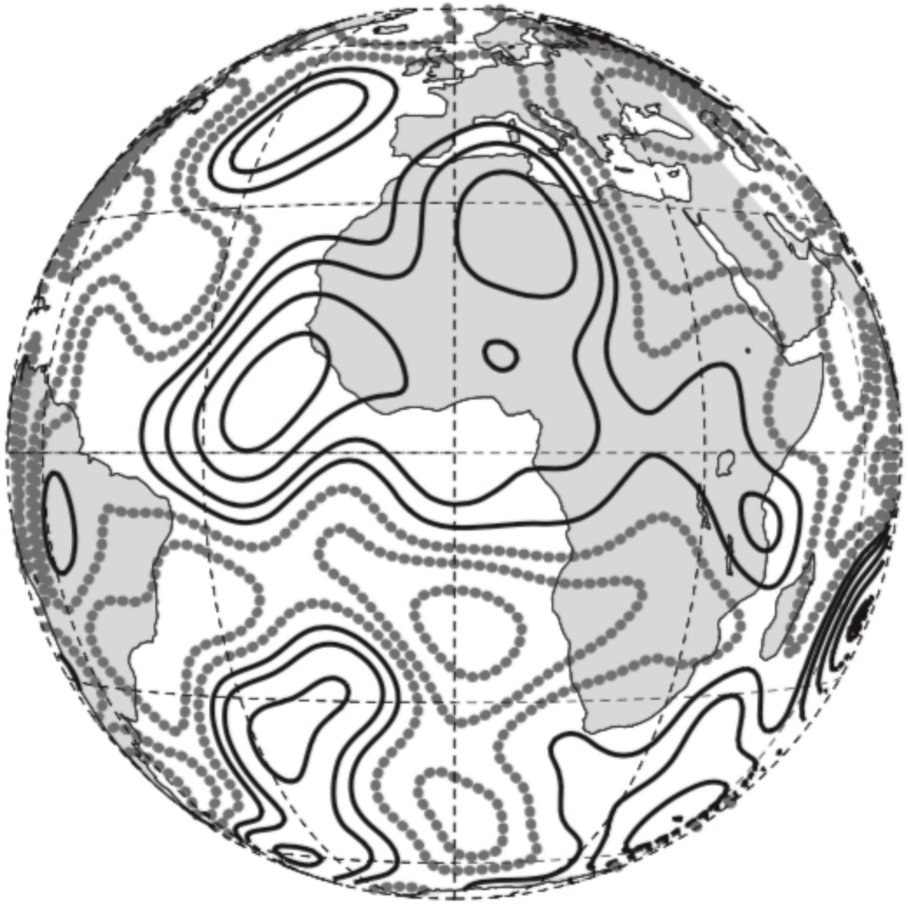
stdev of subgrid orography



Shorter horizontal correlation scale of the random fields

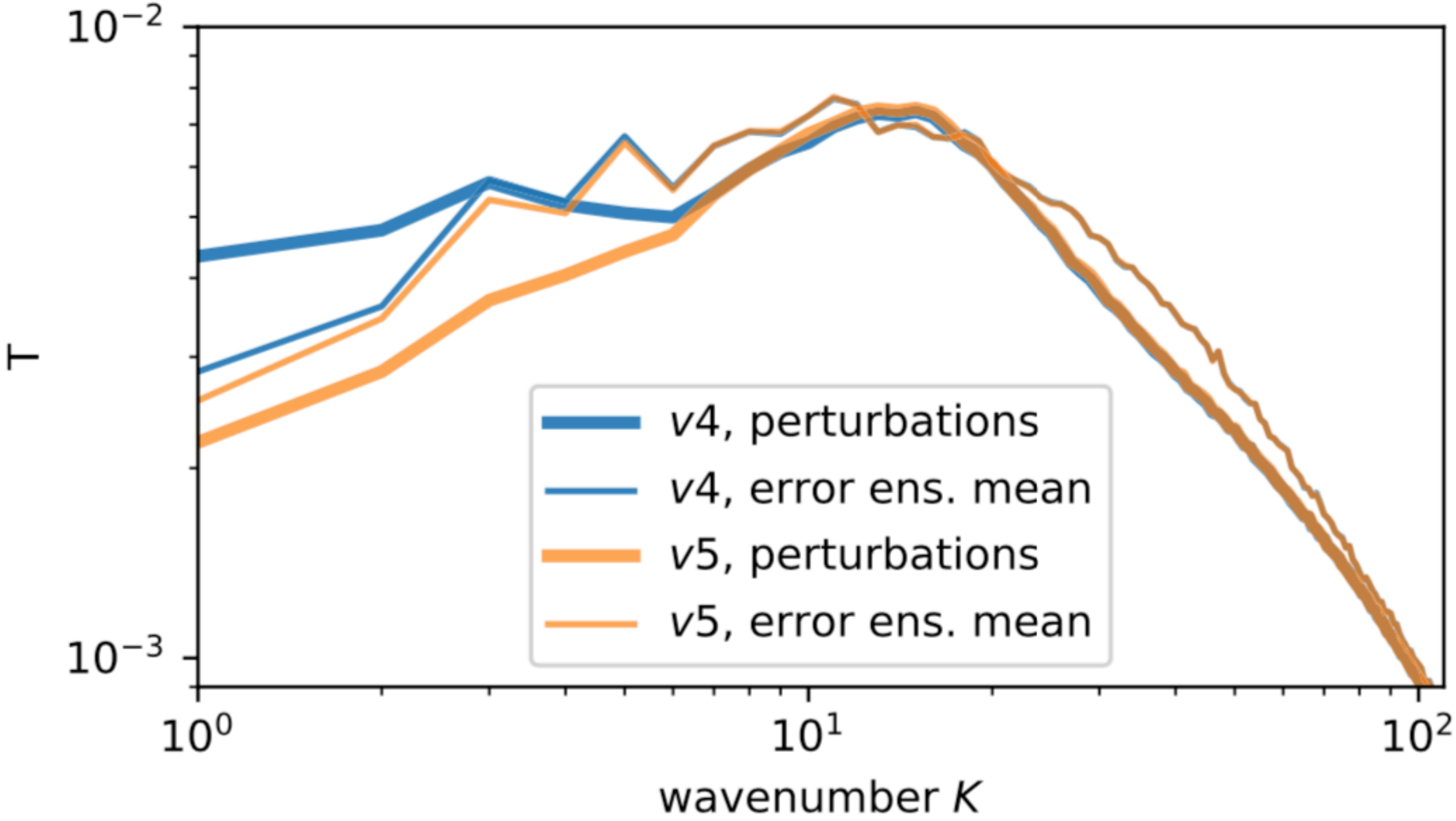
2000 km → 1000 km





Changed correlation scale addresses large-scale overdispersion

500 hPa
temperature
at t=24 h



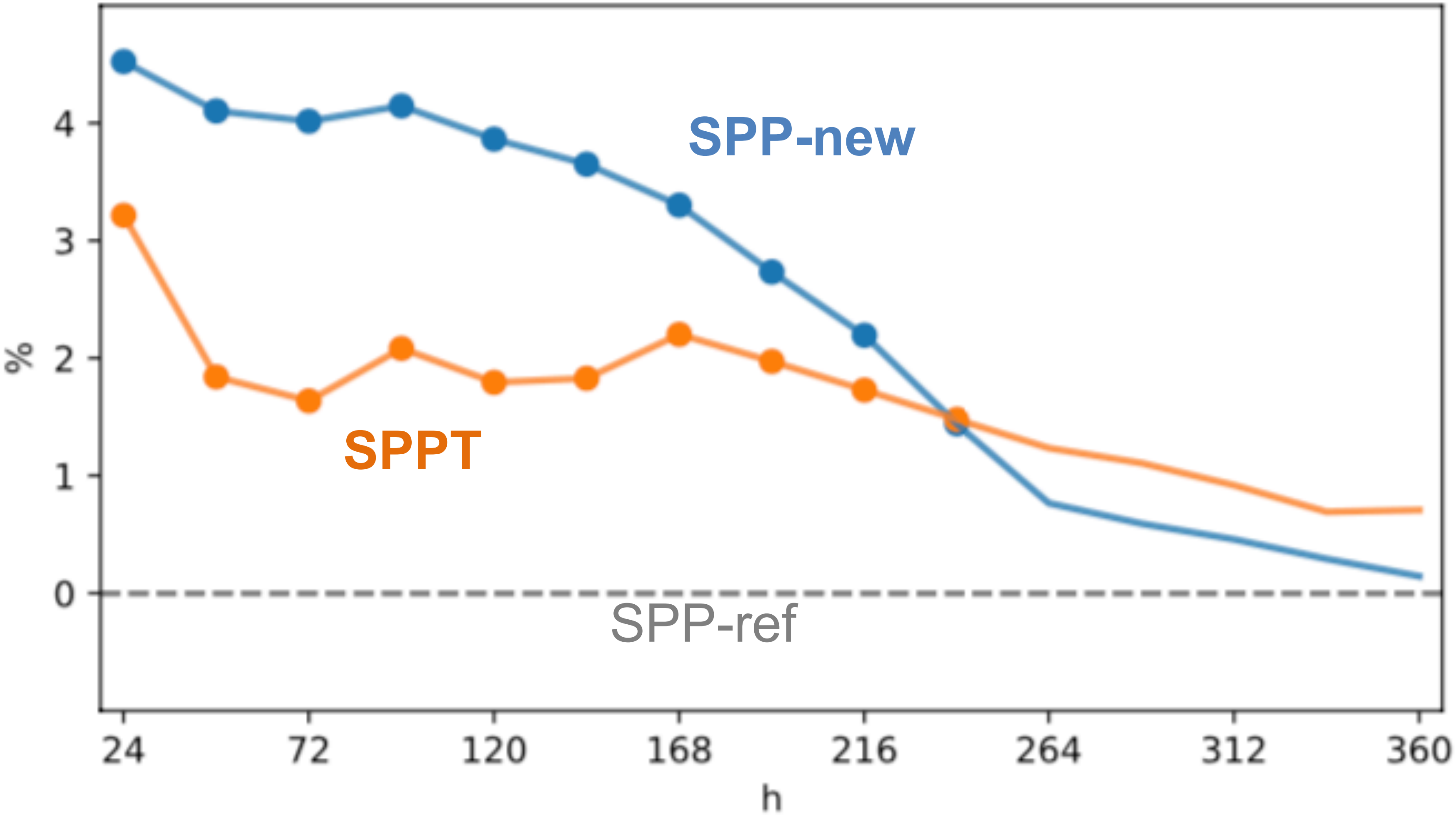
Additional perturbations not present in **ref** version of SPP

- vertical velocity perturbation in cloud scheme to calculate the adiabatic temperature change for saturation adjustment
- rain evaporation rate
- snow sublimation rate
- momentum transport due to shallow convection
- entrainment parameter in the sub- cloud layer
- von Karman constant (to account for uncertainties in quantities that are uncertain and depend on it)

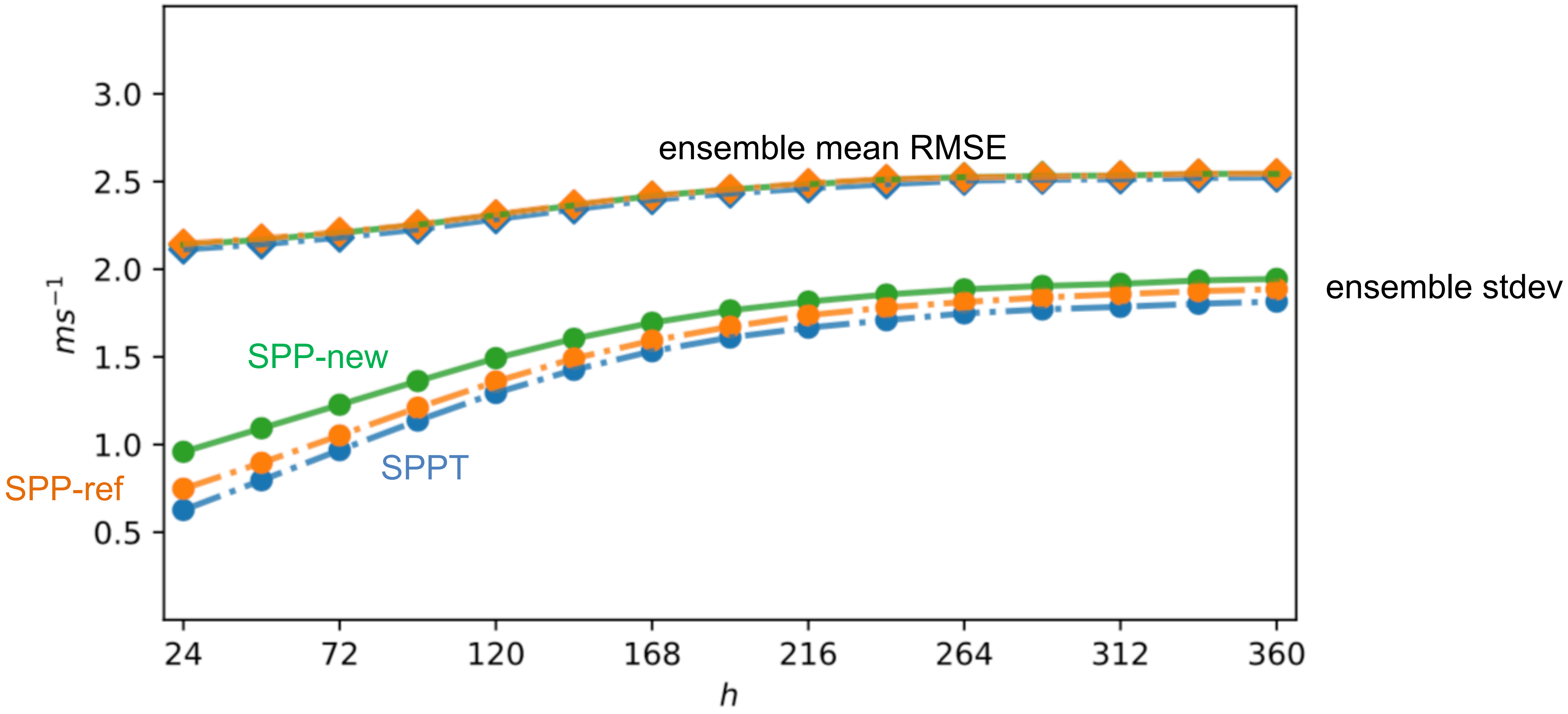
Impact on medium-range ensemble forecasts

- TCo399 (29 km grid spacing), 8 member
- fair CRPS (accounts for small ensemble size, see Ferro et al (2008), Ferro (2014) and Leutbecher (2019), https://doi.org/10.1002/qj.3387)
- one boreal summer and one boreal winter season
- comprehensive verification similar to evaluation of operational upgrades

Z500 ensemble spread increase wrt SPP-ref in N-Hem extra-tropics



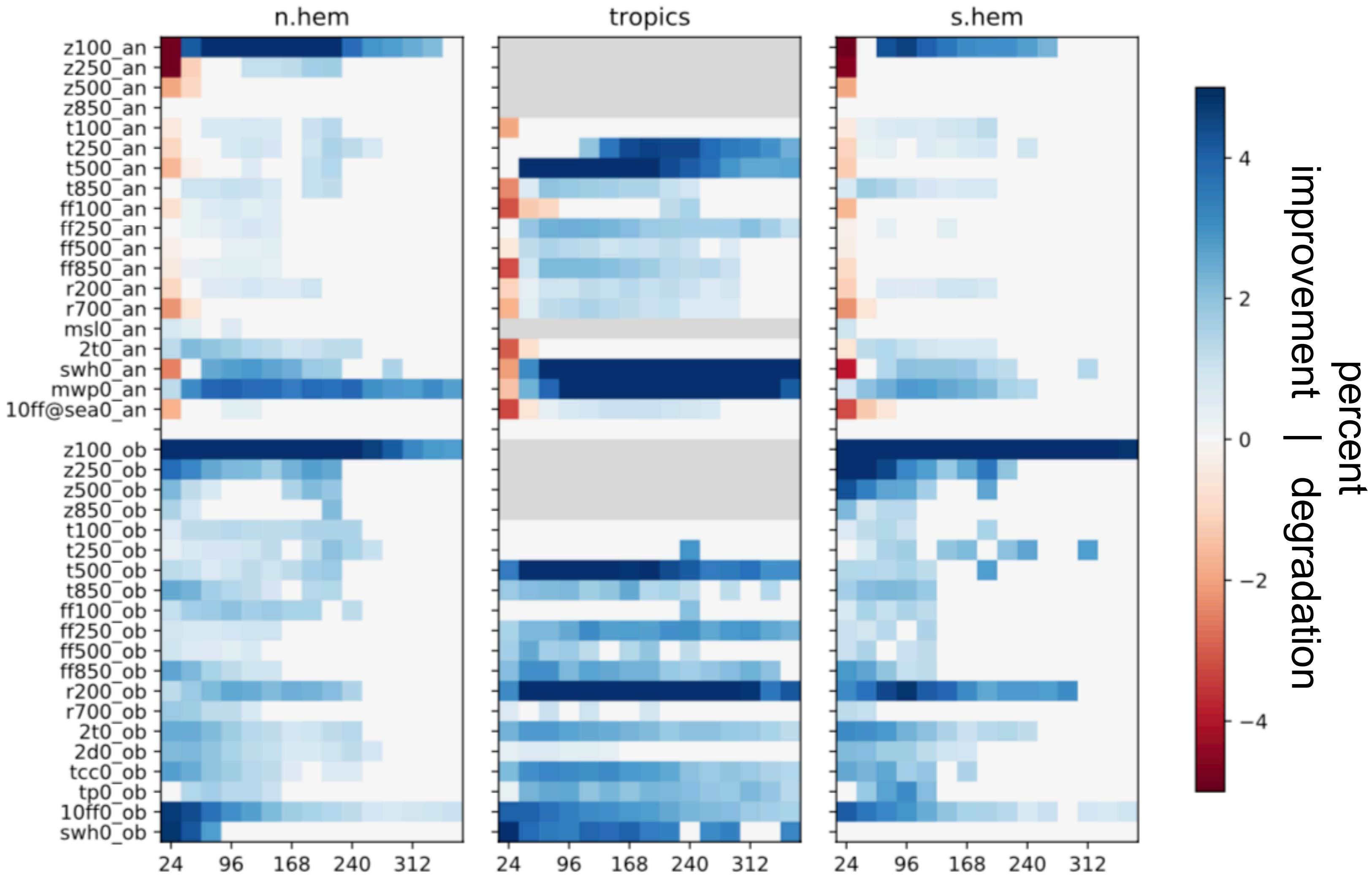
10-metre wind speed ensemble spread and error



SPP-new versus SPP-ref scorecard showing fCRPS changes

verified against analysis

verified against observations



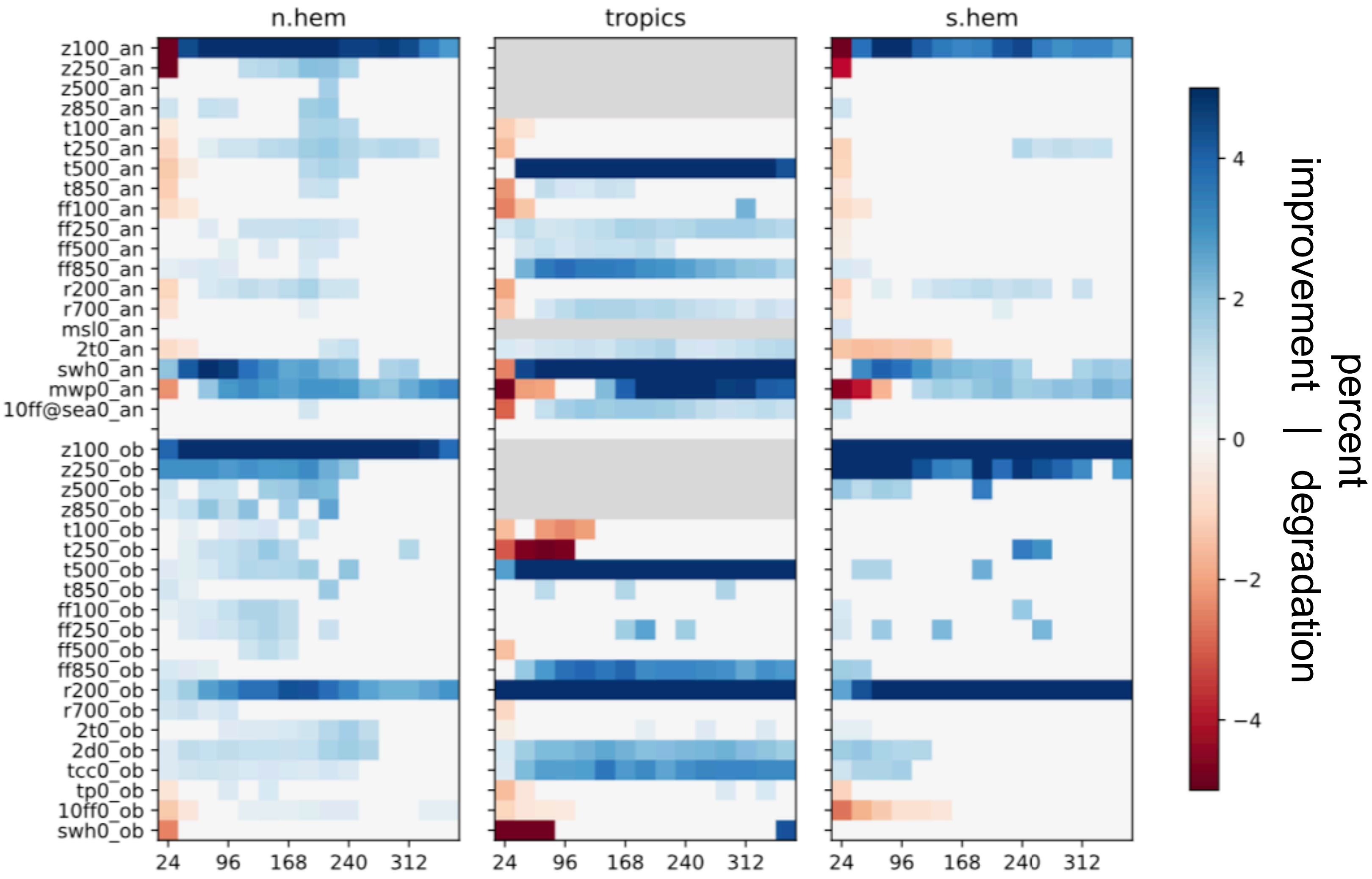
lead time (h)

Coloured: 99.7% sig. level

SPPT versus SPP-ref

verified against analysis

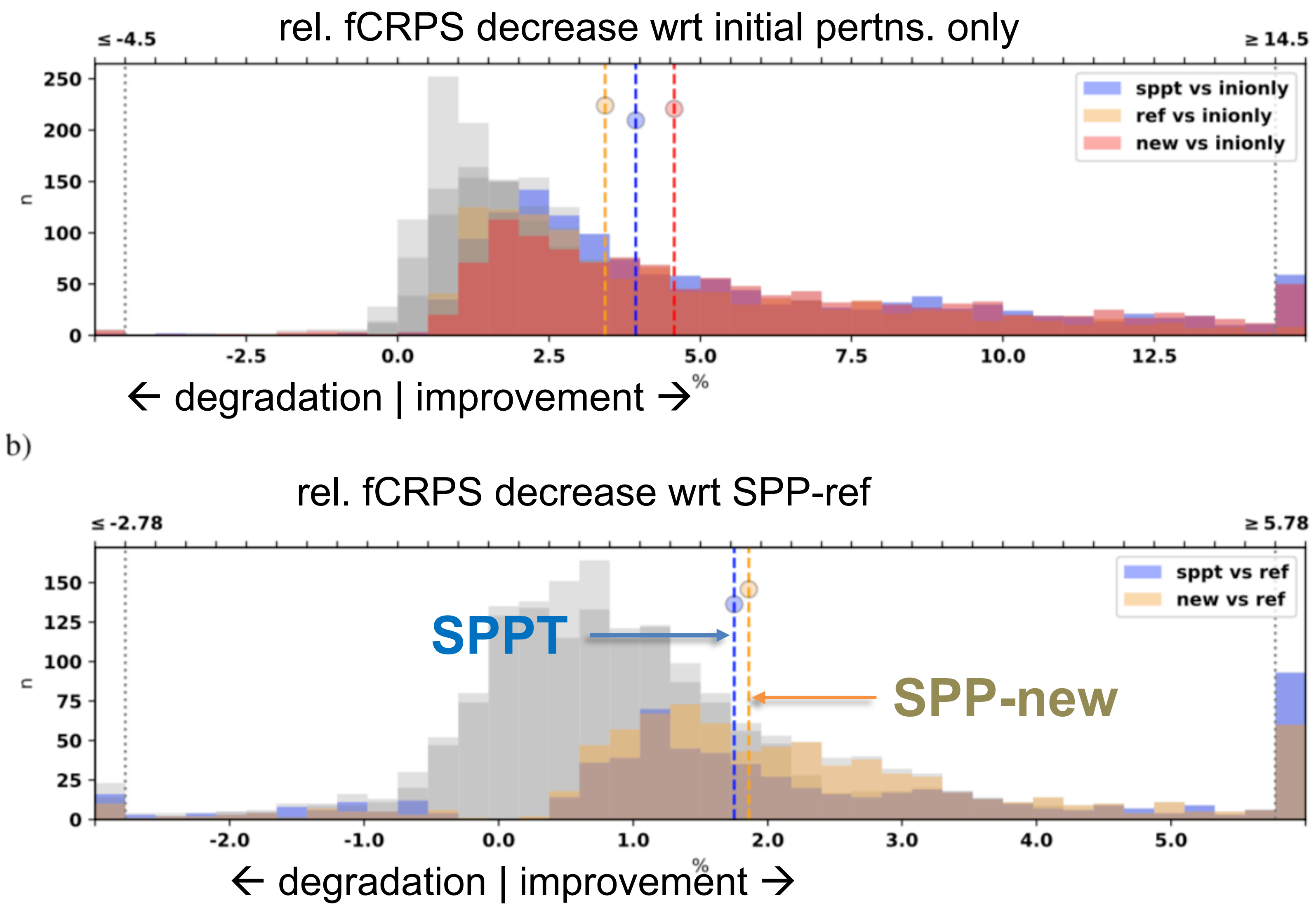
verified against observations



lead time (h)

Coloured: 99.7% sig. level

Histogram of relative fCRPS changes



lead times 24 h ... 360 h
combination of variables and levels evaluated in scorecard
3 regions: N-Hem, S-Hem, tropics

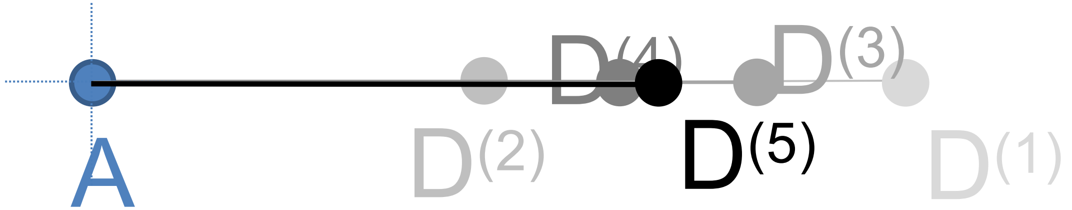
vertical lines: median change

based on 8 members and fair CRPS, boreal summer + boreal winter, 212 start dates, TCo399

colour: stat. significance 99.7%, grey otherwise

STOCHDP:

Stochastically perturbed semi-Lagrangian (SL) departure point (DP) estimates



Diamantakis & Magnusson (2016):

- Explored convergence rate of the iterative DP estimate
- Slowest convergence ←→ most complex flow (strong shear / curvature)
- e.g. Typhoon Neoguri:
  - HRES forecast: initialised: 2014-07-05, 00UTC

Fig. 1c: t+96h, 850hPa windspeeds

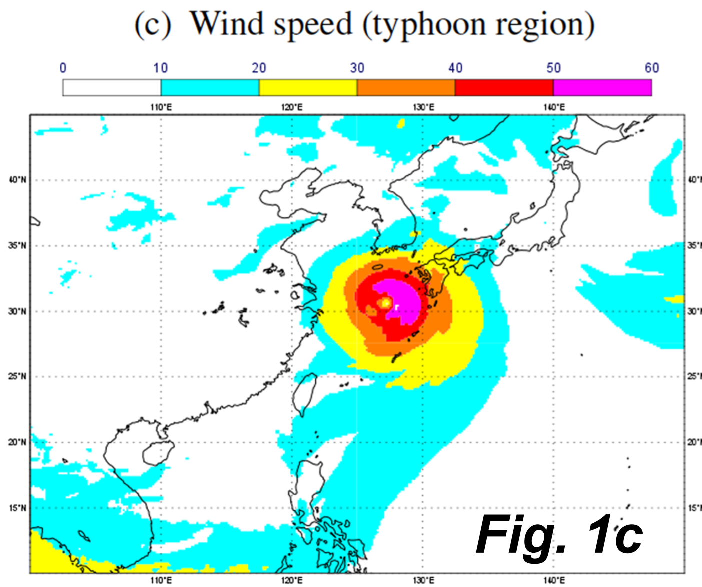
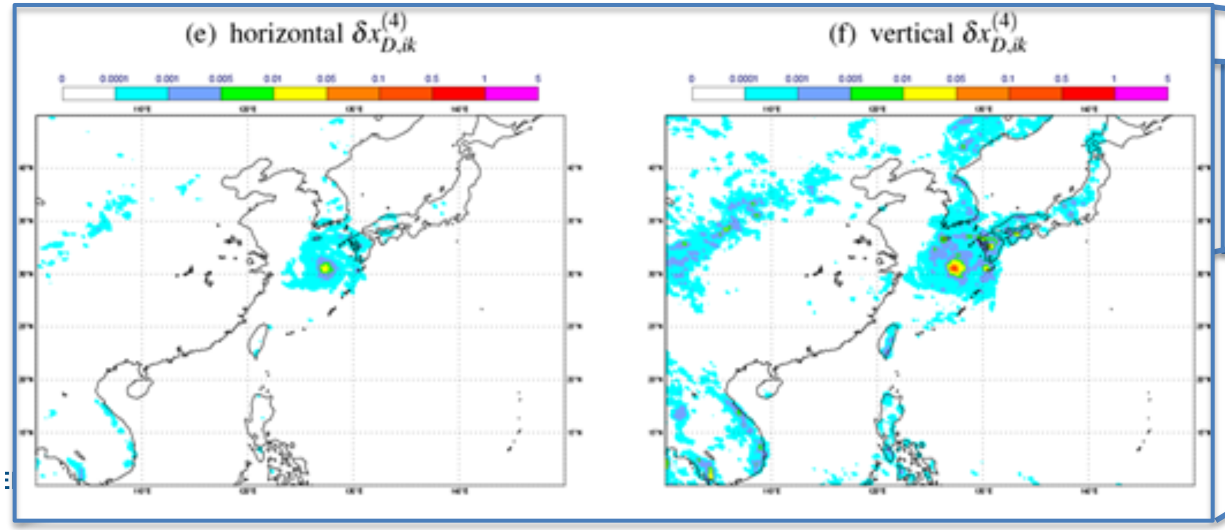
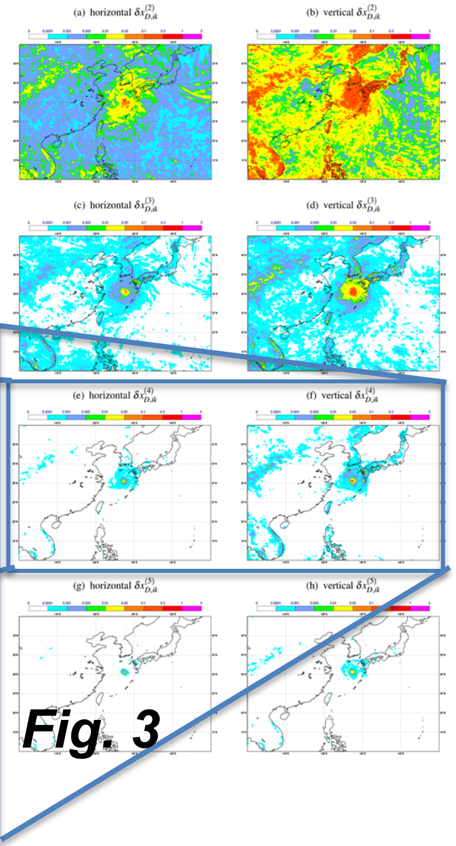


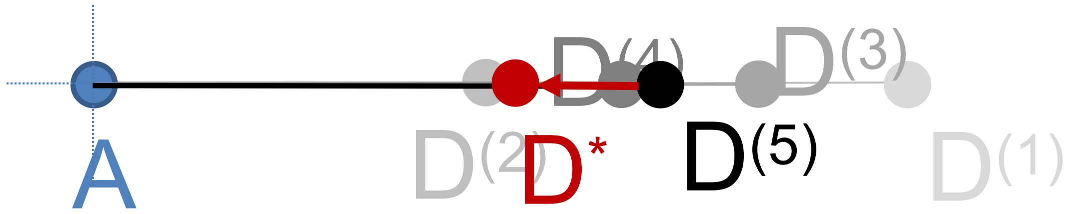
Figure 3: difference in DP estimate between consecutive iterations (scaled)





STOCHDP:

Stochastically perturbed semi-Lagrangian (SL) departure point (DP) estimates



Model uncertainty scheme, “STOCHDP”:

- use the DP estimate convergence rate to attribute MU:

$$D^* = D^{(5)} + r\left(D^{(5)} - D^{(5-i)}\right), i = 1..4$$

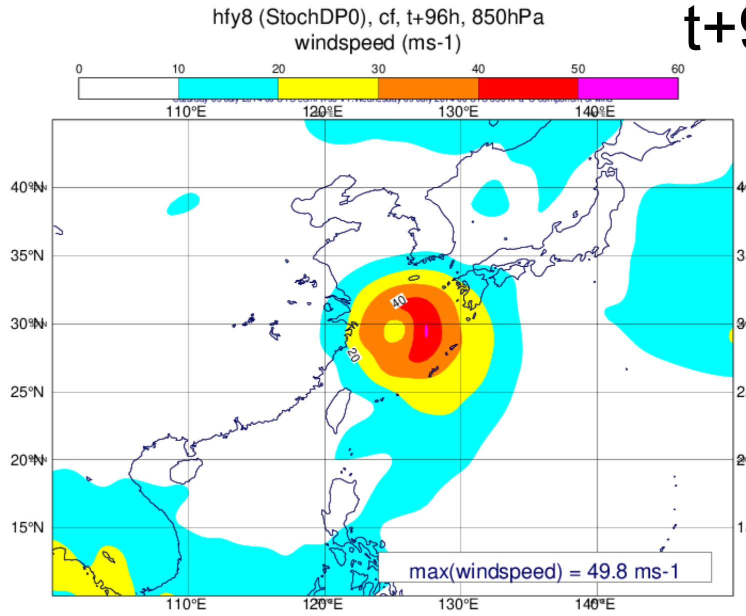
where $D*$ is the perturbed DP and r is a random number

➢ STOCHDP represents MU from SL advective winds

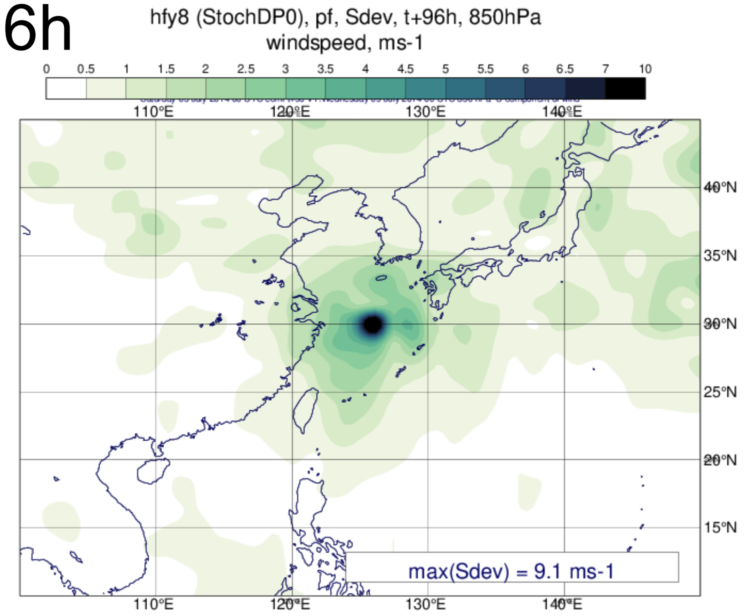
Early results, e.g.:

- Typhoon Neoguri case
- ENS: STOCHDP only
- TCo639L91, dt=720s
- 20+1 members
- Peak ENS stdev develops and tracks with TC

t+96h



Control forecast



Ensemble stdev

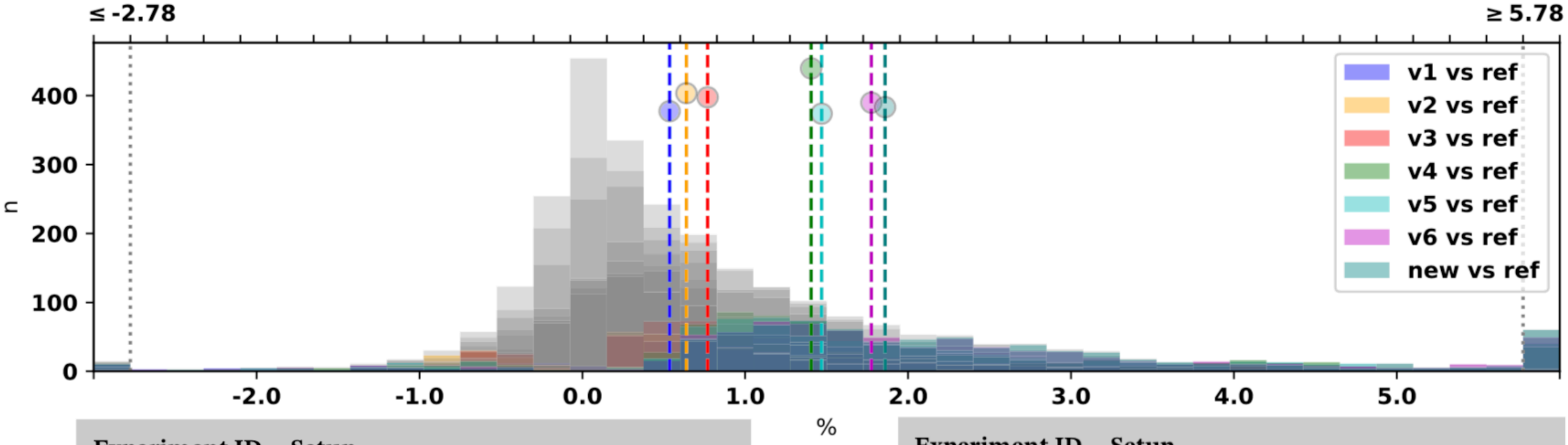
Summary

- Major revision of SPP
  - Represents model uncertainties close to sources, improves physical consistency compared to SPPT, e.g. local conservation properties of energy and moisture
  - new perturbations (19 → 27 variables)
  - changed pdfs (mean and variance)
  - changed correlation scales (2000 km → 1000 km)
  - skill in medium-range now comparable to that obtained with SPPT
  - further testing at all lead times and with revised moist physics planned
  - working towards operational implementation after medium-range horizontal resolution upgrade
- Development of model uncertainty representation in semi-Lagrangian advection (STOCHDP) on-going

Extra slides

- incremental improvements of SPP
- impact on model climate

Improvements in intermediate steps of revision (cumulative)



Experiment ID	Setup
inionly	No model uncertainty representation—initial perturbations only
sppt	SPPT, as currently operational at ECMWF
v0≡ref	Reference SPP configuration
v1	Perturb RAINEVAP, SNOWSUBLIM, QSATVERVEL, CUDUS, CUDVS
v2	Set scheme to "mean" for all parameters
v3	Correlate CUDU, CUDV and CUDUS, CUDVS respectively

Experiment ID	Setup
v4	Increased amplitude
v5	Reduced decorrelation length-scale from 2,000 to 1,000 km
v6	Revised perturbations for turbulent diffusion CFM_OC, CFM_LA, RKAP
v7≡new	Perturb ENTSTPC1

Rel. change in RMS error of seasonal mean relative to unperturbed model