Representing model uncertainty for climate forecasts

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Outline

1. Atmospheric stochastic physics and model bias in the coupled ECMWF model
2. Impact of atmospheric stochastic physics on climate forecast quality
3. Non-conservation of humidity with SPPT
4. Model uncertainty of the land surface

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Seasonal forecast experiments:

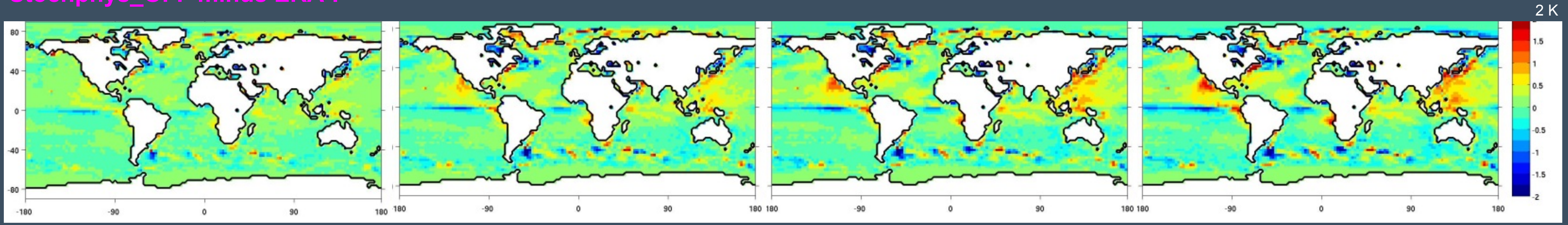
- Stochphys_ON = System 4 CY36R4 T255L91 NEMO1° 7-month hindcasts from 1981-2010 51 ensemble members (Nov, May, Aug), SPPT and SPBS in atmosphere
- Stochphys_OFF: as above but without SPPT and SPBS

Monthly forecast experiments:

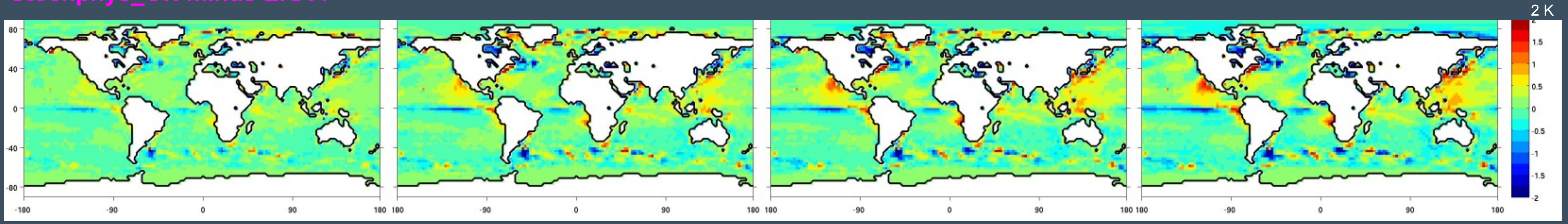
- CY40R1 T399/T255L91 NEMO1° 32-day hindcasts from 1989-2008 11 ensemble members 4 start dates per year (Nov, Feb, May, Aug), SPPT and SPBS ON/OFF in atmosphere

Systematic errors: SST during the first forecast month
(initialised 1st August 1989-2008)

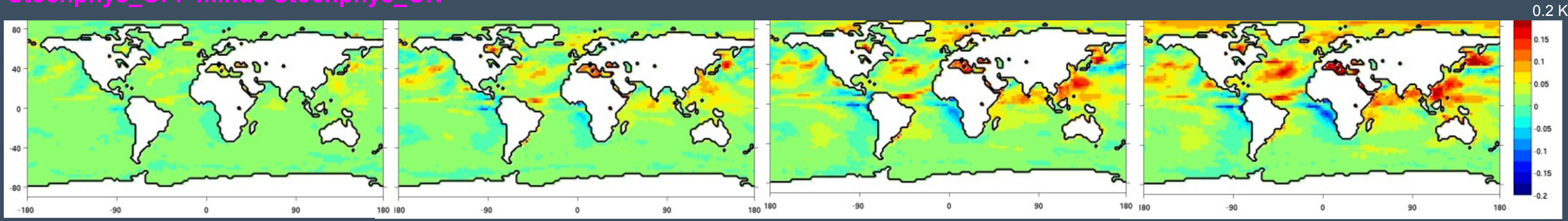
Stochphys_OFF minus ERA-I



Stochphys_ON minus ERA-I

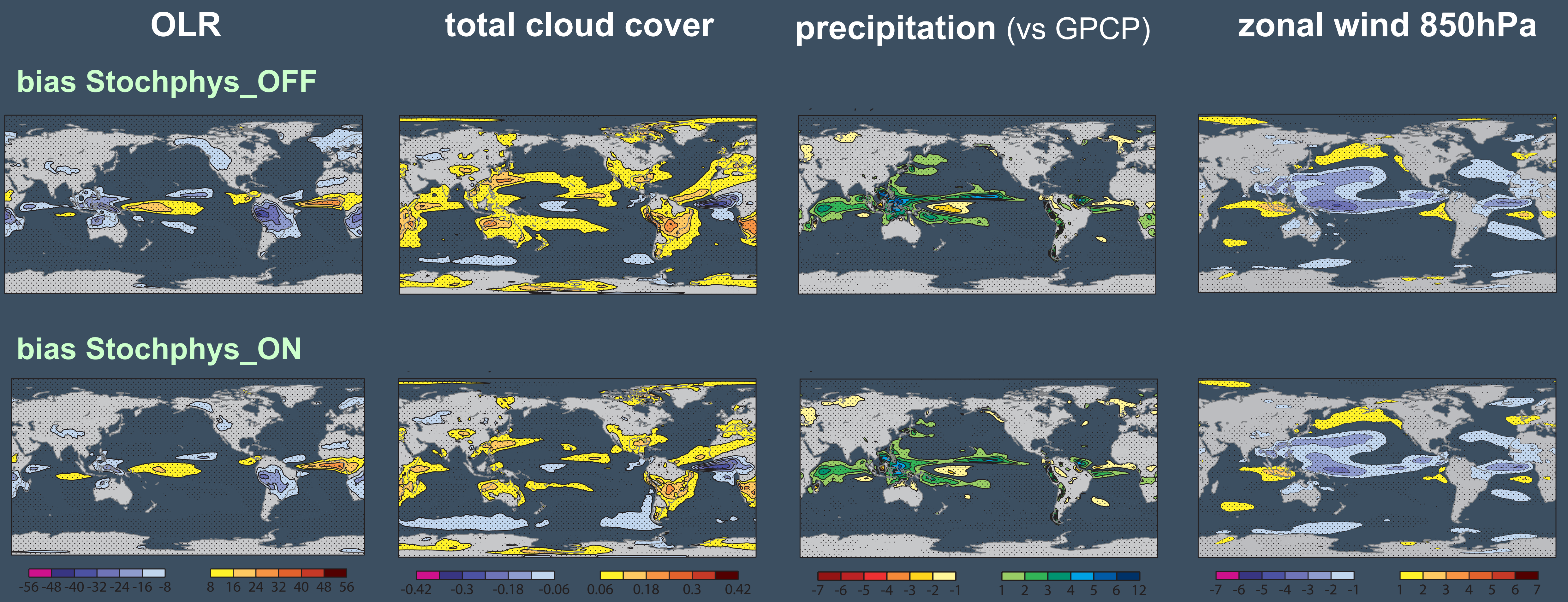


Stochphys_OFF minus Stochphys_ON



week 1 **week 2** **week 3** **week 4**

Systematic biases in seasonal forecasts



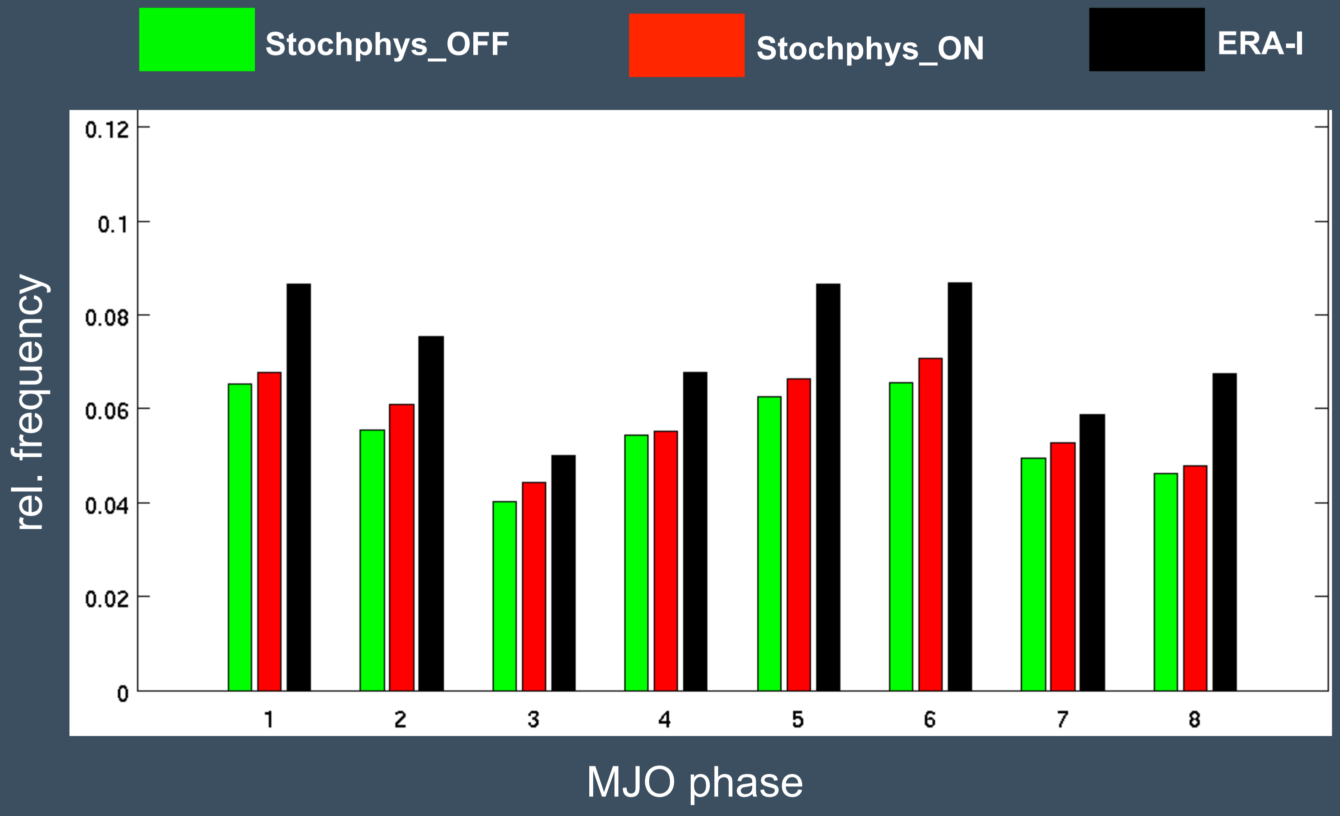
- Reduction of overly active tropical convection
- Reduced precipitation and easterly wind biases over the tropical West Pacific

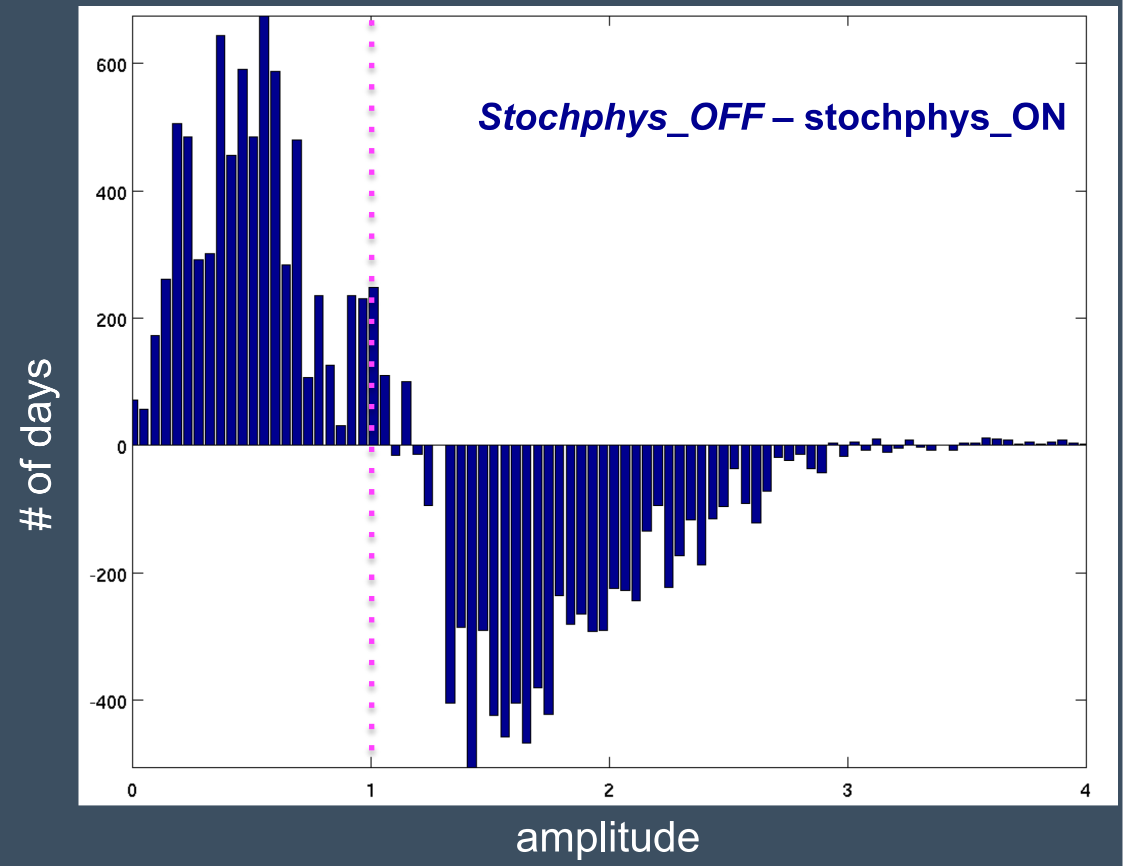
Weisheimer et al. (Proc. Roy. Soc. A, 2014)

Cliimatology of the Madden Julian Oscillation (seasonal forecasts)

System 4 (Stochphys_ON) shows increased frequencies of MJO events

- in all phases of the MJO
- for strong MJO events





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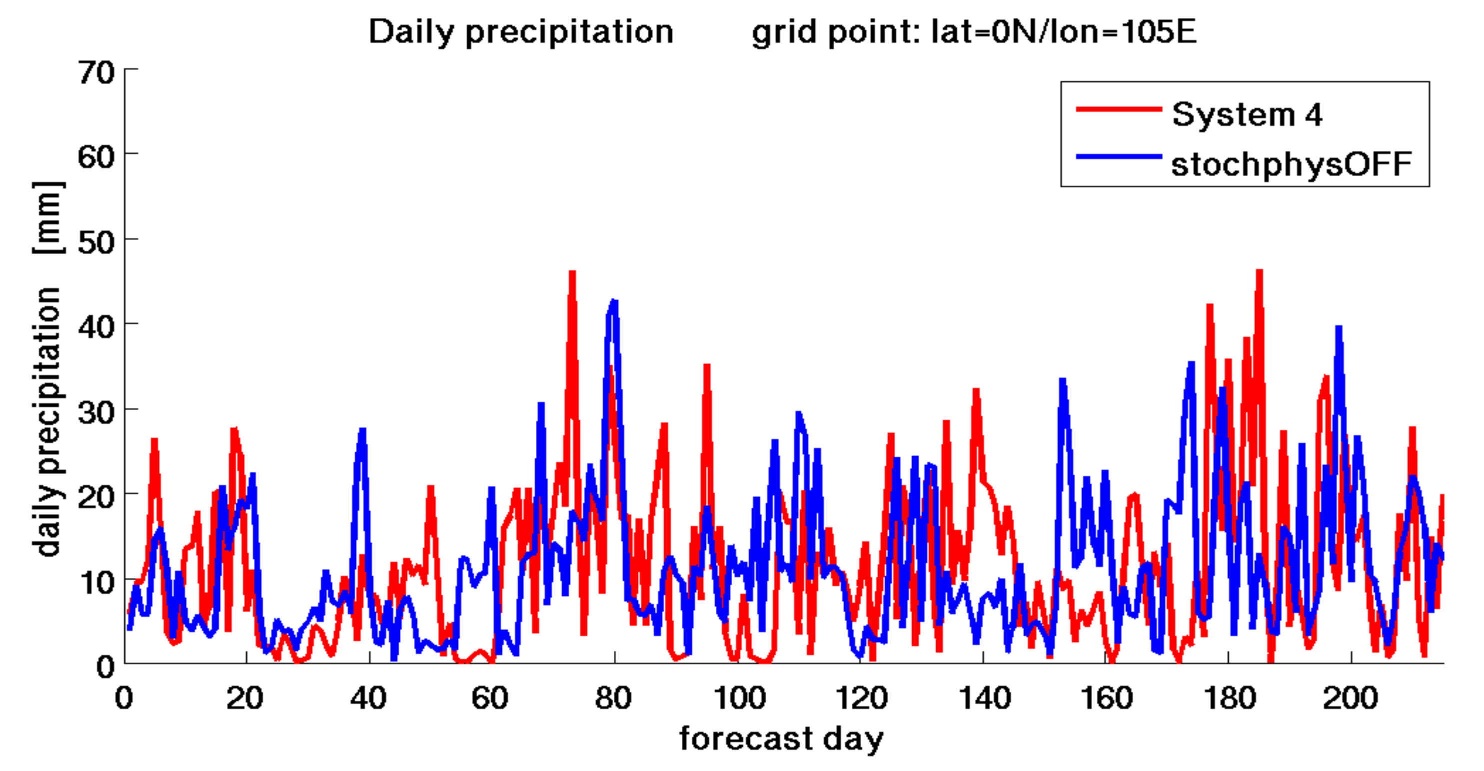

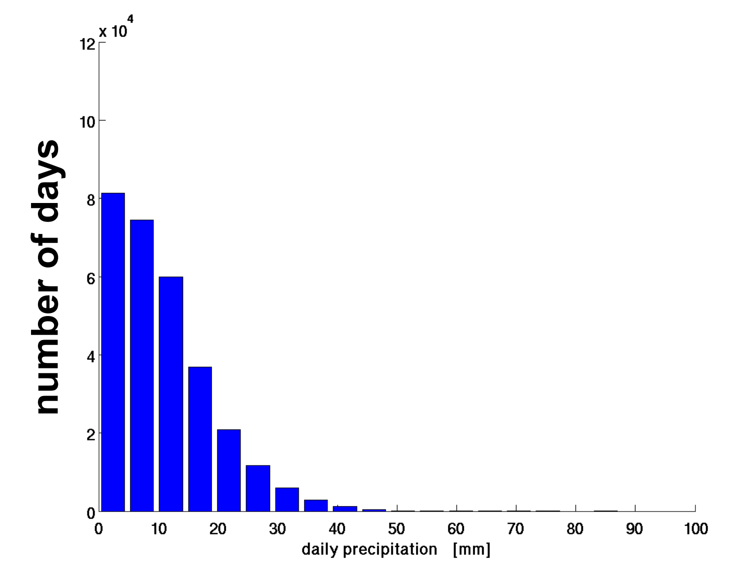

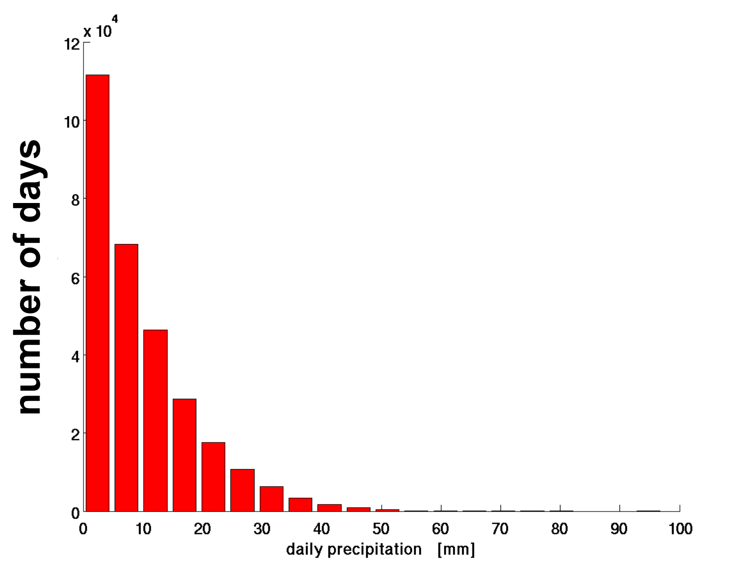

Example: grid point near Singapore

daily precipitation

System 4 has

- reduced mean of daily precip
- increased variance of daily precip
- increase in number of nearly dry days

See also Peter Watson's poster:

Does stochastic physics improve tropical variability in atmospheric models?

Peter Watson[1], Antje Weisheimer[1,2], Tim Palmer[1]

1. Atmospheric, Oceanic and Planetary Physics, Oxford University 2. ECMWF

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1. Introduction

Low resolution atmospheric models generally have less tropical variability on time scales of several days than is observed (e.g. [1]). Stochastic physics (SP) may reduce this bias by increasing the variability in the simulated tropical convection. SP has already been shown to improve NWP skill and reduce some biases in the mean state [2,3]. Here we quantify the impact of SP on tropical variability in the ECMWF seasonal forecasting system (System 4). We also quantify the impact on simulating tropical precipitation extremes, which have large societal impacts [2].

2. Data

- We use seasonal hindcasts of daily-mean precipitation from System 4 and compare these with equivalent hindcasts with the SP schemes deactivated (DET).
- These begin on May 1 and Nov 1 of each year between 1998–2010 and we use hindcast months 2-7.
- 10 ensemble members are used so that sampling variability is small.
- System 4 uses two SP schemes: the Stochastically Perturbed Parametrization Tendencies Scheme (SPPT) and the Spectral Stochastic Backscatter Scheme (SPBS) [2]. Comparing with hindcasts with just one of SPPT or SPBS activated indicates that most of the effects of SP are due to SPPT (not shown).

We also compare the model output with the observational GPCP 1DD and TRMM 3B42 V7 datasets. Note that these show considerable differences in the estimated precipitation amounts in individual heavy rainfall events, suggesting there is considerable uncertainty in the true variability, so comparisons with the model data should be made cautiously.

3. Impact on the standard deviation of precipitation

Why do we see a systematic impact on the model climate with SPPT?

- Product of two random variables?
  - Product distribution depends crucially on input distributions (tendencies)
  - Product of two normally distributed variables with $\mu=0$ is “well behaved” distributed (e.g. symmetric)
  - This is not generally the case, especially not for $\mu \neq 0$
- Nonlinear thresholds (e.g. trigger for convection)?
- Asymmetric nature of q and precipitation?
- Tuning of the model for deterministic formulation versus stochastic model?
- Tapering of the boundary layer and related inconsistencies?

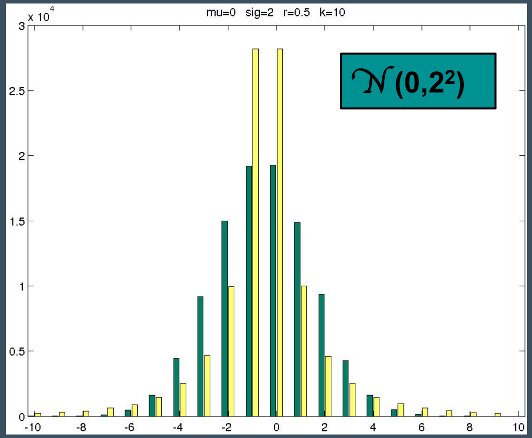
Multiplicative noise

$X \sim \mathcal{N}(\mu,\sigma^2)$ … initial distribution of X

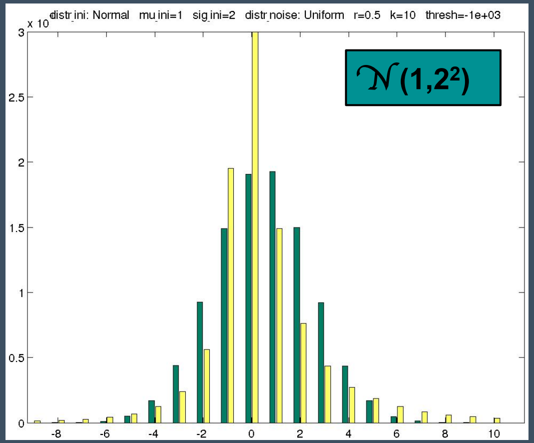
$r \sim \mathcal{U}(0.5,1,5)$ … distribution of random noise r

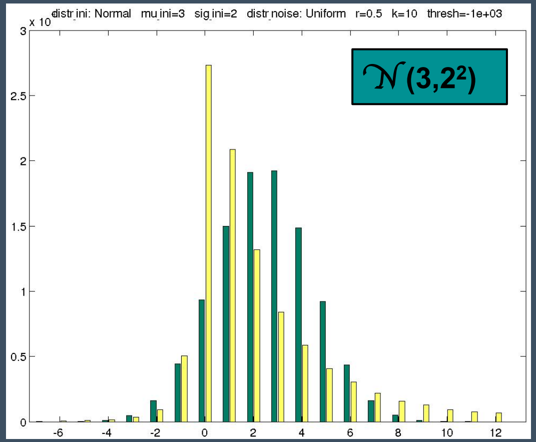
product distribution

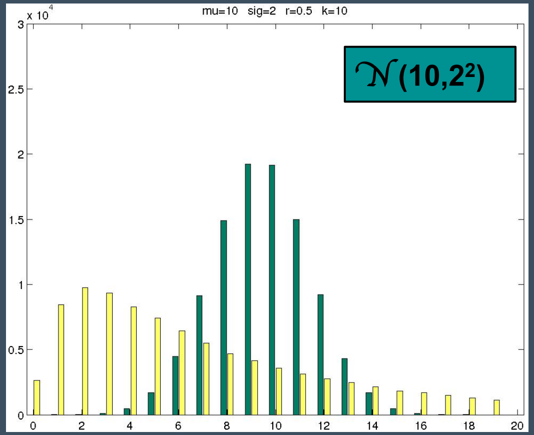
$X * r \sim ?(\mu,\sigma^2)$



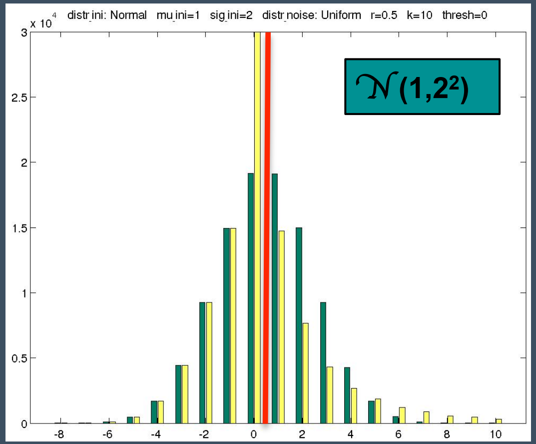
effect of mean ≠ 0

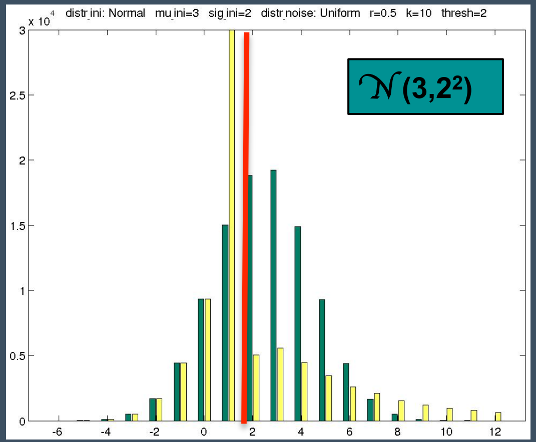


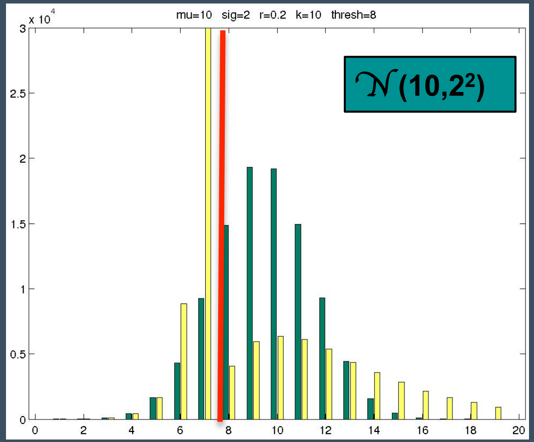




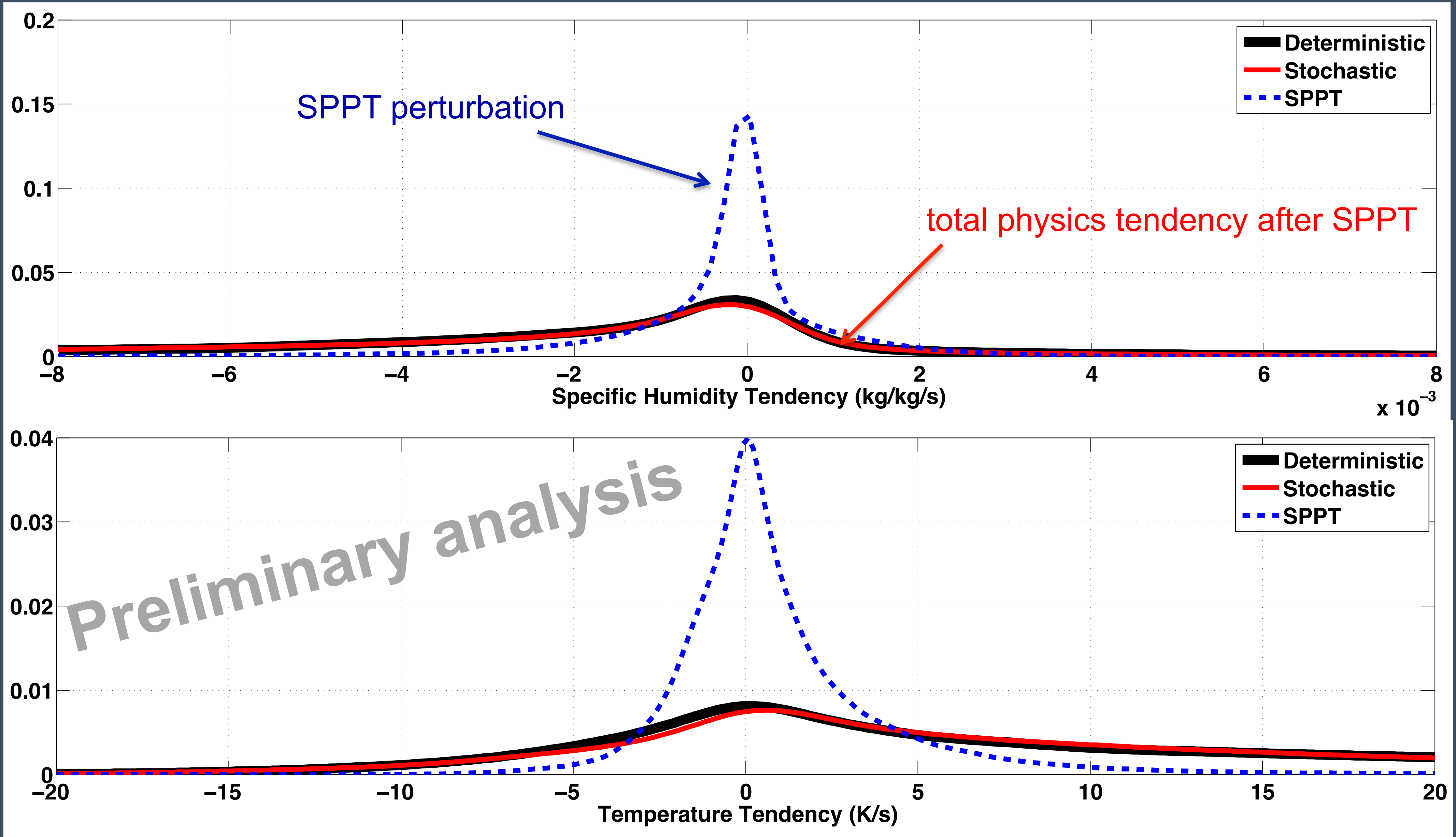
effect of threshold







Distribution of humidity and temperature tendencies in free troposphere over the tropical West Pacific



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- Nonlinear thresholds (e.g. trigger for convection)?
- Asymmetric nature of q and precipitation?
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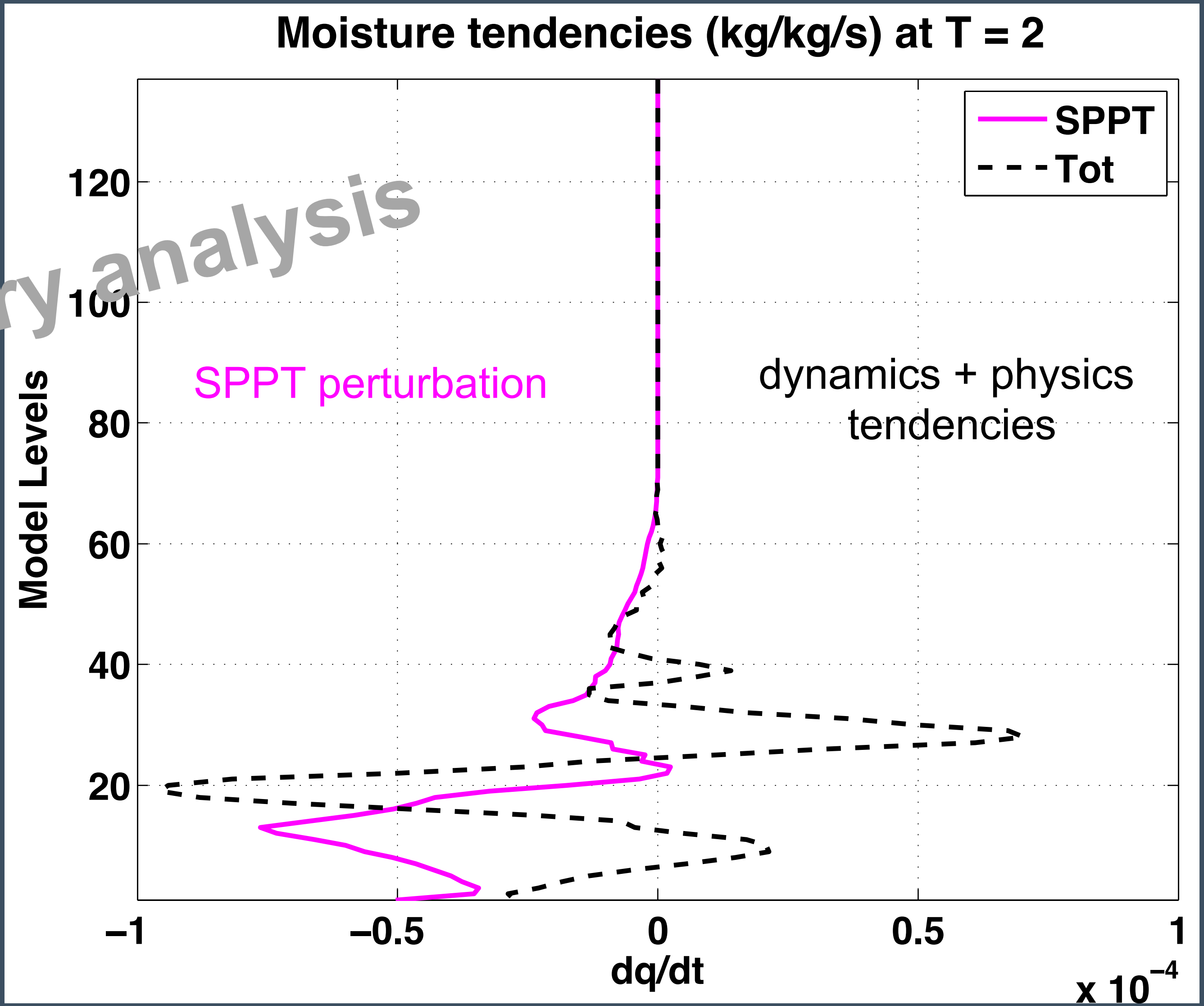
- Tapering of the boundary layer and related inconsistencies?

Global mean humidity tendencies without BL tapering



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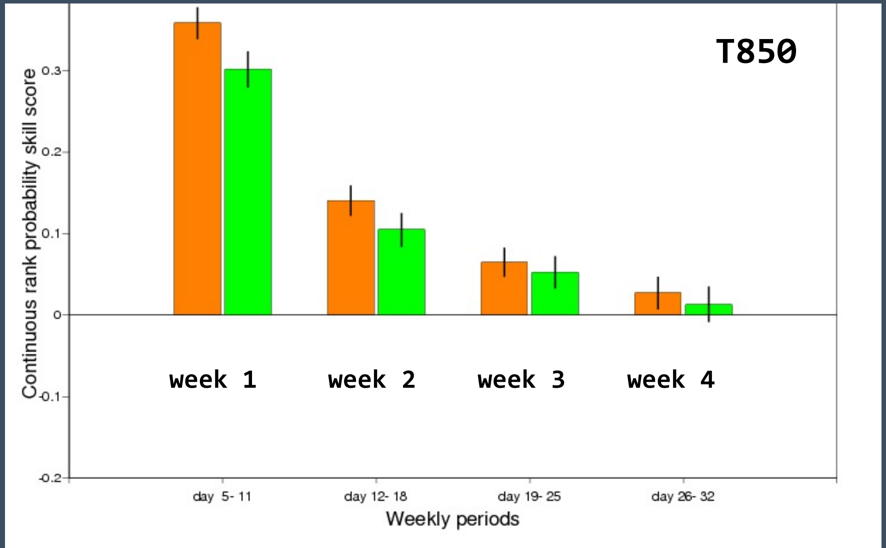
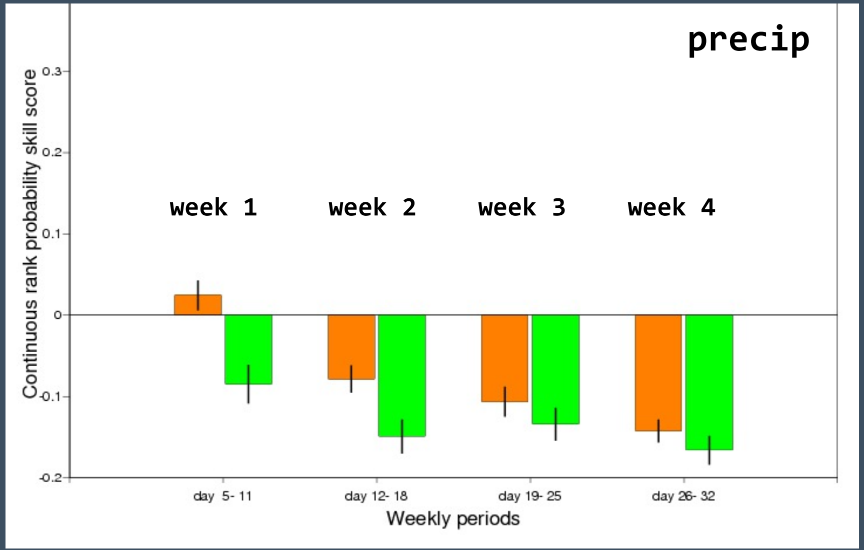
Impact on monthly forecast skill

CRPSS in the Tropics

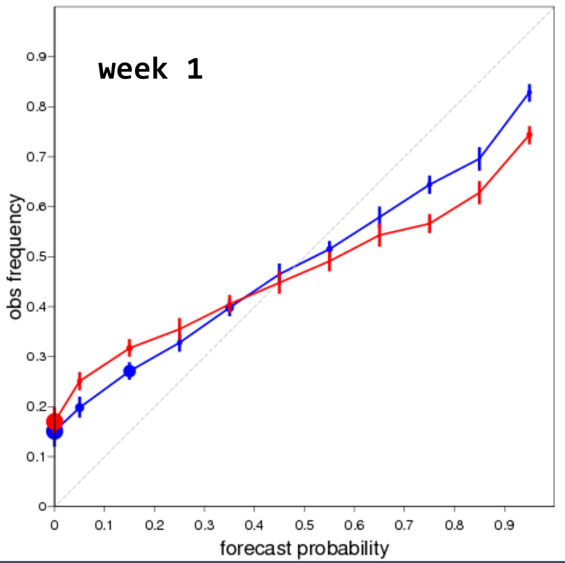


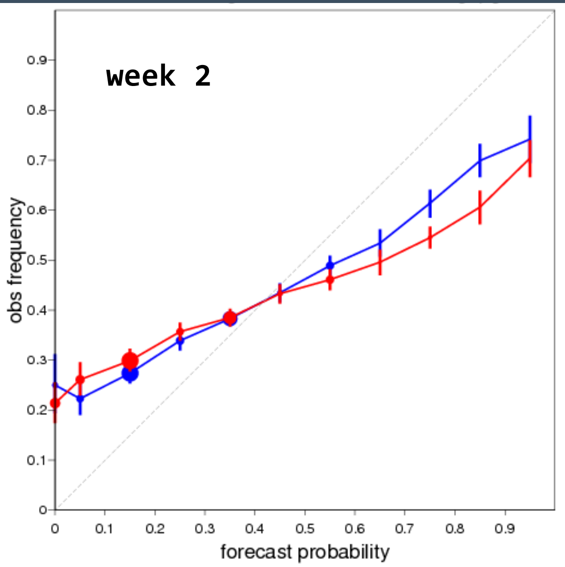


Stochphys_ON

Stochphys_OFF

Reliability of precip in the Tropics (upper tercile)



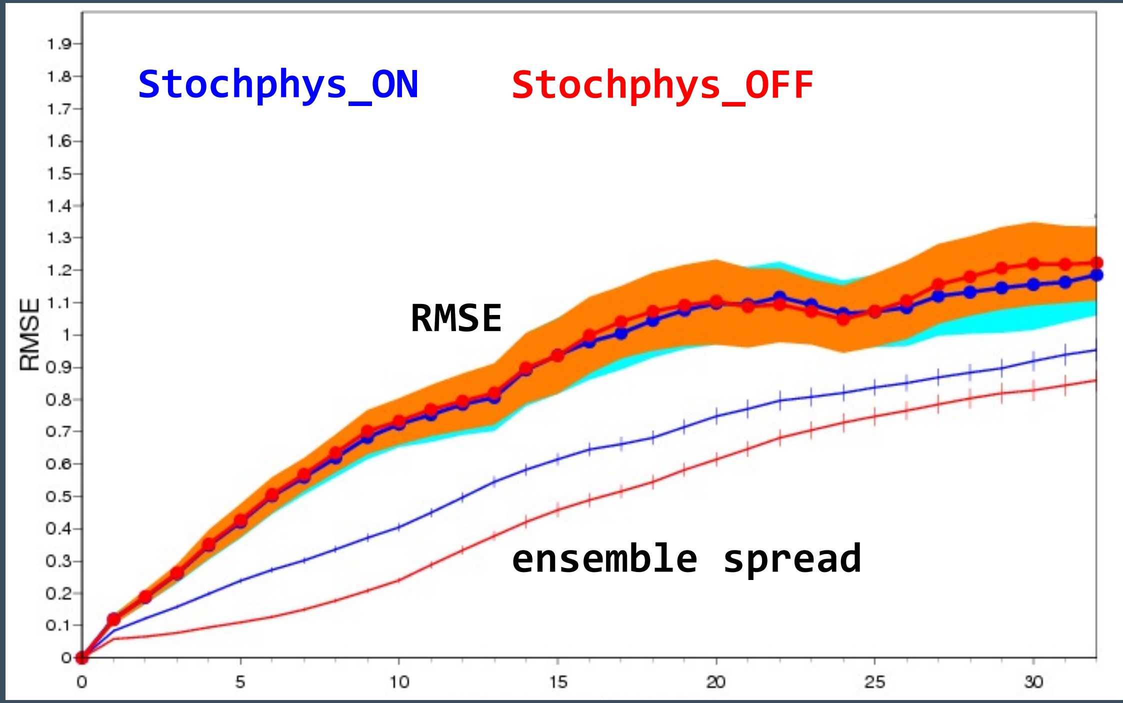


Stochphys_ON

Stochphys_OFF

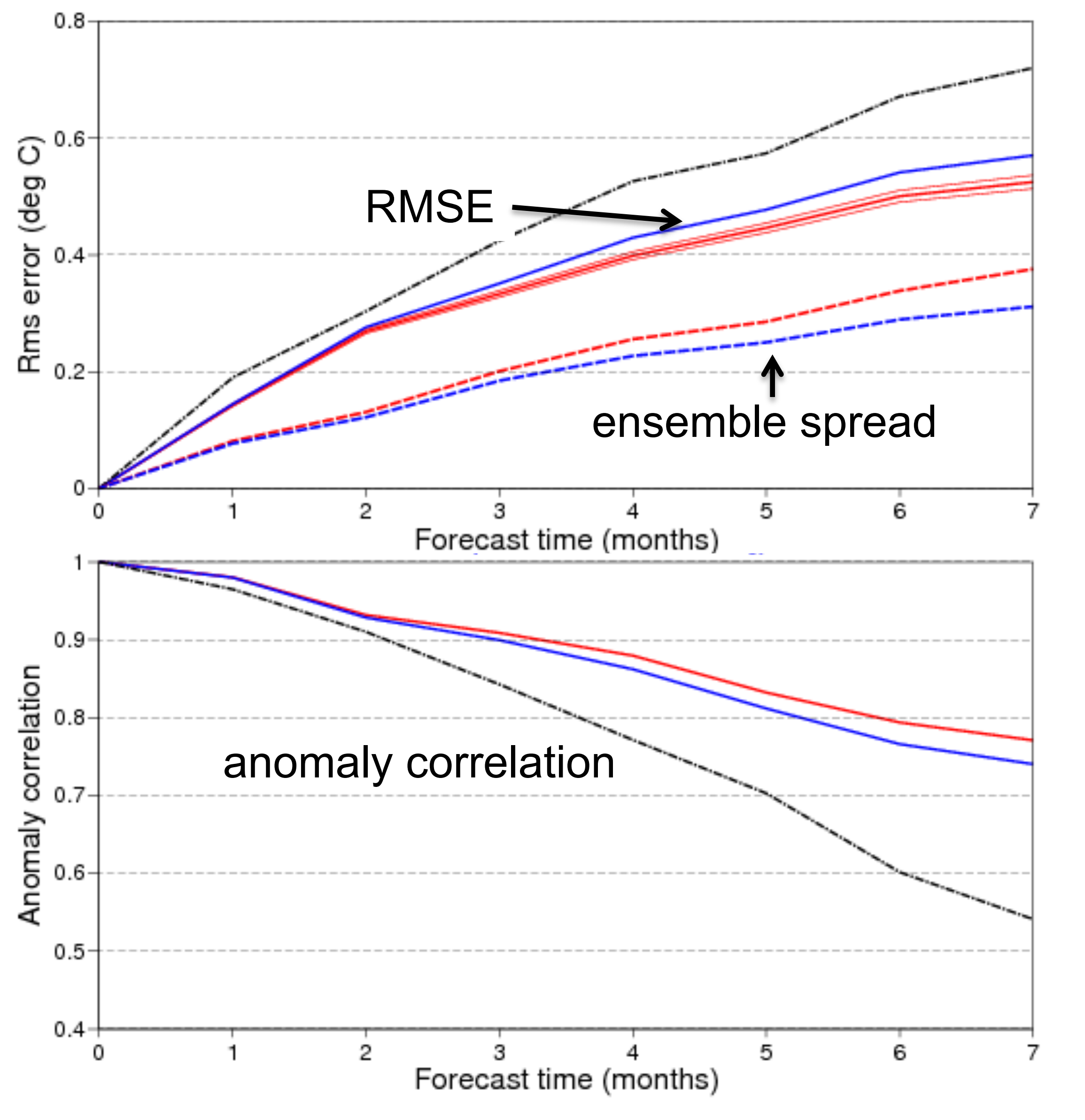
Impact on forecast skill

bivariate MJO index



forecast day

Niño4 SSTs



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Climate SPHINX – Stochastic Physics High Resolution Experiments

Climate simulations of the EC-Earth v3.1 climate model (atmosphere: IFS ~CY36R4 ocean: NEMO 3.3.1) with and without stochastic physics in the atmosphere for a range of horizontal resolutions from T159 to T1279 with 91 levels

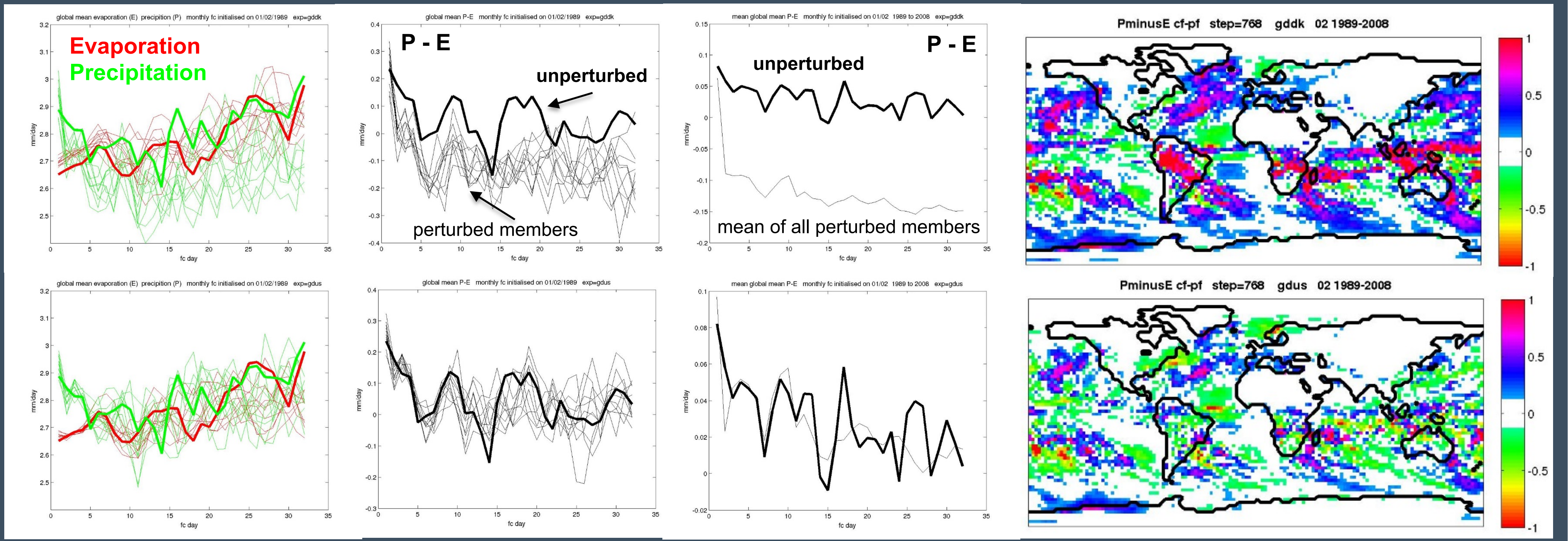
Rather large radiative imbalances for TOA and surface fluxes with SPPT:
10 times larger P – E imbalance: -0.160 mm/day versus -0.015 mm/day

Non-conservation of humidity in SPPT

example 32-day forecast | statistics of 32-day forecasts | $(P\text{-}E)_{CONTROL} - (P\text{-}E)_{PERT}$ @day 32

operational SPPT

SPPT = off



Global average change in humidity/ tendency before and after call of SPPT

Modified version of SPPT

- Ensures that the average change in humidity and temperature tendencies due to SPPT is 0
- Computes global average of tendency change introduced by SPPT (p_0 before SPPT, p_1 after SPPT)

$$p_0 \rightarrow \boxed{\text{SPPT}} \rightarrow p_1$$

- Redistributes the bias $p_1 - p_0$ so that net change is zero using as weights the normalized absolute value of the change

$$\boxed{p_1(x,z) + w(x,z)\cdot\left(\overline{p_0} - \overline{p_1}\right)}$$

$\overline{p_x}$ … global average

$$w(x,z) = \frac{\left|p_1(x,z) - p_0(x,z)\right|}{\left|\overline{p_1} - \overline{p_0}\right|}$$

… local weights

Global constraint for the (instantaneous) spatial averages of p_0 and p_1 to be the same

Conservation of humidity in new SPPT

example 32-day forecast

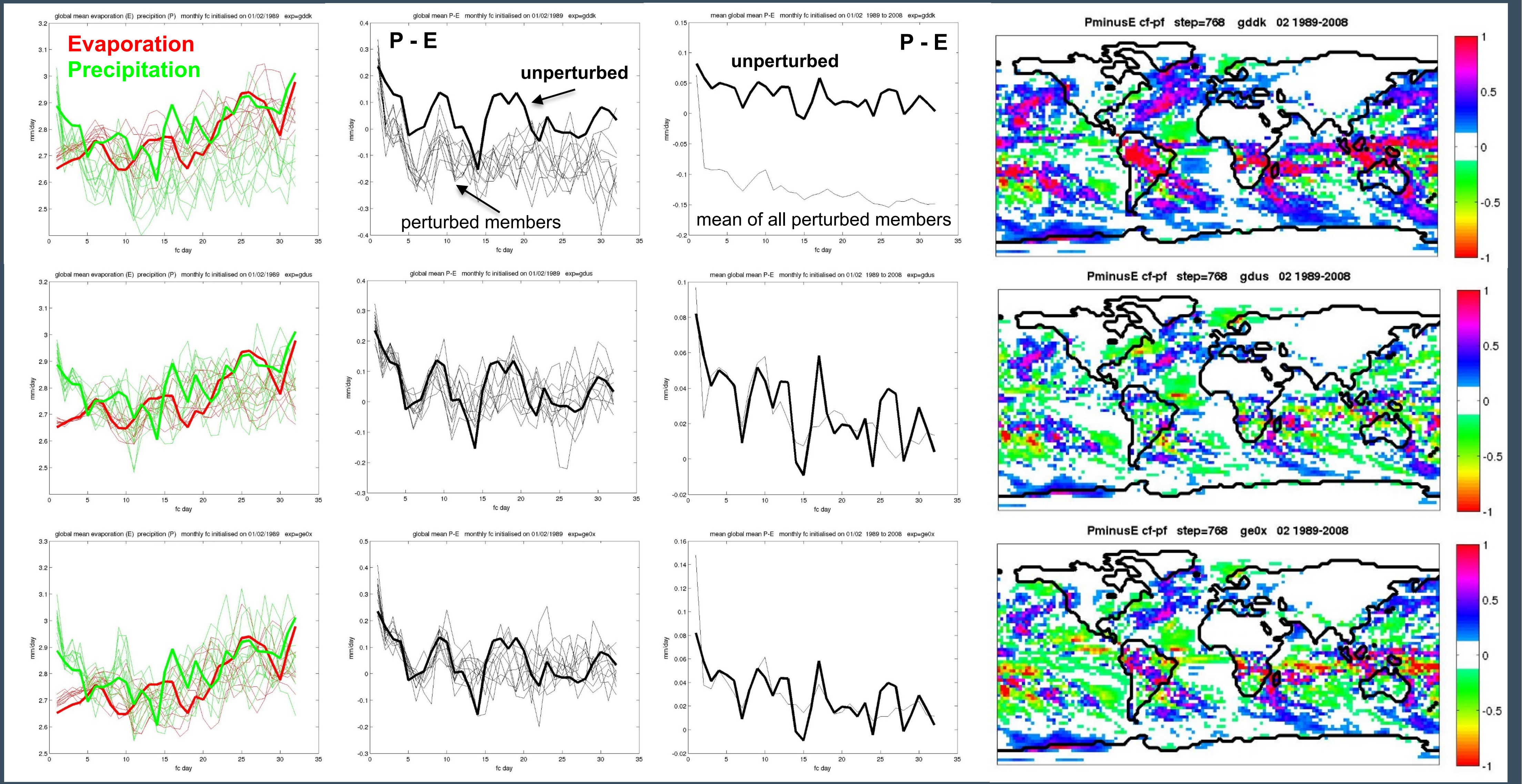
statistics of 32-day forecasts

$(P\text{-}E)_{CONTROL} - (P\text{-}E)_{PERT}$ @day 32

operational SPPT

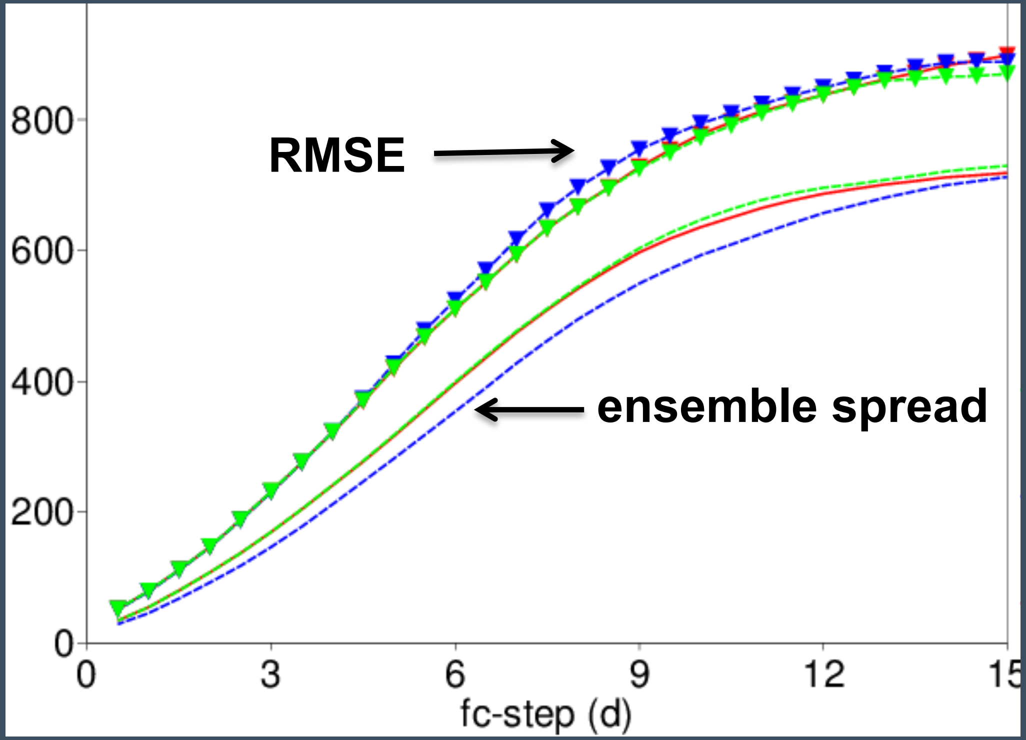
SPPT = off

new SPPT



Conservation of humidity in new SPPT

Z500 NH extratropics

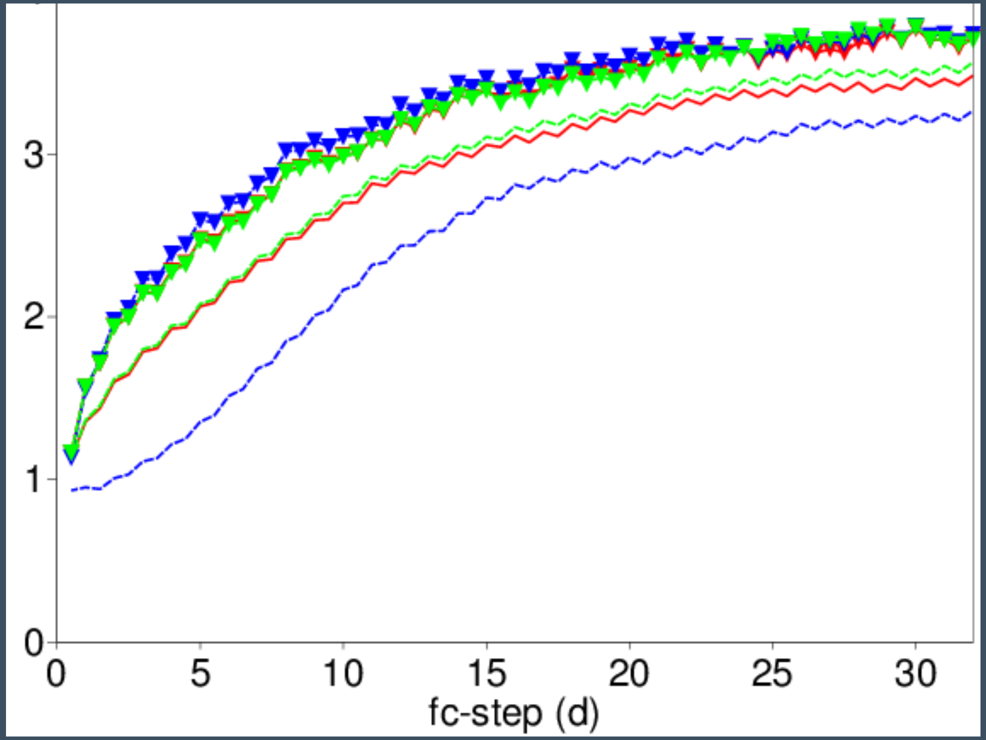


operational SPPT

SPPT = OFF

new SPPT

u850 tropics



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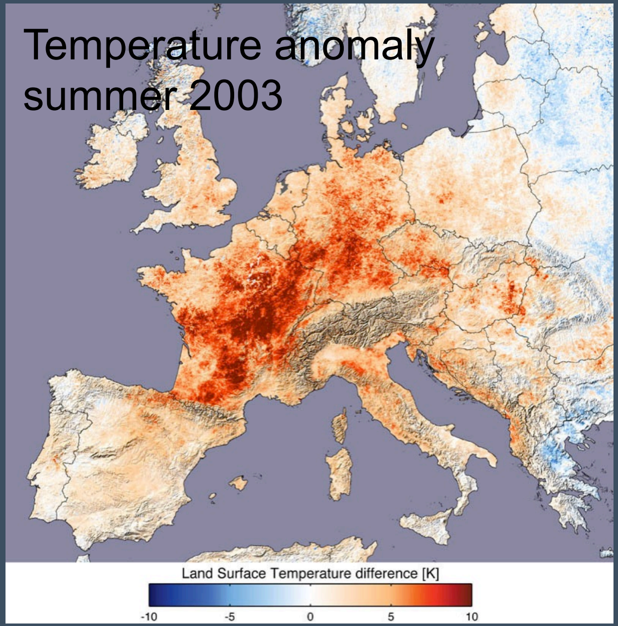


- Land surface is key component in seasonal prediction
- Implicated in development of heat waves
- Unquantified uncertainties exist:
  - what is their impact?
  - by explicitly representing these, can we improve forecasts?

Mean and standard deviation
of saturated hydraulic conductivity
from observations

Soil type	μ	σ
Clay	0.56	1.17
Clay loam	0.72	1.94
Loam	2.89	5.06
Silt	0.69	0.92
Silt loam	1.25	3.42
Silt clay	0.06	0.31

Carsel & Parrish (1998)

Example: seasonal hindcasts of the hot European summer 2003

Control: IFS CY36R4 T255, 4 month forecast initialised on 1st May 1981-2012, 25 members (perturbed IC plus atm. stochastic physics)

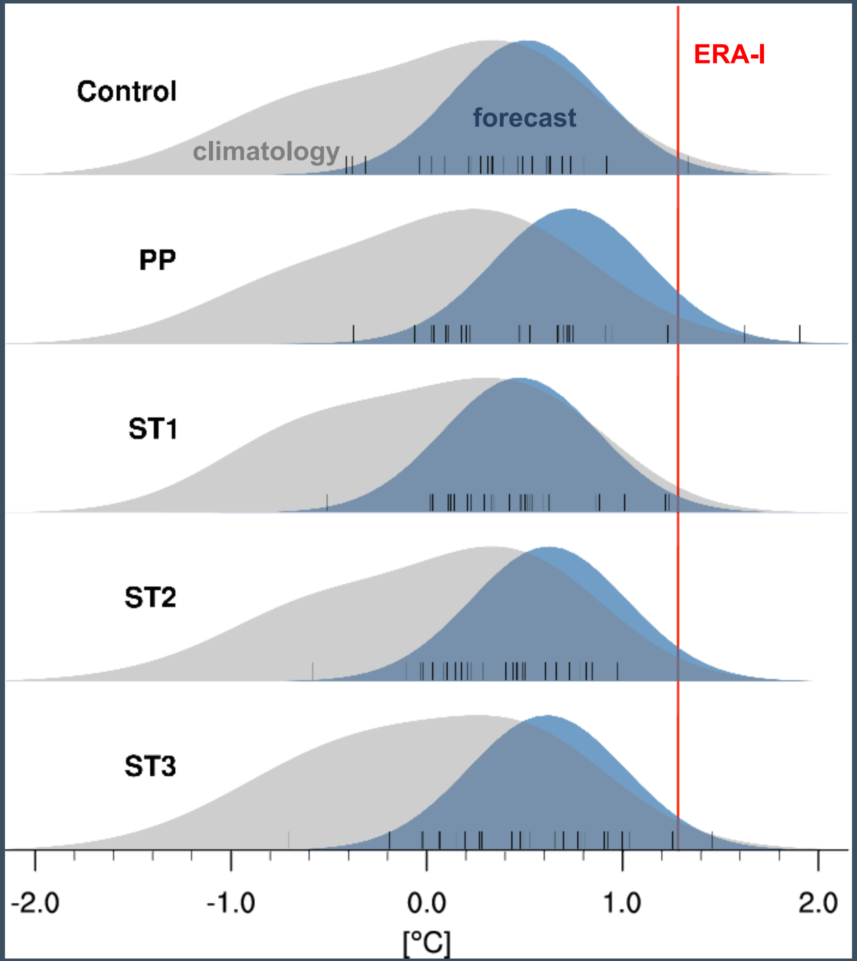
PP: static **parameter perturbations** {0,+/-40,+/-80}% of two key hydrological parameters: Van-Genuchten α (water retention curve) and saturated hydraulic conductivity

ST: **stochastic tendency perturbations** for soil moisture and soil temperature using SPPT-like spectral pattern generator (SPG)

- **ST-1:** default SPG
- **ST-2:** equal scales of the SPG
- **ST-3:** mirrored scales of the default SPG

	small/short scale	medium scale	Large/slow scale
default	0.52	0.18	0.06
equal	0.32	0.32	0.32
mirror	0.06	0.18	0.52

Forecasts of temperature anomalies for JJA 2003



MacLeod, D. et al. (Q.J. 2015)

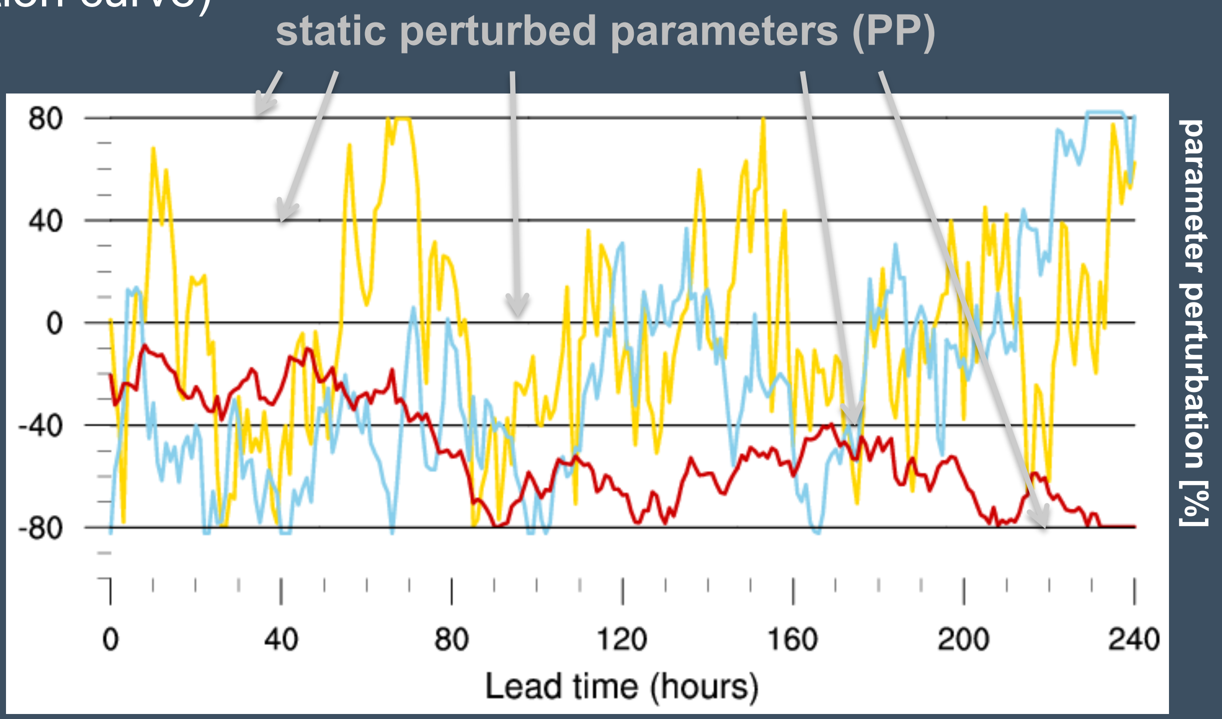
Static versus stochastic parameter perturbations

Control: IFS CY41R1 T255, 4 month forecast initialised on 1st May 1981-2013, 25 members (perturbed IC plus atm. stochastic physics)

PP: static **parameter perturbations** {0,+/-40,+/-80}% of two key hydrological parameters: Van-Genuchten α (water retention curve) and saturated hydraulic conductivity

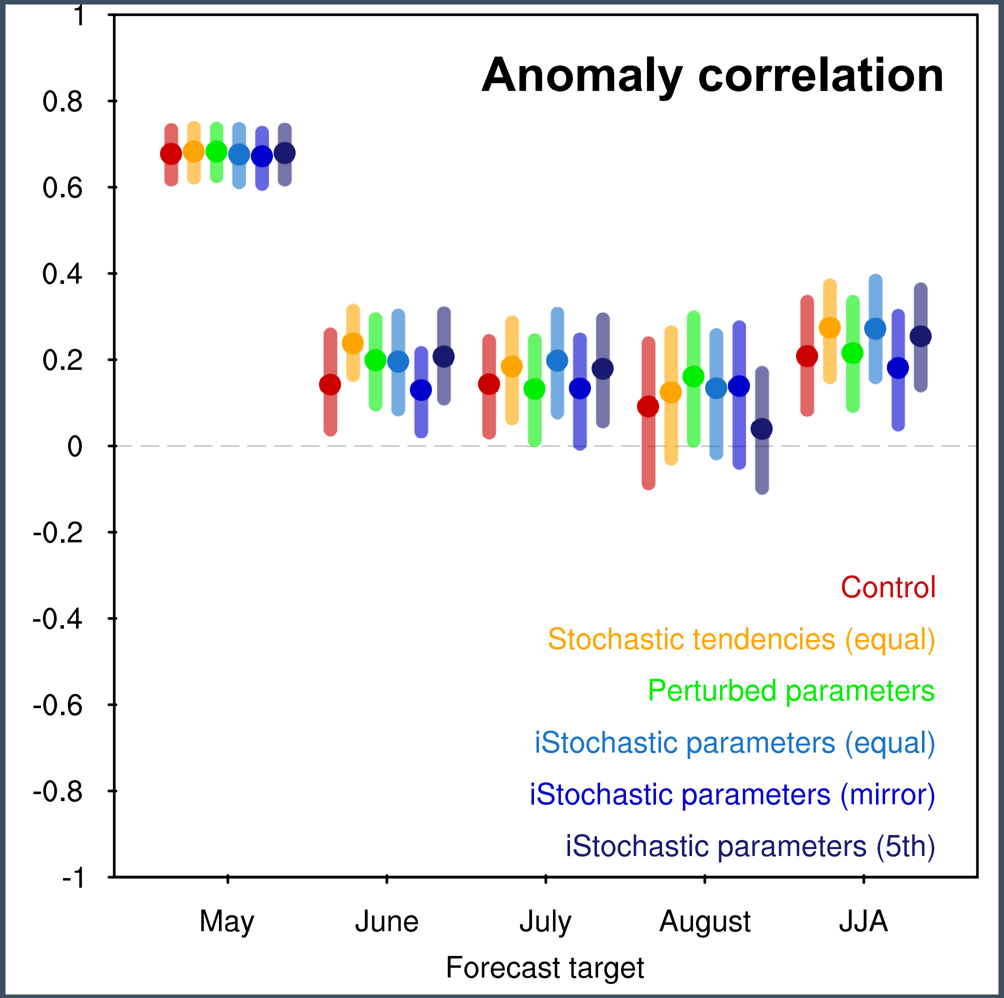
SP: **stochastic parameter perturbations** using SPPT-like SPG

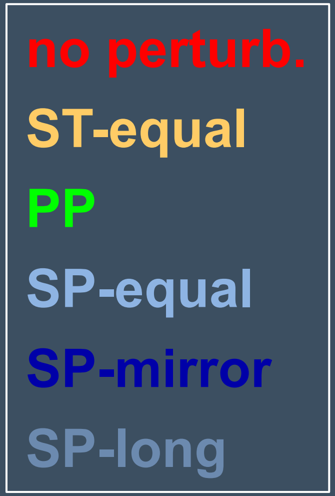
- **SP-default:** default SPG
- **SP-equal:** equal scales of the SPG
- **SP-mirror:** mirrored scales of the default SPG

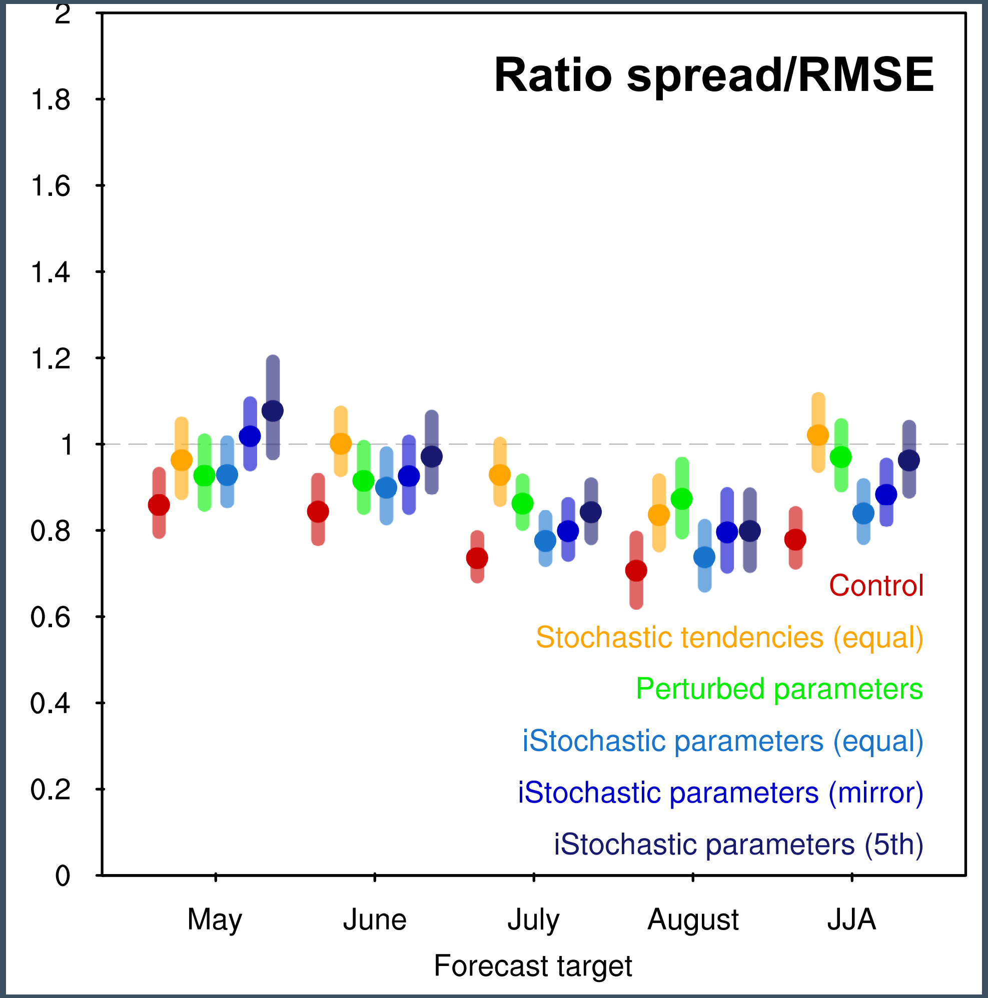


Forecast quality of perturbed land surface schemes

Soil moisture @level 1 over Southern Europe/Mediterranean Basin
reference: ERA Land



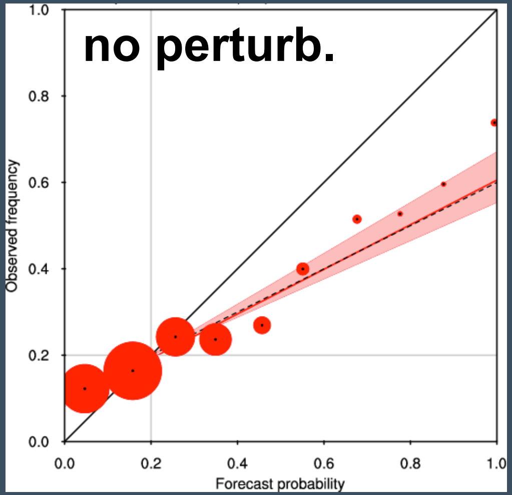


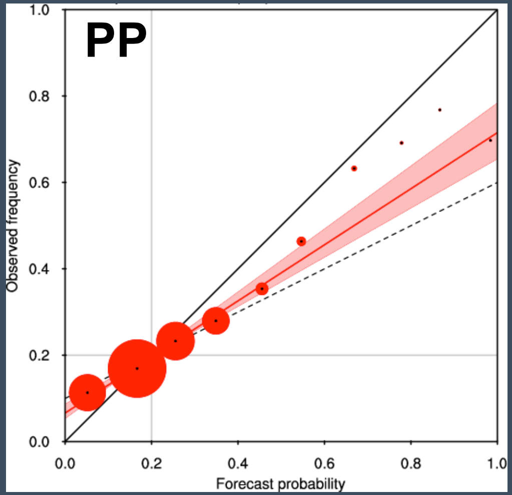


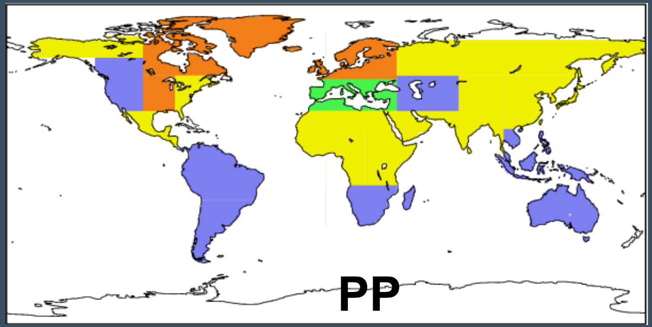
Reliability of Soil moisture @level 1 over global land areas

reference: ERA Land

upper quintile events

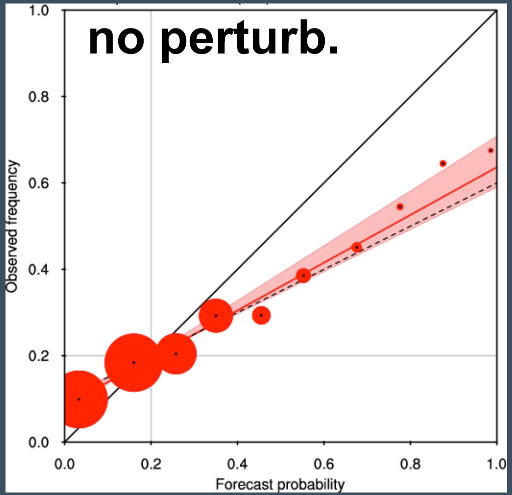


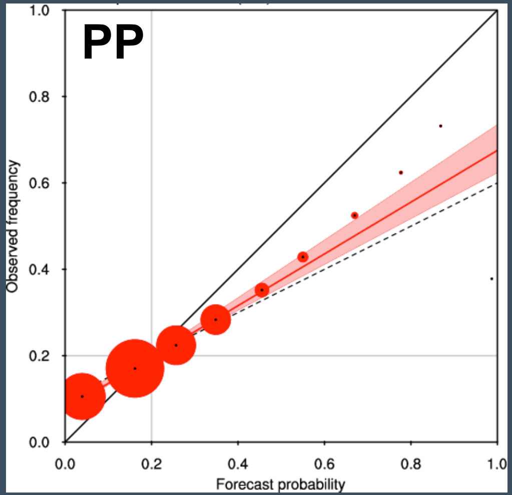


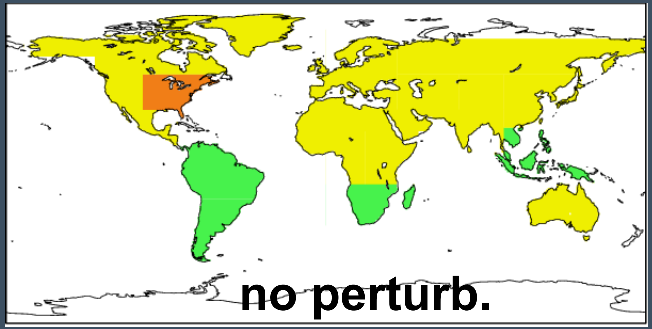


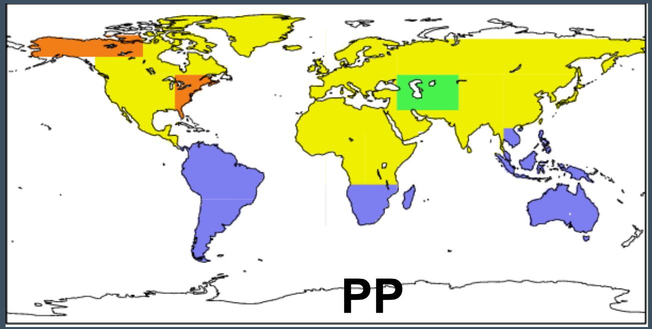
reliability

lower quintile events









See also David MacLeod's poster:

Perturbation of HTESSEL hydrology parameters

David A. MacLeod[a*] Hannah L. Cloke[bc], Florian Pappenberger[d] and Antje Weisheimer[ad]

[a]Deptartment of Physics, University of Oxford, Oxford, UK, [b]Department of Geography and Environmental Science, University of Reading, UK
[c]Department of Meteorology, University of Reading, UK, [d]European Centre for Medium-Range Weather Forecasts, Reading, UK
*E-mail: macleod@atm.ox.ac.uk

SPECS
Seasonal-to-decadal climate Prediction for the improvement of European Climate Services

INTRODUCTION

Methods to explicitly represent uncertainties in weather and climate models have reduced model biases and improved forecast skill when implemented for the atmosphere. However, these methods have not yet been applied to the land surface.

At certain times and in certain places the land surface is strongly coupled to the atmosphere, such as during the 2003 heatwave over Europe when dry soil led to extreme summertime temperatures. Improvements in the representation of uncertainty in the land surface may then lead to improvements in forecast for the atmosphere in cases like this.

We analyze seasonal experiments performed with the ECMWF weather and seasonal climate forecasting model, the Integrated Forecasting System (IFS), with different kinds of perturbation made to the land surface, in order to investigate the effect of explicitly incorporating uncertainty in this domain.

EXPERIMENTS

The control experiment setup is as follows:

- Four month forecast initialised at the start of every May for 1981-2013
- 25 member ensemble, with initial condition perturbations.
- Atmosphere: IFS Cycle 41R1, T255 resolution, 91 vertical levels. Atmospheric stochastic schemes SPPT & SKEB switched on.
- Ocean: NEMO 1 degree, 42 vertical levels

CONCLUSIONS

Previous work with CY36R4 showed that by perturbing land surface parameters with a constant perturbation, forecasts of the hot 2003 European summer are improved (MacLeod et al 2015). Building on this work, we show here that perturbing parameters in CY41R1 gives large improvements in terms of soil moisture reliability, particularly for less frequent events (quintiles).

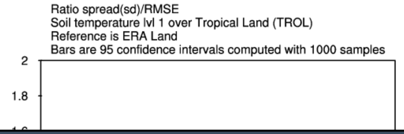
Experiments with stochastic parameters and tendencies have also been carried out, but these do not show the improvement in reliability seen for the static perturbed parameter experiment. Of these, the experiment which uses the "slowest" scale most closely replicates the PP result, however the improvement is not as great.

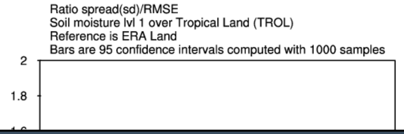
The model spread/error ratio is increased with perturbation. For soil moisture the SP experiments give the largest improvement, however the PP experiment gives an unusually large increase in spread of soil temperature despite only perturbing soil hydrology parameters.

Future work at ECMWF is now looking at perturbations to the land-atmosphere coupling parameter.

RESULTS

Impact on spread





Summary

1. Atmospheric stochastic physics and model bias in the coupled ECMWF model
   - Reduction of tropical biases in convective areas
2. Impact of atmospheric stochastic physics on climate forecast quality
   - Improvements in the tropics
3. Non-conservation of humidity with SPPT
   - (Temporary) fix to SPPT to ensure conservation of humidity (and temperature) tendencies
4. Model uncertainty of the land surface
   - Impact varies across regions and perhaps most noticeable for extreme events

Outlook

CLIMATE SPHINX

PRACE

Climate ***SPHINX*** *(Stochastic Physics High Resolution Experiments)* ***is a PRACE EU project which aims to investigate the sensitivity of climate simulations to model resolution and stochastic parameterizations****, and to determine if very high resolution is truly necessary to facilitate the simulation of the main features of climate variability.*

SPHINX is a project by **ISAC-CNR**, lead by Jost von Hardenberg, in collaboration with Oxford University (Tim Palmer and Antje Weisheimer group).

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