



Motivation

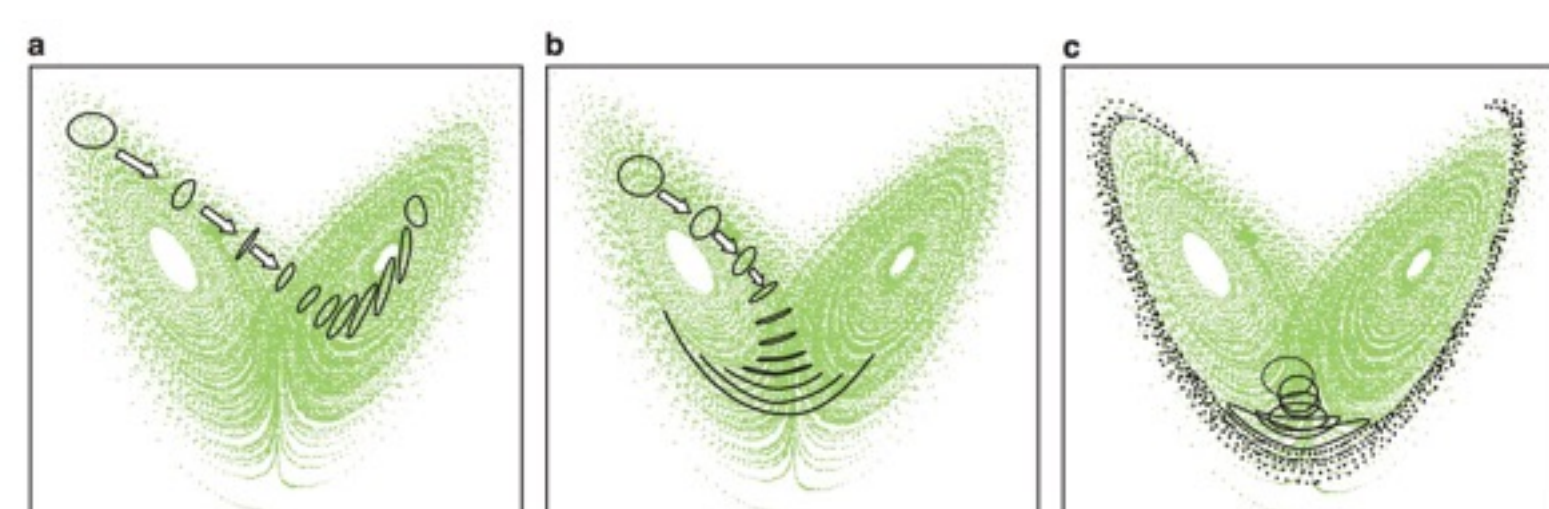
- To improve representation of uncertainty in atmospheric convection parameterization in weather and climate models
- To study changes to the model mean and variability of tropical convection on different timescales using this new method

Modeling Uncertainty

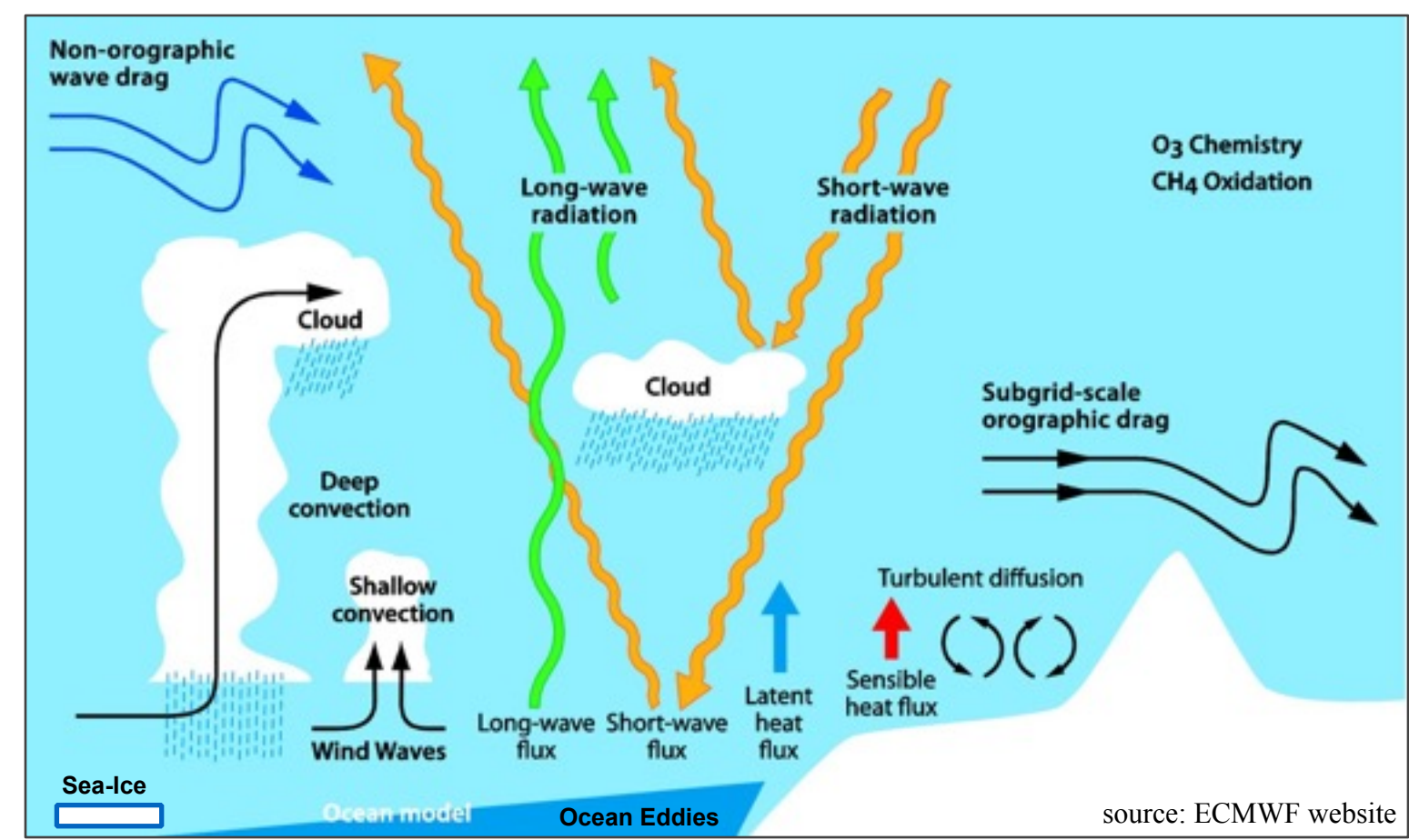
Introduction

"Finite time for error in representation of small scales to affect accuracy of simulation of large scales, no matter how small in scale and hence amplitude this model error is" (Lorenz 1969)

- Predictability of weather and climate forecasts is determined by the projection of uncertainties in both initial conditions and model formulation onto flow-dependent instabilities of the chaotic climate attractor.
- Essential to estimate the impact of such uncertainties on forecast accuracy.
- Weather or climate prediction should also forecast the associated flow-dependent uncertainty.
- Parameterized tendencies in weather and climate models have large uncertainties due to parameter or process uncertainties.
- Current representation of model errors are:
 - multi-model ensembles
 - multi-physics ensembles
 - perturbed parameter ensembles
 - stochastic parameterization



Scientific basis for ensemble forecasting: In a nonlinear system the growth of initial uncertainty is flow dependent here illustrated with the Lorenz (1963) model. The set of initial conditions (black circle) is located in different regions of the attractor in (a), (b) and (c). (Palmer et al. 2006)



Stochastic parameterization

Stochastically Perturbed Parametrization Tendencies (SPPT)

- simulates uncertainty due to sub-grid parametrizations
- Initially implemented in IFS, 1998 (Buizza et al., 1999); revised in 2009:
- taking the net parameterized physics tendency:

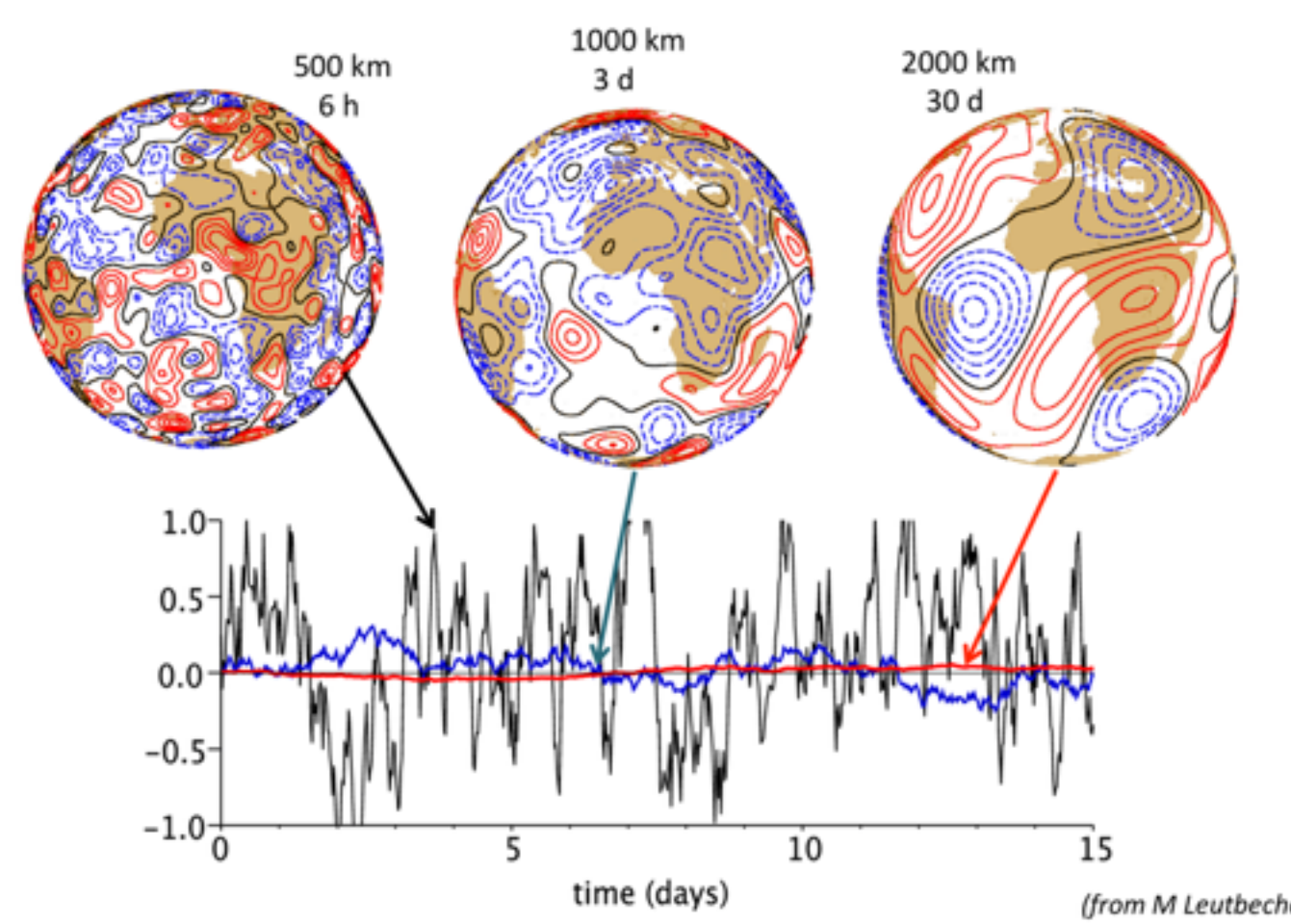
$$X = X_U, X_V, X_T, X_Q$$

coming from: (radiation schemes, gravity wave drag, vertical mixing, convection, cloud physics)

- Perturbed with multiplicative noise $X' = (1 + \mu r)X$
- 2D random pattern in spectral space

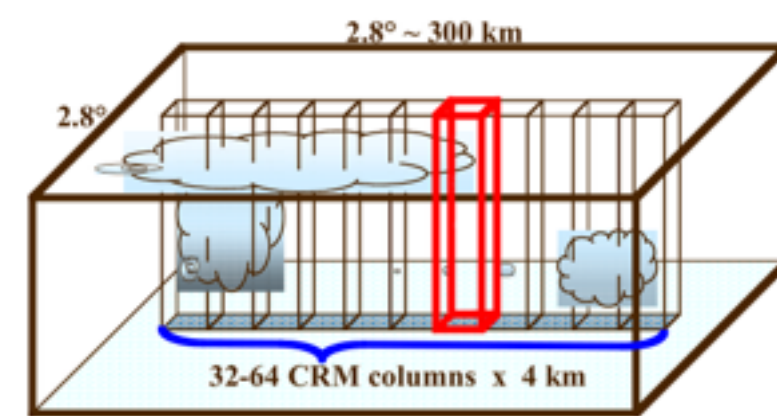
Stochastic Kinetic Energy Backscatter (SKEB)

- Simulates a missing and uncertain process
- Parameterizes upscale transfer of energy from sub-grid scales



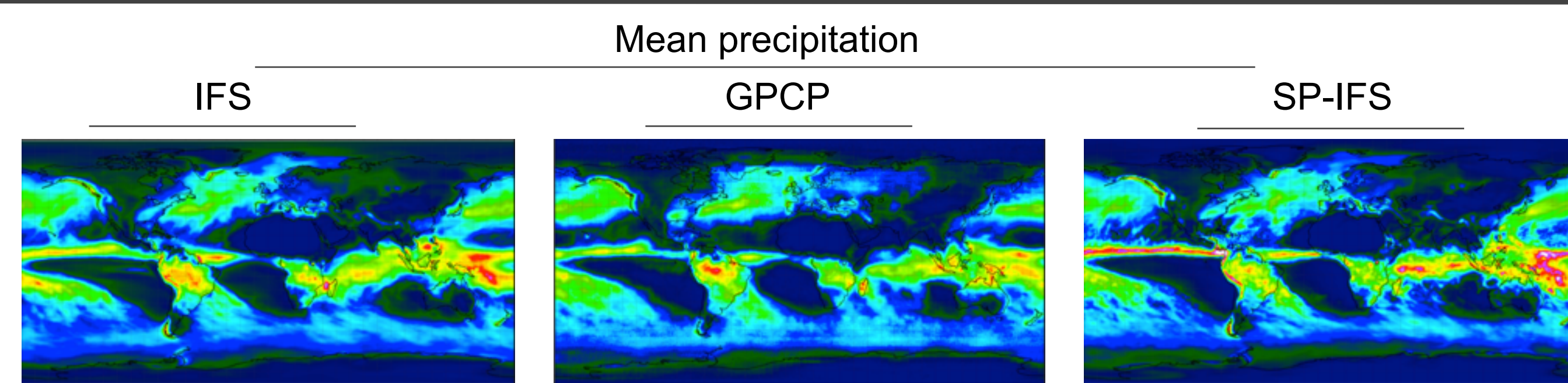
Shutts et al. (2011, ECMWF Newsletter); Palmer et al., (2009, ECMWF Tech. Memo.)

Super-parameterisation

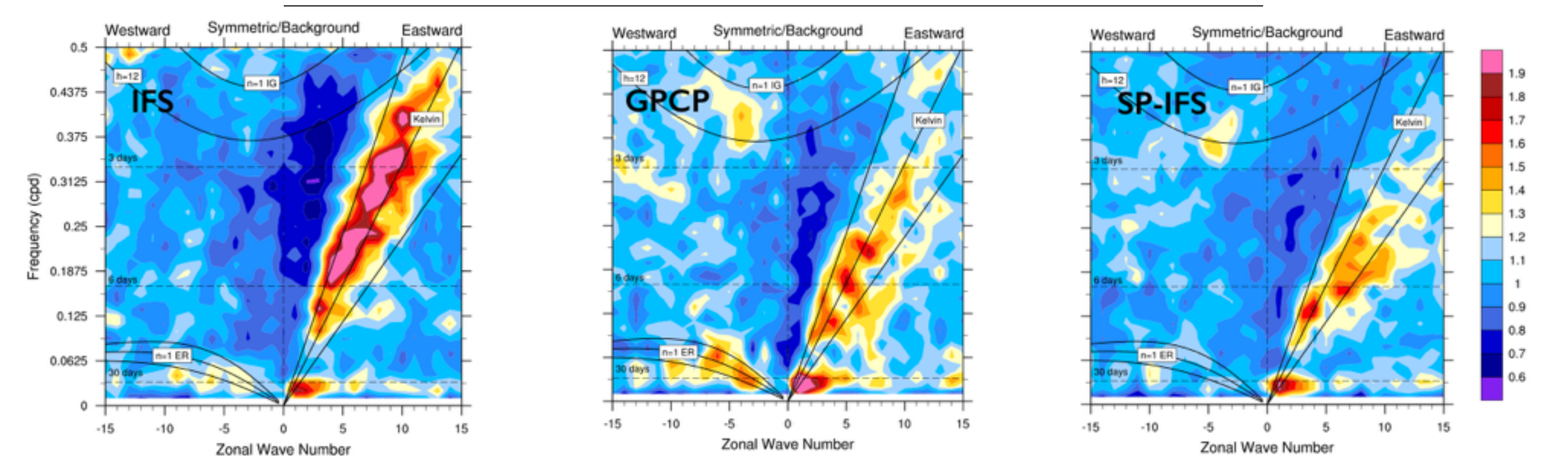


- Super-parameterised IFS model run for 3 years (Aug 2000 until Sep 2003)
- Uncoupled ECMWF IFS used for simulations and comparison with T159 resolution.
- Super-parameterised CRM dimensions: 32 x 91; 4 km horz. resolution in CRM
- Radiation coupled through SP-IFS's mean profiles.

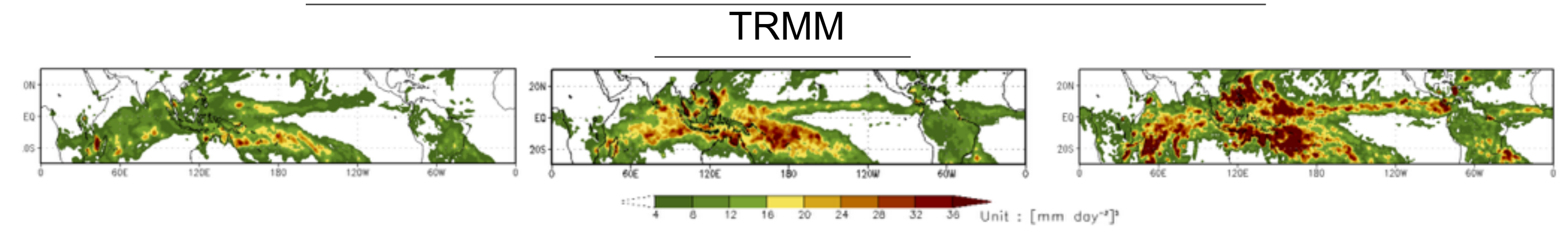
Change in precipitation due to super-parameterisation



Symmetric wavenumber-frequency spectra (SNR) of precipitation



Winter (Nov-Apr) 20-100 day precipitation variance



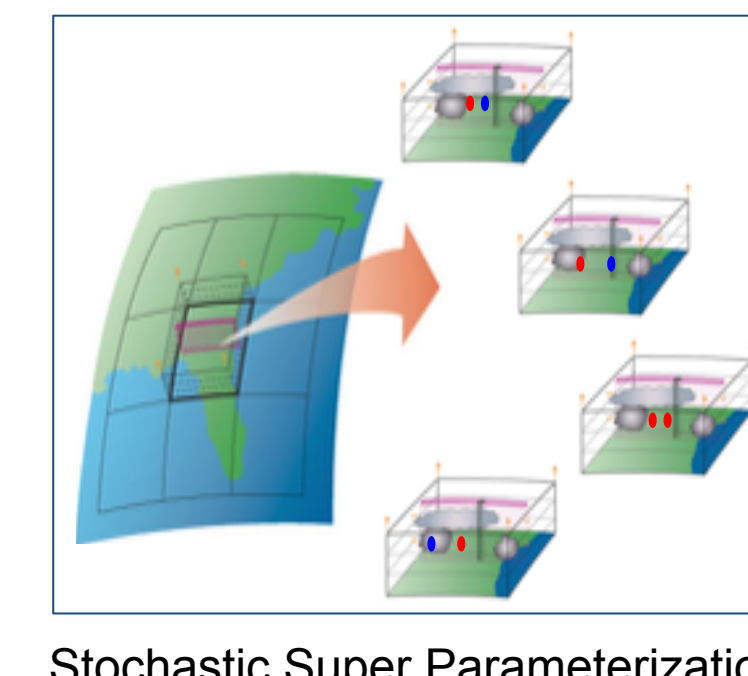
- Super-parameterisation leads to increased precipitation in the Tropics with enhanced intraseasonal precipitation variance and MJO variability compared to IFS.
- Reduced signal in Kelvin wave bands but enhanced power in MJO band.
- Sensitivity experiments are being performed to reduce the biases in the super-parameterisation runs and to test them in an ensemble framework for process-based evolution of model uncertainty.

We are grateful to Filip Vana, Glenn Carver and the OpenIFS effort for all the support for this work.

Stochastic super-parameterisation

Stochastic multi-scale modeling

- Simulates process driven uncertainty by capturing the chaotic evolution of error growth in convection
- Testing SP-IFS in the ensemble mode with stochastic initialization of the sub-grid cloud model
- 25 ensemble members**, 10 different start dates, T159 resolution, CY40R3
- Stochastic SP-IFS (SSP) shows **increased spread** in the ensemble for **tropical convective events**.



Forecast Error and Spread in Precipitation

- Error in Precipitation is of same order of magnitude, but initial spread is greater in SPPT IFS.
- Error in Precipitation is of same order of magnitude, but spread is greater in SSP IFS by forecast day 5.
- More intense rain events in SSP than SPPT IFS, indicate IFS is deficient in extreme precip.

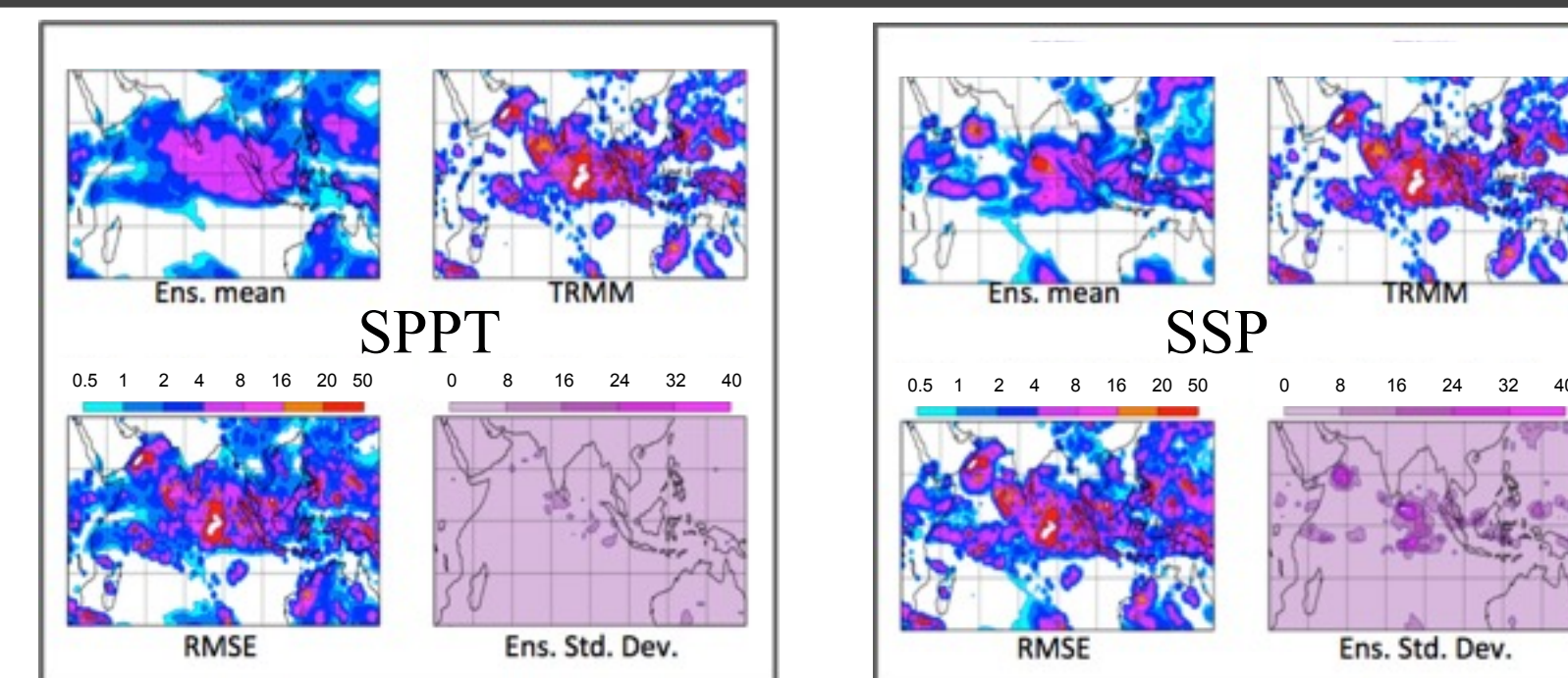
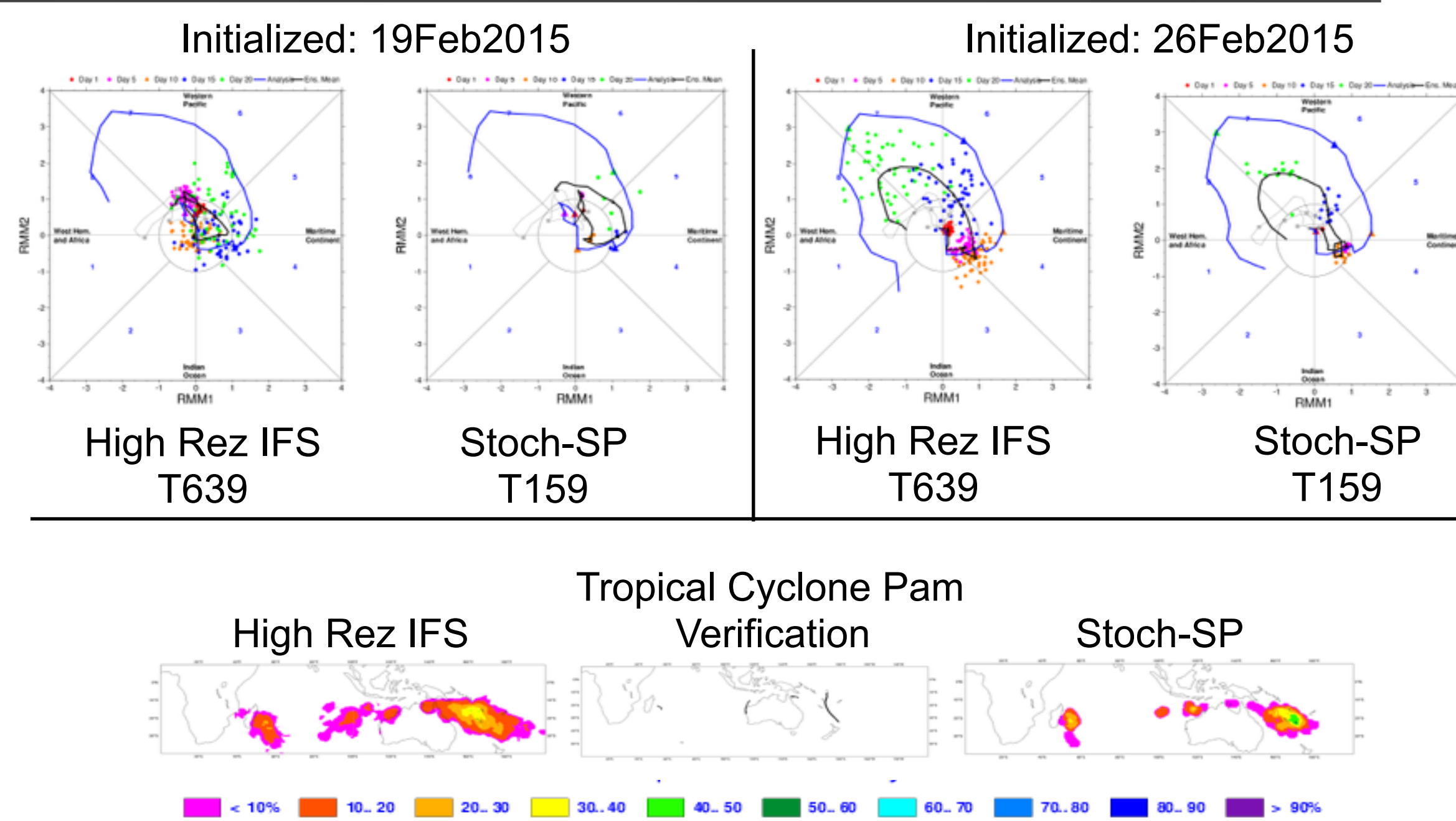


Figure: 21 Ens member, 240h verification of tropical precipitation, Initial date: 06Oct2011 (Case: DYNAMO MJO event)

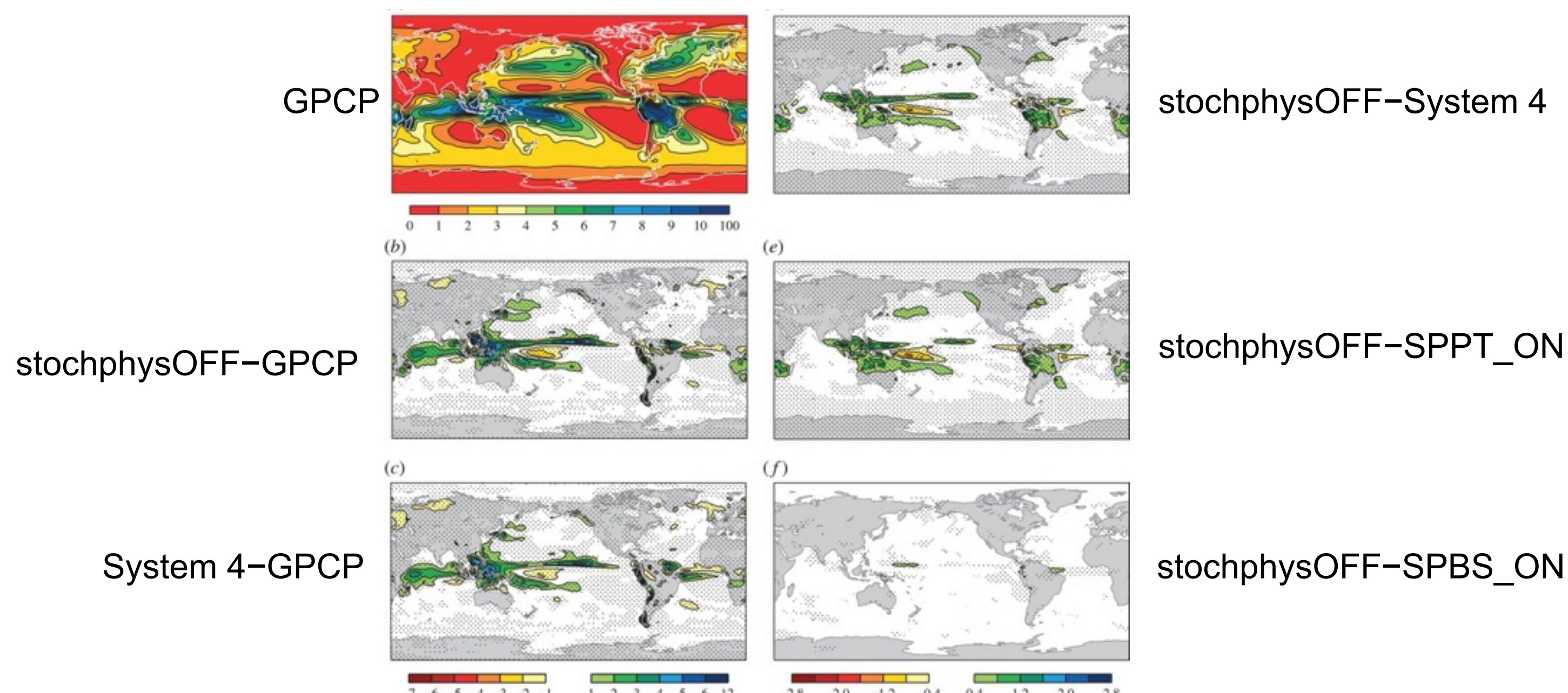
MJO and Tropical Cyclone Forecast (Feb-Mar 2015)

- MJO initiation better captured by stochastic super-parameterization in this test case
- Tropical cyclone probabilistic forecast is slightly better in stochastic super-parameterization
- More intense wind and precipitation events of tropical cyclone Pam captured by super-parameterization (not shown)



Stochastic Parameterization

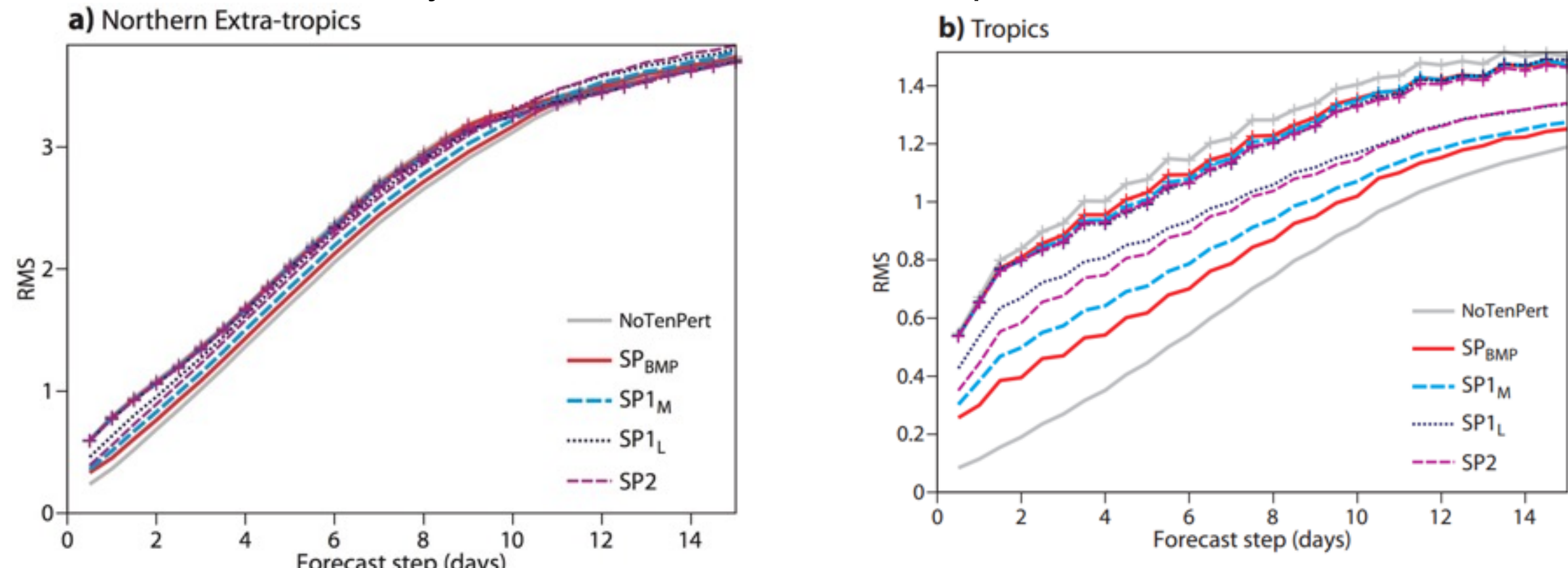
Impact on the mean climate



Weisheimer et al. (2014) showed that stochastic tendency perturbations in the ECMWF IFS helps reduce the positive precipitation and convection biases over the Maritime continent and Western Pacific. Stochastic perturbations of the physical tendencies (SPPT) have the largest positive impact on reducing biases.

Reliable forecasts

Why do we need Model Error Representation?



- The grey line shows the Root Mean Square error for forecasts with no stochastic perturbations and the other colors are for experiments with different stochastic perturbations. Lines with no markers are for the ensemble spread. Reliable ensembles should have ensemble spread = RMSE.
- Spread is least and error is maximum for forecasts with no perturbations.

Summary

- Super-parameterization
 - has increased climate variability in intraseasonal timescales
 - improved modeling of tropical waves in the IFS model with super-parameterization
- Stochastic super-parameterization
 - improves modeling of uncertainty in tropical convection compared to SPPT
 - improved MJO initialization and tropical cyclone forecasts with stochastic super-parameterization