NCAR

NATIONAL CENTER FOR ATMOSPHERIC RESEARCH

Stochastic parametrisation

Reducing model error in the Community Earth System Model

Hannah Christensen, Judith Berner

hannahc@ucar.edu

National Center for Atmospheric Research

With thanks to Dani Coleman, Justin Small (NCAR)
Tim Palmer (U. Oxford),
Susanna Corti, Chunxue Yang, Jost von Hardenberg (ISAC-CNR), Paolo Davini (LMD-ENS, Paris)

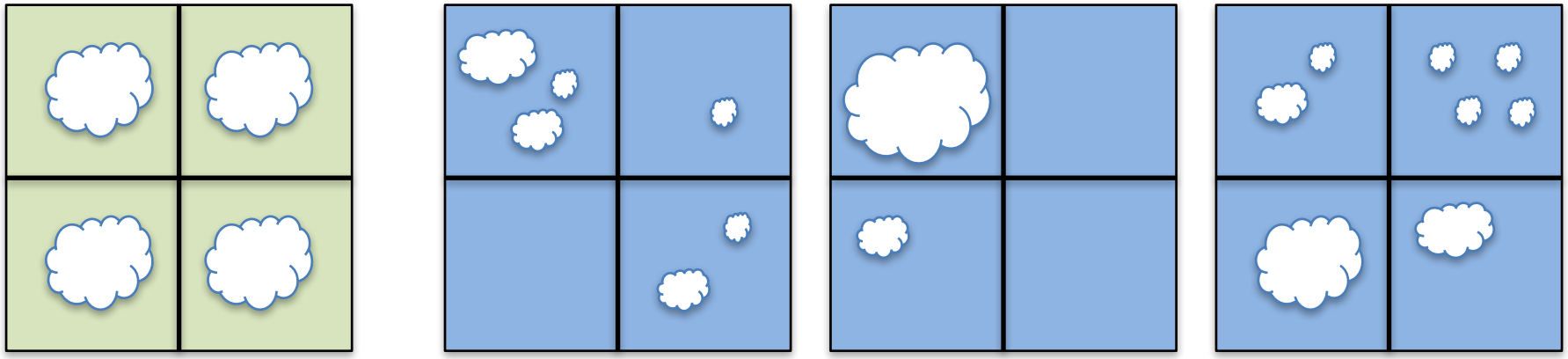
WGNE Workshop on systematic errors, 21st June 2017

Why stochastic parametrisation?

- Stochastic parametrisation seeks to represent unresolved sub-grid variability
  - Grid-scale variables do not fully constrain sub-grid motions
  - Describe sub-grid tendency in terms of a probability distribution constrained by the resolved-scale flow
  - Include random numbers in our equations of motion
- Necessary in NWP to achieve reliable ensemble forecasts, in which the probability distribution accounts for all uncertainty in the forecast

Deterministic

Stochastic realisations



Why stochastic parametrisation in climate models?

- Stochastic parametrisation can improve variability of small-scale 'weather', which can in turn improve statistics of the modeled climate
  - 'slow changes of climate are explained as the integral response to continuous random excitation by short period "weather" disturbances'
    (Hasselmann, 1976)
- noise-induced drift, noise-enhanced variability, noise-activated regime transitions

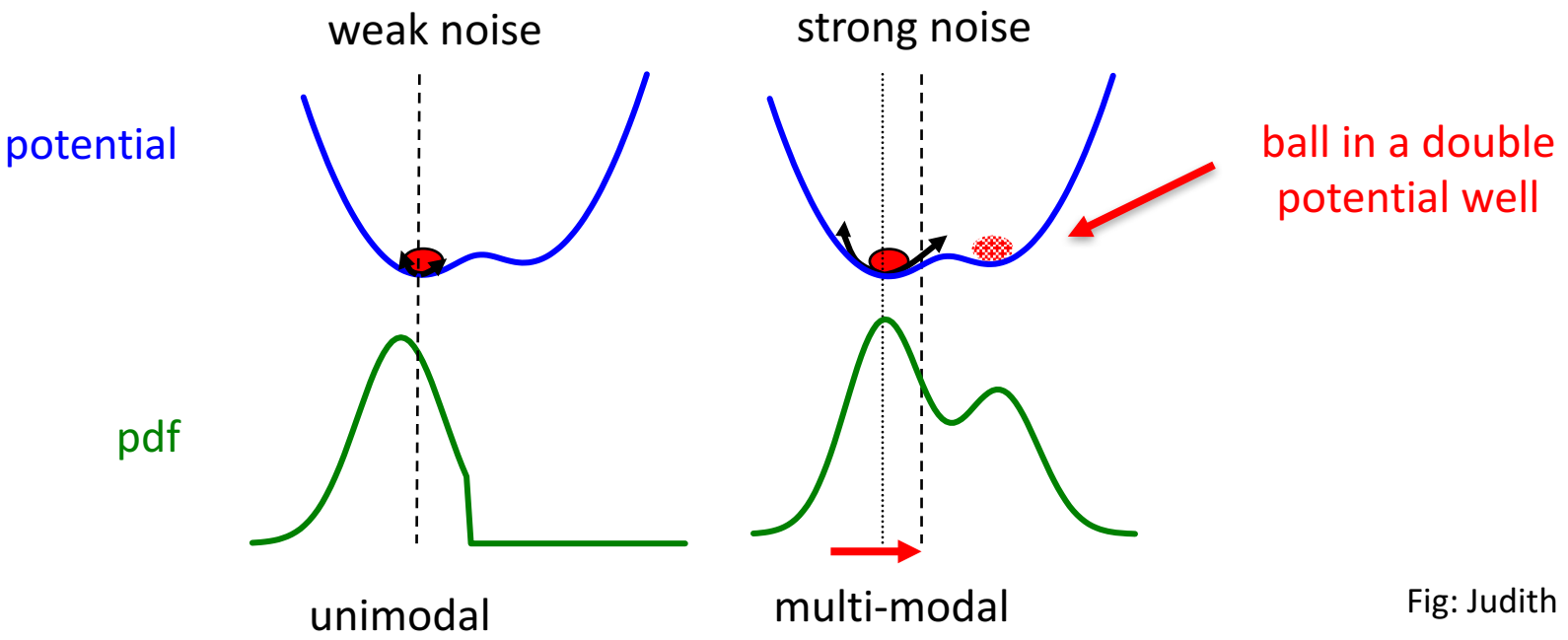
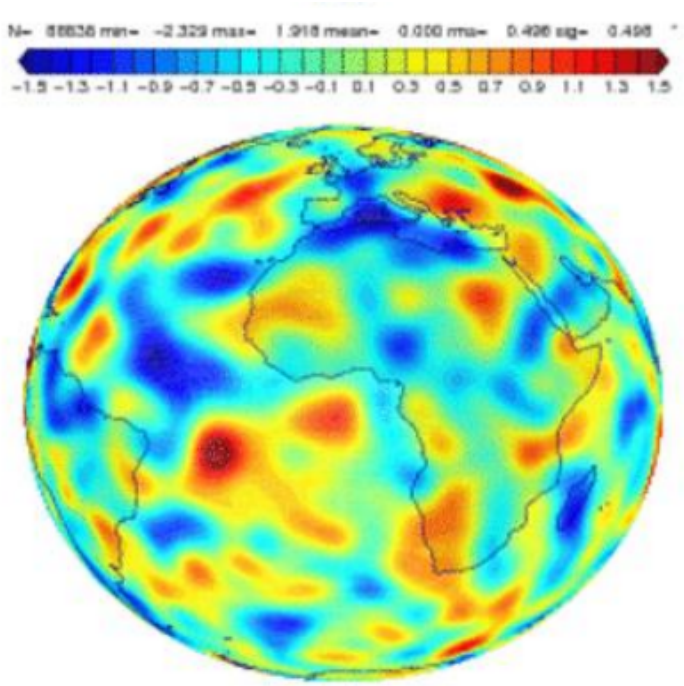


Fig: Judith Berner

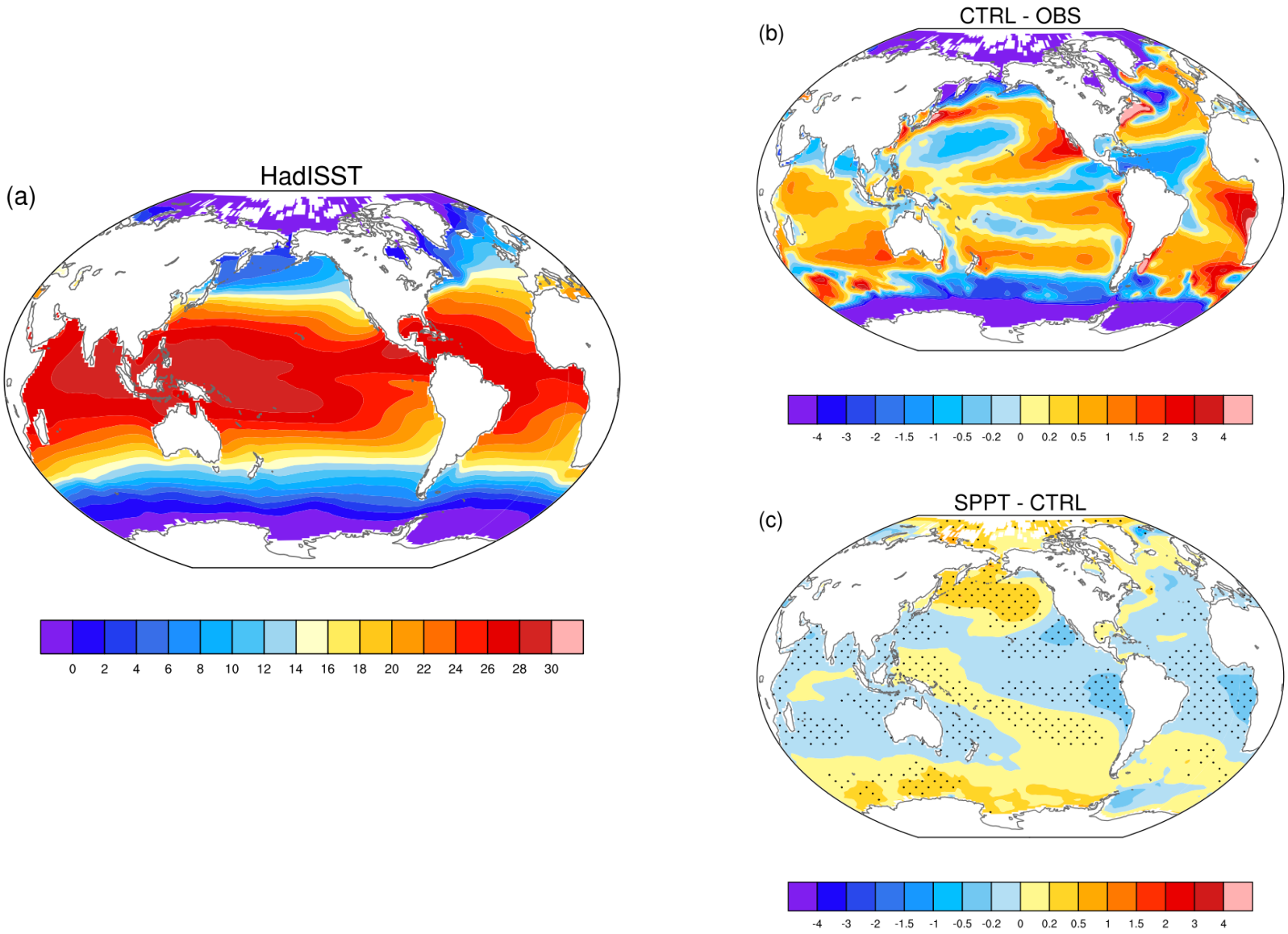
Test SPPT scheme in coupled CAM4

- **Stochastically Perturbed Parametrisation Tendencies (SPPT)**
  - represents random errors due to the model's physical parametrisation schemes
  - Multiplicative noise used to perturb the total physics tendencies (Palmer et al. 2009)
  - Noise follows spectral pattern, 6hr, 500km decorrelation scales

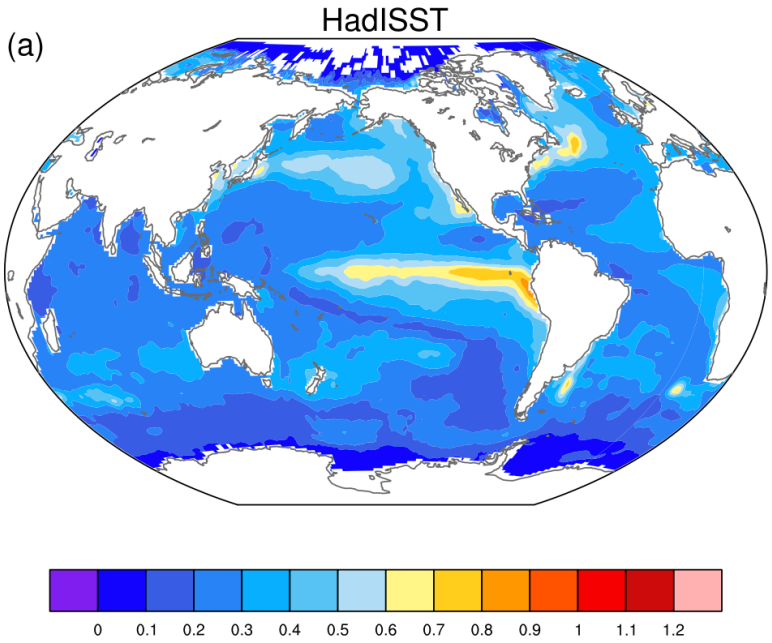


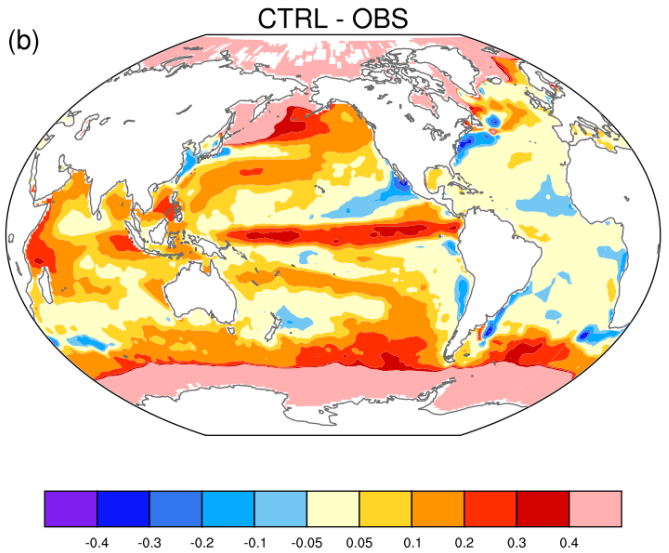
- **Simulations**
  - Community Atmosphere Model v4, 1°
  - Community Ocean model, 1°
  - Transient (historical) forcing
  - 1870-2004 (135 years)

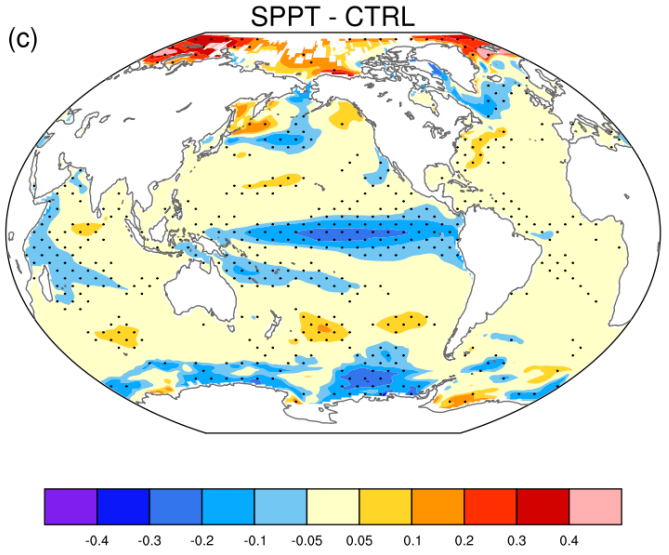
SPPT has modest impact on mean state



SPPT has large impact on variability

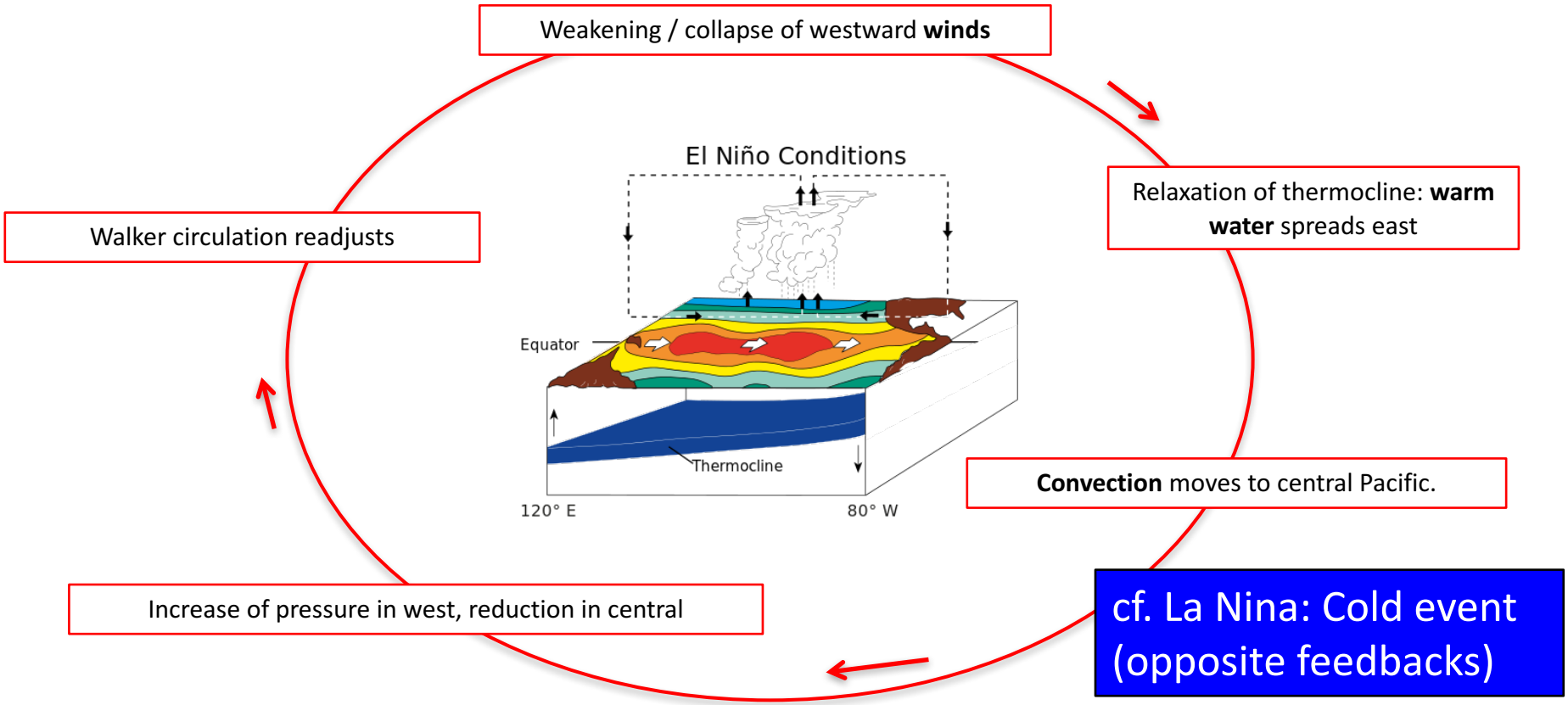




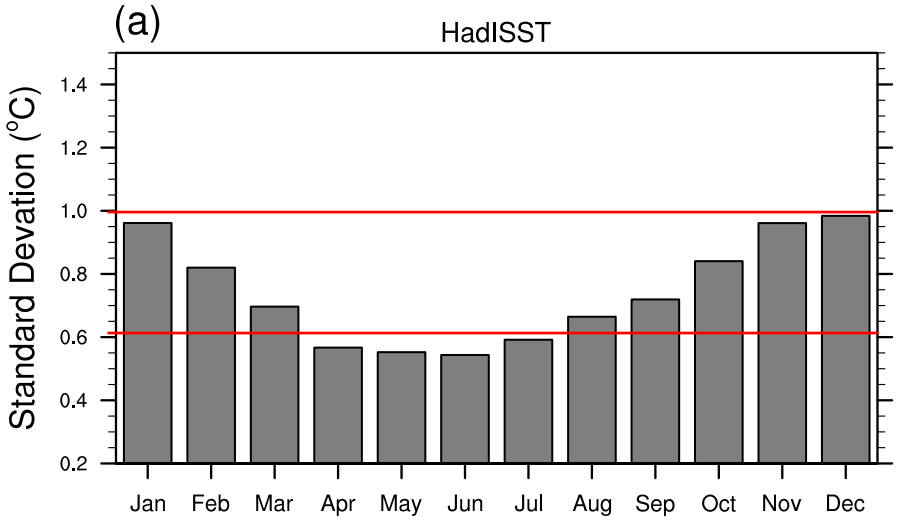


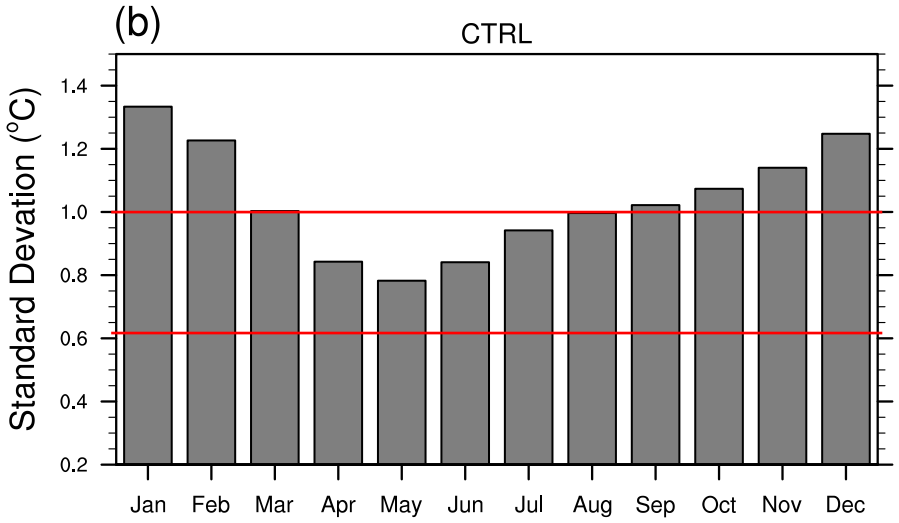
SPPT has a large impact on El Nino-Southern Oscillation

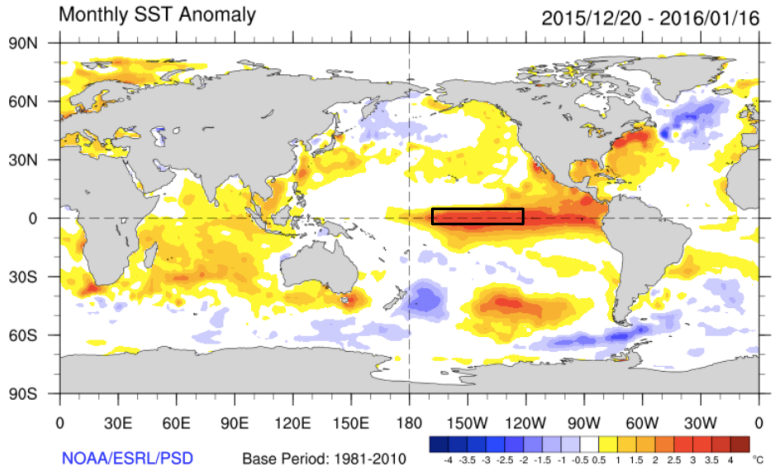
- Dominant mode of climate variability in Tropical Pacific
- Coupled atmosphere-ocean phenomenon:



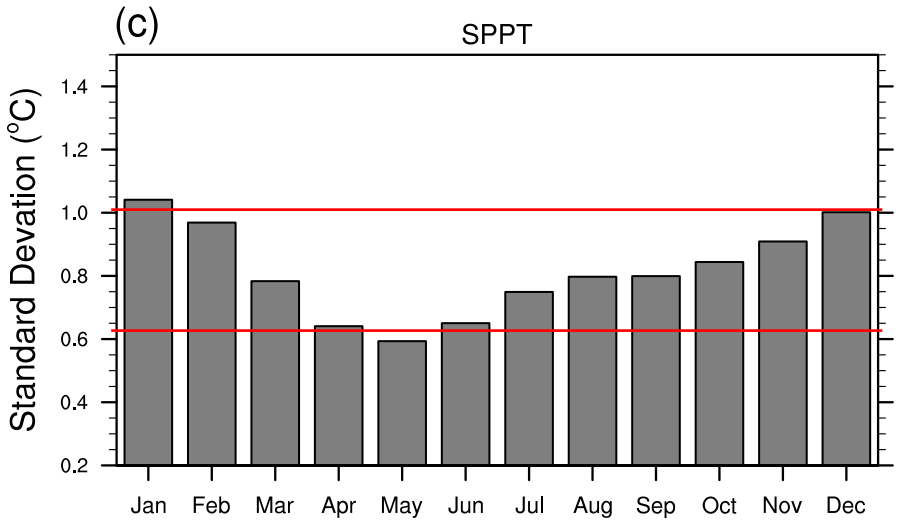
SPPT impact on ENSO amplitude



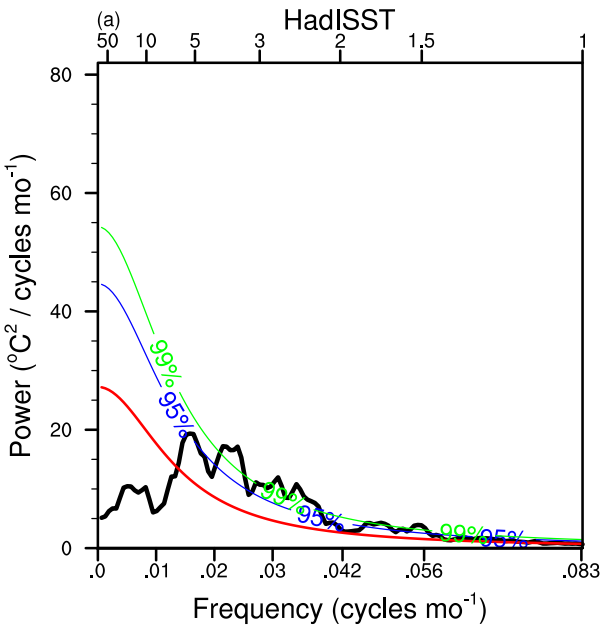


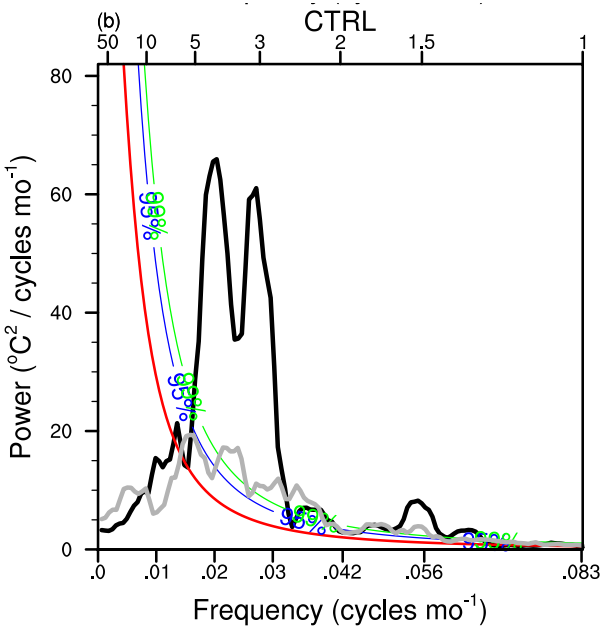


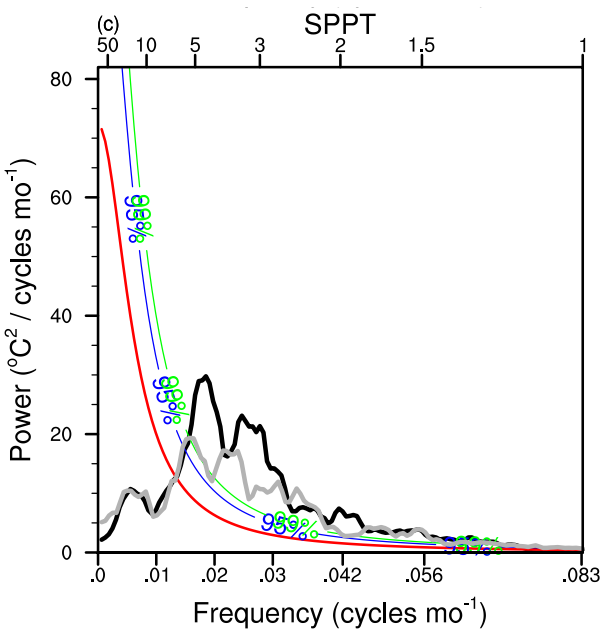
Box shows Nino 3.4 region



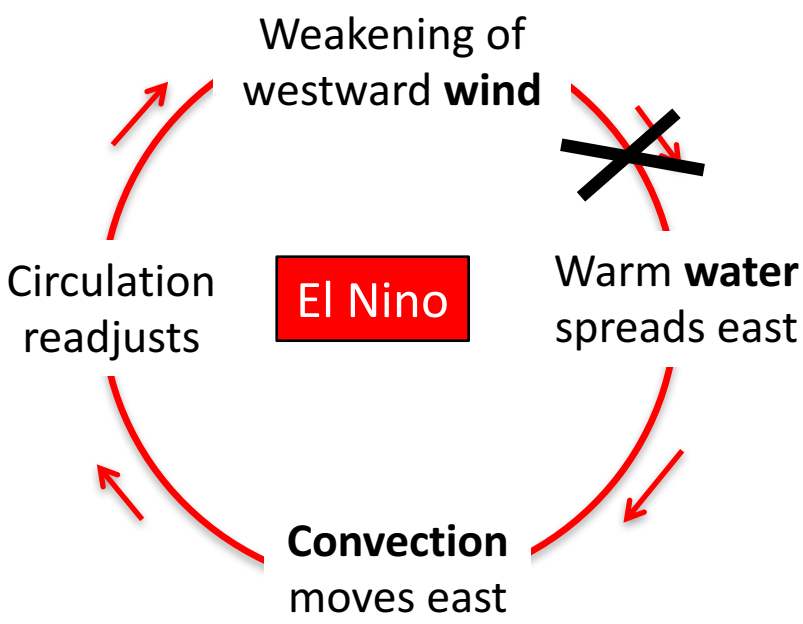
SPPT impact on ENSO variability



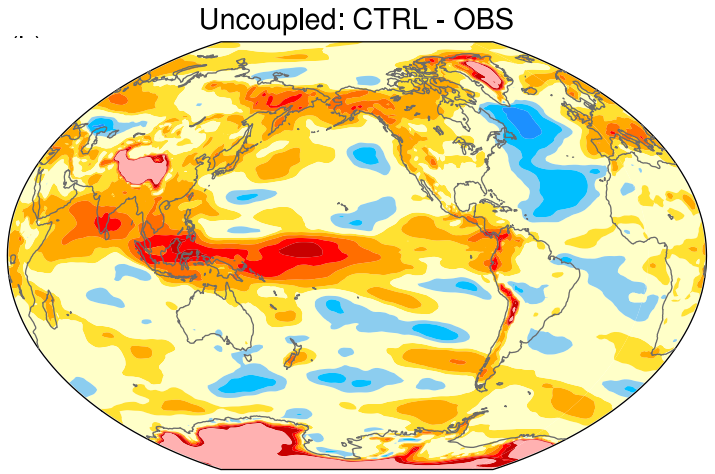


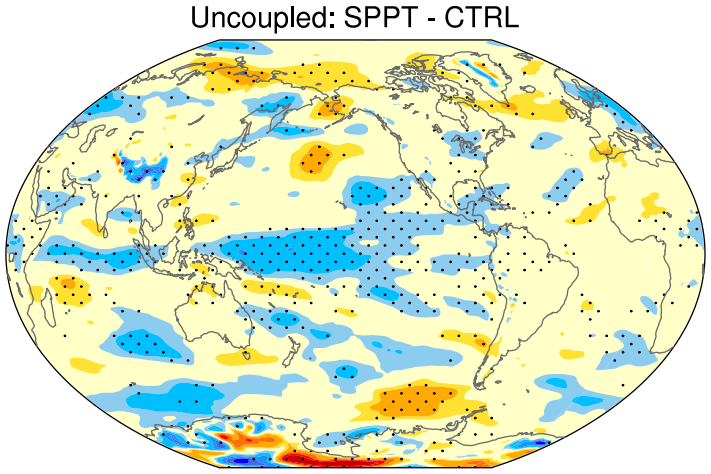


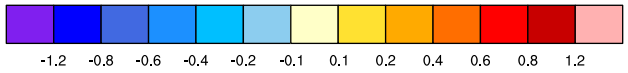
Untangling the mechanisms



Variance of U850

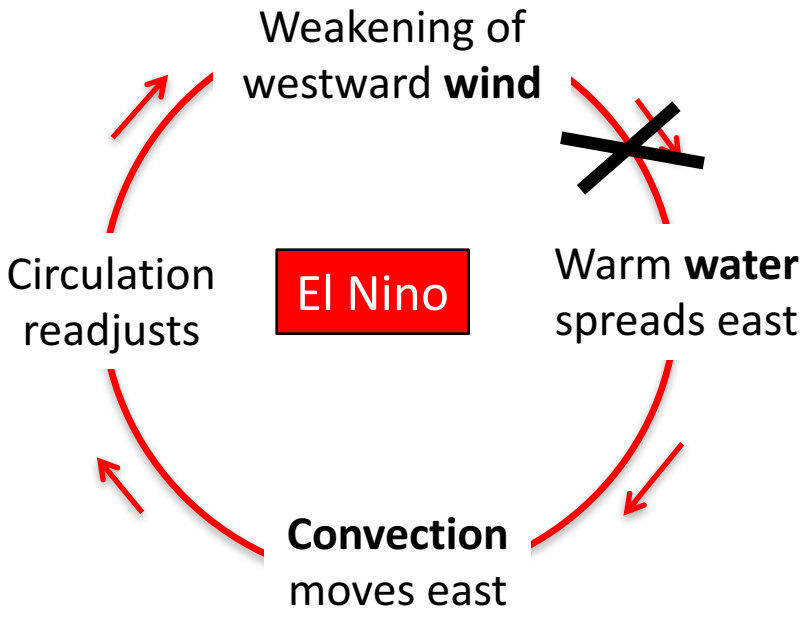




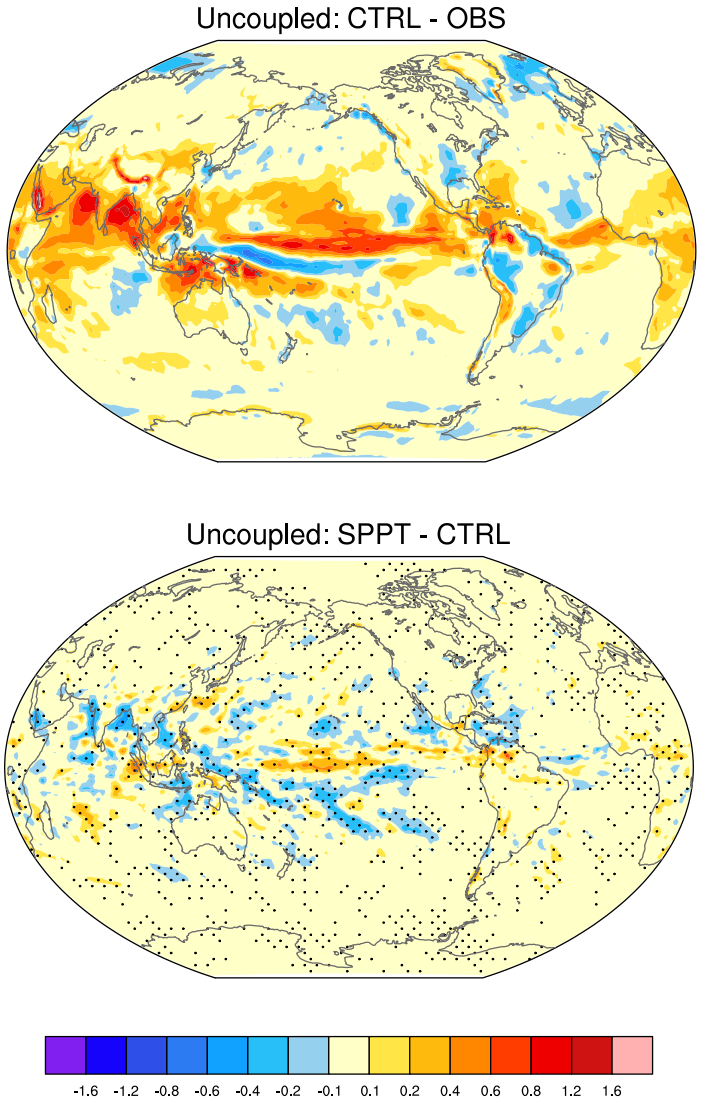


- Use atmosphere-only simulations to break feedback loop

Untangling the mechanisms



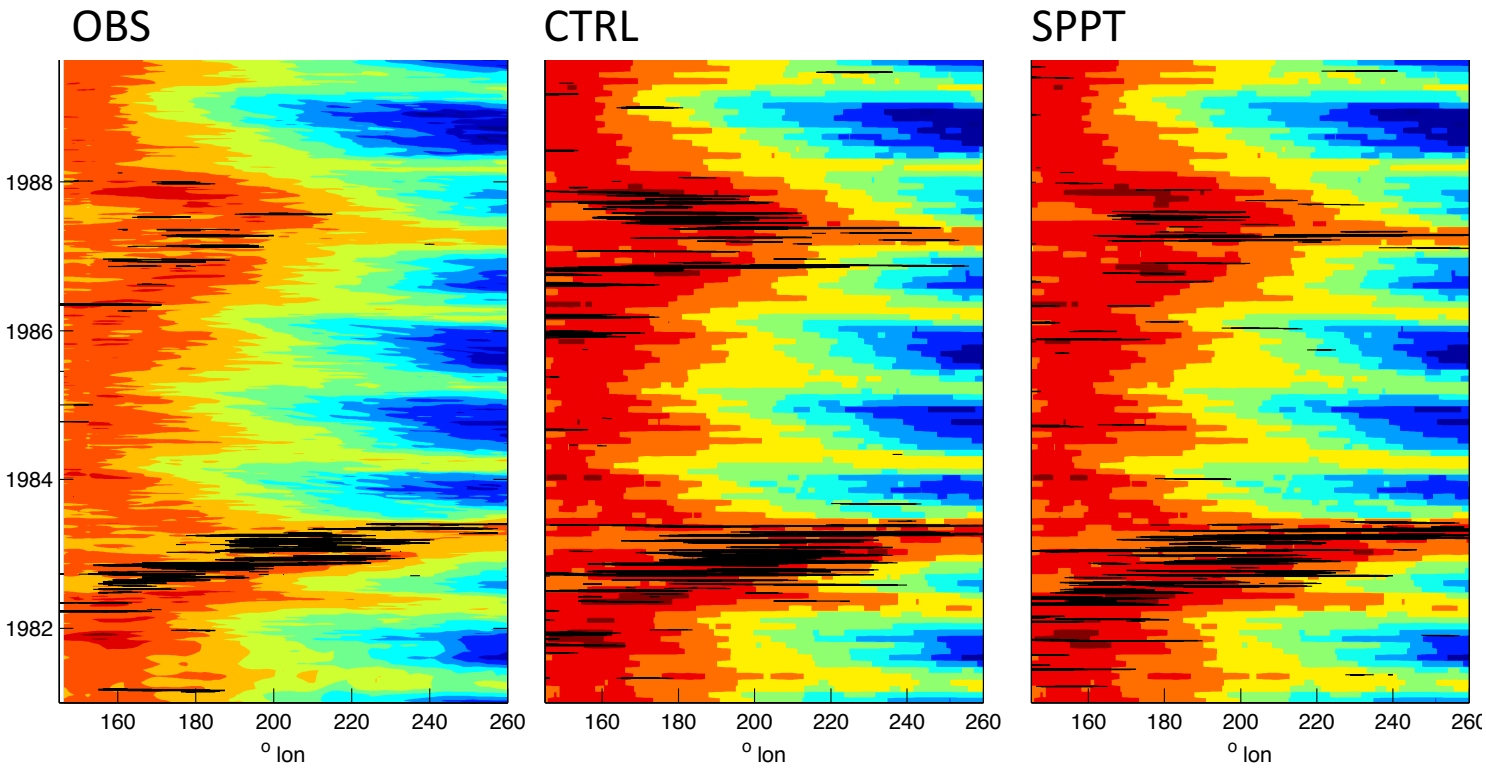
Variance of precip



- Use atmosphere-only simulations to break feedback loop

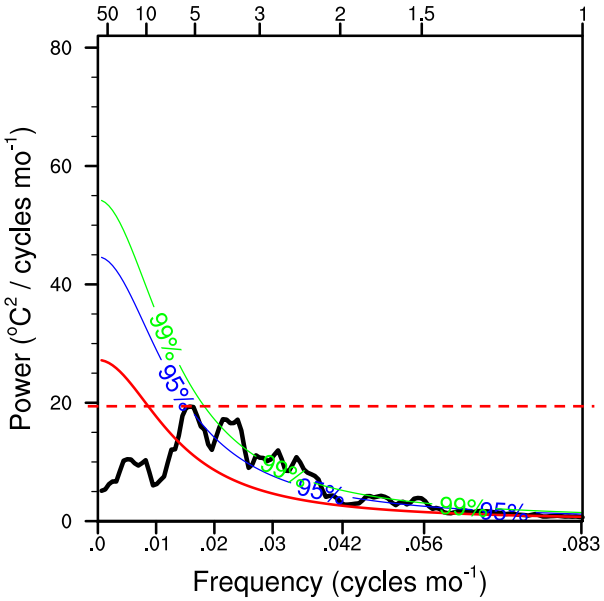
SPPT impact on WWB statistics

- In CCSM4, WWBs are too tightly correlated with SST
  - Overly periodic ENSO
- SPPT reduces correlation, increasing stochasticity of events

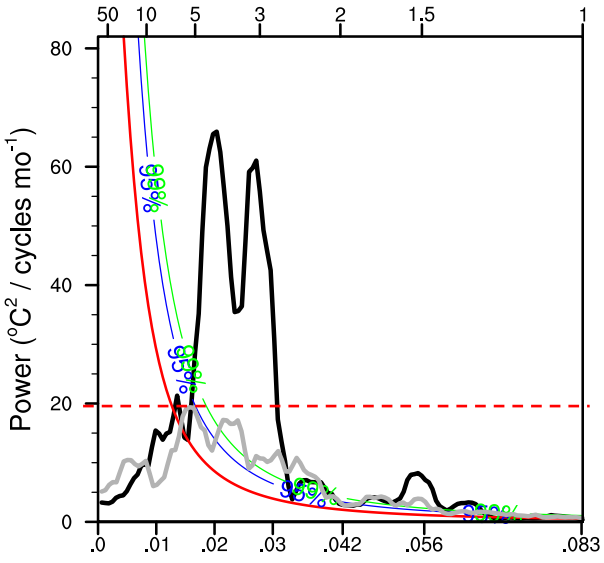


Compare to enhanced resolution

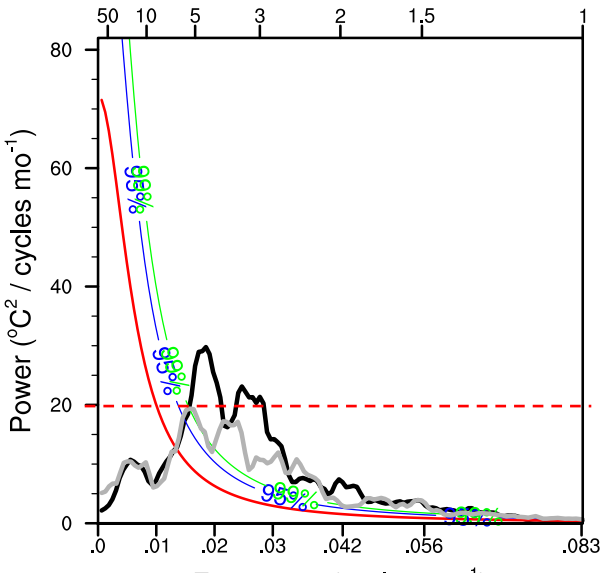
Observations



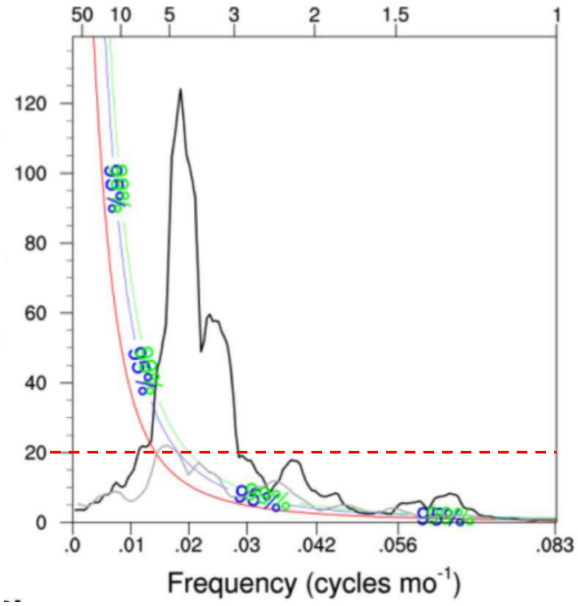
CCSM4



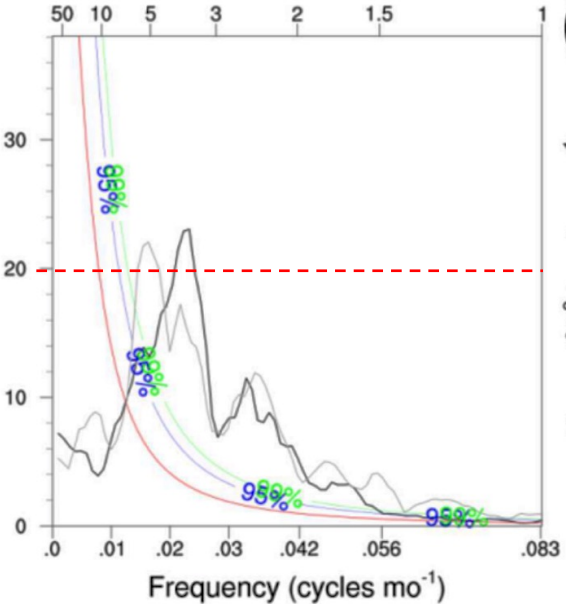
SPPT



CESM: 1° atmos, 1° ocean



CESM: 0.25° atmos, 0.1° ocean

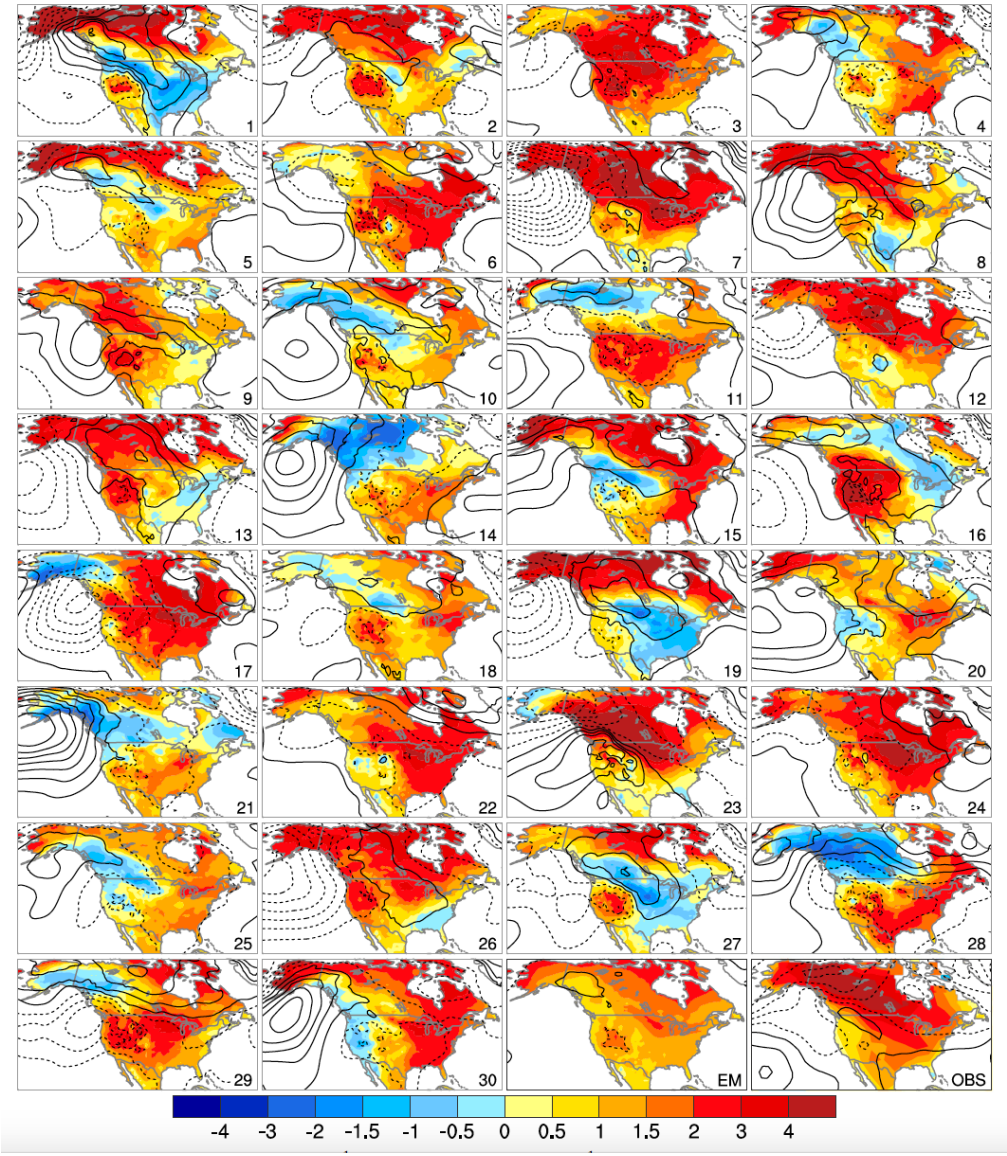


Christensen et al, 2017, J. Climate

Small et al, 2014, JAMES

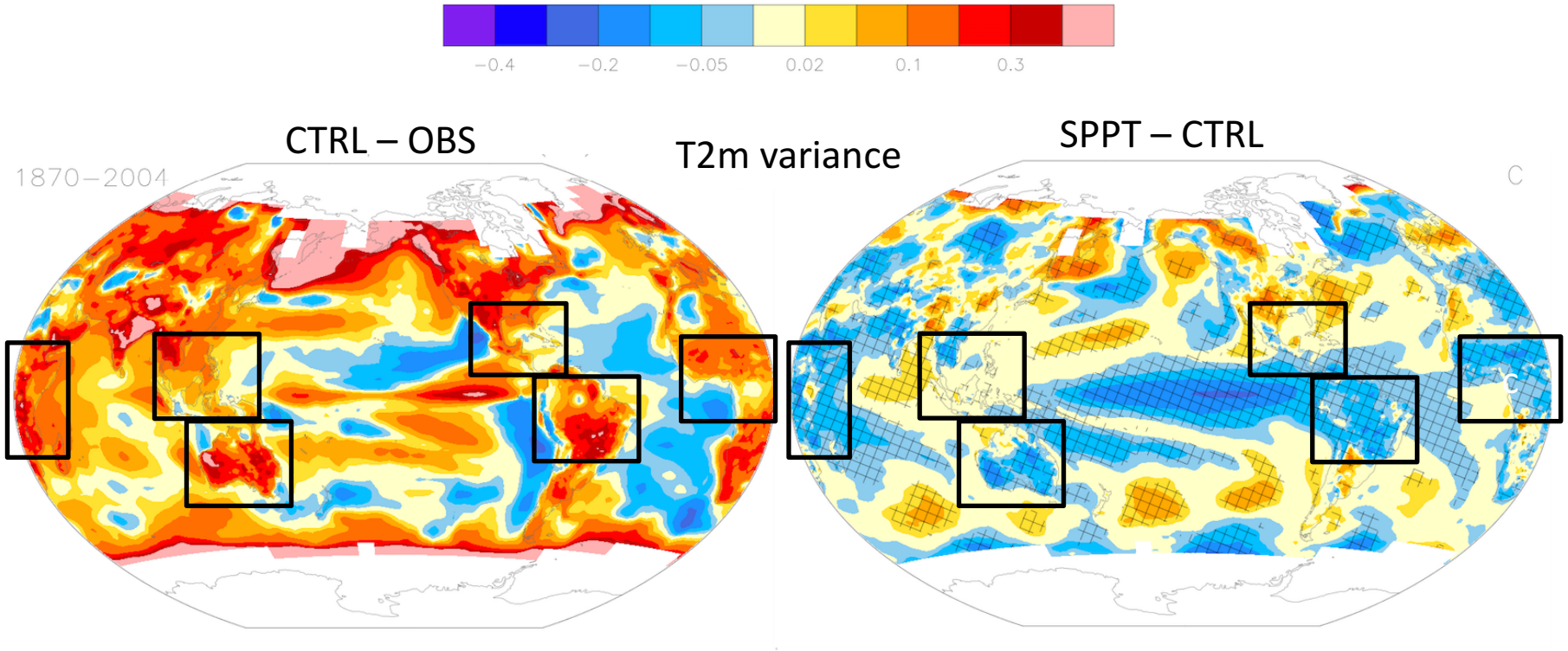
What next? Test in ensemble of climate simulations

- CESM has too much internal variability
  - E.g. NCAR Large Ensemble (LENS)
  - Deser et al, 2016, J. Clim.
- Could a stochastic scheme improve this?
  - Create sister experiment to LENS with stochastic parametrisation

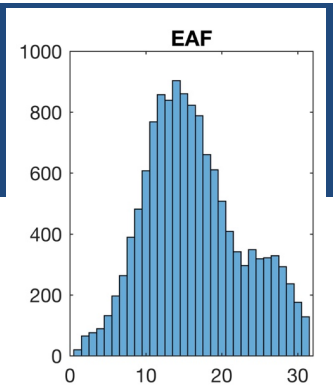


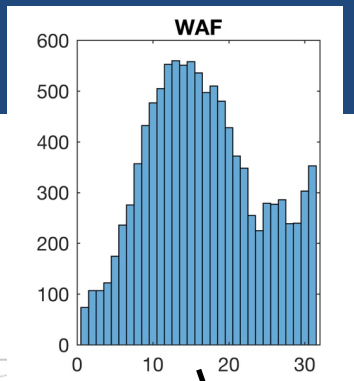
Deser et al,
J. Climate, 2016

SPPT impact on T2m variance



LENS predictions of 20-yr trends

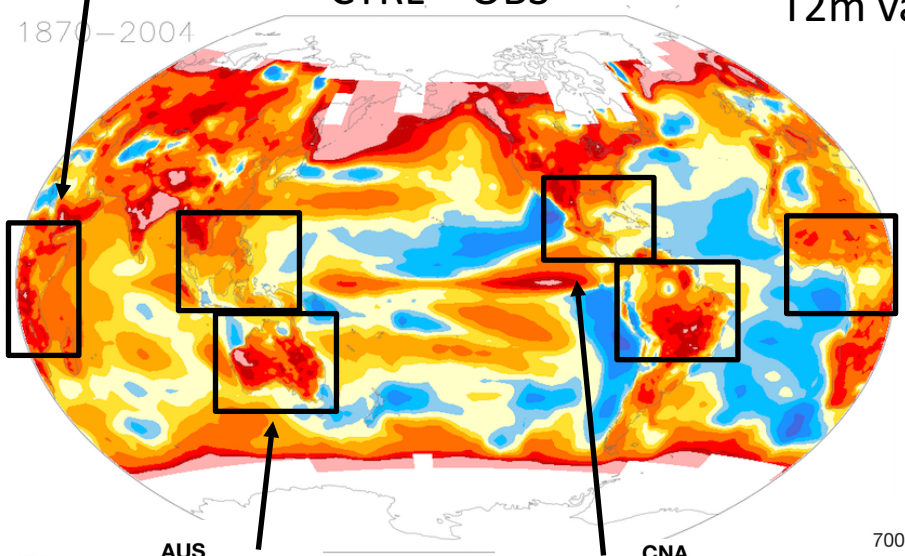


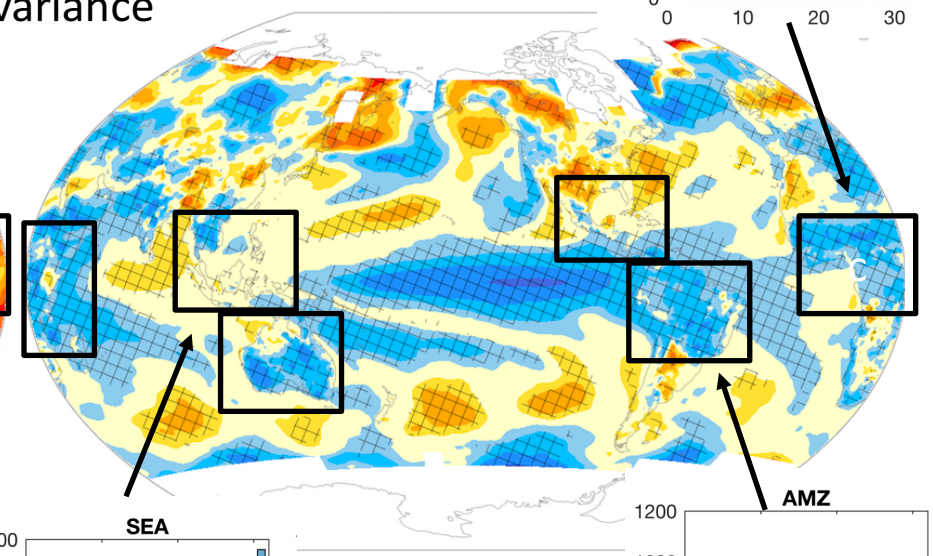


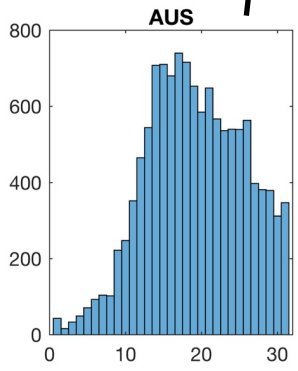
CTRL – OBS

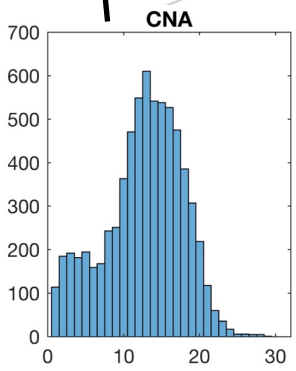
T2m variance

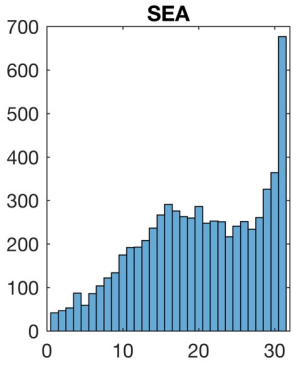
SPPT – CTRL

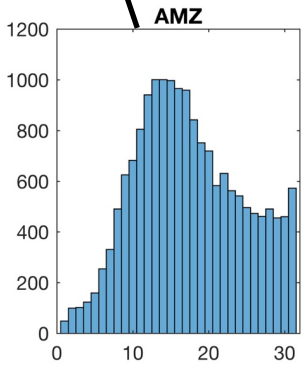








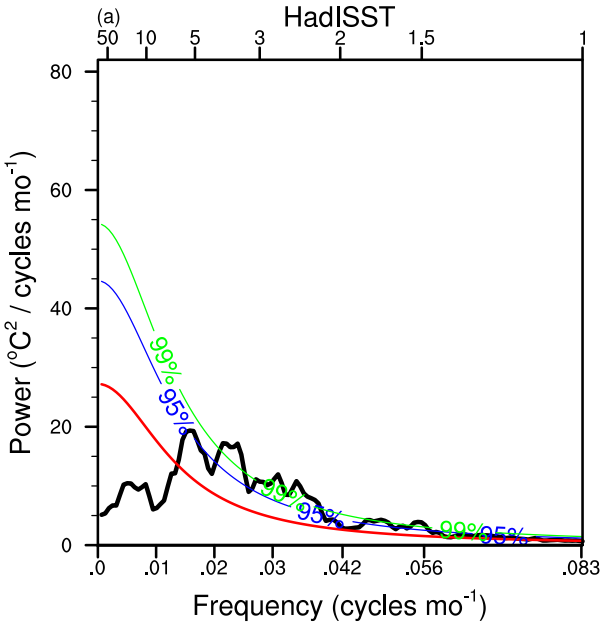


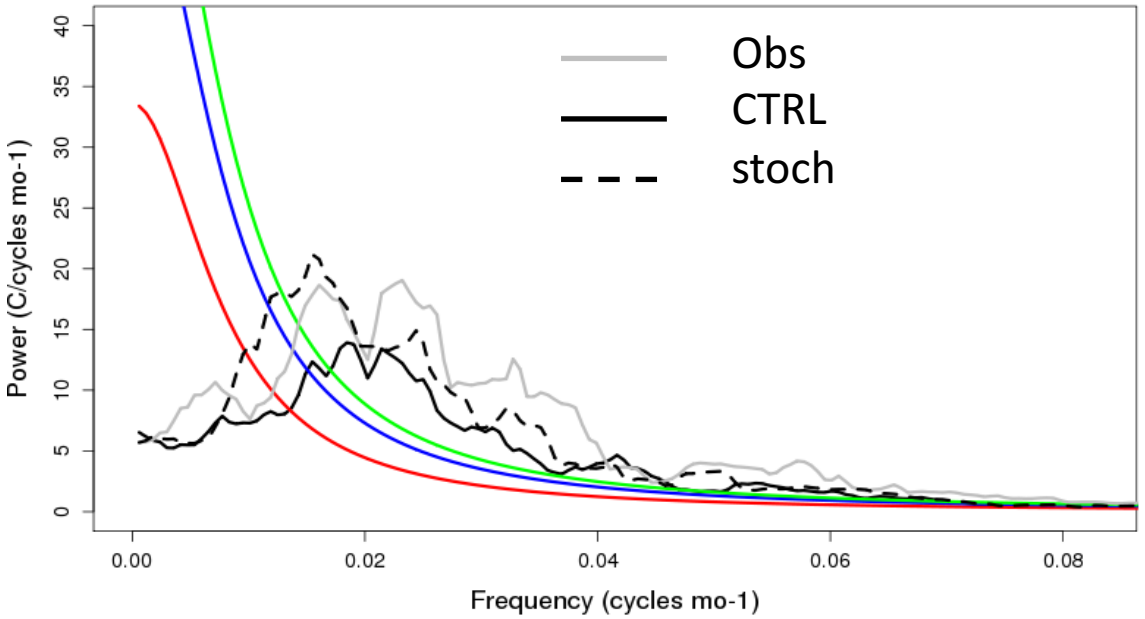


Following van Oldenborgh et al, 2013, ERL.

What next? Consider impact in EC-Earth

Coupled EC-Earth (T255, 1º Nemo), 160 years, 3 ensemble members





Yang, Christensen, Corti, von Hardenberg and Davini, in prep
Davini et al, 2017, GMD

Concluding remarks

- Stochastic parametrisations can alleviate model bias in climate simulations
  - Important to consider biases in mean and variability
  - Some similarities with improvements on increasing resolution

- Future work will consider impact of stochastic schemes on ensembles of climate simulations
- CCSM4 and EC-Earth both show improvements, but in opposite direction
  - What can we learn about deterministic model biases from the way stochastic schemes impact those models?

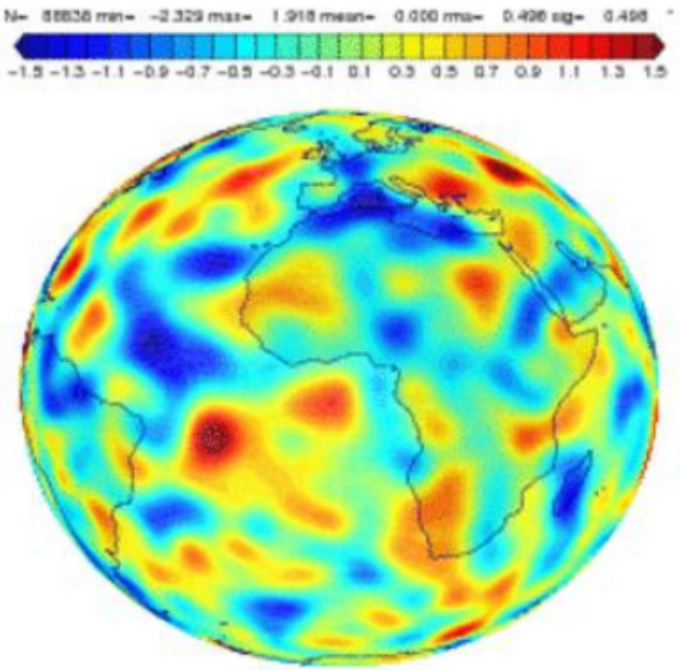
Thanks for listening

References:
Christensen, Berner, Coleman and Palmer, 2017, *J. Climate*
Small et al, 2014, *JAMES*, 6,1065–1094.
Yang, Christensen, Corti, von Hardenberg and Davini, in prep for *GRL*.
Davini et al, 2017, *Geosci. Model Dev*

Perturbation varies smoothly

$$T = D + (1+e)\sum_{i=1} P_i$$

T – Total tendency
D – Dynamics tendency
P – Physics tendency

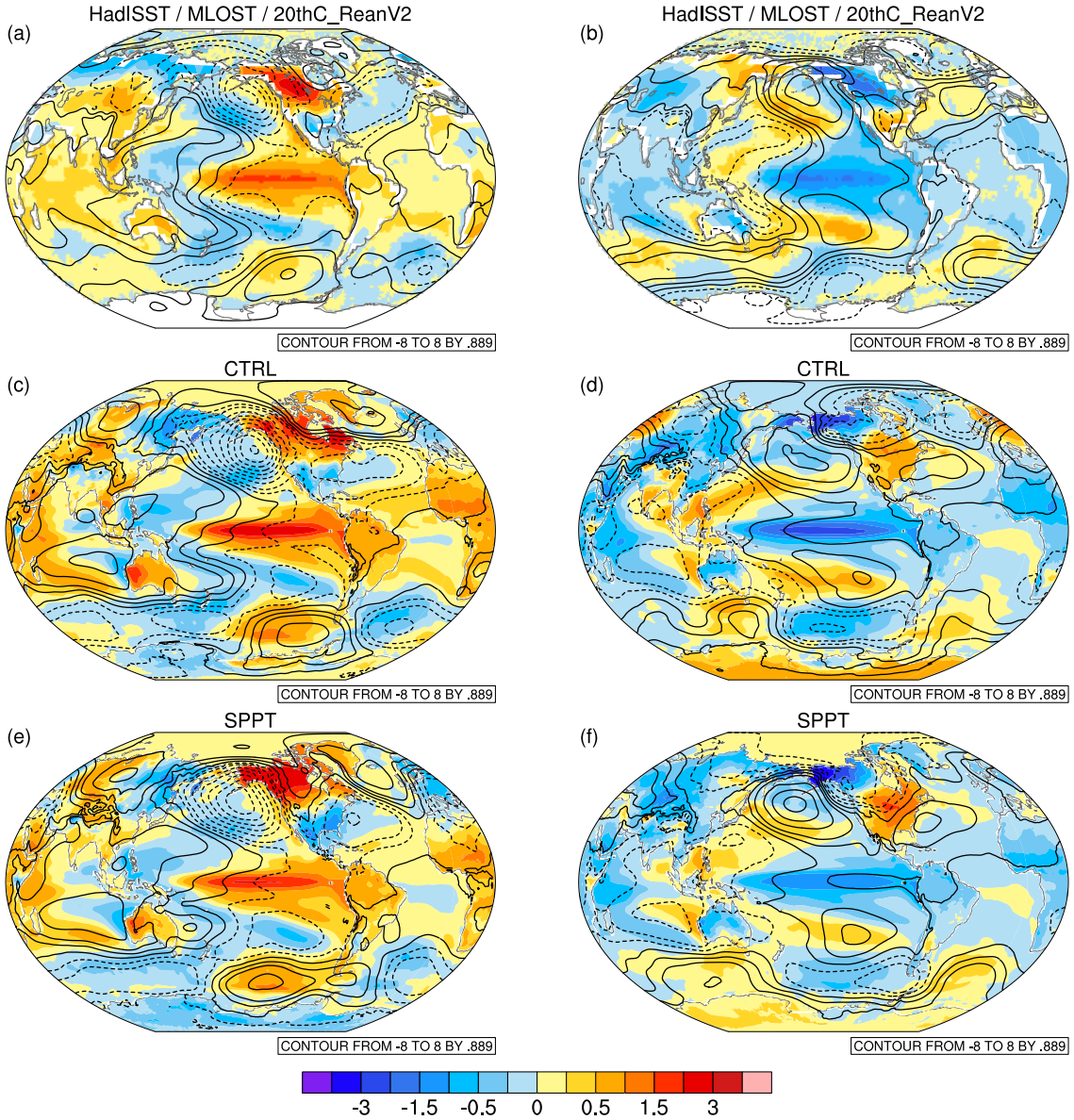


Pattern correlated in space: 500km length scale
AR(1) process in time: 6hr decorrelation

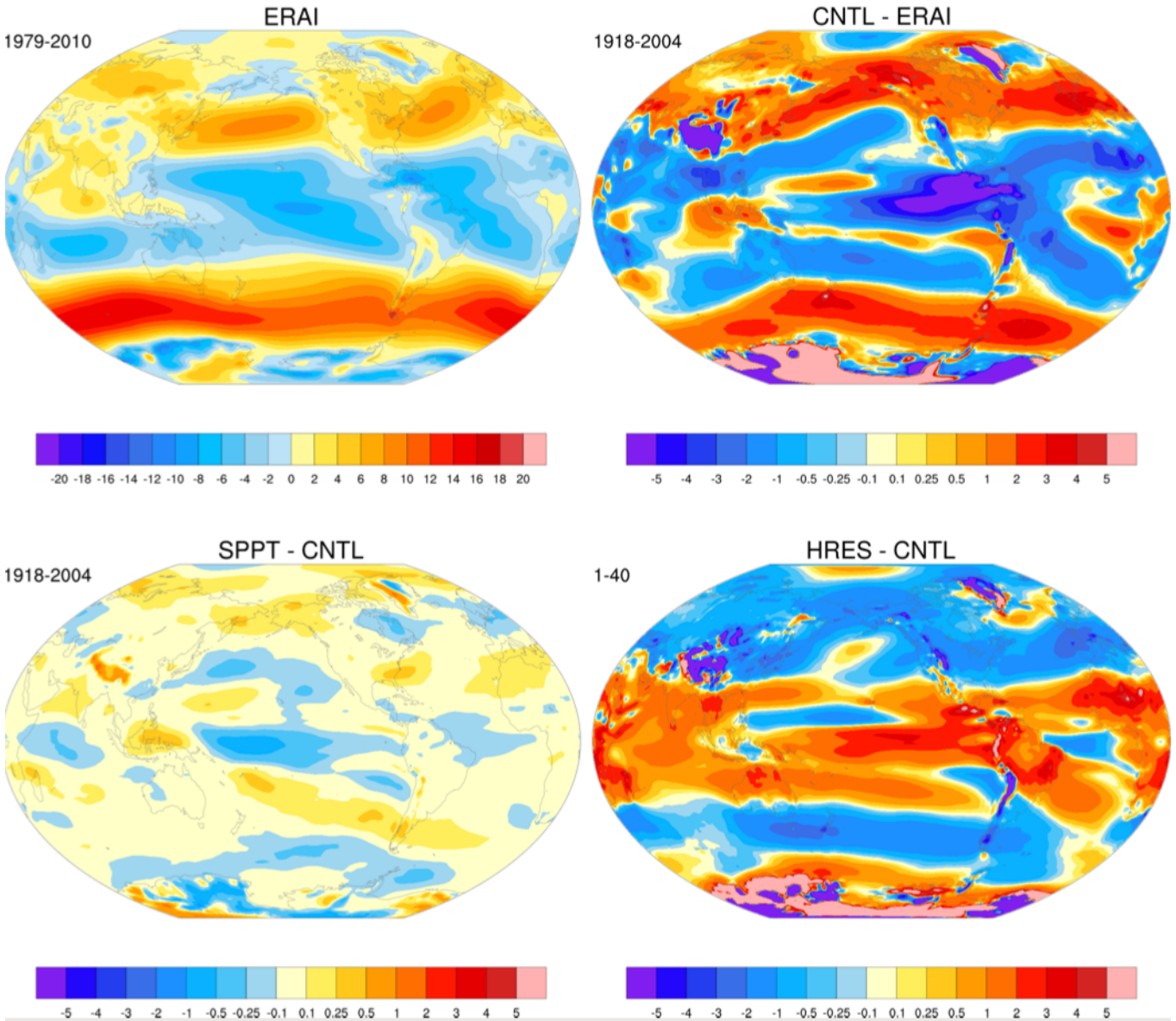
All schemes are perturbed using same pattern.
All variables perturbed using same pattern.
Pattern constant in height

Palmer et al, 2009.
ECMWF Tech Memo 598

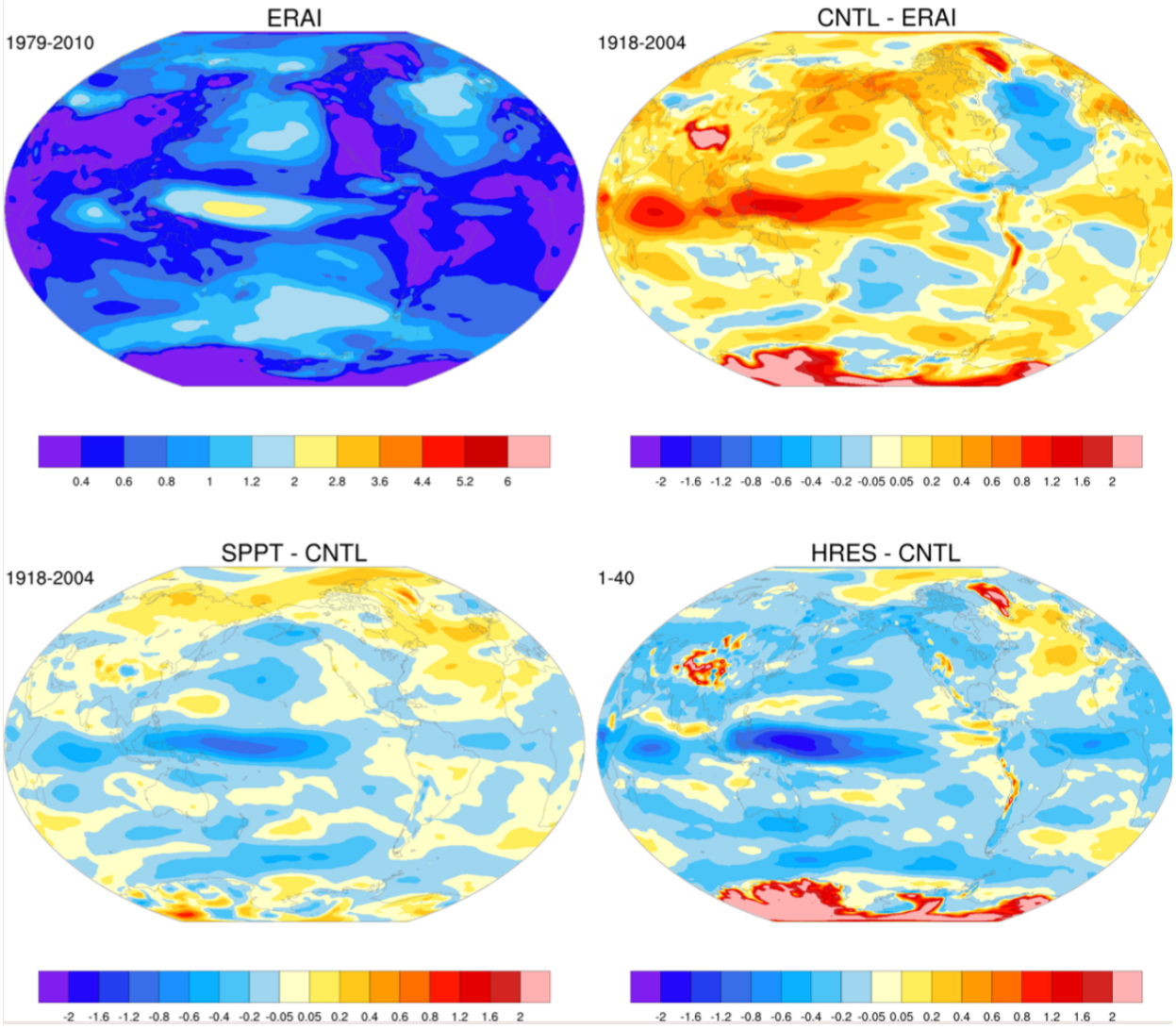
Impact on El Nino smaller than on La Nina



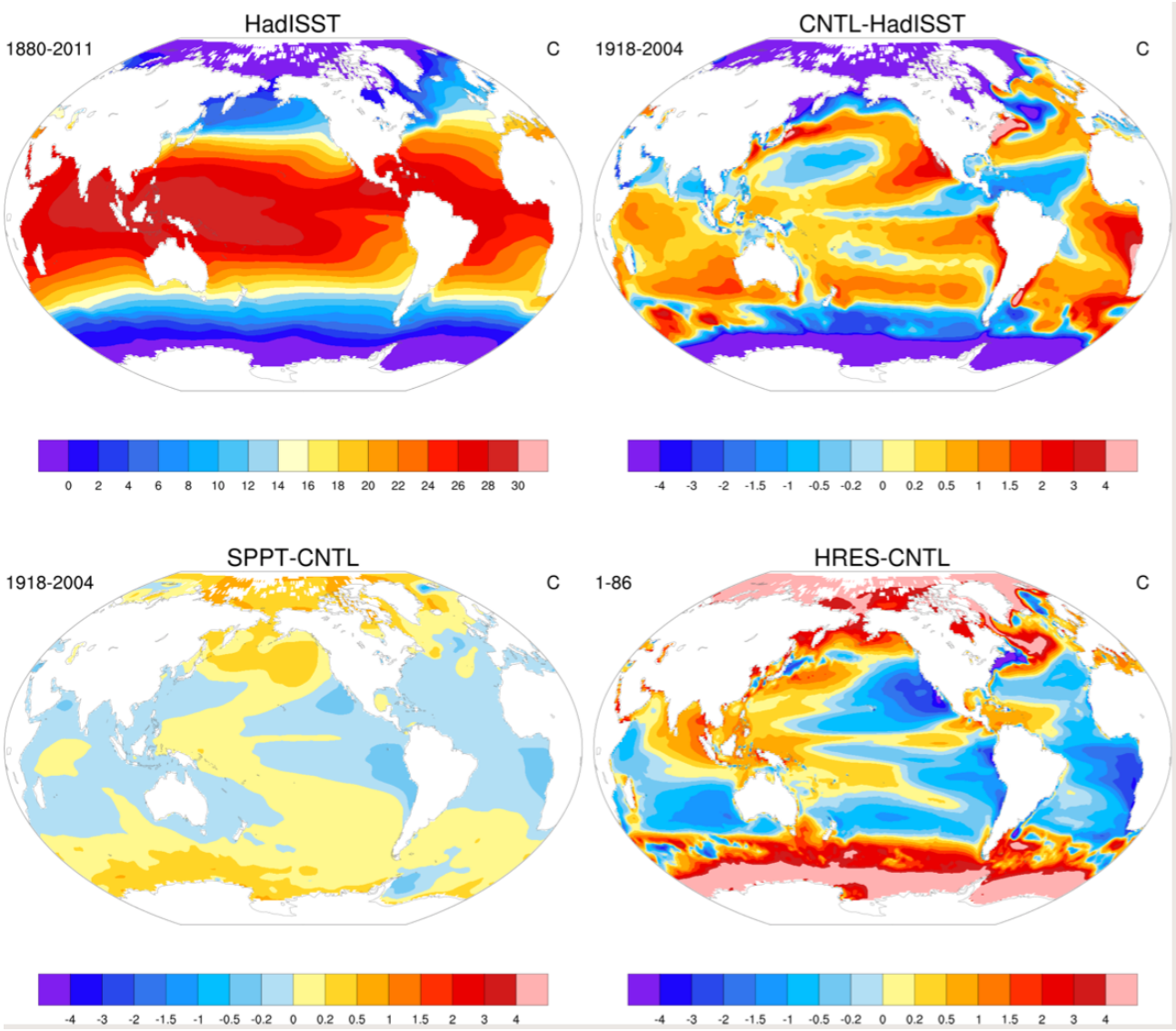
SPPT vs enhanced resolution: mean U850



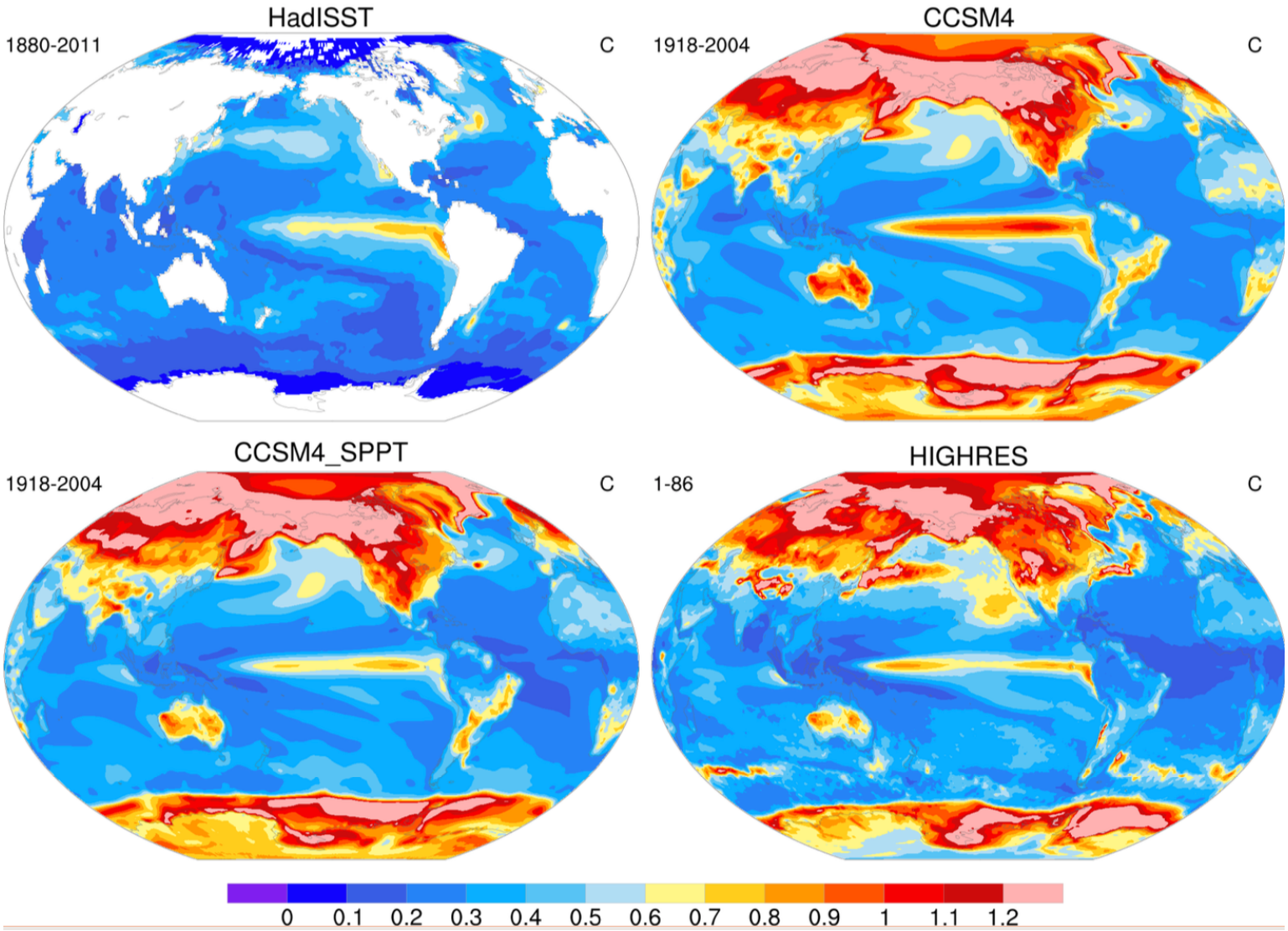
SPPT vs enhanced resolution: U850 variability



SPPT vs enhanced resolution: mean SST



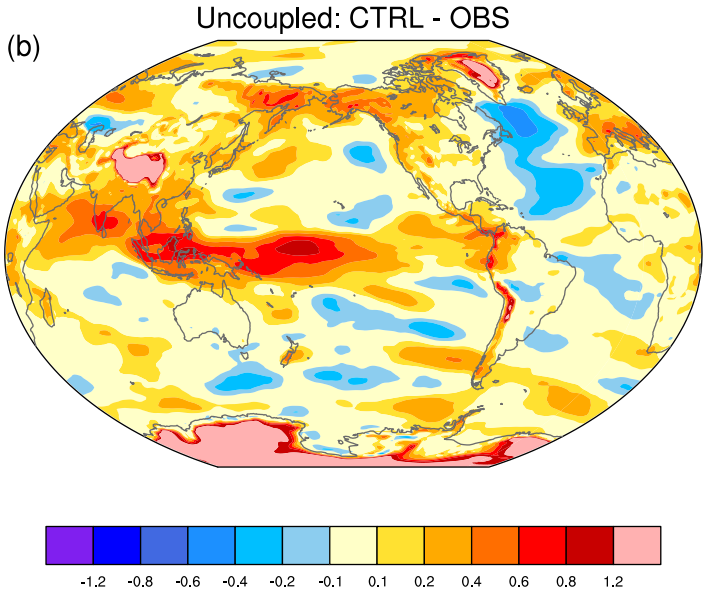
SPPT vs enhanced resolution: SST variability



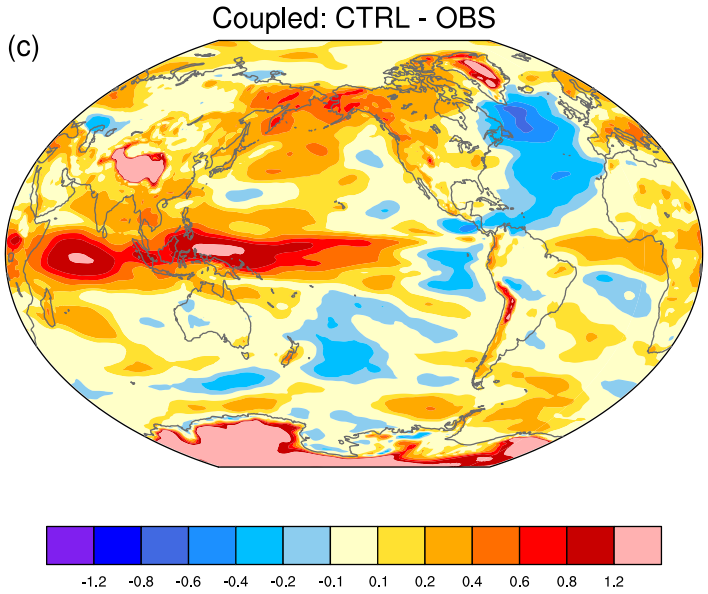
Uncoupled

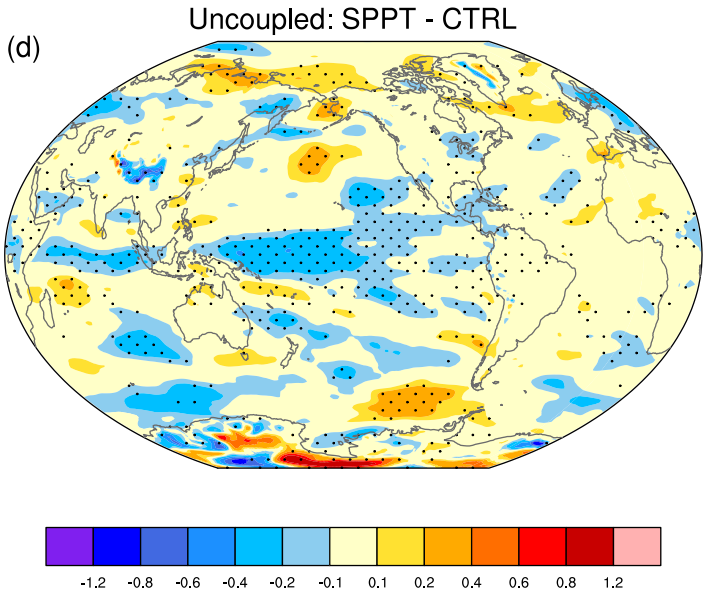
U850

Coupled

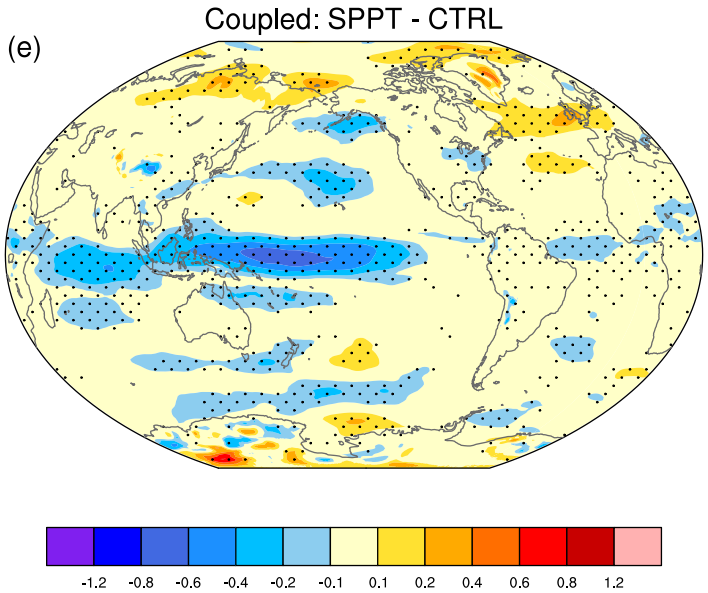


CNTL - OBS





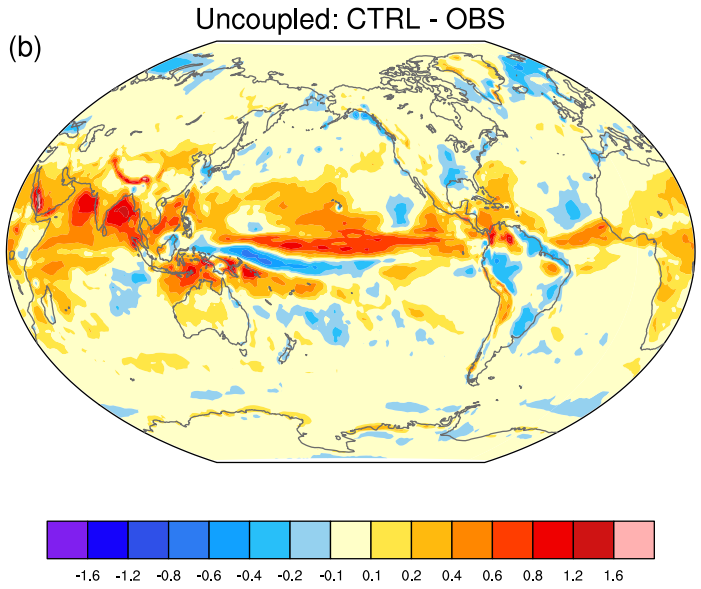
SPPT - CNTL



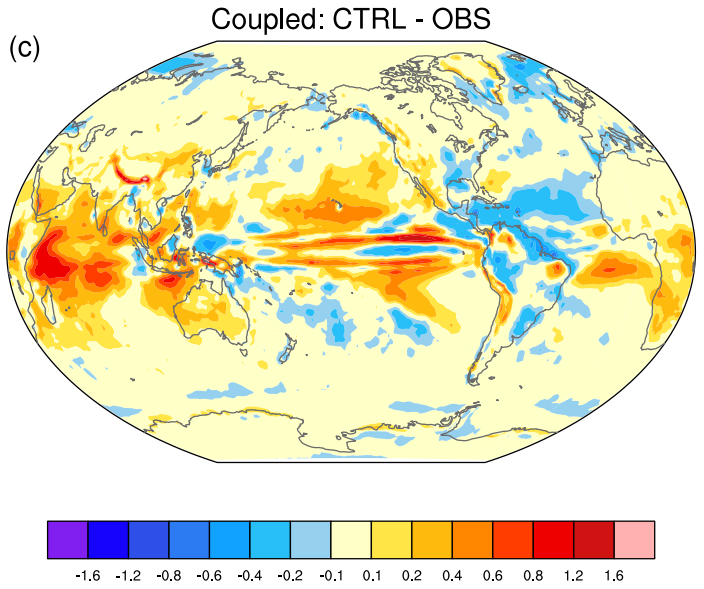
Uncoupled

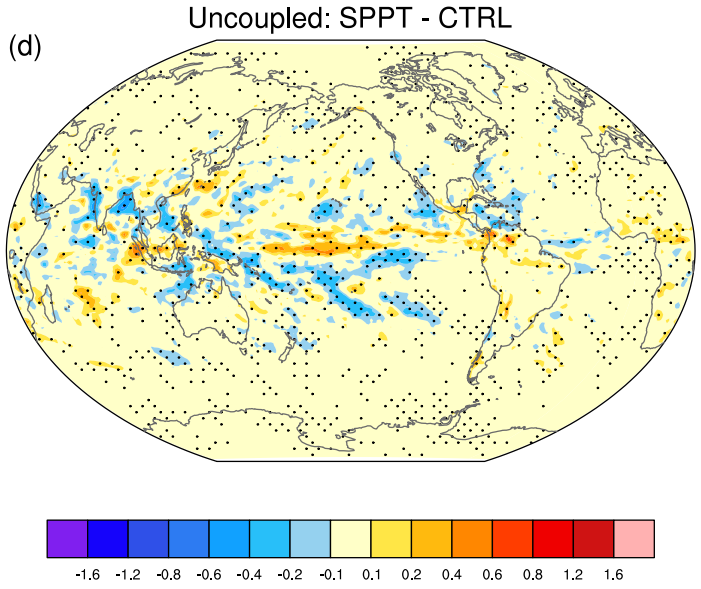
Precip

Coupled

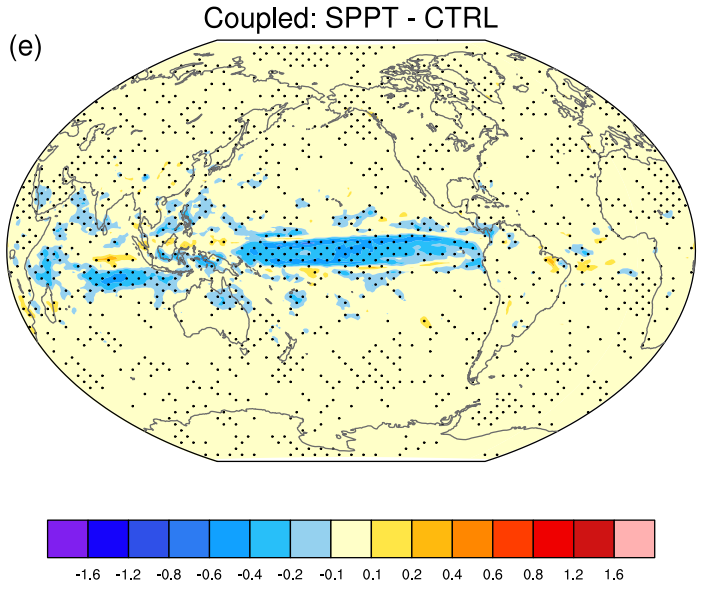


CNTL - OBS





SPPT - CNTL



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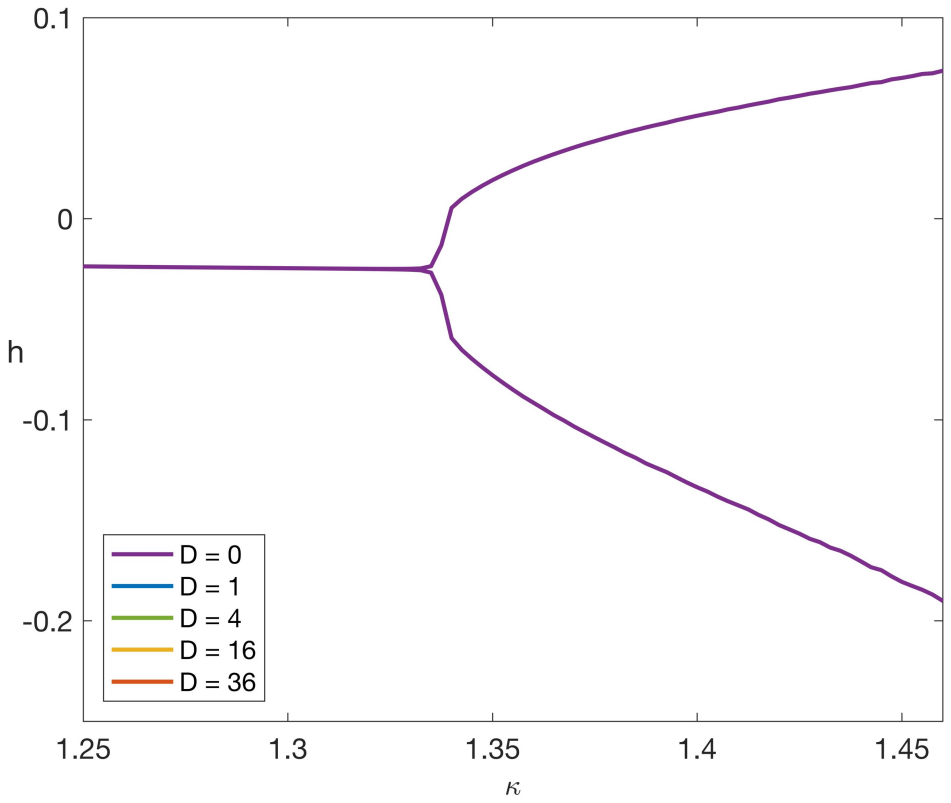
- Impact of multiplicative noise in a simple DO model of ENSO can provide insights



Christensen et al, 2017, J. Climate

Yang, **Christensen**, Corti, von Hardenberg and Davini, in prep

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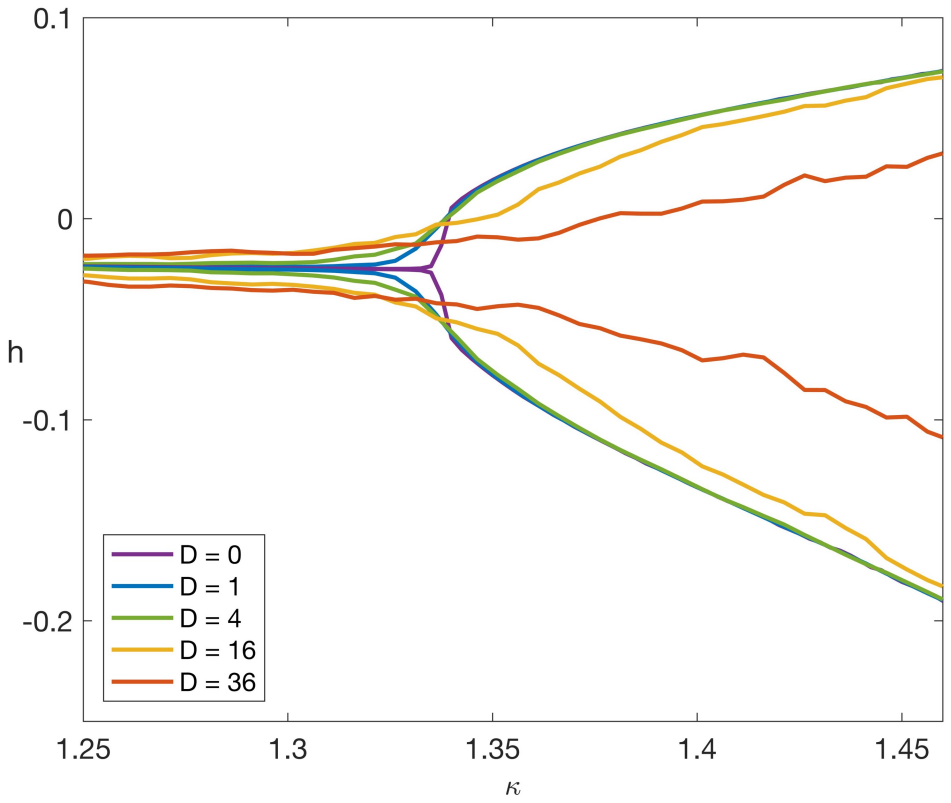

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