Employing stochastic ocean parametrization to include uncertainty estimates and subgrid-scale variability in global ocean models

Met Office HRCP Workshop

Stephan Juricke

15th April 2016

Tim Palmer, Laure Zanna

Overview

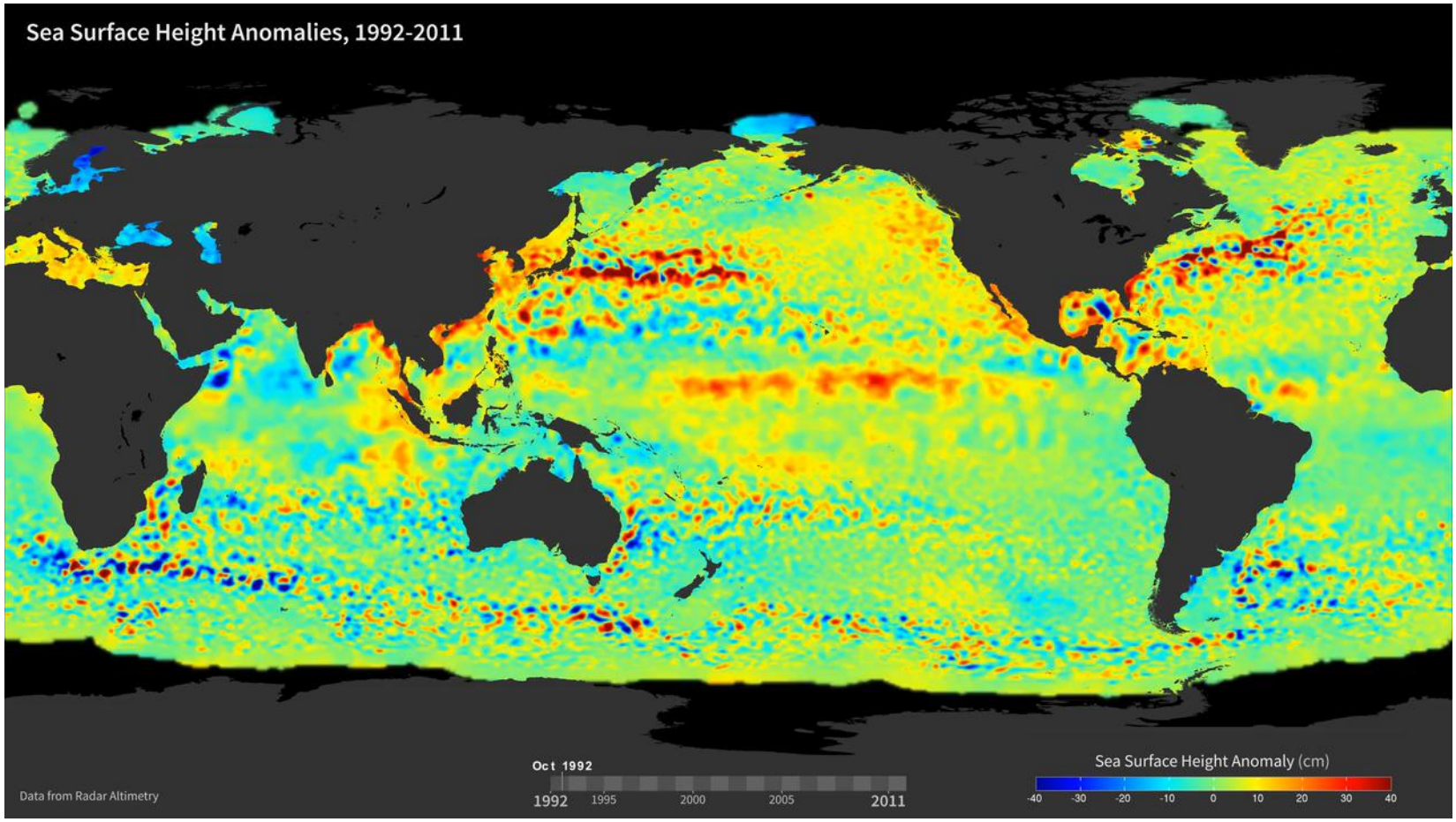
1. Introduction: Sub-grid scale variability and model uncertainty

2. Stochastic parametrization approach

3. Results

4. Conclusions & Outlook

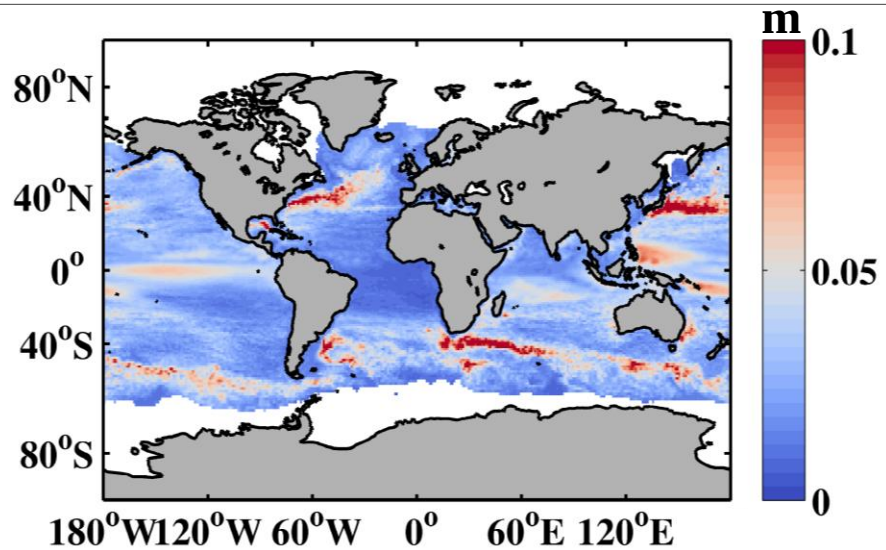
Introduction



http://svs.gsfc.nasa.gov/cgi-bin/details.cgi?aid=30502

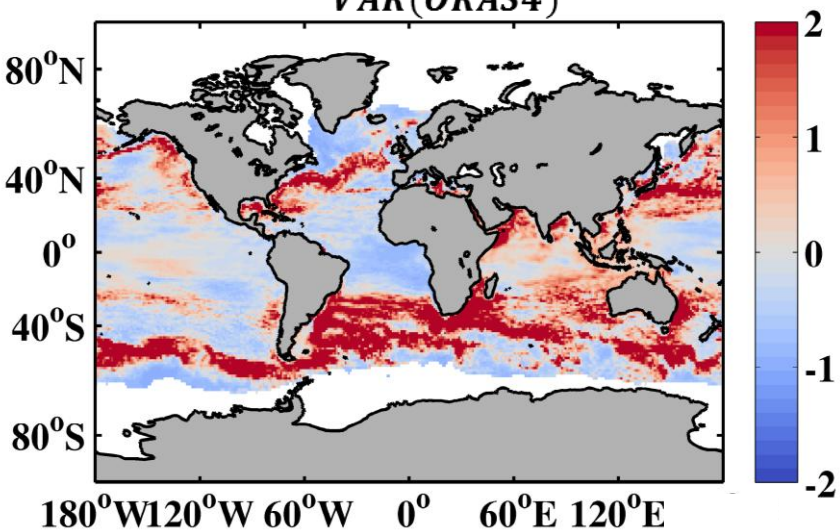
Introduction

AVISO standard deviation of annual mean SSH, 1993-2013

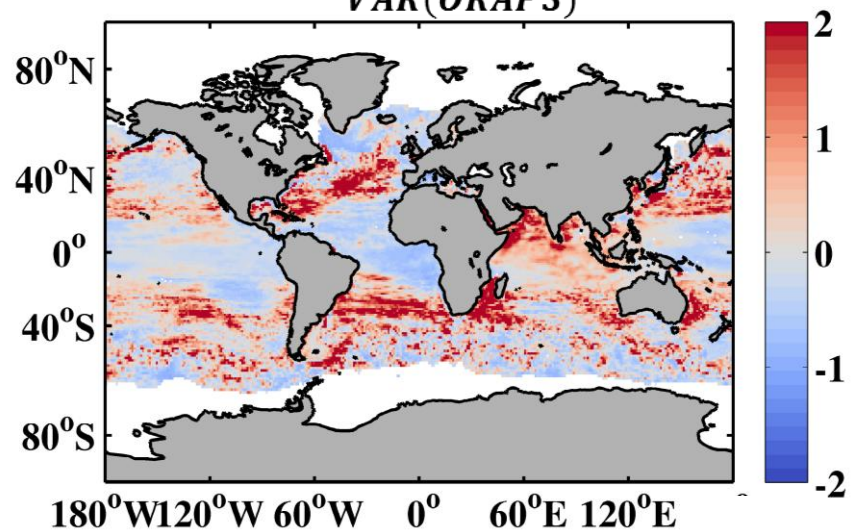


Relative difference in variance of annual mean SSH

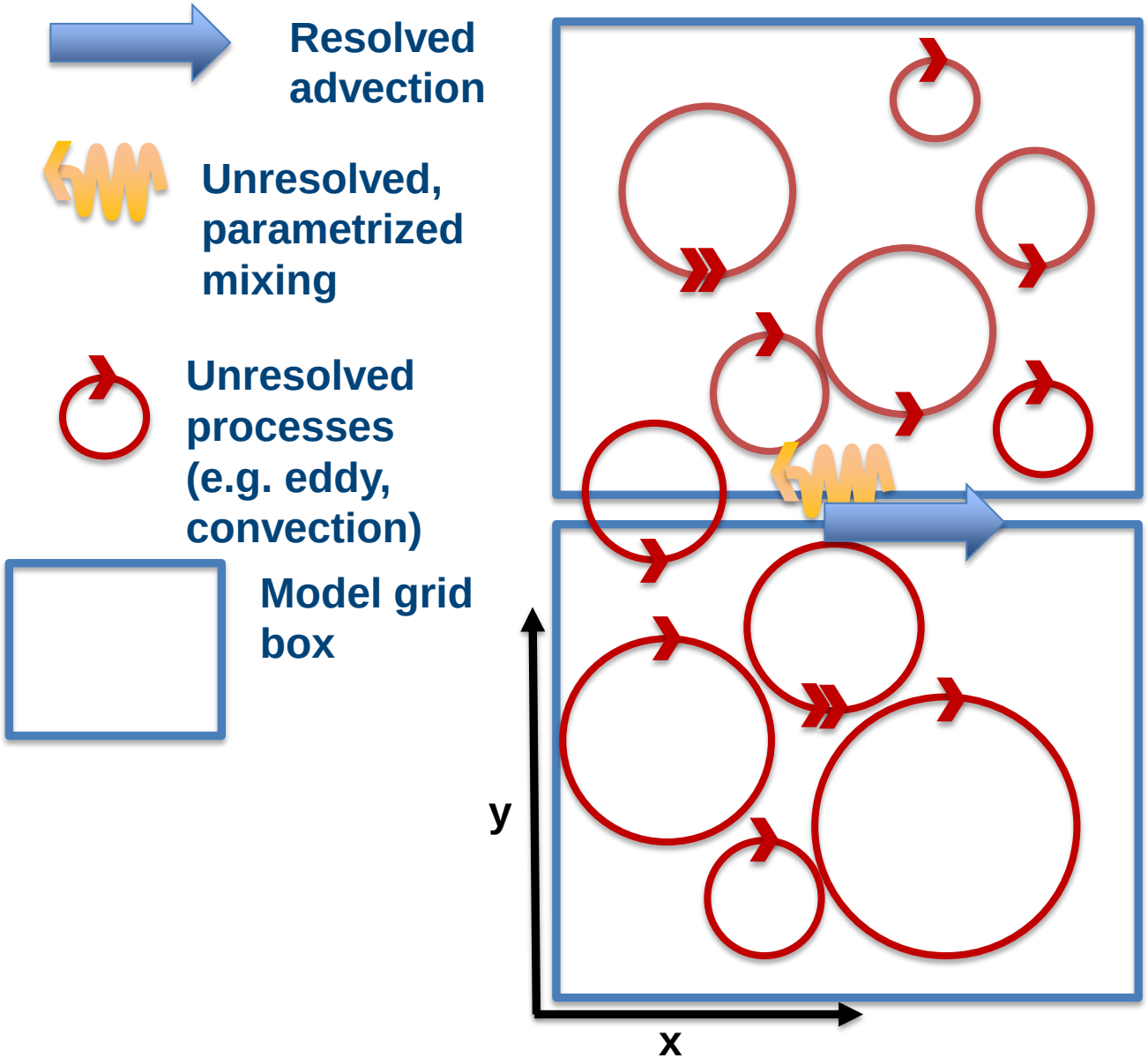
$$\frac{VAR(AVISO) - VAR(O}{VAR(ORAS4)}$$



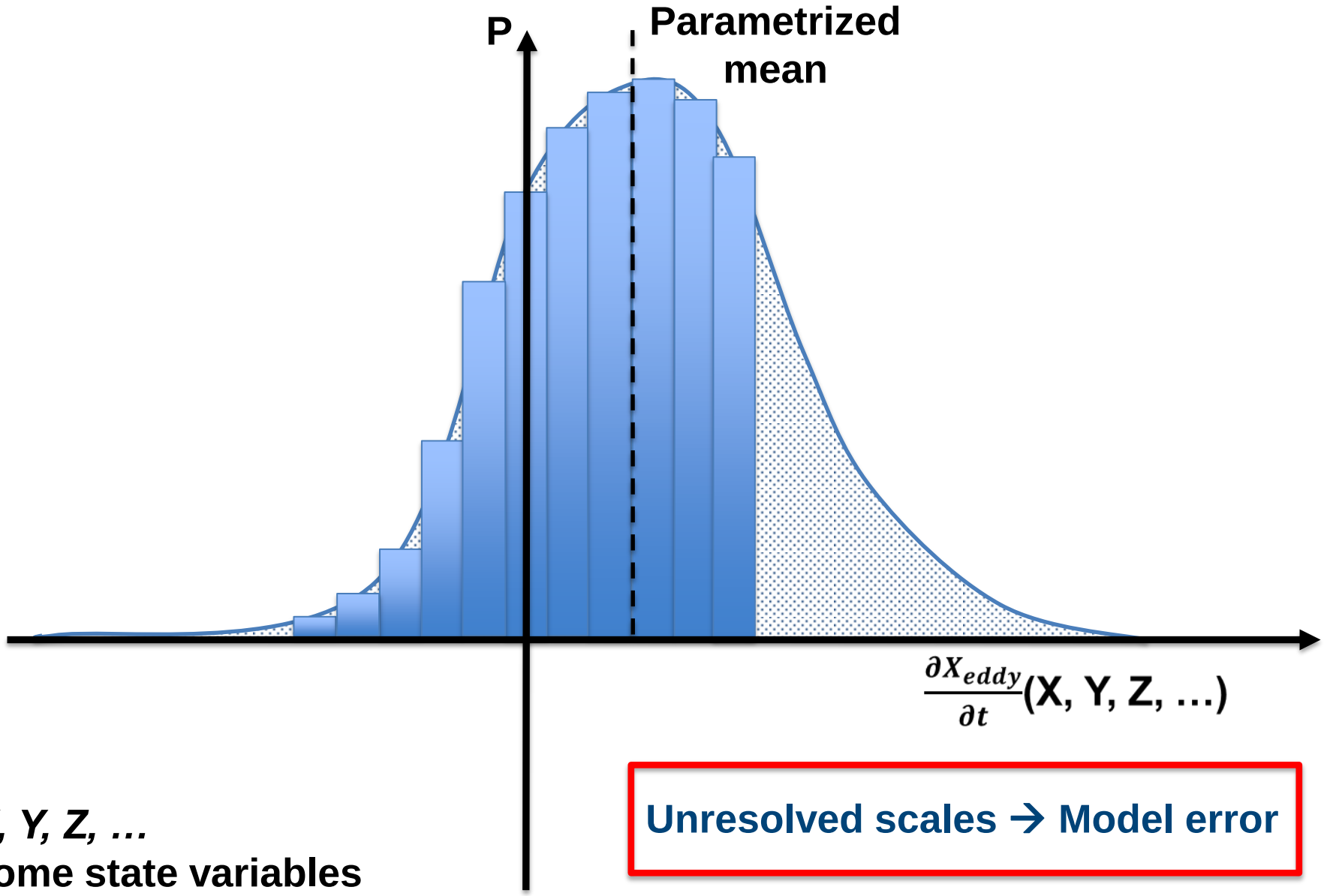
$$\frac{VAR(AVISO) - VAR(O}{VAR(ORAP5)}$$



Introduction



Introduction



X, Y, Z, …
some state variables

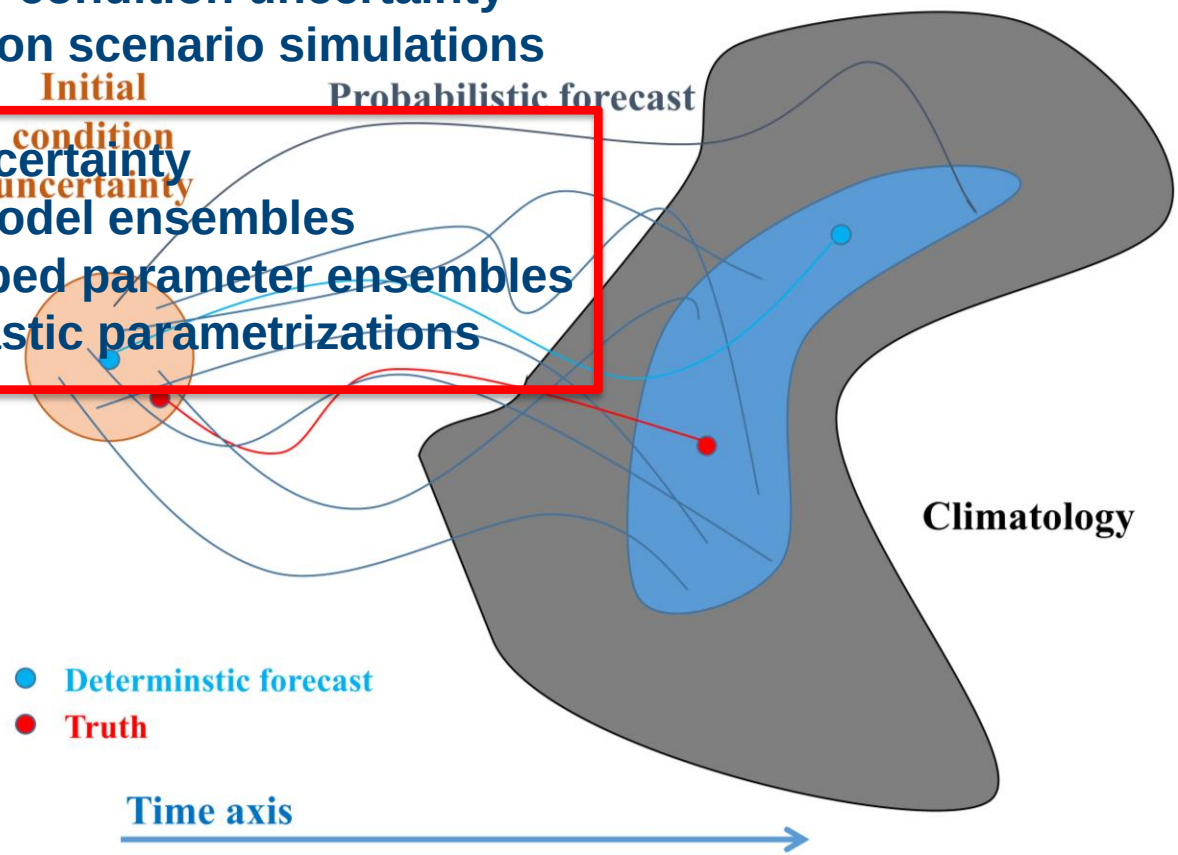
Unresolved scales → Model error

Introduction

1. **Initial condition uncertainty**
   → Ensemble simulation with initial condition perturbations

2. **Boundary condition uncertainty**
   → Emission scenario simulations

3. **Model uncertainty**
   → Multimodel ensembles
   → Perturbed parameter ensembles
   → Stochastic parametrizations



Stochastic parametrization

UNIVERSITY OF OXFORD

Aim is to:

1. Represent uncertainty in unresolved scales
2. (Re-) Introduce sub-grid scale variability

General approach:

Perturbations to crucial and imperfectly constrained parameters and/or tendencies in established parametrizations

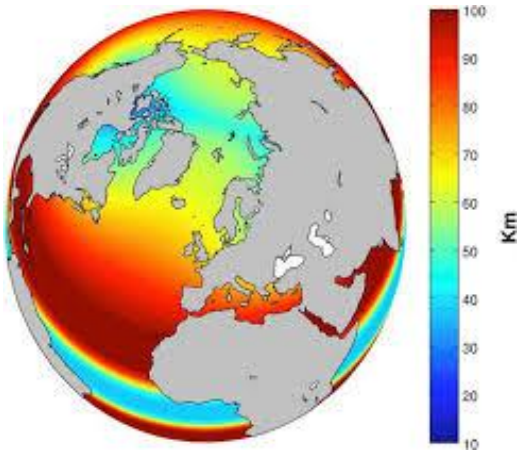
For example:

$$P(i,j) = \left(1 + x(i,j)\right) \cdot P_{ref}(i,j)$$

Stochastic parametrization

Model configuration:

- **NEMO v3.3**
- **1° Resolution ORCA1L46 grid**
- **DFS atmospheric forcing for uncoupled simulations**



Stochastic parametrization

UNIVERSITY OF OXFORD

Stochastic peturbations to:

1. **Gent-McWilliams coefficient**
2. **Enhanced vertical diffusivity in case of unstable stratification**
3. **Shear and buoyancy tendencies in the prognostic equation of turbulent kinetic energy used to parametrize vertical viscosity and diffusivity**

Example: Prognostic equation for temperature:

$$\frac{\partial T}{\partial t} = -\nabla\left(T\left(\vec{U} + \vec{U}_{eddy}\right)\right) + D_T + F_T$$

with 3D velocity U, parametrized eddy velocity U_{eddy}, parametrized temperature tendencies D_T and forcing F_T

Gent-McWilliams eddy induced velocity (*u* component): $\mathbf{u_g} = -\frac{\partial}{\partial z}(A\,S)$

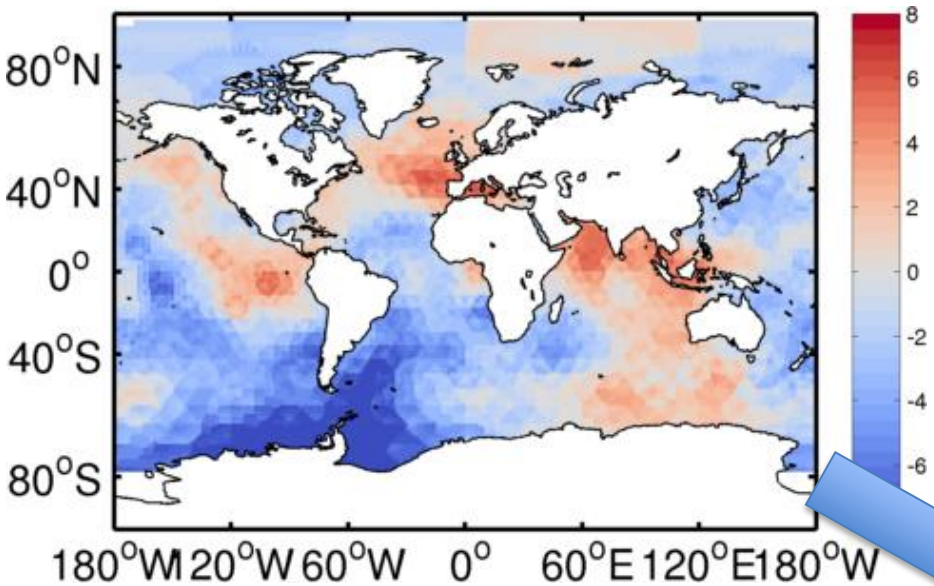
with A eddy induced velocity coefficient, S slope of isoneutral surfaces (with regard to geopotential surfaces) → formulation is non-divergent, adiabatic

$$\Rightarrow \mathbf{u_g} = -\frac{\partial}{\partial z}\left((1 + r_{GM}) * A\,S\right)$$

with random number r_{GM}

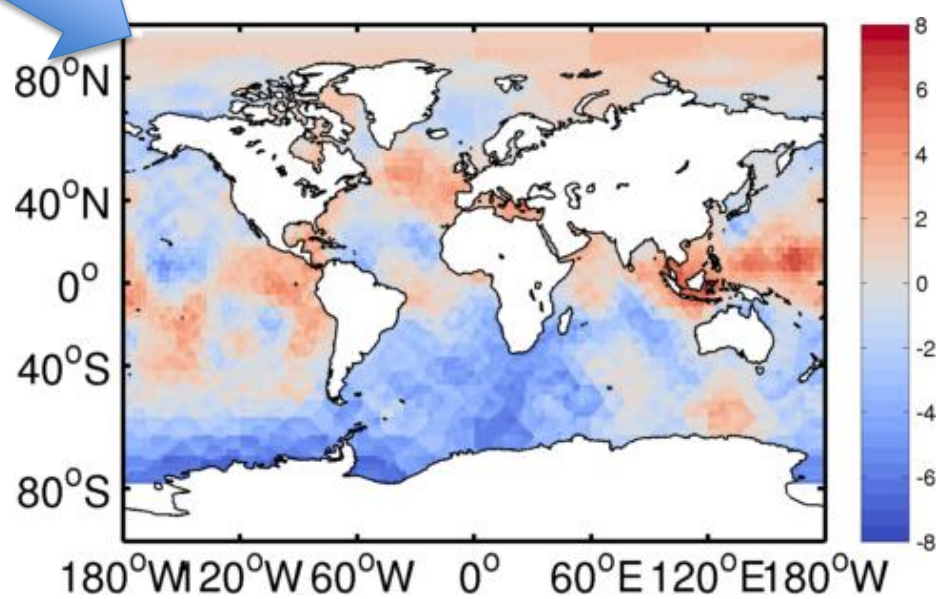
Stochastic parametrization

UNIVERSITY OF OXFORD



Day 1

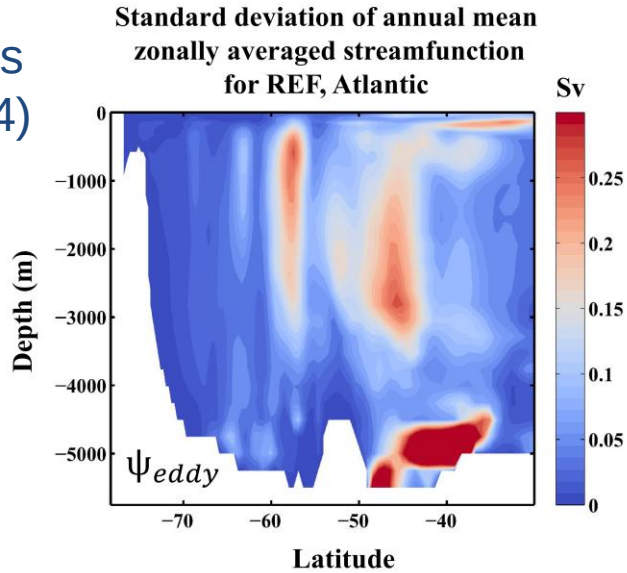
Stochastic pattern with temporal and spatial correlation, before transformation into bounded range

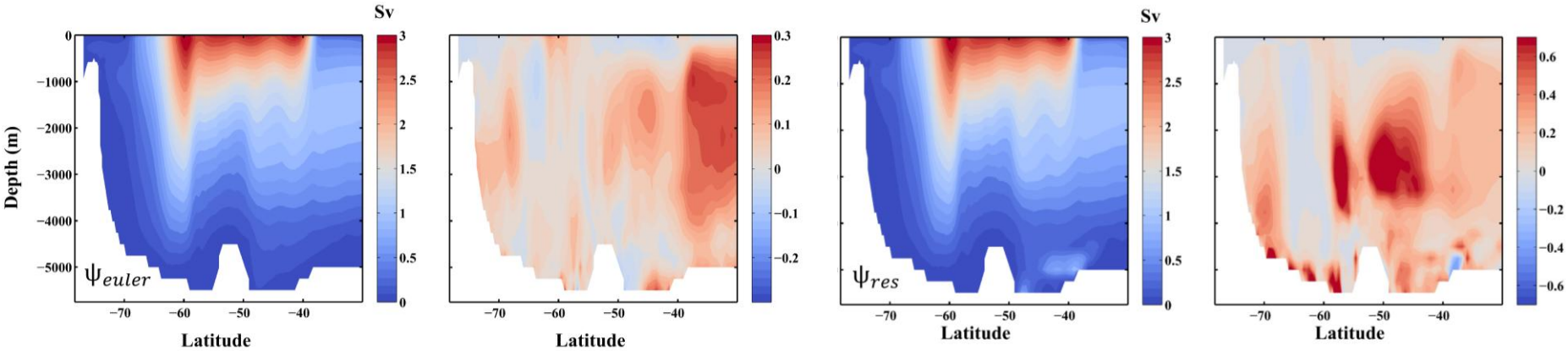


Day 2

Results: Uncoupled

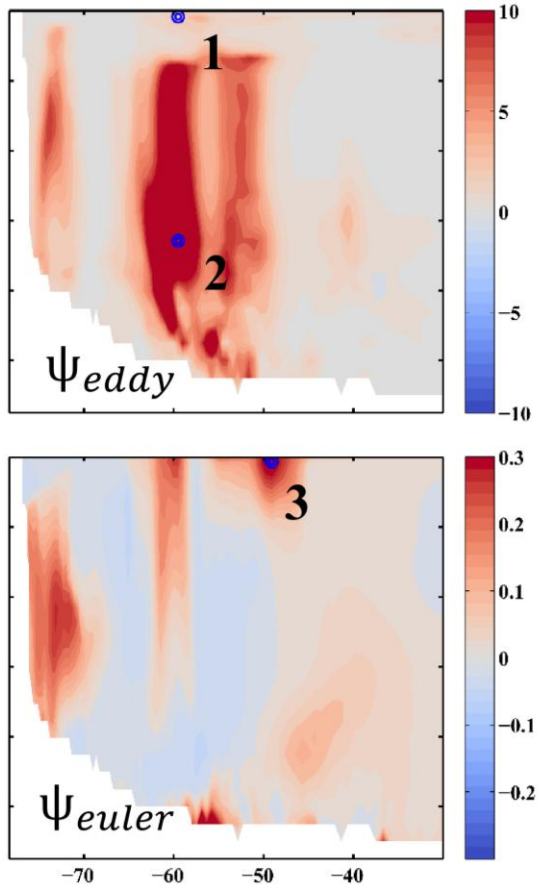
105 years, repeated cycles
(1990-2004, 2x 1960-2004)



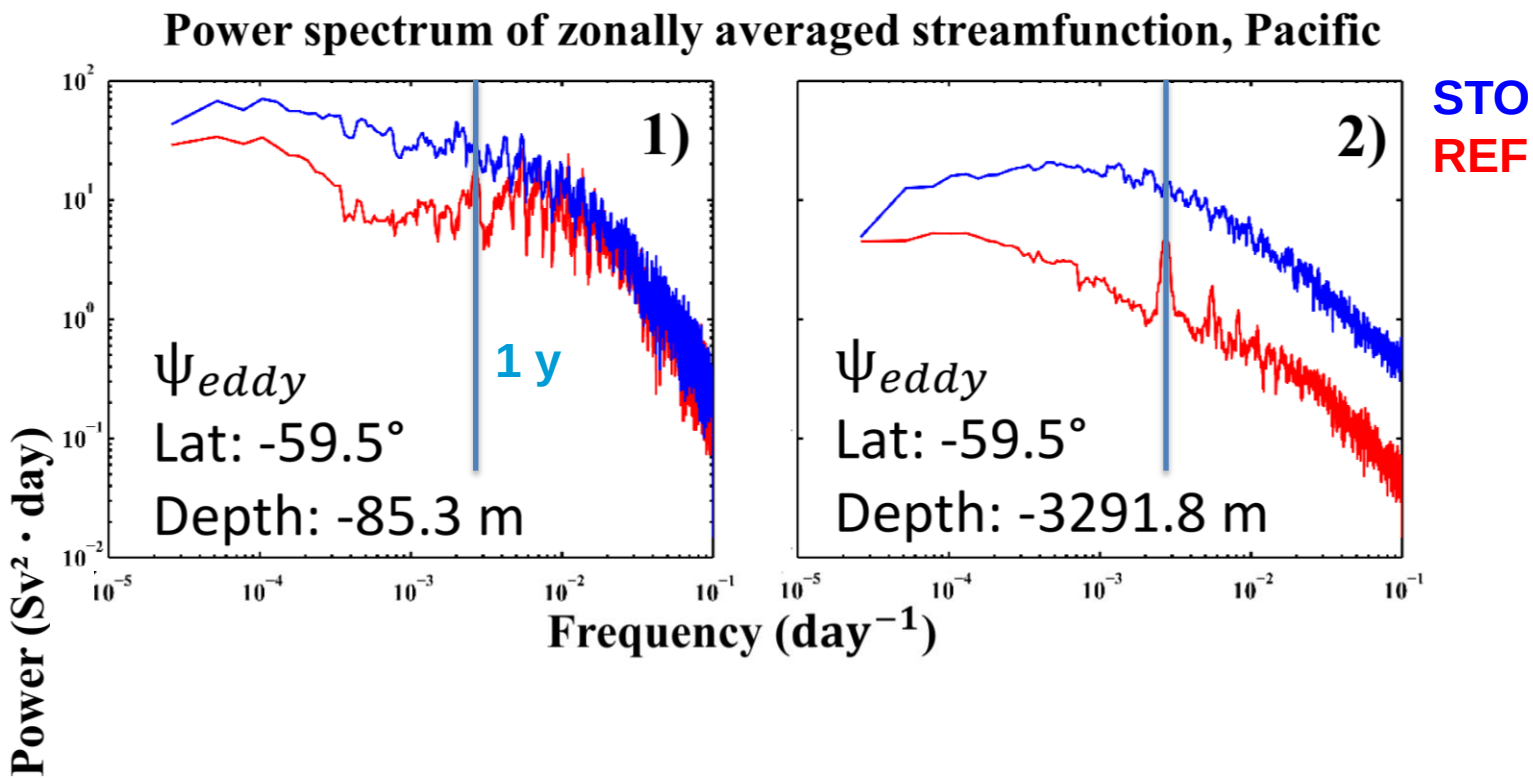


Results: Uncoupled

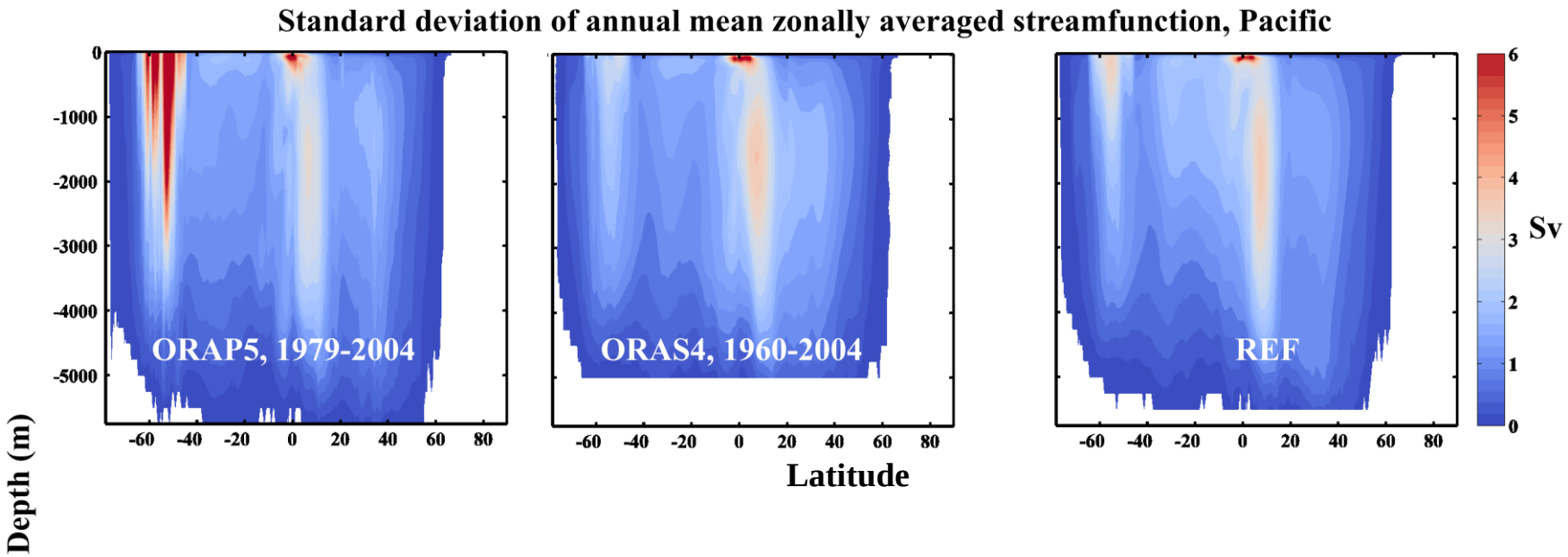
Relative change in variance of annual mean zonally averaged streamfunction between REF and STO, Pacific



Results: Uncoupled

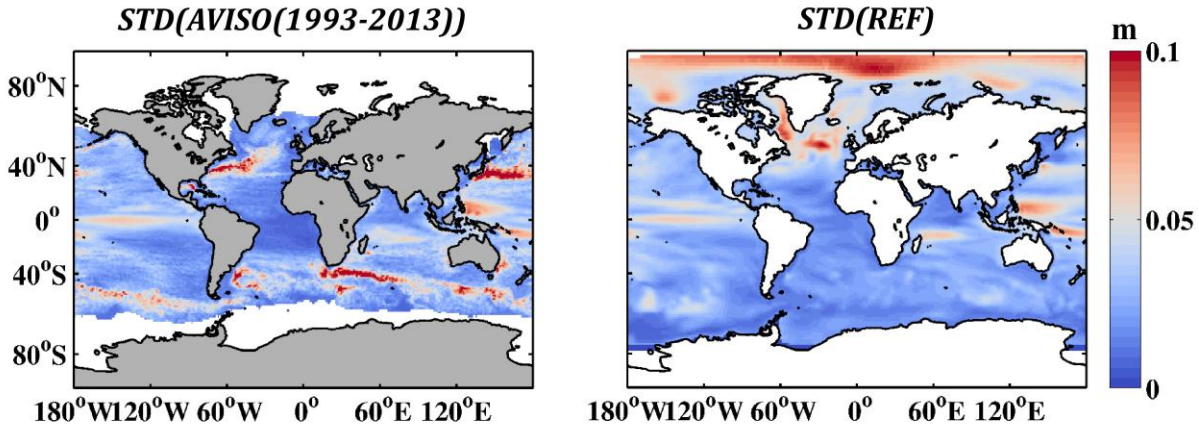


Results: Uncoupled



Results: Uncoupled

Standard deviation and relative difference in variance of annual mean SSH



Conclusions

- **Stochastic mixing schemes introduced to represent sub-grid scale variability and model uncertainty**
- **Improvement in low frequency variability (compared to OBS and reanalysis) of circulation as well as sea surface height (up to 20 to 30% increase in variance)**
- **Potential improvements on representation of low frequency climate modes → Improved mean, variance, and response to forcing without the computational cost of higher resolution**
- **The basics physical principles are not violated (adiabatic, non-divergent GM for example)**
- **Increase in ensemble variance for seasonal forecasts (around 30%)**

Outlook

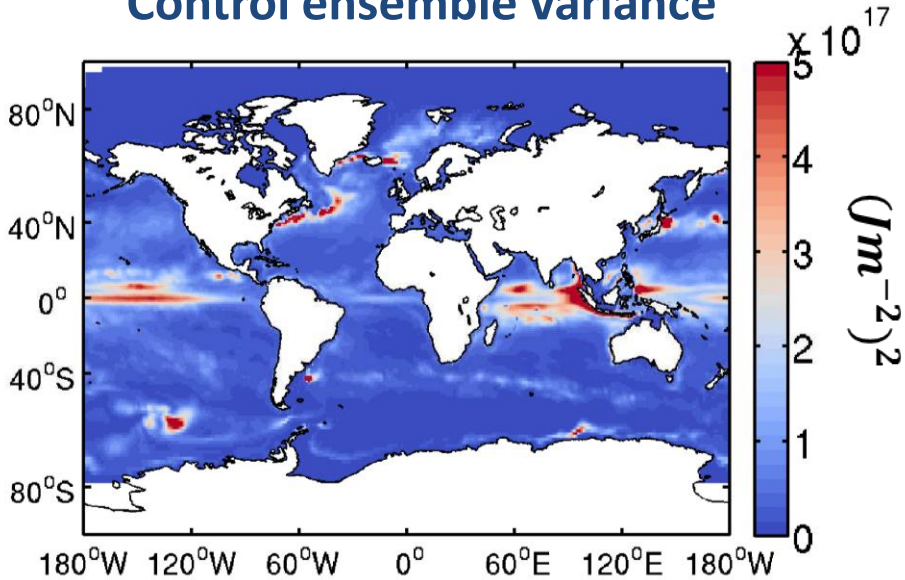
- **Further investigate impact on seasonal forecasts**
- **Investigate impact in coupled climate models**
- **Test schemes in higher resolution simulations (potentially develop new schemes)**
- **Estimate parameters for amplitude, temporal and spatial correlations of noise from high resolution simulations and observations**

Results: Seasonal

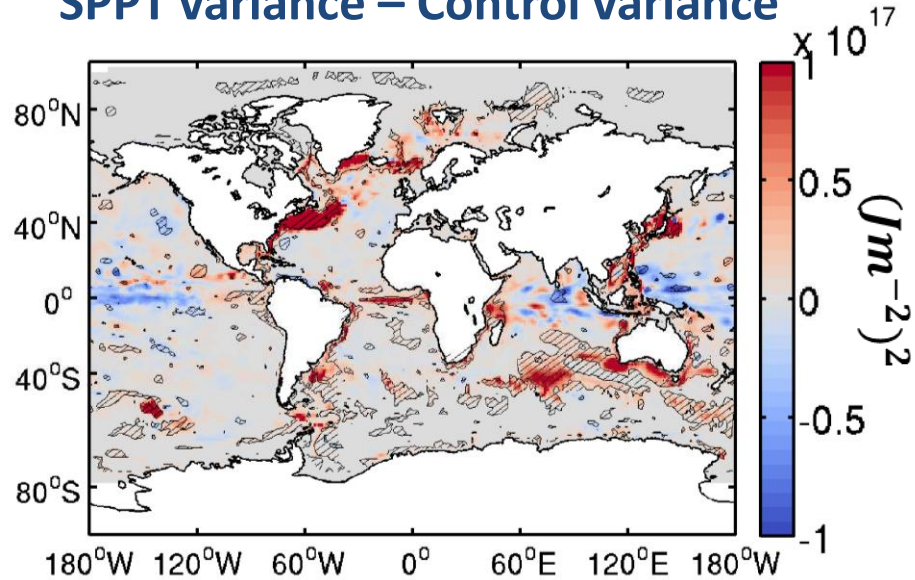
Andrejczuk et al., 2016

300 m heat content
Month 3

Control ensemble variance



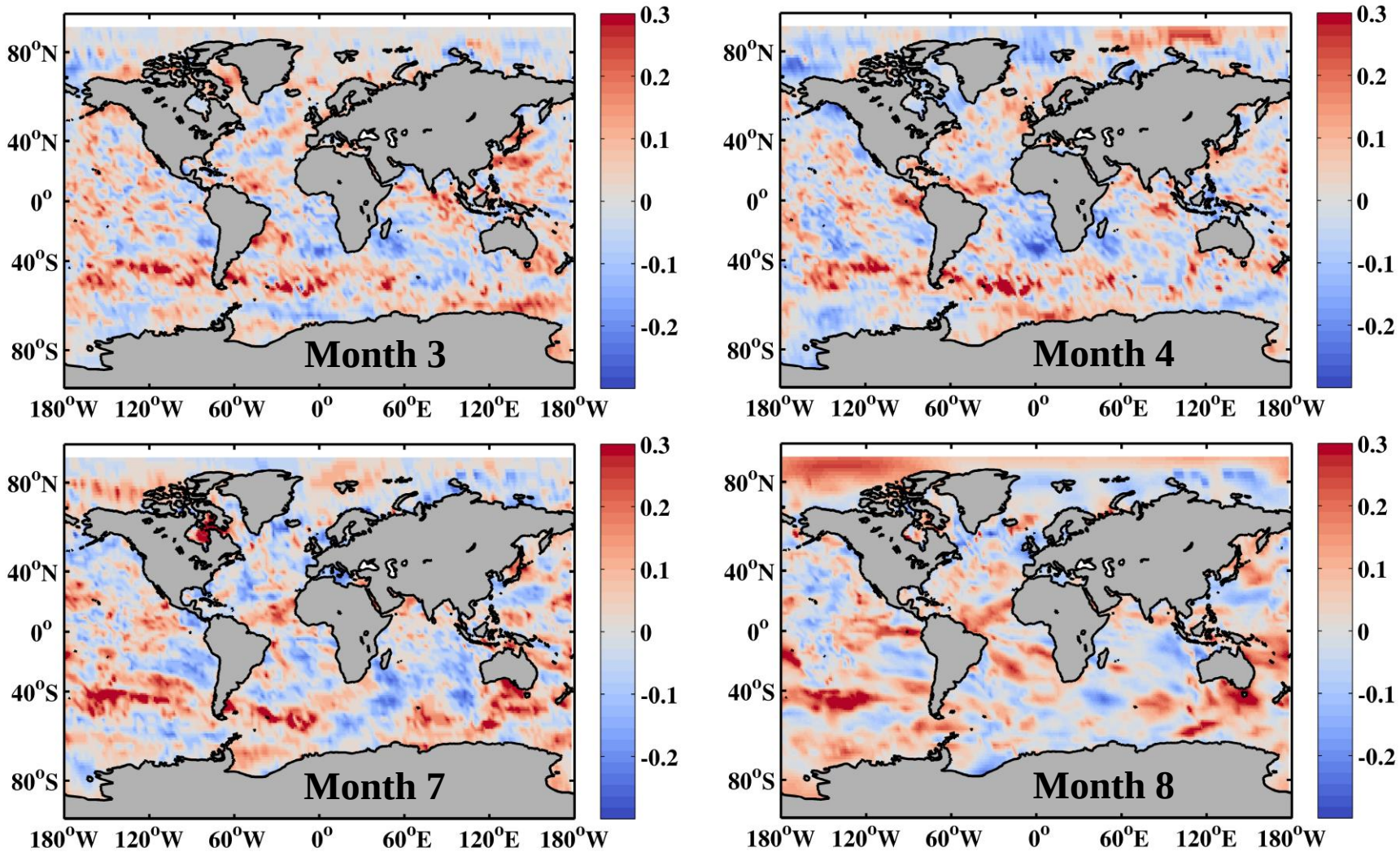
SPPT variance – Control variance



Deterministic and stochastic (ocean SPPT) ensembles
3 months forecasts
10 years, 10 ensemble members, ECMWF System 4, NEMO ORCA1L42

Results: Seasonal

Relative change in ensemble variance for SST



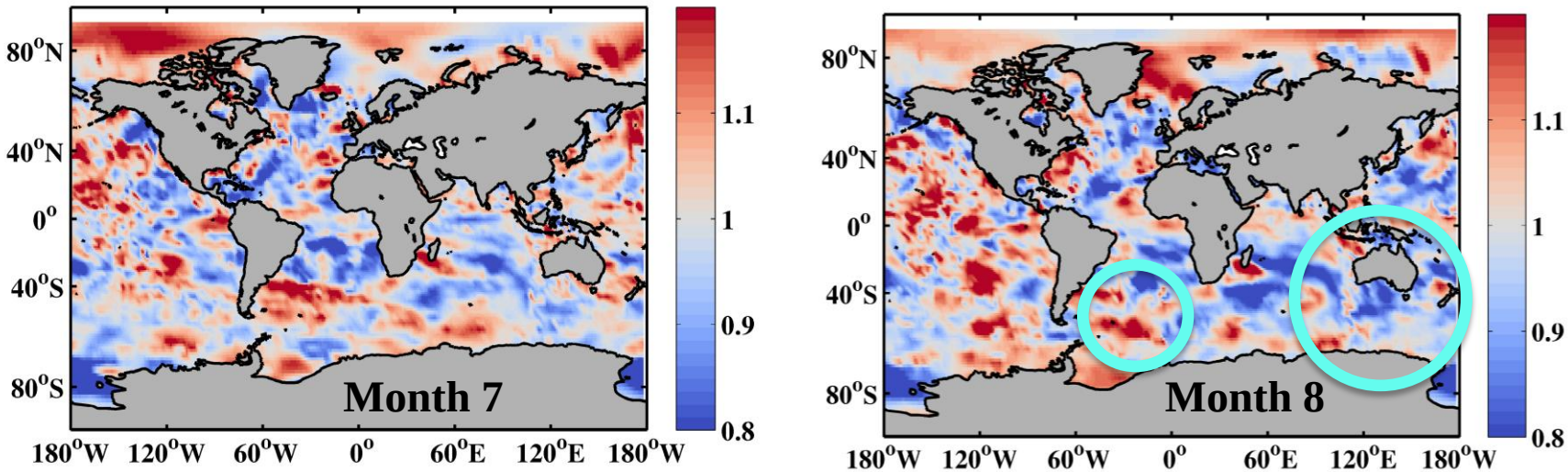
D

1

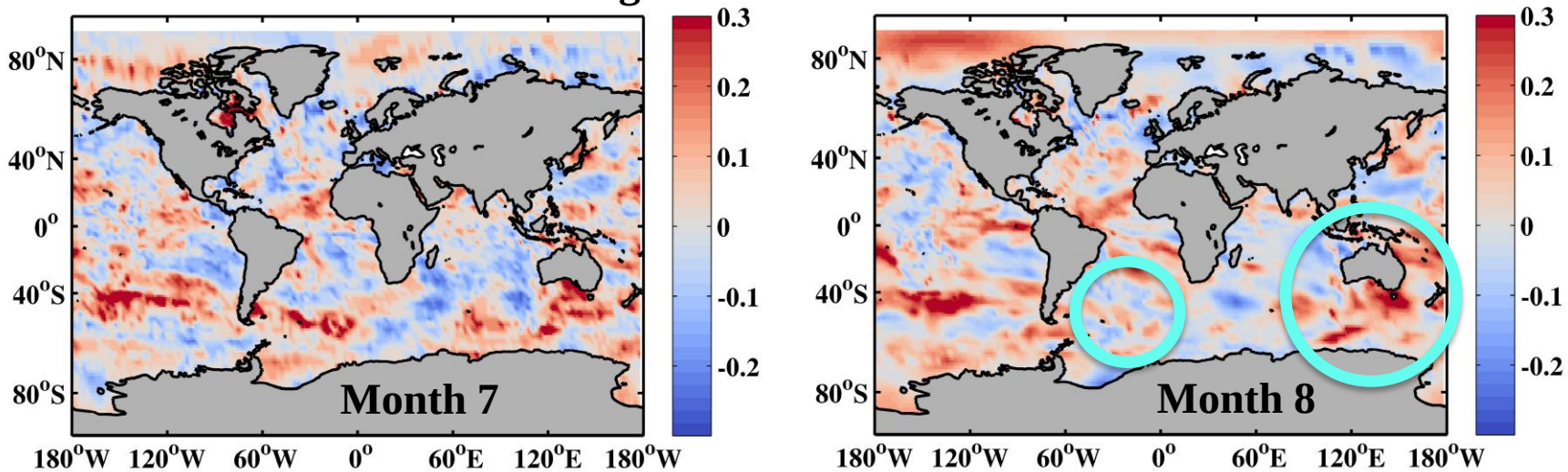
35 years, 20 ensemble members, ECMWF System 4, NEMO ORCA1L42

Results: Seasonal

RMSE ratio (STO/REF) for SST

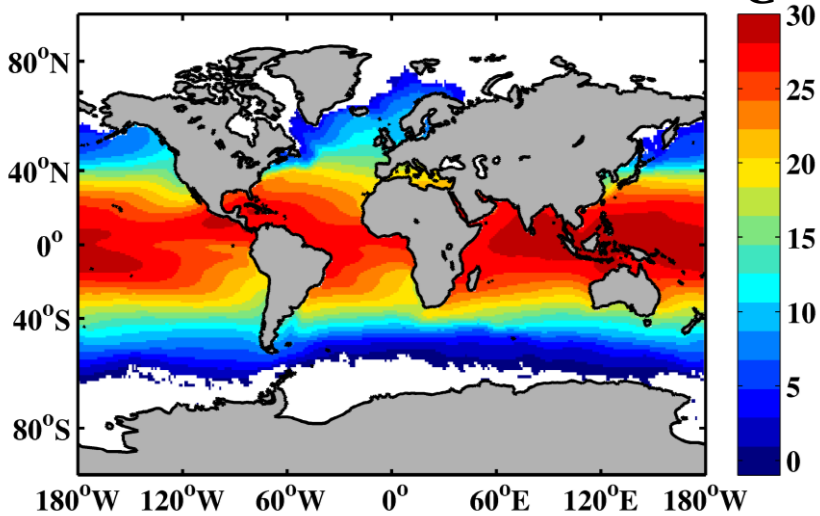


Relative change in ensemble variance for SST

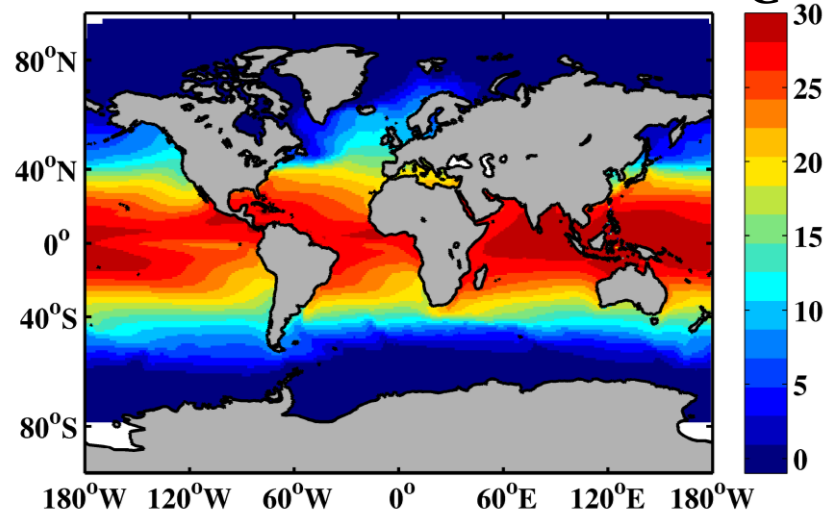


Introduction

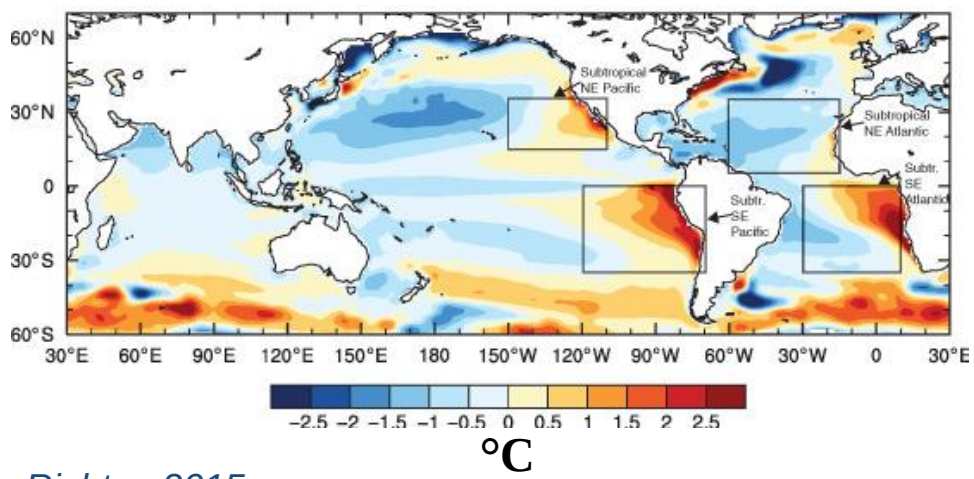
HadISST mean SST, 1960-2004 °C



REF model mean SST °C



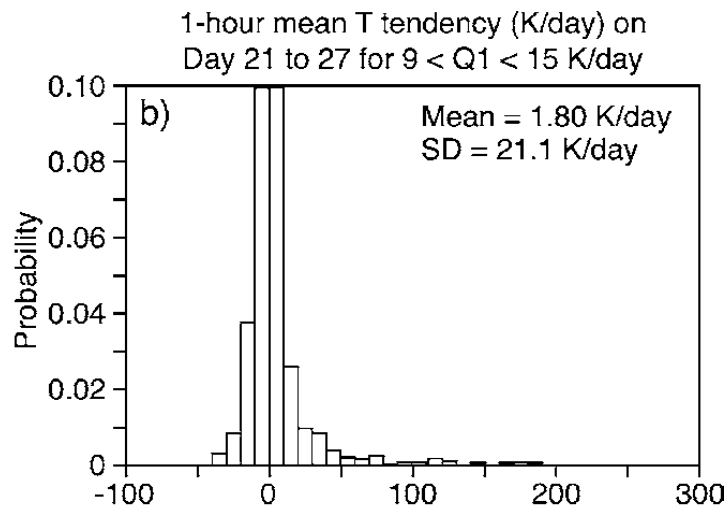
Annual mean SST error in CIMP5 ensemble

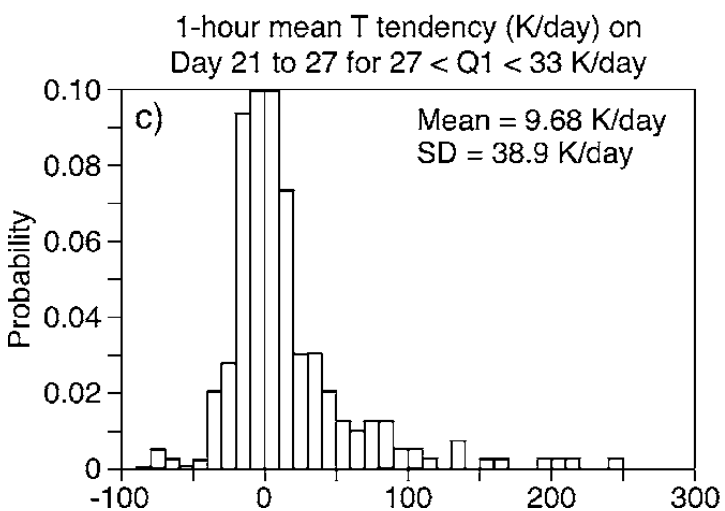


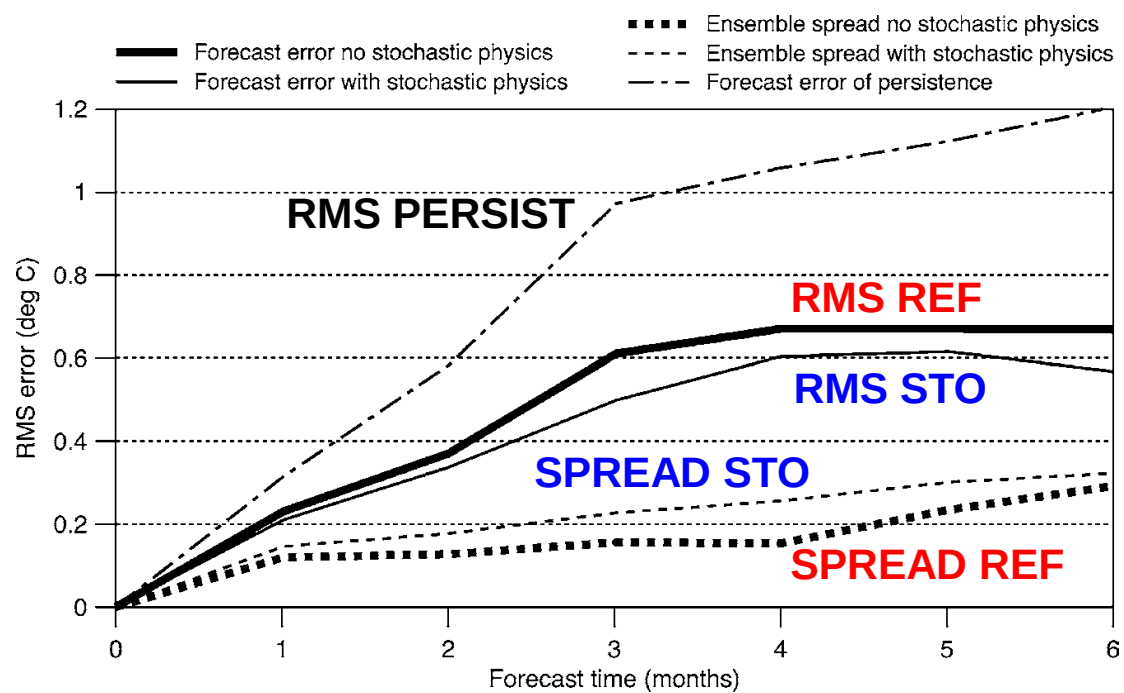
Richter, 2015

Introduction

Stochastically perturbed parametrization tendencies (SPPT) : Larger uncertainty/variability when tendencies are large







Palmer et al., 2005