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

Met Office HRCP Workshop

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Overview

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

2. Stochastic parametrization approach

3. Results

4. Conclusions & Outlook
Introduction

AVISO standard deviation of annual mean SSH, 1993-2013

Relative difference in variance of annual mean SSH

\[
\frac{\text{VAR}(AVISO) - \text{VAR}(O)}{\text{VAR}(ORAS4)}
\]

\[
\frac{\text{VAR}(AVISO) - \text{VAR}(O)}{\text{VAR}(ORAP5)}
\]
Resolved advection

Unresolved, parametrized mixing

Unresolved processes (e.g. eddy, convection)

Model grid box

Introduction

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Parametrized mean

\[ \frac{\partial X_{edd}}{\partial t}(X, Y, Z, \ldots) \]

Unresolved scales \(\rightarrow\) Model error

\(X, Y, Z, \ldots\)

some state variables
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

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**Introduction**

1. **Introduction**
2. **Stochastic parametrization**
3. **Results**
4. **Conclusions & Outlook**
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:
\[ P(i,j) = (1 + x(i,j)) \cdot P_{ref}(i,j) \]
Stochastic parametrization

Model configuration:

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

Stochastic perturbations to:

1. Gent-McWilliams coefficient

\[ \frac{dT}{dt} = \nabla \left(T(\mathbf{u}) + T_{eddy}\right) + D_T + F_T \]

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

Gent-McWilliams eddy induced velocity (u component):

\[ u_g = -\frac{\partial}{\partial z} (A \cdot S) \]

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

\[ u_g = -\frac{\partial}{\partial z} \left((1 + r_{GM}) \cdot A \cdot S\right) \]

with random number \( r_{GM} \)
Stochastic parametrization

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

Power spectrum of zonally averaged streamfunction, Pacific

\[
\psi_{eddy}
\]
Lat: -59.5°
Depth: -85.3 m

Frequency (day\(^{-1}\))

\[
\psi_{eddy}
\]
Lat: -59.5°
Depth: -3291.8 m

1 y
Results: Uncoupled

Standard deviation of annual mean zonally averaged streamfunction, Pacific

ORAP5, 1979-2004

ORAS4, 1960-2004

REF
Results: Uncoupled

Standard deviation and relative difference in variance of annual mean SSH

STD(AVISO(1993-2013))

STD(REF)
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

300 m heat content
Month 3

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

Andrejczuk et al., 2016
Results: Seasonal

Relative change in ensemble variance for SST

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**Results: Seasonal**

**RMSE ratio (STO/REF) for SST**

- **Month 7**
- **Month 8**

**Relative change in ensemble variance for SST**

- **Month 7**
- **Month 8**

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HadISST mean SST, 1960-2004 °C

REF model mean SST °C

Annual mean SST error in CIMP5 ensemble

Richter, 2015
Stochastically perturbed parametrization tendencies (SPPT): Larger uncertainty/variability when tendencies are large.