Model uncertainties in climate prediction: Don't forget the oceans!

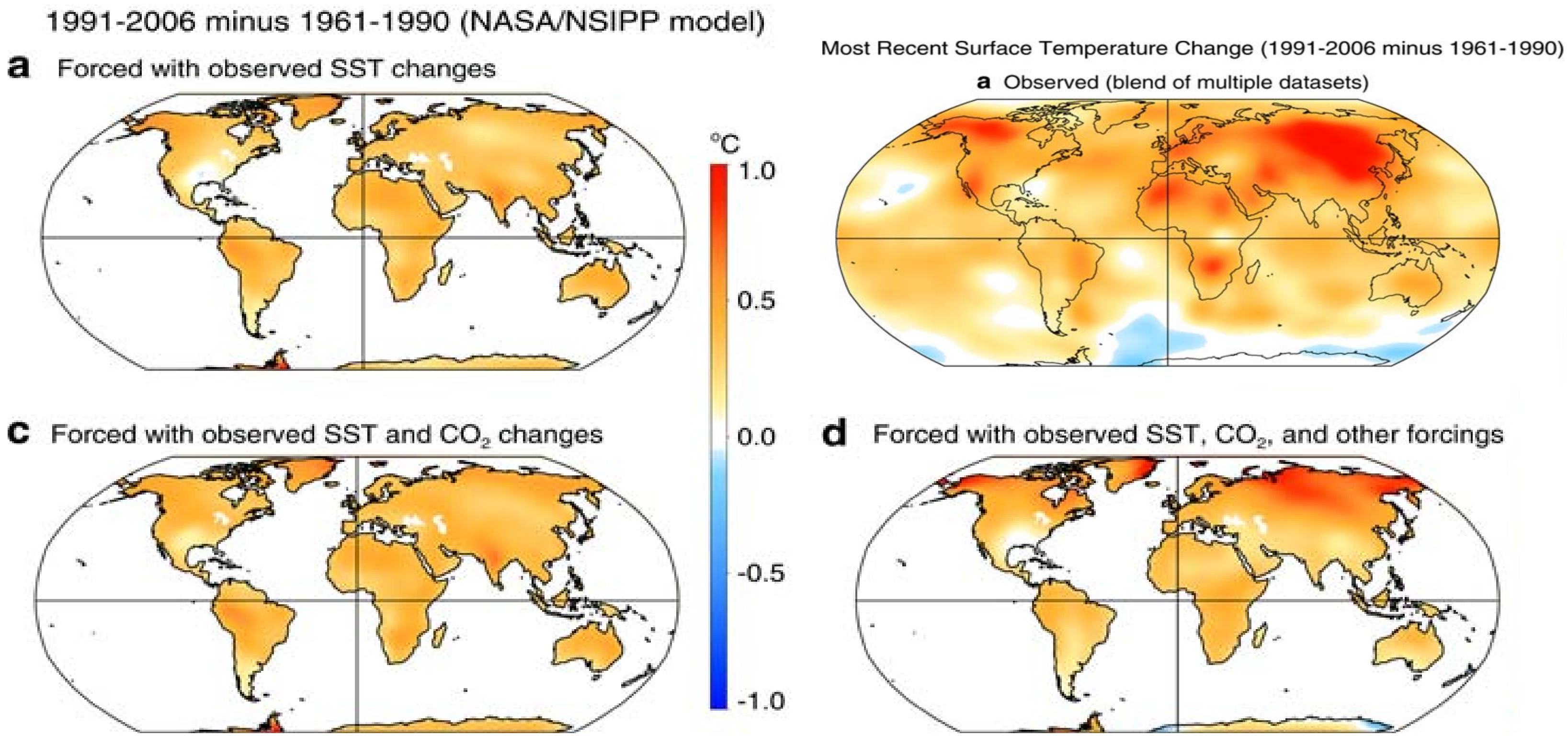
Laure Zanna (Oxford Physics)

ECMWF, June 21st 2011

Outline

- Role of ocean in recent continental warming
- Examples of uncertainties & errors in ocean models
- Recent studies dealing with uncertainties, high-latitudes processes
- Possible Future directions: Observations to reduce uncertainties, Stochastic physics
- → not enough to rely on global climate models, stronger links between theory/obs and modeling centers

Continental warming influenced by ocean temperatures



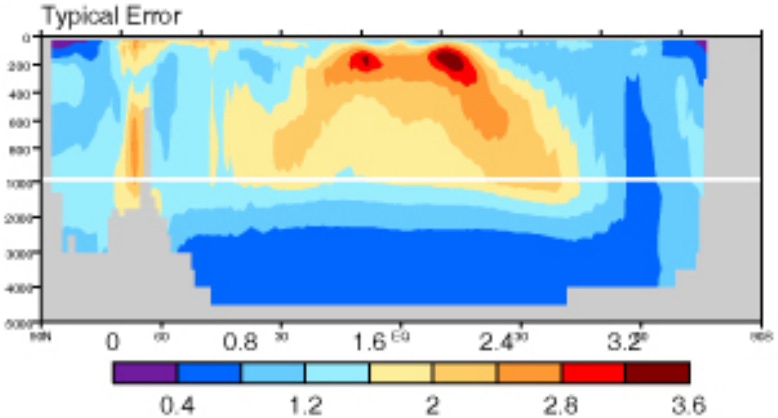
Winton et al, 2010, Compo & Sardeshmukh, 2009

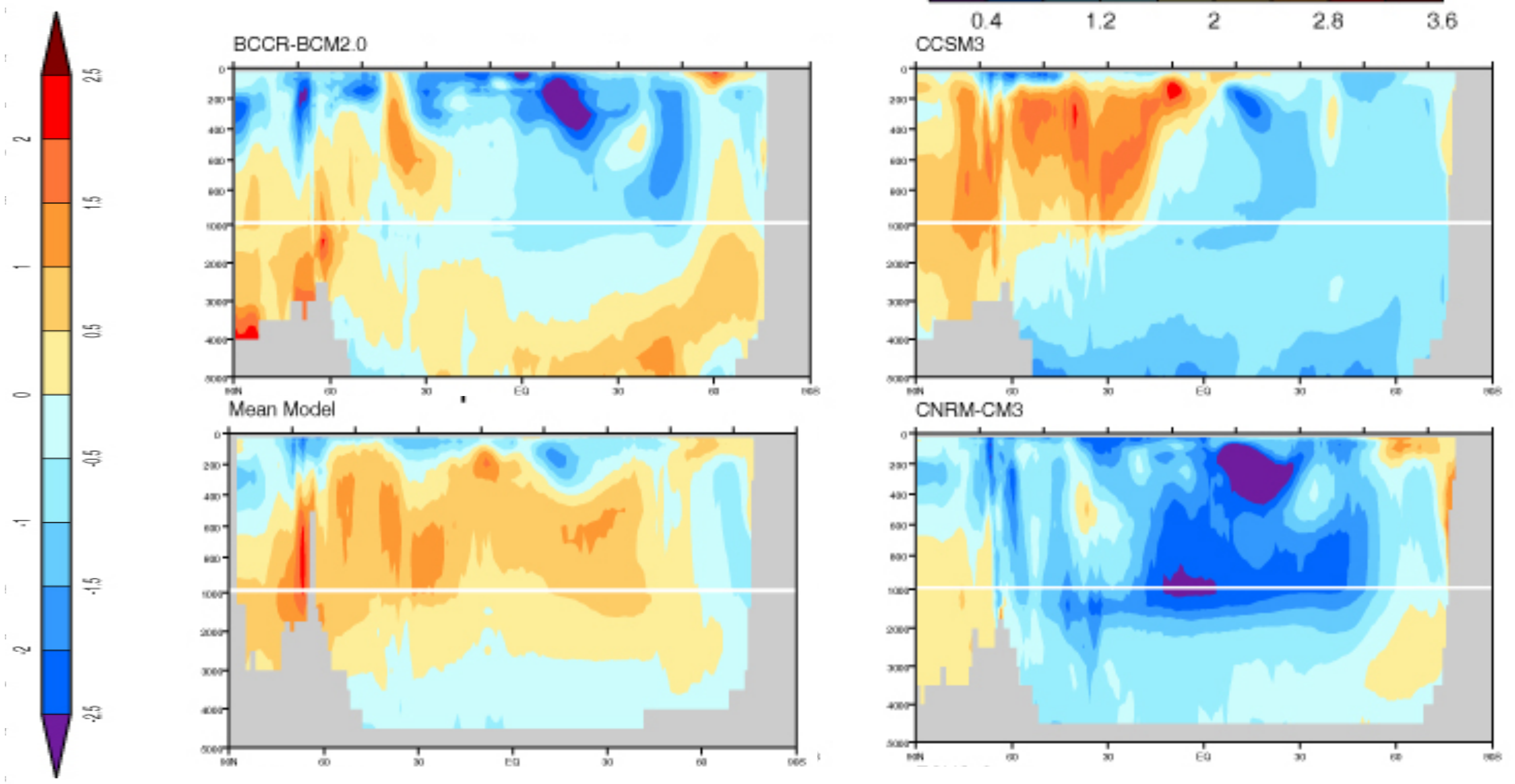
Surface & ocean interior properties are important including circulation

Multi-model Error in Temperature

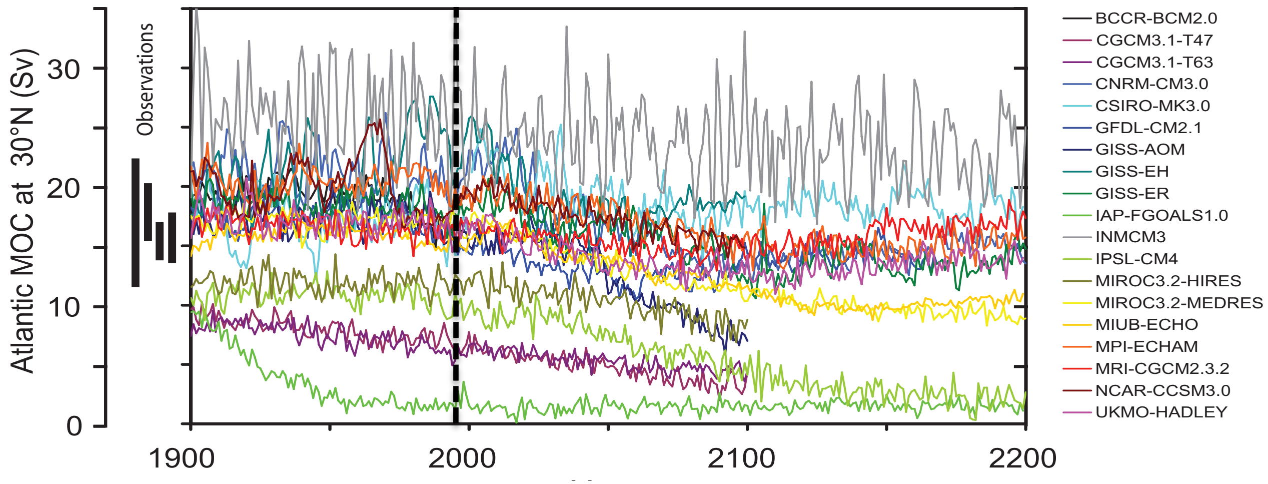
Zonal Mean global ocean potential temperature difference (C)

(IPPC AR4, Ch.8 supp)

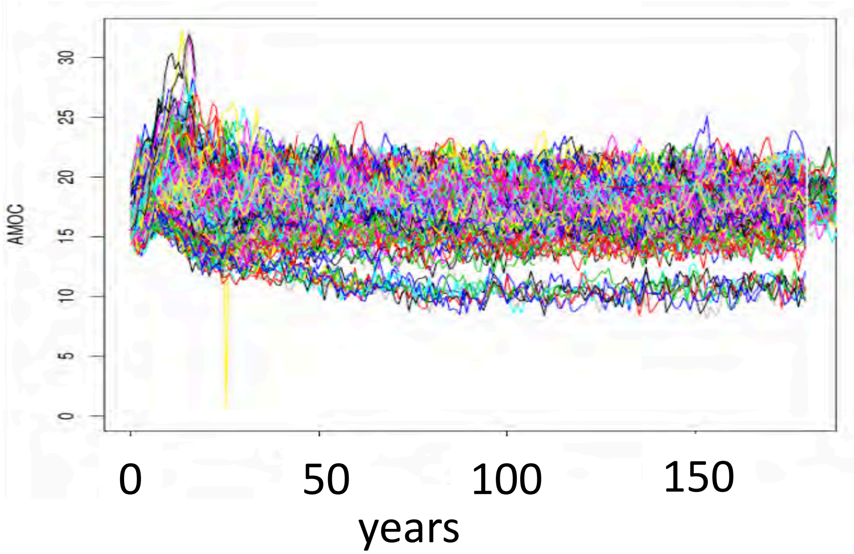




Climate Projections



- Multi- Model, AR4

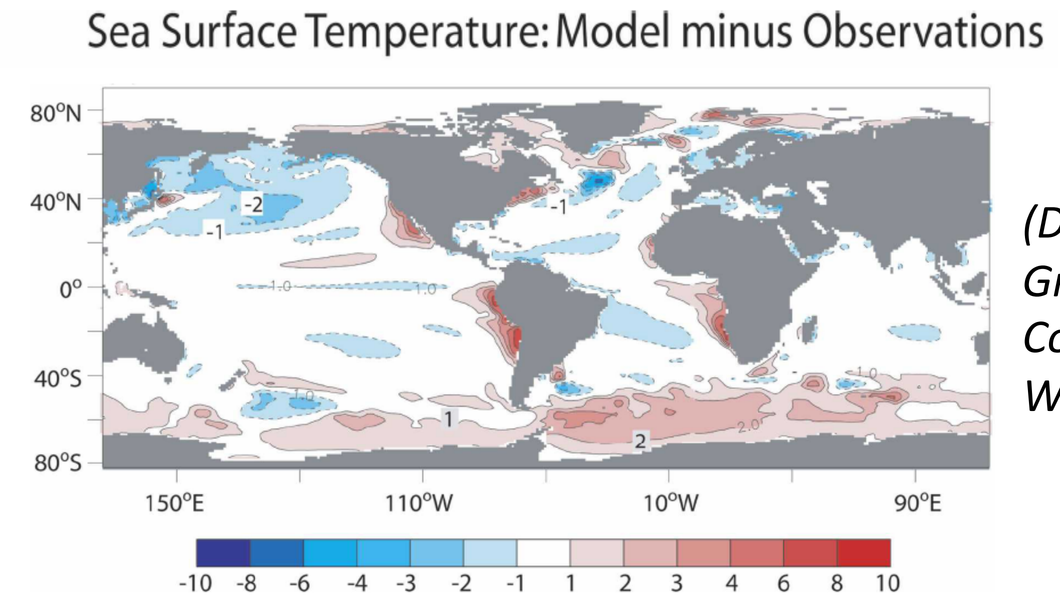


- Climateprediction.net ensemble (~700 members) with FAMOUS *(Yamazaki et al)*

- Seven CO2 emission scenarios

- Not easy to understand the behavior of the models and uncertainties

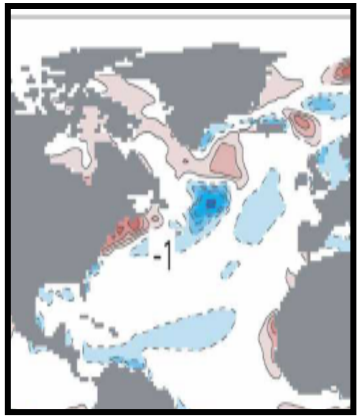
Singular Vectors in IPCC AR4 model



GFDL CM2.1

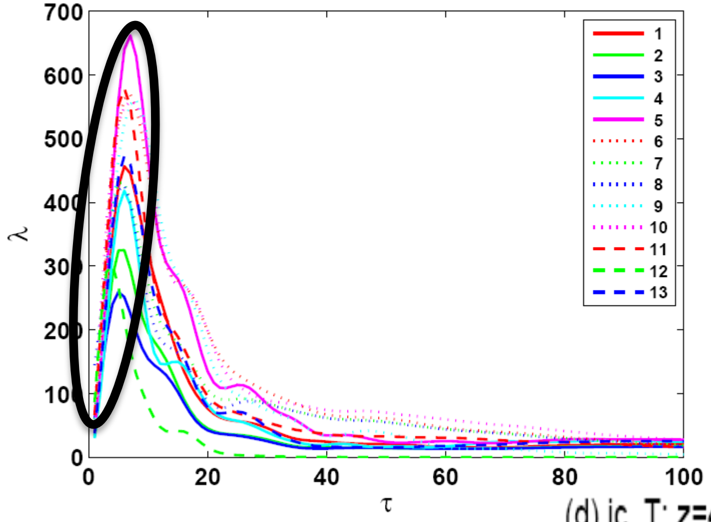
(Delworth 2006; Delworth et al. 2006; Gnanadesikan et al. 2006; Griffies & Coauthors 2005; Stouffer et al. 2006; Wittenberg et al. 2006)

- 1000 years of control run from GFDL CM2.1
- North Atlantic annually averaged temperature and salinity fields
- Reduced space based on EOFs



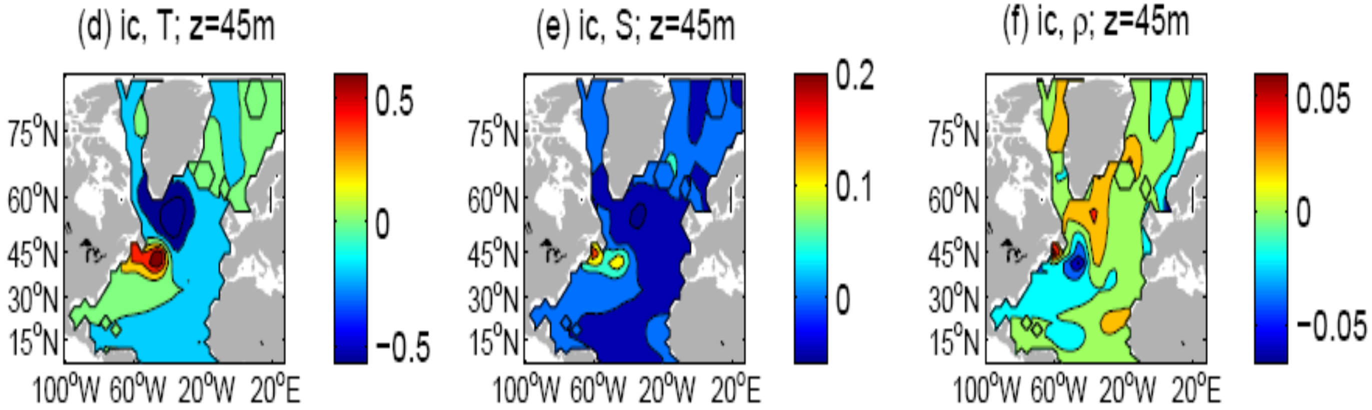
SVs to detect most sensitive regions

Maximum MOC Amplification Curves



→Maximum growth of energy and MOC 5-8 yrs
Can be used to sample uncertainties

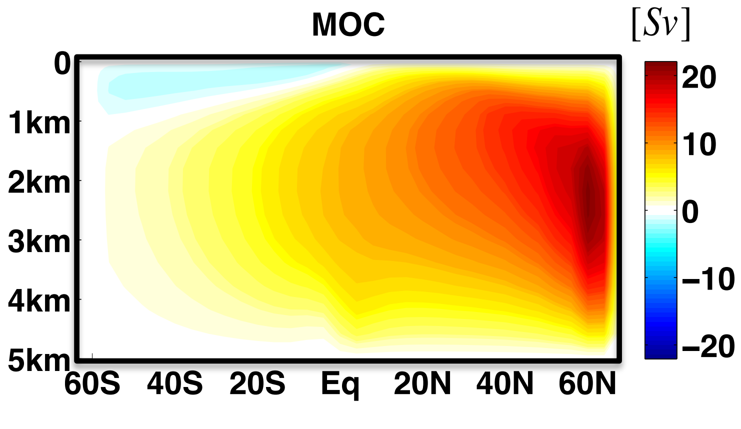
(Tziperman, Zanna & Penland 2008)



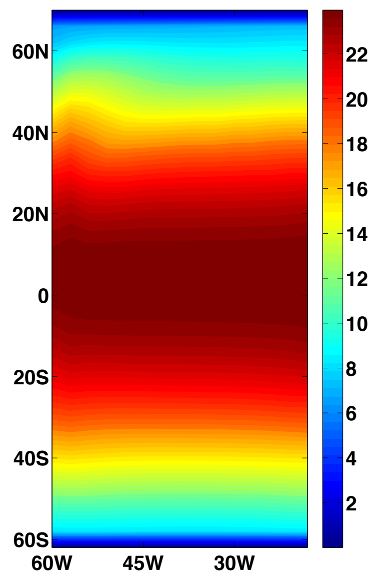
- Build on reduced space; the SVs could potentially project on higher order EOFs *(Similar analysis in HadCM3, Hawkins & Sutton, 2009)*
- Can be used to initialize climate predictions

SVs in idealized ocean MITgcm

Primitive equations, 1°x1°, 15 Levels, Annual averaged Wind & Buoyancy forcing *(Marshall et al, 1996)*

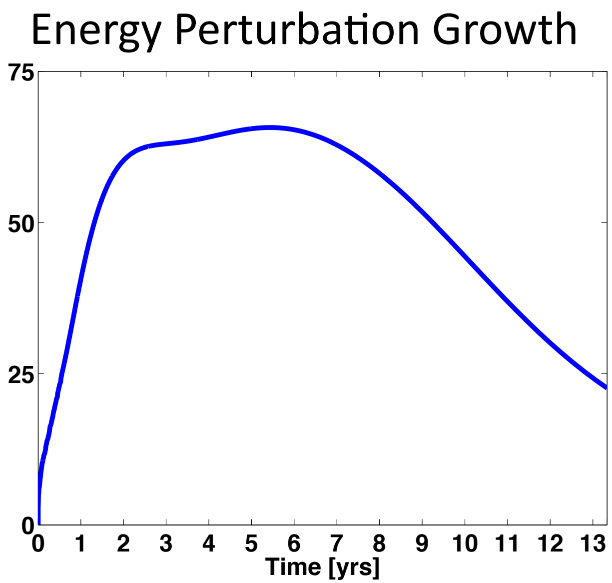


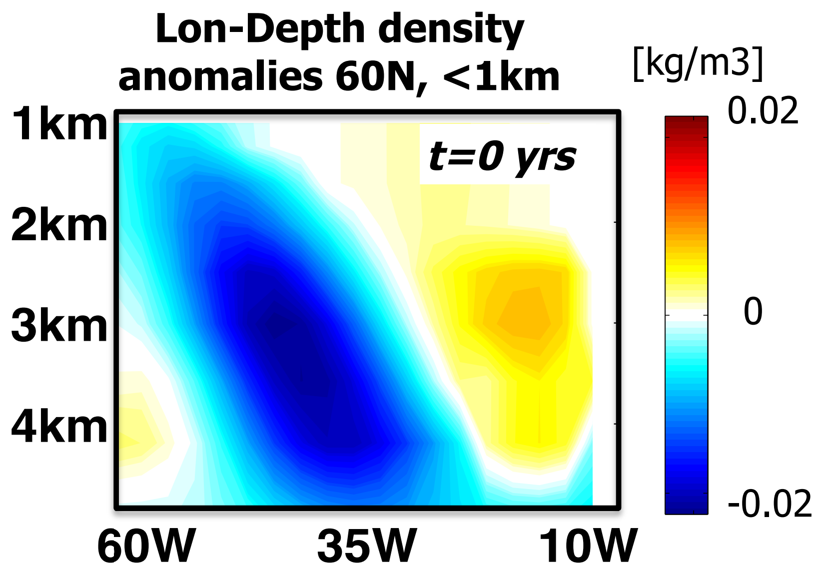
SST [C]



SVDs in idealized ocean MITgcm

(Zanna et al 2011)



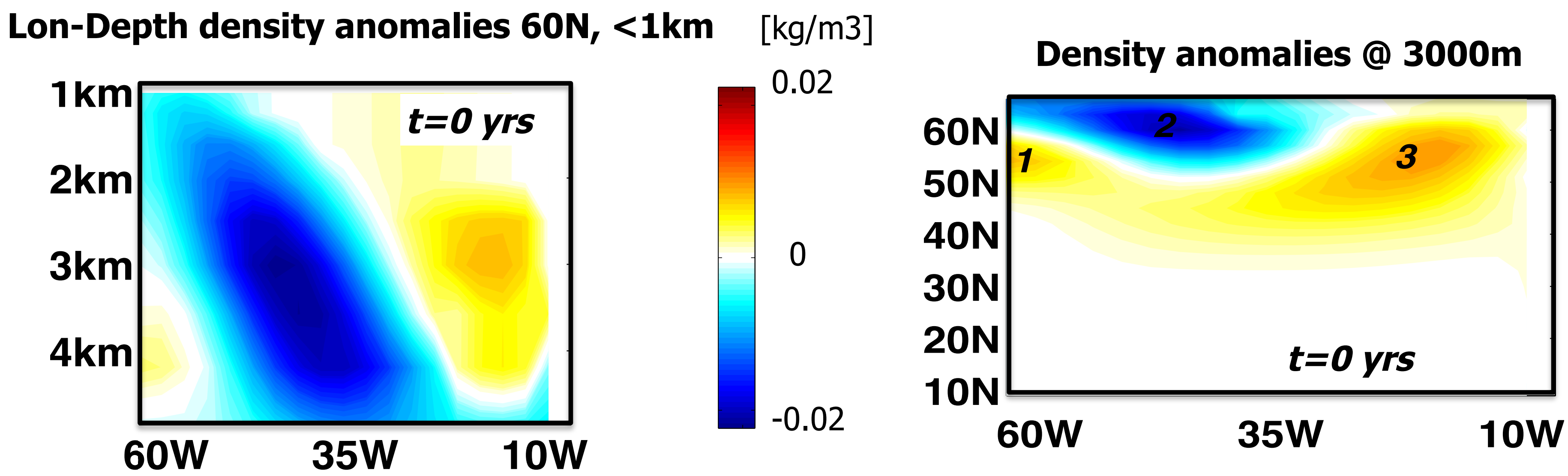


- Growth → conversion of mean available potential energy into perturbation kinetic and potential energy

- Perturbations "leaning" against the mean flow (~baroclinic instability)

Leading 3D Singular Vector

- = largest sensitivity of MOC’ to perturbations at depth & high-latitudes



- Perturbation estimate: $\vec{P}_0' = 0.1C \rightarrow MOC'(7.5yrs) = 2.4Sv \ (12\% \ mean)$

- Errors at high latitudes, at depth in ocean i.c. & model representation (overflows, eddies, deep convection) limit predictability; large impact on the ocean and climate

- Additional observations and better parameterizations are necessary

High-latitudes ocean processes are important for climate

- Upper ocean dynamics = communication between the atmosphere & the oceanic reservoir of heat, freshwater & CO2

- Small-scale & local processes impact the large-scale ocean circulation and uptake of tracers (temperature + carbon)

→Mesoscale & microscale variability (turbulent mixing due to breaking internal waves & convection) are sub-grid scale & are parameterized; most models have similar parameterizations

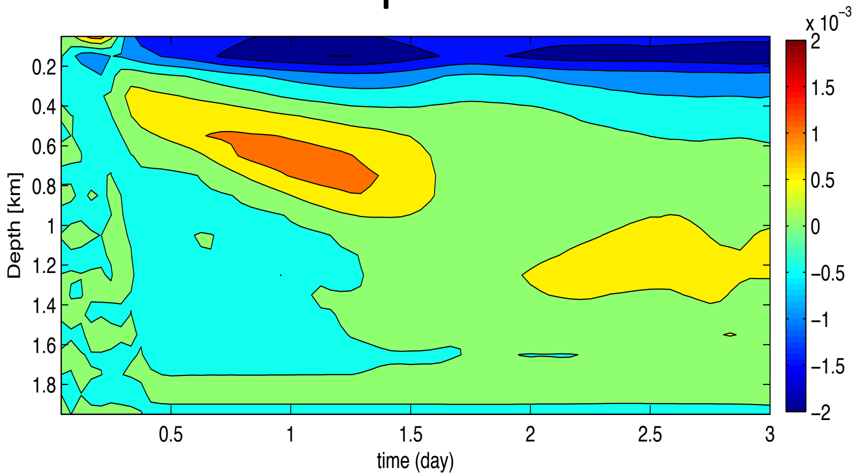
→ Examples of new parameterizations for deep convection and eddy-mixed layer

Open Ocean Deep Convection

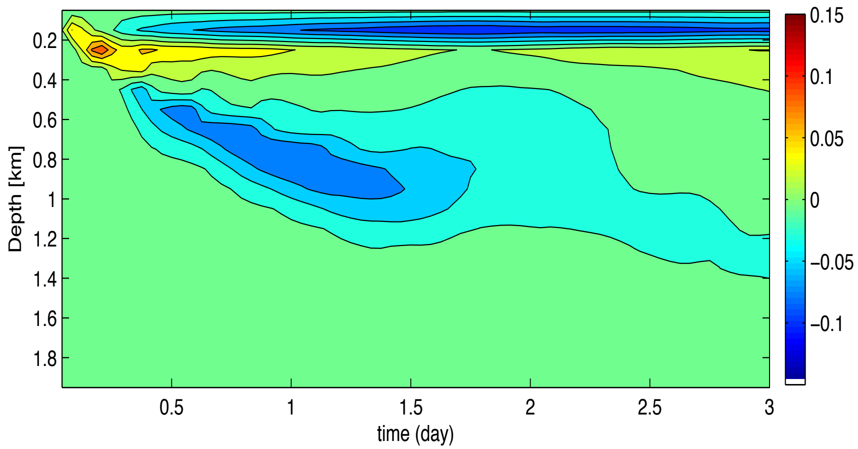
Deep convection: role in global ocean circulation & heat and carbon uptake

Difference between Hydrostatic and Non-hydrostatic

Temperature



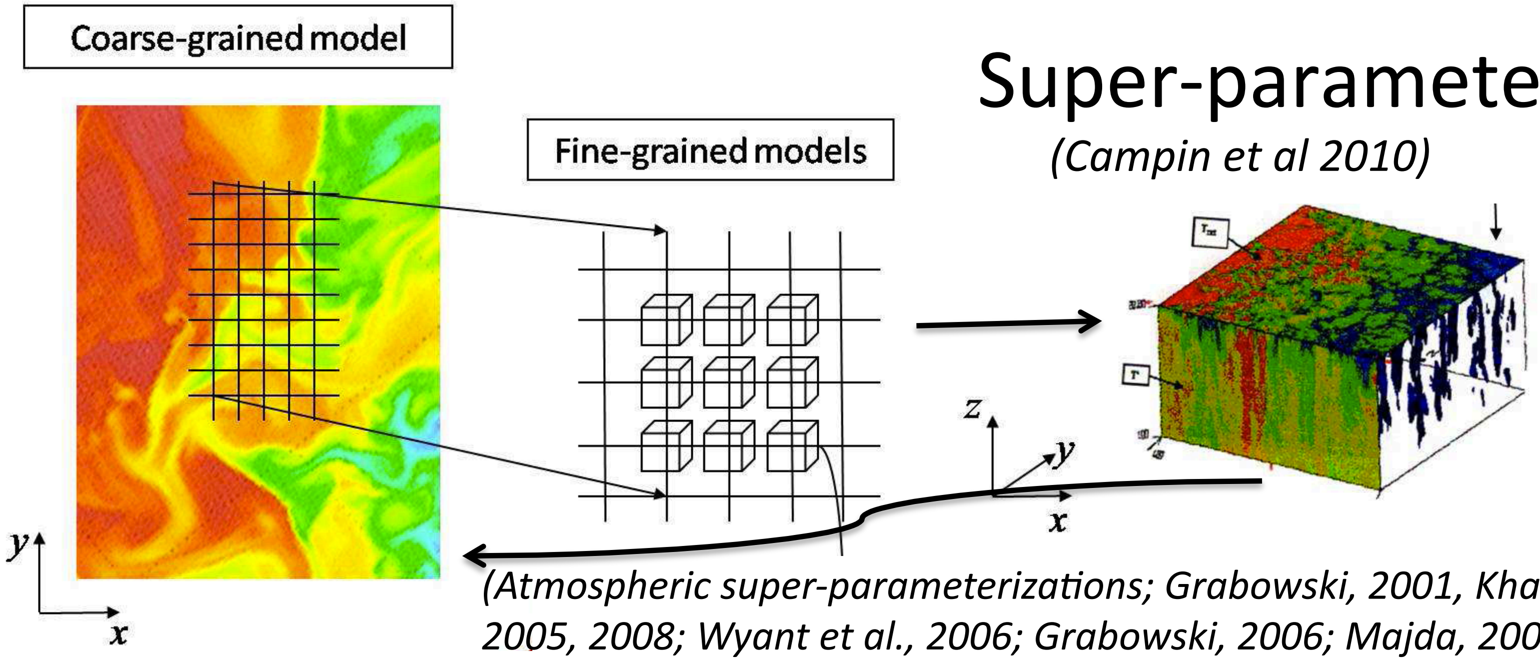
Tracer



Open Ocean Deep Convection

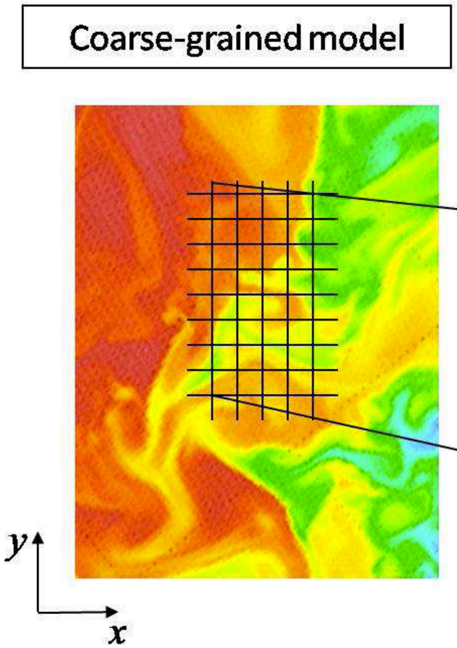
Super-parameterization

(Campin et al 2010)



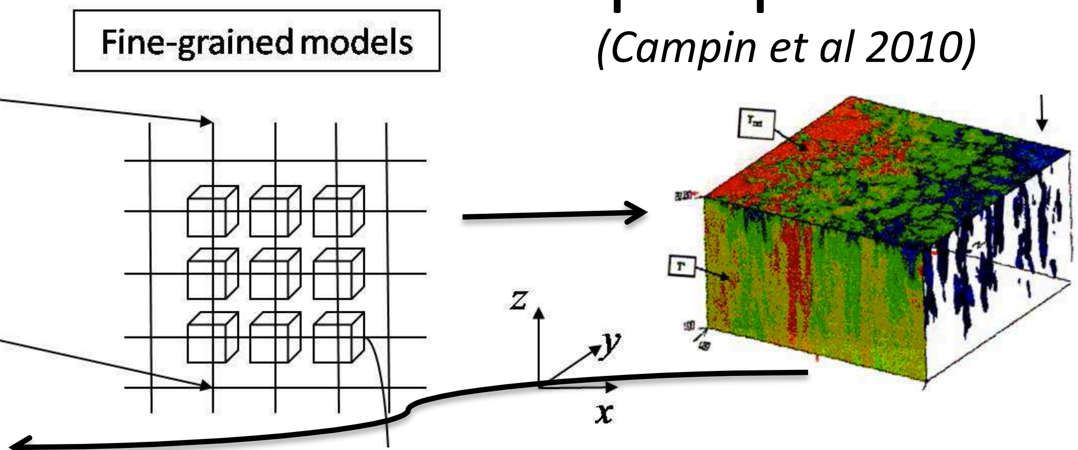
(Atmospheric super-parameterizations; Grabowski, 2001, Khairoutdinov et al., 2005, 2008; Wyant et al., 2006; Grabowski, 2006; Majda, 2007; Tao et al., 2009)

Open Ocean Deep Convection



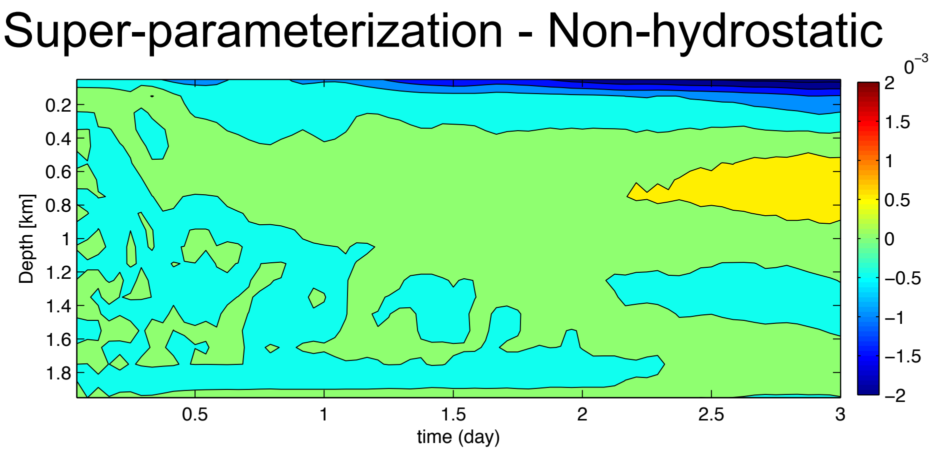
Super-parameterization

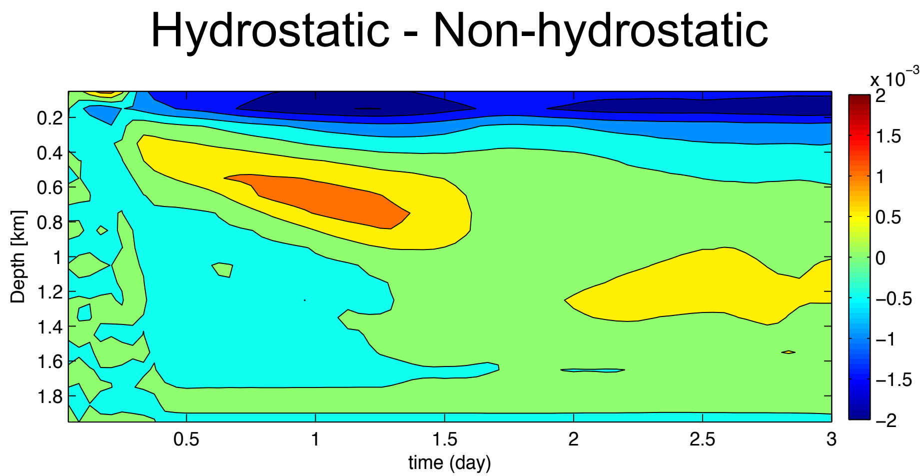
(Campin et al 2010)



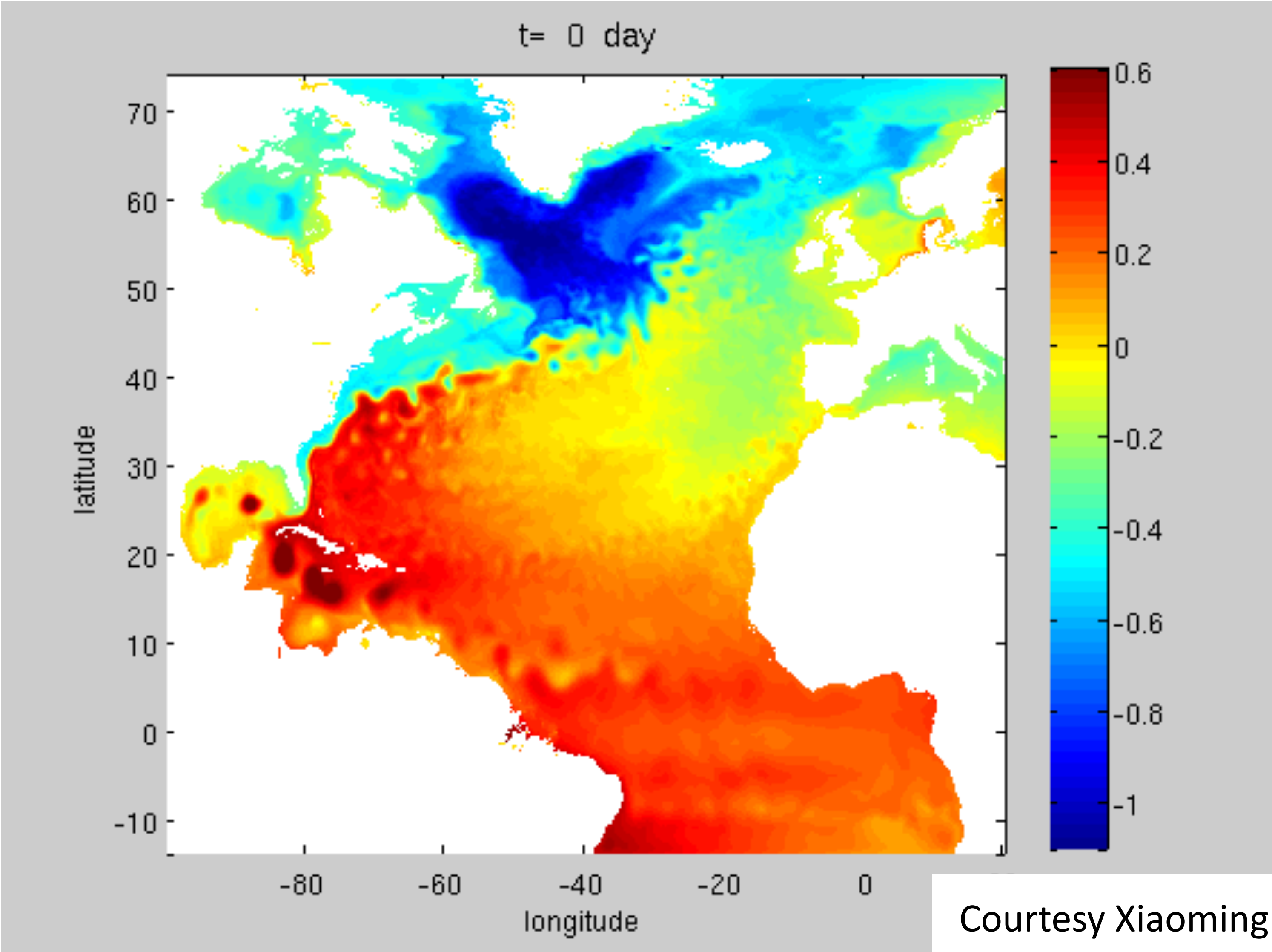
(Atmospheric super-parameterizations; Grabowski, 2001, Khairoutdinov et al., 2005, 2008; Wyant et al., 2006; Grabowski, 2006; Majda, 2007; Tao et al., 2009)

Temperature





Sea level height – 1/10◦ eddy resolving simulation



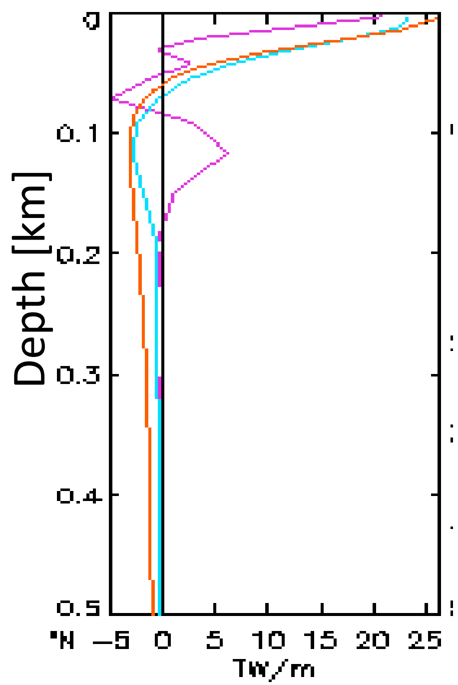
Courtesy Xiaoming Zhai

Eddy-Mixed Layer Interactions

- Mesoscale eddies: Ocean interior = Gent-McWilliams parameterization (adiabatic eddy-induced velocity); *Turbulent BL = eddy induced* velocity with zero shear (well-mixed BL models) + an along-boundary down-gradient flux of density (diabatic mesoscale eddies in the BL)

Fox-Kemper et al 2010

zonally averaged heat flux across 47◦S



control run with GM

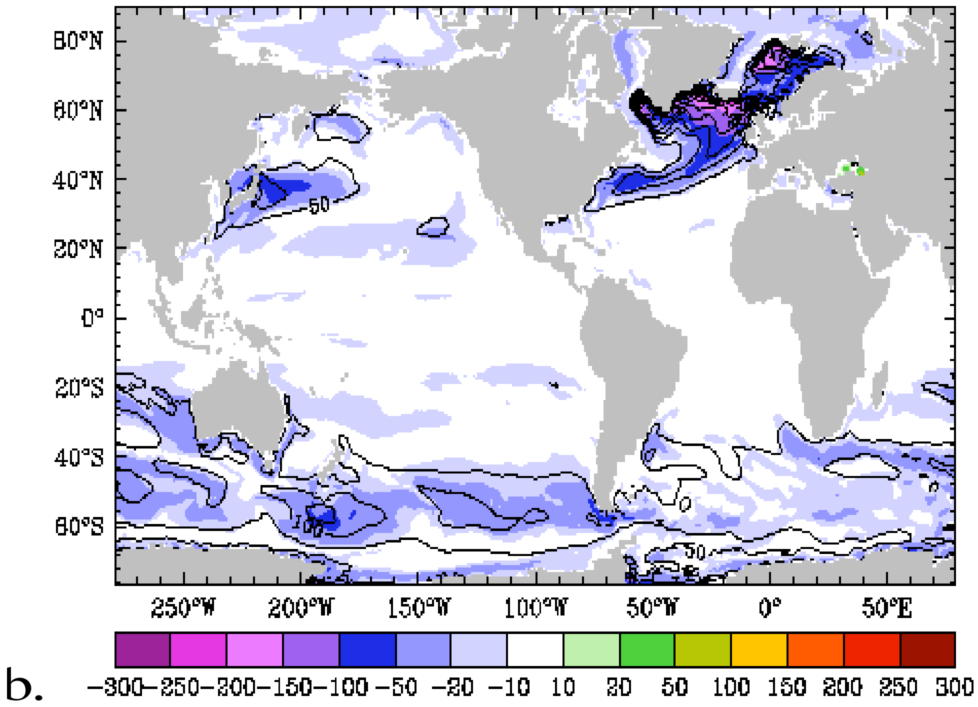
run with new parameterization

1/8◦ global eddy resolving simulation

Eddy-Mixed Layer Interactions

- Submesoscale eddies: buoyancy gradient & front development

Mixed layer depth changes after 10 yrs between
control run & run with submesoscale restratification



Ferrari et al 2008

Future Directions

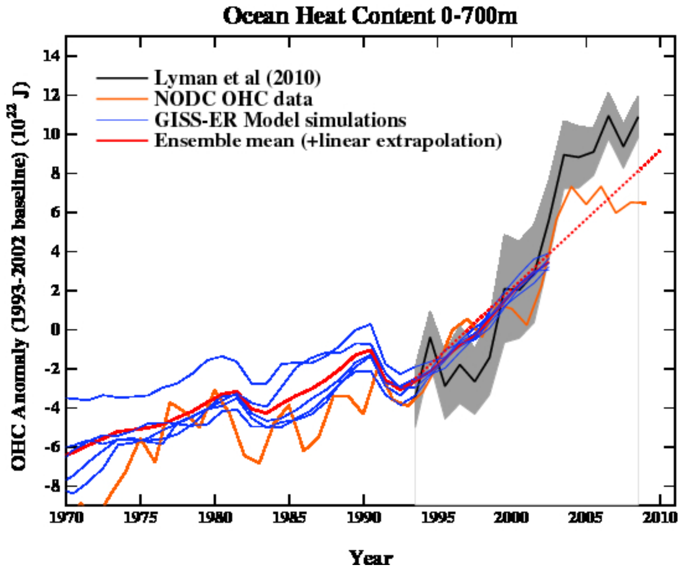
- Using observations to constrain & test the models especially on regional scales

- Stochastic physics in ocean models

- → Linking theory/obs /idealized studies with global climate models is crucial

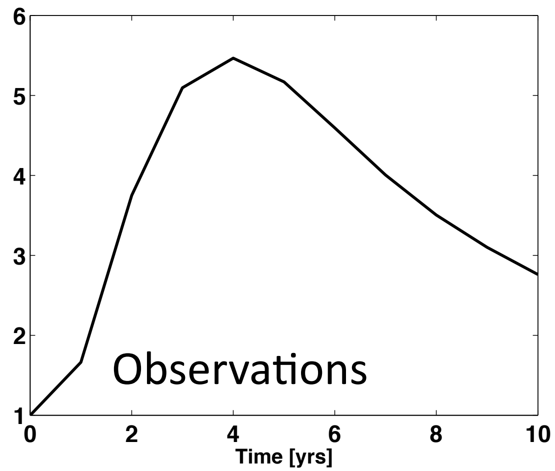
Using observations to reducing uncertainties

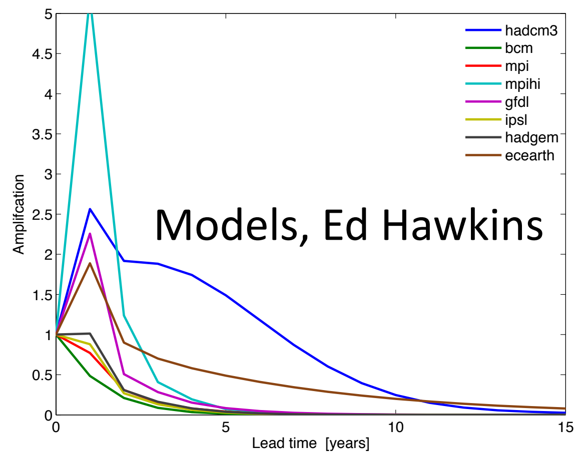
- Ocean heat content, ARGO & altimetry: large uncertainties with obs, analysis & models; can be used to reduced model uncertainties to increasing CO2



- Regional statistical models based on observations can be used as benchmark for IPCC models

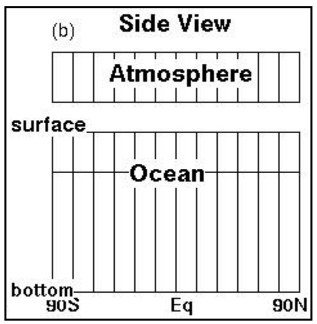
Annual averaged Atlantic SSTs, maximum amplification curves
(Zanna 2011)



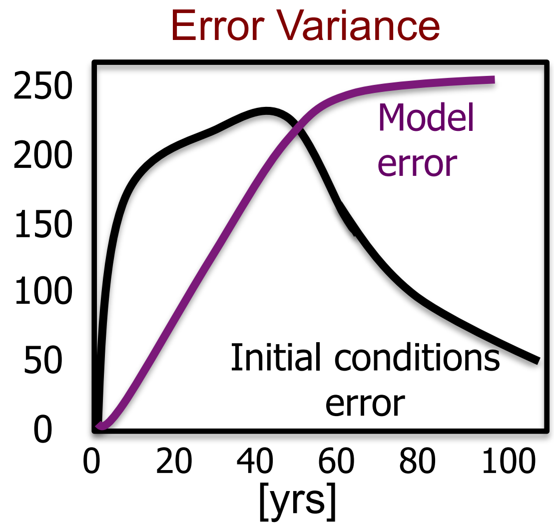


Role of Stochasticity

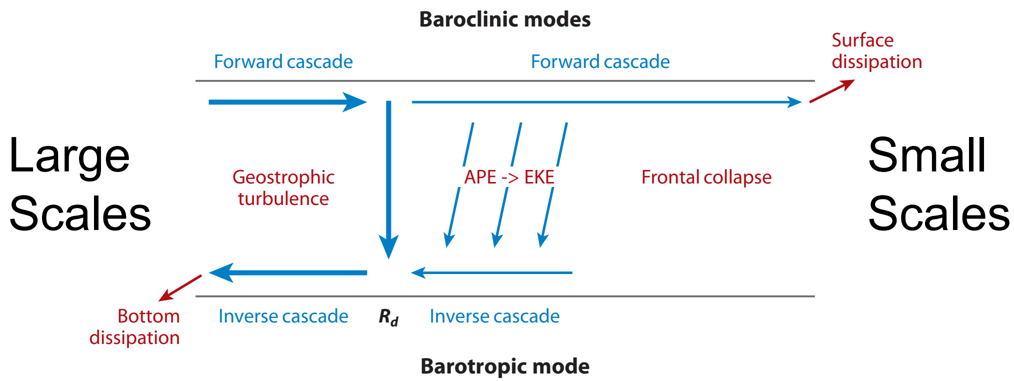
- Stochastic Physics in simple model of the ocean circulation



Zanna Tziperman 2008



- Stochastic parameterization: turbulent mixing & convection



- Implementation of stochastic physics in ocean models and coupled ensemble data assimilation