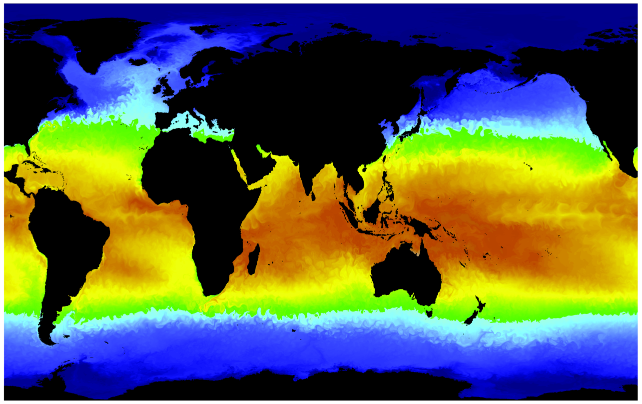
Fully-Coupled, Fine Resolution CESM Simulations: A Prototype and Planned Advancements



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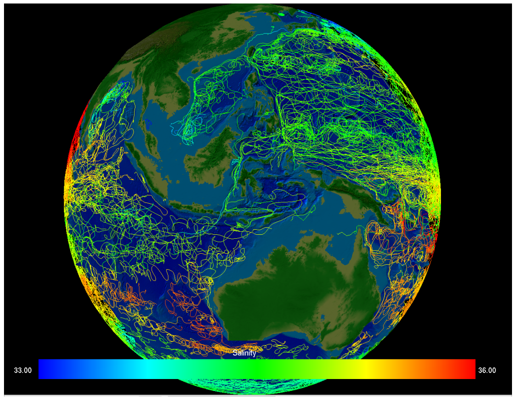


Funding: Department of Energy, Office of Science (BER).

High Performance Computing Resources: Computer time on Lawrence Livermore National Laboratory's Atlas machine was provided under LLNL's Multi-programatic and Institutional Computing Initiative.

Data: Altimeter products from Ssalto/Duacs, Aviso and Cnes. Mixed layer depths from de Boyer Montegut et al. (2004, JGR). MDOT from Makimenko et al. (2009, JPO).

Motivation

- How realistic are the climatologies of the simulated upper ocean circulation in a fully-coupled fine resolution prototype CCSM4 simulation (McClean et al., 2011) and a stand-alone forced 0.1° POP (Maltrud et al., 2010) compared to present-day observations?

- What impact does full air-sea coupling at fine resolution have on both the large-scale and mesoscale oceanic circulations?

Outline

- Review of prototype fine-resolution fully-coupled CCSM4 set-up: known as the LLNL Atlas simulation.
- Comparison of key upper ocean climatologies from the Atlas run, stand-alone 0.1° POP, and data.
- Depiction of Agulhas eddy pathways.
- Addition of model surface velocities to wind stresses forcing 0.1° POP.
- Early results from a suite of global fully-coupled high- and low-resolution simulations (ORNL-LANL-SIO-LBL-LLNL consortium).

"A Prototype Two-Decade Fully-Coupled Fine Resolution CCSM Simulation"

McClean et al., Ocean Modelling, in press.
http://linkinghub.elsevier.com/retrieve/pii/S1463500311000461.

CCSM4 (ccsm4_0_alpha31) Components:

- Community Atmosphere Model version 3.5 (CAM): FV, no tuning
- Community Land Model version 3.0 (CLM3)
- Parallel Ocean Program version 2.0 (POP)
- Los Alamos Sea Ice Model version 4.0 (CICE)
- Coupler version 7.0

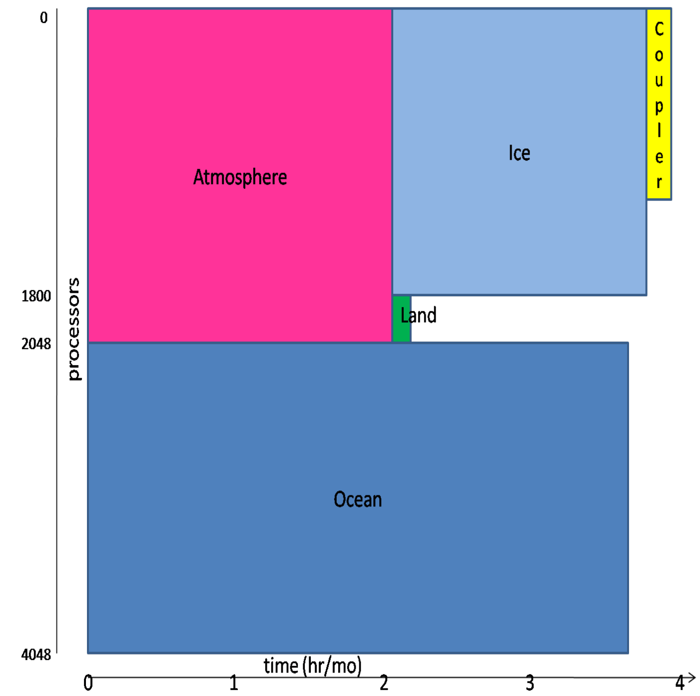
Configuration:

- 0.25° ATM, LND + 0.1° OCN,ICE

CCSM4: Grids, Decompositions and Time Steps

Atmosphere

- 0.23°x 0.31°x 26 levels: spherical grid
- Dynamics uses 128 x 8 lat-vertical decomposition
- Physics time step = 15 minutes
- Dynamics time step = 0.75 minutes



Ocean

- 0.1° tripole grid with 42 levels
- Ocean uses 72 x 60 block sizes
- Ocean time step = 4.65 minutes

Ice

- 0.1° tripole grid
- Ice uses 2x2400 block sizes
- Ice time step = 15 minutes
- Ice dynamics time step = 5 minutes

Coupling

- CAM, CLM, CICE: Coupling time = 15 minutes
- POP couples every 6 hours

CCSM4 Initial Conditions

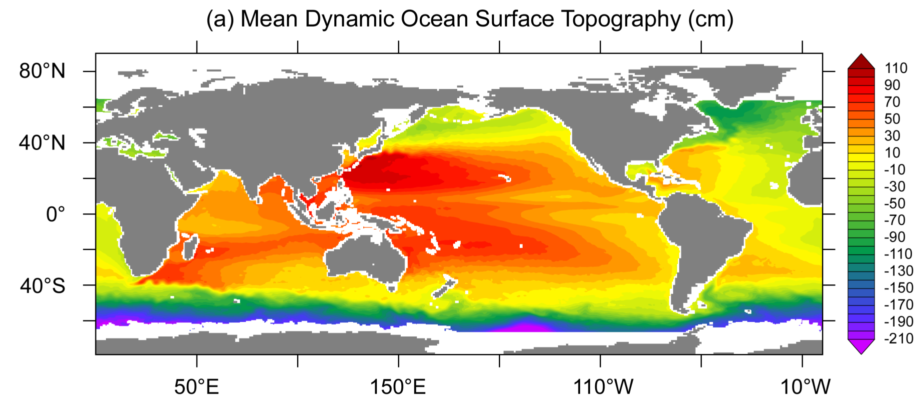
– CAM and CLM started from rest.

– POP was initialized from a 2-yr spinup of a CCSM4 configuration with all the same components but a 0.5° ATM; in turn the latter was initialized from θ and S from World Hydrographic Program Special Analysis Center (HP SAC) climatology (Gouretski and Koltermann, 2004).

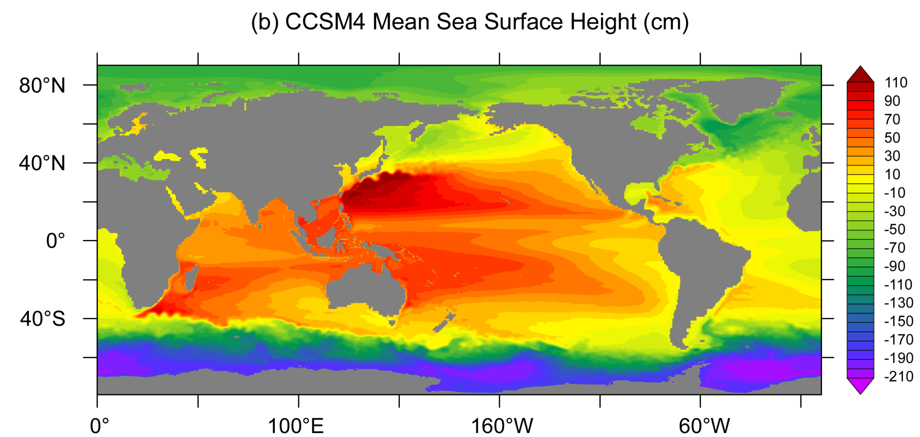
– Ice cover initialization: specified non-linear sea-ice thickness distribution same at all grid points poleward of 70°N and 60°S.

– 1990's GHG forcing: 355 ppmv for CO_2

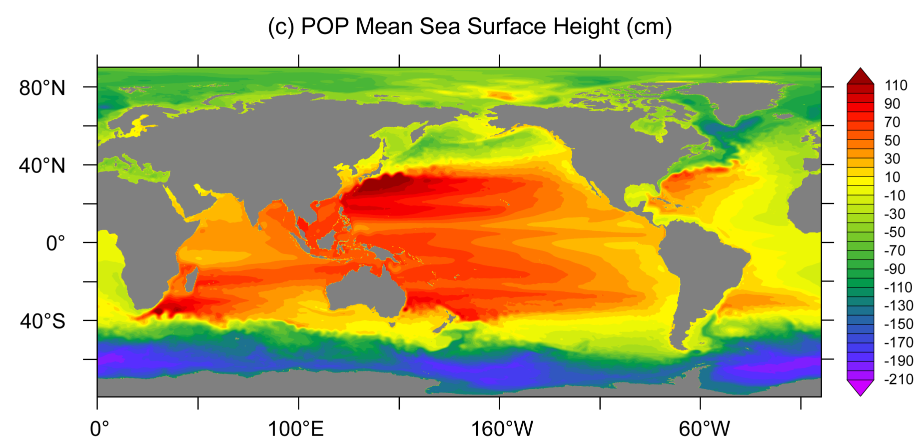
Mean Dynamic Ocean Surface Topography (cm) Maximenko et al. (2009)



Mean Sea Surface Height (cm) from CCSM4 (model yrs 13-19)

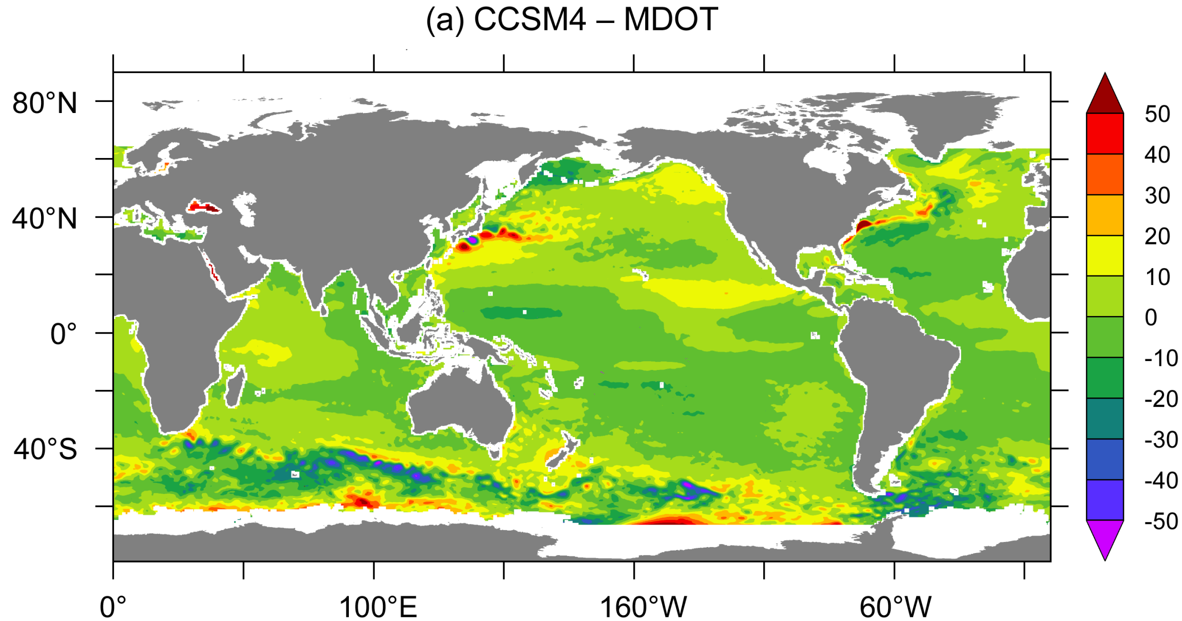


Mean Sea Surface Height (cm) from stand-alone 0.1° POP (model years 95-99). Forced with CORE NY atmospheric fluxes (Maltrud et al., 2010).

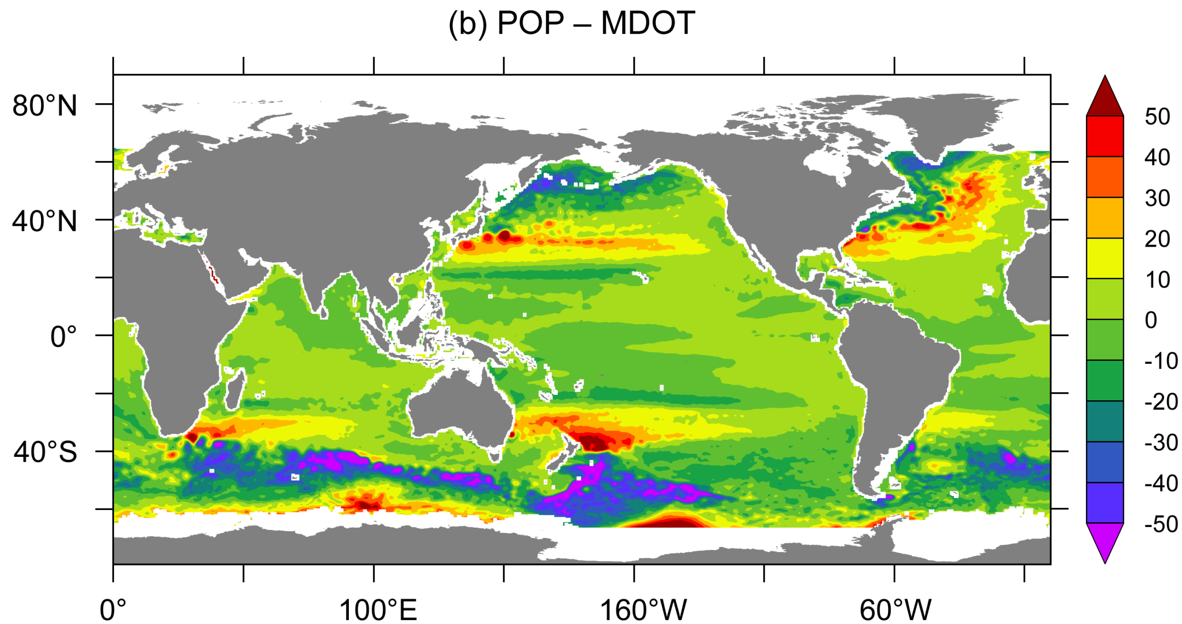


Difference Fields (cm):

CCSM4 mean SSH (model yrs 13-19) – MDOT

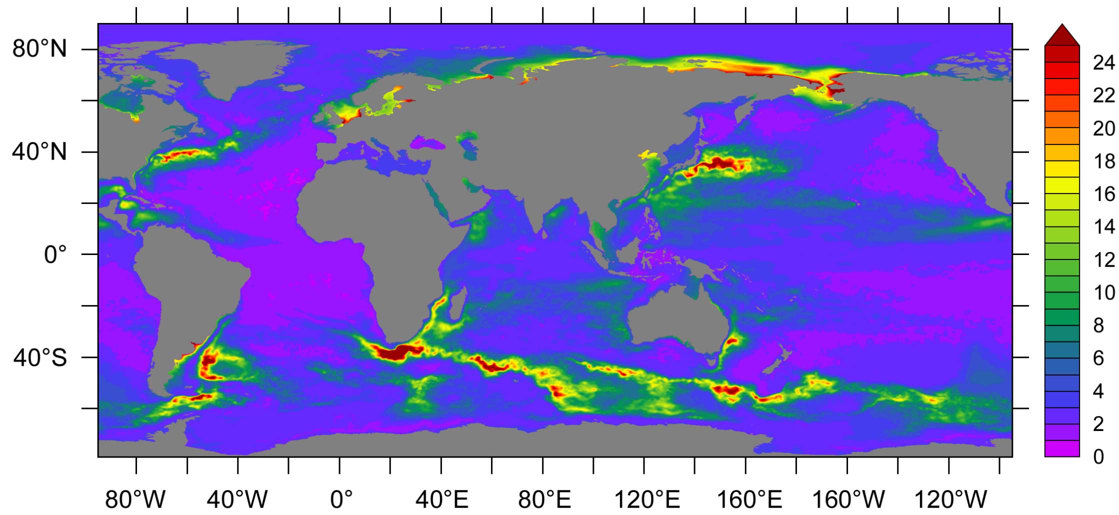


Stand-alone 0.1° POP mean SSH (model yrs 95-99) - MDOT

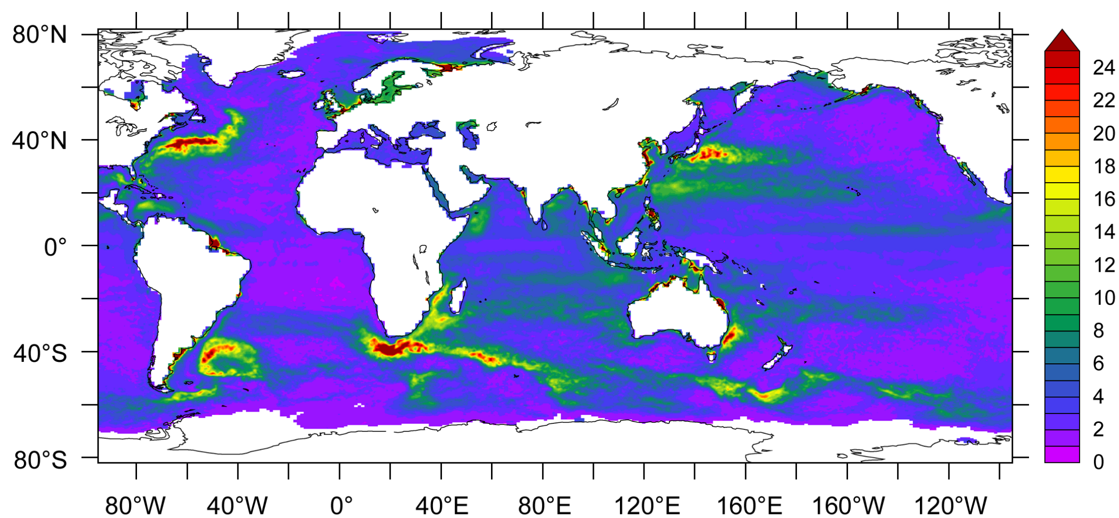


Mesoscale (20-150d) RMS SSHA (cm) from CCSM4 (yrs 15-19) and AVISO Altimetry (1997-2001)

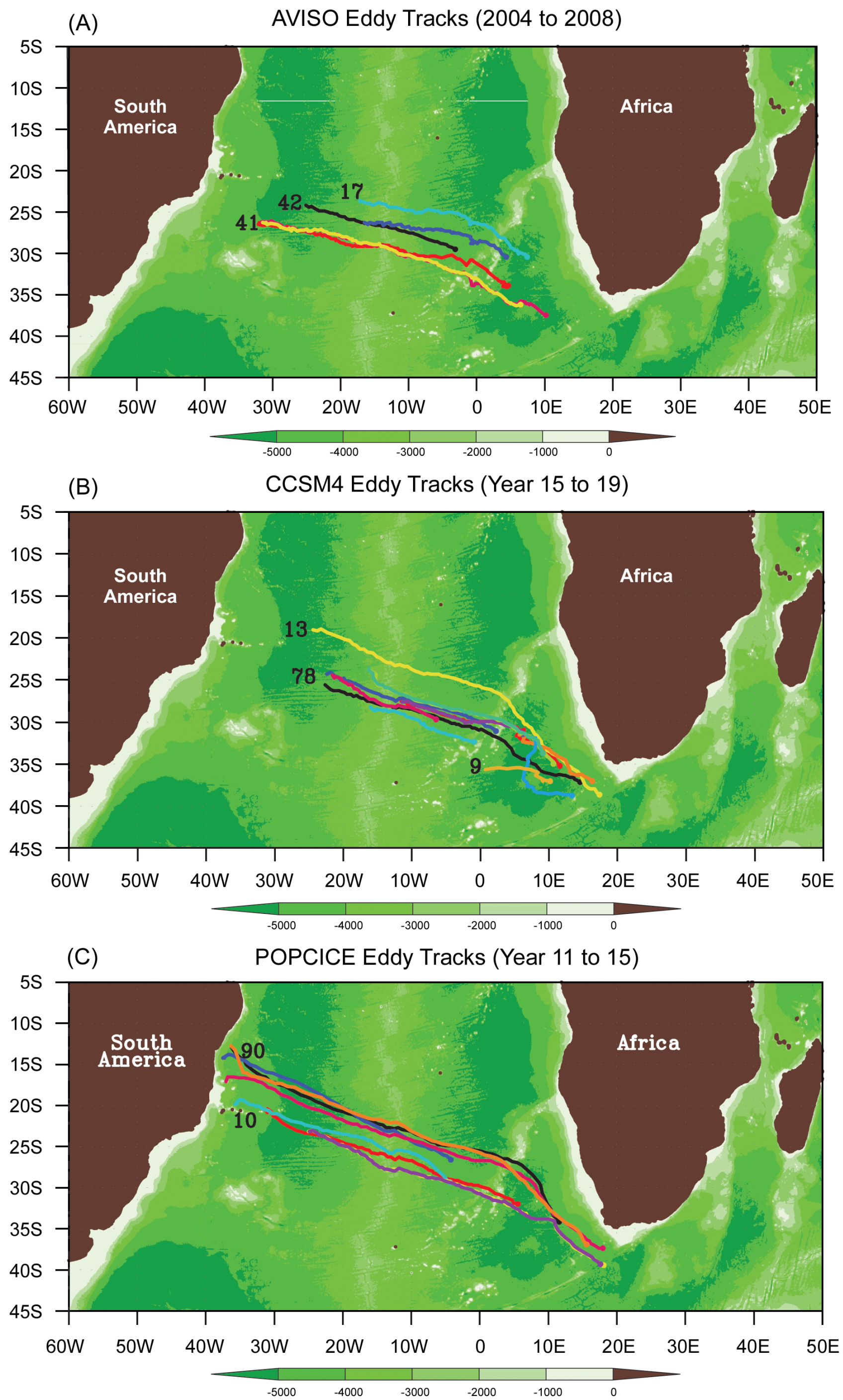
(a) CCSM4 Mesoscale RMS SSHA (cm)



(b) T/P & ERS Mesoscale RMS SSHA (cm)



Agulhas Eddy Tracks



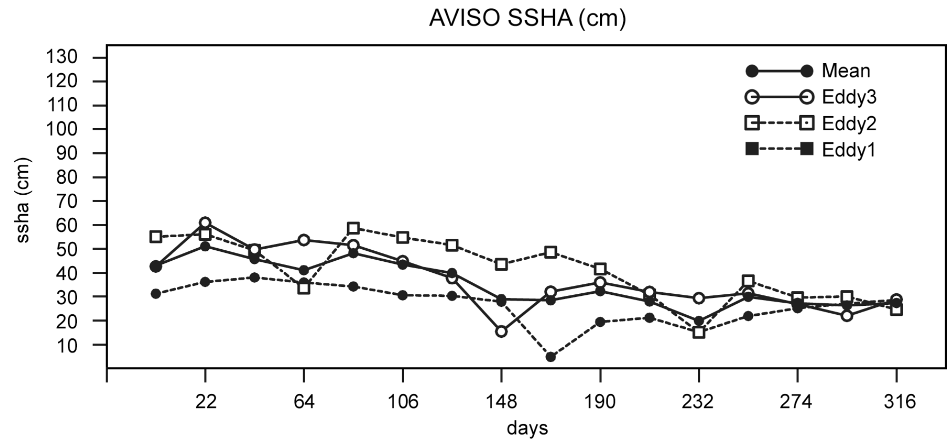
AVISO

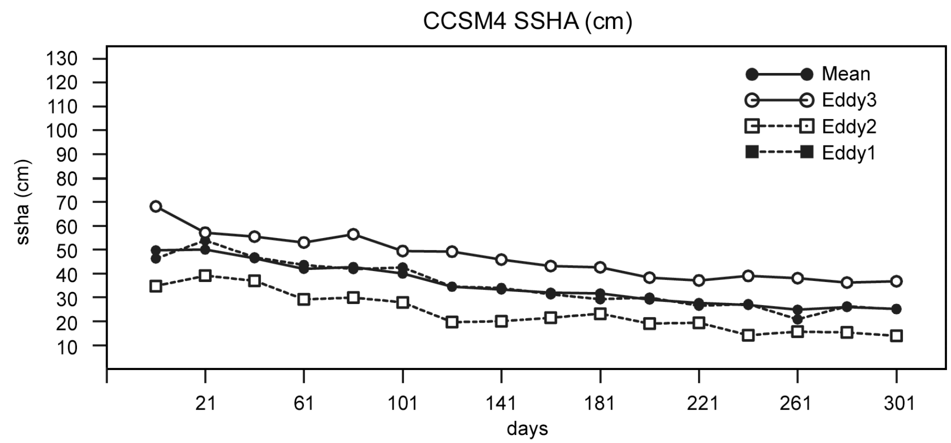
Okubo-Weiss tracking procedure:
Eddies are identified by closed contours of the Okubo-Weiss parameter, *W*, a measure of the relative importance of strain and vorticity. $W = -0.8 \times 10^{-12} s^{-2}$

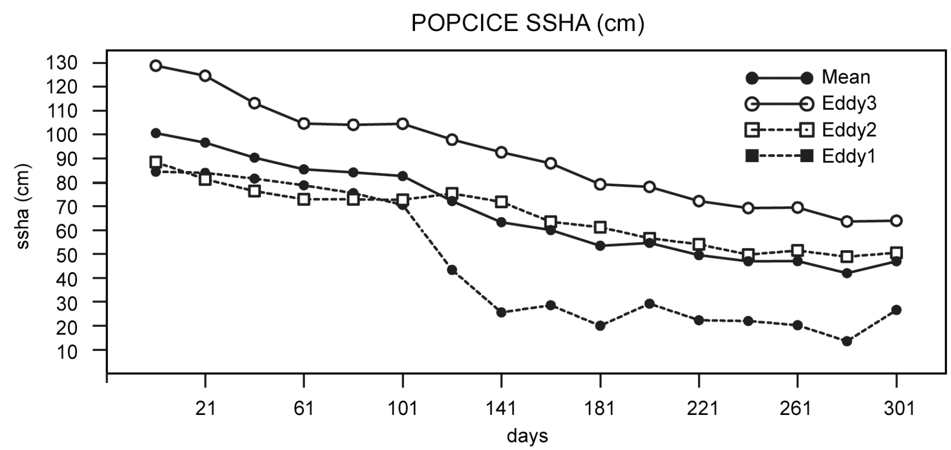
CCSM4: Eddy signatures disappear between 20° and 30° W and ~ 25°S.

Global Coupled 0.1° POP/CICE on tripole grid with partial bottom cells. Forced with Normal year CORE forcing. Eddies follow a too northwesterly path across the entire South Atlantic as in M&M2005 where standard *z*-levels were used in 0.1° POP.

Evolution of along-track amplitude of SSHA (cm) as a function of time since eddy formation for AVISO, CCSM4 and POP/CICE





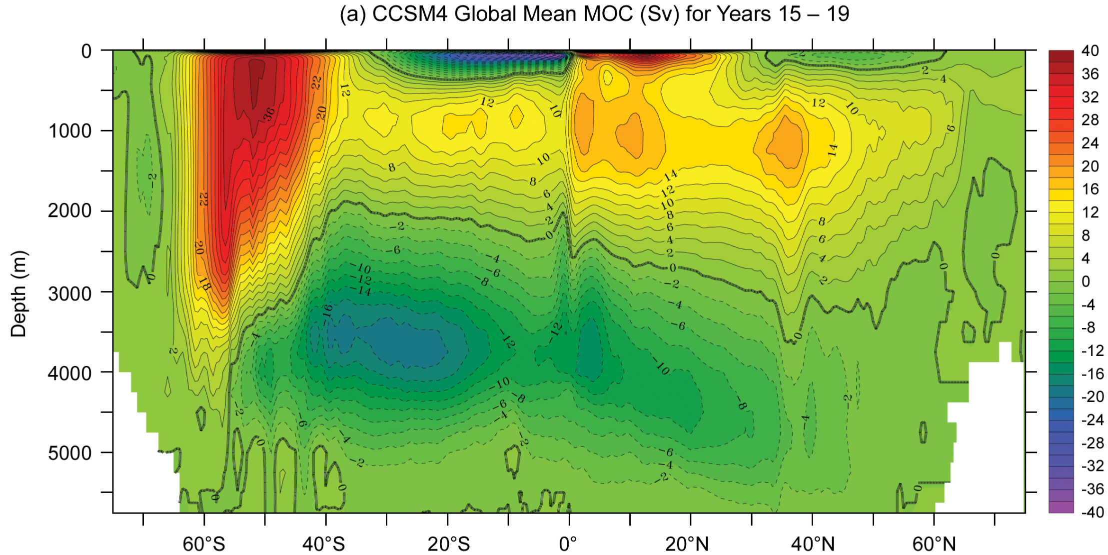


NCEP products are T62-about 210 km grid spacing. Underestimate latent and sensible heat transfers from Agulhas Current and Retroflection.

Meridional Overturning Streamfunction (Sv): CCSM4 (yrs 15-19)

Global

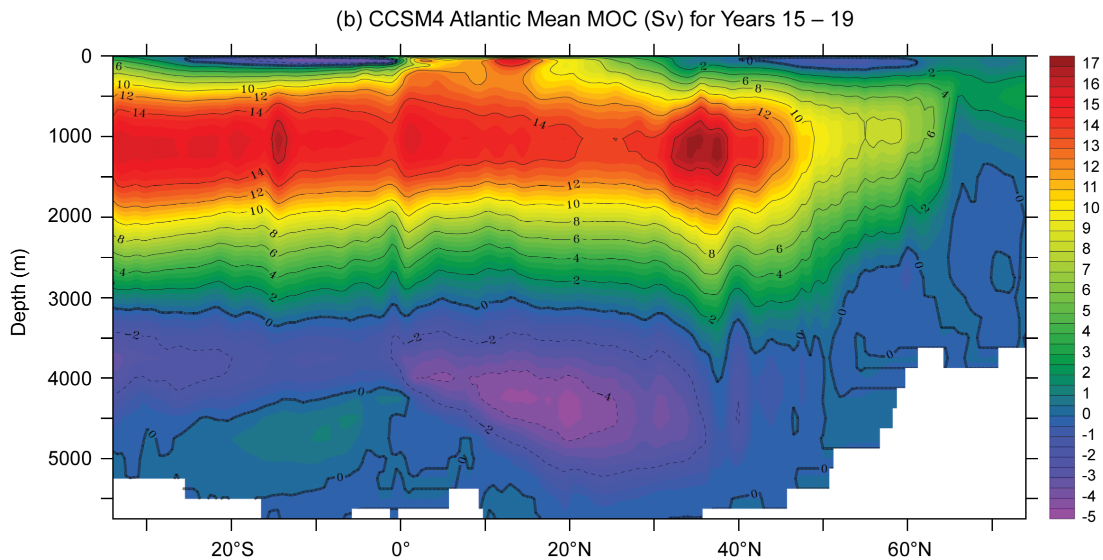
Deacon cell: 38 Sv



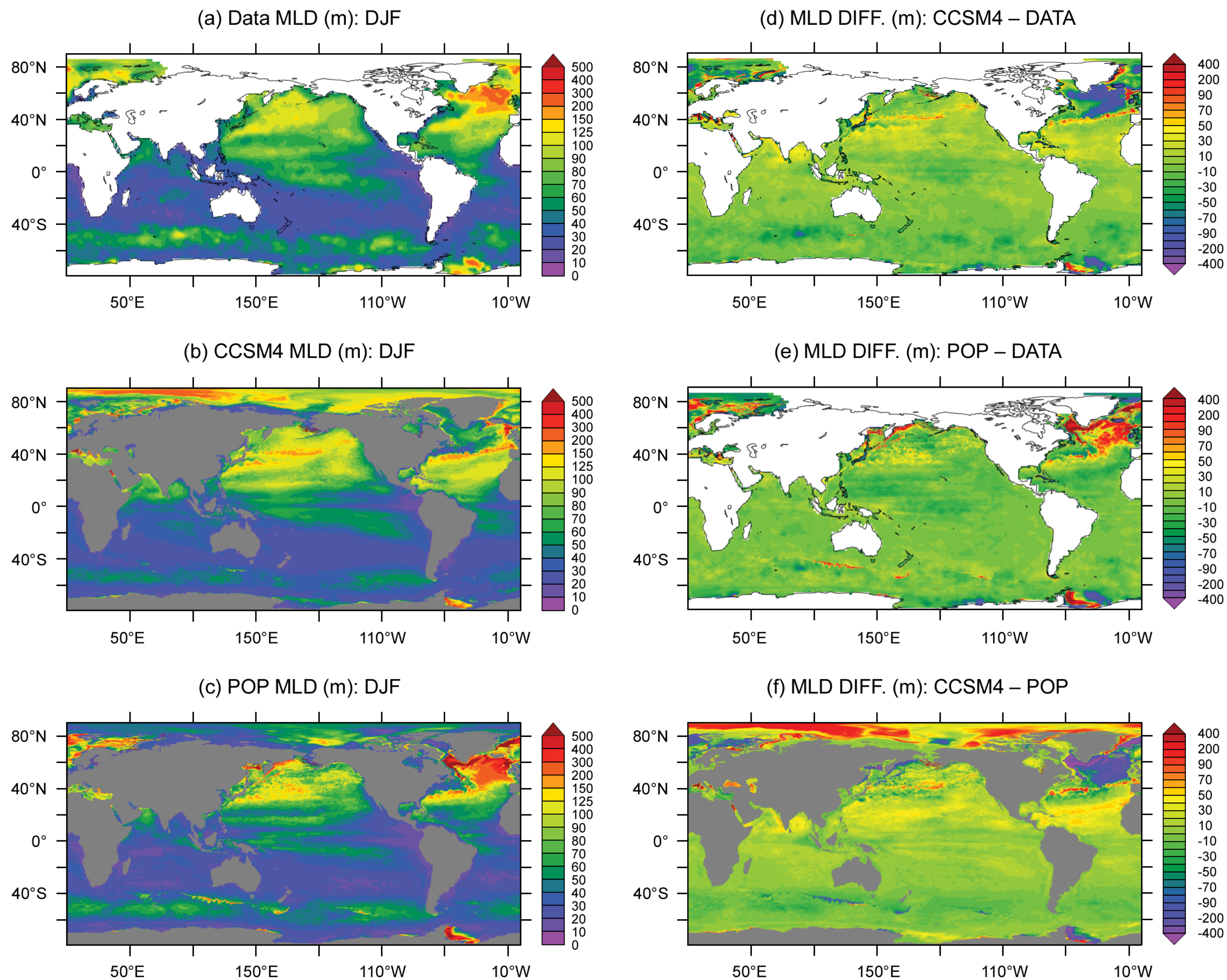
Atlantic

Max@40N : 18Sv, 14 Sv in SH and Bottom cell is 5 Sv

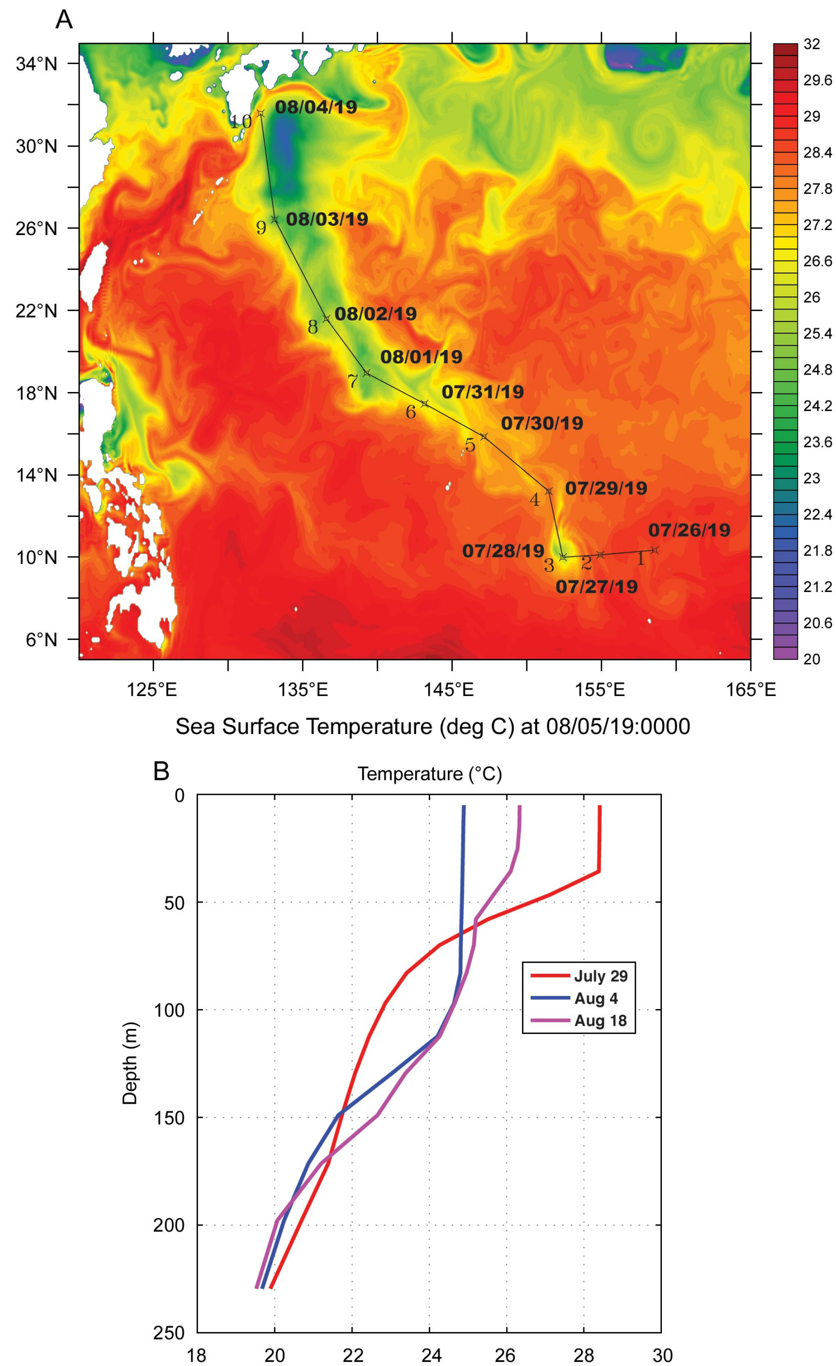
POP: 25,18, and 3 Sv



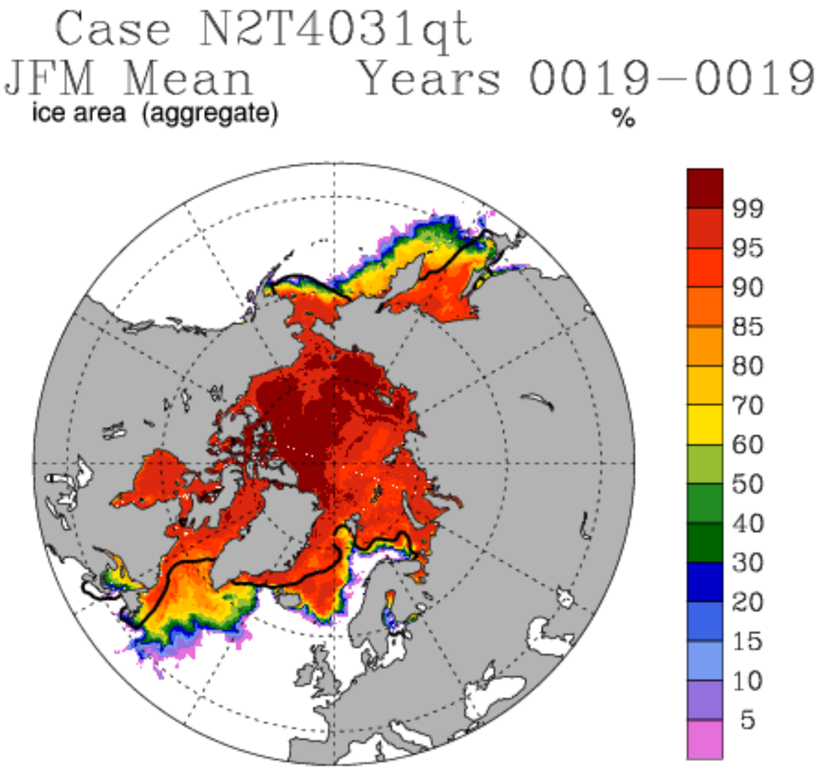
Mixed Layer Climatologies: DJF   Data: de Boyer Montegut et al. (2004, JGR)

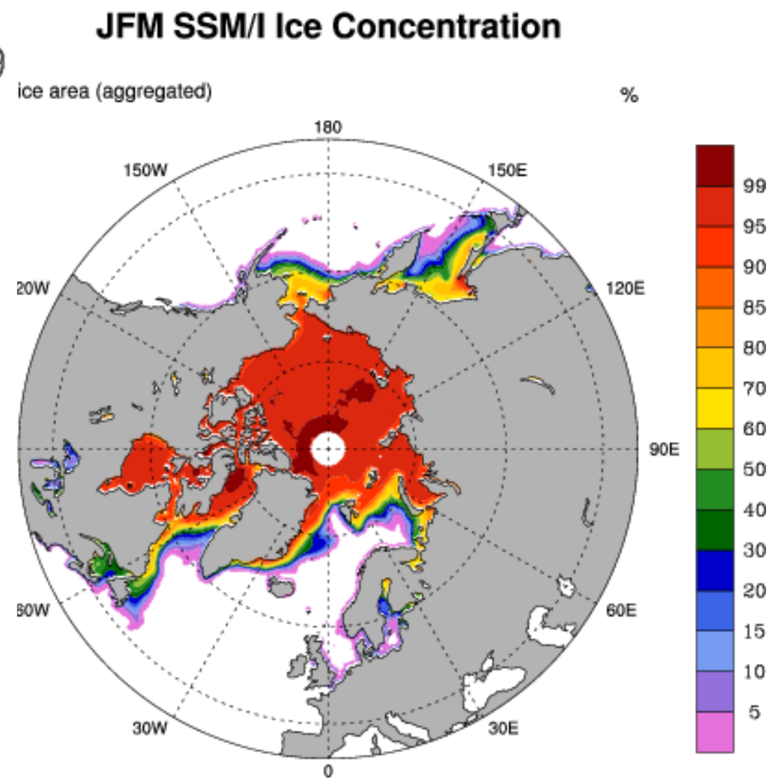


First Global Simulation to Resolve Both Atmosphere and Ocean Tropical Cyclone Behavior



Ice Biases Resulted in Unrealistic Climate Simulation





Time series of ice concentration and area showed problem is not transient

Conclusions

•The simulation's climate is very reasonable considering that no tuning has been done to correct for finer resolution.

•Global mean SSH from CCSM4 in better agreement with dynamic topography estimate from MDOT than stand-alone POP.

•CCSM4 provided an improved depiction of paths of Agulhas eddies relative to those in standalone POP.

•First global fully-coupled fine-resolution simulation to resolve both atmosphere and ocean tropical cyclone behavior

•Concluded experiment due to excessive ice coverage in the Northern Hemisphere.

•Output available through Earth System Grid

Ongoing Work

- Need to incorporate model upper ocean velocities in wind stress forcing of stand-alone 0.1°POP. Eddy damping? Less momentum imparted to western boundary currents?

- Ice coupled to POP: see 20 year 0.1° POP/CICE simulation (http: icemodel.ucsd.edu)

- Atlas simulation provided directions for Ultra-High Resolution Project
  – Ocean initialization at High Resolution
  – Parameterization Scaling
  – Extreme Event Simulation and Statistics

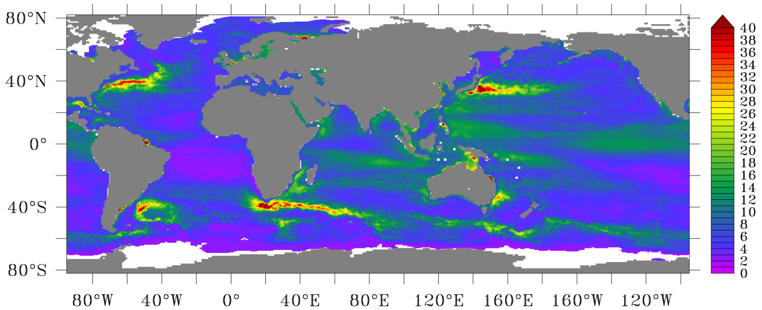
- Demonstrated need for isotropic atmospheric grid for high resolution simulations

- Volume of model output requires new solutions

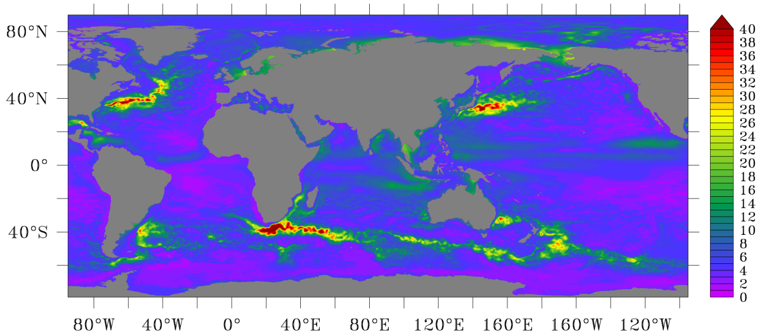
Stand-alone 0.1° POP (94/95) forced with CORE CIAF wind stresses that include model surface velocities.

Test of Hutchinson et al. (2010) globally: reduces basin-integrated power and damps eddies.

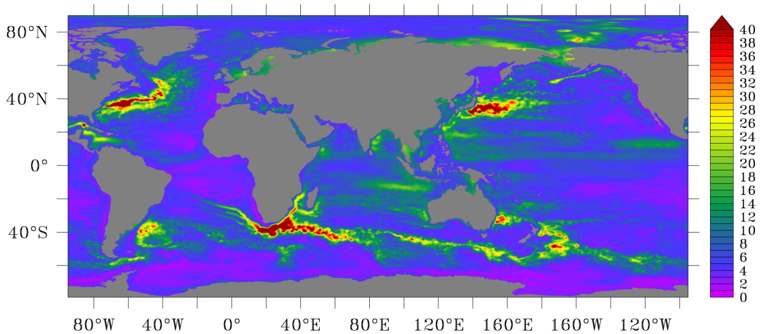
(a) T/P & ERS RMS SSHA (cm)



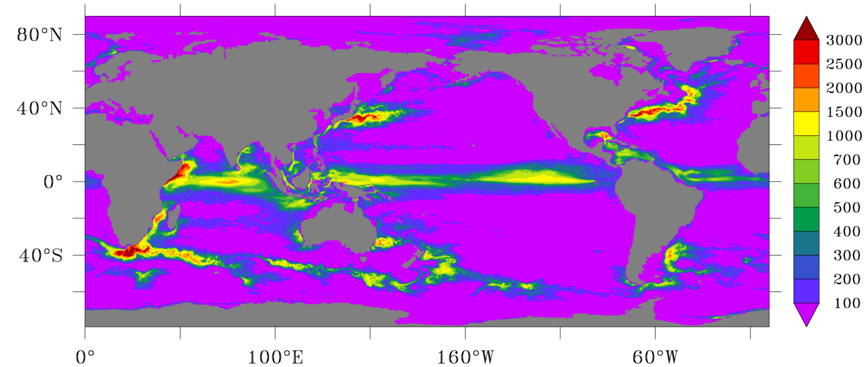
(a) POP (corrected) RMS SSHA (cm)



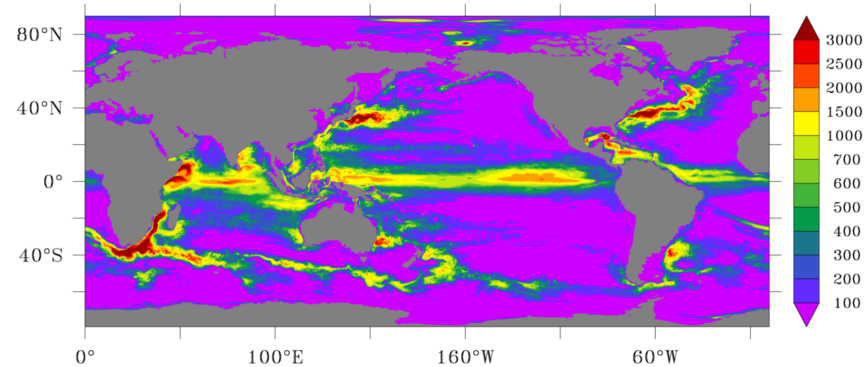
(c) POP (NOT corrected) RMS SSHA (cm)



(b) EKE POP 0.1 Tripole (wind cor) (cm2/s2)

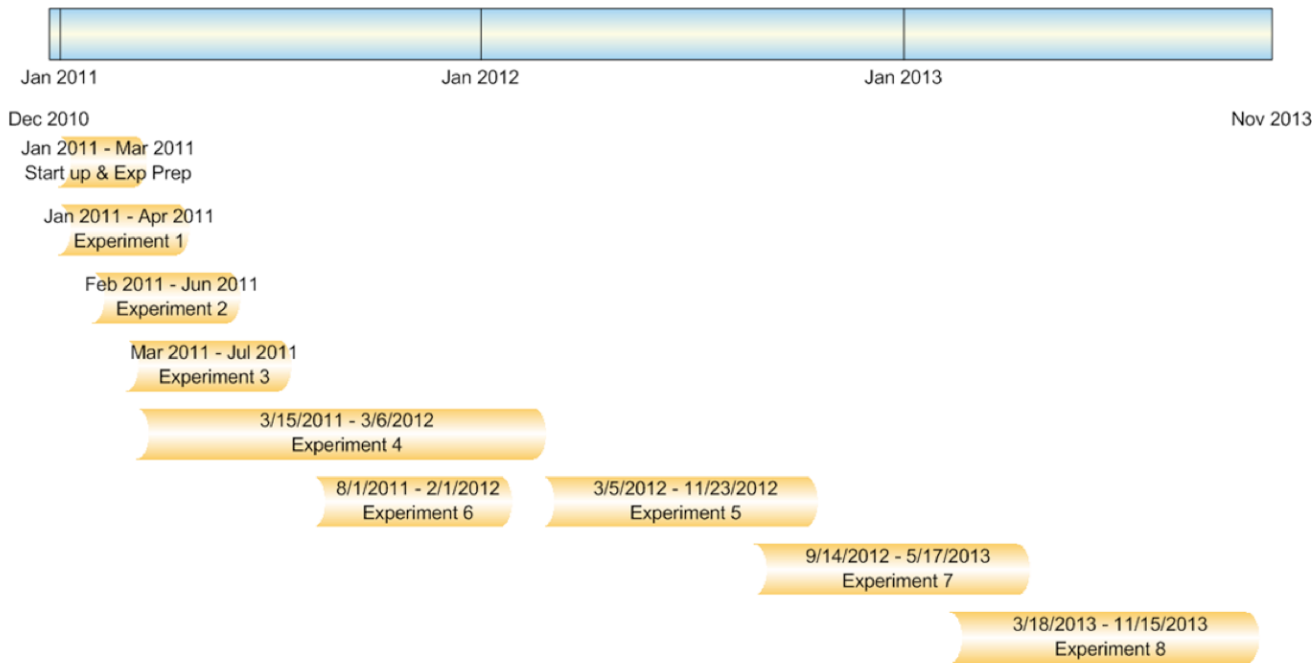


(c) EKE POP 0.1 Tripole (no wind cor) (cm2/s2)



Ultra High Resolution Global Climate Simulation to Explore and Quantify Predictive Skill for Climate Means, Variability and Extremes

Partners: ORNL, LANL-SIO, LBL, SIO, LLNL



1. T85 CAM/CLM with 1° POP/CICE (5 member ensemble) 30 years each
2. T85 CAM/CLM with 0.1° POP/CICE (single experiment) 30 years
3. T341 CAM/CLM with 1° POP/CICE (single experiment) 30 years
4. T341 CAM/CLM with 0.1° POP/CICE (5 member ensemble) 30 years each
5. Climate change runs: continue each of the above runs in (4) to 2035 using RCP 4.5 (30 years each)
6. Pre industrial control (1850 conditions) 186 years.
7. Single historical run 1850-2008. 158 years
8. A 1%/yr increasing CO2 starting in 1850 to doubling. 70 years

Coupled benchmark 1 degree runs using T85/gx1 CCSM4

- First 13 years of Pre-Industrial (PI) control run has very similar climate as “standard” CCSM4 (FV)
- Uses tri-pole ocean grid
- Hadley preindustrial SST dataset
- Extend PI simulation to 50-years
- Ensemble of 5 1975-2005 simulations for evaluation with “present day” observations

The End