Mesoscale Air-Sea Interaction in a Fine-Resolution Earth System Model : Agulhas Eddies

Julie McClean

Elena Yulaeva, Yoo Yin Kim

Scripps Institution of Oceanography

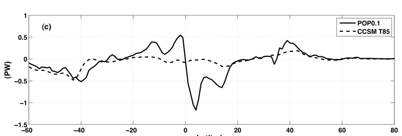
jmcclean@ucsd.edu

INTRODUCTION

Emerging fine resolution Earth System Models (ESMs) with weather-scale atmospheres and largely eddy-resolving oceans afford us the opportunity to study mesoscale air-sea interactions on scales approaching their true dynamical scales. The depiction of these interactions impact the representation of mesoscale eddies whose role and importance in the meridional overturning circulation (MOC) are still not well understood. An example important to climate is the Agulhas Leakage at the southern tip of Africa, which is characterized by variability on intraseasonal to interannual scales. Agulhas eddies are the main source of the warm and salty waters carried towards the North Atlantic as the upper limb of the Atlantic MOC (Biastoch et al., 2008). In the oceans of standard climate models eddies are parameterized and Agulhas eddies are absent.

Comparisons with available observations inform us as to whether the fine-resolution coupled model can be reliably used to study mesoscale air-sea interactions. We used AVISO sea surface height anomaly (SSHA), the Mean Dynamic Ocean Surface Topography (MDOT) product by Makimenko et al. (2009) and surface drifting buoys at 15m as gauges of model reliability. Our fully coupled model is a 20-year simulation of the Community Climate System Model (CCSM) that has 0.1-deg ocean and ice, and 0.25-deg atmosphere and land. Stand-alone 0.1° POP and POP/CICE simulations, forced with Common Ocean-Ice Reference Experiment (CORE) normal year atmospheric fluxes, were used for comparative studies. Since the meshes of the reanalysis atmospheric flux forcing are coarser than the spatial scales of some of the mesoscale frontal structures, the coupled model can also be used to understand the impact of a fine-resolution atmospheric state on the depiction of the mesoscale.

Global Meridional Ocean Eddy Heat Transport (PW) in a Standard Resolution Climate Model and an Eddy-Resolving Ocean Model.



Global meridional eddy heat transport (PW) from stand-alone 0.1° POP and CCSM3-T85. CCSM3 uses Gent and McWilliams (1990) for the eddy parameterization. Apart from the Southern Ocean and north of 45°N CCSM3 under-estimates the 0.1° POP eddy heat flux component (McClean et al., 2008).

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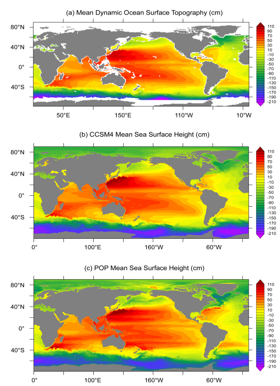
A Prototype Two-Decade Fully-Coupled Fine-Resolution CCSM Simulation: McClean et al (Ocean Modelling, 39, 10-30, 2011)

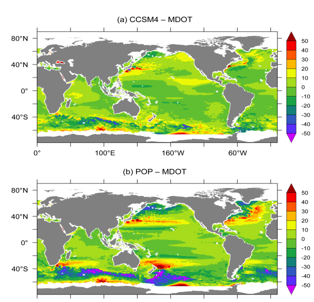
0.25° CAM3.5 (FV), CLM3	1990s GHGs
0.1° POP2.0,CICE4.0	Coupler 7.0

Observed Mean Dynamic Ocean Surface Topography (MDOT) and Mean Sea Surface Height from CCSM4 and Stand-Alone 0.1° POP

Global mean CCSM4 sea surface height (SSH) for years 13–19 is compared with the 0.5 mean dynamic ocean surface topography (MDOT) product of Maximenko et al. (2009). They combined satellite radar altimetry with the geoid model of the GRACE Recovery and Climate Experiment (GRACE) and synthesized upper-ocean velocities from 15-m drifting ocean buoys, hydrographic profiles, and ocean wind. For contrast with CCSM4, we also consider the mean SSH field from stand-alone global 0.1° POP (Maltrud et al., 2010) for years 95–99. The patterns and magnitudes of mean SSH from CCSM4 agree best with MDOT. The difference plot between POP and MDOT highlight overly high POP mean SSH values in western boundary current frontal and recirculation regions: The Tasman Front in the southwestern Pacific near New Zealand, the Agulhas Current System, the Kuroshio Extension and the Gulf Stream-North Atlantic Current. In the Southern Ocean to the south of Australia and New Zealand and in the southeastern Atlantic sector POP values are more negative relative to MDOT.



Difference Fields (cm):



Conclusions

Mean SSH and Agulhas eddy pathways from CCSM4 agree better with observations than those from POP. NCEP products forcing stand-alone POP are T62- about 210 km grid spacing so would underestimate latent and sensible heat transfers from Agulhas Current and Retroflection. We attribute the greater realism in CCSM4 to two-way coupling of an ocean and atmosphere that both have fine meshes. However…

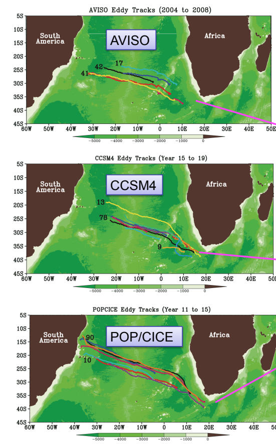
AGULHAS EDDIES

Okubo-Weiss Tracking Procedure (Isern-Fontanet al., 2006, JPO):

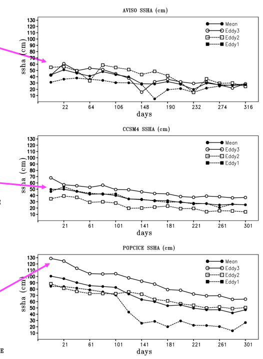
Eddies are identified by closed contours of the Okubo-Weiss parameter, *W*, a measure of the relative importance of strain and vorticity, $W = -0.8 \times 10^{-12}\ s^{-2}$.

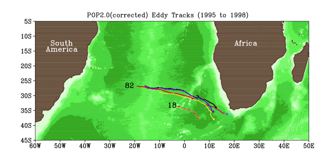
Numbers are % of times that eddies follow that same path

Eddy pathways are tracked using AVISO altimetry, CCSM4 and global coupled 0.1° POP/CICE (P/C) that is configured on the same grid as CCSM4. P/C is forced with CORE Normal year forcing. Eddies follow a too northwesterly path across the entire South Atlantic in P/C.



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



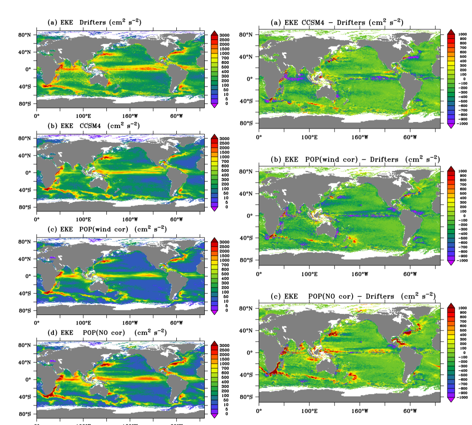


Agulhas eddy trajectories from the corrected stand-alone 0.1° POP run. Interestingly the eddies take a realistic path to the mid-basin where they dissipate. However they do not seem to follow multiple pathways.

Global Stand-Alone 0.1° Ocean: Inclusion of Ocean Surface Currents in Wind Stress Drag Law Calculations

We are now running stand-alone 0.1° POP with ocean surface velocities incorporated into the wind stress drag law calculation as is done in CCSM4. Using an eddy-resolving quasigeostrophic model of the Southern Ocean Hutchinson et al. (JPO, 2010) found that the relative velocity scheme had substantially lower power input, resulting in a weaker eddy field. To understand the impact of this scheme in POP we are running two simulations: one with the correction and one without.

Earlier POP simulations did not have this correction. Below we show eddy kinetic energy (EKE) at 15 m from surface drifting buoys, CCSM4, corrected POP, and uncorrected POP. Difference fields (below) show that the corrected POP EKE values are in closer agreement with observations in the western boundary currents, the Agulhas Retroflection, and the Antarctic Circumpolar Current. However in the central subtropical gyre regions the EKE is under-estimated. Mean SSH from the corrected POP run agreed better with MDOT than the uncorrected run (not shown).



The input of power by the mean wind to the ocean can be separated into power that is added to the general circulation and power that drives the mixing of the upper ocean (Dawe and Thompson, 2006).To the right we show

$$P_{circ} = \boldsymbol{\tau} \bullet \mathbf{u}_{geo}$$

from POP (with the ocean surface current correction) and from QuikSCAT wind stresses and geostrophic velocities from altimeter-derived SSHA. The model underestimates circulation power in the ACC and the northern hemisphere western boundary currents. This may be due to the coarseness of the atmospheric CORE fluxes used to force POP. This work is ongoing. We need to calculate the power input from the wind for both CCSM4 and the uncorrected POP and then adjust the biharmonic mixing coefficients in POP to more closely match the observations in future simulations.