Upwelling and coastal current biases in climate models (Part 1) –Modelling the ocean

Translating process understanding to improve climate models. GFDL, October 15-16, 2015.

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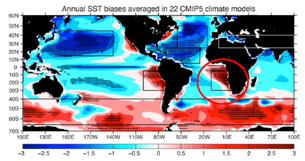
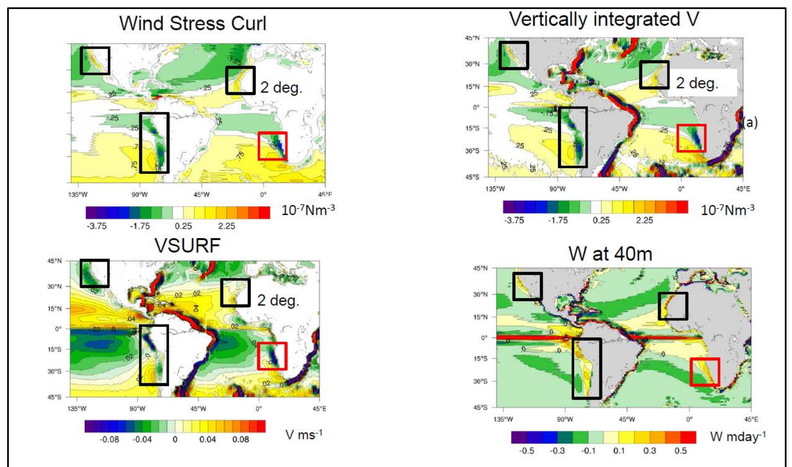
Introduction: Of all the major coastal upwelling systems in the World's ocean, the Benguela, located off south-west Africa, is the one which climate models find hardest to simulate well (see figure at right). This poster investigates the sensitivity of upwelling processes, and of sea surface temperature (SST), in this region to resolution of the climate model and to the offshore wind structure. The Community Climate System Model (version 4) is used here, together with high-resolution, regional Weather Research and Forecasting (WRF) and Regional Ocean Modeling System (ROMS) simulations. It is found that increasing atmosphere resolution substantially improves SST, but in order to get a realistic upwelling system, a high-resolution ocean model is also required. Reasons for this are discussed below, together with potential applications: for other upwelling regions (including California Current, Peru and Chile), and for ecosystem modelling.



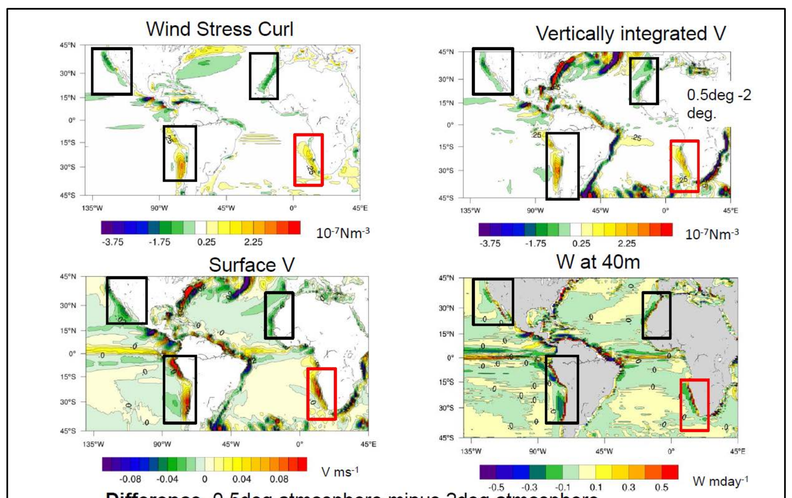
CMIP5 Multi-model mean (Provided by Roberto Mechoso, Matt Masarik). Long term, annual mean SST difference from observations.

Ocean response to changing atmosphere resolution

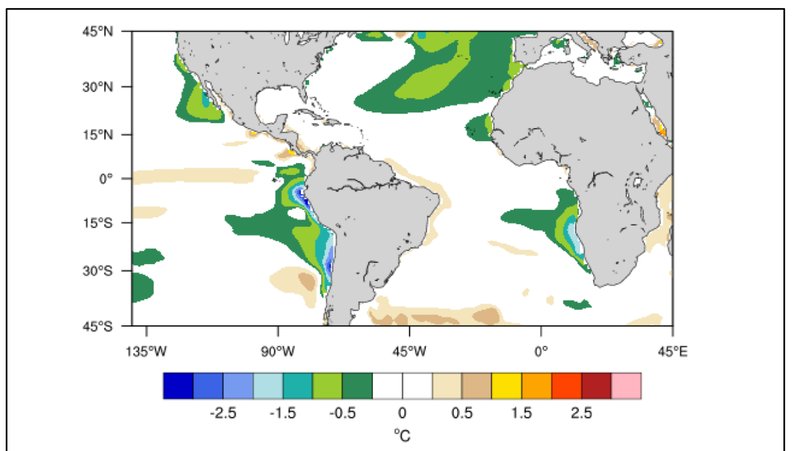
Here the ocean resolution of CCSM4 is fixed at 1deg., whilst atmosphere resolution is varied.



CCSM4 with 2deg. Atmosphere, 1deg. ocean



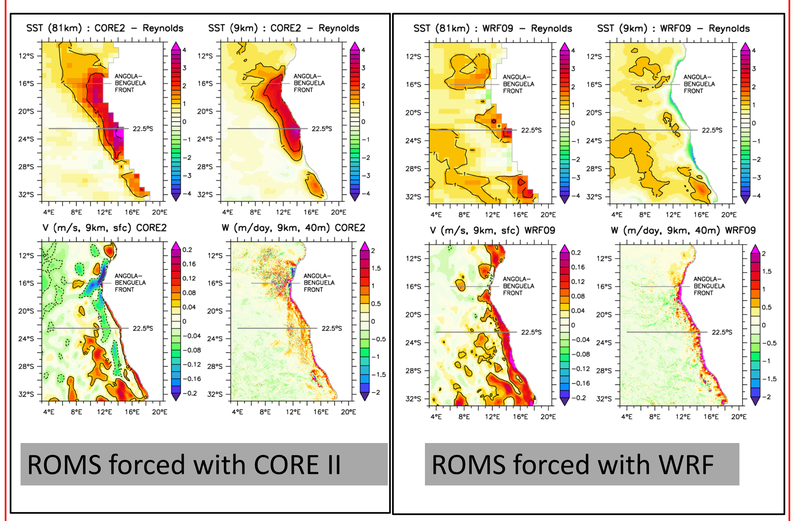
Difference, 0.5deg atmosphere minus 2deg atmosphere



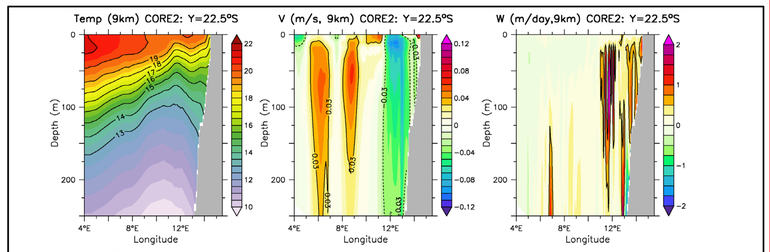
Difference of SST due to changing the atmospheric resolution in CCSM4. CCSM4-0.5° minus CCSM4-1°, in JJA.

Sensitivity to Ocean model resolution

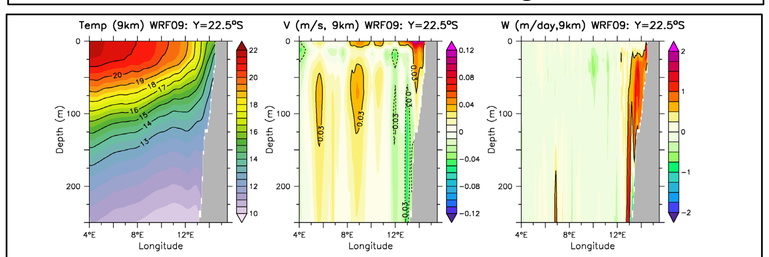
ROMS is run at 81km or 9km. Forcing is either CORE2 or a 9km WRF run with forcing interpolated onto ocean grid.



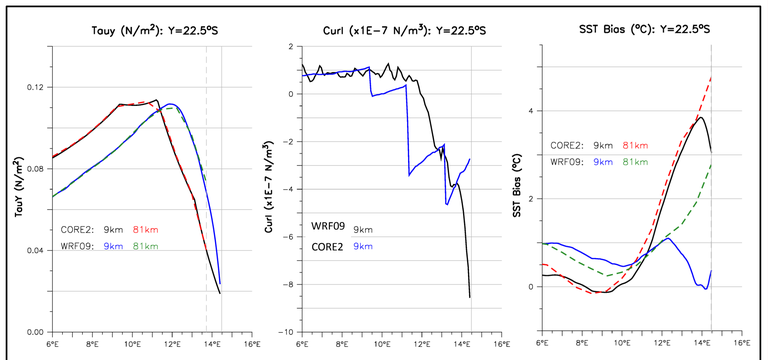
ROMS forced with CORE II | ROMS forced with WRF



CORE-forced: Vertical sections at 22.5deg.S, T: V: W



WRF-forced: Vertical sections at 22.5deg.S, T: V: W



Wind stress and SST: Sections at 22.5deg. S: meridional wind stress: wind stress curl: SST bias.

Summary

- At low resolution (~100km or coarser), broad and strong wind stress curl leads to Sverdrup dynamics and Ekman pumping – warm advection/weak broad upwelling, warm SST.
- Increasing atmosphere resolution to 50km reduces wind stress curl, increases cold advection and coastal upwelling –cools SST. However currents and upwelling are still weak and broad when the ocean model is non-eddy resolving (~100km).
- Increasing ocean resolution to ~10km for a fixed, low-res atmosphere product (CORE) does not improve SST.
- Increasing ocean resolution when using a high-resolution atmosphere product (WRF- 9km) does lead to cooling of SST at the coast and a cold coastal bias. (The high-resolution ocean resolves the Rossby radius, coastal jet and upwelling.) The cold bias may relate to a lack of coupling.

Applications to Ecosystem Modelling

Recent high-resolution ocean-biogeochemistry simulations with the Community Earth System Model show low chlorophyll productivity biases in the eastern boundaries (figure at right). As the model was forced by CORE, one of the factors governing this bias might be the weak upwelling.

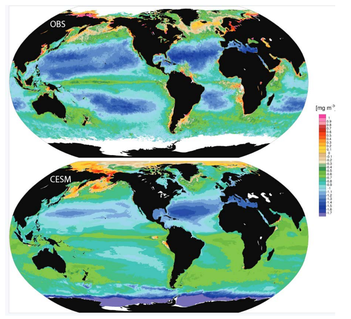


Figure courtesy Matthew Long, NCAR

Application to other upwelling regions

California Current . From the first figure, CCSM4 shows Equatorward surface flow in this region, despite a strong wind stress curl and poleward depth-averaged flow. This may be due to the stronger coastal winds in the model off the US west coast, relative to model winds in the Benguela.

Peru-Chile - Here there is a similar ocean current and upwelling response to changing atmosphere resolution as seen in Benguela. However it is easier to reduce SST in Peru-Chile (bottom left figure). This may be due to a lack of an equivalent frontal zone to the Angola Benguela Front, which is hard to model correctly.