Community Earth System Model

Embedding a high resolution regional ocean model of the North-East Pacific in a coupled Global Climate Model

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Introduction

This is a study of the regional atmosphere-ocean interactions, and the global ramifications, that result from a more accurate treatment of eastern boundary coastal upwelling regions in a fully coupled global multi-scale climate model. The nested Regional Climate Model (nRCM) has been implemented in the Community Earth System Model (CESM) framework. For these experiments we are interested in whether the nRCM can be used to reduce the well known warm SST biases that occur off eastern boundary regions in global climate models (e.g. Large and Danabasoglu 2006[1]). It has previously been suggested that this bias has its root in poor representation of coastal winds (see Gent et al. 2010[2]), or of the persistent stratocumulus deck (Philander et al. 1996[3]), or of the coastal upwelling (see Large and Danabasoglu 2006[1], deSzoeke et al 2010[4]). In this poster we focus on the latter process and look at the effect of using ROMS in the upwelling region off the US West Coast.

Nested Regional Climate Model

Here the Regional Ocean Modeling System (ROMS) is used for an inner ocean nest, which receives lateral boundary conditions from the global Parallel Ocean Program (POP) model. In addition the POP surface temperature is strongly restored to the ROMS SST with a 10 day timescale.

The sea surface temperature from ROMS and POP is merged and sent to the CESM coupler to interact with the global Community Atmosphere Model (CAM), as well as the ice and land models. In this way ROMS can affect the global climate in what is termed 'upscaling'.

Experiments

This first nRCM experiment considers the US west coast. A 100 year nRCM integration is performed, for comparison with a long baseline (1300 year) CESM integration. The initial conditions are taken from the baseline run, and the only difference in model components between the nRCM and the baseline CESM is the inclusion of ROMS. Fig. 1 shows the ROMS domain (dashed line) and the SST difference between a standard CESM simulation and Levitus/WOA98 observations. The warm SST bias off the coasts of Mexico, California and Oregon is extensive and spreads towards the tropics.

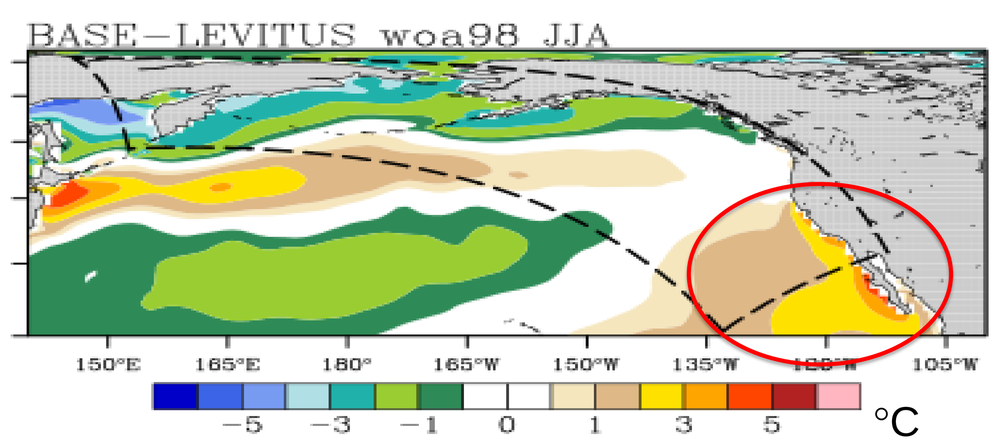

Figure 1. The summer (JJA) bias in SST in the standard CESM (CCSM4) run relative to Levitus WOA98 observations. Note warm bias in the upwelling region (circled in red)

Local Upwelling Response

Northerly winds induce coastal upwelling off the US west coast via Ekman transport. Several previous studies using ROMS at grid spacing of 10km or less have shown that it can replicate typical mesoscale upwelling features[5,6] which are not resolved by typical ocean components of climate models,

Here we use ROMS at 1/10° grid spacing, in the nRCM. When averaged over a long record (40 years used here) of summers, ROMS gives a much stronger and narrower upwelling velocity than the POP model of a CESM standard integration. This leads to much cooler SST near the coast in the nRCM.

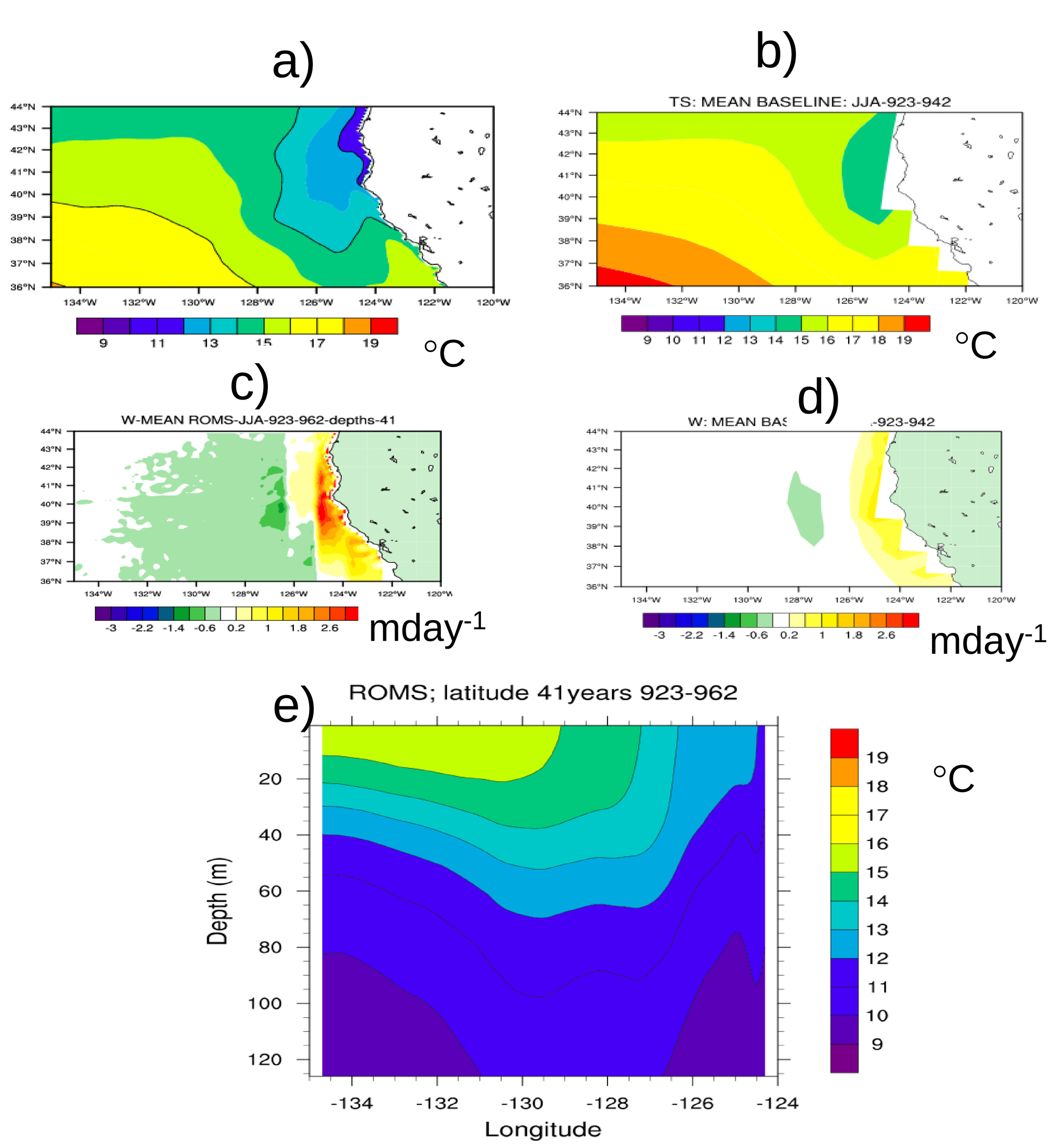

Figure 2. A summer (JJA) average, showing the US west coast upwelling system. a, b): SST. c, d): vertical velocity (m/day) at ~40 m depth. Left panels: ROMS component of the nRCM, based on a 40 years average. Right panels: the POP component of the baseline run based on 20 years. e): a depth-longitude temperature section at 41N from ROMS showing the upwelling in summer.

North-east Pacific SST response

Early in the 100 year nRCM integration the cooling at the coast spreads westwards and southwards. This is mainly a result of the prototype two-way ocean interaction, which enables the cool SST anomaly in ROMS to be passed out of the ROMS domain by the mean POP currents. In addition air-sea interaction can spread the anomaly, such as by the wind-evaporation-SST feedback[7]. The cool anomaly persists year-round south of latitude 40°N.

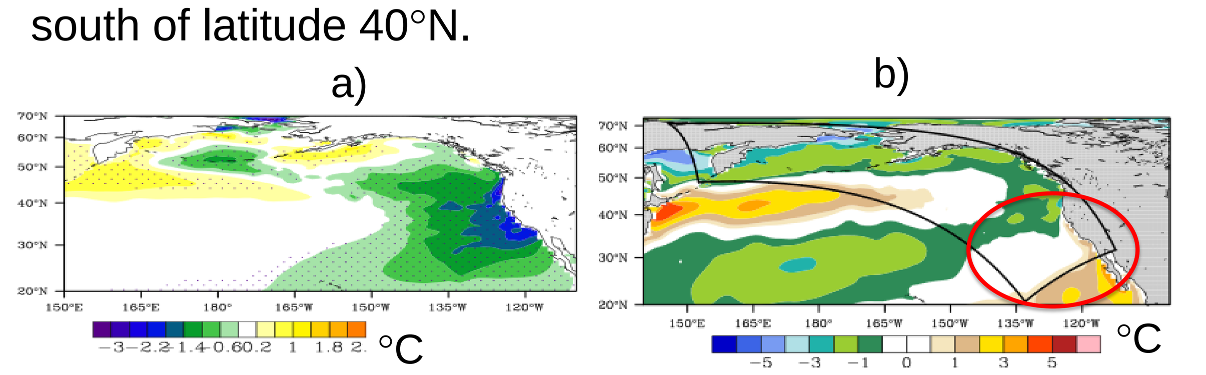

Figure 3. a) The summer (JJA) difference in SST between the nRCM and the baseline CCSM run, averaged over 90 years. Stipling denotes significance at 95% according to the t-test. b) The summer (JJA) bias in SST in the nRCM relative to Levitus WOA98 observations. Note the reduction of bias in the upwelling region (circled in red) compared to the baseline CCSM run (Fig. 1)

Surface fluxes and feedbacks

The eastern boundary regions are covered by extensive stratocumulus decks, something that climate models have traditionally had problems in representing. A stable boundary layer favors stratus formation[8]: the nRCM, by providing a cool SST anomaly (Fig. 3a) enhances the stratus cover and leads to a reduction in short wave radiation reaching the surface (Fig. 4a). This effect is countered by less heat loss by evaporation and upward long wave radiation (Fig. 4b).

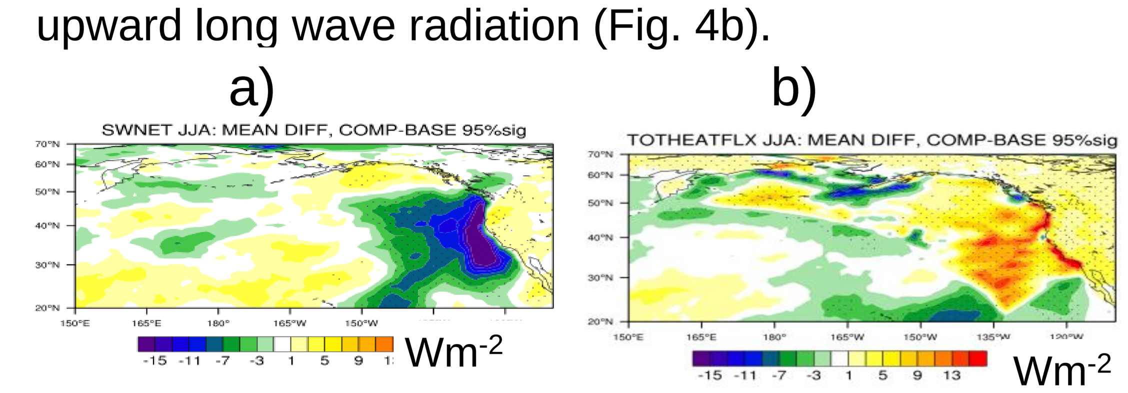

Figure 4. a) The summer (JJA) difference in net surface short wave radiative flux (positive values denote warming of ocean) between the nRCM and the baseline CCSM run, averaged over 90 years. b) same as a), but for all surface heat flux components combined (short wave, long wave, latent and sensible). Stipling denotes significance at 95%.

Atmospheric response

The primary response of the atmosphere is a regional high pressure system that is strongest in the cool seasons. This response is likely a combination of boundary layer adjustment[9] and non-linear effect due to synoptic eddies[10]). In addition, the regional precipitation is reduced due to increased subsidence and reduced evaporation.

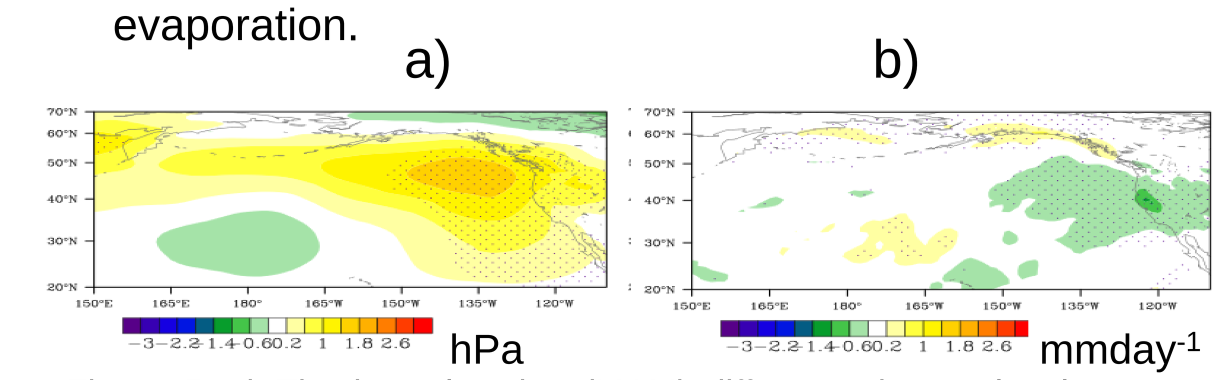

Figure 5. a) The boreal spring (MAM) difference in sea level pressure between the nRCM and the baseline CCSM run, averaged over 90 years. b) as a) but for precipitation rate. Stipling denotes significance at 95%.

Far-field response

In boreal spring (MAM) the SST response extends to the equator. Associated with this is are statistically significant precipitation changes with increased precipitation around 10°N and 10°S in the eastern Pacific.

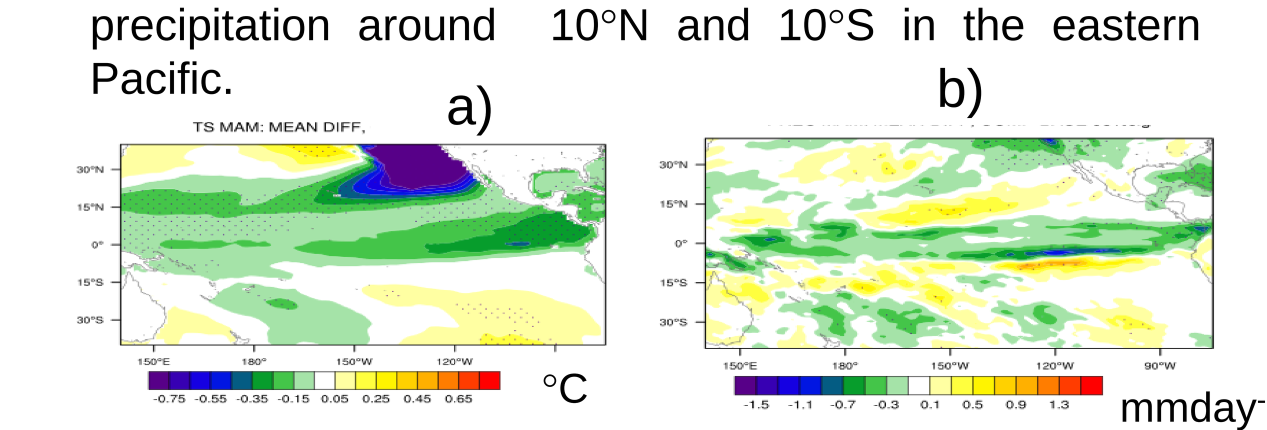

Figure 6. Tropical a) SST and b) precipitation anomalies for boreal spring (MAM). Stipling denotes significance at 95%. SST and precipitation is reduced over the equator and precipitation is increased around 10°N and 10°S.

Summary and Way Forward

The use of the nRCM for the north-eastern Pacific leads to a large and significant regional response, and a moderate and statistically significant change to precipitation in the ITCZ. In future work we will investigate other regions where warm biases exist (Benguela Current system, Peru current system). We will also explore in more detail the pathways by which the local response affects regional and basin scales.

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References. 1. Large, W. G., and G. Danabasoglu, 2006. J. Climate, 19, 2325-2346. 2. Gent, P. R., et al., 2010. Clim. Dyn., 34, 819-833. 3. Philander, S. G. H., et al. , 1996. J. Clim., 9, 2958-2972. 4. deSzoeke, S. et al., 2010. J. Climate, 23, 4152-4174. 5. Marchesiello, P., et al., 2003. J. Phys. Oceanogr., 33, 753-783. 6. Capet, X., et al., 2008. J. Phys. Oceanogr., 38, 29-43. 7. Xie, S.-P., 1999. J. Clim., 12, 64-70. 8 Klein, S. A., and D. L. Hartmann, 1993. J. Climate, 6, 1587-1606. 9. Lindzen, R. S. and Nigam, S., 1987. J. Atmos. Sci., 44:2418-2436. 10. Kushnir, Y., et al., 2002.. *J. Climate*, **15**, 2233-2256.