Exploiting ENSO predictability in forecasting marine ecosystem changes along the U.S. West Coast

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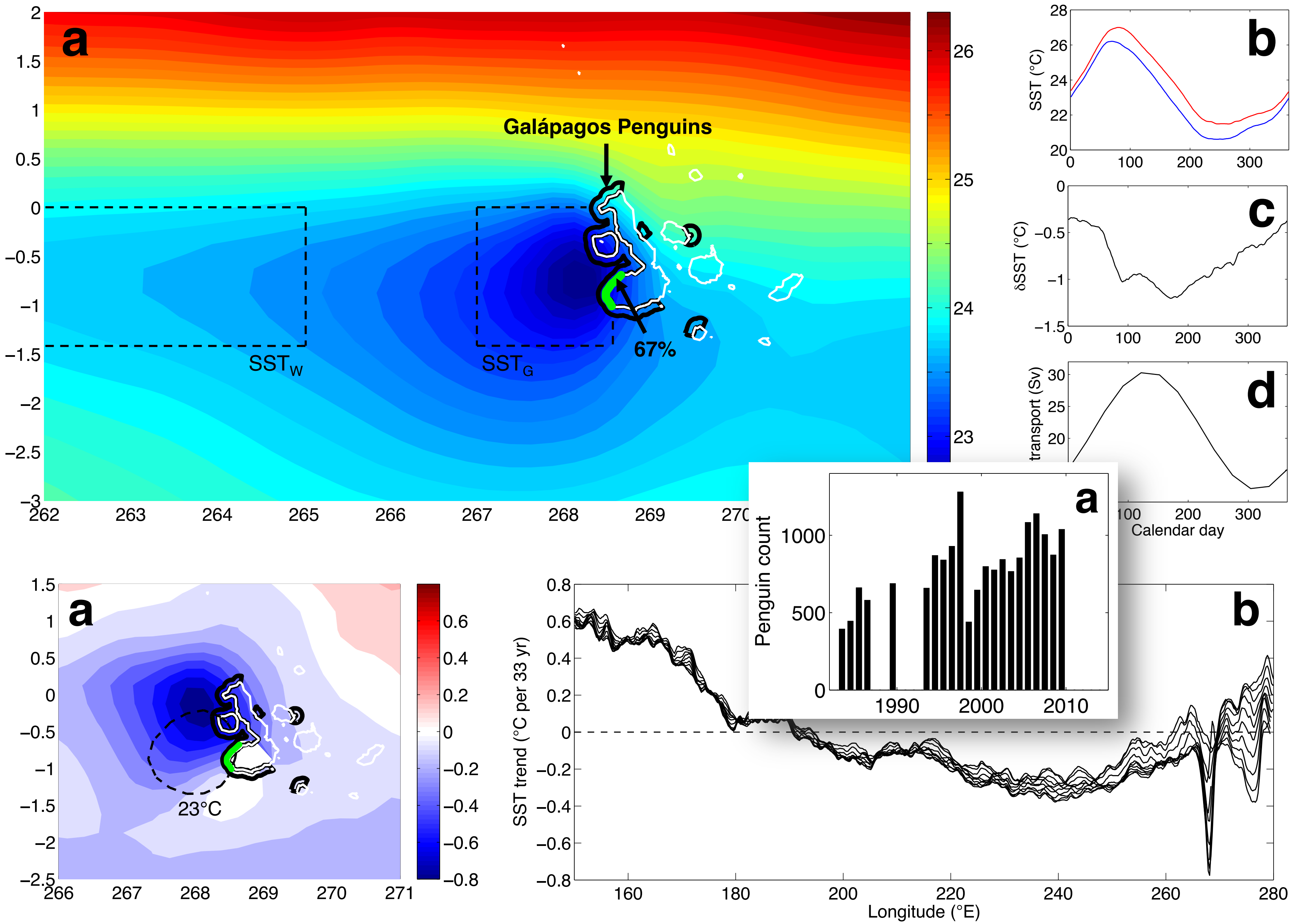
Joint POS/PPAI Session on Predictability of Coastal/Shelf Systems, Including Ecosystems



Karnauskas et al. (2015, *GRL*)

LETTER

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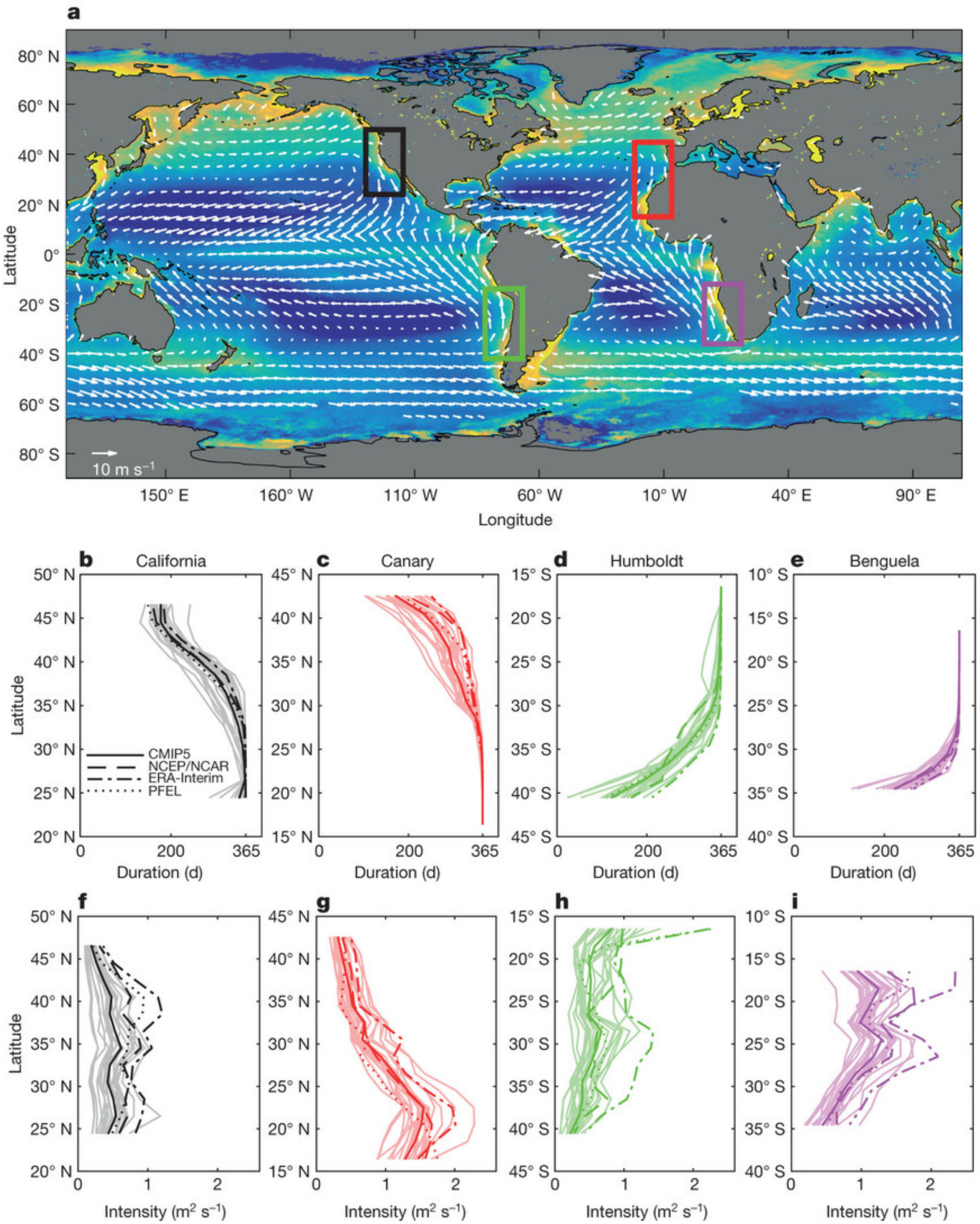
Intensification and spatial homogenization of coastal upwelling under climate change

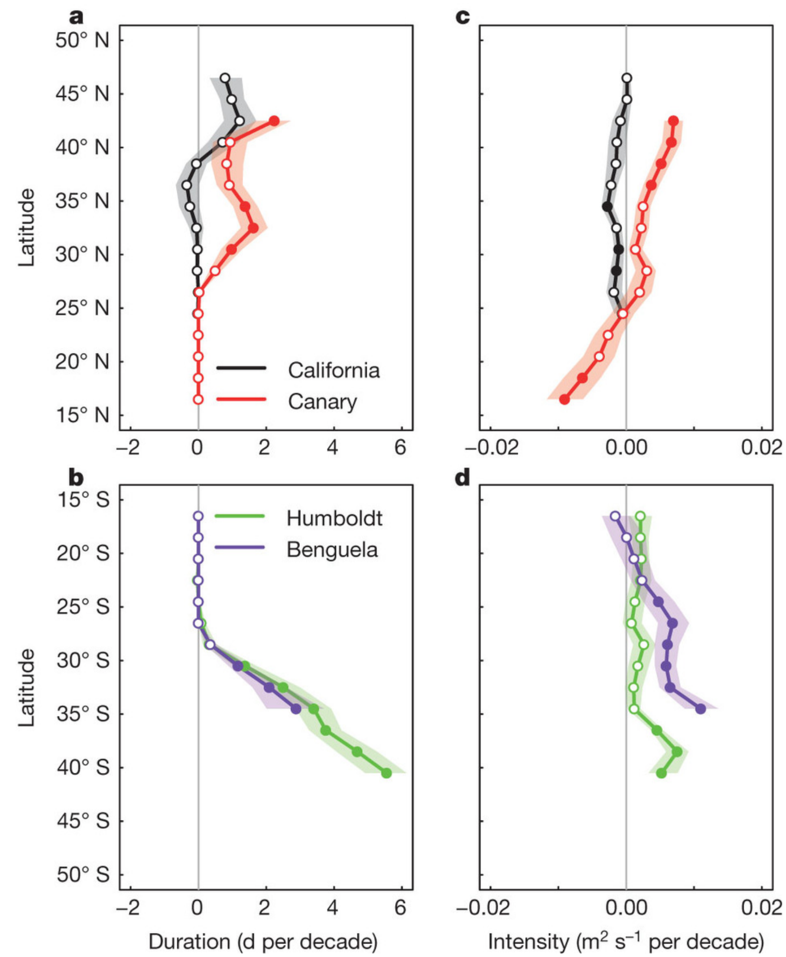
Daiwei Wang[1], Tarik C. Gouhier[2], Bruce A. Menge[3] & Auroop R. Ganguly[1]

The timing and strength of wind-driven coastal upwelling along the eastern margins of major ocean basins regulate the productivity of critical fisheries and marine ecosystems by bringing deep and nutrient-rich waters to the sunlit surface, where photosynthesis can occur[1–3]. How coastal upwelling regimes might change in a warming climate is therefore a question of vital importance[4,5]. Although enhanced land–ocean differential heating due to greenhouse warming has been proposed to intensify coastal upwelling by strengthening alongshore winds[6], analyses of observations and previous climate models have provided little consensus on historical and projected trends in coastal upwelling[7–13]. Here we show that there are strong and consistent changes in the timing, intensity and spatial heterogeneity of coastal upwelling in response to future warming in most Eastern Boundary Upwelling Systems (EBUSs). An ensemble of climate models shows that by the end of the twenty-first century the upwelling season will start earlier, end later and become more intense at high but not low latitudes. This projected increase in upwelling intensity and duration at high latitudes will result in a substantial reduction of the existing latitudinal variation in coastal upwelling. These patterns are consistent across three of the four EBUSs (Canary, Benguela and Humboldt, but not California). The lack of upwelling intensification and greater uncertainty associated with the California EBUS may reflect regional controls associated with the atmospheric response to climate change. Given the strong linkages between upwelling and marine ecosystems[1–3], the projected changes in the intensity, timing and spatial structure of coastal upwelling may influence the geographical distribution of marine biodiversity.

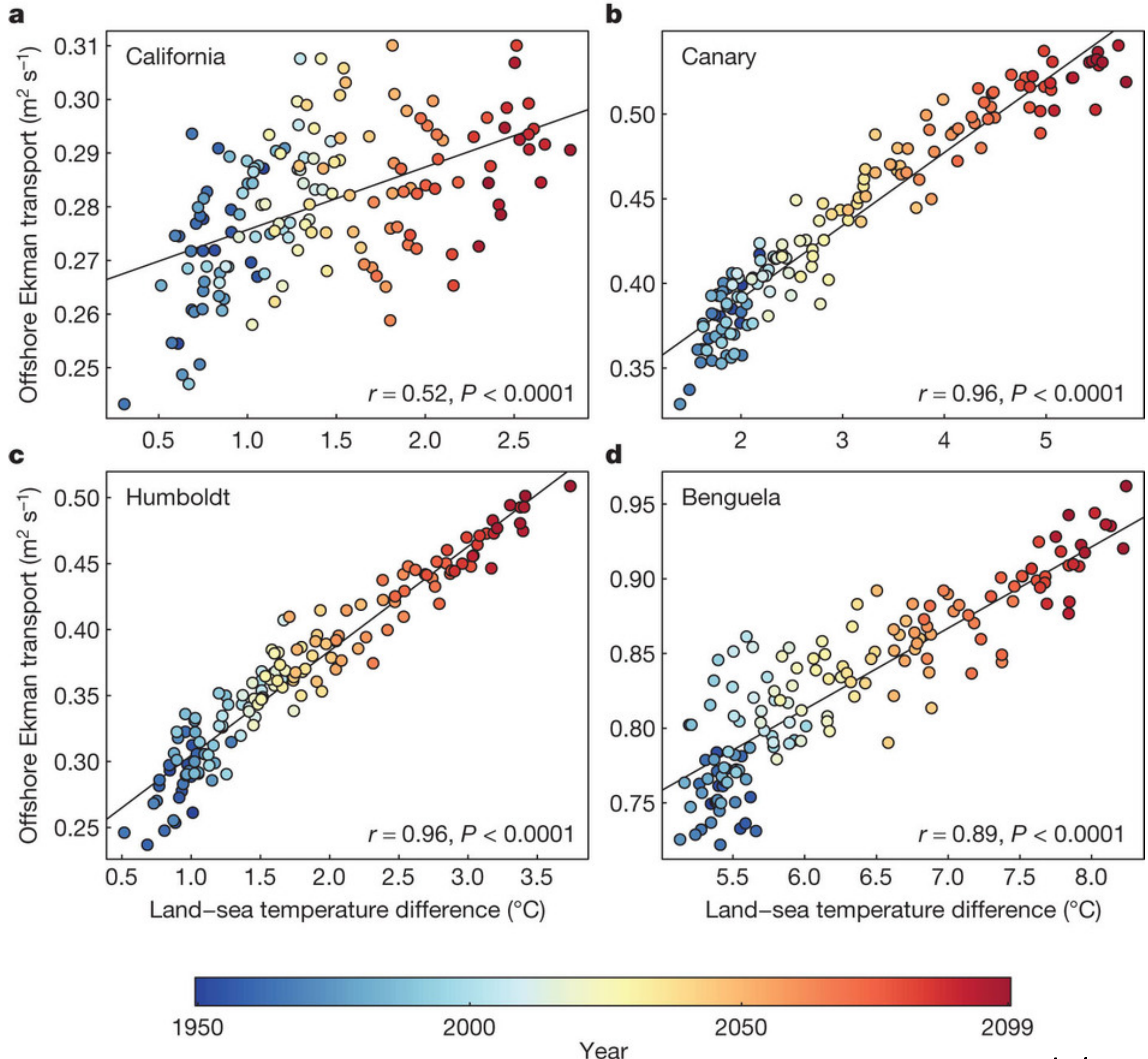
ecosystem processes such as the recruitment of rocky intertidal organisms, and changes in these upwelling characteristics have been shown to cause substantial disturbances to ecosystems at multiple trophic levels[2,3,17].

Climate change is expected to affect coastal upwelling and, thus, marine ecosystems in the EBUSs[4,5]. Bakun proposed a mechanism whereby greenhouse warming would intensify the summertime alongshore winds and coastal upwelling by strengthening the land–sea thermal difference and surface pressure gradient in upwelling regions[6]. Subsequent analyses based on historical observations and palaeoclimate reconstructions have found evidence for increased upwelling-favourable winds in some parts of the EBUSs[8,18,19] but not in others[10,20], leading to disagreements about coastal wind trends across different data sources[9,10]. Climate model studies on projected changes to coastal upwelling have also yielded inconsistent results[11–13]. Thus, there seems to be considerable debate regarding the impact of climate change on coastal upwelling[4]. A recent retrospective meta-analysis partially addressed this controversy by showing that coastal upwelling has intensified over the past 60 years[21]. Here we present a complementary prospective analysis using state-of-the-art climate models to understand how coastal upwelling will change under future greenhouse warming over the course of the twenty-first century. We use offshore wind-driven Ekman transport as an index of coastal upwelling, and analyse historical and future simulations of 22 Earth system models developed for the Coupled Model Intercomparison Project phase 5[22] (CMIP5) at multiple latitudes along the four EBUSs (Fig. 1a and Extended Data Fig. 1). These CMIP5 models reproduce the observed latitudinal variation in upwelling duration (Fig. 1b–e) and intensity (Fig. 1f–i) across all four EBUSs.





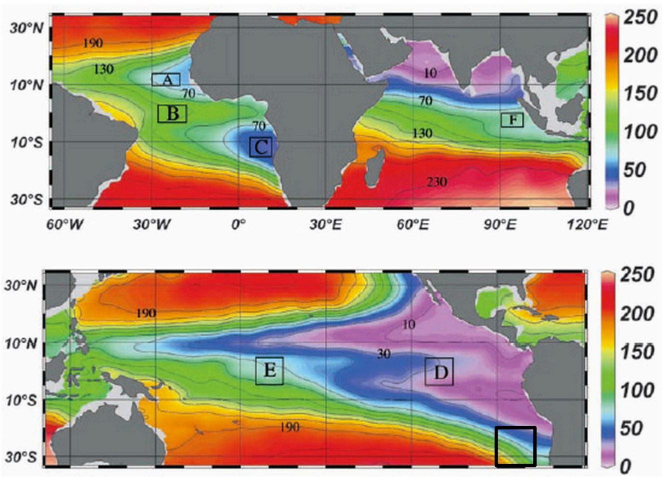
Wang et al. (2015, *Nature*)



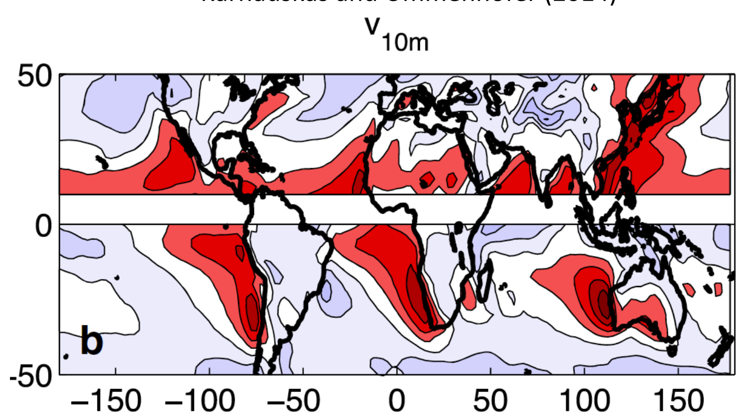
Wang et al. (2015, *Nature*)

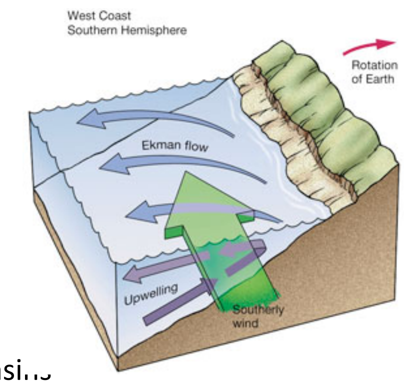
OMZs and the Hadley Circulation?

(Stramma et al., 2008)



Karnauskas and Ummenhofer (2014)





Oxygen Minimum Zones (OMZs)

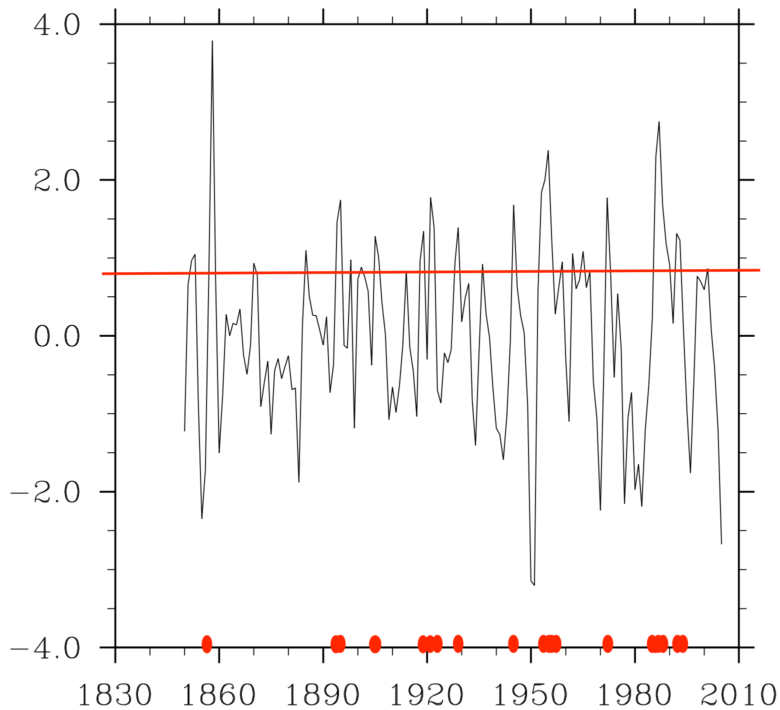
- Many marine animals are stressed in OMZs.
- Located in productive oceanic zones
- Expanded and shoaled over last 50 years
  - Likely to continue with increased temperatures

OMZs and Hadley Circulation

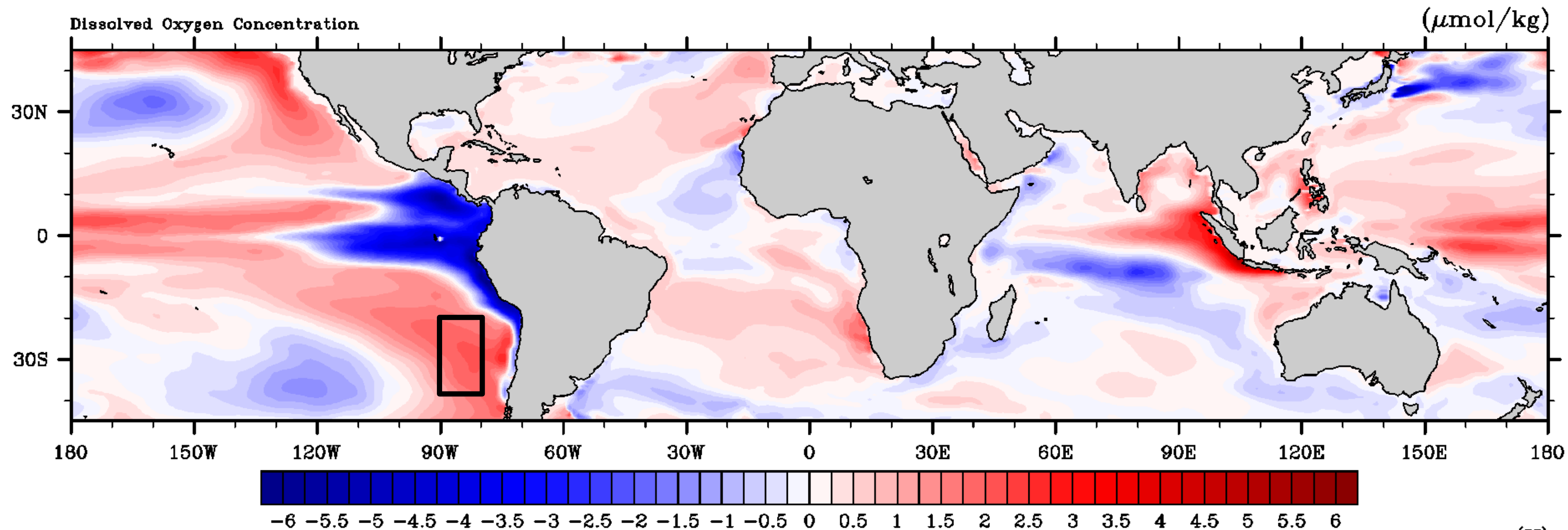
- Co-located at Eastern edge of most ocean basins
- OMZs strongly determined by upwelling
- Meridional winds affect upwelling in Eastern edges of ocean basins

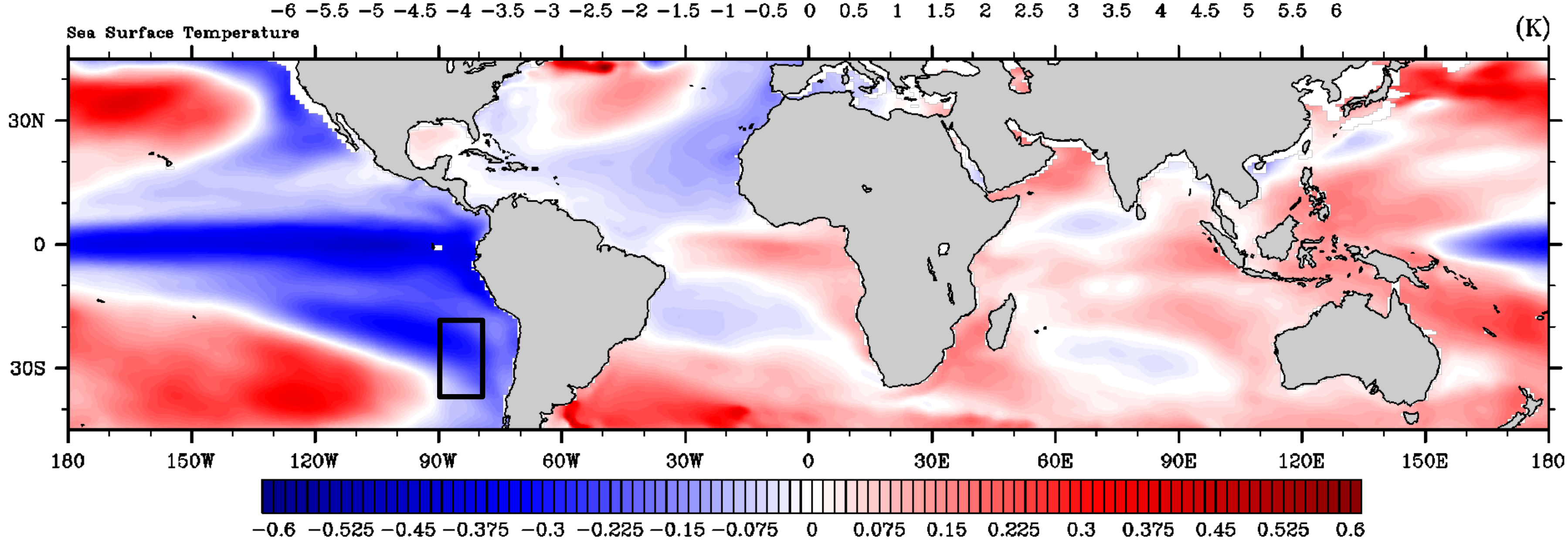
De La Cruz Tello, Ummenhofer, and Karnauskas, in prep.

Composite analysis

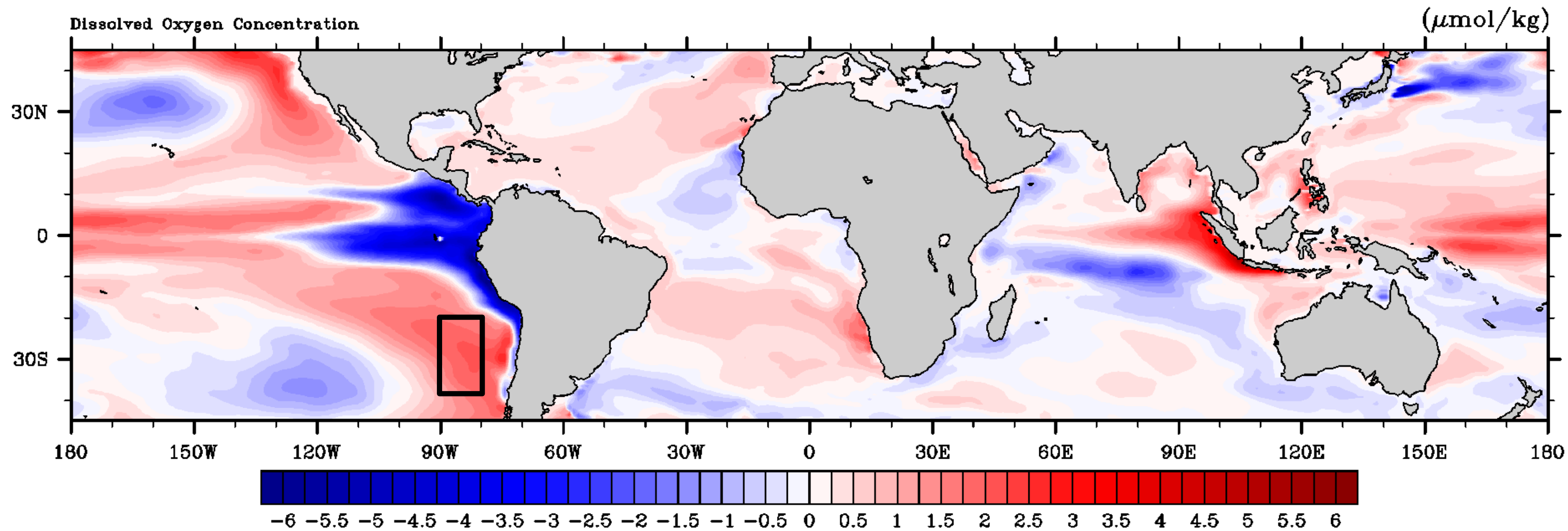


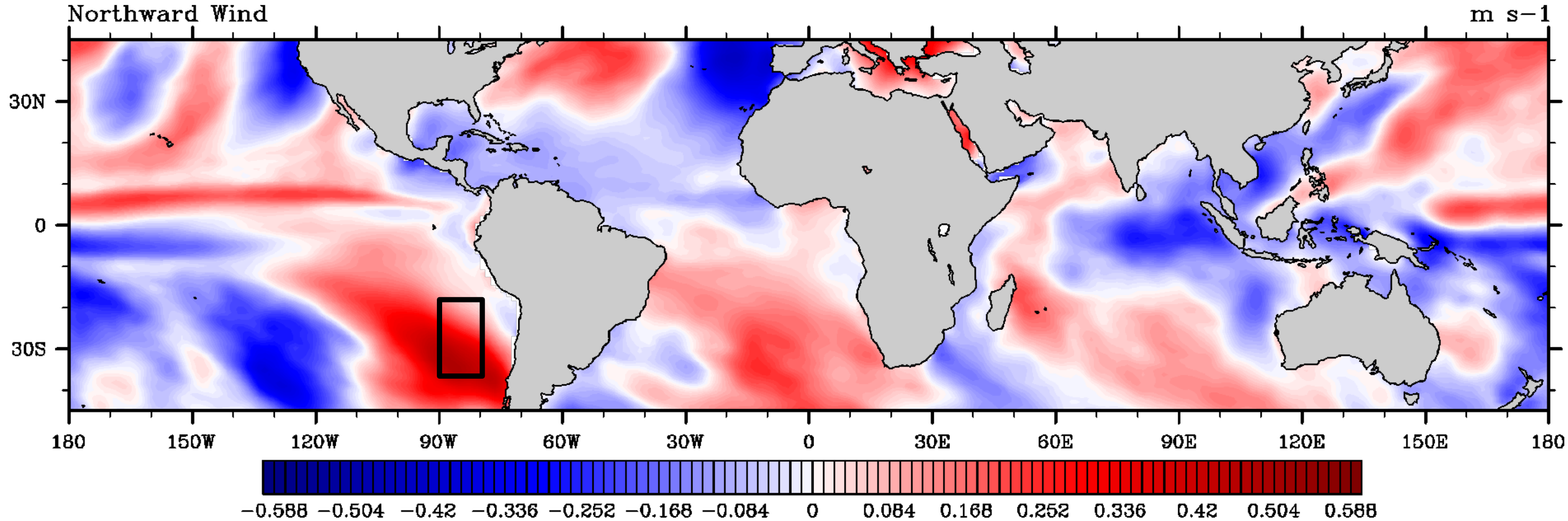
Top 20 Maximum Oxygen Years (40S-20S, 270-280E)			
1858	1894	1895	1905
1919	1921	1922	1929
1945	1953	1954	1955
1956	1972	1986	1987
1988	1989	1992	1993





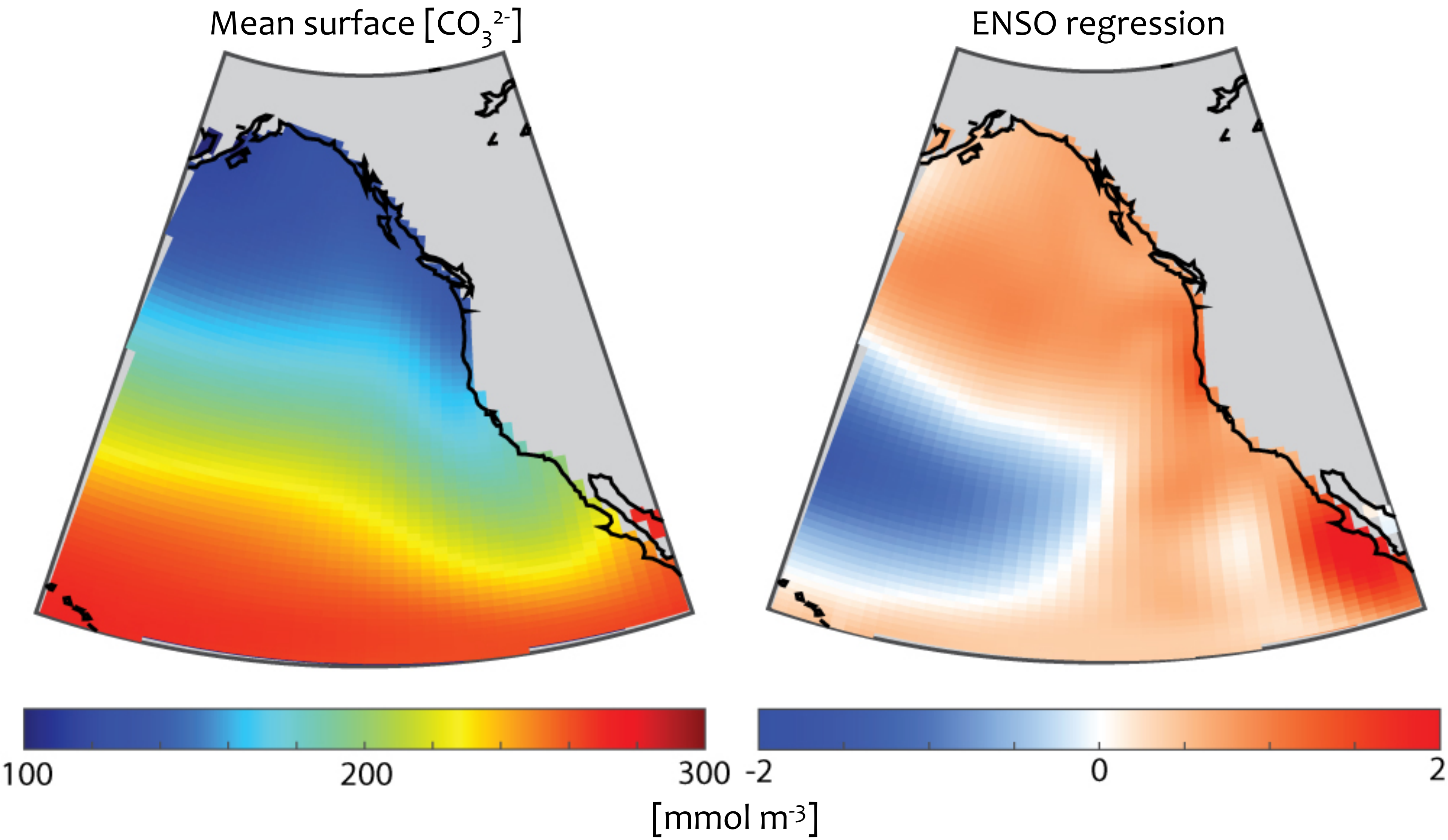
De La Cruz Tello, Ummenhofer, and Karnauskas, in prep.





De La Cruz Tello, Ummenhofer, and Karnauskas, in prep.

ENSO and ocean acidification



Lovenduski et al. (in review), Biogeosciences