Coupled air-sea interaction and variability in ocean biogeochemistry

(Case studies in carbon and oxygen cycles of the tropical Pacific)

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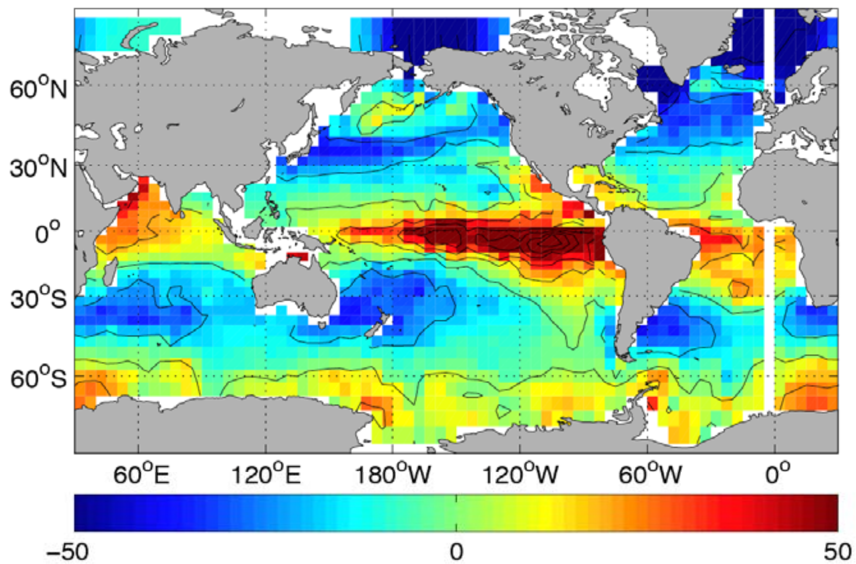
CO_2 and O_2 cycles

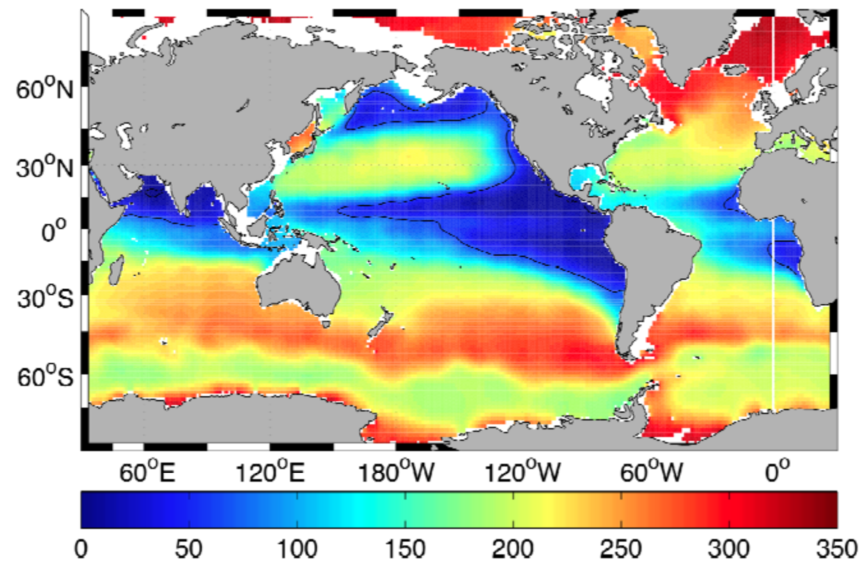
Annual mean ΔpCO_2 (μatm)

Takahashi [2002]



Annual mean O_2 at 400m [μM]

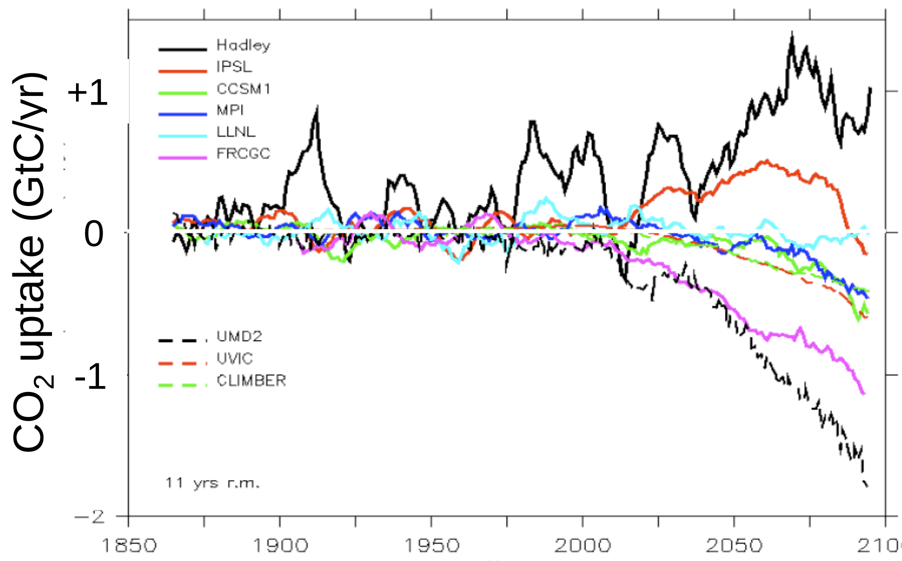
World Ocean Atlas [2005]



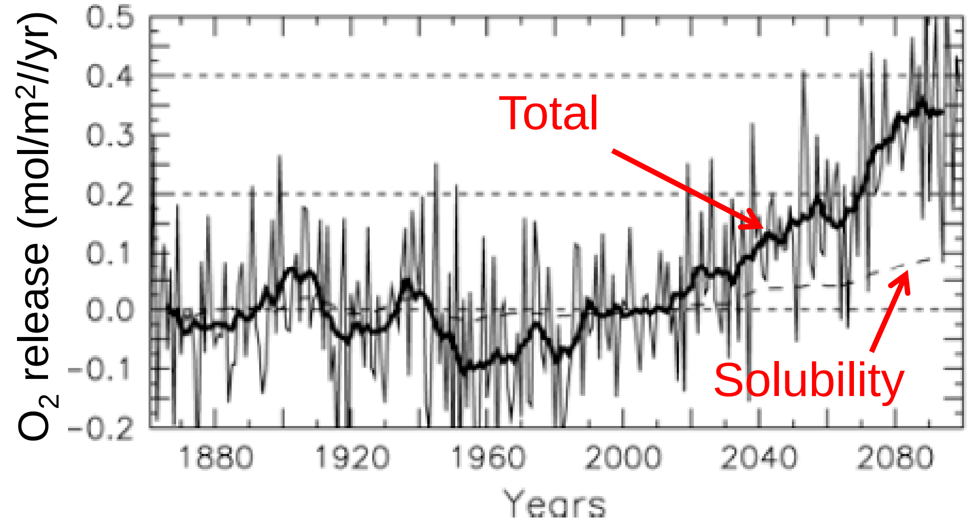
Pattern of surface ΔpCO_2 due to heating (+), cooling (-), photosynthesis (-) and upwelling of respired DIC (+).

Thermocline O_2 is high where water is descending from surface where atmospheric equilibrium, low where water is upwelling and has undergone respiration.

Climate-driven trends



Friedlingstein et al. [2006]



Bopp et al. [2002]

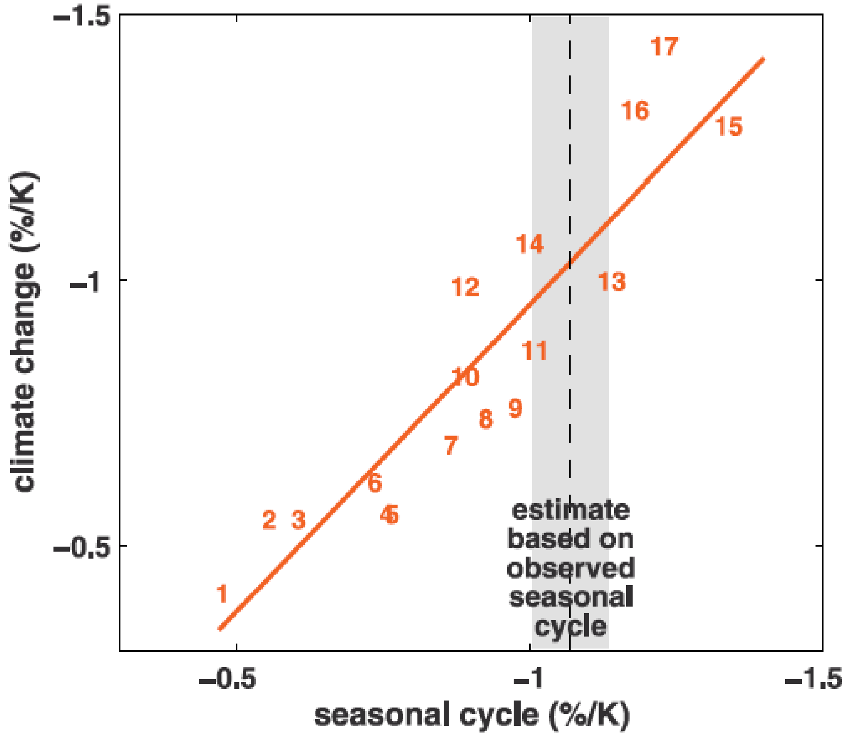
Climate warming is predicted to cause a slowdown of CO_2 uptake and a "deoxygenation" of the ocean.

Common mechanisms (decreased thermal solubility and increased stratification) but magnitudes vary widely.

See also: Sarmiento et al. [1998], Plattner et al. [2001], Matear and Hirst [2003]

Illuminating trends with variability

Snow albedo feedback: $\delta\alpha_s/\delta T$



Hall and Qu [2006]

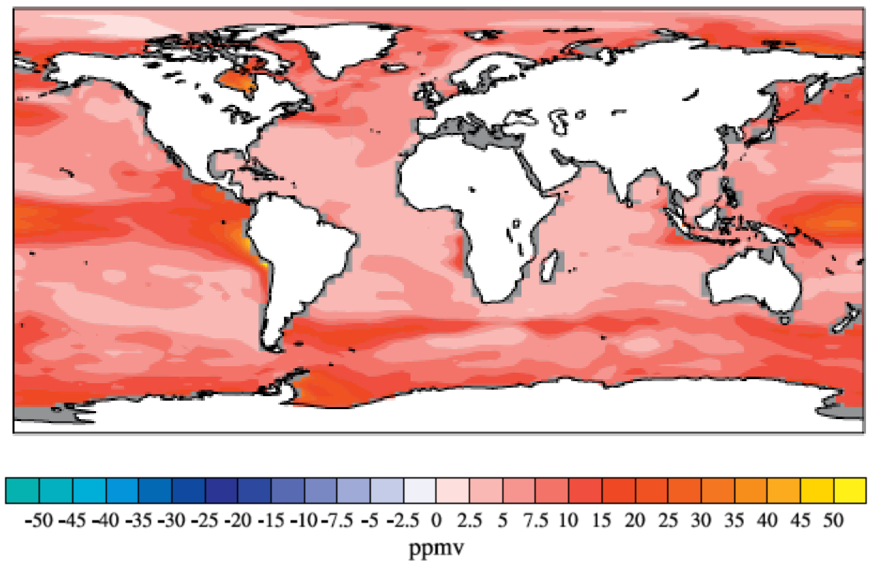
The strength of long-terms trends can be constrained by observing the same process at shorter time scales (if dynamics are similar).

Climate example: snow albedo feedback.

Can this approach be used for climate/carbon cycle interactions?

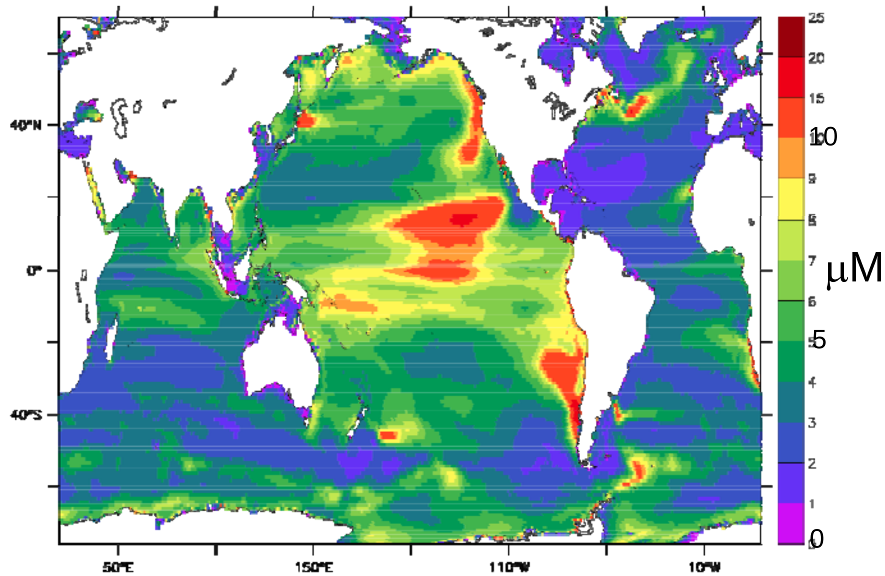
CO_2 and O_2 Variability

RMS of pCO_2 (surface)



Doney et al. [2009]

RMS of O_2 (0-500m)

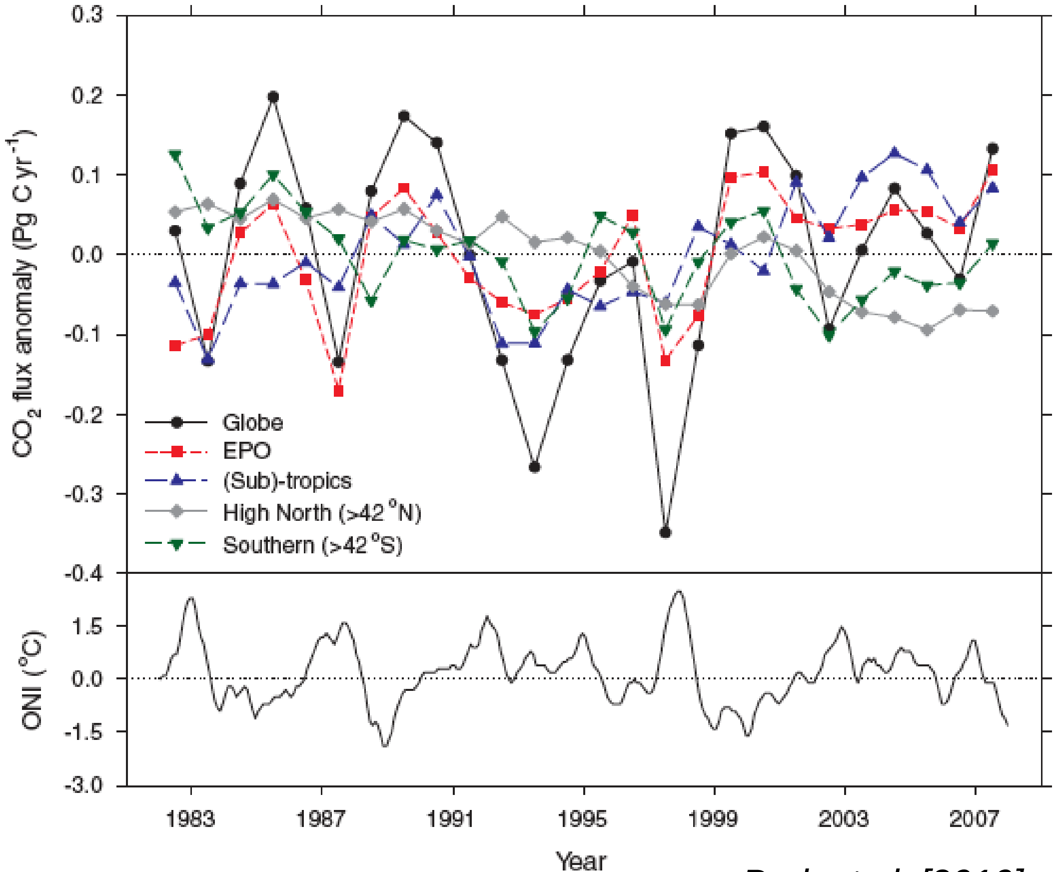


unpubl.

The tropical Pacific is a place of exceptional variability in biogeochemical cycles.
→ A good natural laboratory for quantifying sensitivity to climate?

see also McKinley et al. [2004], LeQuere et al. [2000], Obata and Kitamura [2003]

CO_2 flux – "Observations"



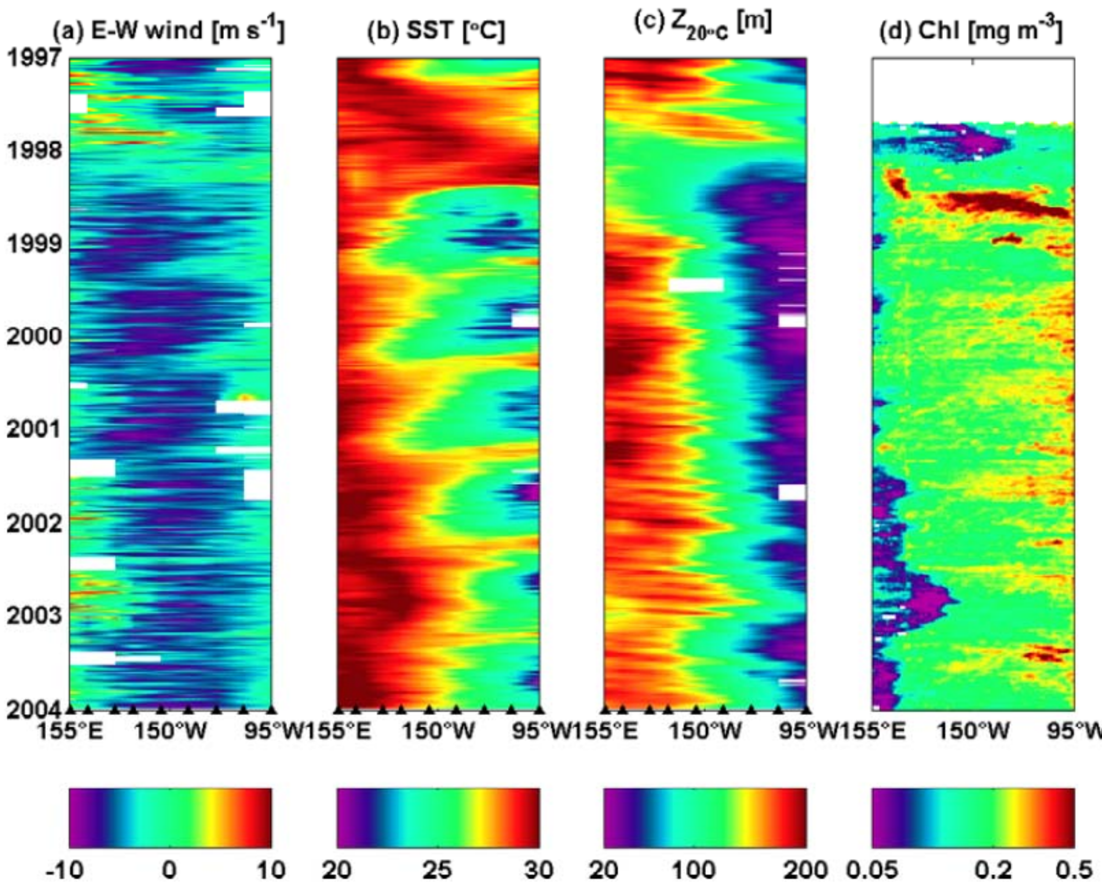
Park et al. [2010]

Based on empirical relationships between pCO_2 and SST.

Suggests the equatorial Pacific (EPO) accounts for the largest fraction of global ocean CO_2 flux variability.

(see also Feely et al. [2006])

El Nino and CO_2 flux drivers



Strutton et al. [2008]

El Nino effect:

“piston velocity”

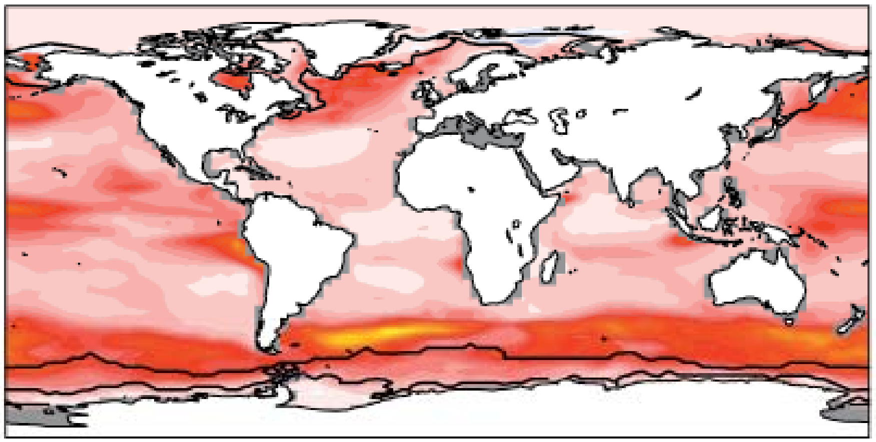
solubility

Upwelling of respired carbon

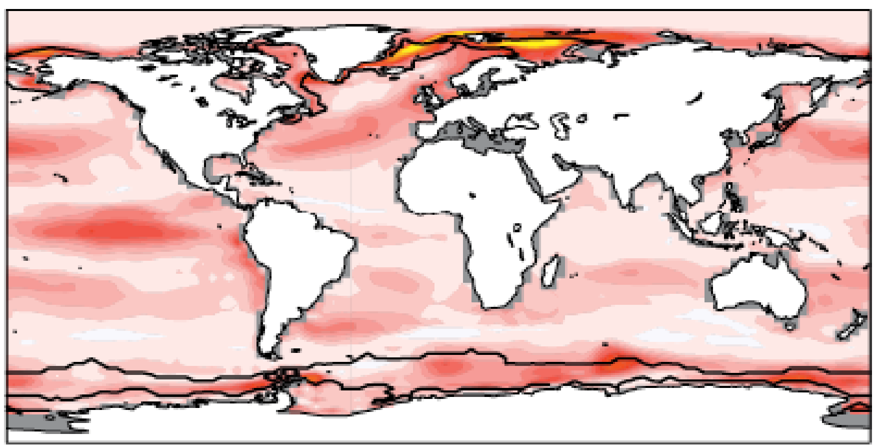
CO_2 fixation

Contributions to CO_2 variability

Contribution of ΔpCO_2



Contribution of Gas transfer velocity



Doney et al. [2009]

Rate of CO_2 exchange depends on

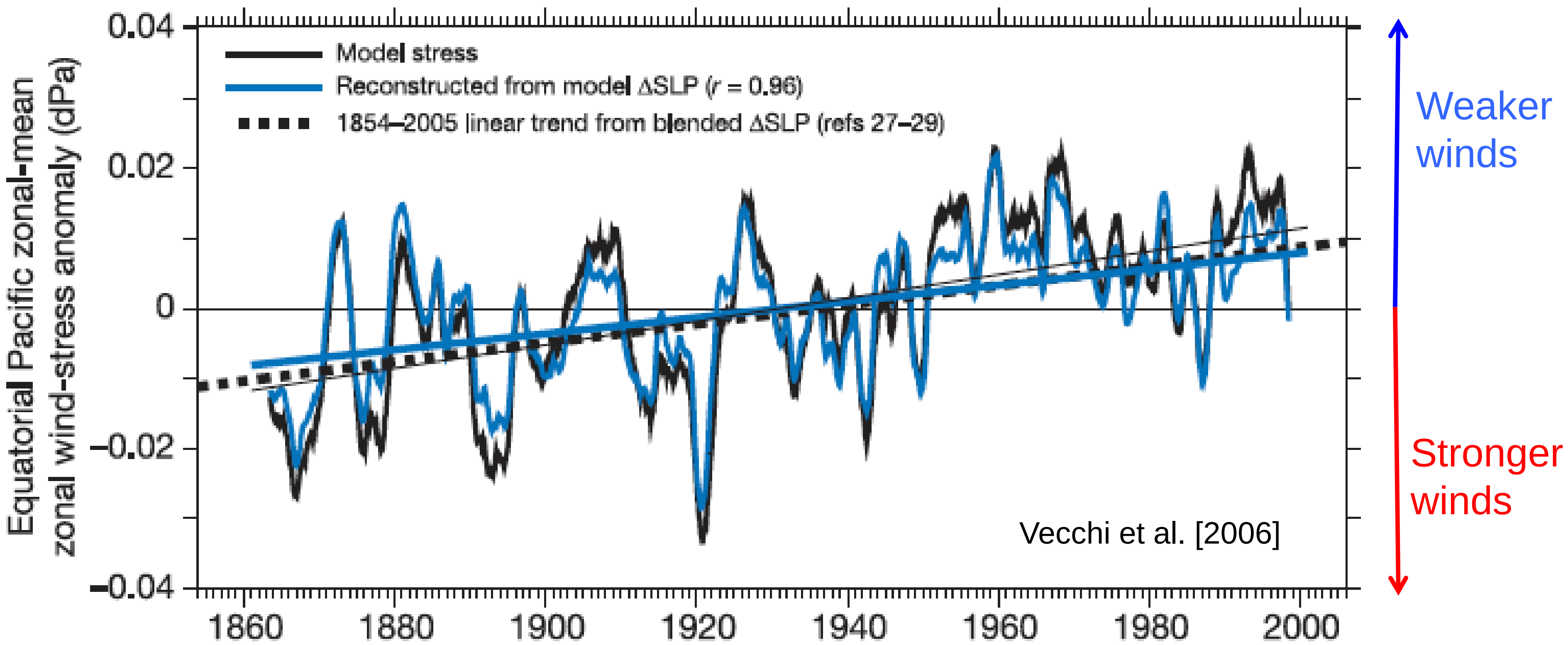
1) Partial pressure gradient (ΔpCO_2)

Largest role in Central Pacific

2) Surface turbulence → wind speed

Largest role in East Pacific

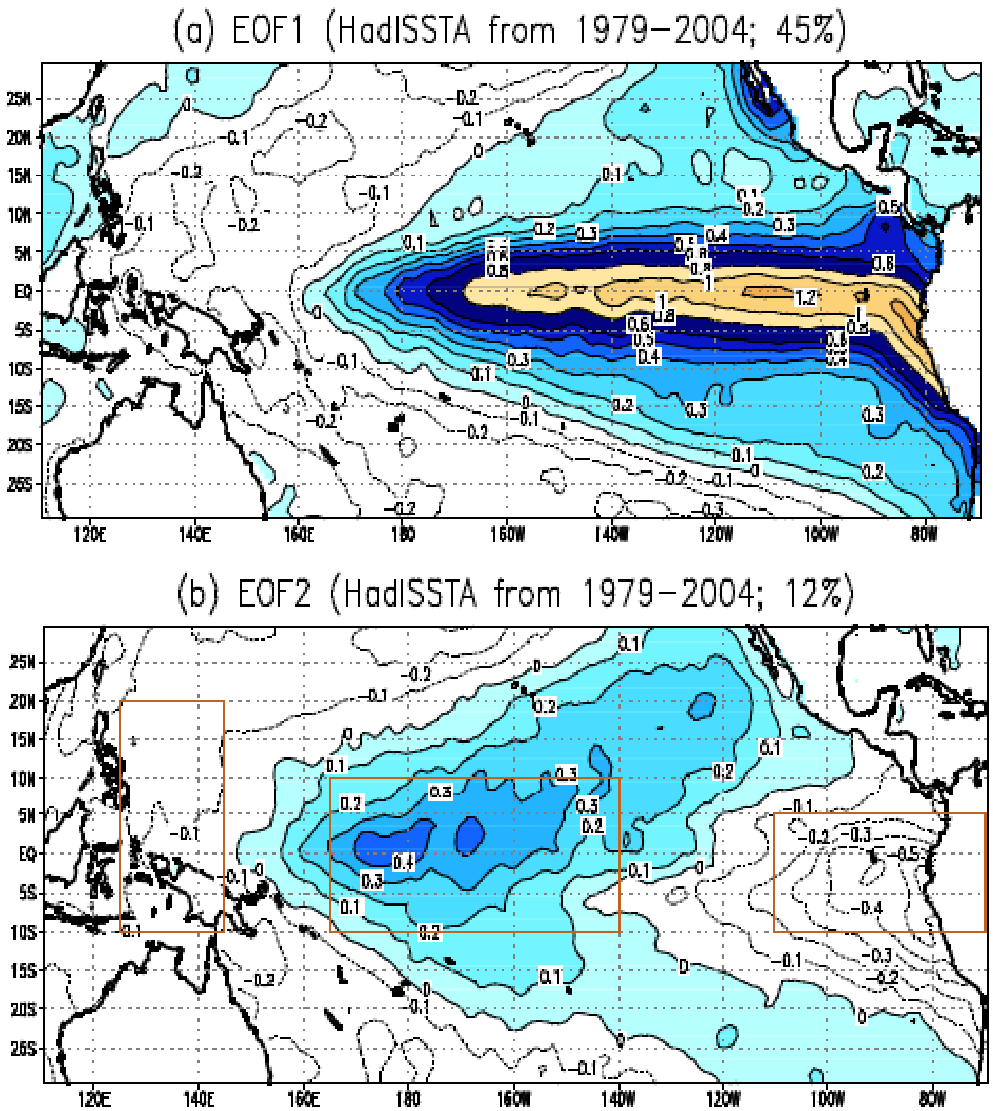
Weakening Walker Cell



Weakened equatorial winds (observed and simulated) lead to:

1) Less upwelling
2) Shallower thermocline in west

Flavors of ENSO

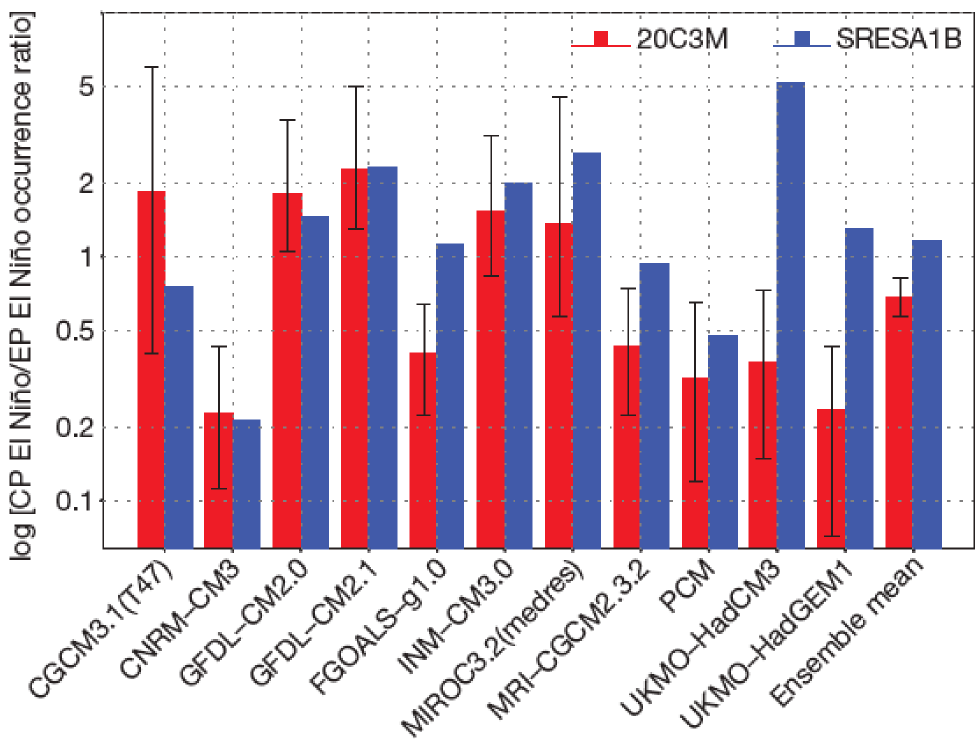


Ashok et al. [2005]

Analysis of tropical SST variability reveals two distinct anomaly patterns:

1) conventional El Nino in the east Pacific (EP)
2) El Nino “Modoki” centered in central Pacific (CP)

Shifting frequencies?



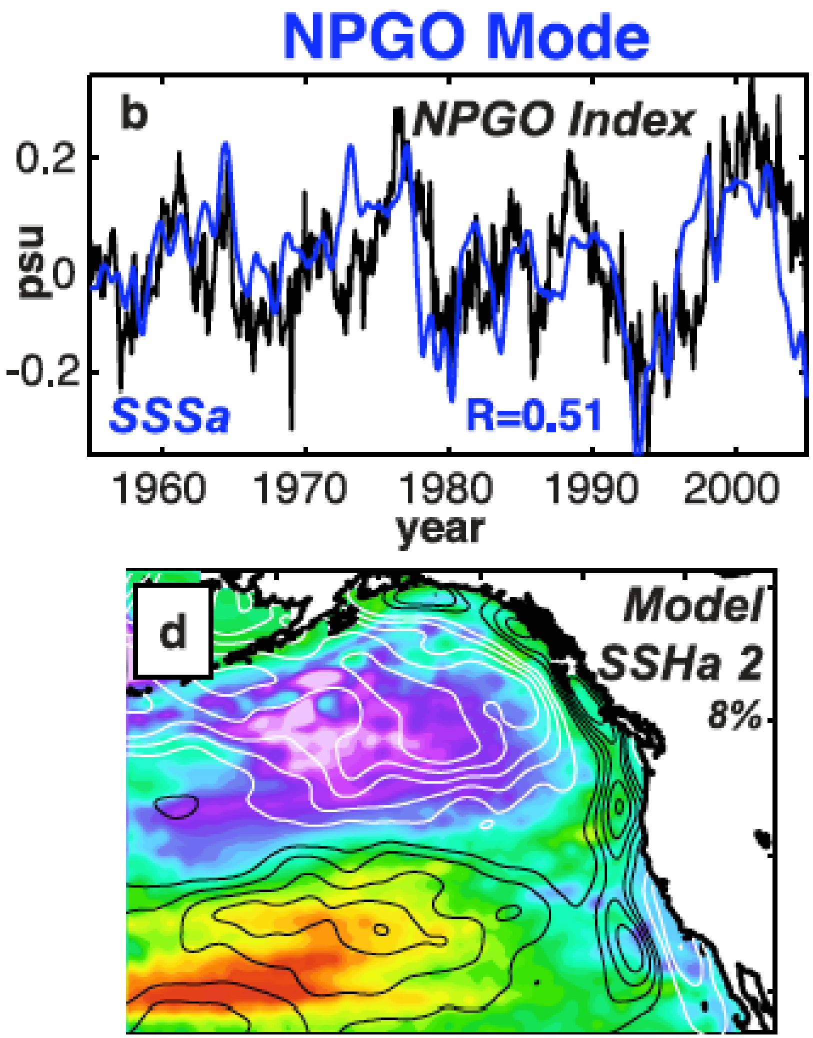
Yeh et al. [2009]

Some indications that the frequency of CP El Nino is increasing relative to EP El Nino.

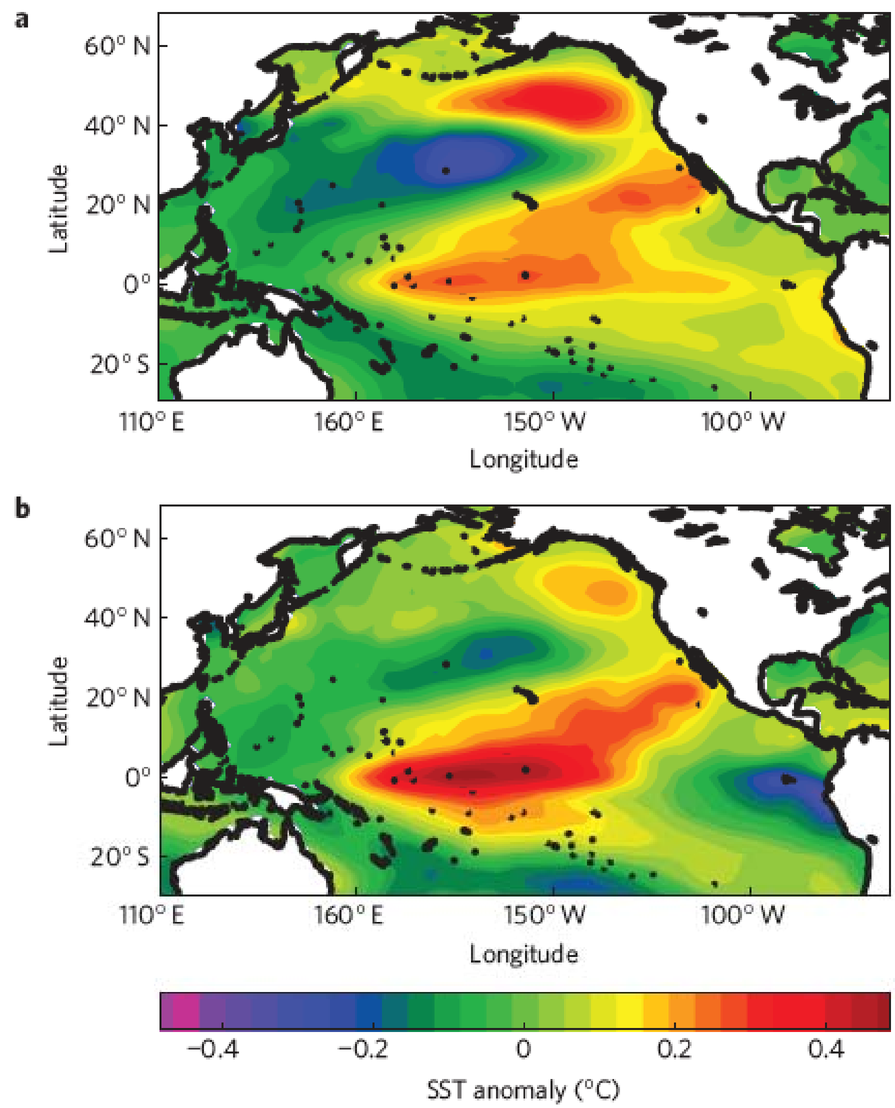
On average, models show this tendency getting stronger under warmer climate.

Associated with overall shoaling of thermocline.

ENSO and NPGO?



Di Lorenzo et al. [2008]

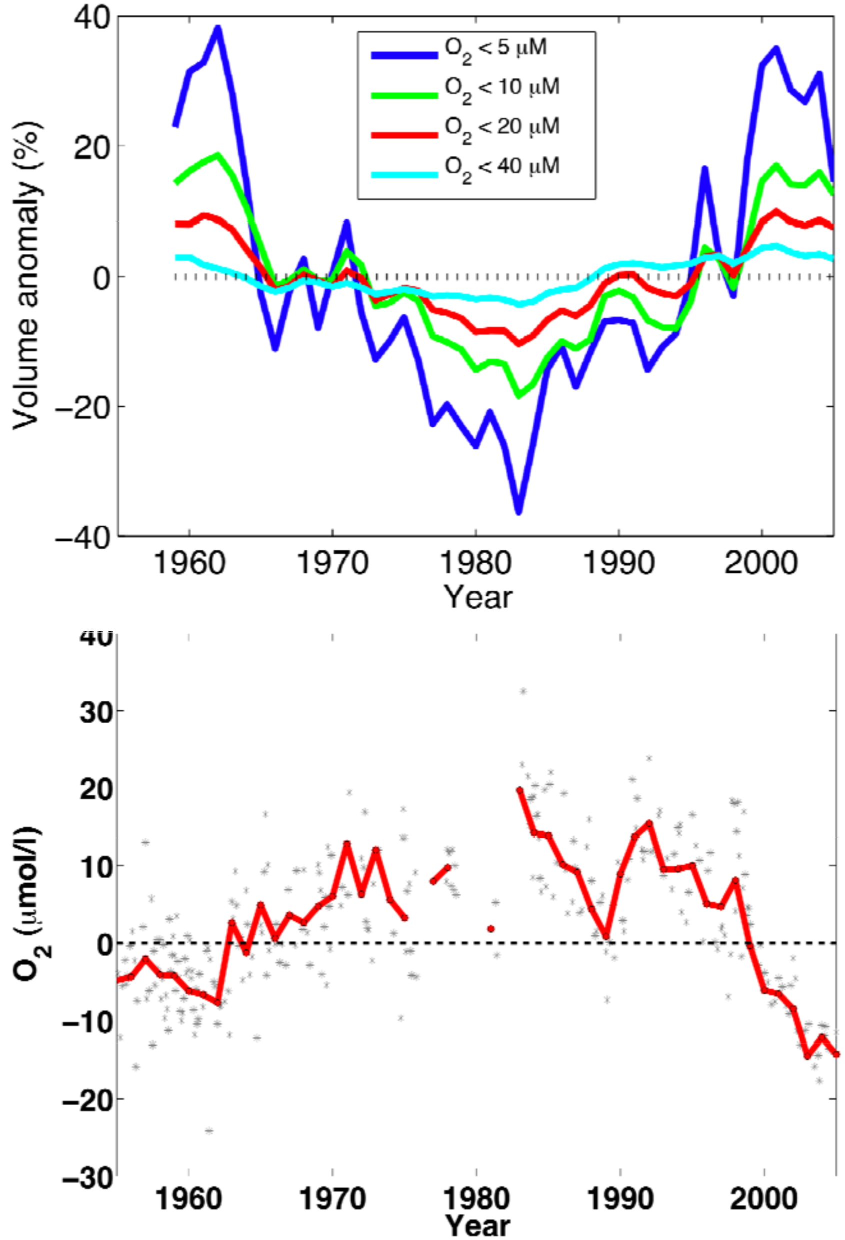


Di Lorenzo et al. [2009]

Future climate and CO_2 outgassing/uptake

- Does a weakening Walker Cell reduce the mean rate of CO_2 release from the tropical Pacific?
- Will the changing character of ENSO alter the dominant interannual variability of oceanic CO_2 sources?
- Can we use the observed interannual changes to better constrain the long-term trends?

Hypoxic Variability



Volume of low O_2 zones is highly variable (model hindcast simulation).

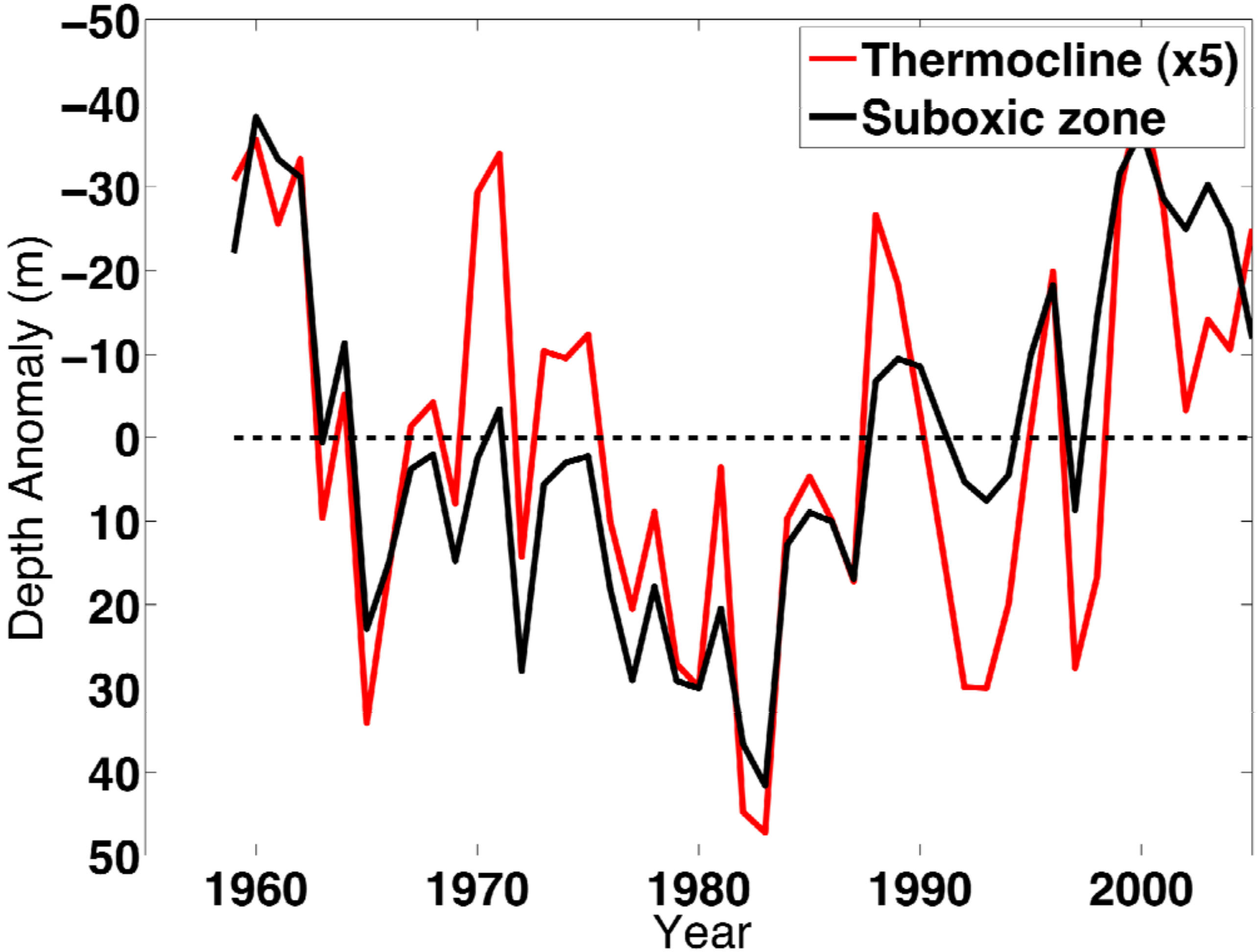
Amplitude grows as O_2 threshold decreases.

Suboxic zone expands/contracts by 2-fold over decades.

Consistent in phase/sign/amplitude with CalCOFI data.

Deutsch et al. [2011]

Mechanisms of O_2 variability



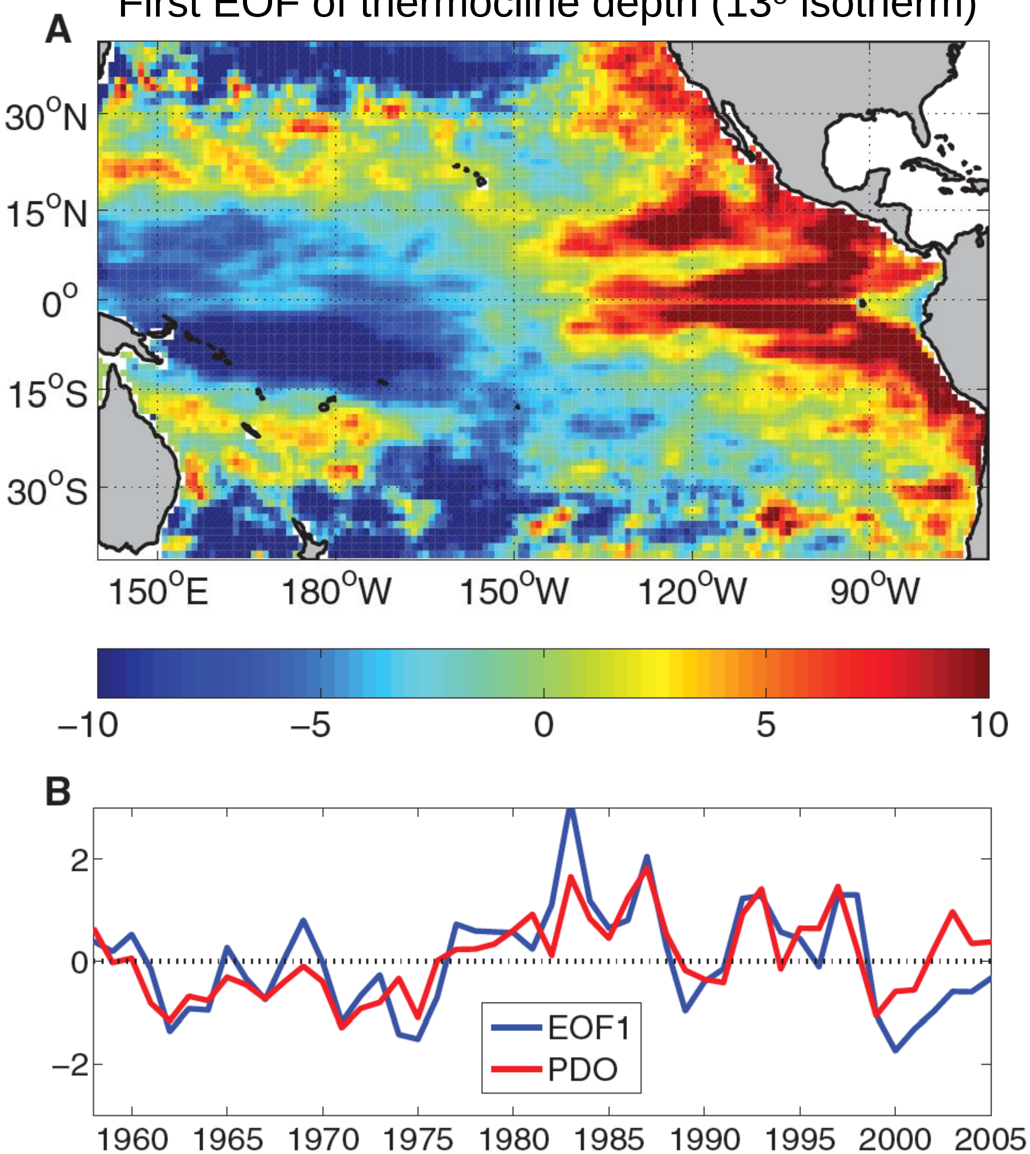
Clear relationship between anomalies in depth of thermocline (13º isotherm) and suboxic zone.

Variations in suboxic zone depth are much greater (5x) than for thermocline depth.

Thermocline heaving/shoaling drives multiplicative effects on export and respiration

Climate Forcing

First EOF of thermocline depth (13° isotherm)



Simple Ocean Data Assimilation (SODA), *Carton and Geise [2008]*

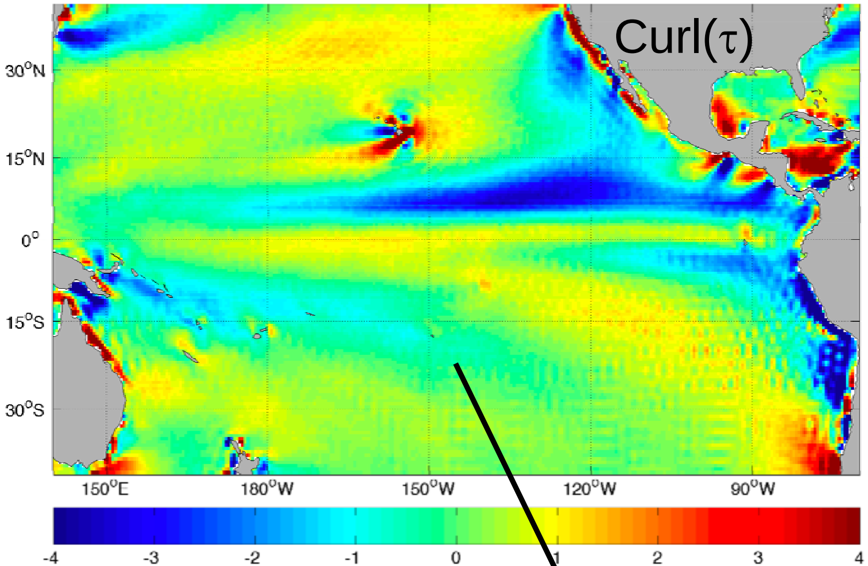
The dominant synchronous mode of low-latitude thermocline depth variations (13% of variance) occurs throughout the Eastern Pacific.

It is highly correlated to the Pacific Decadal Oscillation (PDO).

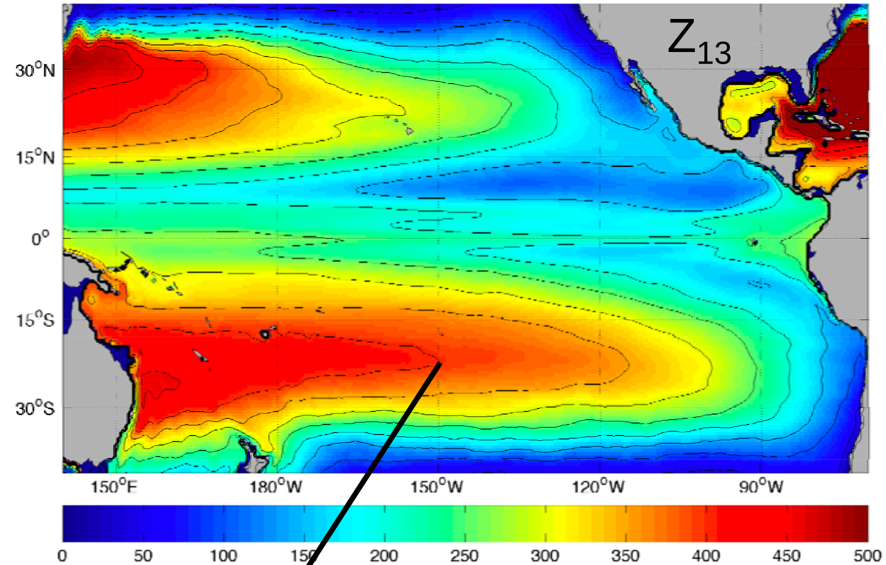
The PDO explains 25% of the variance in suboxic volume (P<0.01).

The Role of Winds

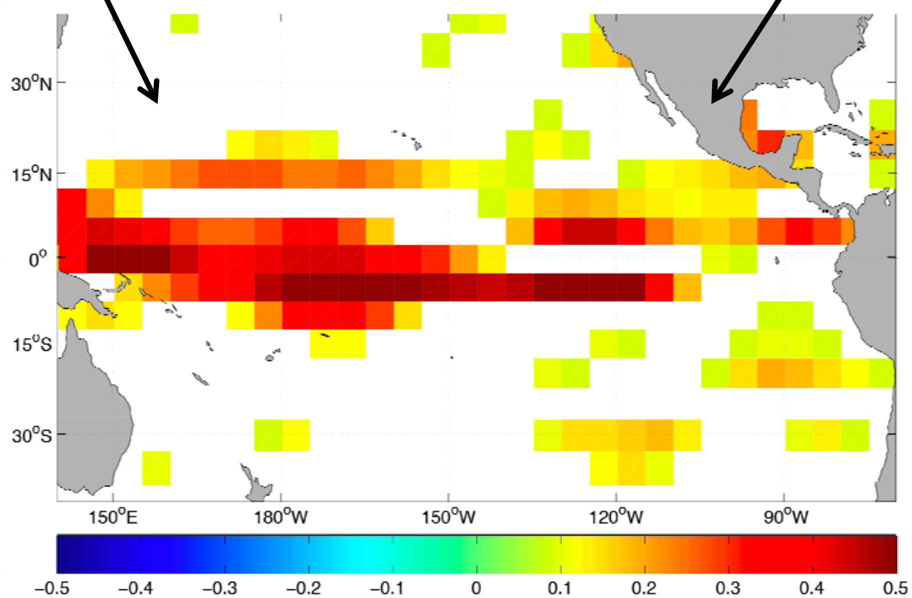
Wind stress curl



Thermocline depth

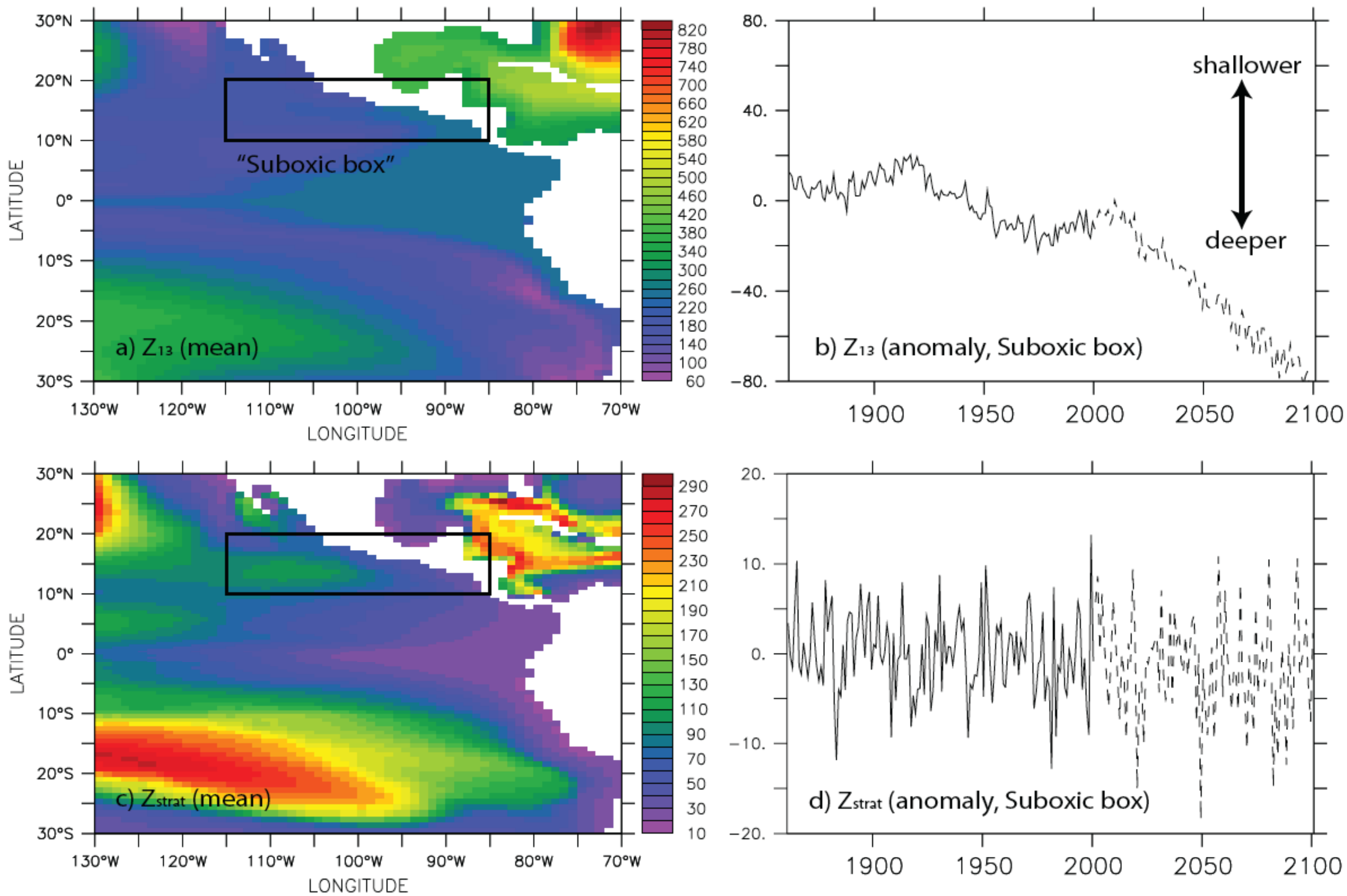


Correlation between Curl(τ) and Z_{13} anomalies, (where $P<0.05$).



Output from Simple Ocean Data Assimilation (SODA), *Carton and Geise [2008]*

Thermocline trends

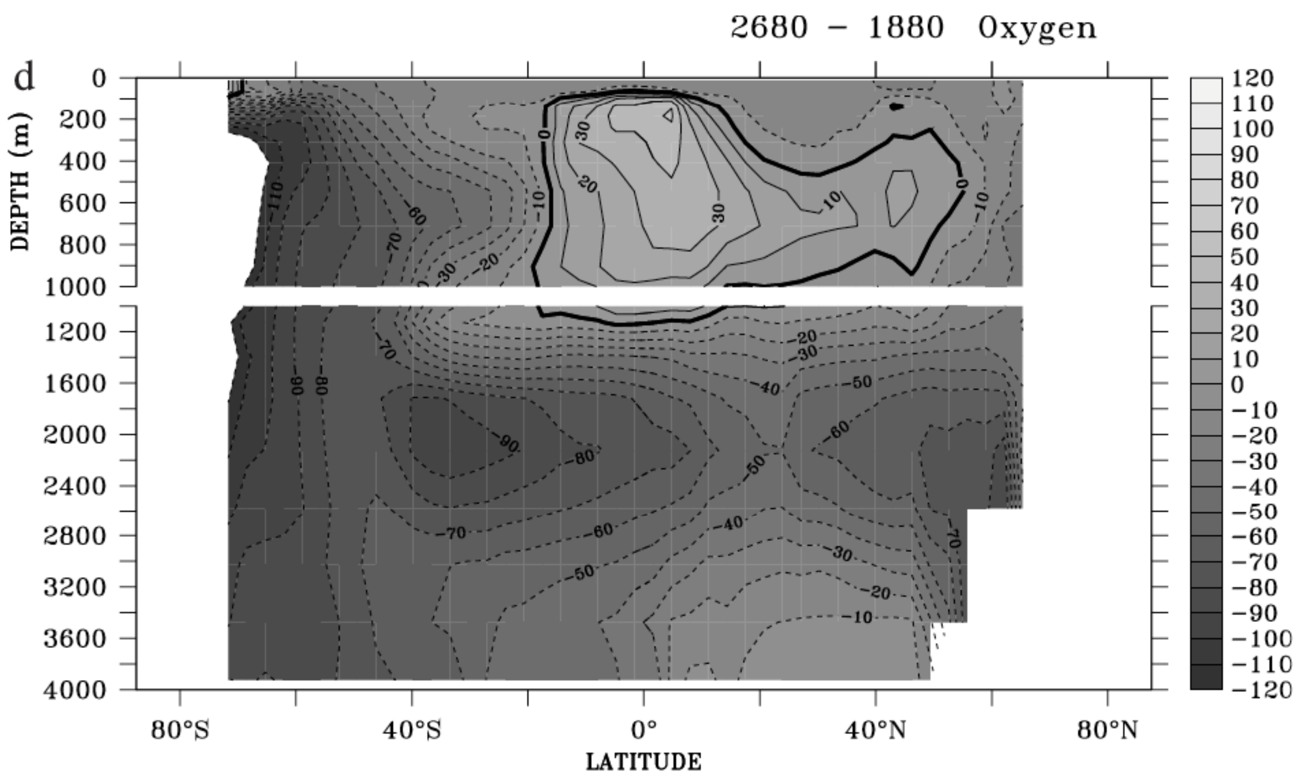


Depth of isotherm → Vertical shift of low-O_2 water mass/respiration rate

Depth of maximum stratification → Vertical exchange and export

Model thermocline in eastern tropical Pacific (off equator) deepens.
Amount depends on metric → export versus water mass view.

Long-term deoxygenation



Matear and Hirst [2003]

Can the tropical OMZ really shrink in the face of ocean deoxygenation?

Future climate and ocean hypoxia/anoxia

- How will the thermocline of the eastern tropical Pacific change in a warmer climate?
- At what time scales are thermocline depth fluctuations the most important? (What about basinwide O_2 adjustment? → Deglacial anoxic expansion)

Discussion Questions

- For which processes, and at which time scales, is natural variability in carbon cycle a useful analogue of long-term trends? (Where are amplitudes likely correlated across time scales?)

- What are the observational requirements to narrow the intermodel range at the shorter time scales (e.g. seasonal cycle to interannual variability)?

- Do we need a coordinated effort to analyze the upcoming IPCC archive in these ways?