

# Modeling Carbon Cycle in the Pacific Ocean

Prof. Fei CHAI (柴扉)

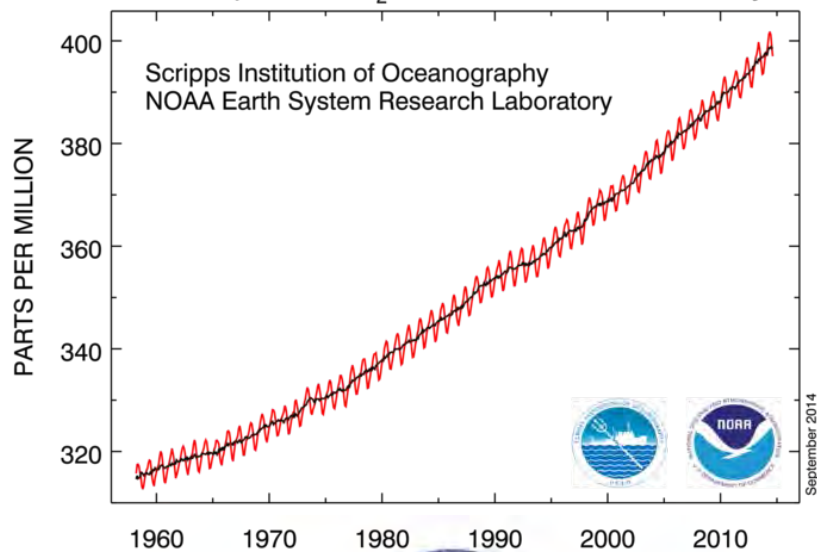
*University of Maine*

Dr. Peng XIU

University of Maine/South China Sea Institute of Oceanology

- Ocean Carbon Cycle and Climate Variability
- Physical and Biogeochemical Models (two models)
- $p\text{CO}_2$  (increasing) & pH (decreasing) Trends
- A Twin Experiments - Anthropogenic  $\text{CO}_2$
- Air-Sea  $\text{CO}_2$  Flux, ENSO and PDO

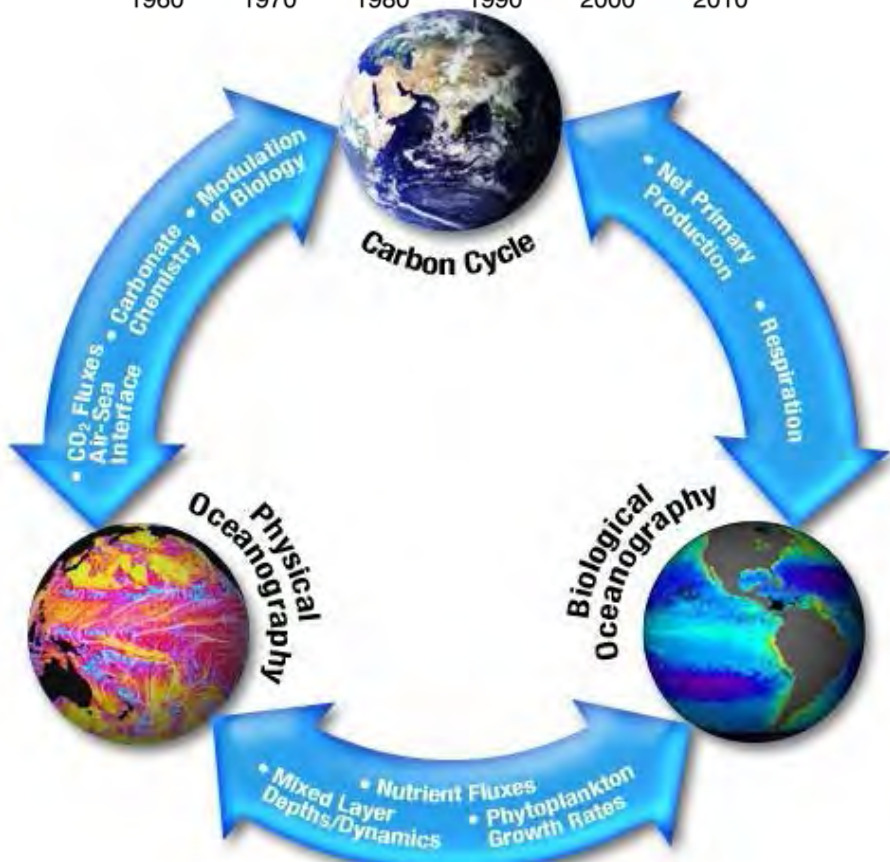
Atmospheric CO<sub>2</sub> at Mauna Loa Observatory



# Ocean Carbon Cycle

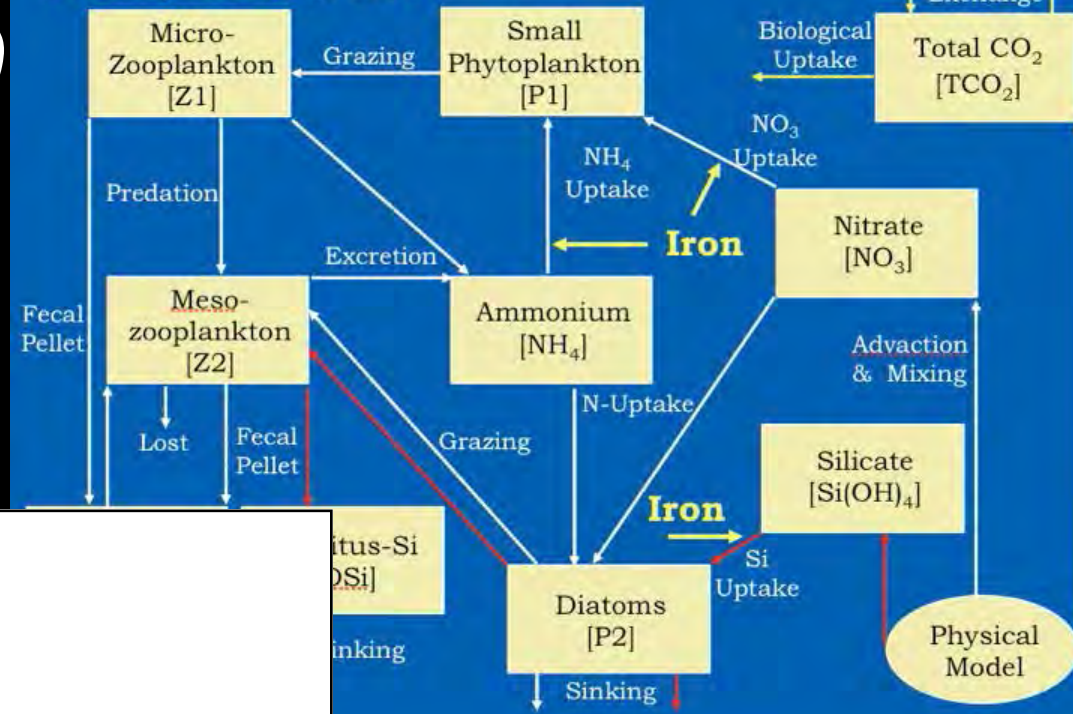
➤ The dominant factors controlling the temporal variability of carbon cycle?

➤ The role of anthropogenic signal in modulating the carbon response to natural variability?



**Regional Ocean  
Model System (ROMS)**  
**1/8 deg. (~7-12km)**  
**(1991 to 2014)**  
**or 1/2 deg. (~50km)**  
**(1958 to 2010)**

**Carbon, Silicate, Nitrogen Ecosystem Model  
CoSiNE, Chai et al. 2002**

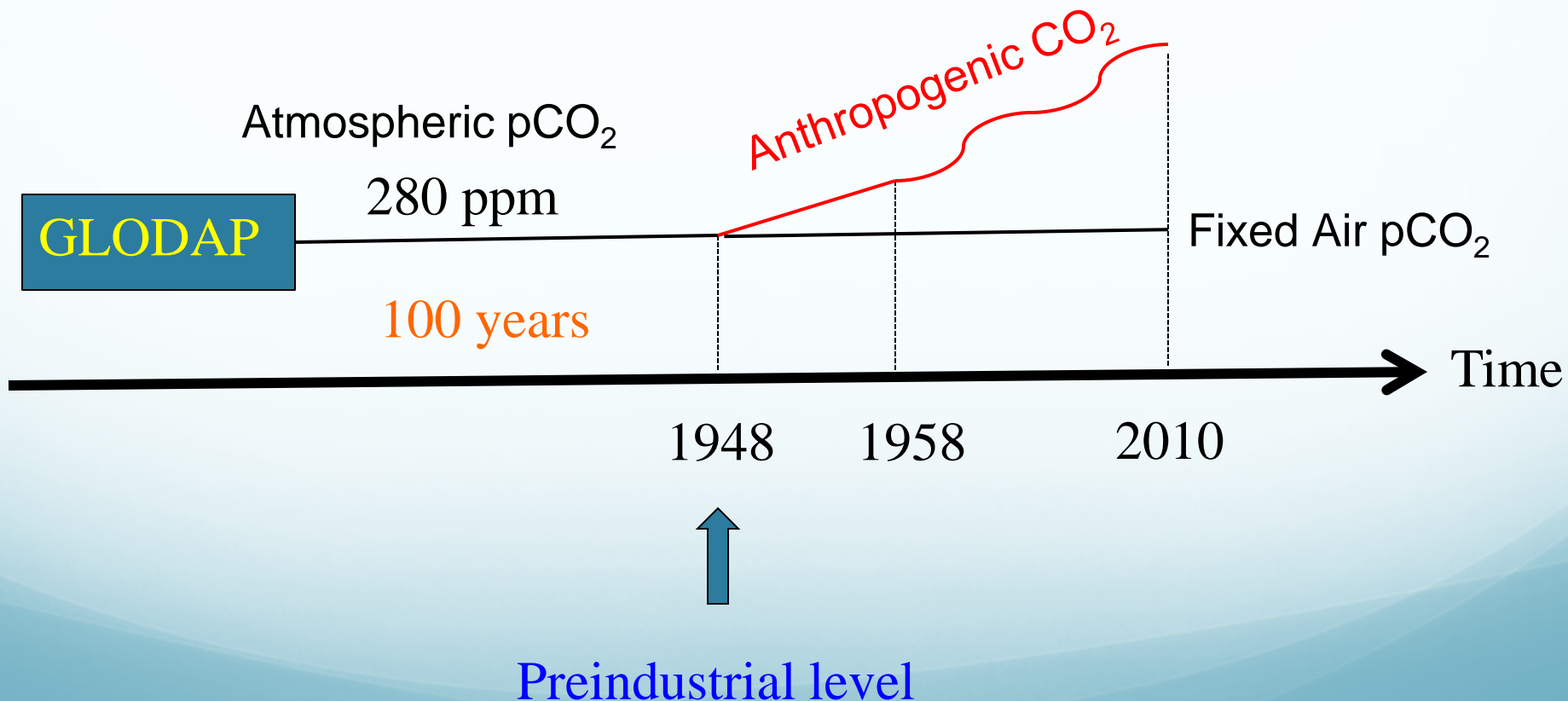


**Carbon, Silicate, Nitrogen  
Ecosystem Model (CoSiNE)**

(Chai et al., 2002, 2003, 2007, 2009; Fujii and Chai, 2007; Liu and Chai, 2009; Xiu and Chai, 2011, Palacz et al., 2011, Xu et al., 2013, Xiu and Chai, 2013, 2014)

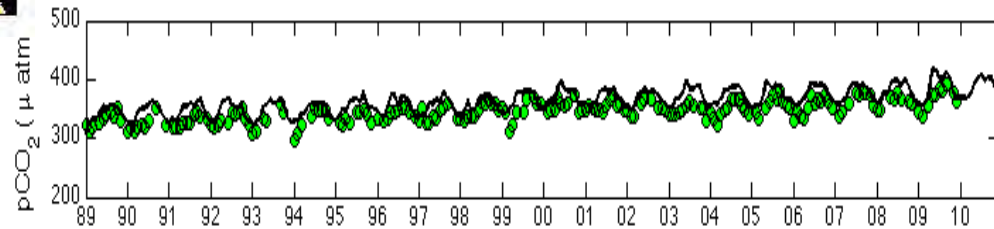
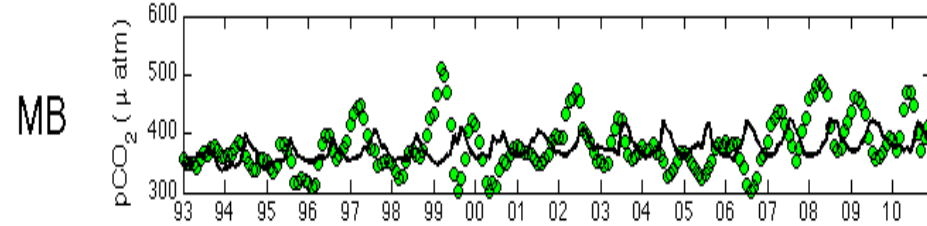
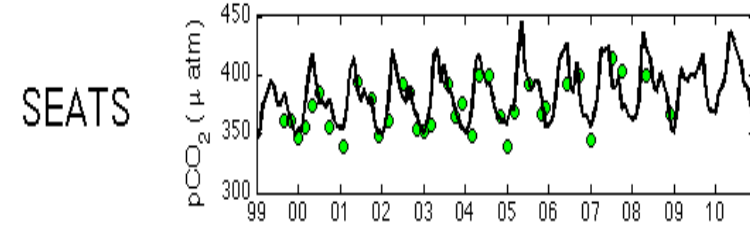
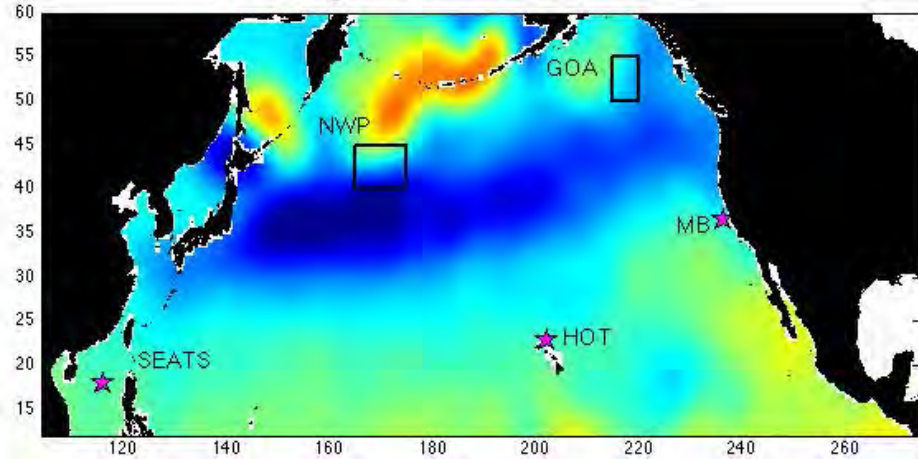
# Model Simulations

Initial conditions of TCO<sub>2</sub> and TALK are from GLODAP climatology



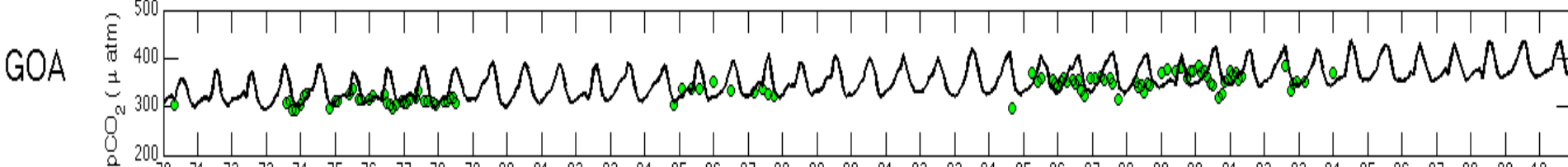
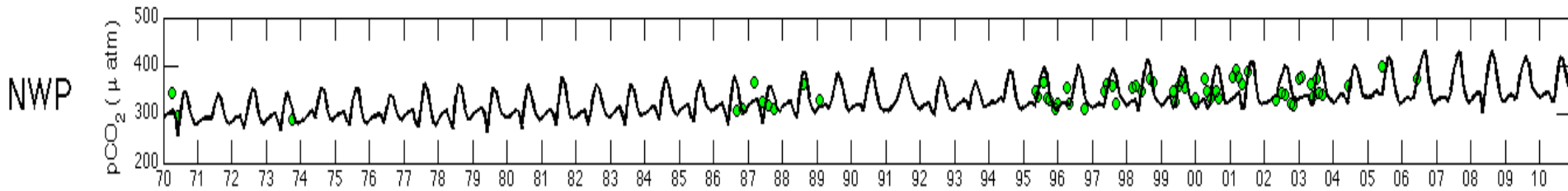
# Sea Surface pCO<sub>2</sub>

LDEO CO<sub>2</sub> flux climatology (g C m<sup>-2</sup> yr<sup>-2</sup>)



Seasonal cycle is largest  
Anthropogenic trend is 1-2 ppm/year

HOT



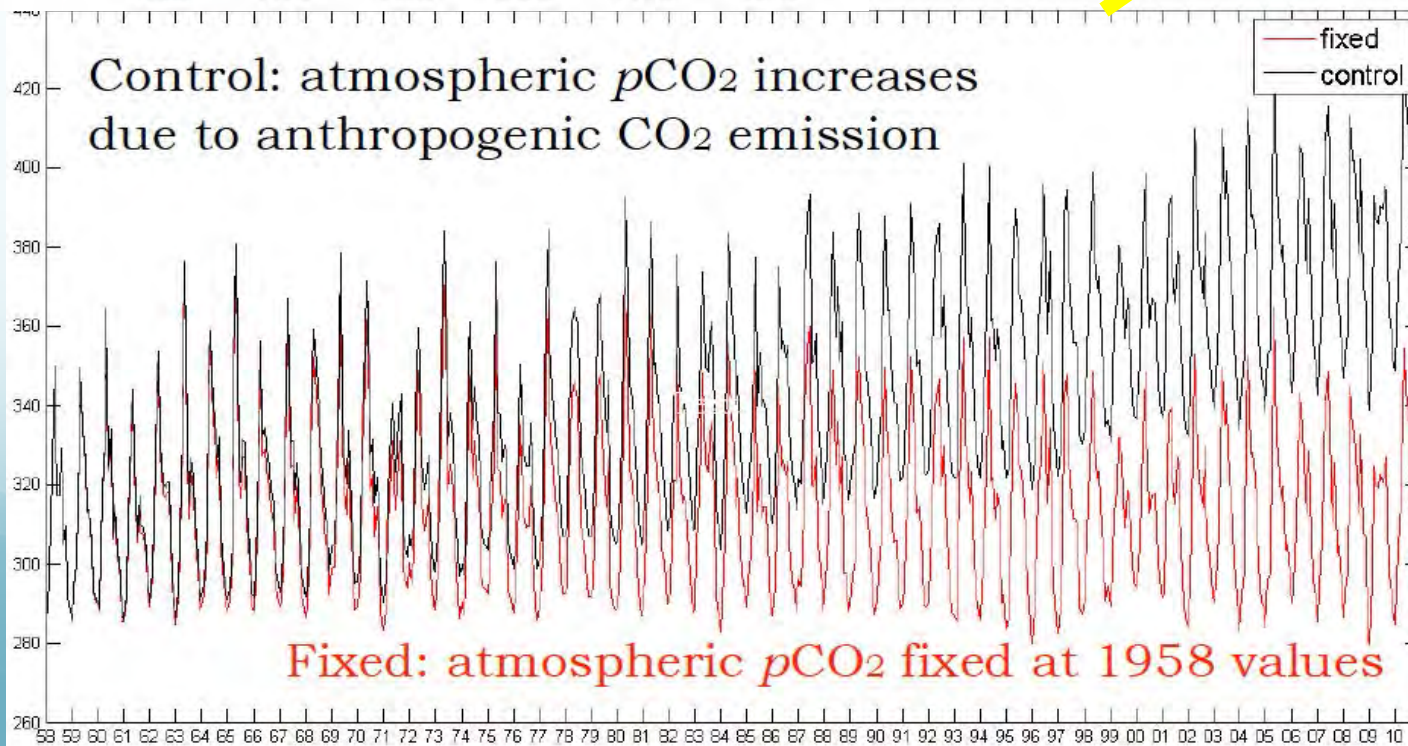
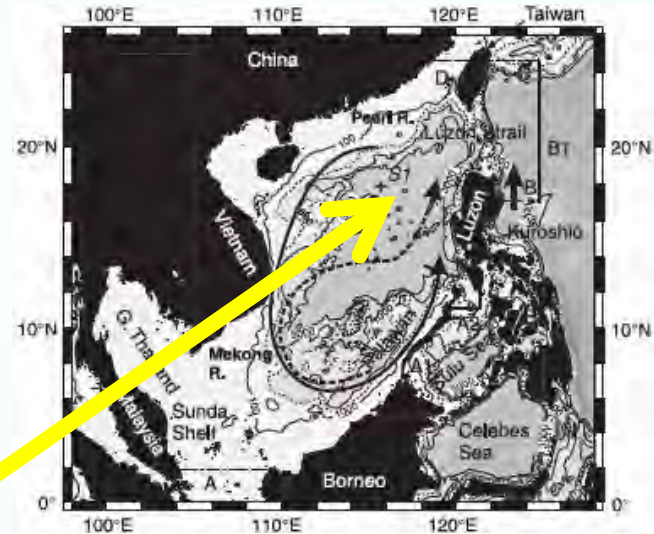
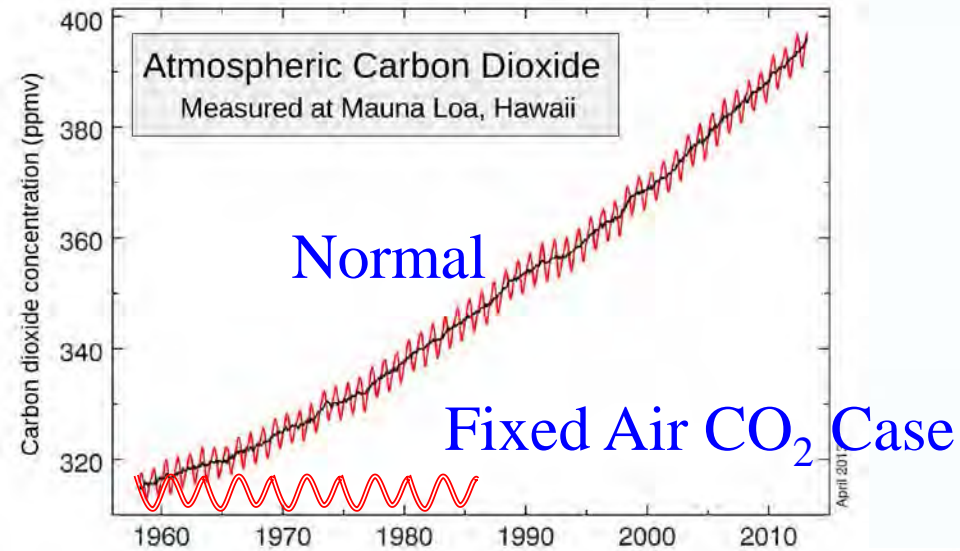
1970

Year Time

Xiu & Chai, JGR-Oceans, 2014

2010

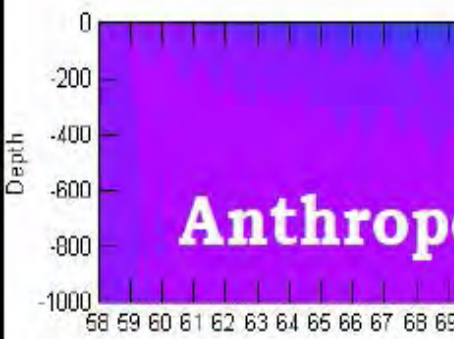
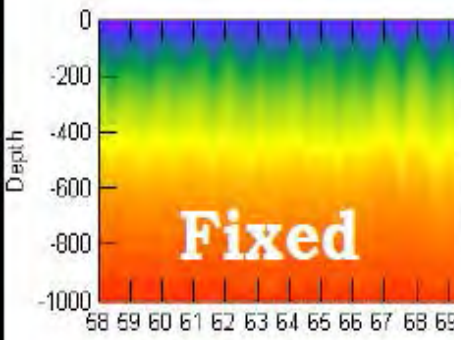
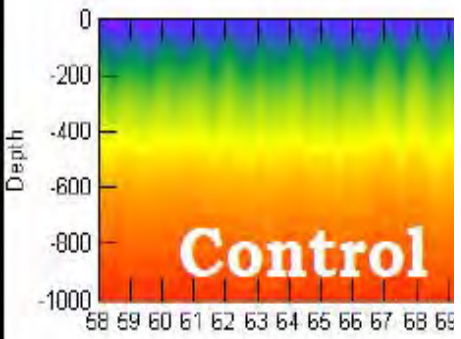
# Model Simulations



Sea Surface  
 $p\text{CO}_2$  at SEATS

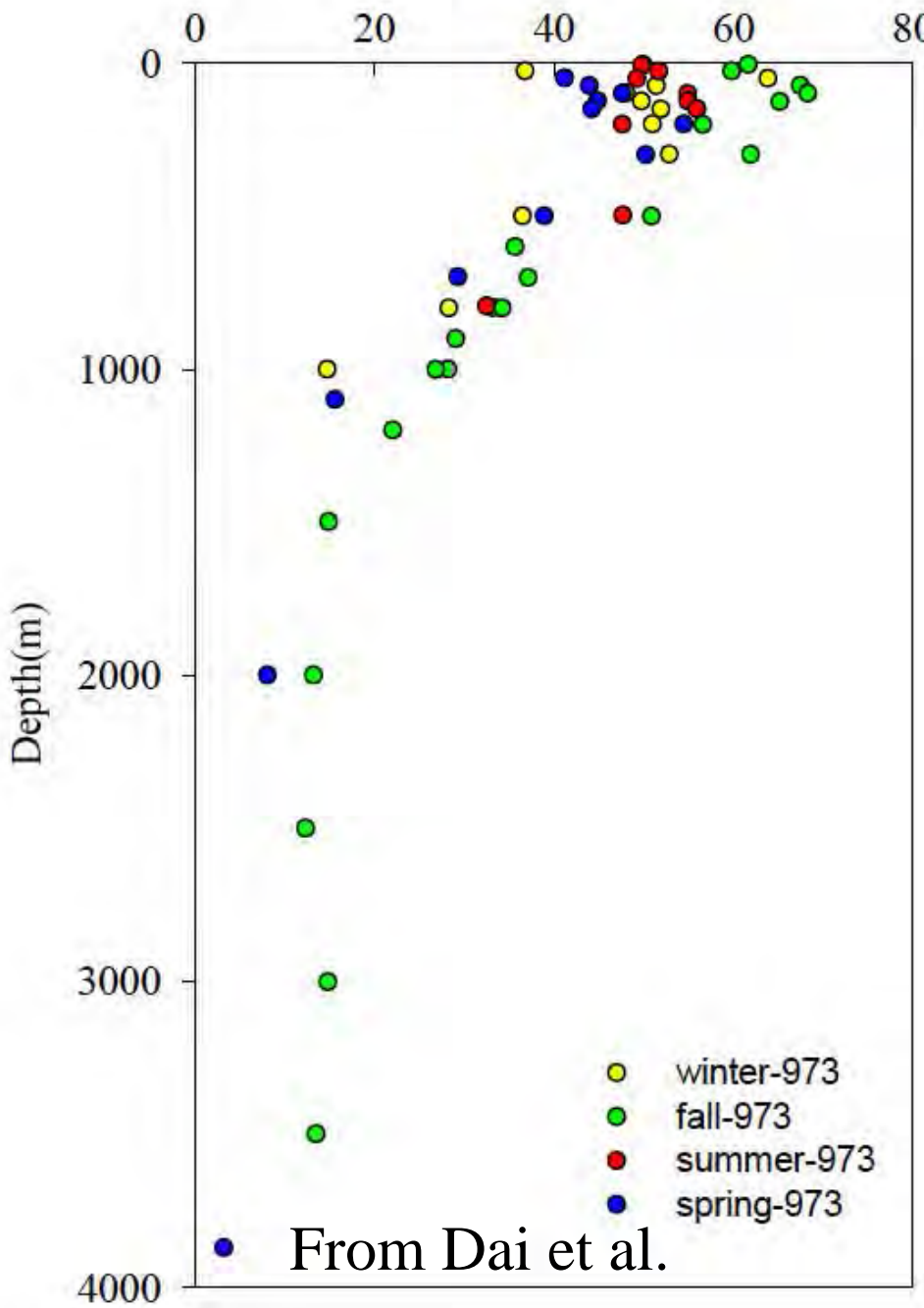
Xiu and Chai,  
JGR-Oceans, 2014

# Two Model Simulations of Anthropogenic CO<sub>2</sub> Increase

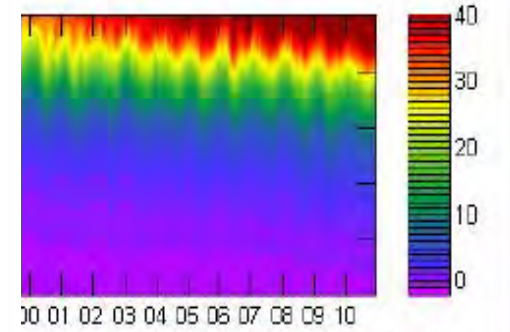
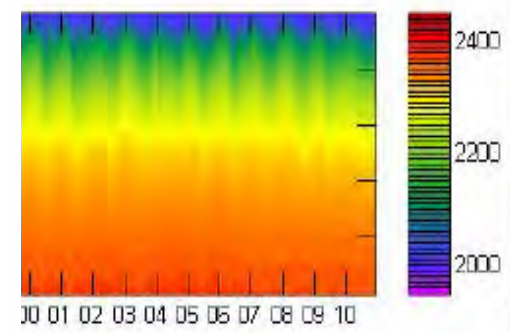
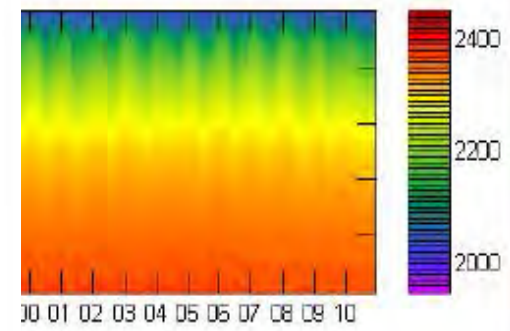


1958

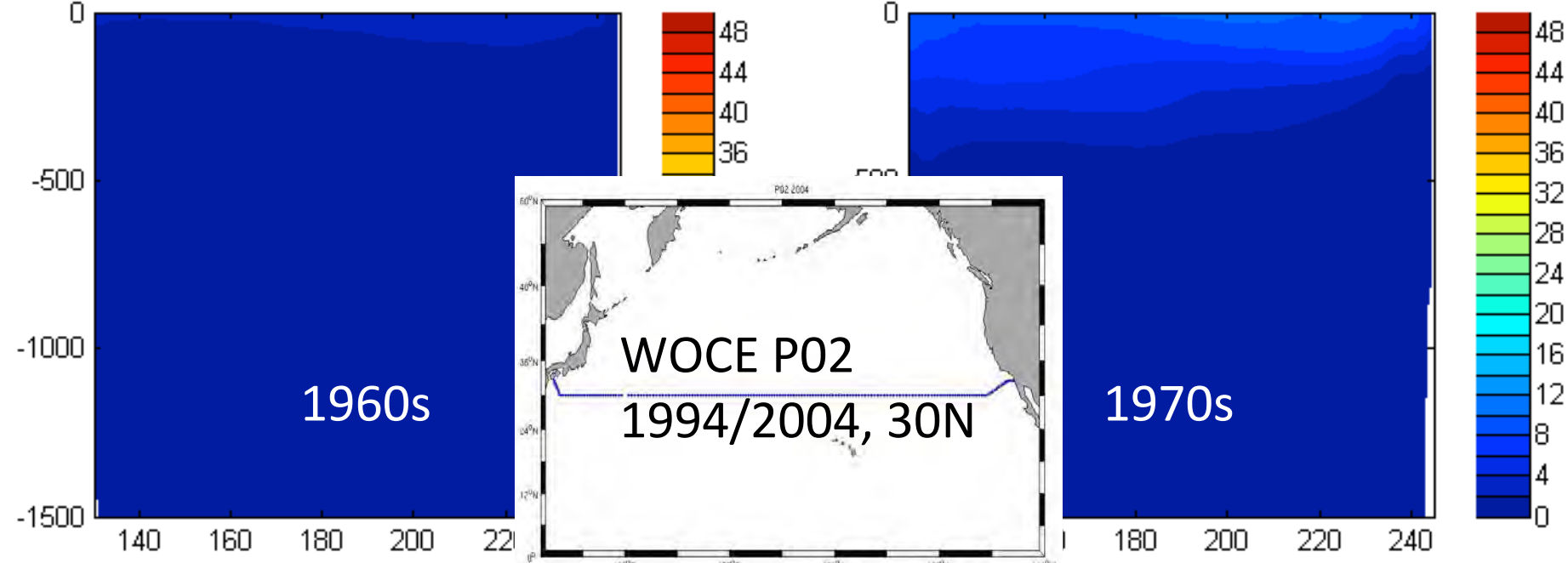
Anthropogenic CO<sub>2</sub> (μmol/kg)



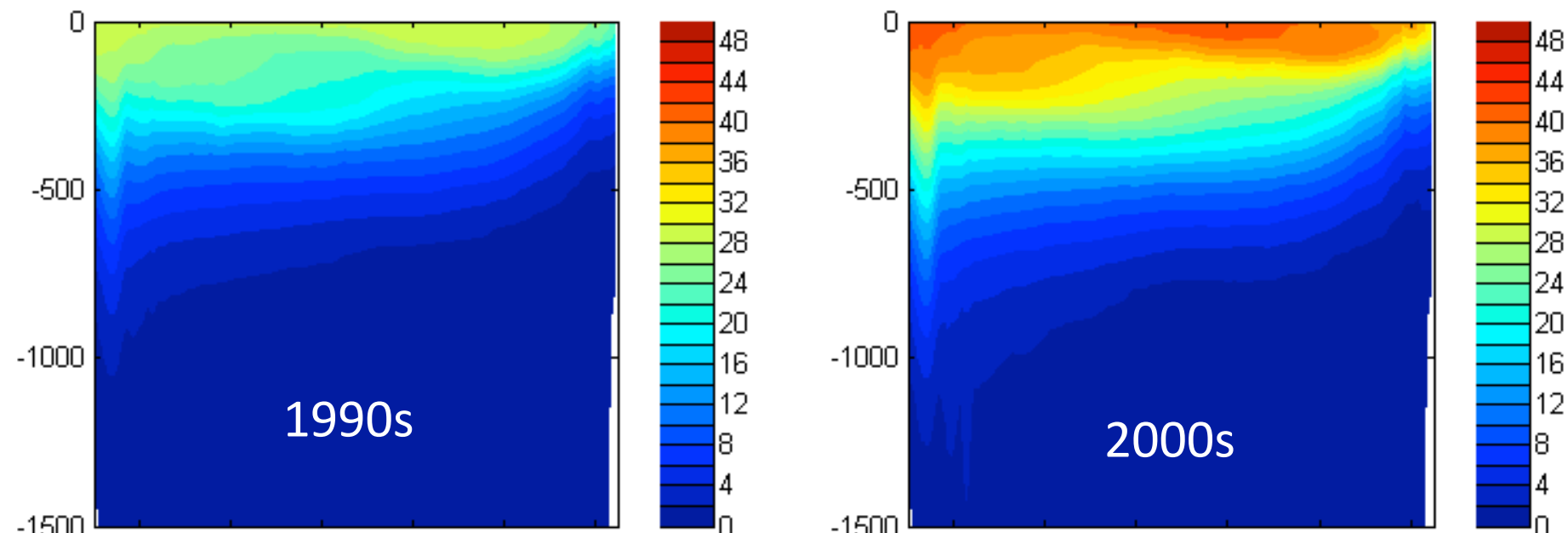
# 958 to 2010 (0-1000m)



IR-Oceans, 2014 2010

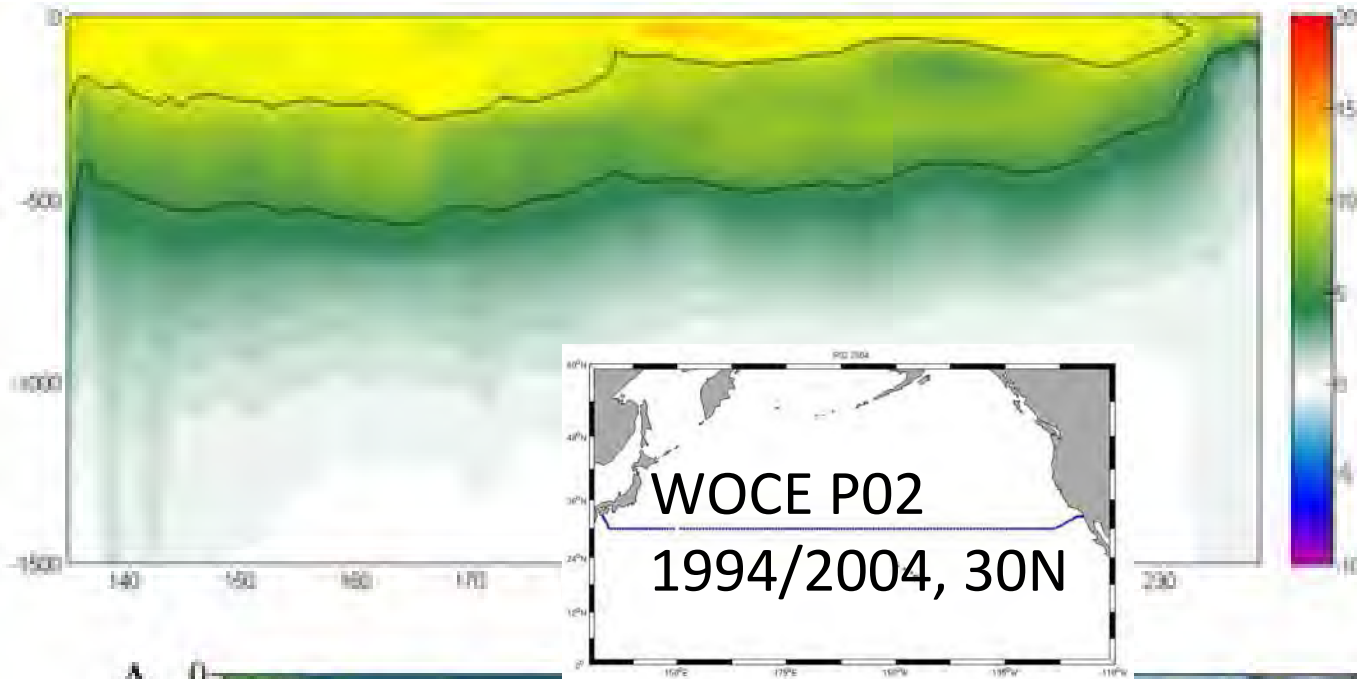


# Anthropogenic CO<sub>2</sub> along 30N

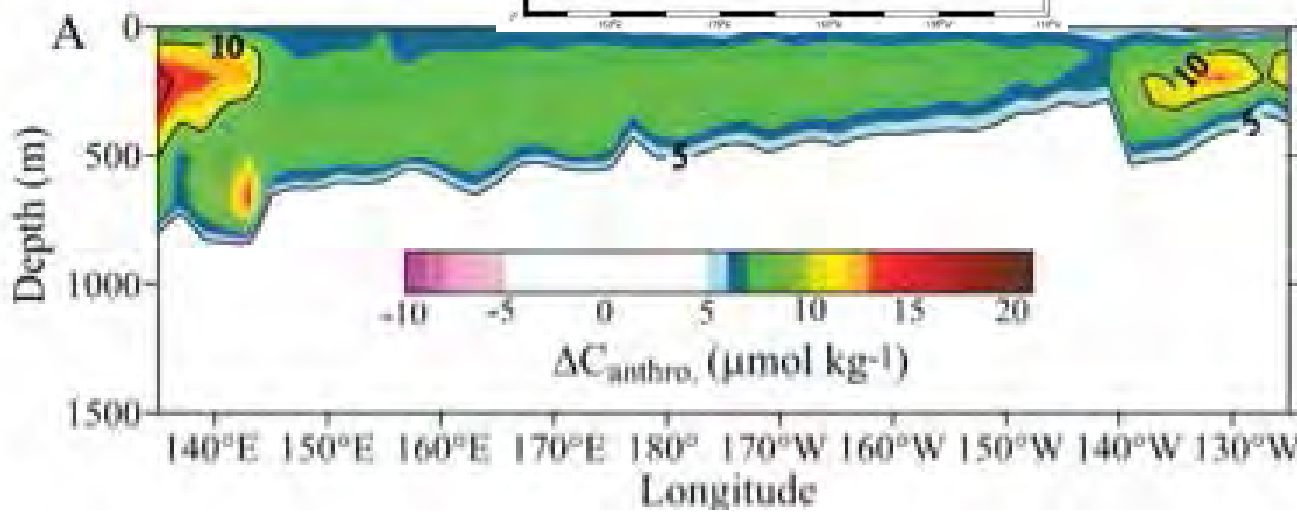




# Anthropogenic CO<sub>2</sub> Distribution in the Pacific Ocean (along 30N, 2004-1994)



Modeled  
Results

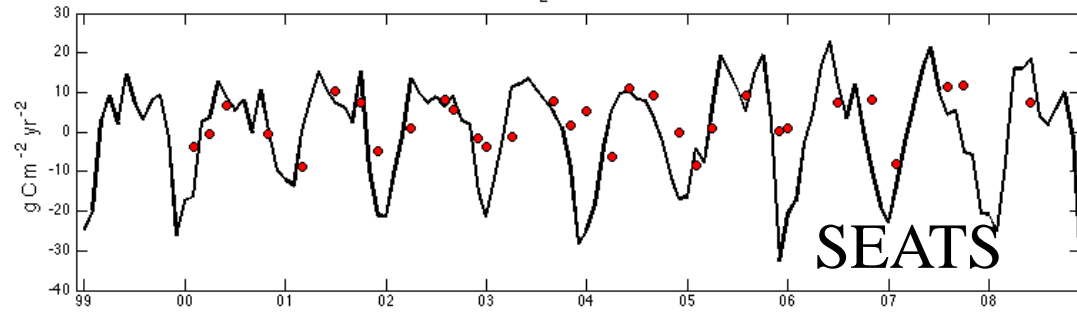


Observational  
Estimates

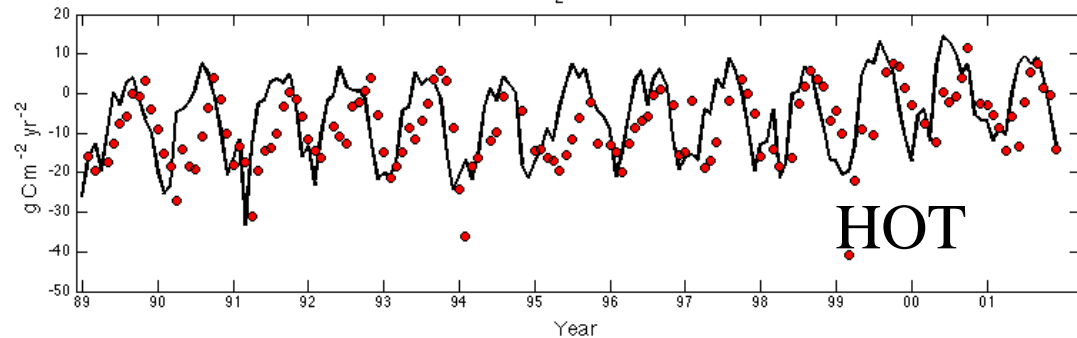
Sabine et al.,  
2004

# Sea-to-Air CO<sub>2</sub> flux

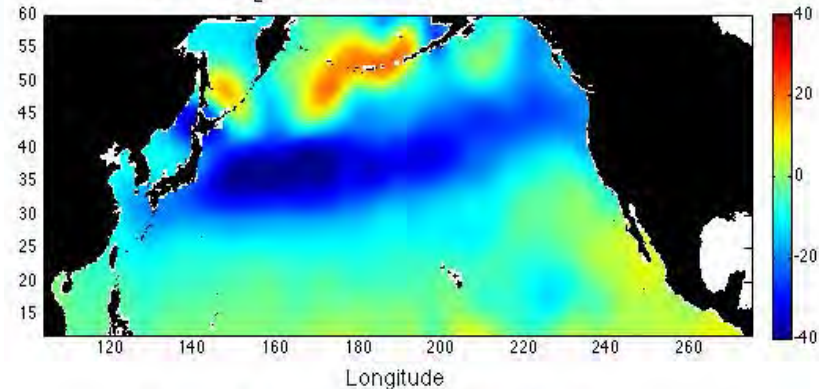
Sea-air CO<sub>2</sub> flux at SEATS



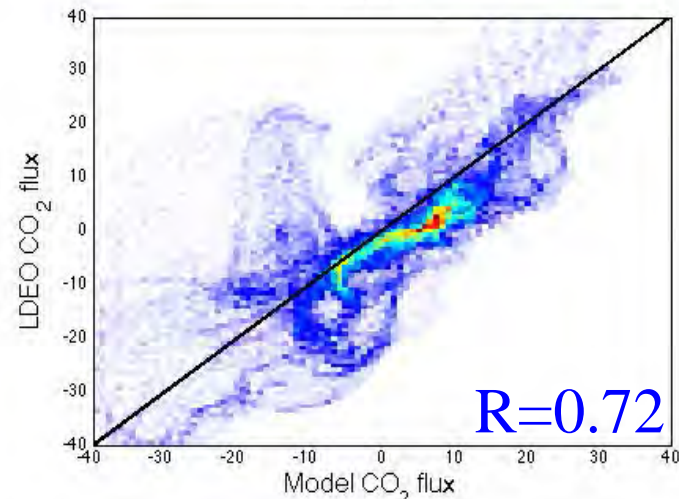
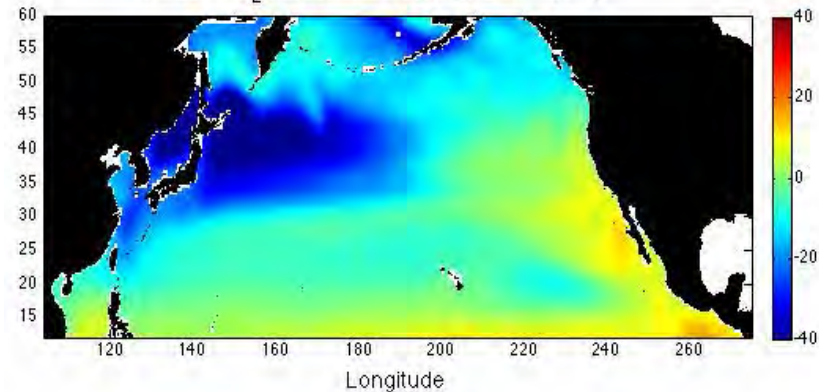
Sea-air CO<sub>2</sub> flux at HOT



LDEO CO<sub>2</sub> flux climatology (g C m<sup>-2</sup> yr<sup>-2</sup>)



Model CO<sub>2</sub> flux climatology (g C m<sup>-2</sup> yr<sup>-2</sup>)



SEATS:  $-0.14 \text{ g C m}^{-2} \text{ yr}^{-1}$

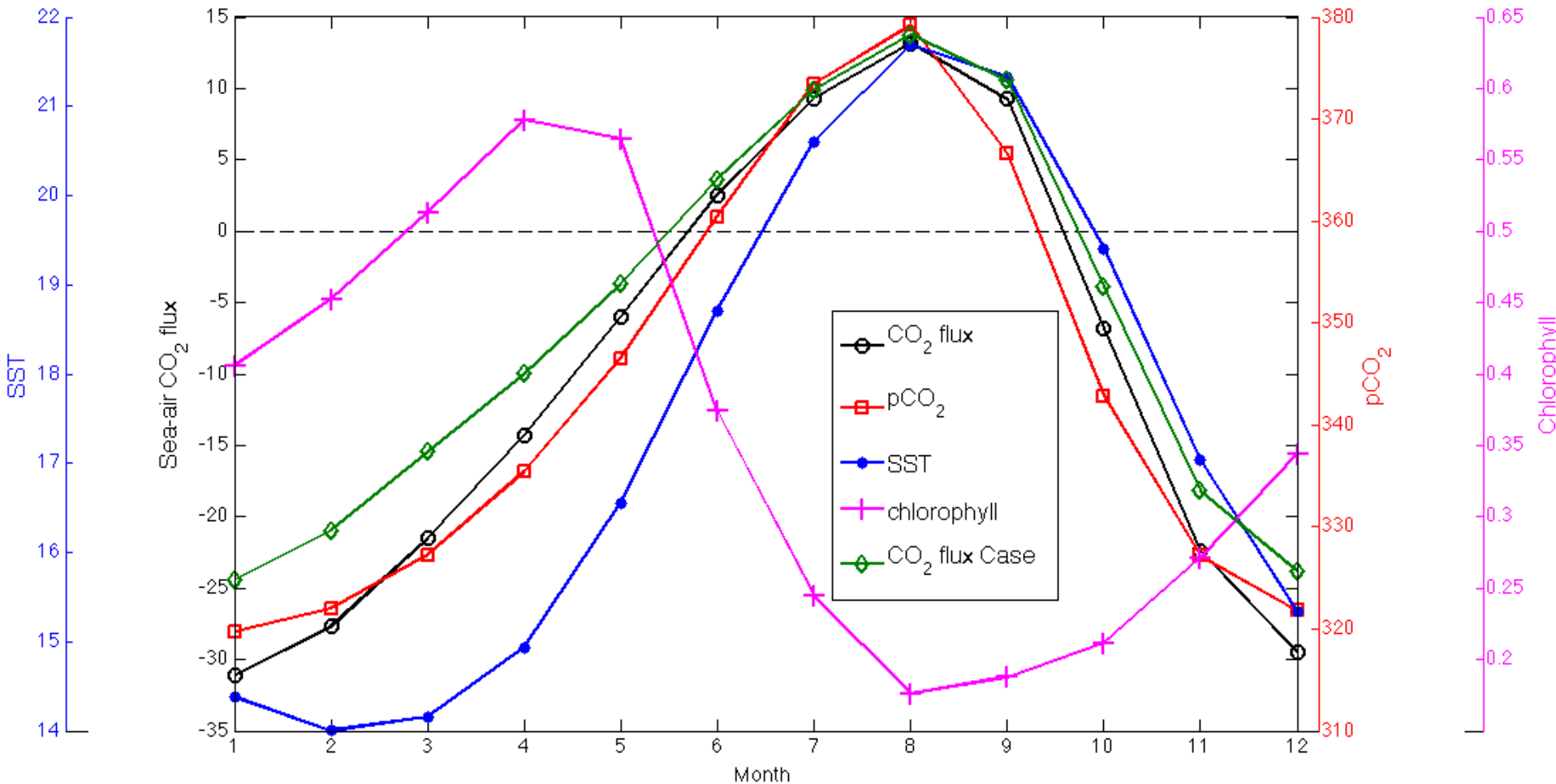
MB:  $4.6 \text{ g C m}^{-2} \text{ yr}^{-1}$

HOT:  $-5 \text{ g C m}^{-2} \text{ yr}^{-1}$

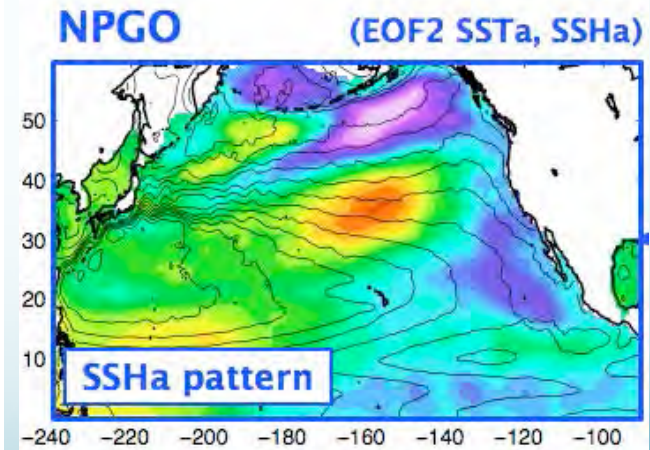
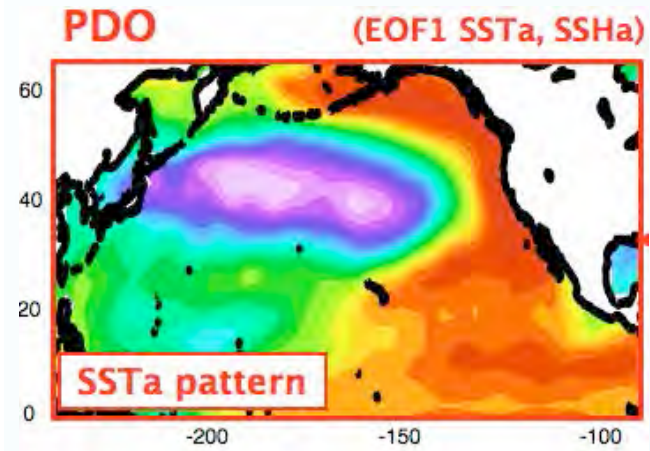
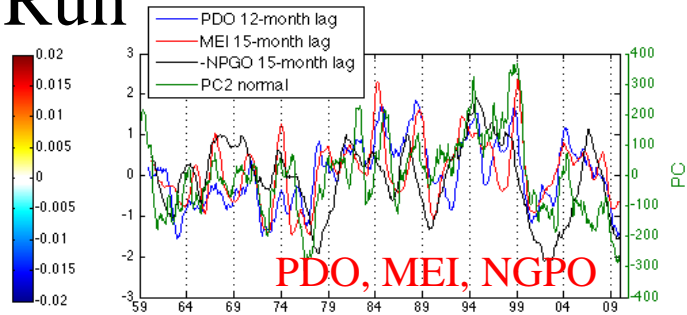
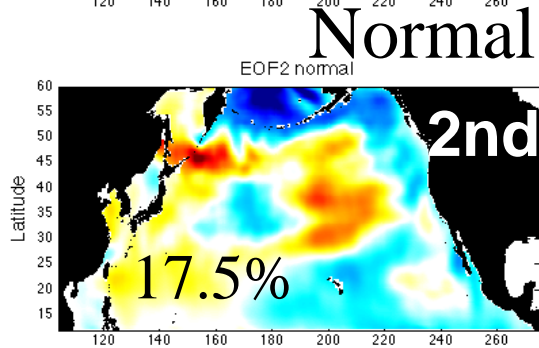
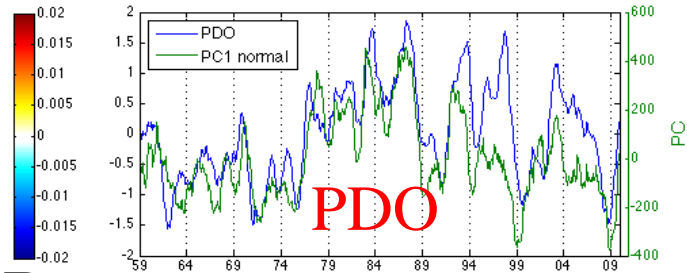
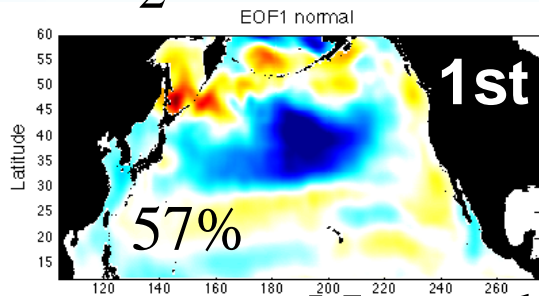
Integrated North PACIFIC (ocean sink):

**$-0.57 \text{ Pg C yr}^{-1}$**

# Seasonal pattern in $p\text{CO}_2$ and sea-to-air $\text{CO}_2$ flux



# CO<sub>2</sub> flux Interannual and decadal variability



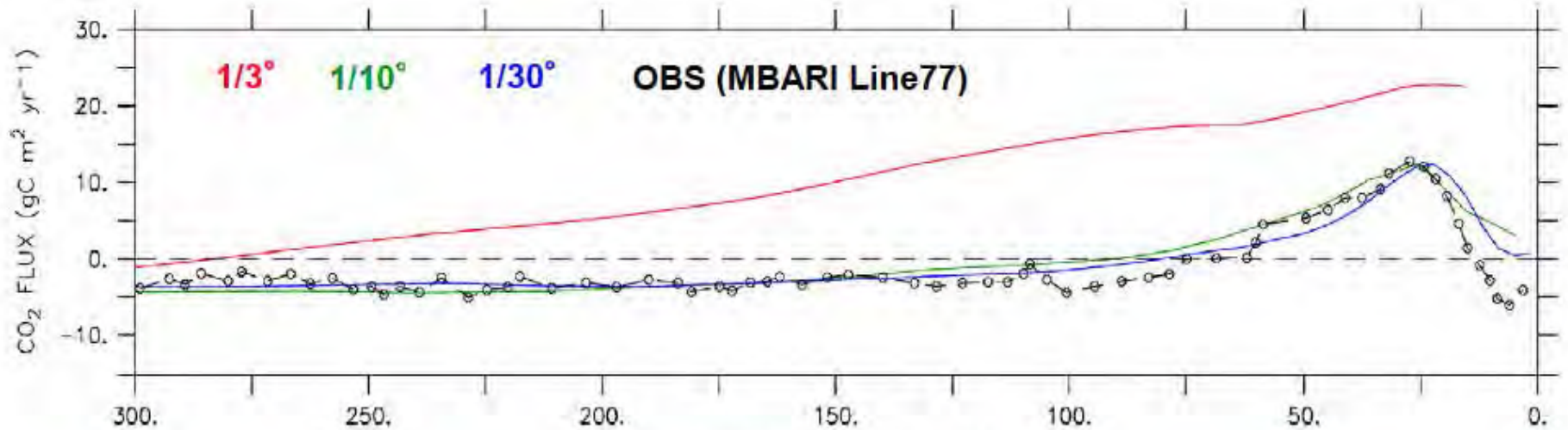
# Sea-to-Air CO<sub>2</sub> flux and correlations with climate indices

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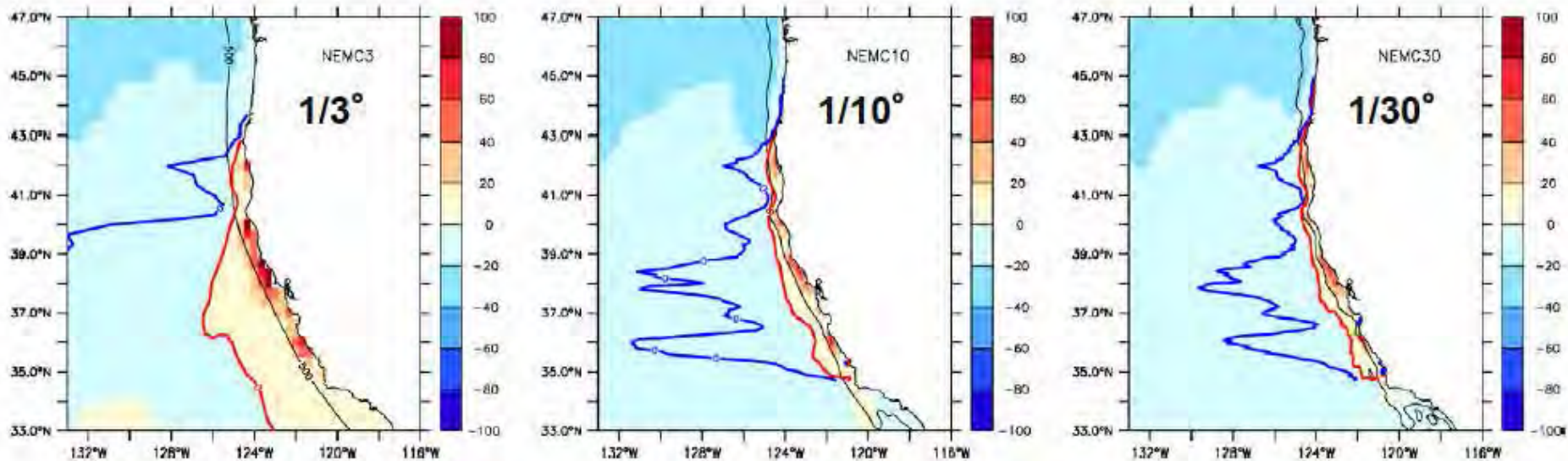
Correlation/Lags	PC1 normal run (57% variance)	PC2 normal run (18% variance)
<b>PDO</b>	<b>0.77/0</b>	<b>0.62/12</b>
<b>MEI</b>	<b>0.53/0</b>	<b>0.59/15</b>
<b>NPGO</b>		<b>-0.51/15</b>

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# Model resolution matters!



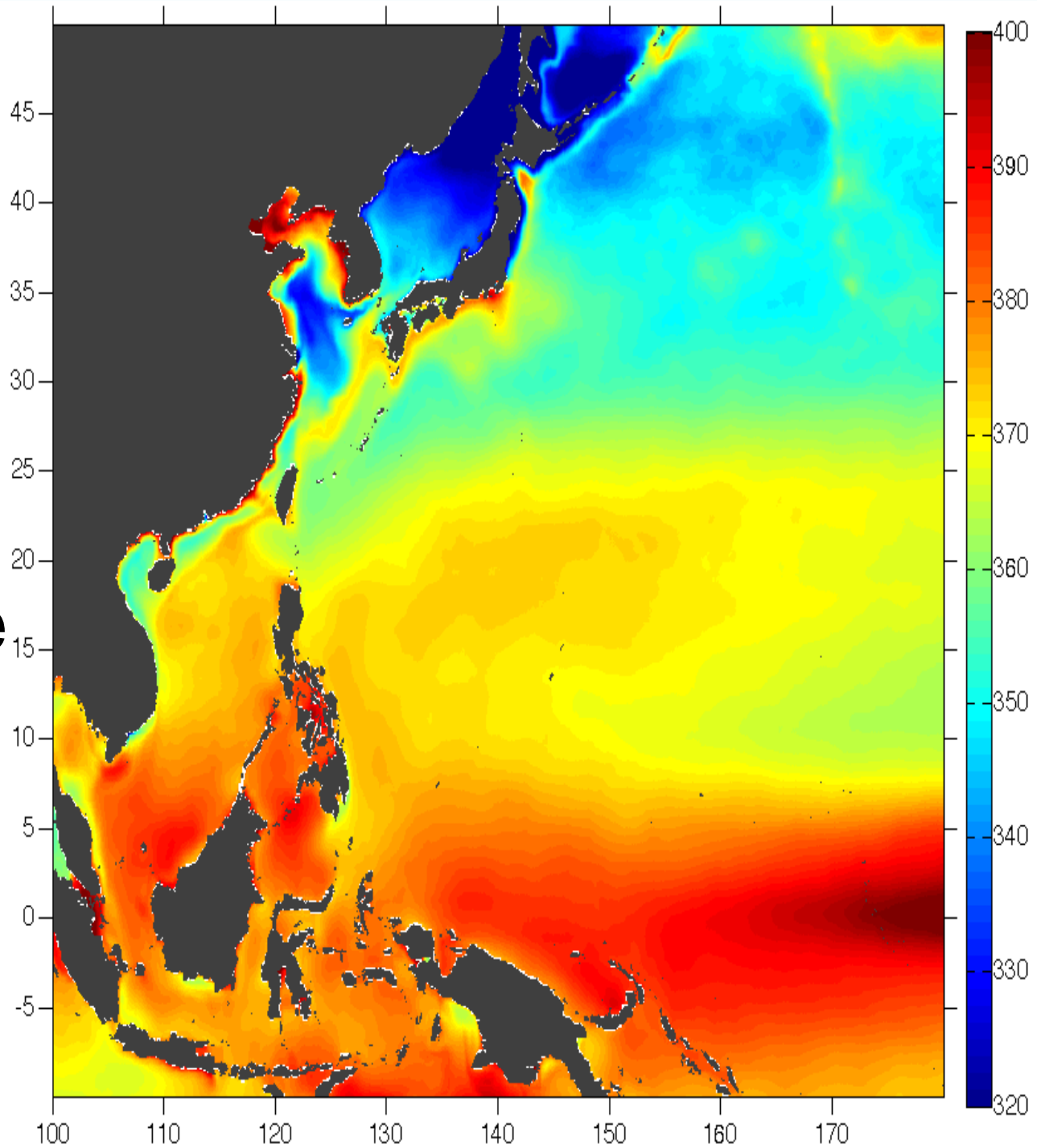
Fiechter, Chai, Curchister, et al., GBC, 2014



Red Line: Outgassing Region Blue Line: Equilibrium Region

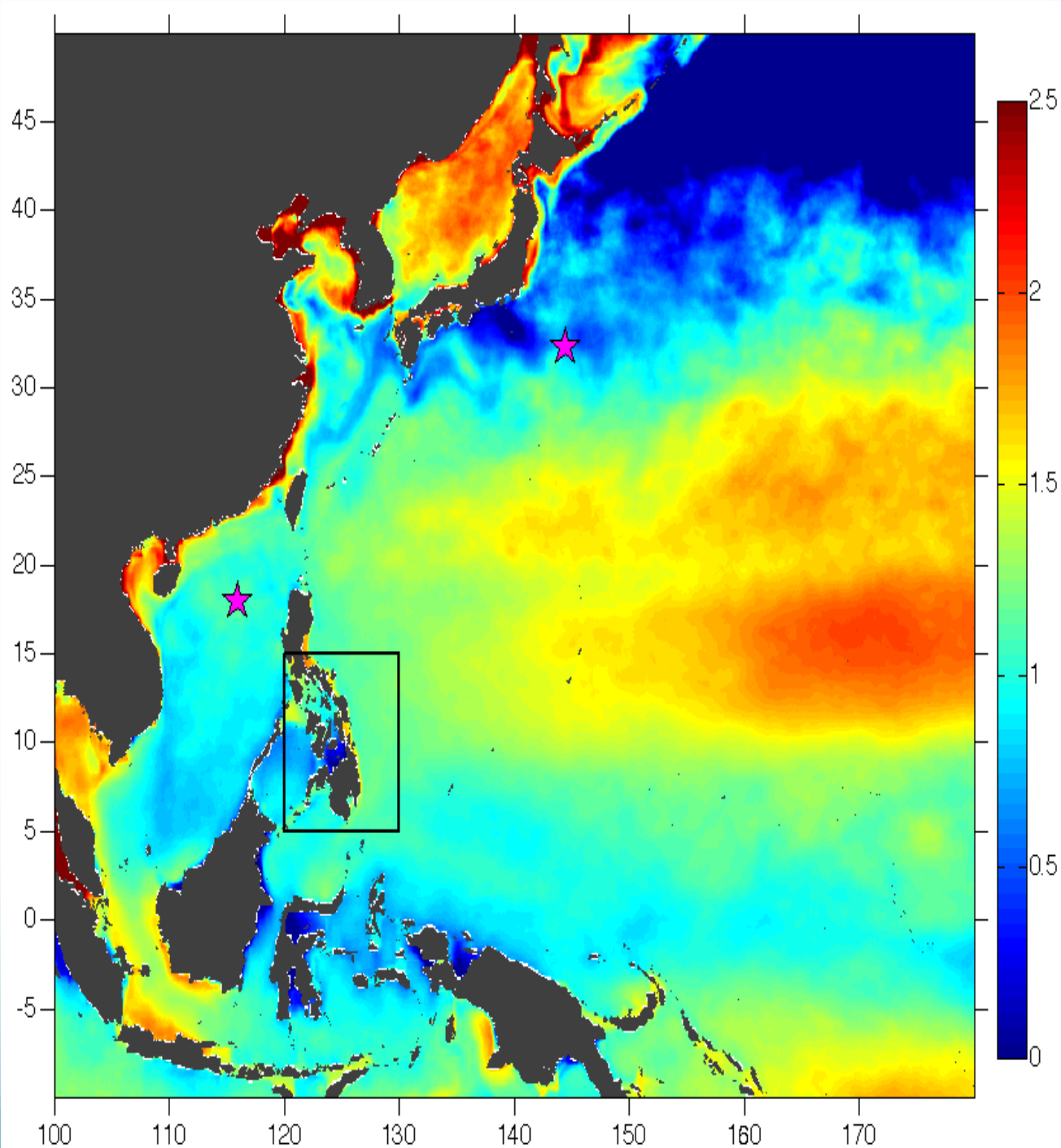
***Regional  
Ocean Model  
System (ROMS)  
and CoSiNE  
(~10 km)  
(1993 to 2013)***

**Mean surface  
pCO<sub>2</sub> during  
1993-2013**



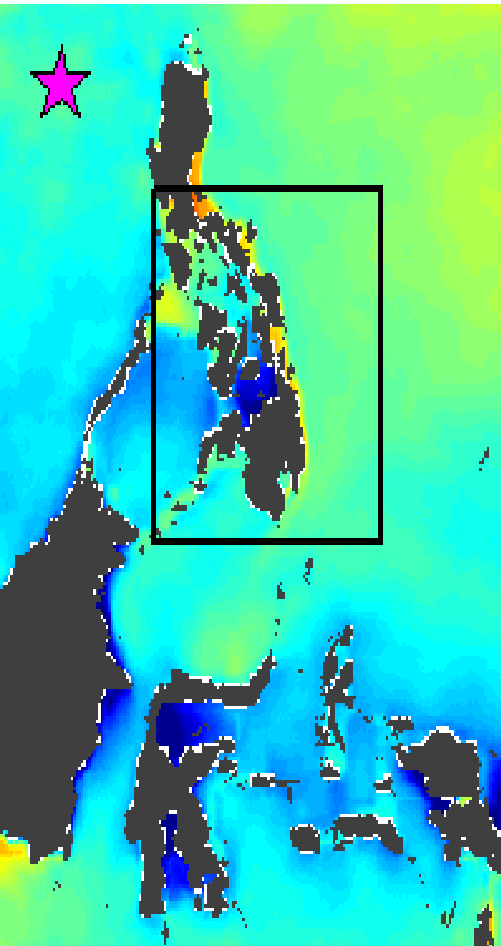
***Regional  
Ocean Model  
System (ROMS)  
and CoSiNE  
(~10 km)  
(1993 to 2013)***

***Linear  
increasing  
trend*** of  
surface pCO<sub>2</sub>  
during 1993-  
2013

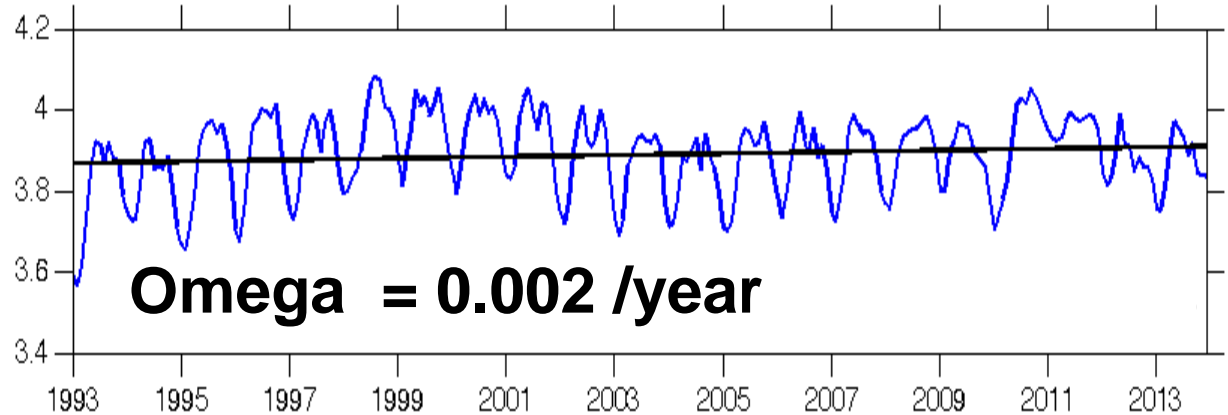
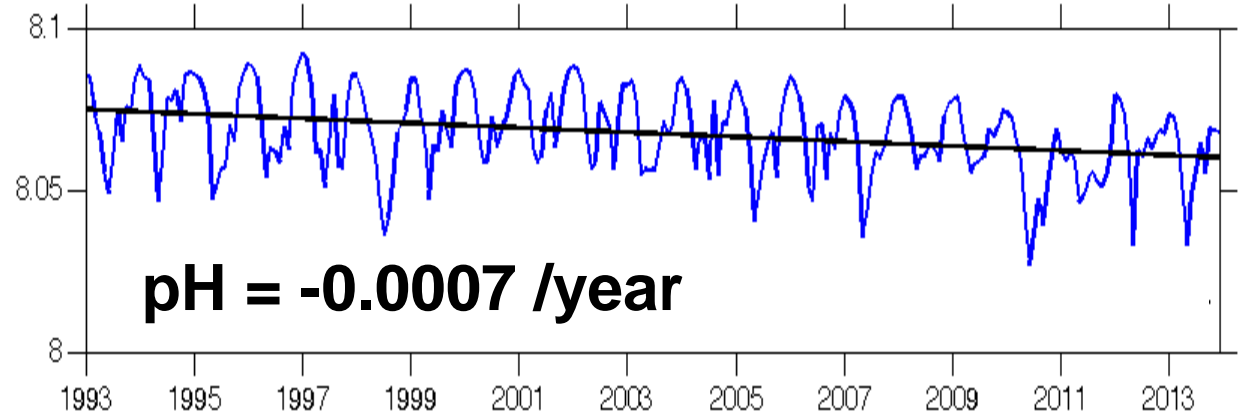
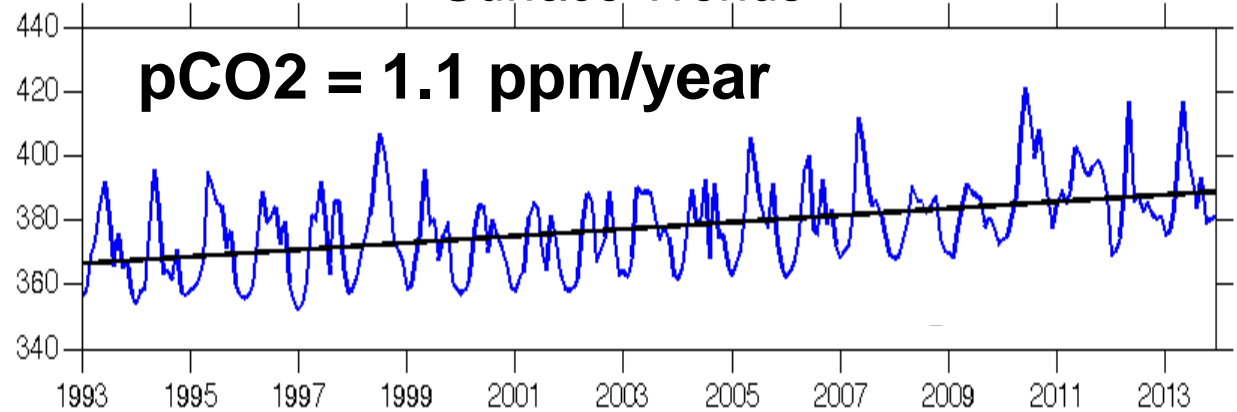




# Coral Triangle

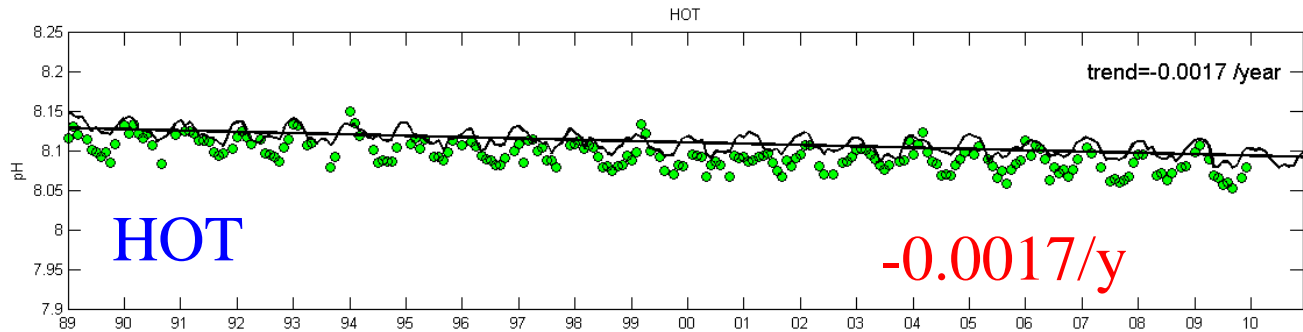
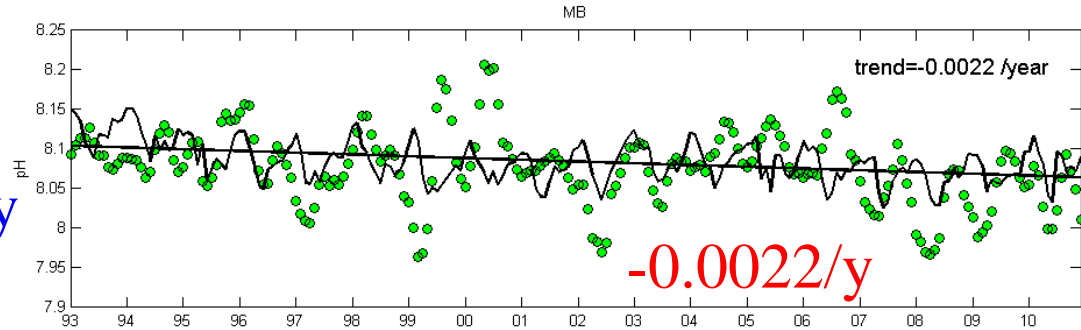


## Surface Trends

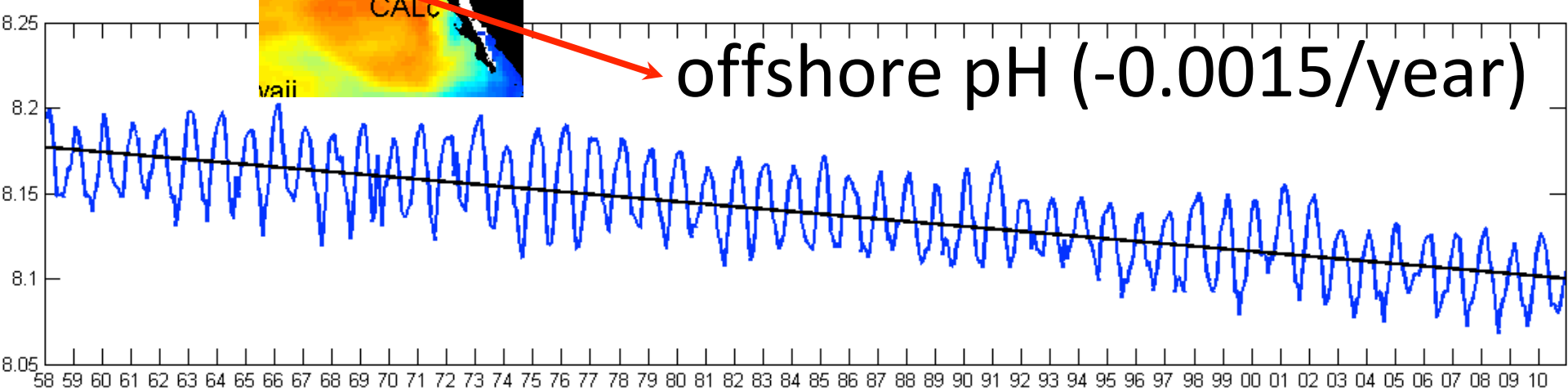
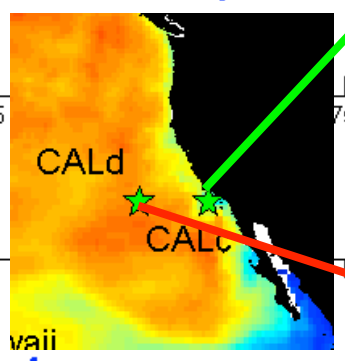
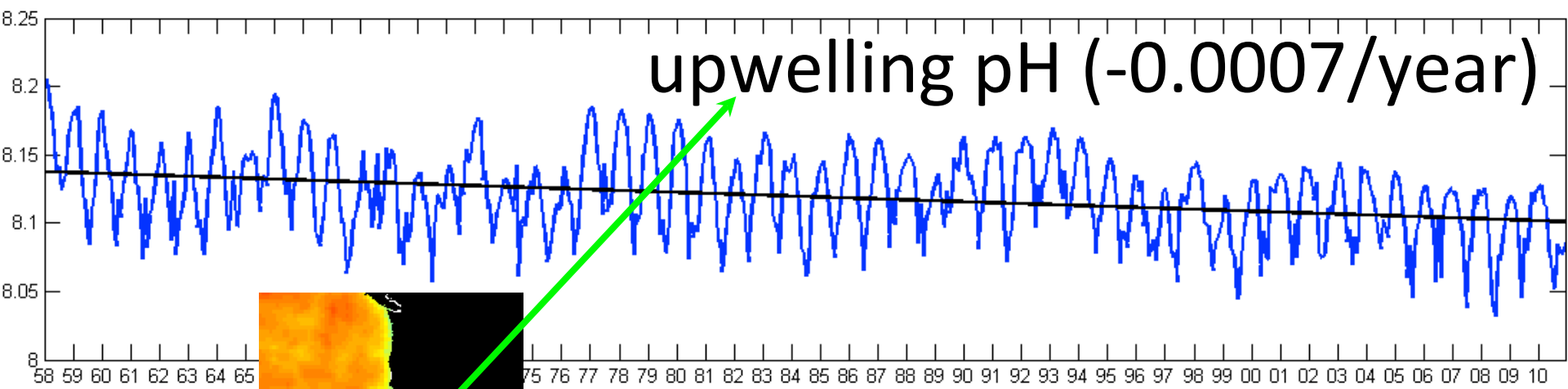


# pH decreasing trend

Monterey Bay



# Surface pH decreasing trends (1958 to 2010) California Current System (upwelling vs. offshore)



1958 2010

# Modeling Carbon Cycle in the Pacific Ocean

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*University of Maine*

- Physical and Biogeochemical Models (ROMS-CoSiNE)
- $p\text{CO}_2$ ,  $\text{CO}_2$  flux, pH Trends (regional dynamics, nonlinear processes, ENSO, NGPO, & PDO)
- A Twin Experiments (separating natural and anth.)
- Model Resolution Matters (global, basin-wide, regional, and local; impacts on ecosystems)