# Future changes of nutrient dynamics and biological productivity in California Current System (CCS)


Prof. Fei CHAI

University of Maine, USA

Second Institute of Oceanography, China

Peng Xiu (SCSIO), Enrique Curchitser (Rutgers University), Frederic Castruccio (NCAR)



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Future changes in coastal upwelling ecosystems with global warming: The case of the California Current System


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*Scientific Reports* **8**, Article number: 2866 (2018) | Download Citation

# Outline

- Motivation - global vs. regional approach for understanding the ocean
- Physical-biological modeling for the Pacific Ocean (ROMS-CoSiNE)
- Future projections for CCS based on GFDL/ESM connecting with ROMS-CoSiNE
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# The Intergovernmental Panel on Climate Change

The Intergovernmental Panel on Climate Change (IPCC) is the United Nations body for assessing the science related to climate change.

PREVIOUS WEBSITE

GLOBAL WARMING OF 1.5°C

WMO UNEP

Nobel
2007 PEACE PRIZE
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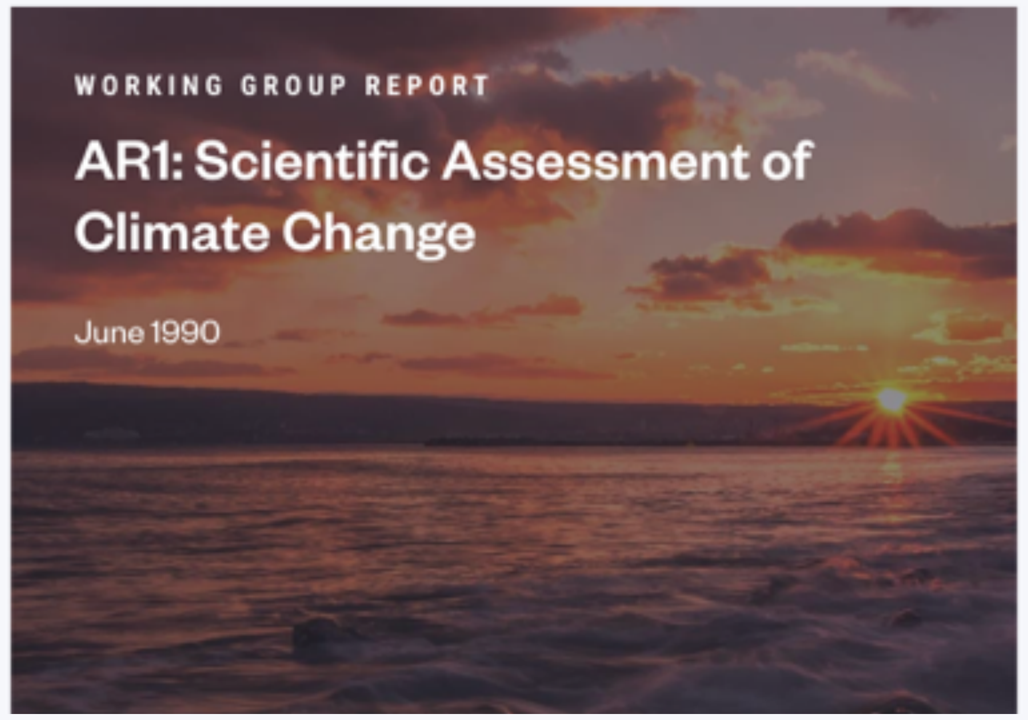





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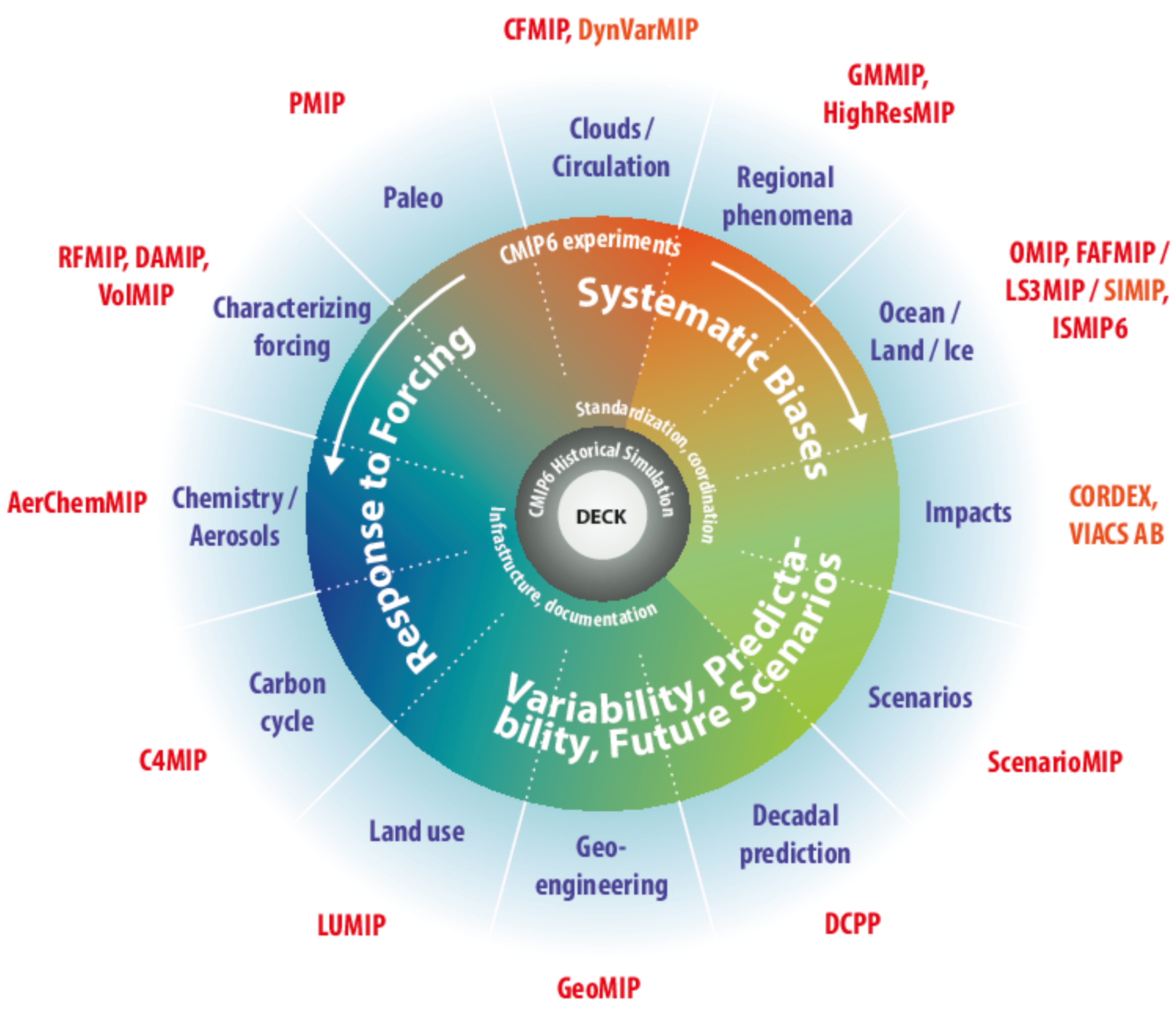
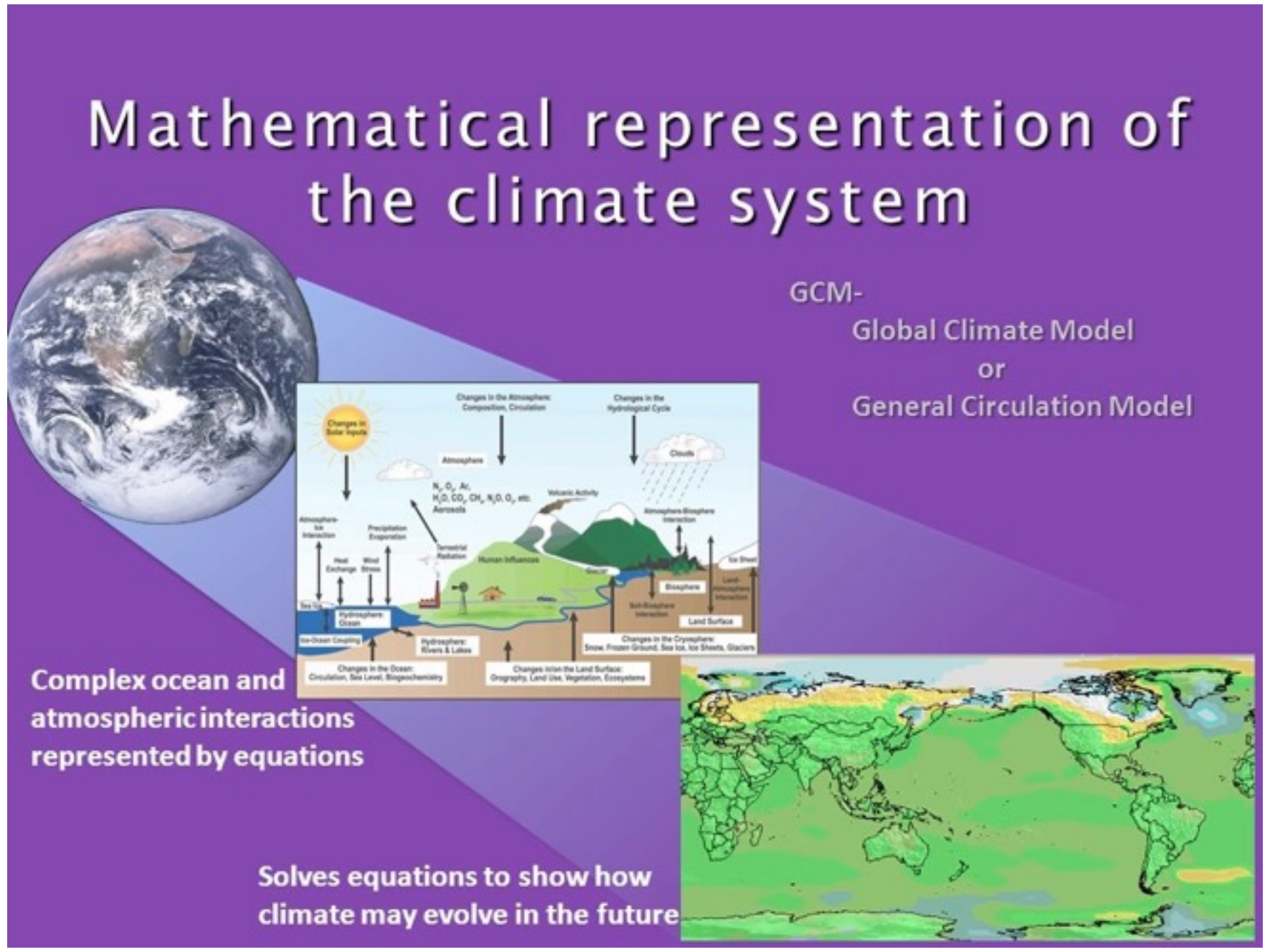
SYNTHESIS REPORT

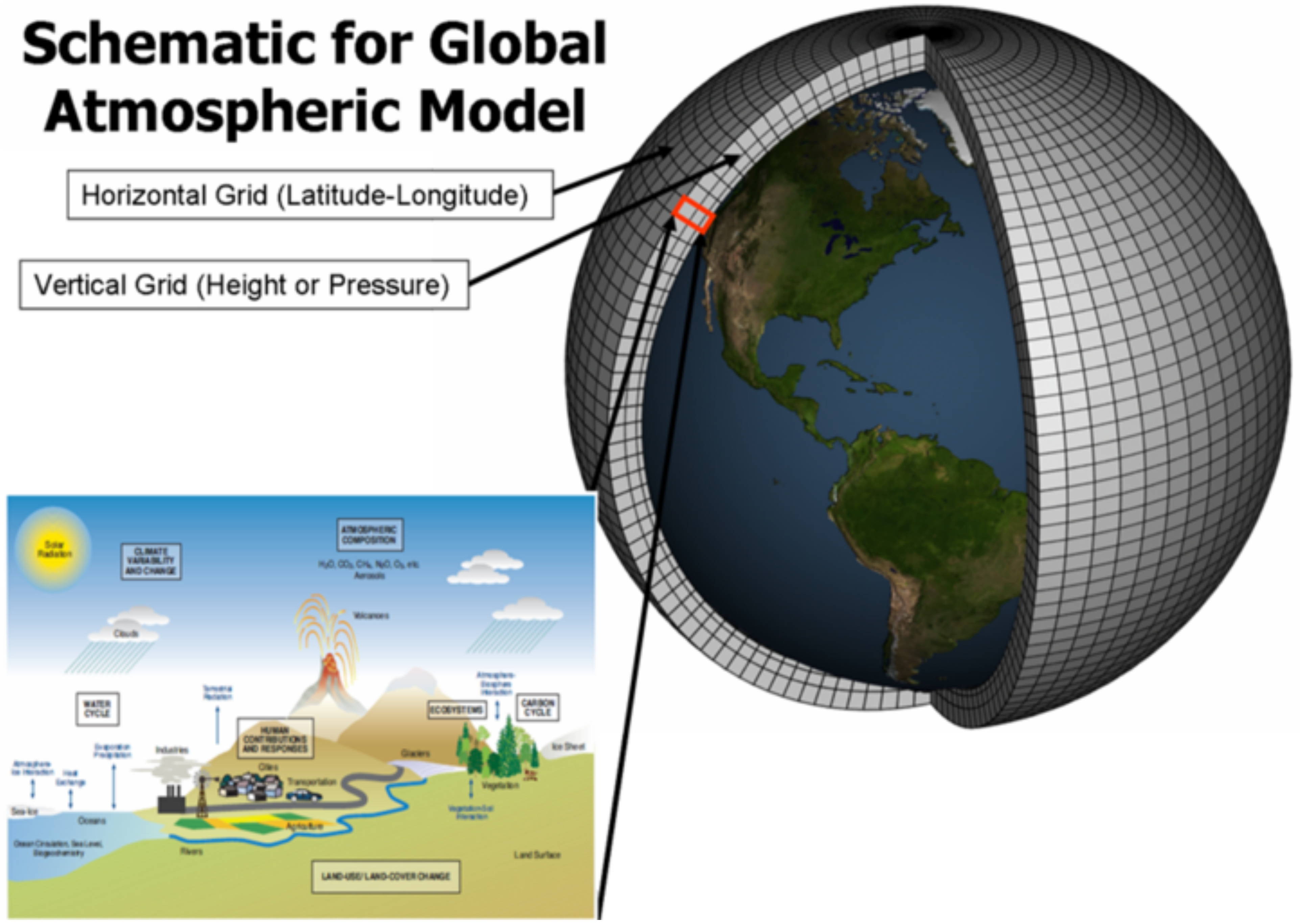
## AR6 Synthesis Report: Climate Change 2022

June 2022

# IPCC Reports and Earth System Models



# IPCC Reports and Earth System Models

## CMIP6: Participating Model Groups

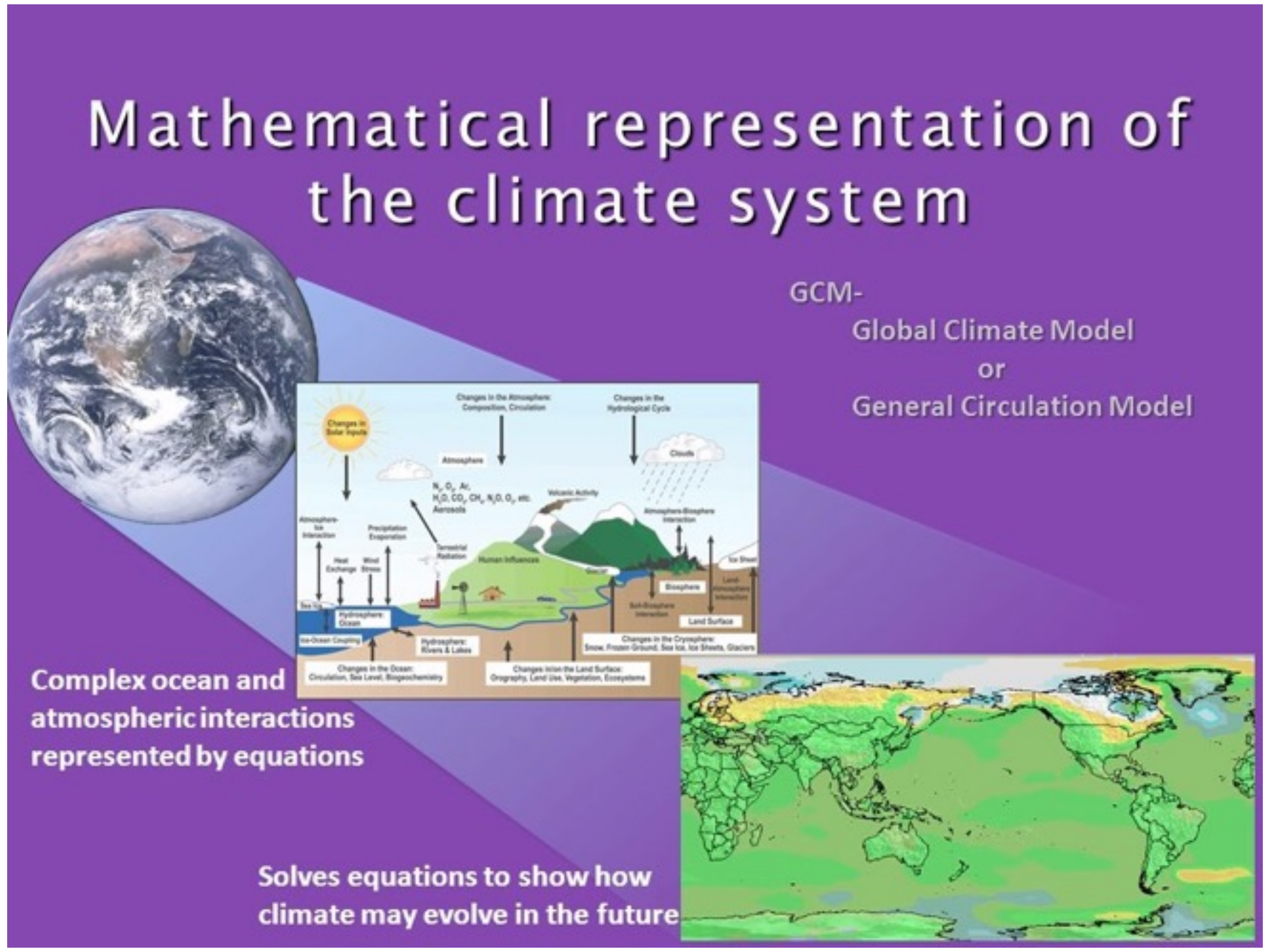
| | Institution | Country | | Institution | Country | | Institution | Country |
|---|---|---|---|---|---|---|---|---|
| 1 | AWI | Germany | 12 | DOE | USA | 23 | MRI | Japan |
| 2 | BCC | China | 13 | EC-Earth-Cons | Europe | 24 | NASA-GISS | USA |
| 3 | BNU | China | 14 | FGOALS | China | 25 | NCAR | USA |
| 4 | CAMS | China | 15 | FIO-RONM | China | 26 | NCC | Norway |
| 5 | CasESM | China | 16 | INM | Russia | 27 | NERC | UK |
| 6 | CCCma | Canada | 17 | INPE | Brazil | 28 | NIMS-KMA | Republic of Korea |
| 7 | CCCR-IITM | India | 18 | IPSL | France | 29 | NOAA-GFDL | USA |
| 8 | CMCC | Italy | 19 | MESSY-Cons | Germany | 30 | NUIST | China |
| 9 | CNRM | France | 20 | MIROC | Japan | 31 | TaiESM | Taiwan, China |
| 10 | CSIR-CSIRO | South Africa | 21 | MOHC | UK | 32 | THU | China |
| 11 | CSIRO-BOM | Australia | 22 | MPI-M | Germany | 33 | Seoul Nat.Uni | Republic of Korea |

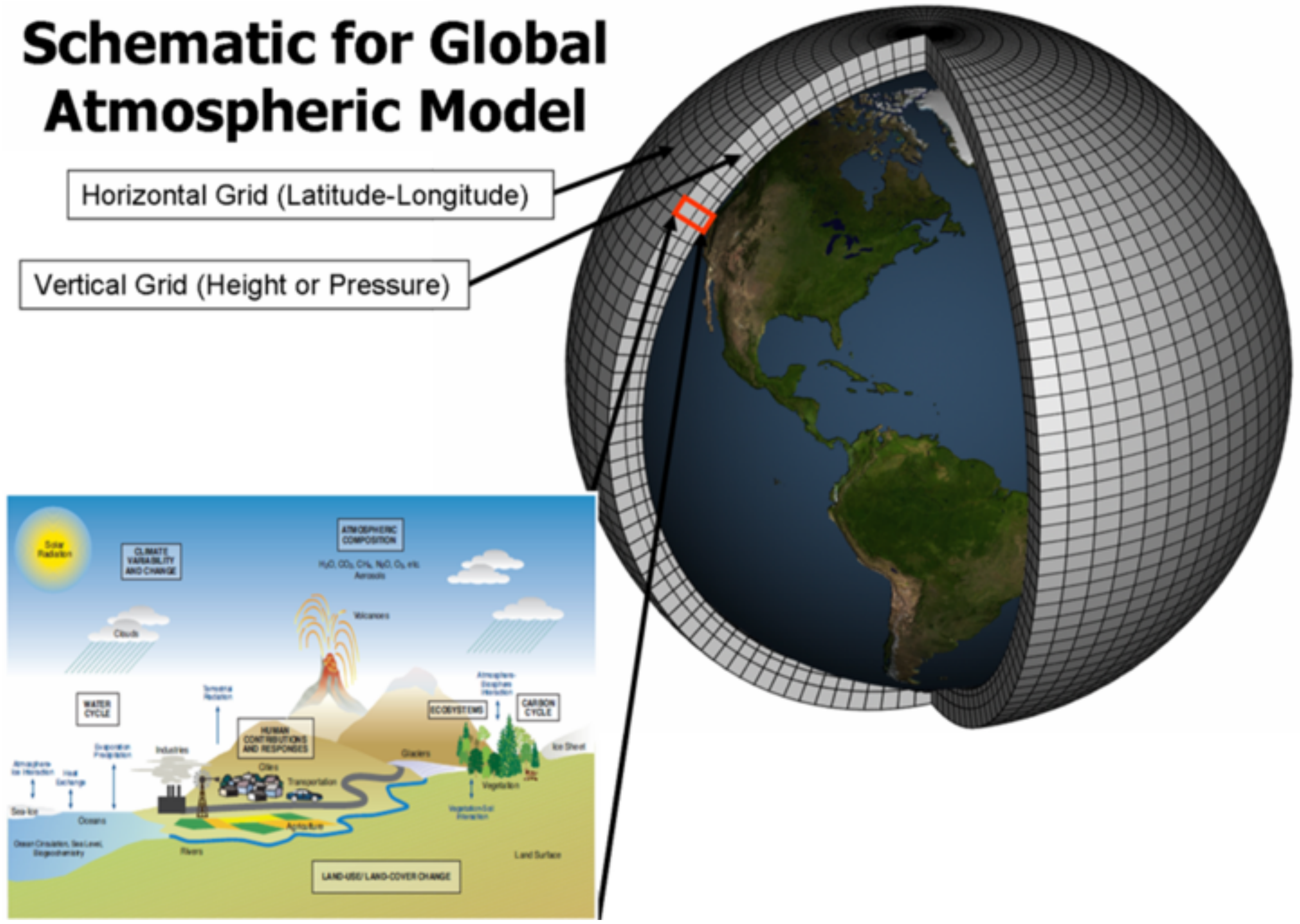
**New in CMIP:**

2 new model groups from Germany (AWI, MESSY-Consortium)
4 new model groups from China (CAMS, CasESM, NUIST, THU)
1 new model group from Brazil (INPE)
1 new model group from India (CCCR-IITM)
1 new model group from Taiwan, China (TaiESM)
1 new model group from USA (DOE)
2 new model group from Republic of Korea (NIMS-KMA, SAM0-UNICON) )
1 new model group from South Africa / Australia (CSIR-CSIRO)
==========================================
⇒ **13 new model groups so far**

More models (>70)
New models
More complex models
Higher resolution models

* Other models can join providing DECK and historical simulations are submitted



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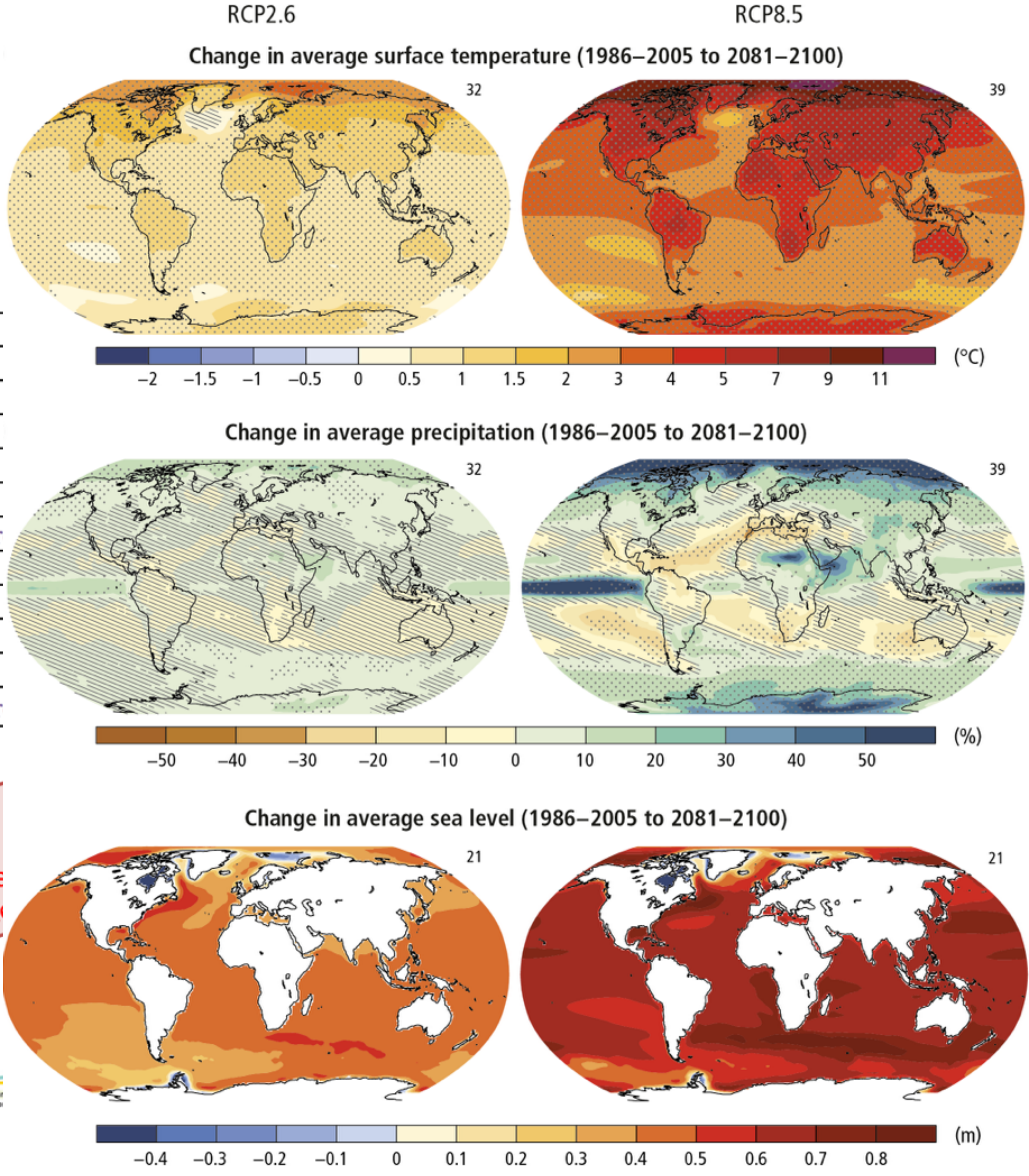

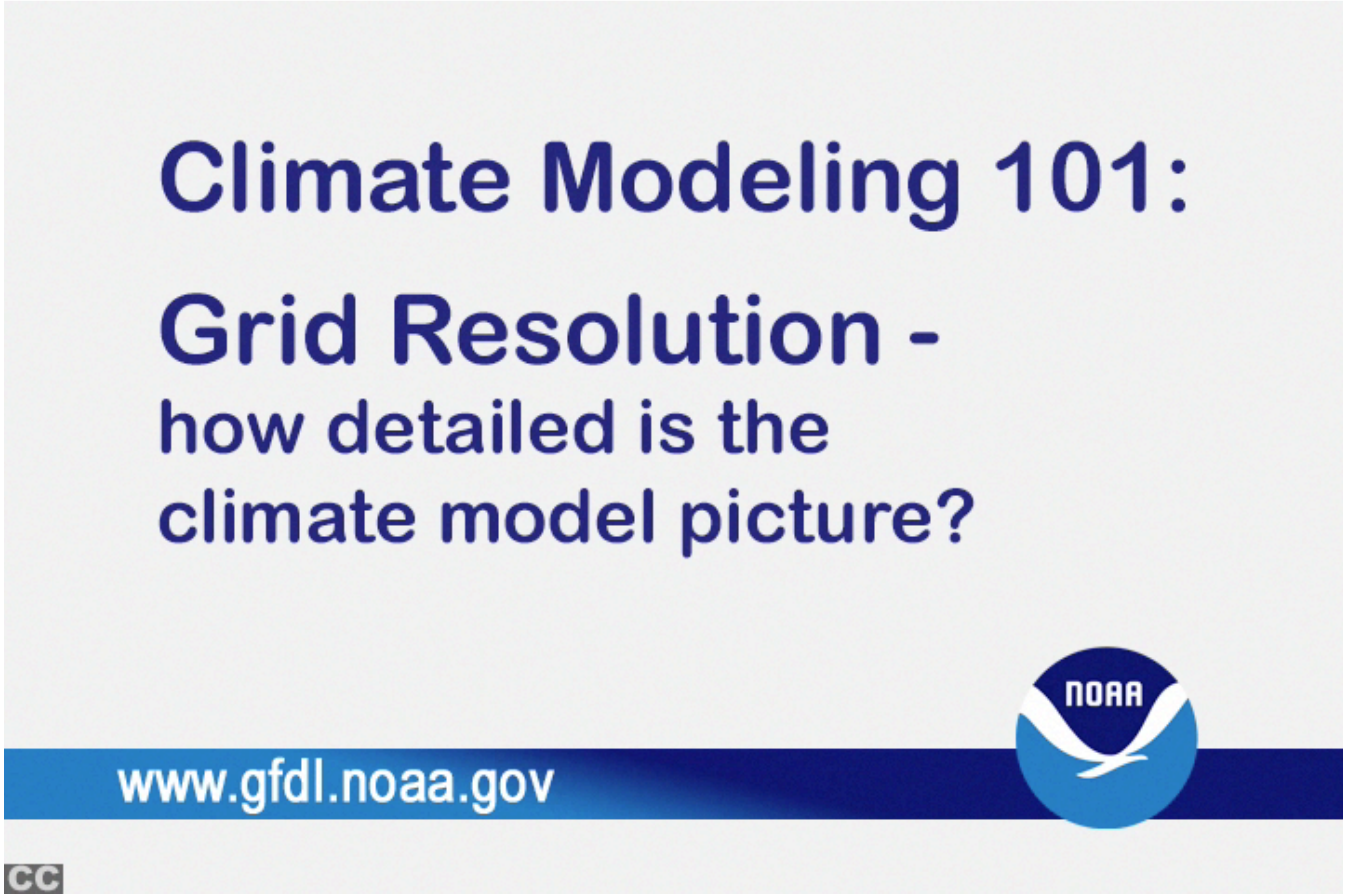


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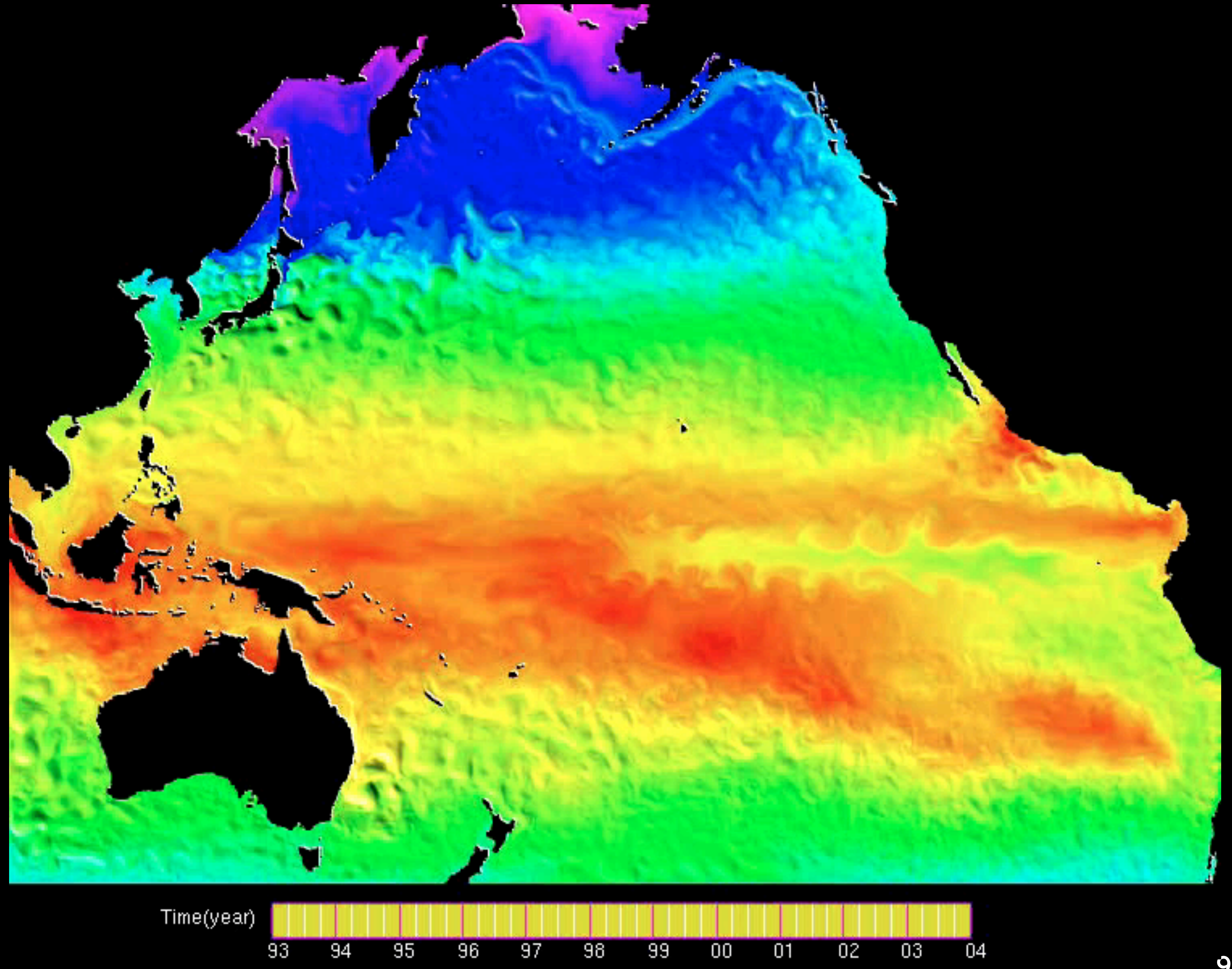
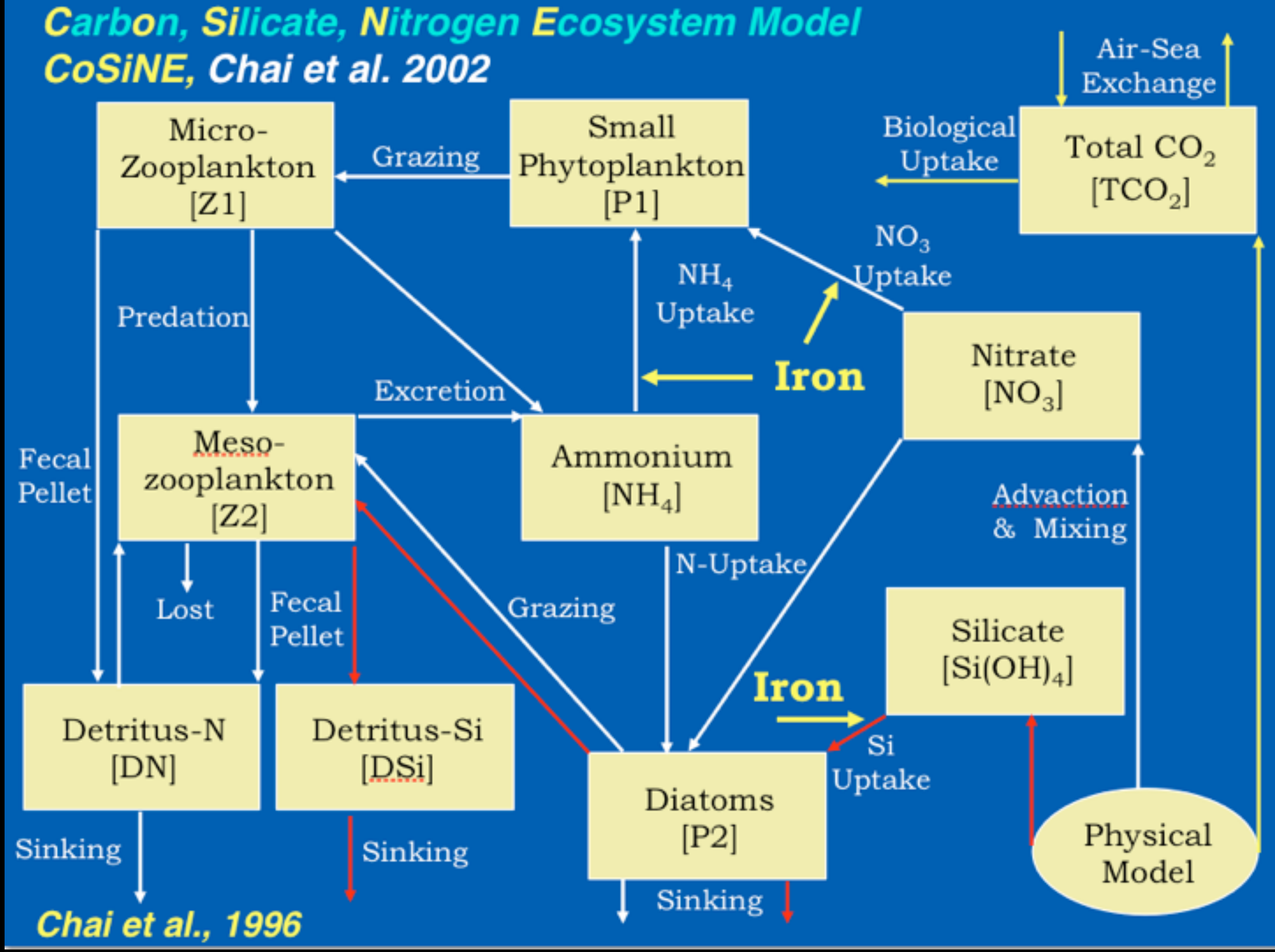
# Regional Ocean Model System (ROMS) (7-12km)

Sear Surface Temperature (SST) (color)
Sea Surface Height (SSH) (elevation)

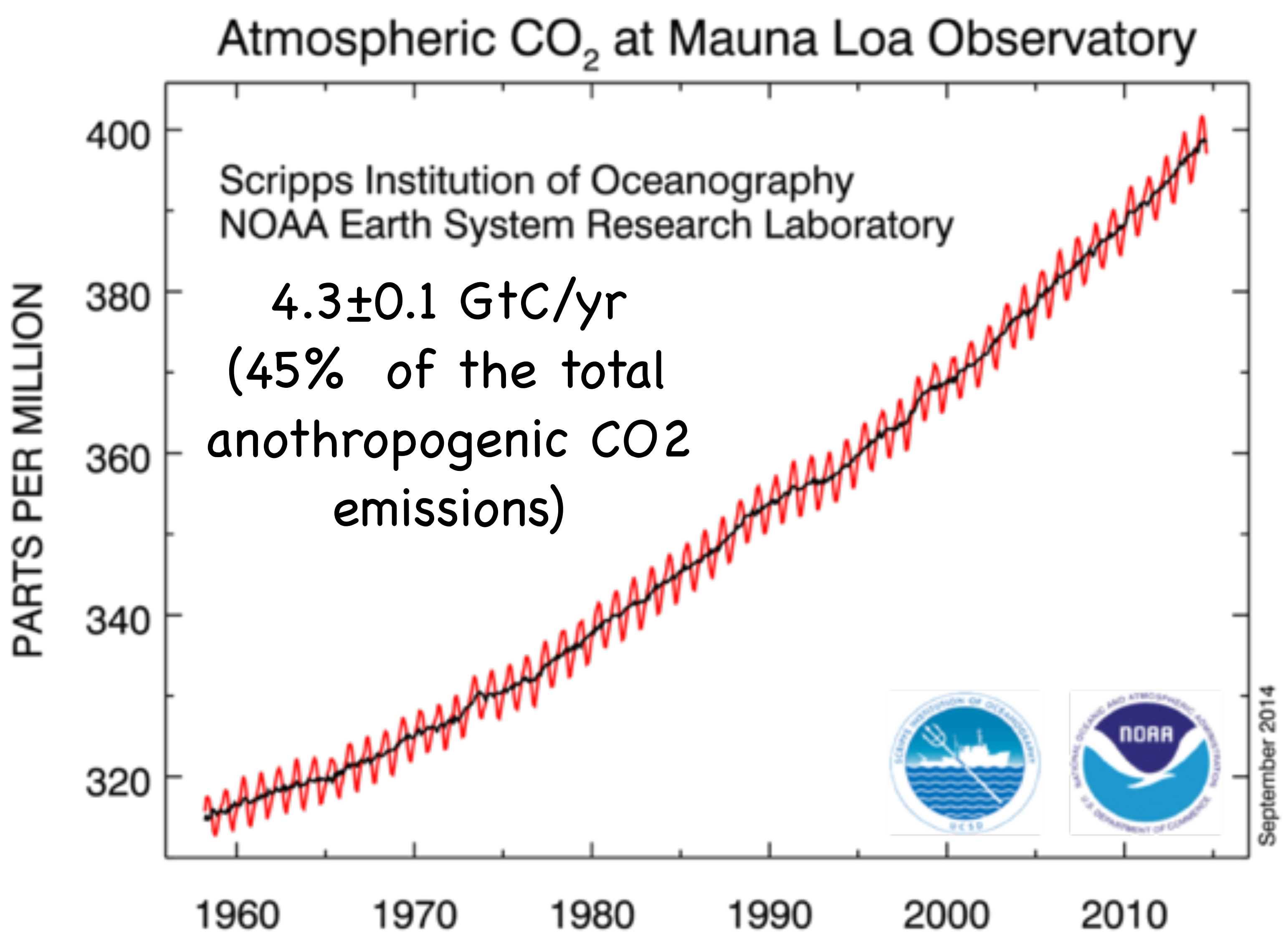


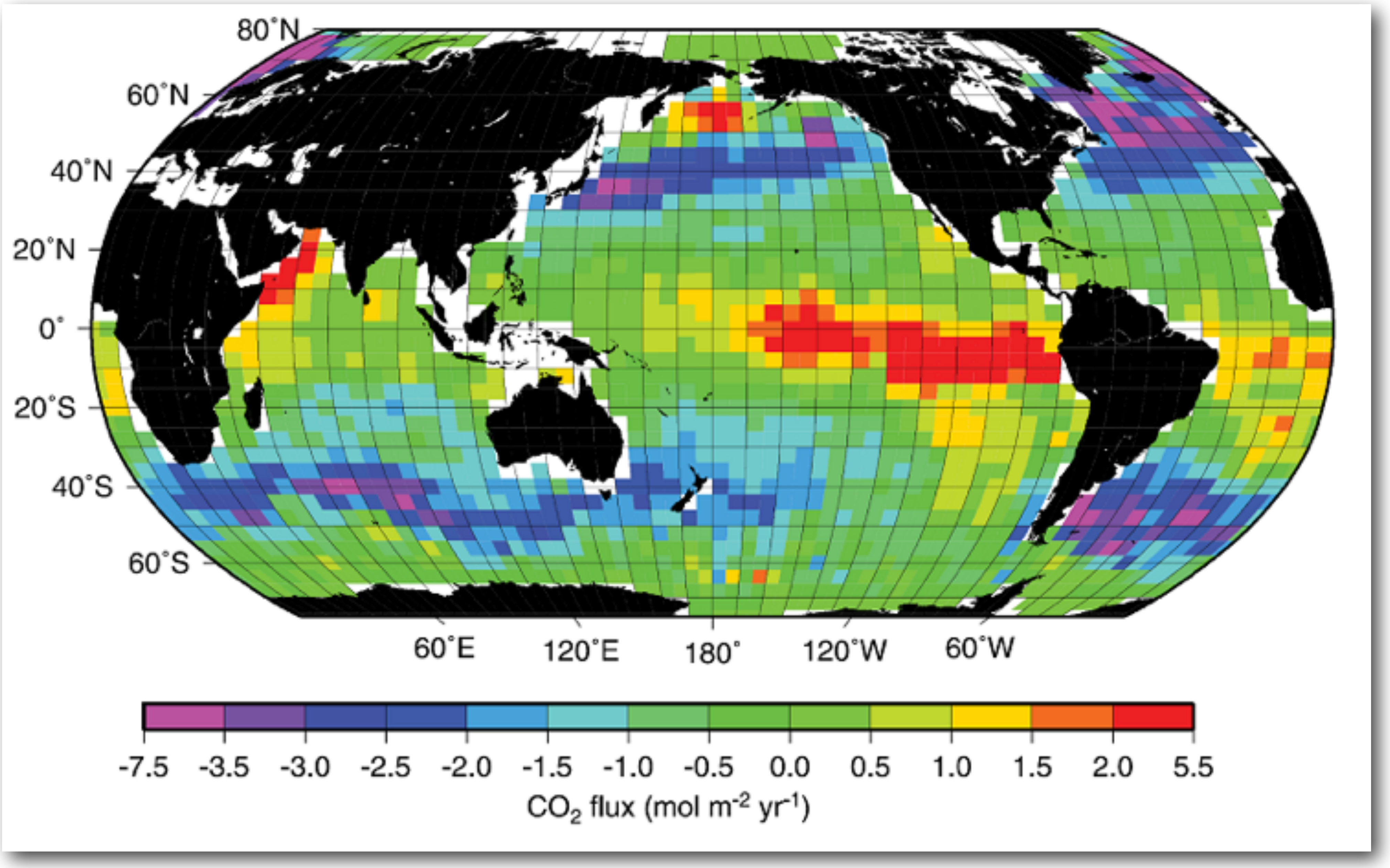




**Carbon, Silicate, Nitrogen Ecosystem Model (CoSiNE)**

*(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, Guo et al., 2014 and 2015; Hsu et al., 2016; Zhang et al, 2017; Xiu and Chai et al., 2018)*

# Global Carbon Cycle



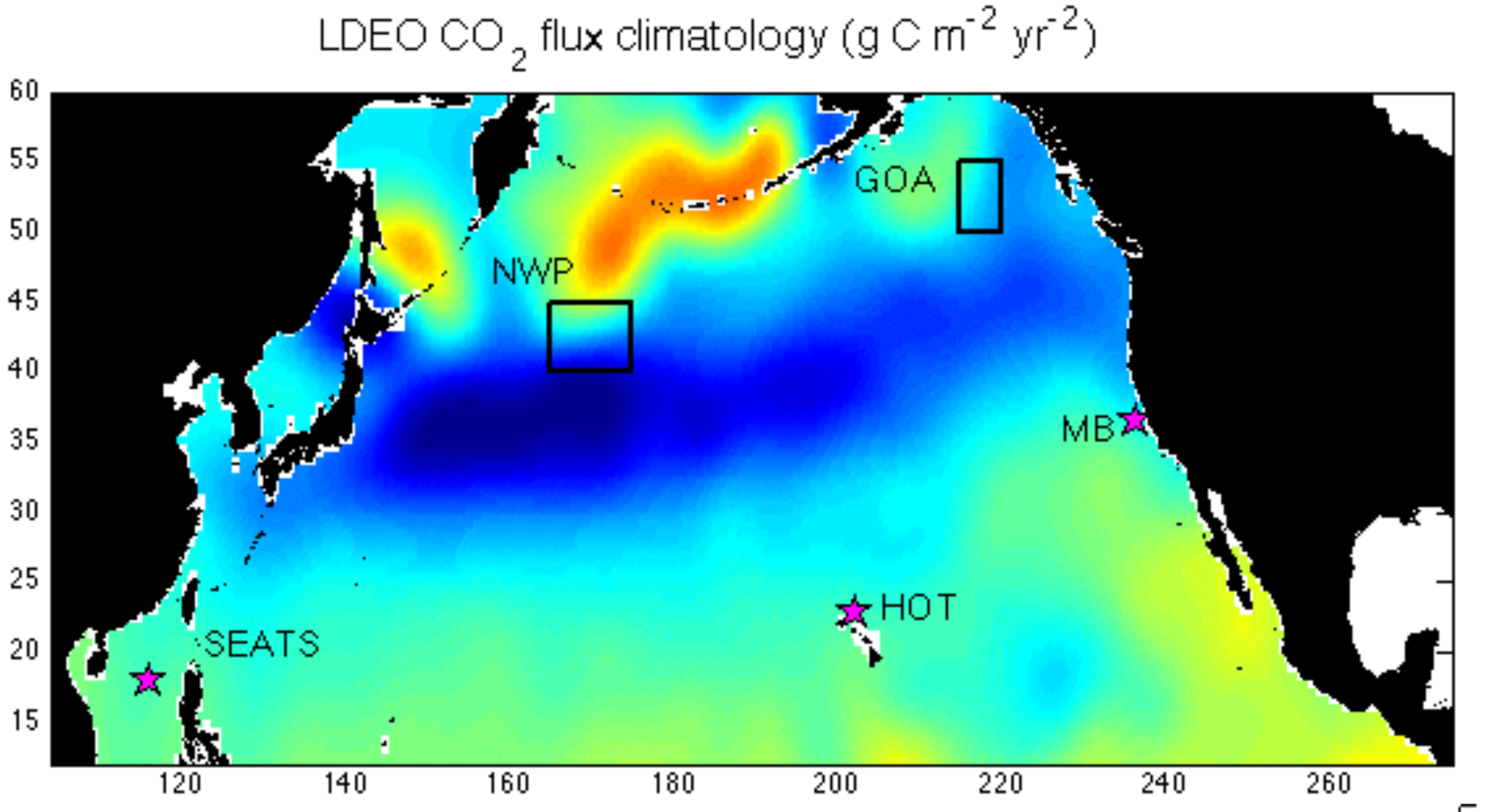





2.6±0.8 GtC/yr (25% of the total anothropogenic CO2 emissions)

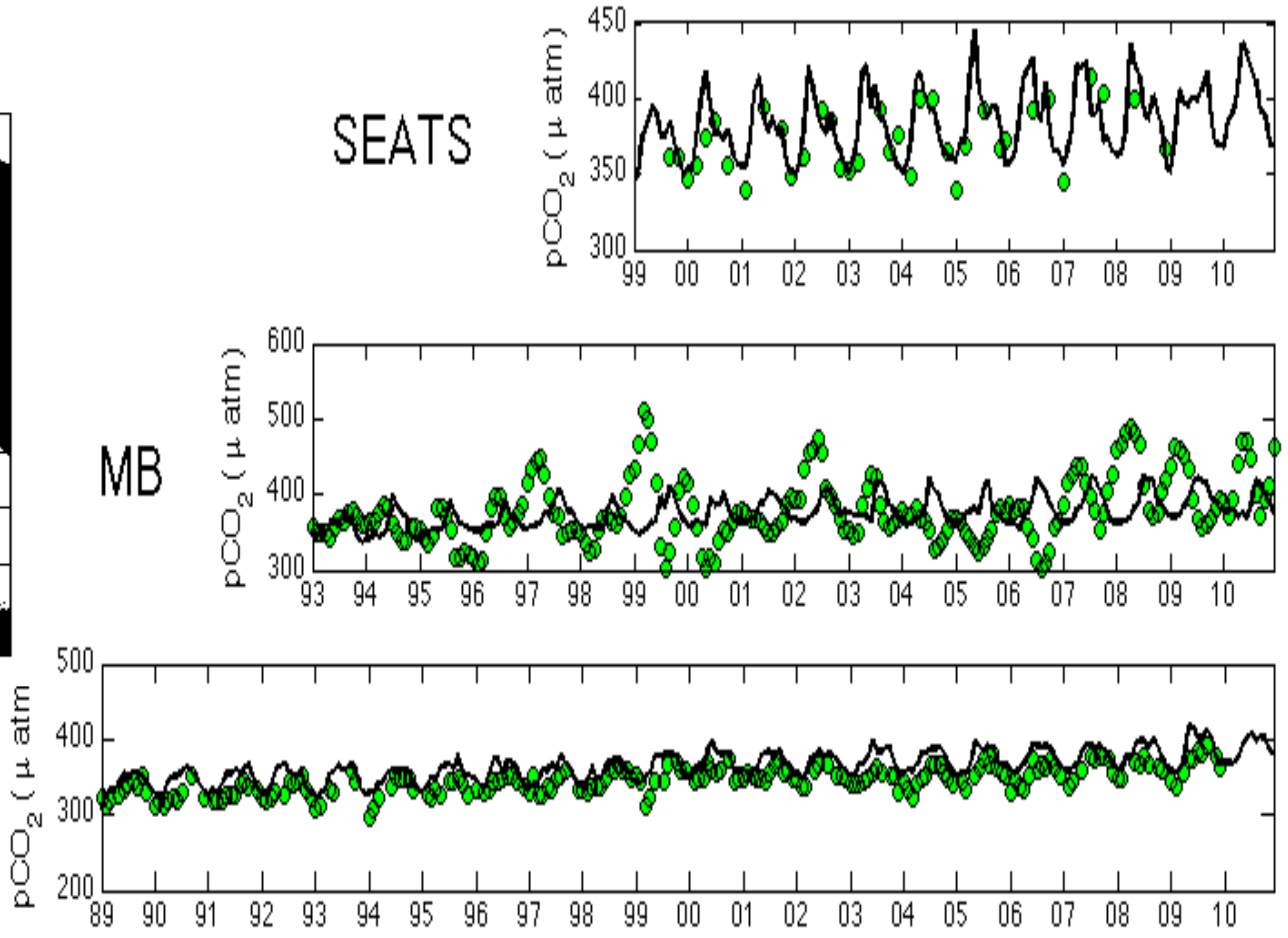
➢ The dominant factors controlling the temporal variability of carbon cycle? (seasonal, interannual, decadel)

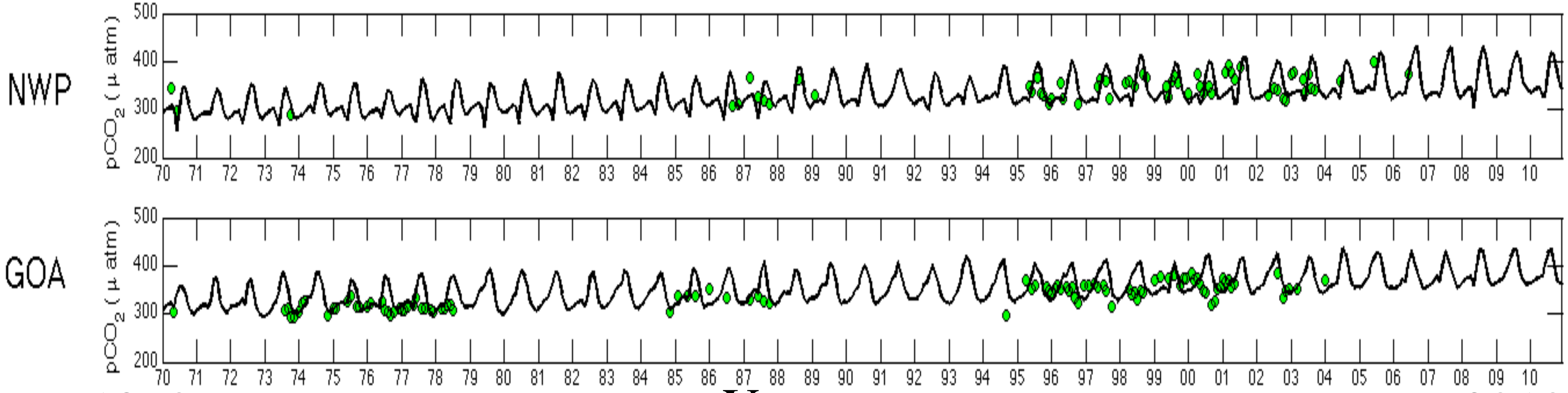
# Sea Surface $pCO_2$




Seasonal cycle is largest

Anthropogenic trend is 1-2 ppm/year

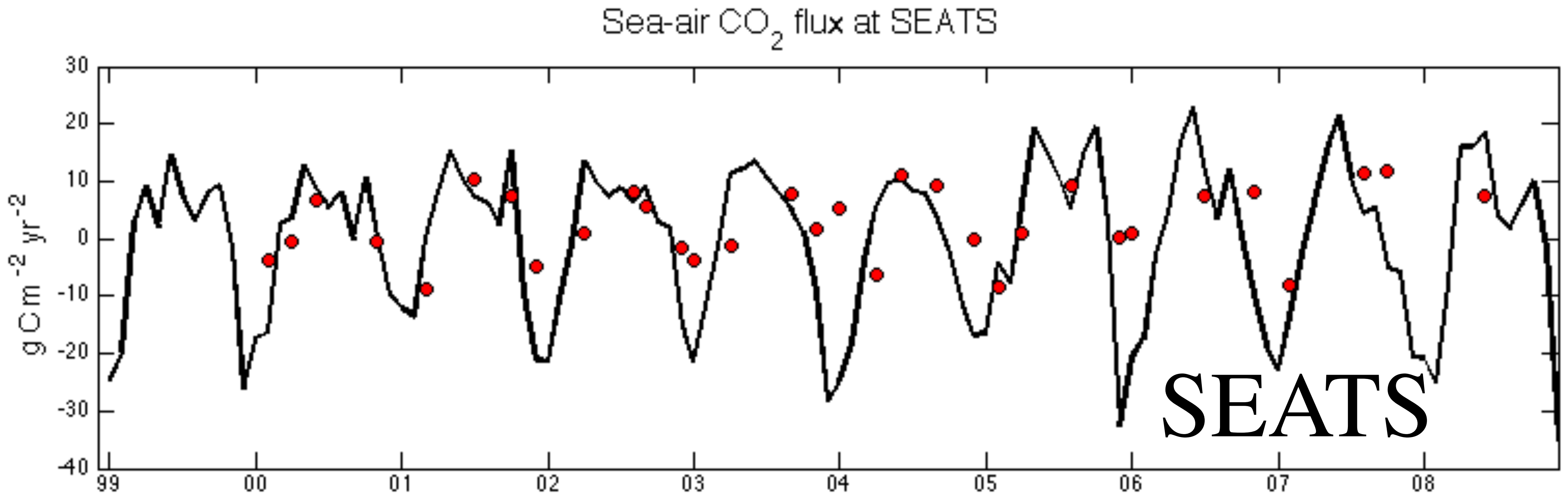


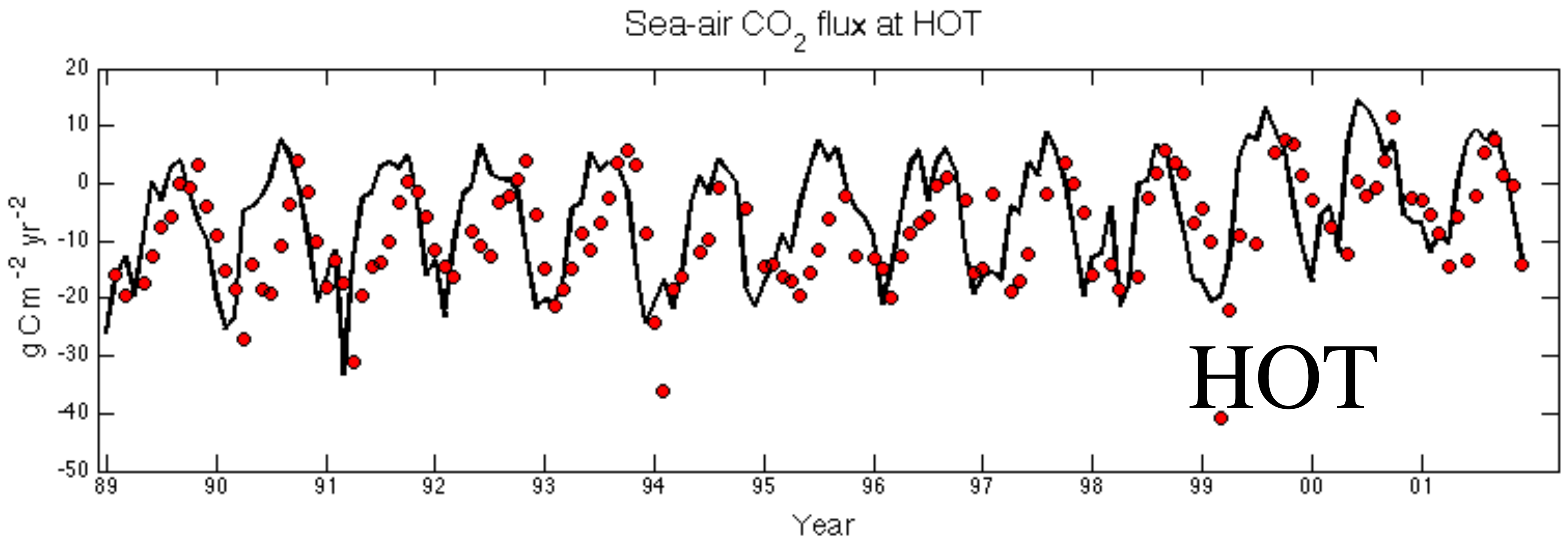



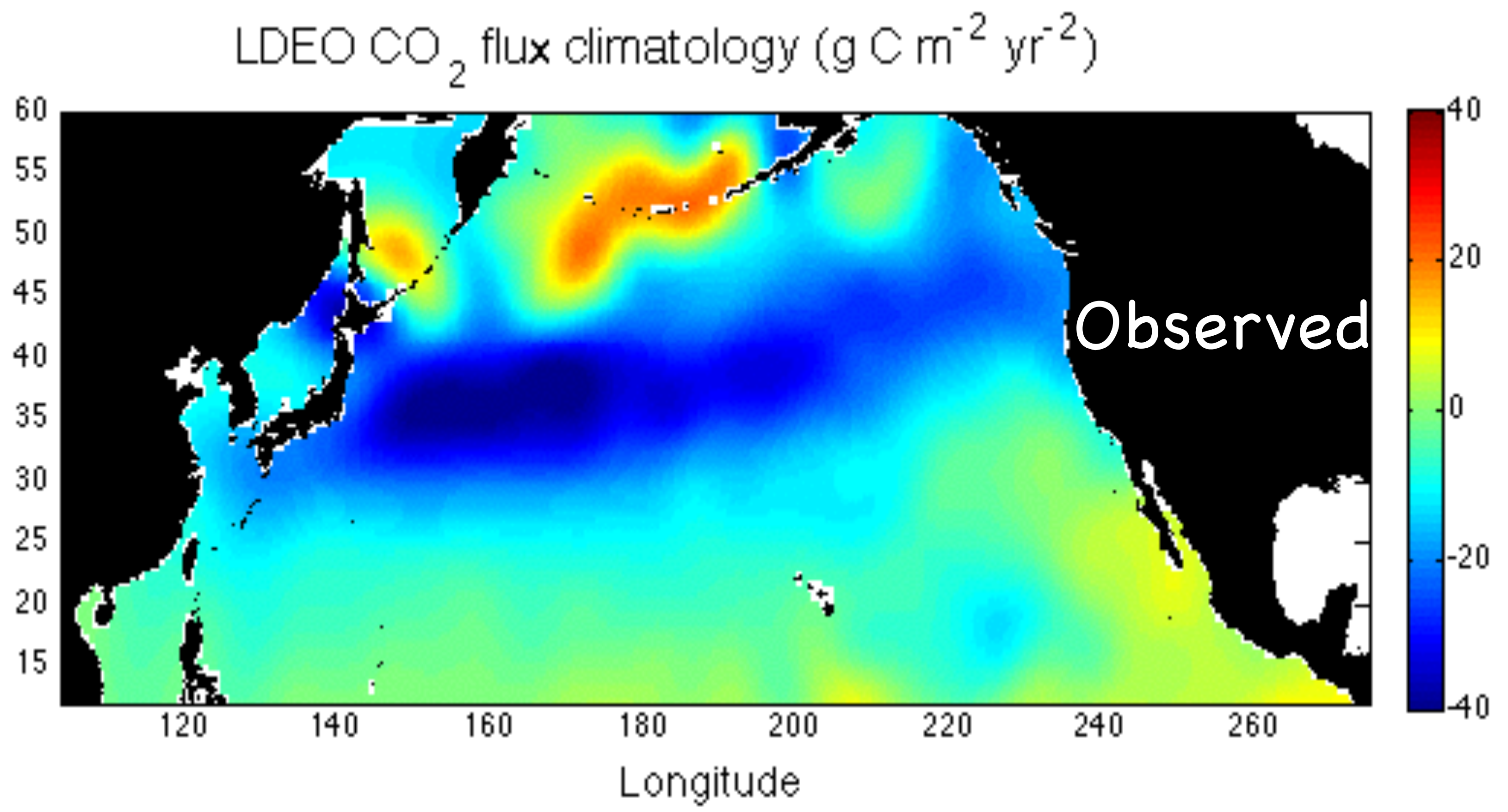

1970 Year 2010

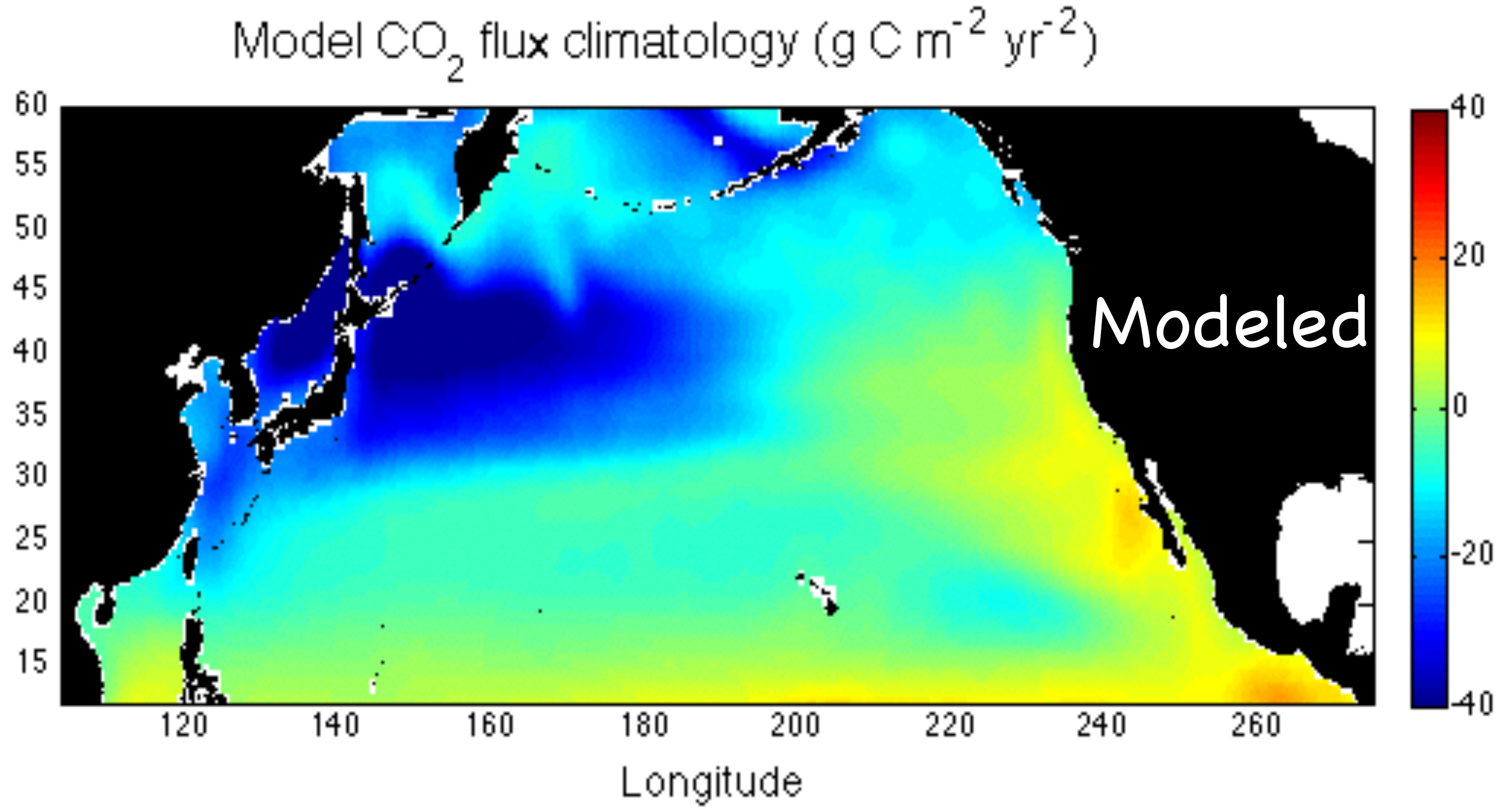
Xiu & Chai, JGR-Oceans, 2014

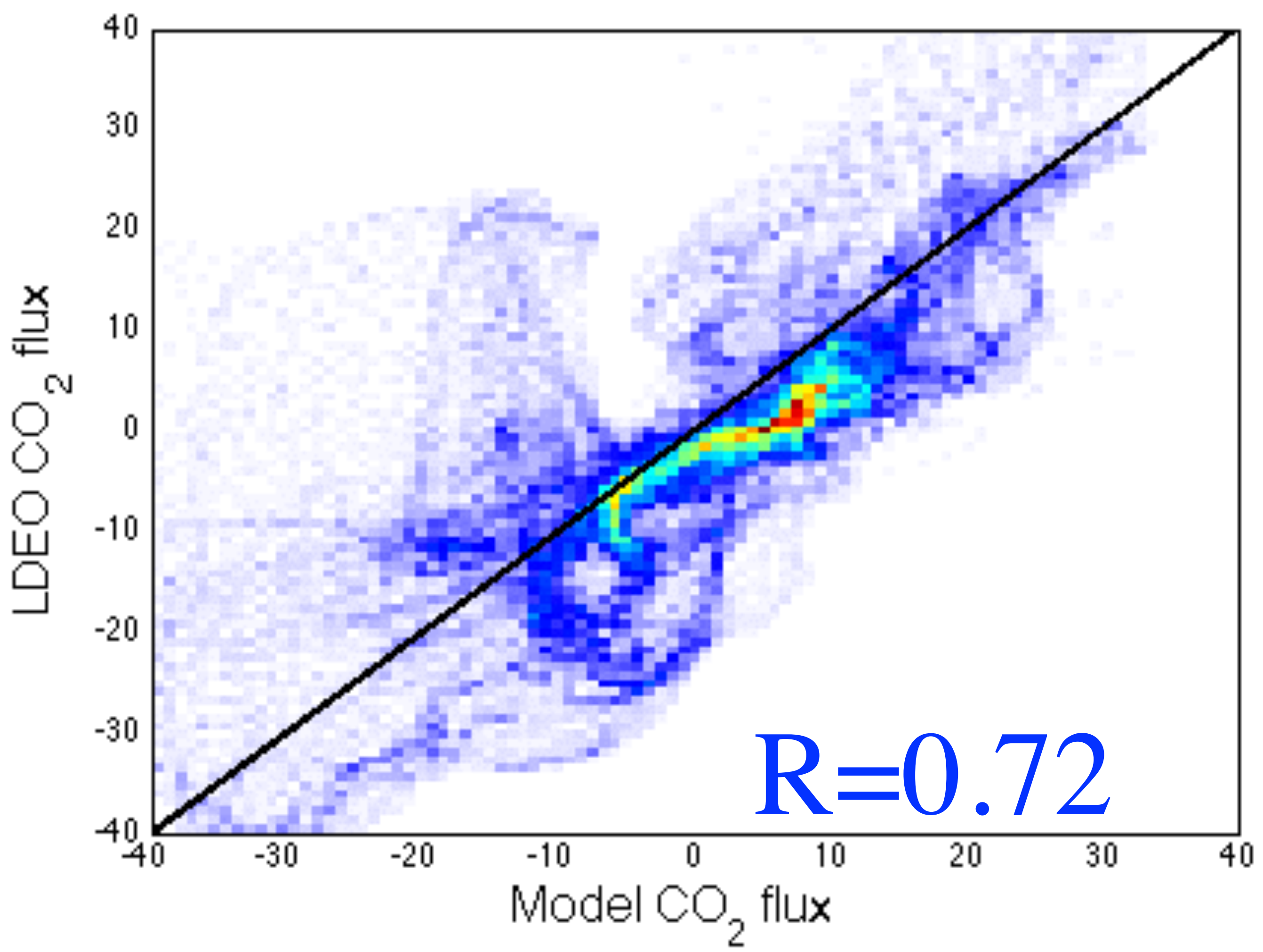
# Sea-to-Air $CO_2$ flux




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

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

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

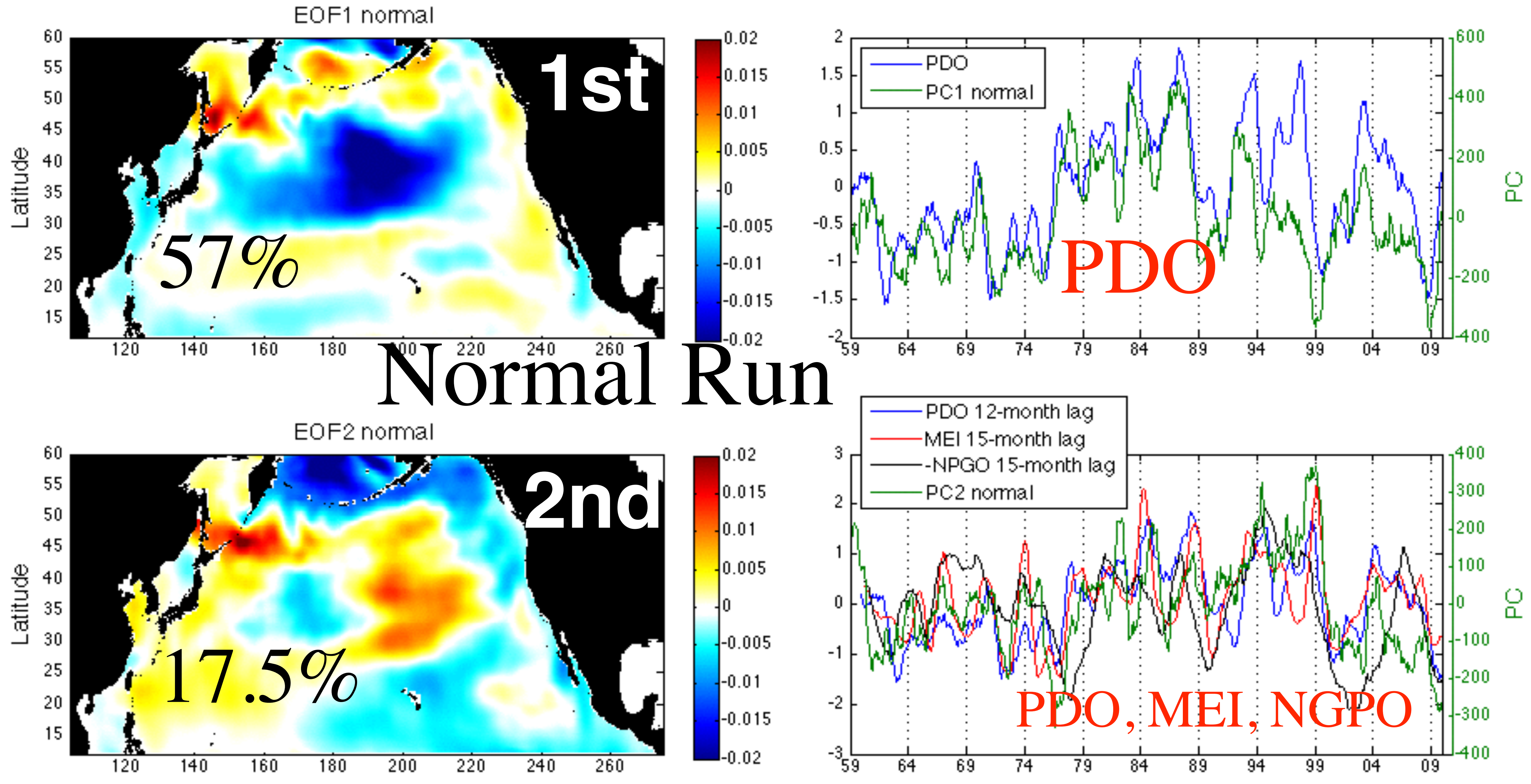
Integrated North PACIFIC (ocean sink):

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

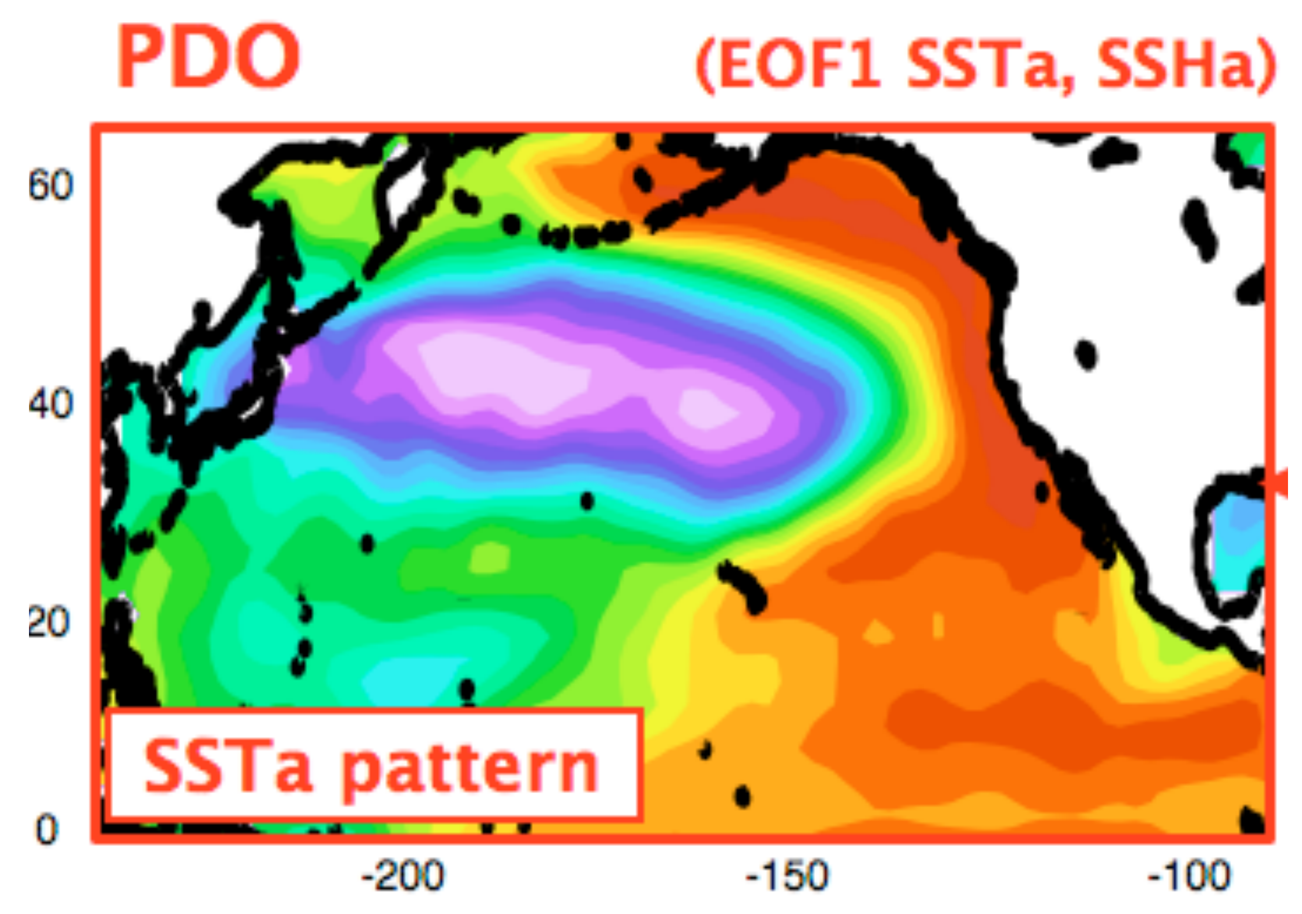
Xiu & Chai, JGR-Oceans, 2014

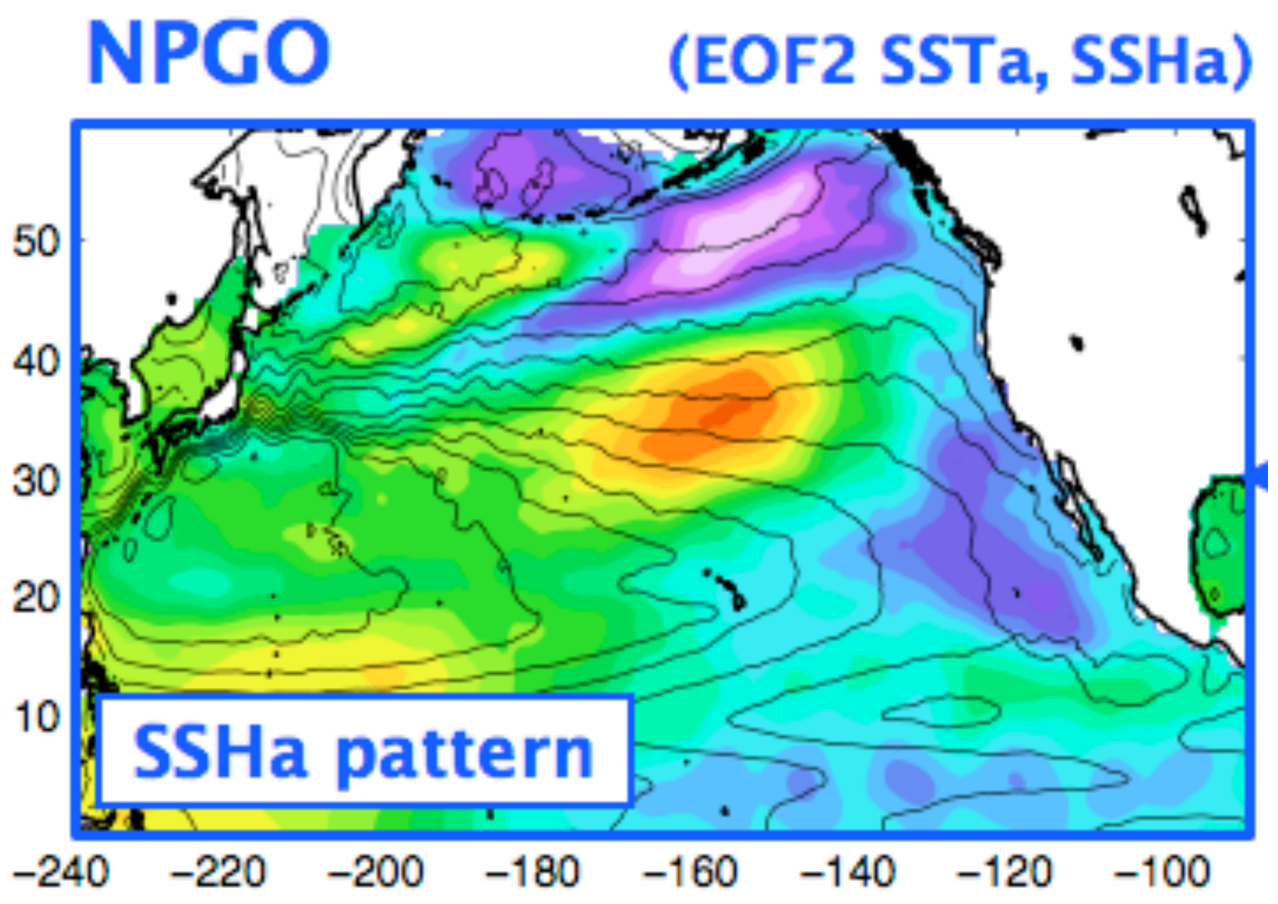
# Sea-to-Air $CO_2$ flux

## Interannual and decadal variability




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

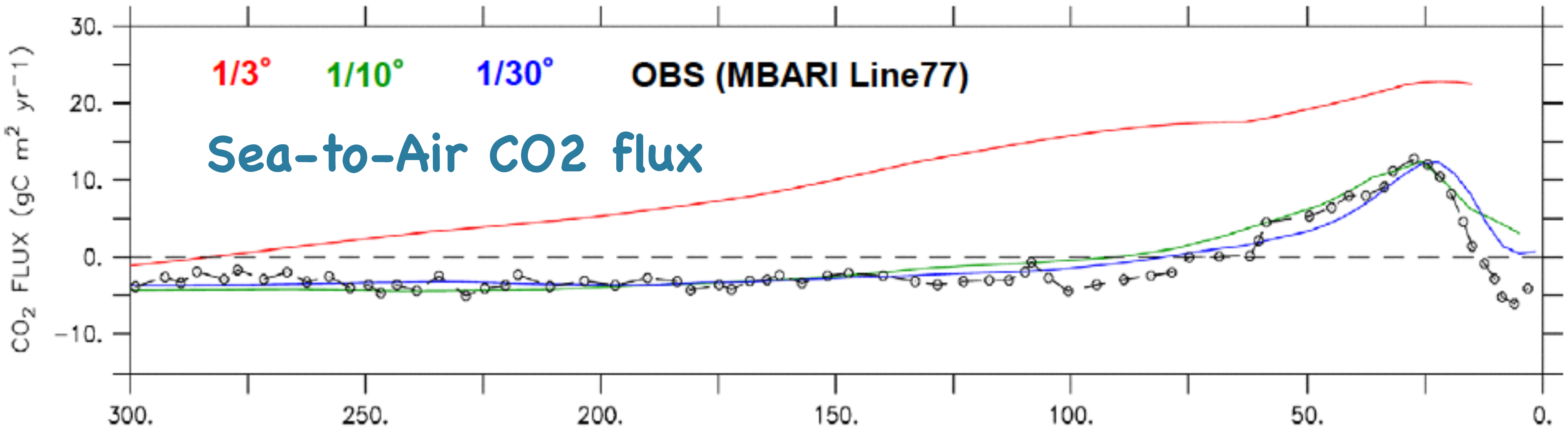


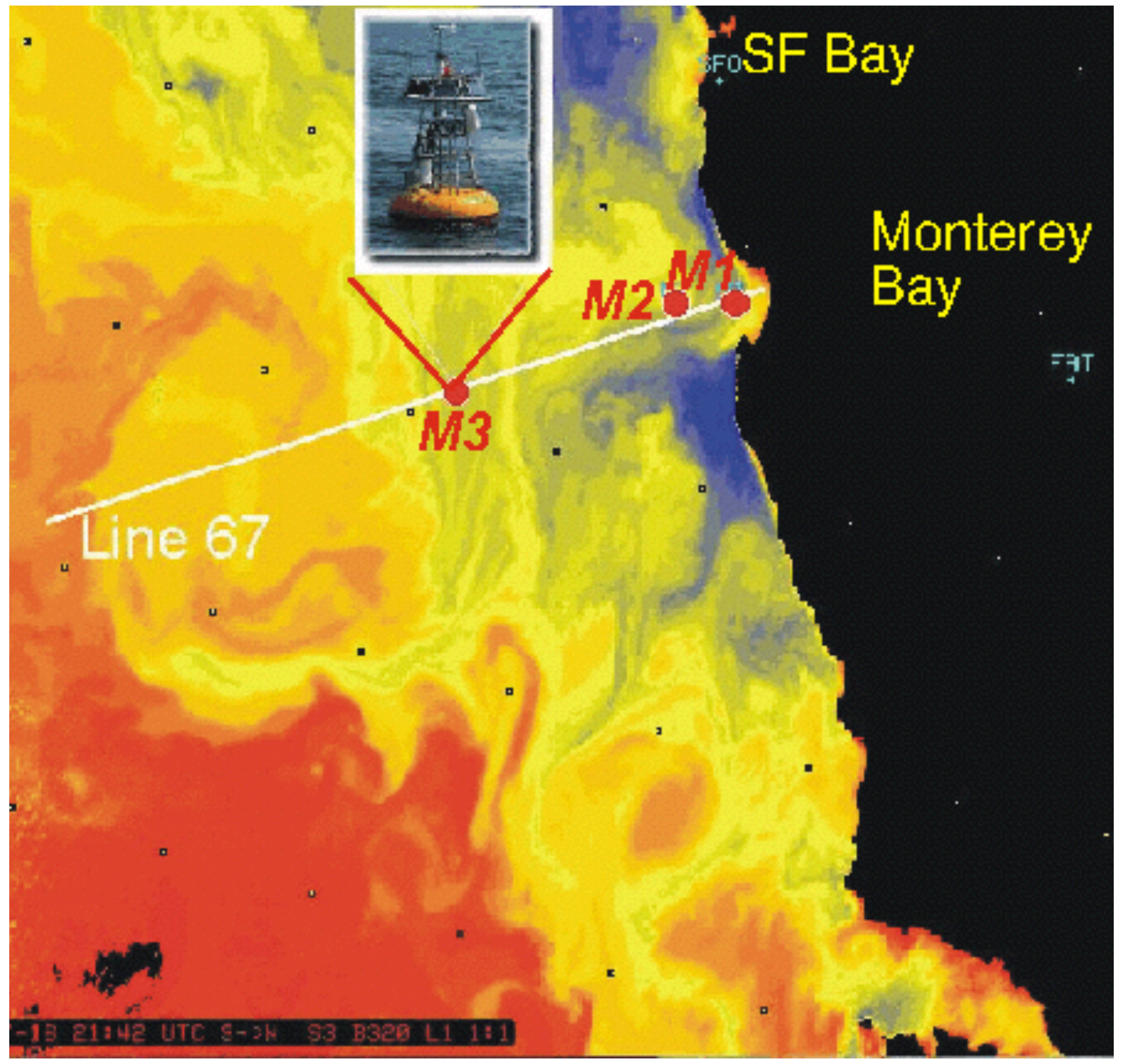



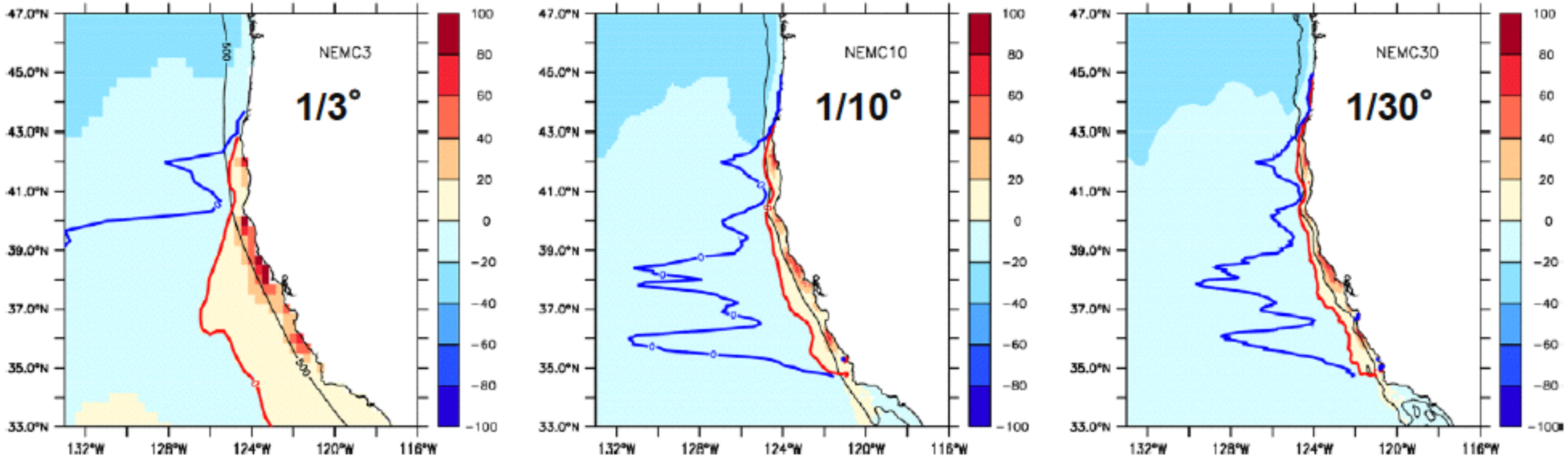

Xiu & Chai, JGR-Oceans, 2014

ROMS-Biogeochemistry modeling for CCS

# Model resolution matters!



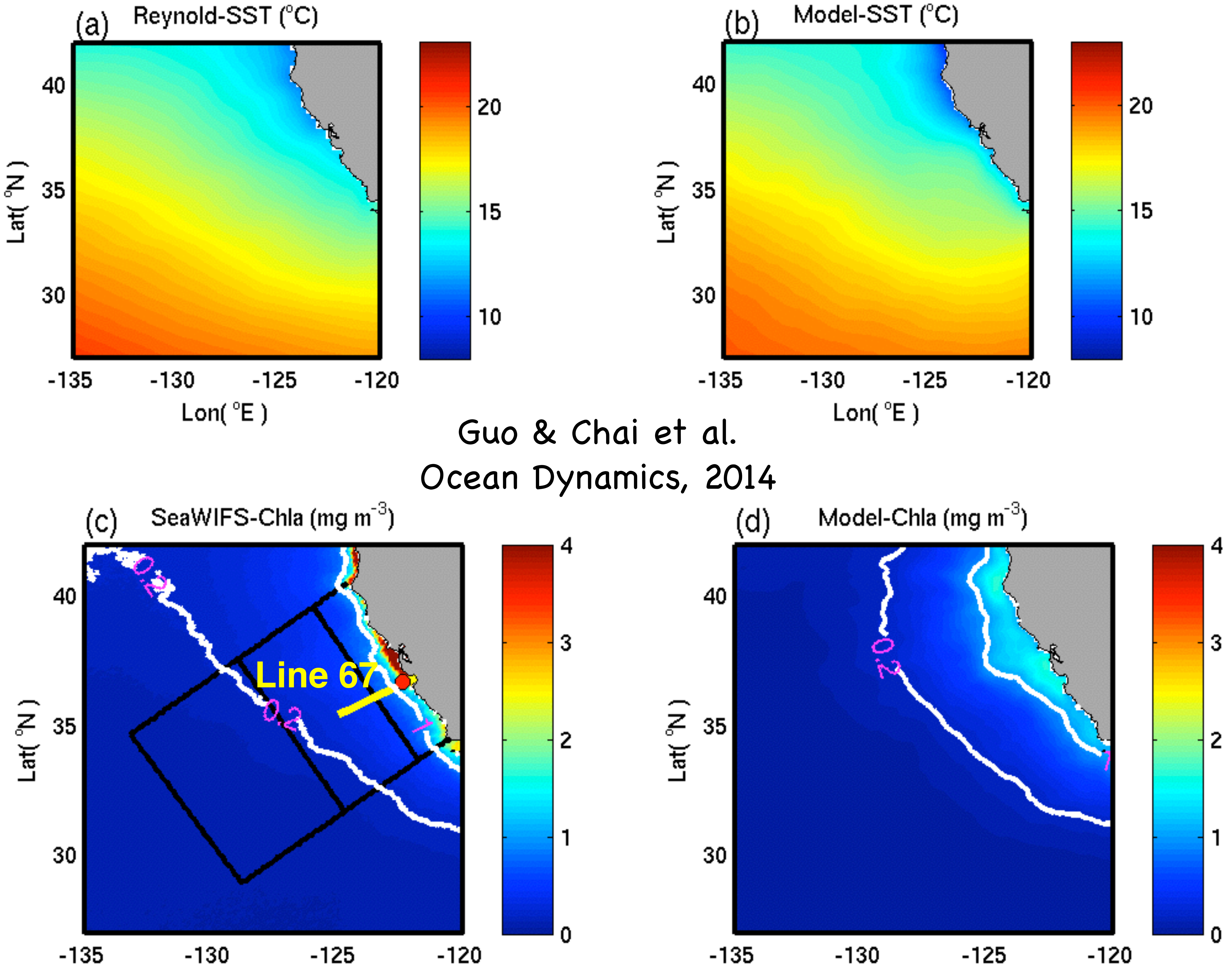

Red Line: Outgassing Region    Blue Line: Equilibrium Region

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

# SST and Chlorophyll Comparison

Observed SST

ROMS-CoSiNE Model SST

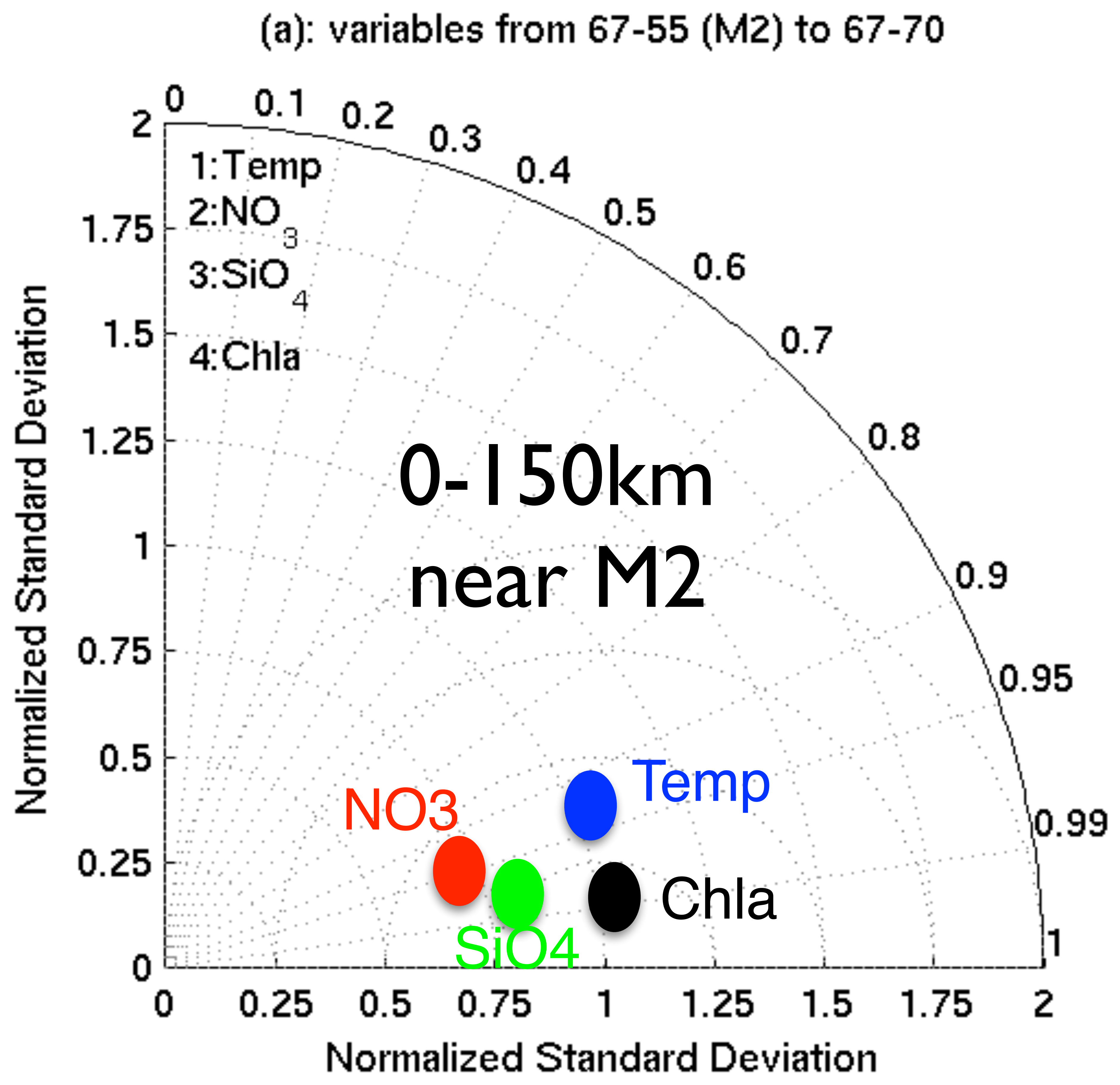


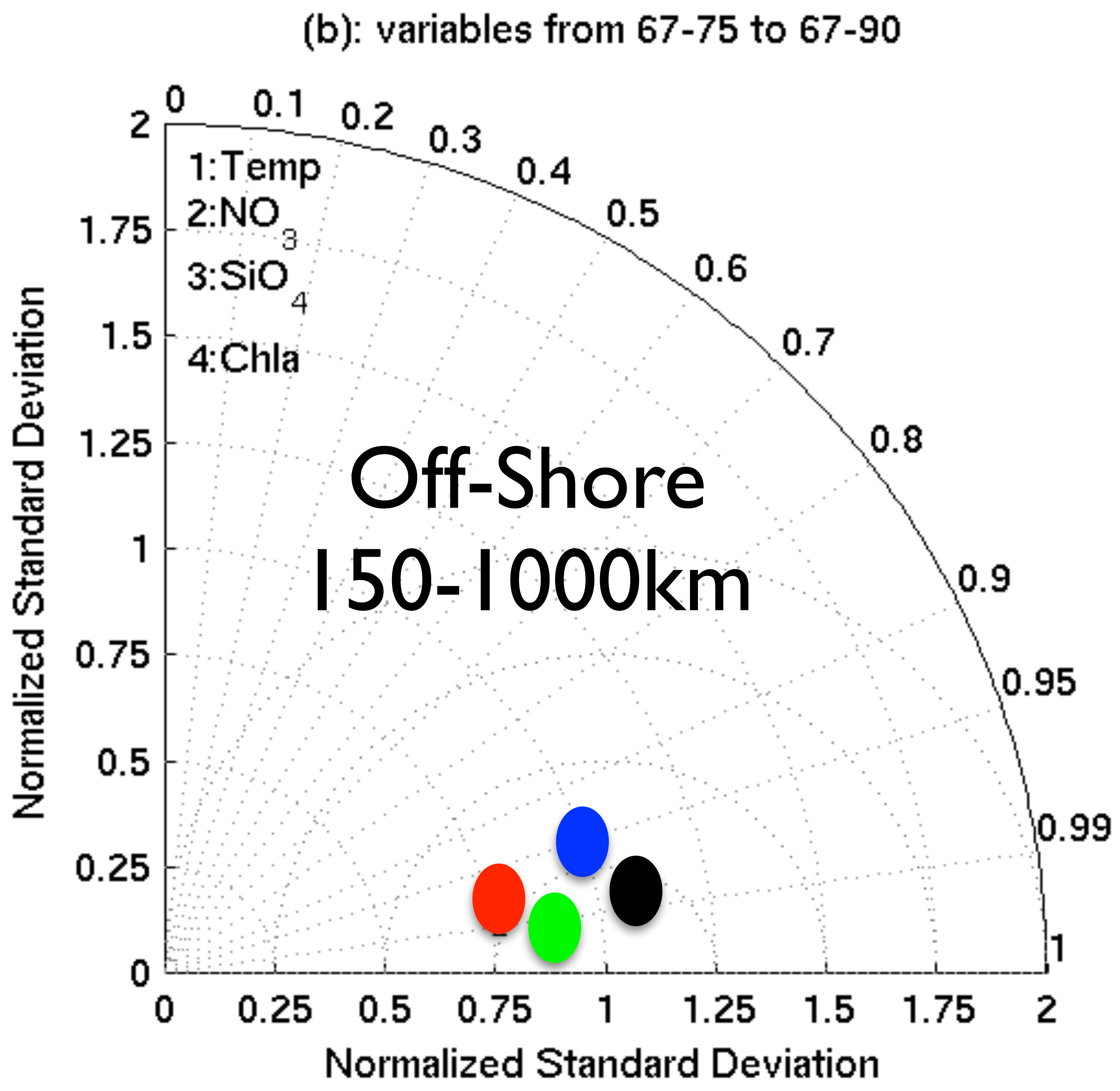

Guo & Chai et al.
Ocean Dynamics, 2014

SeaWiFS Chl-a

ROMS-CoSiNE Model Chl-a

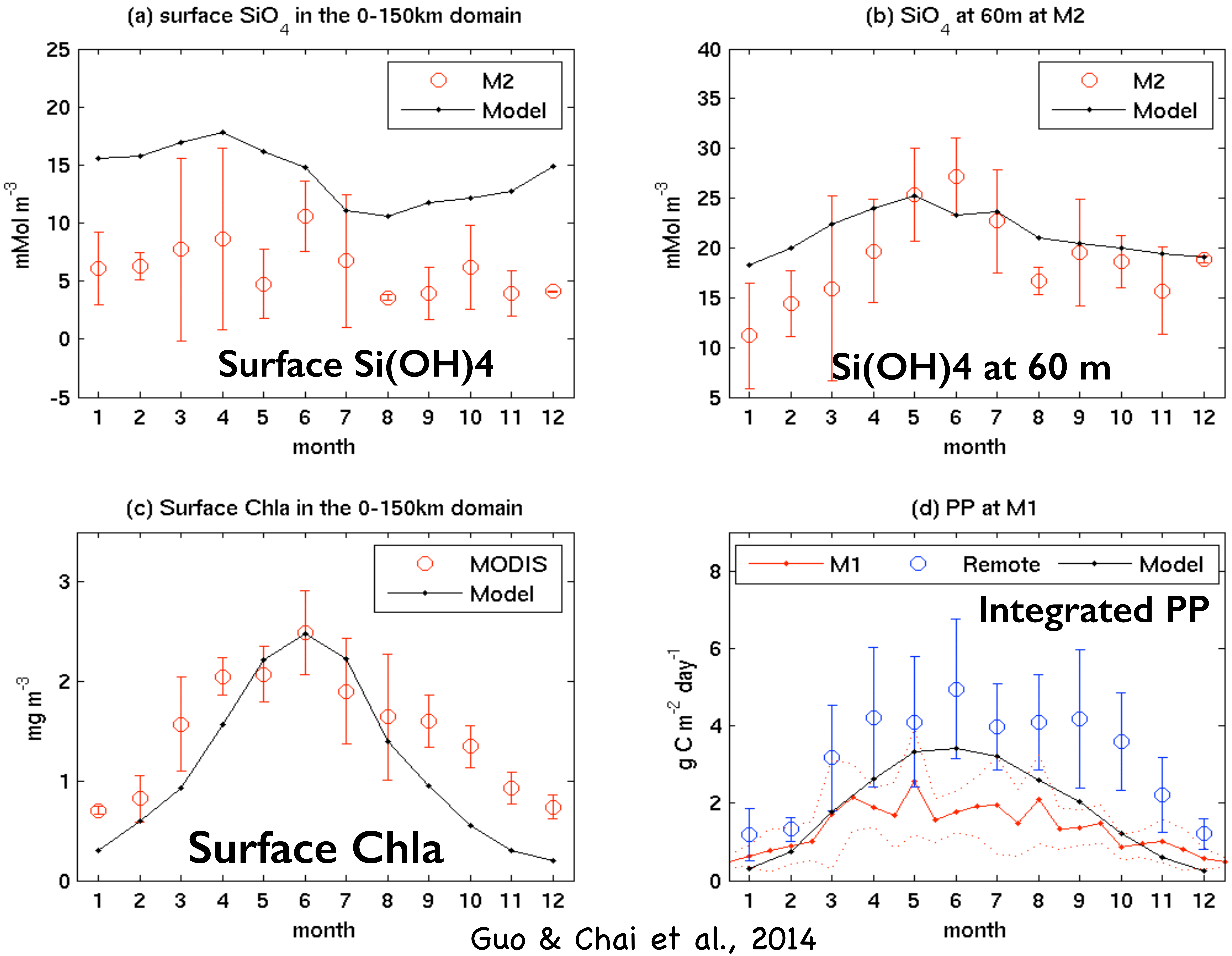
# Temperature, NO3, SiO4, and Chla (along Line 67)



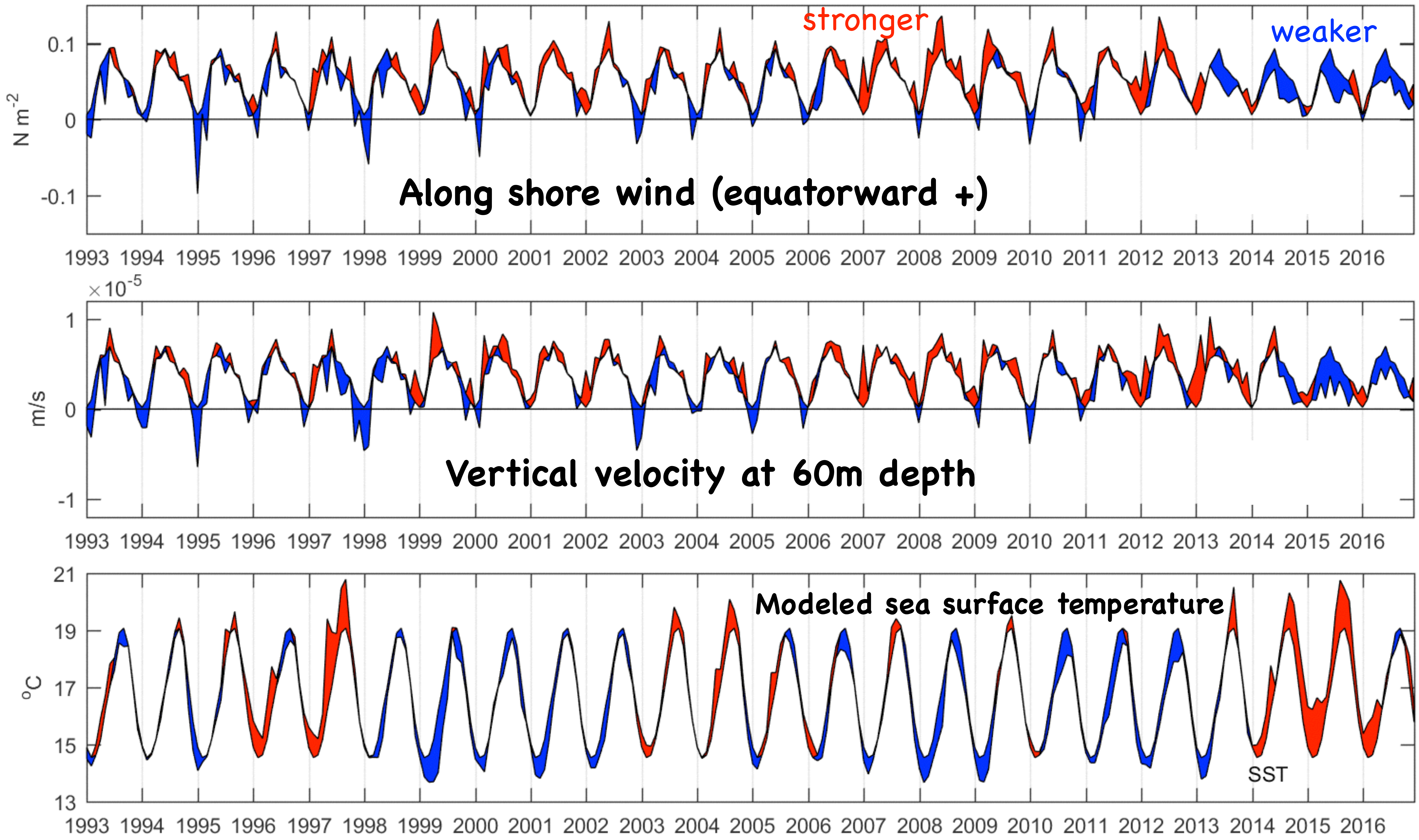

Guo & Chai et al.
Ocean Dynamics, 2014

# Seasonal cycles of variables in the 0-150 km domain




Guo & Chai et al., 2014

# Interannual variation (1993-2016) in the 0-150 km domain




Guo & Chai et al., in prep.

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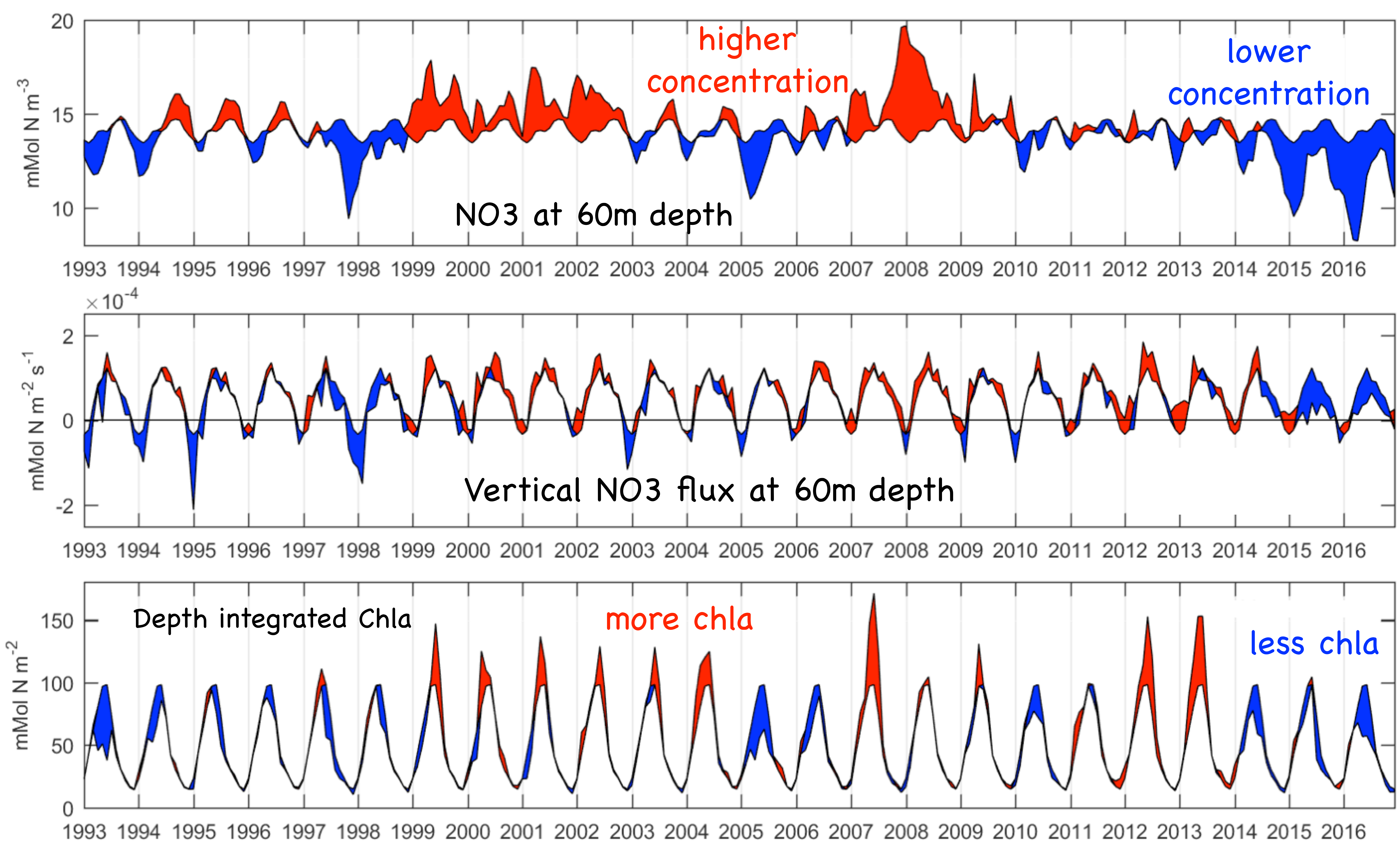


Guo & Chai et al., in prep.

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# Enhanced nutrient supply to the California Current Ecosystem with global warming and increased stratification in an earth system model

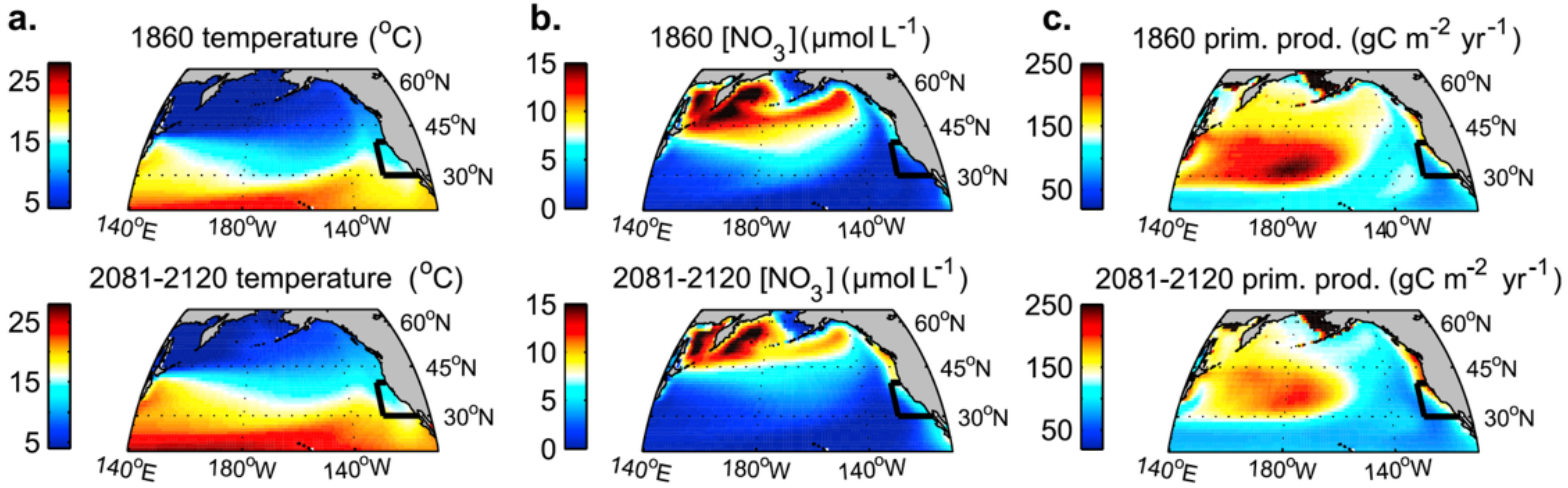
Based on GFDL Global ESM

*Rykaczewski and Dunne GRL, 2010*

Temperature (0-200m) | NO3 (0-200m) | Primary Production

1860 - 1900

2081 - 2120



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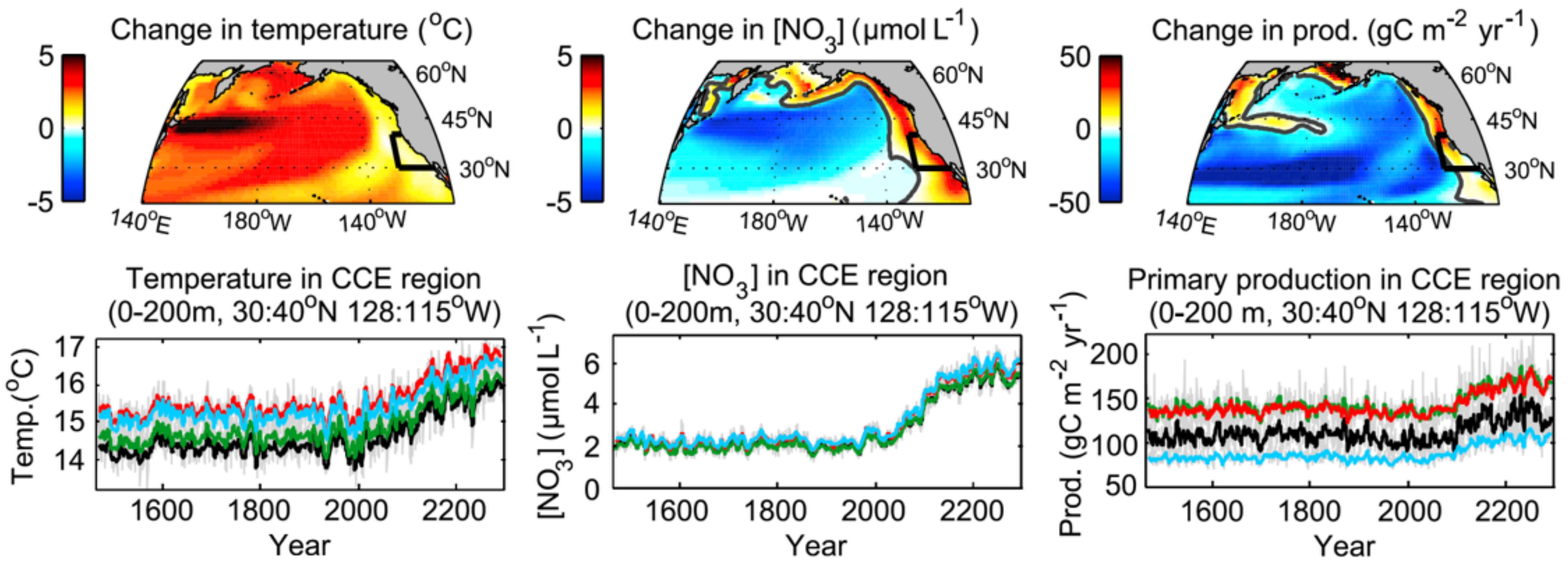
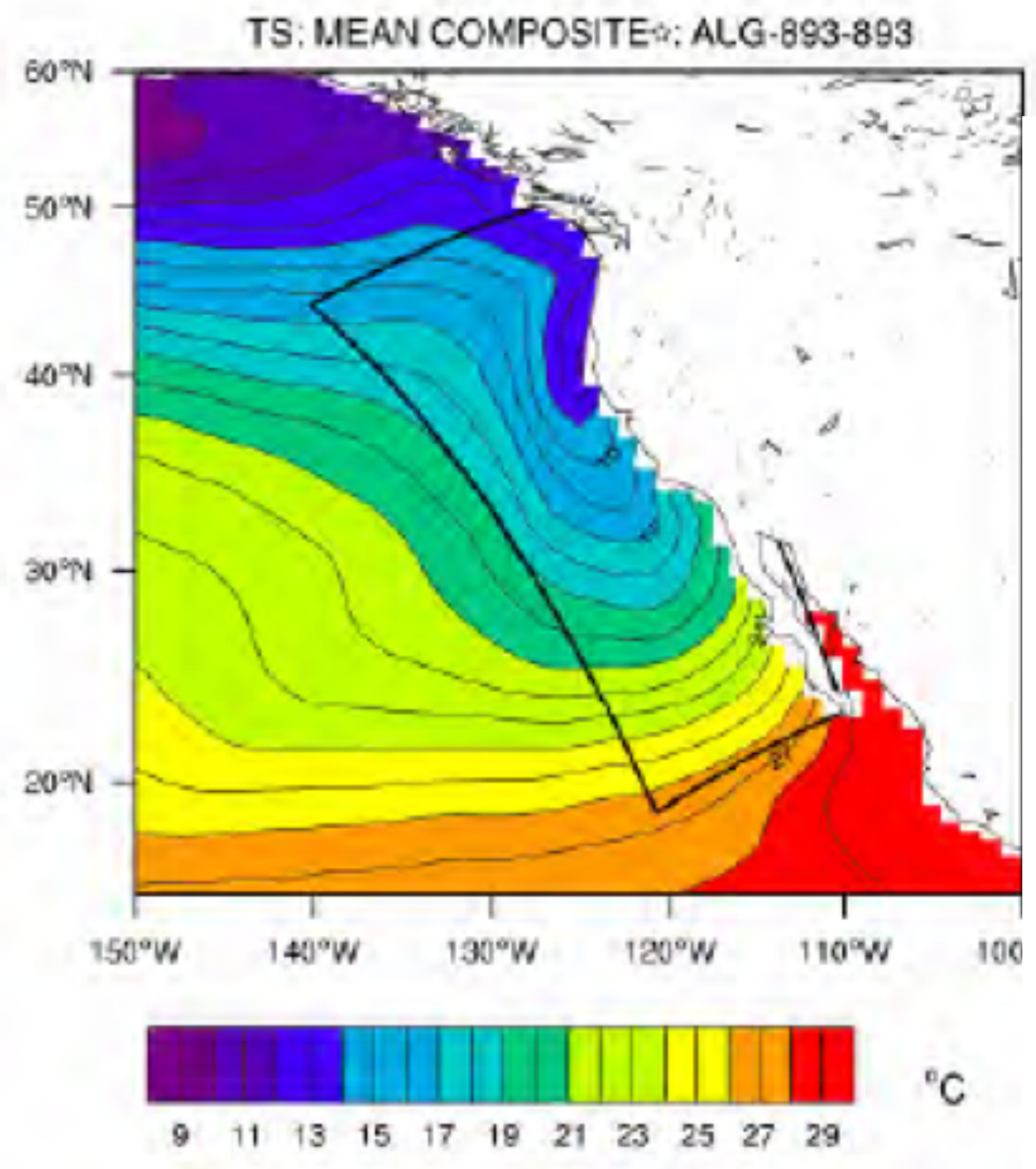
**Temperature (0-200m)** **NO3 (0-200m)** **Primary Production**

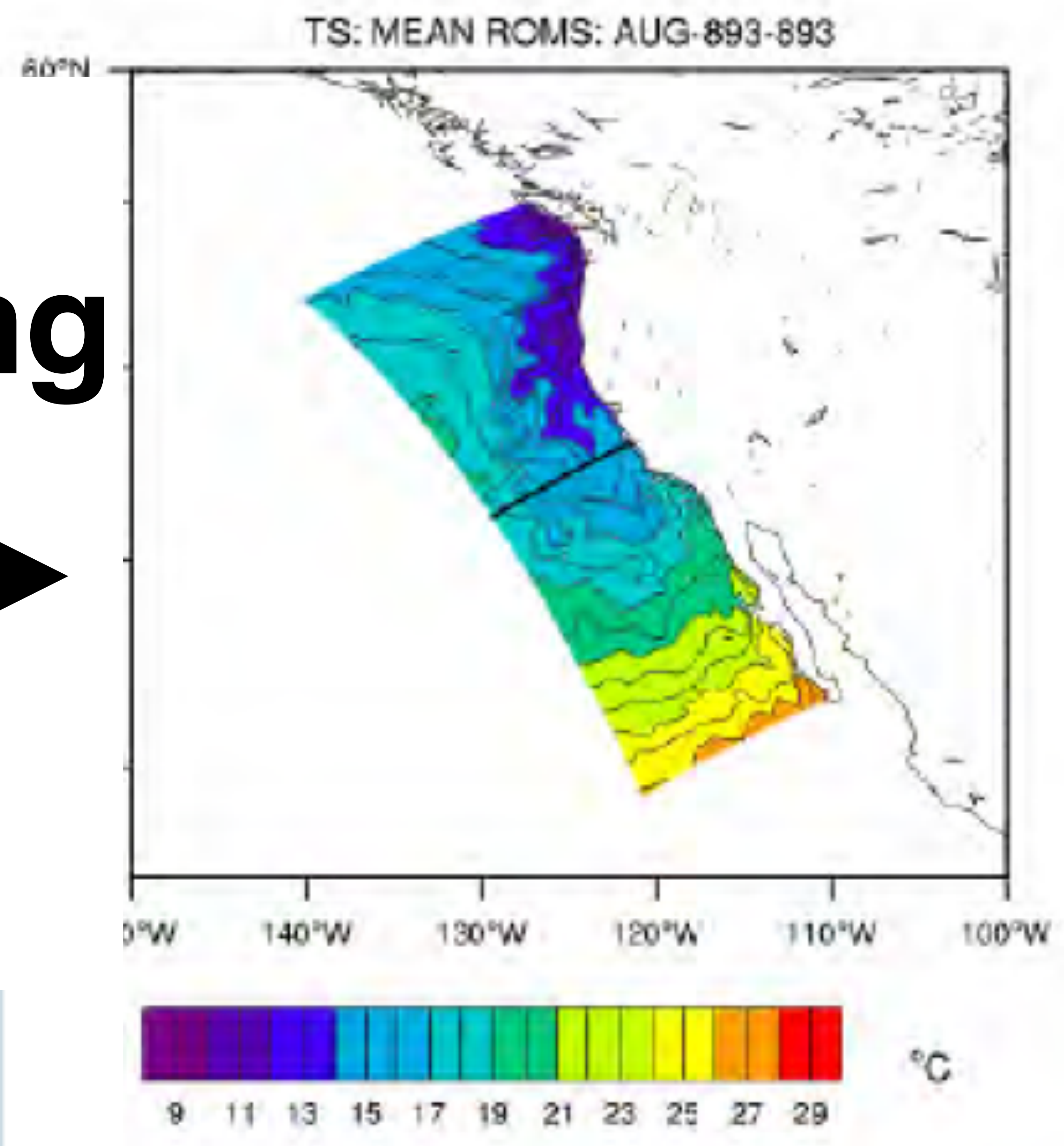
**Difference = (2081/2120) - (1860/1900)**



# Downscaling from Global to Regional Models




One-way downscaling

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**GFDL-ESM**

**100km**

**resolution**

**ROMS-CoSiNE**

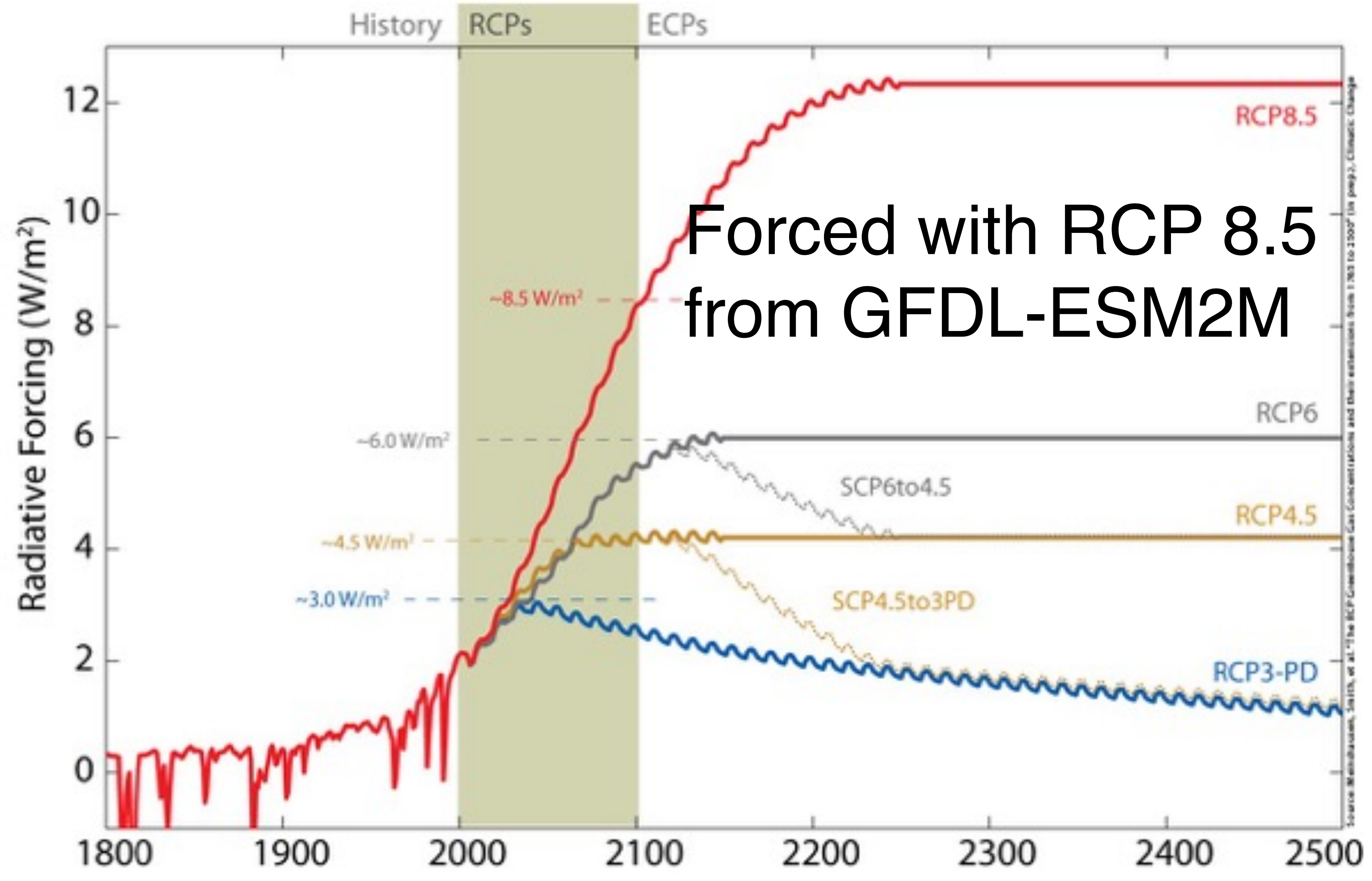
**7km**

**resolution**

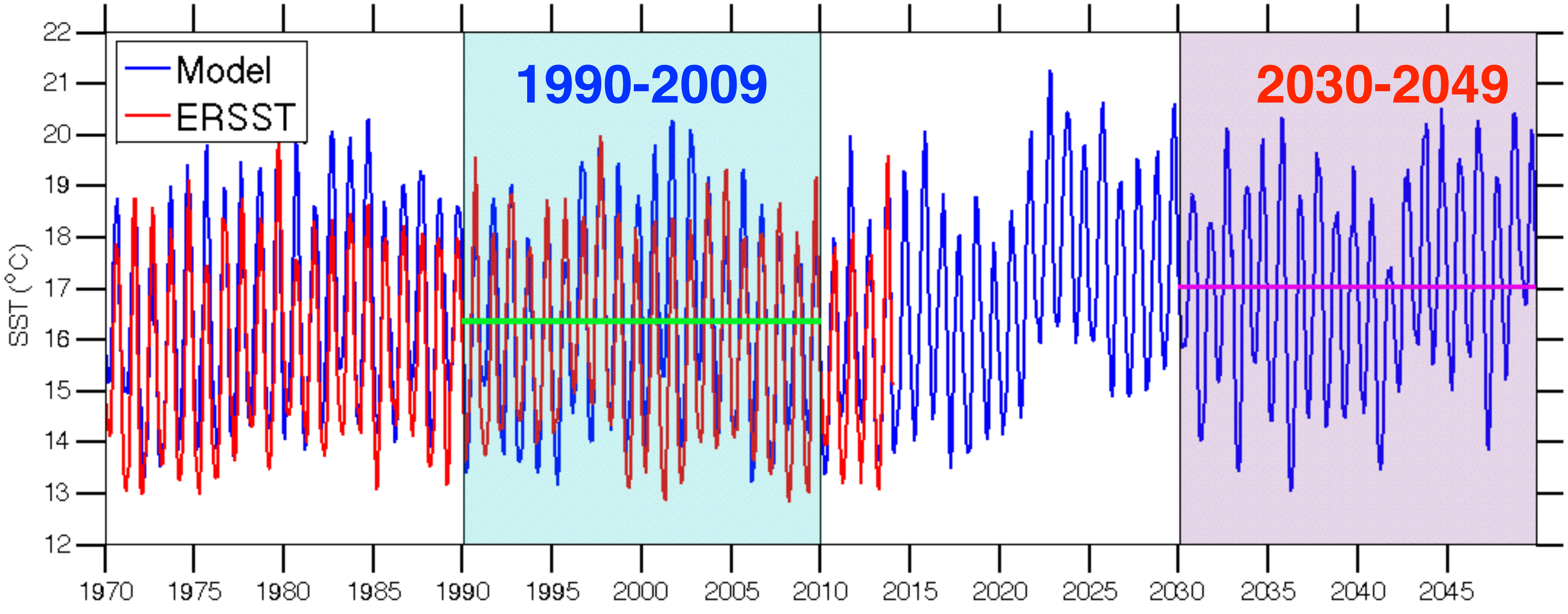
# Comparing two periods (20 years)

**1990-2009** vs. **2030-2049**

Difference = AVG(2030-2049) – AVG(1990-2009)

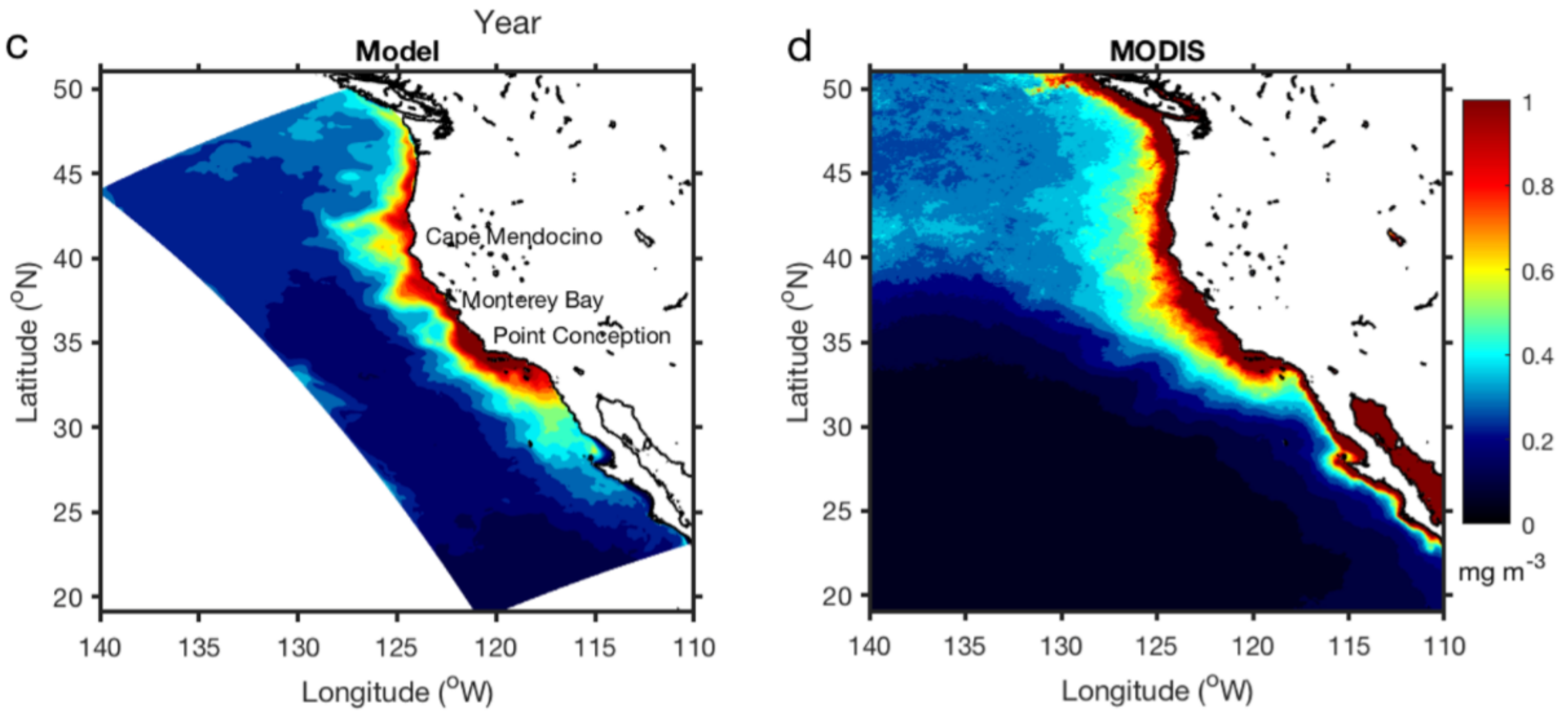



# Temperature Comparison in CCS




Xiu, Chai et al., 2018

# Modeled and Satellite Chlorophyll Comparison

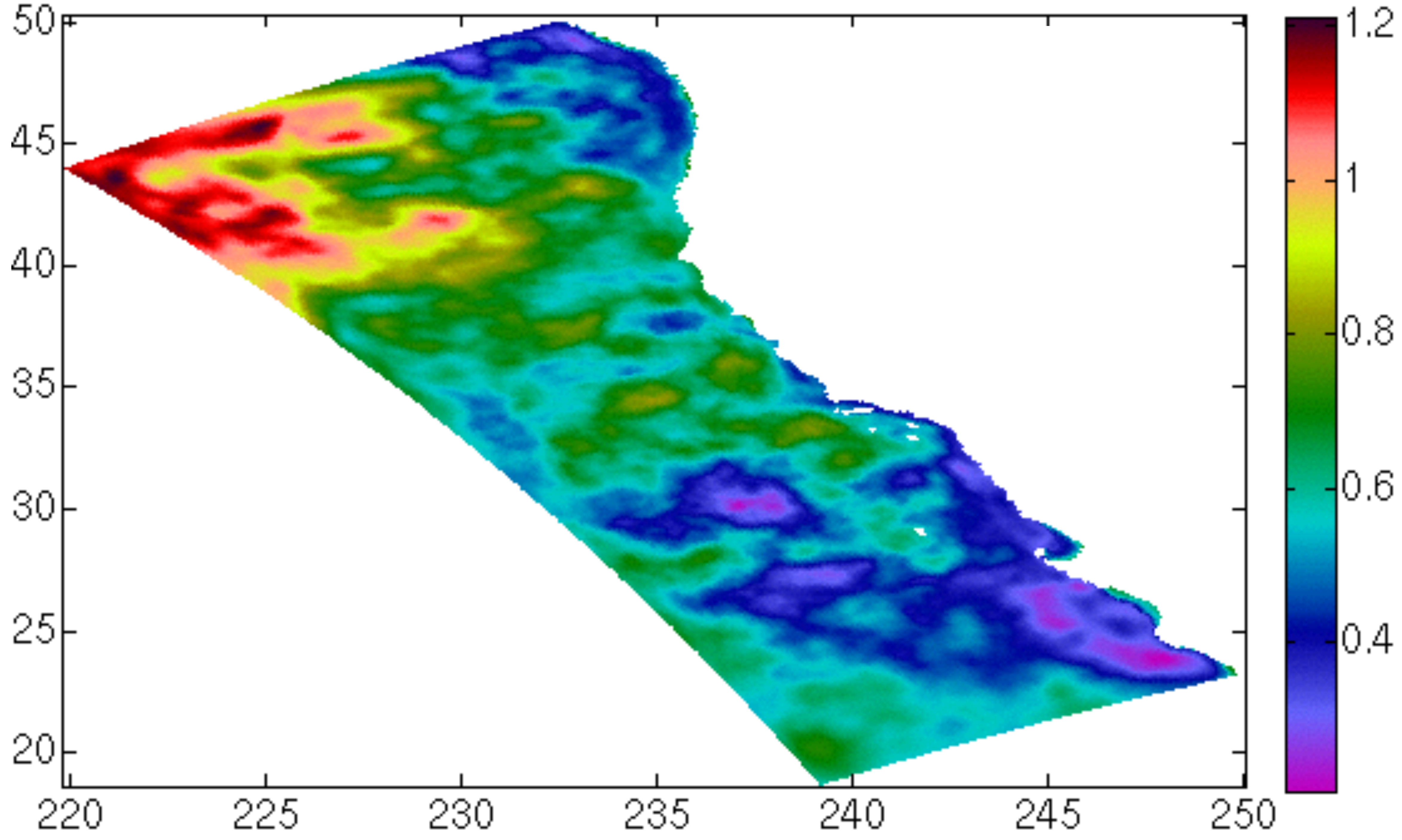



**Modeled** **MODIS**

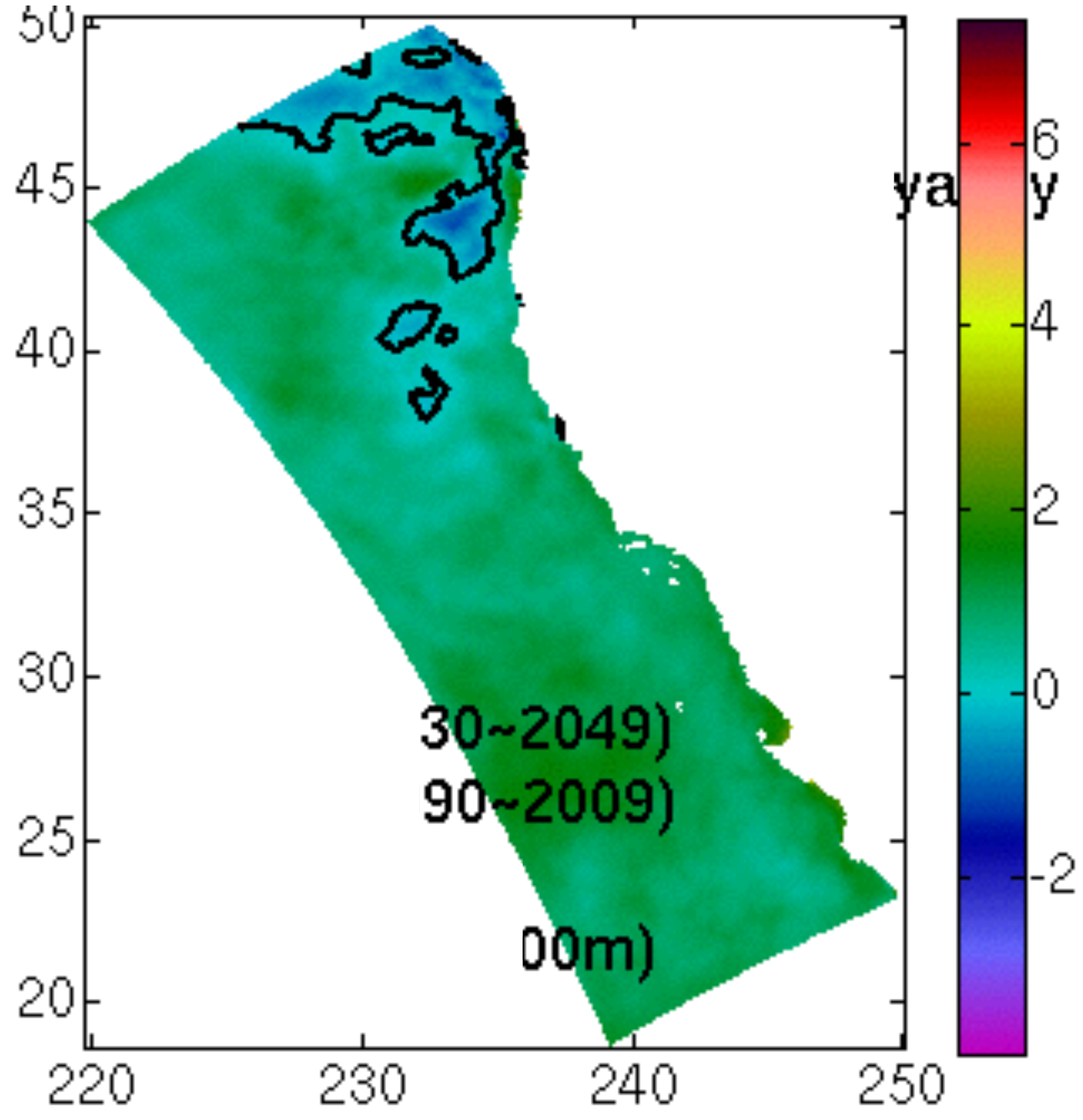
Xiu, Chai et al., 2018

# Comparison of Temperature and Stratification

**Difference = (2030-2049) - (1990-2009)**




**SST Increase**

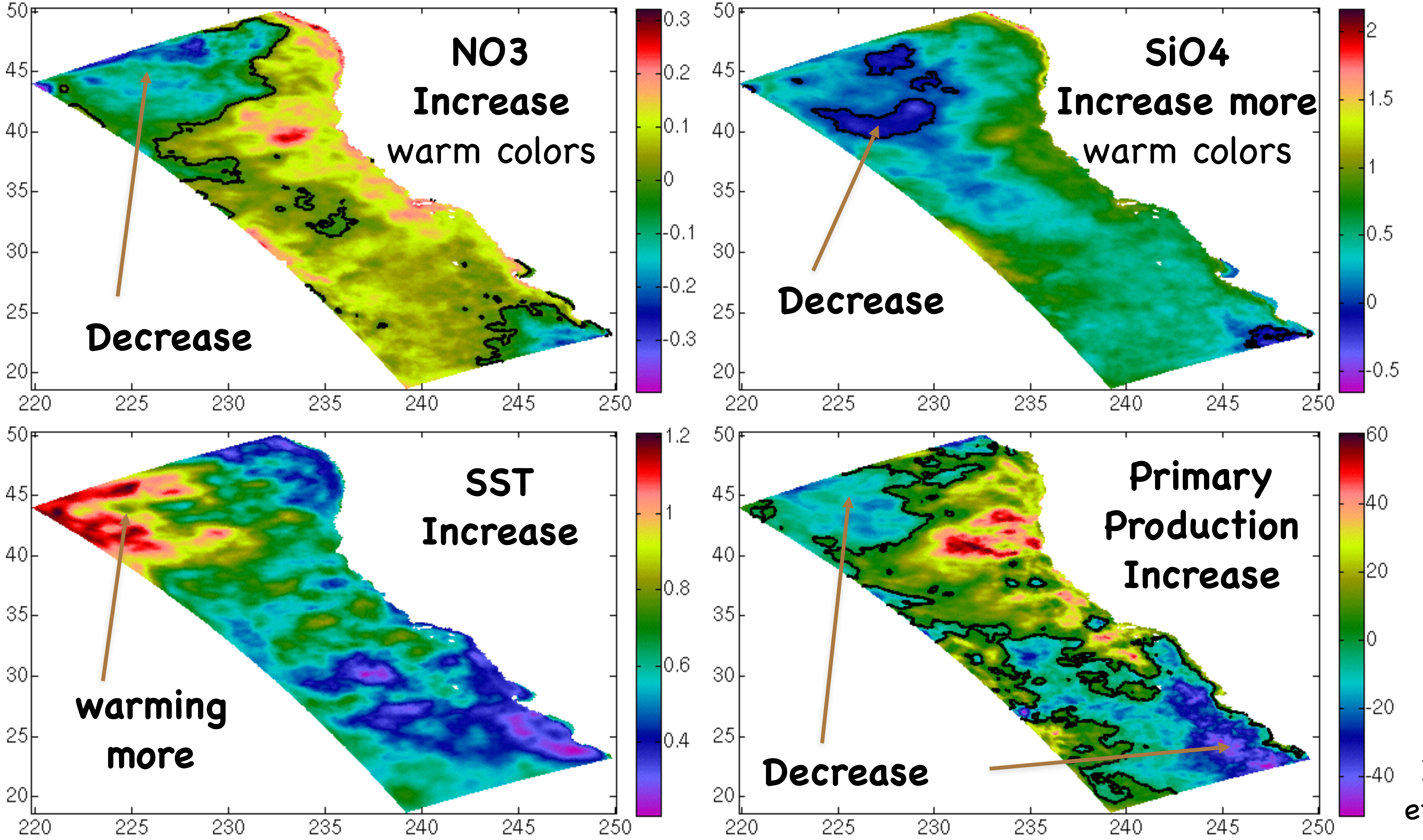



**Stratification (N2) Enhanced**

Xiu, Chai et al., 2018

# Comparison of Nutrients and Primary Production

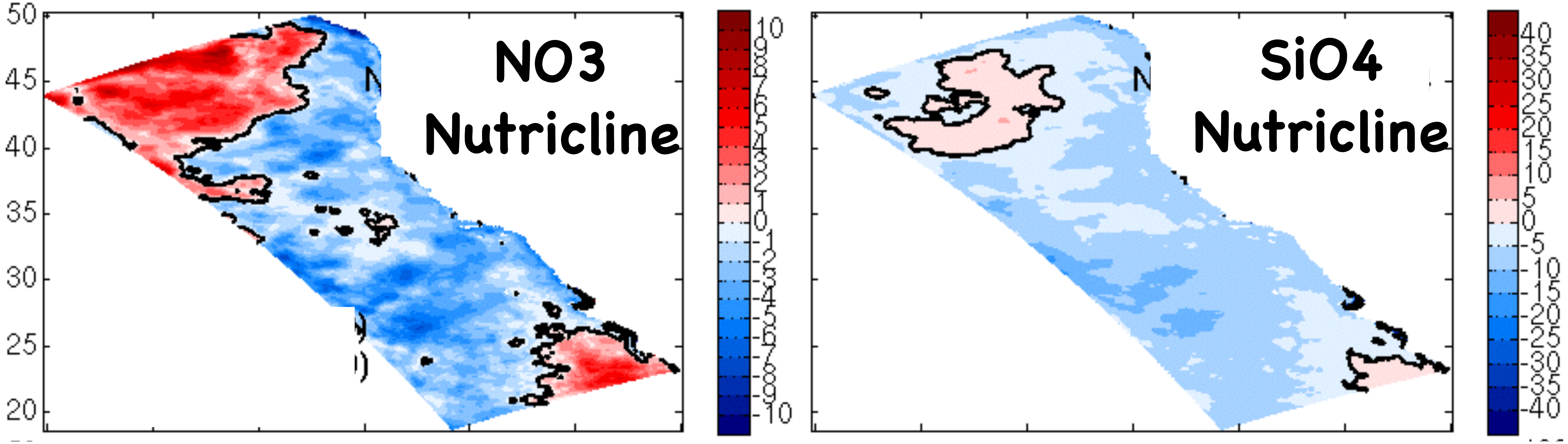
## Difference = (2030-2049) - (1990-2009)




Xiu, Chai et al., 2018

# Comparison of Nutricline Depth (NO3 and SiO4)

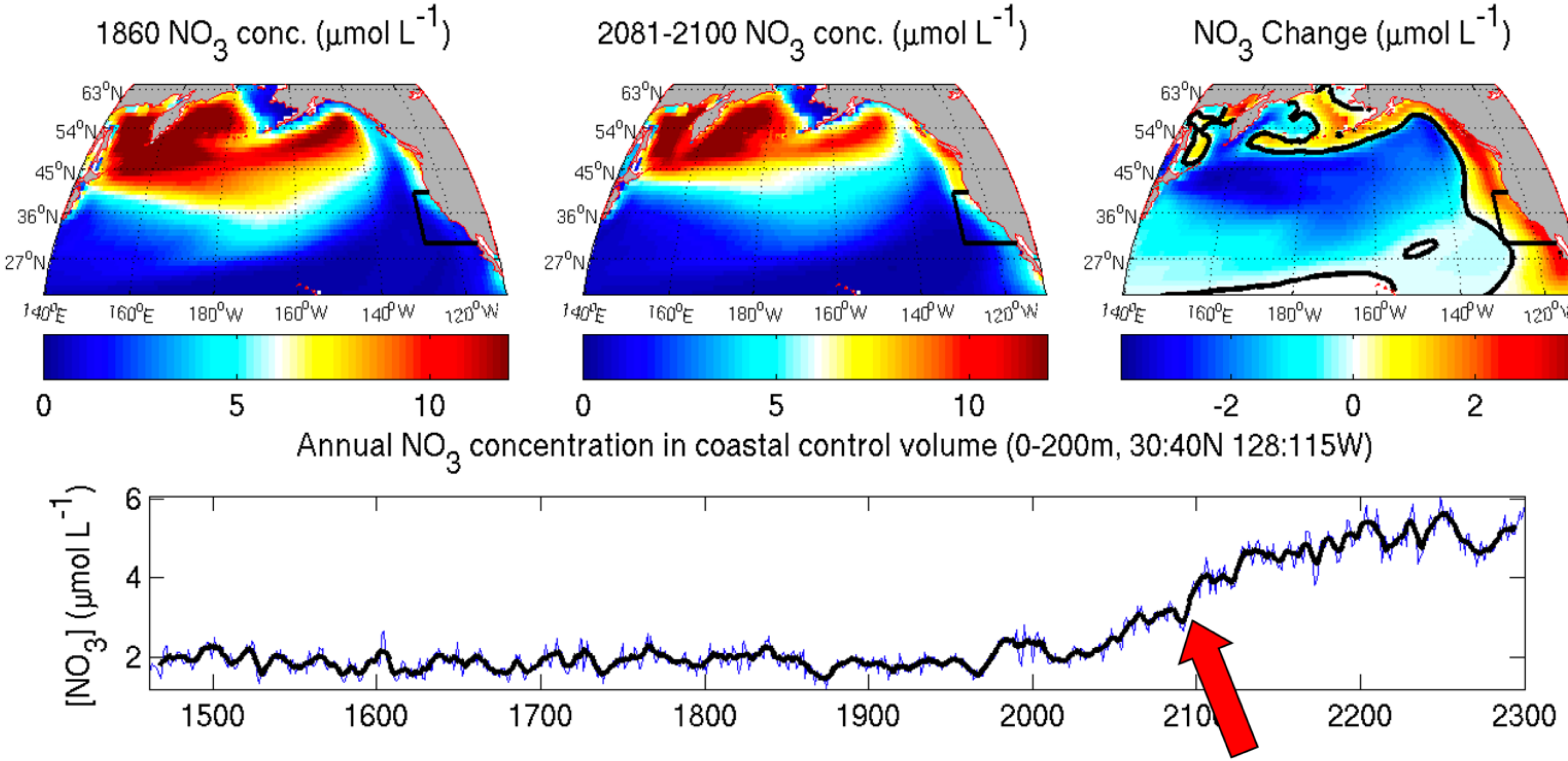
**Difference = (2030-2049) - (1990-2009)**




Nutricline become shallower in most areas, more so for silicate than nitrate. Offshore region in the north, nutricline deepens.

Xiu, Chai et al., 2018

# Nitrate Changes

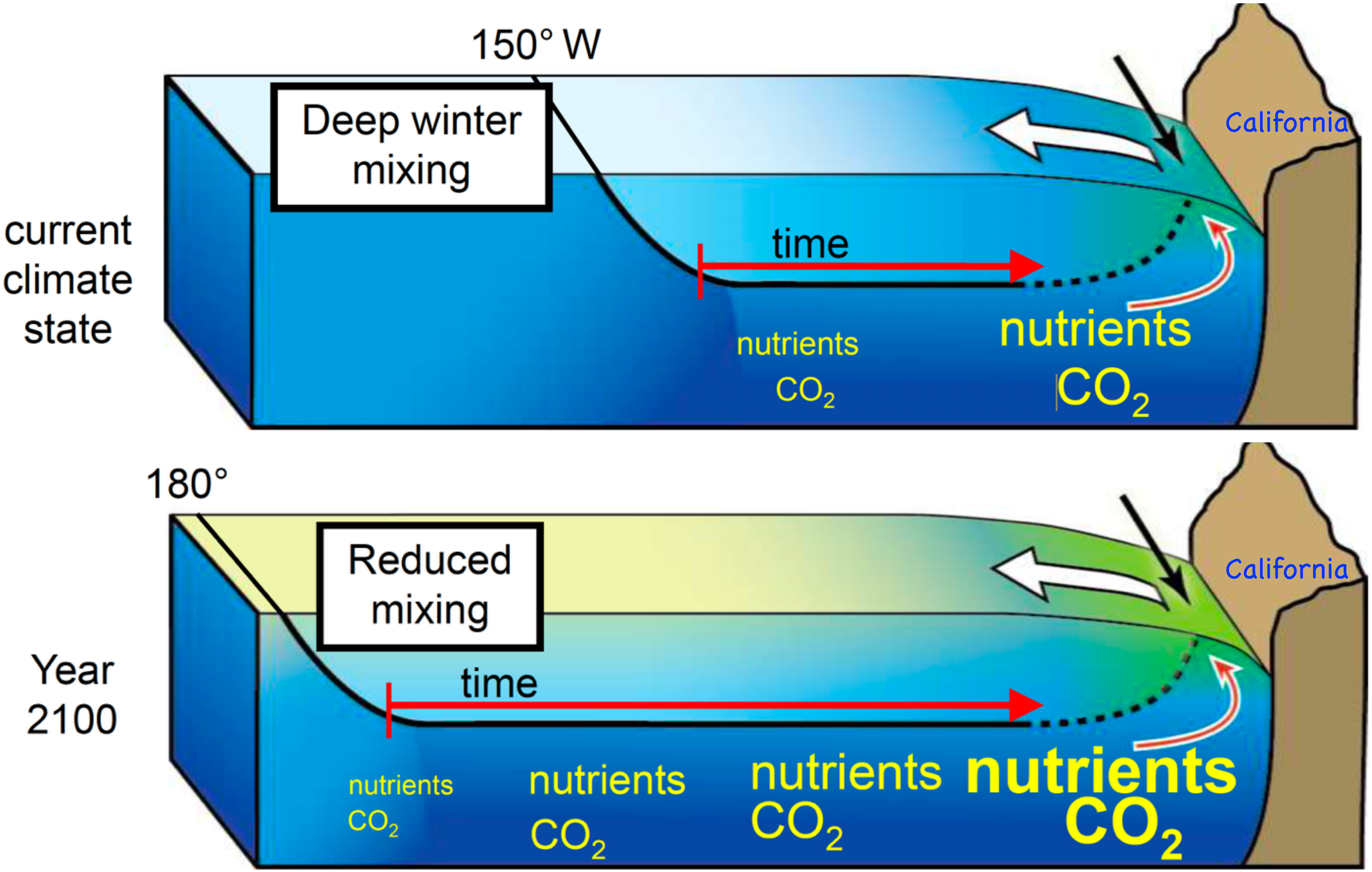



35% decrease in the average nitrate concentration in the North Pacific (20° N to 65° N).

85% increase in average nitrogen concentration between 2000 and 2100 along the US West Coast.

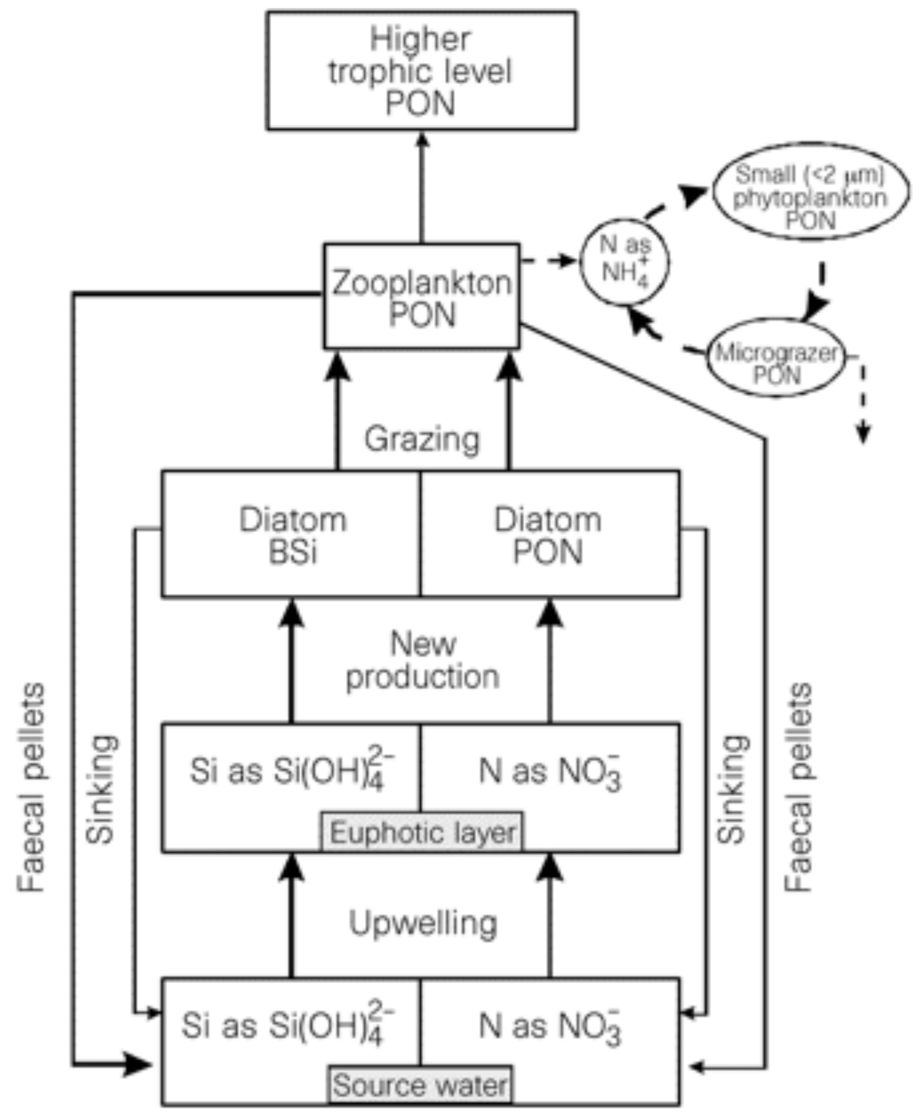
Rykaczewski and Dunne (2010, GRL)

# Open Ocean and Coastal Upwelling - Nutrients Connections




More Si than N

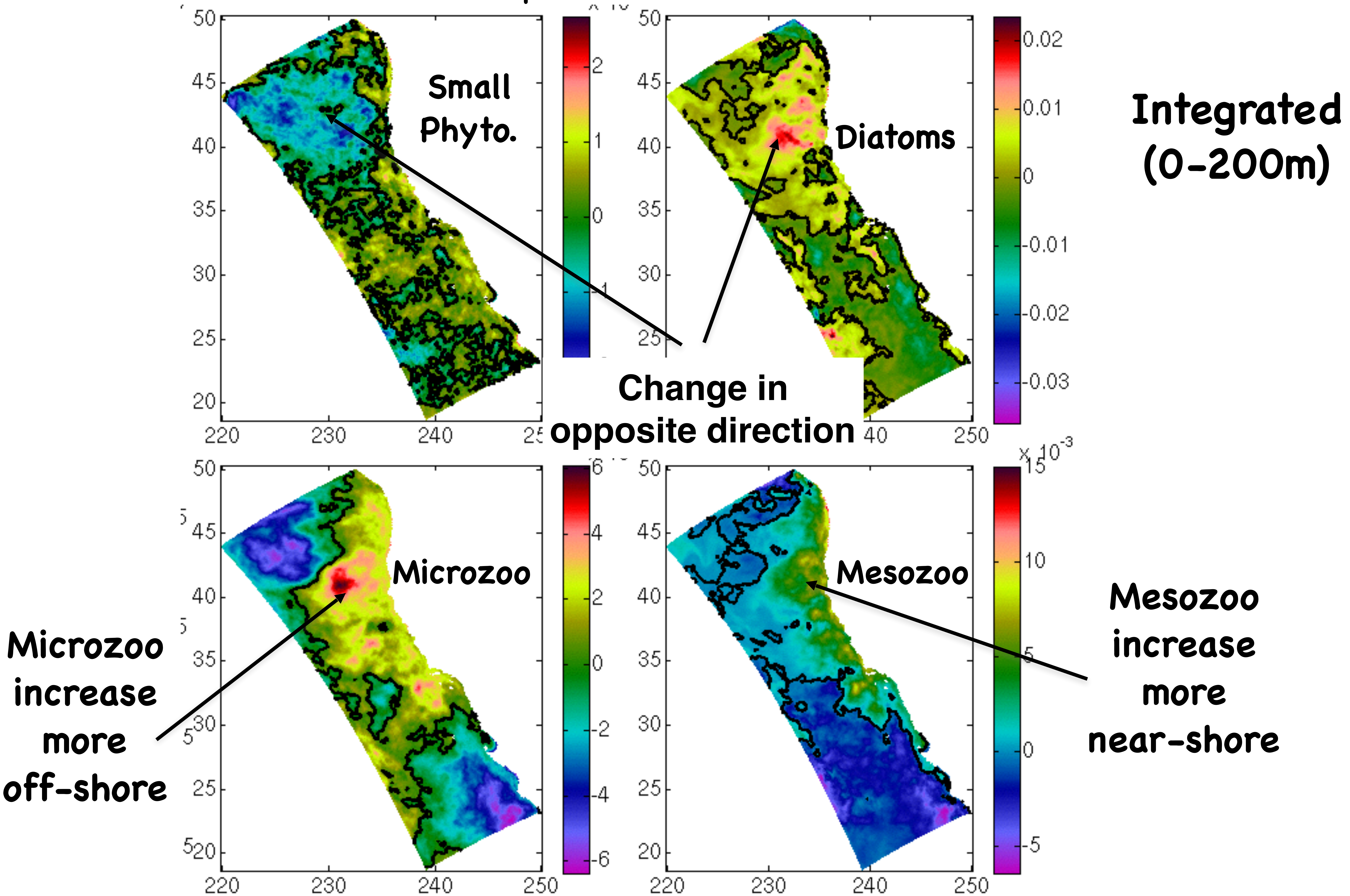
Courtesy of
Ryan Rykaczewski
USC



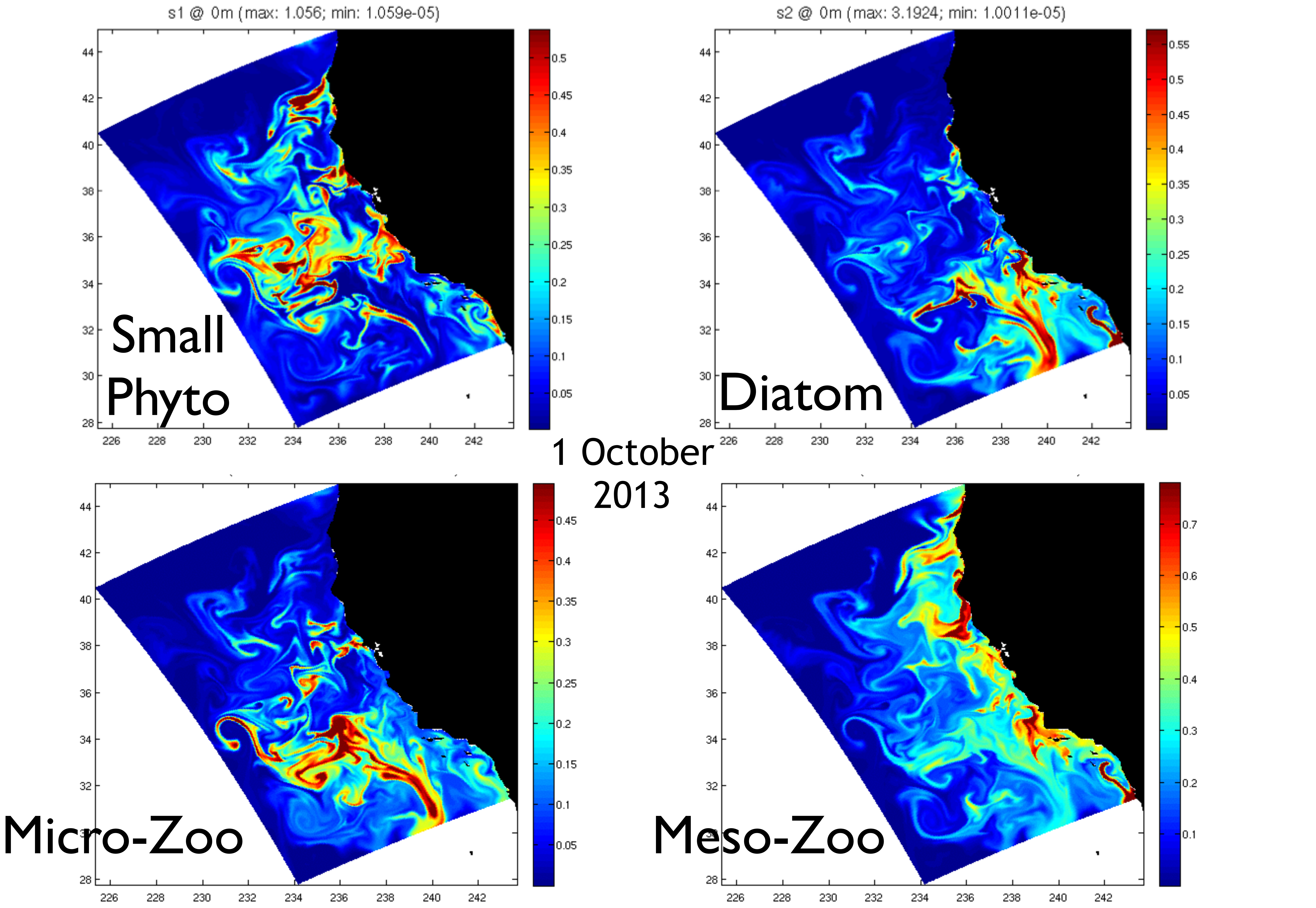

Silicate pump model, Dugdale and Wilkerson, 1998

Our study indicates there will be more silicate upwelled than nitrate in CCS due to difference of Si and N cycling in the open ocean.

# Plankton Biomass Comparions: (2030-49) - (1990-09)

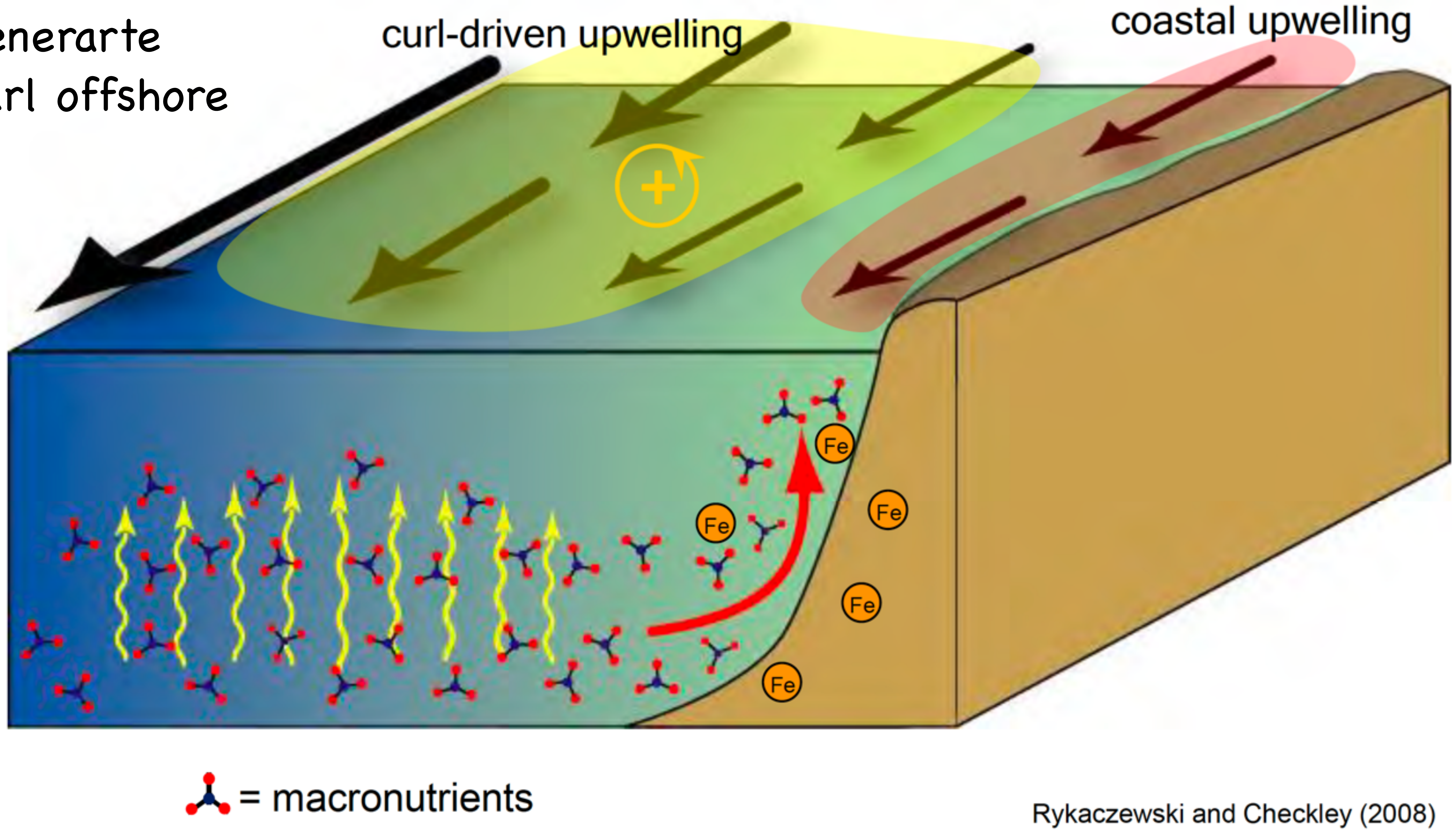


# Modeled Plankton at surface (based 3km ROMS-CoSiNE)

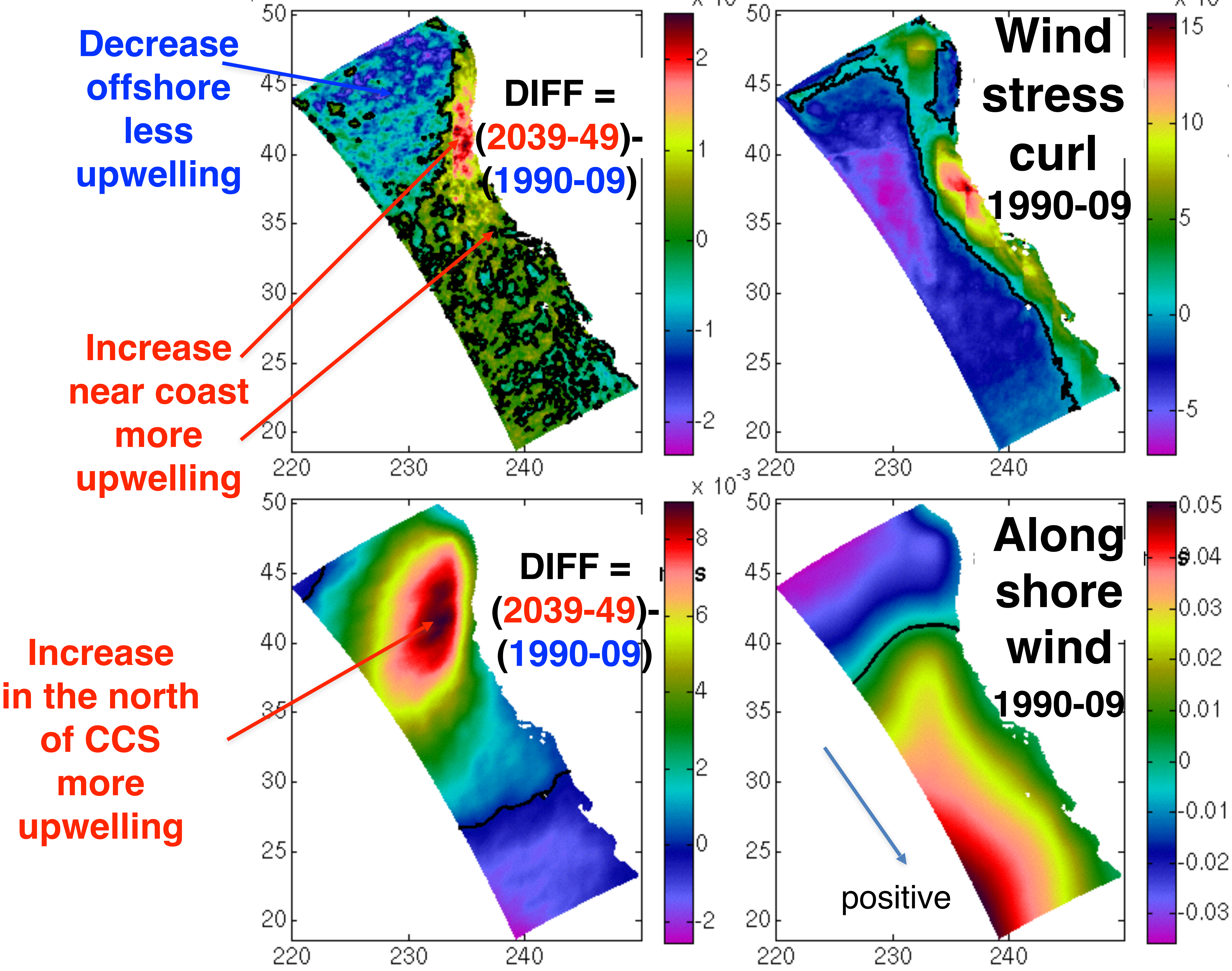


# Coastal upwelling favorable wind and wind stress curl offshore

Land-ocean thermal
contrast generarte
wind stress curl offshore




Rykaczewski and Checkley (2008)



Decrease offshore less upwelling
Increase near coast more upwelling
DIFF = (2039-49)-(1990-09)
Wind stress curl 1990-09
Increase in the north of CCS more upwelling
DIFF = (2039-49)-(1990-09)
Along shore wind 1990-09
positive
x 10^-3

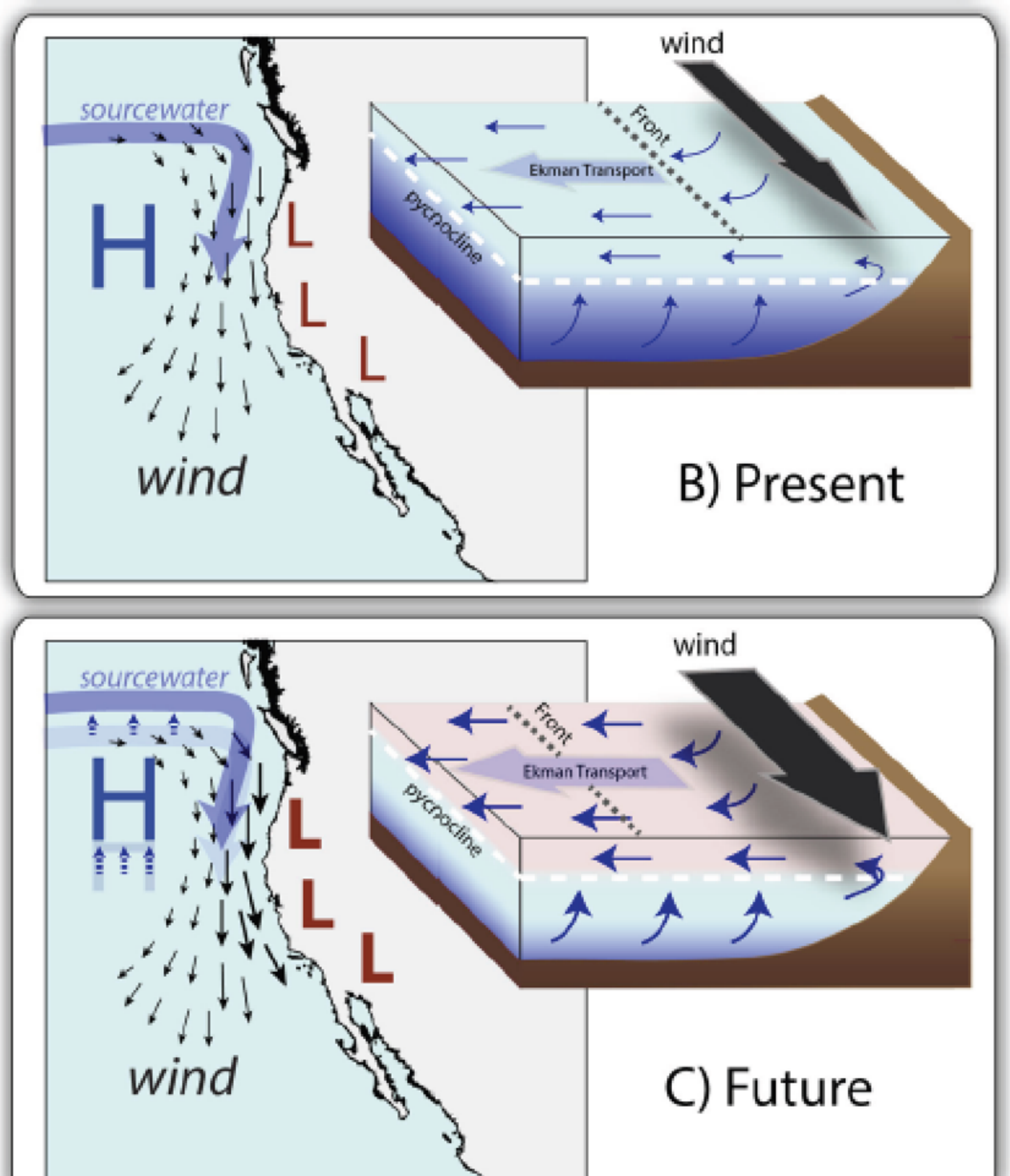
# Future climate change impact on upwelling systems

Bakun Hypothesis

Poleward migration of pressure systems

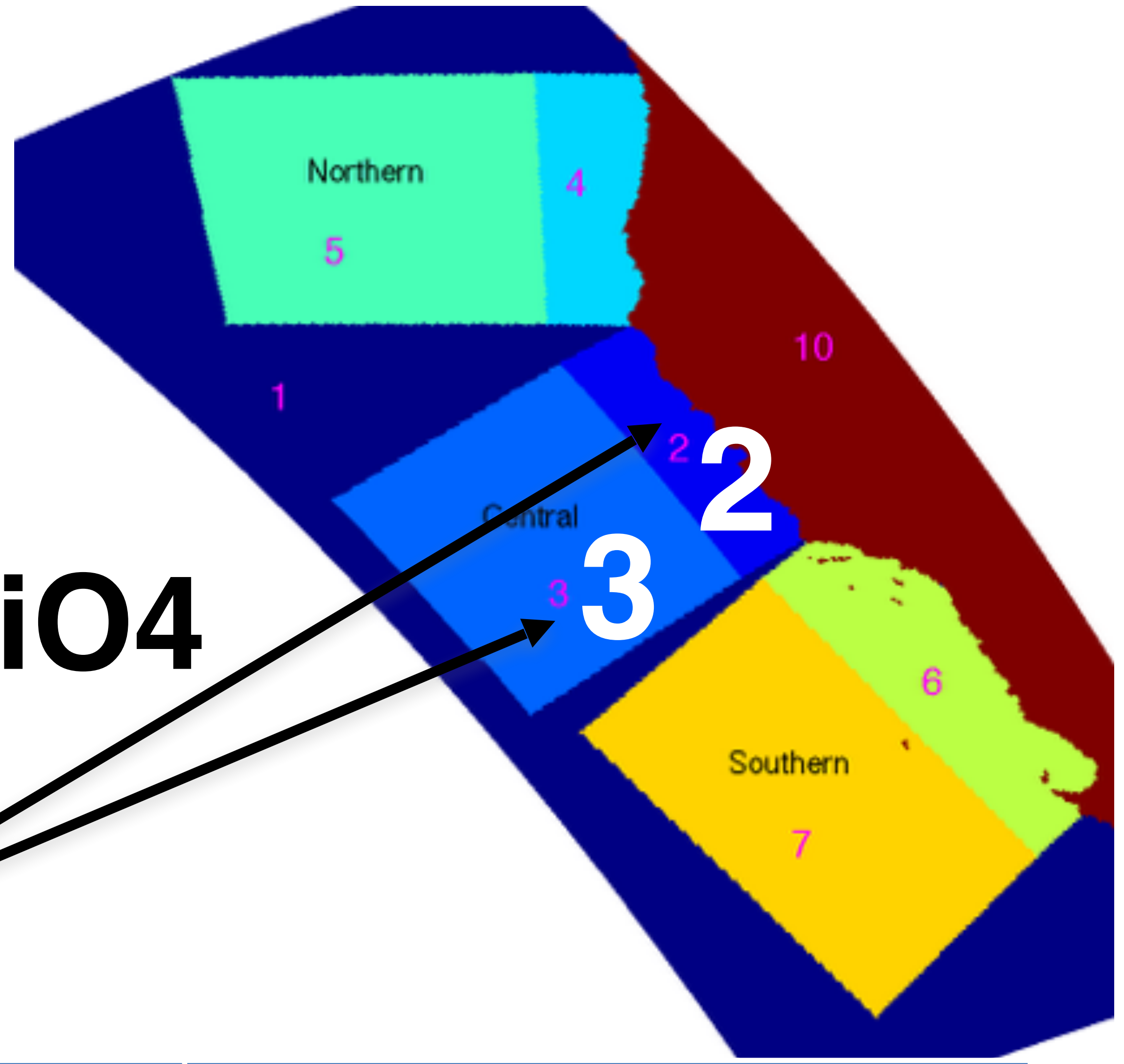
Enhancement of land-ocean thermal contrast along the coast

Bakun et al., 2015



# Vertical Nutrient Flux Calculations

$$\% = [AVG(2030\text{-}49) - AVG(1990\text{-}09)] / AVG(1990\text{-}09)$$

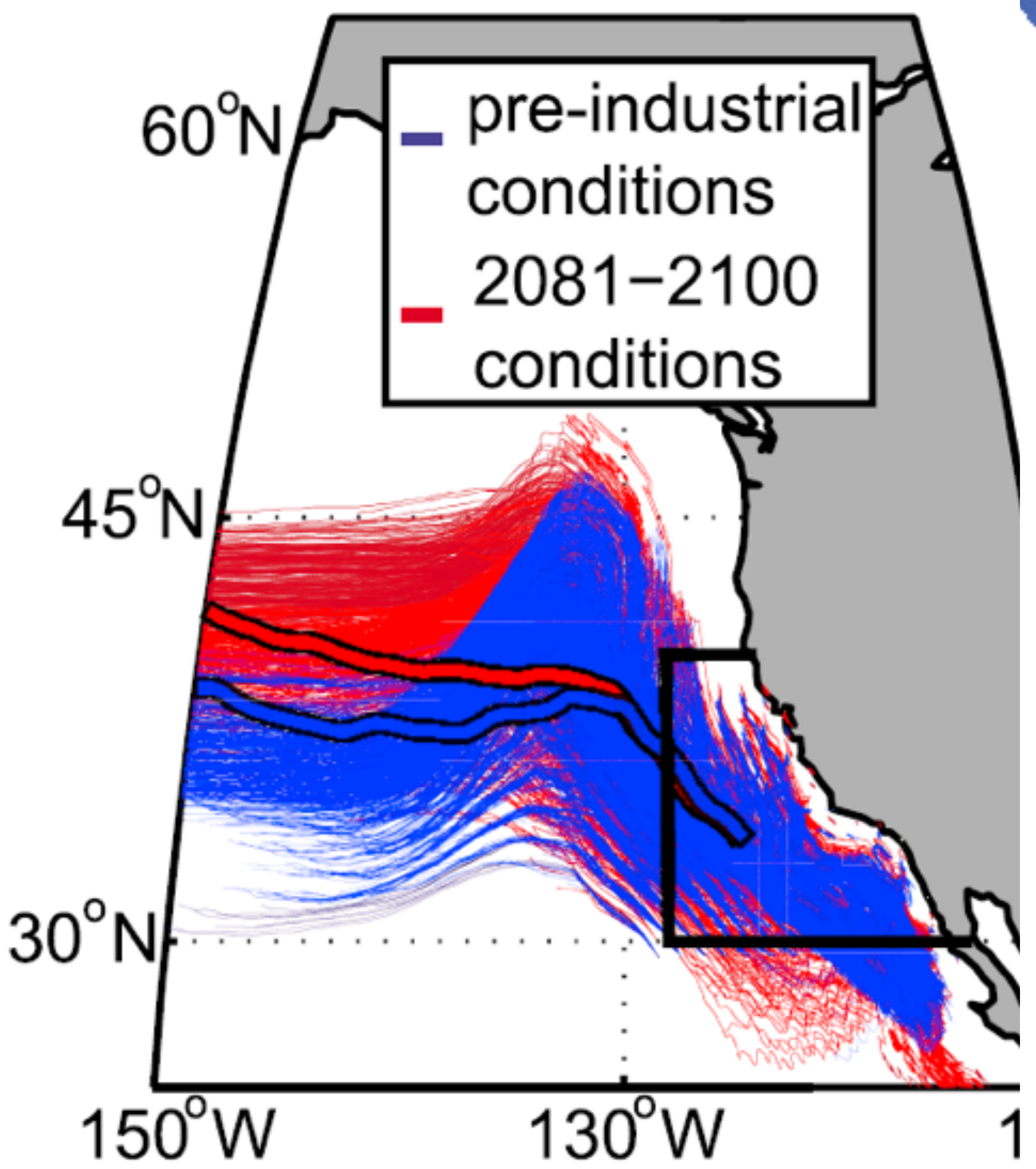


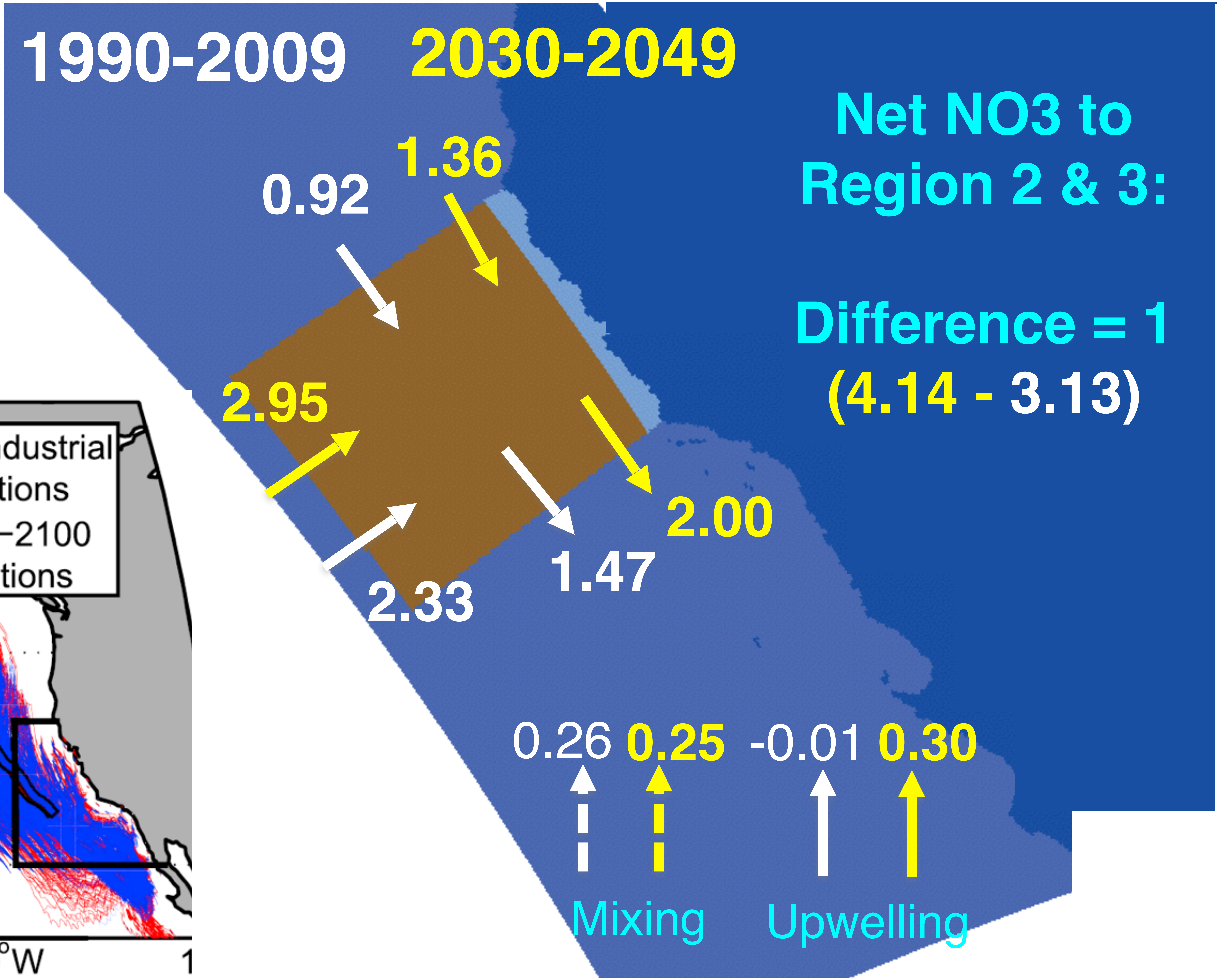

Changes of Vertical Velocity (**W**) and **NO3** and **SiO4** in region **2** and **3**, during **April-July**

| change (%) | W | NO3 | SIO4 |
|---|---|---|---|
| 100 m | 5.6% | 9.9% | 24% |
| 200 m | 21.3% | 5.7% | 18.8% |
| 300 m | -4.0% | 2.9% | 14.8% |

# Annual Mean NO3 Flux (0-200m) (kmol/s)

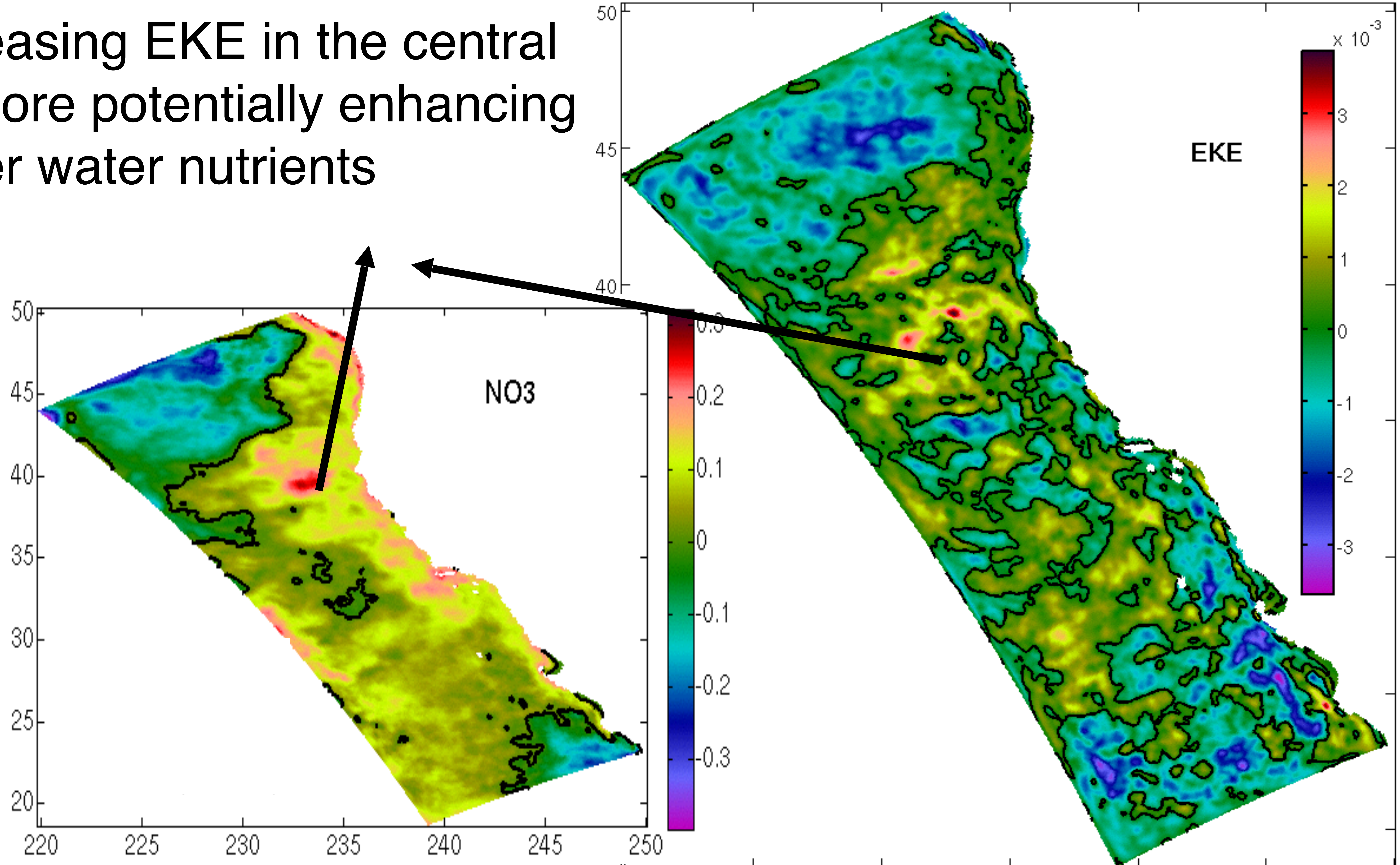
*Rykaczewski and Dunne GRL, 2010*

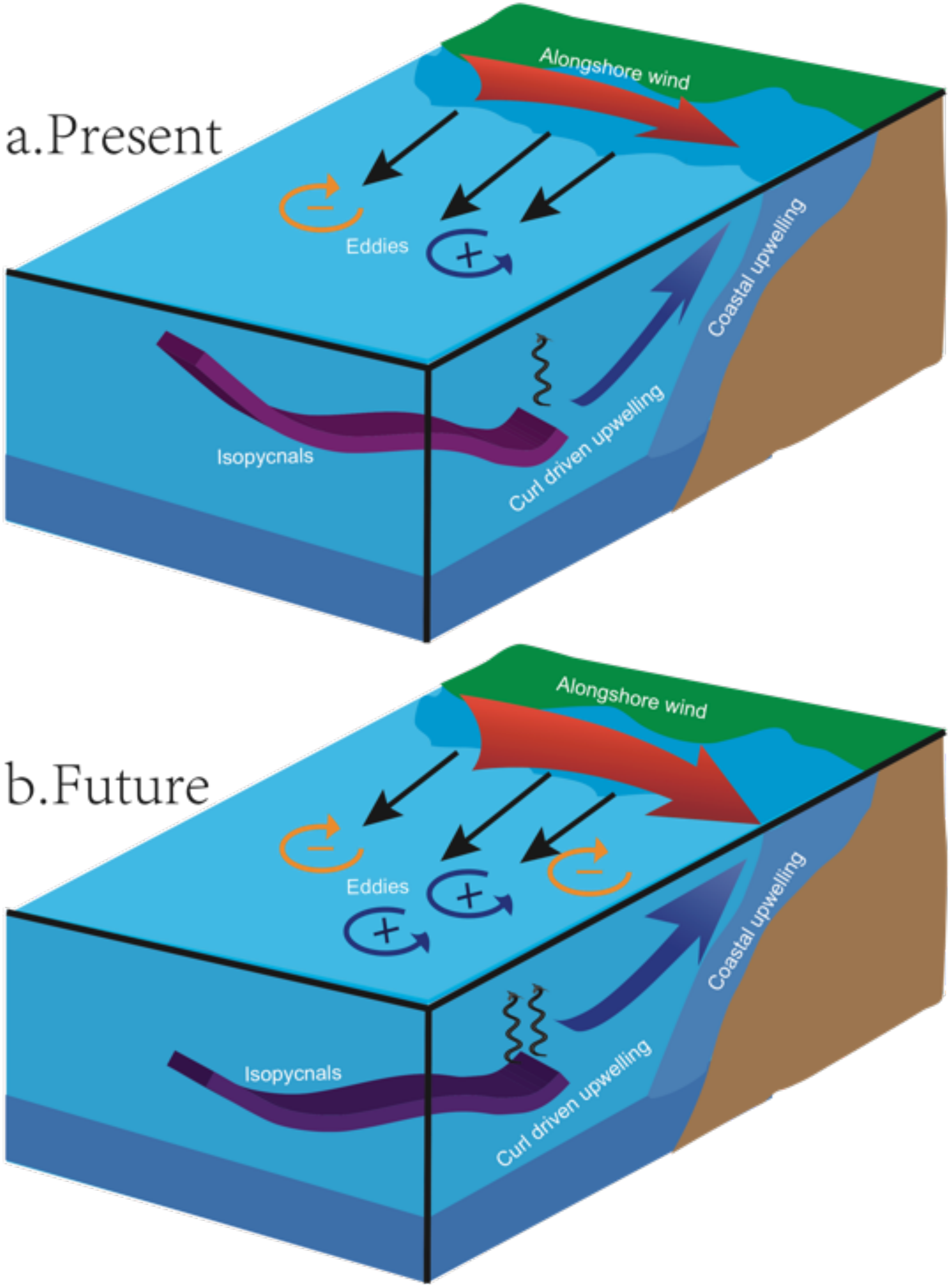


# *Eddy Kinetic Energy (EKE)*
# *Difference = (2030-49) - (1990-09)*

Increasing EKE in the central offshore potentially enhancing upper water nutrients






- Higher resolution coastal model yield more regional difference
- Increasing along-shore wind lead to stronger upwelling; upwelled nutrient (Si/N) concentration increase
- New and primary production increase because more nutrients (Si/N) to CCS
- Diatoms and meso-zooplankton increase more near shore, due to more Si
- EKE also increased in offshore region, enhance nutrient supply

# Summary

- Motivation - global vs. regional approach for understanding the ocean

**Model resolution matters! Global models are improving, but still need regional modeling**

- Physical-biological modeling for the Pacific Ocean (ROMS-CoSiNE)

**Studying physical-biological coupling in coastal regions and eddy dynamics**

- Future projections for CCS based on GFDL/ESM connecting with ROMS-CoSiNE

**Downscaling and upscaling are needed to connect open ocean and coastal seas**

- Controlling factors for increasing nutrients and biological productivity in CCS