Regional Impacts of Large-Scale Climate Variations on the Pacific Ocean Ecosystem

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Scale Interactions of Climate and Marine Ecosystems
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Outline

1. Basic physics that organizes the patterns of Pacific ocean decadal variability
2. Relations to our current research on regional ecosystem response
   a. California Current
   b. Gulf of Alaska
   c. Kuroshio-Oyashio Extension
3. Comments on possible biologically induced feedbacks

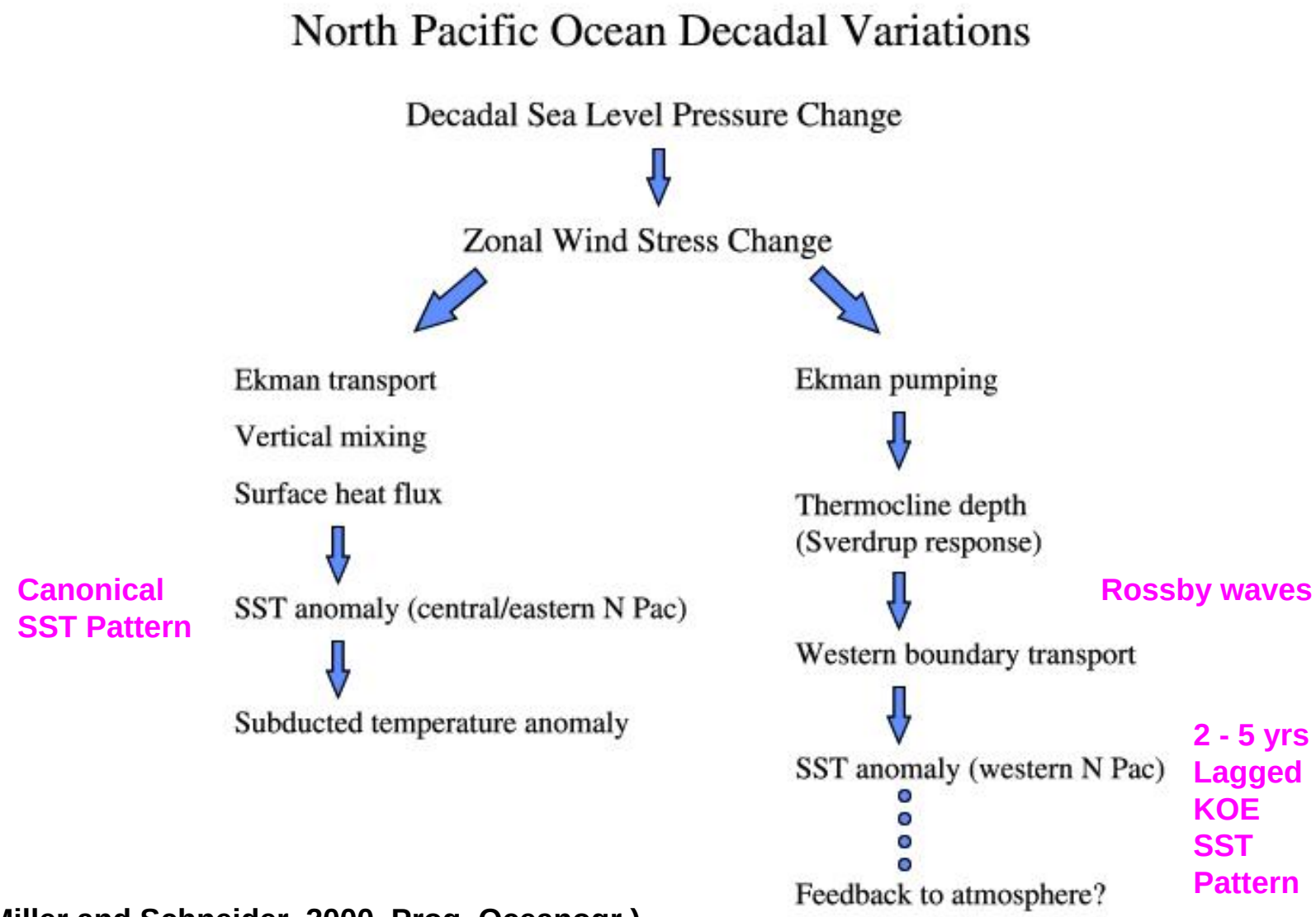
Recent Collaborators

Physics: Schneider, Di Lorenzo, Pierce, Kim, Bograd, Alexander, Capotondi, Deser, Lynn, McWilliams, Mestas-Nunez

Biology: Moisan, McGowan, Neilson, Chai, Chiba, Gabric

Funding: NSF, NASA, NOAA, DOE, ONR

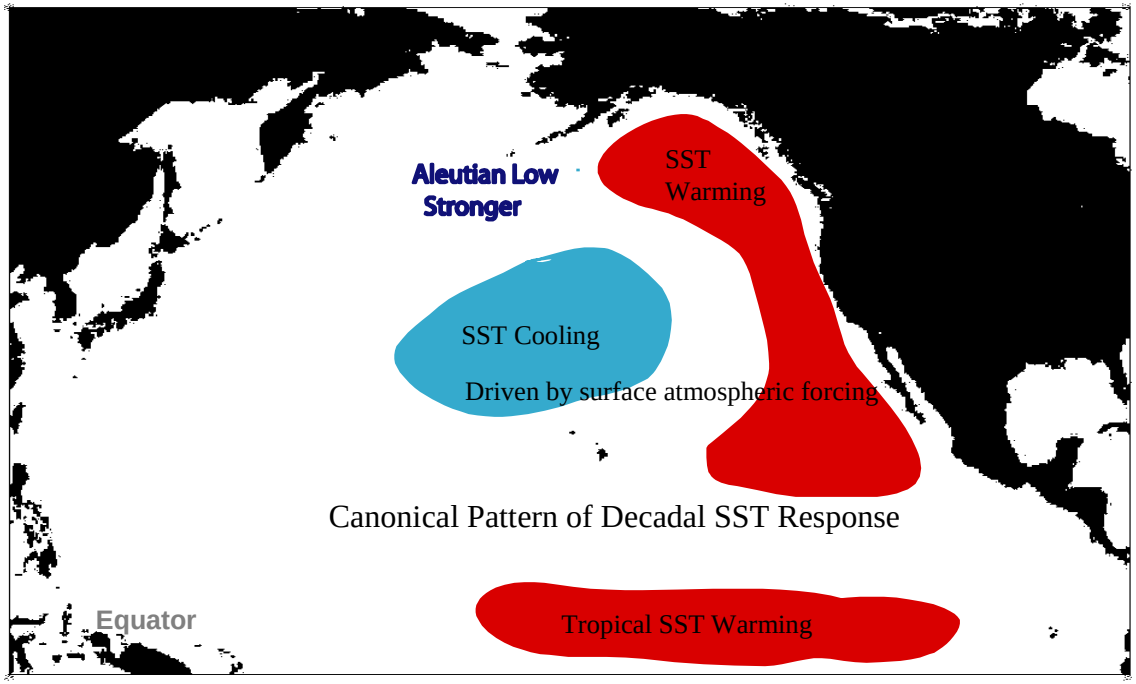
Schematic of Pacific Oceanic Response to Decadal Forcing by the Aleutian Low



(Miller and Schneider, 2000, Prog. Oceanogr.)

Canonical Pattern of Decadal SST Response (Aleutian Low Strengthening)

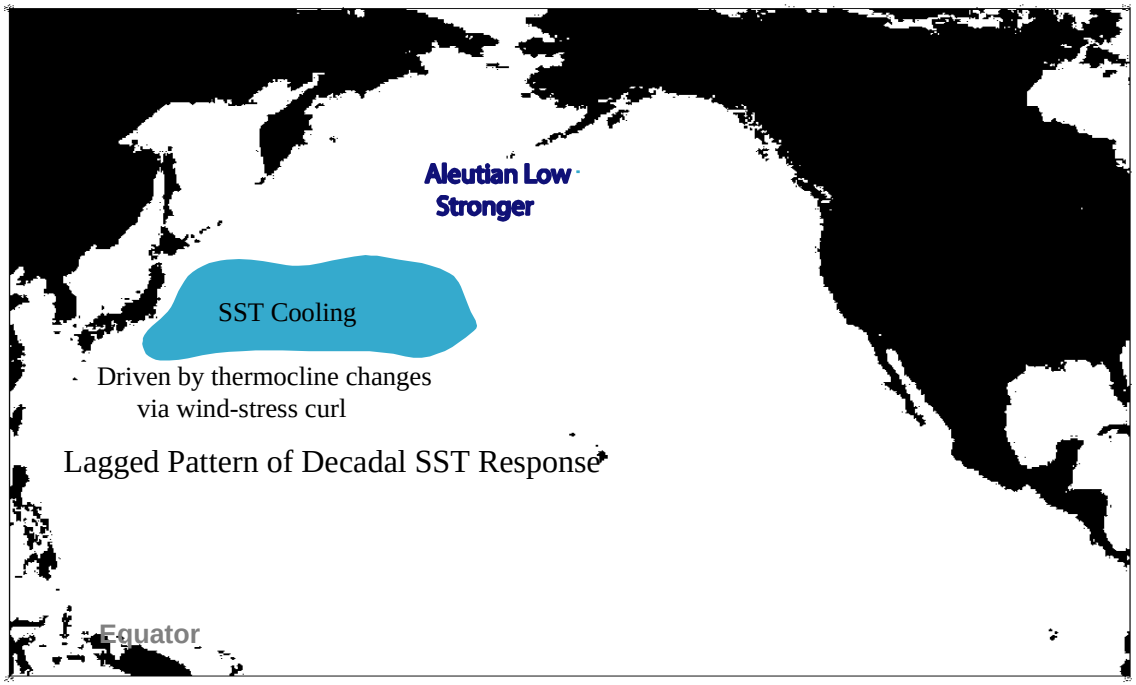
Schematic



From Miller, Chai, Chiba, Moisan and Neilson (2004, J Oceanogr.)

Lagged Pattern of Decadal SST Response (Aleutian Low Strengthening)

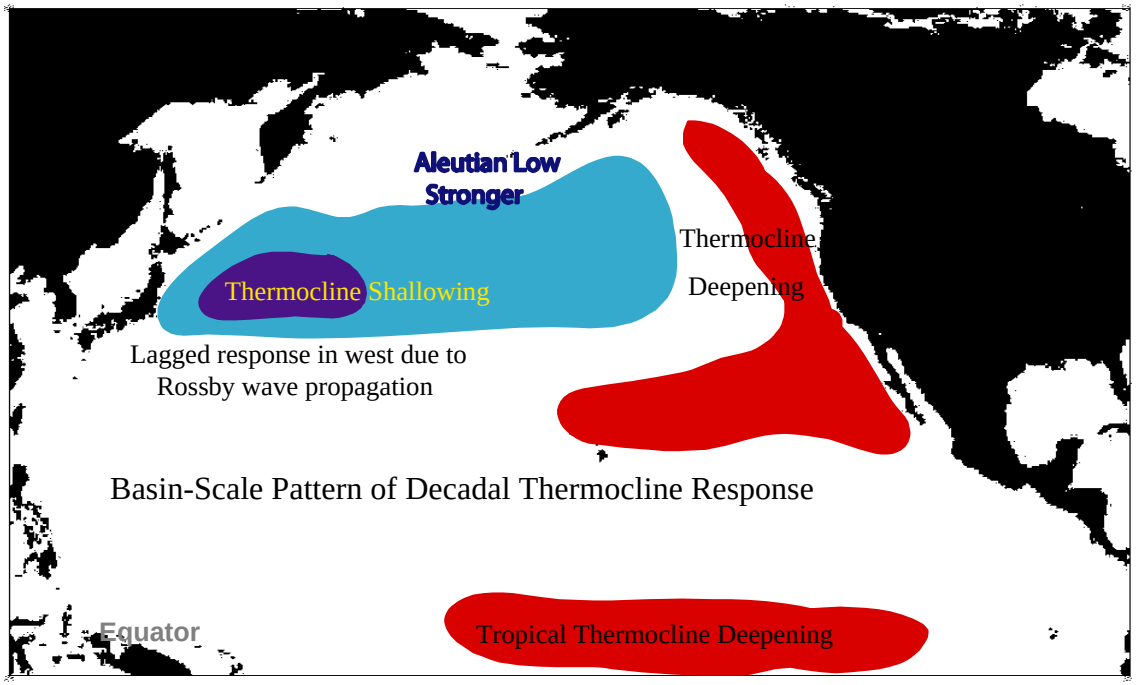
Schematic



From Miller, Chai, Chiba, Moisan and Neilson (2004, J Oceanogr.)

Basin-Scale Pattern of Decadal Thermocline Response (Aleutian Low Strengtherning)

Schematic



From Miller, Chai, Chiba, Moisan and Neilson (2004, J Oceanogr.)

Sources of North Pacific Decadal Variability

1. Tropical Teleconnections (requires tropical decadal mechanism)
   a. Atmospheric (ENSO-like)
      - canonical SST pattern
      - basin-scale thermocline response
   b. Oceanic (ENSO-like)
      - eastern boundary thermocline response

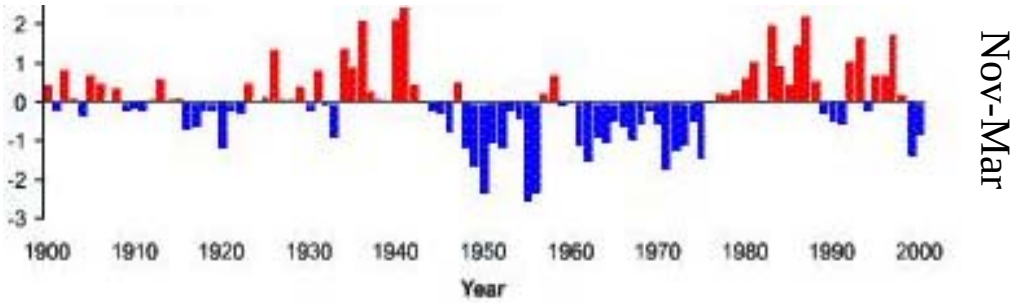
2. Subduction Modes

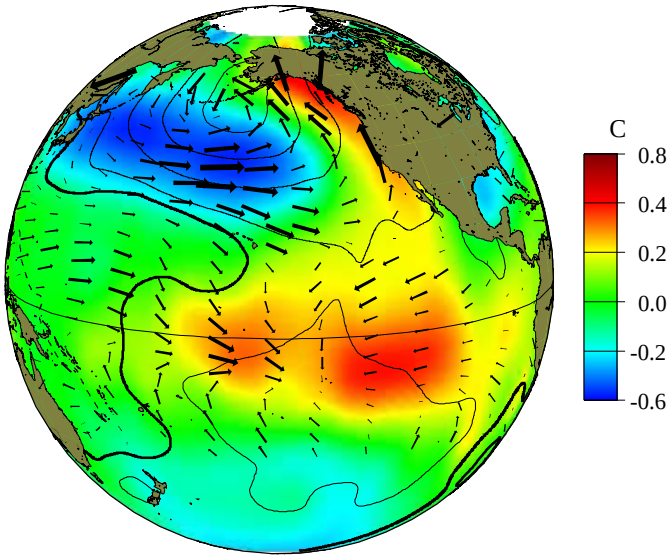
3. Midlatitude Gyre Modes

4. Stochastic Forcing
   - oceanic spectral peaks possible
   - predictable components possible

5. Deterministic Forcing
   - solar cycles, greenhouse gases

What Forces the Pattern and Timescales of the Pacific Decadal Oscillation?





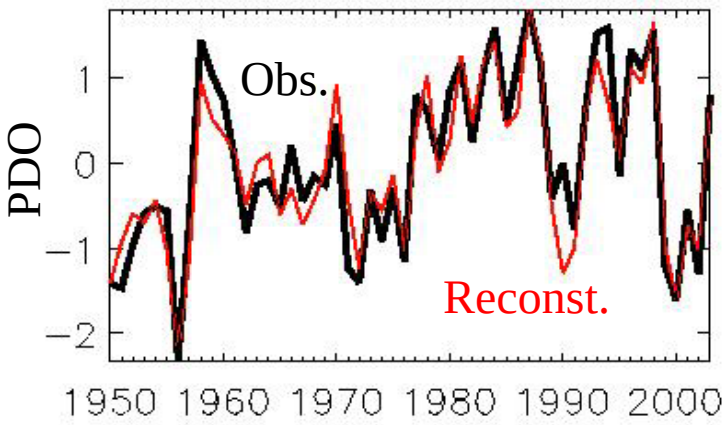
PDO: a response of North Pacific SST to

- El Nino
- Aleutian Low
- Transport of the Kuroshio/Oyashio Extension

Schneider and Cornuelle, *J. Climate*, submitted

Hindcast of annual averaged values of SST: the PDO

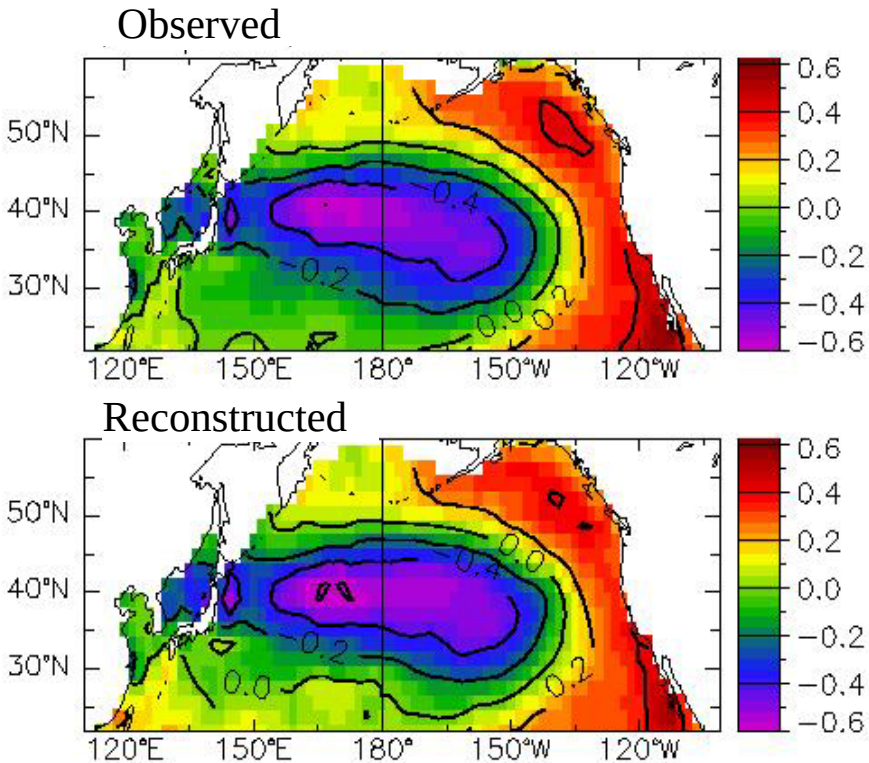
Schneider and Cornuelle, *J. Climate*, submitted

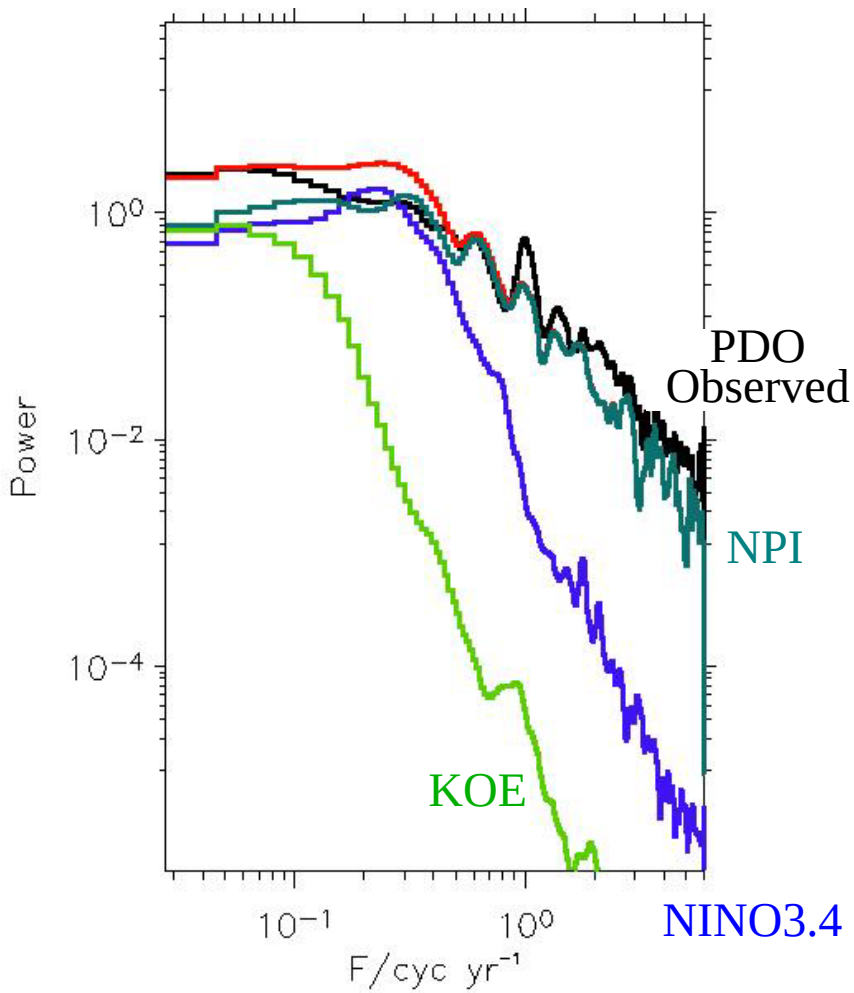


$$T_n = \alpha T_{n-1} + \gamma_i F_{i,n}$$

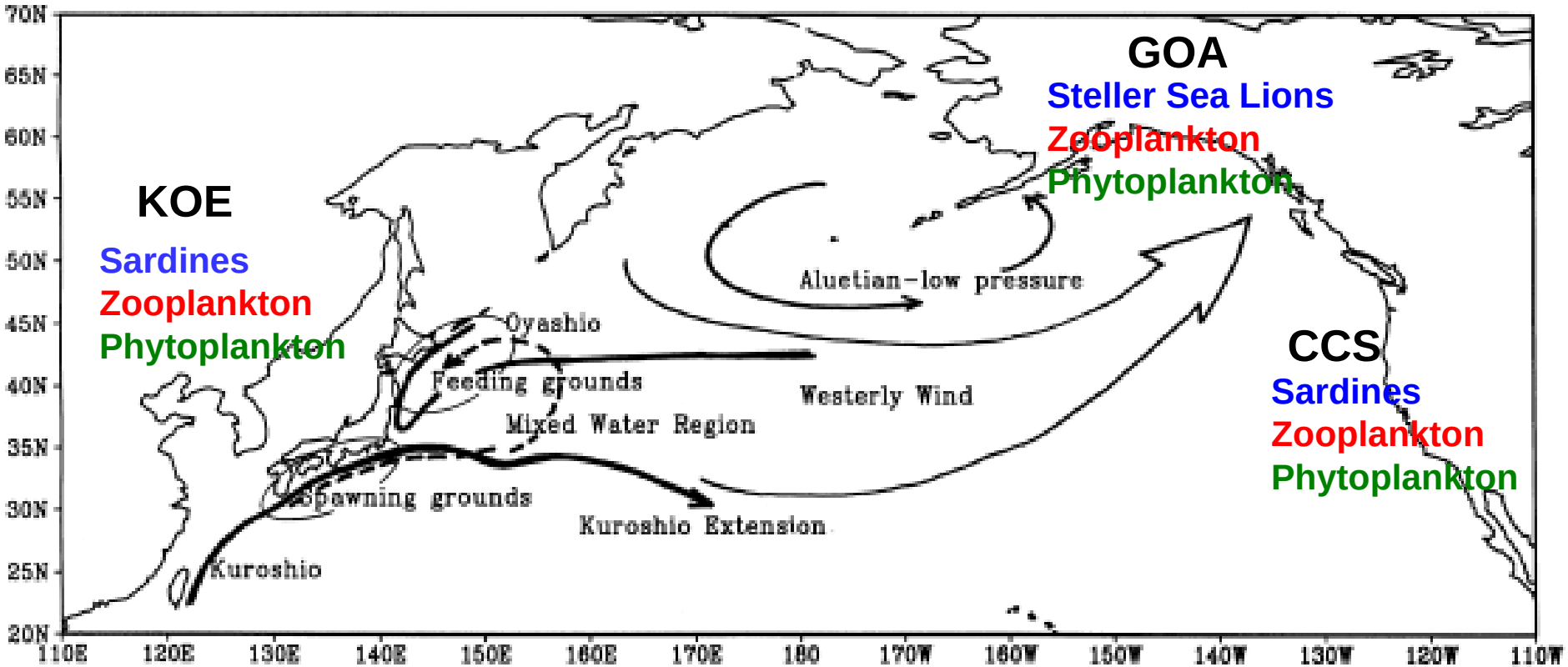
Autoregressive model forced by

- El Nino
- Aleutian Low
- KOE adjustment to Ekman pumping

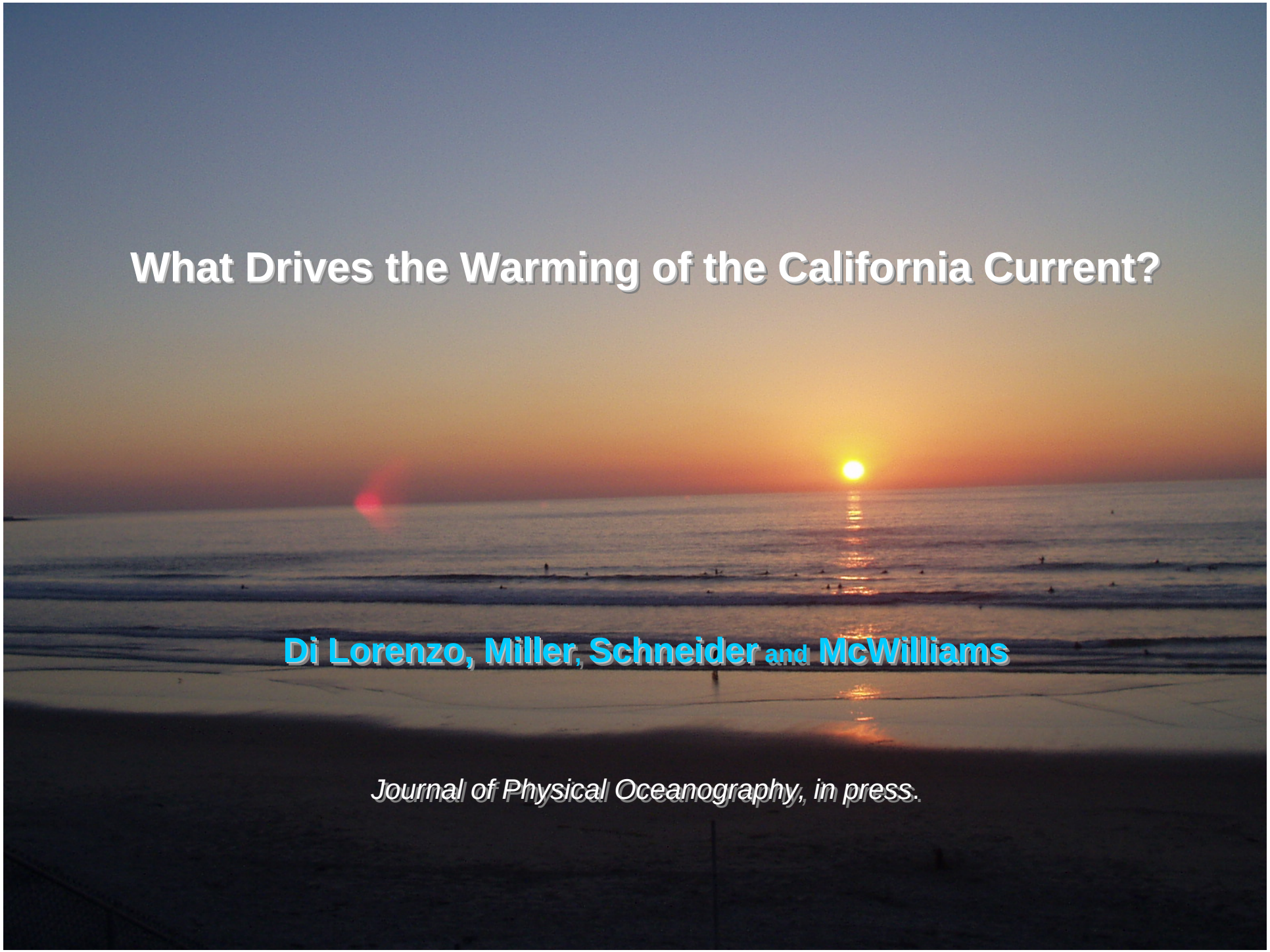




Summary of Some Regional Ecosystem Impacts Organized by Pacific Decadal Variability



Adapted from Yasuda et al., 1999, Fish. Oceanogr.

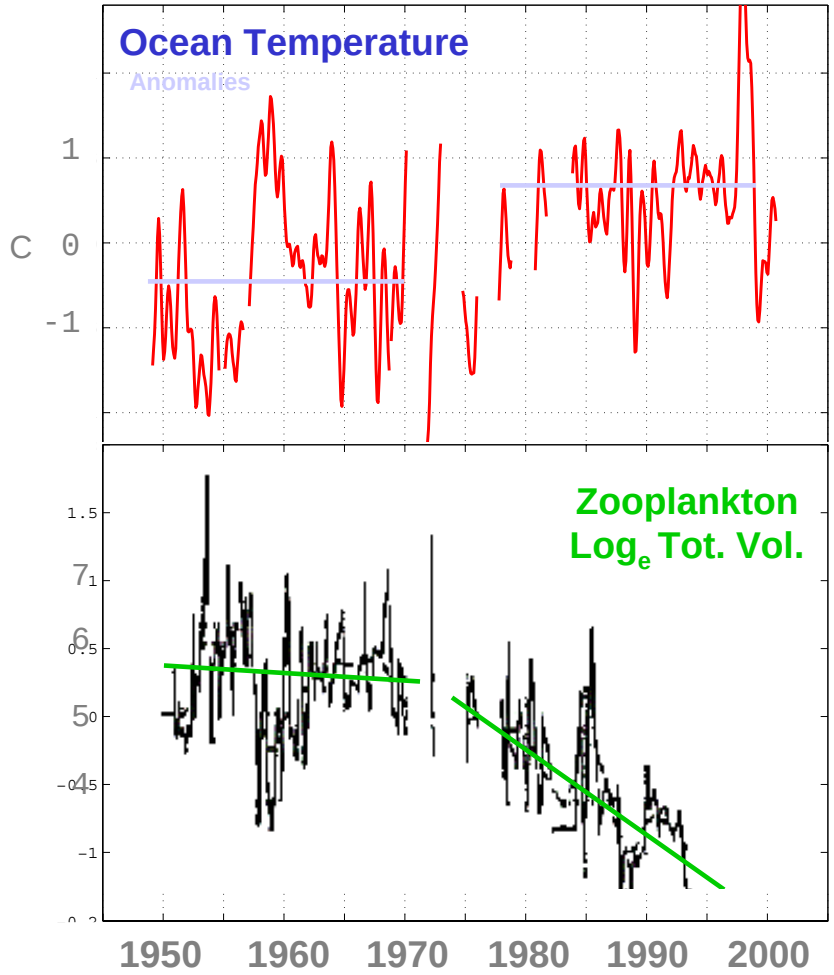


What Drives the Warming of the California Current?

Di Lorenzo, Miller, Schneider and McWilliams

Journal of Physical Oceanography, in press.

CalCOFI Observations along the Southern California Coast



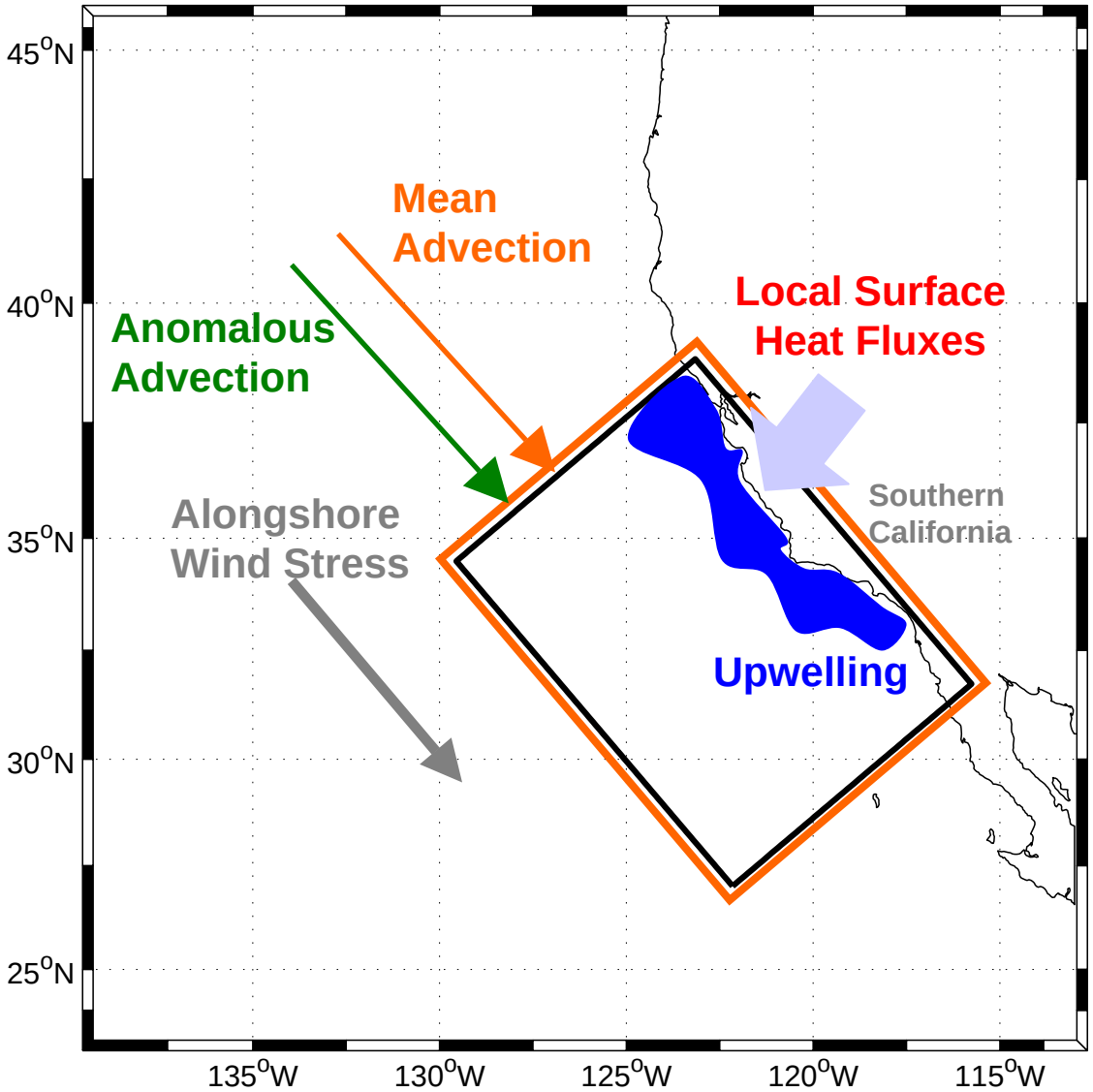
Over 50 yrs…

1 deg C warming of SST…

…70% decline in macro zooplankton

Roemmich and McGowan Science, 1995

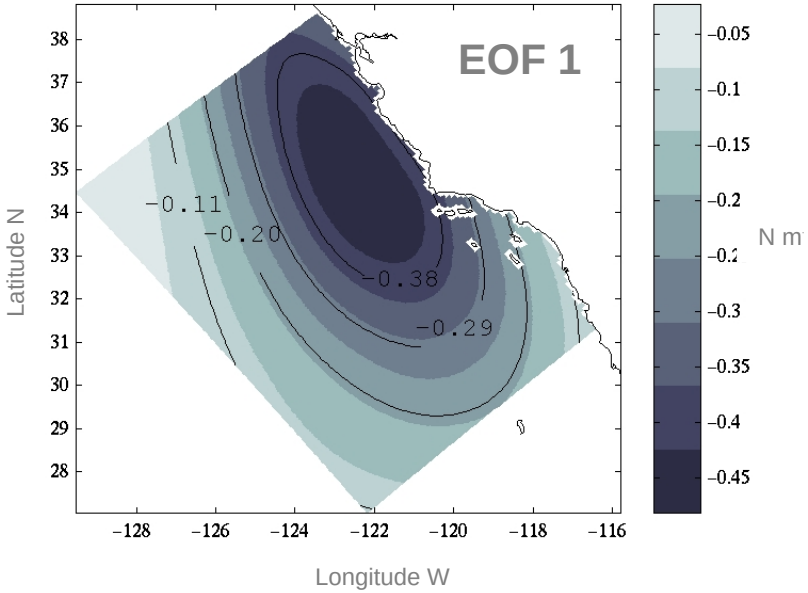
Local Atmospheric and Remote Oceanic Forcings That Can Affect the Regional Oceanic Heat Budget



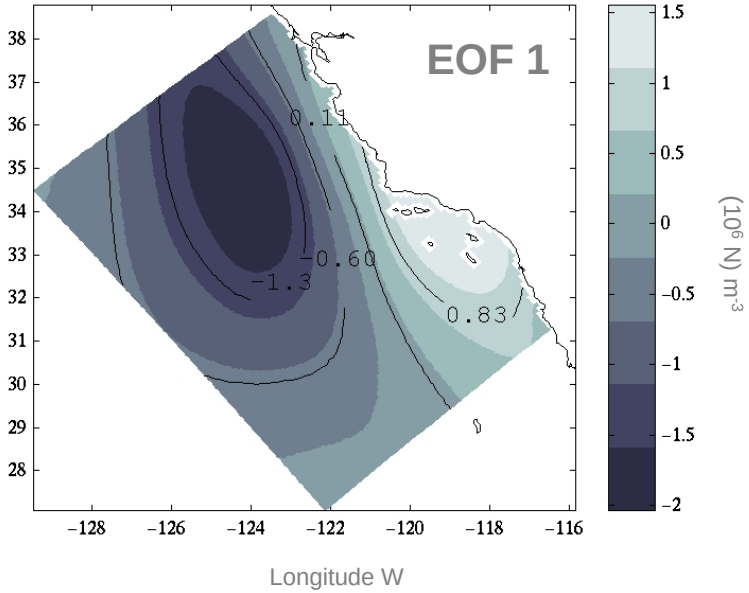
Di Lorenzo et al., JPO, in press

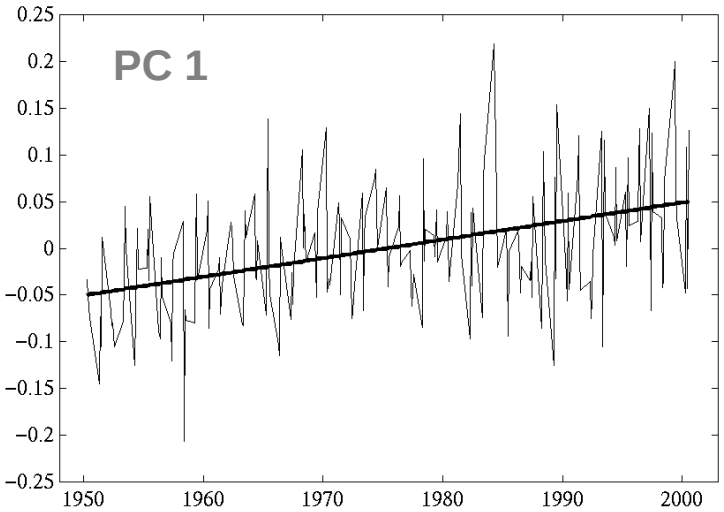
Upwelling Winds have have increased in the CCS

mode 1 : 72 % **NCEP Winds**



mode 1 : 60 % **Wind Stress Curl**



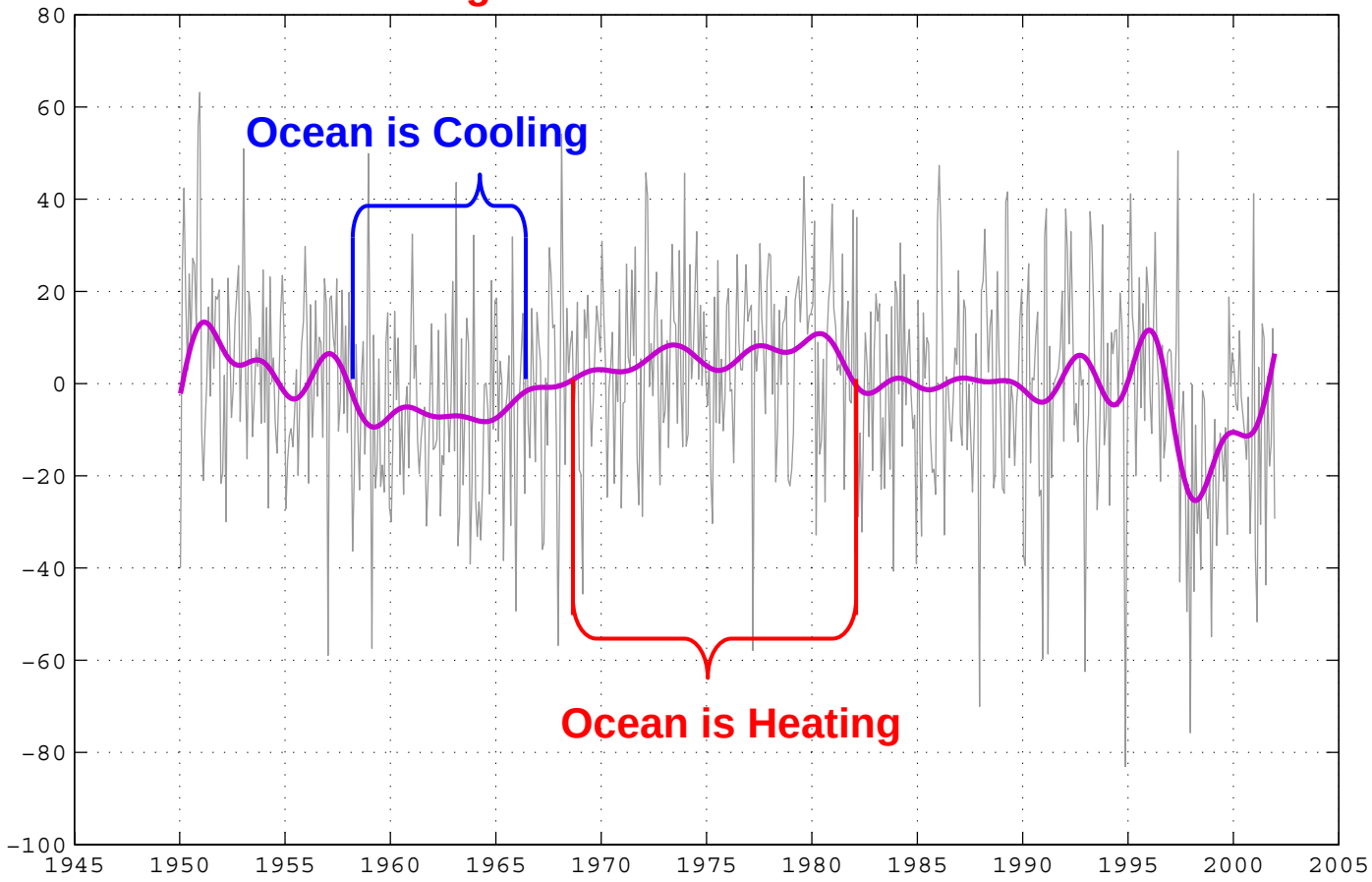


Di Lorenzo et al., JPO, in press

Net Surface Heat Fluxes

EXP 2

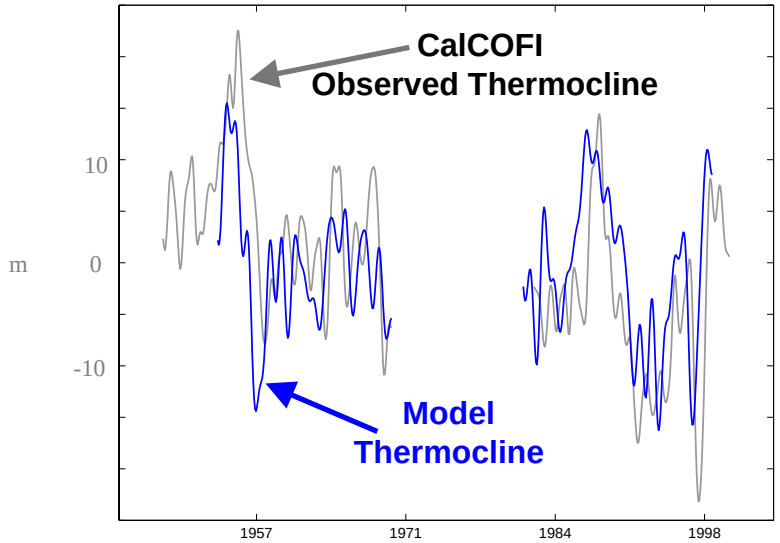
Timeseries of surface net heat fluxes averaged over Southern California



Di Lorenzo et al.,
JPO, in press

An eddy-permitting ocean model hindcast captures the observed SST and thermocline variations

Interannual and Decadal physical variations



Thermocline depth over the last 50 yrs shows an overall deepening of 20 m

Warming is due to large-scale decadal surface heat fluxes combined with southward advection of concomitantly warmed water

Increase in upwelling favorable winds partially cools water column

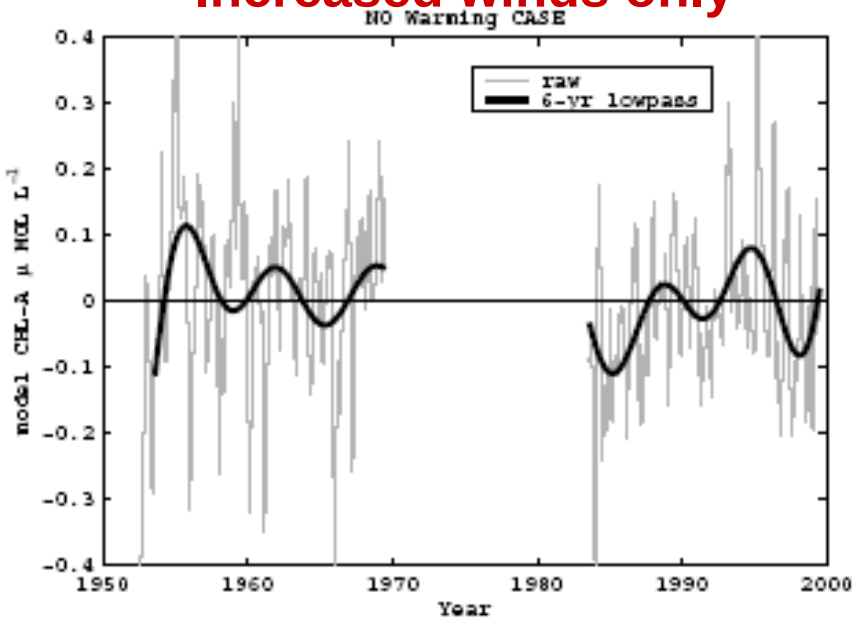
Di Lorenzo, Miller, Schneider and McWilliams, JPO, in press.

How does primary production respond to these modeled changes?

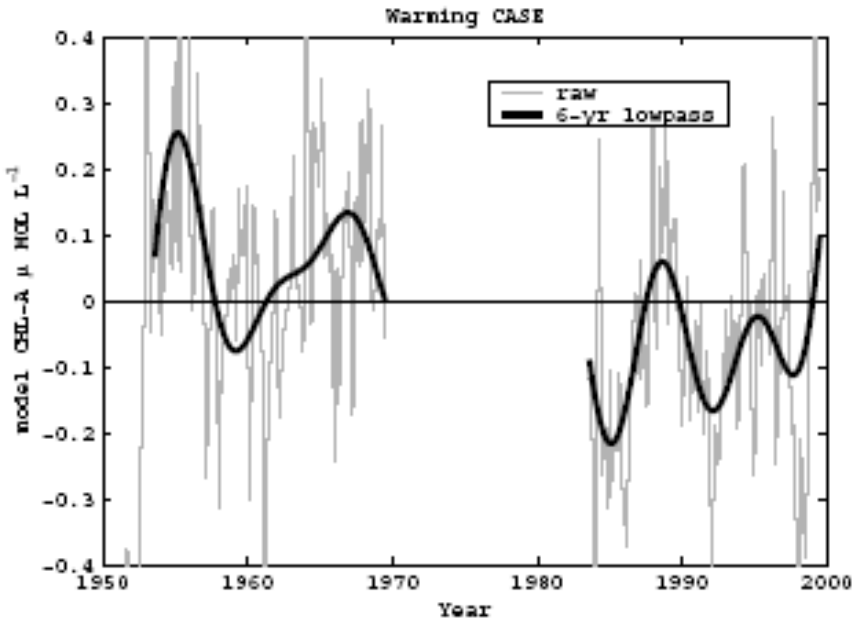
Chlorophyll response to these physical changes

In NPZD-type 7-component model hindcast

Increased winds only



Warming and winds together

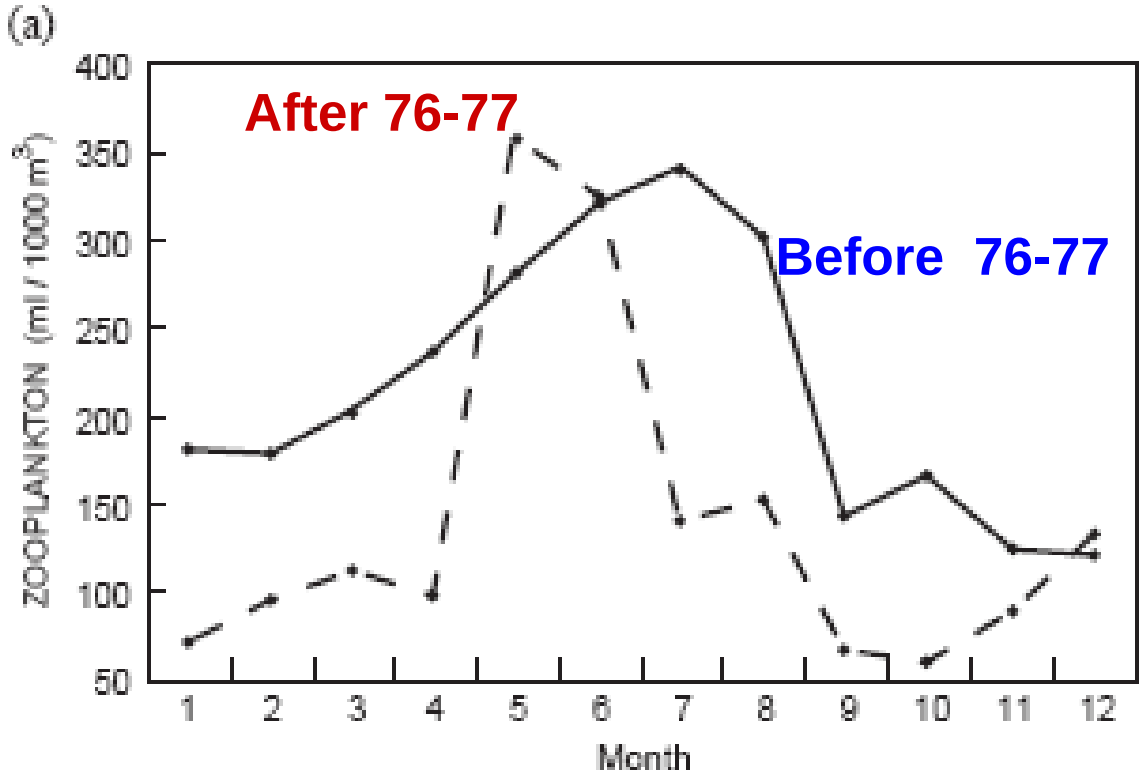


Decline in Chl-a linked to thermocline deepening in the model simulation.

This is consistent with the observed zooplankton decline.

Miller, Gabric, Moisan, Chai, Neilson, Pierce and Di Lorenzo, *sub judice*, 2004

Observed changes in the seasonal cycle of Zooplankton in the CCS



McGowan, Bograd, Lynn and Mller, DSR, 2003

What changes in Mixed-Layer Depth have occurred in CalCOFI data after the 1976-77 climate regime shift?

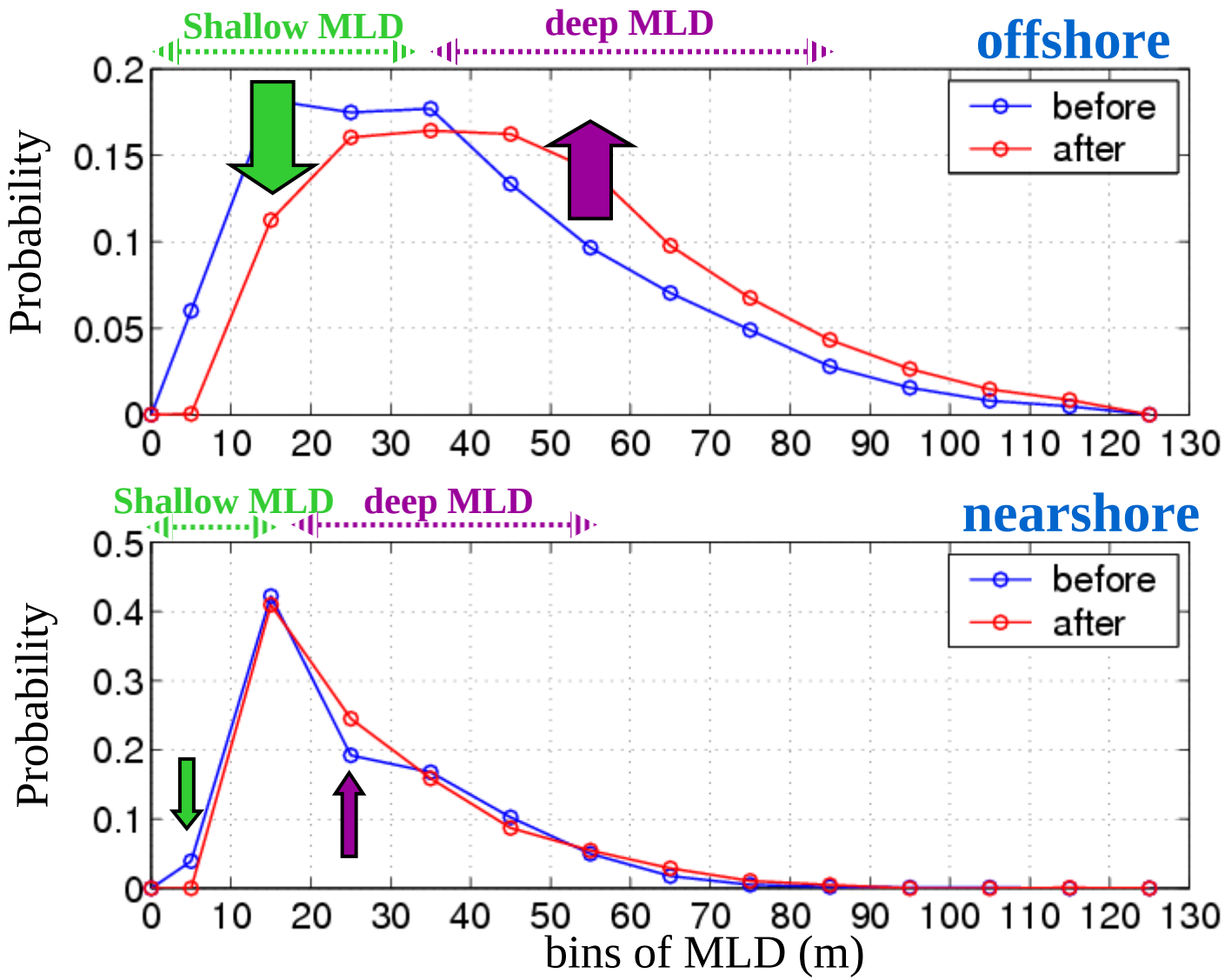
And how are these related to nutricline, thermocline, chlorophyll, and zooplankton changes?

Hey-Jin Kim, Art Miller, Doug Neilson, and John McGowan

Scripps Institution of Oceanography
La Jolla, CA

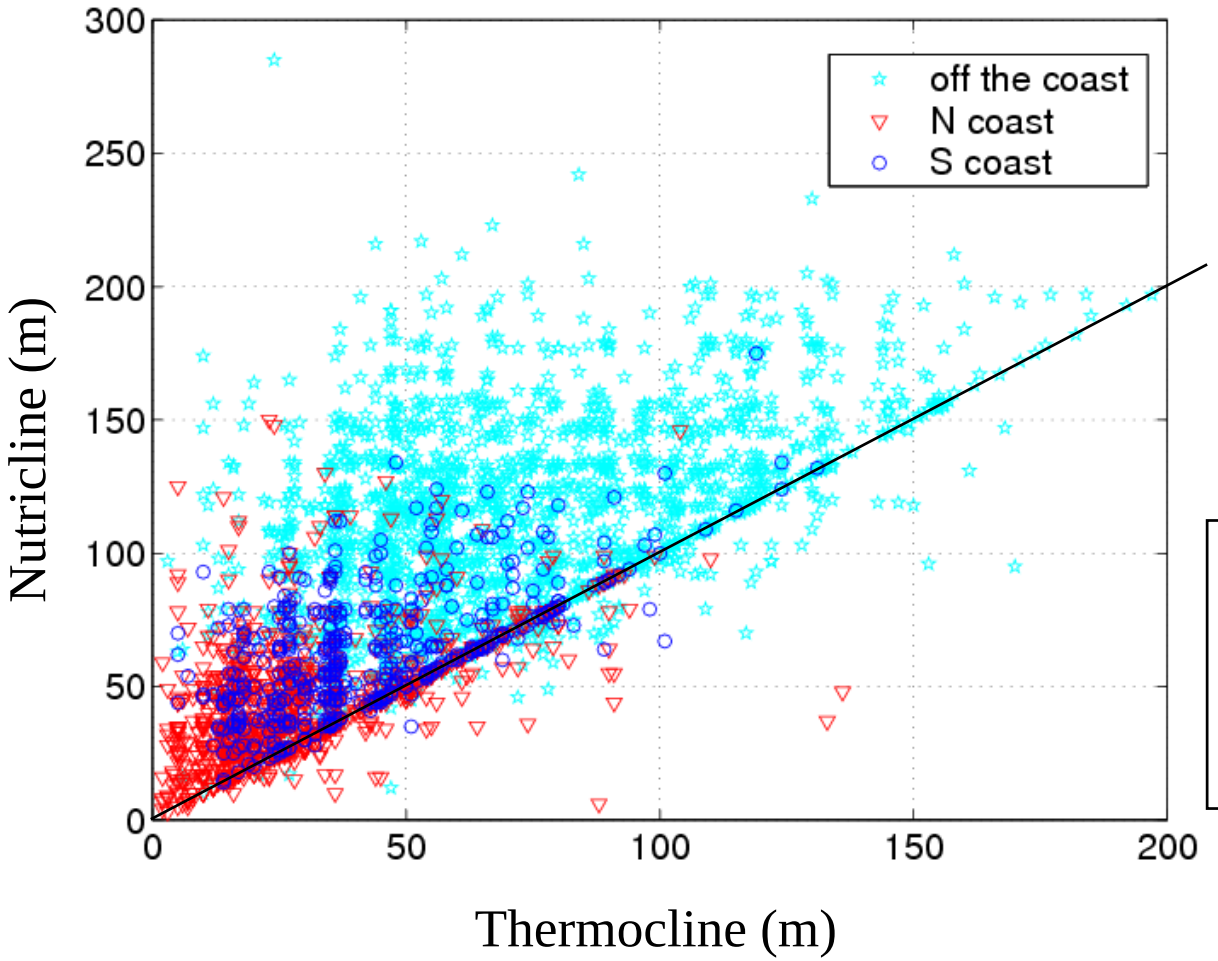
Probability Density Functions of MLD: Pre/Post 1976-77

(Hey-Jin Kim, Miller, McGowan and Neilson, in prep)



Thermocline vs. Nutricline: are they correlated?

Nutricline is much deeper than thermocline, which is deeper than MLD, suggesting decoupling of nutrient fluxes



(Hey-Jin Kim, Miller, Neilson, McGowan, in prep)

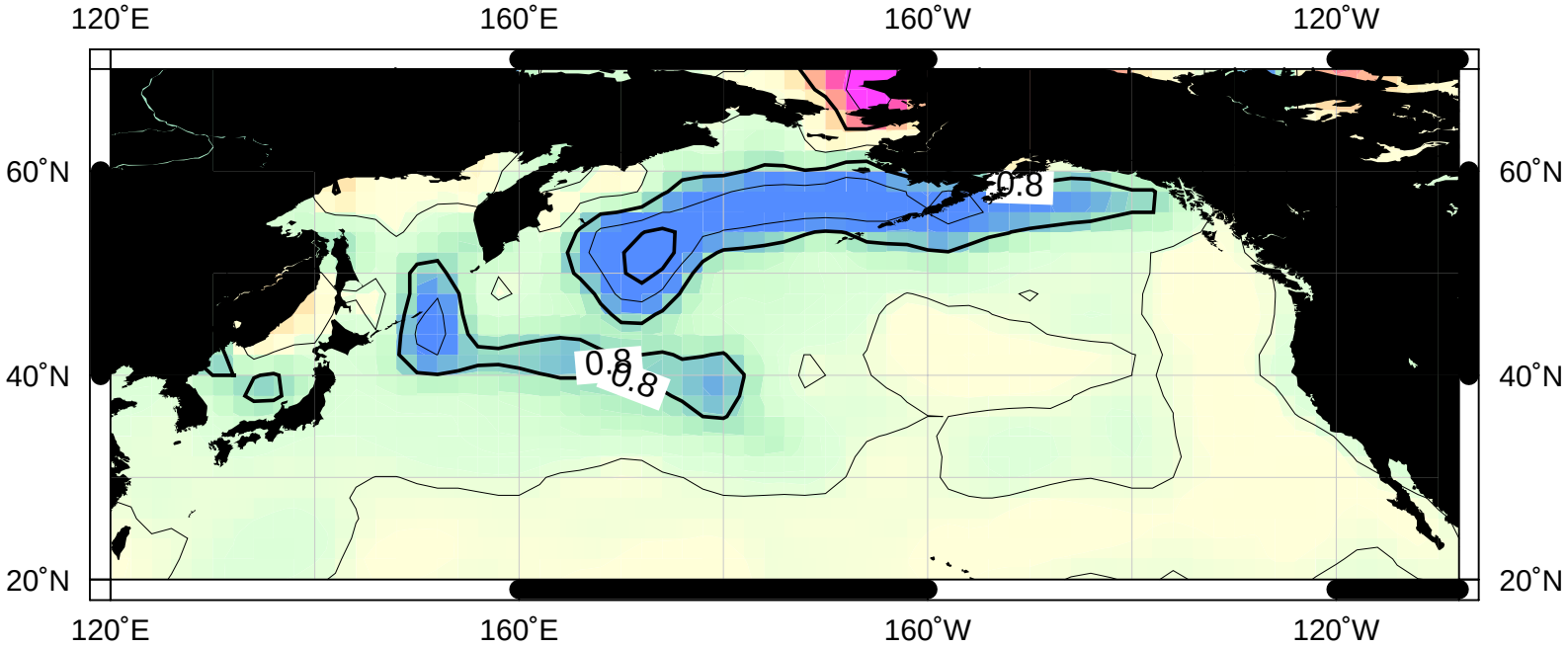
slope= 1

Linear regression :

$\alpha = 1.3 \pm 0.01$

(95 % confidence level, $r^2 = 0.98$)

Effects of anthropogenic forcing on biological activity



Biological Model Phytoplankton [mmol C/m³]

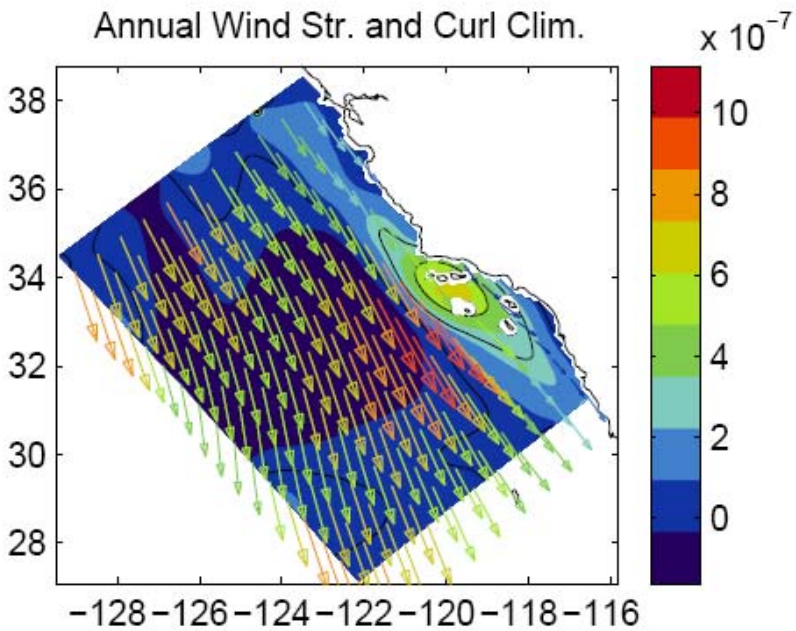
Ratio, Year 2100 / Year 2000

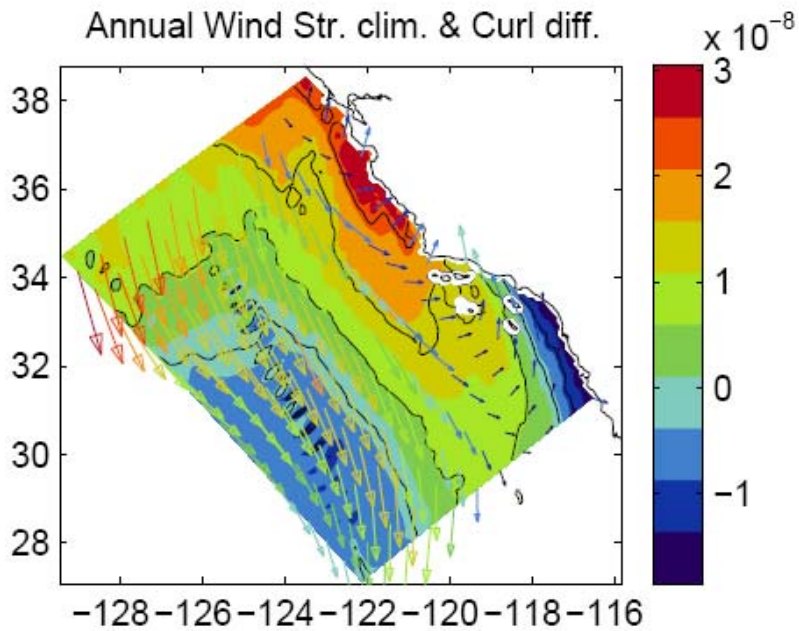
Pierce, Climate Change, 2004

California Current Circulation in a Global Warming Scenario

Baseline: NCEP 50-yr climatology of wind stress and curl

Perturbation: ACPI PCM 2040-2050 climate minus 1986-1996 climate downscaled with RSM

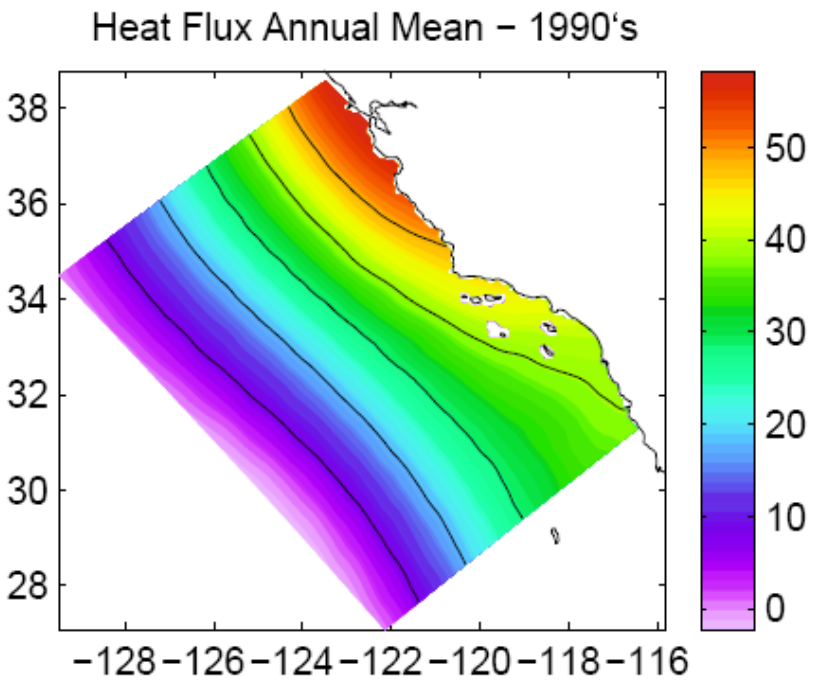


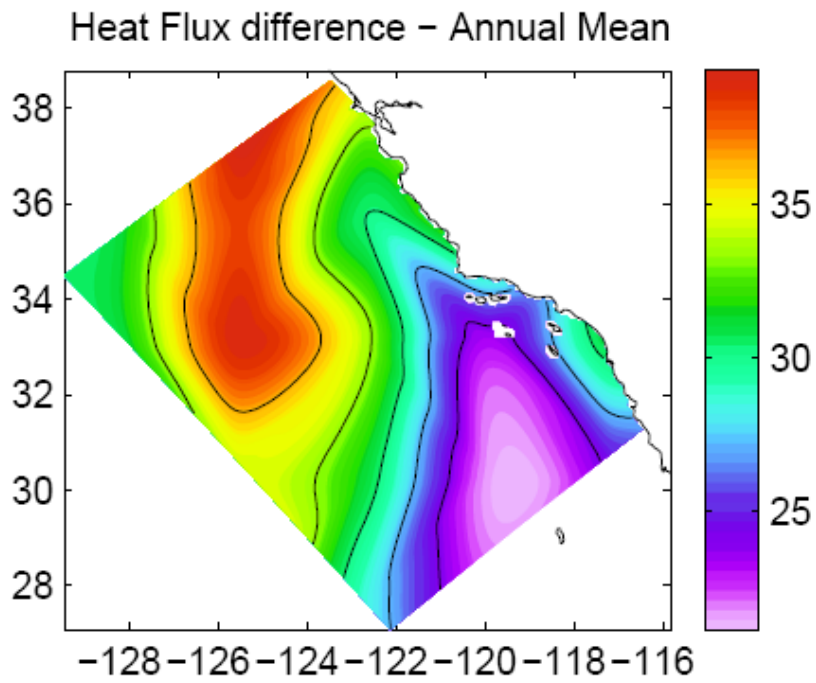


California Current Circulation in a Global Warming Scenario

Baseline: NCEP 50-yr climatology of surface heat flux

Perturbation: ACPI PCM 2040-2050 climate minus 1986-1996 climate downscaled with RSM

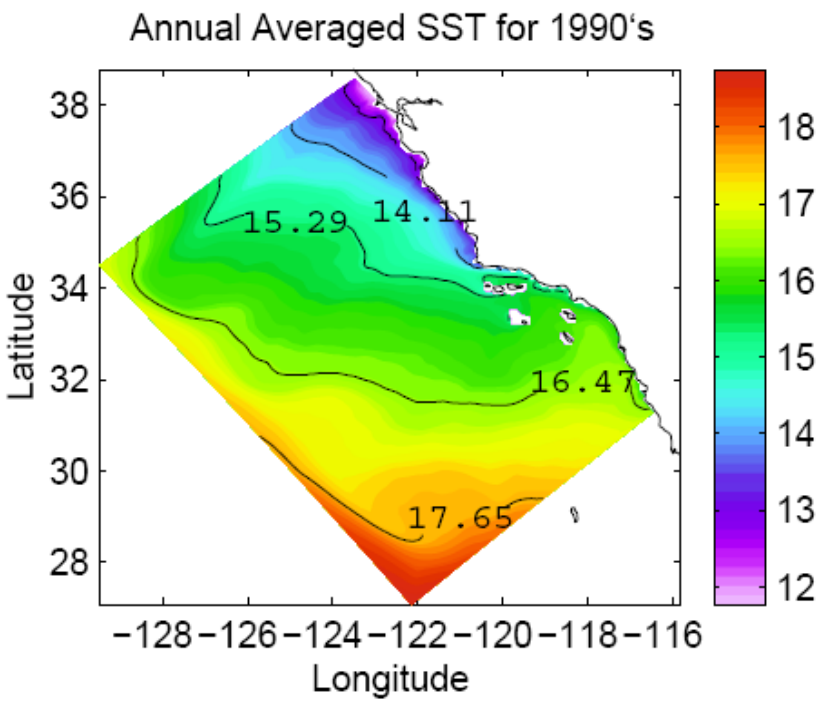


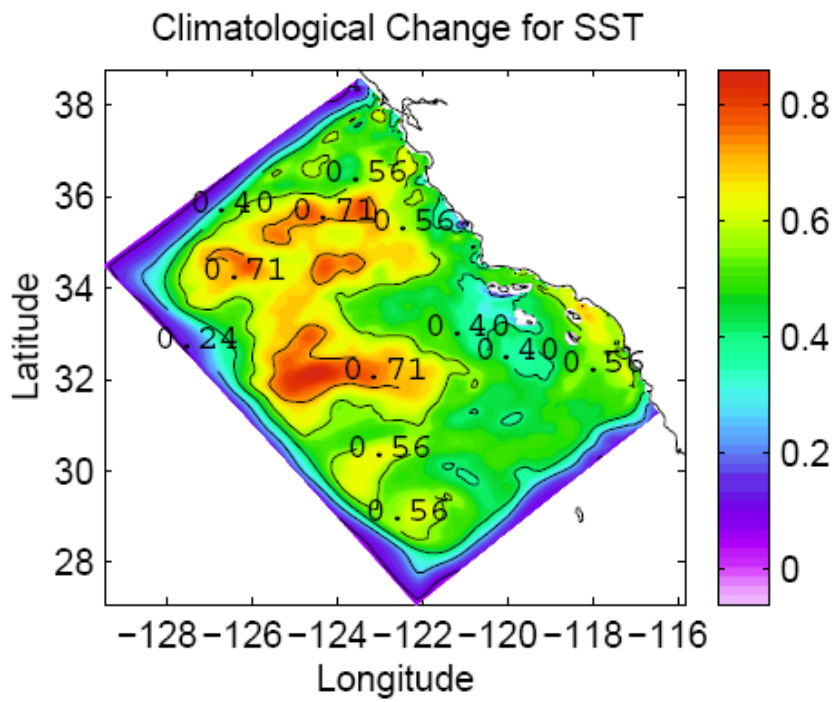


Regional SST Changes in a Global Warming Scenario

Baseline: 1 deg C warming over last 50 years of CalCOFI data

Perturbation: Forced by 2040-50 winds and surface heat fluxes, but not BC changes: SST warmed 0.4 - 0.7 deg C



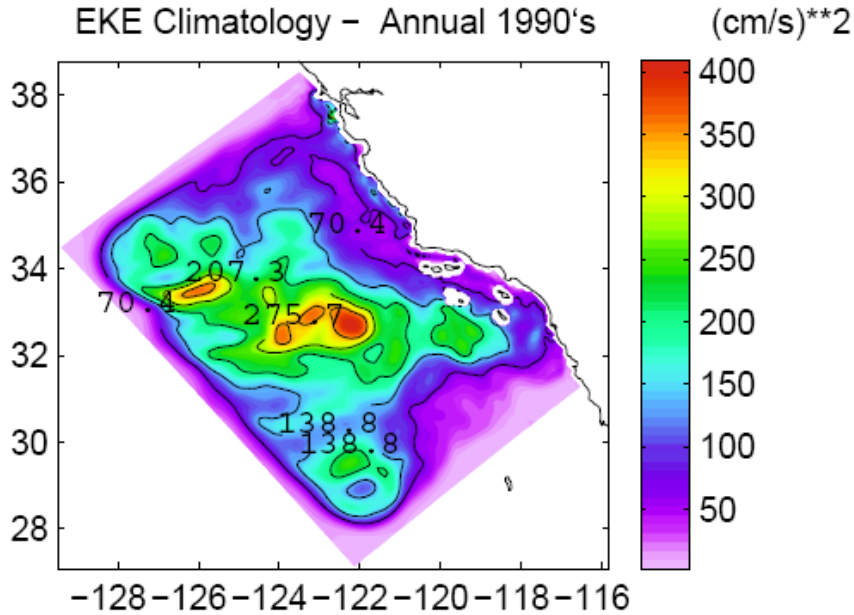


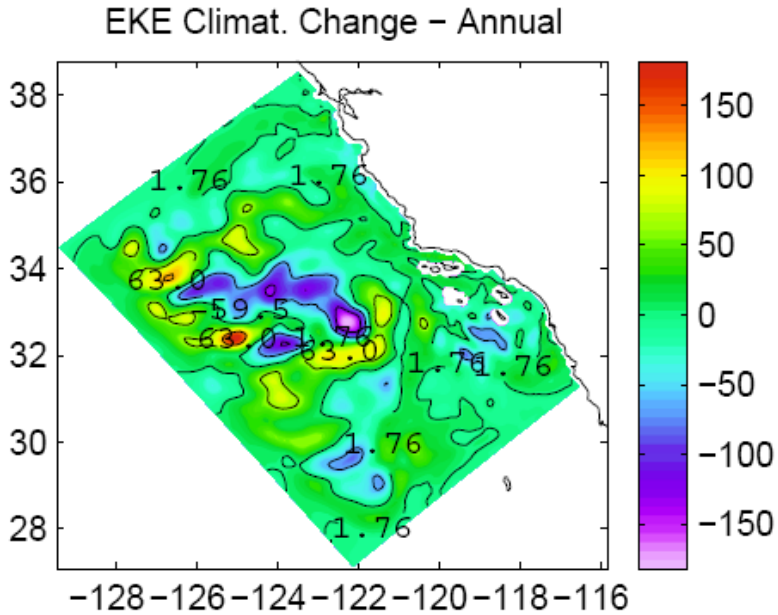
(Auad, Miller, Pierce, Di Lorenzo, in prep)

Mesoscale Eddy Variance Changes in a Global Warming Scenario

Baseline: Offshore variance max increased after 1976-77 shift
(Di Lorenzo et al., 2004)

Perturbation: Forced by 2040-50 winds and surface heat fluxes, but not BC changes: variance generally reduced (only 6 yr long run)



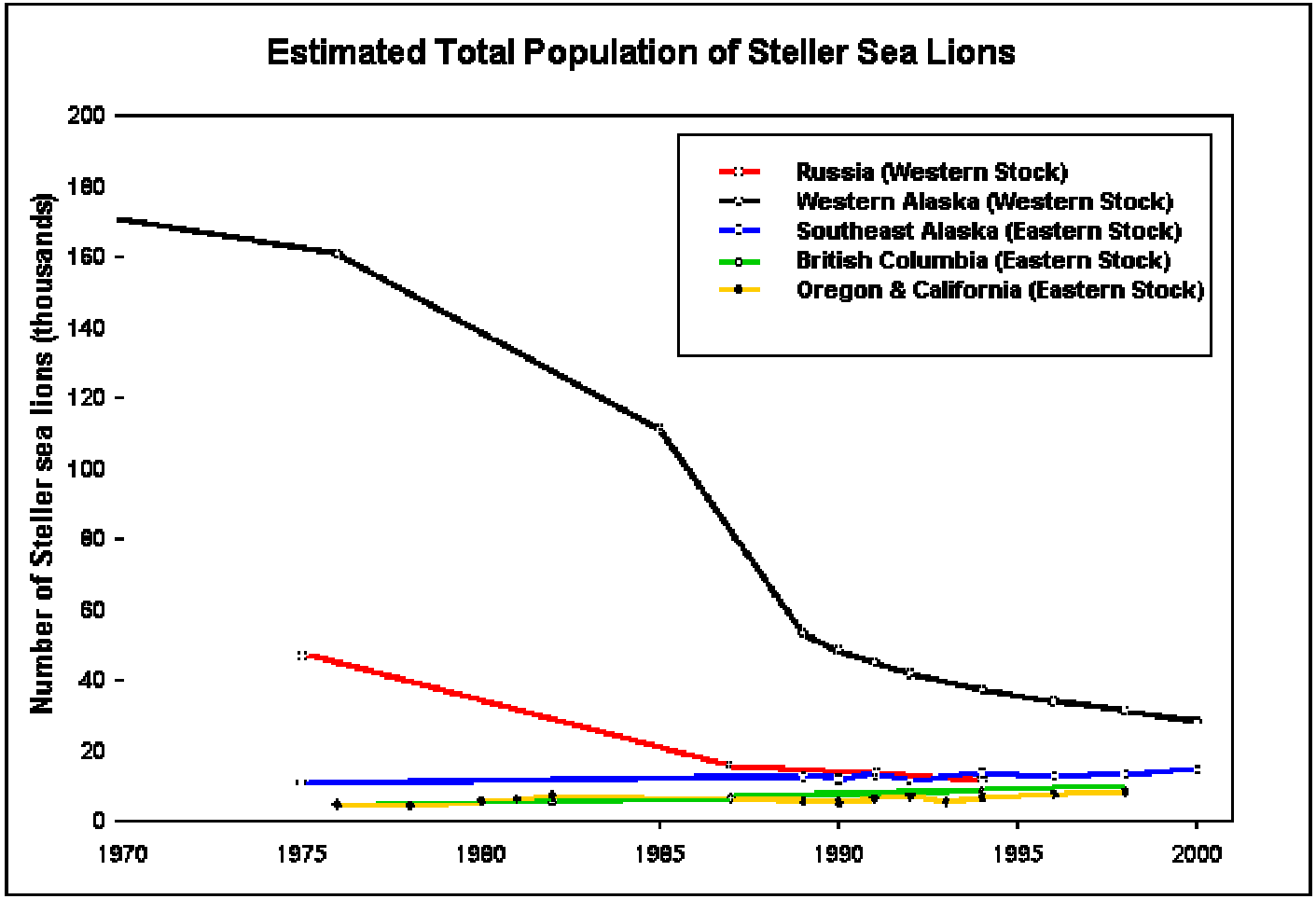


(Auad, Miller, Pierce, Di Lorenzo, in prep)

The Climate-Ocean Regime Shift Hypothesis of the Steller Sea Lion Decline

Relating temporal variability
in the physical system
to ecosystem changes

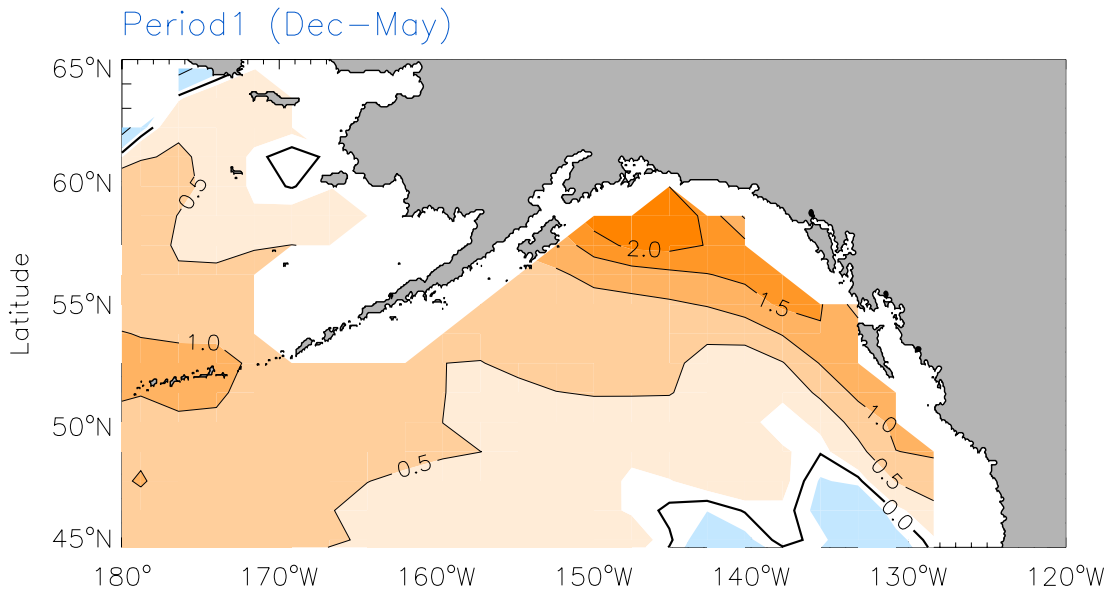
SSL population declines since 1976-77 Climate Shift: Western Gulf of Alaska population dropped Eastern Gulf of Alaska population was stable



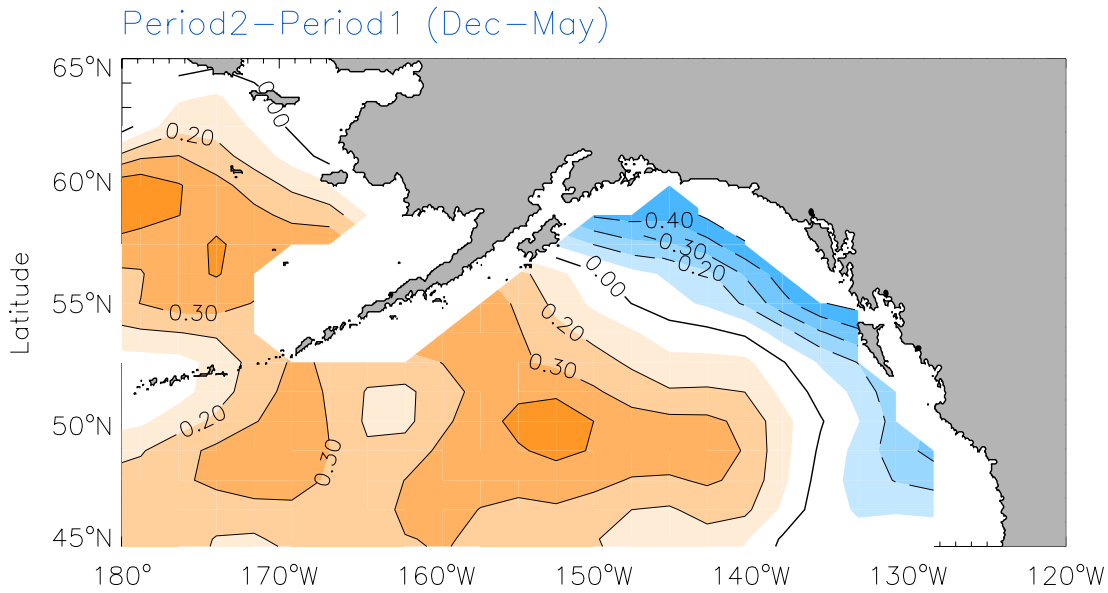
NMFS

(Trites, 2004)

Observed Changes in Ekman pumping



Pre-shift mean conditions 1960-75 Dec-May

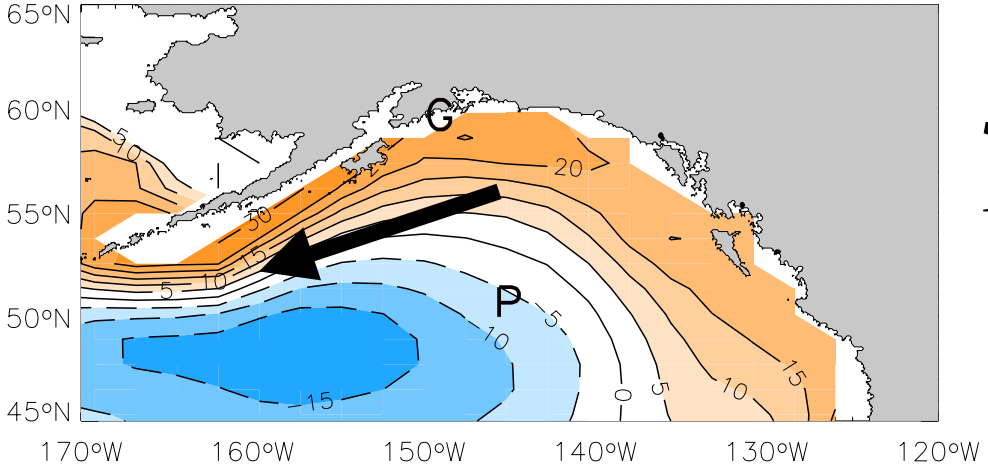


Change after shift (1977-97) -(1960-75)

Capotondi, Alexander, Deser and Miller (JPO, *sub judice*)

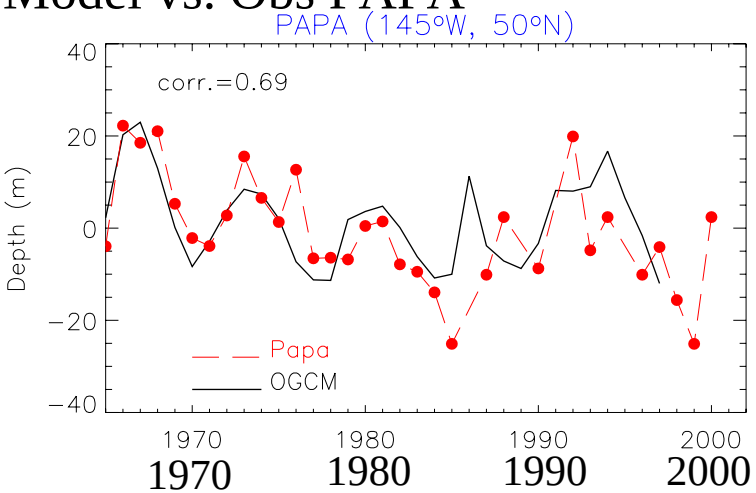
Capotondi, Alexander, Deser, and Miller (JPO, sub judice)

Coarse Resolution Model Pycnocline ($26.4\sigma_\theta$) depth changes Period2 (1977-97) – Period1 (1964-75)

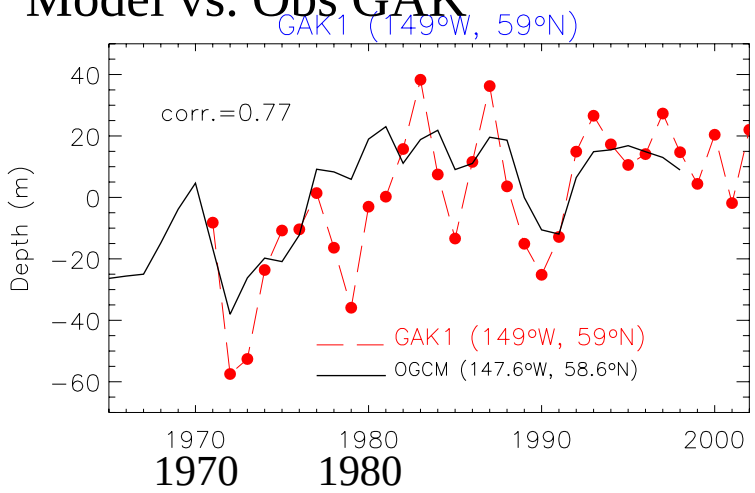


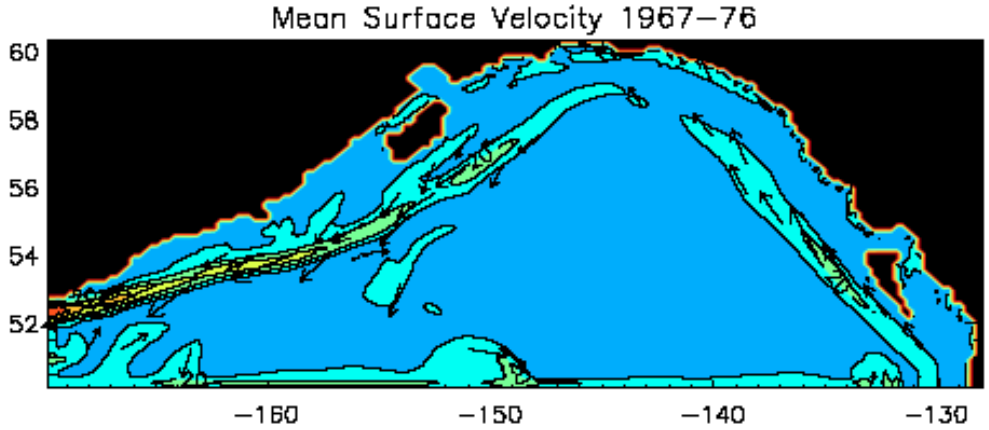
Strengthened Alaskan Stream!

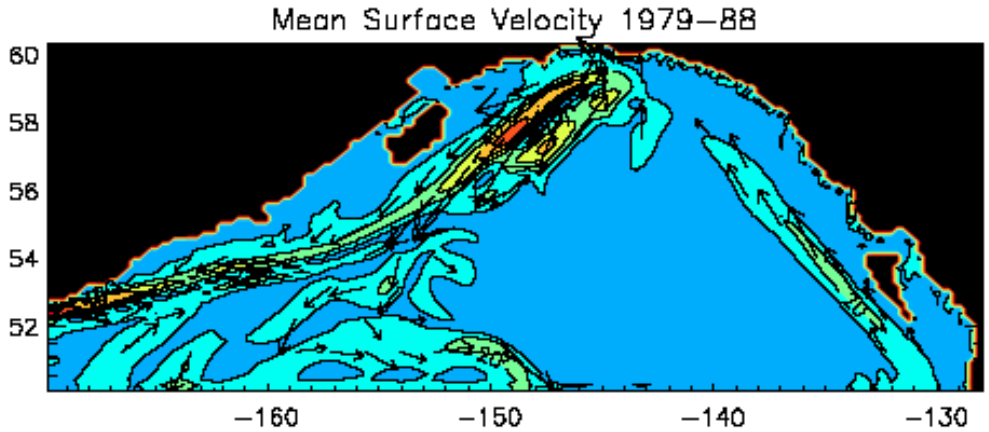
Model vs. Obs PAPA

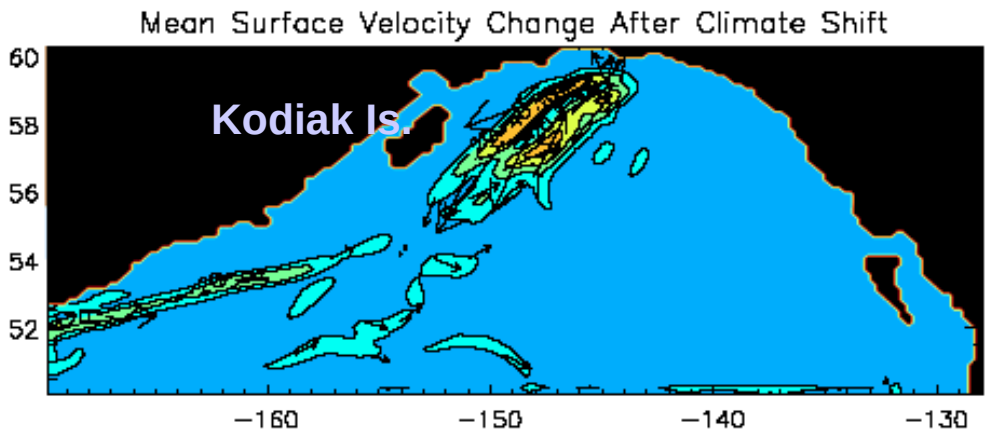


Model vs. Obs GAK









Eddy-Permitting Model Mean Surface Currents

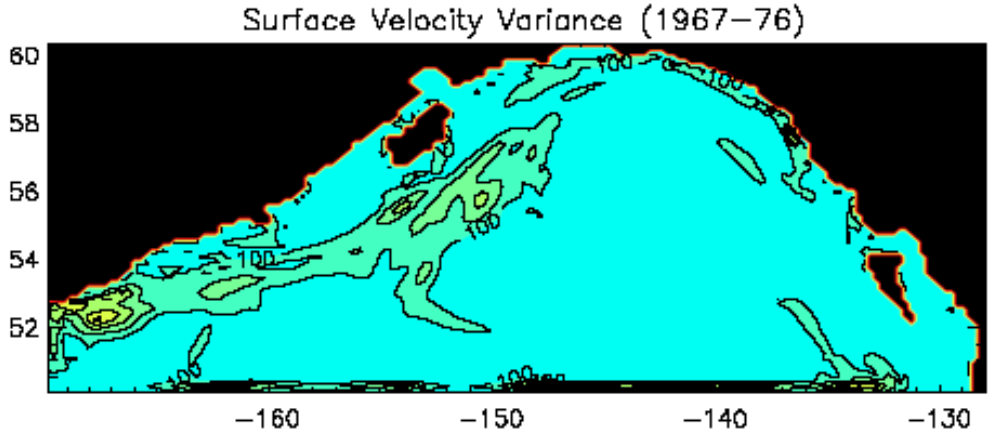
Before 76-77 Shift

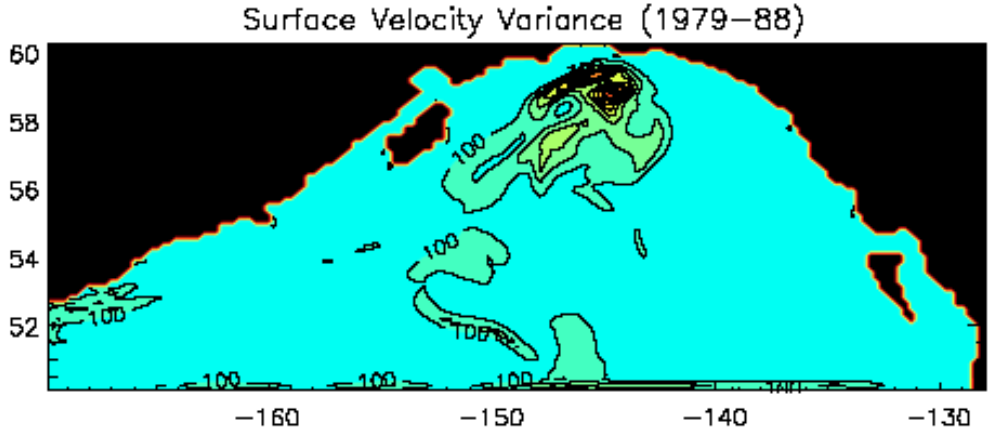
After 76-77 Shift

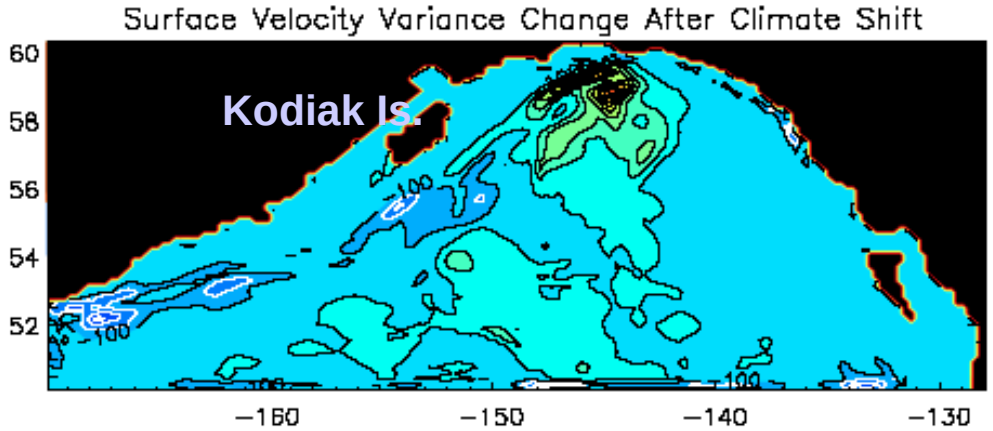
Difference

Large in western gulf
Little change in east

Miller et al., Atmosphere-Ocean, sub judice







Eddy-Permitting Model
Eddy Surface Currents

Before 76-77 Shift

After 76-77 Shift

Difference

More eddies north of Kodiak
Fewer eddies southwards

Miller et al., Atmosphere-Ocean, sub judice

Circulation Changes in the Gulf of Alaska associated with the Decline of the Steller Sea Lion Population

- Post 1976-77, eddy-resolving model hindcast reveals:

  Stronger Alaska Stream north of Kodak Island

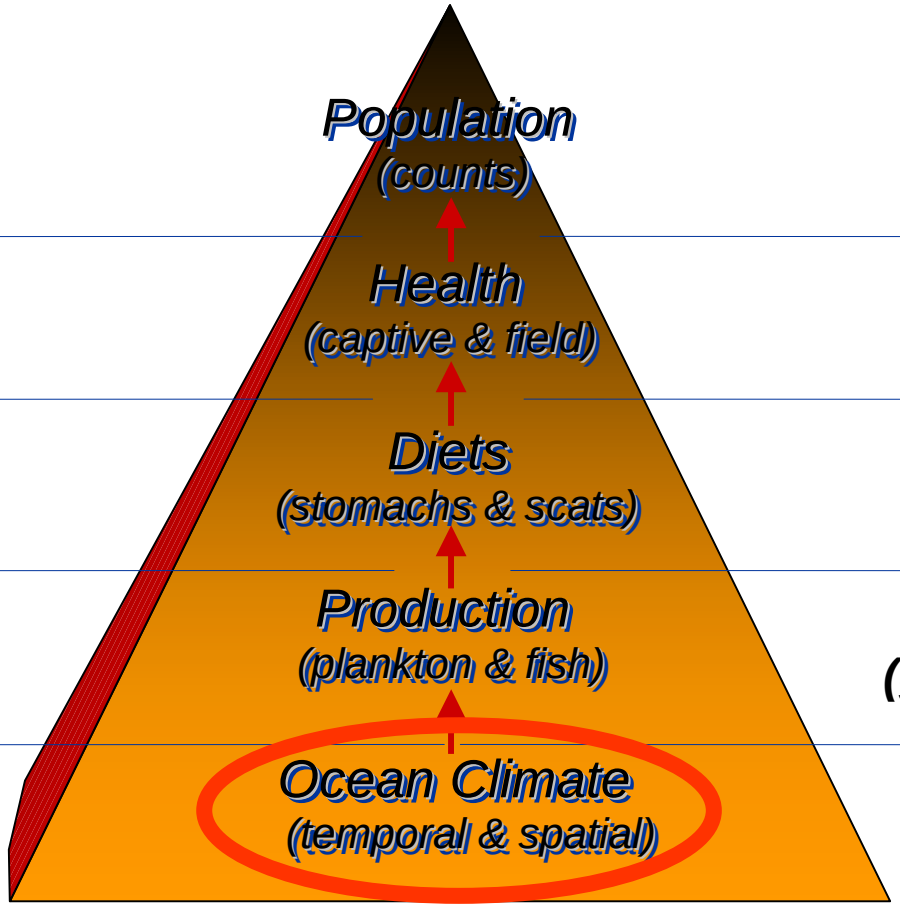
  Reduced eddy variance south of Kodiak Island

  Alaska Current mean and eddy fields **unchanged**
- Consistent with sea lion populations being reduced 80% in the western Gulf, but remaining stable in the eastern Gulf

Miller, Di Lorenzo, Neilson, Alexander, Capotondi, Bograd, Schwing, Musgrave, and Hedstrom, *Atmosphere-Ocean, sub judice*, 2004

Why Did They Decline?

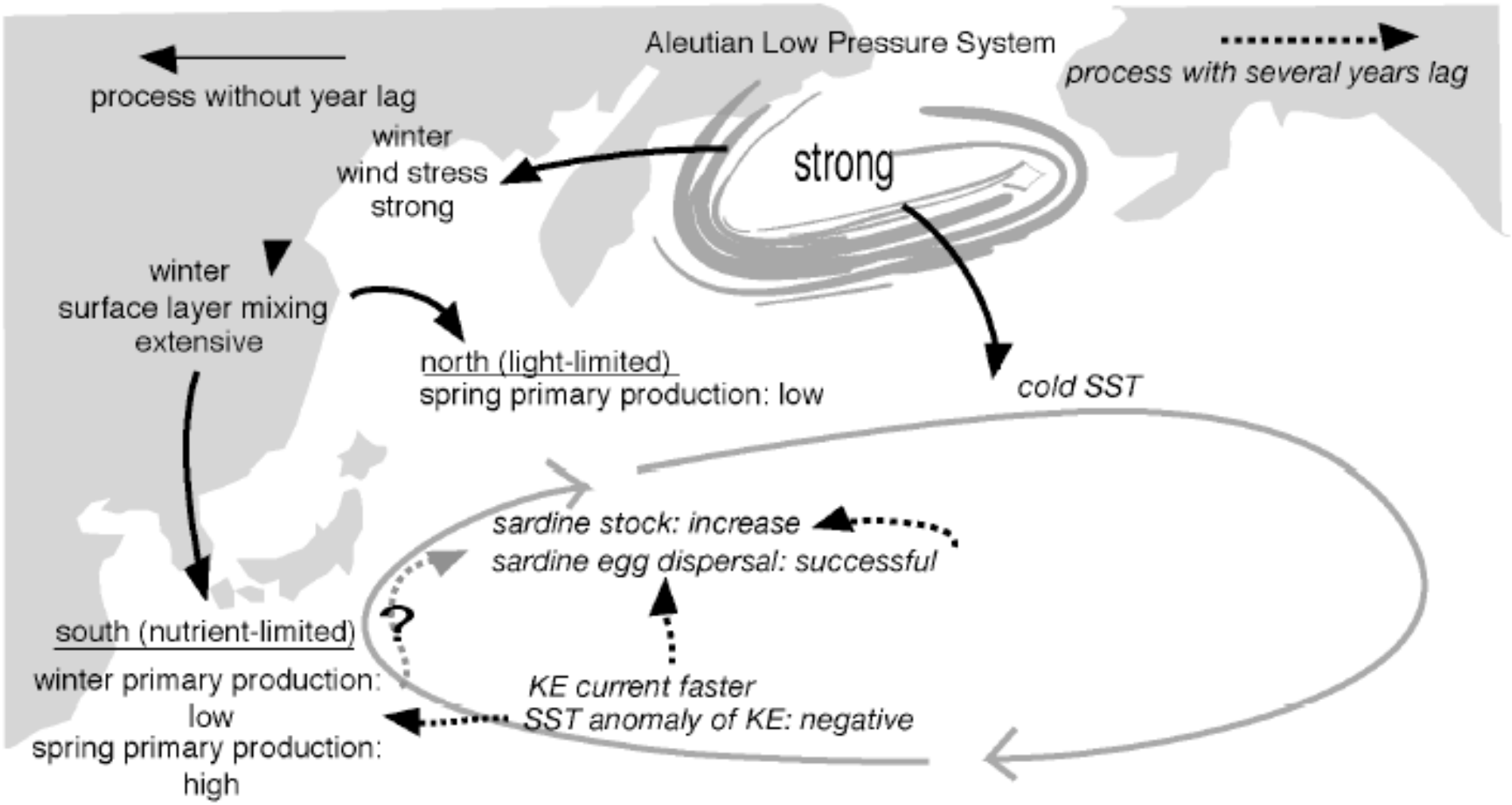
Good		Bad
Increase	Population (counts)	*Decline*
Positive	Health (captive & field)	*Negative*
Energy Richer	Diets (stomachs & scats)	*Energy Poorer*
Fattier fishes (forage fish)	Production (plankton & fish)	*Leaner fishes (gadids & flatfish)*
1950-1976; 1999-2003?	Ocean Climate (temporal & spatial)	*1977-1988; 1989-1998*



Trites, Miller, Maschner and 22 co-authors, *Fisheries Oceanogr., sub judice*

Ecosystem response processes in KOE on long timescales

Strengthened Aleutian Low



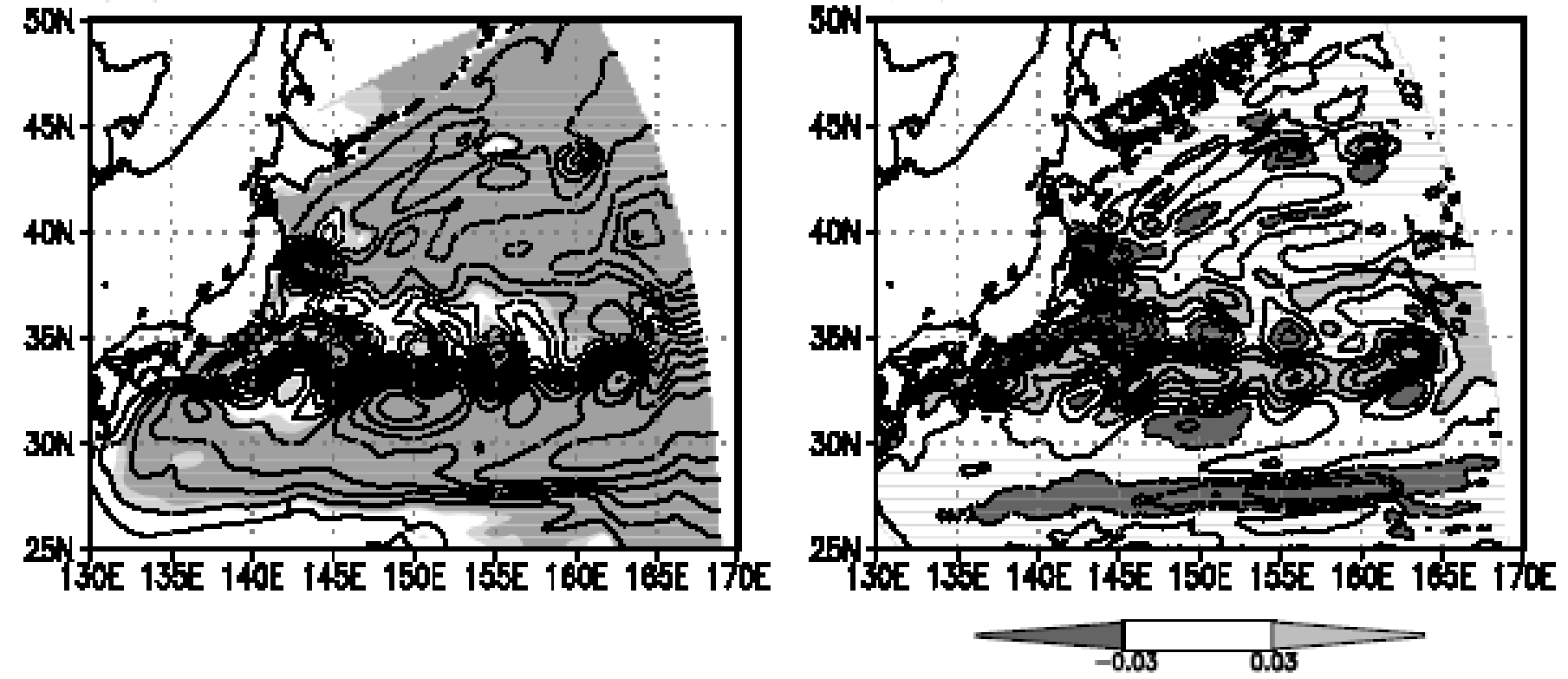
Miller, Chai, Chiba, Moisan and Neilson, J. Oceanogr., 2004

Regional scale influence of Rossby waves on Kuroshio-Oyashio Extension

(**Tagushi, Xie, Mitsudera and Kubokawa**, *J Climate*, submitted)

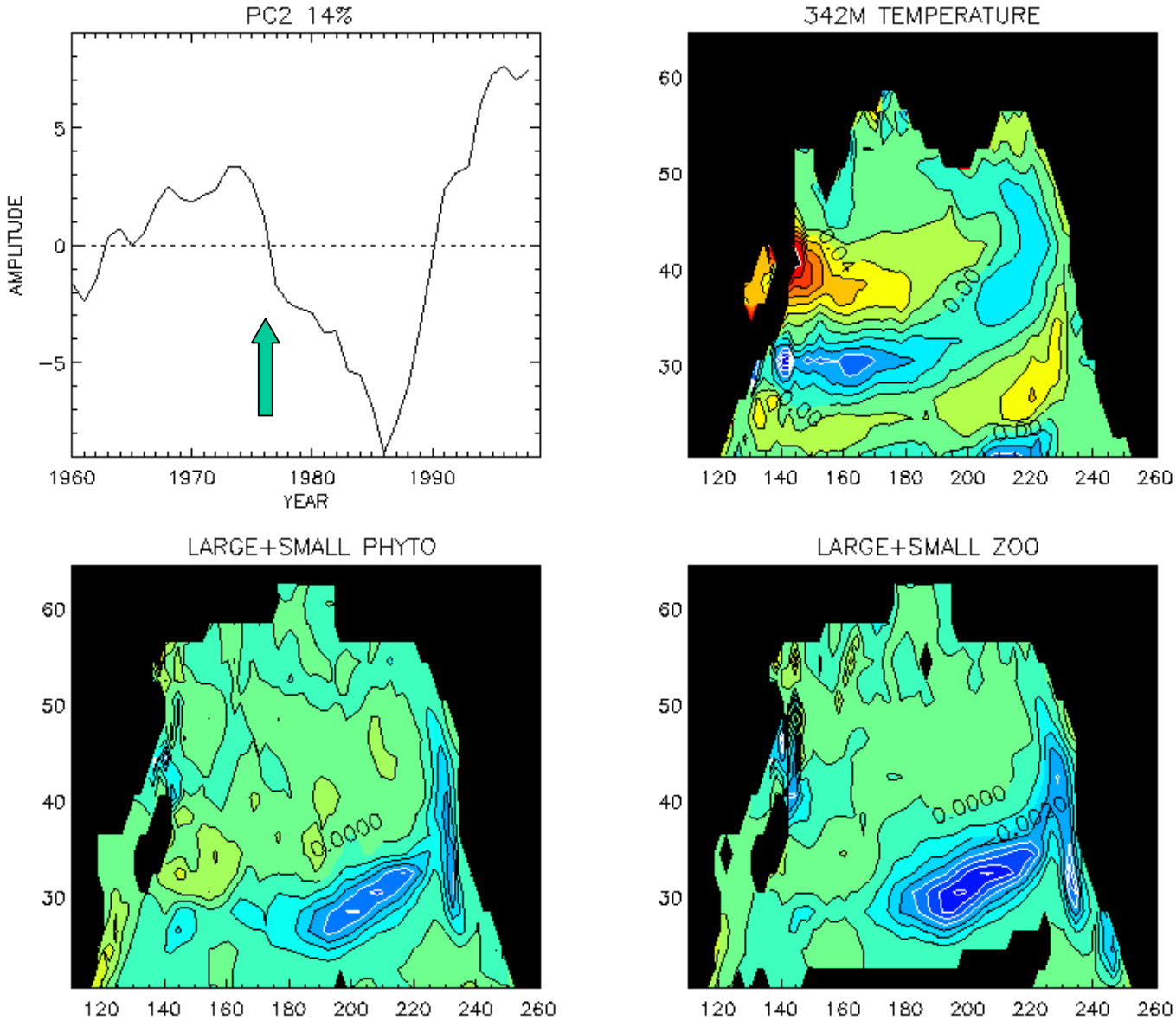
Post 76-77, nonlinear strengthening of eastward flows in KOE

Sea level **Zonal currents**



Physical-Biological Hindcast of Pacific Ocean Decadal Variability

First EOF of Combined Thermocline, Phyto-, and Zooplankton fields

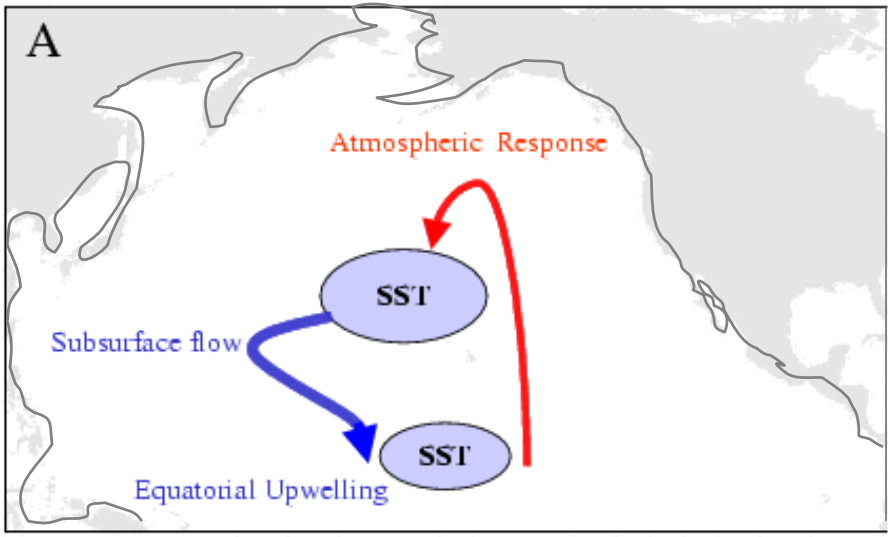


Regional upwelling (downwelling) around KOE…..

…linked to regional enhanced (reduced) primary and secondary production in model

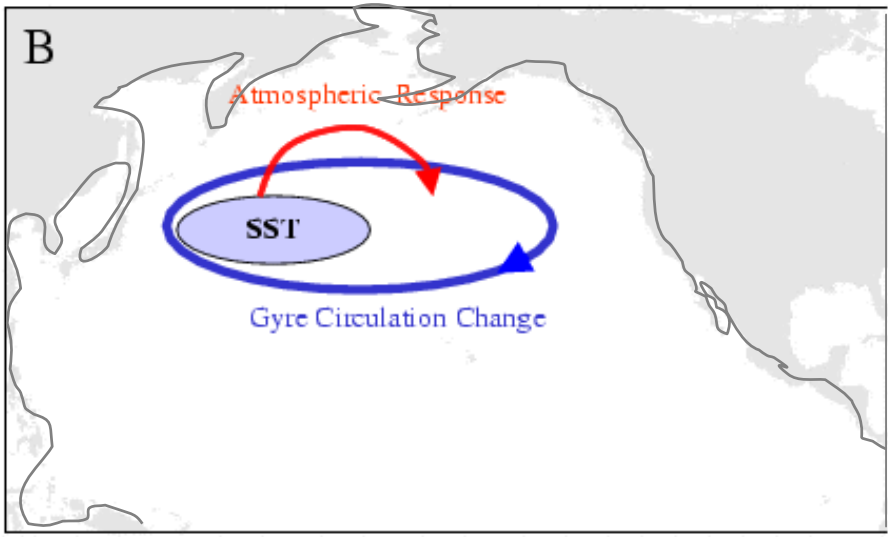
Miller, Chai, Chiba, Moisan, and Neilson, J. Oceanogr., 2004

Subduction Mode



Schematic of the Gu-Philander class of decadal mode

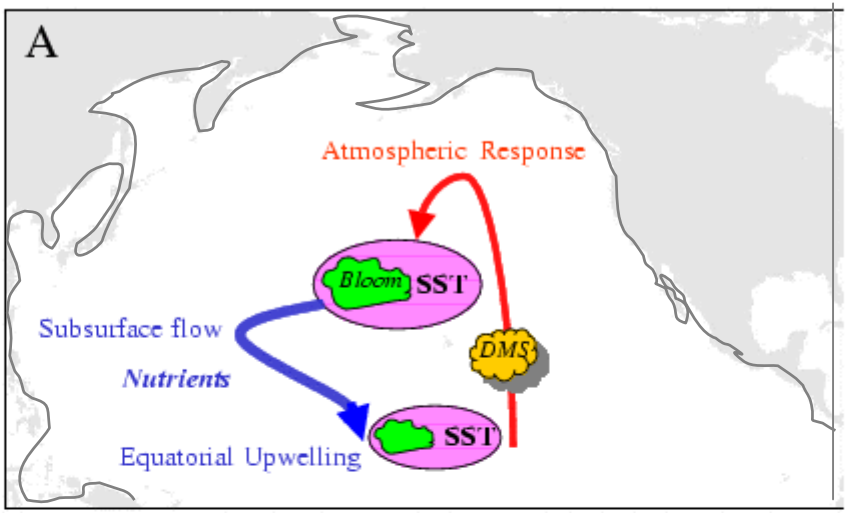
Midlatitude Gyre Mode



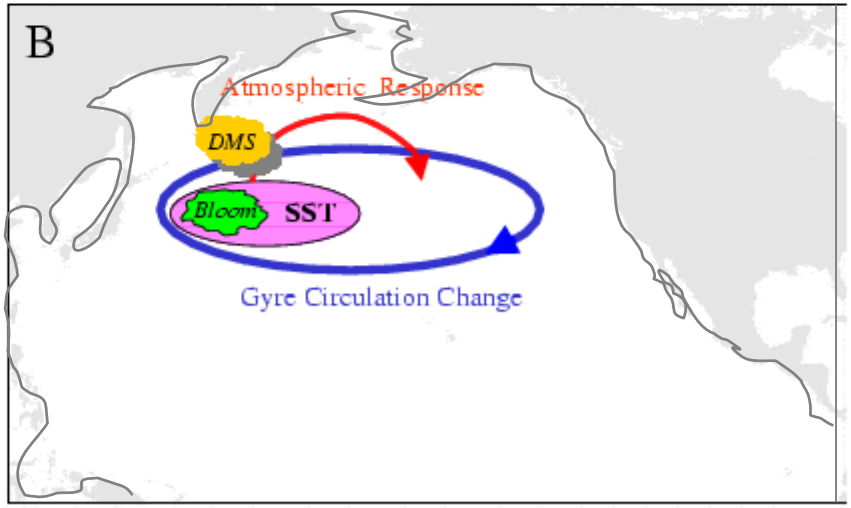
Schematic of the Latif-Barnett class of decadal mode

Miller et al., 2003,
Bull. Am. Meteorol. Soc.

Subduction Mode with Biology



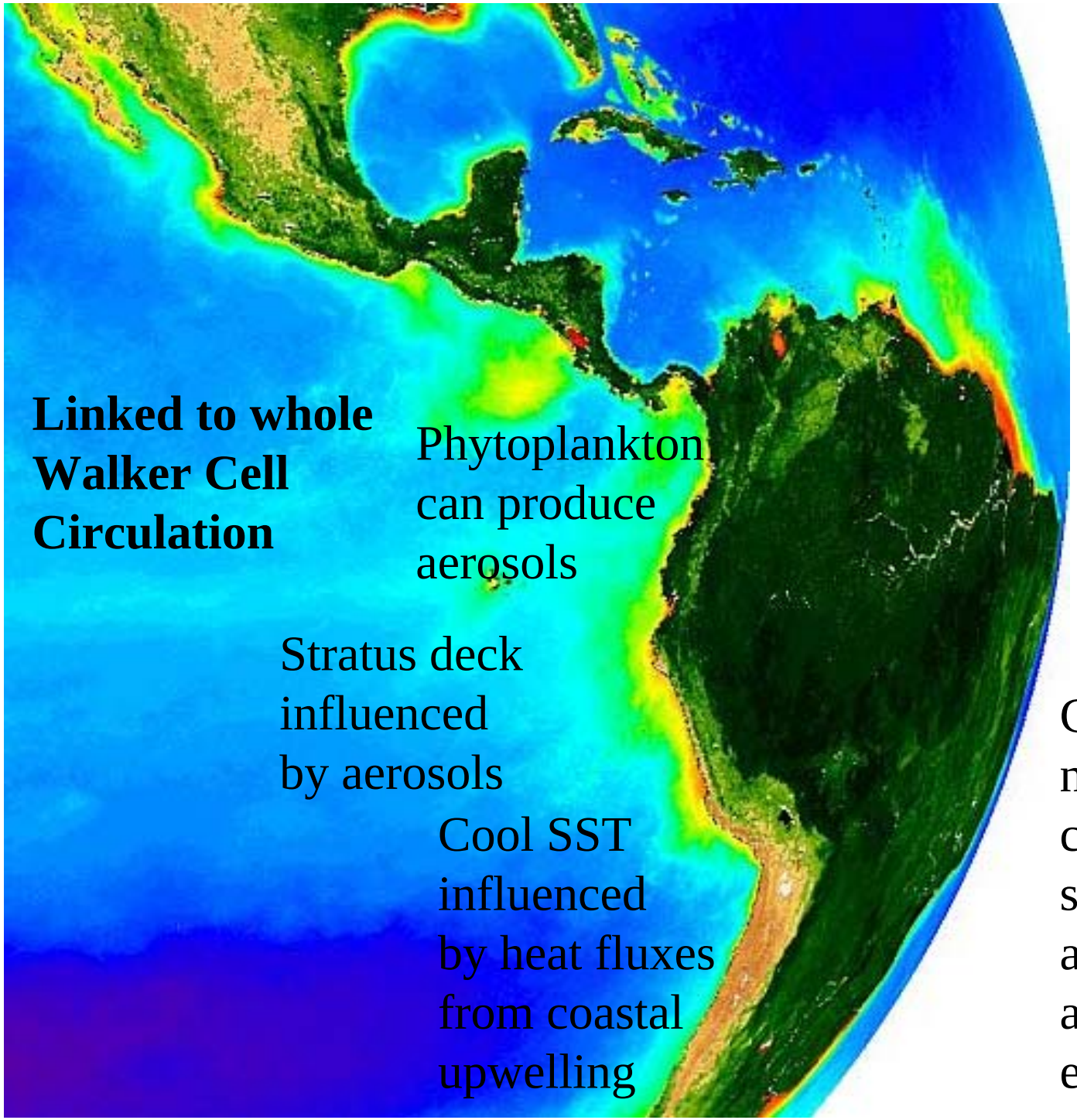
Midlatitude Gyre Mode with Biology



Schematic of the Gu-Philander class of decadal mode with DMS aerosols and phytoplankton heat absorbtion effects

Schematic of the Latif-Barnett class of decadal mode with DMS aerosols and phytoplankton heat absorbtion effects

Miller et al., 2003, Bull. Am. Meteorol. Soc.



EPIC/VAMOS (VOCALS)

What controls the stratus deck off South America?

Coastal upwelling not resolved in climate models, so how would it affect the ocean-atmosphere-ecosystem response?

Directions….

Atmosphere

- **Details of atmosphere response over KOE region**
- **Sensitivity to ocean biology: DMS aerosols**
- **Regional downscaling over mountains and coasts**

Ocean

- **Physical mechanisms of adjustment to forcing**
- **Lags and predictable compoments**
- **Changes in eddy statistics**
- **Sensitivity to ocean biology: phytoplankton absorbtion**

Biology

- **Organization of response by ocean patterns**
- **Lags and predictable components**
- **Distinguishing forced from intrinsic variations**

…and Global Change effects on all these….


Thanks!
PICES CLIVAR Intersection Workshop
Honolulu, Hawaii