CALIFORNIA DEPARTMENT OF FISH and WILDLIFE

Focus on Marine Resources

2014 Climate College

2014 Climate College – Lecture #3

April 3, 2014

2:00 PM - 4:00 PM

CDFW CLIMATE COLLEGE

California Department of Fish & Wildlife

Monterey Bay Aquarium Research Institute

Pacific Forum

7700 Sandholdt Road, Moss Landing, CA

Welcome

MBARI

SCRIPPS INSTITUTION OF OCEANOGRAPHY UC San Diego

CALIFORNIA DEPARTMENT OF FISH & WILDLIFE

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Reminders:

- CDFW Staff: please register for credit
- Non-CDFW: please register for reminders
- Q&A/Discussion topics:
  - ➢ Do you currently use any of this information in your project tasks?
  - ➢ How could you incorporate this information into your management activities?
  - ➢ Would any specific tools (example: summarized data, GIS maps, projected trends) be useful?
- Co-moderators: Laura Rogers-Bennett, Briana Brady

CALIFORNIA DEPARTMENT OF FISH and WILDLIFE

2014 Climate College

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Fish, Wildlife and Habitat Management |

Climate Science Program

- Activities
- Resources
- CDFW Climate College
- CDFW Climate Stakeholders
- CDFW Going Green
- Climate Change Case Studies
- Vulnerability Assessment Tools
- For Teachers
- National Adaptation Forum
- Western Association of Fish and Wildlife Agencies
- Director's Bulletins
- Legislation and Policy

CDFW Climate Science and Renewable Energy Branch
1416 9th Street
Sacramento, CA 95814
climatechange@wildlife.ca.gov

Home » Climate and Energy » Climate Change » Climate College

2014 California Department of Fish and Wildlife Climate College

In Spring 2014, CDFW will hold the second iteration of its Climate College, this time focusing on the state's Marine resources and featuring tribal perspectives on marine ecosystem management.

The CDFW Climate College is intended to provide a basic foundation of knowledge for all staff and partners on climate change science and its impacts to fish, wildlife, and habitats. This iteration of the course will focus on how climate change affects the state's marine resources to enhance participants' understanding of marine-related climate change science, impacts to species and habitats, and the implications for marine region management and planning. In the interest of developing stronger partnerships between tribal nations and the Department, this course is being developed as a collaborative effort with tribal representatives, and will introduce traditional ecological knowledge (TEK). TEK can be defined as the "holistic, evolving practices and beliefs passed down through generations about the relationships of living beings to their environment" (Swinomish 2010, in National Strategy, 2013).

CDFW CLIMATE COLLEGE
California Department of Fish and Wildlife

The course will describe California's unique challenges and opportunities in managing its 1,100 miles of coastline, bays/estuaries, and marine protected areas under climate impacts. The course will also discuss case studies to show examples of responses to climate impacts. Through this course, the Department will demonstrate California's continuing leadership in addressing climate impacts as well as managing natural resources through diverse input and coordination with similar efforts at the federal and local levels.

Lecture topics will cover atmospheric changes, physical oceanic changes, sea level rise, species response, and conservation planning. The lectures will also cover biological ocean changes such as primary productivity and related processes, and productivity/abundance/phenology. This course will also provide examples of adaptation strategies to address the issues discussed.

The course will consist of a 7-part lecture series scheduled to begin in February 2014, however specific course dates and times are still to be determined. Please check this web page for future updates. In the spirit of increasing climate literacy and partnership the course is **open to all partners and the public**. We encourage all who are interested to participate either in person or via WebEx.

http://www.dfg.ca.gov/Climate_and_Energy/Climate_Change/Climate_College/

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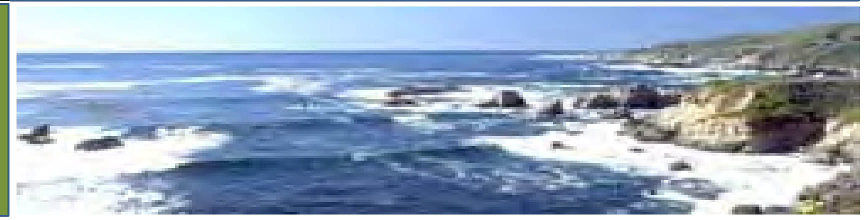
Focus on Marine Resources

2014 Climate College



~For this class~

At the facility:

- Please sign in
- Please mute cell phones

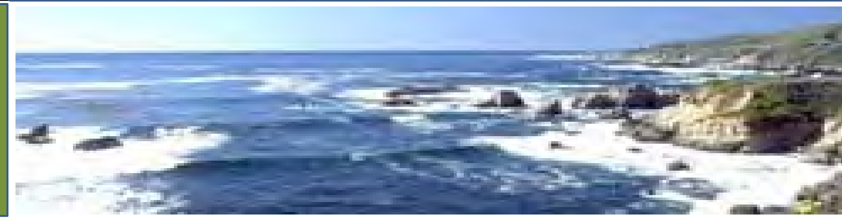
Webex users:

- Remote users will be muted for recording
- Please submit questions via “Chat” feature to the host following class presentation

CALIFORNIA DEPARTMENT OF FISH and WILDLIFE

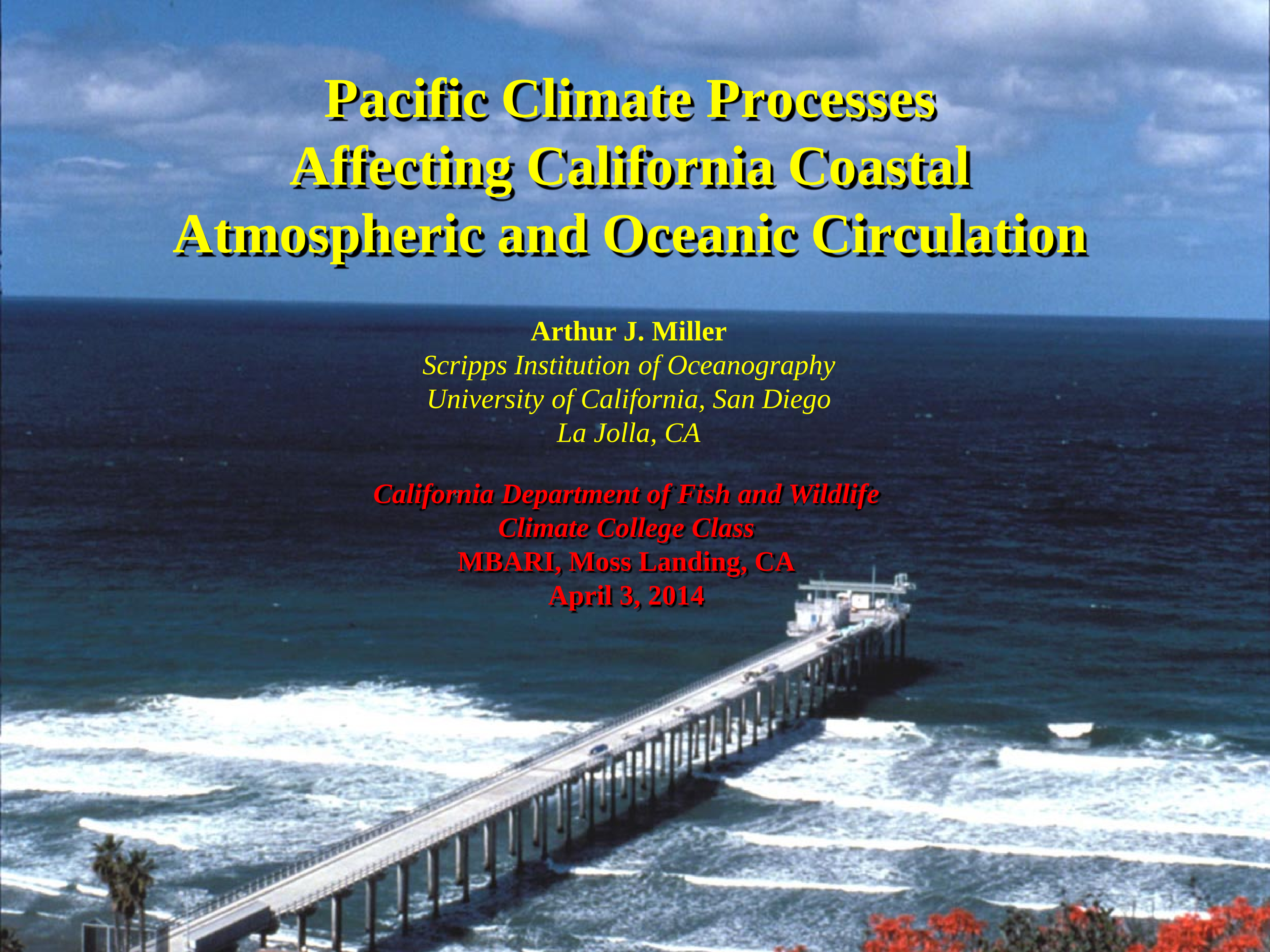
Focus on Marine Resources

2014 Climate College



Dr. Arthur Miller
Research Scientist
Scripps Institution of Oceanography

Dr. Francisco Chavez
Research Scientist
Monterey Bay Aquarium Research Institute



Pacific Climate Processes Affecting California Coastal Atmospheric and Oceanic Circulation

Arthur J. Miller
Scripps Institution of Oceanography
University of California, San Diego
La Jolla, CA

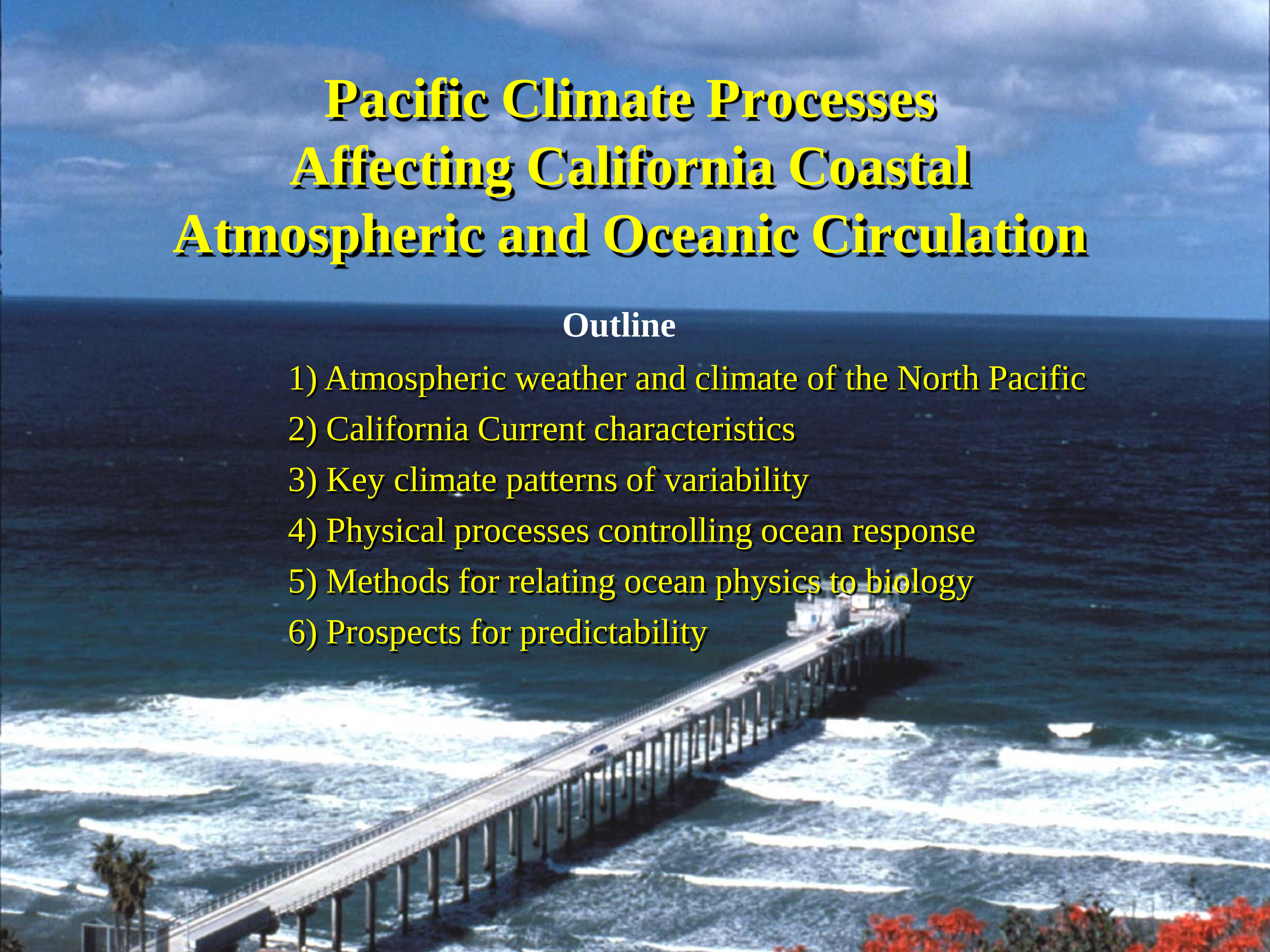
California Department of Fish and Wildlife
Climate College Class
MBARI, Moss Landing, CA
April 3, 2014

Pacific Climate Processes Affecting California Coastal Atmospheric and Oceanic Circulation

An extensive set of North Pacific observational and modeling results motivates studies with this

Unifying Scientific Motivation:

How do changes in surface forcing (heat fluxes, wind stresses) alter ocean stratification, upwelling cells and current statistics and the consequent upward nutrient fluxes that may control ocean biological variations?



Pacific Climate Processes Affecting California Coastal Atmospheric and Oceanic Circulation

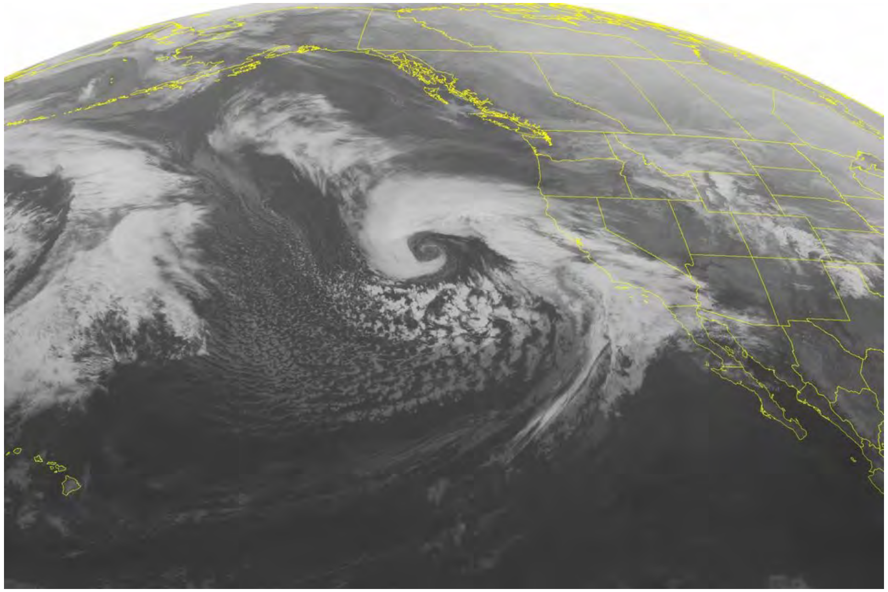
Outline

1) Atmospheric weather and climate of the North Pacific
2) California Current characteristics
3) Key climate patterns of variability
4) Physical processes controlling ocean response
5) Methods for relating ocean physics to biology
6) Prospects for predictability

Weather and Climate

- Weather: Short time scale (days): Affects things directly - storms, rain, winds, heat waves, extreme events, balmy days

Winter storms

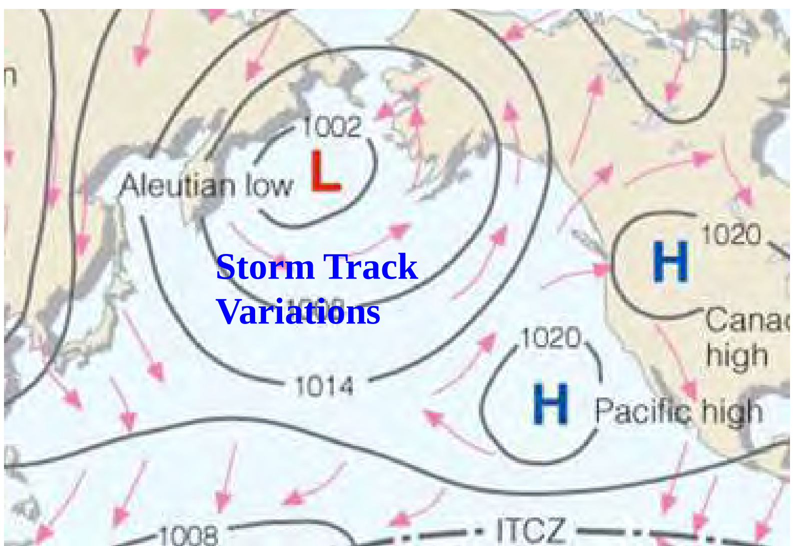


Summer stratocumulus

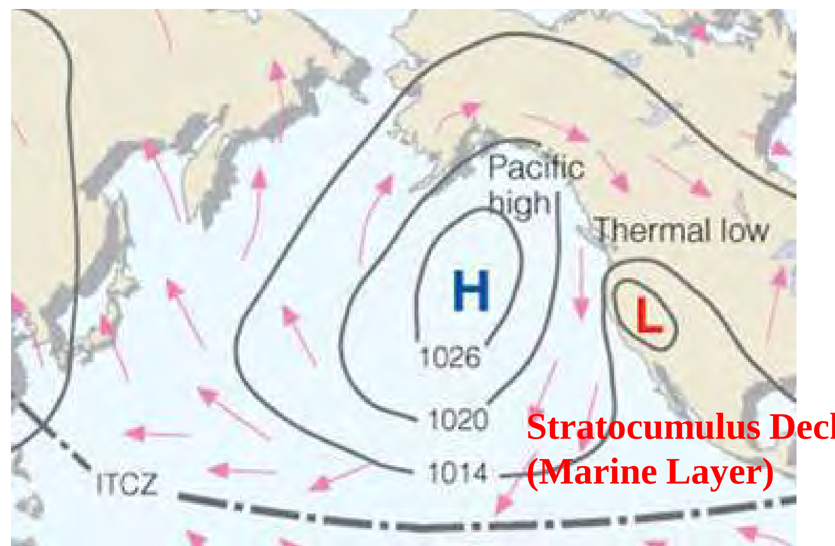
Weather and Climate

- Climate: Long time scale (averages over months, seasons, years, trends) accumulation of weather events that we assume to be meaningful

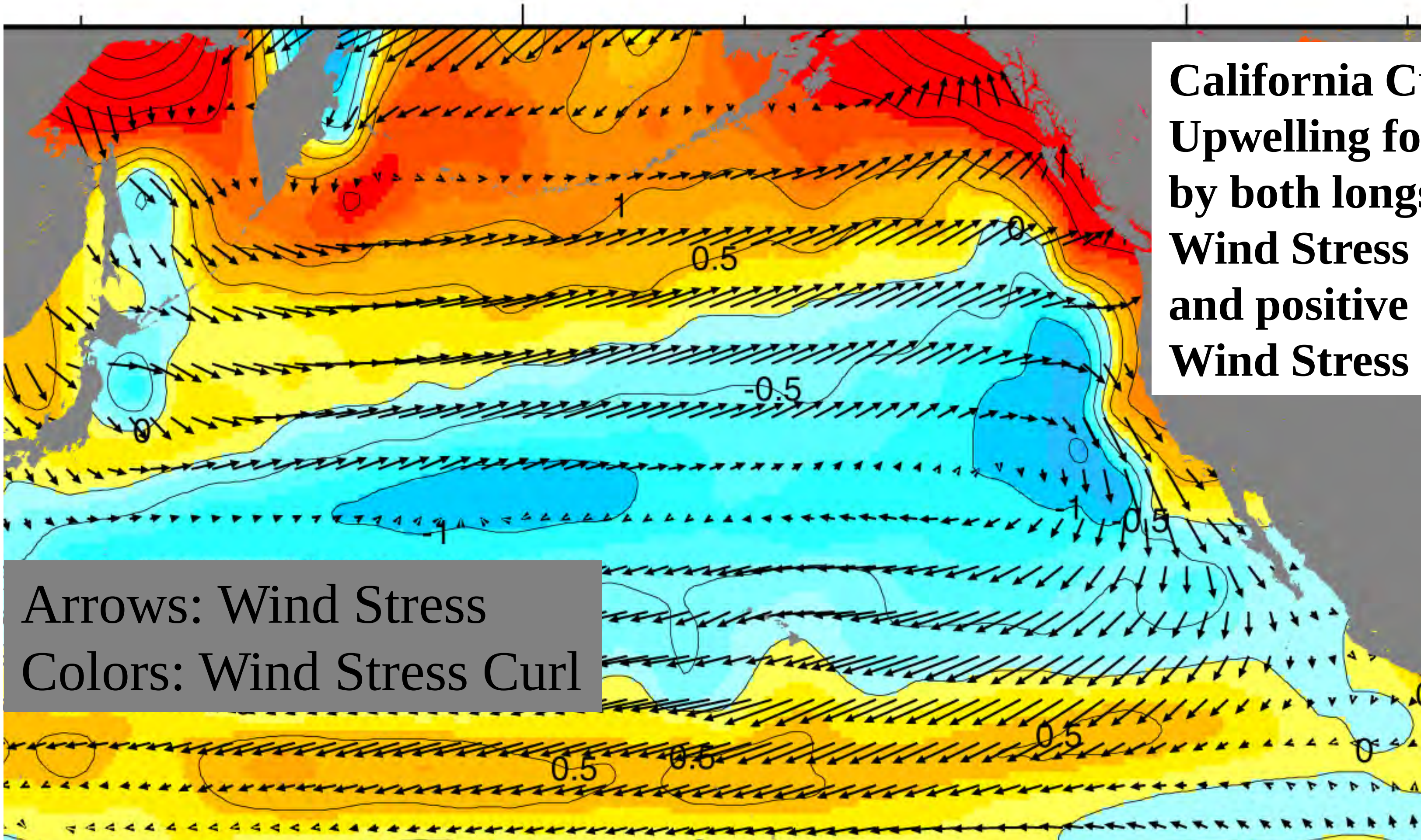
Aleutian Low: Winter



North Pacific High: Summer



Atm Pressure: Wind stress and its “curl”: Drives the Gyres and Boundary Currents

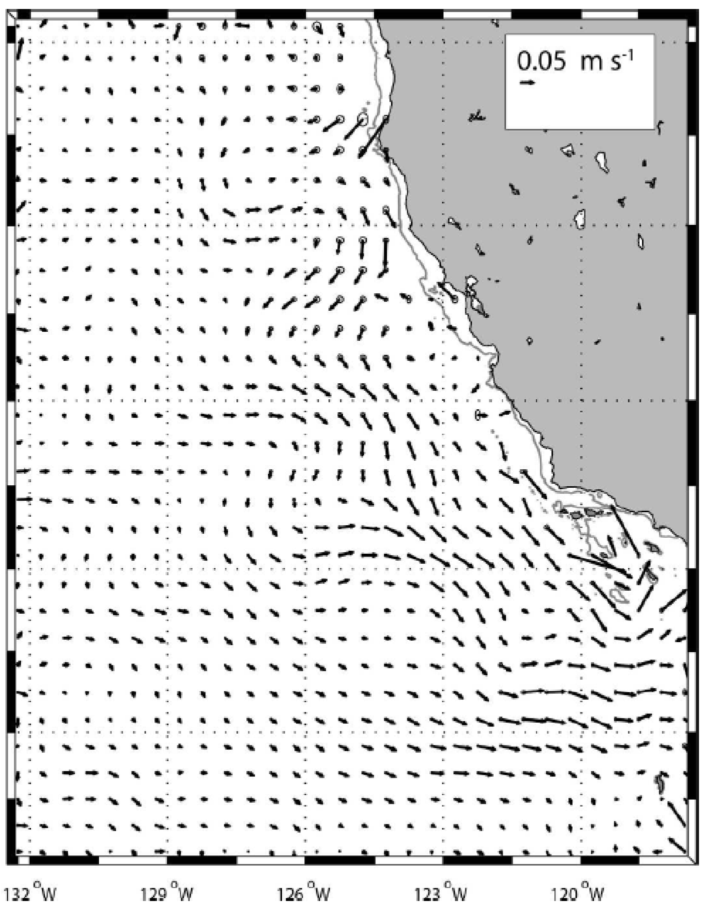


California Current: Upwelling forced by both longshore Wind Stress and positive Wind Stress Curl

Arrows: Wind Stress
Colors: Wind Stress Curl

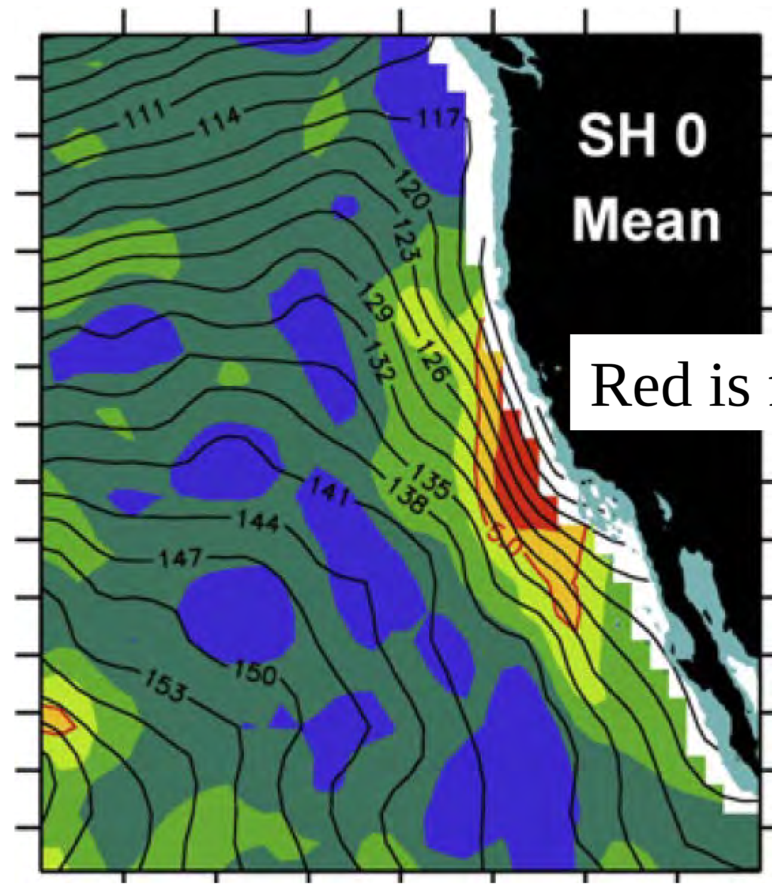
California Current average flow

Surface velocity (arrows) from drifters/sea level



Centurioni et al. (2008)

Surface height and derived velocity from T-S ARGO data

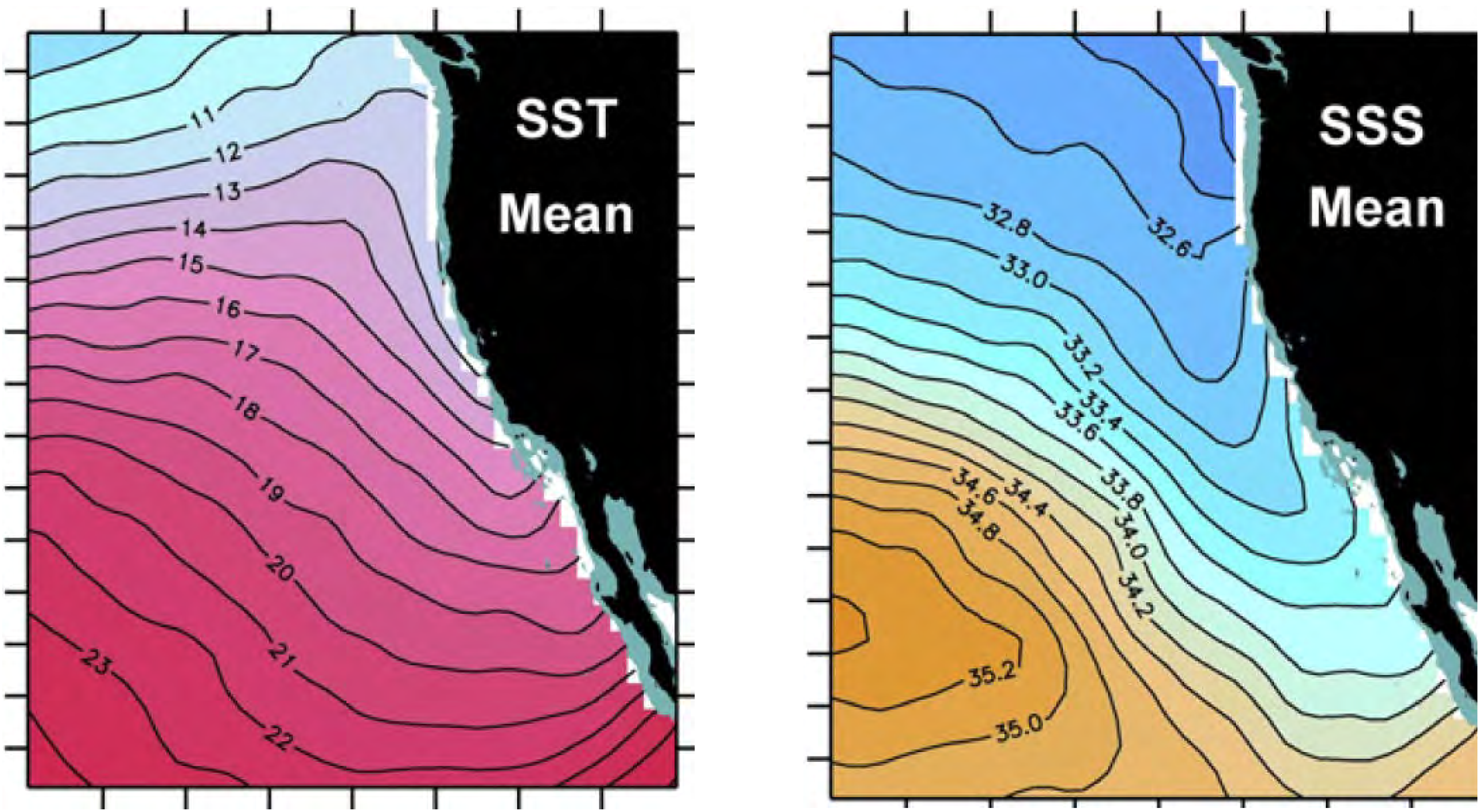


Red is fast

Auad et al. (2011)

Advection of cool and fresh water from the north (plus coastal upwelling)

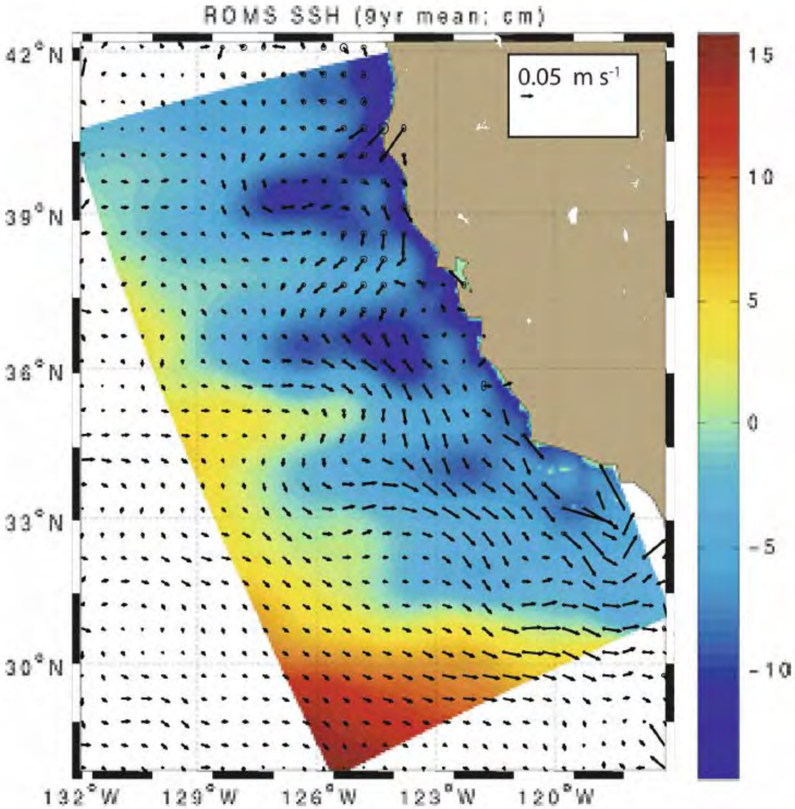
Temperature | Salinity



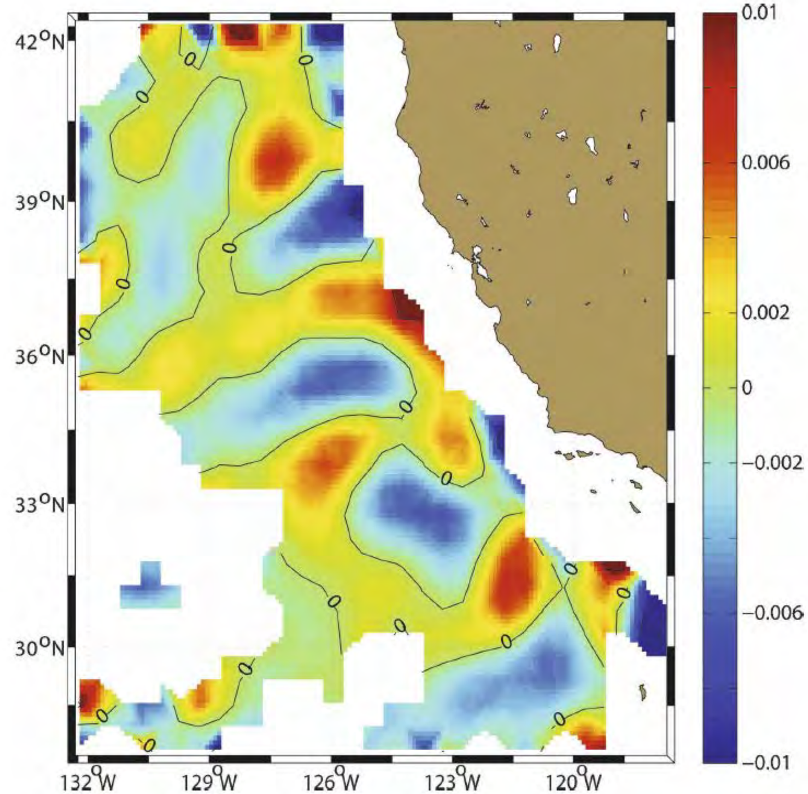
Auad et al. (2011)

Closer Looks: Permanent meanders

Model sea level height and observed currents



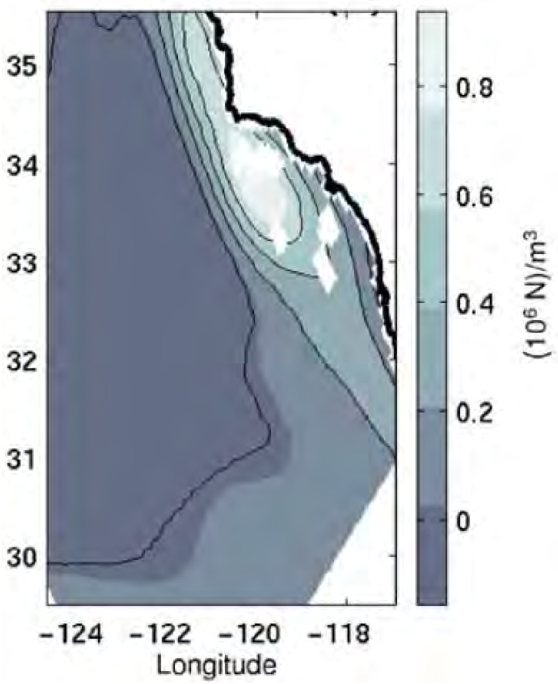
Observed vorticity (curl) of the flows, showing "turns"



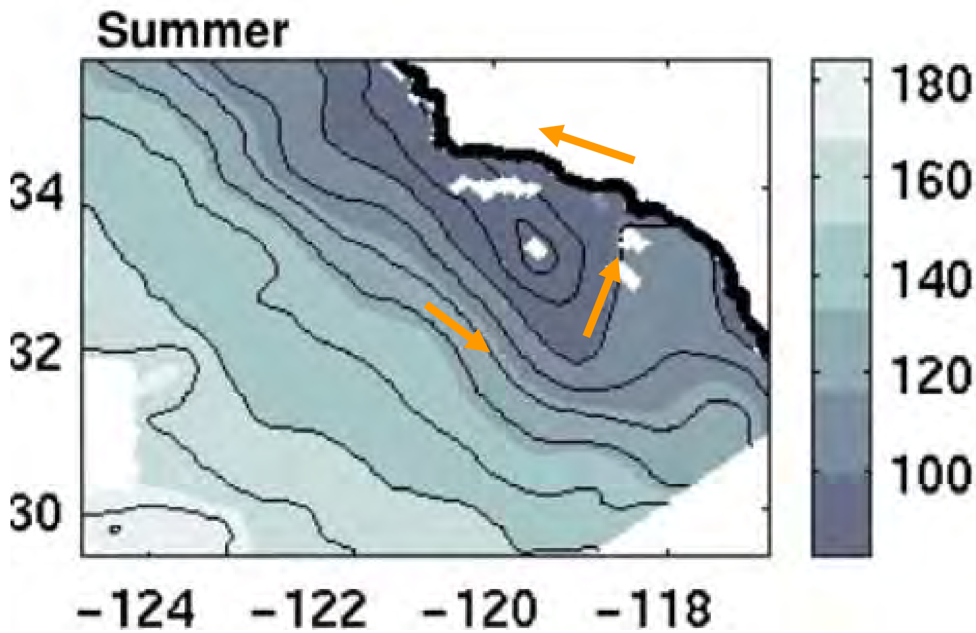
Centurioni et al. (2008)

Closer Looks: Seasonal Deviations from the Average --- Southern California Eddy (Summer countercurrent in the Bight)

Wind stress curl in the SCB deforms thermocline

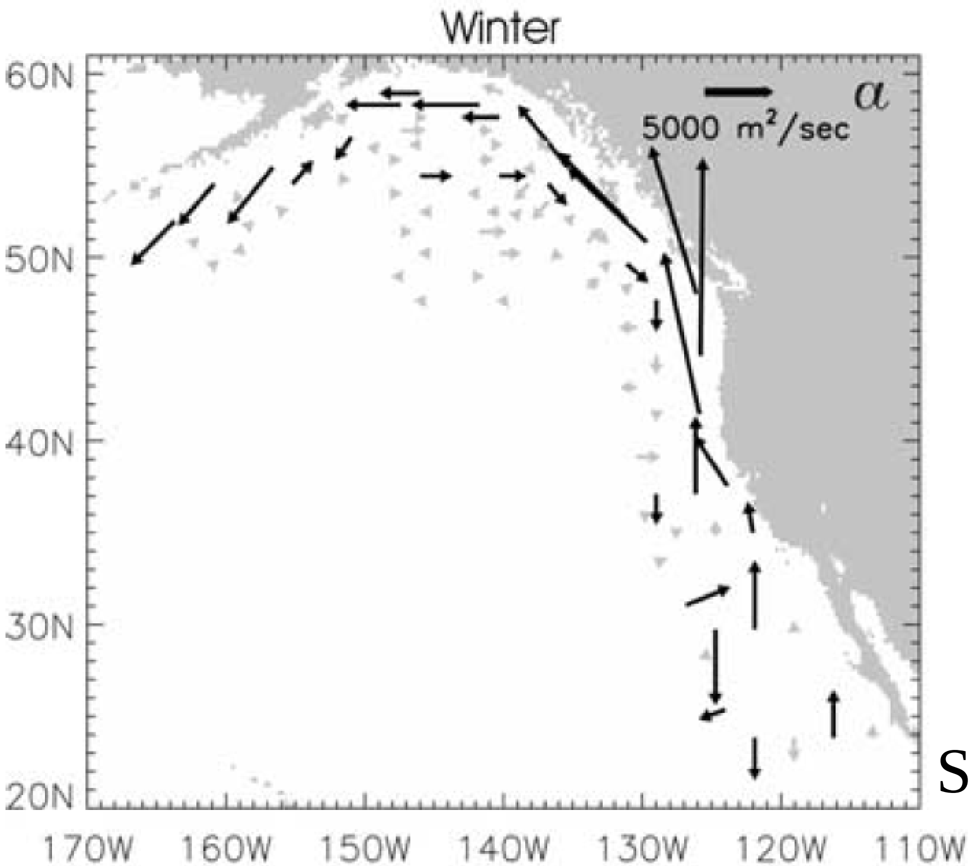


Thermocline depth indicates Seasonal cyclonic flow (SCE)



Di Lorenzo et al. (2005)

Closer Looks: Seasonal Deviations from the Average --- Davidson Current (Winter inshore coastal countercurrent)

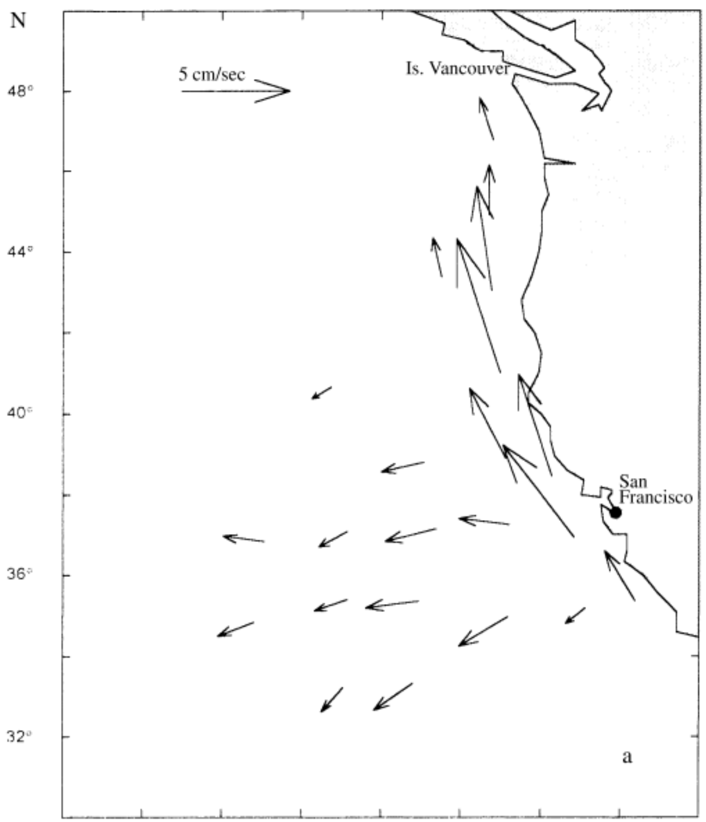


Seasonal anomaly after removing the annual mean

Strub and James (2002)

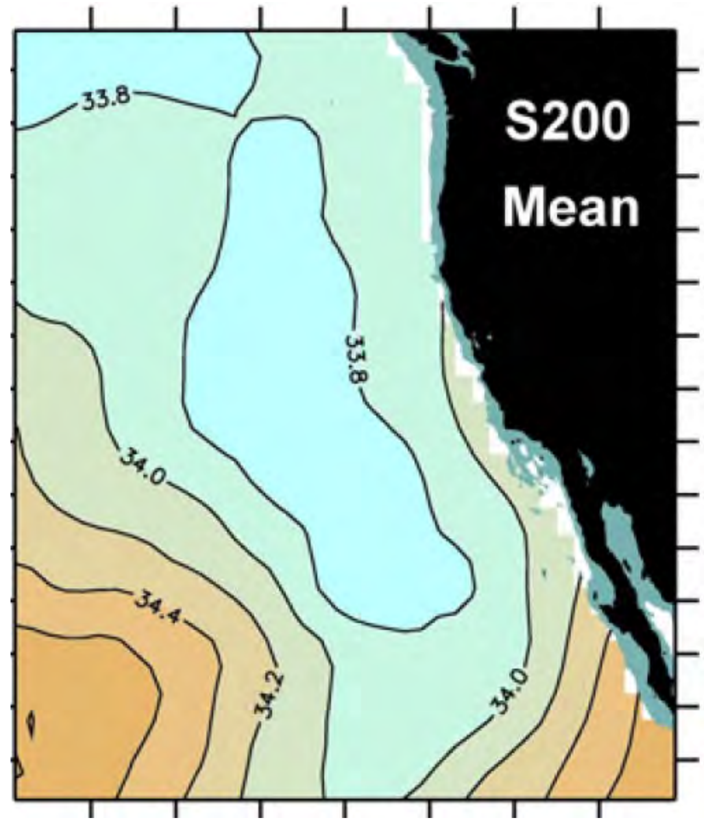
Closer Looks: California Undercurrent (Subsurface mean flow)

250m deep Velocity from floats



Collins et al. (2003)

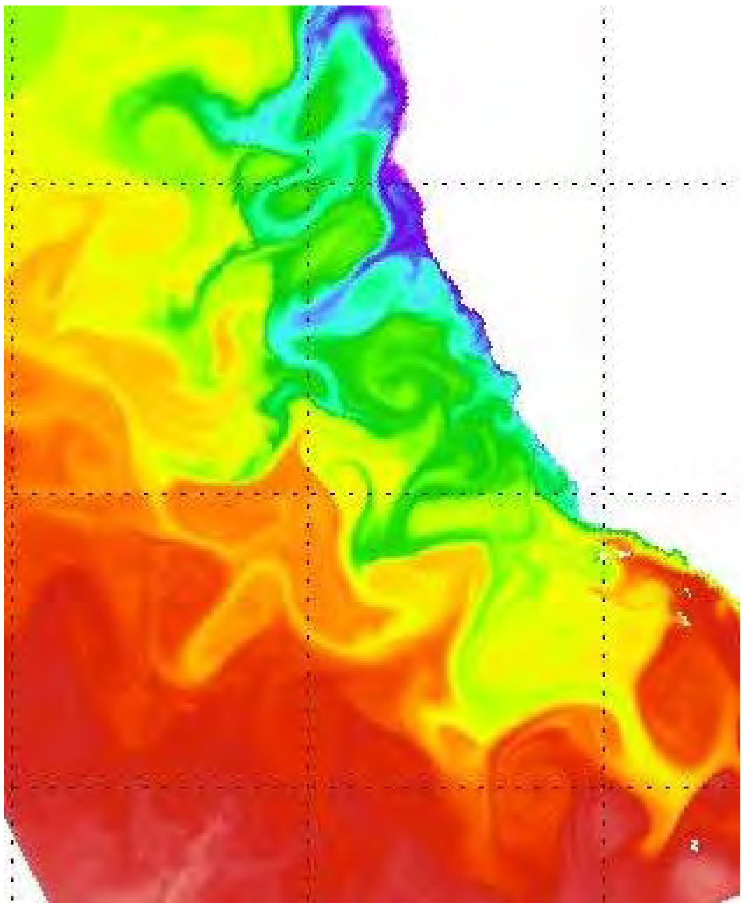
200m deep salinity (ARGO)



Auad et al. (2011)

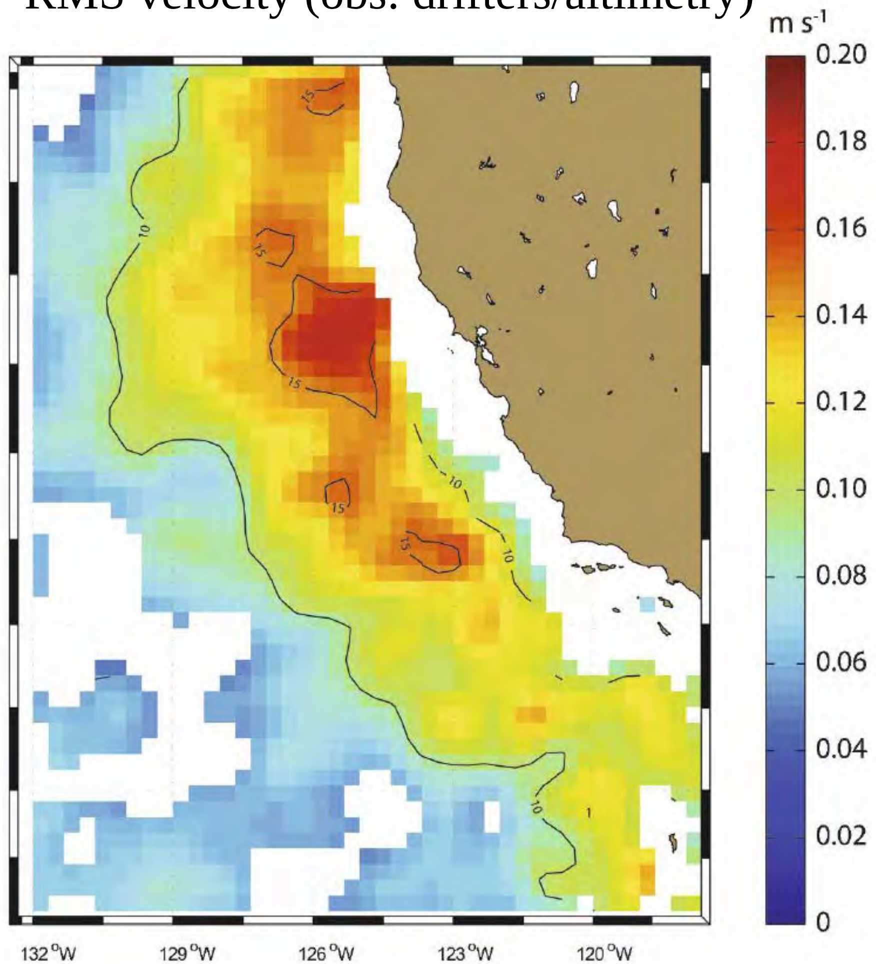
Closer Looks: Deviations from the Average --- Mesoscale Eddies

Snapshot of SST (model)



Capet et al. (2008)

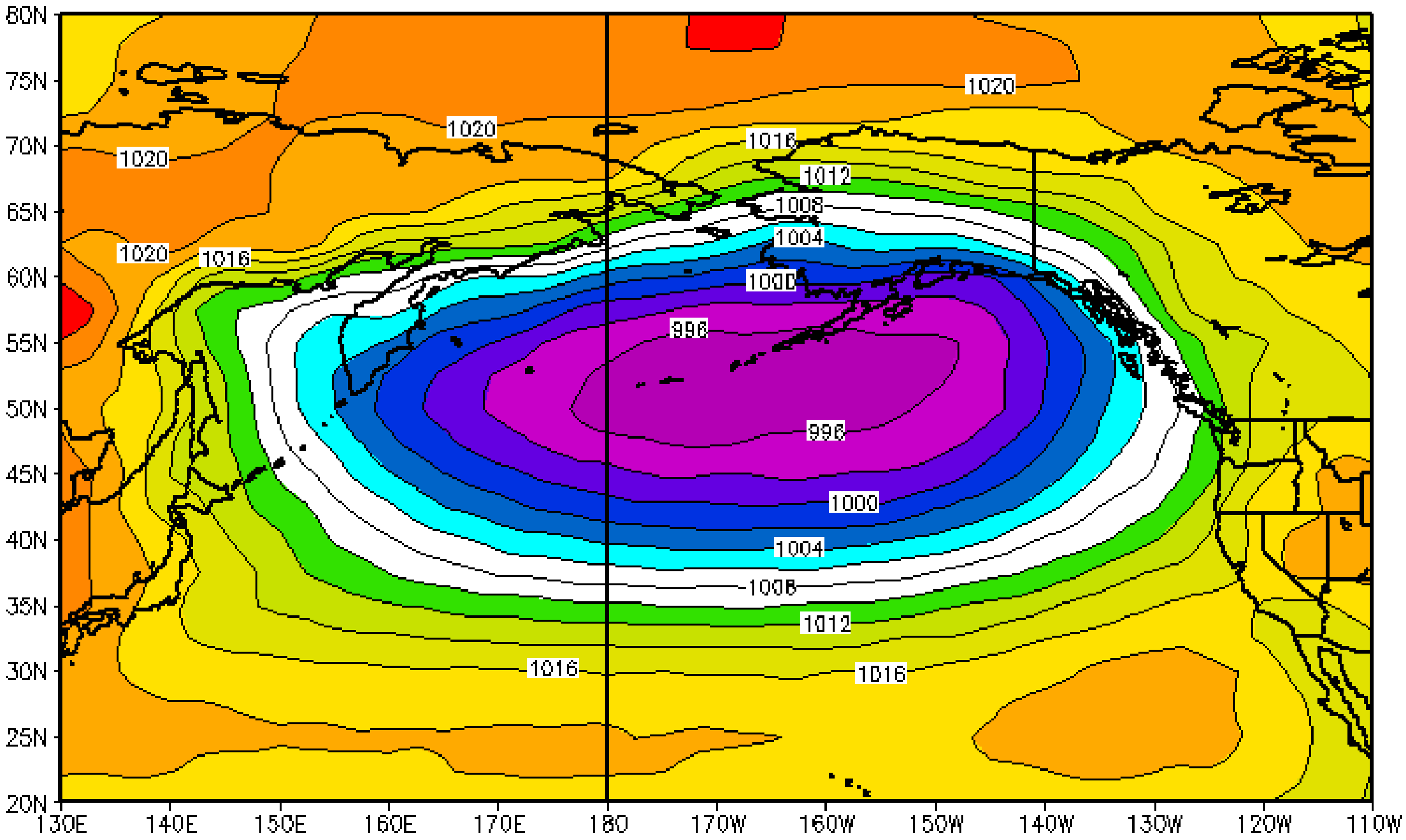
RMS velocity (obs: drifters/altimetry)



Centurioni et al. (2008)

Variability around the averages: What controls the atmospheric forcing?

Focus on Winter: Strong Forcing => Strong response
Focus on Interannual to Interdecadal time scales



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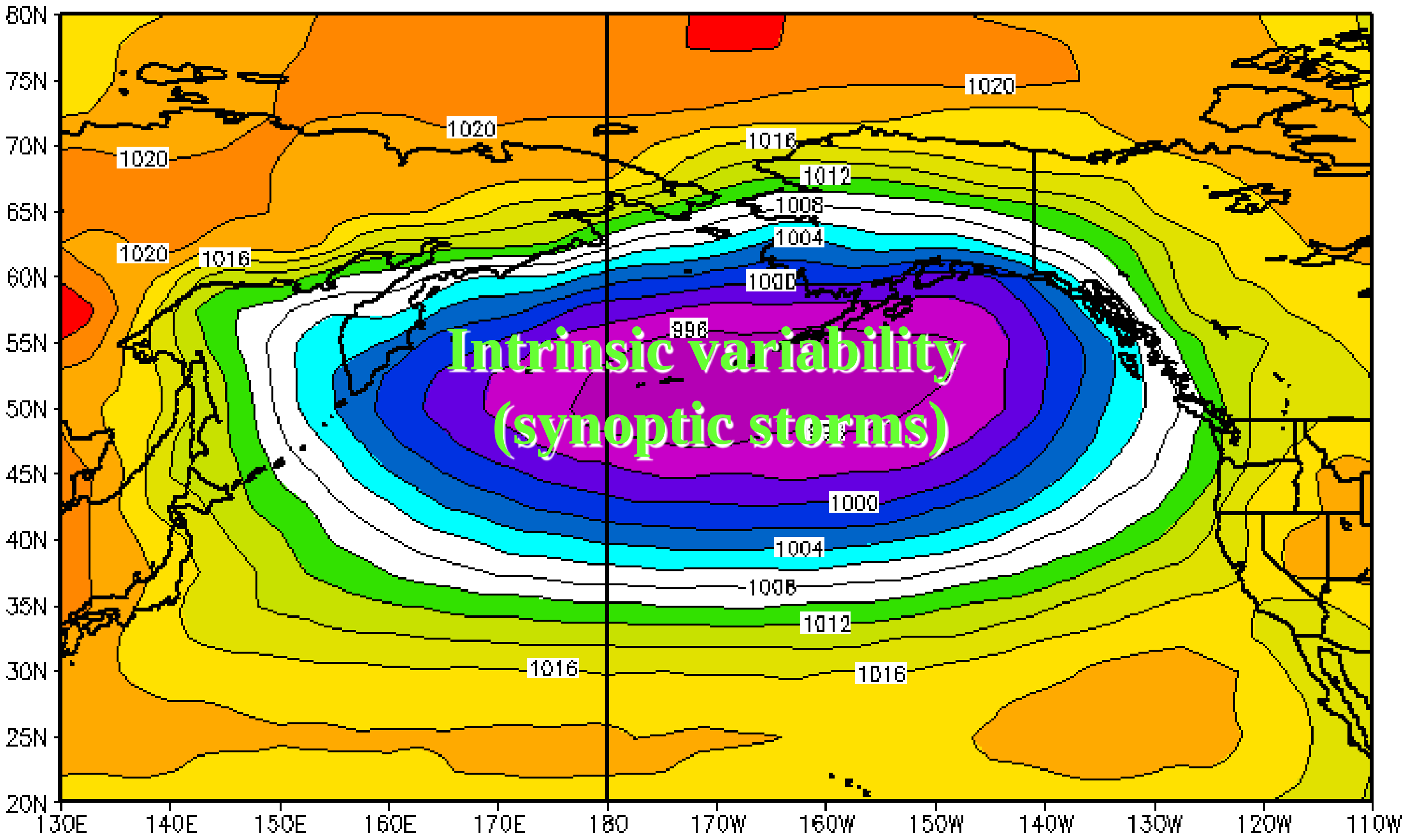

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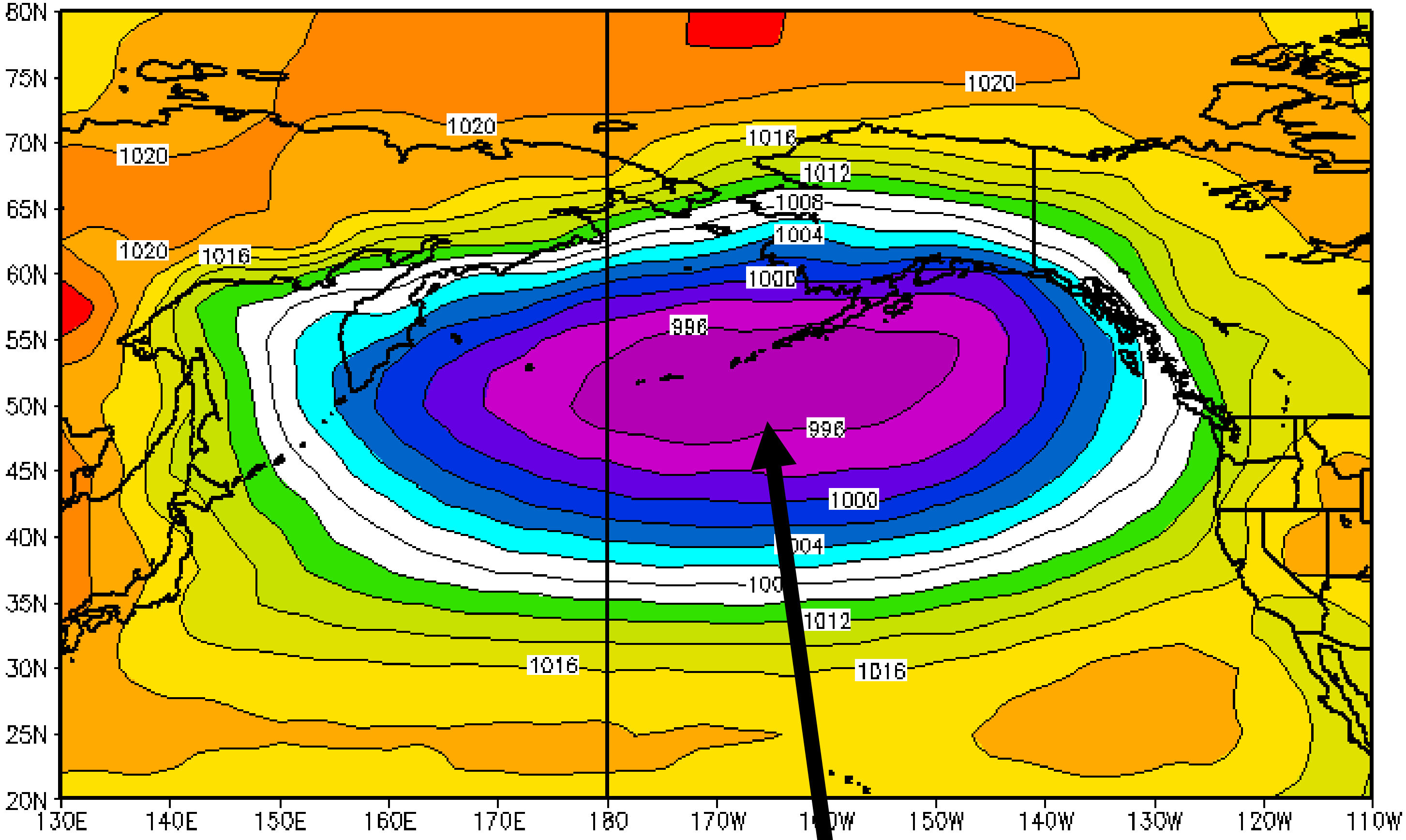

Tropical teleconnections (El Nino/La Nina)

Variability around the averages: What controls the atmospheric forcing?

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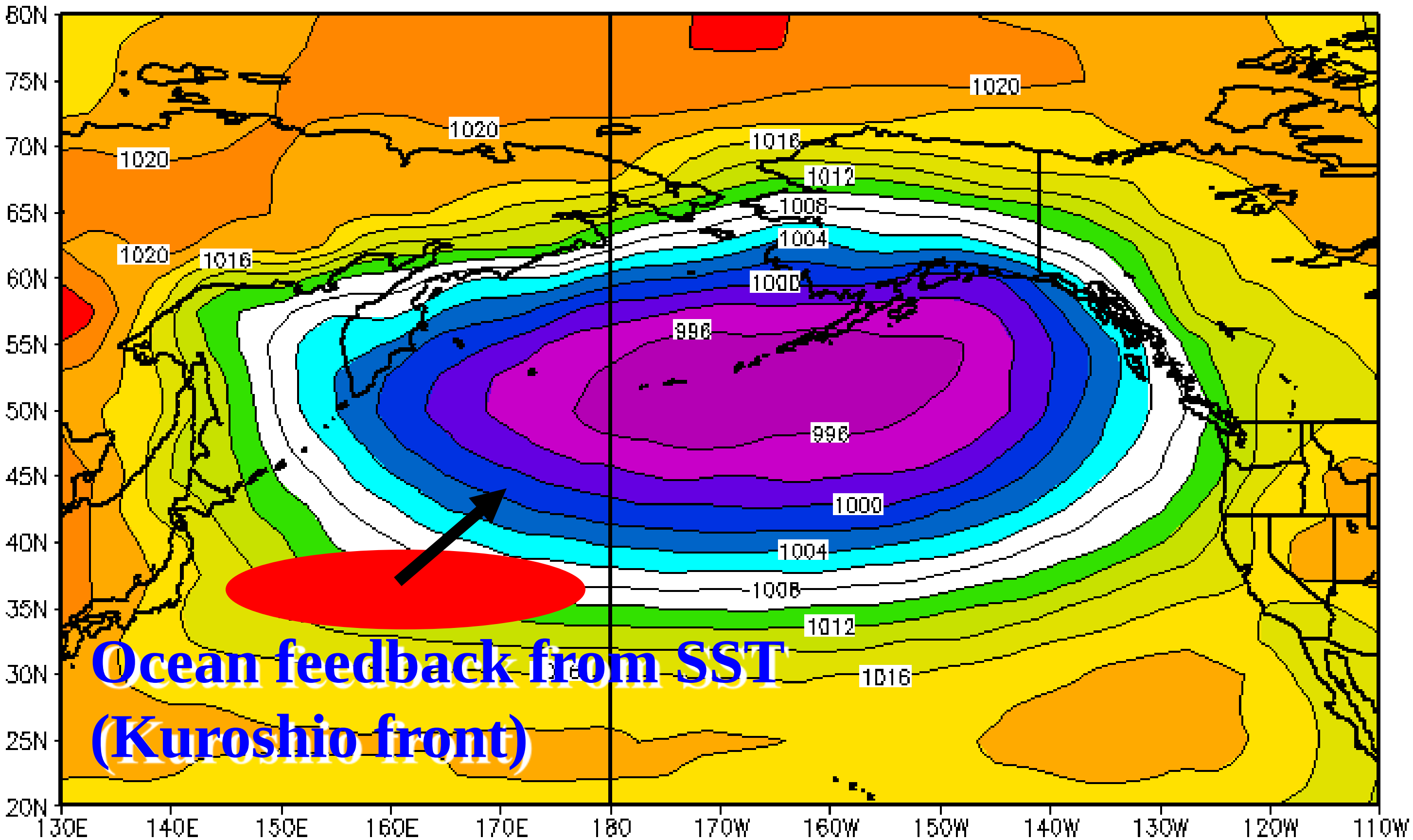


Variability around the averages: What controls the oceanic response?

Focus on Winter: Strong Forcing => Strong response
Focus on Interannual to Interdecadal time scales

Large-scale climate pattern variations organize the oceanic physical processes that affect ocean biology

-***Defining a Climate Index*** and relating to biological variables is frequently done, but…

-***Physical processes*** in the ocean can ***vary*** in space and can therefore affect the biology in different ways

-***Understanding*** these processes is therefore critical to unraveling mechanisms of biological variations

-Plus, lagged effects of climate mode forcing of the ocean may have ***predictable components***

Dynamics and Thermodynamics of Upper Ocean Variability

Dynamics of Currents: (**Adiabatic** Forcing)

Wind Stress (**Ekman transport**: Coastal upwelling)

Wind Stress Curl (**Ekman pumping**: Open-Ocean upwelling)

Thermodynamics of Ocean Temperature: (**Diabatic** Forcing)

Surface Heat Flux (***Latent***, Sensible, solar, radiative)

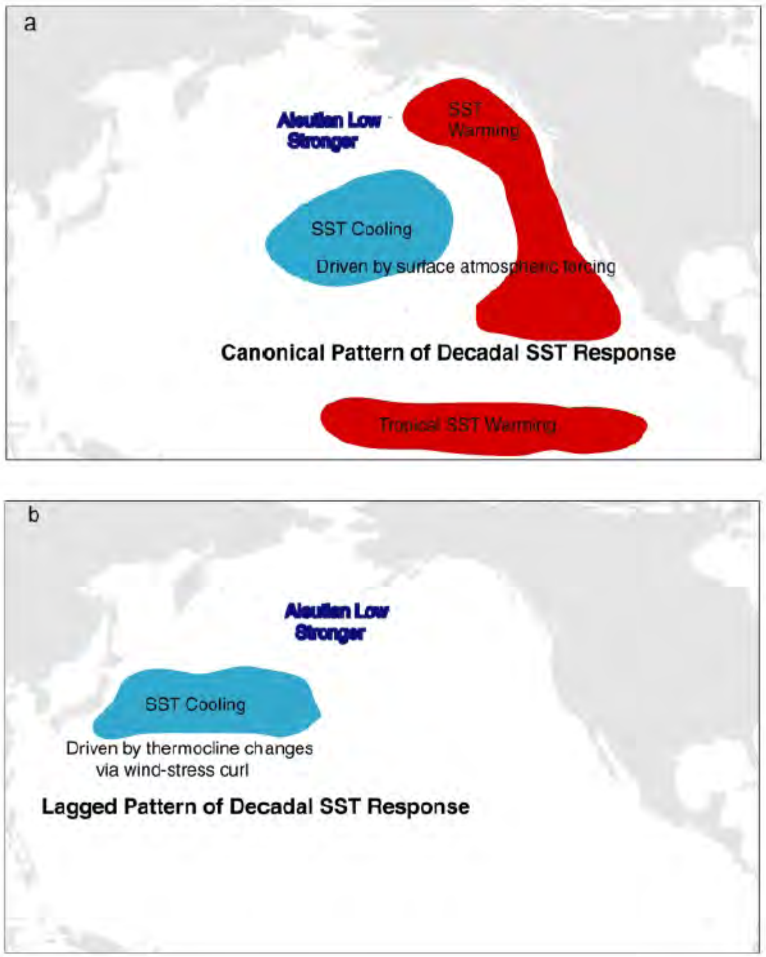
Advection (due to currents: ***Ekman***, pressure-gradient, upwelled)

Vertical turbulent mixing

When the winds change, all these effects act together,
but in different relative strength in different places….

Variability around the Averages: What controls the oceanic response?

Focus on Winter: Strong Forcing => Strong response
Focus on Interannual to Interdecadal time scales



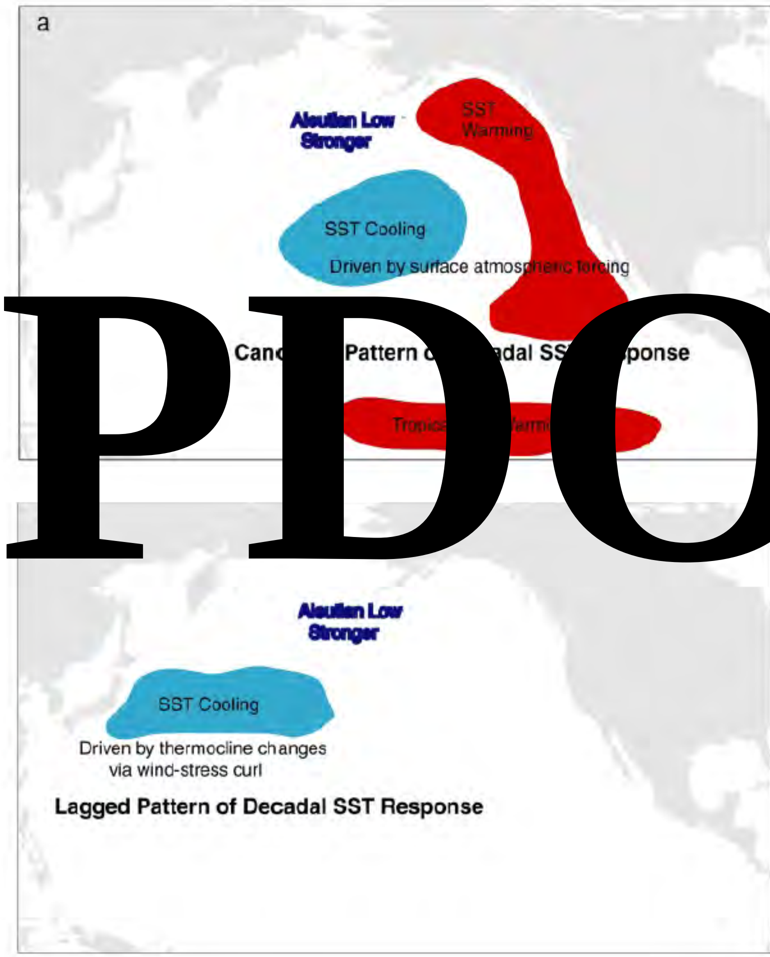
Miller et al. (2004)

Aleutian Low anomalies force surface heat fluxes, Ekman current advection, and turbulent mixing (**diabatic** effects) to drive ***East-West pattern of SST***

Aleutian Low wind stress curl anomalies (**adiabatic**) force thermocline waves that propagate westward (lagged by several years) to force ***SST cooling in the West***

Variability around the Averages: What controls the oceanic response?

Focus on Winter: Strong Forcing => Strong response
Focus on Interannual to Interdecadal time scales



PDO

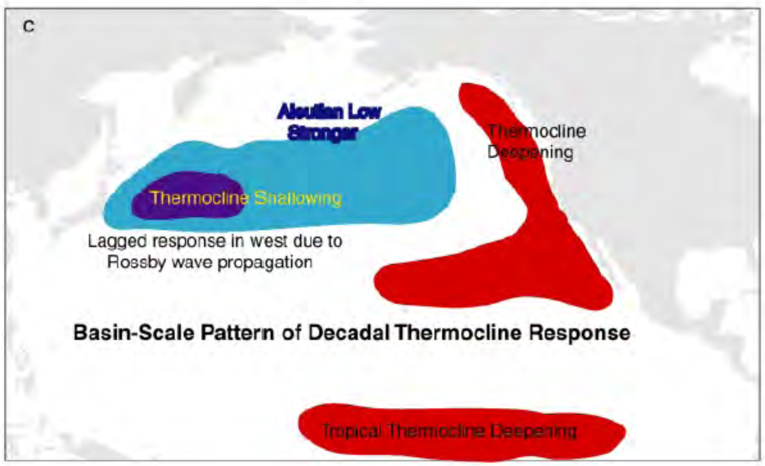
Miller et al. (2004)

Aleutian Low anomalies force surface heat fluxes, Ekman current advection, and turbulent mixing (**diabatic** effects) to drive ***East-West pattern of SST***

Aleutian Low wind stress curl anomalies (**adiabatic**) force thermocline waves that propagate westward (lagged by several years) to force ***SST cooling in the West***

Variability around the Averages: What controls the oceanic response?

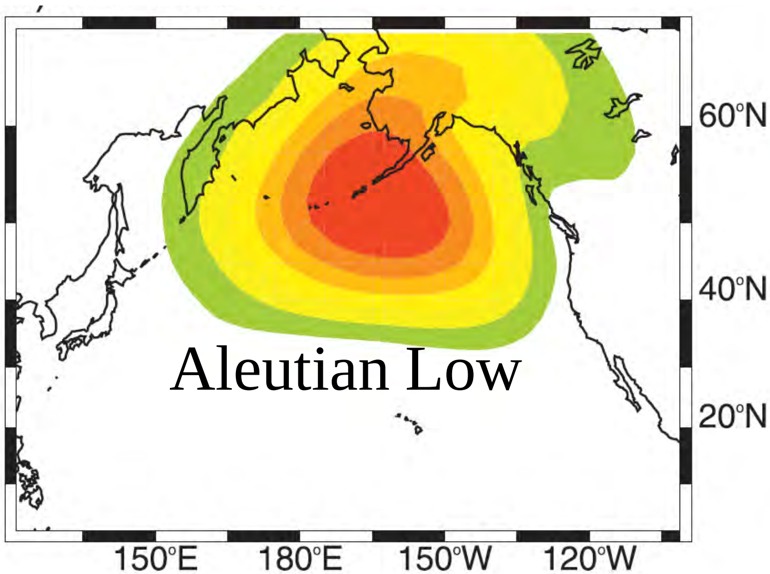
Focus on Winter: Strong Forcing => Strong response
Focus on Interannual to Interdecadal time scales

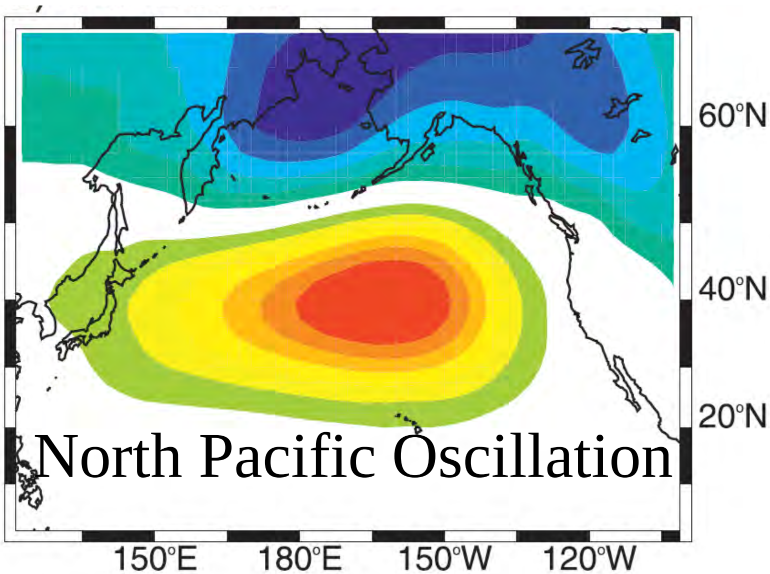


Miller et al. (2004)

Additionally,
Aleutian Low wind stress curl anomalies force (**adiabatically**) thermocline deflections (Ekman pumping) that change the **gyre-scale circulation** and affect the California Current and subsurface temperature (**thermocline**) structure, sea level, and currents

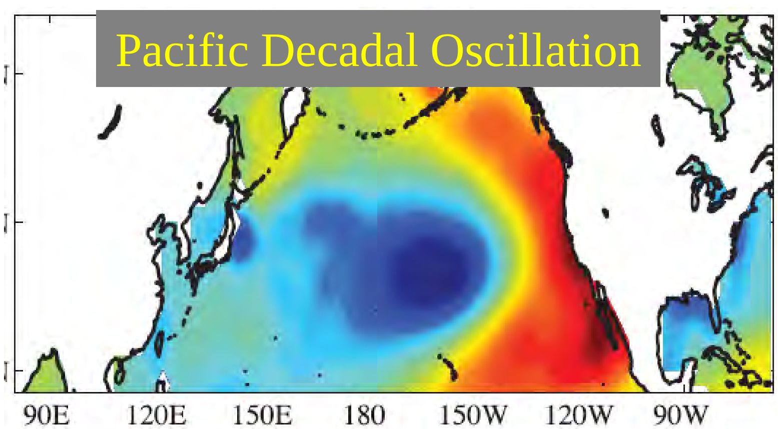
More Excitement: New Ocean Mode (NPGO) Driven by 2nd Atmospheric Pressure Mode (NPO)

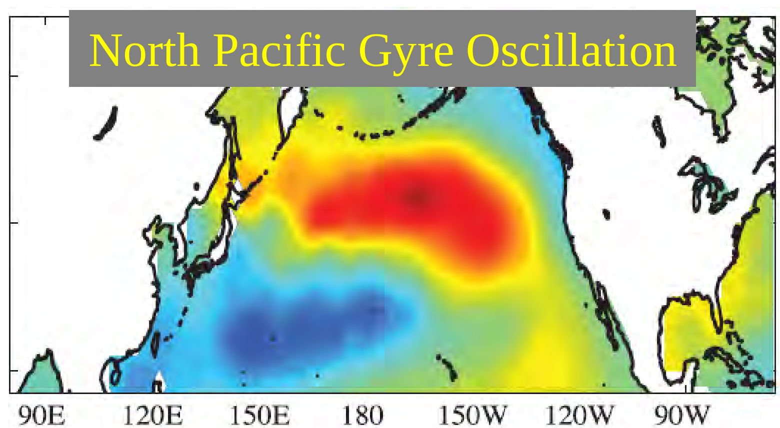




Drives the ***PDO*** pattern of SST

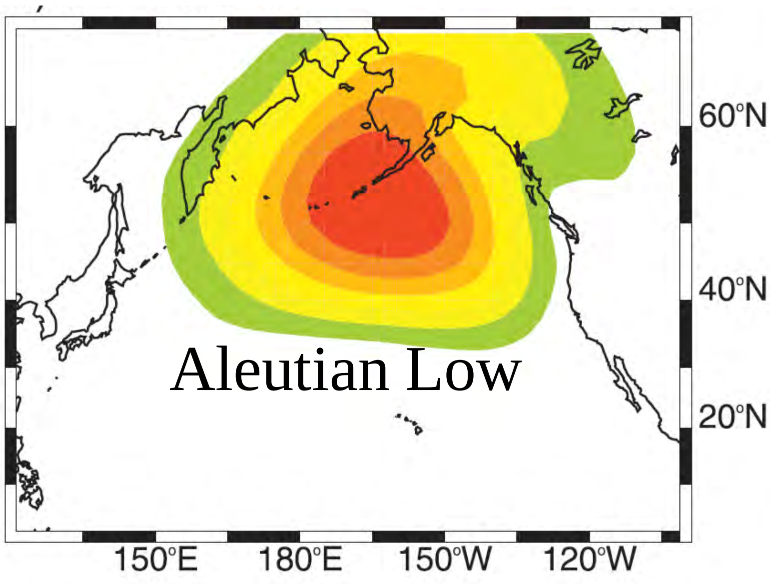
Drives the ***NPGO*** pattern of SST

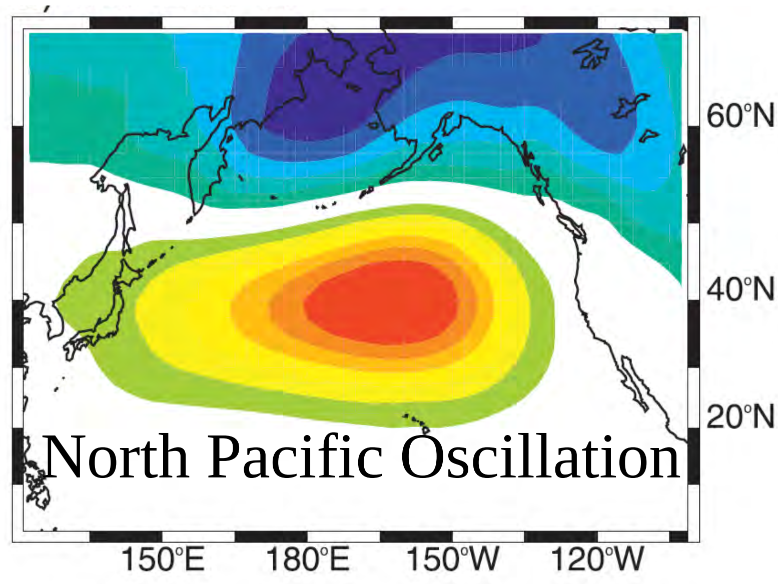




(Ceballos et al., 2009; Furtado et al., 2011)

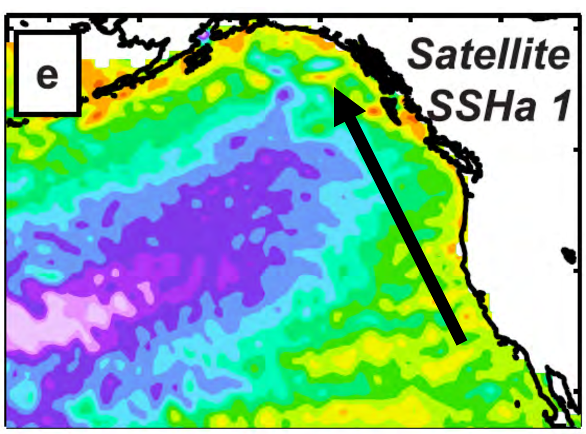
More Excitement: New Ocean Mode (NPGO) Driven by 2nd Atmospheric Pressure Mode (NPO)

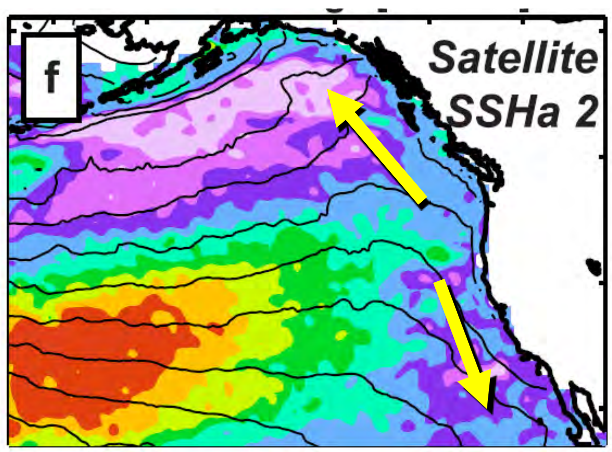




Drives the ***PDO*** pattern of SST, SLH

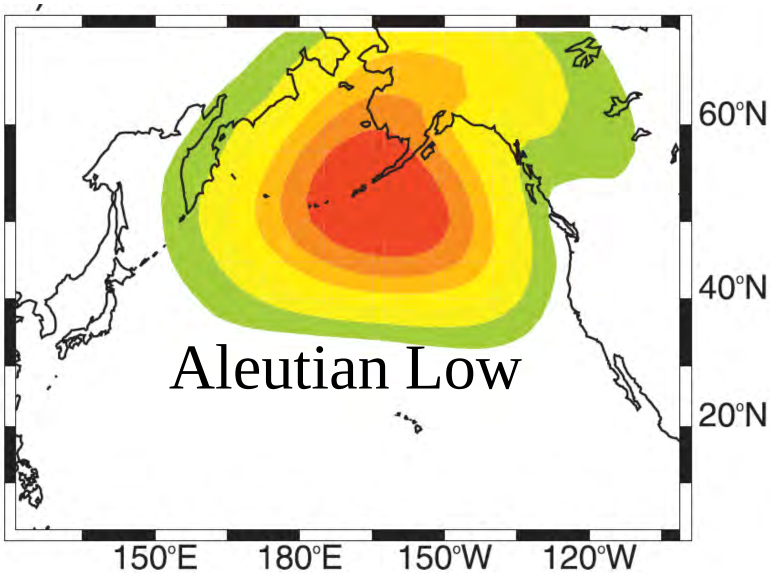
Drives the ***NPGO*** pattern of SST, SLH

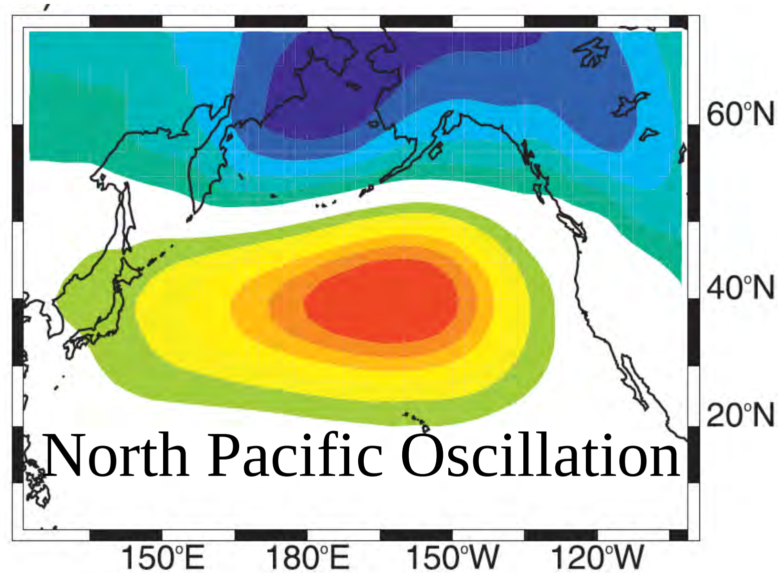




(Ceballos et al., 2009; Di Lorenzo et al., 2008)

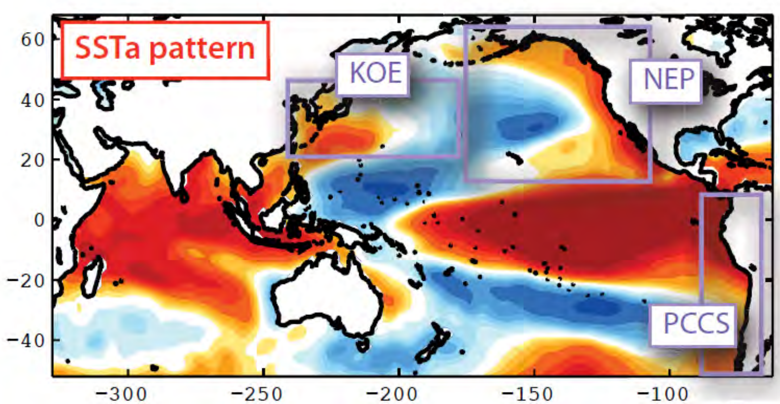
More Excitement: New Ocean Mode (NPGO) Driven by 2nd Atmospheric Pressure Mode (NPO)

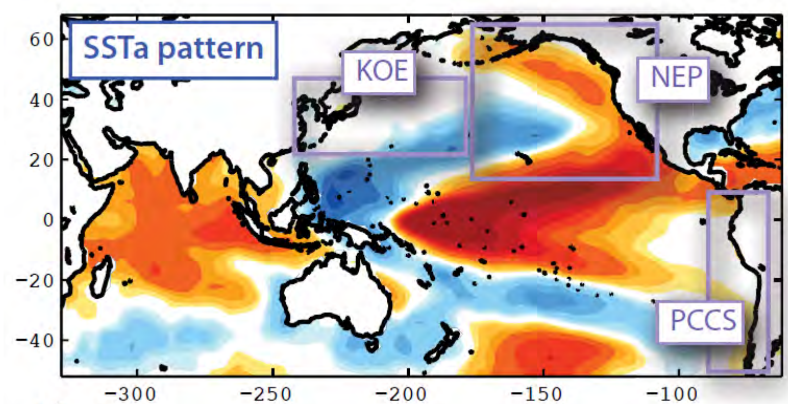




AL/***PDO*** => Eastern Pacific ENSO

NPO/***NPGO*** => Central Pacific ENSO





(Ceballos et al., 2009; Di Lorenzo et al., 2010)

Pacific Climate Processes Affecting California Coastal Atmospheric and Oceanic Circulation

Observational and Modeling Studies (plus Data Assimilation) form the basis for understanding the details of these physical processes

1) Long-term climate hindcasts

- Deterministic: Explain observed changes in forced physical structures

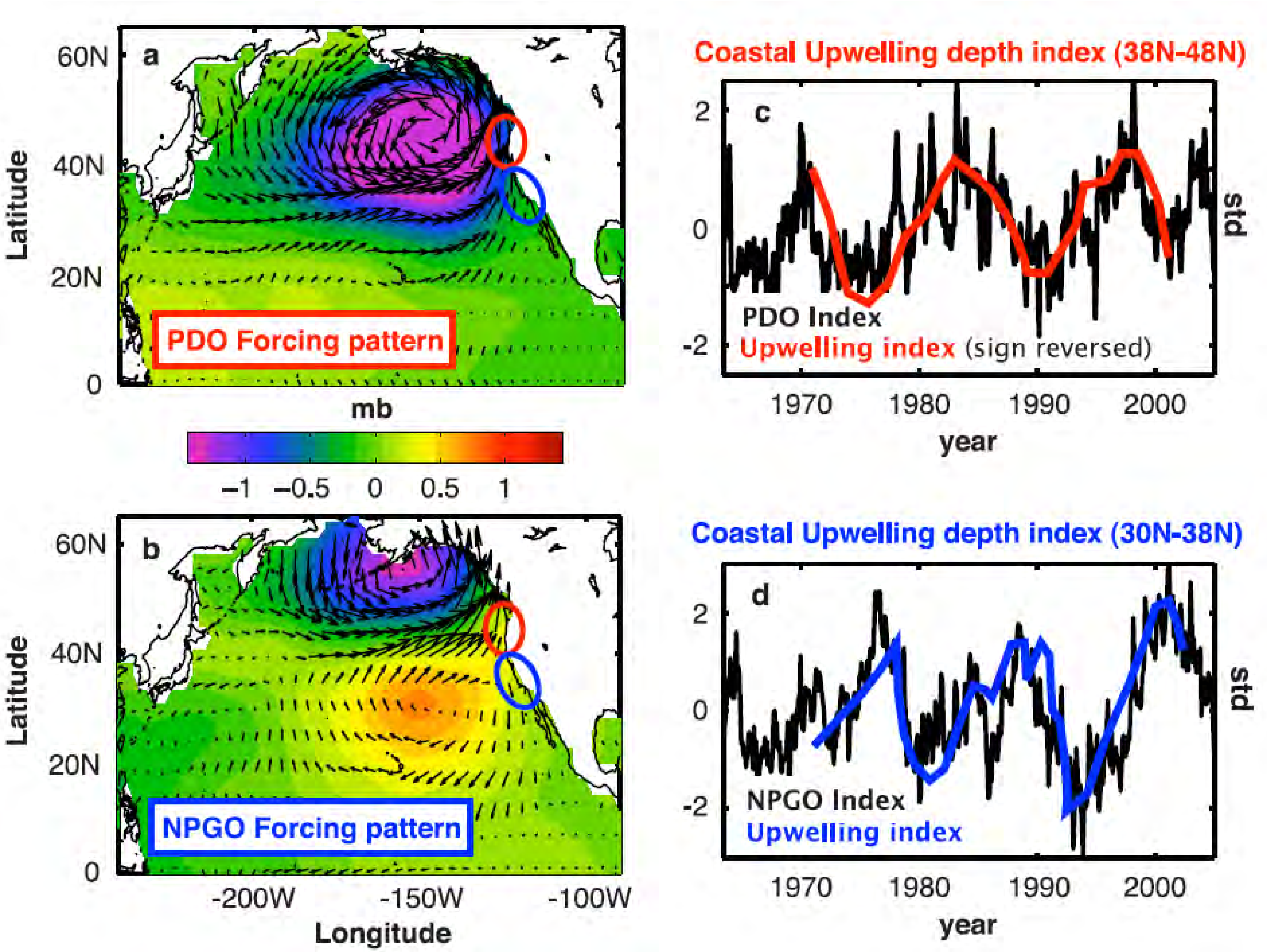
- Stochastic: Identify relations among variables and input forcing

2) Data assimilation runs

- Enhance observations in space and time for process diagnostics

- Initialize predictions of eddies and forced components

Coastal upwelling regions controlled by PDO and NPGO: Northern vs. Southern California Current

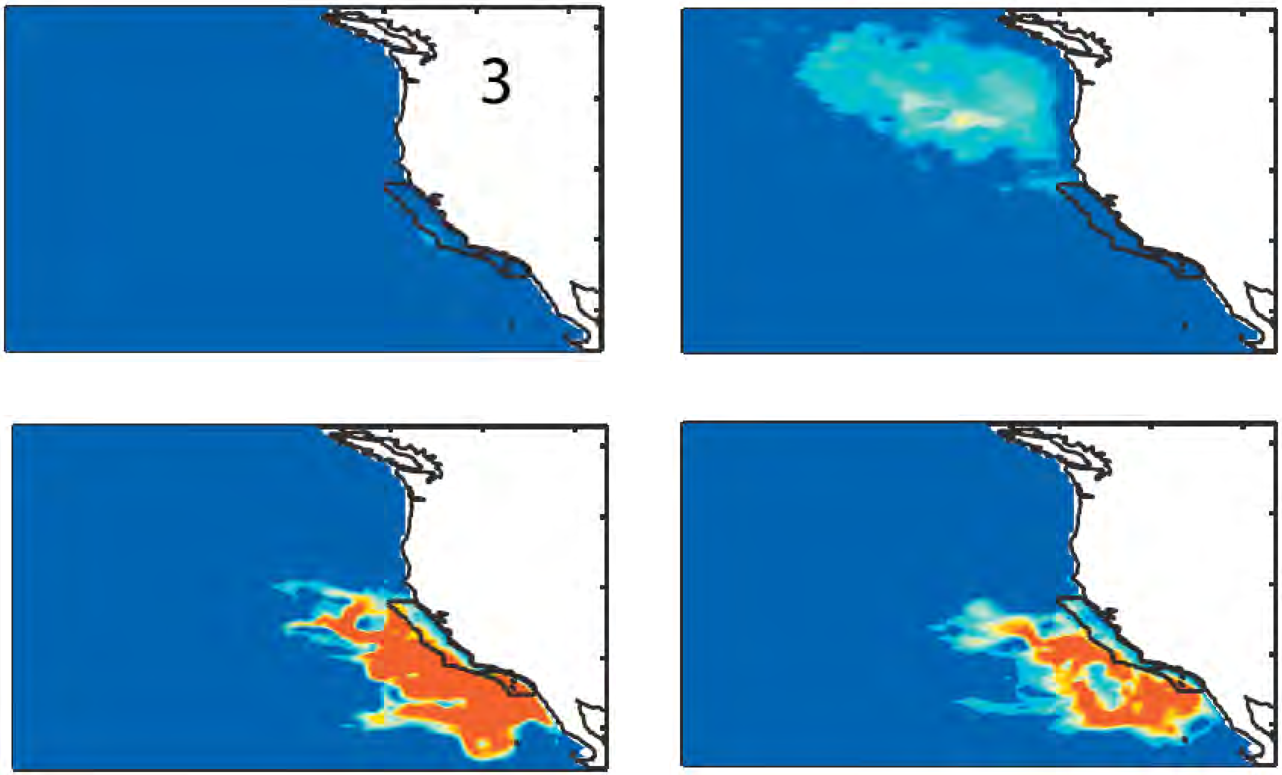


Di Lorenzo et al., GRL, 2008

Biological impacts of PDO phase changes?

Weaker upwelling winds cause shallower coastal upwelling cell

Cool PDO Phase **Warm PDO Phase**



Surface layer transport into coastal upwelling zone

Mid-depth (150m) transport into coastal upwelling zone

More nutrient flux to surface **Less nutrient flux to surface**

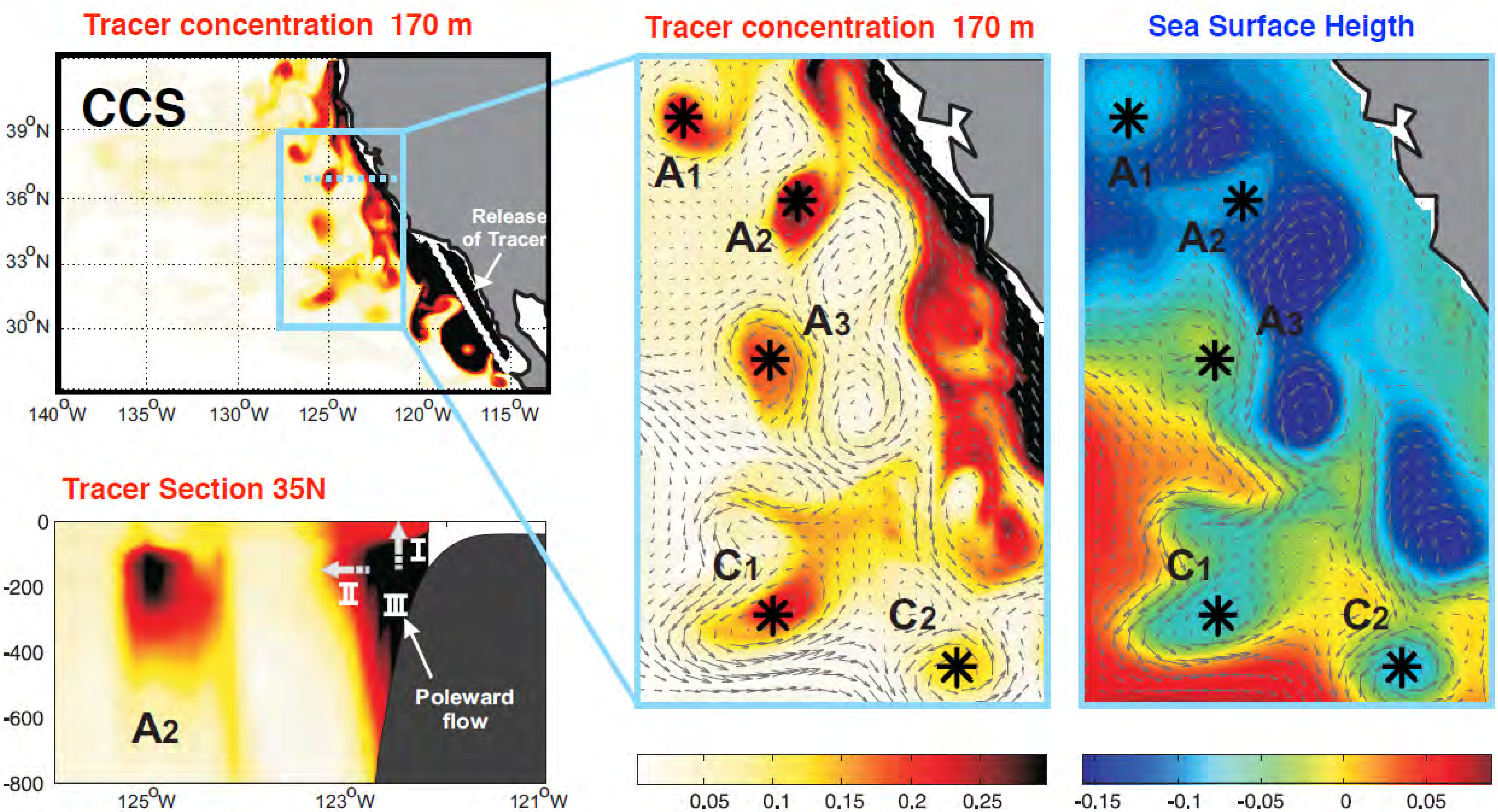
Model Adjoint *backward* runs of passive tracer in upwelling zone

(Chhak and Di Lorenzo, 2007)

Ocean eddies as mechanisms for nutrient flux changes

ROMS eddy-resolving Hindcast

Connecting Cross-shelf Transport to Mesoscale Eddy Variability

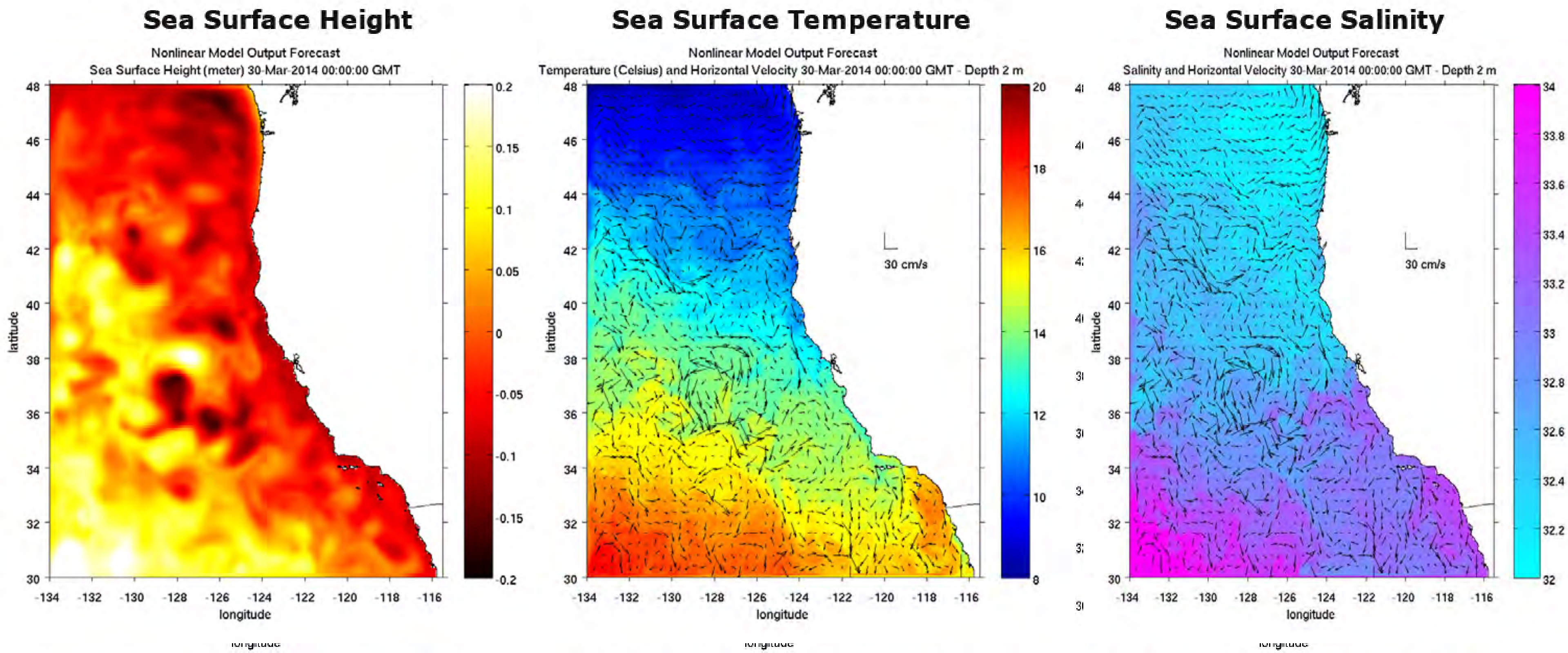


Combes et al., 2012

Near-Real-Time CCS Data Assimilation by UC, Santa Cruz

Broquet et al. (2009)

UCSC California Current Ocean Modeling and Data Assimilation



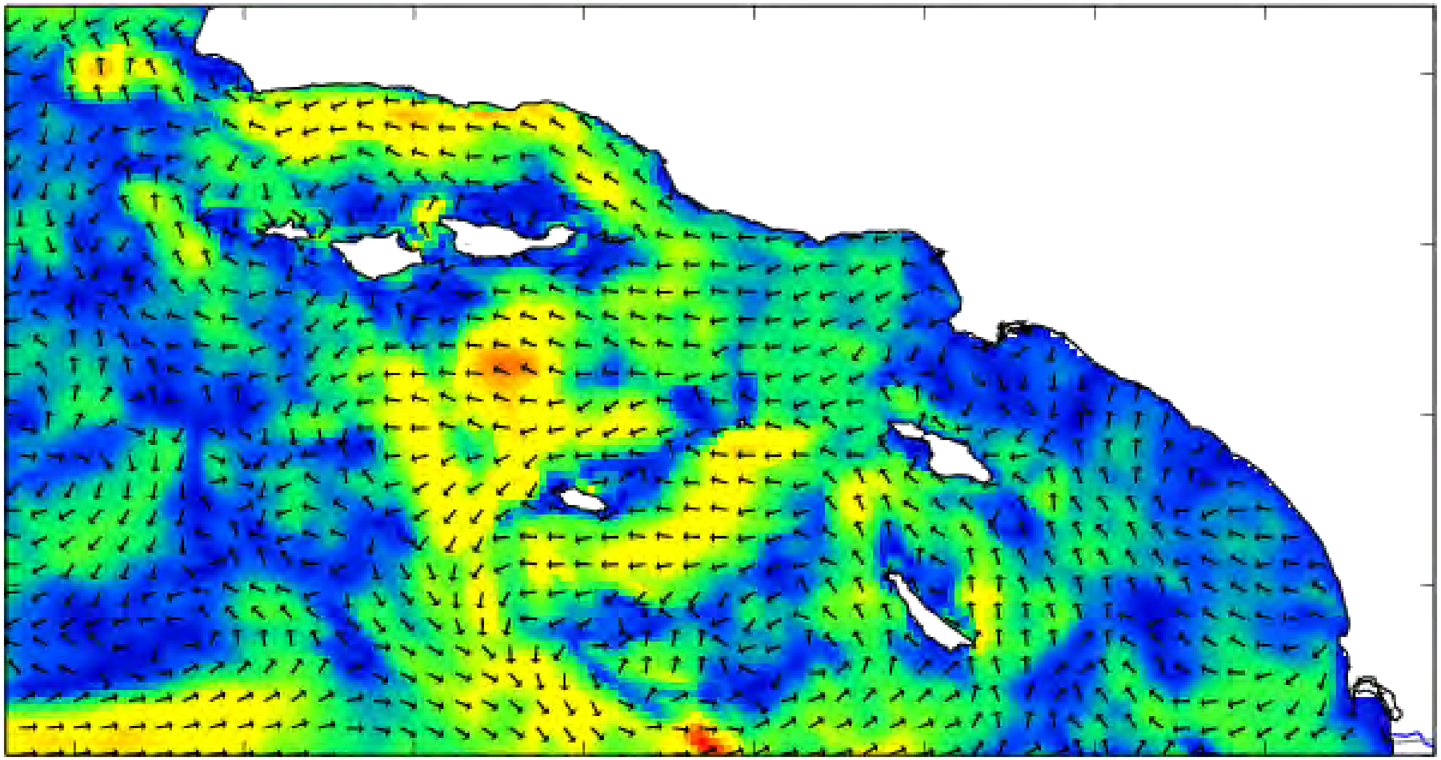
7-day fits using mostly surface data with ROMS @ 10km

March 30, 2014

Also, UCSC has a long-term model-data ocean mapping dataset available since 1980…..

SCCOOS 3DVar ROMS model (JPL-UCLA) give nearshore currents

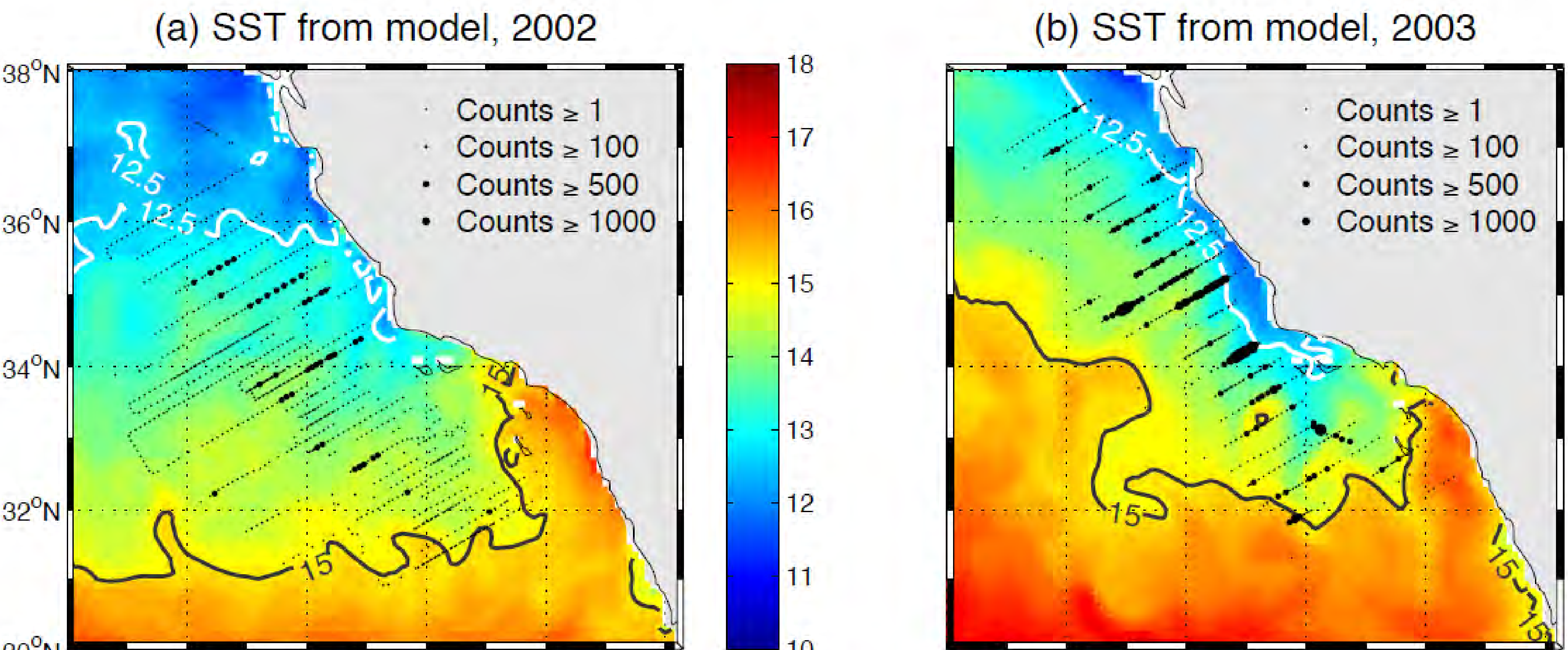
Yi Chao et al.



Surface CODAR is a key variable (not used in the UCSC fits)
Daily updates with 1km resolution every 6 hrs
72-hour forecasts executed daily

Using Physical Ocean Models with Data Assimilation to Explain Changes in Sardine Spawning Habitat Quality

- **2002: stronger offshore transport of surface waters than 2003**
- **2003 source waters in nearshore spawning** area upwell from more productive **deep water in the central California Current**



Offshore spawning, fewer eggs: **La Nina** Nearshore spawning, many eggs: **El Nino**

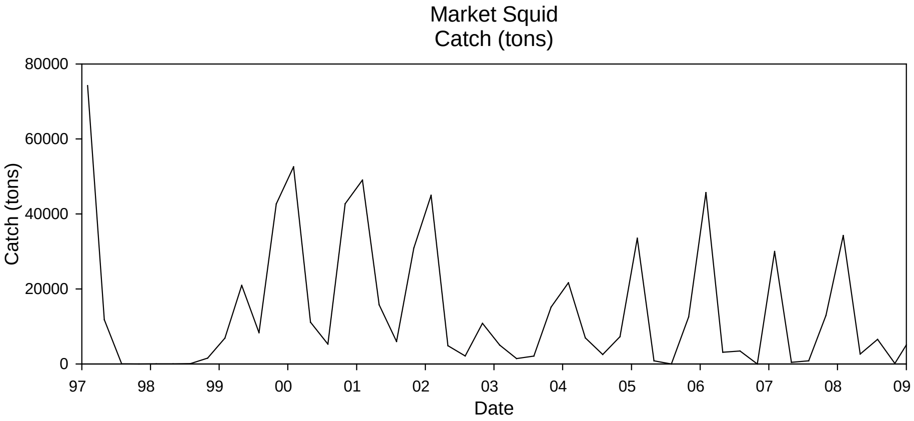
Data includes: T-S (CalCOFI, Argo, CUFES), SLH (AVISO), SST (AVHRR)

Song et al., 2012

Thermocline Influences on Squid Spawning Habitat

Spawning Squid need sandy bottom, depths of 20-70m and temperatures between 10-14°C.

- Winter 1998, only ~4% of potential habitat was cool enough.
- Winter 2000, nearly all of 20-70m depths and sandy substrates were between 10-14°C.



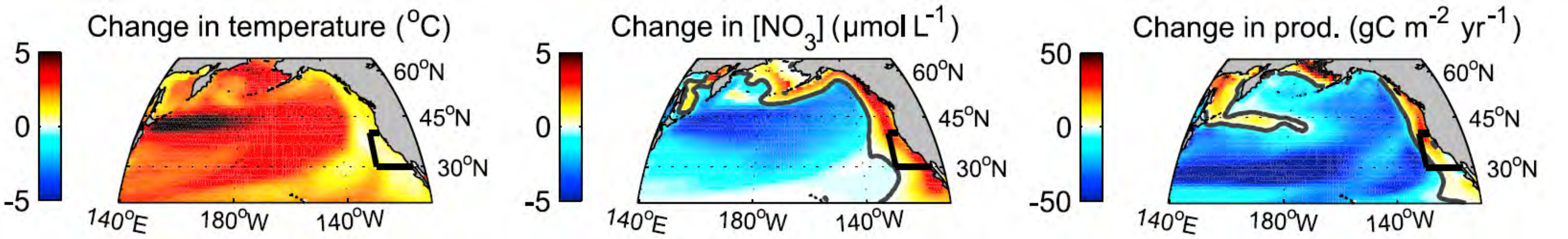
Zeidberg et al., 2011

Prospects for Prediction

- Deterministic forcing (global warming – over decades) vs. natural variations (ENSO, PDO, NPGO – years)
- Even if atmospheric variability is random, the ocean organizes patterns of response that can exhibit predictable components:
  - Thermocline (Rossby) waves
  - Advection of anomalies by mean currents
- Biological “memory” through life histories: e.g., following Year Classes (No Physics!)

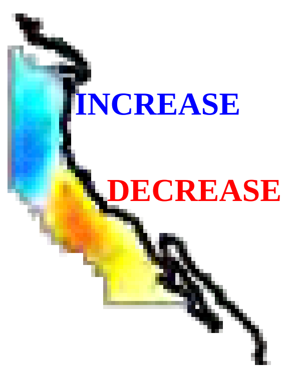
Projections for the CCS under global warming scenarios

- **Rykaczewski and Dunne** (2010) showed that general warming of the North Pacific in the 21st century can enhance nutrients and phytoplankton in the CCS due to deeper, richer source waters of upwelling



- Bakun (1990) suggested an increased land-sea temperature gradient would enhance coastal upwelling: **Rykaczewski** (in prep, 2014) shows it is not so simple…

Change in alongshore Wind Stress: 21st – 20th century

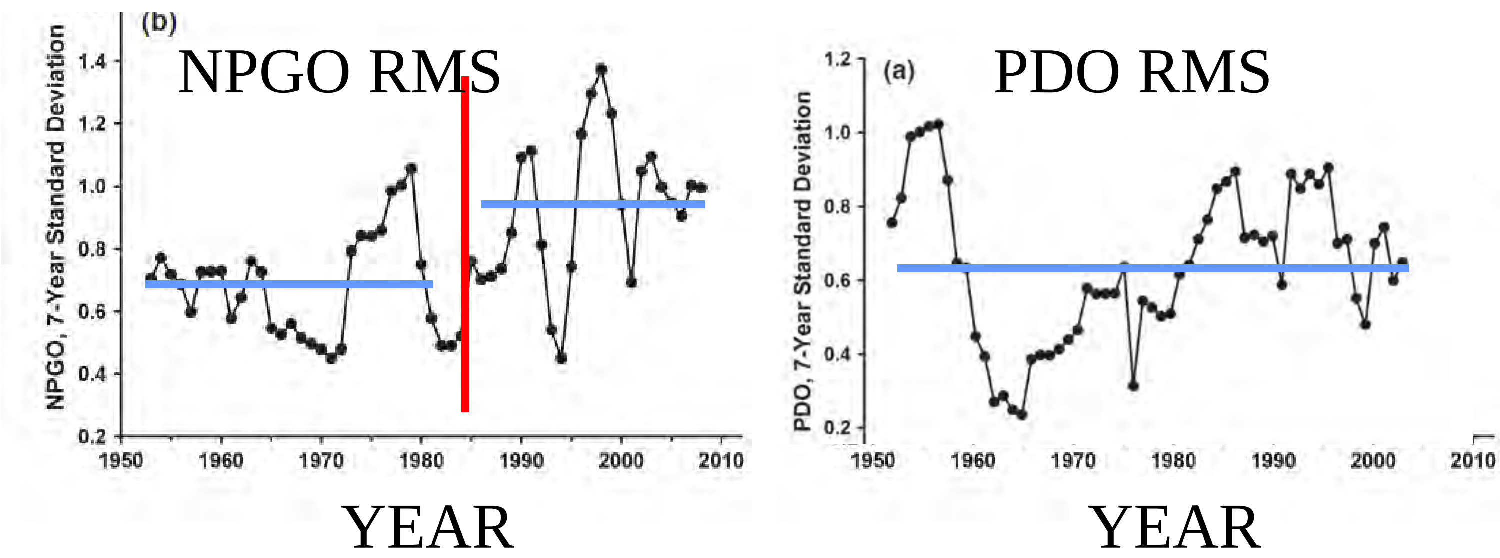


Projected responses of alongshore winds do not confirm Bakun's (1990) predictions.

Multi-model comparison does, however, demonstrate some consistent responses when examining seasonal and latitudinal trends across the four upwelling systems.

Projections for the CCS under global warming scenarios

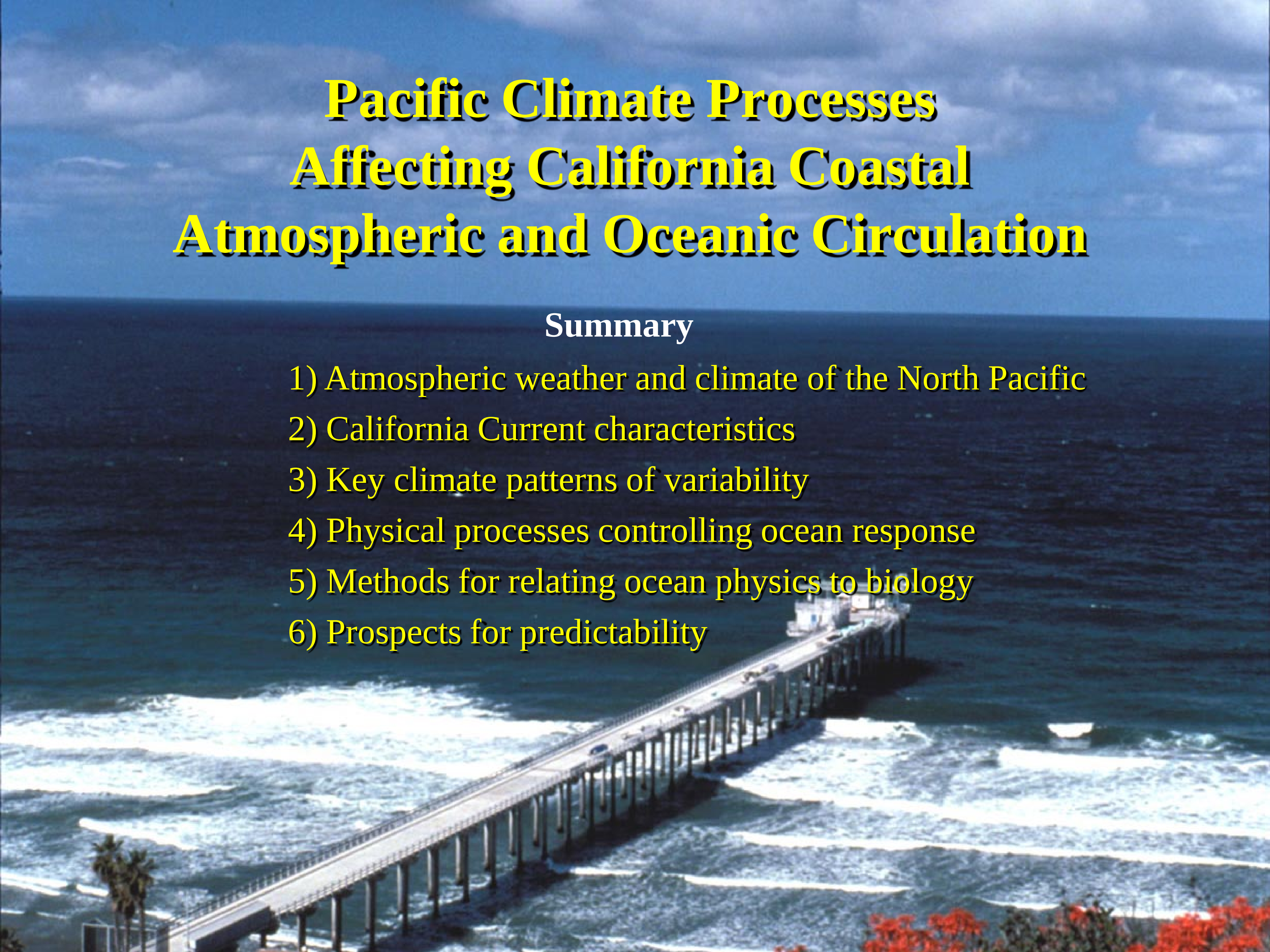
- Furtado et al. (2011) examined AL/PDO and NPO/NPGO statistics in the AR4 future climate model projections: No significant changes in space-time statistics
- Sydeman et al. (2013) suggest a significant change in NPGO variance occurred in the observational record (not so for PDO or ENSO) after 1985, which may be associated with increase variance in ocean biology



Pacific Climate Processes Affecting California Coastal Atmospheric and Oceanic Circulation

Summary

1) Atmospheric weather and climate of the North Pacific
2) California Current characteristics
3) Key climate patterns of variability
4) Physical processes controlling ocean response
5) Methods for relating ocean physics to biology
6) Prospects for predictability



Art Miller
Scripps Institution of Oceanography
University of California, San Diego
La Jolla, CA

California Department of Fish and Wildlife
Climate College Class
MBARI, Moss Landing, CA
April 3, 2014

Thanks!

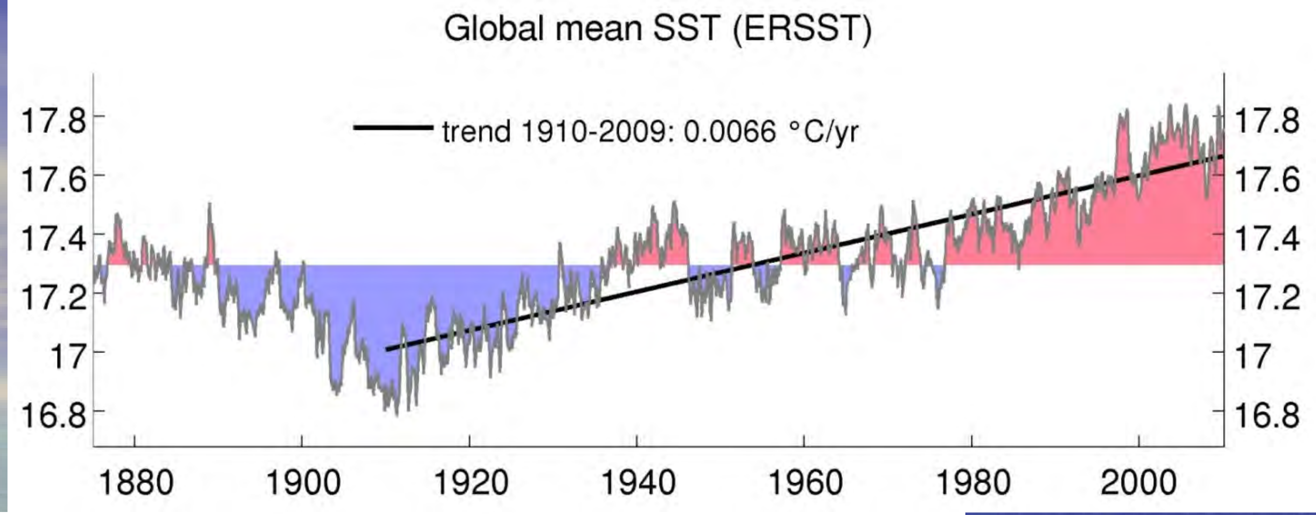
References for further study:
Miller et al., 1999: Observing and modeling the California Current System. *Eos, Transactions, American Geophysical Union*, **80**, 533-539.
Miller and Schneider, 2000: Interdecadal climate regime dynamics in the North Pacific Ocean: Theories, observations and ecosystem impacts. *Progr. Oceanogr.*, **47**, 355-379.
Miller, 2004: Decadal-scale climate and ecosystem interactions in the North Pacific Ocean. *Journal of Oceanography*, **60**, 163-188.
UCSC ocean obs+model: http://oceanmodeling.ucsc.edu/
SCCOOS ocean model: http://www.sccoos.org/data/roms-3km/

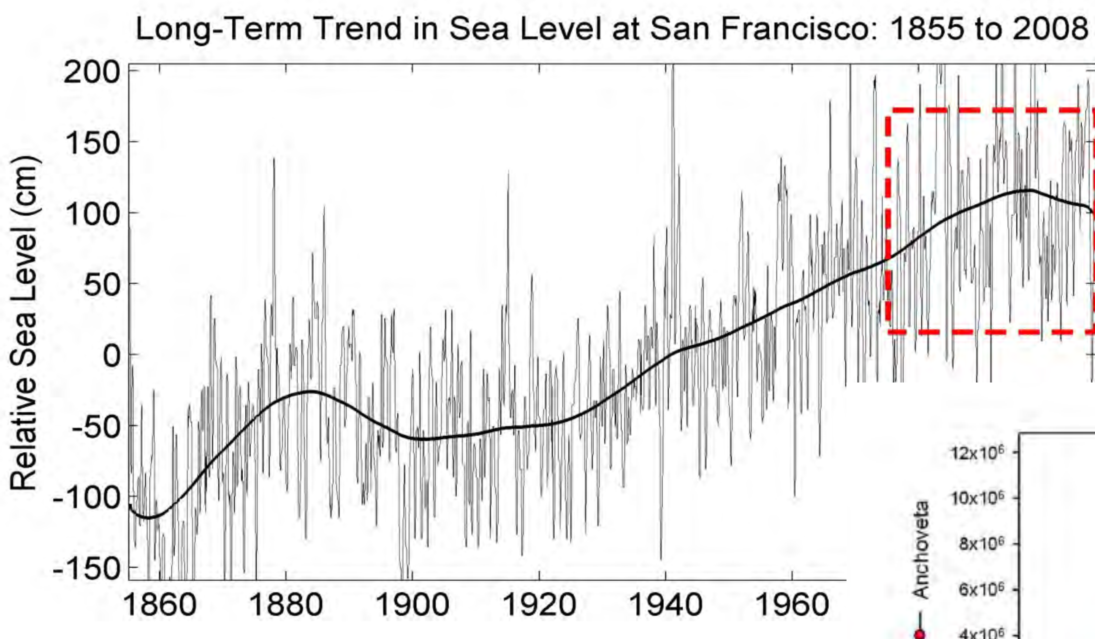
The oceanography of the North Pacific: Past, Present and Future

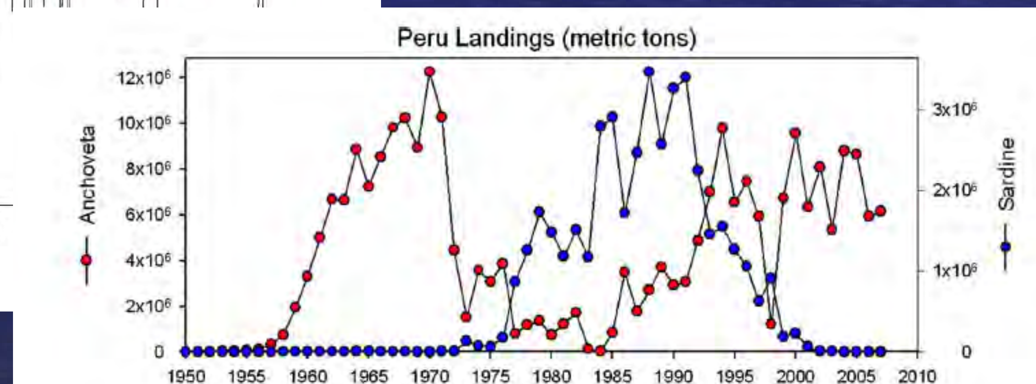
with an emphasis on biology and biogeochemistry

Francisco Chavez
Senior Scientist
Monterey Bay Aquarium Research Institute

With support from the Biological Oceanography group: Blum, Friederich[2], Messié, Michisaki, Pennington, Wahl







Societal drivers with signatures of variability

Key messages

- Climate, ocean physics and biological productivity are linked
- A clear link (so-called bottom-up forcing) is via the supply of nutrients/fertilizer from depth to the surface
- Ocean is a two layer system where nutrients and light are segregated
- At the surface nutrients are made into particles via photosynthesis, then sink by gravity and returned to nutrients at depth

Key messages

- At high latitudes winter mixing dominates nutrient supply (followed by stratification and spring phytoplankton growth)
- At lower latitudes processes that bring the thermocline/nutricline closer to the surface dominate nutrient supply (followed by stratification and growth)
- Greater stratification due to warming presumably reduces nutrient supply (but variations in thermocline depth can override)

Key messages

- Year to year and decade to decade changes in productivity (and heat) are driven by large scale variations in the thermocline and to a lesser extent by local winds – i.e. El Niño
- Due to large scale forcing the central equatorial and eastern Pacific have been cool over the past 15 years
- In Monterey Bay this condition associated with higher nitrate, CO_2, chlorophyll, primary production, flux and jumbo squid, lower O_2

Key messages

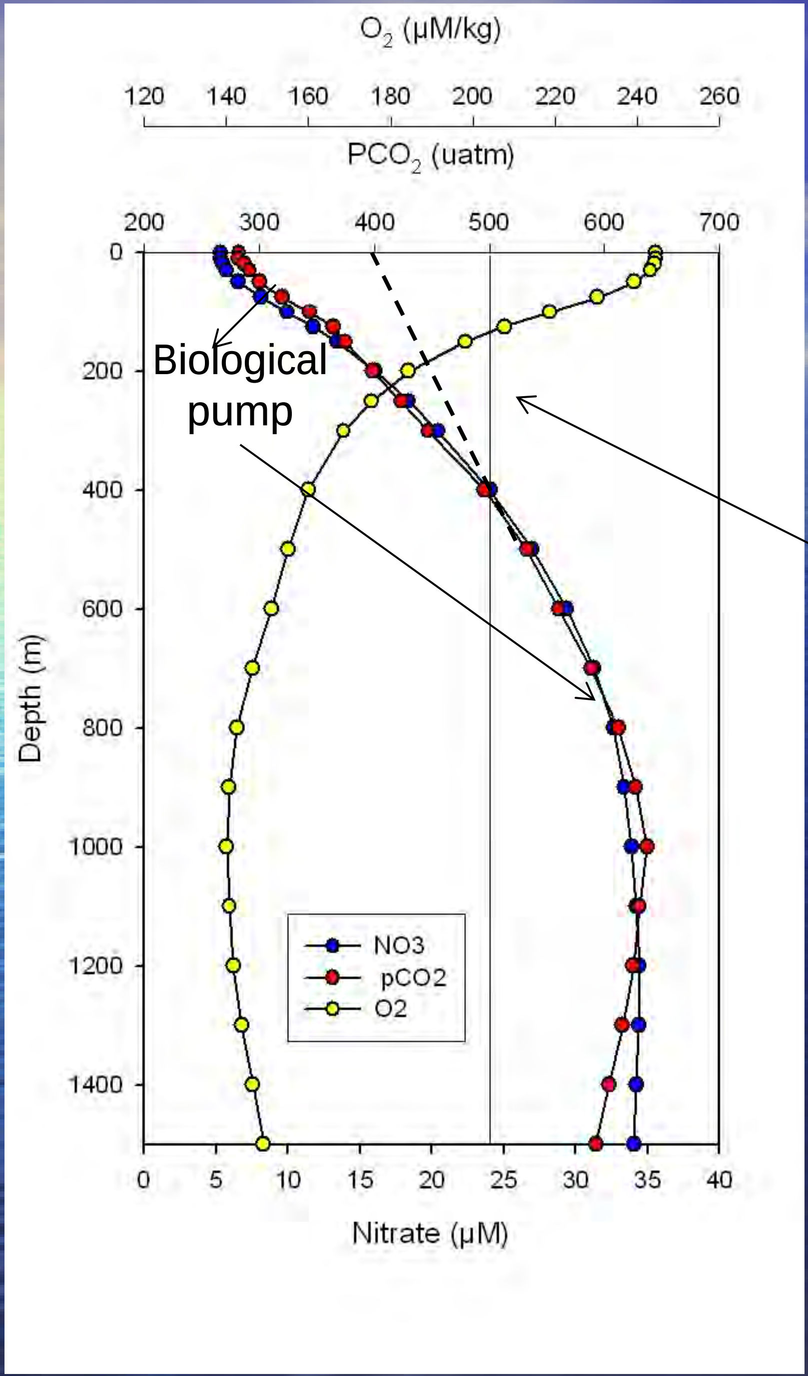
- Pacific dynamics dominate variations in global climate due to its size
- The characteristic shape of Pacific variability includes a triangle from Alaska to the dateline to southern Chile
- Variations in this triangle drive global productivity (and can be tracked in CA)
- The triangle is a feature of a warm world
- The triangle associated with lower oxygen

Key messages

- Primary production (PP, photosynthesis)/chlorophyll and fish abundance related
- Fish production increases non-linearly with increasing PP/chlorophyll
- Fish production 5-10 times higher in marine versus fresh waters
- Transfer of PP to fish non-linear because two variables involved – PP and food web

Key messages

- Climate can influence fish directly (migrations), reproductive success (recruitment), species interactions and habitat
- For example, habitat compression (by decreasing oxygen) can increase pelagic fish yield or decrease benthic fish yield



The ocean is like a big plant, consumes CO_2,NO_3 and releases O_2 at edges, opposite in the interior

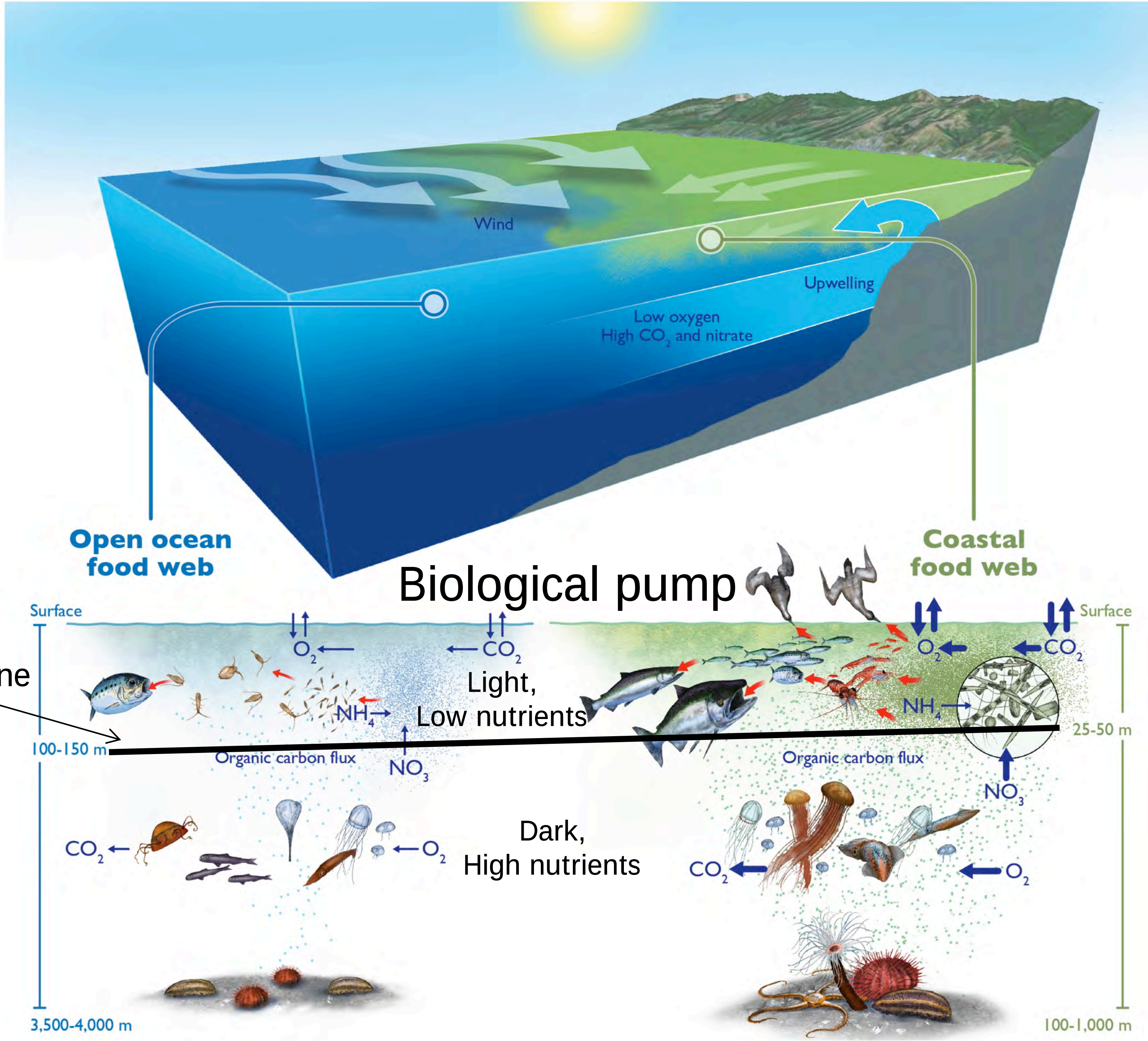
Global mean nitrate = 23.4 uM
If no biology atmospheric
CO_2 would be ~ 500 ppm

Biological pump has already sequestered 500 gigatons C
…… and acidified the ocean

Oxygen is not zero at depth because it is supplied from the atmosphere via sinking of cold water at high latitudes. Apparently more supply in a cold world, less in a warm one

Biological pump

Thermocline
Nutricline



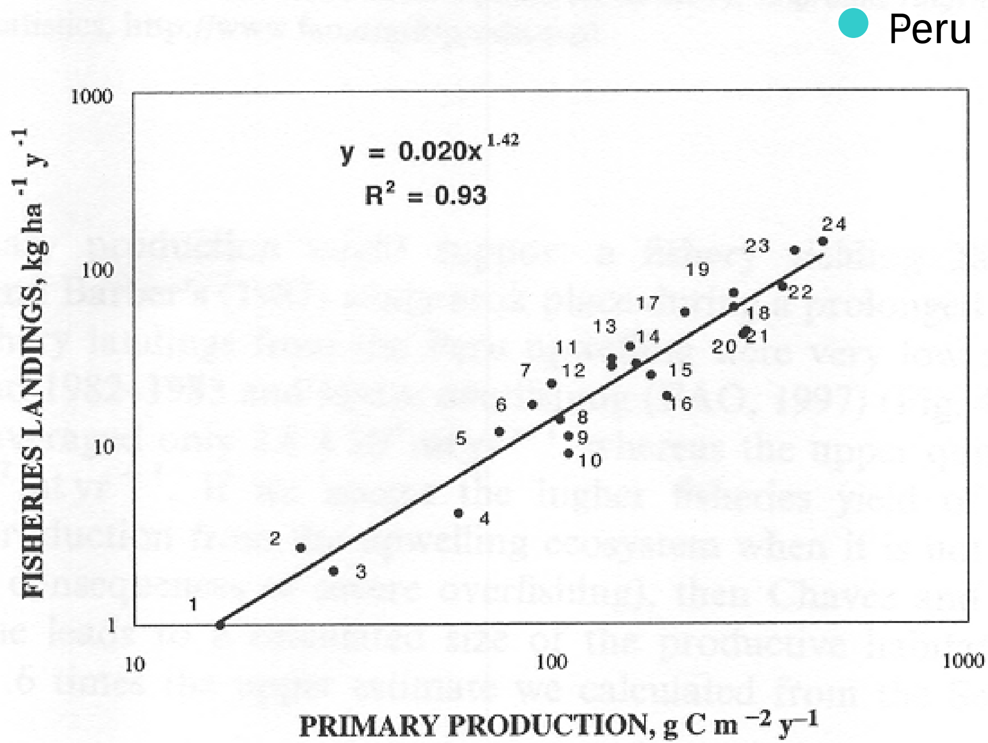


Fig. 3. The annual landings of fish and the primary production (^{14}C uptake) of phytoplankton in a wide variety of marine ecosystems. Measurements are often not contemporaneous. The regression analysis was performed on untransformed data. Systems include: (1) Southeast Mediterranean (postAswan dam construction) (2) Bay of Bothnia (3) Open Gulf of Mexico–Caribbean (4) Sea of Okhotsk (5) Open Mediterranean (6) Adriatic Sea (7) Scotian Shelf (8) Sea of Japan (9) Bothnian Sea (10) Black Sea (11) Gulf of Finland (12) Gulf of Riga (13) English Channel (14) Baltic Sea proper (15) Corpus Christi Bay (16) Gardiners and Peconic Bays (17) North Sea (18) Gulf of Thailand (19) Mid Atlantic Shelf, US (20) Gulf of Maine (21) New England Shelf (22) Apalachicola Bay (23) Georges Bank (24) Great South Bay. Data sources in Nixon (1982) and Nixon et al. (1986). The relationship is discussed more fully in Nixon (1988)

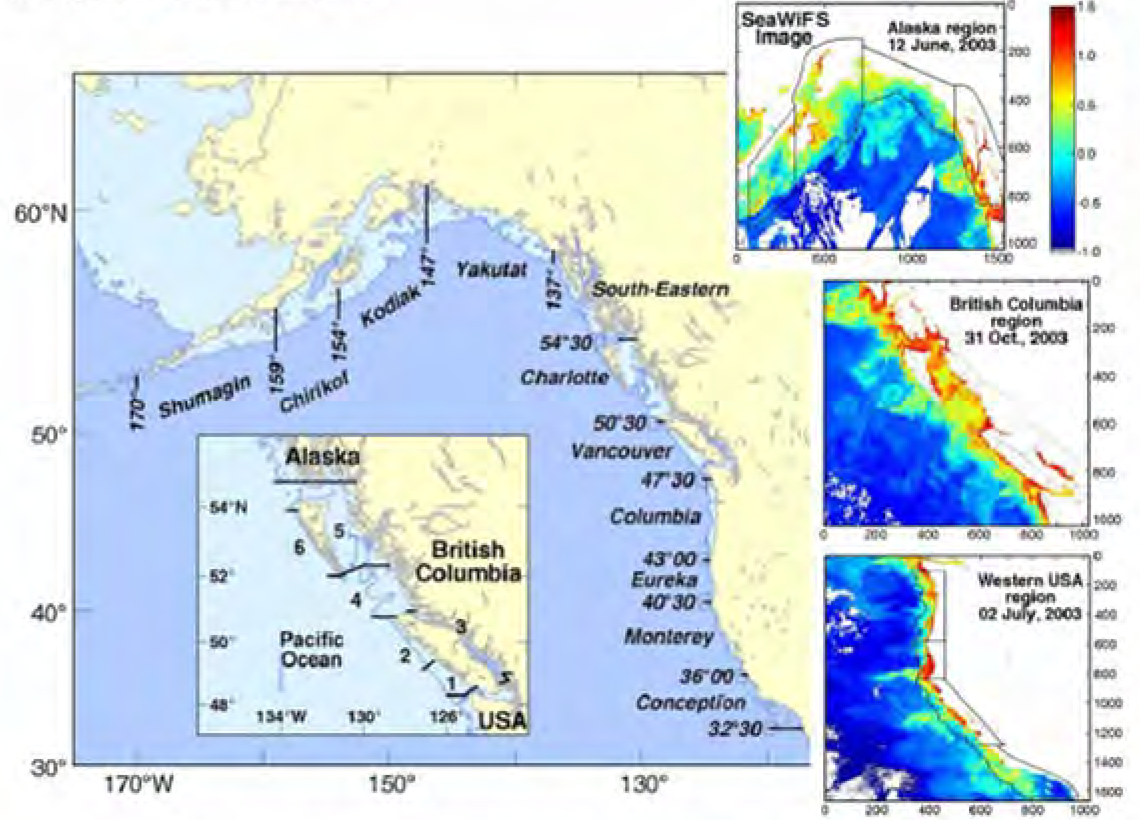
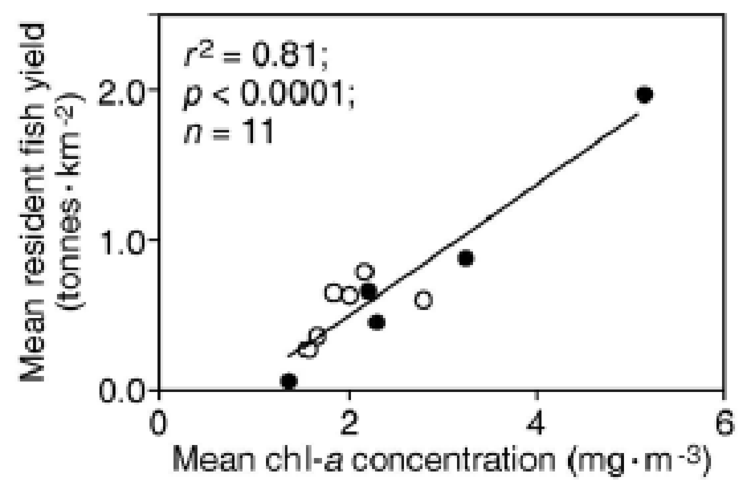
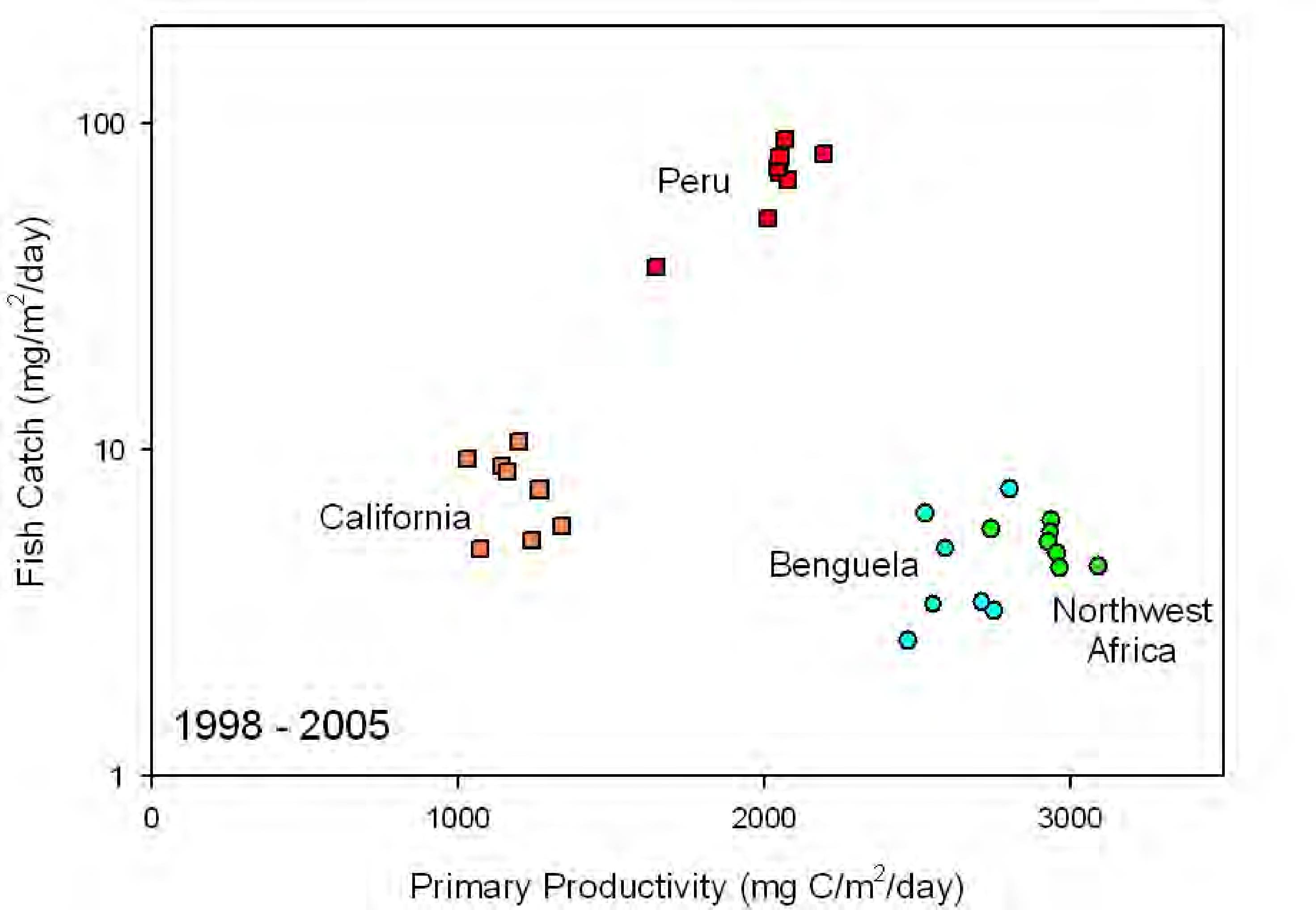


Figure 1. Map of the eleven NPAFC regions extending from "Conception" off California to "Shumagin" off western Alaska. Inset in the ocean shows the areas covered by the six British Columbia sub-regions. Insets on land are examples of daily SeaWiFS chl-a maps for the Alaska, British Columbia and western U.S. regions; grids are in pixels, at 1.1 km/pixel, and the color bar is log(chl-a in mg·m^{-3}).

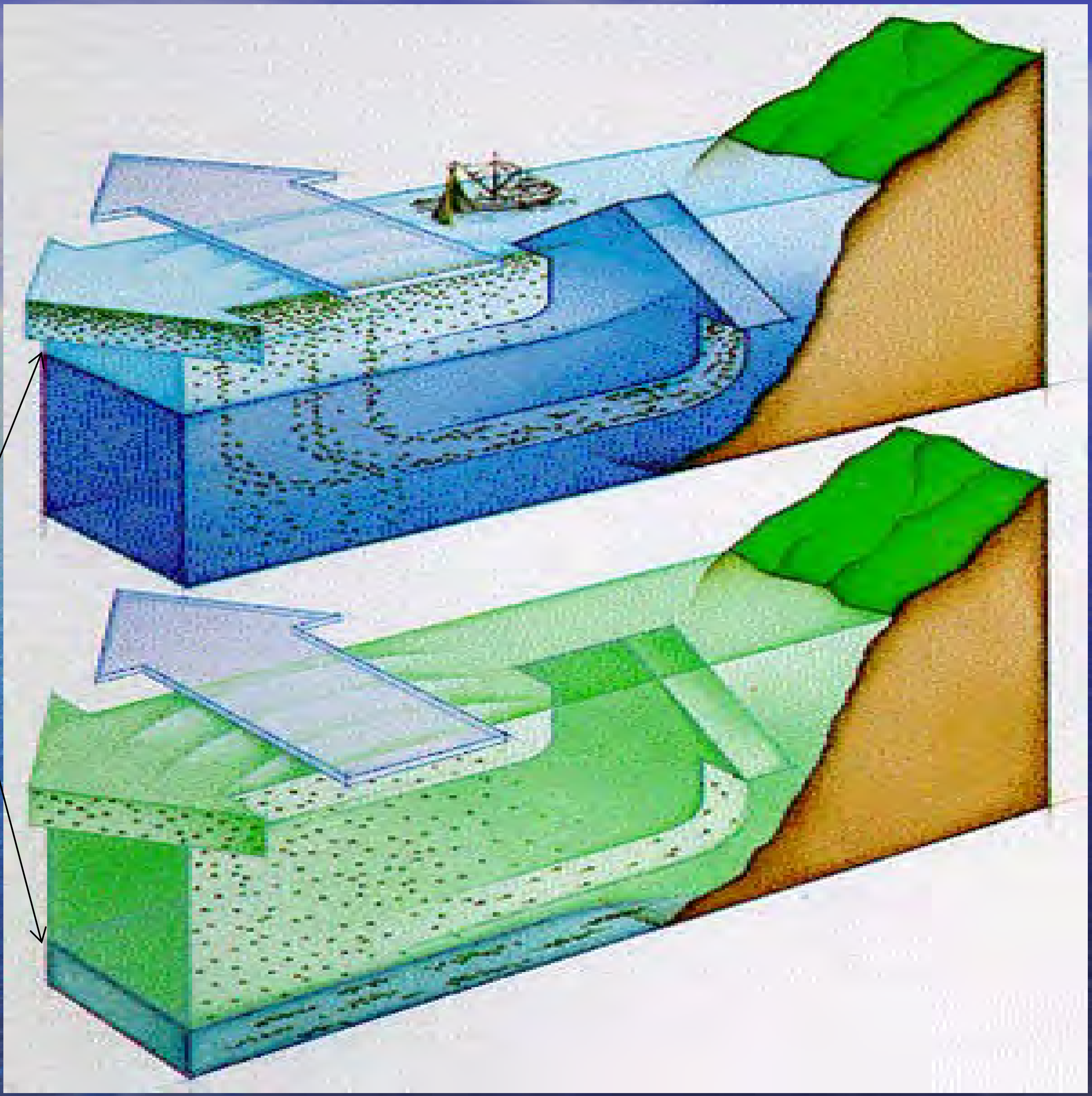
Ware and Thomson, Science, 2005



Peru produces more fish (total and per unit primary production) than any other place in the world!



Is this going to happen to Alta and Baja California in a warm and less oxygenated world?



Global changes, opposite in western Pacific, same in eastern Indian

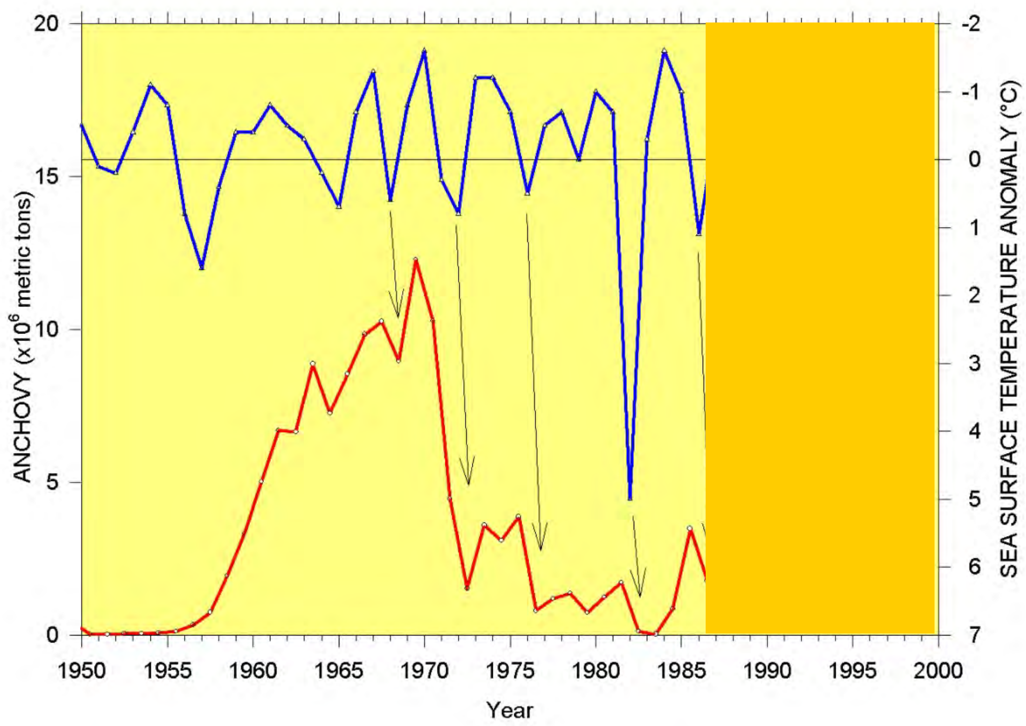
Biological Consequences of El Niño

Richard T. Barber and Francisco P. Chavez

El Niño is defined by the appearance and persistence, for 6 to 18 months, of anomalously warm water in the coastal and equatorial ocean off Peru and Ecuador. However, the anomaly in the eastern tropical Pacific Ocean is only one facet of a large-scale phenomenon involving the global atmosphere and the entire tropical Pacific. In addition to major ecological and agricultural conse-

event. During 1982 and 1983 triweekly observations were made at shore stations in Paita and on the equator at the Galápagos Islands. In addition, shipboard observations were made quarterly along the five transects shown in Fig. 1.

Conceptual Framework



Global EOF analysis

- **Recent period (1993-2010):** global products (temperature (SST), sea level, currents, winds, PAR, salinity, precipitation, Chl, primary production) and equatorial TAO temperature profiles

→ Mode 1 = **ENSO** *(Chavez et al., AR 2011; Messié and Chavez, JGR 2012)*

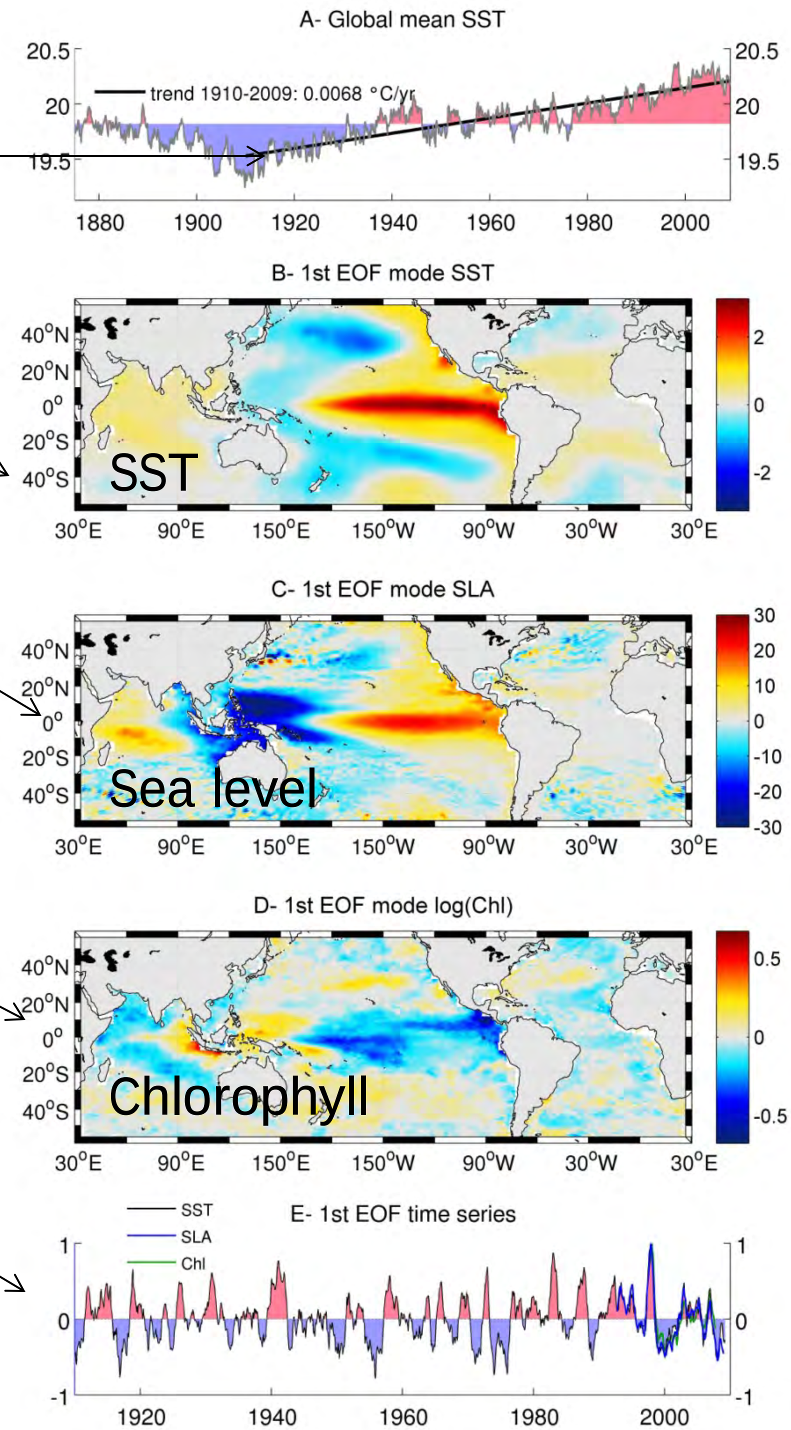
→ Mode 2 linked to **ENSO Modoki** *(Messié and Chavez, JGR 2013)*

- **100-yr analysis (1910-2009):** global SST product (+ Sea Level Pressure)

→ Modes associated with ENSO, PDO (Pacific Decadal Oscillation), NPGO (North Pacific Gyre Oscillation), AMO (Atlantic Multidecadal Oscillation), ENSO Modoki *(Chavez et al., AR 2011; Messié and Chavez, JClim 2011)*

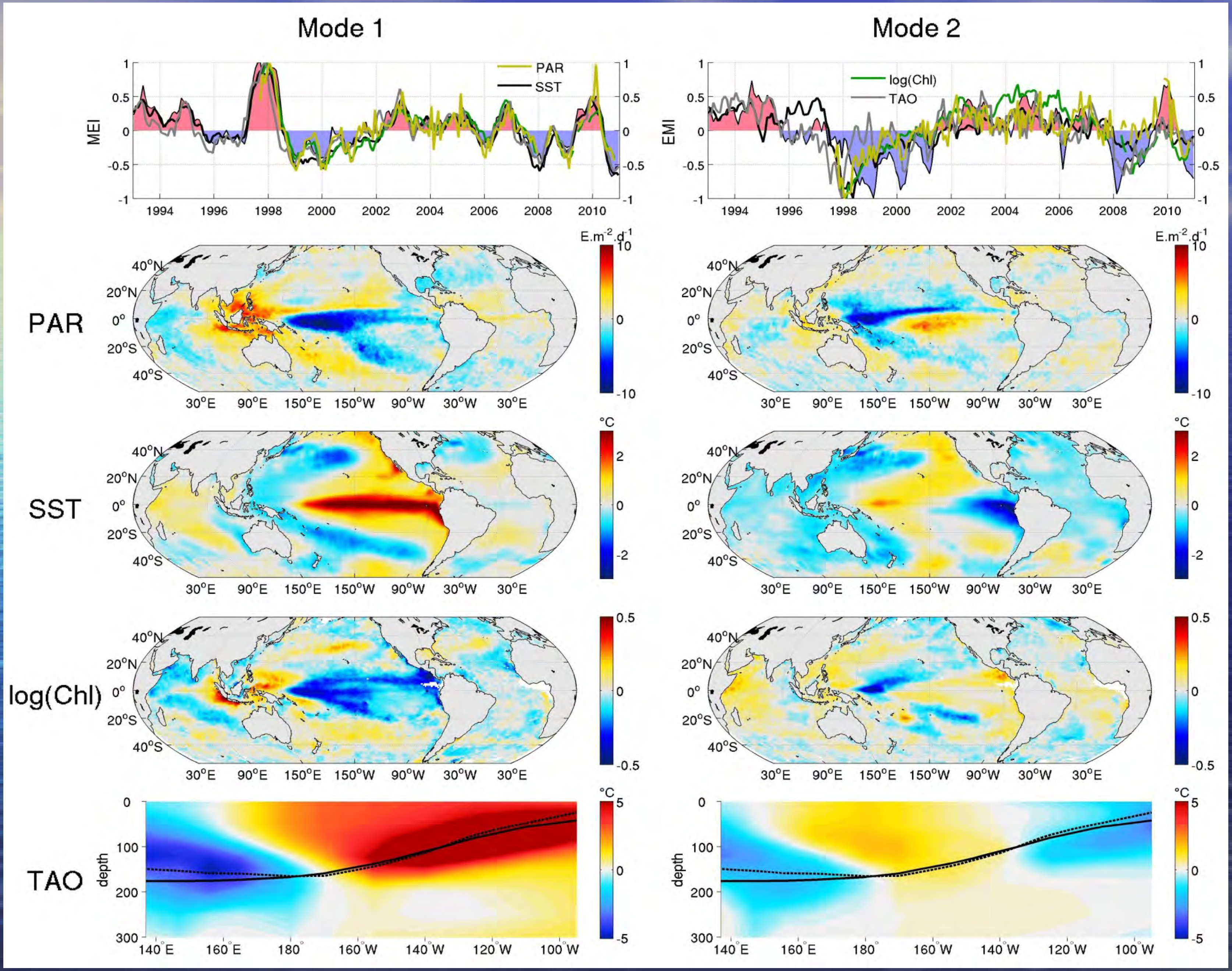
↳ *All variables EOF analysis 1993-2010*
↳ *SST EOF analysis 1910-2009*
↳ *Trends removed*

The global trend from 1910 to 2009 and seasonal cycle has been removed and an EOF analysis performed on SST. The first mode captures ENSO. Many other properties, like sea level, chlorophyll, sea level pressure, PAR or sunlight, winds, currents also display ENSO as their dominant mode.

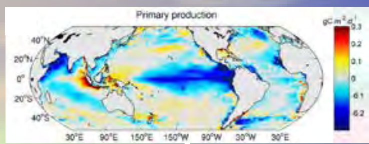


The principal component time series are identical and correlated with the Multivariate ENSO Index (MEI)

Climate, ocean physics and biological productivity intimately linked

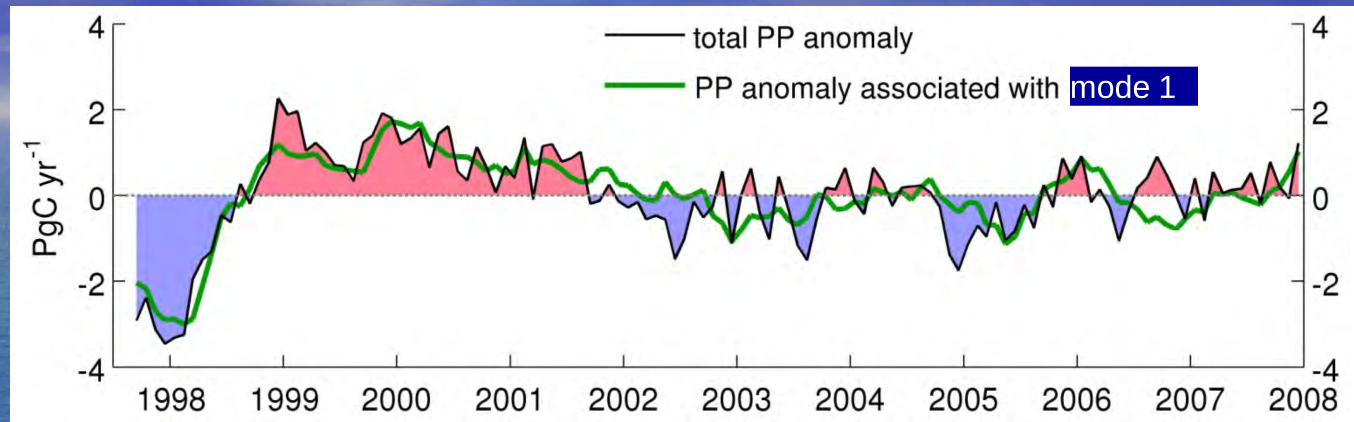


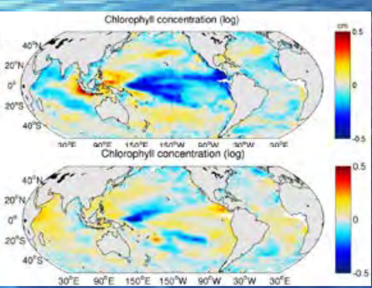
Global impact on primary production / chlorophyll



- 3 PgC / yr
(- 6.3%)

integrated PP

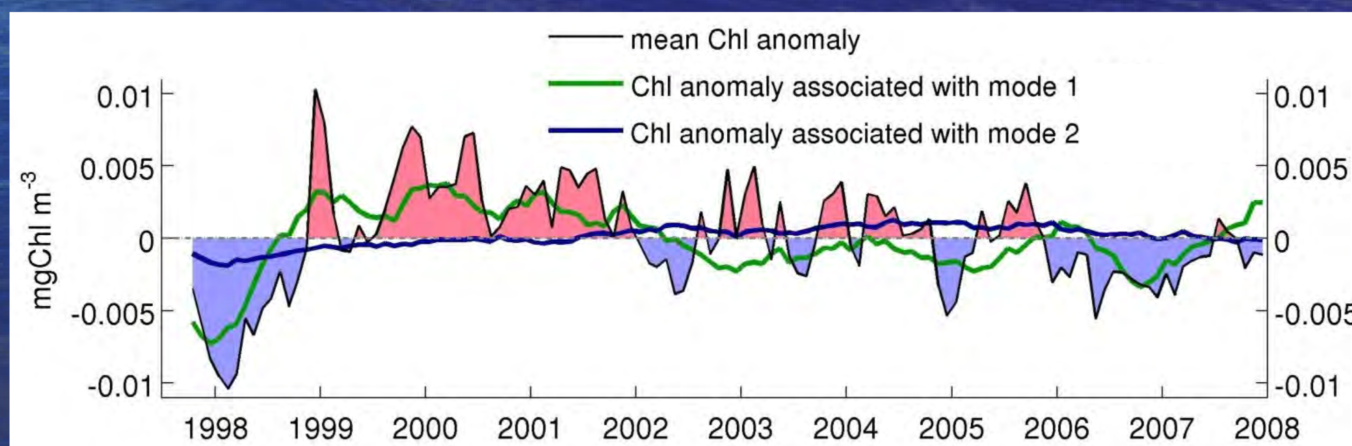




- 4.3 %

+ 1.6%

averaged surface Chl

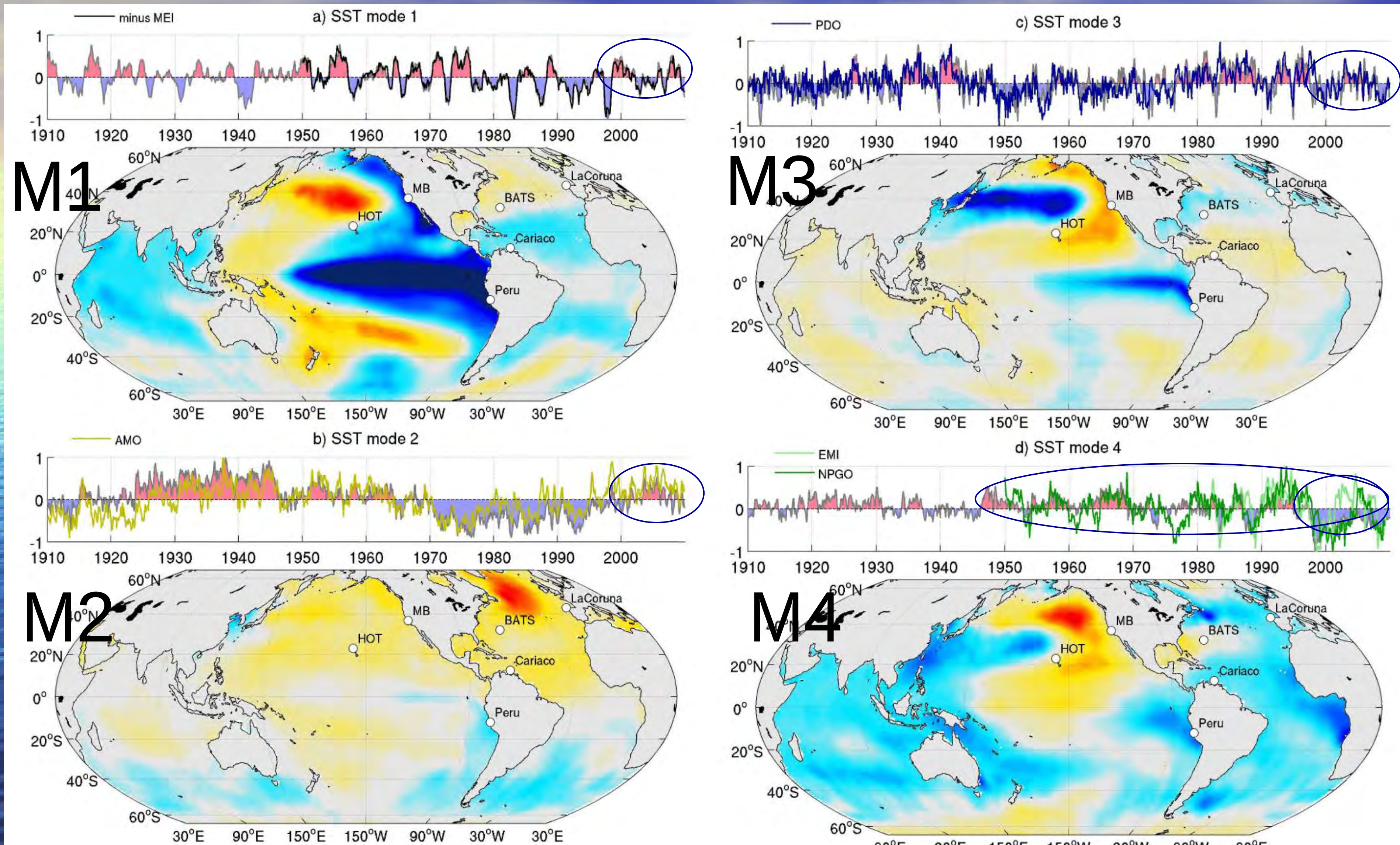


⇒ ENSO in tropics dominates worldwide changes

The first four global modes of SST variability (Chavez et al. 2011)

El Niño/ La Niña

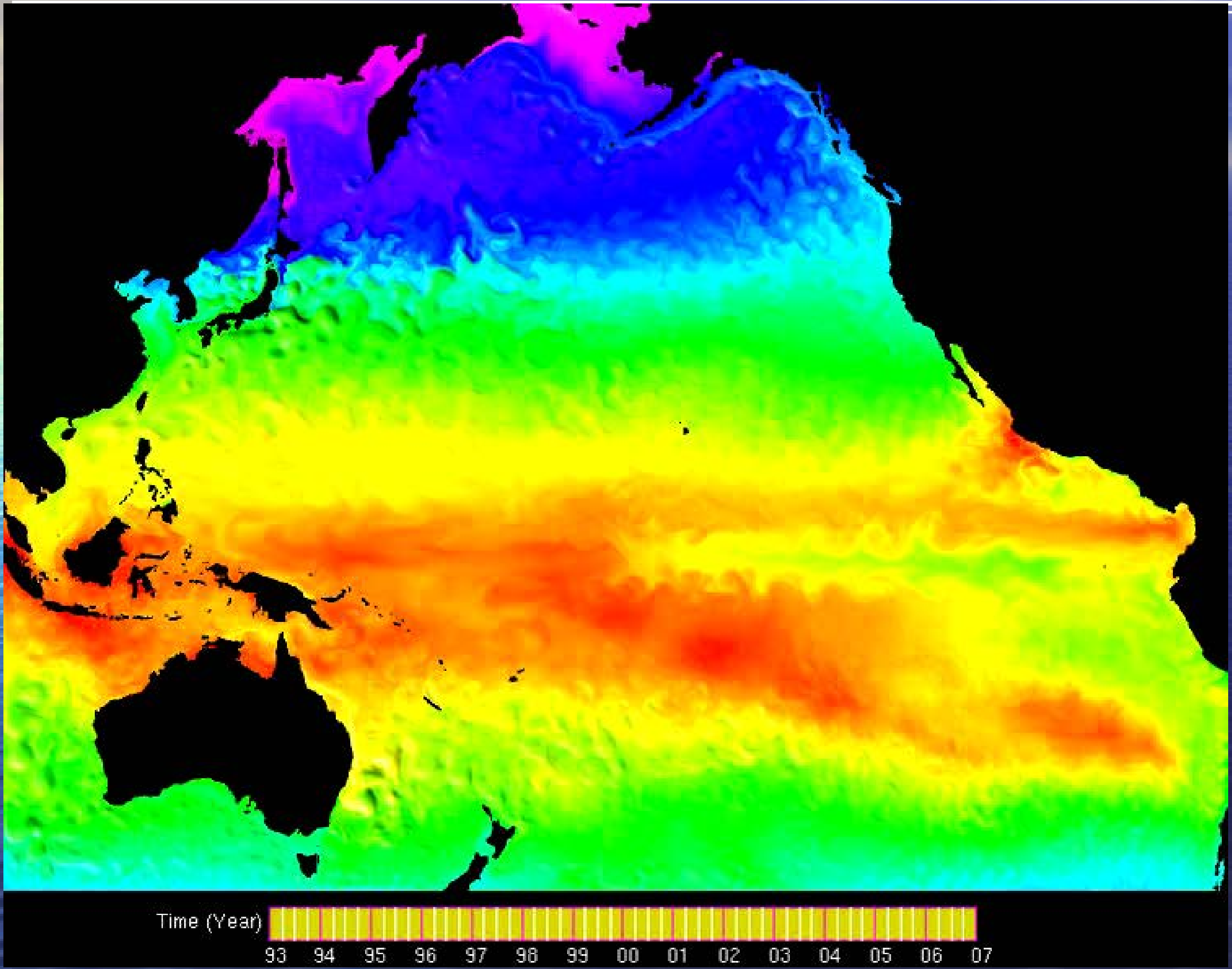
Pacific Decadal Oscillation



Atlantic Multidecadal Oscillation

El Niño Modoki/North Pacific Gyre

Regional Ocean Model System 12-km with NPZ
(red warm, blue cold, relief sea surface height = eddies)

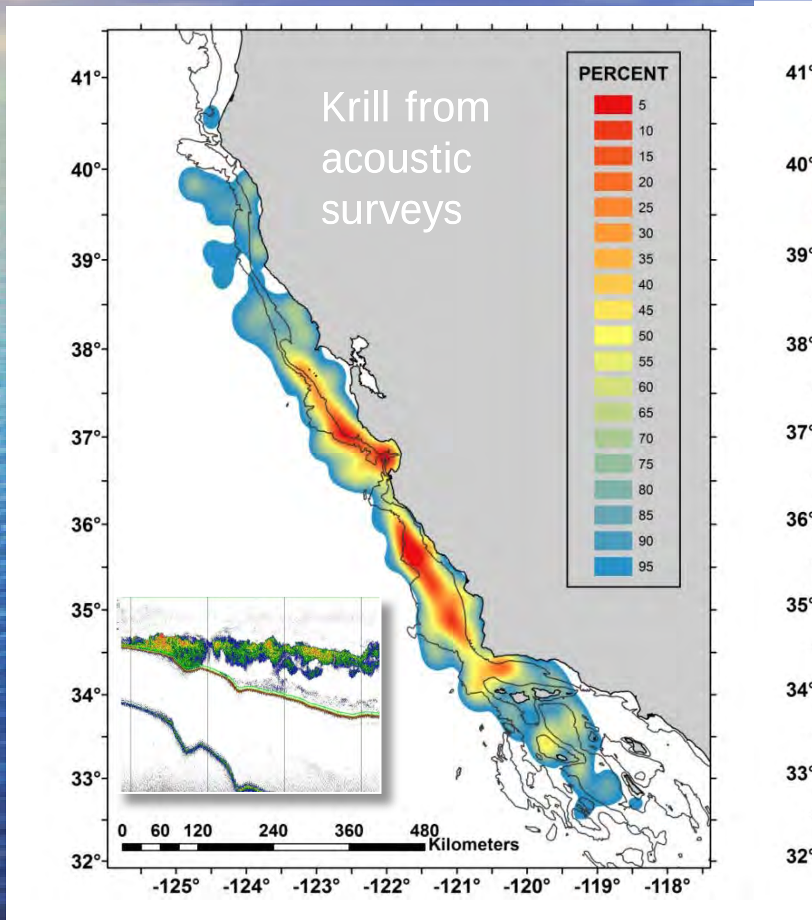


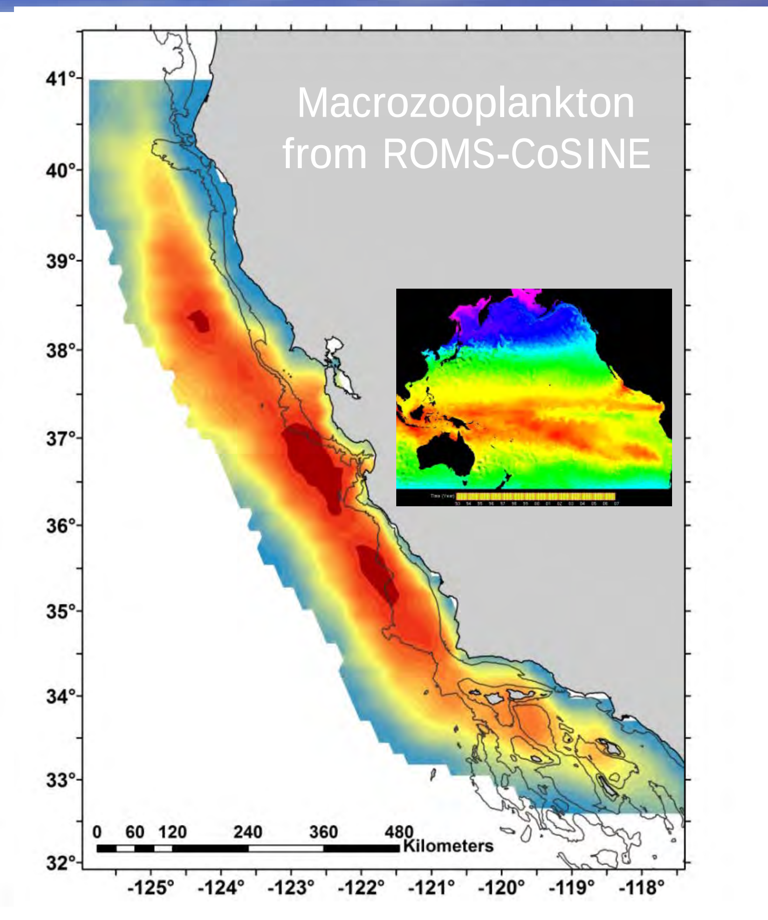
Ecological Forecasting of Central California salmon

Peru: Forecasting Anchoveta and Sardine Transitions (FAST)

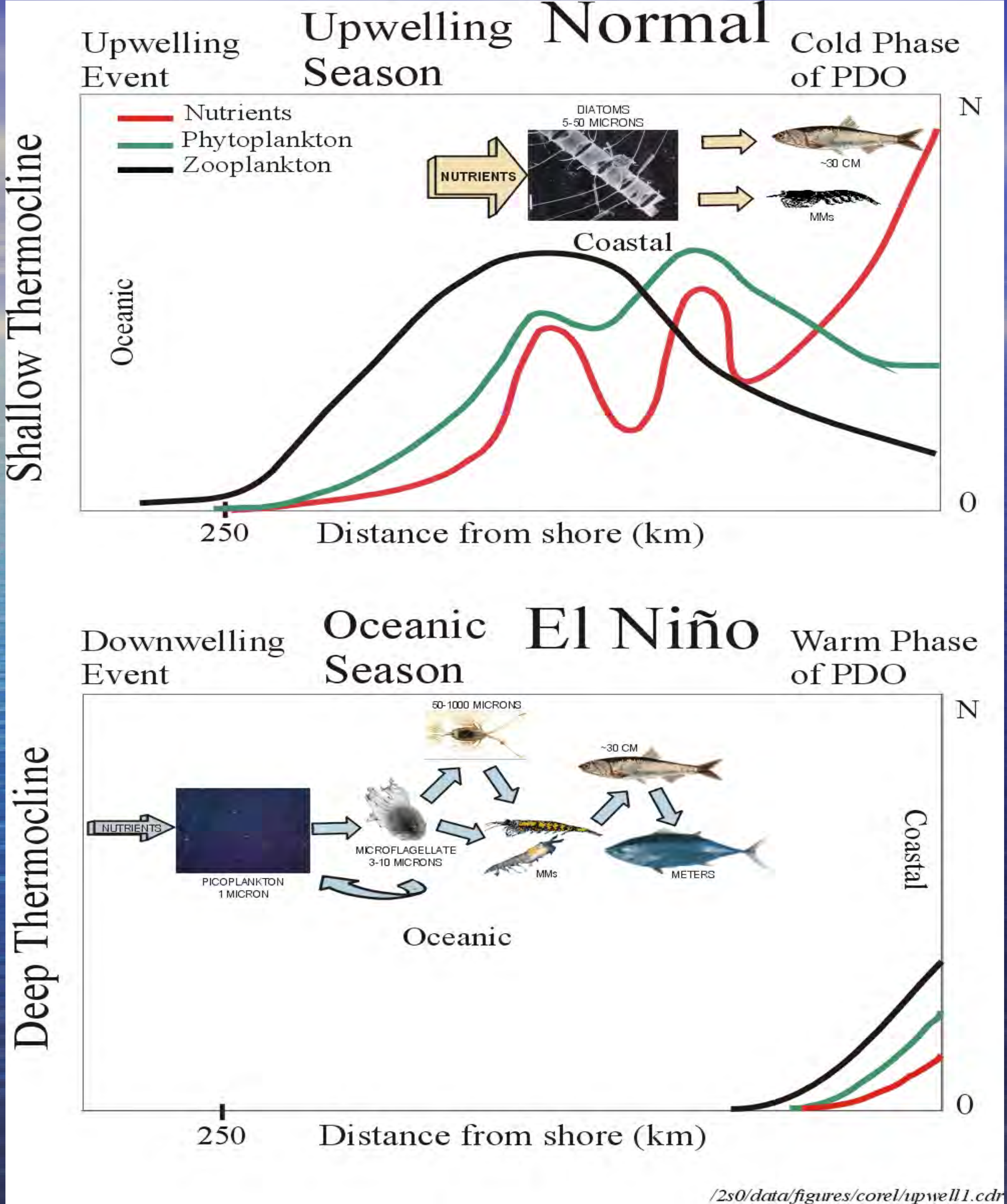
Fei Chai and Yi Chao

ROMS-COSiNE is capable of reproducing the zooplankton climatology demonstrated in empirical studies



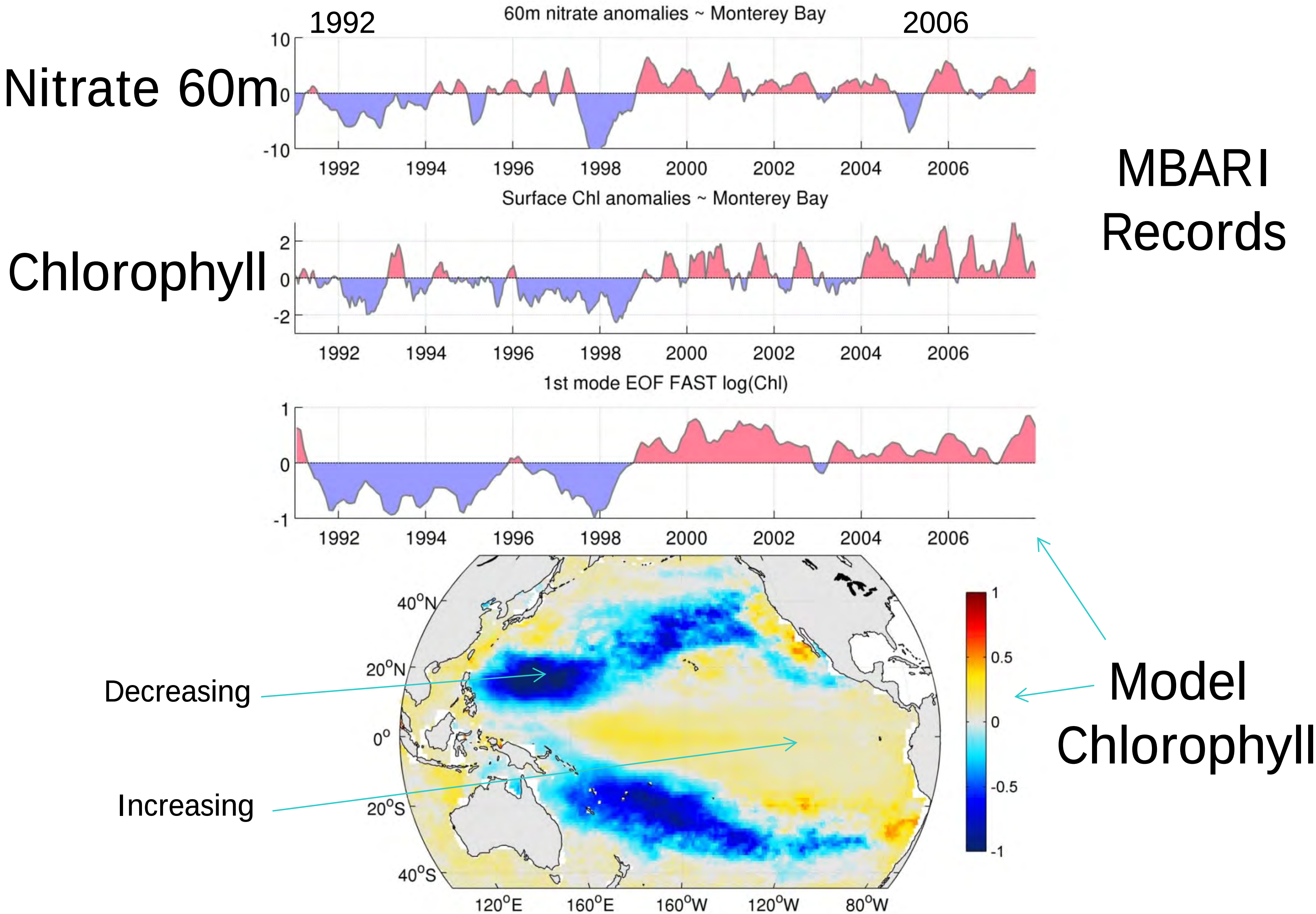


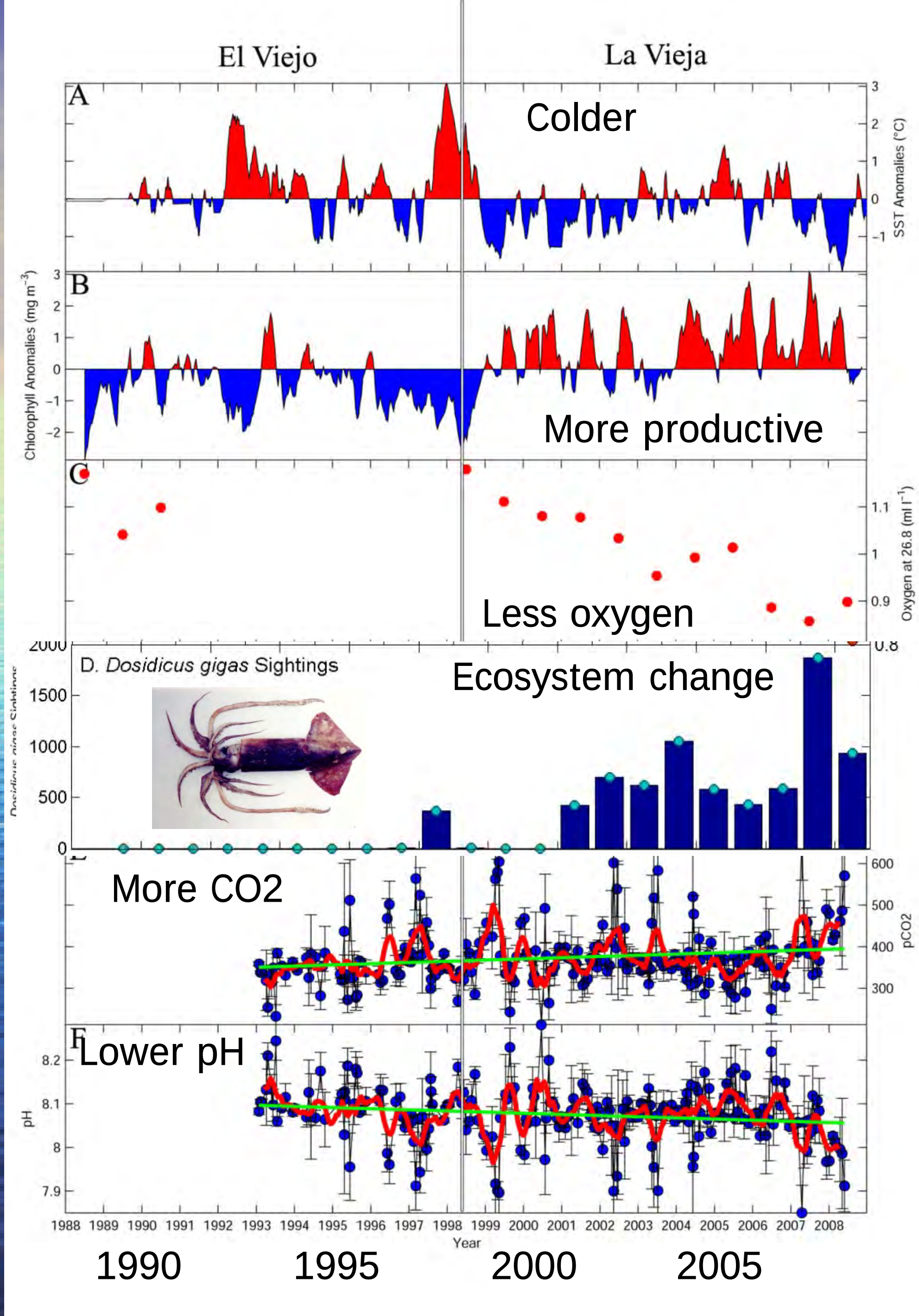
First ever comparison of its kind?

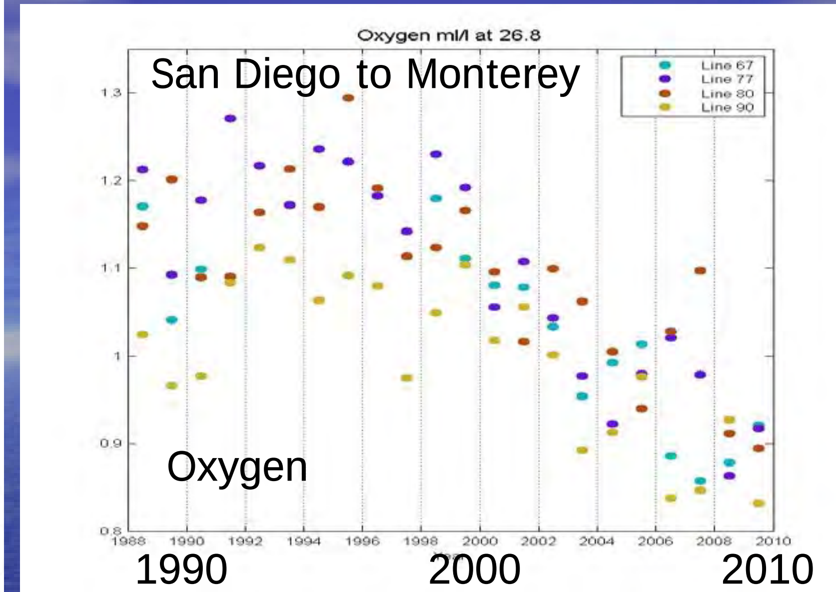


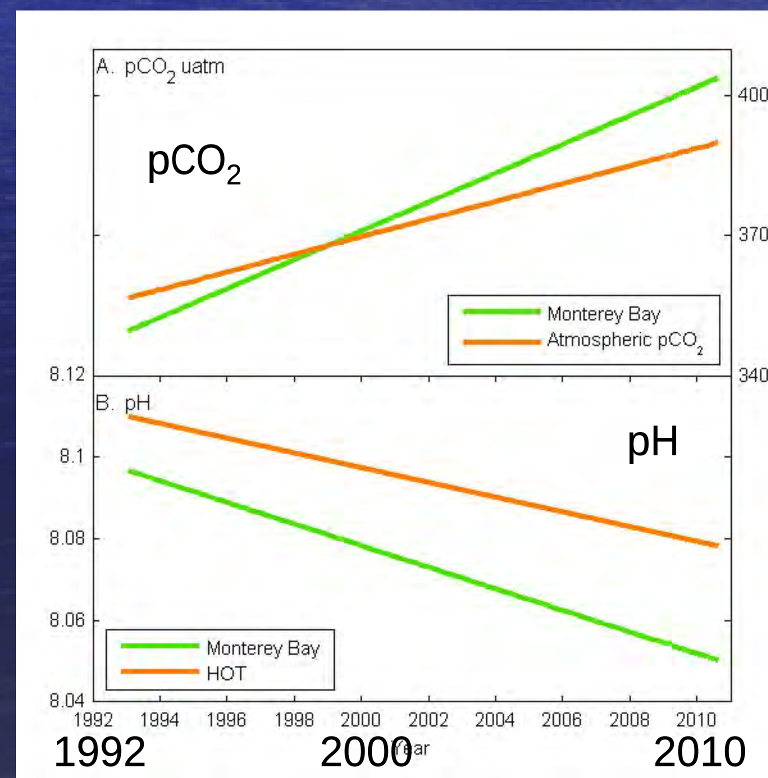
Strong CCS
Low Catchability

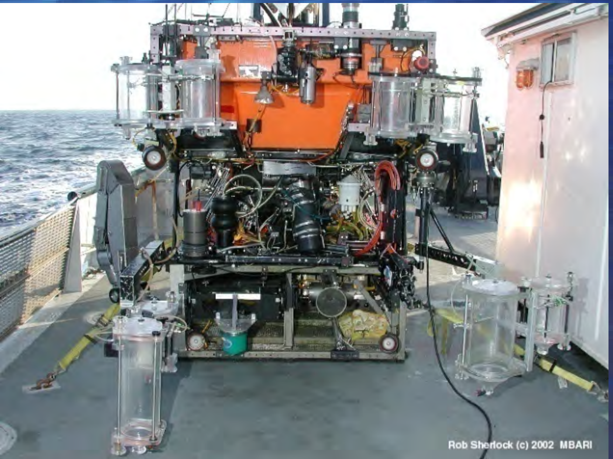
Weak CCS
High catchability


1992
2006
60m nitrate anomalies ~ Monterey Bay
Nitrate 60m
10
0
-10
1992
1994
1996
1998
2000
2002
2004
2006
MBARI
Records
Surface Chl anomalies ~ Monterey Bay
Chlorophyll
2
0
-2
1992
1994
1996
1998
2000
2002
2004
2006
1st mode EOF FAST log(Chl)
1
0
-1
1992
1994
1996
1998
2000
2002
2004
2006
40°N
20°N
0°
20°S
40°S
120°E
160°E
160°W
120°W
80°W
1
0.5
0
-0.5
-1
Decreasing
Increasing
Model
Chlorophyll

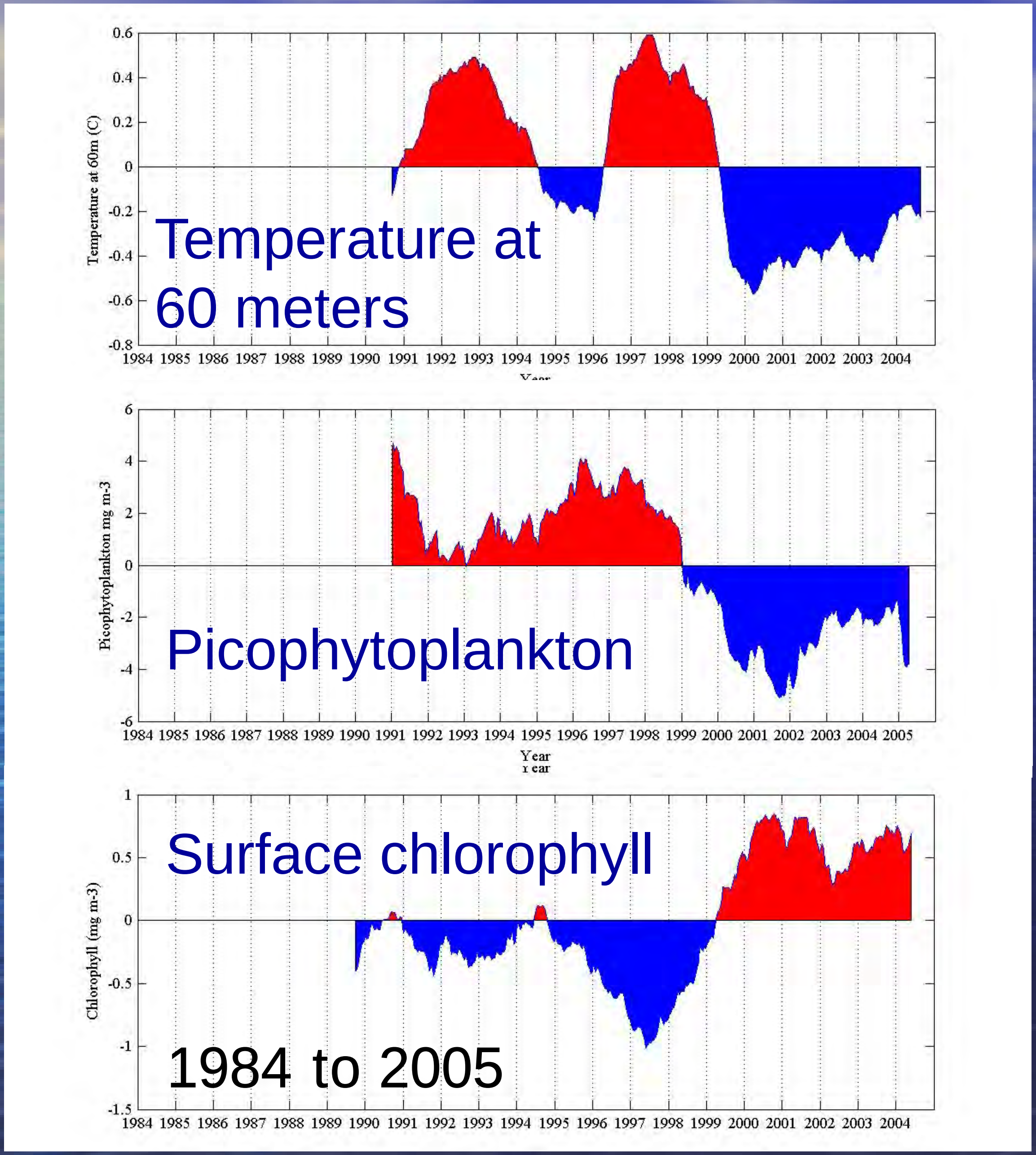

El Viejo
La Vieja
A
Colder
SST Anomalies (°C)
B
Chlorophyll Anomalies (mg m⁻³)
More productive
C
Oxygen at 26.8 (ml l⁻¹)
Less oxygen
D. Dosidicus gigas Sightings
Ecosystem change
More CO2
pCO2
F
Lower pH
pH
1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008
Year
1990
1995
2000
2005


Oxygen ml/l at 26.8
San Diego to Monterey
Line 67
Line 77
Line 80
Line 90
Oxygen
1988 1990 1992 1994 1996 1998 2000 2002 2004 2006 2008 2010
1990
2000
2010


A. pCO2 uatm
pCO2
Monterey Bay
Atmospheric pCO2
B. pH
pH
Monterey Bay
HOT
1992 1994 1996 1998 2000 2002 2004 2006 2008 2010
Year
1992
2000
2010


Rob Sherlock (c) 2002 MBARI

Greening correlated with cooling and increase of nutrients at depth



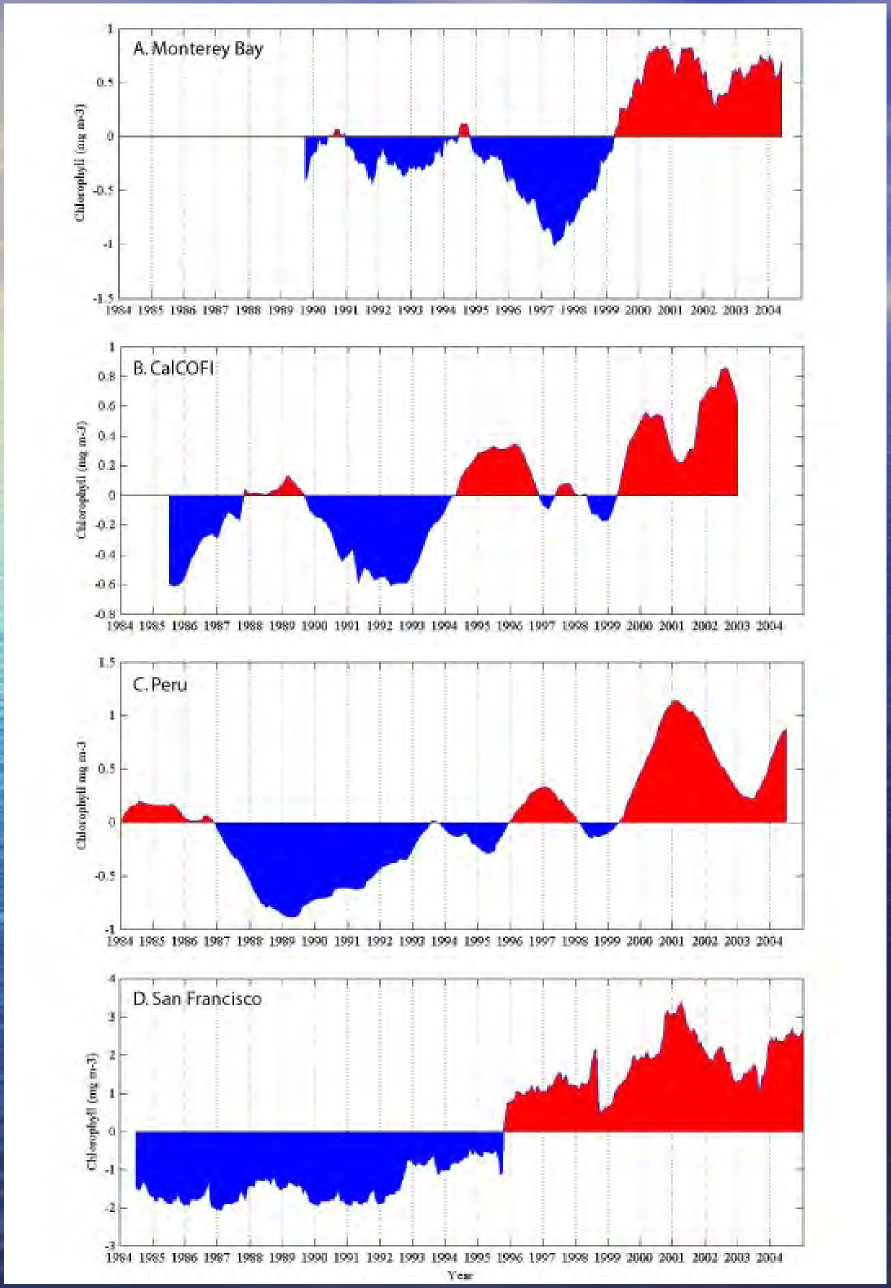
1985 1990 1995 2000 2005

Monterey Bay Temperature at Depth

Monterey Bay Nitrate at Depth

Monterey Bay Surface Chlorophyll

What is responsible for greening of California coastal waters?



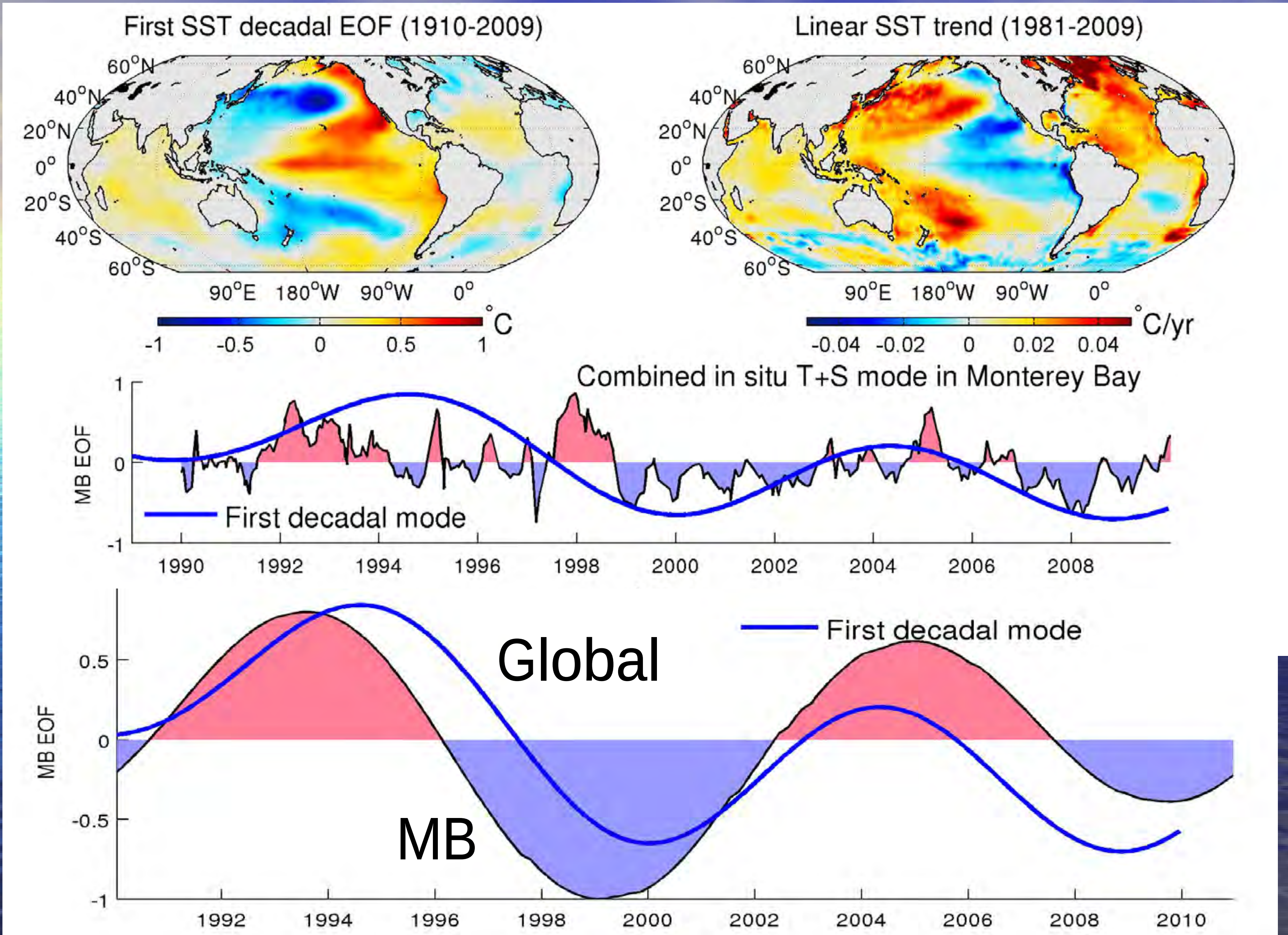
Monterey Bay chlorophyll

Southern California chlorophyll

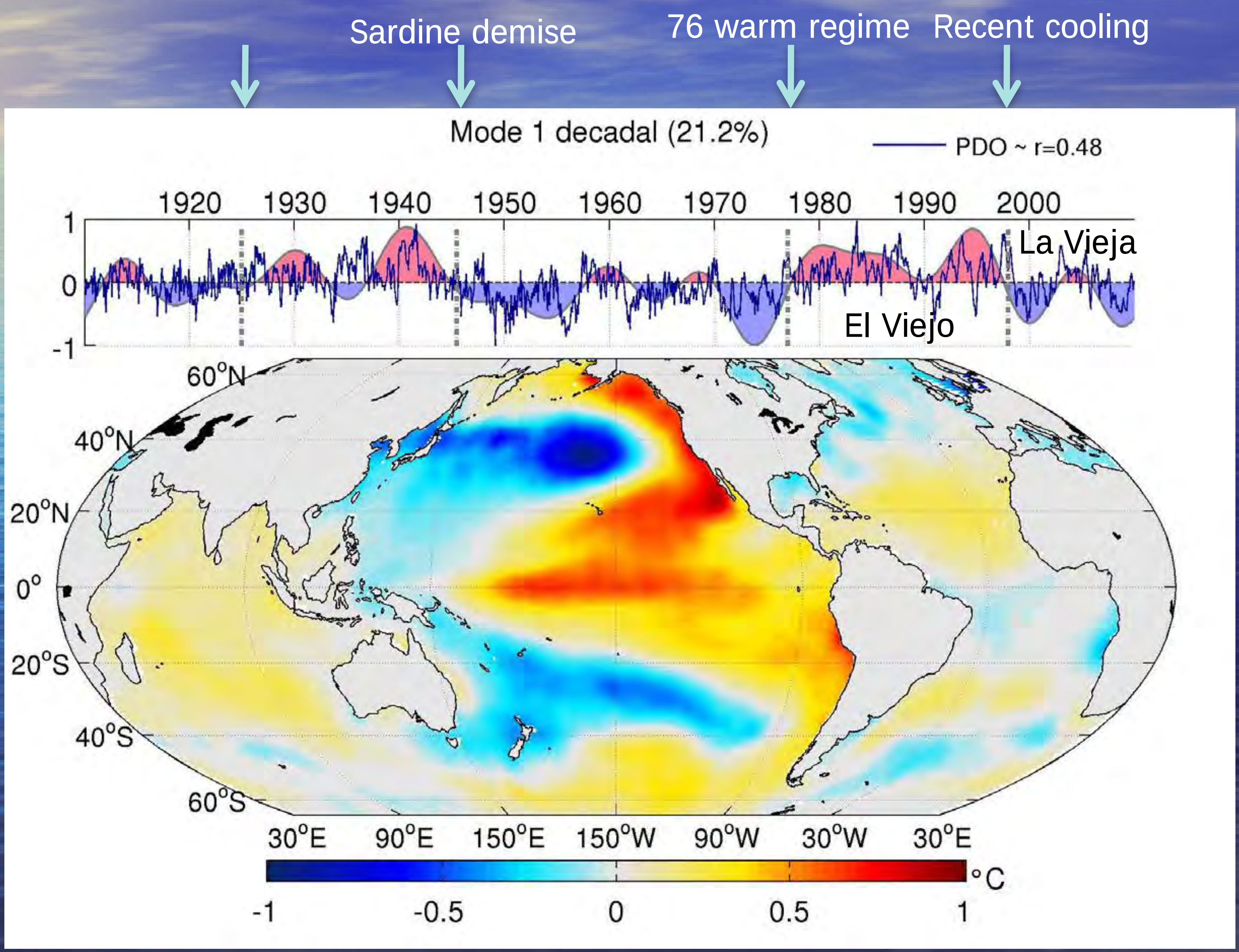
Peru chlorophyll

San Francisco Bay chlorophyll

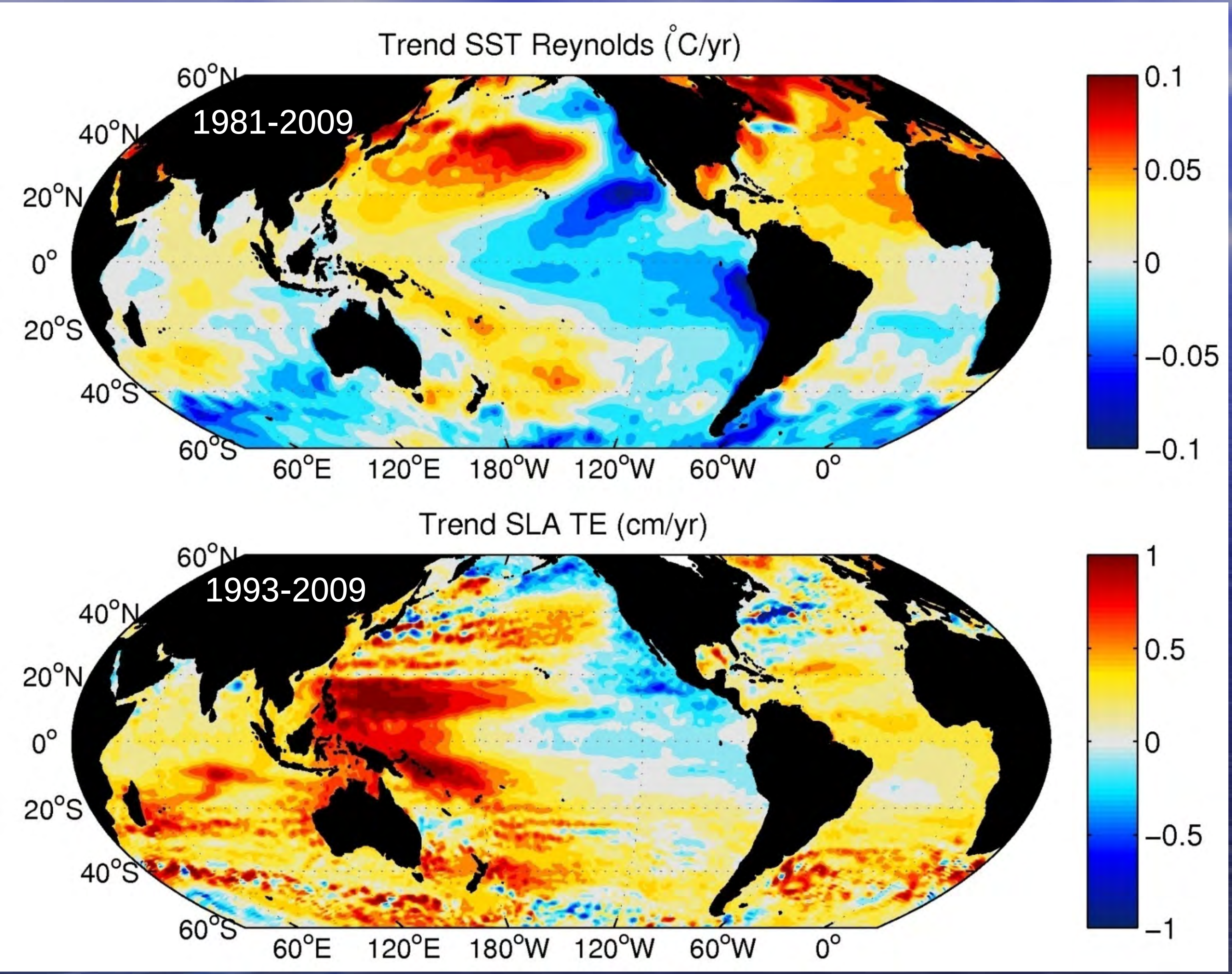
MB region "feels" large scale/global variations in climate



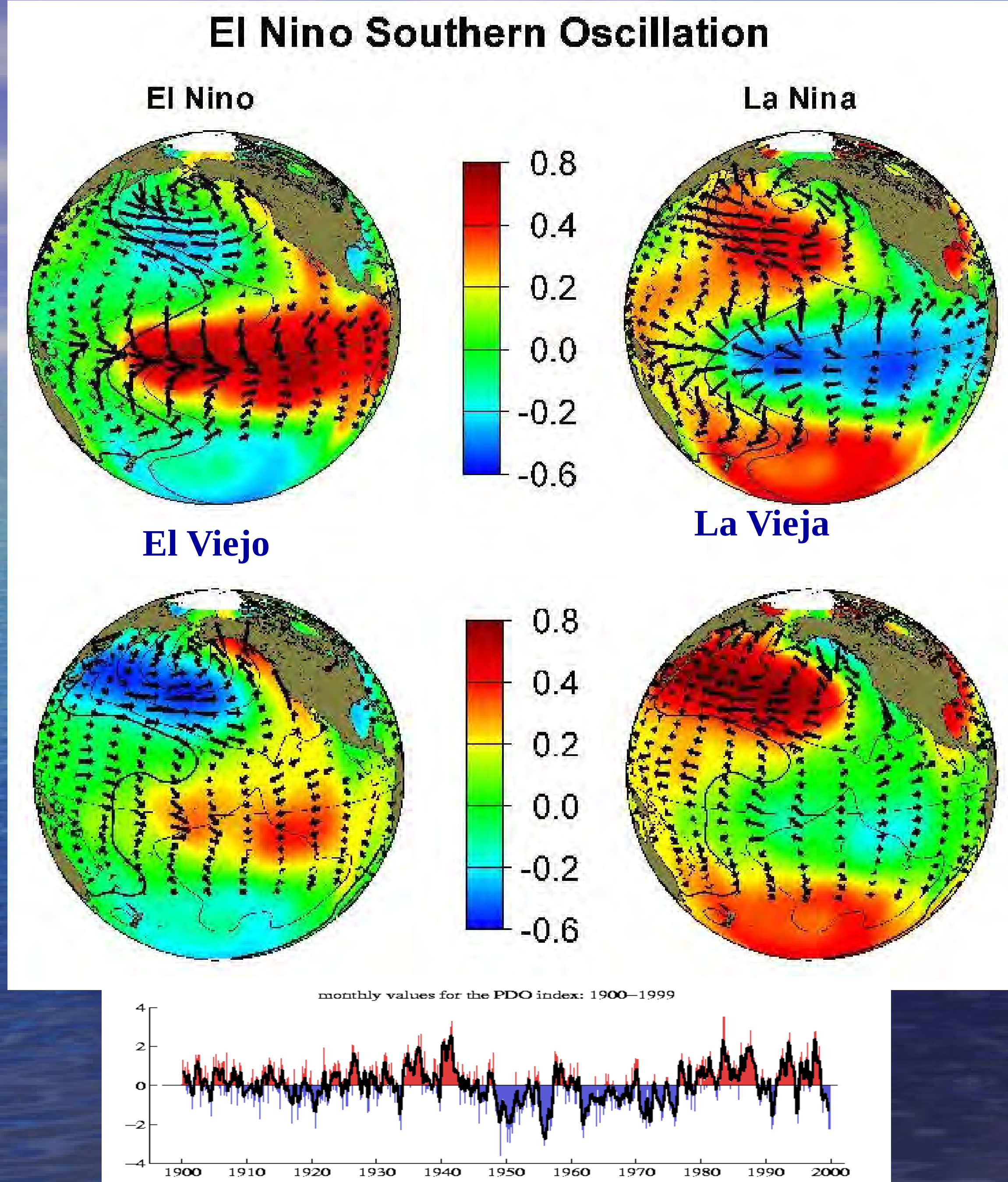
Global multidecadal variability and regime shifts, same pattern as recent cooling (Messie and Chavez, 2011)



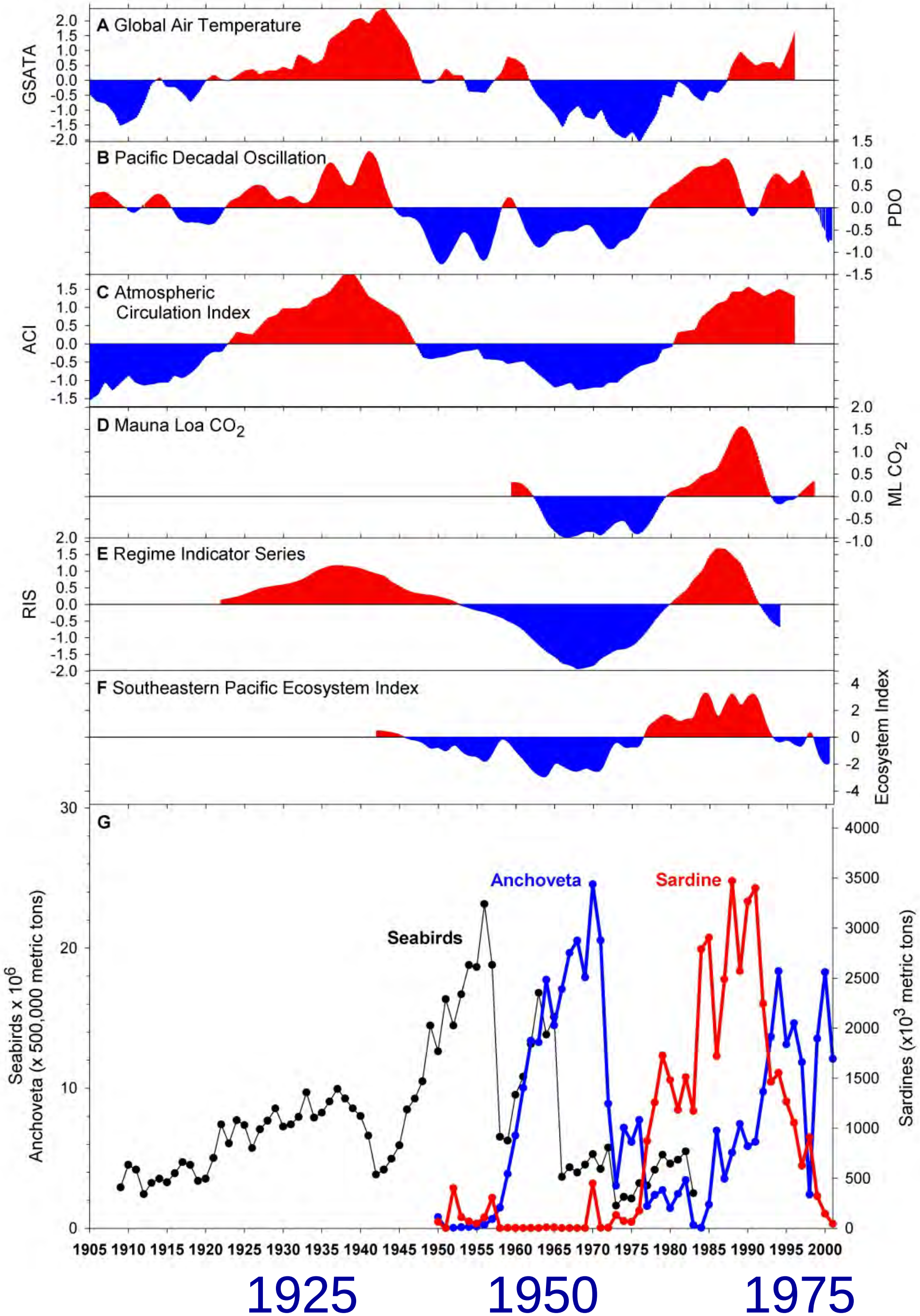
This variability is associated with recent trends in SST y SLA

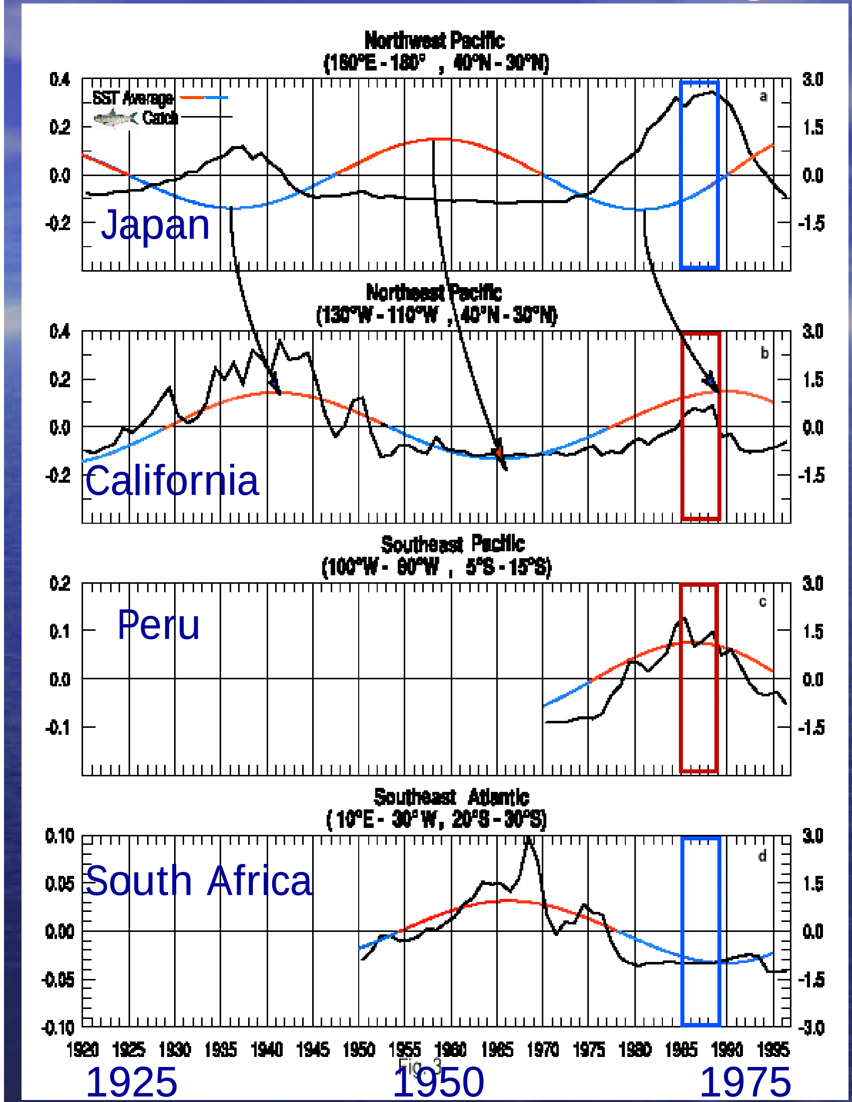


Major change around 97-98 and this regime shift largest in past century because M1, M2 and M4 in phase, coincidence?


El Nino Southern Oscillation
El Nino
La Nina
0.8
0.4
0.2
0.0
-0.2
-0.6
El Viejo
La Vieja
0.8
0.4
0.2
0.0
-0.2
-0.6
monthly values for the PDO index: 1900–1999
4
2
0
−2
−4
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000

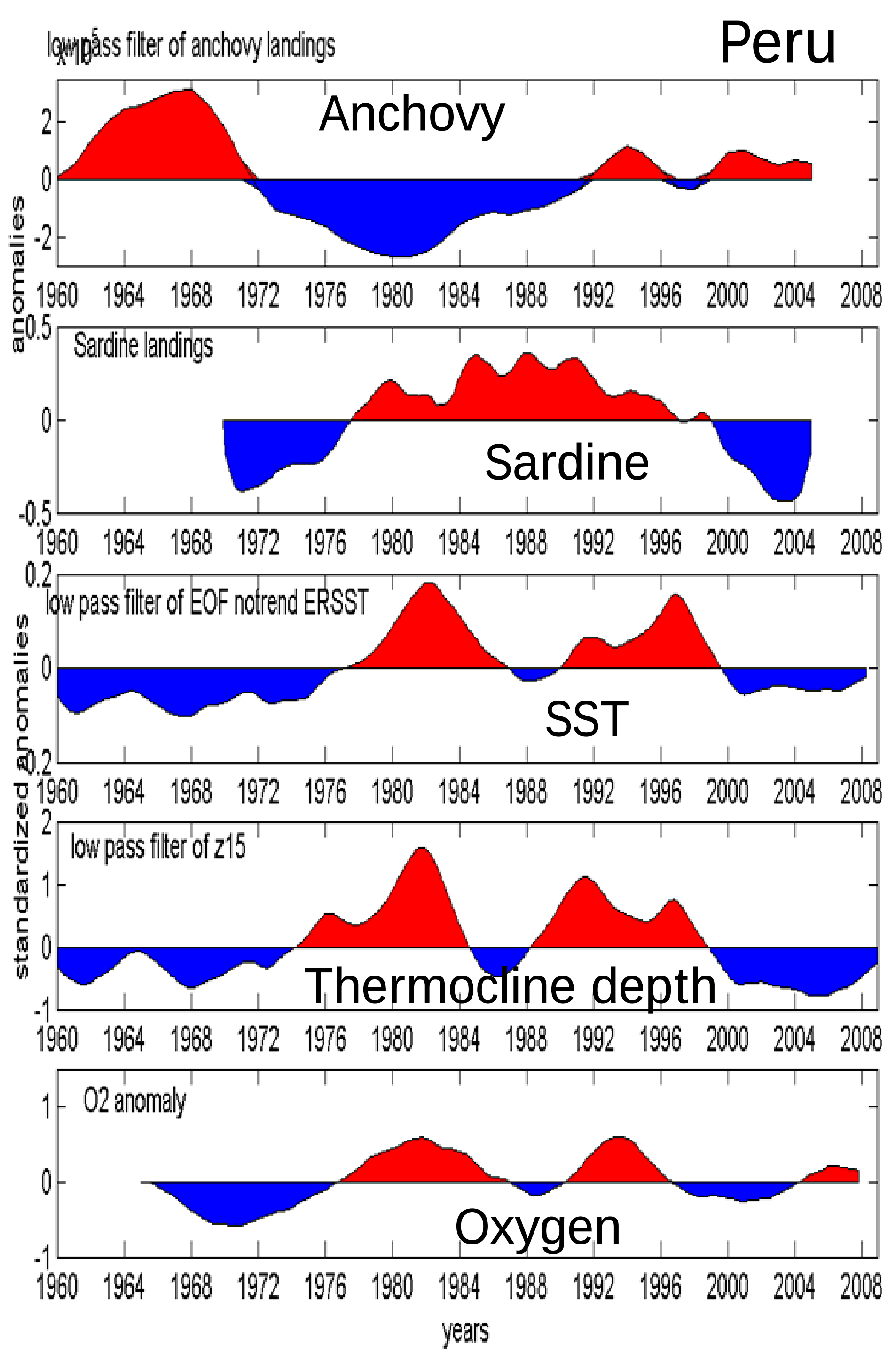
Sardine Landings

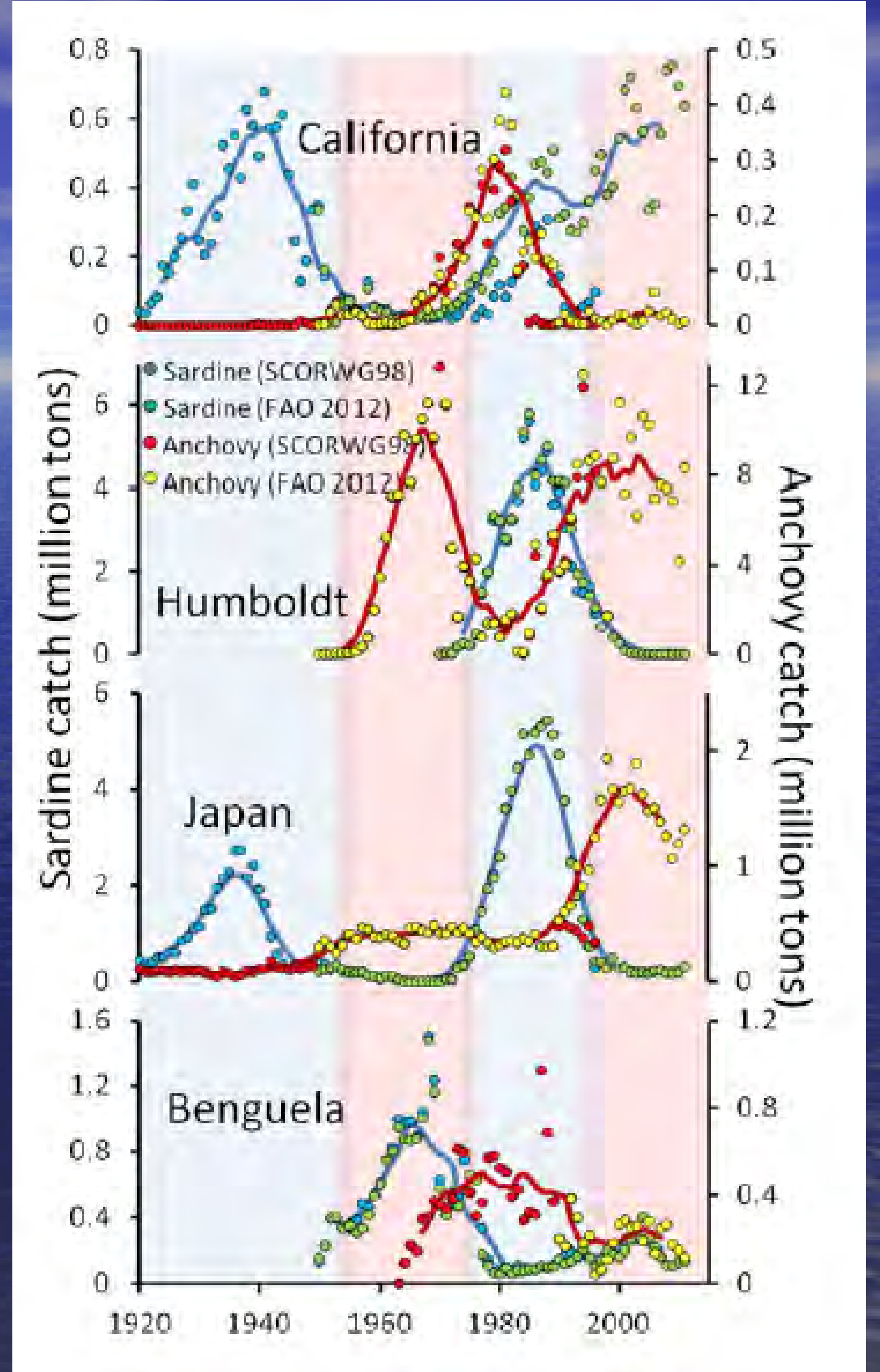


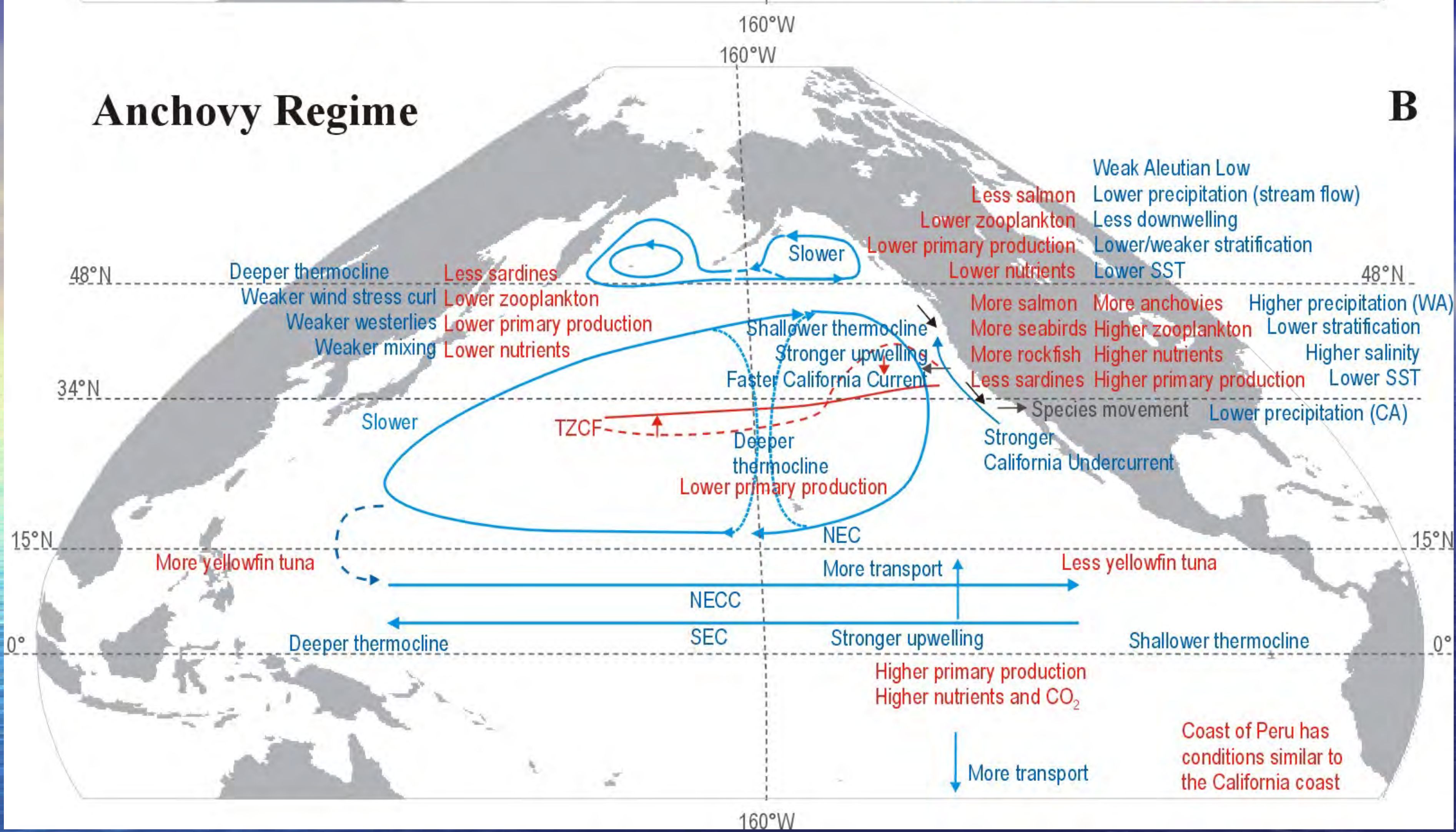


Chavez et al. Science (2003)

2000


Peru
low pass filter of anchovy landings
Anchovy
anomalies
Sardine landings
Sardine
low pass filter of EOF notrend ERSST
SST
standardized anomalies
low pass filter of z15
Thermocline depth
O2 anomaly
Oxygen
years


California
Sardine (SCORWG98)
Sardine (FAO 2012)
Anchovy (SCORWG98)
Anchovy (FAO 2012)
Humboldt
Japan
Benguela
Sardine catch (million tons)
Anchovy catch (million tons)


160°W
Anchovy Regime
B
Weak Aleutian Low
Lower precipitation (stream flow)
Less downwelling
Lower/weaker stratification
Lower SST
Less salmon
Lower zooplankton
Lower primary production
Lower nutrients
Slower
48°N
Deeper thermocline
Weaker wind stress curl
Weaker westerlies
Weaker mixing
Less sardines
Lower zooplankton
Lower primary production
Lower nutrients
More salmon
More seabirds
More rockfish
Less sardines
More anchovies
Higher zooplankton
Higher nutrients
Higher primary production
Higher precipitation (WA)
Lower stratification
Higher salinity
Lower SST
Shallower thermocline
Stronger upwelling
Faster California Current
34°N
Species movement
Lower precipitation (CA)
Slower
TZCF
Deeper thermocline
Lower primary production
Stronger California Undercurrent
NEC
15°N
More yellowfin tuna
More transport
Less yellowfin tuna
NECC
SEC
Deeper thermocline
Stronger upwelling
Shallower thermocline
0°
Higher primary production
Higher nutrients and CO_2
More transport
Coast of Peru has conditions similar to the California coast

La Vieja

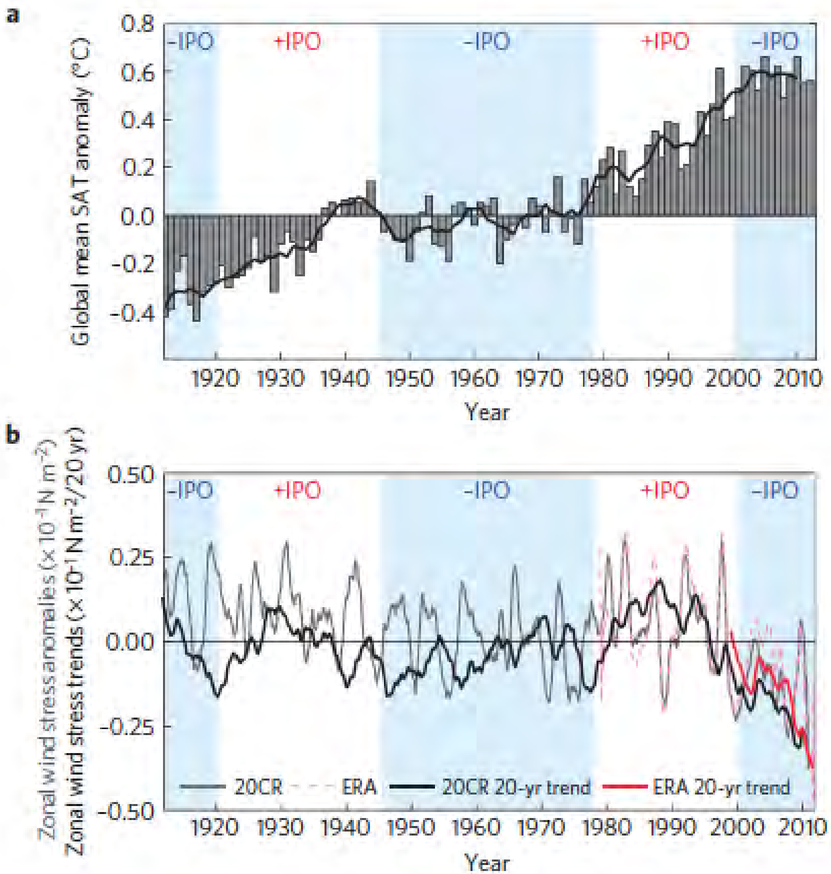
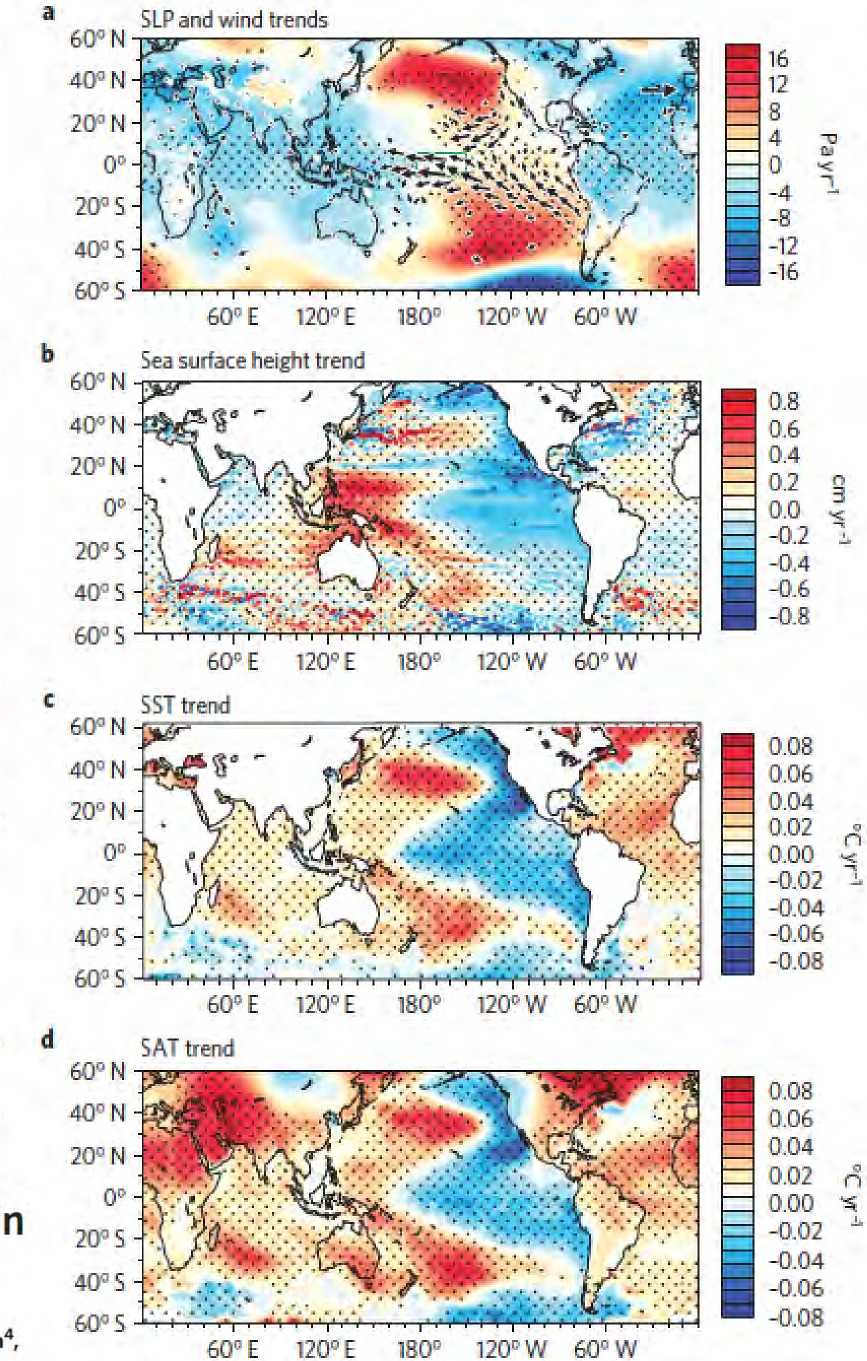


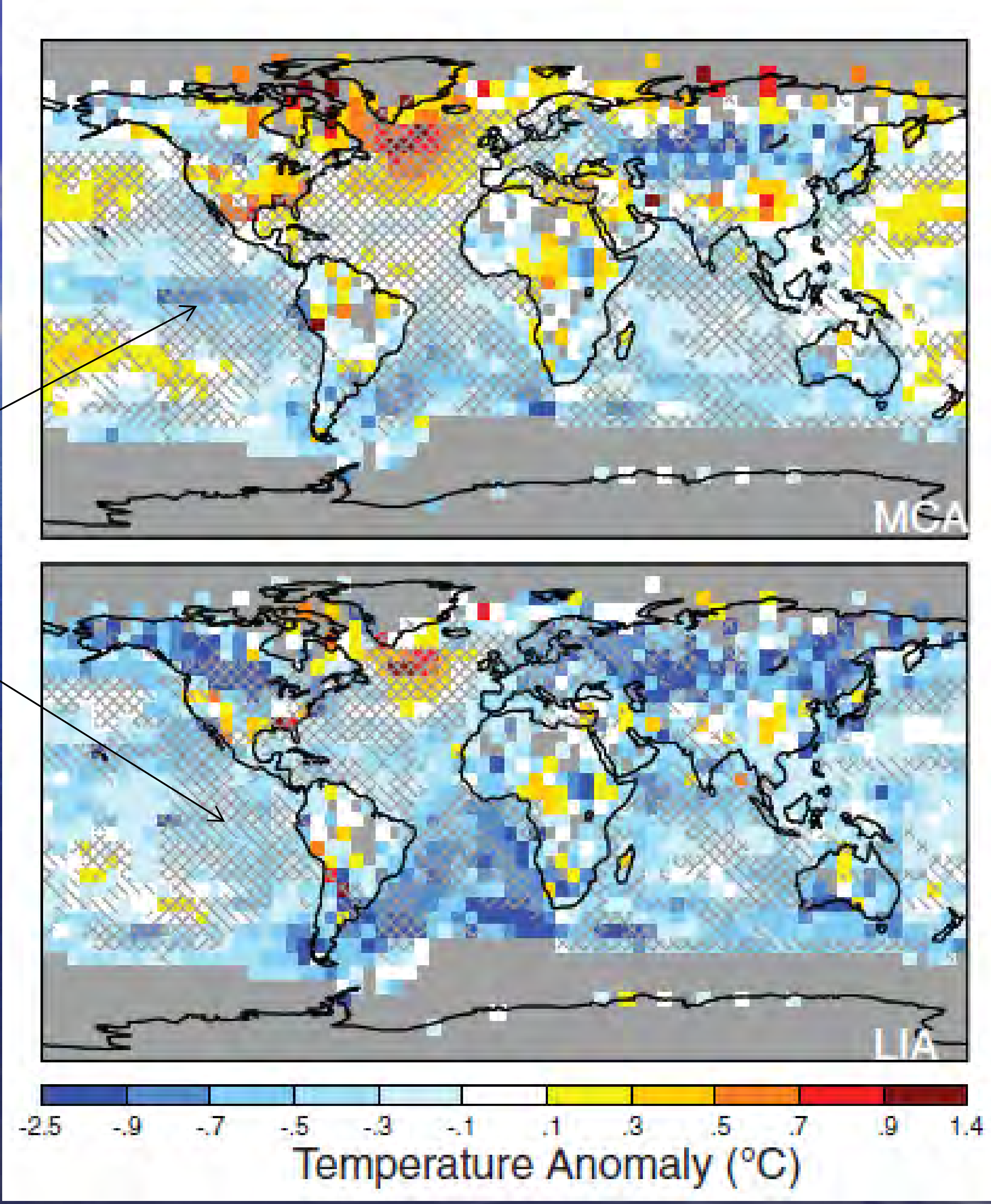
Figure 1 | Global average SAT and Pacific trade wind anomalies over the past century. a, Temperature anomalies are shown as the annual mean relative to 1951–1980, with individual years shown as grey bars and a five-year running mean overlaid in bold. **b**, Pacific wind stress anomalies are computed over the region 6° N–6° S and 180°–150° W (green rectangle in Fig. 2a), corresponding to where the IPO exhibits maximum regression onto Pacific Ocean winds. Anomalies are shown relative to the historical record for two climatologies (Methods), with a bold line indicating the strength of

Recent intensification of wind-driven circulation in the Pacific and the ongoing warming hiatus

Matthew H. England[1,2]*, Shayne McGregor[1,2], Paul Spence[1,2], Gerald A. Meehl[3], Axel Timmermann[4], Wenju Cai[5], Alex Sen Gupta[1,2], Michael J. McPhaden[6], Ariaan Purich[5] and Agus Santoso[1,2]

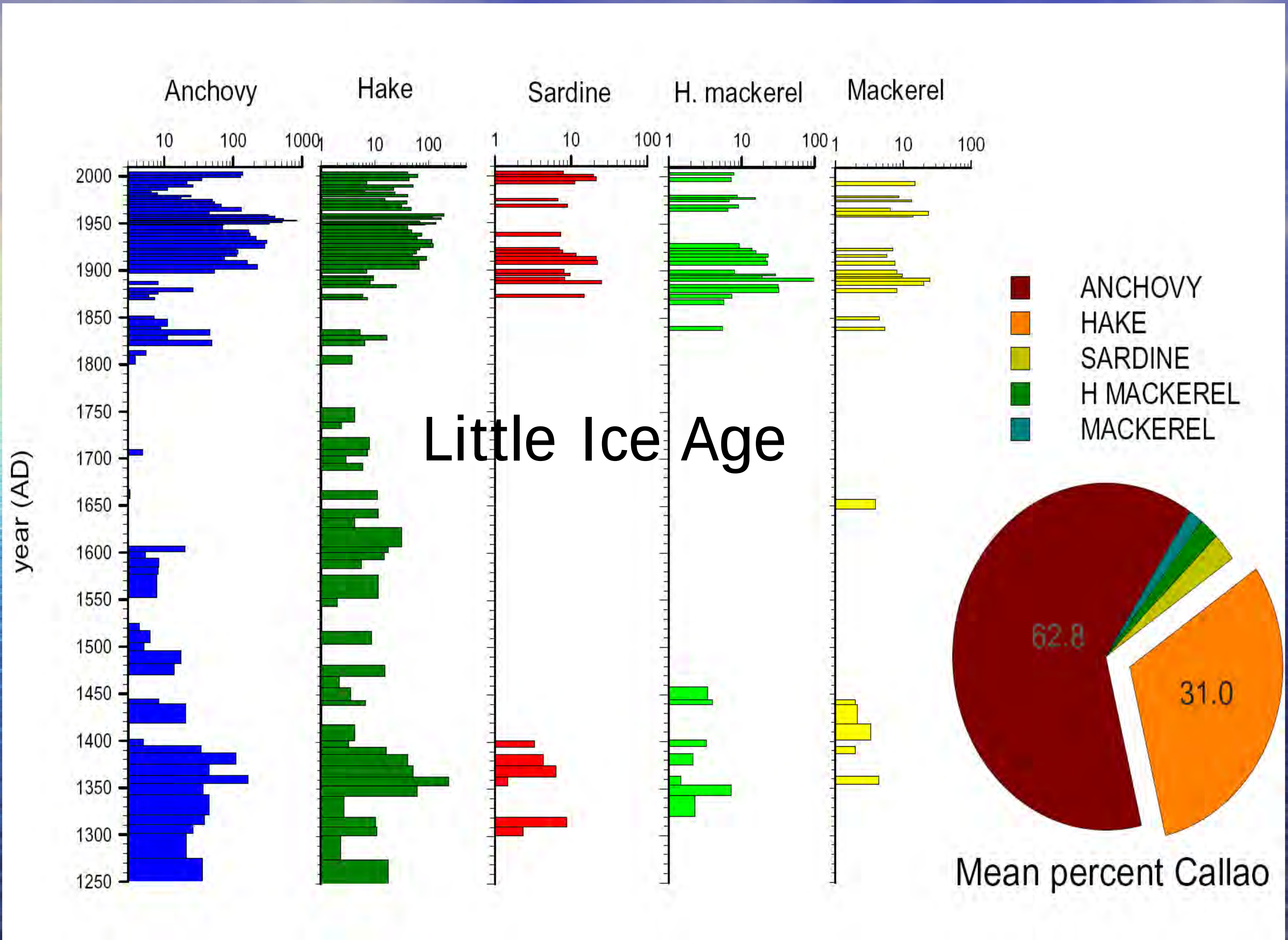


Medieval warm period has the same pattern as present but Little Ice Age does not



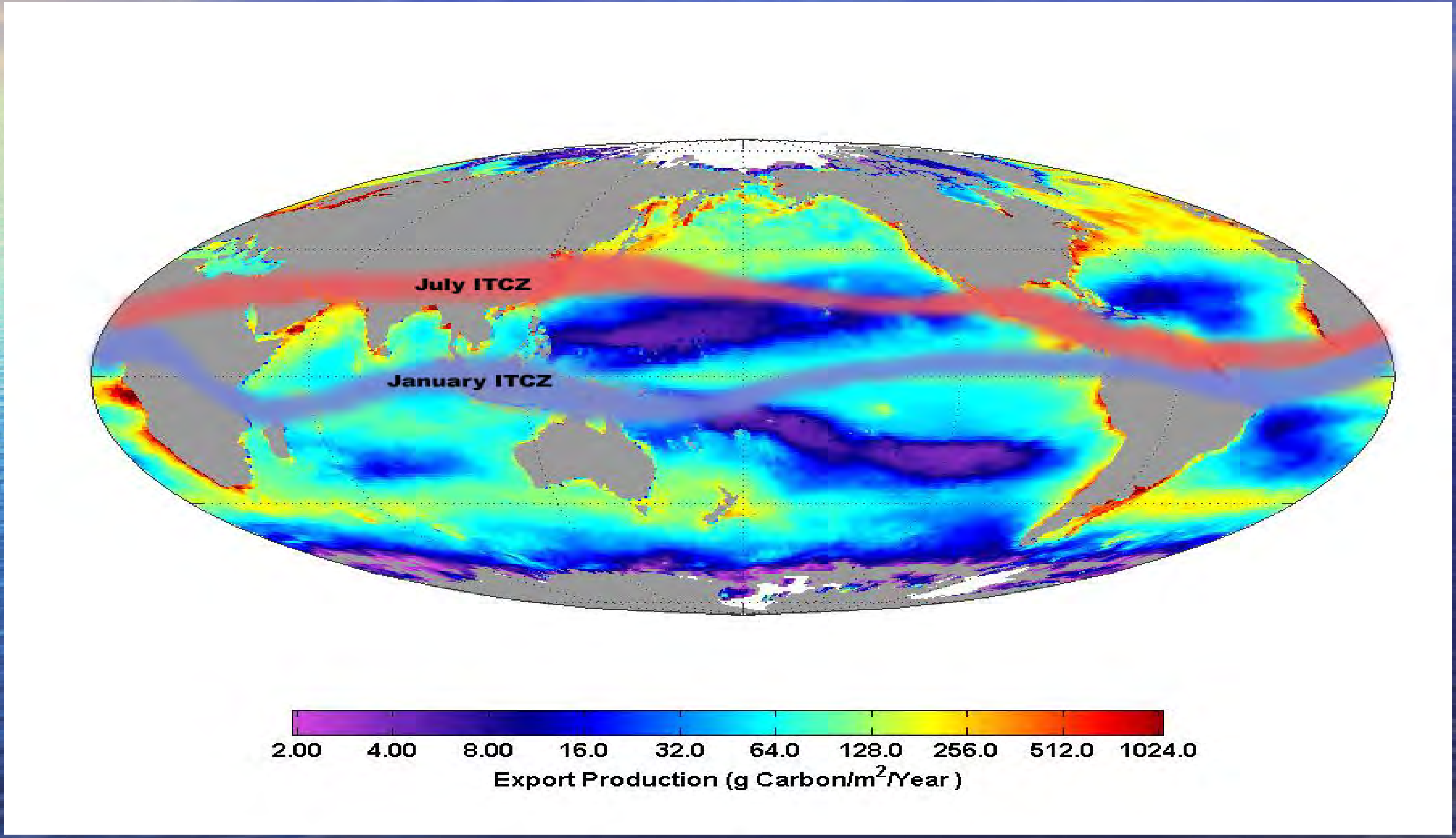
Mann et al. 2009, Science

Fish Scale Record from a core off Peru



Gutierrez et al. (2009) Biogeosciences

Driven by a southward migration of the Intertropical Convergence zone (ITCZ) during the Little Ice Age



Opposite happening today as the world warms

A developing Paradox?

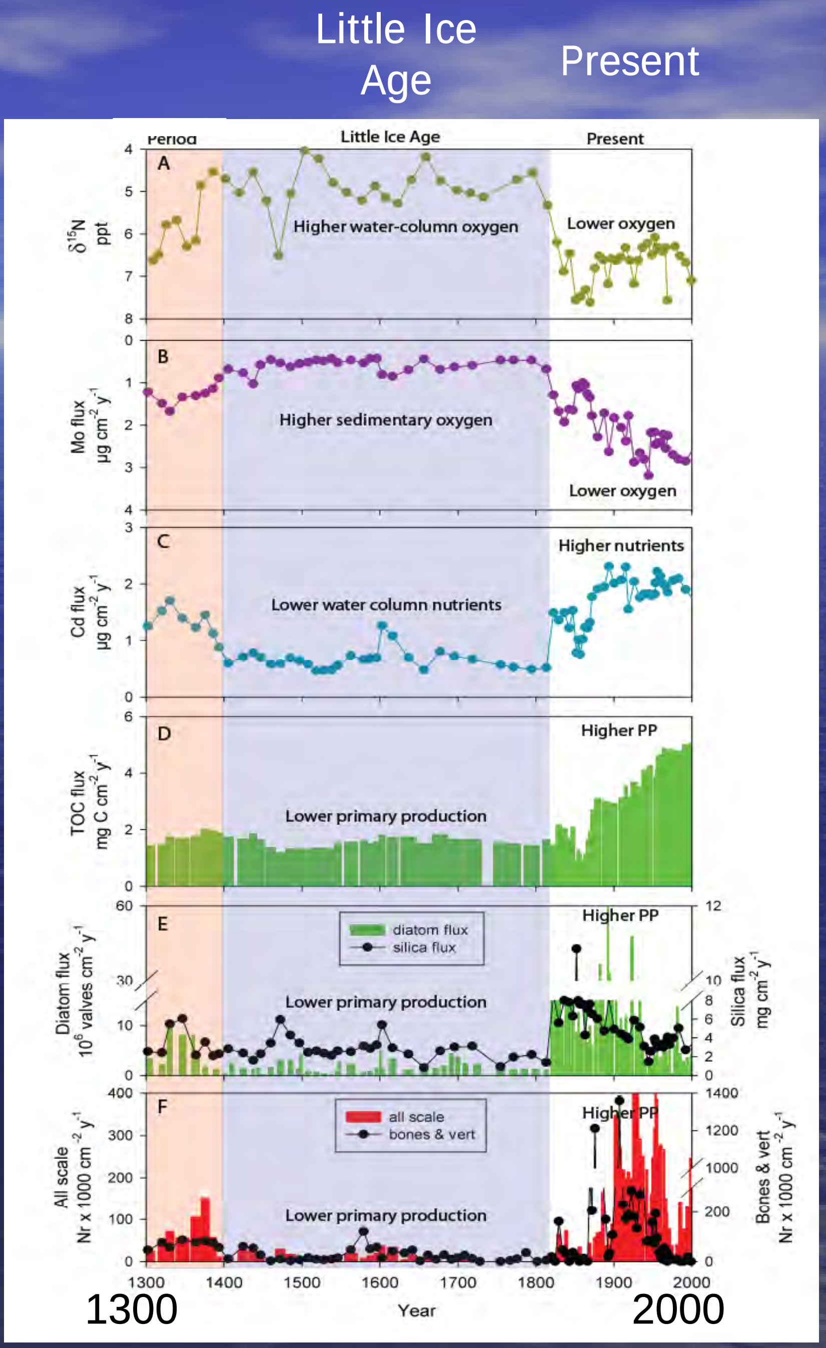
- Observations from the modern record show that the entire globe warms during El Niño and El Viejo and in coastal upwelling systems temperature goes up and biological productivity goes down. The opposite seems to happen during the Little Ice Age when the coastal upwelling system off Peru warmed, ventilated and became less productive. We must be looking at very different mechanisms ….

Oxygen story

- Multidecadal to centennial variability
- Multidecadal variability on local to global scales, big change after 1997

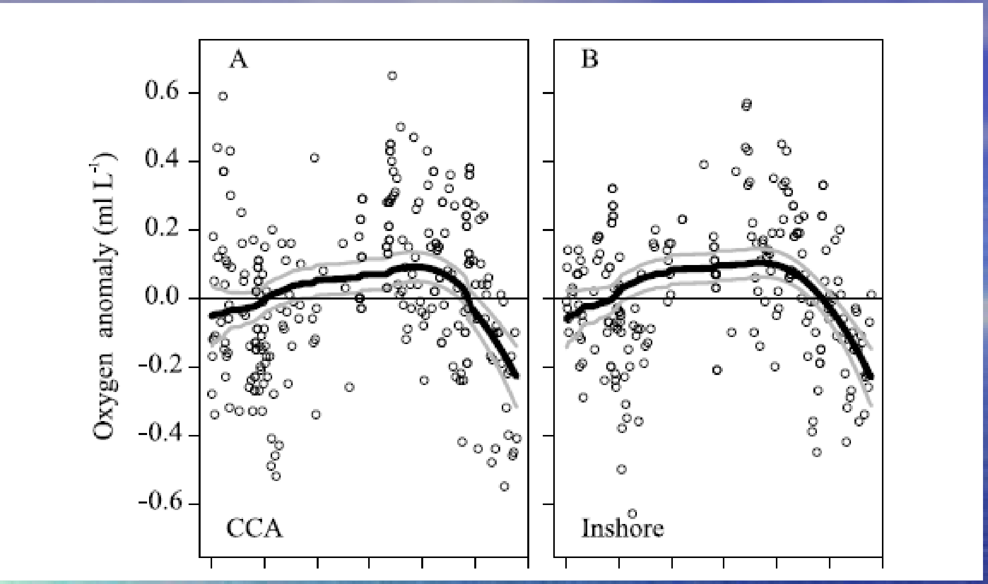
Centennial scale changes

Cores off Callao (and Pisco), Peru show dramatic changes in oxygen and ocean productivity from the LIA (higher oxygen, lower productivity) to the present (lower oxygen, higher productivity). Still increasing? How long can it continue?

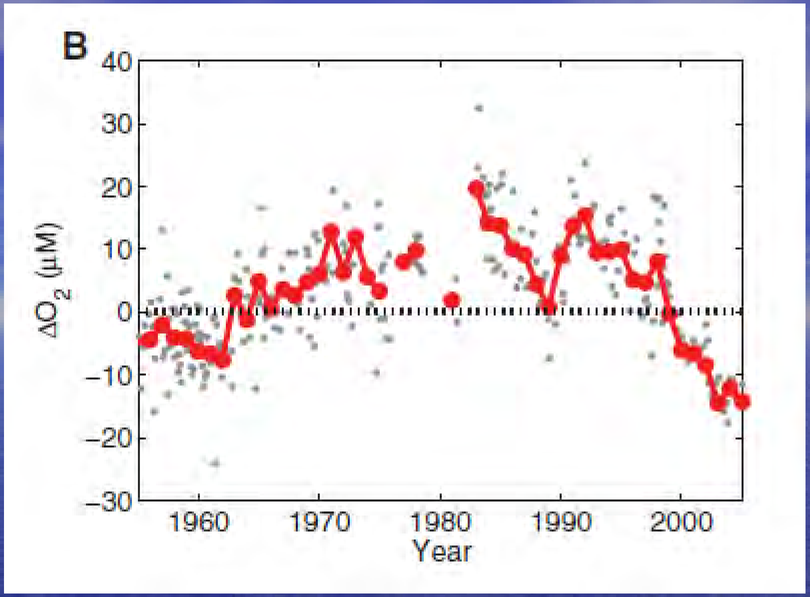


Redrawn from Gutierrez et al. 2009, Chavez et al. 2011

McClatchie et al. 2010

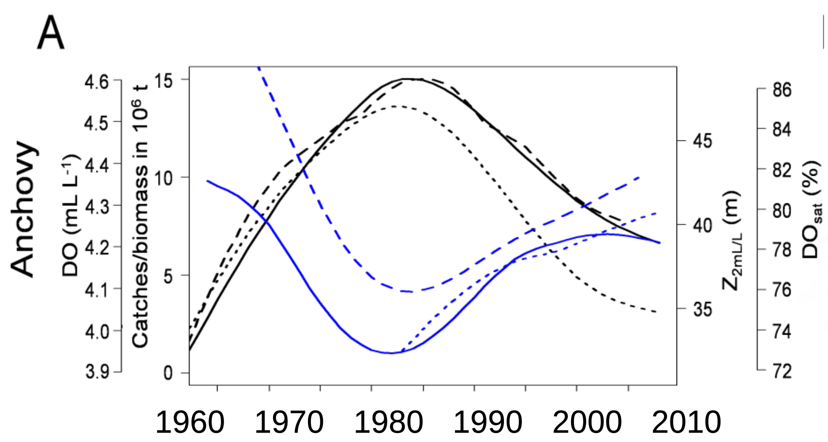


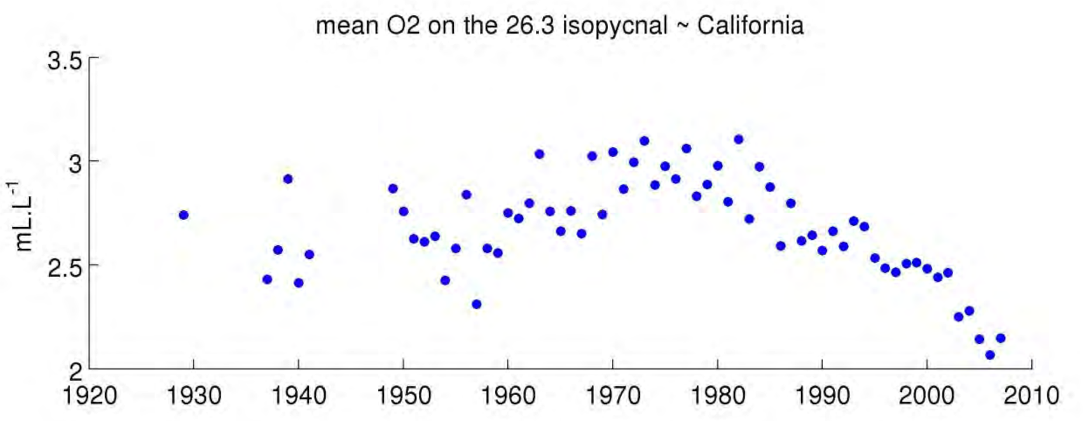
Deustch et al. 2011



Peru

California



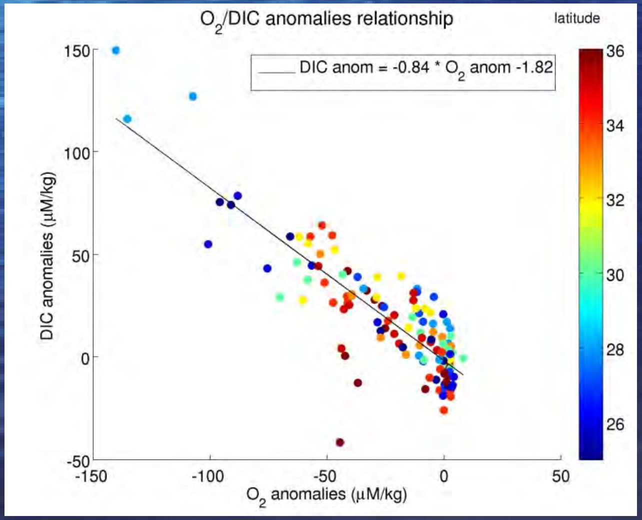


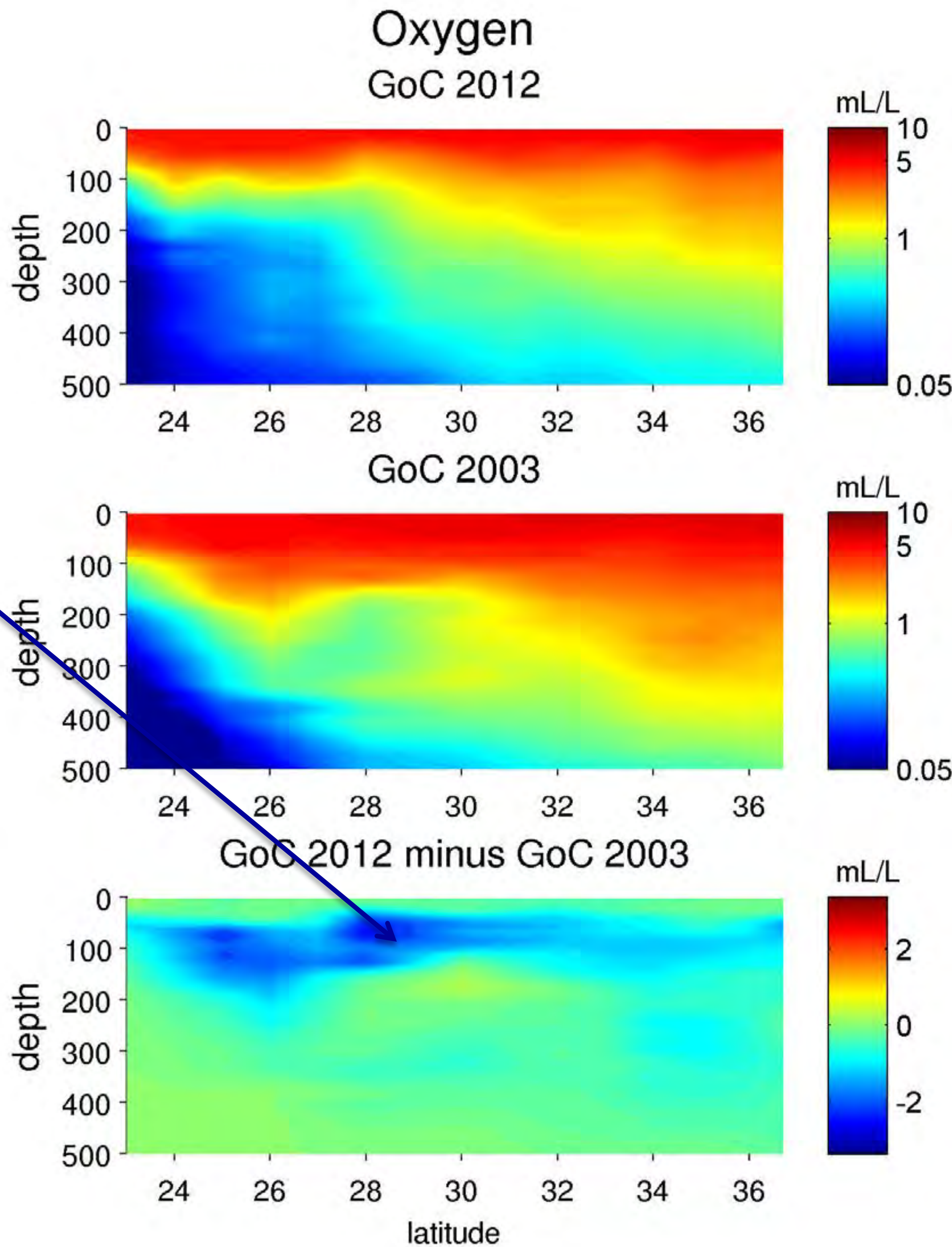
Bertrand et al., 2011 Peru

Multi-decadal changes in oxygen

Goals

- Repeat alongshore section made in 2003 from Monterey Bay to the tip of Baja California to determine changes in ocean chemistry
- Found a lens of lower oxygen, higher dissolved inorganic carbon (lower pH), higher nitrate from 50 to 200 m

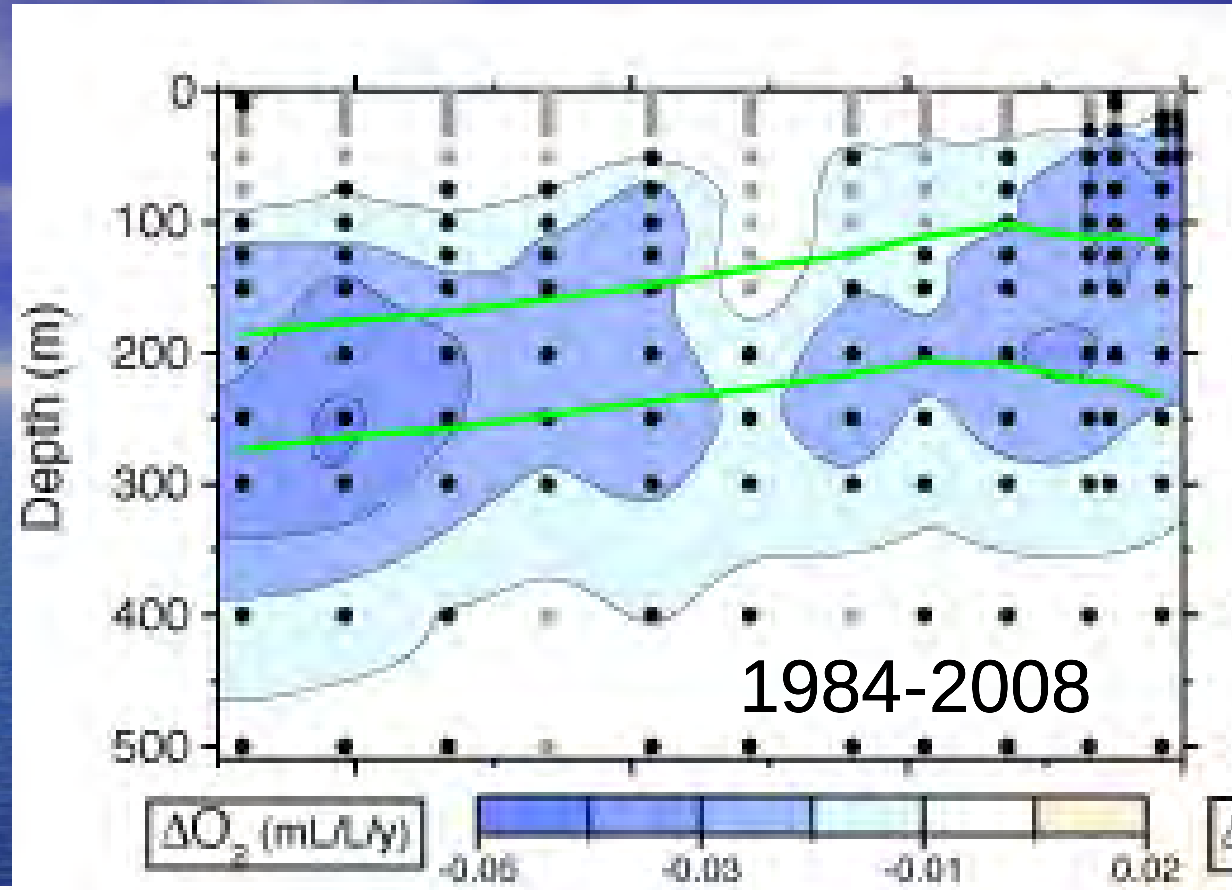


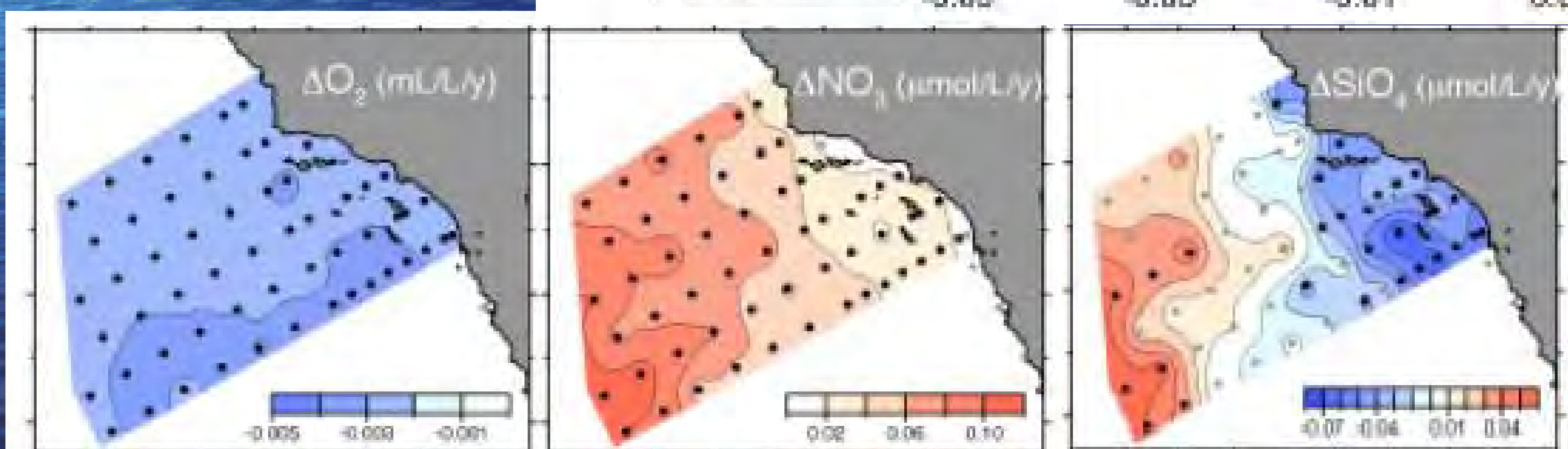


Oxygen decreasing, strongest between 50 and 300 m

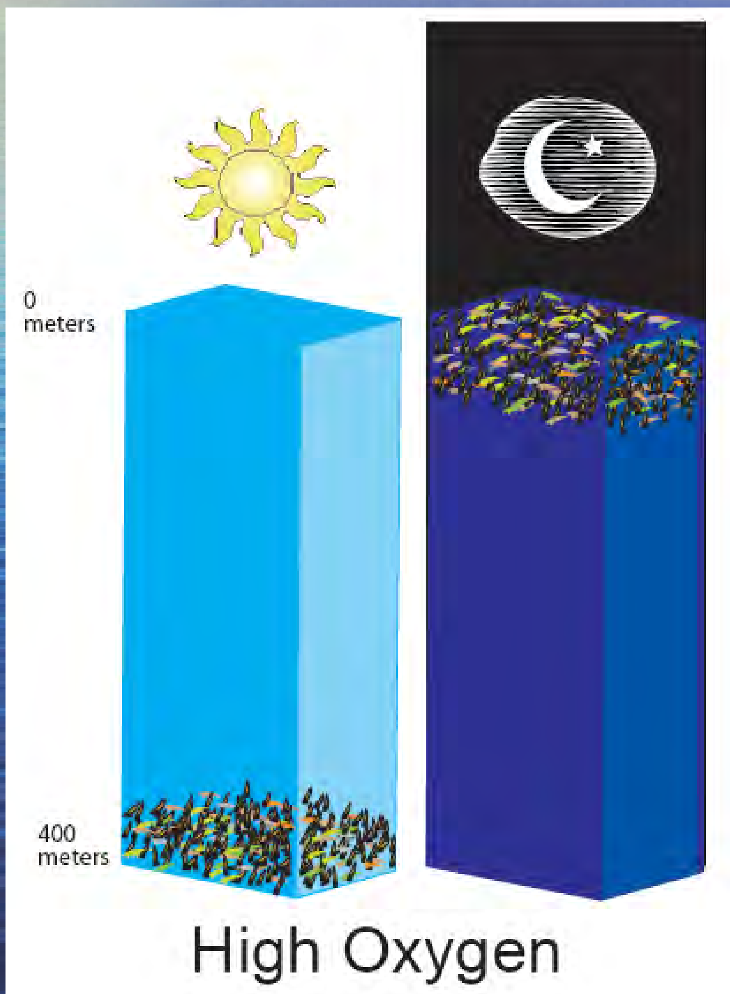
Delta O_2 1.5 – 2.0 umol/kg/year

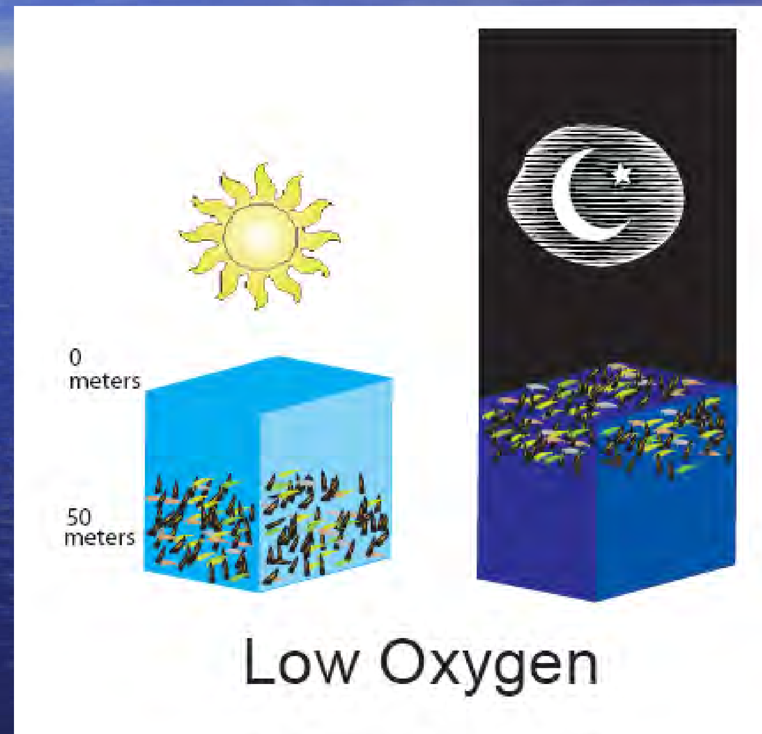
Oxygen decrease evenly distributed, nutrients not



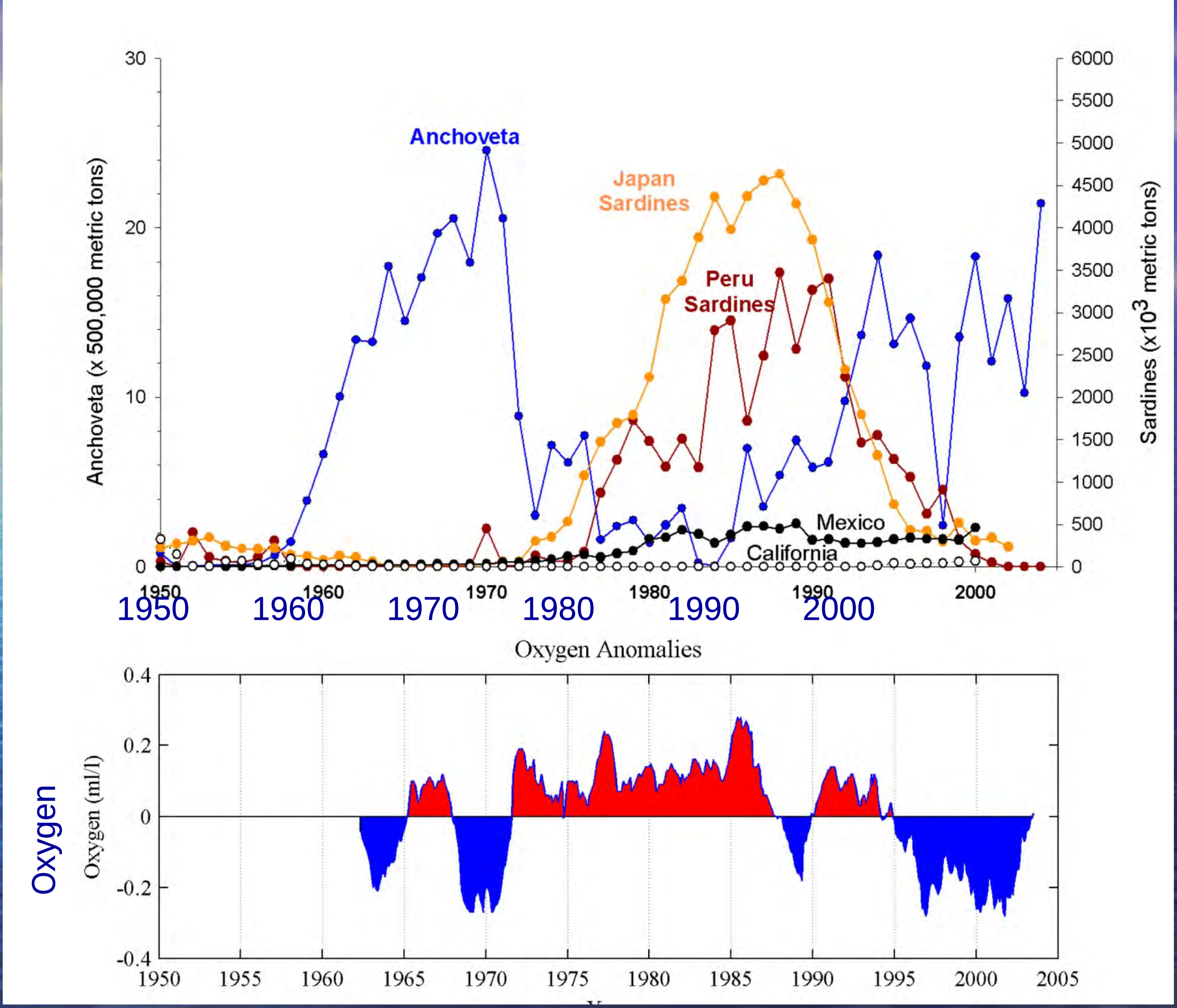


This habitat compression also leaves imprint on fish – why Peru produces more fish than any other region in the world!



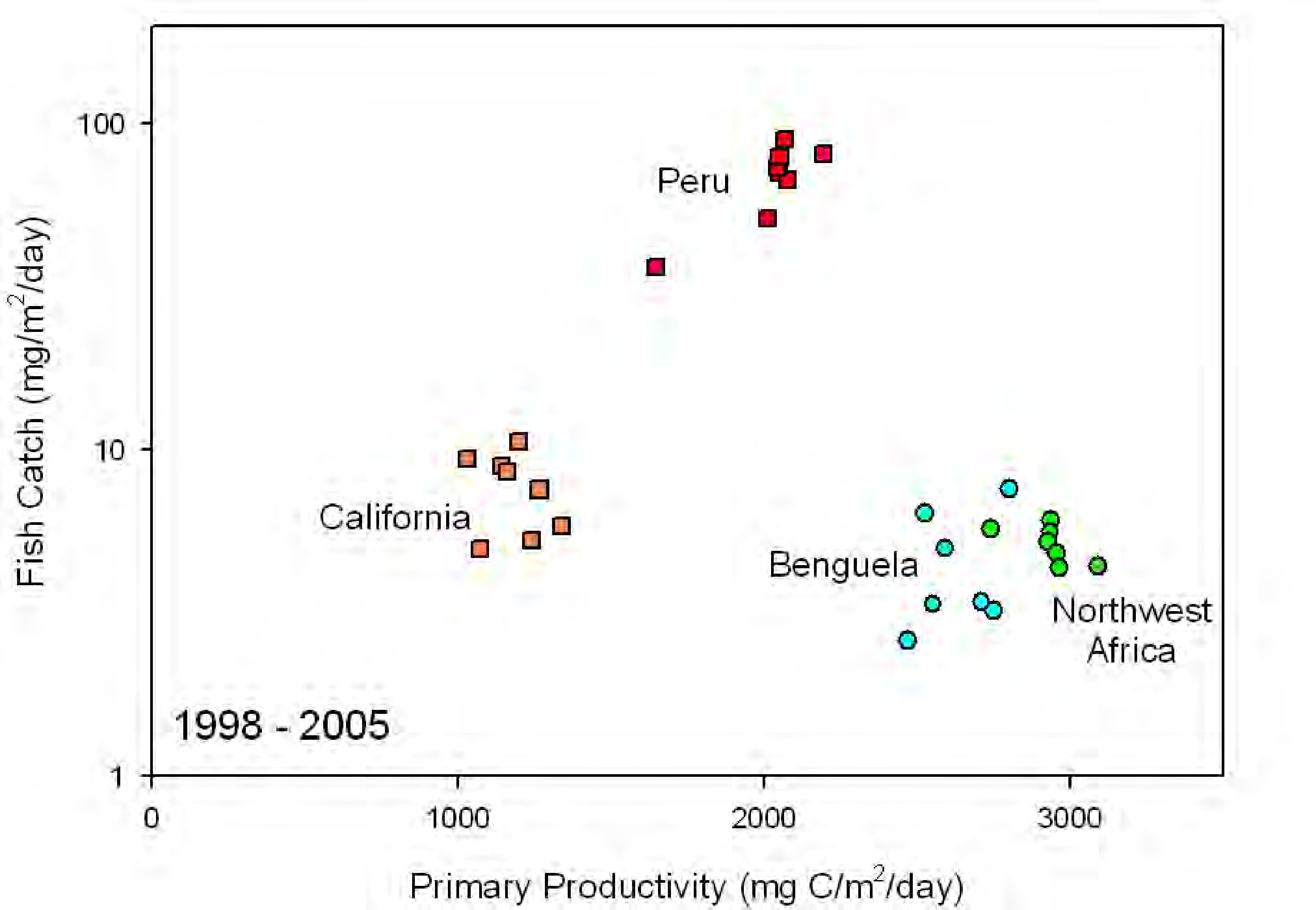


Makes a meal for the fish easier



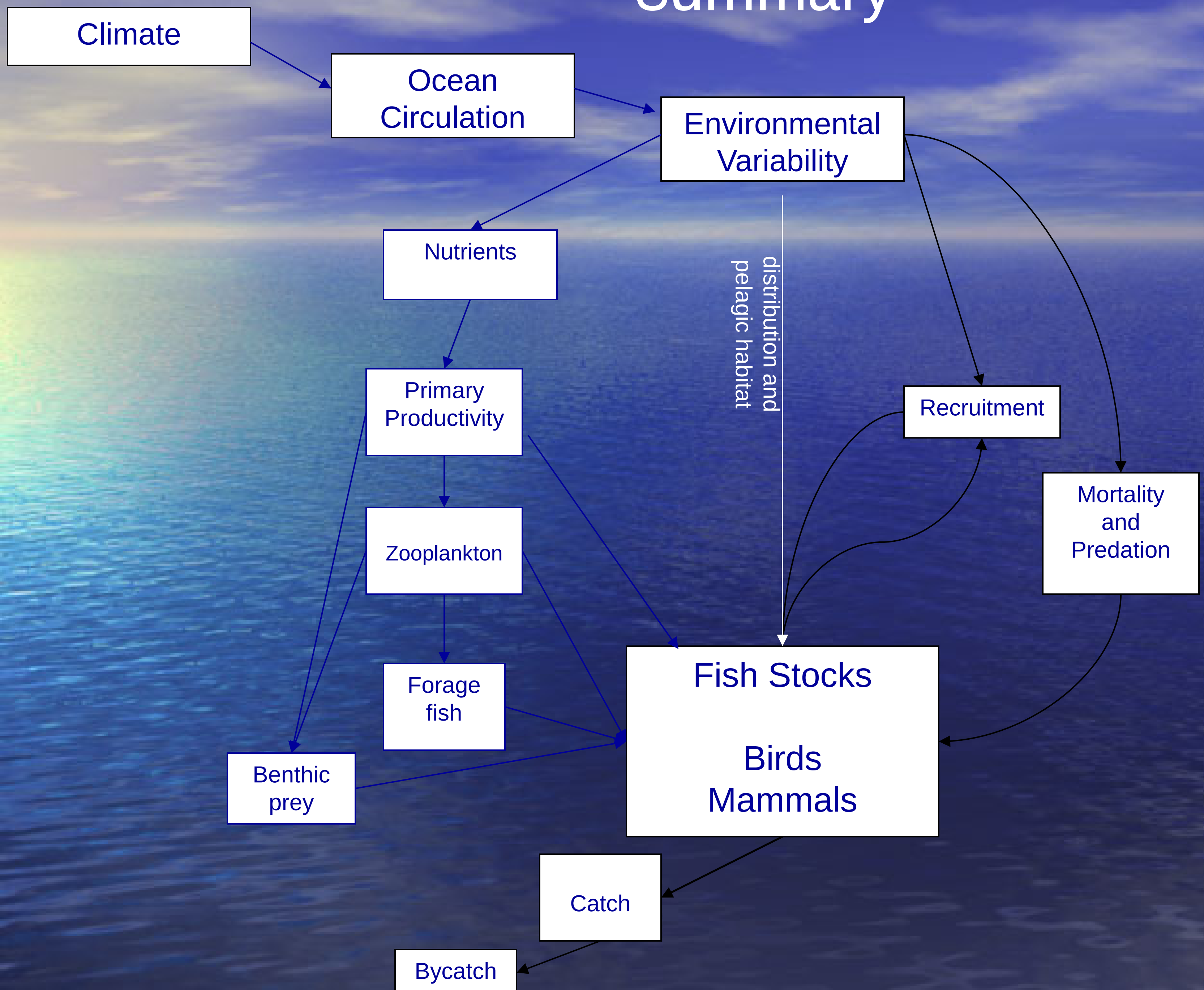
Less oxygen more anchoveta off Peru (Bertrand et al. 2011)

Peru produces more fish (total and per unit primary production) than any other place in the world!



Is this going to happen to Alta and Baja California in a warm and less oxygenated world?

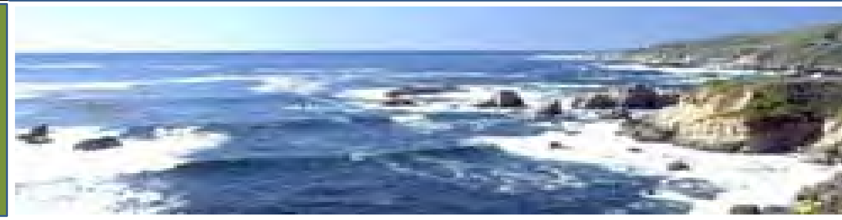
Summary



Climate
Ocean Circulation
Environmental Variability
Nutrients
Primary Productivity
Zooplankton
Forage fish
Benthic prey
distribution and pelagic habitat
Recruitment
Mortality and Predation
Fish Stocks
Birds
Mammals
Catch
Bycatch

Conclusions

- Climate has strong and measurable impact on global ocean ecosystems
- Ocean ecosystems adapt to large natural climate changes – what are their limits?
- Anthropogenic global change (i.e. ocean acidification, fishing) exists without a doubt but climate change (global warming) harder to pinpoint
- There will be ”two faces to global warming-driven climate change” just like there are “two faces to climate variations like El Niño (and El Viejo)”
- There will be many surprises. Predicted decreases in productivity due to greater stratification may be overridden by other processes
- Global warming changes may not follow current patterns of climate variability
- Our science (observing/modeling) and management needs to be adaptive; management needs to include variability and change



Questions/Discussion

- Do you currently use any of this information in your project tasks?
- How could you incorporate this information into your management activities?
- Would any specific tools (e.g.: ones that include summarized data, GIS maps, projected trends) be useful?

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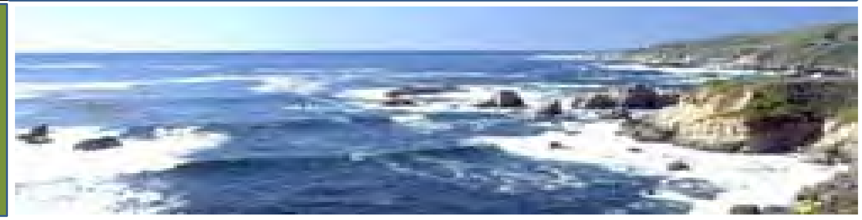

Next Class: Monday, April 21st, 2:00-4:00 pm

- Hypoxia
- Ocean Acidification

-Lisa Levin, Scripps Institute
-Gretchen Hofmann, UC Santa Barbara

-CDFW San Diego Field Office and Laboratory

http://www.dfg.ca.gov/Climate_and_Energy/Climate_Change/Climate_College/

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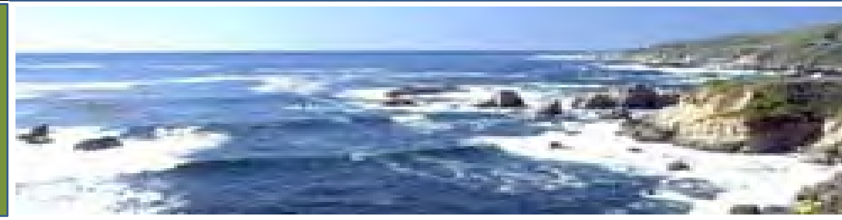

Thank you