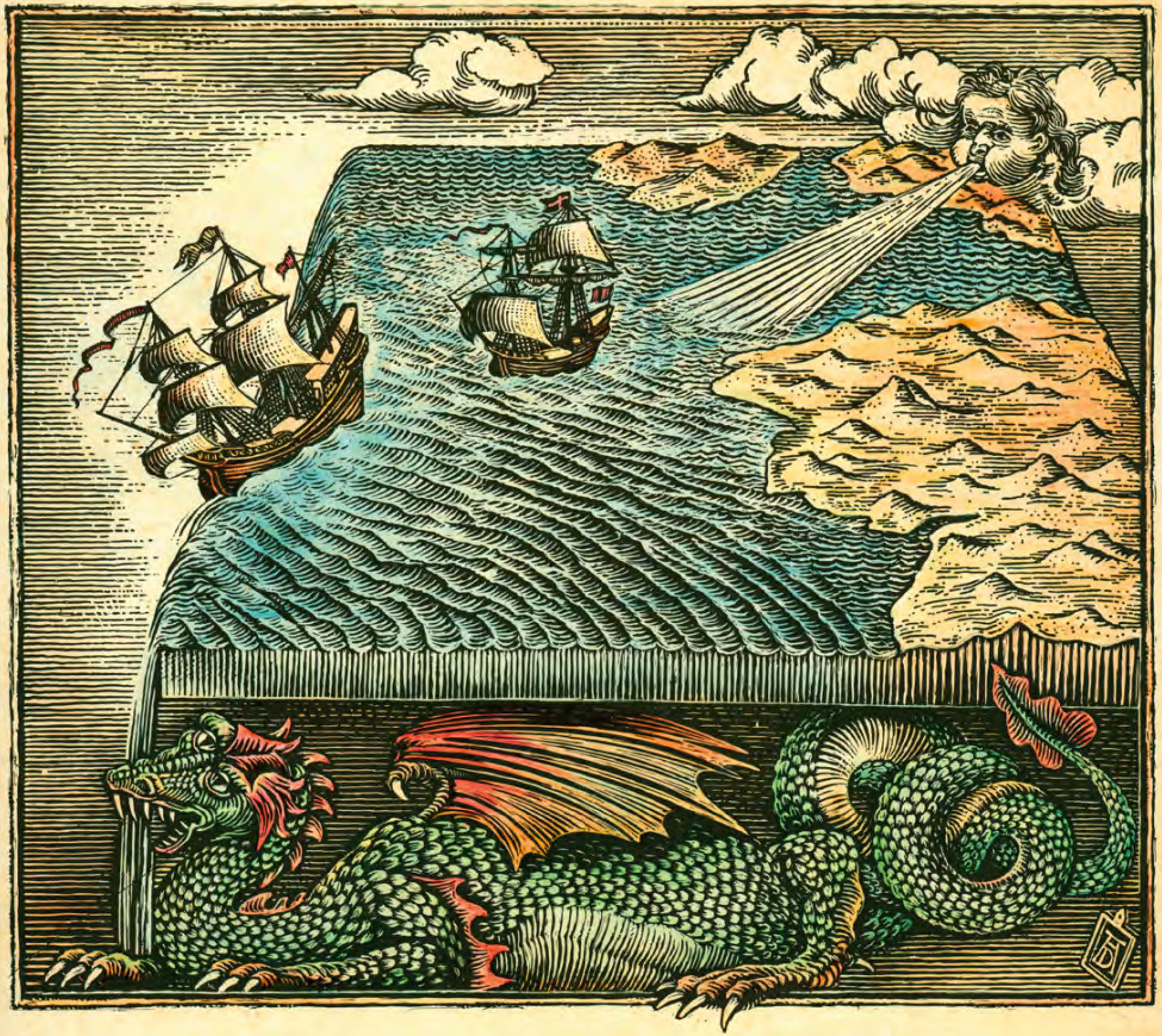
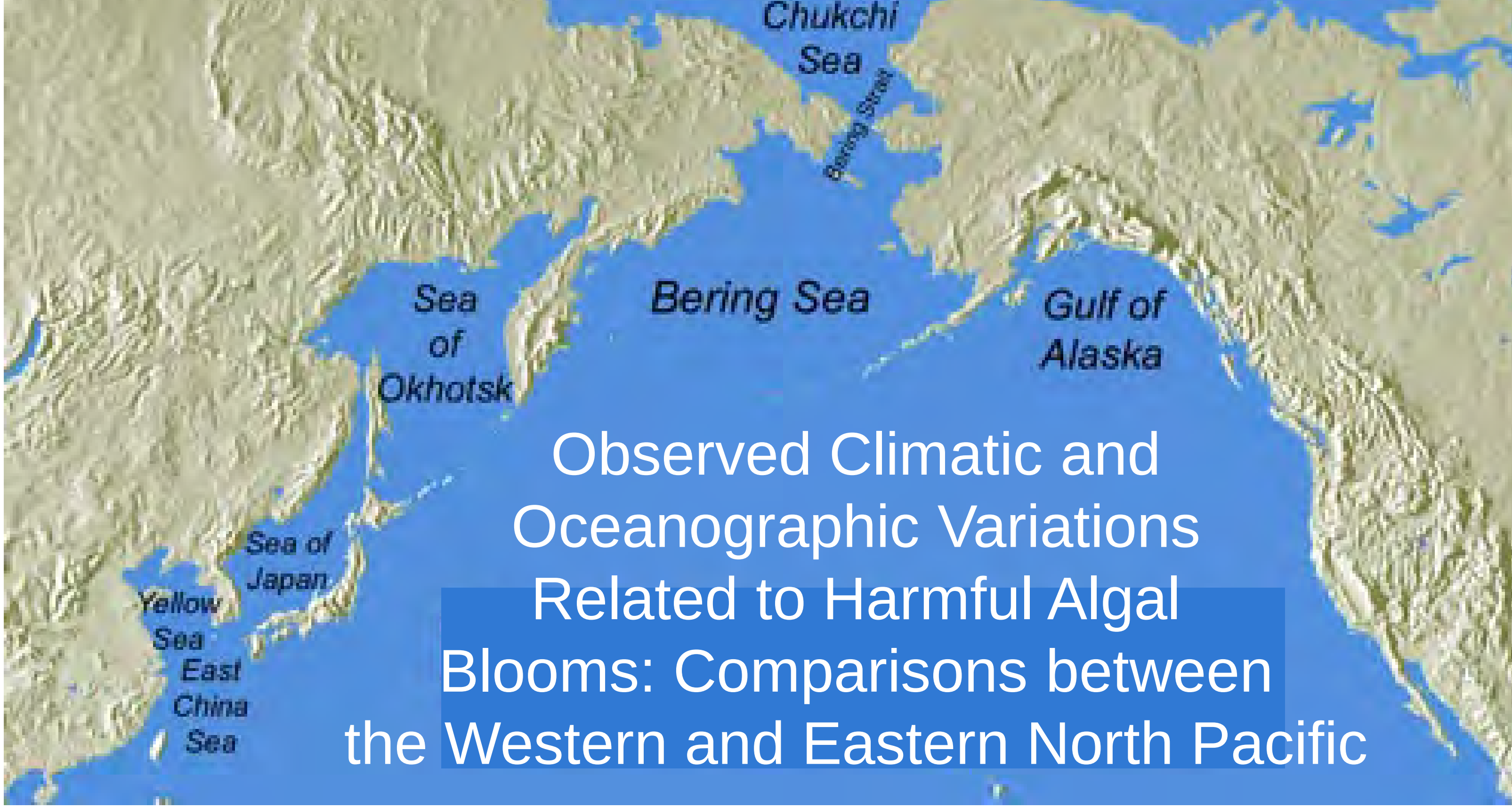


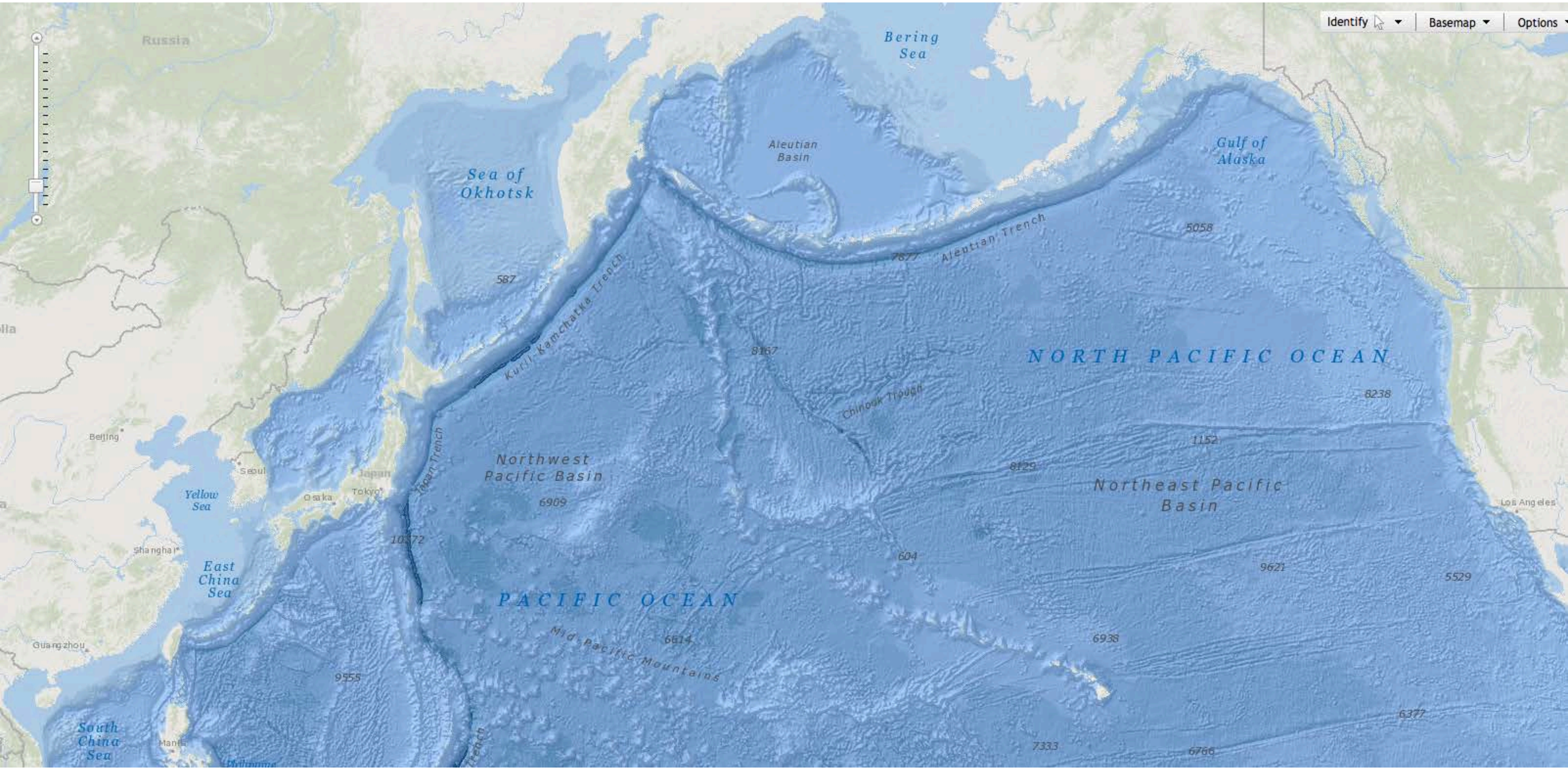


Observed Climatic and Oceanographic Variations Related to Harmful Algal Blooms: Comparisons between the Western and Eastern North Pacific

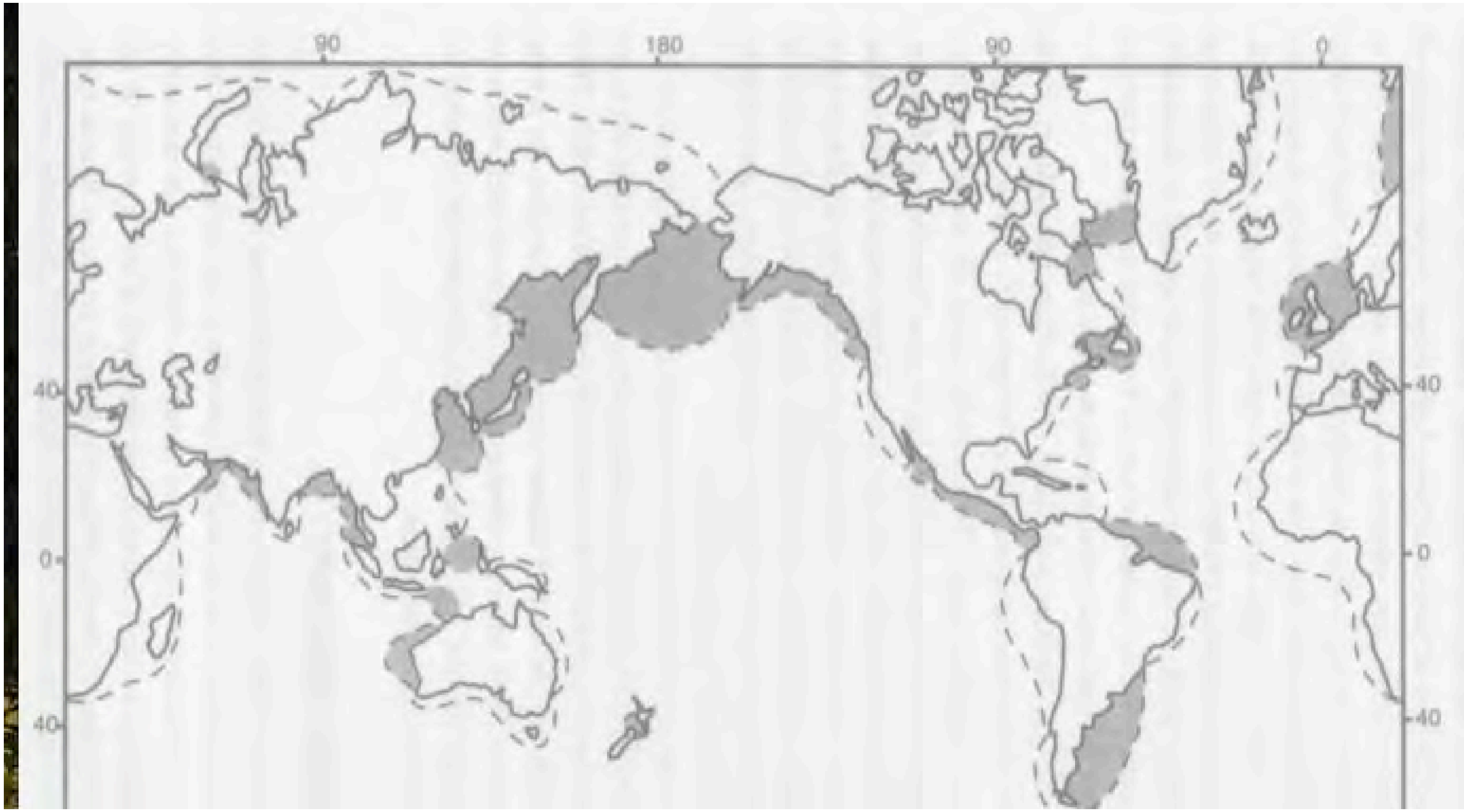
Mean Circulation
Patterns of Variability
Upper Ocean Vertical Profiles
Effects of Climate Change
(from a climate guy perspective)

Nick Bond University of Washington

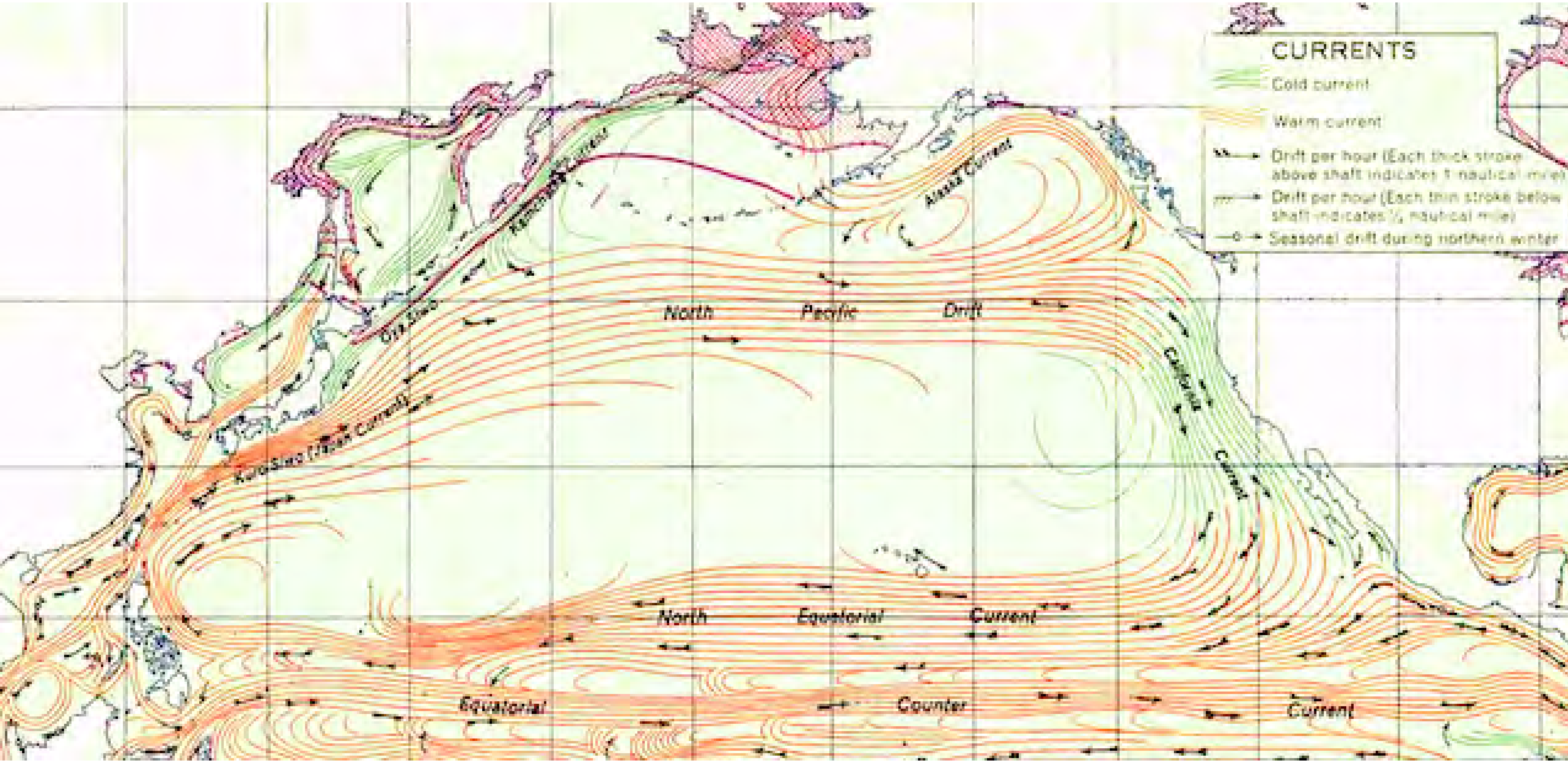
Bathymetry of North Pacific Ocean



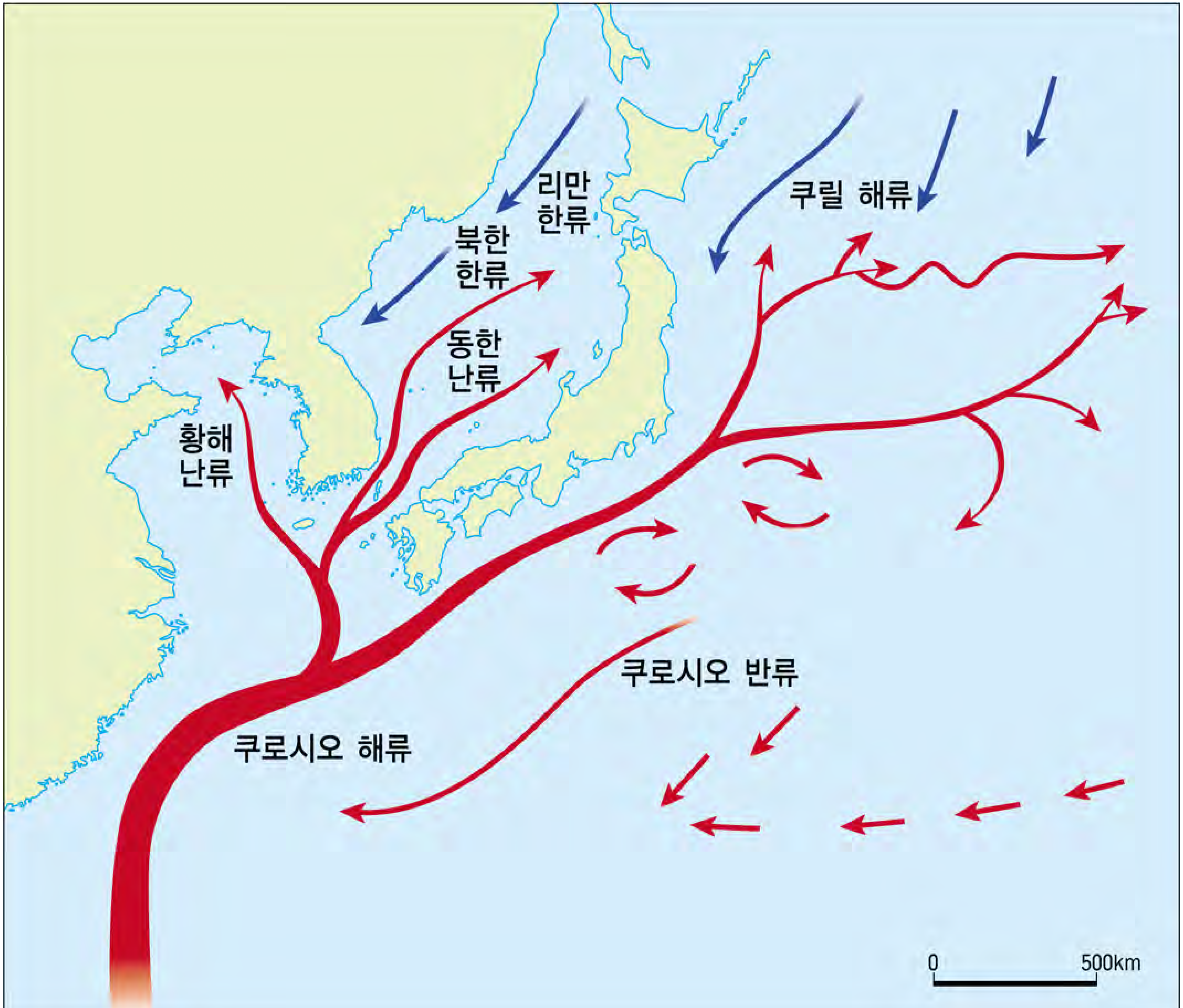
Continental shelf regions of strong tidal mixing



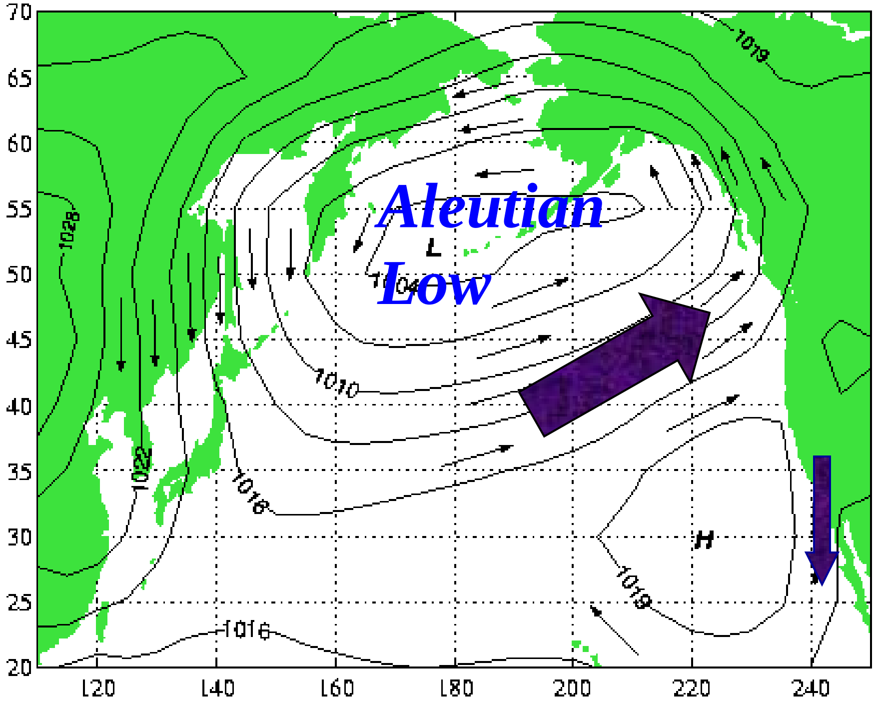
Shaded areas indicate shelf regions of the world with sufficiently strong tidal mixing for likelihood of significant development of shelf-sea fronts (Hunter and Sharp 1983)



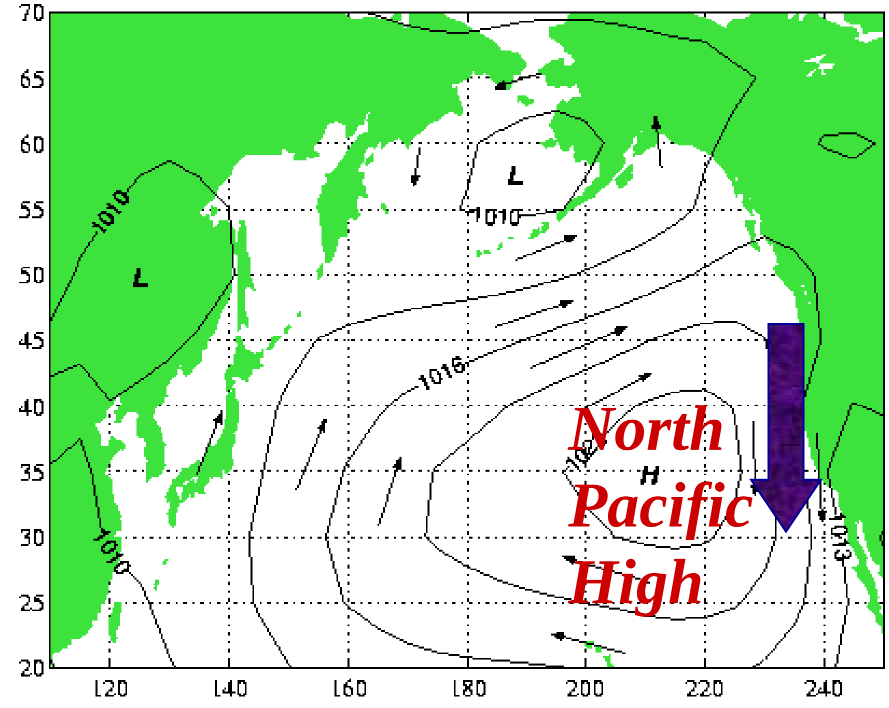
CURRENTS
Cold current
Warm current
Drift per hour (Each thick stroke above shaft indicates 1 nautical mile)
Drift per hour (Each thin stroke below shaft indicates ½ nautical mile)
Seasonal drift during northern winter
Alaska Current
North Pacific Drift
Oya Siwo
Kuro Siwo (Japan Current)
California Current
North Equatorial Current
Equatorial Counter Current


리만 한류
북한 한류
쿠릴 해류
동한 난류
황해 난류
쿠로시오 반류
쿠로시오 해류
0
500km

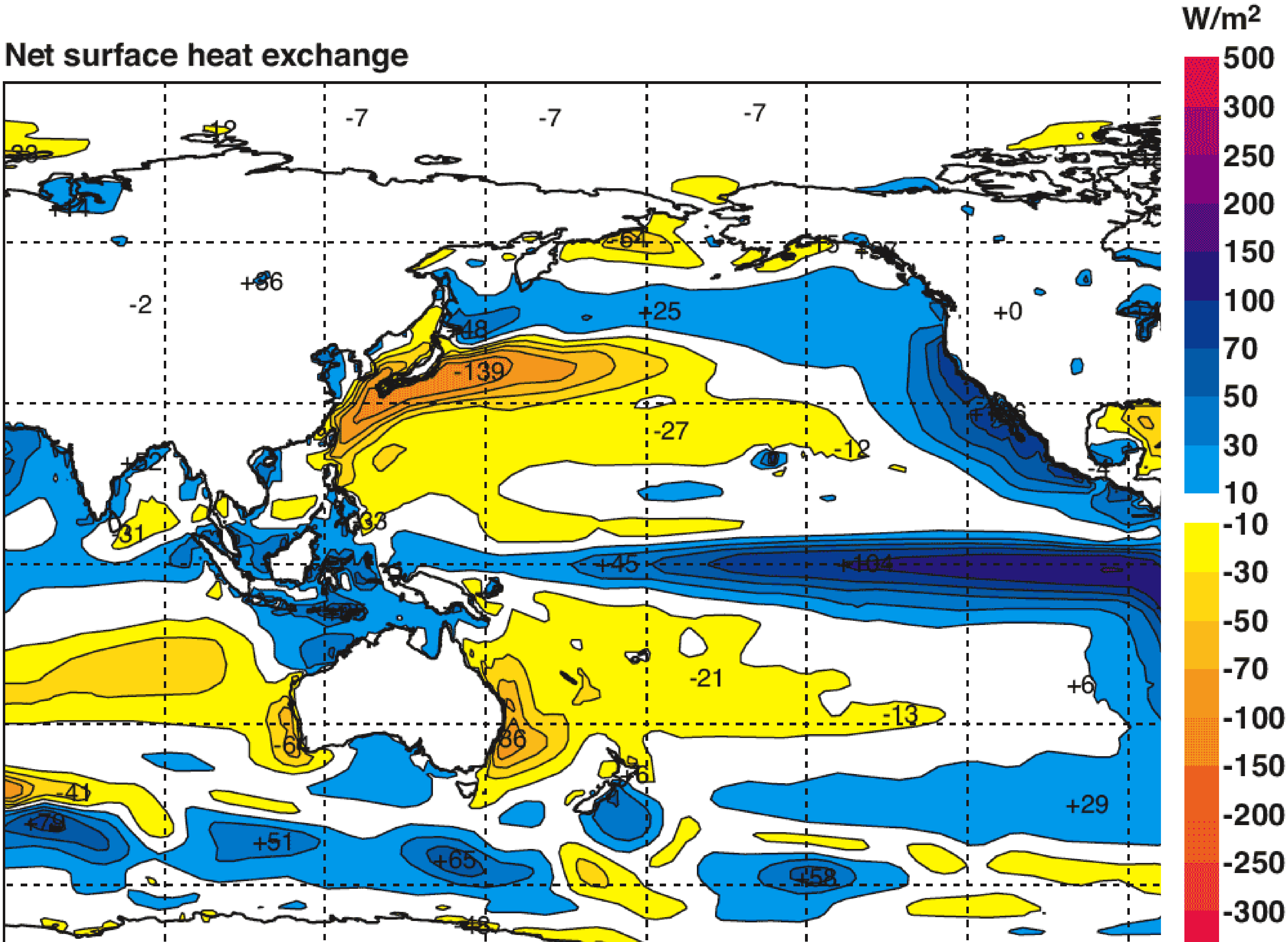
Pacific winds and coastal upwelling

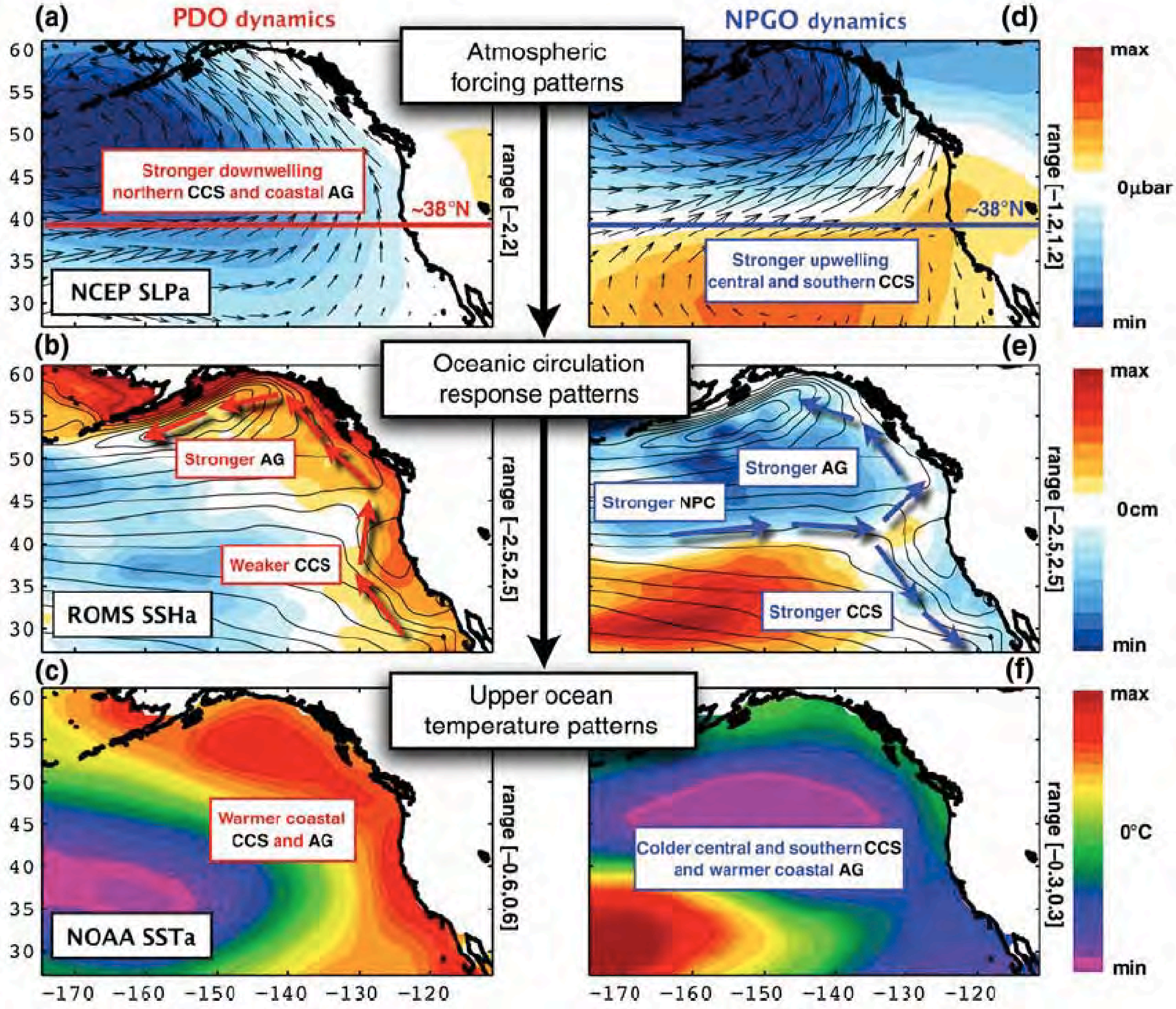


October-March average

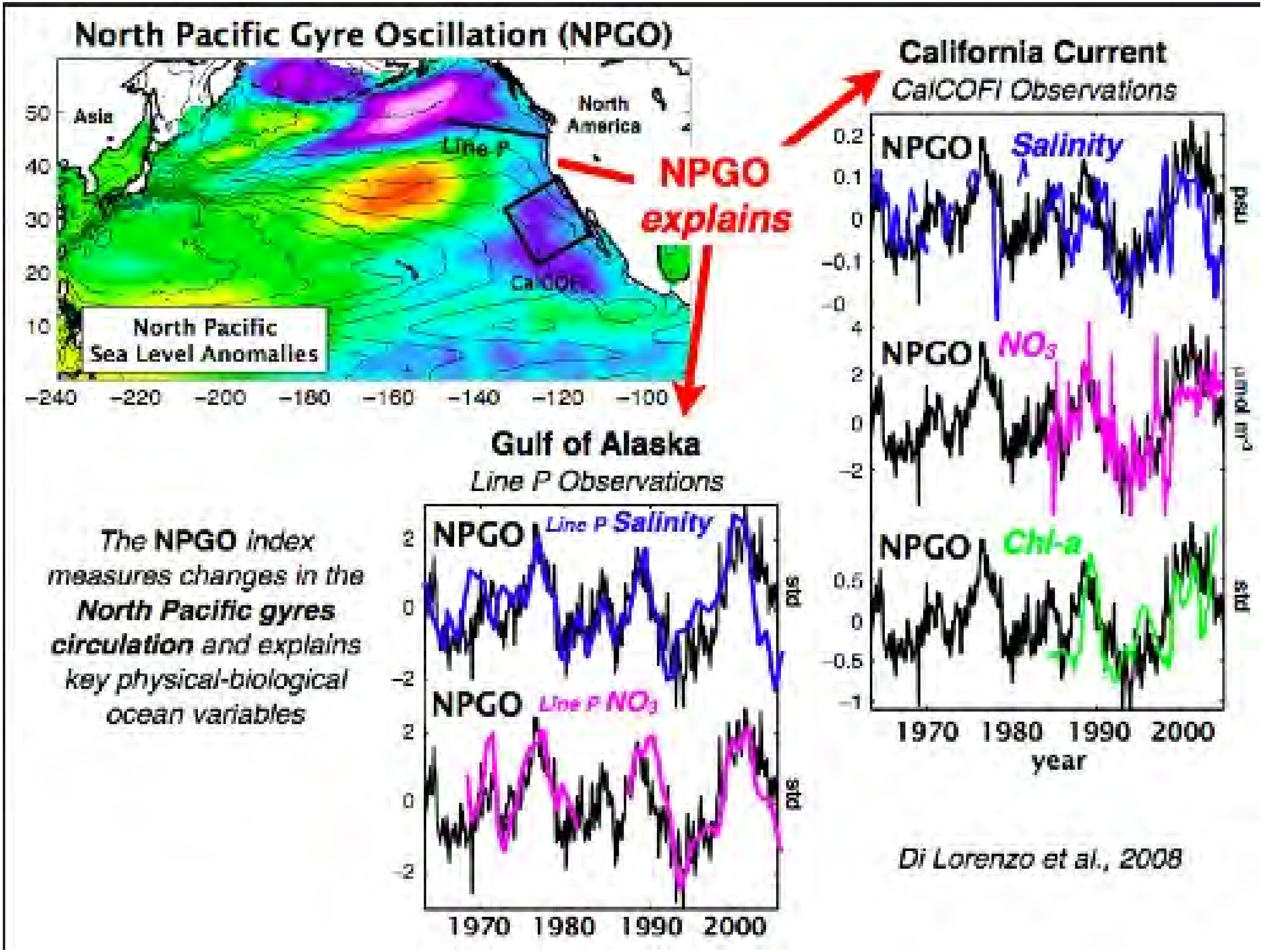


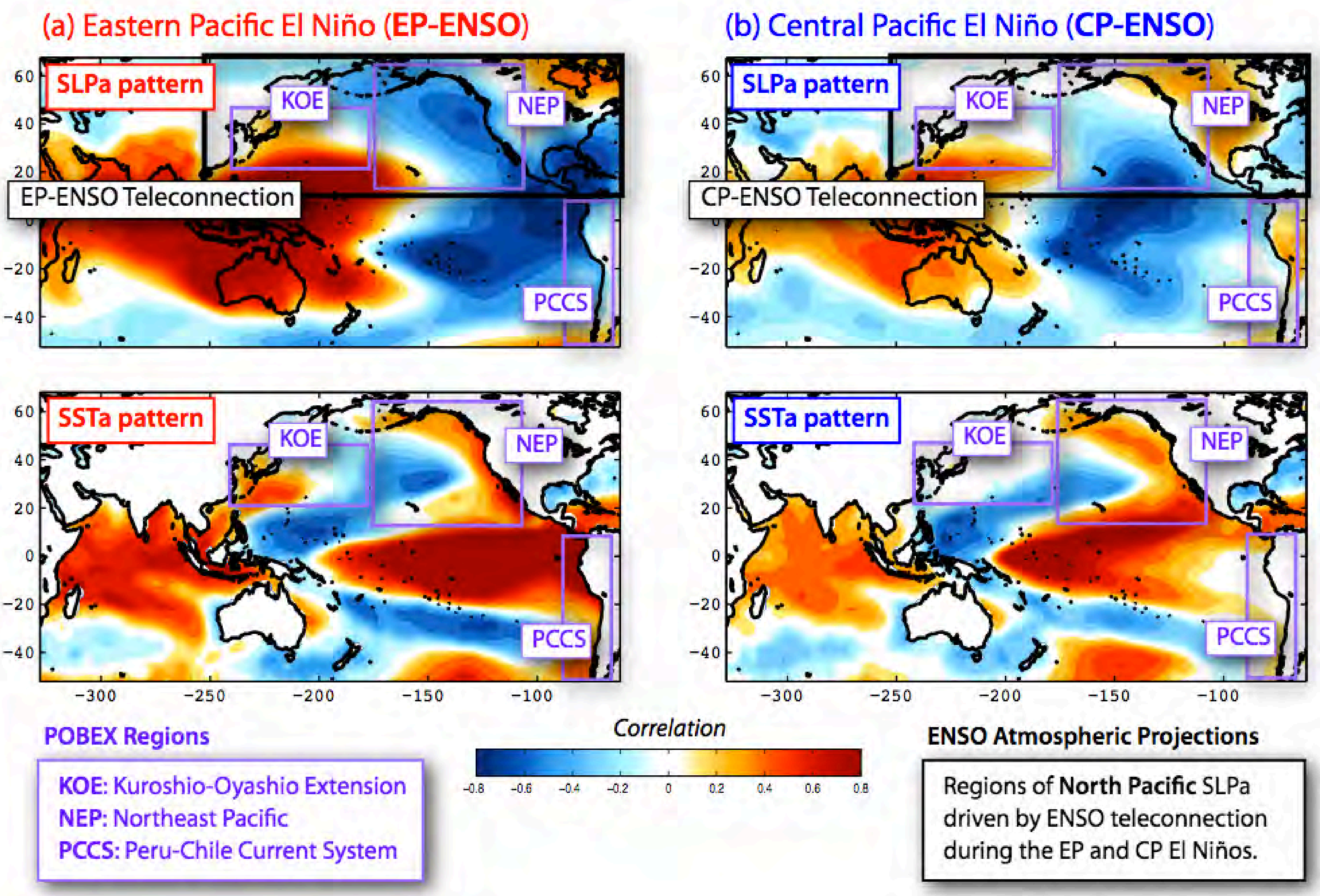
April-September average


Net surface heat exchange
W/m2
500
300
250
200
150
100
70
50
30
10
-10
-30
-50
-70
-100
-150
-200
-250
-300

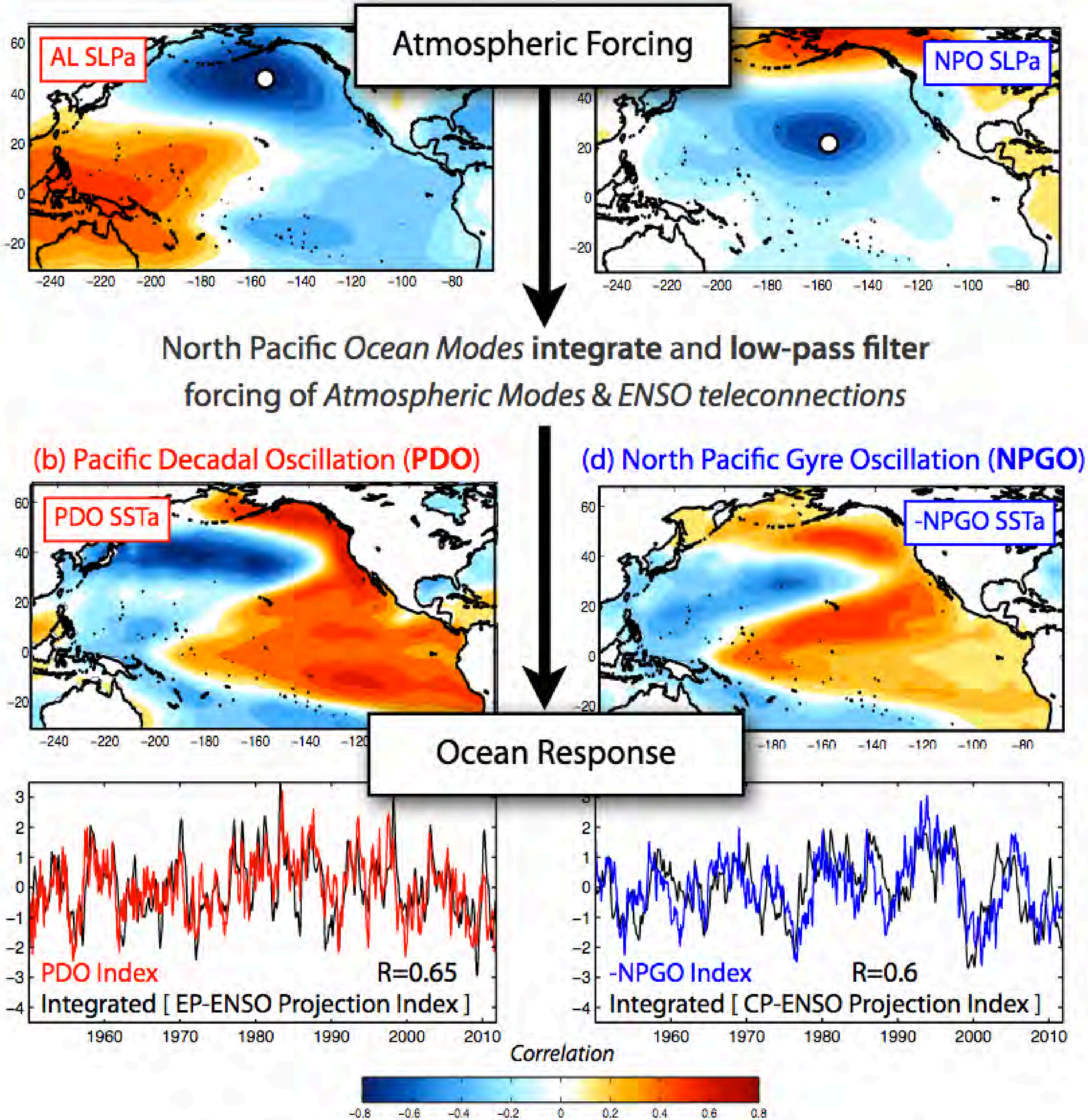


(a)
PDO dynamics
Atmospheric forcing patterns
NPGO dynamics
(d)
Stronger downwelling northern CCS and coastal AG
~38°N
NCEP SLPa
range [−2,2]
Stronger upwelling central and southern CCS
range [−1.2,1.2]
max
0μbar
min
(b)
Oceanic circulation response patterns
(e)
Stronger AG
Weaker CCS
ROMS SSHa
range [−2.5,2.5]
Stronger NPC
Stronger CCS
0cm
(c)
Upper ocean temperature patterns
(f)
Warmer coastal CCS and AG
NOAA SSTa
range [−0.6,0.6]
Colder central and southern CCS and warmer coastal AG
range [−0.3,0.3]
0°C
60
55
50
45
40
35
30
−170
−160
−150
−140
−130
−120


North Pacific Gyre Oscillation (NPGO)
Asia
North America
Line P
CalCOFI
North Pacific Sea Level Anomalies
NPGO explains
California Current
CalCOFI Observations
NPGO Salinity
NPGO NO3
NPGO Chl-a
year
Gulf of Alaska
Line P Observations
NPGO Line P Salinity
NPGO Line P NO3
The NPGO index measures changes in the North Pacific gyres circulation and explains key physical-biological ocean variables
Di Lorenzo et al., 2008

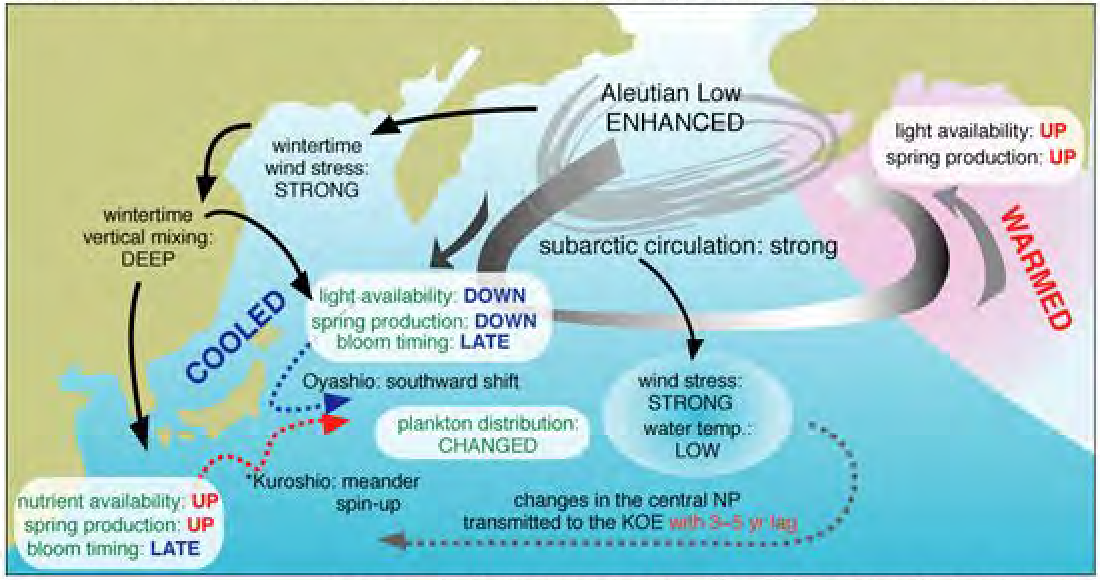


(a) Eastern Pacific El Niño (EP-ENSO)
(b) Central Pacific El Niño (CP-ENSO)
SLPa pattern
KOE
NEP
PCCS
EP-ENSO Teleconnection
CP-ENSO Teleconnection
SSTa pattern
60
40
20
0
-20
-40
-300
-250
-200
-150
-100
POBEX Regions
KOE: Kuroshio-Oyashio Extension
NEP: Northeast Pacific
PCCS: Peru-Chile Current System
Correlation
-0.8
-0.6
-0.4
-0.2
0
0.2
0.4
0.6
0.8
ENSO Atmospheric Projections
Regions of North Pacific SLPa driven by ENSO teleconnection during the EP and CP El Niños.


Atmospheric Forcing
AL SLPa
NPO SLPa
North Pacific Ocean Modes integrate and low-pass filter
forcing of Atmospheric Modes & ENSO teleconnections
(b) Pacific Decadal Oscillation (PDO)
(d) North Pacific Gyre Oscillation (NPGO)
PDO SSTa
-NPGO SSTa
Ocean Response
PDO Index
R=0.65
Integrated [EP-ENSO Projection Index]
-NPGO Index
R=0.6
Integrated [CP-ENSO Projection Index]
Correlation

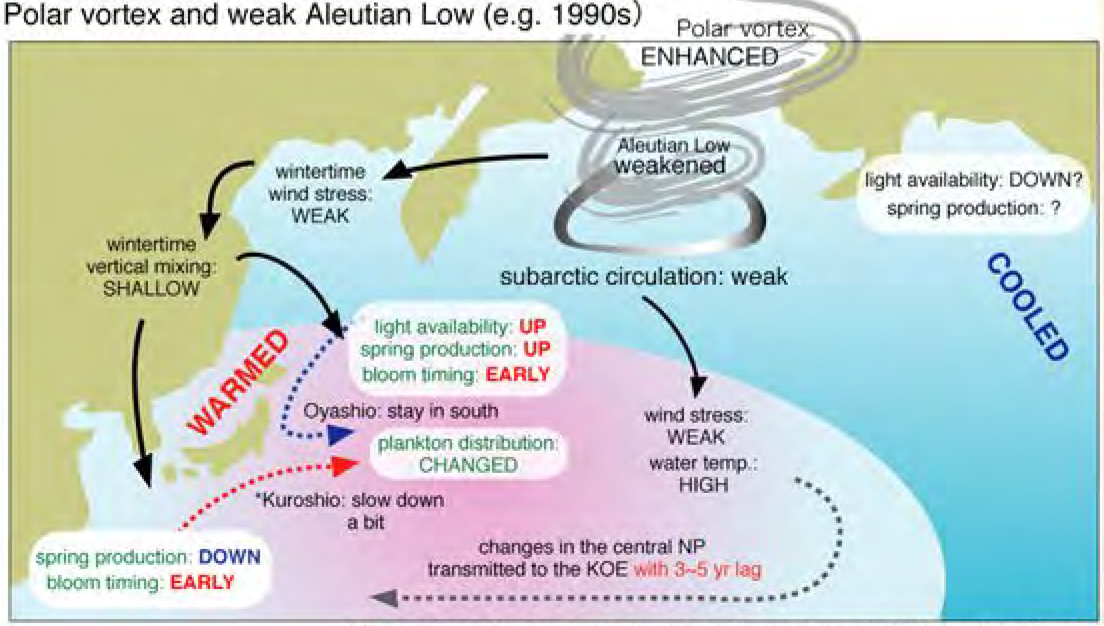
After the mid 1970s

Winter-spring processes during the regime of strong Aleutian Low (e.g. 1976 -)



* Change in the Kuroshio properties occurred several years behind that of the Oyashio

Winter-spring processes during the regime of strong Polar vortex and weak Aleutian Low (e.g. 1990s)



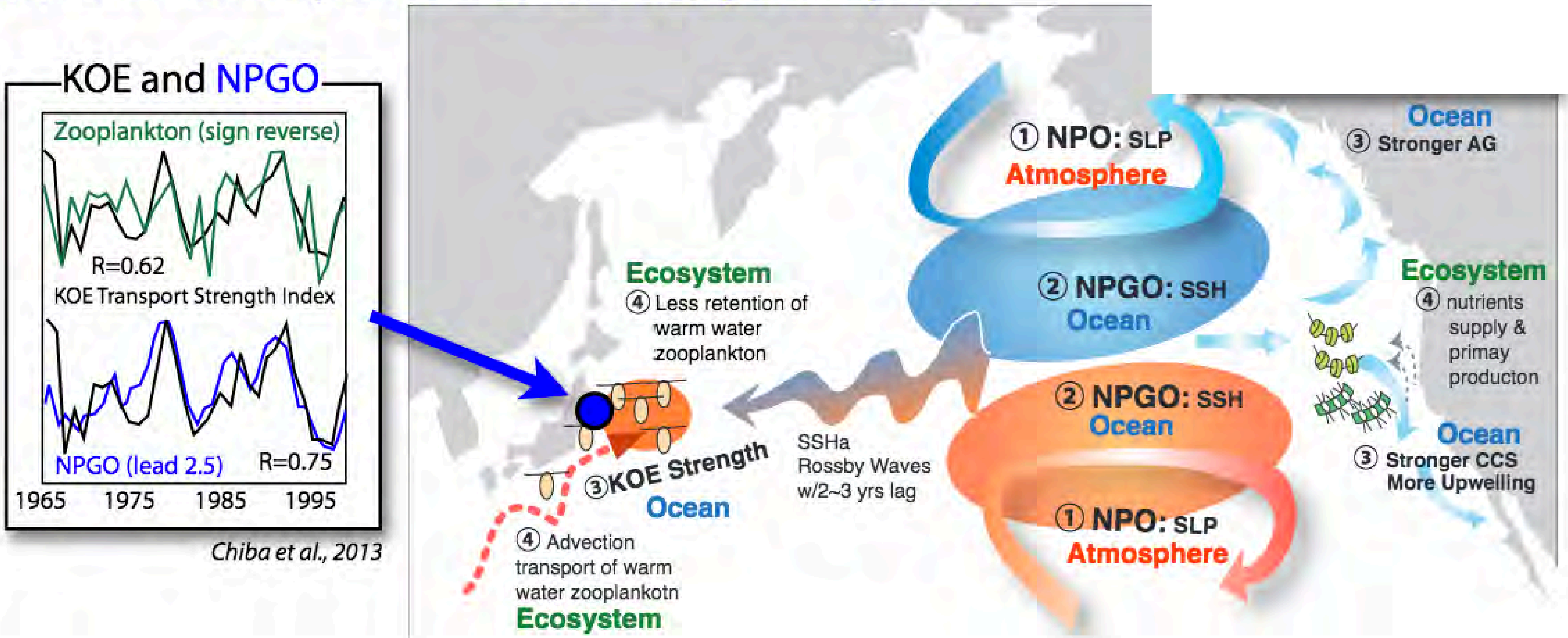
* Change in the Kuroshio properties occurred several years behind that of the Oyashio

Lower tropic level responses to the 1976 and 1988 RS : (winter-spring processes)

After the late 1988s

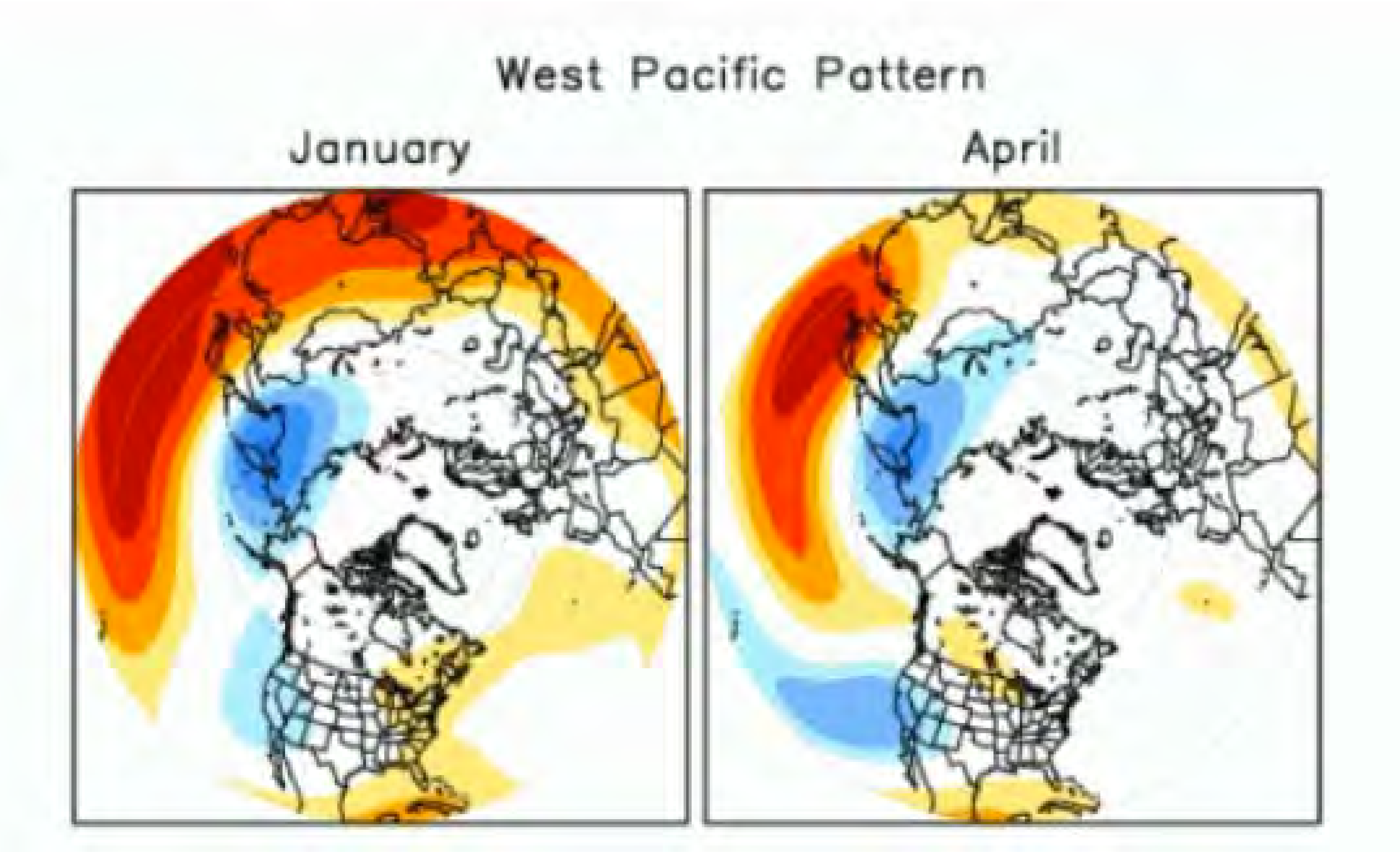
(*Chiba et al, submitted, PO*)

(b) North Pacific Gyre Oscillation (**NPGO**) (positive phase)



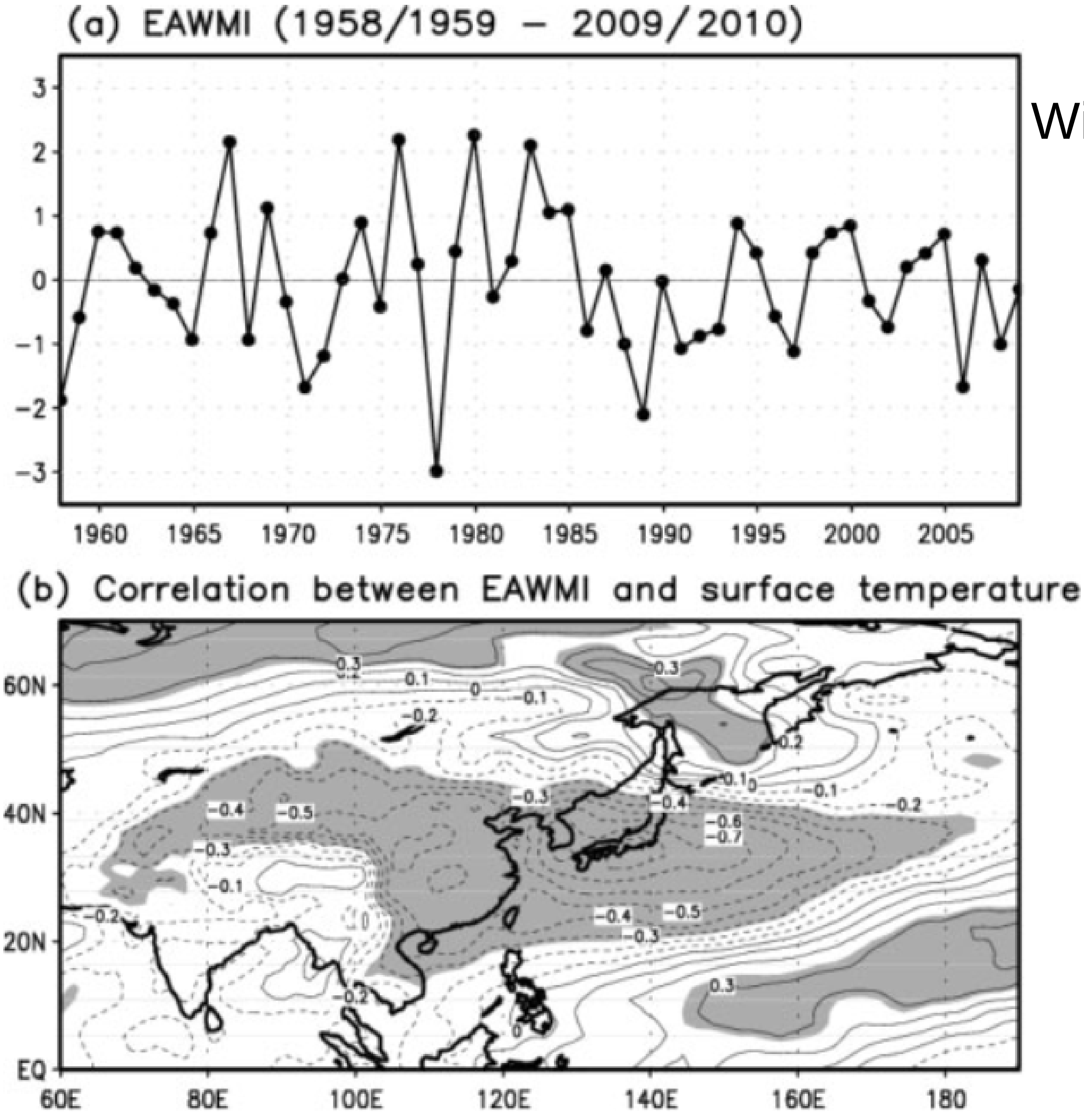
M. Di Lorenzo, S. Chiba and collaborators

WP- A primary mode of NH atmospheric circulation variability



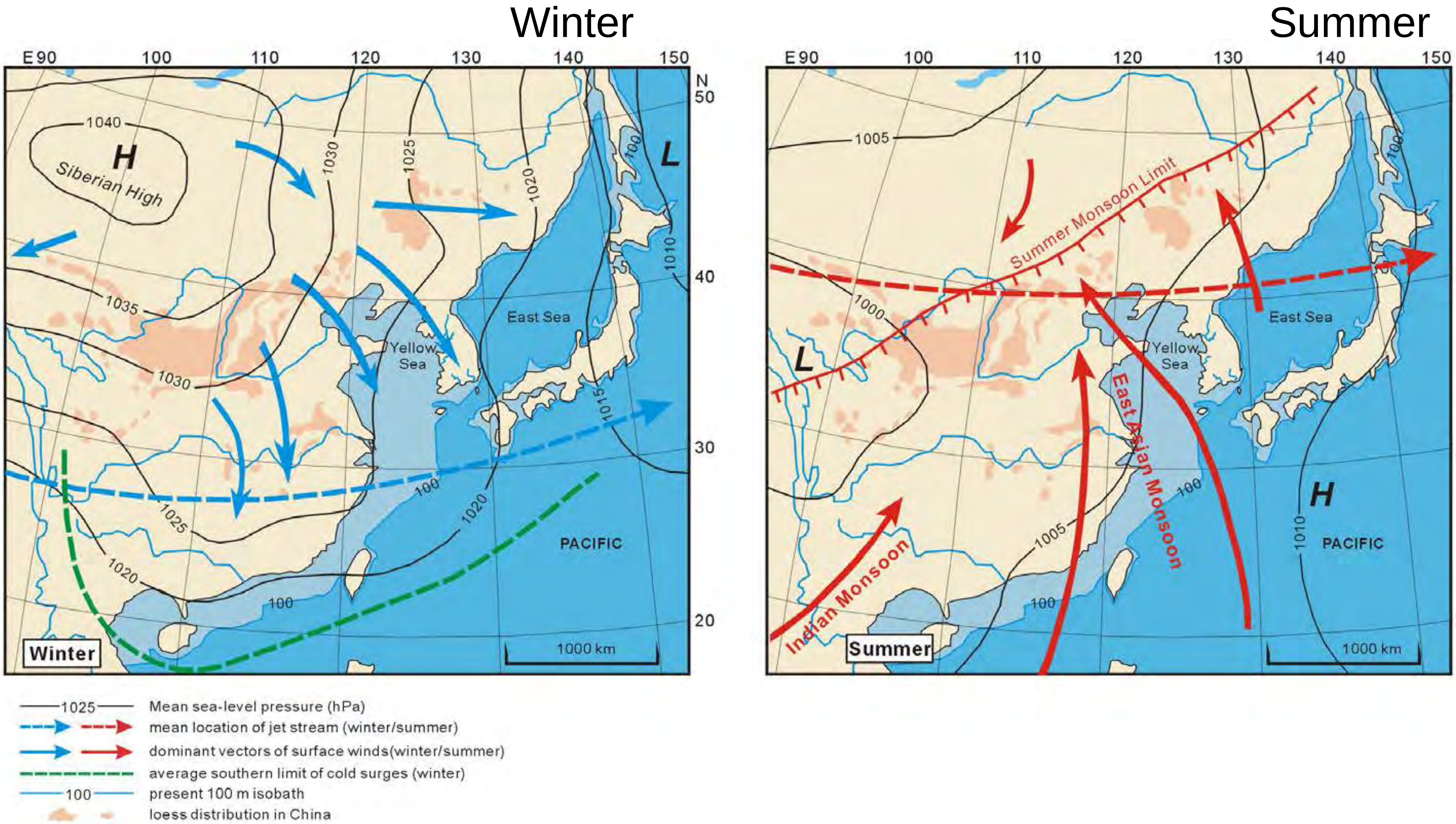
NOAA/Climate Prediction Center

East Asian Winter Monsoon

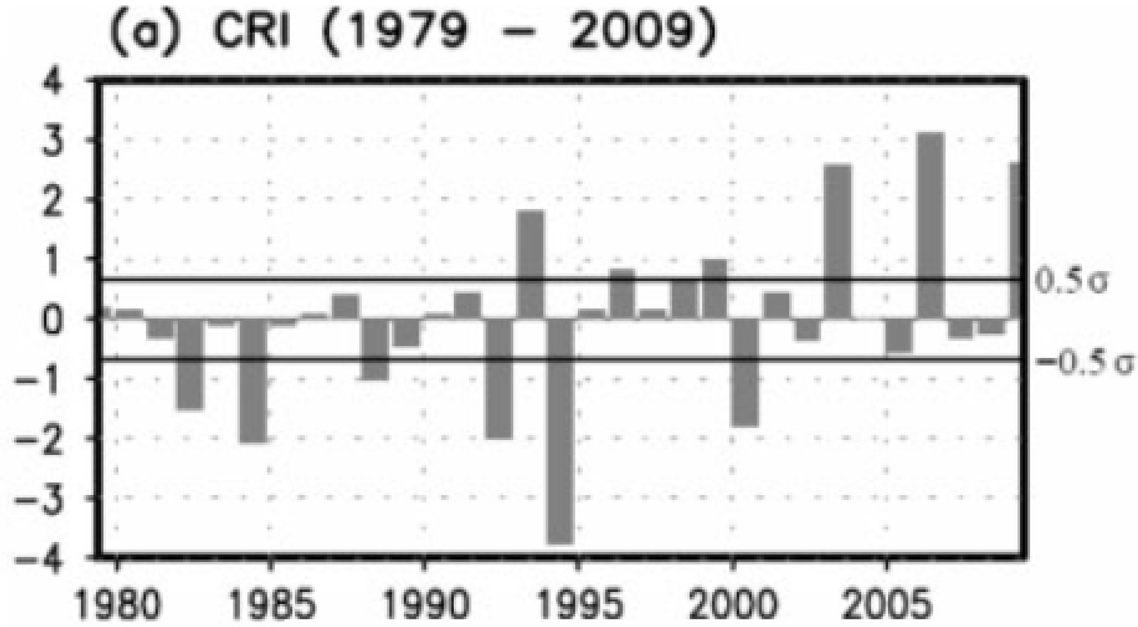


Ha et al. (2012)

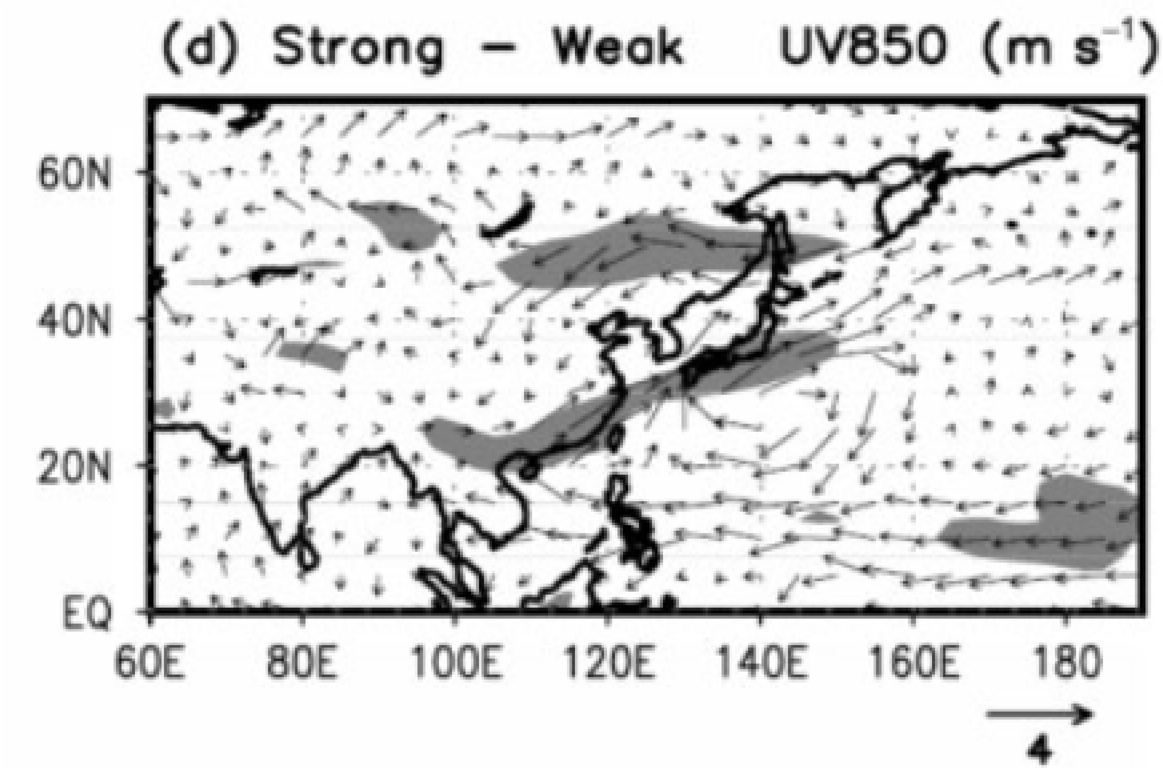
East Asian Monsoon



Yi (2011)



East Asian Summer Monsoon Related to Precipitation and Low-level Winds



Ha et al. (2012)

Three Concepts Related to HABs

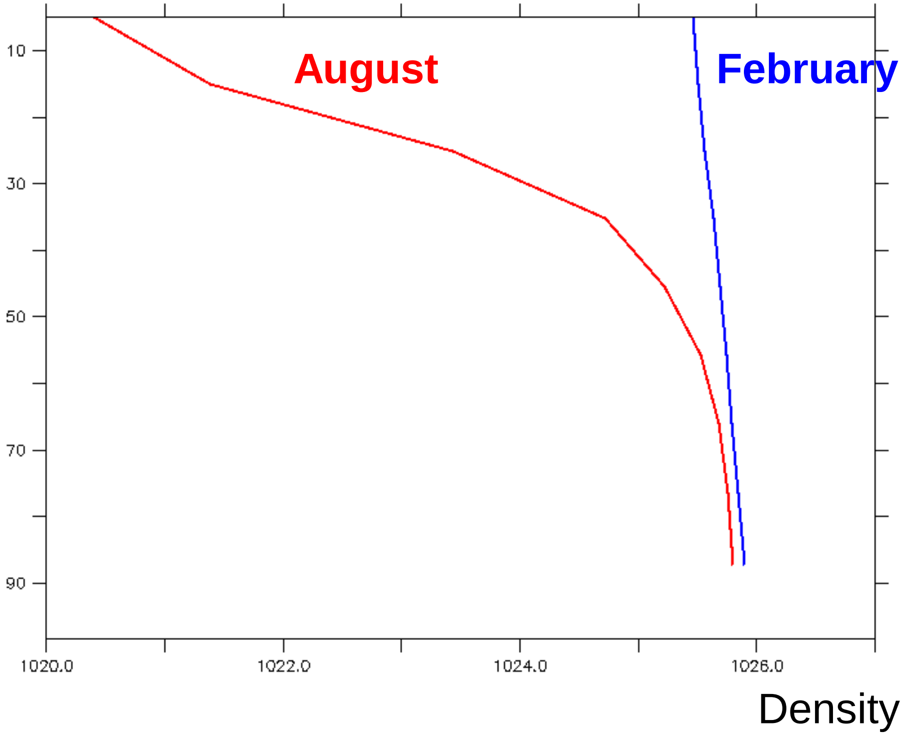
- *Stress* – Macronutrient, micronutrient and contaminant concentrations have been linked to development of domoic acid (DA).

- *Retention* – Prolonged periods of particular conditions appear to be instrumental for toxic levels (e.g., Juan de Fuca eddy).

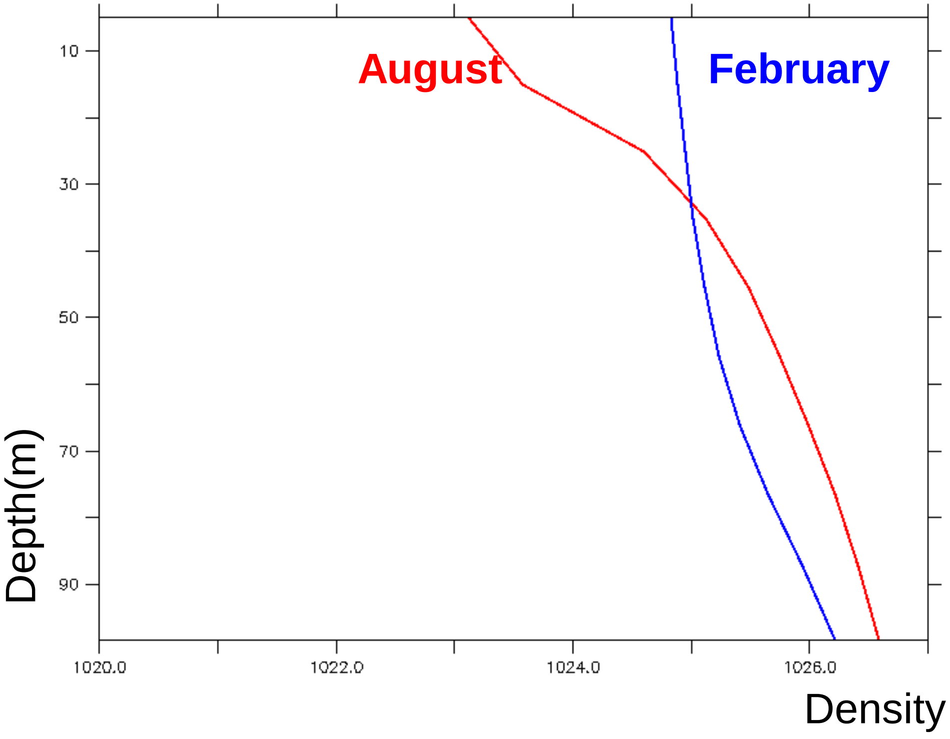
- *Transport* – Onshore directed flow is necessary to infect coastal locations.

Mean Upper Ocean Density Profiles: West versus East

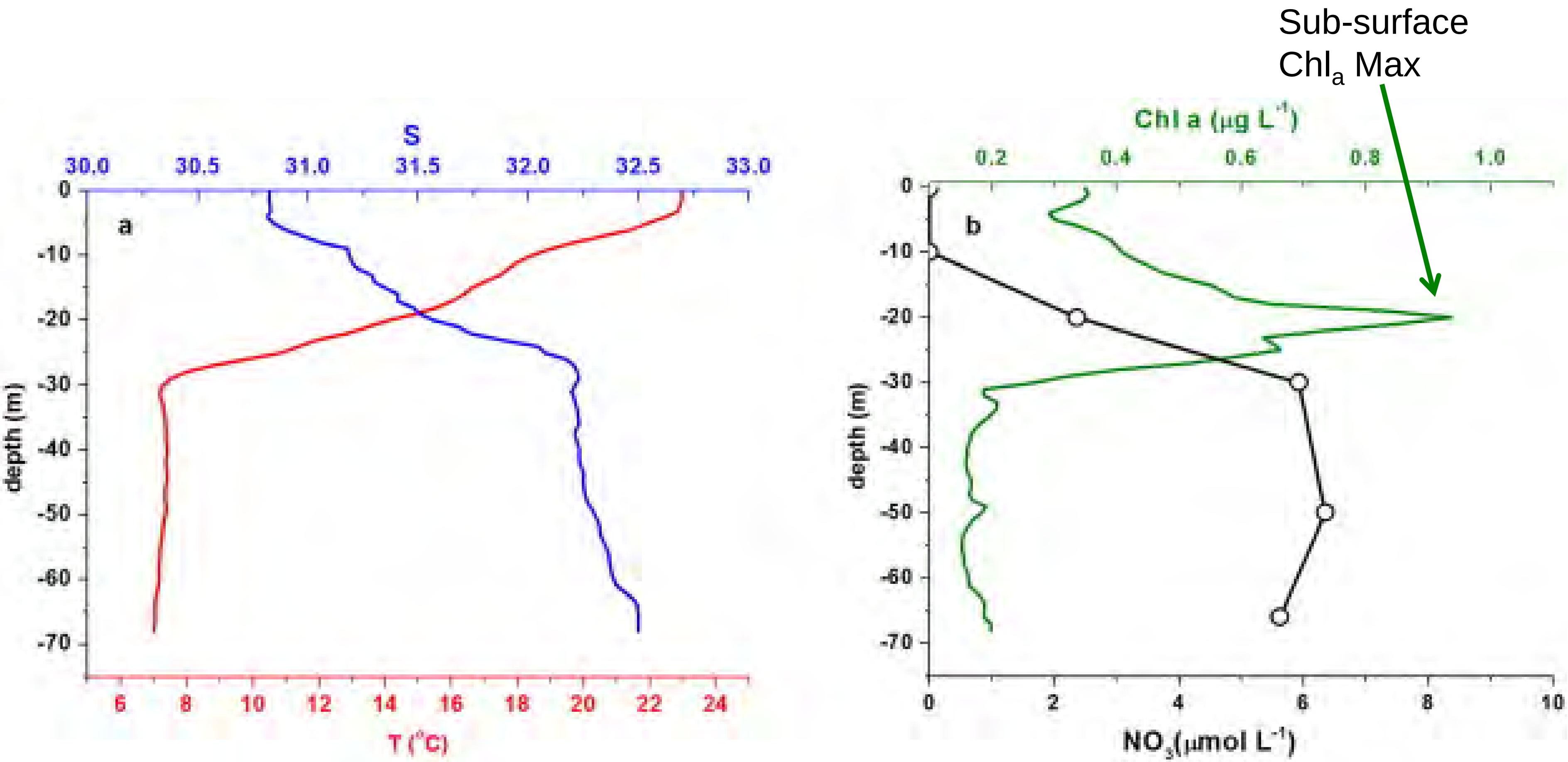
West (35 N, 125 E)



East (48 N, 125 W)

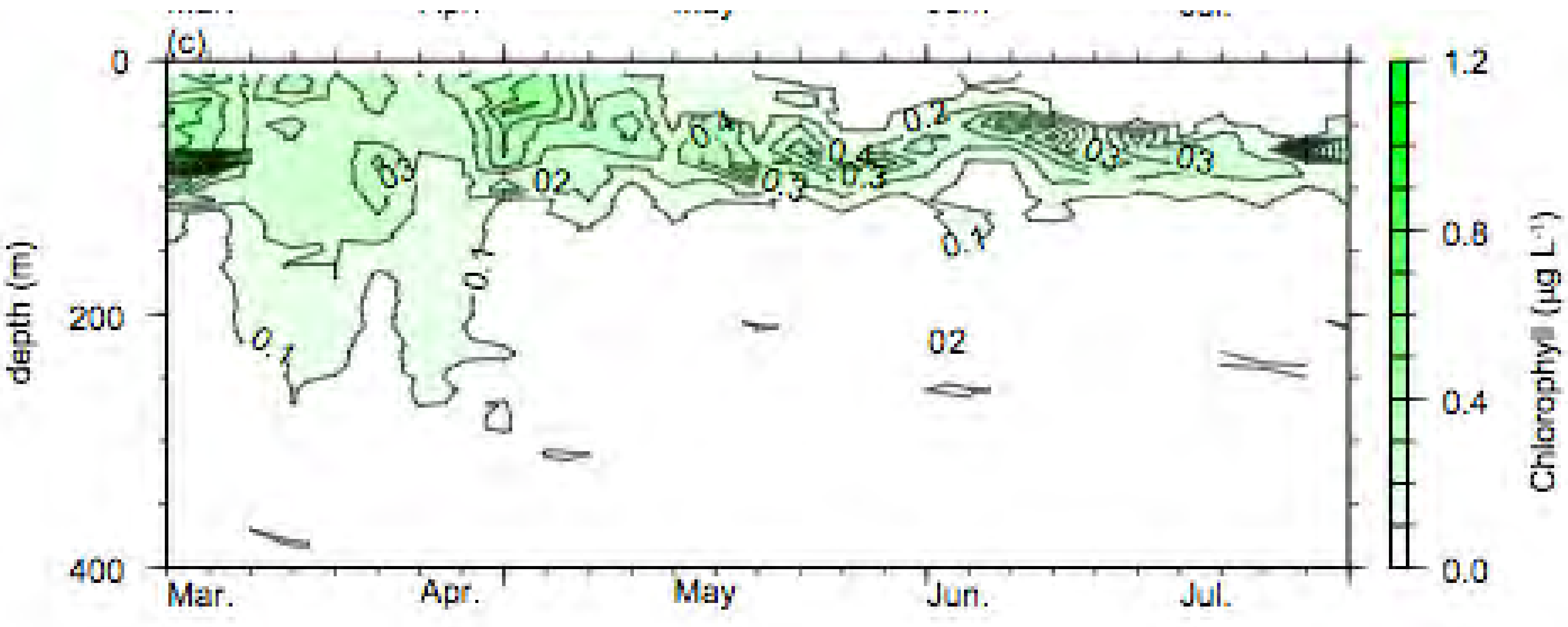


Warm Season (Aug 2011) Profiles in the Yellow Sea

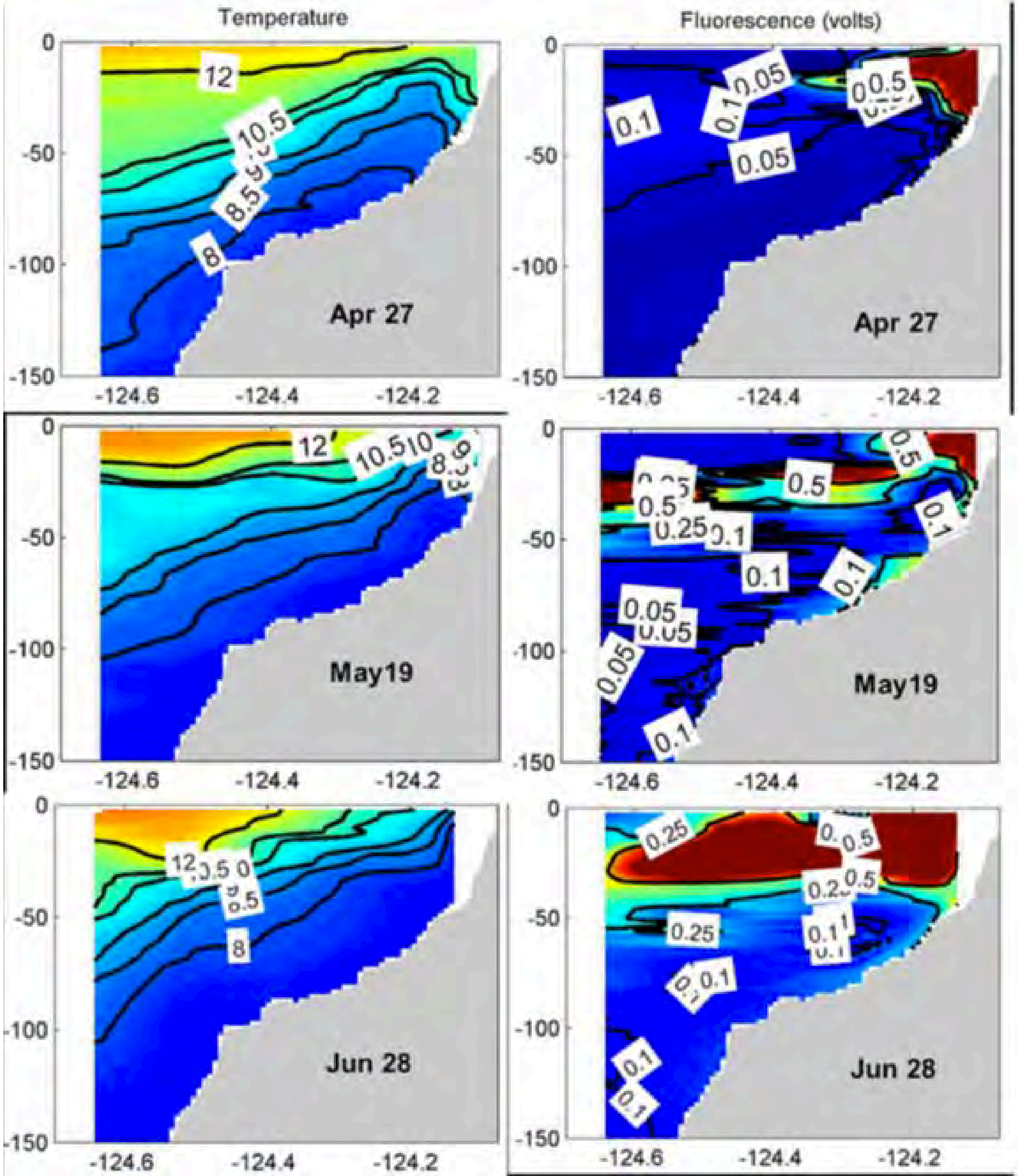


Fu et al. (2016)

Subsurface primary production in the western subtropical North Pacific



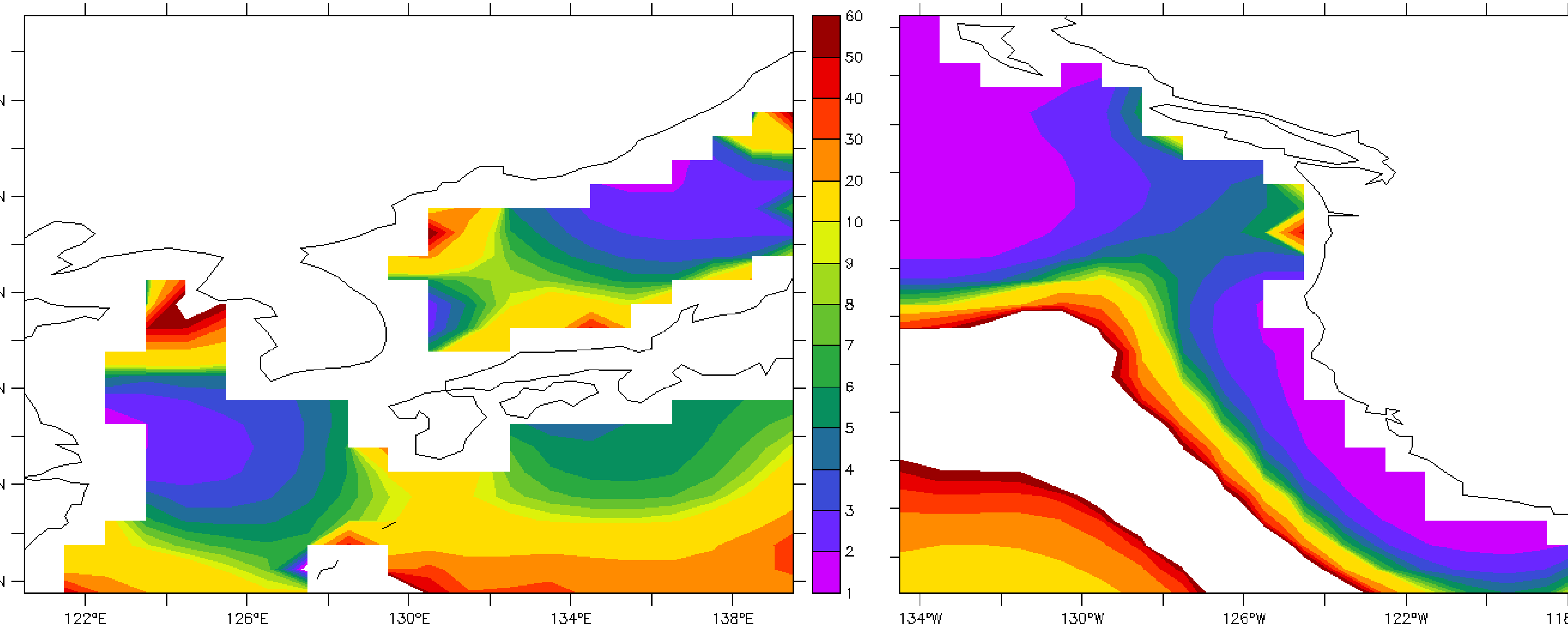
Sukiagara et al. (2009)


Temperature
Fluorescence (volts)
Apr 27
May19
Jun 28
0
-50
-100
-150
-124.6
-124.4
-124.2
12
10.5
8.5
8
0.05
0.1
0.5
0.25

Du et al. (2016)

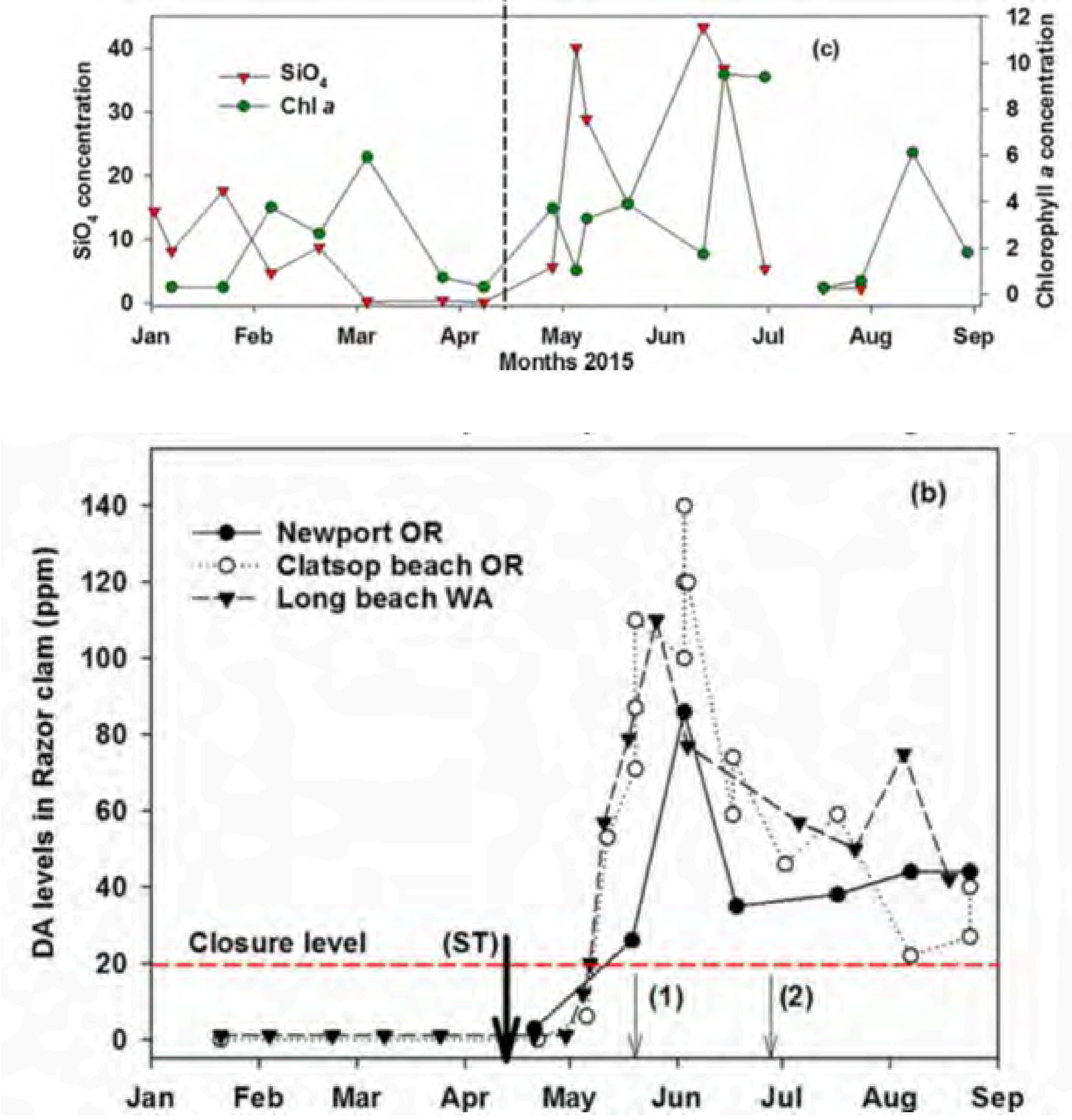
Mean Si:N Ratios in Top 60 meters during May

Greater in the coastal zone of the western North Pacific



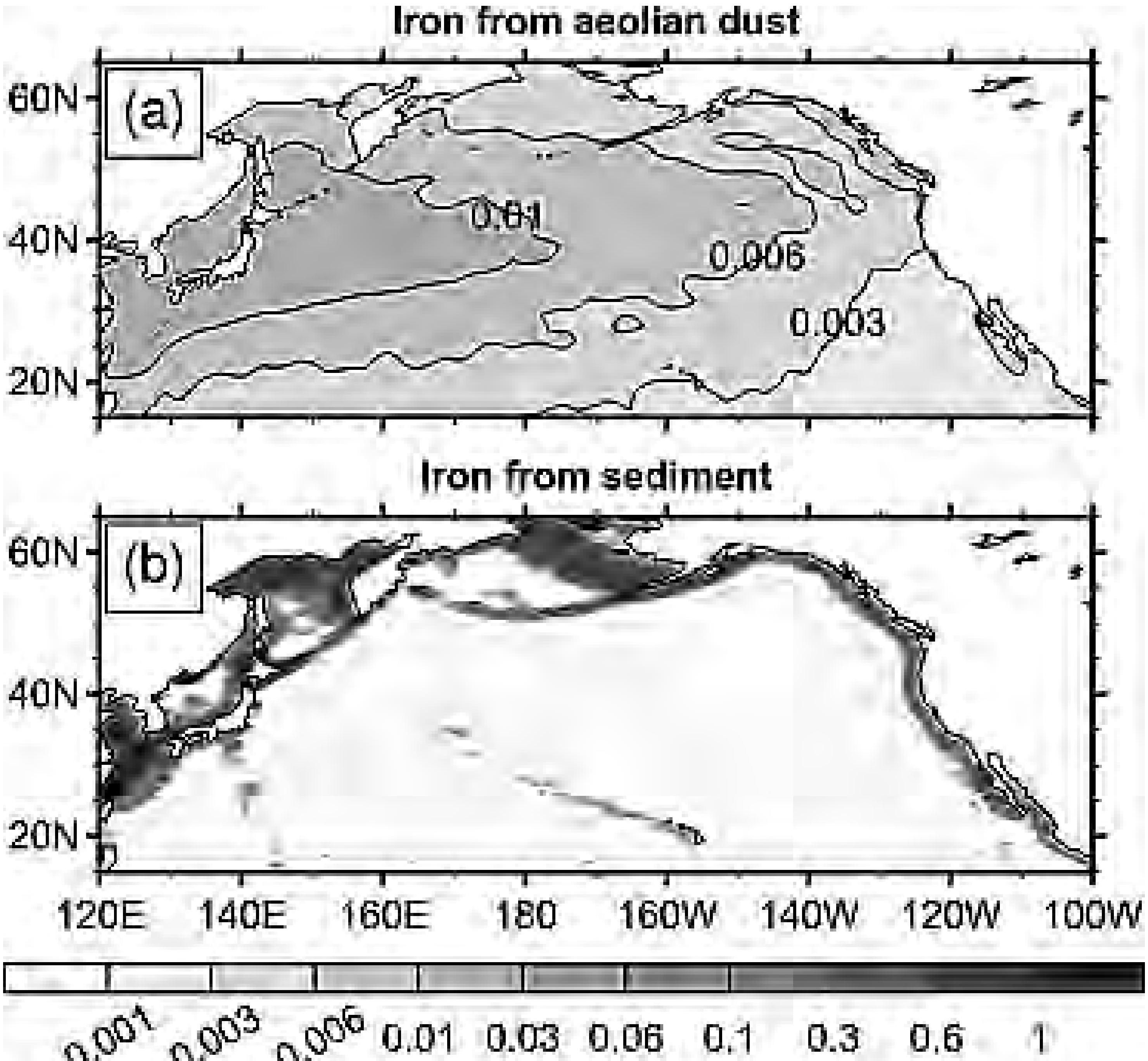
■

from World Ocean Atlas 2013



(c)
SiO4
Chl a
SiO4 concentration
Chlorophyll a concentration
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Months 2015
(b)
Newport OR
Clatsop beach OR
Long beach WA
DA levels in Razor clam (ppm)
Closure level
(ST)
(1)
(2)

Du et al. (2016)



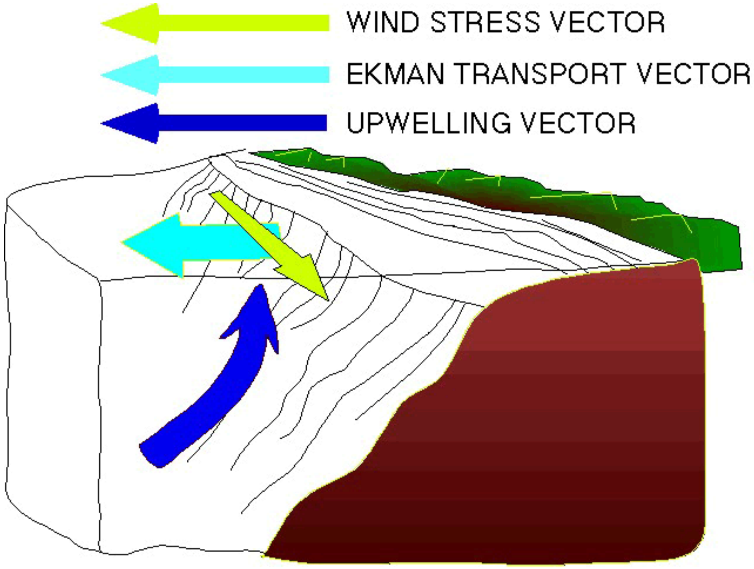
Luo et al. (2003)

Moore and Braucher (2008)

Misumi et al. (2011)

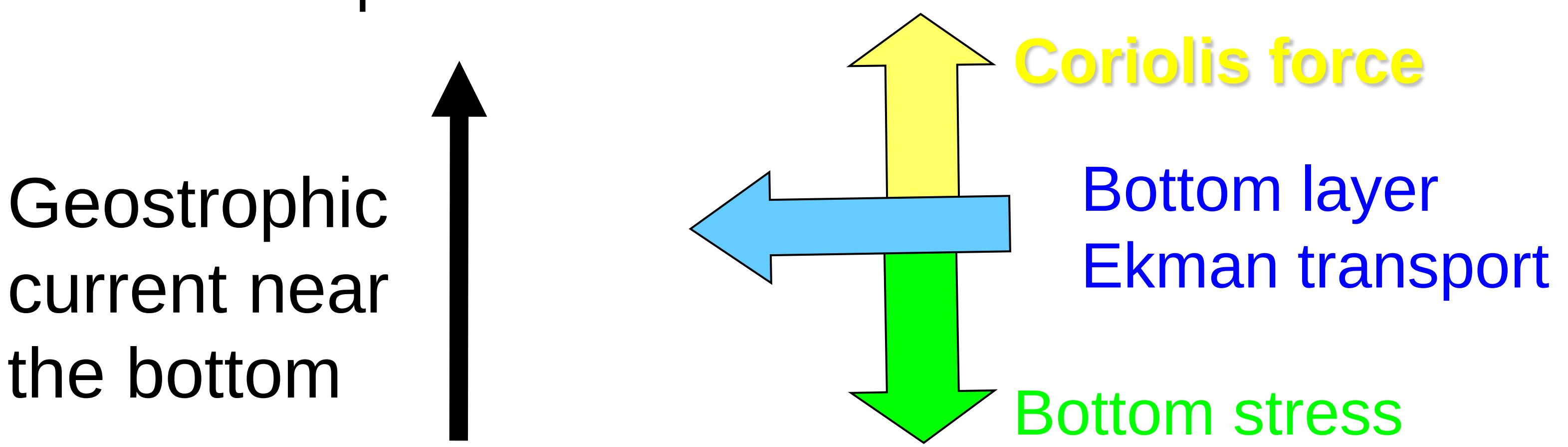
Near-shore circulation associated with coastal upwelling

- In coastal upwelling periods, **<u>offshore</u>** transport in the surface Ekman layer is balanced by **<u>onshore</u>** transport at depth
  - Vertical migration in coastal upwelling regions provides organisms a means for a free-ride offshore and onshore



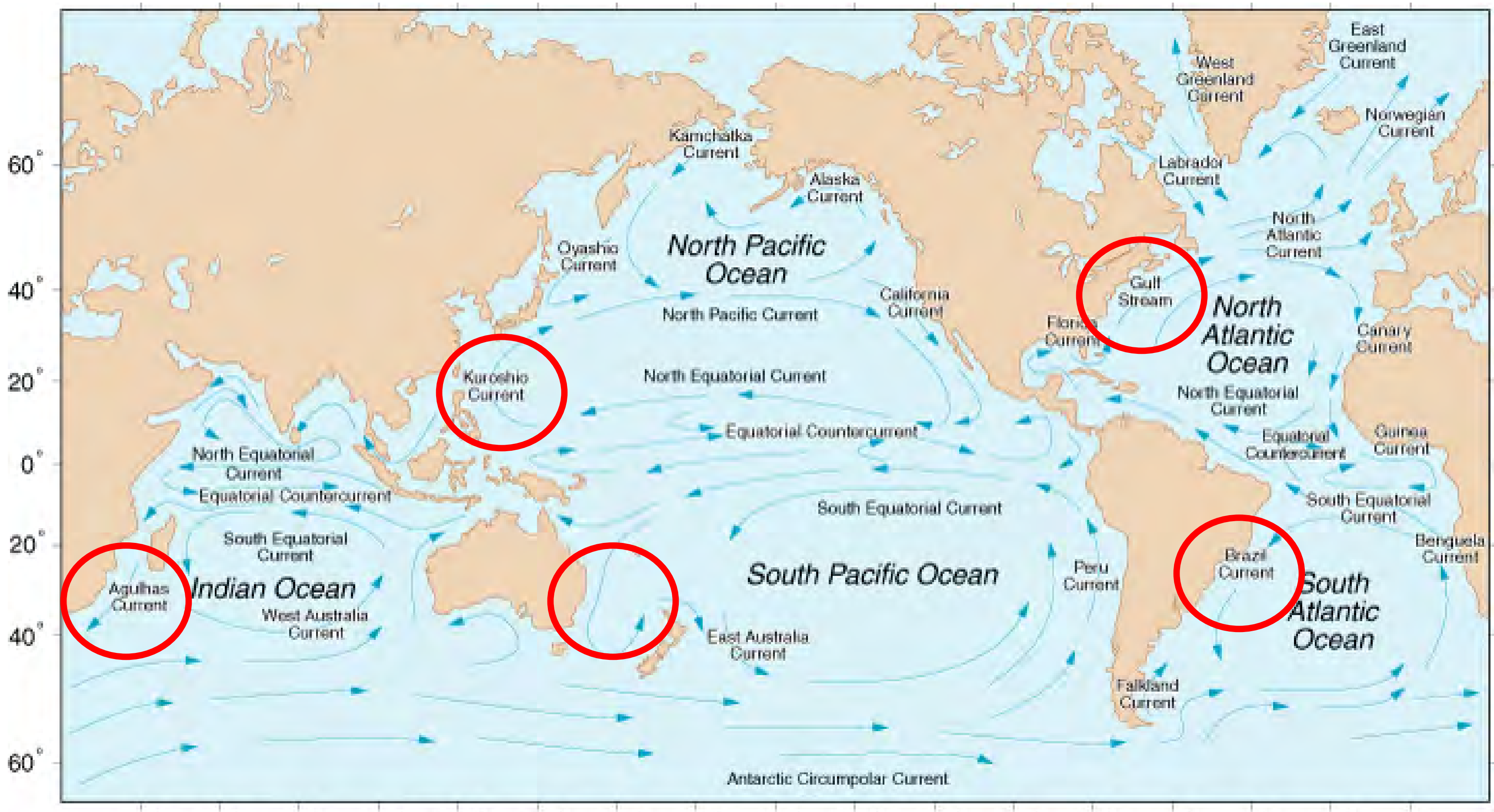
Bottom boundary layers

- Directly adjacent to the ocean bottom, flow is retarded by friction. In large-scale, low-frequency flows, the effect of the earth's rotation is important and results in a ***bottom Ekman layer*** -- analogous to the surface Ekman layer but turned upside down.
- In a bottom Ekman layer, there is frictional transport **to the left of the flow direction** in the Northern Hemisphere.



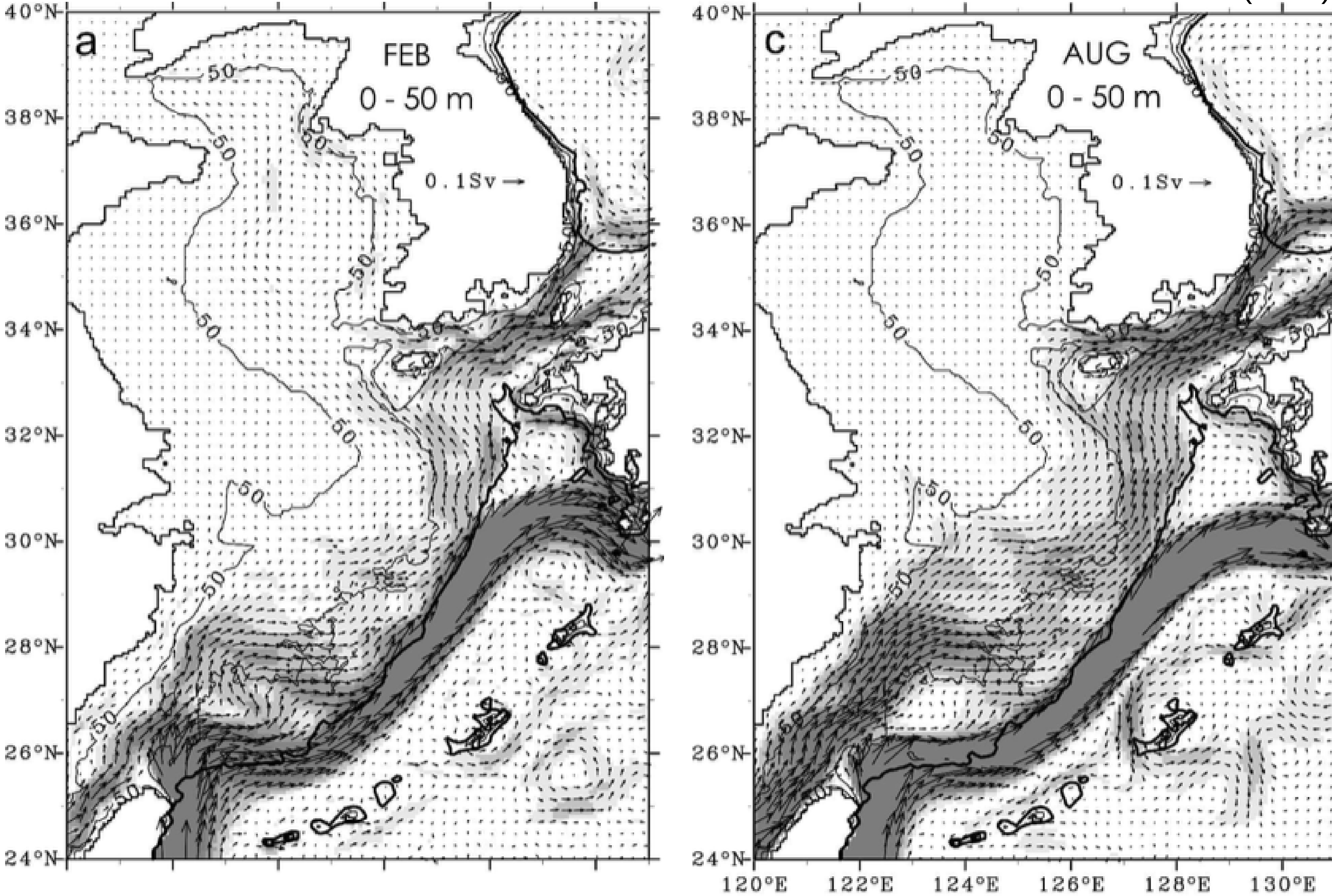
Strong poleward flowing western boundary currents and bottom Ekman layers

- These deep currents directly impinge on the continental shelf and slope -- here expect a substantial bottom Ekman layer in which the flow is upslope and toward the coast

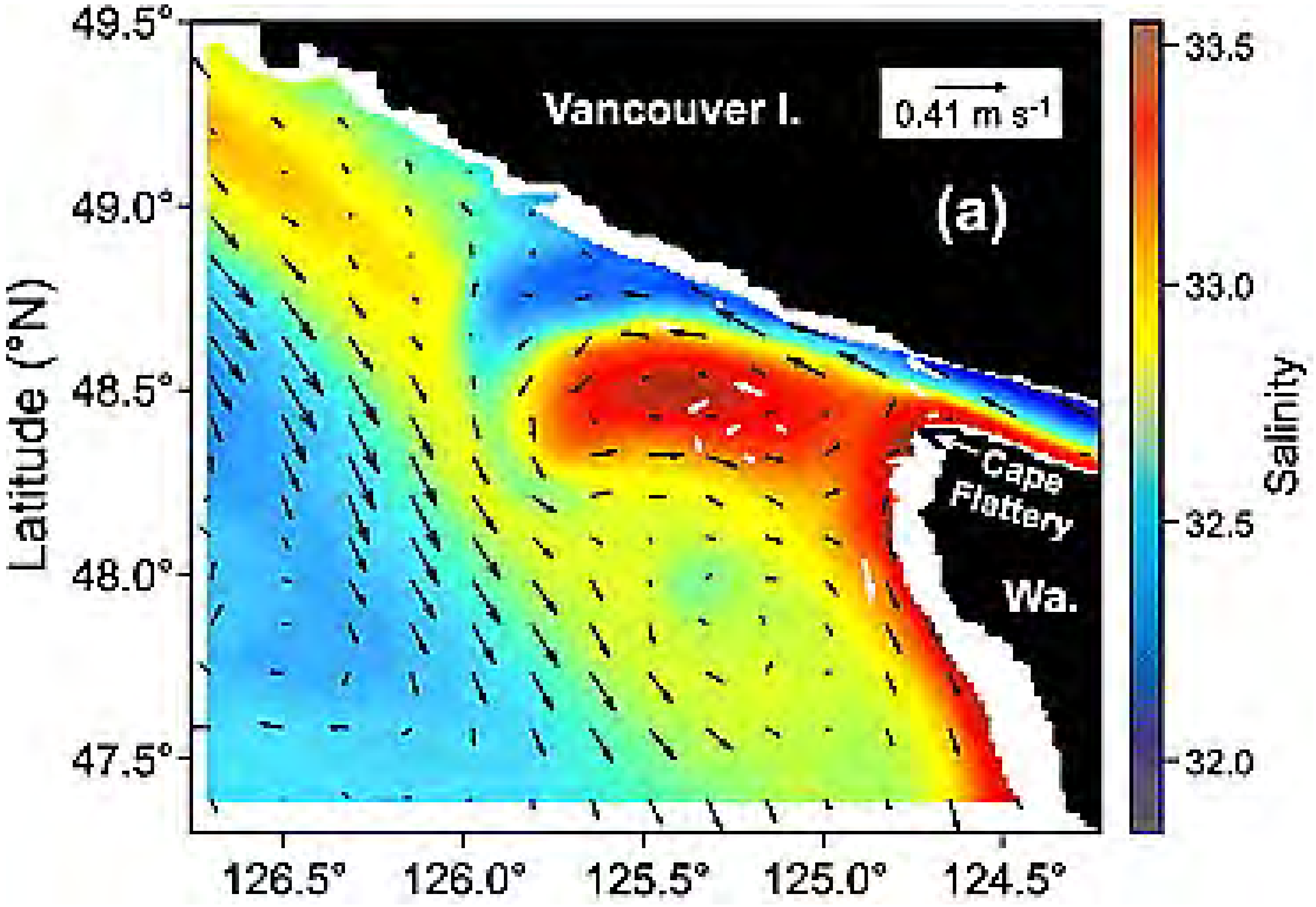


Kuroshio Intrusion for East China Sea (ECS) and Tsushima Warm Current (TWC) Varies Seasonally

Guo et al. (2006)



The Juan de Fuca Eddy at 35 meters



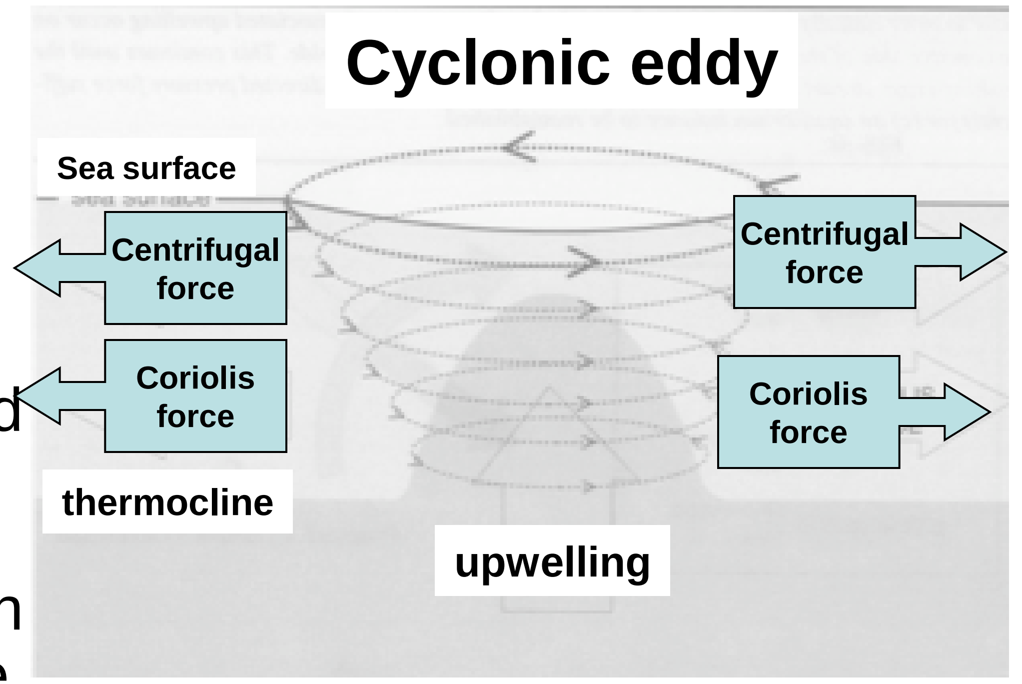
A

r
e

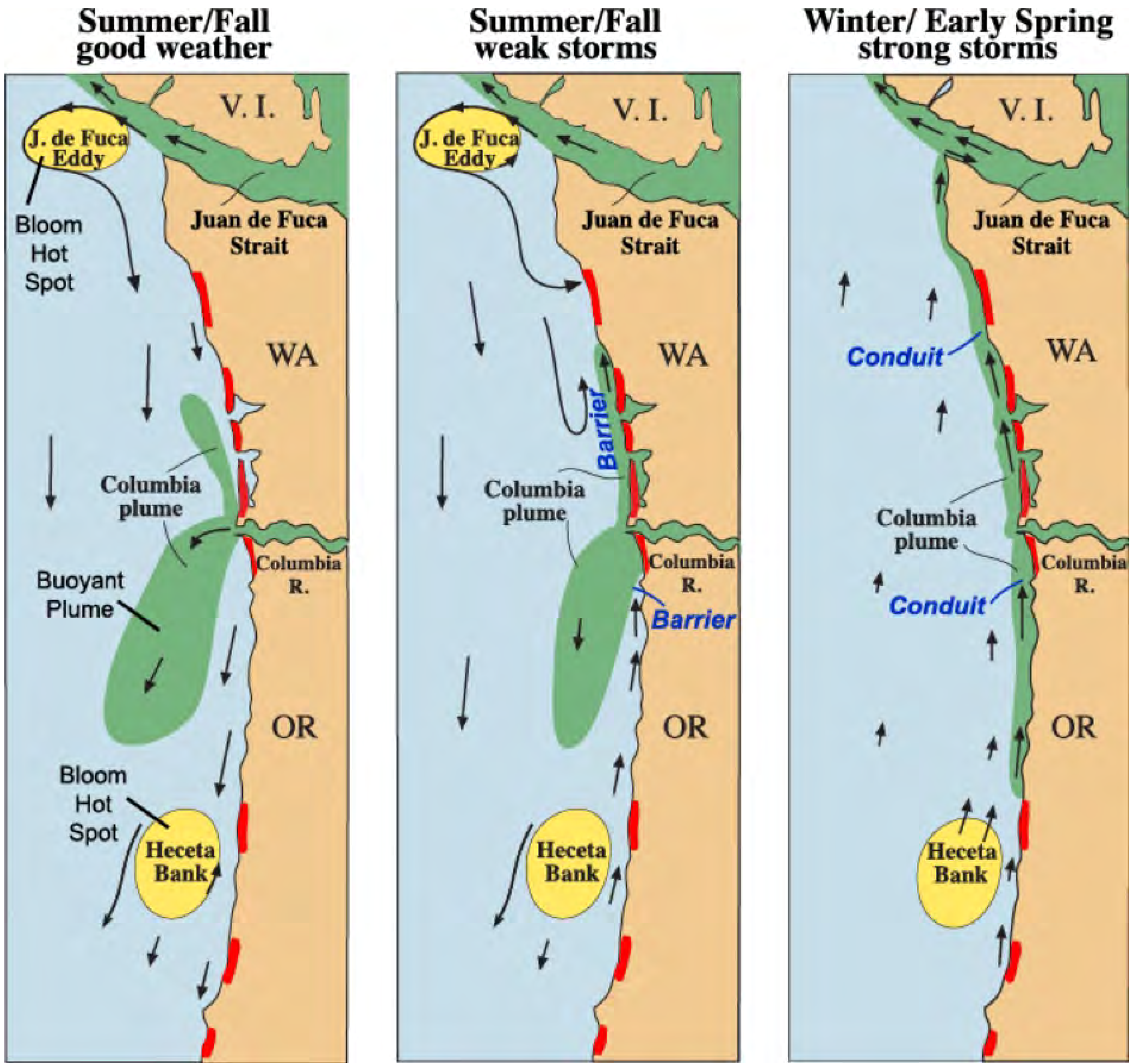
Foreman et al. (2008)

Vortex driven upwelling

- While the pressure force is overbalanced, the outward moving surface waters are replaced by upwelled sub-surface water from the eddy interior
- This loss of surface water and upwelling continues until the resulting sea surface depression, and accumulation of higher-density water, in the eddy interior re-establishes a pressure gradient sufficient to balance the combined Coriolis and centrifugal forces

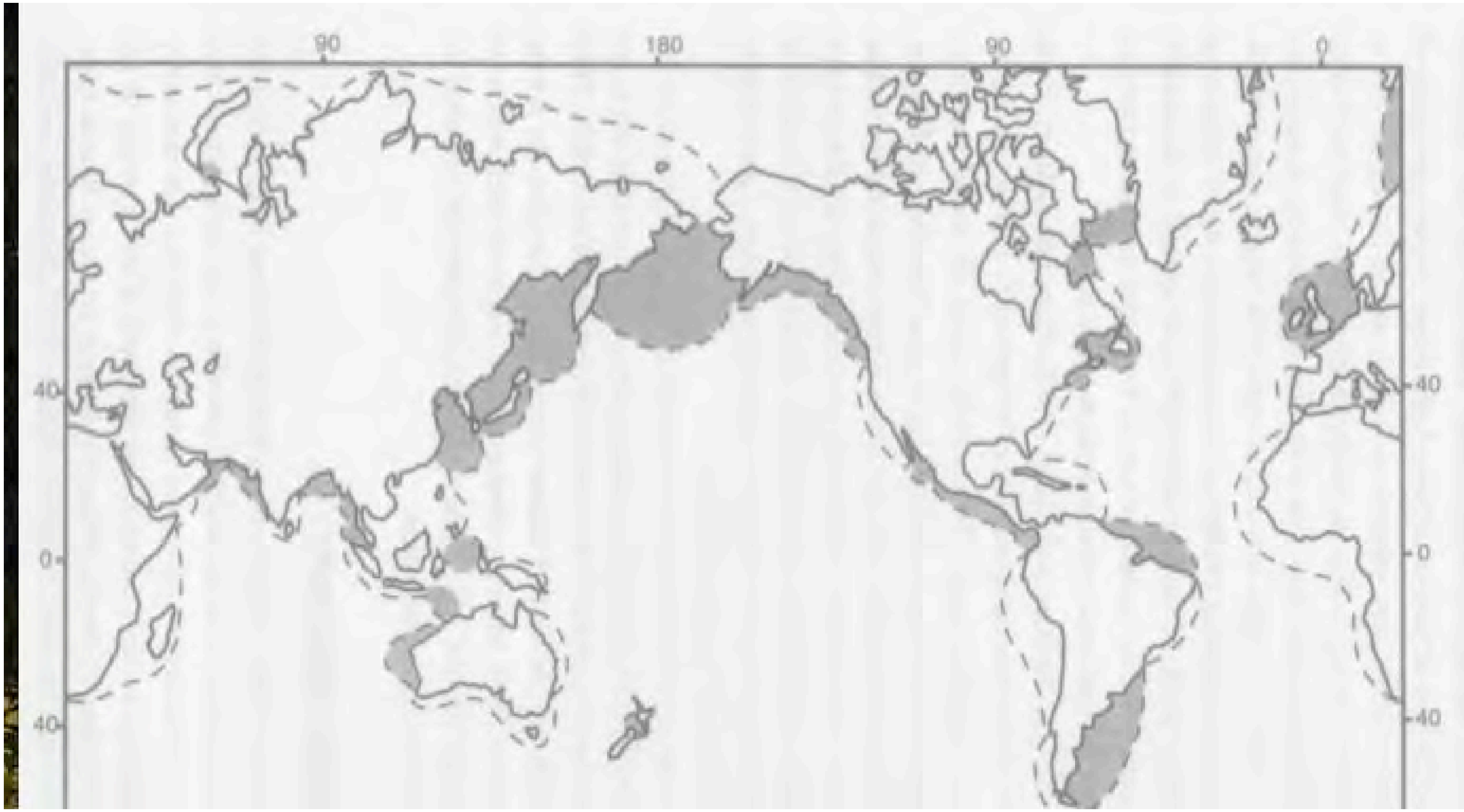


Transport of toxic cells onto beaches in the Pacific NW



Hickey et al (2013)

Continental shelf regions of strong tidal mixing

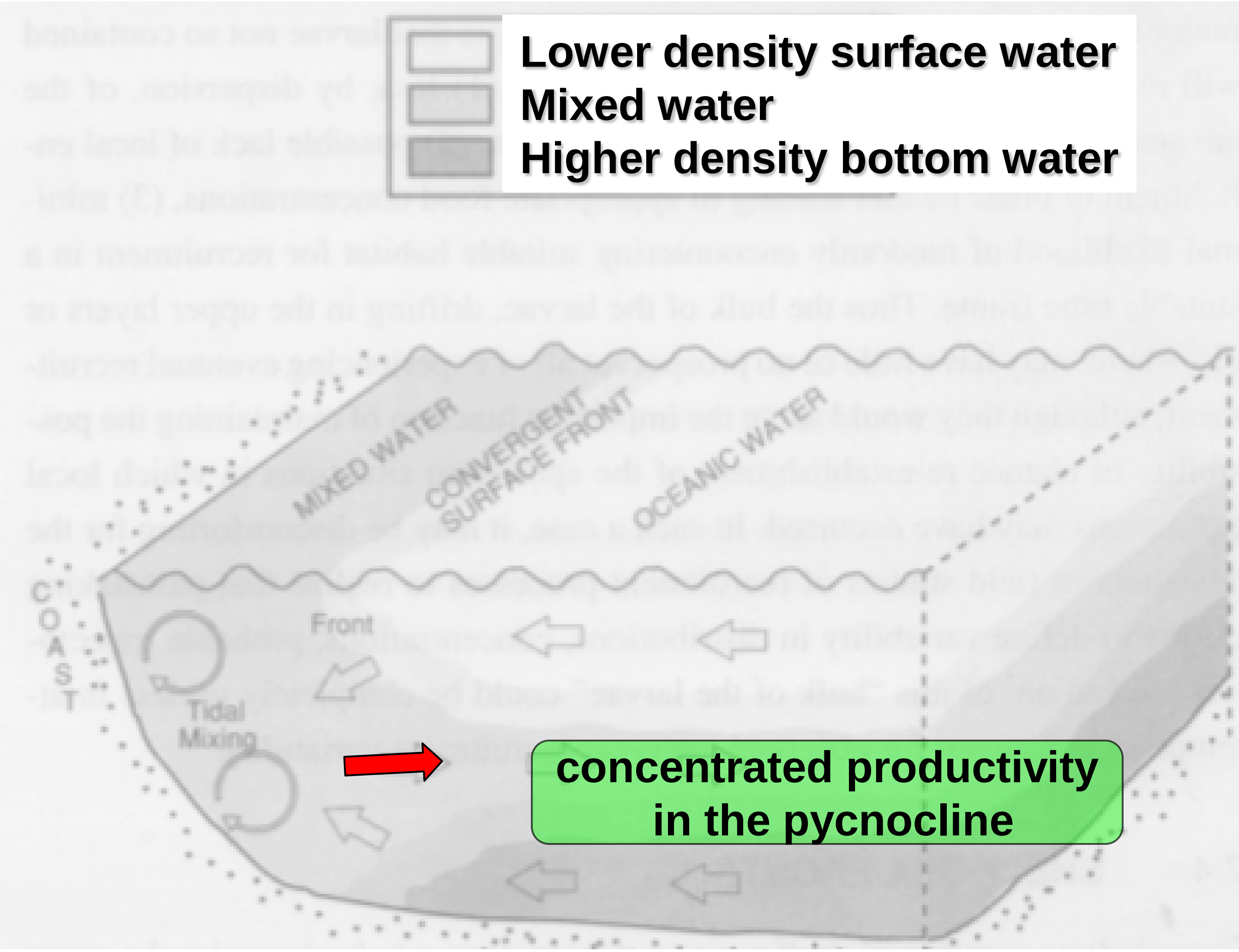


Shaded areas indicate shelf regions of the world with sufficiently strong tidal mixing for likelihood of significant development of shelf-sea fronts (Hunter and Sharp 1983)

Shallow water, greener pastures

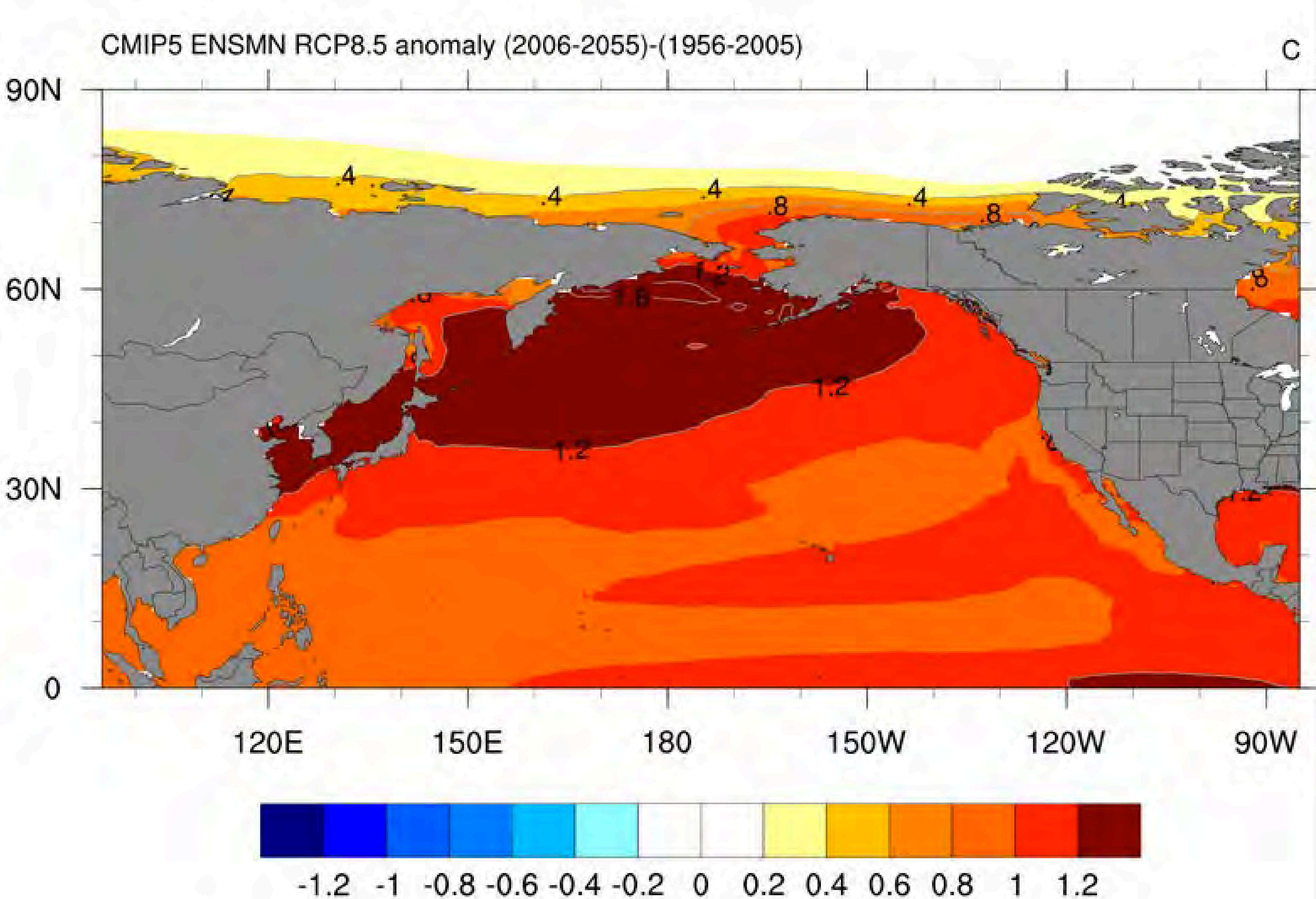
- Over large shallow banks and continental shelf regions of the ocean, organic matter can sink only to the depth of the shallow sea bottom.
  - Remineralization and redissolution of plant nutrients takes place much closer to, or even within, the photic zone
  - This is a major reason for the high rates of primary organic production typical of shallow seas
  - The sediment can also represent a source of iron in a bio-available (reduced) form

Shelf-sea fronts

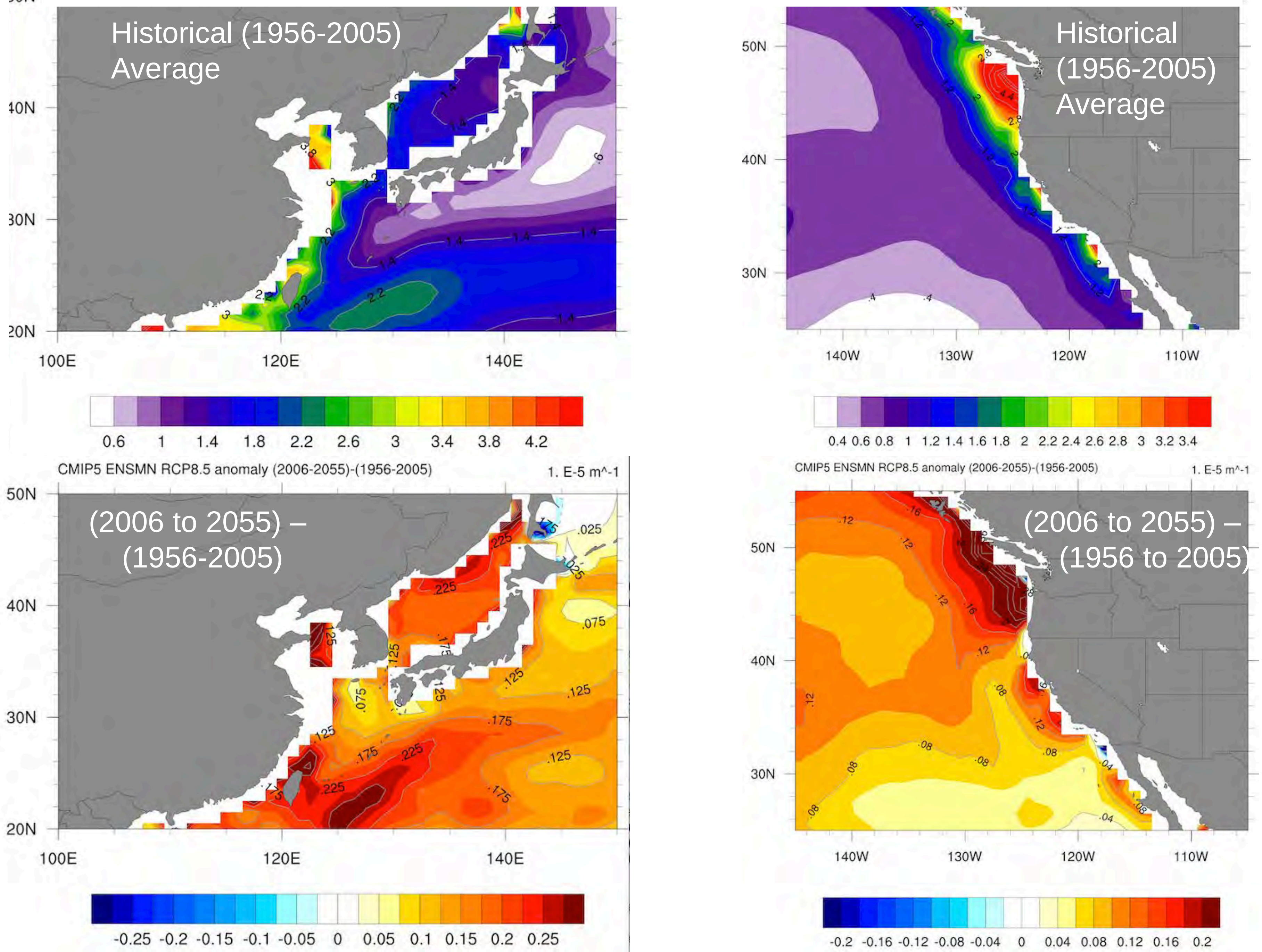


- Over shallow continental shelf regions, tidal mixing may homogenize the water from surface to bottom
- This results in surface water of greater density and bottom water of lesser density over the shelf compared with offshore waters at the same depths
  - Onshore flows in surface and bottom waters, ***offshore flow at mid-depths***

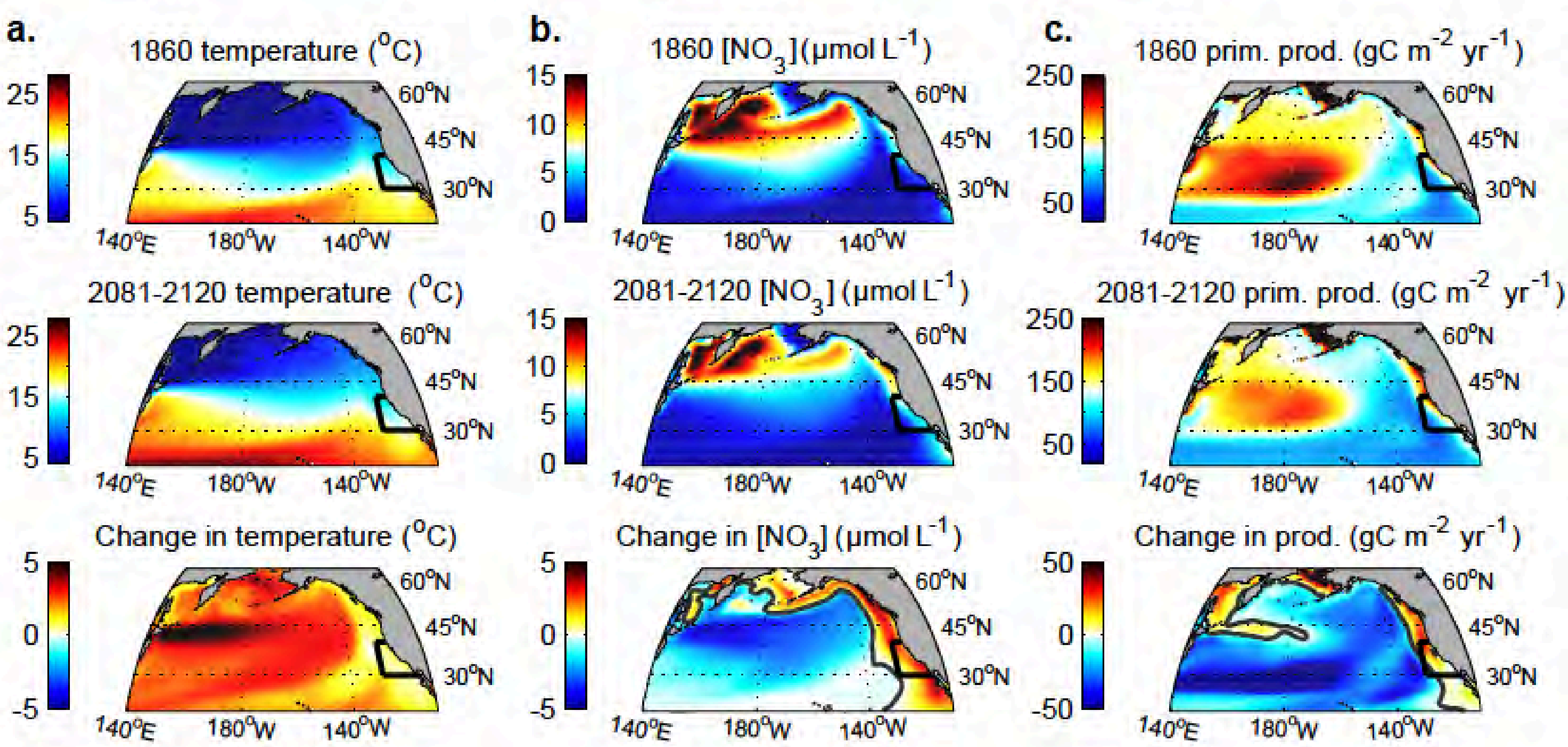
Projected Change in SST (Ensemble Model Average)



Ensemble Model Average Change in 0-50 meter static stability (AMJ)

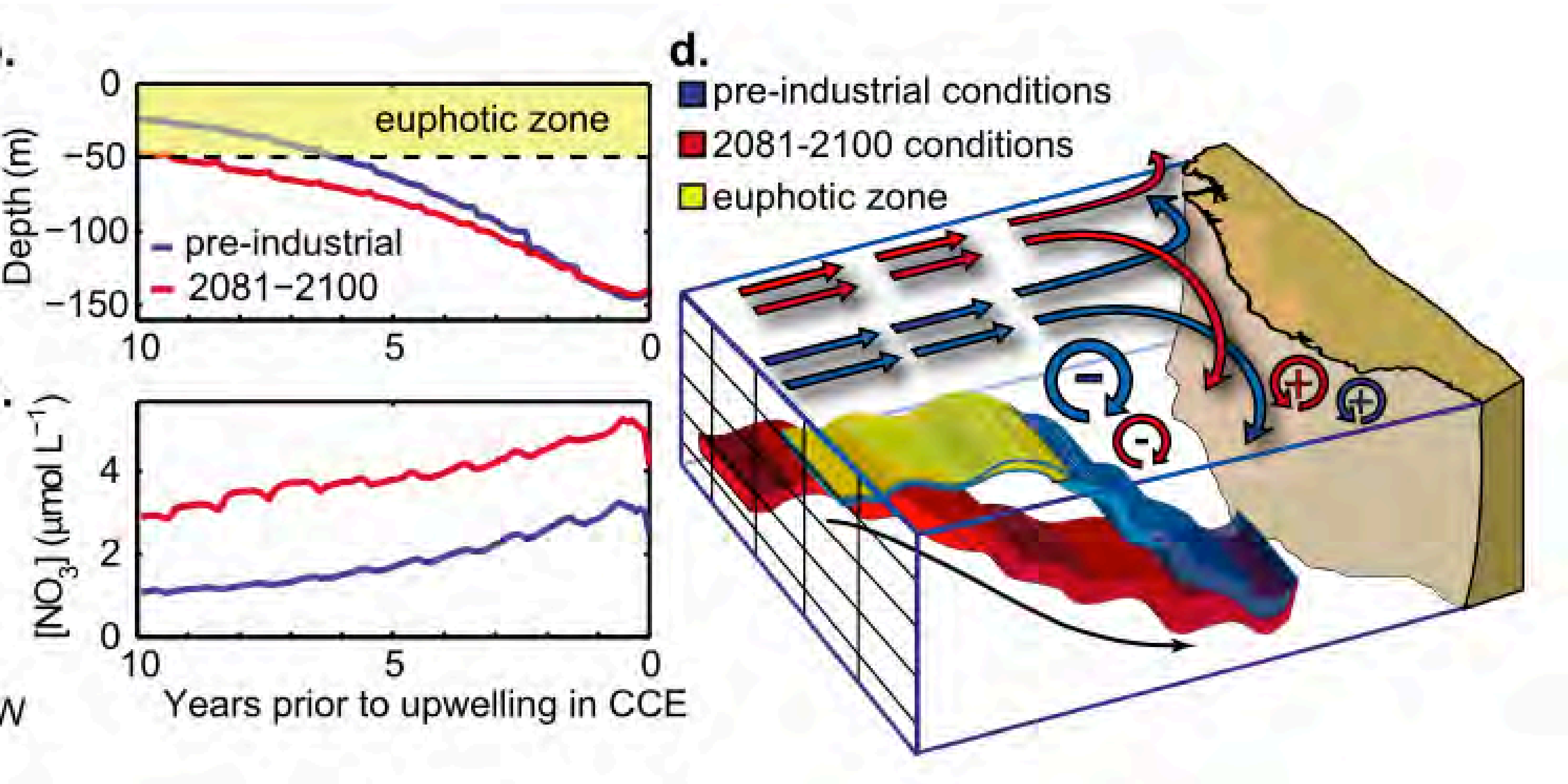


Changes in Nutrient Concentrations and Primary Productivity in the North Pacific



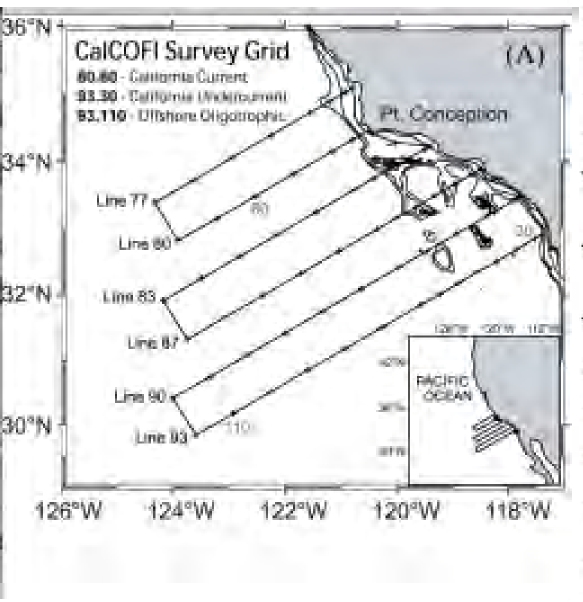
Rykaczewski and Dunne (2010)

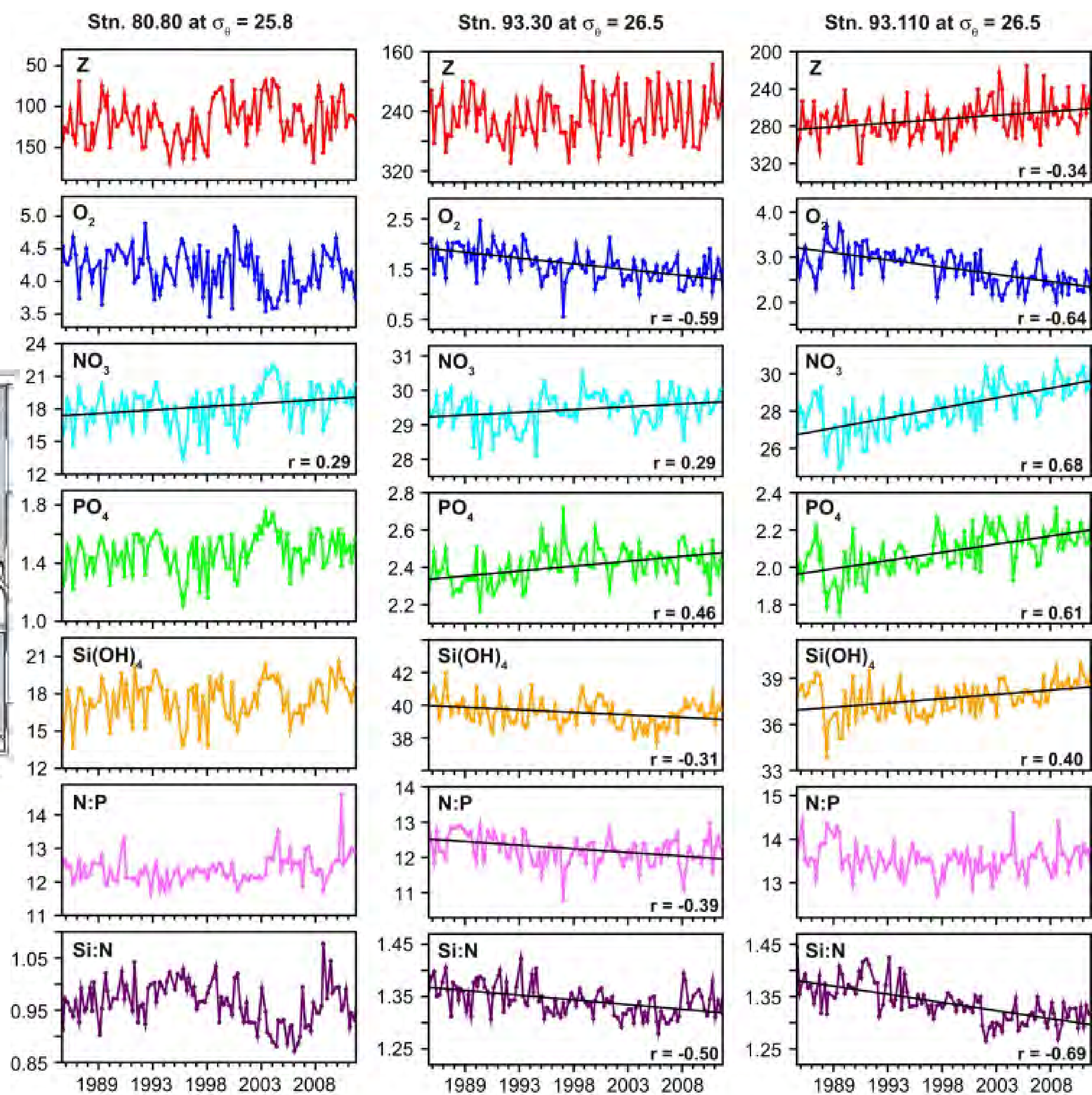
Rykaczewski and Dunne (2010)



Less ventilation of waters below the mixed layer in the North Pacific leading to higher nutrient and lower oxygen concentrations along US West Coast

Changes in Source Waters of the Southern California Bight Based on CalCOFI Time Series





Bograd et al. (2015)

North Pacific: West vs. East Shelf Regions

	West	**East**
Shelf Width	Mostly broad	Mostly narrow
Tidal Mixing	Strong	Moderate
Winter Stratification	Well-mixed	Weak
Summer Stratification	High	Moderate
Source Surface H_2O	Mostly from south	From west
Source Deep H_2O	Kuroshio (winter)	Coastal upwelling (summer)
Si:Nitrate Ratio	High	Moderate
Iron Concentration	High (sediments & dust)	Low (sediments)
Future Stratification	Higher	Higher
Future Primary Prod.	Probably lower	Maybe higher
Future Chemistry	???	Lower pH, O_2