Climate impacts on upwelling and the planktonic prey of anchovy and sardine in eastern boundary currents

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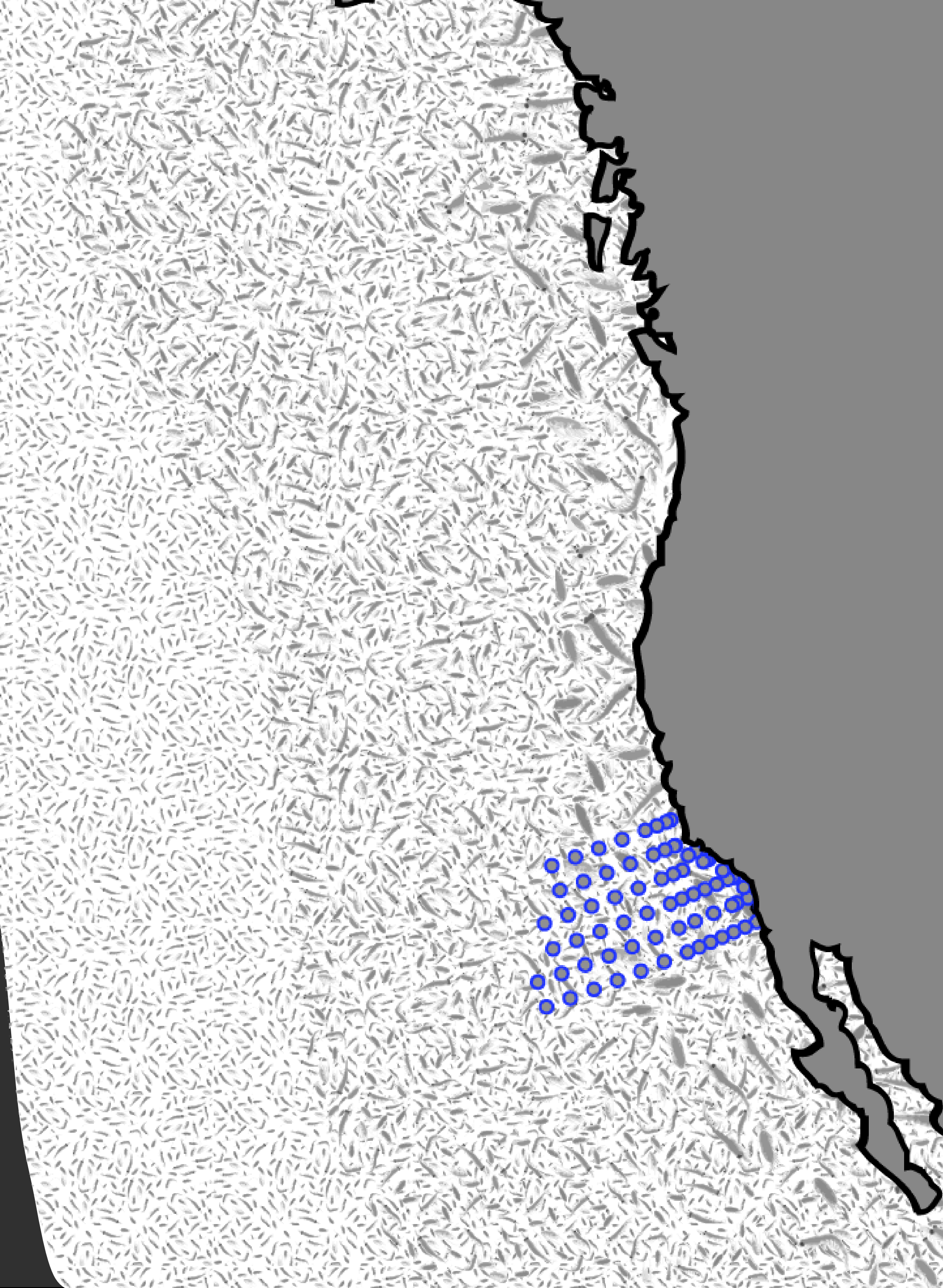
NSF NOAA NEREUS PREDICTING THE FUTURE OCEAN ネレウス 未来の海を考える Farallon Institute Advanced Ecosystem Research

John Dunne, Bill Sydeman, Marisol García-Reyes, Bryan Black, Steven Bograd, and David Checkley



First, two observations so far

1) We have a been discussing sets of clues gathered from different locations and by variety of methods, *each with its caveats*.

    But in addition to these accumulating clues, we have accruing insight from colleagues. Confronting each other with questions and challenging old hypotheses is critical.

2) I have come to recognize that we should cease the search for “one driver.” Rather, we should accept the existence of multiple mechanisms.

    The next step forward might be to seek to understand the factors that mediate alternations between these different controlling processes.`

Outline, as a series of four questions

1) Why might size structure of the plankton community be a critical factor in resolving responses of anchovy and sardine to climate variability and change?

2) Why might the rate of nutrient supply influence size structure of the plankton community?

3) What climate processes influence rates of nutrient supply in upwelling systems?

4) How might these processes change in response to anthropogenic global warming?

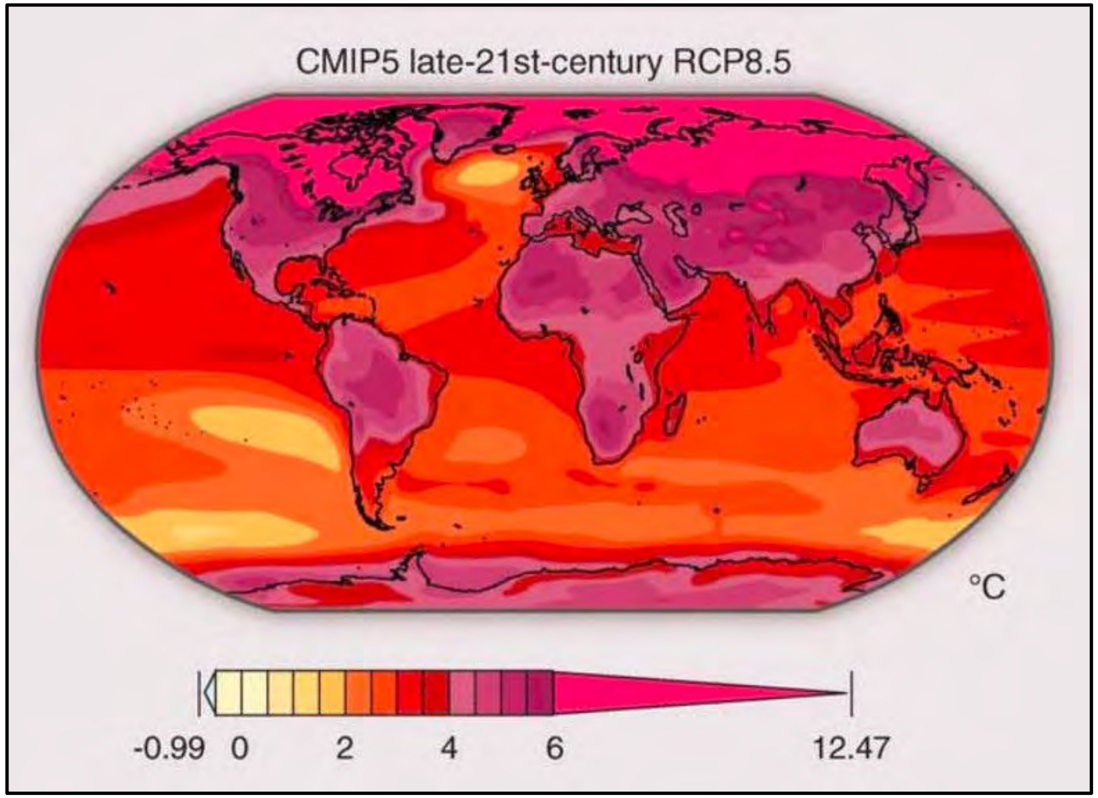
Long-term goal: improve understanding of variability in upwelling ecosystems

Populations of anchovy and sardine inhabit each of the four major eastern boundary currents: Humboldt, Benguela, California, and Canary Currents.

Climate variability is hypothesized to be the driver of dramatic population fluctuations.

Question:

How will anchovy and sardine populations respond to anthropogenic climate changes?



Diffenbaugh and Field (2014)

Clues can be drawn from recent observations

Observations over the last century offer clues about what processes we should consider.

1) Periods of high abundance have been associated with ocean temperature anomalies.

cool periods have favored anchovy
warm periods have favored sardine
(e.g., Lluch-Belda et al. 1991; Alheit and Niquen 2004; van der Lingen et al. 2006; Lindegren et al. 2013)

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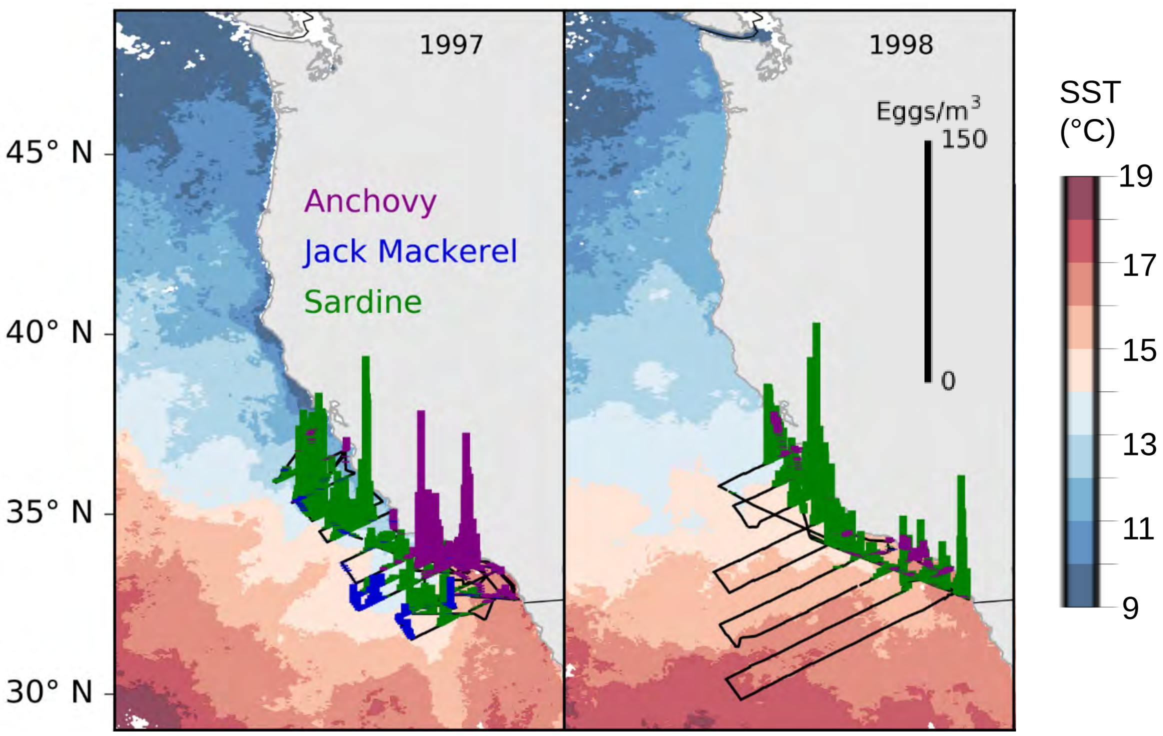

CalCOFI Program; NOAA SWFSC

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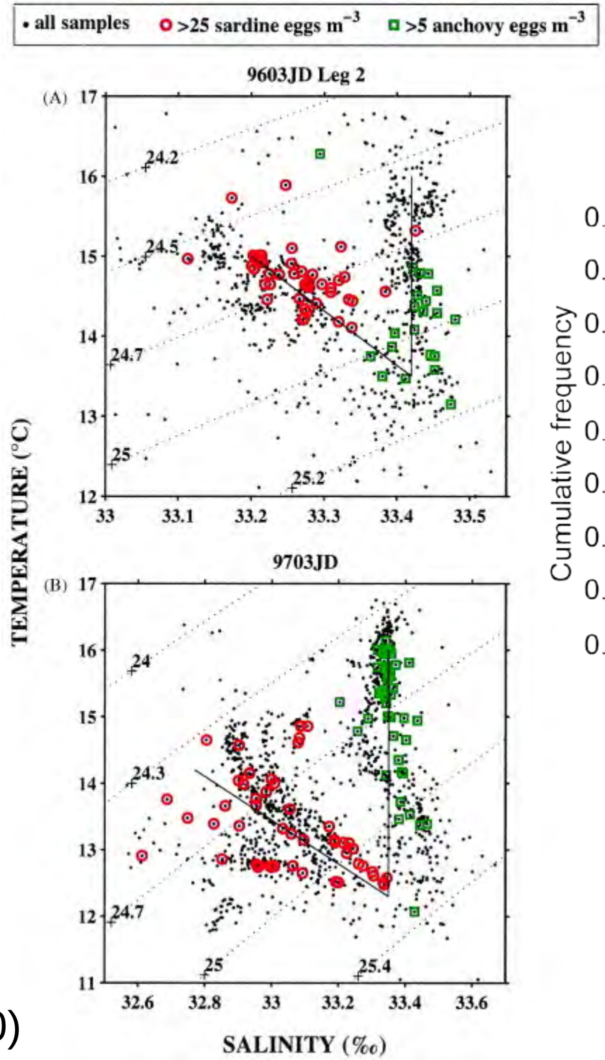
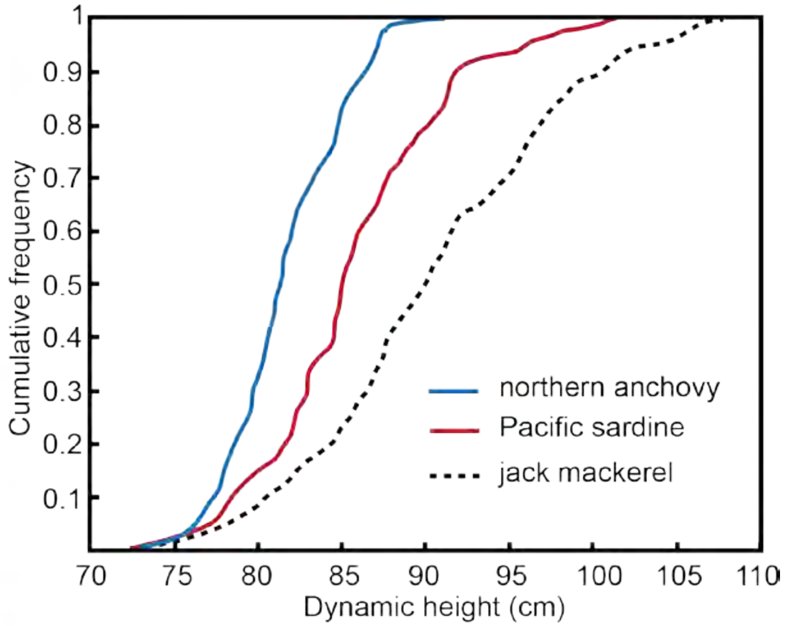


Checkley et al. (2000)



Asch and Checkley (2013)

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1) Periods of high abundance have been associated with ocean temperature anomalies.
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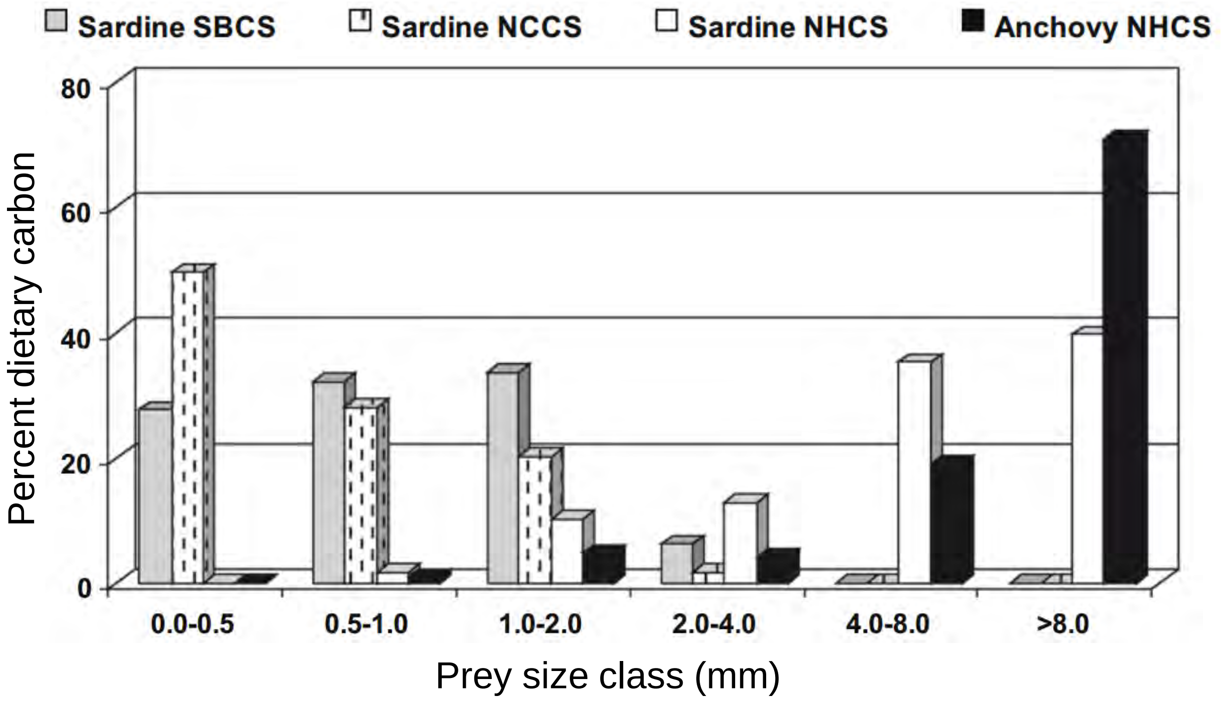
3) Branchial baskets, feeding behaviors, dynamic energy budgets, and diets indicate adaptation for consuming differing planktonic prey.



Espinoza et al. (2009)

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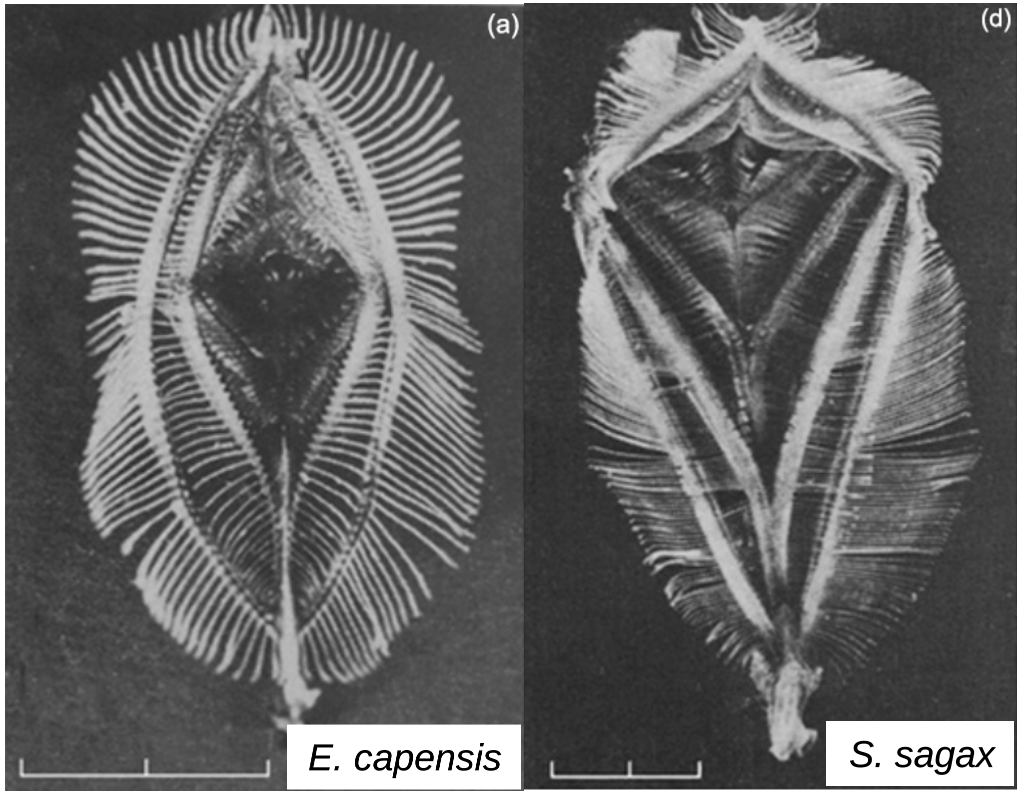

King and Macleod (1976)

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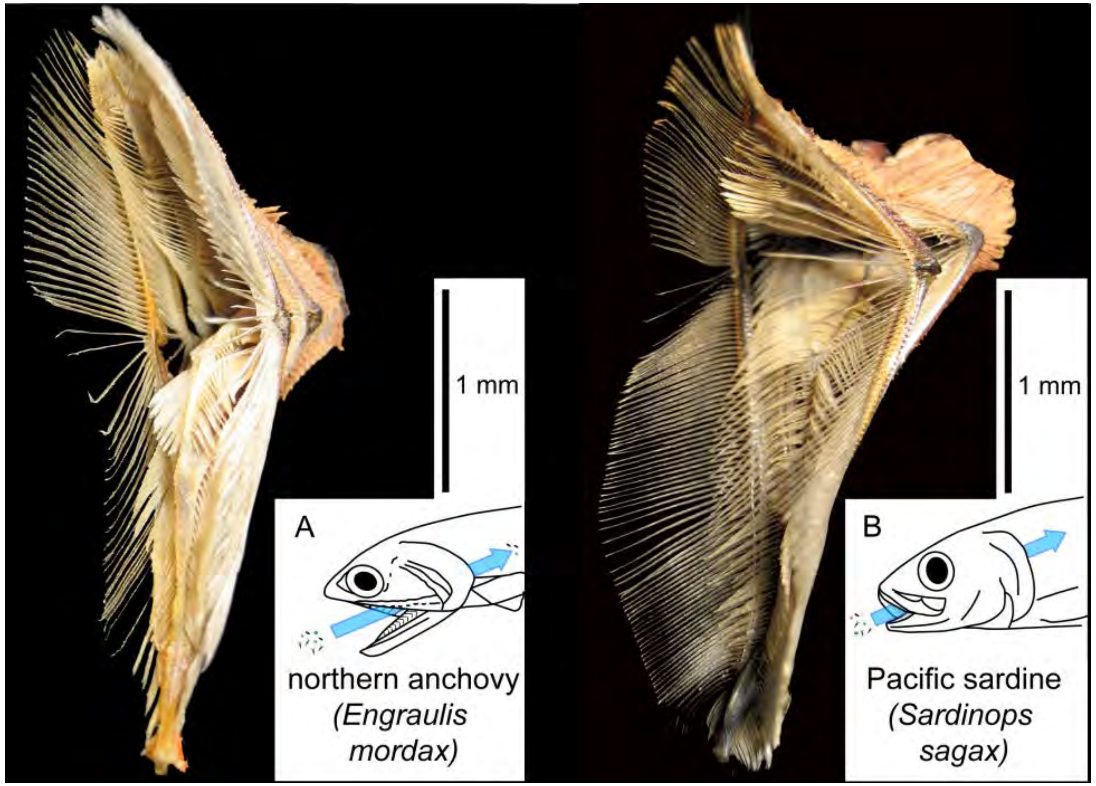

Rykaczewski (2009)

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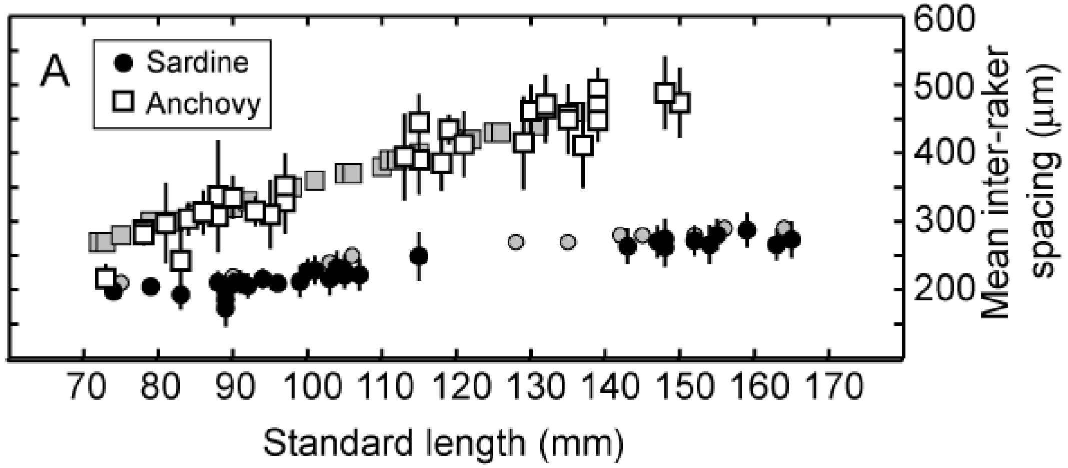


Rykaczewski (2009)

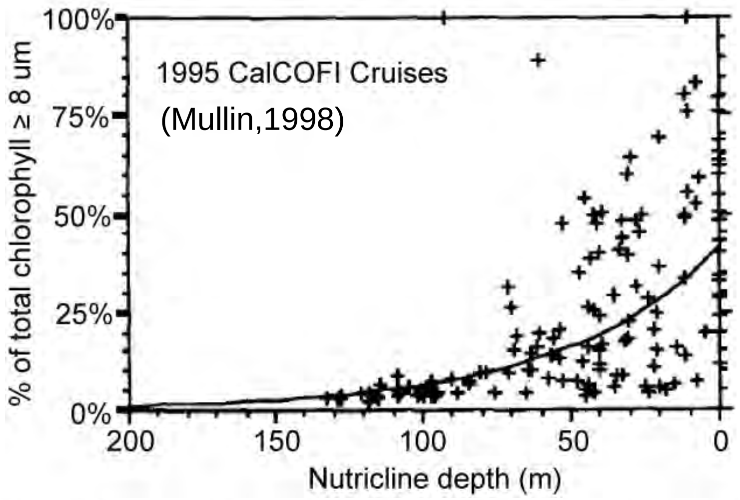
Proposal:

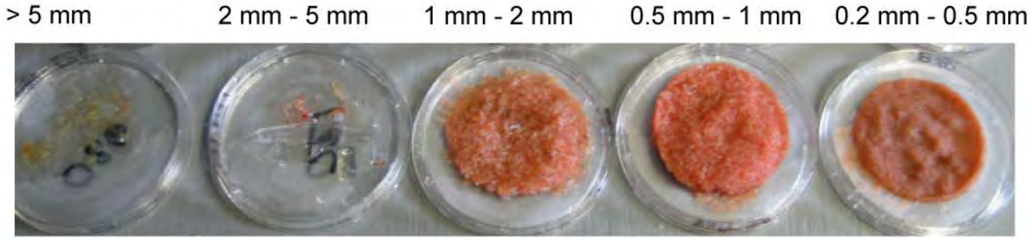
Understanding how climate change will affect the ***size structure of the plankton community*** will help us resolve the future of anchovy and sardine populations.

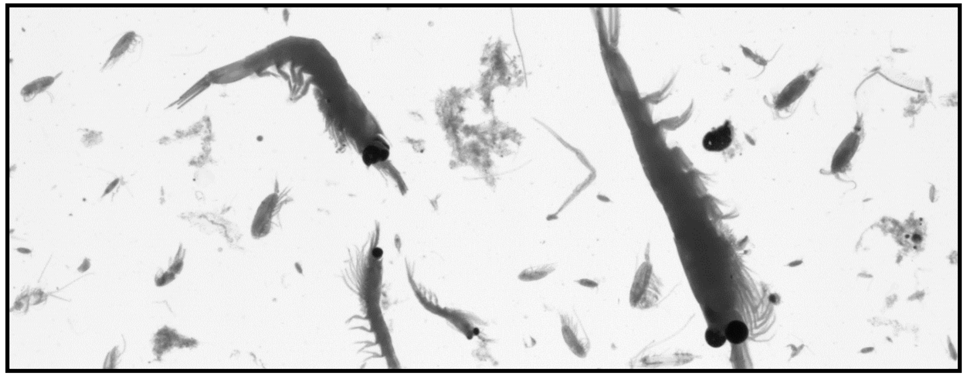
Rates of nutrient supply influence plankton size structure

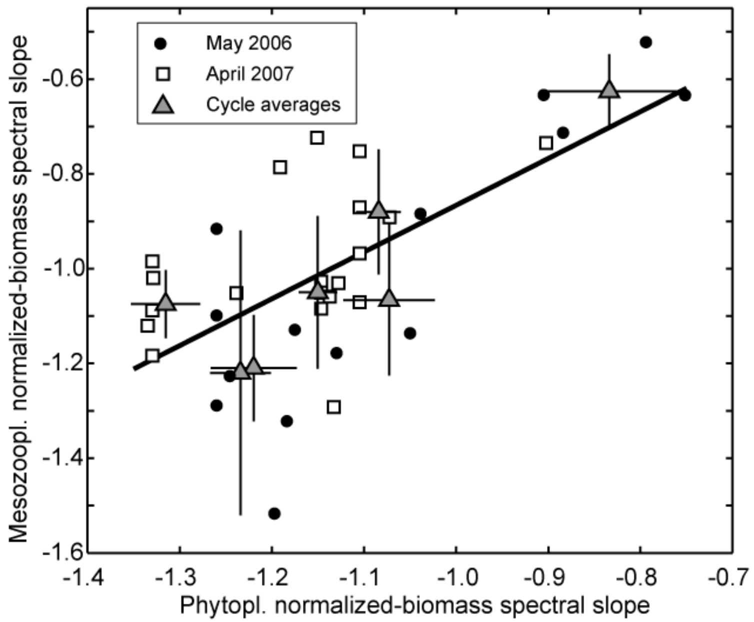
Hypothesis

Size structure of the prey field for anchovy and sardine is influenced by the availability of nutrients.









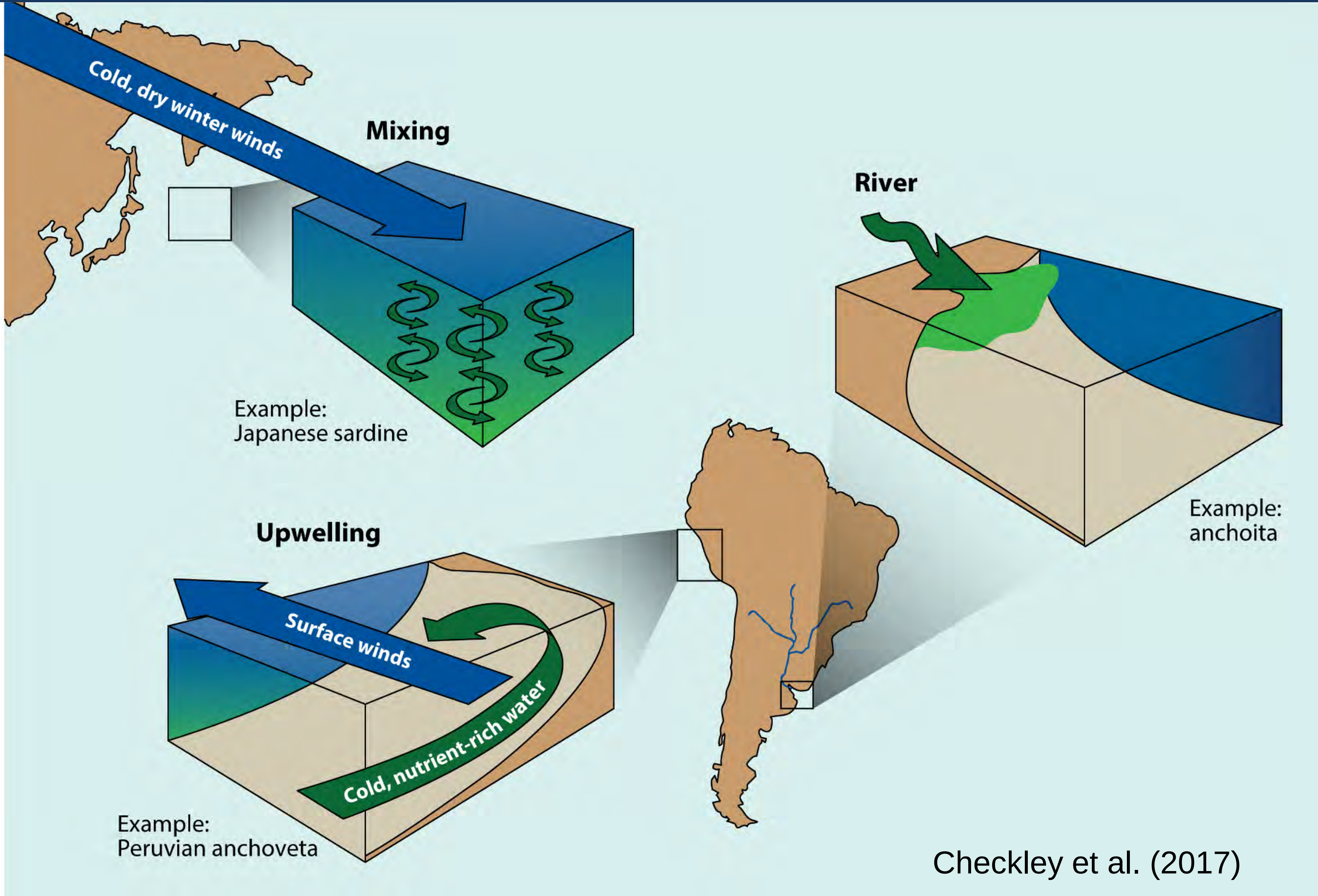
Rykaczewski (2009)

Drivers of nutrient supply to ecosystems supporting anchovy and sardine

<u>Key Question</u>:

What drives nutrient rates of nutrient supply in these systems?

Specifically, how will nutrient supply to upwelling systems change in response to future climate?



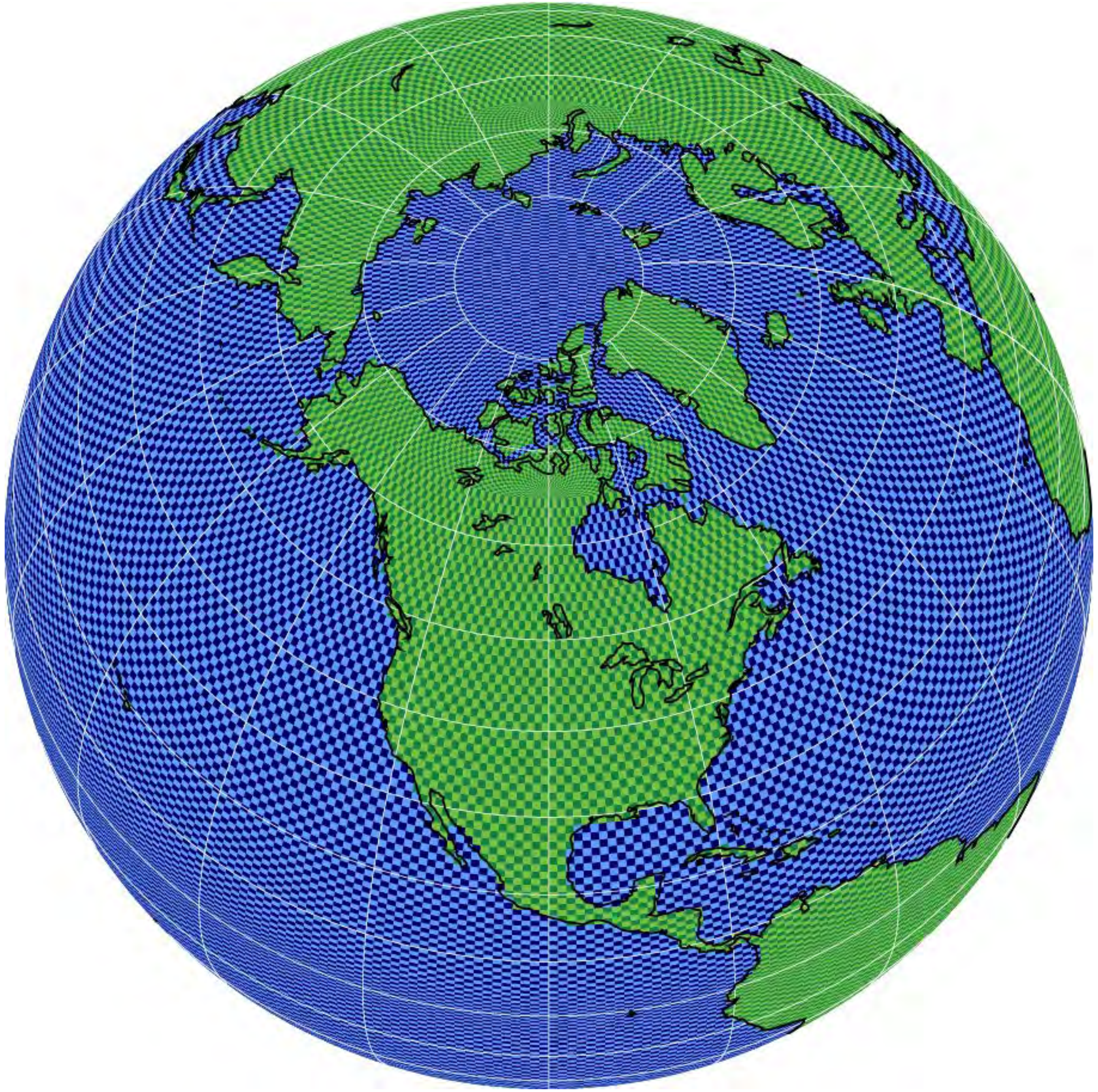
Checkley et al. (2017)

IPCC-style models can offer some insight to future conditions

Changes in response to long-term emissions of greenhouse gases can be modeled mathematically as a general circulation model (GCM).

Including simple biogeochemical components makes this an earth-system model (ESM).

The California Current here serves as an initial area of focus.



Relevant hypotheses describing future nutrient supply

What physical processes can conceivably alter the supply of macronutrients to upwelling ecosystems in response to anthropogenic global warming?

1) The magnitude of upwelling favorable winds along the coast. Bakun (1990)

Drivers of nutrient supply to ecosystems supporting anchovy and sardine

The following plots will have four panels.

Pre-industrial mean
(1860, 20-yr run)

PAST

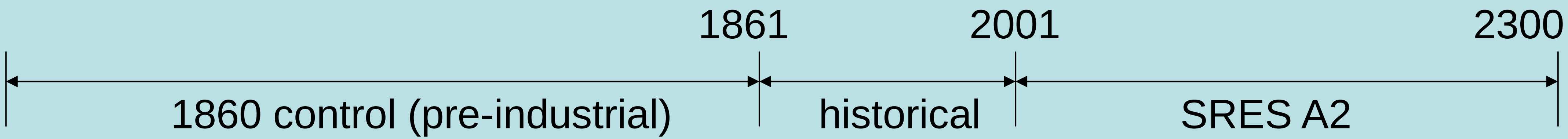
Fossil-fuel intensive mean
(SRES A2 2081-2100)

FUTURE

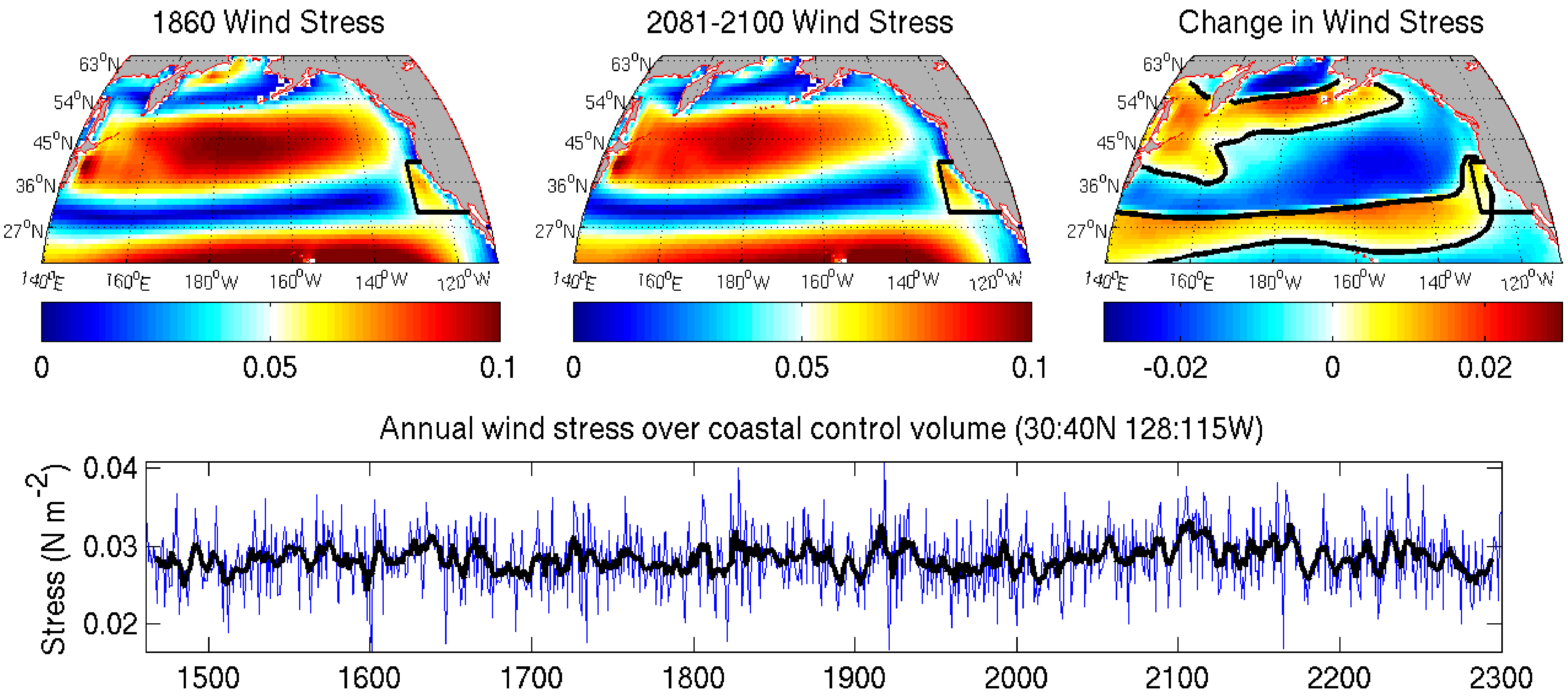
Difference
(Future – pre-industrial)

DIFFERENCE

Time series for the CCE (128^{o}W to coast, 30^{o}N to 40^{o}N)



Changes in wind stress



The magnitude of alongshore winds at the coast does not change significantly.

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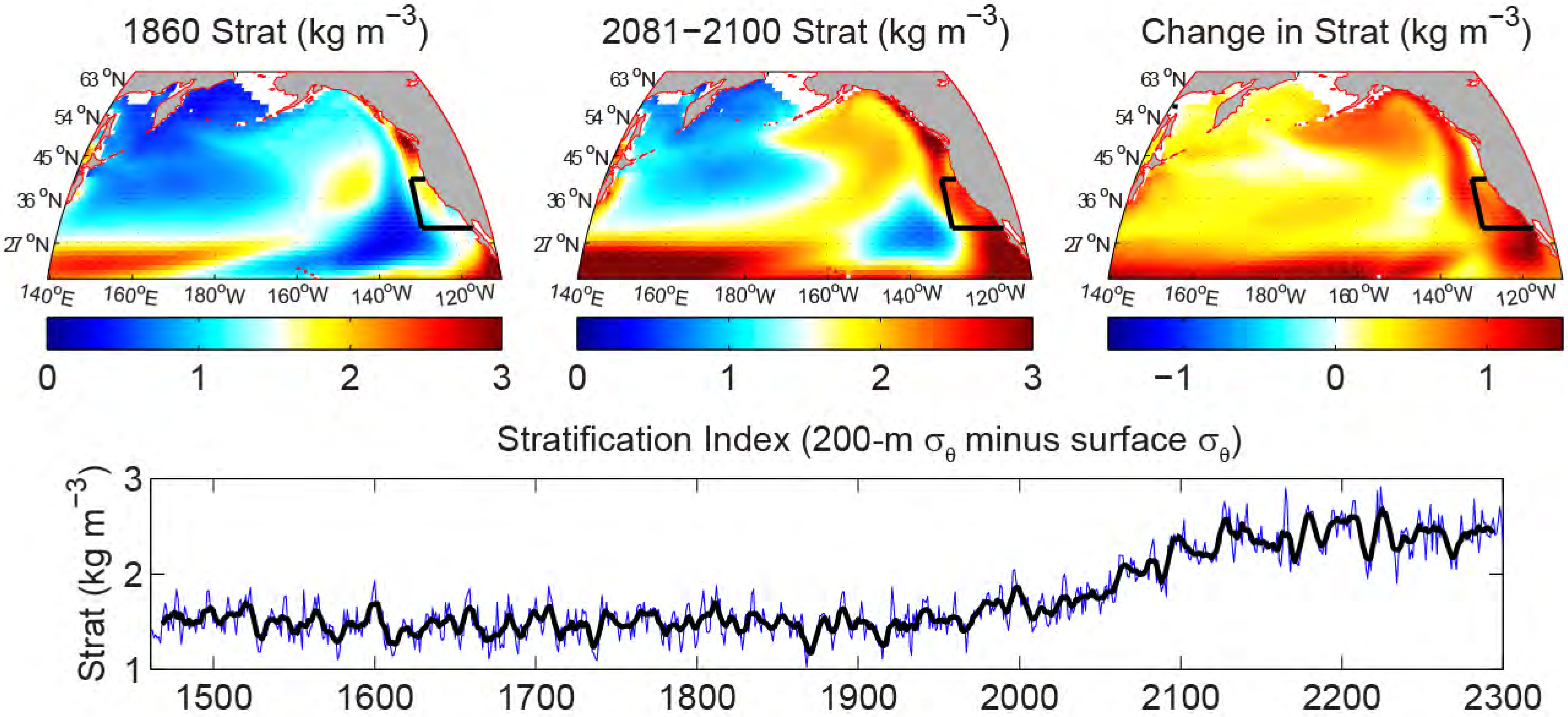
What physical processes can conceivably alter the supply of macronutrients to upwelling ecosystems in response to anthropogenic global warming?

1) ~~The magnitude of upwelling favorable winds along the coast.~~ — Bakun (1990)

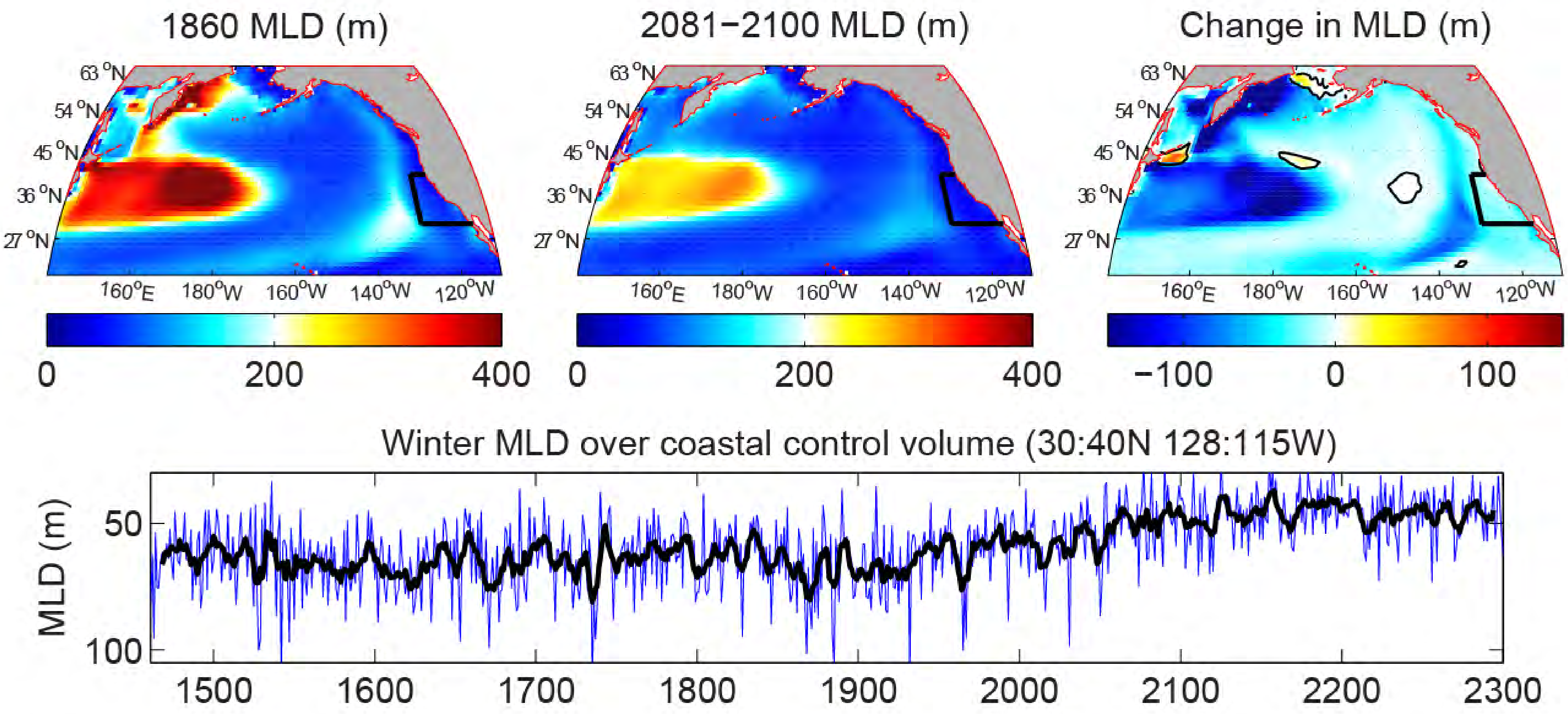
2) Stratification of the water column that might alter the depth from which upwelling waters are drawn. — Huyer (1976), Roemmich and McGowan (1995), Palacios *et al.* (2004), Lentz and Chapman (2004)

Stratification increases, as expected



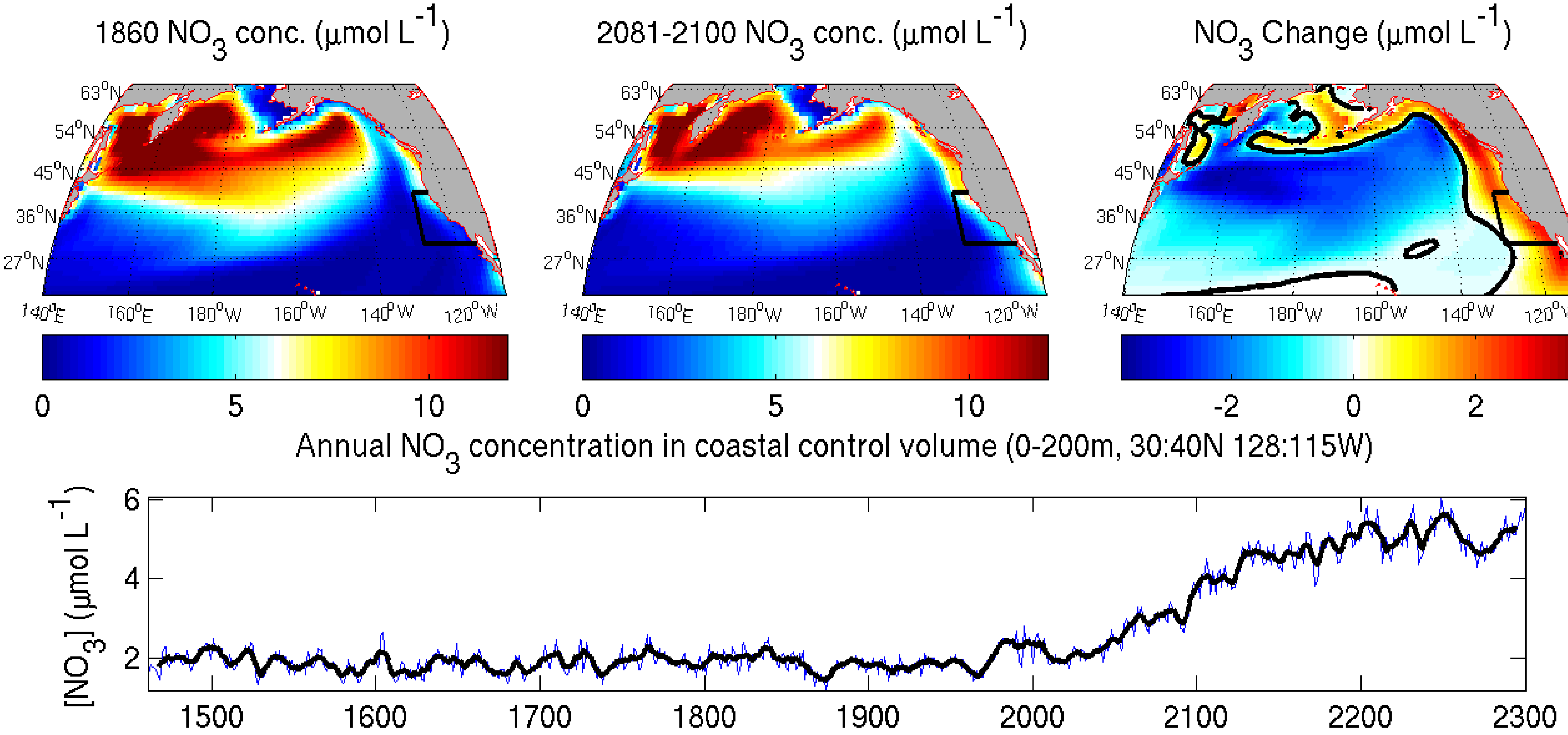
Density stratification increases substantially.

Mixed layer depth shoals across the basin



Mixed-layer depth shoals. With this combination of processes, we might expect reduced nutrient supply to the upwelling region.

Surface-layer NO_3 increases despite stratification and winds



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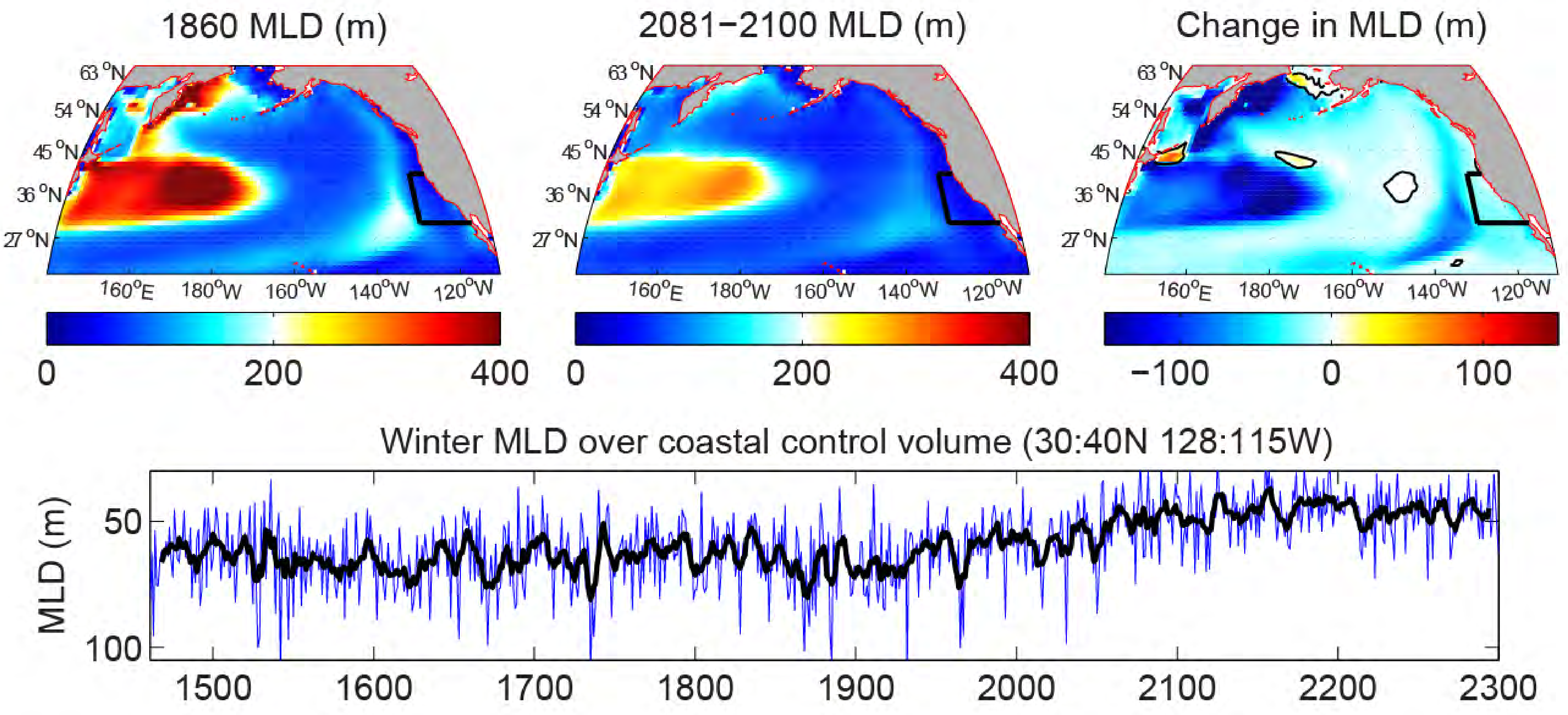
3) Changes in the nutrient concentrations in source waters.
   A. Change in concentration within a source-water mass
   B. Change in the relative contributions of different water masses to the region

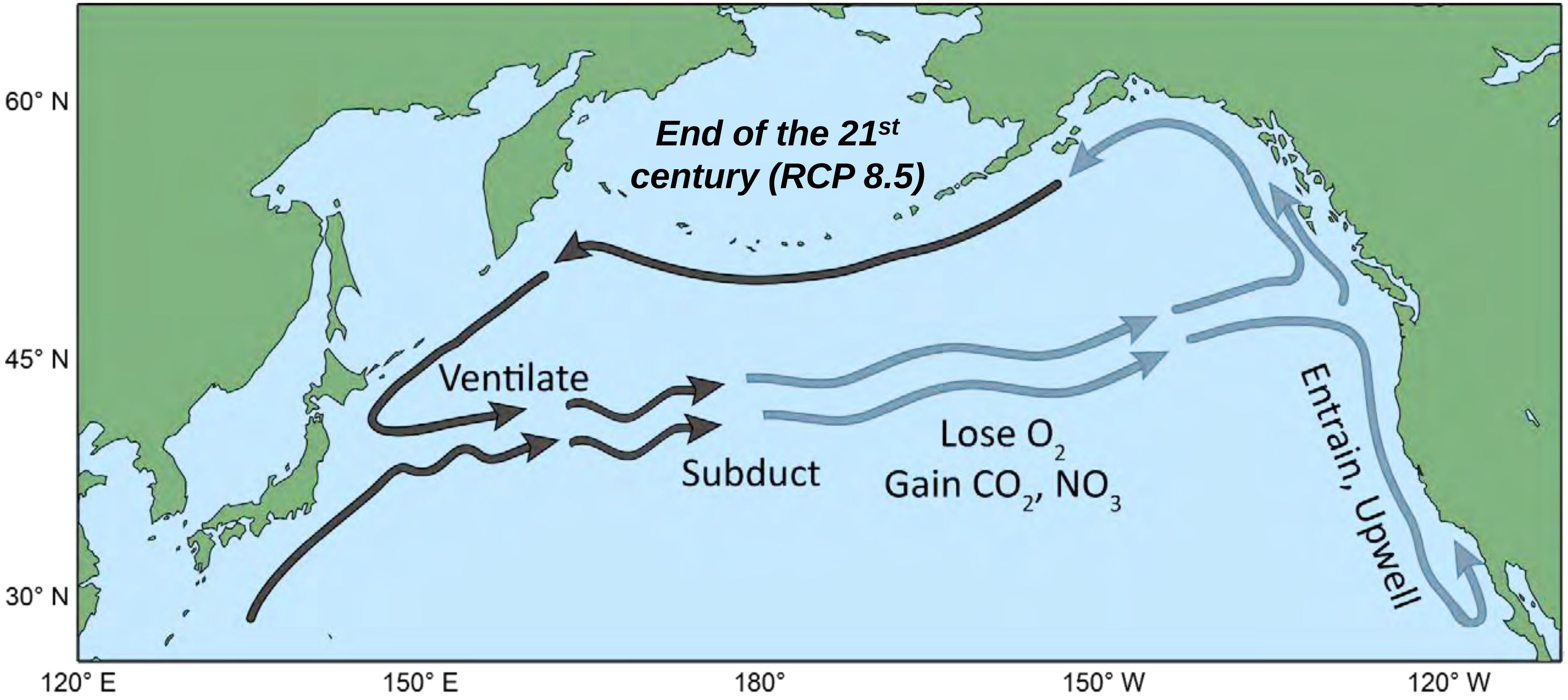
Rykaczewski and Dunne (2010), Bograd *et al.* (2015)

Reduced ventilation in the central North Pacific enriches subsurface nutrients



Ventilation plays a dominant role at centennial scales

The dominant process influencing nutrient supply differs between the historical time period (with which we are accustomed) and the 21st century.

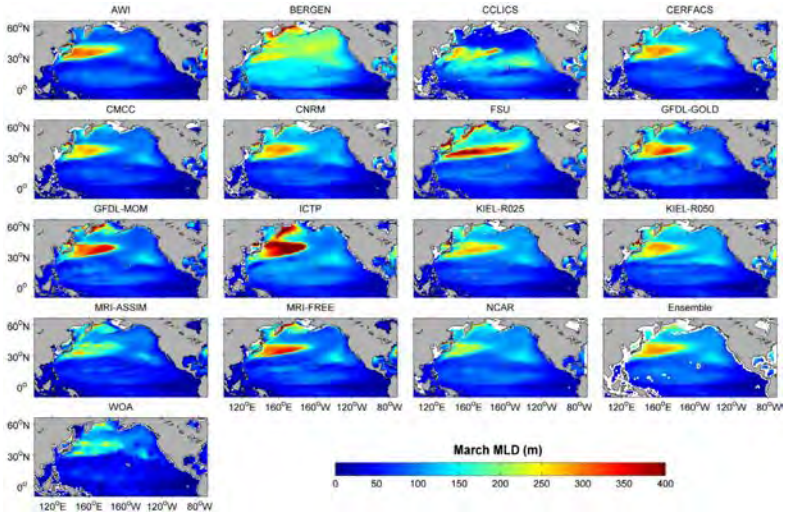


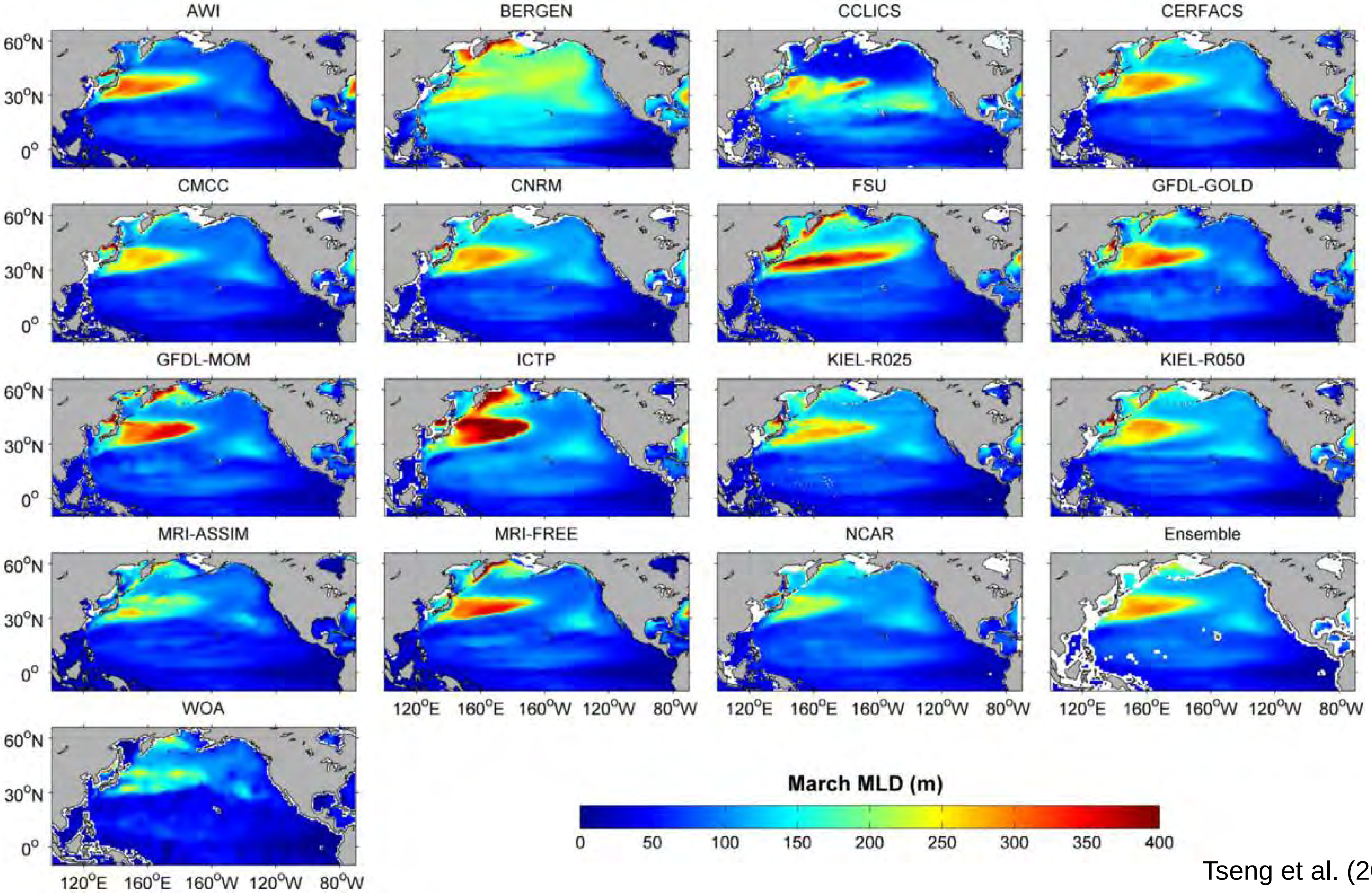
Reduced ventilation in the central and western North Pacific leads to increased accumulation of NO_3 and CO_2 and loss of O_2. This has significant implications for productivity, deoxygenation, and acidification in ecosystems of the eastern North Pacific.

How reliable is this projection of nutrient enrichment of source waters?

This mechanism needs to be explored further.

Ocean models tend to overestimate the deep, wintertime mixing in the western-central Pacific.





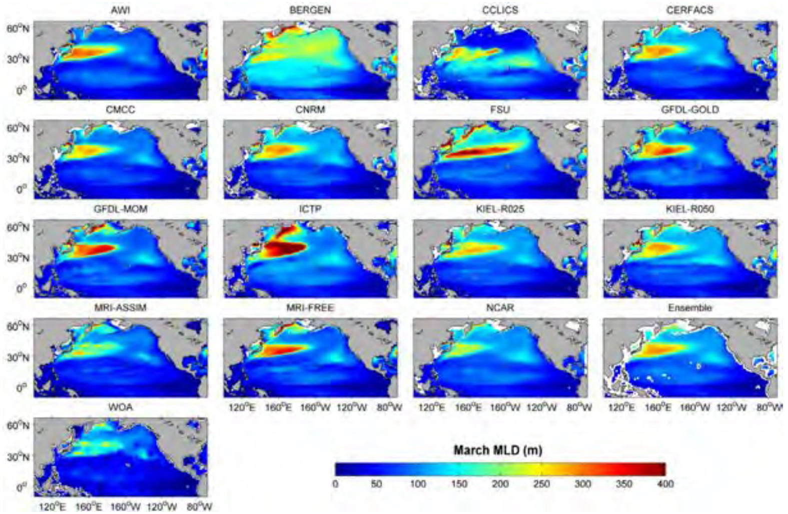
Tseng et al. (2016)

How reliable is this projection of nutrient enrichment of source waters?

This mechanism needs to be explored further.

Ocean models tend to overestimate the deep, wintertime mixing in the western-central Pacific.

But more important than this specific projection is demonstration that the processes controlling key ecosystem conditions changes depending on the scale and persistence of warming.



Interannual-to-decadal variability at regional scales → local wind and stratification

Multidecadal warming over the basin → ocean ventilation and modification of source-water properties

Relevant hypotheses describing future nutrient supply

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    A. Change in concentration within a source-water mass
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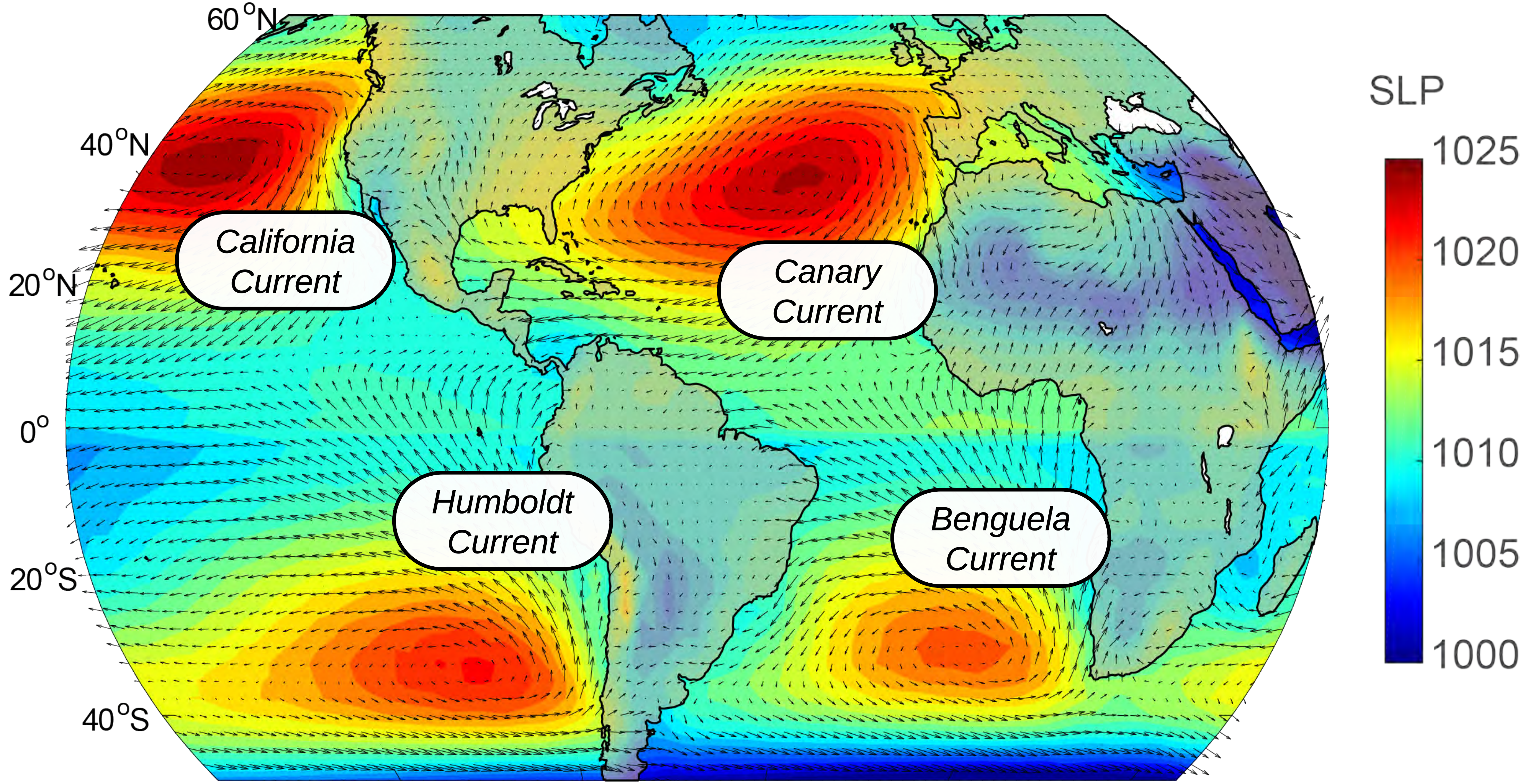
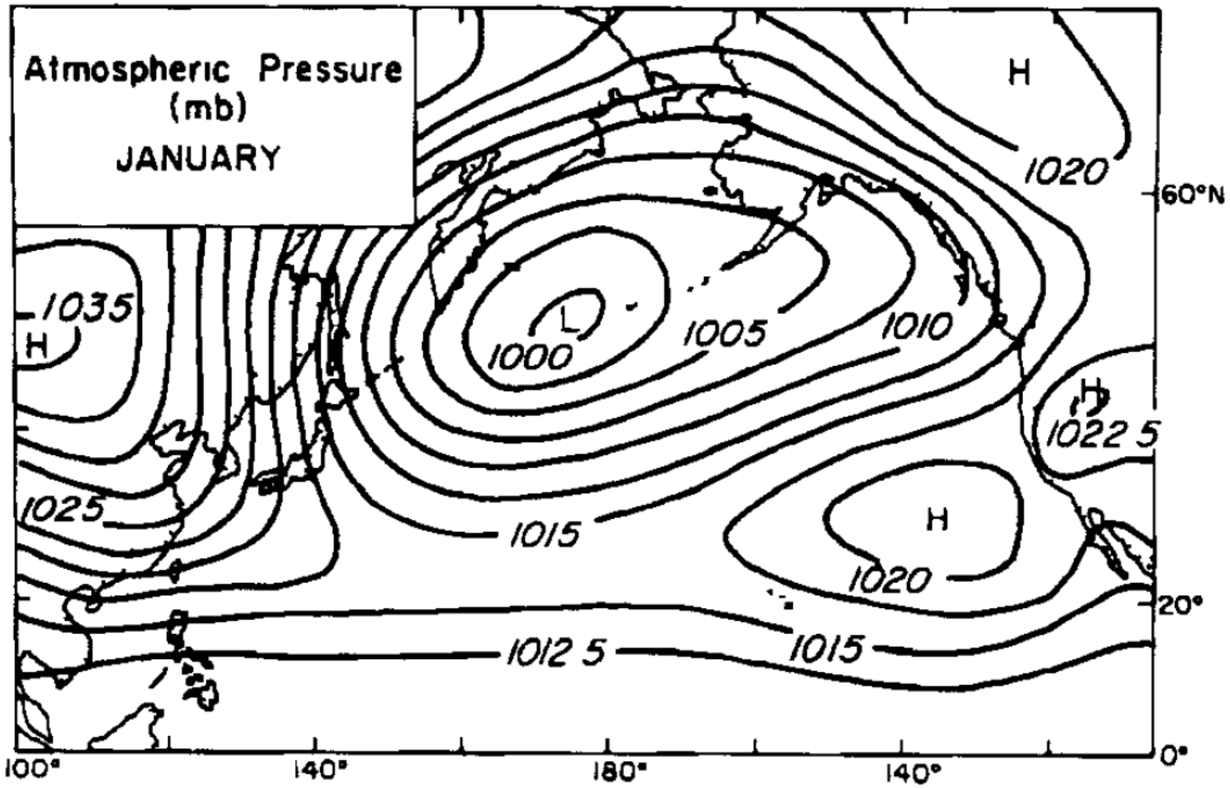
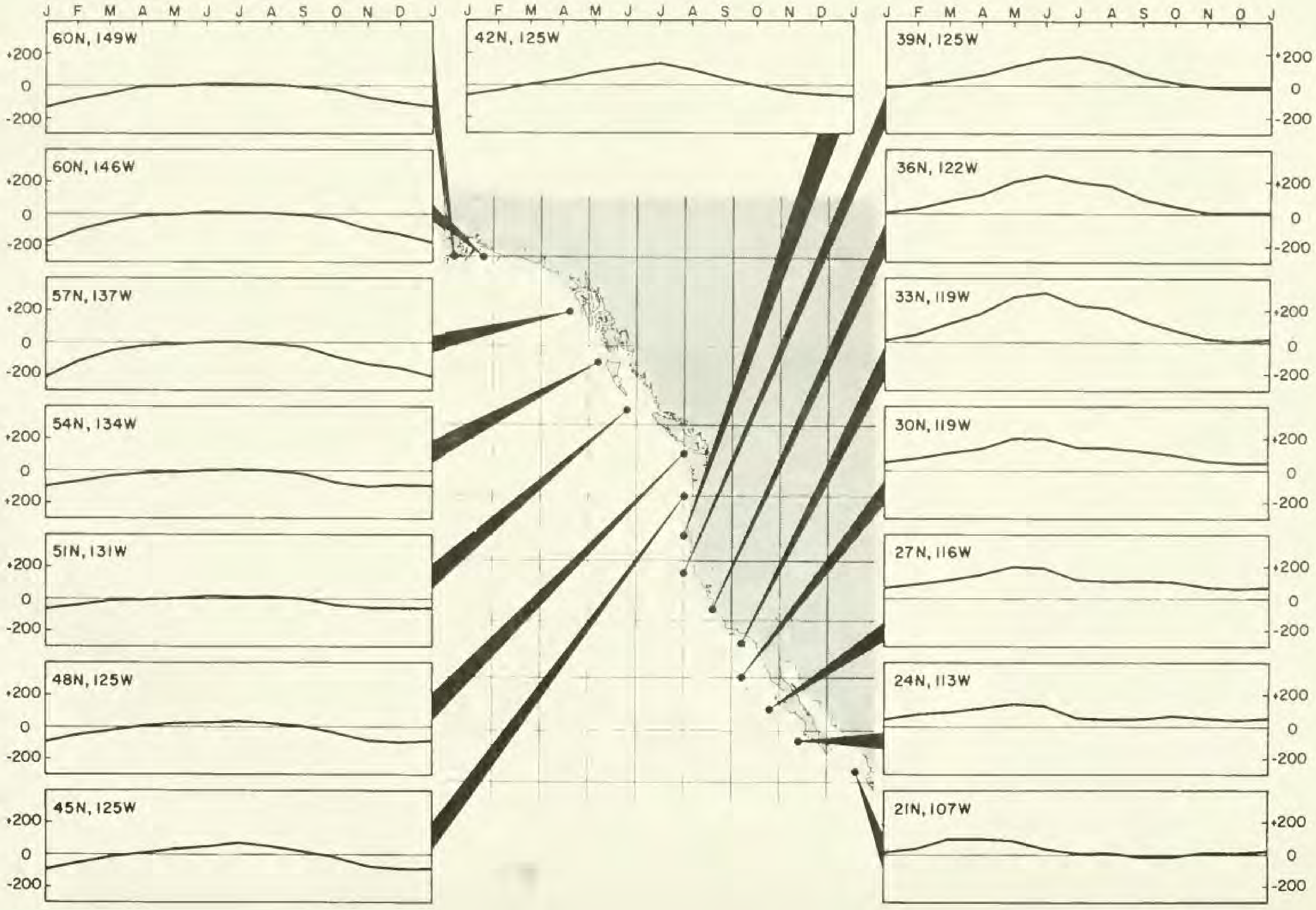
Subtropical eastern boundary current upwelling systems



Alongshore, equatorward winds driven by large-scale pressure fields

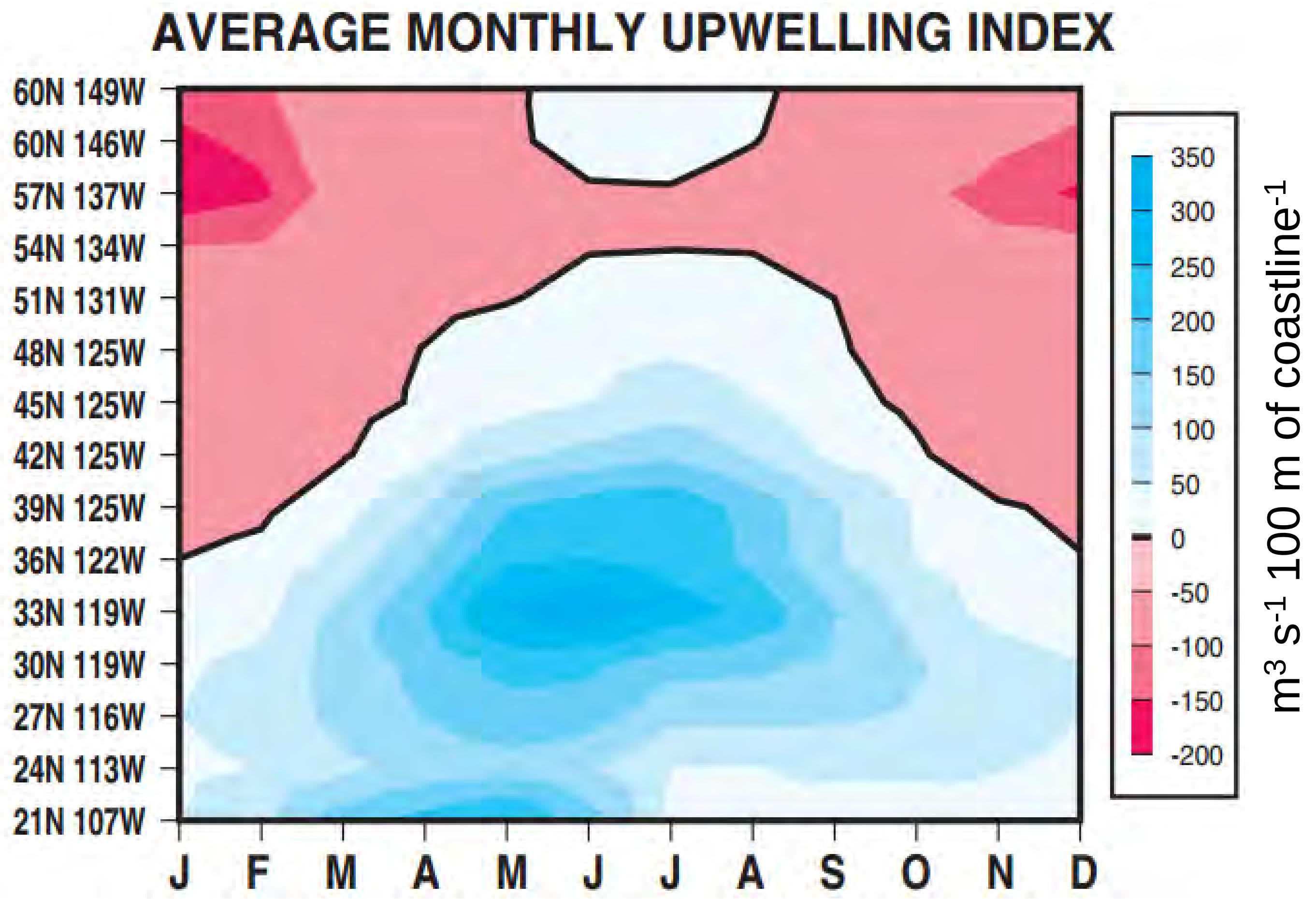


Huyer (1983)


J F M A M J J A S O N D J
60N, 149W
60N, 146W
57N, 137W
54N, 134W
51N, 131W
48N, 125W
45N, 125W
42N, 125W
39N, 125W
36N, 122W
33N, 119W
30N, 119W
27N, 116W
24N, 113W
21N, 107W
+200
0
-200

Bakun (1973)

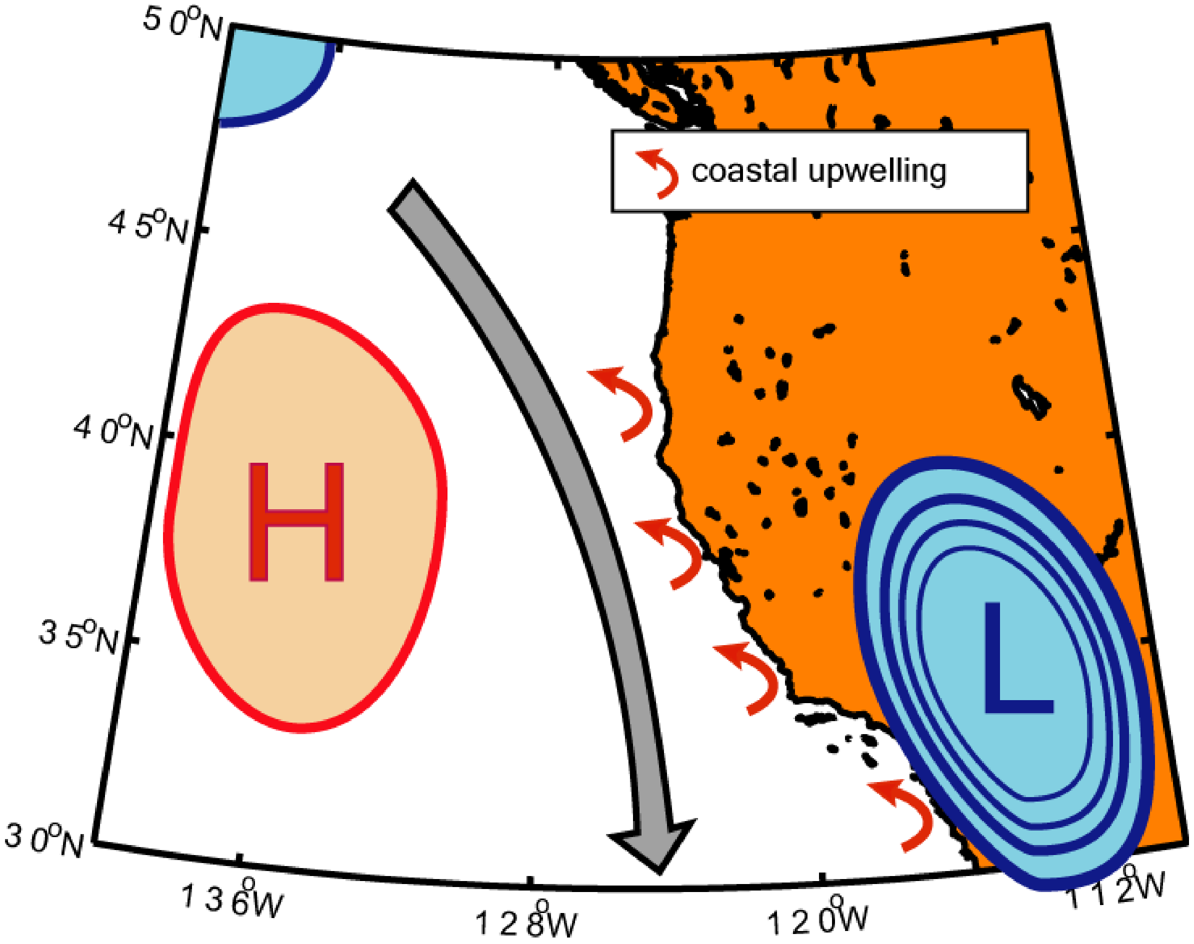
Upwelling winds show clear seasonal and latitudinal patterns



Schwing et al. (1996)

Bakun's proposed mechanism of upwelling intensification

Bakun suggested that global warming would enhance summertime upwelling winds in eastern boundary currents.



Differential heating of the surface air over the landmass relative to the ocean…

…will result in intensification of the thermal Low over the Southwest, generating a stronger pressure gradient.

Issues with reliance on an observational approach

Some issues with observational datasets come to mind:

Although the durations of observational time series have increased, so too has our recognition of decadal scale variability. ***Time series are short***.

The magnitude of historical climate change is rather small relative to what is expected in the future. The “signal” is relatively weak.

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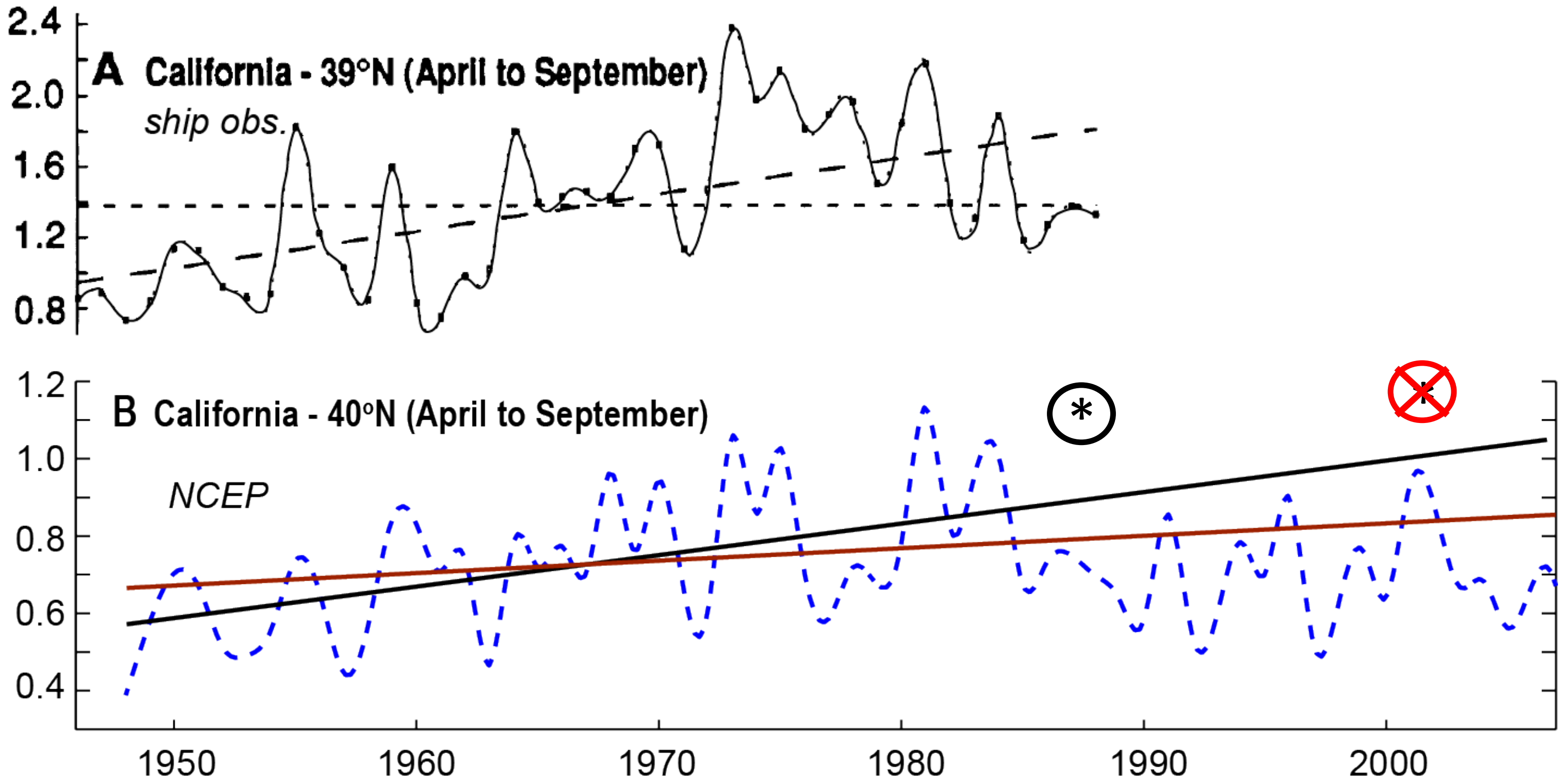
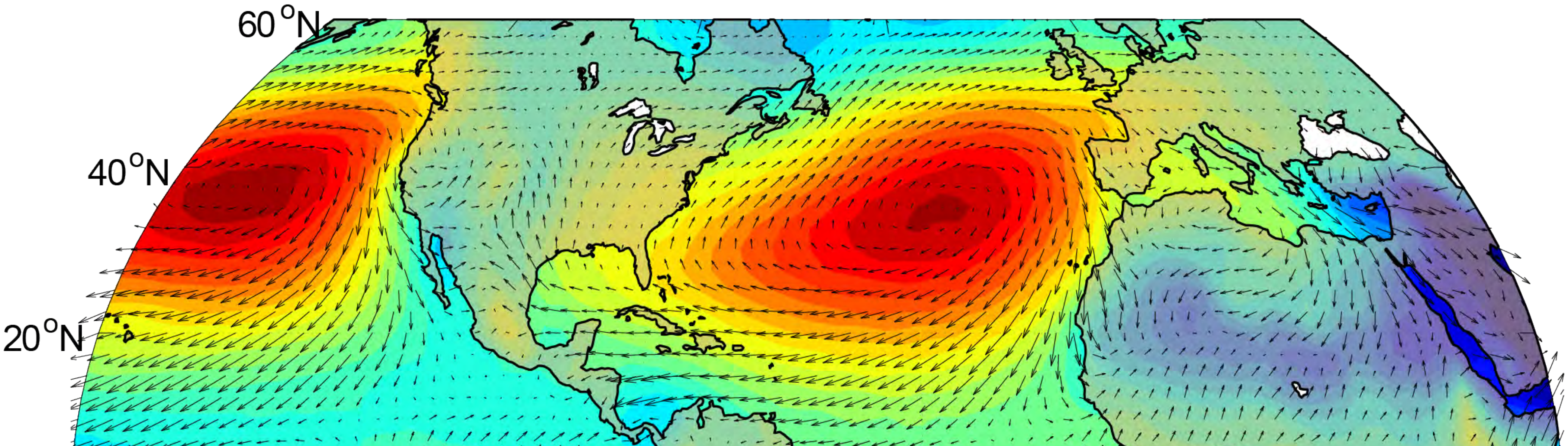


Models can be useful in examining the concept

Atmosphere-ocean coupled climate models (IPCC-style) alleviate some of these issues:

- Not limited by data length or magnitude of historical forcing.
- Not limited by data quality or methodology.
- Offer comprehensive and quantitative results, as well as the ability to test each step (not just the final result).



Steps to explore

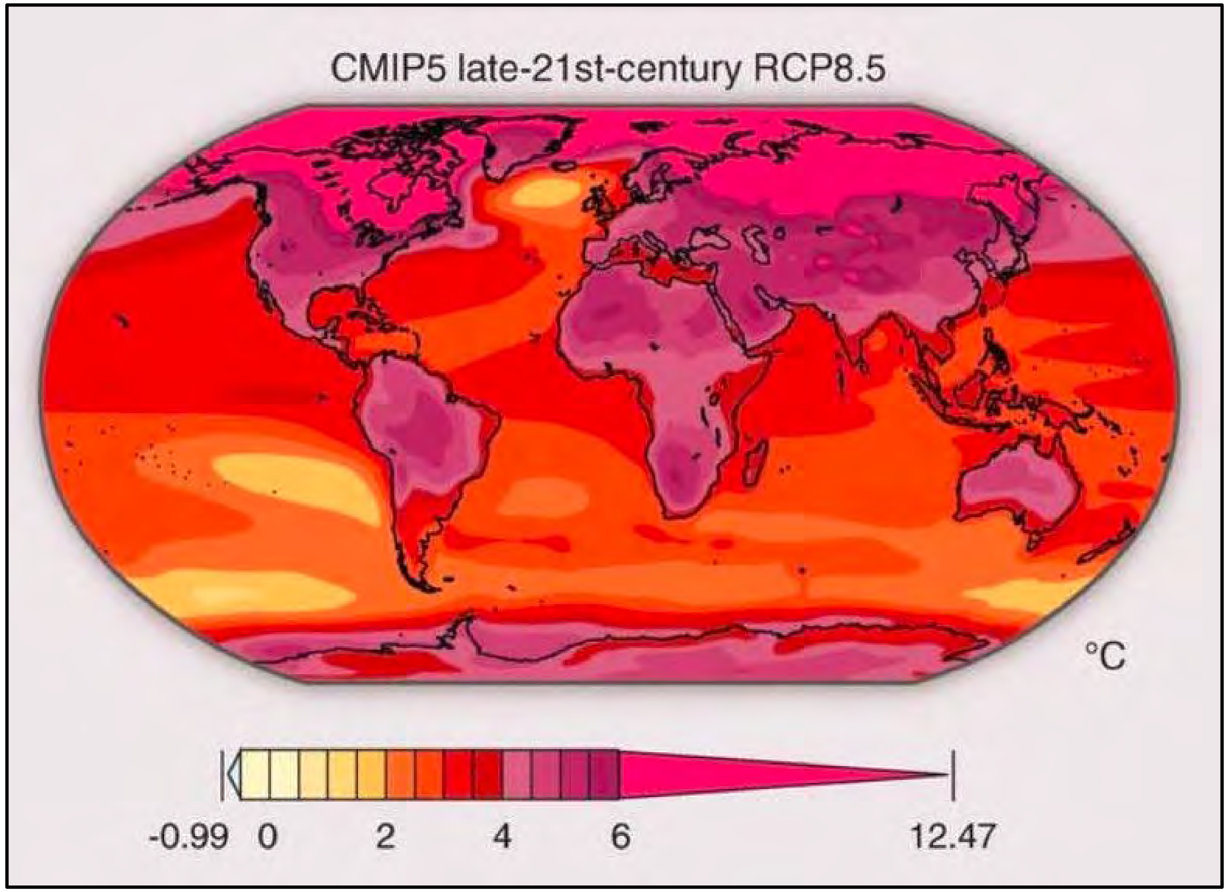
In each of these models, three steps of the hypothesis can be explored:

1. Increases in the land-sea surface temperature gradient?
2. Increased sea-level pressure gradient between the ocean and land?
3. Consistent intensification of upwelling-favorable winds in summer?

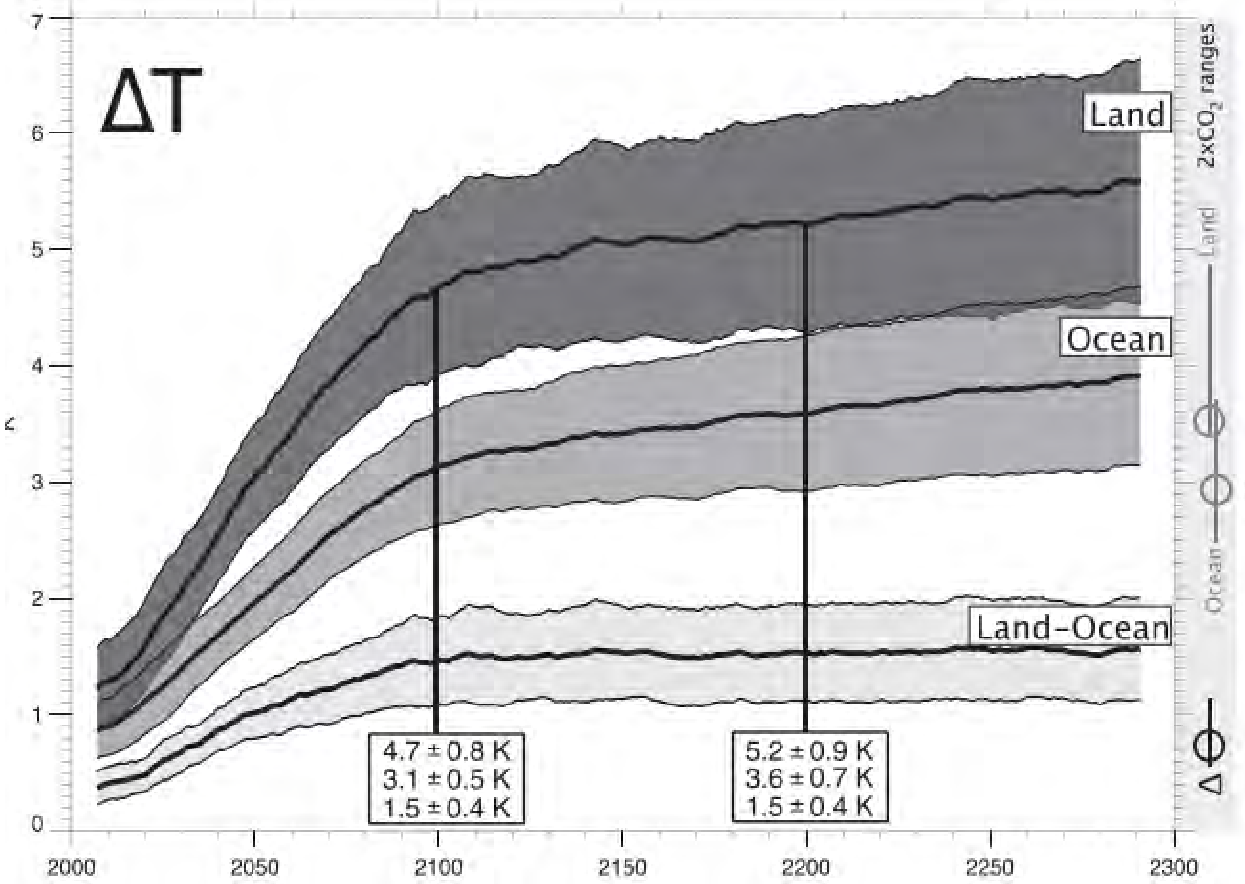
CMIP5 models

Model name	***Atmospheric resolution (km)***	***Oceanic resolution (km)***
1. CanESM2	310 × 262	[illegible]03 × 131
2. CNRM-CM5	156 × 1[illegible]	[illegible] × 93
3. ACCESS1.3	139 [illegible]	[illegible]07 × 93
4. ACCESS1-0	13[illegible]	[illegible]07 × 93
5. CSIRO-Mk3-6-0	207 [illegible]	104 × 174
6. inmcm4	167 × 1[illegible]6	68 × 117
7. IPSL-CM5A-LR	211 × 348	182 × 184
8. IPSL-CM5A-MR	141 × 233	182 × 184
9. IPSL-CM5B-LR	211 × 348	182 × 184
10. MIROC5	156 × 131	115 × 116
11. MIROC-ESM	310 × 262	103 × 131
12. MIROC-ESM-CHEM	310 × 262	103 × 131
13. MRI-CGCM3	125 × 105	56 × 93
14. MRI-ESM1	125 × 105	56 × 93
15. NorESM1-M	211 × 232	54 × 104
16. NorESM1-ME	211 × 232	54 × 104
17. GFDL-CM3	222 × 231	111 × 93
18. GFDL-ESM2G	225 × 234	111 × 93
19. GFDL-ESM2M	225 × 234	111 × 93
20. CESM1-BGC	105 × 116	54 × 104
21. CESM1-CAM5	105 × 116	54 × 104

Land-sea temperature differences do, indeed, increase



Diffenbaugh and Field (2014)



Fasullo (2010)

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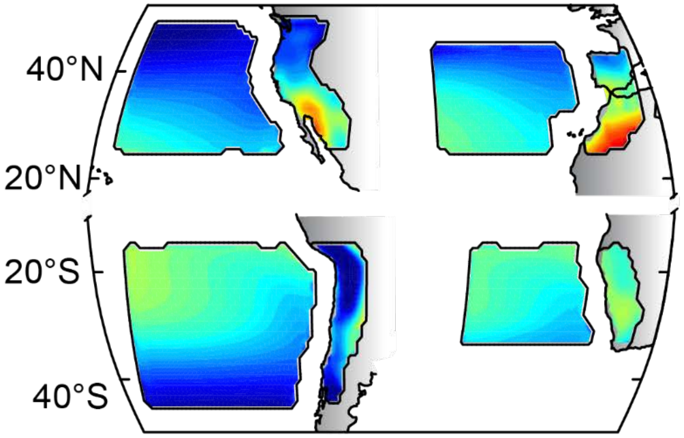
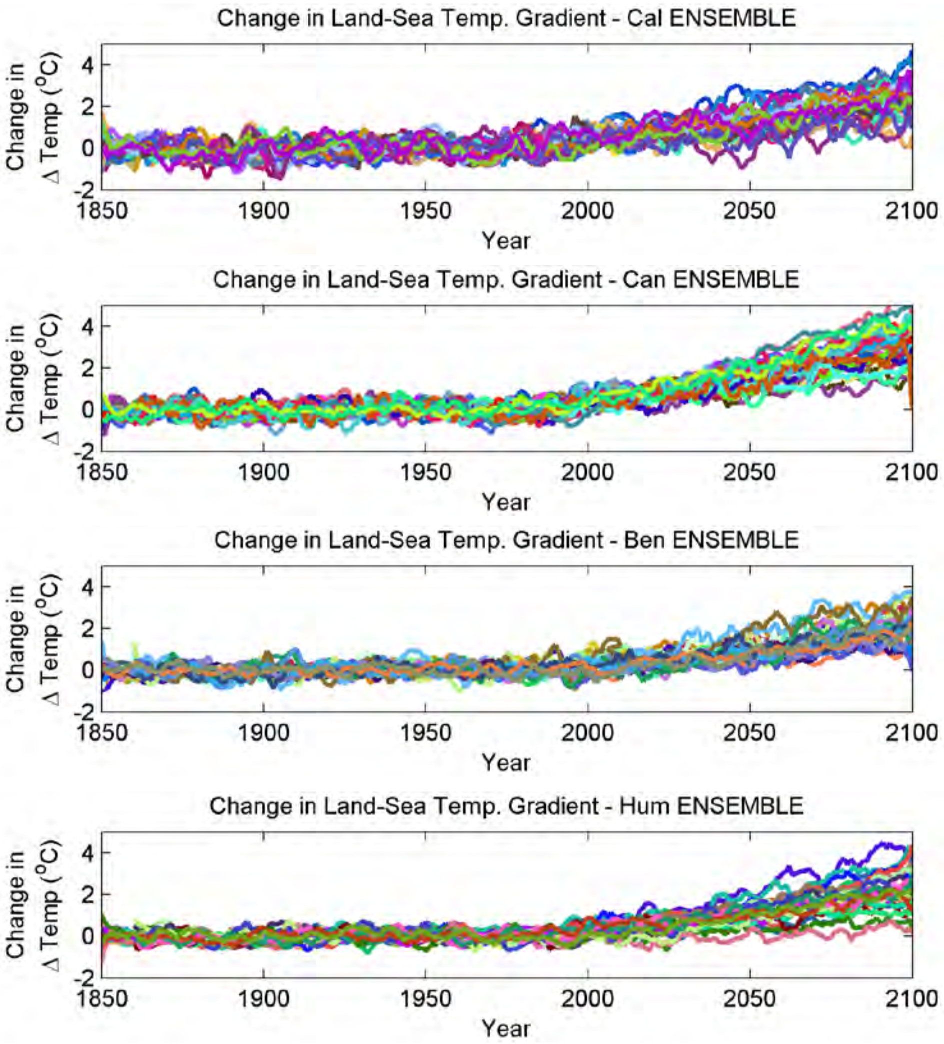
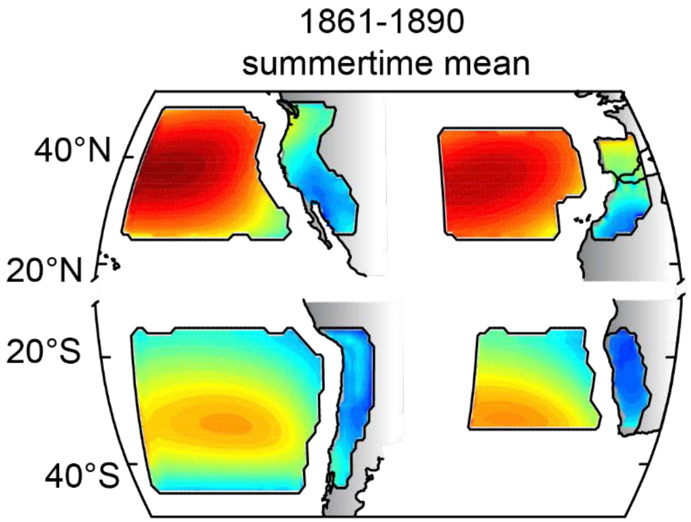
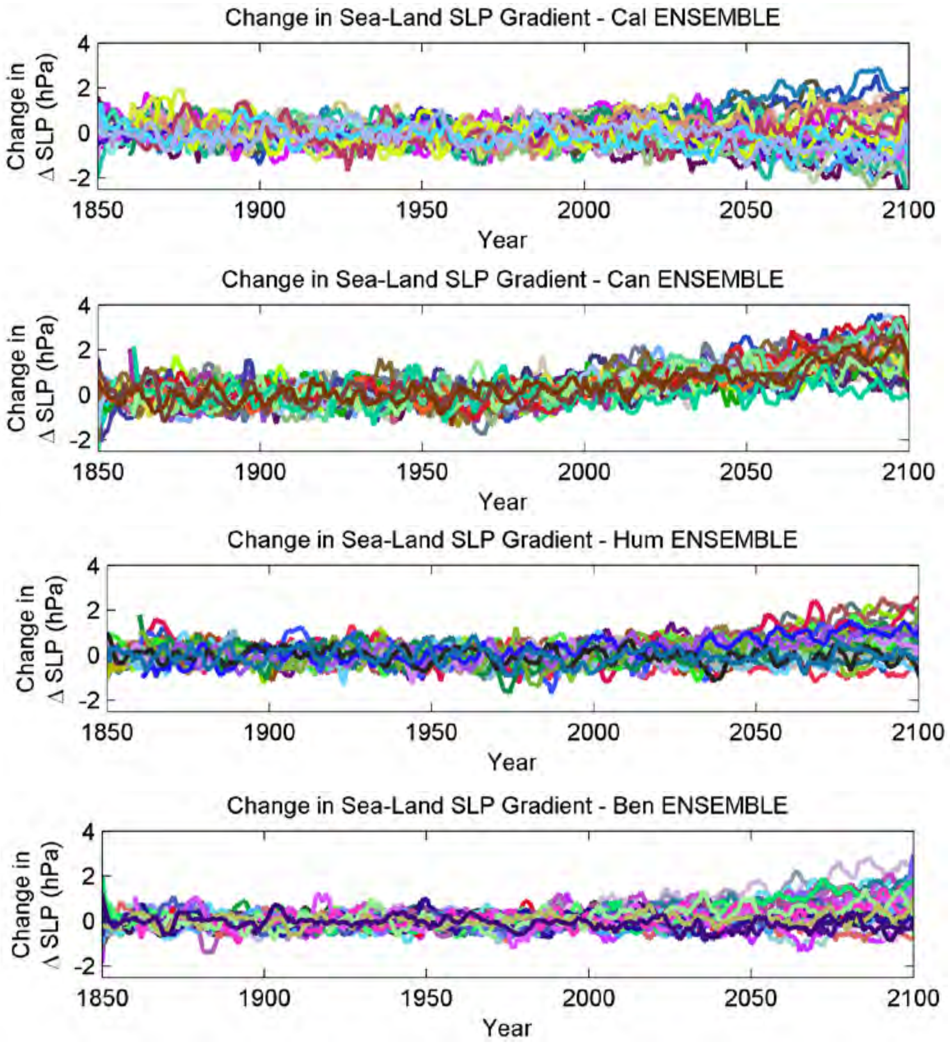




Rykaczewski et al. (2015)

However, continental SLP does not uniformly decrease

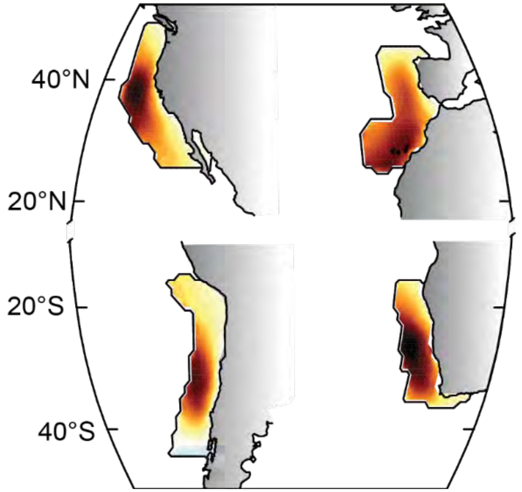


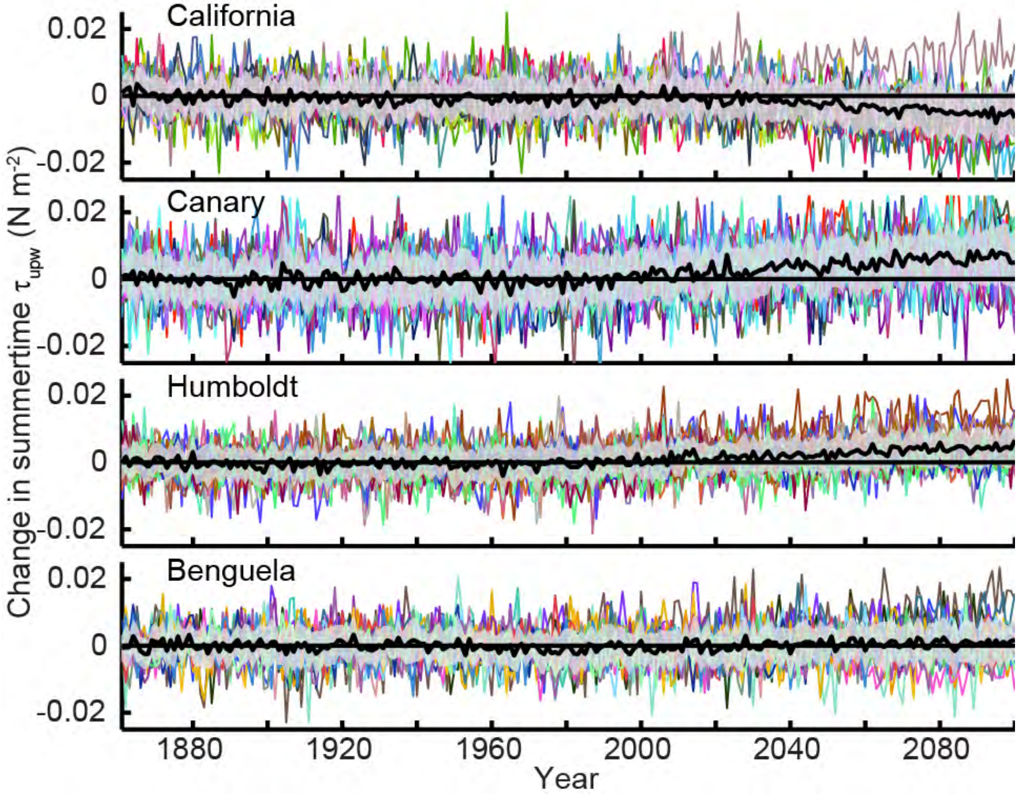


Rykaczewski et al. (2015)

Changes in wind intensity are fairly subtle…

1861-1890
summertime mean





Rykaczewski et al. (2015)

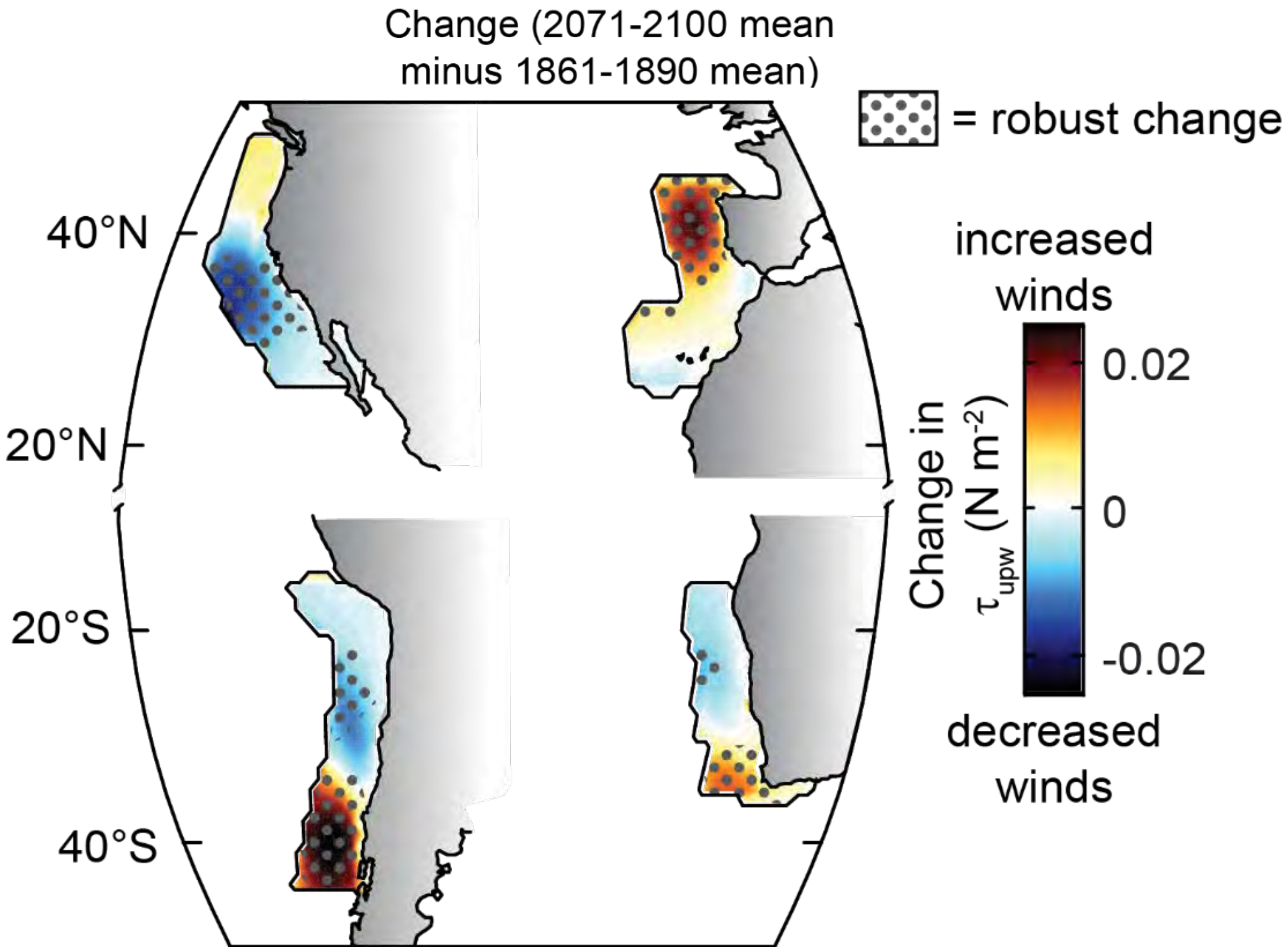
Changes in wind intensity are fairly subtle…

Upwelling intensity tends to increase in the poleward portions…

… but decrease in the equatorward portions of the upwelling systems.

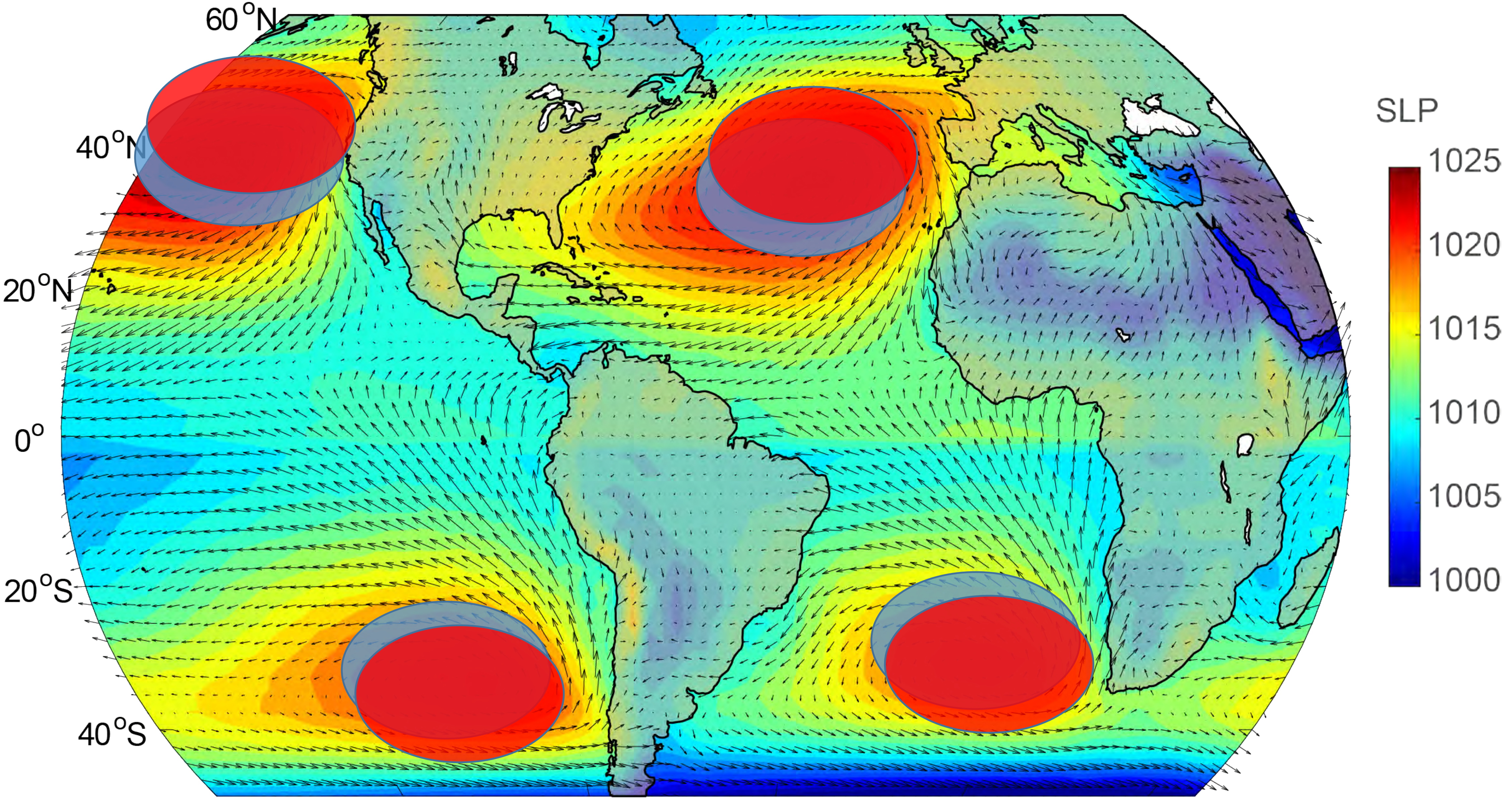
Percentage change in summertime $\tau_{upw.}$

	Complete region	Poleward portion	Equatorward portion
California	-8% (±10 s.d.)	-2% (±18 s.d.)	-13% (±10 s.d.)
Canary	10% (±10 s.d.)	26% (±18 s.d.)	2% (±11 s.d.)
Humboldt	10% (±12 s.d.)	47% (±34 s.d.)	-9% (±9 s.d.)
Benguela	1% (±7 s.d.)	9% (±10 s.d.)	-6% (±9 s.d.)



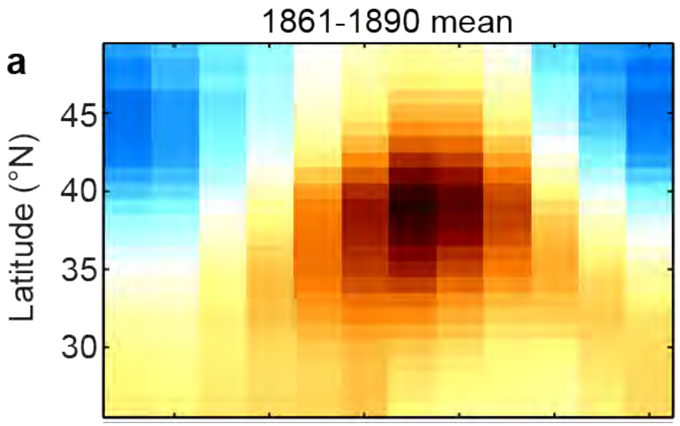
Rykaczewski et al. (2015)

Poleward shifts in high-pressure systems are dominant over land-sea temperature gradients



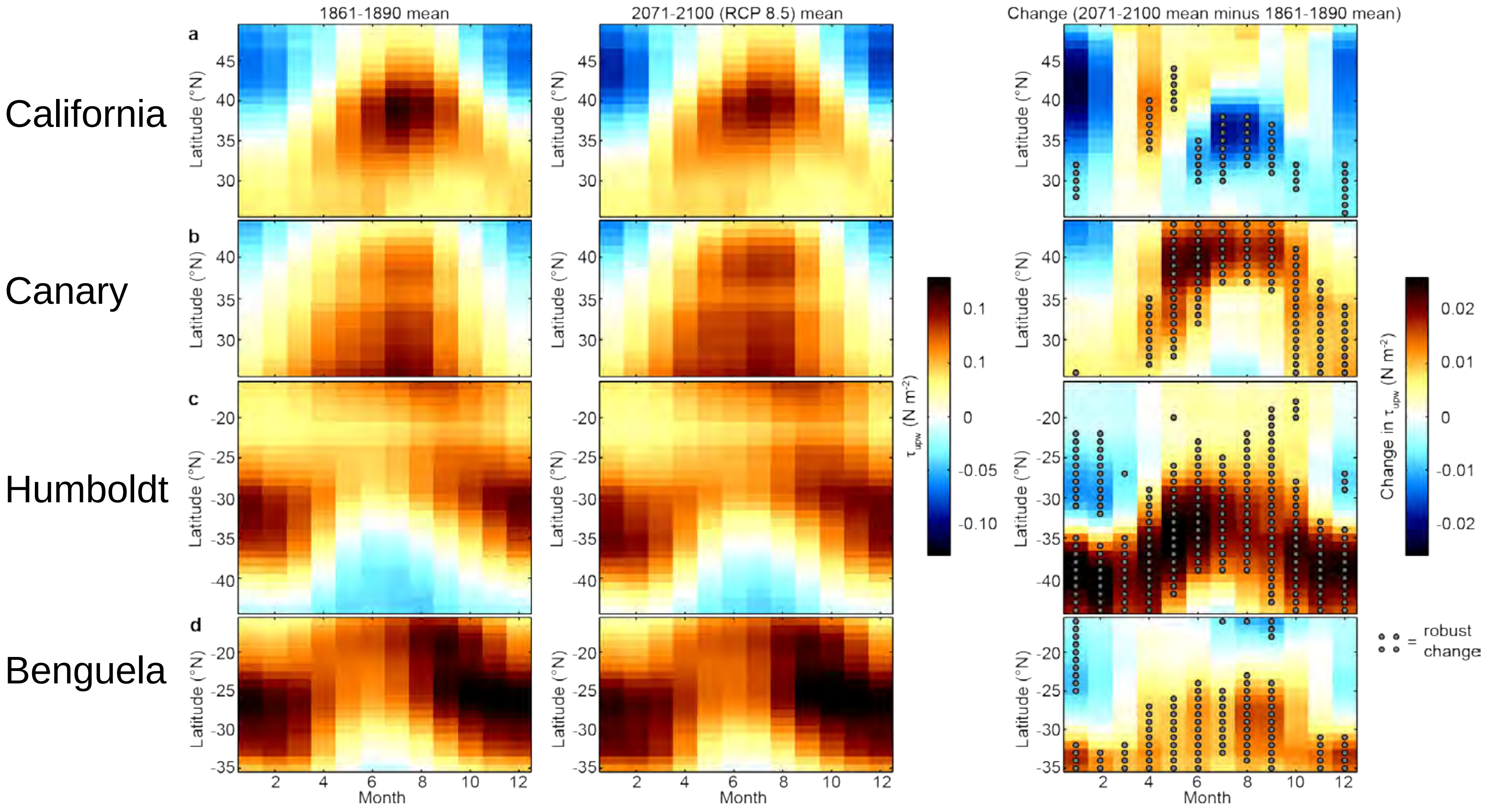
Projected changes are not limited to the summer seasons

In the eastern North Pacific, springtime upwelling winds (March-April) are projected to intensify in north of Point Conception.



Increased upwelling in poleward portions of the regions

Projected changes are not limited to the summer season.



Relevant hypotheses describing future nutrient supply

What physical processes can conceivably alter the supply of macronutrients to upwelling ecosystems in response to anthropogenic global warming?

1) The <u>magnitude of upwelling favorable winds</u> along the coast.

Bakun (1990)

2) <u>Stratification of the water column</u> that might alter the depth from which upwelling waters are drawn.

Huyer (1976),
Roemmich and McGowan (1995),
Palacios *et al.* (2004),
Lentz and Chapman (2004)

3) Changes in the <u>nutrient concentrations in source waters</u>.
   A. Change in concentration within a source-water mass
   B. Change in the relative contributions of different water masses to the region

Rykaczewski and Dunne (2010),
Bograd *et al.* (2015)

Brief Summary

1) *Shifts in plankton size may be a critical parameter influencing small pelagic fishes.*

2) *Change in rates of nutrient supply can be easily explored in many IPCC-style earth system models.*

   Understanding nutrient supply represents a balance between a focus on the physical processes and attempting to interpret dynamics of a more complete food-web model.

3) *Future projections of processes controlling nutrient supply to upwelling systems indicate that changes may be unexpected.*
   a) *Upwelling intensification is limited to poleward portions of upwelling systems (at least during the warm season).*
   b) *Ventilation (not local stratification or winds) is the most important process driving changes in nutrient supply in response to anthropogenic warming.*

Thanks for your attention!