Comparison of the ecosystem response to climate change in the mid-latitude North Pacific and California Current

Funded through a partnership between **NOAA's GFDL** and **NOAA Fisheries**.

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Climate change and the California Current Ecosystem

Basic question:
How will fisheries in a region of the world's oceans (*e.g.*, the California Current) be affected by global climate change?

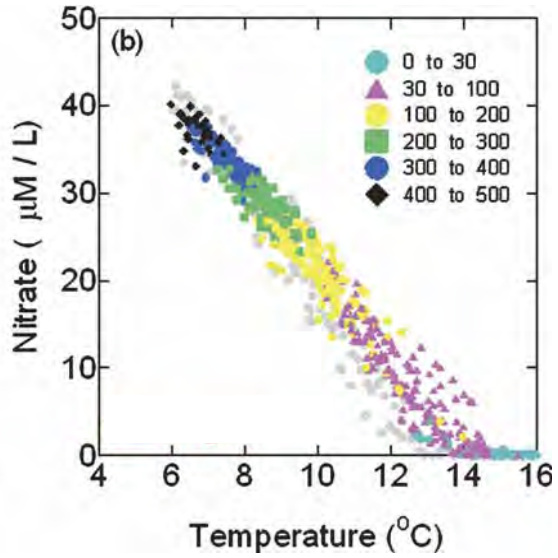
Ultimate goals
- Inform fisheries-management decisions
- Estimate the socioeconomic impacts of continued climate change
- Assess the potential implications to the ecosystem as a whole

Necessary, preliminary questions:
How is productivity expected to change in the California Current with global climate change?

Do we *understand* why these changes are projected?

Temperature-Nitrate relationship of the California Current Ecosystem

Temperature is inversely related to nitrate concentration in the euphotic zone in the California Current Ecosystem (CCE).



Kim and Miller (2007, *J. Phys. Oceanogr.*)

Temperature-Nitrate relationship of the California Current Ecosystem

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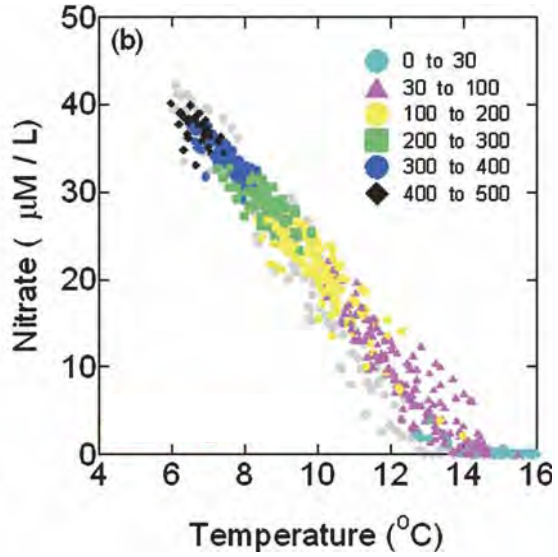
Decreases in ecosystem productivity are coincident with increases in temperature at interannual to decadal time scales.



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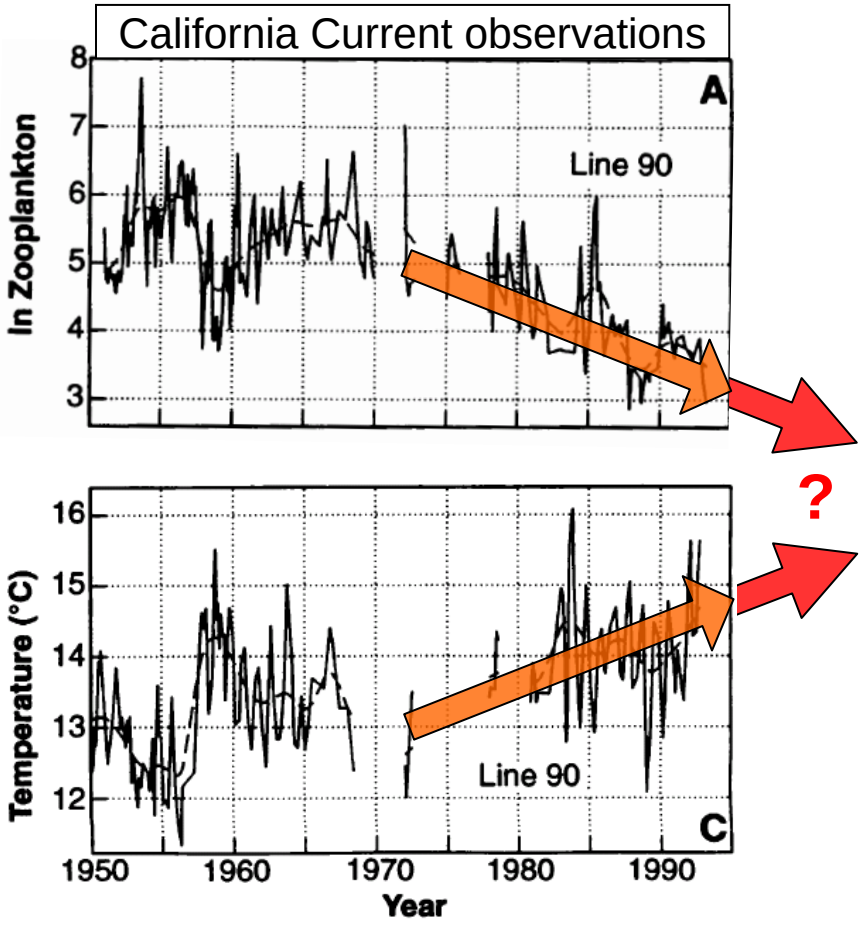


Roemmich and McGowan (1995, Science)

Temperature-Nitrate relationship of the California Current Ecosystem

Our understanding of ecosystem change in the CCE is focused on the variability between warm, unproductive periods and cold, highly productive periods.

Cool Period	Warm Period
replete nutrients high biologic production	limited nutrients low biologic production

Increased water-column stratification with global warming has been hypothesized to result in decreased nutrient supply and reduced primary and secondary production in the CCE.

Temperature-Nitrate relationship of the California Current Ecosystem

Strategy:

Explore the effect of climate change on the nutrient supply and production in the CCE using a basic biogeochemistry model (TOPAZ) coupled to an ocean-atmosphere general circulation model (GFDL CM2.1).

This combination is known as GFDL's Earth System Model (ESM2.1); described by Jeff Polovina this morning.

Earth-System Model 2.1 (ESM2.1)

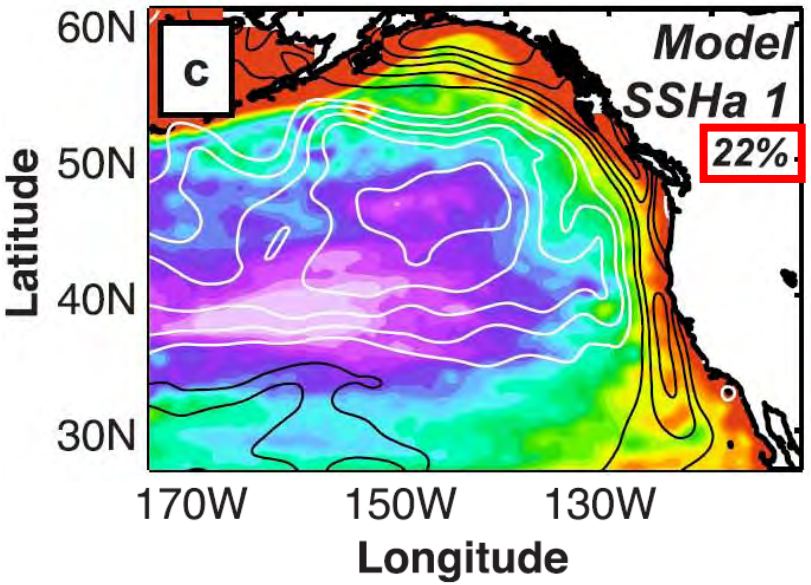
atmosphere-ocean general circulation model: CM2.1 (1^o ocean, 2^o atmosphere)
Delworth, *et al.* (2006, *J. Climate*)

basic biogeochemistry model: TOPAZ - major nutrients (N, P, Si and Fe) and three phytoplankton classes
Dunne, *et al.* (2005, 2007; *Global Biogeochem. Cycles*)

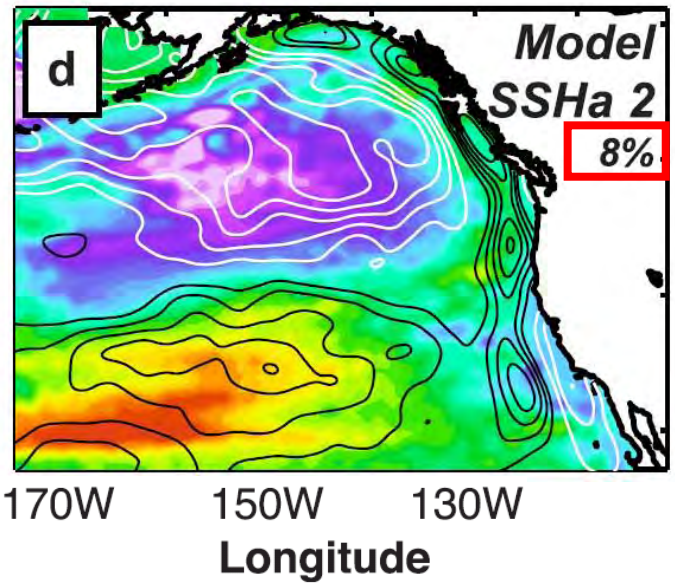
Historic modes of variability

Current understanding is largely based on our knowledge of main modes of natural variability in the climate and hydrography of the Pacific, namely the Pacific Decadal Oscillation (PDO) and North Pacific Gyre Oscillation (NPGO).

PDO Mode; PC1



NPGO Mode; PC2

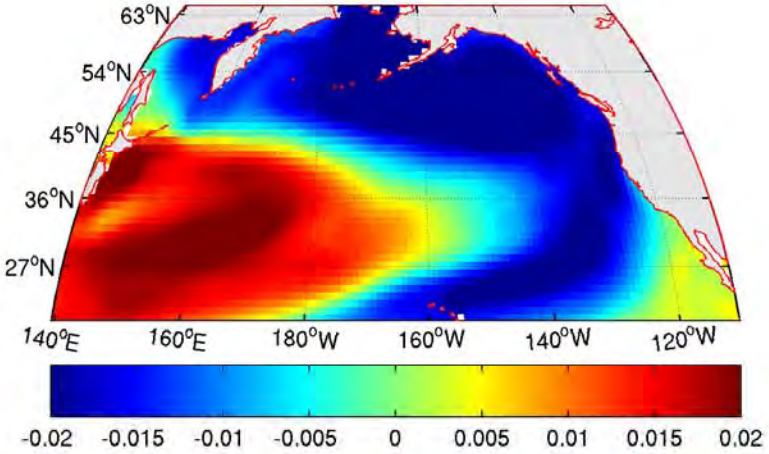


Di Lorenzo, *et al.* (2008, *Geophys. Res. Lett.*)

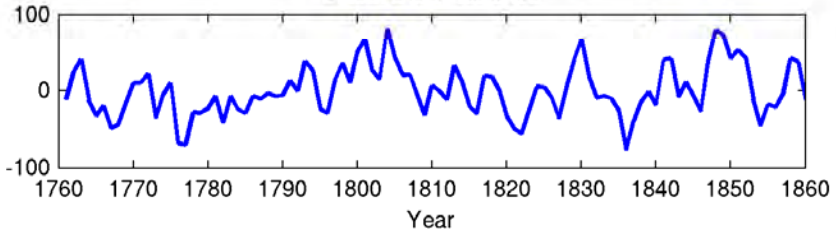
Historic modes of variability in ESM2.1

GFDL climate model ESM2.1 also display variability at decadal frequency in the North Pacific.

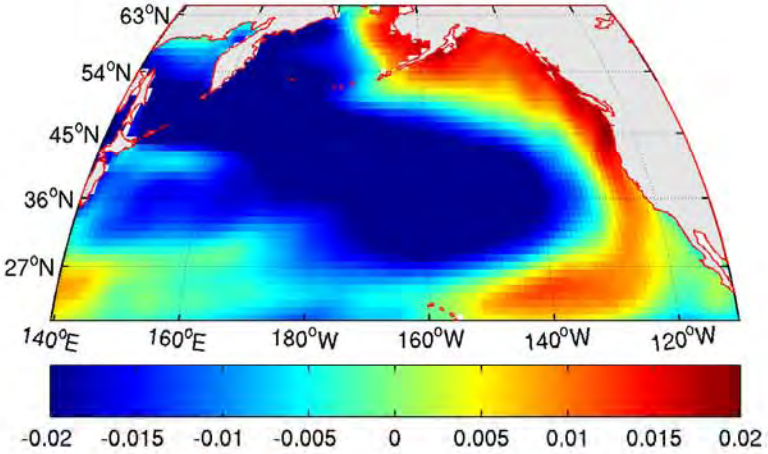
modeled 1860 SST, PC1



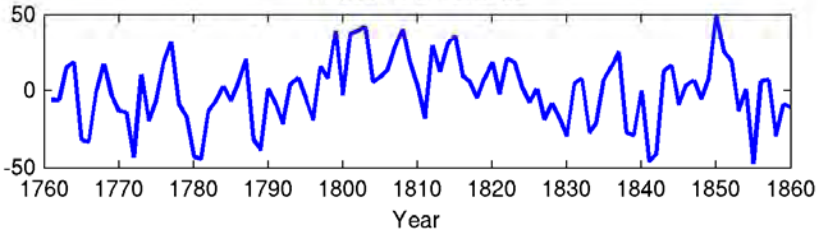
27.03 % of variance



modeled 1860 SST, PC2



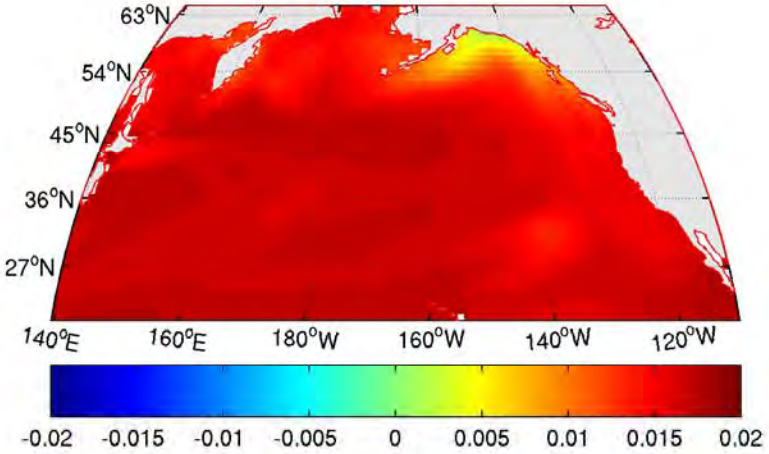
11.84% of variance



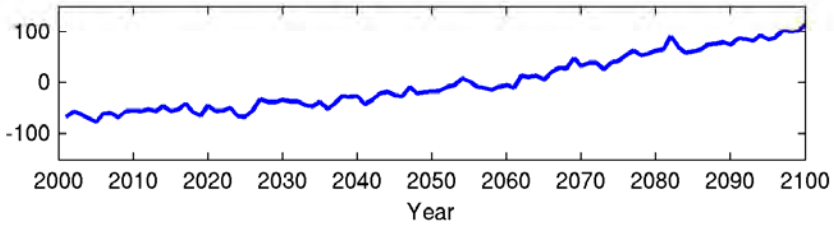
Future modes of variability in ESM2.1

However, in the coming century, variability is expected to be dominated by the long-term trend.

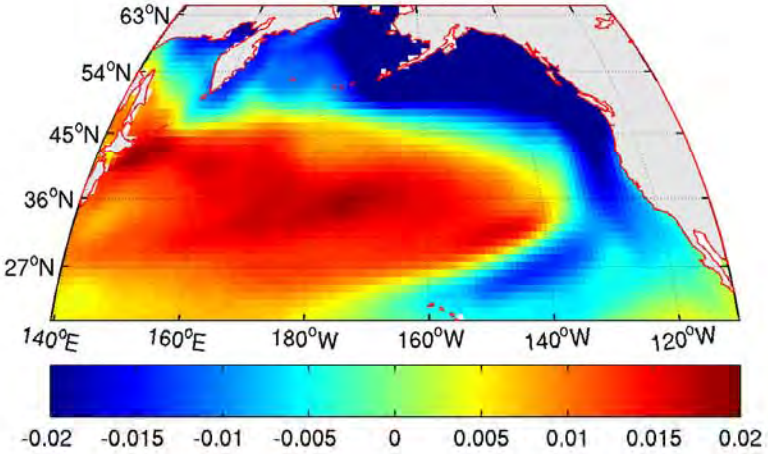
2001-2100 SST, PC1



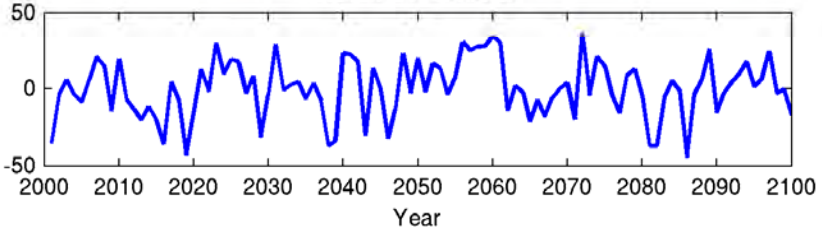
71.34 % of variance



2001-2100 SST, PC2



8.81% of variance



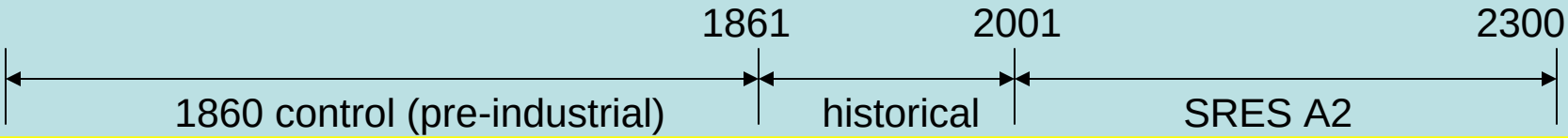
Mean fields and long-term trends

How does the GFDL ESM 2.1 represent different properties of the CCE, and how do these properties change with global warming?

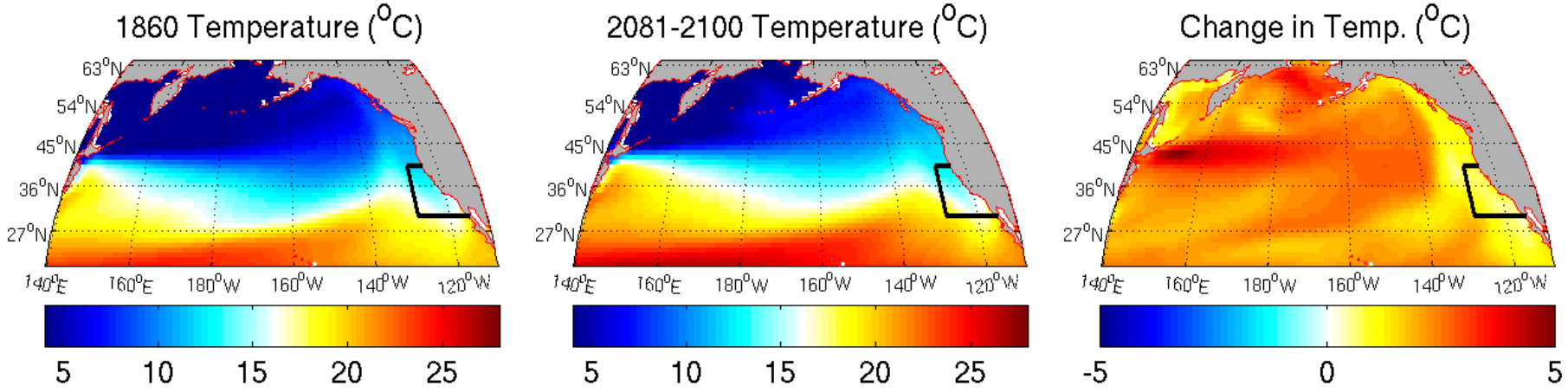
The following plots will have four panels:

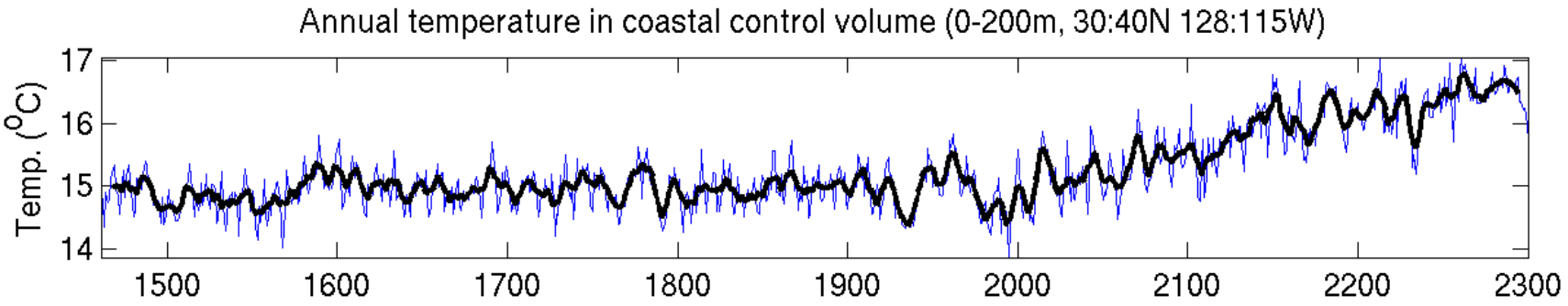
Pre-industrial mean (1860, 20-yr run)	Fossil-fuel intensive mean (SRES A2 2081-2100)	Difference (Future – pre-industrial)
PAST	**FUTURE**	**DIFFERENCE**

Time series for the CCE (128°W to coast, 30°N to 40°N , upper 200-m avg.)

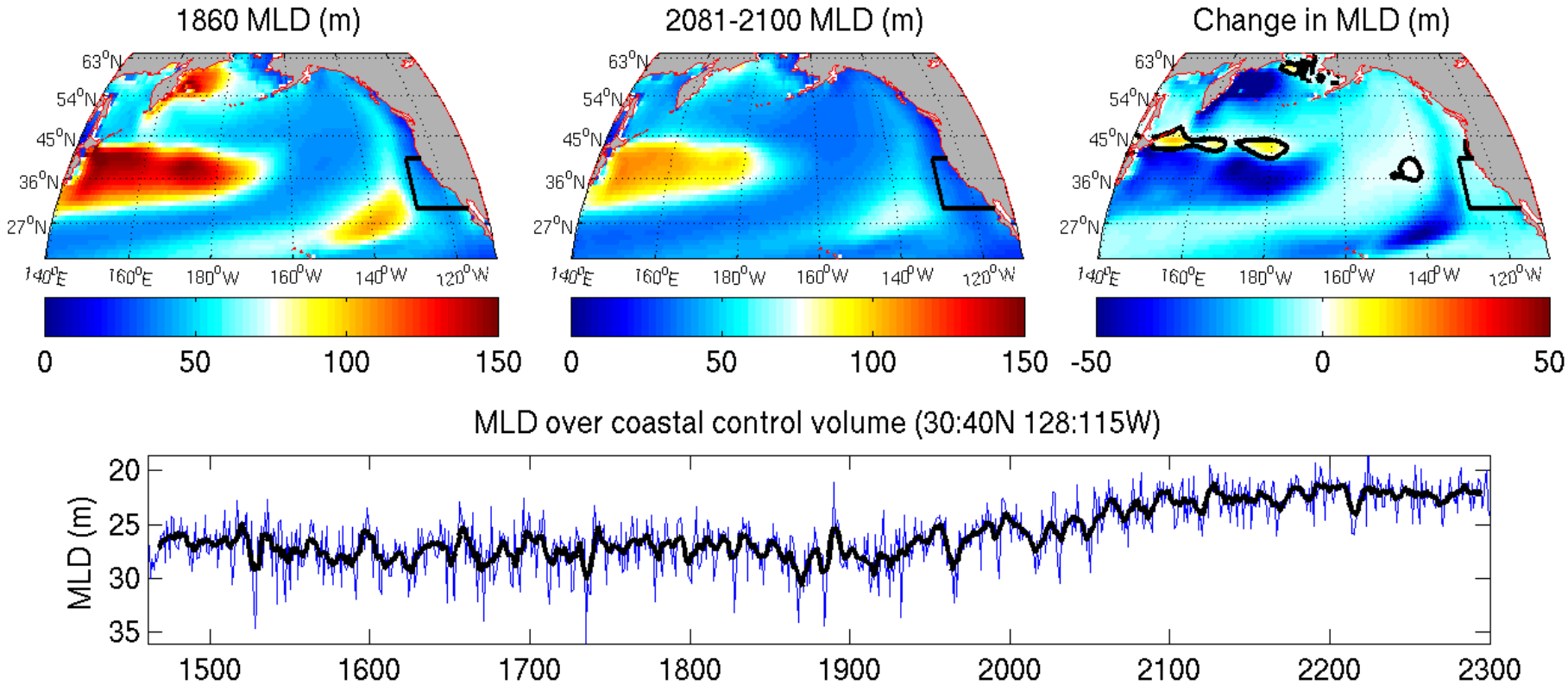


Mean fields and long-term trends: temperature



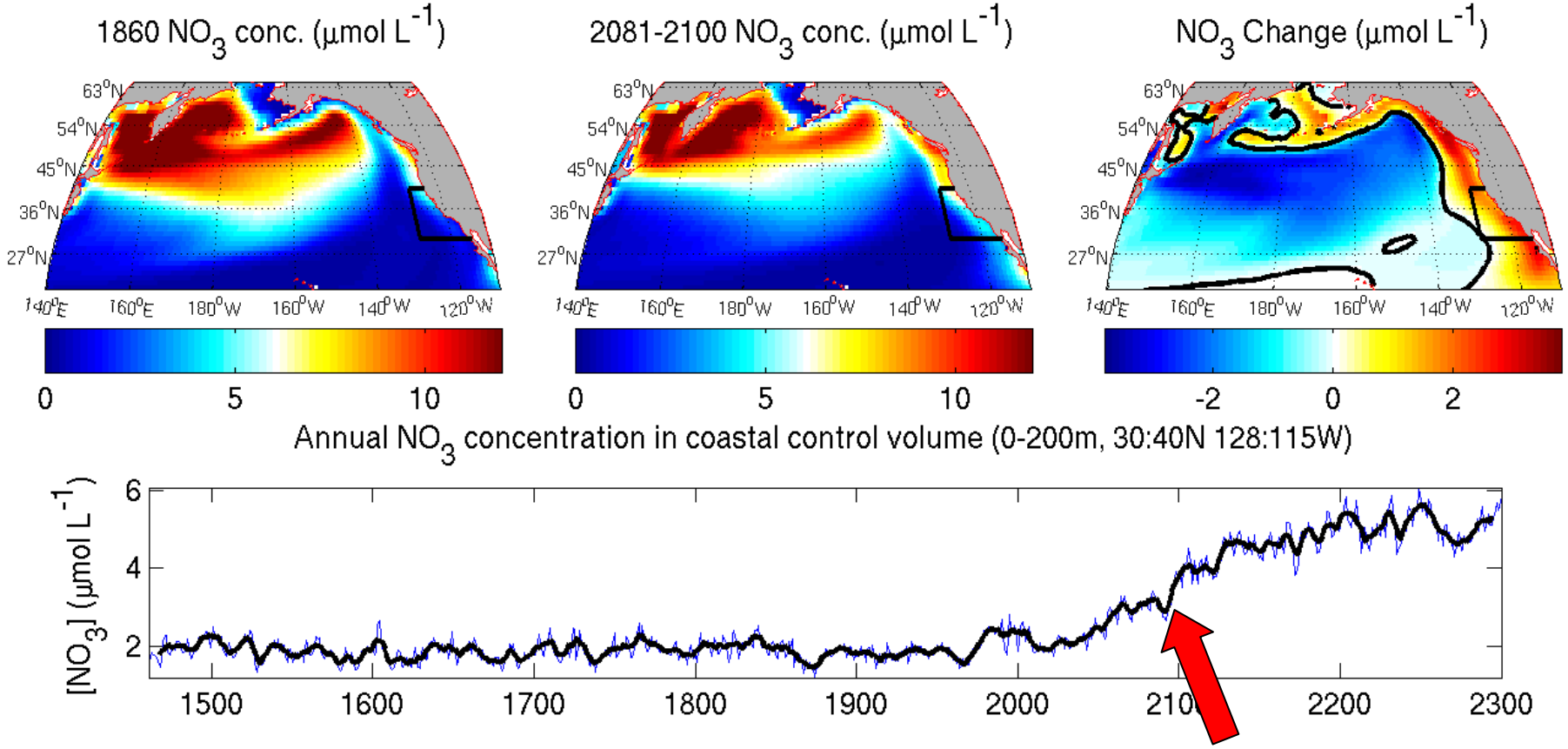


Mean fields and long-term trends: mixed-layer depth



Projected responses in the CCE include a shallower mixed-layer depth and warmer surface layer. Given the historical record, we may expect decreased nutrient supply and reduced production.

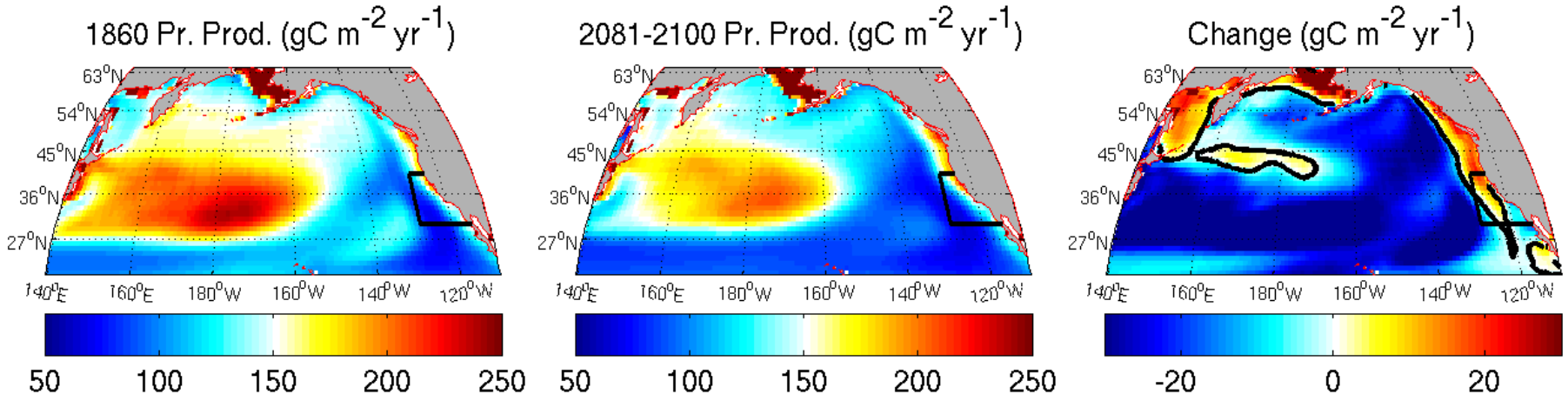
Mean fields and long-term trends: nitrate

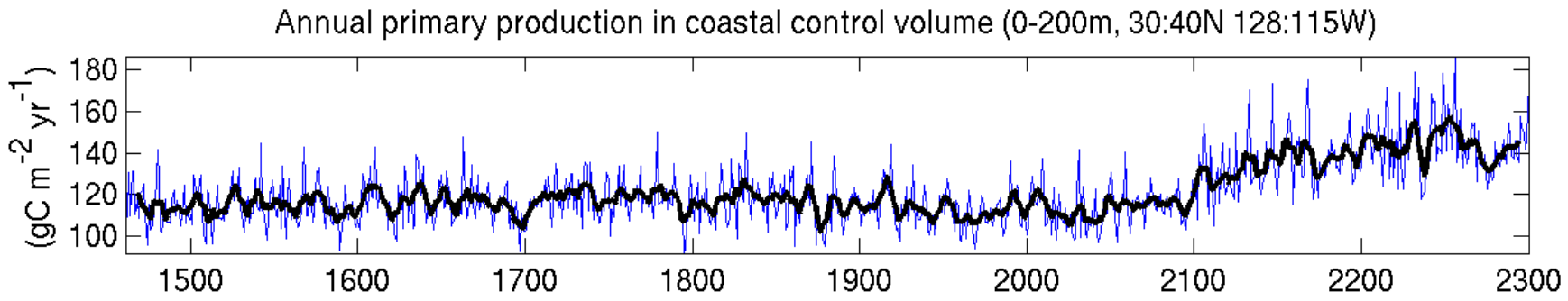


35% decrease in the average nitrate concentration in the North Pacific (20° N to 65° N).

85% increase in average nitrogen concentration between 2000 and 2100 in the CCE!

Mean fields and long-term trends: primary production

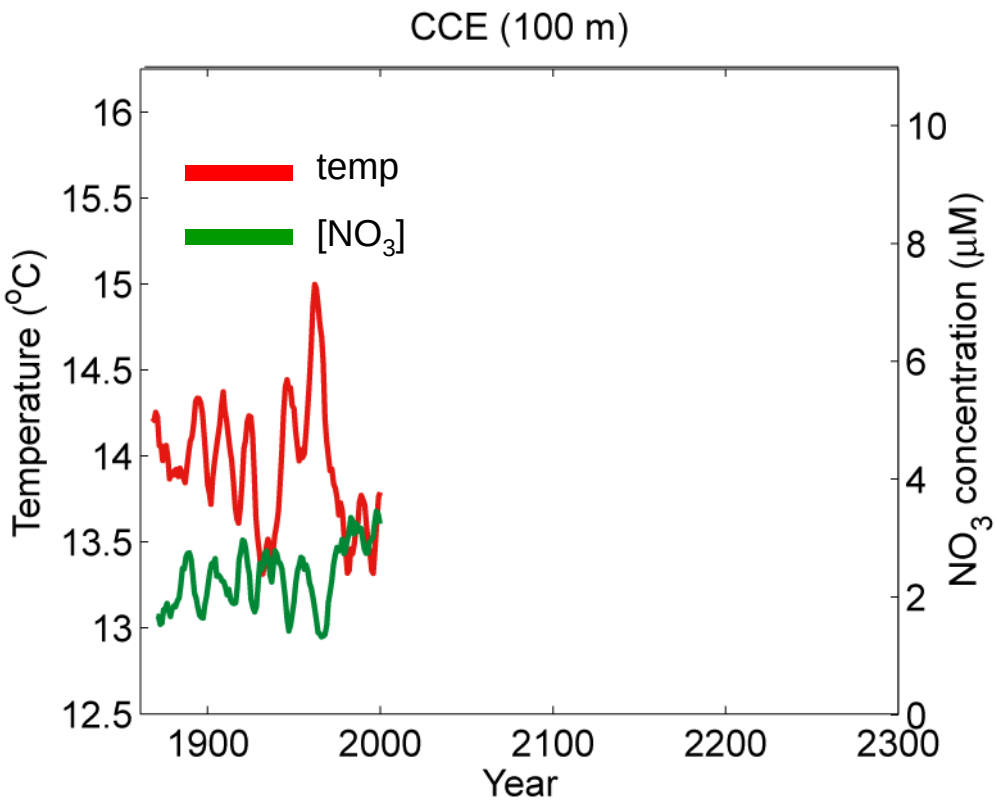




Unexpected biological response in the CCE

Current paradigm of CCE variability:

Cool Period	Warm Period
replete nutrients high biologic production	limited nutrients low biologic production



The nitrate-temperature relationship is negative over interannual to multidecadal periods.

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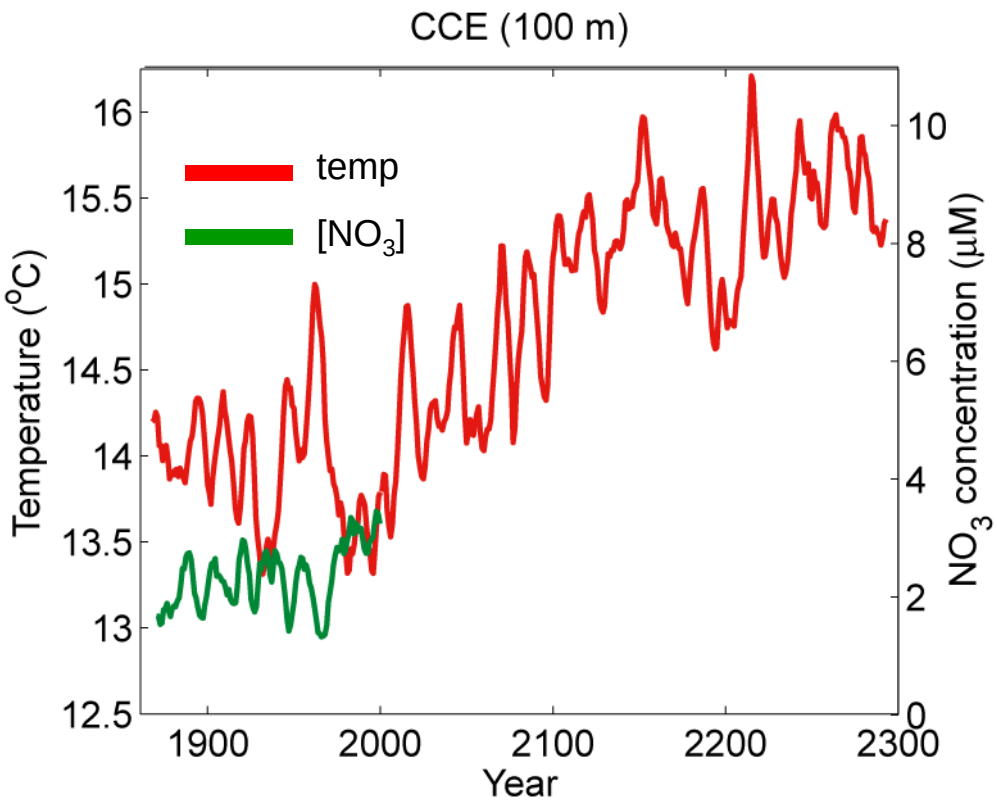

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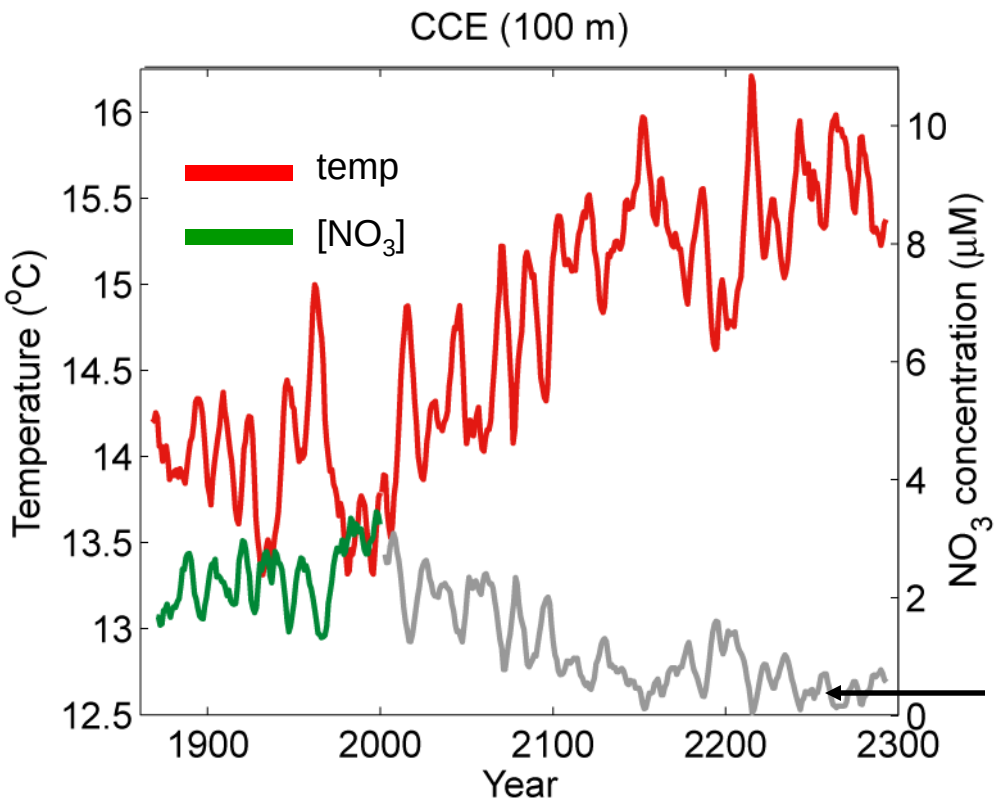

linear expectation for [NO_3] given historical temperature relationship

Unexpected biological response in the CCE

Current paradigm of CCE variability:

Cool Period

replete nutrients
high biologic pr

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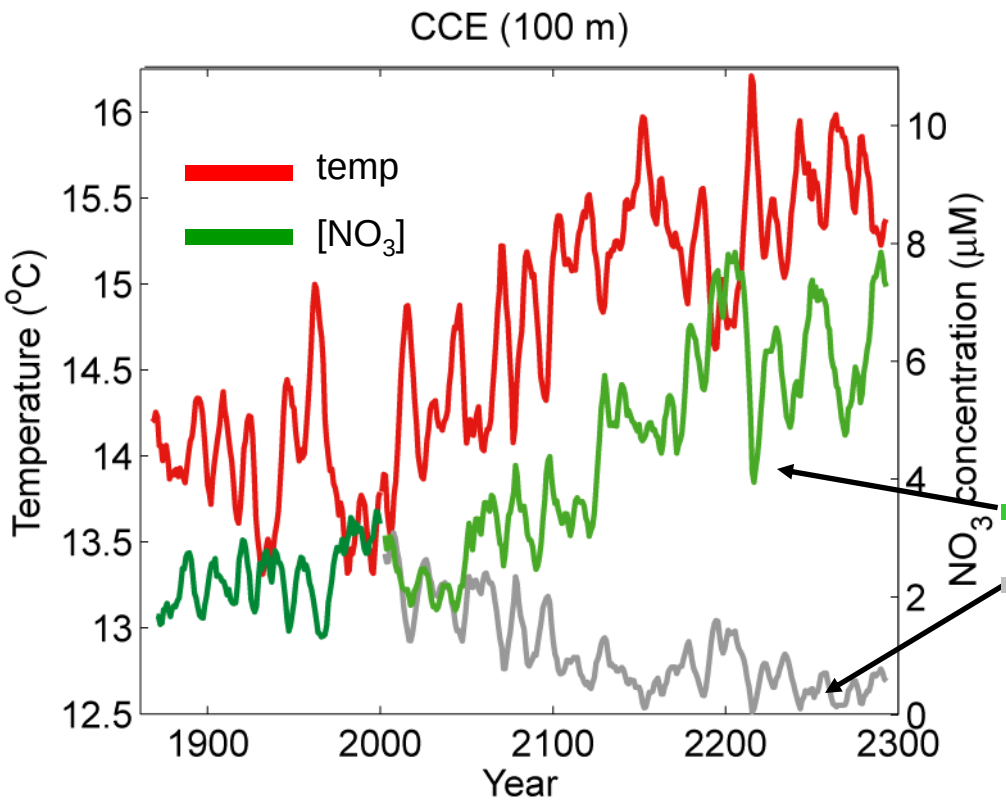
Does not apply to long-term warming



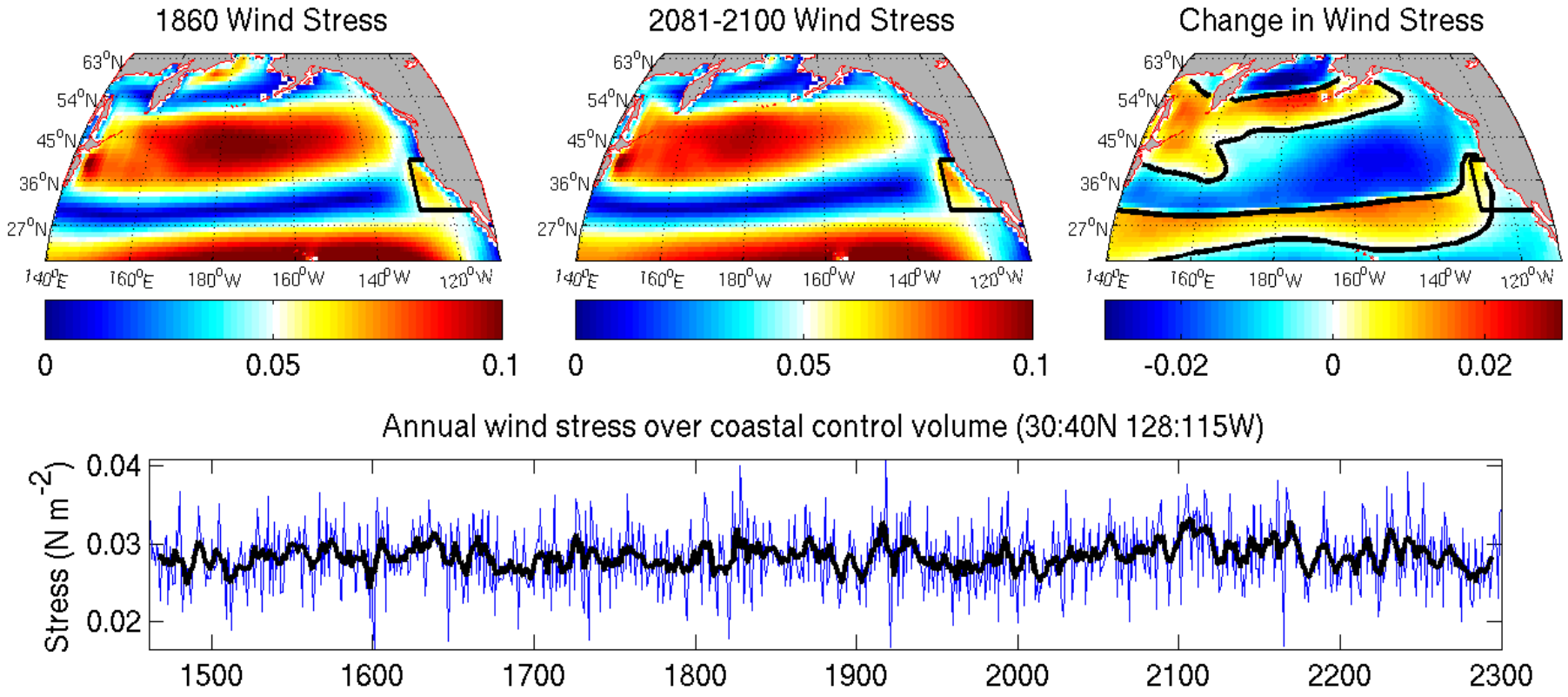
The nitrate-temperature relationship is negative over interannual to multidecadal periods.

However, modeling results show that this relationship ***cannot be extended*** to conclude that nitrate supply will similarly decrease with conditions of global warming.

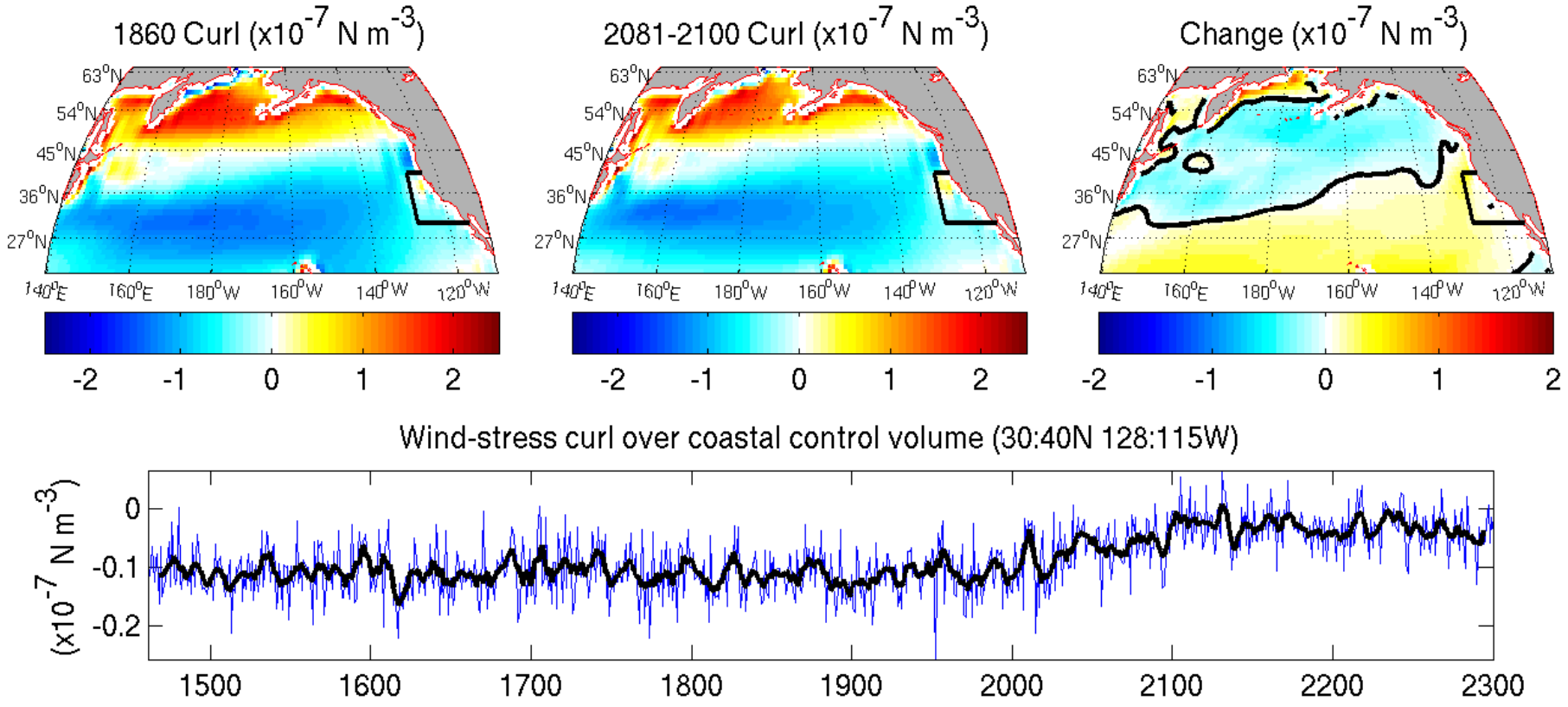
ESM 2.1 projection for [NO3]

linear expectation for [NO_3] given historical temperature relationship

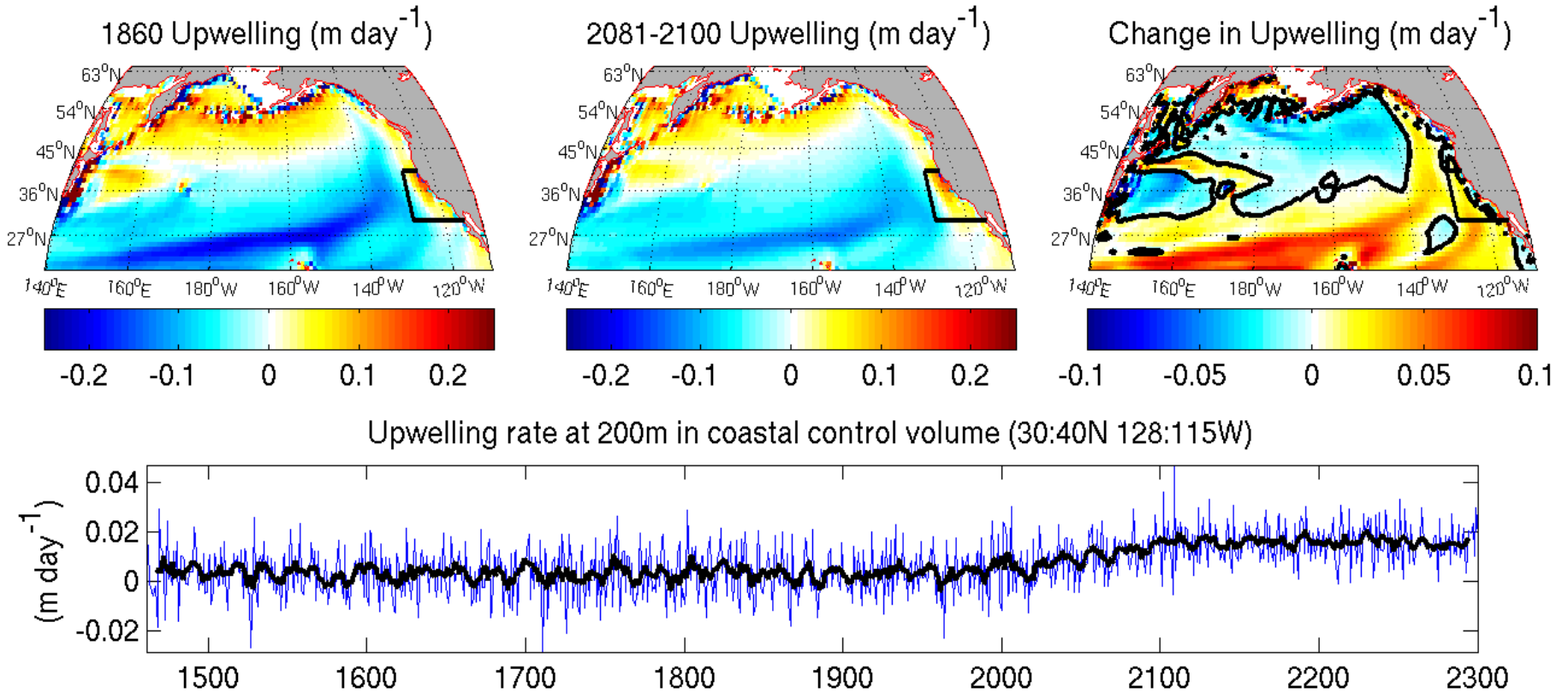
Mean fields and long-term trends: wind-stress



Mean fields and long-term trends: wind-stress curl



Mean fields and long-term trends: upwelling rate



Range of possible causes for the regional increase in NO_3 concentration:

1. Increase in the local vertical velocity of waters upwelled into the euphotic zone with a corresponding increase in NO_3 flux.

2. Change in the horizontal flux of water into the euphotic zone.

3. ~~Increase in the local exchange of NO_3 across the nutricline due to changes in mixing and stratification.~~

4. Increase in the concentration of NO_3 into the source waters supplied to the region.

5. ~~Change in NO3 uptake or remineralization by biological processes.~~

6. ~~Increase in riverine input or atmospheric deposition.~~

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5. ~~Change in~~ses.

6. ~~Increase i~~

Change in water transport of waters to the region?

or

Change in the NO_3 concentration in the waters supplied to the region?

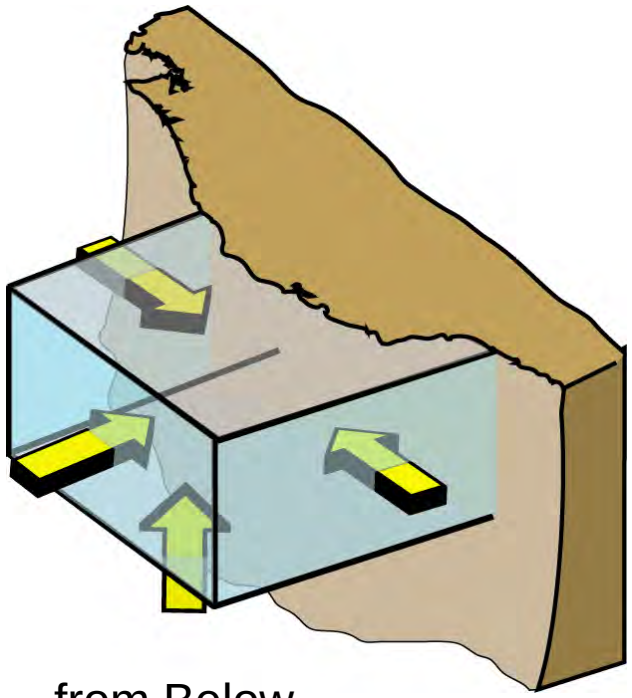
Change in the advective supply of NO_3?

from North

	0.8 kmol s^{-1}	0.3 Sv
	1.0 kmol s^{-1}	0.2 Sv
Δ =	0.1 kmol s^{-1}	0.0 Sv

from West

	3.1 kmol s^{-1}	2.4 Sv
	5.8 kmol s^{-1}	3.1 Sv
Δ =	2.7 kmol s^{-1}	0.7 Sv



FLUX KEY:

1860, 60-yr avg:	NO_3 flux	H_2O flux
2081-2100 avg:	NO_3 flux	H_2O flux
change =	Δ NO_3	Δ H_2O

from Below

	6.3 kmol s^{-1}	0.7 Sv
	10 kmol s^{-1}	0.8 Sv
Δ =	4.0 kmol s^{-1}	0.1 Sv

from South

	0.5 kmol s^{-1}	0.5 Sv
	1.1 kmol s^{-1}	0.4 Sv
Δ =	0.6 kmol s^{-1}	-0.1 Sv

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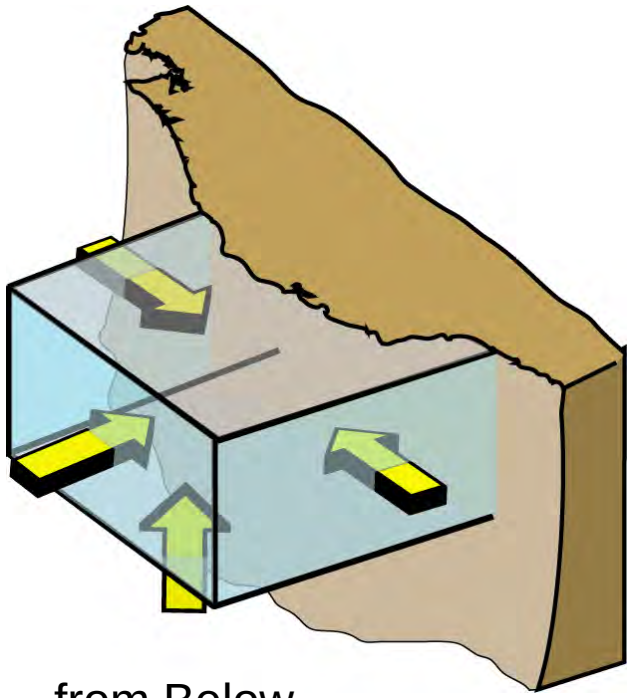

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	1.1 kmol s^{-1}	0.4 Sv
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+ 60% ***+ 10%***

Ventilation of CCE source waters

Changes in local circulation alone cannot explain the projected increase in NO_3 supply. The change in nitrate concentration in the source waters is more important as the local changes in advection.

Ventilation of CCE source waters

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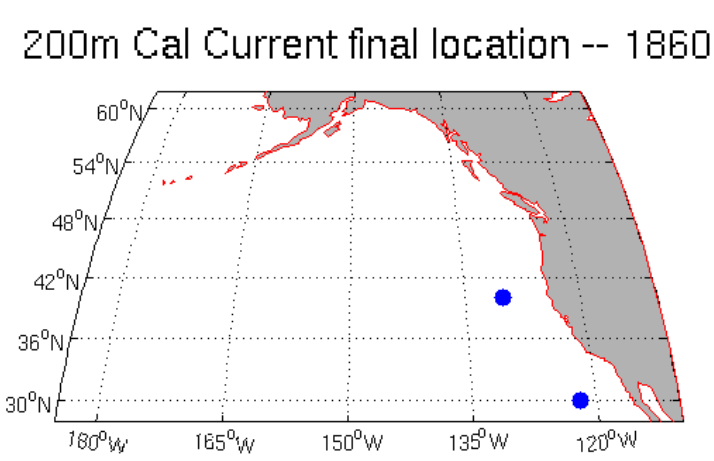
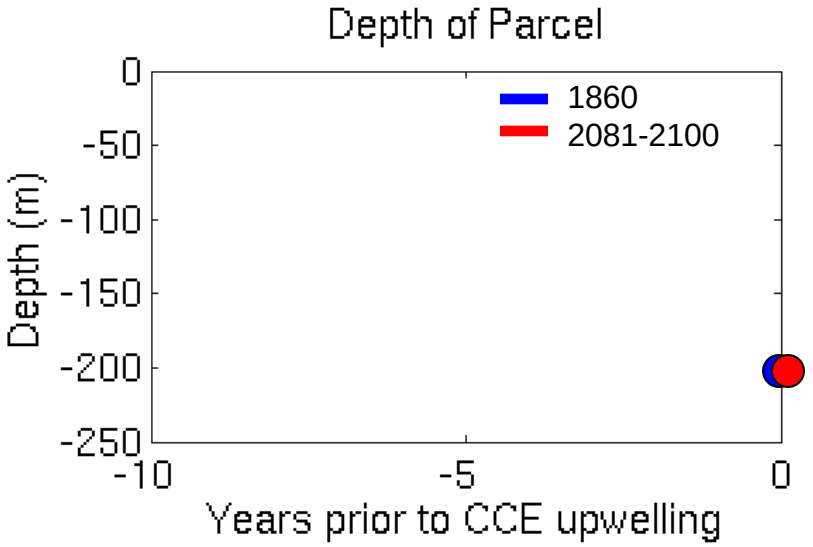
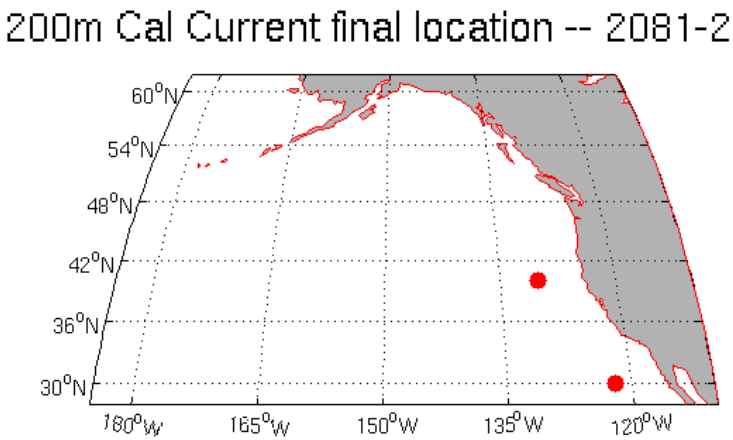
New question:

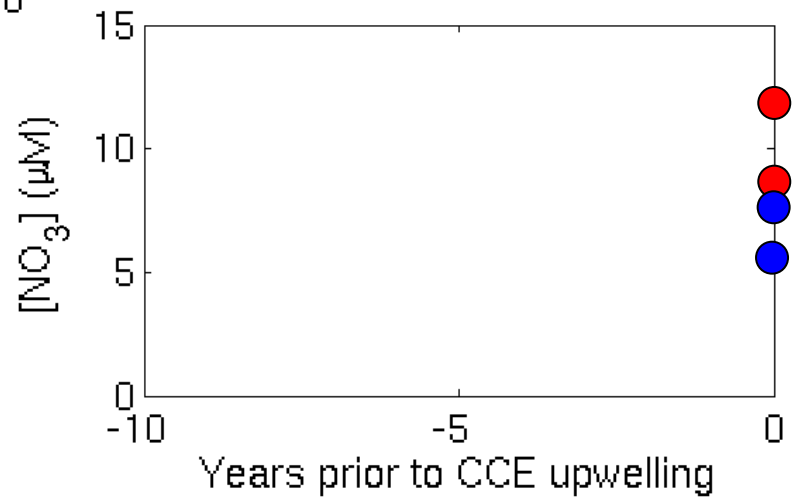
What is the history of waters before they reach the CCE?

Ventilation of CCE source waters









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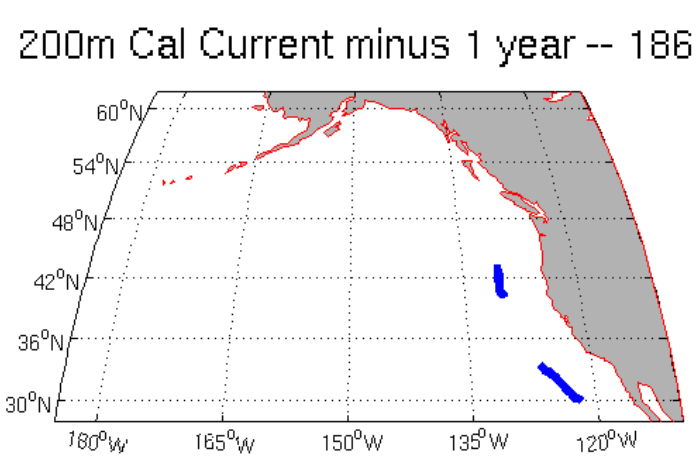

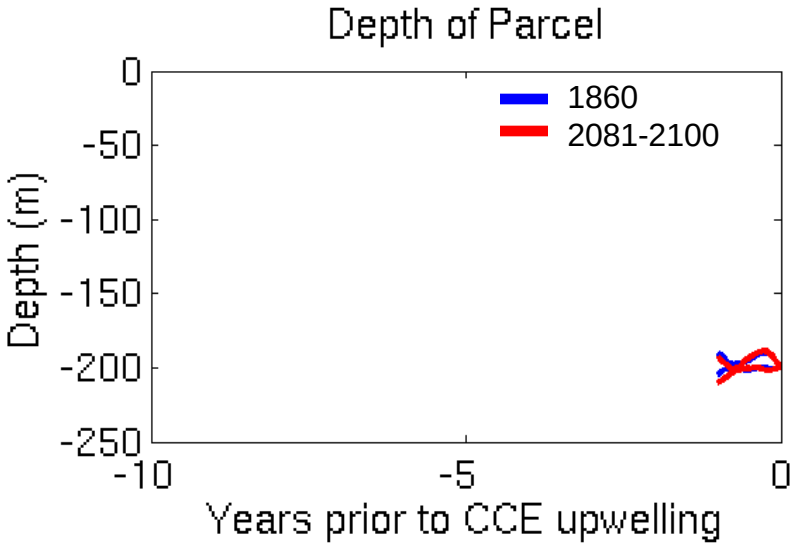

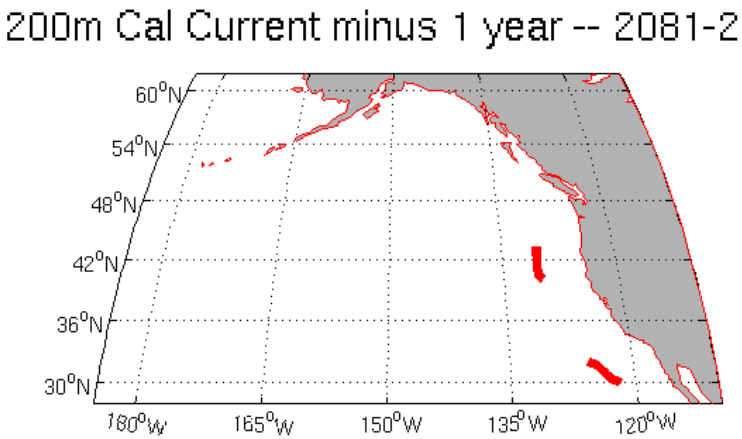

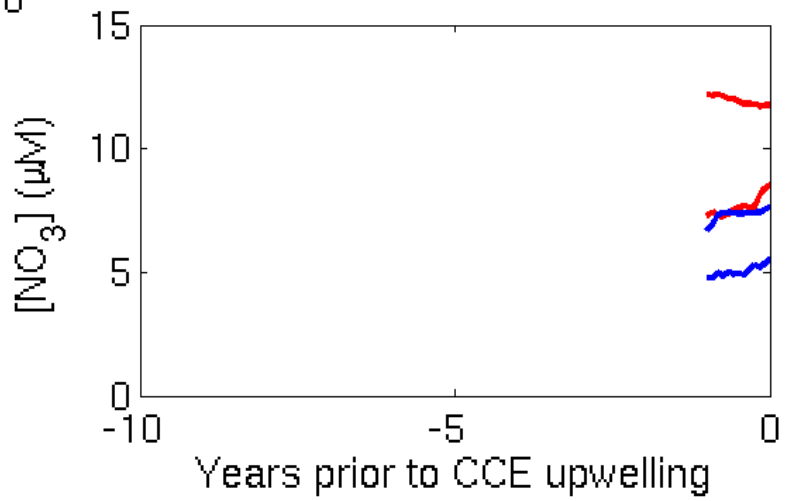

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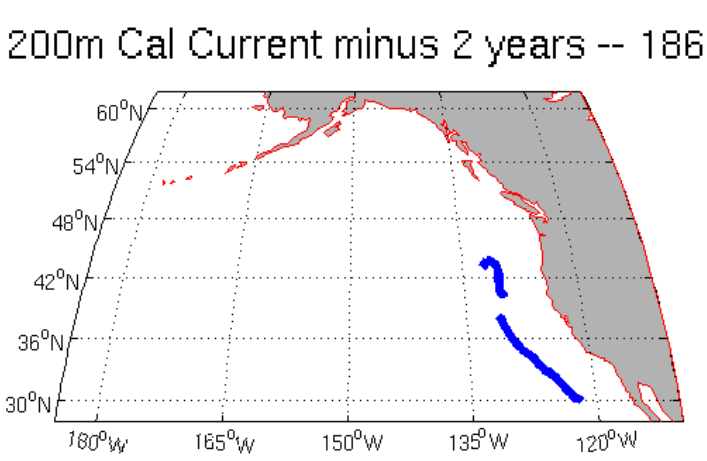
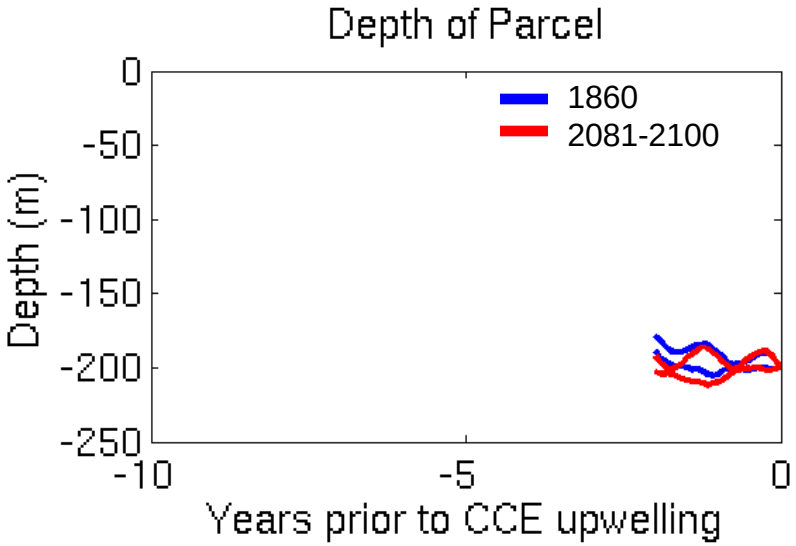
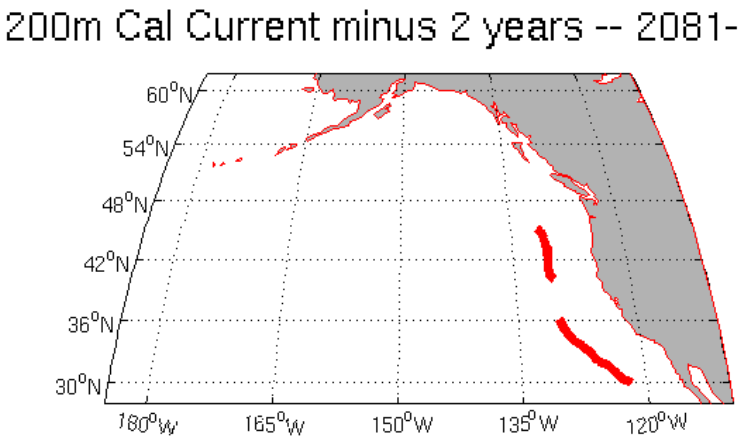
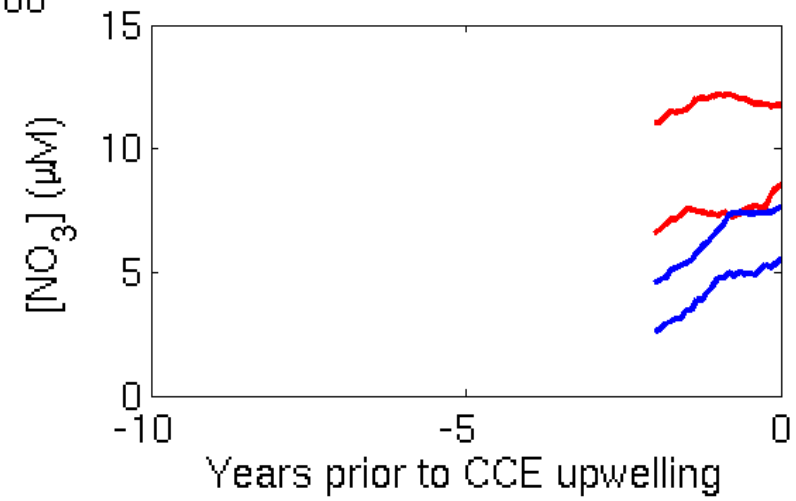
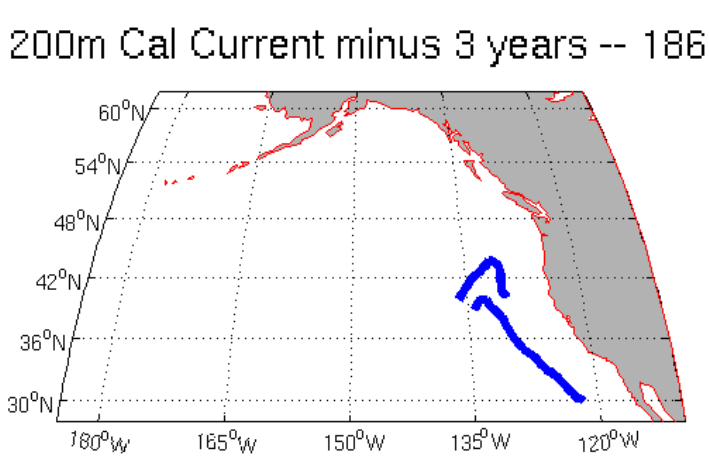


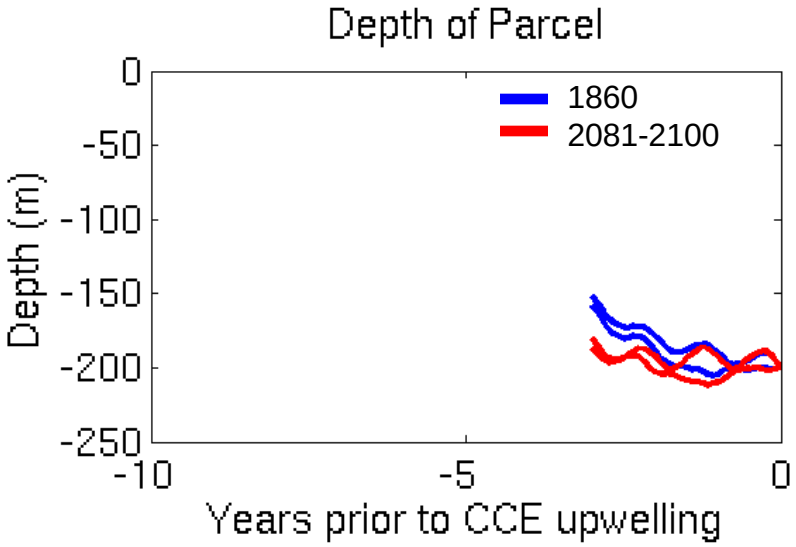


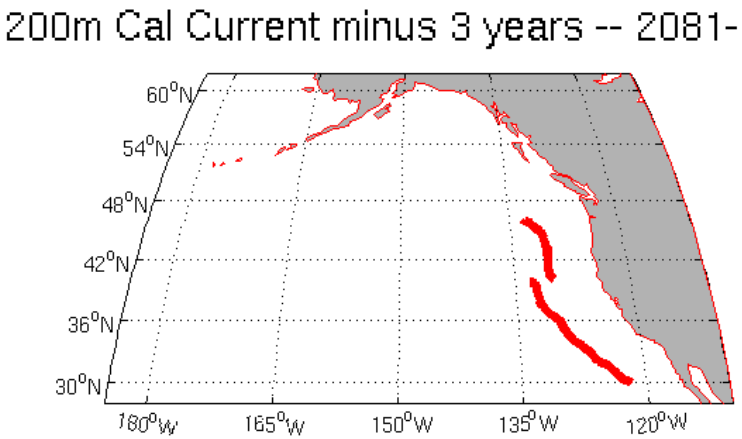


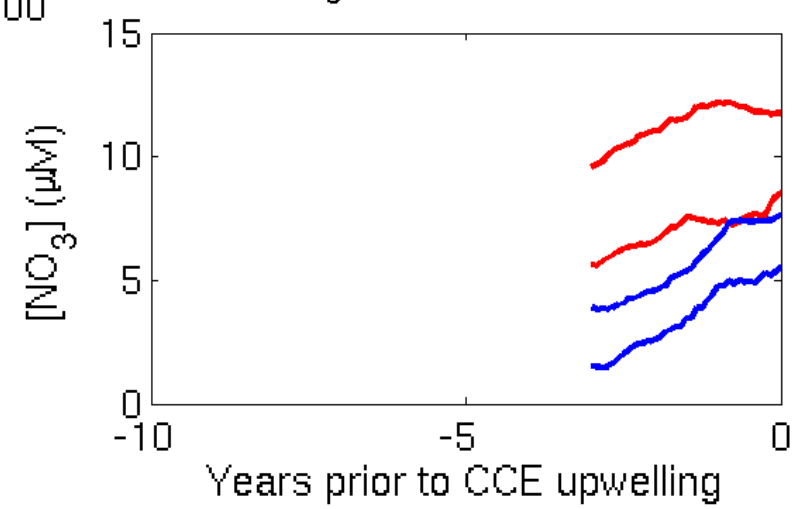


Ventilation of CCE source waters

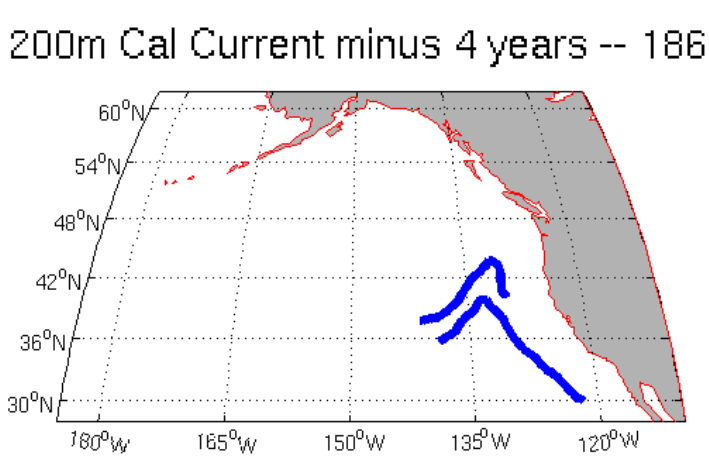


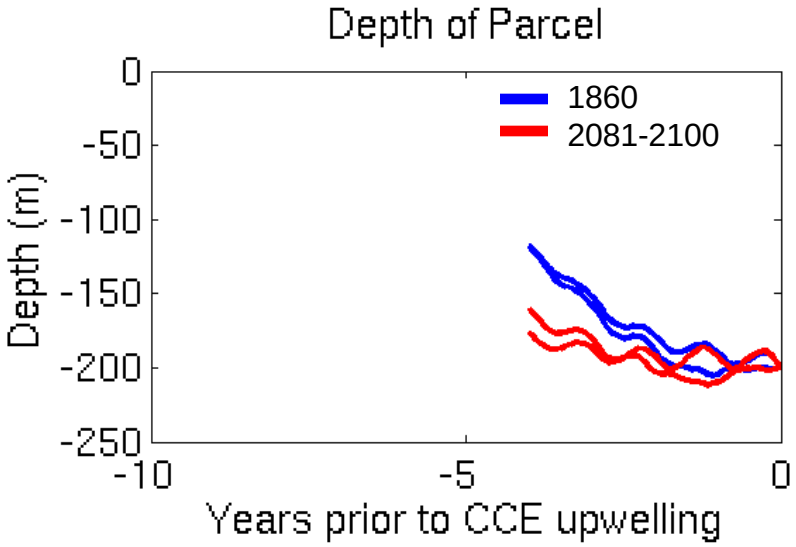


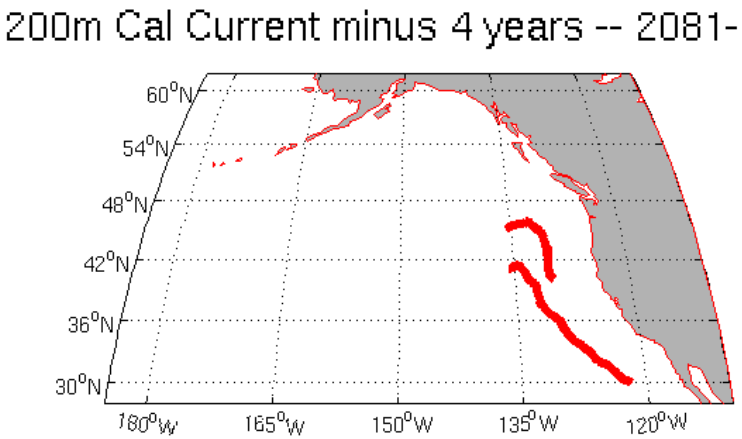


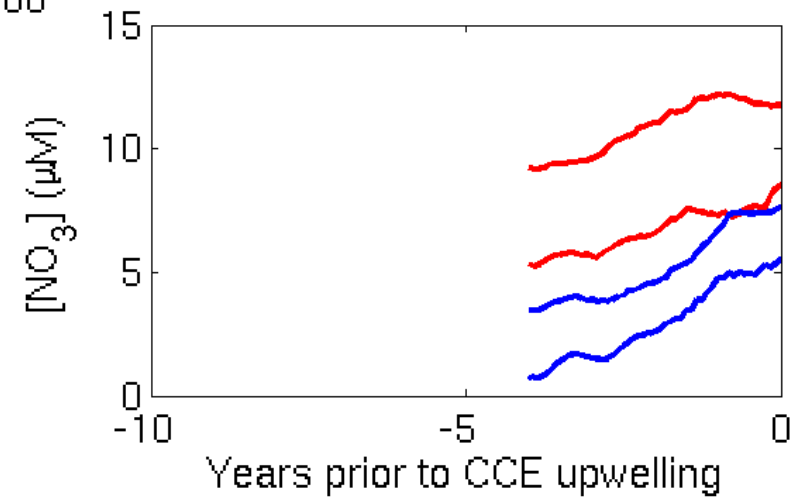


Ventilation of CCE source waters









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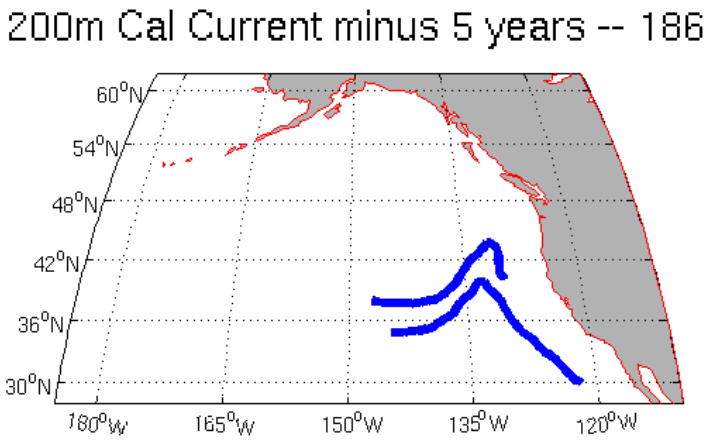

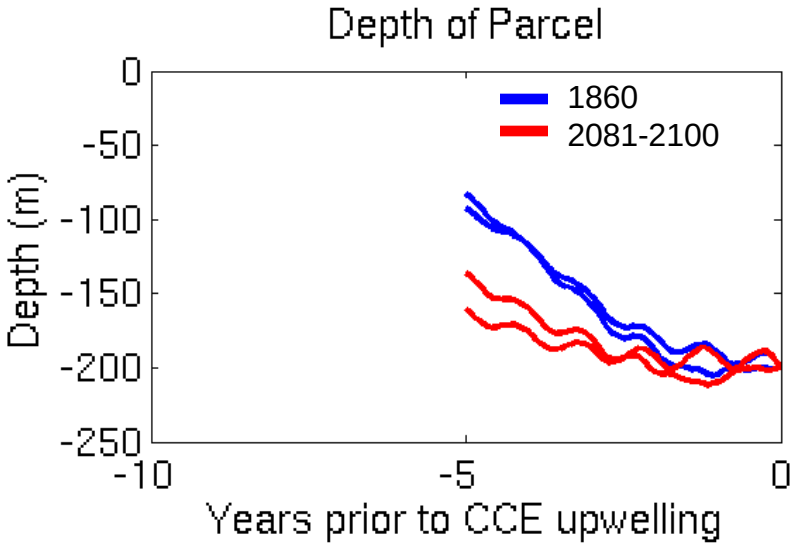

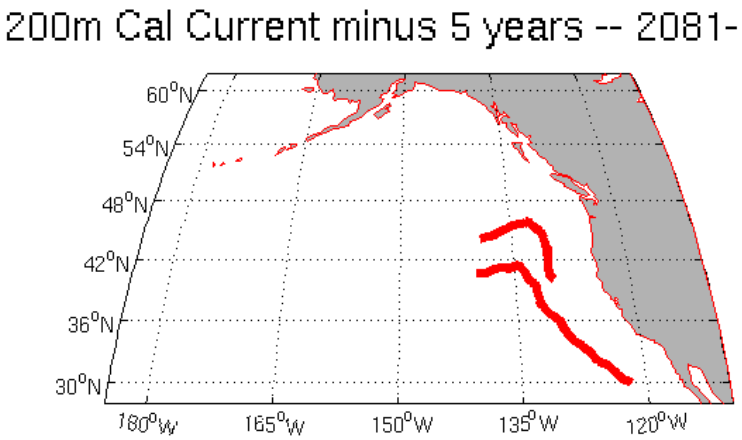

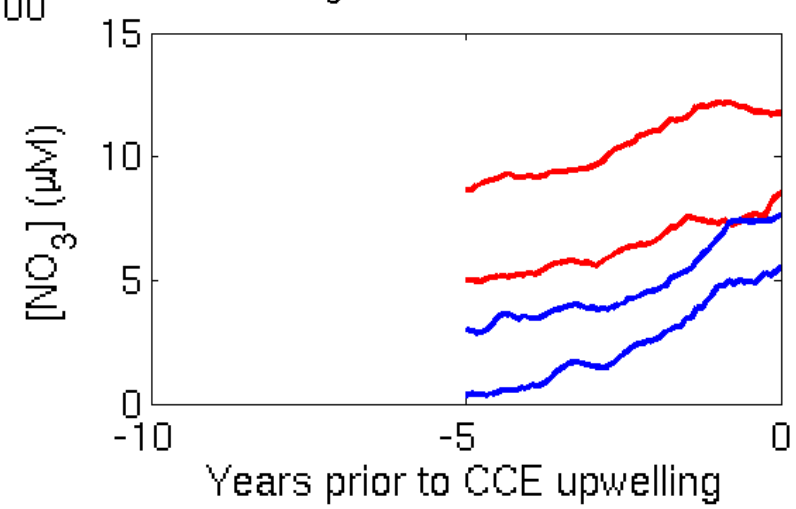

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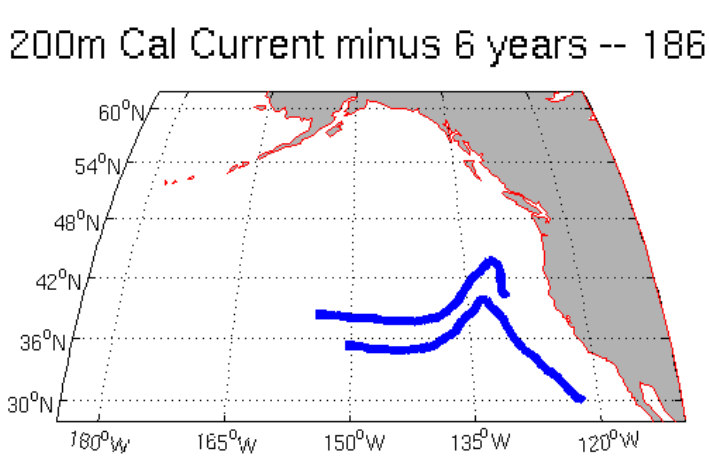

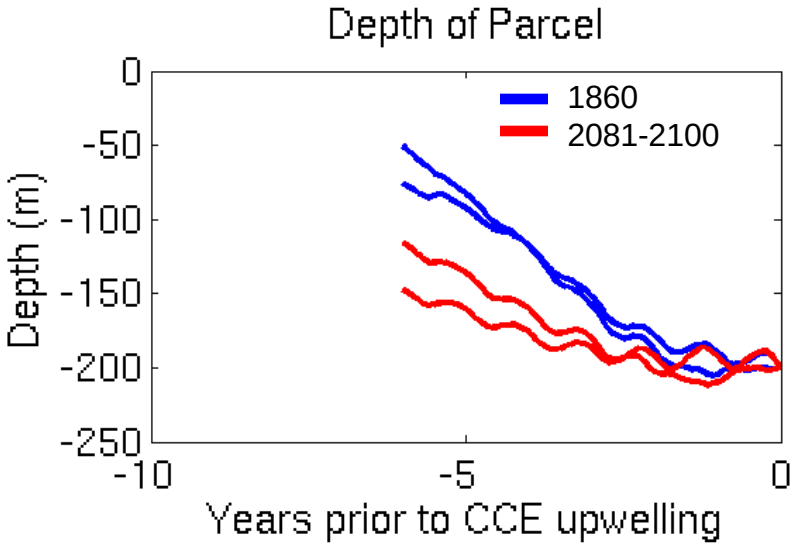

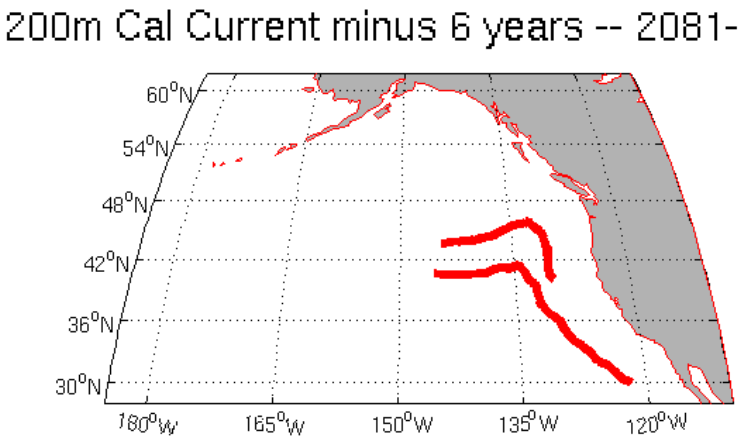

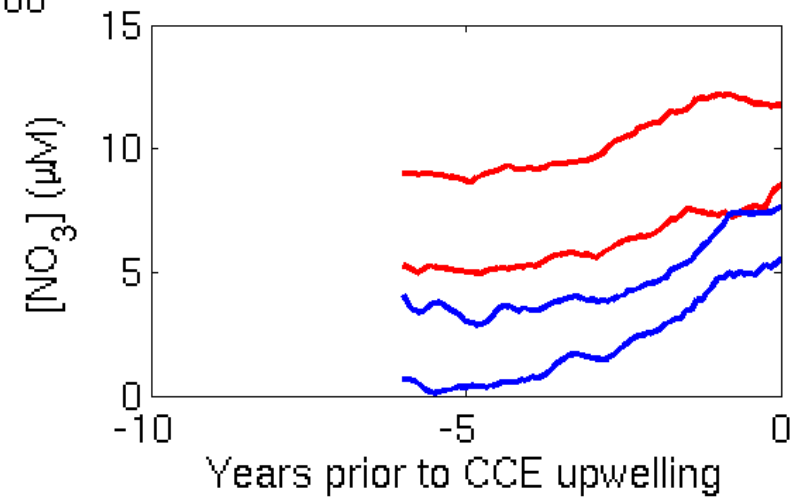

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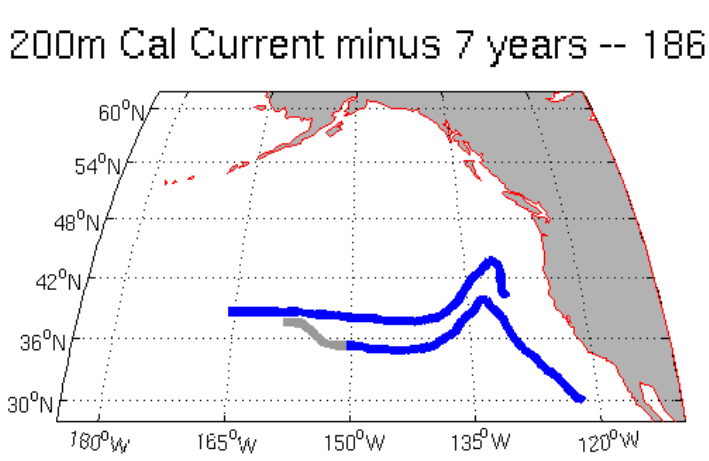
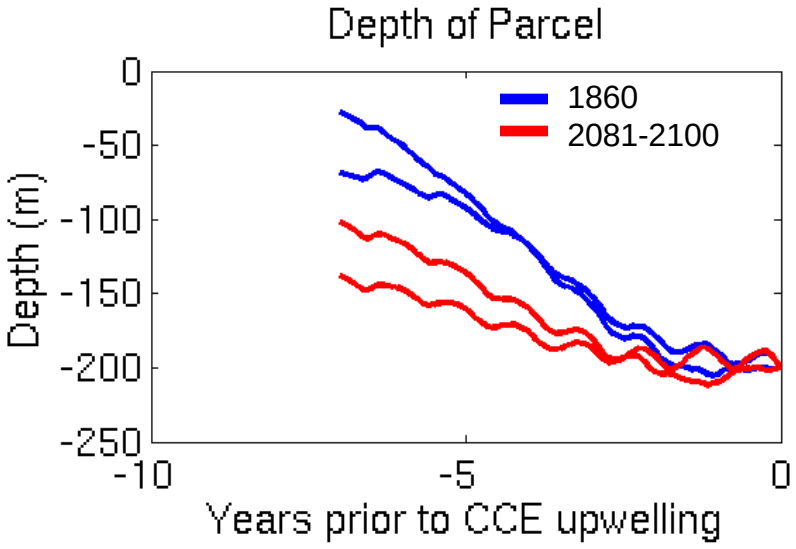
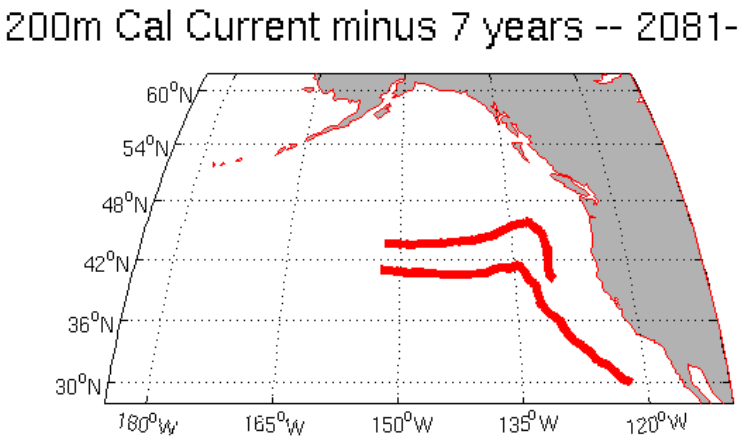
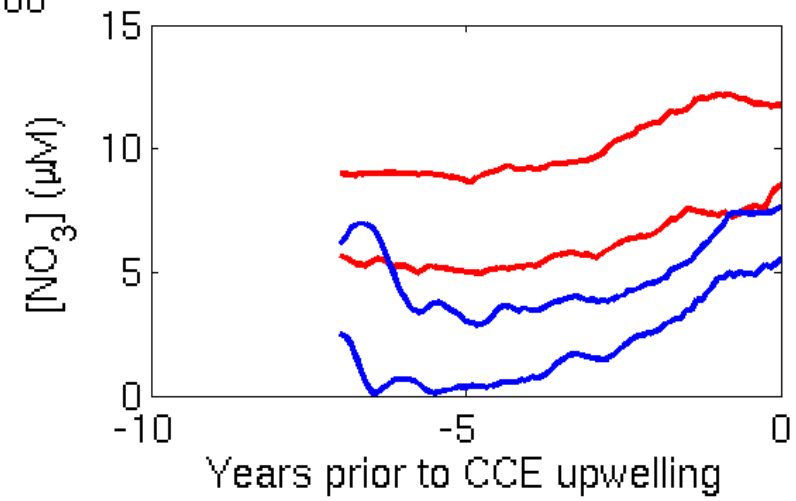


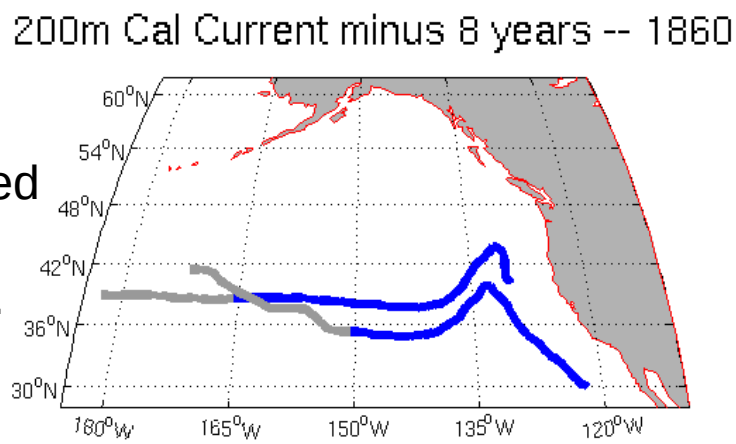


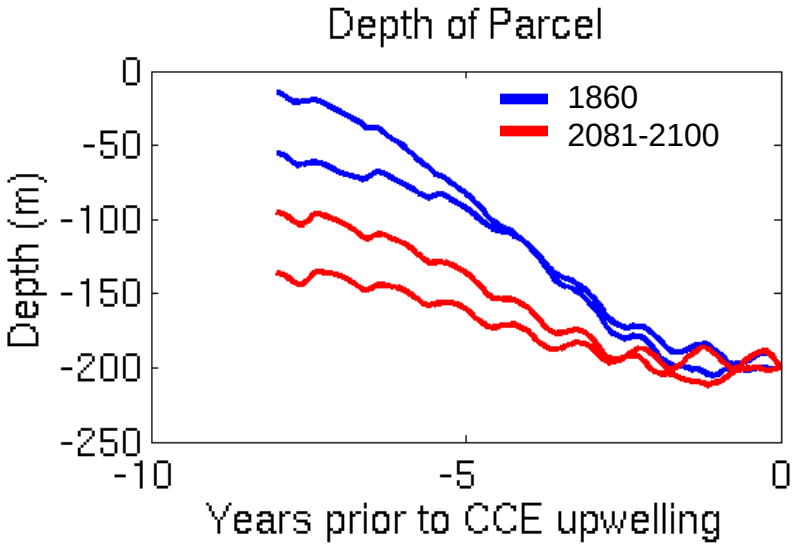




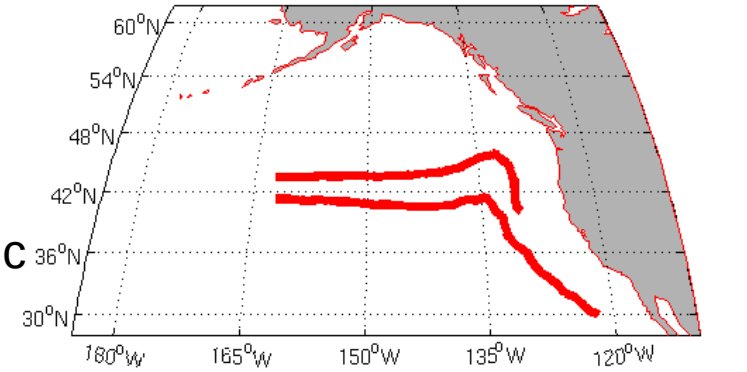
Ventilation of CCE source waters

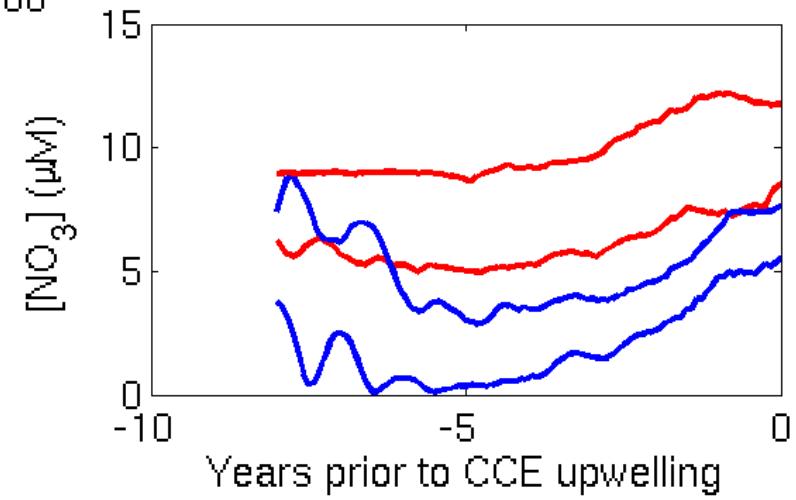
Water ventilated with surface.





Waters remain deep, below euphotic zone.





Ventilation of CCE source waters

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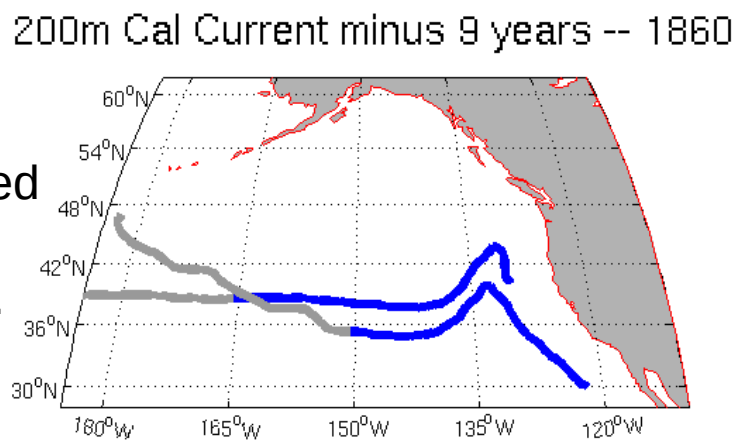

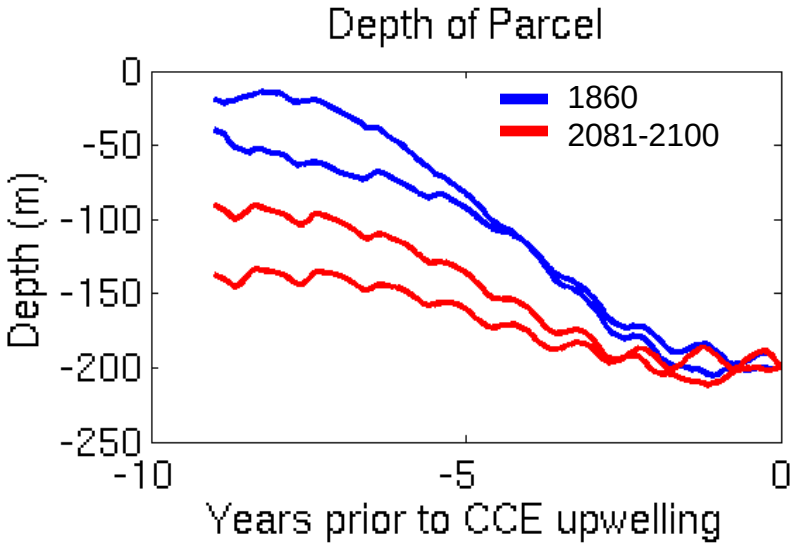

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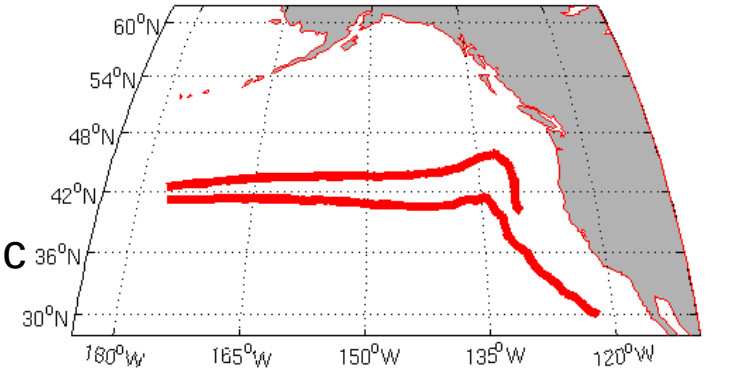

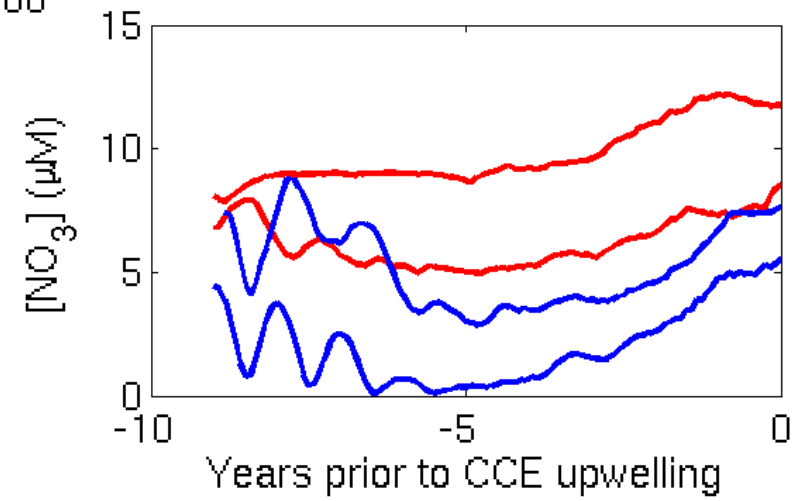

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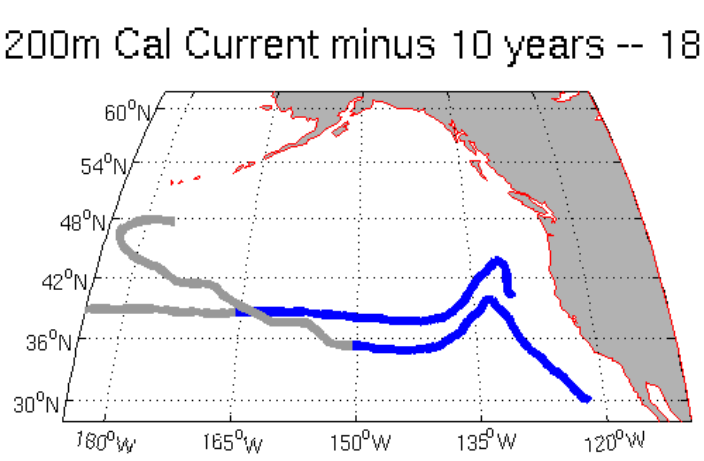
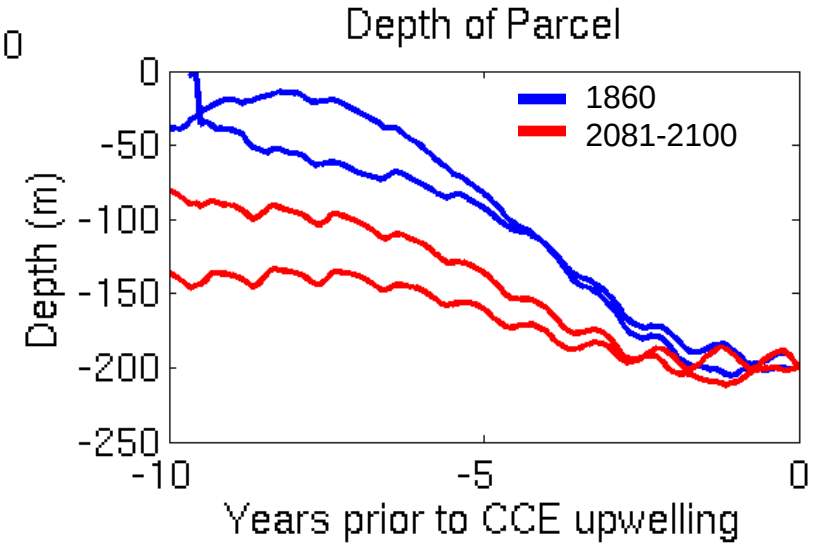
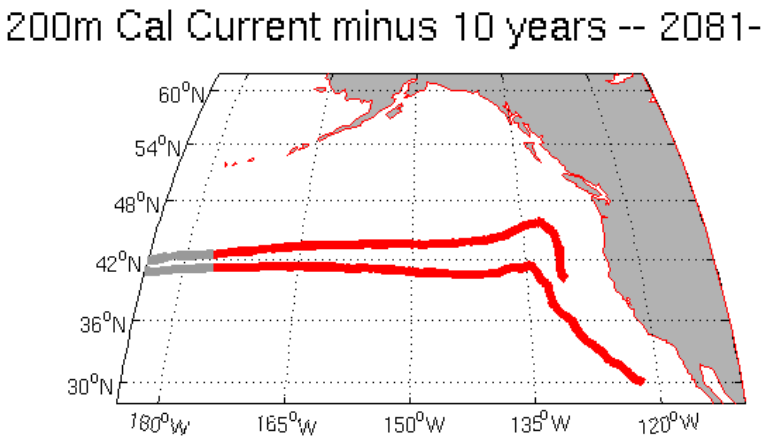
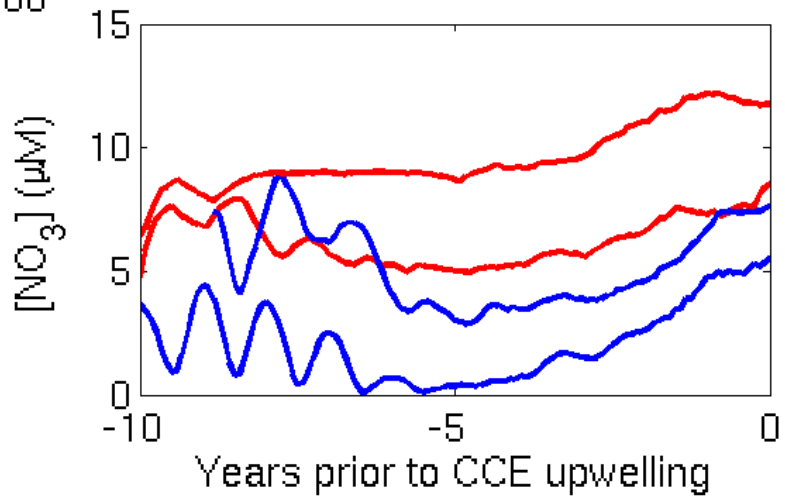








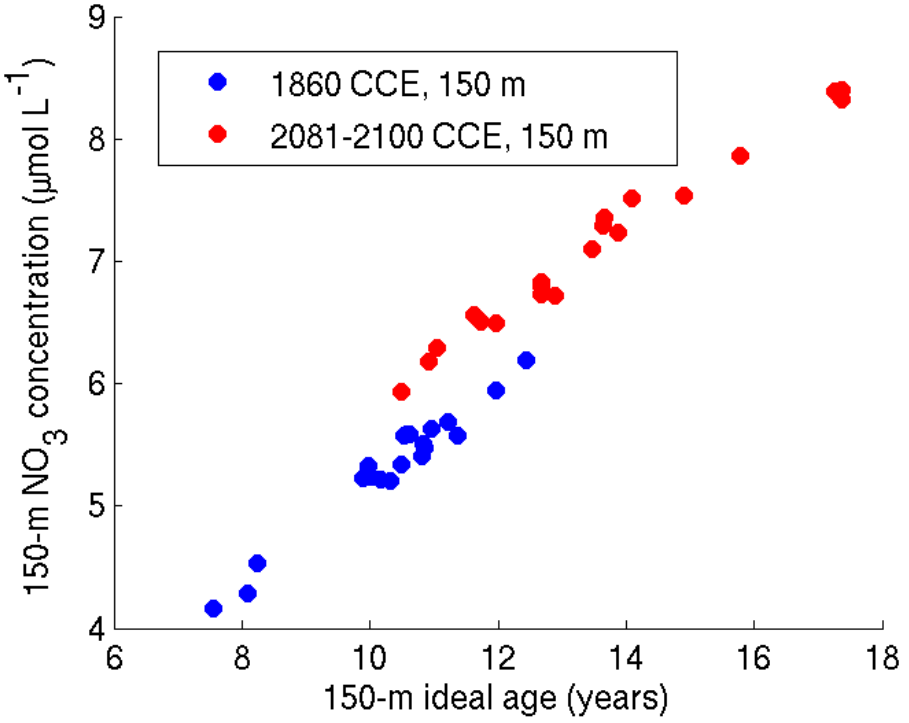
Ventilation of CCE source waters

Waters follow a deeper, *less ventilated* trajectory en route to the CCE. Reduced ventilation of CCE source waters leads to an increase in NO_3 content.

Clue: strong relationship between “ideal age” and nitrate content of the source waters.

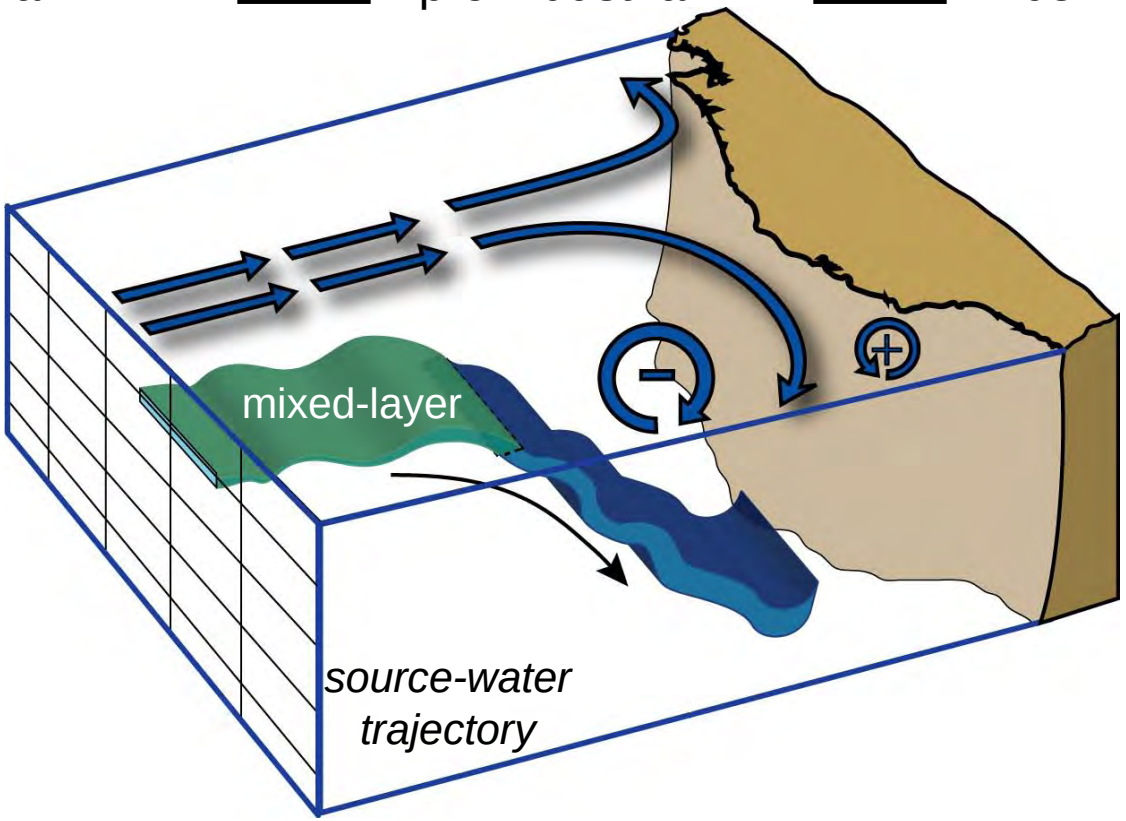
“Age” is reset to zero when the water mass is ventilated at the surface.

This relationship suggests that the increase in nitrate is related to decreased ventilation.



Ventilation of CCE source waters

Conceptual diagram: pre-industrial 2081-2100



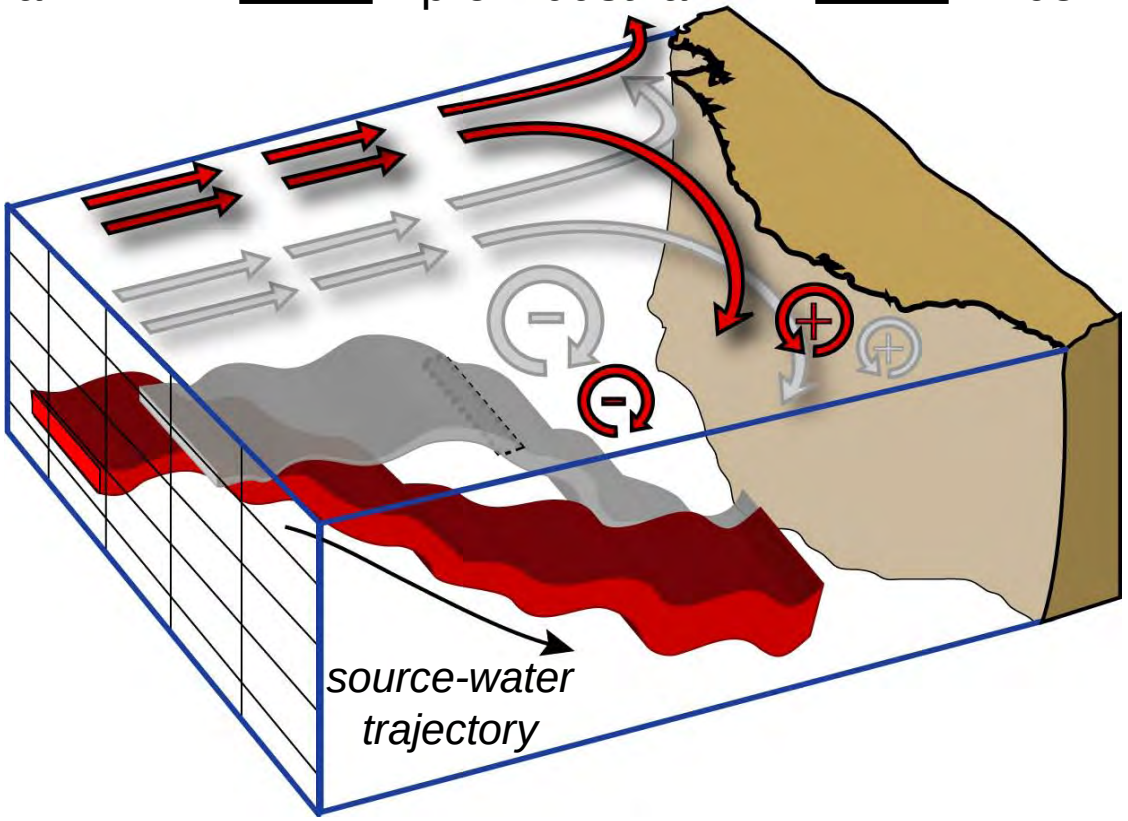
Ventilation of CCE source waters

Conceptual diagram: pre-industrial 2081-2100

poleward shift in westerlies

decreased downwelling over subtropical gyre

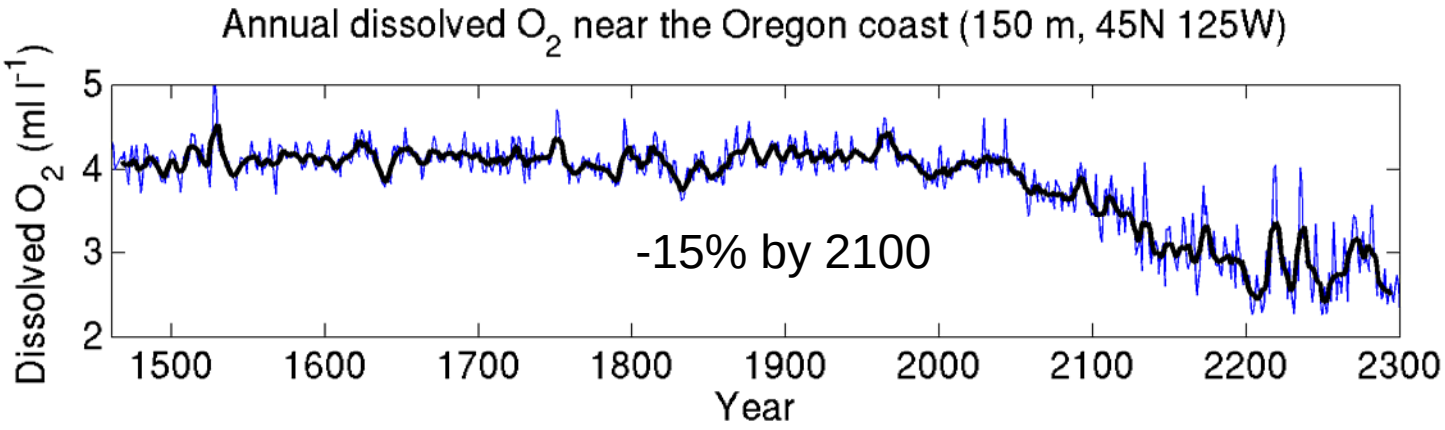
shallower surface mixed layer



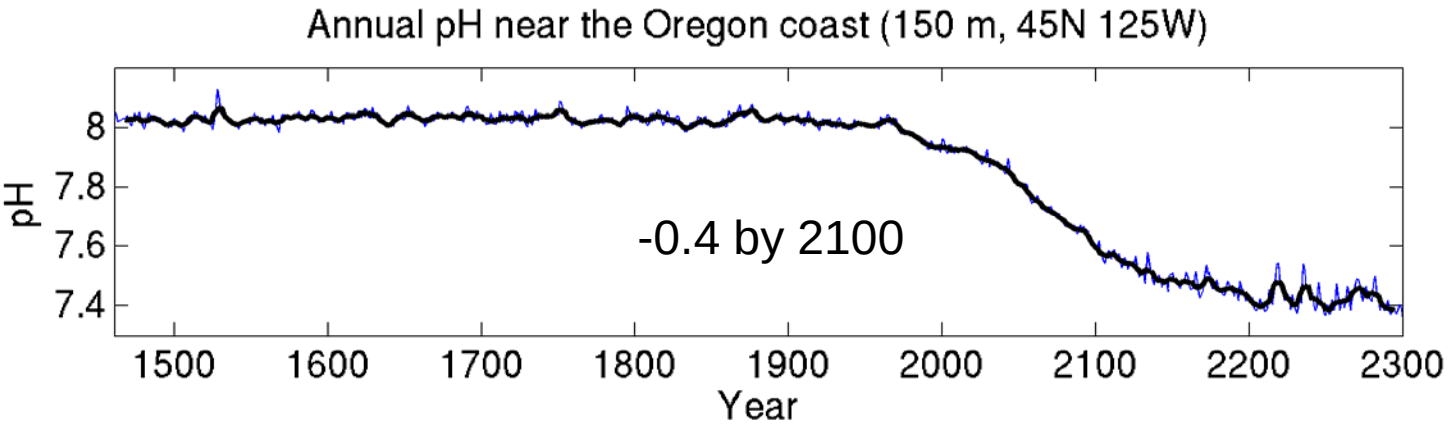
Atmospheric and hydrographic changes have an ecological impact: increased nutrient supply to the CCE with increased North Pacific stratification on centennial scales.

Ventilation of CCE source waters

Decreases in ventilation of source waters to the CCE have biogeochemical consequences aside from increases in NO_3.



DO_2 has decreased by 5% since 1860 and will likely decline by 15% by 2100.



pH has decreased by 0.1 unit since 1860 and will likely decline by 0.4 units by 2100.

Conclusions

GFDL's Earth System Model (ESM2.1) coupled with a biogeochemistry model (TOPAZ) projects that nitrate content, primary, and secondary production of the CCE will increase in the coming century with global warming. Oxygen content and pH will continue to decline.

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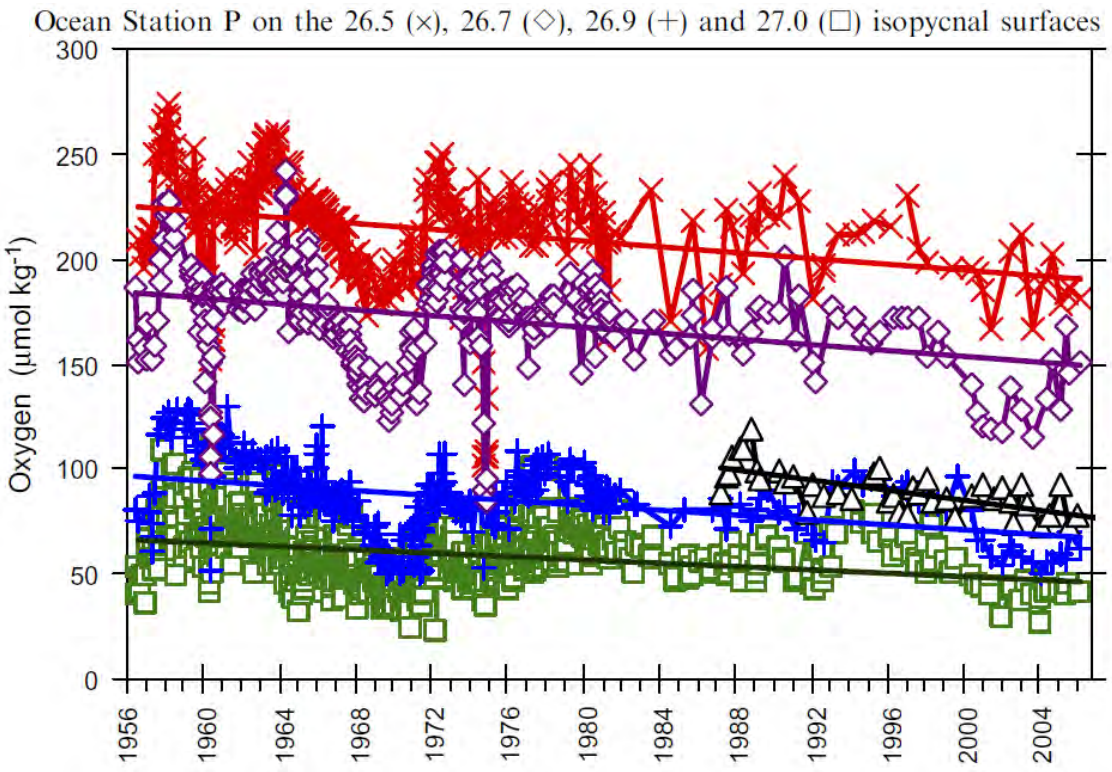
Are we yet able to see this signal in measurements?

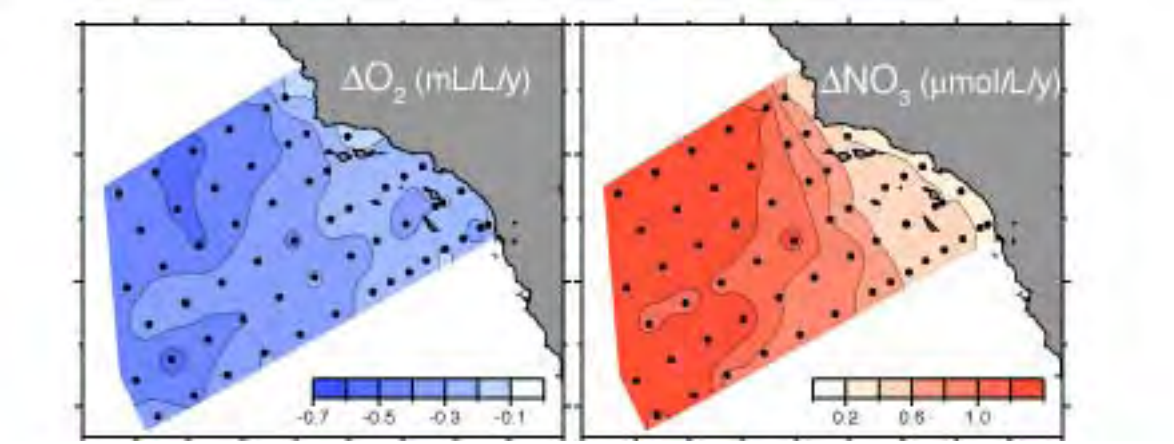
Conclusions



Whitney, *et al*. (2007, *Prog. Oceanogr.*)

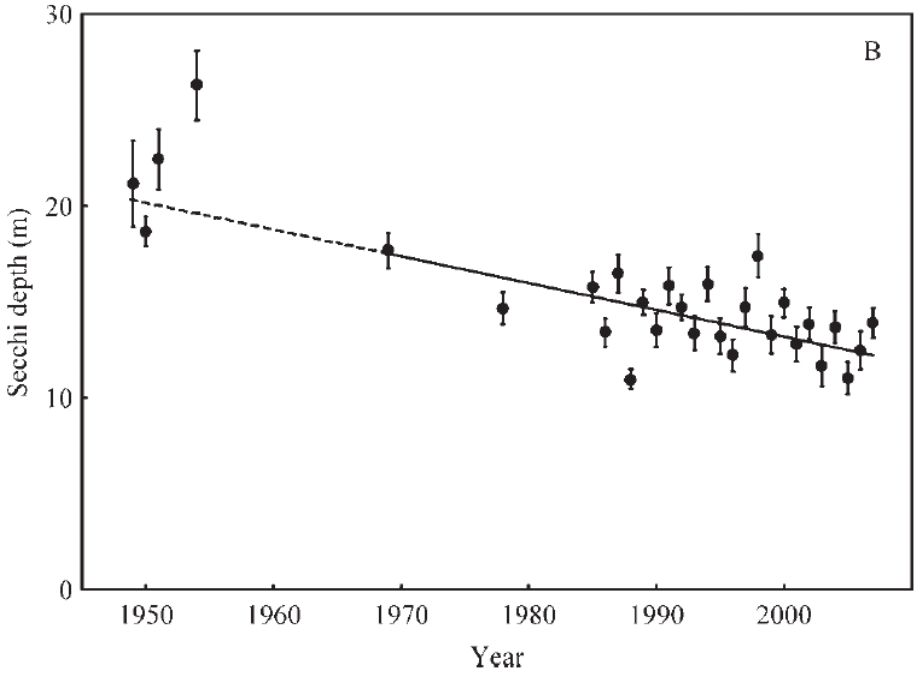
Conclusions

Differences in σ_θ = 26.5, (1999-2009) – (1984-1998)



(Courtesy of Steven Bograd at PFEL, Pacific Grove)

Conclusions



Secchi depth (a proxy for euphotic zone depth and chlorophyll content) has shoaled in in the CCE over 50 years.

(Aksnes and Ohman, 2009, *Limnol. Oceanogr.*)

Conclusions

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This result, though counterintuitive, can be attributed to increased stratification, decreased mixing, and less negative wind-stress curl over the subtropical North Pacific.

This projection has no clear analogue in the observational record; conditions of warm, nutrient enriched waters are unlike what we have observed directly. However, we may be seeing the first signals in the longest time series.

Conclusions

Regarding continued use of climate models for regional projections of ecosystem conditions:

Response at the regional scale may differ substantially from that at the basin scale.

Current paradigms relating climate variability and fisheries may not persist over the long term.

- Empirical relationships may lose explanatory power
- Importance of different mechanisms may change

Regional studies of climate change need to be framed in the context of global scale change. Dominant influences may be overlooked if changes at the regional boundaries are not considered.

Thanks!


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