Climate change and aerobic habitat in the California Current System

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In Collaboration with:
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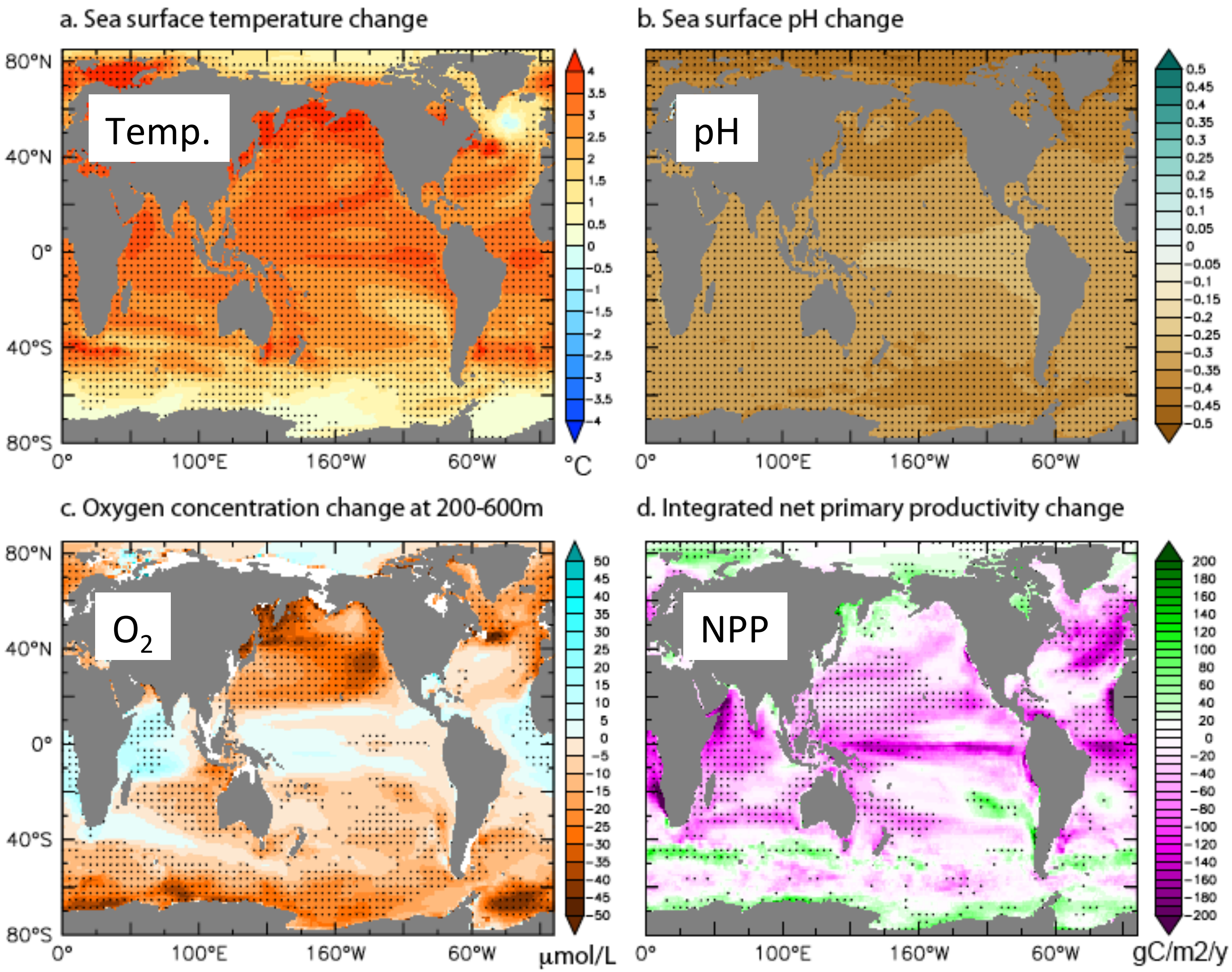
And Funding from:

Global Ocean Climate Change



North Pacific a region of strong ocean change.

However:

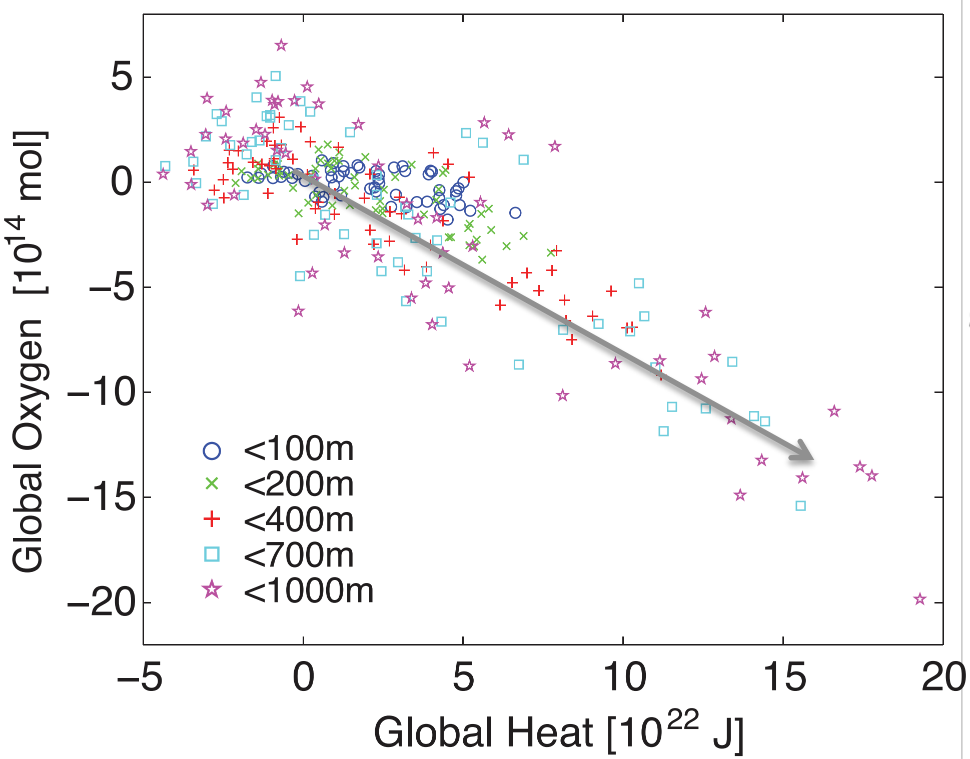
Coastal oceans poorly resolved in Global Earth System Models.

They disagree on magnitude and/or direction of change in key ecosystem properties, NPP and O_2.

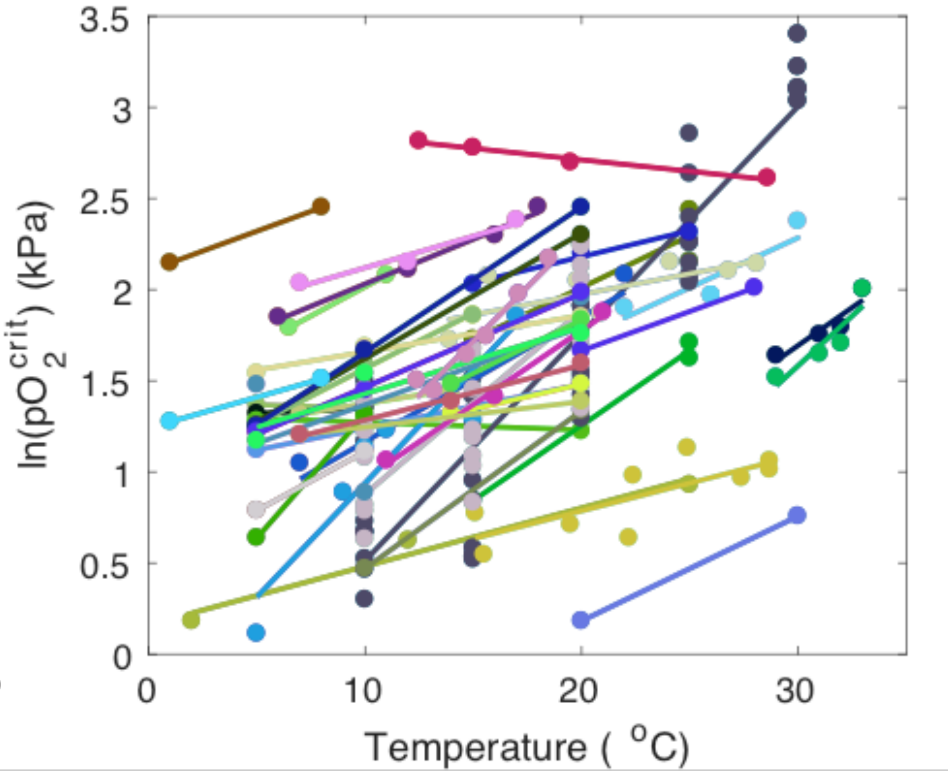
Bopp et al. [2013]

Temperature and O_2

Ocean O_2 content decreases with Temperature



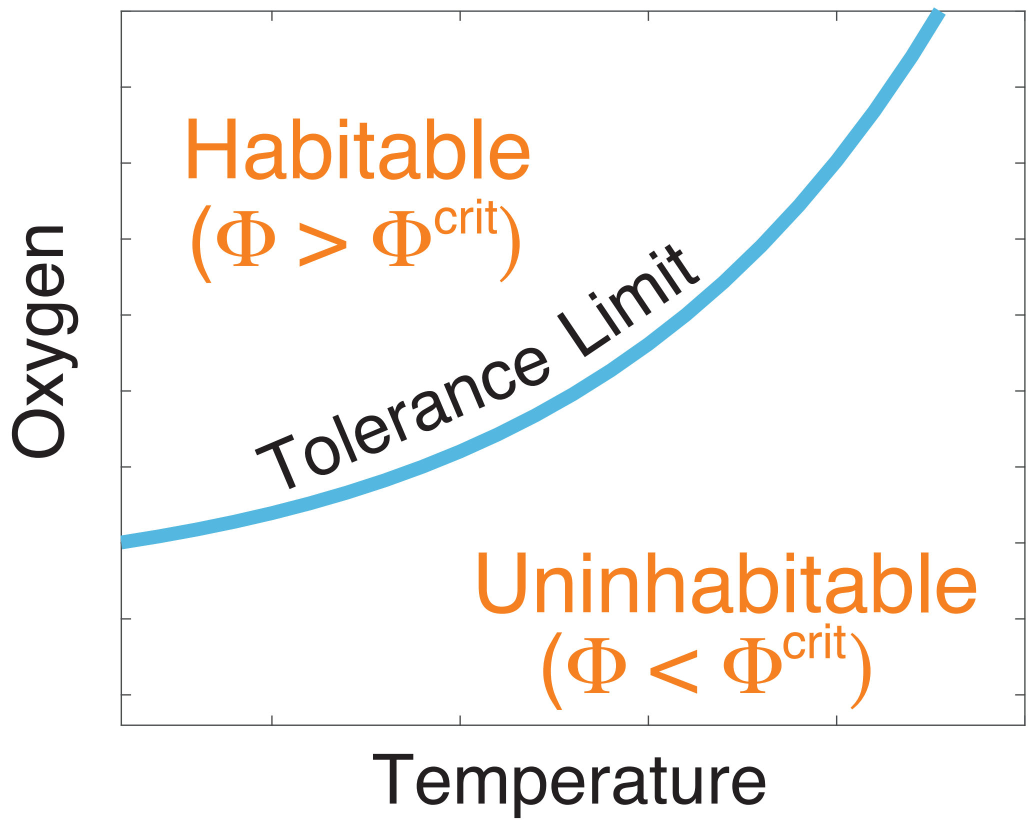
Organism O_2 requirement rises with Temperature



Ito et al. [2017]

Penn et al. [2018]

Habitat: A Metabolic Index



The Metabolic Index, defined as ratio of potential O_2 supply to resting O_2 demand by organism:

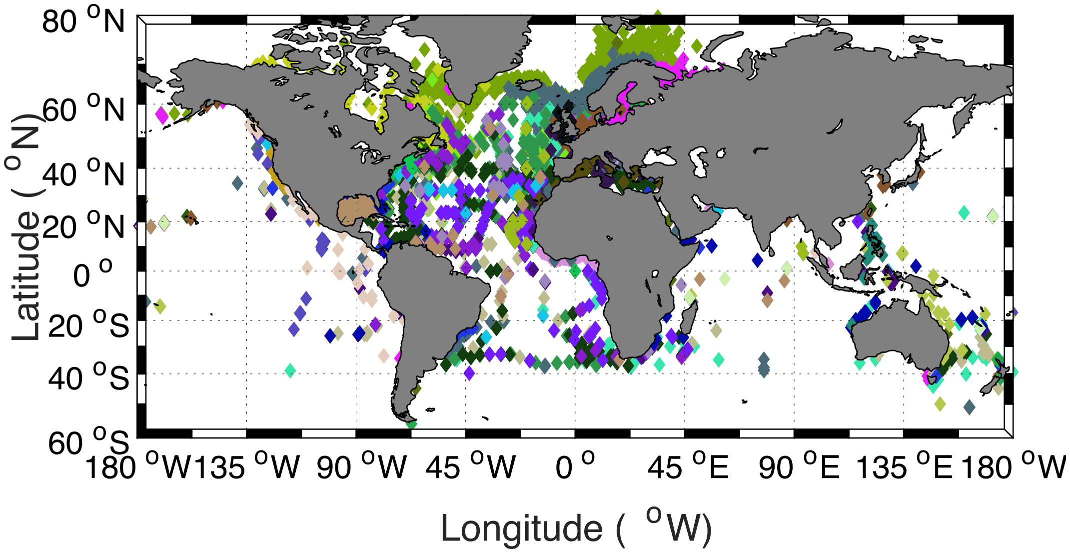
$$\Phi = A_o B^{\varepsilon} pO_2 \exp(E_o / k_B T)$$

Environmental parameters:
- Oxygen pressure (pO_2)
- Temperature (T)

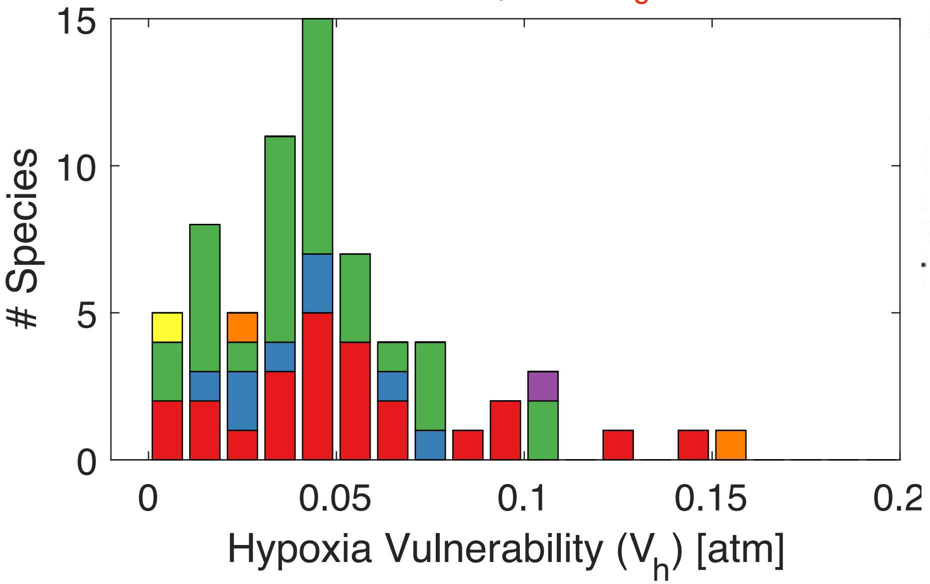
Physiological parameters:
- Oxygen sensitivity
  - -Height of curve ($1/A_o$)
- Temperature sensitivity
  - -Slope of curve (E_o)

Deutsch et al. [2015]

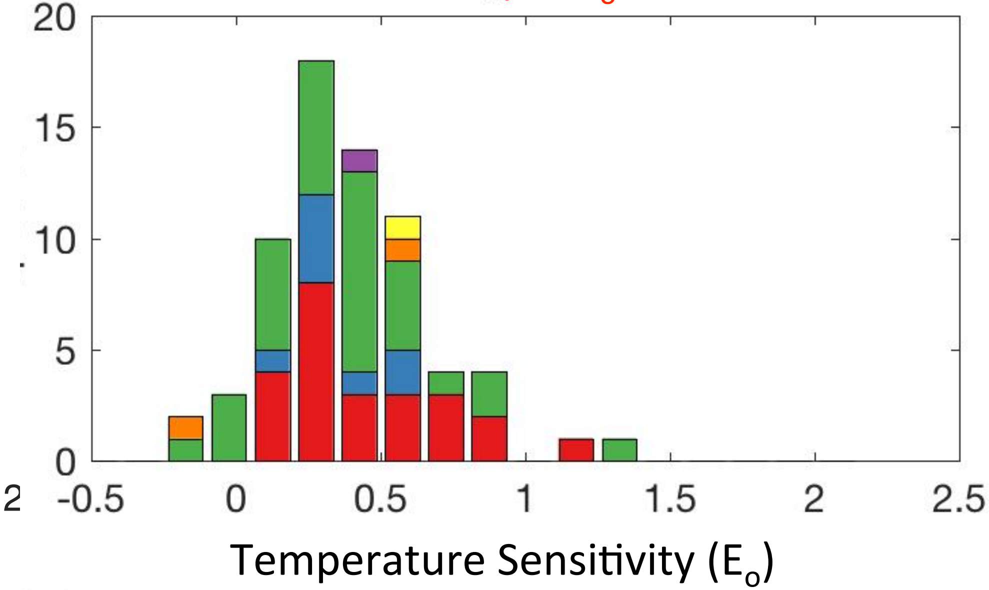
Global Trait Diversity



Intercept ($1/A_o$)

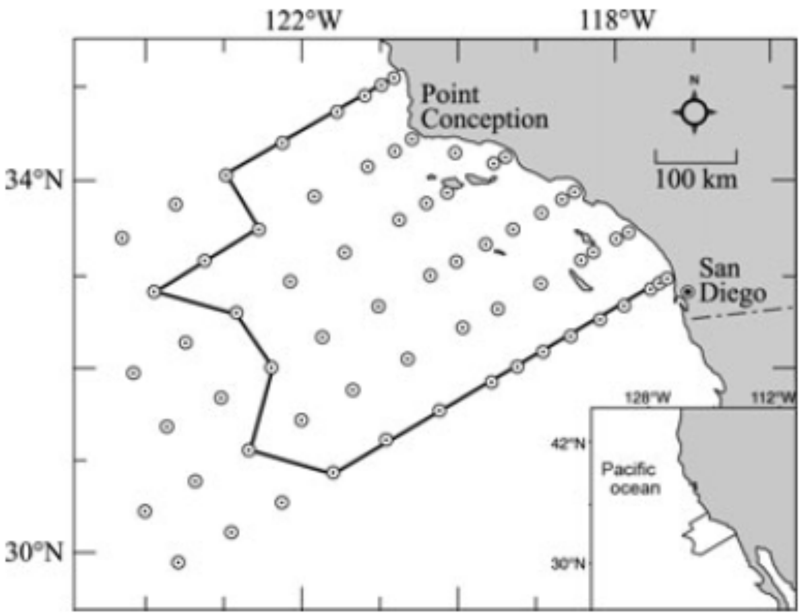


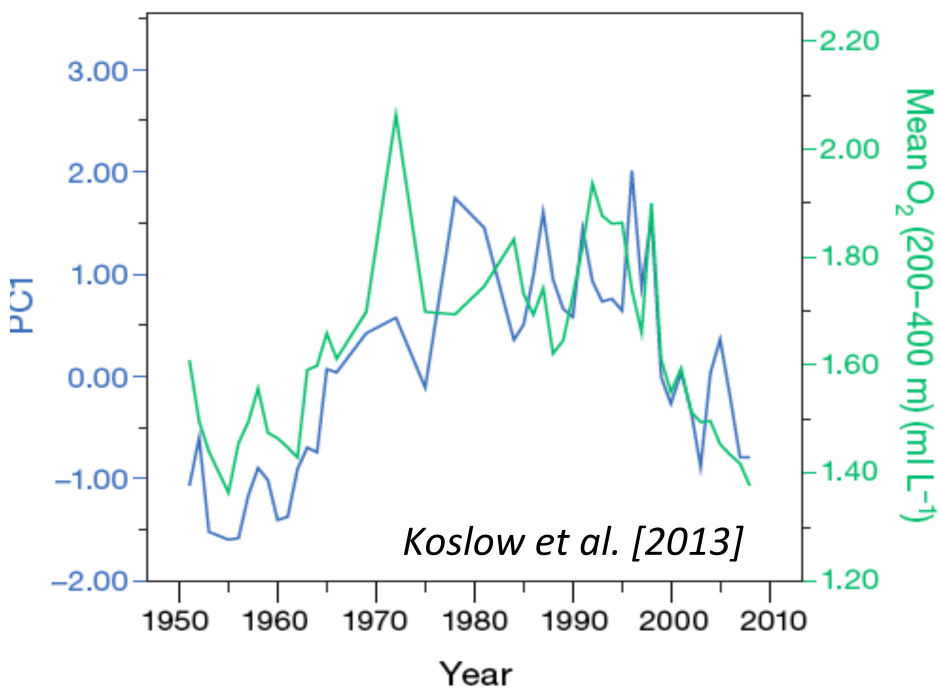
Slope (E_o)



Historical Variability

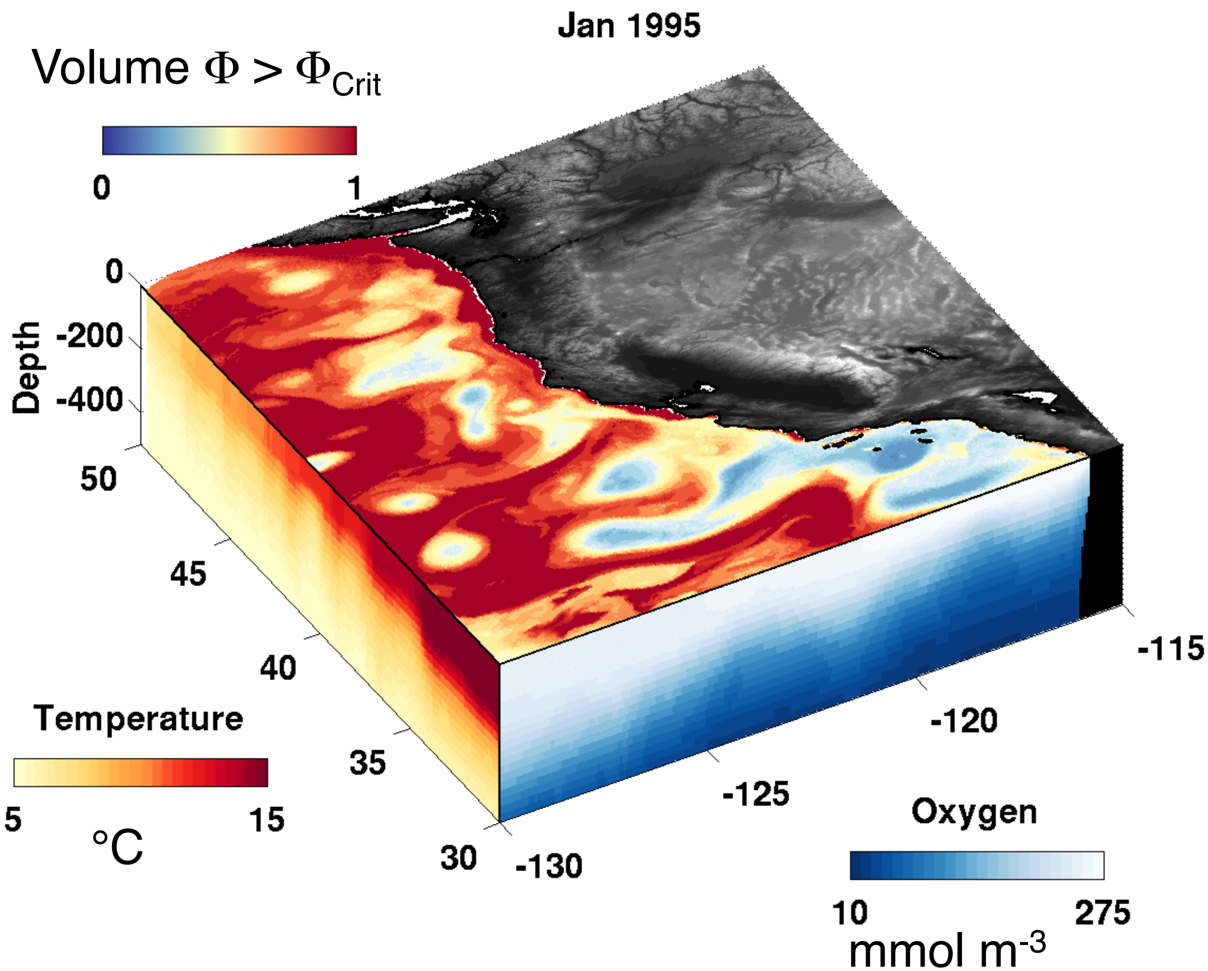
In the Southern California Current, decadal changes in small pelagic fish abundance are correlated with regional O_2 changes.





None of these species has measured Metabolic Index traits.
Strategy: Determine species for which habitat boundaries and time variability can be explained by same set of traits (A_o, E_o).

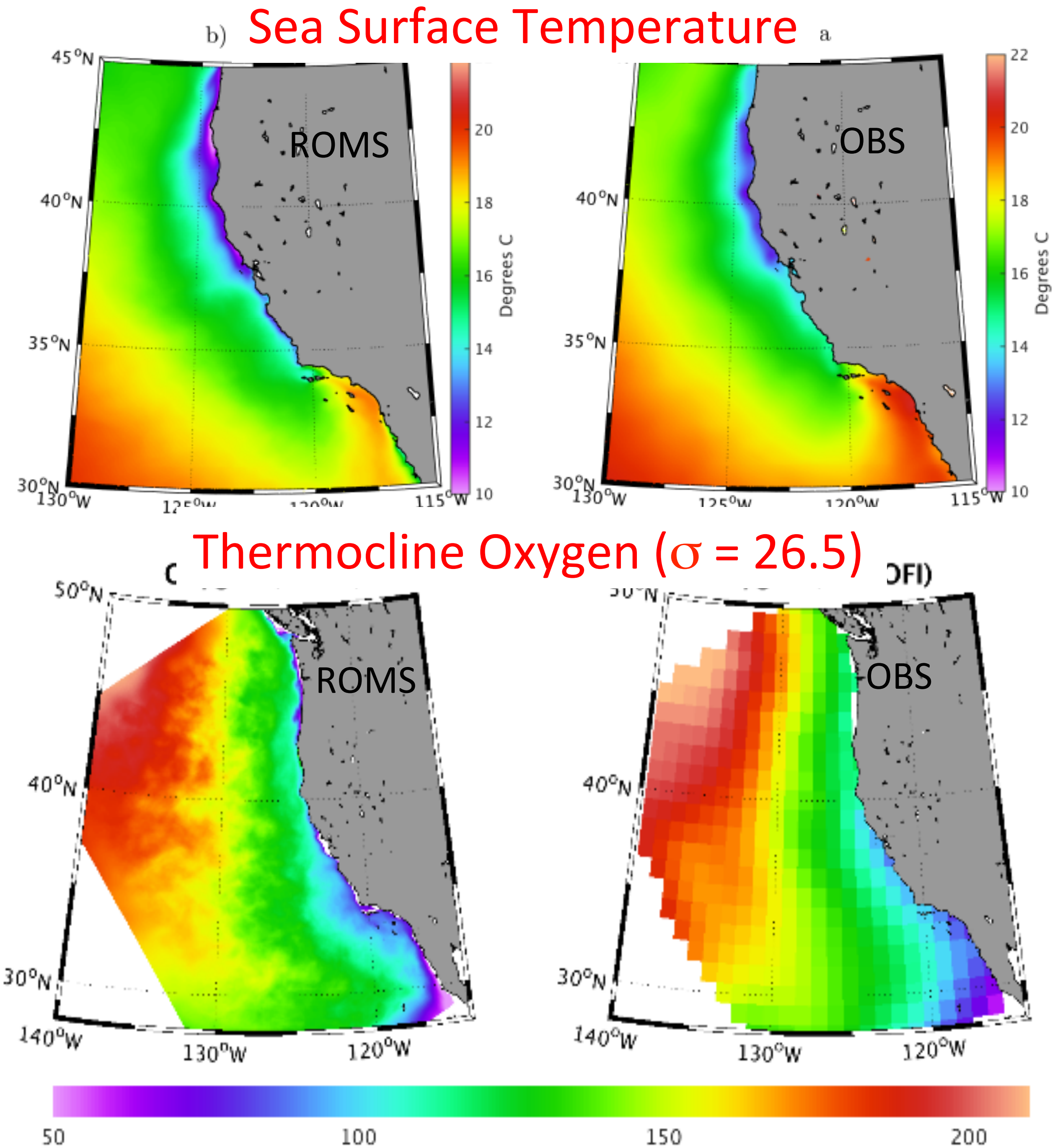
Dynamic Habitat



How has (and will) climate change cause aerobic habitat change and associated shifts in species geographic range or abundance?

These questions require models that resolve coastal processes with high fidelity to (often sparse) observations.

Model Validation

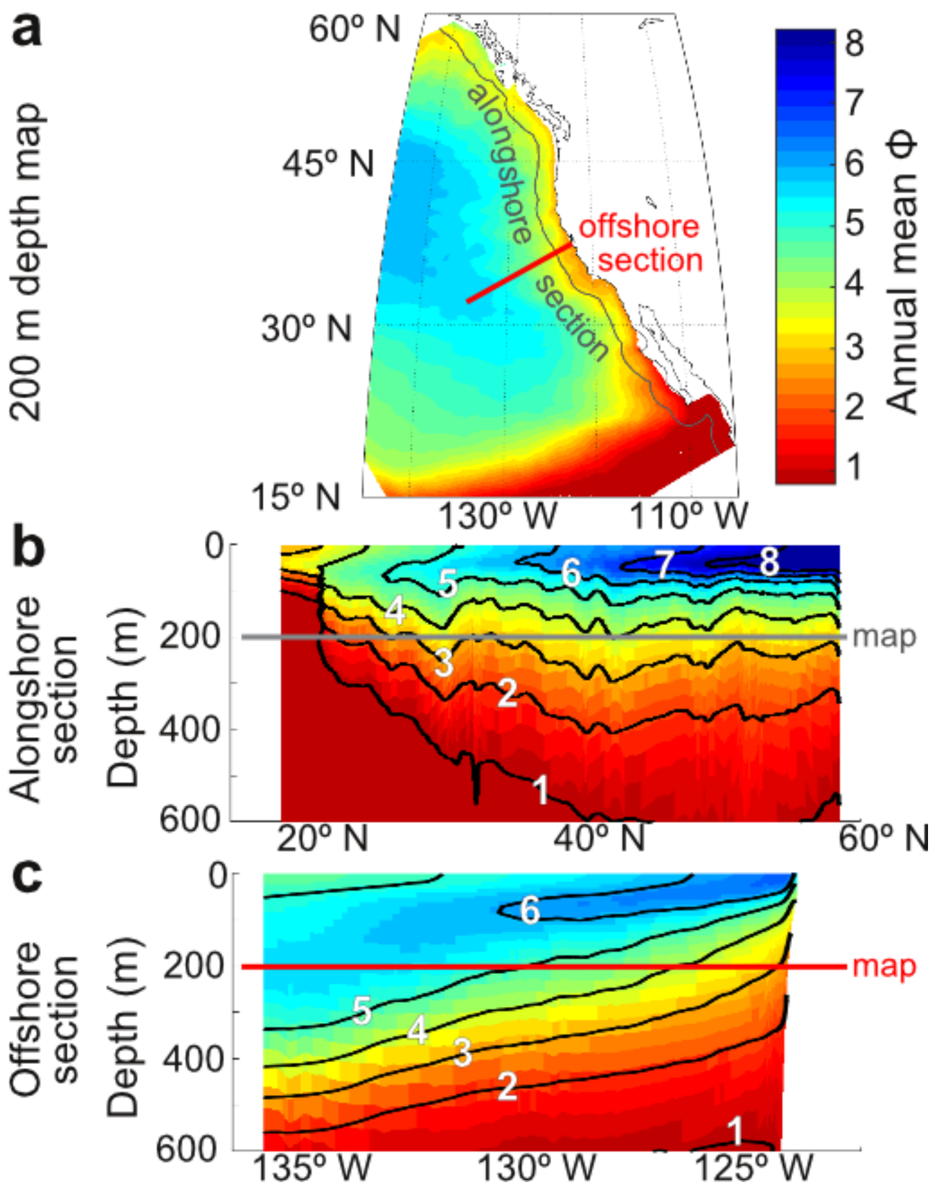


Model physical solution validated against historical hydrographic and satellite observations: Temp, Salinity, SSH, Currents, Eddy energy, nutrients, NPP, oxygen, CO2 parameters

Biases generally low, particularly for well sampled fields needed for Metabolic Index.

Renault et al. [in review]
Deutsch et al. [in review]

CCS Metabolic Index



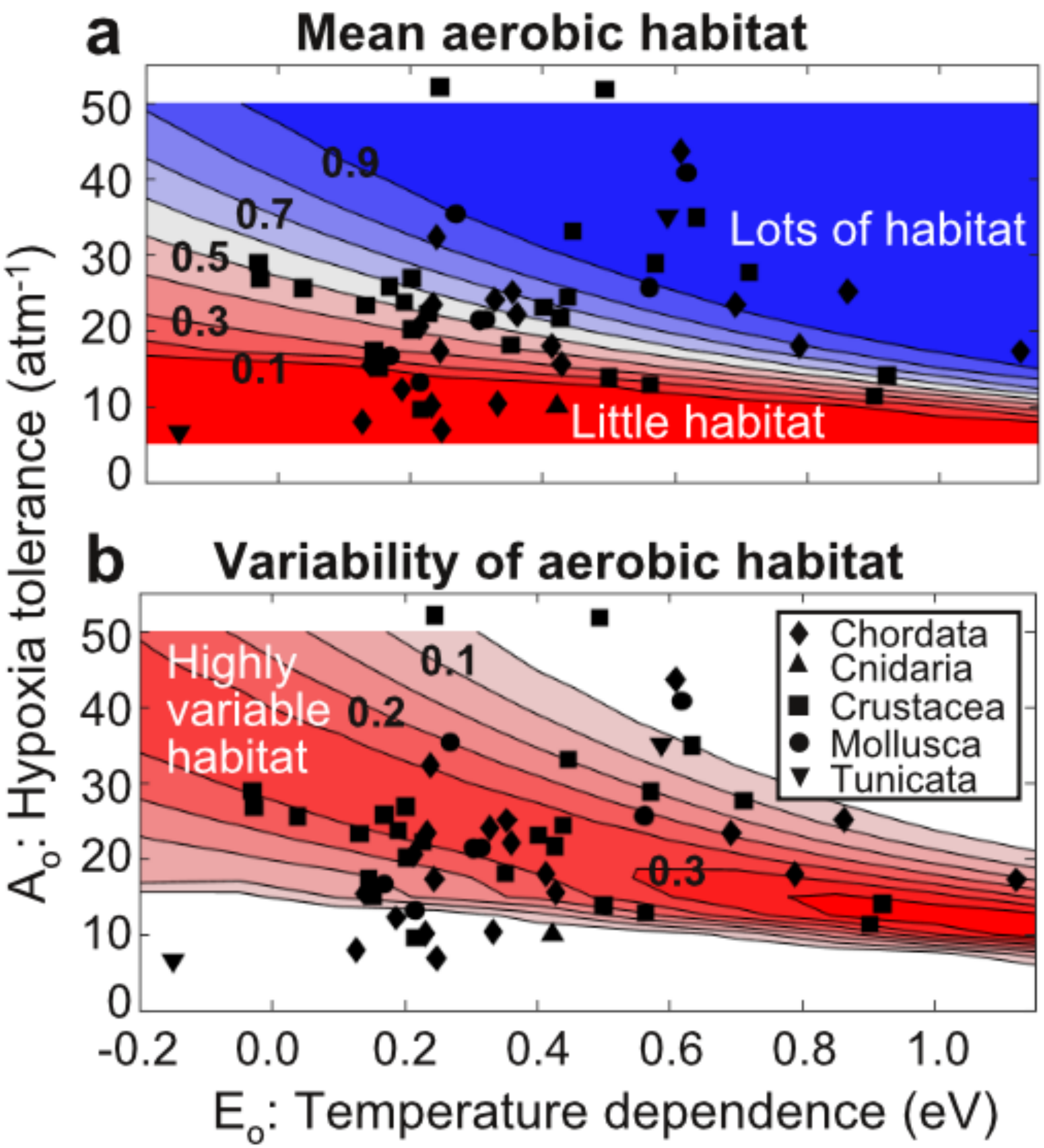
Distribution of Metabolic Index for average species traits:

a) Decreases offshore

b) Decreases with depth

c) Decreases to the south

Aerobic Habitat

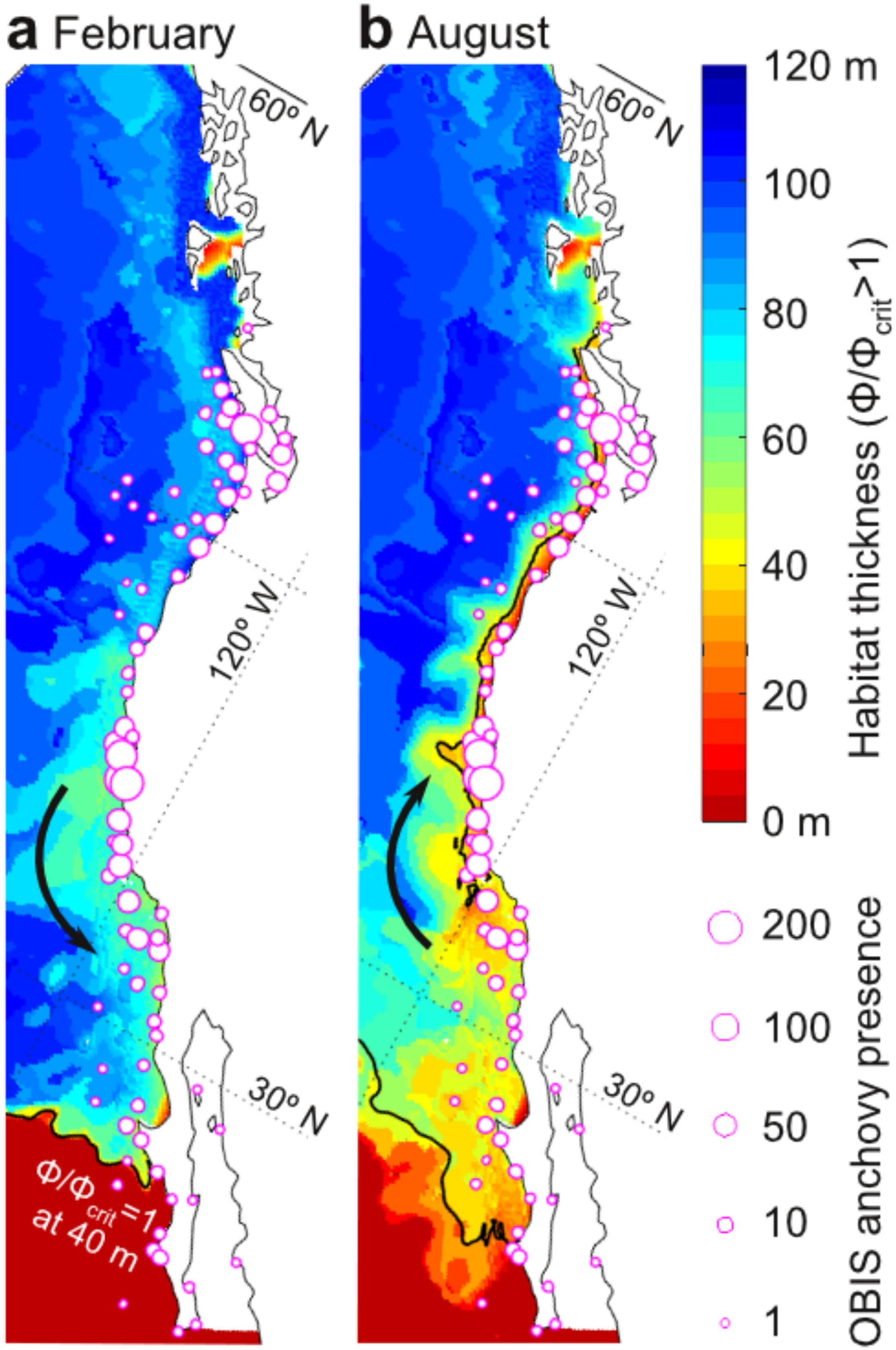


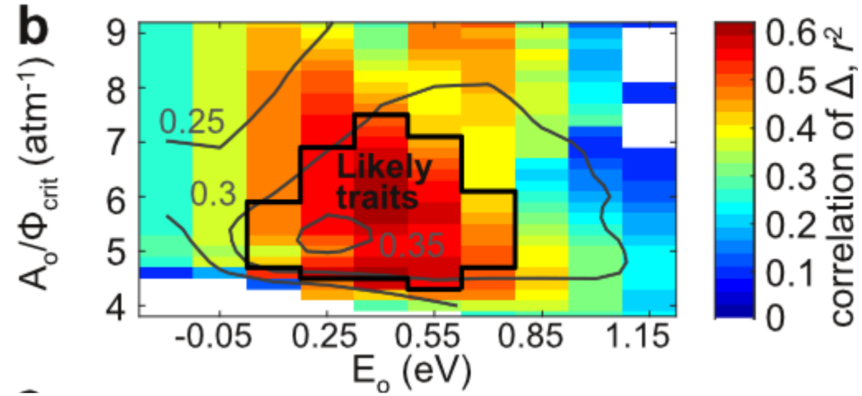
Most species in CCS likely experience strong variability in aerobic habitat.

Can we see this reflected in species abundance?

Howard et al. [in review]

Historical Anchovy distribution

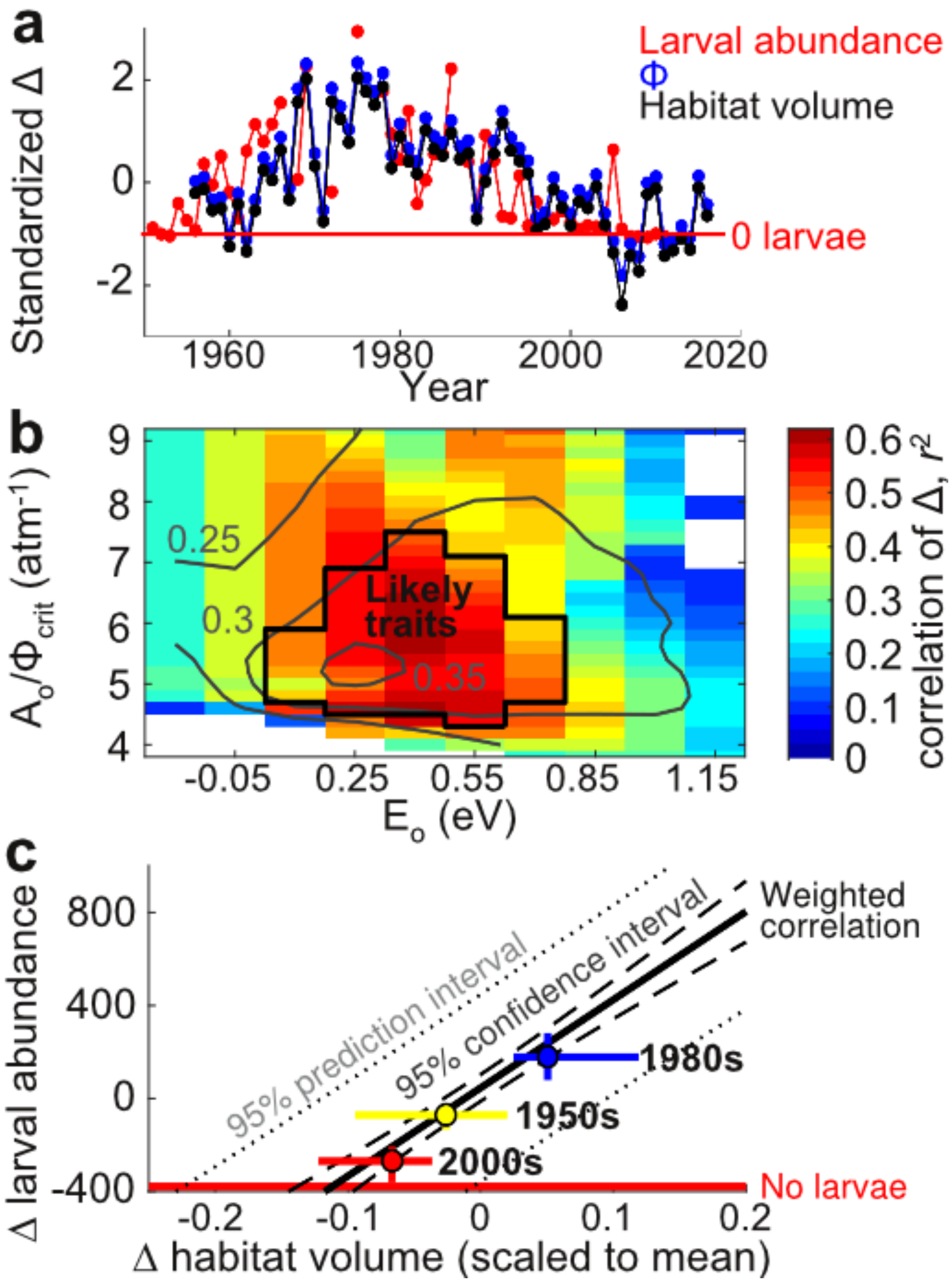




Historical variation of anchovy abundance strongly correlated to aerobic habitat fluctuations from decadal climate variability.

Howard et al. [in review]

Decadal Anchovy variability

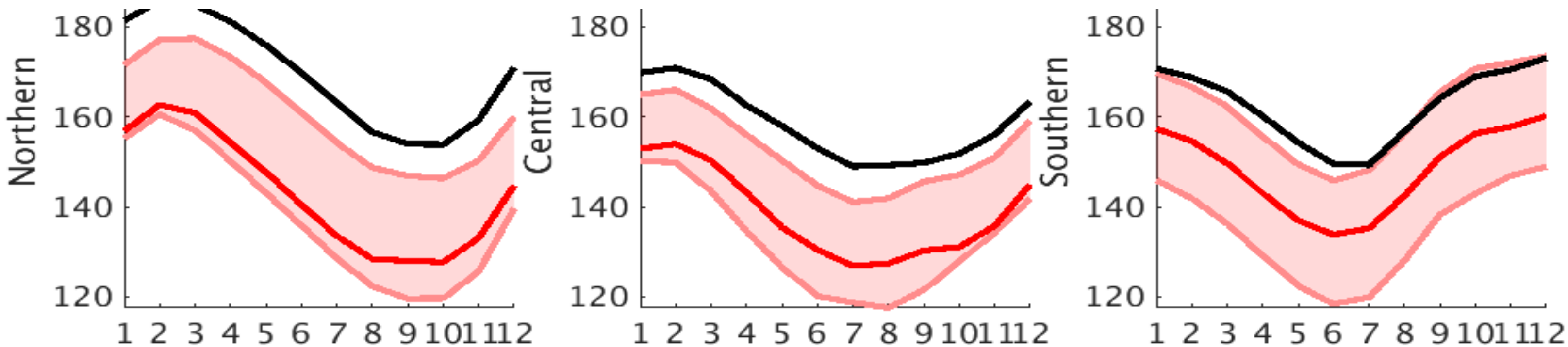


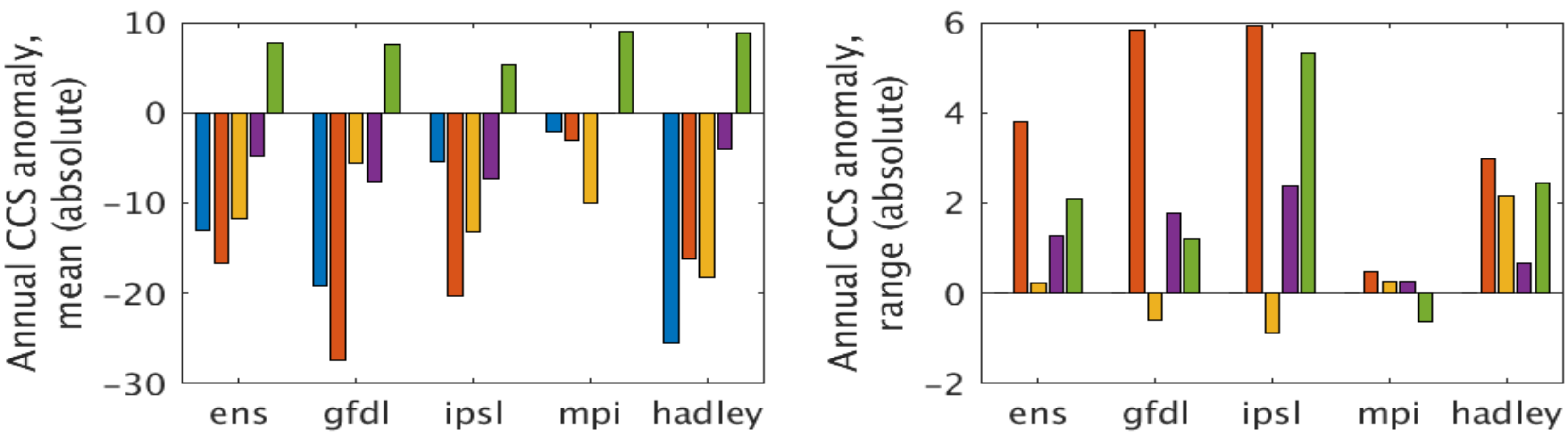
Historical variation of anchovy larval abundance in southern CCS strongly correlated to aerobic habitat fluctuations from decadal climate variability.

Howard et al. [in review]

Oxygen loss in the CCS

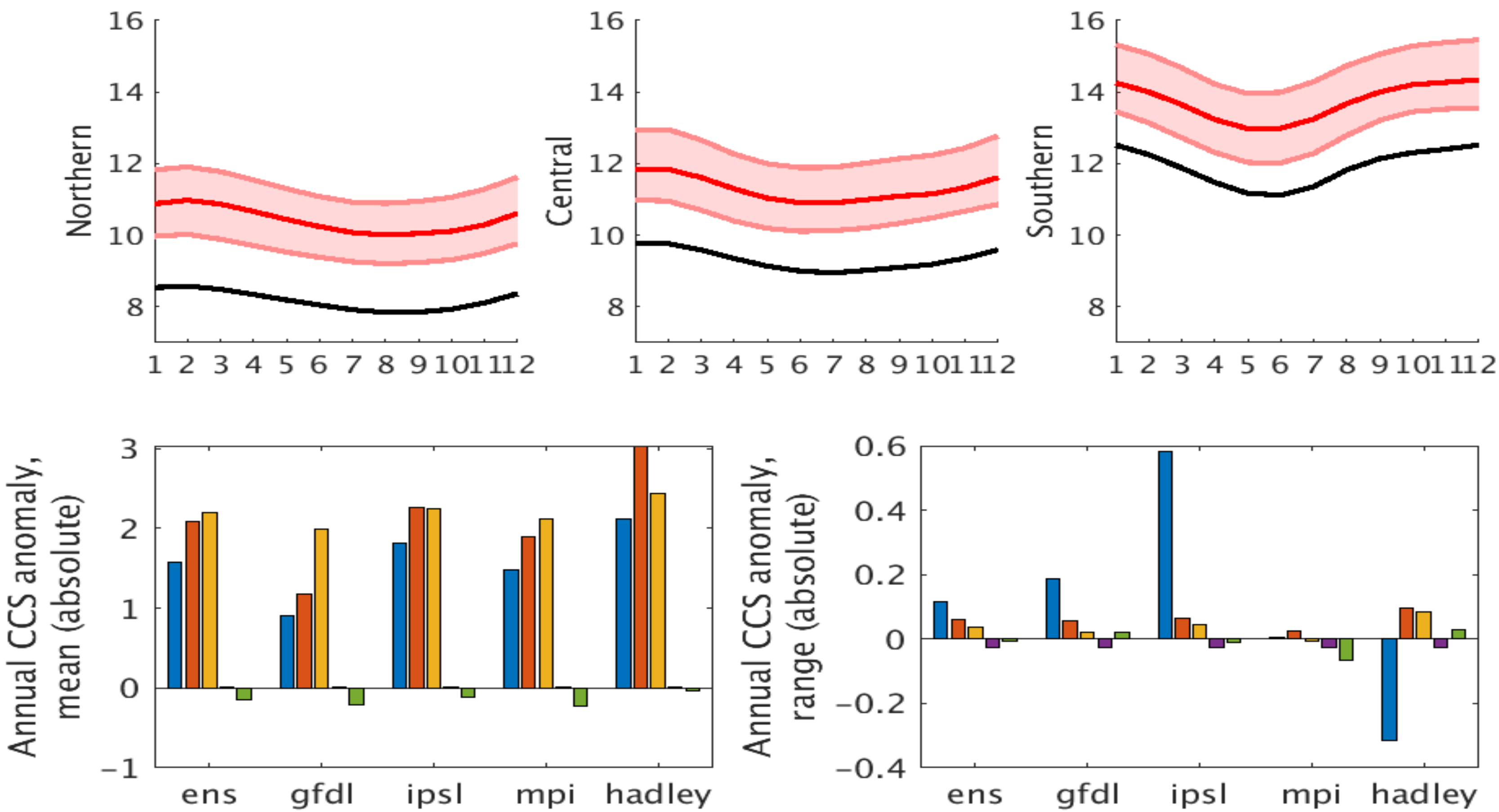
Climate models show large and consistent reductions of O_2 globally and in the CCS.
Dynamical downscaling with ROMS suggest they are even underestimated.
The role of winds opposes warming trend, but is small compared to remote effects.



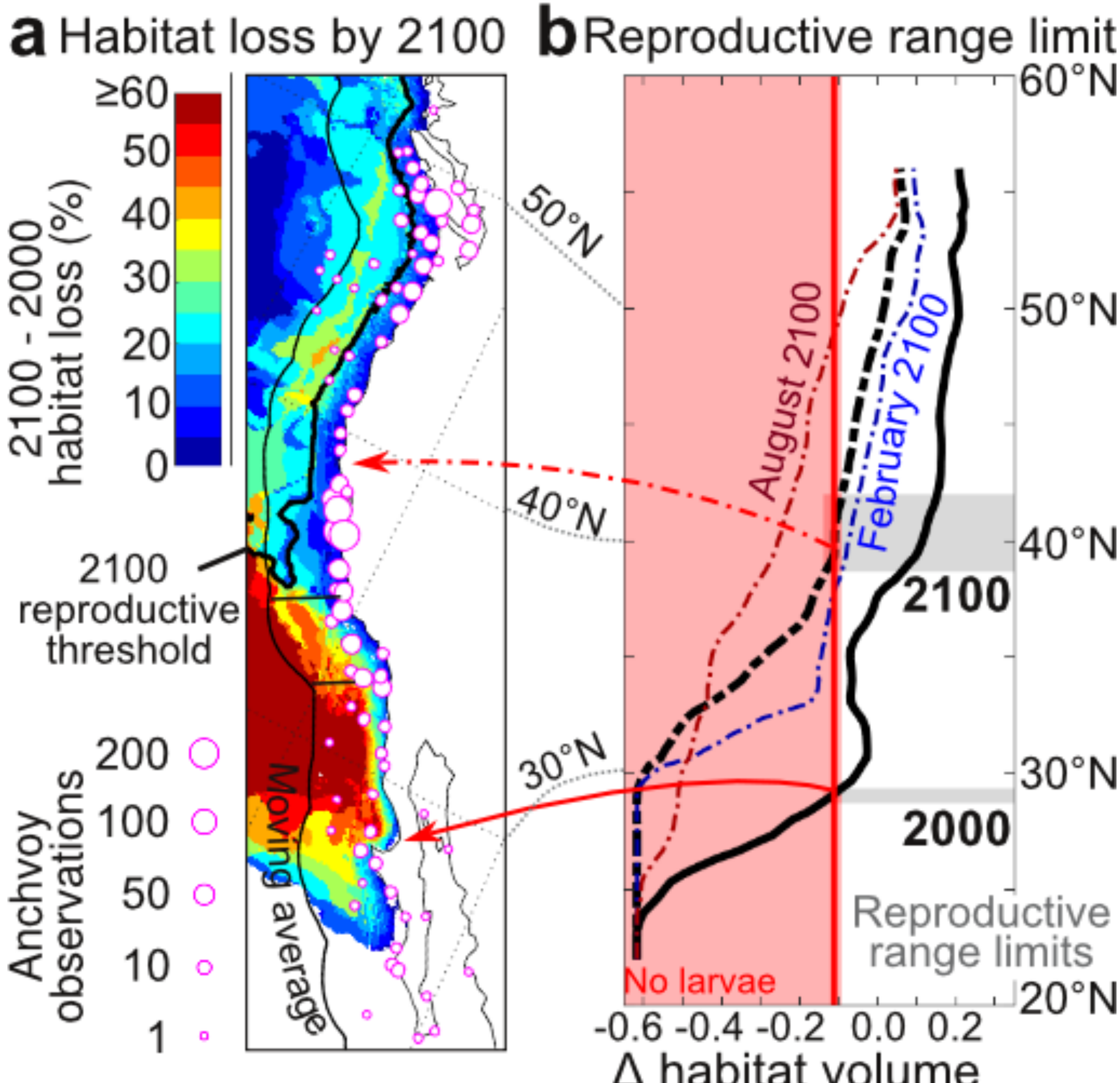


Warming of the CCS

Warming in upper 200m consistent across models.
Magnitude from Stratification forcing is slightly reduced by local wind changes.



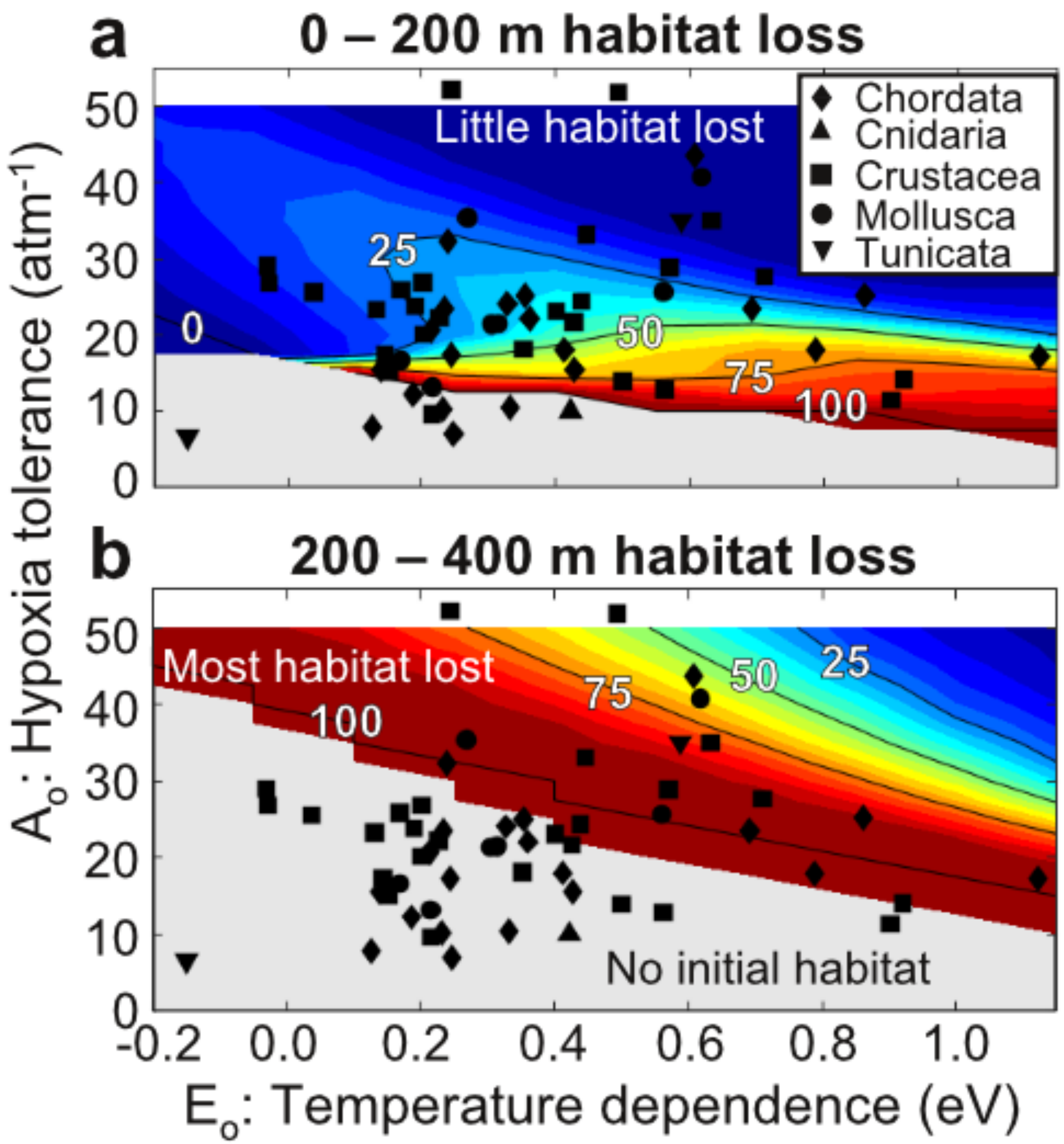
Geographic Range Contraction



Based on historical observations, projected warming and O_2 loss in the California Current System will lead to extirpation of anchovy throughout the southern 1/3 of their range.

Howard et al. [in review]

Ecosystem Implications



Future warming and O_2 loss in the California Current (projected by ROMS downscaling) implies large losses of habitat, but strongly dependent on species traits and habitat depth.

This is likely to reorganize species interactions and food webs.

Howard et al. [in review]

Outlook

- New project to measure the Metabolic Index parameters for >10 CCS species
- Collaboration with Brad Seibel (USF) and Martha Sutula (SCCWRP)
- Funding from NOAA and CA SeaGrant
- Strong connection to management agencies via SCCWRP

Conclusions

1) Historical reconstructions of the California Current with eddy-resolving hindcast model reproduce long-term mean and inter-annual variability in key ecosystem variables.

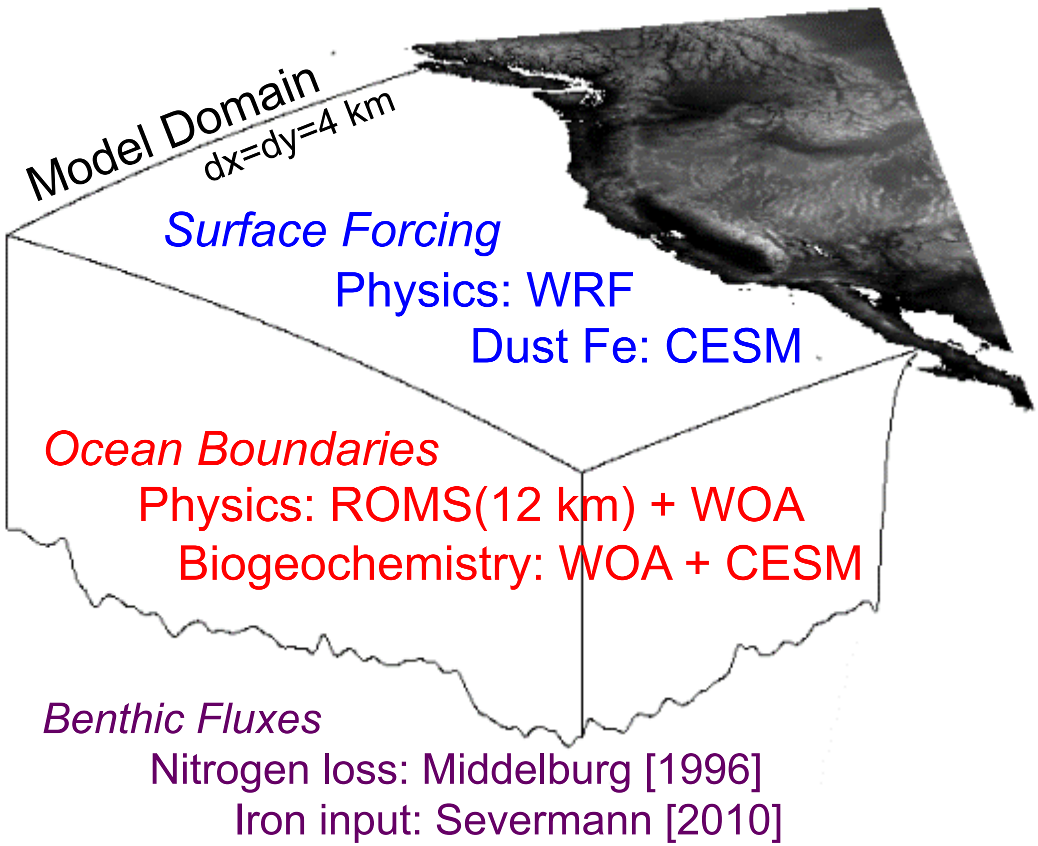
2) Downscaling projections of future climate change with global Earth System Models show large-scale wind changes to have a modest impact on bulk ecosystem metrics, including NPP. Caveat: potential changes in coastal wind drop-off?

3) Climate forcing of sub-surface ocean properties, e.g. Oxygen and pH (not shown) derive primarily from basin-scale impacts on stratification and properties imported into CCS.

4) Intensification of temperature-dependent hypoxia explains large past changes in Northern Anchovy, and appears to be largest perturbation to CCS ecosystem, with large but differential impacts on species habitability.

EXTRA SLIDES

Historical Hindcast & Validation



Regional Ocean Modeling System (ROMS)

- Eddy-resolving ocean model
- 2-decade Hindcast 1994-2013

Forcing

- Atmospheric model (WRF) 6km atmospheric winds, radiation, E-P
- Physical boundary conditions from global reanalysis (Mercator)
- Biogeochemical boundary conditions from climatology

Validation

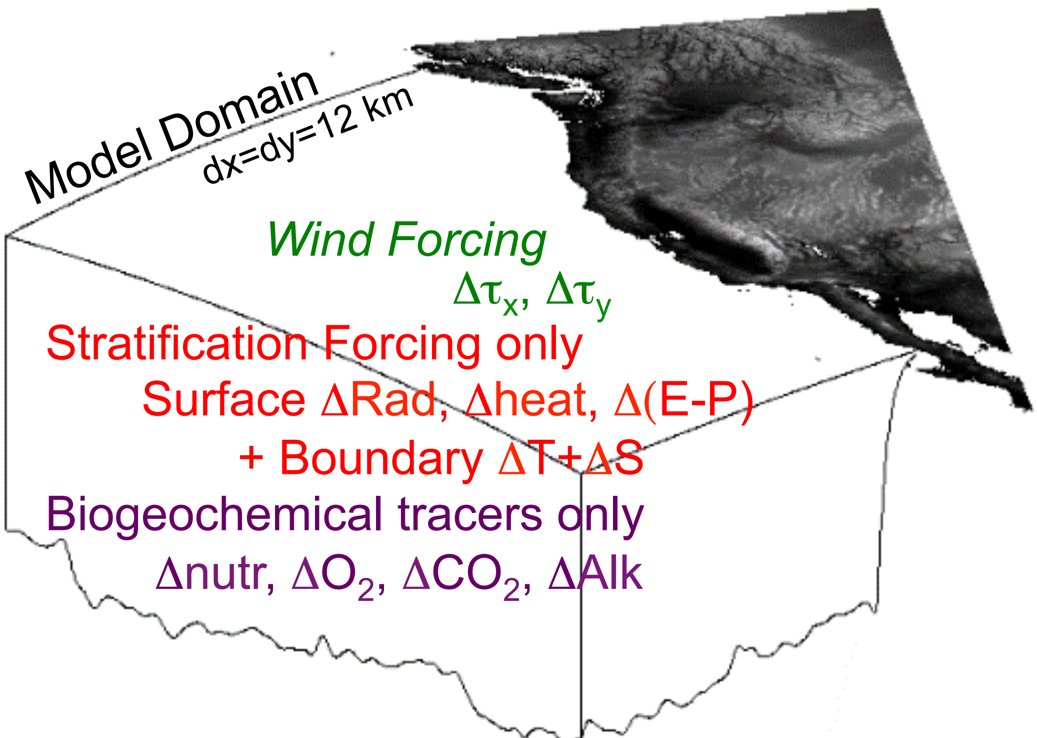
- Historical hydrography
- Satellite remote sensing

Ocean ecosystem model (BEC)

- 3 phytoplankton, 1 zooplankton
- Biogeochemical cycles of C, O_2, P, N, Fe, Si

Future Projection & Attribution

By isolating responses to distinct climate forcings (wind, warming, chemistry), we can attribute the leading causes of CCS ecosystem change



Howard, Frenzel, Deutsch, et al. [in prep]

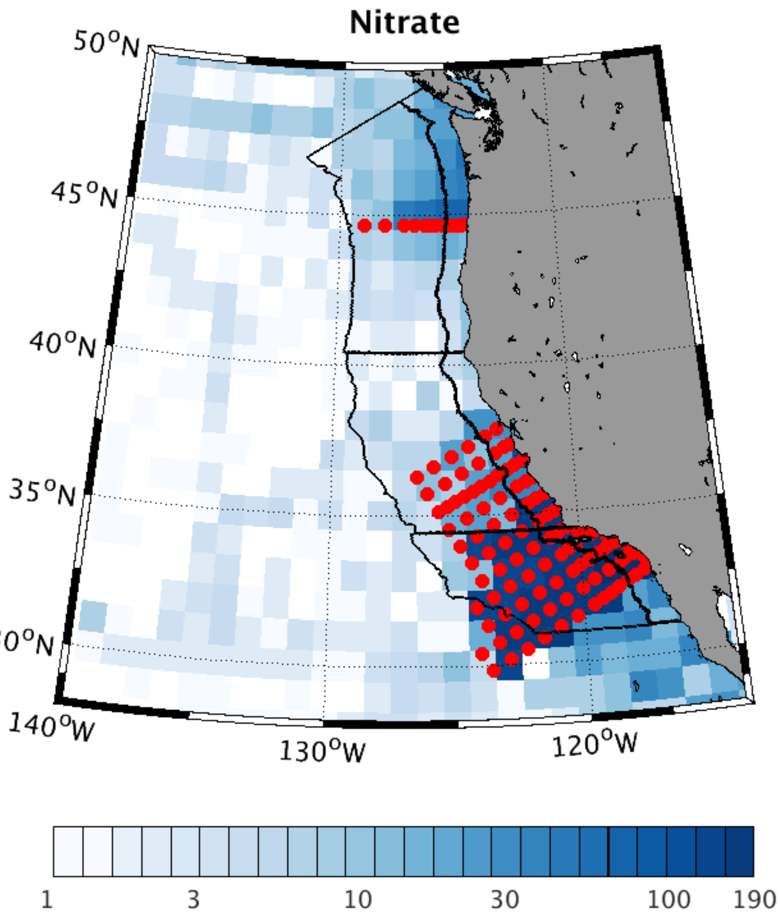
Downscale Global Model projections by applying anomalies at surface and open boundaries, based on Earth System Models

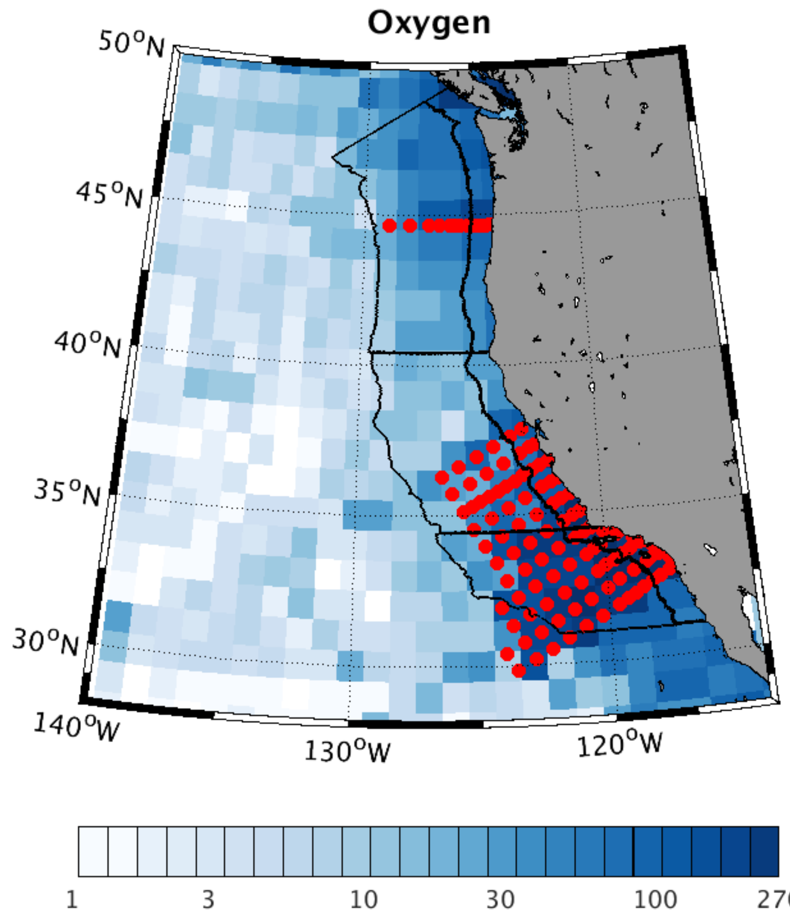
5 Global Models (CMIP5):
- GFDL, MPI, IPSL, Hadley, NCAR, + Model mean

Attribution experiments:
- Stratification only (S)
- Winds only (W)
- BGC tracers only (B)
- All forcings (A)

Historical Validation

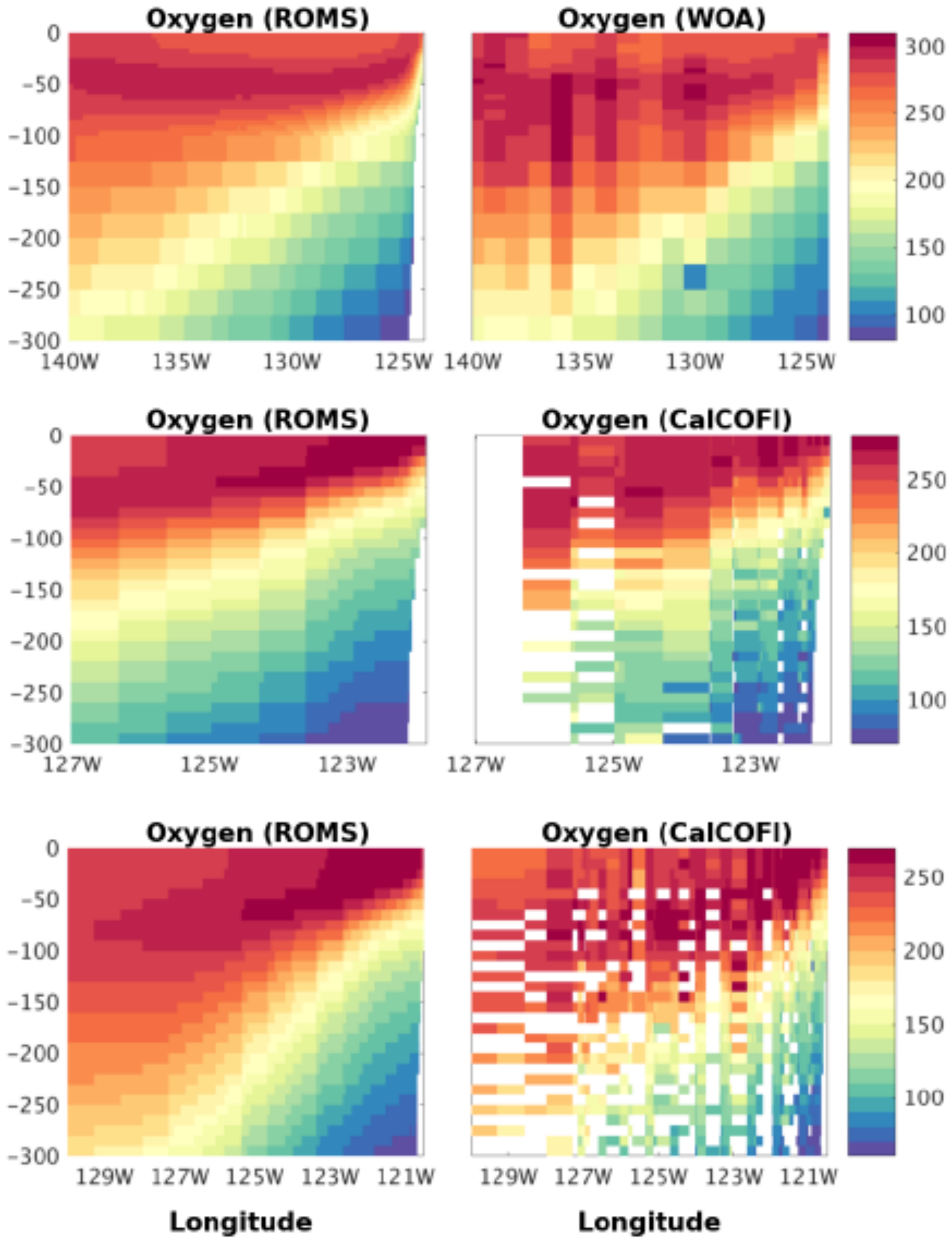
We compare model solutions to mean and variability of historical hydrographic profiles.
The California Current is far less under-sampled than most of the ocean.





Deutsch et al. [in review]

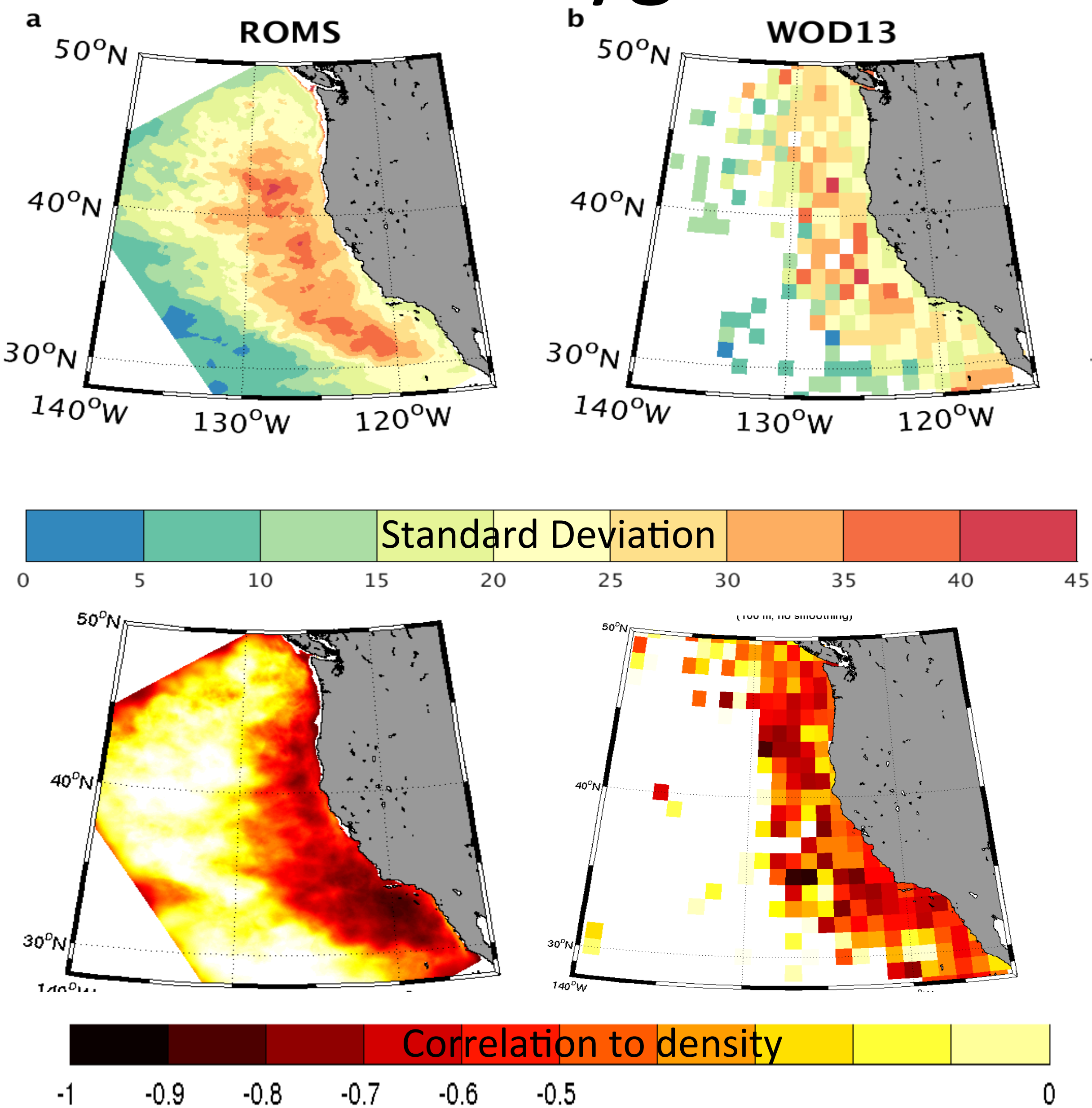
Oxygen and Upwelling



Vertical sections of annual mean O_2, from ROMS (right columns) and WOD (right columns) along three repeat hydrography lines that span the latitude range of the CCS reveal the role of upwelling in bringing low O_2 into shallow environments on the continental shelf.

Deutsch et al. [in review]

Oxygen Variability



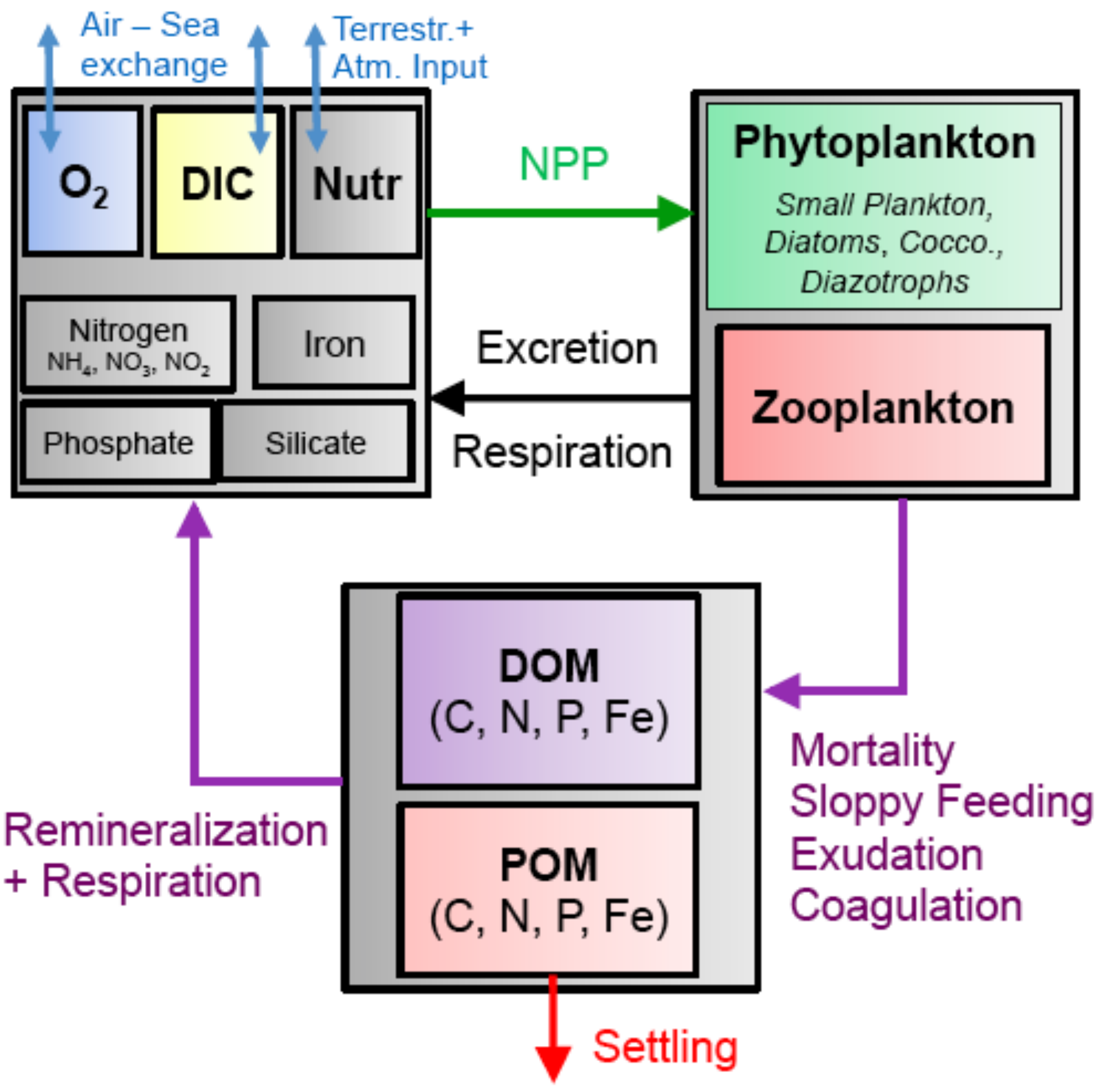
Variability of subsurface (100m) O_2 is high throughout the CCS, and is well reproduced by hindcast simulations.

The primary factor driving these changes is fluctuations in the depth of the pycnocline.

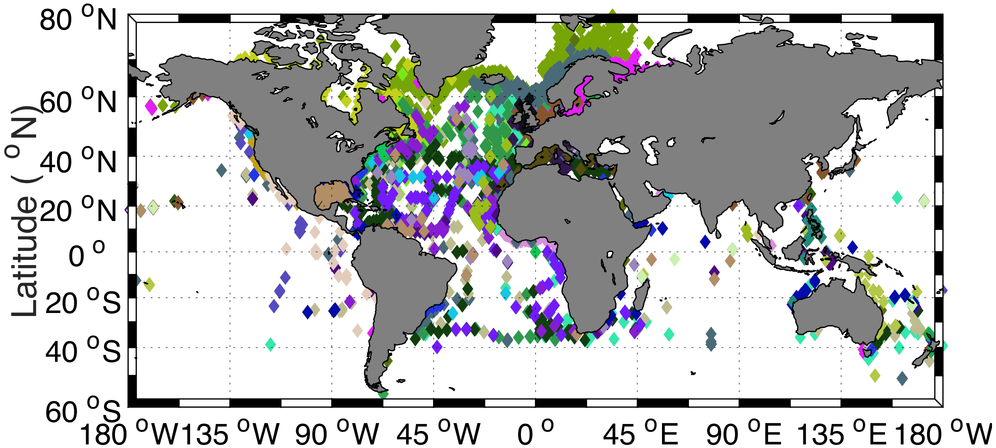
This is revealed by the strong correlation between O_2 and density in both observations and simulations.

Deutsch et al. [in review]

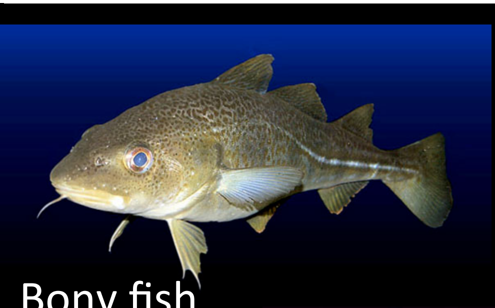
Ecosystem Model

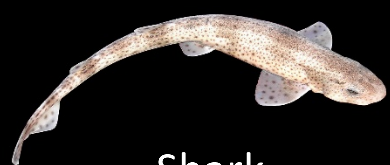


Species Data



Labotatory measurements of Metabolic rate and critical O_2 (P_{crit}) at multiple temperatures.
Database: >70 diverse species, globally distributed, from 5 phyla, wide size range.


Bony fish


Shark


Zooplankton


Shrimp


Crab

Tunicate


Coral


Oyster

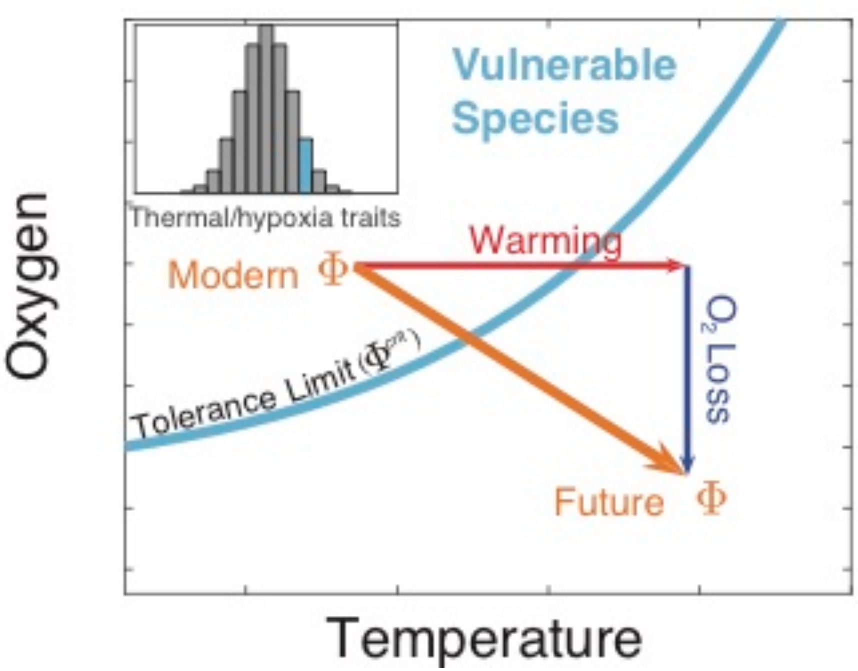
Squid

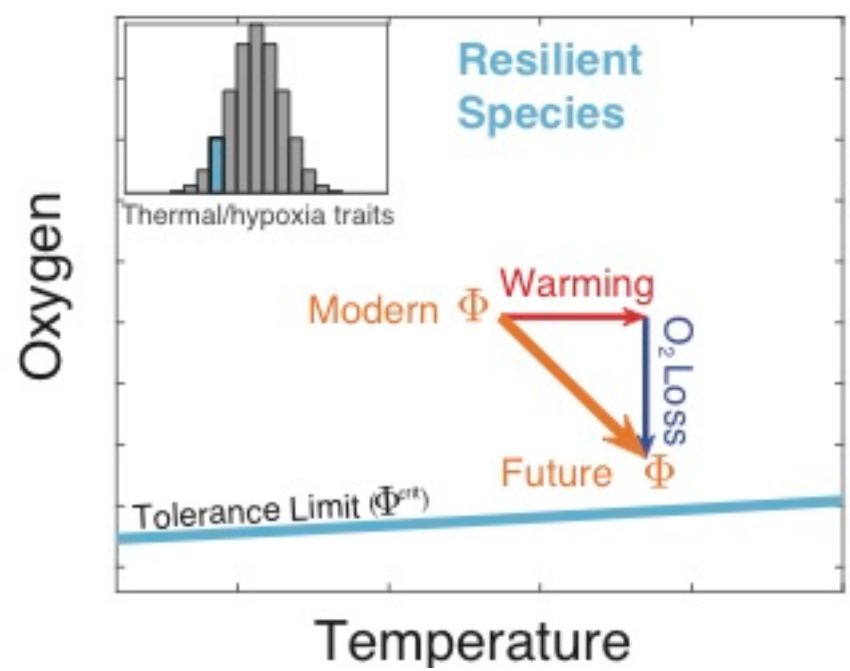

Nautilus

Vulnerable vs Resilient

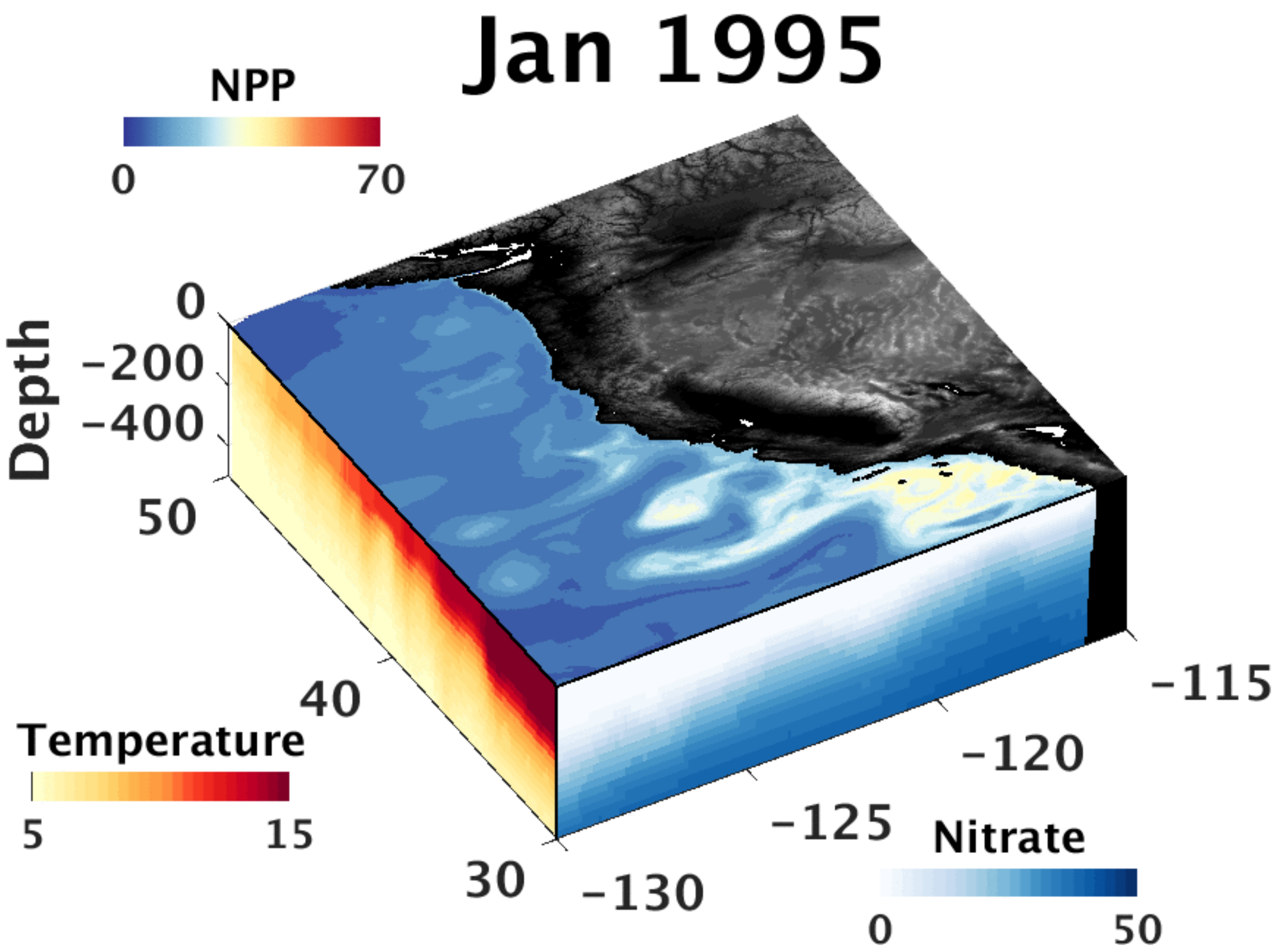
Changing Habitability depends on:

1) Species sensitivity (Slope, Intercept)
2) Environmental change (Temp, O_2)





Part I
Lower Trophic Level

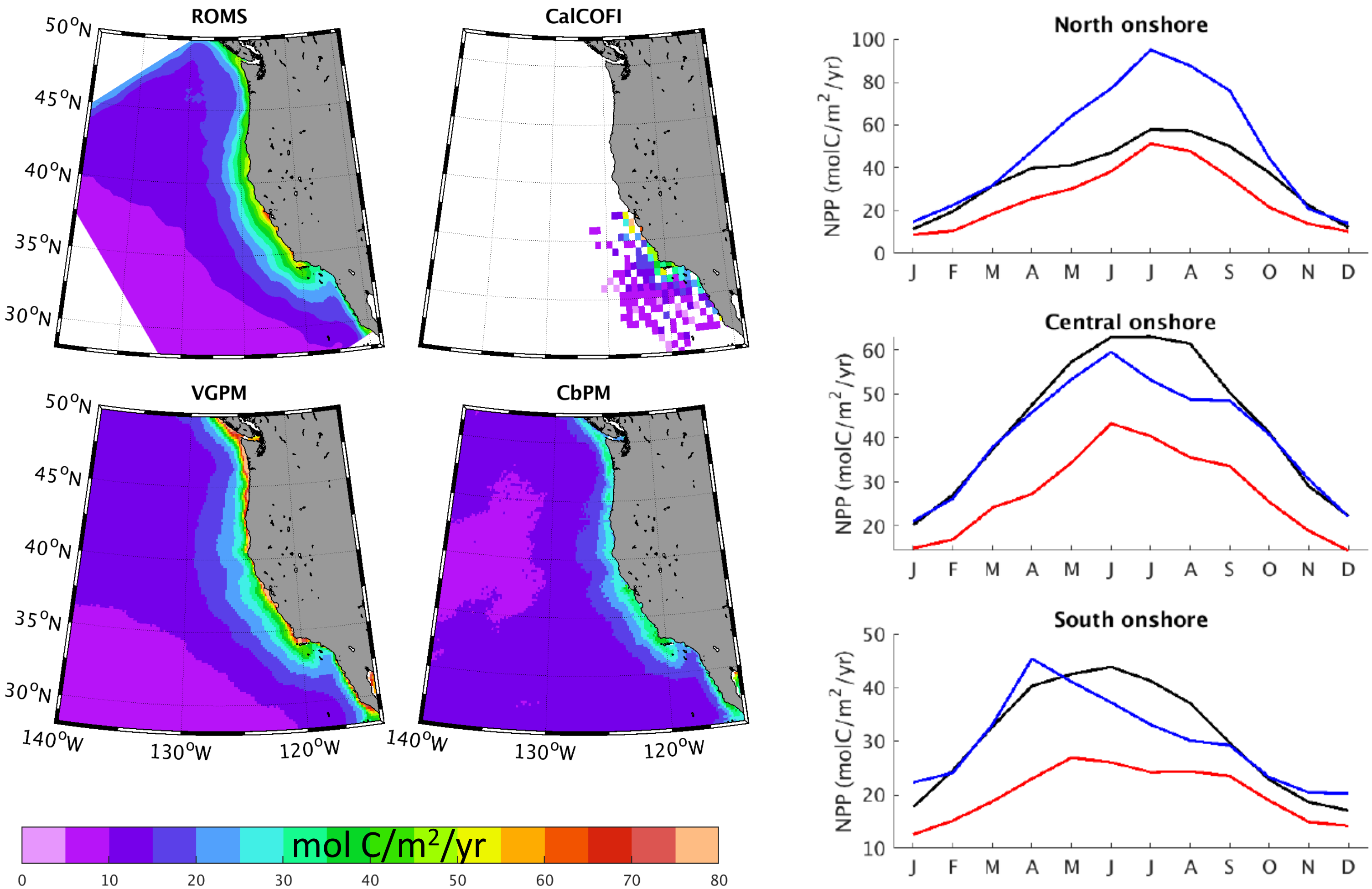


How does Primary Productivity of the California Current respond to climate variations and change?

Net Primary Productivity

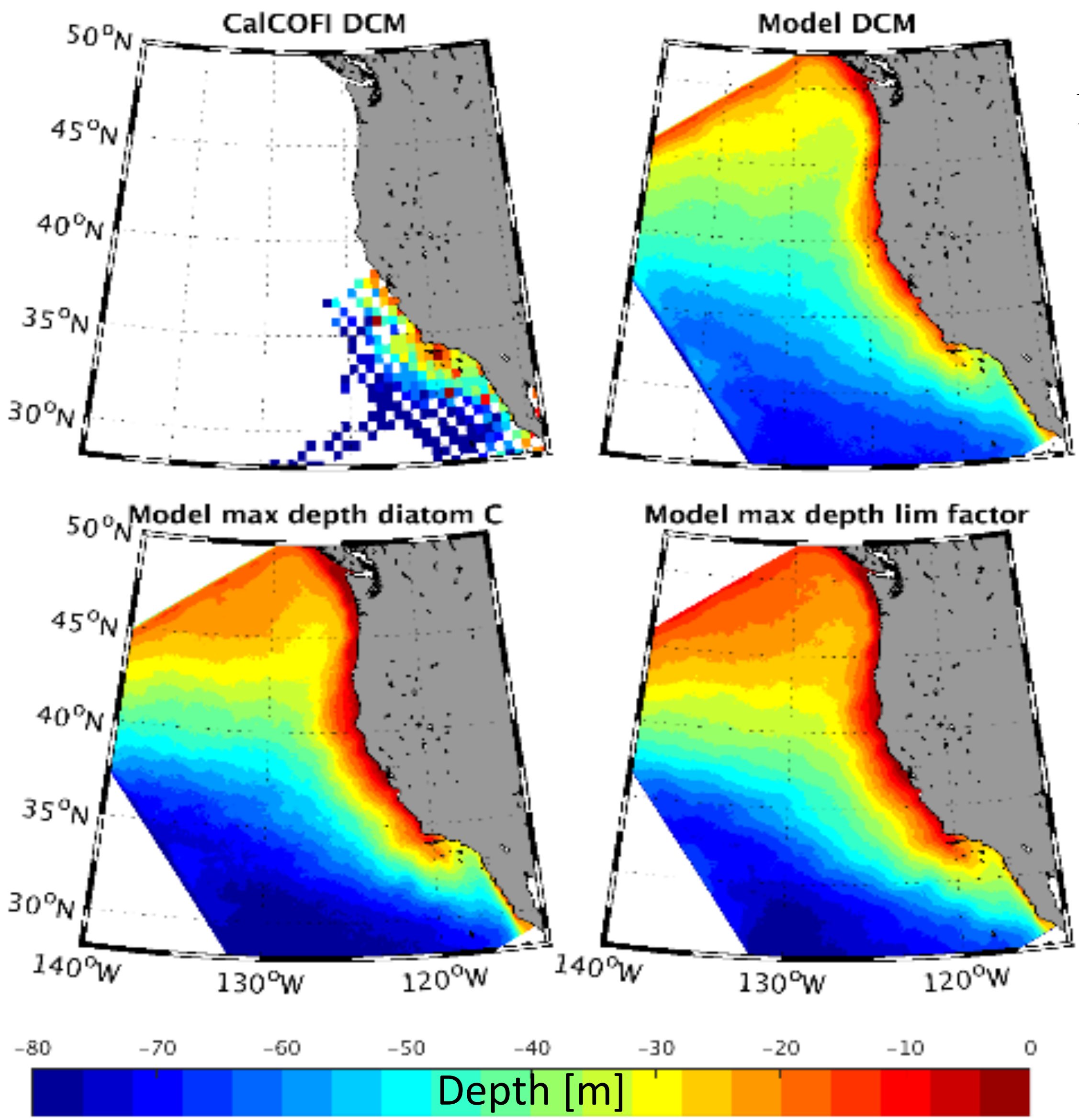
Spatial distribution and Seasonal Cycle of Net Primary Productivity.

$$NPP = \Sigma_j \{\mu_{max} * \gamma_j (I) * min(\lambda(N_{i,j})) * B_j\}$$



Deutsch et al. [in review]

Nutrient vs Light Limitation



$$NPP = \Sigma_j \{\mu_{max} * \boxed{\gamma_j (I)} * \boxed{min(\lambda(N_{i,j}))} * B_j\}$$

Depth of the vertical maximum of Chlorophyll

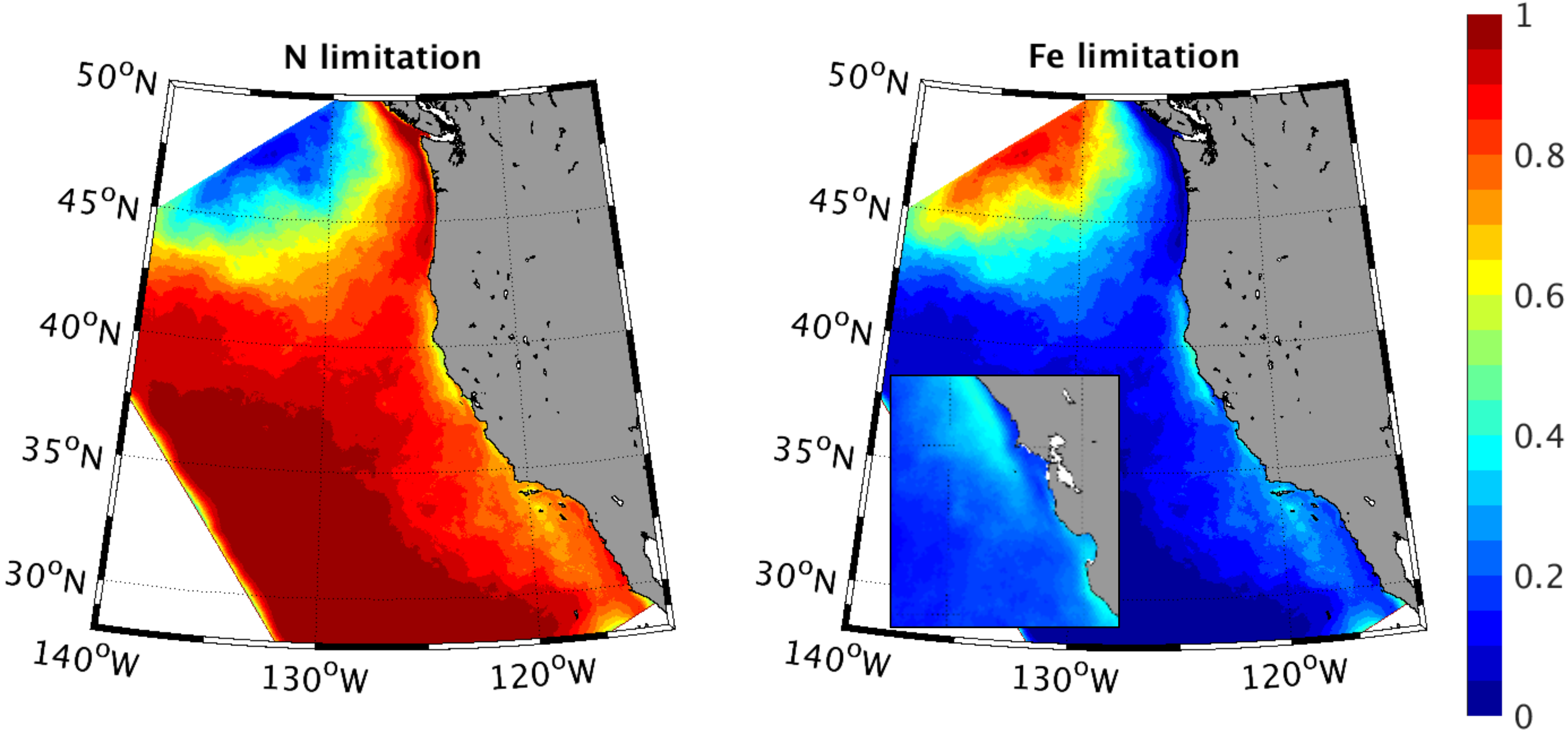
Reflects the trade-off between light (high at surface) and nutrients (high at depth).

Model fidelity to observations implies the model captures a realistic trade-off between nutrient limitation and light limitation.

Deutsch et al. [in review]

Nitrogen vs Iron Limitation

$$NPP = \Sigma_j \{\mu_{max} * \gamma_j (I) * \boxed{min(\lambda(N_{i,j}))} * B_j\}$$

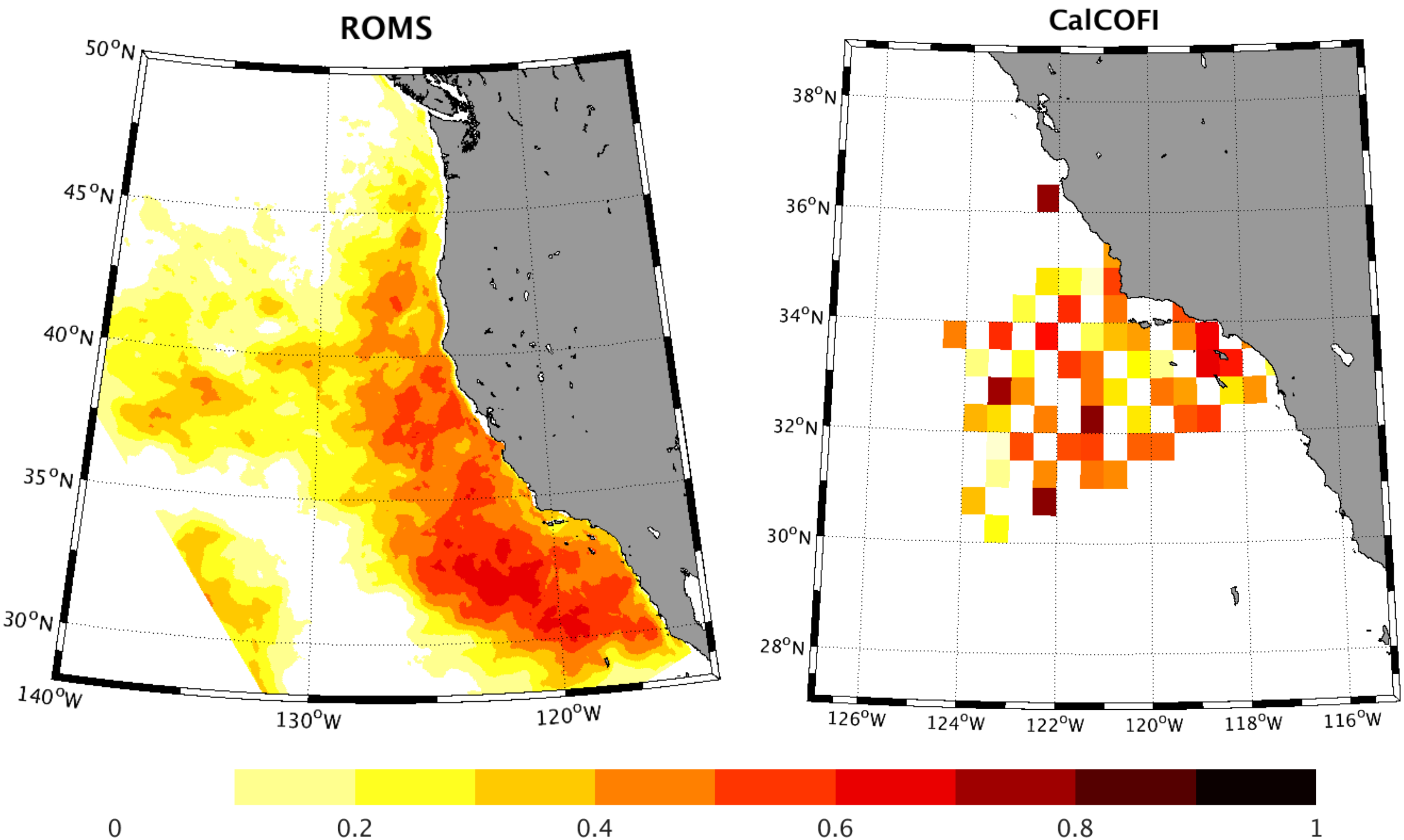


Frequency of limitation by Nitrogen (left) and Iron (right) for the model's dominant primary producer, diatoms. The frequency of limitation is based on 5-day average output, and weighted by biomass. Inset shows offshore band of relatively frequent Fe limitation along the central CCS, as observed by Firme et al. [2008].

Deutsch et al. [in review]

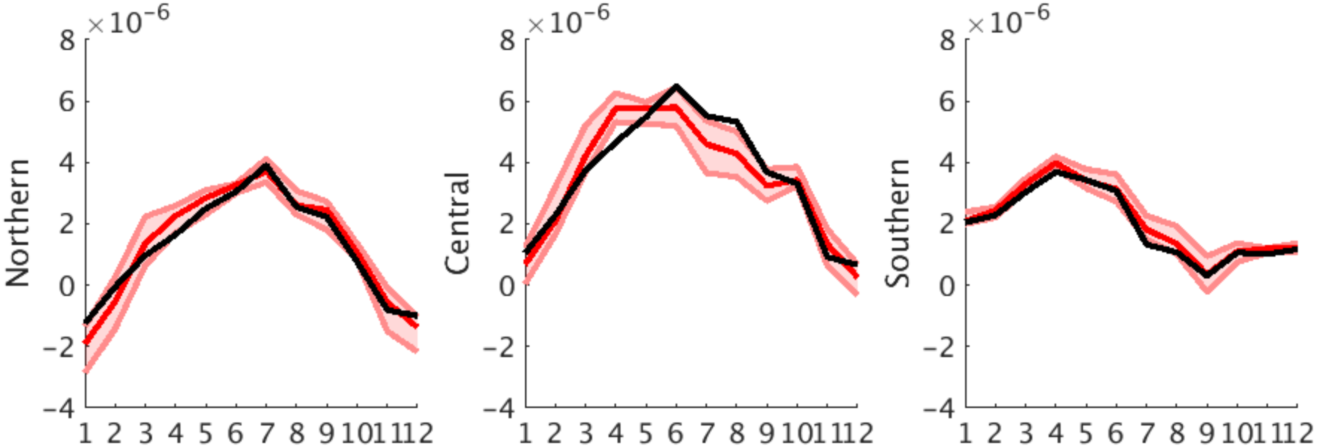
NPP: Interannual Variability

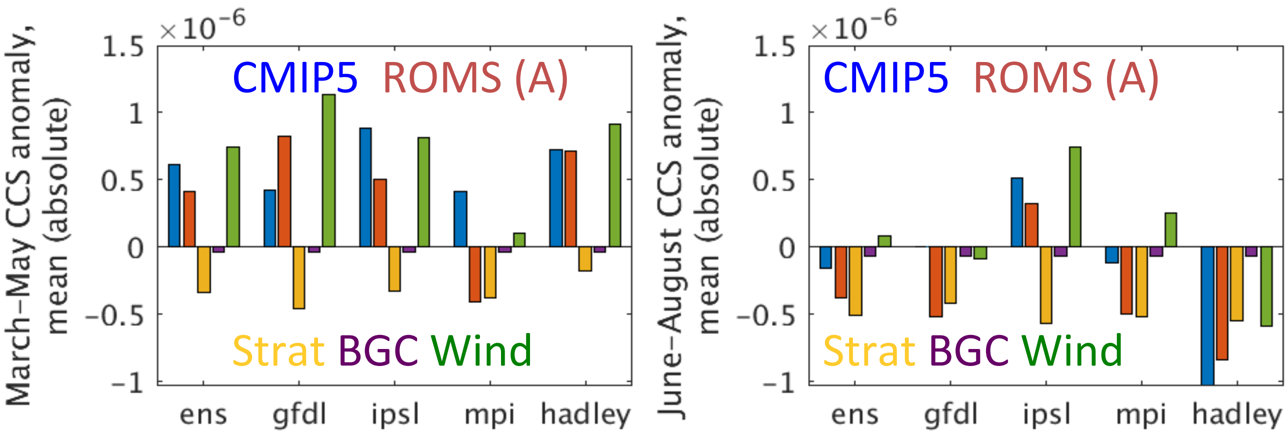
Model exhibits a high correlation between subsurface density and NPP, indicating the strong influence of pycnocline depth on nutrient supply. Similar correlations seen in observations.



Deutsch et al. [in review]

Changing Upwelling





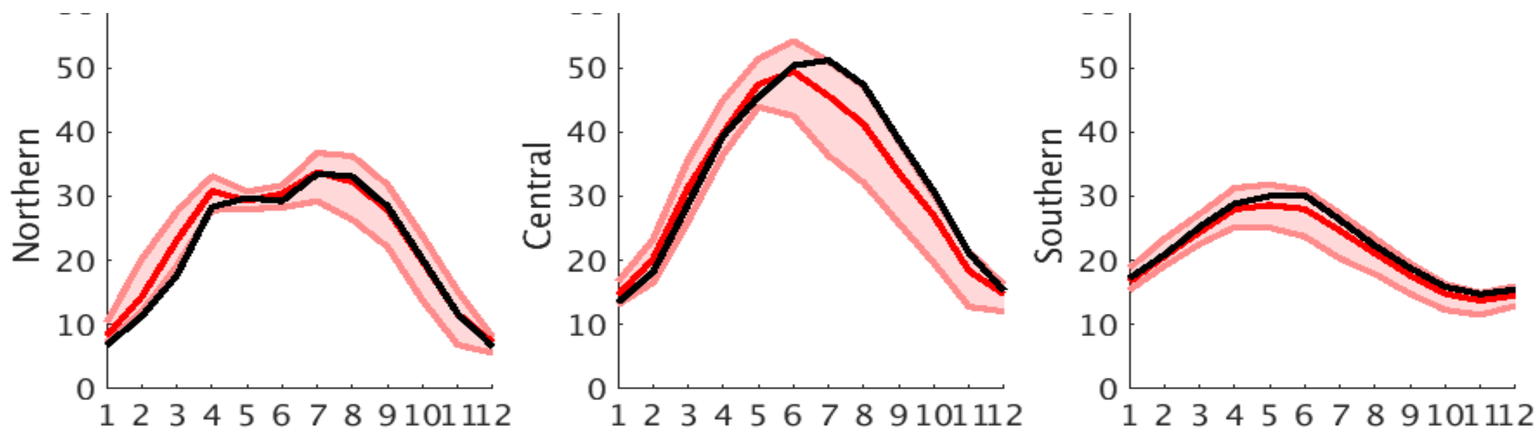
Upwelling changes are subtle, and mostly seasonal, not annual mean.

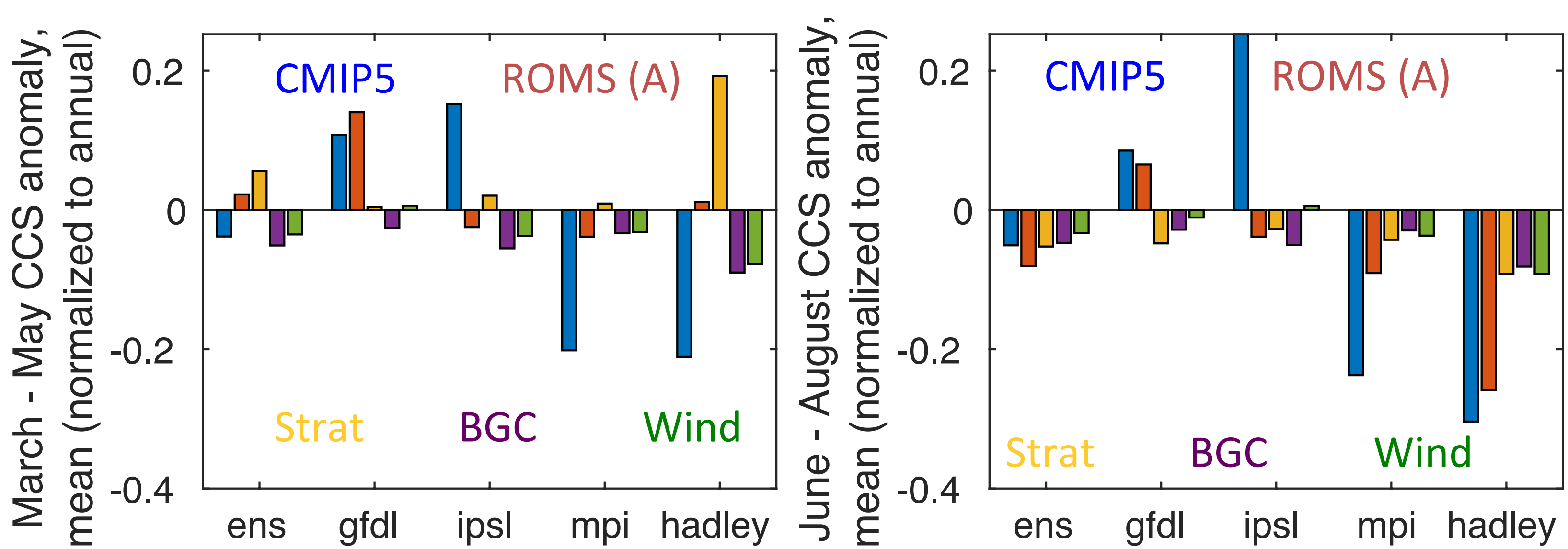
Robust tendency for more in spring and less in summer.

Stratification significantly offsets wind effect in spring, and is decisive in summer!

Changing NPP

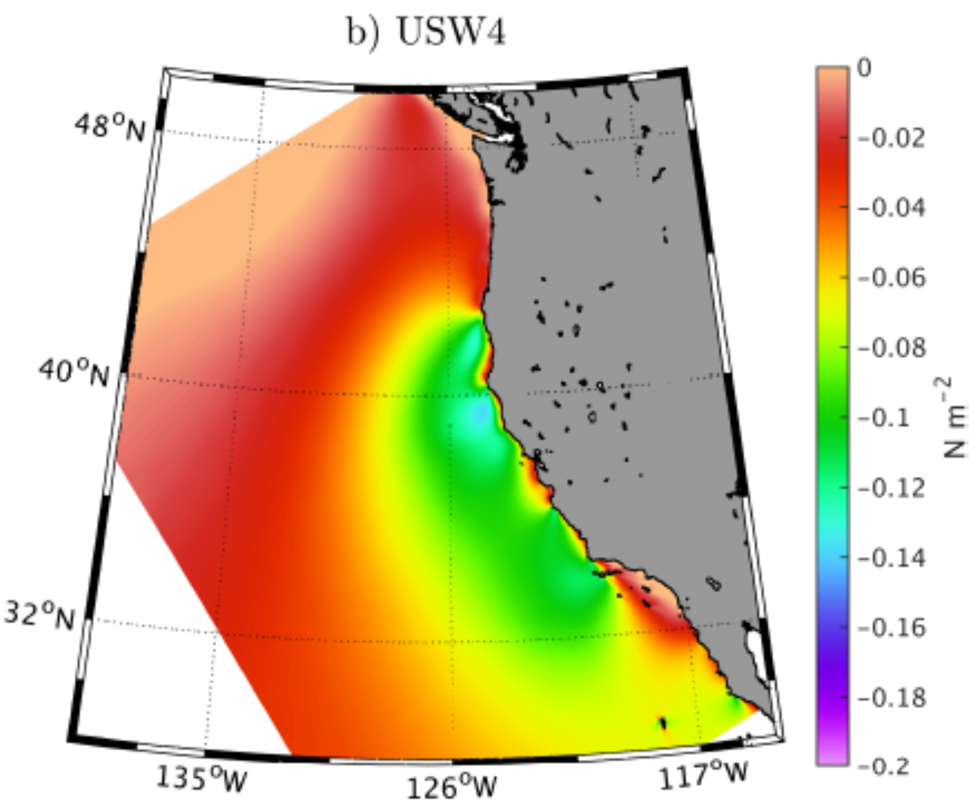
Like wind, changes in NPP also modest (<5%) and mostly seasonal shifts.
Remote nutrient redistribution and stratification (+Temp) more important than winds!

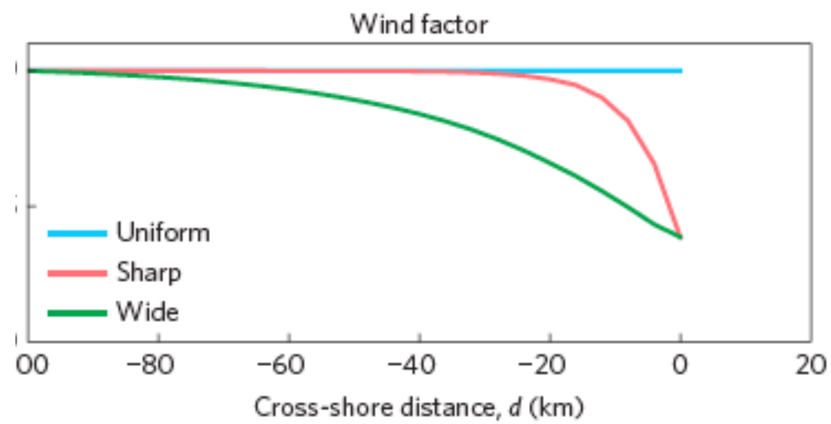




The role of wind structure

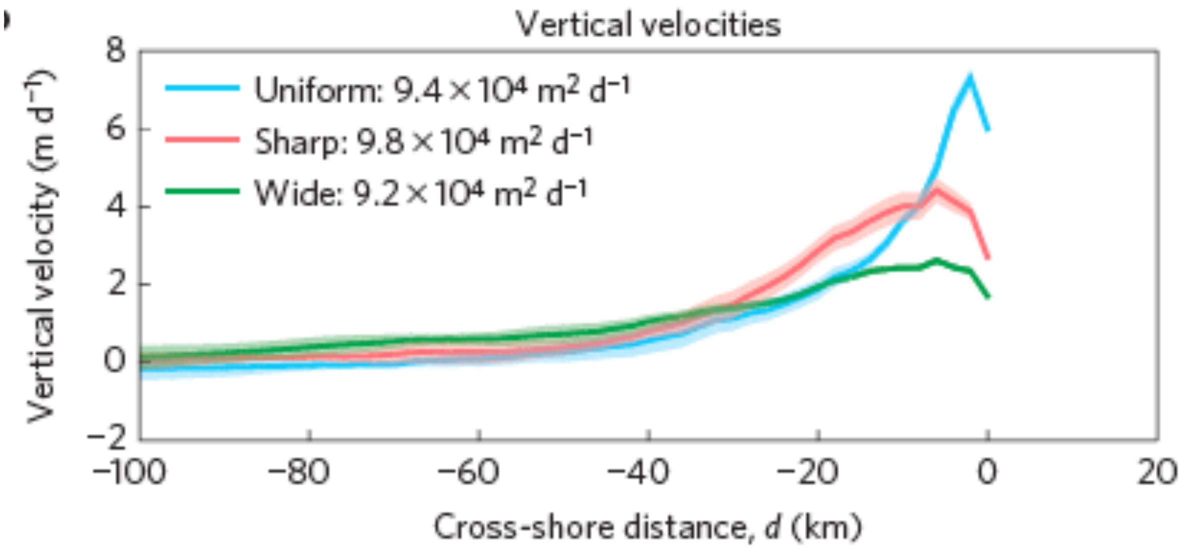
Global models capture large-scale wind changes, but not regional details.
Could those matter? Experiments with the drop-off in wind strength along the coast…

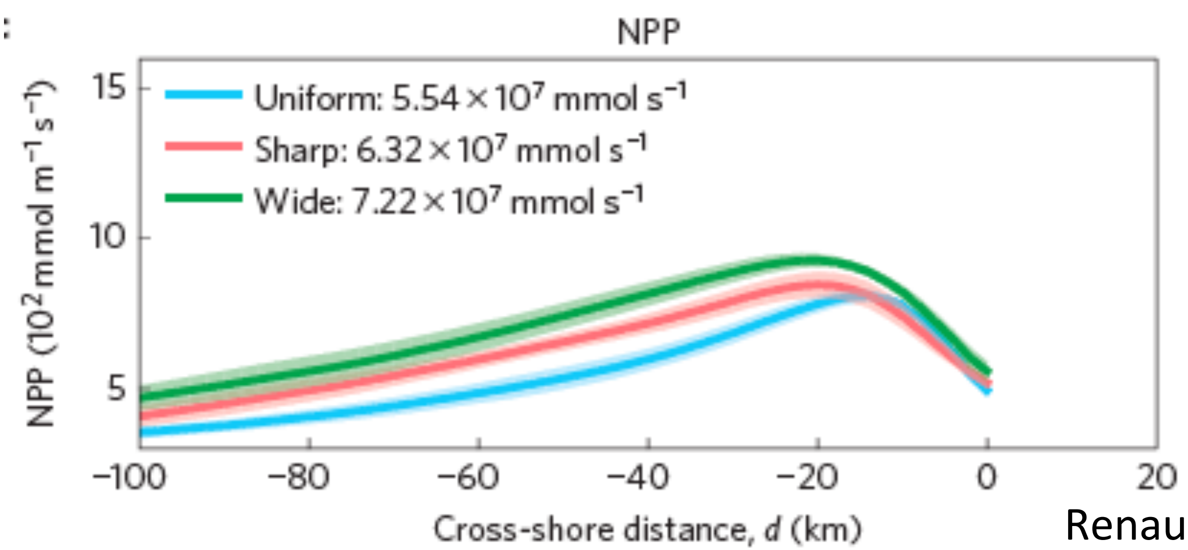




Renault et al. [2016] *Nature Geoscience*

NPP Response to Wind Pattern





Coastal wind drop-off doesn't change the total upwelling, but shifts the balance between coastal and offshore, consistent with expectations.

Despite the same total upwelling, NPP is impacted by wind structure. The reduction is mediated by eddies.

Renault et al. [2016] *Nature Geoscience*