Warming up, turning sour, losing breath
- EBUS as hotspots of global change

Nicolas Gruber

Environmental Physics, ETH Zürich, Switzerland.

Acknowledgments:

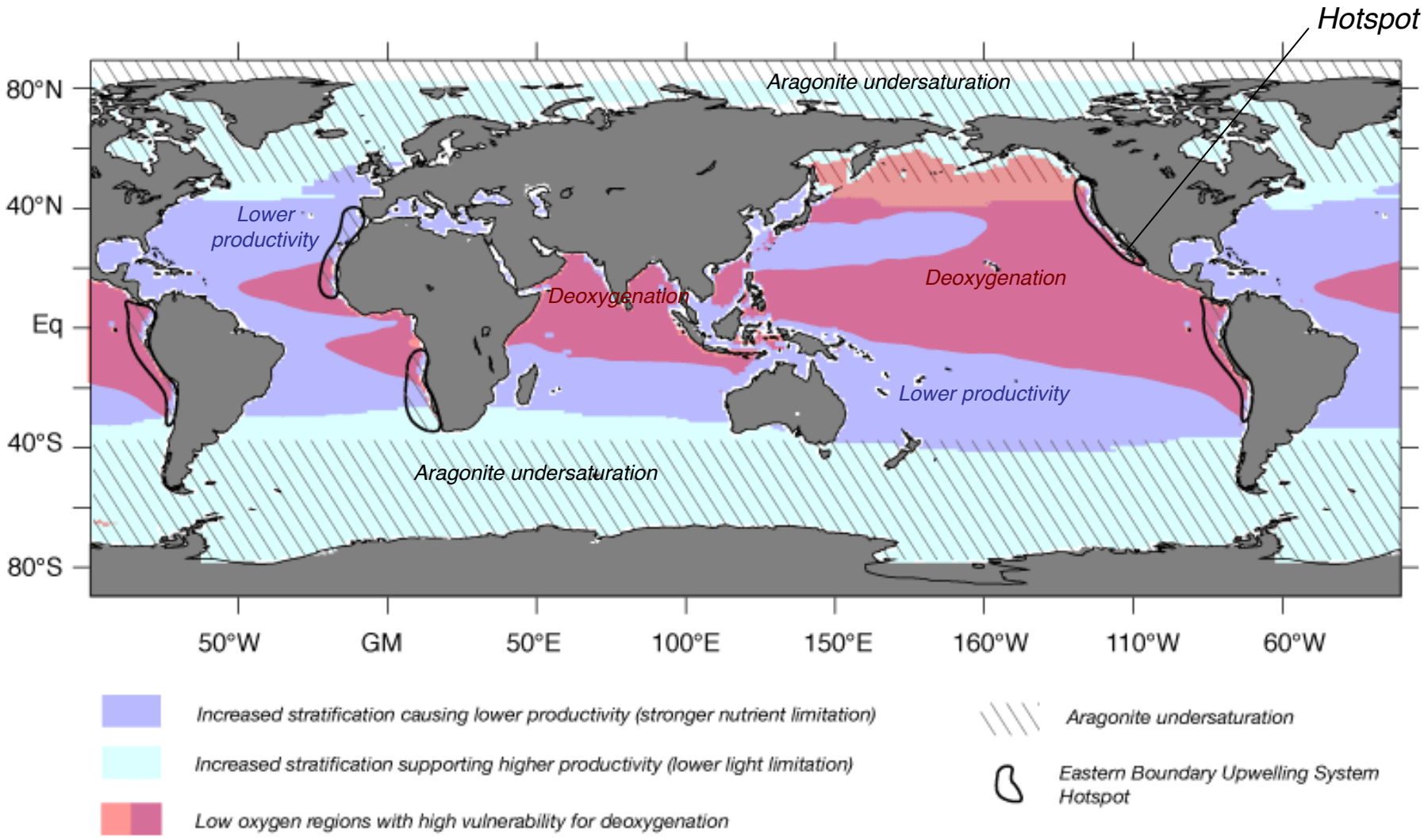
C. Hauri[1], Z. Lachkar[1], D. Loher[1], L. Kropuenske-Artman[1], G. Turi[1], T. L. Frölicher[2], G.-K. Plattner[3]

[1] *Environmental Physics, ETH Zürich, Switzerland.*

[2] *Princeton University, Princeton, USA.*

[3] *Univ. of Bern, Bern, Switzerland.*

The Eastern Boundary Upwelling Regions as Hotspots

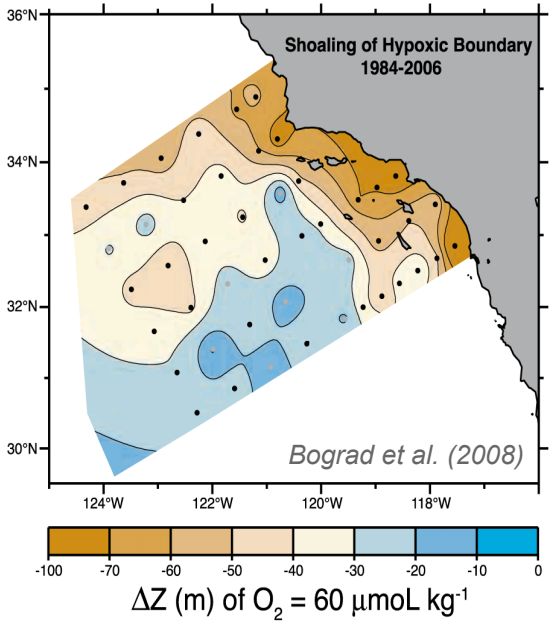


Eastern Boundary Upwelling Regions are hotspots of global change, as they are subject to the simultaneous exposure to multiple stressors.

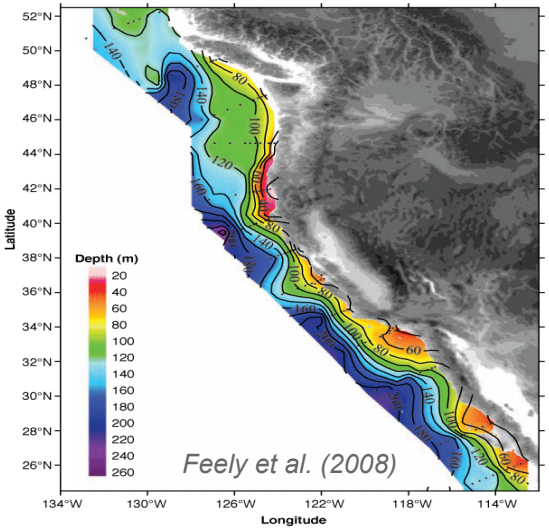
Gruber (2011)

Observed trends and Objective

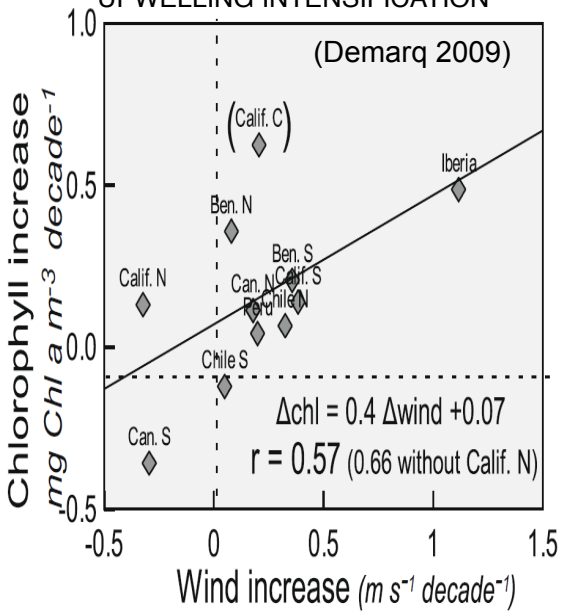
SHOALING OF THE HYPOXIC BOUNDARY



DEPTH OF SATURATION HORIZON



UPWELLING INTENSIFICATION



OBJECTIVE:

To explore the biogeochemical sensitivity of EBUS to simultaneous stressors emanating from changes in:

- *Atmospheric CO_2 (ocean acidification)*
- *Changes in upwelling (ocean acidification & deoxgenation)*
- *Changes in stratification (deoxygenation & ocean acidification)*

NO ECOSYSTEM IMPACT

Outline

1. Introduction

   or why should we be concerned about multiple stressors in EBUS?

2. Ocean acidification

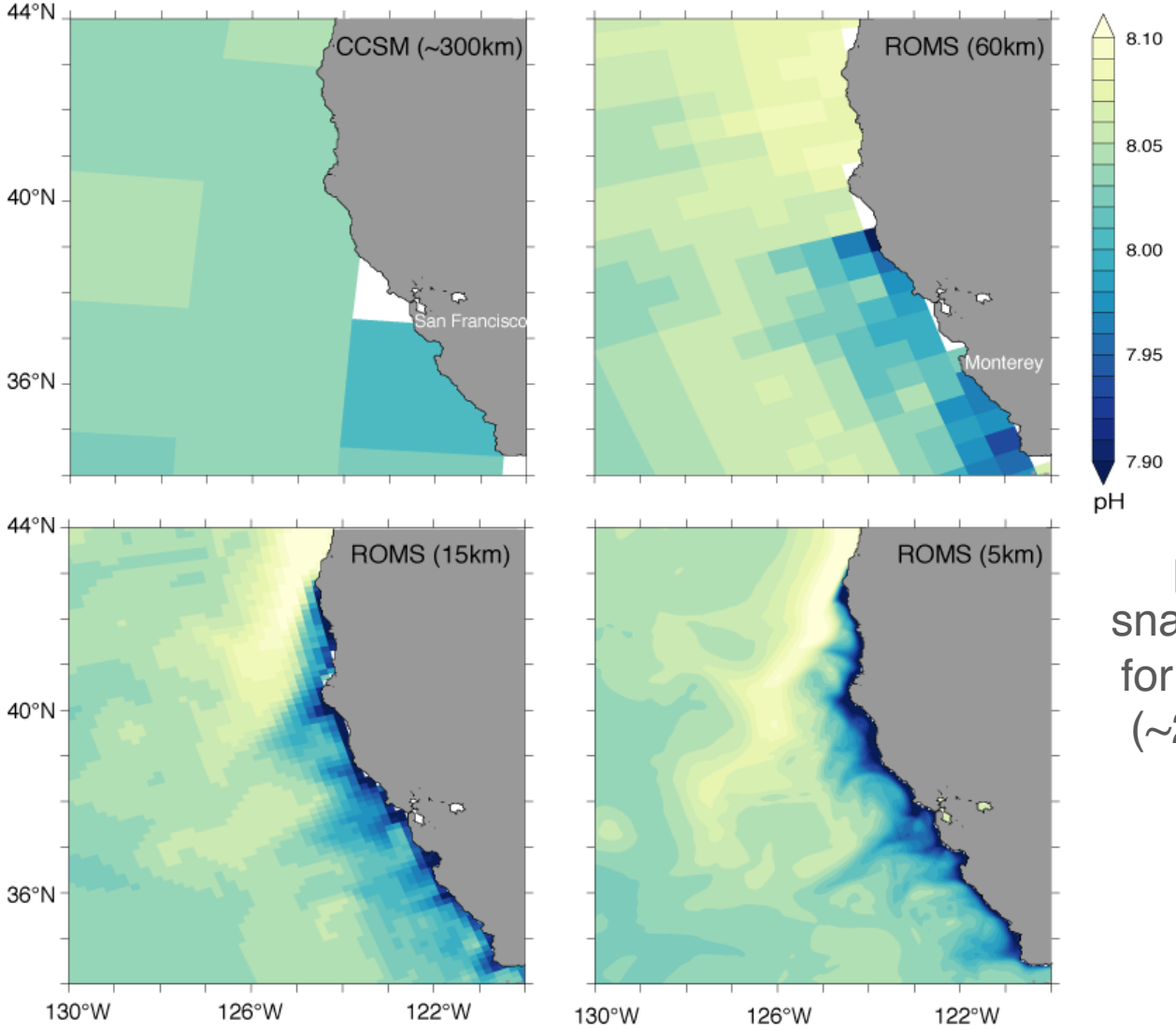
   or how the near-shore CalCS might become undersaturated soon

3. Ocean warming and circulation changes

   or how are ocean warming and circulation changing OA and O_2?

4. Summary and outlook

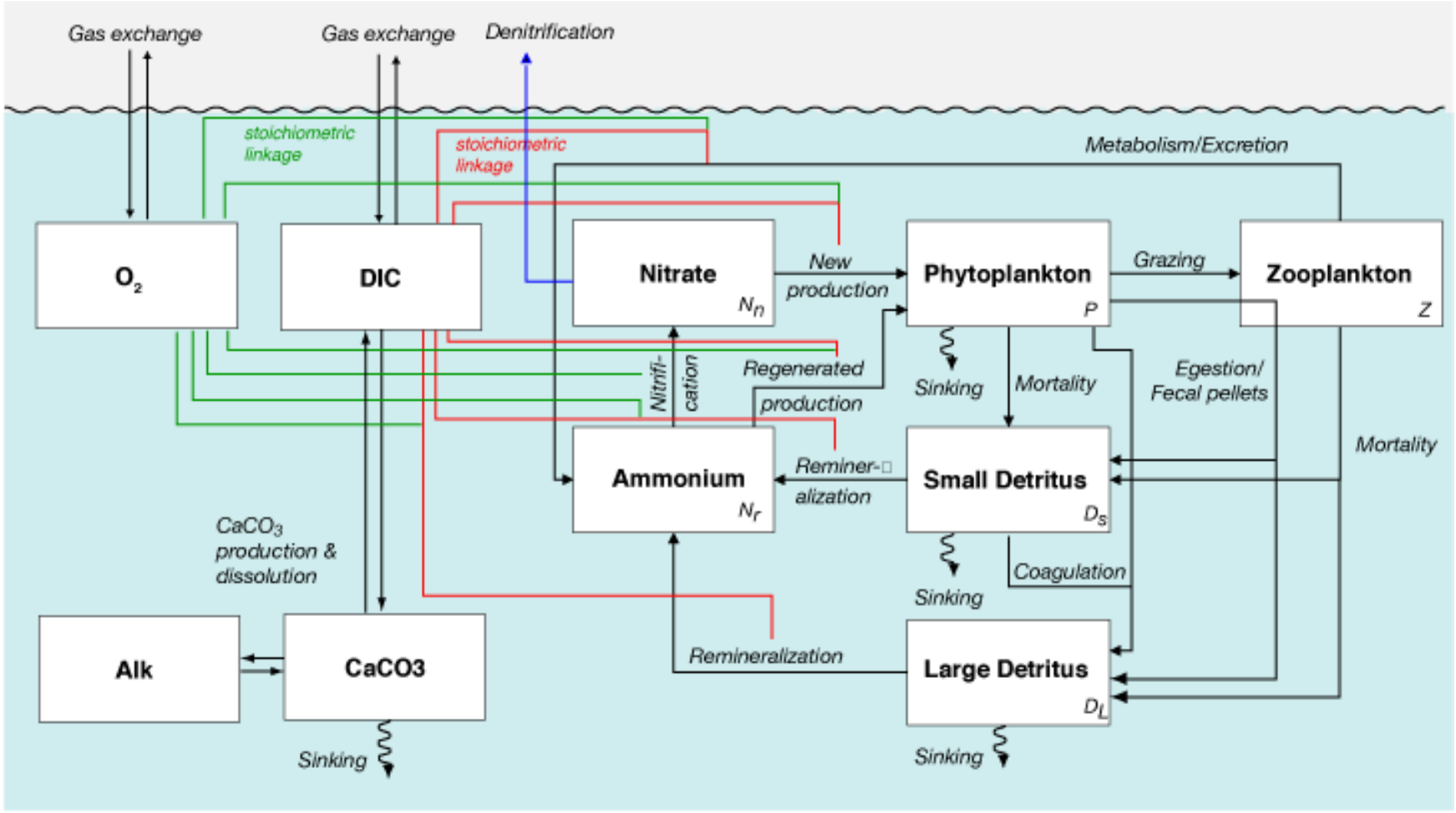
The power of regional modeling



pH snapshot for June (~2000)

Regionalization of models permit us to increase resolution to the level needed to resolve the coastal processes

The N_2PZD_2+CNO_2 model

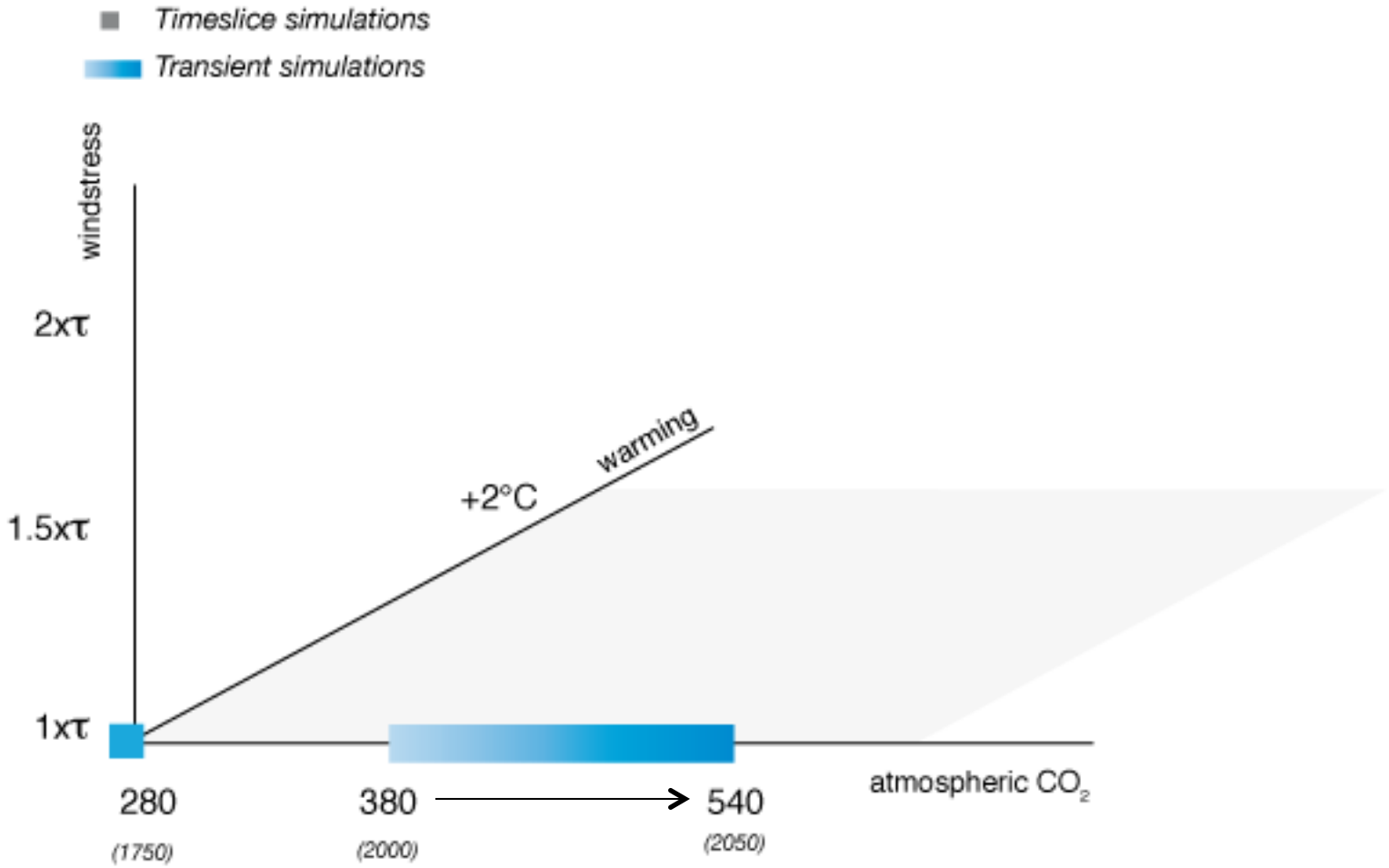


Reduced remineralization rate when $O_2 < 5$ μmol kg^{-1}

No consideration of benthic denitrification

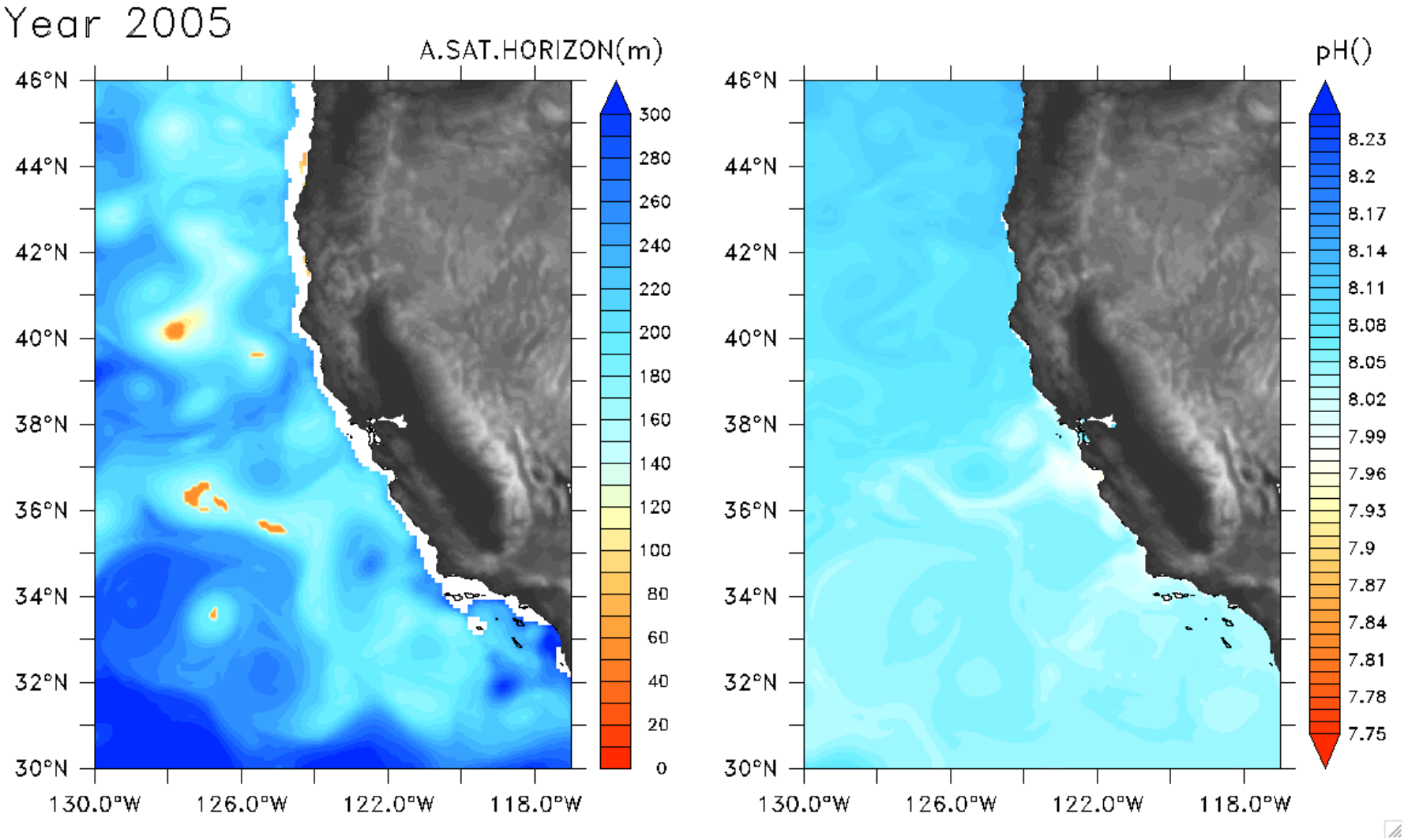
Gruber et al. (2006, 2011)

Modeling multiple stressors in EBUS



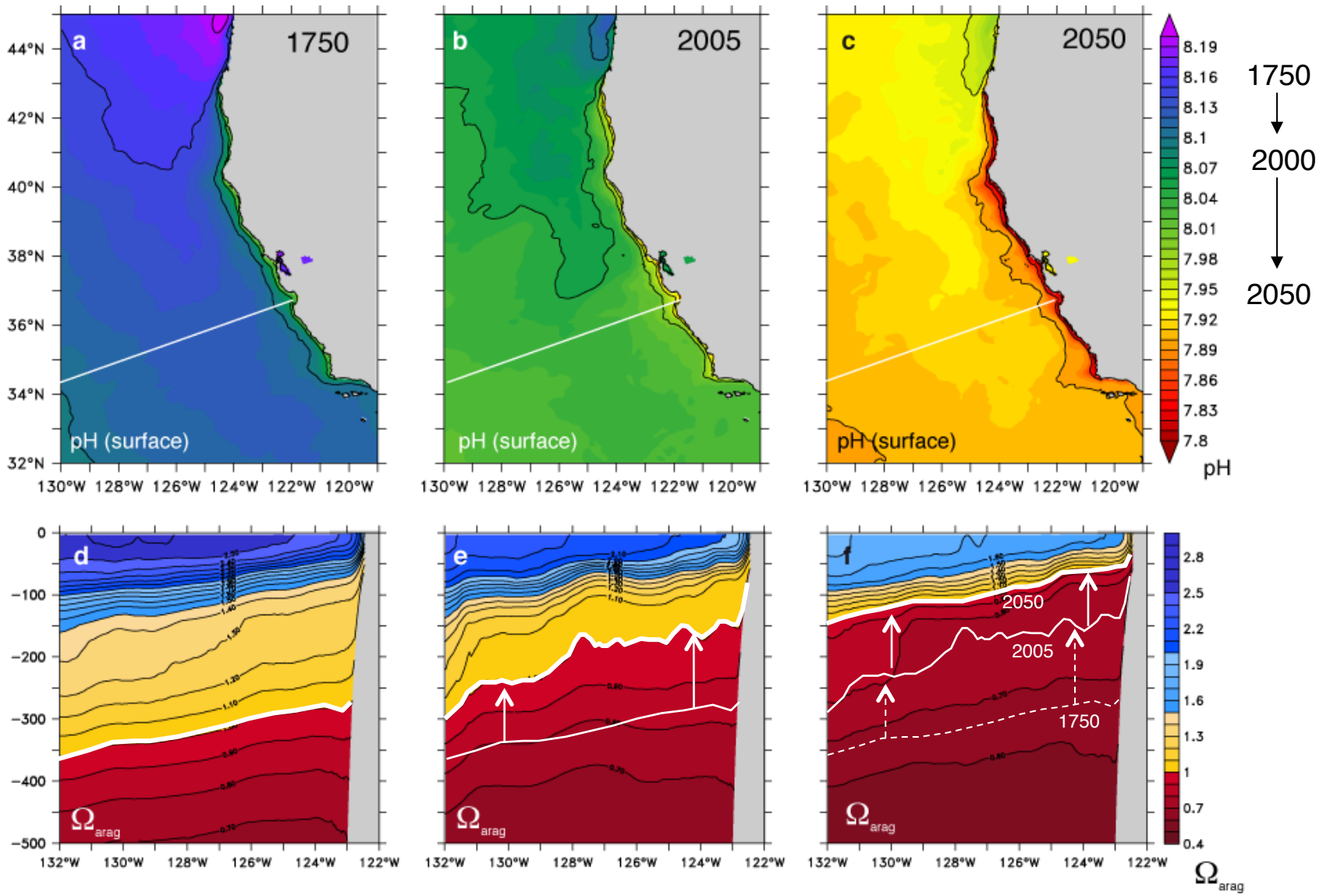
Perturbation simulations with Regional Ocean Modeling System (ROMS) with NPZD model for the California, Canary, and Humboldt CS (5km/7km/15 km resolution)

Evolution of Aragonite saturation horizon and pH



A2-scenario

Evolution since 1750 and projection until 2050

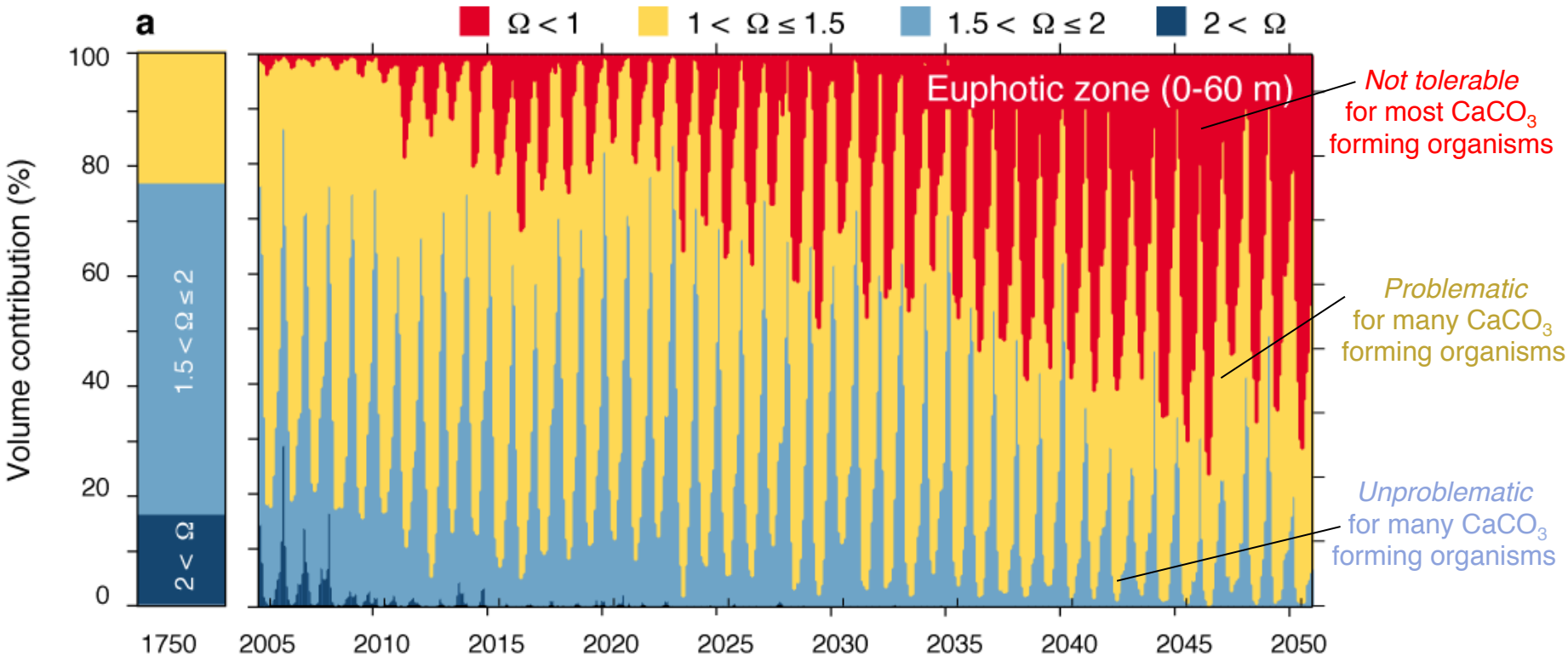


Strong shoaling of the saturation horizon

Gruber et al. (2012)

Evolution of chemical habitats in the CalCS

Relative contribution of volumina with a particular Ω in the upper 60 m and the nearshore 50km



Habitats that are acceptable for most $CaCO_3$ forming organisms become rare, even though most of the upper 60m remains supersaturated.

Gruber et al. (2012)

Outline

1. Introduction

   or why should we be concerned about multiple stressors in EBUS?

2. Ocean acidification

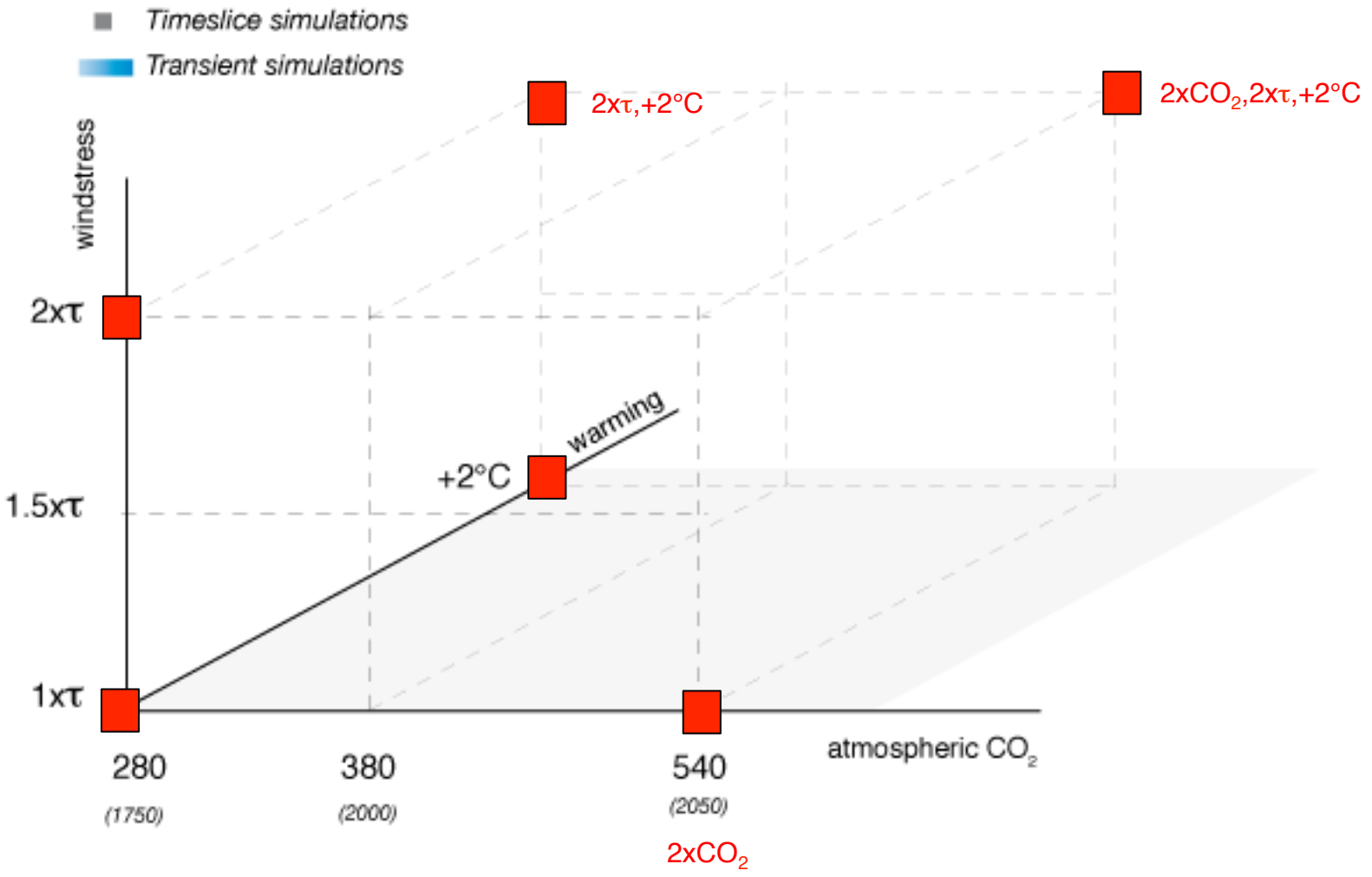
   or how the near-shore CalCS might become undersaturated soon

3. Ocean warming and circulation changes

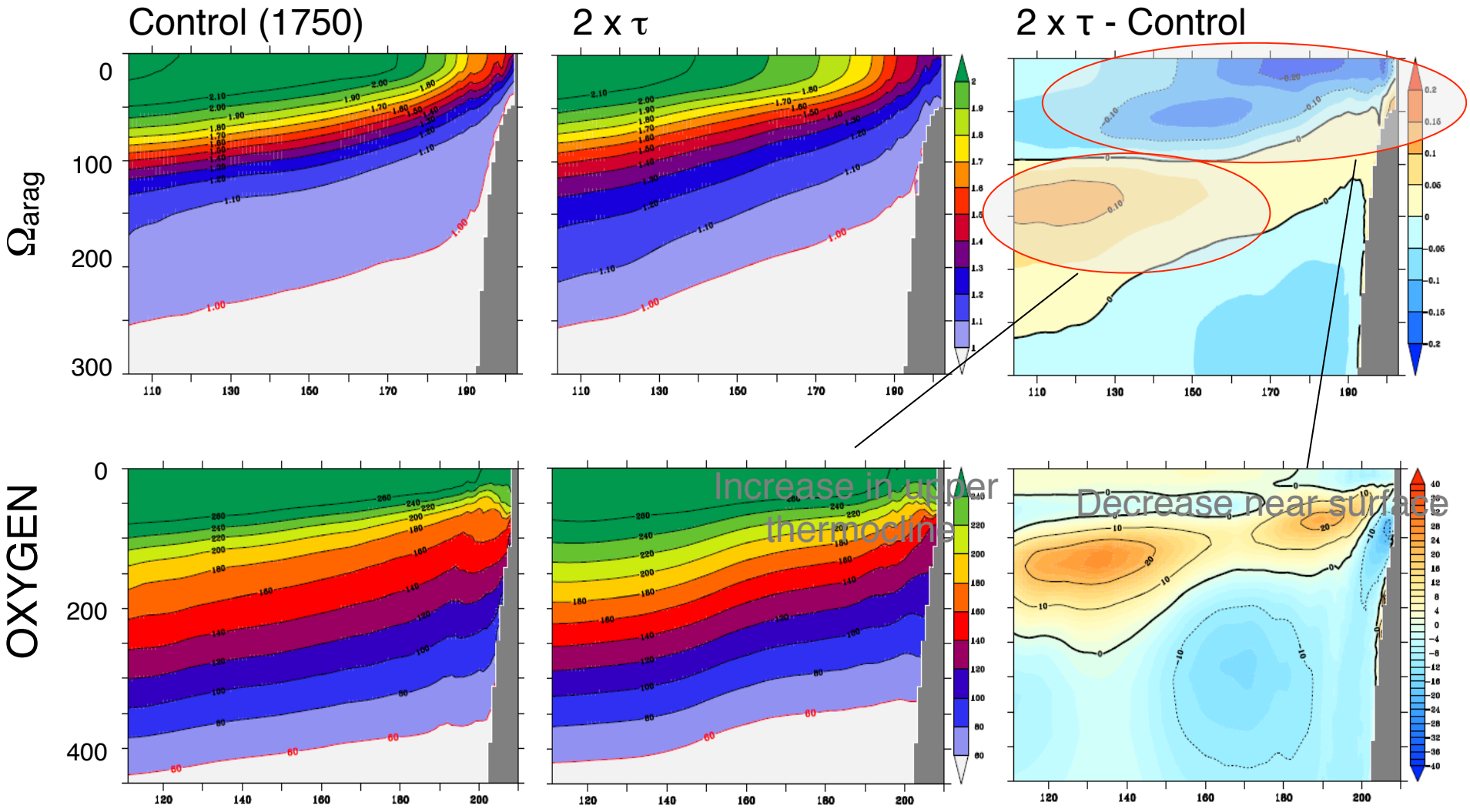
   or how are ocean warming and circulation changing OA and O_2?

4. Summary and outlook

And now add changes in temperature and wind-stress

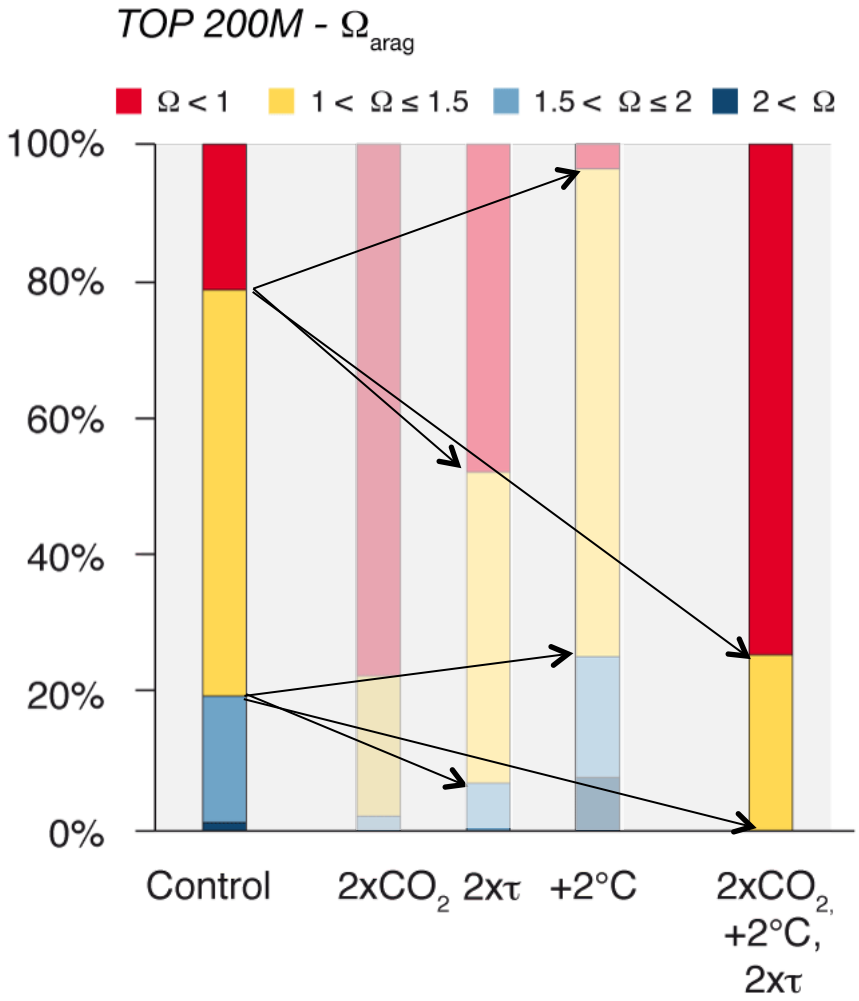


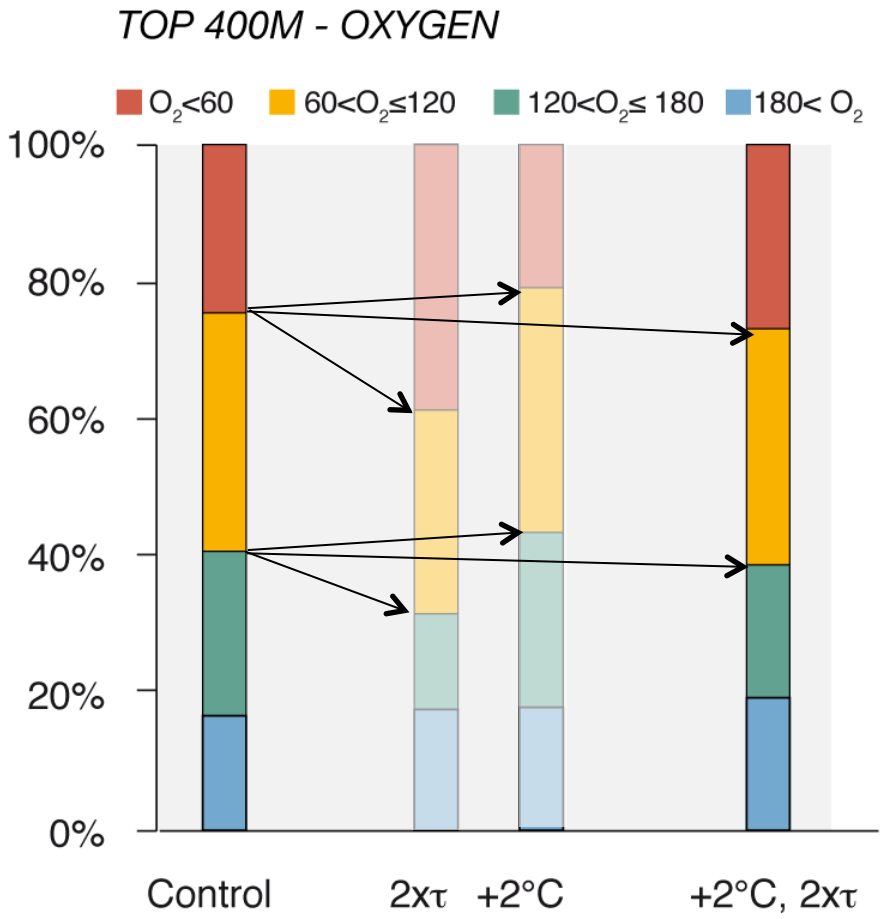
Response to doubling of wind-stress



Changes in winds (and temperature) lead to a complex pattern of changes in Ω_{arag} and oxygen.

Critical Volumina: for Saturation State and Oxygen

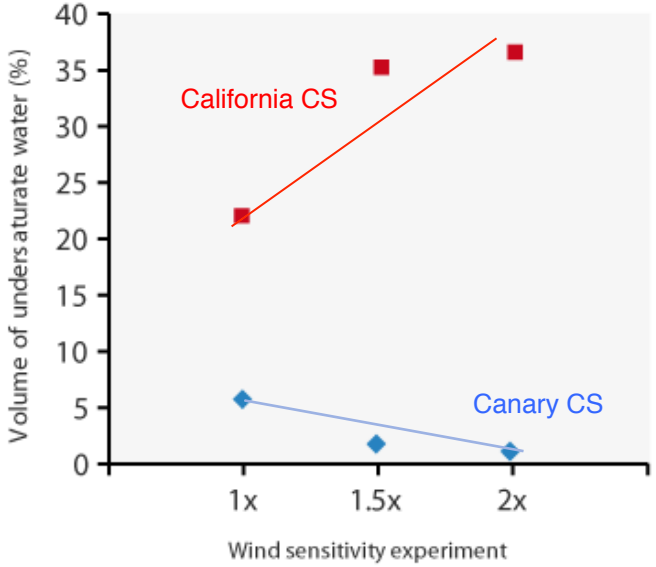


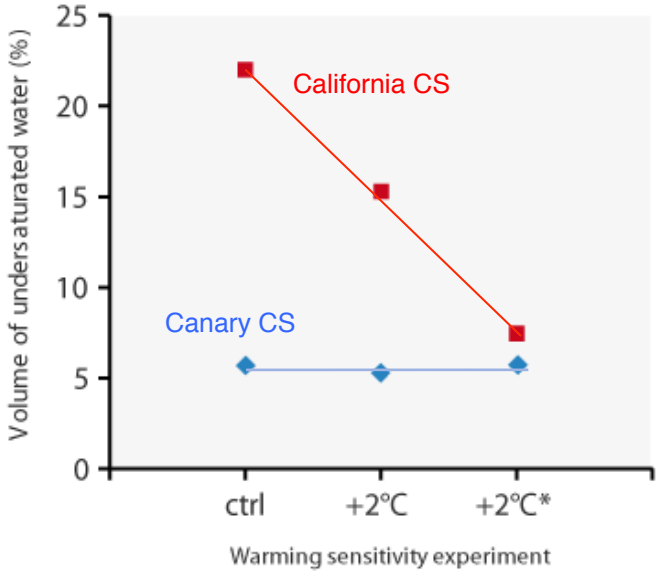


Changes in winds and temperature lead changes in changes in both directions with regard to Ω_{arag} and oxygen.

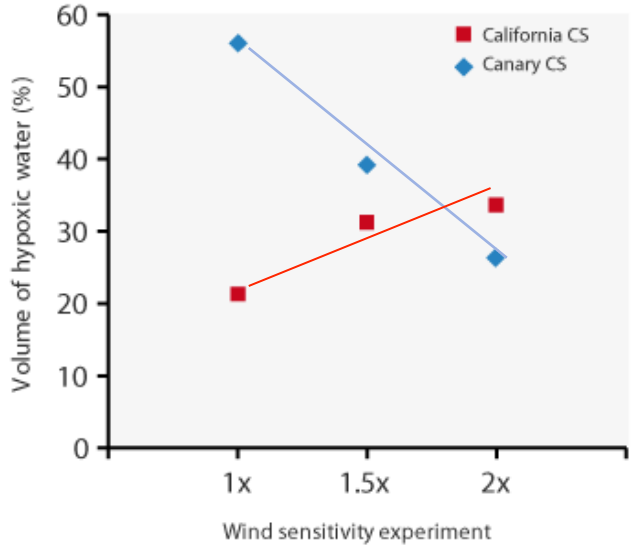
Contrasting responses in the CalCS versus the CanCS

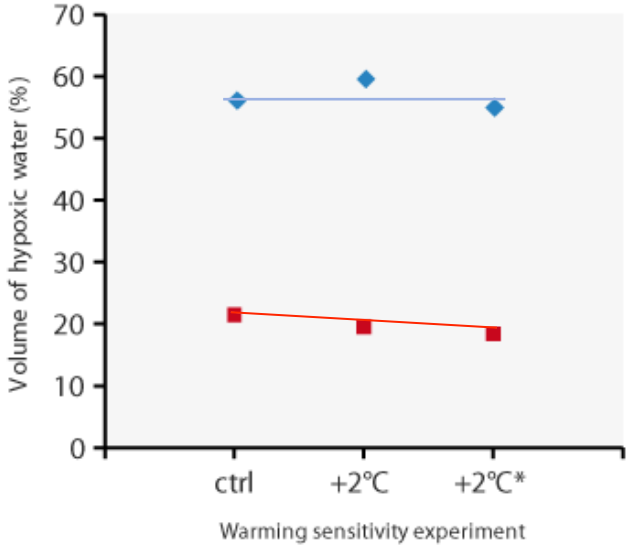
Ω_{arag}





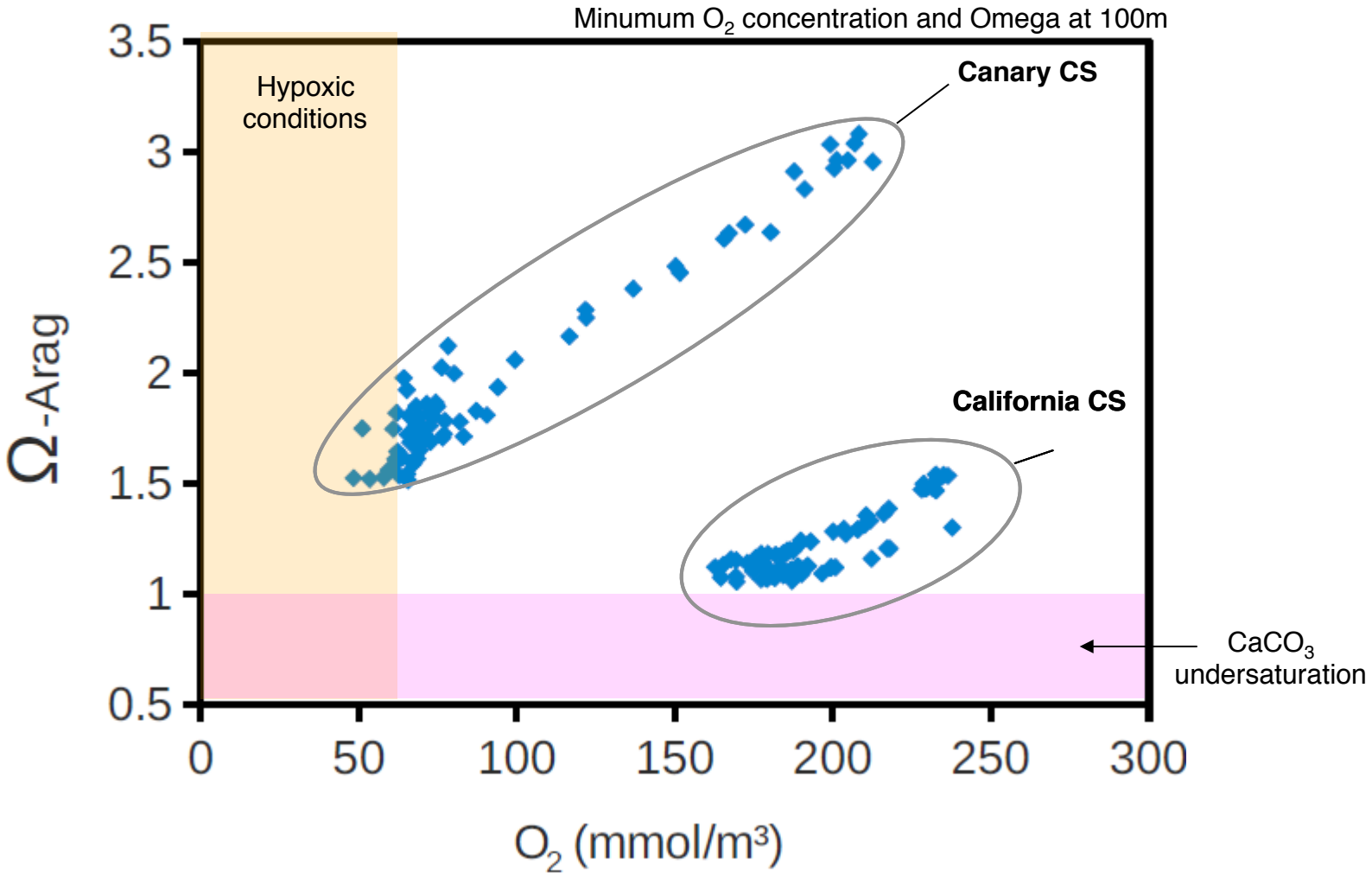
OXYGEN





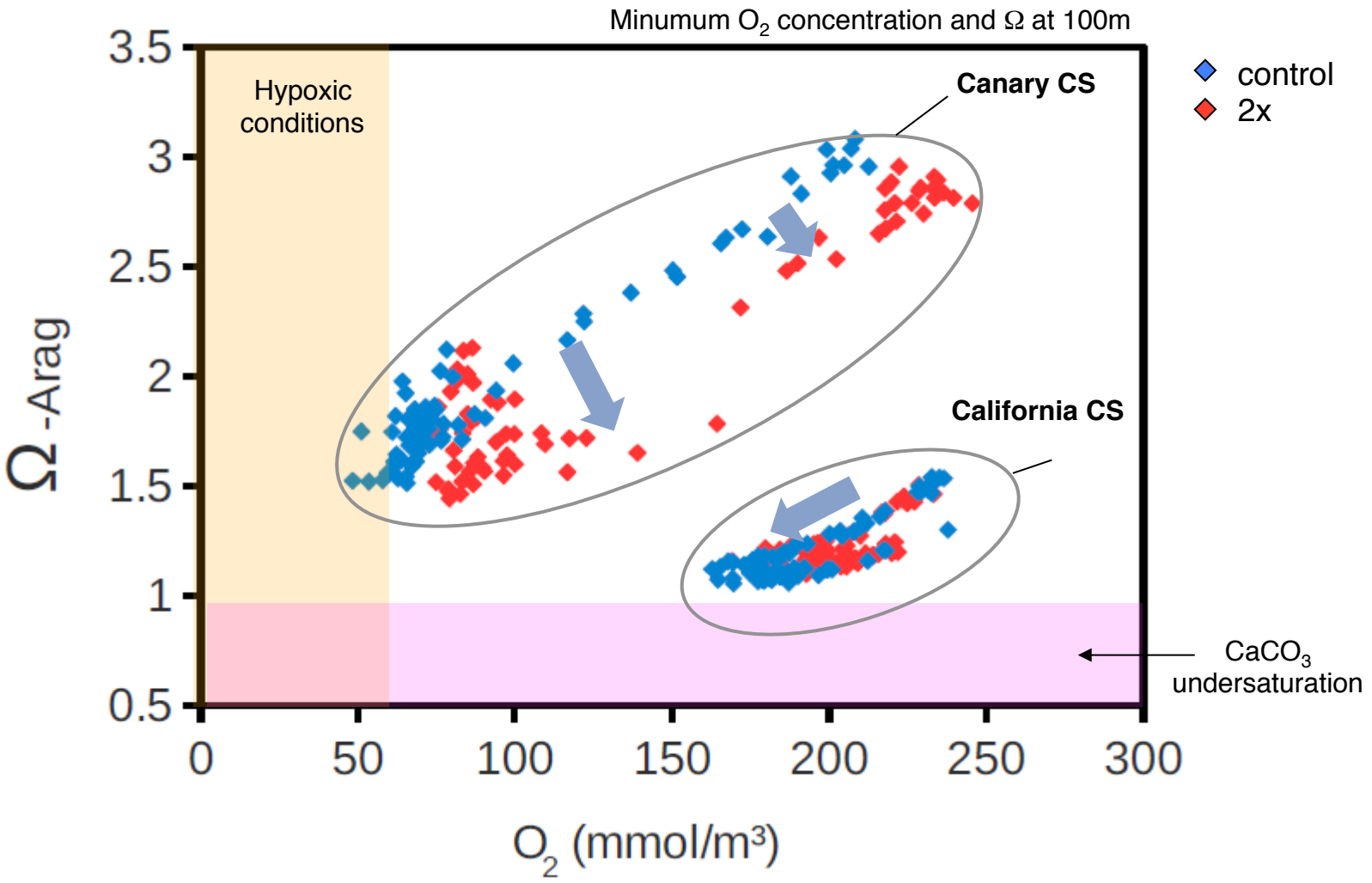
Strongly contrasting responses to changes in winds and temperature.

Understanding the co-variability between Ω_{arag} and O_2



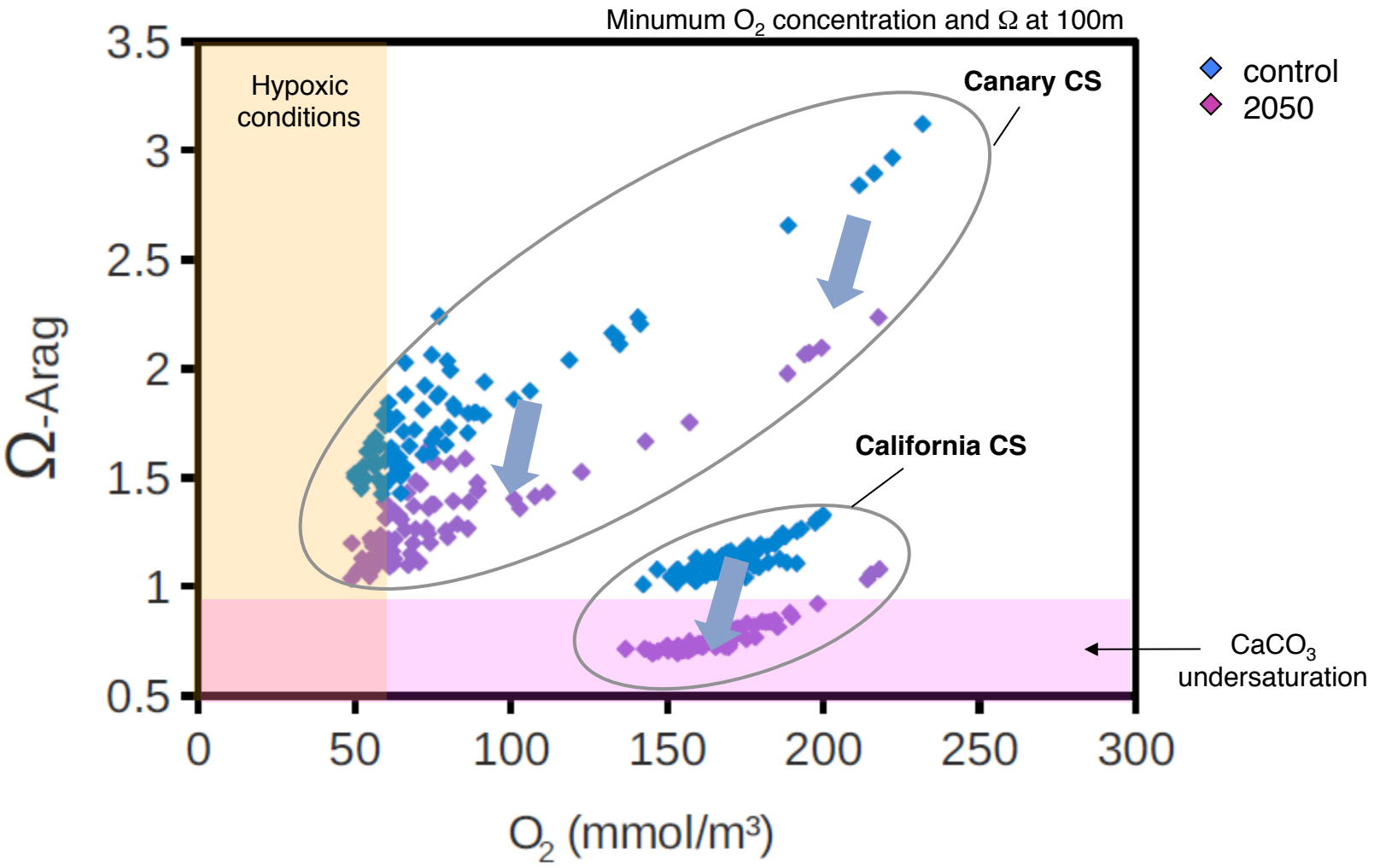
As expected, O_2 and Ω_{arag} co-vary strongly, but with different slopes and intercepts

Adding wind…



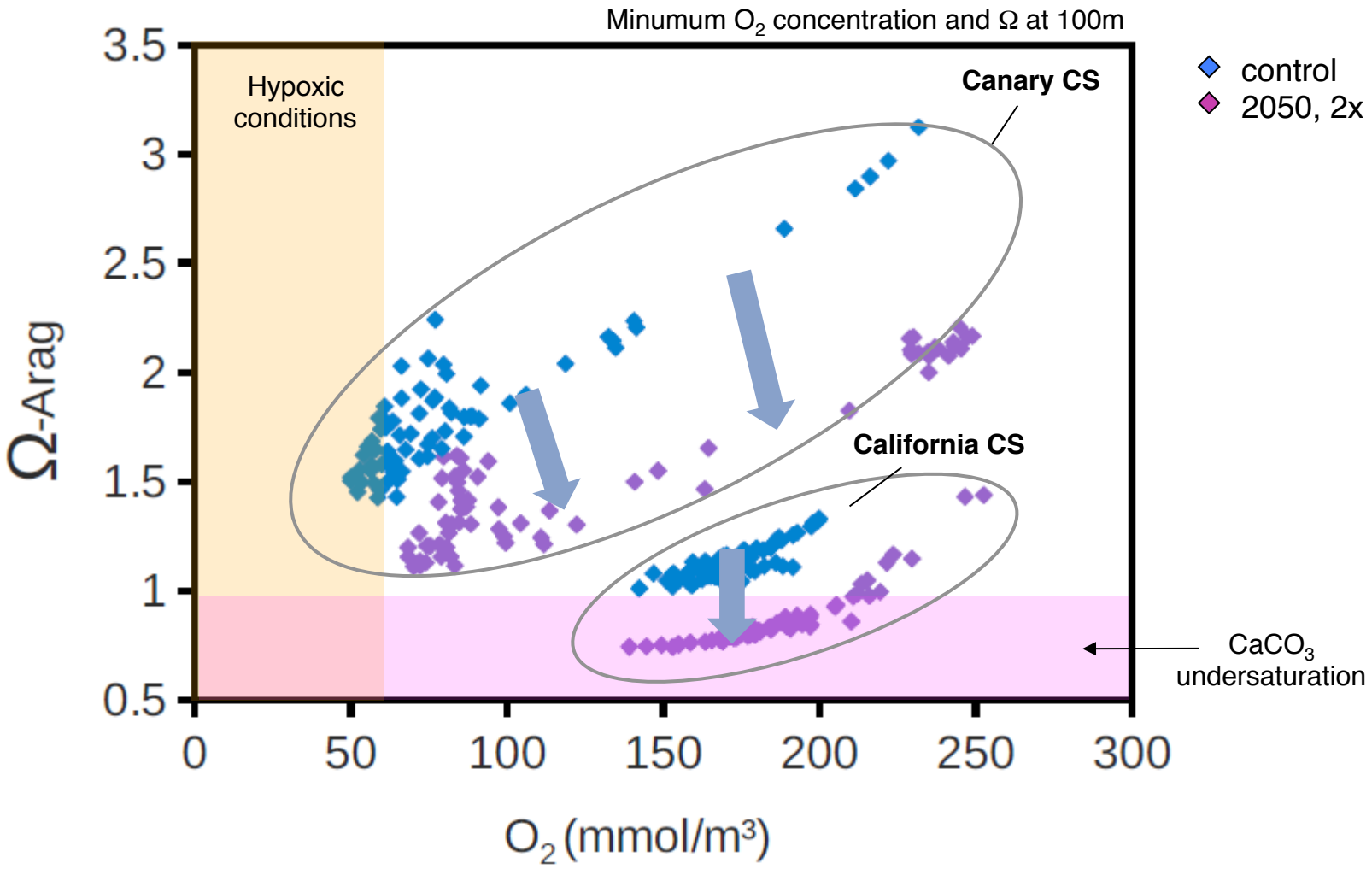
Wind changes affects primarily the Canary CS, while the relationship remains in the CalCS

Adding CO_2…



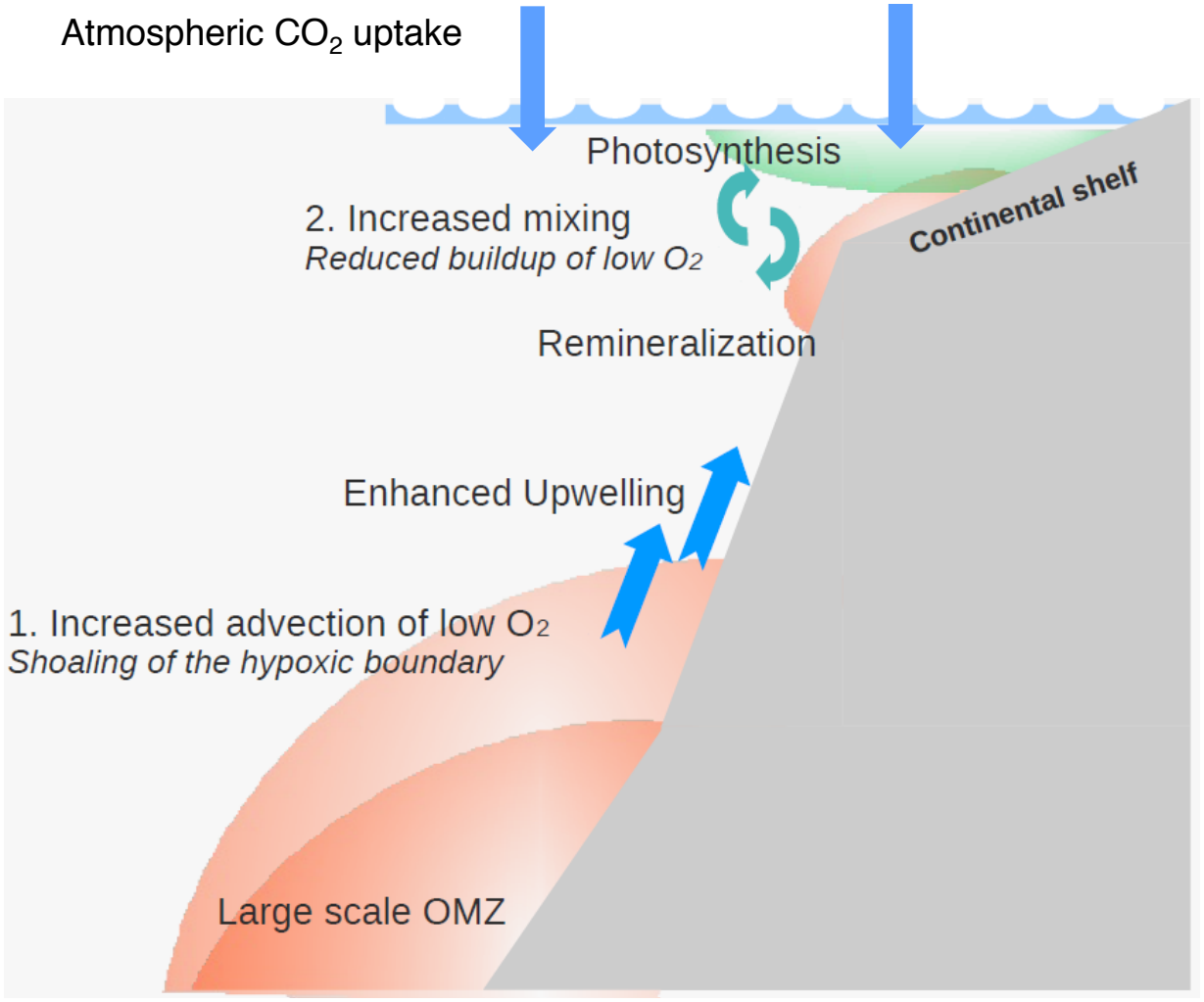
The increase in atmospheric CO_2 decreases Ω_{arag}, while it has no impact on O_2 (in our model)

Adding wind and CO_2…



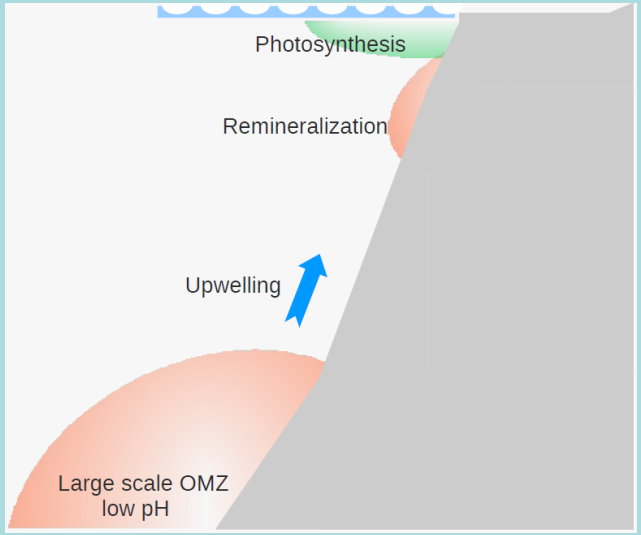
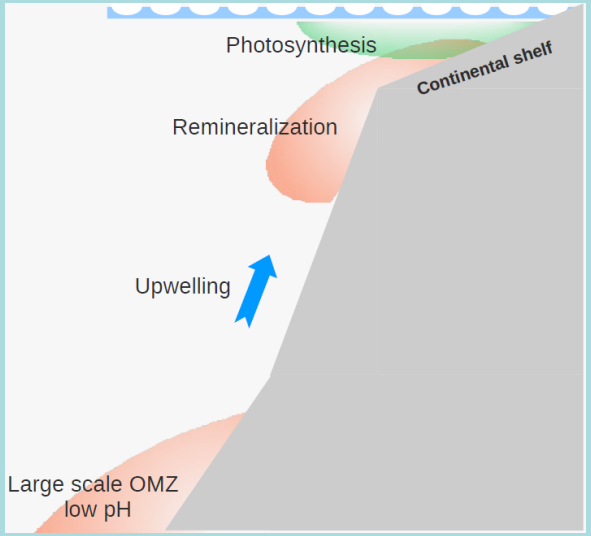
The joint impact is mostly driven by atmospheric CO_2, with wind changes enhancing the changes, particularly in the Canary CS.

Trying to understand the differences…



The changes in Ω_{arag} and O_2 are a result of the balance between advection/ mixing and local sources minus sinks (production & remineralization)

How can we understand the differences…

	California CS	Canary CS
EBUS		
Potential impacts of upwelling increase	Increase of coastal hypoxic & acidification (at depth)	Decrease of coastal hypoxia & acidification (shallow)
Main mechanisms	Upwelling/advection of low O_2, low pH	Remineralization on the shelf

Basin scale forcing (e.g., depth/size of OMZ) + local environmental factors (e.g., shelf width) will strongly control the response of ocean acidification and coastal hypoxia to upwelling/stratification increase in EBUS

Summary and Outlook

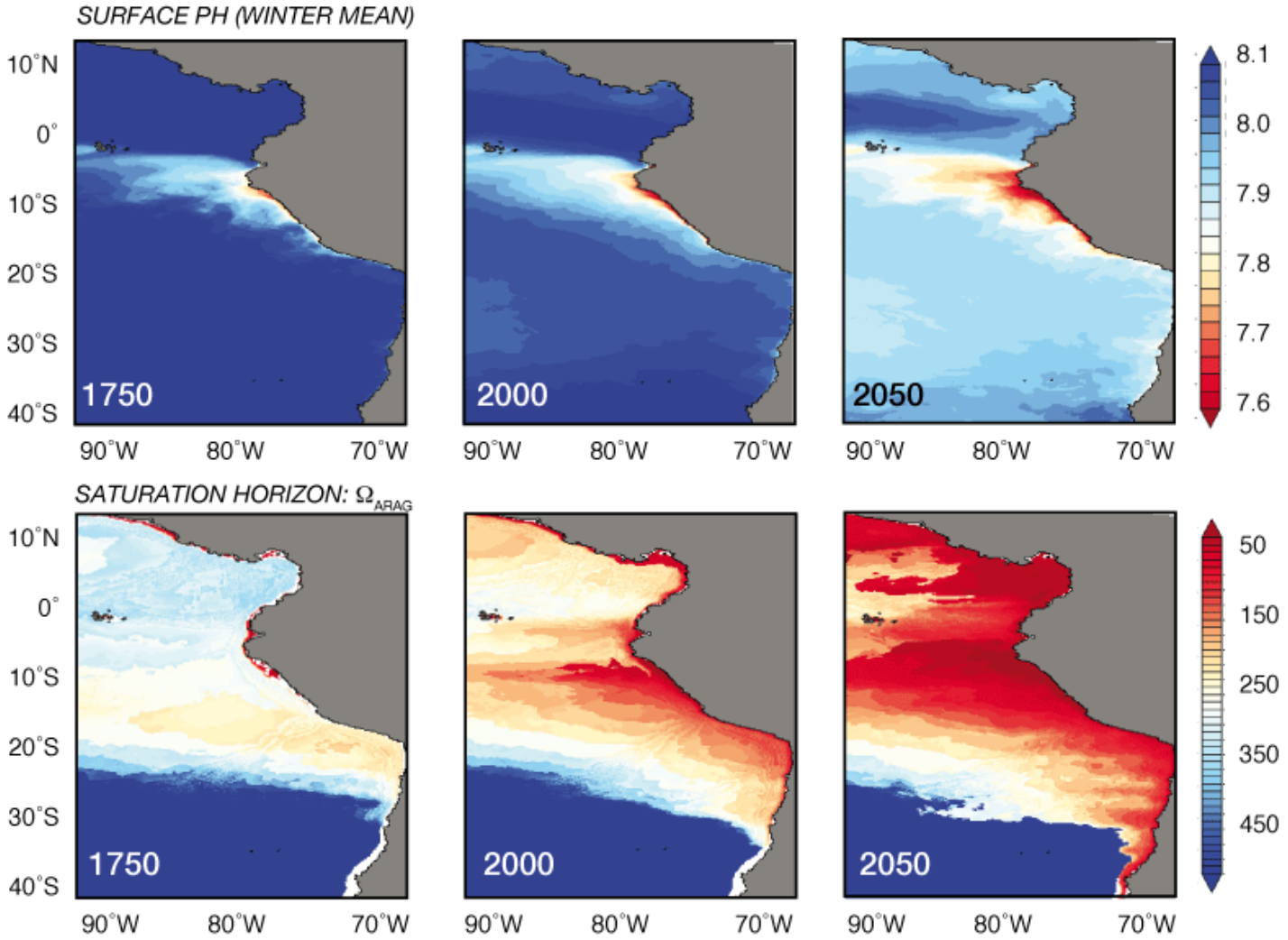
- The California Current System is bound to progress toward large and widespread *undersaturation* with regard to aragonite within the next few decades.

- Changes in *upwelling* and *ocean warming* will modify ocean acidification somewhat. They have much more substantial impacts on oxygen, albeit with large regional differences.

- EBUS are hotspots of change. They may provide an *ideal testbed* for studying the impact of multiple stressors on marine life and biogeochemistry.

Acknowledgments:
Funding from EPOCA & ETH Zürich

Evolution of pH and $\Omega_{aragonite}$ in the Humoldt CS



The Humboldt Current System is highly prone to become undersaturated in the upper ocean, while the Canary Current System will likely remain supersaturated