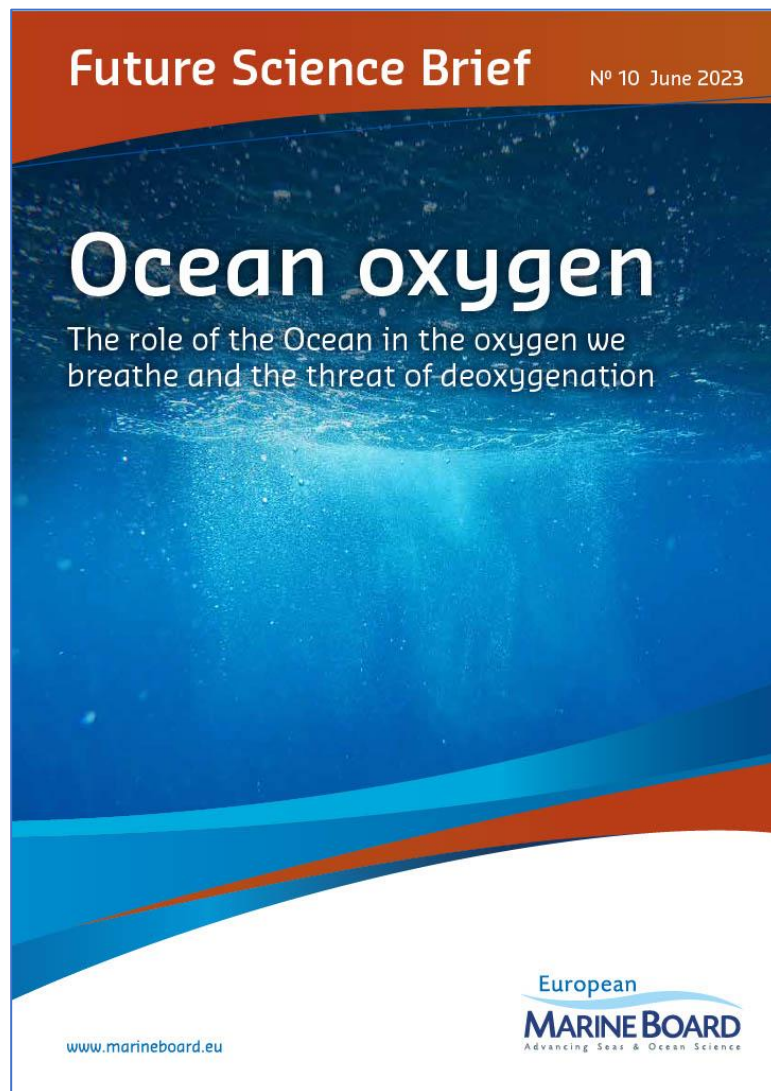


Potential impacts of marine carbon dioxide removal on ocean oxygen

Andreas Oschlies, Caroline Slomp, Marilaure Gregoire, Denise Breitburg, Natalya Gallo, Andrew Altieri, Francisco Chavez, Jeremy Sterling, and Kirsten Isensee





Ocean oxygen

The role of the Ocean in the oxygen we breathe and the threat of deoxygenation

Working Group: Marilaure Grégoire, Andreas Oschlies, Donald Canfield, Carmen Castro, Irena Ciglenc̆ki, Peter Croot, Karine Salin, Birgit Schneider, Pablo Serret, Caroline Slomp, Tommaso Tesi, Mustafa Yücel

External Reviewers: Robert Diaz, Nancy Rabalais, Emily Zakem

Series Editor: Sheila J. J. Heymans

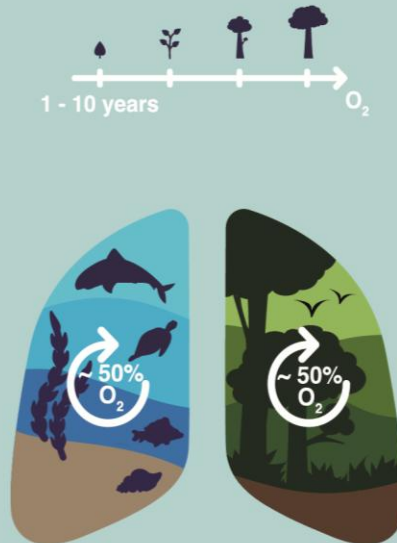
Publication Editors: Ana Rodriguez-Perez, Britt Alexander, Paula Kellett, Ángel Muñiz Piniella, Jana Van Elslander, Sheila J. J. Heymans

Does every second breath we take come from the Ocean?

Does every second breath humans take come from the Ocean?

No, it is more - but it is complicated

The Biological oxygen cycle



The land and sea each produce ~50% of Earth's oxygen, but this oxygen is used again when microbes, plants and animals respire

The **net flux of oxygen** from the Ocean to the atmosphere is **almost zero** over biological time scales

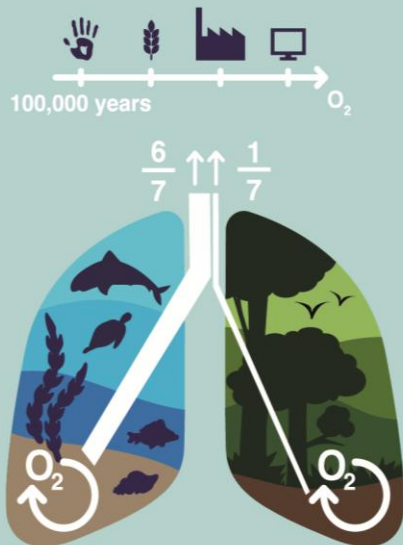
- ✓ The Ocean produces ~50% of Earth's oxygen
- ✓ Every second breath taken by all life on Earth comes from the Ocean
- ✓ On short timescales, oceanic and terrestrial systems produce as much as they consume.

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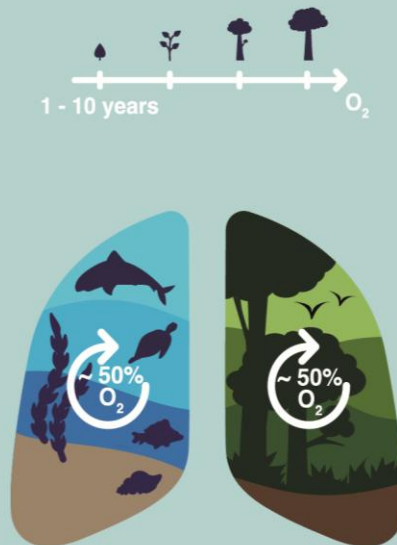
The Geological oxygen cycle



When organic matter is buried, it escapes respiration, leaving oxygen to accumulate in the atmosphere

The Ocean has released 6 of 7 breaths humans take (~86%) over geological time scales

The Biological oxygen cycle

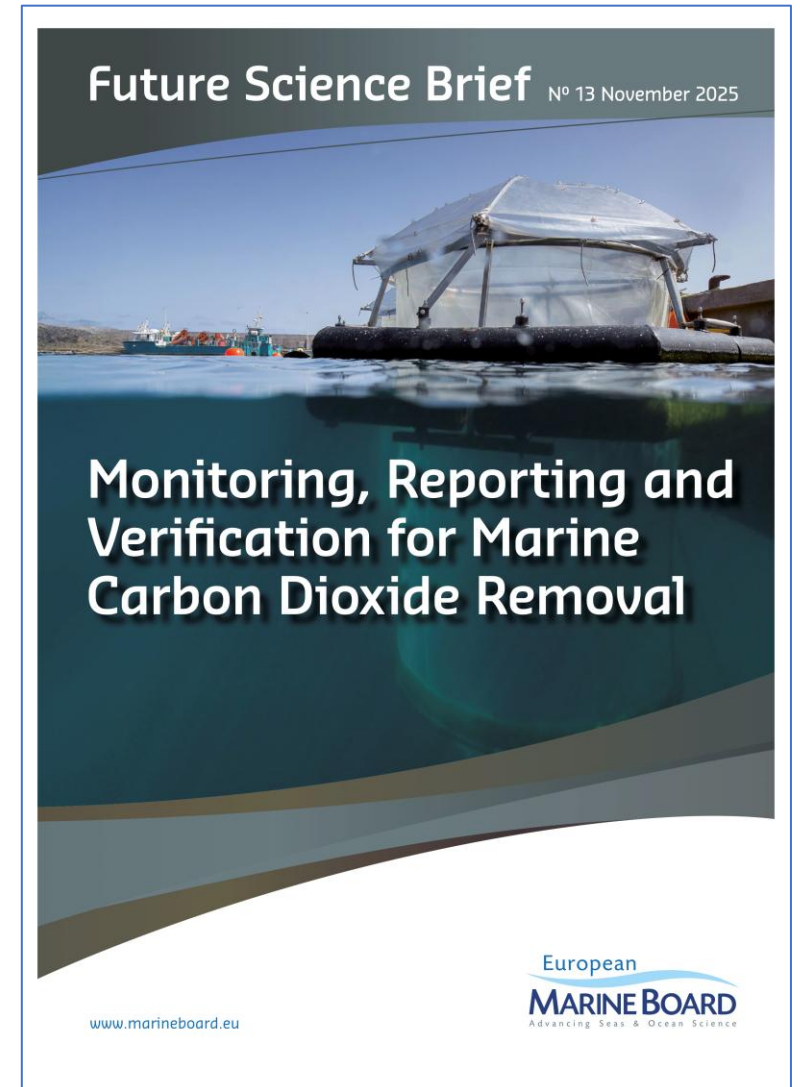
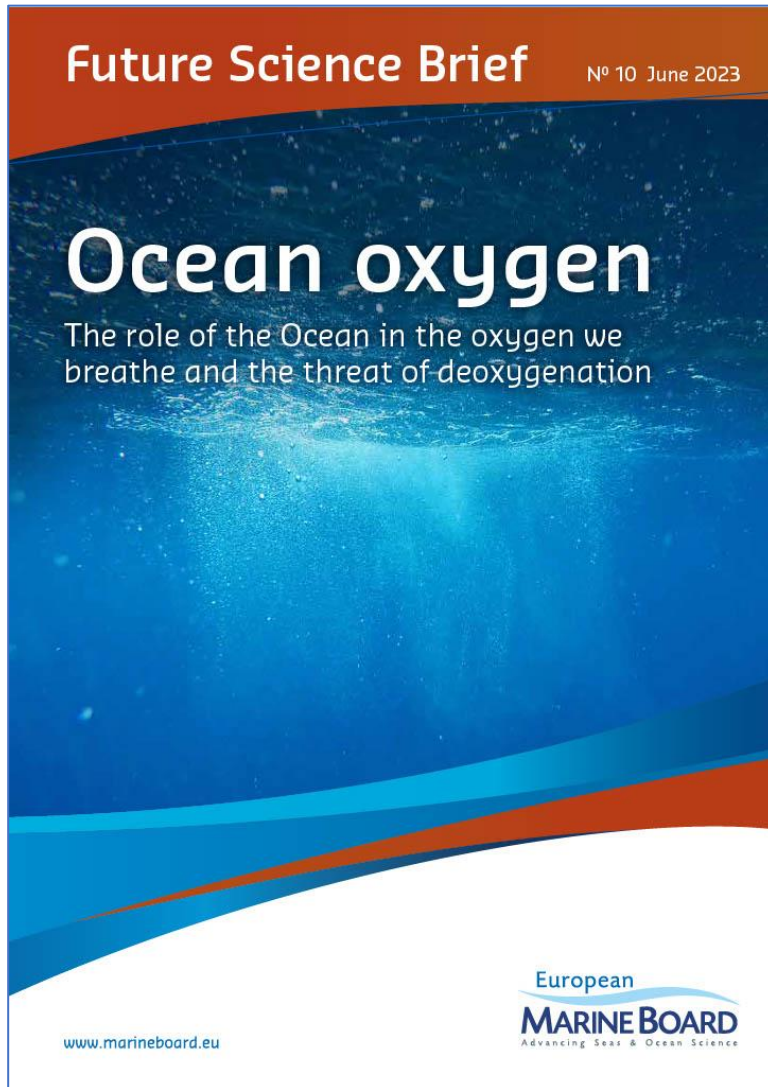


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The net flux of oxygen from the Ocean to the atmosphere is almost zero over biological time scales

- ✓ The Ocean produces ~50% of Earth's oxygen
- ✓ Every second breath taken by all life on Earth comes from the Ocean
- ✓ On short timescales, oceanic and terrestrial systems produce as much as they consume.
- ✓ On long timescales, more organic carbon (and pyrite) is buried in the ocean than on land
- ✓ Since the origin of life, the Ocean has provided most of the oxygen in the atmosphere, and is responsible for 6 of 7 breaths humans take

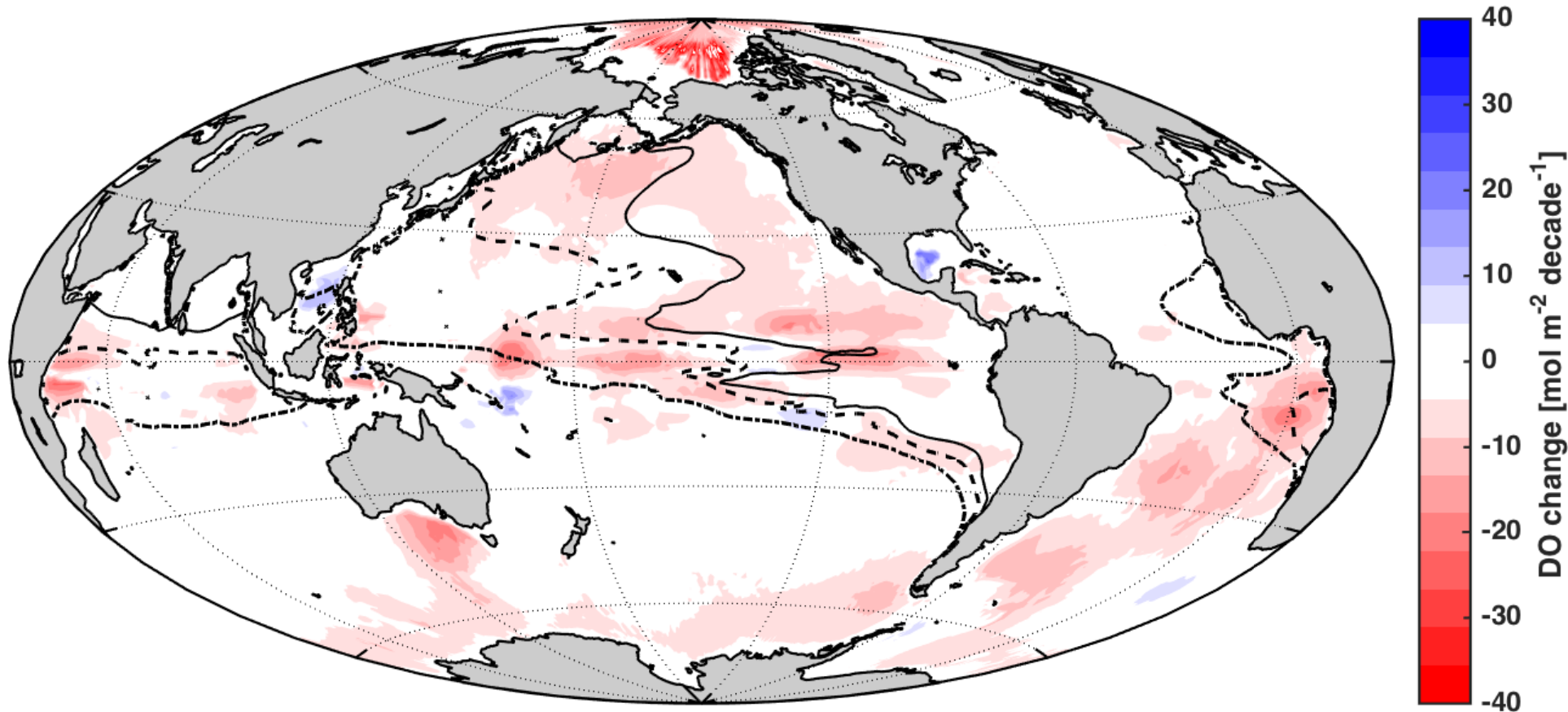
Future Science Briefs N°10 & N°13



(Marilaure Gregoire, A. Oschlies et al., 2023)

(Helene Muri, Olivier Sulpis et al., 2025)

'Observed' oxygen change (1960-2010)

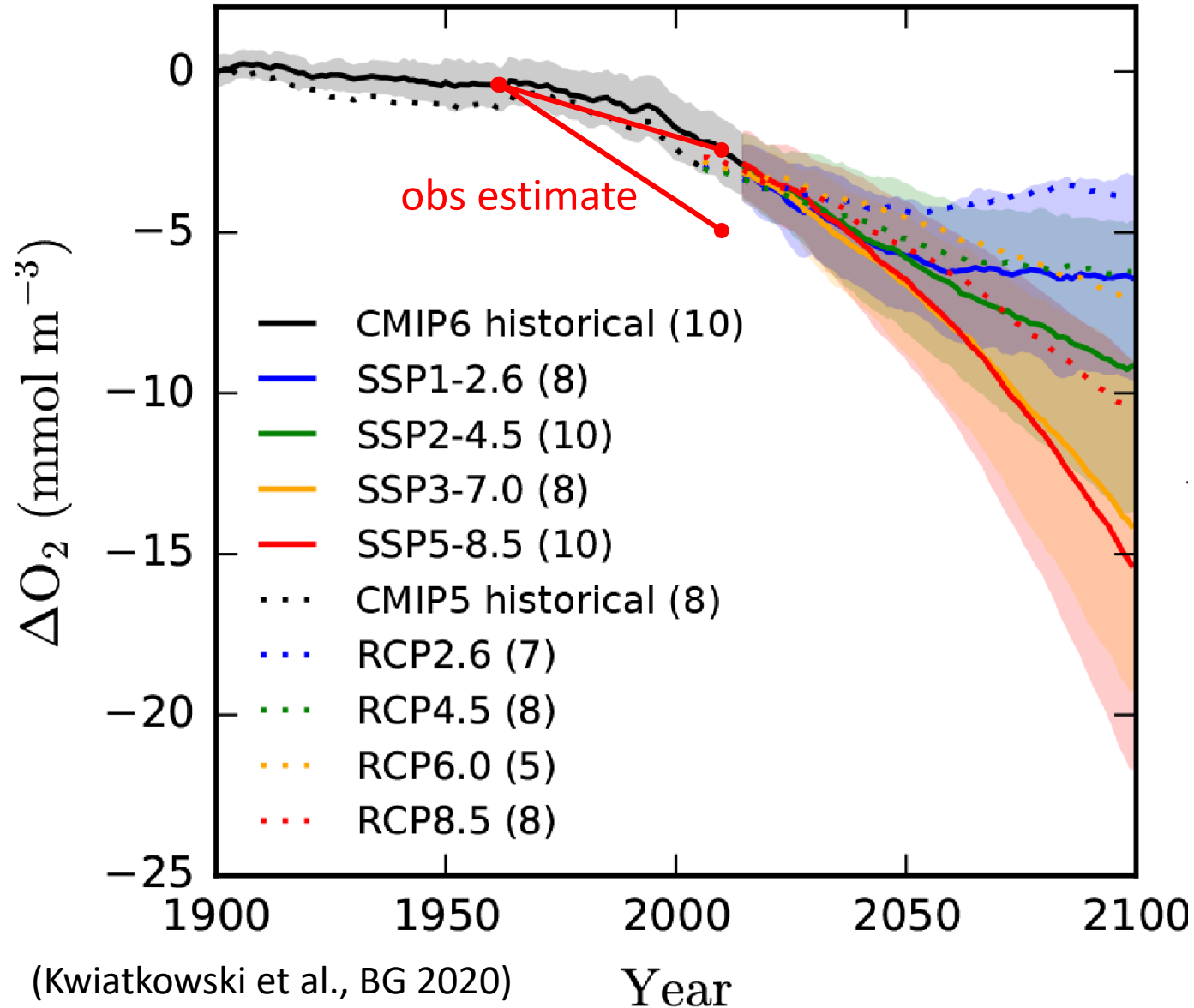


vertically integrated O₂ change

Observational estimate:
Oceanic O₂ loss:
~1 Pmol/decade,
i.e.
**~2 % during past
50 years.**

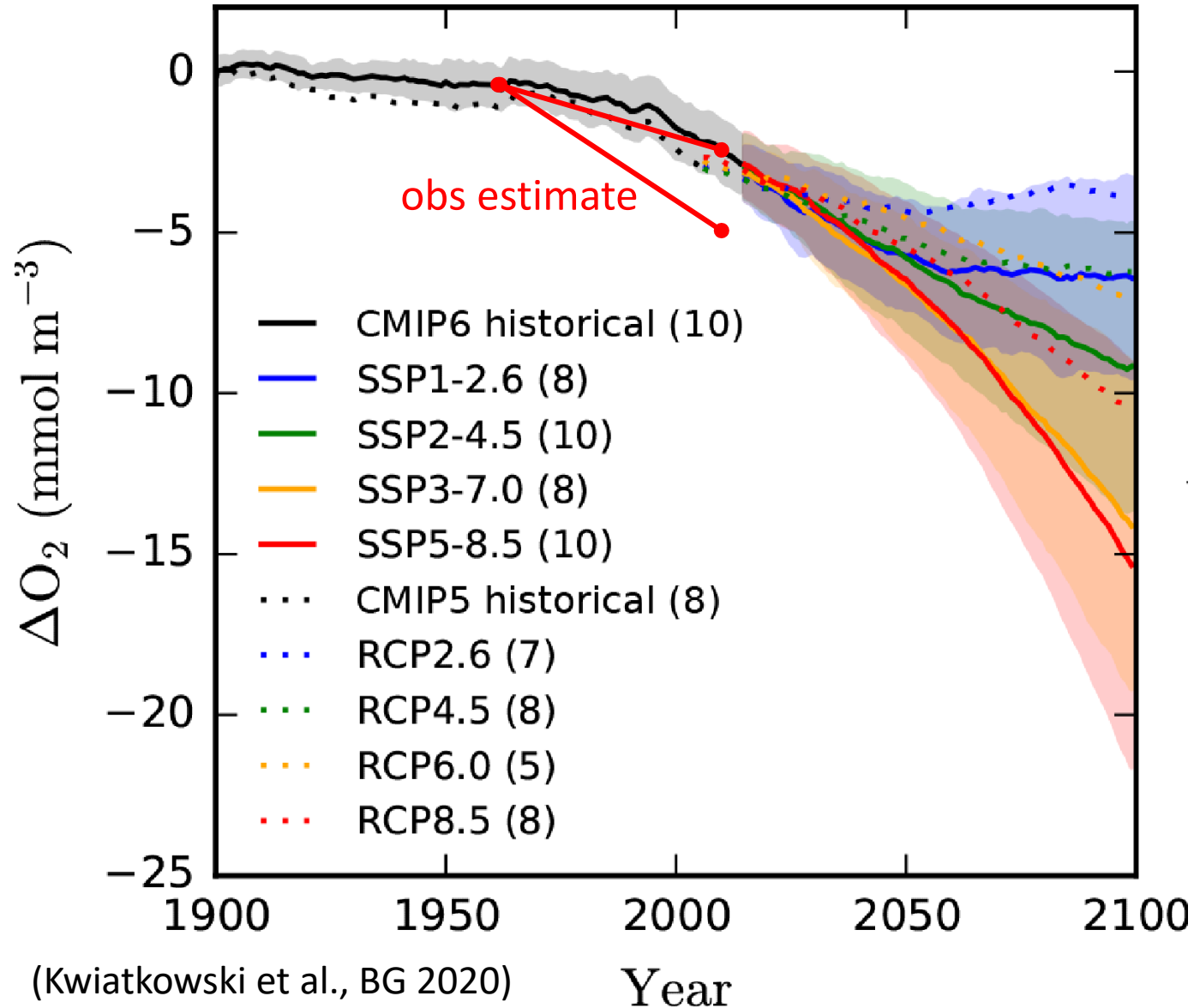
(Schmidtke et al., Nature 2017)

The ocean is losing oxygen at accelerating speed



- Main cause: Global warming (plus eutrophication in some coastal areas)
- Stronger warming induces more severe loss of marine oxygen

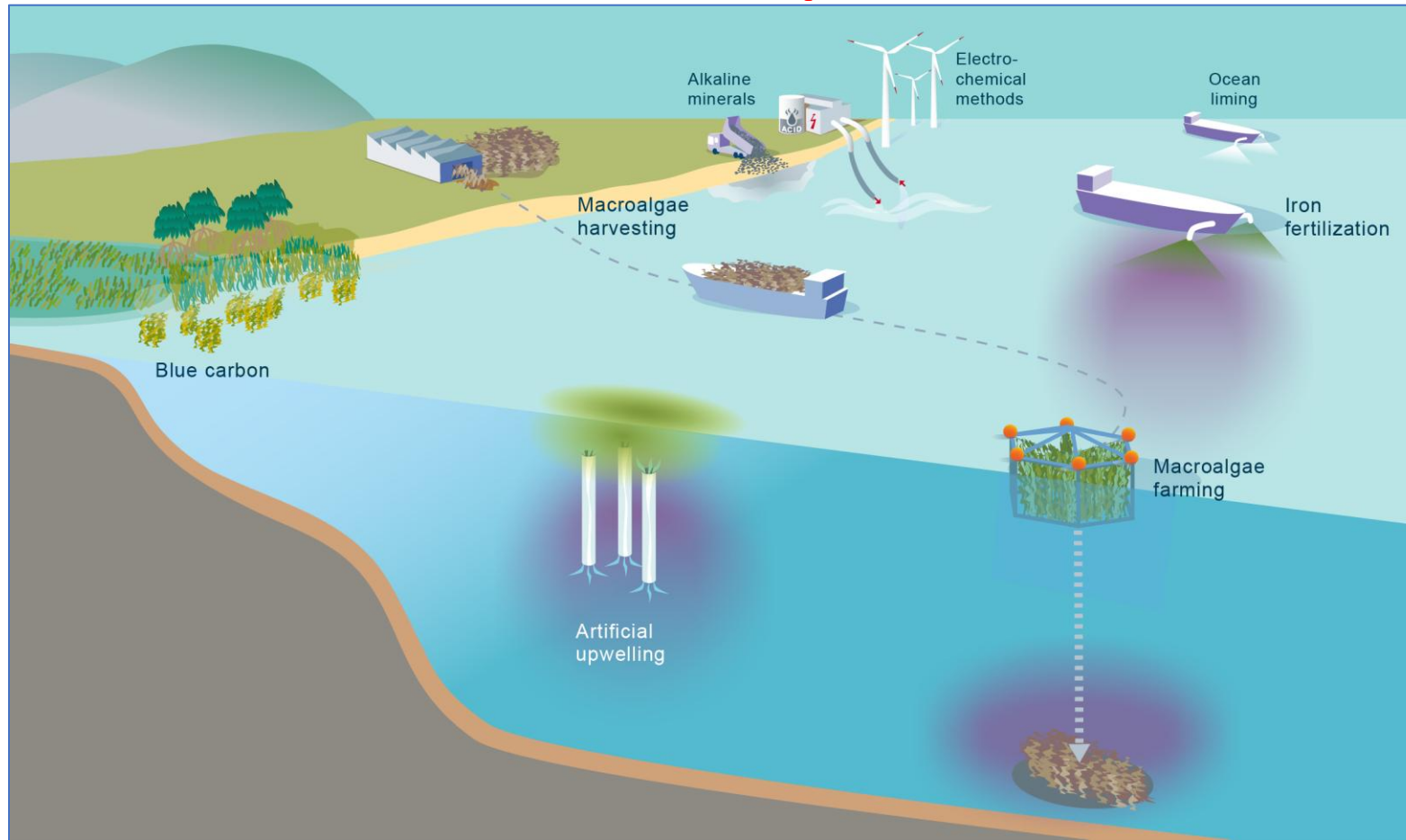
The ocean is losing oxygen at accelerating speed



- Main cause: Global warming (plus eutrophication in some coastal areas)
- Stronger warming induces more severe loss of marine oxygen
- **reduced warming leads to reduced ocean deoxygenation**
- Current models seem to underestimate observed deoxygenation

Marine Carbon Dioxide Removal (CDR) ideas

- Intention: reduction of further global warming, and hence of deoxygenation – if nothing else changes
- **What would be the net impact of marine CDR on ocean oxygen?**

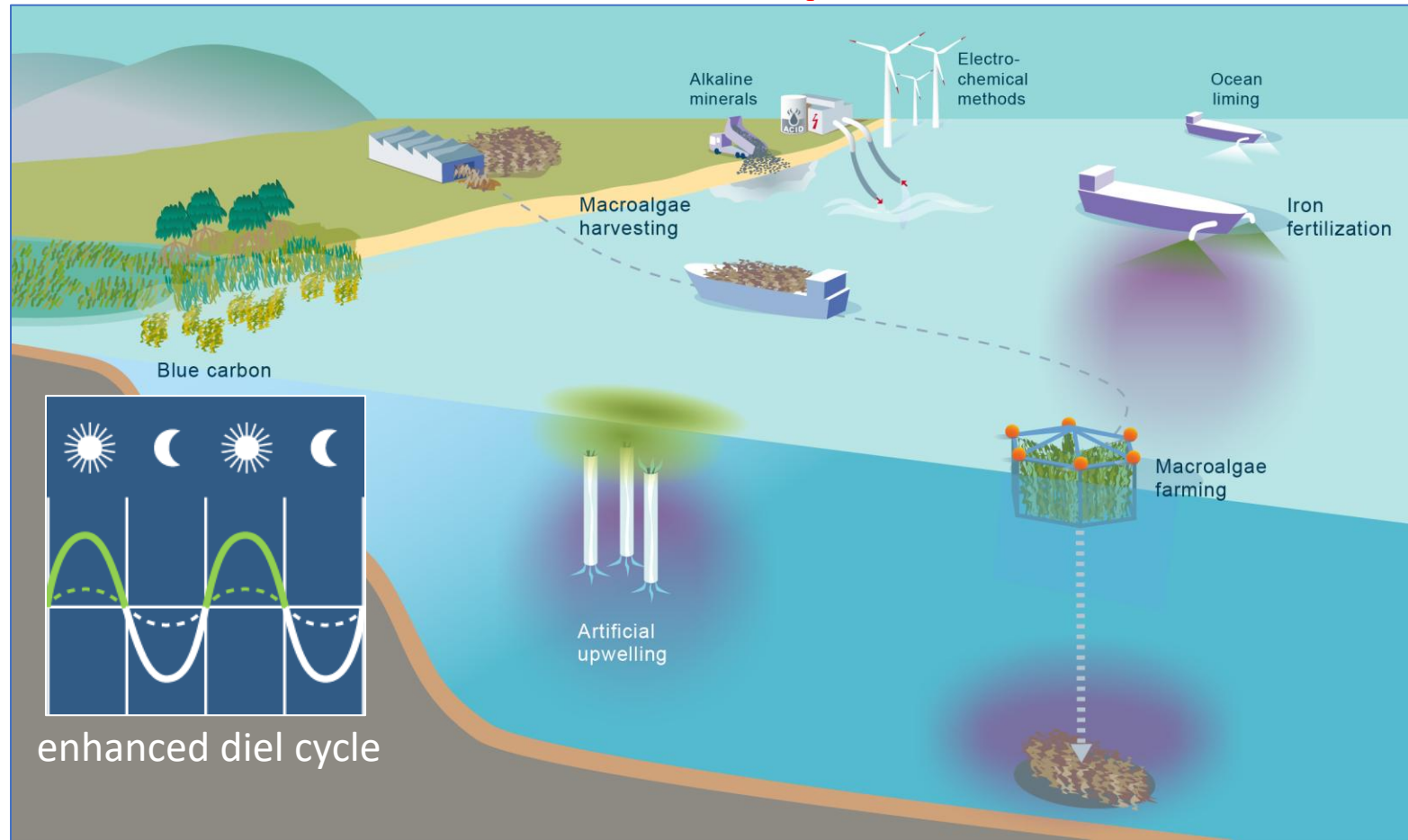


- meta-analysis of available model simulations
- hypothetical large-scale deployment, high-emission scenario, UVic Earth system model

(Oschlies et al., ERL 2025)

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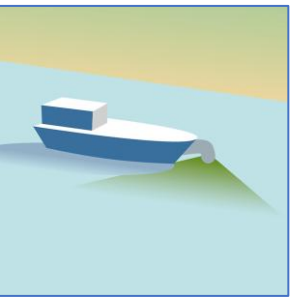
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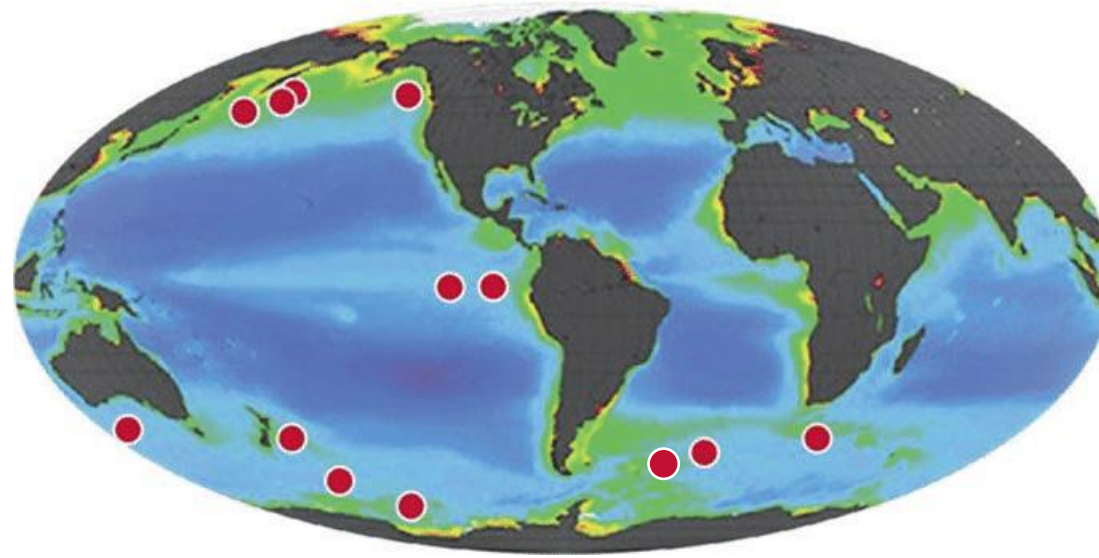
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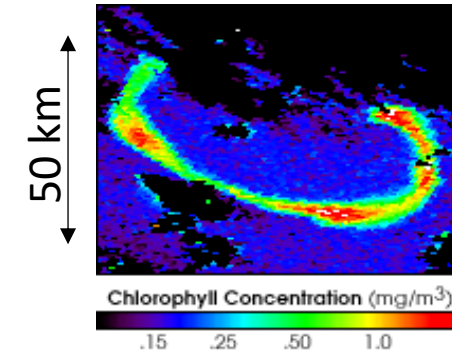
Ocean Iron Fertilization and marine O₂



13 field trials
(1993 – 2009)



(Courtesy of Woods Hole Oceanographic Institution)

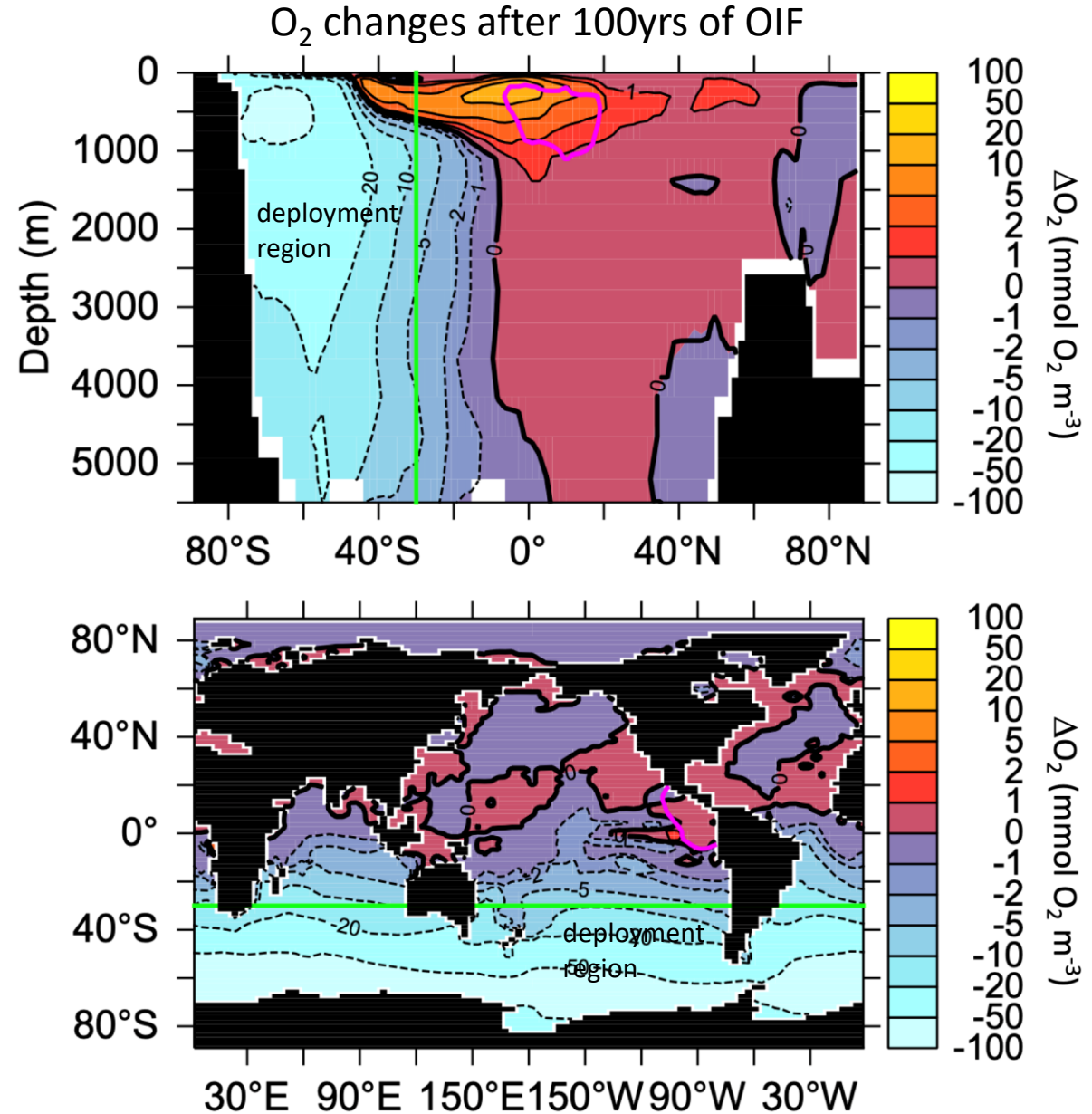


(Courtesy Jim Acker, SeaWiFS, NASA)

- > Major ecological shifts, surface & likely depth (not measured until now)
- > Additionality? Durability?
- > **International governance put in place:**
London Convention & London Protocol: Precautionary approach, no commercial fertilization activities until adequate scientific basis exists.

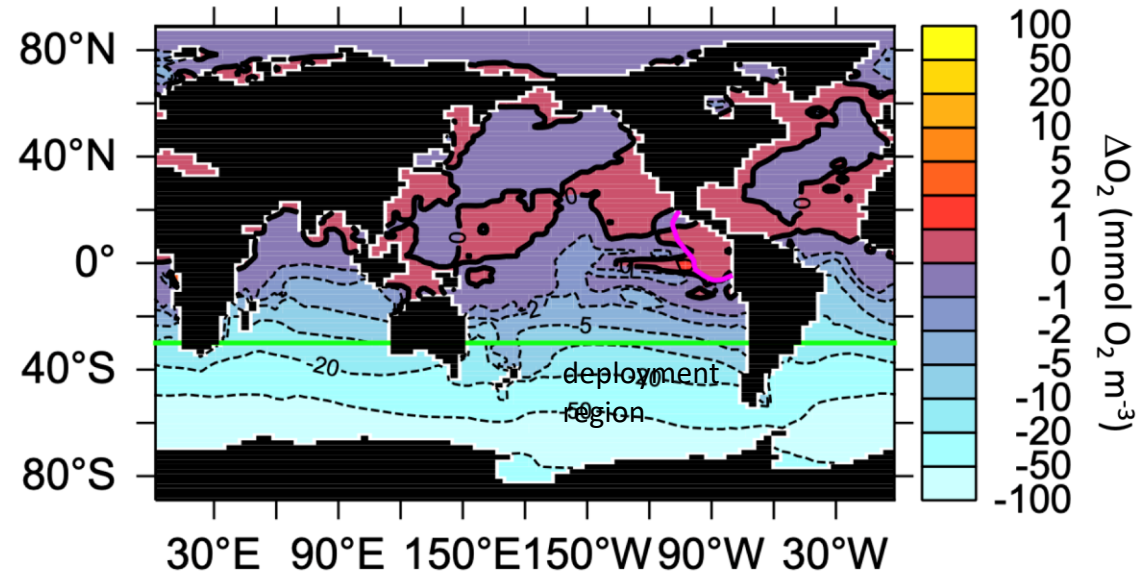
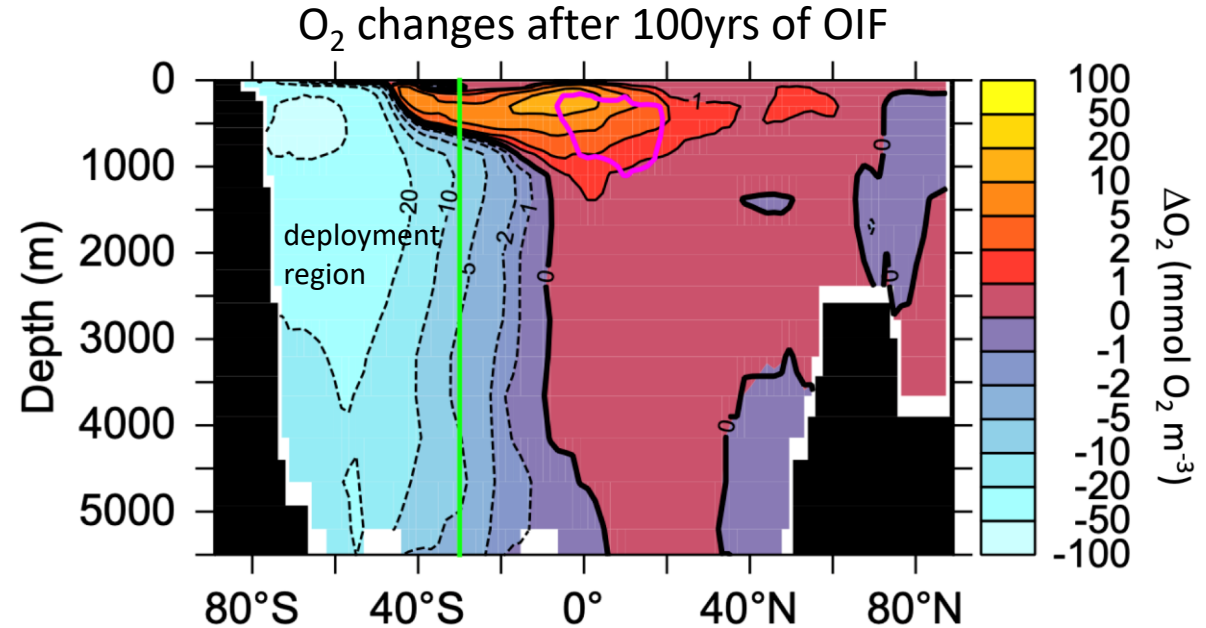
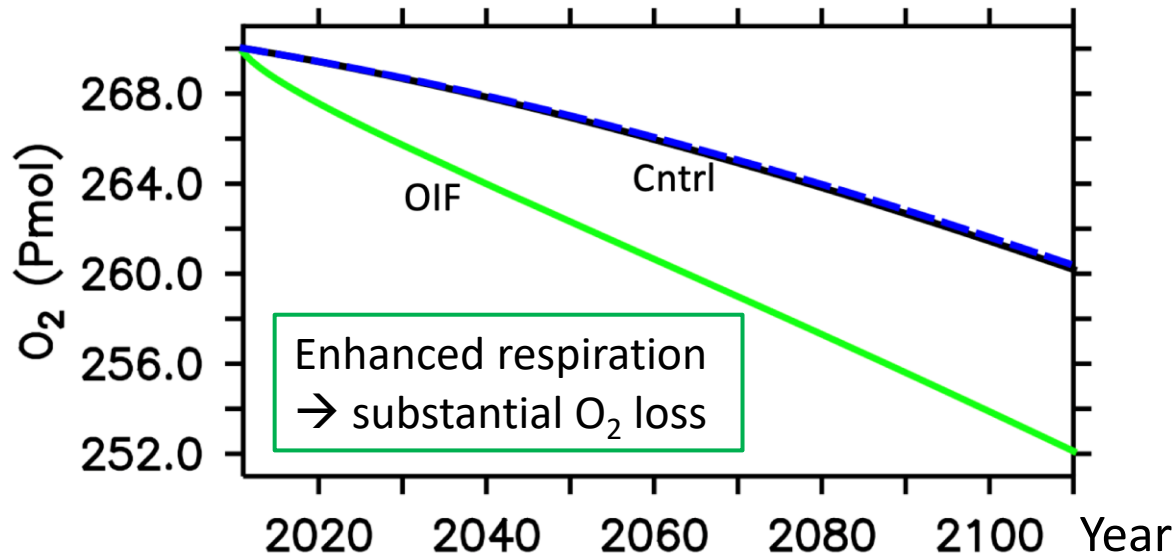
Ocean Iron Fertilization and marine O₂

- Simulated OIF south of 30°S
- CO₂ sequestration → reduced warming & small O₂ gain
- Enhanced respiration & O₂ loss



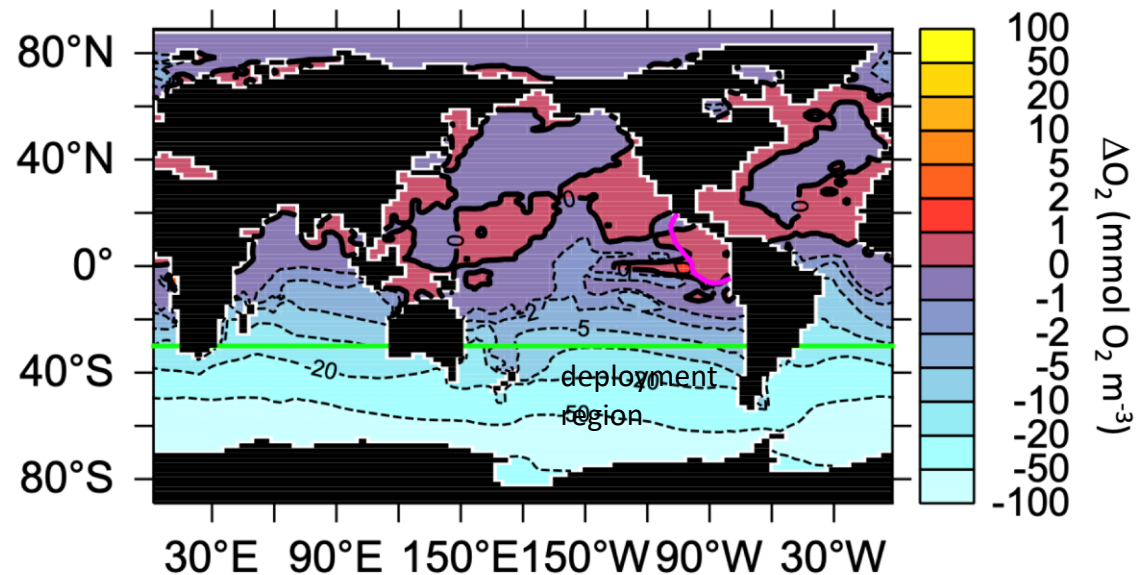
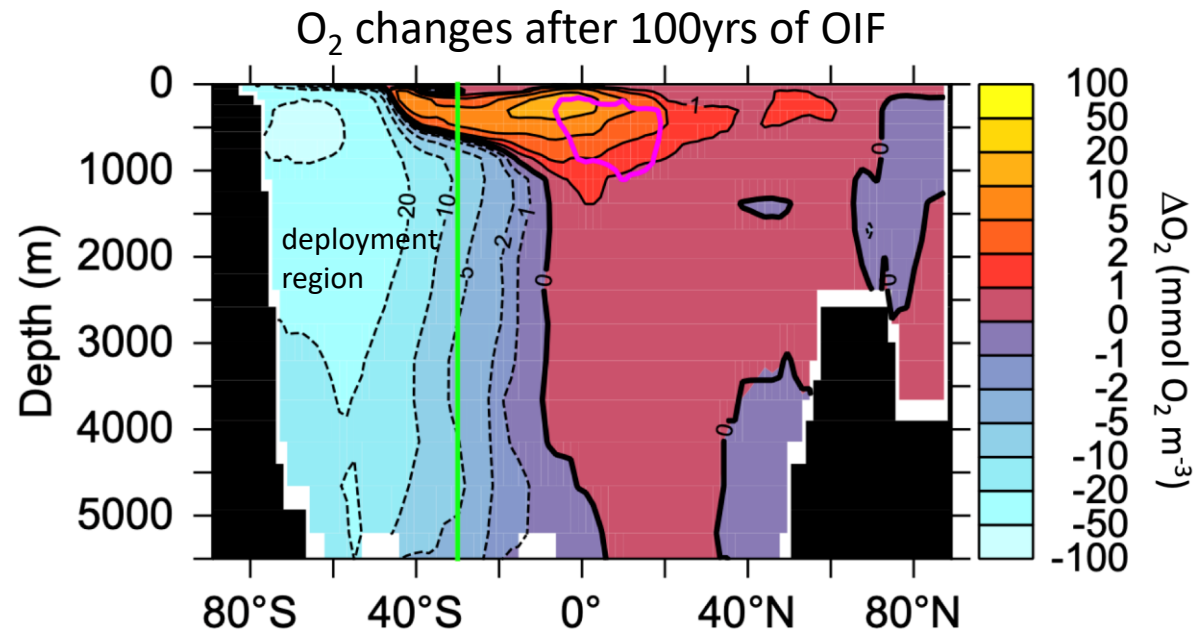
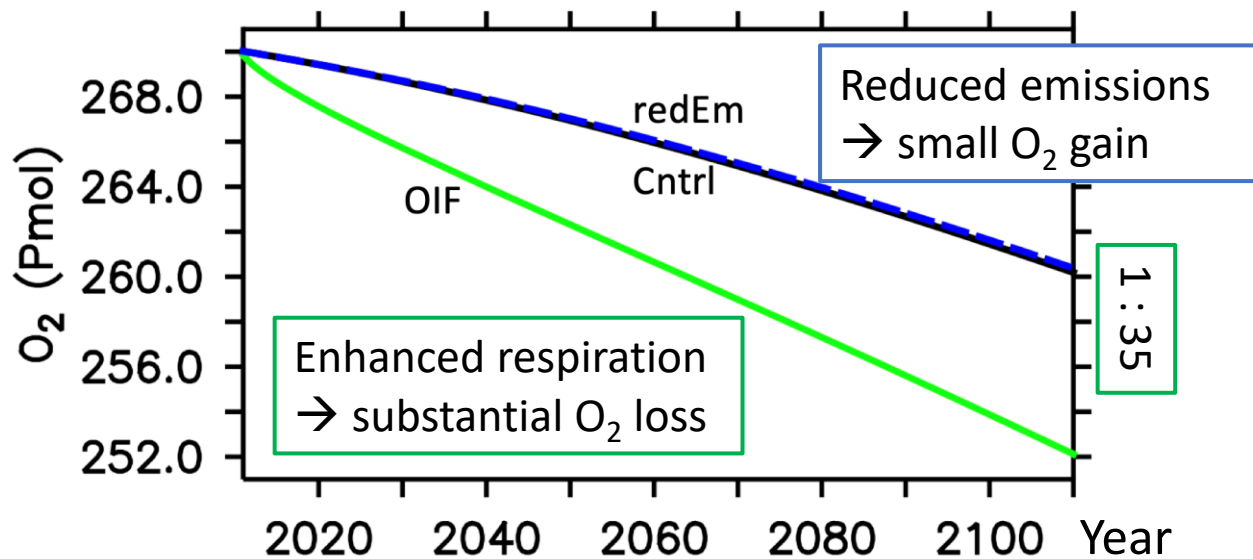
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- **Net O₂ loss!**



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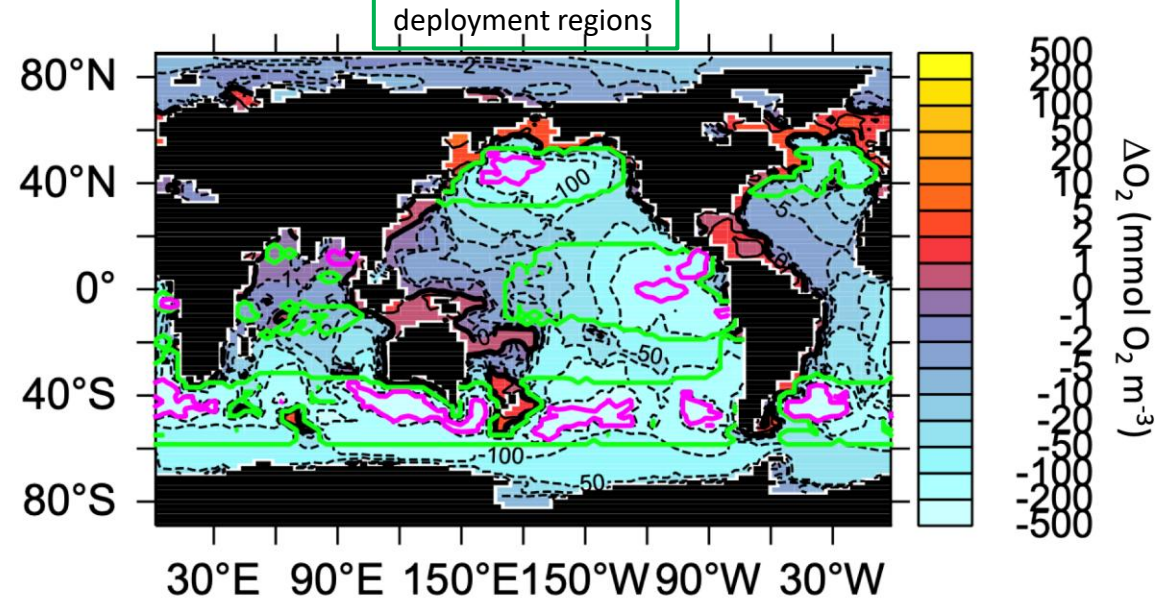
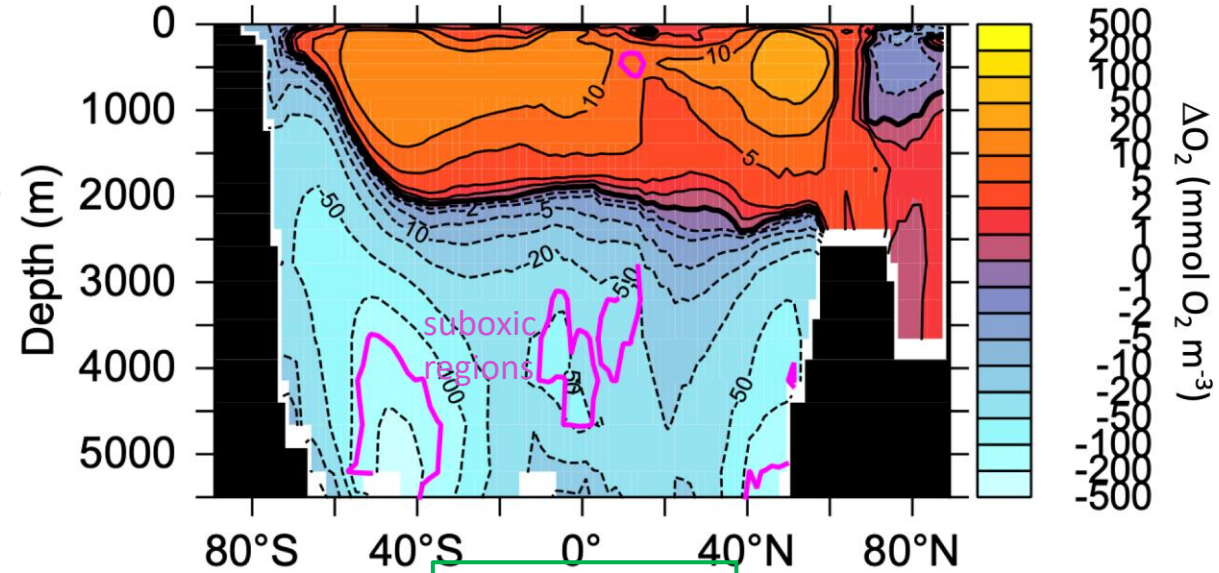


Macroalgae farming and marine O₂

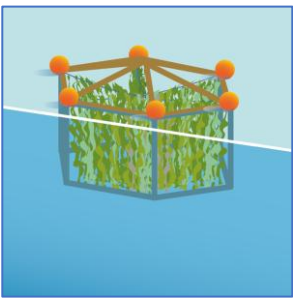


- Simulated maximum deployment & **sinking** (limited by nutrients & light)
- Reduced atm. pCO₂, enhanced respiration & O₂ loss at depth, less respiration in upper ocean

O₂ changes after 90yrs of macroalgae farming & sinking

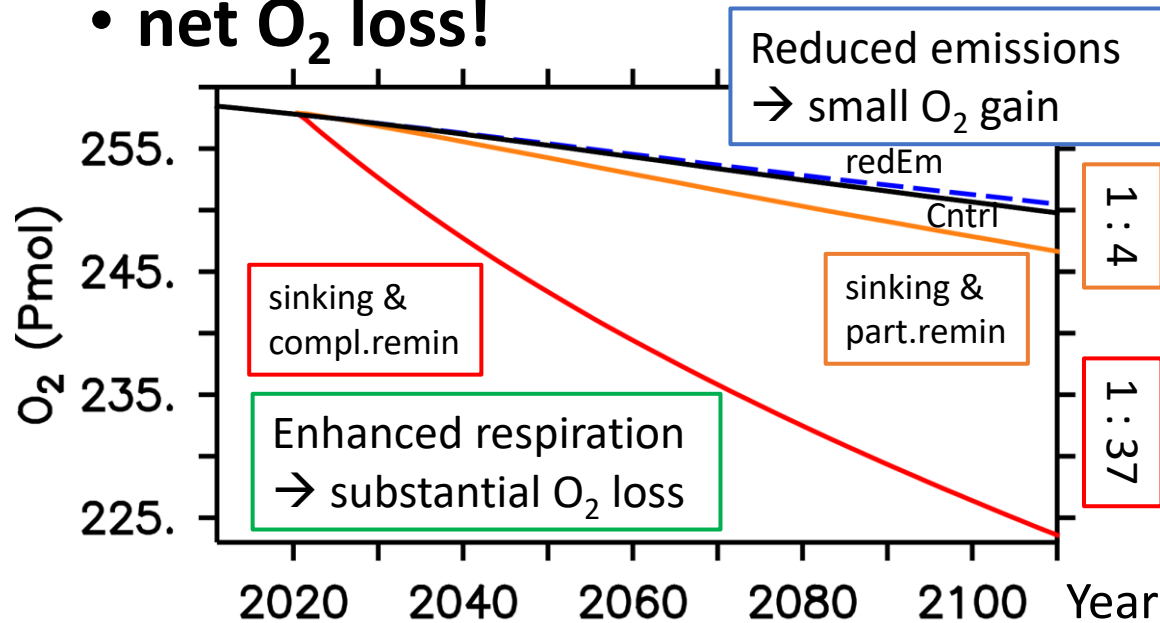


Macroalgae farming and marine O₂

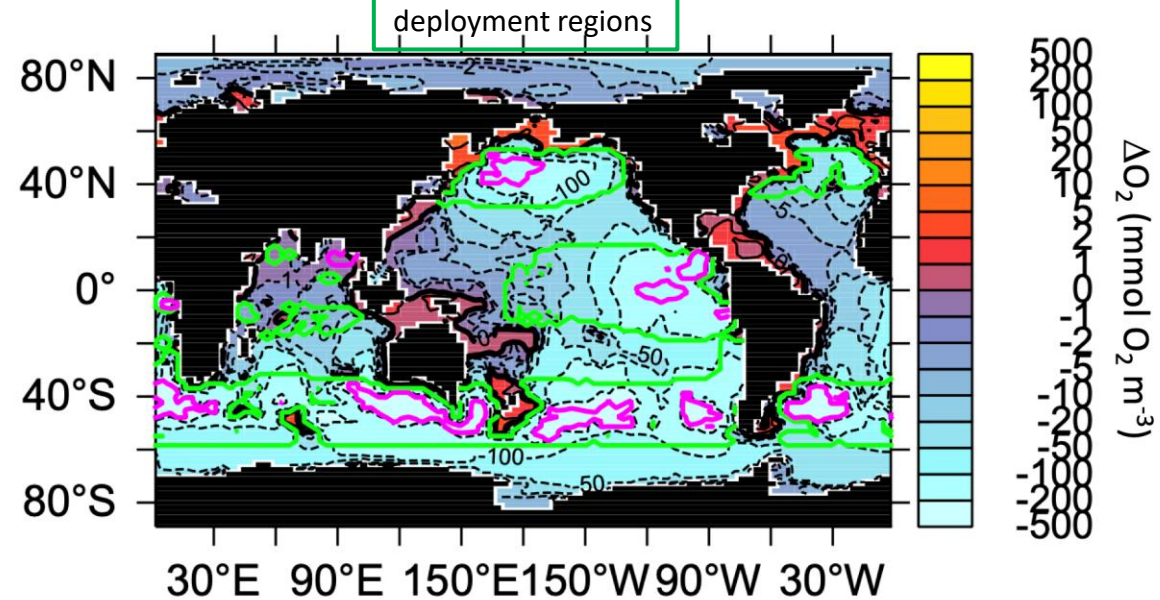
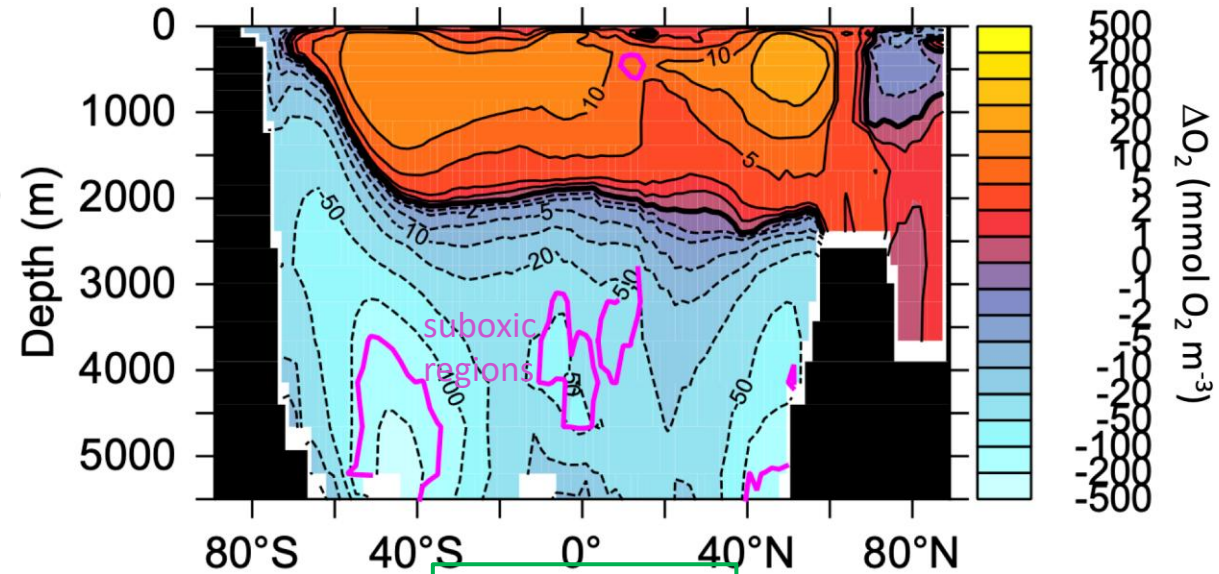


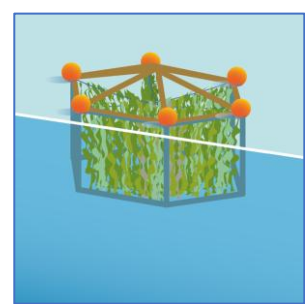
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• net O₂ loss!



O₂ changes after 90yrs of macroalgae farming & sinking

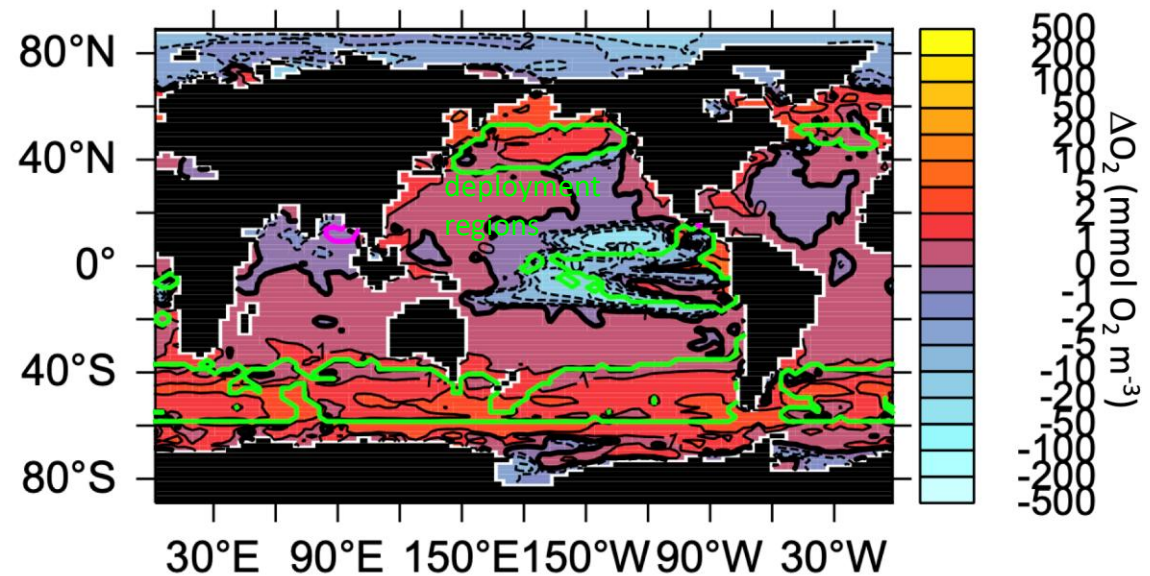
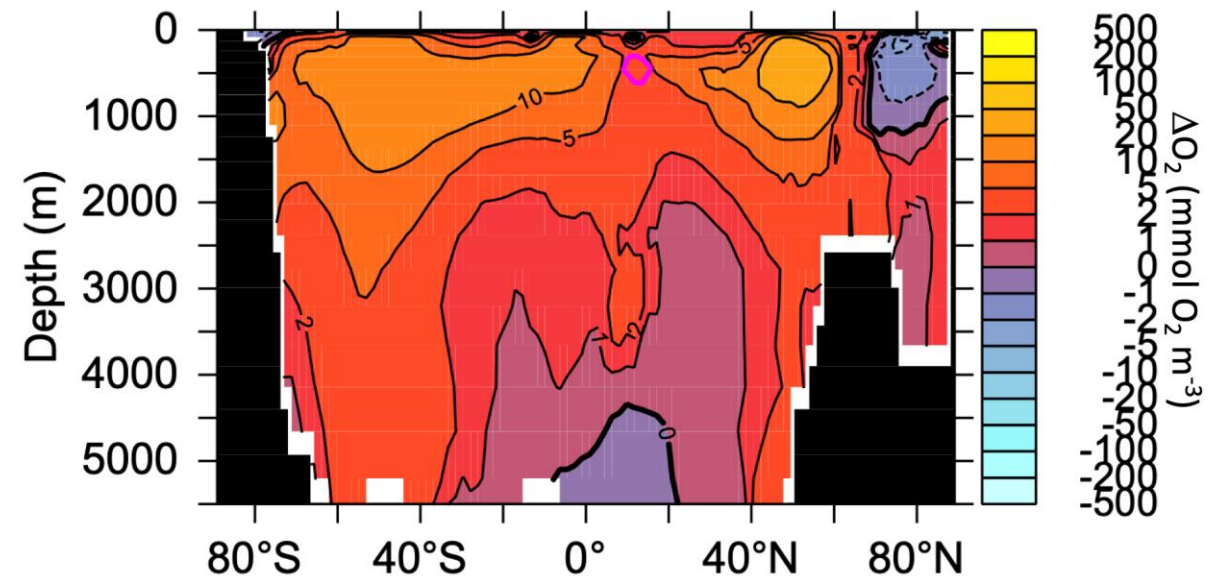




Macroalgae harvesting and marine O₂

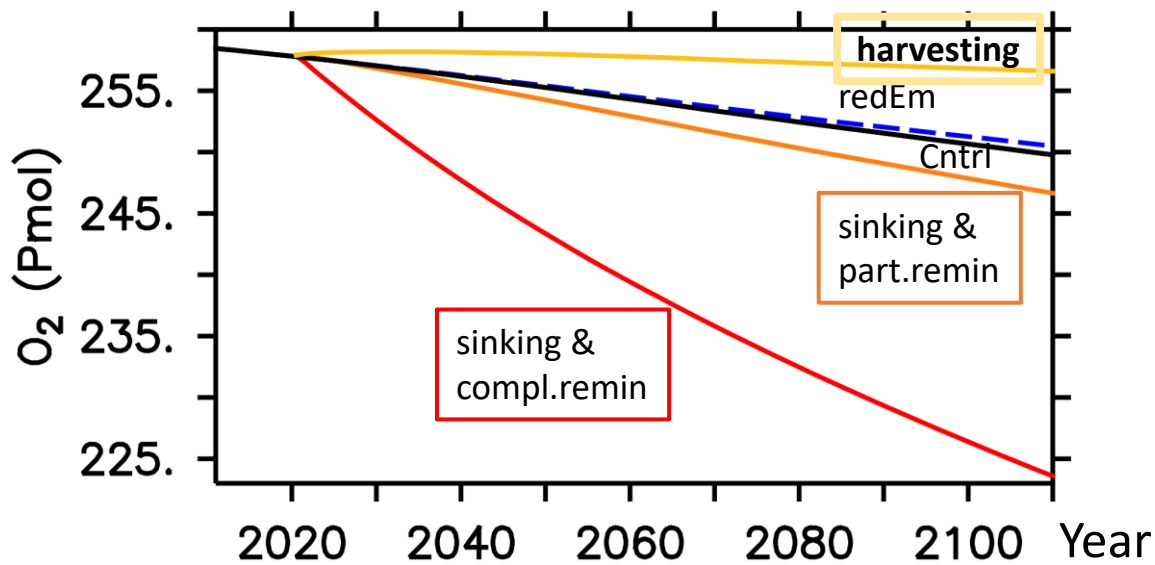
- Simulated maximum deployment & **harvesting** (limited by nutr. & light)
- Reduced atm. pCO₂, reduced remin., reduced nutrient inventory

O₂ changes after 90yrs of macroalgae farming & harvesting

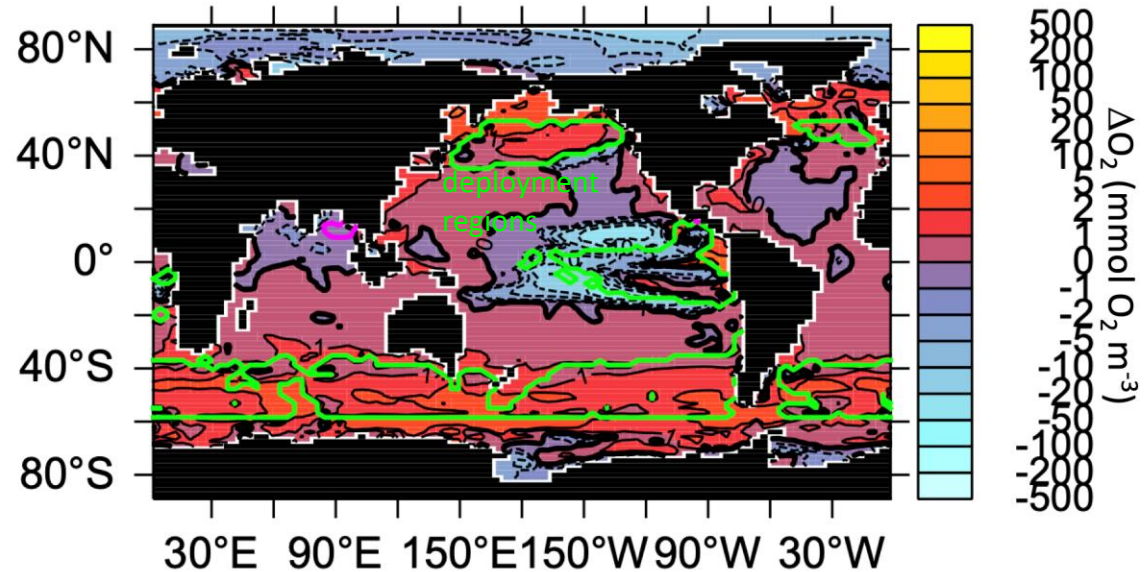
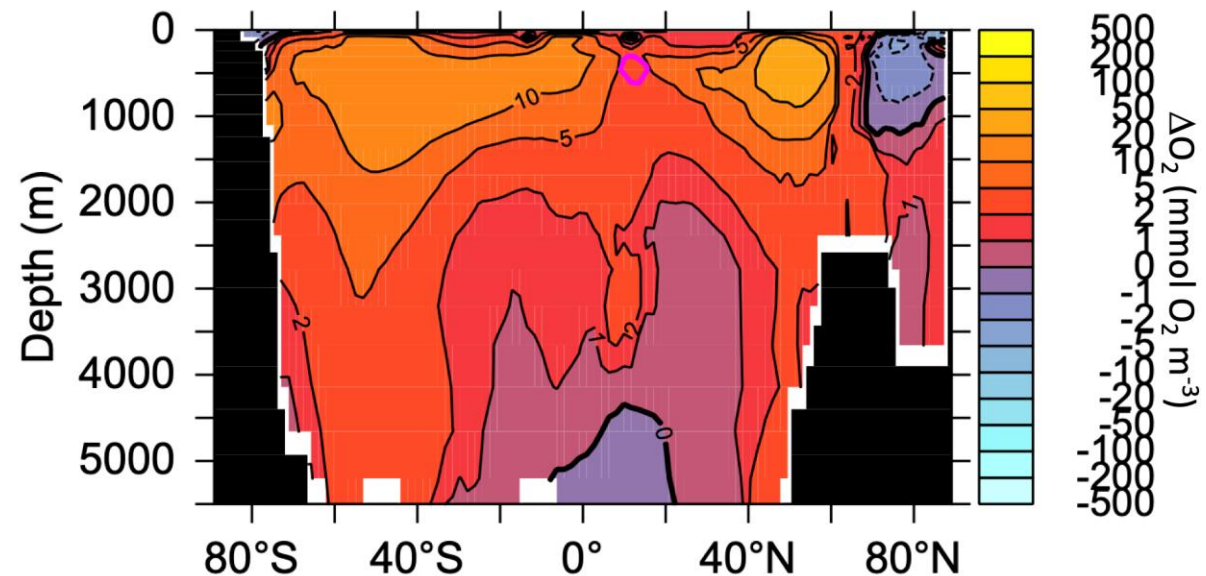


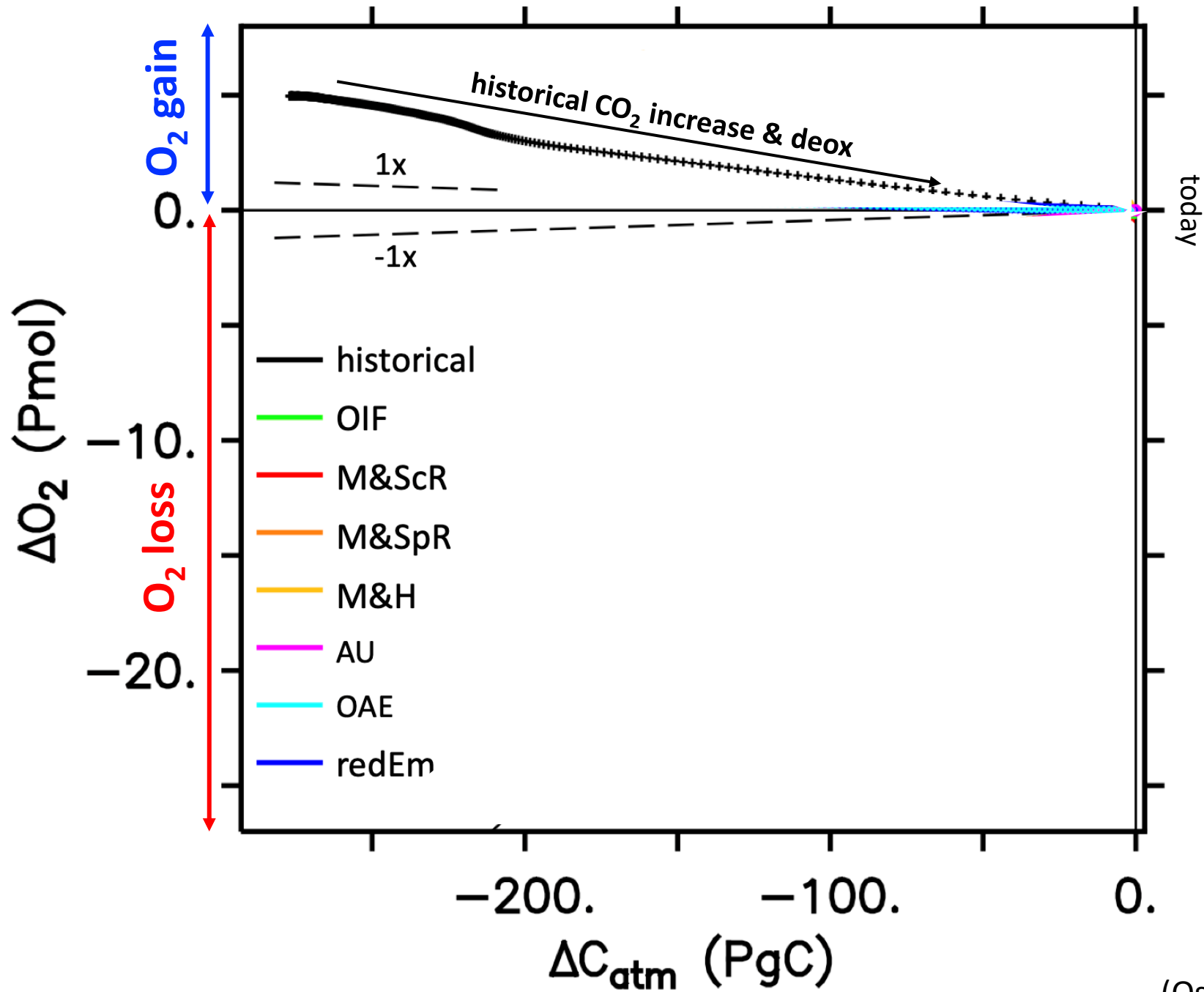
Macroalgae harvesting and marine O₂

- Simulated maximum deployment & **harvesting** (limited by nutr. & light)
- Reduced atm. pCO₂, reduced remin., reduced nutrient inventory
- **net O₂ gain!**

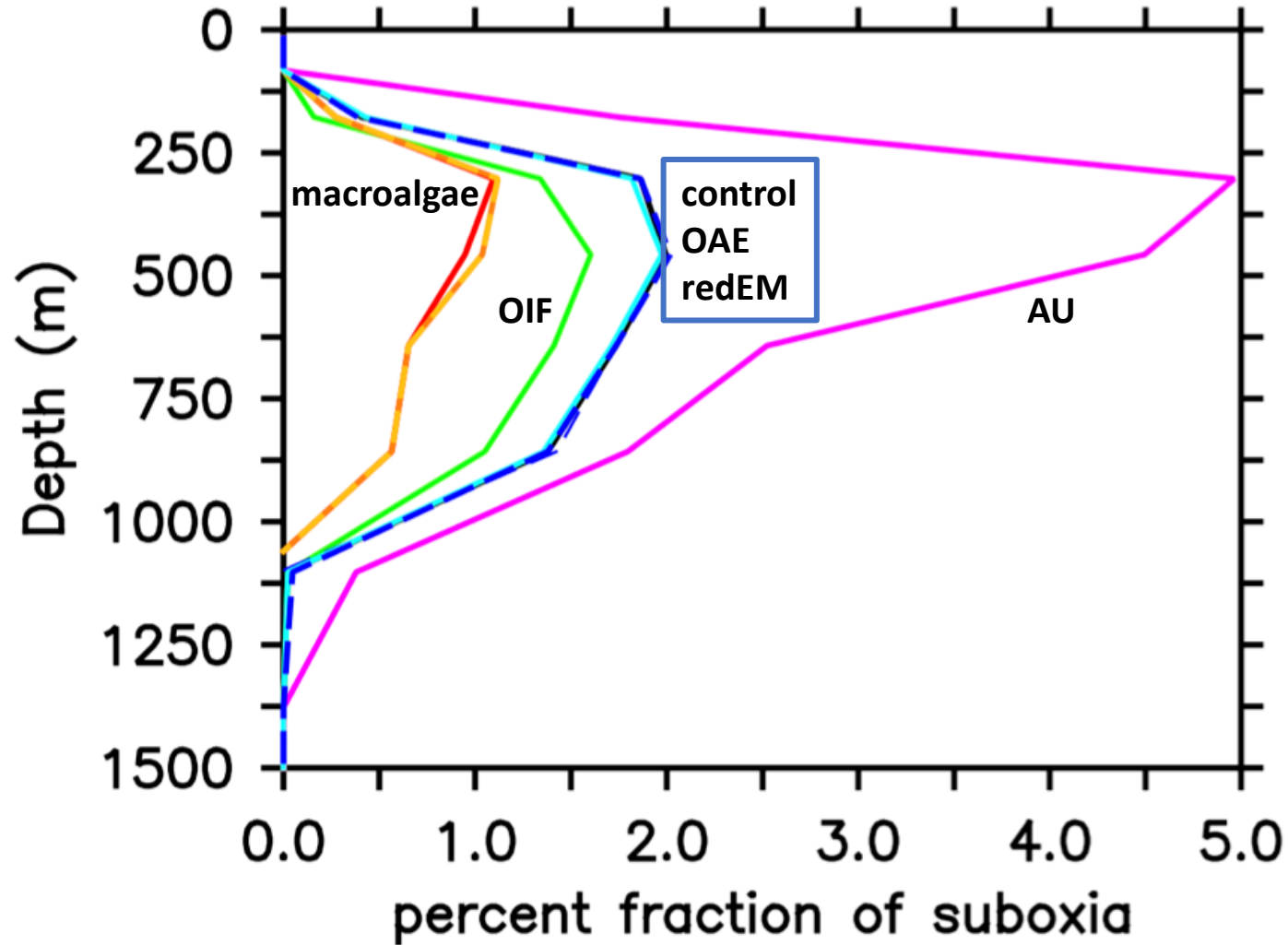


O₂ changes after 90yrs of macroalgae farming & harvesting





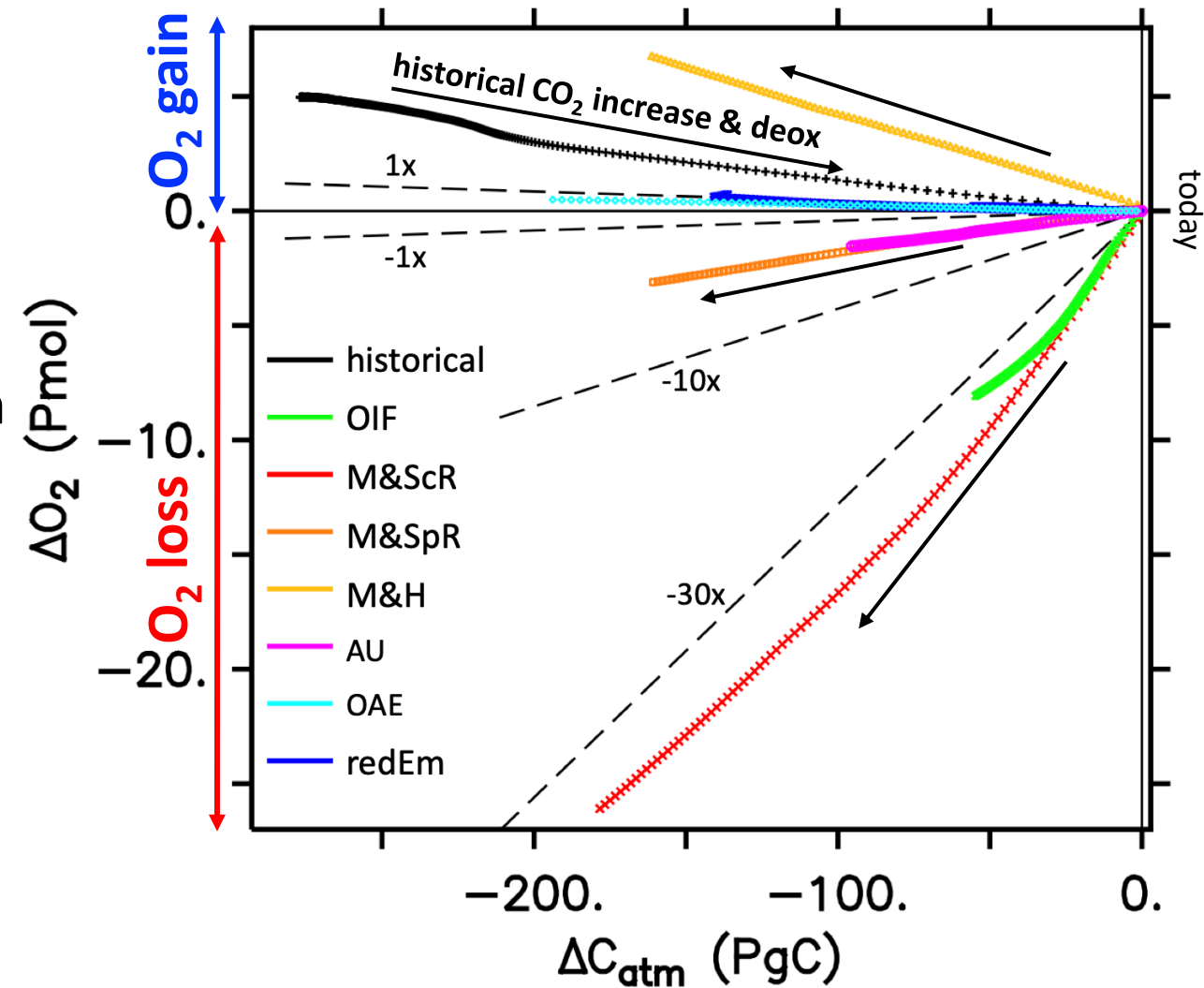
A different metric: suboxic volume



Biotic mCDR methods may reduce suboxic water volume (mainly in the tropical oceans)!

Summary

- All **biotic marine CDR** methods that include aerobic respiration within the ocean lead to **marine O₂ loss many times larger than the O₂ gain associated with reduced warming**
- **Abiotic (geochemical) methods** and emissions avoidance can **reduce ocean deoxygenation**.
- **Biotic methods** may reduce suboxic volume
- **Macroalgae farming & harvesting** has the potential to **revert ocean deoxygenation**.
- **Oxygen** should be one of key variables of mCDR **monitoring!**



Thank you for your attention!

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ENVIRONMENTAL RESEARCH
LETTERS



TOPICAL REVIEW

Potential impacts of marine carbon dioxide removal on ocean oxygen

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