Potential impacts of marine carbon dioxide removal on ocean oxygen

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with input from the GO_2NE group

& the Biogeochemical Modelling group at GEOMAR

GEOMAR

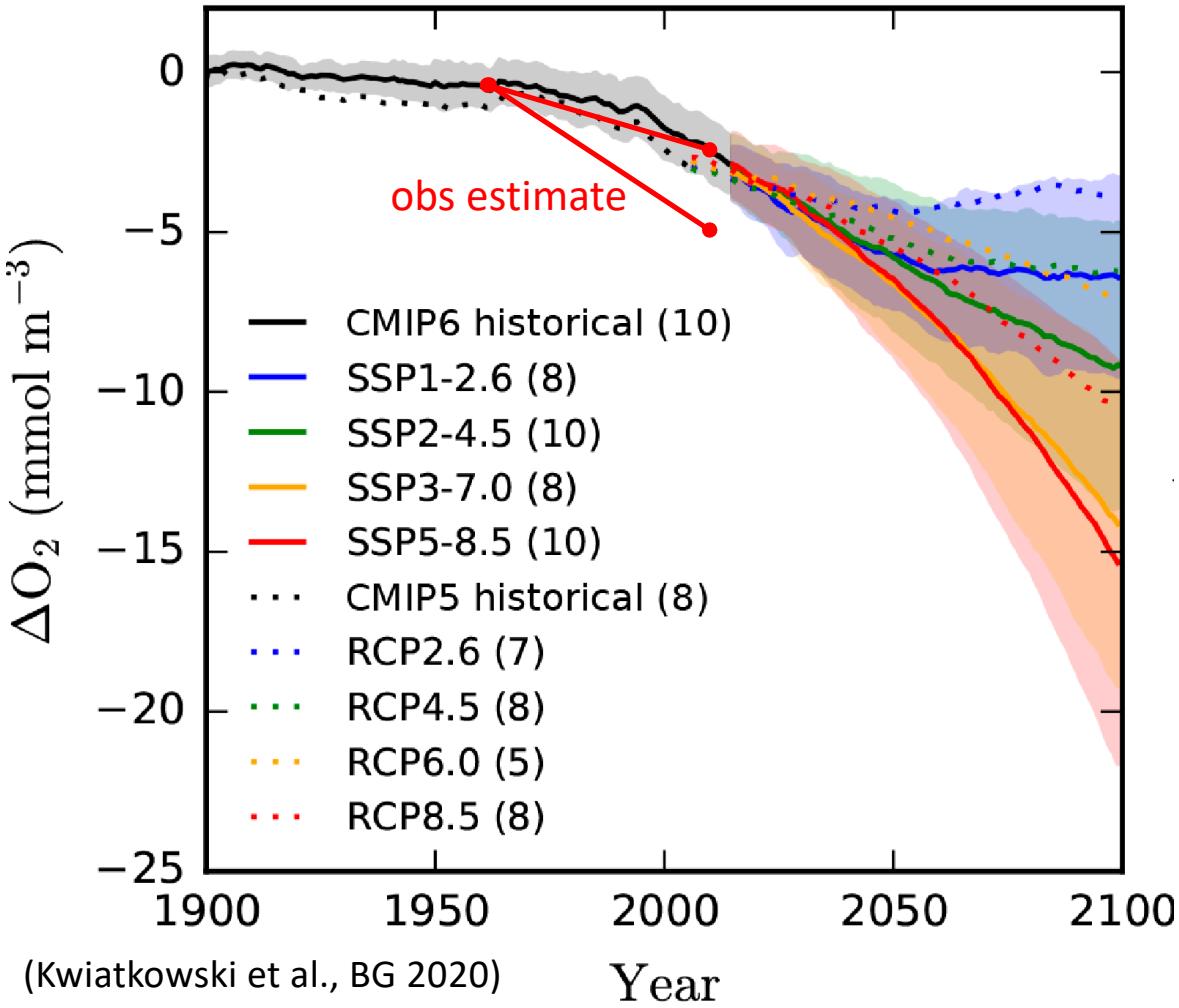
GO_2NE Global Ocean Oxygen NEtwork

GOOD Global Ocean Oxygen Decade

CDRmare

2021 2030 United Nations Decade of Ocean Science for Sustainable Development

The ocean is losing oxygen at a rapid rate



(Kwiatkowski et al., BG 2020)

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

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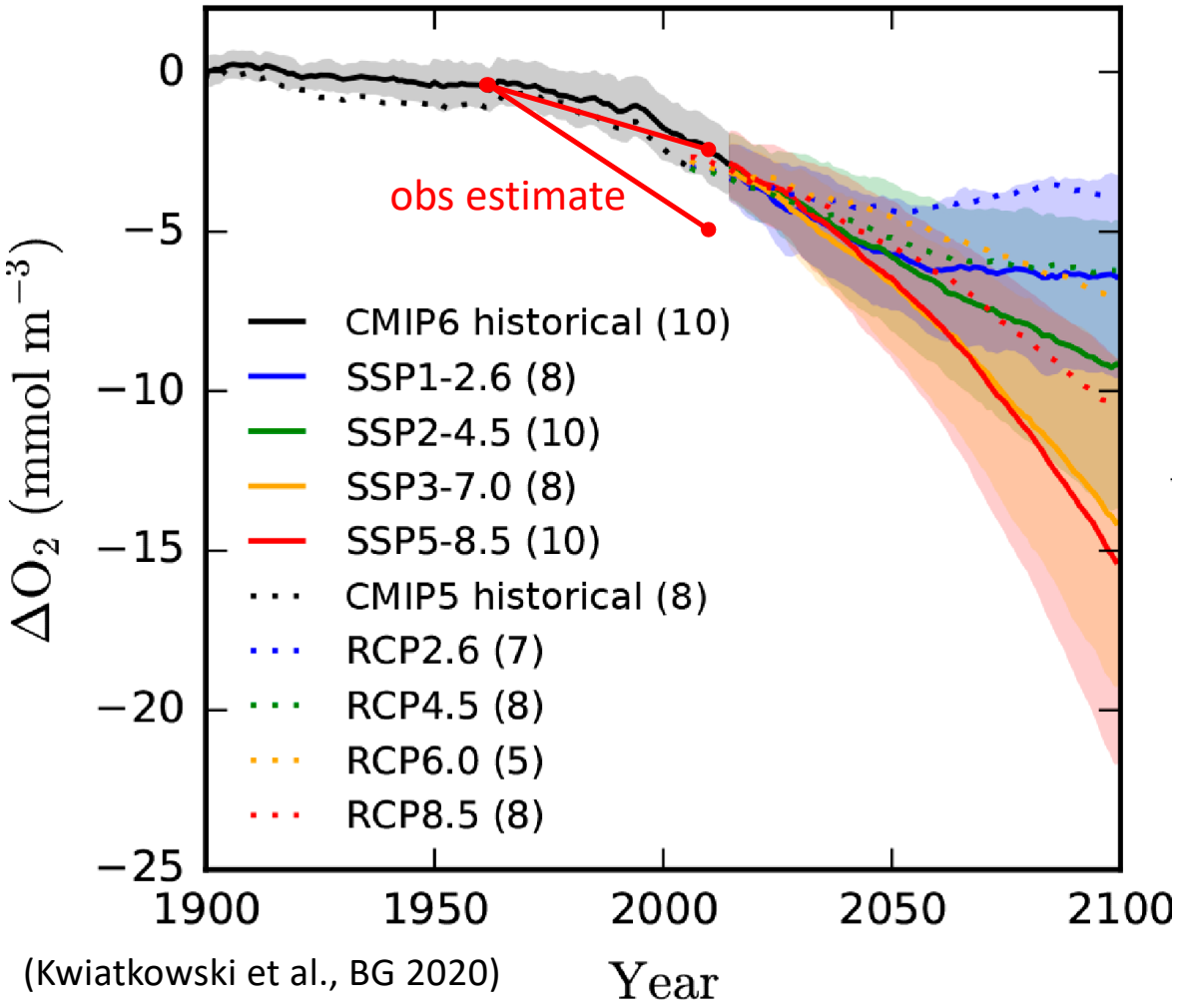


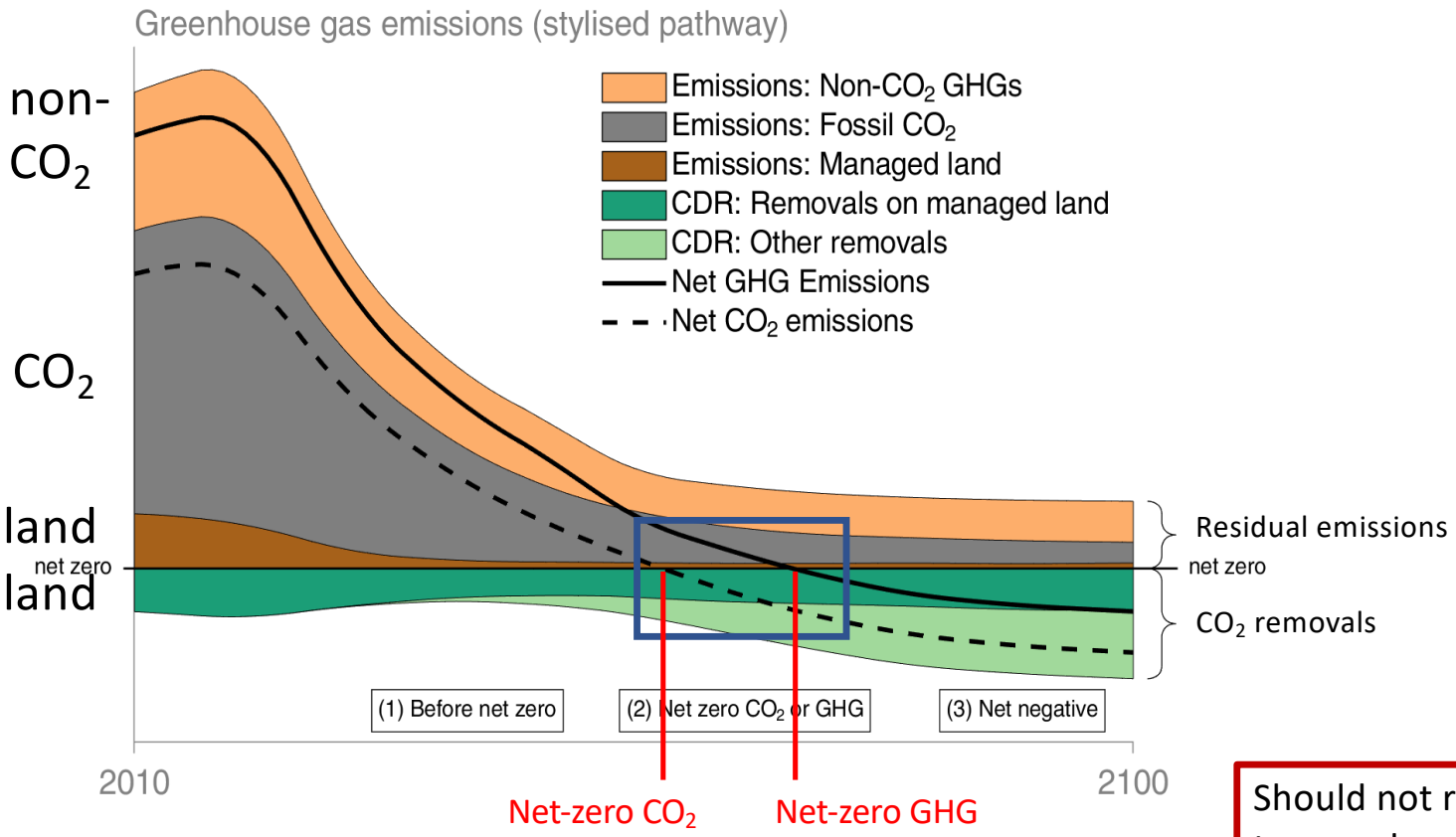
(Kwiatkowski et al., BG 2020)

- 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 oxygen loss**

- Until now, the ocean has lost about 2% of its inventory.
- Caveat: Current models seem to underestimate observed deoxygenation

Ambitious Decarbonization Pathways



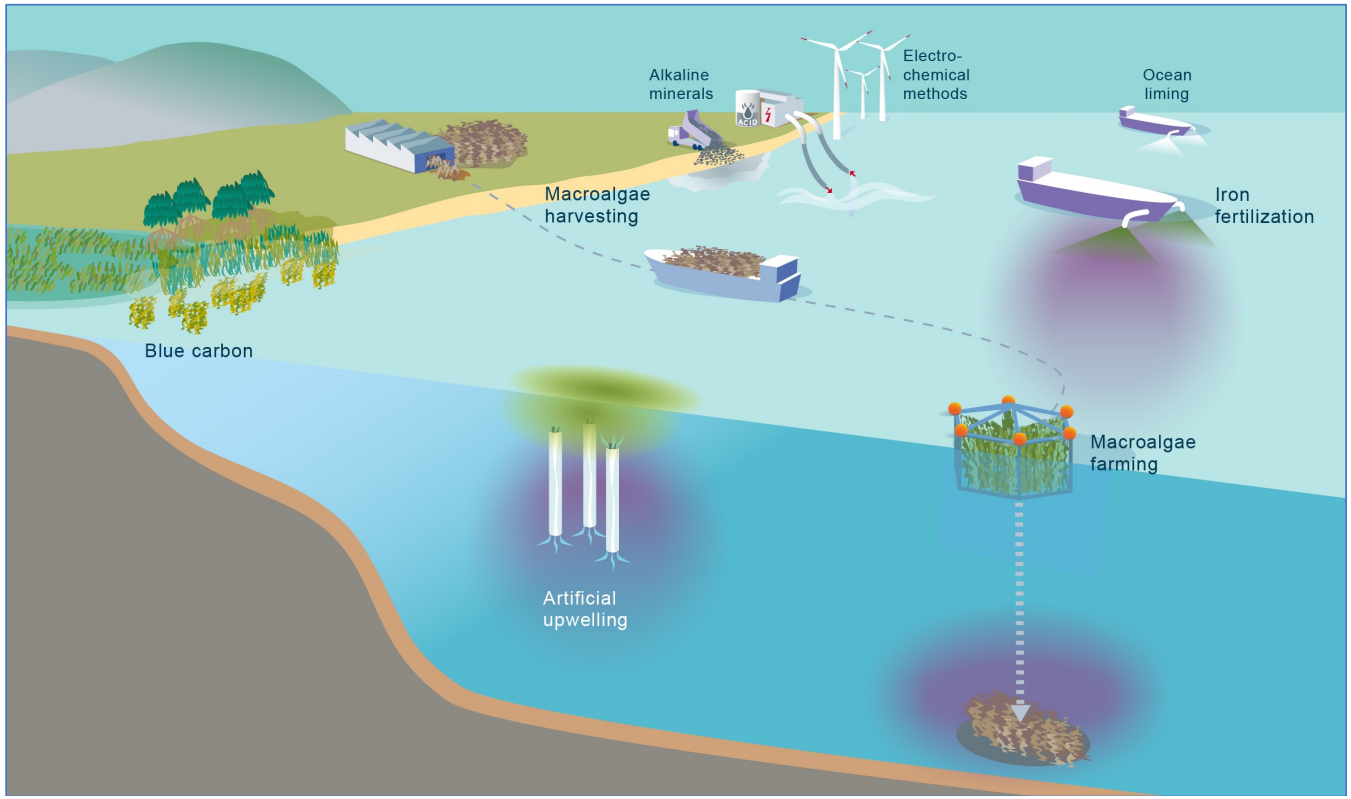
IPCC AR6 WG III, Cross Chapter Box 8

- Priority: drastic emissions reductions
- Residual emissions: non-CO_2 from agriculture, CO_2 process emissions & some transport emissions
- Carbon Dioxide Removal (CDR) is **unavoidable** if net-zero target is to be reached.

Should not rely too much on terrestrial sink!

Marine Carbon Dioxide Removal (CDR) ideas

- Intention: reduction of further global warming, and hence of deoxygenation
- **What would be the net impact of marine CDR on ocean oxygen?**



- meta-analysis of available model simulations
- hypothetical large-scale deployment (for noticeable climate impact), high-emission scenario, Uvic Earth system model

(Oschlies et al., ERL 2025)

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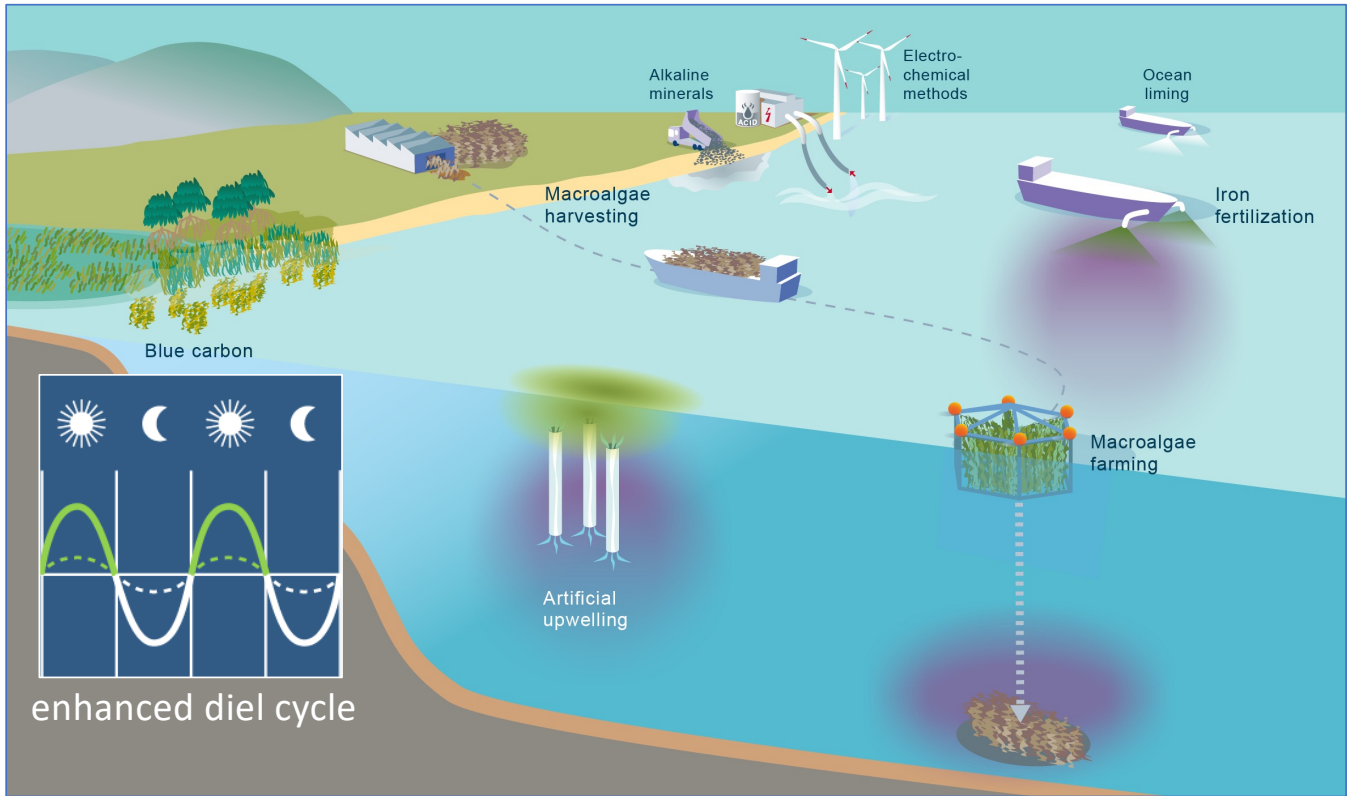

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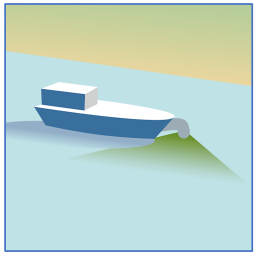
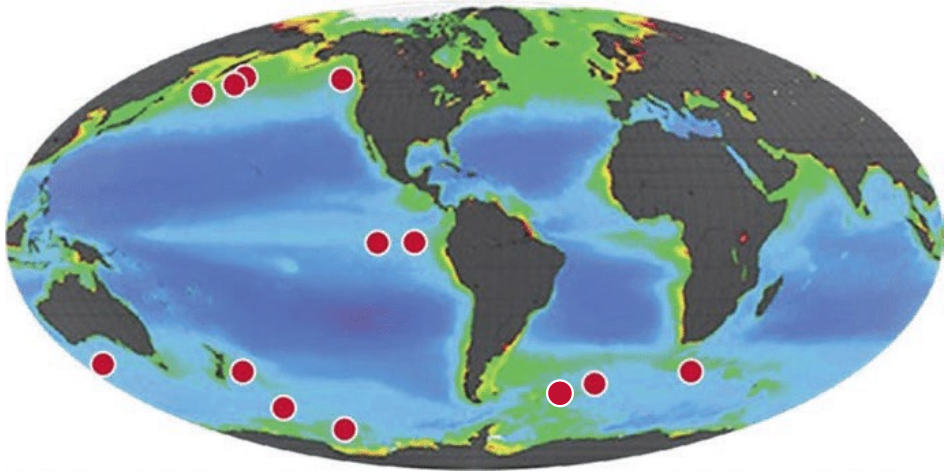
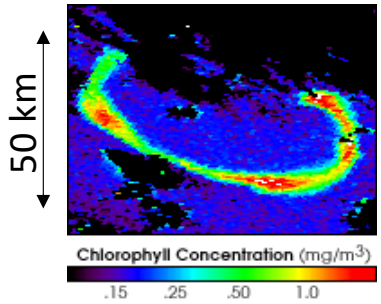


Ocean Iron Fertilization and marine O_2

13 field trials
(1993 – 2009)



(Courtesy of Woods Hole Oceanographic Institution)

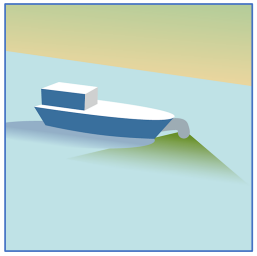


(Courtesy Jim Acker, SeaWiFS, NASA)

> Major ecological shifts, surface & likely depth (not measured until now)

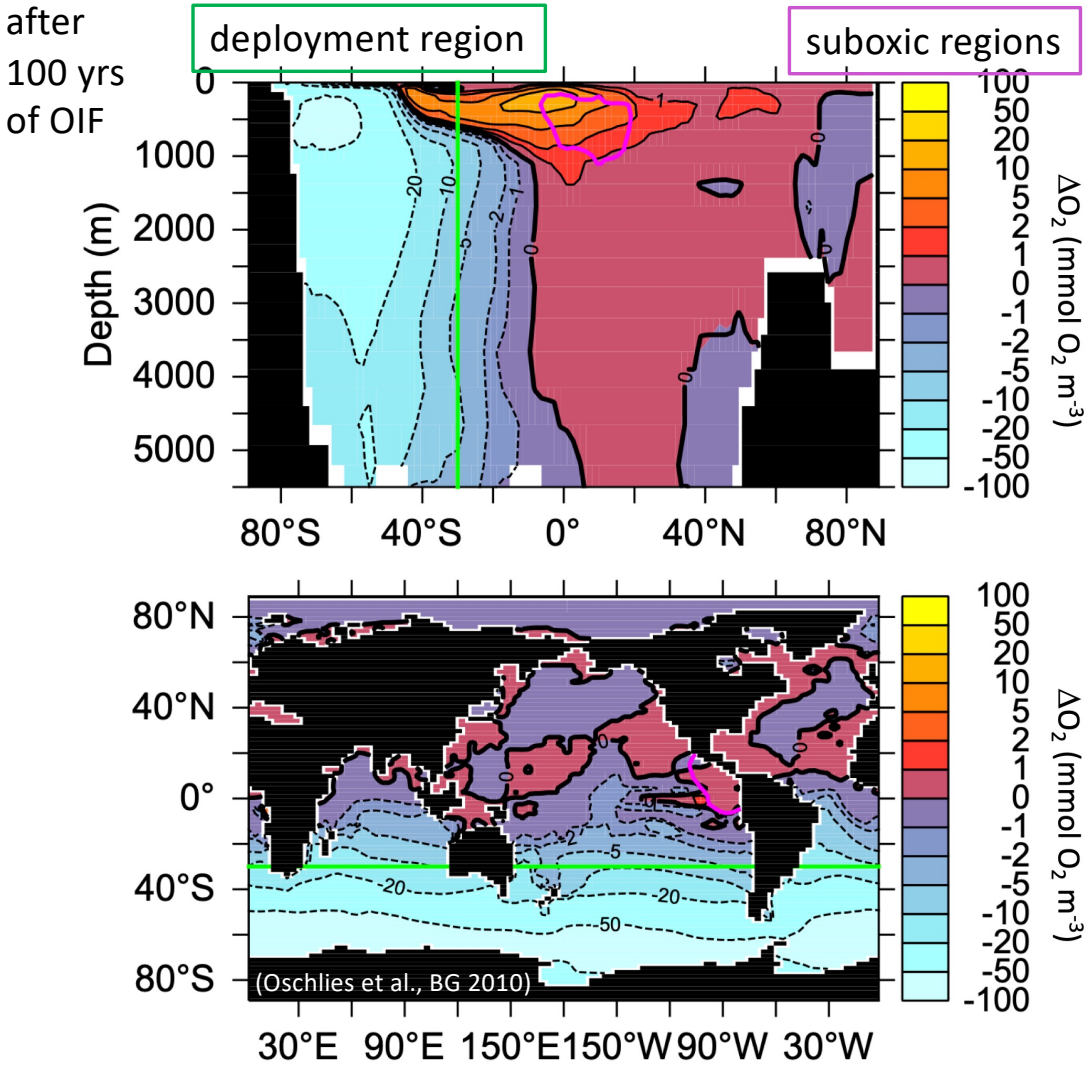
> Additionality? Durability?

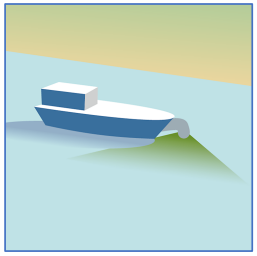
> **International governance put in place:**
London Convention & London Protocol: Precautionary approach, no commercial fertilization activities until adequate scientific basis exists.



Ocean Iron Fertilization and marine O_2

- Simulated OIF south of 30°S
- Enhanced respiration & O_2 loss





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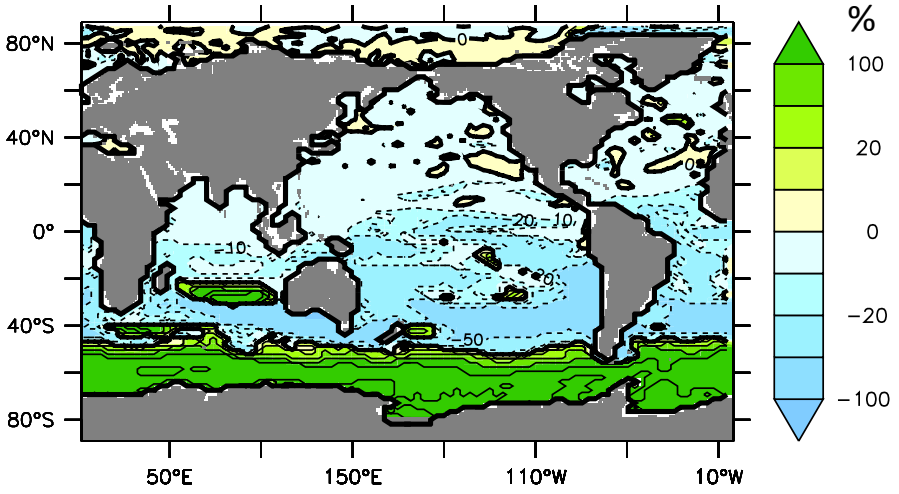
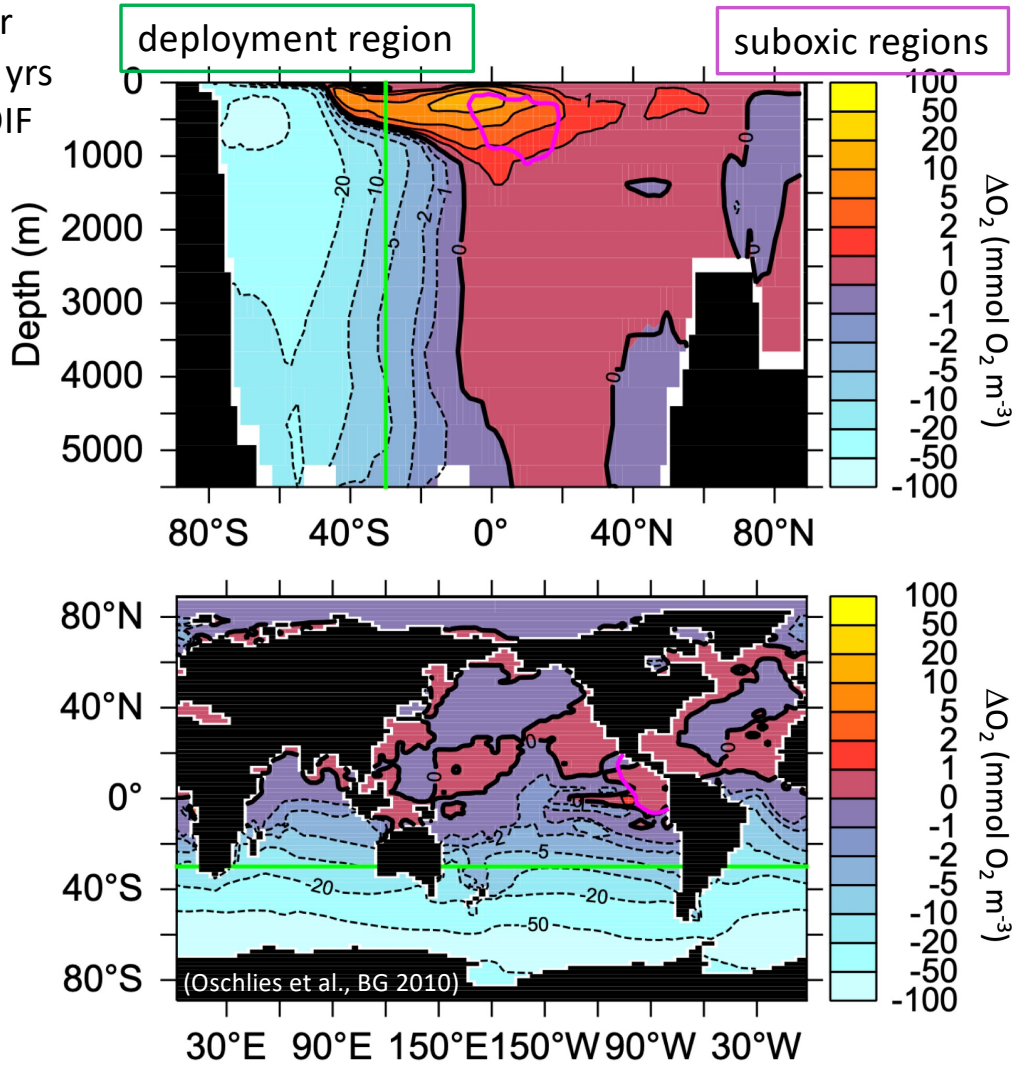
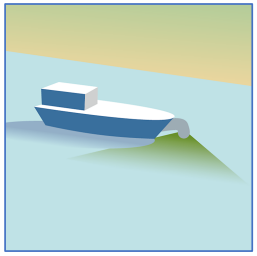
- Reduced NPP elsewhere



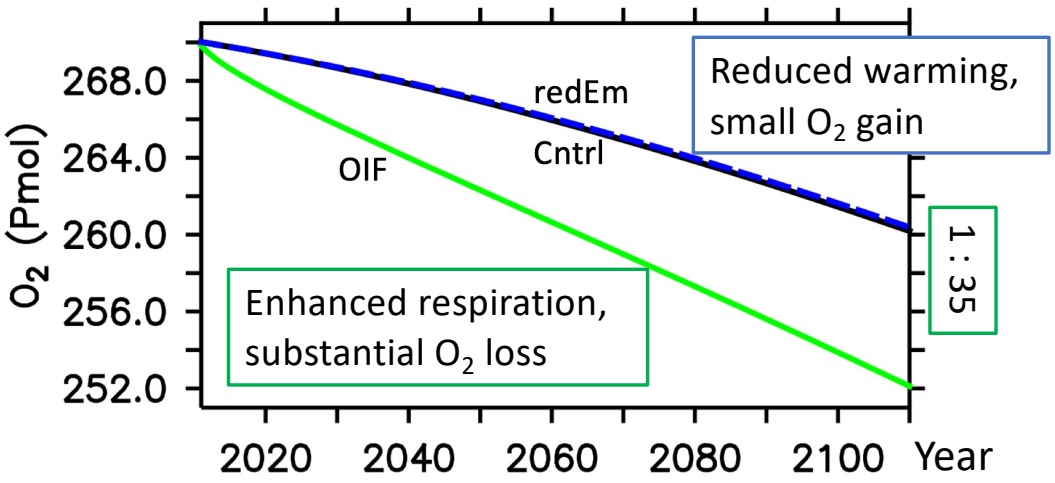
after
100 yrs
of OIF

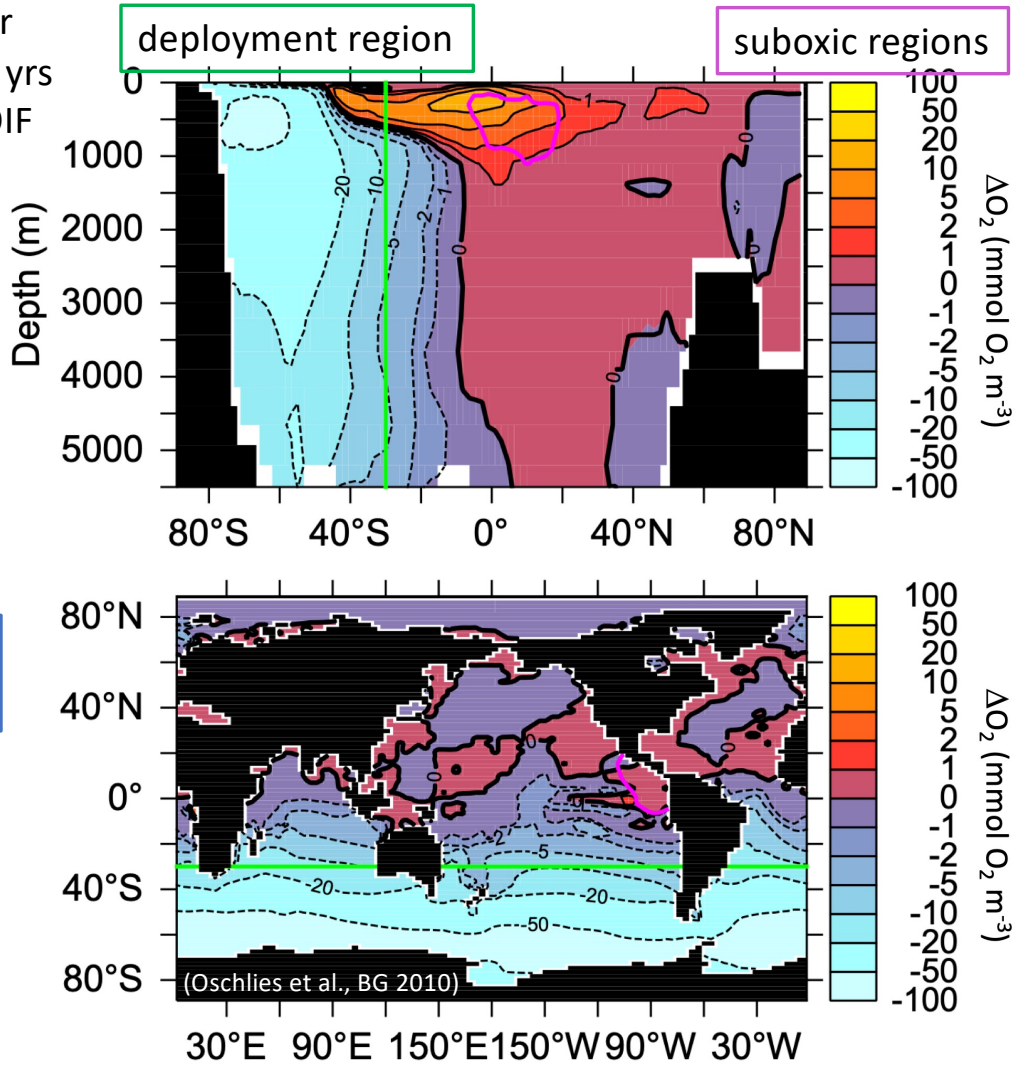


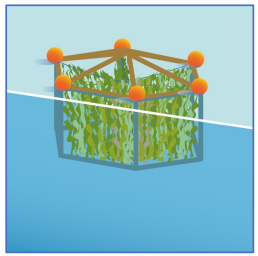


Ocean Iron Fertilization and marine O_2

- Simulated OIF south of 30°S
- CO_2 sequestration (2-3 Gt CO_2/yr)
  → reduced warming, small O_2 gain
- Enhanced respiration & O_2 loss
- **Net O_2 loss!**

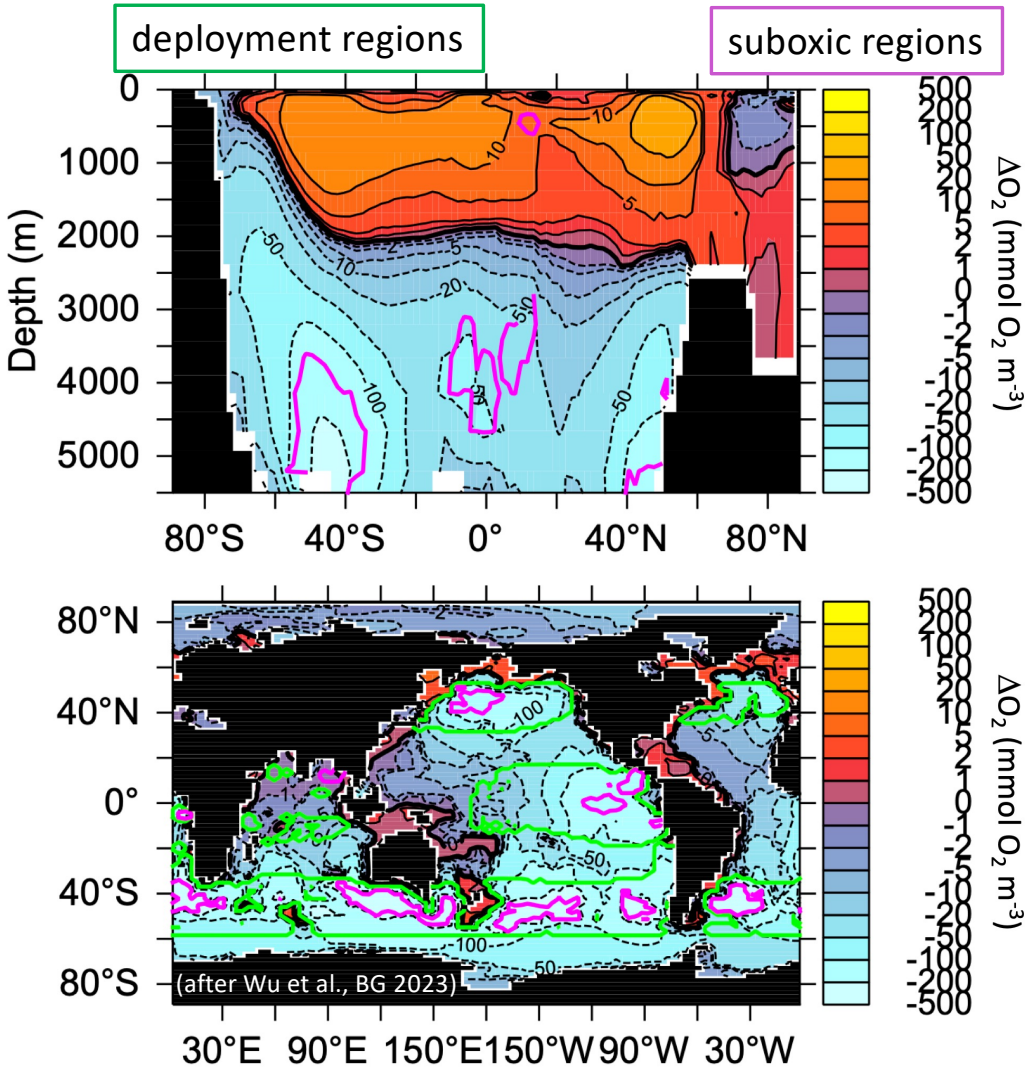


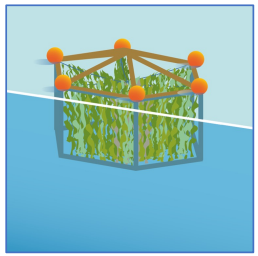




Macroalgae farming and marine O_2

- Simulated maximum deployment & **sinking** (limited by nutrients & light)
- CO_2 sequestration (5-6 Gt CO_2/yr), enhanced O_2 loss at depth, less O_2 loss in upper ocean





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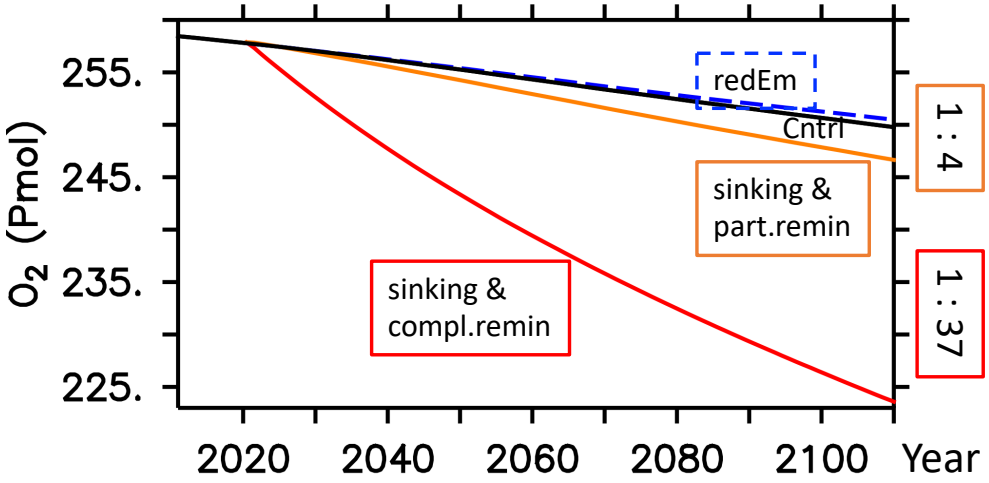

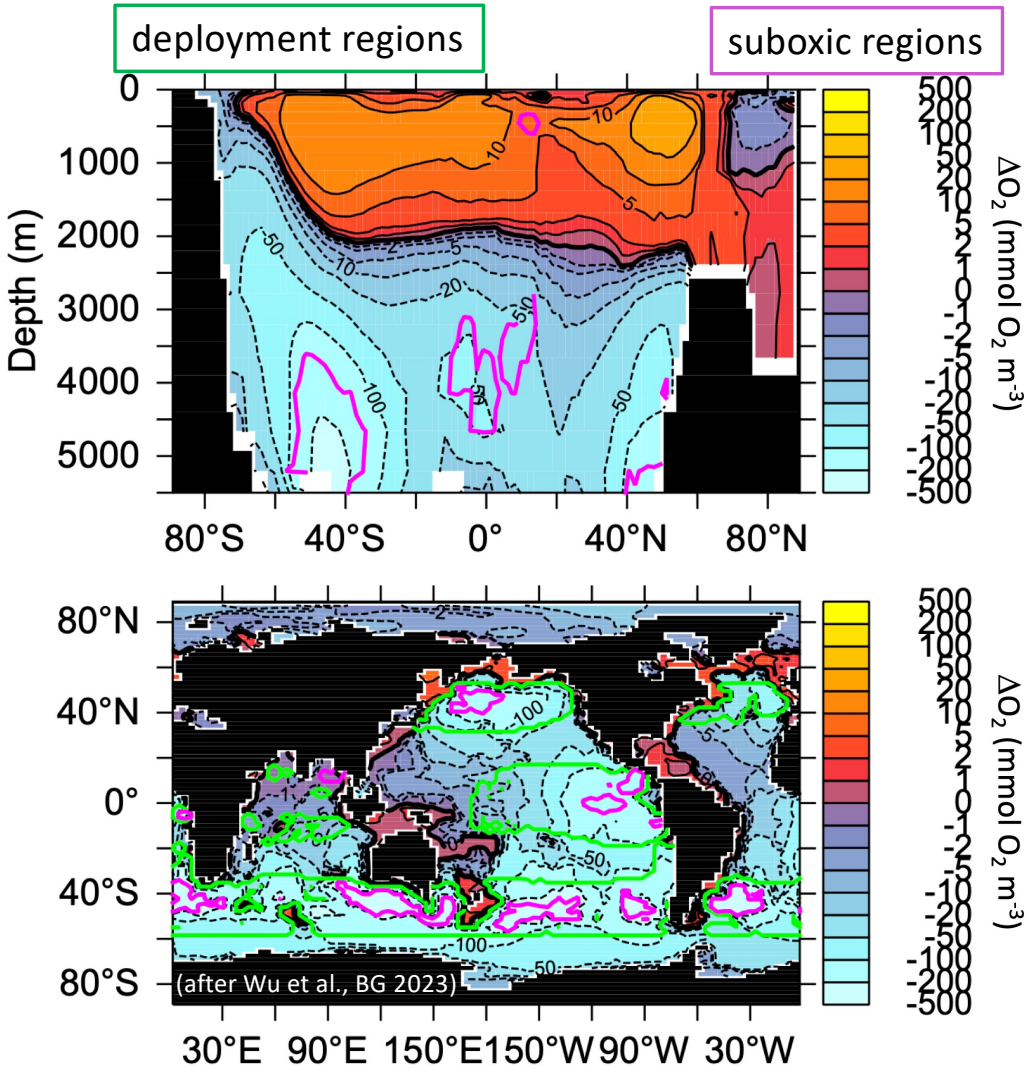

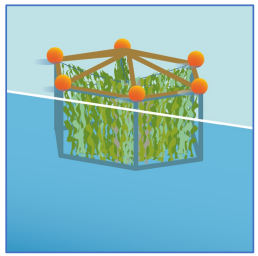

Macroalgae harvesting and marine O_2

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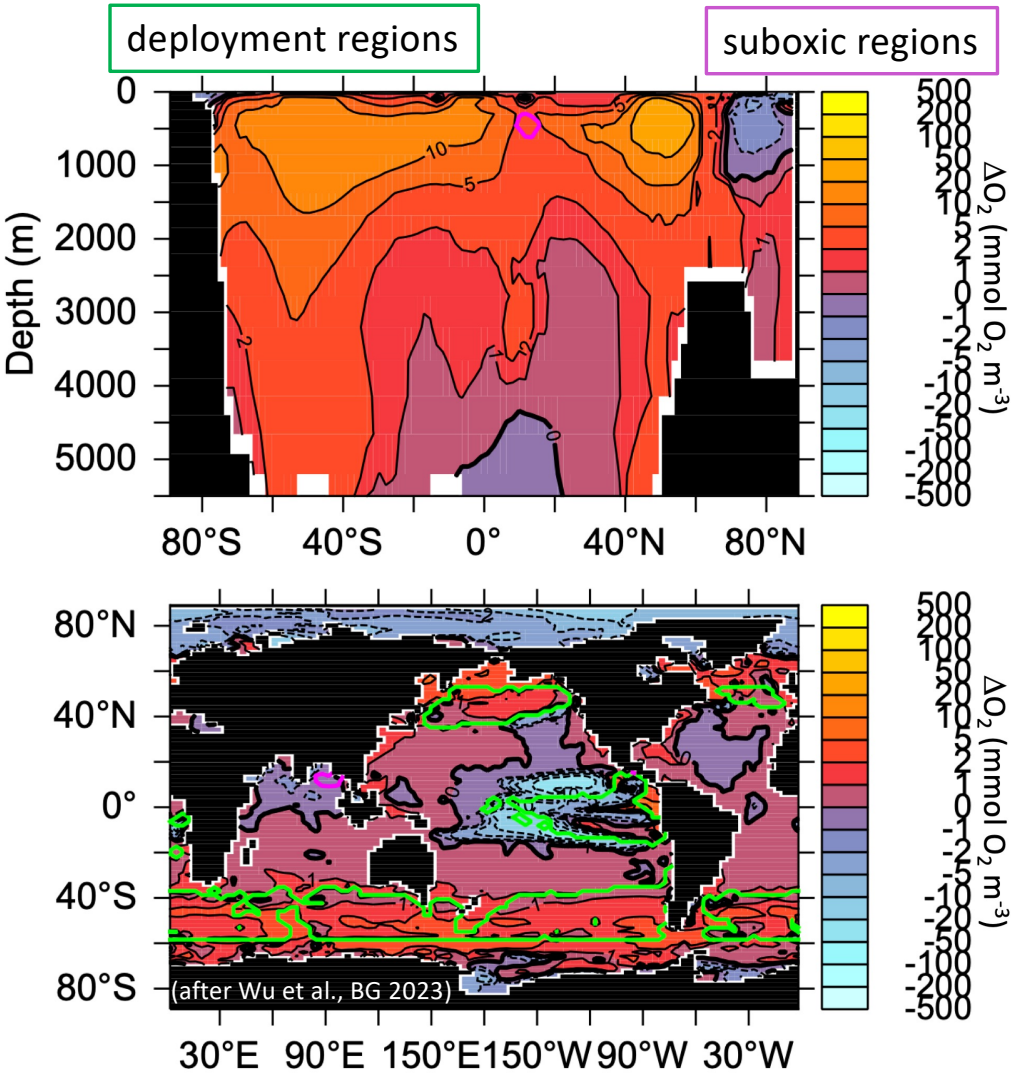
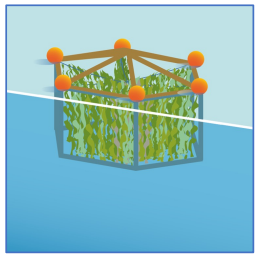
- CO_2 sequestration (5-6 Gt CO_2/yr), reduced remin., reduced nutrients





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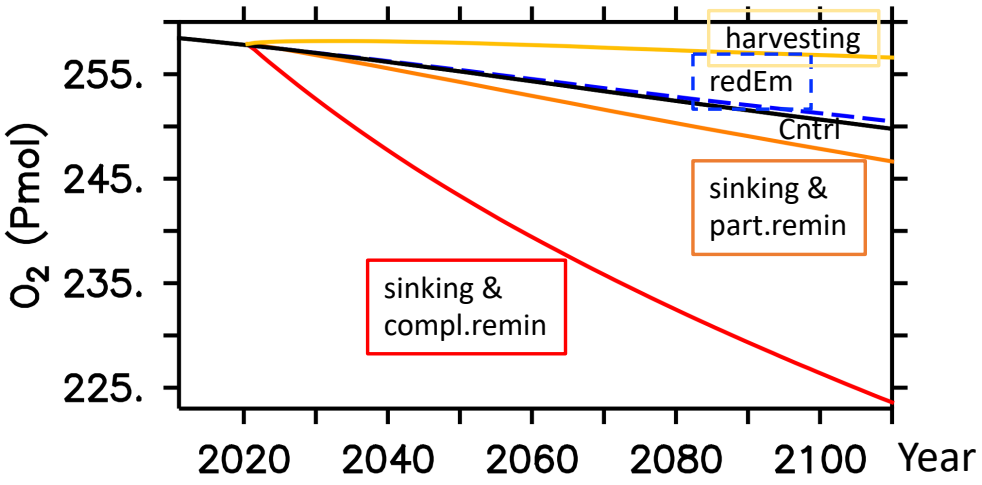
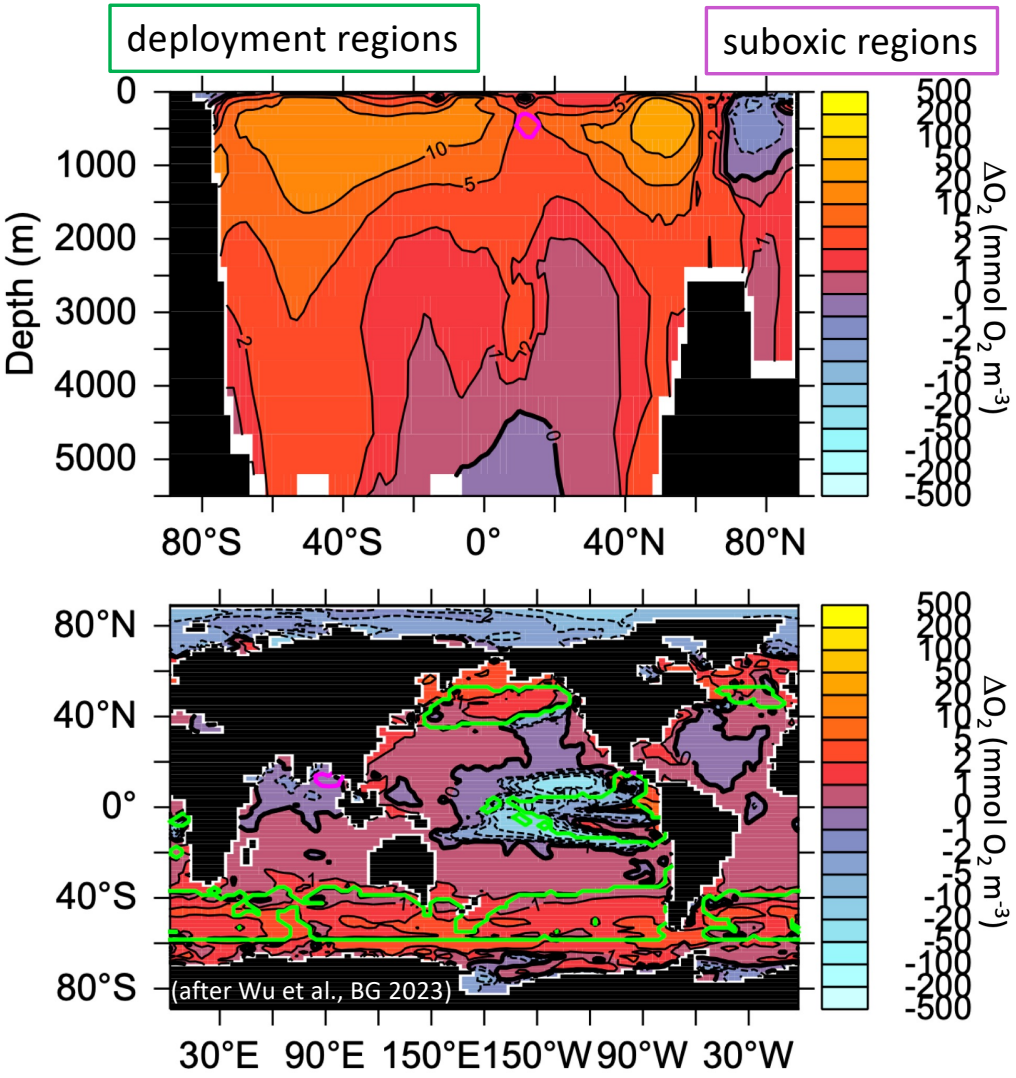
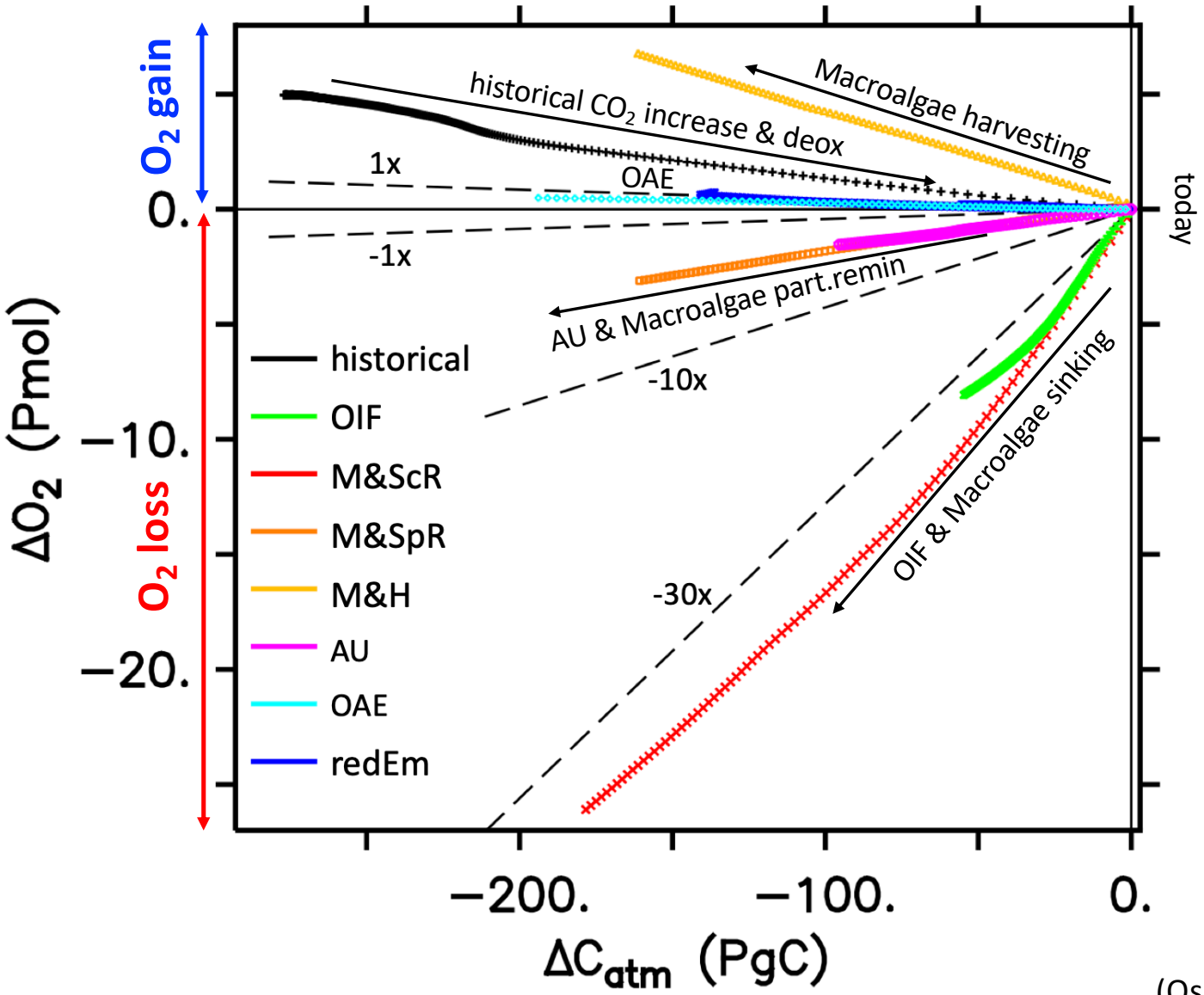
- **net O_2 gain!**



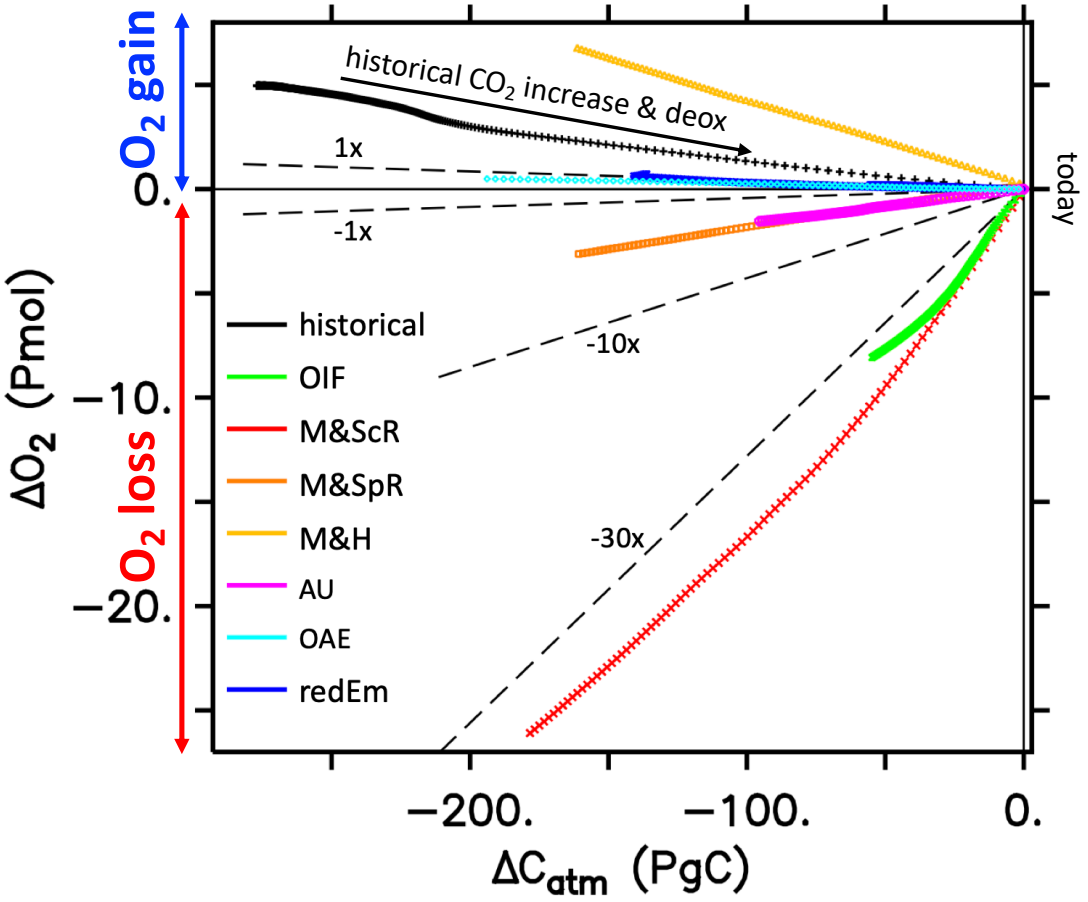




(Oschlies et al., ERL 2025)

Summary

- All **biotic marine CDR** methods that include aerobic respiration within the ocean lead to **marine O_2 loss many times larger than the O_2 gain associated with reduced warming**
- **Abiotic (geochemical) methods** and emissions avoidance can **reduce ocean deoxygenation**.
- **Macroalgae farming & harvesting** has the potential **to revert ocean deoxygenation**.
- Oxygen should be one of key variables of mCDR monitoring!



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