Influence of the biological pump on air-sea CO_2 flux depends on the magnitude and seasonal timing of physical processes

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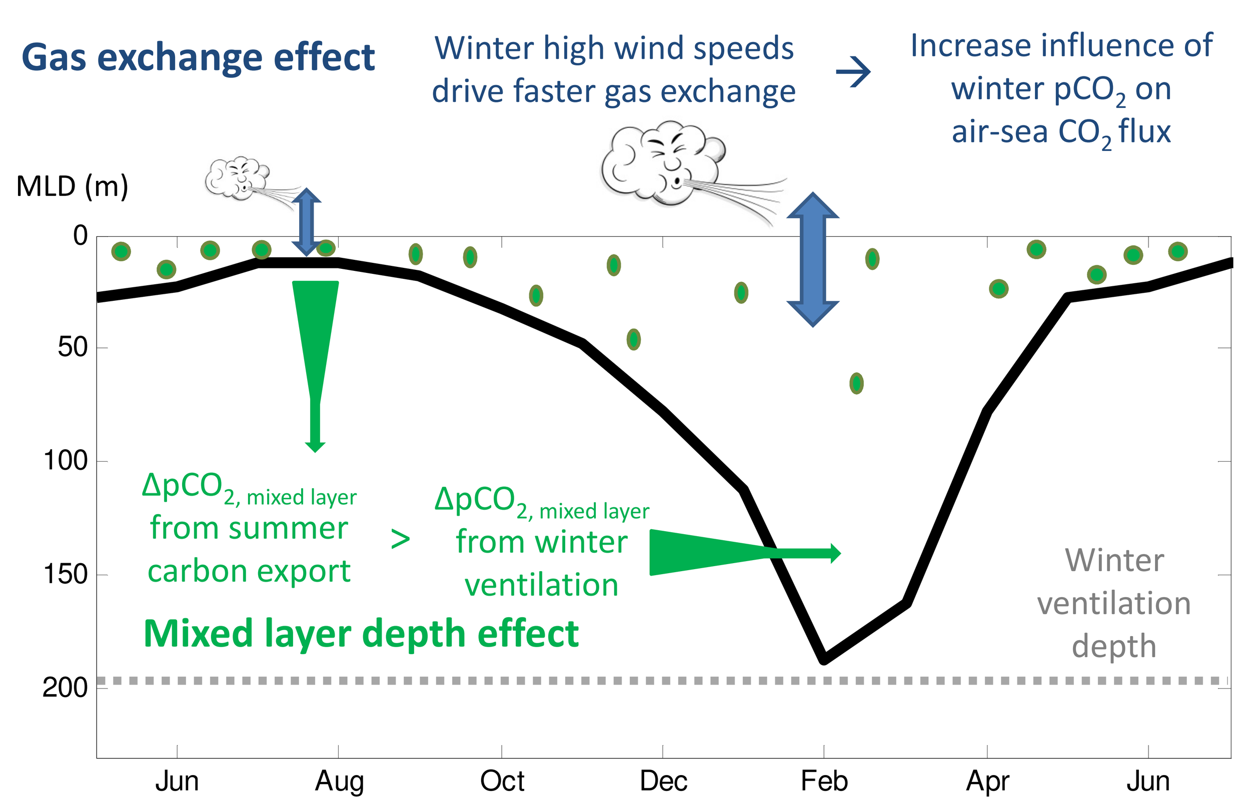
Overview and summary

Key question: How do seasonal changes in surface mixing and air-sea gas exchange influence the ability of the biological pump to take up CO_2 from the atmosphere?

Using a combination of modeling and observational approaches, we find:

1. Deep winter mixing ventilates organic carbon remineralized in the seasonal thermocline, reducing carbon sequestration in regions with deep maximum annual mixed layer depths (MLDs)
2. Net community production (NCP) reduces mixed layer pCO_2 across the North Pacific, but the extent depends on export and ventilation timing as well as the magnitude of export below the winter MLD.
3. The influence of the biological pump on annual air-sea CO_2 flux depends on the seasonality and timing of export, ventilation, and gas exchange.

Mechanisms: How can physical processes influence biologically-driven CO_2 flux?

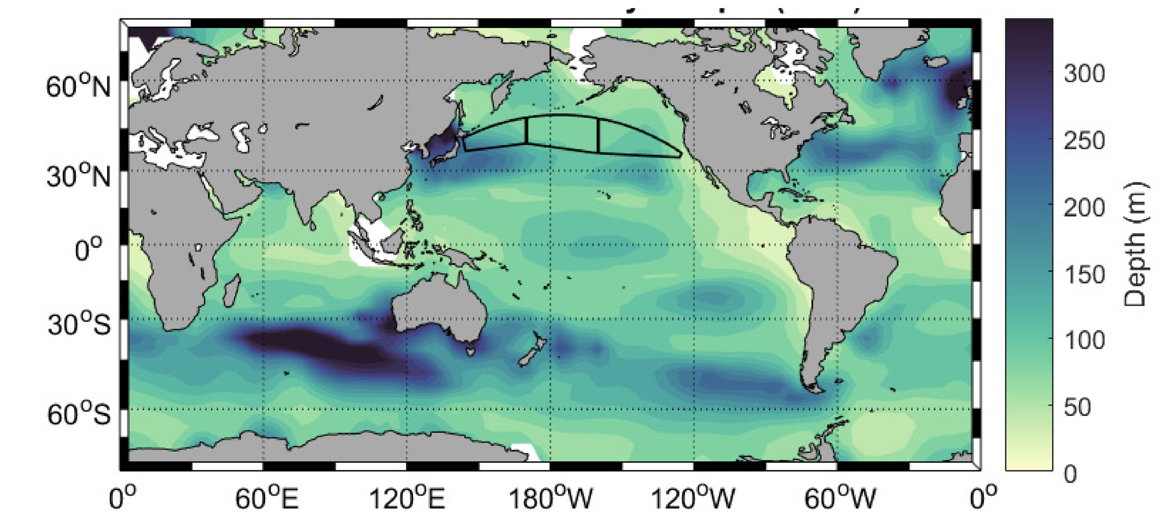


In regions with strong seasonality in mixed layer depth and air-sea gas exchange rates, seasonal timing of biological carbon fluxes in and out of the mixed layer as well as the annual magnitude of export below the winter ventilation depth determine the influence on air-sea CO_2 flux.

1. Global earth system model output:

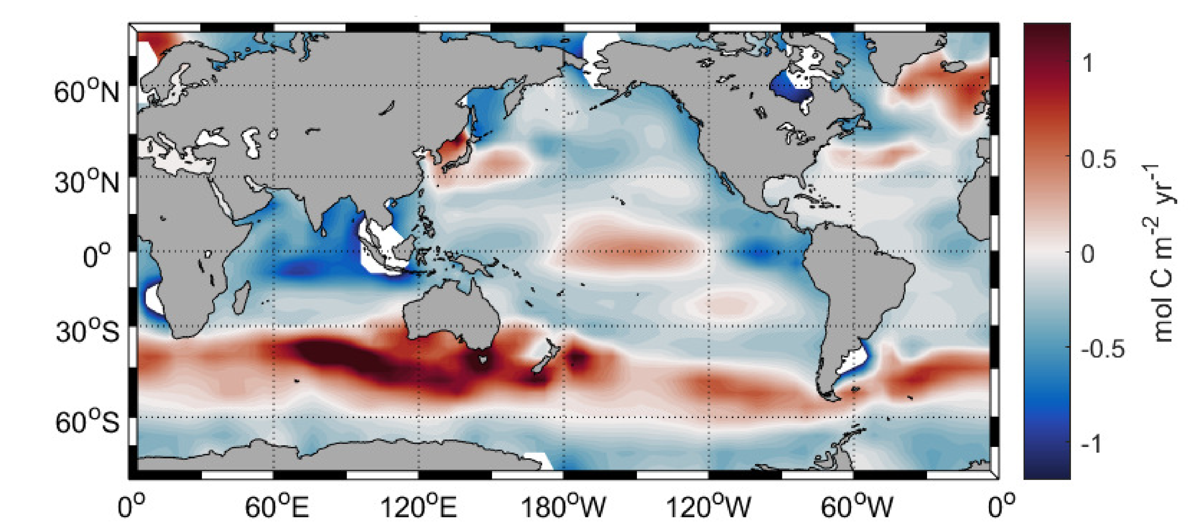
Deep winter mixing ventilates remineralized carbon from the seasonal thermocline

Maximum annual (winter) mixed layer depth (MLD)



ΔParticulate organic carbon flux in seasonal thermocline

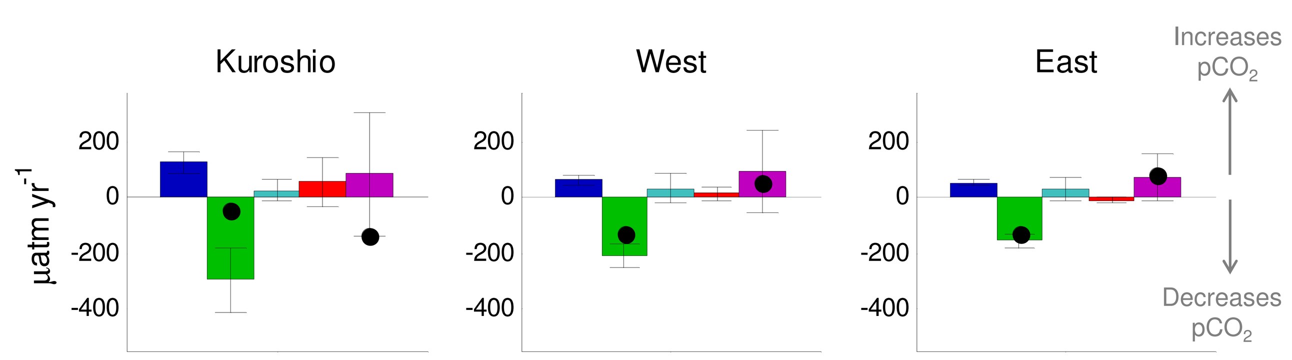
(between seasonally-varying MLD and maximum annual MLD)



CCSM-BEC output from Lima et al. (2014). Black outlines in the top panel show North Pacific container ship sampling regions: from W to E, the Kuroshio, West, and East (Palevsky and Quay, 2017).

2. North Pacific geochemical observations:

Biological pump influence on surface pCO_2 depends on export and ventilation timing



$$\frac{dpCO_2}{dt} = 0 = \text{Air-sea flux} + \text{NCP} + \text{CaCO}_3 \text{ prod.} + \text{Temp. effects} + \text{Phys. supply}$$

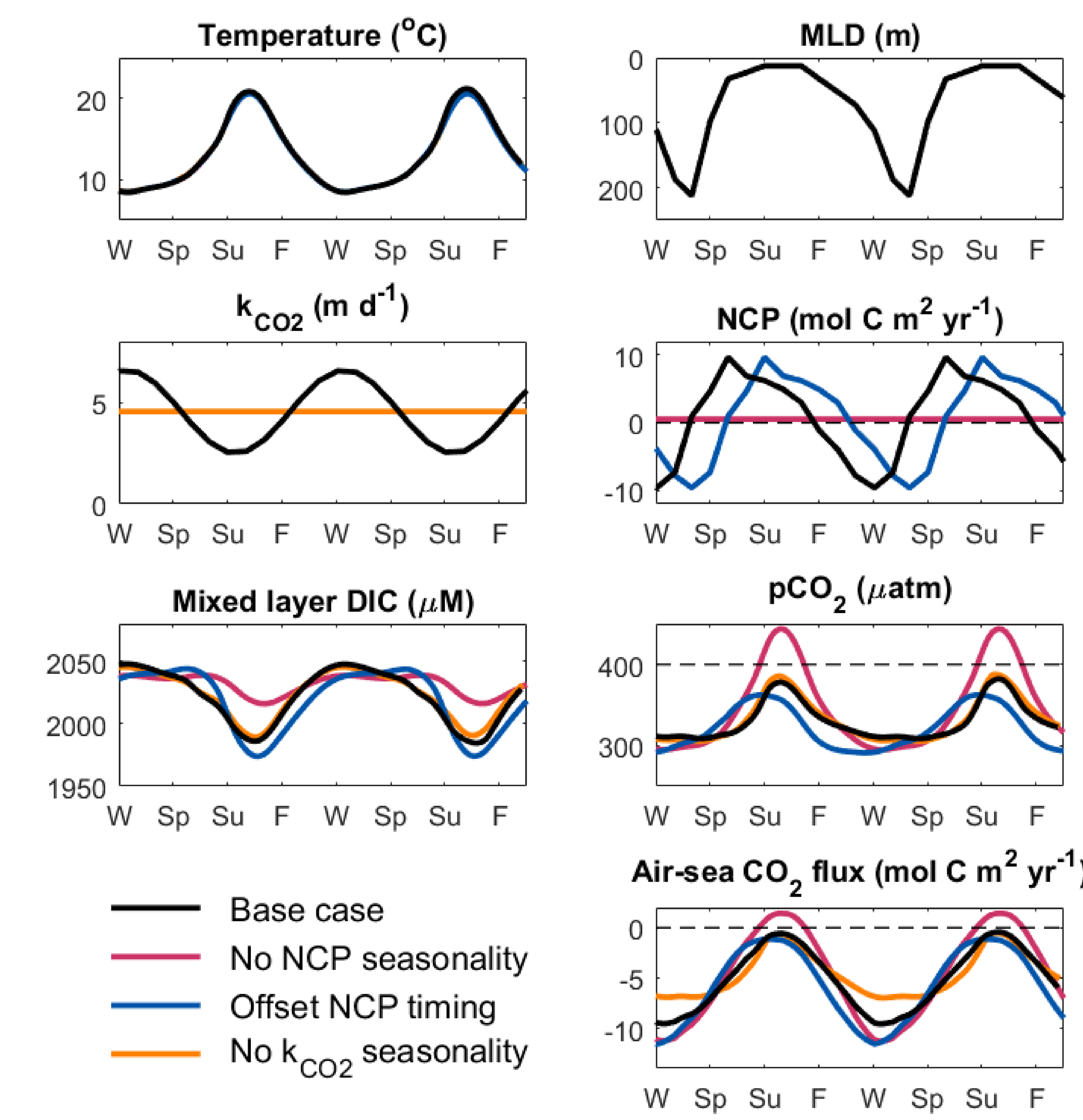
Two cases with the same annual NCP at the winter ventilation depth, but different timing

Bars: Realistic winter ventilation **Black circles:** Without winter ventilation

Analysis of mechanistic influences on surface pCO_2 based on O_2/Ar and carbonate chemistry sampling in three container ship sampling regions (Palevsky et al., 2016; Palevsky and Quay, 2017).

3. One-box model of the Kuroshio:

Seasonal timing influences biologically-driven CO_2 uptake



Results for DIC, surface pCO_2, and air-sea CO_2 flux in a mixed layer one-box model where the base case scenario is based on realistic forcing (heat flux, MLD, k_{CO2}, and mean carbonate chemistry) from observations in the Kuroshio region.

	Annual CO_2 uptake driven by NCP* mol C m-2 yr-1
Base case	0.67
No NCP seasonality	0.33
Offset NCP timing	0.35
No k_{CO2} seasonality	0.21

*Thermal/physical effects drive CO_2 uptake of 4.3 mol C m^{-2} yr^{-1}

Modifying the seasonal timing of NCP and of k_{CO2} reduces the annual ocean CO_2 uptake driven by NCP, even though the mean annual NCP and k_{CO2} are identical in all cases.

Lima, I. D., P. J. Lam, and S. C. Doney (2014), Dynamics of particulate organic carbon flux in a global ocean model, *Biogeosciences*, *11*, 1177–1198, doi:10.5194/bg-11-1177-2014.
Palevsky, H. I., P. D. Quay, D. E. Lockwood, and D. P. Nicholson (2016), The annual cycle of gross primary production, net community production, and export efficiency across the North Pacific Ocean, *Glob. Biogeochem. Cycles*, *30*, doi:10.1002/2015GB005318.
Palevsky, H. I. and P. D. Quay (2017), Influence of the biological pump on ocean carbon uptake over the annual cycle across the North Pacific Ocean, *Glob. Biogeochem. Cycles*, 31, doi:10.1002/2016GB005527.

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