Modified diurnal variability of the surface ocean CO_2 system under climate change

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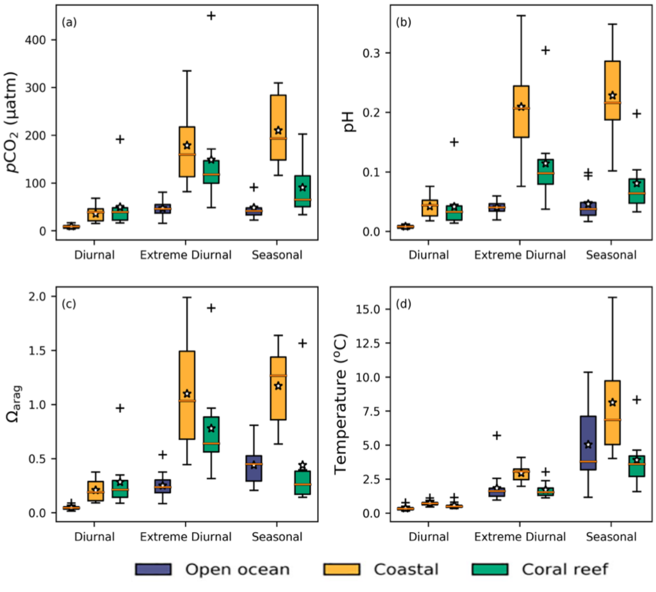
Summary

Ocean acidification and climate change can alter the seasonal variability of marine carbonate chemistry[1-3]. Such perturbations influence marine ecosystems and may affect ocean-climate feedbacks. We modified an ocean biogeochemical model to resolve diurnal CO_2 system variability. Forcing the model with atmospheric fields, we explore how surface ocean diurnal variability responds to climate change. Compared to preindustrial values, the diurnal amplitude of the partial pressure of CO_2 (pCO_2) increases three-fold under high 21st century emissions and 55 % under high-mitigation. The probability of extreme diurnal amplitudes of pCO_2 and acidity also substantially increases (30- to 60-fold under high emissions). The main driver of amplified pCO_2 diurnal variability is enhanced sensitivity to changes in temperature as the ocean absorbs carbon. Our projections suggest organisms will be exposed to enhanced hourly variations in pCO_2 and acidity, with likely increases in the associated metabolic cost.

Background: Observations indicate substantial diurnal variability of surface ocean carbonate chemistry, particularly in coastal and coral reef ecosystems[4]. But how might this change in the future?



Extreme present-day peak-to-peak diurnal amplitudes (1-in-100-day events) can exceed the average amplitude of seasonal cycles.

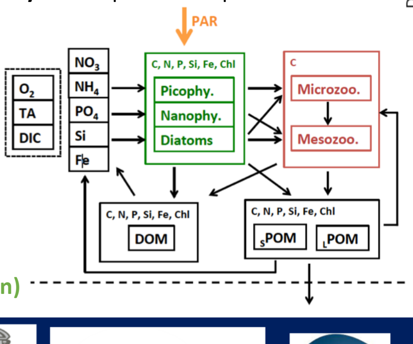
Methods: NEMO-PISCES-QUOTA ocean biogeochemical model[5,6] forced with **3-hourly** atmospheric outputs of IPSL-CM6-LR (ESM)

Preindustrial control

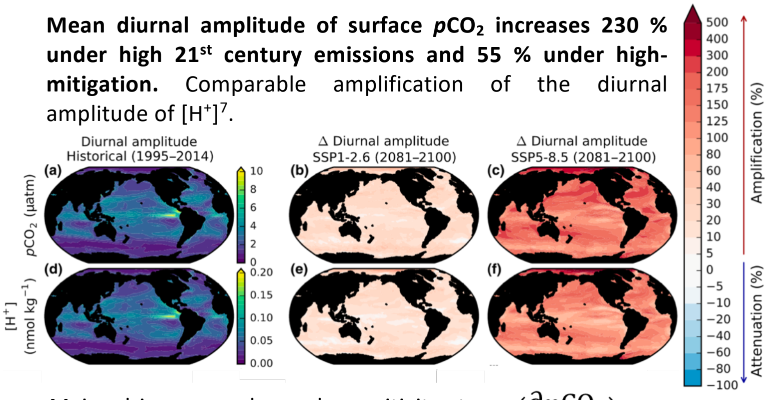
↓

Historical (1850-2015)

SSP5-8.5 (++ emissions) **SSP1-2.6 (++ mitigation)**



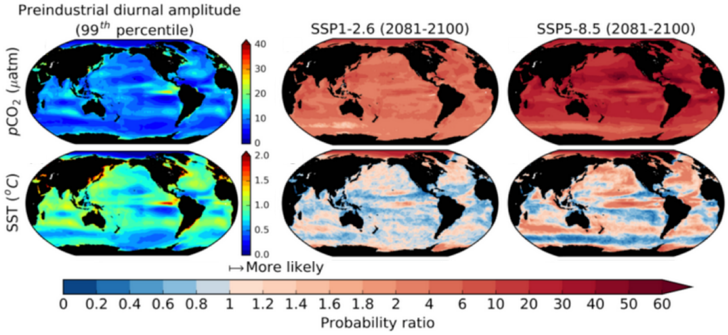
Mean diurnal amplitude of surface pCO_2 increases 230 % under high 21st century emissions and 55 % under high-mitigation. Comparable amplification of the diurnal amplitude of $[H^+]$[7].



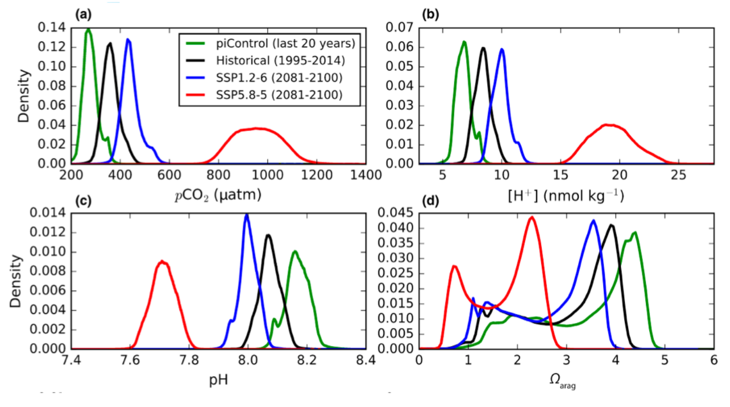
Main driver = enhanced sensitivity to diurnal changes in temperature as the ocean absorbs anthropogenic carbon.

$$\left(\frac{\partial pCO_2}{\partial T}\right)\Delta T$$

Up to 60-fold increases in the probability of extreme diurnal amplitudes of pCO_2 and $[H^+]$ under high emissions. 1-in-100-day diurnal amplitudes of pCO_2 and $[H^+]$ under preindustrial conditions are projected to become approximately 1-in-2 day events by the end of the 21st century under high emissions[7].



But changes to diurnal variability have little impact on projected absolute values of marine carbonate chemistry which are primarily driven by variability on annual-to-monthly timescales (with diurnal-to-daily variability having limited relative influence)[7].



Open question: What matters for organisms?

Absolute thresholds	**vs**	**Rates of change**
(diurnal cycles insignificant)		(diurnal cycles a major driver)

[1]Landschützer et al. (2018). *Nature Climate Change*; [2]Kwiatkowski & Orr (2018). *Nature Climate Chang*; [3]Orr et al. (2022). *Nature*; [4]Torres et al. (2021). *Geophysical Research Letters*; [5]Aumont et al. (2015). *Geosci. Model Dev.*; [6]Kwiatkowski et al. (2018). *Global Biogeochemical Cycles*; [7]**Kwiatkowski et al. (2023). *Global Change Biology*, *29*(4), 982–997.**

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