The Other CO_2 Problem in the Saltless Seas: High-Resolution Observations in Lake Superior

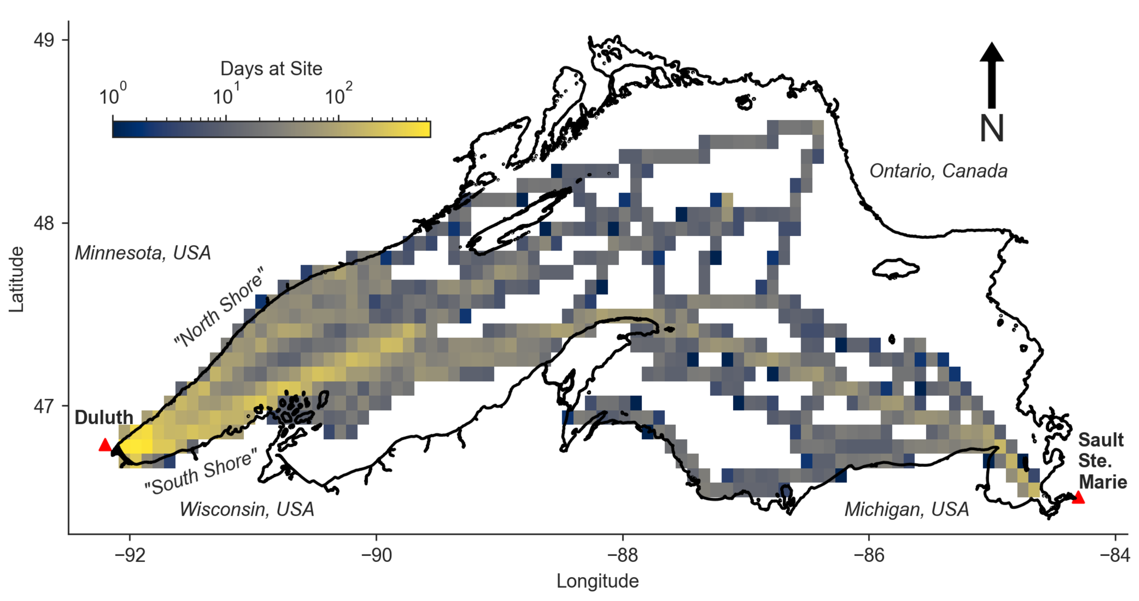
UMD LARGE LAKES OBSERVATORY — UNIVERSITY OF MINNESOTA DULUTH — Driven to Discover

Water Resources Science — UNIVERSITY OF MINNESOTA — Driven to Discover

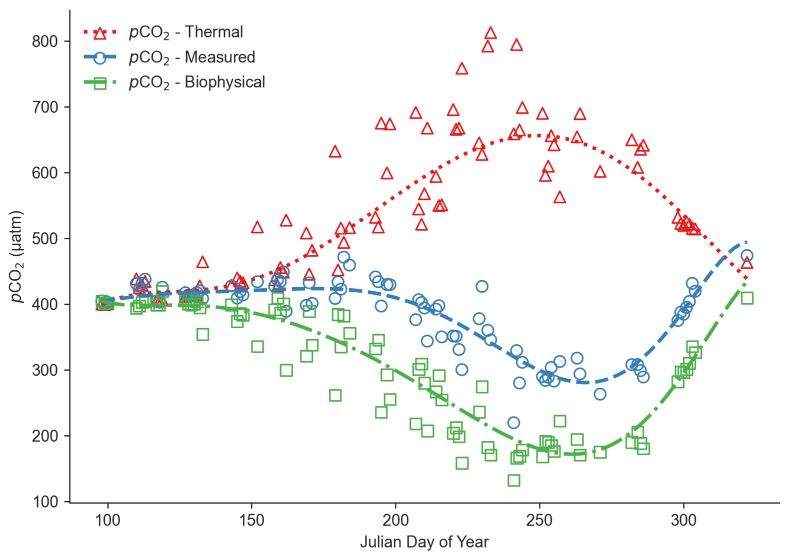
Sandborn, Daniel E.; Minor, Elizabeth C. Large Lakes Observatory — University of Minnesota Duluth

Introduction

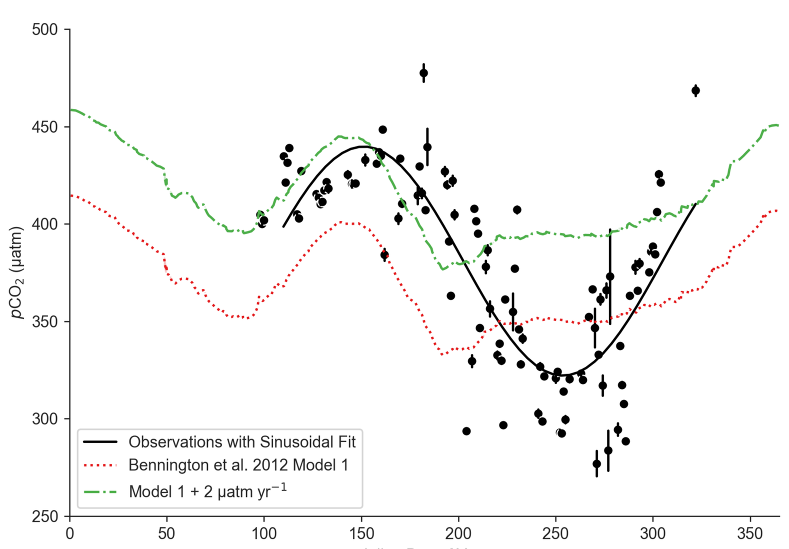
Lake Superior is Earth's largest freshwater body by area. Its great societal importance, immense size, ultraoligotrophic state, low buffering capacity, and rapid mixing period (compared to deep ocean water) highlight its suitability for study in the context of the ongoing perturbation to Earth's C cycle. Acidification of freshwater by CO_2 parallel to ocean acidification has been hypothesized (Phillips et al. 2015) but confounding drivers and few, short, and/or high-uncertainty timeseries of inorganic C parameters have inhibited study of the effects of CO_2 infiltration. **This study presents the first multiannual time series of high-accuracy surface water pCO$_2$ measurements of Lake Superior.**



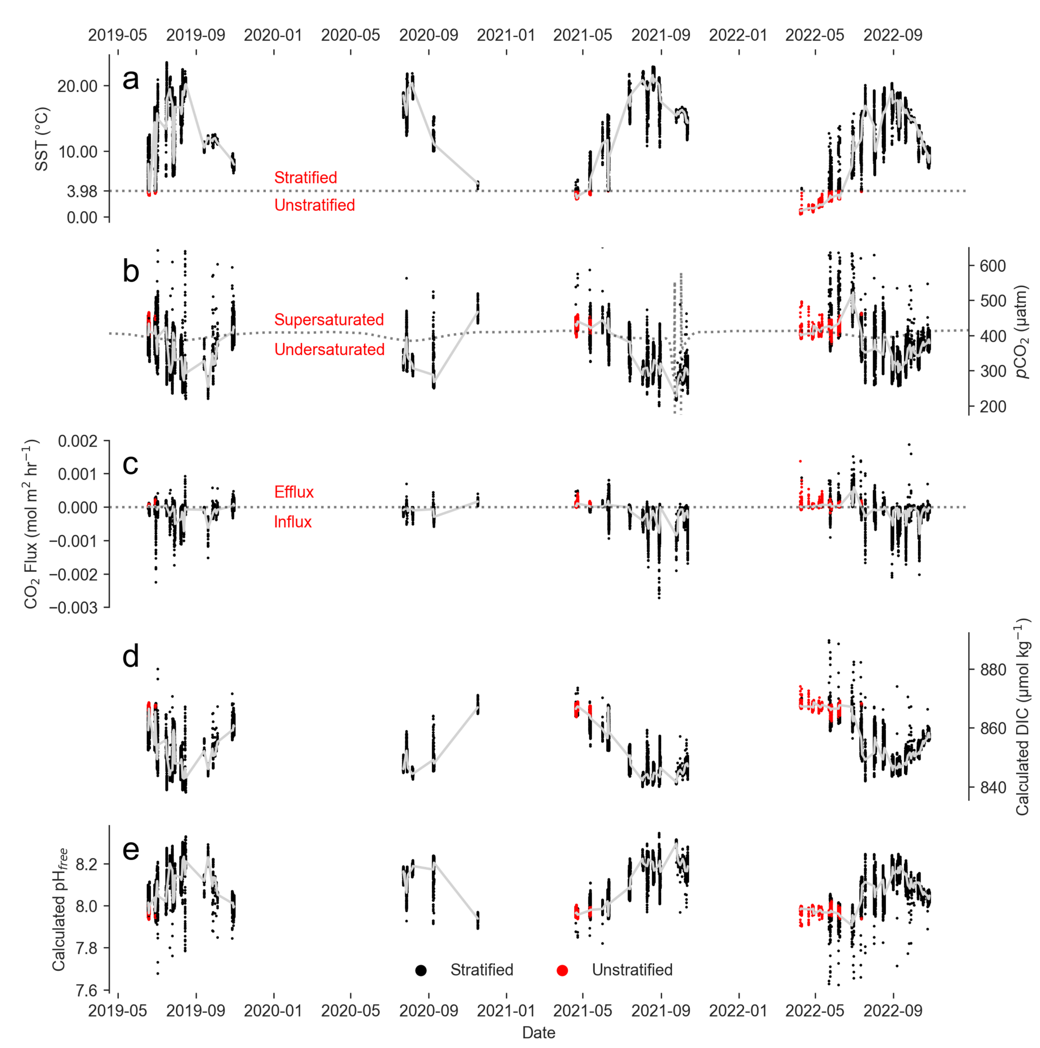
Observation



← Daily mean sea surface pCO$_2$ observed 2019-2022, with power series regression as a visual aid. Decomposition into thermal and biophysical drivers indicates **equal dominance of the two drivers on annual scales.** Thermal drivers dominate early-season pCO$_2$, while late-season biophysical drivers force a local minimum mid-September.



← Daily mean sea surface pCO$_2$ (±se) observed 2019-2022 exhibited a sinusoidal seasonal cycle. **Decadal-scale pCO$_2$ increase is indicated by agreement of early-season predictions from process modeling (Bennington et al. 2012) after adjustment for atmospheric CO_2 increase.** Observations displayed greater seasonal variability (>50 µatm) than previous observations or models.



↑ Complete 4-year time series of underway observations. CO_2 flux parameterized from wind speed (Ho et al. 2006); pH and DIC are calculated using assumed A_T = 850 µmol kg^{-1}.

Methods

Surface water pCO$_2$ was measured during *RV Blue Heron* transects of Lake Superior 2019-2022 using a SuperCO2 instrument. Instantaneous flux was parameterized by measurements of wind velocity (Ho et al. 2006). Four years' underway data were combined into a single year to generate a synthetic April-May time series of pCO$_2$ and CO_2 flux, from which drivers and interannual trends were inferred. A pathway towards a data-based pCO$_2$ product spanning Lake Superior using non-linear ML regression is presented along with the first wintertime under-ice pCO$_2$ time series of Lake Superior.

Questions	Results
How do pCO$_2$ and CO_2 flux vary seasonally? Spatially?	Lake Superior's seasonal pCO$_2$ variability is larger than the equilatitudinal North Atlantic. Riverine influence induces both high- and low-pCO$_2$ deviations from the cycle.
What drives seasonal pCO$_2$ variability?	Thermal and biophysical drivers are evenly-balanced on an annual scale. SST dominates variability in spring; biophysical drivers effect a summertime drawdown.
What is the ice-free-season net CO_2 flux?	A net influx on the order of 20 Gmol C was observed April-November, exceeding process model estimates.
Is L. Superior pCO$_2$ keeping pace with the atmosphere?	**Yes.** A rapid CO_2 equilibrium timescale ($\tau_{eq\ CO2}$) on the order of 100 d. combined with decadal-scale surface pCO$_2$ increase indicate **Lake Superior is undergoing CO_2 infiltration.**

Laurentian Great Lakes in a High-CO_2 World: What's Next?

The outcomes of pCO$_2$ infiltration alone include acidification, decreasing Ω, changes to trace metal speciation, metabolic effects on plankton, and other phenomena paralleling ocean acidification.

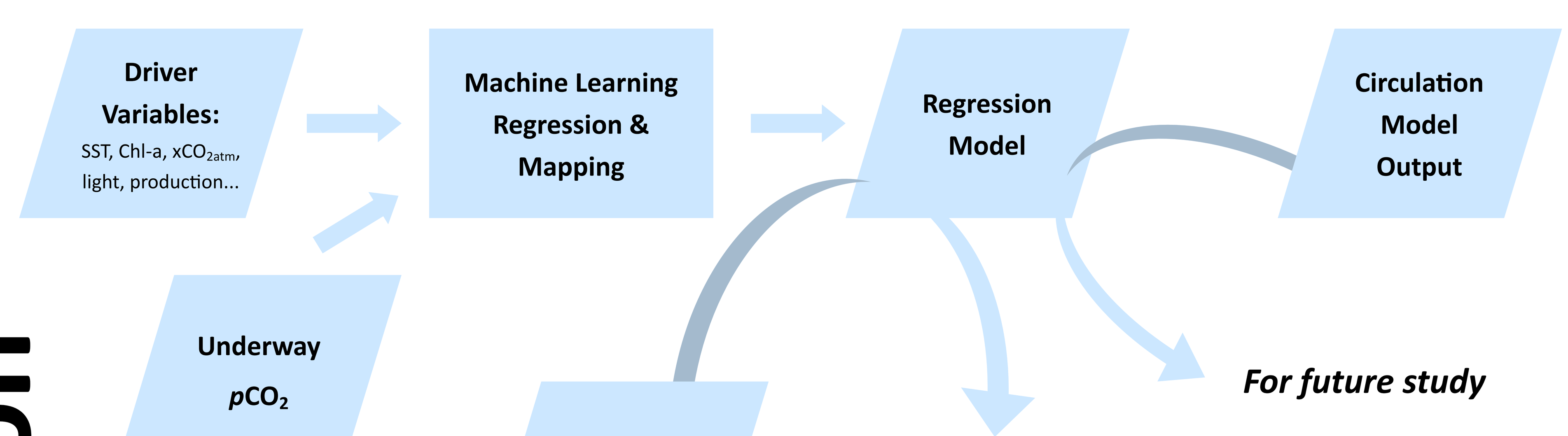
- however -

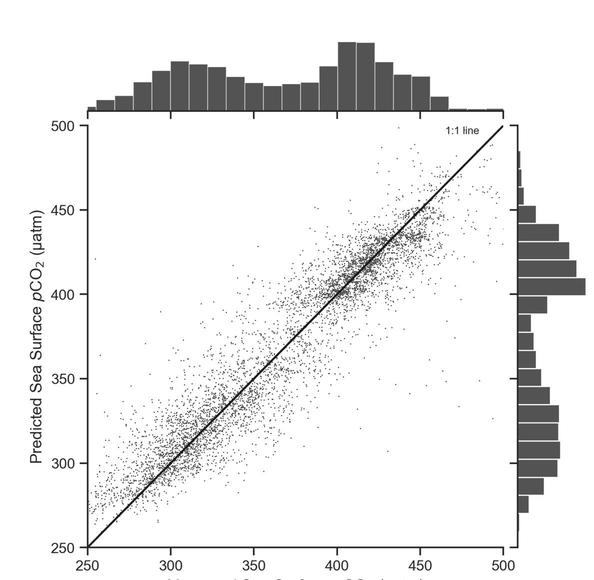
Poorly-understood drivers modify acidification outcomes:

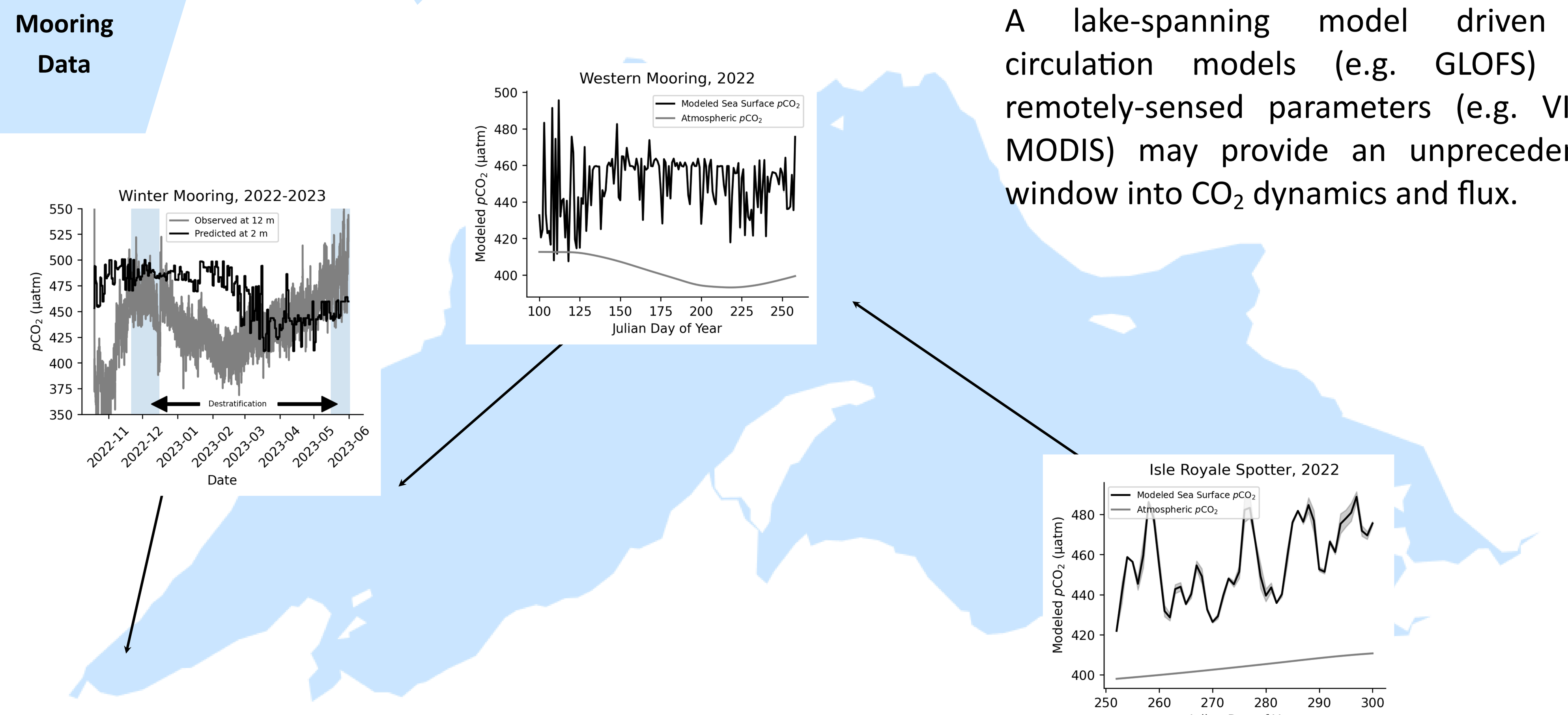
Alkalinization/sediment buffering
Increasing water temperature
Strengthening lake stratification
Shifting ice phenology

- Lake Superior lacks sediment carbonate, but other lakes (e.g. Michigan) may benefit from solid-phase buffering.
- No long-term chemistry timeseries exists with sufficient accuracy to detect acidification in Lake Superior.
- The C budget of Lake Superior is as-yet unconstrained, highlighting the need for a spatially- and temporally-comprehensive understanding of CO_2 cycling and flux.

Prediction







FFNN regression yields very good (R^2>0.9) agreement between modeled and underway-measured pCO$_2$.

Application to mooring data demonstrates scalability as well as challenges to signal reproduction at the limit of training conditions.

A lake-spanning model driven by circulation models (e.g. GLOFS) and remotely-sensed parameters (e.g. VIIRS/MODIS) may provide an unprecedented window into CO_2 dynamics and flux.

Conclusions

Surface water inorganic C complex measurements of unprecedented accuracy and spatiotemporal breadth have allowed inference of CO_2 cycling drivers and flux in Lake Superior. This research described the relative dominance of competing thermal and biophysical drivers, confirmed decadal increase in sea surface pCO$_2$, and lays the foundation for development of a data-based CO_2 flux product with the potential to reshape the understanding of large lakes as significant players in regional and global C cycles.

More Information
Graphics
Author Contact
Daniel E. Sandborn
sandb425@umn.edu
https://d-sandborn.github.io

Acknowledgements

Thanks are due to Dr. Jay Austin for his data processing guidance and provision of winter mooring data, to Payton K. Kittaka, Dr. Luke Busta and Gabriella Brinkley for their sampling and analysis assistance, to Dr. Michael DeGrandpre for technical advice, to Dr. Galen McKinley for her model comparison and visualization suggestions, to the Principal Investigators and Chief Scientists of cruises during which underway data was collected, and to the captain and crew of the *RV Blue Heron*. This research was supported by a Grant-in-Aid from the University of Minnesota from the Office of the Vice President for Research to ECM.