Observing marine carbon dioxide in Alaska's coastal oceans

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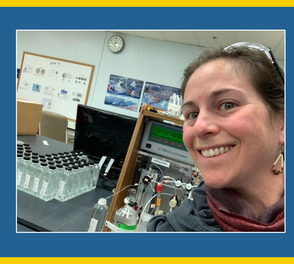
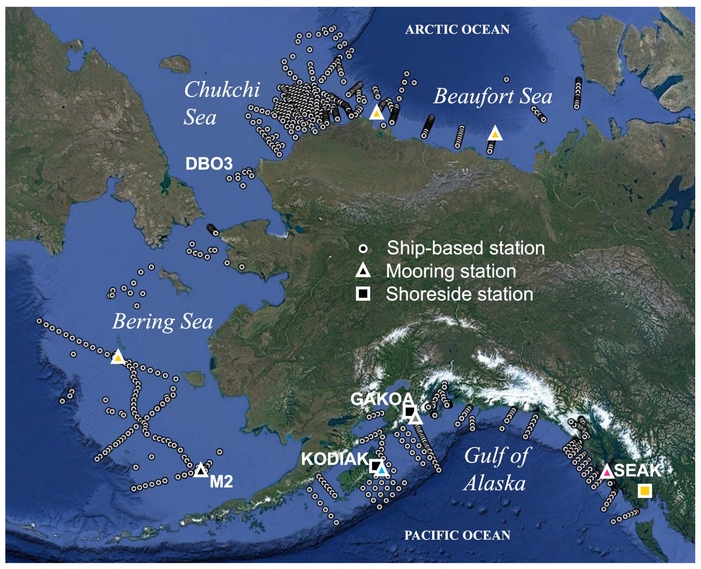
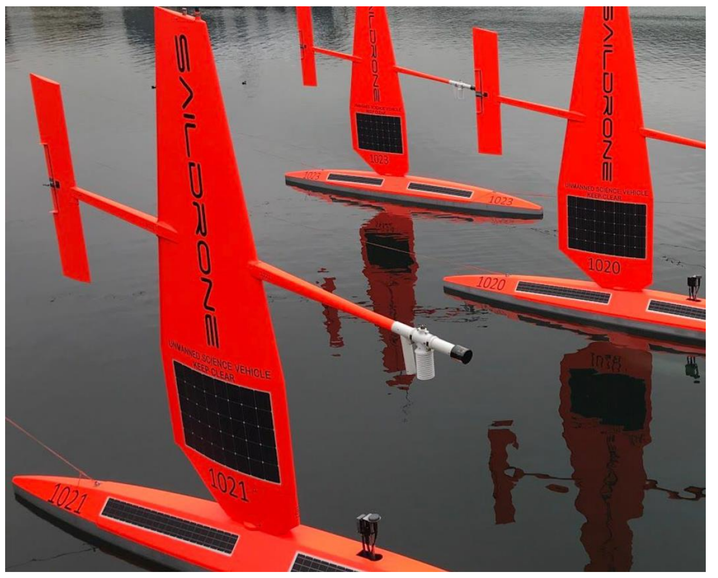


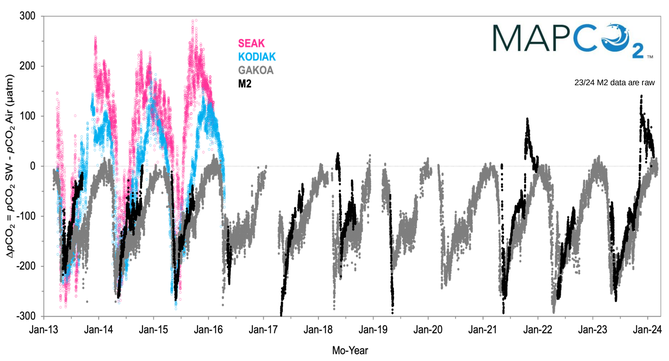
The University of Alaska Fairbanks (UAF) Ocean Acidification Research Center (OARC) monitors the marine carbonate system in the northern Gulf of Alaska, Bering Sea, Chukchi Sea, and Beaufort Sea. We use ship-based oceanography and autonomous platforms to monitor seasonal, annual, and anthropogenic trends in surface seawater carbon dioxide (CO_2). On average, the surface ocean is a sink to atmospheric CO_2 with significant spatial and temporal variability. These observations evaluate carbon cycle dynamics, inform models, and improve the global carbon budget estimates.

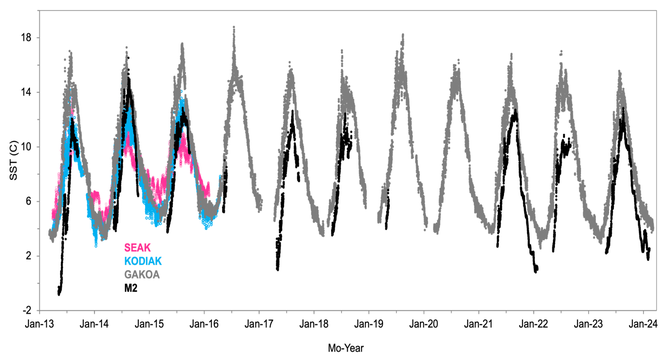


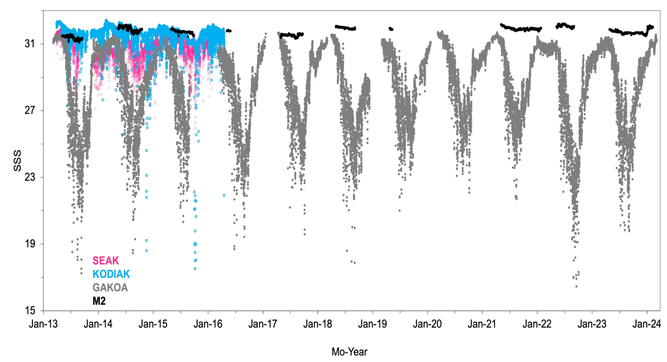


Observing subarctic surface ocean CO_2.

Two surface buoys with a moored autonomous pCO_2 ($MAPCO_2$™) system have been deployed in the Gulf of Alaska (GAKOA) and the Bering Sea (M2) for more than a decade. Two additional sites in the Gulf of Alaska (SEAK and KODIAK) were deployed from 2013 to 2016. The M2 site is the only location with a seasonal deployment, due to sea ice in the Bering Sea.



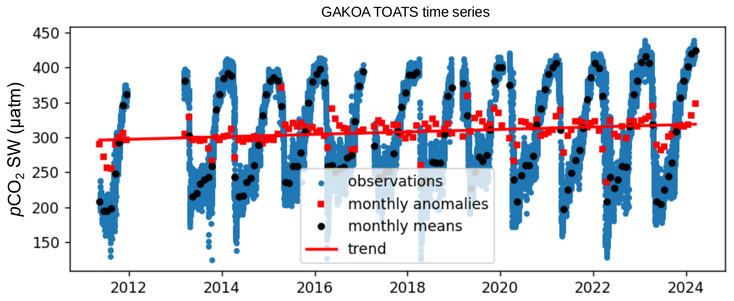




On average, the surface ocean is a year-round sink of CO_2 at GAKOA and M2 with outgassing observed in the Bering Sea during winter. The highest surface ocean CO_2 in Alaska is at SEAK and complements other observations in this region (Evans et al., 2022). The surface ocean at SEAK and KODIAK are seasonal CO_2 sinks during high summer productivity and CO_2 sources later in the year.

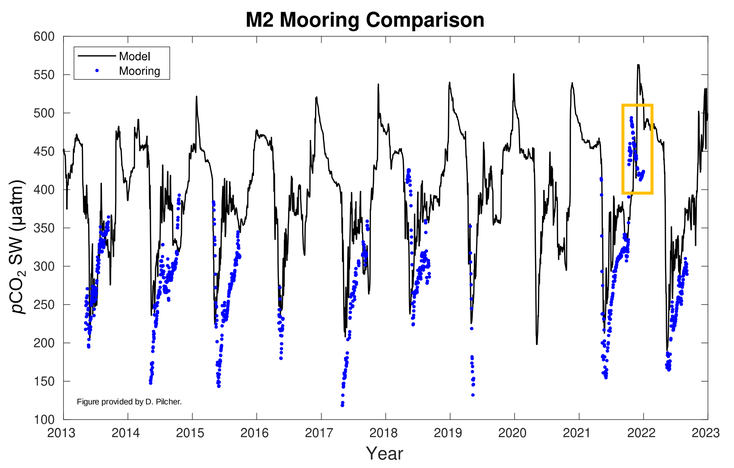
A GAKOA surface ocean CO_2 trend is emerging.

We used the Trends of Ocean Acidification Time Series (TOATS) package available on GitHub* to determine if the GAKOA time series was long enough to detect an anthropogenic trend against the high variability at this site. Sutton et al. (2022) developed the TOATS tool for users to assess data gaps, remove periodic signals, assess a linear fit, estimate whether a trend can be detected, consider uncertainty, and present the trend analysis.



The TOATS results show the seawater pCO_2 trend at GAKOA is significant with an estimated trend of 1.8 ± 0.6 µatm per year. The number of years to detect the trend is 13.9 ± 2.4. The record at GAKOA is 12.8 years; therefore, the trend accuracy and significance will grow as the time series continues.

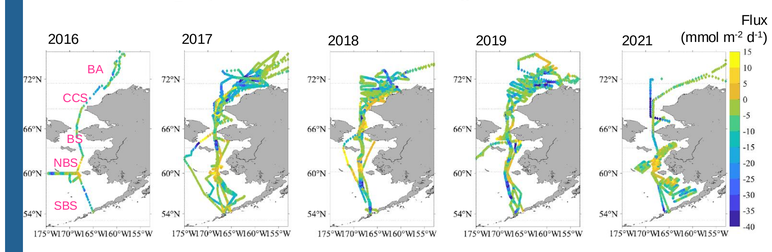
Modeled surface CO_2 at M2 captures outgassing.



Extraordinary circumstances with field work logistics led to the unique opportunity to directly observe surface seawater CO_2 at the M2 site in the southeastern Bering Sea during the winter freeze up in 2021/22 (gold box). This gave us the opportunity to validate the Bering10K model (Pilcher et al., 2022) with direct measurements of seasonal outgassing. We will repeat this effort when the 2023/24 data are final.

USVs observe a strong, summer CO_2 sink.

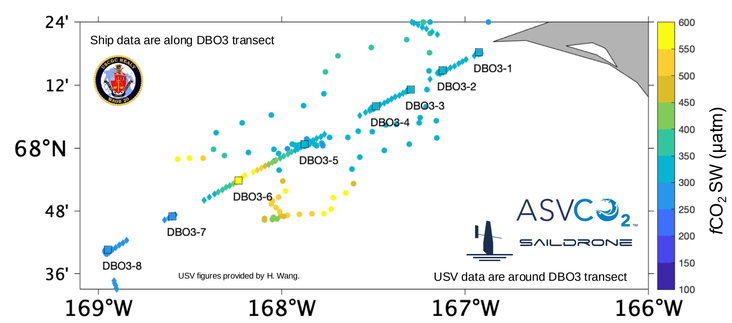
While climate change is faster paced and more advanced in the Arctic, it is still challenging to predict future CO_2 cycle changes due to the lack of baseline data. Uncrewed surface vehicles (USV) were deployed in Alaska's Pacific Arctic Region for five years to improve understanding of surface CO_2 dynamics in the Bering and Chukchi Seas.



The CO_2 flux calculated from five years of summer observations show the Bering and Chukchi Sea shelves act as strong CO_2 sinks during the summer (cool colors), with a few exceptions (warm colors) near the Yukon River plume, Bering Strait, and southern Chukchi Sea.

	2016	2017	2018	2019	2021	5-yr Summer CO_2 flux $\bar{x}$ (mmol m^{-2} d^{-1})
Southern Bering Sea (SBS)	-2 ± 6	-4 ± 4	-6 ± 5	-8 ± 5	-4 ± 4	-5 ± 4
Northern Bering Sea (NBS)	-1 ± 9	-1 ± 4	0 ± 5	-3 ± 5	0 ± 3	-1 ± 2
Bering Strait (BS)	-8 ± 5	-8 ± 11	-4 ± 5	-8 ± 6	-8 ± 15	-7 ± 3
Central Chukchi Sea (CCS)	-11 ± 6	-8 ± 7	-4 ± 4	-6 ± 3	-16 ± 15	-9 ± 3
Barrow Arctic (BA)	-7 ± 6	-8 ± 9	-9 ± 6	-7 ± 4	-5 ± 5	-7 ± 3

Combining observations from USVs and ship opportunities such as the repeat observations on the Distributed Biological Observatory transect 3 (DBO3) will improve the understanding of surface CO_2 dynamics in a rapidly changing Arctic. Autonomous technologies such as USVs provide high-quality, high-resolution data to increase data collection in remote areas. For example, we observed outgassing at higher spatial resolution with the USVs (warm colors).



The Ocean Acidification Research Center is a service laboratory that provides climate quality observations, data resources, and analytical services for numerous stakeholders. All final data are public and submitted to the Surface Ocean CO_2 Atlas and NCEI. This work was funded by the Alaska Ocean Observing System, NOAA Arctic Research Program, NOAA Ocean Acidification Program, North Pacific Research Board, and the State of Alaska.
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