Determining The Drivers Of Long-Term Surface Ocean and Coastal Carbonate Chemistry Change Using Time-Series Data

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Motivation

The ocean absorbs ~25% of annual carbon emissions globally. We aim to answer the question: What are the drivers of carbon change at various locations throughout the globe? ***We hypothesize that at most open ocean locations, changes in surface ocean*** pCO_2***, pH, and aragonite saturation state (Ωarag) are primarily driven by the uptake of atmospheric*** CO_2. **Coastal areas may face additional drivers such as enhanced variability in biological processes and other anthropogenic impacts such as enhanced nutrient inputs. Some locations may exhibit multifaceted drivers; for example, a long-term increase in seawater temperature will impact the solubility of** CO_2. Understanding the primary drivers of long-term trends in carbon change on a local scale may allow for a more nuanced approach to addressing the multitude of factors impacting carbon change in the ocean.

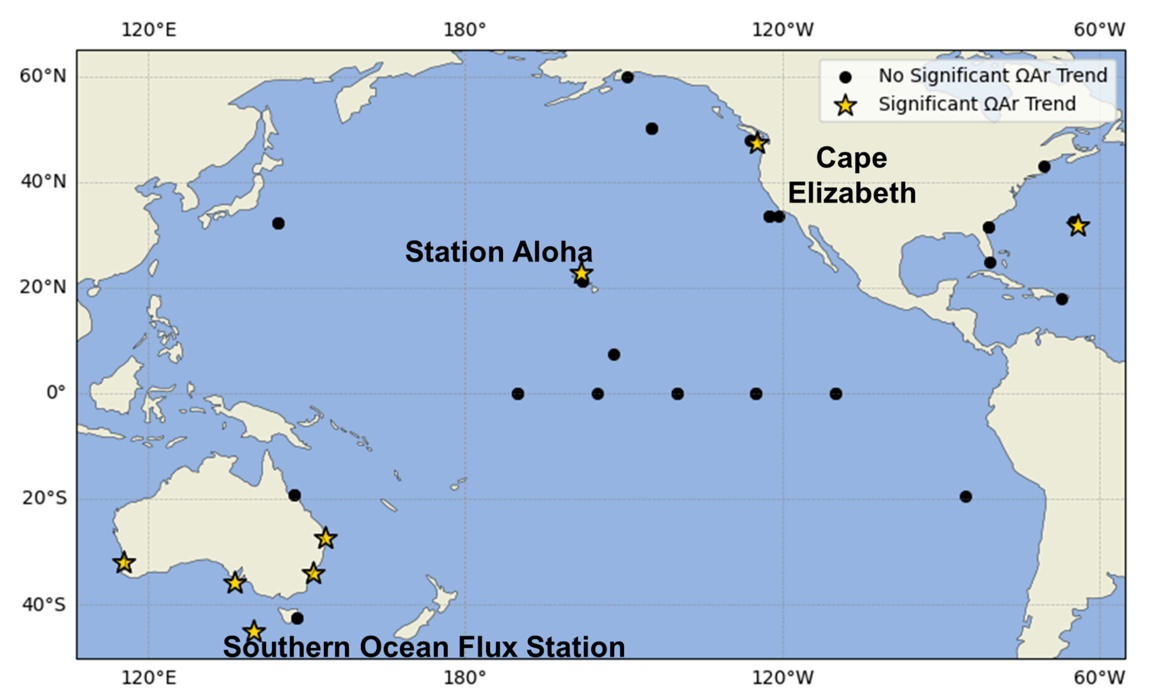

Figure 1. Map representing locations of publicly available surface ocean carbonate chemistry time series longer than a decade used in this study. Sites with statistically significant trends in Ωarag are shown by gold stars.

Methods

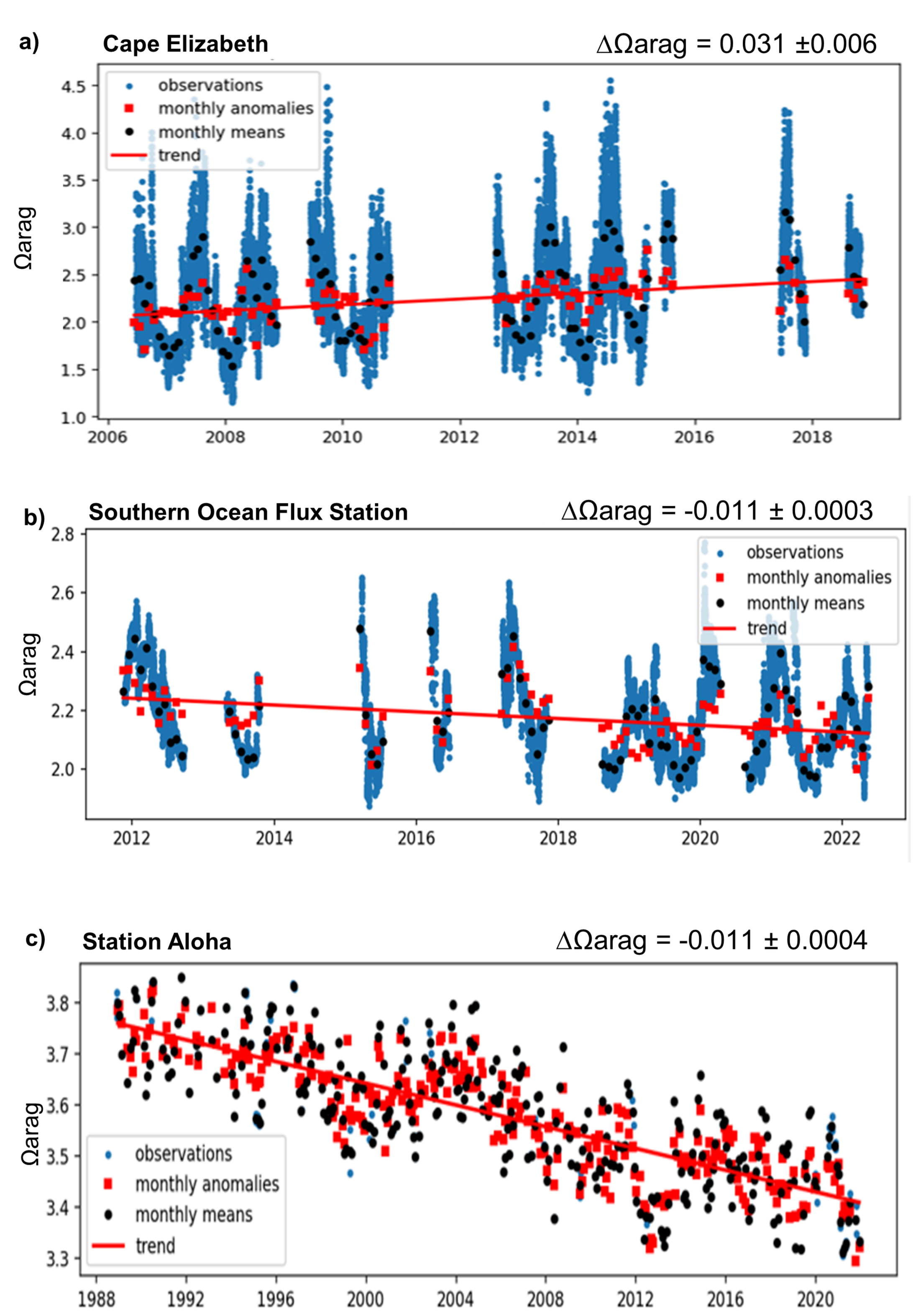

Figure 2. Output from best practices for assessing Trends of Ocean Acidification Time Series (github.com/NOAA-PMEL/TOATS) showing time series of surface ocean Ωarag observations (blue dots), monthly means (black dots), and monthly anomalies (red squares) at the a) Cape Elizabeth, b) Southern Ocean Flux Station (SOFS), and c) Station Aloha. Trends resulting from the linear regression of the monthly anomalies (red line) are also shown.

$$\Delta\Omega arag = \frac{\partial\Omega arag}{\partial DIC}\Delta sDIC + \frac{\partial\Omega arag}{\partial Temp}\Delta Temp + \frac{\partial\Omega arag}{\partial FW}\Delta FW \quad \text{Eqn. 1}$$

$$\frac{\partial\Omega arag}{\partial FW}\Delta FW = \frac{\partial\Omega arag}{\partial S}\Delta S + \frac{\partial\Omega arag}{\partial DIC}\Delta DIC_{salt} + \frac{\partial\Omega arag}{\partial TA}\Delta TA \quad \text{Eqn. 2}$$

$$\Delta DIC_{salt} = \frac{\partial\Omega arag}{\partial DIC}\Delta DIC - \frac{\partial\Omega arag}{\partial sDIC}\Delta sDIC \quad \text{Eqn. 3}$$

Trends: Long-term trends are assessed on carbonate parameters and driver variables using established best practices (Sutton et al. 2022). These steps include: 1) removing the seasonal signal, 2) evaluating the linear fit of the trend in monthly anomalies (i.e., monthly means with the seasonal signal removed), and 3) estimating whether a statistically-significant trend can be detected from the time series.

Driver contributions: Driver variable contributions to the Ωarag trend are assessed by determining the sensitivity of changes in Ωarag w.r.t. changes in DIC, temperature, and freshwater (Franco et al. 2021). The sensitivity component is denoted in Equation 1 by the division of the partial derivatives. The sensitivity is then multiplied by the respective trend, resulting in the contribution of the respective component to the overall trend in Ωarag. The sum of the sDIC, temperature, and fresh water (FW) contributions should roughly equate to the Ωarag trend. The FW trend is derived by a summing the salinity (S) contribution, total alkalinity (TA) contribution, and the DICsalt contribution (Eqn 2). The trend in DICsalt is the difference of the DIC contribution and the sDIC contribution (Eqn 3).

Results

Contribution to ΔΩarag :	Cape E.	SOFS	Station Aloha
sDIC	0.022 ± 0.011	-0.011 ± 0.006	-0.011 ± 0.001
Temperature	0.001 ± 0.001	-0.0001 ± 0.004	0.005 ± 0.0002
Fresh Water(FW)	0.008 ±0.0008	-0.001 ± 0.0004	0.002 ± 0.00004
ΔΩarag	0.031 ±0.006	-0.011 ± 0.003	-0.011 ± 0.0004

Table 1. Ωarag driver contributions to observed trends ± standard error for the Cape Elizabeth, Sothern Ocean Flux Station, and Station Aloha time series. The total Ωarag trends are shaded gray.

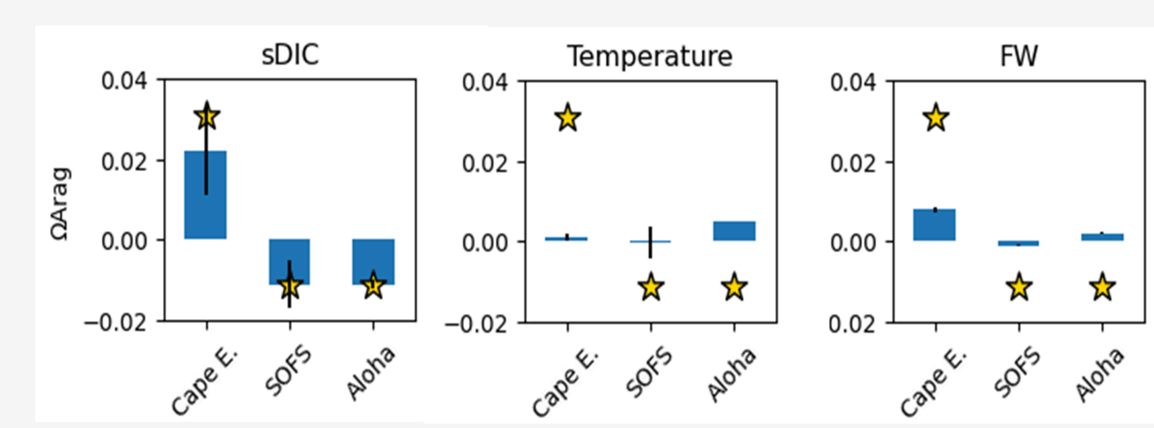

Figure 3. Bar plots of Ωarag drivers contribution breakdown ± standard error for the Cape Elizabeth, Sothern Ocean Flux Station, and Station Aloha time series. Gold stars show the overall Ωarag trend for each respective time series.

- Surface ocean Ωarag has a positive trend at the Cape Elizabeth mooring – a coastal location near Washington, USA (Fig. 2)
- Comparatively, the open ocean Station Aloha and SOFS have negative trends in Ωarag (Fig.2), which are consistent with global average surface ocean Ωarag trends
- The primary contributor to each of these trends is sDIC, with fresh water (FW) and temperature being close secondary drivers for Cape Elizabeth and Station Aloha, respectively (Fig. 3)
- Cape Elizabeth is a coastal location in a prominent upwelling zone experiencing significant changes in salinity and sDIC in addition to changes expected from CO_2 uptake alone.

References, Data Sources, and Acknowledgements

Franco, A. C., Ianson, D., Ross, T., Hamme, R. C., Monahan, A. H., Christian, J. R., et al. (2021). Anthropogenic and Climatic Contributions to Observed Carbon System Trends in the Northeast Pacific. 35(7), e2020GB006829, doi: 10.1029/2020GB006829.

Sutton AJ, et al. 2022. Advancing best practices for assessing trends of ocean acidification time series. Front. Mar. Sci. 9:1045667. doi: 10.3389/fmars.2022.1045667.

Cape E. and SOFS data from: Sutton, A. J., et al. 2019. Autonomous seawater pCO_2 and pH time series from 40 surface buoys and the emergence of anthropogenic trends, Earth Syst. Sci. Data, 11, 421-439, doi.org: 10.5194/essd-11-421-2019.

Station Aloha data adapted from: Dore, J.E., R. Lukas, D.W. Sadler, M.J. Church, and D.M. Karl. 2009. Physical and biogeochemical modulation of ocean acidification in the central North Pacific. Proc Natl Acad Sci, 106: 12235-12240.

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Future Directions

The next step of this project will include evaluating a larger set of publicly available time series data and determining the primary drivers of long-term carbon change at each location. Specifically, we will expand this process to define the sensitivity of each carbon parameter to the trends in pCO_2 and pH, similar to that of Ωarag.