Coastal surface ocean CO_2 dynamics revealed by underway measurements from an Alaskan ferry

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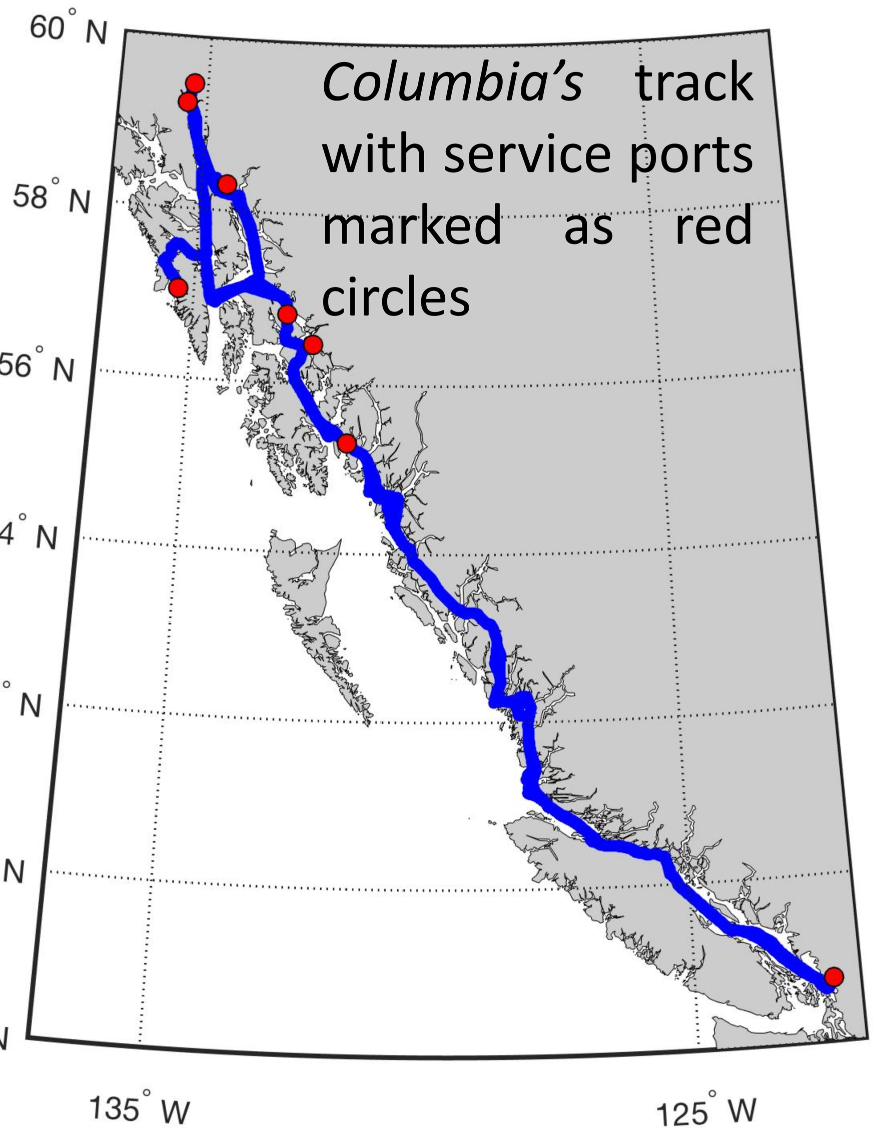
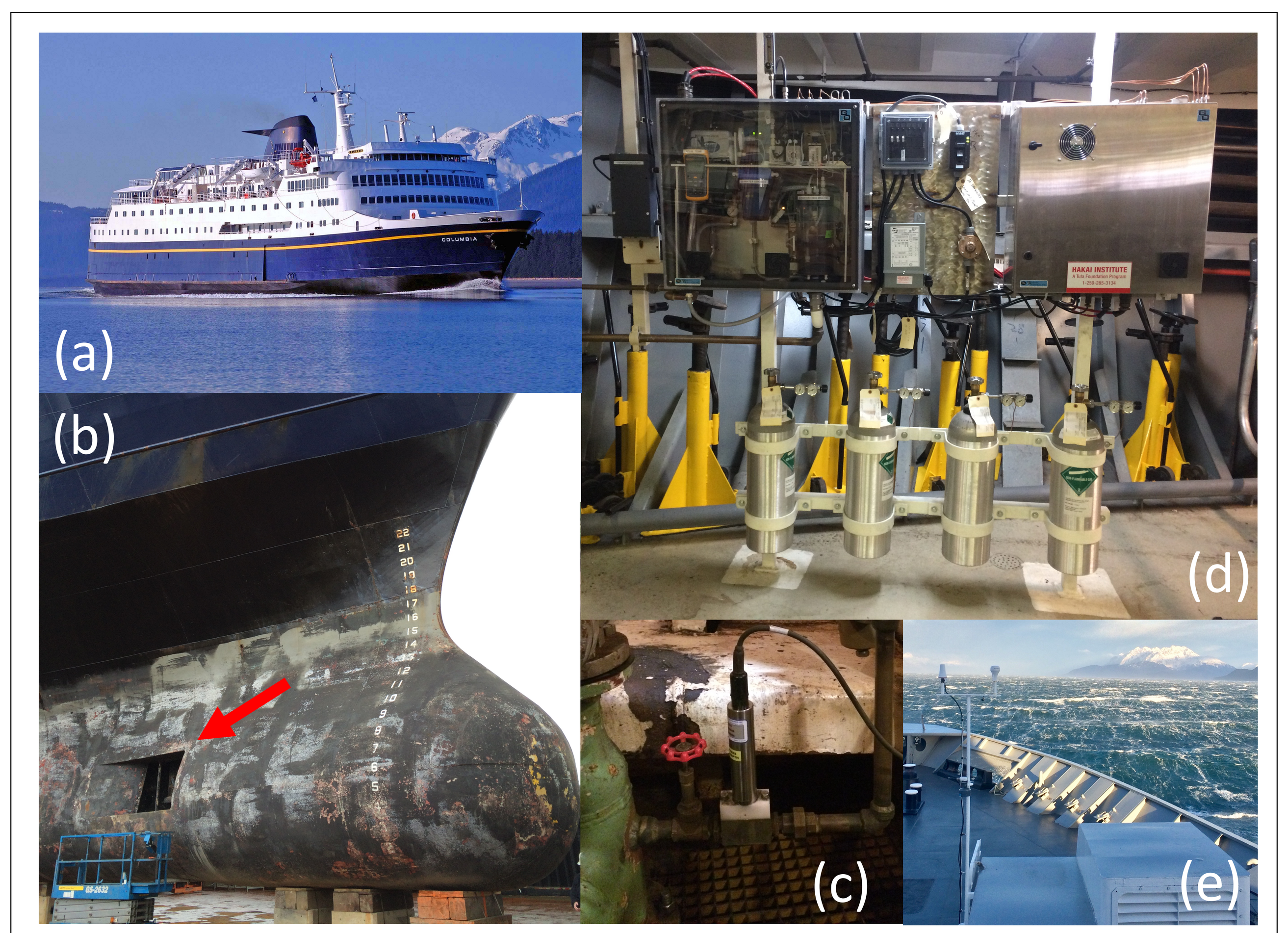
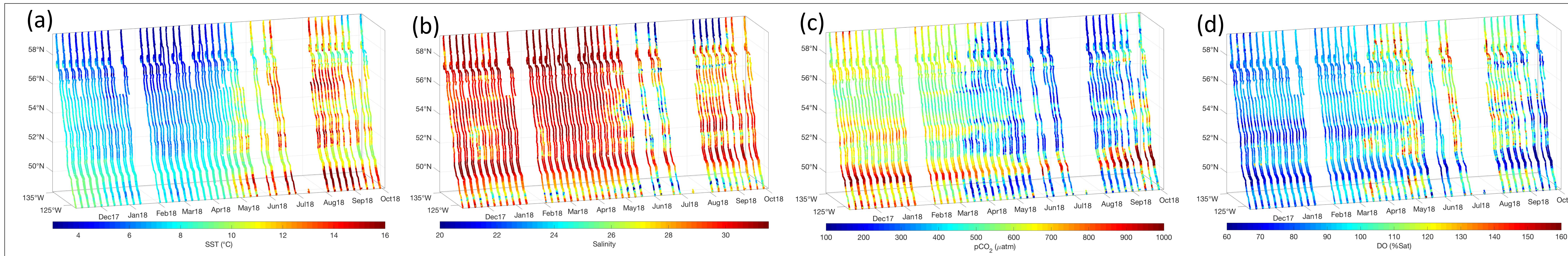


Key Points: (1) Surface seawater pCO_2, temperature, salinity, and dissolved oxygen were measured during 77 transits from Bellingham, WA to Skagway, AK between October 2017 and October 2018; **(2)** Estimates of anthropogenic CO_2 computed using these data varied widely along the transit with minima in areas heavily influenced by freshwater and maxima in regions exhibiting a high buffering capacity; **(3)** Estimated change between current and preindustrial time periods in surface seawater pH and aragonite saturation state (Ω_{arag}) varied seasonally with a larger pH decline in winter and a larger Ω_{arag} decline in summer.

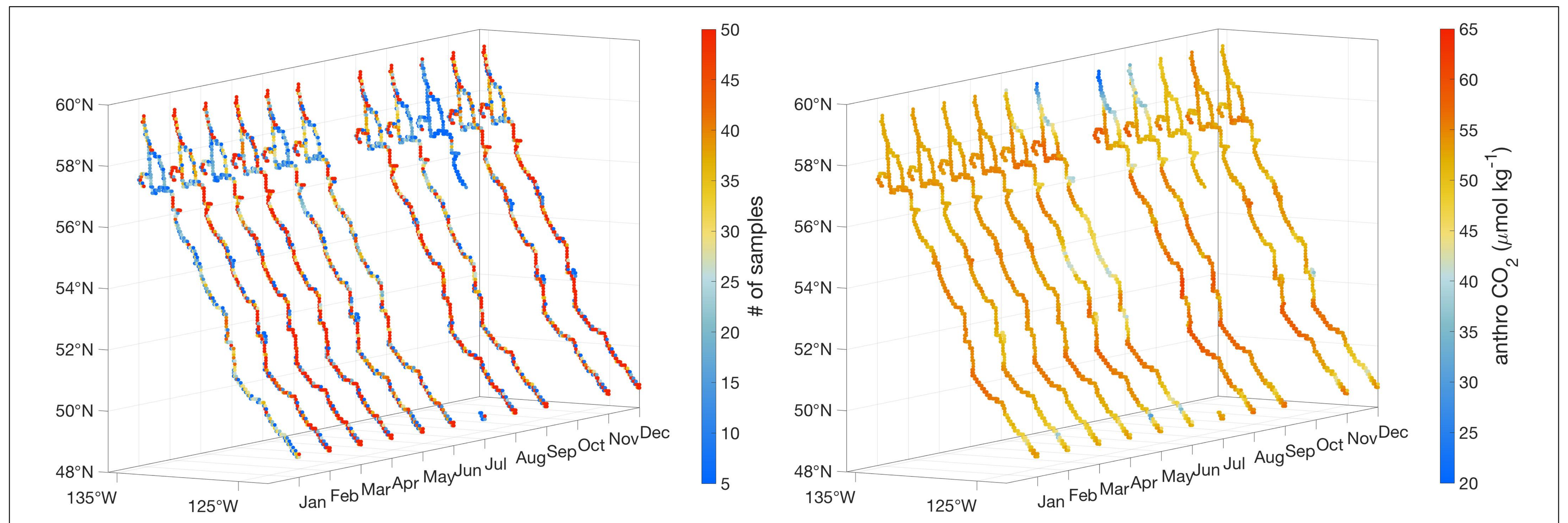
Background: During 2017, a General Oceanics 8050 pCO_2 Measuring System was installed on the the Alaska Marine Highway System (AMHS) ferry *Columbia*. This system measures surface seawater temperature, salinity, CO_2 partial pressure (pCO_2), and dissolved oxygen entering the ship through a ~3 m intake every 2.5 minutes while underway. In addition, discrete seawater samples were collected on two surveys during the first year and used to validate the continuous pCO_2 measurements along with a previously published alkalinity-salinity relationship (Evans et al., 2015). The first year of measurements have revealed dynamic seasonality in surface water across the entire transit between Bellingham, WA and Skagway, AK. Combining the validated alkalinity-salinity relationship with the direct measurements revealed a seasonally-varying mosaic of both refugia and corrosive hotspots for the biomineral aragonite.



System setup: (a) AMHS ferry *Columbia*, **(b)** seawater intake in bow thruster cavity marked by arrow, **(c)** seawater intake temperature measurement, **(d)** GO 8050 pCO_2 Measuring System on the *Columbia*'s car deck, **(e)** atmospheric intake on bow with GPS antenna.



Direct Measurements: (a) sea surface temperature (° C), **(b)** salinity (reported on PSS-78), **(c)** CO_2 partial pressure (pCO_2; μatm), and **(d)** dissolved oxygen content (percent saturation). Some areas have persistently high CO_2 due to mixing, others exhibit seasonal variability due to warming, freshwater input, and productivity.



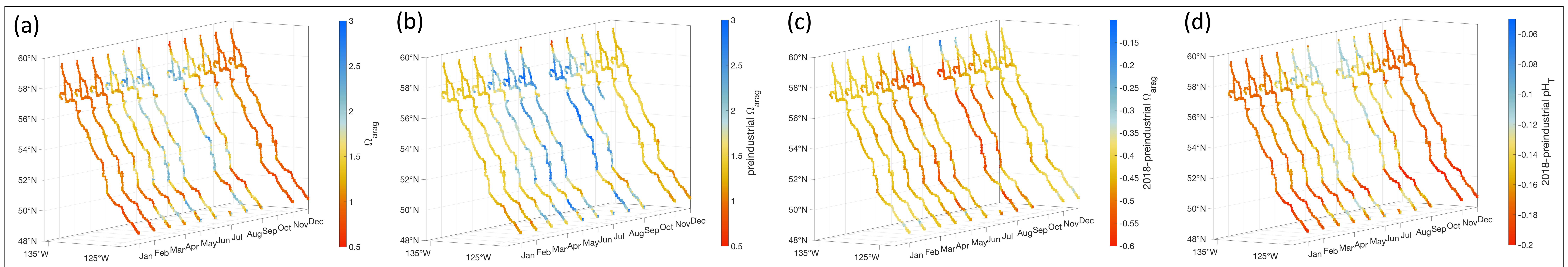
Anthropogenic CO_2 Estimations: Data were gridded on monthly 0.1° x 0.1° grids representing mean conditions for 2018. Left panel shows number of measurements for each grid cell for each month. Following the approach used in Evans et al. (2019) and references therein, anthropogenic CO_2 content was estimated in each grid cell for each month. Right panel shows anthropogenic CO_2 content in surface water varied widely between areas influenced strongly by freshwater and seawater exhibiting a high buffering capacity.

Limitation of Long-Term Assessment: Calculations assume consistency in temperature, salinity, alkalinity, and total inorganic CO_2 variance. This assumption can be violated and requires further evaluation. However, anthropogenic CO2 estimated here is in close agreement with other regional estimates (Feely et al., 2016).

Next steps: (1) data release and Earth System Science Data submission planned in coming month, **(2)** wireless real-time data relay to data portals planned in 2019, **(3)** Additional pH and nitrate sensors being added in 2019 through partnership with the Monterey Bay Aquarium Research Institute.

Acknowledgement: We thank the Tula Foundation, the Alaska Ocean Observing System, and the Alaska Coastal Rainforest Network for funding this effort, and the State of Alaska Department of Transport for providing the Columbia as a platform for ocean acidification research.

References: Evans, W., Mathis, J.T., Ramsay, J., and Hetrick, J. (2015). On the Frontline: Tracking Ocean Acidification in an Alaskan Shellfish Hatchery. *PLoS One* 10, e0130384; Evans, W., Pocock, K., Hare, A., Weekes, C., Hales, B., Jackson, J., Gurney-Smith, H., Mathis, J.T., Alin, S.R., and Feely, R.A. (2019). Marine CO2 Patterns in the Northern Salish Sea. *Frontiers in Marine Science*, doi: 10.3389/fmars.2018.00536; Feely, R.A., Alin, S.R., Carter, B., Bednarsek, N., Hales, B., Chan, F., Hill, T.M., Gaylord, B., Sanford, E., Byrne, R.H., Sabine, C.L., Greeley, D., and Juranek, L. (2016). Chemical and biological impacts of ocean acidification along the west coast of North America. *Estuarine, Coastal and Shelf Science* 183, 260-270.



Anthropogenic CO_2 Implications: (a) aragonite saturation state (Ω_{arag}), **(b)** pre-industrial Ω_{arag} (*i.e.* computed by removing anthropogenic CO_2), **(c)** 2018 – pre-industrial Ω_{arag}, **(d)** 2018 – preindustrial pH_T. Removing anthropogenic CO_2 elevates the state of widespread winter conditions with $\Omega_{arag} < 1$ that are corrosive to aragonite. The largest change in Ω_{arag} was estimated to have occurred during summer, while pH changed most during winter due to pH buffer factor conditions.