Ocean pCO_2 Variability and Drivers at the US Atlantic Coastal Pioneer Array

Alison Thorson[1], Dr. Rachel Eveleth[2]
[1]Sarah Lawrence College, Bronxville, NY
[2]Department of Geology, Oberlin College, Oberlin, Ohio

Introduction

- The ocean plays an important role in the global carbon cycle by taking up and releasing significant amounts of CO_2 each year.
- Characterizing oceanic and atmospheric CO_2 exchange is therefore vital for studying climate change and ocean acidification, but the magnitude, sign, and drivers of this flux vary seasonally and spatially.
- Past studies have characterized the Northwest Atlantic as a sink driven by biological and thermal factors (Fennel et al. 2019, Lauderdale et al. 2016, and Takahashi et al. 2002).
- The objective of this research is to characterize local seasonal and interannual cycles of pCO_2 exchange and its drivers, the spatial and temporal variation, and to identify the extent to which the northern US Atlantic continental shelf is a net carbon source or sink.

Methods

OOI 2020.

- This study takes data from three surface moorings (Inshore, Central, and Offshore) along the Atlantic continental shelf within the Ocean Observatories Initiative Pioneer Array from 2016 and 2017.
- Telemetered data is collected from pCO_2, meteorological, and fluorometer instruments.
- OOI flagged data and outliers outside of 3 standard deviations were removed from the dataset before averaging and plotting.

Calculations

pCO_2 Flux Calculation

$$\text{flux} = k * K0 * (\text{pco2w} - \text{pco2a})$$

Where k = gas transfer velocity and K0 = solubility coefficient.

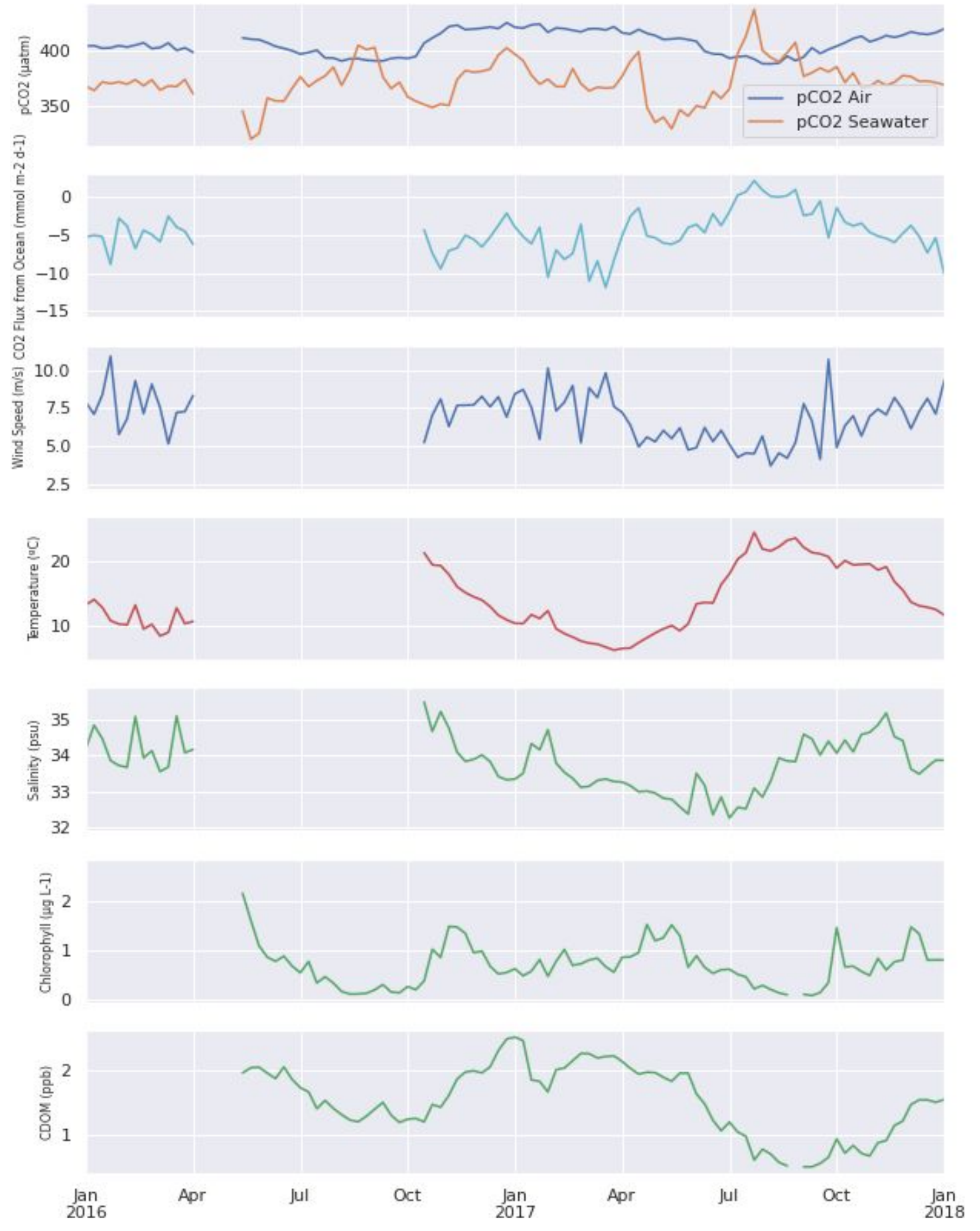
Takahashi Decomposition Calculation

$$(pCO_2 \text{ at } T_{mean}) = (pCO_2)_{obs} \exp[0.0423(T_{mean} - T_{obs})]$$

$$(pCO_2 \text{ at } T_{obs}) = (\text{Mean annual } pCO_2) \exp[0.0423(T_{obs} - T_{mean})]$$

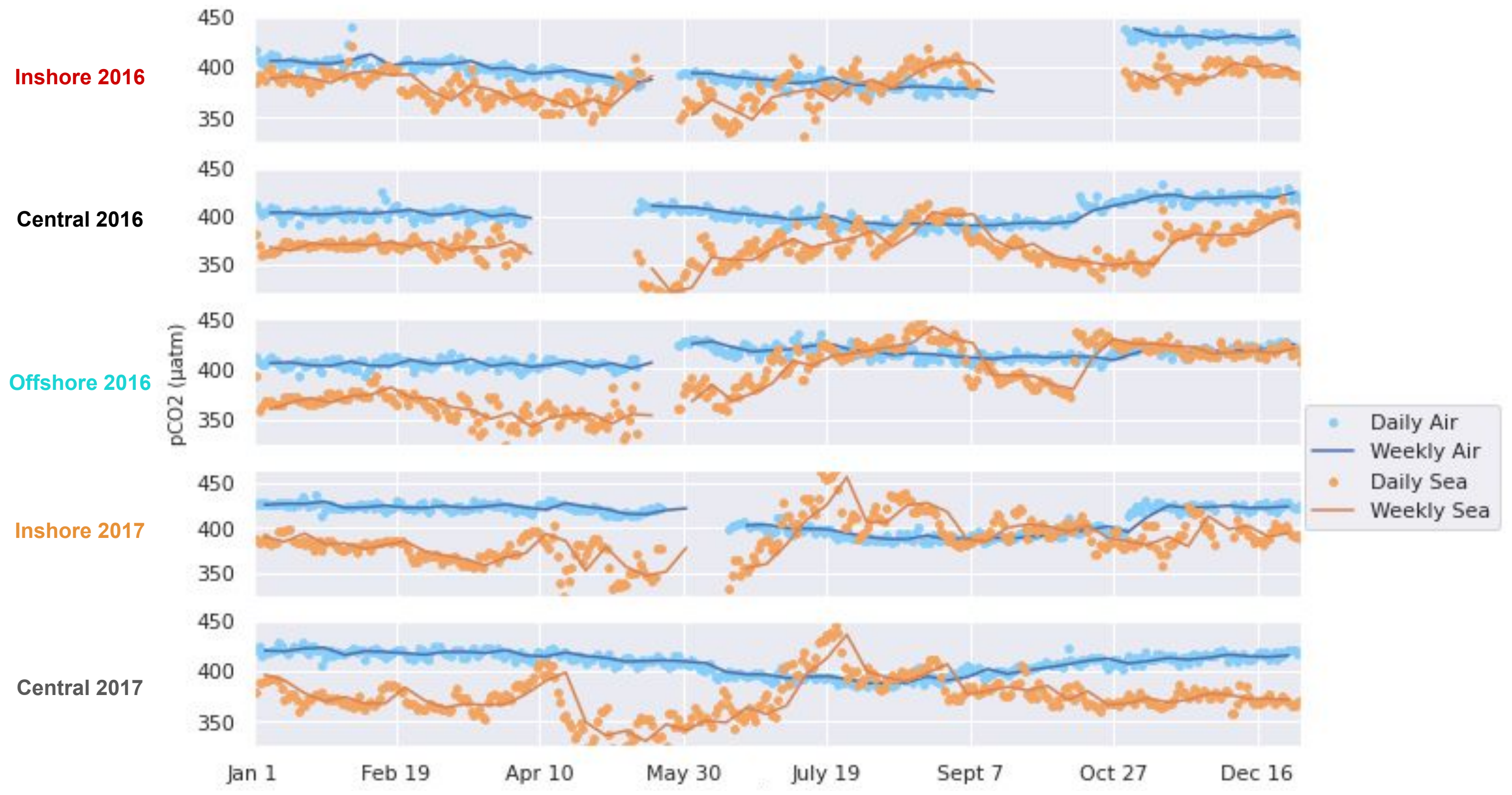
Where T = temperature, obs = observed, and 0.0423 = temperature effect on pCO_2 for isochemical seawater.

Results



1. Seasonal and Interannual Cycles

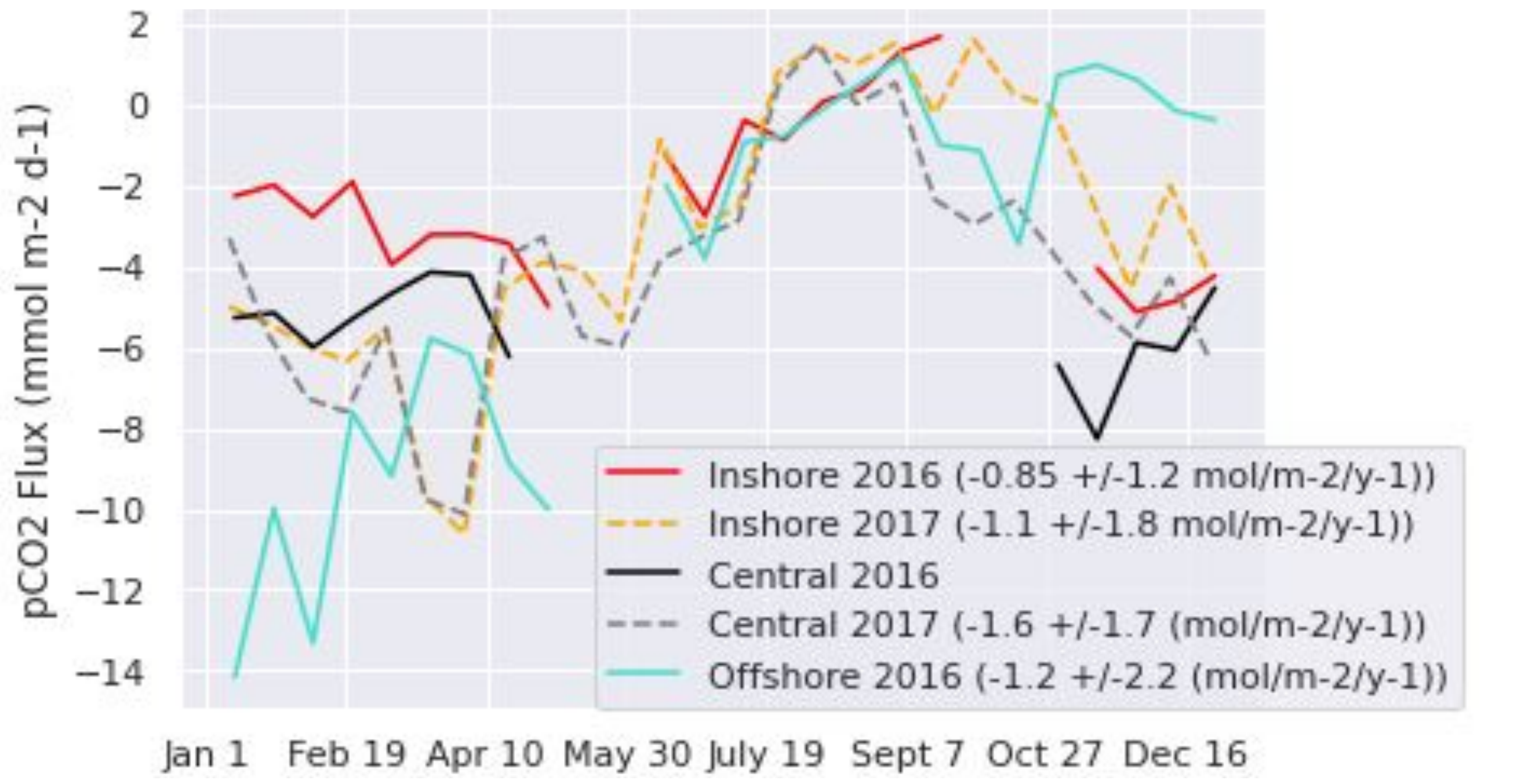
This plot shows 1 week averages of the Central mooring 2016/17 cycles, which show very similar patterns to the other two moorings. Temperature highs and chlorophyll/CDOM lows correspond to positive flux from the ocean in July-September. Atmospheric pCO_2 shows a slight drop in the summer and rise in the winter, due to less photosynthesis on land in the winter. Since temperature and biological activity follow relatively strong seasonal cycles, we would expect to see a stronger corresponding oceanic pCO_2 and flux cycle. However, it is not prominent, so it is important to investigate the drivers of this cycle.



2. Seasonal, Interannual, and Geographic pCO_2 Variability

Spring and summer at the Pioneer Array show slightly more oceanic pCO_2 variability than fall and winter, however the seasonal variance is much less drastic than in other regions (such as recorded at the Endurance Array). July 2017 sees a sharper drop in pCO_2 in the spring and a higher spike in oceanic pCO_2 than in 2016, possibly due to a larger or longer lasting phytoplankton bloom in the spring that led to more primary productivity and then more decomposition.

Despite all the moorings following similar annual trends, there is slight geographic variability between moorings. Central shows a greater drop in oceanic pCO_2 than for Inshore or Offshore, in May of both 2016 and 2017, and a smaller rise above atmospheric pCO_2 in August 2016 and 17. This could be due to the fact that shelf waters have more phytoplankton productivity and cooler waters than the shelf slope, causing lower pCO_2 levels. However we would expect the Inshore mooring to show lower pCO_2 levels, but it is more closely aligned with Offshore.



3. Seasonal, Interannual, and Geographic CO_2 Flux Variability

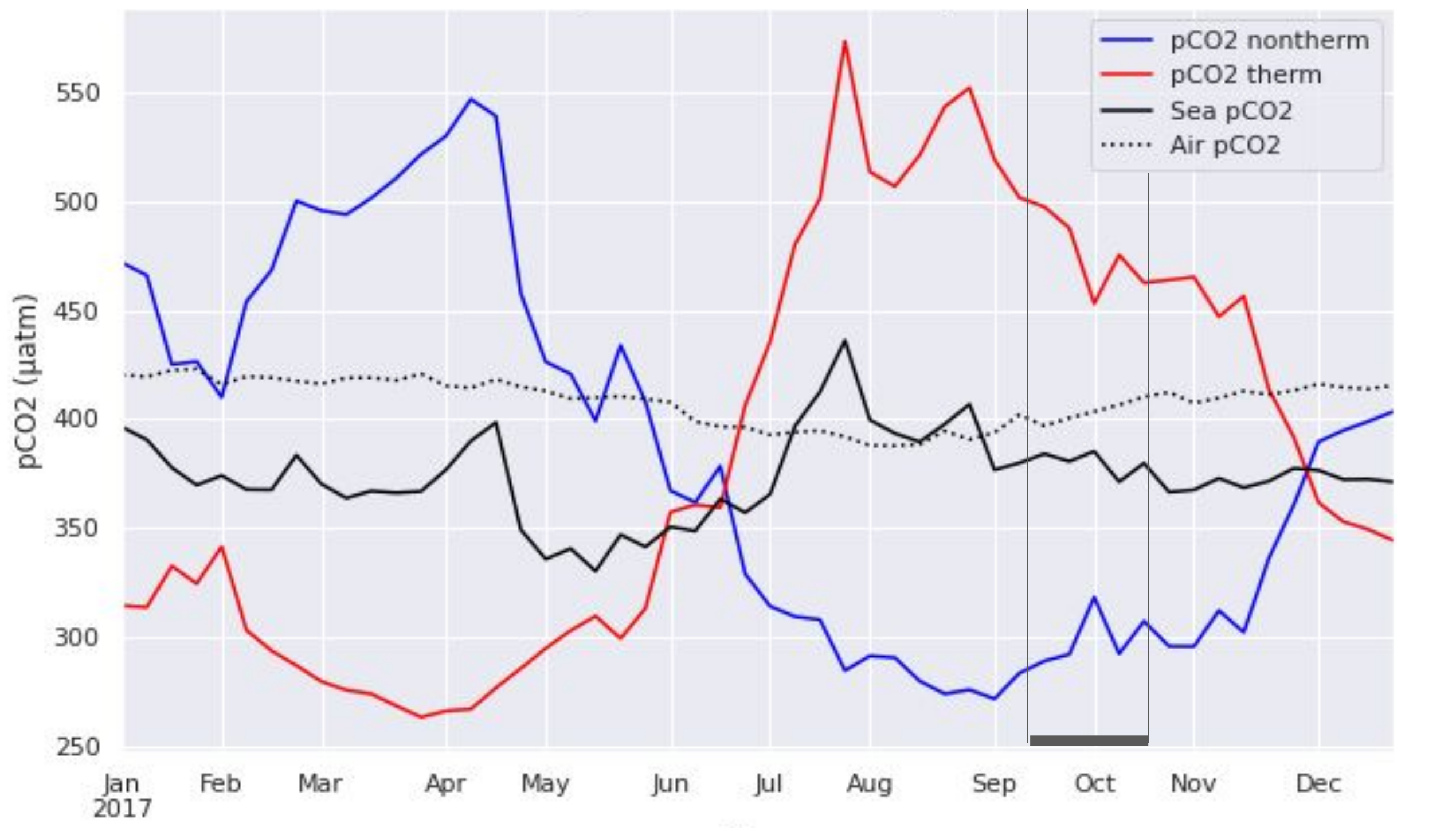
The 2 week flux averages are plotted by year and station, and the total annual flux is calculated. (Negative sign indicates flux into the ocean.) The net annual flux across all stations and years is negative, meaning the US north Atlantic continental shelf acts as a carbon sink. There is surprising variation in flux between moorings and years. In January 2016 there is a difference of 4 mmol m^{-2} d^{-1} from Inshore to Central, and another 7 mmol m^{-2} d^{-1} from Central to Offshore. The drivers behind this variability are unexplored as of now.

There is greater variability between the stations and years in the winter and fall, while from May to September the fluxes are more uniform. Interestingly, this is opposite the greater oceanic pCO_2 variation in spring and summer.

4. Thermal vs. Non-thermal pCO_2 Drivers

The observed atmospheric and oceanic pCO_2 for Central 2017 (1 week averages) are shown here as a representative example of the other moorings and years. Colored lines show the results of the Takahashi et al. (2002) decomposition equation. The thermal (red) line shows expected pCO_2 values if they were only subjected to temperature changes. The non-thermal (blue) line represents expected pCO_2 values when temperature is held at its annual mean, so only nonthermal effects can be observed.

The actual observed oceanic pCO_2 (solid black) line more closely follows the thermal line, notably only becoming a sink when the thermal line spikes in June and July. However, the non-thermal line seems to dampen the effect by working in the inverse direction. It is clear that the drawdown in observed pCO_2 in April is the result of the corresponding nonthermal drop, likely caused by spring blooms. The cycle is temperature dominated but mediated by opposing biological effects. (The black bar indicates a time period where drivers will be explored more closely in section 6.)

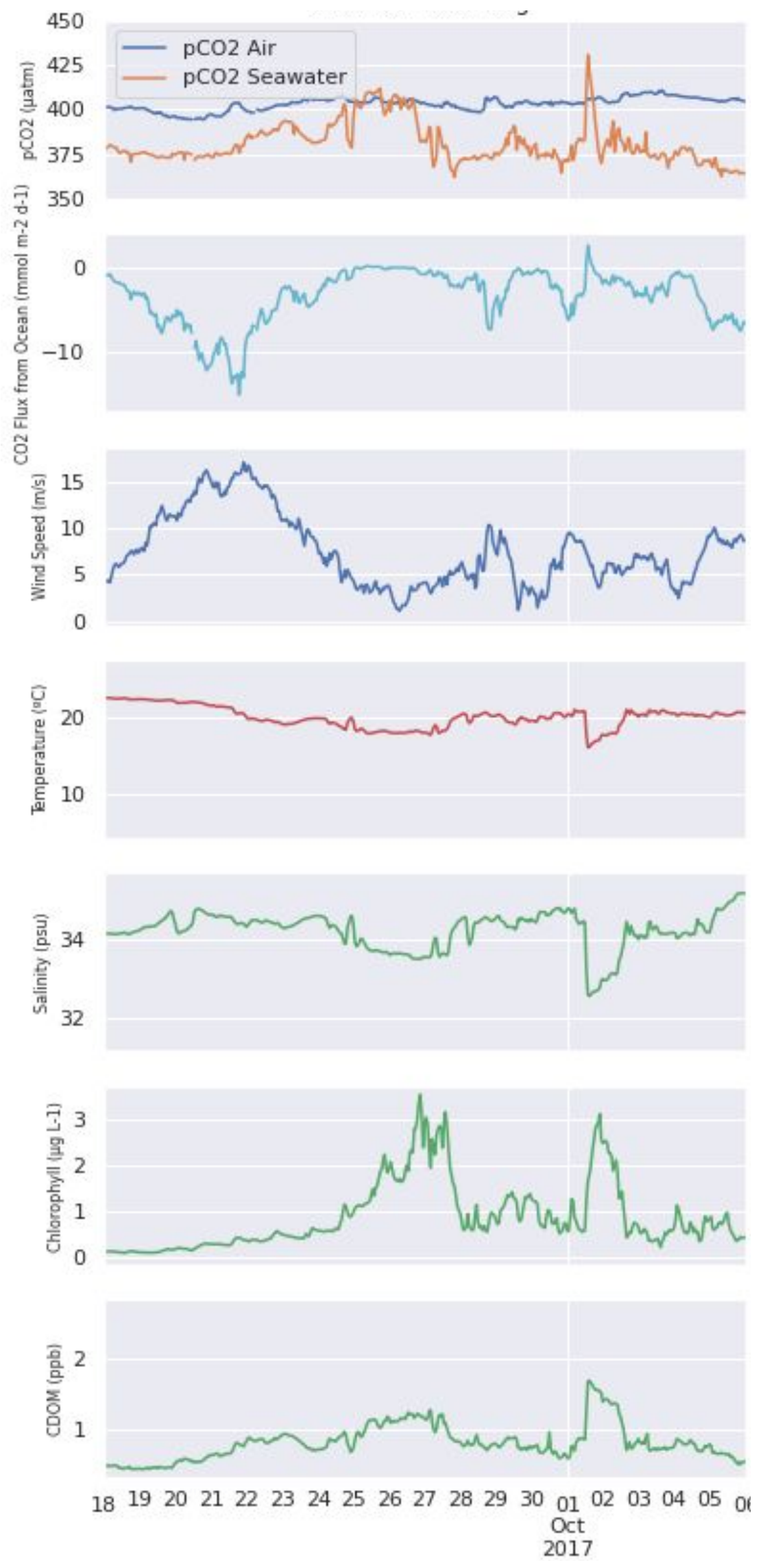


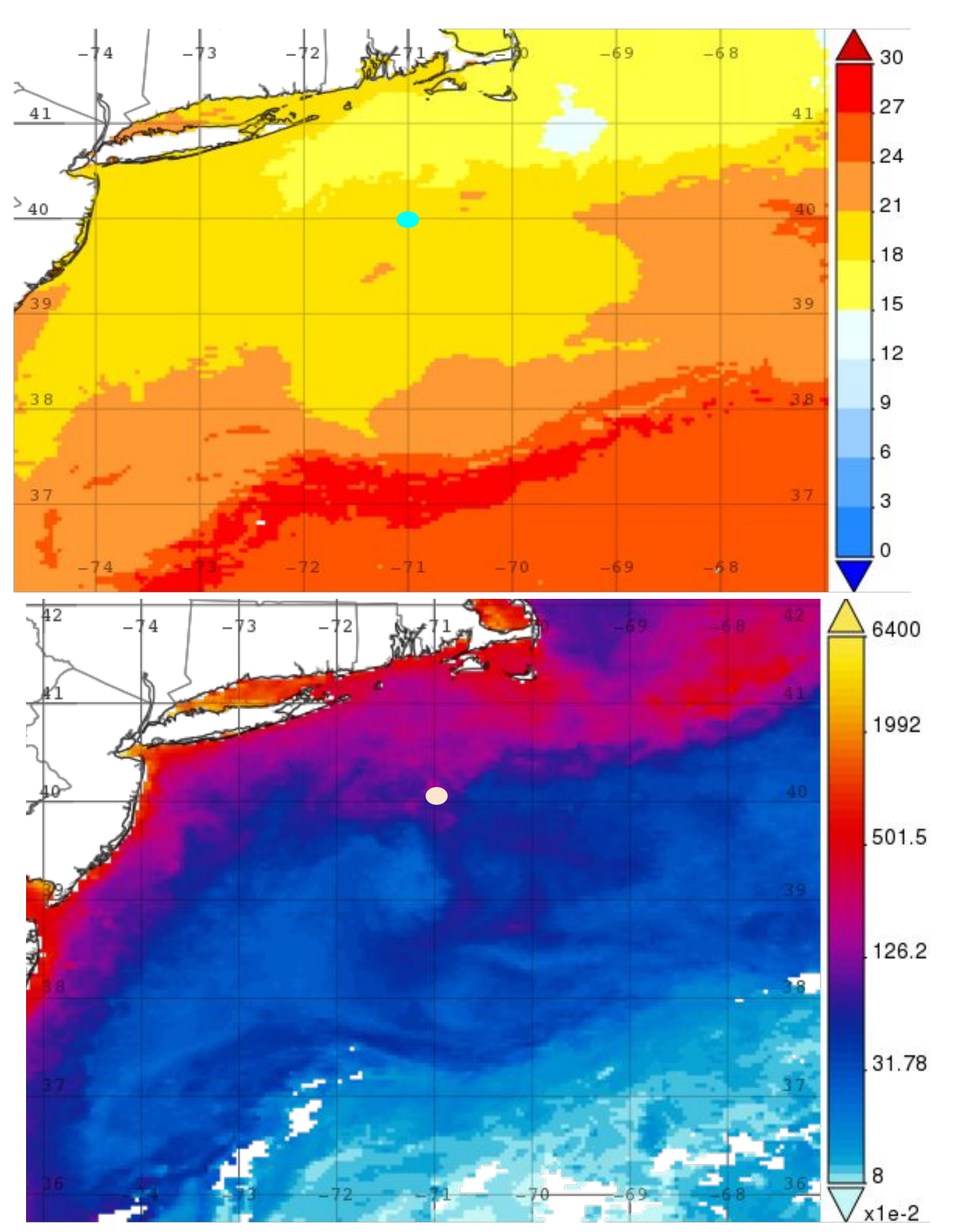
5. Small Scale Event Drivers

This plot shows multiple events in September and October of 2017 at the Central mooring, using 1 hour averages. An increase in wind speed around September 21st, 2017 corresponds to increased flux of CO_2 into the ocean and we consequently observe a slight increase in oceanic pCO_2 in the days that follow.

In late September a spike in Chlorophyll and CDOM (around the 27th) corresponds to a drop in oceanic pCO2 by ~40 µatm, possibly indicating the presence of an eddy. The spike in pCO_2 and primary productivity around October 3rd could be a cold core ring with a bloom passing through, or vertically mixing from deeper currents. Similar spikes can be slightly seen at the Inshore mooring.

This is in line with the temperature driven but biologically dampened seasonal cycle seen in the Takahashi Decomposition plot. The corresponding time marked by the black bar shows a biologically driven decrease in pCO_2 and later a thermally driven increase. The US coastal Atlantic is known to have year long variability due to eddies from the gulf stream.





NASA Giovanni images showing temperature (top) and chlorophyll a concentration (bottom) around the Pioneer array (green and beige dots). Both are an 8 day average around September 30th. A cool spot seems to be drifting towards the mooring along with increased chlorophyll concentration around this time.

Summary and Conclusions

- The Northwest Atlantic acts annually as a strong sink for atmospheric carbon, only acting as a minor source in the late summer; the **annual average flux is -0.85 to -1.6 mol m^{-2} y^{-1}** from across the three moorings and two years.
- **pCO_2 flux varied** by as much as **12 mmol m^{-2} d^{-1} between stations** and **7 mmol m^{-2} d^{-1} between years**. Generalization of this dataset to other locations and time periods may hide distinct cycles or variation.
- Preliminary regression plots that show correlation between pCO_2, sea surface temperatures, and chlorophyll are further supported by Takahashi decomposition plots which show that pCO_2 variation is highly temperature driven, and somewhat dampened by nonthermal (likely biological) processes.
- This study gives new insight into variation in flux and pCO_2 between stations and years, along with reporting annual flux values and relative contributions of different drivers that are in line with previous studies.
- Long term data collection and further quality control through the Ocean Observatories Initiative will allow research to progress on the effects of climate change and ocean acidification in this area.

Acknowledgements: Special thanks to Sage Lichtenwalner, Christine Bean, and Janice McDonnell. This research is funded by the NSF (*Grant No. OCE-183162*).

References:

1. Evans, W, B Hales, and PG Strutton. 2011. Seasonal cycle of surface ocean pCO2 on the Oregon shelf. Journal of Geophysical Research 116(C05012), doi:10.1029/2010JC006625.
2. Fennel, K, S Alin, L Barbero, W Evans, T Bourgeois, S Cooley, J Dunne, RA Feely, JM Hernandez-Ayon, X Hu, S Lohrenz, F Muller-Karger, R Najjar, L Robbins, E Shadwick, S Siedlecki, N Steiner, A Sutton, D Turk, P Vlahos, and ZA Wang. 2019. Carbon cycling in the North American coastal ocean: a synthesis. Biogeosciences 16:1281-1304.
3. Lauderdale, JM, S Dutkiewicz, RG Williams, and MJ Follows. 2016. Quantifying the drivers of ocean-atmosphere CO2 fluxes. Global Biogeochemical Cycles 30:983–999, doi:10.1002/2016GB005400.
4. Takahashi, T, SC Sutherland, C Sweeney, A Poisson, N Metzl, B Tilbrook, N Bates, R Wanninkhof, RA Feely, C Sabine, J Olafsson, and Y Nojiri. 2002. Global sea–air CO2 flux based on climatological surface ocean *p*CO2, and seasonal biological and temperature effects. Deep Sea Research Part II: Topical Studies in Oceanography 49(9-10):1601-1622.

Contact: Alison Thorson
athorson@gm.slc.edu