Direct wintertime pCO_2 observations from the Saildrone Gulf Stream Mission

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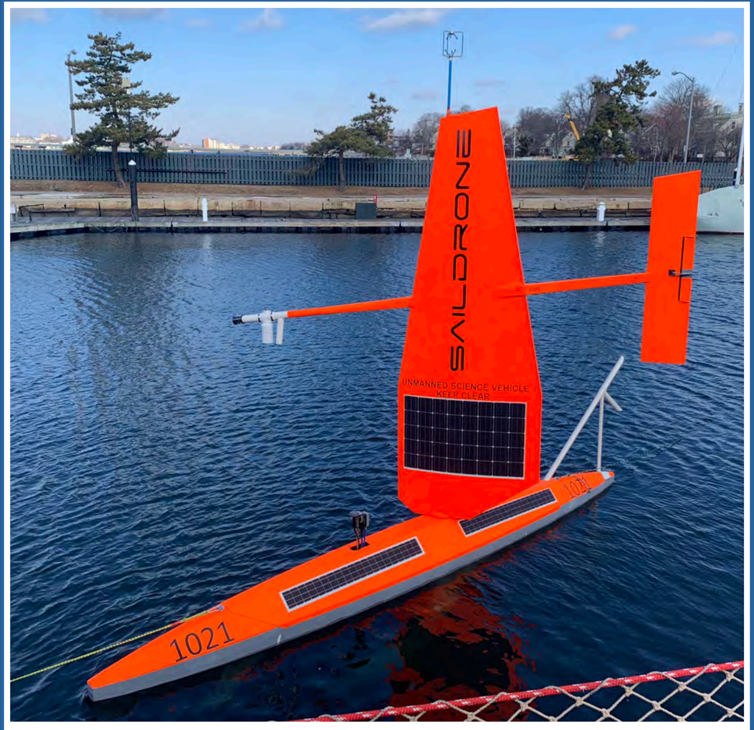

Figure 1. Saildrone at the Newport Shipyard for launch event on January 30th, 2019.

Introduction

Western boundary currents, such as the Gulf Stream, are thought to be hot spots of ocean carbon dioxide uptake. In these regions, the maximum CO_2 flux occurs in wintertime, when in-situ observations are most sparse due to intense weather conditions that challenge sampling from ships. Moreover, the short spatial and temporal scales of variability require dense sampling to resolve the influence of the currents on gas exchange. We show the capability of an Autonomous Surface Vehicle (ASV), called Saildrone, for collecting transformative measurements in the Gulf Stream region during a February 2019 deployment. The Saildrone is a high-endurance (>3 months), fast moving (1-8 knots) ASV that carries a large payload of meteorological and oceanographic sensors. For our deployment, it was equipped with the PMEL-designed ASVCO2 system, which measures pCO_2 in both the atmosphere and the ocean with climate-quality (2 μatm) accuracy using 2-point calibrations before every measurement. With pCO_2, sea surface temperature, salinity, and near-surface wind measurements, we calculate CO_2 fluxes in the cold, nutrient rich Slope Sea, across the Gulf Stream, and into the warm, nutrient poor Sargasso Sea during active convection. On our planned 30-day mission, Saildrone collected 18 days of pCO_2 data as it completed five crossings of the Gulf Stream before 7 m waves caused a leak in the ASVCO2 system.

We hypothesize that the ΔpCO_2 in existing climatologies may be biased because of chronic under-sampling in winter, when heat loss drives a strong increase in oceanic CO_2 solubility, and vertical nutrient fluxes stimulate enhanced phytoplankton productivity.

Motivation

The Landschutzer (2013) and Takahashi (2009) climatologies are based on observations from the SOCAT and LDEO databases, respectively, which have sparse wintertime observations. This may lead to a bias in the estimates of ΔpCO_2 and CO_2 flux, especially in under-sampled western boundary current regions like the Gulf Stream.

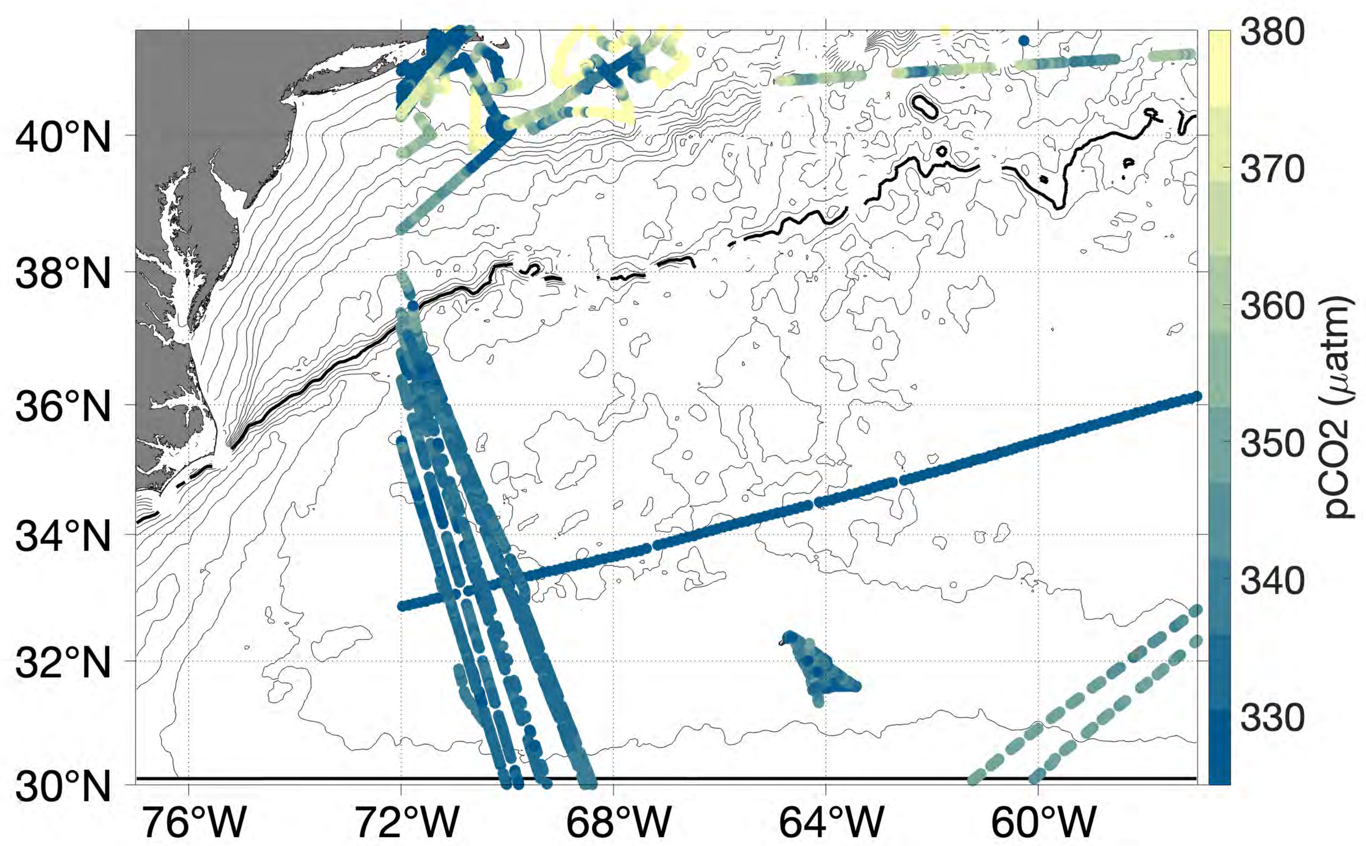

Figure 2. February ocean pCO_2 observations from the SOCAT and LDEO databases. The long term February SST average is contoured at one degree intervals with the 18 °C isotherm in bold.

Saildrone-enabled observations of wintertime oceanic and atmospheric pCO_2 may lead to an upward revision of western boundary current CO_2 uptake

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A crossing of the Gulf Stream

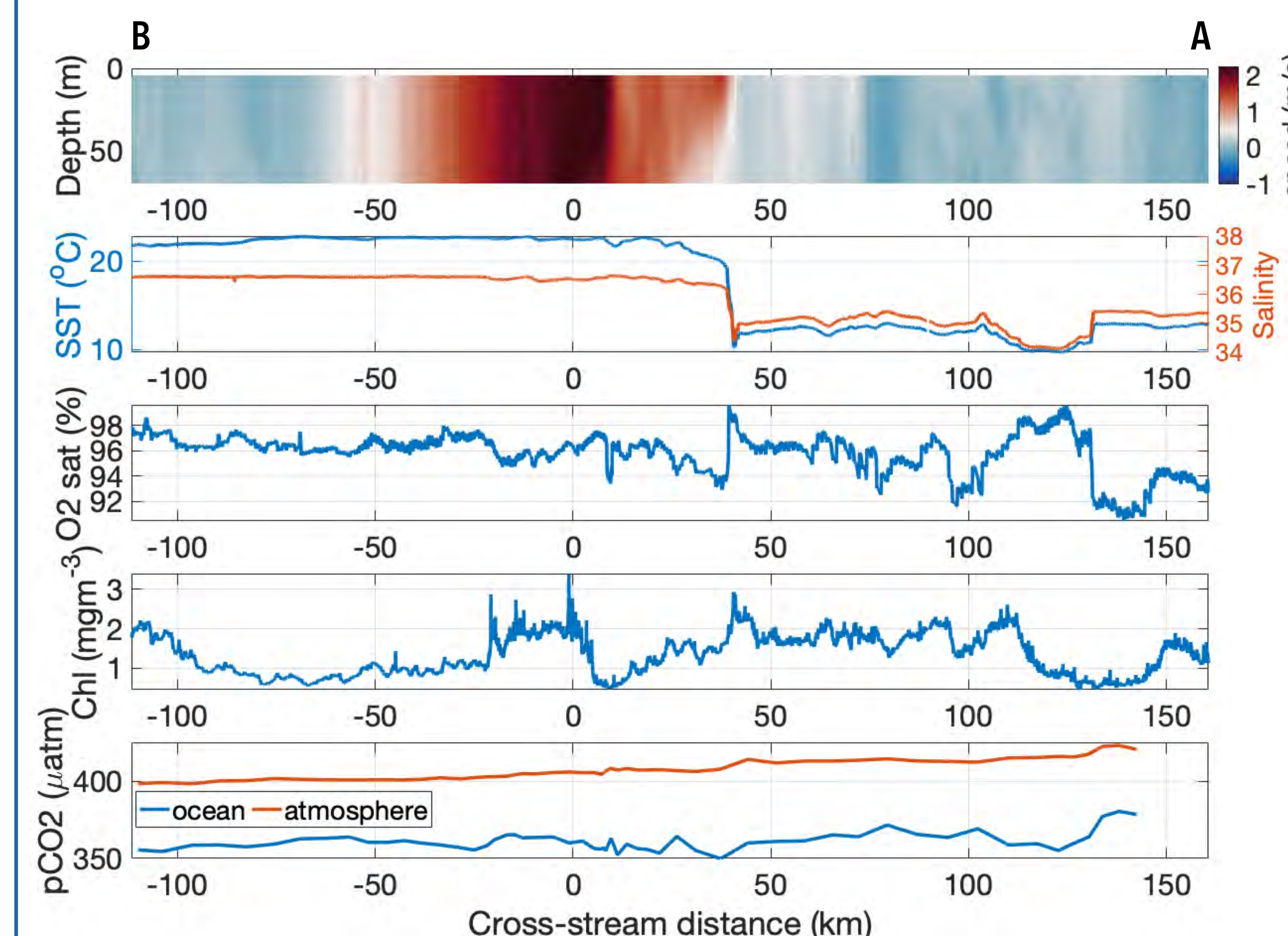
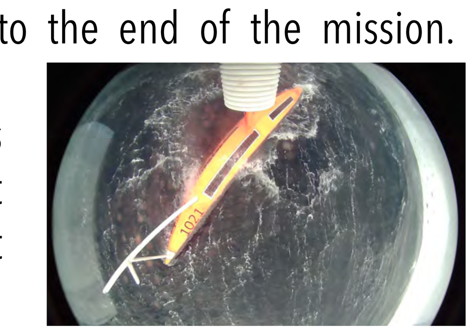
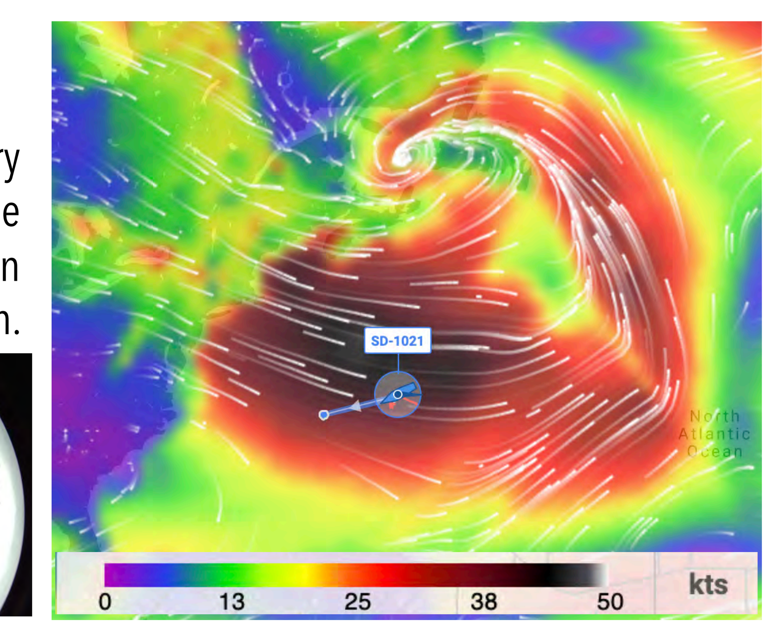


Figure 4. Saildrone's first crossing of the Gulf Stream at 70.5 °W. The top panel shows the along-stream velocity in stream coordinates (Halkin and Rossby, 1985) with the US East Coast on the right and the Sargasso Sea on the left. All variables are plotted versus cross-Gulf Stream distance, where the origin is at the position of the maximum depth-averaged velocity and distances are calculated normal to the velocity vector at that maximum.

The final storm

Saildrone encountered storms about every four days throughout the mission but the intensity and persistence of the final one on 2/26/2019 led to the end of the mission. Winds reached a roaring 46 kts and significant wave height reached 12.6 m.





Comparison to climatology

The average ΔpCO_2 measured during the Saildrone Mission in the Gulf Stream region is **-51 μatm** and in the subtropical interior is **-48 μatm**.

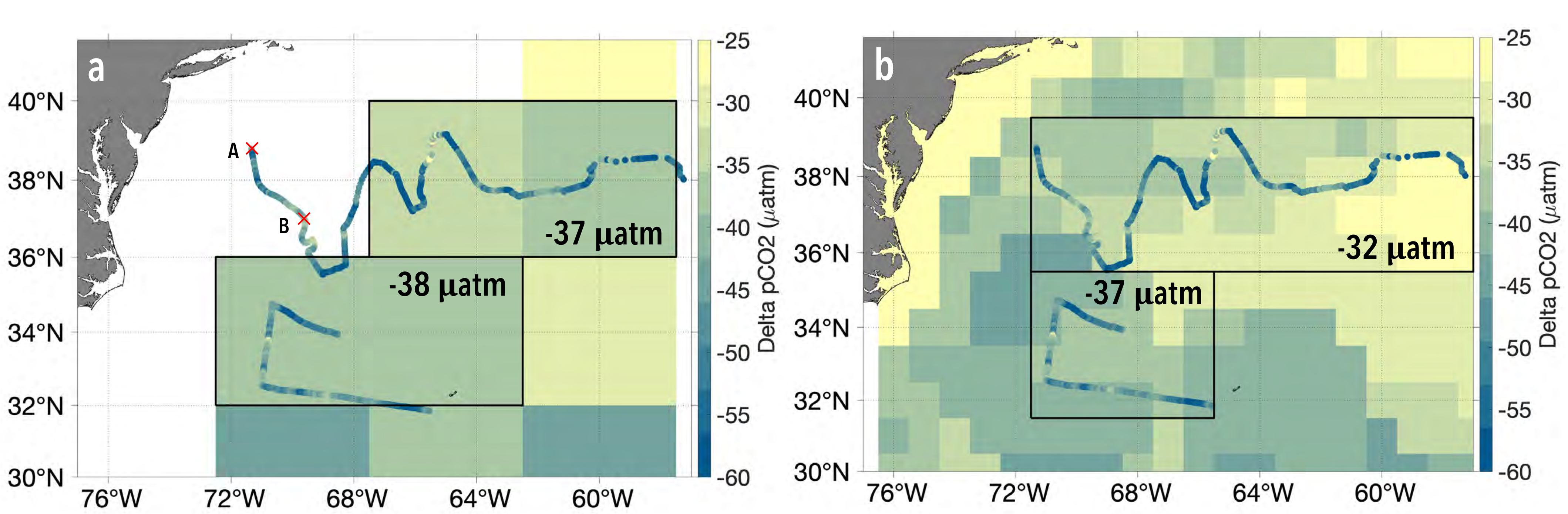


Figure 3. a) Takahashi (2009) climatology of ΔpCO_2 ($pCO_2^{ocean} - pCO_2^{atm}$) with ΔpCO_2 calculated from Saildrone and Endeavor. The boxed region indicates the area in which the average ΔpCO_2 was calculated, shown in black. Red X's indicate start (A) and end (B) points for the first Gulf Stream crossing shown in Figure 4. b) same as a) but for the Landschutzer (2013) climatology.

Conclusions & future work

- ASVs, such as Saildrone, can be utilized to increase the spatial coverage of pCO_2 observations under intense weather conditions.
- Measurements from the Saildrone Mission show ΔpCO_2 values larger than existing climatological estimates of the Gulf Stream region, suggesting a **38% increase** from the February Takahashi (2009) climatology and a **59% increase** from that of the Landschutzer (2013) climatology. These findings may lead to an upward revision of the climatological CO_2 fluxes.
- Measurements from the Endeavor cruise show ΔpCO_2 values larger than existing climatological estimates of the subtropical interior, suggesting a **26% increase** from the February Takahashi (2009) climatology and a **30% increase** from that of the Landschutzer (2013) climatology. The subtropical interior appears to be better represented in the climatological estimates, potentially as a result of a larger number of measurements due to routine BATS cruises.
- The Gulf Stream thermal north wall is offset from the depth-averaged velocity maximum by 40 km. At this location, there are sharp gradients in O_2 % saturation and chlorophyll that are not apparent in hourly oceanic pCO_2 observations.
- During the Saildrone mission, atmospheric pCO_2 varied by 22 μatm, oceanic pCO_2 by 43 μatm and ΔpCO_2 by 46 μatm.

- With the likely recovery of 10-minute pH data, we will be able to resolve sharp gradients such as the thermal north wall.
- The five crossings of the Gulf Stream will allow us to assess changes in each variable as the Saildrone traveled downstream.
- These observations will enable us to explore the relationship between heat and CO_2 fluxes in the Gulf Stream region.
- Saildrone observations will aid in the understanding of temperature and alkalinity controls on the DIC concentration at the ocean surface.