# How are synoptic scale wind bursts impacting the $FCO_2$ through the $\Delta pCO_2$ in the sub-Antarctic Southern Ocean.

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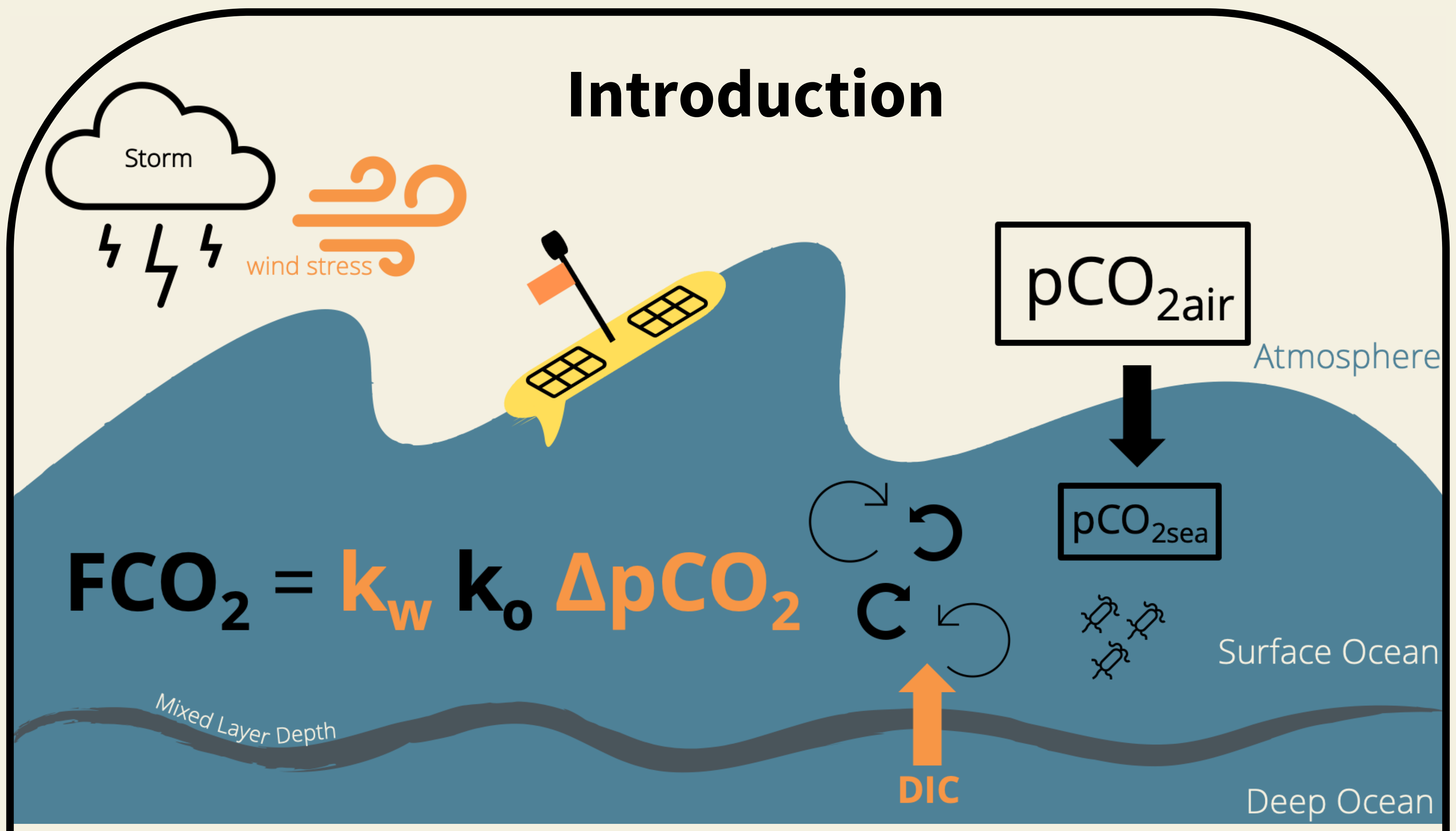
## Introduction



$$FCO_2 = k_w\, k_o\, \Delta pCO_2$$

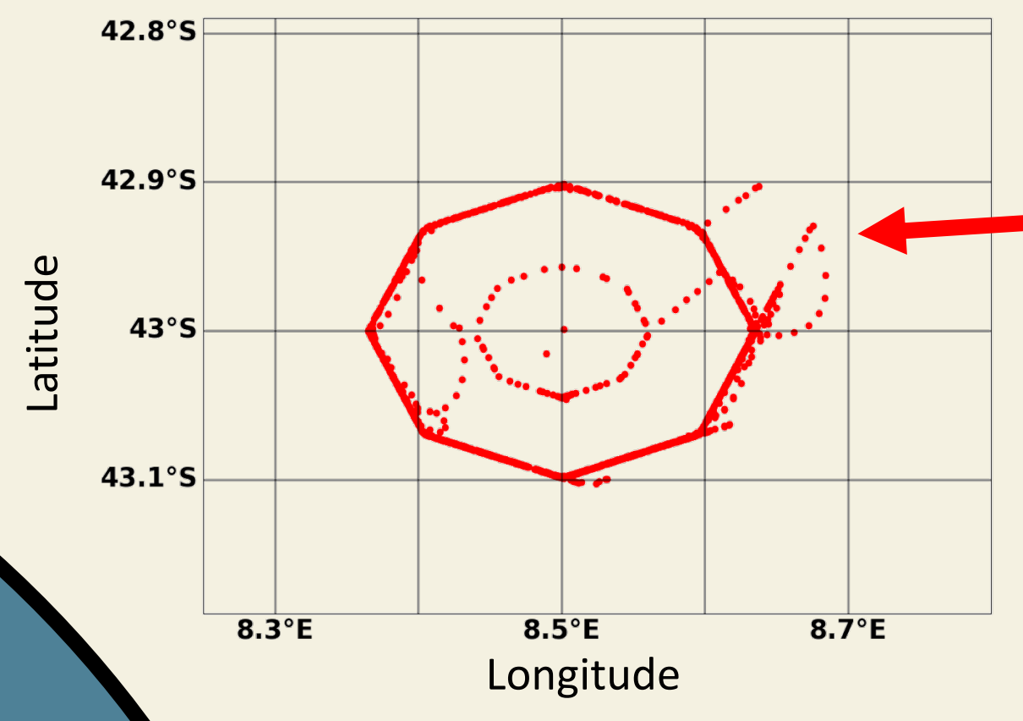
- The process of air-sea $CO_2$ flux ($FCO_2$) is governed by a bulk formulation which constitute of the wind driven gas transfer velocity ($k_w$), the solubility constant ($k_o$) and the gradient between the partial pressure of $CO_2$ in the ocean and in the atmosphere ($\Delta pCO_2$).
- The $\mathbf{K_w}$, calculated here using a quadratic parameterization (Wanninkhof, 2014), is governed by complex boundary layer processes which are largely controlled by the **wind speed**. In high wind speed regime, such as in the sub-Antarctic Zone (SAZ), strong surface ocean turbulence occurs which encourages bubble entrainment causing $K_w$ to have a strong impact on the magnitude of $FCO_2$.
- The $K_o$ varies with the temperature and salinity of seawater and is calculated using an integrated van't Hoff formula (Weiss, 1974).
- In the SAZ, the $pCO_{2sea}$ is smaller than the $pCO_{2air}$ leading to a negative $\Delta pCO_2$ (ingassing) throughout the year, which intensifies in summer and weakens in winter.

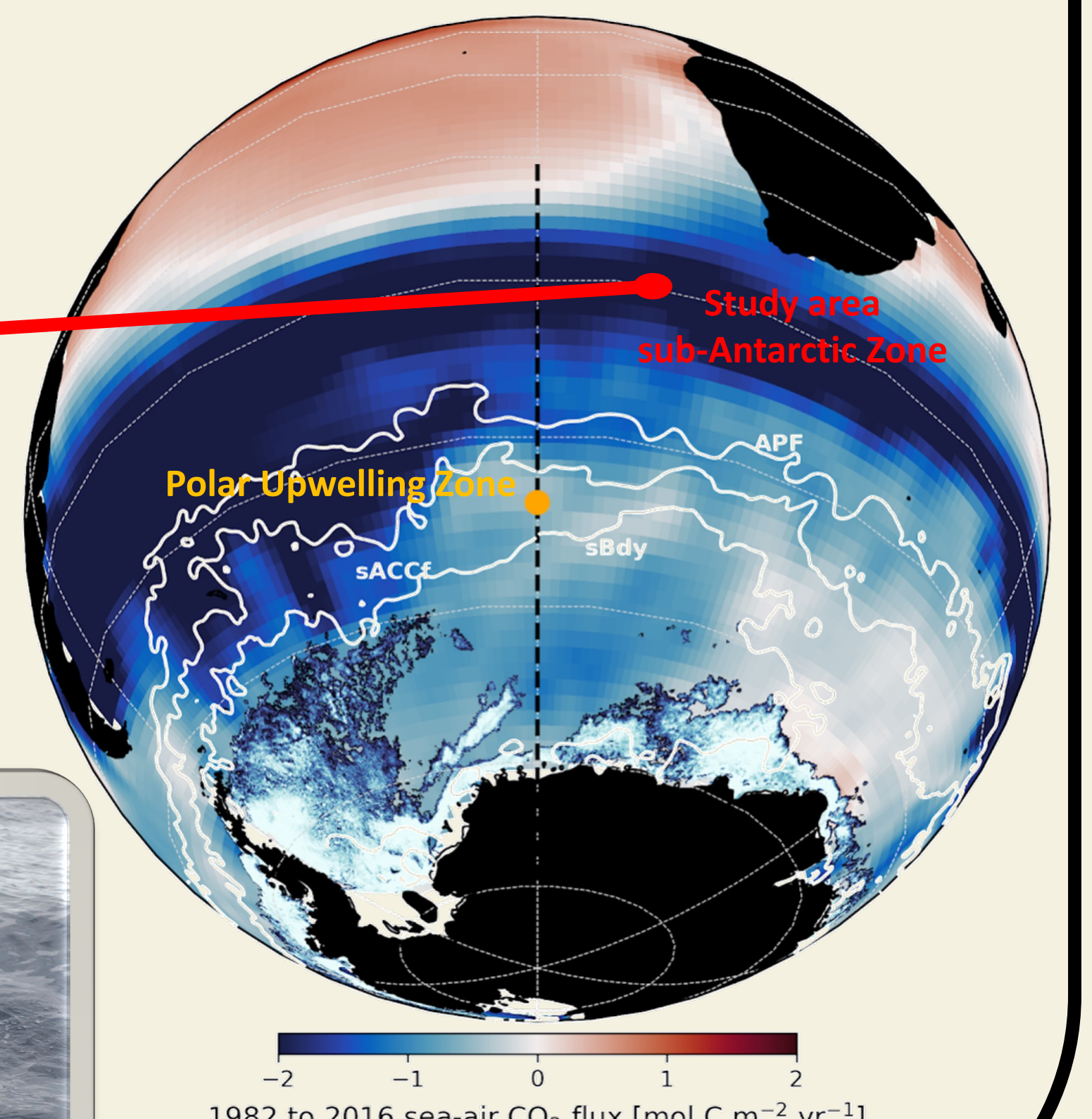
## Rationale and Objectives

- In the SAZ, frequent storm events (4-10 days) induce short but strong wind stress over the surface ocean. These strong winds increase the magnitude of the $FCO_2$ through the $K_w$ but it is not well understood, nor observed, how $\Delta pCO_2$ responds to those storms. These synoptic scale variability in $\Delta pCO_2$ are thus not resolved in Global and Earth systems models.
- In this study, we aim to show that in the SAZ, **strong wind stress associated with storms impact the magnitude of the $FCO_2$ through both the $K_w$ and $\Delta pCO_2$ instead of the $K_w$ only.**
- This would lead to a suppression of the $FCO_2$ when the impact of the wind is accounted for in the $\Delta pCO_2$ showing that the bulk flux formula may not be robust enough to account for high frequency variability in the $\Delta pCO_2$.

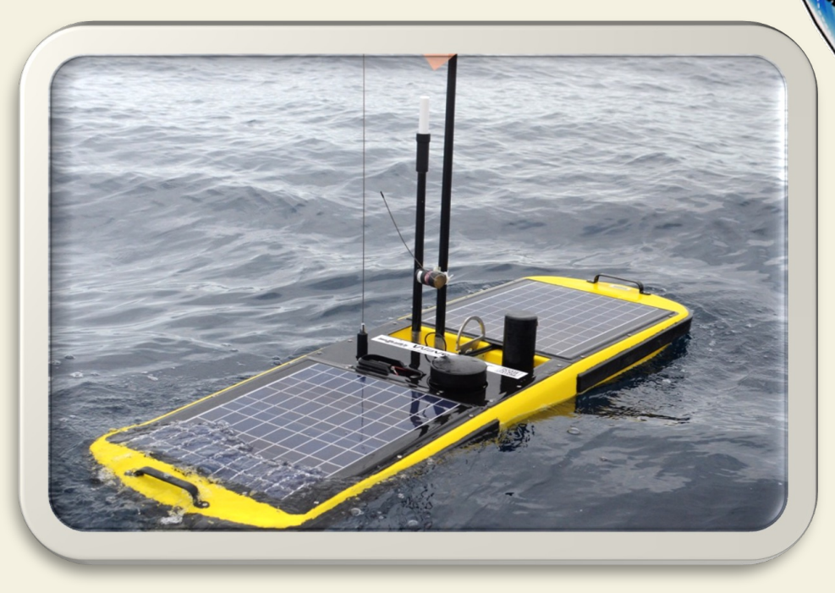
## Data

- High-resolution Wave Glider observation from the third Southern Ocean Seasonal Cycle Experiment (SOSCEx-III) was used in this study.
- **Study period:** 14th August 2015 to 8th February 2016
- **Temporal resolution**: Hourly
- **Pseudo-mooring sampling pattern:**





(Gregor et al. 2019)



## Conclusions

Wind burst associated with storm events in the SAZ during late-winter and spring led to a brief **weakening** of the **$\Delta pCO_2$** which caused **$FCO_2$ ingassing** to **weaken despite** the **high wind stress** during each event**.**

Summer storm events showed both a **weakening** and **enhancing $\Delta pCO_2$** pattern for each wind burst which led to the respective **weakening** and **enhancement** of the **$FCO_2$ ingassing** linked with **high wind stress**.

## Results and Discussion

### How is the $\Delta pCO_2$ responding to each wind burst event?

- A total of **22** storm events were identified for the study period, out of which **3** occurred in Winter, **8** in Spring and **11** in Summer.
- The response of the $\Delta pCO_2$ to each storm event in Winter, Spring and 7 out of 11 Summer events showed the rapid **weakening of the $\Delta pCO_2$** with varying magnitude (Figs. 1-4d).
  - This weakening is likely due to the entrainment of DIC caused by a deepening of the mixed layer depth from storm momentum dissipation.
- 4 out of 11 storms events in Summer however showed the opposite pattern whereby an **increase in the $\Delta pCO_2$** was observed during a wind burst.
  - We speculate that this increase could be due to the simultaneous consumption of DIC by the biology during entrainment.

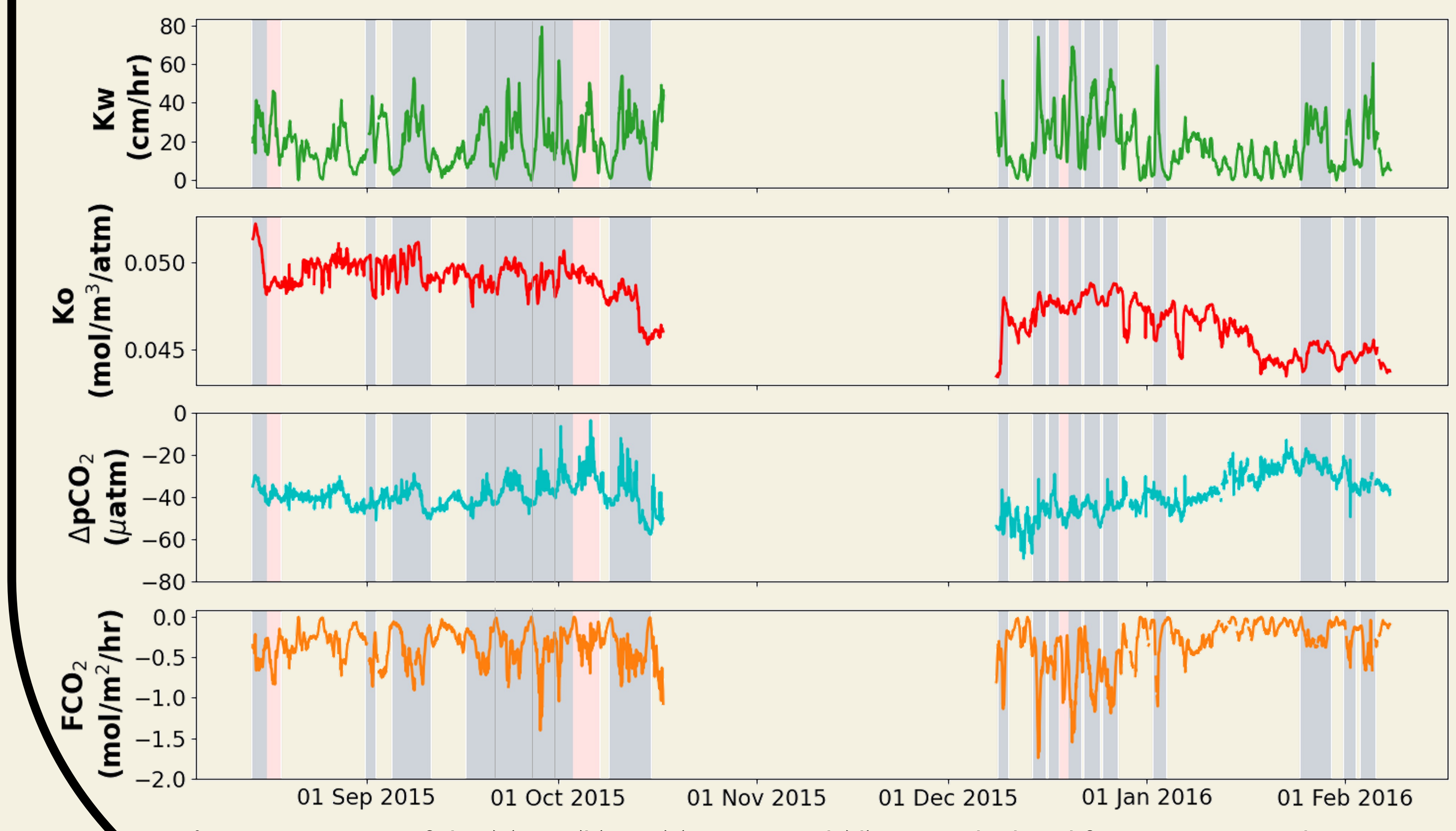


**Fig. 1:** Timeseries of the (a) $K_w$, (b) $K_o$, (c) $\Delta pCO_2$ and (d) $FCO_2$ calculated from SOSCEx-III observations with each storm event highlighted in grey and the storm events shown on in Figs. 2-3 highlighted in red.

### How is this impacting the $FCO_2$?

$$\text{Observed } FCO_2 = K_w\, K_o\, \Delta pCO_{2\text{-observed}}$$

$$\text{Experimental } FCO_2 = K_w\, K_o\, \Delta pCO_{2\text{-start}}{}^{*}$$

$$\text{Difference} = \text{Observed } FCO_2 - \text{Experimental } FCO_2$$

**$\Delta pCO_{2\text{-start}}$* = value at the start of storm event (dashed line) to simulate no impact of wind burst on the $\Delta pCO_2$**

### Winter

For winter storm events, accounting the impact of the wind burst on the $\Delta pCO_2$ showed a ***suppression*** of about **6.67 %** in the mean $FCO_2$ of each event (Fig. 2d&e).

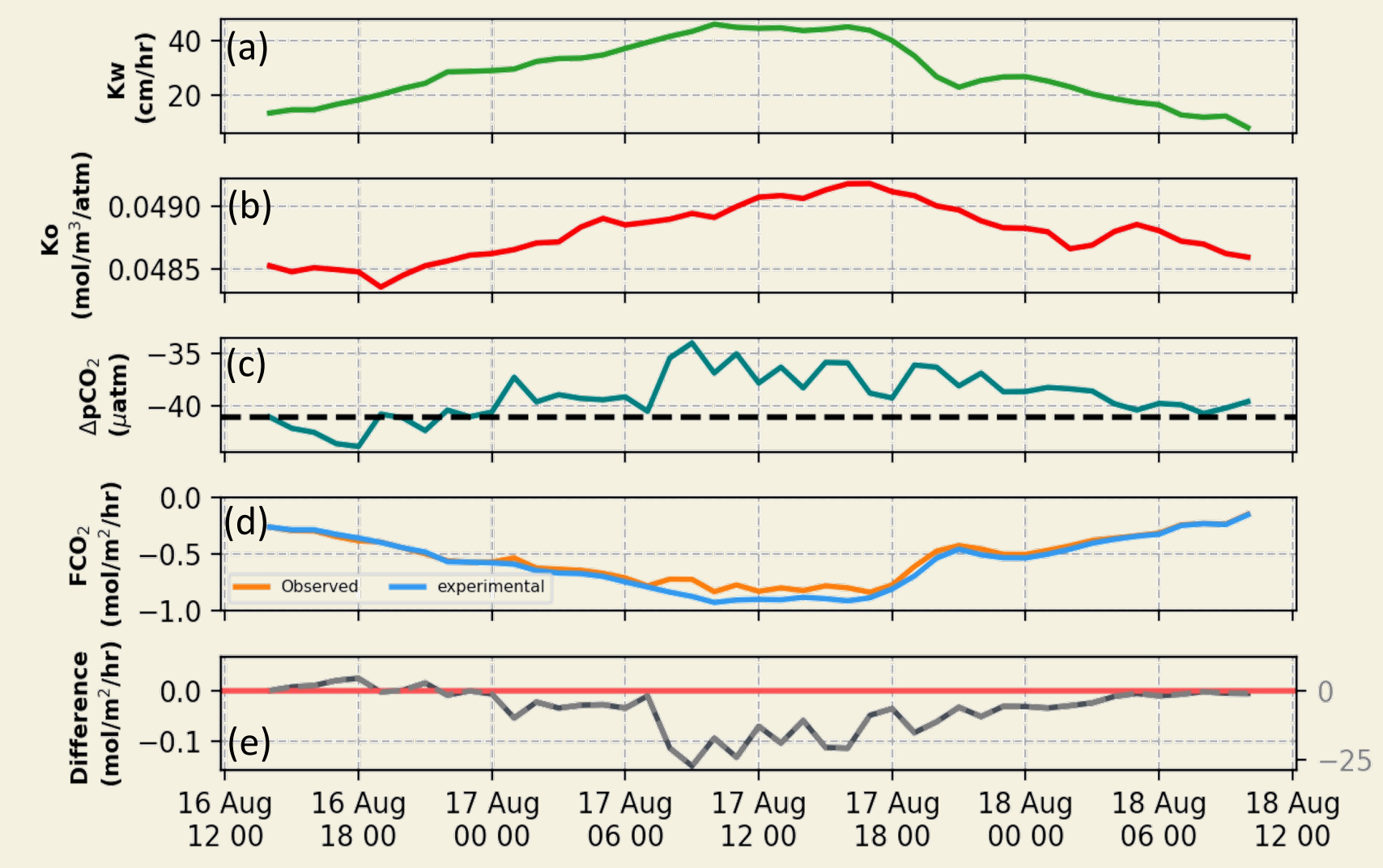


**Fig. 2:** Timeseries of the (a) $K_w$, (b) $K_o$, (c) $\Delta pCO_2$ (d) $FCO_2$ and (e) difference between the observed and experimental $FCO_2$ for the duration of a strong **winter** storm event (max wind stress of 0.682 $Nm^{-2}$).

### Spring

For spring storm events, accounting the impact of wind burst on the $\Delta pCO_2$ showed a ***suppression*** ranging between **10.8 % to 34.8%** in the mean $FCO_2$ of each event (Fig. 3d&e).

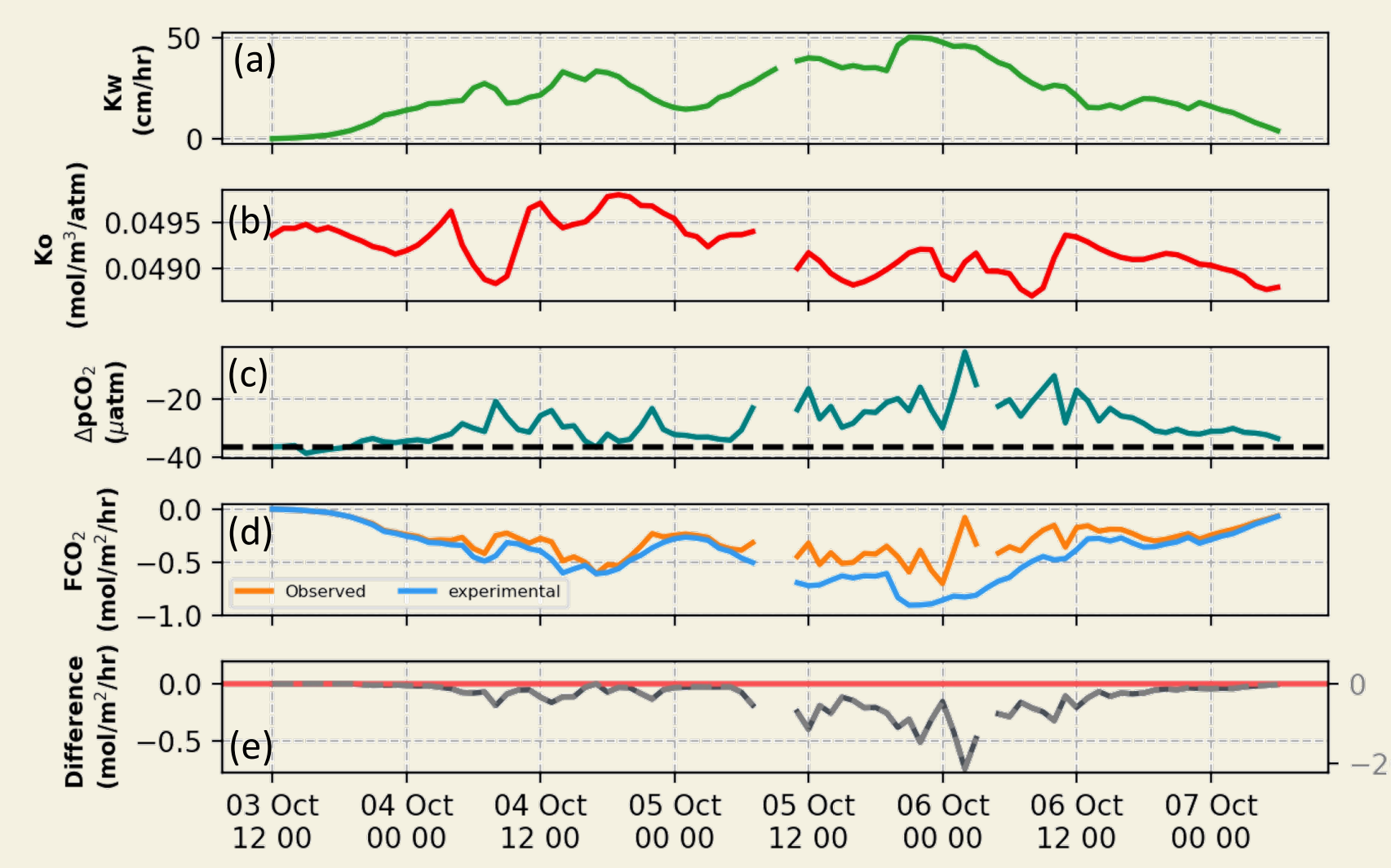


**Fig. 3:** Timeseries of the (a) $K_w$, (b) $K_o$, (c) $\Delta pCO_2$ (d) $FCO_2$ and (e) difference between the observed and experimental $FCO_2$ for the duration of a strong **spring** storm event (max wind stress of 0.669 $Nm^{-2}$).

### Summer

The mean $FCO_2$ of summer storm events showed two different response when the synoptic feedback in $\Delta pCO_2$ to each wind burst was accounted for.

- 7/11 storms which showed a weakening in the $\Delta pCO_2$ indicated a **4.1 % to 20.2 %** ***suppression*** of the mean $FCO_2$ of each event (not shown).
- 4/11 storms which showed an increase in the $\Delta pCO_2$ indicated an ***enhancement*** of **3.2 % to 26.4%** of the mean $FCO_2$ of each event (Fig. 4d&e).

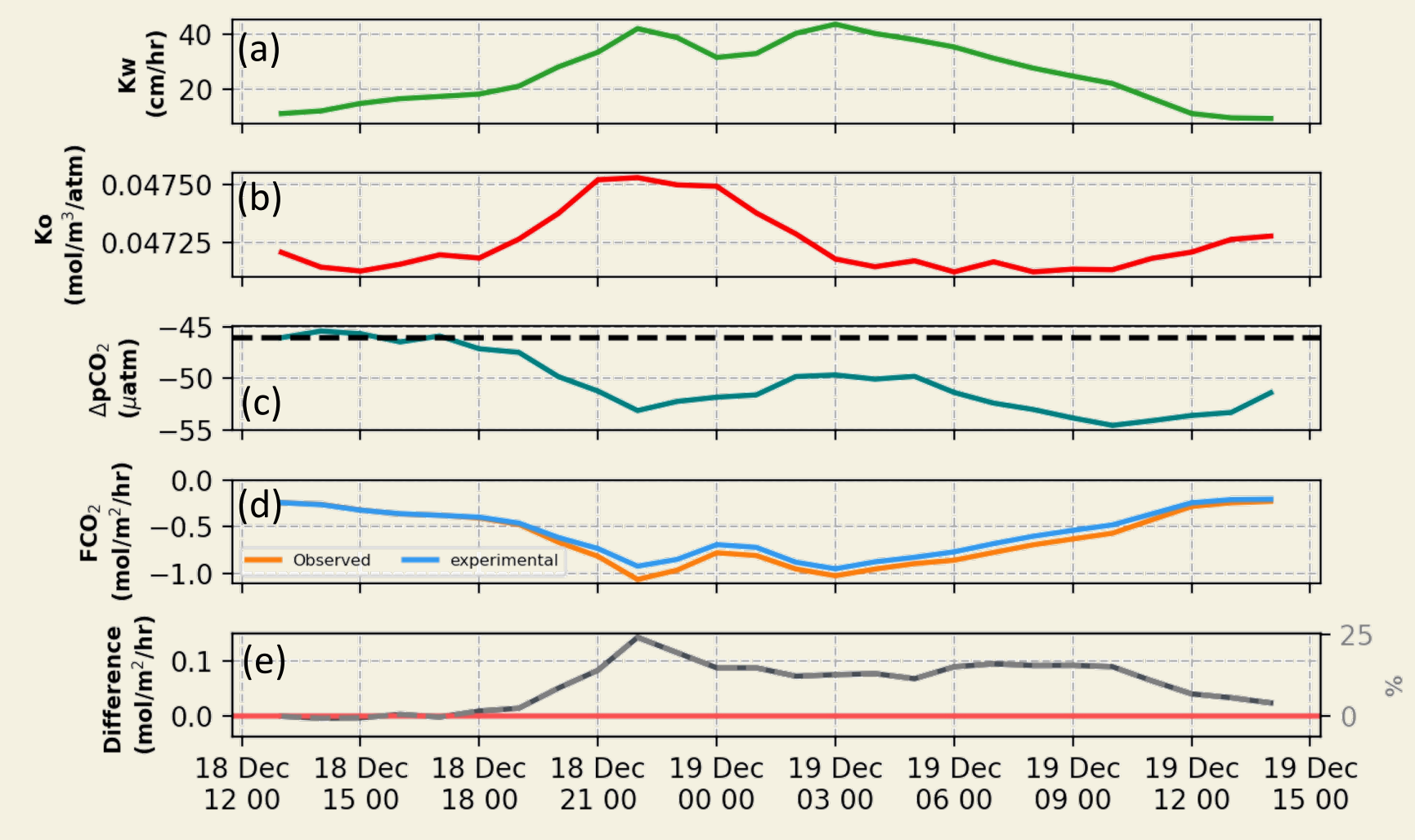


**Fig. 4:** Timeseries of the (a) $K_w$, (b) $K_o$, (c) $\Delta pCO_2$ (d) $FCO_2$ and (e) difference between the observed and experimental $FCO_2$ for the duration of a strong **summer** storm event (max wind stress of 0.749 $Nm^{-2}$).