Global Ocean CO_2 Uptake By Long Lived Mesoscale Eddies Identified With a Synergistic Lagrangian Tracking Approach Driven By Altimeter Data

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1) Introduction

Mesoscale eddies are globally known to affect the physical, chemical and biological properties of the oceans, compared to their surrounding environment. Through modifying the ocean conditions the fugacity of CO_2 in seawater ($fCO_{2\,(sw)}$) and the resulting air-sea CO_2 flux can be modified.

These eddies generally fall into two categories:

(1) Anticyclonic eddies which are thought to increase reduce CO_2 uptake, or enhance CO_2 emission
(2) Cyclonic eddies which are thought to enhance CO_2 uptake, or reduce CO_2 emission

However, eddies are complex features, and previous work has studied individual eddies (Orselli et al. 2019) or regional subsets (Ford et al. 2023; Song et al. 2016) showing differing effects on the air-sea CO_2 fluxes.

Here we investigate the effect of long-lived mesoscale eddies on the air-sea CO_2 fluxes using a Lagrangian tracking approach, a neural network approach to estimate $fCO_{2\,(sw)}$ and a focus on using satellite-based climate data records (i.e. ESA Climate Change Initiative products)

2) Methods

The AVISO+ **satellite altimetry based Mesoscale Eddy Product** was used to identify eddy trajectories greater than a year in length (Pegliasco et al., 2022). Each **eddy was collocated with environmental parameters** including sea surface temperature (CCI-SST), salinity, wind speed using the provided daily eddy polygon. The environmental parameters were used to **estimate $fCO_{2\,(sw)}$ with the University of Exeter Physics Feed Forward Neural Network with uncertainties** (UExP-FNN-U; Ford et al. 2024). **Air-sea CO_2 fluxes were calculated**, and a comprehensive uncertainty budget described in Ford et al. (2024) calculated. Air-sea CO_2 fluxes were cumulatively summed through the eddy lifetime. **An example eddy trajectory shown in Figure 1.**
The process was repeated for the conditions outside the eddy within three eddy radii.

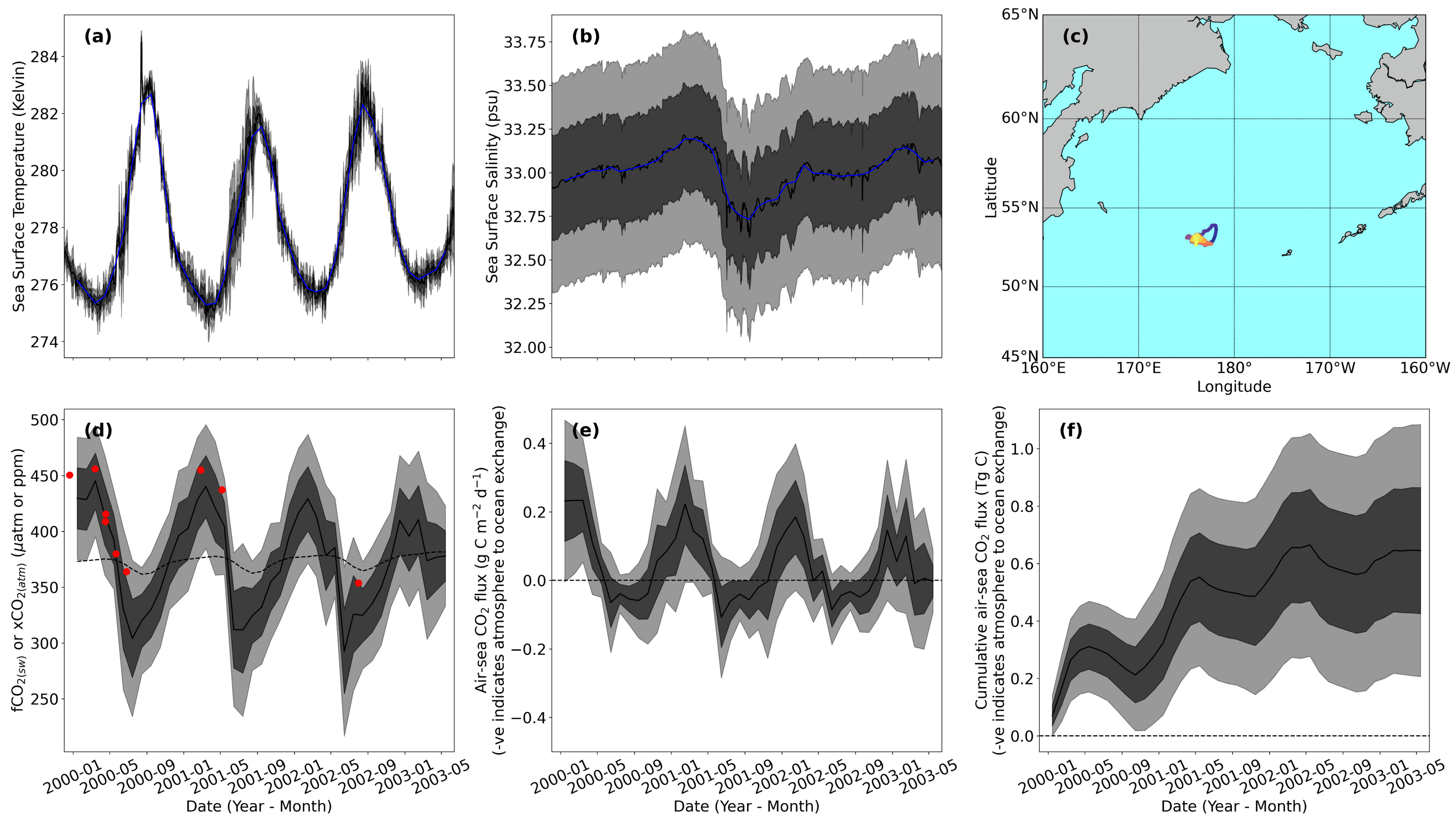

Figure 1: Exemplar eddy trajectory with calculated air-sea CO_2 fluxes. (a), (b), (d), (e) and (f) present the timeseries of the respective environmental parameters or air-sea CO_2 fluxes. Dark grey banding indicates the 1 sigma (~68% confidence), and light grey the 2 sigma (~95% confidence. Red points in (d) indicate in situ fugacity of CO_2 in seawater ($fCO_{2\,(sw)}$) observations. (c) indicates the eddy trajectory through time, where blue is near formation and yellow is at dissipation.

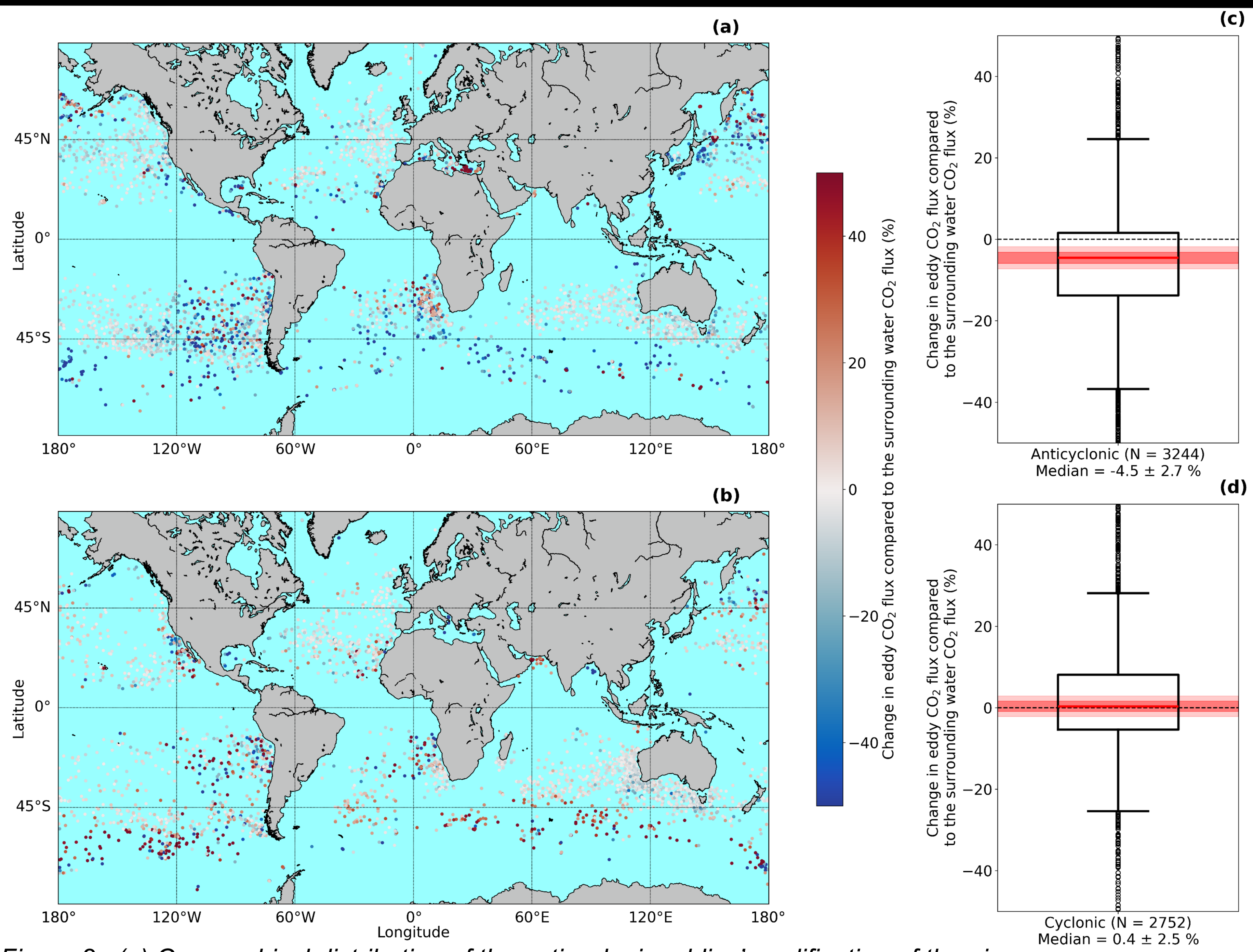

Figure 2: (a) Geographical distribution of the anticyclonic eddies' modification of the air-sea CO_2 flux. Negative values indicate a stronger CO_2 sink, and positive values indicate a weaker CO_2 sink. (b) for cyclonic eddies. (c) Box plot showing the anticyclonic eddy modification of the air-sea CO_2 flux. (d) for cyclonic eddies.

3) Results

The change in cumulative air-sea CO_2 flux at eddy dissipation with respect to the surrounding environment was calculated for a **total of ~6000 eddies** comprising 3244 anticyclonic and 2752 cyclonic eddies

We show for **anticyclonic eddies** globally, there was a tendency for the eddies to **enhance the air-sea CO_2 flux** (Figure 2) with respect to the surrounding environment by **4.5 ± 2.7 %** (range is the 95% confidence interval by propagating the calculated uncertainties through calculations).

For **cyclonic eddies** globally, there was a tendency for the eddies to **supress the air-sea CO_2 flux** (Figure 2) with respect to the surrounding environment by **0.4 ± 2.5 %**. Although this was within the uncertainty range.

Regionally splitting the eddies, we find that in the **Southern Ocean** (Figure 3g) the **anticyclonic eddies enhanced** the CO_2 sink more, **by 6.2 ± 4.8 %,** and **cyclonic eddies suppressed** the sink more by **1.5 ± 4.6 %.**

The South Atlantic (Figure 3e) highlighted the **importance of accounting for the air-sea CO_2 flux uncertainties**, where the eddy signal was within the uncertainty. These uncertainty bands were important when comparing to previous studies such as Ford et al. (2023) who found both eddy types enhanced the CO_2 sink in the South Atlantic.

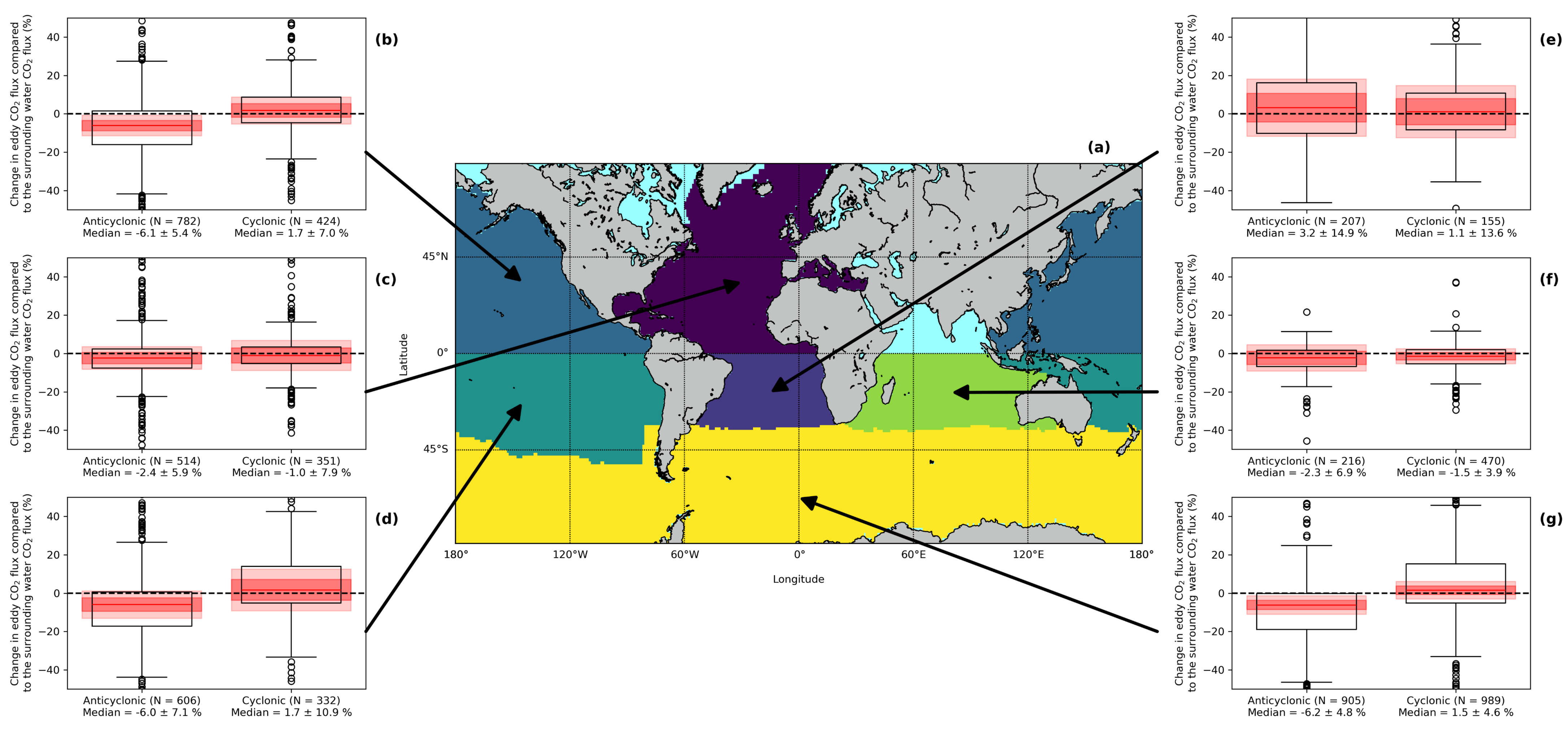

Figure 3: Box plots showing the anticyclonic and cyclonic eddy modifications to the air-sea CO_2 flux for regions highlighted by the arrows

4) Conclusions and Dataset

We investigated the effect of long-lived mesoscale eddies on the air-sea CO_2 fluxes using a Lagrangian tracking approach, a neural network approach to estimate $fCO_{2\,(sw)}$ and a focus on using satellite-based climate data records

Globally anticyclonic eddies **significantly enhanced** the air-sea CO_2 sink by **4.5 ± 2.7 %,** and **cyclonic eddies** indicated a **suppression** of the CO_2 sink by **0.4 ± 2.5 %** (although not significant).

Regional differences were apparent in the eddy modification, for example the **Southern Ocean** showed a **stronger enhancement** of the CO_2 sink by **anticyclonic eddies (6.2 ± 4.8 %).**

We are intending to release the eddy trajectories with air-sea CO_2 fluxes and the environmental data as a publicly available resource for studying eddy modifications of air-sea CO_2 fluxes

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References: Orselli et al. (2019; https://doi.org/10.1016/j.pocean.2018.10.006); Ford et al. (2023; https://doi.org/10.1029/2022GL102137); Song et al. (2016; https://doi.org/10.1002/2016JC011714); Pegliasco et al. (2022; https://doi.org/10.5194/essd-14-1087-2022); Ford et al. (2024; https://doi.org/10.1029/2024GB008188)