

**RC1:** ['Comment on egusphere-2023-1641'](#), Anonymous Referee #1, 07 Aug 2023

Mayen et al present one year of eddy covariance measurement of CO<sub>2</sub> exchange in a temperate salt marsh located at the French Atlantic coast. They assess the net CO<sub>2</sub> uptake on different time scales (diurnal, tidal, seasonal), analyze environmental controls and particularly focus on the impacts of tides on the atmospheric exchange. They find, compared to published values from other tidal wetlands, a large annual net CO<sub>2</sub> uptake.

Coastal wetlands are important for regulating biogeochemical cycling in the coastal zone. C flux studies are still relatively rare, and this study presents a tidal system with different vegetation (and tidal range) than previously published. As such, the study is a good fit for Biogeosciences.

We appreciate Referee#1 comment corroborating our Biogeosciences journal choice to publish this study and fitting the associated manuscript we revised accordingly (see below).

### **Major comments:**

C1: The definition of NEP and NEE should be considered carefully in this case (Chapin et al. 2006). Tidal systems tend to export DIC, which is not captured by eddy covariance measurements, so it is better to use NEE instead of NEP.

We thank Referee#1 for this important comment. In terrestrial ecosystems, NEE fluxes from atmospheric eddy covariance (EC) measurements generally correspond to NEP fluxes (Kowalski et al., 2003; Chapin et al., 2006). However, in intertidal ecosystems, like the studied salt marsh, the later relationship is more complex and NEE measured by EC does not fully correspond to NEP. Indeed, water column processes and fluxes such as lateral DIC exports related to marsh heterotrophic respiration, organic matter mineralisation, carbonate dissolution and benthos-pelagos couplings (Wang et al., 2016) are not capture by EC measurements, especially during transient tidal phases (flooding/ebb). Thus, in our revised manuscript, we replaced NEP by NEE<sub>marsh</sub>. In our study, NEE fluxes correspond to net vertical CO<sub>2</sub> exchanges measured by EC whereas, NEE<sub>marsh</sub> fluxes correspond to net vertical CO<sub>2</sub> exchanges estimated at the marsh-atmosphere interface without any tidal influence.

C2: Random Forest Model for gap-filling: It is not clear whether the data set was split in day and night time. The relatively bad night time model performance could be partially due to PAR being 0, if PAR is still included as driver. In addition, it would be helpful if an uncertainty for the resulting annual budget was presented.

In our study, the Random Forest model did not run separately for daytime and night-time data. We used only one model driven on our full 2020 dataset for gap-fill the 18.3% of missing data, with environmental variables easily available or measured, and identified in the literature to significant control CO<sub>2</sub> fluxes in salt marshes (RF2 in L259-262; Table A.1). Referee#1 is right, our Random Forest model estimated less well NEE data at night (38%) than at day (59%) that corresponds to only 20% of night-time NEE data. This lower performance model for night-time periods for which one of the most important NEE controlling factors (i.e. light) is absent, may

be explained by other processes in presence of waters, as for instance those occurring in winter during night-time (at both emersion and immersion) related to negatively measured NEE fluxes. These weak night-time CO<sub>2</sub> sinks observed at the studied site can be explained by inflow of coastal water undersaturated in CO<sub>2</sub> with respect to the atmosphere and/or CaCO<sub>3</sub> dissolution in waters or sediments. These aquatic processes and their influence on atmospheric fluxes, now more deeply discussed in the revised sections of the manuscript (see sections below), could participate to the difficulty of the Random Forest model to gap-fill these EC night-time data. To be noticed that at the diurnal scale, machine learning approach for predicting ecosystem CO<sub>2</sub> assimilation, even over terrestrial ecosystems in absence of water influence, are in any cases particularly complicated to effectively apply due to non-stationarities coming from multiple processes (see Bartolomeis et al. 2023, <https://egusphere.copernicus.org/preprints/2023/egusphere-2023-1826/egusphere-2023-1826.pdf>).

According to the uncertainty for the resulting annual budget, we computed a value of 0.42% by comparing the cumulative measured NEE (-462 g C m<sup>-2</sup>) and the corresponding cumulative gap-filled NEE (-453 g C m<sup>-2</sup>) on the 81.5% of our dataset where we had both measured and gap-filled values (i.e. 43264 values on 52704 measurements over the year 2020). The difference between EC and Random Forest model cumulative NEE values (1.95%) was then divided by the 43264 values (mean difference for one measurement) and finally multiplied by 9440 values (difference for 9440 gap-filled values over the whole 2020 dataset) to obtain the 0.42% of uncertainty.

### **Section 3.3. Environmental parameters and NEE fluxes at diurnal and tidal scales (this sentence was added in the revised MS)**

p17, L401-L405: “In winter, during some night-time periods, weak CO<sub>2</sub> sinks were recorded both during emersion ( $-0.79 \pm 0.84 \mu\text{mol m}^{-2} \text{s}^{-1}$ ; 137 hours over 71 days) and immersion ( $-0.82 \pm 0.91 \mu\text{mol m}^{-2} \text{s}^{-1}$ ; 143 hours over 55 days associated with a mean Hw of 0.80 m; Fig. A.2) of the salt marsh. The maximal CO<sub>2</sub> uptakes were  $-4.80$  and  $-5.31 \mu\text{mol m}^{-2} \text{s}^{-1}$  during night-time emersion and night-time immersion, respectively (Table 3).”

### **Section 4.2. Metabolism processes and controlling factors at multiple timescales (this paragraph was added in the revised MS)**

p28, L627-L635: “In winter, negative NEE fluxes were measured during some night-time emersion periods in the absence of any photosynthetic processes (18.5% in January, 18.1% in February and 10.7% in March). These negative fluxes could have two mainly sources: (1) an inorganic CO<sub>2</sub> diffusion and dissolution processes in saline/alkaline soils over mudflats (Ma et al., 2013) and (2) an inflow of coastal waters undersaturated in CO<sub>2</sub> with respect to the atmosphere within the footprint area (in channel for instance; Fig. 2) but not seen by the STPS probe due to our one-location water height measurement and immersion marsh heterogeneity (see 2.2 section). The negative values during night-time emersion could reduce the night-time random Forest model performance for EC data gap-filling and produce an underestimation of

respiration coefficients for NEE flux partitioning (particularly *b*) even causing negative coefficient (February; Table A.2)."

#### **Section 4.2. Metabolism processes and controlling factors at multiple timescales**

p29, L661-L666: "In our case, night-time CO<sub>2</sub> exchanges were reduced up to 100% (completely suppressed), sometimes even causing a change in metabolic status of atmospheric CO<sub>2</sub> from source to sink, especially in winter when the R<sub>eco</sub> rates were the lowest (Fig. 8). The presence of tidal waters advected from the shelf during the night and CO<sub>2</sub> undersaturated with respect to the atmosphere due to previous phytoplankton production and/or CaCO<sub>3</sub> dissolution in the water column during the day (Gattuso et al., 1999; Polsenaere et al., 2012), could induce a sink which may lead to a net uptake of CO<sub>2</sub> at night (Fig. 8)."

C3: Use of RH instead of VPD: The use of RH (%) as driver is not clear to me. Why not use VPD instead? It bypasses the problem of relative scale in RH as well as its temperature dependence.

Referee#1 is right. In the revised manuscript, we replaced RH by VPD, especially for the assessment of environmental drivers on NEE (see revised sections below; Fig. 6). We highlighted a significant correlation between NEE and VPD inducing a decrease of marsh CO<sub>2</sub> uptake for highest VPD values (especially, during warm and dry periods). Please refer to the revised sections below.

#### **Section 3.3. Environmental parameter and NEE flux variations at diurnal and tidal scales** (this sentence was modified in the revised MS)

p16, L382-L385: "Over all seasons, similar diurnal variations in measured NEE and estimated NEE<sub>marsh</sub> were recorded with, on average, a rapid increase in CO<sub>2</sub> uptake during the morning up to the middle of the day (low Ta and VPD values) and then, a decrease in CO<sub>2</sub> uptake during the afternoon (high Ta and VPD values) to become a CO<sub>2</sub> source during night-time (Figs. 5 and A.2)."

#### **Section 3.4. Influence of environmental drivers on temporal NEE variations** (this sentence was added in the revised MS)

p18, L426-L429: "During daytime, Vapor Pressure Deficit (VPD) was negatively correlated with NEE (-0.31; n = 27160, p < 0.05) producing a large reduction of CO<sub>2</sub> uptake for all PAR levels and even led to a switch from sink to source of atmospheric CO<sub>2</sub> from VPD > 1200 Pa for low PAR levels (PAR ≤ 500 μmol m<sup>-2</sup> s<sup>-1</sup>; Fig. 6-B)."

## **Section 4.2. Metabolism processes and controlling factors at multiple timescales (these paragraphs were modified in the revised MS)**

p27, L601-L602: “At the studied salt marsh, we showed a significant influence of VPD and RH on daytime NEE variations favouring plant CO<sub>2</sub> uptake for the lowest VPD values (< 1000 Pa) and the highest RH values (> 80%)”

p28, L617-L622: “At our studied site, the highest negative correlations between NEE and PAR were highlighted for low daytime PAR values, indicating that increases in light during the morning strongly favoured CO<sub>2</sub> uptake mainly through plant photosynthesis up to the middle of the day. During the afternoon, the high Ta and VPD values (warm and dry periods) produced a reduction of photosynthetic rates through stomatal closure of the C3 plants (Lasslop et al., 2010). This GPP decrease associated with a R<sub>eco</sub> increase in afternoon reduced the net CO<sub>2</sub> uptake up to reach CO<sub>2</sub> emissions during night-time (Knox et al., 2018; Xi et al., 2019).”

### **Minor comments:**

92: But see published studies such as Kathilankal et al. 2008, Moffett et al. 2010, Forbrich & Giblin 2015, Knox et al. 2018, Nahrawi et al. 2019, Hawman et al. 2023

Yes, please refer to our response to the major comment C1 above. In our revised manuscript, we replaced NEP by NEE<sub>marsh</sub> since NEE measured by EC do not fully correspond to NEP due to DIC lateral export.

106: Considering that land use impacts are being discussed later in the manuscript, it would be helpful here to get a better idea of the on-going restoration, if that is possible.

The Bossys perdu salt marsh is not under on-going restoration. For several centuries, it was used for salt farming and oyster farming; but since 1981, the salt marsh is protected within the maritime part of the national natural reserve (NNR) to restore the natural site hydrodynamics and marsh halophile vegetation without major restoration work here. The specific typology of the marsh due to past human activities (channel network, humps and dykes) remains and induces an immersion/emersion marsh heterogeneity on the site due to the specific associated microtopography. We modified the revised manuscript (see below) to give readers a better understanding of the history of the site and its current management practice. Moreover, we added pictures of the studied salt marsh during emersion to better visualize the specific typology and halophyte vegetation (Fig. 2).

## **Section 2.1. Study site (this paragraph was modified in the revised MS)**

p4, L111-L115: “Between the 17th and 20th centuries, the salt marsh has experienced successive periods of intensive land-use (salt harvesting, oyster farming) and returns to natural conditions before becoming a permanent part of the NNR since 1981 for the biodiversity protection without major marsh restoration work (Gernigon, personal communication). It is

currently managed to restore its natural hydrodynamics while conserving the site's specific typology due to past human activities (channel network, humps and dykes; Fig. 2)."

Is the flux tower site directly or rather indirectly influenced by it? Is the inundation pattern influenced by it and/or vegetation composition?

The Bossys perdu salt marsh did not have a major restoration work (please refer to the responses above). However, past human activities and water management practices for salt farming have shaped the marsh typology (channel network, humps, dykes) and associated microtopography, producing a time-delayed immersion of plants and muds between high and low marsh areas particularly during spring tides. Moreover, we added pictures of the studied salt marsh during emersion periods to better visualize the halophyte vegetation between high marsh levels (*H. portulacoides* and *S. vera*) and low marsh levels (*S. maritima* and mudflats; Fig. 2). We modified the revised manuscript and we discussed more the impact of this immersion/emersion marsh heterogeneity on measured NEE fluxes (see revised sections below).

### **Section 2.3. Footprint estimation and immersion/emersion marsh heterogeneity** (this paragraph was modified in the revised MS and the last sentence was added)

p8-9, L207-217: "At incoming tide, when coastal waters begin to fill the channel and then overflow over the marsh (from 0.5 h in spring tides to 2.5 h in neap tides; data not shown), the SSW sector (Fig. 2) was first immersed and a non-zero  $H_w$  value was measured. However, although some marsh sectors were immersed at the same time, others were still emerged. Indeed, lowest marsh levels (56% of the footprint area), mainly composed of mudflats and *S. maritima* (Table 1 and Fig. 2), were quickly immersed from  $H_w > 0$  m (south) whereas the whole marsh immersion (muds and overall plants) only occurred 0.75 h later from  $H_w > 1.0$  m at high tide during spring tide. Thus, highest marsh levels (44% of the footprint area), mainly composed of *H. portulacoides* and *S. vera* (Table 1 and Fig. 2), were still emerged for  $0 < H_w < 1.0$  m. Conversely, at neap tide, this footprint immersion versus emersion marsh heterogeneity could still be present even at high tide due to insufficient water levels. Although, a digital field model for water heights could not be performed in 2020 to have a better spatial representation of the immersion/emersion footprint, all these important considerations were considered in our interpretations in this study."

### **Section 4.1. Marsh CO<sub>2</sub> uptake and influence of management practices** (this sentence was added in the revised MS)

p25, L436-439: "Thus, due to this emersion/immersion heterogeneity, mud and *S. maritima* areas were quickly immersed by coastal waters whereas, the whole immersion of marsh habitats only occurred during the highest tidal amplitudes favouring a higher atmospheric CO<sub>2</sub> uptake by *H. portulacoides* and *S. vera*"

Also, it would be good to describe here the vegetation. It looks like that the two main species are evergreen shrubs, which will be good to highlight here.

In the revised manuscript, we added the description of the marsh vegetation (evergreen/perennial plants) and associated metabolic pathways. Please refer to the revised section below.

### **Section 2.1. Study site** (these sentences were added in the revised MS)

P5, L134-139: "The marsh vegetation assemblage was mainly composed by three halophytic species as perennial plants (*Halimione portulacoides*, *Spartina maritima* and *Suaeda vera*; Fig. 2) that associated with different metabolic pathways (the C3-type photosynthesis for *H. portulacoides* and *S. vera* and the C4-type photosynthesis for *S. maritima*; Duarte et al., 2013, 2014). Whereas *H. portulacoides* and *S. vera* are evergreen plants throughout the year, the growing season for *S. maritima* was shorter (from spring) with a flowering period between August and October (plants persist only in the form of rhizomes in winter and fall; Gernigon, personal communication)."

Also, if that information is available, it would be helpful to explain here, what the tide range is and how high/low the marsh surface is located within that tide range.

In the revised manuscript, the maximal tidal range of the Fier d'Ars estuary (5 meters) was added (see revised section below).

### **Section 2.1. Study site** (this sentence was modified in the revised MS)

p4, L115-116: "This salt marsh is linked to the Fier d'Ars tidal estuary that exchanges between 2.4 and 10.2 million m<sup>3</sup> of coastal waters with the Breton Sound continental shelf allowing a maximal tidal range of 5 m in the estuary (Bel Hassen, 2001)."

I assume that 0m as reported in the manuscript refer to the marsh surface?

Referee#1 is right, the water height (Hw) values reported in the manuscript were measured by the STPS probe (SSW wind sector; Fig. 2) and referred to the marsh surface.

144-160: This chapter is probably not really necessary, or can be briefly summarized in section 2.3

In the revised manuscript, we reduced the chapter on the Eddy Covariance theory which is well-established in the literature (Aubinet et al., 1999; Baldocchi, 2003; Aubinet et al., 2012; Burba,

2021) and we summarised this theory part in the beginning of the section 2.2. Eddy Covariance and micrometeorological measurements (see revised section below). However, we chose to conserve the theory equation of flux calculations method as well as the associated assumptions to ensure that the Eddy Covariance's technique is well understood by a large number of readers. We removed lines 144-148 and lines 145-160 from submitted manuscript (please refer to Referee#2 comment responses).

## **Section 2.2. Eddy Covariance and micrometeorological measurements** (this paragraph was modified in the revised MS)

p7, L153-155: "The atmospheric eddy covariance (EC) technique allow to quantify the net CO<sub>2</sub> fluxes at the ecosystem-atmosphere interface through micrometeorological measurements of the vertical component of atmospheric turbulent eddies (Aubinet et al., 1999; Baldocchi, 2003; Burba, 2021)."

186-190: How are the periods of flooding treated in the footprint model? Since the flood height seems to be substantial, a constant measurement height seems doubtful. Is the flooding filtered out?

We thank Referee#1 for her/his important comment. In our study, we have chosen to use a constant measurement height (Zm) for the footprint estimation (Zm = 3.15 m; L196) because the Bossys perdu salt marsh is in majority terrestrial (74.5% of the time over the year 2020; Table 2) and during most high tide periods, coastal waters are mainly located in channels representing a minor immersion area (below 7%; Table 1) without influencing Zm. Indeed, marsh immersion could influence Zm only for the highest tidal amplitudes when Hw > 1.5 m (less than 1% of the time over the year 2020; Table 2), thus this time period can be negligible. Moreover, given the accuracy of the Hw measurements ( $\pm 0.3$  m; L186 in the revised MS), we did not wish to add any further uncertainty to the footprint estimate. For this reason, we found it consistent to use a constant measurement height (Zm = 3.15 m) rather than using a variable Zm taking into account water height values measured by the STPS probe or using only data at emersion (Hw = 0 m) for footprint calculation. For comparison and verification, we performed these two footprint estimations both with variable Zm (using Hw measurements) and constant Zm (using data at emersion) and we obtained exactly the same footprint shape and extend as the one in the submitted manuscript. Thus, we have chosen to conserve the footprint from the submitted MS.

## **Section 2.3. Footprint estimation and immersion/emersion marsh heterogeneity** (this sentence was added in the revised MS)

p8, L197-198: "For verification, we performed the footprint estimations both with variable Zm from water height measurements and with constant Zm from data at emersion and we obtained the same footprint shapes and extends."

Also, how does the displacement height relate to vegetation/canopy height, based on Fig. A1-A3, the canopy height is very short?

Referee#1 is right, the canopy height of predominant plants on the studied salt marsh is short (i.e. 0.15 m for *Halimione portulacoides* and 0.30 m at maximum for *Spartina maritima*) as you can see in figure A.1. In our study, instead of using a displacement height (d) value hardly found in the literature for a comparable ecosystem, d was calculated by the EddyPro software from 0.67 times the canopy height according to the following equation (LI-COR Inc.):

$$d = 0.67 \times \text{canopy height} = 0.67 \times 0.15 = 0.10 \text{ m.}$$

As halophile plants (*Spartina maritima*, *Halimione portulacoides* and *Suaeda vera*) at the studied site had a low phenological variation at the monthly scale (Table A.2), we did not record significant variation of canopy height neither over the year, contrarily to the *Spartina alterniflora* specie in some U.S. salt marshes (Nahrawi et al., 2020). Thus, in our study, the displacement height was set constant ( $d = 0.10 \text{ m}$ ; L194 in the revised MS). In the revised manuscript, we added the canopy height in the caption of the figure 2 (L145 in the revised MS) and the calculation of the displacement height estimation in the footprint estimation section (see revised section below).

### Section 2.3. Footprint estimation and immersion/emersion marsh heterogeneity

p8, L192-197: "Footprints were estimated using the model of Kljun et al. (2015) applied to data from the year 2020 to obtain an annual averaged footprint from the constant measurement height ( $Z_m$ , 3.15 m), the constant displacement height ( $d = 0.1 \text{ m}$ , estimated from 0.67 times the canopy height; LI-COR Inc.), mean wind velocities ( $u_{\text{mean}}$ ,  $\text{m s}^{-1}$ ), standard deviations of the lateral velocity fluctuations after rotation [ $\sigma_v$ ,  $\text{m s}^{-1}$ ], the Obukhov length ( $L$ ), friction velocities ( $u^*$ ,  $\text{m s}^{-1}$ ) and wind directions ( $^\circ$ ) obtained from the EC measurements and the EddyPro processing software (EddyPro® v7.0.8, LI-COR Inc.) output."

212: I understand the reasoning for the shorter than usual averaging period, but I would also like to see a statement on how much that impacts the frequency correction, maybe add an average FC correction factor.

Indeed, as Referee#1 understood, we have chosen a time average of 10 minutes due to strong fluctuations of high-frequency EC data during periods of incoming and ebbing tides. EC data were calculated with the EddyPro software and a correction for flux spectral losses in the low frequency range was performed according to Moncrieff et al. (2004). This precision concerning EC data correction in the low frequency range was added in the revised manuscript in p9, L234-235 (see revised section below).

## Section 2.4. EC data processing and quality control (this sentence was added in the revised MS)

p9, L235-236: "During the EC data processing by EddyPro, a correction for flux spectral losses in the low frequency range was performed according to Moncrieff et al. (2004)."

Moncrieff, J. B., R. Clement, J. Finnigan, and T. Meyers. 2004. Averaging, detrending and filtering of eddy covariance time series, in *Handbook of micrometeorology: a guide for surface flux measurements*, eds. Lee, X., W. J. Massman and B. E. Law. Dordrecht: Kluwer Academic, 7-31.

Also, over two time periods without tidal immersion (neap tides) associated with strong variations in wind speeds, we compared NEE fluxes computed for an averaging time of 10 mins *versus* 30 mins. We calculated the ratio "average of the 3 values at 10 mins / the value at 30 mins" and we recorded that the ratio is close to 1 for highest wind speeds ( $1.07 \pm 0.88$  for  $5 < \text{wind speeds} < 10 \text{ m s}^{-1}$ ) and remains at 1 for lowest wind speeds ( $1.01 \pm 0.13$  for  $0 < \text{wind speeds} < 5 \text{ m s}^{-1}$ ). Thus, we can assume that there has been no significant loss at low frequencies in our 10 min. averaged fluxes using the Moncrieff et al. 2004 correction in EC data processing.

Other authors had also chosen a time average of 10 mins like Polsenaere et al. (2012) in the tidal bay of Arcachon where they showed no significant loss of low frequencies neither using this time averaging in these highly variable tidal environments.

233: Is the Random Forest model run/fitted separately for day and nighttime data?

In our study, the Random Forest model did not run separately for daytime and night-time data. There is only one model for the gap-filling of all EC data, with environmental predictors identified in the literature to control CO<sub>2</sub> fluxes in salt marshes (see response to the major comment C2 above).

239-240: Please give the results of this analysis and how you define 'sufficient'.

In fact, the word 'sufficient' is not well adapted here; we modified the submitted manuscript to better understand the choose of the gap-filling model in this study (L266-267). We used the Random Forest 2 (RF2) model with PAR, Ta, Hw and RH as environmental predictors because its performance indicators showed a high Pearson coefficient ( $R^2 = 0.88$ ) and low values of root mean square error (RMSE = 1.27) and model bias (0.0024) allowing to correctly gap-fill a large EC data (Table A.1). The RF3 model had the highest  $R^2$  and the lowest RMSE but we didn't have continuous data of wind direction throughout the year for this using this model.

## Section 2.5. Flux gap-filling and statistic tools (this section was modified in the revised MS)

p10, L251-271: “The random Forest (RF) model was used to gap-fill our EC dataset. Random forest is a supervised machine learning technique proposed by Breiman (2001) that can model a non-linear relationship with no assumption about the underlying distribution of the data population. This method has been shown to be particularly suited to gap-fill EC data (Kim et al., 2020; Cui et al., 2021). Random forest builds multiple decision trees, each of which are based on a bootstrap aggregated data sample (i.e. bagging of the EC data) and a random subset of predictors (i.e. the selected environmental data; Table A.1). We build random forest models with environmental predictors that have been identified in the literature to control CO<sub>2</sub> fluxes in salt marshes and which were available during the gaps and with measurements recorded between 2019 and 2020 (Table A.1). Each random forest model was built from a trained bagging ensemble of 400 randomly generated decision trees (Kim et al., 2020) with the “randomForest” package in the R software (Liaw and Wiener, 2002). In this study, we used the RF2 model with PAR, air temperature, water height and relative humidity as environmental predictors because its performance indicators showed a high Pearson coefficient ( $R^2 = 0.88$ ) and low values of root mean square error (RMSE = 1.27) and model bias (0.0024) allowing to correctly gap-fill a large EC data (Table A.1). The calculated uncertainty of the RF2 model on the resulting annual C budget was 0.43%. Each tree was trained from bagged samples including 70% of the initial dataset. The remaining 30% of the data were used to estimate the fit of each random forest model. The model used was then able to explain 88% of the variability in the test data. Daytime data were better explained than night-time ones (59% vs. 38%), with light being the main parameter of the model. However, only 20% of the night-time EC data were gap-filled with the Random Forest model. Using a partial dependence analysis and an ondelette analysis, we concluded that the relationships and temporal dynamics modelled allowed to correctly fill the gaps in our dataset. However, extreme values of some predictors (i.e. PAR > 1000  $\mu\text{mol m}^{-2} \text{s}^{-1}$ ) can reduce the random Forest model performance for estimation of EC data. This observation is common for random forest models, as they show poor results for extreme values. Other models such as artificial neural networks were also tested but showed poorer results (Table A.1).”

**Table A.1. Performance indicators for each model (RF: Random Forest, ANN: Artificial Neural Network) tested to gap fill the CO<sub>2</sub> fluxes. Predictor variables are PAR (Photosynthetically active radiation,  $\mu\text{mol m}^{-2} \text{s}^{-1}$ ), Ta (air temperature, °C), Hw (water height, m), RH (Relative Humidity, %) and Vd (wind direction,  $\text{m s}^{-1}$ ). The performance indicators are the coefficient of linear determination Pearson which shows the level of variability captured by the model ( $R^2$ ), the racine of the error quadratic average which gives an overview of the uncertainty of the result (RMSE: Root Mean Square Error), as well as the bias of the model.**

Models	Predictor variable	RMSE	Bias	$R^2$
RF1	PAR, Ta, Hw	1.42	0.0039	0.85
RF2	PAR, Ta, Hw, RH	1.27	0.0024	0.88
RF3	PAR, Ta, Hw, Vd	1.19	0.0029	0.90
ANN1	PAR, Ta, Hw	1.95	-0.0003	0.71
ANN2	PAR, Ta, Hw, RH	1.89	0.0021	0.73
ANN3	PAR, Ta, Hw, Vd	1.81	0.0041	0.75

241: Which variables were less influential at high PAR levels?

In gap-filling models, data resulting from the random forest models are generally less well estimated for predictor extreme values (i.e. PAR) because the model is only good within its own limits (we modified the revised MS; see revised section below). For instance, the model underestimated the impact of the immersion ( $H_w > 1$  m) for the highest PAR levels, where the  $CO_2$  sink was up to 90% higher than *in situ* data.

243: If you have run ANN as well, please give the results, maybe add in an appendix to see/justify the use of the random forest model.

In the revised manuscript, we added a supplementary table (Table A.1.; see responses above) showing the performance indicators of the different models (ANN and RF) tested in this study to gap fill NEE fluxes. According to values of Pearson coefficient ( $R^2$ ), root mean square error (RMSE) and the model bias, we have chosen the RF2 model to gap-fill our EC data (18.3% of the EC data were removed and gap-filled with RF2 to obtain continuous flux data in 2020). Please refer to our responses above and the modified section.

247: Why analyze monthly mean values? Please explain the rationale for this analysis.

In our study, we have chosen to perform a pairwise Spearman's correlation analysis on 10 min. values and monthly mean values to assess the influence of the environmental drivers on NEE fluxes at different temporal scales (Schafer et al., 2019). For instance, at the monthly scale (monthly mean values), PAR and Ta displayed the strongest negative correlations with NEE showing that the highest  $CO_2$  uptakes were recorded during warm and bright months of the year.

## Section 2.5. Flux gap-filling and statistic tools (this sentence was modified in the revised MS)

p10, L274-275: "To assess the influence of meteorological and hydrological drivers on NEE at different temporal scales, we performed a pairwise Spearman's correlation analysis on the 10-min. values and monthly mean values ("cor function" in R)."

254-255: Why group into these five PAR classes? Please explain the rationale for this analysis.

In our study, NEE fluxes were grouped into five PAR groups to reduce NEE fluctuations due to PAR variations and to better analyse the potential influence of other environmental drivers on NEE (figures 6 and 7). We modified our revised manuscript in L283-285 for a better explanation of this analysis (see below).

**Section 2.6. Temporal analysis of NEE fluxes and partitioning** (this sentence was modified in the revised MS)

p11, L284-286: “For the NEE flux analysis according to environmental drivers, NEE fluxes were grouped into five PAR groups ( $0 < \text{PAR} \leq 10$ ,  $10 < \text{PAR} \leq 500$ ,  $500 < \text{PAR} \leq 1000$ ,  $1000 < \text{PAR} \leq 1500$  and  $1500 < \text{PAR} \leq 2000 \mu\text{mol m}^{-2} \text{ s}^{-1}$ ) to reduce NEE fluctuations due to PAR variations.”

255-267: I am not sure why this description shows up in this chapter. An explanation of tide height and reference point (datum) would be helpful in the site description. The aspect of the spatial heterogeneity (in elevation and distance to channels) probably merits some explanation in the site description or in the footprint analysis section as well.

In the revised manuscript, we followed the advice of the Referee#1 and we moved the explanation of our one-location water height measurements and the associated immersion/emersion marsh heterogeneity in the footprint analysis section (see 2.3. from L205 to L216).

Overall, the last sentence, that this heterogeneity was taken into account merits more detail. How was this done, if there is no digital elevation model?

We thank Referee#1 for her/his important comment. Indeed, the immersion/emersion marsh heterogeneity could not be considered in our calculations and analyses because we could not perform a digital elevation model for the 2020 data. However, this important consideration has been taken into account in our interpretations. This sentence was corrected in the revised MS (see revised section below). In the submitted discussion, we indicated that further works were performed in 2021 EC data to obtain a digital field model for water heights and determine the exact areas of immersion and emersion of the marsh in each sector (L628-631 in the submitted MS).

**Section 2.3. Footprint estimation and immersion/emersion marsh heterogeneity** (this sentence was modified in the revised MS)

p8-9, L215-217: “Although, a digital field model for water heights could not be performed in 2020 to have a better spatial representation of the immersion/emersion footprint, all these important considerations were considered in our interpretations in this study.”

270: See above: NEP by definition (Chapin et al. 2006) includes inorganic carbon exchange, which in this system is incompletely resolved (due to DIX exchange/export).

Yes, we agree with Referee#1, please see response to the major comment C1 above. Our estimated NEE fluxes at the marsh-atmosphere interface (NEE flux partitioning from Kowalski

et al. 2003) did not correspond to NEP values due to tidal effects and water column processes that are not taking into account with atmospheric EC measurements. Thus, in the revised manuscript, estimated NEE fluxes at the marsh-atmosphere interface without tidal influence correspond to  $NEE_{marsh}$  rather than NEP.

273: Agreed, but there is likely slower porewater DIC transport during marsh exposure as well.

Referee#1 is right, there is likely slower porewater DIC transport during marsh immersion. In 2021, we performed DIC measurements during continuous 24-hour cycles at each season simultaneously with NEE and water  $pCO_2$  measurements to precisely answer this question (L631-642 in the submitted MS).

276-285: How is tidal inundation dealt with in this analysis? Are data points during submergence filtered out?

During the NEE flux partitioning, estimations of the GPP coefficients ( $a_1$  and  $a_2$ ; Eq. 2) and  $R_{eco}$  coefficients ( $R_0$  and  $b$ ; Eq. 3) were computed at the monthly scale during emersion without tidal water where measured NEE fluxes correspond to marsh metabolic fluxes ( $NEE_{marsh}$ ). Then, when all parameters used for NEE flux partitioning ( $a_1$ ,  $a_2$ ,  $R_0$  and  $b$ ) were estimated for each month, they were used to estimated  $NEE_{marsh}$  for each Ta and PAR values measured at a frequency of 10 minutes to obtained  $NEE_{marsh}$  signal over the year corresponding to marsh metabolic fluxes without any tidal water (see paragraph in the revised manuscript from L303 to L313).

p11-12, L305-315: ‘‘During NEE flux partitioning, estimations of the GPP coefficients ( $a_1$  and  $a_2$ ; Eq. 2) and  $R_{eco}$  coefficients ( $R_0$  and  $b$ ; Eq. 3) were performed by the least square method (“minpack.lm” package in R) at the monthly scale only during emersion periods where measured NEE fluxes correspond to estimated  $NEE_{marsh}$  fluxes. Firstly, for each month,  $R_0$  and  $b$  were estimated during night-time emersion periods where  $NEE = R_{eco}$  following Eq. 3 (Wei et al., 2020b). Then,  $a_1$  and  $a_2$  were estimated during daytime emersion periods using night-time respiration coefficients ( $R_0$  and  $b$ ) where  $NEE = GPP - R_{eco}$  following Eq. 2 and Eq. 3 (Kowalski et al., 2003). Finally,  $NEE_{marsh}$  (marsh metabolic fluxes without tidal influence) were calculated for each PAR and Ta value measured at a 10-min. frequency throughout the year using the monthly coefficients calculated for the partitioning (Eq. 2). As our ecosystem had a low phenological variation (Table A.2), we concluded that a monthly time step for the coefficient estimation was sufficient to answer our study objectives. During emersion periods, monthly net C balances (i.e. budgets) of measured NEE and estimated  $NEE_{marsh}$  were very similar as well as the monthly mean fluxes (Table A.3), confirming the correct NEE flux partitioning calculations done in this study.’’

However, in winter, negative NEE fluxes measured during night-time emersion periods due to inflow of coastal waters undersaturated in  $CO_2$  in channels and/or  $CaCO_3$  dissolution in marsh sediments could produce an underestimation of respiration parameters for the NEE partitioning (particularly  $b$ ) even causing negative parameter (see revised section below).

## Section 4.2. Metabolism processes and controlling factors at multiple timescales (this paragraph was added in the revised MS)

p28, L627-L635: "In winter, negative NEE fluxes were measured during some night-time emersion periods in the absence of any photosynthetic processes (18.5% in January, 18.1% in February and 10.7% in March). These negative fluxes could have two mainly sources: (1) an inorganic CO<sub>2</sub> diffusion and dissolution processes in saline/alkaline soils over mudflats (Ma et al., 2013) and (2) an inflow of coastal waters undersaturated in CO<sub>2</sub> with respect to the atmosphere within the footprint area (in channel for instance; Fig. 2) but not seen by the STPS probe due to our one-location water height measurement and immersion marsh heterogeneity (see 2.2 section). The negative values during night-time emersion could reduce the night-time random Forest model performance for EC data gap-filling and produce an underestimation of respiration coefficients for NEE flux partitioning (particularly *b*) even causing negative coefficient (February; Table A.2)."

323-325: How does this flooding relate to marsh surface and canopy height?

Due to heterogeneous typology and microtopography of our study site (see responses above) associated with meteorological conditions, during high tide periods for instance, some wind sectors can be immersed while other sectors are still emerged at the same time, despite a same canopy height ( $d = 0.10$  m). Moreover, due to the incertitude on H<sub>w</sub> measurements ( $\pm 0.30$  m), it will be difficult to answer this question even with a digital field model for water levels.

478-495: I don't see the need for this chapter. It seems to re-iterate information from the introduction.

In our revised manuscript, we followed the advice of the Referee#1 and we strongly reduced the section 4.1. of the submitted MS to avoid repetitions with the introduction and M&M sections regarding methodological aspects of the Eddy Covariance technique. Thus, we removed lines 484-495 from submitted MS.

511: This is really interesting, but should be mentioned and discussed/analyzed earlier than here.

In the revised manuscript, the time-delayed immersion of plants and muds between high and low marsh areas due to specific marsh typology were more discussed at the beginning of the discussion (L527-534 in the revised MS). This emersion/immersion heterogeneity allows a lower immersion duration of marsh plants during neap tide periods (low tidal amplitudes) favouring a higher marsh CO<sub>2</sub> uptake (see the sentence added in the revised MS below).

#### **Section 4.1. Marsh CO<sub>2</sub> uptake and influence of management practices** (this sentence was added in the revised MS)

p25, L536-539: “Thus, due to this emersion/immersion heterogeneity, mud and *S. maritima* areas were quickly immersed by coastal waters whereas, the whole immersion of marsh habitats only occurred during the highest tidal amplitudes favouring a higher atmospheric CO<sub>2</sub> uptake by *H. portulacoides* and *S. vera*.”

515-524: This is important background information. If NPP (based on literature values) is very close to NEE, no heterotrophic respiration occurs, which seems unlikely. It is a common problem in these systems, that the range in different component fluxes is difficult to constrain.

We thank Referee#1 for her/his important comment. The estimated NPP of *H. portulacoides* and *S. maritima* in Sousa et al. (2010) showed a significant contribution of these halophytic species in our marsh CO<sub>2</sub> uptake. However, our net C balance at the annual scale could also be influenced by the heterotrophic respiration of the marsh producing atmospheric CO<sub>2</sub> emissions and lateral DIC exports in tidal waters (see the revised sentence below).

#### **Section 4.1. Marsh CO<sub>2</sub> uptake and influence of management practices** (this sentence was completed in the revised MS)

p25-26, L544-547: “Thus, the net metabolism of these halophytic plants could play an important role in our net C balance but, according to “the marsh CO<sub>2</sub> pump” (Wang et al., 2016), a significant proportion of marsh NPP was respiration by heterotrophic processes in benthos and then (1) emitted as atmospheric CO<sub>2</sub> ( $38 \pm 11\%$ ) and (2) exported by tides as DIC ( $37 \pm 15\%$ ; Song et al., 2023).”

Additional influences from benthos is a possible factor here, but is it large enough? Also, considering the depth of inundation and the length of the submergence, what about lateral exchange? I don't expect that you quantify that, but at least discuss this as possible factor as well.

Referee#1 is right, there is a possible benthos influence along with lateral DIC exports from heterotrophic respiration. The low water level during marsh immersion could favour benthic-pelagic coupling and influence water pCO<sub>2</sub> dynamics (see the sentence added in the revised MS above). In 2021, we performed DIC measurements during continuous 24-hour cycles at each season simultaneously with NEE and water pCO<sub>2</sub> measurements to precisely answer this question (L631-642 in the submitted MS).

528-539: Here is a place to discuss the fact that there is evergreen vegetation (in contrast to some of the published studies) as well as the question of vegetation density/LAI. From the pictures, it looks like that LAI is not very high, which could be a factor in low  $R_{eco}$  values (and NEE).

In the revised manuscript (see the revised paragraph below), we discussed that the halophyte vegetation of the salt marsh, mainly composed of evergreen species, was net autotrophic throughout the year allowing a net  $\text{CO}_2$  uptake during both the growing and non-growing seasons whereas, the smooth cordgrasses as *S. alterniflora* in some tidal salt marshes was net heterotrophic during winter and fall due to the winter plant senescence, producing in turn, atmospheric  $\text{CO}_2$  emissions during these periods of the year.

#### **Section 4.2. Metabolism processes and controlling factors at multiple timescales** (theses sentences were modified in the revised MS)

p26-27, L574-581: “In our studied marsh, the halophyte vegetation, mostly composed of evergreen species, was autotrophic throughout the year allowing a net C uptake from the atmosphere during both the growing and non-growing seasons (between  $9 \text{ g C m}^{-2}$  in December and  $73 \text{ g C m}^{-2}$  in July) whereas, the senescence of smooth cordgrass plants in some salt marshes (*S. alterniflora* and *S. cynosuroides* for instance) from October produced a marsh heterotrophy and a net C source to the atmosphere in winter and fall (Schafer et al., 2014; Artigas et al. 2015; Forbrich et al., 2018). In our case, *S. maritima* is a perennial species but with a relatively short growing period, thus during winter and fall, the metabolism of this halophytic plant could have a significant lower influence on marsh C uptake than *H. portulacoides* and *S. vera*.”

569-571: Does that mean you can exclude the possibility of stomatal closure in the afternoon (high Ta and high VPD)? This is something that C3 vegetation can be sensitive to (see Lasslop et al. 2010).

No, we can't exclude this possibility; indeed, the high Ta and VPD values measured in the afternoon (warm and dry periods) produced a reduction in photosynthesis of marsh plants, particularly the C3 plants (*H. portulacoides* and *S. vera*), through the closure of their stomata (Lasslop et al., 2010). This GPP decrease associated with a  $R_{eco}$  increase in the afternoon reduced the net  $\text{CO}_2$  uptake by the marsh (Figs. 5 and A.2). Lasslop et al. (2010) showed that high VPD values in the afternoon on warm and dry days lead to a limitation of GPP by stomatal closure and thus to higher carbon uptake in the morning rather than in afternoon. In the revised manuscript, the discussion was completed in L610-613 (see revised paragraph below).

#### **Section 4.2. Metabolism processes and controlling factors at multiple timescales** (theses sentences were modified in the revised MS)

p28, L619-622: “During the afternoon, the high Ta and VPD values (warm and dry periods) produced a reduction of photosynthetic rates through stomatal closure of the C3 plants (Lasslop

et al., 2010). This GPP decrease associated with a  $R_{eco}$  increase in afternoon reduced the net  $CO_2$  uptake up to reach  $CO_2$  emissions during night-time (Knox et al., 2018; Xi et al., 2019)”

589-593: This is not the result from the current analysis, but offers a way of elaborating the difference in exchange between the water column and the vegetated marsh.

Referee#1 is right. During some daytime immersion periods, our observations showed a temporary increase of marsh  $CO_2$  uptake, especially for low immersion levels, but further works are needed to study the contribution of planktonic and benthic metabolisms on these  $CO_2$  uptakes during marsh immersion (see the revised paragraphs below).

#### **Section 4.2. Metabolism processes and controlling factors at multiple timescales** (this paragraph was modified in the revised MS)

p29, L648-652: “Indeed, during the brightest periods in winter and spring, the temporary increases in  $CO_2$  uptake recorded during incoming tides could be related to (1) an increase in the GPP of *H. portulacoides* and *S. vera* (highest marsh levels) favoured by VPD and Ta decreases due to tidal conditions and/or (2) tidal waters advected from the shelf that are undersaturated in  $CO_2$  with respect to the atmosphere due to phytoplankton blooms (Mayen et al., in prep.).”

#### **Section 4.3. Salt marsh carbon budgets for future research perspectives** (paragraph from submitted MS)

p30-31, L691-702: “Similarly, during marsh immersion, EC measurements do not directly capture  $CO_2$  fluxes from benthic metabolism because of the physical barrier of the water and the lower  $CO_2$  diffusion rates in water than in air. Consequently, at the same time as when the NEE measurements were taken, water  $pCO_2$  and inorganic and organic carbon concentrations associated with planktonic metabolism were determined each season through 24-hour cycles to provide essential information on the contribution of planktonic communities and plants to  $CO_2$  fluxes during immersion (Mayen et al., in prep.). The lateral C export from salt marshes through tides plays a significant role in the coastal ocean C cycle (Guo et al., 2009; Wang et al., 2016). Plant respiration and microbial mineralisation of marsh NPP could generate DIC in water associated with a strong benthos-pelagos coupling. Thus, our 2021 measurements of the carbon parameters, planktonic metabolism (production/respiration) and other relevant biogeochemical variables over 24-h diurnal cycles, along with measurements of the soil compartment (root OM production vs mineralization; Arnaud et al., submitted 2022) carried out simultaneously in the EC footprint would allow for a more integrative calculation of the studied marsh carbon budget (Mayen et al., in prep.).”