Dear Editor,

Enclosed is a copy of the revised manuscript, "Spring net community production and its coupling with the CO_2 dynamics in the surface water of the northern Gulf of Mexico" by Jiang et al. In this revision, we have fully considered the comments and suggestions from both reviewers. A point-to-point response to the reviews is in the enclosure and a changes-tracked manuscript is also included.

With the agreement of all co-authors of the previous version of the manuscript, we added Najid Hussain, Michael K. Scaboo, Junxiao Zhang, and Yuanyuan Xu to the author list in the revised manuscript. They all attended the Gulf of Mexico cruise for data collection and also contributed to the preparation and revision of this manuscript. Najid measured the spectrophotometric DO onboard. Michael, Junxiao and Yuanyuan precipitated in collection and analysis of DIC and TA samples (see the author contributions section in the revised manuscript).

We thank you again for your consideration of this manuscript.

Sincerely,

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Reviewer 1:

Major comments:

1. This manuscript contains a lot of data that a priori looks very good. Good comparison of the different methods can be done only in a particular area, while the rest of the data, mainly the pCO2 and NCP from O2/Ar, would be a good data set. In the section Methods there are a lot of explanation of how to arrive to the NCP calculations that can be found in the literature but very little is explained about replicates, average, and data quality controls or transformations (e.g. PQ to change from O2 units to C units is missed)
   Response: In the revised manuscript, the Methods section has been shortened by citing literatures for established NCP calculations and by removing unnecessary explanations. Relevant information has been added to explain the replicates, average, standard deviation, and data quality controls of the measurements. The transformations of the NCP units were described in the original manuscript (page 9, lines 17-18) and in the revised manuscript (page 9, line 20 to page 10, line 4).

2. The manuscript needs a little bit of more order to be able to read it fluid. Suggestions are made in the pdf attached.
   Response: We sincerely thank the reviewer for the very detailed comments and suggestions which significantly improve our manuscript. Please see our responses to minor comments below.

3. Part of the discussion is based in differences between methods due to different stratified or mixed column states. I think the writer is interchanging "mixed layer" and "mixing column" concepts and making therefore wrong assumptions.
   Response: In order to clearly show the different stratified or mixed water column states (as well as the different turbidity conditions), the vertical profiles at typical stations have been presented in the revised manuscript as the newly added figures in the supplement. In the nGOM, stratification was observed in the lower Mississippi river channel (Fig. S2) and in plume and offshore regions (Fig. S3) while well-mixed water column was observed in certain Atchafalaya coastal regions (Fig. S4).
   We also discuss the influences of physical processes (vertical mixing and the lateral transport of the strongly net heterotrophic Mississippi and Atchafalaya river water) on NCP_{O2Ar} estimation under different mixing conditions (section 4.1, Fig. 8). Depending on the different mixing conditions, NCP_{O2Ar} reflected: 1) the combined result of NCP in the mixed layer (NCP_{MLD}) and the lateral transportation of heterotrophic signal carried by the river water (NCP_{adv}) in the stratified river channel (Fig. 9a); 2) the combined result of water column production (NCP_{water}), benthic metabolisms ($NCP_{benthic}$), and NCP_{adv} in the well-mixed nearshore waters (Fig. 9b); 3) NCP_{MLD} in the offshore stratified regions where the riverine influence was minor (Fig. 9c). We have revised the results and discussion sections to make these points clear to the readers.

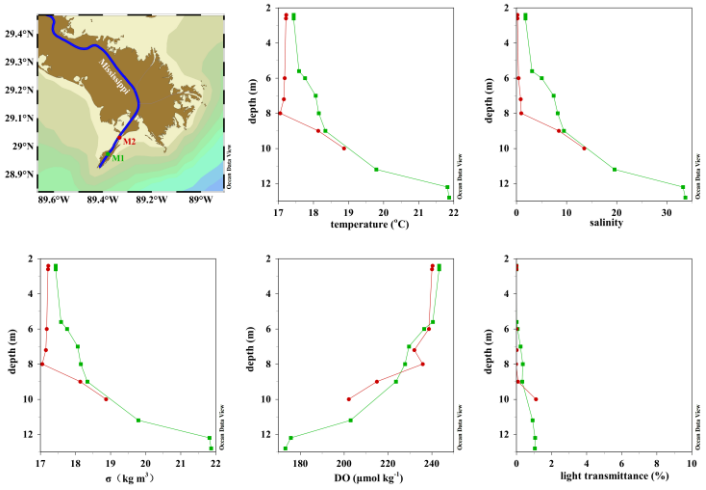


Fig. S2. Vertical profiles of (a) temperature, (b) salinity, (c) density anomaly, σ = density (kg m^{-3}) – 1000, (d) DO, (e) light transmittance in the lower Mississippi River channel. The different symbols correspond to the measurements from different sites shown in the map in the upper left corner.

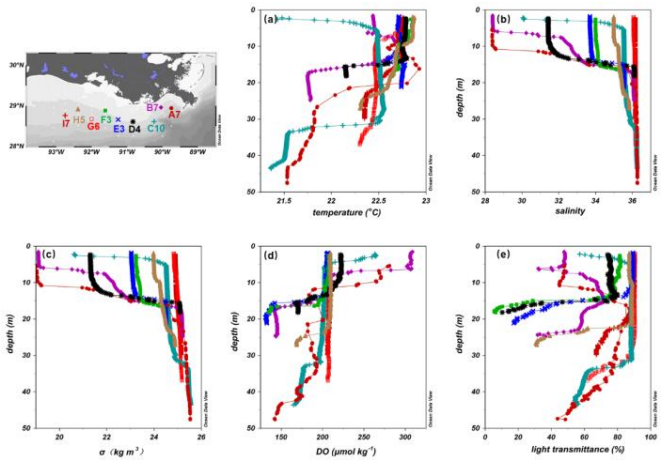


Fig. S3. Vertical profiles of (a) temperature, (b) salinity, (c) density anomaly, σ = density (kg m^{-3}) – 1000, (d) DO, (e) light transmittance at the stratified offshore region. The different symbols correspond to the measurements from different sites shown in the map in the upper left corner.

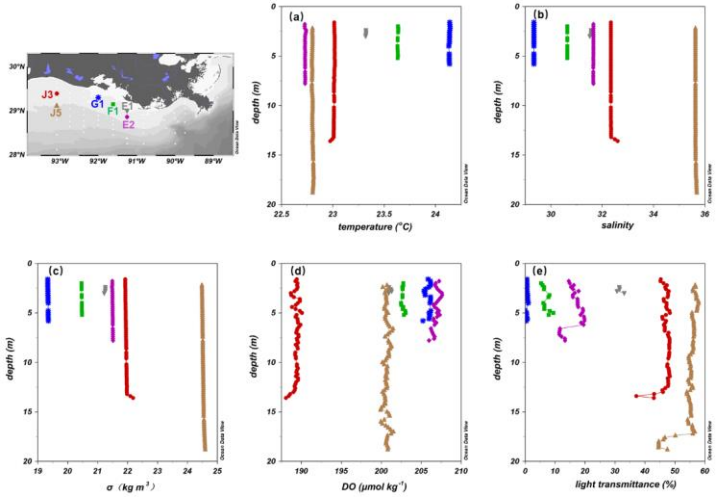


Fig. S4. Vertical profiles of (a) temperature, (b) salinity, (c) density anomaly, σ = density (kg m^{-3}) – 1000, (d) DO, (e) light transmittance in the well-mixed Atchafalaya coastal region. The different symbols correspond to the measurements from different sites shown in the map in the upper left corner.

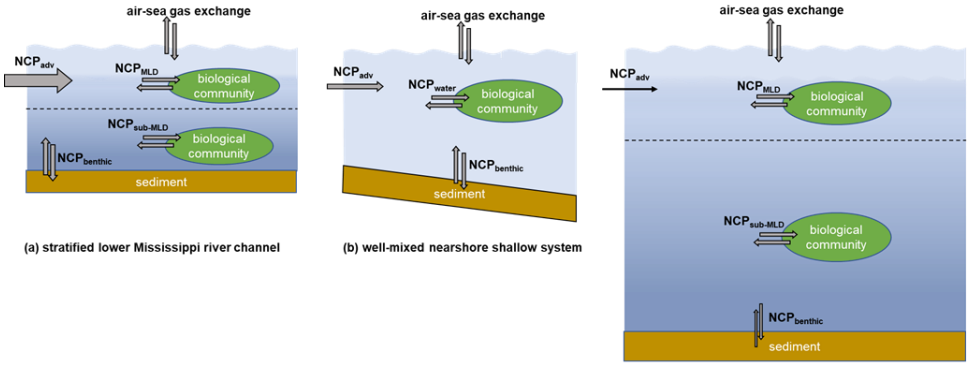


Fig. 9. The differences in water column mixing conditions in the nGOM and their influences on NCP estimation. The dotted lines in panels (a) and (c) indicate the mixed layer depth. In the stratified lower Mississippi River channel (a) and the offshore stratified system (c), $NCP_{DO\text{-}incub}$ equals the *in situ* community production in the mixed layer (NCP_{MLD}), while NCP_{O2Ar} reflects the combined result of the NCP_{MLD} and the influence of lateral advection of the river water (NCP_{adv}). In the nearshore well-mixed shallow system (b), $NCP_{DO\text{-}incub}$ equals the water column community production (NCP_{water}), while NCP_{O2Ar} reflects the combined result of NCP_{water}, $NCP_{benthic}$, and NCP_{adv}. Note that the influence of NCP_{adv} decreases offshore with the increasing water residence time.

4. Uncoupled 02 and CO2 fluxes and definition of sink or source of CO2 can be the result of smoothing CO2 values to a mean, but I cannot really tell without knowing the raw data. Also comments attached.
Response: The O_2 and CO_2 fluxes were both calculated from high-resolution pCO_2 and DO data (1-minute average) from the continuous underway measurements. There was no smoothing of CO_2 values when discussing the uncoupled O_2 and CO_2 fluxes. These points have now been clearly stated in the Methods section in the revised manuscript.

5. Supplementary material of Figure S1. Is the data from the webpage only for the river discharge? This graph doesn't have x axis label. It should use dates instead and change consecutive numbers 1-12 to meaningful dates.
Response: Both the river discharge and NO_x flux data were from the USGS (now explained in the figure caption of Fig. S1). The x axis label "month" has been added and the numbers 1-12 have been replaced by the meaningful dates "Jan, Feb, …Dec" as suggested.

6. Supplementary material of Figure S2 (a,b) shows regresion lines to show tendencies forced by few data points in the river. R2 is not shown but is expected to be very low to use it.
Response: This figure has now been moved to the main text as suggested by minor comment 44 below. The lines in this figure are conservative mixing lines (not regression lines) which demonstrate the changes of concentrations of DIC and

NO_x responding to the conservative mixing between river end member and seawater end member. We have clarified this in the revised figure caption as: "The end member concentrations of the Mississippi river, the Atchafalaya River, and offshore gulf surface water are shown in panels (a) and (b) together with the conservative mixing lines."

Please also note the supplement to this comment:

https://www.biogeosciences-discuss.net/bg-2019-88/bg-2019-88-RC1-supplement.pdf

Minor comments:

1. Page 1, line 23 "use the same number of decimals for each number"
   Response: Corrected as suggested.

2. Page 1, lines 27-28: "need to talk in the discussion about the "slow" air-sea gas exchange"
   Response: In the revised manuscript, we now demonstrate the slow air-sea CO_2 exchange rate (compared to that of O_2) in the model simulation by calculating the re-equilibrium time for CO_2 and O_2 following a biological perturbation (Fig. S5). Both for the autotrophy and heterotrophy simulations, the re-equilibrium time for pCO_2 (more than one month) is significantly longer than that of O_2 (a few days). Because the slow air-sea CO_2 exchange rate is well-known in the carbonate system, we remove the original Figure 10 and add this new figure to the supplement according to the suggestion from reviewer 2 (minor comment 44).

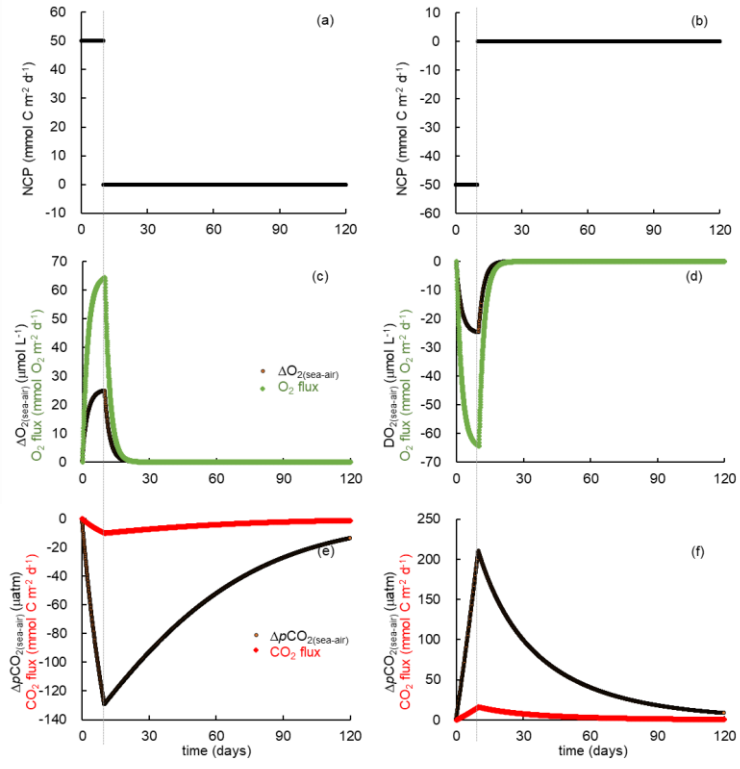


Fig. S5. Simulation of carbon and oxygen dynamics responding to NCP and gas exchange using a 1-D model. The system is assumed to be in equilibrium with the atmosphere on day 0, which is followed by a 10-day (a) autotrophic or (b) heterotrophic production. The variations in (c, d) O_2 flux and air-sea O_2 difference ($\Delta O_{2(sea\text{-}air)}$) and (e, f) CO_2 flux and air-sea pCO_2 difference ($\Delta pCO_{2(sea\text{-}air)}$).

3. Page 2, line 2: “reference”
   Response: Corrected.

4. Page 3, line 14: “if it is the first time you use an acronym, define it”
   Response: Corrected.

5. Page 3, line 19: AND SLOW air-sea exchange
Response: Revised as suggested.

6. Page 3, line 22: “I am struggling to place the sampling site on a map. Give reference context area in the map. show where the river is. From this map it doesn't seem to have a rive but just coast line.”
Response: We have modified Figure 1 and its caption to better show the sampling sites as well as to highlight the Mississippi and Atchafalaya River.

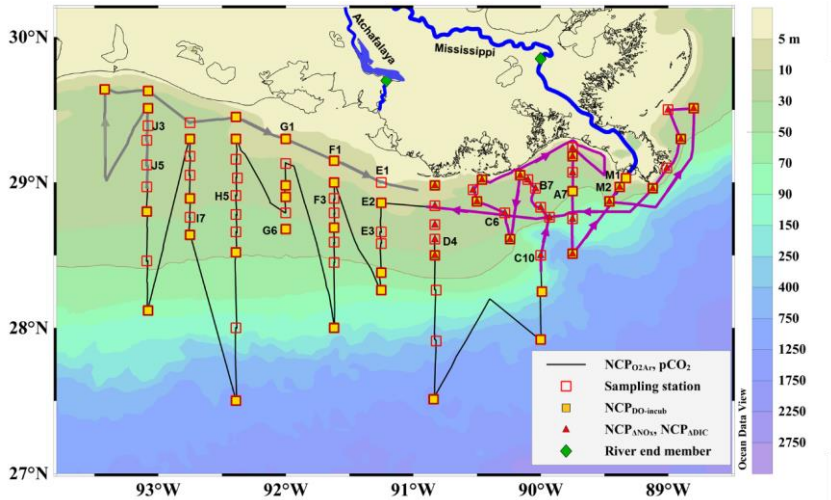


Fig. 1. Map and sampling sites in the northern Gulf of Mexico during the April 2017 cruise. The black dotted line is the cruise track along which the high-resolution underway measurements were made. The track in the Mississippi plume (purple line, 8-11 April) and in the Atchafalaya coastal regions (grey line, 15-17 April) are highlighted. Also shown are the 83 CTD sampling stations (hollow red squares), the 43 stations where light/dark bottle DO incubations were conducted (solid yellow squares), the 30 stations where non-conservative changes in DIC and NO_x were used to estimate NCP rates (solid red triangles), and the 2 stations where the properties of river end members were measured (solid green diamonds). The vertical CTD profiles of the labelled stations were shown in the supplement.

7. Page 3, line 23: “rephrase: "at 83 sampling stations" at the end of the sentence”
Response: Revised as suggested.

8. Page 3, line 24: “active”
Response: Corrected.

9. Page 4, lines 1-2: “of what?”; “change and for a ","”; “profiles or water column profiles”, “remove, you said the brand already in the sentence above”.
Response: This sentence has been revised to now state “Discrete water samples for DIC, TA, DO, and nutrients were collected from 3-12 depths depending on the bottom depth and vertical profiles of temperature, salinity and DO.”

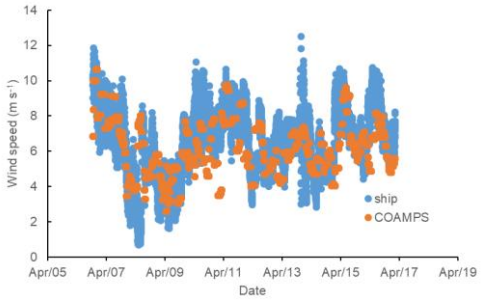
10. Page 4, lines 7-8: “precision and accuracy are not the same thing, you can not give one value for both”, “? why do you cite? did you measure you own accuracy?”
Response: These sentences have been revised to now state “The precision of DIC and TA measurements were both 2 μmol kg^{-1}. DIC and TA measurements were calibrated, both with accuracy better than 0.1%, with certified reference materials provided by A. G. Dickson, Scripps Institution of Oceanography.”

11. Page 4, line 10: “include this two points in the map”
Response: These two sampling points have been included in the updated Fig. 1.

12. Page 5, line 11: “why air and not water equilibrated with air? Give reference of who does calibration with air.”; “the instrument precision needs to be calculated for your instrument, as it may differ from Cassar's equipment”
Response: The calibration of the O_2/Ar instrument was carried out according to an established method by measuring air as the atmospheric O_2/Ar is essentially constant (Cassar et al., 2009). We have added the reference for the calibration procedure and described the instrument precision as “As the atmospheric O_2/Ar is essentially constant relative to that in the surface water, calibrations of the O_2/Ar ion current ratio were conducted by sampling the ambient air every 3 hours through a second capillary (Cassar et al., 2009). The instrument precision estimated from the repeated measurements of atmospheric O_2/Ar ratio was 0.3%.”

13. Page 5, line 13: “Merge 2.3 and 2.4 and use subheadings for the different calculations.”
Response: As the NCP estimates involved several different methods and unit conversion, we think it is better to describe NCP in a separated section.

14. Page 5, line 20, “probably because COAMPS use the buoys data as well. What about the wind measured from the ship?”
Response: The COAMPS wind speed also agreed well with the ship measurement (see the figure below). As wind measured from the ship refers to instantaneous speed while biogeochemistry signals and air-sea flux change on a longer time scale, the daily averaged COAMPS wind speed is preferred in our study. Because the O_2 and CO_2 fluxes were calculated from the same wind speed, using COAMPS data or ship measurement won’t affect the discussion on the relationship between O_2 and CO_2 fluxes.



Comparison between COAMPS wind speed and ship wind measurements

15. Page 5, line 23: "why? and what happen when sea values are close to 405? what % of the sea values where close to 405?"
Response: Paired pCO_{2smeas} and pCO_{2air} are needed for the calculation of air-sea CO_2 flux (Eq. 1). In our study, the underway pCO_2 measuring system switched between the measurements of pCO_{2smeas} and pCO_{2air}. pCO_{2air} was only measured every 3 hours in order to better capture the variability of pCO_{2smeas} and as pCO_{2air} is not expected to change rapidly. "Comparing to the large variations in pCO_{2meas} (110-1800 µatm), the variability of pCO_{2air} was minor (405 ± 4 µatm) so the pCO_{2air} was set at the cruise average value of 405 µatm for the flux calculation." This is a common practice for CO_2 flux calculation in the CO_2 community. When pCO_{2meas} value is close to 405 µatm, the seawater is close to be equilibrium with the atmosphere and the CO_2 flux is close to zero.

16. Page 6, line 1: "define the term before saying how it was calculated"
Response: The definition of γ_{DIC} is "the pCO_2 buffer factor response to change in DIC", so it has already been defined in this sentence. However, this variable (shown in the original Fig. 10) is not very useful in our discussion. It has now been removed from the revised manuscript as the original Fig. 10 (now Fig. 11) was revised without showing this variable.

17. Page 6, line 4: "it is not clear if you calculate oxygen fluxes from the optode, incubations?"
Response: The oxygen fluxes were calculated from the high resolution optode measurements (not from incubations). We have clarified this in the revised manuscript as: "$\Delta O_{2(sea-air)}$ is the difference between the seawater DO concentration from the calibrated underway optode measurement ($[O_2]_{meas}$) and the saturated DO concentration ($[O_2]_{sat}$) calculated from the measured sea surface temperature and salinity (Garcia and Gordon, 1992).".

18. Page 6, line 8: "This section can be reduced by removing the majority of the explanatory equation, leaving only the main ones and citing the authors or papers where the equations are explained."
Response: We have shortened this section as suggested.

19. Page 6, line 10: “you can simplify the subindex, no need to say write incub, it has been already explained.”
Response: In order to make these variables readily understood in figure legend, we have chosen to keep the subindexes as they were originally described.

20. Page 6, line 13: “cite Craig and Hayward [1987]”; “you give details bellow. remove this part of the sentece.”
Response: Revised as suggested.

21. Page 6, line 14: “dissolved oxygen concentration in the surface water is affected by physical (e.g., changes in temperature, salinity and atmospheric pressure, bubble dissolution and/or injection) and biological processes (photosynthesis and respiration) (Fig 2).”
Response: Revised as suggested.

22. Page 7, line 1: “how did you arrive to the equation? say something.”
Response: This sentence has been revised to now state: “By measuring the biologically mediated oxygen supersaturation $\Delta(O_2/Ar)$ (Cassar et al., 2011; Craig and Hayward, 1987; Jonsson et al., 2013; Kaiser et al., 2005)…”

23. Page 7, line 4: “double check this this equation with Kaiser 2005 and Cassar 2011, I do not think it is totally correct.”
Response: We confirmed that this equation is correct (see equations 1 and 3 in Cassar, 2011). According to minor comment 18, this explanatory equation has been removed and only one main equation is now presented in the revised manuscript: $NCP_{O2Ar} = \text{bioflux} = k_{O2}[O_2]_{sat}\Delta(O_2/Ar)$

24. Page 7, line 17: “you have to explain here how you passed from O2 units to C.”
Response: The unit conversions of NCP estimates were described in the original manuscript (page 9, lines 17-18) and in the revised manuscript (page 9, line 20 to page 10, line 4).

25. Page 7, line 23: “what did you do with the dark ones?”
Page 8, line 7: “you do not say how this samples where incubated.”
Response: Change text to: “Clear and dark bottles were placed into a deck incubator screened at 50% of ambient sunlight for 24 hours. The deck incubator was plumbed with flowing seawater from the MIDAS system in order to maintain surface water temperatures.”

26. Page 8, line 3: “how many samples? SD of the spectrophotometric method etc?”
Response: Clarified by adding the following “DO concentrations obtained from the LDO probe were verified by comparison to DO concentrations measured by the spectrophotometric method of Pai et al., (1993) in a subset of samples (n = 14). The mean difference between the two methods of ±5% was consistent with previous comparisons of probe measured versus Winkler measured DO based on several hundred comparisons (Murrell et al. 2013).”

27. Page 8, line 7: “Did you do it as somebody else who publish before? cite. GPP=NCP-R, not sure how you calculated GPP”
Response: In our study, gross primary production (mmol O_2 m^{-3} d^{-1}) was calculated as GPP = $R_{DOlight}$ + $|R_{DOdark}|$, where $R_{DOlight}$ is the change in DO in the light bottles during the 24-h incubation and is equivalent to NCP in these bottles, and R_{DOdark} is the 24-h respiration-induced change in DO in the dark bottles. As R_{DOdark} is negative, our equation GPP = $R_{DOlight}$ + $|R_{DOdark}|$ is equivalent to GPP = NCP - R.

28. Page 8, line 15: “Integration calculation is different than for respiration. Need to justify it better or cite.”
Response: In our study, the respiration rate was assumed to be uniform in the mixed layer and the integrated respiration over the MLD ($Resp_{Int}$, mmol O_2 m^{-2} d^{-1}) was calculated as $Resp_{Int}$ = R_{dark}*MLD. However, the gross primary production (GPP) varied with depth due to the reduction in light availability with increasing depth. To calculate the integrated GPP in the mixed layer (GPP_{Int}, mmol O_2 m^{-2} d^{-1}), the GPP was scaled by the light environment in the MLD. We have clarified our calculation in the revised manuscript (page 8, lines 3-21).

29. Page 8, line 10: “NOT sure about this equation, please CITE does it comes from BEER-LAMBERT? PIERSON 2008?”
Response: Reference (Lohrenz et al., 1999) has been cited.
Lohrenz, S.E., Fahnenstiel, G.L., Redalje, D.G., Lang, G.A., Dagg, M.J., Whitledge, T.E. and Dortch, Q., 1999. Nutrients, irradiance, and mixing as factors regulating primary production in coastal waters impacted by the Mississippi River plume. *Continental Shelf Research*, *19*(9), pp.1113-1141.

30. Page 9, line 17: “I couldn't access to the whole paper but looks like there are extensive studies of this river that may provide tau, for example: Lane, Robert R., et al. “Seasonal and Spatial Water Quality Changes in the Outflow Plume of the Atchafalaya River, Louisiana, USA.” Estuaries, vol. 25, no. 1, 2002, pp. 30–42. JSTOR, www.jstor.org/stable/1352905.”
Response: Although there were some previous studies on the Atchafalaya River (including the one provided by the reviewer), plume resident time for different salinity ranges were currently not available from the literature.

31. Page 10, line 2: “this figure needs to improve x axis”
Response: The x axis label “month” has been added and the numbers 1-12 have been replaced by the meaningful dates “Jan, Feb, …Dec”.

32. Page 10, line 19: “the reader doesn't have to know where is Texas and you already said westward, remove Texas”
Response: Corrected.

33. Page 10, line 19: “from when is this data?”

Response: This sentence has been revised to state "The pattern of the Mississippi and Atchafalaya freshwater transport agreed well with the multiple-year average **(2005-2010)** condition in April by numerical simulation (Zhang et al., 2012)."

34. Page 11, line 1: "remove this"
Response: The repetitive word has been removed.

35. Page 11, line 4: "remove brand name"
Response: Corrected.

36. Page 11, line 8: "this should go up much earlier in the text! just before speaking about figure 5"
Response: Revised as suggested.

37. Page 11, line 24: "this can be due to sedimentation, more light than insitu"
Response: We fully agreed with the reviewer. In the revised manuscript, we have added vertical profiles of light transmittance in different regions (Figs. S2-S4) and discuss the potential bias in light/dark incubation method: "More importantly, for high-turbidity water samples (e.g., samples collected in the Mississippi River channel and in the HTACW), the incubated samples were not mixed in the same way as that in the natural environment and the sedimentation of particles in incubation bottles could alleviate the light limitation for phytoplankton. As a result, the gross primary production (GPP_{Int} in Eq. 8) could be overestimated and $NCP_{DO\text{-}incub}$ would not represent the true *in situ* NCP in but high-turbidity waters but as an overestimation." (page 14, lines 9-13).

38. Page 12, line 1: "subplots of figure 7 and 8 show the same information several times. It is confusing for the reader have to look at both. Choose one represent better what you are explaining and cite only one per time."
Response: The original Fig. 7 (now Fig. 6) is chosen to present the Mississippi results.

39. Page 12, line 1: "instead of calling region 1 2 3 in the text and the graphs, call it by this headaings names, both in the text and in the graphs. remove the regions words
Response: Revised as suggested.

40. Page 12, line 2-3: "Fig 7a"; "give values in brackets"; "Fig 8a";
Response: Revised as suggested.

41. Page 12, line 7: "only 8c"
Response: Revised as suggested.

42. Page 12, line 9: "choose"
Response: Corrected.

43. Page 12, line 8: “minus”
Response: Corrected.

44. Page 12, lines 16-18: “you have to explain this figure first. If it is important it should be a main figure and not as supplementary plot”; “number doesnt agree with figure”
Response: This figure has been moved to the main text and explained. Note that the numbers here are the deviations of DIC and NO_x from the conservative mixing lines but not the absolute concentrations. To clarify this, these sentences have been revised to now state “For both the Mississippi and Atchafalaya plume regions, the three end-member mixing model suggests that the enhanced biological production resulted in significant deviations of DIC and NO_x from their conservative mixing lines (Fig. 8). The amplitudes of the non-conservative biological removal of nutrients (up to 35 μmol kg^{-1} in ΔNO_{xNCP}, Fig. 8a) and DIC (up to 250 μmol kg^{-1} in ΔDIC_{NCP}, Fig. 8b) are similar to the findings of previous studies in the nGOM (Cai, 2003; Guo et al., 2012; Huang et al., 2012).”. Please also see the response to major comment 6.

45. Page 12, line 22: “you said before that chla was low in the Missisipi region. Here you say that Atchafalaya region is chracterized by elevated Chla, but the values are lower than Missisipi region. You have to correct this.”
Response: Here we compared the observation results in the Atchafalaya plume with those in the Mississippi plume (both with elevated Chl-a concentrations in mid-salinity range). Note that low Chl-a concentrations were only observed in the lower Mississippi river channel.

46. Page 13, lines 2-6: “together”; “give numbers”
Response: Revised as suggested.

47. Page 13, line 22: “this graphs shows the MLD but without the sea bed depth we cannot know if there is stratification or not”
Page 13, line 25: “You just said above that the water column was stratified”; “if you said that it is mixed until the bottom, there is no separation between mixed layer and below, do not understand this sentence.”
Page 14, line 1: “I do not see why that would be add uncertainty. Mixed layer represent better fluxes because in contact with the atmosphere, but if the whole water column is mixed, then all water column is in contact with the atmosphere and that is not a bias”
Page 14, line 14: “if it is mixed layer what you sampled, everything is mixed, cannot be heterogeneity inside the mixed layer. You can test this from chla profiles for examples”
Response: Please see our responses to major comment 3.

48. Page 14, line 15: “I think one of the bias here may be the turbidity. If the incubated samples are not mixed in the same

way as natural water, the majority of the sediment probably sink to the bottom of the bottle and the light availability is bigger than in natural waters overstimating NCP."
Response: Please see our response to minor comment 37.

49. Page 14, line 22: "Why are there errors when calculating MLD?"
Response: This sentence has been revised to now read "errors in estimating water residence time and the changes in MLD over the transit time of the plume water lead to proportional errors in the calculation of $NCP_{\Delta DIC}$ and $NCP_{\Delta NOx}$ (Eq. 13 and Eq. 14)".

50. Page 14, line 23: "IS THE co2 flux fast enought to cause this?"
Response: No, the CO_2 flux is generally small compared to NCP (< 10% in most reports); but O_2 flux is nearly the same as NCP. In the revised manuscript, the DIC changes induced by air-sea CO_2 exchange has been considered in calculating the biological-induced changes in DIC (Eq. 8).

51. Page 15, line 3: "here is the only place were you have the four methods. Why in figure 4 seems to agree better than in figure 8? why there are more data point in this figures than sampling point? "
Response: The NCP data presented in the original Fig. 4 and Fig. 8 were the same dataset and the numbers of data points in these two figures were identical to the sampling sites shown in Fig. 1 (n = 43 for $NCP_{DO\text{-}incub}$, n = 30 for $NCP_{\Delta DIC}$ and $NCP_{\Delta NOx}$). These data were more evenly distributed along with time in Fig. 4 but were clustered in the salinity range of 25-30 in Fig. 8.

52. Page 15, line 10: "this can be due to the bottle incubation method that may have exclude grazers. Did you do replicates? how was your standar deviation? if big that would be a reason"
Response: Grazers might be a factor which affected the bottle incubation. "The standard errors of $NCP_{DO\text{-}incub}$ from triplicate bottle incubations across all sites were on average about 16 % of the mean." (page 8, line 21)

53. Page 15, line 11: "you are contradicting again yourself here. If the water column is well mixed, there is not stratification and therefore no mixed layer and pycnocline."
Response: This comment has been taken. In the well-mixed water column, there is no stratification and mixed layer and our measurements reflect the water column NCP rate (Fig. 9b). We have corrected this throughout the manuscript.

54. Page 15, line 16: "there can be understimation if euphotic depth is deeper than mixed layer, but if you took all your four methods at the same depths, there is no bias in the comparison of the methods"
Response: We agree with this comment. As the samples for the four methods were all collected in the surface water, the production beneath the pycnocline did not result in bias in the comparison if no upwelling occurred. This sentence has been deleted.

55. Page 15, line 24: “that could be a result of”
Response: Corrected.

56. Page 16, line 7: “Did you explained anywhere that the values has been averaged? and why?”
Response: There is an ecological gradient along the river-ocean mixing continuum in the Mississippi plume: from high nutrient and turbid freshwater to clear, oligotrophic offshore oceanic waters. Data were averaged over increments of two salinity units in Figure 7 to better present the variations along the increasing salinity. We now explain this both in the main text and in the figure caption.

57. Page 16, lines 11-15: “I do not understand this sentence. Do you mean it was heterotrophic in the river and autotrophic at higher salinities? “; “could be. You didnt measured benthic respiration so you can only use hypotheses”
Response: As the water column in the lower Mississippi River channel was stratified (Fig. S2), benthic respiration had minor contribution to affect the NCP_{O2Ar} in the mixed layer. Whereas, the advection could play a significant role influencing the surface NCP_{O2Ar} signal in the Mississippi River channel due to the short water residence times. In the revised manuscript, the heterotrophy in the lower Mississippi River channel suggested by the negative NCP_{O2Ar} were discussed in Section 4.1. “In the stratified lower Mississippi River channel (Fig. 9a), the influence of lateral transportation of the heterotrophic river water from the upper river channel was significant because of the short water residence time (~1 day, Green et al., 2006). Therefore, the heterotrophic condition in the lower Mississippi River channel could be attributed to the dominant influence of the heterotrophic NCP_{adv} over the local biological production.” (page 16, lines 4-15).

58. Page 16, line 11: “minus”
Response: Corrected.

59. Page 16, line 23: “You can find this explained in Seguro et al 2015 (The presence of a chl a peak in the middle of the inner part, after the salt wedge, is a typical feature of stratified and partially stratified estuaries (Voorhis et al., 1983; Collins and Williams, 1981; Humborg et al., 1997; Cloern et al., 2013). This happens because the decrease in turbidity allows a deeper photic layer than the mixing layer in the middle of the estuary (Sverdrup, 1953) where high concentrations of inorganic nutrients are still available (Figs. 3 and 5).)”
Response: Thanks for pointing out this. These references have been added.

60. Page 17, line 17: “you have to explain this graph first, what is the meaning of each quadrant”
Page 17, lines 17-21: there is a blue shadow in the text...which is coincident with an statement that said that both plumes have opposite patterns. I disagree, opposite patterns would be one plume in quadrant 4 and another in quadrant 2 or 3 and 1”; “this sentence is not clear”; “I think the author was trying to speak about Mississippi plume and HTACW?”
Response: We do agree with the reviewer that quadrant 4 and 2 (or 3 and 1) show the opposite pattern. This figure is explained and discussed in the revised manuscript as: “When plotting the paired CO_2 flux and NCP_{O2Ar} data (Fig. 10),

most data collected in the lower Mississippi River channel fall in quadrant 2 suggesting net heterotrophy coupled with CO_2 outgassing to the atmosphere. The Mississippi plume and Atchafalaya plume exhibited opposite patterns with most data in these regions being in quadrant 4 (net autotrophy coupled with CO_2 uptake from the atmosphere). However, the data in quadrant 1 (autotropic water as a CO_2 source observed near the Mississippi estuary) and quadrant 3 (heterotopic water as a CO_2 sink in the HTACW) suggest decoupling between NCP_{O2Ar} and CO_2 flux." (page 18, lines 17-22)

61. Page 18, line 2: "i THINK THIS DISCUSSION would benefit from including the different residence times of CO2 and O2, as degassing would not occur at the same speed because of different solubilities of o2 and co2."
Response: Please see the response to minor comment 2.

62. Page 18, line 10: "I would add this to the M & M section"
Response: The model description has been moved to the Methods section as suggested.

63. Page 19, line 17: "As explained abpve, I do not agree with this"
Response: See the response to major comment 3.

64. Page 25, line 20: "several typos"
Response: Corrected.

65. Page 27, line 9: "purple line"; "blue line"
Response: Corrected.

66. Page 31, line 2: "It is not clear how figure a and b has been created. Why region 3 is close to 0 in one plot but high numbers in the other? and the same happen with regions 1 and 2. If there is no data, the regions should be white colour."
Response: This figure presented the results of the three end-member mixing model showing the composition of the surface water. Panel (a) showed the fractional contribution of the Mississippi River end member and higher values indicated more significant influence of the Mississippi plume. The same applied to panel (b) for the Atchafalaya River end member. In the revised manuscript, we removed the original panels (c) and (d) according to the major comment 8 by reviewer 2. Instead, we presented the fractional contribution of the offshore surface water end member in the updated panel (c) to better show the results of the three end-member mixing model (see the figure below).

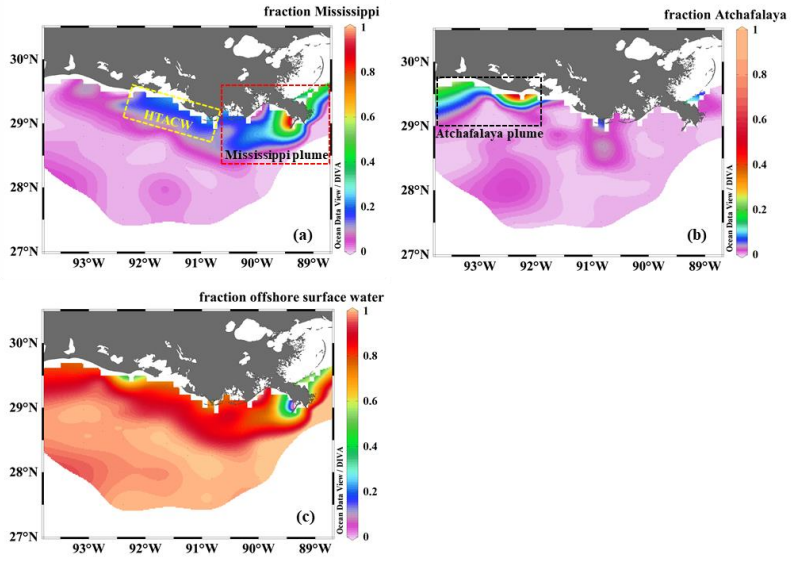


Fig. 4. The fractional contribution of (a) the Mississippi River, (b) the Atchafalaya River, and (c) offshore surface water to the surface water of the nGOM estimated from the three end-member mixing model. The sub-regions shown in panels (a) and (b) are the Mississippi plume, the high-turbidity Atchafalaya coastal water (HTACW), and the Atchafalaya plume.

67. Page 34, line 2: "would it be posible to put the coloured boxed underneath? if not, just finish the box before covering the labels at the bottom, at the end of the y axis."
Response: Revised as suggested.

68. Page 34, line 2: ", CO2 flux and NCP O2/Ar"
Response: Corrected.

69. Page 34, line 4: "why?"
Response: See the response to minor comment 56.

70. Trying to be consistent in the symbols and colours of Figure 7, seems that you accidentally exchanged the colour and symbol of two regions.
Response: The figure legend has been corrected.

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Murrell, M. C., and Lehrter, J. C. 2011. Sediment and lower water column oxygen consumption in the seasonally hypoxic region of the Louisiana Continental Shelf. Estuaries and Coasts, 34, 912-924.

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Reviewer 2:

General comment:

The authors present results of Net Community Production (NCP) in waters of the northern Gulf of Mexico system which includes a portion of the downstream Mississippi and Atchafalaya rivers, and the continental shelf where these rivers discharge in the Gulf of Mexico. The NCP was estimated through four different methods: continuous O2/Ar measurements, light/dark bottle incubations, DIC and NOx measurements. The authors also analyzed the relation between the NCP and pCO2 measurements to complete a picture in the metabolic state of the northern Gulf of Mexico (nGOM). The measurements were done during spring and summer in 2017 at an extensive network of stations sampled in vertical profiles and in continuous underway measurements along the ship track. The authors discuss the difference between the results from the different methods to estimate NCP. Their results show that during the sampling period and along the surveyed areas, the river headwaters are heterotrophic, while autotrophy (signaled by the highest measured NCP) characterized the continental shelf. With a 1-D model, the authors demonstrated a temporal mismatch between the estimated gas exchange and biological production, i.e. due to a decoupling between CO2 fluxes and NCP, at the time of the measurements, and this could be related to the presence of pCO2 transported from headwaters identified in areas where local productivity hints to dominant heterotrophy. The results of this work are interesting because the authors combine the traditional pCO2 measurements to NCP values to better understand the metabolism of the Gulf of Mexico shelf system.

Unfortunately, I find that the quality of the presentation of results, as well as the text itself lacks scientific rigor. The authors make a big effort on trying to explain the results and make use of assumptions that were not really proven by their results (such as the presence of benthic respiration to justify NCP-water column integrated heterotrophy) and make no effort to investigate further the role of physical factors. At this stage, I cannot recommend this manuscript for publication in Biogeosciences. I list major and minor comments in a supplementary pdf aiming to provide a more detailed review. I recommend the authors to consider these comments if they think they might be useful to improve their work.

Please also note the supplement to this comment: https://www.biogeosciences-discuss.net/bg-2019-88/bg-2019-88-RC2-supplement.pdf

Response: We sincerely thank the reviewer for pointing out the weaknesses of our original manuscript and providing constructive comments and suggestions, which significantly improve the quality of this manuscript. In the revised manuscript, we present vertical profiles at typical stations (the newly added Figs. S2-S4 in the supplement) to better describe the different stratified or well-mixed mixing conditions. The influences of physical processes including vertical mixing and lateral advection on the NCP estimated from different methods are discussed (see the response to major comment 5 and section 4.1 in the revised manuscript). Aside from the uncertainties and errors of different methods, we showed that the contrasting results of different methods can be mainly explained by the different spatial and temporal scales associated with these methods responding to the mixing conditions. In addition, we have revised the manuscript throughout to improve English and scientific rigor according to the detailed suggestions from both reviewers.

Review for manuscript bg-2019-88

"Spring net community production and its coupling with the CO2 dynamics in the surface water of the northern Gulf of Mexico" by Jiang et al.

Major comments:

1. The manuscript will benefit greatly by going through a thorough revision on the English language. I am myself not a native speaker, but I can still identify many mistakes in the wording, spelling mistakes, punctuation, etc. I list some examples in the minor comments, but the mistakes are so many that it is impossible to correct all through this review. In this context, the authors also make use several times of subjective terms without giving quantities to justify, e.g. "moderate", "rapid", "deeper", "higher". These words should be avoided or accompanied by a quantity to reference the use of the adjective.
   Response: A thorough revision on the English language has been done by our coauthors who are native English speakers. Subjective terms have been avoided or accompanied by quantities as suggested.

2. The aims of the manuscript are not clearly stated. On the one hand, they aim to compare NCP estimates from four different methods, and on the other hand, they aim also to compare the relation NCP vs. pCO_2 in the area of study. But I think before aiming the second, they should clearly state early in the manuscript what is the purpose of comparing NCP from different methods? What is the gain and need of doing so?
   Response: The main purpose of this manuscript is to better understand the spatial variability of NCP and pCO_2 in the nGOM and to investigate the relationship between NCP and CO_2 flux. Previous NCP studies in our study region have been mainly based on the light/dark incubation and non-conservative changes in DIC and NO_x. However, the detailed relationship between NCP and CO_2 dynamics remains unclear because of the low spatial resolution of the conventional NCP measurements based on discrete samples. To our knowledge, this work is the first attempt to obtain high-resolution NCP_{O2Ar} estimates from continuous O_2/Ar measurement in the nGOM. We thus compared the O_2/Ar result to those from the existing methods to evaluate the consistency of NCP estimates from various methods. Meanwhile, each of the methods have different advantages and shortcomings. By making NCP estimates using the different methods we can get a more robust understanding of the overall metabolism of the system. In the revised manuscript, the purpose of comparing NCP from different methods has been better described in the introduction section and improved method comparisons have been presented in section 4.1.

3. The authors list in the discussion section (Pag. 13-14), mostly the disadvantages of applying the different methods for NCP determination. After reading all these disadvantages and limitations in each method, I see difficult to justify a comparison between these methods at all and making this as one of the main aims for this study. Further, the comparison between the four methods for NCP estimates was also done in only few stations. The authors finally compare the NCP_{O2Ar} vs pCO_2 because both have high spatial resolution, hence proving that the methods comparison done in this work does not contribute substantially to the results presented in this work.
   Response: As previous estimates of NCP for this shelf have mainly been based on light/dark incubations and non-conservative changes in DIC or nutrients, we think it is important to understand how the high spatial resolution NCP_{O2Ar} and the existing methods compare. Similar comparison of NCP estimated from multiple approaches has been carried out by Ulfsbo et al., (2014) in the central Arctic Ocean. Although uncertainties are associated with different approaches and

there was a high variability in NCP over our studied area, we found encouraging agreement among these methods showing elevated NCP rates in the plume regions. In the revised manuscript, we further discussed how different mixing conditions affected the NCP rates estimated from different methods. The DO incubation method represents the NCP by the local plankton community while the O_2/Ar method reflects the metabolic state of the water relating to both biological and physical processes. The comparison of different methods provides us with additional information about the metabolism of the system that is greater than the sum of the individual methods, especially for the regions where their results contrasted (e.g., in the lower Mississippi river channel and in the high-turbidity Atchafalaya water). Please see the revised section 4.1 for details.

4. The methods section lacks of detail and scientific rigor in many parts:
   a) the authors do not show the vertical resolution of the sampled profiles, why they were not done at the same standard depths within each max. depth of the water column?
   Response: Bottom depth varied significantly in our study region from nearshore (a few meters) to offshore (a few thousand meters). As a result, discrete water samples were taken from 3-12 depths depending on the bottom depth and the vertical structures of temperature, salinity and O_2. We sampled standard depths at offshore stations with bottom depth deeper than 200 m. In the nearshore and shelf region, standard depths were preferred but sometime we collected samples at non-standard depths to better characterize the vertical variability. Meanwhile, this study focused on the surface water and the samples for NCP and pCO_2 were all collected within the MLD: samples for NCP_{O2Ar} and pCO_2 were collected from the underway system at a depth of ~2.5 m, while the discrete samples used to derive $NCP_{DO\text{-}incub}$, $NCP_{\Delta DIC}$ and $NCP_{\Delta NOx}$ were collected from the Niskin bottles at ~1.5 m.
   b) No mention of duplicate or uncertainties analysis.
   Response: Information on precision and uncertainties analysis has now been added.
   c) How often were the pCO_2 measurements calibrated? (it is only stated regularly)
   Response: Clarified as "The pCO_2 measurement was calibrated **twice daily** against 3 certified gas standards (150.62, 404.72, and 992.54 ppm) and has a precision of 0.1 µatm and an accuracy of 2 µatm."
   d) Overall the way they are written are all over the place and not rigorously written
   Response: We have revised the methods section thoroughly to improve scientific rigor.
   e) There is no sufficient rigor on writing the equations, e.g. one should not include the units in the equation itself but rather in the text when explaining the variables.
   Response: Equations have been revised as suggested.

5. The authors did not show vertical profiles to evidence their claim that most of the sampled water columns were well mixed. Also, they mention that there is a strong stratification due to buoyancy of the fresher river water plume above the oceanic shelf water. I find hard to believe that it is justifiable to assume steady state in the NCP_{O2Ar} determination. At least, the contribution of horizontal processes into the shelf O_2 budget should have been investigated. I think the authors fall short here by simply assuming steady state, particularly after several works have proven in the past that physical contributions during this method must be considered at best. A great scientific contribution would be for the authors to

provide an effort on quantifying the influence of horizontal processes into the NCP by O_2/Ar measurements.

Response: We sincerely thank the reviewer for pointing out the importance of physical influences on the NCP estimation. The typical vertical profiles for well-mixed and stratified systems have now been added as supplemental figures (Figs. S2-S4). Most of our study regions were characterized by stratification (in the lower Mississippi river channel, Fig. S2 and in the plume and offshore regions, Fig. S3), while well-mixed water column was observed in limited nearshore waters in the Atchafalaya coastal region (Fig. S4).

In the revised manuscript, we present a new figure (Fig. 9) to show the differences in water column mixing conditions in the nGOM and their influences on NCP estimation. The influences of physical processes (lateral advection and vertical mixing) have now been discussed in section 4.1 in the revised manuscript and are briefly summarized as follow:

The DO incubation method is a direct measurement of NCP by plankton community and this method is free from the influences of lateral advection and sediment metabolism. The $NCP_{DO\text{-}incub}$ thus equals the MLD-integrated NCP in the stratified regions (NCP_{MLD} in Fig. 9a, c) or the water column-integrated NCP in the well-mixed regions (NCP_{water} in Fig. 9b). In the stratified regions, the influences of sub-pycnocline ($NCP_{sub\text{-}MLD}$ in Fig. 9a, c) and benthic metabolisms ($NCP_{benthic}$ in Fig. 9a, c) on the surface O_2/Ar ratio were expected to be minor. On the contrary, the surface O_2/Ar ratio in the well-mixed nearshore regions (e.g., the HTACW, Fig. S4) was affected by the water column NCP_{water} as well as the $NCP_{benthic}$ contributed by benthic metabolism (Fig. 9b). Moreover, both Mississippi and Atchafalaya river end members were highly heterotrophic and the lateral transportation of heterotrophic signal carried by the river water (NCP_{adv} in Fig. 9) should be considered. Therefore, NCP_{O2Ar} reflects the combined result of the NCP_{MLD} and NCP_{adv} in the stratified region, and it reflects the combined result of NCP_{water}, $NCP_{benthic}$, and NCP_{adv} in the nearshore well-mixed shallow system. As $NCP_{benthic}$ only affected a small portion of the nearshore water in the Atchafalaya coastal region, the NCP_{O2Ar} measured in this study was mainly modulated by NCP_{MLD} and NCP_{adv}. Considering the nGOM as a whole, lateral advection of NCP_{adv} can be considered as internal transport within the system given that the NCP_{O2Ar} was measured with adequate spatial coverage. As a result, the NCP_{O2Ar} measured in this study well represented the overall metabolic state of the surface water of the nGOM.

We also explained why $NCP_{DO\text{-}incub}$ and NCP_{O2Ar} provided contrasting results in the Mississippi River channel and in the HTACW (see our responses to major comment 7 below).

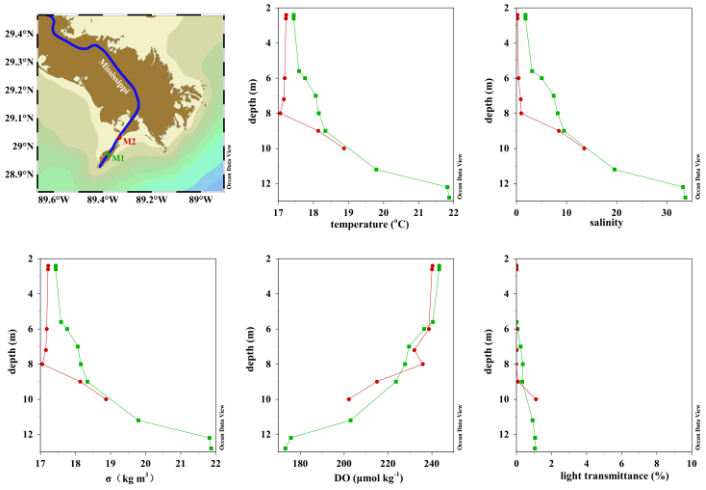

Fig. S2. Vertical profiles of (a) temperature, (b) salinity, (c) density anomaly, σ = density (kg m^{-3}) – 1000, (d) DO, (e) light transmittance in the lower Mississippi River channel. The different symbols correspond to the measurements from different sites shown in the map in the upper left corner.

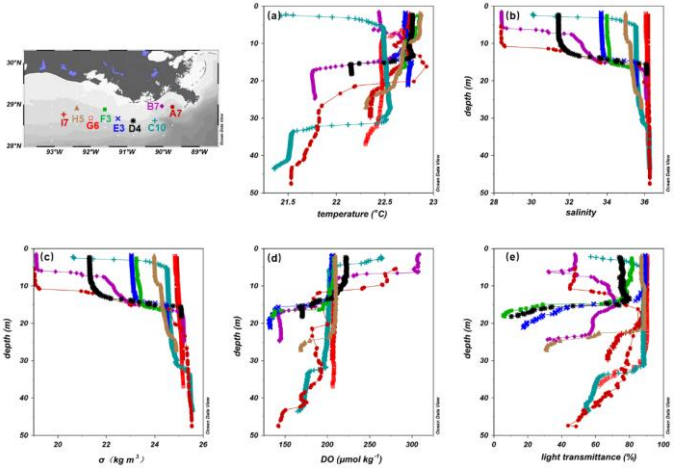

Fig. S3. Vertical profiles of (a) temperature, (b) salinity, (c) density anomaly, σ = density (kg m^{-3}) – 1000, (d) DO, (e) light transmittance at the stratified offshore region. The different symbols correspond to the measurements from different sites shown in the map in the upper left corner.

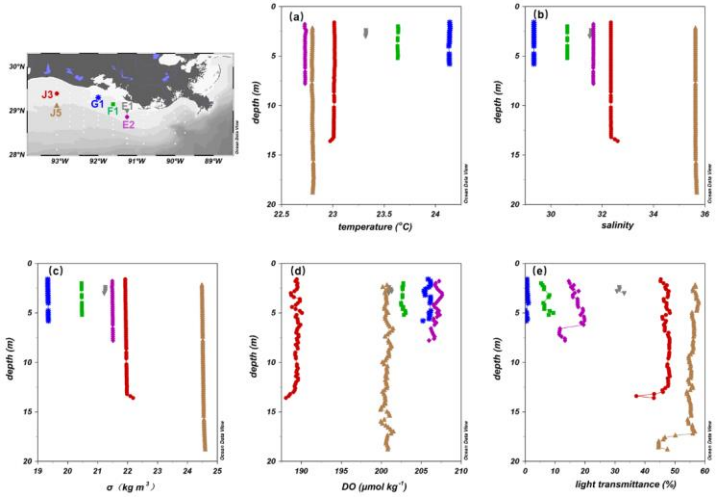

Fig. S4. Vertical profiles of (a) temperature, (b) salinity, (c) density anomaly, σ = density (kg m^{-3}) – 1000, (d) DO, (e) light transmittance in the well-mixed Atchafalaya coastal region. The different symbols correspond to the measurements from different sites shown in the map in the upper left corner.

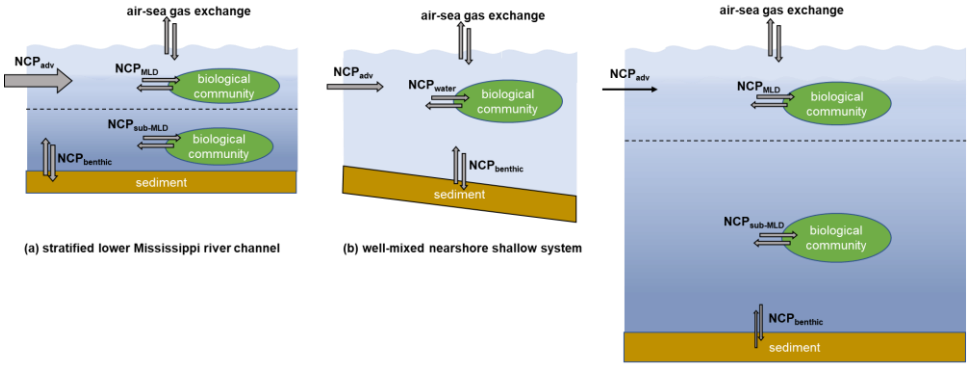

Fig. 9. The differences in water column mixing conditions in the nGOM and their influences on NCP estimation. The dotted lines in panels (a) and (c) indicate the mixed layer depth. In the stratified lower Mississippi River channel (a) and the offshore stratified system (c), $NCP_{DO\text{-}incub}$ equals the *in situ* community production in the mixed layer (NCP_{MLD}), while NCP_{O2Ar} reflects the combined result of the NCP_{MLD} and the influence of lateral advection of the river water (NCP_{adv}). In the nearshore well-mixed shallow system (b), $NCP_{DO\text{-}incub}$ equals the water column community production (NCP_{water}), while NCP_{O2Ar} reflects the combined result of NCP_{water}, $NCP_{benthic}$, and NCP_{adv}. Note that the influence of NCP_{adv} decreases offshore with the increasing water residence time.

6. During the preparation of samples for the $NCP_{DO\text{-}incub}$, the authors mention that after initial measurement of DO, there was a compensation of volume in the incubation bottle by adding an extra volume of water. I find this problematic, by doing this there is introduction of DO from the new added water volume to the sample, hence it will change the initial measured DO conditions. By looking at the results of those 3 stations in the Mississippi river channel (results mentioned in P11, L21-23), it looks like while NCP_{O2Ar} resulted in negative values, the $NCP_{DO\text{-}incub}$ showed positive values, and I wonder how much of that difference is rather the influence of the addition of DO by the volume compensation? Are those the same three points shown in Fig. 4c of the Mississippi plume with high $NCP_{DO\text{-}incub}$ values? Also, consistently $NCP_{DO\text{-}incub}$ is higher than NCP_{O2Ar} also for the Atchafalaya plume. Indeed, incubation methods tend to bias the result due to a lack of homogeneity in the collected sample, and the authors should discuss these differences in the context of methods comparison. However, the introduction of a volume of water has another connotation, hence, I have no reason to trust the $NCP_{DO\text{-}incub}$ results and believe in these differences and going further discussing potential heterotrophy and autotrophy.

   Response: The addition of DO was not corrected because the replacement volume (~ 3 ml) represents on average about 1% of the incubation volume (300 ml) and the addition of any O_2 in the replacement water was negligible. Even in an extreme case, for example a DO concentration of 0 in the bottle and 200 mmol m^{-3} in the replacement volume, the addition of the replacement water would change the DO in the bottle by 2 mmol m^{-3}, which is near the detection limit for this method of ~ 2 mmol m^{-3} d^{-1} (Murrell et al. 2013). Another previous study with this method also found the correction was negligible (Murrell et al., 2009). The high values of $NCP_{DO\text{-}incub}$ reported in Fig. 4c are much greater

than the potential bias introduced by the replacement volume. We have revised the method description to clarify this: "The addition of DO to the bottle from the replacement water was considered small, on the order of the method detection limit of approximately 2 mmol m^{-3} d^{-1} (Murrell et al. 2009; 2013)".

7. Further, they argue that in the Mississippi river channel the NCP_{O2Ar} showed heterotrophy which is dominated by benthic respiration, and results of $NCP_{DO\text{-}incub}$ showed autotrophy. While it is true that the method with O_2/Ar measurements integrates the results in the mixed layer, it is based in surface measurements (one point in the vertical column), just as in the $NCP_{DO\text{-}incub}$. Unless benthic respiration is truly proven, the negative NCP values can well be the result of turbulent horizontal or vertical mixing, hence encouraging the method to include physical factors.
Response: Many thanks to the reviewer for pointing out this mistake. A detailed examination of the data in the lower Mississippi river channel suggests that the water column was stratified rather than well-mixed (Fig. S4). The measured community respiration rates in the lower Mississippi River channel (14.0±0.8 mmol C m^{-2} d^{-1}) and in the HTACW (30.5±10.7 and mmol C m^{-2} d^{-1}) were not able to fully account for the heterotrophy suggested by NCP_{O2Ar} (-51.3±11.9 mmol C m^{-2} d^{-1}) even when the GPP was not taken into account (assuming GPP_{Int} = 0 in Eq. 9). This indicates sources of heterotrophic signal other than the local community respiration. Because of the surface stratification, benthic respiration didn't contribute to the heterotrophy in the surface water indicated by the negative NCP_{O2Ar}. The light/dark incubation experiment at stations M1 and M2 suggested that the low O_2 concentration cannot be explained by in situ community mechanisms (low respiration rates and positive $NCP_{DO\text{-}incub}$ values). However, the Mississippi fresh water in the upper river channel was strongly heterotrophic and the advection of river water could play a significant role influencing the surface NCP_{O2Ar} signal in the river channel because of the short water residence time (~1 day, Green et al., 2006). In the revised manuscript, the heterotrophy in the lower Mississippi River channel were discussed in Section 4.1. "In the stratified lower Mississippi River channel (Fig. 9a), the influence of lateral transportation of the heterotrophic river water from the upper river channel was significant because of the short water residence time (~1 day, Green et al., 2006). Therefore, the overall heterotrophic condition in the lower Mississippi River channel (NCP_{O2Ar}, -51.2 mmol C m^{-2} d^{-1}) can be attributed to the overwhelming influence of the heterotrophic NCP_{adv} over the autotrophic local biological production (NCP_{MLD} = $NCP_{DO\text{-}incub}$, 94.5 mmol C m^{-2} d^{-1})." (page 16, lines 5-18). In the stratified lower Mississippi River channel (Fig. 9a), the heterotrophic condition in the lower Mississippi River channel could be attributed to the dominant influence of the heterotrophic NCP_{adv} over the local biological production.
In the vertically well-mixed HTACW (Fig. 9b), NCP_{O2Ar} reflected the combined result of the water column community production, the lateral advection of CO_2-rich Atchafalaya river water (NCP_{adv}), and sediment metabolism ($NCP_{benthic}$). Although we didn't measure the benthic respiration rates in our study, high sediment oxygen consumption and bottom water community respiration rates were reported in the Atchafalaya River Delta Estuary (Roberts and Doty, 2015) and on the Louisiana continental shelf (Murrell and Lehrter, 2011; Murrell et al., 2013). These studies suggested that the total below-pycnocline respiration rates show low variability over a large geographic and temporal range in the nGOM (46.4 to 104.5 mmol O_2 m^{-2} d^{-1}). The negative NCP_{O2Ar} observed in the HTACW by our study (-39.2±14.0 mmol C m^{-2}

d^{-1}) agreed with the finding of Murrell et al., (2013) which showed shelf-scale net water column heterotrophy on the Louisiana shelf. This water column heterotrophy can be well explained by the combined results of NCP_{water}, $NCP_{benthic}$ and NCP_{adv}.

8. Figure 5 – Did you plot yourself panels c and d? It looks like those are a plain zoomed copy of panels in a figure published in the work by Zahng et al. (2012), which is referenced correctly. The authors should only cite this reference and refer the reader to that citation, and specifically to that figure, for further details. It is not ok to plainly copy and paste here those previously published figures. This does not mean to reproduce a figure with previous data, which instead would mean that you use the original data and produce the figure again. As those panels seem to be a plain copy this action breaches copyrights and authors must avoid doing this. Hence, panels c and d on this figure should be completely removed. Also, Figure 5 is mentioned before than Figure 4, why not switching the order of these figures?

Response: This comment has been taken and we apologize for this mistake. The panels (c) and (d) in the original Fig. 5 (now Fig. 4) have been removed. Instead, we presented the fractional contribution of the offshore surface water end member in the updated panel (c) to better show the results of the three end-member mixing model (see the figure below). We have also adjusted the order of figures as suggested.

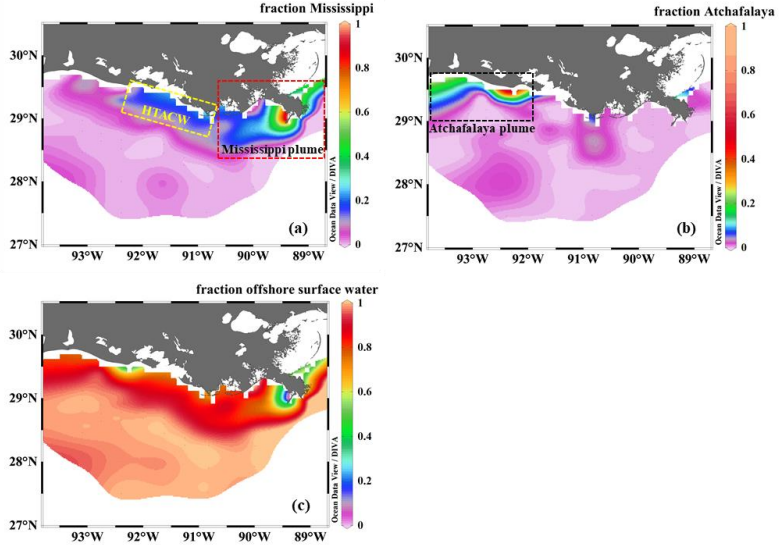

Fig. 4. The fractional contribution of (a) the Mississippi River, (b) the Atchafalaya River, and (c) offshore surface water to the surface water of the nGOM estimated from the three end-member mixing model. The sub-regions shown in panels (a) and (b) are the Mississippi plume, the high-turbidity Atchafalaya coastal water (HTACW), and the Atchafalaya plume.

9. Figure 6 – The spatial interpolation shown in panels a to d is quite bias. Showing a map with only the transect results of the NCP_{O2Ar}, or the spatial interpolation for this result and $NCP_{\Delta NOX}$ and $NCP_{\Delta DIC}$ at best, but not a spatial interpolation for the very scarce $NCP_{DO\text{-}incub}$, where some structures in the spatial distribution of many places seem to be only an artifact of the interpolation, such as the large extent of the high NCP values in the Mississippi plume.
Response: The $NCP_{DO\text{-}incub}$, $NCP_{\Delta DIC}$, $NCP_{\Delta NOX}$ in the original Fig. 6 (Fig. 5 in the revised manuscript) are now shown as colored dots to avoid bias and artifact from interpolation. We kept the contour plot of NCP_{O2Ar} as the underway measurement provide NCP_{O2Ar} with the same resolution as those data presented in Fig. 2.

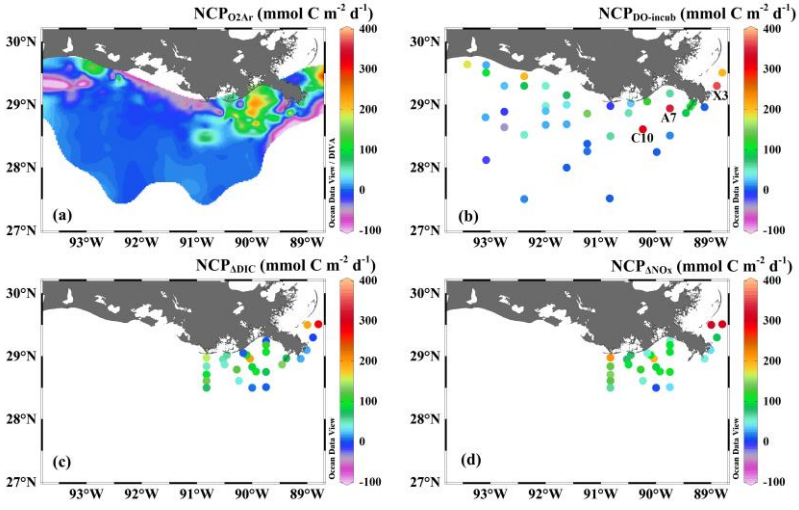

Fig. 5. The spatial variability of (a) NCP_{O2Ar}, (b) $NCP_{DO\text{-}incub}$, (c) $NCP_{\Delta DIC}$, and (d) $NCP_{\Delta NOx}$. Noted that $NCP_{\Delta DIC}$ and $NCP_{\Delta NOx}$ were only estimated in the Mississippi plume (panel c, d).

Minor comments:

1. Between a quantity and its units there must be always a blank space, please revise this, especially for a number in percentage (e.g. 180 %, 10 m, 40 km, 28.5o N).
Response: Corrected as suggested.

Abstract (P1)

2. L23 – remove “the spring season” and change to “during spring in 2017”
Response: Corrected.

3. L23 – use same number of decimals in the degrees
Response: Corrected.

Pag. 3

4. L1 – how much is “moderate salinities”
   Response: Corrected as “intermediate salinities (15 to 30 during this cruise)”.

5. L4 – Photosynthetically Active Radiation
   Response: Corrected.

6. L18-19 this last sentence should be removed from here
   Response: Corrected as suggested.

Pag. 4

7. L8 – Precision AND accuracy?
   Response: These sentences have been revised to now state “The precisions of DIC and TA measurements were both 2 μmol kg^{-1}. DIC and TA measurements were calibrated, both with accuracy better than 0.1%, with certified reference materials provided by A. G. Dickson, Scripps Institution of Oceanography.”

8. L9 – mark this location in Fig. 1
   Response: These two sampling stations are now marked and more information is presented in the updated Figure 1. We have also modified Figure 1 and its caption to better show the sampling sites as well as to highlight the Mississippi and Atchafalaya River.

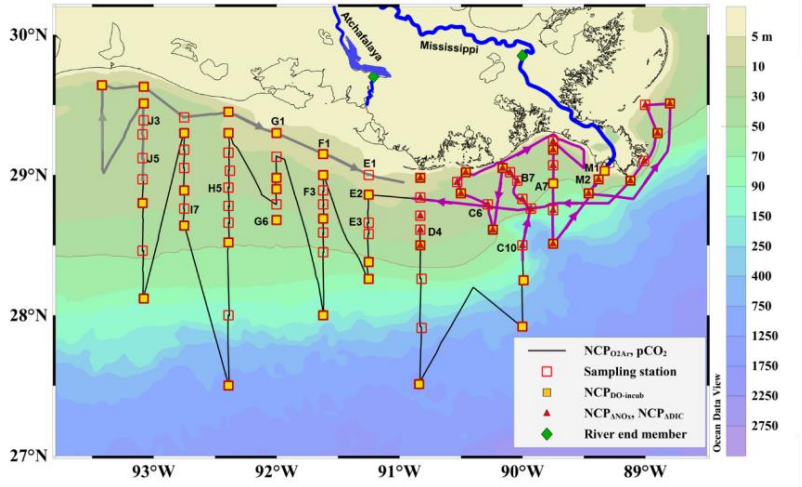

Fig. 1. Map and sampling sites in the northern Gulf of Mexico during the April 2017 cruise. The black dotted line is the cruise track along which the high-resolution underway measurements were made. The track in the Mississippi plume (purple line, Apr. 8-11) and in the Atchafalaya coastal regions (grey line, Apr. 15-17) are highlighted. Also shown are the 83 CTD sampling stations (hollow red squares), the 43 stations where light/dark bottle DO incubations were conducted (solid yellow squares), the 30 stations where non-conservative changes in DIC and NO_x were used to estimate NCP rates (solid red triangles), and the 2 stations where the properties of river end members were measured (solid green diamonds). The vertical CTD profiles of the named stations were shown in the supplement.

9. L10 – DO **in discrete samples** was measured by a ….
   Response: Revised as suggested.

10. L18 – either you use the tilde symbol or explicitly write approximate
    Response: The tilde symbol has been removed.

Pag. 5

11. L5 – against the **surface** discrete
    Response: Revised as suggested.

12. L20 – where is this comparison of wind speeds shown?

Response: This sentence has been revised to now state "The COAMPS daily wind speed agreed well (mean difference = 0.4 m s^{-1}, **figure not shown**) with the measurements from the buoys in our study region". Because the O_2 and CO_2 fluxes were calculated from the same wind speed, using COAMPS data or buoy measurement didn't affect the discussion on the relationship between O_2 and CO_2 fluxes. Therefore, the comparison of wind speeds was not critical for our discussion and its figure was not shown in the manuscript.

13. L16, L20 and L25 – variables should be consistently written in italics (here and elsewhere)
    Response: Corrected as suggested.

Pag. 6

14. L4 – why not referring to O_{2meas} instead of O_{2sea}? You also measure in river waters! And also to keep consistency with O_{2sat}.
    L20 – in Eq. 3 again there is no consistency on the way the concentration of gases are expressed, while in Eq. 2 it was simply O_{2sat} and O_{2sea}, here it is $[O_2]_{sat}$ and $[O_2]$, respectively. Please keep consistency.
    Response: $[O_2]_{meas}$ and $[O_2]_{sat}$ are now consistently used in the revised manuscript.

15. L6 – instead of "observed seawater DO" change to "measured surface water DO"
    Response: Revised as suggested.

16. L7 – which T and S were used to calculated O_{2sat}?
    Response: This sentence has been revised so that it now states: "$\Delta O_{2(sea\text{-}air)}$ is the difference between the seawater DO concentration from the calibrated underway optode measurement ($[O_2]_{meas}$) and the saturated DO concentration ($[O_2]_{sat}$) calculated from the measured sea surface temperature and salinity (Garcia and Gordon, 1992).".

17. L20 – Current Eq. 4 should be shifted to be Eq. 3
    Response: Corrected.

Pag. 7

18. L2 – here the authors need to better justify why in this region it is possible to neglect vertical mixing and lateral advection. They are important physical factors and later in the manuscript they claim it should be relevant to consider them. At least an effort should be done on explaining further why they were neglected.
    Response: We now discuss how physical processes including vertical mixing and lateral advection affect the NCP estimation under different mixing conditions. Pleases see our responses to the general comment and major comments 5 and 7.

19. L4 - Equation 5 is of little use and is also wrong, the first term NCP should be removed because you are calculating NCP with the second term. I will completely remove it from the manuscript and use the term of the left in Eq. 6.

Response: Although Eq. 5 was correct (NCP in Eq. 6 was calculated from Eq. 5 assuming $\mathrm{MLD}\frac{d[O_2]_{biol}}{dt}$ =0 and $\frac{[Ar]}{[Ar]_{sat}}$ =1) (Cassar et al. 2011; Jonsson et al. 2013; Kaiser et al. 2005), this explanatory equation has been now removed to make the method section more concise as suggested by both reviewers.

20. L15 – Is Eq. 9 correct? If you reduce GPP this equation is rather adding a factor to the high GPP value calculated in Eq. 8. Please check it.
Response: The percent signs were absent in these equations and they have been corrected as now read:
if %PAR ≥ 50 %, GPP_{Int} = GPP*MLD
if %PAR < 50 %, GPP_{Int} = 2*%PAR*GPP*MLD

21. L18 – in which depths the BOD bottles were collected?
Response: The depth information has been added as: "Surface water samples **(~1.5 m)** were collected from Niskin bottles into triplicate clear and black 300-ml BOD bottles (Wheaton)."

22. L22 – filtered seawater also introduces DO into the sample, see my major comment above.
Response: Please see the response to major comment 6.

Pag. 8

23. L3 – it is not sufficient to claim that there was no bias between the two methods, some values should be presented here.
Response: Clarified as "The mean difference between DO obtained by the probe and the spectrophotometric method of ±5 % was consistent with previous comparisons of probe measured versus Winkler measured DO based on several hundred comparisons (Murrell et al. 2013)."

24. L4 – the units of the DO rate of change are wrong
Response: The units were correct here as the DO change rates during the incubation experiments (mmol m^{-3} d^{-1}). These rates were then integrated over the MLD to produce the NCP rates (mmol m^{-2} d^{-1}).

25. L16 – why it was chosen 50 % of light?
Response: The text has been changed to answer this question: "In our study, we assumed that GPP was linearly dependent on light up to a maximum GPP_{max} occurred when %PAR = 50 %. This assumption is based on previous measurements from this shelf that indicate photosynthesis begins to saturate at light level of ~200 µmol quanta m^{-2} s^{-1} (Lohrenz et al., 1994), which is roughly 50 % of light in the surface mixed layer (Lohrenz et al., 1999)."

Pag. 9

26. L18 – "To facilitate **the** comparison, we converted NCP estimates from **the** different…."
Response: Corrected.

Pag. 10

27. L5 – the lower discharge in 2017 is also observed in previous months, not only in April
Response: This sentence has been revised to now state “These peaks in spring 2017 occurred later than the average condition during 1997-2017 and the monthly mean values of discharge and NO_x loading in April 2017 were slightly lower than the long-term mean values (Fig. S1).”.

28. L5 – “light”? please complete this to light transmittance
Response: Corrected.

29. L9 – The authors claim a correlation between MLD and salinity, however by looking at Fig. 5 panels b and c, this is not evident. If the authors define MLD based on a potential density criterion, they should make a comparison to density (i.e. incl. temperature which has more structure in surface waters) and not only to salinity.
Response: We agree with the reviewer that both temperature and salinity should be considered when discussing stratification. We have revised this sentence to now state “The Mississippi plume and most offshore regions were characterized by surface stratification, which was mainly caused by the buoyancy of fresher surface water in the plume and vertical temperature gradient in the offshore region (Fig. S3).”

30. L15 – remove “in”
Response: Corrected.

31. L17 – 19 this sentence will benefit by adding the correct punctuation
Response: This sentence has been revised to now state “In spring when river discharge is high and wind is typically downwelling-favourable, the Mississippi River freshwater generally flows westward in a contained nearshore current”.

Pag. 11

32. L2-4 too many subjective words without quantities or comparison in reference to something else (lower, deeper, higher?)
Response: Corrected. Quantities now have been added.

33. L2-4 Whereas I agree in the observations made regarding the HTACW in the Atchafalaya Bay in Fig. 3, I disagree in the MLD which does not look homogeneously deeper in that region. From Fig. 3c, the surface water does not look well mixed as the authors claim in the following sentence (and vertical profiles are not presented). Therefore, this needs more investigation.
Response: We appreciate the reviewer highlighting the need to display the vertical profiles. The HTACW region was, in fact, well-mixed as can be seen in the vertical profiles now provided in supplemental Fig. S4 in the revised manuscript.

34. L7-8 The authors define three sub-regions in Fig. 5 a and b based on the identified water characteristics, but they define them only by in their longitude limits and they should also include the latitude limits.

Response: In the revised manuscript, we divided the coastal region into four sub-regions: 1) the lower Mississippi River channel (Fig. S2, salinity < 2); 2) the Mississippi plume (Fig. 4a, to the east of 90.75° W, to the north of 28.30° N); 3) the high-turbidity Atchafalaya coastal water (Fig. 4a and Fig. 2d, 90.75-92.35° W, light transmittance < 20%, named as HTACW hereafter); and 4) the Atchafalaya plume (Fig. 4b, 92.35-93.50° W, to the north of 29.00° N).". In addition to longitude or latitude limits, we presented salinity limits for the lower Mississippi River channel and light transmittance limits for the high-turbidity Atchafalaya coastal water to better characterize these sub-regions.

Pag. 13

35. L9 – "spatial" instead of space
Response: Corrected.

Pag. 15

36. L1- associated with "the" different
Response: Corrected.

37. L7 – what inherent averaging the authors refer here? If they have continuous highly resolved data at least episodic extreme events would be better captured than discrete sampling.
Response: The modeling study by Teeter et al., (2018) suggested that the NCP_{O2Ar} represents the exponentially weighted NCP over the past several residence times of O_2 (stated in the Methods section). The original expression of "episodic extreme events" was not appropriate and this sentence has been revised to now state "As NCP_{O2Ar} is an exponentially weighted average rate, it is less able to capture high NCP values due to the inherent averaging of the O_2/Ar approach."

38. L12-14 this assumption of integrating vertically the NCP_{O2Ar} can be avoided by considering vertical processes if the authors suspect this is the case (as mentioned in L17 same page).
L12 – also, the authors contradict themselves in the structure of the water column, it is well mixed or not?
Response: The influences of vertical mixing on NCP_{O2Ar} have now been better explained according to different mixing conditions. Please see the response to general comment and major comment 5.

39. L15 – "fraction"
Response: Corrected.

Pag. 16

40. L1 – vertical or horizonal mixing?
Response: As our study focused on the surface water, the mixing here was mainly horizonal mixing between the river water and seawater.

41. L10 – space between “community were”
Response: Corrected.

Pag. 17

42. L17 – before explaining the results in Fig. 9, please explain what it is plotted there.
Response: This figure is explained and discussed in the revised manuscript as: “When plotting the paired CO_2 flux and NCP_{O2Ar} data (Fig. 10), most data collected in the lower Mississippi River channel fall in quadrant 2 suggesting net heterotrophy coupled with CO_2 outgassing to the atmosphere. The Mississippi plume and Atchafalaya plume exhibited opposite patterns with most data in these regions being in quadrant 4 (net autotrophy coupled with CO_2 uptake from the atmosphere). However, the data in quadrant 1 (autotropic water as a CO_2 source observed near the Mississippi estuary) and quadrant 3 (heterotopic water as a CO_2 sink in the HTACW) suggest decoupling between NCP_{O2Ar} and CO_2 flux.”

Pag. 18

43. L3-10 these lines should be part of a methods section where the 1-D model is introduced to the reader
Response: The model description has now been moved to the Methods section as suggested.

44. L11-25 I am not surprised by the results presented in Fig. 10, they are only showing the wellknown changes in the carbonate system, and this figure can only be seen as a proof of their model performance under standard defined initial conditions. I would place this figure in supplement.
Response: We agree with the reviewer that the results shown in this figure are well-known and this figure has been moved to the supplement. According to the suggestion from reviewer 1, we have updated this figure to show the differences in gas exchange rate and equilibrium time of O_2 and CO_2. Please see our response to minor comment 2 by reviewer 1 for details.

Pag. 19

45. L23 – “ has the advantage of being “
Response: Corrected.

Pag. 20

46. L3 – I miss the results on the distribution of nutrients. From the way the results were presented, this conclusion is not clearly supported
Response: In the revised manuscript, the distributions of NO_x, light transmittance, Chl-a, and NCP were presented in Fig. 7a and the relationship between NCP-induced uptake of nutrients and DIC were presented in Fig. 8. There results supports the conclusion of “In the river plume, the light availability generally determined the onset of the biological growth and the river-borne nutrient loading set the magnitude of the biological production (Fig. 7, Fig. 8)”. This sentence has been moved to page 17, lines 17-20.

Figures

47. Figure 1 – I miss some labels in the map. For people that is not familiar with this study region, it will be useful to add directly in the map the labels of the location of the main features that are mentioned throughout the manuscript, e.g., Mississippi and Atchafalaya deltas, Mississippi South Pass, Atchafalaya Bay. Also, add numbers to the stations and remove the units to all of the depths in the color bar, and rather add "m" above the bar as in Figure 3. The figure caption needs to be improved.
Response: We have modified Fig. 1 to add more features accordingly. Also see the response to minor comment 8.

48. Figure 2 – This schematic contains extra information that is not a central part of the manuscript. If you are not talking about the actual biological pump and its components, I will remove it from the figure. I would also invert the order with the CO_2 and carbonate system on the left and the O_2 part on and the O_2 part on the right of the figure.
Response: We agree with the reviewer that this schematic didn't contribute much and it has been removed from the revised manuscript.

49. Figure 4 – This figure needs to be georeferenced, or provide more information in Figure 1, where was the start of the continuous transect? Also, you could add number of stations so it is clearer the geographical position of the points in panel c.
Response: Arrows have been now added in Fig. 1 to better show the direction of the transect and labels have been added for some key stations. In panel c, we heighted three stations with high $NCP_{DO\text{-}incub}$ values and their positions were given in Fig. 5.

50. Figure S1 – add labels to the x-axis
Response: The label "month" has been added to the x-axis.

References

51. - The authors should carefully revise the guidelines for authors before submitting a manuscript to a journal. In this case, for the presentation of references, in the text they are always lacking of a comma between the authors and the year of the publication. Also, the format of the presentation of references at the end of the manuscript, should be also carefully checked (e.g. the year of the publication must precede the doi).
Response: Corrected.

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Spring net community production and its coupling with the CO_2 dynamics in the surface water of the northern Gulf of Mexico

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Abstract. Net community production (NCP) in the surface water of the northern Gulf of Mexico (nGOM) and its coupling with the CO_2 system were examined during the productive spring season. NCP was estimated using multiple approaches: 1) underway O_2 and Ar ratio, 2) oxygen changes during light/dark bottle oxygen incubations, and 3) non-conservative changes in dissolved inorganic carbon or nutrients. NCP rates derived from various methods displayed similar pattern along the river-ocean mixing gradient showing high production rates in the plume region. NCP_{O2Ar} estimated from high-resolution O_2 and Ar underway measurement indicated heterotrophic condition at the high-nutrient and high-turbidity Mississippi river end (-51.3±11.9 mmol C m^{-2} d^{-1} when salinity < 2) resulting from the influence of terrestrial carbon input and light limitation on photosynthesis. High NCP_{O2Ar} rates (105.0±59.2 mmol C m^{-2} d^{-1}, up to 235.4 mmol C m^{-2} d^{-1}) were observed in the Mississippi and Atchafalaya plume at intermediate salinities between 15 to 30 where light and nutrient were both favourable for phytoplankton production. NCP_{O2Ar} rates observed in the high-salinity, oligotrophic offshore waters (salinity > 35.5) were close to zero due to nutrient limitation. Air-sea CO_2 fluxes generally showed corresponding changes from being a strong CO_2 source in the river channel (55.5±7.6 mmol C m^{-2} d^{-1}), to a CO_2 sink in the plume (-13.4±5.5 mmol C m^{-2} d^{-1}), and to be nearly in equilibrium with the atmosphere in offshore waters. Overall, the surface water of the nGOM was autotrophic during spring in 2017 with an area-weighted mean NCP_{O2Ar} of 21.2 mmol C m^{-2} d^{-1} and as a CO_2 sink of -6.7 mmol C m^{-2} d^{-1}. A temporal mismatch between *in situ* biological production and gas exchange of O_2 and CO_2 was shown through a 1-D model to result in decoupling between NCP_{O2Ar} and CO_2 flux (e.g., autotropic water as a CO_2 source outside the Mississippi river mouth and heterotopic water as a CO_2 sink in the Atchafalaya coastal water). This decoupling was a result of *in situ* biological production superimposed on the lingering background pCO_2 from the source water because of the slow air-sea CO_2 exchange rate and the buffering effect of the carbonate system.

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1 Introduction

The continental shelf is among the most biologically active areas of the biosphere and plays a significant role in global biogeochemical cycles (Chen and Borges, 2009; Chen and Swaney, 2012; Gattuso et al., 1998; Muller-Karger et al., 2005). Despite its moderate surface area (~7 %), the continental shelf accounts for 14-30 % of net ecosystem production (Gattuso et al., 1998), 80 % of organic matter burial (Gattuso et al., 1998), and 15-21 % of the CO_2 uptake of the global ocean (Cai, 2011; Cai et al., 2006; Chen and Borges, 2009; Laruelle et al., 2010). Moreover, anthropogenic impacts have substantially changed the nutrient and carbon loads delivered to the coastal oceans (Bauer et al., 2013; Regnier et al., 2013; Yang et al., 2018), with associated development of a series of environmental problems, e.g., coastal eutrophication, hypoxia, and acidification (Cai et al., 2011; Diaz and Rosenberg, 2008; Rabalais et al., 2014; Wallace et al., 2014). Understanding and quantifying how these impacts affect the metabolic balance and CO_2 fluxes of coastal systems is of critical interest to scientists and policy-makers. However, the substantial heterogeneity resulting from physical and biogeochemical interactions makes assessing metabolic state and carbon flux a challenging task in dynamic coastal environments.

Net community production (NCP) is defined as the difference between gross primary production and community respiration (Eppley and Peterson, 1979; Sarmiento and Gruber, 2006) and indicates whether the ecosystem is a net source or sink of organic matter (Eppley and Peterson, 1979; Sarmiento and Gruber, 2006). NCP in the mixed layer plays an important role in regulating the surface CO_2 and O_2 dynamics. It also represents the amount of organic carbon available for export to the subsurface, which is closely related to bottom water biogeochemical processes, e.g., the development and maintenance of hypoxia.

The northern Gulf of Mexico (nGOM) is a river-dominated continental shelf (Mckee et al., 2004) with NCP and CO2 dynamics affected by the terrestrial inputs of carbon and nutrients from the Mississippi-Atchafalaya River system (Lohrenz et al., 2014). The CO_2 variability in the nGOM has been extensively investigated by high-resolution underway measurement of the partial pressure of CO_2 (pCO_2) (Huang et al., 2015). High terrestrial inorganic and organic carbon loading results in CO_2 oversaturation and net CO_2 efflux to the atmosphere in the river channel and estuary of the Mississippi River (Cai, 2003; Guo et al., 2012; Huang et al., 2015; Lohrenz et al., 2010). On the continental shelf, reduced pCO_2 observed in the Mississippi plume (sink for atmospheric CO_2) was attributed to strong primary production supported by the excessive

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riverine nutrient loads (Guo et al., 2012; Huang et al., 2015; Lohrenz et al., 1990; 1999; 2014). With the enhanced surface production and subsequently subsurface respiration of the sinking organic matter, recurring bottom hypoxia that covers large portions of the Louisiana-Texas shelf has been observed in summer when stratification limits O_2 replenishment (Bianchi et al., 2010; Obenour et al., 2013; Rabalais et al., 2002). Springtime riverine nutrient flux and subsequent biological production in surface water play a critical role in determining the size of the summertime bottom-water hypoxia area in the nGOM (Justić et al., 1993; Turner et al., 2012). The rapid subsurface respiration also leads to a significant decrease in pH and a weakening of acid-base buffer capacity, which leads to the enhanced coastal ocean acidification problem (Cai et al., 2011). Previous NCP studies in the nGOM have been mainly based on the oxygen changes during light/dark bottle oxygen incubations and non-conservative removal of dissolved inorganic carbon or nutrients (Cai, 2003; Huang et al., 2012; Guo et al., 2012; Murrell et al., 2009; 2013). However, the detailed relationship between NCP and CO_2 dynamics remains unclear because of the low spatial resolution of the conventional NCP measurements based on discrete samples. In this study, we present the first attempt to obtain high-resolution NCP_{O2Ar} estimates from continuous underway measurement of oxygen to argon ratio (O_2/Ar) in the nGOM in spring 2017. The NCP_{O2Ar} result was compared to those derived from traditional approaches to evaluate the consistency of NCP estimates from various methods. Meanwhile, these NCP methods are associated with different temporal and spatial scales and are affected by different biological and physical processes. By making NCP estimates using the different methods we can get a more robust understanding of the overall metabolism of the system. The simultaneous underway determination of NCP_{O2Ar} and pCO_2, together with measurements of dissolved oxygen (DO), dissolved inorganic carbon (DIC), total alkalinity (TA), nutrients, and other environmental parameters, allow us to better constrain the variability and controls of the metabolic balance and CO_2 flux in the nGOM. We also use a 1-D model to investigate the relationship between NCP and air-sea fluxes of O_2 and CO_2.

2 Methods

2.1 Sample collection and measurements

The cruise was conducted onboard *RV Pelican* during 6-16 April 2017. The study region covered the Mississippi and Atchafalaya estuary and the adjacent Louisiana continental shelf (Fig. 1). Vertical water column profiles of temperature,

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salinity, DO, chlorophyll fluorescence (Chl-a), and photosynthetically active radiation (PAR) were measured by a SeaBird CTD system (SBE 911plus) at 83 sampling stations (Fig. 1). Discrete water samples for DIC, TA, DO, and nutrients were collected from 3-12 depths depending on the bottom depth and vertical profiles of temperature, salinity and DO. River water samples of the Mississippi (89.98° W, 29.85° N) and Atchafalaya (91.21° W, 29.70° N, Fig. 1) were taken on 5 April, one day prior to the cruise, to identify the DIC and TA concentrations of the river end members. Samples for DIC and TA were collected in 250 mL borosilicate glass bottles and preserved with 50 µl of saturated $HgCl_2$ solution (Dickson et al., 2007). DIC was measured by non-dispersive infrared measurement on the CO_2 stripped from the acidified sample (AS-C3, Apollo SciTech). TA titrations were conducted with a ROSS™ combination electrode 8102 (Thermo Fisher Scientific) on an automated titrator (AS-ALK2, Apollo SciTech). The precision of DIC and TA measurements were both 2 µmol kg^{-1}. DIC and TA measurements were calibrated, both with accuracy better than 0.1 %, with certified reference materials provided by A. G. Dickson, Scripps Institution of Oceanography. DO in discrete samples was measured by a Shimadzu UV-1700 at 25 ºC using the spectrophotometric method following Pai et al., (1993) with an accuracy of 0.2 %. For nutrient analysis, water from each Niskin bottle was immediately filtered through 0.22 µm, sterile, polyethersulfone syringe filters and stored frozen for subsequent nutrient characterization. Samples were analyzed in duplicate for dissolved NO_x (NO_3^- + NO_2^-) by Cu-Cd reduction followed by azo dye colorimetry using a Lachat Instruments QuikChem® FIA+ 8000 Series Automated Ion Analyzer at the Louisiana Universities Marine Consortium as described previously (Roberts and Doty, 2015). Standard curves were prepared using standard NO_3-N and NO_2-N stock solutions (Hach, Loveland CO) and yielded r^2 values of ≥ 0.999.

2.2 Underway measurements

The underway system was fed by the ship's seawater supply from an inlet located at an approximate depth of 2.5 m. The flow-through system and the Multiple Instrument Data Acquisition System (MIDAS) provided measurements on sea surface temperature, conductivity (Seabird SBE 21 Thermosalinograph), chlorophyll fluorescence (Turner Model 10 Series Fluorometers), and light transmittance (WETLabs 25-centimeter path length transmissometer). MIDAS also integrated data from the ship's meteorological suite: wind, barometric pressure, temperature and relative humidity (R.M. Young) and PAR (LI-COR LI-190SZ).

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Underway seawater pCO_2 was measured with a precision of 0.1 µatm by an automated flow-through pCO_2 measuring system (AS-P2, Apollo SciTech) with a shower head equilibrator and a non-dispersive infrared gas detector (LI-COR, LI-7000) (Huang et al., 2015). The pCO_2 measurement was calibrated twice daily against 3 certified gas standards (150.62, 404.72, and 992.54 ppm) and the accuracy was better than ±2 µatm. Underway pCO_2 system alternated measurements on a stream of seawater split from the same inlet for the MIDAS and a stream of outside air from the bow of the vessel away from chimney contamination. The atmospheric pCO_2 was measured every 3 hours automatically. The underway DO was measured by an Aanderaa 4835 optode which was calibrated against discrete surface water values by spectrophotometric measurements. Underway high-resolution measurements of O_2/Ar were made by equilibrator inlet mass spectrometry as described by Cassar et al., (2009). Briefly, a fraction of underway seawater (the same supplied to the pCO_2 measuring system) was pumped through a gas-permeable membrane contactor cartridge at a flow rate of 100 mL min^{-1}. The cartridge was connected to a quadrupole mass spectrometer (Pfeiffer Prisma) through a fused-silica capillary which continuously sampled headspace gases for O_2/Ar measurement. As the atmospheric O_2/Ar is essentially constant relative to that in the surface water, calibrations of the O_2/Ar ion current ratio were conducted by sampling the ambient air every 3 hours through a second capillary (Cassar et al., 2009). The instrument precision estimated from the repeated measurements of atmospheric O_2/Ar was 0.3 %.

2.3 Calculations

The mixed layer depth (MLD) was defined as the depth at which the density changed by 0.03 kg m^{-3} relative to the surface value and was calculated according to the density profiles at sampling stations. Air-sea CO_2 flux was calculated as:

$$F_{CO2} = k_{CO2} K_0 \Delta pCO_{2(sea-air)} = k_{CO2} K_0 \left(pCO_{2meas} - pCO_{2air} \right) \quad (1)$$

where k_{CO2} is the gas transfer velocity of CO_2 calculated using the daily mean wind speed from the three-dimensional Coupled Ocean/Atmosphere Mesoscale Prediction System (COAMPS) (Hodur, 1997) and the coefficients of Sweeney et al., (2007). The COAMPS daily wind speed agreed well (mean difference = 0.4 m s^{-1}, figure not shown) with buoy measurements in our study region (s42047, s8768094, FRWL1, MRSL1, LOPL1, GISL1, PSTL1, and PILL1, data from the National Data Buoy Center, http://www.ndbc.noaa.gov/maps/WestGulf.shtml). K_0 is the CO_2 solubility coefficient calculated

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from the measured sea surface temperature and salinity (Weiss, 1974). $\Delta pCO_{2(sea-air)}$ is the difference between the measured pCO_2 in the surface water (pCO_{2meas}) and in the atmosphere (pCO_{2air}). Comparing to the large variations in pCO_{2meas} (110-1800 µatm), the variability of pCO_{2air} was minor (405 ± 4 µatm) so the pCO_{2air} was set at the cruise average value of 405 µatm for the flux calculation. The negative F_{CO2} corresponds to a net CO_2 uptake by the ocean (ocean as a CO_2 sink for the atmosphere). Air-sea O_2 flux was calculated as:

$$F_{O2} = k_{O2}\ \Delta O_{2(sea-air)} = k_{O2}\left([O_2]_{meas} - [O_2]_{sat}\right) \quad (2)$$

where k_{O2} is the gas exchange velocity of O_2 which was calculated in a similar way with that of k_{CO2}. $\Delta O_{2(sea-air)}$ is the difference between the seawater DO concentration from the calibrated underway optode measurement ($[O_2]_{meas}$) and the saturated DO concentration ($[O_2]_{sat}$) calculated from the measured sea surface temperature and salinity (Garcia and Gordon, 1992). The oxygen saturation percentage (DO%) is calculated as DO% = $[O_2]_{meas}/[O_2]_{sat}$.

2.4 NCP estimates

In this study, NCP rates were estimated by three different approaches: underway O_2/Ar measurements (NCP_{O2Ar}), light/dark bottle DO incubations ($NCP_{DO\text{-}incub}$), and non-conservative changes in DIC ($NCP_{\Delta DIC}$) or NO_x ($NCP_{\Delta NOx}$).

NCP from the O_2/Ar method: DO concentration in the surface water is affected by physical (e.g., changes in temperature, salinity, and atmospheric pressure, bubble dissolution and injection) and biological processes (photosynthesis and respiration). Ar and O_2 have similar responses to physical processes as they have similar solubility and temperature dependency (Garcia and Gordon, 1992; Hamme and Emerson, 2004). On the other hand, Ar is biologically inert and can be used to infer abiotic influences on oxygen. Contemporaneous measures of O_2 and Ar thus allow the biological-induced O_2 changes to be isolated (Craig and Hayward, 1987). By measuring the biologically mediated oxygen supersaturation $\Delta(O_2/Ar)$ (Cassar et al., 2011; Craig and Hayward, 1987; Jonsson et al., 2013; Kaiser et al., 2005):

$$\Delta(O_2/Ar) = \frac{[O_2]/[Ar]}{[O_2]_{sat}/[Ar]_{sat}} - 1 \quad (3)$$

the surface NCP can be approximated by the net air-sea biological oxygen flux (bioflux, mmol O_2 m^{-2} d^{-1}) under a physically isolated mixed layer assumption (Jonsson et al. 2013):

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where $[O_2]$ and $[Ar]$ are the O_2 and Ar concentrations of the seawater sample, $[O_2]_{sat}$ and $[Ar]_{sat}$ are the equilibrium saturation concentrations (Garcia and Gordon 1992; Hamme and Emerson 2004), and $\Delta(O_2/Ar)$ is the biologically mediated oxygen supersaturation (Cassar et al. 2011).

$$\Delta(O_2/Ar) = \frac{[O_2]/[Ar]}{[O_2]_{sat}/[Ar]_{sat}} - 1 \quad (4)$$

If the influences of vertical mixing and lateral advection are neglected, the budget of the $[O_2]_{biol}$ in mixed layer can be described as (Kaiser et al. 2005):

$$MLD\frac{d[O_2]_{biol}}{dt} \approx NCP - k_{O2}[O_2]_{sat}\Delta(O_2/Ar) \quad (5)$$

where where $[O_2]$ and $[Ar]$ are the O_2 and Ar concentrations of the seawater sample, $[O_2]_{sat}$ and $[Ar]_{sat}$ are the equilibrium saturation ...
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$$NCP_{O2Ar} = bioflux = k_{O2}[O_2]_{sat}\Delta(O_2/Ar) \quad (4)$$

The modeling study by Teeter et al., (2018) suggested that the bioflux accurately represents the exponentially weighted NCP over the past several residence times of O_2. The residence times of O_2 (MLD/gas transfer velocity of O_2, ~2.3 days during our cruise) refers to the length of time required to exchange O_2 between the mixed layer and the atmosphere (Kaiser et al., 2005; Teeter et al., 2018). To account for the wind speed history prior to the arrival of the ship at each station, the weighting technique of Reuer et al., (2007) modified by Teeter et al., (2018) was applied to calculate the gas exchange velocity of O_2 in this study.

NCP from the DO incubation: NCP was estimated with light/dark bottle incubation method at 43 CTD stations (Fig. 1). Surface water samples (~1.5 m) were collected from Niskin bottles into triplicate clear and black 300-ml BOD bottles (Wheaton). The initial oxygen saturation percentage and temperature in each bottle was measured by inserting a luminescent/optical dissolved oxygen probe (Hach LDO101, Hach Hq40d meter) into the bottle. Care was taken to avoid introducing air bubbles during this step. After recording the initial oxygen saturation percentage value, the probe was removed and the small volume displaced by the probe (3-5 ml) was replaced with filtered seawater from an offshore, low nutrient site. The addition of DO to the bottle from the replacement water was considered small, on the order of the method detection limit of approximately 2 mmol m^{-3} d^{-1} (Murrell et al. 2009; 2013). Clear and dark bottles were placed into a deck incubator screened at 50 % of ambient sunlight for 24 hours. The deck incubator was plumbed with flowing seawater from the MIDAS in order to maintain surface water temperatures. After 24 hours, the oxygen saturation percentage and temperature were measured again with the oxygen probe. DO concentrations obtained from the LDO probe were verified by comparison to DO concentrations measured by the spectrophotometric method of Pai et al., (1993) in a subset of samples (n = 14). The mean difference between the two methods of ±5 % was consistent with previous comparisons of probe measured versus Winkler measured DO based on several hundred comparisons (Murrell et al. 2013).

The respiration rate was calculated from the DO changes in the dark bottles (R_{dark}, mmol O_2 m^{-3} d^{-1}). The respiration rate was assumed to be uniform in the mixed layer, thus, the integrated respiration over the MLD ($Resp_{Int}$, mmol O_2 m^{-2} d^{-1}) was calculated as $Resp_{Int} = R_{dark}$*MLD. The gross primary production (GPP) varied with depth due to the reduction in light

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availability with increasing depth. The mean percentage of PAR (%PAR) in the water column in relation to surface PAR (E_0) was calculated at each station as:

$$\%PAR = \frac{E_0}{K_d MLD}(1-e^{(-K_d MLD)}) \quad (5)$$

where E_0 is 100 %, light attenuation (K_d, m^{-1}) is the rate of exponential decline in PAR as a function of depth as measured by the CTD. In our study, we assumed that GPP was linearly dependent on light up to a maximum GPP_{max} occurred when %PAR = 50 %. This assumption is based on previous measurements from this shelf that indicate photosynthesis begins to saturate at light level of ~200 µmol quanta m^{-2} s^{-1} (Lohrenz et al., 1994), which is roughly 50 % of light in the surface mixed layer (Lohrenz et al., 1999). GPP_{max} was thus estimated as $GPP_{max} = R_{light} - R_{dark}$, where R_{light} is the DO change rate in the light bottles. To calculate the integrated GPP in the mixed layer (GPP_{Int}, mmol O_2 m^{-2} d^{-1}), the GPP was scaled by the light environment in the MLD:

if %PAR ≥ 50 %, $GPP_{Int} = GPP*MLD$ (6)

if %PAR < 50 %, $GPP_{Int} = 2*\%PAR*GPP*MLD$ (7)

The coefficient 2 in Eq. 7 was used so that the product 2*%PAR would scale from 0 to 1, i.e., GPP approaches GPP_{max} at %PAR = 50 %. Finally, the NCP integrated over the MLD ($NCP_{DO\text{-}incub}$, mmol O_2 m^{-2} d^{-1}) was estimated as:

$NCP_{DO\text{-}incub} = (GPP_{Int} - Resp_{Int})$ (8)

The standard errors of $NCP_{DO\text{-}incub}$ from triplicate bottle incubations across all sites were on average about 16 % of the mean.

NCP from the non-conservative changes in DIC or nutrients: NCP can also be estimated from the biological-induced deviations of DIC or nutrients from the conservative mixing. We applied a three end-member mixing model (Huang et al., 2012) to distinguish the contribution from conservative mixing (X_{mix}) and the biological-induced change (ΔX_{biol}). The X_{mix} was calculated from the fractions of gulf surface seawater (f_{sw}), the Mississippi River water (f_{MR}), and the Atchafalaya River water (f_{AR}) together with the corresponding end-member concentrations shown in Table 1:

$1 = f_{sw} + f_{MR} + f_{AR}$ (9)

$X_{mix} = X_{sw}*f_{sw} + X_{MR}*f_{MR} + X_{AR}*f_{AR}$ (10)

We used salinity and potential alkalinity (PTA = TA + NO_x) (Brewer and Goldman, 1976) as the two conservative tracers to constrain f_{sw}, f_{MR}, and f_{AR} using a non-negative least square method (Lawson and Hanson, 1974). The concentrations of

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DIC_{mix} and NO_{xmix} from conservative mixing can then be calculated from Eq. 10, and the biological-induced changes in DIC (ΔDIC_{NCP}) and NO_x (ΔNO_{xNCP}) were estimated as:

$$\Delta DIC_{NCP} = DIC_{meas} - DIC_{mix} - \Delta DIC_{gas} \quad (11)$$

$$\Delta NO_{xNCP} = NO_{xmeas} - NO_{xmix} \quad (12)$$

where DIC_{meas} and NO_{xmeas} are the observed concentrations of DIC and NO_x, and ΔDIC_{gas} is the DIC changes induced by air-sea CO_2 exchange. Note that ΔDIC_{NCP} (mmol C m^{-3}) and ΔNO_{xNCP} (mmol N m^{-3}) represent the cumulative NCP-induced changes in the concentrations of DIC and NO_x since the mixing of river water with oceanic water. In order to calculate the NCP rates derived from DIC ($NCP_{\Delta DIC}$, mmol C m^{-2} d^{-1}) or NO_x ($NCP_{\Delta NOx}$, mmol N m^{-2} d^{-1}), the MLD and plume residence time (τ) need to be considered (Cai, 2003):

$$NCP_{\Delta DIC} = \Delta DIC_{NCP} * MLD/\tau \quad (13)$$

$$NCP_{\Delta NOx} = \Delta NO_{xNCP} * MLD/\tau \quad (14)$$

To facilitate comparison with previous studies (Guo et al., 2012, Huang et al., 2012, Cai, 2003), τ values for the Mississippi plume were taken from Green et al., (2006) as 1, 1.5, and 6 days for salinity range of 0-18, 18-27, and 27-34.5 respectively. In our study, we only calculated $NCP_{\Delta DIC}$ and $NCP_{\Delta NOx}$ for stations in the Mississippi plume because τ for the Atchafalaya plume is not available.

NCP unit conversion: To facilitate the comparison of NCP estimates from the different approaches, NCP rates were converted to the same carbon units (mmol C m^{-2} d^{-1}) using the Redfield ratio of $C:N:O_2$ = 106:16:138. The photosynthetic molar ratio of $C:O_2$ for new and recycled production may vary between 1.1 (NH_4^+ as nitrogen source) and 1.4 (NO_3^- as nitrogen source) (Laws, 1991). In our study region, the riverine input of NO_3^- was the main nitrogen source for biological uptake (Table 1) and we considered the average Redfield ratio of $C:O_2$ = 106:138 to be appropriate. Although biological C:N uptake may differ from the Redfield stoichiometry (Geider and La Roche, 2002; Sambrotto et al., 1993), the applicability of the Redfield C:N ratio has been previously demonstrated in our study region (Huang et al., 2012; Xue et al., 2015) and confirmed in this study.

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2.5 1-D model for NCP and gas exchange

A simple 1-D model was used to examine the relationship between NCP and air-sea fluxes of O_2 and CO_2. The environmental settings of the model were taken from the averaged condition during our study period: temperature = 22 °C, salinity = 35, TA = 2400 μmol L^{-1}, pCO_{2air} = 405 μatm, MLD = 6 m, and wind speed = 6 m s^{-1}. The initial state of the seawater was set to be in equilibrium with the atmosphere, and the concentrations of DO and pCO_2 in the seawater were modulated by time-dependent NCP functions and air-sea gas exchange at hourly time steps. At each time step, the relative changes in concentrations of DIC, TA, and DO resulting from NCP were assumed to follow the ratio of 106:17:138 (Zeebe and Wolf-Gladrow, 2001). The pCO_2 was calculated from DIC and TA using the CO2SYS program (Pierrot and Wallace, 2006). The air-sea flux of O_2 and CO_2 were calculated following Eq. 1 and Eq. 2.

3 Results

3.1 General pattern

The Mississippi and Atchafalaya Rivers typically experience peak discharge and NO_x loading in spring (Fig. S1). The peaks in discharge and NO_x in spring 2017 occurred later than the average condition during 1997-2017 and the monthly mean values of discharge and NO_x loading in April 2017 were slightly lower than the long-term mean values (Fig. S1). Surface water parameters (temperature, salinity, light transmittance, Chl-a, DO%, pCO_2, and $\Delta O_2/Ar$) showed high spatial variability on the inner and middle shelf (bottom depth < 50 m), with much lower variability observed on the outer shelf (bottom depth > 50 m) (Fig. 2). The highest physical and biogeochemical variations were observed in the Mississippi plume during 8-11 April and in the Atchafalaya coastal region during 15-17 April (Fig. 3). In spring when river discharge is high and the wind is typically downwelling-favourable, the Mississippi River freshwater generally flows westward in a contained nearshore current (Zhang et al., 2012; Lehrter et al., 2013). Our three end-member mixing model accurately reproduced the westward extension of the Mississippi freshwater on the Louisiana shelf from the Mississippi bird's foot delta (Fig. 2b and Fig. 4a). The model also suggested a westward Atchafalaya plume trajectory in a narrow band along the coast with little Atchafalaya freshwater was transported upcoast toward the Mississippi Delta (Fig. 4b). The pattern of the Mississippi and Atchafalaya freshwater transport agreed well with the multiple-year average condition (2005-2010) in April by numerical simulation

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(Zhang et al., 2012). To better investigate the variability of surface water parameters, we divided the coastal region into four sub-regions: 1) the lower Mississippi River channel (Fig. S2, salinity < 2); 2) the Mississippi plume (Fig. 4a, east of 90.75° W, north of 28.30° N); 3) the high-turbidity Atchafalaya coastal water (Fig. 4a and Fig. 2d, 90.75-92.35° W, light transmittance < 20 %, named as HTACW hereafter); and 4) the Atchafalaya plume (Fig. 4b, 92.35-93.50° W, north of 29.00° N). Typical vertical CTD profiles are shown in the supplement (Figs. S2-S4) to demonstrate the different mixing conditions observed in the four sub-regions as well as other regions in the nGOM.

3.2 Estimates of NCP

In comparison to the discrete measurements of $NCP_{DO\text{-}incub}$, $NCP_{\Delta DIC}$, and $NCP_{\Delta NOx}$, the underway O_2/Ar measurements provided NCP_{O2Ar} estimates with the highest resolution and most complete spatial coverage (Fig. 5). The $NCP_{DO\text{-}incub}$, $NCP_{\Delta DIC}$, and $NCP_{\Delta NOx}$ were mostly obtained at salinities higher than 20, while the NCP_{O2Ar} covered the whole salinity range (0 to 36.4) providing more information on the NCP variability in the dynamic estuary environments. All methods suggested high variability of NCP in the surface water of the nGOM (Fig. 3c, Fig. 5) and these methods display similar spatial patterns with high production rates in the plume region around the Mississippi bird's foot delta (Fig. 5). The results of $NCP_{\Delta DIC}$ (-19.0 to 274.9 mmol C m^{-2} d^{-1}) and $NCP_{\Delta NOx}$ (1.6 to 314.0 mmol C m^{-2} d^{-1}) were close to each other (Fig. 5c, d), and their ranges were similar to that of NCP_{O2Ar} in the Mississippi plume (-99.6 to 235.4 mmol C m^{-2} d^{-1}) (Fig. 3c). $NCP_{DO\text{-}incub}$ (-56.0 to 360.7 mmol C m^{-2} d^{-1}) gave the maximum NCP estimates in the Mississippi plume (stations C10, A7, and X3 in Fig. 5b and Fig. 3c). As NCP_{O2Ar} is a backward exponentially weighted average rate (Teeter et al., 2018), it is less able to capture high NCP values due to the inherent averaging of the O_2/Ar approach. Moreover, NCP_{O2Ar} could be a poor estimate of daily production rate (e.g., $NCP_{DO\text{-}incub}$ in our study) when the mixed layer is not at steady state (Teeter et al., 2018). These could explain the observed difference between NCP_{O2Ar} and $NCP_{DO\text{-}incub}$ in the dynamic Mississippi plume. In the high-salinity offshore waters, NCP_{O2Ar} and $NCP_{DO\text{-}incub}$ both suggest low NCP rates close to zero (Fig. 5a, b). One major difference between NCP_{O2Ar} and $NCP_{DO\text{-}incub}$ is that the O_2/Ar method generated negative NCP estimates in the lower Mississippi River channel and in the HTACW while $NCP_{DO\text{-}incub}$ suggested positive NCP rates in these regions (Fig. 5a, b).

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3.3 Mississippi River channel and plume

Vertical CTD profiles showed strong surface stratification in the lower Mississippi River channel (Fig. S2). The light transmittance in the surface water of the river channel was close to zero (Fig. 6a) and the Chl-a concentrations were low (Fig. 6b) despite the ample nutrient availability (NO_x up to 123 μmol/kg, Table 1). Similar to most inner estuaries (Borges and Abril, 2011; Chen et al., 2012; Chen and Swaney, 2012), high pCO_2 (up to 1803, μatm, Fig. 6c), undersaturated DO (83.7±0.8 %, Fig. 6d) and net CO_2 efflux (55.5±7.6 mmol C m^{-2} d^{-1}, Fig. 6e) was observed in the lower Mississippi River channel. The negative NCP_{O2Ar} (-51.3±11.9 mmol C m^{-2} d^{-1}, Fig. 6f) suggested net heterotrophic condition in the Mississippi River channel, which contrasts with the positive $NCP_{DO\text{-}incub}$ (94.5±11.6 mmol C m^{-2} d^{-1} Fig. 7c) measured by the DO incubation method.

The Mississippi plume and most offshore regions were characterized by surface stratification, which was mainly caused by the buoyancy of fresher surface water in the plume and vertical temperature gradient in the offshore region (Fig. S3). With the increasing light transmittance (Fig. 6a) in conjunction with persistence of riverine-derived nutrient concentrations (Fig. 7a) along the Mississippi plume flow path, phytoplankton biomass reached high levels at intermediate salinities of 15-30 (Fig. 6b). The high Chl-a concentrations in the plume region corresponded to large decreases in pCO_2 (down to 113.9 μatm, Fig. 6c) and strong oceanic CO_2 uptake (up to -42.7 mmol m^{-2} d^{-1}, Fig. 6e), as well as elevated DO% (up to 180.1 %, Fig. 6d) and NCP rates (Fig. 6f). The observed high NCP rates (e.g., up to 235.4 mmol C m^{-2} d^{-1} in NCP_{O2Ar}, up to 360.7 mmol C m^{-2} d^{-1} in $NCP_{DO\text{-}incub}$, Fig. 7c) are within the range of prior estimates for this region during spring season (up to 624.0 mmol C m^{-2} d^{-1}, Cai, 2003; Guo et al., 2012; Huang et al., 2012; Lohrenz et al., 1990; 1997; 1999), and are among the highest in large river estuarine and shelf waters (Cooley and Yager, 2006; Dagg et al., 2004; Ning et al., 1988; Ternon et al., 2000).

3.4 Atchafalaya plume and HTACW

The Atchafalaya River discharges in a shallow broad, low-gradient shelf (10 m isobath doesn't occur until more than 40 km offshore of the delta, Fig. 1) which frequently experiences cross-shelf currents (Roberts and Doty, 2015). The Atchafalaya plume water, extended westward in a narrow band along the coast (Fig. 4b), generally showed similar biogeochemical variability to that observed in the Mississippi plume (Fig. 6). Within the Atchafalaya plume, elevated Chl-a, DO%, and NCP_{O2Ar} were observed together with a dropdown in pCO_2 and oceanic CO_2 uptake (Fig. 6). For both the Mississippi and

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Atchafalaya plume regions, the three end-member mixing model suggests that the enhanced biological production resulted in significant deviations of DIC and NO_x from their conservative mixing lines (Fig. 8). The amplitudes of the non-conservative biological removal of nutrients (up to 35 μmol kg^{-1} in ΔNO_{xNCP}, Fig. 8a) and DIC (up to 250 μmol kg^{-1} in ΔDIC_{NCP}, Fig. 8b) are similar to the findings of previous studies in the nGOM (Cai, 2003; Guo et al., 2012; Huang et al., 2012). The biological uptake ratio of ΔNO_{xNCP} and ΔDIC_{NCP} (0.14 in Fig. 8c) was close to the Redfield N:C ratio (16/106). However, NCP_{O2Ar} suggested that the southwest part of the Atchafalaya plume was heterotrophic (around 29.30° N, 93.50° W, Fig. 5a). A detailed examination of the CTD profiles revealed that the water column in this area was vertically well-mixed (Fig. S4), which was different than the stratification condition observed in other plume regions.

The HTACW was characterized by a well-mixed water column and low light transmittance (Fig. S4). Although the Chl-a concentrations in the HTACW were similar to those in the Atchafalaya plume in the salinity range of 24 to 32 (Fig. 6b), the DO% was much lower and undersaturated in the HTACW (94.7%, Fig. 6d). The pCO_2 (327.8±34.6 μatm) in the HTACW was higher than that in the Atchafalaya plume (288.7±43.7 μatm) at the same salinities (Fig. 6c), but the HTACW still acted as a weak sink for atmospheric CO_2 (-7.1±3.1 mmol C m^{-2} d^{-1}, Fig. 6e). Similar to that in the Mississippi River channel, the two approaches for NCP estimation presented different results in the HTACW: the negative NCP_{O2Ar} (-39.2±14.0 mmol C m^{-2} d^{-1}, Fig. 5a) suggests net heterotrophic condition while $NCP_{DO\text{-}incub}$ rates were positive (62.6±23.3 mmol C m^{-2} d^{-1}, Fig. 5b),

4. Discussion

4.1 Comparison of NCP estimations

A comparison of NCP estimated from various methods should be interpreted with caution as each approach has its independent assumptions and limitations and refers to different temporal and spatial scale (Ulfsbo et al., 2014). However, applying multiple methods provides complementary information to better understand the processes affecting the metabolism of the ecosystem.

NCP from the DO incubation method: The $NCP_{DO\text{-}incub}$ was estimated from the 24-hour DO changes in incubation bottles, which gives a daily NCP estimate for the plankton community at the sampling location. The DO incubation method is a direct measurement of NCP and this method is free from the influences of lateral advection and sediment metabolism. The

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$NCP_{DO\text{-}incub}$ thus equals the MLD-integrated NCP in the stratified regions (NCP_{MLD} in Fig. 9a, c) or the water column-integrated NCP in the well-mixed regions (NCP_{water} in Fig. 9b). However, there are uncertainties related to scaling from samples collected at discrete depths to integrated mixed layer NCP values. First, the scaling method used here assumes a homogenous distribution of respiration rate over the MLD. Second, we only measured GPP at one light level (50 %) and we assumed that the GPP below 50 % surface PAR was linearly scaled to %PAR (Eq. 6 and Eq. 7). Similar assumptions for the Louisiana shelf were tested previously by Murrell and Lehrter, (2011) who found that single point measurements (vs. multi-point measurements in a layer) provided robust estimates of integrated rates. However, in the current study, the assumption has been further applied to shallow nearshore sites (< 10 m depth), which may exhibit greater heterogeneity in vertical PAR distributions due to the high algal biomass and suspended sediment particle concentrations. More importantly, for high-turbidity water samples (e.g., samples collected in the Mississippi River channel and in the HTACW), the incubated samples were not mixed in the same way as that in the natural environment and the sedimentation of particles in incubation bottles could alleviate the light limitation for phytoplankton. As a result, the gross primary production (GPP_{Int} in Eq. 8) could be overestimated and $NCP_{DO\text{-}incub}$ would not represent the true *in situ* NCP in but high-turbidity waters but as an overestimation.

NCP from the O_2/Ar method: NCP_{O2Ar} is derived from the air-sea biological oxygen flux (Eq. 4), which represents the exponentially weighted NCP over the past several residence times of O_2 (Kaiser et al. 2005; Teeter et al. 2018). When using the O_2/Ar method to estimate NCP_{MLD}, a key assumption is the negligible physical inputs to the mixed layer. However, this assumption can be invalid in the dynamic coastal environments. Recent studies have shown that entrainment and upwelling processes (mixing with O_2-depleted subsurface water) can lead to significant underestimation in NCP_{MLD} using the O_2/Ar method, especially in coastal upwelling zones (Castro-Morales et al., 2013; Nicholson et al., 2012; Shadwick et al., 2015; Teeter et al., 2018). As most regions in our study were characterized by the persistent surface stratification (Fig. S2 and S3), the influences of sub-pycnocline ($NCP_{sub\text{-}MLD}$ in Fig. 9a, c) and benthic metabolisms ($NCP_{benthic}$ in Fig. 9a, c) on the surface O_2/Ar ratio were expected to be minor. On the contrary, the surface O_2/Ar ratio in the well-mixed nearshore regions (e.g., the HTACW, Fig. S4) was affected by both water column (NCP_{water}) and benthic metabolisms ($NCP_{benthic}$) (Fig. 9b). Moreover, both Mississippi and Atchafalaya river end members were highly heterotrophic and the lateral transportation of this heterotrophic signal carried by river water (NCP_{adv} in Fig. 9) should be considered. As it generally takes a few days for O_2 to

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become in equilibrium with the atmosphere (see the discussion below), NCP_{adv} could play an important role affecting the O_2/Ar ratio in the river channel and estuary where water transport speed was rapid (Fig. 9a, b). The influence of NCP_{adv} decreased offshore and the impact of remote source water heterotrophy was negligible in most offshore regions where water residence time was sufficiently long (Fig. 9c). Therefore, NCP_{O2Ar} represented the metabolic state of the water which was affected not only by local aquatic ecosystem (NCP_{MLD} or NCP_{water} in Fig. 9), but also by additional factors including $NCP_{benthic}$ and NCP_{adv} (Fig. 9). Depending on the different mixing conditions, NCP_{O2Ar} reflected 1) the combined result of NCP_{MLD} and NCP_{adv} in the stratified river channel and plume region; 2) the combined result of NCP_{water}, $NCP_{benthic}$, and NCP_{adv} in the well-mixed nearshore waters (e.g., HTACW); 3) NCP_{MLD} in the offshore stratified regions where the riverine influence was minor. As $NCP_{benthic}$ only affected a small portion of the nearshore water in the Atchafalaya coastal region, the NCP_{O2Ar} measured in this study was mainly modulated by NCP_{MLD} and NCP_{adv}. Considering the nGOM as a whole, lateral advection of NCP_{adv} can be considered as internal transport within the system given that the NCP_{O2Ar} was measured with adequate spatial coverage. As a result, the NCP_{O2Ar} measured in this study well represented the overall metabolic state of the surface water of the nGOM.

NCP from the non-conservative changes in DIC and nutrients: The $NCP_{\Delta DIC}$ and $NCP_{\Delta NOx}$ in the Mississippi plume reflected the average community production rate along the flow path during the river-ocean mixing process. There are several sources of uncertainty associated with the NCP estimated from the non-conservative mixing change in DIC and nutrients. First, errors in estimating water residence time and the changes in MLD over the transit time of the plume water lead to proportional errors in the calculation of $NCP_{\Delta DIC}$ and $NCP_{\Delta NOx}$ (Eq. 13 and Eq. 14). The plume water residence time is a function of river discharge and other physical conditions, it is therefore expected that using a set of past model-assessed τ values probably would introduce the largest uncertainty in the estimation of $NCP_{\Delta DIC}$ and $NCP_{\Delta NOx}$. Second, uncertainty may be caused by the changes in the concentrations of DIC and nutrients of the river end members. However, this uncertainty decreases with salinity (Huang et al., 2012) and was generally low in our study.

To better investigate the NCP rates estimated from different methods, we focused on the regions where NCP_{O2Ar} and $NCP_{DO\text{-}incub}$ provided contrasting results: NCP_{O2Ar} suggested heterotrophy in the Mississippi River channel and in the HTACW where positive $NCP_{DO\text{-}incub}$ rates were presented. The contrasting results of NCP_{O2Ar} and $NCP_{DO\text{-}incub}$ can be mainly explained

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NCP from the DO incubation method: Although the DO incubation method is a direct measurement of NCP, there are uncertainties related to scaling from samples collected at discrete depths to integrated surface mixed layer values. First, the scaling method used here assumes a homogenous distribution of respiration rate over the MLD. Second, we only measured GPP at one light level (50%) and we assumed that the GPP at this level was maximal and that GPP below 50% surface PAR was linearly scaled to %PAR (Eqs. 8, 9). Similar assumptions for the Louisiana shelf were tested previously by Murrell and Lehrter (2011) who found that single point measurements (vs. multi-point measurements in a layer) provided robust estimates of integrated rates. However, in the current study, the assumption has been further applied to shallow nearshore sites (< 10 m depth), which may exhibit greater heterogeneity in vertical PAR distributions due to the very high biomass and suspended sediment particles. In addition, the If the incubated samples are not mixed in the same way as natural water, the majority of the sediment probably sink to the bottom of the bottle and the light availability is bigger than in natural waters overstimating NCP.More importantly, the bottle incubation method accounts for the NCP by plankton community but is not able to detect the impact of sediment metabolism (e.g., benthic respiration in the Mississippi river channel and the HTACW). In addition, the If the incubated samples are not mixed in the same way as natural water, the majority of the sediment probably sink to the bottom of the bottle and the light availability is bigger than in natural waters overstimating NCP.
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by the different spatial and temporal scales associated with the two methods responding to the mixing conditions. In the high-turbidity Mississippi River channel (light transmittance close to zero) and HTACW (light transmittance <20 %), the GPP was strongly limited by light availability and the DO incubation method could result in significant overestimation in the *in situ* GPP and NCP due to the improved light environment in the incubation bottles. However, the measured community respiration rates ($Resp_{Int}$ in Eq. 8) in the lower Mississippi River channel (14.0±0.8 and mmol C m^{-2} d^{-1}) and in the HTACW (30.5±10.7 and mmol C m^{-2} d^{-1}) were not able to fully account for the heterotrophy suggested by NCP_{O2Ar} (-51.3±11.9 and -39.2±14.0 mmol C m^{-2} d^{-1} in the lower Mississippi River channel and HTACW respectively) even when the GPP was not taken into account (assuming GPP_{Int} = 0 in Eq. 9). This indicates sources of heterotrophic signal other than the local community respiration in these two regions. In the stratified lower Mississippi River channel (Fig. 9a), the influence of lateral transportation of the heterotrophic river water from the upper river channel was significant because of the short water residence time (~1 day, Green et al., 2006). Therefore, the heterotrophic condition in the lower Mississippi River channel could be attributed to the dominant influence of the heterotrophic NCP_{adv} over the local biological production. In the vertically well-mixed HTACW (Fig. 9b), NCP_{O2Ar} reflected the combined result of the water column community production, the lateral advection of CO_2-rich Atchafalaya river water (NCP_{adv}), and sediment metabolism ($NCP_{benthic}$). High sediment oxygen consumption and bottom water community respiration rates were observed in the Atchafalaya River Delta Estuary (Roberts and Doty, 2015) and on the Louisiana continental shelf (Murrell and Lehrter, 2011; Murrell et al., 2013). These studies suggested that the total below-pycnocline respiration rates show low variability over a large geographic and temporal range in the nGOM (46.4 to 104.5 mmol O_2 m^{-2} d^{-1}). The negative NCP_{O2Ar} observed in the HTACW by our study (-39.2±14.0 mmol C m^{-2} d^{-1}) agreed with the finding of Murrell et al., (2013) which showed shelf-scale net water column heterotrophy on the Louisiana shelf. This water column heterotrophy can be well explained by the combined results of NCP_{water}, $NCP_{benthic}$ and NCP_{adv}. The same logic can be applied to explain the net heterotrophy observed in the southwest part of the Atchafalaya plume with well-mixed water column (negative NCP_{O2Ar} around 29.30° N, 93.50° W, Fig. 5a).

4.2 Controls on the surface NCP and CO_2 flux

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As the underway O_2/Ar method provided the highest resolution NCP estimation coupled with pCO_2 measurement, NCP_{O2Ar} was presented together with the CO_2 variables in the following sections to investigate the variability and controls of the metabolic balance. Nutrients, irradiance, and mixing were considered to be the major controlling factors of biological production in coastal waters of the nGOM (Lehrter et al., 2009; Lohrenz et al., 1999; Murrell et al., 2013; Turner and Rabalais, 2013). Here we use the results in the Mississippi plume (averaged over increments of two salinity units, Fig. 7) to demonstrate the controlling mechanisms of the changes in surface NCP and CO_2 flux along with the increasing salinity. There is an ecological gradient along the river-ocean mixing continuum: from turbid, eutrophic, freshwater to clear, oligotrophic offshore oceanic waters (Fig. 7a). The freshwater input from the Mississippi River was characterized by strong heterotrophy with high DIC and pCO_2, supported by the decomposition of terrestrial organic carbon (Bianchi et al., 2010). Meanwhile, phytoplankton growth and production was limited by light availability in the high-turbidity Mississippi River channel despite the high nutrient concentration (Fig. 7a-c). The net heterotrophy of the water at the low salinity end and the corresponding CO_2 release (Fig. 7d) were attributed to the terrestrial carbon input, light limitation on primary production, and short water residence time (Lehrter et al., 2009; Lohrenz et al., 1990; 1999; Roberts and Doty, 2015). While high CO_2 efflux was observed at low salinities, its contribution to the overall regional CO_2 flux was relatively small due to the limited spatial coverage of low salinity regions (Huang et al., 2015).

Due to the alleviation of light limitation in conjunction with persistence of riverine nutrient concentrations, Chl-a, DO% and NCP_{O2Ar} all showed an increasing trend with salinity along the flow path of the Mississippi plume (Fig. 8). A positive correlation between the mean NCP_{O2Ar} rates and Chl-a concentrations (Fig. 7b, d) was observed in the Mississippi plume (r^2 = 0.75, figure not shown) where light availability generally determined the onset of the biological growth and the river-borne nutrient loading set the magnitude of biological production (Fig. 7, Fig. 8). At intermediate salinities (15 to 30) in the Mississippi plume, there existed an "optimal growth region" where light and nutrient availability were both favourable for phytoplankton growth (Fig. 7) (Cloern et al., 2013; Demaster et al., 1996; Seguro et al., 2015). High NCP_{O2Ar} (114.8±54.6 mmol C m^{-2} d^{-1}) was observed in this optimal growth region corresponding to an oceanic CO_2 uptake of -13.5±5.3 mmol C m^{-2} d^{-1} (Fig. 7d). In high-salinity offshore water, phytoplankton growth and production were primarily limited by depleted nutrient concentration (Lehrter et al. 2009; Lohrenz et al. 1990; Lohrenz et al. 1999). Because of the minor terrestrial

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influence and low biological production, DO and pCO_2 in the offshore gulf water were close to equilibrium with atmosphere and NCP_{O2Ar} and CO_2 flux were close to zero (Fig. 7).

The spatial variability of NCP and CO_2 flux in the nGOM are associated with the trajectory of the Mississippi and Atchafalaya plume as the surface biogeochemical variations are strongly affected by riverine influences. For instance, an unusually broad plume extension in the nGOM in March 2010, driven by upwelling favourable wind and high freshwater discharge, was associated with elevated chlorophyll concentrations and stronger biological CO_2 uptake (Huang et al., 2013). Modeling studies also suggested that NCP and CO_2 flux in the nGOM were susceptible to changes in river and wind forcing (Fennel et al., 2011; Xue et al., 2016). To better study the variability of surface NCP and CO_2 flux, further studies are needed to investigate how the seasonal and inter-annual variations in environmental conditions (freshwater discharge, riverine inputs of carbon and nutrients, wind forcing, coastal circulation etc.) affect the trajectory of the river plume and the biological processes therein.

4.3 Coupling between NCP and CO_2 flux

Overall, the surface water of the nGOM (93.00-89.25° W, 28.50-29.50° N) was estimated to be net autotrophic during our study period with an area-weighted mean NCP_{O2Ar} rate of 21.2 mmol C m^{-2} d^{-1} and as a CO_2 sink of -6.7 mmol C m^{-2} d^{-1}. When plotting the paired CO_2 flux and NCP_{O2Ar} data (Fig. 10), most data collected in the lower Mississippi River channel fall in quadrant 2 suggesting net heterotrophy coupled with CO_2 outgassing to the atmosphere. The Mississippi plume and Atchafalaya plume exhibited opposite patterns with most data in these regions being in quadrant 4 (net autotrophy coupled with CO_2 uptake from the atmosphere). However, the data in quadrant 1 (autotropic water as a CO_2 source observed near the Mississippi River mouth) and quadrant 3 (heterotopic water as a CO_2 sink in the HTACW) suggest decoupling between NCP_{O2Ar} and CO_2 flux.

Here we use the 1-D model (Section 2.5) to investigate the relationship between NCP and air-sea gas fluxes of O_2 and CO_2. We calculated the re-equilibrium time for O_2 and CO_2 following the occurrence of 10 days biological modification: NCP was set as 50 (net autotrophy) or -50 (net heterotrophy) mmol C m^{-2} d^{-1} from days 0 to 10, and as zero after day 11 (Fig. S5). The air-sea O_2 flux rapidly reached a balance with the NCP-induced O_2 changes for both the autotrophy and heterotrophy simulations with the re-equilibrium time for O_2 for each estimation to be a few days (Fig. S5). Given the same environmental

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settings, the re-equilibrium time for CO_2 was much longer (more than one month, Fig. S5). This is related to the relative slow air-sea CO_2 exchange rate, and, more importantly the carbonate buffering system, i.e., the gas exchange-induced changes in aquatic CO_2 are buffered by a much larger carbon pool of HCO_3^--CO_3^{2-} (Zeebe and Wolf-Gladrow, 2001). NCP affects air-sea gas exchange of CO_2 through its influence on pCO_2 in the surface water. Net autotrophy results in a net biological uptake of CO_2 from the seawater (decrease in $\Delta pCO_{2(sea-air)}$ in Eq. 1) while net heterotrophy has the opposite effect. However, $\Delta pCO_{2(sea-air)}$ is not only affected by the *in situ* NCP (ΔpCO_{2NCP}), but also by the background level of ΔpCO_2 which is related to the preceding mixing and biological processes ($\Delta pCO_{2background}$): $\Delta pCO_{2(sea-air)} = \Delta pCO_{2background} + \Delta pCO_{2NCP}$. Therefore, local ecosystem net autotrophy (negative ΔpCO_{2NCP}) does not necessarily result in CO_2 uptake from the atmosphere (negative $\Delta pCO_{2(sea-air)}$) if the NCP-induced pCO_2 decrease occurs in a water with high heterotrophic background (highly positive $\Delta pCO_{2background}$). Similarly, net heterotrophy does not necessarily result in a CO_2 outgassing if the $\Delta pCO_{2background}$ of the source water is highly autotrophic.

In the simulation with time-dependent varying NCP rates (Fig. 11), we demonstrated how the preceding biological processes and the lingering background pCO_2 affect the relationship between NCP and CO_2 flux. The NCP rate in this simulation was set as 0 during days 0 to 30, changed to -50 mmol C m^{-2} d^{-1} (net heterotrophy) during days 31 to 60, then to 100 mmol C m^{-2} d^{-1} (net autotrophy) during days 61 to 90, and to -50 mmol C m^{-2} d^{-1} again during days 91 to 120 (Fig. 11a). Although NCP changed instantly, the backward exponentially weighted NCP derived from the bioflux of O_2 (NCP_{O2Ar} in Fig. 11a) lagged a few days behind NCP. After each change in NCP, the memory effect of the preceding NCP on DO tends to be small as the air-sea O_2 exchange quickly balanced the NCP-induced O_2 production or consumption within several days (Fig. 11b, c). On the contrary, the slow CO_2 gas exchange and long re-equilibrium time of CO_2 generated a significant memory effect of the preceding NCP on $\Delta pCO_{2(sea-air)}$ (Fig. 11b, c). The combined result of *in situ* production and the lingering effect of background pCO_2 thus resulted in the decoupling between NCP_{O2Ar} and CO_2 flux (data in quadrant 1 and quadrant 3 in Fig. 11d). One typical example is the results during days 91 to 120 (data in quadrant 3 in Fig. 11d): the strong preceding autotrophic production during days 61 to 90 led to highly negative $\Delta pCO_{2background}$ (-315.5 μatm on day 90, Fig. 11c), which makes the water acted as a CO_2 sink during days 91 to 120 (Fig. 11b) when the *in situ* heterotrophic NCP increased pCO_2 during this time period (Fig. 11c).

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In summary, the decoupling between NCP and CO_2 flux can be the result of competing effect of $\Delta pCO_{2background}$ and ΔpCO_{2NEP}. In our observation, surface waters with oversaturated pCO_2 and positive NCP_{O2Ar} (data in quadrant 1 in Fig. 10) were observed directly outside of the Mississippi River mouth. This is the region where *in situ* autotrophic biological productivity began to increase due to the alleviated light limitation, but the highly heterotrophic $\Delta pCO_{2background}$ from the river channel made the water still acted as a CO_2 source. Decoupling was also observed in the HTACW where CO_2 uptake occurred under heterotrophic condition (data in quadrant 3 in Fig. 10). As discussed above, this phenomenon can be explained by *in situ* heterotrophy superimposed on surface water with low background pCO_2 resulting from the preceding autotrophic biological production.

Conclusions

During a spring cruise in the northern Gulf of Mexico in April 2017, we found encouraging agreement among NCP estimates from multiple approaches despite the different temporal and spatial resolutions and uncertainties associated with each approache. Our study showed that the DO incubation method represents the daily NCP by the local plankton community while the O_2/Ar method reflects the metabolic state of the water relating to both biological and physical processes over longer time scales. The DO incubation method may significantly overestimate NCP rates for high-turbidity water samples due to the improved light environment in the incubation bottles resulting from the settling of particles. The O_2/Ar method has the advantage being able to provide high-resolution NCP estimates matching the underway pCO_2 measurement, which provides more accurate estimation of the overall metabolic condition of the surface water of the nGOM and also allows a better examination on the NCP and CO_2 dynamics. The NCP_{O2Ar} and CO_2 flux showed higher spatial variability on the inner and middle shelf which was strongly influenced by the Mississippi-Atchafalaya River system. Along the river-ocean mixing gradient, NCP_{O2Ar} and CO_2 flux were characterized by 1) heterotrophy and CO_2 release at low salinities resulting from the decomposition of terrestrial carbon and light limitation on photosynthesis, 2) strong autotrophy and CO_2 uptake at intermediate salinities of 15-30 where light and nutrient are both favourable for phytoplankton growth, 3) close-to-zero NCP rate and CO_2 flux in the offshore seawater resulting from nutrient limitation. This study also demonstrated that, due to the slow air-sea CO_2 exchange and the buffering effect of the carbonate system, decoupling between NCP and CO_2 flux could be

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Acknowledgement

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Table

Table 1 The end member properties used in the three end-member mixing model.

End member	Salinity	TA (μmol kg^{-1})	DIC (μmol kg^{-1})	NO_x (μmol kg^{-1})
Atchafalaya River	0	2091	2128	113.14
Mississippi River	0	2314	2312	123.27
Gulf surface seawater	36.15	2407	2076	0.44

Figure

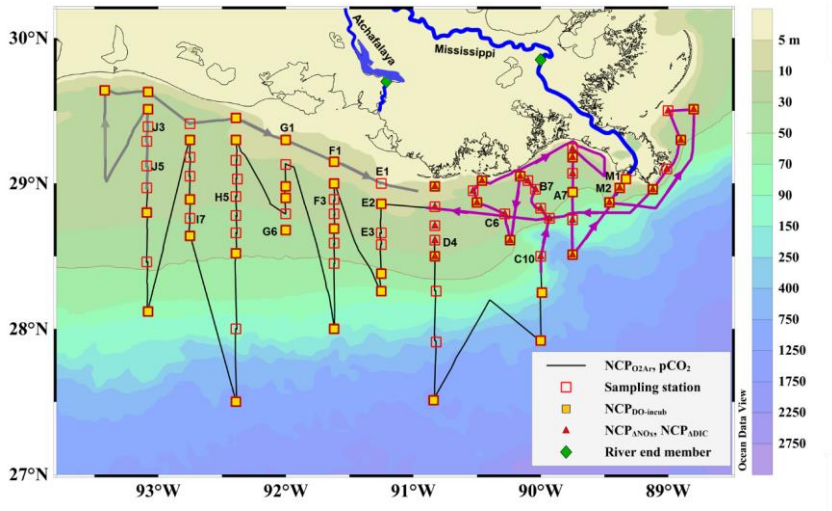

Fig. 1. Map and sampling sites in the northern Gulf of Mexico during the April 2017 cruise. The black dotted line is the cruise track along which the high-resolution underway measurements were made. The track in the Mississippi plume (purple line, 8-11 April) and in the Atchafalaya coastal regions (grey line, 15-17 April) are highlighted. Also shown are the 83 CTD sampling stations (hollow red squares), the 43 stations where light/dark bottle DO incubations were conducted (solid yellow squares), the 30 stations where non-conservative changes in DIC and NO_x were used to estimate NCP rates (solid red triangles), and the 2 stations where the properties of river end members were measured (solid green diamonds). The vertical CTD profiles of the labelled stations were shown in the supplement.

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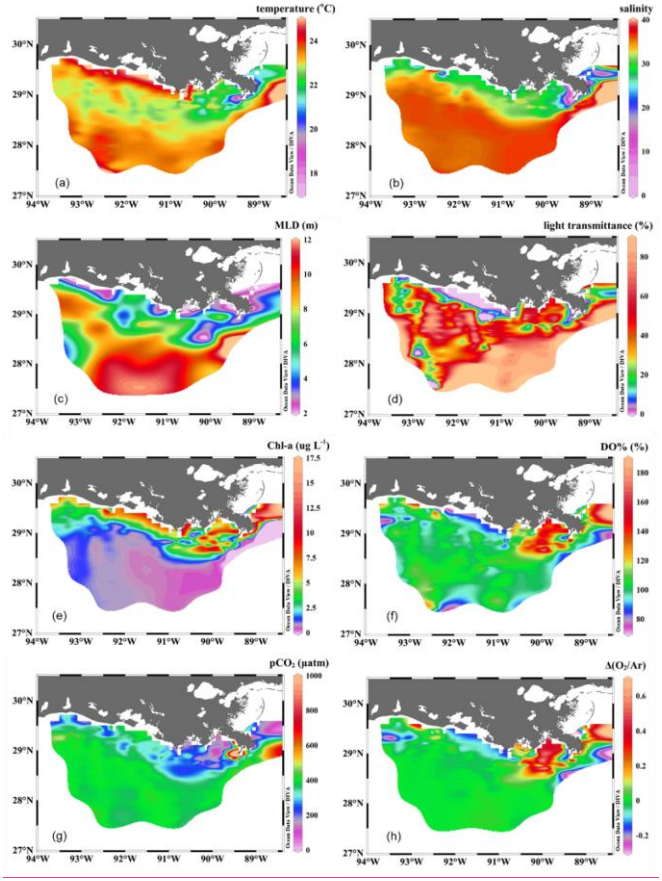

Fig. 2. The distribution of (a) temperature, (b) salinity, (c) mixed layer depth (MLD), (d) light transmittance, (e) chlorophyll-a concentration (Chl-a), (f) oxygen saturation percentage (DO%), (g) partial pressure of CO_2 (pCO_2), and (h) biological-induced oxygen supersaturation ($\Delta O_2/Ar$) in the surface water of the nGOM.

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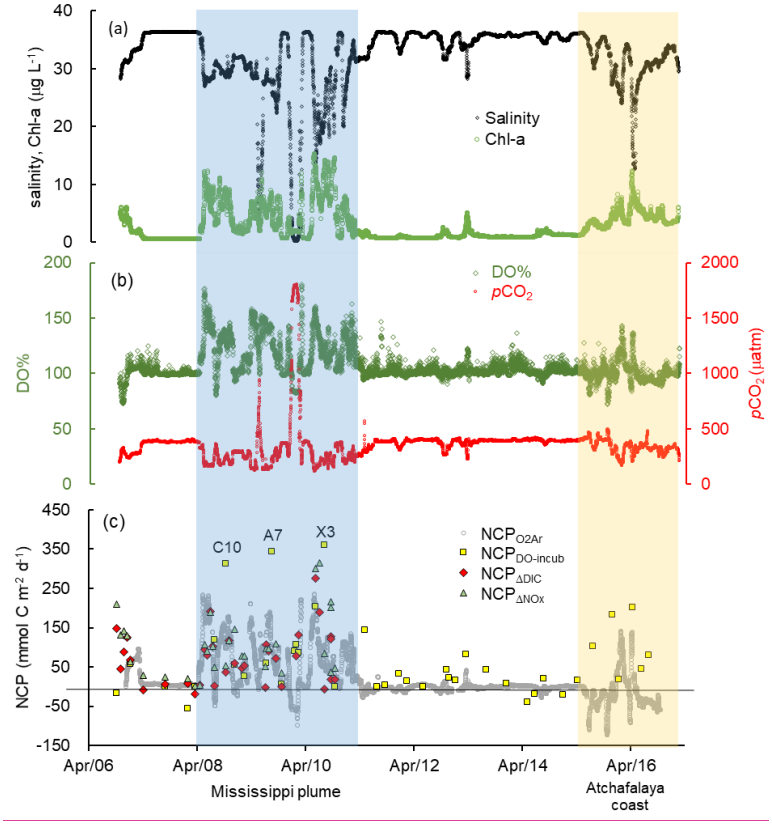

Fig. 3. The underway measurements of (a) salinity and Chl-a, (b) DO% and pCO_2, and (c) NCP rates estimated from the O_2/Ar measurement (NCP_{O2Ar}, grey circles). Also shown in panel c are the NCP rates estimated from the light/dark DO incubation ($NCP_{DO\text{-}incub}$, yellow squares), non-conservative changes in DIC ($NCP_{\Delta DIC}$, red diamonds) or NO_x ($NCP_{\Delta NOx}$, green triangles). See Figure 1 for the cruise track in the Mississippi plume (8-11 April) and Atchafalaya coast (15-17 April). See Figure 5 for the positions of stations C10, A7, and X3 in the Mississippi plume.

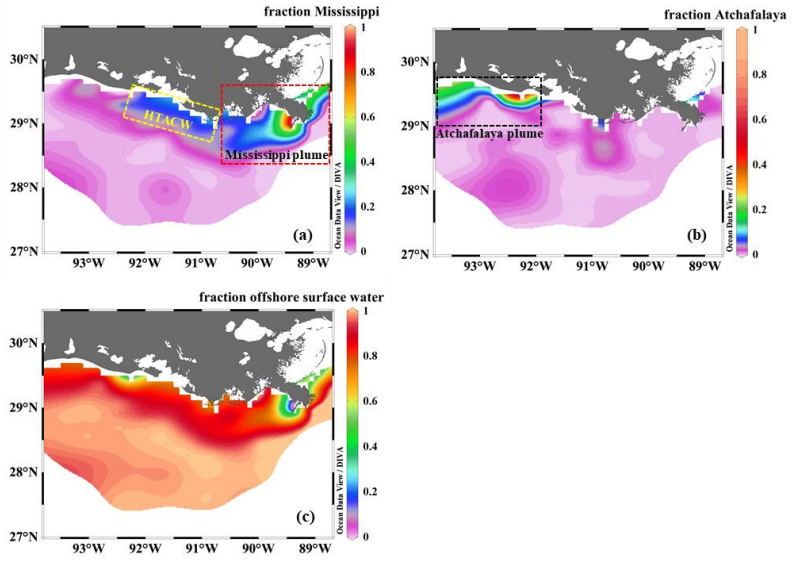

Fig. 4. The fractional contribution of (a) the Mississippi River, (b) the Atchafalaya River, and (c) offshore surface water to the surface water of the nGOM estimated from the three end-member mixing model. The sub-regions shown in panels (a) and (b) are the Mississippi plume, the high-turbidity Atchafalaya coastal water (HTACW), and the Atchafalaya plume.

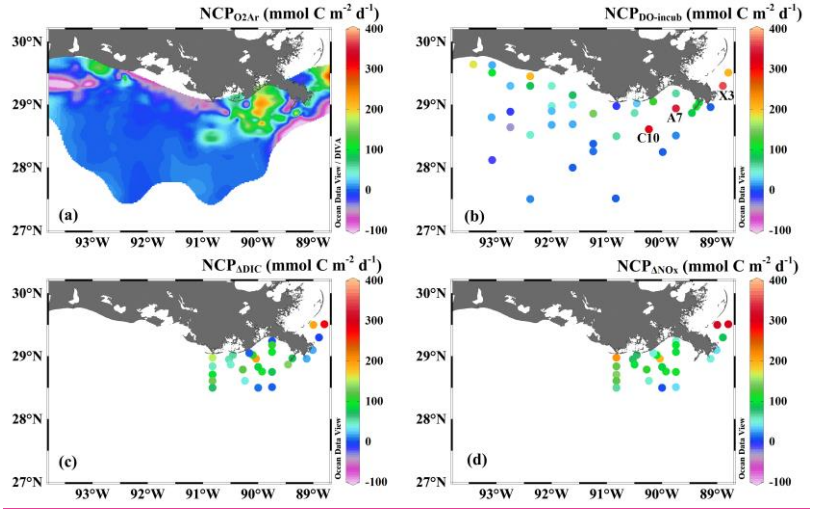

Fig. 5. The spatial variability of (a) NCP$_{O2Ar}$, (b) NCP$_{DO-incub}$, (c) NCP$_{\Delta DIC}$, and (d) NCP$_{\Delta NOx}$. Noted that NCP$_{\Delta DIC}$ and NCP$_{\Delta NOx}$ were only estimated in the Mississippi plume (panels c, d).

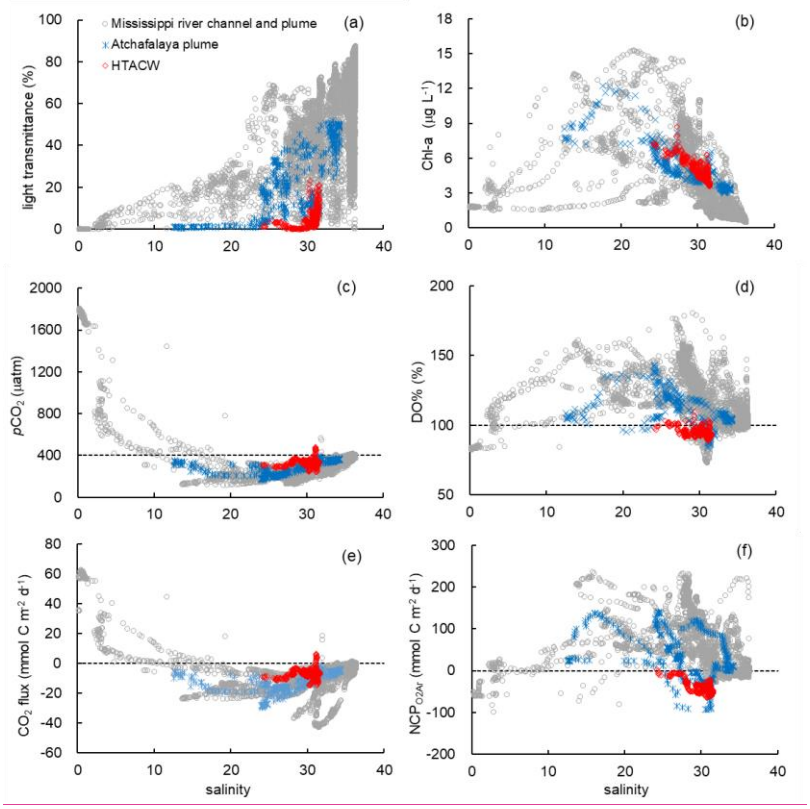

Fig. 6. The distribution of (a) light transmittance, (b) Chl-a, (c) pCO_2, (d) DO%, (e) CO_2 flux, and (f) NCP_{O2Ar} along the salinity gradient in different sub-regions. The dash lines in panels c to f are the atmospheric pCO_2 (405 μatm), DO% of 100 %, zero CO_2 flux, and zero NCP_{O2Ar} respectively.

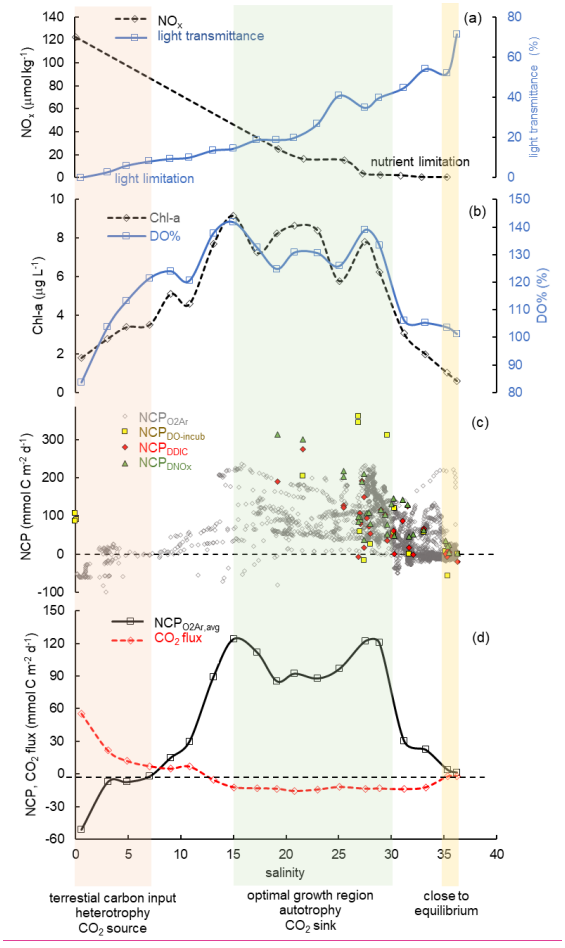

Fig. 7. The distribution of (a) NO_x and light transmittance, (b) Chl-a and DO%, (c) NCP estimated from various methods, and (d) NCP_{O2Ar} and CO_2 flux along the salinity gradient in the Mississippi plume. Data in panels (a), (b), and (d) were averaged over increments of two salinity units.

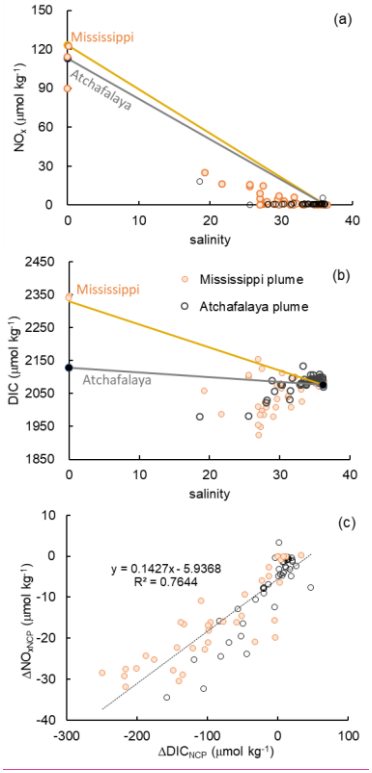

Fig. 8. Scatter plots of (a) DIC and salinity, (b) NO_x and salinity, and (c) the non-conservative changes in DIC (ΔDIC_{NCP}) and NO_x (ΔNO_{xNCP}) in the Mississippi and Atchafalaya plumes. The end member concentrations of the Mississippi river, the Atchafalaya River, and offshore gulf surface water are shown in panels (a) and (b) together with the conservative mixing lines.

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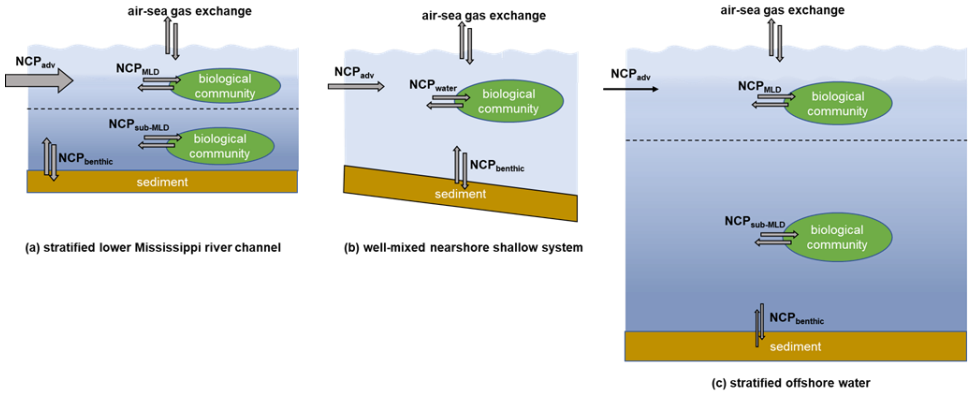

Fig. 9. The differences in water column mixing conditions in the nGOM and their influences on NCP estimation. The dotted lines in panels (a) and (c) indicate the mixed layer depth. In the stratified lower Mississippi River channel (a) and the offshore stratified system (c), $NCP_{DO\text{-}incub}$ equals the *in situ* community production in the mixed layer (NCP_{MLD}), while NCP_{O2Ar} reflects the combined result of the NCP_{MLD} and the influence of lateral advection of the river water (NCP_{adv}). In the nearshore well-mixed shallow system (b), $NCP_{DO\text{-}incub}$ equals the water column community production (NCP_{water}), while NCP_{O2Ar} reflects the combined result of NCP_{water}, $NCP_{benthic}$, and NCP_{adv}. Note that the influence of NCP_{adv} decreases offshore with the increasing water residence time.

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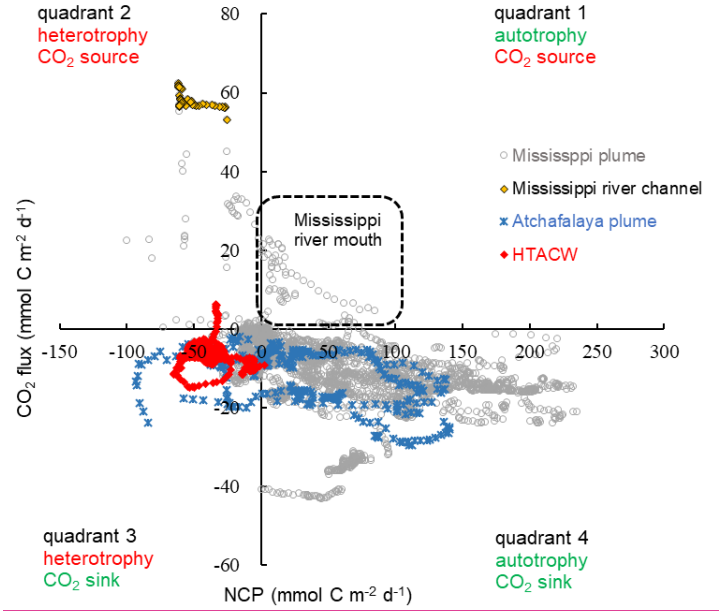

Fig. 10. Scatter plot of NCP_{O2Ar} and CO_2 flux observed in the surface water of the nGOM. Positive NCP implies net autotrophy and negative CO_2 flux implies net oceanic CO_2 uptake from the atmosphere.

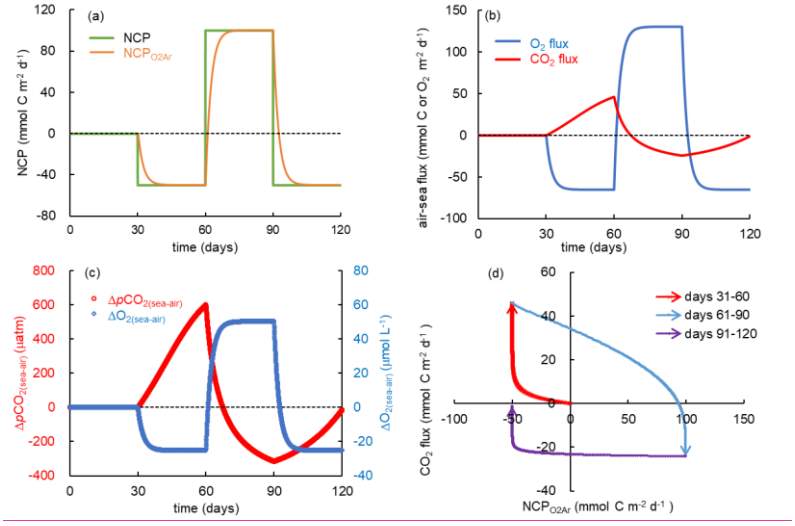

Fig. 11. Simulation of carbon and oxygen dynamics responding to time-dependent varying NCP rates and gas exchange using a 1-D model. The variations of (a) NCP and exponentially weighted NCP (NCP_{O2Ar}), (b) air-sea CO_2 flux and O_2 flux, and (c) air-sea pCO_2 difference ($\Delta pCO_{2(sea-air)}$) and O_2 difference ($\Delta O_{2(sea-air)}$). (d) Scatter plot of CO_2 flux and NCP_{O2Ar}. Positive NCP implies net autotrophy and negative O_2 and CO_2 fluxes implies gas influxes into the water. See the text for details.

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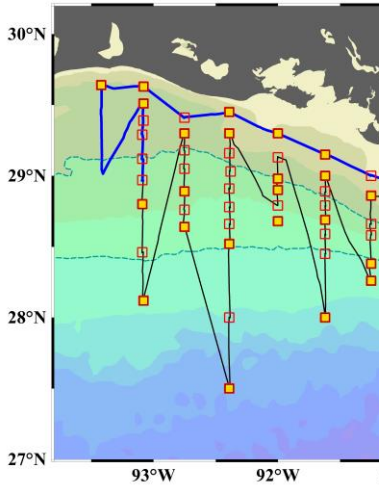

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Figure 1: The underway measurements (black lines), sampling stations (red squares), stations where light/dark bottle DO incubations were conducted (yellow squares), and stations where non-conservative changes in DIC and NO_x were used to estimate net community production (NCP) rates in the Mississippi plume (red triangles). The 20 m and 50 m isobaths are highlighted, as well as the cruise track in the Mississippi plume (purple, Apr. 8-10) and the Atchafalaya coast (blue, Apr. 15-17).

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