Response to Reviewer #1

We thank the two anonymous reviewers for their useful comments on the paper. Please find below our corresponding responses (in blue color) to the comments one by one embedded in the original review. We have also revised the manuscript accordingly.

Anonymous Referee #1

Received and published: 2 October 2013

Upwelling is a physical process that exposes sub-thermocline pools of nutrient elements and CO2 in the ocean to biological productivity in the surface mixed layer and to lower partial pressures of CO2 in the atmosphere. If upwelling is a transient feature and occurs in an isolated system (as is the case with cyclonic eddies in the ocean), a simplified time line of CO2 fluxes between ocean and atmosphere should image an initial pulse of CO2 flux from the ocean surface to the atmosphere, which in the course of time subsides and changes sign due to CO2 and nutrient assimilation (generally in stoichiometric balance) by photosynthetic organisms. They produce sinking organic matter that returns the same amount of CO2 and nutrients to the deep ocean over time. In this simplified case, the net effect of upwelling should be neutral with respect to CO2 fluxes over the entire course of the time line (which does not necessarily coincide with the physical lifetime of the eddy). The matter is complicated (or simply prolonged) by biological processes: By different responses (bloom dynamics, nutrient requirements) of potential primary producers to the nutrient injection; and by organisms that shunt part of the assimilated CO2 into a dissolved organic C pool in the mixed layer rather than into sinking organic matter, and others that take their own good time to mineralize this dissolved pool. In that case, CO2 from DOC mineralisation will be emitted to the atmosphere some time after the upwelling feature has vanished.

Jiao and colleagues studied the physical, chemical and biological states of two cyclonic eddies and a reference site in the South China Sea with a comprehensive suite of methods. Their aim was to clarify the balance of CO2 associated with eddy-induced upwelling, and the roles that biological processes have in determining either sink or source function for CO2 of these transient features. Although they only establish states and fluxes for a limited time window of the eddies' lifetimes, they also applied radiochemical methods permitting them to estimate integrated particle fluxes from the mixed layer over the eddies' history. Based on differences in the chemical and biological states of the two eddies, the authors come to the conclusion that the depth of the thermocline induced by eddy dynamics determines the biological community structure, which in turn determines whether or not the system is a sink or source of CO2.

This is a very ambitious and interesting manuscript that makes an admirable attempt to shed light on some really complex relationships between physics, chemistry and biology in transient upwelling systems caused by mesoscale ocean dynamics. My first thought while reading the manuscript was that upwelling in essence should be neutral with respect to CO2 fluxes, because the basic stoichiometry between nutrient and CO2 release and assimilation should even out all the differences seen in the instantaneous data over space and time (see above). My second thought (which I essentially still stick to) was that all the features can possibly also be explained by a succession of events in the course of/different stages in the life cycles of the two eddies – the authors also hint at this possibility occasionally. My third thought was that the absolute depth of the shoaled thermocline (travel path for thermocline CO2 to equilibrate with the atmospheric) in relation to light penetration and phytoplankton preferred habitat depth range may be key; this is a variant of the authors' preferred interpretation.

Response:

(1) We agree that an upwelling could be neutral with respect to CO_2 fluxes in steady state over time. However, it could be case by case for eddy-induced upwelling events, and consequent variable biological responses could significantly affect "source" or "sink" of a marine region as demonstrated in our study.

(2) We agree to the comment that the features can possibly be explained by a succession of events in the course of different stages in the life cycles of the two eddies. We stated this point in the Abstract (Page 13400, Line 8-10), Introduction (Page 13401, Line 14-16) and Results & Discussion (Page 13407, Line 18-23; Page 13408, Line 16-22) sections of the original manuscript. In the revised version, we further added this statement in the Summary section: "*The results from the present study indicate that when nutrient-rich deep water with low-abundance of prokaryotes is upwelled to the upper ocean, a corresponding rapid growth of phytoplankton and an initial reduction in total bacterial respiration might result in increase of POC export flux, as demonstrated in the case of CE2 whose age was younger and whose upwelling was stronger than that of CE1. In the case that phytoplankton bloom does not occur or picophytoplankton dominates the community, like the case of CE1 that was in the later intensification period, the injected nutrients and phytoplankton originated labile organic carbon could stimulate microbial respiration which exacerbates the attenuation of POC flux.*"

(3) We have added depths of mixed layers, euphotic depths (1% light level) and nitracline depths in Table 1 of the revised version (see below). The relevant description was added in paragraph 3.1 ("*Apparently, the cyclonic eddy isopycnal uplift resulted in shoaling of the mixed layer and nitracline at both cases (Table 1; Fig. 2). Consequently the nutrients injected into the nutrient-depleted euphotic zone effectively stimulated phytoplankton growth*"). The relevant discussion was also supplied in paragraph 3.1 ("*CE2 upwelling brought nutrients to the upper layer of the euphotic zone where light was replete as indicated by the mixed layer, eutrophic depth and nitracline depth (Table 1), diatoms responded and bloomed; CE1 upwelled nutrients can reach only the lower layer of the euphotic zone where picoplankton are dominant, diatoms did not respond much due to lack of enough light down there.*"). In addition, two scenario models are established in paragraph

3.5 (“*When an upwelling bring nutrients to the upper layer of the euphotic zone where light is replete, diatoms respond and bloom, and consequently enhance POC export; Meanwhile, total microbial respiration would be slowed down due to low abundance and low temperature brought by the deep water. As a result, POC export flux exceeds respiration flux (Fig. 7a; instance: CE2). This would deepen the mineralization depth and thus favor CO_2 uptatke by the ocean (Kown et al., 2009). If the upwelled nutrients can reach only the lower layer of the euphotic zone where picoplankton especially Prochlorococcus are dominant, diatoms do not respond much to the upwelling due to lack of enough light down there, instead, microbial loop could be very active (Hagström et al., 1988; Azam et al., 1993). As a result, microbial respiration flux would exceed POC export flux (Fig. 7b; instance: CE1). This would shoal the mineralization depth and result in decrease in ocean’s DIC capacity (Kown et al., 2009).*”).

Table 1. Hydrographic characteristics, phytoplankton, particle export parameters, bacterial abundance and respiration and air-sea CO_2 flux in CE1, CE2 and surrounding waters. CE1: cyclonic eddy #1; CE2: cyclonic eddy #2. Error bars indicate standard deviation. TChl a: total chlorophyll *a*; SS: stable state; POC: particle organic carbon; BA: bacterial abundance; BR: bacterial respiration rate. Non-parametric Kruskal-Wallis Test was used for comparison of variables between sites.

Parameters	**CE1**	**CE2**	**Reference site**
Hydrography			
Depth of mixed layer (m)	~25 [a]	~15 [b]	~40 [c]
Euphotic depth (1% light level, m)	~62 [a]	~63 [b]	~78 [c]
Nitracline depth (m)	~20 [a]	~10 [b]	~70 [c]
Temperature (°C, at 25 m)	27.72[a]	23.33[b]	29.63[c]
Salinity (PSU, at 25 m)	34.12[a]	34.08[b]	33.99[c]
AOU (mol m^{-2}, 50-100 m)	4.83[a]	5.89[b]	2.31[c]
Phytoplankton[d]			
TChl *a* (mg m^{-2}, 0-50m)[**]	12.3±3.68 (N=23)	13.8±4.91 (N=11)	10.1±7.89 (N=47)
Fucoxanthin (mg m^{-2}, 0-50 m)	0.60±0.26 (N=22)	1.14±1.10 (N=11)	1.07±1.89 (N=47)

Divinyl chorophyll *a* (mg m^{-2}, 0-50 m)**	2.88±1.13 (N=22)	1.97±2.02 (N=11)	1.72±0.90 (N=47)
Particle export[d]			
SS ^{234}Th flux @100 m (dpm m^{-2} d^{-1})*	712±521 (N=8)	1609±572 (N=6)	1279±697 (N=22)
POC (×10^2 mol C m^{-2}, 0-100 m)*	1.76±0.26 (N=8)	2.18±0.38 (N=6)	1.78±0.35 (N=17)
POC/^{234}Th @100 m (μmol C dpm^{-1})	3.43±1.00 (N=8)	3.66±1.00 (N=6)	3.66±1.12 (N=22)
POC export @100 m (mmol C m^{-2} d^{-1})*	2.50±2.03 (N=8)	6.16±3.74 (N=6)	4.92±3.63 (N=22)
Bacteria			
BA (10^5 cells ml^{-1})	2.41[d] (N=2)	1.73[b]	2.14[c]
BR (mg C m^{-2} d^{-1}, 0-100 m)	327[d] (N=2)	255[b]	292[c]
Air-sea CO_2 flux[d]			
CO_2 flux (mmol m^{-2} d^{-1})**	4.15±0.84 (N=9112)	3.43±0.59 (N=1330)	2.82±0.65 (N=13754)

[a] Data from the CE1 center site TS1;
[b] Data from the CE2 center site Y12;
[c] Data from the reference site SEATS;
[d] Data were mean ± SD (standard deviation) from the CE1 and CE2 regions and the reference sites of surrounding waters.
** $P < 0.01$;
* $P < 0.05$.

Many of the details and methods are beyond me and I cannot judge for example, if the particle export reconstructions are sound (although they appear to be). In my opinion, a revised manuscript should discuss the points made above in more detail: a) That the described (instantaneous) states of the two eddies are in effect snapshots of different stages in the life cycle of these features and that an integration over the entire life time may even out the differences. b) That the physical vigour of eddies (whether CO2-rich water penetrates to atmospheric contact) as opposed to nutrients only exposed to photosynthesis changes the CO2 balance. In the latter case the DOC fraction and its mineralisation should be the only mechanism that causes air-sea exchange in the aftermath.

Response:

(1) For the different stages in the life cycles of the two eddies, we stated the point in the Abstract (Page 13400, Line 8-10), Introduction (Page 13401, Line 14-16) and Results & Discussion (Page 13407, Line 18-23; Page 13408, Line 16-22) sections

of the original manuscript. In the revised version, we further added this statement in the Summary section: "*The results from the present study indicate that when nutrient-rich deep water with low-abundance of prokaryotes is upwelled to the upper ocean, a corresponding rapid growth of phytoplankton and an initial reduction in total bacterial respiration might result in increase of POC export flux, as demonstrated in the case of CE2 whose age was younger and whose upwelling was stronger than that of CE1. In the case that phytoplankton bloom does not occur or picophytoplankton dominates the community, like the case of CE1 that was in the later intensification period, the injected nutrients and phytoplankton originated labile organic carbon could stimulate microbial respiration which exacerbates the attenuation of POC flux.*"

(2) We agree to the point that "integration over the entire life time may even out the differences" in some cases, but we did not have data to back up the point in this study. So we put a statement in the Section 3.5 that "*Therefore, the adjudgement of a marine region to be a carbon sink or source should be carefully made on the long-term balance between the amount of outgassing carbon and the sum of the outputs of the BP and the MCP, rather than simply according to momentary CO_2 partial pressures.*"

(3) The two mechanisms (physical vigour and DOC mineralization) occurred synchronously in both CE1 and CE2, as mentioned in the original manuscript (Page 13410, Line 13-25; Page 13411, Line 1-6). Although deep water was injected into the shallower mixed layer in CE2 than CE1 as indicated by the mixed layer and nitracline depths data (please refer to the above supplied data), air-sea CO_2 flux was higher in CE1, suggesting that DOC mineralization should be the major mechanism that caused air-sea exchange in CE1. The relevant discussion was in paragraph 3.3 and we made some revision in conjunction with the mixed layer and nitracline depth data ("*In CE1, POC export flux was lowest whereas BR was highest, corresponding to the highest air-sea CO_2 flux (4.15±0.84 mmol m^{-2} d^{-1}) among all the investigation sites. This cannot be attributed to dissolved inorganic carbon (DIC) release as seen from the fact that CE2 rather than CE1 had the strongest upwelling and thus the strongest DIC release from subthermocline water as indicated by the mixed layer and nitracline depths (Table 1) but the total CO_2 outgassing in CE2 was actually lower (3.43±0.59 mmol m^{-2} d^{-1}) than CE1 (4.15±0.84 mmol m^{-2} d^{-1}).*").

The manuscript is well written and concise, tables and illustrations are all necessary and of good quality. Below are some suggestions on style and wording and some queries.

Abstract line 1: What is the difference between marine and oceanic upwelling regions?

Response:

We have replaced the term "marine upwelling" with "ocean upwelling in the revised version.

Line 14: increasing instead of aggravating?
Response: Revised as suggested.

Line 17 delete meanwhile
Response: Deleted.

Line 22: subthermocline instead of deep water
Response: Revised as suggested.

L25: cause upwelling to different extent
Response: Revised as suggested.

13401 L4 . . .). Other studies
Response: Revised.

13 . . .). Instead, they. . .
Response: Revised.

14: Eddy age is another control on. . ..(?) the extent of . . .
Response: Revised as suggested.

13402 L1 observations in two
Response: Revised.

L19 monitoring instead of indicating?
Response: Revised as suggested.

13403 24: using a recently. . .
Response: Revised as suggested.

13404 L 7: What do you mean with "assuming no physical transport" in connection with export flux?
Response: We mean "assuming no physical horizontal transport". Revised.

13405: L 14: The relationship
Response: Revised.

L15 estimate instead of provide
Response: Revised.

13406 L4 , residual (or recycled) silicate was present in the mixed layer at station CE1. Can you exclude that silica was present because a diatom bloom has decayed and silica was present from dissolution?

Response:
We cannot exclude this possibility due to lack of observations on the entire life time of CE1. The relevant statement was added in paragraph 3.1 ("*Photosynthetic pigments analysis indicated that the dominant autotrophs at CE1 were cyanobacteria rather than diatoms as occurred at CE2 (Table 1, Fig. 3b and c), suggesting that diatoms in CE1 were surpassed by cyanobacteria and not well developed, allowing extra silicate left over in the environment. Alternatively, a diatom bloom has decayed and silicate was present from dissolution. Therefore, the less intense upwelling (e.g. during the later intensification period) and consequently higher temperature (which favors cyanobacteria) at CE1 than CE2 could be responsible for the corresponding differences between their community structures.*").

L15 upwelling conditions/impacts (?)
Response: Replaced "impacts" with "conditions".

L16 have different abundances among sites
Response:
Sorry for the misleading mean of this sentence. It was revised as "*…got a ranking order of abundance among sites (CE1 boundary > CE1 center > CE2 center) similar to Prochlorococcus, rather than to diatoms*".

L26 similar pattern in that
Response: Revised.

13407 L2 consistent with
Response: Revised.

L3 diatoms contribute more to POC. . ...at CE2 that at CE1
Response: Revised.

Paragraph 3.3 This paragraph is important, because the text addresses the possibility that the two eddies have different stages. It also argues that the state of the microbial loop determines the CO2 flux. However, I do not follow the logic of CE2 having a stronger upwelling than CE1, and how that relates to CO2 outgassing, when there is an ongoing diatom bloom in CE2 and the entire story may be one of different upwelling stages. This paragraph must be carefully structured and precise in wording. It should possibly be expanded to discuss the different possibilities
Response:
CE2 had a stronger upwelling than CE1, so deep water was injected into the shallower mixed layer as indicated by the mixed layer and nitracline depths (please refer to the above supplied data) resulting in a stronger DIC release. However, our data indicated that the CO_2 outgassing was lower in CE2 than CE1, suggesting that increase of primary production weakened the CO_2 outgassing in CE2 while DOC mineralization might be the major mechanism causing the higher CO2 outgassing in CE1. We

revised the original sentence as "*This cannot be attributed to dissolved inorganic carbon (DIC) release as seen from the fact that CE2 rather than CE1 had the strongest upwelling and thus the strongest DIC release from subthermocline water as indicated by the mixed layer and nitracline depths (Table 1) but the total CO_2 outgassing in CE2 was actually lower (3.43±0.59 mmol m^{-2} d^{-1}) than CE1 (4.15±0.84 mmol m^{-2} d^{-1}).*"

Line 25 ff In CE1 POC export flux was lowest whereas BR was high, corresponding to. . ... This cannot be attributed to..
Response: Revised.

13408 Line 14 consuming POC and attenuating POC export flux.
Response: Revised.

24: Centers of cyclonic eddies in the northwestern . . ..were associated. . .
Response: Revised.

27. 2005). This was attributed to. . ..maintenance respiration of hetero. . ..
Response: Revised.

13409 2+3: gradually increasing BR is the prevailing . . ..
Response: Revised.

11: have shown
Response: Revised.

12: centers than at the reference
Response: Revised.

13: In our study (?) humic type
Response: Replace "Here" by "In our study".

18: organic matter and consuming oxygen
Response: Revised as suggested.

The paragraph 3.5. should be rewritten – sentences are too long and often awkwardly structured and worded. The meaning often is not clear. On the other hand this is a crucial paragraph. Title of the paragraph is possibly wrong: the theme are transient eddy upwelling situations – you cannot generalise for upwelling at large.
Response:
Sentences in section 3.5 will be shorten and restructured to deliver the meaning more clearly. The title has been changed to "*Upwelling status influencing CO_2 outgassing and carbon sequestration*".