Interactive comment on "Diagnosing CO_2 fluxes in the upwelling system off the Oregon coast" by Cao et al.

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Response to the comments from Dr. Debby Ianson

Cao et al. use a relatively simple end-member mixing scheme to estimate the air-sea CO_2 flux from two transects in the coastal upwelling zone along the west coast of North America during the spring of 2007. This method has been used elsewhere but not yet applied to coastal upwelling.

General comments

This work uses an end-member scheme that relies on conservative behavior of total alkalinity and salinity (and a suite of other assumptions nicely laid out in the Wanninkhof review). The simplicity of the method is appealing and a useful tool to investigate CO_2 fluxes, at least to first order, as long as assumptions are not violated (which is tricky in coastal upwelling zones as the authors point out). I have a few recommendations/comments (below) mainly involving the addition of sensitivity analyses, which would add significant value to the interpretation.

[Response]: We thank Dr. Ianson for the valuable comments and suggestions, which have been fully considered in our revisions.

1. Since upwelling regions push the assumptions involved I suggest a sensitivity/error analysis/discussion be added. The limitations of the method could then be discussed in a quantitative fashion and perhaps boundaries on its utility imposed. For e.g. the X^{eff} terms are nicely discussed in the context of CR data and TA intercepts (with S) but then a single number is used for each of DIC and NO3 (eff).

[Response]: We agree that a single number of X^{eff} is to some extent not convincing. While we are certain that NO_3^{eff} from the Columbia River plume is zero, we have performed a sensitivity analysis showing the minor influence of the DIC^{eff} variations on our diagnosis approach (Table R1-2 of the "Response to the comments from Dr. Rik Wanninkhof").

2. Including data below 200 m (or below a salinity of 34) in the TA-S plots in this dataset make the determination of the 'end-member' a little murky in my opinion. At about S=34 (a little shallower) the TA-S 'curves' become more steep in these data, presumably getting into the California Undercurrent and/or aragonite dissolution (relatively shallow in this part of the world). I don't dispute the author's choice of regression and end-member necessarily - but again recommend a sensitivity analysis (choose a range of end-members) and suggest showing the data below 200 m in Fig. 2 even if they are coloured differently (which could convince the reader that the end-member really was tight and unambiguous).

[Response]: Per the reviewer's suggestion, we have plotted the TAlk-Sal relationship through the entire water column on Transects 4, 5 and 6 (Fig. R3-1; we have added in our revisions the diagnosis of Transect 6 per the suggestion from Referee #1; please also see Fig. R1-1 of the "Response to the comments from Dr. Rik Wanninkhof" and Fig. R2-1 of the "Response to the comments from Referee #1”). It’s now easy to see that the deep water end-member for the upper waters was a little shallower than ~200 m, corresponding to an average salinity of 33.9. As a result, we have changed “in the upper 200 m waters” to “in the upper 175 m waters” in our revisions and removed data points of ~200 m from the TAlk-Sal plot for the upper 175 m waters.

In the original MS, we stated that selecting ~200 m waters as the deep water end-member, whereas the real data used were those collected at ~175 m. We apologize for this misleading statement and have made this point clearer in our revisions. Moreover, we have also performed a sensitivity analysis of this deep water end-member demonstrating that our choice of ~175 m was in order (Table R1-3 of the “Response to the comments from Dr. Rik Wanninkhof”).

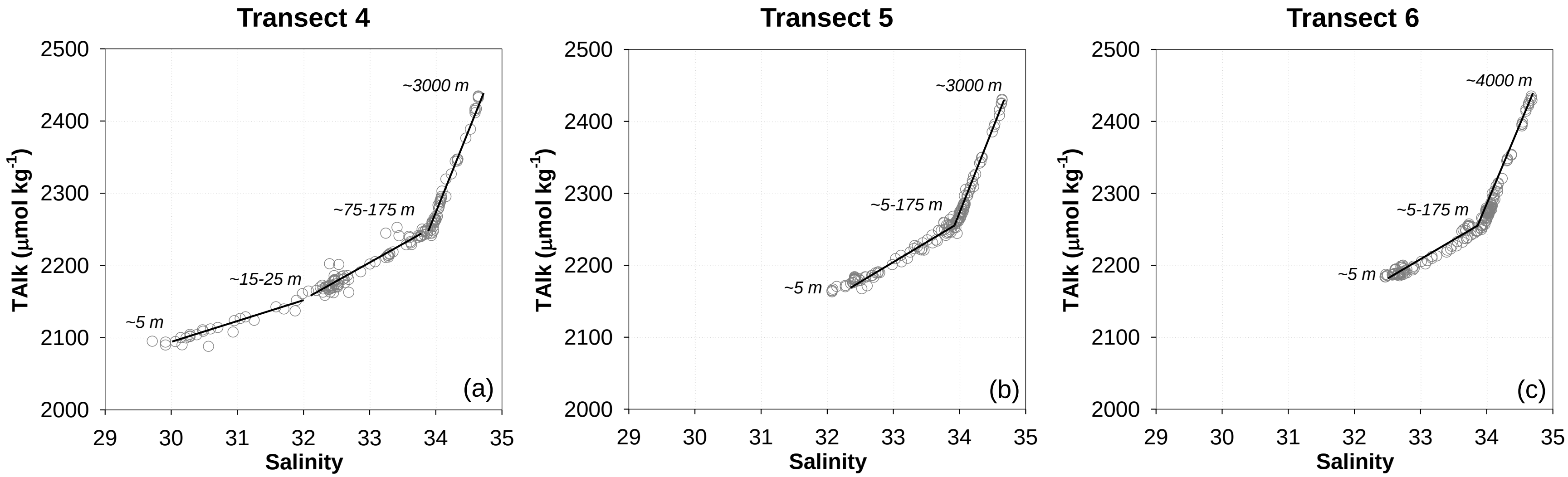

Fig. R3-1. Total alkalinity versus salinity through the entire water column of sampling stations along Transects 4 (a), 5 (b) and 6 (c) off Oregon and northern California in spring/early summer 2007. The solid lines indicate various linear relationships observed on each transect. The numbers in italic denote the sampling depth/depth range of the endpoints of each line. Three generally linear relationships between TAlk and salinity were observed through the entire water column along Transect 4. The first one was for waters with salinity lower than ~32.0 (corresponding to the depth of ~15-25 m), which were significantly influenced by the Columbia River (CR) plume. The second one was for waters composed primarily of the California Current (CC) with salinity between ~32.0 and ~33.9, including those immediately below the top buoyant layer at stations 26-32 and the surface waters at the outmost station 33. The higher-end salinity value of ~33.9 corresponded to a depth range of ~75-175 m, composed possibly of the upwelled high-salinity California Undercurrent (CUC) waters. At station 27 (water depth ~170 m) for instance, salinity at depths of ~130 m and ~160 m reached ~34.0 with TAlk values of ~2260 μmol kg^{-1}, which were even higher than those of offshore waters at ~175 m (~2250 μmol kg^{-1}). These two data points were thus located on the third linear relationship for waters with salinity higher than ~33.9, the slope of which became much steeper, mainly reflective of the mixing between the approaching CUC and deep waters of the eastern North Pacific. All salinity values, including surface samples on Transects 5 and 6, were higher than 32.0. With minor influence of the CR plume, the TAlk-Sal relationship displayed two generally linear phases through the entire water column along both transects, while the TAlk/salinity endpoints of each comparable to those of the latter two ones observed on Transect 4. Note that the turning point with salinity of ~33.9 corresponded to a wider depth range of ~5-175 m, resulting from the most intensified upwelling on Transects 5 and 6 bringing deep waters to the nearshore surface (Feely et al., 2008).

3. Related to the previous point, the authors do not discuss the California Undercurrent (CUC) and its unique properties. At least along T4, the core of the CUC is above 200 m (Thomson and Krassovski 2010 JGR) and must be present at some stations on the transect.

[Response]: We have added a couple of sentences discussing the CUC based on the TAlk-Sal relationship through the entire water column (Fig. R3-1). But again, we don't intend to distinguish all of the water masses and identify their initial end-member values one by one. We used field observed values as end-members which might have experienced physical or biological alterations from their original water masses.

4. The authors discuss the method in the context of determining net source and sink (for CO_2) regions in a general sense - but with two transects (single visit) they are only able to look at a couple of snapshots in time in a system with large spatial and temporal variability. They would need seasonal data, in particular from the winter (downwelling) season where PP is light-limited on T4, to make a firm assessment of the source/sink capability of a region. (The steady state assumption is clearly violated.) This caveat should be more clearly stated.

[Response]: Our main objective is to test the OceMar conceptual model and our diagnosis approach in coastal upwelling systems and the Oregon-California shelf is selected as a representative case. It is not the scope of this paper to systematically investigate the distribution and seasonality of CO_2 source/sink nature in this area, which however has been well reported in relevant studies such as Evans et al. (2011).

5. There is evidence for 'excess' DIC uptake (uncoupled from NO_3) when phytoplankton become nutrient limited (Ianson and Allen 2002 GBC and Druon et al. 2010 ECSS model this uptake - but the concept is much older - e.g. Sambrotto et al. 1993 Nature) which would affect the estimation of air-sea flux if present. For these transects (esp. T5) this feature may not be an issue (although on T4 depletion of silicic acid suggests that it might), but it should at least be discussed in the paper and again sensitivity analysis would be valuable.

[Response]: We think the issue of excess DIC uptake relative to NO_3 is similar to that of non-Redfield C/N uptake ratio so that they were discussed together in our revisions. We have tested the OceMar approach with another empirical C/N uptake ratio of 7.3 (Anderson and Sarmiento, 1994), which to some extent suggests the excess DIC uptake. Please also see our response to the comments from Dr. Wanninkhof.

Specific comments

1. p.7391 l.2-5 for general source/sink discussion need seasonal context (state)

[Response]: Modified as suggested.

2. p.7391 l.13 - why mention Ca ion if not measured?

[Response]: Ca^{2+} is used as a conservative chemical tracer in Dai et al. (2013).

3. p.7392 l.7 - eNP - add 'Subtropical Gyre' to distinguish from Alaskan Gyre - eNP.

[Response]: We have deleted this sentence.

4. p.7392 l.15-20 - a good place to mention the possibility of excess DIC uptake

[Response]: We don't think here the excess DIC uptake works because the undersaturated *p*CO_2 off Oregon were well predicted with the Redfield C/N uptake ratio in both Hales et al. (2005) and this study.

5. p.7393 l.3 300 m seems too deep for CC ?

[Response]: We have changed to 0-200 m.

6. p.7393 l.9 - CUC is shallower than that (Thomson and Krassovski 2010 JGR)

[Response]: We have changed to 150-300 m according to Thomson and Krassovski (2010).

7. p.7993 l.13 - I work further north, but these upwelling depths look too deep. Are you sure?

[Response]: Yes. The vertical sections of some physical/chemical parameters including temperature, pH and DIC show that the subsurface water is upwelled from the depths of 150 m to 200 m onto the Oregon-California shelf (see Feely et al., 2008, Figure 2), while other studies also prove these upwelling depths (e.g., Hales et al., 2005).

8. p.7396 l.1 - remove 'very good' or be quantitative

[Response]: We have added the r value to quantitatively show the good TAlk-Sal relationship.

9. p.7396 l.9 and l.15 'should' - why 'should' they? do they? suggest more explanation or better word choice.

[Response]: Modified as suggested.

10. p.7397 l.2-3 - given that it's an upwelling zone wouldn't it be smarter to use a set isopycnal instead of depth? and I would choose a shallower depth in this zone as my end-member to stay in a linear zone of TA-S etc (see general comments above).

[Response]: While the isopycnal mixing dominated the nearshore upwelling zone off Oregon and northern California, upper waters in offshore areas beyond the upwelling circulation were largely fed by on-site deep waters via diapycnal mixing. In this context, we kept using depth which is more straightforward than density.

We have clarified that the values at ~175 m were selected as the deep water end-member. Please also see our response to general comment #2 from Dr. Ianson.

11. p.7398 l.5 (and further) what about non-Redfieldian C:N?

[Response]: We have tested the OceMar approach with another C/N uptake ratio. Please also see our response to the comments from Dr. Wanninkhof.

12. p.7399 sect.3.3 - again - consider ‘excess DIC’ uptake
[Response]: Please see our response to general comment #5 from Dr. Ianson.

References

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