Reviewer #1

We are particularly thankful to the anonymous referee for her/his numerous comments and suggestions on our manuscript. We agree with most comments and have modified and/or updated the manuscript accordingly. Details and answers are provided below in italics.

Comments to the Authors

General comments: This is an interesting paper examining particle distributions and modeled carbon fluxes across the Arabian Sea Oxygen Minimum Zone (OMZ). The primary data collected are particle size distributions and concentrations obtained with a transmissometer and the UVP imaging instrument, plus some zooplankton net tows and CTD and satellite data. The fluxes are calculated from a model (not measured by direct collections such as sediment traps); therefore, I suggest that the title be modified to "modeled carbon flux" to make that clear (Note that "Particle" should be singular in the title also.) The combination of new technology leading to unique observations, sophisticated modeling, and an interesting discussion make this a valuable contribution to science and the increased focus on OMZs in the context of climate change.

We agree with the reviewer, we have changed the title to "Particle size distribution and estimated carbon flux across the Arabian Sea Oxygen Minimum Zone"

Scientific questions and issues: In my opinion, the effect of OMZs on particle fluxes to the deep sea (below the OMZ) remains an open question, and these uncertainties could be more fully highlighted in the discussion.

Reviewer 3 also points to this 'open question'. We have modified a few sentences in the abstract, the discussion and the conclusion sections.

- ➔ *In the abstract, we have replaced the 5 last sentences by :*

"Enhanced bacterial activity and zooplankton feeding in the deep OMZ is proposed as a mechanism for the observed deep particle aggregation. Estimated lower flux attenuation in the upper OMZ and re-aggregation at the lower oxycline suggest that OMZ may be regions of enhanced carbon flux to the deep sea relative to non OMZ regions. However, large uncertainties exist on processes that call for additional sampling of these regions.

- ➔ *In section 4.3 of the discussion, we have added the following paragraph about physico-chemical aggregation (raised by reviewer 3) to stress more on such an open question:*

"Physico-chemical aggregation processes rely on increased collision between organic or inorganic precursors by change in the concentration of cations as observed in estuary (Wetz et al., 2009) or

turbulence (Jackson et al., 1995). However, no study is available for both processes in the deep sea but turbulence can be ruled out in quiet deep water (Burd and Jackson, 2008). Colliding particles can be aggregated if glued in a TEP like matrix of biological origin. The latter can be affected by direct effect of high metal concentrations (Mari and Robert, 2008), modification of pH (Riebesell et al., 2007; Mari, 2008), and to microbial processes (e.g. Muylaert et al., 2000). A recent study in the South Pacific OMZ (Ganesh et al., 2014) has shown that particle attached bacteria are particularly present (and possibly active) in oxygen deficient water. Knowledge on the processes remains spares at the lower oxycline but repeated observation by us and other (Wishner et al., 1995, 1998 and 2008; Lee et al., 1998) supports the fact that this place is a site of enhanced bacterial and plankton activity acting on particles."

➔ *In the conclusion, we have reformulated several sentences:*

We observed strong vertical gradients in particle size distribution, biogeochemical and biological variables at the upper boundary of the OMZ. A gradient in particle concentration was also observed at the lower oxycline but less intense. Although many aspects of the OMZ functioning still remains unknown, our results support earlier studies showing a strong layering of biological communities and processes. Our new results can be used to further discuss causal mechanisms. In the upper part of the OMZ core, the anaerobic microbial respiration probably enhanced production and accumulation of observed particles < 100 µm but did not modify the calculated particulate vertical flux. No specific vertical change of PSD>100µm was observed in the core of the OMZ suggesting that particulate flux transformation was low in that layer. At the lower oxycline of some stations, changes of abundances in both small and large particles classes are associated to zooplankton-enriched layers. There, the accumulation of large particles enhanced the calculated POC vertical flux to the bathy- pelagic zone of the ocean. Finally, the lack or low intensity of large particle remineralisation in the core of the OMZ and possible particulate repackaging in the lower oxycline may further increase the ocean carbon sequestration in the OMZ of Arabian Sea relative to non-OMZ situations However, large uncertainties still exist on processes that call for additional sampling of these deep layers.

This paper models overall fluxes (Martin curve) only into the OMZ core (Fig. 11). What happens to the Martin curve when you include the particle layer at the lower oxycline?

In non-OMZ open sea, particle concentration decrease with depth and the Martin adjustment is not affected by the maximum depth considered, implying that a unique value of the b exponent could describe flux attenuation. Here we show that in some OMZ-stations, because of the particle increase

at depth, the Martin adjustment does not fit the profile if we consider deep values. Therefore, we fitted the Martin model only using the water column above the lower oxycline.
We explained that better in the method section 2.3:
Because of flux increase with depth at the lower oxycline, the Martin model was fitted using only the portion of the water column above the lower oxycline.

We made this point also clear in the discussion (line 12287) using the following sentences:

- ➔ *page 12287; and lateral particle transport (see large change in PSD associated to the PGW in Fig. 10a)*
- ➔ *Therefore, 1-D vertical assumption for station 37 cannot be assumed and the Martin model cannot be applied. By contrast, stations 39 and 40 can be considered 1-D but due to deep increase in the calculated flux at the lower oxycline, we fitted the Martin model using only the points above the lower oxycline.*

When examined in detail, previous papers are also not clear about this. The comprehensive summaries of Berelson, Lee, and Honjo (about sediment trap results (direct flux measurements) during JGOFS (including the Arabian Sea program) could not define (with statistical significance) a clear difference between OMZ and non-OMZ regions, especially when lateral advection and technical differences likely played a role. The Van Mooy et al. (2002) paper deals with degradation experiments and does not include the lower oxycline as a feature. Of course, most earlier flux papers do not address the lower oxycline particle increase since it was not recognized. A more comprehensive discussion including analyses of the various methodologies and their uncertainties would be scientifically beneficial for this unresolved issue.
We agree with this comment. Generally, the low vertical resolution of sediment traps, variable trapping efficiencies, lateral transport make it difficult to use traps to make vertical profiles of flux specially in the upper midwater. So the issue of more or less flux attenuation in OMZ is still unresolved. However, common striking patterns, from the literature, complementary to our observation can be inferred from different studies. In the JGOFS paper published by Lee and al. 1998, figure 2 shows that 4 vertical profiles of flux inferred from sediment traps (S2, S3, S4 and S7) among 5 are affected by an increase from 1 to 5% of carbon flux around 900m depth and this pattern is more or less pronounced depending on the time period (see fig. 3 from Lee et al. 1998). All the traps were in OMZ and the lack of standard situation make it difficult to assess differences with non OMZ situations. Therefore, the author could not conclude on the OMZ consequence on the flux. Devol and Hartnett (2004) compared POC fluxes in two OMZ oceanic situations located along the Washington State and Mexican continental margins. The Mexican profile is strongly affected by the

deoxygenation in the water column, much more than the Washington profile (figure 1), and is comparable to the Arabian Sea OMZ (the OMZ core extends between 100 and 1000m). The POC flux (figure 3 in the manuscript) presents a strong difference between these two locations and the deep increase associated to the lower oxycline is well visible for the Mexican profile, exactly as in our results.

In the revised manuscript, we have modified the introduction and discussion to reflect the uncertainty of the vertical flux efficiency in OMZ.

In the introduction, page 19273, line 23: we added: "However, other studies in the Arabian Sea revealed no clear patterns in the flux attenuation with the OMZ (Lee et al., 1998). Therefore, the impact of low oxygen layers on particle stocks and vertical flux must still be understood.

In the discussion we have added the following sentence to section 4.3

"Knowledge on the processes remains sparse in OMZ anaerobic systems but repeated observation by us and other (Vinogradov and Voronina, 1962; Wishner et al., 1995, 1998 and 2008; Lee et al., 1998) supports the fact that this lower oxycline is a site of enhanced bacterial and plankton activity acting on particles. To date, this layer remains un-explored because of technological issues in sampling (by traps, pumps and nets) or observing (with in situ sensors) such a deep layer."

The lower oxycline biology section 4.3 should refer to the recent paper by Wishner et al. (2013, DSR I 79:122-140), which includes a comprehensive discussion of the biology of the lower oxycline boundary layer (Eastern Tropical North Pacific). It is especially pertinent that the zooplankton increase below the OMZ in that region represents an abrupt order of magnitude biomass peak and that zooplankton stable isotopes indicate active trophic processing (feeding), possibly on particles similar to those observed with the UVP in the Arabian Sea.

Thank you for the suggestion. We included this reference in our manuscript to complete the results concerning vertical distribution of zooplankton as seen by the UVP in the OMZ area.

However, it is interesting that the UVP results from the present paper do not record a similar abrupt particle layer at the lower oxycline (Fig. 8, 9). In fact, at some stations, there is really no clear difference (and in some cases a decrease) between particle abundance within and below the OMZ. Although the Fig. 8 caption refers to a peak at 900 m, it is not obvious in most of the profiles. The zooplankton profiles do not show the lower oxycline layer either, probably because of the large depth interval of the nets.

The first size class of particles by the UVP and mostly beam attenuation show a clear change at the lower oxycline in all stations. In contrast, zooplankton and large particle variability at the lower oxycline is not observed at all stations (see for example stations 38 and 41). Technical issues can *explain the lack of variability in large particles and zooplankton at the lower oxycline. First the small volume (approx. 50 L in 5 meter bins) observed by UVP would not allow detecting small changes in large rare zooplankton (<0.005 ind. L^{-1} in OMZ, Figure 7) and aggregates at this layer (and see response to reviewer 3). Second, the thickness of the layer sampled by multinet does possibly mask the thin vertical layering of zooplankton. However, our dataset and also previous findings (discussed above) suggest that this layer may be the site of higher biological activity. So we kept our hypothesis but discussed it more in the light of the reviewer's comments in the discussion section 4.3 (see above).*

The "zooplankton activity" referred to in the abstract is confusing wording since only distributions were obtained. The authors should be more specific in their description and include more about these world comparisons and spatial variability issues in their discussion.

We rephrased this sentence in the abstract. Details of each point are given in the abstract:

"Lateral transport, microbial processes in the core of the OMZ, and enhanced biological processes mediated by bacteria and zooplankton at the lower oxycline".

Technical corrections: Oxygen axis labels are missing from Figs. 2, 5, 7, 8, and 11. Figs. 10 and 11 are not referenced in the text. I assume Fig. 11 should be noted in section 3.8, in which case it is out of order. Pg 19272 line 1: impact (not retroactions) Line 16 trap Line 26 particle Pg 19273 line 15 day Pg 19274 line 13 as (not than) Line 14 other Pg 19276 Line 20 delete "a" Pg 19278 Line 13 chose Pg 19281 Line 2 zooplankton were, Line 13 particle Pg 19282 Line 7 subsurface maximum Pg 19284 Line 17 Cariaco.

We corrected all of these issues. Thank you for all your comments that helped improving our manuscript.

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