

Interactive comment on “Formation and maintenance of high-nitrate, low pH layers in the Eastern Indian Ocean and the role of nitrogen fixation” by A. M. Waite et al.

A. M. Waite et al.

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[note author comments in response to review are appended in bold]

Anonymous Referee #2

Received and published: 21 March 2013

Comments are appended. Overall I like the paper. However I don't think the discussion of particle transport to the low oxygen layer is sound.

Please see first comment below.

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Other minor revisions are also

needed. In many regions, and for a number of reasons, low oxygen/high nutrient layers form in oceans. Because these waters are isolated from the atmosphere (thus low oxygen), they are bound to become more acidic as nutrients accumulate and oxygen is consumed. This paper identifies one such water mass off the northwest coast of Australia, suggesting much of the nitrate (and therefore the oxygen loss) in it arises from nitrogen fixation.

General comments

I cannot see that particles trapped in density layers are a cause of low oxygen waters below (**abstract and discussion**). Particle rich layers look more like they were recently transported from the ocean surface to depth (as you discuss in section 4.2). Most models of particle remineralization suggest an exponential decline with depth, although some work is suggesting zooplankton play a significant role in transport and turnover (e.g. Steinberg et al., 2008 *Limnol. Oceanogr*, 53(4), 2008, 1327-1338). It is unusual to see particles sink and concentrate on a density surface.

- **We agree that particle sources are not geographically well-constrained. However, we believe that there is a significant body of work starting with MacIntyre et al (1995) *Limnol. Oceanogr*, 40(3), 995, 449-468 “Accumulation of marine snow at density discontinuities in the water column”, which suggests that this is a reasonably common occurrence. We have tried to make our conclusions more clear in the text and softened the inference that particles are likely to be, mostly, locally sourced.**

This does not affect the main tenet of your work, that nitrate in the low oxygen layers arises from fixed N. It just suggests the process is not local (not arising from particles sinking to depth along the Australian coast. Imasoto et al 2000 (*J. Oceanogr* 56) provide estimates of oxygen consumption rates in the Indian Ocean which may help es-

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establish the age of the LDOHN waters, although **I don't think** such a discussion would assist your paper.

Specific/technical comments

- Indicate which data have been used in all figures (missing in Fig 2, 6, 7)
 - **We will check that this is clear – unless otherwise indicated, we have used all data available from the whole research voyage.**
- In methods, supply dates of survey cruises.
 - **Adjusted, 10 May to 22 May 2010**
- I gather circulation is strongly seasonal in this area, so we need to know when sampling was carried out.
 - **Adjusted, 10 May to 22 May 2010**
- Various currents could be identified in Fig. 1. I concur with reviewer 1 that the map size could be increased, also the domain may have to increase slightly to help identify currents.
 - **Map size adjusted**
- Note the frequent use of LODHN (all figures) but the water mass is defined as Low Dissolved Oxygen, High Nitrate (**LDOHN**) in the introduction and discussion. Maybe LOW Dissolved oxygen High Nitrate is the easy way out.
 - **LDOHN is correct as pointed out by the reviewer**
- Fig. 1. Units needed for most parameters.
 - **Adjusted units on figures**

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- Show current directions on the map which may require expanding its domain (S and C trajectories if possible).
 - **We have indicated the general current directions on the figure legend**
- Please confirm transmission is a voltage. Units look like % light transmission over the optical path length (e.g. %/25 cm or %/m). I don't see SB shown on the map.
 - **% transmission is correct = over 25 cm and 660 nm (now included in text)**
 - **SB now included**
- Also what is the colour shading, perhaps temperature? You could use satellite chlorophyll (monthly averaged from NASA's Giovanni site for example, see below) if this helps identify particle sources.
 - **Bathymetry – we have redone this figure to make more clear**
- Fig. 2. use S for salinity to shorten.
 - **Adjusted in figure**
- Note spelling error of salinity, line 11 of caption.
 - **Adjusted in caption**
- Fig 1 shows high particle concentrations only in surface waters. Are the particle rich layers associated with LC and EGC?
 - **See green layer in Fig 1B associated with the density anomaly (0.025) which extend west at ~100 m depth to the edge of the study region**
- What is missing is a plot of oxygen vs light transmission which would show whether particles are associated with LDOHN layers.

- **See figure 2 B – transmission low points are associated with (variably) low DO**

- Fig. 7. add to caption GROUP 3 where appropriate.

- **Adjusted in figure**

- (B) Remove space in "based".

- **Ok, done**

- Axis labels (B and C) and panel identification (A, B, C) should be enlarged. I am squinting to read them at 150% enlargement.

- **We have enlarged the axis labels.**

- I'd also love to see these groups of data plotted on e.g. Fig. 4 or some graph which helps show exactly where the groups are found within the water column.

- **The depth of each point is indicated in Figure 7B and C – Essentially, we only measured significant N-fixation source of nitrate above 200 m – we have tried to indicate this in Fig 4 without making it too cluttered**

- Fig. 8. correct spelling of periodically

- **Spelling corrected.**

- Define current directions for both symbols (x and dot).

- **Defined and adjusted.**

- Some of this information would be helpful in Fig 1 to inform the reader earlier about current directions.

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- **We have numerous figures showing this now- hopefully this informs the reader without cluttering up Fig 1 which is already very busy?**
- Reword the last sentence - as it stands it reads that nitrate is remineralized.
 - **Thanks for picking that up. Ok, sentence adjusted**
- I am more familiar with density quoted as σ_t or σ_θ . Make it clear in methods you are using *in situ* density.
 - **Adjusted in material and methods**
- p 9, l 19-20 - remove one "nominal" from sentence
 - **Ok, adjusted in text**
- I plotted March 2010 (and April, not shown) chlorophyll in your study region to help understand where particles may come from. In both months, increased chl was observed over a broad shoal, upstream of your study site.
 - **We are enthusiastic about this input, which we only withheld for fear of information overload. We have now added a new plot showing the earlier bloom from Giovanni etc.**
- Giovanni [plots](http://gdata1.sci.gsfc.nasa.gov/daac-bin/G3/gui.cgi?instance_id=ocean_month) (http://gdata1.sci.gsfc.nasa.gov/daac-bin/G3/gui.cgi?instance_id=ocean_month) of MODIS chlorophyll, averaged for March 2010. Surface chlorophyll is generally low, although the survey line at 21 S does show levels >0.1 mg m⁻³. The area of elevated chlorophyll is evident also in the April average. White dotted line represents the 21 S survey line.
- **Again, we thank the reviewers for this helpful input.**