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Comment on bg-2020-486

V. Valsala

Community comment on "Reviews and syntheses: Physical and biogeochemical processes associated with upwelling in the Indian Ocean" by Puthenveetil Narayana Menon Vinayachandran et al., Biogeosciences Discuss.,
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This is an excellent and timely review of the Indian Ocean's physical and biogeochemical processes associated with the upwelling zones. There has been a considerable amount of observational and modeling studies in this area and are very well covered in this comprehensive review.

However, the Biogeochemistry about the carbon cycle in the upwelling zones is somewhat found less emphasized despite a considerable number of studies and research has gone into it. These studies are also useful to highlight potential gap areas in the observations of the Indian Ocean carbon cycle, pCO₂, and acidification. A few are mentioned below, kindly incorporate them also in this review and synthesis effort.

Lines-1034:1035: Being 1034 limited with very few studies on carbon dynamics over both east and west coasts, the temporal evolution of surface ocean acidification is still not clear.

Takahashi et al, (2014) compilation show the clear seasonal cycle of pH in the western Arabian Sea. Further, modeling studies show that the western Arabian Sea has been acidified from a pH of 8.12 (in 1960) to a pH of 8.05 (in 2010). The trend in pH over the western Arabian Sea is due to contributions from dissolved inorganic carbon (DIC) and SST at a value of 109% and 16%, respectively. The effect of alkalinity (ALK) is to buffer the trend in pH by -36% while salinity contribution is only +7%. Collectively, DIC and ALK contribute up to 73% to the net pH trend. SST warming alone contributes another 16%, which is quite alarming considering the intense warming of the western Indian Ocean (Roxy et al., 2016). This calls for the sustained observational efforts required for the Indian Ocean upwelling zones to monitor and model ocean acidification.

Lines-1401-1403: Efforts to develop and improve biogeochemical models of the 1401 upwelling systems are also in progress (e.g., Sreeush et al., 2018).

In addition, Sreeush et al., (2020) showed improving biogeochemical models in upwelling zones using inversion of surface observation such as pCO₂ and imposed constraints that can cascade through solubility and the biological pump in the upwelling zones to retrieve valuable subsurface ocean parameters such as community compensation depth in models.

Lines-1665:167: biogeochemical modeling results indicate that neither phytoplankton biomass nor carbon export from the euphotic zone changes significantly in response to seasonal and interannual variability of the SCTR thermocline depth (Resplandy et al., 2009)

Lines-1673:1674: Finally, there is still considerable uncertainty in whether the Indian Ocean is a net source or sink of carbon to the atmosphere because the variability in pCO₂ fluxes across the air-sea interface is poorly constrained by existing observations, particularly in active upwelling zones like the SCTR

Other studies also highlighted the variability of seasonal and interannual cycles of sea-to-air CO₂ fluxes, pCO₂ in the upwelling regions of the Indian Ocean. Valsala and Maksyutov (2013) identified that the interannual variability of western Arabian Sea sea-to-air CO₂ fluxes and pCO₂ are complementarily controlled by ENSO and IOD-related forcing and dynamics. In the south of Sri-Lanka, the interannual variability of the carbon cycle is controlled by variability in wind-induced upwelling dynamics of the dissolved inorganic carbon (Valsala and Maksyutov, 2013). The western Arabian Sea is also home to intra-seasonal variability in sea-to-air CO₂ fluxes and pCO₂ due to the eddy dynamics associated with Great Whirl and Southern Gyre (Valsala and Murtugudde, 2015) as verifiable with limited observations of surface ocean pCO₂. More observational efforts are required to understand such fine-scale variability of pCO₂ in the Indian Ocean.

Recent studies pointed out that the south Java-Sumatra coast also exhibits interannual variability in sea-to-air CO₂ fluxes and pCO₂ due to upwelling variability linked to IOD, as identifiable from gap-filled observations using neural networks (Valsala et al., 2020, Lanschutzer et al., 2016). The sea-to-air CO₂ fluxes, surface ocean partial pressure of CO₂ (pCO₂), the concentration of dissolved inorganic carbon (DIC), and ocean alkalinity (ALK) range as much as $\pm 1.0 \text{ mole m}^{-2} \text{ yr}^{-1}$, $\pm 20 \text{ } \mu\text{atm}$, $\pm 35 \text{ } \mu\text{mole kg}^{-1}$, and $\pm 22 \text{ } \mu\text{mole kg}^{-1}$ within 80°E-105°E, 0-10° S due to IOD. The DIC and ALK are significant drivers of pCO₂ variability associated with IOD. The roles of temperature (T) and biology are found negligible. A relatively warm T and extremely high freshwater forcing make the southeastern tropical Indian Ocean carbon cycle variability submissive to DIC and ALK evolutions in contrast to the tropical eastern Pacific where changes in DIC and T dominate the pCO₂ interannual variability (Valsala et al., 2020).

Lines-733-736: On the other hand, studies with the help of more complex models, in the last couple of decades, suggest that phytoplankton growth in this region are prone to iron limitation (Wiggert et al., 2006; Wiggert and Murtugudde, 2007) and also likely to be silicate stressed (Konecny et al., 2009; Resplandy et al., 2011).

Anju et al, (2020) used a 13-component silicate limiting biogeochemistry ecosystem model to study the impact of Silicate limitation in the western Arabian Sea. The new production represents 80% of the total primary production in the AS and implicitly controls 70% of total zooplankton production annually. The regenerated production augments small phytoplankton (by ~50%; e.g., flagellates) and small zooplankton (by ~20%; e.g., ciliates) growth with negligible effects on large phytoplankton (e.g., diatom) and predatory zooplankton (e.g., copepods). The diatom production remains within the observed range due to silicate limitation, which is fundamental in the models for realistic simulation of sub-surface chlorophyll maxima.

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