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Ocean Science
Discussions

Interactive comment on “Seasonal and interannual variability of water column properties along the Rottnest continental shelf, south-west Australia” *by* Miaoju Chen et al.

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Seasonal and inter-annual variability of water column properties along the Rottnest continental shelf, south-west Australia by Miaoju Chen, Charitha Pattiaratchi, Anas Ghadouani and Christine Hanson.

We would like to thank and acknowledge both reviewers and the editor for their careful reading and constructive comments on the manuscript. There were no public comments. We believe that we have addressed the issues raised by reviewers and the

proposed changes to the manuscript are detailed in this document. We trust that the reviewers and the editor will find that the suggested changes will make the manuscript to be suitable for publication.

In the following, black indicates the comments by the reviewer; blue is our response to the reviewers. The text in red are suggested changes to the manuscript.

Reviewer #1

(1) The abstract is toooooooo long. Can it be shortened?

The journal guidelines does not specify a word limit for the abstract and currently consist of 360 words. At the suggestion of the referee we will revise and shorten the abstract

(2) Colors can be deceptive. Please add contours to Figures 6,7 and 8.

At the suggestion of the referee we have included contours in Figures 6, 7 and 8. As an example, the temperature distribution for spring is provided below:

(3) What do you mean by structure anomalies in Figures 6,7, and 8? Anomalies relative to a surface value? Relative to a seasonal average? Or an annual average? Please show absolute distributions or, at least, the reference value/profile that your anomalies are based on. Perhaps, you should also present seawater density distributions and discuss seasonal variations of the density structure.

Thank you for your comments. We first examined the mean values by season. However, the seasonal variation in parameters obscured the patters and thus we presented anomalies that were calculated relative to the seasonal mean over the measurement period calculated though water depth and distance. For reference we have included absolute distributions as well as density distributions as supplementary information. The mean distribution for each parameter for the different seasons are included as a Table.

We have also modified the text to make clearer how the anomalies were calculated with the following text with a new Table added to indicate the value for the mean for each parameter over different seasons.

The text has been modified as follows:

When examining the seasonal changes it was found that the changes in the mean values obscured the seasonal variability of each parameter (temperature, salinity, and chlorophyll). Hence, in addition to presenting the measured values we also calculated anomalies to remove the influence of the seasonal variability. The procedure for each parameter ($\sim$28 million individual points) was as follows: (1) data were interpolated onto a common grid across the cross shelf transect; (2) transects were then sorted according to season: spring (September-November), summer (December-February), autumn (March-May) and winter (June-August); (3) the mean value across the whole transect (i.e. through water depth and across distance) for each season was calculated (Table 1); and, (4) the anomaly at each grid point was calculated by subtracting the seasonal mean from values at each point.

Table 1 – Mean values of temperature. Salinity and chlorophyll fluorescence for each season used to calculate the anomalies. Temperature (°Celsius) Salinity Chlorophyll fluorescence (mg/m^3) Spring 19.4 35.35 0.49 Summer 21.9 35.61 0.46 Autumn 22.4 35.42 0.71 Winter 19.8 35.27 0.68

âĂČ (4) Figure 9 is difficult to interpret. Is there a way to fill the data gaps using satellite SST? Why do you present this figure? Perhaps this would be better placed in the methodology section together with a discussion of data gaps?

It is not possible to fill the data gaps using satellite imagery (for SST or chlorophyll) as these are not surface values – rather they are depth integrated (surface 30 m) values. They are also time averaged – each line represent a single glider deployment lasting 3-4 weeks. In the methods section we have noted that as the glider moved in a saw tooth pattern, and gaps in the data occur when sampling deep waters – resulting in

data gaps in the deeper waters.

We have retained this figure as we believe that it illustrates the inter-annual variability. For example it highlights the marine heat wave (red lines - summer 2011) and cooler summers (yellow line – summer 2009, 2015). Similarly the figures indicates higher salinity during these summers (red line - summers 2010, 2014, 2015). We have highlighted these in the revised manuscript.

(5) It would be nice to have true chl-a values rather than just data from the BBFL2SLO optical sensor. How confident are you that your fluorescence data represent true chl-a, in particular close to the seafloor? How is this bottom chl-a maximum created? Is there any reason why you decided not to discuss CDOM?

We agree with the reviewer that ‘true’ chlorophyll values will add great value to this study, and we are aware that a common practice for compensating for the variability in fluorescence yield is to calibrate a fluorometer through the statistical comparison of fluorescence readings with measurements of concentration of chlorophyll from concurrently collected water sample (Cullen and Lewis 19956; Hersh and Leo 2012). However, due to the nature of glider deployments, which operate for extended periods of time and space without human interaction, marinating a water sampling regime is neither logistically nor financially feasible.

Should be noted that few studies have used ‘true’ chlorophyll a to define seasonal and inter-annual variability through the water column. The collection of routine water samples (say for HPLC or acetone extractions) for long time period are often not possible due to operational and financial considerations. Similar studies use satellite derived chlorophyll which is an indirect measurement relating upwelling radiance to chlorophyll a but is also limited mainly to surface values. Thus we believe that the data presented in this paper is unique.

However, as part of the IMOS ocean glider program we have undertaken many studies to address the conversion/relationship between the fluorescence values from the

BBFL2SLO optical sensor and ‘true’ Chlorophyll a. These were undertaken both in the laboratory (Earp et al., 2011) and in the field (Thomson et al., 2015). In the latter, we attached a glider to a rosette sampler and collected concurrent data from the glider and Niskin bottles at surface, mid-depth and bottom of the water column in 100m depth. The water samples were subjected to HPLC analyses to determine the ‘true’ Chlorophyll a concentrations. The comparison between ocean glider derived fluorescence and the HPLC Chlorophyll a concentrations was very good with r2 > 0.75 (n > 100) in the range 0.17 to 0.21 (mg m-3).

A recent study by Beck (2016) found that, through inter-comparison of chlorophyll a and Wetlabs ECOPUCK derived fluorescence on ocean gliders, the original manufacturer’s recommendation for the estimation of chlorophyll a from fluorescence provided the best estimate.

The bottom chl-a maximum is created in many ways. The study region has very clear water and thus light penetrated is large (1% light level is > 100 m). The region is oligotrophic so there is no nutrients in the water column. Our shipborne measurements indicates that the nitrate concentrations were below detection levels (Twomey et al., 2007). We believe that there is some supply of nutrients onto the bottom layer through two possible sources: (1) regeneration from the organic matter on the seabed particularly during storm events; and, (2) advection onto the shelf from offshore through upwelling – this also may indicate the sub-surface chlorophyll maximum ‘migrating’ onto the shelf.

Yes there is a very good reason why we decided not to discuss CDOM – in a region with very little riverine input the CDOM concentrations were very small – almost negligible – except during occasional storm events. When averaged over a season there was no detectable changes. Similarly backscatter (a proxy for suspended matter). Hence, this paper is addressing the variability in chlorophyll concentrations only. A paper in preparation for publication is addressing the short-term changes of order days.

(6) In our previous study (Kämpf and Kavi, 2017), we identified seasonal chl-a maxima in the Great Australian Bight in austral autumn months. Is this feature, which is not too far away from your study region, consistent with your observations? If so, please discuss this.

Thank you for the comment. We have read through Kämpf and Kavi, (2017) and included this reference and discussed in section 4 as follows:

The observed surface chlorophyll features agreed with Kämpf and Kavi (2017), who showed widespread phytoplankton blooms (chlorophyll concentrations $\sim$1mg/m3) during autumn and winter using satellite data along the southern Australia coastline.

(7) In the last sentence of the abstract you claim that "It is concluded that the observed seasonal and inter-annual variability in chlorophyll fluorescence concentrations were related to the changes in physical forcing (wind forcing, Leeuwin Current and air-sea fluxes)." This statement is far too general and misleading given that you didn’t analyze air-sea fluxes. You also don’t specify what type of air-sea flux you are referring to. Dust influences? Heat fluxes? Neither did you calculate the classical upwelling index or estimate the possible influence of mesoscale eddies that could lead to dynamic uplift of nutrient-rich water across the shelf break or passing baroclinic coastally trapped waves.... Much more effort would be required to identify reasons of the observed variability of chlorophyll fluorescence concentrations.

We acknowledge that we have not fully elaborated on the changes to the physical forcing that contribute to the observed variability chlorophyll fluorescence concentrations. There are many different physical processes that contribute to this variability: the Reviewer has highlighted meso-scale eddies, coastally trapped waves as examples, others include diurnal upwelling and action of storms. However, all of these processes act over periods of order days or weeks. This study is concentrated on seasonal scales and higher – thus data have been averaged over a period of 3 months which does not allow for these processes to be identified – follow up publications will address diurnal upwelling and impact of storm systems.

The Reviewer questions why the classical upwelling index was calculated. There are many reasons: 1. The paper is not based on upwelling. Upwelling favorable winds occur during spring/summer but the maximum chlorophyll occur in late autumn and winter. Thus chlorophyll fluorescence concentrations are is not only controlled by the wind and upwelling 2. The classical upwelling index is not applicable to this region due to the presence of the pressure gradient due to Leeuwin Current. This was addressed in a recent paper by Rossi et al. (2013) who applied an improved composite dynamical upwelling index that accounts for the role of alongshore pressure gradients counteracting the coastal Ekman divergence. The results indicated that upwelling was sporadic along the whole coast with the occurrence of transient upwelling events lasting 3–10 days changing in space and time. The study regions (at 31.5o) and consisted of up to 12 upwelling days per month during the austral spring/summer. The intensity of intermittent upwelling is influenced by the upwelling favourable winds, the characteristics of the Leeuwin Current and the local topography. As this study already exists there was no requirement to calculate the classical upwelling index in the paper. However, reference to Rossi et al. paper and its findings are included in the revised paper.

The physical forcing that influence chlorophyll concentrations are changes in wind forcing, Leeuwin Current and air-sea fluxes of heat and water. We have highlighted this in the discussion of the revised paper. We have indicated seasonal changes in each of these processes are: (1) strong southerly winds in spring/summer, weak in autumn and storms during winter; (2) LC being weak in summer and strong in winter; and, (3) evaporation dominance in summer and cooling in winter due to changes in air-sea fluxes of heat and water that leads to the formation of dense shelf water cascades in autumn and winter. We have referred to Pattiaratchi et al. (2011) paper that describes the seasonal cycle of air-sea fluxes and its influence on the continental shelf.

(8) In the autumn of 2014, the chlorophyll fluorescence increased (> 1 mg m–3). Do you know why?

Thank you for your comment. Yes we do have an explanation and it explains the peak during autumn 2009. The Leeuwin current is strongest in autumn and winter (mean transport: ∼5–6 Sv) and weaker during summer (mean transport: ∼2 Sv). A recent paper by Wijeratne et al., 2018) presented results of boundary current transport around Australia from a high resolution simulation over a 15 year period. The transport across a cross-shelf section at 31.5oS extending to the deeper ocean indicated that in January/February of 2009 and 2014 the southward mean monthly transport of the Leeuwin Current was very weak, < 0.5 Sv and close to zero. In contrast during the period 2010-2013 the monthly mean transport was mainly > 1.0 Sv. So how could lead to increased chlorophyll values – one explanation is that a reduction in Leeuwin Current would lead to a shallower mixed layer during the summer. When the winter storms arrive in late autumn the shallow mixed layer broken down more easily bringing nutrients onto the upper layer that allows for higher phytoplankton growth and thus higher chlorophyll. We highlight this process in Figure 12. We have also examined the number of major storms that impacted the study region over the period April-June with the following results: 2009: 7; 2010: 2 ; 2011: 5 ; 2012: 0; 2013: 5 ; 2014: 7. Thus over this period 2009 and 2014 had the more storms than other years, perhaps giving credence to this theory. We have included this explanation in the final manuscript.

References: Beck M. (2016), Defining a multi-parameter optics-based approach for estimating Chlorophyll a concentration using ocean gliders. Unpubl. MSc Thesis, Dalhousie University, Canada. Kämpf, J., and A. Kavi (2017), On the “hidden” phytoplankton blooms on Australia’s southern shelves, Geophys. Res. Lett., 44, 1466–1473, doi: 10.1002/2016GL072096. Rossi, V., M. Feng, C. Pattiaratchi, M. Roughan, and A. M. Waite (2013), On the factors influencing the development of sporadic upwelling in the Leeuwin Current system, J. Geophys. Res. Oceans, 118, 3608–3621, doi:10.1002/jgrc.20242. Thomson, P.G., Mantovanelli, A., Wright, S.W., Pattiaratchi, C.B. (2015). In situ comparisons of glider bio-optical measurements to CTD water properties. Australian Marine Sciences Conference, Geelong, Victoria, July 5th – 9th 2015.

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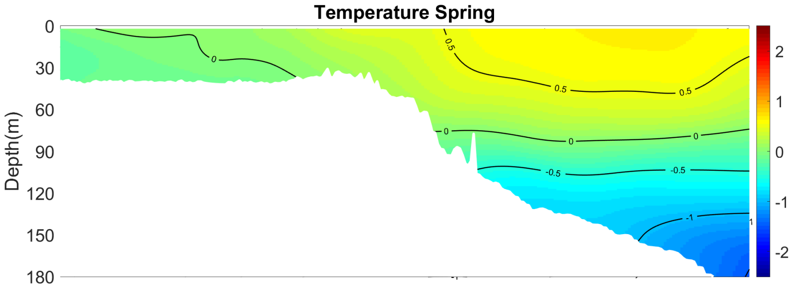

Fig. 1. Example of Figure with contours