Reply to reviewer #2

General comments: This research presents the shipboard currents, hydrographic and biogeochemical properties observation and satellite remote sensed sea surface temperature and sea level anomaly over the slope off the central Peru-Chile coasts. The authors used these data to investigate the possible scheme that determines shift of the upwelling system associated with the eastern boundary current in the southern hemisphere. Their most striking conclusion is that the southward propagating coastally-trapped waves (CTW), sourced from the equatorial current, played key (the authors used the word "likely" in the abstract) roles in determining those aforementioned variability in the upwelling system, or these CTW strengthened the southward transport of the sub-surface waters, which then "supersedes the simultaneous effect of downwelling in terms of nutrient response". In my opinion, this conclusion is interesting, but still questionable, since the authors didn't provide sufficient solid analyses to support the schematic they drew in the abstract and conclusion section. Before presenting more specific comments, I have to admit that the results from their field measurements are invaluable and comprehensive, and the author put a lot of effort on the quality control and demonstrating them by using nice figures, although it took me some time to link the caption of those figures will the contents presented. Another great point of this research is that the authors did this research in a very interdisciplinary way. The combined discussion based on theories of physical and biogeochemical oceanography is very enlightening. The general comments, if I correctly summarized those specific ones, are that "the posted evidences cannot sufficiently support the conclusions" and "you need more evidences about the changes in the currents, not only in nutrient responses".

We would like to thank reviewer #2 for his/her encouraging but critical review of our manuscript and for the corrections and suggestions to improve the manuscript. We believe to have significantly improved the revised version of the manuscript upon his/her remarks and suggestions.

As detailed below, major changes in the revised version include a detailed analysis of the wind forcing and sea level anomaly using satellite observations, a rewritten introduction, an elaborate discussion of the possible impact of bathymetric features onto our alongshore flow observations, a more throughout discussion of the results and a better reasoning as far biogeochemical processes are concerned. Finally, we polished the writing of the text and the figure captions.

In our detailed response below, comments by the reviewer are in bold letters and changes in the manuscript are expressed in italic letter. We belief that some of the reviewer comments originated from sections where our writing was misleading. We hope to have corrected that in the revised version.

Specific Comments:

1) It is worthy for the authors to further polish their writing. The meaning of majority of those sentences is not easy to extract, since some sentences are too long and composed by many elements. I noticed that there is another published comment on the details about writing, and skipped them then.

We made great effort to improve the writing and comprehensibility of the manuscript. Please accept our apologies for not having done that before submitting the first version.

2) The authors listed too many details in the data processing section without paying sufficient attention to the interlinkages among these data. Yes, processing data is important, but it is more important for the authors to guide us towards the mainstream of their research flow by introducing the procedure of data processing. I can just get what did you do, this or that, but cannot understand why did you do that. There are too many subsections in the section 2. Please also make sure that tides are not important in determining the general characteristics of the general circulation in your study area.

Thank you for this comment. We significantly shortened the data and methods section wherever possible and tried to motivate our use of processing and analysis techniques. However, we think that our brief descriptions in the data and method sections are necessary to allow replicability of our results from the published data. The different subsections in section 2 and 3 will allow the reader to extract specific information on data or methods without needing to go through longer data or methods section. We thus decided to retain most subsections in section 2 and 3.

3) The introduction section is not well written either. The only points I can get are that the eastern boundary current and upwelling system experience multiscale variabilities that were not well studied, and the anomaly in winds (actually not only winds) can stimulate southward propagating CTW along the coastline. The authors didn't extract enough information from those cited historic studies to persuade us that CTW was found to greatly alter the regional upwelling processes, for example, strong downwelling signal from historic studies was observed during upwelling-favorable forcing conditions. Those historic studies were just cited in and out without sufficient investigation. The novelty of this research is missing in this section, although it is much better summarized in the summary section.

We agree with your comment. In the revised version, the introduction was reorganized and rewritten. We now focus on describing the Peruvian upwelling system, the consequences of variable nutrient and oxygen availability on biogeochemical processes, local and remote forcing of intraseasonal flow variability including effects of variable topography and the impact of intraseasonal flow variability on biogeochemistry. While doing so, we build upon historical studies. Finally, we improved the motivation of our study.

4) I don't quite understand why did the authors link the effect of CTW to the intraseasonal variability of eastern boundary current, especially when they didn't do any analyses on the wind (stress and its curl) fields in the manuscript. Although they compared the observed currents with the climatological ones from, for example, numerical simulations, we still don't know whether the wind is comparable to is climatological conditions during

the observation periods. Thereby, we cannot grantee that the variability is due to CTW, instead of migration of the wind system.

Thank you for pointing this out. We addressed this comment by including a detailed analysis of the wind variability prior and during the observed strengthening of the poleward boundary current flow. Additionally, we added a discussion of possible local wind forcing mechanisms in the introduction. Finally, we included an analysis of equatorial winds that triggered an equatorial Kelvin wave. In the results section of the manuscript, we added two subsections analyzing local and remote winds:

4.2.1 Role of local wind stress

A potential local forcing mechanism of the intensified PCUC flow are anomalies of local wind stress curl. An increase in the magnitude of near-coastal negative wind stress curl leads to increased poleward flow along the eastern boundary through Sverdrup dynamics (e.g., Marchesiello et al., 2003). The adjustment of the circulation to changes in the wind stress curl at the eastern boundary is rather fast and occurs within a few days (Klenz et al., 2018). Wind stress curl along the Peruvian continental margin between 10° S and 14° S was negative throughout the observational period (Fig. 4), continuously forcing poleward flow. However, during the period of PCUC acceleration between end of April and mid-May, the magnitude of negative wind stress curl decreased (Fig. 4c, d, e, f). It can thus be ruled out that local wind stress curl forcing is responsible for the observed intensified PCUC. Nevertheless, elevated negative wind stress curl was observed from May 18 – 22, which may have contributed to maintaining a strong PCUC in late-May.

Variability of near-coastal alongshore wind stress excites CTWs which propagate poleward (e.g. Yoon and Philander, 1982) and thereby enhance or decrease poleward flow within the depth range of the PCUC. Model studies show that CTWs are excited near the equatorward edge of the region of wind variability (e.g. Fennel et al., 2012). In Mid-April through May 2017, alongshore wind stress between 6°S and 15°S was variable (Fig. 5). While moderate wind stress (0.03-0.06 N m-2) prevailed from mid-April to May 3, it was weak during the first two weeks of May (Fig. 5d,e, g). However, during the later period the strong acceleration of the poleward flow occurred, requiring an intensification of alongshore wind stress. Thus, the initial acceleration of the PCUC during this period (Fig. 2d, e) cannot be related to local wind stress variability. Alongshore wind stress did significantly strengthen on May 15 and remained elevated for a period of about 5 days. This wind event was intense between 15° and 8° S, but did not occur north of 8° S. CTWs were likely excited in the region between 12° and 8° S that contributed to the elevated poleward velocities observed in the later phase between May 17 and 26 (Fig. 2f).

4.2.2 Equatorial winds and wave response.

A weakening of the trade winds at the equator by e.g. westerly wind events forces downwelling on the equator which in turn generates an eastward propagating equatorial Kelvin waves, which in turn may have transmitted parts of its energy to a CTW at the eastern boundary. Indeed, several westerly wind anomalies occurred in the central and eastern equatorial Pacific during the first 6 month of 2017 (Fig. 6). A particularly elevated westerly wind anomaly between the date line and 120° W occurred during the first two weeks of April (Fig. 7a). A positive SLA propagating along the equator appears to the east of the wind event at about 100° W (Fig. 7b).

Moreover, there were plenty of studies, for example, Zhang and Lentz [2017], have clearly showed that the response of shelf currents to the regional topography will also greatly modulate the domestic response of the current system. So, variability of the along-slope current itself is also worthy to be investigated.

We fully agree. However, as written above, the changes in local winds did not force the accelerated Peru-Chile Undercurrent. We added a discussion on the effect of variable bathymetry to section 6 (please also see our response to 5) below).

Talking about the time scale of intraseasonal, I also suggest the authors to investigate whether there are any meso-scale processes, for example, eddies, formed or detached from the main currents to generate the transition.

Our data set collected during the cruise as well as SLA data from satellites did not indicate any mesoscale eddy generation during the alongshore flow acceleration period. This argument also hold for the period of elevated flow from May 17 to May 26.

5) We knew that Kelvin waves or CTW will be continuously stimulated in its source region and propagate along the path you sketched. The authors used this process to explain the intraseasonal variability in the cold half year. Does that mean when the first CTW propagate through the system, the upwelling system will be shifted to a downwelling one and never switch back in the coming season? What will happen in, for example, December and January, when the downwelling system is switching back to an upwelling-dominant condition?

Thank you for pointing out difficulties in understanding our previous version of the manuscript. It was not our intention to argue that the described CTW is changing the state of the upwelling system. Instead, we use the term “downwelling CTW” exclusively to define the sign of velocity and SLA anomaly. In our definition, a downwelling CTW depresses the thermocline and is associated with an increase of SLA near the coast and enhanced poleward flow. However, as we also state in the manuscript, near-coastal surface temperatures decrease during the passing of the downwelling CTW. In more general terms, we cannot conclusively determine the impact of the CTW on the upwelling system itself. The decreased SSTs near the coast were not associated with enhanced but with declining chlorophyll concentrations. It is thus likely that elevated local wind from May 15 - 20 enhanced near-surface heat loss leading to cooling of the top few meters of the coastal water column. We added parts of this discussion to section 4.1 of the manuscript, where the near-surface cooling during the CTW event is mentioned.

The focus of our manuscript is on the variability of hydrography, oxygen and nutrient distributions in the upper thermocline of the Peruvian upwelling system. This depth range often lacks oxygen and variability of nutrients and oxygen here is very relevant for biogeochemical processes. We hope to have improved the focus of the paper by restructuring the introduction and by improving the discussion in the manuscript.

It was also known that those CTW will be domestically arrested by irregularity of the along-slope topography to form standing waves and alter the regional cross-slope processes. The recent study of Kämpf [2018] also showed that there will be downstream propagation of topographic waves after the strong current passing through an irregular

topography, for example, canyon or ridge. This is another possible process that determine the domestic response of the regional dynamics to the CTW or general disturbances in both barotrophic and baroclinic modes.

We thank the reviewer for pointing out that a discussion of the impact of irregular along-slope topography on the observed flow variability was missing in the previous version of the manuscript. In the revised version, we enlarged the insert in Fig.1 showing the distribution of topography between 10° S and 15° S and discuss topographic features near our sampling site. There is a small ridge to the north and the shelf narrows south of our sampling site. However, other than that there are no elevated topographic irregularities such as canyons. Nevertheless, CTW scattering at the upstream ridge can potentially increase the flow at our sampling site (Wang, 1980; Wilkin and Chapman, 1990). The narrowing of the shelf further downstream may also potentially influence the upstream circulation (e.g. as described by Wilkin and Chapman, 1990). However, we also point out that observations and models suggest that equatorially-forced first mode CTWs along the South American coast propagate past 25° S (e.g. Shaffer et al., 1997, Illig et al., 2018). As discussed by Illig et al (2018) in terms of the Burger number variability (Huthnance, 1978) the effect of stratification on the CTW parameters is found to be more important than irregular along-slope topography in the region of our sampling location. We added the following paragraph to the discussion in our manuscript:

Local bathymetry interacts with the passing CTW as well. North of our sampling site the continental slope bends offshore at depths between 500 m to 1000 m (Fig. 1, insert) and the shelf narrows south. Changes in coastline, shelf width, and along-slope bathymetry leads to a transfer of CTW energy into higher modes (scattering) and upstream backscattering (Wang, 1980; Wilkin and Chapman, 1990; Kämpf (2018); Brunner et al., 2019). The influence of the changes in shelf width on the upstream alongshore flow structure can extend to 200 km upstream (Wilkin and Chapman, 1990). Furthermore, the bent of the continental slope north of out sampling site may lead to CTW scattering which may additionally intensify the poleward flow at our sampling site. A recent model study suggests that differences between the theoretical CTW solutions and observations are predominately due to wave scattering (Brunner et al., 2019).

In summary, this study is a great try to advance our understandings on the transition of the eastern boundary currents, and they provided us invaluable observational evidences and detailed analyses. However, it is not easy for this single research (not their series of studies) to answer all those previous questions. I suggest the authors to investigate the spatial and temporal variation of winds (stress and curl) and variability of the currents from, for example, numerical simulations or some widely used global simulations (e.g. HYCOM and CMEMS) to expand the vision of this research and make sure that the variability is mostly determined by the southward propagating CTW, instead of the other processes, including, for example, migration of wind system, along-shore variability of slope current and response of slope currents to the domestic irregular topography. The authors didn’t show us the general distribution of the regional topography, yet. The authors are also suggested to more explicitly define the timescale of intraseasonal variability in the manuscript. In my opinion, CTW may determine the synaptic variation of the current system, while migration of the wind system (and the associate variation in the

eastern boundary currents) will determine the entire background characteristics of the flow condition (upwelling or downwelling pattern). This will possibly be clearer than the term "intraseasonal" in your manuscript. A three-dimensional schematic of the flow pattern, propagation of CTW and responses in biogeochemical processes will greatly elevate this research, too.

We thank the reviewer for providing very valuable comments and suggestions for improving our manuscript. As detailed above, we considered most of his/her corrections and suggestions. We think that by including additional analysis of winds, sea level anomaly and irregular topography in the revised version of the manuscript, we provide sufficient evidence for understanding the nature of the observed flow intensification. Thus, we refrained from looking into global simulations such as HYCOM or CMEMS.

References: Kämpf, J. (2018), On the Dynamics of Canyon–Flow Interactions, Journal of Marine Science and Engineering, 6(4), 129.

Zhang, W., and S. J. Lentz (2017), Wind-driven circulation in a shelf valley. Part I: Mechanism of the asymmetrical response to along-shelf winds in opposite directions, Journal of Physical Oceanography, 47(12), 2927-2947.

Huthnance, J. M.: On Coastal Trapped Waves: Analysis and Numerical Calculation by Inverse Iteration, J. Phys. Oceanogr., 8(1), 74–92, doi:10.1175/1520-0485(1978)0082.0.CO;2, 1978.

Illig, S., Bachèlery, M.-L. and Cadier, E.: Subseasonal Coastal-Trapped Wave Propagations in the Southeastern Pacific and Atlantic Oceans: 2. Wave Characteristics and Connection With the Equatorial Variability, J. Geophys. Res. Oceans, 123(6), 3942–3961, doi:10.1029/2017JC013540, 2018.

Wang, D.-P.: Diffraction of Continental Shelf Waves by Irregular Alongshore Geometry, J. Phys. Oceanogr., 10(8), 1187–1199, doi:10.1175/1520-0485(1980)0102.0.CO;2, 1980.

Wilkin, J. L. and Chapman, D. C.: Scattering of Coastal-Trapped Waves by Irregularities in Coastline and Topography, J. Phys. Oceanogr., 20(3), 396–421, doi:10.1175/1520-0485(1990)0202.0.CO;2, 1990.