Reviewer #2

In this study, the authors conducted statistical analysis on the co-variability among SST, wind stress, and chlorophyll (CHL) concentration using satellite-derived high spatial and temporal resolution data. The study is focused on an Eastern Boundary Upwelling Systems (EBUS), the southern California region. The results suggest that the dominant mode of co-variability among SST, wind stress and CHL does not reflect the Ekman upwelling process. The second and third modes of co-variability are found to reflect upwelling patterns but exhibit complicated region and timescale dependence. The authors findings imply that paleoclimate records over the EBUS may reflect complicated physical processes other than the Ekman upwelling. The scope of the study is of course important as there is large uncertainty in the interpretation of paleoclimate reconstructions and the related implications are huge. However, I think the limitation from short length of data could be better explored. Physical process-based interpretations of statistical results should be better presented. Please see my detailed comments bellow.

We thank the reviewer for pointing out sections that require clarification and providing constructive comments. Point to point reply to comments are below.

Major comments:

1. Page 9 Line 19: "Instead of strong cross-shore gradients, TAU and CHL display a weak cross-shore gradient, and SST exhibits a meridional gradient pattern (Fig. 5)." Can you be more quantitative? How is the gradient defined? How big are the gradients to be considered strong or weak?

Yes. We now take 3 points that are approximately meridional and cross-shore (will be marked as stars in figures 5-7 in the revised manuscript) and compute the difference divided by its arc length to define the gradient. The strength of the gradients is defined in a relative sense by comparing cross shore, meridional gradients and gradients using different time average. Based on this definition of gradients, we have refined our discussion quantifying the changing patterns.

2. What is the physical meaning of EEOF1 in Figure 5? Are these statistical results physically meaningful? The authors briefly described the spatial pattern but did not show any results on the temporal variability (PCs). What do the PCs tell us about the co-variability among these variables?

We believe the EEOF1 pattern shown represents annual cycle in conditions of SST, CHL, and TAU. They are statistically meaningful in the sense that they optimize the compaction of data according to the standard EEOF approach, but physical meaning is not a requirement of the EEOF method so this interpretation is only suggestive of the physical process. We do show the 30 day averaged PCs1-3 in Figure 8-9. We now include PCs in Figures 5-7 as well. The PCs describe how these covarying patterns (each EEOF) change over time. We expand our discussion of the meanings of EEOF and PC in the methods section to clarify their physical meaning.

3. Limitation from short instrumental data could be better explored. Length of data analyzed in the manuscript is only seven years, which could limit interpretations of the results, especially considering the interannual and decadal variability in the system. The co-variability between SST and TAU could be explored in high-resolution ocean reanalysis, e.g., the Simple Ocean Data Assimilation (SODA; http://www.soda.umd.edu/). SODA provides SST and wind stress data of 1 4 ◦ -horizontal and 5-day temporal resolution with a length of 30+ years. The spatial and temporal resolution of SODA is

comparable to the data sets in the authors' manuscript, but the data length is much longer. With longer data coverage, we can, at least, examine (1) whether the dominant co-varying pattern between TAU and SST reflects Ekman upwelling, (2) whether results from satellite data are consistent with reanalysis, (3) how the results depend on low-frequent climate variability, and (4) how CHL variation may further complicate the co-variability among these variables.

We agree that SODA data covers a longer period and has resolution comparable to the interpolated data used in this study and can potentially provide additional information about longer term climate variability. However, many other issues can arise if we use SODA or any other model for analysis. Firstly, although SODA is modeled at 0.25 x 0.25 resolution, the reanalysis assimilates observations at 1 x 1 resolution (Carton et al. 2018). Hence, SODA relies on the ocean model to simulate <1º resolution properties, and modeling of any features smaller than 0.25 degrees are parameterized. Secondly, although the GFDL CM2.5 model is eddy permitting, it is only mesoscale eddy permitting. Yet, previous studies have suggested abundant submesoscale fronts, eddies, and other features inhabit and dominate short term variability of upwelling systems, which can affect spatial structure of sea surface temperature and marine productivity, and a minimum resolution to simulate these features is in the 500m to 1km range (Capet et al. 2008), 25 times higher than in SODA. Using a mesoscale-permitting model such as SODA means that parameterizations are expected to represent these phenomena. Satellite data, while limited in sampling resolution, of course relies on the true biophysical system behavior not a simulated version of it. Thirdly, the quality of reanalysis depends on initialization, surface forcing, open boundary conditions, model physics, and measurement biases. All these factors come with their own associated uncertainties. At the moment, we use only satellites and EEOFs, and the discussion of those uncertainties is already a large fraction of the paper. Hence, the number of additional uncertainties that need to be discussed and taken account of when using reanalysis products is considerably larger than compared to satellite data for the specific process of upwelling. Therefore, we decided not to pursue the path of using reanalysis product. We will include a brief discussion on the rationale of using exclusively satellite data in the revised manuscript.

Minor comments: 1. What is the variance explained by each EEOF mode?

By analyzing the singular values, EEOF1 explains ~84% of the total variance, EEOF2 and 3 each explains ~5% of the total variance. This is not mentioned explicitly in the text.

References:

Capet, X., McWilliams, J. C., Molemaker, M. J., & Shchepetkin, A. F. (2008). Mesoscale to submesoscale transition in the California Current System. Part I: Flow structure, eddy flux, and observational tests. *Journal of physical oceanography*, *38*(1), 29-43.

Carton, J. A., Chepurin, G. A., & Chen, L. (2018). SODA3: A new ocean climate reanalysis. *Journal of Climate*, *31*(17), 6967-6983.