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Interactive comment on "The OMZ and nutrients features as a signature of interannual and low frequency variability off the peruvian upwelling system" *by* M. Graco et al.

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Dear reviewers,

We highly appreciate all the comments and suggestions from both reviewers about our manuscript entitled "THE OMZ AND NUTRIENT FEATURES AS A SIGNATURE OF INTERANNUAL AND LOW FREQUENCY VARIABILITY OFF THE PERUVIAN UPWELLING SYSTEM" by Michelle Graco, Sara Purca, Boris Dewitte, Octavio Morón, Georgina Flores, Jesús Ledesma, Carmen G. Castro, and Dimitri Gutiérrez (This manuscript is for the Special Issue: Biogeochemical processes, tropospheric chemistry and interactions across the ocean/atmosphere interface in the coastal upwelling off Peru).

The manuscript is being revised following the reviewers' suggestions, which are greatly improving it. Based on their comments, we are rebuilding the entire time series expanding them till December 2011. This task is taking more time than expected and consequently we are still working on the revised manuscript. In the following paragraphs, we are answering all reviewers' comments, describing in detail the way we are proceeding. We really appreciate if you could consider them to continue working on the modified version of our manuscript.

We agree that expanding the time series still 2011 will reinforce our results and clarify the interannual/ intraseasonal variability as both reviewers indicate. In this way, we would also cover La Niña 2010-11 event, as indicated by reviewer 1. In the section of results we present some details about that.

Regarding the impact of local winds on the intraseasonal variability, we completely agree with reviewer 2 's suggestion about including it in our discussion. We have expanded the discussion on the role of wind forcing based on previous studies (Dewitte et al 2011, Echevin et al 2014; Illig et al., 2014) (see discussion section). In our study we are not addressing the higher-frequency variability associated to wind forcing owed to the limitations of the data sets (monthly resolution). We now mention such a limitation of our study in the revised manuscript.

Regarding the reviewer 2 comment that the characterization is strongly dependent on El Nino 1997-98 and subsequent La Nina disturbances and the novel scenario after 2002. We have toned down the idea that two different scenario exists from before and after 2002, and rather contrast the response of biology to two different types of events, a strong Eastern Pacific El Niño event associated to a radical change in the regional hydrological conditions, and Central Pacific El Niño events that are associated to a significant high-frequency remote forcing under relatively mean normal conditions (see Dewitte et al. (2012)).

We have thoroughly checked over the grammar and syntax, and a native English speaker will examined the revised manuscript. The paper is being shortened and reshaped to state explicitly the main goals of the manuscript. Thank you for all the specific comments that will be taken into in order to improve each section.

1- About the INTRODUCTION:

We agree with reviewer 2 that is necessary a more concise and better definition of manuscript objectives.

2- About METHODOLOGY:

a-Following the reviewer's 1 and 2 recommendation, we rewritten the description of the method to derive the Kelvin wave. The new paragraph 2.4 writes as follows.

The amplitude of the Intraseasonal Equatorial Kelvin Wave (IEKW) is derived from the SODA oceanic Reanalysis (Carton and Giese, 2008). The method consists in projecting the pressure and current anomalies from SODA between 15°S and 15°N onto the theoretical vertical mode functions obtained from the vertical mode decomposition of the mean stratification. Kelvin wave amplitude is then obtained by projecting the results onto the horizontal modes at each grid point in longitude. The method has been shown to be successful in separating first and second baroclinic waves (Dewitte et al., 1999, 2008) that propagate a different phase speed and impact the Peru coast in a very specific way (Illig et al., 2014). In particular due to the sloping thermocline from west to east along the equator, the second baroclinic mode Kelvin wave is more energetic and influential on the upwelling variability off the Peruvian coast (Dewitte et al., 2011, 2012). For the correlation analysis with the dissolved oxygen data, we select the IEKW amplitude at 90°W.

To extend the IEKW for 2011, we will use the outputs of a general circulation model forced by an atmospheric Reanalysis. This simulation belongs to the set of MERCATOR global OGCM simulations (http://www.mercator-ocean.fr/) was used in Mosquera et al. (2014) to estimate the Kelvin wave amplitude.

References added to the revised manuscript:

Illig S., B. Dewitte, K. Goubanova, G. Cambon, J. Boucharel, F. Monetti, C. Romero, S. Purca and R. Flores, 2014: Forcing mechanisms of intraseasonal SST variability off Peru in 2000-2008: local versus remote forcings. J. Geophys. Res.-Oceans, Vol. 119, 6, 3548-3573. Mosquera-Vásquez, B. Dewitte and Serena Illig. The central Pacific El Niño intraseasonal kelvin wave JGR: Oceans (2014). 10.1002/2014JC10044.

b- About the change of instrumentation, we perform comparative analysis between CTD and salinometer analysis during all the monthly cruises in order to present consistent information. We will include a discussion about that in this section as the reviewer 1 recommend.

c- Regarding the EOF analysis the reviewer 2 ask if is really needed PC1 and PC2 if only the PC1 time series were shown.

The EOF analysis is performed in order to provide a synthetic view of the variability for physical and biogeochemical parameters. We focus on the first two EOF, in the case of the physical the PC1 explained up to 84.5 % of the variance but in the chemical parameters the PC1 explained 50% and the PC2 30%. We now provide both the eigenvalue (timeseries) and eigenvectors (vertical profiles) of the EOF analysis, and also the EOF analysis combining all the variables (physic, chemistry) and also the Kelvin Wave data. We can include more detail when we present the EOF analysis, fig. 6. We have expanded the description of the results and the discussion.

d- About the spatial pattern, to answer the reviewer 2, in the study area we present the study site. A station located in the continental shelf in front of Callao at 20 nm. Previous studies in the same area but in a more coastal area at 8 nm show also the influence of the remote forcing in the benthic community and the environmental conditions particularly during El Niño.

e- The reviewer 2 indicate that the wavelets in the time-frequency domain could be more informative that the global wavelet spectrum.

We perform an analyze in the time frequency wavelet frequency in addition to the global wavelet spectrum and finally we decide to use the GWS because both present the same information for the time series indicate the strong interannual signature associated with El Niño and also the intraseasonal signature that appear in the band of 180 days (6 months)-90 days (3 months). In the Figure 8 The GWS showed the significance interannual periods for all-time series, over the dotted line.

About RESULTS:

a- Following the reviewer 1 recommendation we have extended the period for the observations. Unfortunately we were not able to extend the series for the Intraseasonal Kelvin Wave since our estimate is based on an oceanic Reanalysis that is only available until Dec 2008. After 2008 will be necessary to use other product and perform comparative analysis.

We have also extended the IEKW timeseries until 2011. To do so, we used the outputs of a general circulation model forced by an atmospheric Reanalysis. This simulation (referred to as Mercator hereafter) was also used in Mosquera et al. (2014) to estimate the Kelvin wave amplitude. Although it is not an assimilation product like SODA, the simulation is realistic. We will also include the correlation between the Kelvin wave amplitude at 90°W for SODA and Mercator the first and second baroclinic modes, respectively.

b- We agree with reviewer's statement that the year 2008 with an El Niño 3.4 index does not indicate a warm event. However the costal El Niño index 1+2 indicate a warm period. The Peruvian coast is one of the few regions in the world that requires two indexes for monitoring El Niño. In 2012, the national technical committee for El Niño study (ENFEN; http://www.met.igp.gob.pe/variabclim/enfen/) defined the ICEN (Coastal El Niño index) based on the anomaly of the sea surface temperature of the El Niño region 1+2 (90° W- 80°W, 10°S-0°). The ICEN index is better indicator of the

ENSO cycle off the Peruvian coast. It gives an idea not only of the El Niño impact on the physical and chemical fields but also on the El Niño consequences on the biota and consequently on the economic resources. We will include this in the methodology.

We will also extend the discussion indicating that after the 1997/98 El Niño, the interannual variability in the equatorial Pacific consists in a different type of El Niño events. Those events are referred to as Central Pacific El Niño events and are characterized by an increased variability of the intraseasonal Kelvin wave activity during the development and peak phase compared to the strong El Niño events (See Mosquera et al. (2014). Therefore the period 2000-2008 can be considered as a period with enhanced intraseasonal variability compared to the previous decade.

c- As reviewer 2 recommend we will explore the regional models outputs in order to compare our results of the IEKW.

We agree that model experiments could provide additional material for interpreting the observations. For OMZ regional modeling, we are only aware of the study by Montes et al. (2014) that addresses the seasonal cycle, not the interannual variability. It is beyond the scope of the present study to present model simulations over the period of interest, which would deserve a thorough validation. This is actually a work in progress and the results will be reported later.

d- As reviewer 2 recommended to show the quantification of connection between PC2 and the intrasesonal variability.

Page 16: The equatorial forcing the physical and chemical modes of variability is less than 60%. The linear correlation (r coefficient) between IEKW_1 and IEKW_2 and PC1 physical time series are -0.35 and -0.67, respectively and also significant correlations between the IEKW_1 and 2 with the EOF1 (PC1) for the chemistry (-0.29, -0.52 respectively) and with the oxygen minimum zone upper layer position (-0.28, -0.55) were significant during the study period. We will include a table with the lineal correlations between the mode 1 and 2 of the IEKW and the PC1 and 2 of the physical and chemical time series. We will also explain in more details this results.

e- The reviewer 2 consider that t is not possible to discriminate properly the intraseasonal from the seasonal variability with monthly observations.

We agree with the reviewer that the monthly resolution will tend to damp the amplitude of the intraseasonal variability. However since we focus on the frequency band [40-90] days, we believe it is still reasonable to address the intraseasonal variability with the monthly data. We now will expand the discussion about this and mention in the text limitation associated to aliasing that would require to be investigated further based on mooring data for instance. There is however no biogeochemical data from a mooring available in this region. This is actually plans that IMARPE and the international community (TPOS2020 program) have.

All the specific comments and minor changes will be taken into consideration in order to improve this section.

6. About DISCUSION

In accord with the reviewer 2, we agree to include a better discussion about the biogeochemical process that significantly impact in the nutrients and oxygen profiles.

As recomended reviewer 1 We will extend the discussion indicating that after the 1997/98 El Niño, the interannual variability in the equatorial Pacific consists in a different type of El Niño events and associated with those events an increased variability of the intraseasonal Kelvin wave activity during the development and peak phase compared to the strong El Niño events (See Mosquera et al. (2014).

The reviewer 2 also recommended to discuss the local effect of Winds on the intraseasonal signature. We recognized that this is an important point to include. We have expanded the discussion on the role of wind forcing based on previous studies. In particular, Dewitte et al. (2011) shows that there exist two distinct regimes of intraseasonal variability for SST and winds along the coast of Peru: One regime with variability

timescales in the frequency band [2-30 days] and another one centered on the peak frequency of 50 days-1. While the former one is associated to local wind forcing, the latter is due to the remote equatorial forcing. Here we focus on the intraseasonal variability associated to the equatorial Kelvin wave that is the frequency band of [30-90] days that the data (model and in situ) can resolve. Echevin et al. (2014) shows evidence that subsurface nutrient and chlorophyll intraseasonal variability are mainly forced by the coastally trapped waves triggered by intraseasonal equatorial Kelvin waves reaching the South-American coast. In the northern part of the Peru shelf (latitudes 4°– 8°S) on [50–90] day time scales the authors show that the impact of the local wind-forced intraseasonal variability on the ecosystem is of a similar order of magnitude to that remotely forced. In the central and southern part of Peru, that include our study area (Callao 12°S), IEKW-forced CTW signature emerges as dominant over the local wind impact.

In our study we are not addressing the higher-frequency variability associated to wind forcing owed to the limitations of the data sets (monthly resolution). We now mention such a limitation of our study in the revised manuscript.

All the specific comments and minor changes will be taken into consideration in order to improve this section.

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