El Niño Southern Oscillation and nutrient dynamics in the Peruvian Upwelling System

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Abstract
El Niño Southern Oscillation (ENSO) represents the largest natural perturbation to the climate system, affecting ecosystems around the world. El Niño conditions allow for a reduction in the trade winds, meaning reduced upwelling in the eastern Equatorial Pacific, whereas La Niña conditions allow for an increase in the trade wind intensity and therefore upwelling intensity. Using data from the Ocean General Circulation Model For the Earth Simulator, this study finds that ENSO controlled nitrogen and phytoplankton abundance in the surface waters of the Peruvian Upwelling System from 2005 to 2007 through altering the strength of upwelling in the region. For the period of 1999-2005 the system may have been influenced by another factor or the biogeochemical model was in drift.
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1. Introduction

The Peruvian Upwelling System, part of an upwelling area that extends between 4°S and 40°S along the western coast of South America (Tarazona 2001), is one of the most important coastal upwelling systems in the world (Espinoza-Morriberón et al., 2017). Along the coast of Peru, equatorward winds allow for persistent coastal upwelling of cold, nutrient rich waters via Ekman transport of surface waters away from the coast (Fig. 1) (Bakun et al., 2010). This upwelling allows the area to be of great ecological and economic importance as it represents almost 20% of the world’s landings of industrial fish (Tarazona 2001). The system is affected however at interannual timescales by the El Niño Southern Oscillation (Espinoza-Morriberón et al., 2017).

The El Niño Southern Oscillation (ENSO) is the most important year to year fluctuation of the climate system (Cai et al., 2015), causing and exacerbating major flooding events, massive wildfires and severe droughts around the world (Sadékov et al., 2013). ENSO events are characterised by variation in the sea surface temperature of the eastern equatorial Pacific, varying between anomalously warm El Niño and anomalously cold La Niña (Kim et al., 2014). During El Niño conditions, a weakening of the trade winds over the equatorial Pacific allows for the eastward migration of the West Pacific warm pool, causing positive sea surface temperature anomalies in central and eastern Pacific (Espinoza-Morriberón et al., 2017). This weakening of the trade winds also causes a weakening in upwelling in the Peruvian Upwelling System, reducing the nutrient rich waters brought to the surface. La Niña conditions involve an intensification of upwelling favourable winds, resulting in negative sea surface temperature anomalies and increased export of cool, nutrient rich water from depth to the surface in the Peruvian Upwelling System (Espinoza-Morriberón et al., 2017).

Figure 1: Process by which upwelling occurs in the Southern Hemisphere, such as in the Peruvian Upwelling System. As the land warms faster than the ocean due to preferential heating, a low pressure cell forms over the land. This exerts an equatorward geostrophic wind stress on the surface waters. Through Coriolis deflection to the left, this then allows Ekman transport of surface waters away from the coast and upwelling of deeper waters to replace the transported water (Bakun et al., 2010).
In the current study the relationship between ENSO and nutrient dynamics in the eastern Equatorial Pacific is investigated, with a focus on the Peruvian Upwelling System.

2. Method

2.1 OFES simulation

To investigate how ENSO effects nutrients in the Peruvian Upwelling System, sea surface temperature (SST), nitrogen, phytoplankton and vertical velocity data for the Equatorial Pacific was obtained from the Ocean General Circulation Model For the Earth Simulator (OFES). The OFES simulation was conducted on the Earth Simulator under the support of JAMSTEC. The output data used in this study is a 0.1 degree monthly mean with QSCAT wind forcing (APDRC, 2018). SST data from 1999-2009 was used, nitrogen data 1999-2007, phytoplankton data 1999-2008 and vertical velocity data 1999-2008.

2.2 El Niño and La Niña conditions

El Niño and La Niña events peak in the austral summer months of December-January-February (DJF), therefore these were the focus of this study (Cai et al., 2014a). To allow El Niño and La Niña conditions to be determined, ‘normal’ conditions for DJF over the study period had to be determined. This was done by calculating average conditions for each month over the period of December 1999 – October 2009 and then averaging the December, January and February values. Figure 2 shows the ‘normal’ SST conditions for the Equatorial Pacific as DJF mean. El Niño conditions were determined when SST in the Niño 3.4 index region, shown as the black dashed box in Figure 2, were over +0.5 STDEV from mean conditions and La Niña conditions below -0.5 STDEV. The Niño 3.4 index is an area average of SST over 5°S – 5°N and 170°W – 120°W.

2.3 ENSO and Peruvian Upwelling Zone

The relationship between ENSO and nutrient dynamics was then investigated using nitrogen, phytoplankton and vertical velocity data from the same OFES model, focusing on the Peruvian Upwelling Zone, shown in the green dashed box in Figure 2. An area average value was calculated for the upwelling region for the months of December, January and February and then a DJF value calculated as a mean of the three months.

![Figure 2: Mean December-January-February Sea Surface Temperature for the Equatorial Pacific across the study period of December 1999 – October 2009. The black dashed box shows the Niño 3.4 index region and the green dashed box indicates the Peruvian Upwelling System.](image-url)
3. Results and Discussion

SST anomaly in the Niño 3.4 region, shown in Figure 3A, allows for the identification of El Niño events as those above the red dashed line and La Niña events as those below the blue dashed line. Values are a December-January-February mean for the Niño 3.4 index area, with the year 2000 representing the December-January-February period of 1999-2000.

Figure 3:
A) December-January-February mean SST across the Niño 3.4 region, with El Niño events identified as those above the red line and La Niña events as those below the line. B) SST anomaly for DJF 2002-2003, with black dashed box indicating the Niño 3.4 region. C) SST anomaly for the DJF 1999-2000, black dashed box also Niño 3.4 region.

El Niño years were identified in 2003, 2004, 2005 and 2007, with the strongest in 2003. La Niña events were identified in 2000, 2001 and 2008, with 2000 the strongest. Figure 3B shows the SST anomaly for the 2003 strongest El Niño event, with SST anomalies within the Niño 3.4 region over +1.5°C compared to ‘normal’ conditions. A warm anomaly is also present off the coast of Peru, with temperatures around 1°C warmer in the Peruvian Upwelling System compared to ‘normal’ conditions. Anomalies of greater than -2°C occurred in the Niño 3.4 region in the strongest La Niña event of 2000, shown in Figure 3C. Again, the Peruvian Upwelling System is also cooler than normal at this time, with an anomaly of around -1°C. This reflects ENSO’s ability to influence SST across the whole Pacific region. The El Niño and La Niña years identified are in agreement with the National Oceanic and Atmospheric Administration (NOAA) historical records for all but 2006 (NOAA 2018). The year 2006 was identified by NOAA as a stronger La Niña year than 2001, yet the data from OFES shows 2006 as a near zero SST anomaly. This could be due to NOAA using the ONI index based on a 30-year base period updated every 5 years as oppose to this study which uses the Niño 3.4 index and 10-years of data as base conditions.

Figure 4 illustrates the relationship between ENSO and nutrients within the Peruvian Upwelling System. The axis for nitrogen, phytoplankton and vertical velocity have been flipped, as higher sea surface temperature anomalies, characteristic of La Niña conditions, increase upwelling in the area (Tarazona 2001), and therefore nitrogen and phytoplankton abundance in the surface waters. However, the lowest nitrogen value is the La Niña event of 2000 (Fig. 4B). The latter part of the data from 2005 onwards does follow the predicted trend more clearly than the earlier years, as lower SSTs equate to an increase of nitrogen in the surface waters. Phytoplankton abundance displays similar behaviour to the nitrogen data, with the lowest value observed also during the La Niña conditions of 2000 (Fig. 4C). The abundance increases with temperature up until 2003, where it then begins to follow the expected trend of higher abundance with lower SST anomaly. Vertical velocity data follows the expected trend, as it exhibits a similar pattern to the SST anomaly data (Fig. 4). During El Niño conditions the vertical velocity is lower, and during La Niña conditions the vertical velocity is higher, consistent with the
weakening and strengthening of the trade winds under the two ENSO states.

After 2005, the data sets all follow the expected trend, with warm SST anomaly El Niño conditions having lower nitrogen in the surface waters, lower phytoplankton abundance and decreased vertical velocity in the Peruvian Upwelling System. Therefore, the variation in ENSO between El Niño and La Niña conditions seems to explain the variance in phytoplankton and nitrogen in this period. The weakening and strengthening of the trade winds allows for ENSO to induce interannual ecosystem variability in the Peruvian Upwelling System (Tarazona 2001). This is consistent with previous studies, which found surface chlorophyll, planktonic biomass and the abundance of primary producers all decrease during El Niño events (Espinoza-Morriberón et al., 2017). These changes have far reaching consequences within the ecosystem, triggering habitat changes and mass mortality of several species of fish (Espinoza-Morriberón et al., 2017).

In the period prior to 2005 the data does not follow the expected trend. Both nitrogen and phytoplankton datasets indicate their lowest value during the strongest La Niña in the study period, where the highest values were expected to be found. This points to either another controlling factor in the system other than ENSO or anomalous data from the OFES simulation. There is the possibility that the data is anomalous as the simulation would still have been in the drift period for the first few years of the biogeochemical data. To truly establish the cause of this unexpected data further analysis should be undertaken. This would be done using other records of nitrogen and phytoplankton, as well as other nutrients, to gain a better insight into the impact ENSO has on nutrients in the Peruvian Upwelling System.

Potential future changes in the climate system from greenhouse gas emissions means that extreme El Niño and La Niña events may double in frequency (Cai et al., 2014a; Cai et al., 2014b). This increase in the frequency of extreme ENSO events will cause greater variation in the nutrients available in the surface waters of the Peruvian Upwelling System, with possible detrimental impacts on the ecosystem and those that depend on it.

Figure 4: A) December-January-February mean SST across the Nino 3.4 region, with El Niño events identified as those above the red line and La Niña events as those below the line. B) December-January-February mean nitrogen in surface waters of Peruvian Upwelling System over time. C) December-January-February mean phytoplankton in surface waters of Peruvian Upwelling System over time. D) December-January-February mean vertical velocity in Peruvian Upwelling System over time.
5. Conclusion

ENSO controls nitrogen and phytoplankton abundance in the surface waters of the Peruvian Upwelling System in the period after 2005. Low sea surface temperature anomalies, which characterise La Niña conditions, are accompanied by increased nitrogen and phytoplankton abundance due to increased upwelling intensity via strengthened trade winds. During warm El Niño conditions the upwelling favorable winds are diminished, causing lower nitrogen and phytoplankton due to decreased upwelling intensity. In the period prior to 2005 the system may be influenced by another factor, or the OFES simulation is still in drift. To determine the source of this anomalous data further work should be conducted using other datasets.

Acknowledgements

I would like to thank Professor Tomoki Tozuka, Mr Kazumichi Murata and Mr Marvin Seow for all of their guidance, especially with Python coding. In addition I would like to thank all of those within the Department of Earth and Planetary Science, Graduate School of Sciences for their kindness and hospitality and the UTRIP Office staff for their support.

References


For OFES model


