Referee 1 Observations

Comment

P 181 / line 5 What properties are transported?

This CTZ contains large filaments and eddies that contribute to the offshore transport of properties (Brink and Cowles, 1991).

Response

For more clarity it now says:

This CTZ contains large filaments associated with flowing squirts or jets (Davis, 1985; Rienecker and Mooers, 1989; Thomson and Papadakis, 1987) and eddies that contribute to the offshore transport of properties (Brink and Cowles, 1991) such as heat, nutrients, oxygen, chlorophyll and salinity (Roemmich, 1989; Bograd et al., 2001)

Comment

P 1981 / line 7 Unsure of the meaning of the sentence: 'The western shelf is part of the active geological features of the peninsula, so it is actually formed by intense bathymetric gradients.

Response

For more clarity it now says:

In the western shelf the width varies from a narrow coastal shelf with steep gradient to a wider shelf with gentle slopes ……

Comment

P 1981 / lines 11 – 15. Description of Ekman pumping is wordy and unclear. Reference a paper with a full description of the process.

The shelf of the western Baja California Peninsula has been considered highly productivity, especially on the coastal upwelling regions (Lluch-Belda, 1999; Zaytsev et al., 2003). This coastal upwelling process is developed when equatorward winds blow over the ocean surface creating a stress that gives the ocean a horizontal initial velocity in the direction of the wind, but the Coriolis Effect due to the Earth's rotation exerts acceleration proportional to velocity at right angles to the direction of motion, this turns the ocean velocity away from the direction of the wind, and the resulting Ekman transport is 90.

Response

The references to Ekman process have been modified, they now say:

The shelf of the western Baja California Peninsula is highly productive, especially the wind-driven upwelling regions (Lluch-Belda, 1999; Zaytsev et al., 2003). These provide nutrient-rich water to the euphotic zone and support a productive ecosystem. Coastal upwelling occurs due to intense equatorward winds that blow on this coast throughout the year creating the necessary wind stress and ensuing offshore Ekman transport (see for instance, Gill, 1982).

Comment

P 1983/ Line 25- Reason behind using 11µm daytime SST from MODIS A only? Other satellite SST products or even a composite of MODIS A and MODIS T night-time SST would possibly give more reliable results? A reference to another paper using this 11µm product would be of use.

Response

The reason to use the daytime 11µm band is to have temperature simultaneous with the measurement of chlorophyll, in order to obtain estimates of productivity. Additionally, Wan (2002) and Uiboupin and Sipelgas (2007) had reported good accuracy in the use of this algorithm.

Comment

Fig.1. This map is generally clear and easy to read. The bathymetric lines are too small and close together. I'd suggest using a more "zoomed in" view, showing the shelf at a higher resolution. Additionally, there are 6 grey circles, possibly indicating sampling sites this is not explained in the caption or the text.

Response

The bathymetric lines are more readable now, as the bathymetric lines of 200 m and 1000 m are to closer, the 1000 m was substituted by the 1500 m instead and colors were added for more clarity.

The map has been zoomed.

The explanation about the 6 grey circles was already in the figure caption, however it has been extended and moved to the end of the caption paragraph for more clarity.

The caption now says:

Fig. 1. The Gulf of Ulloa. The thin blue and green lines indicate the isobaths of 200 m and 1500 m, respectively. The 6 grey filled circles on the limit on the continental shelf

are the sample sites of the NPP, currents and winds to generate mean time series for the region.

Comment

P 1984/ line 6-'Zeu is the euphotic zone depth in m. For this study, the euphotic zone depth was substituted by the mixed layer depths (MLD) obtained from results of the high resolution ocean general circulation model, HYCOM (Bleck, 2002)'.

Is there a reference for another paper on eastern boundary upwelling where actual CTD PAR sensor derived Zeu values having been compared to MLD? Using MLD only assumes that no deep chlorophyll maximum ever forms below the mixed layer. The authors comparison with MODIS derived Zeu partially satisfies this, but a reference to previous research would be useful.

Response

We couldn't find a reference where actual PAR sensor and derived Zeu values have been compared to MLD. The following explanation is now included:

We use MLD to implicitly include the dynamics of the coastal region as obtained from the HYCOM model results. Integrating to the MLD also recognizes that satellite data cannot resolve the vertical distribution of chlorophyll (ie, depth of the maximum of chlorophyll). We know that the chlorophyll distribution is not vertically uniform across the euphotic zone but it can be assumed to be uniform by layers, as suggested by Platt and Sathyendranath (1993). These authors say that the vertical distribution of the phytoplankton over the water column can be divided in layers where each one of them contains a uniform concentration. In these layers models can be applied to estimate the rate of net primary production. We do this in the MLD as a function of available light and phytoplankton chlorophyll (Platt et al., 1977; Platt and Gallegos, 1980; Cullen, 1990; Platt et al., 1990).

Comments

Results, Discussion and Conclusions The results and discussion section, along with their respective graphs need major revision. Starting with the graphs:

p 1983/ line 10 & reference to figure 2a&b

1. The figure text is too small

2. Titles, labels and equations are unlabelled, and too small

3. Axes scales too large and should be changed to fit the data

4. Best fit line and equations are questionable, especially for ’b)’ which looks bi-modal.

5. Equations are in the form y=ax, and don’t detail actual parameters being represented.

Response

As a result of a new justification on the use of MLD instead of de ZEU we omitted this figure 2.

The results and discussion section has been revised and improved as detailed below.

Comments

Fig 3-6 Better figures, and reasonably easy to read. Issue with Fig. 4’s caption- ’sea surface’ typo. The mean field for the geostrophic currents on fig 6. is also particularly interesting, and might benefit from more discussion in the text, especially in the reasons behind its difference to the WSC on fig.5. Figure 5 would benefit from a colour-scale with more variability between the 0 values and the maximums.

Response

Fig 4, The issue caption (surfer) has been corrected (surface).

Fig 5. The scale has been extended to 10.

Fig 6. A more detailed discussion is intended in the results-discussion section.

Comments

Fig 7. This is the major figure for the paper, however it is in too small a format to comfortably view on a standard sized print out of the manuscript. The figure may need to be rotated to landscape, and have the font size of the labels, and axes increased.

Response

The Fig 7 is already in a landscape form, we will ask the editor to present it in landscape. However the labels and additional text were improved for better readability.

Comments

Changes to the text: In general, the results and discussion does not do a satisfactory job explaining the results expressed in the abstract. There are general descriptions of the data seen in each of the figures on p1985 to 1989, but a fairly limited attempt has been made at linking the observations seen in the different datasets (which is the key finding of the paper). This discussion and comparisons with other published work on the region (or other similar regions) needs to be made, before the key scientific findings of the paper can be expressed. For revisions, the paper would be enhanced by a more thorough comparison of the different datasets, identifying similar features that can be seen in the different datasets, and suggesting reasons why these features can be seen. An excellent example of where this has been done on primary productivity is: On the relationship between stratification and primary productivity in the North Atlantic, Lozier, S et al. GRL, VOL. 38, L18609, doi:10.1029/2011GL049414, 2011.

Response

For more clarity this section was re-organized, the first climatological monthly figure (Fig 2) it is now the one corresponding to wind and WSC (previously figure 4), the other figures were renumbered accordingly. Comparisons with the other data sets is also made.

An improved result and discussion is offered (3.4 Time series section it is not included in this response). Additional bibliography was also revised and included (see below).

Results and discussion

3.1 Wind and Wind Stress Curl (WSC)

Wind vectors and WSC Climatological monthly maps are shown in figure 2. Wind vectors are included only to show the regional monthly pattern. The monthly maps show that the wind flows parallel to the coast throughout the year, and particularly so near the coast. This wind pattern off Baja California was pointed by Bakun and Nelson (1977), who concluded that seasonal variability of wind speed is more important than direction (implying conditions are generally favourable for coastal upwelling throughout the year). With this wind pattern, the resultant WSC (figure 2) is positive all over the year, except for small areas in February and October south Gulf of Ulloa. The months with the highest positive values of coastal WSC are March through June (values > 4.5 $m\ s^{-1}\ e^{-7}$ from 25 to 27° N). In July-August coastal values of WSC range from 1.5 to 4 $m\ s^{-1}\ e^{-7}$. From September to January values fall below 2 $m\ s^{-1} e^{-7}$. In the oceanic dominion the values of WSC are always negative.

From these maps an important question arises, if the wind and the WSC patterns provide upwelling conditions throughout the year, why the resultant NPP is not always high? It is clear that in the Gulf of Ulloa wind favourable conditions are not the only forcing required for high values of NPP. The presence of rich-nutrient water is inhibited in the summer by other processes. To provide support to this hypothesis, maps of climatological NPP, SST and geostrophic currents (mean monthly values between 2003 and 2007) are discussed next.

3.1 Climatological maps of Net Primary Productivity (NPP)

The climatological monthly maps of NPP are shown in the figure 3. In January NPP values are below 600 mg C m−2 d−1. The values of NPP start to increase in February in the north (27◦ N) Gulf of Ulloa with values that reach 1000 mg C m−2 d−1. By March, NPP increases to 1500 mg C m−2 d−1 in the northern Gulf and high values of NPP are present all along the coast of Gulf of Ulloa, with values between 900 mg C m−2 d−1. In April the coastal values increase to 1600 mg C m−2 d−1. This month is the most productive of the climatological year (2003-2007). In May the NPP starts to diminish, with the coastal values in the range of 900 to 130 mg C m−2 d−1. By June, the values in the coastal band are now between 600 and 1250 mg C m−2 d−1 but now only from middle to northern of the gulf (26-28◦ N). In July-August there only two small coastal regions can be observed with high values of NPP, between 600 and 900 mg C m−2 d−1. From September to December NPP values are very low in all the Gulf of Ulloa, all estimates are below 100 mg C m−2 d−1. From the maps of figure 3 a seasonal behavior in the NPP values is evident with maxima in spring and early summer (March to June) and minima from September to December, what is consistent with the upwelling season (see for instance Zaytsev et al., 2003).

NPP estimates made by the IMECOCAL program in a few of their coastal stations (Martinez-Gaxiola et al., 2010) can be used to determine variability rates in organic carbon synthesis. Their measurements however, cannot give us NPP global values for comparison with our estimates in Gulf of Ulloa. According to Karu et al. (2009), chlorophyll-a (chla) drives most NPP response along the coast of the California current, and therefore the observed increase in biomass will lead the corresponding increases in NPP. The IMECOCAL data supports our findings (figure 3) regarding the spatial distribution of NPP. For instance, in the data from 2003 to 2007 the distribution of chla in the Gulf of Ulloa shows similar coastal increases, with higher values south Punta Eugenia in April associated to upwelling process. Similarly to the description in figure 3, a seasonal pattern occurs, associated to upwelling. Chla reaches maximum values in April and decreases towards late summer (Goericke et al., 2004; Goericke et al., 2005; Peterson et al., 2006; Goericke et al., 2007; Mcclatchie, et al., 2008).

3.2 Climatological maps of Sea Surfer Temperature (SST) and Geostrophic Currents

3.2.1 SST

Climatological monthly maps of SST are shown in the figure 4 (current fields are superimposed). In January, SST has values from 14°C in the north (28°N) to 23°C in the southern (25°N) Gulf of Ulloa. During February-March lowest temperatures in the northern coastal band reach ~15°C and the maxima decreased to 21°C. During April-May coldest water (around 12°C) again was found at north, but it now extends to middle of the Gulf of Ulloa (26-28°N) and cover not only the coastal zone (the water over the continental shelf, indicated by 200 m isobaths, Fig. 1) but oceanic water too. For these months in the reports of several years, IMECOCAL program reports a coastal band of cold water with high productivity near Punta Eugenia (Goericke et al., 2004; Goericke et al., 2005; Peterson et al., 2006; Goericke et al., 2007; Mcclatchie, et al., 2008). By June this behavior is restricted to the northern coast (south of Punta Eugenia) with the lowest temperatures close to 15°C. This appears to be the start of the upwelling relaxation because the oceanic water is also less cold, at the same time a mass of coastal warm water (temperatures near to 21°C) is present in southern Gulf of Ulloa (25-26°N). In July-August this warm water advances poleward to the middle Gulf of Ulloa (26.5°N) not only along the coast but throughout the gulf with temperatures of 26°C and higher, while coldest water (18-19°C) is restricted to a narrow coastal band in the north (27-28°N). By July the core of the California current is divided in two branches due to the presence of an eddy north Punta Eugenia (Venrick, et al. 2003; Goericke et al., 2004; Peterson et al., 2006; Goericke et al., 2007; Mcclatchie et al.;2008). The first branch is oceanic and it has warm temperatures; the second one is a narrow coastal equatorward jet of cold water associated with the remaining high values of chla in the north coast. During September-October (figure 4) monthly maps show warmer water covering all the central Gulf of Ulloa (26-27°N) with temperatures of 28°C. The minimum temperature of 20°C is found at about 27.5°N and there is no evidence of cold water associated to upwelling. During the same months the IMECOCAL program also reports the presence of warm water (22-24°C) and no evidence of upwelling processes. By November, the temperature starts to decrease in the northern gulf, SST values are around 18°C, while at the southern end (25°N) SST remains near 25°C. By December, the cooling reaches 16°C in a small zone at the northern Gulf (28°N) and the higher values decrease to 23°C in the south (25°N). The maps of SST (figure 4) showed that favourable stronger upwelling conditions (the lowest coastal cold water) are present in April and are coincident with highest positive WSC (figure 2) and highest NPP values (figure 3) supported bye corresponding high chla values in all the IMECOCAL reports previously mentioned.

3.2.2 Geostrophic Currents (Currents)

Climatological monthly maps of geostrophic currents are shown in figure 4 (superimposed over SST). Monthly maps show that in January there is a coastal weak equatorward current in the northern Gulf of Ulloa. This current becomes stronger and wider from February to June, being strongest (maxima values > 0.20 m s^{-1}) during April-May. During July-August the equatorward current flows away from the coast creating oceanic meandering conditions, no coastal current is evident during these months. In September a warm poleward enters the Gulf of Ulloa from the south, and by the month of November it occupies its southern half. By December the same circulation persists except that the surface temperatures start to decrease. When comparing the seasonal variations in the geostrophic currents as estimated here, with those reported by the IMECOCAL program results are very similar. The main features in the circulation patterns shown in figure 4 can also be found in the CALCOFI reports that include IMECOCAL data (Venrick et al., 2003; Goericke et al., 2004; Goericke et al., 2005; Peterson et al., 2006; Goericke et al., 2007; Mcclatchie et al., 2008).

Once the currents are considerate in conjunction with the other variables, the highest NPP values are a consequence of a positive WSC, lowest SST values, and strong equatorward flow. These oceanic conditions were found clearly in Gulf of Ulloa during March-June with maxima in April. When positive WSC values, relatively low SST values and weak equatorward flow are combined, the NPP values are not so high. Such conditions are found during January-February and July-August in the north of the Gulf of Ulloa. Moreover even with positive WSC values, when warm water provided by the poleward coastal flow is present, the NPP values are always low (September-December). This behavior suggests that the local primary productivity results from local upwelling and also from the advection by the equatorward flow carrying cold nutrient-rich water. Roemmich, 1989 and Bograd et al., 2001 describe the nutrient-rich California Current waters flowing south offshore. A similar process appears to occur in the very coastal region and is partly responsible for the enhanced NPP.

To clarify this fact, maps of climatological currents are shown superimposed over NPP climatological monthly maps (same period) in figure 5. The circulation pattern from February to June shows a coastal equatorward current in the Gulf of Ulloa. The current is more intense from April to June, the presence of this equatorward current coincides with the increase of NPP coastal values in March-June. During July-August the equatorward current is located offshore, the lack of a coastal flow in these months and the presence of a warm poleward current the rest of the year is associated with a sharp decrease in NPP values.

See at the end of the responses for the new bibliography

Comments

1 Other smaller problems include: p1986 /line 11- What is being defined as the coastal zone?

2 p1989 The Harmonic analysis section of the graph needs better explanation.

3 Conclusion- This is slightly too brief, and appears to focus on further work (such as correlations with ENSO), more than the actual findings of the paper. The conclusion would be improved with a more focused summation of the key findings of the paper-clearly defining the ’normal conditions’ seen, and how these change under changing

meridional current forcings in terms of VGPM model output, surface temperature and currents. A brief note on the correlation between VPGM output, currents and WSC would also be of use in the conclusion too.

Response

1 A short explanation about coastal zone has been added,

In the introduction:

The coastal zone will be defined in this paper not by the width of the shelf or the continental slope. Instead we prefer to define this coastal region from the coastline to, and including, the Coastal Transition Zone as defined in (Chavez, 1991).

2. The following explanation was included in the harmonics analysis methods section it now says:

A harmonic analysis of the last three time series (NPP, GAC and WSC) was carried out. We used the method of periodic regression (Bliss, 1958) to find the dominant harmonic. This method finds the trend and periodic components of a time series as defined by its frequency, amplitude and phase. The addition of several components can be used to describe most of the variability of the original time series. Here, a cross-correlation test was performed between the dominant harmonics of the three time series. These describe the largest percentage of the variability of the original time series and are assumed to be the best choice to determine their interaction in seasonal time scales.

The harmonics analysis of the last three time series (NPP, GAC and WSC) was carried out to obtain all the significant harmonics presents in their respective time series. The method of periodic regression (Bliss, 1958) and the cyclic descent method (Bloomfield 1976) were chosen. As usual in methods for fitting polynomials to data, an F test was applied to evaluate the statistical significance of each harmonic. These describe the largest percentage of the variability of the original time series and are assumed to be the best choice to determine their interaction in seasonal time scales. Once the main harmonics of the three time series (NPP, GAC and WSC) are found, cross-correlation tests were performed to get the time lag (in months) among the different time series.

3 The conclusions are now as follows:

Favourable upwelling conditions are present throughout the year in the Gulf of Ulloa but high NPP exhibit a clear seasonality. Upwelling winds are necessary but not a sufficient condition for high coastal primary productivity.

The highest levels of NPP are found in the months March through June when a combination of positive WSC, lowest SST values and equatorward current carrying cold nutrient rich water occur throughout the coastal region. When the equatorward current is strongest (April-June), NPP values are the highest of the year, and when this current is weaker (January-February) or reversed (poleward flow in July-August) the corresponding NPP is inhibited.

During July a transition occurs in the southern half of the California Current, as described in many CALCOFI reports. Off the Gulf of Ulloa it splits in two branches near Punta Eugenia (28 N), an oceanic branch that separates from the coast and a coastal branch that weakens towards the coast. At the same time at the Gulf of Ulloa arrive the warm waters of a poleward coastal flow. Both factors contribute to the decrease of NPP observed in the imagery and supported by data gathered by the IMECOCAL program.

The WSC time series shows two extreme levels. The more intense one occurs during spring-summer and it is associated to the highest NPP levels of the year. The second period of high WSC occurs at the beginning of the autumn but NPP levels are the lowest of the year. In this case the warmer and nutrient-deficient water carried by the poleward current are thought to be responsible of the low NPP levels, despite the upwelling-favourable winds.

The NPP rich waters of the Gulf of Ulloa are due both to the local upwelling and to the equatorward coastal currents that carry nutrient rich waters from neighboring upwelling areas to the north. Advection plays an important role in modulating the productivity of the west coast of Baja California, at subtropical latitudes. The evidence presented over this five-year period is consistent with the seasonal modulation of the NPP by coastal upwelling and coastal currents.

Summarizing, high NPPs occurs during the months of March-June when WSC is positive near the coast, coastal SST are lowest and the currents flow stronger towards the equator. Lowest NPP's occur near the coast from September to December also with positive WSC but with high coastal SST and a poleward coastal current. This suggests that variability of coastal productivity is not only due to local processes such as upwelling but that advection along the coast plays an important role in controlling its seasonal variations.

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