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Comment on os-2021-13

David Webb (Referee)

Referee comment on "Interannual variability in contributions of the Equatorial Undercurrent (EUC) to Peruvian upwelling source water" by Gandy Maria Rosales Quintana et al., Ocean Sci. Discuss., https://doi.org/10.5194/os-2021-13-RC1, 2021

Review of: Interannual Variability in contributions of the Equatorial Undercurrent (EUC) to Peruvian Upwelling
By: Gandy Maria Rosales Quintana, Robert Marsh and Luis Alfredo Icochea Salas

Overall this is a well presented and nicely written paper on the sources of upwelled water off Peru and Ecuador. It does this by following particle tracks from the upwelling regions and shows that much of the upwelled water comes from the Equatorial Undercurrent.

The authors show that the fluxes change from year to year and relate this to the changing El Nino/La Nina signal. These are both significant results but I found that the discussion of the role of the El Nino and La Nina was weak and needs to be improved.

Main points

1. The paper only considers upwelling that occurs in the December of each year studied but do not give a reason for this. Figures 3 and 4 indicate that December is a period of weak upwelling off Peru and Ecuador. Was December chosen because it includes the height of the fishing season, is the time when large El Ninos have the most impact, or for some other reason?

2. The paper needs more detail on the criteria used for the seeding. Was it for example one particle per cubic metre upwelled during each December?

3. I find it difficult to reconcile figures 5 and 6, in which few particles travel 5 degrees

eastward during December, with figure 10, b and d, which show 20% of all particles travelling 70 degrees during the year, or figure 7 which implies that some particles come from beyond the dateline.

4. Figure 7 needs more explanation, especially 7 a and b (where the caption should refer to the log scale and the base). I presume that 'particle concentration' is not 'the average of the particle concentrations at the start of each year' but is more 'the average of the number of particles passing through each averaging box during the course of the year'.

I would also like to see a figure showing where particles started. Many obviously started in the regions where, on average, the age is greatest, but as the paper is really about where the upwelled water comes from, age by itself is not enough. Such figures might also help to clarify point 3 above.

5. My main problems with this paper occur once it starts discussing year to year variations.

Around line 35 the paper discuses how the easterly trade winds generates a pressure head in the western Pacific and how below the surface the pressure gradient (high in the west, low in the east) drives the undercurrent. Then around line 195 it discusses the flattening of the thermocline during the onset of an El Nino and that this "allowed more of these waters to progress all the way to the eastern boundary, where upwelling continued along the Peruvian coast. Conversely ... ".

To me this does not make sense because if the thermocline is flat, there is no east-west pressure gradient and no Undercurrent.

There are related problems with figure 10. Upwelling is largest in December 1997, at the height of one of the strongest El Ninos when the fraction of particles coming from the central Pacific is also very large. The year 2000 has similar properties at the time of a weak La Nina, but almost nothing happened in 1998 and 1998 when there were strong La Ninas. In 1992 there was also a reasonable El Nino, but with hardly any upwelling.

To me this means that the simple arguments in the paper are not working - maybe scatter plots of upwelling volume against El Nino index or mean distance travelled in the Undercurrent against El Nino index would show something - but I suspect that more is needed.

One of the problems appears to be the length of time integrated. Although the index indicated a large El Nino in December 1997, this was after a full year in which the El Nino

was developing. Particles starting in the west or central Pacific early in the year would have travelled eastwards on a strong undercurrent. As the year developed the particles may have stayed ahead of the change in surface winds and so reached the western Pacific. If this is the case, then it was the strong undercurrent early in the year which carried the water eastwards to be upwelled, not the fact that the El Nino index was large in December. In addition - why, in the middle of a strong El Nino, when the trades had failed, why was there so much upwelling in the east?

There is also a problem with the year 2000 when there was a weak La Nina. Then both the undercurrent and the winds would have been strong - so by the normal theory all the undercurrent water would be expected to be upwelled before arriving off South America. So why was upwelling so strong this year and why was so much of it from the undercurrent?

Also why also was upwelling less in other weak La Nina years and why, when there were strong La Ninas of 1998 and 1999, was there so little upwelling and so little water coming from the central Pacific?

6. Another area in which I am unclear is the relation of El Ninos to fisheries. As I understand it the fisheries in the region are successful because the upwelled water is full of nutrients. This normally implies that it comes from deep in the ocean and that it has not recently been within the surface photic zone where it would loose nutrients. So Undercurrent water is just perfect.

I also understand that the reason research on the El Nino started was that with the relaxation of the trades during an El Nino, the surface mixed/nutrient poor layer became thicker and any upwelled water was nutrient poor.

So how does this match with so much December 1997 water coming from the undercurrent? At the height of a strong El Nino the water in the photic zone above 100 m should have all have spent some time near the ocean surface.

Conclusion

Given these problems I do not really want to spend time on other details. I think a full solution needs a lot more work, a better knowledge of the winds causing upwelling, the effect of stratification on the amount of upwelling, the changing strength of the undercurrent and upwelling at different longitudes and different times of year.

I do not think that I can ask for this to be done before publication but I see two ways

forward:

The first is to accept the difficulties. The paper successfully shows that, on average, a large fractions of the upwelled water can come from the Undercurrent as opposed to currents running along the coastline. The variations with time can also be presented but with the difficulties pointed out and possible explanations noted. Papers that highlight problems with current ideas often get many citations.

Another possibility is to concentrate on just the last three months or so of each year, during which the El Nino index will not have changed so much. You should already have the data and it may be simpler to relate the amount of upwelling and contribution from the undercurrent (near the Galapagos) to the El Nino index and the winds near the coast.

Regards,

David Webb.