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Discussions

Interactive comment on "Surface circulation and upwelling patterns around Sri Lanka" *by* A. de Vos et al.

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Please see the list of changes below (red text) in response to the reviewer comments. Both reviewers have made substantial comments and suggestions to improve the paper which we have addressed these below. We would like to thank the reviewers for their comments which are very constructive, resulting in a much improved manuscript.

Reviewer #2

This study discusses near-surface circulation and coastal upwelling around Sri Lanka using satellite data and the Regional Ocean Modelling Systems (ROMS). The model was run for 2 year period to investigate the seasonal and shorter term variability. The model result shows that the transport of eastward South East Monsoon Current (SMC)

during the Southwest (SW) Monsoon is 11.5 Sv while the transport of the westward Northeast Monsoon Current (NMC) during the Northeast (NE) Monsoon is 9.5 Sv. Based on a series of model experiments, they concluded that Sri Lanka Dome is primarily the result of the interaction between SMC and the Island. Also, they found that the major upwelling region is located along the south coast during both monsoon periods. This explains the blue whale aggregations in this region in both monsoon periods. This is the first detailed analysis which focuses on the circulation and upwelling around Sri Lanka using a high resolution (2 km) model in relation to the blue whale aggregations. Thus the results are worth publishing. However, I have several major concerns described below.

No comment required

This is probably one of the worst periods to discuss the seasonal variation. This is the period of very strong 2010-2011 La Nina. Pacific SST anomalies associated with ENSO influence surface winds (and thus ocean currents) over the Indian Ocean through atmospheric bridge. Therefore we expect that the circulation in the tropical Indian Ocean is far from the normal at least during 2010-early 2011, which includes the analysis period. The model should be run for a longer period to discuss the seasonal variation. If it is not possible, it should be run during the period of normal year. If the new experiments are not possible, the authors should justify that the model experiment period is appropriate for studying the seasonal cycle. For example, surface wind variability during 2011 should be compared with other years, and describe how the wind fields during 2011 around Sri Lanka are different from those in other years.

We agree with reviewer comments that the 2011 was a strong La Nina year. As suggested by reviewer, we have compared wind fields from different years (as shown in Figure REF2.1) to examine the inter-annual variability of wind (speed and direction) around Sri Lanka. Although there are some changes in the wind fields, they are not significant to result in major changes to the circulation patterns. We have included additional text to describe the inter-annual variability of transport south of Sri Lanka.

Analysis of wind fields from different years suggested that winds south of Sri Lanka during the south-west monsoon was slightly higher during 2011 compared to 2007, 2008 and 2009. However, winds for 2010 were in closer agreement to a 'normal' year (2007, 2008 and 2009) winds and also we believe that 2010 was not a very strong La Nina year.

The authors argue that "the predicted transport for the SMC and NMC of 11.5 and 9.5 Sv respectively are more realistic than previous estimates" (page 14975). But this discrepancy could be due to the inter-annual variation.

We wanted to highlight the results from Schott et al. (1994) estimates of 8 and 12 Sv for the SMC and NMC indicated that the transport during the south-west monsoon was weaker than those during the north-east monsoon. Our results indicate higher values during the south-west monsoon. It could be due to the inter-annual variability – however – the comparison of the wind field indicates that there were no major changes in the wind fields

Upwelling is inferred from the satellite-derived and model SSTs. The upwelling should be explicitly described from the divergence field of surface currents derived from the model output. Maps of the divergence field on different time scales should be created to confirm the region of upwelling inferred from SST fields.

We tried to do this. The problem is that which layers to include the calculation of the divergence field. After several attaempts we came to the conclusion that the SST distribution provided the best example. We also examined several published papers dealing with upwelling using ROMS (off California, South Africa and Iberia) and none had used the divergence field to define upwelling regions.

Page 14970, "a primary formation mechanism of the SD is the interaction between the SMC and the land mass of Sri Lanka. This does not rule out the possibility that Ekman pumping may play a role in strengthening the dome" The relative importance of Ekman pumping and the interaction between SMC and Island is not known from a series of

model experiments. If the authors want to argue that the interaction between Island and SMC is "primary" mechanism, at least the Ekman pumping should be calculated, and discuss the magnitude of SD possibly formed by Ekman pumping only.

We agree that Ekman pumping may be a source would be operating independently. However, additional simulations undertaken with the Island of Sri Lanka removed do not indicate the presence of the dome Figure REF2.2). Thus the main forcing for the formation of the Sri Lanka appears to be

4. Page 14969 "..resulting in a convergence region" along the southern half of the island" It is not clear what "a convergence region" means in this case. Is it a convergence of the velocity component along the coast? The contours in Fig. 14 should be clearly explained. What are the values of these contours? The explanation of the relation between converging currents and upwelling is found near the end of the discussion (page 14974). This explanation should be provided earlier when the discussion of the convergence of the current and upwelling begins. This discussion is quite confusing in the current form.

This is the region where the southward flows along the east and west coast converge. The flow then moves offshore creating an upwelling region at the coast which may be identified through the presence of colder water in the shape of a tongue. The SST patterns observed through satellite were also predicted in the ROMS output. In the figure, the contours are SST. This is now highlighted in the figure caption. We have also changed the order in the text as requested by the reviewer.

5. Arrows (velocity vector) in most of the figures are very difficult to see. They should be improved. For example, the resolution could be lower and the size of the arrow could be bigger in some of the figures.

We have updated the figures.

Minor points:

1. Page: 14956 "The Bay of Bengal receives _1500 km3/yr of freshwater through freshwater run-off whilst the total total freshwater input into the Arabian Sea is _190 km3/yr" (Ref). A reference of these values would be useful.

Reference: Vinayachandran et al. 2013 is now included

2. Page 14957 last paragraph "This circulation pattern is confirmed by Shankar et al. (2002). However, Varkey et al. (1996) and Shankar and Shetye (1997) both provide a different interpretation and suggest that currents along the east coast of Sri Lanka flow south to north irrespective of season." It should be explained how these contradictory results are reconciled based on this study?

This is now included in the discussion.

3. Page 14960 "This model was driven with 3 hourly atmospheric forcing and daily surface heat and freshwater fluxes using ECMWF ERA interim data". This is not clear. Surface fluxes are also atmospheric forcing. 3 hourly surface wind stress from ERA Interim are used? Is the solar radiation daily (not include the diurnal cycle)? In general, the model SST, air temperature and humidity from the reanalysis are used to calculate latent and sensible heat fluxes in order to avoid the SST trend. In this study, is the surface heat flux directly derived from ERA Interim? If so, are there large SST trends in the model output?

We directly specified heat and fresh water fluxes using ECMWF ERA data, for heat fluxes, i.e. sum of short and long wave radiation. For net freshwater supply, we used the precipitation and evaporation data from ECMWF ERA and neglected the river inputs. In response to the comment by Reviewer#1, we have made this clearer in the text.

4. Page 14966, 2nd paragraph "During the NE monsoon, currents along the east coast of Sri Lanka flow southwards closer to the coast and northwards further offshore, separated by a shear zone (Figs 10a, 4a and 4b)" It is not clear in Fig. 10a.

We have removed the remove reference to Fig 10a

5. Page 14975, conclusion 1 "The predicted transport for the SMC and NMC of 11.5 and 9.5 Sv respectively are more realistic than previous estimates." The difference could be due to the inter-annual variation as mentioned in the major point (1).

We have examined the wind fields over several years and have shown that they did not vary significantly during this period (see Fig. REF2.1).

6. Fig. 5 Could the size of two panels be the same for the comparison?

Yes, We have modified the figure âĂČ

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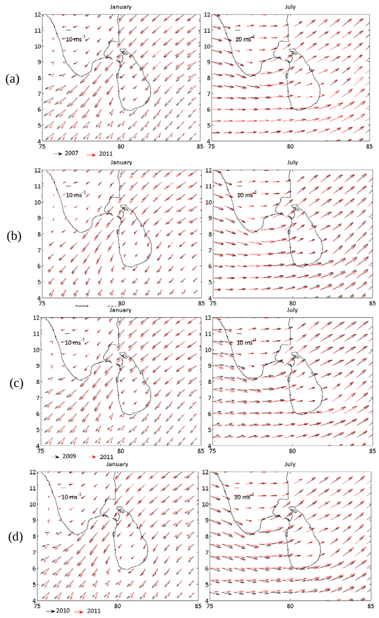

Fig. REF2.1 – Comparison of the wind fields from ECMWF ERA data during January (NE monsoon) and July (SW monsoon) to detect any significant changes in the wind during the La Nina year 2011. (a) comparison between 2007 and 2011; (b) comparison between 2008 and 2011; (c) comparison between 2009 and 2011; (d) comparison between 2010 and 2011.

Fig. 1.