

Interactive comment on “Variability in the air–sea interaction patterns and time-scales within the Southeastern Bay of Biscay, as observed by HF radar data” by A. Fontán et al.

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The authors would like thank the referee for his/her valuable comments yielding a significant improvement of the article. We have performed all the recommendations and suggestions given by the referee. The point-by-point reply to the referee’s comments is presented below.

General Comments:

This manuscript describes a 2-year study of wind-driven currents in the southeastern part of the Bay of Biscay based on NCEP (National Centres for Environmental Prediction) reanalysis data of wind patterns and directly-measured surface currents (upper

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2–3 m) from two land-based high frequency (HF) radars. The radars were deployed along the southern coastal boundary of the Bay of Biscay near where the coastline exhibits a 90 degree change of direction. The main result of the paper is that two current patterns prevail: (1) Ekman transport to the right of the wind at this northern hemisphere site; (2) a rotary flow pattern. A diurnal wind pattern commonly occurs in the study region and the authors speculate that it extends beyond the area covered by the HF radars. Figure 3 nicely summarizes the spatial patterns of the diurnal wind component. The analysis procedures are well described and thorough.

The paper could be improved with a more extensive analysis of the results. For example the relationship between wind and current directions is only qualitatively described. The magnitude and variability of the interesting rotary current pattern of CCA mode 2 was not explained in any detail.

Reply: With regard to the relationship between wind and current directions, we have quantified the veering angle and we have discussed this topic in detail (see the reply to the last comment of the referee). Regarding the magnitude and variability of the rotary current pattern of the CCA mode 2, the variability of both patterns was presented in Figure 6 (now Figure 7) by means of spectral analysis. The magnitude of the patterns can be expressed by plotting the time series of the temporal expansion coefficients. However, these time series contain many data gaps and we have rejected the idea of plotting them. We would like to mention that we have performed other analysis in order to investigate the second pattern, even though we have not included it within the manuscript. We calculated the composites of the average sea level anomalies (SLA) and currents for the cases where the second CCA temporal expansion coefficient corresponding to the wind is below the 20th percentile and above the 80th percentile. We applied a t-test to determine the difference of means in two SLA composites. It was concluded that the differences between the two composites are not significant at the 95% confidence level. This suggests that the anticyclonic circulation is not related to significant differences in sea level. In our opinion, the understanding of this rotary

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pattern needs an exhaustive analysis, based on thermal satellite imagery and altimetry and numerical models and consequently, it requires further investigation which is out of the scope of the present study (see page 2803, lines 10-27 and in page 2804, lines 18-22). We will certainly consider the investigation of this pattern for future work.

Overall, I think this is a solid contribution in its description of winds and ocean circulation in the interesting “corner” region of the Bay of Biscay with its changing coastline direction, offshore canyons, and variable shelf widths.

Reply: we appreciate this comment, thank you very much.

Specific Comments:

I have a couple of structural issues with the paper.

First, the paper devotes much of its text to the methods used such as canonical correlation analysis (CCA) and empirical orthogonal function analysis (EOF), both of which are appropriate for this analysis. There was considerable mixing of methods with results that I found distracting. For example, practically all the text on page 2801 could have been moved to Section 2 Data and Methods.

Reply: we agree with the referee’s comment. We have moved most of the text related to the methodology to Section 2.

Second, I would have liked a clearer separation between what is new here and previous results. Perhaps a discussion section could be added where new results from this study are considered in light of previous results.

Reply: all the results obtained are new since they are based on relatively new HF radar measurements. The first paragraph in the Conclusion section summarises now the new results and conclusions. To this end, we have rewritten the conclusions accordingly. Now, Section 5 is divided in: new results and conclusions (paragraph 1) and future perspectives (paragraph 2). The first paragraph has been rewritten as follows: “The new results and the main conclusions obtained from the diagnostic of wind-induced currents

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can be summarised as follows. In 2009, a HF radar monitoring system was installed on the Southeastern Bay of Biscay. It measures large coverage surface currents with high spatial and temporal resolutions, providing an unprecedented picture of the upper circulation in the Southeastern corner of the Bay. The wind–current interaction spatial patterns and time–scales have been determined quantitatively based on those measurements and reanalysis winds for the first time in the area. The Barnett-Preisendorfer approach to CCA adequately addresses the purpose of this study. As such, the air–sea interaction patterns obtained reveal that the currents respond almost instantaneously to wind forcing at hourly resolution. The local winds are the main driving force of the upper currents at the Southeastern Bay of Biscay. The Barnett-Preisendorfer approach to CCA yields two canonical patterns, which explain each of about 43% and 26% of the wind and current variance, respectively. The first wind-current interaction pattern corresponds to the classical Ekman drift at sea surface, with current deflected a clockwise angle with respect to the wind forcing. This deflection angle exhibits significant spatial and seasonal variability, being larger in summer and offshore. Conversely, the second canonical pattern reveals an anticyclonic water movement. Although this appears to be partially wind-driven, other driving mechanisms may contribute to it. Further research is required to identify other possible driving mechanisms of the upper water circulation in the Bay, in order to fully substantiate this mode from statistical and physical points of view. With regard to the air–sea interaction time-scales, these are related to diurnal periods, revealing that the breezes force diurnal currents at the continental shelf and slope. Synoptic wind circulation also affects surface water circulation over the area. The extension of the area, where the amplitude of diurnal cycle is larger than that of the seasonal cycle (Fig. 3), indicates that this process is probably affecting surface water circulation over considerably wider areas than that covered by the HF radar system”. We have also emphasised within the Introduction (in page 2796 and line 8) that before the installation of the HF radar system: “The surface current measurements were scattered in temporal and spatial distribution at the Southeastern Bay of Biscay. The lack of long-term and large spatial coverage measurements impeded the understanding of

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the time-scales and spatial patterns associated with the wind-induced currents in the area”.

Page 2801, lines 15-16: It was not explained why currents were filtered with a 3-hr moving average; this could have been done in Section 2.

Reply: done in Section 2 by adding the following text: “The data were pre-processed by applying standard procedures according to manufacturer’s recommendations. Thus, radial velocities were obtained with the Multiple Signal Classification (MUSIC) algorithm (Schmidt, 1986). These velocities were then 3-h moving averaged, to increase the statistical robustness of the estimates”.

Page 2801, lines 17-18: It would have been helpful to explain exactly how the CCA modes were scaled in units of the original fields.

Reply: we think that the above matter refers to page 2802 instead of page 2801. We have now explained exactly how the CCA modes are scaled in units of the original fields as follows: “The spatial patterns corresponding to each CCA mode have been scaled in the units of the original fields. To this end, maps of homogeneous regression coefficients have been constructed, i.e. the temporal expansion coefficients of canonical modes have been regressed onto the time series of both current and wind fields. Thus, the regression coefficients represent the change (in m/s) of the original fields associated with one unit change in the temporal expansion coefficients”. We have changed slightly Figure 5 and Figure 5 caption to include that the regression coefficients are in m/s, statistically significant at the 95% confidence level, as follows: “Fig. 5. Maps of homogeneous regression coefficients (m/s) (statistically significant at the 95% confidence level) of the: (a) first and (b) second CCA modes for the currents (blue) and winds (black) at the D1 domain. Bathymetric contours show the 200, 1000 and 2000 m isobaths”.

Page 2802, line 25: As mentioned by the authors and shown in Figure 5, current vectors lie typically to the right of the wind for mode 1, but the angle varies considerably.

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I was surprised the authors did not explore this more thoroughly. For example, the angle appears to be greater for locations offshore of the 200 m isobath and decrease at shallower depths. However, this is only an impression based on the figure. Quantifying variation of the angle would require more analysis and might provide new insights.

Reply: the referee is right. We have quantified the angle as a function of the depth and the season of the year. We have included a new Figure (now Figure 6) to provide spatial and seasonal variability of the deflection angles. We found that the angle increases offshore and in summer. We have included the following paragraph supported by new references: “The deflection angle increases from onshore (depth < 200 m) to offshore (depth > 200 m). It varies from 20-35° at the continental shelf to 60° (at a maximum) offshore (Fig. 6a). In shallow water depths, the Ekman spiral motion is not fully developed and this leads to deflection angles which are less than the theoretical value of 45°. This is in agreement with the results of Kim et al. (2009) in waters of San Diego and Arduin et al. (2009) in the western coast of France. The deflection angle also varies seasonally, being larger in summer than in winter. As such, the deflection angles onshore change from 5-20° in winter to 25-40° in summer (Fig. 6b and 6c). Offshore, the angles are of about 55° in winter and 70° in summer, at a maximum. Río and Hernández (2003) and Yoshikawa and Masuda (2009) also reported a larger deflection angle of the wind-induced flow in summer than in winter due to changes in the momentum penetration by seasonal stratification change”.

Note that we have only included the Figures that have changed in relation to the previous version of the manuscript.

Interactive comment on Ocean Sci. Discuss., 9, 2793, 2012.

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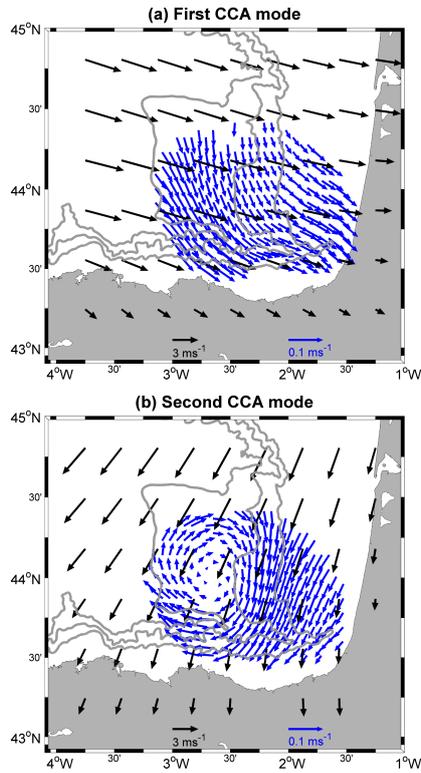


Fig. 1. Fig. 5. Maps of homogeneous regression coefficients (m/s) (significant at the 95% confidence level) of the: (a) first and (b) second CCA modes for the currents (blue) and winds (black) at D1 domain.

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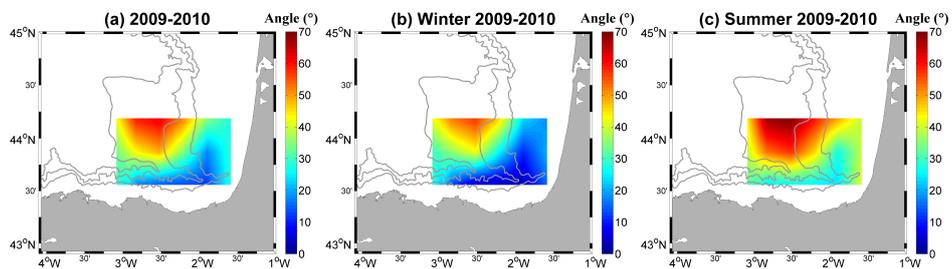


Fig. 2. Fig. 6. Deflection angles of the wind-induced surface flows for the first CCA mode in: (a) 2009-2010, (b) wintertime (October-March) 2009-2010 and (c) summertime (April to September) 2009-2010 periods

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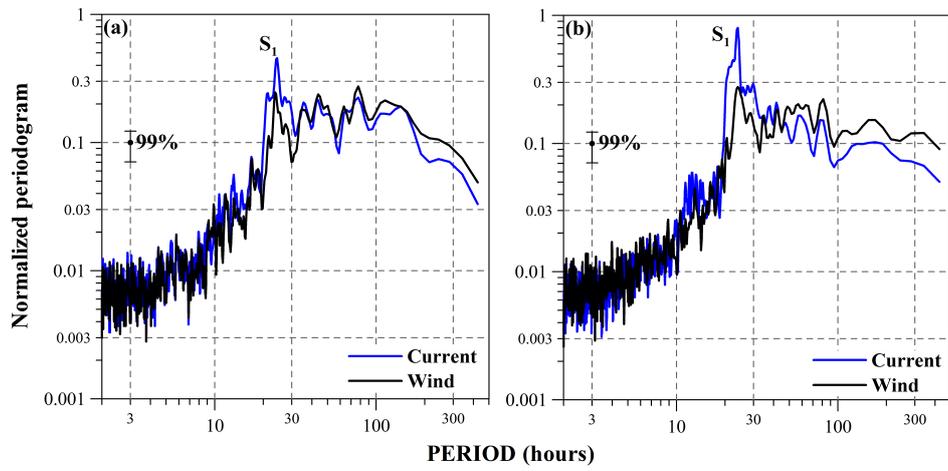


Fig. 3. Fig. 7. Normalised Lomb-Scargle periodograms (99% confidence level) for: (a) the first and (b) the second canonical variables of the currents (blue) and winds (black).