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Dr J. Soares

Dear J. Soares,

you will find here our answer to the comments you made on our article "Generation of Rossby waves off the Cape Verde Peninsula; role of the coastline" which has been submitted to "Ocean science".

We first want to thank you. We appreciated your careful reading of the article and your numerous and interesting suggestions. We explain below how we took them into account. The corresponding modifications on the manuscript are also explicited.

You first suggest us to indicate more precisely which is new in the paper. We modified the conclusion to emphasize the novelties. Three points seemed important to us :

1. The existence of a Chlorophyll signal far from the coast – here extending up to 750 km west to the Cape Verde has to our knowledge never been described. This strongly differs from the most common signals which ar found along the coast and which can be easily associated with coastal Kelvin waves.

2. The method we developped to decipher the mechanisms at play in this region is new. It allows us to study up to 1000 km from the coast the wave dynamics. This method generalizes the method previously used by Clarke (1980).

3. Combining this analytical work, observations of SSH and numerical experiments we have been able to associate the existence of this signal to the propagation of a Rossby wave generated by a wind burst. We showed that the duration of the wind burst has not a direct relation with the period of the waves and that the size of the wind burst was more relevant. Lastly, we proved that the pattern of the coast does not not have in this case a prominent role because the wave has a long period (longer than two months). We showed that a strong impact could be only expected if the wave period was shorter than about 15 days.

In italic are the main changes we have done in the conclusion:

This pattern suggested the existence of locally generated Rossby waves, which slowly propagated westward. Indeed such a wave can generate an elevation of the lower layers of the ocean corresponding to an upwelling of nutrient-rich water. The *existence of this wave was confirmed by the study of the SSH signal coming from AVISO satellite data. It evidenced a wave propagating westward with a velocity of about 4.5 cm s^{-1}. The existence of a Chlorophyll signal far from the coast – here extending up to 750 km west to the Cape Verde – has to our knowledge never been described. This strongly differs from the coastal signals associated with Kelvin waves which have been previously carefully analyzed (see Ndoye et al. 2016 and the references herein).*

In this study we thus investigated the mechanisms which could lead to the existence of such a wave and analyzed the potential role of the cape, by first doing numerical experiments with a forced nonlinear model, then by analytically studying a linear reduced gravity model.

The analytical study is new and extends the method suggested by Clarke and Shi (1991) to the open sea up to a distance of about 1000 km away from the coast. It helps us interpret the numerical results and gives futher results.

An important problem is the detectability of these waves. Dealing with a reduced gravity model whose characteristics are fitting the observations, we found that the elevation of the interface probably does not exceed a few meters. The interface elevation facilitates the nutrient enrichment of the surface layers and consequently favours phytoplankton blooms. As the elevation of the interface is relatively small, the phytoplankton bloom is likely to occur only under very specific conditions such as a relatively small average thermocline depth or the presence of phytoplankton species capable of rapid growth, with a strong chlorophyll signature like diatoms. In fact, phytoplankton pigment retrieval from ocean color satellite observation shows that the chlorophyll signal we observed is dominated by fucoxanthin, which is a signature of diatoms (Khalil et al, 2019, submitted)

We are concious that this study is preliminary. In particular we think that it would be of interest to look for Chlorophyll signals up to 1000 km off the coast since satellite data have been available for twenty years. The existence of such blooms far from the coast could be of interest for the economy of fishery in Senegal and Gambie.

Then you make more specifc suggestions, which are generally very close to those made by the first reviewer. You suggest us to document more precisely from other observations than Chlorophyll the signal we observed, to give more details about the numerical model, to improve the presentation of the analytical study, and to modify the conclusion to put in light more clearly the novelty of the results (this corresponds to the general comment about the paper and we have just given our response above). Six other comments were made to improve the lisibility of the figure and text. I detail below how these comments have been addressed.

1. **Wave observations** To make more visible the Chlorophyll pattern we consider, we have cercled it. As you suggest, we have completed this observation by Sea Surface Height observations coming from AVISO altimeter data. Consequently we have added a supplementary figure (new figure 2) which is a Hoevmuller diagram of the SSH at different latitudes off the Cape Verde

(11°N, 13.5°N, 15°N, and 16.5°N). This figure clearly shows the existence of a wave whose zonal velocity is about 4.5 cm/s, a value which corresponds to the estimation we have previously obtained from the observations and the theoretical study.

Here is the text we have added:

... To corroborate this hypothesis, we analyzed the Sea Surface Height (hereafter SSH) obtained from AVISO satellite altimeter data for the corresponding period (December 2002 - January 2003). Hoevmuller diagrams are shown at $12°$*,* $13.5°$*,* $15°$*, and* $16.5°$ *in figure 1; they clearly confirms the existence of a Rossby wave propagating westwards with a velocity of about* 4.5 *cm* s^{-1}*. The amplitude of this wave becomes smaller northwards: it peaked at 13 cm between* $12°$ *and* $13.5°$ *degrees but did not exceed 7 cm at* $16.5°$*. The wavelength is around 700 km, comparable with the extent of the Chlorophyll signal.*

A figure of the wind stress has also been added (new Figure 3). This figure has been drawn from the ERAInterim reanalysis corresponding to the period December 2002-January 2003. The mean wind stress and the wind burst occuring around December 8 are both shown. This figure has been introduced in the section about the numerical model (see just below) to justify how we calibrate it.

Note that we decided not to add figures to document the existence of Kelvin waves propagating along the coast but only to add new references. Indeed we think that an originality of this paper is to consider signals – and specifically biological signals – far away from the coast. The dynamics of the Kelvin waves in this area have received much more attention (the work of A. Lazar exemplifies this fact) and consequently we prefered to emphasize the existence of the Rossby wave and its biological signature.

2. **The model**

   First of all this model has been used in different configurations (with one or two active layers). References can be found for example in the following publication: Février, S., J. Sirven, C. Herbaut, 2007: Interaction of a coastal Kelvin wave with the mean state in the gulf Stream separation area, *J. Phys. Oceanography*, which has been added. Note that the numerical technique that is used (enstrophy conserving) is the same as the one used in the OGCM NEMO (which is quoted in much more than one hundred articles; see for example the publications with G. Madec as coauthor).

   We made several test on the dissipation coefficient. It damps the response of the model as expected from theory. In the retained configuration, the amplitude of the anomaly is divided by 2 after 45 days, which corresponds to the damping coefficient we used. We chose to use a resolution of 1/12° (much smaller than the Rossby radius of deformation $\simeq$ 55 km: eddy permitting model) and a small viscosity coefficient. Surprisingly, when we made experiments at a coarser resolution, the results were not dramatically modified.

As indicated in the text, no slip boundary conditions are used everywhere. We are concerned here by the offshore velocity of the Rossby waves which weakly depends on the dissipation coefficient and the boundary conditions. A discussion of Kelvin waves velocity in simple models can be found in Février et al. 2007.

We have chosen a mean state which more or less corresponds to the mean state observed in this region (a dominant wind stress blowing from the north-north-east (see the new figure 3) but which remains simple enough to permit ulterior analytical work. The reference state has a negligible impact on the solution – only some details are modified and we decided not to develop this point. However, we had to verify this to be sure that our results were not dependent of a simpler choice – for example a resting state with a uniform layer which does not take into account the poleward variation of the topography. The model has been calibrated so that the Rossby radius has a reasonable value in this area and consequently that the propagation velocity of the waves is realistic. Actually, the phase velocity of the waves is about 4. cm s^{-1}, which corresponds to the phase velocity of the waves shown by AVISO data.

Note that the paper is devoted to the study of Rossby waves which mainly propagate westwards. The model we use – which would be perhaps too simple to study the poleward propagation of coastal Kelvin waves – seems ro reproduce, albeit its simplicity, the westward propagation of Rossby waves that have left the continental shelf.

Just below is given in italic the text of the subsection which has been added in section 2 and the corresponding figure showing the observed mean wind stress and the wind anomaly.

. . . **3.3 Numerical set-up of the model**

In Figure 2 the mean wind for the considered period (December 2002-January 2003) is shown. It exemplifies the situation which is normally found in this region. The wind regularly blows from the north-north-east with a velocity ranging from 4 to 8 m s^{-1}. To take this into account, a constant mean wind stress of amplitude equal to 0.06 N m^{-2} (corresponding to a mean wind velocity of about 5 m s^{-1} and a value of $\boldsymbol{\tau}_0$ equal to 6×10^{-5} m^2 s^{-2}) and oriented along a south-south-west direction is applied from rest during four years, until a stationary mean state, which verifies the theoretical relation given in section 3.1, is reached.

As shown by Figure 2, a wind anomaly was active when the wave of Figure 1 begins to be observed. This anomaly obviously is transient, but to the south of the Cape Verde, it mainly points southwards. To represent this situation in a simplified way, we defined in a first experiment a north-south wind stress *anomaly which extends over approximately 500 km and whose maximum is still equal to 0.06 N m^{-2}. This anomaly is applied during five days (see Fig. 4 first panel). The integration is continued during 45 days, after the anomaly has disappeared.*

To explore the sensibility of the model response to the wind anomaly, others wind anomalies were applied (see below, in particular Figures 6 to 8). The results obtained for these anomalies are discussed in the next section.

3. **Analytical study**

Clearly this section needed to be improved. We have put a maximum of expressions in Appendix A to alleviate the sufferings of the reader but found difficult to shift section 4.2 from the main text to a new Appendix. Consequently, we decided to follow the suggestion of Rémi Tailleux (first reviewer) and summarized at the beginning of the analytical study the main steps of the study.

Here is the text which has been introduced in section 4.

In this section, we aim at understanding if the coastline may influence the propagation of the Rossby waves which are created close to the coast and propagate towards the open sea. The impact of the coastline has been investigated by Crépon and Richez (1984), Clarke (1977), and Clarke and Shi (1991) for the Kelvin waves using an analytical approach. Here we focus on the Rossby waves; as we consider an area which extends up to about 1000 km from the coast, we have to generalize the approach followed by Clarke and Shi, which introduced a local system of coordinates dependent of the coastline to study Kelvin waves along an irregular coastline. We try to answer the following questions:

a) Are there time scales for which the impact of the coastline (small in the numerical experiments) becomes more important ?

b) A dissymetry between the response north and south of the Cape was visible in the numerical experiments; can this dissymmetry be dependent on the existence of the Cape ?

The analysis begins by defining and building a system of coordinates that permits to follow the coastline geometry. This procedure is a standard one in mathematics when boundaries are complex; indeed the the boundary conditions can be simply written, which constitutes a substantial advantage. however, it has a drawback: the differential equations which characerize the problem become slightly more complex because they must include geometrical factors that take into account the deformations associated with the new system of coordinates. This drawback is small in comparison with the advantage.

When these new equations are established, staightforward calculations are made to obtain a unique partial differential equation (equation (7)), which characterizes the evolution of η (the thickness of the active layer). This equation is a *wave equation. Consequently the ray theory (or equivalently the WKB method) can be applied. When the forcing terms are neglected, this yields a first order nonlinear differential equation (equation (11). No new ideas are introduced after this. We just rewrite equation (11) by introducing new notations, in order to facilitate its study and the presentation of the results (end of paragraph 4.2). We then describe the results when the tranport along the coast is much larger than the transverse transport (section 4.3).*

Yes, the analytical study is new (as well as the numerical experiment, even though the model has been already uesd).

4. **Conclusion** We have already considered this point at the beginning of our answer.

5. **Other comments**

   Abstract line 2 we replaced “kms” with “km”.

   Page 5, line 20-25 of the previous manuscript. The wave we are refering to have been named.

   Figures The presentation of the Figures have been modified. We have put an identification in the figure panels and described the panel in the figure caption as you suggested. No results are discussed in the caption of the Figures.

   The coordinate system referenced in Figure 8 is now explicitely named to avoid any confusion.

   Figure 10 has been redrawn (in color) to increase its lisibility.

   Figures 11 to 14 have been redrawn (in color) to increase their lisibility.

Sincerely yours, Jérôme Sirven

The new figures are just below.

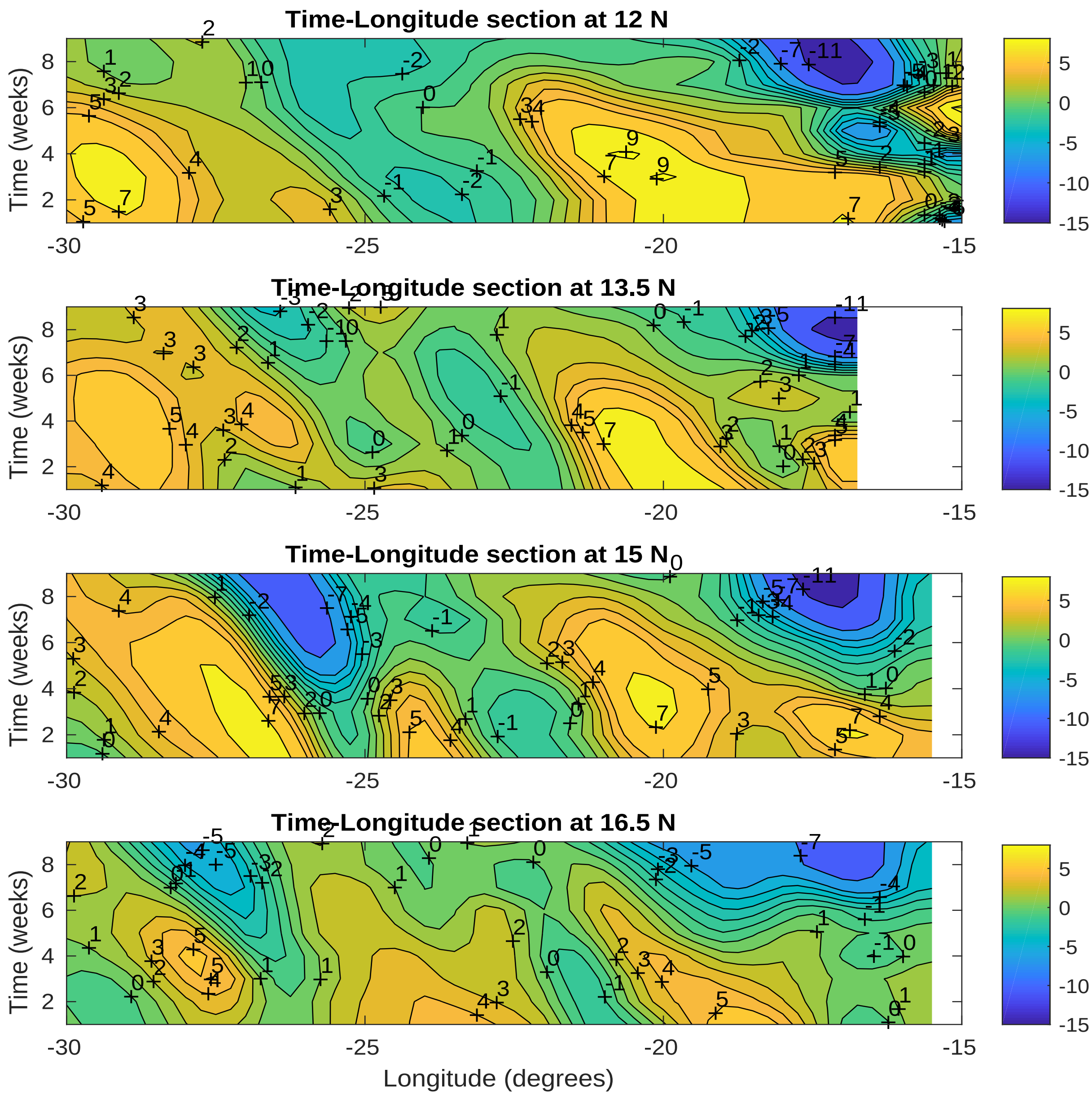

Figure 1: Hoevmuller diagrams of the SSH at latitudes 12°N, 13.5°N, 15°N, and 16.5°N (units: cm). Note the decrease of the amplitude at 16.5°N. The phase velocity of the wave is about 4.5 cm/s.

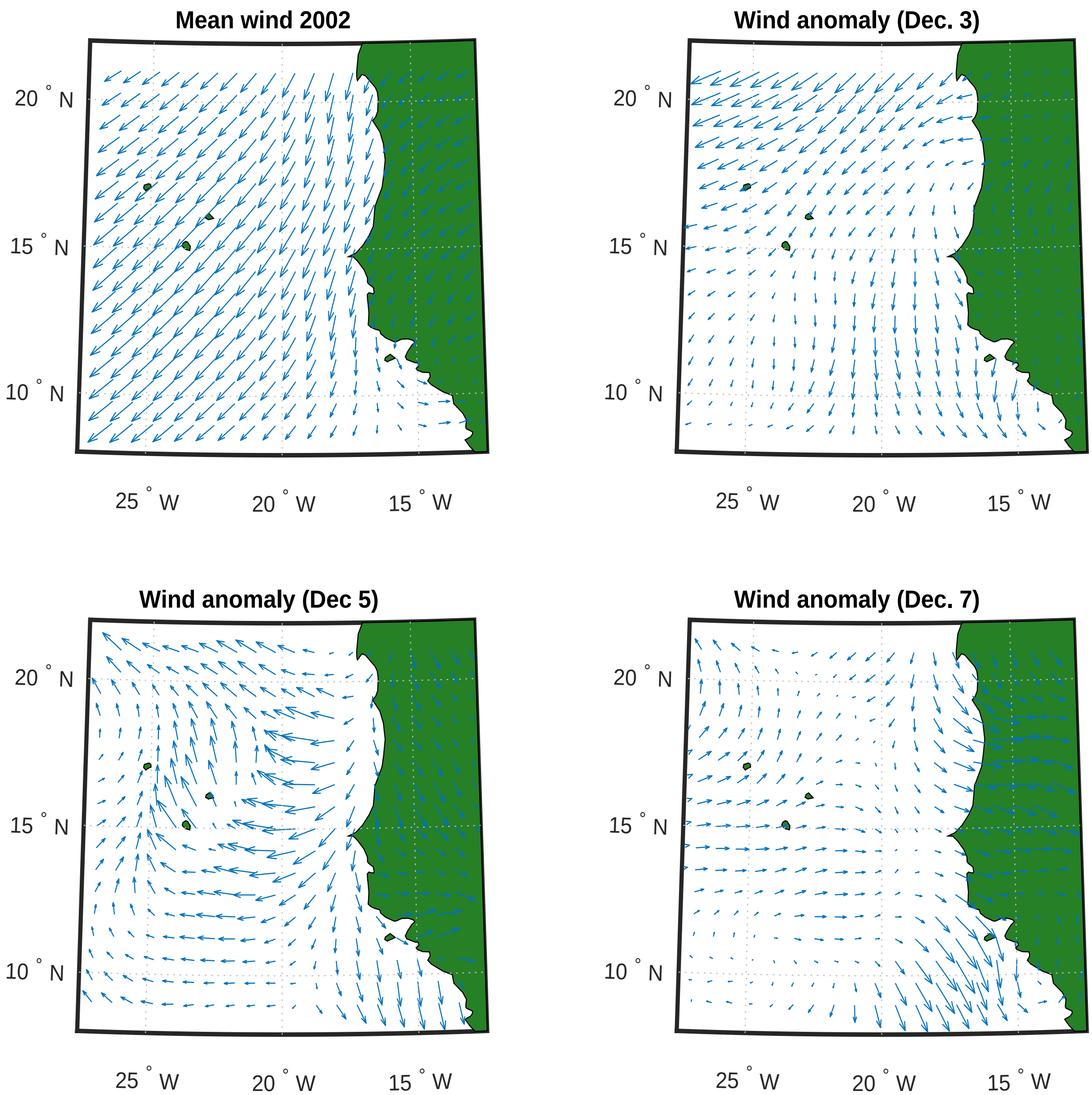

Figure 2: Mean wind velocity in December 2002 (maximum of about $\simeq 8$ m s^{-1}) and wind velocity anomaly in December 3, 5, and 7 (maximum of about $\simeq 4$ m s^{-1}).