Authors' response to Referee 1

Journal: Ocean Sciences

Title of paper: Impact of intraseasonal wind bursts on SST variability in the far eastern Tropical Atlantic Ocean during boreal spring 2005 and 2006. Focus on the mid-may 2005 event.

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We thank Reviewer 1 for his comments and suggestions that allowed improvements of our paper. We have made all needed information to make the figures easily understandable and conforming with general publications criteria (figures size, labels, etc). We also worked to make the manuscript easier to read and understand, by adding some information and removing others.

Response to major comments

1. RC: The study focusses on the years 2005 and 2006. Most of the features discussed in section 4.2, however, appear to occur in both of these year. Maybe it would be more instructive to contrast 2005 to an interannual warm event year?

AC: To contrast interannual events in 2005 and in a warm year (like 1998) would be indeed also interesting. However, the comparison with the year 2006, considered as a "normal year", shows that the interannual events are a common feature impacting the SST variability in the studied area and highlights what makes the year 2005 as a "cold" year. To illustrate, the figure X1 (not added in the revised manuscript) below shows the longitude-time diagram of the SST in CLR (Figure X1 a & f) as well as the intraseasonal variations of the wind stress speed (Figure X1 c & h), the 20°C-isotherm depth (Figure X1 d & i), and the sea surface heat flux (Figure X1 e & j) for 1998 (warm year) and 2005 (cold year). We see indeed that the SSTs in boreal spring are higher in spring 1998 than spring 2005. The wind bursts during spring 1998 are not as stronger than during spring 2005. Moreover, the 20°C-isotherm is deeper in spring 1998 than during 2005, making the SST less reactive to wind intensification. What makes the particularity of the year 2005 is not the occurrence of intraseasonal events but their time of occurrence, their strength, and the favorable combination of local and remote forcing with the arrival of Kelvin wave at the time of strong local winds which induces shallower thermocline.

Thus, we have not described the conditions for 1998 because we have preferred to focus on the year 2005 and understand what makes it an anomalous year compared to a “normal” year. However, it would be interesting to add in the Discussion section some lines about the conditions of a warm year such as 1998. These lines would be added :

“The occurrence of intraseasonal wind intensification in CLR is not specific to the spring/summer 2005 and 2006 and is observed every year over the 1998-2008 period of study (not shown). However, their impact on SST variability in the region is modulated depending on the strength of wind intensification and of the subsurface preconditioning. For example, the year 1998, known as a ”warm year”, is characterized by anomalous warm SST in boreal spring/summer in the CLR., associated with anomalous weak winds and anomalous deep thermocline. “

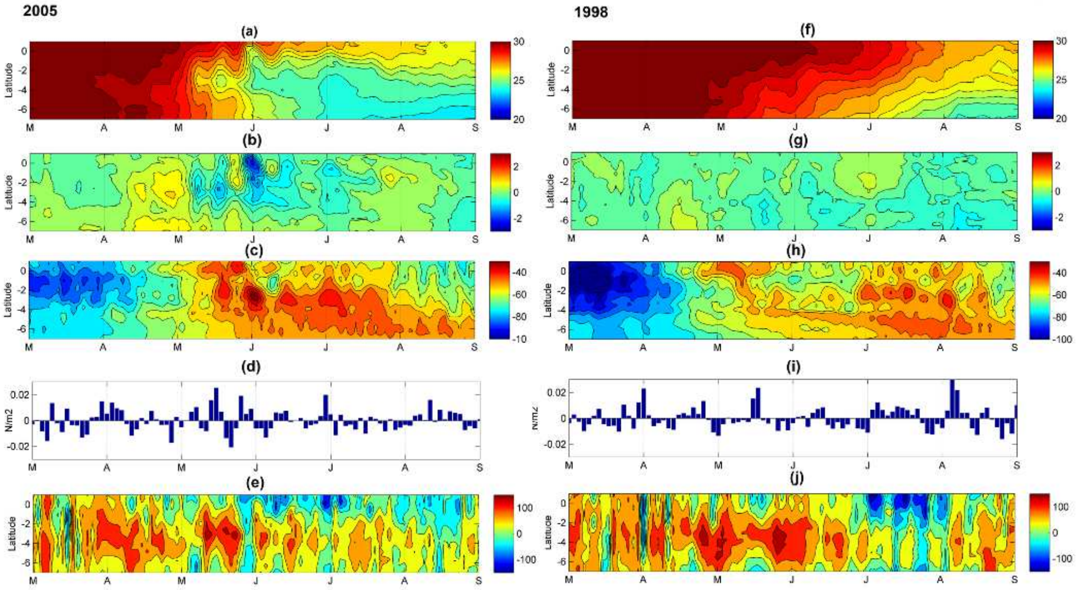


Figure X1: (a & f) Latitude-time diagram of 2-daily SST (°C) ; (b & g) intraseasonal variations of SST (°C); (c & h) intraseasonal variations of wind stress; (d & i) 20°C-isotherm depth ; (e & j) surface heat flux; from 1st March to 31 August 2005 (left panels) and 1998 (right panels) and averaged from 5°E to 12°E. The intraseasonal variations are computed by remove the 30 days low-pass filtered field to the total field.

2. RC: Also, it is not clear whether the processes discussed in section 4 and 5 are specific to 2005 or whether some of them play a role in every spring cooling and/or other interannual cold events as well. In other words: Do intraseasonal wind bursts impact

SST in the Cape Lopez region in every summer or during every interannual cold event or just in very specific years as 2005?

AC: The comparison with 2006, considered as a “normal” year, precisely shows that the intraseasonal wind bursts also occur in spring/summer during normal conditions and that is not a particularity of the year 2005. However, in 2005, there are successive strong wind bursts in April-May combined with favorable subsurface conditions (shallow thermocline) due to the arrival of Kelvin wave, that make the cooling more efficient than in 2006 and which occurs earlier than usual. In order to clarify this point in the text, this phrase has been added in the conclusion: “The occurrence of intraseasonal wind intensification in CLR is not specific to the spring/summer 2005 and 2006 and is observed every year over the 1998-2008 period of study (not shown). However, their impact on SST variability in the region is modulated depending on the strength of wind intensification and of the subsurface preconditioning.”

3. RC: Related to point 1 and 2, the time scales discussed tend to get mixed up a bit. The relationship between the intraseasonal wind bursts, the seasonal cycle of SST, and interannual variations should be sorted out more clearly.

AC: In order to sort out the different times scales more clearly, we decide to show the interannual component of SST/winds/vertical current shear/Ekman pumping variability on figure 3 and 4, by removing the 30-days low-pass filtering to the annual time series. An effort has been made in the text in order to describe more clearly the time scales studied. In addition, some lines have added in section 4.3 (“Westward extension of the CLR cooling”) about the climatological behavior of the connection between CLR and equatorial region and the particularity of the year 2005.

Response to Specific comments:

1. RC: I am missing a motivation on why the Cape Lopez region is of interest.

AC: The initial reason that motivates the study of the SST variability in the Cape-Lopez region is the observation in satellite SST data of cold coastal waters independent from those observed off shore in the cold tongue region around 10°W (see the map of satellite SST data for the 8 June 2005 shown on the Figure X2) which raises the question of the link of such cooling with the cold tongue development.

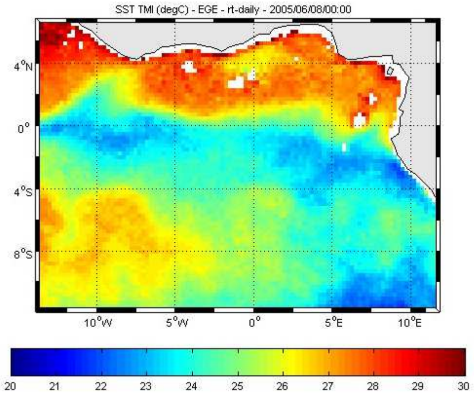


Figure X2: SST (°C) from TMI satellite data on 8 June 2005.

The equatorial region and the processes implied in the cold tongue development are largely studied contrary to the Cape-Lopez region. Other several studies focus on SST variability in more southern region such as Angola-Benguela front, but very few in the Cape-Lopez region. However, we thought that better describe the SST variability in the Cape-Lopez region is needed and interesting especially because of the numerous processes in play notably due to the presence of the coast and the proximity of the equator. In addition, some studies (such as DeCoëtlogon et al., 2010) suggest that at short time scale (a few days), more than half of the cold SST anomaly around the equatorial cooling could be explained by horizontal oceanic advection controlled by the winds. Therefore, a better understanding of the SST variability in the CLR may also help to better understand the SST variability in the equatorial region.

2. RC: Related to comment (3) above, the time scales of interest should be specified somewhere in the beginning, and it should be stated whether the data were filtered or averaged over time to focus on them individually.

AC: In order to isolate the interannual component, we removed the low-pass filtering (cutoff frequency of 30 days) of the annual time series to the total field. As suggested, we have added this information in the text.

3. RC: line 184/185: The highest temperatures occur more towards boreal spring than winter.

AC: Thank you for the remark. Indeed, the highest temperatures occur at the end of March, i.e. at the late of boreal winter and the beginning of boreal spring. The text has been modified accordingly.

4.RC: line 188/189: I think all of the references given here discuss biases in coupled climate models while in this study an ocean-only model is used.

AC: Thanks to point this. The phrase line 188/189 has been changed as following:

"Despite a warm bias (~1°C) compared to satellite observations, the model pretty well reproduces the satellite pattern. While this warm bias in the eastern tropical Atlantic is well known in coupled climate models (e.g. Zeng et al., 1996; Davey et al., 2002; Deser et al., 2006; Chang et al., 2007; Richter and Xie, 2008), results from Large and Danabasoglu (2006) show that a warm SST bias may also be present along the Atlantic coast of southern Africa in forced ocean-only simulation."

5. RC: lines 200-202: A number of previous studies have shown this and could be cited (e.g. Schouten et al., 2005).

AC: Thank you for point this. Reference has been added as following:

"The region is also characterized by a shallow thermocline which depicts a strong semi-annual cycle (Fig. 1d). The evolution of z20 reveals a thinning of the thermocline during May-July and a thickening up to October-November when it exhibits a minimum, in agreement with previous studies such as the one realized by Schouten et al. (2005) who find a similar seasonal cycle from SSH altimetric data."

6. RC: It is hard to directly compare the conditions in 2005 and 2006 as they are presented in different figures (Fig. 3 and 4) on different pages of the manuscript. I would suggest to combine those figures. Also, the individual dates given in the text (e.g. lines 231 to 233, lines 257 to 259) are impossible to identify in these figures and should be illustrated in a different way.

AC: The choice to separate 2005 and 2006 has been made to highlight the correlation between the different fields. In order to have better clarity, we decided to show the total field of SST and 20°C-isotherm depth for 2005 and 2006 on Figure 3 and the intraseasonal variations (by removing the 30-days low-pass filtered data from the total field) of SST/wind/vertical current shear/Ekman pumping for 2005 and 2006 on the same Figure 4, in order to better highlight the intreaseasonal events. In addition, we have made a zoom on March-August period for better visibility of the events.

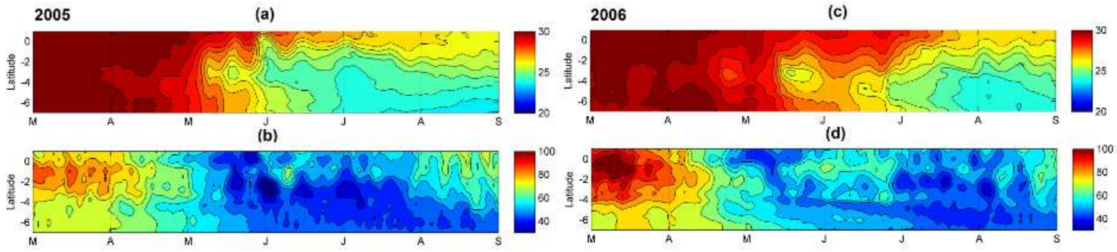


Figure 3: (a & c) Latitude-time diagram of the sea surface temperature (°C); (b & d) Latitude-time diagram of the 20° C-isotherm depth (m); from 1st March to 31 August 2005 (left panels) and 2006 (right panels) and averaged between 5°E and 12°E.

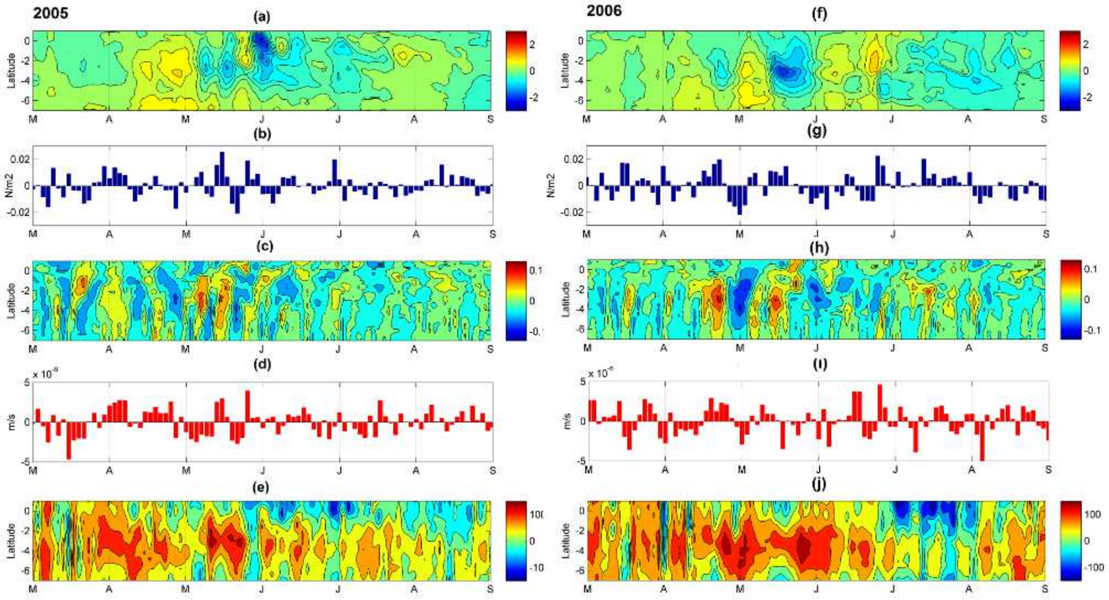


Figure 4: (a & f) Time-latitude diagram, from 7° S to 1° N, of the intraseasonal variations of sea surface temperature (in ° C) averaged between 5° E and 12° E; (b & g) Time evolution of the intraseasonal variations of wind stress amplitude (N.m^{-2}) averaged between 5° E and 12° E; (c & h) Latitude-time diagram of the intraseasonal variations of the maximum of the zonal current vertical shear magnitude (m.s^{-1}) averaged between 5° E and 12° E ; (d & i) Longitude-time diagram of the intraseasonal variations of Ekman Pumping (m.s^{-1}) averaged over the CLR. Ekman pumping values >0 indicate upwelling; (e & j) Latitude-time diagram of the net heat flux (W.m^{-2}) averaged between 5° E and 12° E; from 1st March to 31 August 2005 (left panels) and 2006 (right panels).

Modifications have also been made on the plot of 20°C-isotherm depths, Fig.3 : weaker values of 20°C-isotherm depths indicate shallower thermocline to be consistent with the modifications made on the Fig.1, Fig.5, Fig. 9, Fig. 7 and Fig. 13.

7.RC: lines 254/255: Are the data filtered to focus on the intraseasonal time scale? (see comment above)

AC: Yes, the wind stress magnitude field shown on Figure 4 has been obtained after remove the low-pass filtering (cutoff frequency of 30 days) to the total field (see the modified Figure 4 in the response of the previous question).

8. RC: line 336: How did the timing of the preconditioning impact the intensity of the cooling?

AC: In 2005, the arrival of the upwelling Kelvin wave in CLR brings the thermocline close to the surface that makes the wind burst, which occurs simultaneously, more efficient in cooling the SST. As explained in line 336, stronger wind intensification and simultaneously favorably preconditioned oceanic subsurface conditions, made the coupling between surface and subsurface ocean processes more efficient than in 2006, resulting in stronger cooling.

9. RC: Fig. 7 and Fig. 10 are very small and thus hard to read.

AC: The Figure 7 has been modified and zoomed over January-June. The Figure 10 has been also modified and the wind and precipitation pattern have been separated for more visibility.

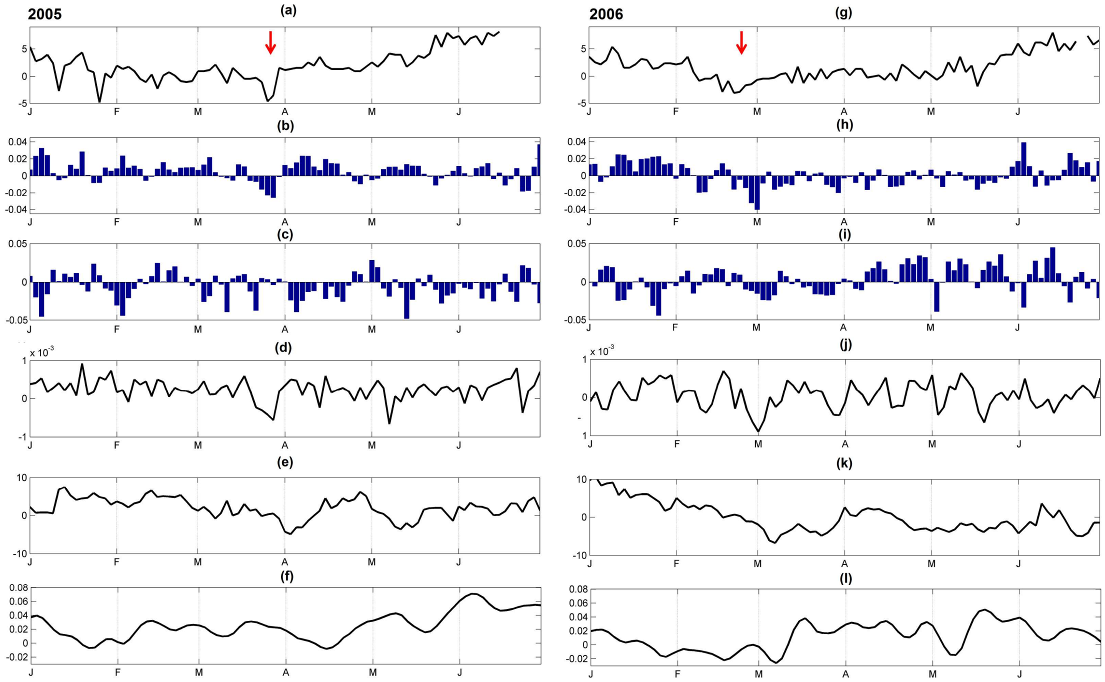
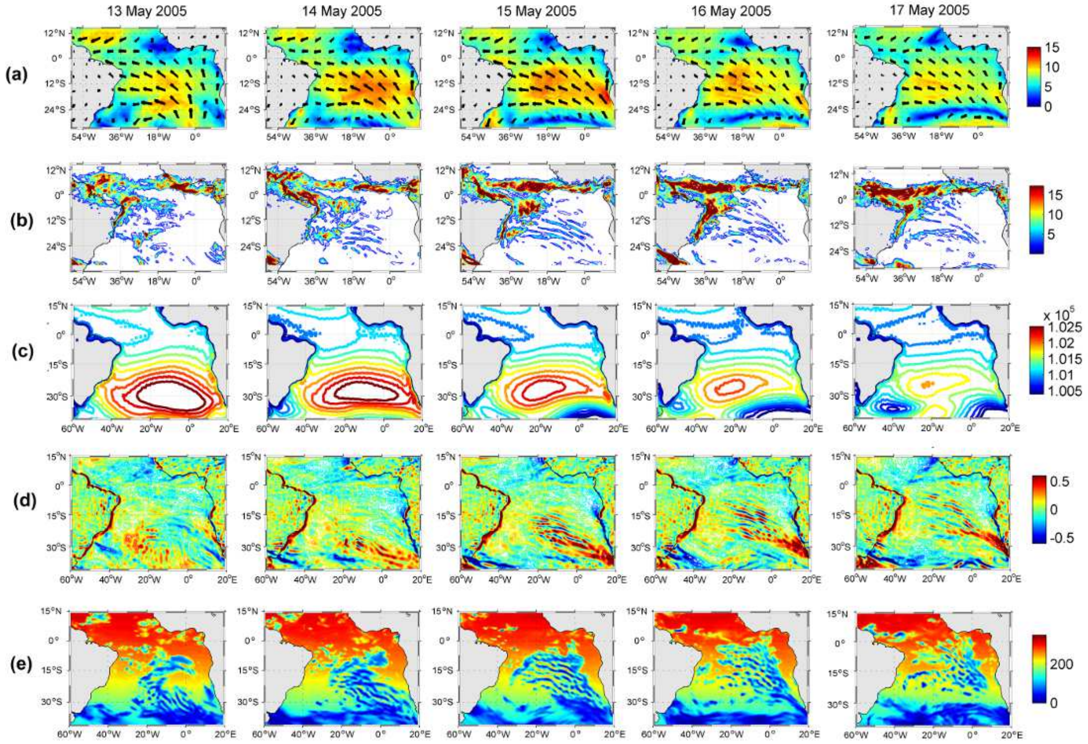


Figure 7: Time evolution, from 2-days averaged model outputs, of (a) the position (in latitude, between 5° S and 10° N) where the meridional wind stress value equal zero (indicator of the position of the ITCZ), over Jan-June 2005 (left) and Jan-June 2006 (right); (b) the meridional wind stress (N.m^{-2}) averaged between 50° W and 35° W and between 1° S and 1° N; (c) same as (b) but for zonal wind stress (N.m^{-2}) (in blue); (d) the wind stress curl (N.m^{-2}) ; (e) the 20° C isotherm depth (m); (f) the sea level (m). For all fields, except for the position of the ITCZ, the 30 days low-pass filtered annual field averaged over 1998-2008 period has been removed to the total field. The red arrow in (a) indicates the southward shift of the ITCZ before the excitation of the Kevin wave (see text).


13 May 2005

14 May 2005

15 May 2005

16 May 2005

17 May 2005

Figure 10: Daily-averaged, from 13 May to 17 May 2005 (left to right panels), of (a) the precipitation rate (kg.m^{-2}/day) ; (b) the wind speed vectors superimposed with wind magnitude (color field) (m.s^{-1}) from CFSR fields; (b) the surface pressure (hPa) from ERA-20C reanalysis; (c) the wind speed curl (m.s^{-1}) computed from CFSR wind speed fields; and (d) the downward short-wave radiation (W.m^{-2}) from CFSR fields.

10. RC: Section 5.2: You mention in the introduction that the monsoon onset happened early in 2005, but this information should be repeated in this section.

AC: The following sentences have been added as an introduction of the section 5.2.

: “The mid-May 2005 wind event was found to be involved in the early onset of the ACT development (Marin et al. 2009, Caniaux et al., 2011). Due to the influence of the cold tongue on the WAM onset (Okumura and Xie, 2004; Caniaux et al., 2011; Nguyen et al., 2011; Thorncroft et al., 2011), the mid-May wind event is therefore also linked to the onset of the WAM in 2005 which has been the earliest over 1982-2007 period from Caniaux et al. (2011). In this section we aim to better understand how this single wind event may have such impact.”

11. RC: Fig. 13 looks rather strange because of the discontinuities between May of one and April of the next year. Maybe you could separate the years more clearly with vertical black lines.

AC: Vertical black thick lines have been added and the figure 13 has been modified for more clarity.

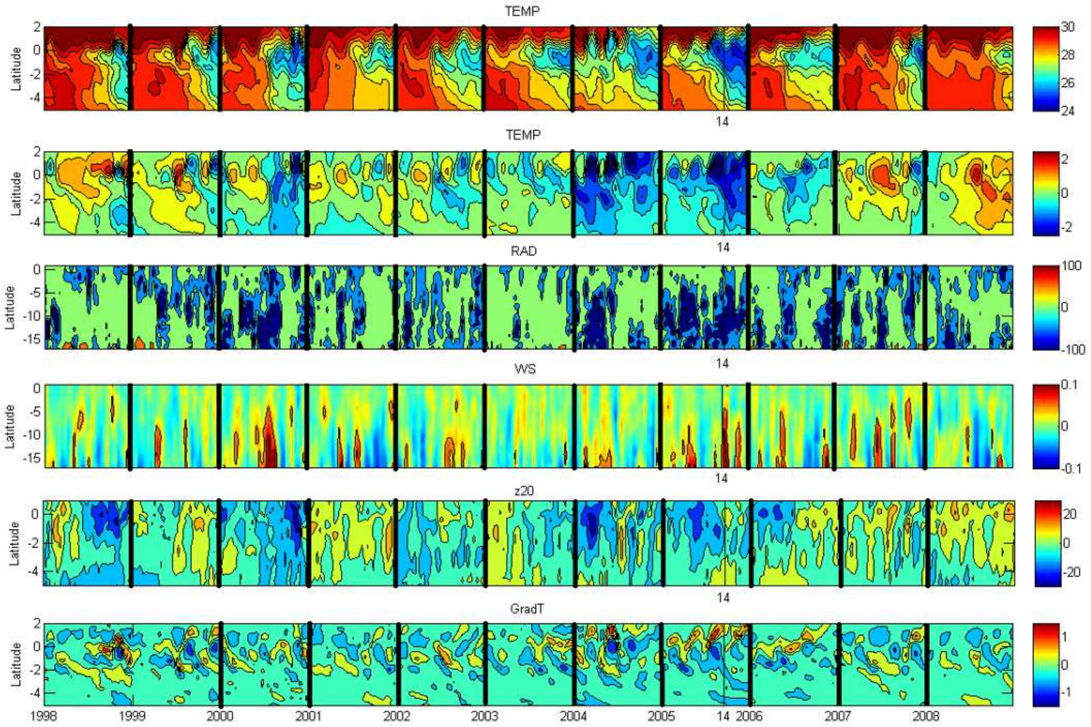


Figure 13: Time-latitude diagrams for April-May along the 1998-2008 period, of 2-days average, from top to bottom i) SST (°C); ii) intraseasonal variations anomalies of SST (°C); , iii) intraseasonal variations anomalies of wind stress magnitude ($N.m^{-2}$) from CFSR fields; iv) intraseasonal variations anomalies of short-wave radiation surface flux ($W.m^{-2}$) from CFSR fields; v) intraseasonal variations anomalies of 20°C-isotherm depth (m) computed from the forced model SST; vi) intraseasonal variations anomalies of meridional SST gradient (every 0.5° of latitude), from the forced model; averaged over 10° W-6° W. For all fields, except for the first

SST field, the 30 days low-pass filtered annual field averaged over 1998-2008 period has been removed to the total field. The vertical black thin line indicates the date of 14 May, 2005.

Modifications have also been made on the plot of 20°C-isotherm depths : weaker values of 20°C-isotherm depths indicate shallower thermocline to be consistent with the modifications made on the Fig.1, Fig.3, Fig.5, Fig. 9 and Fig. 7.

12. RC: Instead of Fig. 14 a and b, I would suggest to show a map of the surface pressure for May 2005. The time series can then highlight that the pressure gradient was special.

AC: Thank you for the suggestion. In fact, maps of the surface pressure from May 13 to May 17 2005 are already shown on figure 10. We decided to remove the figure 14 and to modified the comments of the figure 10 about the surface pressure as following:

“The mid-May 2005 event was also characterized by a particularly low surface pressure under the ITCZ, as shown on Fig. 10c. The pressure fall during the mid-May 2005 event appeared as the lowest in May over the whole decade (not shown). It coincided with particularly high surface pressures in St. Helena Anticyclone region 4 days earlier. The meridional surface pressure gradient during the event is thus found to be the strongest over 1998-2008 period. That suggests strong Hadley circulation intensity during the mid-May event and therefore strong anomalous equatorward moisture flux, allowing the deep atmospheric convection in the Gulf of Guinea to be triggered at a self-sustaining level, as previously described in Sect. 5.2.”

13. RC: Please check that the figures are numbered in the order in which they are referenced in the text.

AC: Thanks, this was checked.

RC: Fig.1: I woud suggest to plot the line for 2005 on top of the other lines as it it very hard to see. It would also be helpful to plot a larger area in the maps on the right hand side. What are the vectors shown in Fig.1b and Fig1c ?

AC: Thanks for suggestions. The modifications have been made (see Fig.1). The vectors shown in Fig1b and Fig1c are respectively the wind vectors and the surface current vectors. The indications have been added in the legend. In addition, modifications have been made on the plot of 20°C-isotherm depth: weaker values of 20°C-isotherm depth indicate shallower thermocline to be consistent with the modifications made on Fig.3, Fig.5, Fig.7, Fig. 9, and Fig. 13.

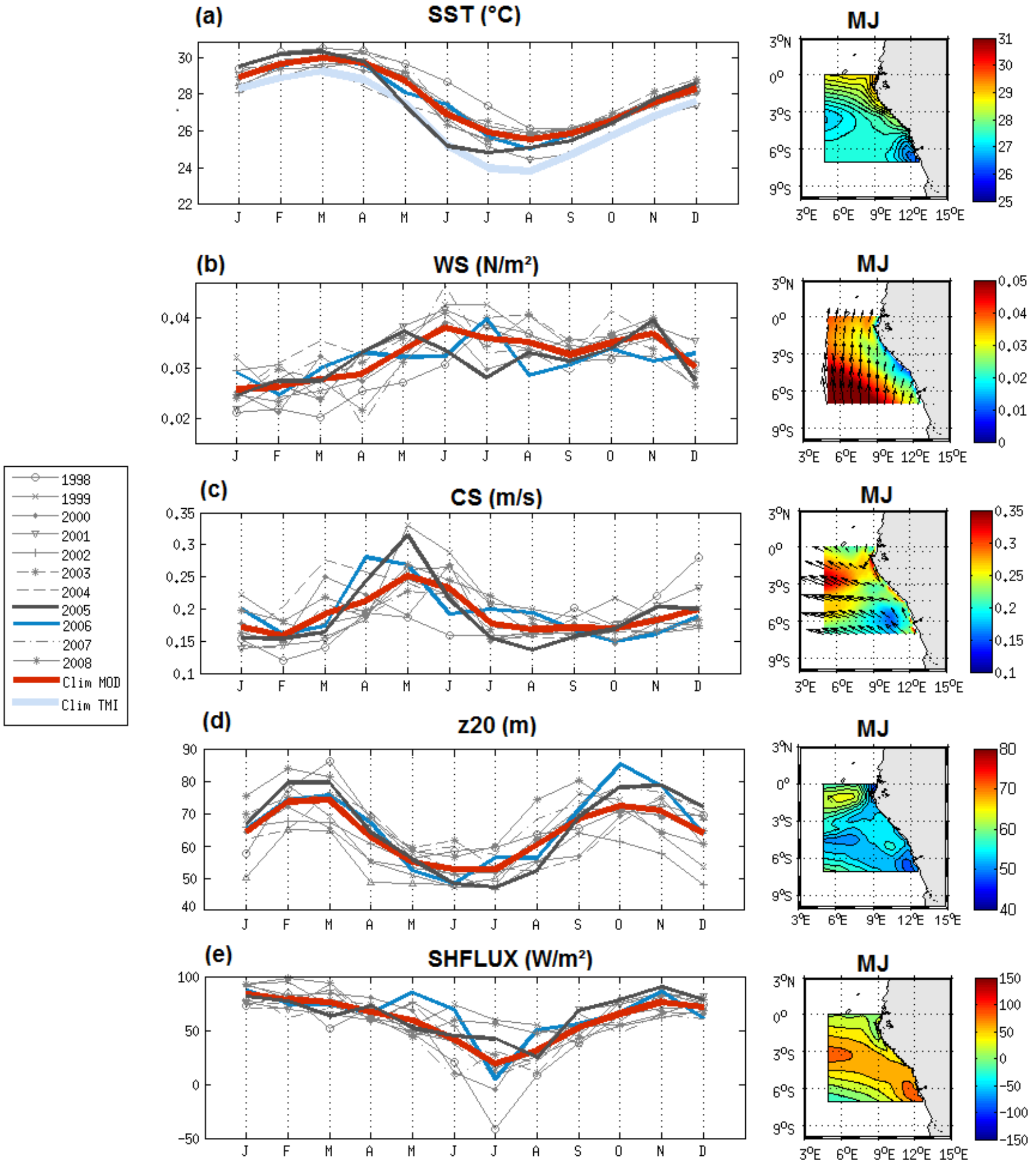


Figure 1: Monthly average of the (a) sea surface temperature (°C); (b) wind stress direction (vectors) and magnitude (color field) (N.m^{-2}); (c) horizontal surface current direction (vectors) and speed (color field) (m.s^{-1}) ; (d) 20° C-isotherm depth (m); and (e) surface heat flux (W.m^{-2}; positive values indicate downward flux) from January to December from 1998 to 2008 and for the climatology (averaged over 1998-2008) simulated by the model (red curve) and from the observations : monthly average TMI 3-daily SST data (light blue curve in (a)); averaged over 5° E-14° E and 7° S-0° S. Right panel: maps of each variable over May-June.

RC: Fig.5 : I would suggest to use red for deeper and blue for shallower thermocline to be consistent with SST.

AC: Thanks for suggestion. The modifications have been made on Fig.1, Fig.3, Fig. 5, Fig. 9, Fig. 7, and Fig. 13.

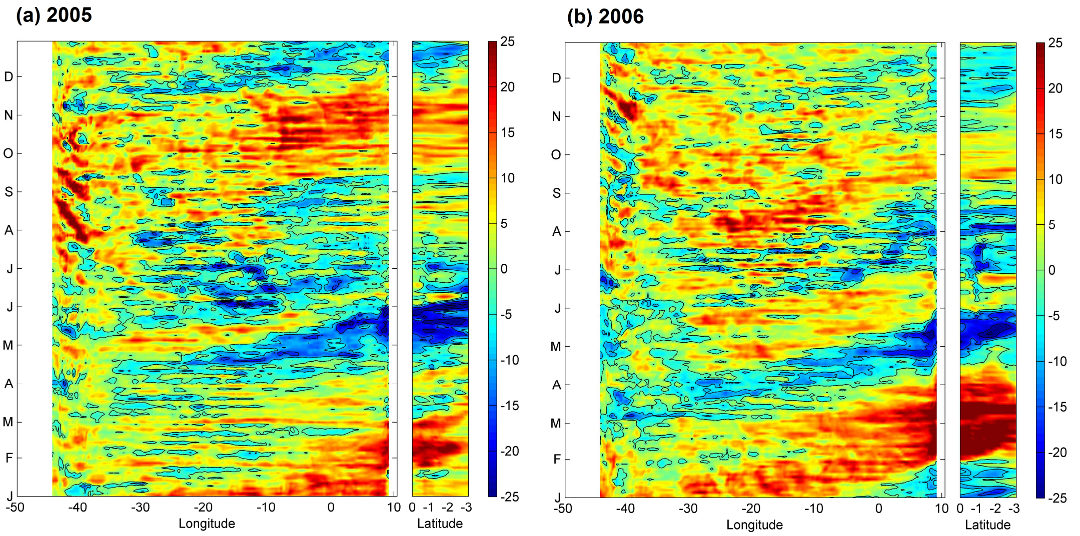


Figure 5: Time evolution of the intraseasonal variations anomalies of the 20° C-isotherm depth (m) along the equator (between 54° W and 12° E) and along 9° E (between the equator and 3° S) for 2005 (left) and 2006 (right). Negative values indicate a 20°C isotherm closer to the surface.

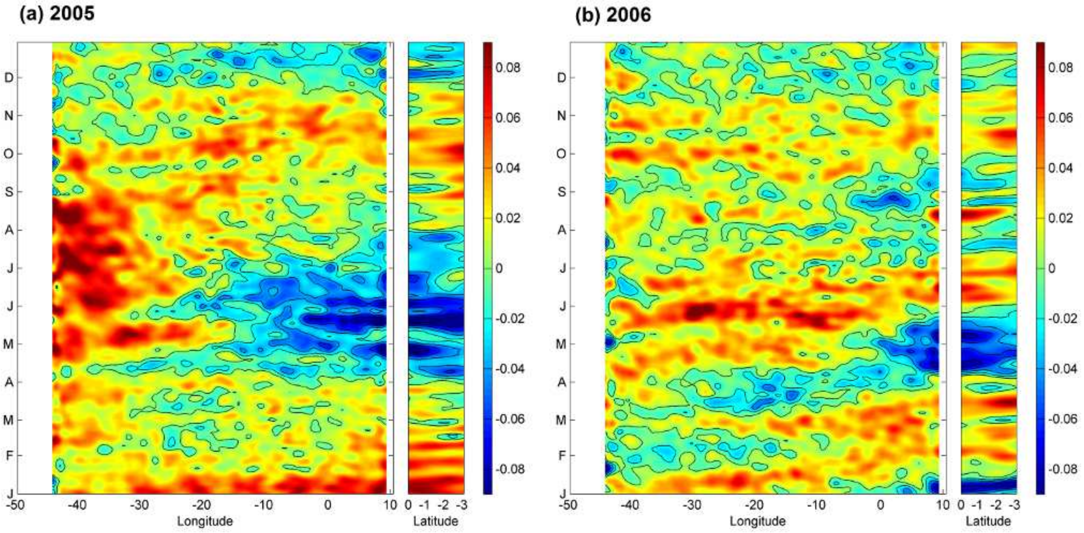


Figure 6: Time evolution of the sea level anomaly (m) along the equator (between 54° W and 12° E) and along 9° E (between the equator and 3° S) for 2005 (left), and 2006 (right) from AVISO data.

Additional authors' comments:

Thanks a lot for the technical notes. The corrections have been made in the text.