ANSWER TO REVIEWS

Interactions between the Somali Current eddies during the summer monsoon: insights from a numerical study

by

C.Q.C. Akuetevi, B. Barnier, J. Verron, J.-M. Molines & A. Lecointre

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The reviewers comments are reproduced in blue and our answers are written in black and the changes added to the manuscript are given in "*italic*".

Answer to Reviewer # 2

General comments: The manuscript describes the fast interactions between the large anticyclonic gyres, Southern Gyre, Great Whirl and Socotra Eddy, developing off the Somali coast during the Southwest Monsoon. The study based on three hindcast simulations of the global ocean circulation, which differ by resolution, atmospheric forcing and parametrization. The authors focus on the generating mechanism of the cyclones flanking the Great Whirl and on the nature of interaction between the Southern Gyre and the Great Whirl. As direct observations are very sparse in this region this is an important contribution to the analysis of the development of the fast dynamics of the Somali eddies as the 5 days snapshots of all three simulations allow to follow the evolution of the eddies. My main concerns are that some parts of the text are unclear, lack discussion and need to be better structured.

In chapter 4.2.2 several points are a bit vague, the cyclones should be described more precisely and it is very difficult to follow the conclusions of the authors (see my detailed comments below).

We (Akuetevi Wirth).

Has been modified with a clarification of the mergingof cyclones into GW

Chapters 4.3.1 and 4.3.2 should be restructured.

Chapter 4.3.1 starts with the results by presenting three different scenarios, which are discussed in the next chapter 4.3.2. I find these two chapters extremely difficult to read, as it suffers from jumping back and forth between the figures and chapters. The text would be easier to follow if each scenario would be addressed in a separate chapter. Therefore, I think that the paper could be significantly improved by rewriting and restructuring of the paragraphs. Thus, I recommend publication of this manuscript after major revision.

We examined the suggestion of the reviewer to change the structure of the paper but we ended up with the conclusion that the structuring we proposed is the best one, for the reasons given below.

1 - Before a given scenario can be followed, it needs to be identified and at least briefly characterized with regard to the others. This is exactly what section 4.3.1: describe briefly what happens and identify

scenarios that will be discussed in details later.

2 - But the scenarios that we identified are:

Scenario 1 - the collision without merging. It is a "dominant" scenario that occurs 75% of the time. What happens during this scenario is rather complex.

Scenario 2 - the case when the SG does not move and does not interact with the GW. This is a less frequent but robust scenario (robust because seen at least once in every simulations). But since the two eddies do not interact, there is not much to say on their interactions.

Scenario 3 – This is the case when the SG and a large part of the GW are merging. This is a "rare" scenario, the robustness of which is not demonstrated as it is seen in only one of the 3 simulations. And it can be seen as a "particular case" of Scenario 1.

Therefore, it is natural that a large part of the paper be focused on the "collision" process to which a full section is dedicated (section 4.3.2). Having dedicated sections for every other scenario is not justified because:

- Scenario 2: no interaction between SG and GW. Since the objective of the paper is to describe how the interactions between the SG and the GW develop, there is not much to say. But this does not mean that it is not important. Note that this scenario is somewhat describe in the new section that we added to answer Review#1 (new section 4.4)
- Scenario 3: it is treated as a "particular case" of scenario 1 (collision but with partial merging), thus in the same sections.

Therefore, we have decided to keep the initial structure of the paper, but re-wrote several parts of the text in an attempt to make the reading much easier. We hope that the revised version of the paper is not that difficult to read anymore. In particular, we now organize the discussions on one figure at a time to prevent the reader to jump between several figures at a time.

Specific comments:

1 P737, l7: "is the GW" – A sentence about the generation mechanism of the GW would be helpful here (as on p752, l1-4).

Text added:

Its generation mechanism involves the arrival of remote Rossby Waves in spring (see Beal et al., 2013) and amplification in summer by the monsoon winds via intensification and a retroflection of the Somali Current.

2 P738, l6-9: Sentence too long and clumsy, please rewrite.

New text:

The lack of understanding of the processes governing the dynamics of the large circulation features that are the Southern Gyre, the Great Whirl and the Socotra Eddy largely resides in the lack of dense in space and time observations.

3 P740, l25: "Monthly mean" – too imprecisely, you should say that the monthly mean is calculated for the last 10 years of the simulation (as written in the Fig. 1 figure caption).

New text:

" *... displays the climatological (10 year average) mean for the month of June ...*"

4 P741, l19: The GW and the SE disappear in November – do you know what happens to the SG?

A marked southern gyre is still seen north of the equator until the end of December (see Figures A1 attached to this review). Text added:

The SG persists until the end of December (not shown)

5 P743, l6-8: In Fig. 3-5 results from only two experiments, $1/4^{\circ}$ MJM95 and $1/12^{\circ}$ MAL84, are shown, but the text says that “detachments of positive vorticity from the WBC are observed in all three experiments”.

They are also seen in MAL95 in Fig. 8.

(e.g. Fig. 3,-5) is replaced by *(e.g. Fig. 3, 4 and 8)*

6 P744, l6: I can’t see the cyclone in the currents, maybe a close up with a higher resolution would be helpful.

The cyclones are the red features in Fig. 3. The legend of Fig. 3 did not mentioned this fact. This has been corrected. Text added to the figure legend:

The bursts are the filaments of positive (red) vorticity, and the cyclones are the circular features of positive (red) vorticity.

7 P744, l9-10: I can’t see that the cyclone weakens the eddy or even contributes to its decay – Fig. 3 shows a strong GW.

The weakening of the cyclone can be seen in Fig. 3. The top-right and middle right panels of Fig. 3 (in which time is bottom-up) show a “merging” outlined by the green arrows. We clarify this in the revised paper. See also our answer to Review #1 where we show sequences that outline this merging. Text added:

This is illustrated in Fig. 3 for the 1/12° simulation: On 19 June (middle-right panel), the cyclone is located in the center of the GW (the red spot outlined by the green arrow). On 9 July (top-right), the cyclone has greatly diminished its intensity and is being absorbed into the GW.

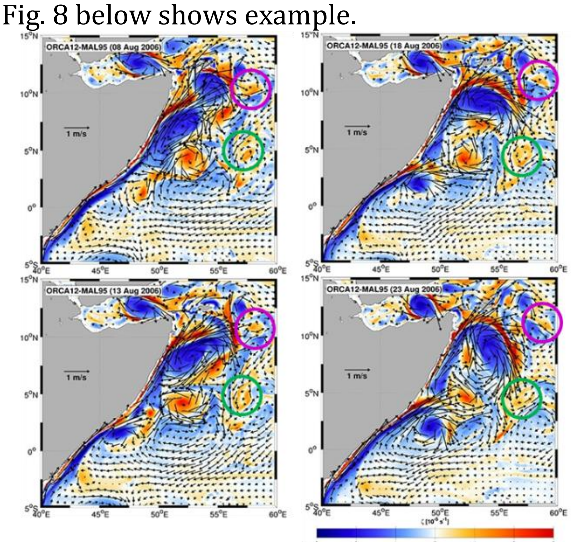
We did not quantify how much a cyclonic vortex that is absorbed into a greater eddy of opposite vorticity contributes to its decay. Therefore, it is more appropriate in the paper to mention a "possible contribution to the decay".

The text now reads:

"It is possible that this process weakens the large anticyclonic eddy and contributes to its decay."

8 P744, l15: I don’t understand the statement that the cyclonic vortex “drifts in the open ocean” – in which figure is this shown.

No every cyclone gets re-absorbed into the GW or the WBC. Some remain off shore until they dissipate. The sequence extracted from Fig. 8 below shows example.



The following text has been added (and Fig. 8 modified accordingly):

This is illustrated in Fig. 8 where most cyclones located East of 55°E (outlined by the purple and green circles) will not re-enter the boundary current system and will remain off shore.

9 P744, l19: "clearly influences the circulation" -This statement is very vague. 10. P744, l24: "greatly triggering the mixing of upwelled waters within the eddies and offshore region" – There is no mixing in offshore regions shown.
A remark also made in Review #1 (see comment 16). The text has been modified as follows:
The behavior of the bursts after ejection followed by the dipoles formation is a very well-marked phenomenon which entrains the upwelled-water masses detached by the bursts from the cold wedge and could contribute to their offshore mixing.

10 P746, l7: The SG should not be renamed in "new Great Whirl". This is confusing as it is still the northward migrated Southern Gyre (same on p748, l12).
OK. Indeed we wondered how to call it, ande "migrated SG" sound much more pertinent.
"*The migrated SG takes the place of the GW*" replaces "*the SG becomes a new GW".*

The sentence of page 748 has been removed, as it repeats the same thing.

11 P746, l12: Fig. 7 does not show SST.
True. This is corrected, and the SST refers to Fig. 5.

12 P748, l14: The GW should not be renamed in "Socotra Eddy" or "new SE" just because the GW took its place (same on p750, l17).
OK. The sentences do not mention a *new SE*.

The GW with a decreased spiciness and pushed to the east of the Socotra Island in the position where the SE is usually observed.

When the collision of the SG and the GW develops, this early SE is rapidly destroyed or absorbed by the GW.

13 P748, l22: "This formation process of the new GW and the SE were not previously identified and it challenges the collapse interpretation based on the collapse of the two cold wedges." I don't understand the sentence.
As we mentioned in the introduction, the merging (or collapse) of the two cold wedges has been in few previous studies interpreted as the merging of the SG and the GW. Our model results suggest that this merging does not necessarily means that the two anticyclones are merging. This is just what this sentence aimed to say. We agree it is not clear and that it also appears as a quite unnecessary statement at this place of the paper. The sentence is removed and the text is simplified::

The collision did not produce the coalescence between the SG and the GW, but their respective cold wedges have merged.

14 P753, l20-21: remove the following part of the sentence as it is needless: "which are not the reality but an attempt to represent it as well as possible"
OK. Removed.

15 P759, Fig. 1: Do you have an idea why the anti-cyclonic SG cannot be identified by an elevated SSH – in contrast to the GW. For a better validation maybe you should show SSH as well as surface circulation from observations, maybe from AVISO or, for the surface circulation, from the YoMaHa climatology from Argo floats. The surface circulation does not show the resolution of 1/4°.
See also review # comment 21.
It is possible that the southern gyre is not easily detectable is SSH data because of its vicinity with the equator (it is likely largely ageostrophic). Indeed, our model dat show a small signal in SSH and a large signal in vorticity (Fig. A4 below).

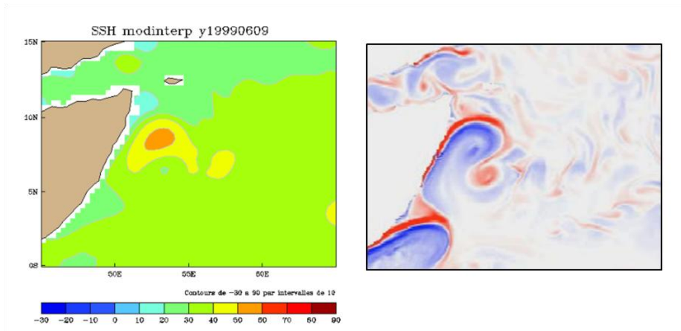


Figure A4: Snapshot of SSH and relative vorticity on the same day (6 June 1999) in simulation MAL95 showing that the Southern Gyre which is clearly visible in the vorticity map has a very weak signature in the SSH map. This figure is not shown in the paper, but is presented to the reviewers to confirm what we say in the paper.

We did look carefully at AVISO data (period 1993-2004). We combined these SLA data with the mean SSH of Maximenko and Niiler (2005) in the exact same way as it was done in Beal and Donohue (2013) to produce an absolute SSH that can be compared to the model SSH. To verify the correctness of our procedure, we reproduced their results. Then we also collocated (in space and time) the SSH from the 1/12° MAL95 simulation onto the Aviso data base to make comparisons (same period 1993-2004).
Following the reviewers comment, we extended this discussion in the revised paper. A new paragraph has been added, which challenges the finding of this study. If required, the above figures could be proposed as additional material to be put on line but not in the paper itself because it will require four additional large figures.

<u>Change in text (new paragraph is the conclusion):</u>

Model results produced by a single numerical code must be interpreted with caution as they are, to a degree that is often not possible to assess, influenced by specificities of the numerical code used, and the scenarios described here are no exceptions. Therefore it cannot be ruled out that the numerical model used here (i.e. NEMO) although describing the various possible scenarios in rather robust way may unrealistically favors one specific scenario (i.e. the collision without merging of the GW and the SG) rather than the others. Indeed, it is somewhat puzzling that our most frequent scenario is not being frequently mentioned in the literature. A reason could be that this event is not as frequent in the real ocean as the model shows, and that the northward motion of the Southern Gyre is more often limited below 5°N. Our models would therefore be biased toward one specific scenario for reasons that still have to be determined but might well be related to the fundamentals of the numerical code (e.g. vertical coordinate system, order of the numerical schemes, etc.) rather than configuration settings (all three configurations used here are favouring the same scenario). But studies of the Southern Gyre are rare (attention is usually given to the Great Whirl) and to our knowledge satellite altimetry has not been applied to the dynamics of this circulation feature. Looking at the model 5 day snapshots of Sea Surface Height (SSH) we found that the Southern Gyre begins to be detectable in this variable only after it reaches latitudes of 4 to 5°N (not shown).
To further investigate this issue, we compared our model outputs with satellite altimetry data. We combined the AVISO sea level anomalies (SLA) data with the mean SSH of Maximenko and Niiler (1995) in the exact same way as it was done in Beal and Donohue (2013) to produce an absolute SSH that can be compared to the model SSH. Then we collocated (in space and time) the SSH from the 1/12° MAL95 simulation onto the AVISO data base. We processed both data sets on the same period (from 1993 to 2004).
We found that the Southern Gyre does not appear clearly in the AVISO or in the model sampled like AVISO (not shown). A reason for that could be that the Southern Gyre is largely ageostrophic in the vicinity of the equator and therefore has a weak signature in SSH. We also found a number of sequences in AVISO data that could correspond to the collision scenario because of a (subjective) analogy with MAL95 data (not shown), and fewer that are clearly consistent with a southern gyre that does not migrate northward (again by

analogy with the model, not shown). But analogy with a model sequence is certainly not accurate enough to to reach a clear conclusion on the process described by the satellite data. It is therefore possible that the present nadir altimetry which provides heavily filtered/extrapolated maps of SSH every 7 days, do not have the adequate sampling to follow this circulation feature with the required level of details, and that additional observations or a different processing that take into account the fast evolution of the signal are necessary.

16 P760, Fig. 2: Do you use the current speed U or the current speed, which is orthogonal to the oblique section? I recommend the latter (same for Fig. 6).
The section is oblique because it is chosen to cross (as far as possible) the center of the 2 Anticyclones. We use the current speed (calculated with both components), so it is independent of the orientation of the section. We consider this is the best choice here because we want to show the existence and amplitude of a velocity front whatever its orientation is. Using the velocity normal to the section would no catch the front if it is aligned with the section. It would be relevant to estimate transport, but we are not interested in this quantity.
No change in text.

17 P762, Fig. 4: Remove the last four sentences of the figure caption ("The Southern Gyre (SG) does not move northward. . .A Socotra Eddy (SE) is seen east of the Socotra island."), as this does not belong to the figure caption and should be written in the text.
OK. Removed from the caption, but then included in the text (section 4.3.1).

18 P763, Fig. 5: Remove the last sentence of the figure caption ("It illustrates the collision. . .and the Socotra Eddy."), as this should be described in the text.
OK. This is already said in the text. Removed.

19 P764, Fig. 6: Fig. 6 should be moved after Fig. 8.
Right. Done.

20 P765, Fig. 7: The figure caption should provide information about the figure (relative vorticity and spiciness). "to illustrate the collapse of the two cold wedges. . . to become a new Great Whirl" does not belong to the figure caption. Please, rewrite the figure caption.
Figure caption re-written.

21 P766, Fig. 8: Please add information about the figure (relative vorticity and spiciness).
Done

Technical corrections:

Every technical correction has been implemented as suggested.
Regarding the figures, we agree with all the remarks made (label to small, missing labels, order of panel, heterogeneity of color bars, etc..) . We are producing a new set of corrected figures, but for technical reasons, they could be finished before the deadline. The new figures will be given before the edition of the final paper.

1 p737, l15: in size
2 p737, l17: Jensen (1991) and Wirth et al. (2002)
3 p739, l4 and p752, l20: Southwest Monsoon
4 P742, l7: Fig. 2c - Fig. 2b
5 P745, l16: Figs. 4 to 7.
6 P746, l10: For a better understanding add the number of the chapter "discussed in detail below (4.3.2)"
7 P748, l19: Fig. 36 (typo?)

Yes. It is their Fig. 1. Corrected.

8 P752, l15: They are sometimes detached. . .

9 P759-767, Fig. 1-9: The labeling of the axes and/or color bars is too small in all of figures. Small letters in the plots would help to indicate the plots.

10 P759, Fig. 1: The current vectors are too small, it's hard to recognize any of the currents. "SC", "EACC" and "SECC" are very difficult to see, maybe you show mark them in black.

11 P760, Fig. 2d: Depth labels should be positive (same in Fig. 6). Small letters (a-d) are missing in the panels.

12 P760, Fig. 2a: The color map of the relative vorticity should be consistent: color map of Fig. 2a and 3 differ from Fig.4, 5, 7, 8 and 9.

13 P761, Fig. 3: The panels should be arranged so that time increases from top to bottom as in the following figure.

14 P763, Fig. 5: Spiciness (middle sequence of snapshots) and SST (lower sequence of snapshots) are in a different order as in the figure caption. The colorbars should be placed on the right side of each sequence (or the sequences should be arranged from top to bottom with the colorbar below).

15 P765, Fig. 7, figure caption: From $1/12^{o}$ MAL84 experiment.

16 P766, Fig. 8, figure caption: . . .from $1/12^{o}$ MAL95 experiment.

17 P767, Fig. 9: Please add (a) and (b) to the panels.

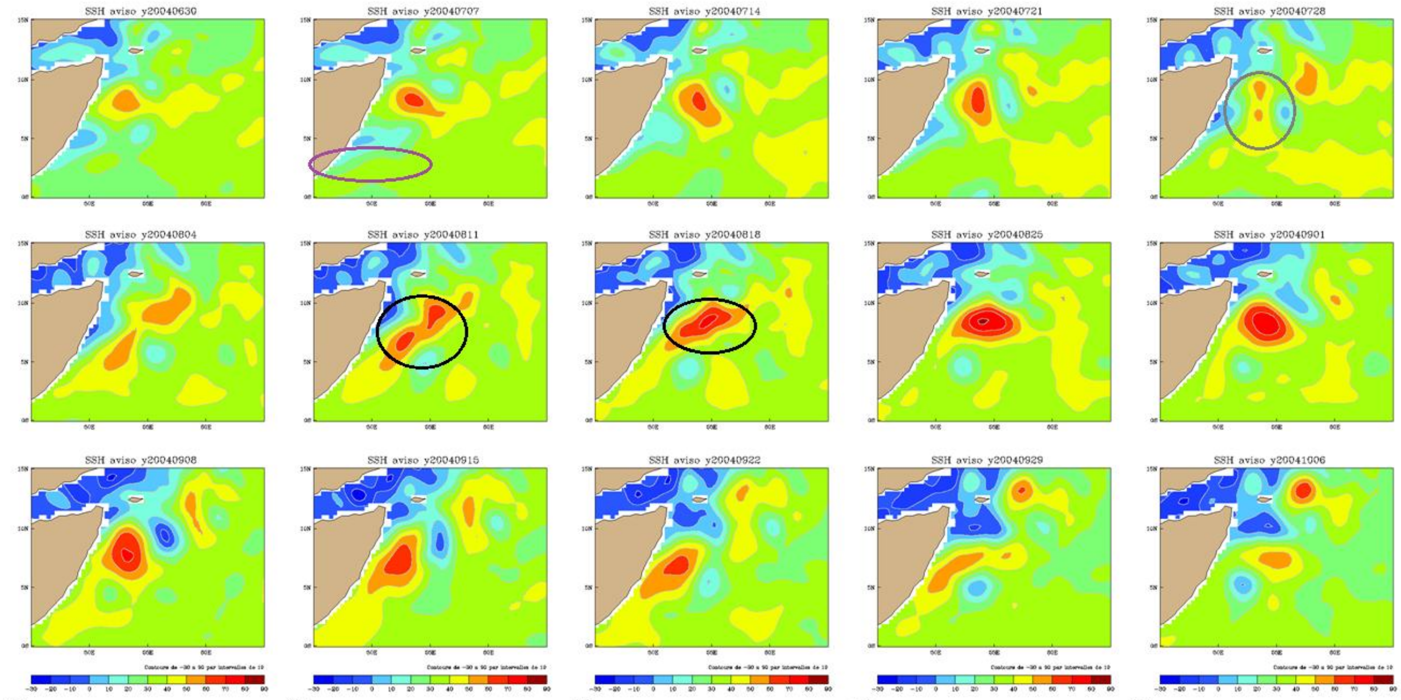


Fig A9a. Sequence from 30 June to 6 October 2004 of 7-day snapshots of SSH from the AVISO SLA data to which the mean SSH from Maximenko and Niiler (1995) has been added. The SSH high outlined by the purple circle on 7 September suggests that a SG in growing. The sequence suggests that the SG migrates northward and collides with the GW (grey circle on 28 July). Then, the sequence shows that only one eddy remains (black circle on 11 and 18 August). The sequence could very well correspond to a collision without merging of the two eddies because it is very similar to that shown in Fig. 9Ab for the 1/12° MAL95 simulation which corresponds to a year when the SG and the GW collided but did not merge.

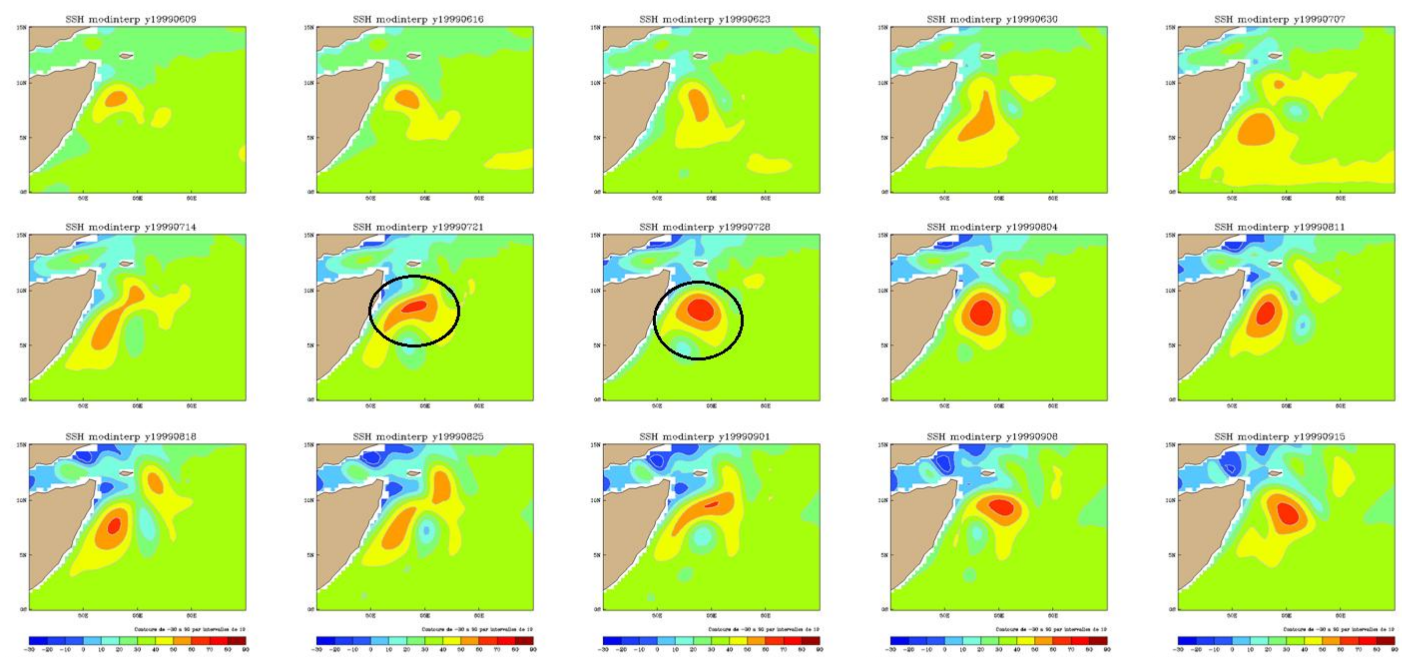


Fig A9b. Sequence (from 9 June to 15 september 1999) of 7-day snapshots of SSH from the 1/12° simulation MAL95 outputs collocated in space and time onto the AVSISO data. The southern Gyre did migrate northward that year and collided with the Great Whirl. The black circles outline the occurrence of the collision. The GW moved to the northeast and in the place where the Socotra Eddy is usually found. This situation is comparable to that shown with the AVISO data in Fig. 9Aa above.

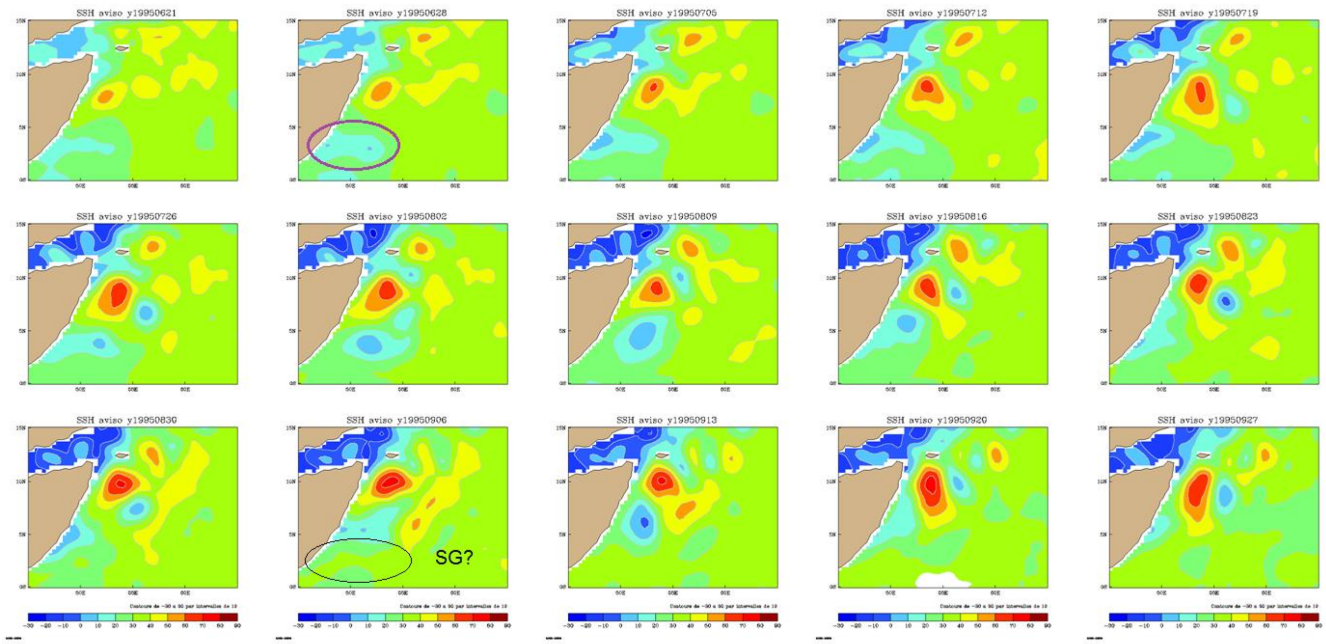


Fig A10a. Sequence from 21 June to 27 September 1995 of 7-day snapshots of SSH from the AVISO SLA data to which the mean SSH from Maximenko and Niiler (1995) has been added. The SSH low (purple circle) that is found to persists along the Somali coast below 5°N suggests that there is no SG (which should be a high) before 6 September when a SSH high appears (the black circle). This suggests that collision occurred between the SG and the GW that year.

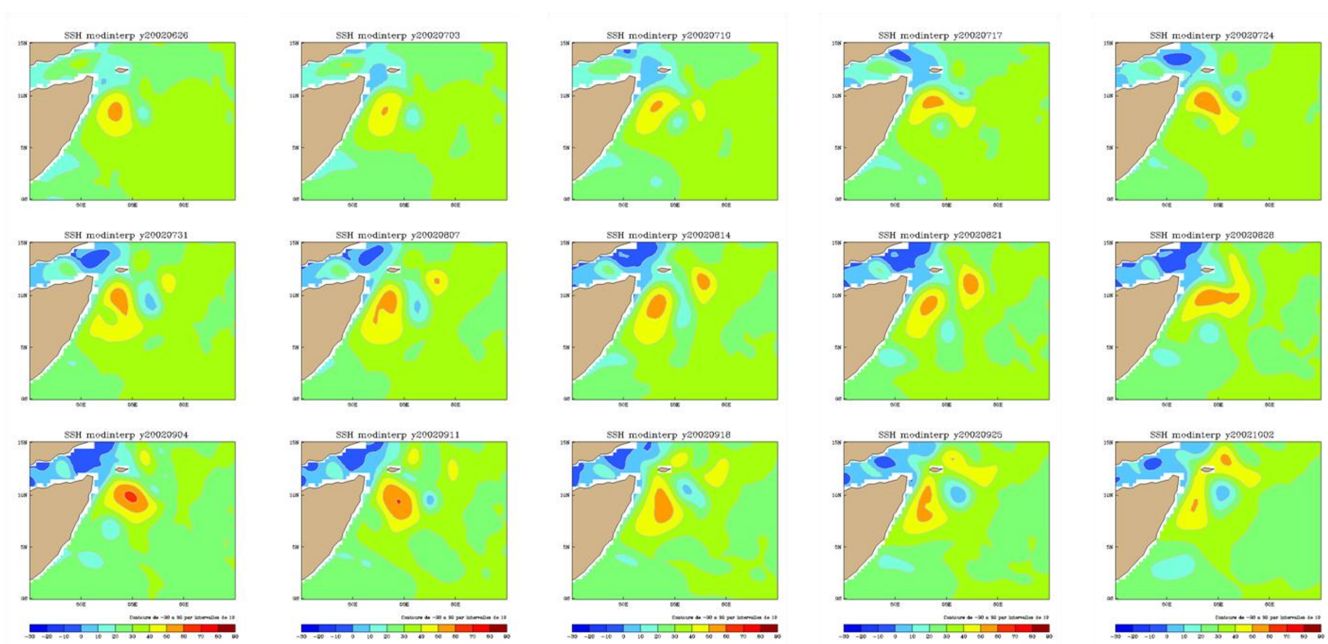


Fig A10b. Sequence (from 26 June to 2 October 2002) of 7-day snapshots of SSH from the 1/12° simulation MAL95 outputs collocated in space and time onto the AVSISO data. The southern Gyre did not migrate northward that year and no collision occurred. This situation is comparable to that shown with the AVISO data in Fig. 10Aa above.