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THE SOUTH ATLANTIC SUBTROPICAL FRONT / CURRENT OF ST. HELENA

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ABSTRACT

A large-scale climatic ocean circulation model was used to study the Atlantic Ocean Circulation. This inverse model is an extension of the Stommel and Schott (1977) and Schott and Stommel (1978) beta spiral formulation with a more complete version of the vorticity equation, including not only the planetary vorticity effect, but also that of the relative vorticity. Also, a more complete database for hydrological measurements in the Atlantic Ocean was used, including not only the NODC database, but also WOCE data and cruises near the Azores, Angola and Guinea-Bissau.

A detailed analysis of the northern hemisphere Azores Current and Front shows that this new database and the model results were able to capture all major features reported in previous works. In the southern hemisphere we have identified and fully described the subtropical front that is the counterpart of the Azores Current, which we call the St. Helena Current and Front. Studies involving high-resolution mapping of ocean circulation from satellite altimetry, also show its presence. Both current systems of both hemispheres have similar intensities, depth penetration, volume transports and zonal flow. Both have associated subsurface adjacent counter-current flows and their main cores flow at similar latitudes (around 34ºN for the Azores Current and 34ºS for the St. Helena Current). We argue that both current systems and associated fronts are the poleward 18ºC discontinuities of the two Atlantic subtropical gyres and that both originate at the corresponding hemisphere western boundary current systems from which they penetrate into the open ocean interior. Thus, both currents should have a similar forcing source, and their origin should not be linked to any geographical particularities.

1. DATA AND METHODS

For our Atlantic Ocean climatology [80ºS–80ºN, 100ºW–35ºE], we have used the hydrological data (temperature and salinity) as a function of pressure, longitude, latitude and time, obtained through historical databases; NODC ("National Oceanographic Data Center"); GTSPP ("Global Temperature Salinity Profile Project") and WOCE ("World Ocean Circulation Experiment"). To these databases we have also added data from oceanographic cruises carried out in the region of the Azores, Angola and Guinea-Bissau. The resulting database covered the period from 1940 to 1999 and 89 vertical levels unevenly distributed between 5 db and 6000 db, with a horizontal resolution of 0.5º x 0.5º degree (latitude x longitude) covering the Atlantic Ocean. The entire data set was submitted to a quality and validation control procedure, followed by objective interpolation (Juliano and Alves 2005; Alves *et al*. 1994; Juliano 2003).

For the altimetry data, we got the corrected sea level anomaly (SLA) along-track delay time data from the Topex/Poseidon (TP), ERS-1/2, Jason-1 and Envisat altimeters distributed by AVISO (CLS Archiving, Validation, and Interpretation of satellite Oceanographic Data project). Further, this data where grouped into a series of 10 days files, each one containing data from two altimeters (TP, ERS-2 or/and Jason-1, Envisat). The data was optimally interpolated using the same algorithm as described in Ducet *et al*. (2000), and gridded in a 0.5º of resolution (latitude x longitude). This resolution was chosen to be compatible with our climatological data set. The time period concerning this study varies from 1995 to 2005.

From the climatological data field we have obtained the mean dynamic topography (hereinafter as MDT-Juliano) referred at 1500 db. This was used to calculate the absolute dynamic topography (ADT) and consequently, the absolute geostrophic currents at the surface, using the altimetry data sets.

1.1 The ocean circulation model

In the present study we chose to develop and apply a modified version of the β-Spiral method (Stommel and Schott 1977; Schott and Stommel 1978). The inclusion of momentum boundary conditions at the surface and at the bottom, and a vorticity equation that contains the non-linear relative vorticity advection terms, as well as the advection of planetary vorticity (Juliano and Alves 2005) are the major modifications to the traditional model. To our knowledge, consideration of the non-linear terms is novel (Juliano and Alves 2005). The nonlinear terms are important, but not crucial, for the present subtropical analysis. However, since the Atlantic

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is tackled as a whole, they are of central importance in those areas where strong currents occur and at the equator.

For the planetary scale circulation models, it is important to know the average and collective effect that eddies of smaller scales can have in the flow and in the large-scale vorticity balance. Such impact can alter the Sverdrup relation (Pedlosky 1996). Hence, we will consider that the large-scale flow does interact with mesoscale and can be modified by it. The 3-dimensional field of the absolute velocity was determined for the Atlantic Ocean (see Juliano and Alves 2005).

2. RESULTS

We can now say that an increased database and resolution, together with a new circulation description has made it possible, to fully describe the counterpart of the Azores Current (AzC) in the South Atlantic, which we have called the St. Helena Current, (StHC), by analogy with the Azores Current. Such similarity between the StHC and the AzC is evident not only in their horizontal structure location, meridional width, intensity), but also in their vertical structure and volume transport (Juliano and Alves 2005). Another clear similarity is their origin. Both start from the corresponding western boundary currents of each hemisphere and interact with the North Atlantic Current (AzC) and the South Atlantic Current (StHC). Also, their thermohaline properties mirror each other. The most significant difference is that the SAC remains closer to the StHC than its North Atlantic equivalents. Also, since the South Atlantic basin is wider than that of the North Atlantic at these latitudes, it is clear why the AzC has a shorter extent than the StHC.

To further illustrate this inter-hemispheric mirror resemblance between the two current systems, some zonal means have been further calculated for the annual mean distribution (Fig. 1) (Juliano and Alves 2005).

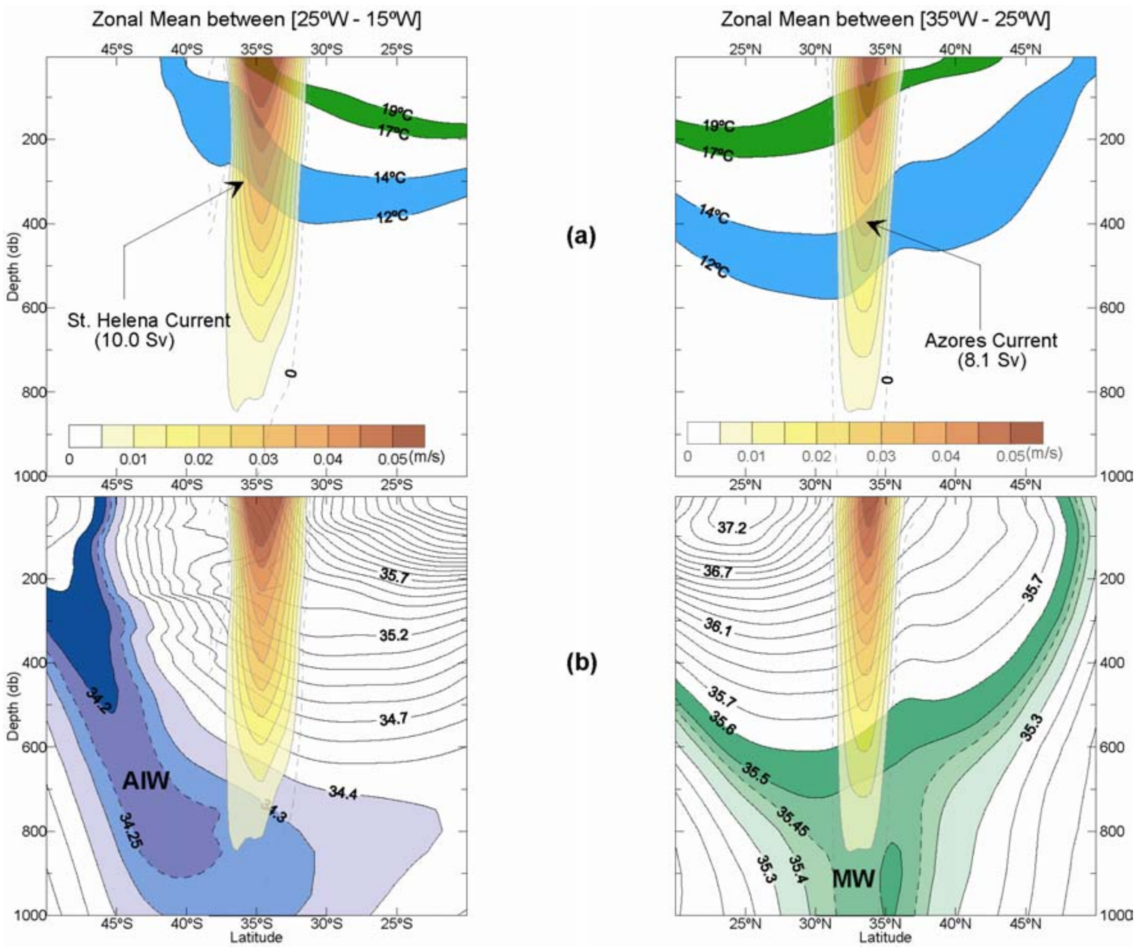

Fig. 1. Annual and zonal mean vertical distribution of (a) temperature (ºC) and (b) salinity, between [25ºW-15ºW] in the southern hemisphere and [35ºW-25ºW] in the northern hemisphere, respectively, and for the latitude range shown. Superimposed to these thermohaline fields onto each hemisphere are the StHC and AzC cores only. AIW and MW water masses are colored in (b) using the salinity signature. Volume transports are also indicated for each current in part (a) (from Juliano and Alves 2005)

The temperature (ºC) and salinity cross-sections of zonal averages between [25ºW-15ºW] for the southern hemisphere and [35ºW-25ºW] for the northern hemisphere were overlaid with the main zonal mean cores of StHC and AzC respectively. These sections were chosen because they are situated approximately in the central part of the trajectory of the two currents. The resemblance between the two zonal mean components (AzC and StHC) in location, intensity, transport, depth attained and meridional width is evident.

The Azores Front/Current (AzFC) is seen as a boundary separating the 18ºC modal water (to the south) and the 13ºC water (north), particularly in its western-most region, and its main body is filled with North Atlantic Central Water (NACW), whereas Mediterranean Water fills its lower boundary (Harvey and Arhan 1988; Alves 1996; Juliano 2003). These structures are obvious in Fig. 1, with respect to the AzC. Looking now to the StHC region, the resemblance and symmetry are remarkable. With respect to the vertical distribution of the average temperature, we observe the presence of the same 13ºC and 18ºC mode waters placed south and north of the StHC core, despite its smaller thickness. The main difference is in the depth of the 13ºC water when compared to the AzC. This mode water relationship with the AzC was first described by Pollard *et al*. (1996) where it is referred that the Azores Counter Current (AzCC) coincides with the southern limb of the anticyclonic circulation of the 13ºC Subpolar Modal Water. The main body of the StHC is filled with South Atlantic Central Water, whereas, for the AzC, it is the North Atlantic Central Water that plays this role (Fig. 1a,b). The StHC lower limit is filled with Antarctic Intermediate Water (AIW) (cold and diluted water) that contrasts with the Mediterranean Water (MW) (hot and salty water), for the AzC case. Since the AIW and the MW have similar densities it explains why symmetry is preserved even with such deep thermohaline differences (Juliano and Alves 2005).

There is prior literature that references the presence of a thermohaline front in the South Atlantic region with St. Helena's front characteristics (Provost *et al*. 1999; Tsuchiya *et al* 1994). Provost *et al*. (1999) even mentioned that this front could extend further to the east, towards the interior of the South Atlantic.

Presently we have evidences that show the existence of St. Helena's Current and are not only based in hydrological data, but also in satellite altimetry. We initially identified St. Helena's current on the basis of climatological data and then searched for its surface signal trough satellite altimetry. The usage of independent data is fundamental to corroborate its presence.

Fig. 2a) represents the annual mean absolute horizontal velocity distribution (m s^{-1}) at the surface, using the non-linear model formulation and the climatological data set (~60 years) (Juliano and Alves 2005). For the Southern Atlantic Subtropical zone (Fig. 2 a,b), it is possible to identify the two main South American western boundary currents: the Brazil Current (BzC) flowing poleward, and the Malvinas Current (MC) flowing equatorward. When the MC encounters the BzC at the latitudes of about 35ºS – 40ºS (Garzoli 1993; Garzoli and Giulivi 1994; Juliano 2003) off the coast of Argentina and Uruguay, they deflect eastward towards the open ocean. In the lower part of Fig. 2a), south of 45ºS, one can identify the upper branch of the ACC, flowing eastward with a zonal trajectory. A further analysis of Fig. 2a) shows that, from the Brazil-Malvinas confluence zone, there are two main eastward flowing branches. The one further south constitutes the origin of the South Atlantic Current (SAC).

The northern ramification at about 35ºS, coincides in this region with the position of the Brazil Front/Current and a close inspection of the results depicted in Fig. 2 shows that although some recirculation occurs towards the Brazil Current, the majority of its flow inflects eastward, towards the open ocean (at about 35ºS) in a quasi zonal path all across the South Atlantic basin. This current has a well-defined baroclinic structure and flows zonally eastward all across the eastern South Atlantic basin. At about 35ºS, 10ºE it inflects northeastward feeding the Benguela Current (much like the Azores Current feeding the CC). This main zonal current constitutes the St. Helena Current (StHC). All along its path we can observe interactions with the flows situated in the northern side (South Equatorial Current) and in the southern side (South Atlantic Current).

Fig. 2b) represent the annual mean (1995-2005) absolute horizontal geostrophic velocity distribution field, obtained via altimetry data (with MDT-Juliano). Again the St. Helena Current appears identical to Fig. 2a). One must mention that these two results are not independent, since we used the same mean dynamic topography (MDT-Juliano). To verify if the results we obtained with climatological data and satellite altimetry were or not dependant of this choice, we have done the same calculations using the mean dynamic topography generated by Rio (2005) and kindly granted to us by Helene Rio (CMDT-RIO05). The obtained results show that the signal of St. Helena's current is well defined in both representations and present the same type of structures and intensities. For the sake of data compatibility we then opted for doing our calculations based on the MDT – Juliano.

As another example we represent at the Fig. 3 the latitude-time geostrophic velocity variation averaged in the meridional band (35ºW-10ºW), for the northern and southern hemisphere. The St. Helena Current is well defined at ~35ºS and its mean position kept constant throughout the years. The same happens with the Azores Current, located close to 35ºN.

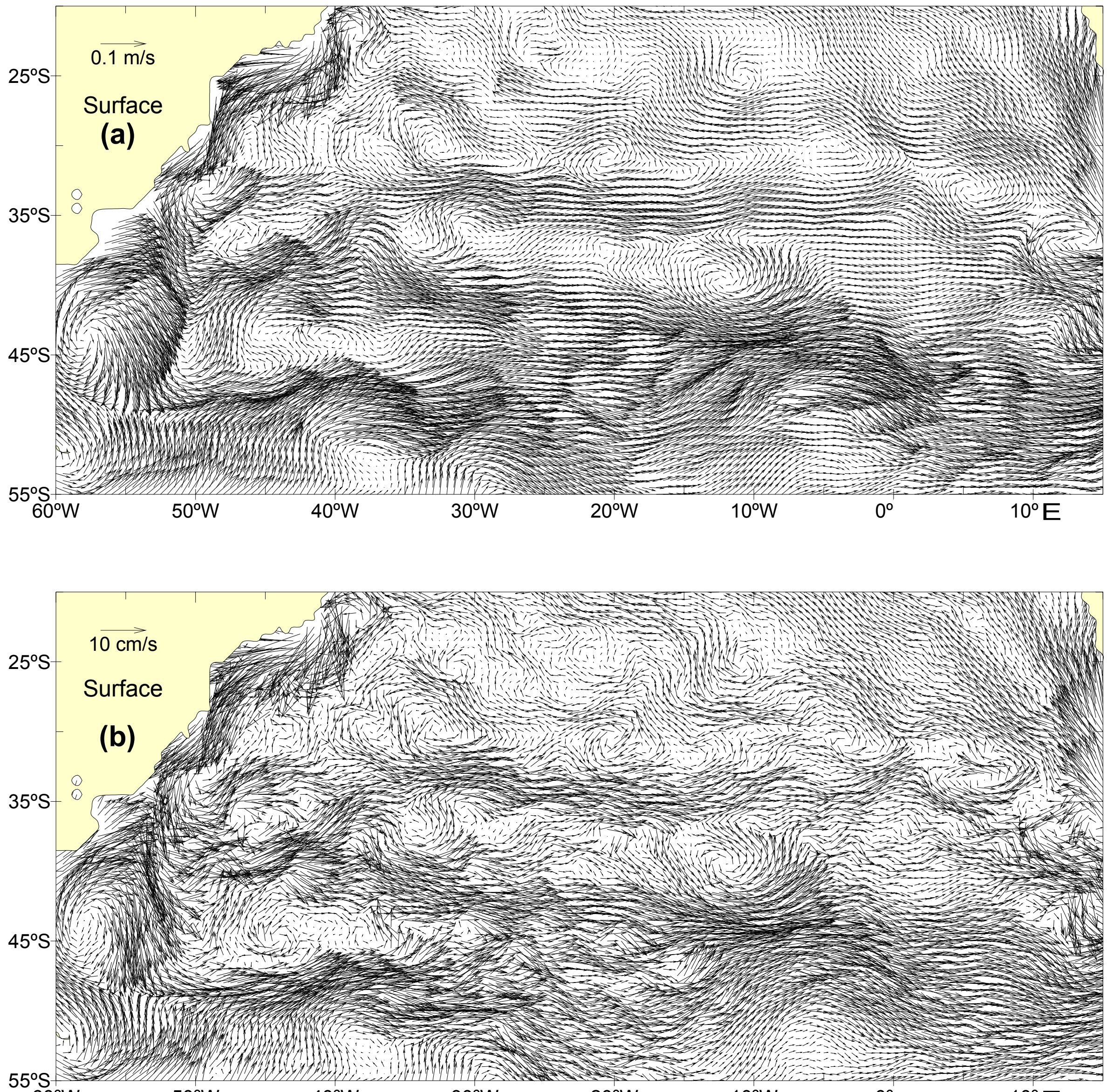

Fig. 2 a) Annual mean (~60 years) absolute horizontal velocity distribution (m s^{-1}) at the surface using the non-linear model formulation (from Juliano and Alves 2005). b) Annual mean geostrophic horizontal velocity distribution (cm s^{-1}) using the altimetry data for the time period (1996-2004).

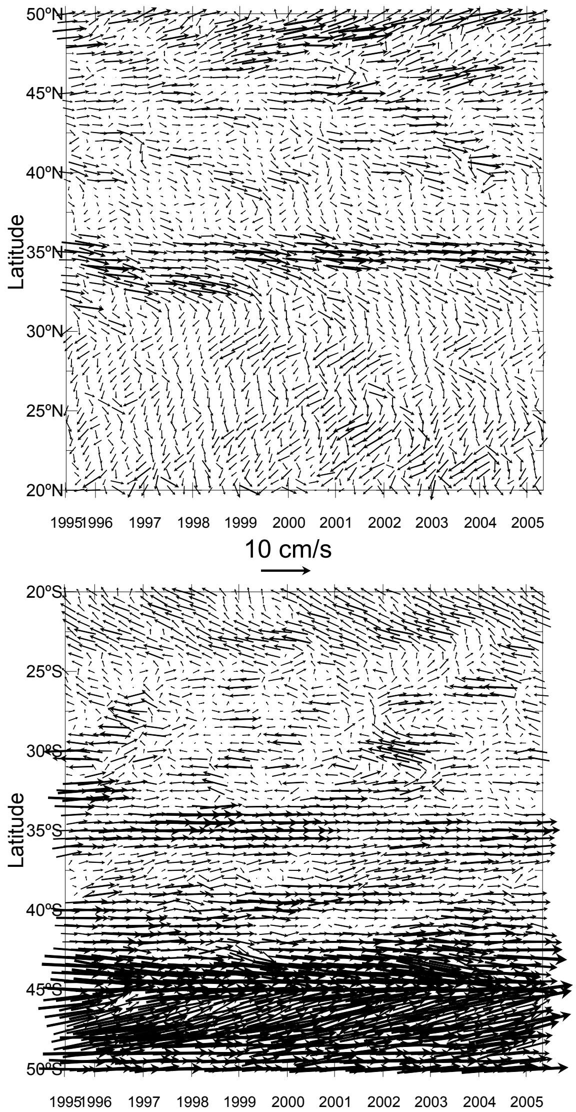

Fig. 3. The latitude-time geostrophic velocity variation averaged in the meridional band (35ºW-10ºW), for the northern (top) and southern (bottom) hemisphere.

3. CONCLUSIONS

A more complete hydrological database for the whole Atlantic Ocean, together with an increased spatial resolution and an improved mean circulation estimation method, with the introduction of the non-linear relative vorticity advection terms in the computation of large-scale ocean currents, has enabled us to fully describe, for the first time, the St. Helena Current and show its similarity with the Azores Current.

Similarly, it is possible to show unambiguously that the St. Helena Counter Current emerges in exactly the same symmetric position of its counterpart in the Azores Current.

Satellite altimetry also allows the detection of the St. Helena current at the surface and it also shows that the current mean position as been kept throughout the last 10 years.

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