Water mass analysis of the Benguela upwelling system referring to the oxygen minimum zone

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Motivation

The Namibian upwelling region is one of the four Eastern Boundary Upwelling Ecosystems (EBUs) and among the most productive areas in the World Ocean. One important question is how the upwelling dynamics have varied in the past and will change in the future. The identification of the influence of the large-scale climate patterns on the Namibian EBU can shed light on this question (*Tim et al. 2014*).

The oxygen minimum zone (OMZ) in the Benguela region has an important impact on the ecosystem and local fisheries. The content of South Atlantic Central Water (SACW) on the shelf drives the intensity and extension of the oxygen minimum zone. Therefore, the water masses, their origin and pathways through the South Atlantic as well as trends and variabilities of the OMZ are investigated. The SACW (nutrient rich and oxygen poor) is transported into the Benguela region by the poleward undercurrent (PUC). The Eastern South Atlantic Central Water (ESACW, nutrient poor and oxygen rich) is transported from the south into the Benguela region by the Benguela Current (Fig.1). SACW is the dominant central water mass in the Angola Dome, ESACW in the Cape region. The content of SACW on the shelf controls the intensity and extension of the oxygen minimum zone (OMZ).

Data and Methods

Here, we present a statistical analysis of two ocean-only simulations driven by observed atmospheric fields and one coupled simulation over the last decades with the aim of identifying the large-scale drivers of upwelling intensity. Two types of upwelling indices were defined. One is directly the vertical velocity at 50 m depth (close below the thermocline). Here, Benguela is divided into a northern part (15S-28S, 8E-coast) and a southern part (28S-40S, 8E-coast) (Fig.2). The second is derived after an Empirical Orthogonal Function (EOF) analysis of detrended coastal sea surface temperatures (SSTs). Atmospheric variables (10-m wind, wind stress, 2-m air temperature, sea level pressure, latent- and sensible heat flux) were obtained from NCEP reanalysis 1 (Table 1).

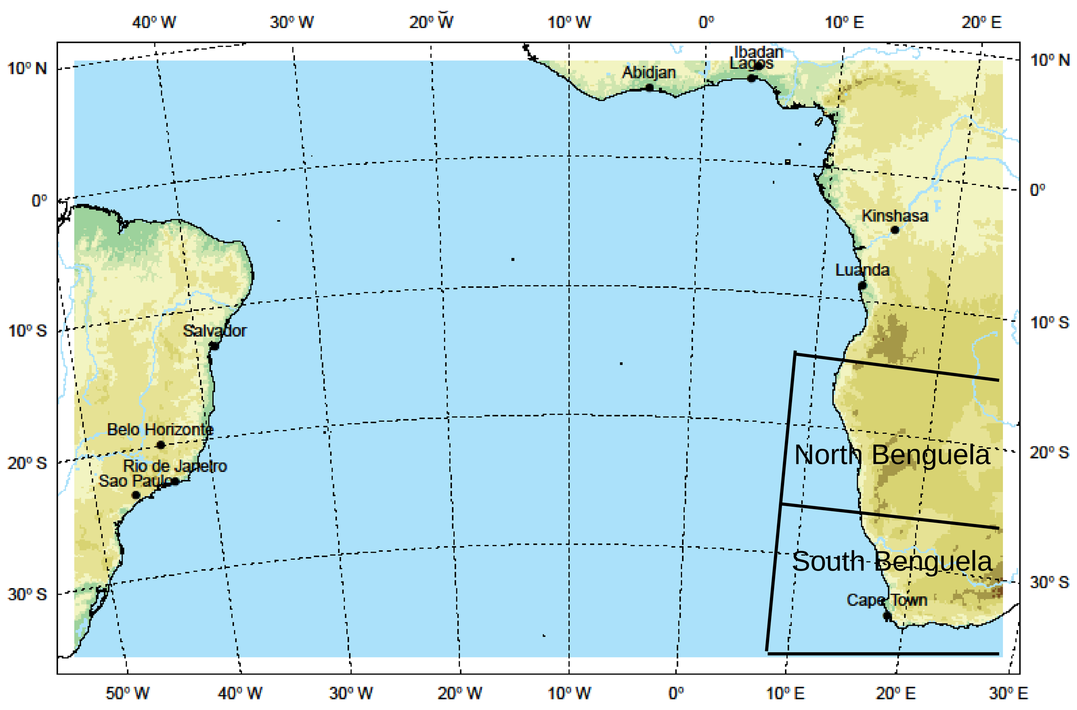

Figure 2 Research area (50W-30E, 10N-40S).

Table 1 Datasets used for this study

Acronym	Data description	Time period	Grid	Reference
Model simulations				
STORM	global ocean-only simulation/ model MPI-OM	1950 - 2010	0.1°	von Storch et al. 2012
MPI-ESM-MR historical	global coupled atmosphere-ocean simulation /model CMIP5 MPI-ESM-MR	1850 - 2005	~1.9°	Giorgetta et al. 2013
GENUS	regional (6.63N -34S, 10W -18E) ocean-only simulation / ecosystem model Modular Ocean Model 4.0	07/1999 - 05/2012	0.1°	Schmidt and Eggert 2012
Observational data				
NCEP	Reanalysis data	1948-2011	2.5°	Kalnay et al. 1996
HadISST1	gridded observations	1870 - 2012	1°	Rayner et al. 2003
Climate Indices				
MEI	Multivariate ENSO Index	1950-2012		Wolter and Timlin 2011
AAO	Antarctic Oscillation Index	1957-2012		Marshall 2003
ATL-3	Tropical Atlantic SST (HadISST, STORM)	1870-2012 1950-2010	1° 0.1°	Rodriguez-Fonseca et al. 2009

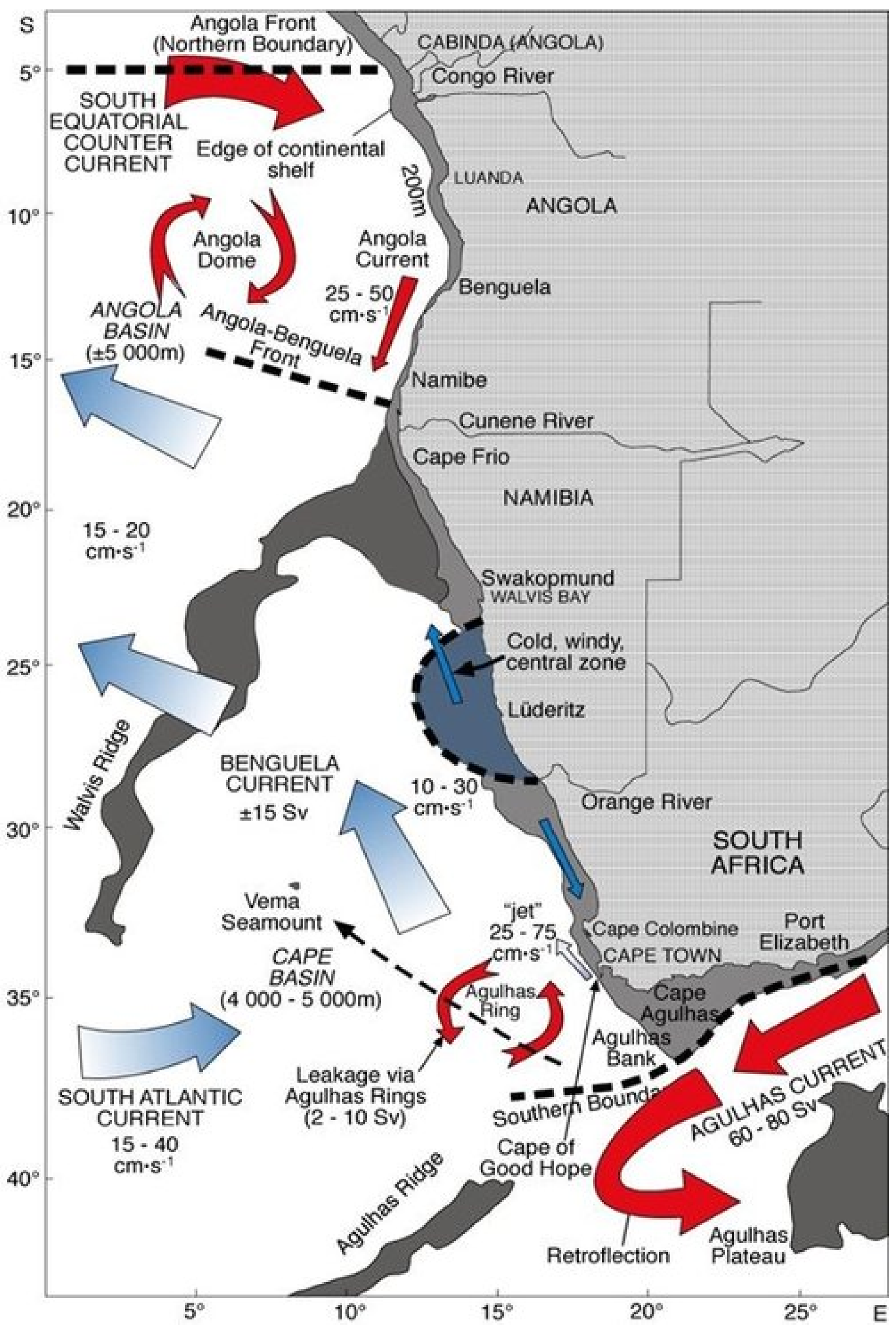

Figure 1 Benguela Upwelling region (Shannon & O`Toole 2003).

Results

Large-scale influence

Correlations with the upwelling indices show that an intensified sea level pressure of the South Atlantic High (Fig.3a), strong and southerly wind/wind stress (Fig.3b) and a temperature and pressure contrast over land and ocean favors upwelling in Northern Benguela. The upwelling in Southern Benguela shows an unclear pattern of favorable winds but mainly the same characteristics.

Influence of climate modes

Correlations of the upwelling indices and climate modes detect a significant influence of El Niño Southern Oscillation (ENSO, MEI index) on the upwelling, especially in austral summer (December-January-February). The index derived of the SST provides a significant influence of the tropical Atlantic SST, while the index of the vertical velocity shows significant influence by the Antarctic Oscillation (AAO).

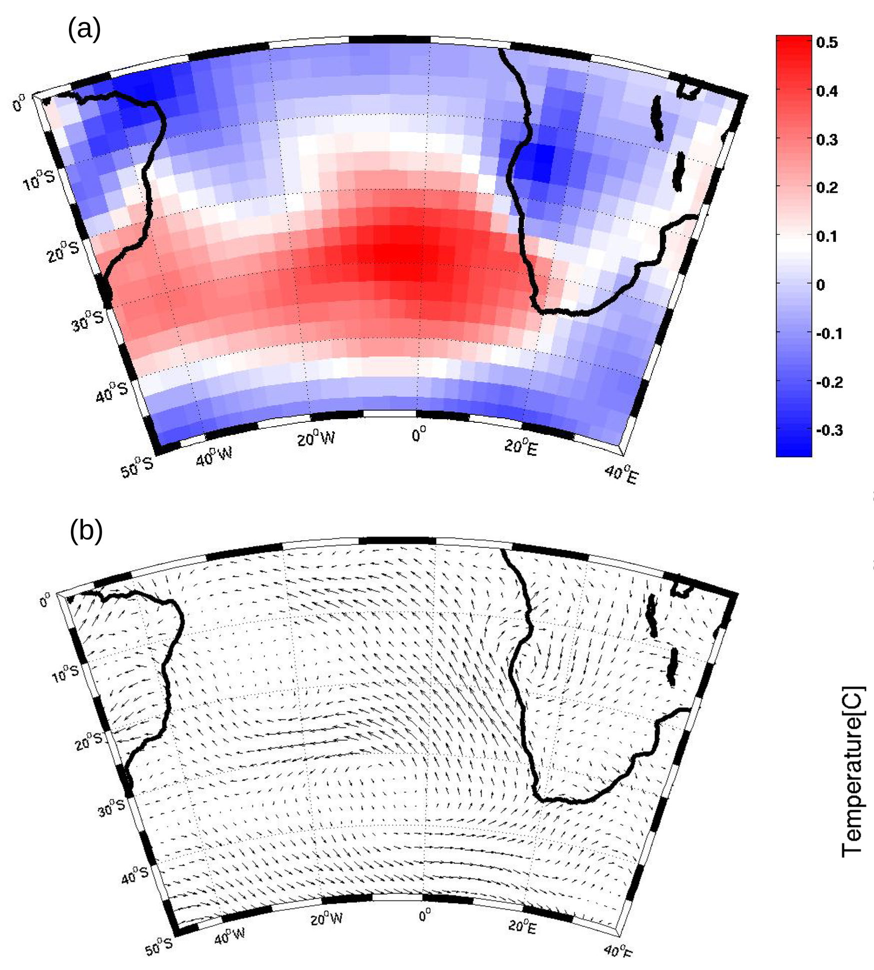

Figure 3 Correlation pattern of the vertica velocity of STORM and (a) the sea leve pressure, (b) wind stress of NCEP inn austral spring (September-November).

Water masses and oxygen minimum zone

The two central water masses SACW and ESACW can be detected in the STORM (Fig.4a) and CMIP5 MPI-ESM-MR (Fig.4b) simulations. In the GENUS simulation their characteristics are too similar, possibly due to the boundary conditions. The region of ESACW is the Cape region, close to the boundary of the model domain of the GENUS simulation.

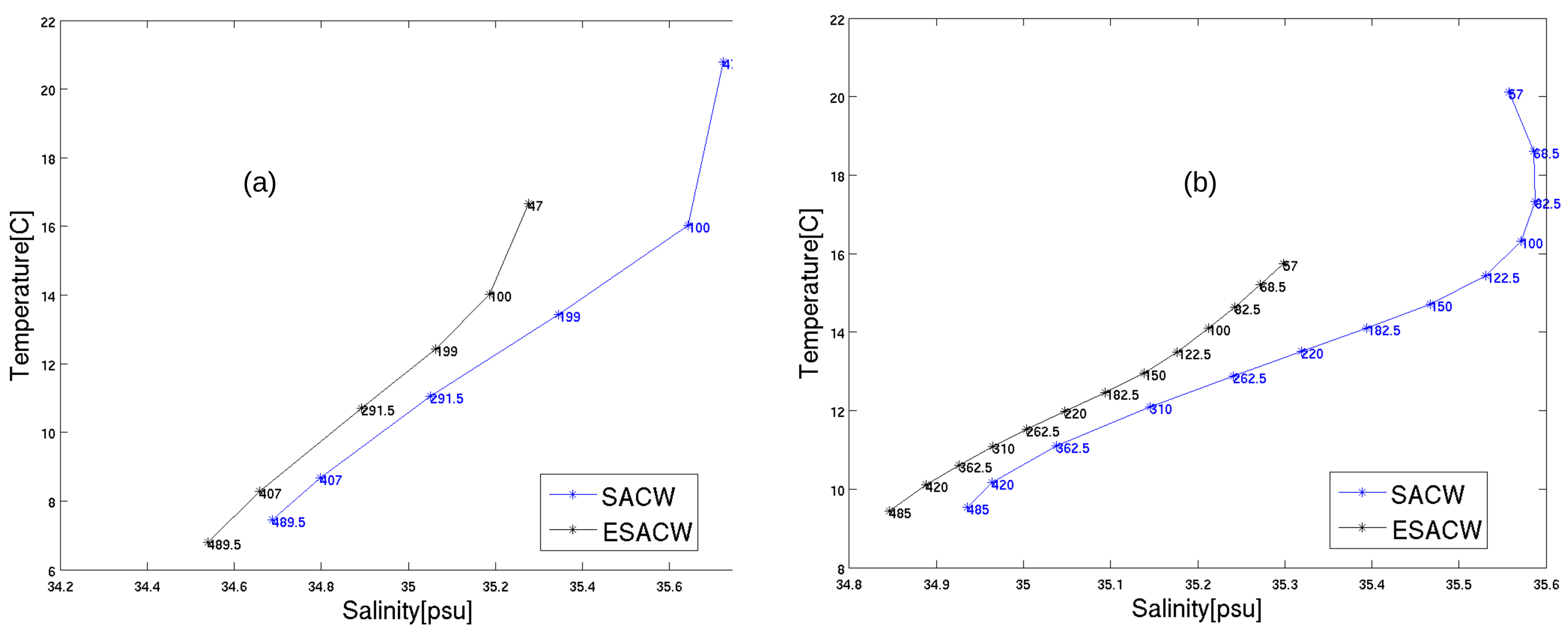

Figure 4 TS-diagram of SACW and ESACW in (a) STORM and (b) MPI-ESM-MR.

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Conclusion

Strong subtropical high, stronger than usual trades as well as a negative phase of ENSO and tropical Atlantic SST and a positive phase of the AAO favor the upwelling off Namibia. The extension and intensity of the OMZ is driven by the intensity of the PUC which brings oxygen poor SACW into the region. The simulations STORM and CMIP5 MPI-ESM-MR are able to capture the characteristics of the central water masses in Benguela (SACW and ESACW).

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GENUS