A Study of the Variability of the Benguela Current

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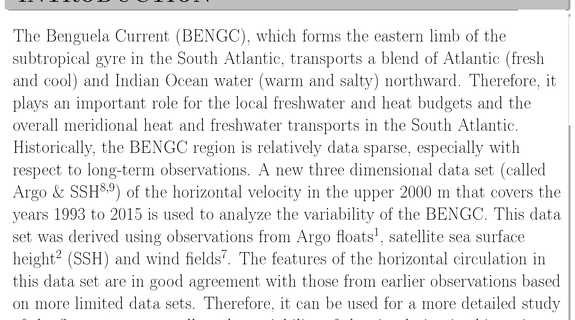
INTRODUCTION

The Benguela Current (BENGC), which forms the eastern limb of the subtropical gyre in the South Atlantic, transports a blend of Atlantic (fresh and cool) and Indian Ocean water (warm and salty) northward. Therefore, it plays an important role for the local freshwater and heat budgets and the overall meridional heat and freshwater transports in the South Atlantic. Historically, the BENGC region is relatively data sparse, especially with respect to long-term observations. A new three dimensional data set (called Argo & SSH[8,9]) of the horizontal velocity in the upper 2000 m that covers the years 1993 to 2015 is used to analyze the variability of the BENGC. This data set was derived using observations from Argo floats[1], satellite sea surface height[2] (SSH) and wind fields[7]. The features of the horizontal circulation in this data set are in good agreement with those from earlier observations based on more limited data sets. Therefore, it can be used for a more detailed study of the flow pattern as well as the variability of the circulation in this region. It is found that the mean meridional transport in the upper 800 m between the continental shelf of Africa and 3ºE, decreases from 23±3Sv at 31ºS to 11±3Sv at 28ºS. In terms of variability, the 23-year long timeseries at 30ºS and 35ºS reveal phases with large energy densities at periods of 3 to 7 months, which can be attributed to the occurrence of Agulhas rings in this region. Because 35ºS is closer to Agulhas retroflection than 30ºS, and more likely to be impacted by the Agulhas rings, the energy density associated with mesoscale variability at this latitude is larger than at 30ºS. The prevalence of these rings is also behind the fact that the energy density is low at the annual period, especially at 35ºS.

With respect to the forcing, the significant correlations between the Sverdrup balance derived from the wind stress and the observed transports at 30ºS are 0.4 to 0.7, while the correlations at 35ºS are insignificant.

MEAN FLOW FIELD

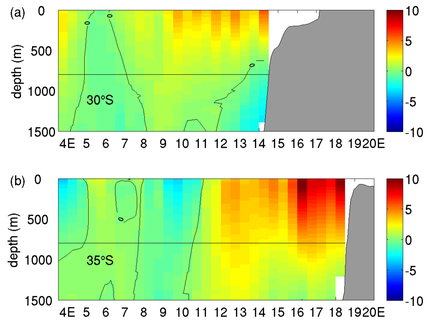


Red and black arrows indicate flow to the north and south respectively. The shading represents magnitude. The region ABCD indicates the lines across which transports are derived to study the variability.

The panels clearly visualize:

- the northwestward flowing BENGC and the Agulhas retroflection
- that the BENGC is fed by water from the southern Atlantic as well as the Indian Ocean
- the eastern (steady) regime near the African coast with relatively strong northward flow, and a western (transient) regime dominated by meanders and eddies.

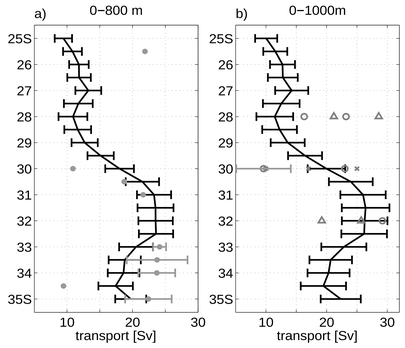
VERTICAL STRUCTURE



Climatological mean of meridional velocities at two latitudes. Black contours indicate zero velocity and the black line marks the depth of 800 m.

- The meridional flow at 30ºS is weaker than at 35ºS.
- The vertical extent of the BENGC at 30ºS is smaller than at 30ºS.
- Compared to the steady regime the velocity in the transient regime is mostly much smaller and of alternating sign.
- At 35ºS, two distinct branches can be seen in the steady regime. The main difference is the magnitude of the velocity.
- Missing velocities near the coast account for about 2 Sv at 30ºS and 35ºS.

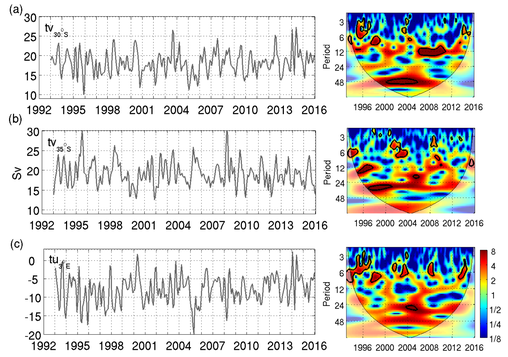
LATITUDE DEPENDENCE OF BENGC



Gray dots are based on velocity transects derived by Garzoli et. al (2013)[6]. Other gray symbols are based on transport estimates from Garzoli and Gordon (1996)[5], Clement et. al (1995)[3], and Stramma and Peterson (1989)[10]. Gray triangles (circles) indicate that the western integration limit was the Greenwich Meridian (the western edge of the Benguela Current). All other gray symbols represent estimates based on a western integration limit at 3ºE. All error bars represent standard deviations.

- The transports from Argo & SSH (black line) are relatively stable between 35ºS and 31ºS as well as north of 28ºS.
- From 31ºS to 28ºS the transport in the upper 800 m (1000 m) decreases from 23±3 Sv to 11±3 Sv (26±3 Sv to 12±3 Sv). This can be attributed to the westward turn of the flow as the Benguela Current feeds into the southern South Equatorial Current.

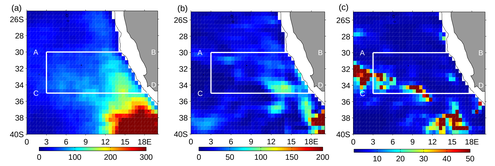
TEMPORAL VARIABILITY



Time series of transports and their wavelet spectra in the upper 800 m for 30ºS (across AB, a) and 35ºS (across CD, b). Same for the zonal transport at 3ºE (across AC, c).

- Mean values are 18±3 Sv, 19±3 Sv, and 8± 4 Sv across lines AB, CD and AC.
- Phases of significant energies are found with periods of 3-7 months for all lines.
- Occasional phases with significant energy at the annual period occur at 30ºS and 35ºS.
- No statistically significant trend is detected.

KINETIC ENERGY



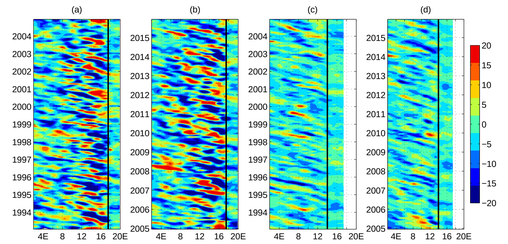
Climatologies of eddy (a), and mean kinetic energy (b) in $(cm/s)^2$, and their ratio (c).

- The eddy kinetic energy is significantly higher in the eastern Cape Basin which is dominated by the retroflection and the effect of newly formed Agulhas rings.
- Agulhas rings typically follow a northwestward path that can be detected as a high ratio of eddy to mean kinetic energy (>10).

CONCLUSIONS

- The mean meridional transports of the BENGC estimated from the 23-years long time series are consistent with estimates from previous studies within the error bars when considering the fact that the latter are from short timeseries and often used different criteria for defining the current.
- No persistent statistically significant annual cycles can be seen at 30ºS and 35ºS due to the influence of Agulhas rings.
- The Sverdrup balance can not reproduce the magnitude of the meridional transport in the BENGC.
- The Sverdrup balance reproduces some of the variability across AB (at 30ºS) but not across CD (at 35ºS) where the impact of the Agulhas rings is larger.

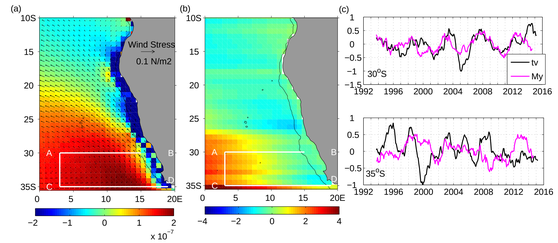
AGULHAS RINGS IN SSHA



Hovmöller diagrams of monthly SSH anomalies (in cm) across 35ºS (a,b) and 30ºS (c,d). Anomalies are stronger west of the black line located at 17.5ºE for 35ºS and at 14ºE for 30ºS.

- Anomalies of SSH are about two times larger at 35ºS than at 30ºS, suggesting a stronger mesoscale activity at 35ºS.
- Because individual Agulhas rings only cover a small part of the longitude range used to compute integrated transport, their impact can be masked in the wavelet plots.

SVERDRUP TRANSPORT



(a) Climatologies of ERA[4] interim wind stress curl (Nm^{-3}, in color) and the wind stress (Nm^{-2}, arrows). (b) Climatology of the Sverdrup stream function (in Sv). (c) Zonally integrated normalized anomalies of Sverdrup transport (M_y, magenta) and meridional transport (tv, black) at 30ºS and 35ºS. Both time series are smoothed using a 18-month running mean.

- The transport from the Sverdrup stream function is significantly lower (∼ten times) than the observed meridional transport in the BENGC.
- There is some similarity in the variability of the scaled Sverdrup transport and meridional transport across AB, however, this is not the case across CD.

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