Cross-Shelf Exchanges in the South African EBC/WBC System: Model Analysis

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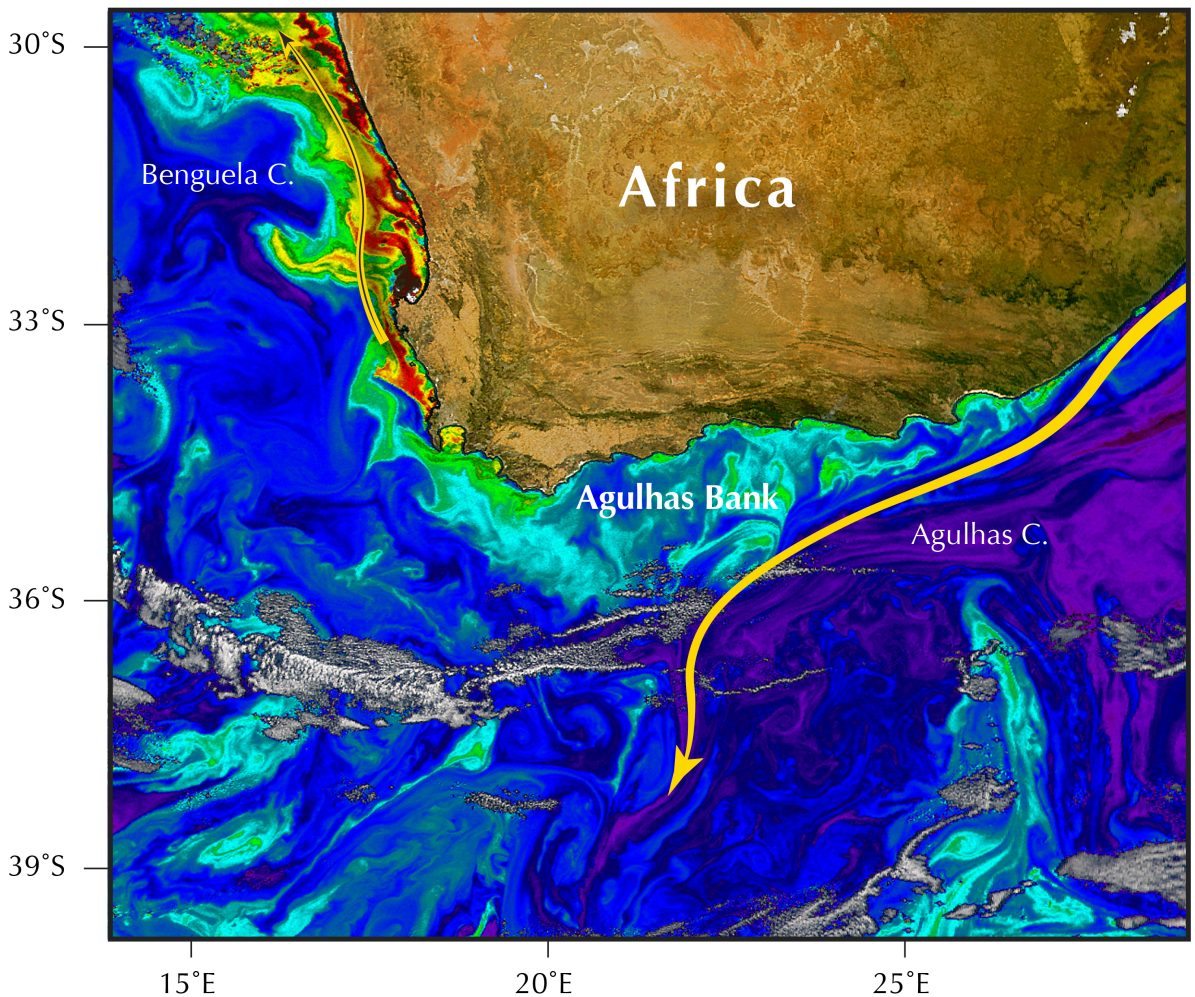


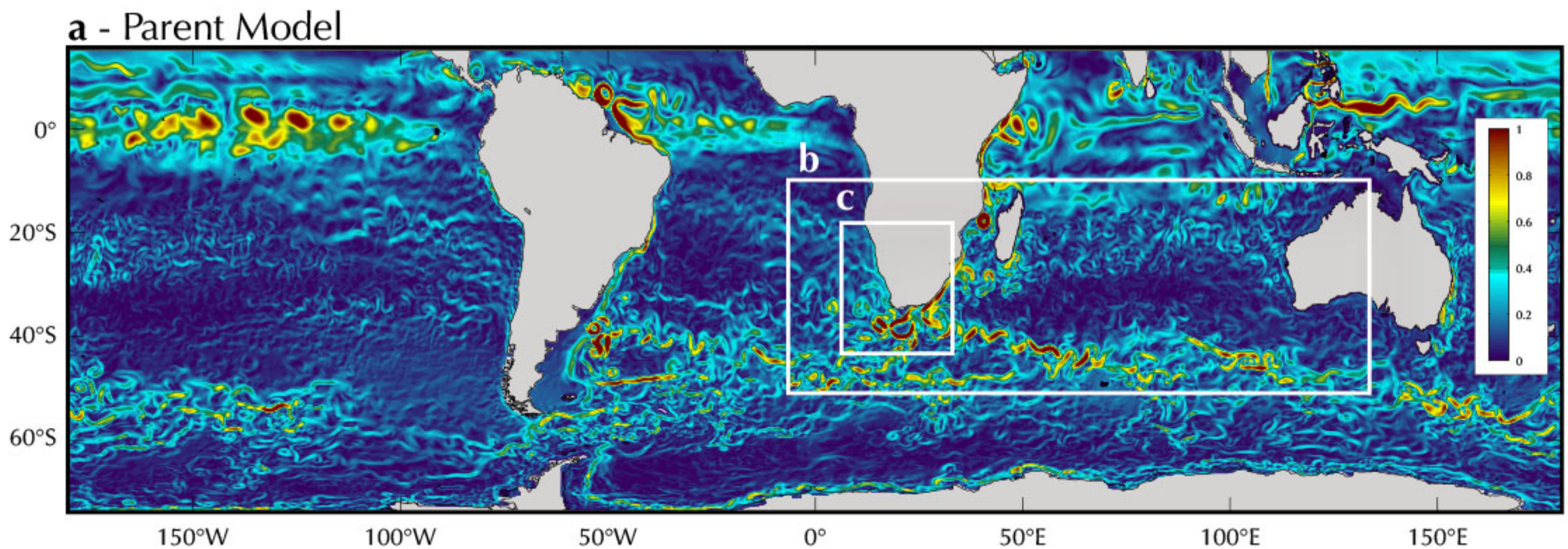
Introduction

This presentation uses the results of a high-resolution numerical model to characterize the impact of the Agulhas Current (AC) over the Agulhas Bank (AB) circulation. In a separate presentation Strub et al characterizes the shelf/deep-ocean interactions through the use satellite data.

Organization

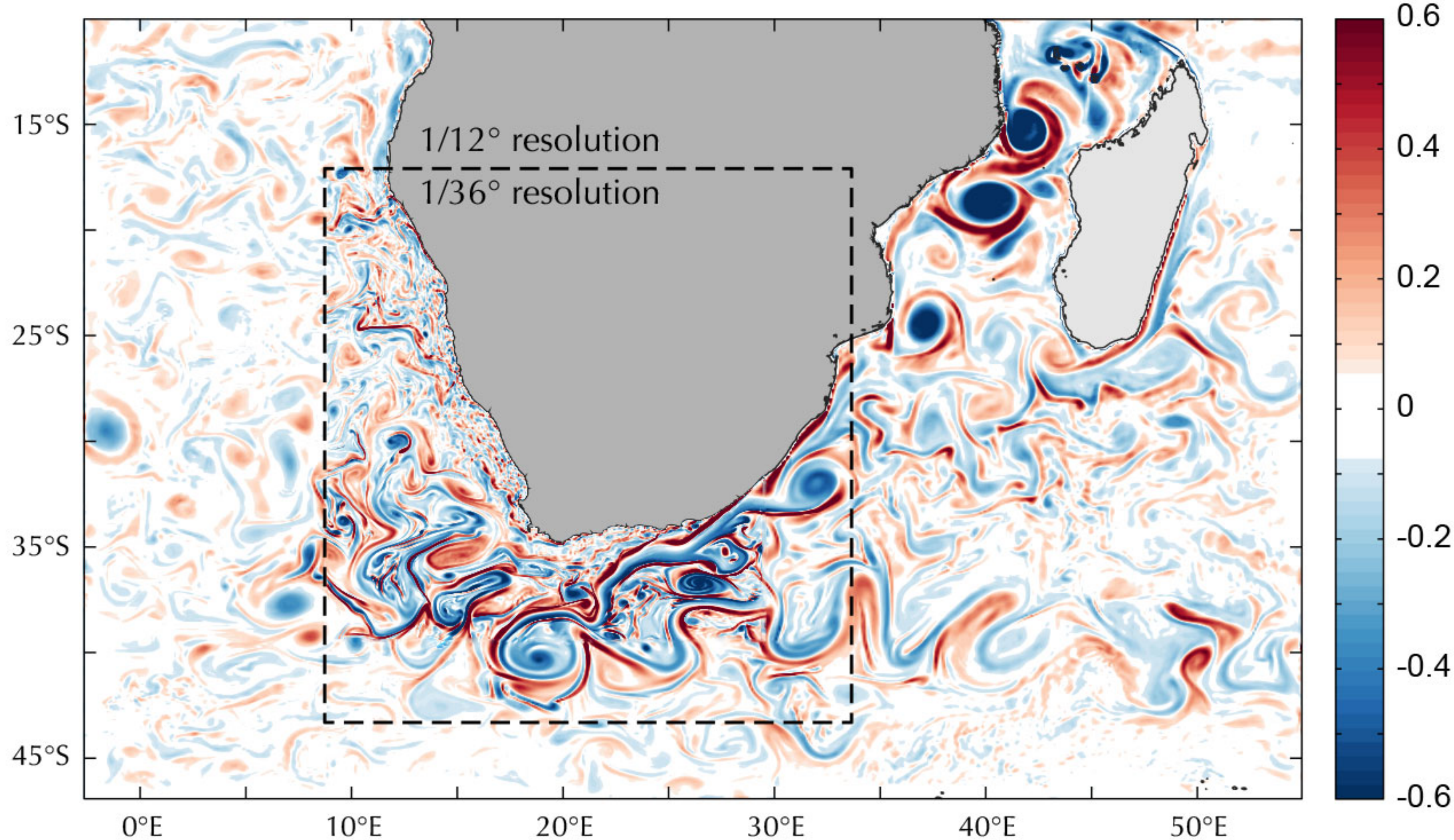
The presentation is organized as follows: **Slides 2&3** describe the model configuration. **Slides 4&5** compares model results with observations (4,5). **Slides 6&7** describes the mean circulation and seasonal changes. **Slide 8 to 12** focuses on shelf/deep-ocean exchanges. **Slide 13** conclusions.

Model Description



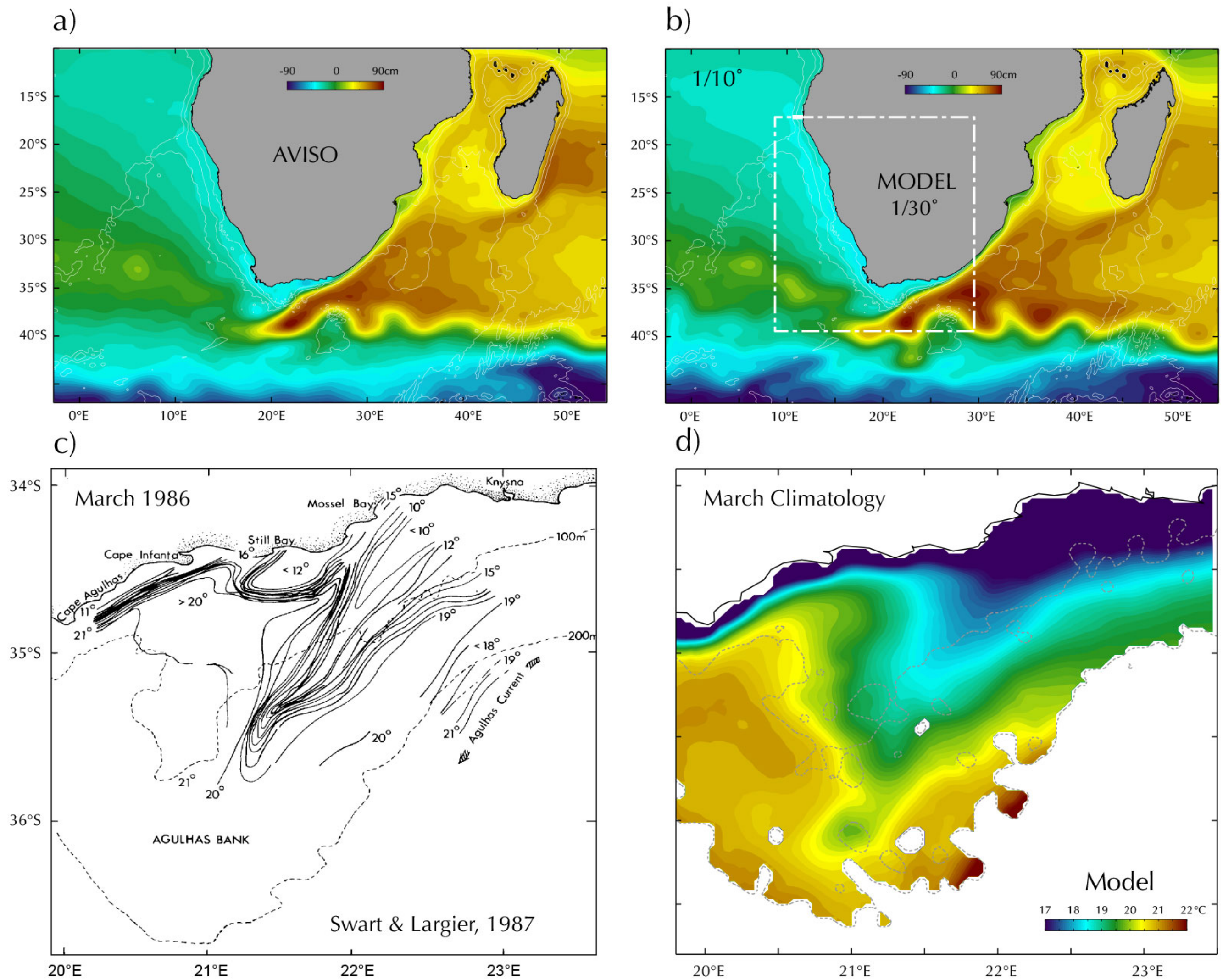
We use a nested configuration of the ROMS model. The parent grid (a) has a spatial resolution of 1/4°and 60 terrain-following levels in the vertical with enhanced resolution at the surface. The first child grid (b) has a spatial resolution of 1/12˚, and the second child 1/30˚ (2-3km) (c). The bottom topography of the model was derived ETOPO1 and the model was forced with one-day averaged fluxes from ERA5 covering the 1979-2019 period. Heat fluxes will include a tendency restoring term to the Pathfinder SST climatology. Tidal forcing includes the amplitude and phase of the tide generating potential of the first 8 tidal components (M2, S2, N2, K2, K1, O1, P1, Q1). At the northern open boundary we nudge the parent to the monthly mean climatology provided by the high resolution GLORYS12V1 global simulation (1/12˚). The initial condition is obtained from the month of January of the same model. Horizontal diffusion is represented by a bi-harmonic operator satisfying the Peclet constraint (Marchesiello et al., 2009). For vertical mixing we use a KPP scheme (Large et al., 1994). No explicit diffusion and viscosity is added to the high order diffusive schemes of the model. The model also includes a quadratic representation of bottom friction.

Model Description



This snapshot of the normalized relative vorticity in the two child grids illustrates the sub-mesoscale resolving capabilities of the model configuration used in this study.

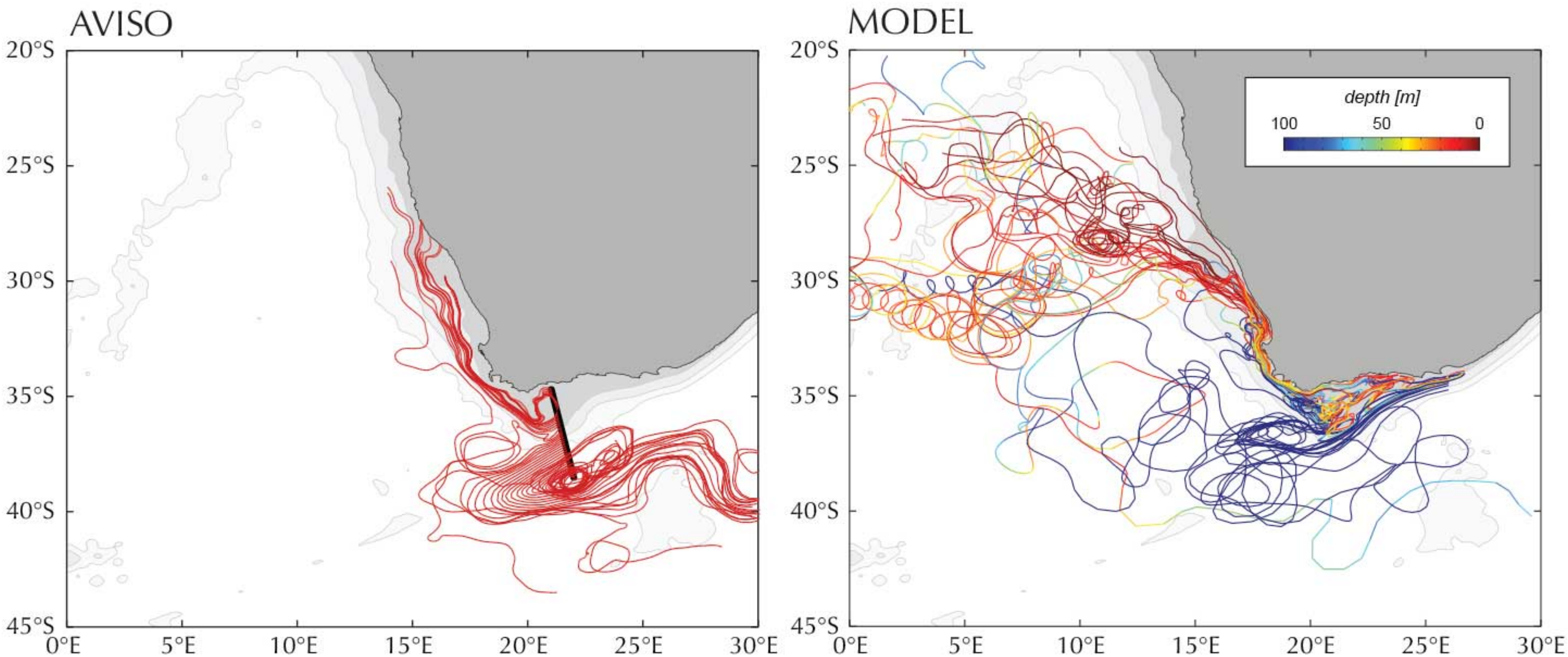
Model & Observations



Model evaluation: Top panel compares time mean SSH from: (a) AVISO and (b) model. Bottom panels compares upper temperatures distribution from: (c) hydrographic observations and (d) model.

The cold ridge. The tongue of cold and relatively fresh waters depicted in the observations is a characteristic feature of the AB, which has been dubbed the "cold ridge". Ancillary analysis of the model shows that this ridge is generated by the offshelf advection of cold waters upwelled along the coast.

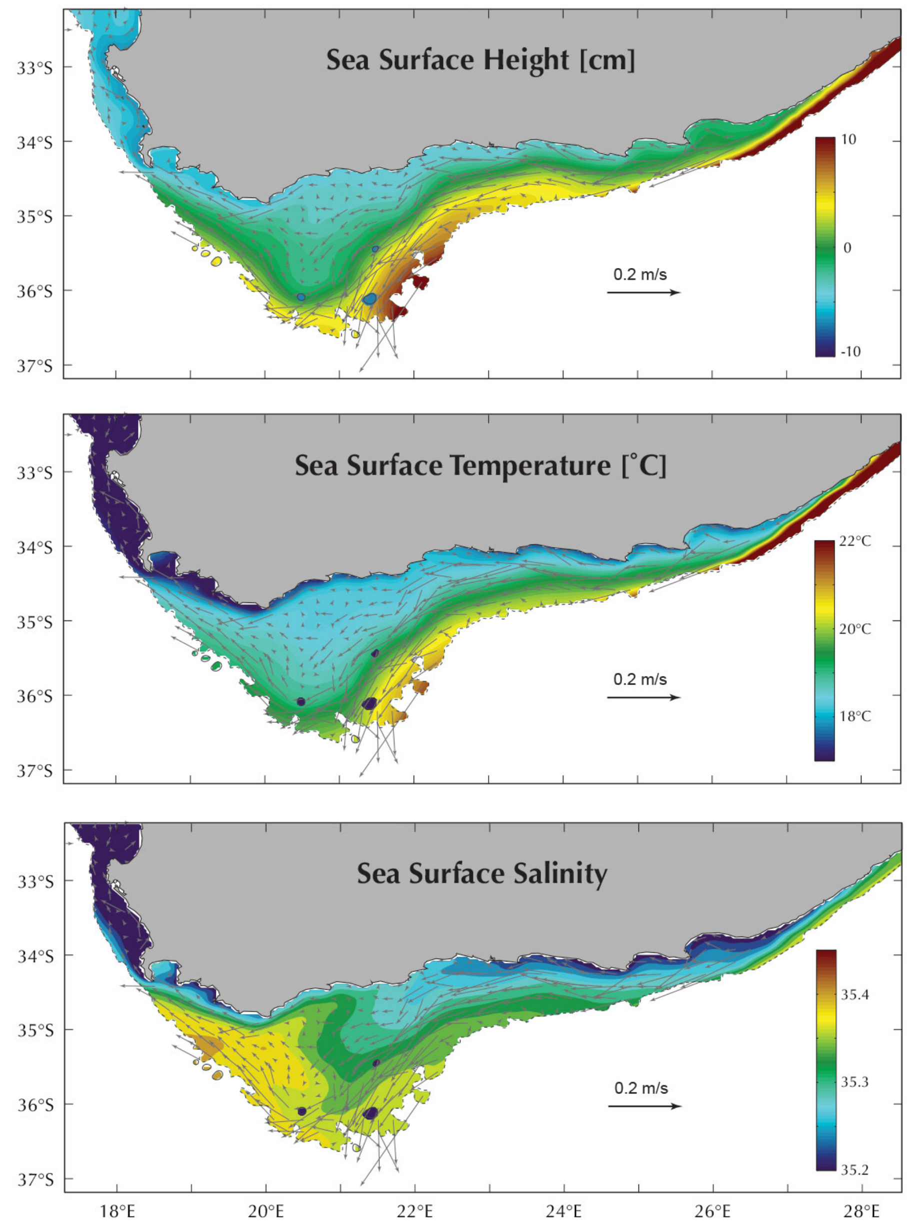
Model & Observations



Model evaluation: Particles trajectories calculated from geostrophic velocities derived from AVISO altimeter data (left panel) and from floats released in the model (right panel). Color shows particles depth, which in the AVISO calculation represent the upper layer of the ocean. Particles in the model show more convoluted trajectories, reflecting their higher spatial and temporal resolution however, both estimates (model and AVISO) show similar connection patterns in the shelf and deep ocean.

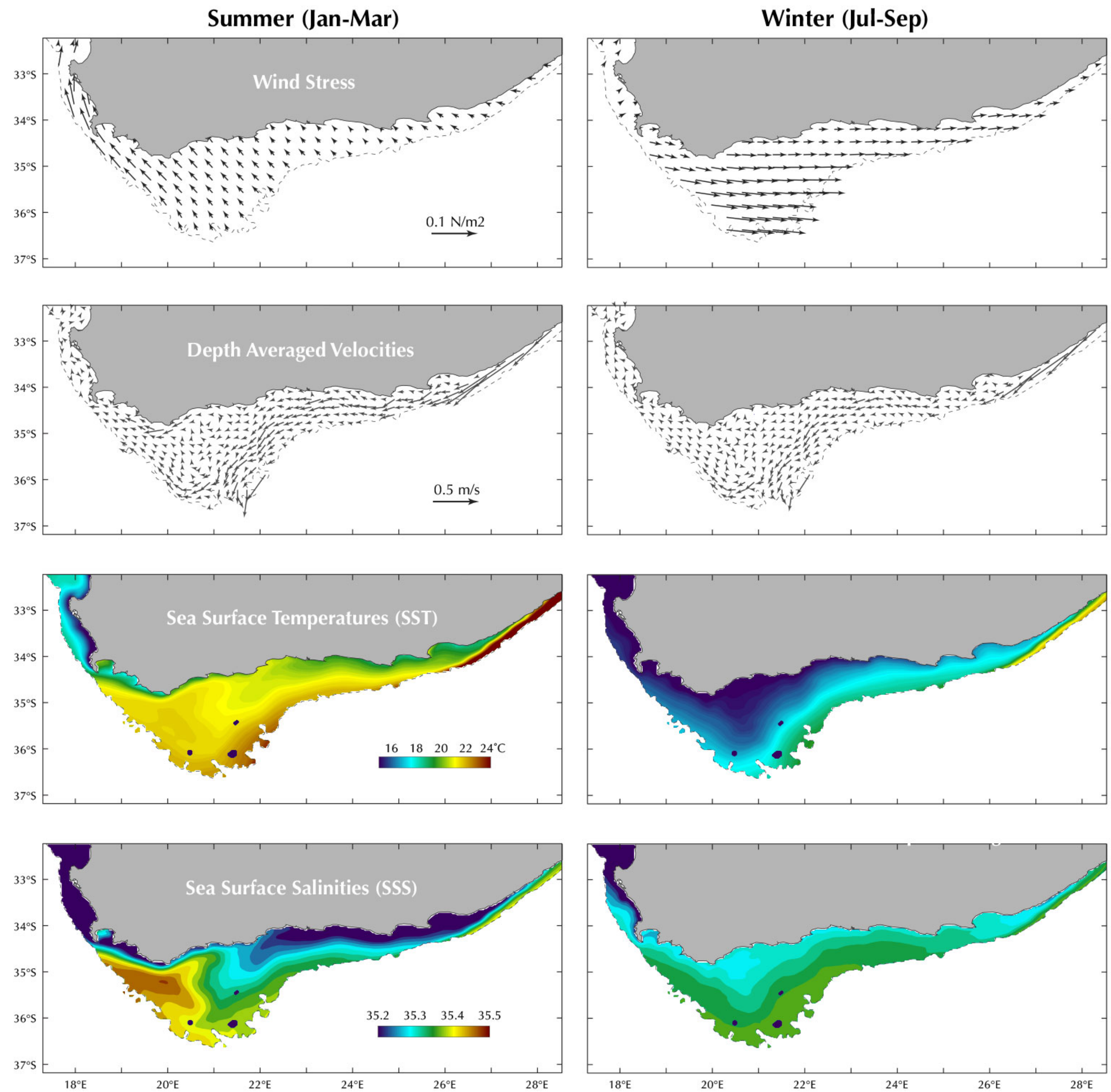
Agulhas Bank Circulation: Time Mean Circulation

The time mean circulation over the AB is dominated by a cyclonic flow that intensifies towards the shelfbreak. This circulation pattern is relatively uniform although the importance of its drivers varies on location: in the outer shelf the circulation is strongly influenced by the Agulhas C. while in the inner shelf is by local winds, solar heating, tides and propagating coastal trapped waves. The middle shelf is a transition region that may respond to local (winds, tides, waves, etc.) or remote (AC) forcing at any given time. Density and velocity gradients are larger on the eastern region on account of the influence of the AC; its interaction with the bottom creates onshore Ekman veering and shelf break upwelling of cooler water, which spreads into the bottom of the shelf.

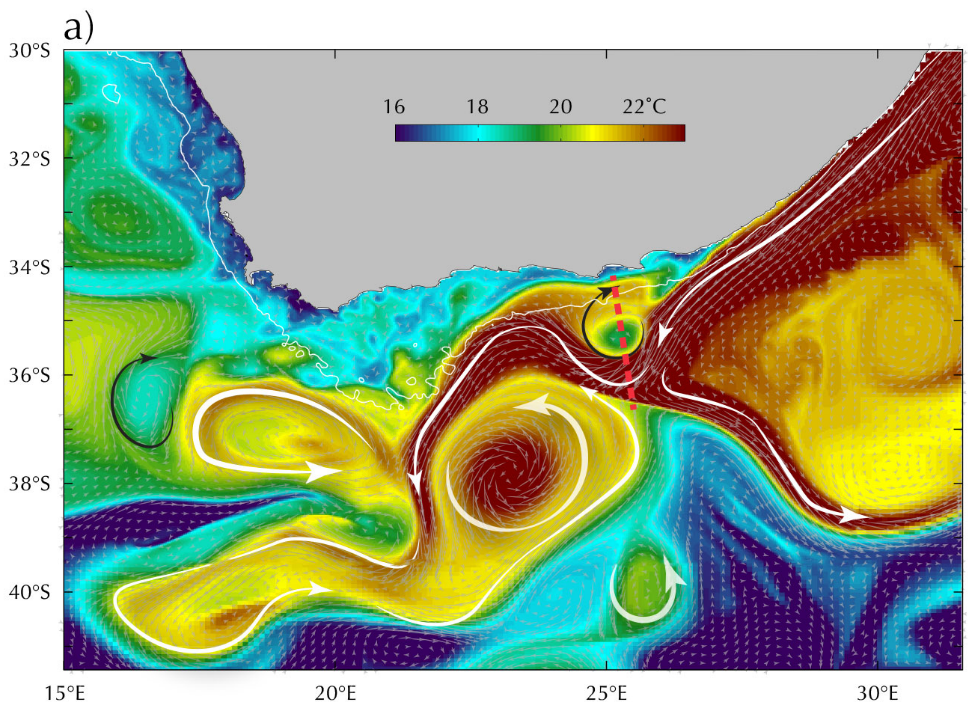


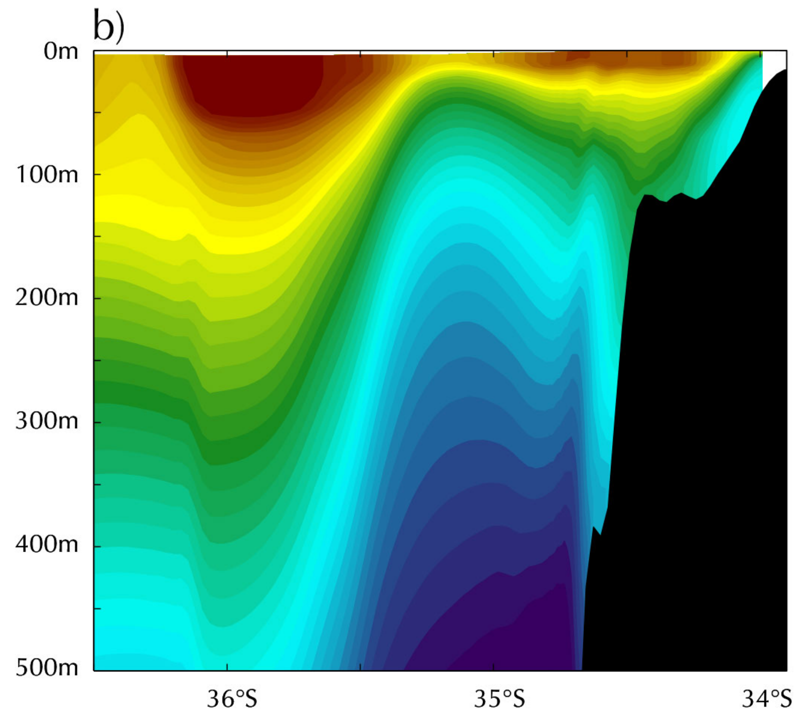
Agulhas Bank Circulation: The Seasonal Cycle

Seasonal evolution of the wind stress forcing, depth averaged velocities and SST and SSS over the Agulhas Bank region.



Natal pulses: Shelf/open ocean interactions along the Agulhas Bank are enhanced by the passage of Natal Pulses (a), which are eddies generated in a farther upstream location (Natal Bight). These events generate a cold dome on the bottom layers and a ridge of warm water along the upper layers of the shelf break, a phenomenon well documented in observational. In our simulation the dome of cold water is entrained from depths greater than 500m (b). The generation of shear-edge features, like the one shown here, is quite irregular both in observations and the present model. Altimeter data indicate an average of one to two shear-edge eddies/year although there are years with five or six and others with zero (Krug et al., 2014).

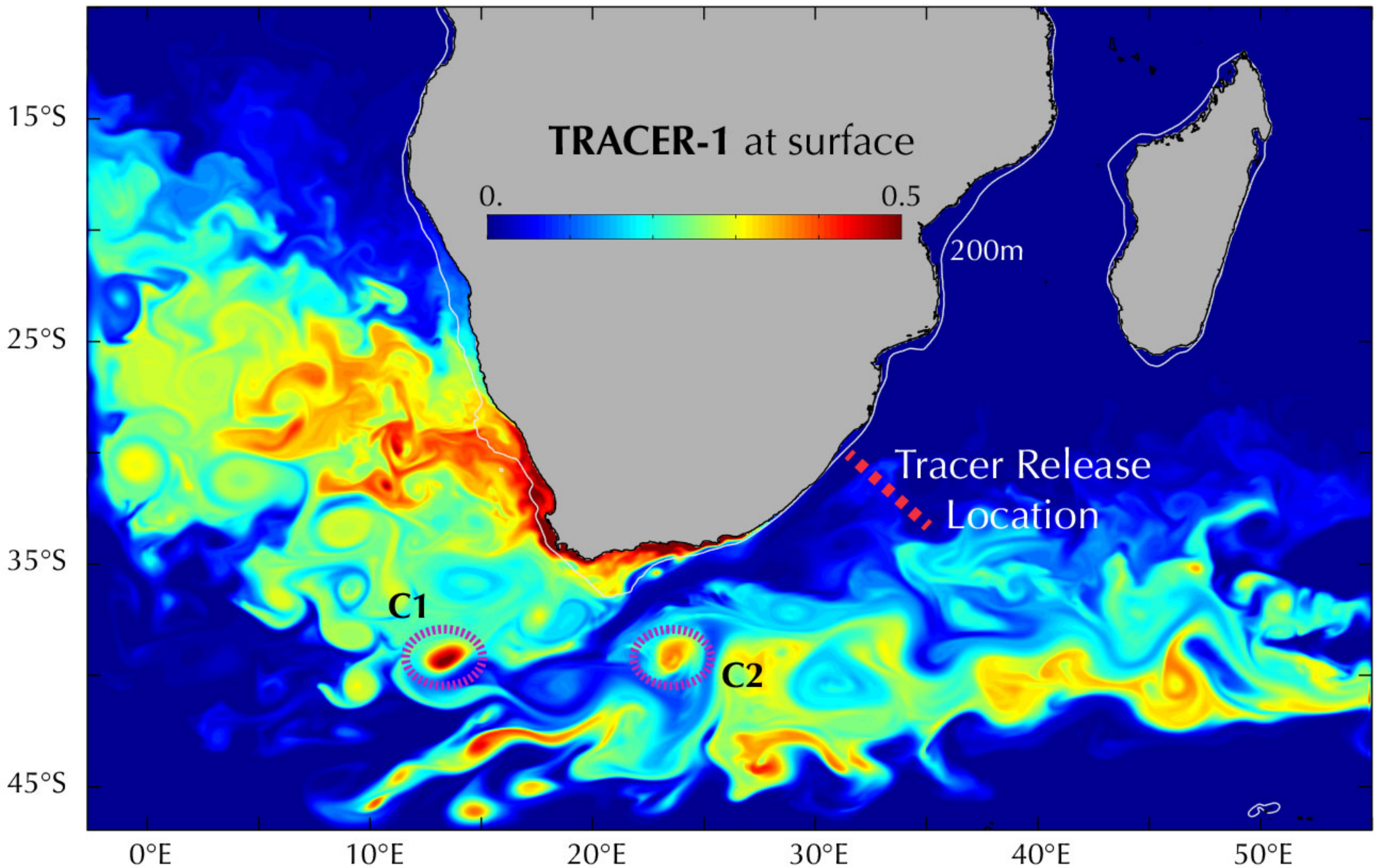




Natal pulses: a) SST and thermocline velocities (0-500m), the red dotted line mark the cross-shelf section shown in the right panel; (b) Depth profile of temperature during the passage of a Natal pulse.

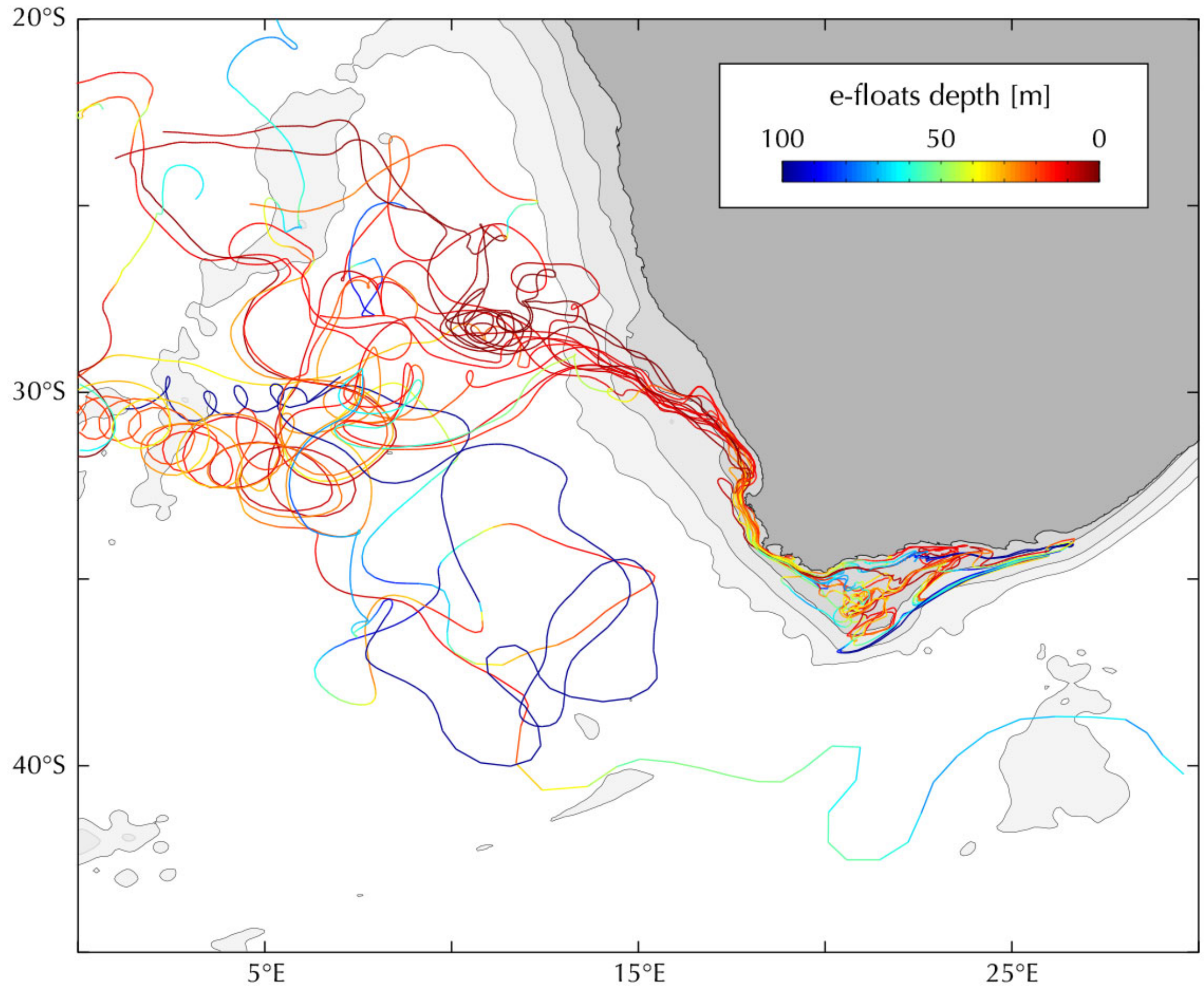
Cross-Shelf Exchanges: Tracer Experiments

To characterize these exchanges we injected a passive tracer at an upstream cross section located in the core of the AC and below 200m (red dotted line). No portion of the tracer is released over the shelf. After a five-year integration the model generates a surface tracer plume that peaks along the African coast and extends into the Benguela region, where the tracer is detrained into the deep ocean. Only the portion of the released tracer closest to the continental slope of Africa is uplifted into the bottom layers of the shelf; note, for example, the absence of tracer over the main axis of the AC.

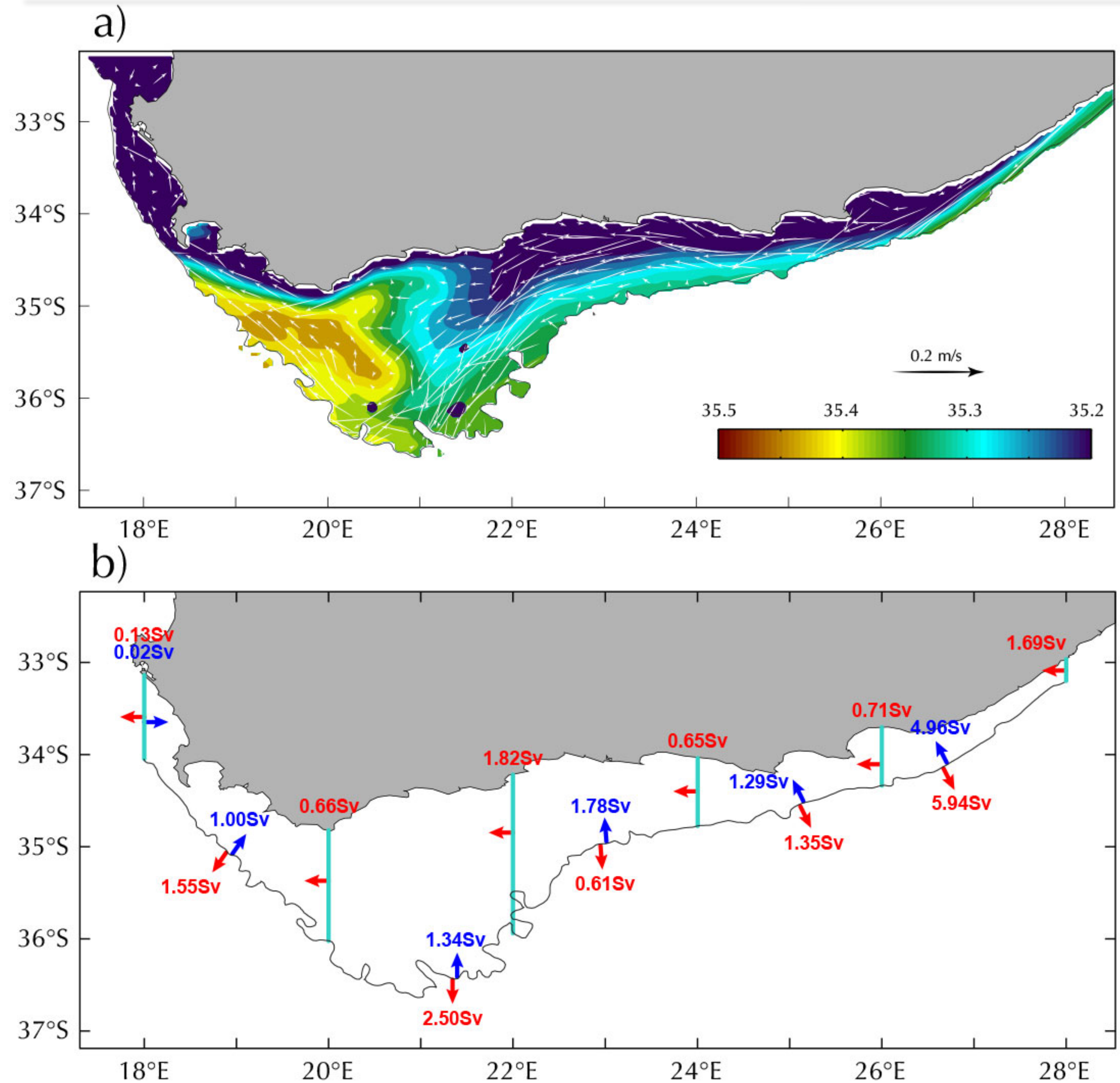


Cross-Shelf Exchanges: Floats Release

To further characterize the shelf/open-ocean exchanges we released neutrally buoyant floats at the same location. Float trajectories show their entrainment into the shelf, their transit to the Benguela upwelling region and their detrainment into the open ocean. Both calculations, tracer and floats, indicate that shelf/open-ocean exchanges are an alternative method of Indian/Atlantic mass exchange.



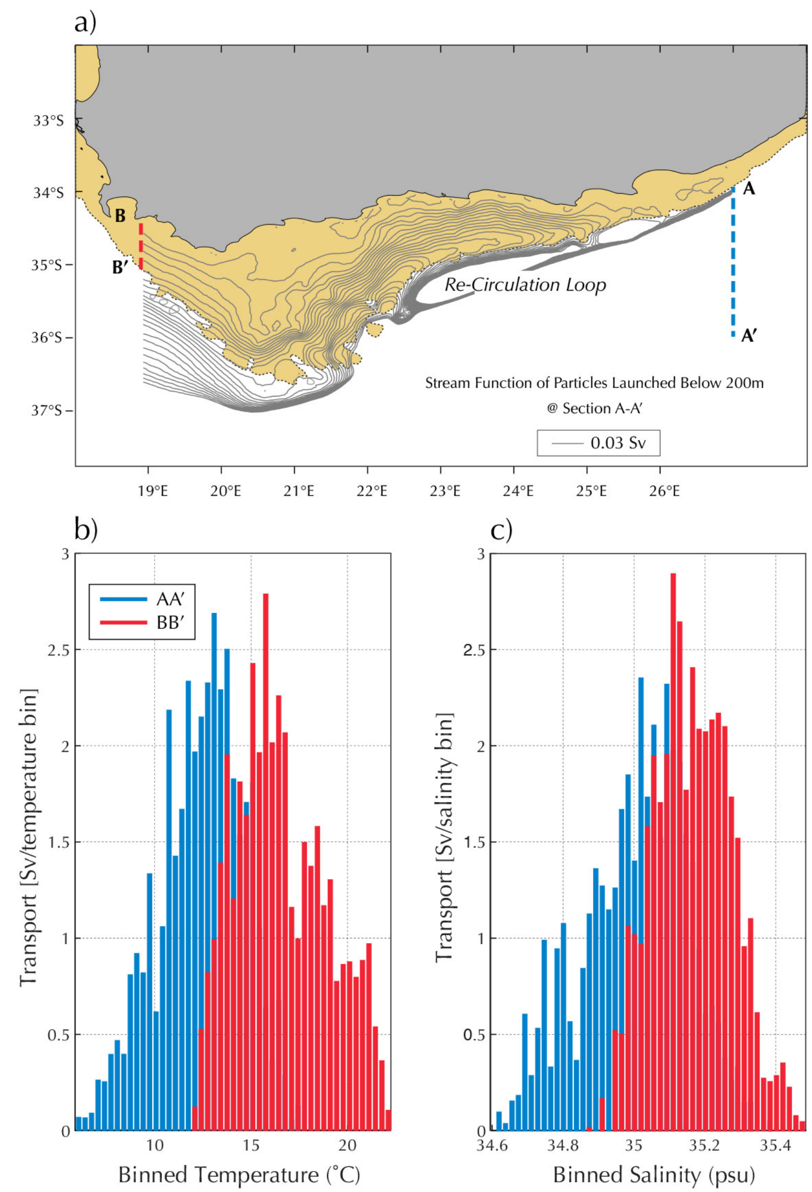
Cross-Shelf Exchanges: Transports



A mass budget shows that the transport over the Agulhas Bank transport is largely controlled by exchanges with the deep ocean region. The impact of shelf/deep-ocean interactions on the deep ocean region is reflected in the magnitude of net cross-shelf exchanges, which is obtained by integrating all the onshelf (or offshelf) transports (blue or red arro). Net cross-shelf mass fluxes, ~10 Sv, are the same order of magnitude as the net Indian/Atlantic interocean exchange (~15 Sv), representing ~16% of the Agulhas Current mean volume transport.

Cross-Shelf Exchanges: Water Mass Conversions

Transports and water mass conversions in the Agulhas Retroflection Region calculated from ARIANE floats. a) Stream function derived from float trajectories. Approximately 500,000 floats were released during a 5-year intervals at the cross-section AA'. Floats were released below 200 m. Stream function contour is 0.03 Sv; b) Histogram of binned temperatures at cross-sectios AA' (blue) and BB' (red). c) Idem for binned salinity. These histograms show the water mass transformation associated with the particles journey from the deep ocean region towards the shelf.



Conclusions

Natal pulses control the mass and energy exchange between the Agulhas Bank and the Agulhas Current. Eddy-driven interactions between the Agulhas Current and the African continental slope dominate mixing and water mass transformations along the Agulhas Current pathways, leading to a substantial contribution to the Indian/Atlantic interocean exchange. We speculate that climate change will lead to an enhancement of the impact of shelf/deep-ocean interactions on both oceanic realms.