The remote and local physical forcing in the Northern Benguela upwelling system and its impact on the environmental conditions.

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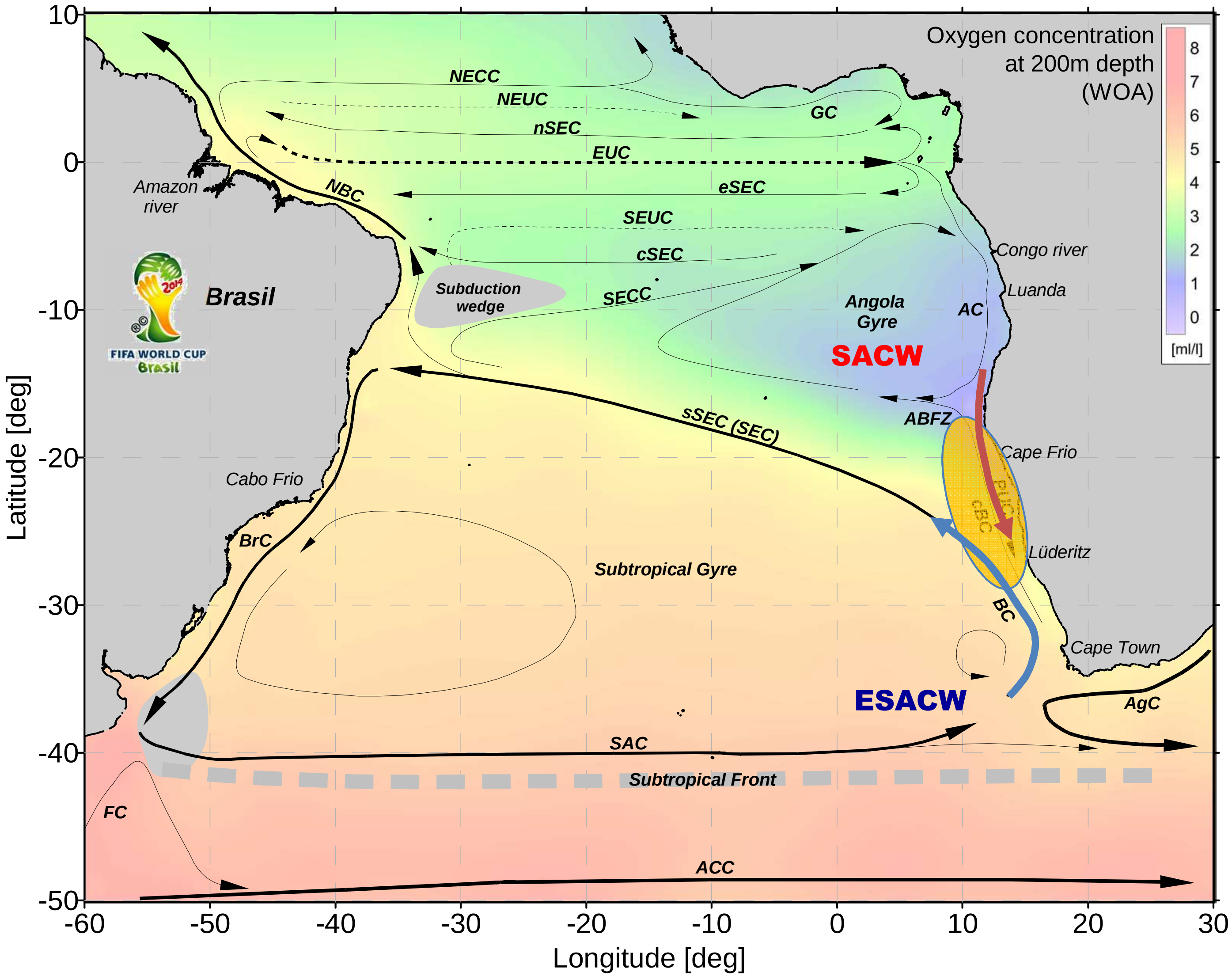
Study carried out in frame of the GENUS I + II project
Geochemistry and Ecology of the Namibian Upwelling System

http://genus.zmaw.de

SEA surface circulation



- Northern Benguela is embedded between the Angola Gyre and the subtropical gyre
- Different oxygen conditions in the upper central water
- Two different central water masses
- enter the Northern Benguela upwelling system by the Benguela current and the poleward undercurrent.

(Lass and Mohrholz, 2008)

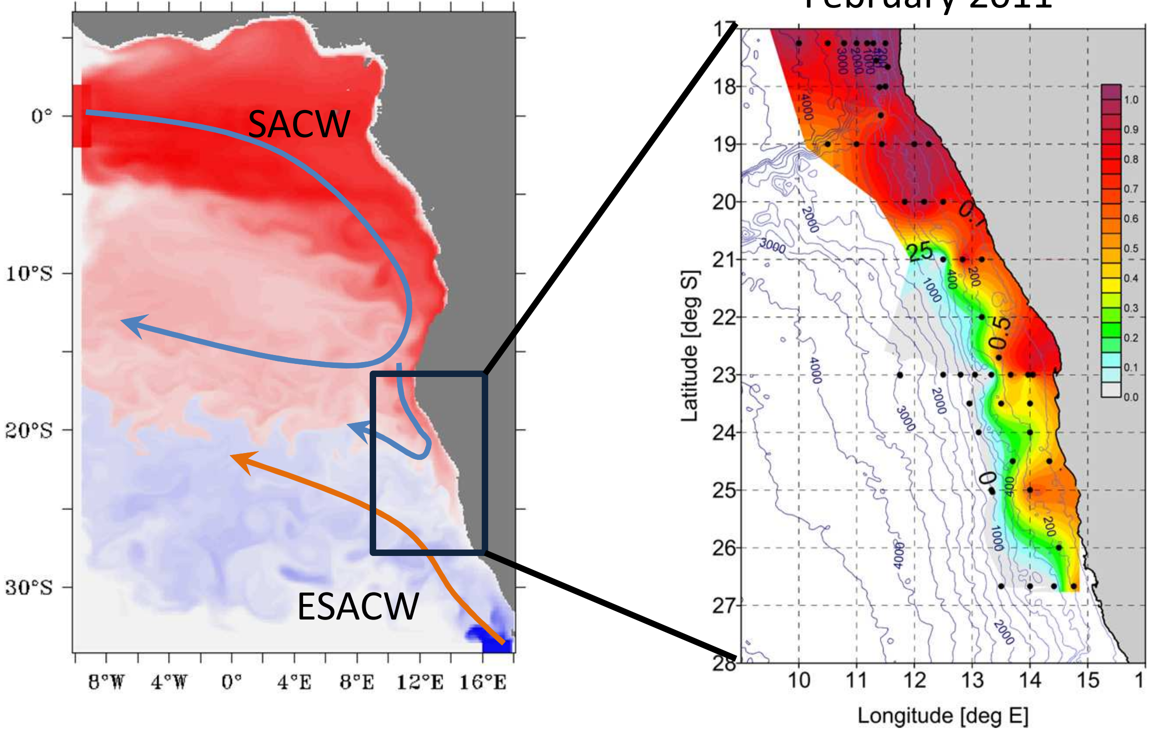
Two central water masses

- feed into upwelling, and their distributions determine to a large extent the hydrographic conditions in the Northern Benguela.

- Oxygen depleted but nutrient rich SACW
- and oxygen rich, nutrient poor ESACW and converge at the northern Namibian shelf.
- The oxygen and nutrient supply to the Namibian shelf is mainly controlled by the pole ward undercurrent.

Equator tracer (SACW)
Cape basin tracer (ESACW)

SACW fraction
February 2011



Tracer experiment with numerical model

SACW fraction based on field data

(Fennel et al., 2012)

Wind forcing by SET

- Strong saisonal and interannual variability of windfield and coastal upwelling

- Decreasing wind intensity towards the coast causes a band of negativ wind stress curl, and thus curl driven upwelling off the coast.

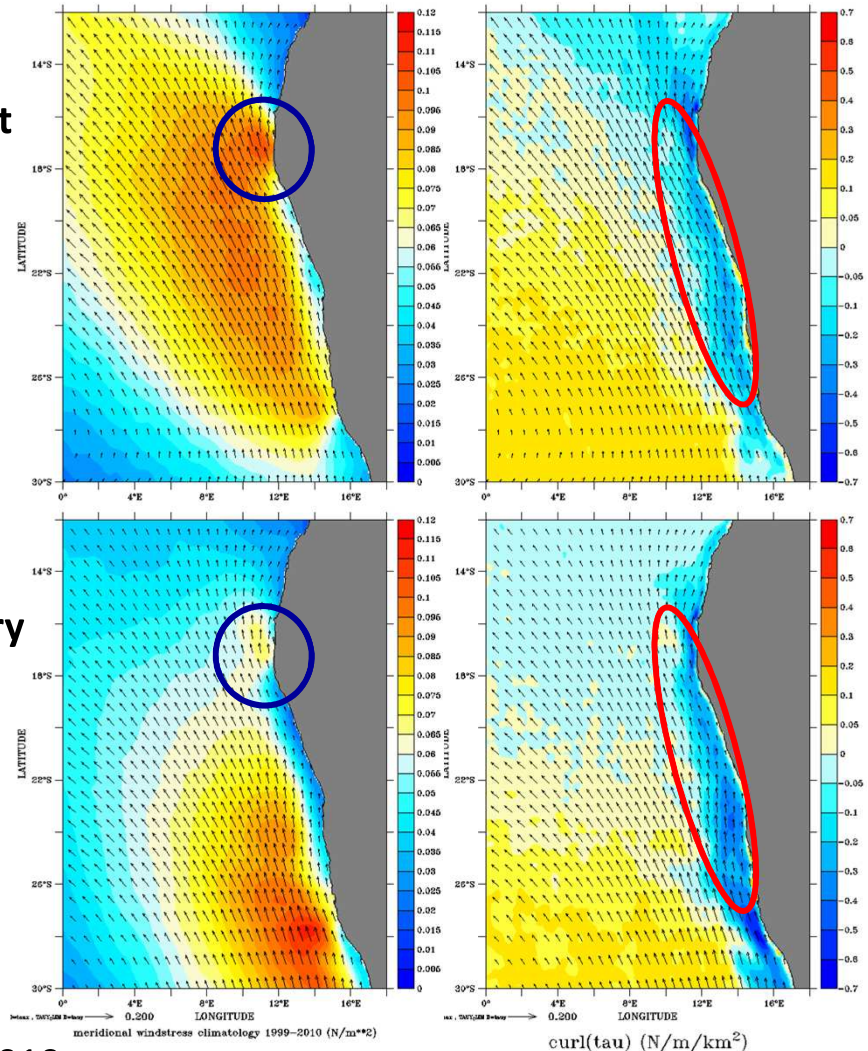
- The Kunene upwelling cell modulates the intensity of the pole ward undercurrent.

Meridional wind stress

Wind stress curl

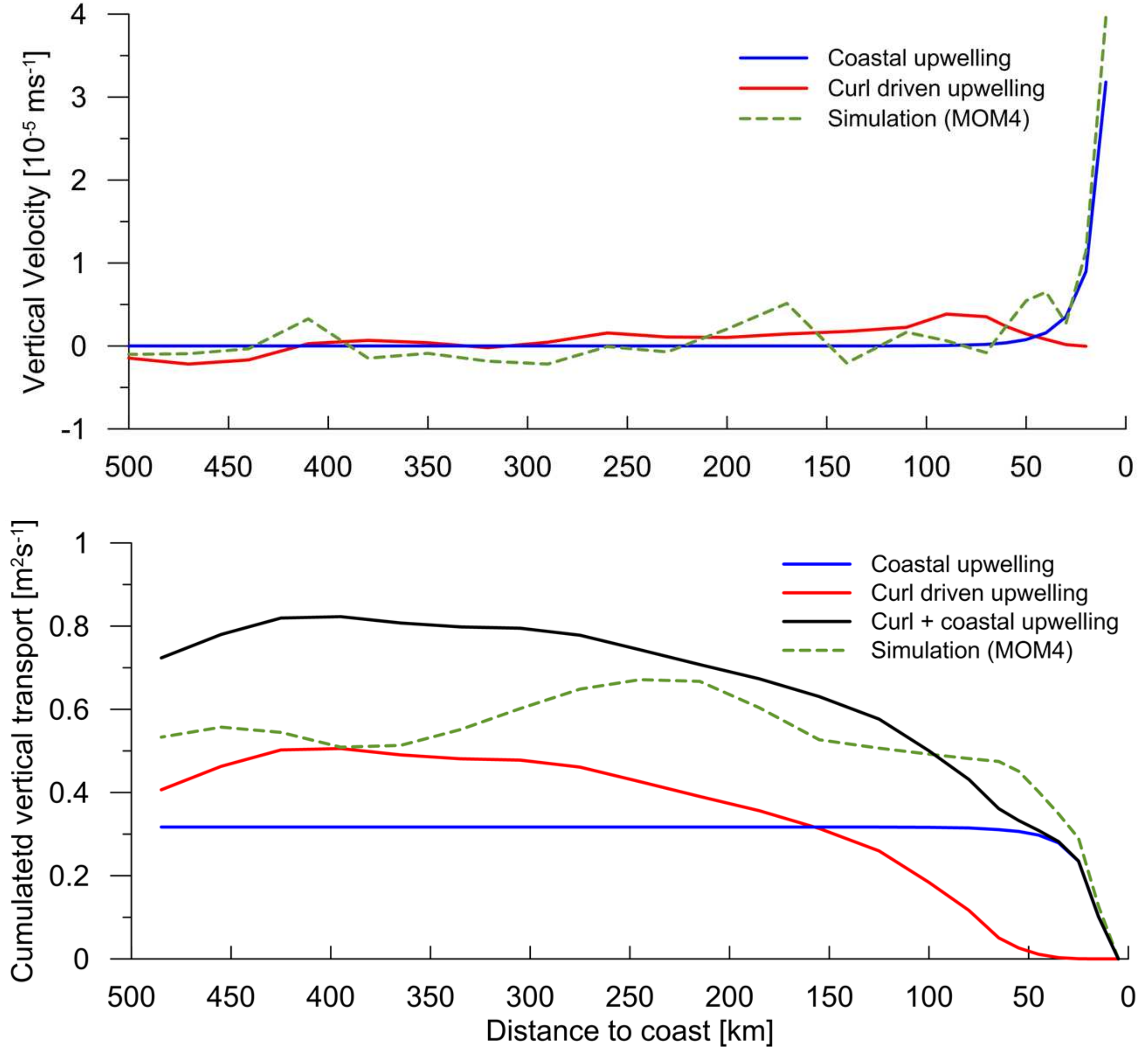
August

January



QuikSCAT monthly climatology 1999 - 2010

Coastal and curl driven upwelling



Vertical velocity at mixed layer depth along a cross shelf transect at appr. 21°S

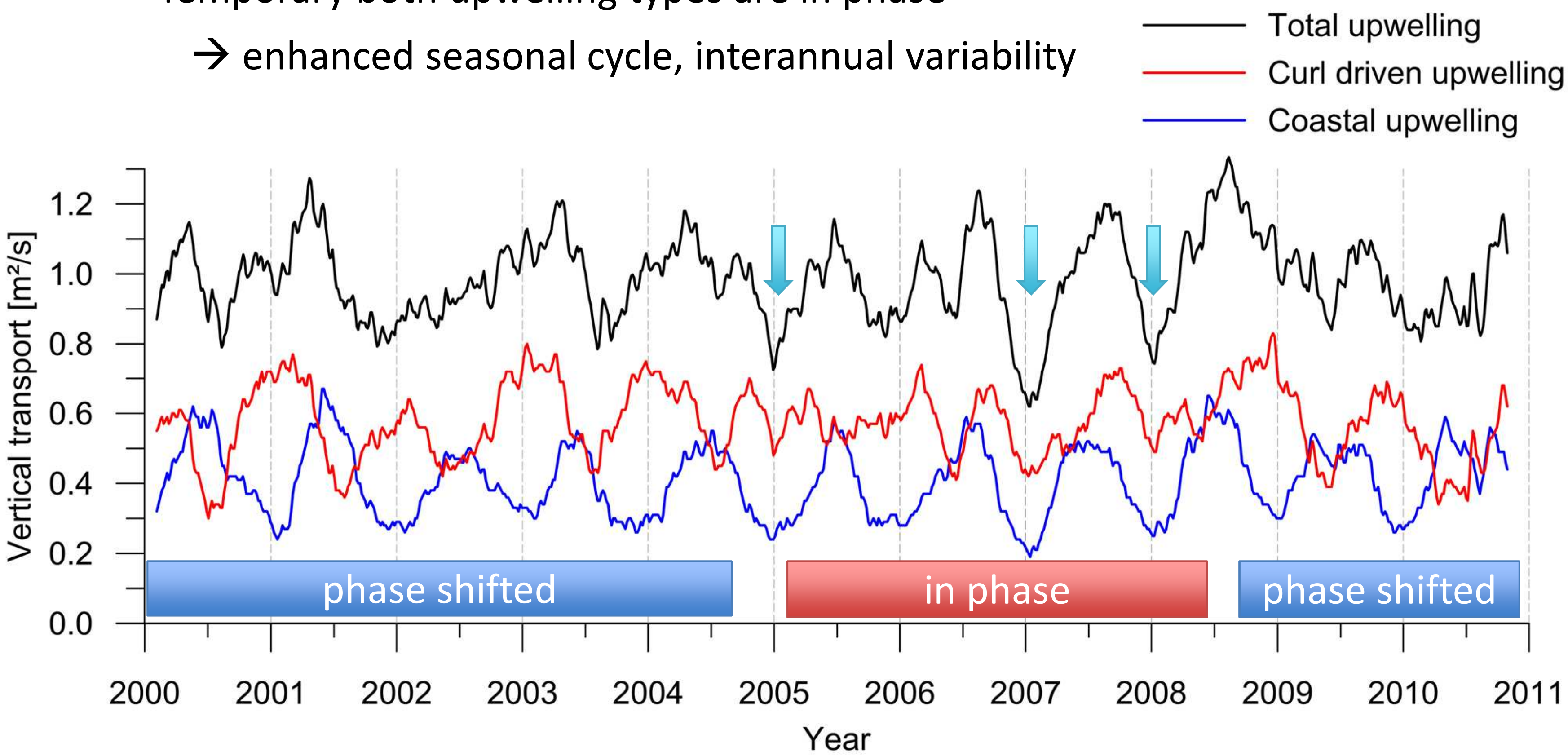
- Coastal upwelling dominates the inner shelf (~ 50km)
- The cumulative effect of curl driven upwelling exceeds the coastal upwelling.
- The numerical modell results depict a higher variability than the estimates from wind forcing.

(Mohrholz et al., 2014)

Upwelling seasonality

- Coastal upwelling depicts a regular seasonal signal, whereas curl driven upwelling has a higher variability
- Curl driven upwelling is usually phase shifted to coastal upwelling
- Temporary both upwelling types are in phase

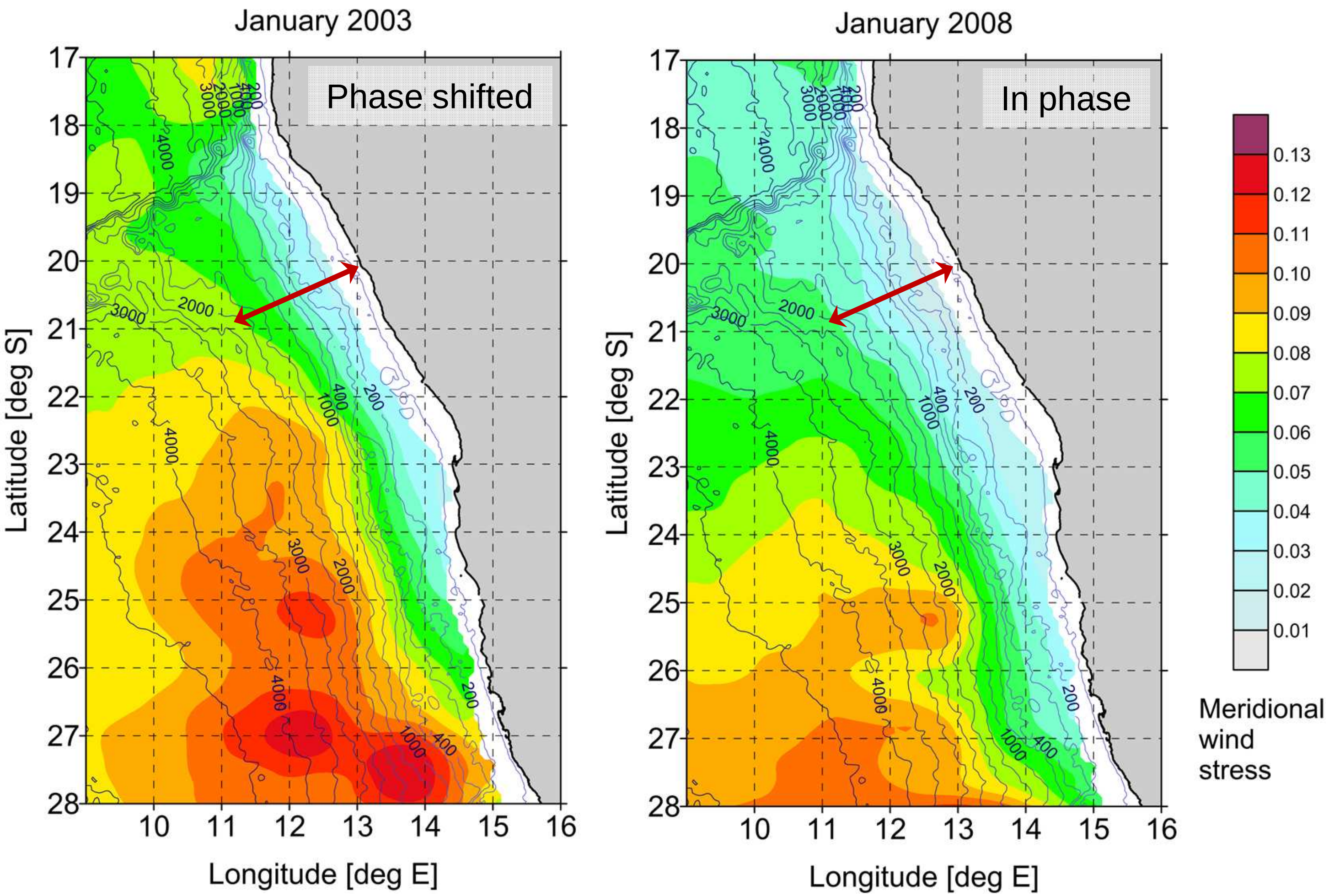
  → enhanced seasonal cycle, interannual variability



(Estimated using QuikSCAT wind data and analytical theory) (20^oS, H_{mix} = 30m, H=200m, N = $8*10^{-3}s^{-1}$)

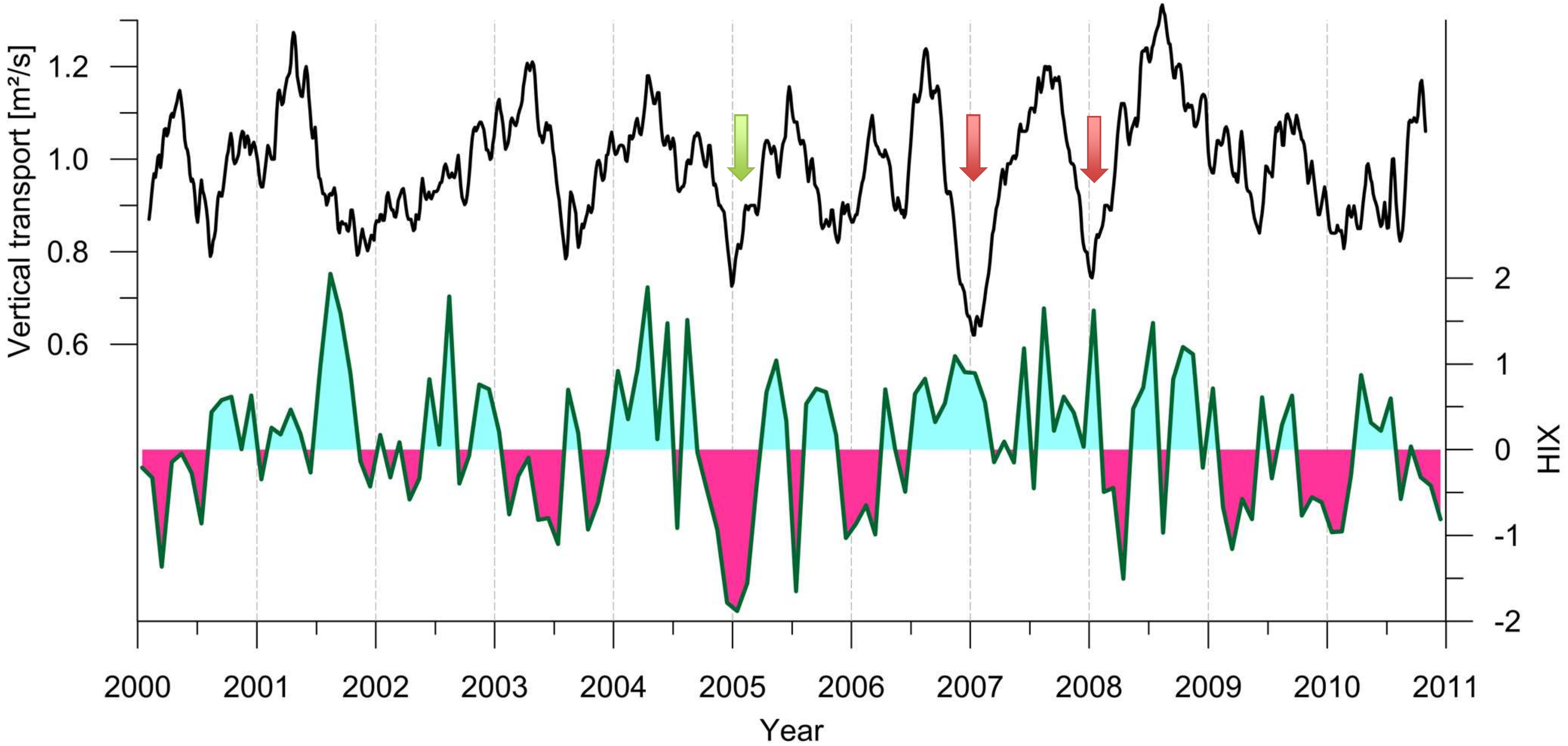
Meridional wind stress

- Core of wind patch is shifted southward
- Offshore gradient in 2008 was weak



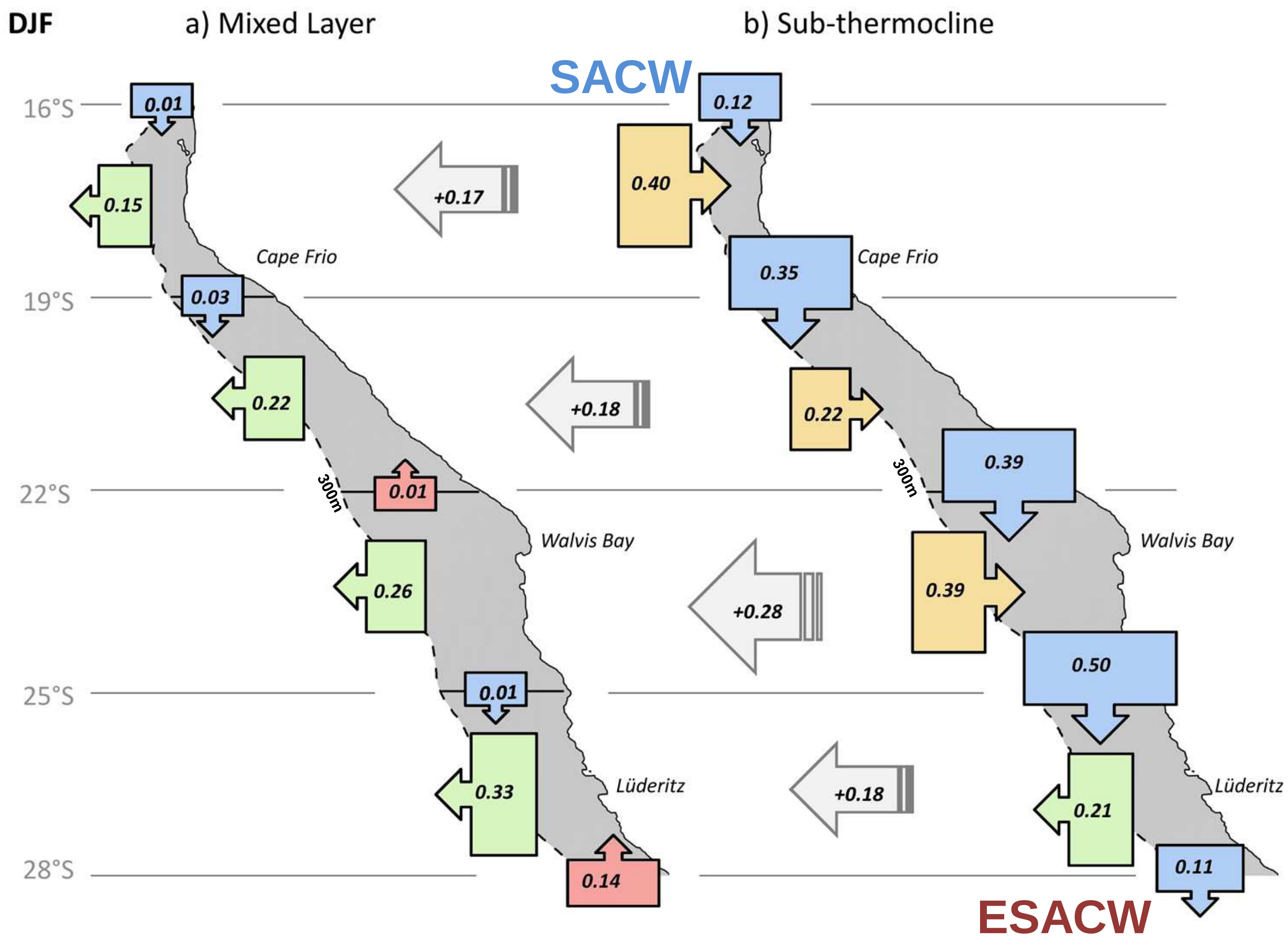
Upwelling vs. HIX

- Total upwelling and St. Helena Index (HIX) are not well correlated
- The change in phase shift occurs concurrently with the negative HIX anomaly
- The 2007 and 2008 event are not represented by the HIX



Transport budget (summer)

Climatology (2000-2008) based on numerical model



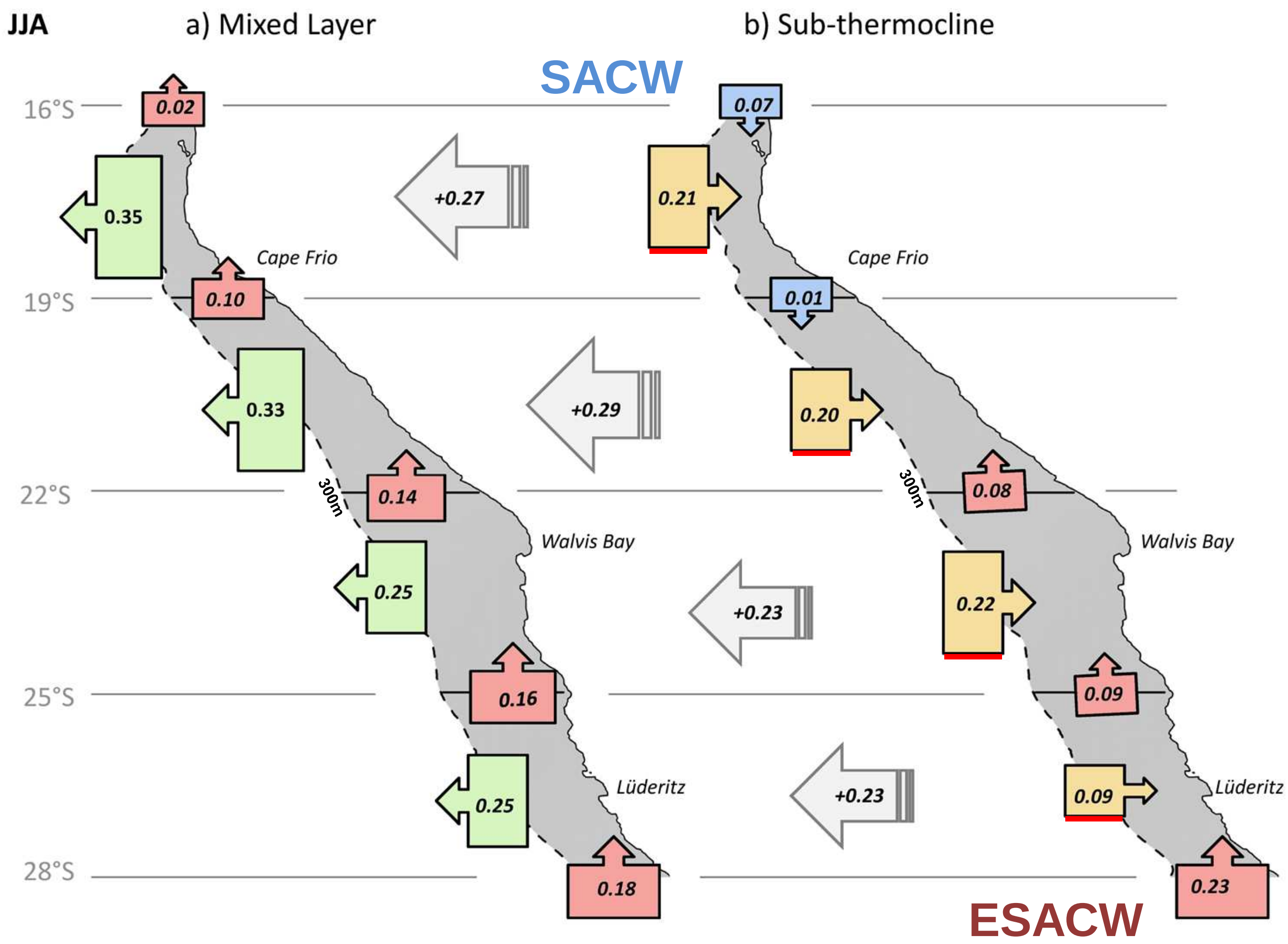
(Transports in [Sv])

- Weak meridional transports in the mixed layer
- Strong poleward undercurrent along the entire northern shelf
- Local wind stress curl enhances the poleward flow in the northern Benguela
- Offshore transport in the sub-thermocline layer off Lüderitz

(Muller et al., 2014)

Transport budget (winter)

Climatology (2000-2008) based on numerical model



(Transports in [Sv])

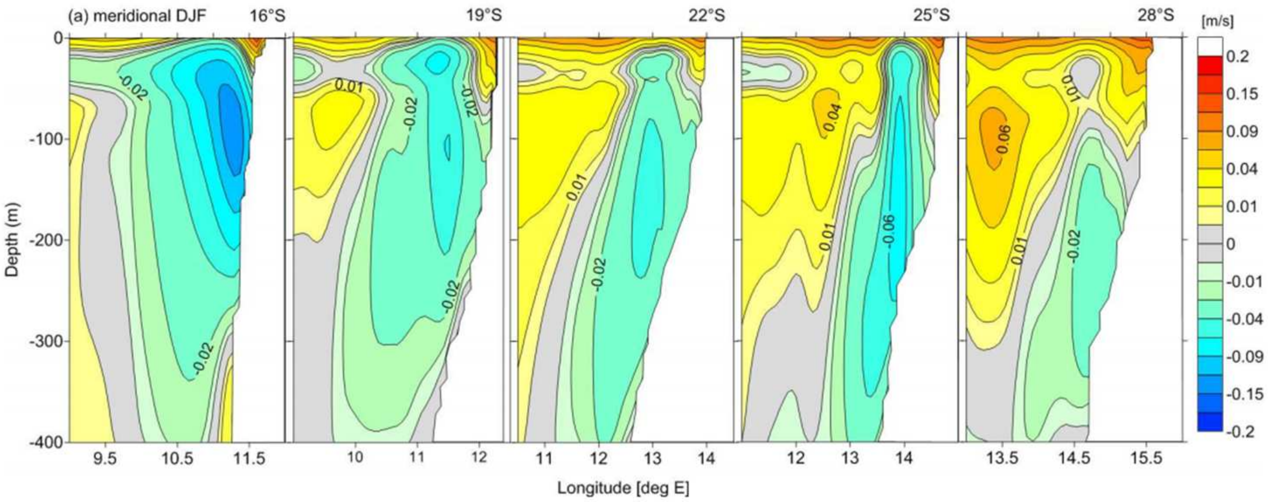
- Surface northward flow along the entire northern shelf
- Poleward subsurface transport stops at about 20°S
- Onshore transport in the sub-thermocline layer at the entire shelf, but significantly lower in the Lüderitz cell

(Muller et al., 2014)

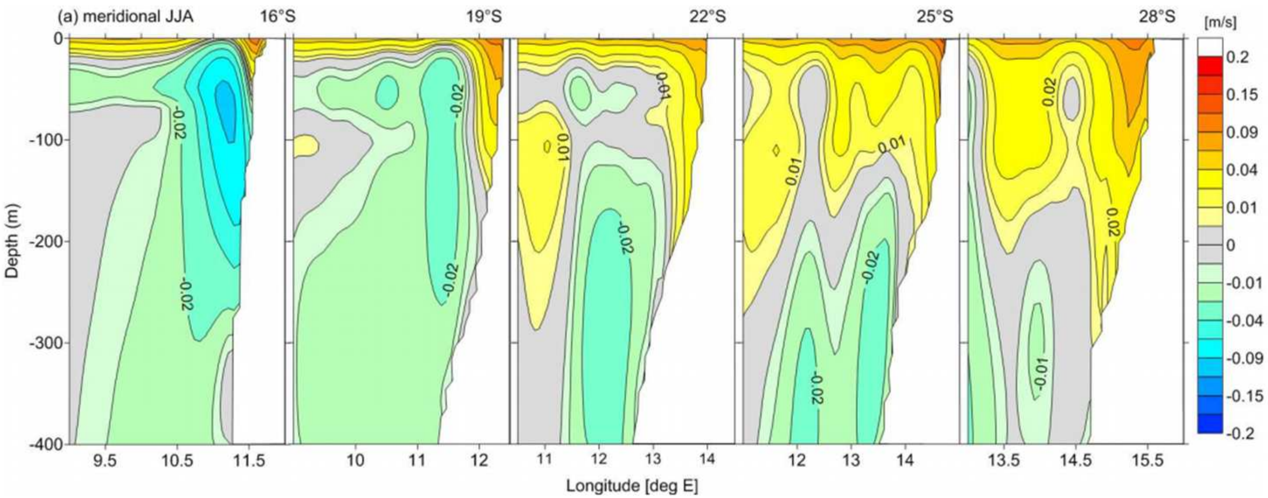
Meridional currents at cross shelf transects

Climatology (2000-2008) based on numerical model

Summer (DJF)



Winter (JJA)



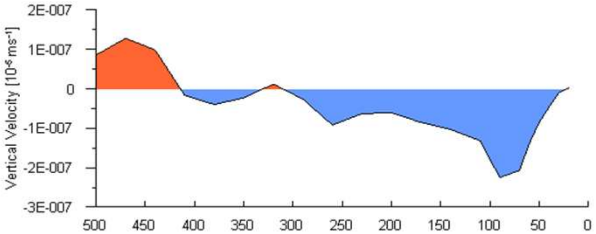
- Strong poleward current along the entire northern shelf
- Core at southward increasing depth
- Northward jet at the coast

- Weak poleward current in winter
- Change of current pattern between 19°S and 22°S

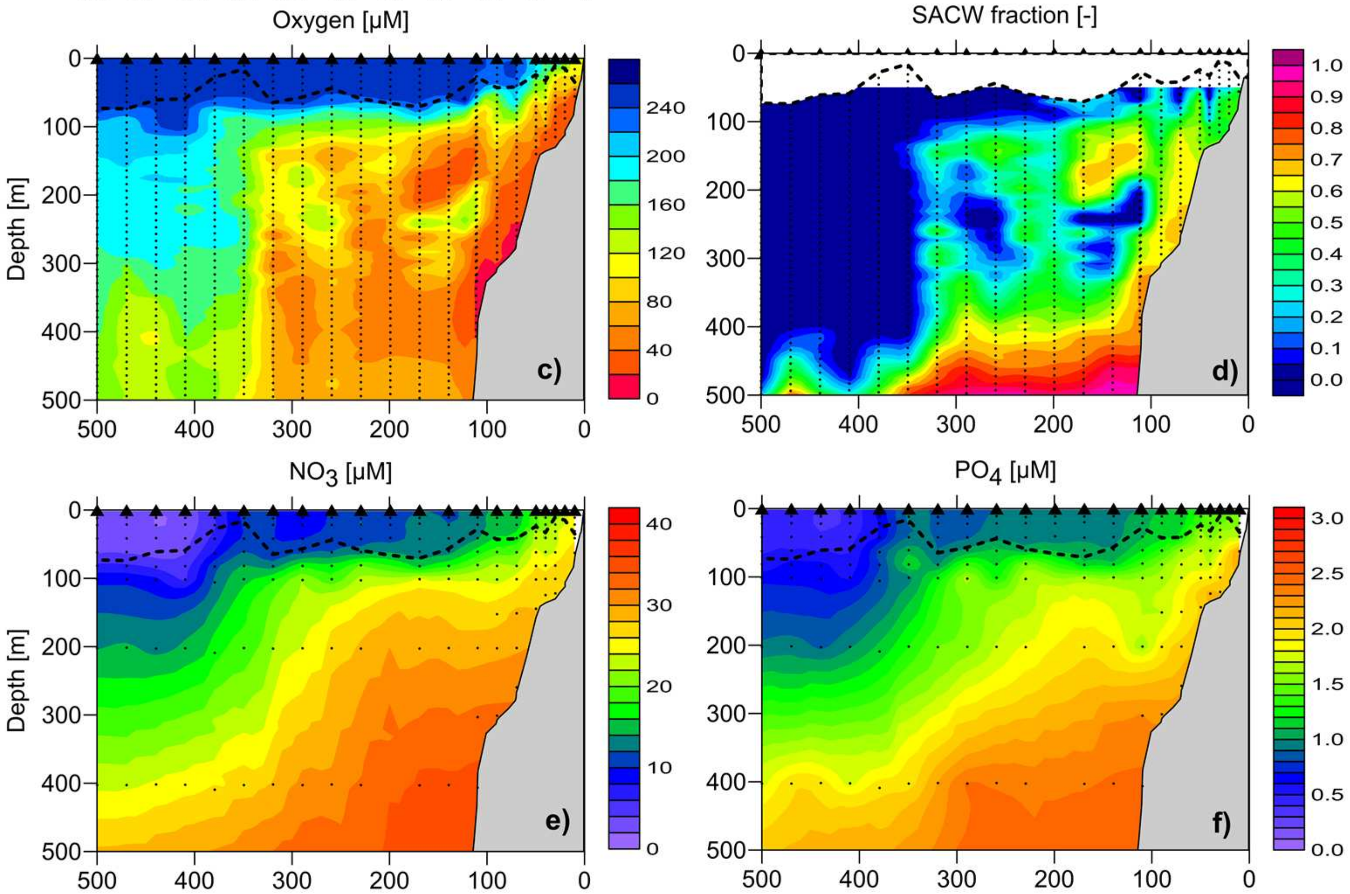
(Muller et al., 2014)

Distribution of water masses

Wind stress curl



cross shelf transect
at appr. 21°S



- Distinct vertical front between SACW and ESACW
- Controls also nutrient distributions
- Offshore occurrence of SACW confines to the negative wind stress curl band
- Confirms with Sverdrup balance

$$\beta \rho M^{(y)} = -\frac{\partial \tau^{(x)}}{\partial y} + \frac{\partial \tau^{(y)}}{\partial x}$$

(Mohrholz et al., 2014)

Summary

- The wind forcing off northern Namibia causes coastal upwelling and wind stress curl driven upwelling of the same order of magnitude.
- The seasonal signal of coastal and wind stress curl driven upwelling is usually phase shifted by about six month.
- Unusual drop in upwelling intensity occurs when both upwelling types are in phase.
- HIX and total upwelling intensity are not well correlated.
- Modeled transports budgets at the shelf coincide with the local wind forcing
- Distribution of negative wind stress curl compares to the off shore occurrence of SACW. → Sverdrup regime

Thank you!

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