Large-Scale Interannual Variability of Sea Level and Water Mass Properties in the Southeast Pacific in 1993 – 2011

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1. Sea Level and Wind Forcing

Almost two decades of satellite altimetry observations in the Southeast Pacific (SEP) have revealed a large-scale interannual variability pattern of sea level anomaly (SLA) that is significantly correlated with the local wind stress curl (WSC) and Southern Annual Mode (SAM) index (Fig. 1).

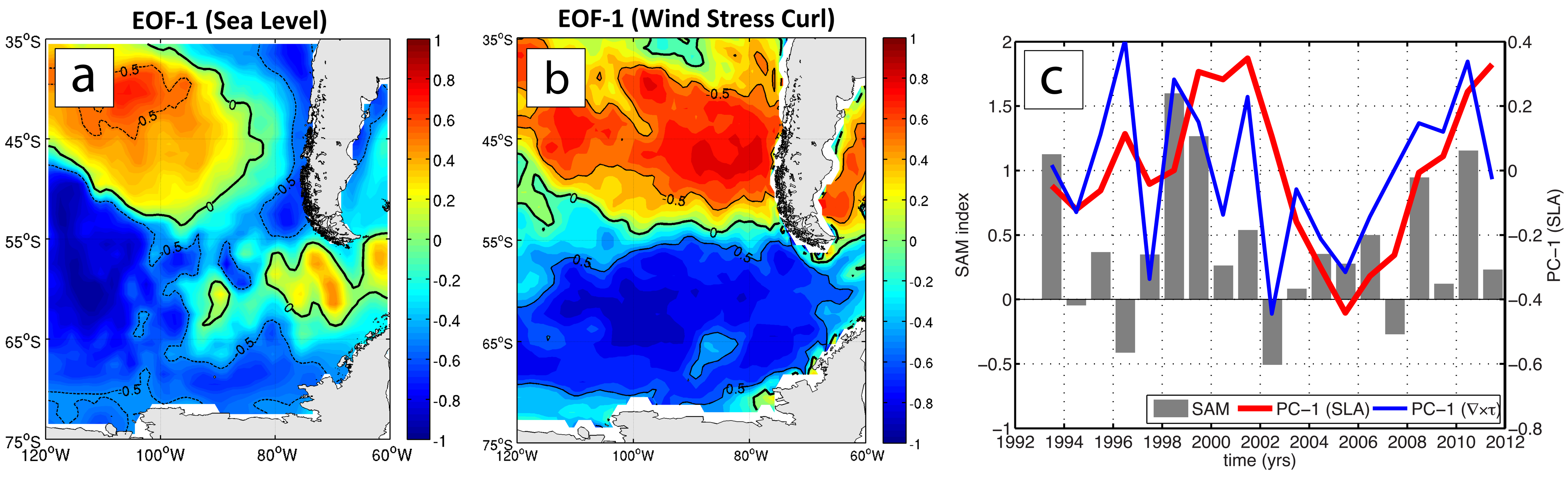

Figure 1.
The spatial patterns of the first Empirical Orthogonal Function modes (EOF-1) of the interannual variability of SLA (a) and WSC (b), and (c) their corresponding temporal evolutions or Principal Components (PC-1) explaining 44.1% and 37.1% of variance, respectively. The yearly averaged SAM index is shown by bars. The maximum correlation of 0.58 between the PC-1 of SLA and the PC-1 of WSC is observed when SLA lags behind by 1 year. The maximum correlation of 0.42 between the PC-1 of SLA and the yearly averaged SAM indices is observed at 1-year lag (PC-1 lags behind the SAM). WSC is obtained from the ERA-Interim wind stress data.

2. Steric Sea Level

The EOF-1 and PC-1 of the thermosteric and halosteric SLA, estimated from the Argo JAMSTEC data set (http://www.jamstec.go.jp/ARGO/) suggest that until 2007 the ACC waters in the SEP region warmed south of about 50°S and salinities decreased south of 55°S and north of 45°S. This can be explained in terms of the wind-induced divergence and convergence. The years of 2000-2007 were characterized by low SAM indices (Fig. 1c) and, consequently, by reduced divergence south of 55°S. The reduced divergence south of 55°S implies weaker upwelling of the cold and saline Circumpolar Deep Water (CDW) (Fig. 4.3), which leads to higher thermosteric and halosteric sea levels (Fig. 2). North of 45°S, the wind-induced convergence in 2000-2007 was also relatively weak. This implies reduced advection of warm and saline near-surface subtropical waters. Therefore, compensating each other, the thermosteric sea level decreased and the halosteric sea level increased (Fig. 2).

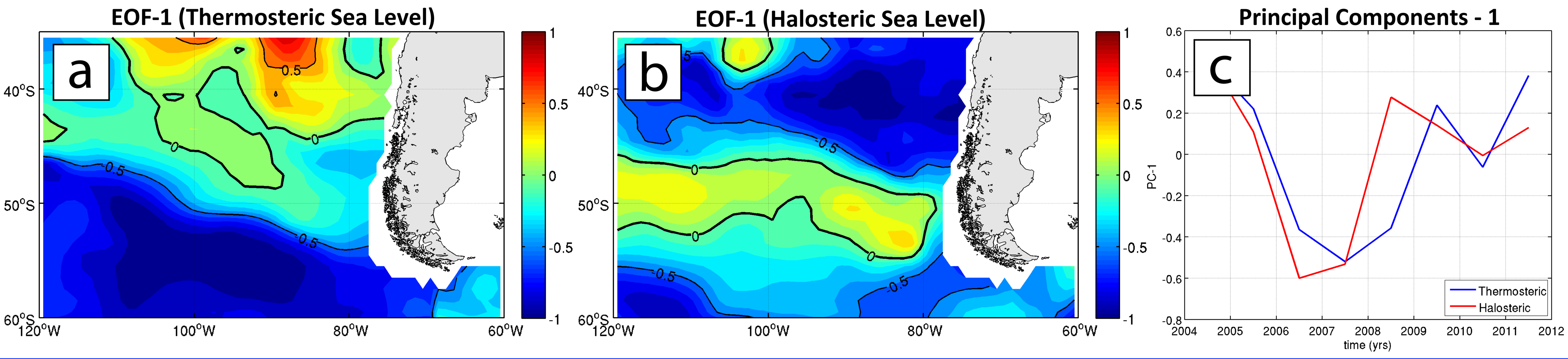

Figure 2.
EOF-1 of the thermosteric (a) and halosteric (b) SLA and PC-1 of the thermosteric (blue curve) and halosteric (red curve) SLA explaining 50% and 55.1% of variance, respectively. The thermosteric and halosteric SLA were computed relative to 2000 db.

3. Variability of Frontal Positions

The positions of the Antarctic Circumpolar Current fronts, estimated from altimetry measurements, respond to the atmospheric forcing. The ACC fronts in the SEP region are located in the divergence zone, where the meridional Ekman transport is directed northward (Fig 3.1, 4.3). The SAM forcing determines the strength of the Ekman transport. Strong SAM forces the near-surface isopycnals and, hence, the fronts to move northward (Fig. 3.2). The alteration of the near-surface isopycnal gradient propagates to the interior by geostrophic adjustment [1].

The maximum correlation of 0.6 (0.5) between the Sub-Antarctic Front (SAF) position and the SAM index (PC-1 of the wind stress curl) is observed at 2-year (1-year) lag. The maximum correlation of 0.44 (0.67) between the Polar Front (PF) position and the SAM index (PC-1 of the wind stress curl) is observed at 2-year (0-year) lag.

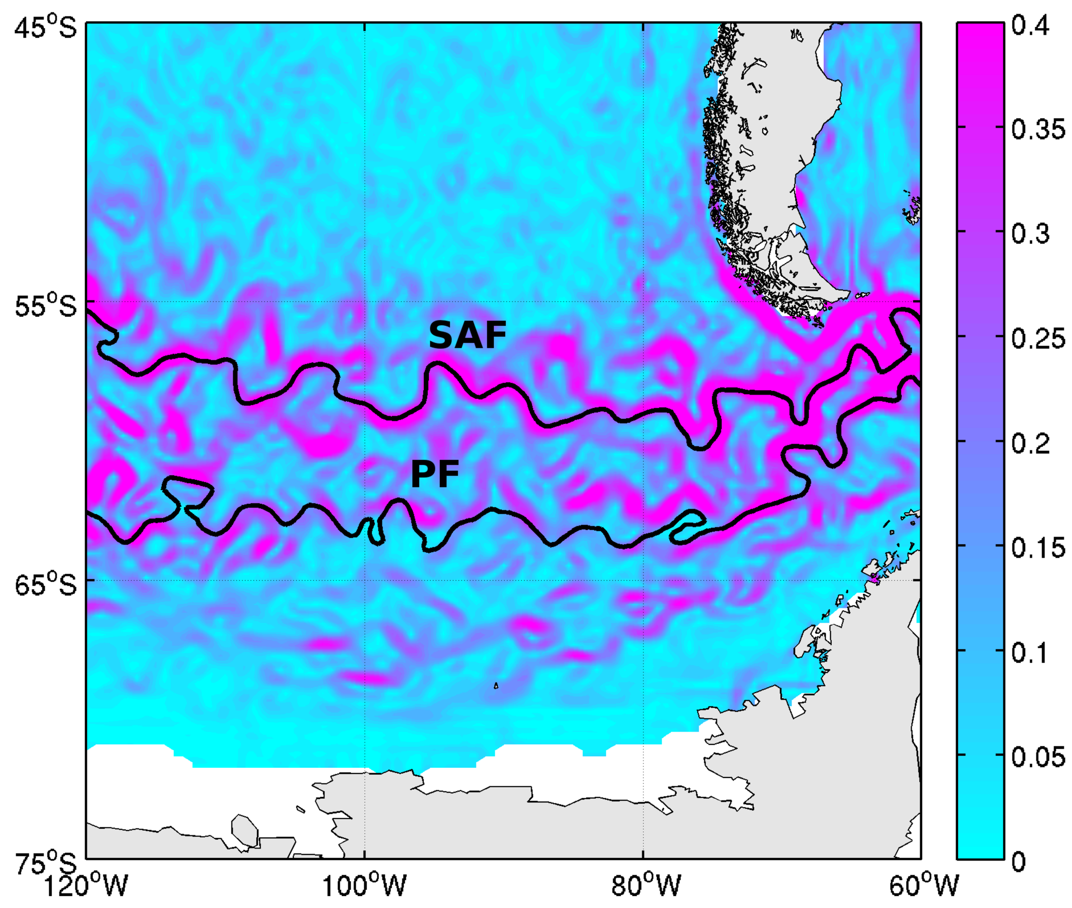

Figure 3.1. Absolute SSH gradient (m/100 km, color) and the locations of SAF and PF on 5 August 2005.

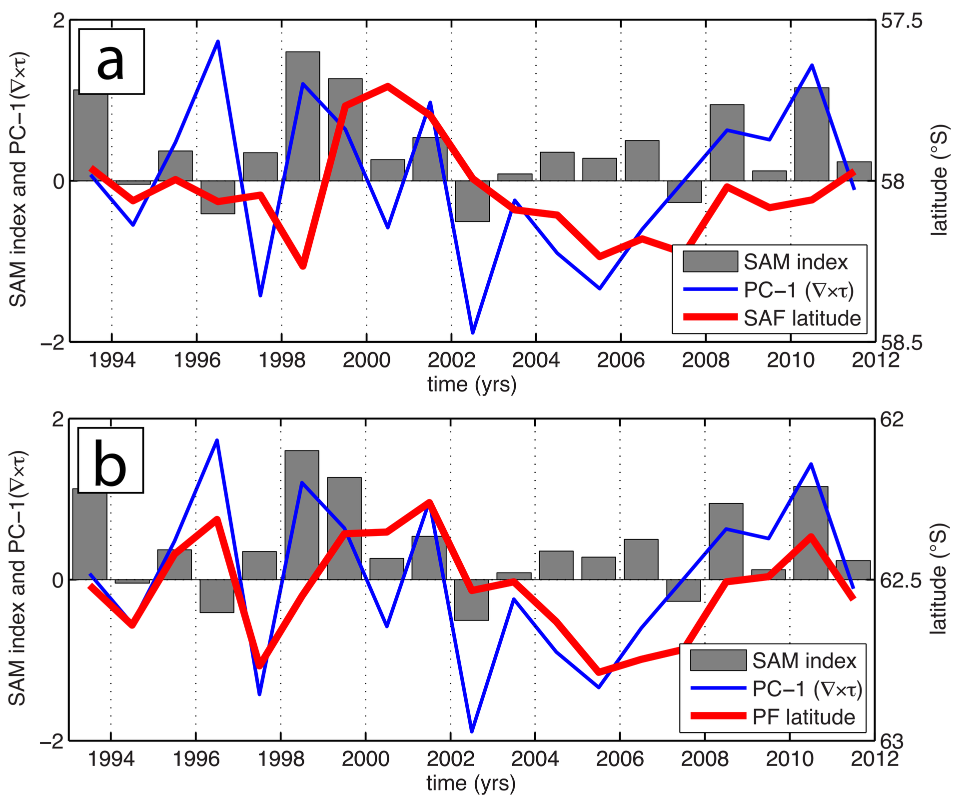

Figure 3.2. The root-mean-square latitudes of (a) the SAF and (b) PF (red curves). Bars show the yearly averaged SAM index and the blue curve shows the PC-1 of the yearly wind stress curl over the SEP region.

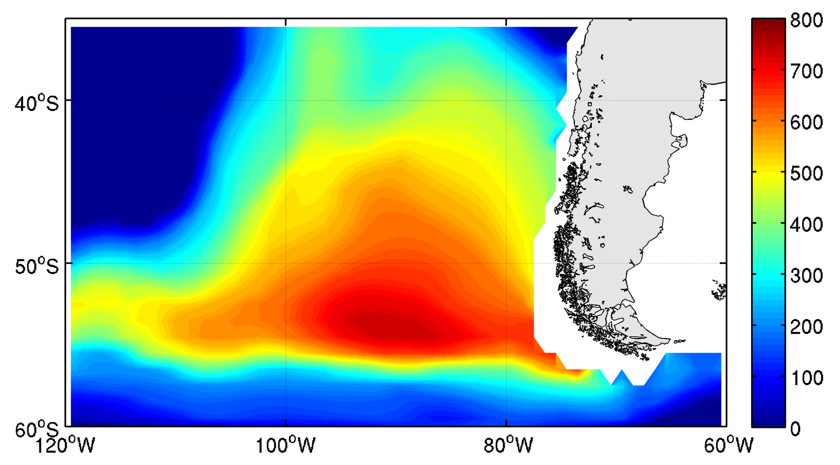

Figure 4.1.
The 2004-2011 average thickness of the layer between 34.34 and 34.44 g/kg isohaline surfaces occupied by the AAIW.

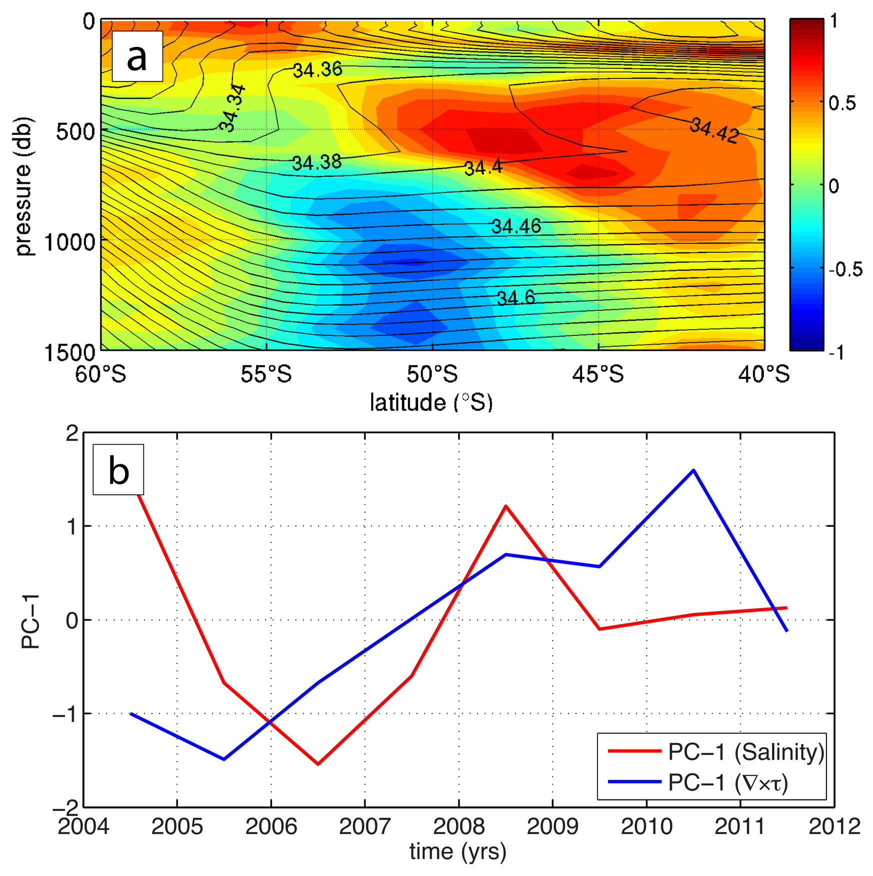

Figure 4.2. (a) EOF-1 of the vertical salinity section (color) and salinity (contours) averaged over 80°W-100°W; (b) PC-1 of the vertical salinity section (red) and wind stress curl over the SEP region (blue).

4. Antarctic Intermediate Water (AAIW) and Wind Forcing

The formation of the AAIW is usually attributed to two mechanisms: i) the sinking of the Antarctic Surface Water (AASW) near the SAF and ii) the transformation of the densest Subantarctic Mode Water (SAMW) on the equatorward side of the ACC [2]. The thickness of the AAIW varies greatly between the formation region and its northern extent (Figure 4.1). The EOF-1 (Fig. 4.2 a) and PC-1 (Fig. 4.2 b) of the vertical salinity profile averaged over 80°W-100°W show that until 2006 salinity was decreasing in the core of the AAIW and near the surface on both sides of the ACC. After 2006, the trend reversed. Thus, the variability of the salinity profile resembles the variability of SLA and WSC that both exhibit the trend reversal at about the same time (Fig 1 c).

The interannual variability of the vertical distribution of salinity reveals the periods that are more or less favorable for the AAIW formation. During the positive wind stress curl anomaly south of 55°S, which lasted until 2008, divergence south of 55°S became weaker. This means that the upwelling of the CDW decreased leading to the lower near-surface salinity. At the same time, the convergence and, consequently, the near-surface salinity north of 55°S also decreased. In this period the AAIW layer is more pronounced as suggested by the AAIW salinity minimum in 2006 (Fig. 4.2b). After 2008, divergence south of 55°S and convergence north of 55°S strengthened and the AAIW salinity increased.

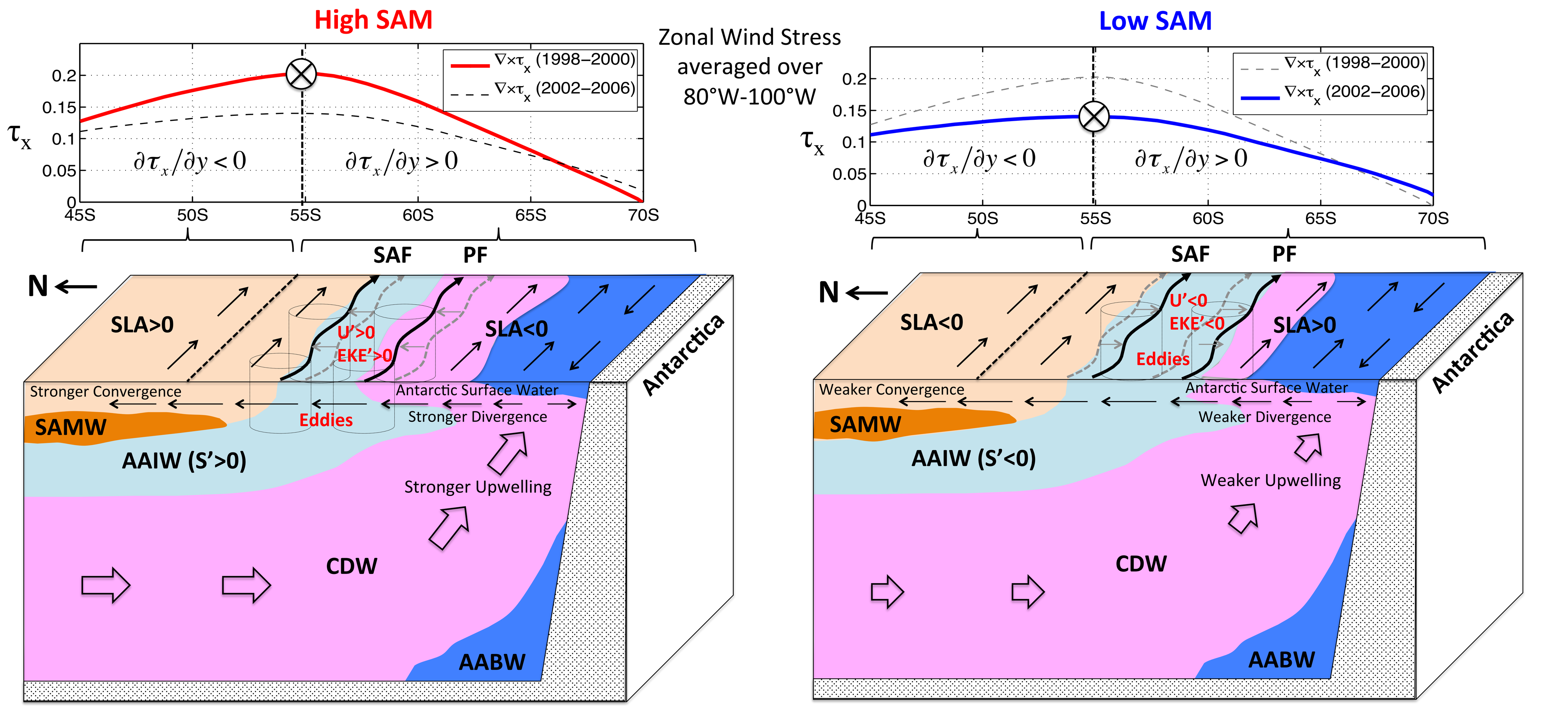

Figure 4.3. Scheme showing response to the SAM-modulated local wind forcing in the SEP region. Abbreviations: SLA – Sea Level Anomaly, SAF – Sub-Antarctic Front, PF – Polar Front, SAMW – Sub-Antarctic Mode Water, AAIW- Antarctic Intermediate Water, CDW – Circumpolar Deep Water, AABW – Antarctic Bottom Water, S' – salinity anomaly, U' – zonal velocity anomaly, EKE' – Eddy Kinetic Energy anomaly.

References:

1. Sallee, J.B., K. Speer, R. Morrow (2008). Response of the Antarctic Circumpolar Current to atmospheric variability. J. Clim. 21.
2. Hanawa, K., and L.D. Talley (2001): Mode Waters, Chapter 5.4. In: Siedler G et al. (eds) Ocean Circulation and Climate, International Geophysics Series, vol 77.

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