Large-scale fluctuations of sea level and winds in the southeast Pacific sector of the Southern Ocean

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1. Overview

The southeast Pacific sector of the Southern Ocean plays an important role in regulating the climate of Antarctica. This is the region where the Antarctic Circumpolar Current (ACC) reaches its southernmost latitude, and where the biggest source of the Antarctic Intermediate Water (AAIW) formation is located. Satellite observations of low-pass filtered (with 1-year running mean) sea surface height (SSH) from October 1992 to January 2011 have revealed a large-scale pattern of the interannual/interdecadal variability. The positive (negative) phase is associated with higher (lower) than average sea level west of the South America and lower (higher) than average sea level over the ACC and south of it. Similar pattern of the interannual variability has also been observed in sea surface temperature (SST) data (not shown). We show that the observed variability of SSH is related to wind forcing over the region, and to Pacific Decadal Oscillation suggesting the importance of large scale teleconnections. The wind strengthens/weakens the convergence/divergence zones that is reflected in the SSH variability. The coupled empirical orthogonal functions analysis of an ocean data synthesis product shows that the observed variability of SSH and wind stress is correlated with subsurface salinity distribution and can possibly be indicative of the Antarctic Intermediate Water formation rates. This is an ongoing work that is aimed to establish relationship between the interannual changes in SSH, the ACC frontal locations, winds, and the AAIW formation rates.

2. Data

- Sea Surface Height: satellite altimetry observations, processed by SSALTO/DUACS, distributed by AVISO with support from CNES
- Monthly wind stress and sea surface temperature: ERA-Interim reanalysis, provided by the European Center for Medium Range Weather Forecast (ECMWF)
- Climate indices: Antarctic Oscillation index provided by the NOAA Climate Predictions Center, Pacific Decadal Oscillation index provided by JISAO (University of Washington)
- ECCO2 ocean data synthesis product: temperature, salinity, and wind stress.

3. Sea Surface Height variability

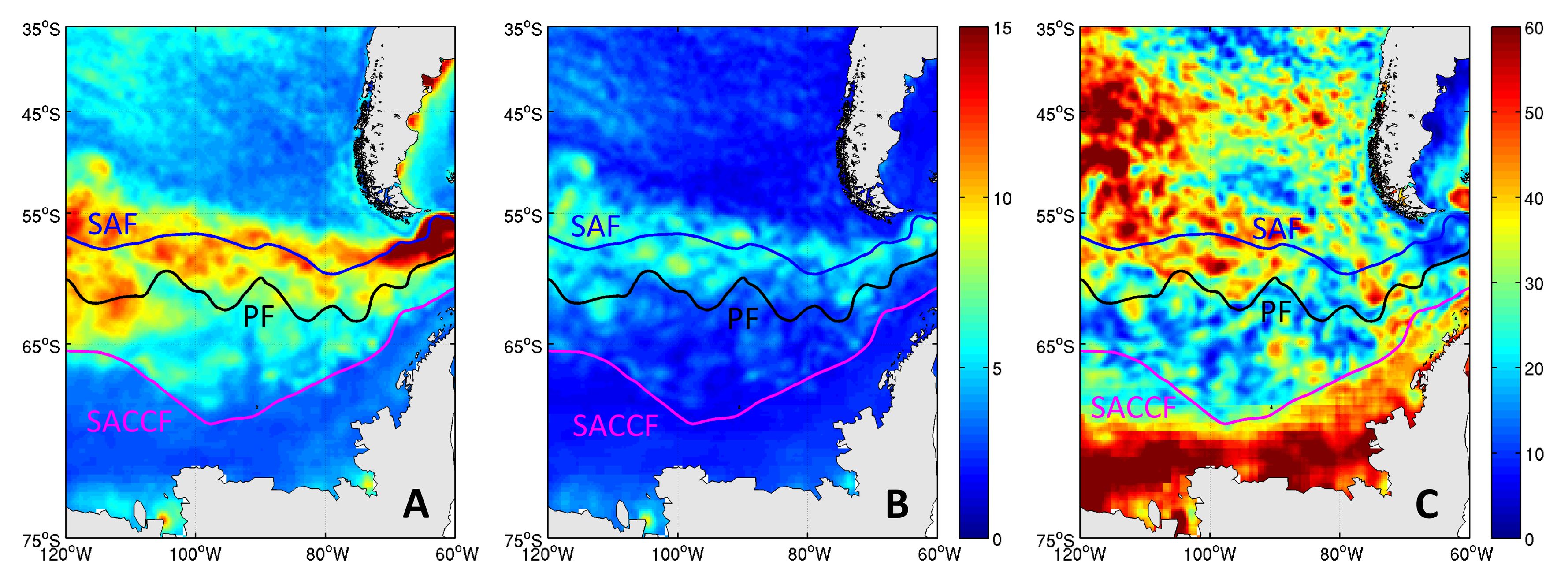
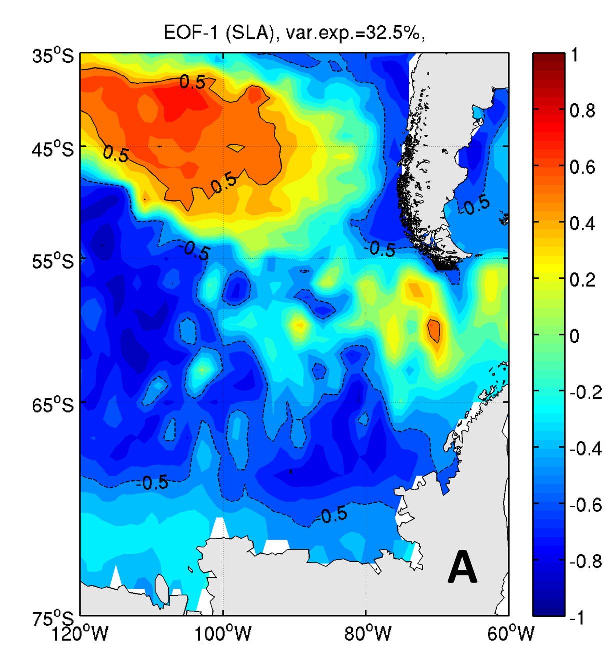


Figure 1.

Standard deviations of SSH (A) and its interannual signal (B). The portion of variance explained by the interannual signal of SSH (C). The time mean locations of the ACC fronts from Orsi et al. [1998] are shown: Sub-Antarctic Front (SAF, blue), Polar Front (PF, black), and Southern ACC Front (SACCF, magenta). The interannual signal of SSH is relatively small along the ACC. North of the ACC it constitutes over 30% of the total variability.



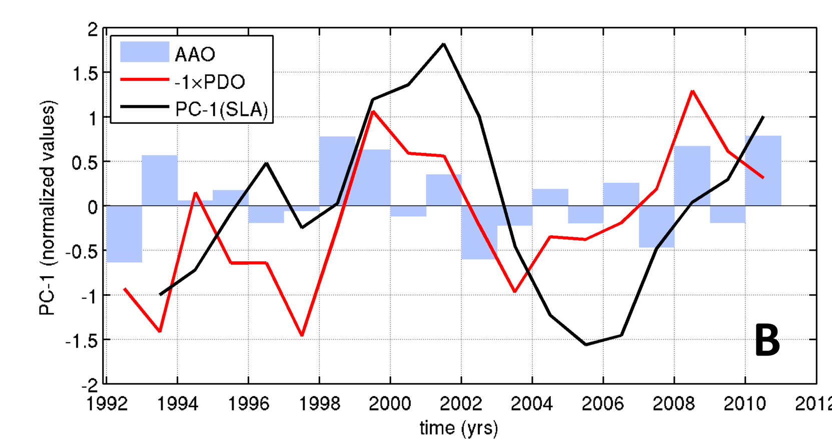


Figure 2.
The leading mode of the interannual SSH variability: (A) spatial pattern and (B) principal component (PC-1). The time series plot also shows the Antarctic Oscillation (AAO, bars) and Pacific Decadal Oscillation (PDO, red) indices. The maximum correlation between the PC-1 of SSH and PDO is -0.54 at 1 year lag. He correlation between the AAO and PC-1 is not significant.

4. Relation to wind forcing

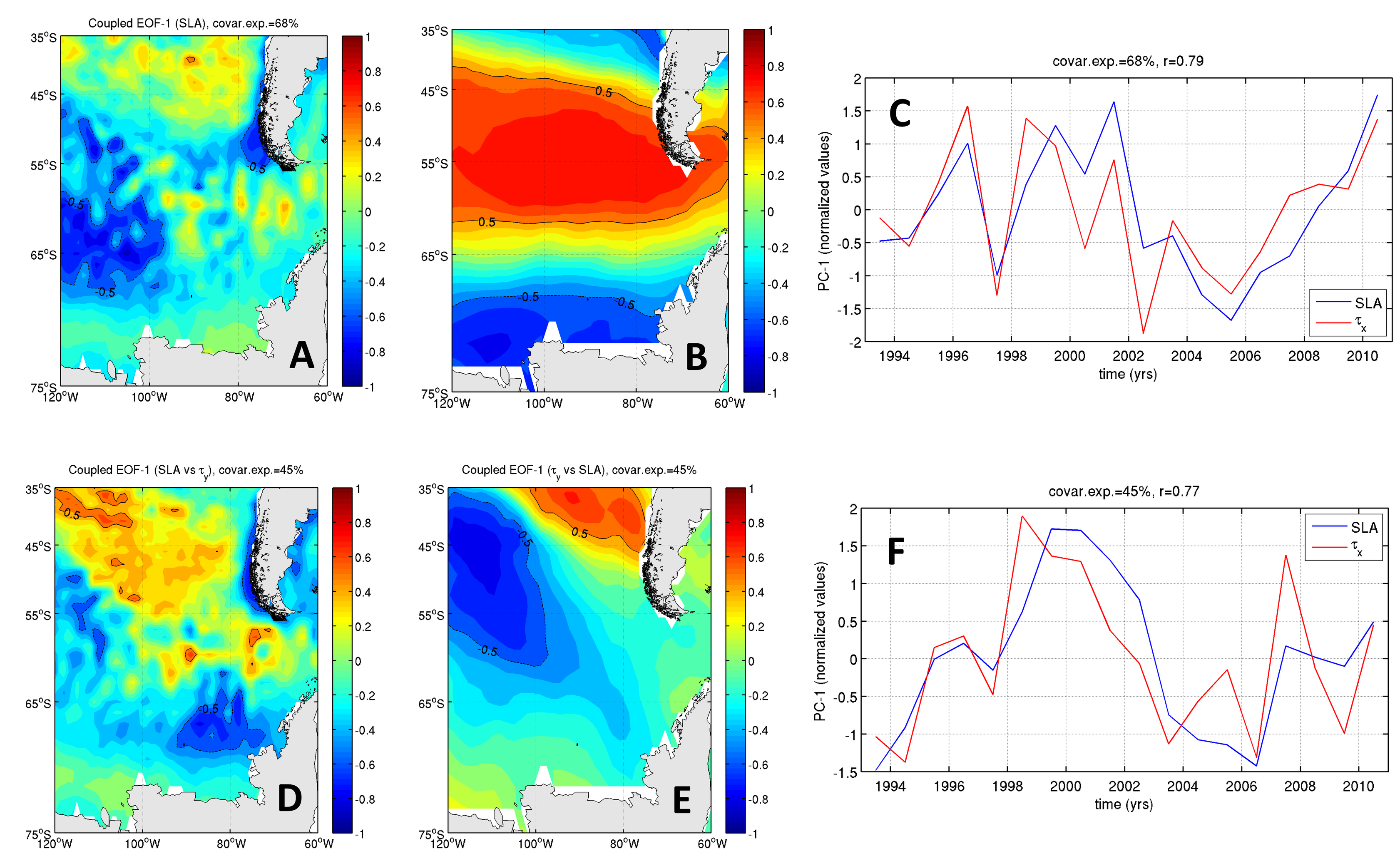


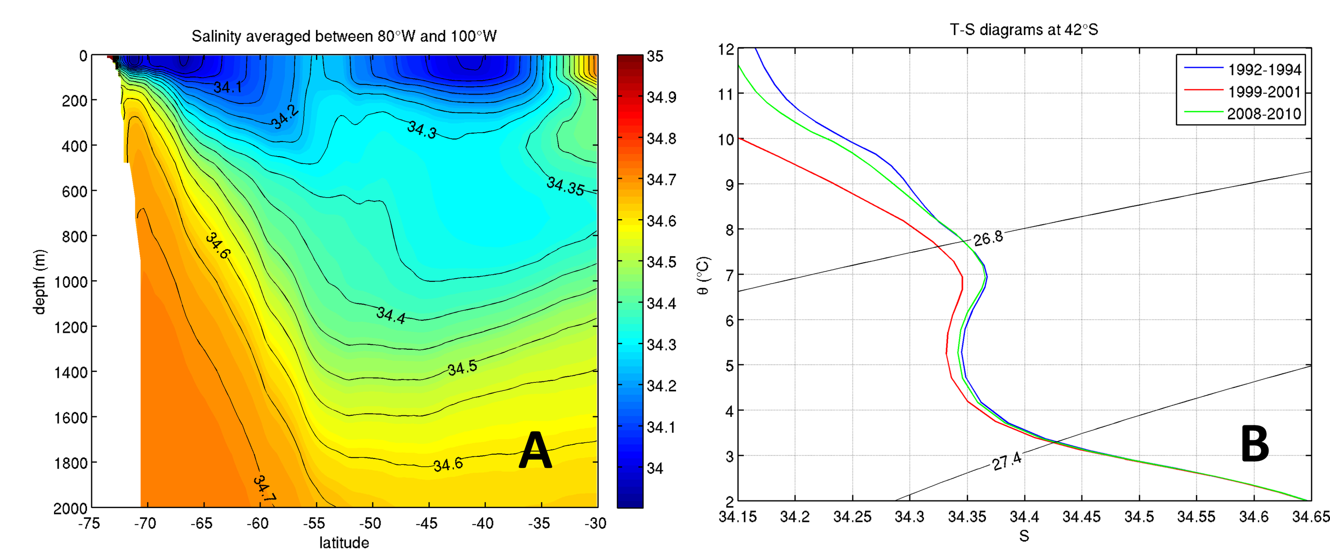
Figure 3.

The first coupled EOF mode of SSH and wind stress components: (A and D) – spatial patterns of SSH, (B and E) – spatial patterns of τ_x and τ_y, (C and F) – time series of expansion coefficients for SSH (blue), τ_x and τ_y (red). This mode explains 68% and 45% of the covariance of SSH and τ_x, and SSH and τ_y, respectively. In contrast to the individual EOF analysis, the coupled EOFs identify the modes of behavior in which sea level and wind stress are strongly coupled. The first coupled mode of variability between SSH and wind stress can be described as a strengthening and weakening of westerly and easterly (near Antarctica) winds, which is accompanied by fluctuations in SSH possibly related to convergence and divergence of Ekman transport. Note that the maximum SSH variability occurs around the convergence anomaly zone at 45°S and the divergence anomaly zone at 65°S. This statistical relationship suggests that the interannual variability of SSH in the region is wind-driven and barotropic in nature.

5. Large-scale sea level, winds, and salinity in ECCO2

Figure 4.

The ECCO2 salinity section averaged between 80°W and 100°W (A) and (B) T-S diagrams at 42°S for the 1992-1994 (blue), 1999-2001 (red), and 2008-2010 (green) averaging time intervals. ECCO2 produces AAIW seen as a salinity minimum at about 700 m depth. The salinity at the core of the AAIW in 1999-2001 was lower than in 1992-1994 and in 2008-2010.



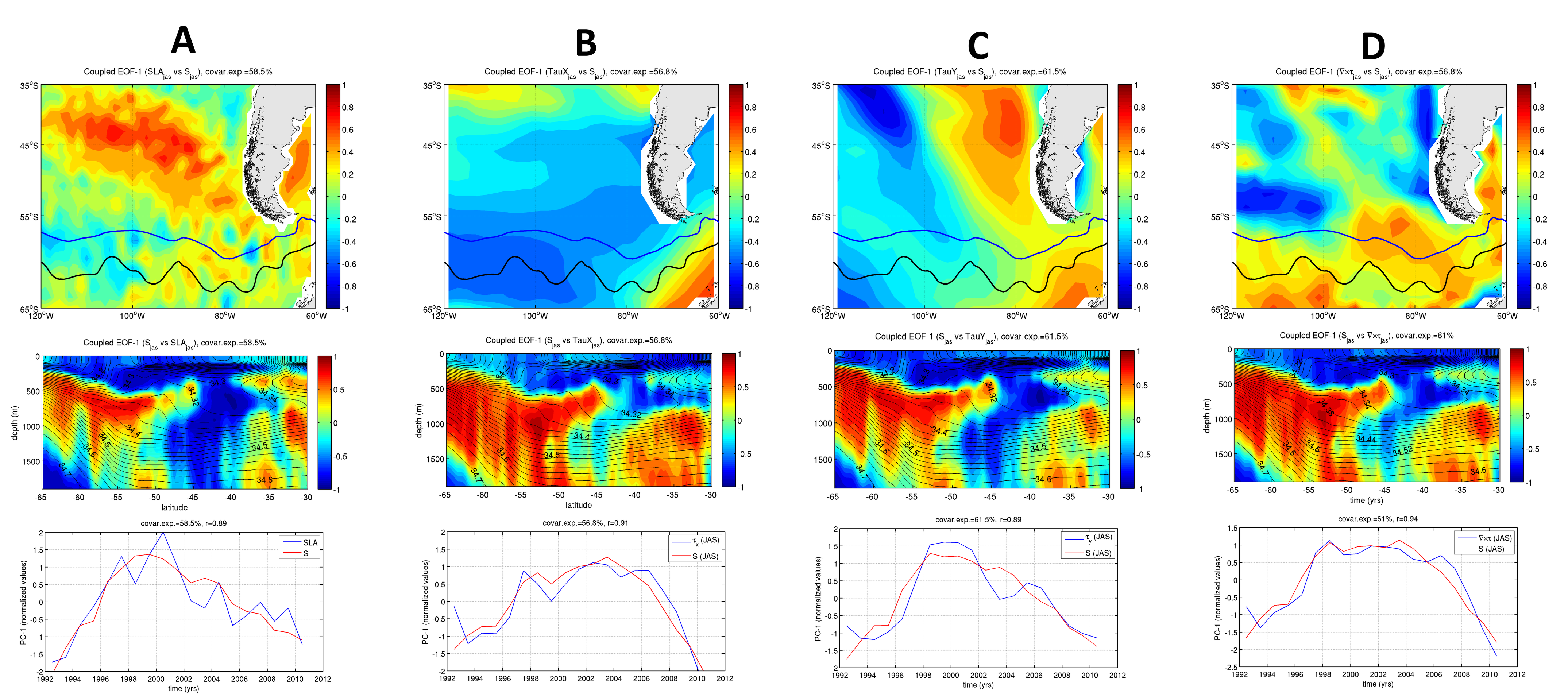


Figure 5.

The first coupled EOF modes of SSH and salinity (A), zonal wind stress and salinity (B), meridional wind stress and salinity (C), and wind stress curl and salinity (D) in ECCO2. The first row shows the spatial patterns for SSH and wind stress, the second row shows the spatial patterns for salinity section, and the third row shows the time series of the expansion coefficients. The time mean locations of the Sub-Antarctic Front (blue) and Polar Front (black) are drawn in the upper plots. The July-September mean salinity averaged between 80°W and 100°W is contoured in the middle plots. SSH, wind stress, and salinity were averaged over austral winter (July through September) when the AAIW formation is maximum.

Despite some differences with observations, ECCO2 captures interdecadal variability. It appears that SSH and wind stress are strongly coupled to the vertical salinity distribution. The AAIW is formed at the Antarctic Convergence zone between about 50°S and 60°S west of the Drake Passage. The formation of the AAIW can be explained through the Ekman transport processes and the divergence and convergence of water masses. When the northward flowing low-salinity Antarctic Surface Water encounters the Antarctic Convergence zone it starts sinking. Note that the maximum (positive) wind stress curl west of the Drake Passage induces Ekman convergence and corresponds to minimum salinity in the surface layer and in the core of the AAIW (Figure 5D).

6. Summary and Outlook

- 18 years of satellite altimetry observations have revealed a large-scale pattern of interannual/interdecadal variability of sea level; this variability is related to wind forcing possibly through wind-induced convergence/divergence (barotropic sea level variability); the correlation with PDO suggests the importance of large-scale teleconnections
- The analysis of the ECCO2 model output shows that the vertical distribution of salinity is strongly coupled to sea level and wind stress; convergence/divergence of Ekman transport west of the Drake Passage corresponds to an decrease/increase of salinity in the surface layer and in the core of the AAIW

Next steps:

- Quantify the formation of the AAIW in the ECCO2 model and analyze its relationship to wind forcing
- Investigate the relationship between the ACC frontal locations and the AAIW formation

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