Observations for Climate:
Multi-Decadal Waming and Shoaling of Antarctic Intermediate Water*

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Introduction

- Antarctic Intermediate Water (AAIW) is a prominent water mass that ventilates the base of the subtropical thermocline in the Southern Hemisphere (Figs. 1, 2)

- AAIW is found north of the Antarctic Circumpolar Current (ACC) and spreads northward to at least 20°S globally (Figs. 1, 2).

- AAIW has a pronounced salinity minimum from 600 to 1000-m depth (Figs. 1 -3).

- Studies of AAIW change almost uniformly find warming and salinification on isopycnals denser than the AAIW salinity minimum (Fig. 3).

- These studies also usually note a cooling and freshening over time on lighter isopycnals (Fig. 3).

- This dipole pattern is consistent with an overall warming of the AAIW salinity minimum, as discussed below.

- Recent comprehensive global data from the Argo Program allows investigation of past anomalies with unprecedented accuracy.

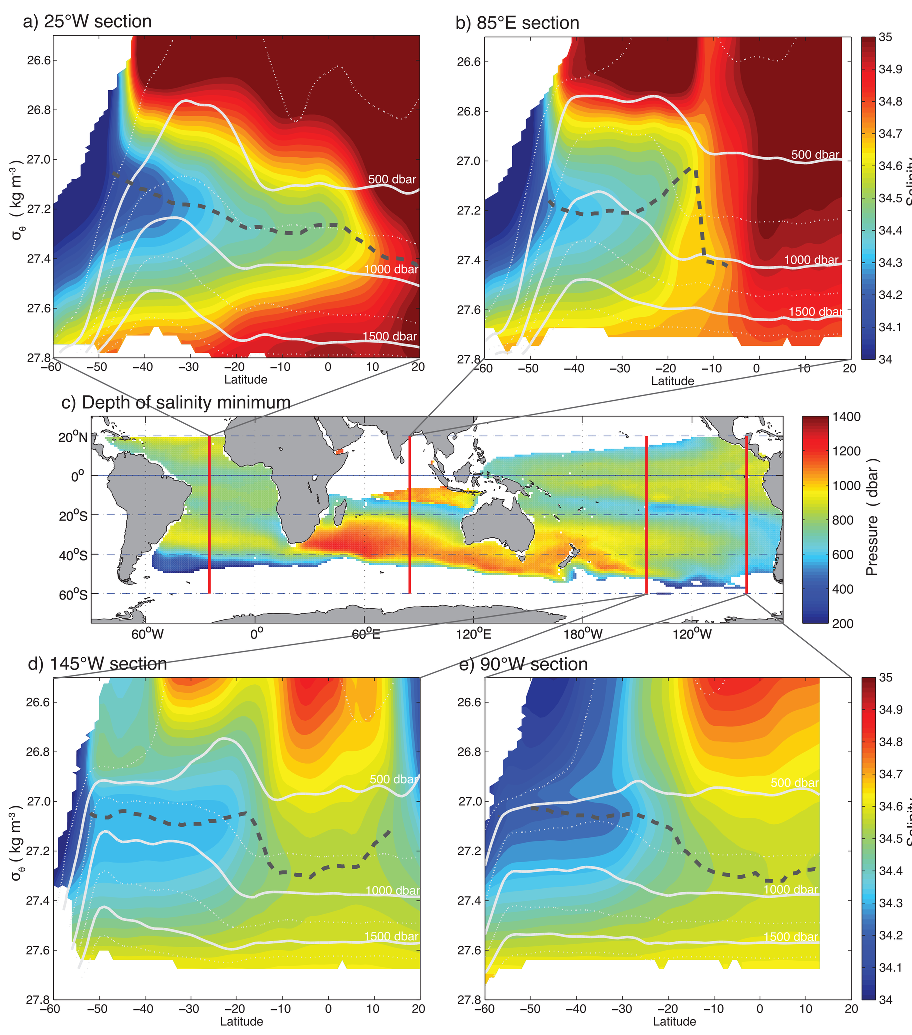

Figure 1: Meridional-vertical sections of Argo float climatology salinity (colors) and pressure at 500-dbar intervals (thick solid white lines) as well as intermediate 250-dbar intervals (thin dotted white lines) with a vertical axis of potential density in the (a) Atlantic, (b) Indian (b), and (d), (e) Pacific oceans. The AAIW core (salinity minimum) is also indicated (thick dashed grey lines). (c) Argo climatology AAIW core pressure (colors) south of 20°N with section locations indicated (red lines).

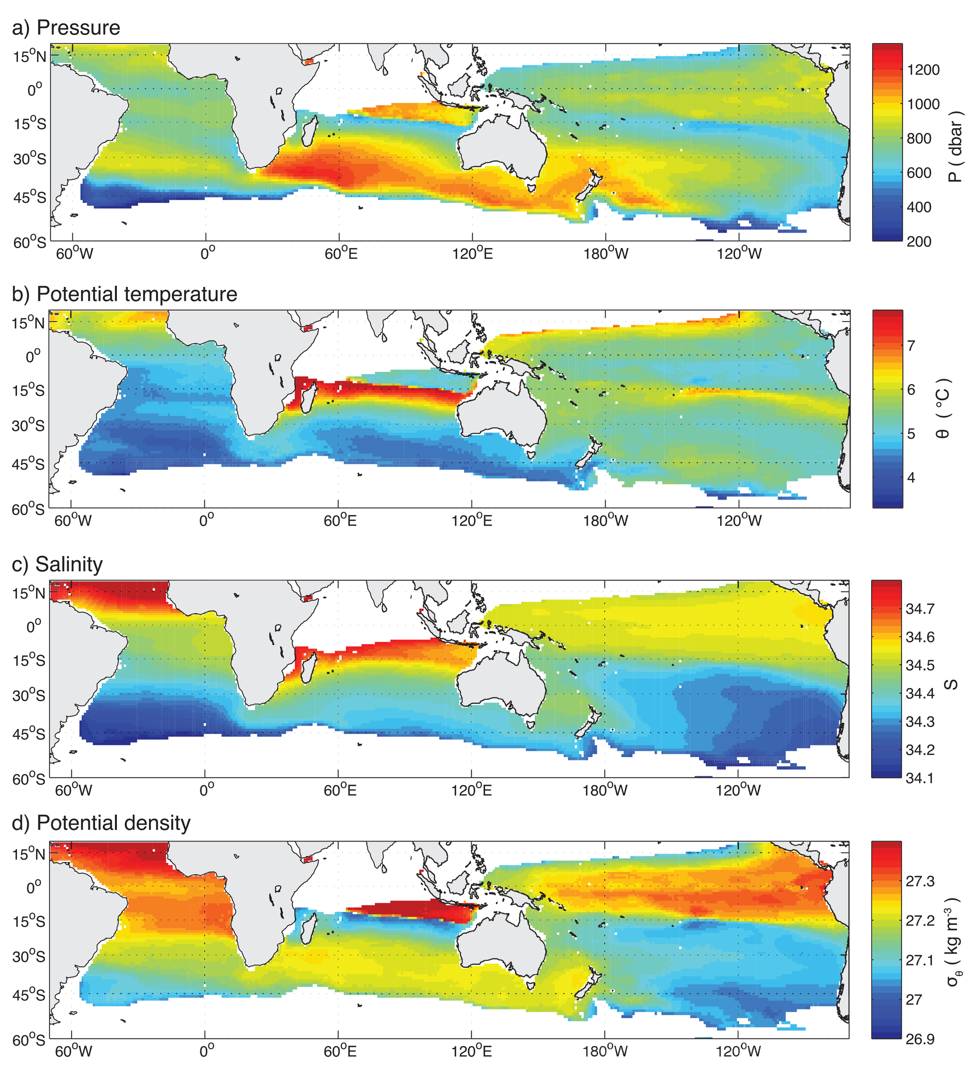

Figure 2: Maps of (a) pressure, (b) potential temperature, (c) salinity, and (d) potential density at the AAIW core (salinity minimum, see Fig. 1) of the Argo climatology **used as reference for this analysis.**

Data and Methods

- Isopycnal Argo float climatology is used as a reference to compute historical anomalies relative to today's state of the ocean (Fig. 2).

- Ship-based CTD data used in this study encompass the HydroBase2 database[2] (HB2) and the CLIVAR & Carbon Hydrographic Data Office (CCHDO) database.

- Maps of trend (Fig. 4) since 1970 are computed from ship-based CTD derived anomalies anchored in the present by the Argo climatology.

- Sparse historical bottle data are used to determine biennial means and medians of AAIW core θ anomalies in two distinct latitude bands for each basin since 1925 (Fig. 6).

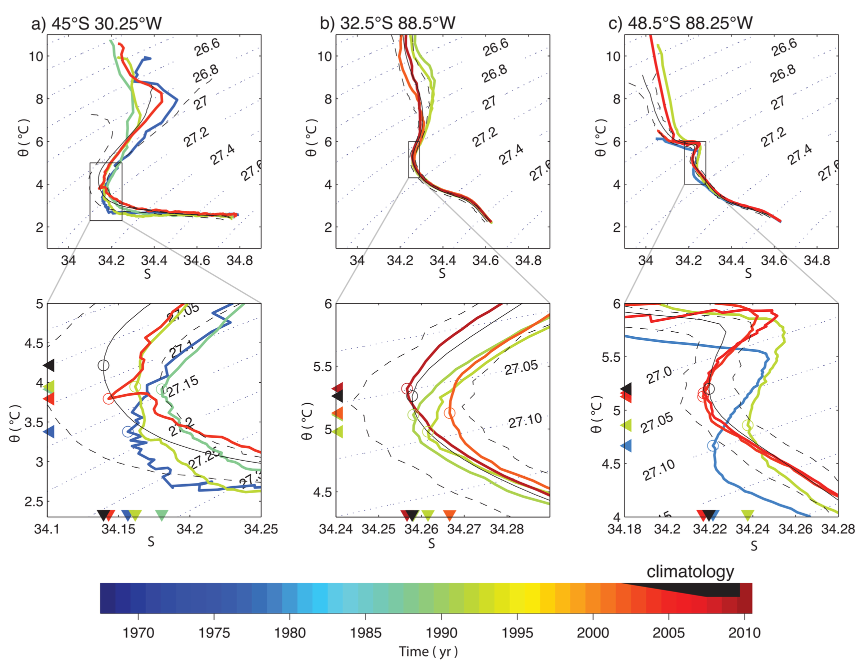

Figure 3: CTD station θ–S curves color-coded by age show AAIW water warming in relatively frequently sampled areas in the (a) South Atlantic and (b), (c) South Pacific oceans with a focus on the AAIW core (salinity minimum, circled) in the lower panels. Argo float climatology θ–S curves (solid black lines) are shown with one standard deviation S envelopes (dashed black lines). AAIW core θ and S values color-coded by age are marked (triangles) on the left and bottom axes of the lower panels, respectively, with Argo climatology values in black. Potential density contours (dotted grey lines) are overlaid at 0.2 kg m^{-3} (upper panels) and 0.05 kg m^{-3} (lower panels) intervals. Lower panel scales vary.

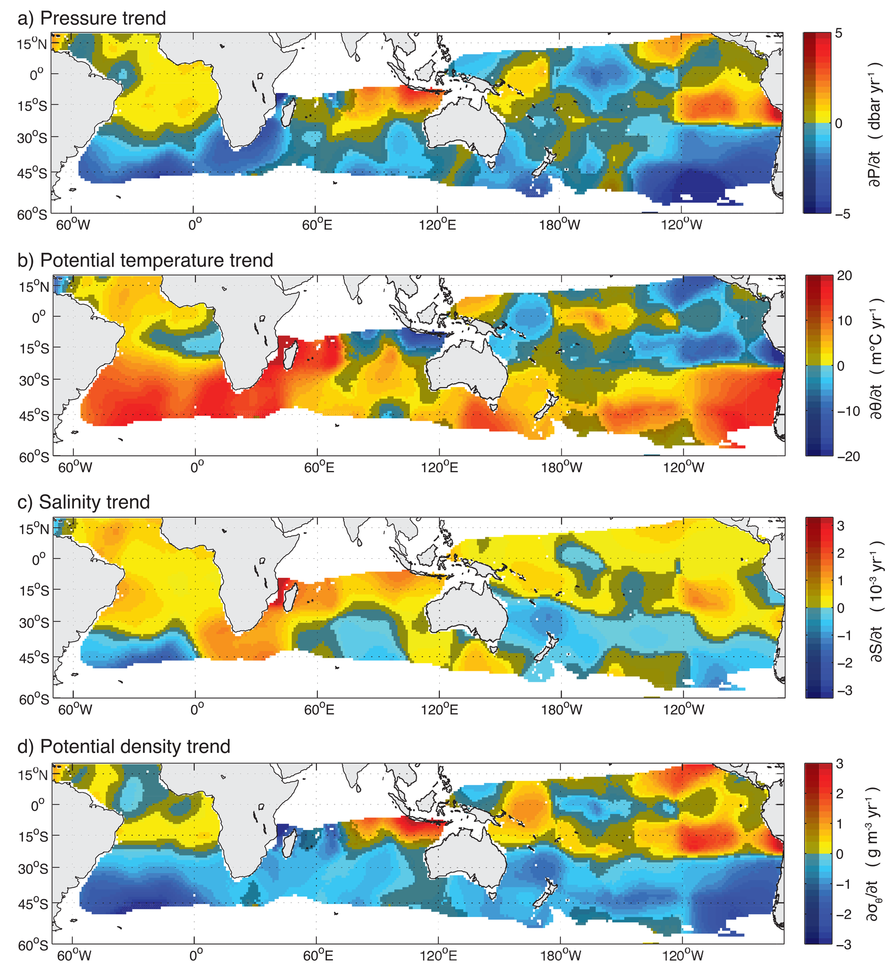

Figure 4: Maps of linear trends in AAIW core properties over the time-period of ship-based and Argo float CTD sampling for (a) pressure, (b) potential temperature, (c) salinity, and (d) potential density. Regions where trends are not significantly different from zero at the 95% confidence level are shaded dark.

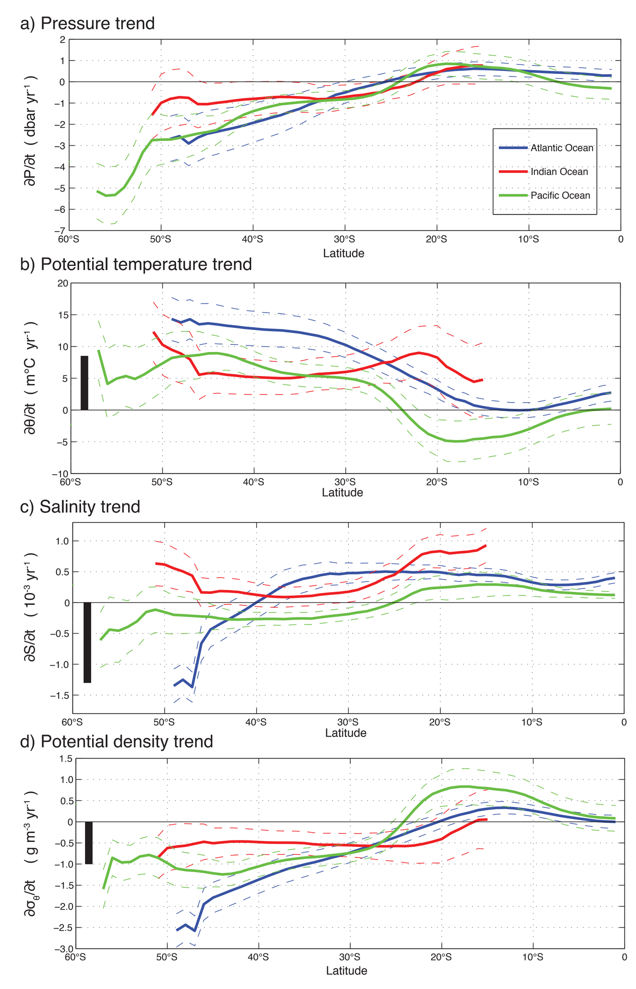

Figure 5: Zonal mean temporal trends at the AAIW core (salinity minimum) estimated over the CTD sampled time-period of (a) pressure, (b) potential temperature, (c) salinity, and (d) potential density in the three ocean basins (color coded thick lines) with 95% confidence limits (dashed lines). Black bars indicate relative influences of potential temperature and salinity trends on the density trend at 34.4 and 5°C. Each bar corresponds to a change of -1 g m^{-3} yr^{-1} in density.

Results

- Large-scale multi-decadal shoaling, warming, and reduction in density of the AAIW core found since circa the mid-1970s (Figs. 3-6).

- Recent AAIW core warming is apparently unprecedented since the beginning of observations with sufficient vertical resolution (Fig. 6).

- AAIW core salinity changes are generally small and variable with respect to temperature changes in terms of their relative effects on density (Fig. 5).

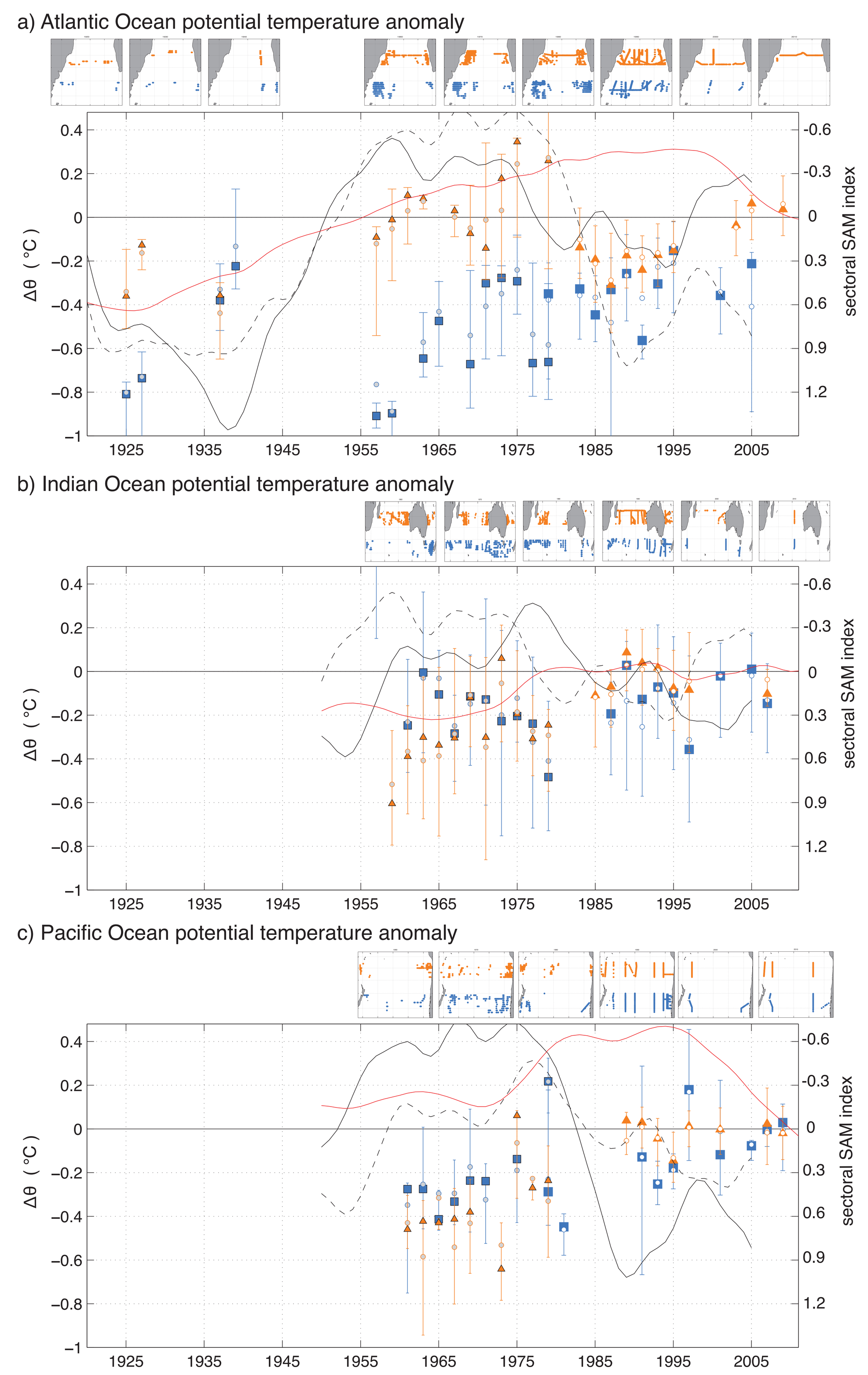

Figure 6: Time evolution of median AAIW core θ anomalies for the (a) Atlantic, (b) Indian, and (c) Pacific oceans in two latitude bands: 50–40°S (blue squares) and 30–20°S (orange triangles) estimated in biennial time bins from bottle (black edges) and CTD (no edges) data with first and third quartiles (whiskers) shown for all bins with more than 5 data points. Potential temperature anomaly means are also indicated for bottle (grey-filled circles) and CTD (open circles) data. Sectoral winter SAM indices (Visbeck 2008, 2011, personal communication) smoothed with a 8-year radius LOESS smoother (black line for the east and black dashed line for west boundary of each basin) with sign reversed and similarly smoothed winter 60–55°S SST anomalies (red line) from the 2° × 2° gridded NOAA extended reconstructed sea surface temperature (ERSST v3b) for each basin (Smith et al. 2008) are shown—see text or details. Small maps at the top of the three large panels show data locations for each basin and decade centered on 1930, 1940, . . . 2000, with half-decade distributions prior to 1925 and after 2005.

Discussion

- Lack of a global coherent AAIW core S change is interesting in light of expected changes in the hydrological cycle as Earth warms. (Figs. 4, 5)

- Southern Annular Mode (SAM) variations via Sea Level Pressures(SLP, thus wind) and winter Sea Surface Temperature (SST) near the AAIW formation latitudes may be related to AAIW core property variability (Fig. 6).

- Mid 20th century warm anomaly in the Atlantic (Fig. 6) might be related to increased Angulhas leakage driven by SAM changes.

Acknowledgements and References

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2 Curry, R., Hydrobase2, 2008, http://www.whoi.edu/science/PO/hydrobase/

* Schmidtko, S. and G.C. Johnson, 2011: Multi-decadal warming and shoaling of Antarctic Intermediate Water. J. Clim., in press. DOI: 10.1175/JCLI-D-11-00021.1