Antarctic Bottom Water Warming and Freshening; Contributions to Sea Level Rise, Ocean Freshwater Budgets, and Global Heat Gain

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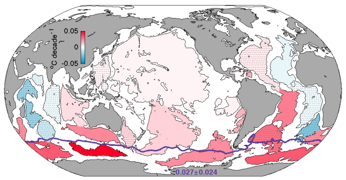
1. Background

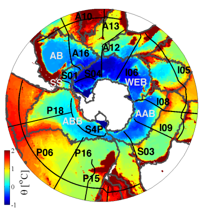
•Antarctic Bottom Water (AABW; θ < 0 °C), forms in at least 3 locations around Antarctica, where dense shelf water spills down the continental slope entraining Circumpolar Deep Water (CDW).
•AABW fills most of the deep oceans around the globe (Johnson 2008)
•It feeds the bottom limb of the Meridional Overturning Circulation (MOC).
•Increases in glacial melt have freshened shelf waters and AABW in the South Indian and South Pacific (e.g. Jacobs and Giulivi 2010).
•AABW has warmed globally in recent decades (below). Basin mean warming rates (color) below 4000 m between 1980s and 2000s. Stippling indicates values are not statistically significant from zero at 97.5% confidence (Purkey and Johnson 2010).



•We quantify a volume loss within deep temperature classes and estimate the implied slowdown of the lower limb of the MOC (Purkey & Johnson, 2012).
•We separate salinity changes in the deep Southern Ocean into isotherm heave and water-mass components and calculate their contributions to freshwater, heat, and sea level rise (SLR; Purkey & Johnson, 2013).

2. Data

•Fifteen full-depth, high-quality hydrographic sections occupied two or more times between 1980 and 2012 (right; black lines with World Ocean Circulation Experiment (WOCE) ID).
•Accuracies: 0.002 PSS-78 (salinity-S), 0.002 °C (potential temperature-θ), 2 dbar (pressure-P).



•Results averaged in deep basins (right; gray lines) shown over climatological (Gouretski and Koltermann, 2004) bottom θ.

References

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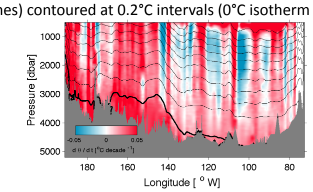
•Rignot E., J. L. Bamber, M. R. van den Broeke, C. Davis, Y. Li, W. J. van de Berg, and E. van Meijaard, 2008, Recent Antarctic ice mass loss from radar interferometry and regional climate modeling, *Nature GeoScience*, **1**, 106–110. doi:10.1038/ngeo102.

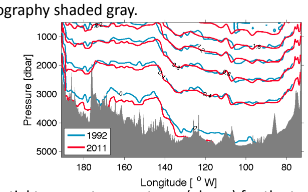
Method

3. Decrease in AABW Volume

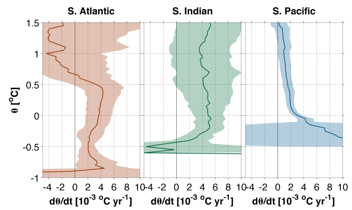
Example below uses S4P across the Ross Sea at 67 °S. Property plots are longitude-pressure with mean isotherms (black lines) contoured at 0.2°C intervals (0°C isotherm bold). Bottom topography shaded gray.

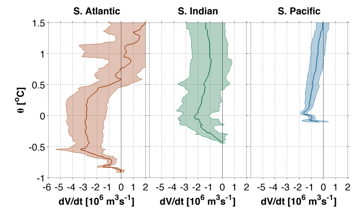


•Temperature trend (dθ/dt). Red indicates warming and blue cooling (above).
•Basin-mean dθ/dt (black) with 95% confidence intervals (shading) along isotherms for the three southernmost basins (below).

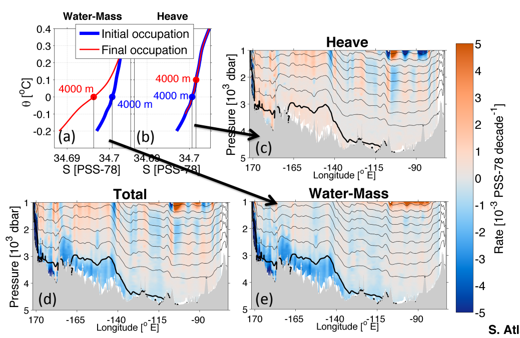


• Potential temperature contours (above) for the two occupations of S4P. Isotherms descend with warming, implying a volume loss in the coldest waters.
•Basin-mean rate of change in volume with time (dV/dt) for each isotherm for the three southernmost basins (below).



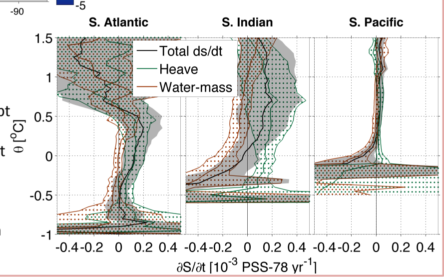


4. AABW Freshening



•Heave vs. water-mass change (upper left): Water-mass change (a) is a temporal change in the θ-S curve. Heave (b) is a vertical displacement of θ, causing water at a given depth (colored dots) to change θ and S without changing the θ-S curve.
•Total S rate of change, dS/dt_{total} (d). Blue indicates freshening and orange salinification.
•The heave portion, dS/dt_{heave} (c), is estimated using measured dθ/dt and local θ-S relations at each measured location and depth.
•The water mass portion, dS/dt_{wm} (e) is a residual, dS/dt_{total} - dS/dt_{heave}.

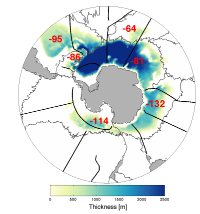
•Mean dS/dt_{total} (black), dS/dt_{heave} (green), and dS/dt_{wm} (red) vs. θ for three southernmost basins with 95% confidence intervals (grey shading/colored dots; right).
•Water-mass freshening dominates total for θ < 0ºC except in the Weddell Sea
•Heave salinification more important for θ > 0ºC and most of Weddell Sea.
•AABW is freshening owing to increases in a fresher variety of AABW
•AABW volume is decreasing, causing salinification from the fall of isotherms in the deep Southern Ocean.



Results

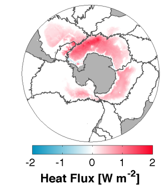
5.1 Volume Loss

•AABW basin-mean dθ/dt (red numbers) shown over AABW thickness (right).
•Volume loss of 8 SV for θ < 0 °C
•Deep volume loss continues, albeit attenuated, northward along 3 of the 4 braches of the lower MOC, suggesting a global-scale contraction of AABW



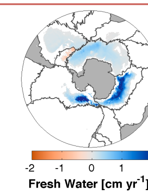
5.2 Heat Flux

•Local heat flux (W m^{-2}) across θ = 0 °C (right).
•Warming from isotherm heave equates to ~14 TW (1 TW = 10^{12} Watts) of heat uptake in AABW, largest in the South Atlantic, then South Indian, then South Pacific.

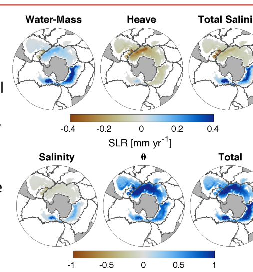


5.3 Freshwater Flux

•Local freshwater flux (cm yr^{-1}) across θ = 0°C (right), using basin means of dS/dt_{wm}.
•Water-mass freshening of AABW in the Pacific and Indian sectors of the Southern Ocean amounts to 73 Gigatons yr^{-1} of freshwater.



5.4 Sea Level Rise



•Local SLR rates below 0°C owing to water-mass S changes (upper left), heave S changes (upper center), total S changes (upper right/bottom left), θ changes (bottom center), and their total (bottom right).
•Water-mass freshening causes positive SLR in the deep ocean, while heave salinification causes negative SLR throughout the water column.
•Water-mass freshening dominates the total SLR owing to dS/dt in the Australian-Antarctic Basin and Ross Sea, while heave salinification dominates changes in the Weddell Sea.
•Warming dominates SLR increases compared to salinity changes.
•Property changes of AABW result in ~0.5 mm yr^{-1} SLR locally