The Cold Transit of Southern Ocean Upwelling

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What we find…

In the Southern Ocean, intermediate water forms from upwelled deep water that transits through the cold and fresh corner of temperature/salinity space driven by seasonal air-ice-sea buoyancy fluxes and subsurface mixing.
• Deep water upwells in the Southern Ocean
• This deep water either looses buoyancy to form bottom water…
• …or it gains buoyancy to form intermediate water (Speer et al., 2000)
Southern Ocean Meridional Overturning Circulation

Recent results…

• Lagrangian upwelling pathways in the Southern Ocean (Tamsitt et al., 2018)
• Deep water cools and freshens as it upwells into the mixed layer
• Role of sea ice melting in the transformation of deep water into intermediate water (Abernathey et al., 2016)

Tamsitt et al. (2018)
Southern Ocean Meridional Overturning Circulation

- Data from ECCOv4r2 state estimate
- Examination of the global thermohaline streamfunction shows that there is room for improvement in our classic interpretation of deep water upwelling in the Southern Ocean
- Deep water makes a cold transit, via winter water, before forming intermediate water
- What process drive these water mass transformations??
Understanding water mass transformations

Use a thermohaline based water mass framework

• Based on the Walin (1982) framework, developing existing methods used in Evans et al. (2014, 2017, 2018)

\[
\begin{align*}
G_\theta & \quad \text{Diathermal transformation} \\
G_S & \quad \text{Diahaline transformation}
\end{align*}
\]
Southern Ocean water mass transformations

- Volume changes highlight the seasonal formation of winter water
- Vectors show water mass transformations
- Transformation by air-ice-sea fluxes drive transformation between winter water and intermediate water
- Transformation by mixing drive transformation between winter water and deep water
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The cold transit of Southern Ocean upwelling…

1. Surface cooling and sea ice formation, WW production
2. Brine rejection increases salinity of WW
3. Weakening stratification triggers mixing and CDW upwelling
4. Surface warming and sea ice melting
5. Warming and freshening of AAWW, production of AAIW

Heat flux
Salt flux
Mixing
Adiabatic upwelling/ downwelling
What drives the mixing between deep water and winter water?

\[ \Delta \rho_{\text{static}} = \rho_{\text{EOS 2010}}(S_d, \Theta_d, \bar{p}) - \rho_{\text{EOS 2010}}(S_w, \Theta_w, \bar{p}), \]

\[ \Delta \rho_{\text{nonstatic}} = \rho_0 \left[ -\alpha(S_d, \Theta_d, \bar{p})(\Theta_d - \Theta_w) + \beta(S_d, \Theta_d, \bar{p})(S_d - S_w) \right]. \]
What drives the mixing between deep water and winter water?

To explore how EOS non-linearities influence the vertical structure of the upper ocean in polar regions, we compare the relative stability of individual \( \Delta \rho \) profiles to gravitational instability (static) and EOS non-linearities (non-static), where winter water overlies deep water. We determine the stability by computing the density difference between winter water and deep water as follows:

\[
\Delta \rho_{\text{static}} = \rho_{\text{EOS 2010}}(S_d, \Theta_d, \bar{p}) - \rho_{\text{EOS 2010}}(S_w, \Theta_w, \bar{p}),
\]

\[
\Delta \rho_{\text{nonstatic}} = \rho_0 \left[ -\alpha(S_d, \Theta_d, p_d)(\Theta_d - \Theta_w) + \beta(S_d, \Theta_d, p_d)(S_d - S_w) \right].
\]
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What is the role of EOS non-linearities?
Read our paper: