Isopycnal thermohaline intrusions in southern Drake Passage

Dafydd Stephenson (UoS)
Teresa Chereskin (SIO)
Yvonne Firing (NOC)

Contact:
Dafydd Stephenson
National Oceanography Centre,
University of Southampton
D.Stephenson@noc.soton.ac.uk

Introduction

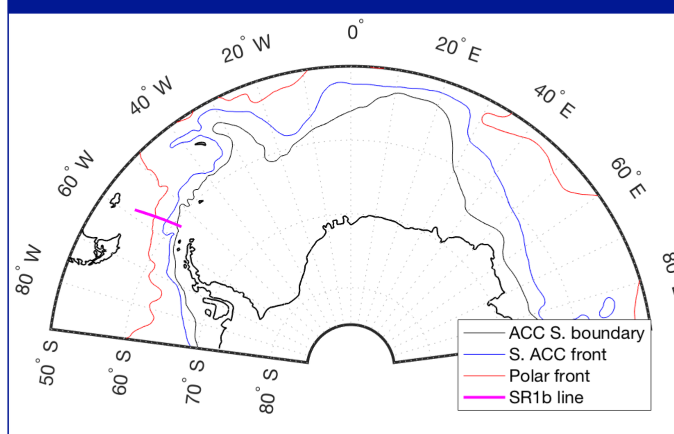

Figure 1: Southern Ocean (Atlantic and Indian sectors) showing SR1b line (magenta) and fronts from Orsi (1995) [1]

The Southern Ocean facilitates an enormous amount of water mass transformation, with mixing in many forms which remain poorly parameterised.

We consider a 25-year set of hydrographic data from the SR1b line (Fig. 1) alongside other cruise data and Argo profiles to determine the nature of observed compensated water mass intrusions.

Key points

- A 25-year dataset of hydrographic sections of Drake Passage shows frequent examples of density-compensated intrusions of cold shelf water into the warmer waters of the Antarctic Circumpolar Current (ACC)
- Multiple lines of evidence suggest that these intrusions are driven by double-diffusive instability
- Optimum multiparameter (OMP) analysis of additional CTD and Argo data highlights the Weddell Sea as the origin of the intrusive water type
- Potentially a key mechanism for mixing continental and ACC waters, but has no reliable parameterisation in models[2]

Density compensation & double diffusion

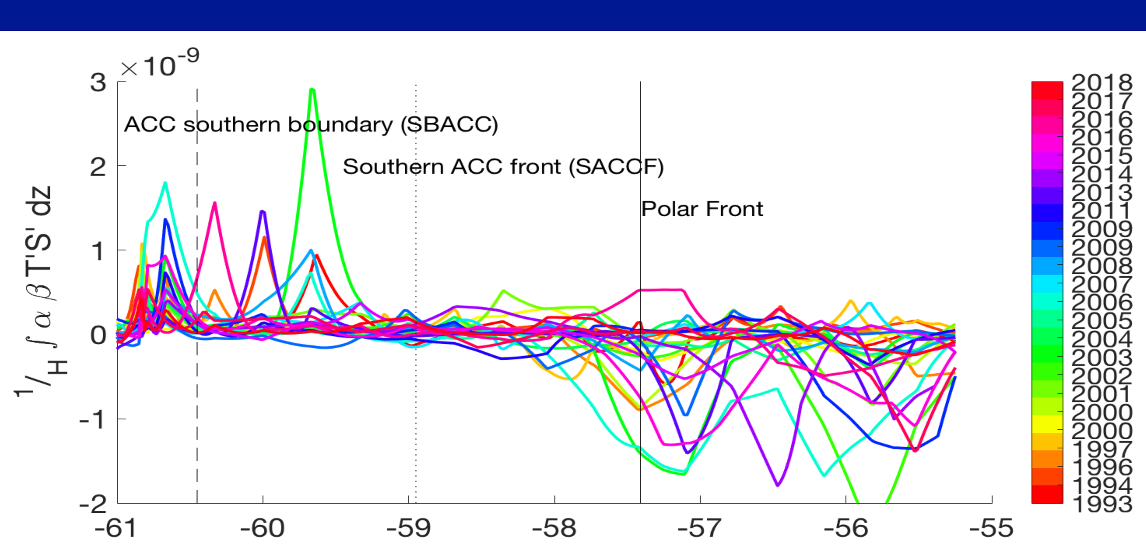

Figure 3: Latitude v. M_c for all SR1b cruises. Vertical lines show ACC fronts

- Can isolate compensated intrusions from background variability using the quantity

$$M_c = \frac{1}{H}\int_0^H \alpha(T-\bar{T})\beta(S-\bar{S})dz$$

Where H is the profile depth, $\bar{T}$ and $\bar{S}$ are time-averaged gridded temperature and salinity in latitude and depth. An exactly compensated intrusion is proportional to $(\alpha T')^2$, corresponding to a positive spike (*Fig. 3).*

- These spikes are largely contained between the SBACC (--) and SACCF (..).

- Water columns which are not statically stable in both T and S are susceptible to double-diffusive instability[3]. SR1b intrusions occur where Turner angles $\mathrm{Tu} \in \left[-\frac{\pi}{2}, -\frac{\pi}{4}\right]$, suggesting vulnerability to double-diffusive convective instability

- Double-diffusive instability may drive the intrusions: quasi-lateral intrusions can develop given:

- A strong, compensated thermohaline front (e.g. SBACC)
- Vertical structure conducive to double-diffusive instability $\left(|\mathrm{Tu}| \in \left[\frac{\pi}{4}, \frac{\pi}{2}\right]\right)$

- Vertical/horizontal intrusion scales (100 m/1-10km[4]), staircase structures and smaller-scale inversions provide further evidence that intrusions are double-diffusive in nature.

Anatomy of an SR1b intrusion

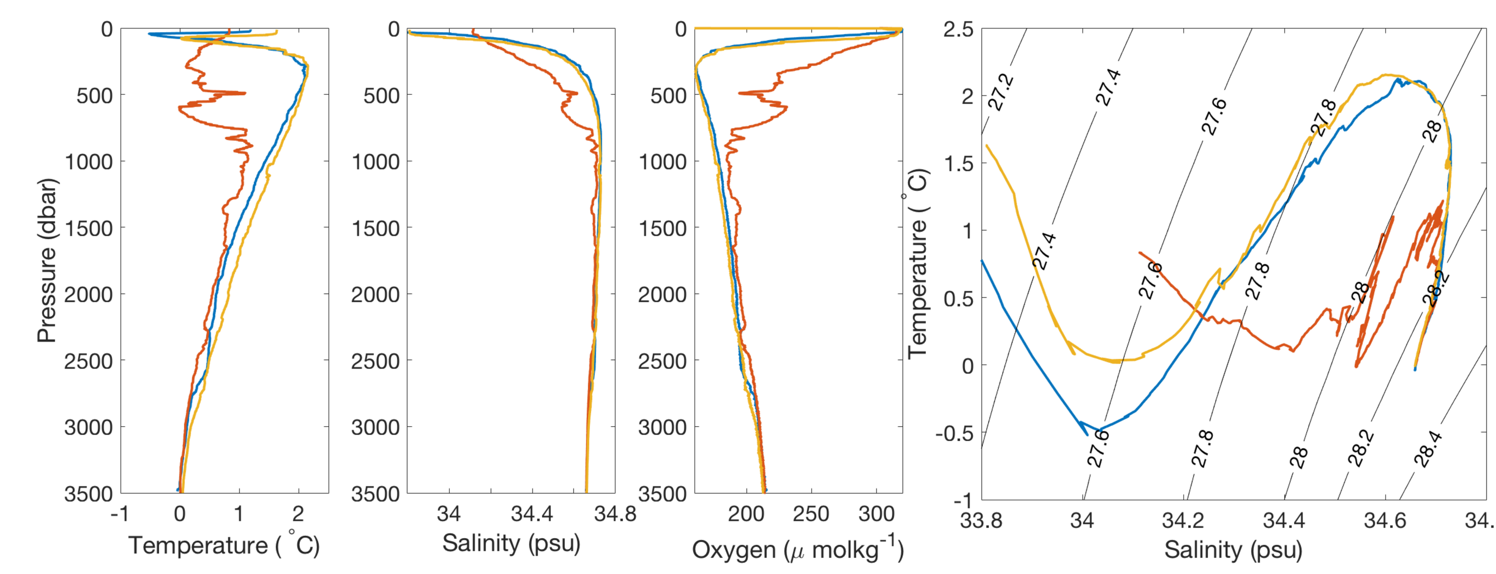

Figure 2, from left: Temperature, Salinity and Oxygen profiles within (orange), 39 km north (yellow) and 39 km south (blue) of an intrusion, 2009. Right: TS plot with 1000 m neutral density contours

- Cold
- Fresh
- Oxygenated
- Density-compensated

- O(100)m thick, limited lateral extent
- Slightly north of the ACC southern boundary (~60.5°S)
- No signature in velocity or dynamic height

OMP analysis & intrusion origins

Overview

OMP analysis determines concentrations of source water masses which mix to produce observed values by solving an over-determined linear system of equations[5]:

Weighting matrix · Source (A,B,C) definitions · Concentrations (unknown) = Observed values + Residuals

$$\begin{pmatrix} W_T & 0 & 0 & 0 & 0 \\ 0 & W_S & 0 & 0 & 0 \\ 0 & 0 & W_O & 0 & 0 \\ 0 & 0 & 0 & W_{PV} & 0 \\ 0 & 0 & 0 & 0 & W_M \end{pmatrix}\begin{pmatrix} T_A & T_B & T_C \\ S_A & S_B & S_C \\ O_A & O_B & O_C \\ PV_A & PV_B & PV_C \\ 1 & 1 & 1 \end{pmatrix}\begin{pmatrix} c_A \\ c_B \\ c_C \end{pmatrix} = \begin{pmatrix} T_{obs} \\ S_{obs} \\ O_{obs} \\ PV_{obs} \\ 1 \end{pmatrix} + \begin{pmatrix} r_T \\ r_S \\ r_O \\ r_{PV} \\ r_M \end{pmatrix}$$

Defining source water types

The southern end of SR1b has a three-water-mass structure (Fig. 4):

- (Drake Passage) Shelf Water ([DP]SW, core: on-shelf T_{min})
- Circumpolar Deep Water (CDW, core: mid-depth S_{max})
- Antarctic Surface Water (AASW, core: PV_{min}).

Determining weights

The elements of the weighting matrix are determined by[6]:

- Spread of parameter values within the source water definitions
- Spread of parameter values within the analysed data (Fig. 5)

Analysis results

- Intrusions are identified as shelf water (Fig. 6)
- Incorporating local Argo profiles → shelf water closely related to Weddell Sea water along the South Scotia Ridge (SSR, Fig. 7)
- Very few intrusions west of Shackleton Fracture Zone. Here, lack of distinct shelf water → weaker frontal gradients[7]
- Separate OMP analysis on the ALBATROSS along-SSR cruise shows Philip Passage as the primary source of shelf water – a lighter form of Weddell Sea Deep Water

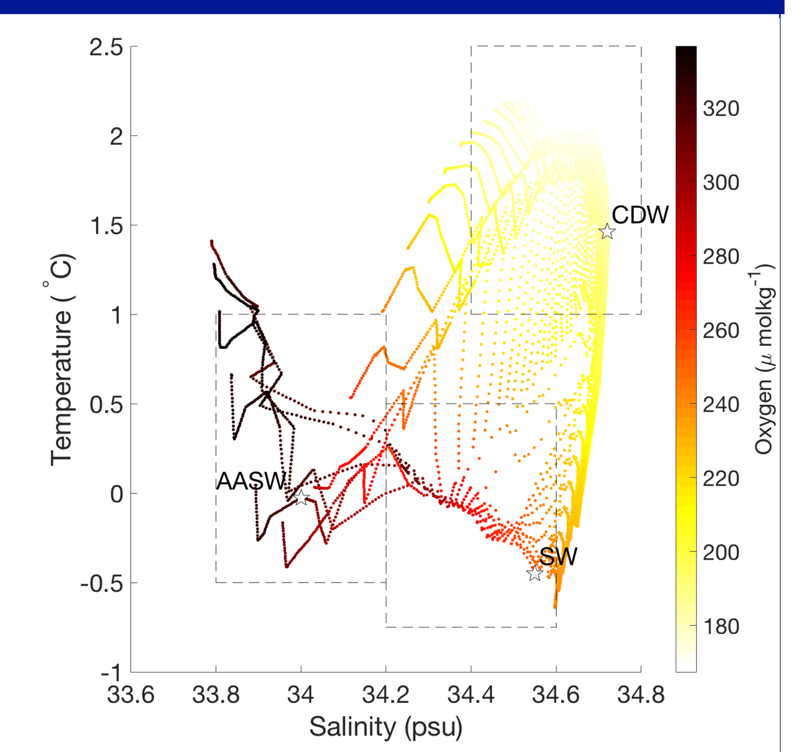

Figure 4: SR1b gridded and time-averaged salinity, temperature and oxygen showing source water cores

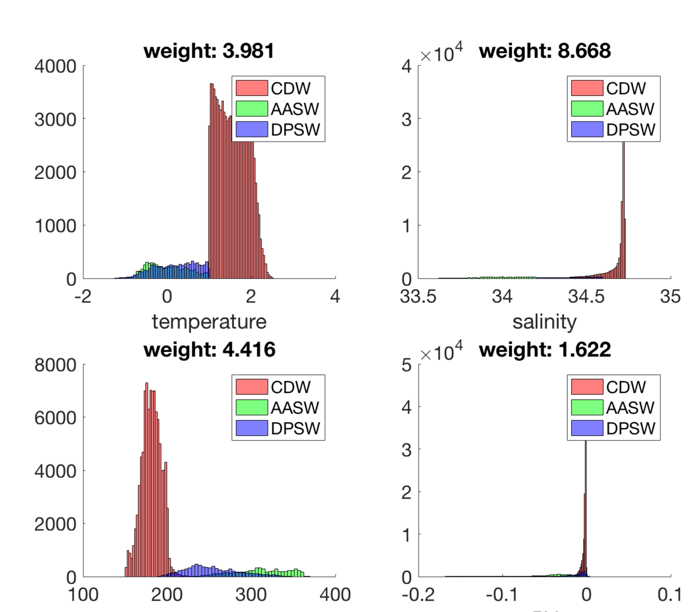

Figure 5: Spread of SR1b parameters within source waters and corresponding OMP weights from gridded data

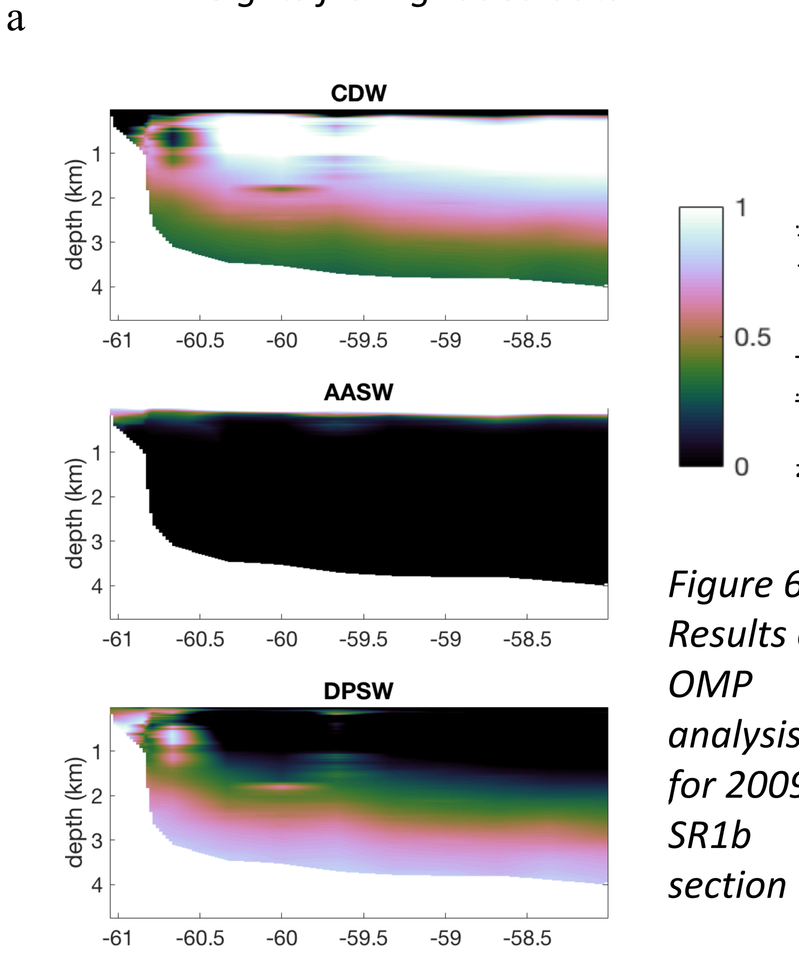

Figure 6: Results of OMP analysis for 2009 SR1b section

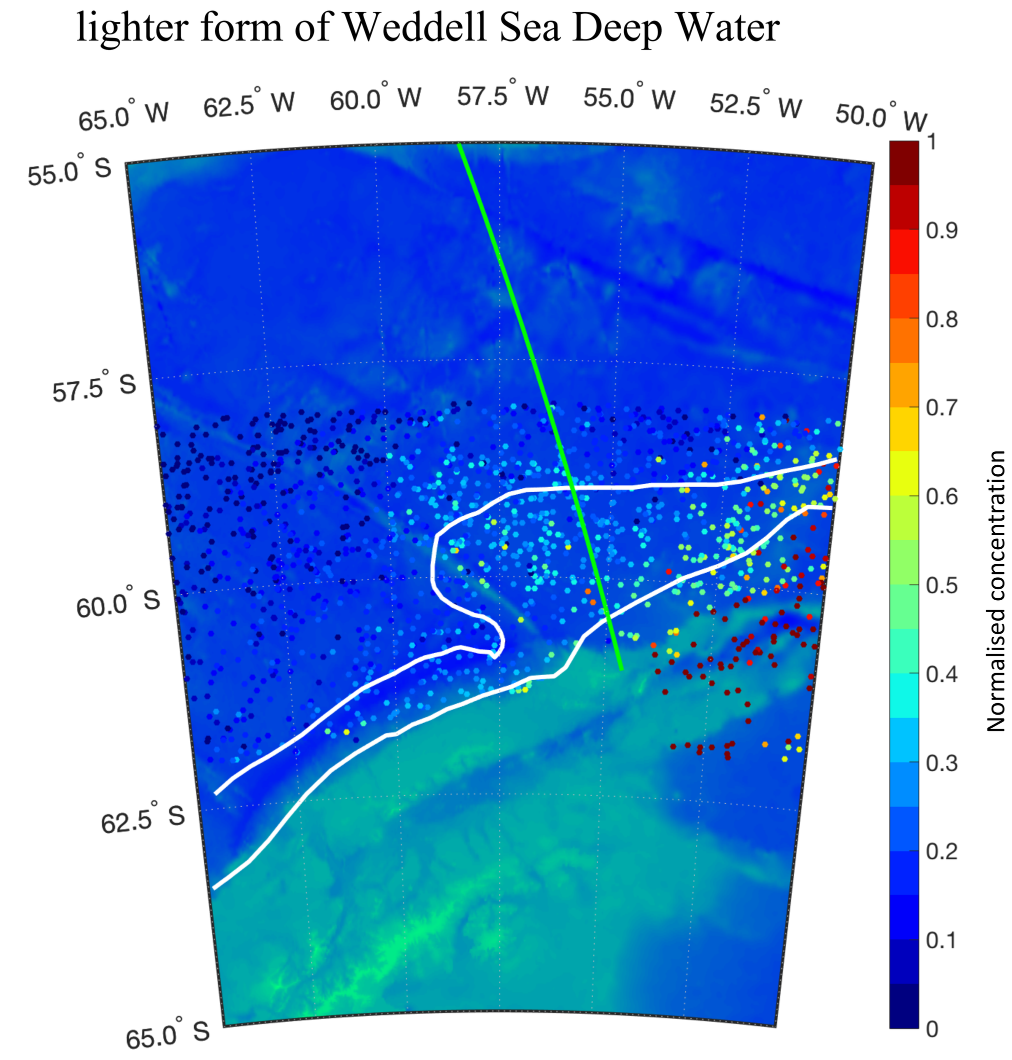

Figure 7: Maximal concentration of shelf water in 1844 Argo profiles. White lines show SACCF and SBACC. Green shows SR1b line.

References

[1] Orsi, A. (1995) On the meridional extent and fronts of the Antarctic Circumpolar Current, *Deep Sea Res. Pt. I, 42, 641-673*
[2] Ruddick, B. and Gargett, A., (2003) Oceanic Double-diffusion: Introduction, *Prog. Ocean., 56, 381-393*
[3] Turner, J. (1979) Double-diffusive intrusions into a density gradient, *J. Geophys. Res., 83, 2287-2901*
[4] Toole, J. and Georgi, D., (1981) On the dynamics of double-diffusively driven intrusions, *Prog. Ocean., 10, 123-145*
[5] Tomczak, M., Large, D.G.B. (1989). Optimum multiparameter analysis of mixing in the thermocline of the Eastern Indian Ocean. *J. Geophys. Res.* 94, 16141–16149
[6] Frants, M., Hewes, C., Holm-Hansen, O. et al. (2013), Optimal multiparameter analysis of source water distributions in the Southern Drake Passage, *Deep Sea Res. Pt. II, 90, 31-42*
[7] Ruddick, B. and Turner, J., (1979) The vertical length scale of double-diffusive intrusions, *Deep Sea Res. Pt. I, 26, 903-913*