WARM WATER FLOW AND MIXING
BENEATH THWAITES GLACIER ICE
SHELF, WEST ANTARCTICA


TARSAN and THOR projects
https://thwaitesglacier.org
Thwaites Glacier: New data from a data desert

Two AUV missions (panels b and c) in deep troughs B and C (partway under the ice shelf)

CTD in neighboring basins (colored circles)

Ship-borne ADCP in deep troughs (A, B and C in map)

Ice shelf draft by multibeam (panel d)
Background: Hydrography from two expeditions (2010\(^1\) and 2014\(^2\))

Consistently saltier deep water (by 0.02 g/kg) in Thwaites Trough (light colors) compared to Pine Island Basin (dark colors)

Temperature variability (both time and space) larger in Pine Island Basin


Background

Ship-based CTD transects\textsuperscript{1,2} from the Pine Island Trough show that the deep water (800-1300 m) there is warm (CT = 1.1 - 1.2 °C), salty (SA = 34.85 - 34.87 g/kg) and weakly stratified. In Thwaites Trough the deep water is more well mixed (more uniform) with salinity SA = 34.885 and temperature 1.13 - 1.15 (2014) and 1.15 - 1.20 °C (2010). The higher salinity in Thwaites Trough indicates that it receives a deeper type of Circumpolar Deep Water, which is possible since it has a greater sill depth than the eastern part of Pine Island Trough. The variability in deep water temperatures is larger in Pine Island Basin than in Thwaites Trough (temporal variation as well as vertical and horizontal), reflecting that temperature varies substantially in time and space in Pine Island Trough due to local and cross-shelf forcing\textsuperscript{3}. This variability ultimately originates from the source water, Lower Circumpolar Deep Water (LCDW), which outside the shelf at 600-800 m depth has a temperature range 0.95 - 1.5 °C but a narrow salinity range of 34.895 - 34.905 g/kg\textsuperscript{4}. The westernmost stations show evidence of melting of glacial ice as the temperature- and salinity values in pale blue trend toward the black meltwater mixing line (or ‘Gade line’) in temperature-salinity space.


# AUV ‘Ran’

A Kongsberg Hugin 3000 m Autonomous Underwater Vehicle

<table>
<thead>
<tr>
<th>Dimensions</th>
<th>Depth rating and range</th>
<th>Power supply</th>
<th>Endurance</th>
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</thead>
<tbody>
<tr>
<td>Length: approx. 7.5 m</td>
<td>3000 m</td>
<td>4 (max 6) rechargeable and swappable Lithium Polymer batteries</td>
<td>36 hours</td>
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<tr>
<td>Diameter: 875 mm</td>
<td>300 km</td>
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<tr>
<td>Weight: 1850 kg</td>
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Ran hydrographic / chemical sensors

- Dual Sea-Bird SBE-19plusV2 (T, S, P) and SBE-43 Dissolved oxygen
- Upward looking DVL / ADCP (Nortek 500 kHz)
- Contros HydroC CO2
- Sea-Bird/Wet-Labs ECO Triplet (FLBBCD)
- Sea-Bird/Satlantic Deep SUNA
- Fluidion water sampling system
- General payload area (60x87 cm) where sensors and instruments can be placed, 6 RS232 connectors plus ethernet / LAN connection
The AUV followed a path at an altitude of 50 m above the seabed for most of the missions, except for a number of cross-trough movements at constant depths. Warm water (0.8-1.05 °C) was observed in both troughs.
When warm salty ocean water comes in contact with and melts glacial ice it becomes colder (due to loss of latent heat and cooling by the ice\textsuperscript{5}), fresher (due to the mixing with meltwater), and gets higher dissolved oxygen concentration (due to high levels of dissolved oxygen in the melt water\textsuperscript{5}). Using this reveals that the water in trough ‘B’ (red markers) contains more glacial meltwater than trough ‘C’ (blue markers).

\textsuperscript{5} Jenkins, A. The Impact of Melting Ice on Ocean Waters. J. Phys. Oceanogr. 29, 2370–2381 (1999)
In trough 'B' the ship's hull-mounted ADCP system show there is a northward outflow of water above 500 m, while in trough 'C' there is southward flow at all depths transporting warm water towards the ice shelf cavity. The southward heat transport in trough 'C' alone was estimated as 0.8 TW, which is sufficient to melt 50 km$^3$ glacial ice per year. This is close to recent estimates of net thinning.

**Heat transport in trough 'C':**
0.8 TW

**Meltwater exits in trough 'B'**
Origin of water in troughs and under the ice shelf

Water in trough ‘C’ has T-S-O$_2$ properties similar to Pine Island Bay (pink markers), while trough ‘B’ has water more similar to that in Thwaites Trough (blue and green markers) and higher concentration of glacial melt. The observations imply that near-bottom water in trough ‘C’ is derived from the same source as water in Pine Island Trough while trough ‘B’ is a site where meltwater-laden water flows between the ice cavity and Thwaites Trough. West of 107$^\circ$W, meltwater-laden lighter water is observed to flow northwards out of the cavity in trough ‘B’.
We have presented the first direct observations of ocean temperature, salinity, and oxygen underneath Thwaites Ice Shelf. These indicate that water underneath the central part of the ice shelf is derived from water in Pine Island Bay. Further, the observations show that warm water enters the cavity underneath the Thwaites Glacier Tongue (TGT) from the north in two troughs separated by a pinning point. The easternmost of these troughs has southward flow from surface to bottom towards the ice shelf cavity, and no indication of recent contact with glacial ice. The westernmost has a northward flow of meltwater-enriched water near the surface, and a deeper southward flow of warmer and saltier water.
Thanks to the ITGC program: http://thwaitesglacier.org