UNIVERSITY OF GOTHENBURG

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

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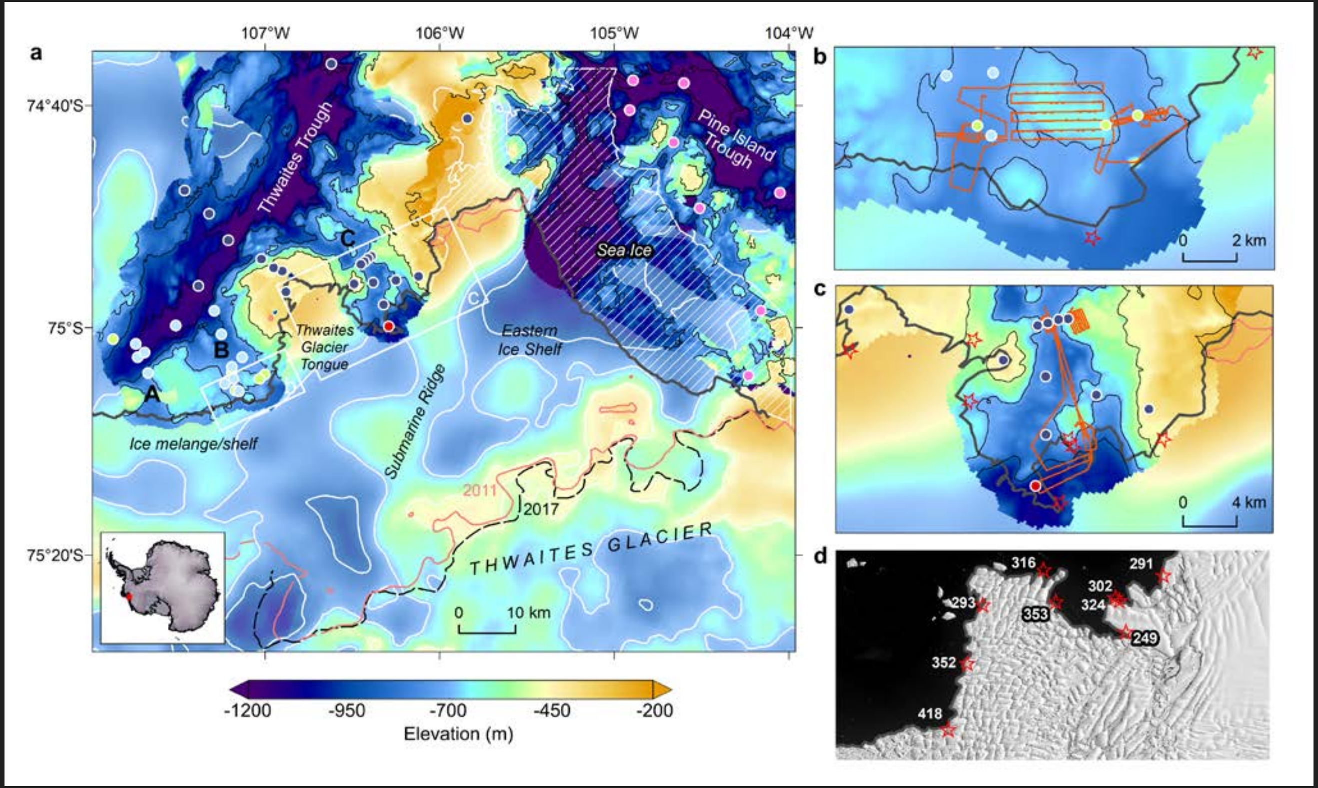
TARSAN and THOR projects
https://thwaitesglacier.org

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)

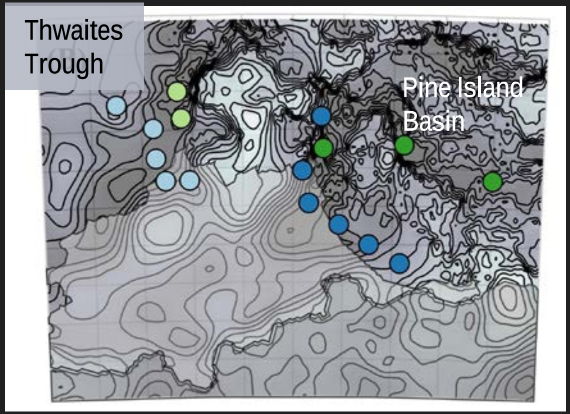
Ship-borne ADCP in deep troughs (A, B and C in map)

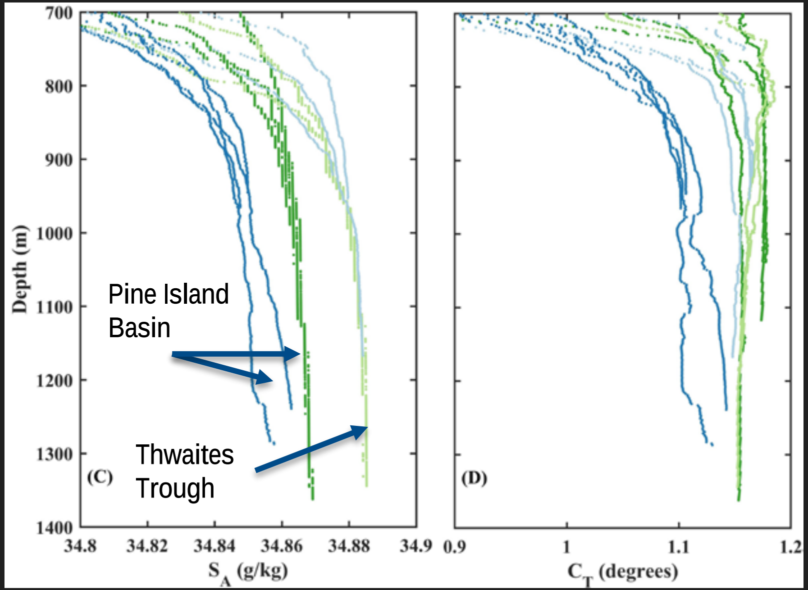
Ice shelf draft by multibeam (panel d)

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

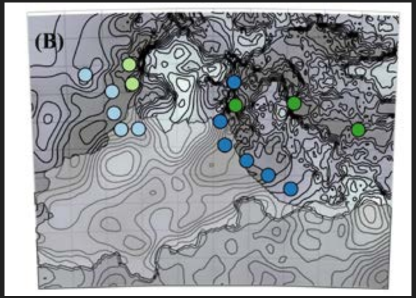




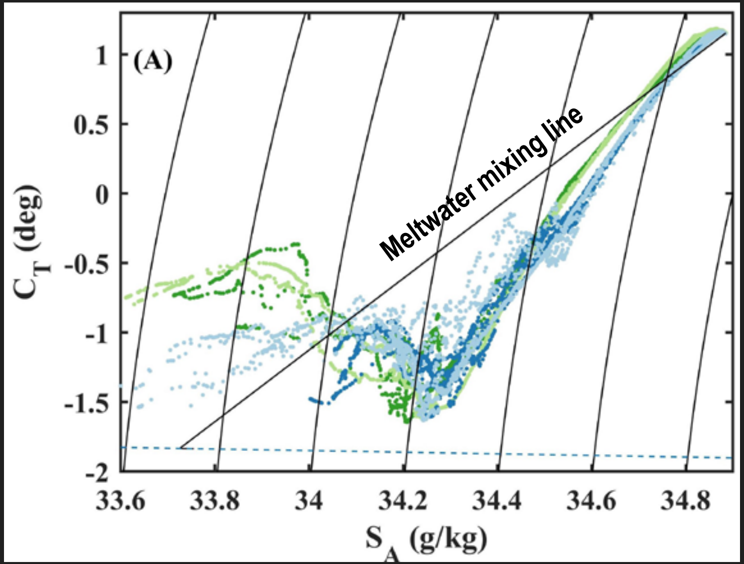
1) Nakayama, Y., Schröder, M. & Hellmer, H. H. Deep-Sea Research I From circumpolar deep water to the glacial meltwater plume on the eastern Amundsen Shelf. Deep. Res. Part I, 77, 50–62 (2013)

2) Heywood, K. K. J. et al. Between the devil and the deep blue sea: The role of the Amundsen Sea continental shelf in exchanges between ocean and ice shelves. Oceanography 29, 118–129 (2016)

Background



Ship-based CTD transects[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 (S_A = 34.85 - 34.87 g/kg) and weakly stratified. In Thwaites Trough the deep water is more well mixed (more uniform) with salinity S_A = 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[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[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.



3) Webber, B. G. M. et al. Mechanisms driving variability in the ocean forcing of Pine Island Glacier. Nat. Publ. Gr. 8, 1–8 (2017).

4) Moffat, C., Owens, B. & Beardsley, R. C. On the characteristics of Circumpolar Deep Water intrusions to the west Antarctic Peninsula Continental Shelf. J. Geophys. Res. 114, 1–16 (2009).

AUV '*Ran*'

A Kongsberg Hugin 3000 m Autonomous Underwater Vehicle

Dimensions	Depth rating and range	Power supply	Endurance
Length: approx. 7.5 m Diameter: 875 mm Weight: 1850 kg	3000 m 300 km	4 (max 6) rechargeable and swappable Lithium Polymer batteries	36 hours

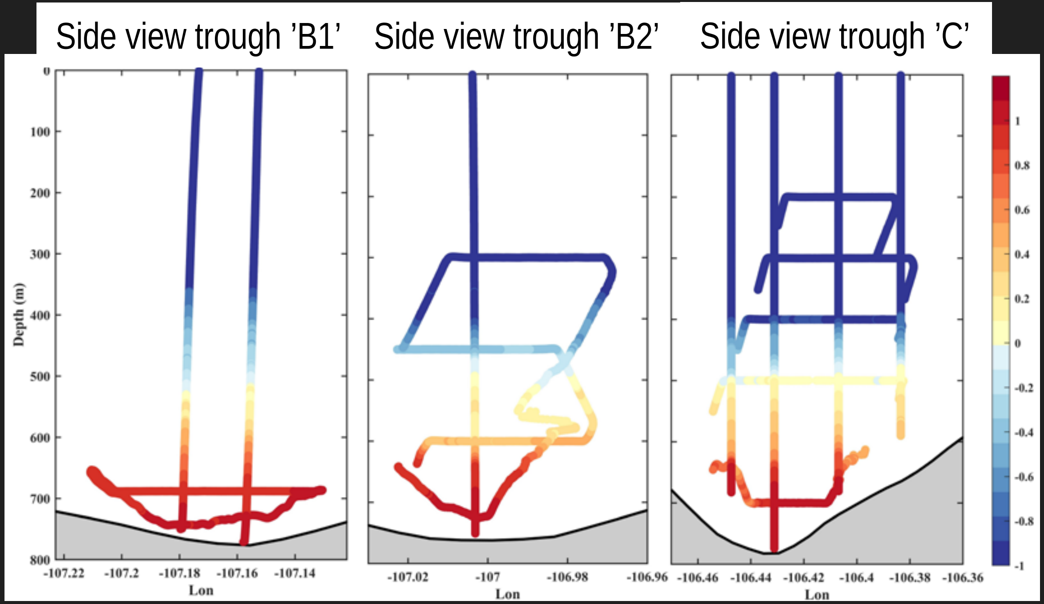
Ran hydrographic / chemical sensors

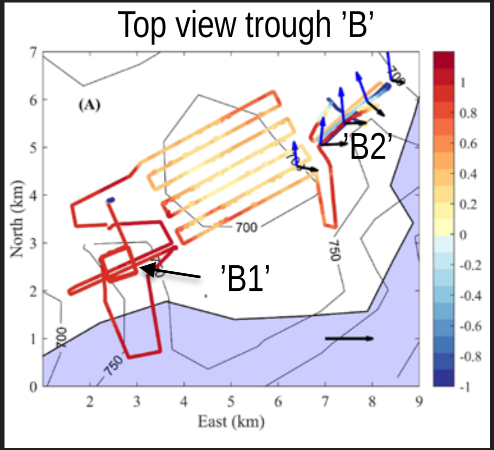
- Dual Sea-Bird SBE-19plusV2 (T, S, P) and SBE-43 Dissolved oxygen)
- Upward looking DVL / ADCP (Nortek 500 kHz)
- Contros HydroC CO2
- Sea-Bird/Wet-Labs ECO Triplet (FLBBCD)
- Sea-Bird/Satlantic Deep SUNA
- Fluidion water sampling system
- General payload area (60x87 cm) where sensors and instruments can be placed, 6 RS232 connectors plus ethernet / LAN connection

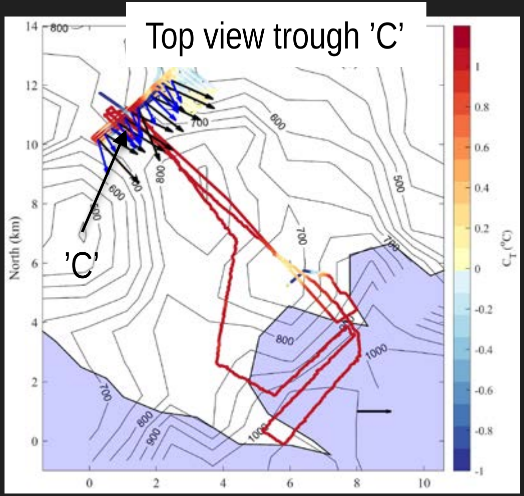
SMaRC SWEDISH MARITIME ROBOTICS CENTRE

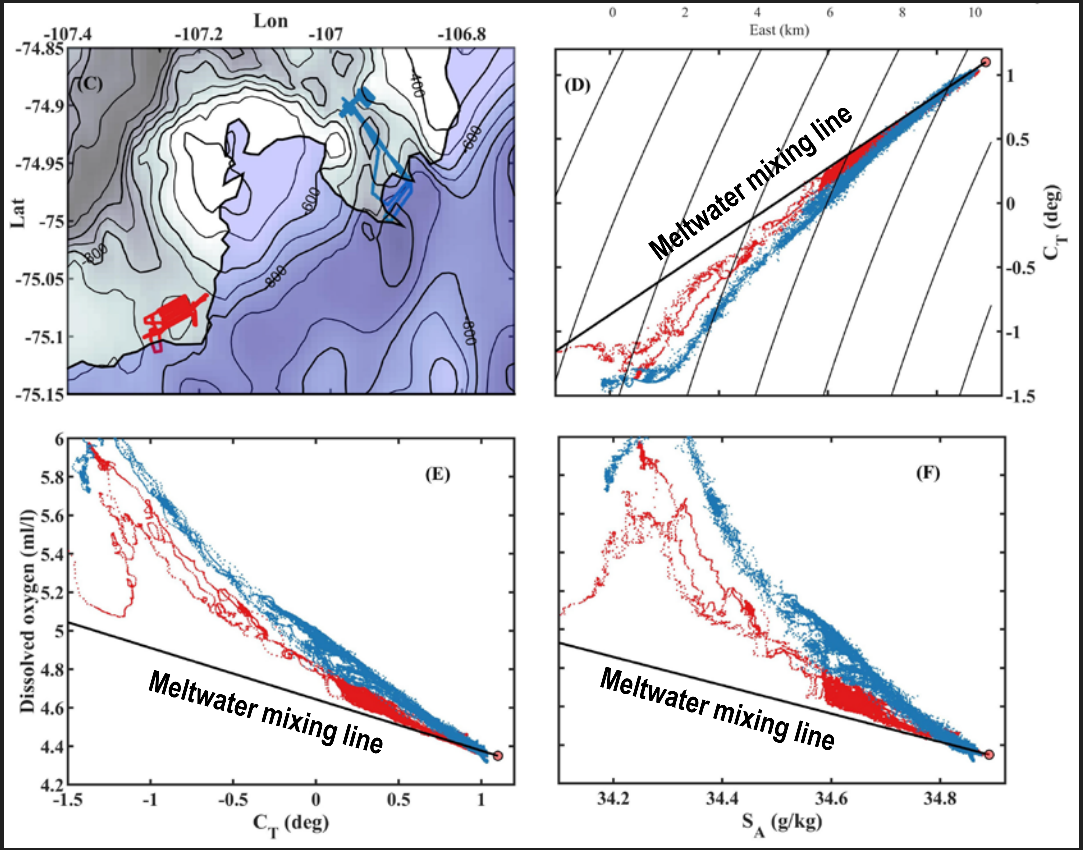
Temperature in deep troughs

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 ^{o}C) was observed in both troughs.







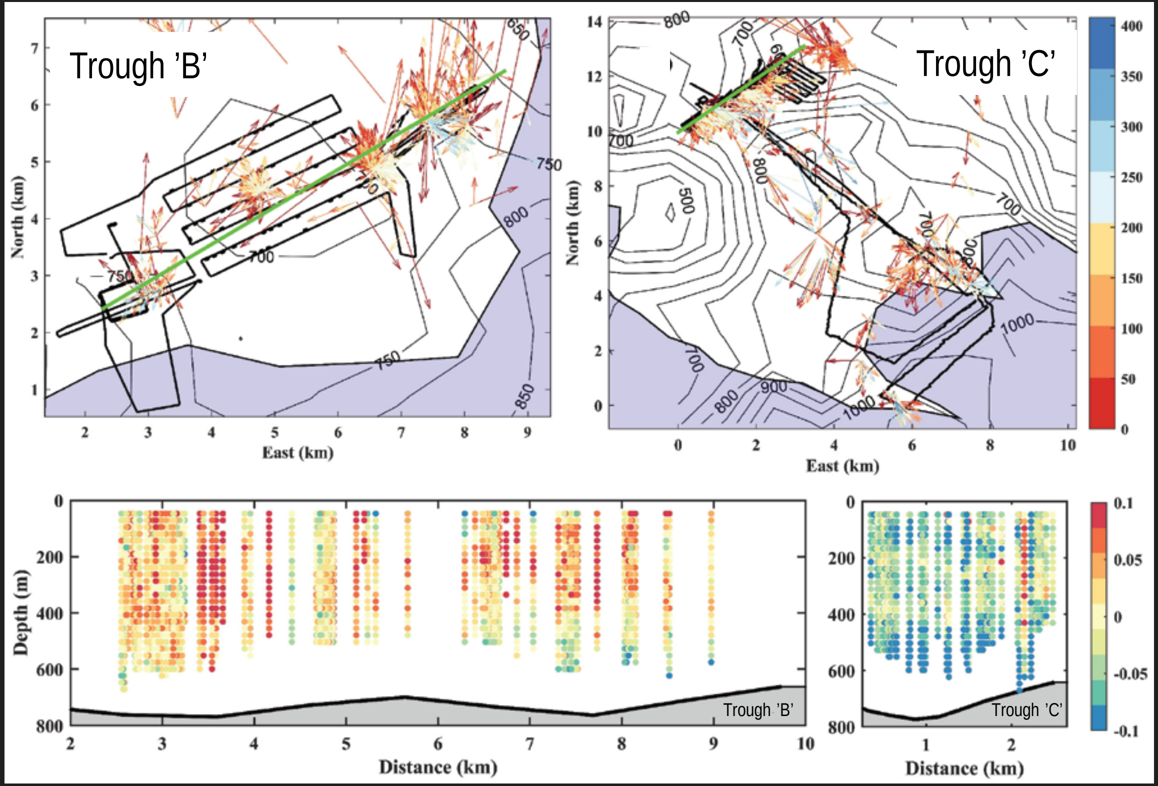


Temperature and salinity in deep troughs

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[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[5]). Using this reveals that the water in trough 'B' (red markers) contains more glacial meltwater than trough 'C' (blue markers).

5) Jenkins, A. The Impact of Melting Ice on Ocean Waters. J. Phys. Oceanogr. 29, 2370–2381 (1999)

Velocity in deep troughs



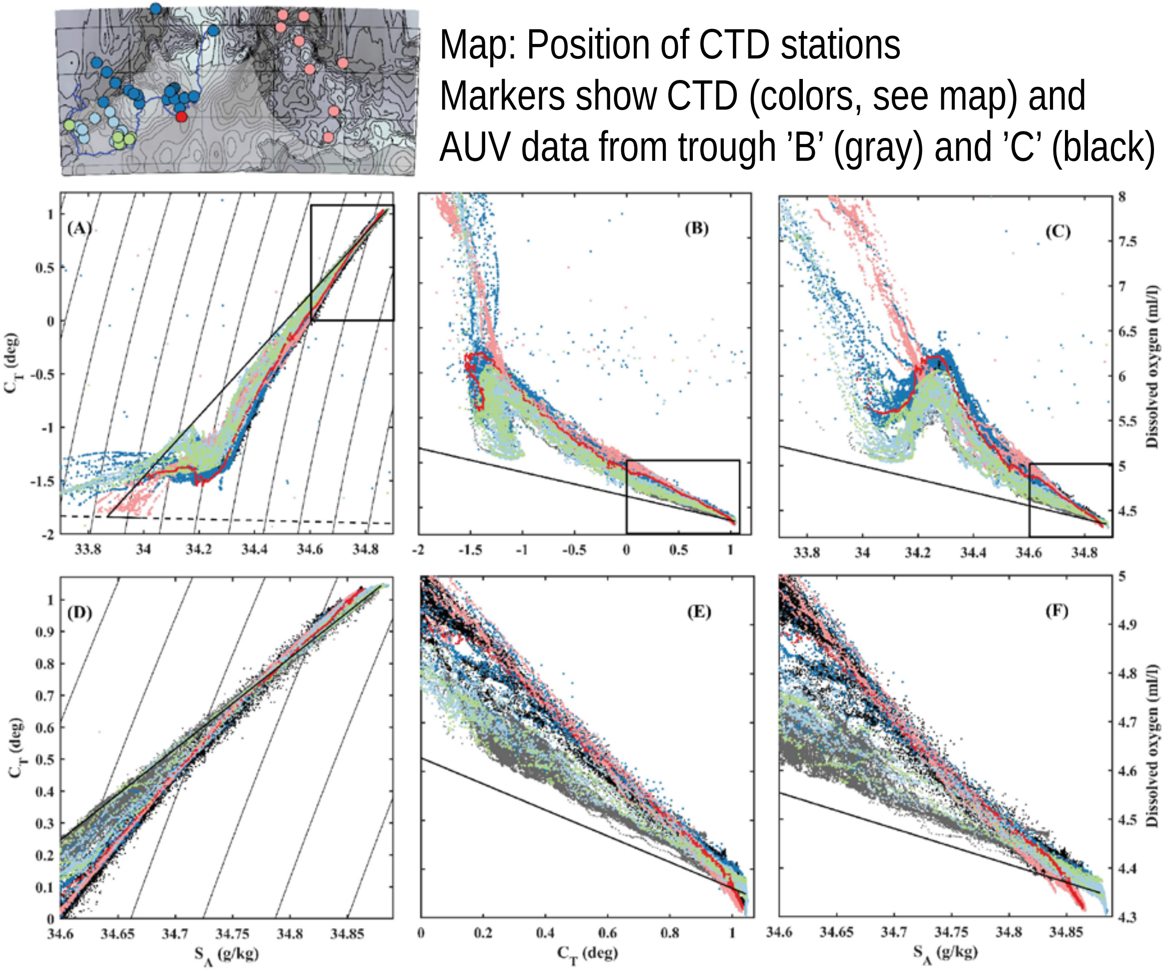
Top panels: ADCP velocity (all data), color indicate depth.
Bottom panels: Along-channel velocity components on the green lines in the top panels

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.

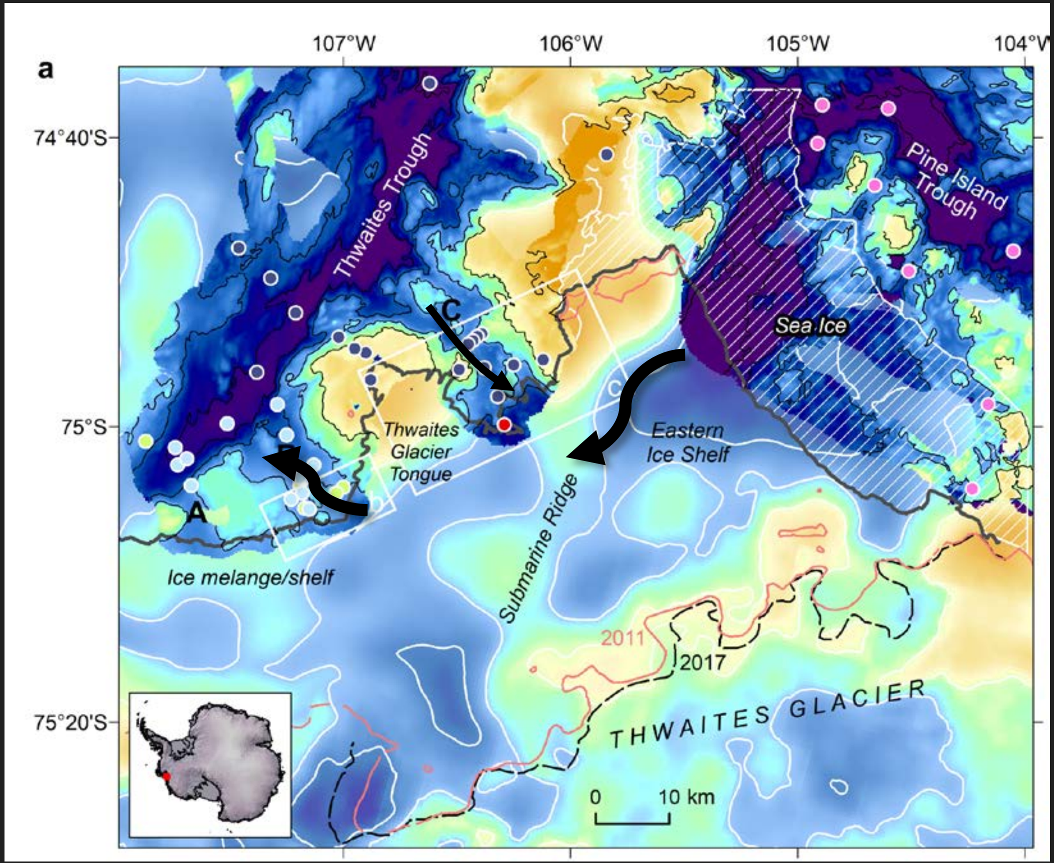
Heat transport in trough 'C': 0.8 TW
Meltwater exits in trough 'B'

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 107ºW, meltwater-laden lighter water is observed to flow [northwards out of the cavity in trough ‘B'].



Summary: Suggested flow paths



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