McMurdo Ice Shelf as an ocean world analog: supercooled water and ice mass balance


Background

The regions below Antarctica’s ice shelves are among Earth’s largest remaining unexplored environments, and are important analogs for the physical processes occurring on other ocean worlds such as Europa or Enceladus. On Earth, these processes control sub-shelf ice flux through supercooling (the ice pump, Fig. 1) [1], provide habitable niches at the ice-ocean interface, and entrain and transport organics through the ice [2].

NASA’s Astrobiology Science & Technology for Exploring Planets program funded the Sub-Ice Investigation of Marine and Planetary-analog Ecosystems project to explore beneath the McMurdo (MIS) and Ross (RIS) Ice Shelves with submersible vehicles (ROV/AUVs). Here, we characterize the relationship between ice and ocean with salinity, temperature, and depth (CTD) data (Fig. 2) compared to imagery from beneath the MIS (Figs. 4, 5, 6).

Methods

**ROW/AUVs Deployed**
- SCINI (SJS), 2012
- Icefin (Georgia Tech, Fig. 7), 2014
- ARTEMIS (Stone Aerospace), 2015
- RBB Concerto CTD (independent sensor, hand-deployed)

**Data Collected**
- 35 conductivity, temperature, and depth (CTD) profiles
- Sub-shelf and sea ice imagery
- Up to the full water column, ~500 m below the MIS

**Data Processing**
- Via Gibb Sea Water Python module (gsw 3.0.3) according to the TEOS-10 standards [3]
- Calculated (SA, [g kg]), conservative temperature (θ, [°C]), surface and in situ freezing points (Tf)

Note: SA differs from practical salinity [psu], and is reported utilizing v3.0 of the McDougall et al., (2012) database

**Figure 1.** The ‘Ice Pump’, or how basal melting and freezing redistributes ice via supercooling. High Salinity Shelf Water (HSSW) forms in a polynya from the brine rejected by sea ice formation (1) and sinks, flowing into the shelf cavity (2). At depth, the freezing point (Tf) is lower and the ‘warm’ HSSW causes melting. Fresher, buoyant Ice Shelf Water (ISW) forms as a result, fixed at the deep Tf (3). As ISW rises and pressure falls, Tf increases and so the ISW becomes supercooled. As a result, frazil ice forms at the basal interface or in the water column and accretes into marine ice (4). Camp icons indicate prior investigations below the Ross Ice Shelf.

**Figure 2.** Temp vs. salinity of water columns corresponding to 2012, 2014, and 2015. Black line is the freezing temperatufe (Tf) note where water is colder than T (ISW) accreting ice is observed (Figs. 6, 7). If the water is warmer than T (HSSW), the ice appears smooth (Fig. 3).

**Figure 3.** Adapted from the 2017 Europa Lander SDT Report; this schematic diagrams some of the ice-ocean and intra-ice processes hypothesized to be occurring on Europa. With temperatures and pressures similar to Earth (low gravity compensated by thick ice), the ice pump may operate to entrain materials which can then be transported through the shell via diapirs [2].

**Figure 4.** Below the MIS in Nov 2015 at SIMPLE Site. Supercooling was present (Fig. 2 blue profiles, T>Tf), panel A is a closeup of accribing ice below the shelf, B is the ARTEMIS HUD, and C shows rough morphology with platelet ice crystals below adjacent sea ice.

**Figure 5.** Nov 2014 images from below the MIS. Panel A is site F, panel B and C are from site E. Panel C depicts the communities observed at E. Supercooling was present at all sites in 2014 (Fig 2 orange profiles, T>Tf) and the ice morphology is rough with platelet ice.

**Figure 6.** A-D: Imagery from SCINI looking upward at the MIS from 23 Dec 2012 at the SCINI site. No supercooling was detected here (Fig. 2 green profile, T>Tf), and the ice is smooth and ablated.

**Figure 7.** Forward Module + Sonar, CTD, DO + Camera, laser

**Takeaways**

**Supercooling & the Ice Pump**
- Varies spatially (Fig. 2) and temporally in Antarctica
- If no supercooling was present, ice was ablated (Fig. 4)
- If supercooling was present, so was accreting ice (Fig. 5, 6)

**Astrobiology Implications**
- Europa and Enceladus likely have a similar ice pump mechanisms, influencing:
  - Ocean-surface material cycling
  - Ice shell thicknesses
  - Basal interface habitability and organics entrainment
  - Ocean circulation

**AUV/ROV exploration of Earth’s cryosphere advances:**
- Ability to model ice processes on other ocean worlds
- Autonomous robotics for in situ planetary exploration
- Terrestrial climate change & sea level rise models

**Future**

From 2017 to 2019, we will deploy the ROV/AUV Icefin (Georgia Tech, below), beneath the MIS and RIS as part of the next field campaign, RISE UP (NASA NNX16AL07G).