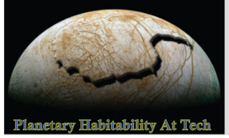

Insights into Ice-Ocean Interactions on Earth and Europa

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Sub-Ice Marine and PLanetary-analog Ecosystems

Europa and Earth appear to be drastically different worlds, yet below their icy crusts the two likely share similar oceanic conditions including temperatures, pressures (relatively), and potentially salinity. Earth's ice shelves and ocean provide an important analog for the physiochemical, and potentially microbial, characteristics of icy worlds. NASA's ASTEP program funded SIMPLE to help address the fundamental processes occurring at ice ocean interfaces, the extent and limitations of life in sub-ice environments, and how environmental properties and biological communities interact. The technologies supported by SIMPLE are also supporting the ice penetrating radar on the upcoming Europa Flagship mission, and will hopefully inform future in situ ocean world exploration. Here, we present results from CTD and imaging data gathered beneath the McMurdo Ice Shelf (MIS) to highlight how the ice and ocean interact in a Europan analog environment.

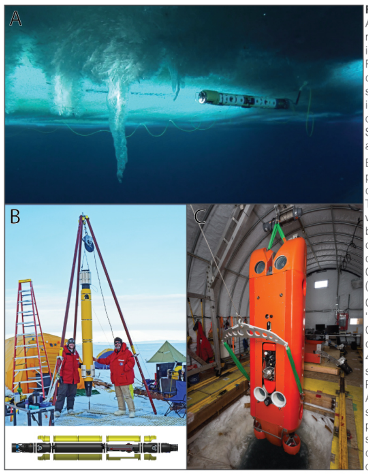
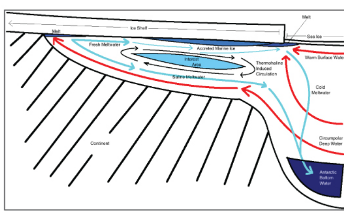


Figure 1.
A: SCINI exploring brine rejection features under sea ice. SCINI is a 1.5 m long ROV rated to 300 m developed for imaging the sub-shelf environment and identification of macrofaunal organisms. For SIMPLE, SCINI was also outfitted with a CTD.
B: Icefin is a modular, portable AUV rated to 1500 m designed and built at Georgia Tech for characterizing the water column, ice, and benthic environments. In the current configuration, Icefin carries imaging sonars, a CTD, ADCP, DVL and IMU (Image: Jacob Buffo).
C. ARTEMIS hangs out in the 'Bot Garage' at SIMPLE Camp in 2015 prior to deployment. ARTEMIS is a 4.3 m, 1 km rated AUV with sensors including CTD, pH, PAR, DOM, turbidity, chl-a, ADCP, sonars, water sampler, and an experimental protein fluorescence spectrometer for testing life detection technology ahead of a potential Europa lander.

The MIS is "ice starved," an ideal place to study basal accretion and melt. As supercooled water flows upward along the basal slope of the shelf, frazil ice precipitates and rises, accumulating at the interface (Fig. 2). In thermally stable regions, platelet ice grows in situ and contributes to the marine ice layer. The thickest sub-shelf marine accretions on Earth exceed ~500 m.



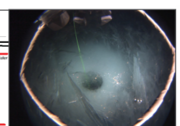
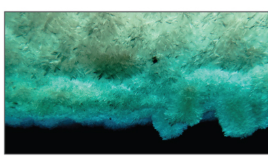


Figure 2. Left: 'Ice Pump' schematic depicting sub-shelf melt and accretion. Above: 2014 SCINI image looking upward at sub-shelf platelets.



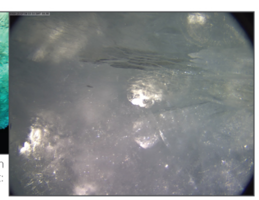


Figure 3. Left: Platelet ice formations beneath columnar sea ice in the McMurdo Sound. Right: Closeup of sub-shelf platelets taken by ARTEMIS.

CTD Profiles from Three Field Seasons

2012 | SCINI

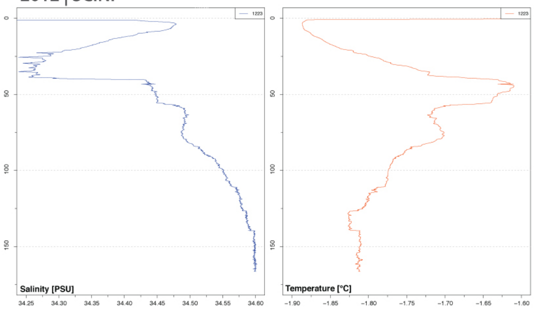


Figure 4. SCINI (Submersible Capable of under Ice Navigation and Imaging, SJSU, S. Kim) was deployed 5 km back from the front of the ice shelf and observed ablation in a heterogeneous water column, consistent with melting by fast moving inbound currents.

2014 | SCINI & Icefin

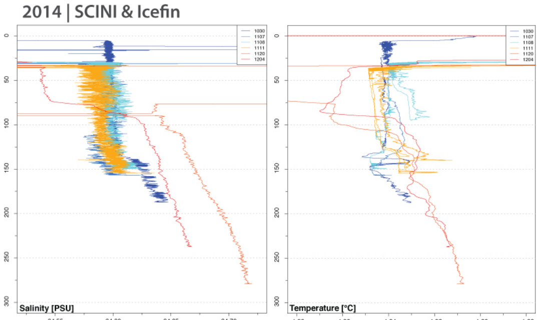


Figure 5. SCINI and Icefin were deployed at 5 sites 10 to 20 km from the MIS shelf front, and encountered very different ice conditions than in 2012. The above profiles depict a more homogeneous water column, and imagery showed larger amounts of platelet ice formation, between 1 and 3 m thick layers with varied platelet macro structure including spears and columns. SCINI also observed a complex community of benthic organisms near Black Island.

2015 | ARTEMIS & RBR Concerto

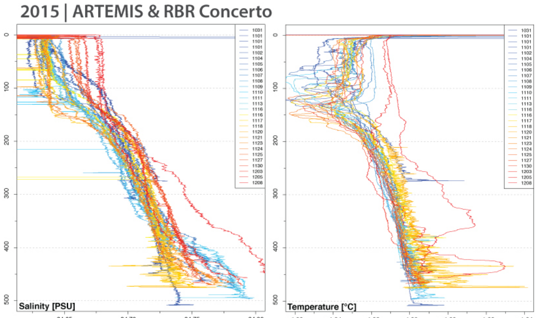


Figure 6. Daily profiles from the 2015 SIMPLE sea ice camp, approximately 150 m north of the MIS front, are saltier than the sub-shelf casts in 2012 and 2014. Ice thickness measurements and vehicle data indicated significant platelet growth beneath the sea ice, at rates up to 0.5 m week^{-1}, with total accumulations reaching 5 to 6 m. Imagery and sonar data (Fig. 8) showed more muted platelet structure on the shelf than 2014.

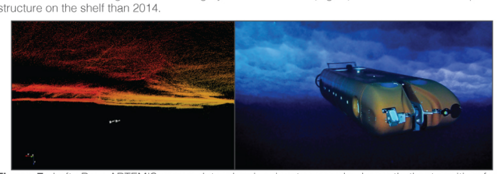


Figure 7. Left: Raw ARTEMIS sonar data showing ice topography beneath the transition from multi-year sea ice to the MIS. Right: ARTEMIS below similar platelet topography at SIMPLE Camp.

Results

Over the course of three field seasons, we observed temporal and spatial variation in both water column and platelet accumulation trends. The single dive from 2012 shows the most heterogeneous waters in an area of ablation (Fig. 4). 2014 study sites recorded more homogeneous waters with large and varied structures of platelet accumulations at the interface (Fig. 5). In 2015, a time series of casts over the month of November through the sea ice at SIMPLE Camp shows Antarctic Surface Water to about 120 m depth, transitioning to Antarctic Bottom Water below 450 m (Fig 6). Bottom depth was 529 m. Sub-shelf casts (2012, 2014) are generally fresher (< 0.05 PSU) at the interface and slightly colder than the 2015 sea ice casts. Most interesting is the differences observed between dives 11 (ebb) and 17 (high), in which temperature-salinity trends near the ice interface invert, and may suggest that tidal influence changes the interaction over short windows during high tide. Sources of error potentially include vehicle noise and sensor configurations, thus this conclusion is preliminary pending continued analysis.

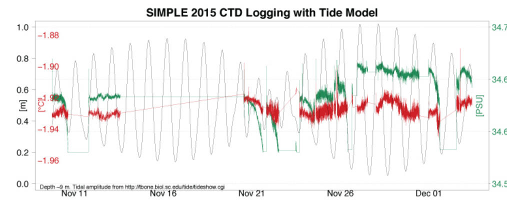
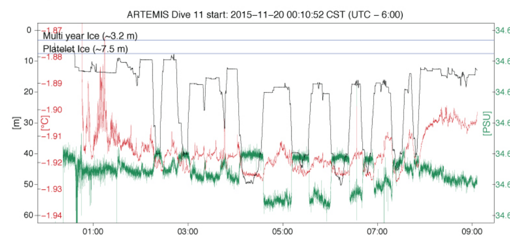


Figure 8. 2015 CTD logging data at 9 m depth at the sea ice interface, with tidal model. While no deployments had ice accumulate on the sensor, the 11/23, 11/24, 11/25, 11/27, and 11/30 deployments came up with 5 - 40 cm of platelet growth on the line, which may have influenced salinity readings.



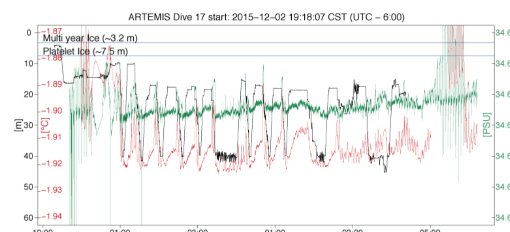


Figure 9. Two sub-shelf ARTEMIS mission profiles including the same 1 km transect show potentially interesting opposing salinity trends during ~25 m 'casts' from 40 m nominal travel depth to a 1 m standoff sampling depth below the interface (~18 m depth). This may be attributed to tidal influence- Dive 11 occured during flood, while Dive 17 was mostly during ebb.

Future Work

We have just begun to analyze the full data sets from each field season. We will correlate these results with finer detailed analysis of the CTD and other sensor data (including pH, dissolved oxygen, sonar, imagery and in situ water samples). Additional sub-shelf ROV and AUV studies are planned to further constrain the relationship between oceanographic conditions and ice growth. Future field expeditions will return to areas with biological communities, search for more, and work to advance AUV and life detection technology in support of continued planetary exploration.

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