National Aeronautics and Space Administration

Under Ice-Shelf Ocean Exploration

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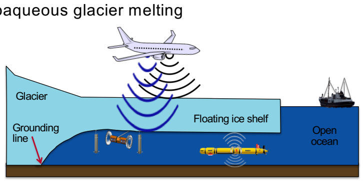
Program: Strategic Initiative

Project Objective:

The objective of this work is to develop and field test an under ice exploration system, laying the foundation for conducting in-situ grounding zone explorations deep underneath ice shelves and an approach to tie these measurements to more readily obtained airborne and/or satellite observables.

Goal 1: Demonstrate an instrumented dual-vehicle system for exploring under ice shelves which includes
(a) deployment of AUV navigation and localization autonomy
(b) data communications between two vehicles, and
(c) a range-based position estimation system between a buoyant vehicle and the AUV under ice.

Goal 2: Evaluate the remote and in situ measurements and accuracies needed to reduce the uncertainty in subaqueous glacier melting



Long term vision.

BRUIE

IceNode

Local measurement will allow for understanding the ice/ocean interface:
- Thermal exchange coefficient
- Biology and biogeochemistry at the ice/ocean interface

Small scale

AUV will allow for understanding the ice cavity shape and ocean properties:
- Temperature and circulation in the cavity
- Biology and biogeochemistry in the cavity

Airplane measurements will allow for understanding large-scale ice shelf properties:
- Melt rates and ice shelf thickness
- Biology at the edge of ice/ocean interface

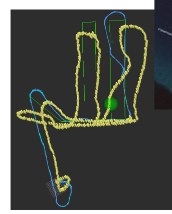
Large scale

FY19 Results:

The the focus of the third year of the task was on field testing integrated system autonomy capabilities on the AUV, accommodating the instruments to acquire key in situ measurements, and drafting a design for an EV-S field campaign.

Autonomous Underwater Vehicle (AUV)

Key AUV accomplishments:
- Successfully completed field test of full capability Representative Mission with onboard motion planner (local and global), localization, and obstacle avoidance (4.5 km total distance)
  - Independent underwater acoustic (UGPS) ground truth position information
  - Iver3 AUV compass and DVL, but no INS or sonar
- 24-Hour Simulation run of AUV Iver Backseat Autonomy Software (no hardware-in-the-loop) - resource metrics all within nominal range for the AUV (memory, CPU, disk space)



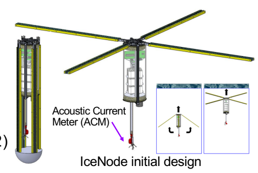
Under water GPS compared to perceived path

Autonomy system ocean field test off coast of Catalina Island

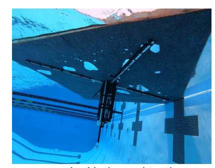
Iver-3 in ocean at Cataline test site

IceNode

Key IceNode accomplishments and capabilities:
- V1 and V2 IceNode designs to accommodate the acoustic current meter instrument
- Ascent and leg release pool test (v1)
- Burn release and CTD acquisition tank test (v2)



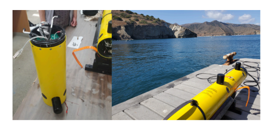
IceNode initial design



IceNode pool testing

System

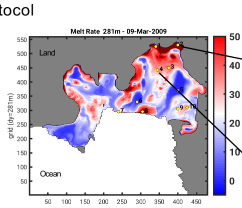
Key accomplishment: communication between assets - WHOI Micromodem in-water tests between Iver3 and BRUIE/Deckbox
- WHOI micromodem integrated into extended payload bay of Iver3
- Testing focused on message passing between BRUIE/Deckbox and AUV for coordinated acomms capabilities (position estimation, data store/forward) since micromodems were previously proven to work by BRUIE Team
- Tests successfully completed
  - Ping
  - Arbitrary data transmitted and recorded between Deckbox and AUV
  - Backseat Autonomy Vehicle state messages from Iver periodically sent to Deckbox
  - Interference tests – determined that Iver native Teledyne and WHOI modems cannot run simultaneously, developed interleaving protocol



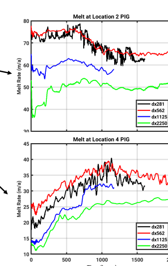
Iver-3 with integrated WHOI Micromodem

Science

Key accomplishments:
- Conducted preliminary simulation experiments of ice-shelf cavity ocean circulation and analysis necessary to design an in-situ and airborne campaign that would inform and constrain coupled ice-shelf ocean numerical ocean models.
- Held science workshop to build a consolidated scientific case for coordinated in-situ and airborne observations of ice-shelf cavities, and to bring together the scientists and engineers who can lay the foundations for pursuing this idea towards an EV-S proposal to NASA. This is one of the first systematic attempts to organize and mobilize a concerted effort across cryospheric and oceanographic disciplines towards the goal of combining airborne and in-situ observations of ice-shelf cavities.



Model estimate of under ice-shelf melt rate for Pine Island Glacier, Antarctica.



Benefits to NASA and JPL:

This task contributes towards capabilities that will lead to an improved understanding of sea level rise and the carbon cycle, current thrust areas for JPL Earth Science. The task also leverages Earth as an analog for Ocean Worlds exploration. The most significant increases in basal melting of ice shelves in Greenland and Antarctica has taken place, near the grounding zone at the point where the grounded glaciers start to float [1,2]. These environments are significant to sea-level rise and global oceanic primary productivity; however, our understanding of the mechanisms affecting ice stability and productivity [3, 4] is limited due to sparse sampling in these extreme and rather inaccessible environments. This work is developing new technology needed to explore and characterize the poorly known ice physics of these ocean cavities and its unique, unknown biology.

References:

[1] Pritchard, H.D., et al., "Antarctic ice-sheet loss driven by basal melting of ice shelves, " *Nature* **484**(7395) 2012: pp. 502-505.
[2] Rignot, E., et al., "Ice Shelf Melting Around Antarctica," *Science*, **341**(6143) 2013: pp. 266-270.
[3] Bhatia, M., et al., "Greenland meltwater as a significant and potentially bioavailable source of iron to the ocean," *Nature Geoscience*, **6** 2013: pp.274-278.
[4] Death, R., et al., "Antarctic ice sheet fertilizes the Southern Ocean," *Biogeosciences*, **11** 2014: pp. 2635-2644.

Publications and NTRs:

Castano, R., C. Boening, E. Clark, I. G. Fenty, M. Gierach, K. P. Hand, A. Khazendar, A. Klesh, J. M. Leichty, D. Limonadi, E. Rignot, C. J. Naify, M. Schodlok, S. T. Szanto, C. C. Walker, G. Woodward (2018) "Heterogenous System for *in situ* Measurements from within Ice Shelf Cavities to Improve Predictions of Sea Level Rise, Abstract C21B-1314, presented at 2018 Fall Meeting, AGU, Washington, D.C., 10-14 Dec.

Clark, E., J. Schachter, D. Limonadi, R. Castano, "IceNode: a buoyant sensor pod for persistent in-situ measurements beneath ice shelves," International Glaciology Society Sea Ice Symposium, Winnipeg, Canada, Aug 18, 2019.

NTR 50656 - ISPACE: Integrated Suite of Planners for Autonomously Conducted Exploration
NTR 50670 - EKF-based drift-robust localization with sonar scans

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Poster No. RPC-068