National Aeronautics and Space Administration

IceNode: Enable persistent multi-point in-situ melt interface measurements near deep ice-shelf grounding zones

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Strategic Focus Area: Ocean and ice

Objectives: The successfully completed objective of the third year of this R&TD was to design, build, and test an engineering unit of sufficient fidelity to raise the TRL of IceNode through field trials. A fleet of distributed IceNodes that drift autonomously, represents the only documented approach to affordably capturing in-situ data across an entire ice shelf. Sufficiently maturing the IceNode vehicle to be eligible for inclusion in future science missions was a primary objective.

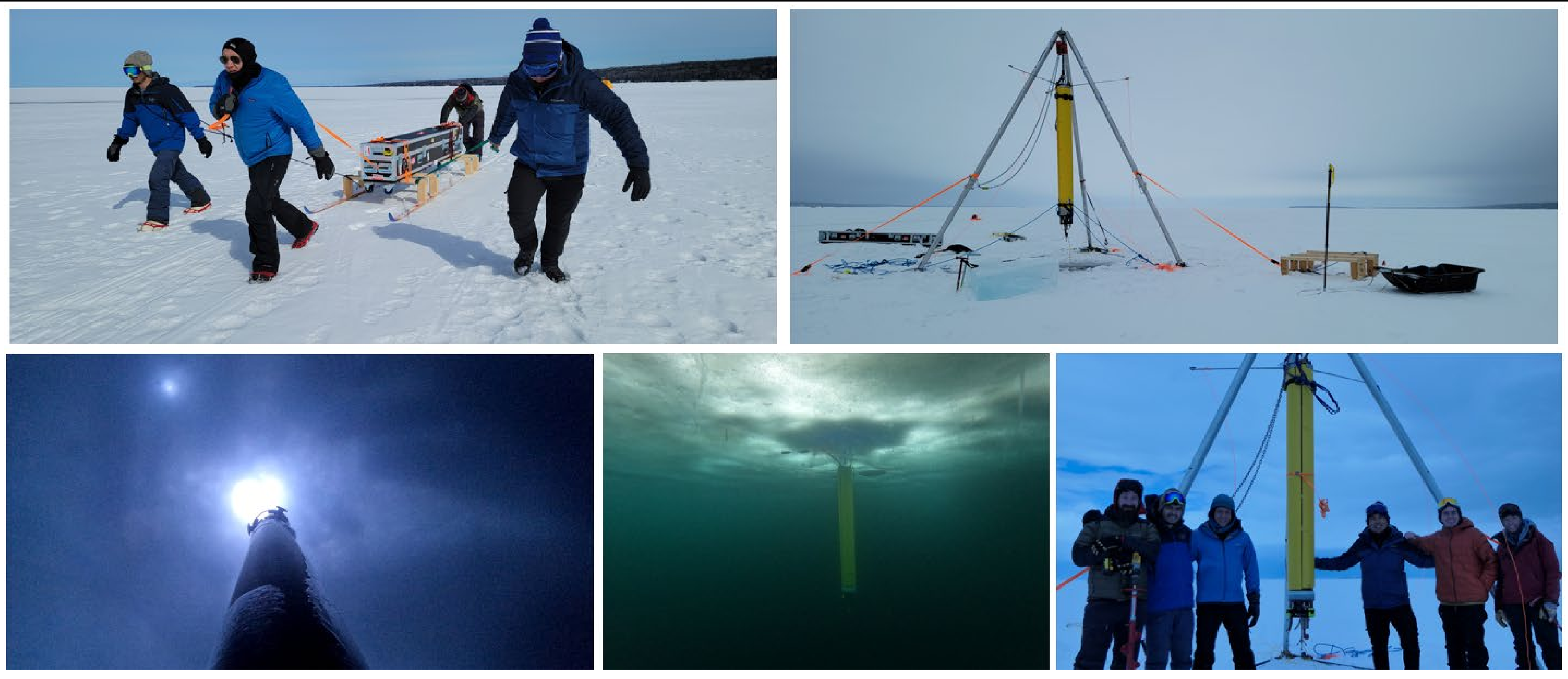
Background: By the end of the century, the collapse of Antarctic ice shelves could trigger a meter or more of sea level rise and these ice shelves hold back more than 50 meters of sea-level rise equivalent in total. However, a lack of detailed understanding about how ice shelves will behave in a warming climate remains a primary obstacle to accurate sea level rise projections. Predictive numerical melt models require better constraining ground-truth data near the grounding zones of ice shelves, but the field suffers from a dearth of in-situ measurements because these extreme environments are difficult to access and operate in and cut-off from communication with the outside world. The IceNode platform will enable scaling of this critical measurement reducing the cost of each measurement from the cost of a borehole (several $M) to the cost of a vehicle (~$100K).

Approach and Results: During this Fiscal Year, the IceNode team successfully raised the TRL of the vehicle by designing, building, and field-testing a high fidelity prototype. We identified and retired key risks including a) ballast release mechanism robustness, b) ballast release mechanism clearance during ascent, c) vehicle metacentric stability during ascent, d) vehicle stability in landing, e) vehicle stability in the presence of currents, f) float release mechanism functionality, g) float hinge strength requirements, h) closed loop depth control authority, i) vehicle reliability in saltwater, j) vehicle performance landing/descending from a non-horizontal surface, k) reliability to 80m depth, and l) vehicle performance in sub-zero temperatures. These tests were performed in both laboratory and field conditions.

Significance/Benefits to JPL and NASA: IceNode represents an exceptional opportunity to acquire unprecedented datasets directly addressing the 2015 KISS study *The Sleeping Giant: Measuring Ocean-Ice Interactions in Antarctica*. This data is key to studying effects of warming climate on polar ice caps and predicting the widespread ramifications sea level rise will have on humanity. This research strongly supports JPL Quest 1: “Understand how Earth works as a system and how it is changing” and JPL Quest 7: “Use our unique expertise to benefit the nation and planet Earth”. IceNode is a vehicle *uniquely capable* of providing in-situ data to support NASA/JPL’s satellite-based observations and answer hypothesis that require more granularity than shelf-wide mass balance. In addition, IceNode is borehole deployable, capable of supporting scientific payloads at the ice-water interface- directly maturing technology needs for future subsurface mission to Europa or Enceladus.

Figure 1. Ocean-environment field testing at the Scripps Institute of Oceanography Keck Pool and in the Monterey Bay aboard the R/V John Martin. These tests showed IceNode completing key phases of an ocean mission including closed-loop depth control, landing on a mock ice shelf, and take-off from a mock ice shelf. Additionally, it did so in full salt water and using mission-rated pyrotechnic k-cutters. These activities validated IceNode’s survivability and core functionality.

Figure 2. Field testing IceNode in the Keweenaw peninsula underneath frozen lake ice. These tests simulated a scientific mission with a borehole deployment. IceNode successfully gathered data and provided a stable platform for the primary instrument even under currents from under-ice seiches. This activity demonstrated sufficient maturity for IceNode in a borehole mission.



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Publications: [A] Clark, Evan Bock, et al. "IceNode: a Buoyant Vehicle for Acquiring Well-Distributed, Long-Duration Melt Rate Measurements under Ice Shelves." IEEE *OCEANS 2021*
[B] Rossi, Federico, et al. "Stochastic Guidance of Buoyancy Controlled Vehicles under Ice Shelves using Ocean Currents." *2021 IEEE/RSJ IROS*. IEEE, 2021.
[C] Schoelen, Dane, et al. "System Analysis and Generative Design for IceNode” IEEE *OCEANS 2021*
Manuscripts for review and publication
[D] Fenty, Ian, et al “An Observing System Simulation Experiment (OSSE) to design a fleet of autonomous ocean robots for ice-shelf cavities,” *Journal of Applied Meteorology and Climatology.*
[E] Rossi, Federico, et al. “Stochastic Guidance of Buoyancy Controlled Vehicles” *IJRR.*
[F] Glick, Paul E., et al. “The IceNode vehicle platform” *IEEE Robotics and Automation Letters.*

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