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

Principal Investigator: Evan Clark (397); Co-Investigators: Andrew Branch (397), Dane Schoelen (347), Ian Fenty (329), Flora Mechentel (355), Michael Schodlok (329), Eric Rignot (334), Daniel Limonadi (800), Timothy Stanton (San Jose State University)

PI/Task Mgr Contact
Email: Evan.Clark@jpl.nasa.gov

Program: FY21 R&TD Topics **Strategic Focus Area: Ocean and ice**

Clearance Number: URS303489
RPC/JPL Task Number: R20120

Background

The collapse rate of Antarctic ice shelves is one of the largest sources of uncertainty in global sea level rise projections, but the dynamics of Antarctic ice shelf melt in a warming environment are poorly understood. Distributed, long-duration in-situ melt rate measurements are needed, but no appropriate platform exists. IceNodes obtain such measurements in a low-cost, expendable, and logistically simple manner, enabling scientists to deploy scalable arrays that acquire co-varying melt rate timeseries over large spatial areas, thereby providing an unprecedented view of ice shelf melt rate variability and its drivers [1].

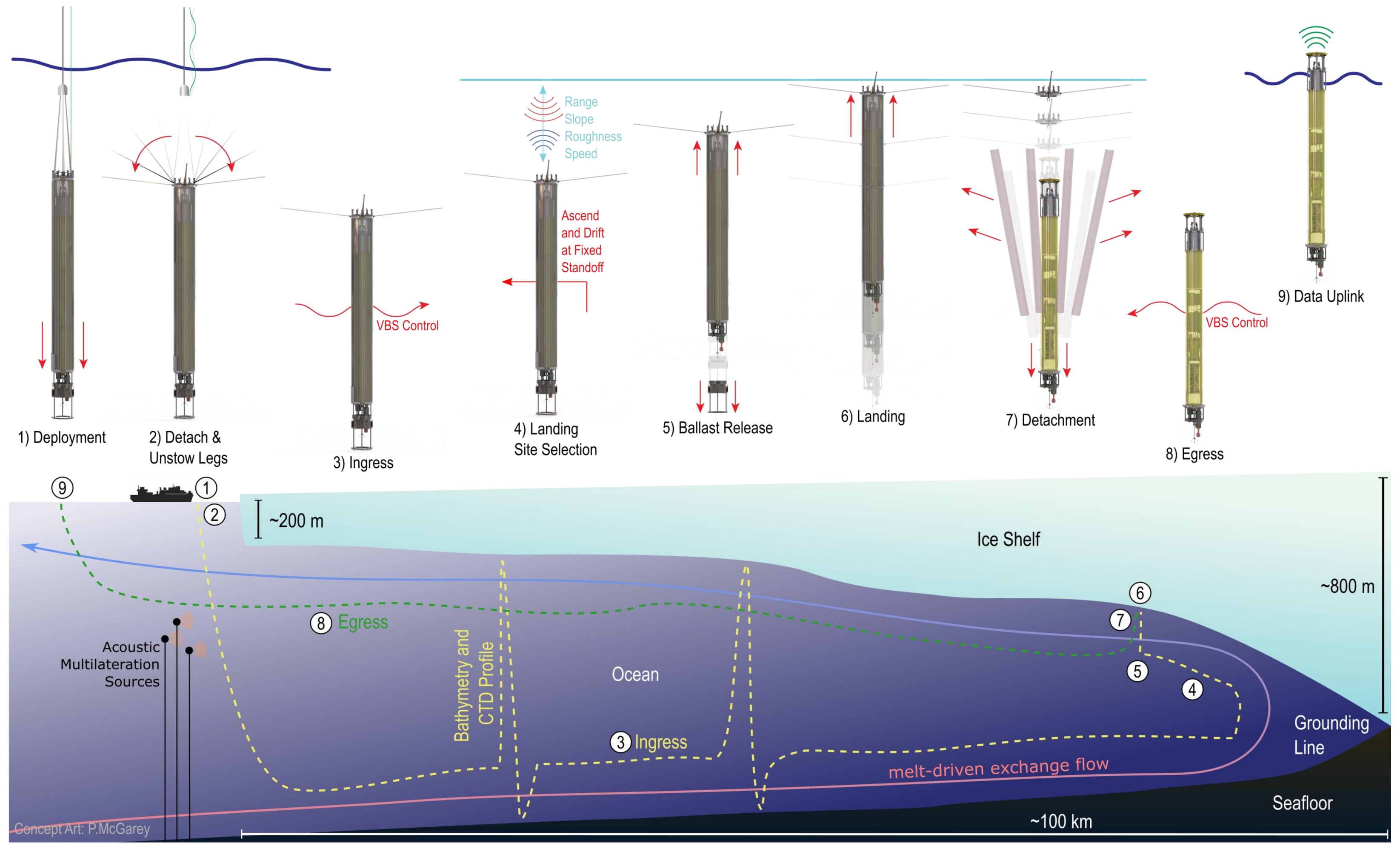

Figure 1: IceNode CONOPS

Significance to NASA and JPL

Because an arbitrary number of IceNodes may be deployed by a single icebreaker in front of an arbitrary number of ice shelves, IceNode is much more scalable than traditional borehole based-approaches for collecting basal melt rate observations, which are logistically complex, can cost millions of dollars per borehole, and are limited in their placement due to crevassing and complex surface topography. Development of IceNode will enable scalable, unprecedented acquisition of long-duration, spatially distributed datasets of co-varying ice shelf melt and ocean conditions over large spatial areas and multiple ice shelves, with the following impacts:

- Greatly improve understanding of ice shelf melt rate variability and its drivers
- Ground-truth airborne and spaceborne remote sensing data
- Constrain numerical model parameters for predicting future ice shelf melt, collapse, and sea-level rise
- Strategically position JPL for NASA Earth Ventures - Suborbital (EV-S) proposals targeting Antarctic contributions to sea-level rise (next call expected FY23Q2)
- Strengthen JPL's portfolio and expertise in under-ice/underwater exploration for future Ocean Worlds missions
- Significantly contribute to 2018 NASA Earth Science Decadal Science Survey Question C-1

Objectives

Our objectives for FY21 (year 2 of 3) were to develop the IceNode prototype vehicle hardware and to develop a guidance technique capable of drifting IceNodes on melt-driven exchange currents from the ice shelf edge to beneath a realistic pre-specified landing area.

Prototype Vehicle Design

We have completed detailed mechanical and electrical design of the vehicle prototype, building off systems analysis work from [2]. All parts are now fabricated and we are conducting assembly and sub-system tests. In FY22 we plan to demonstrate the capabilities of the prototype vehicle in a series of field tests. Along the way, we solved many detailed design challenges further discussed in [3]:

- component packing
- ballast system
- landing legs
- bottom release system
- top release system
- release actuators
- landing impact robustness
- landing feet
- drift + ascent stability
- 4 custom avionics PCBs
- instrument placement and noise
- manufacturability

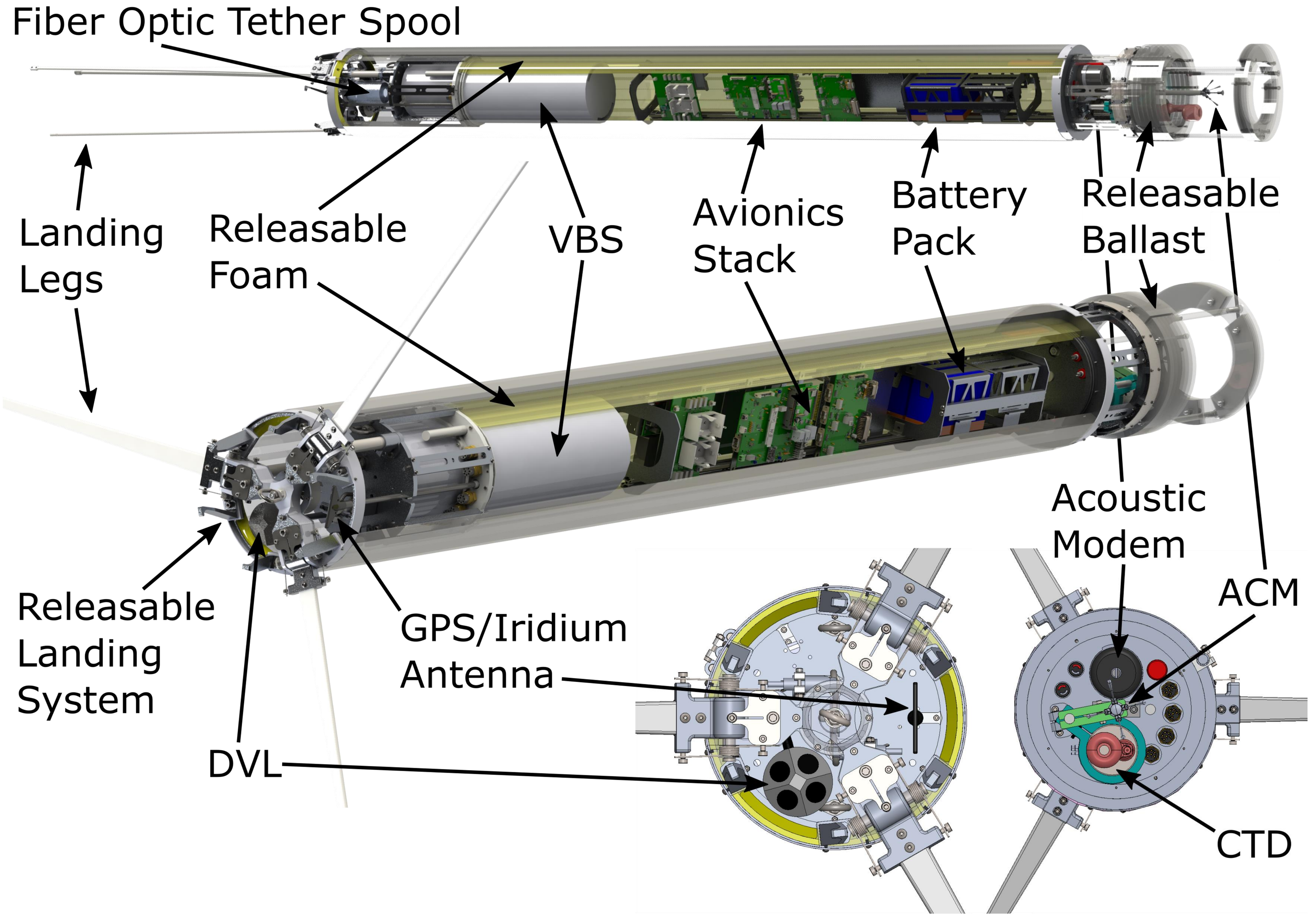

Figure 2: The IceNode vehicle prototype

Autonomous Guidance

We developed in simulation a Q-function Markov Decision Process (QMDP) based guidance technique to drift IceNodes from the shelf edge to below pre-specified targets using melt-driven exchange currents. The algorithm determines the probabilistically best drift depth to reach a given target area for each x, y location under the shelf, then commands IceNode to move to that depth using its variable buoyancy system (VBS). Our technique delivers 88.8% of vehicles to the target, representing a 262% improvement over uncontrolled drifting and a 33% improvement over state-of-the-art techniques, and does so 21% faster, leaving more battery available for landed science operations [4].

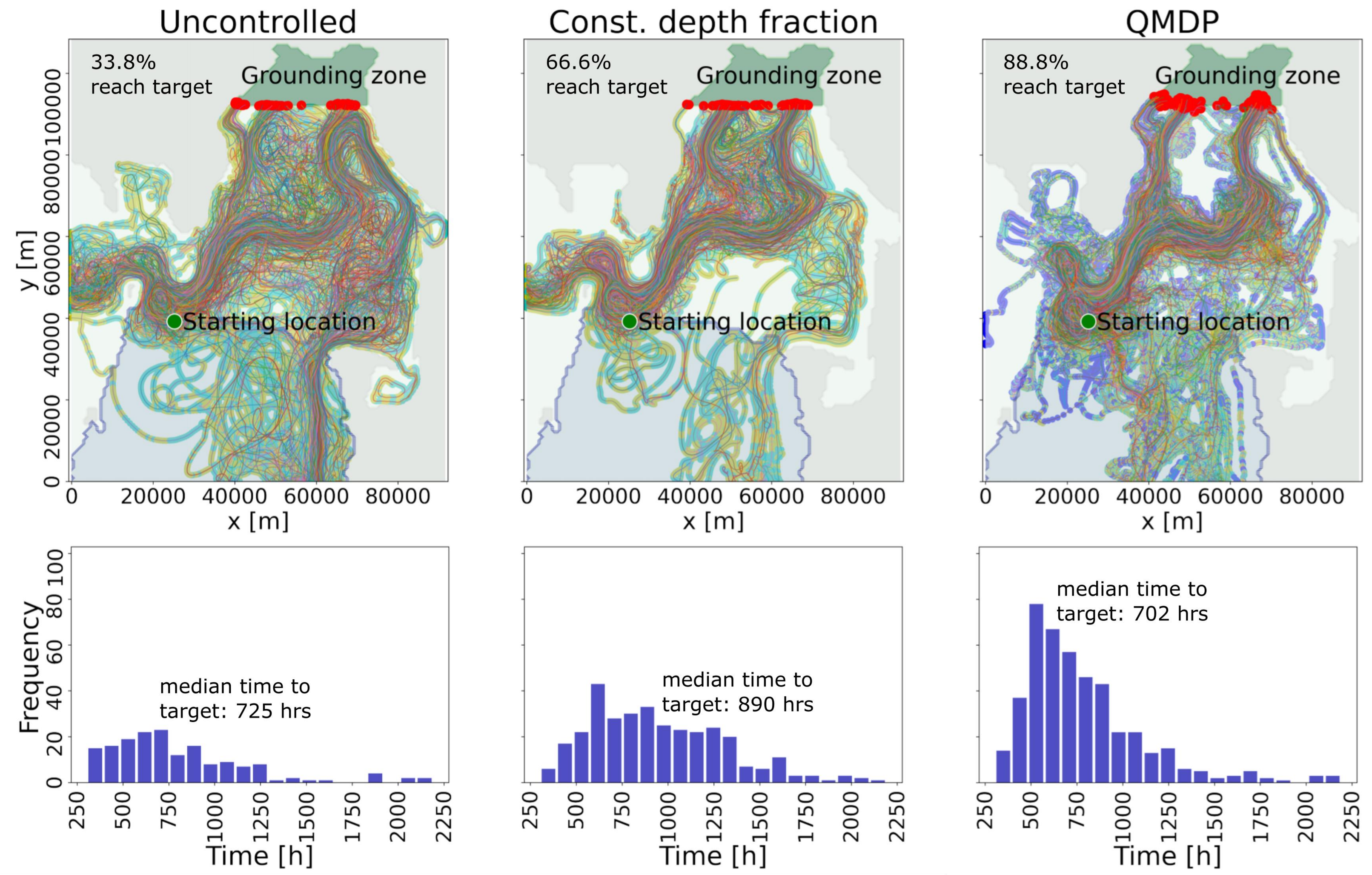

Figure 3: 500 simulated attempts to drift from shelf edge to grounding zone, using uncontrolled drifting, constant depth fraction (state-of-the-art) and IceNode QMDP guidance techniques

Publications

[1] E. B. Clark, J. Schachter, D. Limonadi, and R. Castano, "IceNode: A Bouyant Sensor Pod for Persistent In-situ Measurement Beneath Ice Shelves," Sea Ice Symposium, International Glaciological Society, Winnipeg, Canada, Aug. 2019.
[2] D. Schoelen, E. B. Clark, F. Mechentel, and C. Gebara, "System Analysis and Generative Design for IceNode, a Buoyant Vehicle for Measuring Melt Rate under Ice Shelves," IEEE/MTS Oceans 2021, San Diego, CA, Sep. 20-23 2021.
[3] E. B. Clark *et al.*, "IceNode: a Buoyant Vehicle for Acquiring Well-Distributed, Long-Duration Melt Rate Measurements under Ice Shelves," IEEE/MTS Oceans 2021, San Diego, CA, Sep. 20-23 2021
[4] F. Rossi *et al.*, "Stochastic Guidance of Buoyancy Controlled Vehicles under Ice Shelves using Ocean Currents," IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS 2021), Prague, Czech Republic and Online, Sep. 27 – Oct. 1 2021.
[5] NTR 50967

Acknowledgements

Our project would not be possible without the contributions of the core IceNode team and many other people. Thank you!

Core IceNode Team: Evan Clark, Andrew Branch, Rebecca Castano, Ian Fenty, Christine Gebara, Ara Kourchians, Daniel Limonadi, Gauri Madhok, Patrick McGarey, Flora Mechentel, Kelly Nguyen, Tyler Okamoto, Eric Rignot, Federico Rossi, Brendan Santos, Justin Schachter, Michael Schodlok, Dane Schoelen, Tim Stanton, Ben Wolsieffer, Xavier Zapien
MRV Systems Team: Theresa Friske, Fritz Stahr, Ian Culhane, Christian Sarason, Ronnie Nigash, and David Faust
Design Review Panels, Informal Advice, and Resources: Matt Gildner, Chris Yahnker, Justin Koch, Jackie Sly, Andy Klesh, Kevin Hand, Dan Berisford, Gail Woodward, Chuck Bergh, Ara Kourchians, Fernando Mier-Hicks, Becky Castano, Russel Smith, Spencer Backus, Alex Gardner, Josh Willis, Josh Vander Hook, Steve Chien, Samuel Case Bradford, Robert Moncada, Amir Rahmani, Hari Nayar, Charles Dandino
OCSCT/8X Stakeholders: Mark Simons, Cinzia Zuffada, Duane Waliser, Jason Hyon, Sabrina Feldman, Daniel Limonadi, Randy Friedl, and Frank Webb

