Polar Technology Conference, March 10-12, 2020, Boulder, CO
Arctic Research Consortium of the United States (ARCUS) / National Science Foundation NSF)
https://www.arcus.org/logistics/2020-polar-technology

Documenting High Latitude System Dynamics: New Technologies for Persistent Monitoring of Critical Parameters at Appropriate Time-Space Scales

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Outline of Talk:

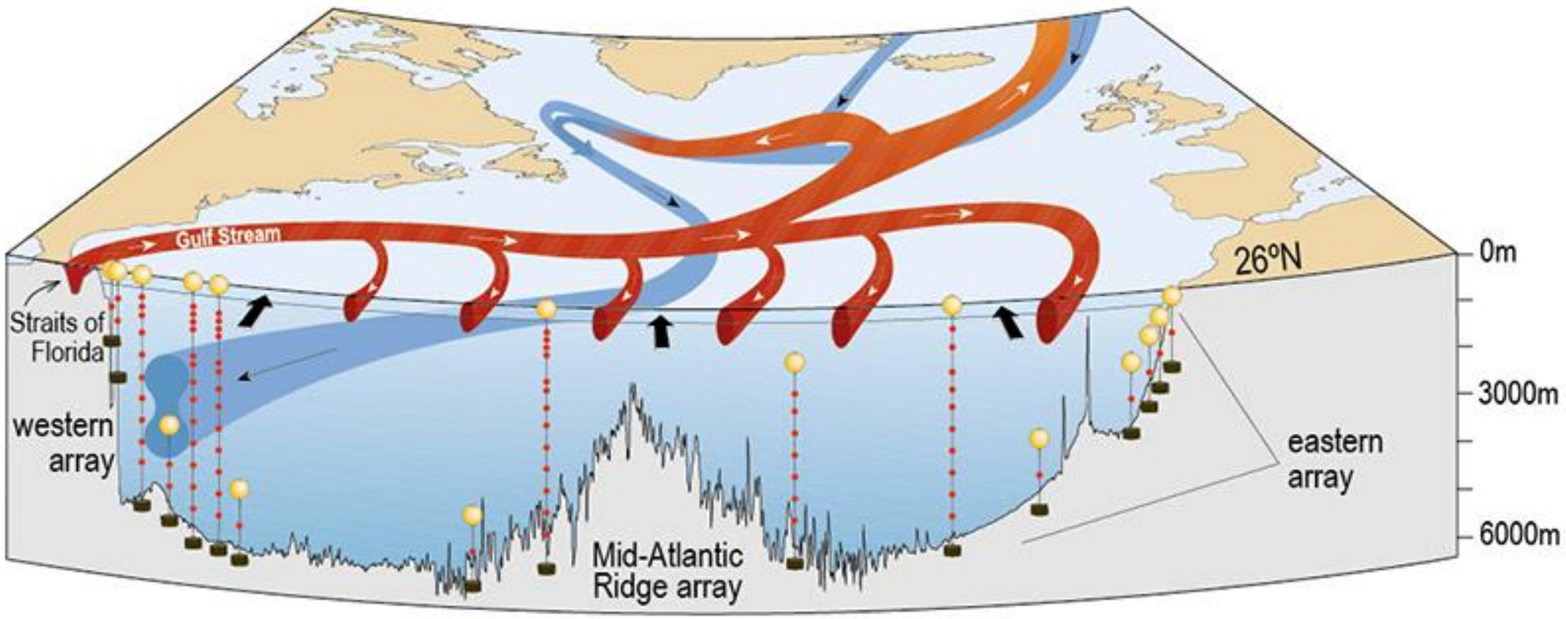
- Introduction to Key Issues / Scope of the Problems
- Platform Technology: Underwater, Surface, Aircraft
- Sensor Technology: Leveraging Multi-platform & Quantum Sensors
- Communications Technology: Optical Comms
- Computing Technology: Machine Language & Real-Time Data Analysis
- Human 'Technology': Training in New Technologies;
  Tech for Improving Public Outreach
- Summary: Testing and Operationalizing New Technologies

Introduction: Scope of the Problem

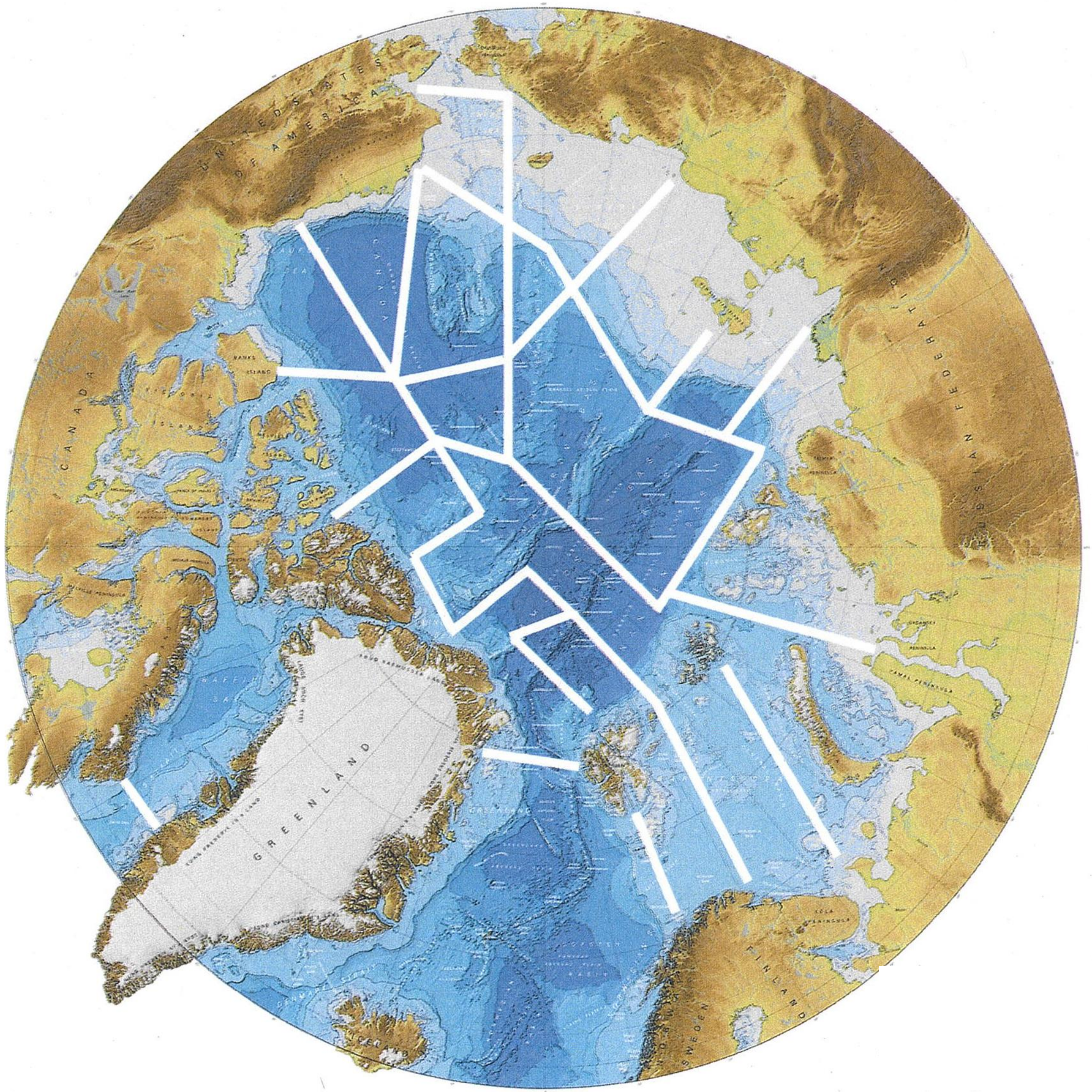
Research priorities for the polar regions per SAS (Synoptic Arctic Science Plan, https://synopticarcticsurvey.w.uib.no/science-plan/): focus on physical drivers, ecosystem response, and C cycling and ocean acidification effects

Arctic Ocean transects documenting: freshwater & heat flux effects on currents; nutrient and productivity fluxes, biomass and species movements; Arctic role in CO2 and OA fluxes

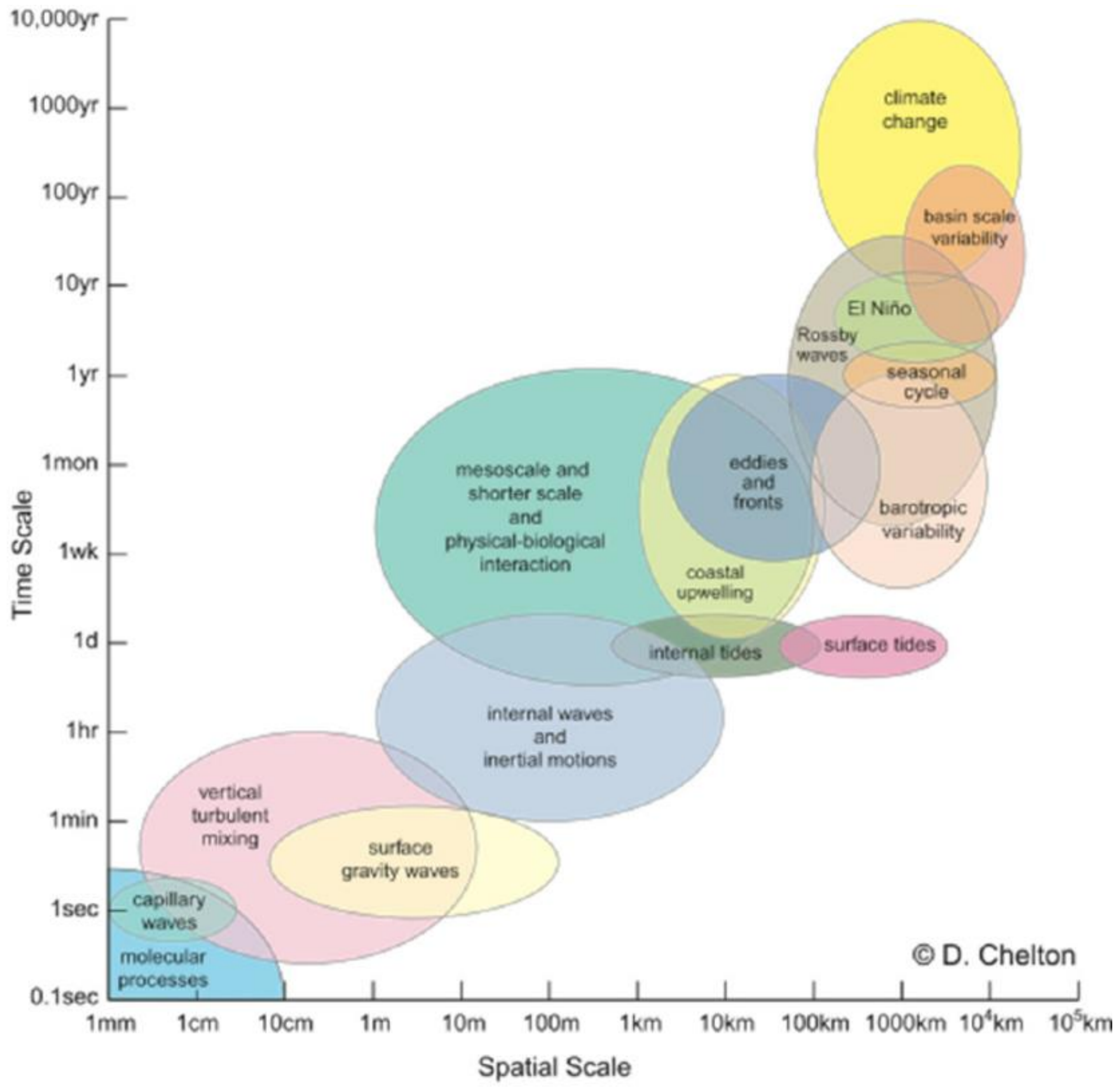
Per OSNAP (Overturning in the Subpolar N. Atlantic Program):Sensor array at 26.5°N (Rapid Climate Change-Meridional Overturning Circulation & Heat Flux project, RAPID/MOCHA)



Synoptic Arctic Survey Proposed Ship Transects for 2020,2021



Scope of time-space sampling problem: high latitude eddy scale is O(10-20km)



Time-space scales of ocean variability, Dudley Chelton, 2012.

Two recent references point out the 'problem':

"Enhanced eddy activity in the Beaufort Gyre in response to sea ice loss." W. Thomas, et al., Nature Comms. 11, article 761, 2020.
Concludes freshwater mixing estimated from wind stress and Ekman pumping in Beaufort Gyre has to be happening due to peripheral eddy dissipation.

"Observations of internal waves generated by an anticyclonic eddy: a case study in the ice edge region of the Greenland Sea." O. Johannessen, et al., Tellus A: Dyn. Meteor. & Oceanography, 71(1), Article 1652881, Aug. 2019.
Using drifting thermistor arrays conclude IWs were draining energy from a small (5km) highly mobile ice edge eddy.

How can we sample high latitude fronts & eddies that vary over short space and time scales?

Scope of time-space sampling problem: ice keels/ridges & ice leads, and ice breezes and ice lead atmospheric flux measurements

Wieslaw Maslowski (NPS) is using a multi-level Arctic Ocean model to study ice ridging by modeling at spatial scales <2km, down to possibly 500m to capture ice ridge features.

Ice ridges/keels not only affect ice movement, but also water column and nutrient mixing below the surface, air-sea fluxes (being more porous than ice itself), and are important as habitat determinants marine species up to and including ice seals.

However, our understanding of ice ridge occurrence and dynamics, over both short, medium and long-term time scales is highly data deprived.

Likewise, out ability to sample horizontal and vertical scales of ice edge ice-sea breezes and fluxes over ice leads across relevant time-space scales is also currently possible only with short term, localized observations.

How can we improve persistent sampling of ice ridges/keels, leads, and ice edge and ice lead atmospheric features over appropriate time-space scales?

Platform technology: Underwater – Long Range Under-Ice AUVs

DHS has recently purchased for the CG two ‘Tethys’ LR-AUVs, made by MBARI, the first of which is currently undergoing acceptance testing by the WHOI Center for Marine Robotics. It includes a docking system on the nose to attach to vertical lines (photo right from Amy Kukula, WHOI CMR).

When the second LR-AUV is delivered one goal will be to coordinate communication between the two AUVs, as well as associated RVs.

Platform technology: Underwater – Long Range Under-Ice AUVs

Canada also has an 8.5m Long Range Under-Ice AUV, the SOLUS-LR, made by Cellula Robotics. It uses pressurized H2 and O2 as fuel, and has a reversible suction mooring anchor that can keep it in place in 2 knot currents. Intended for multi-week 2-4K km missions; a fuel cell follow on is forthcoming. Intended for shore (not ship) launching.

Canada is also engaged in efforts to patrol its Arctic maritime boundary both underwater and under-ice by developing additional technologies through their, the Canadian Arctic Underwater Sentinel Experiment, or CAUSE. This may include use of Oxis Energy’s Ultra-Light High Energy Li-S pouch cell batteries, which have >400Wh/kg power, nearly twice that of current Li Ion batteries: also good for UAS! But limited to shipping by ship for now.

Platform technology: Other Under-Ice AUV tech – Gliders & New Power Sources

Photo courtesy Justin Shapiro, UW APL, with ONR support

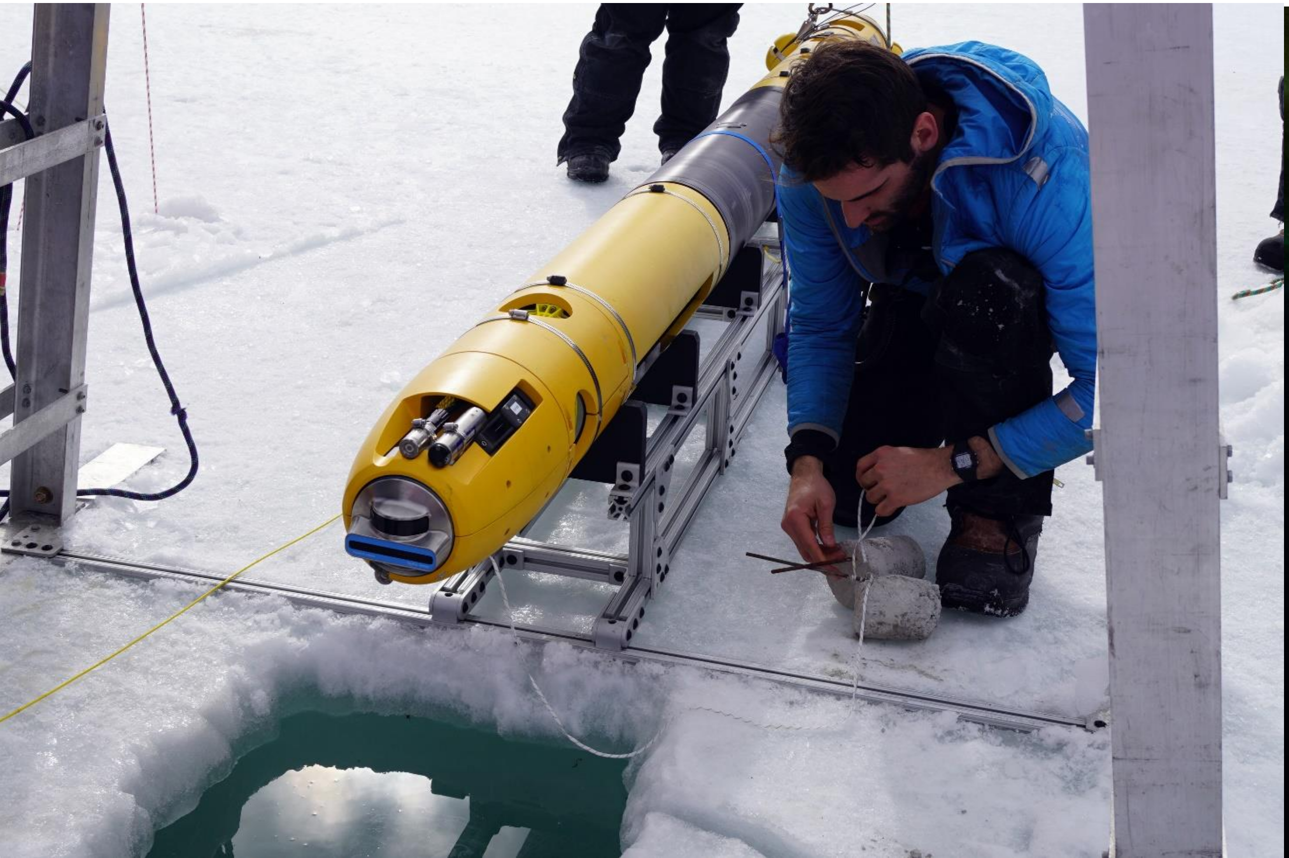
A single glider cannot keep up with moving Arctic eddies or fronts, but a network of gliders can sample in a manner to provide data on such features over long periods. Justin Shapiro (UW APL) has used gliders with turbulence sensors in both the Arctic and Antarctic that can monitor eddy, front or internal wave turbulence.

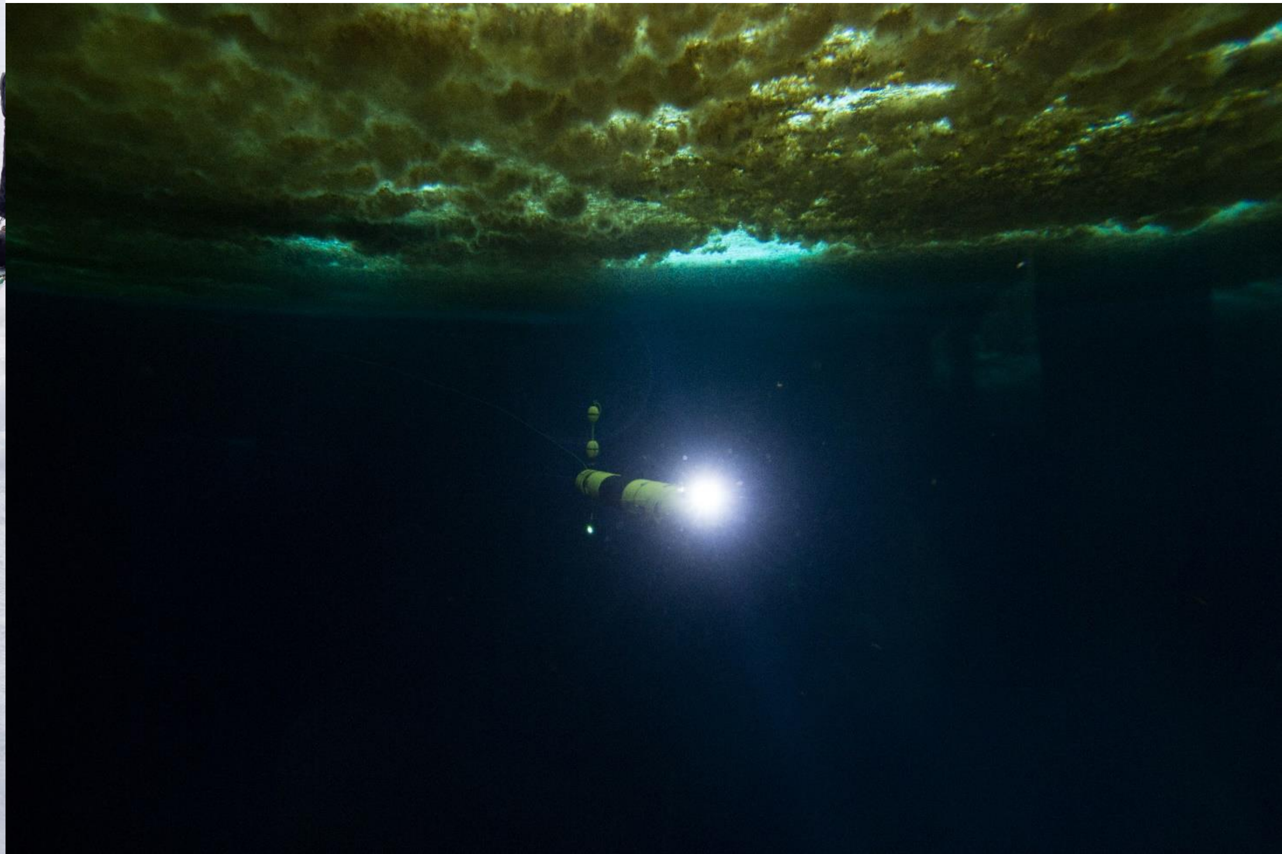
He used a WaveGlider (WG) Autonomous Surface Vessel (ASV) to receive acoustic data from the gliders. Over time the WG and glider would become separated, and the glider would surface to re-establish contact. However, by using other ASVs, this method could provide adequate time-space sampling of high latitude hydrographic features.

A new power method, the Open Water Power system (now part of L3-Harris) uses simply seawater and a block of aluminum to provide power to AUVs for up to 5 days. This can be refreshed with additional seawater or used in series to provide longer duration AUV operations, as shown on the IVER-4 below.

Platform technology: Autonomous Underwater Vessels (AUVs)

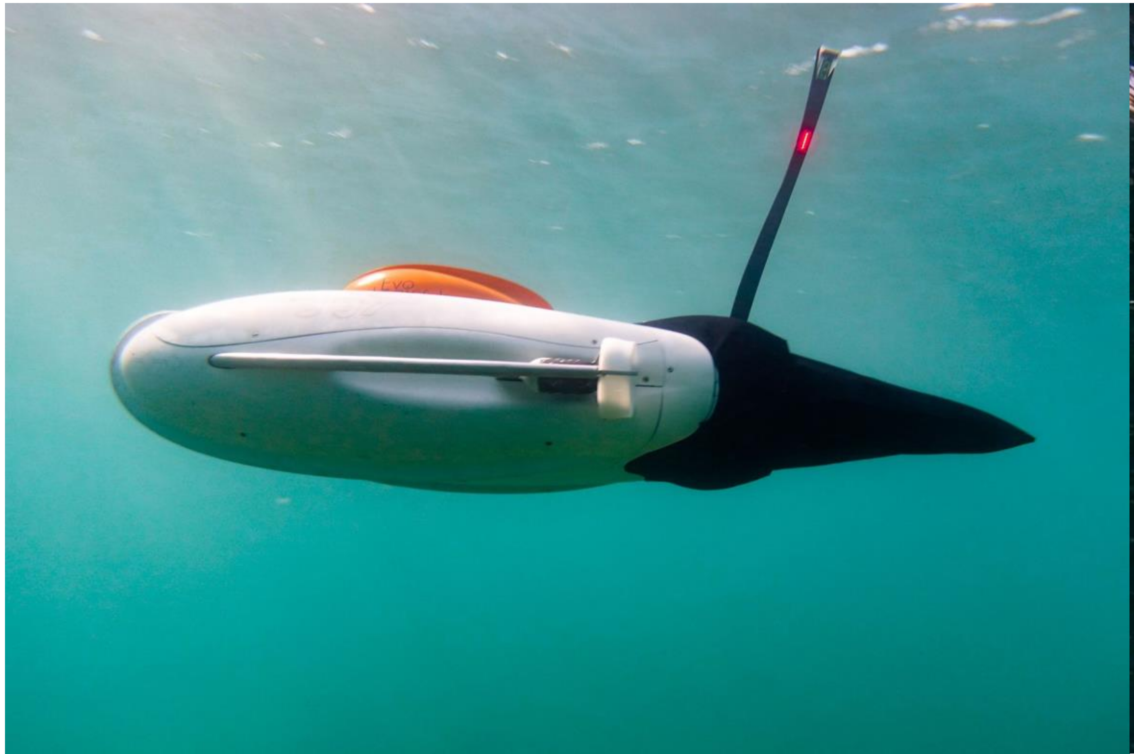
A variety of recent under-ice AUVs have also been demonstrated for ops near/under ice shelves. Most recently the IceFin has been used to study the grounding line zone of the Thwaites Glacier Ice Shelf, and also in the Ross Sea. Developed through NASA & NSF funding by Schmidt Ocean Institute to Georgia Tech, it is 23cm x 3.3m, with 3.5km range. It can be tethered or operate autonomously.





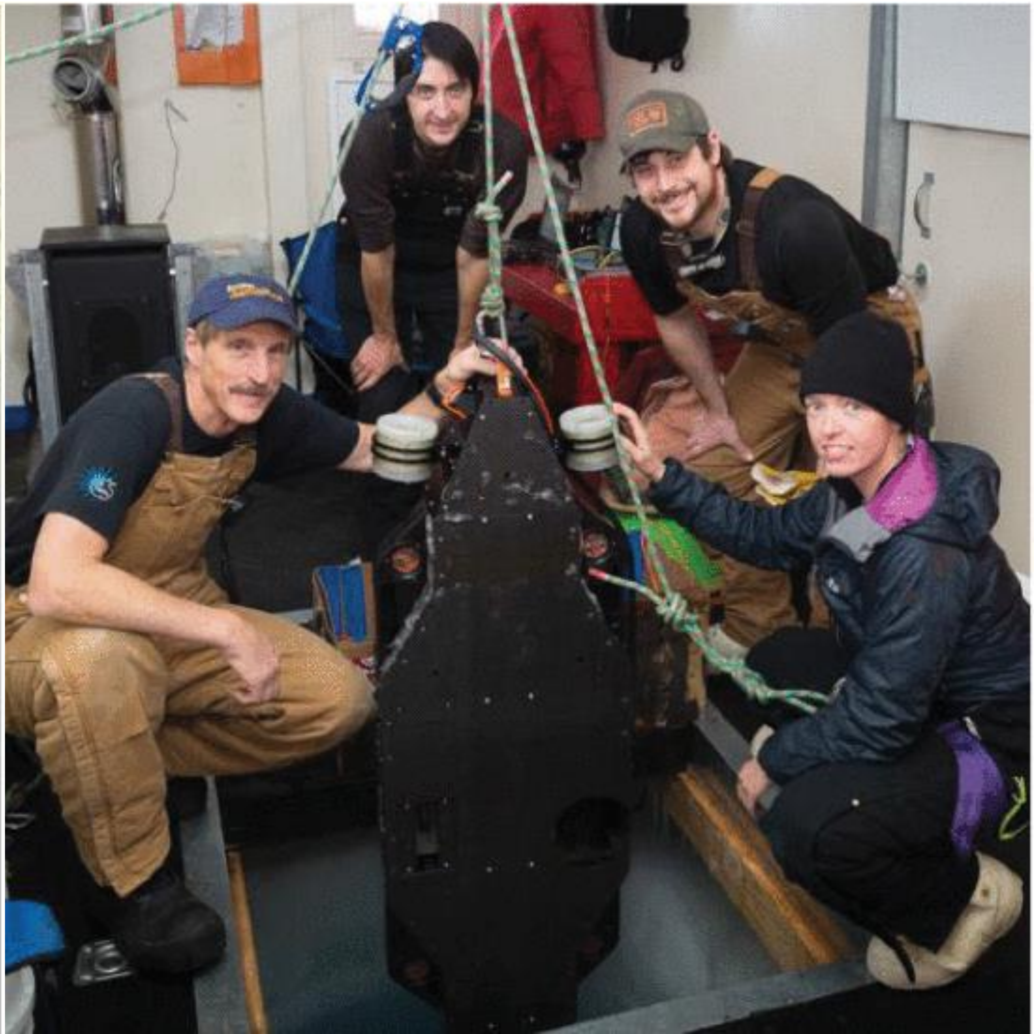
Platform technology: Autonomous Underwater Vessels (AUVs)

Poggy is a Manta Ray-inspired AUV from Evologics that was demonstrated at the Breaking The Surface meeting in Croatia this past fall intended for studies of groundwater fluxes into nearshore and ice shelf/glacier zones. Being designed by Evologics, it is also intended to act as a communications node/mule, and is adapted for use of Hydromea optical modem high bandwidth communications.



Platform technology: Autonomous Underwater Vessels (AUVs)

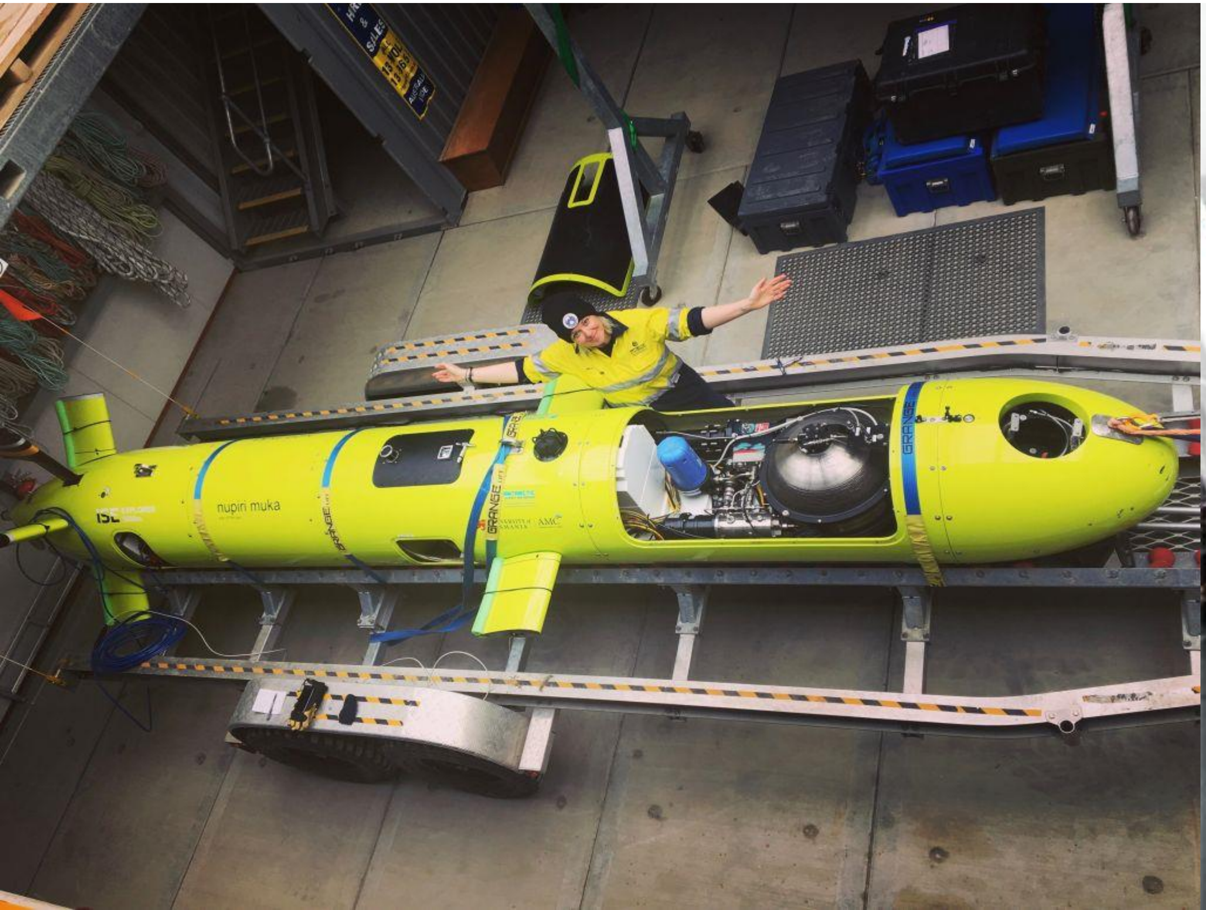
Schmidt Ocean Institute also funded Sunfish, Inc., a subsidiary of Stone Aerospace, to make a hovering AUV (HAUV) for mapping the underside of glaciers and icebergs which has been deployed in Antarctica.



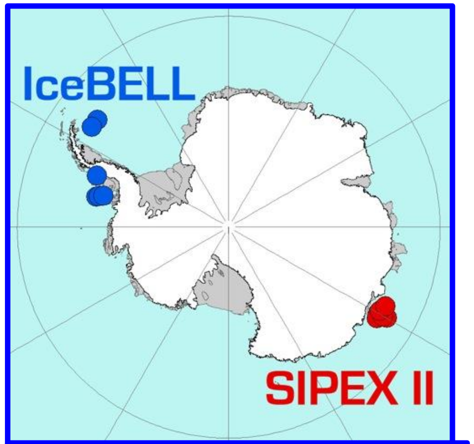
Platform technology: Autonomous Underwater Vessels (AUVs)

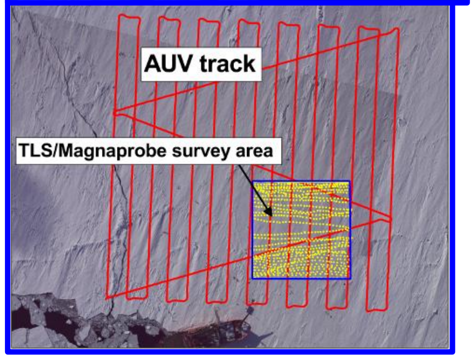
U. Tasmania (Austr. Ant. Div.) used an ISE-built AUV, Nupiri Makua, to study environments under the Sordal Glacier in Antarctica (left pix).

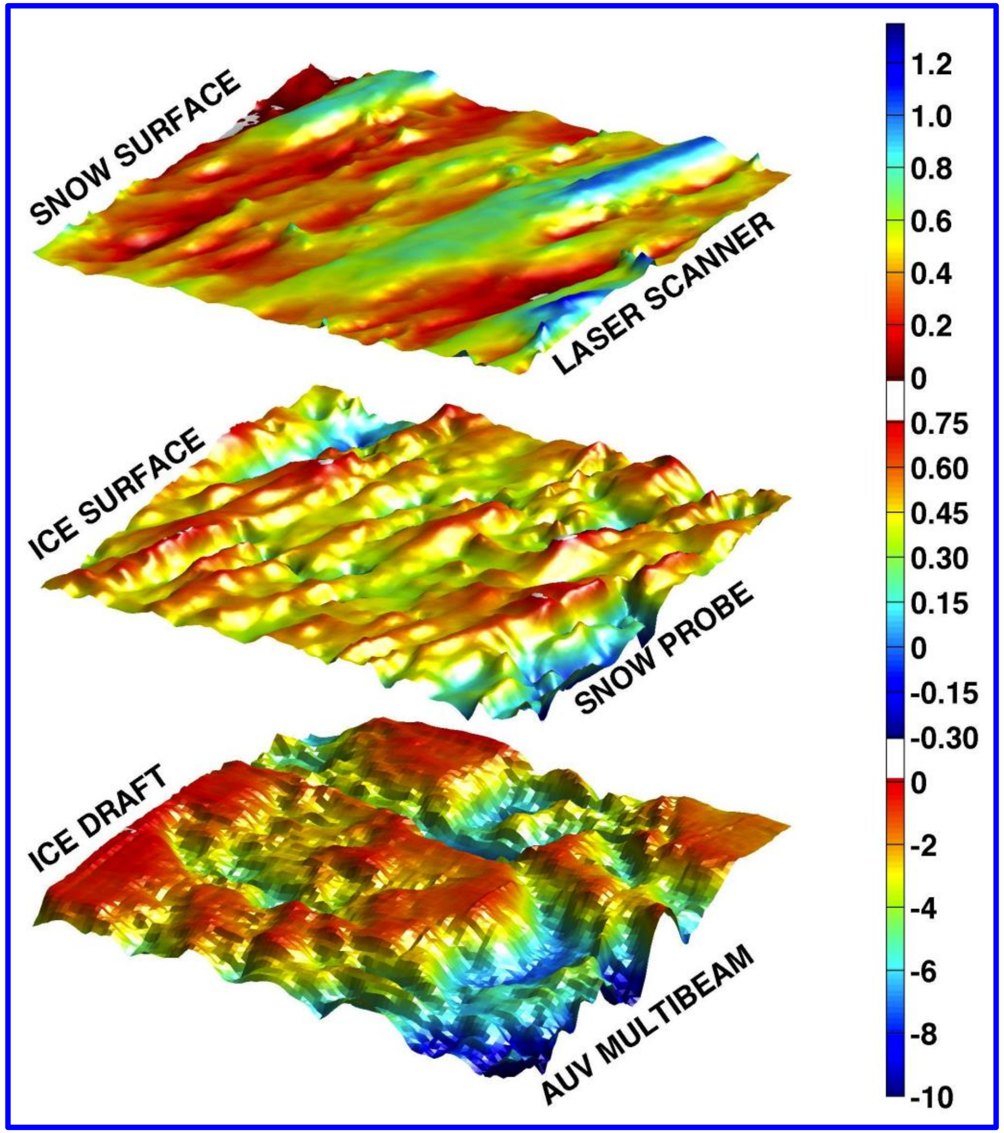
Scottish Association for Marine Science (SAMS) used a Gavia AUV (‘Freya’) to study melt rate of a retreating glacier in Svalbard, rated to 500m (right pix); they are also working on a robotic kayak ASV.



Platform technology: Autonomous Underwater Vessels (AUVs): SIPEX II Expedition (Hanu Singh, NE U) concurrently maps surface (UAS) ice ridges and ice keels with “Jaguar” hovering AUV.



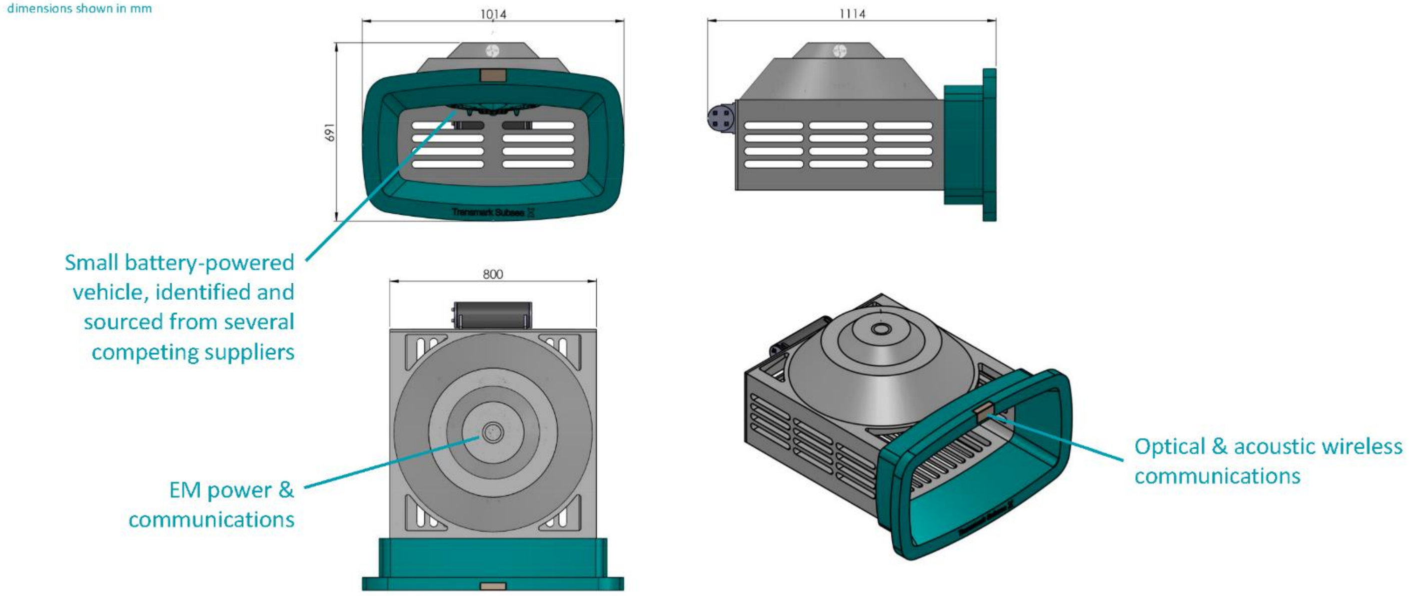


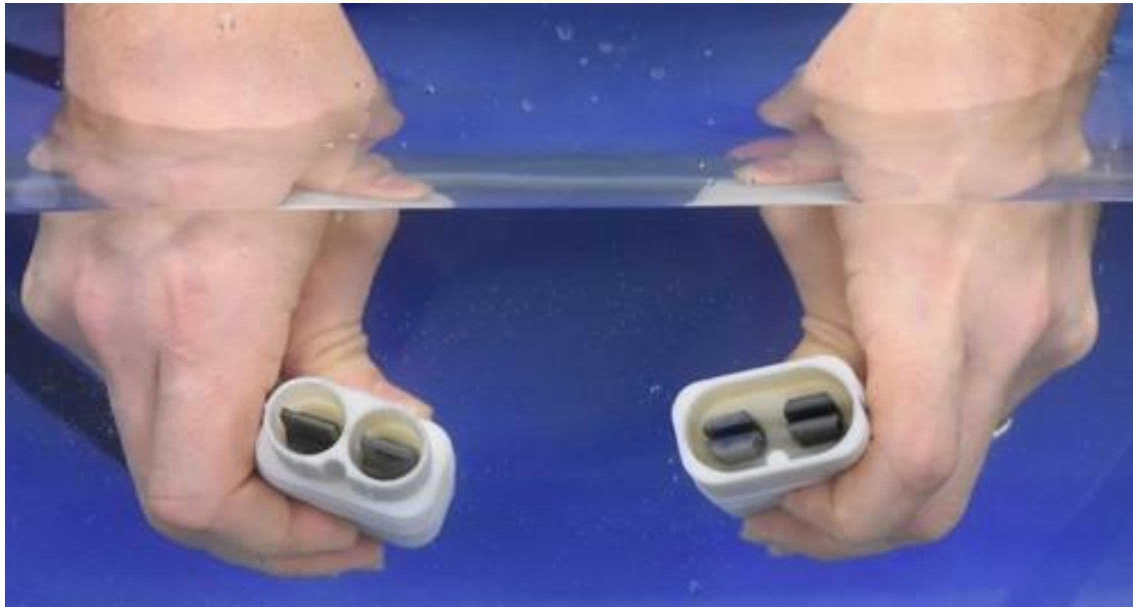


Platform technology: Autonomous Underwater Vessels (AUVs)

AUV persistence can be advanced via new battery technology, larger long-term AUVs, or recharging at docking stations from ships or powered by currents, surface or internal waves. Transmark Subsea's Halo suspended docking station uses both acoustic modems and the Hydromea optical modem with a pinless power/comms connector. (Left image)

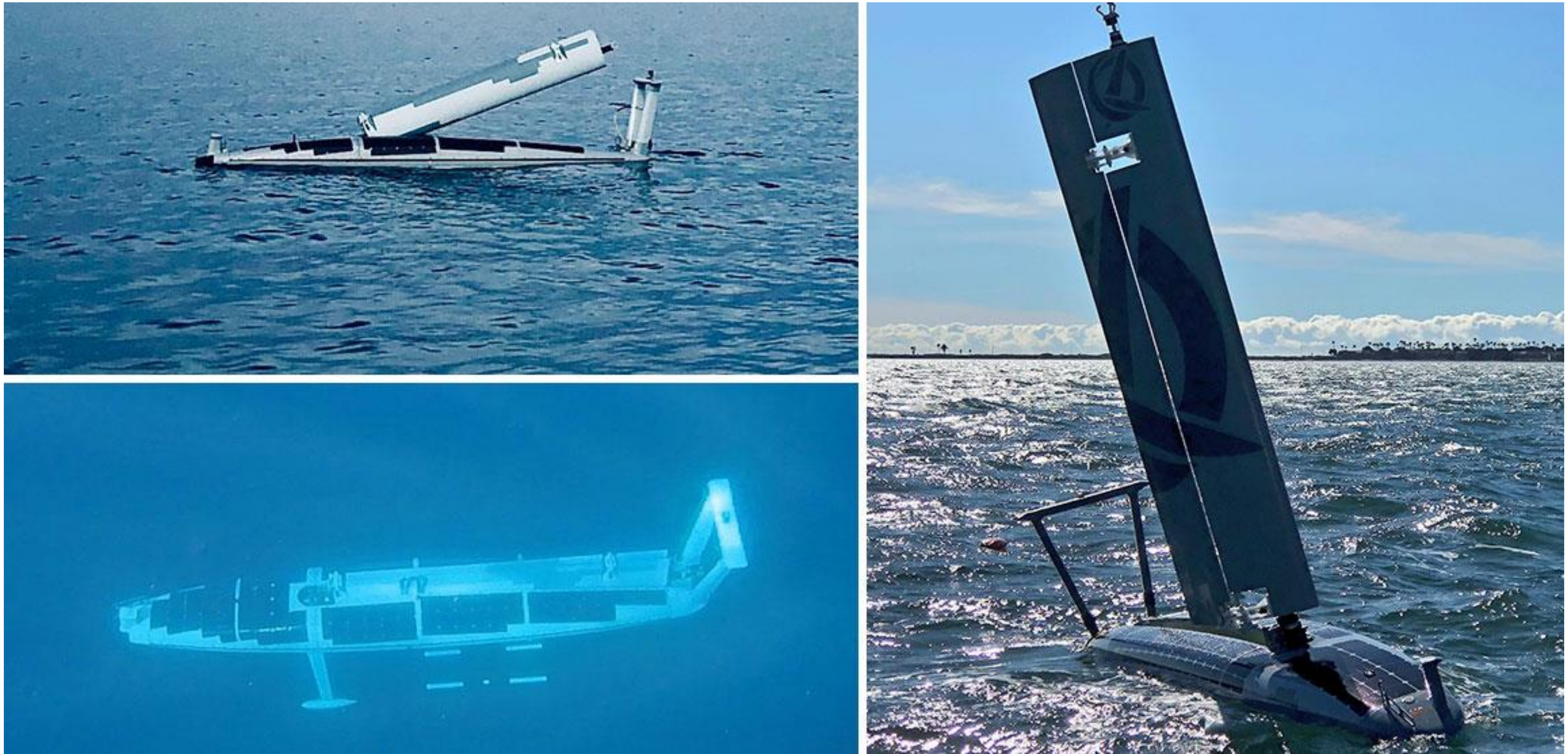
The development of the non-fouling Niobium charging system from Niobicon, which allows wet-mate connections, is also a game-changer in underwater repowering. The connections can be laid flat on a docking station, which an AUV can simply 'sit' on to re-power. (Right image)





Platform technology: Hybrid AUV - Autonomous Surface Vessels (ASVs)

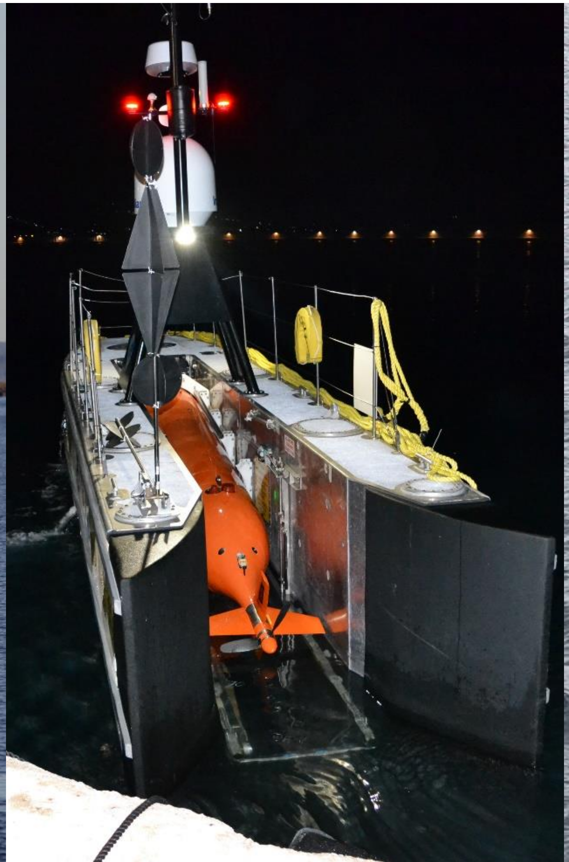
With DHS S&T support, Ocean Aero has built an ASV that could likely keep up with gliders using a retractable sail and solar panels, but can also transform to be an AUV for under-ice surveys.



Platform technology: Autonomous Surface Vessels (ASVs)

A number of ASV technologies have arisen in the past several years for work in open or ice-edge waters. Saildrone is perhaps the best known, which has operated in both the Arctic and Southern Ocean in the past year, but other ASV makers have also emerged.

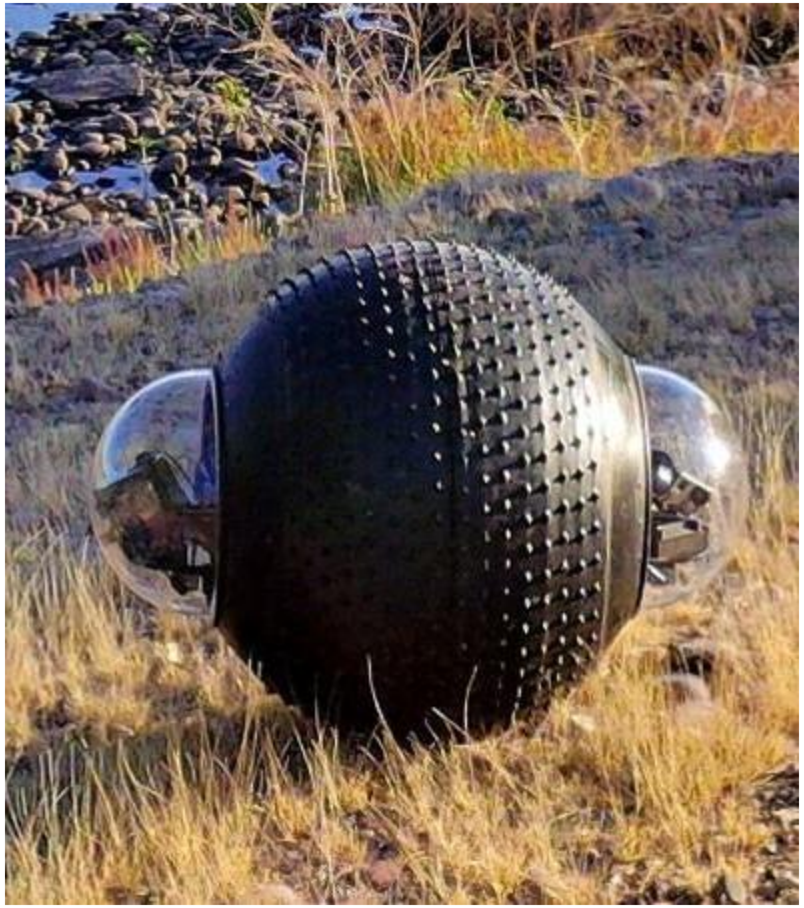
Notable is the Sea Kit ASV, selected for the X-Prize seafloor mapping effort, which can autonomously launch & recover an AUV with multi-beam.



Platform technology: Autonomous Surface Vessels (ASVs)

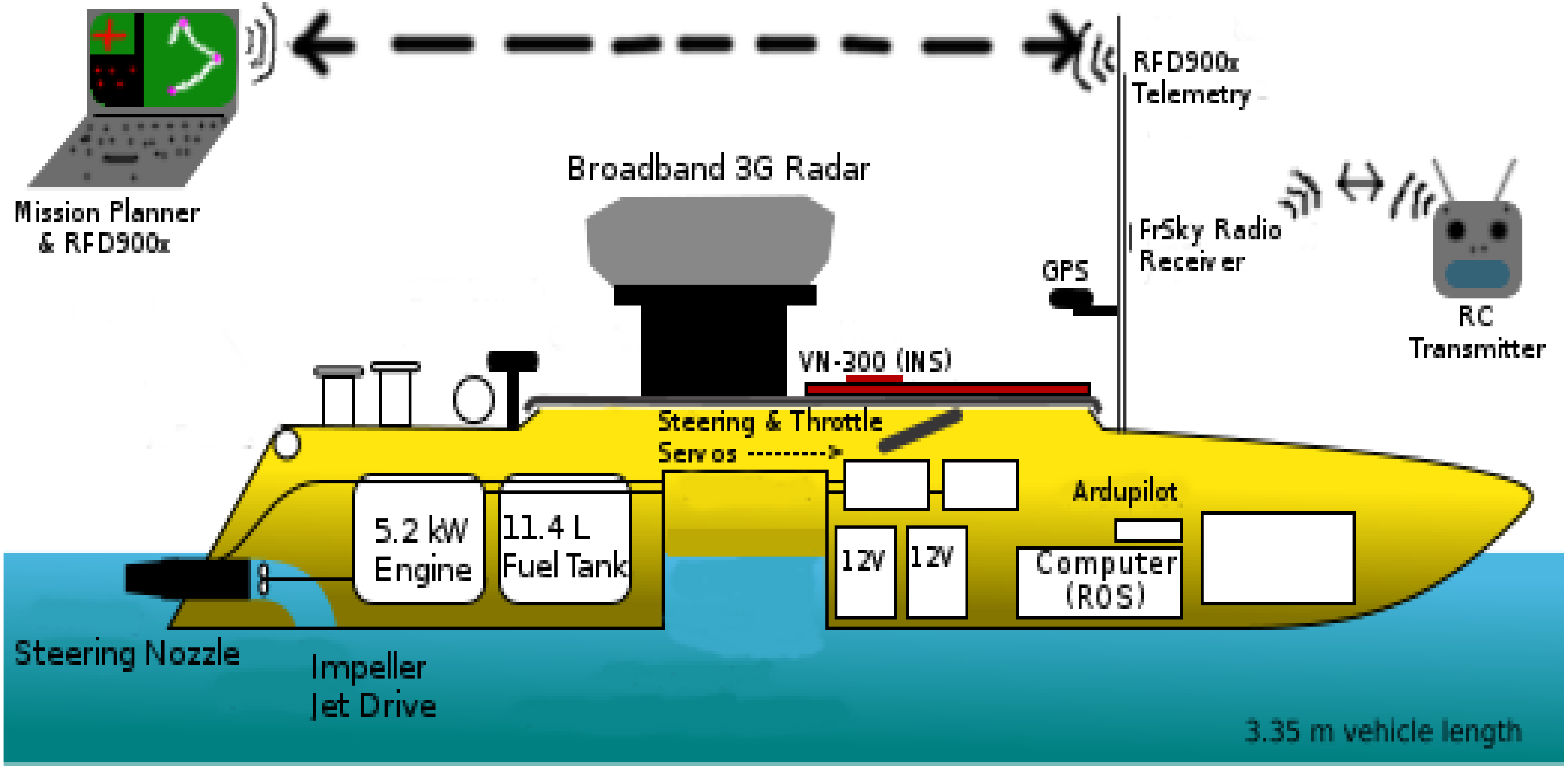
The XOcean XO-450 is a catamaran style ASV, 4.5m long, with “Human in the Loop” control, and @18 day/1500km endurance via micro-diesel engine, solar and Li-ion batteries, 4 knot speed. Very stable in high seas.

Platform technology: Autonomous Surface Vessels (ASVs)



There are also a couple of ASVs that are either designed or capable of moving through slush ice, such as in the Marginal Ice Zone (MIZ), or moving over ice surfaces. In fact some are designed to climb ice ridges. One example for MIZ work is the Aquiline Drones/GuardBot ASV, which has sensors along the edges, and can move over solid surfaces, and through/liquids, which was designed for NASA work on icy planets. It is intended to operate for 24+ hours at 3mph in water and includes full satellite comms.

Platform technology: Autonomous Surface Vessels (ASVs): The JetYak, Hanu Singh, NE U.



Platform technology: Autonomous Surface Vessels (ASVs):

JetYak (Hanu Singh, NE U.), tracks drifting Greenland iceberg, mapping both surface melt (with lidar) and subsurface melt (with acoustics) over time, by circling the berg while maintaining precise relative positioning.

Platform technology: Unmanned Aircraft Systems (UAS)

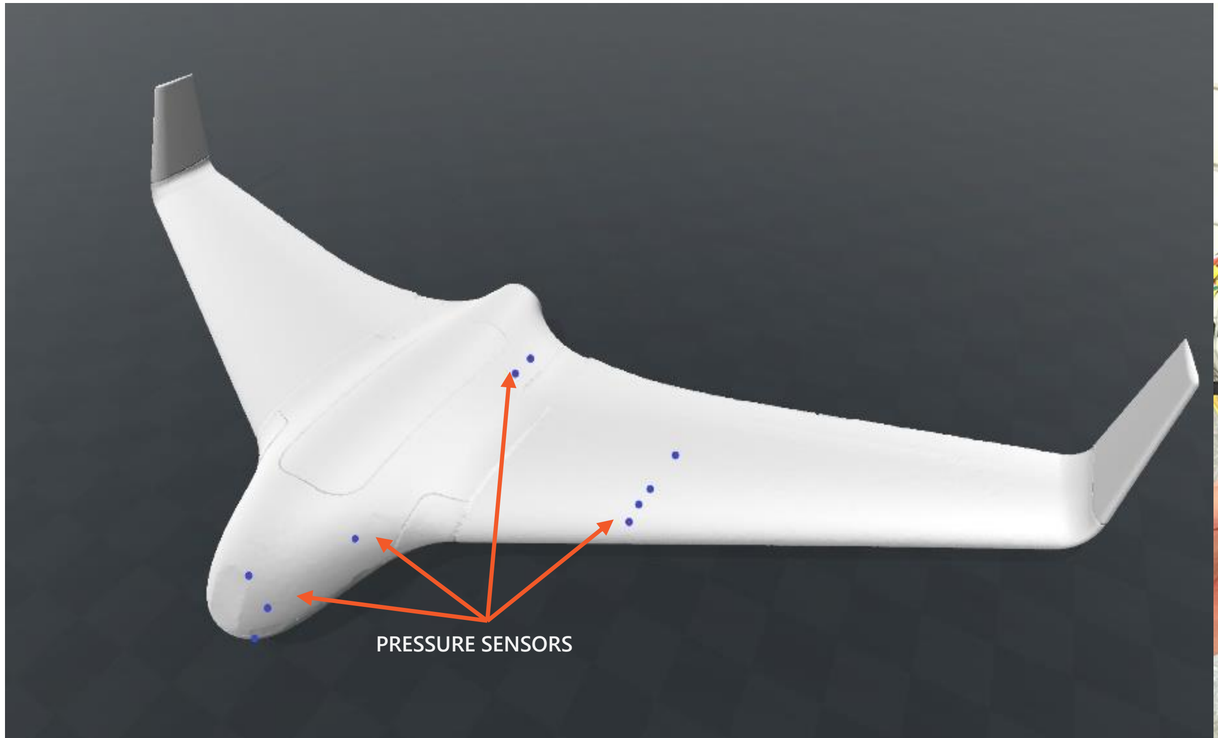
Chris Zappa (LDEO), who works in both Arctic & Antarctic regions, has been using Latitude Engineering VTOL UAS for SST, ice melt (from IR) and and air-sea flux studies, and has shown success with these in winds up to @25 knots (left pix).

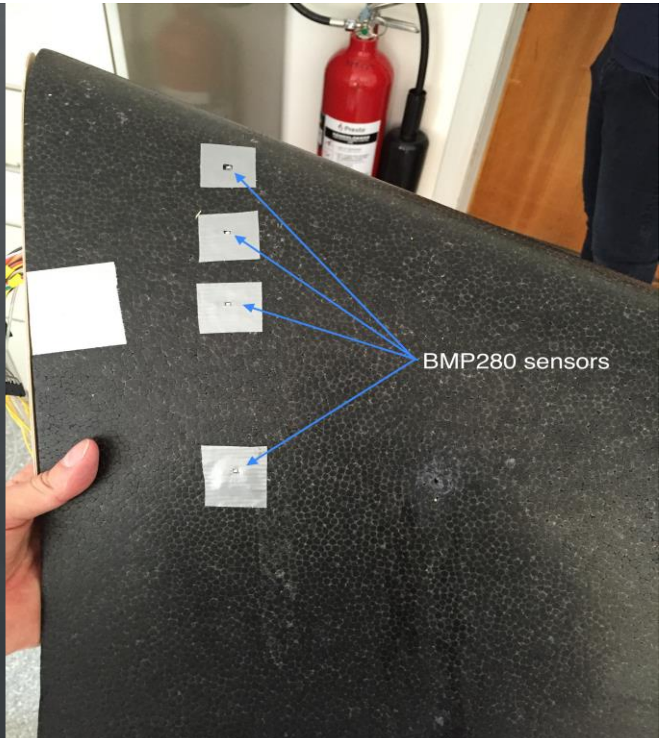
Tetra Drones (*www.tetradrones.co.uk/*) are designed to both fly, and get in the water and take samples (right pix).

Platform technology: Unmanned Aircraft Systems (UAS)

Kasper Trolle Borup (NTNU) has developed a fixed wing UAS with multiple pitot tubes across the wingspan, which allows it to measure wind speed and direction while flying. This elegant solution is an improvement to the alternative of using multiple UAS to do this.

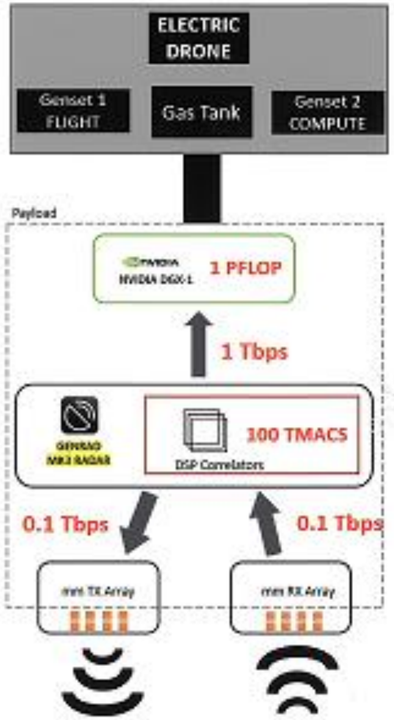
See: “A Machine Learning Approach for Estimating Air Data Parameters of Small Fixed-Wing UAVs Using Distributed Pressure Sensors.” IEEE Trans. Aerospace & Electronic Systems, 2019. DOI: 10.1109/Taes.2019.2945383.





Platform technology: Unmanned Aircraft Systems (UAS)

UAS w/ Mm-wave Radar & Petaflop Computing for Real-time Ice Ridge/Keel Mapping



This is a fully autonomous utility drone.
It's capable of 4hr flights without refueling
It carries a state of art Radar which allows it to reliably see and navigate around any obstacles.
In addition, it has 1 PFLOP of on-board compute which allows it to conduct a wide variety of tasks, ranging from Ground-Penetrating-Radar, navigation and path planning, to higher-level AI.

General Radar, Inc. UAS w/ radar capable of measuring ice ridges with 1.5cm accuracy through fog/snow, with real-time and data processing via onboard 1 petaflop computer.

System can provide ice keel depth at an estimated 6-10' deep (TBD) while flying or much deeper if landed. Plans for field demo are in 2020.

Platform technology: Unmanned Aircraft Systems (UAS)

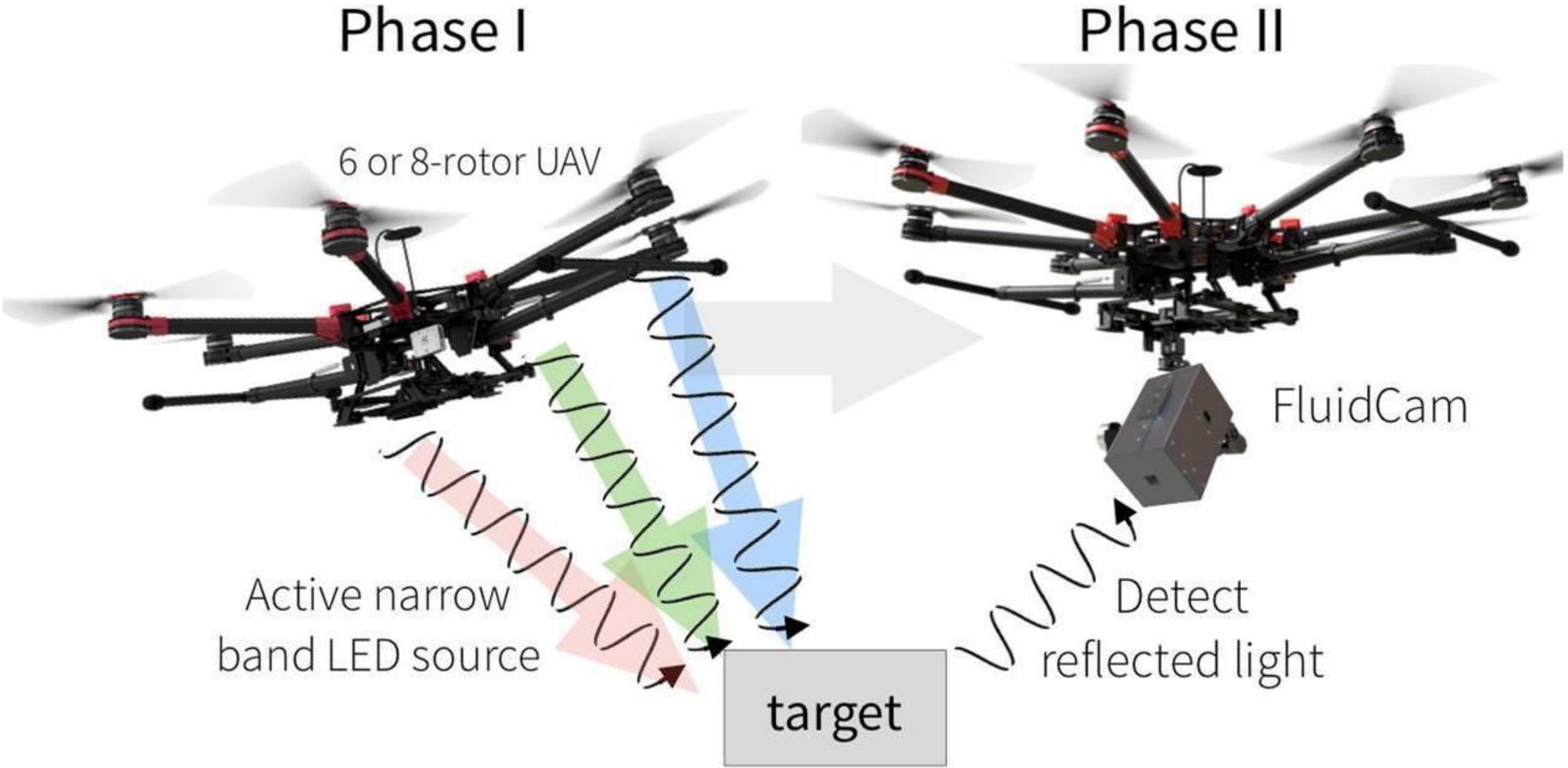
Critical to high latitude UAS operations is an anti-icing mechanism. We have been using the very thin, low power 'D-Ice' active carbon nano-tube anti-icing coating developed by Ubiq Aerospace (as a PhD project at NTNU, now commercialized). It works in marine (salt spray) environments (which many anti-icing coatings do not), and has a control system which only activates it when conditions warrant.

See: IEEE Feb. 2020, https://spectrum.ieee.org/the-institute/ieee-member-news/ubiq-aerospace-brings-the-first-drone-deicing-system-to-market

And: https://www.ubiqaerospace.com/

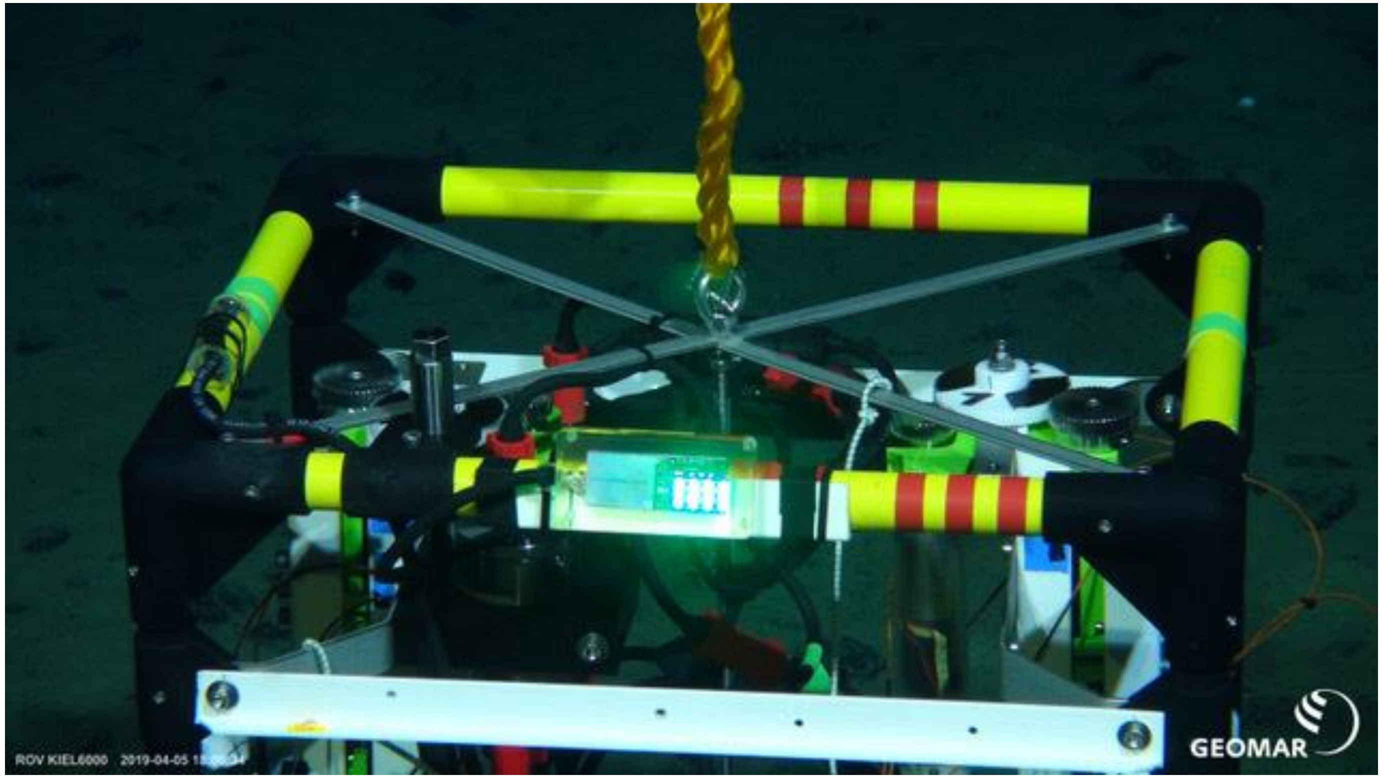
Platform technology: Unmanned Aircraft Systems (UAS)

NASA Ames MIDAR & Fluid Lensing developed by Ved Chirayath: Active Multi-spectral Imaging System deployed using two UAS (one a source & one a detector). This system allows measurement of primary productivity integrated over @ the upper 100' of water column, and can also be used for marine debris and other ocean data mapping missions. Combined with Fluid Lensing technology, the system allows optical comms from an AUV at depths of @100m directly to an unmanned aircraft in full sunlight at @1Mbps.



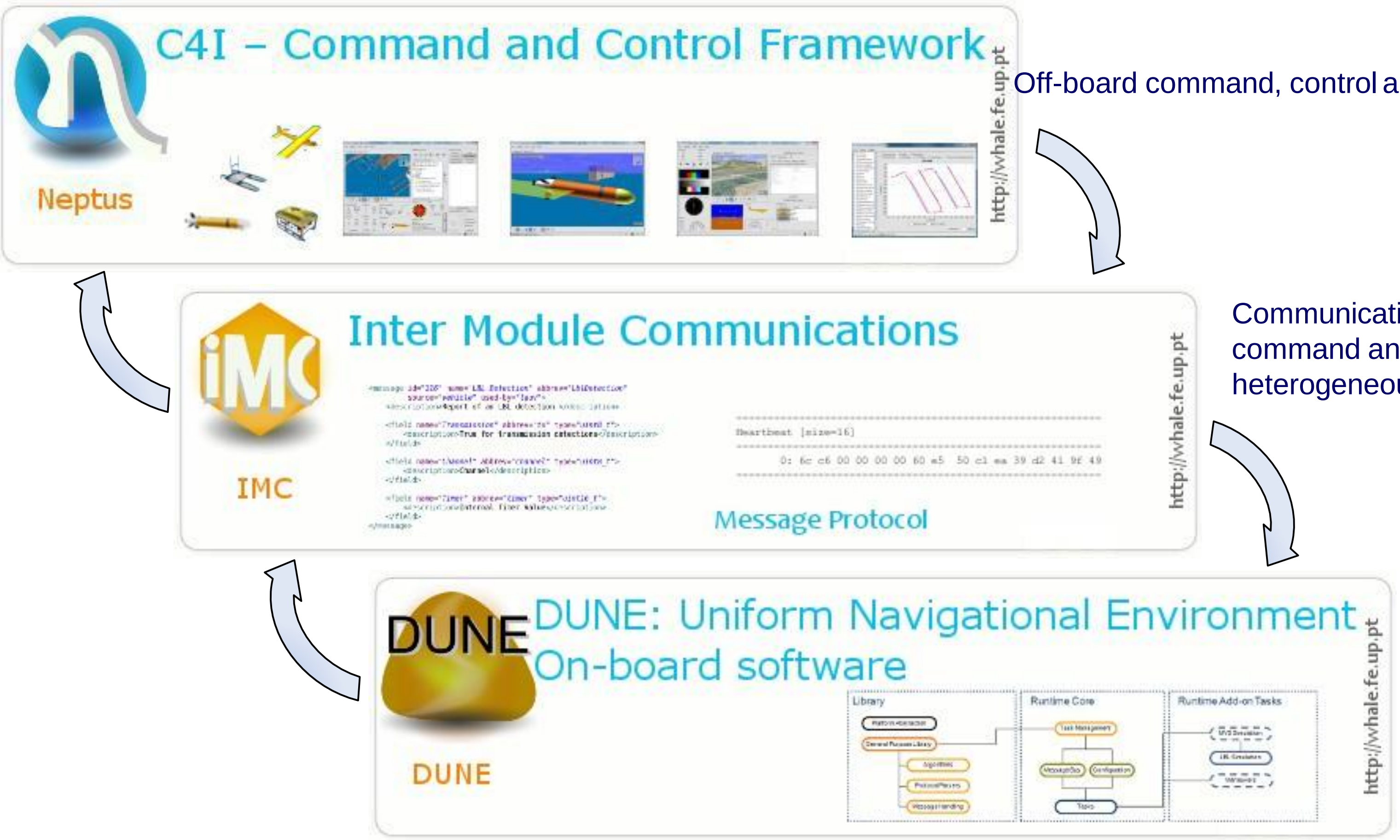
Communications Technology: Optical Comms

Several COTS optical modems already operate in deep-sea darkness; we've worked on optical modems that work in full sunlight. Those from Hydromea can do both, are small (size of a deck of cards), need little power, and communicate across distances of 30-50m in bright light, and 3-7m in full sunlight, and were recently used by AWI to rapidly download data from a deepsea mooring and re-programming it (pix below). Bandwidths 250-500kbps (full sun/partial).



Sensor Technology: Leveraging Multi-platform & Quantum Sensors

Persistent sampling at appropriate space-time scales needs networked unmanned systems.
We've used the widely used LSTS software (J. Tasso de Sousa, U.Porto), for command &control.



Off-board command, control and communications

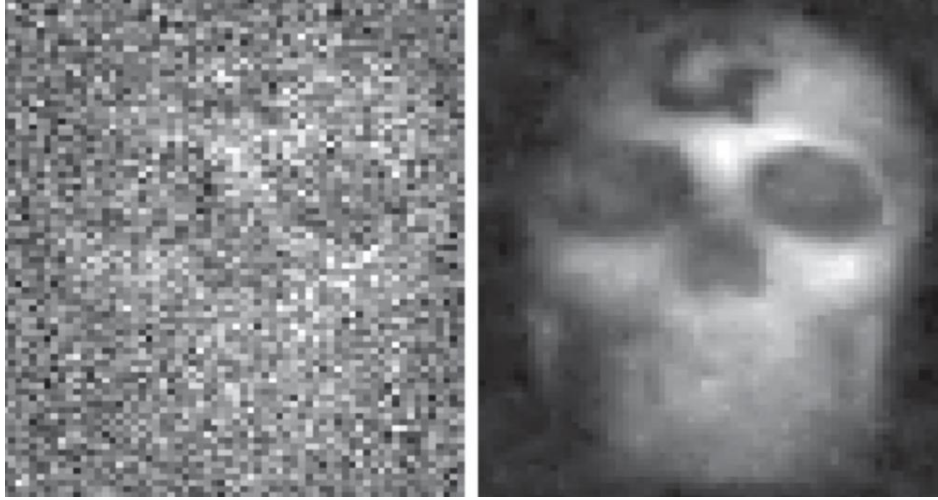
Communication protocols for command and control of heterogeneous systems

Onboard software (vehicles, buoys, data loggers)

J. Pinto, P. Sousa Dias, R. Martins, J. Fortuna, E. R. B. Marques, and J. Borges de Sousa, "**The LSTS tool chain for networked vehicle systems**", Proceedings of the IEEE/MTS OCEANS'13, Bergen, June, 2013.

User group: PT, US, NL, NOR, SWE, SP, FR, UK, DE, GR, IN, QT

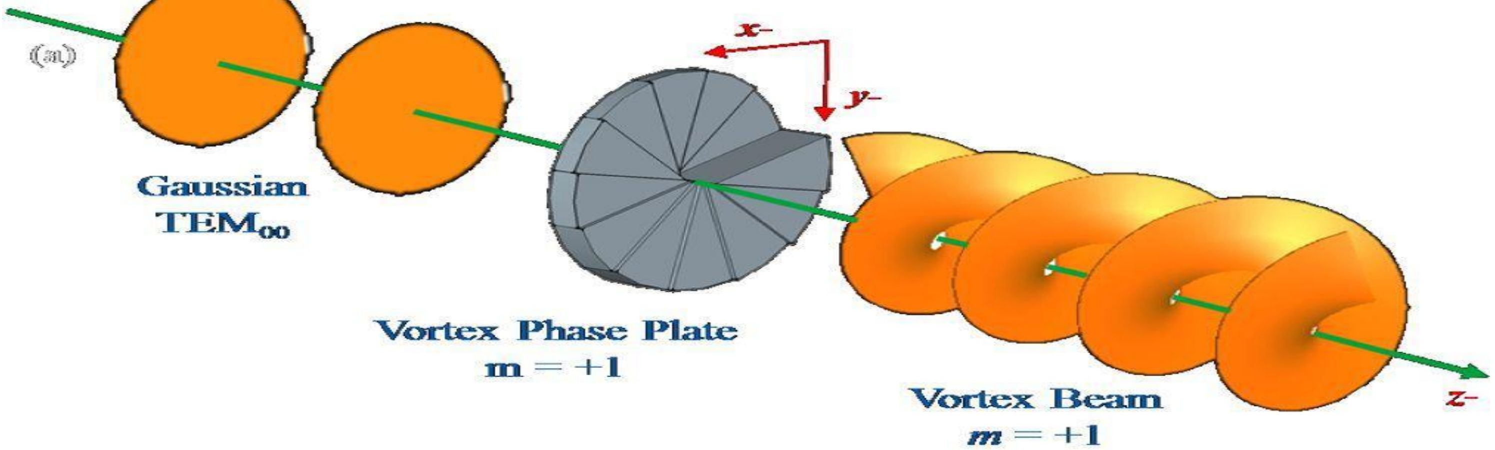
Sensor Technology: Leveraging Multi-platform & Quantum Sensors



- In ‘ghost imaging’ an object is imaged using quantum correlations of OAM, analyzed computationally, between the intensities of two entangled light beams, one of which impacts the object, one of which does not (it may be simply run through free space or an optical fiber), and is sent to a detector
- Because the beams are entangled, and one has not been through a randomly scattering medium, when they are ‘subtracted’, the random scattering is removed, and an object previously obscured by scattering in turbid or turbulent waters is made visible
- **Figure from: Padgett, M.J. & R. W. Boyd, 2016. An introduction to ghost imaging: quantum and classical. Phil. Trans. Royal Soc. A 375:20160233. http://dx.doi.org/10.1098/rsta.2016.0233**

Sensor Technology: Leveraging Multi-platform & Quantum Sensors

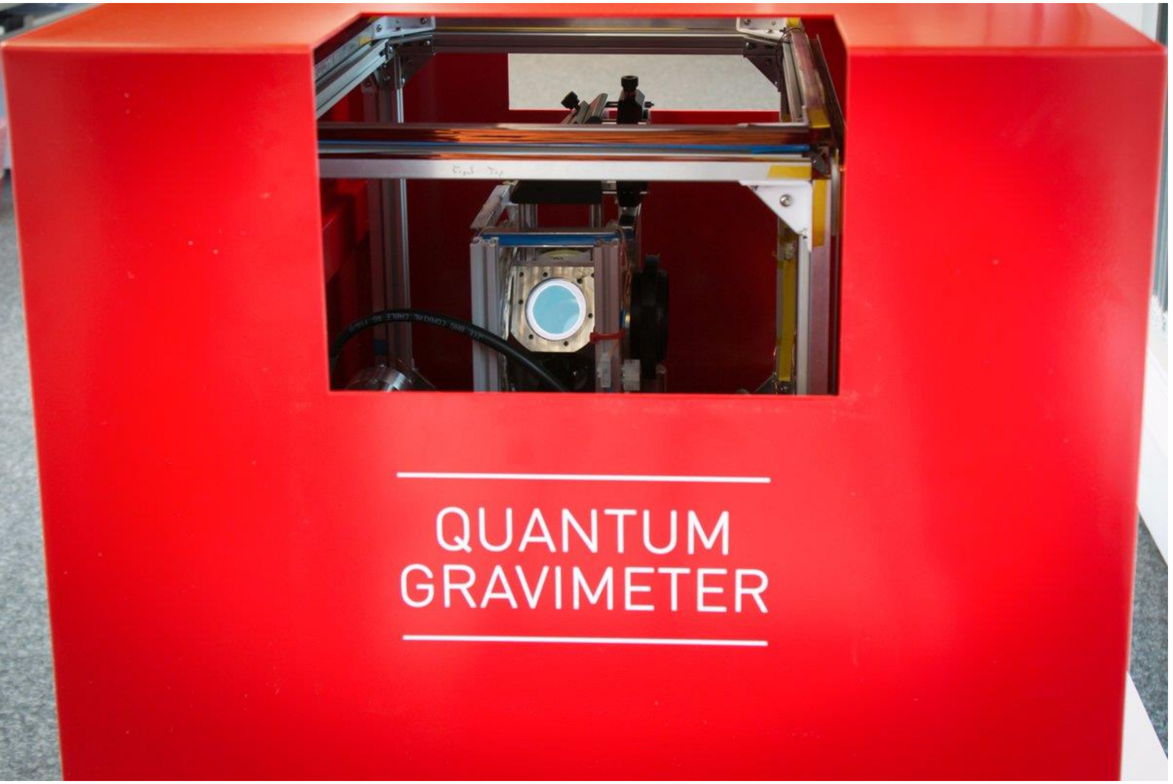
- Fraser Dalgleish (late of HBOI/FAU, now at L3-Harris) has successfully tested ‘ghost imaging’ with single photon detectors, with excellent results in air. His images involve a S/N ratio of 30:1, but the 1 quantum ‘un-entangled’ photon can be easily time sliced out with a 15 picosecond time slice, leading to excellent images.
- Fraser will undertake imaging of 3D objects underwater later this year, and should be able to achieve 1mm resolution with the 15psec time slicing.
- While currently using active illumination, we have suggested that it should be possible to use ambient Cerenkov radiation filtered as Orbital Angular Momentum (aka ‘corkscrew light’) which has very high S/N ratios to eliminate the need for any active light source.



Sensor Technology: Leveraging Multi-platform & Quantum Sensors

Quantum Magnetometry – made by Geometrics for UAS; scarcely bigger than a wine cork
Quantum Gravimetry – some quite small, most only on ASVs
or large UAS…already being flown on those.

M Squared quantum gravimeter.



Microquans Absolute Quantum Gravimeter

Sensor Technology: Leveraging Multi-platform & Quantum Sensors

Quantum navigation systems

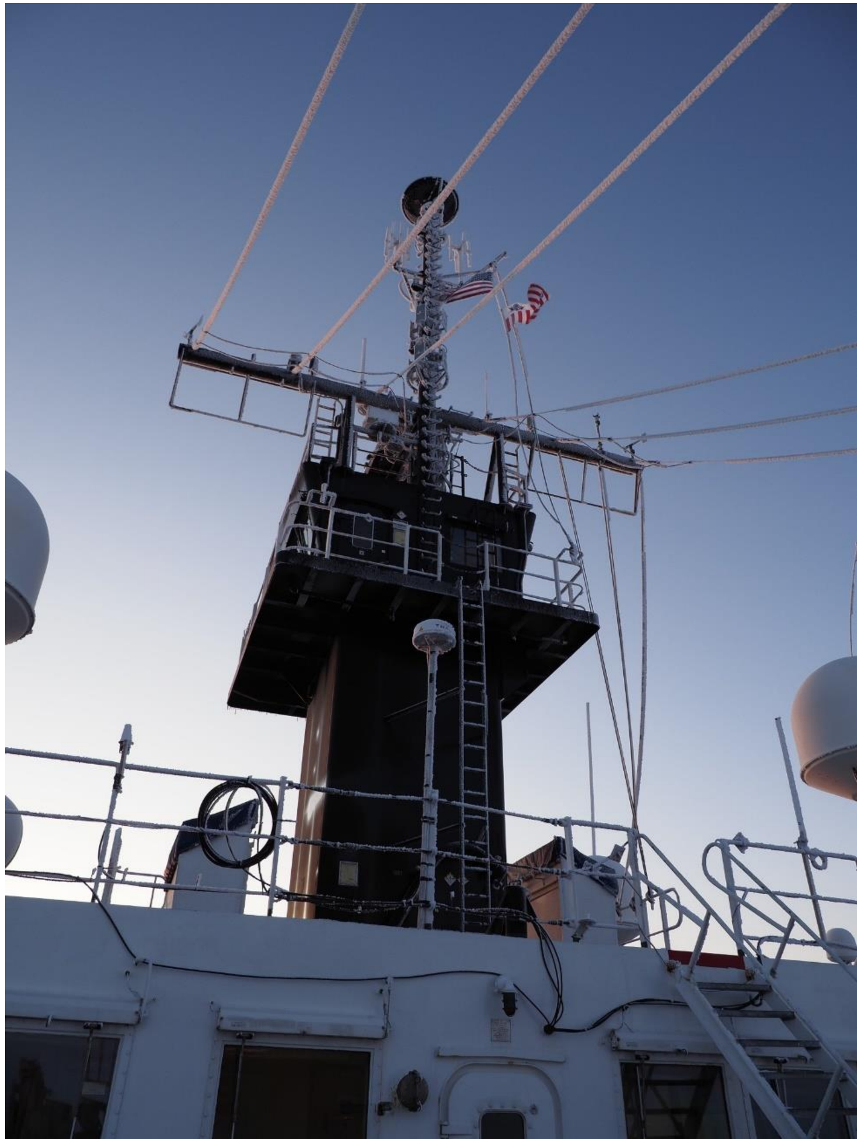
- It is believed the Chinese may have already developed quantum navigation systems for their AUVs
- There is a very active international effort underway within NATO to develop quantum navigation systems using proto-types of already existing quantum chips that operate at room temperature with quantum entangled photons
- This system would allow gliders/AUVs to accurately know their positions.
- Kongsberg's "Sunstone" project is using a quantum accelerometer to calibrate drift of a MEMS IMU for their HUGIN AUV. This is a hybrid approach to achieving more accurate AUV positioning without requiring quantum entangled photons.

Sensor Technology: Leveraging Multi-platform & Quantum Sensors

- Canadian QEYSSAT: Quantum Encryption & Science Satellite, design contract Aug. 2018, see:
  - https://www.photonicssociety.org/conferences/summer-topicals
  - http://spaceq.ca/Canadian-qeyssat-quantum-satellite-program-gets-next-round-of-funding/
- US-Canada-UK-Australia "Quantum Initiative" announced Sept. 2018,
  - See: https://fedscope.com/military-collaborate-allies-quantum-navigation-project/

Computing Technology: Machine Language & Real-Time Data Analysis
Human ‘Technology’: Training in New Technologies; Tech for Improving Public Outreach

- Computing Technology now includes use of Quantum Computers from IBM (available free!), and increased use of Machine Language/AI. These allow automated identification of phyto & zooplankton, identification of whales/marine mammals from UAS imagery or acoustic recordings, and automated quantification of ice melt ponds, ice ridges and percent ice cover.
- To quote former NSF Arctic program manager Michael Ledbetter: “Most people are not going to get to the polar regions, you have to bring it to them.” With the advent of the new Iridium CERTUS system bandwidth for comms in the polar regions will be greatly increased, and should greatly facilitate this. (Photo of Iridium CERTUS antenna on CGC HEALY in 2019.)



Summary: Testing and Operationalizing New Technologies

To achieve proficiency with the new technologies described both graduate students and Marine Science Techs will need to be trained in these systems.

In Europe a consortium of all Marine Robotics institutes has embarked on an annual training cruise (coordinated by U. Porto) to provide such training, and permit networking among grad students so each academic institution doesn’t ‘re-invent the wheel’. The cruise is followed 6 months later by a Symposium to allow exchange of information on what worked, and what didn’t.

We need to have a similar program in the US to keep up with technological advances both in the US and elsewhere, which are developing at a much more rapid rate than in the past.

…To quote my mentor, Walter Munk…

Always remember to "Keep It Simple" and "Make it Fun"

Questions?