New technology to conduct under-ice observations using instrumented autonomous underwater vehicles and rovers

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An Unexplored Ice-Covered Ocean World on Earth

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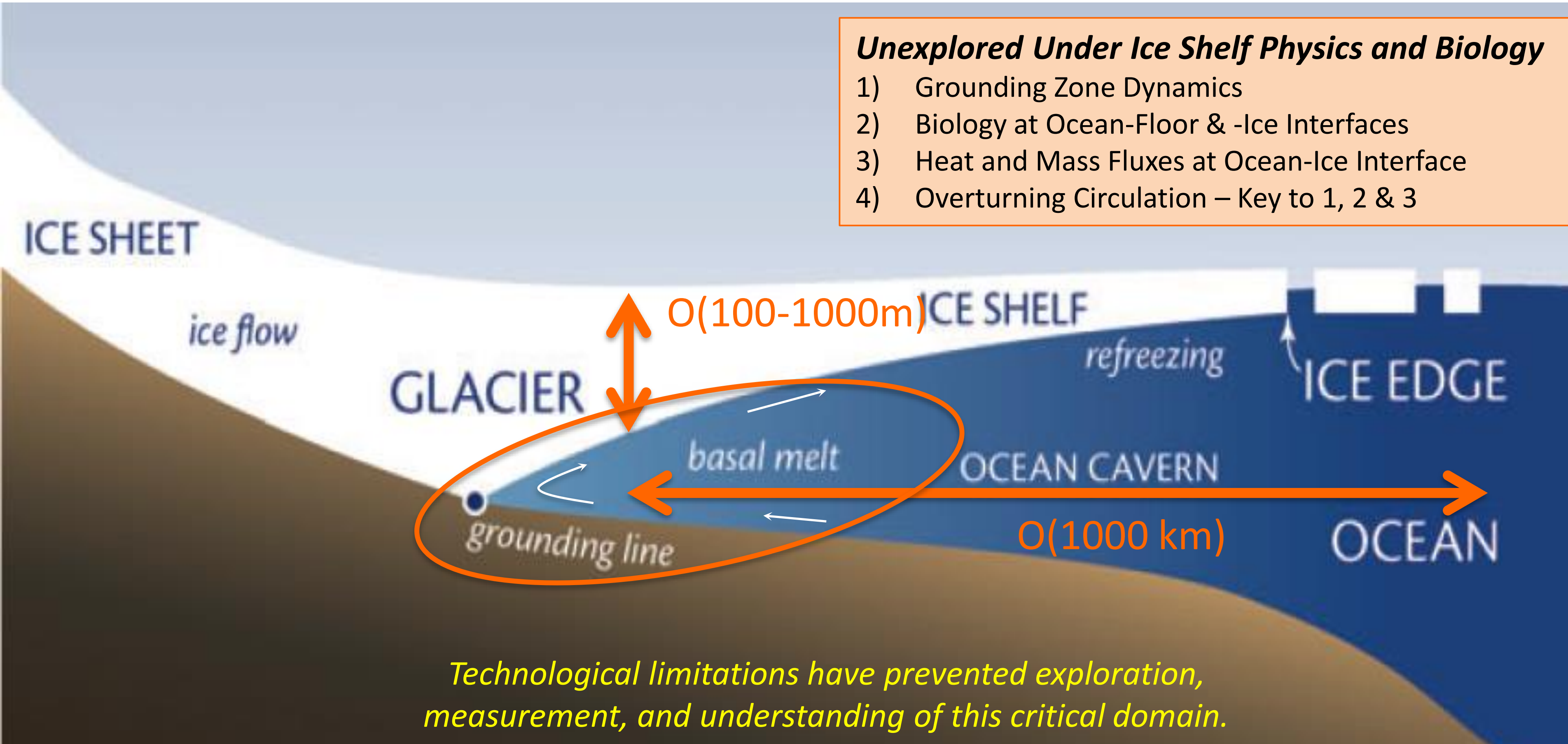

From Munk et al. (2011, Tellus)

High-latitude environments are significant to global oceanic primary productivity and sea level rise; however, our understanding, characterization, and prediction of the mechanisms affecting ice stability and productivity is limited due to sparse sampling in these extreme and rather inaccessible environments.

New technology is needed to explore and characterize the poorly known ice physics of these ocean cavities and its unique, unknown biology.

1931 Wilkins-Ellsworth Submarine Expedition

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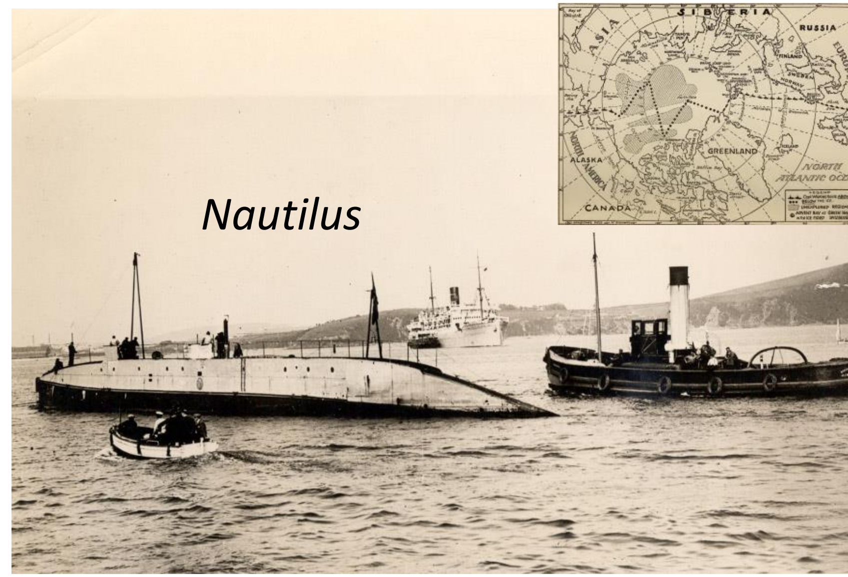
"One of my earliest memories is listening to Sverdrup talk about his Arctic experiences and the ill-fated attempts of the submarine Nautilus to dive under the ice.

He told about glaciers flowing into the sea until they come off the bottom at the 'grounding line' and continue for long distances as floating ice tongues.

.... Sverdrup emphasized that we know nothing about this ocean cavern, not a single observation.

This was true 60 yr ago, and is nearly so today."

From Walter Munk et al. (2011, Tellus)



In 1931, Australian explorer Sir George Hubert Wilkins and a volunteer crew of submariners and scientists set out in a decommissioned U.S. Navy submarine to sail under water from Spitsbergen to the Bering Straits by way of the North Pole. *(American Philosophical Society)*

Key Science Questions

Glaciology

1. How does the ice-shelf cavity shape influence the spatial distribution and magnitude of ocean circulation and ice shelf melt rates?

Oceanography

2. What controls the spatial distribution and temporal variability of ice-shelf melt rates and water mass modification near the grounding zone?

Biology

3. How does liquid and sediment transport across the grounding zone influence local microbial diversity?

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Scientific Measurements

Physical Parameters	Observable
Ice Melt Rate	*Temperature*
	Salinity / Conductivity
	Ocean velocity
Ocean circulation	*Ocean velocity*
Cavity Shape	*Sea floor and ice bottom topography*
	Ice surface roughness/texture
Environmental Context	*Images/Video*
Sediment Transport	*Turbidity*
Microbial Abundance	*Flourescence/Scattering*
	Flourescence
Microbial Habitat	*pH*
	Dissolved Oxygen
Ice Thickness	*Ice Thickness*
Ice Physical Properties	*Temperature, Density, Composition*

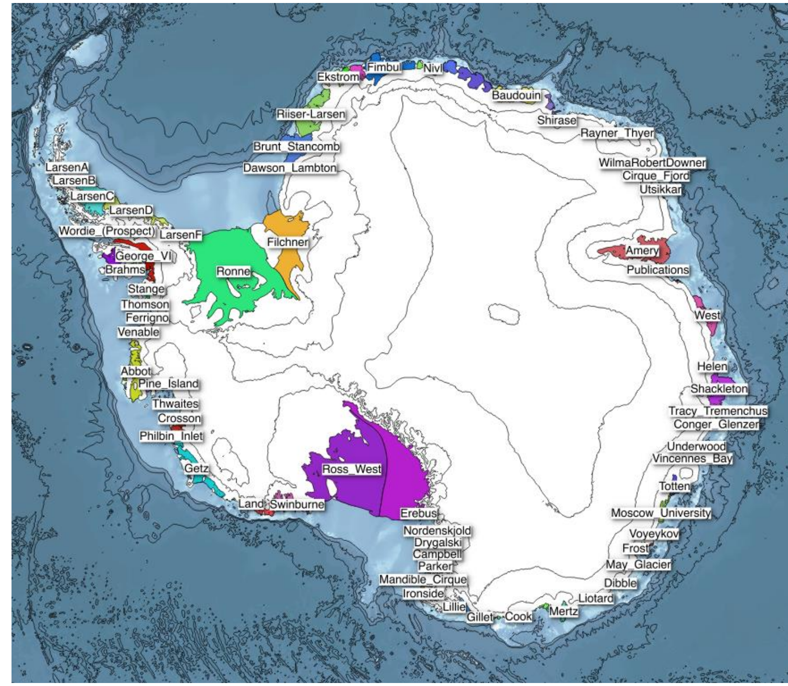
Goals

1. Introduce the under-ice observing system community to our concept.

2. Identify instruments or instrument requirements that enable ice-shelf cavity melt rates to be inferred from measurements of turbulent heat and salt fluxes from an autonomous robotic platform.

3. Discuss design considerations for an autonomous underwater vehicle (AUV) to accomplish robot deployment and measurement objectives.

4. Identify potential partners for field campaigns.



Under Ice-shelf Ocean Exploration

Technical and Science Approach Highlights

– The dual heterogeneous vehicle approach
  - Autonomous Underwater Vehicle (AUV) for mapping of cavity geometry and hydrography
  - Buoyant under ice rover (BRUIE) for in situ data collection close to the ice/water interface

Buoyant Rover (BRUIE): *A mobile under-ice explorer continuously in contact with the frozen surface*

AUV: *Cavity exploration*

- Existing Near-ice observations are limited and unique
- Survey of under-ice topography for understanding melt rates and the ice/ocean interface (biophysical properties)
- Autonomy enables potential long-range and long-time scale measurements crucial for connecting open ocean to ice shelf cavity processes

National Aeronautics and
Space Administration

Jet Propulsion Laboratory
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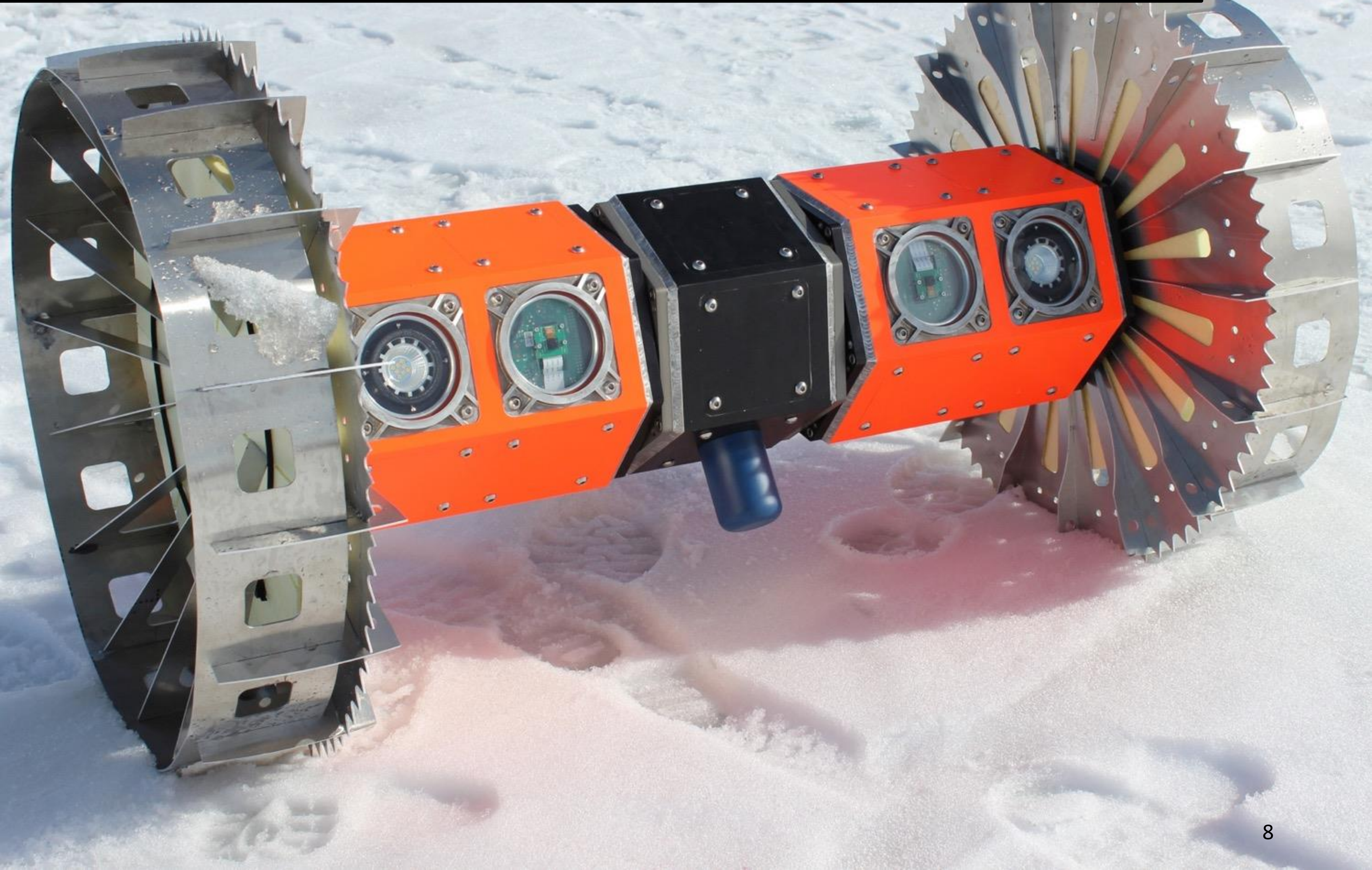
Pasadena, California

Touching the Grounding Line

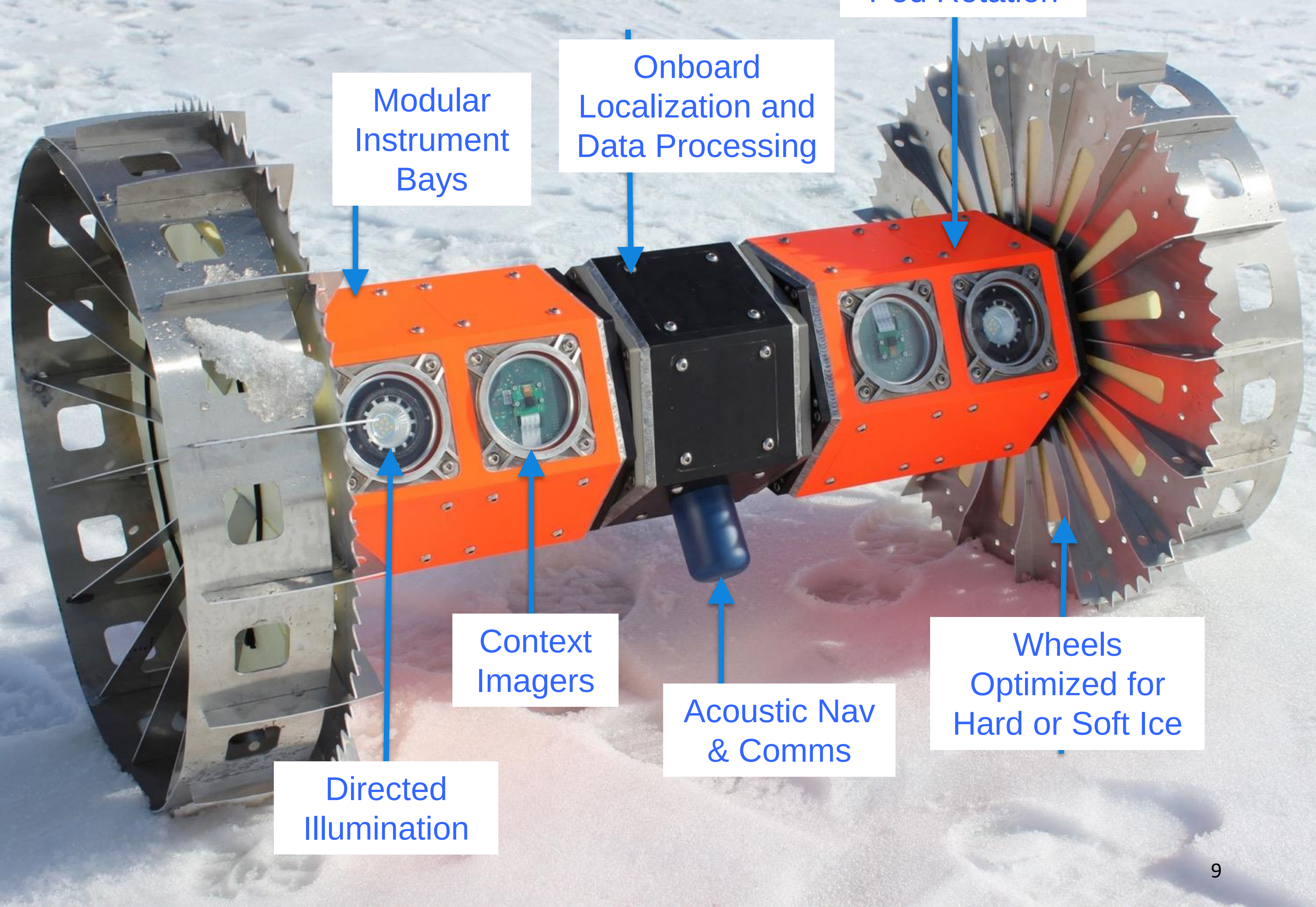
In-Situ Exploration with the Buoyant Rover

What is the Buoyant Rover?

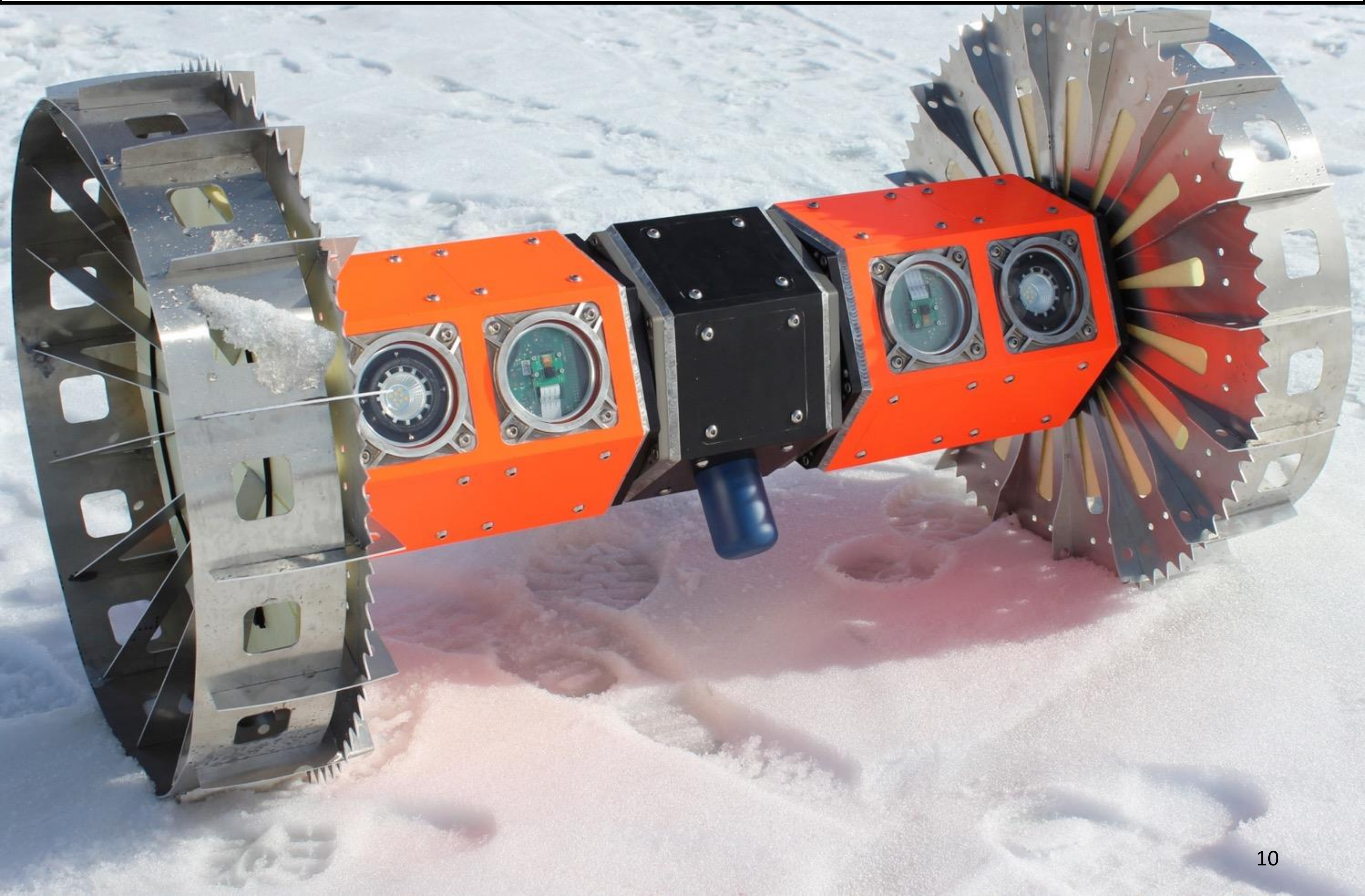
A novel instrument to explore ice-water interfaces



What is the Buoyant Rover?



What modifications to the BRUIE are required for the necessary instruments to be installed?



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JPL Maritime Technology Snapshot

History: JPL has been under contract since 2004 to transition NASA flight-derived intelligent autonomy technology to unmanned surface and underwater vehicles (USV, UUV). Sponsors include ONR, DARPA, OSD, NOAA, JPL-Earth Science

Aim: Mission-level autonomy for operation with onboard self-contained sensing and decision making.

Missions:

AUV: Adaptive area surveys, oceanographic adaptive sampling (feature detection/tracking);

USV: swarms, patrol, track/trail, intercept/inspect)

JPL Autonomy Engine: CARACaS

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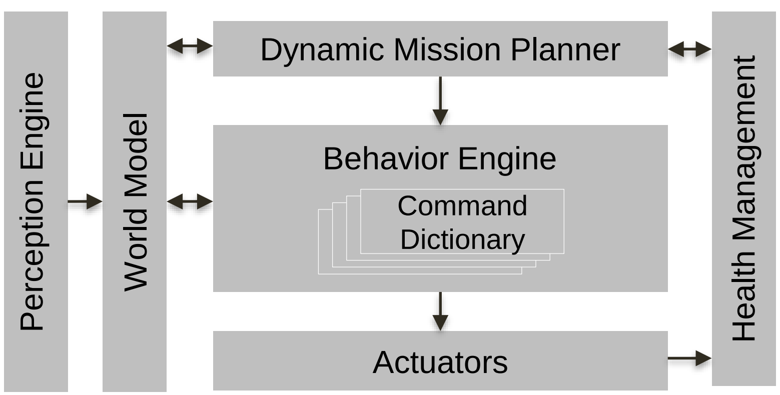
CARACaS



Open Architecture Autonomy Engine

CARACaS (Control Architecture for Robotic Agent Command and Sensing) designed using JPL flight-derived technology with an integrated blend of hard real-time and periodic process control.

- Provides the foundational software infrastructure, core executive functions, several robotic technology modules, and a development environment for new modules and mission behaviors.
- Interfaces are all defined with Interface Control Documents (ICDs) and use industry standard communication protocols.
- Safe navigation of vehicles by onboard hazard detection and avoidance.

AUV Cavity Exploration

- Key points:
  - We are not building an AUV
  - JPL’s contribution in this area will be its expertise in developing key intelligent and adaptive autonomy technologies
  - Currently in discussions with potential partners

Engineering Campaign: Sea Ice

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Purpose:

Demonstrate underwater assets working together

Capabilities Tested

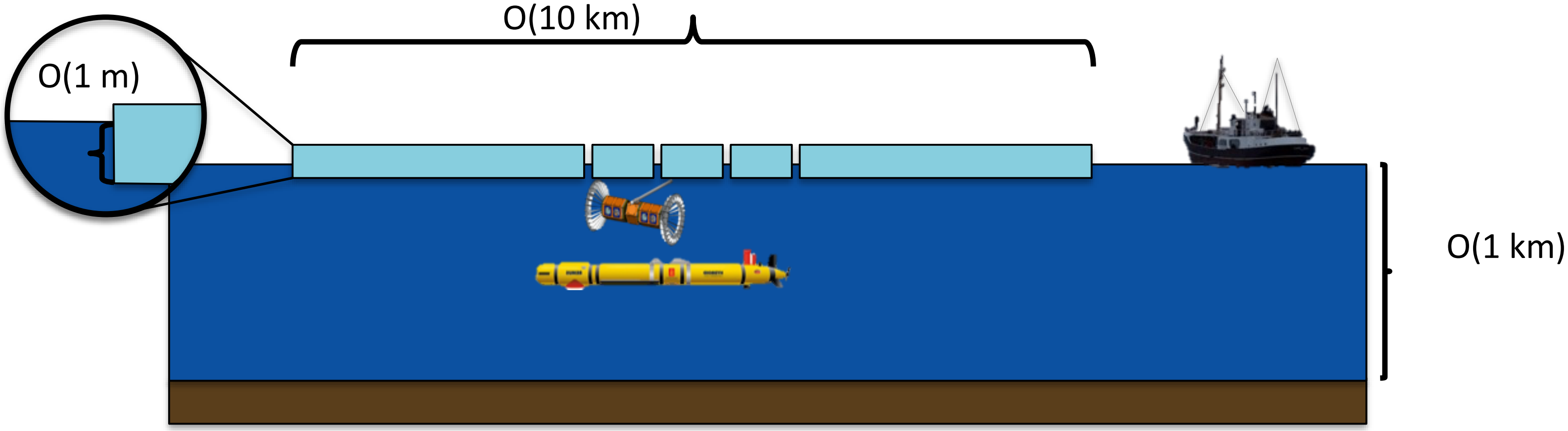
- BRUIE under ocean ice
- AUV transports BRUIE to site
- BRUIE relays data to AUV

Scenario

- AUV deploys from ship with BRUIE,
- AUV deploys BRUIE

Concurrent macro/micro measurements

- AUV: CTD, bathymetry, currents
- BRUIE ice/water interface measurements
  - near-ice (within a meter or so of the ice-water interface at the grounding line, and at cm or greater resolution),
  - important measurements to be made include: image microscopy, ice-boundary flow rates, localized (cm-level) texture, local microbial analysis



Measurement Campaign: Small Ice Shelf

Purpose:

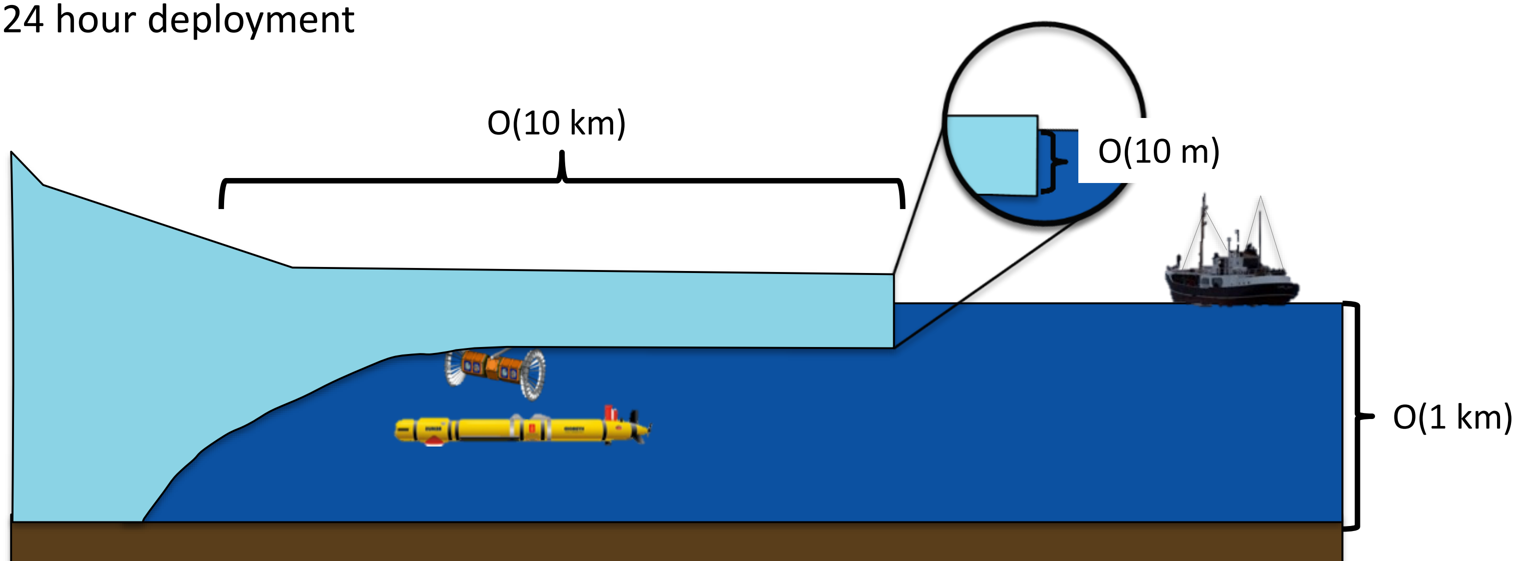
Engineering - Demonstrate borehole capabilities; exploration to 40 km
Science - Data measurement in cavity from ocean outlet to grounding zone

Capabilities Demonstrated

- AUV transports BRUIE to site under shelf
- BRUIE relays data to AUV
- Communications through borehole
- Localization through borehole
- Power recharge through borehole
- 2 x 24 hour deployment

Science Observations

- Ice melt rate/water circulation
- Water circulation
- Cavity Shape
- Sediment Transport
- Local microbial abundance



Science Campaign: Large Ice Shelf

Purpose:

Characterize the physical, thermodynamic and biomass characteristics under a warm ice shelf near the grounding zone.

Summary

- Measures key parameters for characterizing processes impacting ice melt at grounding zone
- Data will be used to improve models and constrain future sea level rise predictions.

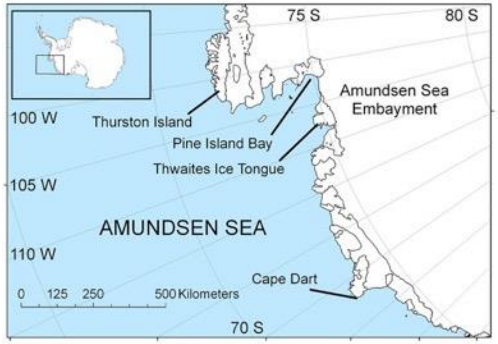
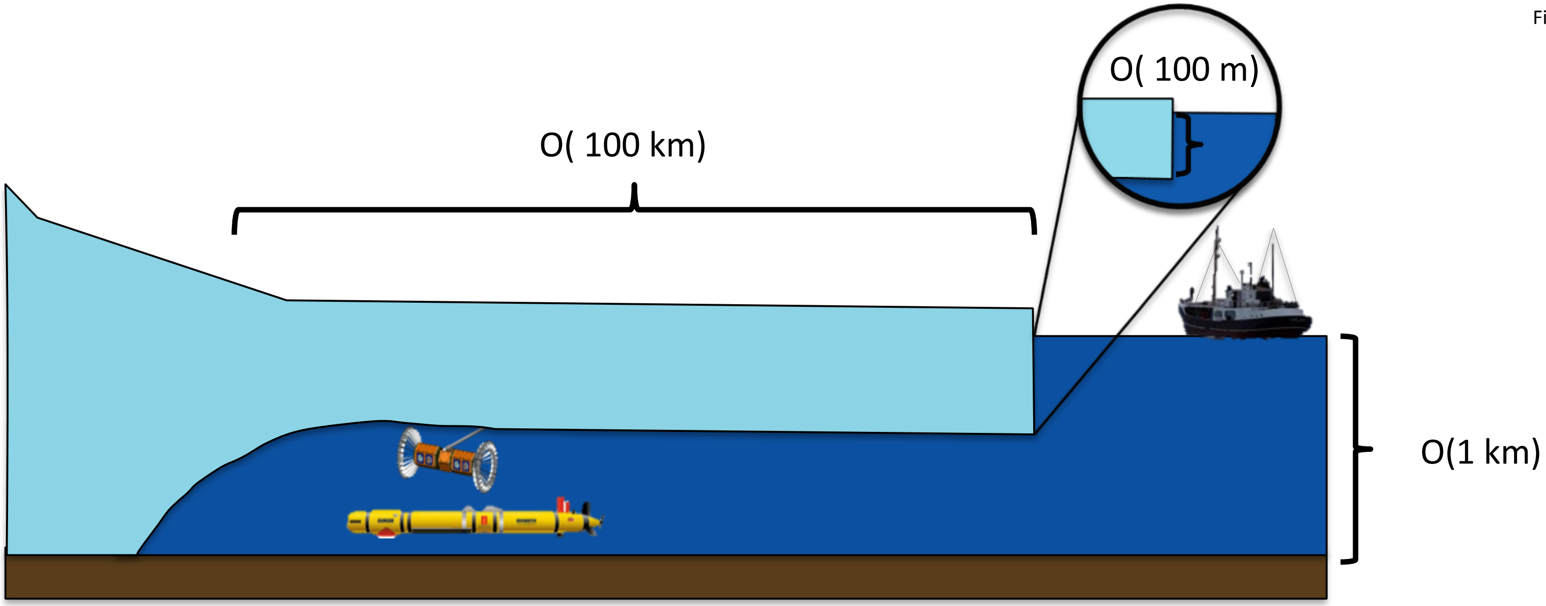


Figure: wikipedia



Summary

- JPL is developing new technology to enable autonomous *in situ* measurement of the under-ice environment.
- Combining an AUV delivery system/science platform and BRUIE science platform.
- We must ensure that BRUIE science platform has the capability of being properly instrumented through collaboration with experts.
- We will incorporate JPL autonomous mapping technologies into an AUV platform.
- A series of increasingly complex engineering and science campaigns concepts have been proposed.
- Need to identify potential partners for field campaigns.