AUTONOMOUS PLATFORMS IN THE ARCTIC OBSERVING NETWORK

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INTRODUCTION

Rapid Arctic environmental change, recently exemplified by the 2007 summertime sea ice minimum, presages broad shifts in global climate and exerts socioeconomic and climate impacts that extend beyond the Arctic itself. Arctic change must be monitored and understood both due to the Arctic's role in global climate and to inform efforts directed at managing and mitigating impacts. The Arctic Observing Network (AON) must provide both extensive sustained measurements to reveal and understand Arctic change and real-time data for environmental forecasting. Fortunately, the AON can exploit new autonomous observing technology that has transformed ocean observing at lower latitude. Extended-endurance Ice-Based Observatories (IBOs), floats, gliders, drifters and moorings offer complementary capabilities for observing and relaying data from remote regions, facilitating broad spatial coverage over decades. The new technology used in combination with conventional instruments offers varied approaches for different challenges. Ongoing efforts are yielding sensors to expand the suite of autonomously observable physical and biogeochemical properties. This is an opportune time to promote their use in the Arctic.

TECHNOLOGY OVERVIEW

Autonomous platforms address the challenges of Artic observing by providing:

- Remote access
- Long-term persistence
- Spatial coverage (e.g. distributed ice thickness, upper ocean profile)
- Real- or near-real time data return
- Adaptability- respond to changing environment (marginal ice zone)
- Cost-effective scalability

Need acoustic positioning and telemetry to replace GPS and Iridium in ice-covered environments. Several community workshops have explored platform technologies (see References).

ICE-BASED OBSERVATORIES

- Exploit drifting sea ice to support wide range of autonomous instruments designed to sample the upper ocean, ice and atmosphere.
- Provide acoustic navigation and communications links for platforms operating beneath the ice.
- Decreasing ice extent restricts area accessible to IBOs and shortens lifespan due to expanded marginal ice and open-water regions.
- Buoy hulls capable of surviving breakup and freeze-in under development.
- Data from ensembles of Ice-tethered Profilers (ITPs, WHOI) and Polar Ocean Profilers (POPS, JAMSTECH) are being used to construct true synoptic sections across the Arctic (by, for example, analyzing all the profiles obtained on a specific day) and map spatial fields such as fresh water anomalies (Fig. 1).

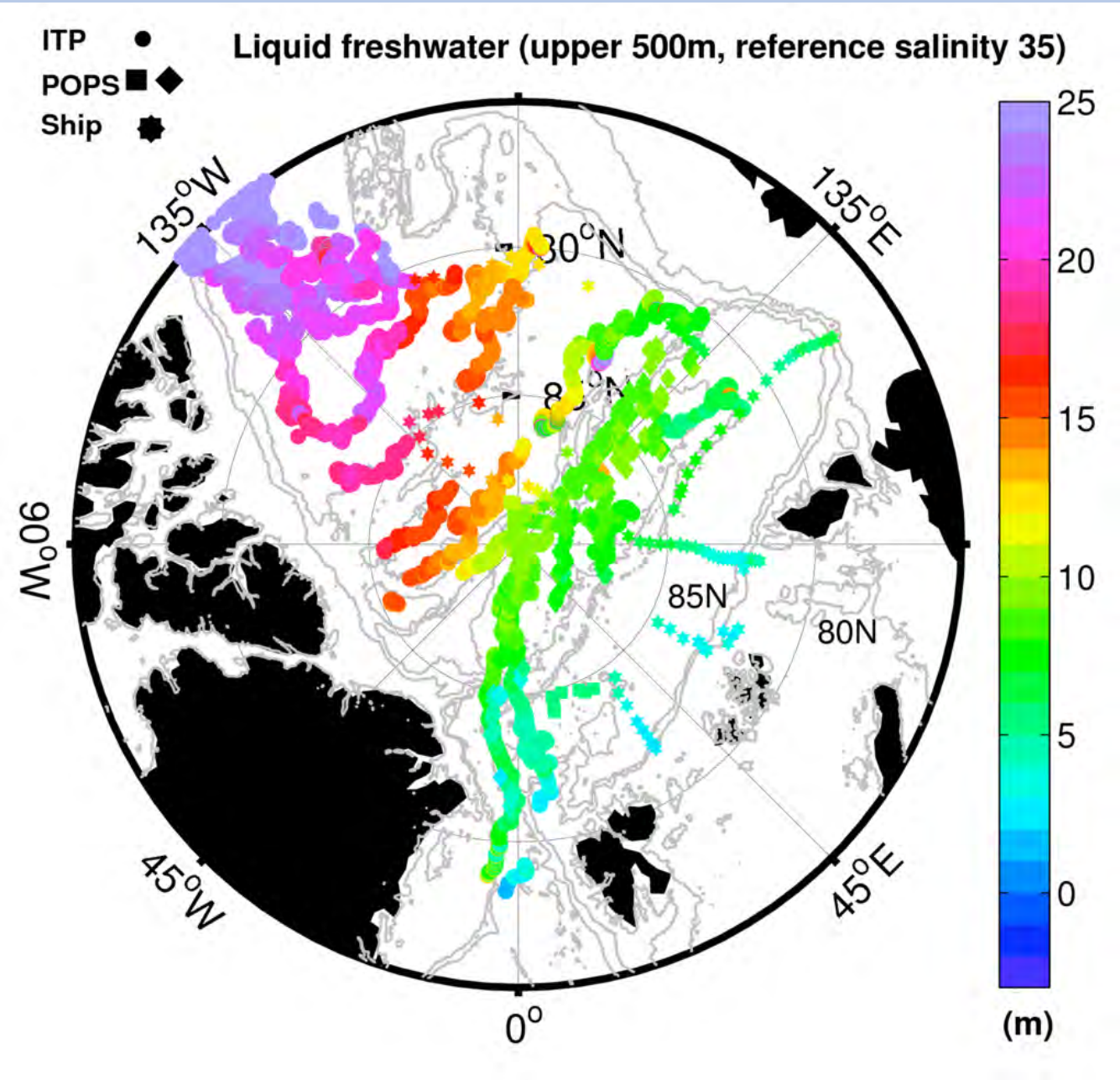
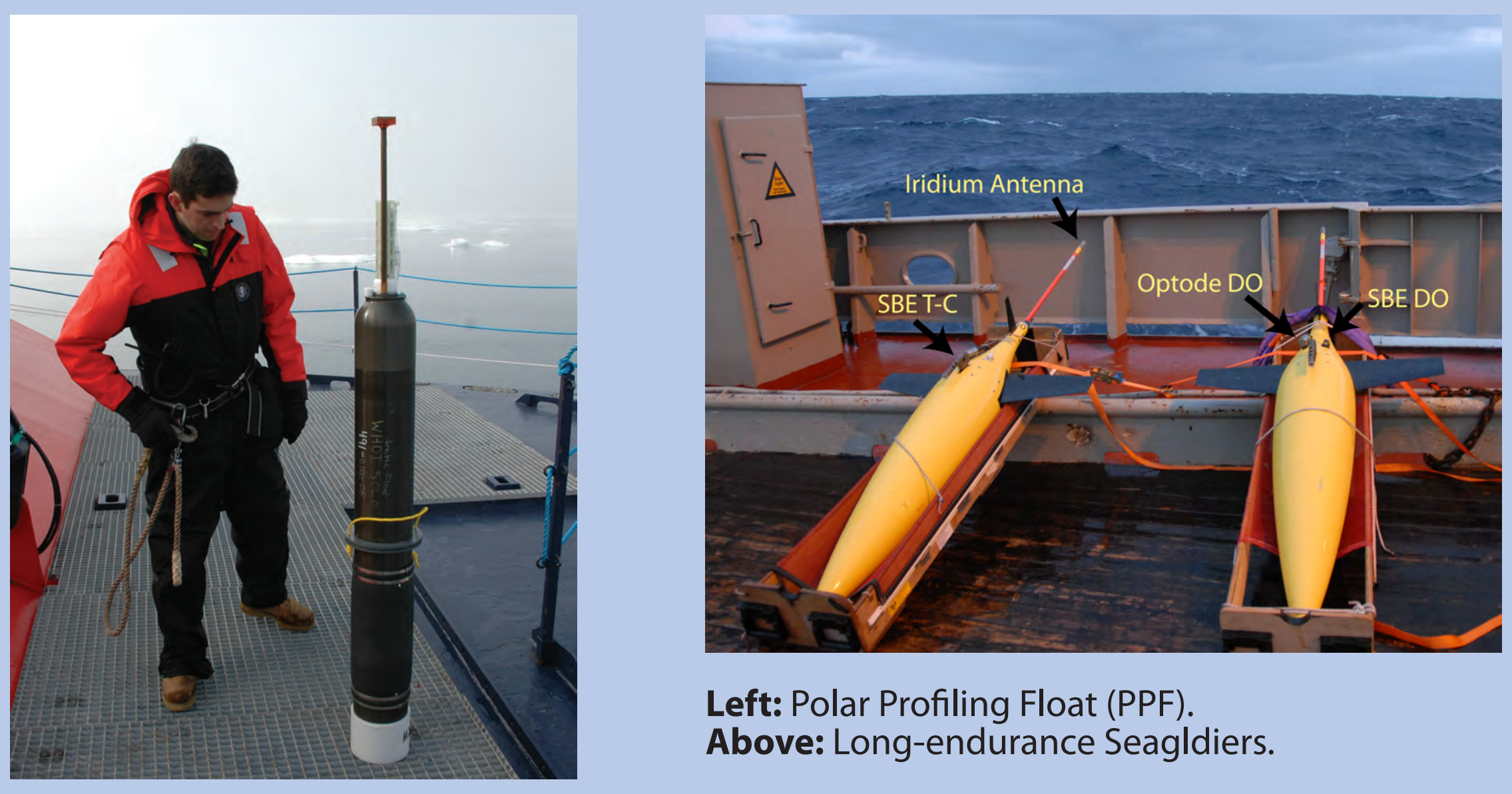


Figure 1. (from Dickson et al., 2009, figure by B. Rabe, AWI) Distribution of liquid freshwater (expressed in meters with reference salinity S0 = 35) within the upper 500 m, calculated from measurements collected by drifting ITPs and POPs. Data are preliminary, with some corrections still to be applied.

Above: WHOI Ice Tethered Profiler.

FLOATS

- Sample broad spatial domains over extended (years to decades) time periods.
- Low-cost autonomous floats, adapted from instruments used in ARGO by WHOI and the DAMOCLES partners.
- DAMOCLES floats carry compact upward-looking sonars for measuring ice-draft and rely on an array of IBOs for acoustic navigation and telemetry.
- An array of 8 PPFs, along with the first DAMOCLES floats, was deployed in summer 2008.



Left: Polar Profiling Float (PPF).
Above: Long-endurance Seaglidiers.

GLIDERS

- Mobility and adaptability for operations across key sections and straits.
- Provide access to the ice-ocean interface and marginal ice zone.
- Vehicle size and energy budget place severe restrictions on payload.
- Navigate using GPS or 780 Hz RAFOS acoustic array in ice-covered conditions.
- Incorporate enhanced autonomy for making unassisted mission decisions and responding to problems during extended operation under ice.
- Refinements to autonomy and navigation, acoustic communications to enable data transfer and enhanced endurance under development.
- Successful under-ice surveys across Davis Strait in December 2006 and winter 2008/2009. The most recent mission spanned 6 months, including 51 days and 450 miles of fully autonomous under-ice operations (Fig. 2).

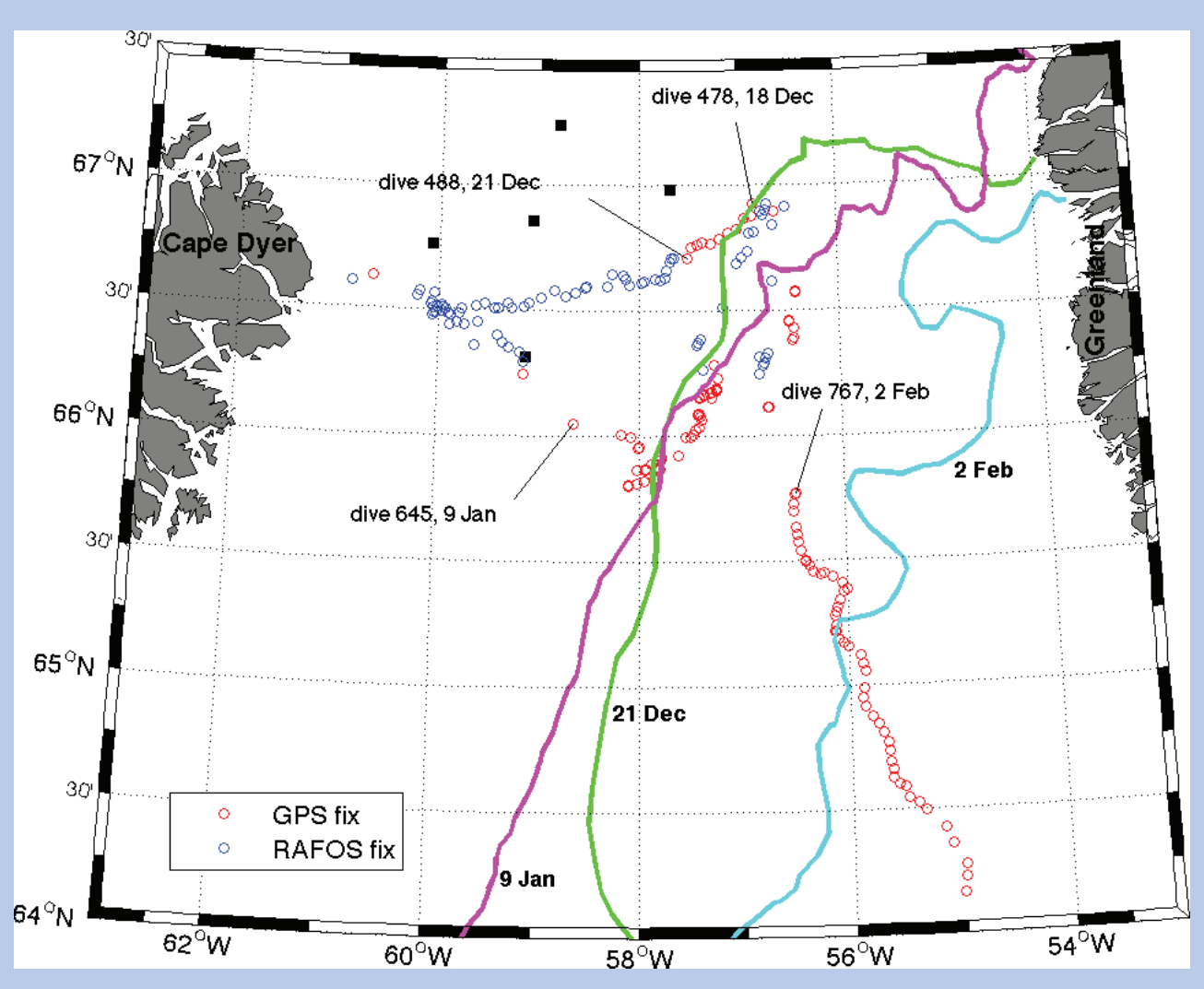


Figure 2. (a) Seaglider track for one under-ice section. Green (21 Dec), pink (9 Jan) and light blue (2 Feb) lines mark the ice edge (as defined by the Canadian Ice Service). Small circles mark glider profile positions, with red indicating GPS positions and blue indicating positions derived from real-time acoustic ranging. The glider surfaced frequently near the ice edge (likely the marginal ice zone) and found leads several times even when well inside the ice-covered region. After completing this section, the glider transited south for recovery offshore of Nuuk.

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CHALLENGES

ACCESS

- Poor for ships, good for aircraft (at least for now…).
- Exploit ice as measurement platform.
- Limited access to critical services (GPS, Iridium).
- Difficult, costly logistics (remoteness- icebreakers, aircraft)

RISK MITIGATION

- Unforgiving operating environment.

PERSISTENCE

- Maintain observing system across multiple decades.

ADAPTABILITY

- Sea ice decline- seasonal ice cover, increasing importance of marginal ice zone.
- Needs evolve with environmental change.

SCIENCE AND STAKEHOLDER NEEDS

The AON must balance needs for information and products relevant to stakeholders against those relevant to change. Data needs can be considered in three overlapping categories:

- **Policy:** Governance and science. Understanding environmental change, long-term planning, disaster reduction, regulation and environmental protection. Large (Pan-Arctic) geographic scope, timescales of decades or longer. Does not require rapid access to data, but places high value on long records.
- **Strategy:** Government, science, industry and communities. Medium-term planning of expensive or hazardous activities (e.g feasibility of trans-Arctic shipping or design of offshore platforms). Focused geographic scope (but may include remote sites), with timescales of seasons to decades. Data access in near real-time (days) to yearly, with value placed on long records.
- **Tactics:** All levels of society (e.g. Is there risk in traveling to the floe edge? What is the best route for a barge through ice?). Geographically focused on regions frequented by human activity. Short timescales. High demand for real-time data access with limited use for long records- data shelf life is short.

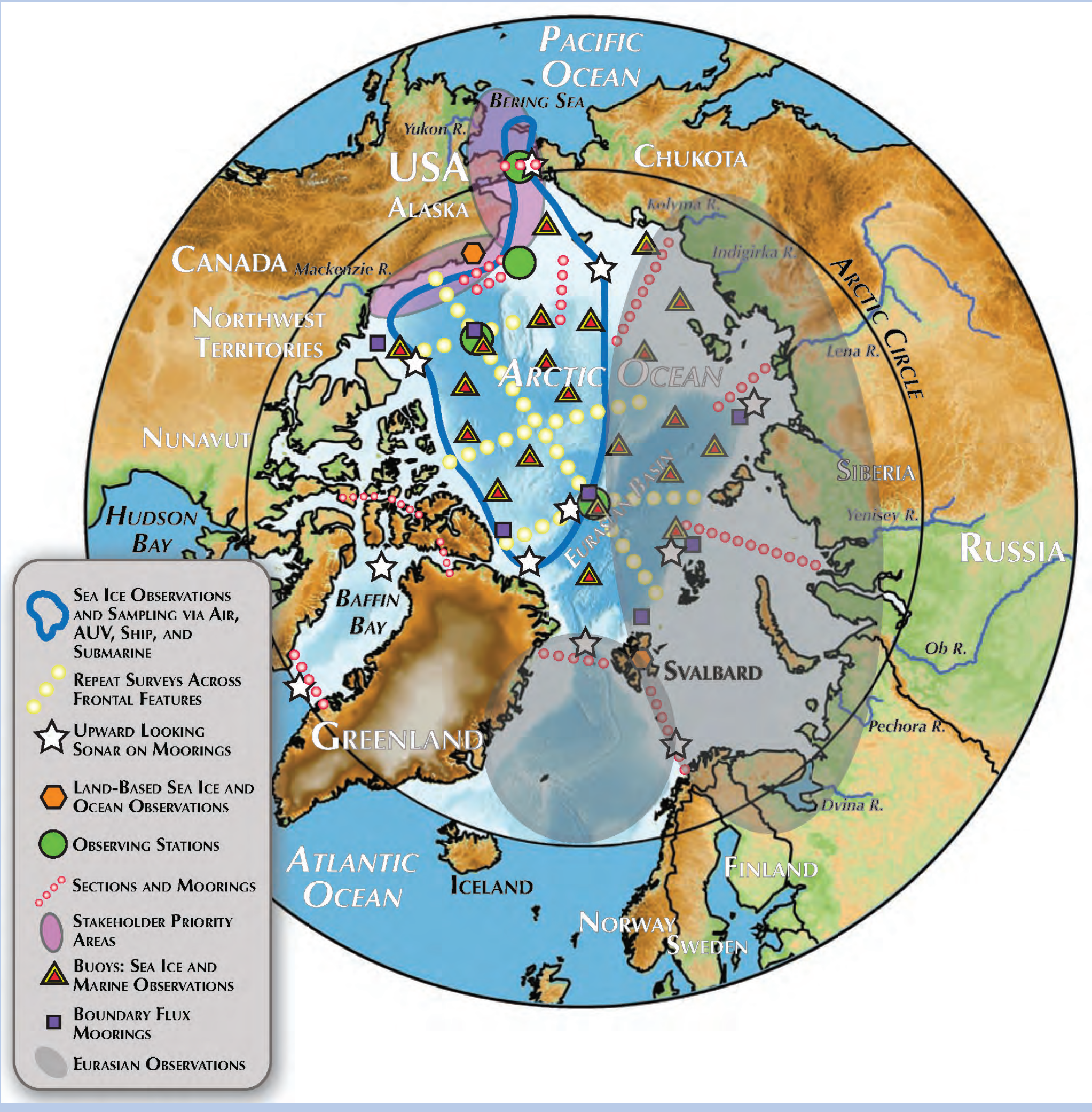


Figure 3. (from the SEARCH Implementation Plan, SEARCH 2005) Priority areas for ocean and sea ice measurements. High priority areas include gateways for exchange between Arctic and Subarctic basins, major storage basins, the broad shelf-slope systems and sections across critical frontal regions. Many sites target long timescale change and sit far from centers of human activity, while others (pink shading) might deliver more targeted tactical information to stakeholders. Drifting autonomous assets (e.g. IBOs) would be distributed through the deep basis as depicted by the red triangles. Moorings and gliders monitor the gateways and shelf-slope regions (red circles and grey squares) while gliders conduct repeat occupations of cross-basin sections that span key frontal features (yellow circles).

MOORINGS

- Excellent temporal resolution, extensive payload capacity for collecting persistent measurements at a few key locations.
- Deploy from ships or from aircraft landed on the ice.
- New, lighweight designs for air-supported deployment offer three-year lifespan with acoustic data upload, making costly recoveries optional.
- Profiling packages, tube moorings and expendable near-surface elements with remote data logging provide access to ice-threatened regions (e.g. shallow shelves and region near ice-ocean interface).

PROPELLER-DRIVEN AUTONOMOUS UNDERWATER VEHICLES

- Short-duration, rapidly occupied synoptic surveys and process studies.
- Uses have included cable laying, under-ice mapping, measuring turbulence.
- Newest AUVs (e.g. Hydroid's REMUS) are compact and relatively easy to use, lowering the logistical barriers that have limited Arctic use.

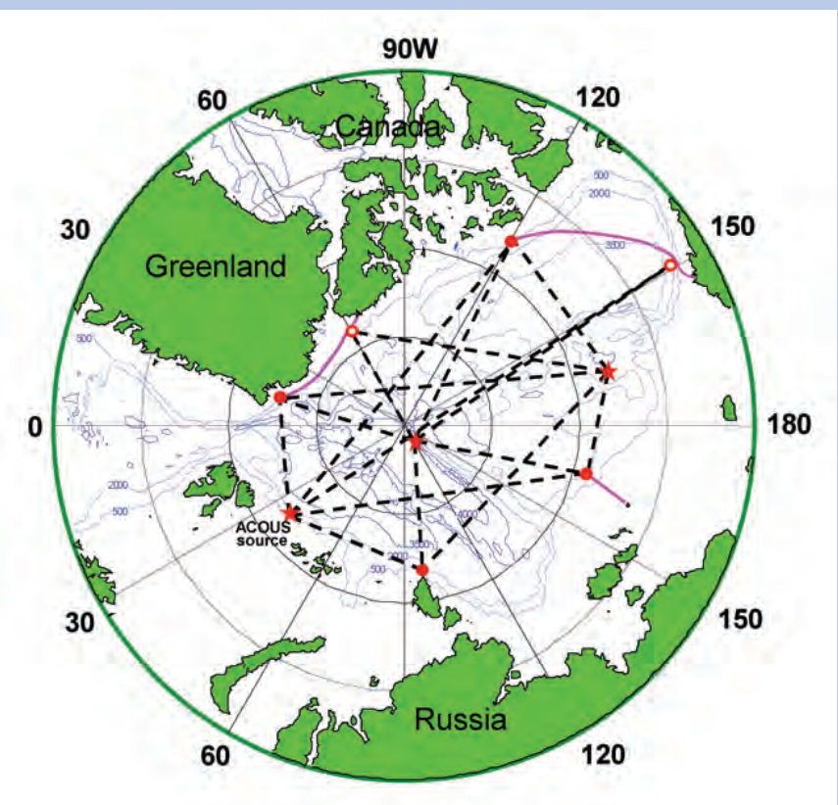
NAVIGATION AND COMMUNICATIONS

- Existing systems rely on 'mid-frequency' (260 Hz or 780 Hz) acoustics, ensonify domains of O(100 km) (e.g Davis and Fram Straits).
- Possible impacts on marine mammals warrant careful consideration.
- Commercial products provide short-range O(1 km), high-rate acoustic communications.

SENSORS

- Growing suite of compact, low-power sensors for physical and biogeochemical variables suitable for autonomous applications.
- Optical measurements that can be interpreted as proxies for key components of the oceanic carbon balance, chlorophyll and CDOM fluorometers, dissolved oxygen, nitrate concentration and turbulence.
- Acoustics for sensing plankton, marine mammals.
- Significant investments in biological and chemical sensor development should yield additional sensors, hopefully including pH and additional nutrients, within a timeframe relevant to AON.

Figure 5. (provided by P. Mikhalevsky, SAIC) Notional low-frequency (10 – 100 Hz) acoustic navigation and thermometry array. Black dashed lines indicate paths for acoustic thermometry while pink lines mark possible cables for supporting selected moorings. Array geometry and assumed transmission ranges were informed by low-frequency results stemming from the ACOUS program. A network such as this could supply acoustic navigation for the entire Arctic basin.



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NETWORK INTEGRATION

Close coordination will be required to deliver sustained observations that meet stakeholders' needs while responding to environmental and societal change. The AON must:

- Integrate national and international activities, via prioritization of sites, selection of technologies and methodologies and coordination of implementation, logistics, data processing, dissemination and analysis.
- Be nimble in adopting new approaches in response to rapid change and new understanding of the Arctic system.
- Provide an integrated system capable of spanning the requirements of Policy, Strategy and Tactics.

Significant national and international effort has been invested toward planning an integrated Arctic observing system (e.g. IARPC, 2007; APSB, 2005; U.S. Polar Research Board, 2006; ISAC, 2009; Arctic Regional Ocean Observing System (Arctic-ROOS); Sustained Arctic Observing Network (SAON)) .

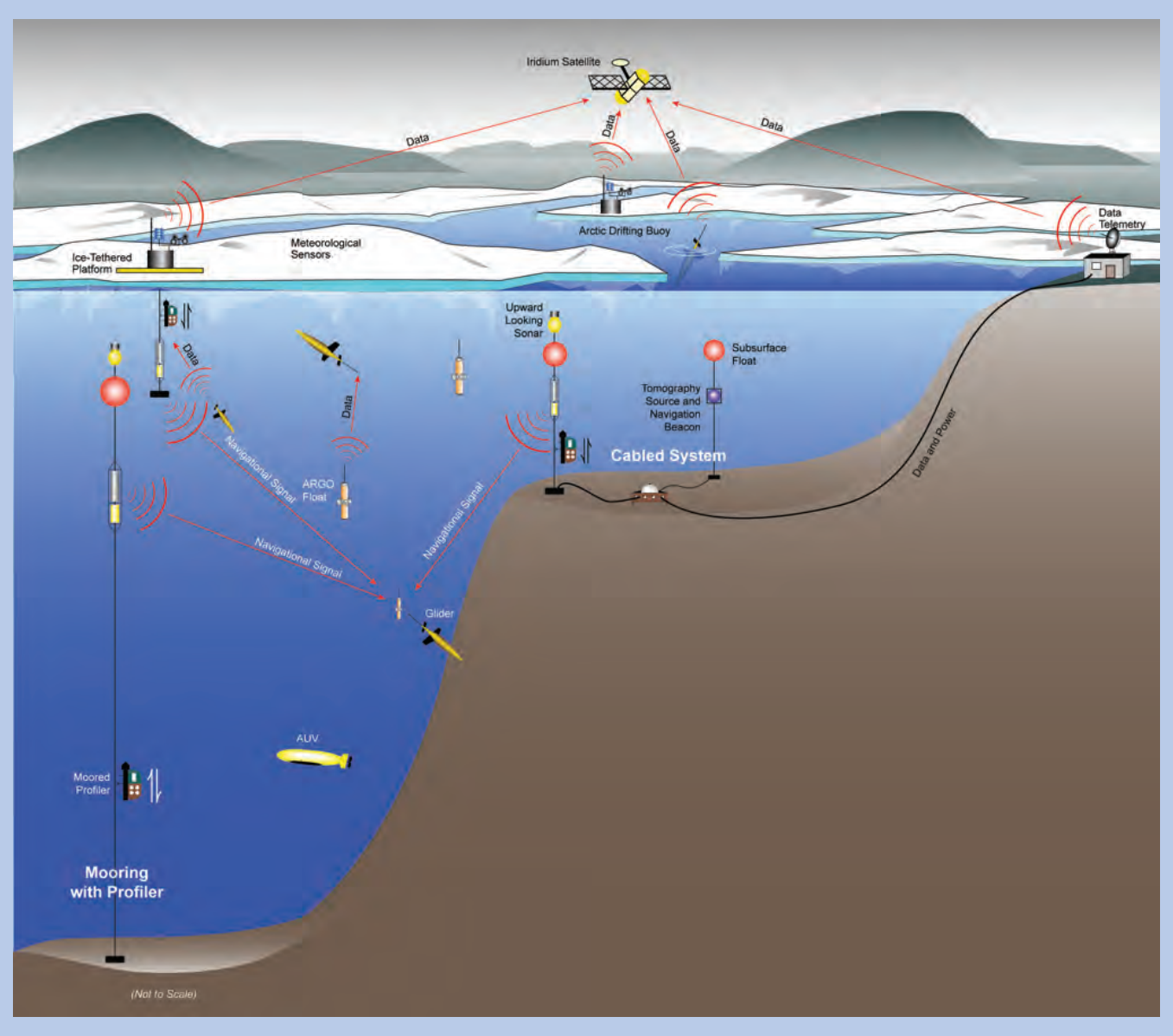

Figure 4. Autonomous platforms and their interactions in the Arctic Observing Network. Gliders, floats, IBOs and moorings sample the deep basins, slope regions and gateways while moored technologies collect measurements over the shelves. IBOs, and glider and floats (when they find open water) communicate via satellite. When ice blocks surface access, gliders, floats, moored data depots and IBOs form a somewhat diffuse store-and-forward network, passing data between themselves and eventually back to the laboratory by forwarding through and IBO or through an vehicle that has found a lead. Faster, more capable propeller-driven AUVs conduct routine sections in regions where logistics allow, supporting a broad suite of sensors and acting as a truck to interrogate instruments isolated beneath the ice and carry their data back to shore. Autonomous platforms navigate using low-frequency acoustic signals broadcast by moored sound sources and, perhaps, by some sources operating from a shore-side cable. Low frequency sources might also be used for acoustic thermometry.

AUTONOMOUS PLATFORMS WITHIN AON

Policy and Science: Access, persistence and scalability provided by autonomous platforms facilitates pan-Arctic quantification of fundamental variables (e.g. ice cover and drift, sea level, ocean current, temperature and salinity, basic meteorological and biological variables) at a cost that could allow sustained operations across decades. The SEARCH Implementation Plan (SEARCH, 2005) and the IPY network summarize measurements and sites deemed critical (Fig. 3).

Strategic: Autonomous platforms offer flexible operation and access to the challenging marginal ice zone and shallow shelf environments that may demand more intesive observations. These studies would be nested within the larger array.

Tactical: The flexibility and real-time reporting offered by autonomous approaches allow rapid implementation of new observing missions with simple re-tasking as needs evolve. Selected autonomous components of larger networks could also be reprogrammed in response to evolving needs. Real-time data access demands capable infrastructure for timely relay, processing, analysis and dissemination.

AON can exploit the complementary capabilities of the various autonomous platforms (Fig. 4) to meet observing needs across a broad range of scales and operating environments.

- Low-cost profiling floats characterize large scale circulation, watermass evolution and changes in storage within the basins.
- Drifting IBOs profile upper ocean, collect sea ice and meteorological measurements and relay data from platforms operating beneath the ice.
- Gliders repeatedly occupy critical sections across boundary currents, fronts and basins. and relaying data from other platforms operating beneath the ice.
- Moorings provide detailed time series of ice and ocean variables at critical sites such as polynyas, gateways, continental shelves, slopes and ridges.
- Larger, propeller-driven AUVs carry extensive sensor payloads to supplement or replace some ship- or aircraft-based surveys.
- In situ measurements analyzed alongside data acquired through satellite remote sensing. (e.g. Kwok et al., 2009).
- Ships and aircraft conduct intesive measurements, service autonomous platforms and supporting navigation and communications infrastructure.

Scalable autonomous operations in AON will require a comprehensive, Arctic-wide acoustic navigation and communications system.

- Low-frequency signals O(10 Hz) provide basin-scale navigation using a modest number of acoustic sources (Fig. 5).
- Mid-frequency (~1 kHz) systems provide regional-scale O(100 km) navigation and low-bandwidth, one-way source-to-platform communication.
- Commercial acoustic technologies for high-rate, two way communications.
- Engage Arctic residents and marine mammal specialists to understand and mitigate impacts on marine mammals.
- Hydrophones also provide data to track and count marine mammals. Use to assess and improve mitigation strategies and study the animals themselves.

SUMMARY

Autonomous floats, gliders, IBOs, AUVs and moorings provide highly scalable, flexible, cost-effective observing technologies for AON. Floats, gliders and IBOs excel at providing year-round measurements over extended (years) time periods, while their relatively modest per-platform operating costs permit deployment in quantities that are large enough to provide unprecedented spatial coverage. Most importantly, these platforms can be efficiently operated in large numbers and employ operating modes and logistics that can readily respond to evolving observational priorities. These autonomous technologies enhance AON's flexibility to meet the broad needs discussed above within a cost structure allowing prolonged (decades) observation, while interoperating with a broader range of AON approaches not discussed here.

Moving beyond the IPY 2007 - 2008, AON should exploit autonomous technologies to enhance the spatial and temporal coverage of the existing network, with an eye toward establishing a sustainable, long-term observing system. Beyond the examples shown in this paper, autonomous approaches could address challenging AON priorities that include measurements in marginal ice zones, the atmospheric boundary layer, distributed ice thickness measurements and surveys across important frontal zones. The establishment of long-range acoustic navigation and communications should be given high priority, as this infrastructure is needed to achieve the scalability that has radically altered lower-latitude observing. Although preliminary studies have outlined this system's shape, significant effort must be directed at defining scope and cost of this important AON component.

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