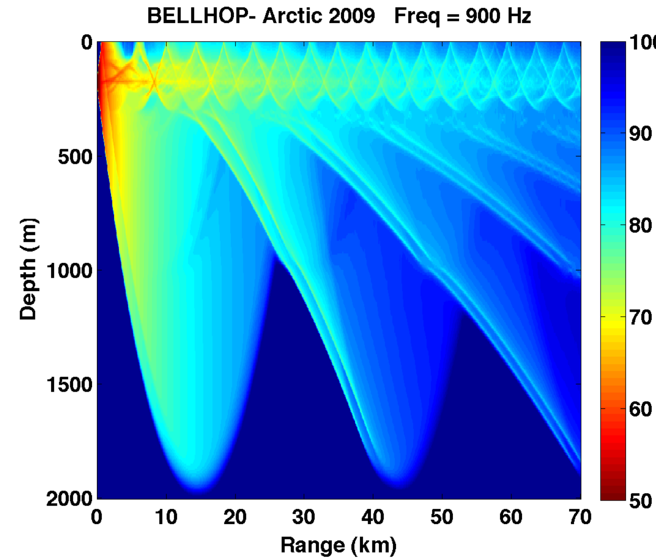
Acoustic Sensing, Navigation and Communications

Outline

- I. **Sensing**
  - I. Bioacoustics – active
  - II. Passive acoustics – rainfall to mammals.
  - III. Acoustic tagging and tracking
- II. **Navigation**
  - I. RAFOS, underwater GPS
  - II. Tracking, relative (USBL).
- III. **Communications**
  - I. Technology and capabilities
  - II. Acoustic data retrieval
- IV. **Summary and Conclusions**



Understanding propagation and selecting proper transducers are critical to performance

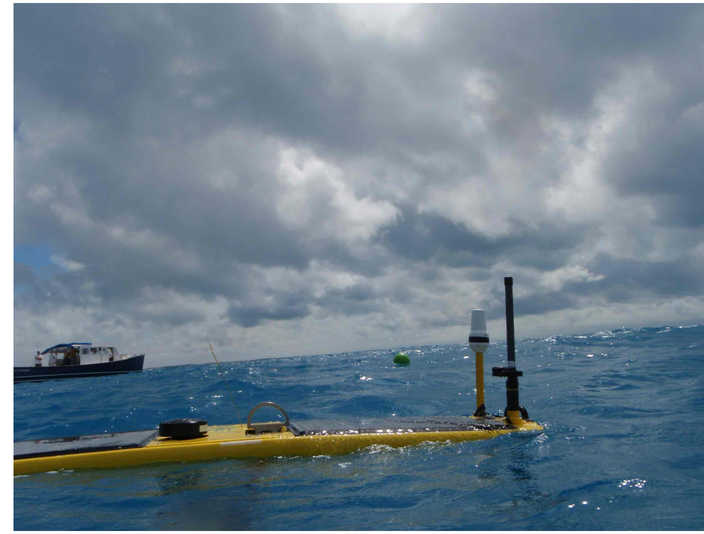
General Thoughts on Acoustic Sensors and ALPS

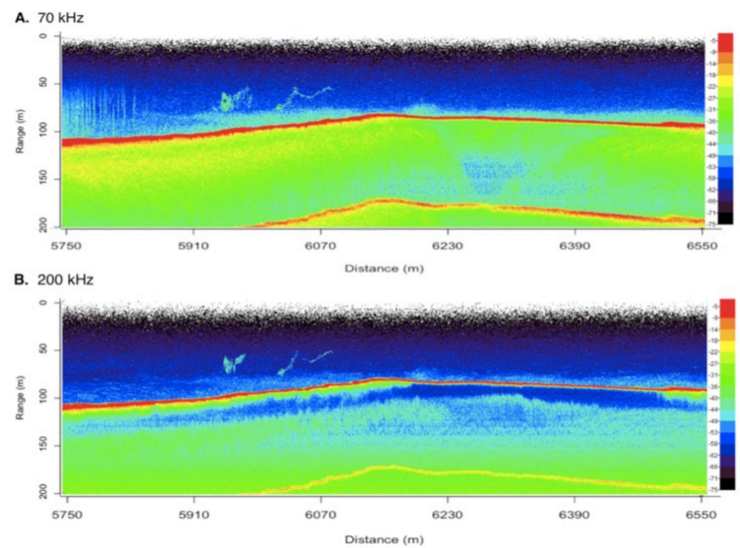
Common attributes of active acoustics, e.g. fisheries, and marine mammal detection for real-time monitoring:

- Sensors are very data intensive.
- Small platforms are bandwidth limited in the open ocean.
- Low frequency active sonar requires large transducers and large vehicles.

Therefore:

- Continuing need to improve on-board processing prior to transmission to shore.
- But, on-board processing requires both *ability* to process autonomously AND a consensus on *how* to process the data (e.g. common algorithms).
- Novel techniques and transducers required to push envelope of sensor for ALPS.





Echograms at 70 and 200 kHz from sounders towed by a Wave Glider. From Meyer-Gudbrod, 2015

Example: Active Bioacoustics

Objective: Perform acoustic surveys for fisheries management using autonomous platforms.

What's made progress possible?

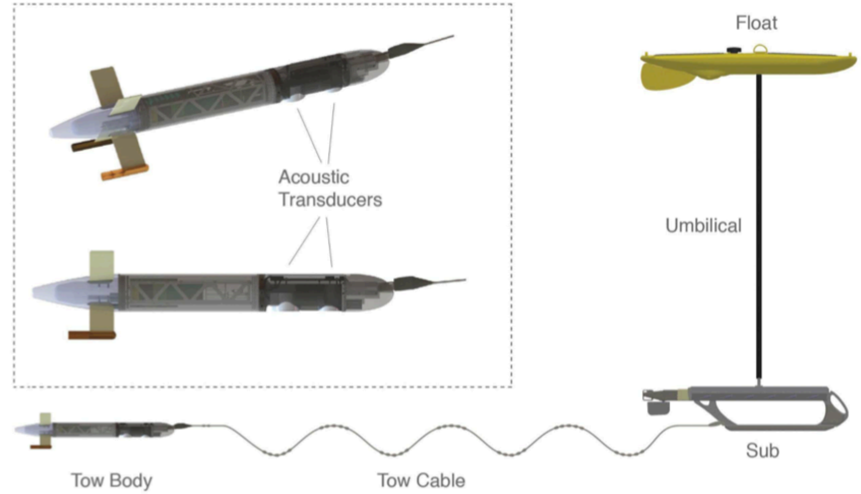
- **A specific need** (and thus market): augment ship-based measurements due to cost and feasible coverage.
- **Industry standard** sensors and method.
- **Reduced power processing** due to advances in sensor technology.
- **Investment** and development over multiple years by government sponsors and corporate partners (LRI and BioSonics.)

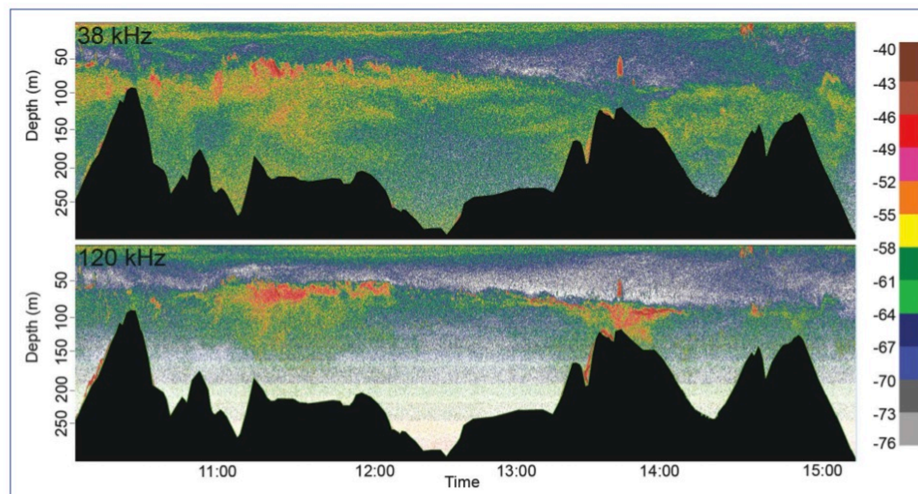
Active bioacoustic mapping systems installed on autonomous platforms with on-board processing will likely to be a growth market with considerable potential in the short term.

Example state-of-the-art bio- acoustics technology integration on Wave Glider:

- 4 frequency echosounder (BioSonics): 38, 70, 120 and 200 kHz.

Meyer-Gutbrod, E., C. Greene and L. McGarry, "Wave Glider Technology for Fisheries Research: New Integrated Instrumentation Expand the Fisheries Acoustics Toolbox," Sea Technology, 2015.





Passive Acoustic Listener (PAL)

Objective: Utilize acoustic signatures to characterize both rainfall and wind speed from Argo profiling floats.

Method:

- Install monitoring hydrophone and small processor on standard Argo float.
- Use multivariable spectral analysis to make estimates of wind and rainfall-generated acoustic energy.
- Transmit estimates on Argo float telemetry.

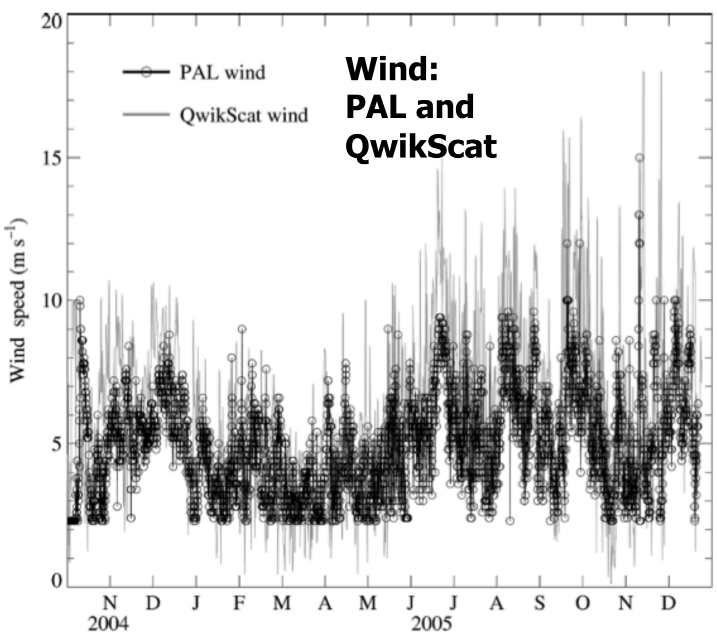


Fig. 8. A comparison of float-derived wind speed and QwikScat wind speed estimates interpolated to the float position and time.

Rainfall: Bay of Bengal.
PAL and NASA Tropical Rainfall Measurement Mission (TRMM)

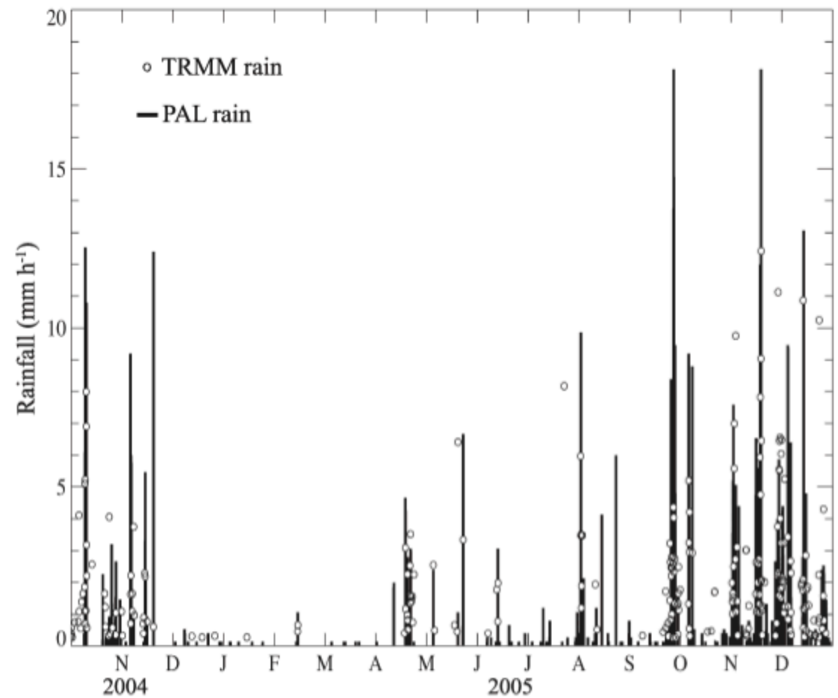


Fig. 6. A comparison of float-derived rainfall rate and TRMM 3B42 rainfall estimates interpolated to the float position and time.

Key points: Concomitant satellite and Argo observations of wind and rain enhance global observing without persistent surface expression.

Reference:

Riser, S.C., Nystuen, J. and Rogers, A., 2008. Monsoon effects in the Bay of Bengal inferred from profiling float-based measurements of wind speed and rainfall. *Limnology and Oceanography*, *53*(5), p.2080.

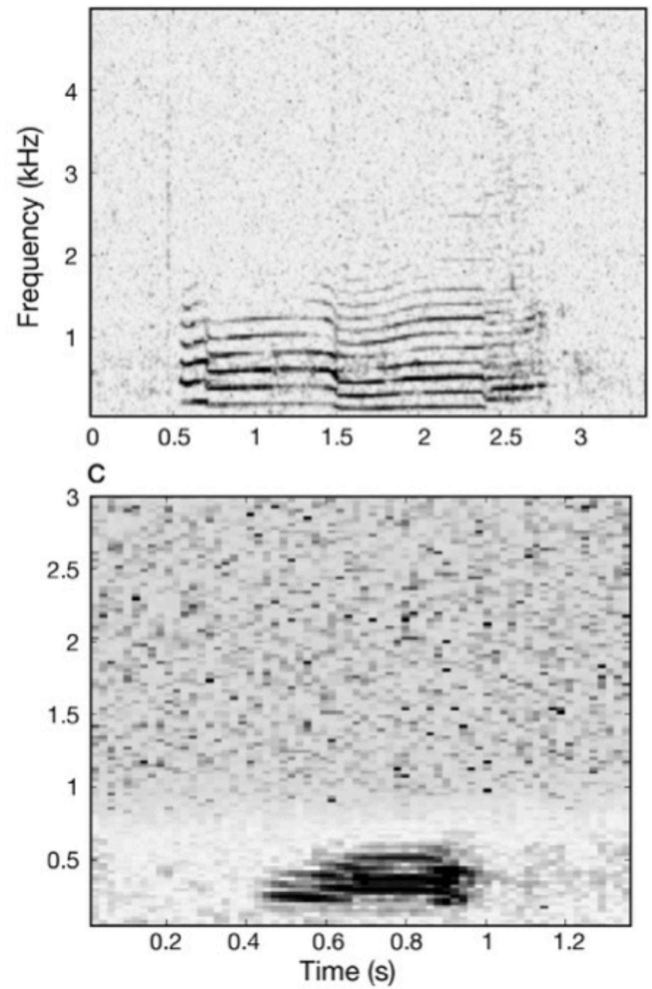
Example: Passive Bioacoustics on Gliders

Objective: Passive acoustic survey using fish sounds detected on a single hydrophone on a glider.

Methods:

- Simple acoustic sensor for fish detection.
- Leverage the other environmental sensors already installed on gliders.
- Utilize mobility to provide a 3D picture of the temperature, salinity, chlorophyll and other sensors.

Passive bioacoustics on gliders offers potential but transition to general field use will require ground truth with other methods and real-time algorithms for detection.



Unknown fish sounds recorded on the West Florida Shelf, 2011. (Wall, 2012)

Wall, C.C., Lembke, C. and Mann, D.A., 2012. Shelf-scale mapping of sound production by fishes in the eastern Gulf of Mexico, using autonomous glider technology. *Marine Ecology Progress Series*, *449*, pp.55-64.

Passive Acoustics: Marine Mammals - 1

Objective: Detect and map the distribution of vocalizing marine mammals via quiet and persistent autonomous platforms, in real-time if possible to allow avoidance of sensitive species.

Methods:

- Surface-based autonomous craft (Wave Glider, sailboat, etc.)
- Subsurface:
  - Gliders and floats
  - Powered AUVs
- Each method has advantages and disadvantages. Select based on species, frequency, location, etc.

Status of Technology

- Marine mammal recording on fixed and mobile platforms is mature.
- ***The challenge is real-time detection and reporting using on-board processing.***

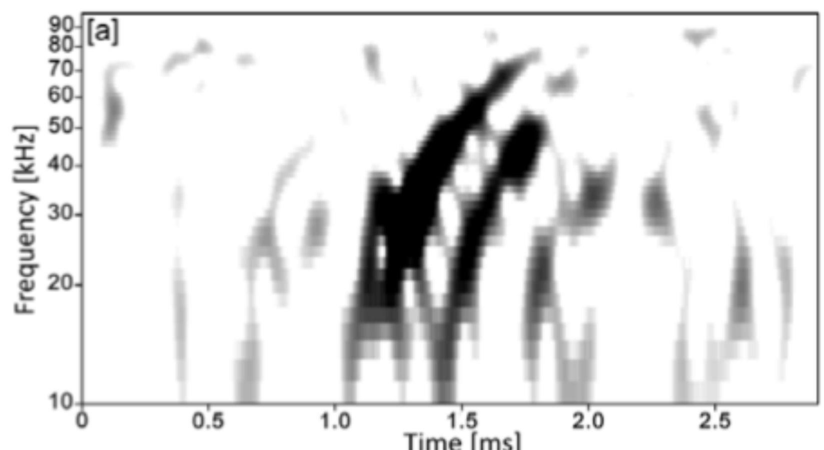
Reference:
Klinck, H., Mellinger, D.K., Klinck, K., Bogue, N.M., Luby, J.C., Jump, W.A., Shilling, G.B., Litchendorf, T., Wood, A.S., Schorr, G.S. and Baird, R.W., 2012. Near-real-time acoustic monitoring of beaked whales and other cetaceans using a Seaglider™. *PloS one*, *7*(5), p.e36128.

Example, Seaglider (Klinck, 2012):

- Goal: beaked whales, high frequency impulsive signal, real-time detection.
- Species is known for deep vocalization, therefore surface craft not effective. Seaglider selected for monitoring at depth and tested off Hawaii.
- Results: proof-of-concept successful,

Multi-disciplinary team included vehicle designers and operators, electro-acoustic engineers, and biologists.

Likely beaked whale echolocation click spectrogram.



Klinck, 2012 (Fig. 7)

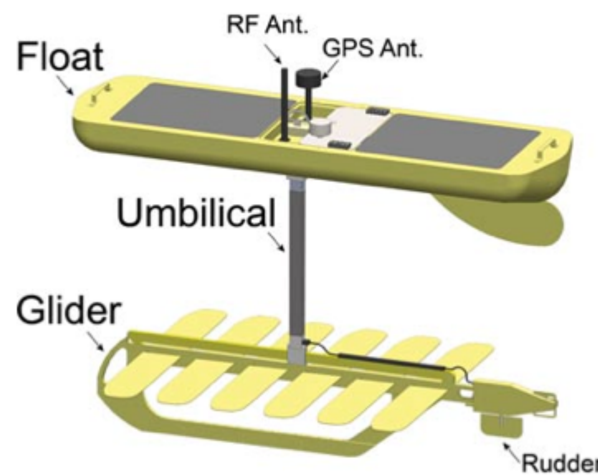
Passive Acoustics: Marine Mammals - 2

Example, <u>Surface Craft</u> (Wiggins, 2010):

- Wave glider based recorder utilized HARP recorder.
- Challenges of low-noise recordings recognized early and made part of the project.
- Results included towed hydrophone for low-noise, low-frequency recordings.

Addressing the practical issues associated with this particular platform pays off because of its persistence.

Liquid Robotics SV-2 Wave Glider



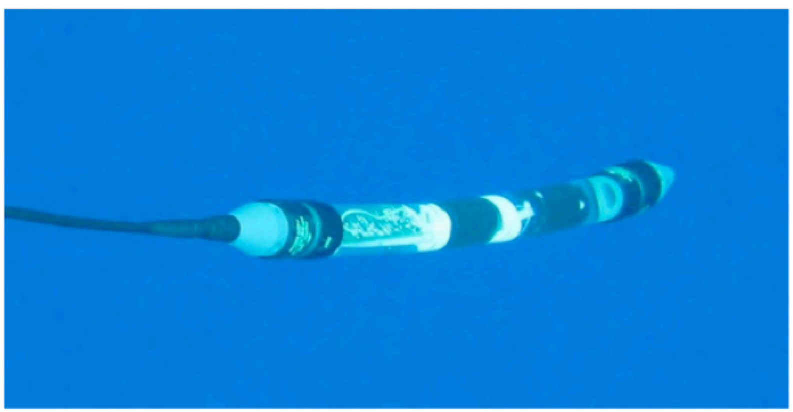


Figure 4: Photo of the hydrophone and tow cable as it is towed behind the Wave Glider at sea.

From: Wiggins, 2010

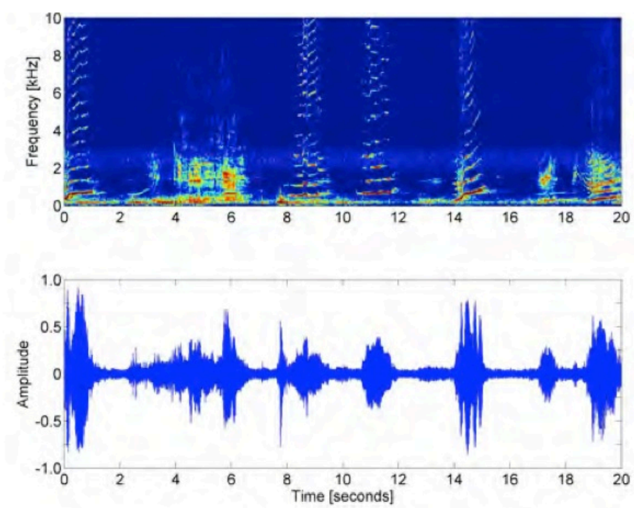


Fig 8: Spectrogram and waveform of humpback sounds show intense, low-frequency song during March 2010.

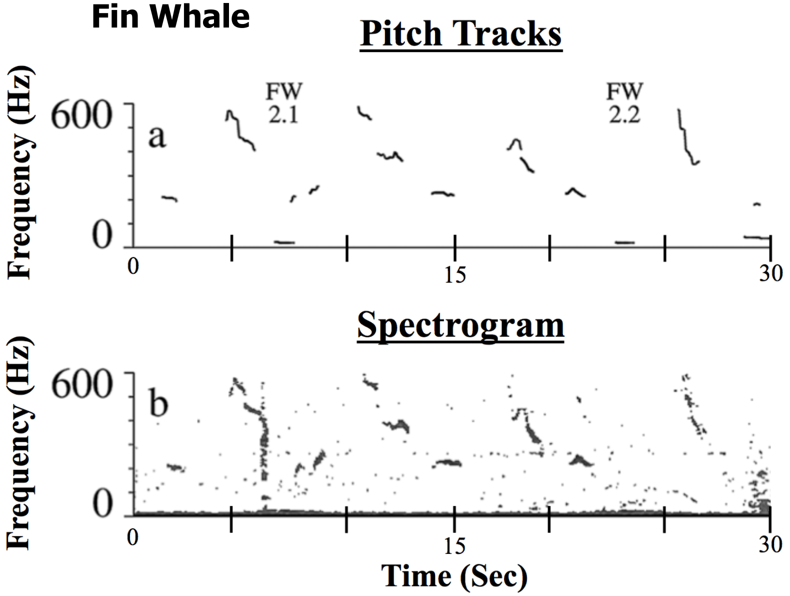
<u>Reference:</u>
Wiggins, S., Manley, J., Brager, E. and Woolhiser, B., 2010, September. Monitoring marine mammal acoustics using wave glider. In *OCEANS 2010* (pp. 1-4). IEEE.

Passive Acoustics: Marine Mammals - 3

Detection and Characterization:

- Pitch tracks derived from spectrograms greatly reduce the amount of data that must be transmitted over Iridium from a glider.
- WHOI DMON (digital monitor) offers a platform for both recording and pre-processing to allow detections and statistics to be transmitted over Iridium.

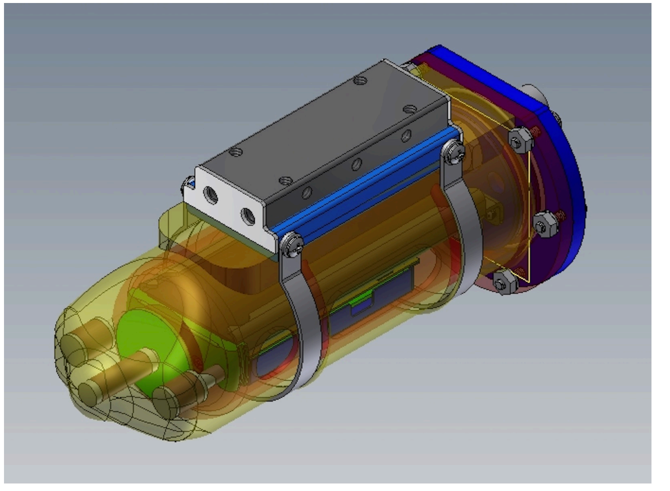
Fin Whale



Reference:

Baumgartner, M.F., Fratantoni, D.M., Hurst, T.P., Brown, M.W., Cole, T.V.N., Van Parijs, S.M., & Johnson, M. 2013. Real- time reporting of baleen whale passive acoustic detections from ocean gliders. J Acoust Soc Am.

WHOI DMON (Digital Monitor)



DMON Hydrophone Array Adapted to glider hull section.

Incorporating new transducers onto low-drag platforms always requires engineering but results in a low-impact product.

Example: Active Acoustic Tags & AUVs

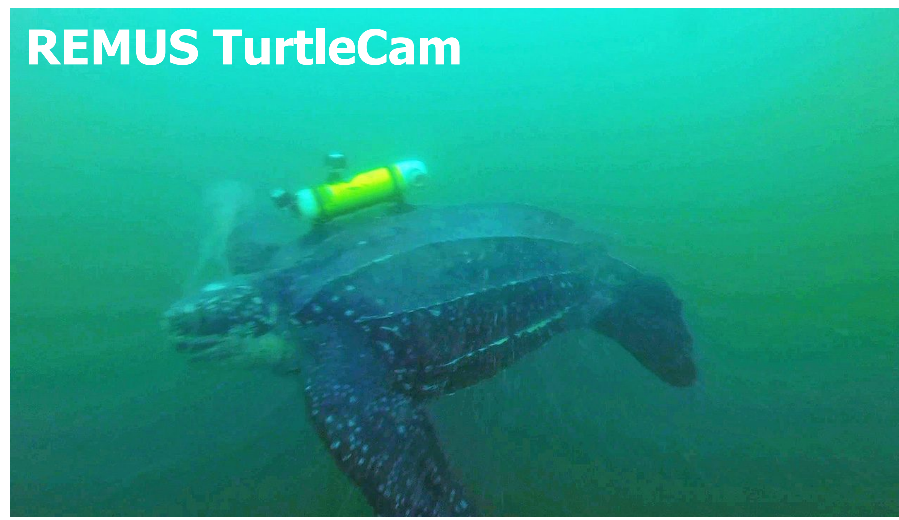
Objective: in-situ following and observation of fish and mammals to better understand their behavior and environment. Augments human-based observations from the surface or by diving. Ideal application for robots.

Base Technology

- Low-power USBL homing array developed for small vehicles.
- Mini acoustic pinger.
- “Homing and docking” autonomy behavior.

What did it take?

- Inexpensive high-quality cameras (GoPro).
- Several years of continued development (some trial and error) to refine method, *even though much of the basic technology was already in existence.*
- Multiple investments, including from the media, which implies popular public interest.



Images from WHOI.EDU

ALPS and the Reality of Underwater GPS - 1

Background:

- The RAFOS system was rightly showcased at APLS-I as a breakthrough capability for tracking Lagrangian platforms at long ranges in the open ocean.
- RAFOS depends on sound channel propagation but the depth range is quite wide and as shallow as a few hundred meters, depending on the sound speed in the region.
- The small size and low power of the receivers makes it ideal for small platforms.
- The size, cost and availability of the sources is a drawback which is minor for many projects, but sometimes too much for small or opportunistic programs.

The RAFOS System

T. Rossby, D. Dorson* and J. Fontaine

Graduate School of Oceanography, University of Rhode Island, Kingston, RI 02881

(Manuscript received 13 March 1986, in final form 13 June 1986)

Arrays of RAFOS sound sources enabled float tracking at depth, opening a new area of ocean research for small, autonomous sensors.

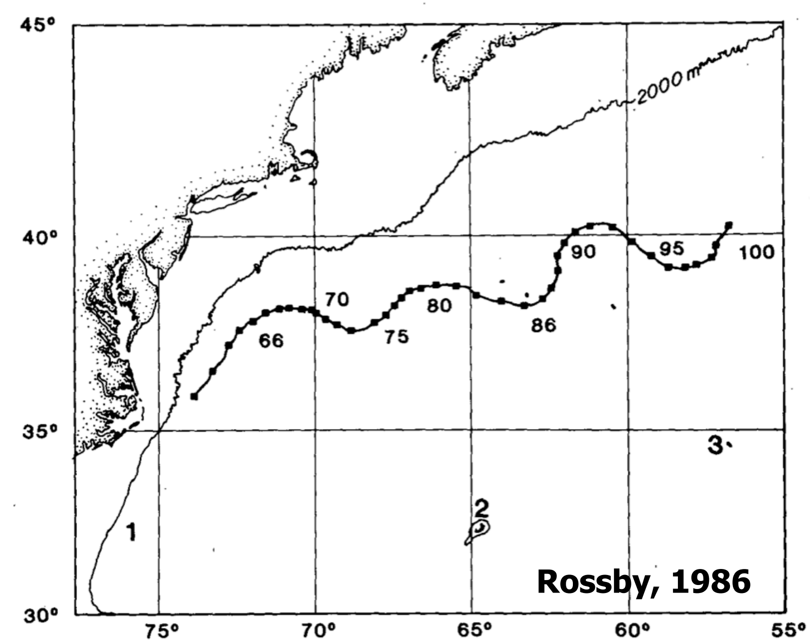


Fig. 7. The 45-day trajectory of RAFOS float 29. Elapsed time in yeardays (1985) is indicated with one dot per day. The trajectory has not been smoothed. The numbers 1, 2 and 3 indicate the locations of the three sound sources.

ALPS and the Reality of Underwater GPS - 2

Opinion:

- Prospects for a semi-permanent acoustic navigation system funded by community science funding remains uncertain, except for unique situations, e.g. the Arctic.

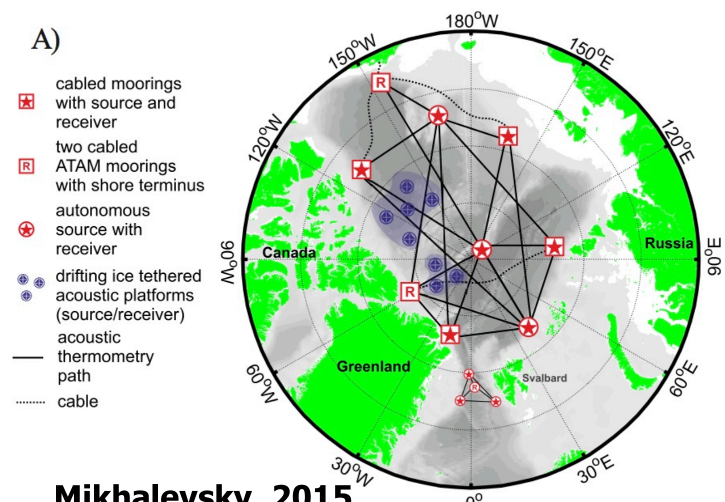
Why? (More opinion):

- The environmental impact of low frequency sound on marine mammals remains an open issue.
- Thus, an acoustic navigation network may not have more impact than global shipping but is contentious.
- International infrastructure projects are challenging to fund.
- The ARGO float program works without it…

Mikhalevsky, P.N., Sagen, H., Worcester, P.F., Baggeroer, A.B., Orcutt, J., Moore, S.E., Lee, C.M., Vigness-Raposa, K.J., Freitag, L., Arrott, M. and Atakan, K., 2015. Multipurpose acoustic networks in the integrated Arctic Ocean observing system. *Arctic*, pp.11-27.

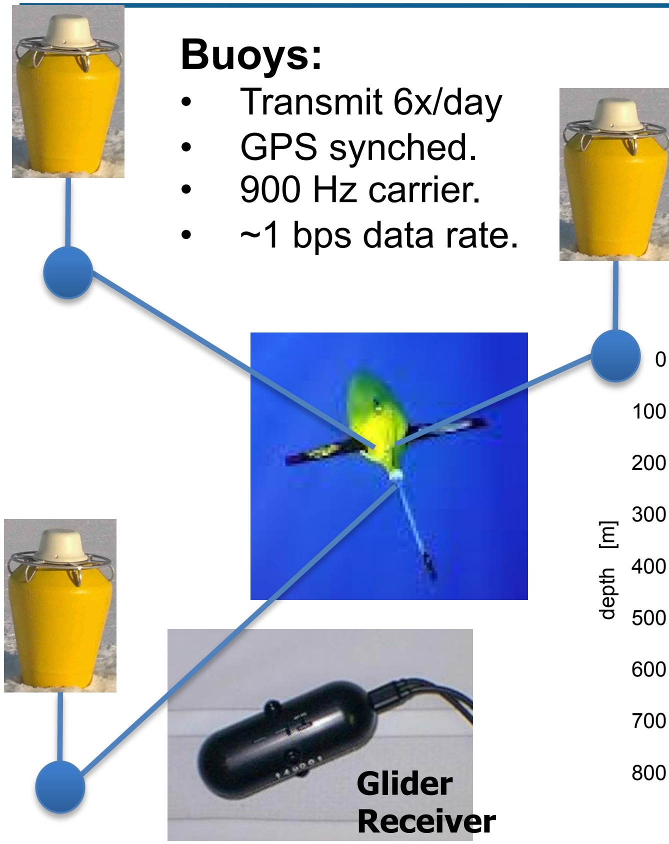
Questions & Discussion:

1. **What is the future of large-scale RAFOS networks or underwater GPS in general?**
2. **Where should this community put its support?**
3. **Should we put more effort into large networks?**
4. **Or focus on specialty projects (e.g. Arctic) and improving commercial RAFOS technology to increase use?**



Mikhalevsky, 2015

Example of New Capability: Acoustic Navigation and communications for Arctic Gliders and Floats

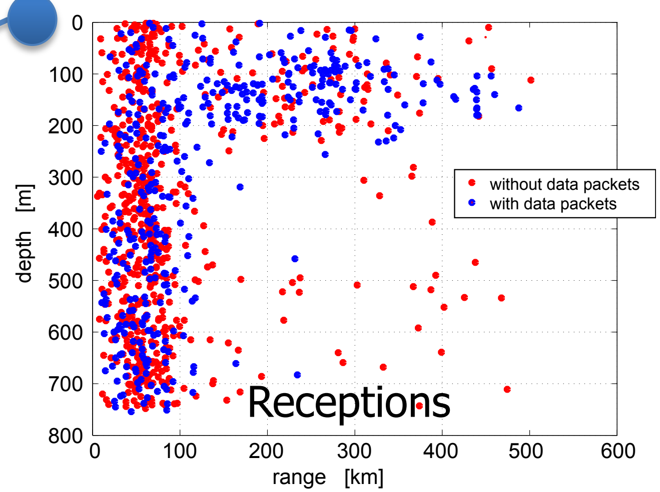


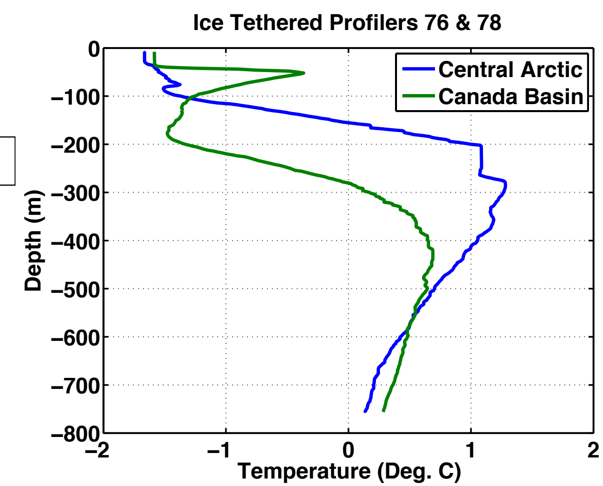
Buoys:

- Transmit 6x/day
- GPS synched.
- 900 Hz carrier.
- ~1 bps data rate.

ONR ice-based buoy navigation system:

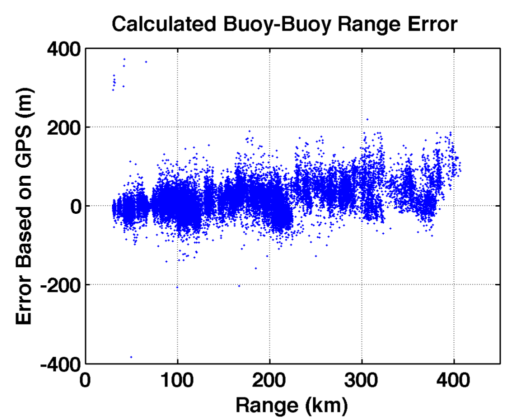
- Ice-based sensor array is <u>mobile</u>.
- Therefore <u>must transmit source positions</u> to allow real-time geo-location by gliders.
- Data transmission capability also means <u>commands can be sent to glider</u>.





Receiver on Glider:

- Measures time of arrival and computes range to buoy.
- Decodes data with location of buoy.
- Multiple ranges and source locations used to compute real-time position.



Performance:

Ranges to 400+ km, Std. dev. 40-60 m.

Glider ranges typically 100 km except when in 100-200 m duct.

Navigation of ALPS via External Tracking

Problem: Some ALPS studies require accurate mid-water navigation in areas where acoustic networks are not feasible to deploy, or accurate enough due to mooring wander and clock drift.

Possible Solution (New project at WHOI and UW funded by NSF)

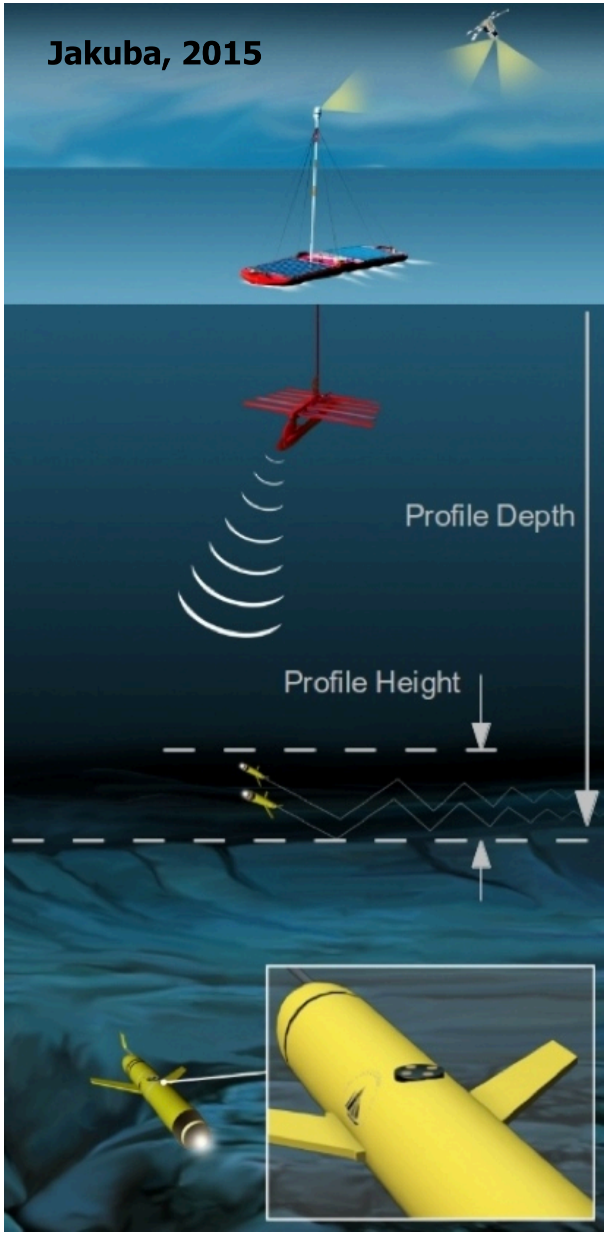
One-way travel time inverted USBL:

- *Wave Glider* transmits synchronous signals.
- *Autonomous platform* uses accurate clock for ranging and “good” attitude sensors plus USBL receiver to measure position with respect to surface platform.
- Accuracies of 250-400m are possible at 5000m depth using low-power sensors already in use on glider.
- 10-100 fold improvement in positioning accuracy (very depth and time dependent) over the current paradigm (i.e., infrequent GPS fixes) and would allow vehicles to spend more time at depth.

Observations:

This is a complementary alternative to large, low-frequency, underwater GPS and appropriate for some applications.

Cannot replace RAFOS and is not cheap, but if a wave glider is already on site to provide communications relay or measure upper ocean and atmospheric parameters then the tracking system is a reasonable add-on.



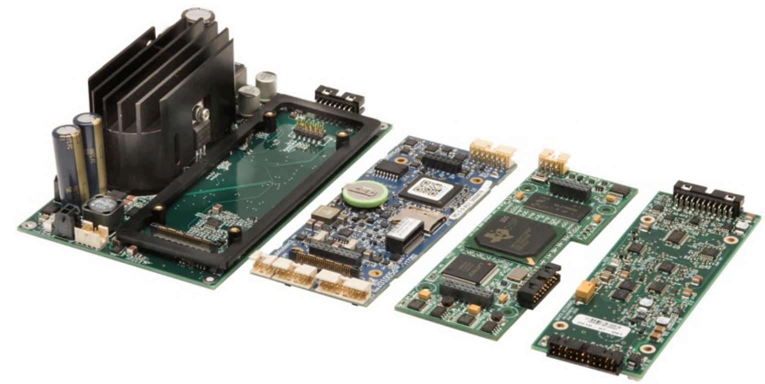
Michael V. Jakuba, James C. Kinsey, James W. Partan, and Sarah E. Webster. Feasibility of low-power one-way travel-time inverted ultra-short baseline navigation. In Proceedings of IEEE/MTS Oceans Conference, pages 1–8, Oct. 2015. Available at: http://tinyurl.com/jbdu7mf.

Underwater Communications for ALPS

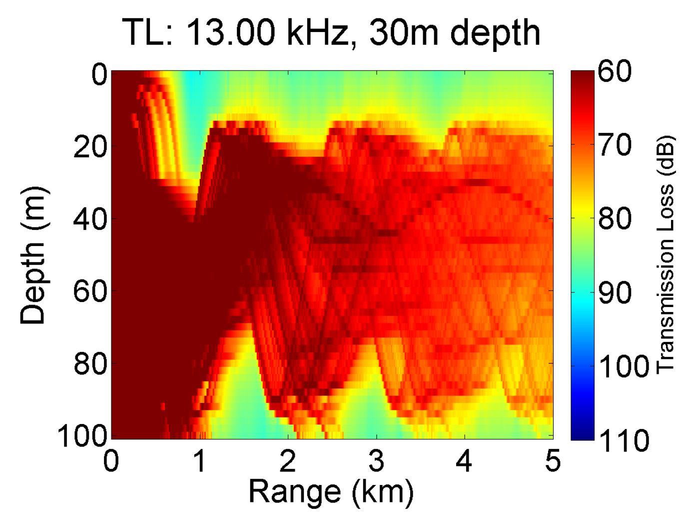
Objective: Provide command, monitoring and data telemetry for underwater vehicles and sensors.

Key points:

- No single solution, highly dependent on science needs and installation platform.
- Tailored solutions offer best "bits per Joule" efficiency. Pick frequency, and transducer beam pattern.
- Long range will be very, very low efficiency (e.g. less than 1 bit/J). However, adequate for control functions.
- High-rate vertical links are very efficient, 1000 bits/J. Great for wireless data transfer.



WHOI Micro-Modem is an example of a flexible and modular acoustic system for communications and navigation that can be installed on a range of vehicles and sensors.



The achievable range is a function of frequency and acoustic propagation conditions. Exploiting ducts offers very long ranges, potentially.

Underwater Communications Range Space

Range Scales	Platform	Area(s), Application	Frequency ranges (approx.)	Data Rate (depends on environment, source level and receiver gain)	Notes
100s of meters	Tetherless ROV	Data upload, multi-vehicle coordination, sensor networks	50-200 kHz	10kbps – 50+kbps	Feasible, just becoming available.
~ 2-4 km	Small vehicles, e.g. REMUS	"Standard" REMUS applications	25 kHz	80-5000 bps, depends on modem configuration	Mature technology, delivered on every REMUS or similar AUV.
4-20 km	UUVs	Upper ocean studies, deep survey	1-10 kHz	4 km: ~2 kbps 20 km: 50-300 bps	Demonstrated with vehicles and remote sensors.
20-200 km	UUVs Gliders	Upper ocean studies, ASW. Exploit upper part of SOFAR channel.	500–1000 Hz	10-50 bps	Demonstrated 900 Hz system in Arctic to 400 km.
200-2000 km	UUVs Gliders Floats	Regional, basin scales in SOFAR channel. Underwater GPS.	20-500 Hz	0.1-10 bps	Acoustic sources too large for vehicles. Transmit from ships or moorings.

Frequency governs range and system size and cost.

Example: Gliders for Acoustic Data Retrieval

Objective: Offload data from bottom and water column sensors to save ship time. Supports real-time recovery of data for updating models (e.g. California currents.)

Method:

- Acoustic modem on glider and sensor.
- Glider behavior to approach, connect and transfer data.

Initial results: Demonstrated to be feasible by U. Send for sensors off California to allow estimates of geostropic transport

- **The method and hardware have been improved since, and acoustic data recovery is now practiced regularly for the OOI flanking mooring using survey gliders.**
- **This application is a great example of how acoustic communications and vehicles can be used together to recover data from remote instruments without ships or buoys.**

Satellite to shore

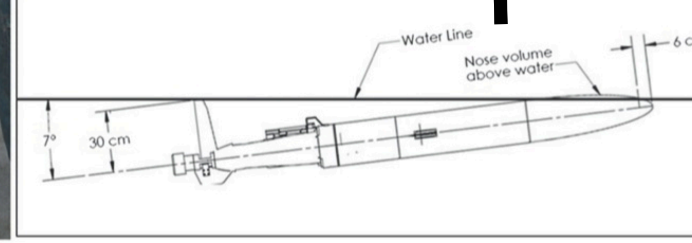
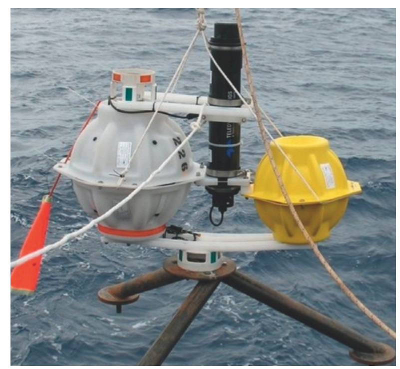


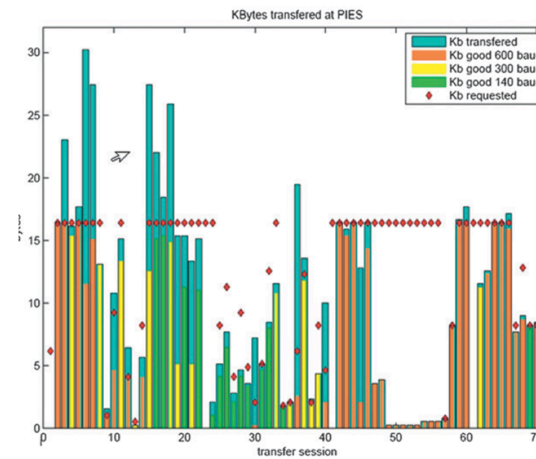
FIG. 3. Mounting of the acoustic transducer on Spray glider.

Acoustic Data Transfer



Subsea instrument collects data

From: Send, 2013



Transfer of 16 kbytes per session often achieved, depending on range and geometry.

Send, U., Regier, L. and Jones, B., 2012. Use of underwater gliders for acoustic data retrieval from subsurface oceanographic instrumentation and bidirectional communication in the deep ocean. *Journal of Atmospheric and Oceanic Technology*, *30*(5), pp.984-998.

Summary and Conclusions

This is a large topic space and this material just hits the surface.

Key take-away points:

- Wide range of common threads in installation and use. Includes:
  - Transducers.
  - Power
  - On-board processing.
- For acoustic sensing, processing on board is key for systems with high data rates.
- Multiple scientists pointed out that environmental context and multiple sensors are required for most problems. No single sensor ever is sufficient.

Ideas for Discussion:

- Where should the investment be for these areas based on ALPS II goals:
  - Bioacoustics
  - Passive acoustics
  - Communications
  - Navigation
- What investment models have worked for technology improvement and integration?
- How can ALPS II focus both researchers and sponsors to achieve goals?
- What happened organically and successfully since ALPS I? How to nurture that?