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Observing the Oceans Acoustically

Jennifer L. Miksis-Olds[1], Eric Rehm[2], Bruce M. Howe[3], Peter F. Worcester[4], Georgios Haralabus[5], Hanne Sagen[6]

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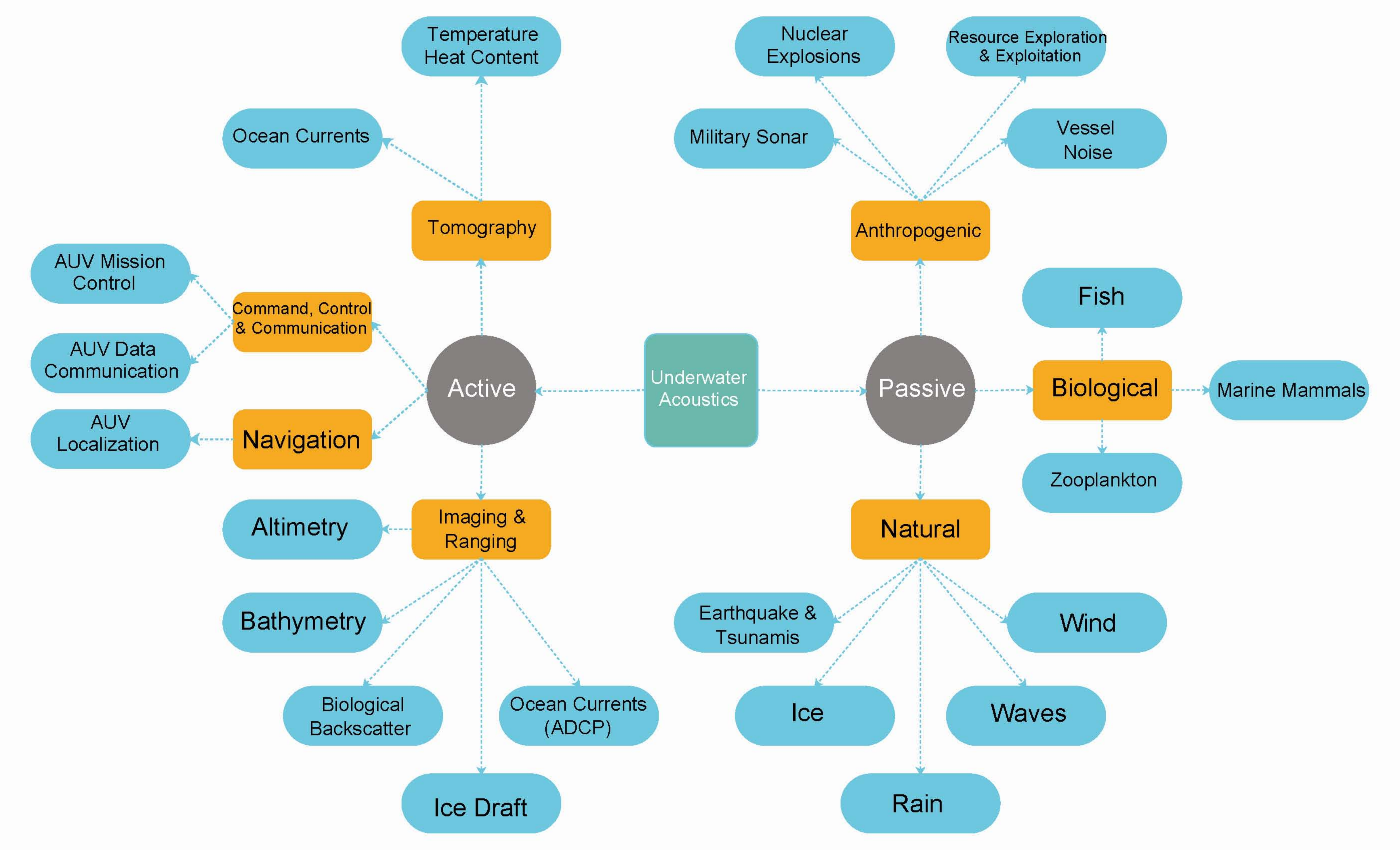
Introduction

Passive Acoustics

Active Acoustics

UN Decade Challenges

Our vision is a global-spanning multi-purpose ocean acoustic network in direct analogy with GPS required to transform use and observation of the world below the ocean surface. A small number of judiciously-placed low-frequency acoustic sources transmitting to globally distributed receivers enable: 1) acoustic geo-positioning ("underwater GPS") for real-time, basin-scale undersea navigation and management of floats, gliders, and AUVs; 2) daily measurements of large-scale ocean temperature/heat content; 3) global ambient ocean sound time series.



Ocean sound is now a mature Global Ocean Observing System (GOOS) Essential Ocean Variable, which is one crucial step toward providing a fully integrated global multi-purpose ocean acoustic observing system. Ocean observing applications of a multipurpose acoustic system (blue), building on the core observing elements (orange).

Ocean Sound is an Essential Ocean Variable making passive acoustic monitoring routine; every hydrophone, every platform becomes a "GPS" receiver, while also listening to the ocean soundscape. Such a network will lead to multi-disciplinary discovery and improve understanding of ocean ecosystem health and biodiversity, climate variability and change, and marine hazards and maritime safety while providing the basic and essential infrastructure of geo-positioning.

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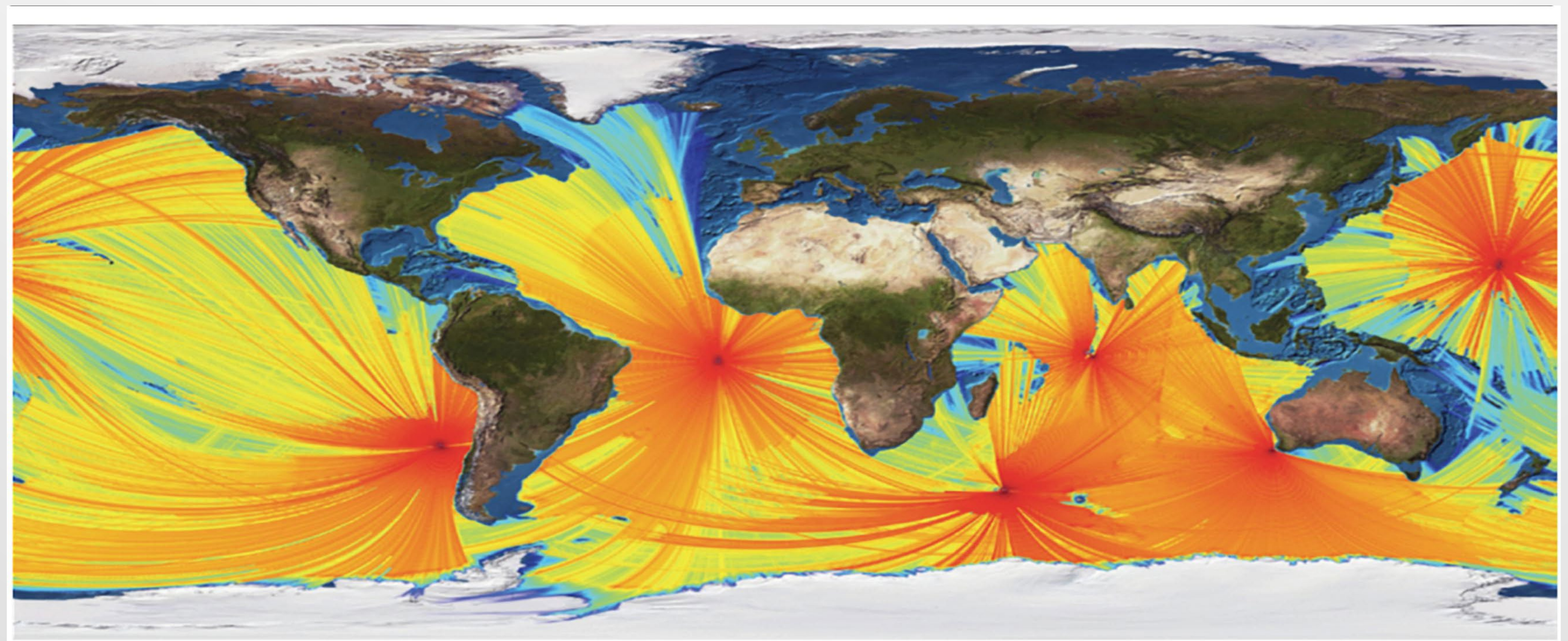
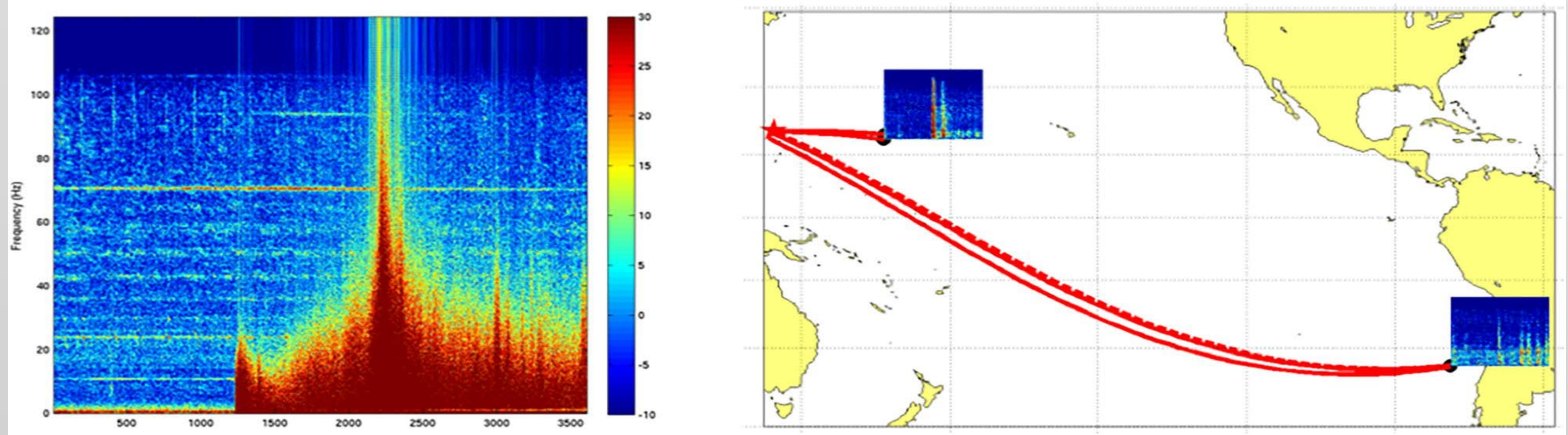
Passive Acoustics

Passive listening to ocean "soundscapes" informs us about the physical and bio-acoustic environment from earthquakes to communication between fish.

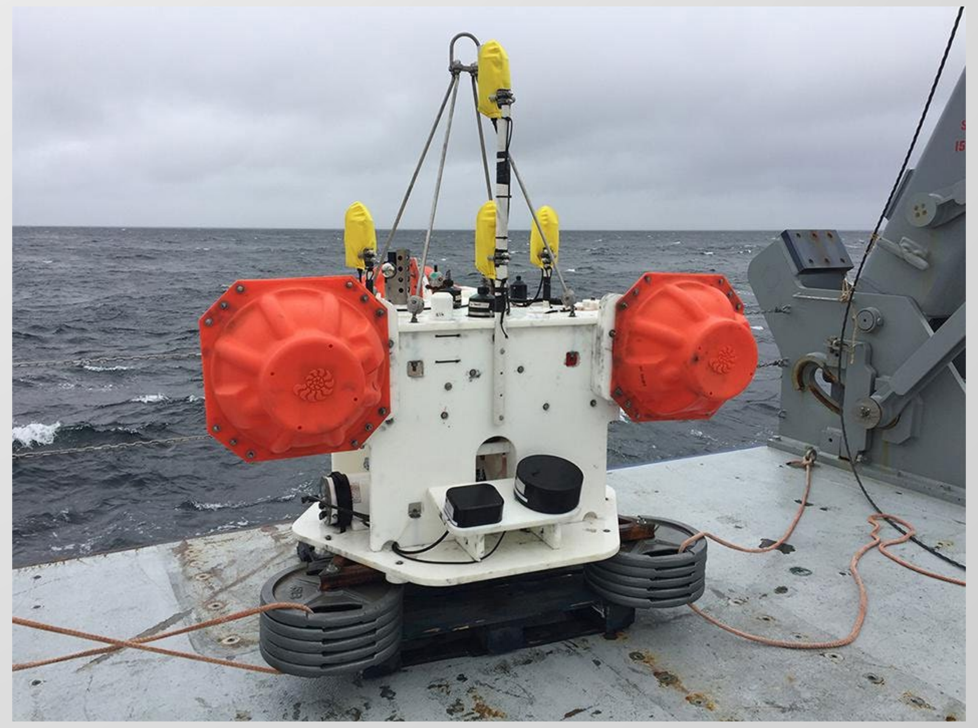
Passive acoustic monitoring (PAM) of sound generated and utilized by marine life as well as other natural (wind, rain, ice, seismics) and anthropogenic (shipping, surveys) sources, has dramatically increased worldwide, enhancing our understanding of ecological processes and human ocean use.



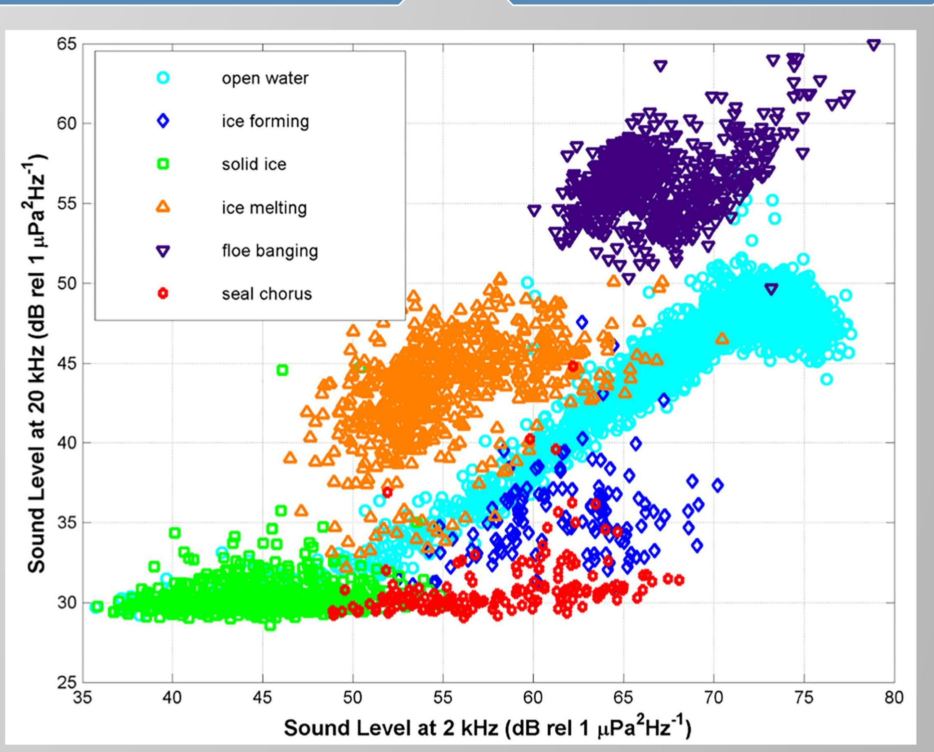
Comprehensive Nuclear-Test-Ban Treaty (CTBT) global acoustic coverage offered by the six hydrophone stations able to detect natural and anthropogenic underwater sounds - simulation shows modelled results for low (1-100 Hz) frequencies (Heaney, 2015).



Examples of CTBT hydroacoustic network detections (Left) Frequency content versus time (seconds), 1 April 2014 northern Chile earthquake signal on CTBT HA03 hydrophone (Juan Fernandez, Chile). Color scale (dB), where red denotes higher energy content. Early arrivals are attributed to seismic waves traveling through the ocean crust and leaking acoustic energy into the water, however, most of the acoustic energy arrived later in the form of T-phase propagation in the SOFAR channel. (Right) Hydrophone recordings at HA11 (Wake Island, USA) and HA03 (15,000 km away) pertaining to bursting underwater gas bubbles emitted by an undersea volcano near the Mariana Islands.



Atlantic Deepwater Ecosystem Observatory Network (ADEON) acoustic lander. A tetrahedral hydrophone array comprising four sensors located under the yellow protection covers. Recordings from the array provide information on vocalizing marine life, regional human activity, and a time series of ambient ocean sound. The array design allows for localization of identified sound sources. The time series of sound levels affords the opportunity to monitor ocean dynamics and impacts of oceanographic features such as ocean fronts and hurricanes.



Polar Acoustic Environment: Ice + Mammals Soundscape recorded in the winter/spring of 2009 in the central region of the Eastern Bering Sea Shelf. Each point on the image represents the ratio of sound pressure level between 2 and 20 kHz at a specific time. The acoustic environment changed based on the presence of vocalizing ice seals and state of sea ice at the surface. Sources are color-coded based on their stereotyped source characteristics. (Van Opzeeland & Miksis-Olds, 2012)

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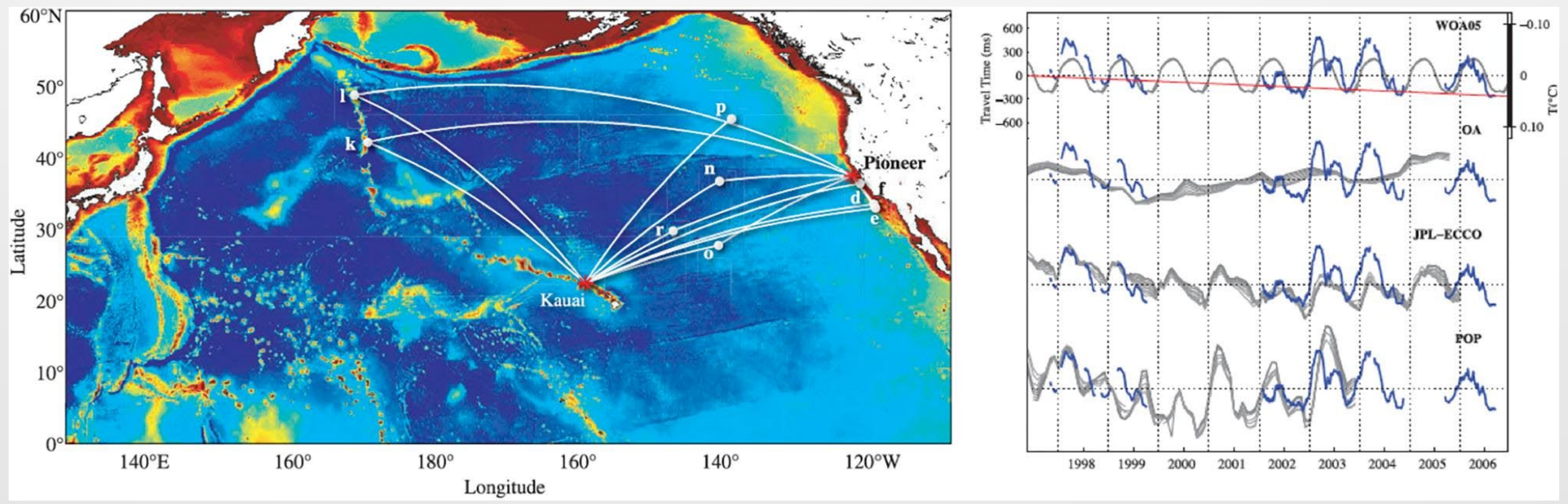
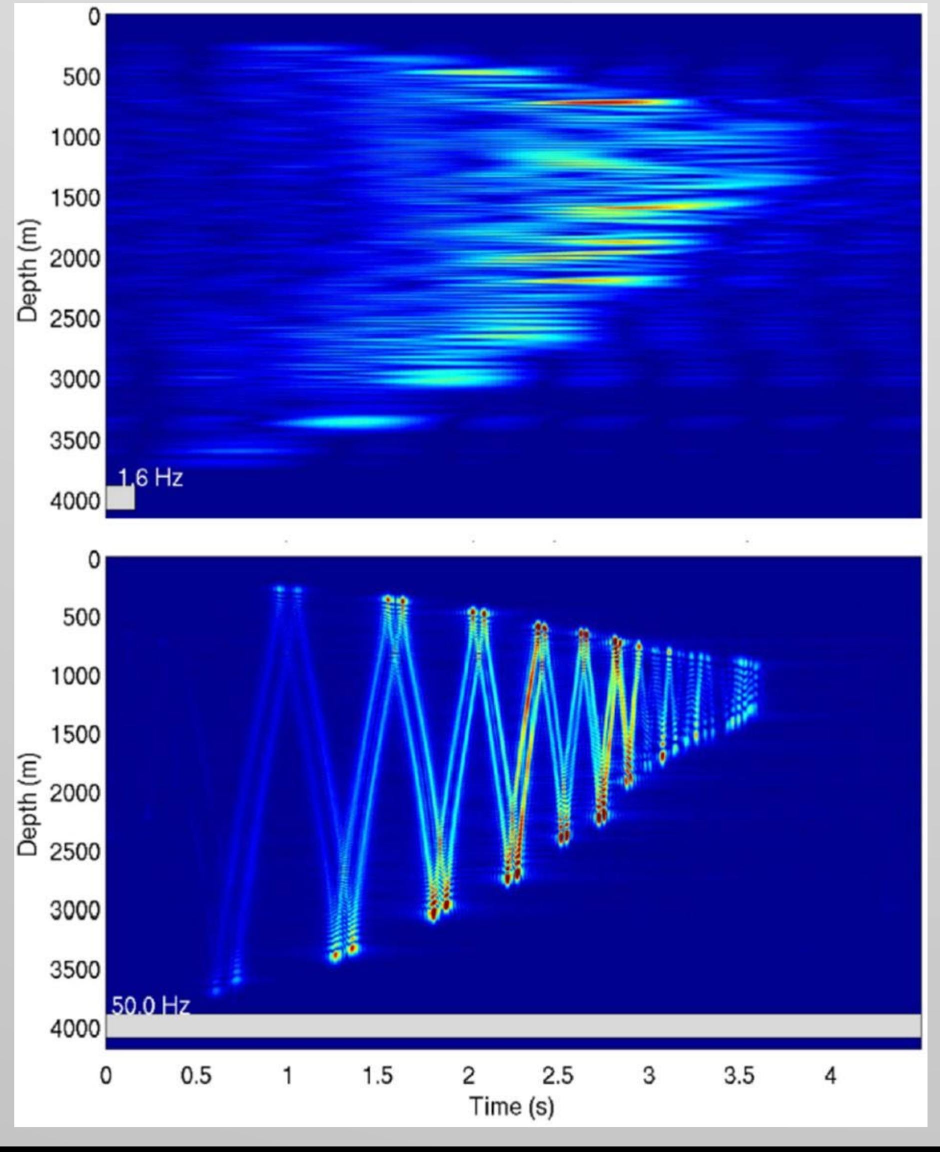
Active acoustic probing of the environment informs us about ocean topography, currents and temperature, and abundance and type of marine life vital to fisheries and biodiversity related interests. Acoustic receivers are now routinely acquiring data on a global scale, e.g., CTBT International Monitoring System hydroacoustic arrays, regional integrated ocean observing systems, gliders (Ocean Tracking Network), and profiling floats.

Judiciously placed low-frequency acoustic sources transmitting to globally distributed PAM and other systems provide: (1) high temporal resolution measurements of large-scale ocean temperature/heat content variability using tomography; and (2) acoustic positioning ("underwater GPS") and communication services enabling basin-scale undersea navigation and management of floats, gliders, and AUVs.

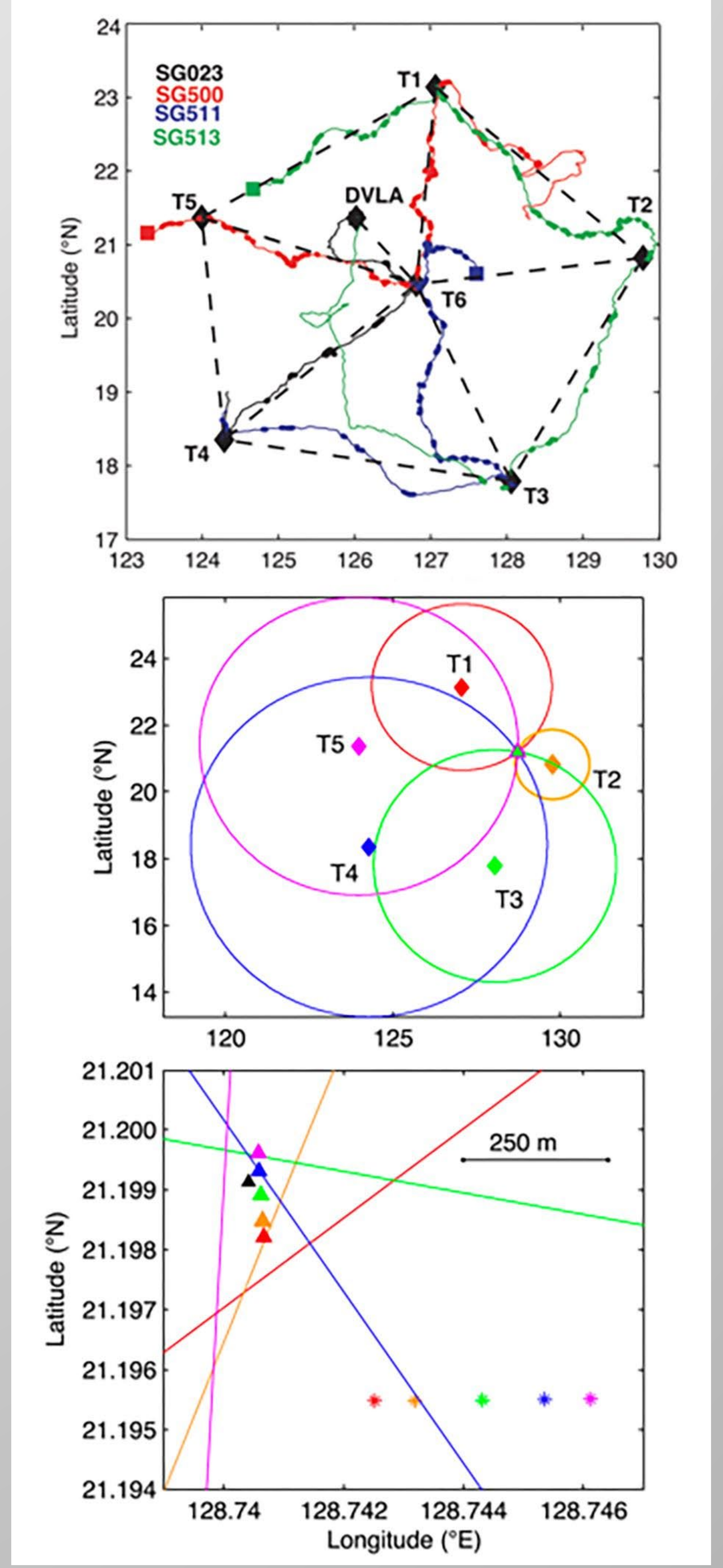
New Transducer Technology: The GeoSpectrum Tech., Inc. low frequency source (f_0 = 32 Hz, Δf = 10 Hz, 1 m diameter, 0.2 m thick, 270 kg).



Temperature from sound: (Left) Acoustic propagation paths from the Kauai and Pioneer Seamount sources to receivers in the Pacific for the Acoustic Thermometry of Ocean Climate (ATOC) program. (Right) Comparison of measured travel times from the Kauai source to receiver k with travel times computed using various other estimates of ocean temperature along the path. Acoustic methods provide a stringent test of the large-scale temperature variability in ocean models (Dushaw et al., 2009).



Multipurpose acoustic signals: Arrival patterns for a 1145-km transmission path in the N. Atlantic Ocean. Systems with 80-s linear FM signals of 1.6-Hz (top, RAFOS) and 50-Hz bandwidth (bottom, RAFOS-2/tomography) and 260-Hz center frequency (source at 700 m depth, receiver at 2000 m depth). Positioning uncertainty for the first case is (sound speed/bandwidth) ~1000 m, while for the second it is 30 m (Duda et al., 2006)



Acoustic Seagliders, Philippine Sea: (Top) ● show glider positions. ◆ show moored acoustic transceivers. (Center) Circles indicate acoustically- derived ranges from sources ◆ T1-T5. (Bottom) Expanded view: Stars ✷ are dead-reckoned positions. Triangles ▲ are glider-estimated positions for each source reception. Black ▲ shows least-squares position estimate, neglecting glider motion between transmissions. (Van Uffelen et al., 2016)

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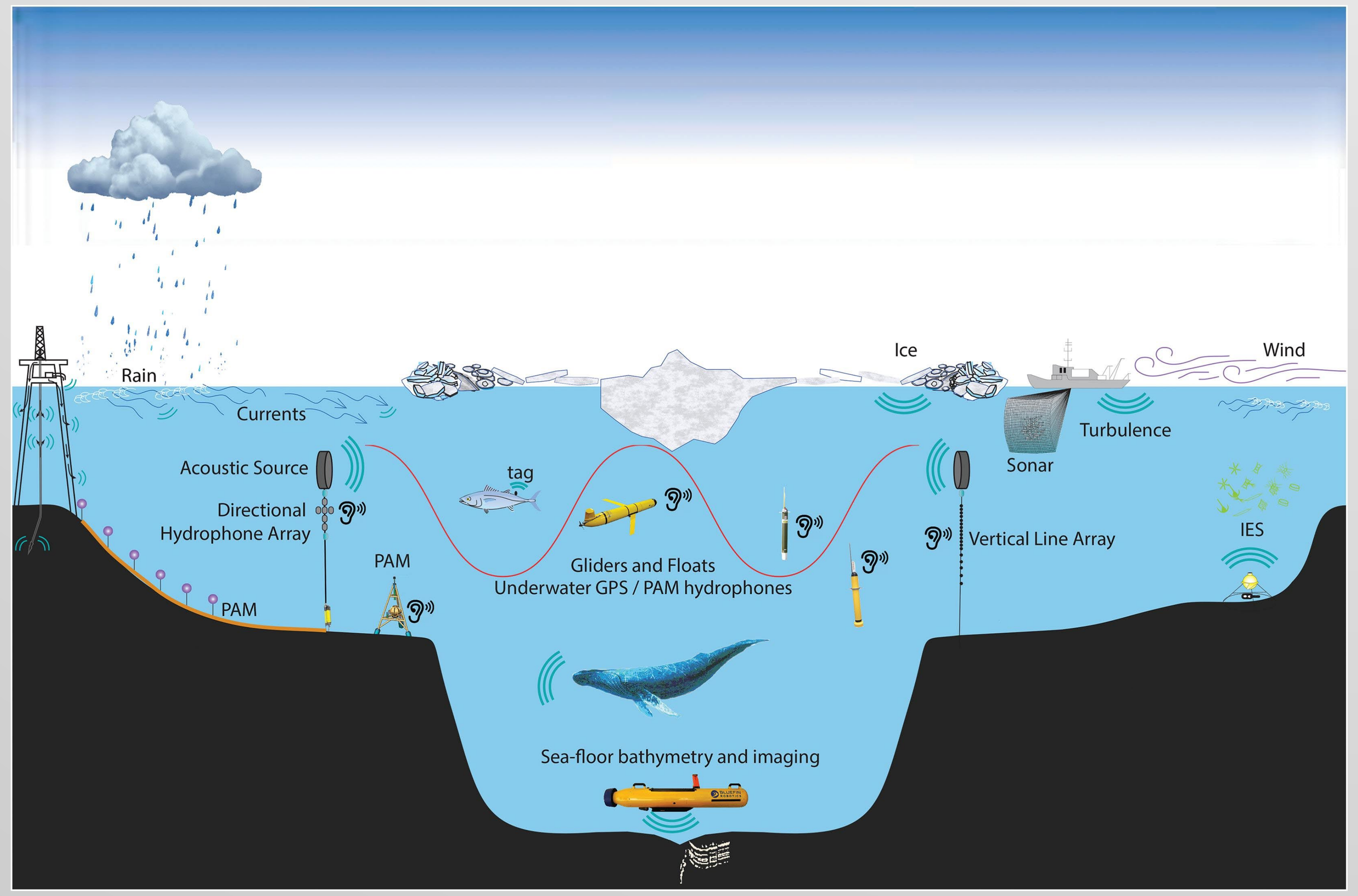
Ocean Acoustics Directly Contributes to Meeting 3 UN Decade Challenges

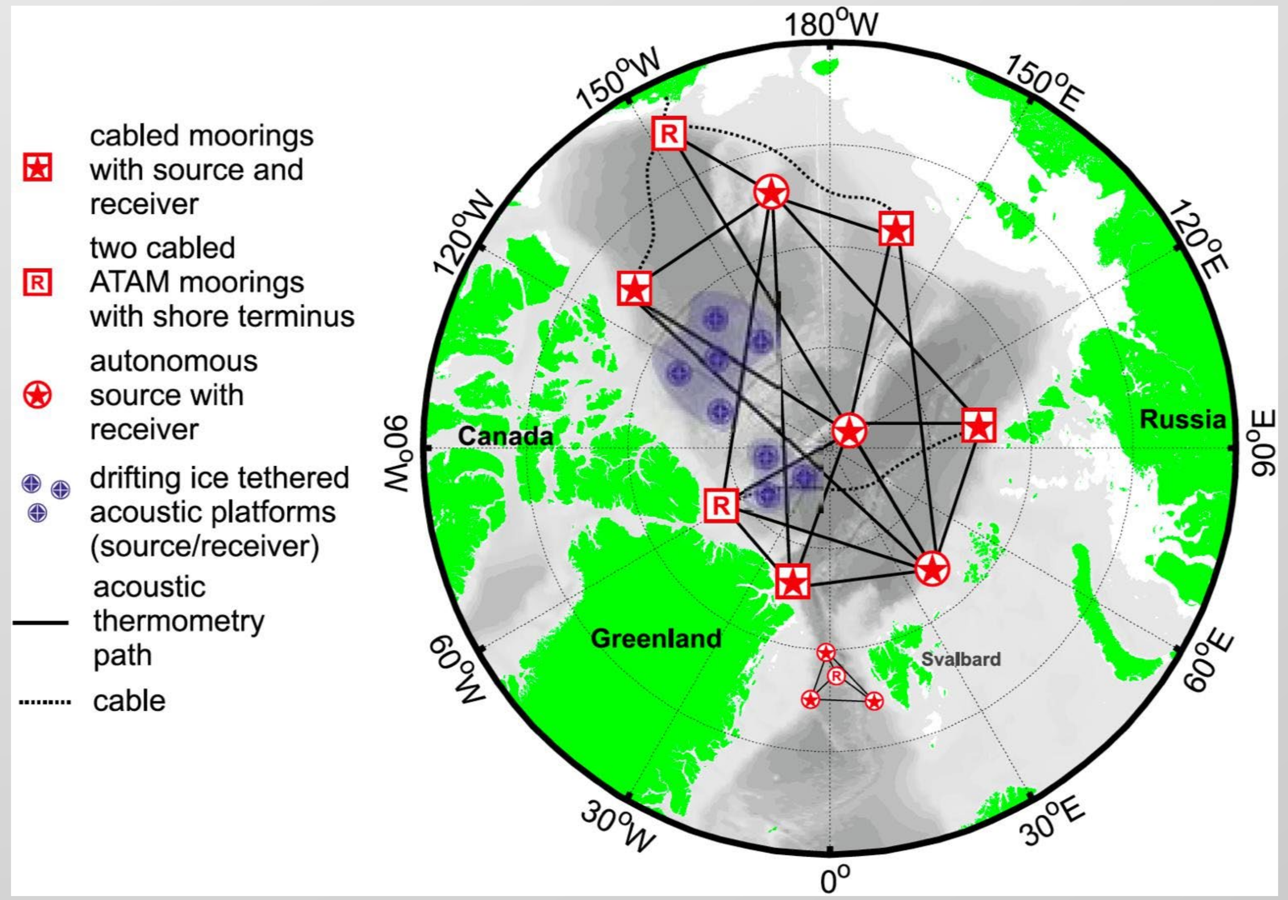
Challenge 5: Enhance understanding of the ocean-climate nexus and generate knowledge and solutions to mitigate, adapt and build resilience to the effects of climate change across all geographies and at all scales, and to improve services including predictions for the ocean, climate and weather.

Global Ocean Acoustics is realizable in addressing the 3 identified Challenges: Active and passive systems together in a multi-purpose network can lead to discovery and improve understanding of ocean ecosystem health and biodiversity, climate variability and change, and marine hazards and maritime safety. The collaborative and international Acoustic Thermometry of Ocean Climate project (1996-2006) demonstrated the value of acoustic data for ocean climate/temperature/heat content.

Challenge 6: Enhance multi-hazard early warning services for all geophysical, ecological, biological, weather, climate and anthropogenic related ocean and coastal hazards, and mainstream community preparedness and resilience.



Multipurpose acoustic observing systems provide a range of capabilities: two-way transceivers support acoustic tomography, navigation, and communications as well as passive acoustic monitoring (PAM). PAM stations observe soundscapes of natural, biological, and anthropogenic sources. Shifting ocean currents and zooplankton populations can be detected using inverted echo sounders. Autonomous platforms (floats, gliders) take advantage of acoustic sources providing "underwater GPS" services and can also provide PAM and hazard early warning services.



A Multipurpose Acoustic Network for the Arctic: A notional basin-wide Arctic mooring network for acoustic tomography, oceanography, PAM, and underwater "GPS" system for navigation and low bit rate communications for floats, gliders, and UUVs. The Acoustic Thermometry and Multipurpose Mooring (ATAM) applies to all the moorings shown (Mikhalevsky et al., 2015)

Challenge 7: Ensure a sustainable ocean observing system across all ocean basins that delivers accessible, timely, and actionable data and information to all users.

While this project can start in the US, it is inherently an international effort. We expect this to be a significant component of GOOS, just like Argo, OceanSites, GO-SHIP, drifters, etc. Other international programs would include the Comprehensive Nuclear Test Ban Treaty Organization (CTBTO), International Quiet Ocean Experiment (IQOE), SMART Subsea Cables (Science Monitoring And Reliable Telecommunications), and the European Integrated Arctic Observation System (INTAROS).