ACOUSTIC TECHNOLOGIES FOR OBSERVING THE INTERIOR OF THE ARCTIC OCEAN

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ABSTRACT

Operational monitoring and forecasting system for global and regional oceans, including the Arctic, combines observations from different satellite remote sensing techniques and in-situ open ocean measurements with ocean circulation models through advanced assimilation techniques. Satellites can sufficiently monitor changes in surface properties of the polar oceans, while the interior of the ocean is poorly observed since the water mass is opaque to electromagnetic waves and Argo floats cannot yet be used in the Arctic. Correspondingly, the internal of the Arctic Ocean is not monitored on a systematic basis, and this represents a significant gap in the Global Ocean Observing System. It is recommended to design and implement a cost-efficient, multi-purpose acoustic infra-structure for ocean acoustic tomography, navigation/positioning of gliders and floats under ice, and monitoring of ambient noise and marine mammals.

1. INTRODUCTION

The Arctic Ocean plays an important role in climate change observed in the Arctic in the last decades. However, oceanographic data from the Arctic Ocean, especially the deep ocean, are very scarce. It is therefore necessary to develop in situ observing systems, for ice-covered seas, using several methods. This will be part of operational open-ocean monitoring and forecasting systems, such as the EU projects MERSEA-IP (2005-2008, http://www.mearsea.eu.org) and MyOcean (2008-2011, http://www.myocean.eu.org/), combining satellite remote sensing and in-situ open ocean measurements (mainly Argo floats and moorings) with ocean circulation models through advanced assimilation techniques. Satellites can monitor surface changes in the polar oceans, such as sea ice coverage, but the interior is another matter. The Argo float system, a component of the Global Ocean Observing System (GOOS), cannot yet be implemented in ice-covered waters. Thus, Arctic Ocean interior conditions remain poorly observed. This represents a significant gap in GOOS. Acoustic technologies can help fill this gap both by providing direct measurements of temperature and current under the ice (ocean acoustic tomography) and by providing under ice navigation and communication for autonomous sampling systems. Integrated acoustic systems can be used simultaneously for tomography, navigation, communication [1], [2], ambient noise, and bioacoustics [3].

2. ACOUSTIC TOMOGRAPHY AND THERMOMETRY IN THE ARCTIC

Acoustic tomography uses precise measurements of acoustic travel times between acoustic sources and receivers. Through inversion techniques, internal ocean temperature can be retrieved with an accuracy of 0.01°C over a 200 km distance [4], [5]. In the same way, precise measurements of average current velocities can be determined from the difference between reciprocal travel times produced by simultaneous transmission of acoustic pulses in opposite directions along an acoustic path. Because of the integral nature of the data, tomography is best employed in conjunction with numerical ocean circulation models and data assimilation [4], [6], [7].

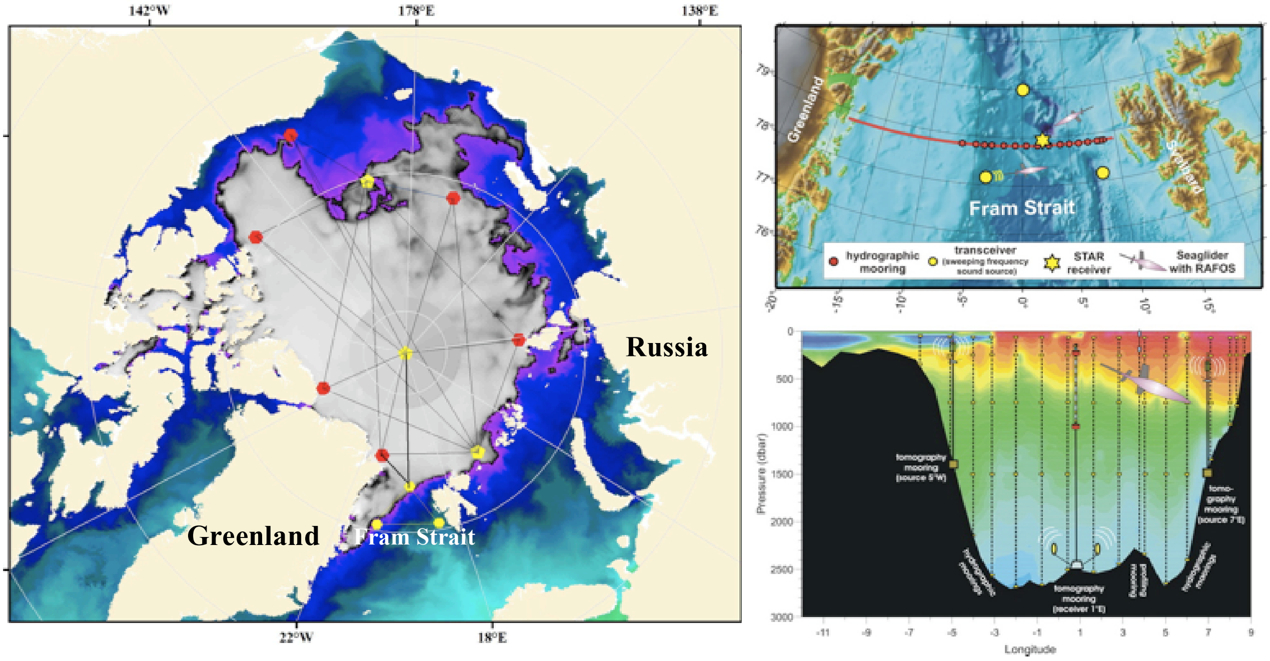

Figure 1. *The envisioned basin-wide integrated ocean-acoustic mooring grid in the Arctic Ocean overlaid ice-ocean model output from TOPAZ system (left panel) and the existing moored observatory (tomography and oceanographic) in Fram Strait (right panels). In addition to moored instrumentation, profiling gliders capable of under-ice acoustic navigation will be employed. The Fram Strait acoustic observation system is co-located with the fixed array of oceanographic moorings array across the strait at 78° 50' N. The lower right panel shows positions of acoustic and oceanographic moorings overlaid on the temperature distribution in Fram Strait where red is warm water and blue is cold water. The blue square in the upper right figure the bottom-mounted 'Hausgarten' system for biology and geology studies, indicated (See http://www.oceanlab.abdn.ac.uk/esonet/arctic.php).*

OceanObs'99 identified high-latitude regions and the Arctic Ocean as key areas where ocean acoustic tomography should be applied [8], [9], [10].]. Stand-alone high latitude acoustic tomography systems have been developed and successfully tested in ice covered regions, including the 1988-1989 Greenland Sea Experiment [11] and the 6-year Labrador Sea experiment [12]. Successful trans-Arctic acoustic thermometry experiments demonstrated the unique capability of underwater acoustics to measure large-scale changes in temperature and heat content of the Arctic Ocean. The 1994 TAP (Transarctic Acoustic Propagation) experiment revealed, for the first time, basin-scale warming of the Arctic Intermediate Water [13], which was confirmed by submarine measurements [14]. The ACOUS (Arctic Climate Observations Using Underwater Sound) experiment in 1998–1999 detected an extraordinary warm and wide mass of Atlantic water crossing the Nansen Basin north of the Franz Victoria Strait in August-December of 1999, which would have been extremely difficult and expensive to observe by conventional oceanographic means [15]. This experiment also showed that the received acoustic energy was correlated with integral path-average ice thickness changes, which could provide means for continuous remote observation of basin-scale changes in the Arctic sea ice thickness.

More recently, the DAMOCLES EU/FP6 project (2005-2010, http://www.damocles-eu.org/), has taken the first steps towards an integrated data and model system in the Fram Strait, combining ice-ocean models, ocean acoustic tomography, gliders and traditional oceanographic moorings through data assimilation. The Fram Strait is the main connection between the Atlantic and Arctic Ocean, and the integrated system is intended to improve the estimates of the heat, mass and freshwater transports through the Strait. Source and receiver moorings were deployed in August 2008 for one year [16]. The two moorings were separated by 130 km at 78°30'N. The ACOBAR EU/FP7 project (2008-2012, http://acobar.nersc.no) will extend the tomographic array in 2010 to three acoustic transceiver moorings in a triangle configuration, with a receiver mooring in the middle [16] (Fig. 1). Each source [17] will transmit both broadband signals for tomography and narrowband 260-Hz RAFOS signals for navigation of autonomous underwater vehicles.

3. UNDERWATER ACOUSTIC COMMUNICATION AND NAVIGATION

Gliders and floats have become important platforms for oceanographic data collection. Under ice-free conditions, gliders have been successfully used in sub-Arctic areas, such as the Labrador Sea, Davis Strait (where the first under ice section was achieved in 2006) and Fram Strait, where a Seaglider operated for 2.5 months in summer 2008 (http://acobar.nersc.no). In ice-covered areas, gliders and floats will only occasionally manage to surface to use satellite-based navigation (GPS) and data telemetry via IRIDIUM or ARGOS. For the Arctic, it is therefore necessary to develop underwater acoustic navigation and telemetry systems for gliders and floats in the Arctic [2].

The first successful winter-long, under-ice operation of a glider using 780-Hz, narrow-band RAFOS sources was accomplished in Davis Strait in 2008 under the NSF AON Award #0632231 (Dickson, 2008). The first glider trial under ice in Fram Strait is planned for 2010 under the ACOBAR project in collaboration with the NSF AON Award #0632231, using 260-Hz RAFOS signal transmitted by the tomographic sources [16] and employing navigation technology developed for and already proven in Davis Strait. In the Antarctic Argo floats were traceable at distances of up to 600 km under the ice by use of RAFOS signals at 260 Hz [18], and in combination with ice-sensing algorithms the floats have spent up to 7 years in seasonally ice-covered regions. The next step is to increase navigational accuracy for gliders and other AUVs by using broadband tomographic signals for acoustic navigation, instead of the narrowband RAFOS signals [19].

Advanced Ice Tethered Platforms (AITP) are under development for regional implementation in the central Arctic Ocean [20]. The AITPS are currently equipped with SOFAR 1560-Hz and 780-Hz sound sources to provide acoustic navigation and communication for gliders and floats operating under ice. The AITPs are planned to be deployed in clusters of 3 to 5 covering areas of 100 km by 100 km up to 200 km by 200 km, depending on acoustic frequency. Recent studies indicate that these navigation signals from clusters of AITPs can also be used for regional first order acoustic tomography [21]. In near future, the acoustic sources will be mounted to the CTD profiler, which scans temperature, salinity and pressure from surface to 1000 m depth. In this way acoustic propagation conditions and optimal receiving conditions are obtained in real time, allowing the CTD profiler carrying the acoustic source to park at an optimal depth for transmission of navigation signals to glider and floats. The profiler transmits data to a surface buoy, using inductive modem, providing near real time capability through satellite communication.

The integrated system of AITPs and gliders and floats will sample the upper and lower haloclines, in addition to the surface fresh water layer and the intermediate Pacific (shallow) and Atlantic (deep) layers. This is important for understanding the interaction between the ocean and sea ice and the heat flux from the ocean to the sea ice.

4. AMBIENT NOISE AND BIOACOUSTICS IN THE ARCTIC

The anticipated increase of human activities in the Arctic will lead to higher noise levels, e.g., from shipping, seismic exploration, fishing vessels, oil and gas installations, leisure and research activities. It is important to detect these changes and understand any influence on marine mammals in the Arctic [22]. Currently observations of marine mammals in the Arctic, mainly obtained from ships and aircraft, are sparse in time and space. Marine mammals use sound signals for social communication, and at least odontocetes (toothed whales and dolphins) also use sound for foraging and navigation. Mounting autonomous acoustic recorders on fixed moorings, floats, gliders, and AUVs, systematic measure of the seasonal occurrence of vocal cetaceans [23], a window into the large-scale seasonal movements and habitat selection of Arctic marine mammals [24]. For example, passive acoustic monitoring has been used since the early 1980's to study the migration of bowhead whales (*Balaena mysticetus*) in the western Arctic (e.g., [25]). In the Fram Strait, passive recorders were deployed on oceanographic moorings along the 78° 50' N latitude line at 4° W and 1° E in 2008, as part of an IPY project to develop underwater sound budgets for Arctic waters (Fig 2). This data set will be the first long term recording of ambient sound in the Fram Strait and will complement similar data from Davis Strait [26], providing year-round information about cetaceans, pinnipeds, sea ice and anthropogenic sound in polar seas. Furthermore, climate driven changes such as the break up intensity of ice shelves and icebergs can be remotely monitored by passive acoustic observation of ocean ambient noise [27].

Recent research has focused on methods for estimating the population density of cetaceans from passive acoustic recordings [28]. These methods rely on counting the number of calls detected, estimating the probability of detecting a call as a function of distance, and measuring the average call rate. The result is an estimate of the number of animals (or groups) per unit area for the region monitored by the passive acoustic sensors. Acoustic models used for ranging and tracking of marine mammals require accurate knowledge of the sound speed profile and, and monitoring systems of marine mammals will therefore benefit from integration with the acoustic thermometry systems.

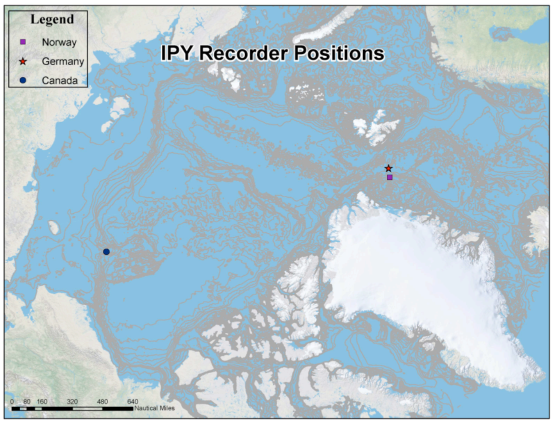

Figure 2. Locations of recorders deployed on moorings in the Arctic as part of the IPY project: Acoustic Monitoring for Marine Mammals and Anthropogenic Sounds in the High Arctic

5. RECOMMENDATIONS FOR AN ARCTIC OCEAN OBSERVING SYSTEM.

The development of an integrated Arctic Ocean Observing System (AOOS), capable of performing sustained observations of the ocean interior under ice and constraining Arctic Ocean circulation models on a regular basis through assimilation, is a major challenge for the oceanographic community. Tomography systems, ice-tethered platforms, gliders and floats are complementary observing systems, that together with satellite remote sensing will bring unique data into an integrated ocean model and data system for the Arctic.

We recommend the design and implementation of a cost-efficient multi-purpose acoustic infrastructure for the Arctic Ocean to perform tomography, navigate gliders and floats under ice, position data from gliders and floats during missions under ice. Furthermore, a multi-purpose acoustic observing system in the Arctic should include ambient noise and marine mammals monitoring. This can be used to assess potential impacts of changes in climate and human activities in the Arctic on ambient noise levels and marine mammals.

To do this we can capitalize on experience from the previous acoustic tomography experiments in the central Arctic Ocean [15], the regional multi-purpose acoustic system currently under implementation in the Fram Strait [16], the development and implementation of the AITP clusters in the Arctic, the development of glider navigational techniques in the NSF Arctic Observing Network [20], and the ongoing acoustic monitoring of marine mammals in the Fram Strait.

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