INTERNATIONAL QUIET OCEAN EXPERIMENT – ARCTIC ACOUSTIC ENVIRONMENTS

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Abstract: *High-latitude regions like the Arctic Ocean are becoming increasingly important as global warming makes them more accessible, raising economic and political interests. Sea ice reduction is facilitating resource exploration, marine transport and other activities. Warming waters and changing sea ice conditions lead to shifts in ecosystems. Resource exploitation will grow in the coming decades, offering new opportunities but also new challenges to these fragile environments and their biodiversity. The natural and anthropogenic changes in this region will change the characteristics of soundscapes. To measure and assess them at a variety of spatial and temporal scales, the International Quiet Ocean Experiment created in 2017 a working group on Arctic Acoustic Environments. First activities focus on synthesising state-of-the-art knowledge of Arctic sounds—past, present and future. WG activities were presented at the Arctic Observing Summit 2018 and its recommendations adopted at the 2nd Arctic Science Ministerial. We are linking with indigenous communities and other stakeholders to address emerging trends, plan where/when to conduct optimal acoustic surveys, and prioritise metrics. We present the plans and first actions of this IQOE WG.*

Keywords: *Arctic acoustics, ambient noise, International Quiet Ocean Experiment (IQOE)*

1. ARCTIC ACOUSTIC ENVIRONMENTS

Arctic regions are directly and visibly affected by climate change, and they are expected to see major transformations over the coming decades [1]. For example, the extent of sea ice has decreased at a rate of – 0.78×10^6 km^2 (6.15%) per decade over the period 1993 – 2016, and the volume of sea ice has decreased at a rate of 15.4% per decade, increasing freshwater content of the Arctic Ocean [2]. Warming extends deep: models using surface data (satellite and *in situ* measurements) conclude there were changes of $+(0.6 \pm 0.1)$ W/m^2 in the upper ocean (0–700 m) during the same period [3]. Fig. 1 shows how these important changes correlate and how they affect other parameters (e.g., increasing wind velocities over the entire Arctic region). Recent, important changes in exchanges between the Atlantic Water and the Arctic Ocean [4] are further influencing sea-ice cover, in particular in the Barents Sea and near Svalbard. Since 1993, this contributed 15% of the total contributions to sea level rise [1].

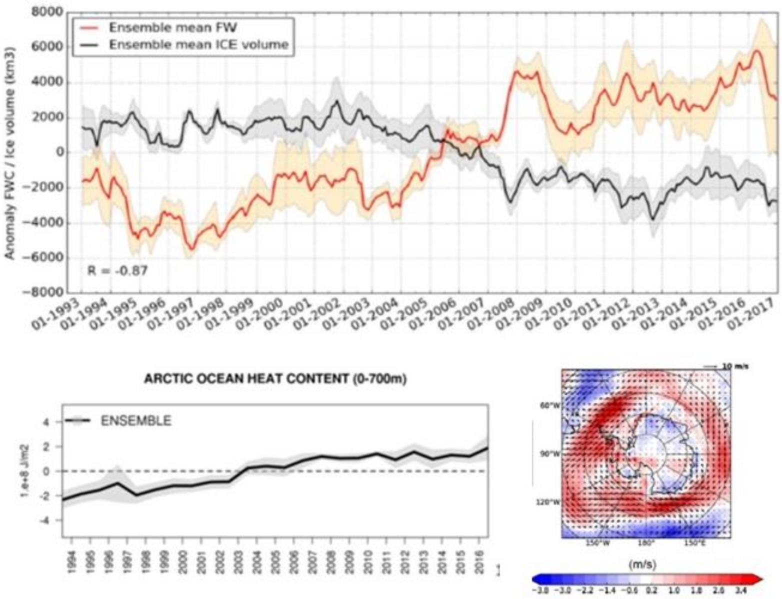

Fig.1: Arctic changes, 1993-2016, derived from models and in situ observations. Top: Freshwater content (red) and sea ice volume (black) in areas above ocean depths of more than 500 m [8]. Bottom left: basin-average temperatures over the upper 700 m [3]. Bottom right: average wind speeds (colours) and wind velocities (black arrows) [2].

Decreases in glaciers and ice caps contributed another 28% to sea level rise [1, 5]. These changes are expected to increase substantially to the end of this century [6]. Submarine melting and calving of tidewater glaciers represent a significant source of cold freshwater, increasing the variability of temperature and salinity in the water column of glacial bays and fjords [7]. Changes in the timings and lengths of seasons, along with warmer waters, are also changing the distributions and quantities of different marine species, with “detrimental effects on many organisms including migratory birds, mammals and higher predators” [1], making them more vulnerable. Impacts on human communities in the Arctic, although mixed, will particularly affect infrastructures and traditional indigenous ways of life [1].

These changes are projected to accelerate in the 21st century [1] and changes in underwater soundscapes will become more pronounced. Large-scale acoustic propagation is particularly sensitive to changes in water temperatures and sea ice properties (e.g., [9]) and changes in under-ice ambient sound are already noticeable in some regions (e.g., [10]). Increased winds and changes in ice types, areas and volumes will also affect both natural sound generation and sound propagation at larger spatial scales. Acoustic impacts of melting tidewater glaciers [11] and freshwater ice [12, 13] will be more frequent [14] and Arctic Ocean areas will potentially become louder. These changes will also affect marine animals dependent on sound [15].

The Arctic Ocean and surrounding regions host important natural resources, resulting in growing economic and political interests, and transforming a pristine wilderness into a "useful" region. Under-ice soundscapes already combine noises from marine natural background noise and mammal vocalisations, but also noise from ship cavitation (from ice-breaking) and seismic airguns (sometimes audible more than 800 km away) [16-19]. Sea ice reduction will facilitate navigation, resource exploration and exploitation, and associated offshore activities. Noise levels are therefore expected to increase in the coming years.

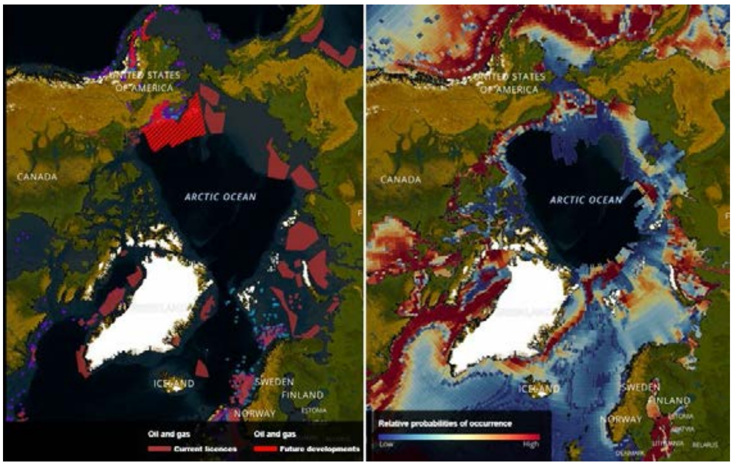

Fig.2: The "useful" Arctic. Current and future activities related to oil and gas (left) and fisheries potential (right). Both baseline maps adapted from wwfarcticmaps.org.

Recent assessments of mineral resources in the Arctic [20] concluded that it contains about 30% of the world's undiscovered gas and 13% of the world's undiscovered oil, mostly offshore under less than 500 meters of water (Fig. 2, left). Natural gas reservoirs are largely concentrated in Russia, and some deposits in Norwegian waters (e.g., Johan Castberg field, Barents Sea) have recently been approved for exploitation. Seismic exploration (using airguns) will be supplemented with offshore construction and drilling, with significant acoustic impacts (e.g., [21]). The Barents Sea is also the most important fishery area in Europe, and because of global warming there is a large potential for increased exploitation of living marine resources in the Arctic seas (Fig. 2, right). A 16-year ban on commercial fishing in the high seas portion of the Central Arctic Ocean was endorsed in 2018, although there are questions about its enforceability (especially in international waters) and long-term sustainability as pressures from declining fisheries in the rest of the world will intensify, and there are no restrictions on fishing in other areas of the Arctic. The retreat of sea ice also leads to increases in shipping, with more traffic along the Northern Sea Route (Fig. 3, left). Russia aims to open the Bering Strait for large tankers, and China is planning to expand its One Belt One Road Initiative to include Arctic routes. The Arctic Transportation Accessibility Model [22] uses different IPCC representative concentration pathways (RCPs) for radiative forcing. By 2050, the RCP 4.5 medium-low projection leads to predictions of expanded navigability for common open-water ships crossing the Arctic along the Northern Sea Route, robust new routes for moderately ice-strengthened ships over the North Pole, and new routes through the Northwest Passage for both classes (Fig. 3, right). Increased tourism will increase sound levels at low frequencies (e.g., the 63 Hz and 125 Hz used by the European Marine Strategy Framework Directive for shipping (MSFD, 2014)) and at higher frequencies (e.g., [17]).

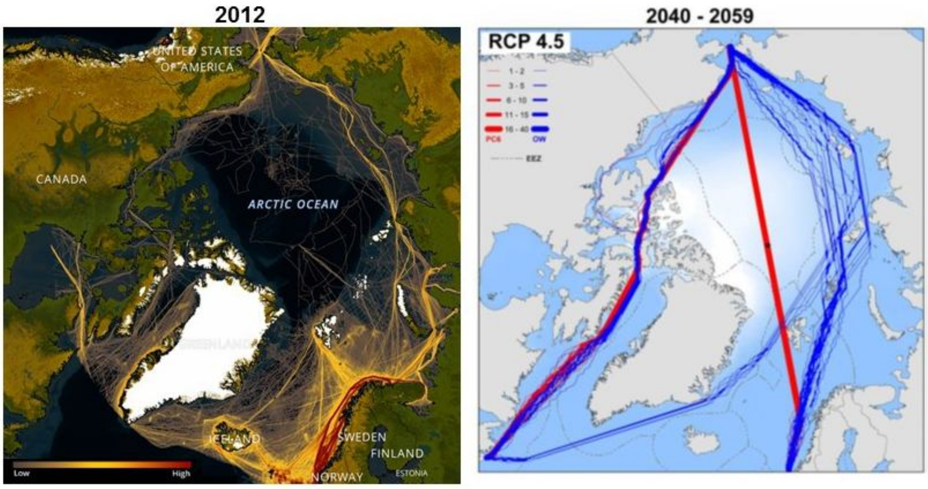

Fig.3: Changes in Arctic shipping. Left: current traffic, based on AIS recordings (from wwwfarcticmaps.org). Right: new routes [22] in red (polar vessels) and blue (other vessels).

2. THE INTERNATIONAL QUIET OCEAN EXPERIMENT

Several actors—academic, governmental and commercial—are already collecting passive acoustic data in the many marine environments encompassing the Arctic region, but the different activities are not coordinated, and communication is not very developed. It is therefore imperative to increase collaboration in the Arctic in order to obtain a better knowledge of current noise status and more coordinated observing programs in this harsh environment. This is the goal of the *International Quiet Ocean Experiment*. Its Science Plan was reviewed and approved by the Scientific Committee on Oceanic Research (SCOR) and the Partnership for Observation of the Global Ocean (POGO). In late 2017, IQOE established the Working Group on *Arctic Acoustic Environments* (www.iqoe.org/groups/arctic). This builds on previous efforts, e.g., Oceanoise'2015 and Oceanoise'2017 [23]. We aim to produce acoustic baselines against which future changes can be compared, and sustainable management practices considered and benchmarked. Our objectives are to:

- Identify locations of existing acoustic receivers in the Arctic Ocean
- Identify potential sources of historic acoustic data from the Arctic Ocean
- Inform IQOE Data Management & Standardization WGs of past/current data sources
- Compile existing acoustic data to determine whether time series showing evolution and future trends of relevant acoustic metrics can be created
- Create a synthesis of research papers and state-of-the-art knowledge on the effects of sound on organisms in the Arctic Ocean
- Identify data/research conducted on the effects of permafrost and gas-saturated sediments on Arctic Ocean soundscapes
- Identify an ideal receiver array (location, number of receivers, types of receivers) to observe the baseline acoustic environment for the Arctic Ocean
- Identify ongoing and planned experiments with passive acoustics planned or possible
- Conduct and support endorsement processes with the Arctic Council

3. ARCTIC ACOUSTIC ENVIRONMENTS – FIRST ACTIVTIES

The Working Group on "Arctic Acoustic Environments" comprises all authors of the present article, spanning 10 countries and a wide range of Arctic field work and research activities. Its first e-meeting took place in November 2017, and a co-chair meeting was organised in February 2018, with further *ad hoc* meetings at conferences. WG plans were presented at the Arctic Observing Summit AOS-2018. The IQOE WG's goals and activities were endorsed by the Arctic Observing Summit, and WG members participated in the Summit's themes of "Need for the Observing System", "Implementation and Optimisation" and "Leveraging Observing Systems and Networks". The AOS-2018 recommendations were taken aboard at the 2nd Arctic Science Ministerial in October 2018 attended by the science ministers of 26 Arctic-concerned nations and the representatives of six Arctic indigenous peoples' organizations. The final report [24] concluded in particular:

- *"We recommend exploring the possible call of a forum of Arctic science funders to discuss strategies for supporting the research that is necessary to achieve the goals agreed at this Ministerial meeting";*
- *"There is a need to enhance reciprocal collaboration and coordination of efforts on Arctic observations of all types, spanning from community-based observatories to high-tech autonomous systems, and increase their spatial and temporal coverage".*

Subsequent WG activities (e.g., [25]) led to the first full meeting in January 2019 in Paris (France). Compilation of existing and past research is supporting (and supported by) the Aquatic Acoustic Archive Literature Library (iqoe.org/library). We are building links with other existing initiatives, from European consortium research like INTAROS (www.intaros.eu) to organisations like the Arctic Council (arctic-council.org), the working group on Protection of the Arctic Marine Environment (PAME: www.pame.is) and the Arctic Monitoring and Assessment Program. We are reaching out to policy-makers at national and international levels. Our ultimate goal is to create awareness of acoustic environments and get the topic on funding agencies research agenda. Finally, we are actively supporting worldwide efforts to build an integrated Arctic Ocean observatory system, or system of systems.

4. ACKNOWLEDGEMENTS

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