The Future Arctic Ocean Observing System

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The Arctic region is exposed to significant environmental changes including the overall thinning and melting of sea ice, which opens up new areas for resource exploitation and ship traffic. The increased human activities will put more pressure on the Arctic ocean environment including the underwater acoustic environment. While polar orbiting satellites collect large amounts of data from the ocean surface including sea ice (e.g. the Sentinel programme under Copernicus), there are huge gaps in the data coverage *under* the sea ice. The Arctic Ocean is among the least observed oceans in the world, and there is practically no long-term observing infrastructure for the central Arctic Ocean. Around 70 % of the ocean data collected in the Arctic are funded by time-limited research programs. It is therefore important to establish long-term funding of ocean observing in the Arctic (Ludwigsen et al. 2018).

The United Nations have dedicated the next decade to achieve sustainable development goal number 14 (SDG14): 'Conserve and sustainably use the ocean, seas and marine resources for sustainable development'. Existing ocean research and observing systems must be improved significantly to achieve this. At the OceanObs19 several recommendations were made for the way forward to establish sustainable ocean observing systems globally and regionally. The recommendations include cross-disciplinary engagement and partnership, addressing stakeholder and societal needs as well as improved and shared technology for ocean observing. From the OceanObs19 Arctic Observing Breakout session it was recommended that "by 2029, the Arctic should prominently demonstrate that it has a fully developed, implemented, sustained ocean observing system that meets – at a minimum earth system prediction needs – but also other critical societal needs."

Several European and national infrastructure programs, plan or have already started to build ocean components of Arctic in-situ observing systems, addressing specific thematic areas (e.g. ICOS - Integrated Carbon Observation System, EPOS -The European Plate Observing System, Long-Term Ecological Research [LTER] HAUSGARTEN), platform technologies (e.g. NorArgo, EMSO - European Multidisciplinary Seafloor Observatory, FRAM – FRontiers in Arctic marine Monitoring), or regions (e.g. SIOS Svalbard Integrated Arctic Earth Observing System) in order to serve different application areas or stakeholder groups. This leads to a complex landscape of (national) infrastructures which must be coordinated and developed into a holistic and multidisciplinary ocean observing system to efficiently address societal needs. It will be important to define a backbone observing system with long-term funding and show how research program can complement and improve the observing capacity. To support this, it is crucial to develop roadmaps for building and operating an integrated Arctic Ocean Observing System. The roadmaps should address solutions regarding collaboration and governance; best practice and standards for the different subsystems, how data management should be implemented, and which technologies can and should be used.

To make continuous ocean observation in the Arctic requires autonomous systems capable to operate for sustained periods with minimum human interference. A sparse network of drifting ice-based observatories is currently the only source of year-round near real-time ocean data from central Arctic. Deployment of ice-based observatories are relatively expensive and requires ship time with ice breakers into the central Arctic Ocean. Existing autonomous underwater observing platforms frequently used in open ocean such as Argo floats, and gliders are not yet used operationally in ice-covered regions in the Arctic. This is because sea ice prevents satellite connections necessary for navigation and data transfer, and acoustic networks for navigation and communication are only installed and used for time limited experiments e.g. CANAPE in the Beaufort Sea and ACOBAR in the Fram Strait (e.g. Howe et al. 2019). To improve the Arctic Ocean Observing capability OceanObs19 recommended '*to pilot a sustained multipurpose acoustic network for positioning, tomography, passive acoustics, and communication in an integrated Arctic Observing System, with eventual transition to global coverage*'(Howe et al 2019a, Mikhalevsky et al 2015). Observing systems based on moorings and seafloor installations are multipurpose, robust, provide year-round observations from fixed positions and can support acoustic networks for geo-positioning of underwater platforms independent of ice cover. We recommend that a Future Arctic Ocean Observing System should be based both on mobile and fixed platforms. It is imperative to perform innovation using subsea technology to bring data from underwater installations in near real time.

Cabled systems and observatories are the most secure way to provide a large amount of multidisciplinary data to the user in real-time and would also provide power supply to the instruments. Several large-scale cabled observatories exist in coastal areas in world oceans, but none in the Arctic Ocean. OceanObs19 recommended to *transition SMART subsea cable (combined communication and science) systems from present pilots to trans-ocean implementation, to address climate, ocean circulation, sea level, tsunami and earthquake early warning, ultimately with global coverage.* Cabled observatories, either stand alone or branching from a hybrid cable system, could provide power and real time communication to support connected water column moorings and sea floor instrumentation as well as docking mobile platforms. In recent years the concept of sharing communication cables with science has been launched as SMART-cables (e.g. Howe et al., 2019b). Subsea communication cable developers are looking into the possibility to deploy a communication cable across the Arctic Ocean from Europe to Asia, because this offers a much shorter communication route compared to the terrestrial cables. The perspective is that this cable also can facilitate for scientific instrumentation.

The road towards the operational *Future Arctic Ocean Observing System* is complex and expensive and needs careful planning to meet the needs from different users and stakeholders e.g. Lee et. 2019. It is therefore imperative to perform a detailed analysis of the required infrastructure including both fixed and moving platforms. An international consortium of leading scientists in ocean observing with experience in state-of-the-art technologies on platforms, sensors, subsea cable technology, acoustic communication and data transmission should be established to work together across projects to design, test and implement systems building on experience ongoing and previous Arctic observing system experiments.

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