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Ice-tethered observational platforms in the Arctic Ocean pack ice

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Abstract: The Arctic Ocean faces rapid climate change, which impacts both physical and biological components of the marine ecosystem. Due to complicated and costly logistics inherent to sampling ice-covered areas, most studies conducted in the Arctic are based on relatively short-term sampling (weeks to months) centered around the minimum ice season. Given the need for longer-term monitoring, several autonomous ice-tethered observational platforms have been developed and deployed in the Arctic since the last decade. This review outlines their abilities, conception, and limitations. Most platforms were developed to measure physical data, which highlights a critical need for ice-tethered observatories monitoring biological processes.

Keywords: Arctic, Ice-tethered platforms, Biosphere, Cryosphere, Autonomous observations.

1. INTRODUCTION

The complex interactions within and between the biosphere, hydrosphere and cryosphere are central, yet poorly understood, features of the Arctic Ocean. Environmental variability and change result from the dynamic and complex interactions between these realms in time and space. A perturbation in one or more may propagate and amplify through complex interactions, resulting in disproportionately large changes and/or regime shifts (Duarte et al., 2012). The fast warming of the Arctic and loss of sea ice (Parkinson et al., 2013) are two well-documented examples of such amplifications, potentially affecting most living organisms in the region. There is already evidence for altered pelagic and benthic trophic dynamics due to changes in primary productivity, biomass and biodiversity, species range expansions, shifts in phenology cascading through trophic levels, and an increased zooplankton diel vertical migration affecting the biological pump (Brierley et al., 2009, Wassmann et al., 2011, Kortsch et al., 2012).

Several observations and predictions suggest that an *ice-free Arctic summer* is likely to occur within the next few decades (e.g. Cavalieri et al., 2012), posing even more *significant consequences and challenges for ice-adapted flora and fauna*. A suite of animal taxa depends on the sea ice habitat for food and reproductive success, and some complete their entire life cycles in association with the ice (Bluhm et al., 2011). The current reduction of Arctic sea ice is, thus, likely to have both direct and indirect impacts on marine organisms, their interactions and ultimately ecosystem processes (Slagstad et al., 2011). However, such ecosystem effects resulting from climate change have been primarily considered from the perspective of the polar summer, while the polar winter has essentially remained a black box (Berge et al., 2015) – *a box that is rarely considered and less frequently opened*. Autonomous observational platforms deployed in the Arctic Ocean to monitor several seasons or a complete annual cycle have the capability to fill this seasonal gap. Detecting and characterising climate and ecosystem variability and/or change requires long-term observations on seasonal, interannual, and decadal time scales. Inherently, such observations are challenging to obtain in any system, but especially so in the ice-covered Arctic Ocean. Technological advances have resulted in great strides in physical measurements of

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atmospheric, hydrographic, and sea ice properties, but biological measurements are lacking (Grebmeier et al., 2010; Wassmann et al., 2011). Yet, the need for providing answers on ecosystem response to climate variation (e.g. light regime, temperature and ice cover) and change has never been greater than in this era of rapid increase of the human footprint in all areas of the Arctic marine ecosystem (Ruddiman, 2013). Our view of the Arctic is shaped by summer studies that capture only a part of the highly seasonal production and life cycles of Arctic biota (Berge et al., 2015). Highly seasonal patterns are particularly obvious in the development of the spring bloom and its subsequent fate, DVM, ontogenic migrations, reproductive cycles, body composition such as lipid content, etc., and stress the need for seasonal coverage. Based on this incomplete seasonal coverage, we have been extrapolating estimates of total primary and secondary production, and essentially have made educated guesses on biological activity in the missing seasons. The few seasonal and interannual studies available (e.g. Rozanska et al., 2009, Kortsch et al., 2012, Laney et al., 2014, CASES, CFL, Tara Oceans Polar Circle, N-ICE) document the challenge of separating variability from long-term change and provide context for the short point-in-time studies that prevail (Grebmeier et al., 2015).

Pioneered by Nansen from the *Fram* during its ice-drift, sampling across the Arctic Basin became increasingly important in the latter half of the 20th century. Historically, drifting platforms have played a key role for the exploration and scientific discoveries in the Arctic. The Transpolar Drift was documented by the Fram expedition's unanticipated drift with the sea ice, and drifters on the ice have demonstrated close connections between the Kara Sea and the Fram Strait (Vize, 1937). In 1957, the US initiated their first year-round drifting scientific base when the Fletcher ice Island T-3, last visited in 1979, was established (Crary et al 1952). Since 1937, Russian drift ice stations (Frolov et al., 2006) have been instrumental in documenting that Atlantic water is circulating in the Eurasian Basin, and returning into the Fram Strait on the Greenland side as Arctic Intermediate Water (e.g. Proshutinsky et al., 1999). Since 2002, autonomous platforms have been developed and deployed to monitor the Arctic Ocean during the ice season. Here, we review these and outline their abilities, conception, and limitations. The review is based on information available through published descriptions / sources, resulting in a sometime uneven level of detail in the descriptions.

2. DESCRIPTION AND APPLICATIONS OF EXISTING PLATFORMS

2.1 WHOI's ice-tethered profiler (ITP)

The Woods Hole Oceanographic Institution's (WHOI, USA) Ice-Tethered Profilers (ITP) were developed and deployed for the first time in 2004 (Krishfield et al., 2008). The ITP is designed to measure temperature and salinity down to 800m depth, and is based upon the ARGO float (Roemmich et al., 2009) which essentially is an autonomous undulating temperature and salinity profiler that transmits data in semi real-time via the Iridium network to a ground station. In 2004 and 2005, three ITP prototypes were deployed in the central Arctic Ocean, and two units were still functional after 10 months and 1200 profiles. Based on the WHOI-developed Moored Profiler (Krishfield et al., 2008), the ITP system consists of three components: (1) an above-ice unit that is frozen into an ice floe and houses a GPS, controller and data telemetry electronics, (2) a weighted, plastic-jacketed wire-rope of up to 800m in length suspended from the surface instrument, and (3) an instrumented underwater unit that profiles up and down the wire tether at a user-selected frequency. The profiling underwater unit has similar shape and dimensions as an ARGO float, except that the float's variable-buoyancy system is replaced with a traction-drive unit (Krishfield et al., 2008). Between 2004 and 2008, a total of 30 ITPs were deployed in the Arctic Basins (Rachold et al., 2011) with an autonomy of up to 3 years (Timmermans et al., 2011), and the last deployment of an ITP was in September 2015. In 2011/2012 a set of upgraded ITPs with instruments for biological measurements got deployed. The upgraded ITPs included ECOtriplets measuring chlorophyll and dissolved organic matter fluorescence and optical scatter. In addition a PAR and dissolved oxygen sensor was attached (Laney et al, 2014). Several upgraded ITPs are still operational today. Many ITP deployments are accompanied by SIMBA (see below) deployments to study variations in ice thickness. For further details about specifications of the ITPs and online data see http://www.whoi.edu/itp or key references (Krishfield et al., 2006; Williams et al., 2010; Jackson et al., 2012; Timmermans et al 2010).