AUTONOMOUS OBSERVATION OF THE ARCTIC OCEAN BELOW SEA ICE

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ABSTRACT

The Ice-Tethered Profiler program at the Woods Hole Oceanographic Institution was initiated in late summer, 2004 with the deployment of the first prototype system in the Arctic's Canada Basin. Over the subsequent 13 years, with contributions from European, Asian, and fellow North American investigators, 97 ITP systems have been fielded in the Arctic that have collectively returned nearly 100,000 data files containing information about the Arctic Ocean's thermohaline stratification and a variety of other parameters. The design and performance of these ITP systems are reviewed, recent enhancements and capabilities summarized, and challenges to the future of the program are discussed.

INTRODUCTION AND SYSTEM DESCRIPTION

The Ice-Tethered Profiler system (ITP) was designed to sample the upper ocean below drifting sea ice and return data in near real time. Krishfield et al. (2008) and Toole et al. (2011) describe the technology and system performance (see also www.whoi.edu/itp). In short, the expendable ITP consists of a surface buoy (housing telemetry and GPS electronics) that supports a weighted wire-rope tether extending through the ice and down to (at most) 800 m, Fig 1a. The heart of the ITP system is a cylindrical vehicle fitted with sensors (similar in size and shape to an Argo float) that employs a traction wheel to travel up and down the tether at a nominal speed of 25 cm/s. Sensors are operated continuously (at native sample rate) during profiling; data are uploaded to the surface buoy after each profile using inductive modem technology and then telemetered to shore via Iridium Rudics. Data may be stored in the underwater vehicle and/or surface buoy should satellite telemetry be interrupted. Discrete sensors may be additionally affixed to the tether above and/or below the profiling interval, with data telemetry managed similarly. ITP sampling is governed by a user-defined schedule that may be modified in near real time after deployment. Sampling options include the timing of observations and pressure interval to profile, as well as ability to make observations for a specified period at a constant depth. Deployments may be done from ice camps (supported by fixed wing aircraft or helicopters) or ships. The majority of deployments have been through holes augured through ice floes but a handful of systems have been installed in open water (the buoy has sufficient buoyancy to support the system); most of those have survived fall freeze-up.

The basic ITP system was designed for an operational lifetime of more than 2 years assuming approximately 1500 m of profiling per day (e.g., 2 one-way profiles of 750-m span). Actual lifetimes of the full ITP system are often less than this, Fig 1b. There are two major failure modes of ITPs: crushing of the surface buoy and/or breaking of the tether in ice ridging events and dragging of the tether in shallow water (causing the vehicle to be ripped off the wire or the tether to break). Attempts to restrict deep profiling as ITP systems approach shallow water have had mixed success. As is evident in Fig 1b, ITP surface buoys frequently transmit position data for extended time after communication with the underwater units is lost (returning ice drift information). A small number of ITP systems that were rafted over by ice later reemerged and sent backlogs of observations obtained while the system was buried. In these cases, ice drift estimates from neighboring buoys and satellite products are used to estimate where those observations were made.

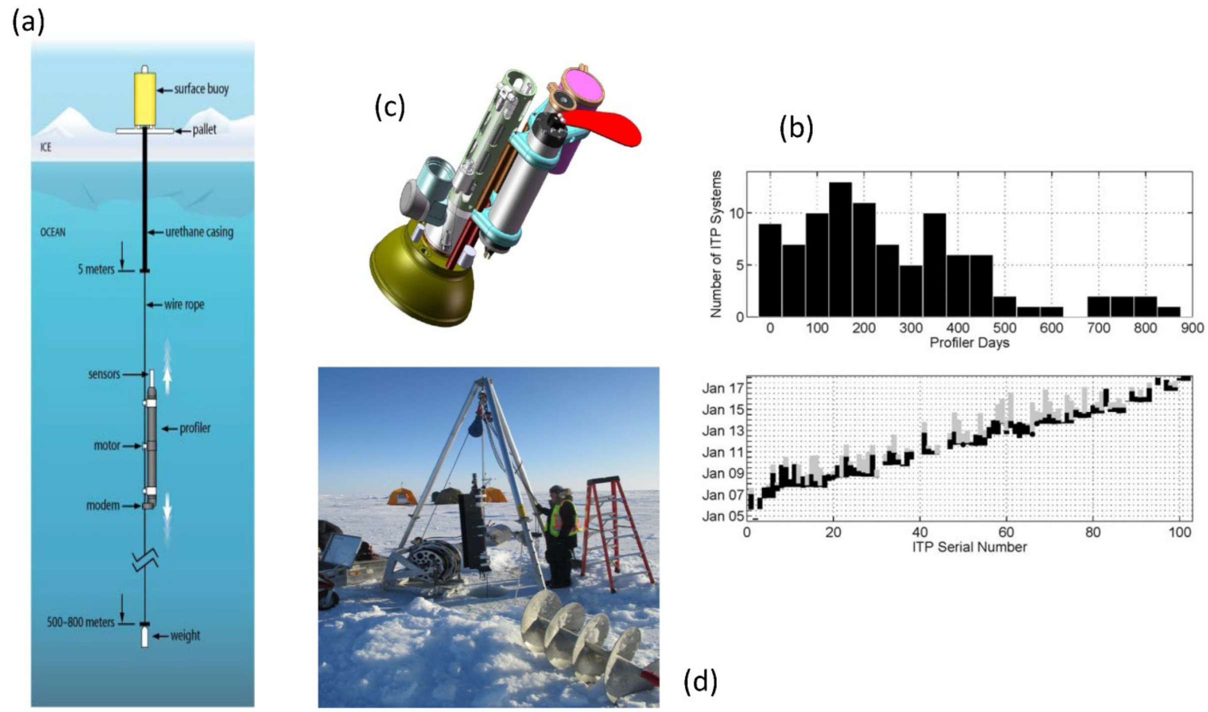

Figure 1. (a) Schematic drawing of the WHOI Ice-Tethered Profiler system; (b) Histogram of ITP underwater vehicle lifetimes (top) and (bottom) the periods (shown as black vertical bars) over which telemetry was received from each ITP underwater unit and from each corresponding surface buoy (black plus gray bars). The history of ITP systems deployed in the Southern Ocean and in lakes are excluded from this plot. (c) Schematic drawing of the bio-optical ITP sensor suite with CTD/O2, chlorophyll fluorescence, CDOM, optical backscatter and PAR (the latter suite housed under a retractable shutter), and (d) installation photograph of an Ice-Tethered Profiler with Velocity (ITP-V).

SENSORS AND RECENT ENHANCEMENTS

The first ITP systems were equipped with Sea-Bird Electronics, Inc. Conductivity-Temperature-Depth (CTD) sensors for observing the ocean's thermohaline stratification. Subsequent systems have incorporated a variety of additional sensors on the profiling vehicle including dissolved oxygen (Timmermans et al., 2010), bio-optical sensors (Laney et al., 2013), and current meters (Thwaites et al., 2011; Cole et al., 2015). In addition, temperature-conductivity, SAMI pCO_2, dissolved O_2 and pH sensors have been deployed on ITP tethers just below the ice-ocean interface (Islam et al., 2016).

ITPs record and telemeter full-resolution, full-sample-rate data, allowing accurate sensor response correction (e.g. Johnson et al., 2007) and study of small-scale ocean structures such as double diffusive staircase stratifications (Timmermans et al., 2008; Shibley et al., 2016). To reduce telemetry energy, time and cost, data compression was implemented in the ITP system, possible because of a new controller installed in the surface buoy (O'Brien et al., 2015; 2016). Work is underway presently to adapt this controller to the ITP underwater vehicle, allowing compression to occur prior to inductive telemetry to the surface buoy (saving energy in the underwater vehicle). The more capable controller will also support more complex sampling schemes, such as selectively powering sensors subsets on specified profiles. In addition, design for a new, lower-cost measurement system (allowing more widespread deployment) that focuses on the upper 1-200 m of the water column is under development.

SCIENTIFIC ANALYSES

ITP data have been and continue to be used to support a range of scientific investigations and student projects. The basin-wide and year-round coverage facilitates studies of seasonal to interannual physical and biogeochemical processes (e.g. Rabe et al., 2010; McPhee, 2013; Laney et al., 2013, 2017; Islam et al., 2017) and basin-scale phenomena (e.g. Timmermans et al., 2014), as well as supports the initialization/validation of and/or data assimilation into numerical models (W. Maslowsky, J. Carton, A. Nguyen, personal communications). Smaller scale processes may also be investigated with ITP data, including meso- and sub-mesoscale variability (e.g. Zhao et al., 2014; 2016; Timmermans et al., 2011), near-inertial internal waves (Dosser et al., 2014; Cole et al., 2014) and double diffusion (e.g. Shibley et al., 2017). Notably, the range of sensors able to be supported on ITPs and their sampling flexibility provide a wide-ranging view of the evolving Arctic Ocean system.

CHALLENGES FOR THE FUTURE

It is widely known that sea ice in the Arctic is shrinking in areal coverage, thinning, and becoming more mobile. All present complications to an ice-based observing system. Although diminished, the sea ice will remain critically important to earth's climate- and eco-systems as well as transportation and tourism, making ice-following observing platforms necessary into the future. The WHOI ITP is able to float and has demonstrated resilience during fall freeze-up. But thinner, more mobile ice can be more prone to ridging that can damage ice based buoys. It has not proven feasible to maintain the array of 20 ITP systems in the Arctic that was envisioned at program initiation. Nevertheless, ITPs have and are continuing to return valuable ocean data from the Arctic. Buoy clusters sampling various elements of the atmosphere, sea ice and upper ocean have proven particularly valuable. Beyond the cost of the ITP system (significantly greater than an Argo float), deployment logistics have constrained where and when ITP systems are deployed. It is hoped that international collaborations will continue in future to facilitate deployment of polar ocean instruments. Similar wishes extend to open, rapid data sharing of observations from all autonomous instruments deployed in the polar oceans.

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