AUTONOMOUS OBSERVATION OF THE POLAR OCEANS 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, New Zealand and fellow North American investigators, 99 ITP systems have been fielded, the majority of which were deployed in the Arctic. (The exceptions include two systems deployed adjacent to Antarctica in the Southern Ocean and three others installed in North American lakes.) The performance of these ITP systems are reviewed (updating Toole et al., 2011), recent enhancements and capabilities are summarized and challenges for the future are discussed.

INTRODUCTION AND SYSTEM DESCRIPTION

The ITP system was designed to sample the upper ocean below drifting sea ice and return data in near real time to shoreside users. 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 1. The heart of the ITP system is a cylindrical vehicle (of size and shape similar to an Argo float) fitted with sensors 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. Fixed 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 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.

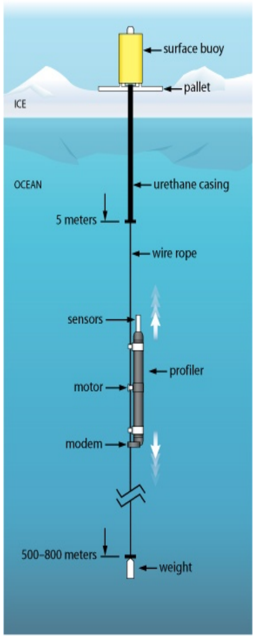


Figure 1. Schematic drawing of the ITP system

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 2. 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 2b, 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 climatology is used to estimate where those observations were made.

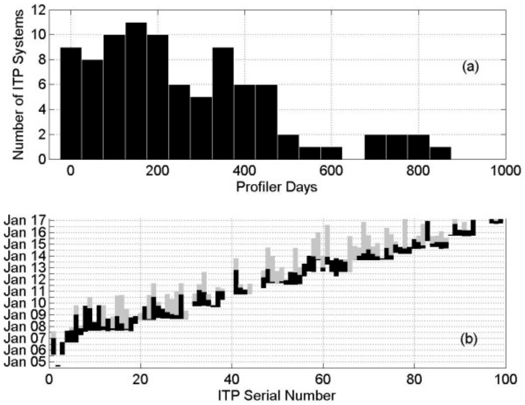


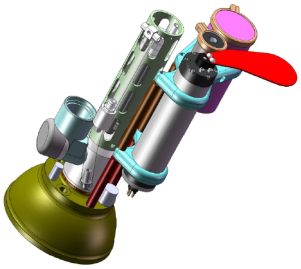
Figure 2 Histogram of ITP underwater vehicle lifetimes (a) and the periods (shown as black vertical bars) over which telemetry was received from each ITP underwater unit and from each corresponding surface buoy (black plus gray bars) (b). The history of ITP systems deployed in the Southern Ocean and in lakes are excluded from this plot. Updated from Toole et al. (2011).

SENSORS AND RECENT ENHANCEMENTS

The first ITP systems were equipped with Sea-Bird Electronics, Inc. Conductivity-Temperature-Depth (CTD) sensors for observing ocean temperature and salinity features. Subsequent systems have incorporated a variety of additional sensors on the profiling vehicle (Fig. 3) 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 (Islam et al., 2016), dissolved O_2 and pH sensors have been deployed on ITP tethers just below the ice-ocean interface.

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 recently 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.

The WHOI ITP program continues to push the technology while conducting operational deployments. Parallel development efforts are underway presently to improve the performance and data quality of the (bottom-anchored) Moored Profiler, including adoption of a streamlined vehicle body able to orient into the 3-D relative flow and place sensors upstream of any wakes from the vehicle. Ideas are in hand to extend this concept to the ITP.



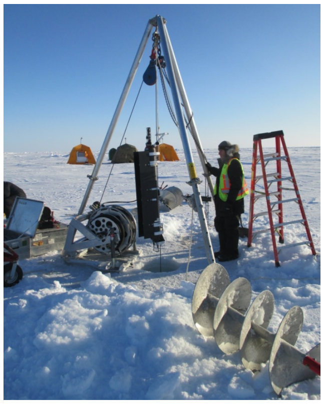


Figure 3. Schematic drawing of the bio-optical ITP sensor suite (left) with CTD/O2, chlorophyll fluorescence, CDOM, optical backscatter and PAR (the latter suite housed under a retractable shutter), and (right) a drawing and installation photograph of an Ice-Tethered Profiler with Velocity (ITP-V).

SCIENTIFIC ANALYSES

ITP data have been and continue to be used to support a range of scientific investigations and student projects. The Arctic-wide and year-round data coverage provided by ITPs facilitates studies of seasonal to interannual physical and biogeochemical processes (e.g. Rabe et al., 2010; Laney et al., 2013; Islam et al., 2017) and basin-scale phenomena (e.g. McPhee, 2013; 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 have also been 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 (e.g. 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 polar 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. But though diminished, the sea ice will remain of central importance in earth's climate- and eco-systems, which makes such 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. Some attempts have been made to make similar observations in the Southern Ocean, but no sustained measurement program using this technology has emerged. 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. (Buoy clusters sampling multiple elements of the atmosphere, sea ice and upper ocean have proven particularly valuable.) Similar wishes extend to open data sharing of observations from all autonomous instruments deployed in the polar oceans.

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