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Lagrangian sediment traps for sampling at discrete depths beneath free-drifting icebergs

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ABSTRACT

The recent proliferation of icebergs in the Southern Ocean and the chemical and biological enrichment recently identified in the surrounding water raise the question of whether these icebergs are major contributors to drawdown of CO_2 and the export of organic carbon to the deep ocean. The Lagrangian sediment trap (LST) was developed to measure the carbon export associated with these free-drifting icebergs. The core of the LST is a neutrally buoyant Sounding Oceanographic Lagrangian Observer (SOLO) float (Davis et al., 2001) that contains a variable-buoyancy engine, enabling it to sink to a set depth (600 m for the iceberg study), drift at that depth, then resurface on preset time intervals. Four sediment-trap funnels and opening/closing sample cups mounted around each SOLO float collect sinking particulate matter. Additionally, an upward-looking acoustic system mounted on the float detects the presence of ice cover above. In March/April 2009, three LSTs were deployed in the NW Weddell Sea for a total of five successful missions. Four of these LST deployments were made near or under a large iceberg. The fifth deployment was made at a control site 74 km from the nearest large iceberg. Sinking particulate matter was collected on each deployment. Despite the high-risk nature of the deployments, the LSTs successfully sampled particulate matter beneath drifting icebergs.

1. Introduction

The proliferation of icebergs originating from Antarctic ice shelves and glaciers over the past decade has raised questions about their potential impact on the surrounding pelagic ecosystem of the Southern Ocean. An earlier study suggested that free-drifting icebergs could serve as areas of enhanced production and export of organic carbon to the deep sea (Smith et al., 2007). One of the key issues yet to be resolved in evaluating the role of icebergs in the global carbon cycle is the production and export of particulate organic carbon associated with the surrounding pelagic community. The question remains whether these icebergs significantly influence the carbon cycle of the Southern Ocean.

Determining the amount of particulate matter associated with a large, unstable, chaotically drifting iceberg is a technical challenge. Due to their irregular and, at times, treacherous shapes and propensity to calve without warning, it is dangerous to navigate around or beneath icebergs with traditional underwater vehicles such as remotely operated vehicles (ROVs) or autonomous underwater vehicles (AUVs). For an ROV, one considerable risk is entangling the tether connecting the vehicle to the ship on protrusions from the iceberg or on surrounding brash ice (Hobson et al., 2011). AUVs have been used successfully under ice shelves (Brierley et al., 2002; McPhail et al., 2009). However, the constant motion of a free-drifting iceberg changes the frame of reference creating navigational issues for an AUV (Kimball and Rock, 2011).

Bottom-moored and surface-tethered sediment traps have been used routinely to collect particulate matter through the water column to estimate sinking particle flux. However, there have been serious biases of such designs due to turbulent flow across the collection surface (e.g., Gardner, 1980; Gust et al., 1994; Buesseler et al., 2007a). Neutrally buoyant sediment traps were developed to drift with the surrounding water at discrete depths to collect sinking particulate matter while minimizing turbulent flow and contamination by “swimmers” (Buesseler et al., 2000; Lampitt et al., 2008). The neutrally buoyant sediment trap (NBST) was developed to sample upper-ocean particle fluxes at discrete predetermined depths using an auto-ballasting controller and cylindrical collection tubes that close on recovery (Valdes and Price, 2000). A similar free-drifting sediment trap was designed around an Autonomous Profiling Explorer (APEX) buoyancy engine float with either isobaric or isopycnal capabilities for sampling at a predetermined depth or density surface using four collection funnels (Lampitt et al., 2008).

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The more stringent criteria for sampling under free-drifting icebergs required a neutrally buoyant sediment trap that could be quickly deployed to depth in front of an on-coming iceberg, be acoustically tracked during sampling at depth, and be recalled when in open water. Here we describe the development of the Lagrangian sediment trap (LST) and the five deployments made under two icebergs in the NW Weddell Sea during March/April 2009.

2. Lagrangian sediment trap development

For this project, we required a low-cost vehicle that could be deployed autonomously to drift beneath an iceberg and collect sinking particulate matter. Following the collection period, the vehicle would drift clear of the iceberg and safely resurface. The LST consists of five critical components: a descent weight with a guillotine release, a buoyancy engine, an acoustic modem, sediment traps, and surface tracking devices.

2.1. Buoyancy engine

The LST was developed around an existing buoyancy control system, the Sounding Oceanographic Lagrangian Observer (SOLO) float (Davis et al., 2001). These floats have a variable-buoyancy engine and control system enabling them to change their density relative to the surrounding water. SOLO floats can perform over 200 conductivity-temperature-depth (CTD) profiles between 2000 m and the surface over a period of several years. In such missions, the SOLO float sinks to a set depth and drifts along within the surrounding water mass for a pre-programmed interval. At the end of the interval the buoyancy engine pumps oil out of the pressure hull to increase the vehicle's displacement and the float slowly rises to the surface, collecting CTD data on the ascent. On the surface, the SOLO float uses an Argo satellite transmitter to send data back to shore. An additional air bladder fills when the vehicle surfaces to ensure reliable communications to the Argo satellite network in rough seas. The SOLO float was incorporated into an autonomous vertical profiling instrument to estimate particulate organic carbon distribution to 100 m depth in the Southern Ocean (Bishop et al., 2004).

For the iceberg sampling mission, the SOLO floats met several requirements: the ability to sink well below a deep-draft iceberg and drift at a fixed depth for a programmable interval, a means of communicating its position to aid surface recovery, and a cost that did not prohibit deploying several of these instruments on risky missions. One of the technical challenges of this project was to modify the SOLO floats in such a way that they could sample particulate matter sinking beneath icebergs. Combining sediment traps with neutrally buoyant floats has been done for sampling in the open ocean (Valdes and Price, 2000; Lampitt et al., 2008). The remaining challenge for our study was to use neutrally buoyant sediment traps to sample beneath free-drifting icebergs.

2.2. LST mechanical system

The SOLO float is encased in an anodized aluminum cylinder, 110 cm long and 17.3 cm in external diameter, with a hemispherical top end cap (Davis et al., 2001; Fig. 1). The LST, with all components mounted onto the vehicle, weighs 45 kg in air. The batteries, air valve, pumps, and ball-screw-driven piston are mounted on an internal frame. The oil-filled rubber bladder, located at the bottom of the internal chassis, is protected inside a plastic sleeve. During assembly the internal chassis slides into the cylindrical body and an O-ring provides a seal. The SOLO controller board set is mounted onto a snap ring at the top of the cylindrical housing. The electronics for the CTD (Seabird, SBE 41CP) are housed in the top end cap.

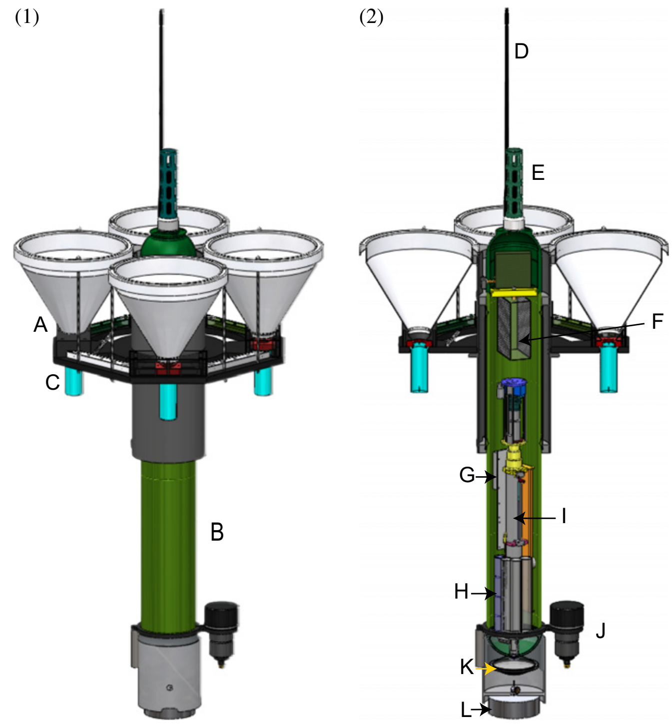

Fig. 1. The LST design was based on adding sediment traps and an upward-looking sonar to the existing SOLO float. (1) A solid model of the Lagrangian sediment trap (LST) illustrates the placement of the sediment traps (A) on the SOLO frame (B). The collection cups (C) are shown in the collection position. The ARGO satellite antenna (D) and the CTD sensors (E) are mounted on top of the float. (2) A cut-away view of the LST displays the internal mounting of the SOLO controller (F), the serial datalogger (G), and the lithium battery packs (H). In the center of the internal chassis is the piston (I) that pushes oil into the external bladder (J). External to the vehicle are the modem transducer (K) and the descent weight (L).

A ball-screw-actuated piston pushes oil in and out of a rubber bladder external to the pressure housing. As more oil is pushed into the bladder, the overall displacement of the vehicle increases, but since the weight remains the same, the vehicle becomes more buoyant. Reversing the process results in the internal void being filled with oil and thus the vehicle becomes denser. The piston is retracted at the commencement of a mission, drawing oil into the housing from the bladder, thus making the vehicle dense and minimizing the time it takes to sink to depth. Once at depth the float controller drives the piston in or out to maintain the programmed depth, allowing the SOLO float to drift with the current. After a preset interval the buoyancy engine pumps oil into the bladder for resurfacing.

In addition to the buoyancy control systems built into the SOLO float, we added two separate weight releases. Because our mission plan consisted of deploying the LST in the path of a drifting iceberg, it was important to have the vehicle sink very quickly to the target depth. To achieve this, a 7-kg descent weight was added to each LST. With the addition of the descent weight, the vehicle could reach 500 m, well below the iceberg, within 15 minutes. The descent weight was attached to the bottom of the vehicle with a piece of monofilament fishing line (45 kg test). The line was fed through a pressure-activated guillotine, which was calibrated to cut the line at 500 m. An ascent weight was also added to the system to increase the speed at which the vehicle resurfaced. The ascent weight was released by a burnwire as described in the electronics section below. The SOLO's buoyancy engine is mainly used to make small corrections in depth and not to change depth by significant amounts.