

—Report—

## Upper Ocean Heat Observation using UpTempO buoys during RV *Mirai* Arctic cruise MR14-05

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This report describes surface water temperature measurements obtained by an autonomous observing instrument “UpTempO” as a part of RV *Mirai* Arctic cruise in 2014, MR14-05. The UpTempO is a drifting buoy consisting of an underwater thermistor chain, carrying 16 thermistors and 3 pressure sensors, and a surface floating unit for Iridium satellite communication with sensors of sea surface temperature and sea level pressure. Three UpTempOs have been deployed from RV *Mirai* in the ice-free Chuckchi Plateau. UpTempOs have successfully collected the near-surface temperature data to reveal seasonal change of surface layer heat content during a transition from late summer to mid-winter. The past *Mirai* expeditions, aiming to reveal the yearlong air-sea heat exchange in the Arctic, has faced difficulties to continue the observation after the surface freezing onsets since RV *Mirai* is not designed to sufficiently resist pressures from surrounding ice floes. Then, deploying the autonomous instrument such as UpTempO from the ship could make it possible to carry out the prolonged observation even the freezing onset onward.

**Keywords :** UpTempO, Arctic Ocean, RV *Mirai*, oceanic heat content, sea ice

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## 1. Introduction

The Arctic ice cover has experienced an extreme reduction over the last few decades (Comiso, 2008; Parkinson and Cavalieri, 2002). The Arctic sea-ice extent reached a record minimum in September 2012 displacing the same month in 2007. This diminished ice condition in the Arctic Ocean could massively influence the global climate system by causing the enhanced atmospheric disturbances (Honda et al., 2009; Inoue and Hori, 2011), propagating towards the lower latitudes as planetary waves, since the air-water heat exchanges can be promoted.

In the polar seas, there has been common difficulties in executing scientific observations, especially collecting under-ice hydrographical data because it requires many research staff, technical facilities and operational platforms such as ships with ice-breaking ability, submarines and sea-floor moorings (e.g. Surface Heat Budget of the Arctic (SHEBA)). Currently, non-manned hydrographical observation using autonomous observing systems, which are mostly installed on perennial ice floes and communicate via an Iridium satellite, are partly replacing the ship-based *in situ* observation in the Arctic (e.g. Krishfield et al., 2005; Richter-Menge et al., 2006).

The JAMSTEC Arctic research team has investigated the atmospheric and oceanographic changes in the use of autonomous observing instruments: JAMSTEC Compact Arctic Drifter (J-CAD) for 2000–2005 (Kikuchi et al., 2002) and Polar Ocean Profiling System (POPS) for 2006–2013 (Kikuchi et al., 2007; Kawaguchi et al., 2012) as a part of the North Pole Environmental Observatory Program (NPEO; principal investigator, James Morison of U. Washington). During MR14-05, the western Arctic summer expedition of the RV *Mirai*, we have deployed a new type of autonomous observing instrument “UpTempO”, carrying an under-water thermistor chain, in the ice-free Chukchi Plateau.

This article describes the observation of upper water temperature and heat content using the UpTempO buoys. Section 2 gives the detailed description of UpTempO and MR14-05. In Section 3, the observed temperature from UpTempOs and their trajectories are illustrated. In Section 4, a brief conclusion and future works will be noted.

## 2. Methods

### 2.1 UpTempO

UpTempO (product name: Marlin Iridium SVP-BTC/RTC/GPS Ice Buoy, manufactured by Marlin-Yug) (Fig. 1) is an autonomous instrument capable of automation operation on ice and in water. The buoy executes measurements of barometric pressure, sea surface temperature, and temperature profile down to the depth of 60 m. The wire line has 3 ocean pressure sensors at 20, 40, and 60 m, and 16 thermistors at vertical intervals of 2.5 m over 2.5–20 m depth and 5 m over 20–60 m. The under-water thermistors are 0.1°C in accuracy and 0.01°C in resolution. The data sampling and transmission through Iridium satellite system are made every an hour.

The UpTempO buoy project is led by Mike Steele and Ignatius Rigor of Polar Science Center, University of Washington. They aim to reveal how the magnitude of ocean surface warming is accelerating in the pan Arctic region as sea ice thins and retreats in the recent summers. Nearly

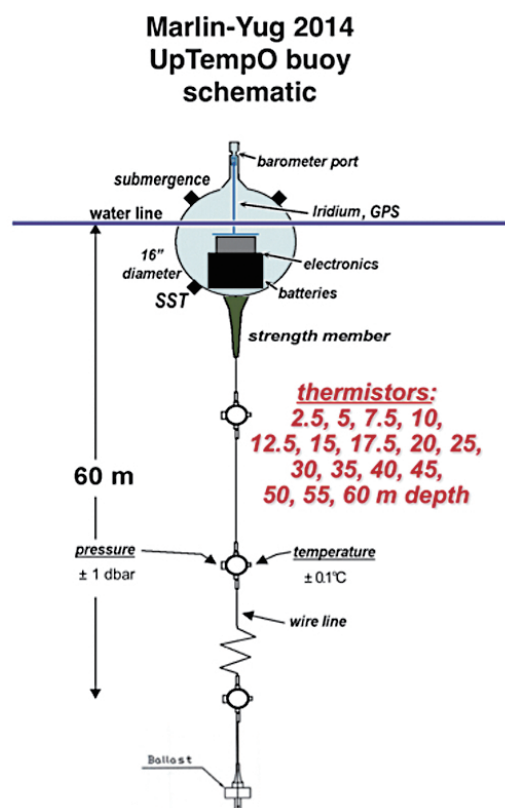


Fig. 1. A schematic representation of the UpTempO, deployed in the ice-free Chukchi Plateau during MR14-05. Note that the present version of the instrument is partly different from the generic one on the webpage.

real-time data and detailed information of UpTempO is available from

<http://psc.apl.washington.edu/UpTempO/UpTempO.php>  
(web & data manager: Wendy Ermond).

## 2.2 MR14-05

MR14-05 is an Arctic summer expedition based on RV *Mirai* with a scientific theme of “The Predictability Study of the Arctic Cyclones” (Inoue, 2014). The entire observation period was between August 31 and October 10, 2014. As a main program during this cruise, we carried out a fixed-point-observation (FPO) at location of (74.75°N, 162.0°W) in the Northwind Abyssal Plain (the east of Chukchi Plateau) in the ice-free Arctic (Fig. 2), where 147 radiosonde launches, 97 conductivity-temperature-depth (CTD) casts, 177 microstructure measurements were carried out.

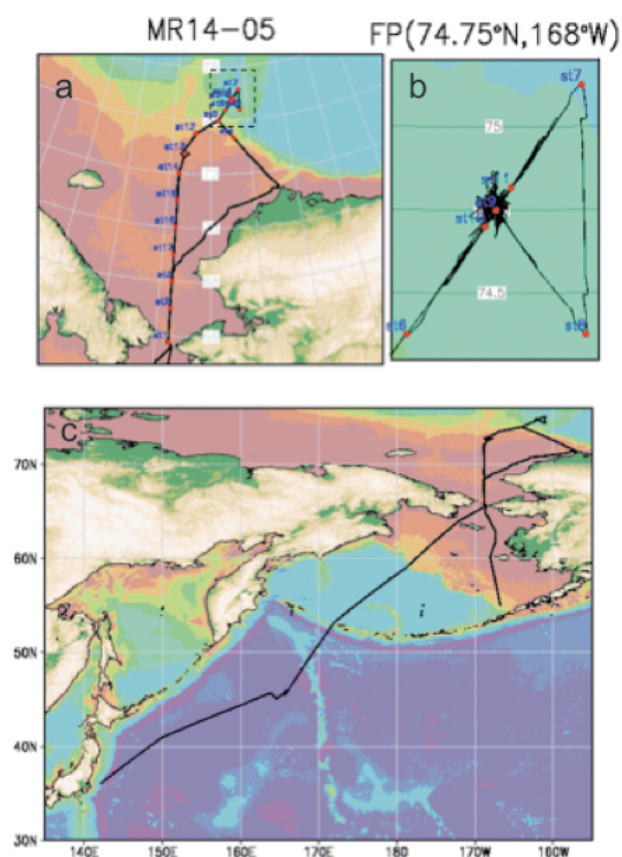


Fig. 2. Cruise track and study domain of MR14-05. (a) CTD stations in the Arctic Ocean (north of the Bering Strait), (b) detailed ship track and CTD stations during FPO (magnifying a dashed-line box in (a)), and (c) overall cruise track between Japan and the Arctic stations. Color shade denotes bathymetry. (Figure courtesy: J. Inoue)

Three UpTempOs were deployed during the FPO program, referred to as UpT13, 14, and 15 for their identification. All buoys were placed into surface water from *Mirai*'s stern deck. The deployment of UpT13, 14 and 15 was made respectively at location of (74-22.75°N, 163-57.46°W), (74-33.02°N, 163-30.14°W) and (74-54.74°N, 163-34.98°W) and at time of 01:06Z on 6th, 10:32Z on 14th, and 16:32Z on 14th September 2014 (Fig. 3a).

As of the late February in 2015, UpT13 has been only buoy that is reporting the seamless data. Meanwhile, other two UpTempOs (UpT14 and 15) terminated its data sending following the surface freezing onset, at which almost simultaneously all of the instruments entered the marginal ice zone (Fig. 3b). This probably means that the spherical-shaped surface floats have either underlain the ice floes or been breached by lateral pressure from surrounding ice floes. To prevent this fault, we will attempt to replace the spherical float into conical-shaped one in the future opportunity because the lateral ice pressure may less affect it.

## 3. Preliminary Results

This section describes the preliminarily upper water temperature recorded by the UpTempOs between early September and mid-November when the seasonal change in surface heat content is the most dramatic.

Initially, from early September to mid-September, the sea water is the warmest at depths shallower than 20–30 m, underneath which it is colder with the lowest temperatures of  $-1.3$ – $-1.2$ °C at 30–40 m depth (Fig. 3b). In the near-surface warm layer, UpT13 and 14 show the maximum temperature being about 1.3–1.5°C, while UpT15 shows temperatures no warmer than 0.2°C, implying there is a horizontal surface front structure between the deployment positions of UpT14 and UpT15 (Fig. 3b). Therefore, the total heat content within the 20 m surface layer, an accumulation of temperature deviation from the freezing point, is about  $1.5 - 2.4 \times 10^8 \text{ J m}^{-2}$ . According to the shipboard meteorological observation, the sum of net shortwave, longwave, latent, and sensible heat fluxes near the water surface was approximately  $50\text{--}60 \text{ W m}^{-2}$  (air cools the water) on average for 5–26<sup>th</sup> September. With this surface flux, it takes roughly a month to release the overall heat content within a surface mixed layer (SML) to the air.

Unfortunately, we cannot determine the exact depth of SML since the present type of UpTempOs carries no conductivity sensor. Instead, with hydrographical profiles obtained by an expendable CTD observation at nearly the same position as UpT14 was, the SML depth was calculated at about 18–22 m on 6<sup>th</sup> September, where the maximum stratification is mainly responsible for a salinity gradient ranging 27.4–29.5 psu over vertically 10 m; this halocline depth gives a good agreement with the maximum gradient in UpTempO’s vertical temperature profile.

In the surface layer within 20 m depth, temperature continues to decrease until the mid-October when it gets to almost the freezing point of  $-1.6^{\circ}\text{C}$  (Fig. 3b). Prior to the late September, the thermistor chain of UpT13 and 14 shows that there is a vertical temperature inversion – the colder

water (~10 m depth) overlies the warmer water in the deeper SML. In this period, we guess the surface heat flux due to the atmospheric cooling deprives the oceanic heat mostly from the thin boundary layer, and there is surely insignificant heat supply from the layer underneath the SML (i.e. no catastrophic mixing eroding the SML base). In fact, the ship-based microstructure measurement at the FPO station depicts that the deeper SML is relatively quiet from the mid-to late September, where the buoyant Reynolds number is generally less than 20 (Yamazaki, 1990). After the freezing temperature achieved, temperature profile becomes nearly homogeneous and gradually deepened down to ~35–40 m depth by 25<sup>th</sup> October. This suggests that the buoyancy-driven convective motion, accompanying sea-ice formation in the surface water, actively eroded the SML base (e.g.,

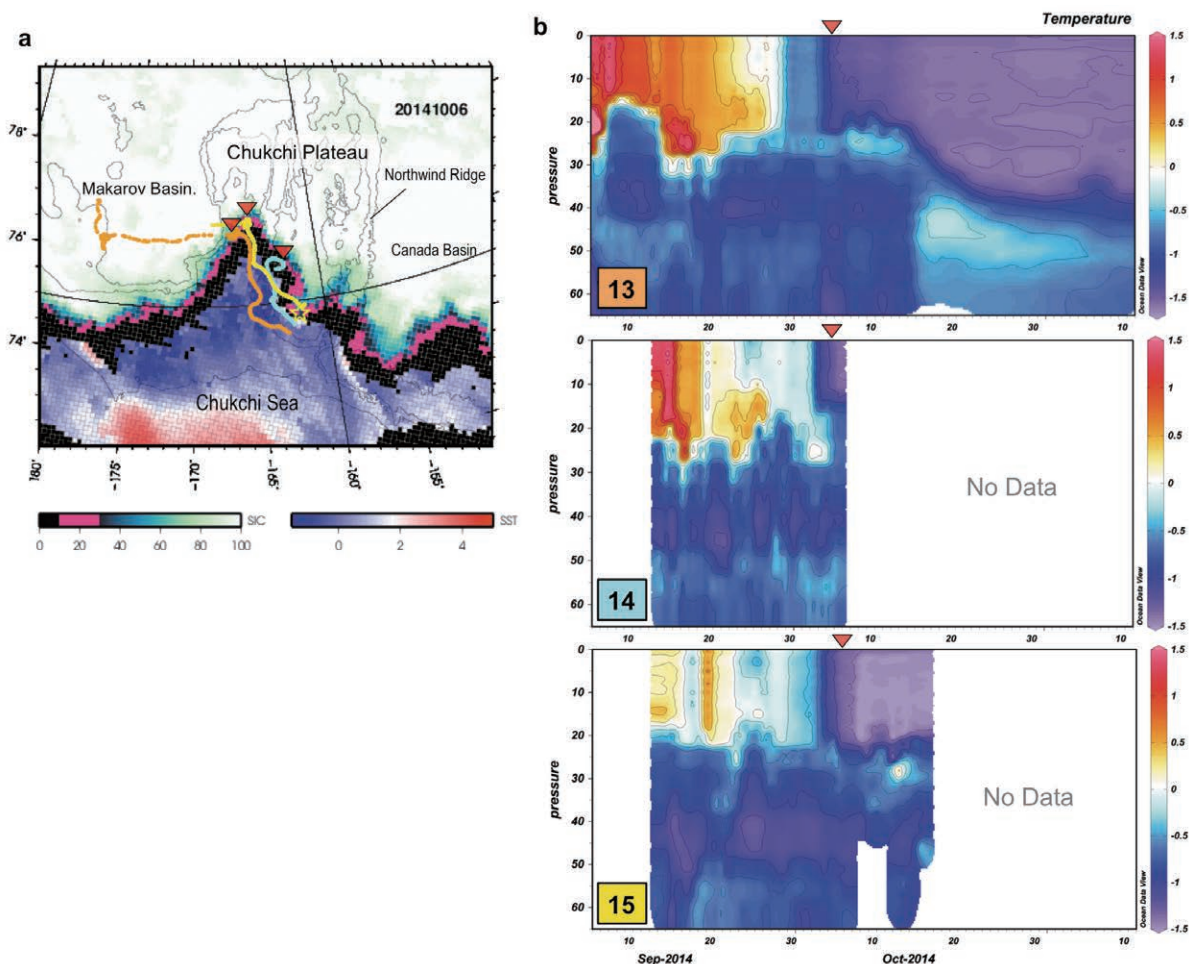


Fig. 3. (a) Trajectories and (b) time series of upper water temperature by UpTempOs. In (a), green-white color denotes the Advanced Microwave Scanning Radiometer 2 (AMSR-2) sea-ice concentration on 6<sup>th</sup> October 2014, where marginal ice zone (MIZ) with ice concentration being 10–30% is marked in magenta. Blue-red color shade indicates AMSR-2 sea surface temperature on the same date. A yellow star marks location of the FPO station. Bathymetric contours indicate 100, 500, 1000, and 2000 m. Red, inverted triangles mark UpTempO’s geographical positions on 6<sup>th</sup> October. In (b), the red triangles on top of each panel mark the corresponding time. Contour intervals for temperature are  $0.2^{\circ}\text{C}$ . In (a), orange, cyan, and yellow lines indicate trajectories of UpT13, 14, and 15, respectively. In (b), digits 13–15 denote the identification number.

Kikuchi et al. 2004; Peralta-Ferriz and Woodgate, 2015). After that, it persists at the nearly freezing temperature.

The all buoys travelled towards northwest along the local bathymetry (Fig. 3a). The traveling speed was approximately between 10 to 30 cm s<sup>-1</sup>. This can be considered that the travelling of the UpTempOs was influenced by the westward flow of Beaufort Gyre (BG), located to the north of the Alaskan continental shelf (McPhee 2013; Brugler et al. 2014; Nishino et al. 2011). Considering initially 0.2–1.3°C warm SML (1.8–2.9 kelvin above the freezing), the near-surface current may produce a lateral heat flux of  $1.5 - 7.2 \times 10^7$  W per width towards the central Chukchi Plateau in the early September. Indeed, the obvious delay of surface freezing was observed in the BG's downstream region including the west of Chukchi Plateau, (75–76.5°N, 163–166°W), where the buoys actually went through (Fig. 3a). This consequence may be applied to that in the other recent summers; e.g. surface velocity profiler's trajectories in October 2013 (deployed off the Barrow Canyon during MR13-06) similarly indicated the delay of ice formation along the pathway of the BG's westward current (Kawaguchi and Nishino, 2014). Similarly, based on their mooring array across the Beaufort shelf-break and -slope, Brugler et al. (2014) show that the eastward boundary current transporting the warm Chukchi summer water has dramatically decreased between 2002 and 2011. They argue that the warm Chukchi water instead exits the Barrow Canyon entering the Canada Basin and then is transported towards the Chukchi Plateau by the BG westward jet.

#### 4. Conclusion and Future Works

Upper water temperature observation was performed using the UpTempO buoys during MR14-05 in collaboration with Polar Science Center of U. Washington. During the cruise, three UpTempOs were deployed in the east part of ice-free Chukchi Plateau. The UpTempOs have successfully collected the data to show how upper water temperature is changing during a transition between late summer to mid-winter including the surface freezing event.

In the past *Mirai* expeditions we have had difficulties retrieving the hydrographic data in the ice-covered Arctic Ocean especially once the surface water starts to freeze. Hence, it is rather rare to obtain the year-round temperature data in the seasonally open water region near

the central Arctic, which describes the surface water being cooled by the air and frozen. In this sense, utilizing the autonomous observing instrument would be a very effective means to gain a better understanding about the yearlong air-ice-ocean coupling system in terms of heat in the western Arctic Ocean. Thus, in future on-site examinations, the combination of the ship-based manned observation and the use of autonomous instrument would give a particular advantage and progress in this scientific field.

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