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Observing Thermohaline Structure of Polar Ocean with XCTD Launched from Helicopter

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ABSTRACT

A new operational method of launching XCTD (expendable conductivity-temperature-depth profiler) probe from helicopter is presented. The method provides a means to observe vertical temperature and salinity profiles in polynyas and other openings surrounded by sea ice that obstructs research vessels to enter. Several experiments conducted in partially ice-covered regions, the Prydz Bay in the Southern Ocean and the Canada Basin in the Arctic Ocean, have confirmed the applicability of this method. Although comparative tests of ship-board CTD and helicopter-launched XCTD show very limited errors, the effect of extremely high launching position on the depth accuracy of helicopter-launched XCTD still needs to be investigated in future.

KEY WORDS: XCTD; error; fall rate; helicopter; polar ocean.

INTRODUCTION

As free-fall instruments, both XCTD (expendable conductivity-temperature-depth profiler) and XBT (expendable bathythermograph) have been widely used for hydrographic measuring of the upper ocean since they were initiated in 1970s. For seawater, the density and thus, the dynamics is defined more by salinity than by temperature in cold conditions. Therefore, XCTDs are more useful than XBTs for observations in polar ocean even though they are more expensive. Besides ship deck from where XCTD probes usually are launched, ice floes in the polar ocean provide a convenient platform for XCTD deployments. The operator can stand on sea ice and launch XCTD into the ocean through a drilled hole or any natural opening. By landing on the ice, a helicopter or aircraft can transport people and instruments to XCTD deployment sites where ships can not reach. However, in some regions, e.g., polynyas and heavily broken ice, it is impossible to land the helicopter or airplane. Although AXCTD (airborne XCTD) can be considered in this situation, it has seldom been applied due to its complicated hardware and great expenses. In this paper, we will introduce a new way to conduct observations with XCTD in polar ocean beyond ship's scope, i.e. launching XCTD from a helicopter hovering above the sea surface. Firstly, we present a brief introduction of the operation and experiments; then we show the data and discuss the possible influence of this new method; finally, we draw a preliminary conclusion.

OBSERVATIONS

The first test of XCTD and XBT launching from helicopter was conducted in Antarctica in December 2007. More XCTD probes were launched from helicopter during the Chinese cruise in the next summer. Finally, the vertical temperature and salinity profiles of a polynya in Antarctica were observed by 3 XCTD probes launched from helicopter in December 2008.

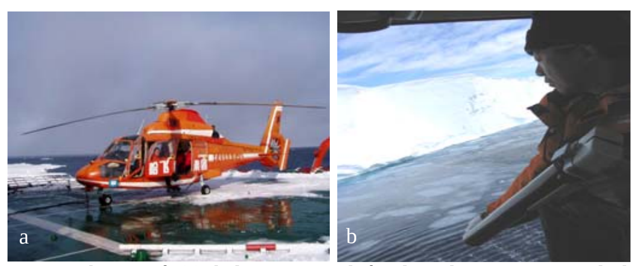

Fig. 1 Photos of (a) helicopter used for launching XCTD and (b) launching XCTD from helicopter into a polynya at north of Amery Ice Shelf, Antarctica on December 17, 2008.

Operations

XCTD probes used for our observations are the model XCTD-1 made by TSK (Tsurumi-Seiki Co.). A TSK TS-MK-130 System powered by a battery was used to control the XCTD measurements and a laptop was used for data acquisition. All the instruments were fixed in the passenger compartment of a helicopter (Model Zhi-9, similar to AS365 Dauphin). On reaching the deployment site, the probe was launched through the open helicopter door while the helicopter hovered at 20 m altitude. The measurement followed the standard procedure. An advantage of launching the probe from helicopter is that there is less chance the XCTD wire will be damaged in the air. However, the strong air flow driven by the airscrew might pull more wire released from the launcher. In the most serious situations, the excessive wire might be cut by the turning airscrew. Therefore, the operator had to control the wire with his fingers very carefully.

Experiments in Antarctica

During the first test conducted on December 11, 2007, two XCTD probes and one XBT probe were launched from a helicopter into a small opening in the ice covered ocean at north of the Amery Ice Shelf (Fig 2a). Data of the two XCTDs were sent back successfully but one of them was not recorded by the laptop due to a mistake at operation. An XBT probe of model T-7 made by Sippican Co. was used but it sent back data with unrealistic values. In this test, a ground wire connected to a TS-MK-130 system was lowered into the sea water through the door on the other side. The noise in the XBT data looks like the result from the faulty ground wire. In fact, it is hard for a person on the helicopter to make sure the ground wire is immerged in the seawater. So we give up the test of launching XBT from hovering helicopter. The ground wire was not connected to the TS-MK-130 system in later experiments for it is not necessary for XCTD measurements.

Table 1. Station information of XCTDs launched in Antarctica

No	Date and Time	Latitude	Longitude
1	2007-12-11 15:13	72°32.02′ E	68°34.08′ S
2	2008-12-17 05:40	71°07.02′ E	68°40.25′ S
3	2008-12-17 05:52	70°58.13′ E	68°37.38′ S
4	2008-12-17 05:58	70°52.44′ E	68°35.35′ S

The other experiment in Antarctica was conducted on December 17, 2008. After about one hour's flying, the helicopter reached a polynya at north of Amery Ice Shelf (Fig. 2b). Three XCTD probes were launched from the hovering helicopter above the polynya. All of the XCTD data were recorded successfully.

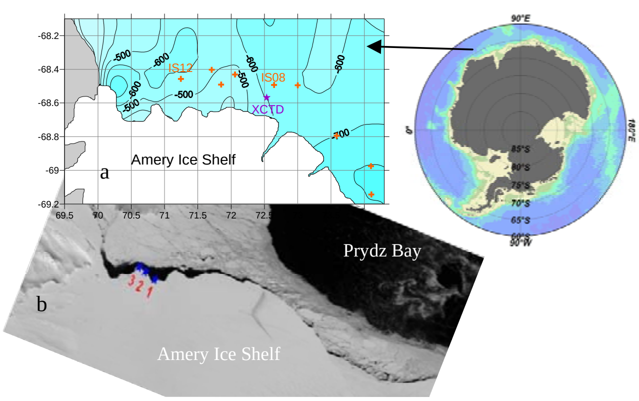

Fig. 2 Locations of XCTDs launched from helicopter at north of Amery Ice Shelf. (a) XCTD (purple star) launched on December 11, 2007. CTD stations (orange crosses) conducted February 2008 are also labeled on the map with depth contours in meters. The base map is a MODIS visible image on that day. (b) 3 XCTDs (blue stars numbered 1, 2 and 3) launched into a polynya on December 17, 2008. The base map is a MODIS visible image on that day.

Observations in Arctic Ocean

Totally seven XCTD measurements (Stations X07-11, X18 and X19) were conducted by the way of being launched from helicopter during the Chinese cruise to the Arctic Ocean in the summer of 2008. However, two of them (X10 and X11) were interrupted due to the broken XCTD wire. Locations of some XCTD measurements (Stations X07-11) as well as CTD deployments (Station B79-B82, P80, N81 and N82) in the Canada Basin are shown in Fig. 3.

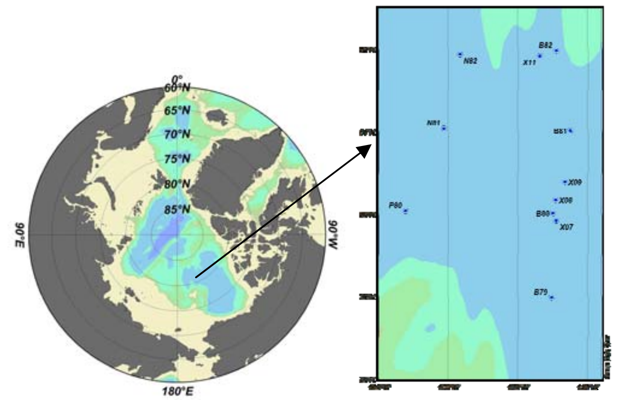

Fig. 3 Locations of XCTD and CTD observations in the Canada Basin conducted by Chinese cruise in the summer of 2008.

DATA

Temperature and conductivity are measured by XCTD directly during its descent in the water. Depth is calculated based on a formula

$$d(t) = at - bt^2 \qquad (1)$$

where d is the depth in meters and t is the elapsed time in seconds. The coefficients used in the manufacturer's TS-MK-130 XCTD system are: a = 3.42543, b =4.7026 $\times 10^{-4}$. The negative sign before b indicates a slow decrease in fall speed due to wire loss and drag increase. The sampling rate of the XCTD measurements by the TS-MK-130 is 25 Hz. This translates into a vertical resolution of about 14 cm for the XCTD. Both raw data and 1 m interval data are presented by the data processing software of XCTD.

Preliminary results in Antarctica

The temperature and salinity profiles of the first XCTD launched from helicopter in December 2007 are presented in Fig. 4 and the data of CTDs observed in nearby locations two months later are also shown for comparison. Although the upper ocean has become warmer and fresher in summer as shown by observation at IS12, no obvious bias exists in data at all 3 observations for the lower ocean below the summer thermocline and halocline. The extreme cold water at depth of ~150 - 300 m is super-cooled water originating from the cavity under the ice shelf. More discussions of the super-cooled water and XCTD data obtained in the Antarctica could be found in another paper (Shi et al., 2011).

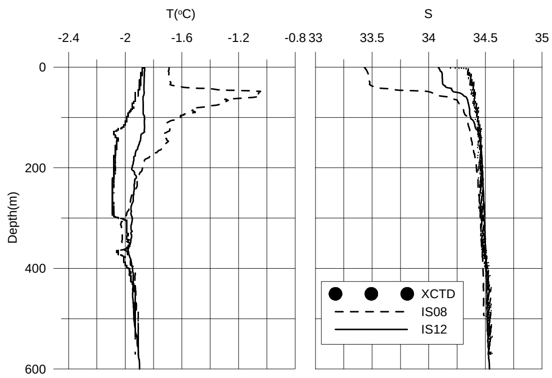

Fig. 4 Profiles of temperature and salinity observed by XCTD launched from helicopter in December 2007 and by CTD at Stations IS08 and IS12 in February 2008 at north of Amery Ice Shelf.

Comparison with CTD in Canada Basin

Since no side-by-side XCTD-CTD comparison experiments had been conducted, data obtained by CTD in nearby locations are to be used for comparison (Fig. 5). There is no obvious bias between data of XCTD and CTD except for the temperature below depth of 400 m where the temperature observed by XCTD is greater than that by CTD at the same depth. This bias indicates that the depth of XCTD launched from helicopter might be underestimated by the manufacturer's formula.

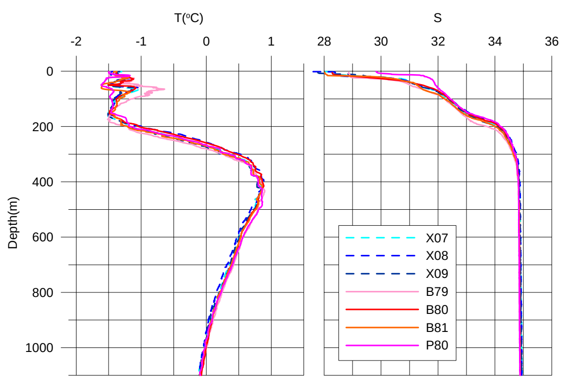

Fig. 5 Profiles of temperature and salinity observed by XCTD at Stations X07, X08 and X09 and by CTD at Stations B79, B80,B81 and P80 in Canada Basin in 2008.

Stations X07 and X08 are closed to Station B80 with a distance of 11.6 km and 17.5 km, respectively, and they were conducted within 5 hours (Table 2). So profiles of these 3 stations are chosen for a more detailed comparison (Fig. 6). The differences of temperature and conductivity between XCTD data and CTD data at the same depth calculated with 1 m interval data are shown in Fig. 7, and the statistics results for depth greater than 20 m are listed in Table 3.

Table 2. Station information of XCTD and CTD observations in the Canada Basin in 2008.

Station	Date and Time	Latitude	Longitude
X07	2008-8-16 22:01	79°54.93' N	147°17.00' W
X08	2008-8-16 22:21	80°09.94' N	147°16.69' W
B80	2008-8-16 17:59	80°02.08′ N	158°02.97′ W

The standard deviations of differences are beyond the range of nominal accuracies of XCTD, i.e. ±0.02 °C and ±0.03 mS/cm for temperature and conductivity, respectively. The mean of temperature differences is negative, which also indicates a bias for the XCTD. This bias also can be found in the profiles of temperature differences in Fig. 7. The largest differences occur in the depth range of 200-400 m where the permanent thermocline and halocline are located. Both positive and negative errors are found in this layer, which implies that the differences do not result from the spatial variations of the thermohaline structure, but rather from wrong estimates of the XCTD depth, although the negative temperature bias below 400 m is a clue that the XCTD depth might be underestimated.

Table 3. Statistics of differences between XCTDs and CTD at depth > 20 m

Value	Station	T (°C)	C(mS/cm)	S
Mean	X07	-0.045	-0.035	0.023
	X08	-0.031	-0.004	0.049
Standard deviation	X07	0.051	0.074	0.079
	X08	0.041	0.048	0.046

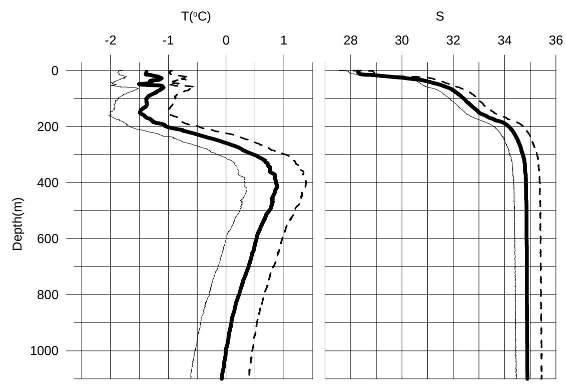

Fig. 6 Profiles of temperature and salinity obtained at Stations B80 (thick line), X07 (thin line, shifted by -0.5°C for temperature and -0.5 for salinity) and X08 (dashed line, shifted by 0.5°C for temperature and 0.5 for salinity) in the Canada Basin in 2008.

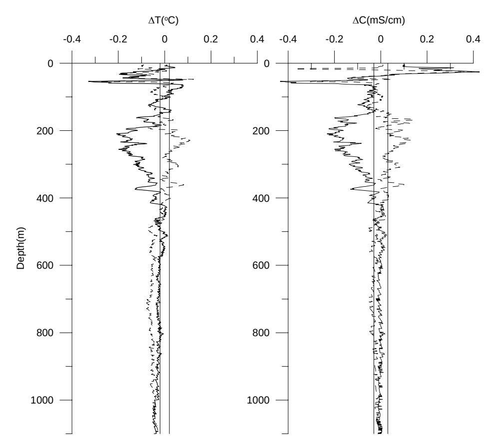

Fig. 7 Temperature and conductivity differences of X07 (solid line) and X08 (dashed line) relative to B80. The vertical lines define the interval of nominal accuracies.

DISCUSSIONS

The essential difference of XCTD deployments between the traditional way and our new way is the launch height, i.e. the altitude of a hovering helicopter is much higher than that of a ship deck. Theoretically, the longer distance between launch position and the sea surface will result in a higher descending speed for XCTD probe. The coefficients in the Equation (1) should be modified according to XCTD-CTD comparison experiments results. However, this type of experiments has not been conducted until now. We will discuss the effects of the changed launch height as well as the special problem of XCTD used in cold regions on the basis of previous studies. More studies of XBT than that of XCTD are referenced in our discussions for the former advanced the latter remarkably.

Effects of launching position

The manufacturer did not provide limits for the XCTD launch height. 2.5m is recommended by the manufacturer for the XBT launch height. If external causes do not modify the fall, the entry speed when the XBT probe touches seawater is about $w_0 = 6.5$ m/s, as great as the coefficient *a* in the fall rate equation for XBT that is the same as Eq. 1. According to the manufacturer's (Sippican's) specifications, the minimum and maximum launch height for XBT are 1 m and 15 m, respectively. However, the influence of the launch height on the probe's fall rate in water is still unclear. A probe freely falling from a higher position will reach a higher speed before entering the water. Ignoring the transient effects when the probe strikes the sea surface, the problem of launch height could be reduced in consideration of the initial speed when the probe hits the water. With a bulk dynamic model, Green (1984) evaluated factors affecting the dynamics of XBT, including probe mass, bulk drag coefficients, wire loss and initial fall speed. He found that the initial speed and orientation of the probe contribute to the depth error and the depth error is a constant offset below the first 10 m. Initial speed of 2 and 3 times of w_0 will result in 1.1 m and 1.9 m increase in depth, respectively. Aiming to check Green (1984)'s predictions, field comparisons have been conducted by making twin XBT drop during the same CTD cast from different heights of 2.5 m and 8.0 m, respectively (Reseghetti et al., 2007). Unfortunately, the dataset of twin drops has poor statistics, and the results of the test are uncertain: the starting depth of the upper thermal gradient measured by XBT probes is either deeper or shallower than the true depth, without apparent correlation with the launching position height and time delay. Therefore, further tests are required in order to obtain an answer to such a problem.

After striking the water surface, the XBT probes usually orient vertically within 1 s (Green, 1984) and require more or less 1.5 s to reach a falling speed of w_0, independent of the entry speed (Hallock and Teague, 1992). The transient adjustment is too fast to be measured, and a number of factors, such as probe orientation, fall speed at impact, vertical speed of the water surface, ship speed through the water, and probe mass influence the dynamics of the transient state(Green, 1984). So this process and its influence on depth estimates are still unknown.

Particularity in the polar ocean

The coefficients used in the manufacturer's TS-MK-130 XCTD System are obtained by Mizuno and Watanabe (1998) on basis of 6 XCTD/CTD comparison tests in the north Pacific Ocean near Japan (~34°N, 143°E) and the south Indian Ocean south of Java (~13-17°S, 108-115°E). Recently, Kizu et al (2008) evaluated XCTD fall rates based on more co-located measurements with CTD profilers in the North Pacific (20-55°N). They confirmed that the present manufacturer's fall rate coefficients satisfy the accuracy guarantee of 2% of depth, at depths greater than 20 m. Furthermore, they found that the coefficients in the formula of the XCTD fall rate are dependent on water temperature, and the probes tend to fall slightly faster in warmer water. The inapplicability of the acquired XBT fall-rate coefficients in low temperature regions was proved by Thadathil et al. (2002) using controlled XBT–CTD datasets collected in the Southern Ocean (~30-70°S). Their results show that the manufacturer's equation slightly overestimates the fall rate in cold regions, which is opposite to the situation reported earlier for tropical and subtropical regions (Hanawa et al, 1995). They attributed this difference to the variation of viscosity and pointed that the probe will have more significant decelerating tendency due to the higher viscosity effect in cold high-latitude waters. According to the XBT/XCTD standard test procedures (Sy and Wright, 2000), the method of Hanawa et al. (1995) is usually applied to estimate the coefficients in the fall-rate equation. This method was proposed for XBT firstly and then was used for XCTD on the basis of temperature profiles of XCTD/CTD pairs (e.g., Mizuno and Watanabe, 1998; Kizu et al, 2008). Temperature rather than conductivity is chosen simply because the latter is greatly more sensitive than the former. However, the vertical temperature gradient is too small (~5°C, but ~25°C in the lower latitude ocean) to provide fine reference for comparison due to the narrow range of temperature in the cold water regions, which challenges the efforts to improve the accuracy of depth for extendable probes in polar oceans. XCTD fall-rate variations in waters of polar oceans and the resulting depth errors should be addressed using more controlled XCTD–CTD datasets collected in the Arctic Ocean and in the Southern Ocean.

According to above discussions, with the manufacturer's formula, the XCTD depth in our experiments might be underestimated due to the higher launch position and be overestimated due to the colder temperature. Therefore, the correction of XCTD depth becomes more complicated for the XCTD data collected with our new method.

CONCLUSIONS

In order to conduct hydrographic observations in polynyas and other openings surrounded by sea ice that obstructs research vessels to enter, we provided a new operational method of launching XCTD probes directly from helicopter hovering above sea surface. Several experiments conducted in partially ice-covered regions, the Prydz Bay in the Southern Ocean and the Canada Basin in the Arctic Ocean, have confirmed the applicability of this method. Without pressure sensors, XCTD estimates depth from the time elapsed after the probe hits the water surface, under the hypothesis that the probe descends in the water at a steadily but slowly decreasing velocity.

Due to the higher altitude relative to that of the XCTDs usually deployed from ship deck, the depth data of helicopter-launched XCTDs should be corrected. Although the comparative tests of ship-board CTD and XCTD launched from a helicopter hovering ~20 m above the sea surface in the Canada Basin show very limited errors in depth data of XCTD, more experiments still need to be conducted to confirm the accuracy of the depth data. Once data are available to correct the XCTD depth formulation for larger launch altitudes, this method will expand the CTD survey of research vessels that are unable to penetrate high ice concentration.

Because the depth estimation formula for the XCTD is obtained from ship-board CTD and XCTD side-by-side comparison data in the middle and low latitude oceans, it needs to be assessed and modified for XCTDs used in polar oceans (temperature near freezing point, very weak vertical temperature gradient, stratification mainly depending on salinity) and with different launching altitude (also including the decreased altitude when a XCTD is deployed from a floe).

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