# Towards ice core sampling by subsea robotic vehicles

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**Abstract.** Ice coring has developed into one of the most frequently used sampling methods across cryospheric sciences. Sea ice, firn and glacial ice are sampled using a range of different coring systems. These systems can retrieve core samples with lengths ranging from several cm to tens of meters when operated by hand or drilling machines, while specialized coring systems have retrieved cores from Antarctica's ice caps with a length of over 3 km. In the last decade more robotic subsea vehicles like remotely operated vehicles (ROV) and autonomous underwater vehicles (AUV) have ventured into polar waters beneath sea ice and ice shelves, but retrieval of ice samples from the sub-ice environment has not been achieved on a regular basis. Other geophysical investigation methods such as push core sediment coring and rock drilling have been successfully adapted for subsea robotic vehicles. Hence the purpose of this work is to investigate the feasibility of adapting the techniques of retrieving short ice cores from sea ice and glacial research to the subsea environment. We successfully demonstrate the retrieval of an ice sample in a laboratory setting using traditional ice coring systems in conjunction with a subsea manipulator arm. We discuss challenges and further improvements to our experiments towards enabling reliable ice sampling in the subsea environment using generic tooling readily available on subsea vehicles. In conclusion, ice core sampling in the subsea environment seems feasible using industrial work class manipulators particularly when cartesian inverse-kinematic control is available.

## 1. Introduction

Obtaining ice samples from frozen water ice is an important sampling method for cryospheric science. Ice core samples allow for investigations of the physical, biological and chemical properties of sea ice as well as glacial ice and firn. The retrieved samples allow for a diverse set of analyses, that require melting or other processing such as sectioning, which would not be possible in situ. Hence ice coring has developed as a central method throughout all cryospheric sciences. Deep holes have been drilled to retrieve ice cores of several hundred meter lengths from polar ice sheets and glacier caps using highly advanced drilling systems. Shorter core-samples are most often retrieved either by handheld ice coring systems or using regular power tools (Rand and Mellor, 1985). A complete review of different existing coring technologies is available in (Talalay, 2016; Talalay and Hong, 2021).

While obtaining ice samples is a common procedure starting from earth's surface, ice sampling from the subsea environment is less common. Scientific interest in sampling the sub-ice environment particularly under sea-ice was already raised in the late 1980ies, when a subice suction corer was operated on an articulated arm as well as by a diver underneath sea ice (Welch

et al., 1988). This device however only used a suction pump to collect cuttings chipped from the ice by a rotary drill bit and did not retrieve an actual ice core. Since then, subsea robotic technologies have evolved significantly, but no further attempts of retrieving ice samples from underneath the ice are known to the author except from some concept sketches (Vedachalam et al., 2015). Two studies (Vedachalam et al., 2017; Yang 2019) have investigated thermal ice coring drills for remotely

35 operated vehicle (ROV) or underwater glider deployments. These works however focus on numerical simulation of the coring process and present laboratory tests. From a practical standpoint however, these thermal methods require a lot of electrical power >1000W and are quite slow in retrieving an ice core. Hence thermal drilling methods do not seem to provide the ease of use to be easily integrated in routine subsea operations underneath polar ice.

As existing ice-coring systems are readily available and provide easy handheld retrieval of ice cores, this work aims to

40 investigate the applicability of standard ice coring systems for retrieval of ice-samples from subsea robotic platforms. Subsea use of existing coring systems is characterized along with the capabilities of current subsea robotic manipulator arms. While specialized drilling tools could certainly be constructed, only an easy operation principle building on existing vehicle components will enable widespread use such as with push coring of sediment samples.

## 2. Materials and Methods

45 ### 2.1. Ice coring systems

For the trials two different coring systems were used: One of them was built in-house based on an open-source design, while the second coring system is a commercially available one (Fig. 1):

As small size of the coring system comparable to a typical sediment push corer would provide realistic chances for being incorporated into under-ice robotic sampling strategies, a small ice corer was built by the AWI workshop. It was based on an

50 open-source design (Thomsen et al., 2020) provided by the University of Aarhus (Denmark) which was initially developed for robotic ice-sampling as payload underneath an aerial drone (Carlson et al., 2019). The corer has a length of 19 cm and retrieves a core with just under 7 cm diameter. The coring bit consists of three cutting teeth which have a staggered design, so that each cutting tooth is only cutting one third of the slot. The corer is designed to be used on a regular battery powered drill and provides a hexagonal shaft interface for the drill chuck.

55 The second corer was a Mark II Coring System (Kovacs Ice drilling equipment, Alaska, USA, https://kovacsicedrillingequipment.com/coring-systems/coring-systems/). This coring system is widely used in the cryospheric science community and provides an ice core of up to 100cm in length and 9 cm in diameter. The cutting head consists of two identical cutting teeth and the corer is designed to be both operated by a power drill or using the supplied T-handle for manual coring. The significant length is not optimal for efficient subsea operation, but the manufacturer confirms,

60 that a shorter version can be easily manufactured for subsea operations. The system is also available in versions retrieving a 7.5cm and 14cm diameter core.

In typical field operations both coring systems would be operated using the same handheld cordless power drill, hence in a similar range of rotation rate, torque and drill thrust. However the Mark II coring system is also designed for manual operation at lower rotation rate (revolutions per minute: rpm) and higher torque. Both systems were interfaced to the manipulator arm using a T-handle, a common interface in scientific subsea manipulations. While the T-handle included in the system for manual coring was used for the Mark II corer, a T-handle was improvised for the hexagonal interface on the smaller corer using parts from a ratchet toolbox.

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**Fig. 1. Experimental ice drilling setup. The manipulator arm is mounted to a wooden pallet for both coring systems. Panel A and C show the self-constructed short ice corer, while panel B and D show the setup using the commercially available Kovacs Mark II**

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coring system. Panel B shows the control laptop running the "Reach Control" software as well as the pendant master arm controller just in front of the manipulator arm.

### 2.2. Subsea manipulator arm

For these trials we did not use a specialized electric or hydraulic subsea drill, but the rotary function of a standard subsea
75 manipulator wrist joint. While this is not designed for drilling, it is designed to replace a human hand under water and hence should be able to operate ice corers designed for manual operation. If standard vehicle parts can be used in contrast to additional drills it would enable a much easier integration of ice core sampling on existing remotely operated vehicles.

The manipulator was a Bravo 7 Pro (Reach Robotics, Sydney, Australia) 7 function manipulator arm. While the arm provides a depth rating of 450m water depth, we performed our tests in air for easier observation. The Bravo 7 is one of the
80 most powerful electric subsea manipulators with a lift capacity of 10kg at full reach and a weight of 9.5kg. A particular feature of this manipulator arm is the advanced inverse kinematic control that allows control of the end-effector in cartesian coordinate space. This is particularly well suited to allow for exactly aligned drilling motions in axis with the coring device. The manipulator was equipped with an end effector consisting of 4 interlocking jaws that was used to reliably grab the T-handles on both corers. The arm can be controlled by a pendant master arm for manual operation, but drilling trials were
85 performed using the "Reach Control" software in conjunction with keyboard control of the motion in cartesian space. This essentially enabled ice coring to be a two button operation, where one key controlled corer thrust in the axis of the corer and one key controlled the rotary motion of the wrist joint. According to the specification sheet, the wrist joint provides a torque of 20 Nm and a rotational speed of 7.5rpm. Torque on all motor axes is monitored and can be limited during operation.

### 3. Results

90 Ice coring tests were performed with a sample tray of tap water frozen into a solid ice block at approximately -15°C. This ice provides similar mechanical properties to dense glacial ice and is much harder than typical sea ice. The ice block was taken out of refrigeration shortly before each coring trial, but no efforts were undertaken to conserve the temperature of the ice.

First tests were performed using the in-house built corer (Fig. 1A and C). However several problems arose with this system: The staggered cutting teeth did not protrude the corer enough to evenly penetrate an uneven surface, leading to strong
95 wobbling of the corer on the ice surface. The hole could not be started using the manipulator due to the low rpm. Only after the hole was started using a cordless power drill the manipulator arm could continue coring to a depth of a few cm. However coring progress was very slow and soon the operation had to be ended, after significant damage had occurred to the sensitive cutting teeth rendering the corer dull and unable to progress. No ice core sample could be retrieved in this first test.

The second round of tests was more successful when the Mark II Coring System from Kovacs Ice Drilling was used. Starting
100 the coring was also difficult, as the corer length made it somewhat too big for easy handling with the Bravo 7 manipulator, and because the larger diameter T-handle provided by the coring system did not provide a stiff enough connection between corer and manipulator end effector. Nevertheless, after some tries the hole was started successfully and the corer did cut the

ice. In several occasions the more aggressive cutting teeth of this system cut too deep into the ice leading to torque values too high for the manipulator wrist joint. Rotating the corer counterclockwise to re-engage the cutting teeth in a different

105    position was able to overcome these points where the corer had become stuck. This problem can be avoided by reducing the protrusion of the cutting teeth from the coring head by utilizing the so called "elevating screws" to keep the coring head further away from the cutting front and hence limit drilling torque (Rand and Mellor, 1985).

When rotating, the corer proceeded into the ice with a speed comparable to that of manual ice core sampling. Due to the comparably slow rotational speed of the manipulator wrist joint and the corer getting stuck several times, retrieval of the

110    17cm long core was achieved within approximately 35 minutes (Fig. 2). This time can be significantly improved by fine tuning the coring head to the available torque to avoid the corer to get stuck. As this work only aims to investigate the feasibility of subsea ice coring, no further optimization of the drilling process was performed.

As drilling trials were performed in air, excessive heating of the manipulator arm's rotary joint was observed and alleviated by cooling with ice cuttings from the drilling process. Such overheating will likely not occur, when the manipulator is

115    operated submerged in water close to its freezing point and heat can dissipate much more effectively.
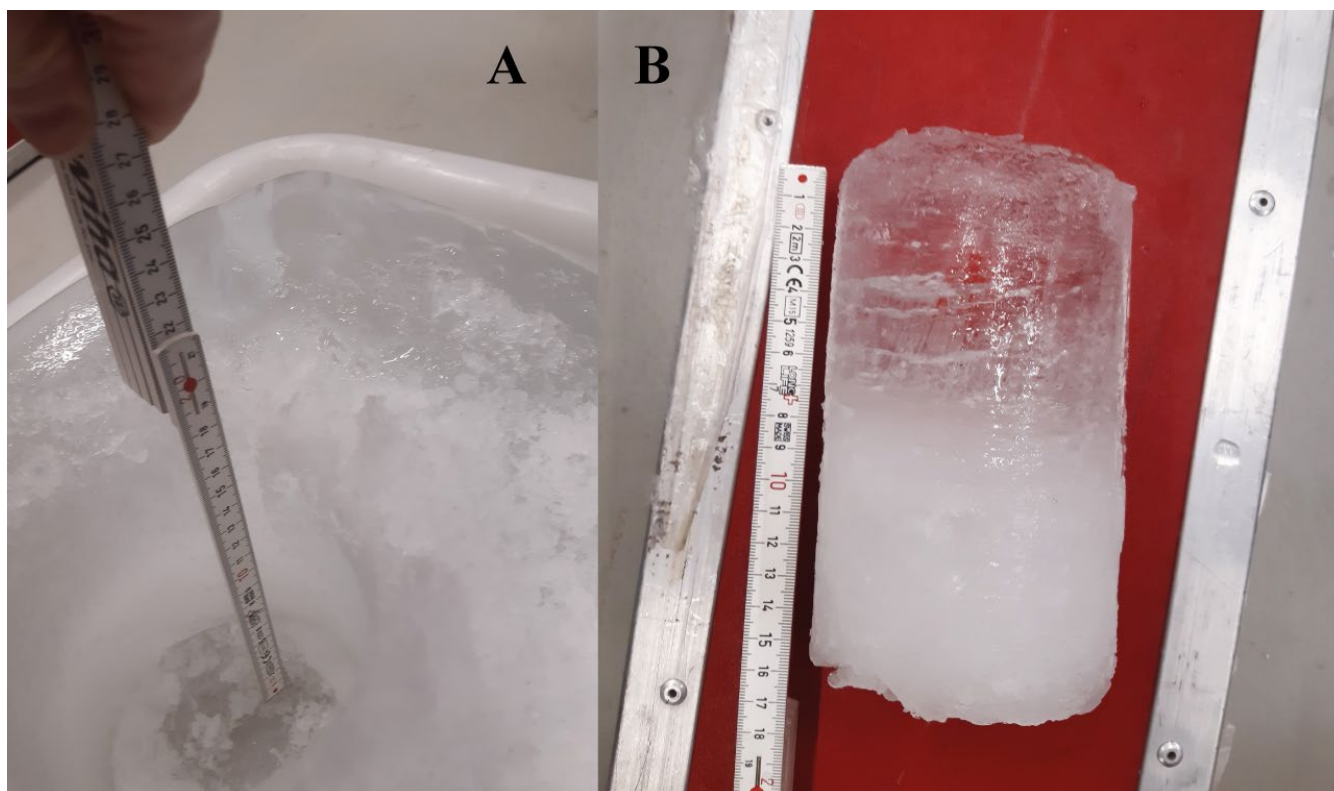
**Fig. 2. A) The core hole drilled into the test ice block and B) the retrieved ice core sample.**

## 4. Discussion

The results of these ice coring tests using subsea manipulator arms will be discussed in the following and set into context of
120 the specifications of ROV manipulator arms as frequently used by industrial and scientific ROV teams:

### 4.1. Challenges

As already reported above, several challenges occurred during the drilling process. The corer got stuck several times as the
settings of the coring head lead to higher torque than the manipulator's wrist joint could deliver. This can be both improved
by accurately setting the "elevating screws" of the coring head to limit drilling torque, as well as be compensated by using
125 bigger work class manipulators that provide roughly ten times more torque than the Bravo 7 manipulator arm. A higher wrist
rotational rate as present on these work class manipulators will also lead to a significantly faster drilling that should be able
to achieve rates at least as high as manual driving of the ice coring system. Table 1 provides an overview about the
characteristics of frequently used robotic manipulator arms in the work class ROV segment. Typically wrist torques of
subsea manipulators range from 8-350 Nm (Sivčev et al., 2018a) at 6-35 rpm.
130 Starting the coring was challenging at times, but an improved T-handle (or fishtail) interface optimized to snugly fit into the
end-effector, as well as a shorter coring system will improve rigidity of the manipulator-corer-system and ease the first phase
of coring. A big advantage of using the manipulator arm and not a dedicated coring drill is, that the corer can be
disconnected from the arm at any point in the drilling process. Hence it does not pose a threat to vehicle safety if a corer
becomes completely stuck even without any additional safety system.
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**Table 1: Specifications of different typical work class manipulator arms in comparison to the model used in this study**

| Manipulator Arm | | rpm | Torque (NM) | Control |
|---|---|---|---|---|
| Bravo 7 Pro (Reach Robotics) | electric | 7.5-10 | 20 | Master arm, cartesian |
| Saab Seaeye eM1-7 (Saab Seaeye) | electric | 20 | 330 | Master arm, cartesian |
| Orion 7 (Schilling Robotics) | hydraulic | 6-35 | 205 | Master arm, (cartesian)* |
| Titan 4 (Schilling Robotics) | hydraulic | 6-35 | 170 | Master arm, (cartesian)* |

* Cartesian control for the Schilling Robotics manipulators is not commercially available but has been demonstrated in
multiple research papers(Sivčev et al., 2018b; Hildebrandt et al., 2008).

### 4.2. Control of manipulator arm

During our drilling trials, it became apparent, that a key to successful subsea ice core sampling is control of the manipulator's end effector in a cartesian space using inverse kinematics. Due to the comparably long duration of coring operations it is difficult to keep the coring axis unchanged while advancing the corer using a conventional pendant master arm controller. Being able to fix the axis of coring progression and separating the drilling control to two buttons: advancing and rotation enables consistent coring without the risk of additionally introducing high torque due to misalignment of the corer axis. This 6 degree of freedom inverse kinematic control is becoming more common particularly on modern electric manipulators, but also has been implemented within research projects on more traditional hydraulic manipulator arms [12].

### 4.3. Sample handling and preservation

While these trials covered only the mechanical act of ice core sample retrieval from subsea vehicles, several other issues remain to be tackled for true subsea ice core sampling.

Impact of the sample being completely submerged in seawater will need to be assessed, as well as the possibility to store the retrieved ice corer with sample in some sort of thermally isolated holster, which is also sealed against fluid exchange. The implications will highly depend on the scientific method used to further investigate the ice core sample, but we expect that sufficient scientific value remains. Processing methods would need to be developed how the samples could be best retrieved after an ROV dive and how long they can be conserved during a dive.

### 5. Conclusion

In conclusion our series of trials demonstrates that standard coring systems from the cryospheric sciences can be used for subsea ice core sampling with minor modifications. Current working class manipulator arms provide enough force, torque and rpm for a coring process comparable to manual ice core retrieval. Integration of additional electric or hydraulic drilling tools seems unnecessary, hence making it possible to retrieve ice cores with standard ROV manipulator arms. Easy ice coring requires cartesian inverse kinematic control of the manipulator arm, which is becoming more frequently available on modern work class manipulator systems.

### Video supplement

A video of drilling experiments can be accessed as electronic supplemental material here: doi:10.5281/zenodo.13221220

### Competing Interests

The author declares that they have no conflict of interest.

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