Development of a Second-Generation Ice Tethered Profiler with Velocity Sensor

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Abstract—**The Woods Hole Oceanographic Institution has developed Ice Tethered Profilers (ITP) with velocity sensors to measure mean current vs. depth and the turbulent flux beneath the ice of momentum, heat, and salinity. The ITP climbs up and down a mooring hanging under the Arctic ice sheet. After a profile, the data is sent up the mooring cable with an inductive modem and telemetered back to shore with an Iridium modem. The first deployment showed larger measured velocity noise than desired due to wakes of the velocity sensor advecting though the sensed volume and the amount of data sent back was very large. The two goals of the present development are to reduce the self-generated noise in measured velocity and reduce the bandwidth of data sent back without compromising the data quality.**

Two approaches were tried to reduce noise in the measured velocity. The first was over-sampling and averaging of the current measurement and second was designing a new sensor geometry optimized for profiling. Over-sampling and averaging can average out much of the Strouhal wake of the upstream bluff structure of the acoustic-travel-time sensor. This reduced the self noise on ascents from 5.2% to 2.26% of profile velocity.

The second approach to reduce measured current noise was a new sensor geometry optimized for a profiler. A general purpose current sensor must be pretty good from all directions. In the middle of the ocean, the density of scatterers is often very low making the use of Doppler velocity sensors problematic. Acoustic travel time sensors do a good job of measuring water velocity along their acoustic paths, but if the wake of the transducers or structure supporting the transducers advects into the measured volume, the velocity measured will not be the undisturbed velocity. When a current sensor is mounted on a profiler that turns into the relative current, the geometry can be optimized to avoid causing wakes in the sensed volumes. The acoustic paths were also lengthened from 10 cm to 20 cm. This reduced the self noise on ascent from 5.2% to 1.36% of profile speed.

The second goal, of reducing the bandwidth of data sent back, was addressed by changing the attitude measuring system. If a sensor is just measuring scalers in the ocean, the profiler only needs to measure pressure to get depth. In order to rotate measured current into earth coordinates, the attitude of the profiler must be measured. The first version had three-axis angle-rate gyros, three-axis accelerometers, and three-axis magnetometers. The sensors were polled at two Hertz, the data sent to shore, where the attitude processing was done. The two Hertz sampling was required because, in strong current, the profiler had a heading wander of about one degree at about a half Hertz. In simulation, this wander would have been aliased if measured at one Hertz. The new system has a VectorNav VN-100 attitude heading reference system which calculates the attitude at a 200 Hertz in situ. This sensor is then polled at one Hertz to reduce the data volume sent back without aliasing

Keywords—current measurement, MAVS, vortex shedding, moored profiler

I. INTRODUCTION

The Ice Tethered Profiler (ITP) was developed at the Woods Hole Oceanographic Institution and was developed from the Moored Profiler [1],[2]. The ITP climbs up and down a mooring cable hanging from a buoy in the Arctic ice. The bottom of the mooring cable is a weight creating cable tension which is not meant to hit or drag on the bottom. After a profile, data is telemetered up the cable by an inductive modem to the top buoy, and then to shore via Irridium. Because of the cost of sending an ice-breaker to the Arctic ice, the normal plan is to get the data back by satellite until the batteries die. The first ITP's had just a Conductivity, Temperature and Depth (CTD) sensor. There is much interest in understanding and modeling the melting of the Arctic ice cap.

To better measure the flow under the Arctic ice, a current sensor was added to the ITP to measure mean current vs depth and the turbulent fluxes under the ice of momentum, heat, and salinity, Fig. 1, [3][4]. In order to rotate the measured relative current into earth coordinates, the attitude of the profiler has to be measured.

It is expensive bringing the equipment needed to bore a hole in the ice for the deployment, so the ITP was designed to minimize the required hole size. There is a tradeoff of distance between the flow sensor and profiler which decreases the flow disturbance in the measured volume and the size of the hole needed. The sensor is held upstream of the cable and close to the CTD for the turbulent flux measurements. The fin design is also a compromise between whole size and heading wagging from vortex shedding. There are two fins extending back from the diameter normal to the flow. Vortex shedding oscillation could be completely avoided with a fairing that keeps the boundary layer attached, but this fairing would be

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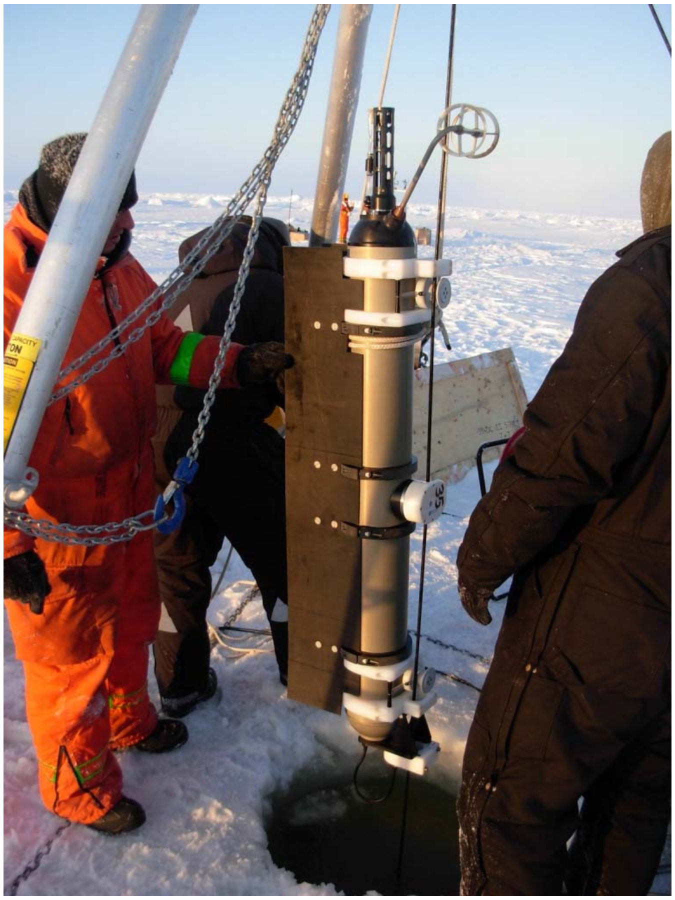

Fig. 1. Deployment of the first ITPV. The profiler has to be lowered through a hole in the ice. The plastic tail fins point the profiler into the relative current and reduce wagging of the profiler from vortex shedding.

significantly longer than the fins used. The fins used result in about a plus or minus one degree wagging in a 35 cm/s flow.

The first ITPV was deployed but the flow measurement was noisier than hoped for, Fig. 2. Acoustic travel time current sensors can be thought of as measuring a line integral of current along an acoustic path. This profile is from a particularly quiet time and in this profile, most of the variance on each path was caused by the motion and shape of the profiler and sensor. The metric that will be used to measure self-created flow noise is the standard deviation of velocity divided by the velocity of the profiler. This metric is good when the water is still, but overestimates the noise when the water is not still by adding the residual flow to the noise estimate. The descending profiles are also noisier than the ascending profiles due to wakes of the profiler advecting into the measurement volume. This could be reduced if the sensor could be held farther in front of the profiler but this would increase the size of the needed deployment hole.

A second issue with the ITPV has been the volume of data sent back. The acoustic current meter with the rate gyro creates a 31 byte record at two Hertz which takes a significant amount of energy to send up the inductive modem and cost to send back via Iridium

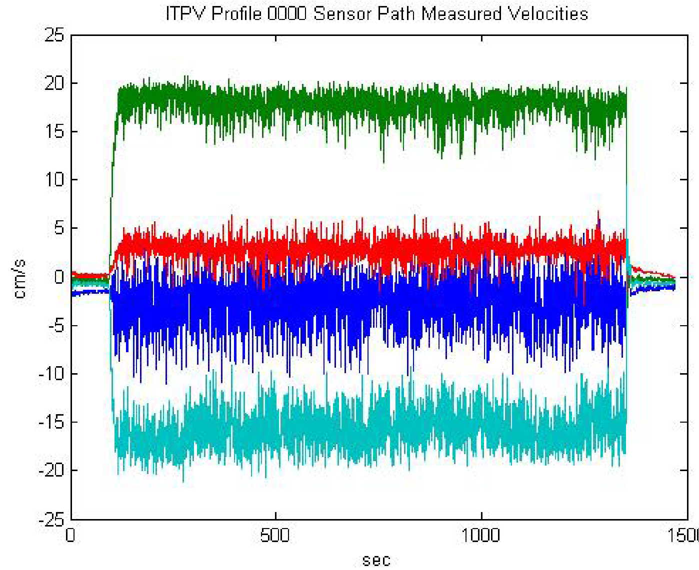

Fig. 2. Sensor path velocities from the first down-going profile of the ITPV. The red path is the upstream path and the noisy blue path is downstream of the bluff structure holding the transducers

II. Analysis

Flow past a bluff structure creates a vortex street downstream of the structure, Fig. 3. An object can not be streamlined for flow from all directions. Acoustic travel-time current sensors are good at measuring a line integral of current

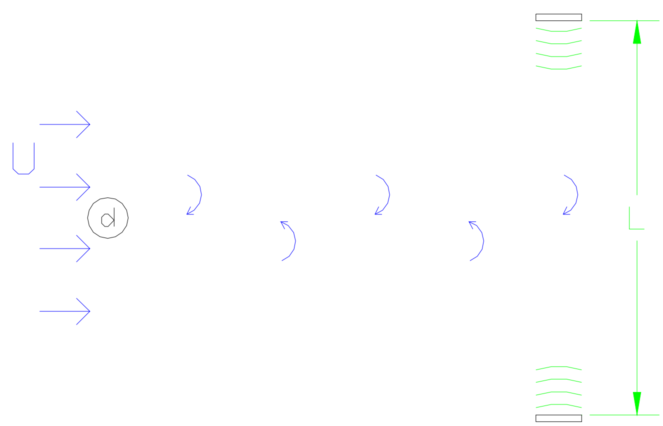

Fig. 3. Two dimensional diagram of flow past a cylinder creating a vortex street that advects downstream. If the flow is measured downstream of the cylinder, the measured flow has been disturbed.

along their acoustic paths, but if the measured volume is downstream of a bluff structure, it is not measuring undisturbed flow. The dominant frequency of the wake is given by the Strouhal number multiplied by the flow velocity divided by the cylinder diameter. The Strouhal number is about 0.2. The fluctuating velocity measured by an acoustic travel-time current sensor scales with the current velocity multiplied by the cylinder diameter divided by the acoustic path length. On a motorized profiler, this current velocity, that the noise scales with, is the relative velocity between the water and the profiler. On a motorized profiler in still water, this can result in a lower signal to noise ratio than measured by the same current sensor held still.

The ITPV1 used a modified Modular Acoustic Velocity Sensor (MAVS), which is pretty good in all directions, but not perfect in any, Fig. 4 [5]. In this figure, the

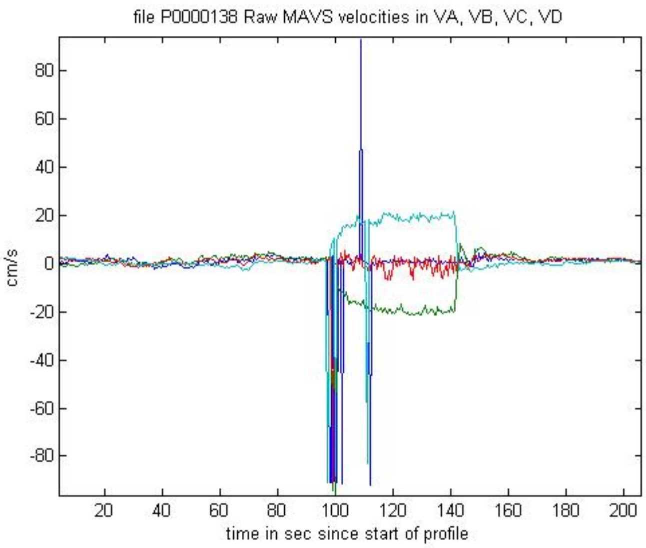

Fig. 4. Tank test profile showing the four acoustic paths measured by the first ITPV. The red path is downstream of the support cylinder and measures the vortex street created by the cylinder.

measured velocities along the four acoustic paths are shown. The profile was done without a large settling time after the previous profile resulting in measuring some of the residual wake of the previous profile. The spikes shown in the figure at the start of the profile result from a soft start system that switches power to the drive motor with an increasing duty cycle to slowly ramp up the drive wheel speed. This creates significant electrical noise in the profiler during the speed ramp-up

III. SOLUTIONS

The first solution to reduce self-induced flow noise was over-sampling and averaging [6]. Vortex streets of cylinders tend to be very regular so if a pair or more of alternating vortices are averaged, the noise from the vortices can be largely reduced. The minimum resolvable eddy is twice the acoustic path length. If the structure diameters are significantly smaller than the acoustic path length, this averaging can be done without increasing the minimum resolved eddy size. By over-sampling and averaging, the noise measured as standard deviation of measured velocity divided by profile speed was reduced from 5.45% to 2.26 %, Table 1. The descents are noisier than ascents because the sampling volume has to be close to the profiler to fit through a modest hole. The over-sample and average scheme did however increase the power consumption. The acoustic current meter uses modified MAVS electronics which turn on fast, higher-power, electronics when a measurement is made and turns the fast electronics off between measurements. By turning on the fast electronics more often, the average power was increased, Table 2.

TABLE I. STANDARD DEVIATION OF MEASURED VELOCITY DIVIDED BY PROFILER SPEED.

ITPV version	*Ascent*	*Descent*
ITPV1	5.45%[a]	6.8%
Over-sample and average	2.26%	4.04%
ITPV2	1.36%	5.05%

TABLE II. POWER USED BY THE CURRENT METER AND ATTITUDE SENS0R.

ITPV1 MAVS + rate gyro	475 mw
Over-sample and average + rate gyro	1320 mw
ITPV2 and VN-100	550 mw

The second solution is to design and build a sensor optimized for a profiler that turns into the relative flow, Fig. 5. For a profiler that turns into the relative flow, the sensor only needs to be good for relative flow angles of +/-15 degrees of yaw and +/- 90 degrees of pitch. This contrasts to a general purpose current sensor that needs to be pretty good for flow from all directions. This sensor cantilevers the transducers such that for the flow angles seen by the profiler, the measured volumes are not in the wake of the sensor structure. The acoustic path length was increased from 10 cm to 20 cm to further reduce noise. The acoustic paths form a square whose sides are bent 30 degrees to the plane normal to the expected horizontal flow. The geometry of the sensor was made more complicated by the requirement to be held upstream of the mooring cable and close to the CTD for flux measurements. The sensor structure is welded tubes of 316 stainless steel, which is more robust than the ITPV1 sensor. There had been a concern that the original sensor might be broken during deployment through the ice hole. The tubes are oil-filled and pressure balanced.

The second goal was to reduce the volume of data sent back. The ITPV1 had a three-axis angle-rate gyro, a three-axis accelerometer, and a three-axis magnetic flux sensor that was sampled at two Hertz. The attitude calculation was done in post processing on shore. A magnetic compass measures the magnetic flux in the plane normal to gravity. The instantaneous pitch and roll need to be accurately known to rotate the instrument relative magnetic flux vector into a horizontal computational reference frame because in the arctic the magnetic lines of flux are close to vertical. In previous deployments, there were motions in pitch and roll at 0.55 Hertz, 0.6 Hertz, and 0.68 Hertz and in strong currents, a yaw oscillation at about 0.6 Hertz. With this post-processing of

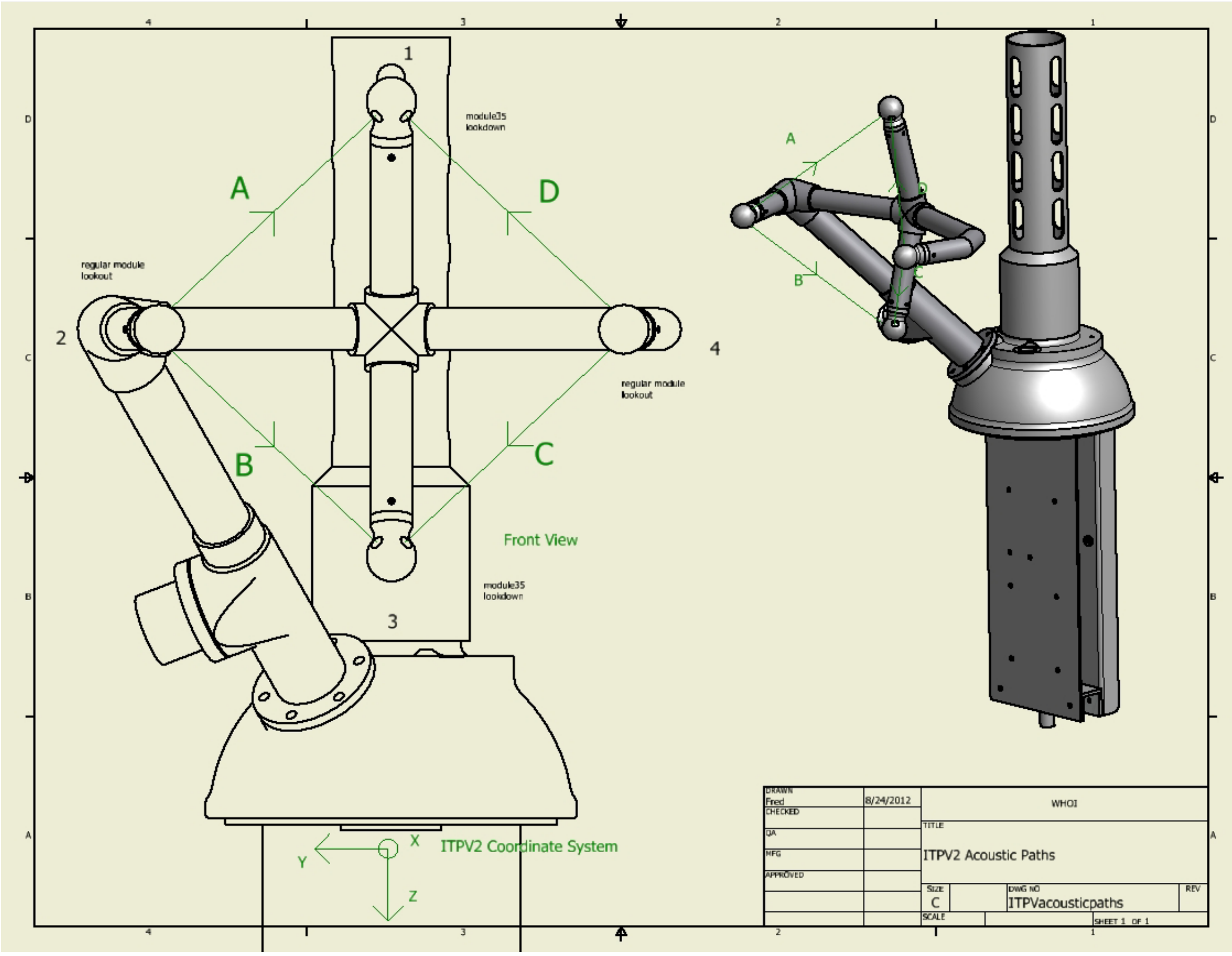

Fig. 5. Drawing of the ITPV2 sensor which was optimized for a profiler that turns into the flow.

attitude, if the sampling was reduced to one Hertz, these motions would be aliased. In simulation, slower sampling caused significant errors in computed attitude. The solution was to use an attitude heading reference system (AHRS), a VectorNav VN-100, which processes the profiler attitude at 200 Hz. This attitude is then polled at one Hertz which should avoid aliasing the attitude estimate.

The MAVS poles the VN-100 and after the profile, sends the acoustic current meter data along with the AHRS data to the profiler controller which then sends the data via the inductive modem up to the surface buoy which then transmits the data to shore via Iridium. The MAVS can either send a narrow data packet of N (the sample count), the four acoustic path velocities, yaw, pitch, and roll at 21 bytes, or a wide package of N, the four acoustic path velocities, yaw, pitch, roll, the three angle rates, the three accelerations, and the three axes of magnetic flux at 58 bytes. The first two units which are on their way to the Arctic were programmed to send the wide format to allow double checking of the attitude processing to gain confidence in the AHRS's ability to measure heading near the magnetic pole. Additionally, the possibility of removing profiler motion from the flow measurements will be tried. Another four ITPV2's will be sent to the Arctic next year as part of the Marginal Ice Zone experiment and depending on analysis of the data from these first two ITPV2's,the next four will either be programmed to send the narrow data packet or reduce the size of the support variables. The support variables are currently native IEEE four byte floating point numbers which could be reduced to two byte integers if they need to be retained. We hope to go to the narrow data packet format

IV. Results

Two ITPV2 profilers have been built and are on their way to the Arctic. The self-induced flow noise was significantly reduced, Table1, Fig. 6. In the figure, the measured velocities along the four acoustic paths are shown for an ascent profile in a still tank.

The dropouts during the start were caused by two issues, the switching of the drive motor causing electrical noise and the first sensor used a urethane overmold of the transducer modules that absorbed most of the acoustic energy at the transmit frequency of 1.75 MHz. This required the electronic thresholds to be reduced which increased sensitivity to noise. Two new sensors were built with a different urethane that, while harder to work with, absorbs less acoustic energy allowing higher thresholds. This dropout issue should be greatly reduced.

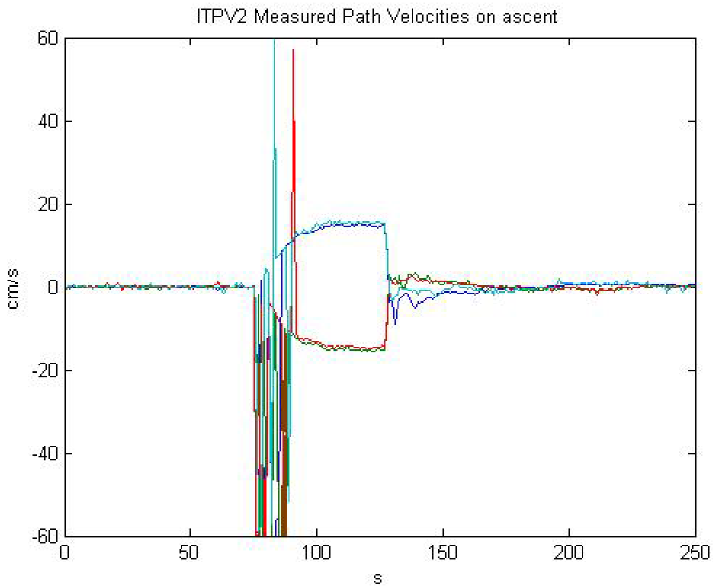

Fig. 6. Measured path velocities of an ITPV2 sensor on ascent in a still tank.

The two profilers sent to the Arctic look like the drawing in Fig. 7. The fins used in a previous deployment kept the yaw wagging in a 35 cm/s current to about +/- one degree at about 0.6 Hertz.

SUMMARY

A second generation ice tethered profiler with velocity sensor has been designed and two have been built. The self-induced flow noise has been significantly reduced and the sample rate has been slowed to one Hertz. After analyzing the data from the first two units, it is hoped to reduce the amount of data sent back to shore

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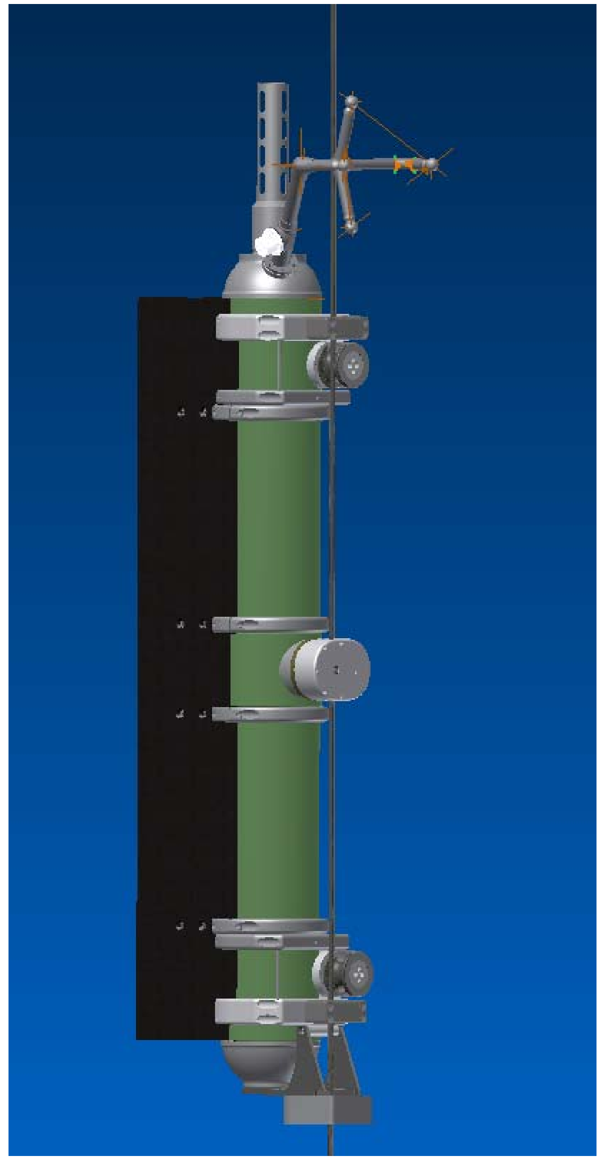

Fig. 7. ITPV2 with fins sent to the Arctic.

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