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A low-cost coastal buoy for ice and metocean measurements

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ABSTRACT

Regionally, an ice cover in fjords of mainland Norway may form and break up repeatedly during winter. Due to relatively high water temperatures, the freeze-up process is expected to be related to freshwater-induced stratification in the fjords in conjunction with low air temperatues. In an attempt to identify the variability of water conditions in the fjords leading up to and during ice cover development, a low-cost buoy had been developed to cope with the high potential of loss of equipment during break-up of ice. The current version of the buoy logs GPS coordinates and ocean, ice and air temperature, and transmits data through the cell phone network. Experience from the first season of multiple deployments showed that the concept is working but the physical design of the buoy could be improved to withstand forces in open water.

KEY WORDS Ice; Ocean; Measurements; Instrumentation

INTRODUCTION

Data acquisition in harsh environments can be accomplished by a small number of installations of expensive, environmentally hardened equipment, or by a larger number of (possibly repeat) installations of lower-cost equipment.

The latter approach was chosen in this study in order to maintain multiple deployments simultaneously. The design criteria were:

1. Temperature measurements in atmosphere–ice–ocean to monitor
    - ice formation and thickness, and
    - variations in ocean temperatures (e.g., sporadic surface plumes),
2. Installation needs to be largely stationary, and deal with open water, drifting ice floes, and repeat freeze-up and break-up cycles,
3. Method of determining the geographic location of the probe,
4. Automated transfer of all acquired data at regular intervals to ensure data are available even if equipment is lost,
5. The design length of operation is 12 months under high latitude conditions and surrounded by steep mountain faces (i.e., low temperatures, limited direct sunlight).
6. Costs of hardware was to be minimized to cope with loss, re-deployments were

acceptable.

This paper presents method and initial results of an attempt to balance these criteria.

METHODS

The design criteria were addressed as follows:

1. The temperature signals to be detected in ice and oceans were expected to exceed 1 °C. Based on this, the 0.06 °C resolution of digital temperature sensors Maxim Integrated DS18B20 was deemed sufficient. The sensors were mounted along a backbone data cable deployed from a platform. Platform design was chosen to not interfere with temperatures close to the atmosphere–ocean or atmosphere–ice interface.
2. The platform was anchored to the ground to allow the platform to stay in place in open water and pose minimal resistance to ice drift once frozen in. The anchor was supposed to hold the platform in place in open water but had to be dragged if the frozen-in platform moved. Floatation and anchor mass were balanced such that the platform would not sink if it melted out in deep waters.
3. The on-board logger contained a GPS/GLONASS satellite receiver to determine its location periodically. In addition, cell phone tower IDs were logged.
4. Since measurements were to be performed in mainland Norwegian fjords, cell phone coverage could be assumed. Data were pushed to a remote FTP server periodically through the cell phone network. The logger contained a Simcom SIM7600 processor which provides a cell phone modem (2G, 3G, 4G), GPS/GLONASS receiver, and SD card management for long-term data storage.
5. The logger was battery powered with a capacity to last for 12 months operation. The Microchip ATmega328p processor and temperature sensors operate over a wide voltage range that allows their direct connection to Lithium batteries. 1.5V Lithium batteries were used due to their excellent performance at low temperatures and very low rate of self-discharge. Temperature sensors were powered by the same battery source. An external 64 kB SRAM (23LCV512) was attached to the processor to reduce access frequency to the SD card.
6. Low material costs were achieved by using cost-effective temperature sensors that contain a digital interface, removing the need for temperature-compensated electronics at the logger end. The logger circuit was designed in-house and built by an assembly service, the modem used was the Waveshare SIM7600 HAT module. Both were housed with antennas and battery in a Pelican 1200 Protector Case atop a simple floating platform.

Maxim Integrated DS18B20 are bandgap-based temperature sensors with integrated 12-bit analogue-to-digital converter, corresponding to 0.06 °C resolution (Maxim Integrated, 2002, 2018). The sensors are factory-calibrated to an accuracy of ±0.5 °C (3-sigma range) and are reasonably common in geophysical applications (e.g., Petrich et al., 2014; Cui et al., 2015; Netto & Arigony-Neto, 2019). The manufacturer indicates an ensemble-averaged bias of approx. -0.15 °C at 0 °C. Bi-directional communication with an external master takes place over a single data line. Several sensors can be attached to the same data line as they are addressed by a factory-lasered unique 64-bit address. We performed a zero-point calibration in an ice–water bath on all sensors (Mangum, 1995). Further measurements at temperatures < +10 °C (i.e., in the relevant ocean temperature range) indicated that we have no empirical basis to justify higher order temperature corrections. We obtained waterproofed versions of the sensors from various third-party suppliers. Those sensors were encapsulated with epoxy in 6 mm diameter stainless steel tubes.

The sensors were attached to Cat 5e gel-filled ethernet cable. The electrical connections were water-proofed either with heat shrink filled with CT1 sealant (C-Tec N.I. Ltd.), or with Electrolube polyurethane resin. The resin was poured into silicone molds made from a 3D-printed template. Special care had to be taken to immobilize the cables during the setting process of the polyurethane. The earliest probes used indoor Cat 5e cable and epoxy for water-proofing and cable conduit for support. Each temperature probe consisted of approximately 20 sensors down to typically 10 m depth with a 1 kg mass at the bottom. Water depths at the places of deployment were between 10 and 40 m.

The platform was designed to leave the water and ice around the probe undisturbed. It was an H-shaped low-lying wood construction with flotation attached to the side beams (Figure 1). 5 and 10 cm thick insulation was used, resulting in 30 and 60 kg equivalent floatation, respectively. The temperature string was suspended from the center of the cross beam. Various diameter lines were used to anchorage, from 1.4 to 8 mm. Lines at the thinner end of the scale tended to break under circumstances that are not entirely clear. Anchorage had a total weight in water of the equivalent of 8 to 25 kg. Platforms were either attached to a single anchor or to two anchors. The anchors were not designed to dig into the floor. In one case, a single inflatable boating buoy was used as a basis to attach probe, logger, and anchor line instead of a platform.

The almanac of the GNSS (GPS/GLONASS) receiver was downloaded through the cell phone network, resulting in typically 15 to 20 seconds until a fix was obtained after cold start.

Once data were transferred to an FTP server, an automated script compiled them into a single data file and generated plots made available on an online server (https://ndat.no/).

The logger unit used two sets of batteries: three sets of 3x1.5 V batteries in series to permanently power logger and temperature sensors, and three sets of 4x1.5 V batteries in series to power the modem on demand. Based on the observation that one set of Alkaline batteries was found to be good for 300 data transfers at room temperature under favorable conditions we expect that the battery power is sufficient for one year of operation with data transfer every 8 hours. Temperature data were logged every 5 minutes.

(a) (b)

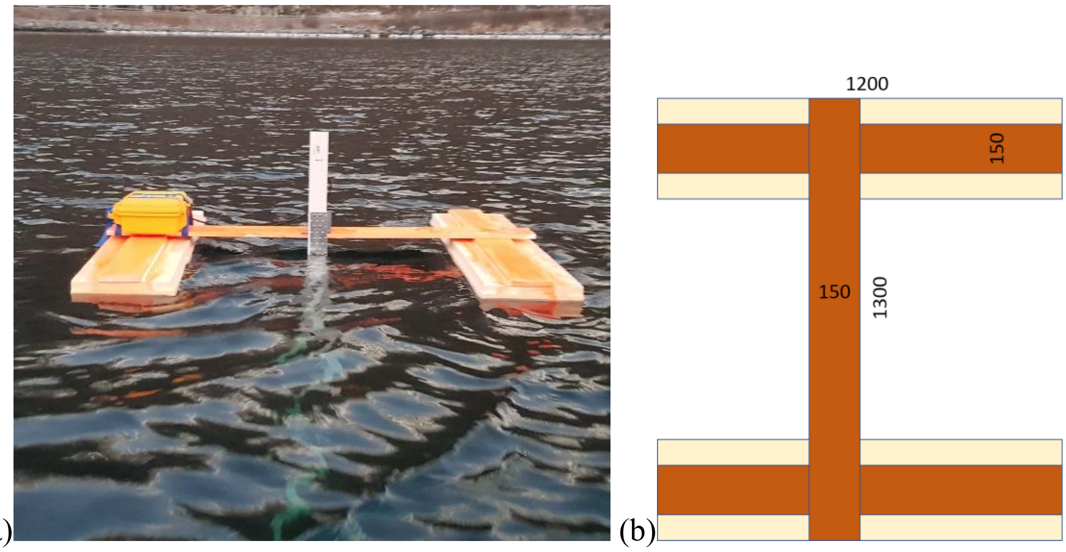

Figure 1. Platform with conduit-supported temperature string (a) deployed in Beisfjorden, near Narvik, (b) schematic view with dimensions in mm. Light brown areas are 50 mm foam insulation, dark areas are 15 mm thick wooden boards. Counter boards are mounted below the foam insulation to hold the insulation in place.

RESULTS AND DISCUSSION

Our measurements of several hundred temperature sensors resulted in an ensemble average of -0.15 to -0.20 °C at 0 °C and were consistent with the manufacturer's stated 3-sigma range. In addition, there was no appreciable noise on the signal, i.e., the resolution of 0.06 °C is above the noise floor. While this applies to the majority of our sensors, there are notable differences in bias in some manufacturing batches (as revealed by the serial number ("ROM code"), Figure 2). In particular, we found batches in circulation with appreciable noise (>0.12 °C) and bias of individual sensors exceeding ±1 °C (Figure 2, point group around sensor number 500). While we will not speculate on the authenticity of those sensors their existence in circulation serves as a warning that sensors should be tested (and that price and outside appearance are not useful indicators of performance).

We found that a semi-rigid probe design with cable conduit was not sustainable in the fjords studied. In the shallowest regions at the mouth of the fjord tidal currents were sufficiently strong to prevent us from mounting the probe vertically and later ripped out screws from the wooden platform as a result of drag forces from high currents. It was possible to mitigate the problem by retrofitting a swivel joint. However, the advantage of that system over a free-hanging cable appeared to be small. We also experienced failure of the semi-rigid conduit construction in one case which we currently ascribe to material fatigue due to tidal forces or excessive bending.

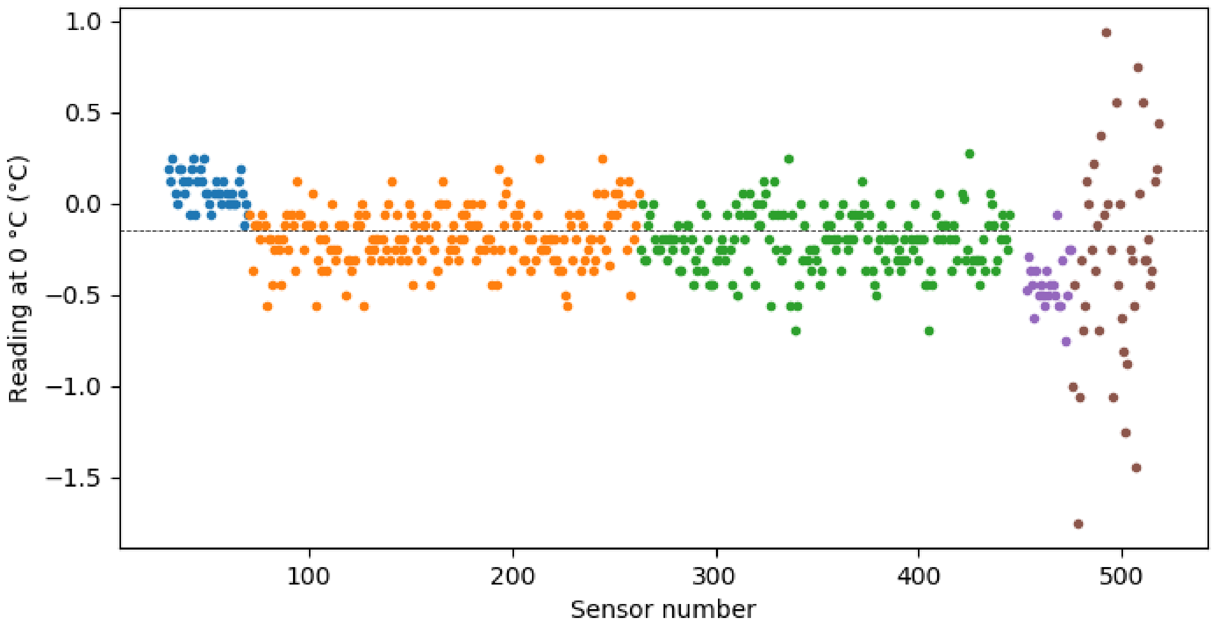

Figure 2. Actual sensor readings at 0 °C. Colors are used to separate distinct patterns in serial numbers.

We found significant challenges in the platform design combining constraints of surface temperature measurements (#1) from a stationary deployment (#2) in open water and drifting ice (#3). A platform with a relatively large footprint was constructed in order to obtain relatively undisturbed near-surface measurements. However, this platform provided a large attack surface for drag from wind, currents, and drifting ice floes which lead to sporadic (and significant) drift events. At the same time, the anchor weight (and corresponding platform floatation) could not be increased arbitrarily since the anchors still had to be able to be dragged once the platform was frozen in. All H-shaped platforms drifted at least once in response to currents or moving ice floes. One platform seemed to have been overridden by advancing ice, submerging it completely. The design that withstood environmental forces best was the inflatable boating buoy which had the smallest footprint in the water but unfortunately interfered the most with the surface temperature measurements (Figure 3).

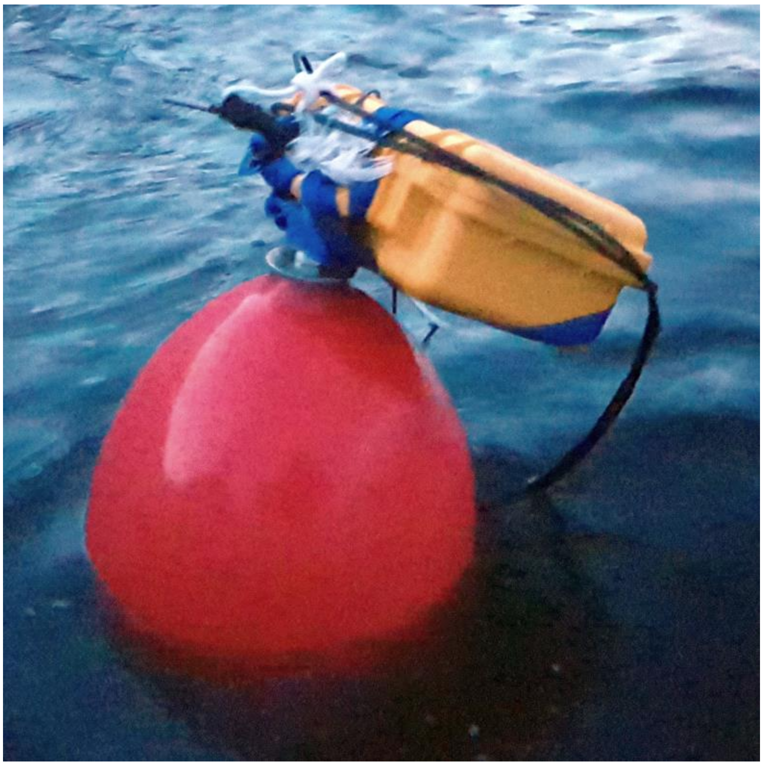

Figure 3. Direct deployment of logger and temperature cable from a boating buoy.

The loggers and modems worked flawlessly but we noticed that we had to perform temperature conversion one-at-a-time rather than all-at-once once after the batteries had been in operation for a few weeks. As a temperature conversion takes up to 750 ms, this increased the time the logger is active and will reduce battery lifetime. However, bigger issues were elsewhere:

- One string in cable conduit was separated in two when the bottom section was torn off. The top section continued to work.
- Two strings experienced partial failure of their respective bottom section after weeks to months of operation.
    - In one case we are assuming water ingress into the indoor Cat 5e cable after 1 week.
    - The other case after 10 weeks is less clear as the sensors in the bottom section do continue to report very occasionally for brief periods of time. Fracture of a solid core wire could be the reason, with occasional contact restored due to tidal or wind-driven movement. Mechanical force may have played a role in the fracture as failure started to occur at about the same time two nearby platforms got submerged and relocated by ice, respectively. I.e. significant forces acted in the fjord.
- Three strings failed completely after hours to a few days after deployment which we attribute to cable movement before the polyurethane curing process had completed. This created a path for water to reach the electrical connections and led to an electrical short in the probe shortly after it had been submerged in seawater.

- One string worked flawlessly for 6 weeks until the entire platform got submerged beneath sea ice.
- One string continues to work flawlessly after 11 weeks in service.

I.e. 3 strings died because of a systematic production flaw, 1 string presumably had a design flaw (wrong kind of cable), 2 strings developed problems presumably due to external mechanical forces, and 2 strings did not have problems.

CONCLUSION

We found that low cost mass deployment can be done but that problems lurched in unexpected areas. The biggest surprise was the underestimated current drag on the original platform. There is strong indication that a single floater with minimal footprint in the water is necessary to keep the buoy stationary in open water, requiring a new approach to minimize disturbance of temperature measurements at the ocean surface and in ice. Another issue is waterproofing of the solder joints of the temperature strings. We are working to improve the manufacturing method to strike a balance between reliability and efficiency of production.

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