Master Thesis

Designing a cost-efficient drifter to track freshwater fluxes from the Greenland Ice Sheet

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Abstract

The Labrador Sea is an important area for wintertime convection, with possible influences on global overturning. While there is a debate in the scientific community as to the exact effects of deepwater formation on the overall circulation, recent studies have shown that the area is susceptible to very small-scale processes that conventional model resolutions can, if at all, only reproduce with immense effort and at times large error due to parameterization. There is a need for more observational data to validate models and provide initial conditions, especially concerning the pathways of freshwater off the Greenland ice shelf, which could disrupt the convection process. For this project, drifters at under £300/ each are supposed to be deployed in a cluster. Conventional surface drifters are analysed and, because they are not sufficiently suited to this task of following the freshwater currents off Greenland at the surface, a new drifter is designed and presented. Given the time constraints of the project, the design involves a working (dry tested) prototype with regards to the sampling of temperature, locating the drifter through GPS and transmitting the data via the Iridium network at reprogrammable intervals. Power usage and optimization has been analysed, tested and calculated, but not implemented. The exterior casing, including materials and deployment, as well as the overall costs of the drifter have been conceptually designed, calculated and discussed, and alternatives and suggestions for future work are presented.

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1 Introduction

The Atlantic Meridional Overturning Circulation (AMOC) is essential for the global climate and responsible for a significant heat transport to higher latitudes, with warm surface waters flowing northwards, where the heat is lost to the atmosphere and the following densification of the waters leads to convection, allowing the water to flow southwards at depth (Jackson et al., 2015). In the northern hemisphere, one of these areas of convection where deep water is formed is the Labrador Sea. Under normal conditions, a lack of buoyant surface waters in the interior of the Labrador Sea means the region is very sensitive towards temperature changes (Bailey et al., 2005).

During winter months, when the heat-loss is more pronounced (especially during strong North Atlantic Oscillation phases (Oka et al., 2006)), and evaporation or ice-formation have left the surface salty, these now denser waters will sink through the weakly stratified water column and mix to form Labrador Sea Water (LSW) which flows south as part of the overall meridional return flow, eastwards into the Irminger basin or north into the Atlantic (Kieke and Yashayaev, 2015, see Figure 1). Because this convection depends on weak stratification to allow sinking, it has been assumed that a large input of freshwater into the region, which would introduce a strongly buoyant surface layer, could suppress convection and significantly affect the AMOC (Böning et al., 2016).

While the AMOC transport has indeed been found to have decreased in comparison to past time periods (Smeed et al, 2018), the exact reason is unclear, as the currently available time series are short, and underlying, lower frequency oscillations might obscure trends. At the same time, Labrador Sea convection seems to have increased, with LSW density at its highest since the mid 90s (Yashayaev and Loder, 2017).

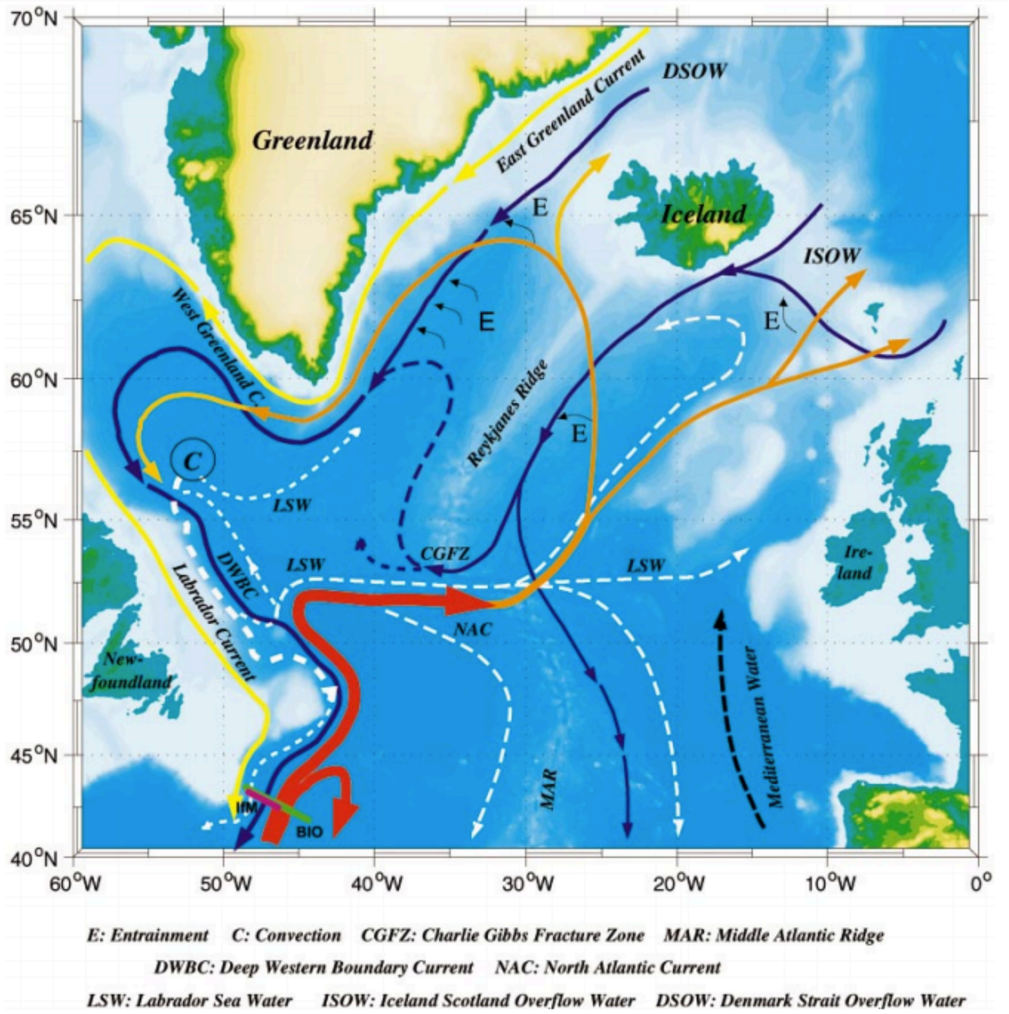

Figure 1 - from Schott et al., 2004, circulation diagram with currents (red warm, blue cold) and LSW paths

The freshwater that could possibly infringe on the interior Labrador Sea to cause a slowdown is thought to stem from the Greenland ice sheet (GrIS), which is the second largest ice sheet that exists today, and is melting at an unprecedented rate –

the cumulative anomaly since 1995 exceeds 3200 ± 358 km^3 in 15 years, a value which is reminiscent of the Great Salinity Anomaly of the 1970s (where unusually low salinity concentrations caused the convection to shut down for the following three years) and could even be exceeded if the current trends were to continue until 2025 (Bamber et al., 2012).

The direct link between deepwater formation and overall circulation, which has long been assumed to be a driving force behind the entire MOC, has been challenged by recent observation - see review by Lozier (2012) and references therein, who could find no evidence for such a link in observations. Paleo-oceanographic studies however have shown a drastic relationship between freshwater input into the Labrador Sea and the climate, most recently about 8'200 years ago, when during the retreat of the Laurentide ice sheet over 10^{14} m^3 of freshwater were suddenly released into the Labrador Sea (Barber et al., 1999). This flooding event has then been linked to an 'off' state of the MOC, inferred from the low temperatures recorded afterwards in Greenland due to the lack of a meridional heat transport (e.g. Teller et al., 2002).

While the exact cause of the cooling has been called into question as well - Clarke et al. (2009) found that the freshening could have produced an abrupt climate change without causing a shutdown or in fact a substantial decrease in meridional heat transport - it certainly shows that large freshwater, which dominates the GrIS mass loss and will likely continue to do so in the future (Smith et al., 2017) remains an important factor to consider with regards to climate, regardless of whether or not the exact mechanism is understood.

Of great importance for an accurate response of the AMOC (or other systems), is the accurate representation of the freshwater pathways off Greenland. In order to reach the interior of the Labrador Sea, the meltwater has to move off the shelf, which happens due to eddies and/ or Ekman transport (Schulze, 2016). Because of difficulties in measuring in situ due to the remoteness of the area, surface currents are usually calculated from geostrophic approximation; however sub-mesoscale motions (like small eddies) are distinctly ageostrophic (McWilliams, 2008).

Additionally, hosing experiments, where freshwater is uniformly distributed over an area, disregard the highly localised input trends (Mernild et al., 2017). Different model resolutions further exacerbate the situation, with eddy-permitting models finding the Greenland meltwater in Hudson Bay, with minor contribution to the Labrador Sea (Marsh et al., 2010), and higher-resolution tracer simulations (Luo et al., 2016) finding eastern Greenland meltwater runoff had a larger impact on the northern Labrador Sea (see Figure 2), a trend confirmed by Wang et al., (2018).

Saenko et al., (2014) found that an accurate representation of the Labrador Sea and all the relevant components, especially the highly important eddies, which most likely contribute to the replacement of buoyant water at the surface and around the boundaries, requires an actual eddy-resolving model. The most commonly used grid spacing for coupled models at this time is around 1° (Heuzé, 2017), which is by far too coarse, as Dukhovskoy et al. (2016) have found that not even the finest model they analysed (0.08° or 1/12° or 4 - 5km) could completely resolve this system. Instead, a 2 – 4 km/ 0.02°, high resolution model is advisable, which should be able to represent mixing in the surface ocean buoyant layer (OBL), which is severely affected by submesoscale processes, at scales of 0.1–10 km across and 0.01 to 1km depth (McWilliams, 2016). This pulls into question papers that show drastic impacts of ice melt, e.g. Fichefet et al. (2003), where only coarse models are used.

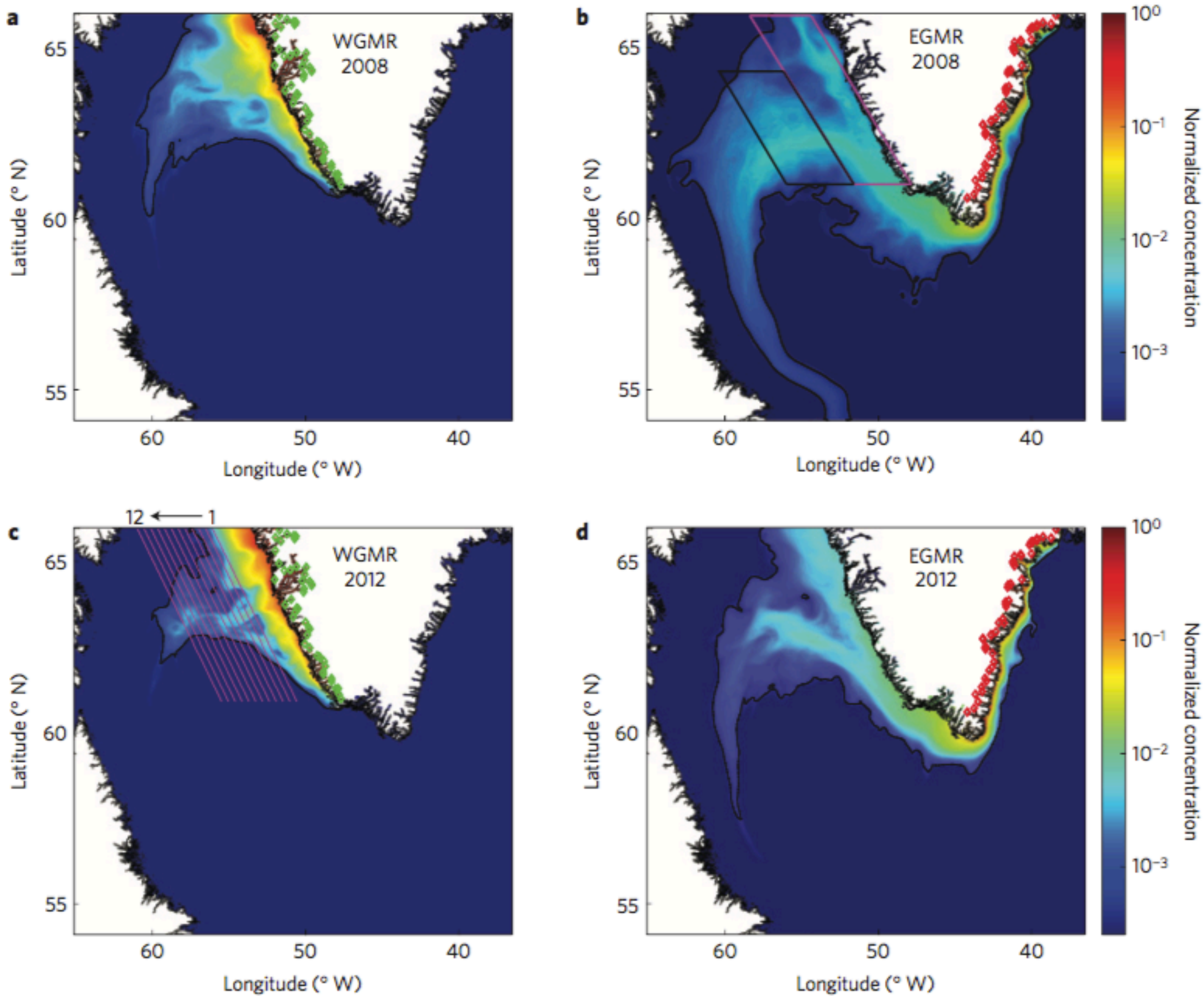

Figure 2 - from Luo et al., (2016) simulated West and East Greenland meltwater runoff in 2008 and 2012 respectively, see their Figure 2 for detailed description

Scientifically, the question remains, whether or not the surface is the place to look for freshwater inputs. While the GrIS melt has the potential to cause a global sea level rise of up to >0.7 mm/y (Smith et al., 2017), they also found that compared to their field-estimates, models tend to overestimate the rate at which freshwater enters the sea by about +21 to +58%, which they credit to the model's current disregard of fluvial catchments and a lack of field calibration.

Recent studies by Moon et al., 2018 have found that in fjords, where 30-50% of freshwater leaves the glaciers in the form of icebergs, almost three-quarters of this freshwater will be released at a depth of about 20m. They found the large majority of this volume remains at depth, which, should this stratification hold all the way to the ocean, would put it past the reach of a surface drifter. The discrepancy between model meltwater and observations could also be due to porous ice sheets, which can retain a large amount of melt water. Cooper et al., (2018) have analysed ice-cores and found that meltwater might have permeated into the lower-density surface of weathered crust, creating a saturated layer, so at least some the observed “loss” of ice mass to meltwater could be more of a “relocation” instead. With the changing topography of the ice sheet, wind patterns over the area could change, as Merz et al. (2015), found in their model (but only for glacial periods), further affecting the changes in melting and pathways.

To overcome all these complications and be able to create reliable models based on real observations, and validate other models and results, more data is needed. Satellite data does not offer high enough resolution, HF Radar measurements are only available close to the coast and Argo floats not usually moving onto the Greenland shelf (Frajka-Williams et al., 2016), surface drifters offer the possibility to measure in-situ, by being tracked through satellite positioning to reveal their paths and distribution. Because the area is historically under-sampled (see Figure 3), the aim is to release a large cluster of cost-efficient drifters in an area of interest, specifically for the purpose of tracking the freshwater from this point and help infer the behaviour of the water mass (Kjellsson and Döös, 2012).

This paper is slightly unusual in its subject, as it contains no data analysis, results or discussion section per se. Instead, it first introduces the concept of drifters and analyses relevant commercially available examples by examining their advantages and disadvantages with regards to the project requirements (chapter 2), followed by the design of a prototype that fulfils them, including reasoning behind the selection of parts, testing, discussion of alternatives and suggestions for future work (each in chapters 3 - 6) and a concluding summary (chapter 7).

2 Drifters

2.1 History of Drifters

Observing the oceans is one of the most important disciplines of Oceanography. While paleo-oceanography allows for the reconstruction of past incidents, and computer models predict future events, observations provide us with real data to validate these reconstructions and predictions. Lagrangian instruments, such as drifters and floats, which passively follow the flow, can provide valuable information about the ocean circulation down to very small scales (Lumpkin et al. 2017). Floats, like ARGO, follow at depth, whilst drifters are constraint to the surface or near surface. They have been used to validate physical theories or follow surface currents in search and rescue operations or oil in spills (Liu et al., 2014), while at the same time improving our understanding of the entire surface circulation, which is one of the essential variables for the understanding and modelling of our climate (Bojinski et al., 2014).

This technique was used as early as 1872, when passive drifters were deployed and monitored from the RMS Challenger (Isern-Fontanet et al., 2017). While these past drifters were tracked either visually or with radio triangulation (before the 1970s), modern day drifters are equipped with GPS trackers and satellite communication, which allows for very exact (error of ca 6m) positioning and instant communication. Since the advent of satellite drifters, multiple large-scale experiments have been undertaken and provide the scientific community with invaluable data, through projects like the Global Drifter Array (GDP, 2018).

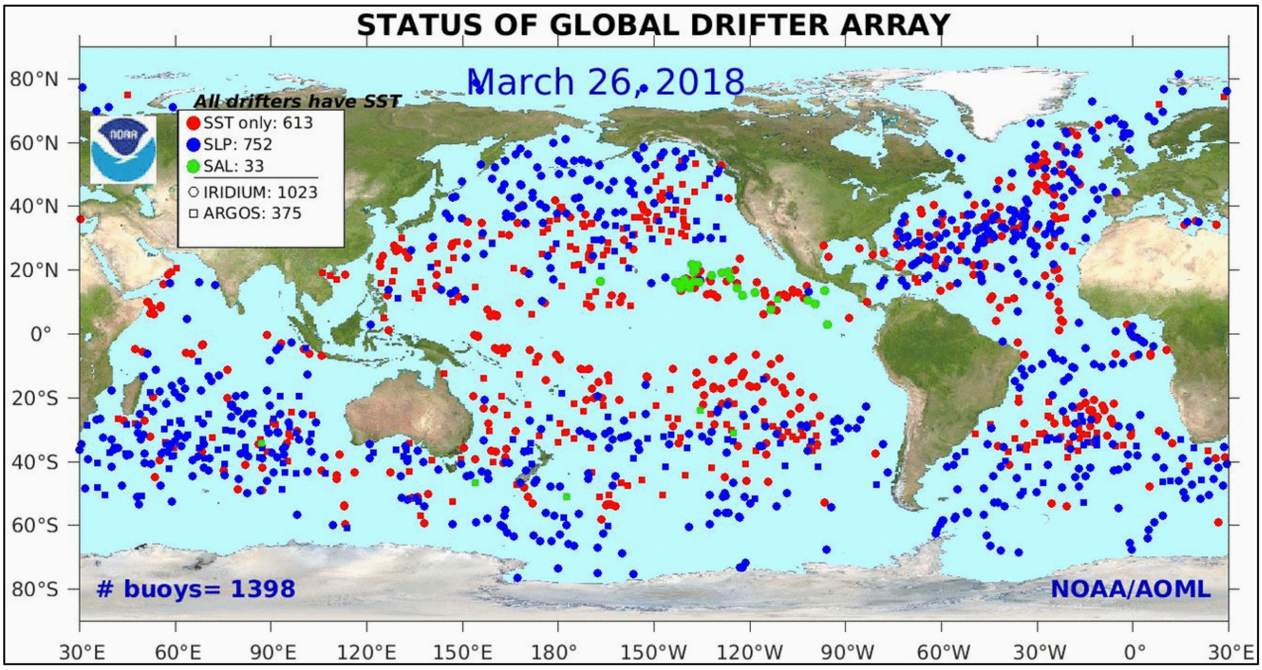

Figure 3 - Global Drifter Array with types of measurements (sea surface temperature, red, sea level pressure, blue, and salinity, green, and their respective telemetry displayed by the shape (GDP, 2018)

Modern day drifters can be grouped by the presence – or not – of a drogue, which is, in essence, a submerged "sail" that increase the drag of the drifter below the waterline compared to the drag above (ideally at a ratio of 40:1, Lumpkin et al., 2017), to reduce the effect of wind on the drifter movement (Maximenko et al., 2013). Due to the stress of being moved into different directions at different speeds, loss of drogue is a problem that often occurs - within the first two months of deployment of the LASER experiment, 40% of the CARTHE drifters lost their drogues (Haza et al., 2018). For small drifters, loss of drogue can change how easily they can be tipped over (thus preventing a direct line of sight with the satellites), as well as affect drift behaviour. Larger drifters, like the Surface Velocity Program (SVP), are not exempt either; of the 1398 currently active drifters, almost half have lost their drogues, which will increase their downwind speed due to slip by 122% (Pazan and Niiler, 2001). This needs to be corrected for in the databases, which is why the drifters have either strain or submergence gauges to show the status of the drogue.

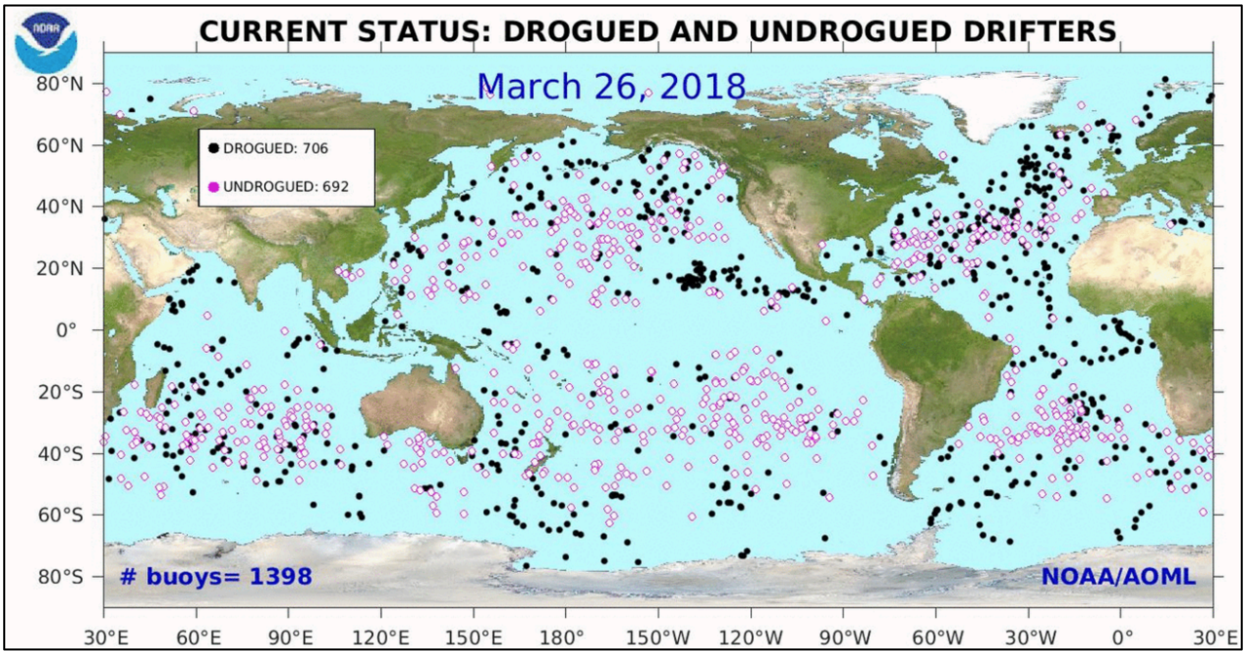

Figure 4 - Drogued (black) und undrogued (pinkish) drifters (GDP, 2018, 26/03/2018)

Undrogued floats are not as widely used, and mainly recorded as drogued drifters that lost their drogues. They, as well as surfaced Argos floats (during transmission), are subject to the same type of surface movements, which Lumpkin et al. (2017) describe as a combination of surface drift, Stokes drift, and windage (the effect of the wind directly on the drifting body). While this type of movement is disadvantageous for surfaced Argos floats, which are used to create vertical profiles and normally follow deep currents, there are manufacturers that purposefully design drifters to be used without a drogue in order to follow debris, oil spills or other tracers constrained to the surface (Woodbury, 2013).

2.2 Criteria for a suitable drifter

To gain a reliable amount of information on current speed and dispersion, 300 cost-efficient (~£300 each) drifters are to be deployed off the coast of Greenland. The drifters are then supposed to measure the sea surface temperature (SST) and transmit their exact position and the SST to be analysed. Because the Labrador Sea is very remote, no commercial vessel can be used to deploy along the way, and a designated cruise just for deployment would far exceed all means. The drifters will therefore not be recovered, and deployment is planned via helicopter. This places restrictions on the drifters' size and weight and means no elaborate pre-deployment assembly will be possible. In order to acquire the necessary measurements, the drifter will need a suitable power supply, temperature sensor, location tracker and reliable telemetry system.

Power

Because the drifter will not be recovered, a primary (non-rechargable) battery system should be chosen. The two main types of primary batteries are Alkaline (short for Alkaline-Manganese Dioxide) and Lithium (BU, 2018a). Both have advantages and disadvantages.

For environmental reasons, modern Alkaline cells are certainly the only choice. They are leak-proof even when fully discharged and environmentally friendly, as they rely on a combination of zinc and potassium hydroxide, which reacts to create manganese dioxide (Duracell, 2016), which has been classified as non-toxic (NEMA, 2002). Lithium batteries are not fully leak-proof, can have corrosive elements that can be harmful to the environment (depending on composition), and batteries that have not fully been discharged could short-circuit and explode, releasing toxins (Larsson et al., 2018). Lithium-metal batteries are also classified as class 9 hazardous (thermally and electrically unstable), meaning air-transport is severely restricted (Huo et al., 2017).

While Alkaline cells are of less environmental concern, Lithium is by far superior in terms of energy efficiency, especially under heavier (1C, which is 1 Amps/s) loads (BU, 2018a). Although this might make them a preferred energy supply, environmental consciousness dictates that a non-recoverable drifter should not contain Lithium batteries - especially as the drifter will be bio-degradable and could therefore reach the end of its operational life (no longer waterproof) before the batteries are drained, which can cause problems in Lithium batteries.

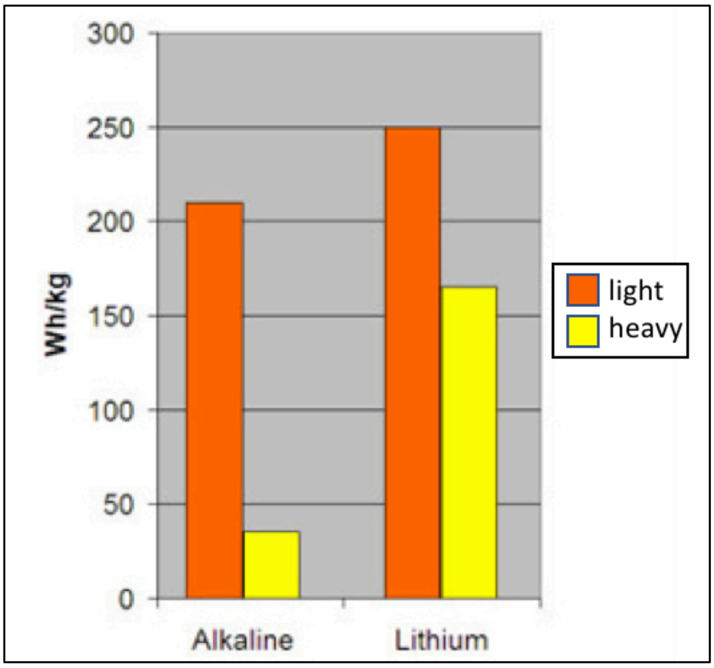

Figure 5 - Energy comparison between Alkaline - Lithium under light (orange) and heavier (1C, yellow) load, adapted from BU, 2018a

Temperature Measurements

While the new SVP drifters have thermistors accurate to ± 0.05°C, which is still not precise enough for an overlay with satellite temperatures (Meldrum, 2017 and following within), most drifters only feature a rough temperature sensor, accurate to ± 0.5°C (see below). Measurements are made through a thermal resistor which measures the temperature by converting increasing or decreasing resistance into a corresponding temperature with the help of the Steinhart-Hart equation (SRS, 2012). These thermistors measure either indirectly, from within the drifter, or directly, from a waterproof probe which is in contact with the sea surface.

Location Tracking

Tracking a drifter can be achieved in multiple ways. Earlier drifters used the Advanced Research and Global Observation Satellite (ARGOS) system, locating a drifter through a Doppler shift with the drifter moving relative to the satellite. The best possible location quality for this system is a class 3, which is accurate to less than 150m (GDP, 2018). While this might be enough for large ocean currents, modern drifters, and especially the ones required here, where small changes need to be recorded, use GPS receivers. These can access any part of the GNSS (Global Navigation Satellite System), and consists of the GPS, GLONASS, Galileo and BeiDou systems, with a usual error of around 3m (Cowley, 2012). In their most recent paper, Kazmierski et al. (2018) found that while using the entire GNSS instead of just the GPS could help reduce fix times when no GPS satellite was available, improper weighing of the different systems can easily occur and might affect the repeatability of the coordinates and introduce errors. When being mindful of these possible problems, the GNSS can be helpful in remote areas.

Telemetry

The cheapest possibility to access data would be storing it on an SD card or similar within the drifter to evaluate it later on, however this drifter will not be recovered and therefore needs to be equipped with cost-efficient telemetry that can remotely and reliably submit the obtained data. Remote communication can be achieved either through the General Packet Radio Service (GPRS) network, which is an advanced version of the normal cellular GSM network, and therefore restricted to land or (populated) coastal areas (Ghribi and Logrippo, 2000), and therefore not suited for remote Greenland or the middle of the Labrador Sea; or through satellite telemetry, which occurs either in a simplex, half-duplex or duplex mode.

Simplex is a pure one-way communication, same as a radio which can receive a signal but not send, half-duplex allows two-way communication, but only one way at a time (like a walkie-talkie), and duplex enables a full two-way communication (bi-directional, like a telephone). Normal communications satellites are usually in geostationary/ geosynchronous orbit (~36k km) and therefore have quite a large delay due to the distance. Instead, low earth orbit (LEO) satellites can be used (at a height of 800 km), of which only 64 are necessary to cover the entire globe. The navigational satellites mentioned above are in between, in mid-earth orbit at around 2000 km height (Cowley, 2012).

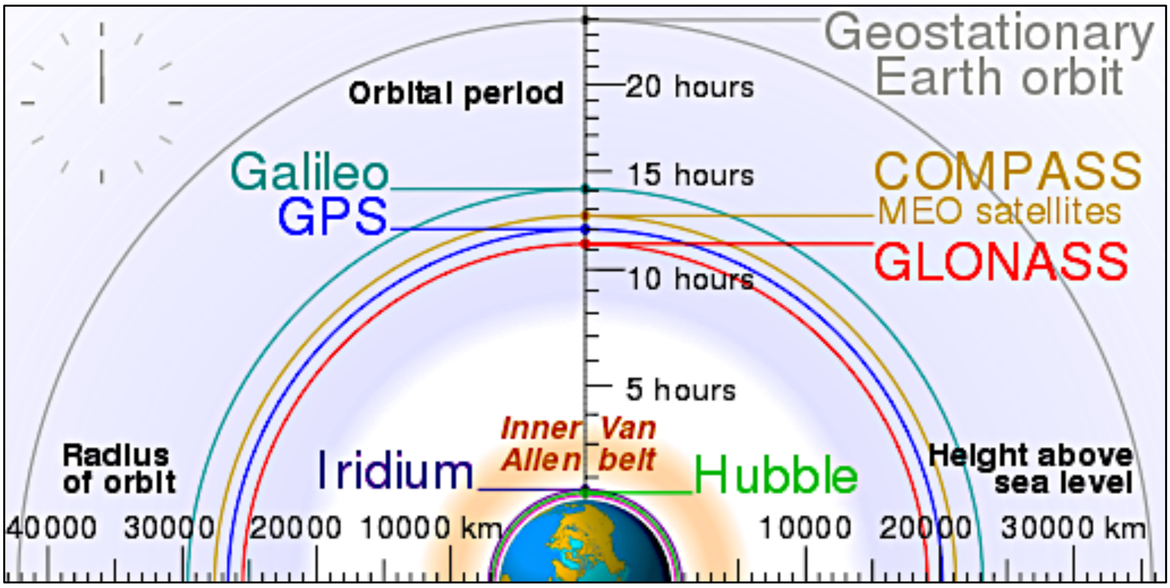

Figure 6 - Orbits of communication and navigation satellites, showing Iridium in low earth orbit (same as Globalstar and Argos), GNSS in mid earth orbit and communication satellites in geostationary/ geosynchronous orbit (adapted from Swan, 2016).

There are three commonly used satellite systems, Argos, Iridium and Globalstar, all of which operate in LEO. The Globalstar network employs 24 satellites and while it has great simplex coverage, its duplex coverage is best on land, making it a good choice for satellite phones and wildlife tracking (Globalstar, 2018), but less suited in the ocean.

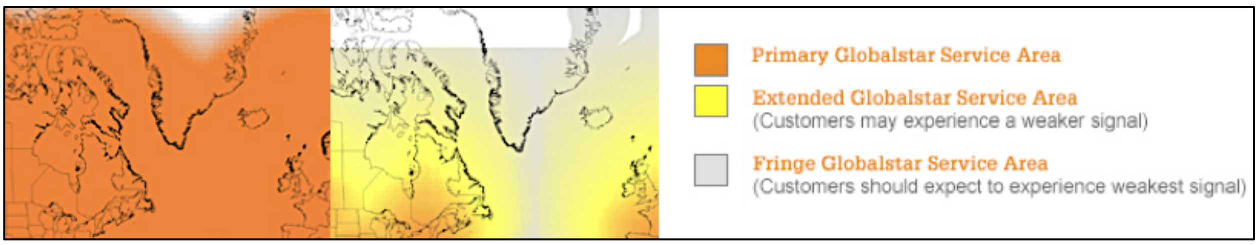

Figure 7 - Globalstar simplex (left) and duplex coverage in the relevant study area (adapted from Globalstar, 2017).

The Iridium system is by default duplex, and with a network of 66 satellites provides reliable and continuous world-wide coverage in real time. The system uses short message burst (SBD), is being overhauled since 2015 (Iridium, 2017) and also used for new ARGO floats (Lumpkin, 2017). The Iridium link usually completes a transmission in less than 5 minutes from instrument to end user, using inter-satellite communication, making it the fastest telemetry system (André et al., 2015).

The Argos system uses polar orbiting satellites and is much more limited, employing only six satellites as of 2015. This leads to a delay in message delivery of anywhere from a few minutes to hours, depending on latitude (a satellite passes 14 times/day at the poles, around 12 times at 65° and twice daily at the equator). Argos tracking also provides a location, see above, and on its most recent, third iteration, the Argos-3 system also supports bi-directional communication. It will transmit in less than 15 minutes, compared to several hours with Argos-2, while still using ground-based collection and relocation, enabling data storage and quality control (André et al., 2015).

In their test, they analysed Argos-3 vs Iridium in the use of drifting buoys, but found that while costs were similar, the Argos-3 system suffered from noise and software problems, as well as satellite positioning, and although it offers quality control on the ground as well as data storage, could not compete with the Iridium system. Argos-4 is set to remedy these problems but is not yet available as of April 2018.

In order to transmit data from the Labrador Sea, a strong, global satellite network is needed. As it is important to get precise information, the Argos system with its noncontinuous service is less suited. If duplex communication is the preferred way of telemetry, the Iridium network is an obvious choice for drifters that might travel anywhere. If only simplex communication is required, the Globalstar system is sufficient.

2.3 Comparison of commercially available drifters

A multitude of surface drifters which could potentially fulfil the aforementioned requirements are commercially available, so the first step has to be a comparison of their abilities and constraints. Certainly the most well-known drifter is the SVP, which is built following the work of Sybrandy & Niiler (1992) and consists of a large buoy with a tether of around 15m, centring a 6m holey sock drogue. It is the basis of the GDP and widely spread; out of 5'222 drifters with sub-surface floats deployed to date, 4'942 have or had their drogue centred around 15m (GDP, 2018 as of March 26th, 2018). The system is currently transitioning from Argos to Iridium telemetry and on-the-hour GPS location (Lumpkin et al., 2017). While the array provides great global coverage (see Figure 3), due to their centred depth of 15m SVPs are unsuited for surface measurements, unlike the following drifters, which feature either drogues centred at most at 1m depth, or no drogue at all. These drifters will be introduced and compared in terms of telemetry, location tracking technology, SST sensor, battery life, the practicality of deployment (based on size and necessary assembly) as well as price, to see if they fit the requirements. Details on the instruments and battery life can be found in Table 1.

CODE/ Davis Drifter

An inexpensive, drogued surface drifter that has first been described by Dr. Russ Davis from the Scripps Institute of Oceanography (1985). Its main point of deployment is sampling coastal and estuarine currents one meter below the surface. Due to its use in the Coastal Ocean Dynamics Experiment, the drifter is also known as a CODE drifter (CODE, 2018). Because of its popularity and relative simplicity, it exists in different versions, some of which are built by students (NEFSC, 2018), and features a submerged cylindrical body with vane-like wings functioning as drogue and only an antenna and floats to hold the wings at the surface (see figures 8 and 10).

SLDMB

Similar to the CODE drifter, the Self-Locating Datum Marker Buoy (SLDMB) features a drogue centred at ca 0.7 m depth. It consists of a surface buoy and diamond-shaped drogue attached via tether (see figures 8 and 10). It is available in a self-locating, and airplane deployable version (SLDMB), as well as a 'normal' version (Microstar). The design is based on the Tristar II drogue described by Niiler et al. (1987), which was similar in size and drift behaviour to the predecessor of the SVP drifters ("LORAN", Mackas et al, 1989).

CARTHE/ LASER Drifter

As result of the Deepwater Horizon oil spill in 2010, over 300 CODE type drifters were released in the Gulf of Mexico, as part of the Grand Lagrangian Deployment (GLAD), to better understand the sub-mesoscale movements of surface waters by transmitting their position in 5-minute intervals (Poje et al. 2014). Following suggestions for improvement from this, CARTHE (Consortium for Advanced Research on Transport of Hydrocarbon in the Environment) developed a more practical, 85% biodegradable "throw-away" drifter, which follows oil spills by tracking currents in the top ca 60cm. During the Lagrangian Submesoscale Experiment (LASER), 1'000 such drifters, which have nearly identical water-following qualities as the CODE drifter, where released (Novelli et al., 2017). They have a donut-shaped surface float and a vane shaped drogue and have to be assembled from three parts before deployment.

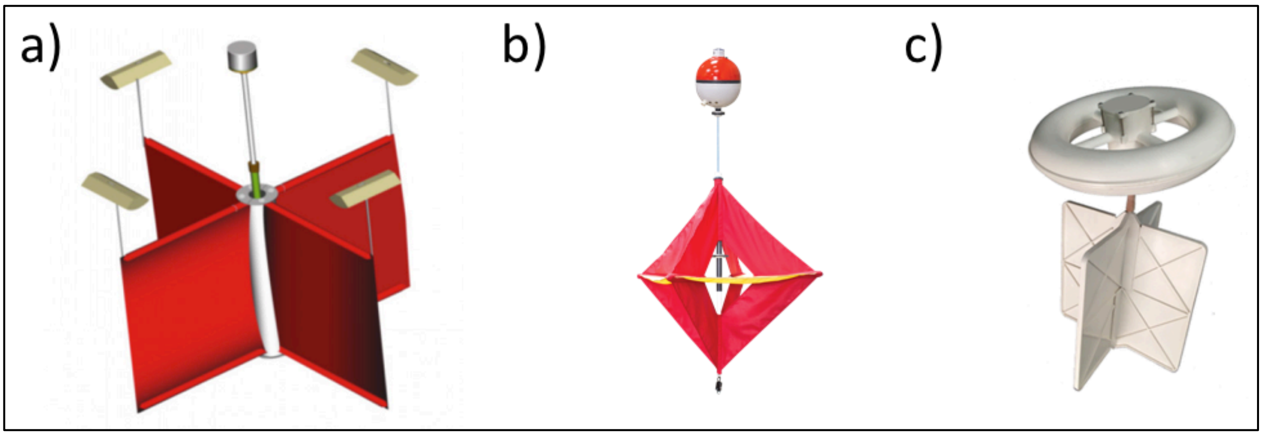

Figure 8 - a) CODE/ Davis Surface Drifter (CODE, 2018), b) SLDMB/ Microstar (SLDMB, 2018), c) CARTHE / LASER Drifter (CARTHE, 2018).

In contrast, the following drifters are either used without drogue or indented for use without drogue. They mainly differ in their position in the water column (see figure 10), and their life expectancy due to the battery power (see table 1).

iSphere

The iSphere was developed specifically to track and monitor oil spills and features are sturdy shell to enable deployment from a vessel or oil platform (fall height up to 10m). According to its datasheet, the iSphere is actually intended for use with drogue (iSphere, 2016). However, to compare their behaviour to CODE drifters, Röhrs et al. (2012) and Rhörs and Christensen (2015) used undrogued iSpheres. They did note that the drifters sit relatively high in the water, with the entire top half exposed, making them more vulnerable to wind effects.

Wavy Drifter

One of the most recent innovations in undrogued drifters is the wavy drifter, developed by the MELOA- consortium. The currently existing version (base model) is a ball with ca 12 cm diameter, completely enclosed in soft plastic, to let it absorb shock in surf areas, where it has so far been restricted to (Wavy, 2018). This European-funded project (Horizon 2020) will include several larger types of wavy drifters, including larger ones equipped with ARGOS telemetry and solar/ wave energy harvesting, however it is not due for completion until 2021. The main advantages of the idea behind the wavy drifters are the small size and optimised buoyancy, which allows it to sit far lower in the water than the iSphere (with only about the top third exposed), thus reducing the wind effect, and experience less tilt, which could negatively affect its positioning (Meloa, 2018).

MAR- GE/T

Designed by French scientists around the NCES, which also founded the Argos-network, this 'thermos'-shaped surface float has a similar size to the wavy and can be deployed from up to 30m height. (CLS, 2016).

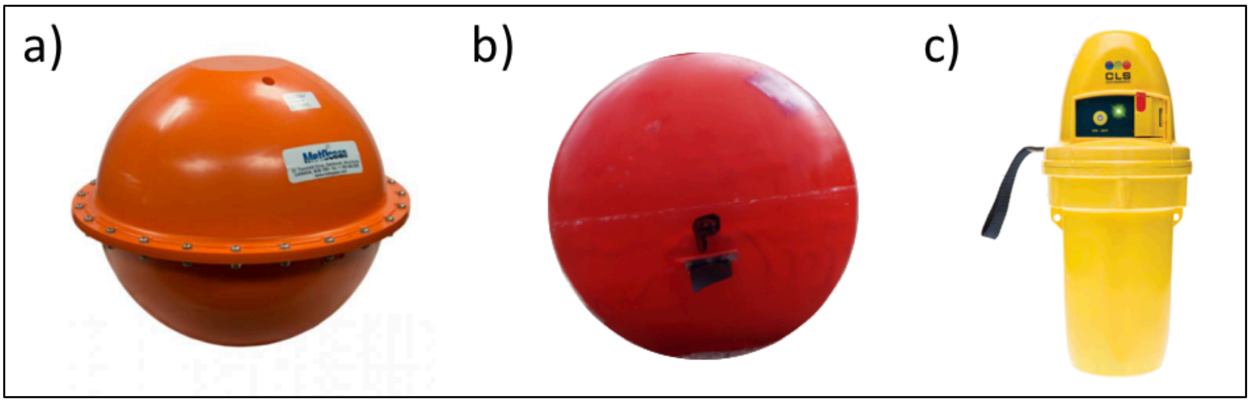

Figure 9 - a) iSphere drifter (iSphere, 2016), b) wavy drifter (adapted from Wavy, 2018) and c) MAR-GE/T (CLS, 2016)

Other drifters that have been discovered during research but are not further mentioned due to their similarity in style and/or suitability to the drifters above include the "mini drifter mobile buoy" (similar to wavy), which only features GSM communication and a battery life of around 100h; the "MD03i" (similar to MAR-GE/T), which features Iridium but only has a life expectancy of 14-21 days, and the "Ocean drifter iridium" (similar to iSphere), which is energy independent as it features solar panels, but costs £2600 with the necessary drogue (all Albatros, 2018).

2.4 Details and suitability of available drifters

Table 1

Summary of drifter characteristics

Name	Telemetry	GPS	SST	Battery	Life	Drogue	Price ~
CODE	Iridium, duplex	Jupiter F2	±0.5° C	10 AA Alkaline	3-12 months	0.7m	£1400[1]
SLDMB	Iridium, duplex	?	±0.1° C	12V 15.6Ah Alkaline	1-12 months	1m	£ 1660[2]
LASER	Globalstar, simplex	?	no	6V 15Ah Alkaline	<3 months	0.4m	£ 915[3]
iSphere	Iridium, duplex	Navman Jupiter 32	yes	?	6-12 months	surface	£1800[1]
Wavy Ball	cellular	?	yes	4.4Ah Lithium	18-25 hours	surface	No reply
MAR-GE/T	Argos	Fastrax IT1500	no	38Ah Lithium	<450 days	surface	£1018[4]

All prices would also include telemetry fees, but depending on transmission rate, these favour either Argos (flat-rate) or Iridium/ Globalstar/ cellular (per message). This however depends on frequency of transmission etc. and is not included in the prices.

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[1] Personal correspondence, S. Forbes, RS Aqua Ltd.

[2] SLDMB, 2018

[3] CARTHE, 2018

[4] Personal correspondence, B. Robert, CLS

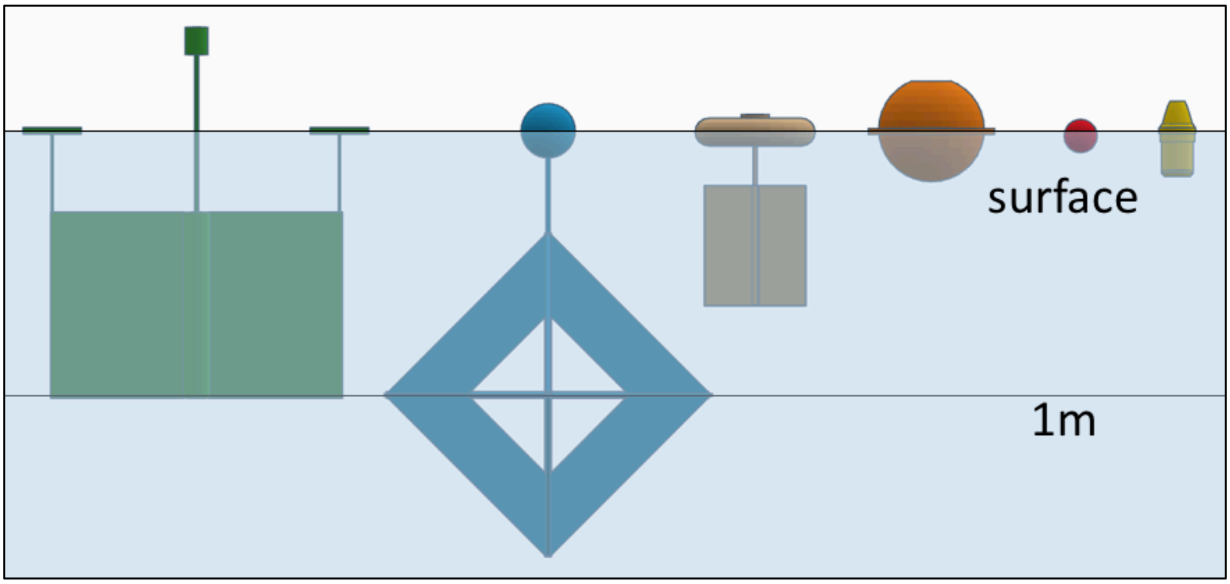


Figure 10 - Size and drogue depth comparison of all six drifters, left to right: CODE, SLDMB, LASER, iSphere, Wavy and MAR-GE/T (made with TinkerCAD, 2018, based on the measurements given in the individual datasheets above).

Table 2

Drifter suitability to requirements

Drifter	Telemetry	Location	SST	Battery	Practical	Price
CODE	✓	✓	✓	✓	✗	✗
SLDMB	✓	✓	✓	✓	✗	✗
LASER	✗	✓	✗	✓	✗	✗
iSphere	✓	✓	✓	?	✗	✗
WAVY	✗	✓	✓	✗	✓	?
MAR-GE/T	✗	✓	✗	✗	✓	?

The tabled comparison above highlights that while CODE, SLDMB and iSphere use the preferred Iridium network, they are too expensive. The LASER and MAR-GE/T drifters have no SST sensor, as well as the wrong telemetry and battery type. The WAVY drifter could be useful in a future iteration, but no information was provided on its price, and the current version does not fulfil the requirements.

It follows from this overall unsuitability that a new drifter should be designed specifically for the given task. The following chapters will outline the thought-processes involved in the design, covering foremost the electrical components and programming. Battery life will be considered, and suggestions are made for a possible exterior, the actual design and manufacturing of which was out of the scope of this project.

3 Designing a prototype - interior

The interior of the drifter is designed, built and tested in prototype form. This includes the following (more detailed descriptions see below) hardware and software components:

Hardware

- Arduino Uno
- Adafruit Ultimate GPS
- Iridium RockBLOCK v2.C
- Thermistor
- AA Alkaline Manganese-Dioxide Batteries with holder
- Breadboard, resistors, jumper wires as well as tools like soldering iron, pliers, wire strippers and suchlike for general assembly and background work.

Software

- **Arduino IDE** (https://www.arduino.cc/en/Main/Software)
  - IridiumSBD and TinyGPS libraries (http://arduiniana.org/libraries/iridiumsbd/)
- **Fritzing** (http://fritzing.org/home/)
  - Inkscape (https://inkscape.org/en/)
- **TinkerCAD** (https://www.tinkercad.com/)

As well as access to the RockBLOCK modem (account needed), which can be reached under **https://rockblock.rock7.com/Operations**

3.1 Hardware

On top of the components discussed in Chapter 2.2, the drifter will require a processor and power supply (here 5 AA Alkaline; see Chapter 4). The components covered here are the parts used in the making of this project. Discussions and possible alternatives are provided throughout when found necessary and summarised in Chapter 7. Costs and alternatives are covered in Chapter 6.

Processor

While commercially available drifters have their own ‘brain’ created by the manufacturer, such as the “MetOcean’s Global Platform Transceiver Controller TM” (iSphere, 2018), this prototype will be using the “Arduino Uno R3”. Arduino boards are open-source, leading to a large community of users and knowledge, and through their user-friendly software (Arduino IDE), enable fast prototyping, as well as being very inexpensive (Arduino, 2018a).

Location tracking

The GPS fix for the prototype, as well as date and Time in UTC, is acquired through an Adafruit Ultimate GPS breakout board. The board has an integrated ceramic patch antenna that has to face upwards in order to find its position. It can search for 22 satellites on 66 channels and has a low power consumption (Adafruit, 2018a). The board was chosen because it has a complete setup, including backup energy (3.3V coin cell) and even data logging for up to 16h. Some basic soldering is needed for assembly.

Telemetry

Following the analysis in Chapter 2.2, the drifter is using an Iridium modem, a RockBLOCK v2.C. This modem is commonly used in drifters, as well as other commercial or private applications and projects (Rock7mobile, 2018). It is relatively easy to install and offers support and coding libraries that are meant to make implementation feasible even for beginners (Hart, 2013). In case of a lost GPS signal, it will provide a very rough position for the message itself (CEP), which can be 1-100km accurate (RockBLOCK, 2018).

Temperature

The prototype is equipped with a simple NTC thermistor (±0.5°C), which has a negative correlation between resistance and temperature, meaning a temperature increase will lead to a decrease in resistance. This thermistor has been chosen because it was available in the Arduino kit and works like a higher-quality thermistor, for which it can easily be exchanged if a higher accuracy is required for future work.

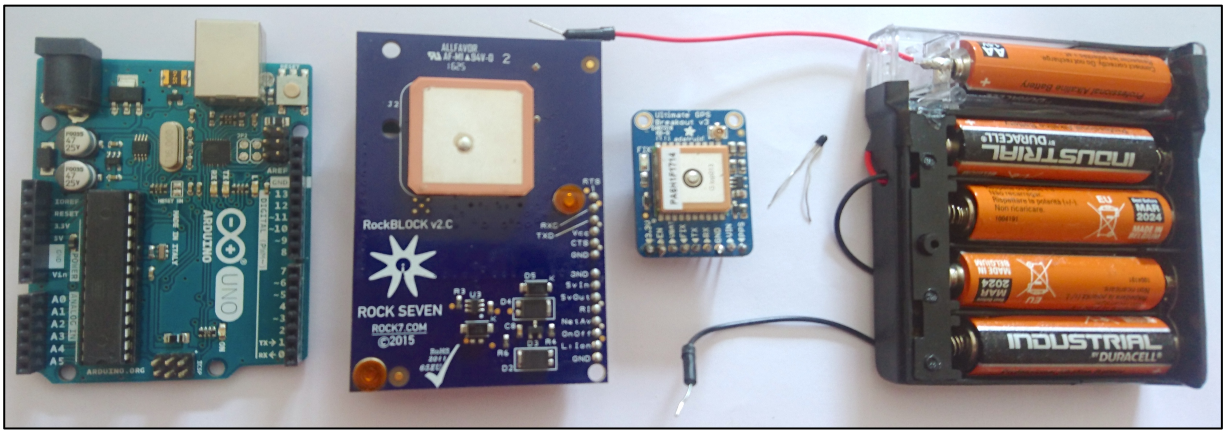


Figure 11 - Hardware, left to right: Arduino Uno R3, RockBLOCK, Adafruit GPS, Thermistor, batteries in self-made holder.

3.2 Setup

These hardware components are then connected through use of a breadboard and jumper wires, which is ideal for prototyping, as no soldering is required, different setups can be tested, and troubleshooting can be done very easily. The connections below are shown first in a general breadboard view, with wire colours representative of the actual wires (apart from cyan, which is white in the prototype), then through a schematic, electrical view. The battery is representative for the five batteries used. Apart from the RockBLOCK file, which had to be specifically made using Inkscape, all parts are available in the Fritzing catalogue. The file for the RockBLOCK can be found in the electronic appendix. For an actual drifter, connections would be soldered directly, and the breadboard would be removed.

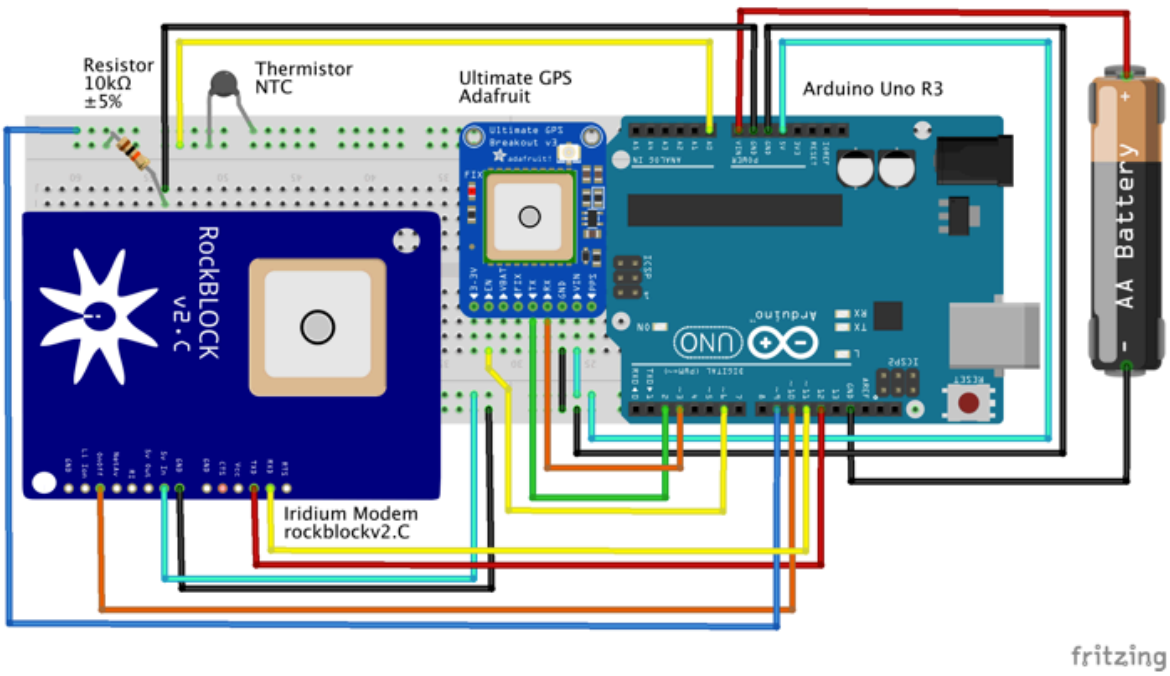


Figure 12 - Breadboard view of the prototype, made with Fritzing.

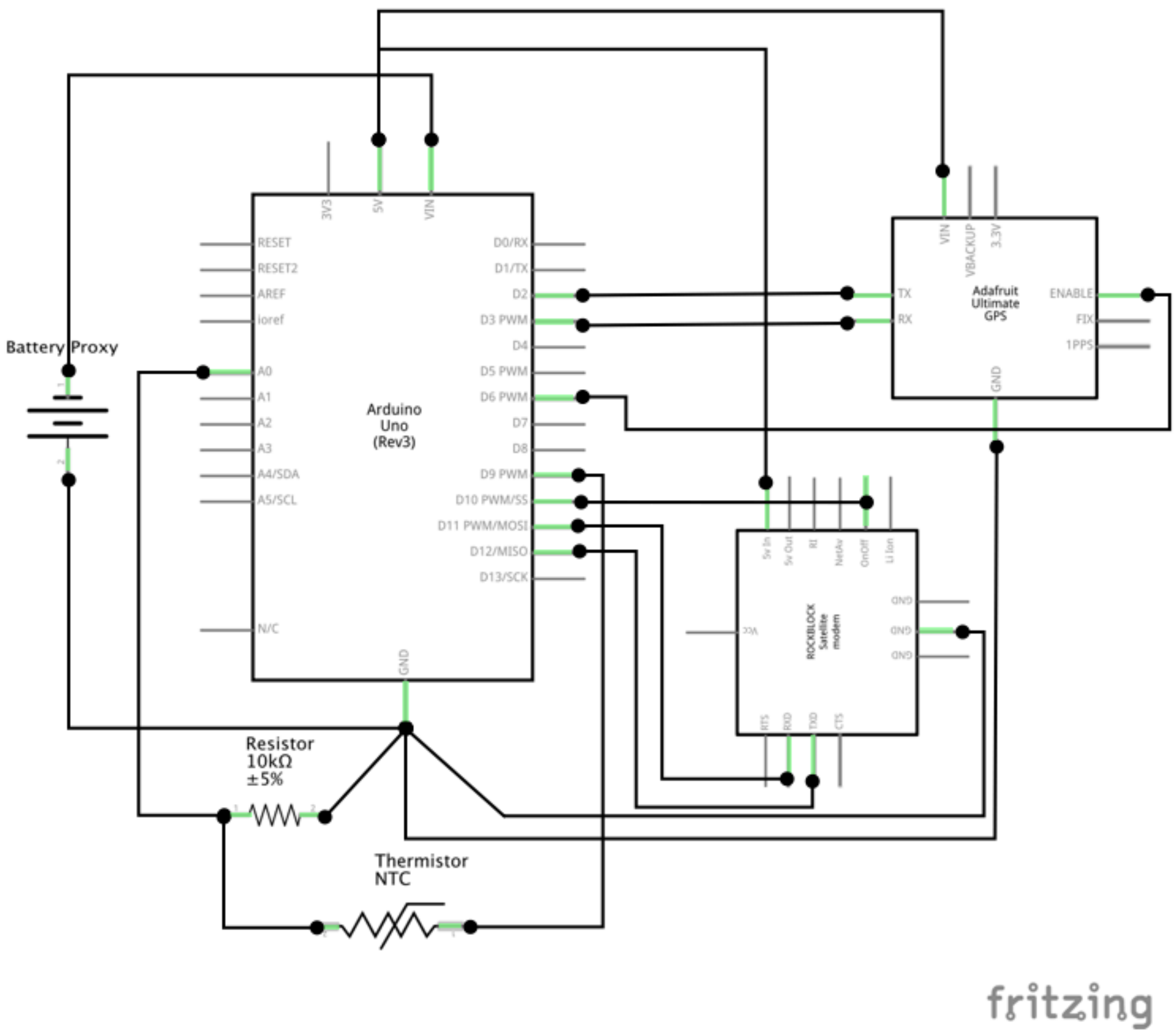


Figure 13 Schematic view of the prototype seen above

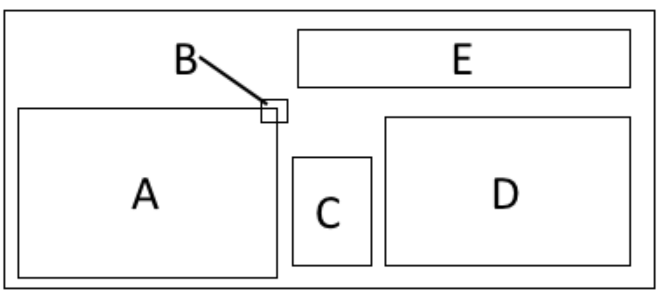


Figure 14 - Schematic of prototype, with A) RockBLOCK, B) Thermistor, C) Adafruit GPS, D) Arduino and E) batteries, see picture below.

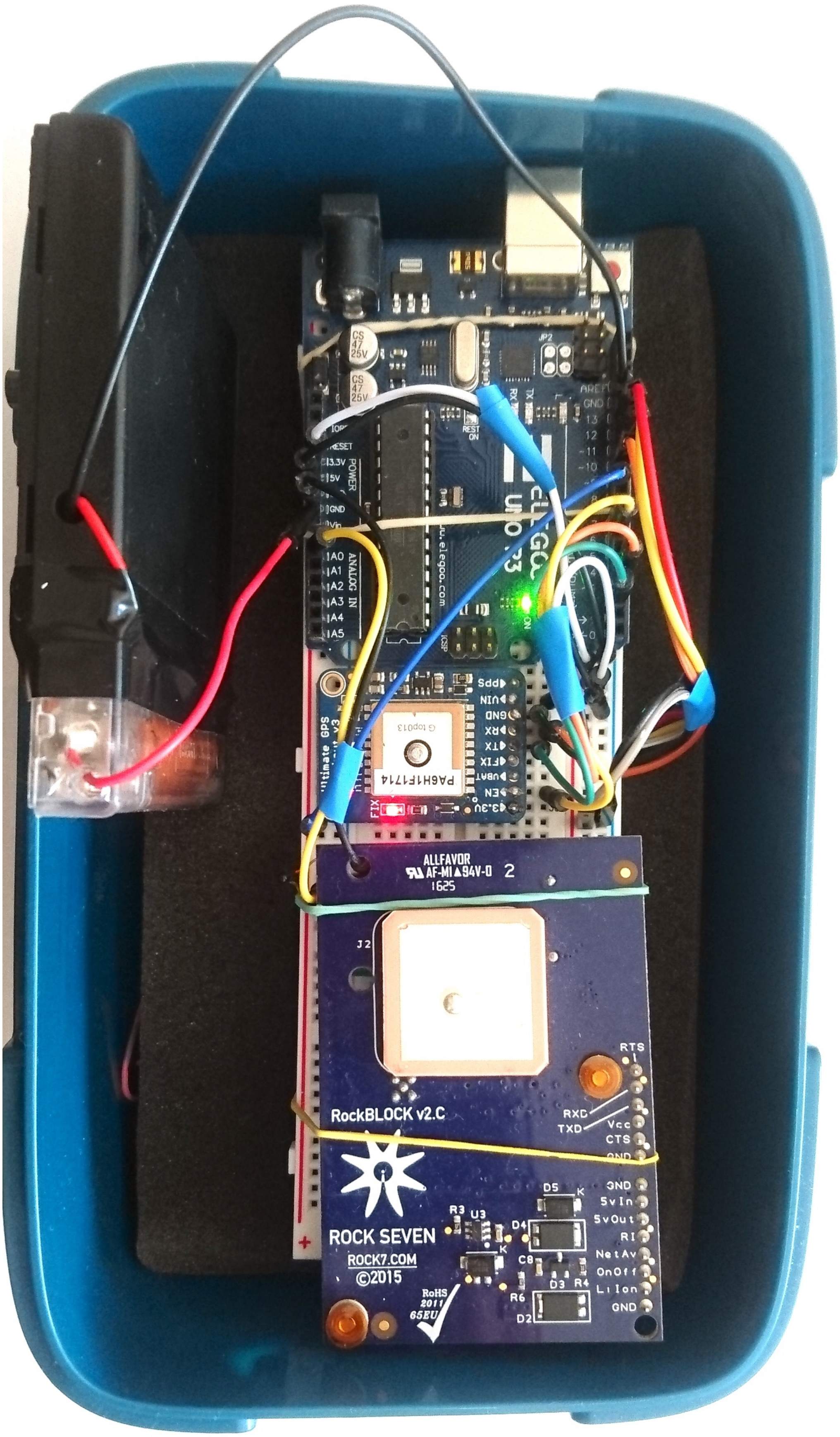


Figure 15 - The assembled interior, in the prototype casing (IKEA lunchbox), see Figure 14 for part description.

3.3 Coding

In order for the prototype to actually measure and transmit, it has to be programmed. Programming for an Arduino is done using the Arduino IDE software which uses a simplified version of C/ C++ and is separated into *libraries*, running background processes, and *scripts*, running the actual code. Arduino coding follows a pre-set structure, with a basic setup at the beginning, where libraries are included, and hardware is introduced (e.g., pins are allocated), followed by a specific set-up where starting parameters are set, which the Arduino will execute once on start-up, and finally a loop which includes the main code, and will be re-run until power is lost.

The code needed to locate the drifter, sample water temperature and communicate it via the Iridium satellite network - in real time - is adapted from examples and libraries provided by the IridiumSBD and TinyGPS (Hart, 2013), as well as additional code for the thermistor and duplex communication (to allow reprogramming while deployed), and can be found in the electronic appendix and is commented throughout to explain the individual steps. The drifter, following this code, will try to get a GPS fix, measure the temperature and communicate the findings and sampling interval. It will either give the coordinates or “no GPS” if no fix could be obtained. If the RockBLOCK fails to communicate with the satellite, the drifter will try once more, circa 5 minutes later. It will restart the sampling as well, as the RockBLOCK antenna is stronger and it stands to reason that if the RockBLOCK fails to communicate, the GPS will not have gotten a fix either. After successful transmission (or the second attempt), the system will go to sleep for a pre- or newly determined time. If the drifter is connected to a computer, the software terminal will print the result of each step.

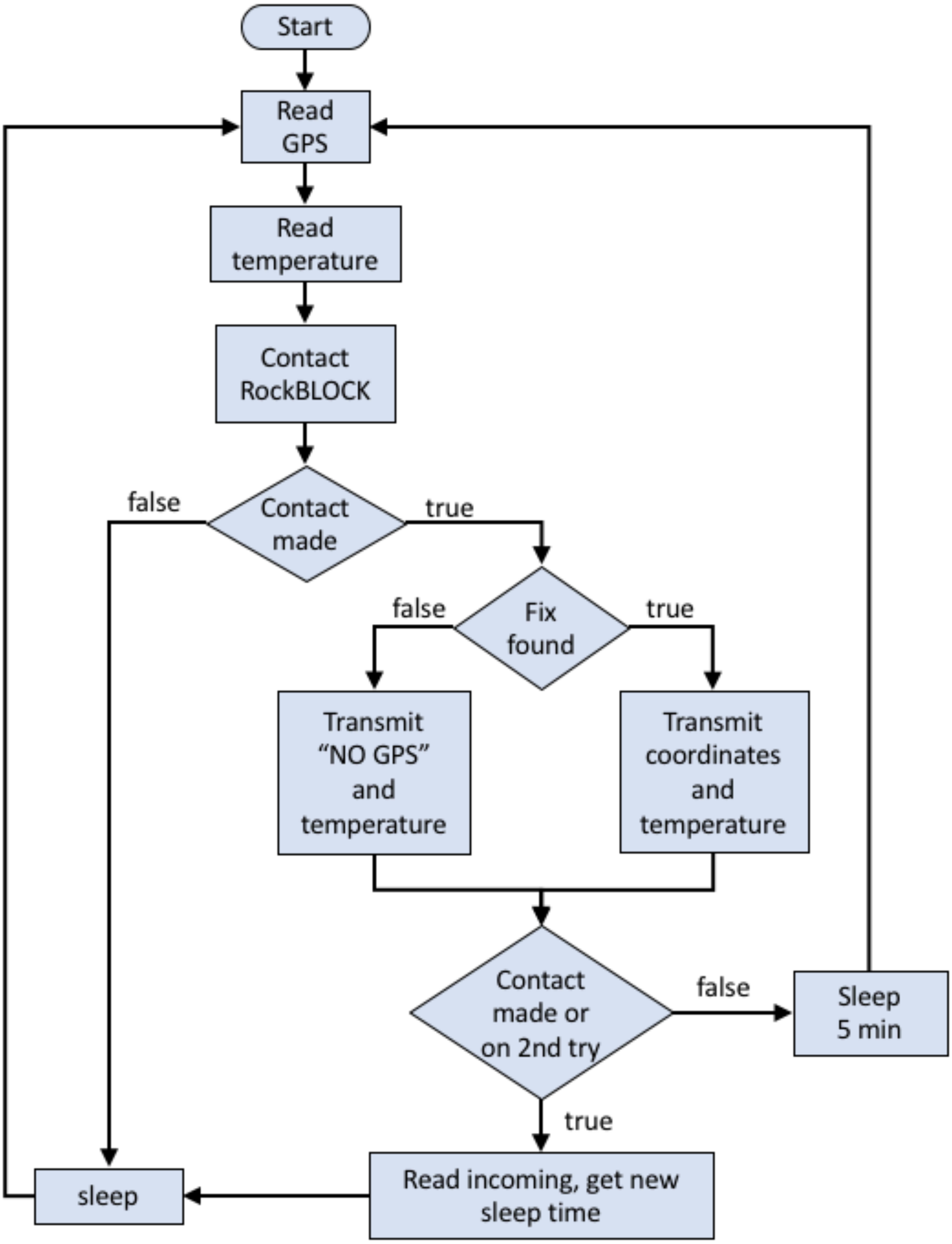


Figure 15 – Conceptual structure of the code for real-time transmission, with adjustable sampling interval

By sending a single message to the RockBLOCK (via the website given above), the code can change the sampling interval to up to 9h (less than 15 min is not practical, as one cycle can take up to 11 min, see chapter 4.2). The message must be the time in seconds. It must be 5 digits (padded with zeroes if necessary). It cannot exceed 32767s. It should for example be:

07200

for a desired sampling interval of 2h. Only one message can be sent to the RockBLOCK per cycle (the website shows if it has been delivered). These restrictions are due to the rather complex setup that the RockBLOCK requires. In fact, anything but the most basic operation for the RockBLOCK tends to become very complicated very fast, which proved to be a very time-consuming factor in the design of this prototype.

A second code was also created using the in-built GPS logging the Adafruit breakout board provides. This design was discarded, as the GPS logger saves too much unnecessary data (like altitude) and cannot store the values from the temperature sensor. Storing this additional data on the internal memory of the Arduino itself (SRAM) or its flash memory (which is significantly larger than the SRAM (Arduino 2018b)) causes the system to break down, as the data file gets very large with shorter sampling intervals; and is therefore not advisable. For a drifter that will be recovered, the GPS' internal flash can provide useful, high resolution tracking (every 15s, Adafruit 2018b) data, with additional data stored on an SD card (see chapter 4.2).

3.4 RockBLOCK communication

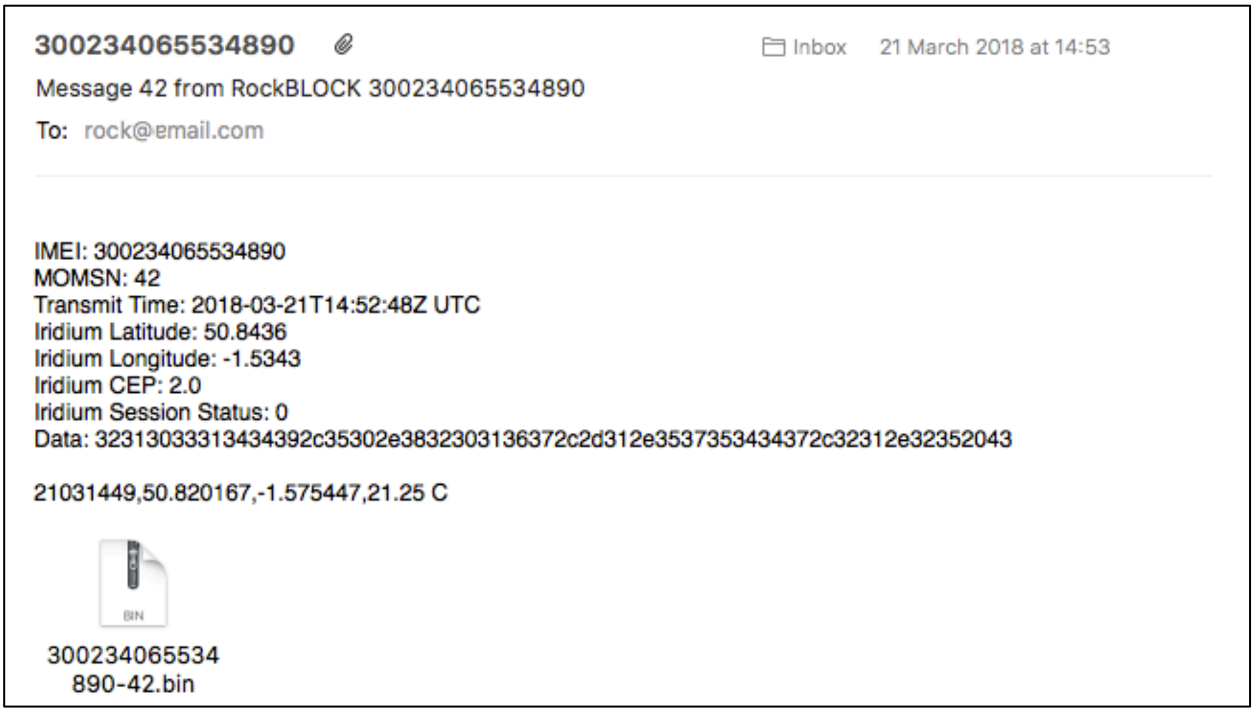
The code sets the RockBLOCK messages up in packages of 50 bytes (characters), costing one credit. It has been optimised to always stay below 50 bytes by keeping the messages very concise. A successful message (a) consists of date and time, latitude, longitude, temperature and sampling interval (ca 47 bytes). Should there be no GPS signal (b), the message will state that, as well as give the temperature and the sampling interval.

a) 21031449,50.820167,-1.575447,21.25 C, RSM1800
b) No GPS, 15.42 C, RSM1800

In a) the characters in front of the first comma, 21031449, are date and time, without the year, in this case the 21st of March, 14:49 UTC. The next part shows the latitude in decimal form (50.820167), followed by the longitude (-1.575447), with negative representing South and West, and positive representing North and East respectively. This is followed by the temperature in °C. The last bit is the same for a) and b) and shows the 'RockBLOCK sleep time in minutes' (because it uses less digits than seconds). The RockBLOCK modem will send this as a hex-encoded data package, which will be decoded again on arrival, and for this example is, again with and without GPS signal:

a) 32313033313434392c35302e3832303136372c2d312e3537353434372c32312e323520432c2052534d31383030
b) 4e6f204750532c2031352e343220432c2052534d31383030

All messages from the RockBLOCK will include the ID of the modem, ID of the message, time the message was received, a rough location (circular error probability (CEP), in km radius), a session status and the file itself attached. Because of this, the message itself will not include the year of the data measurements, only month and day.



300234065534890   Inbox   21 March 2018 at 14:53

Message 42 from RockBLOCK 300234065534890

To: rock@email.com

IMEI: 300234065534890
MOMSN: 42
Transmit Time: 2018-03-21T14:52:48Z UTC
Iridium Latitude: 50.8436
Iridium Longitude: -1.5343
Iridium CEP: 2.0
Iridium Session Status: 0
Data: 32313033313434392c35302e3832303136372c2d312e3537353434372c32312e32352043

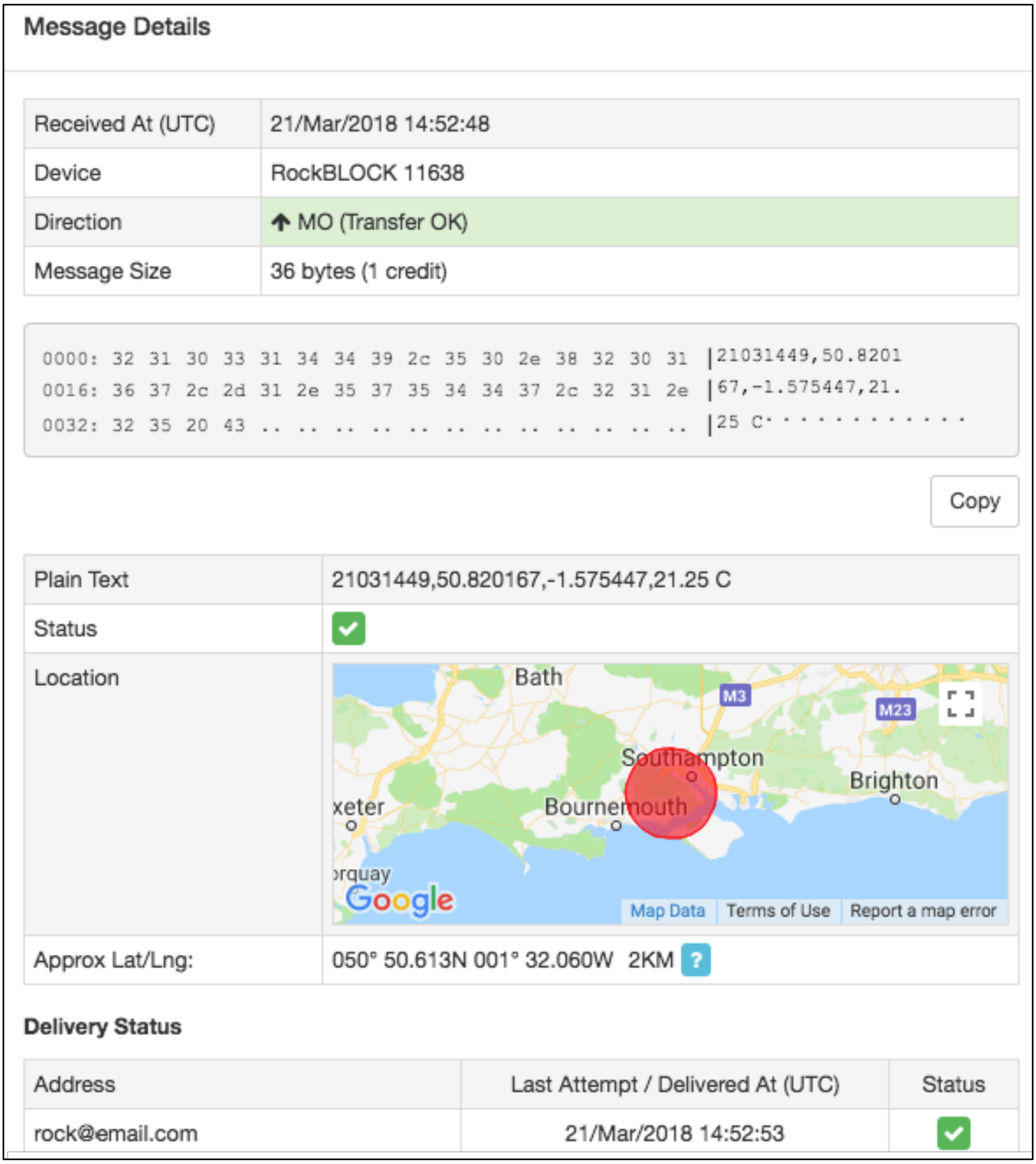
21031449,50.820167,-1.575447,21.25 C

BIN

300234065534890-42.bin

Figure 16 - Typical email from the RockBLOCK (here from earlier in the project, without the RSM)

On the RockBLOCK admin site, the data is available in a full breakdown, including an attempt at locating the modem given with CEP. It provides a rough location with its data messages, which can be accurate up to 1000m, but is only accurate to within 10 km 80% of the time (Iridium, 2012). There is also a map with a corresponding marker, as well as a full dissection of the sent data into bytes.



Message Details

Received At (UTC)	21/Mar/2018 14:52:48
Device	RockBLOCK 11638
Direction	MO (Transfer OK)
Message Size	36 bytes (1 credit)

```
0000: 32 31 30 33 31 34 34 39 2c 35 30 2e 38 32 30 31 |21031449,50.8201
0016: 36 37 2c 2d 31 2e 35 37 35 34 34 37 2c 32 31 2e |67,-1.575447,21.
0032: 32 35 20 43 .. .. .. .. .. .. .. .. .. .. .. .. |25 C............
```

Copy

Plain Text	21031449,50.820167,-1.575447,21.25 C
Status	✓
Location	
Approx Lat/Lng:	050° 50.613N 001° 32.060W 2KM ?

Delivery Status

Address	Last Attempt / Delivered At (UTC)	Status
rock@email.com	21/Mar/2018 14:52:53	✓

Figure 17 Information available for each message on the RockBLOCK site (here from earlier in the project, without RSM)

3.5 Testing the interior

A first test examined simply the wiring and coding while connected to the computer. Multiple iterations where tested, and the connection to the terminal (through the Arduino IDE) allowed immediate debugging. A second, and first full system test was of the functionality under mobile conditions, with the prototype powered by a 9V battery and carried in a backpack. The test area was the New Forest, far from buildings, to test the GPS behaviour in an open area. In order to get enough data, the transmitting frequency was set to once every 5 minutes, with a GPS fix time of 1 minute, over 4 hours. The last test included changing the sampling intervals.

Test Results

The first test managed to achieve a GPS fix and temperature reading and transmit all data, however a problem was encountered with the temperature being impossibly wrong (from -273.15°C, over - 59.6°C, up to 193.9°C).

The mobile test, where the drifter was carried around the New Forest at walking speed, was mainly successful. A GPS fix was found 97% of the time (29/30), showing that the GPS worked almost perfectly in an open / lightly wooded area. In covered area, it failed at times. The temperature was consistently wrong, and while data was transmitted reliably, it happened far too slow (at a rate of double the programmed five-minute interval).

The sampling interval test was successful for all messages sent in the correct format, see chapter 3.3.

Figure 18 - Plot of the GPS coordinates obtained during the mobile test (map created with Ward, 2018).

Corrections and Fixes

The incorrect temperature was either due to a wrong resistor for the thermistor was used (a lower resistance suggested higher temperatures than were accurate) or, in the other cases, the resistor disconnecting from or touching other parts of the breadboard. A value of -237.15°C will be shown if the thermistor completely disconnects, as it is caused by the Fahrenheit conversion programmed within the code.

The incorrect sampling interval was due to a mistake in the order of commands to be executed by the system, so the code caused the RockBLOCK to turn itself off, instead of on, while initialising, during every 2nd cycle.

Both problems have been fixed, the first by switching in the correct resistor (10kΩ) and attaching it more securely, the second by reorganizing the code.

The GPS fix could be improved by adding an active antenna, which the modem has a connection port for, but in a remote ocean this should not be necessary, as the open area test worked very well.

Using CEP for locating

Unlike Argos, which can locate its transmitters up to 150m accurately, the CEP gives only a very rough location of up to 1000m accuracy. Satish et al. (2014) however found in their study a statistical value of about 0.03 degrees (on average) in difference between the Iridium and GPS locations of their Argo floats. In their case, over 91% of messages had a CEP radius of 1 - 4 km, providing valuable data in the case of a GPS loss. For the first 84 messages received on this prototype, while not as extreme, the distribution looks similar even though the drifter was in a covered area. For the mobile, the CEP of 1-4 km was 80% (excluding time spent indoors), indicating that the RockBLOCK can provide at least some backup indicator of the location should the GPS fail to acquire a fix.

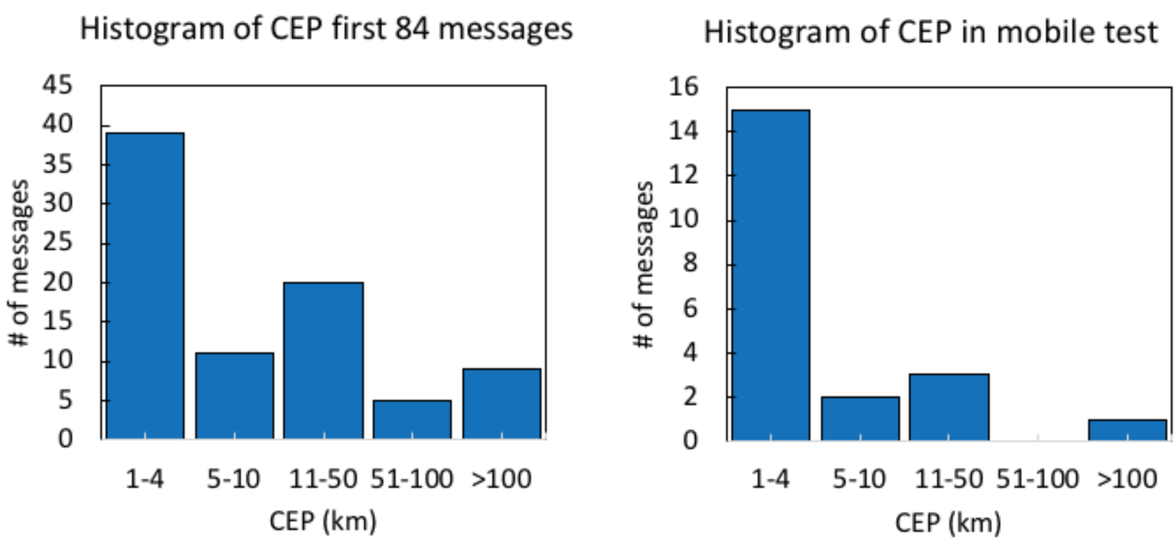


Figure 19 – left, CEPs of the first 84 messages received, right, CEP from the mobile test.

4 Designing a prototype - power

The analysed drifters in chapter 2 use a wide range of power for their drifters, and life for the Iridium drifters ranges from 1-12 months. Since the drifter will not be recovered and recharged and will not have any energy harvesting devices on board (like solar panels or even wave energy, see Meloa, 2018), it should be optimized for the longest possible duration, as well as be equipped with a battery with a low environmental impact. As discussed in the drifter requirements in Chapter 2.2, Alkaline batteries will be used.

4.1 Requirements and configuration

Arduinos theoretically operate on 5V, but the internal voltage regulator requires a certain “drop voltage”, so a minimum of 6V is recommended. The best operating voltage is between 7V and 12V (Arduino, 2018b). This could be achieved by using a 9V – Alkaline battery, however 9V batteries have notoriously low capacity (see figure below). Following the energy density guide from Duracell (2016), AA and C batteries are preferable, since they have the highest energy density (energy provided per weight). Because AA cells are more easily available and therefore usually cheaper, with holders easier on hand and the smaller size giving more options to arrange the batteries, the prototype will also feature AA cells.

SIZE	NOMINAL VOLTAGE	RATED CAPACITY*	WEIGHT	ENERGY DENSITY
	volts	ampere-hours	kilograms	watt-hours per kilogram
D	1.5	15.000	0.138	130
C	1.5	7.800	0.065	144
AA	1.5	2.850	0.024	143
AAA	1.5	1.150	0.011	126
N	1.5	0.800	0.010	96
J	6.0	0.580	0.034	82
Lantern	6.0	11.500	0.612	90
Lantern	6.0	24.000	1.270	91
9V	9.0	0.580	0.046	91

Figure 20 - Energy densities of Alkaline Manganese Dioxide cells (adapted from Duracell, 2016)

In order to obtain the necessary preferred minimum of 7V, as well as a higher capacity to supply the drifter with more energy, several AA cells have to be connected to form a battery. AA cells weigh 24g each, with a capacity of 2.84 Ah and a voltage of 1.5V (Duracell, 2016). They can be connected in series, which will raise the voltage, parallel to increase the capacity, or first in series, and then parallel, to increase both (BU, 2018b). In order to reach the 7V, five AA cells will be connected in series, providing 7.5V.

For the end product, one or two more of these new 7.5V batteries can be connected in parallel, which would triple the capacity, as can be seen in the figure below. However, each 7.5V battery weighs at least 120g (5 x 24g), which is a significant weight for a small drifter. For the prototype, only one battery at 7.5V and 2.8 Ah is used.

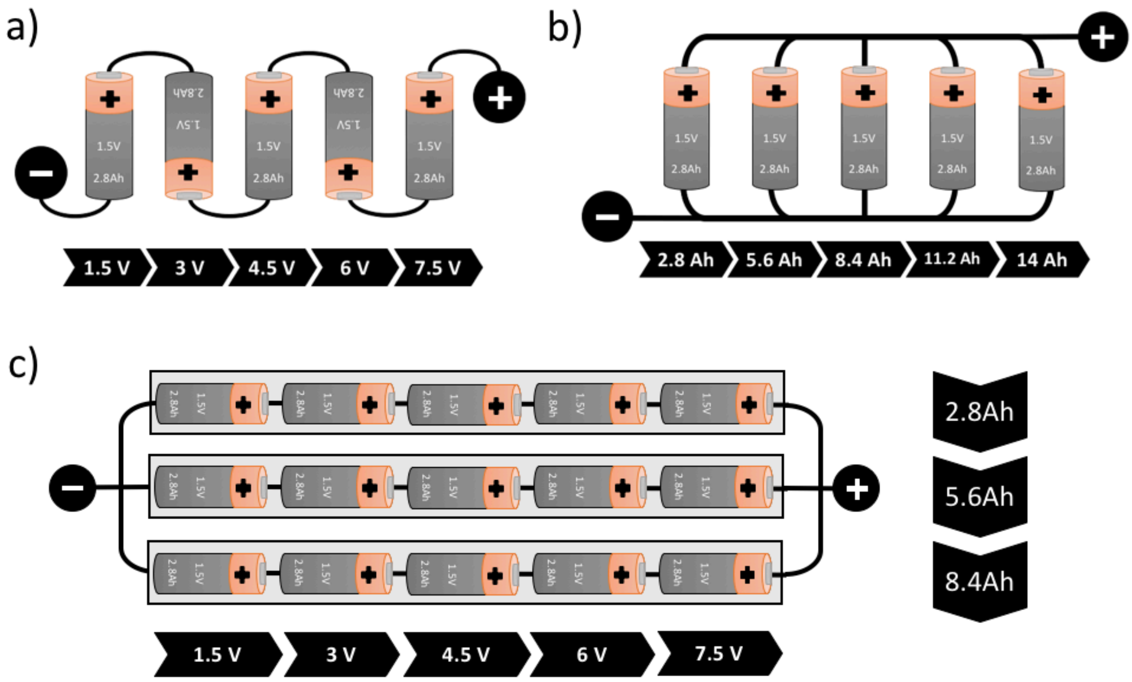


Figure 21 - AA cells connected in a) series, increasing voltage, b) parallel, increasing capacity and c) first series, creating three 7.5V batteries, then parallel to raise the capacity by 2.8Ah per battery.

4.2 Power Consumption

In order to test the power consumption, the code was set for a 30 min sleep duration between operations, and a 3 min GPS fix window. The Arduino itself has a rather high power consumption, with 46.5mA when active, and 34.4mA in normal sleep (Gammon 2015).

According to its datasheets, the RockBLOCK will draw an initial current of 450mA upon start up, to charge its internal systems, which takes about 25s. This charge will then be maintained as long as the RockBLOCK is connected to a power source, even in sleep. The idle current on which it receives alerts is 50mA, in sleep mode this can be reduced to 20µA. While in operation, with 50% visibility of the sky, the RockBLOCK will draw about 78mA for up to 8 minutes (sending and receiving, Rock7, 2016).

The GPS-board will draw 20 mA during navigation and will be switched off by using the ENABLE pin while not in use, while keeping its fix through the backup battery, the holder for which has to be soldered on before it can be used (Adafruit, 2018b). The thermistor is powered over a digital pin and will receive 20mA for about a second while a current is run through it, and no power at other times (Arduino, 2018b).

This could be confirmed by using a multimeter (ULTRICS UT0021YB), connected in series, and taking readings every 2s. The setup included a GoPro taking a picture every 2s, these readings were then transcribed.

Figure 22 - Measuring energy consumption of the prototype with a multimeter set at 10A sensitivity to capture the initial large draw by the RockBLOCK

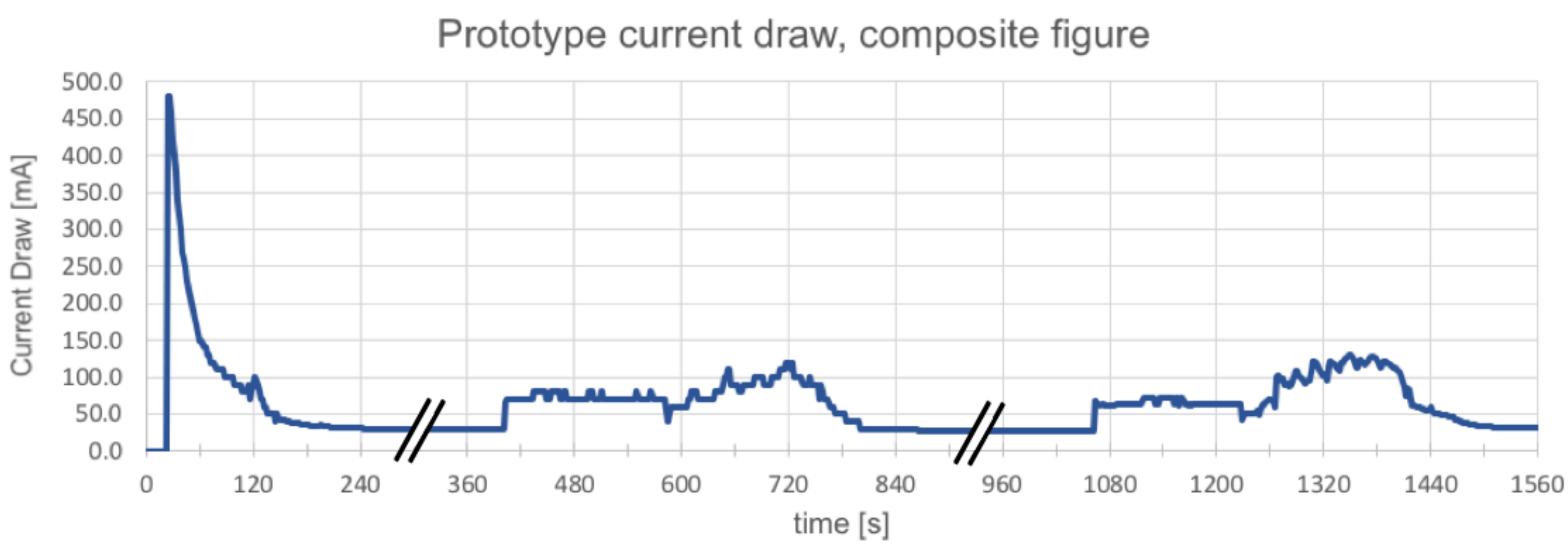


Figure 23 - Power consumption of the prototype, measured in 2s intervals over multiple tries, here shown as a composite figure with three representative cycles from different tries. This shows the large initial draw immediately after activation and a very short first measurement (immediate Iridium contact) for the first cycle; and for the second and third cycle, a plateau-like GPS-activity, followed by a dip where only temperature was measured and finally the very spiky (compare Rock7, 2016) RockBLOCK satellite communication-phase; the periods of sleep (30min in the setup) are shown shortened by //

The multimeter readings confirm the values reached within the datasheets. Upon start, around 480mA are drawn, as the Arduino and RockBLOCK are active. The draw then quickly falls to around 100mA, which is the Arduino and GPS, dips when the GPS is turned off and temperature is read. It increases again when the RockBLOCK sends and receives, drawing around 80mA on top of the ca 45mA for the Arduino. During sleep, the system draws around 29mA (including 20µA for the RockBLOCK), which, curiously, is less than the predicted sleep draw for an Arduino. The minimum recorded value was 28.0mA.

In the first cycle in the figure above, the GPS signal was found almost immediately, and contact with the RockBLOCK could be established very rapidly as well – the first reading of 480mA was taken at 09:16:38 that day, the successful email from the RockBLOCK arrived at 09:19:35. The latter two (the sleep time has been cut out) cycles both took much longer to get a GPS fix and contact with a satellite. It can be assumed that the worst-case scenario for power consumption is the full GPS-fix window (set to 180s) plus the full RockBLOCK transmit time until timeout (ca 640s, defined by the library). Assuming

$$D_{cycle} = (Rock_{initial}) + T_{active} * D_{Arduino} + T_{GPS} * D_{GPS} + T_{Rock} * D_{Rock},$$

where T and D are the respective time and draw, and the thermistor neglected as its contribution is miniscule, this gives a worst-case consumption of

$$D_{cycle} = (25s * \ 450mA) + 660s * 45mA + 180s * 20mA + 640s * 78mA = \mathbf{27.16mAh}$$

for the first cycle, and then **24.03mA** over 11m for the following cycles (worst case, but no longer including the initial draw of 450mAh over 25s). While these values are easily covered with the proposed battery, the problem is the period during which the drifter is asleep. One hour of sleep draws – as measured - **29mA**. Following these calculations, for a deployed drifter which would measure every 3h (so eight times per day, for 11 minutes at most), the current draw would roughly be

$$D_{daily} = 8 * 24.03mAh + (24h - 8 * 11min) * 29mA = 192mAh + 653.66\,mAh$$

$$= \mathbf{845.7}\boldsymbol{A/day}$$

Even with three sets of 7.5V batteries, giving 8400mAh, this drifter will only last 9 days under ideal conditions, and less if the cut-off voltage for AA batteries (0.8V) is considered (Duracell, 2016). It is obviously apparent that the current draw during sleep is unsustainably high. This is due to the Arduino itself. The best alternative for this is foregoing a pre-made board completely and using a specifically designed printed circuit board (PCB). There are numerous tutorials online dealing with this problem, one of the most comprehensive is surely Gammon, (2015), who managed to lower the sleep draw of his board to below the self-discharge rate of most batteries, at under 100 nano (!) amps. A custom-built circuit board at only a 10th of this efficiency, (1µA +20µA for the RockBLOCK during sleep) would already drastically increase the life expectancy to

$$D_{daily} = 8 * 24.03mA + 22.53h * 21\mu A/h = \mathbf{192.71mA/day},$$

which, with the current battery configuration of 8.4Ah, gives over 40 days and with the LASER's battery configuration of 15Ah, would also give around 3 months of life time (same as the LASER drifter).

However, even with the PCB replacement, a draw of 192 mA/day is still rather high. This could be improved by not transmitting the data in real time, and instead by collecting time, location and temperature from different sampling times, storing them on an SD card and only transmitting them once or twice per day. Since a 3-minute GPS locating attempt at most takes $180s * (20\ (GPS) + 45\ (Arduino) mA/h) = 3.25\ mA/try$, reducing the transmissions to once a day could, with a 3h GPS interval and the larger RockBLOCK transmission assumed to take 30 min, reduce the overall daily draw to ca

$$D_{daily} = 8 * 3.25mA + 23.6h * 21\mu A/h + 0.5h * (78 + 45)\ mA/h = \mathbf{88mA/day}$$

which is less than half (46%), and could therefore double the drifter life, or allow for more frequent sampling –even hourly sampling would still save 27%, though some loss depending on the SD card implementation has to be considered as well.

Future iteration should also feature a magnetic reed switch, so the drifter does not lose energy before deployment. It works through the presence of a magnetic field which is used to keep the drifter circuit open, and only the removal of the magnet will allow the circuit to close and the drifter to power on (REE, 2018). While this prototype however does NOT include either of these alternatives, since the skills and tools (and time) involved in their construction and/ or setup were beyond the scope of this project, they should definitely be considered for future work.

5 Designing a prototype - exterior

The current (working) prototype's casing has been limited to an IKEA lunchbox, the actual drifter however has to have a cost-efficient exterior that allows for easy handling and deployment by helicopter and, most importantly, is waterproof, floats and follows the surface currents. Because this is a more technical process that requires a lot of testing, and project time was limited, this remains theoretical. Still, the mechanics for a potential shape, material and deployment of the drifter have been examined, and suggestions are made towards a viable exterior which should be further explored in future work.

5.1 Casing

The drifter is meant to follow the freshwater from the GrIS, which Dukhovskoy et al., (2016) state should mostly be in the top 0.5m. The motion of a drifting object follows the leeway (or windage), which Allen and Plourde (1999) describe as the resulting motion from wind (at 10m) and waves relative to the ambient current measured between 0.3 and 1m depth. Breivik et al. (2012) found that increased immergence significantly reduces the downwind and crosswind (perpendicular to the wind direction) speeds of leeway, and while De Dominics et al., (2016) confirmed that a submerged drifter follows surface currents better than a partially submerged one, Schulze's (2016) simulations implied that freshwater entering from Greenland might be subject to wind forcing, rather than eddy activity when moving off-shelf, suggesting a drifter should be directly at the surface to experience the same forces. The RockBLOCK and GPS require direct line of sight to a satellite (above the waterline), so the drifter has to always remain upright. For the drifter, it therefore holds that it must (see also Chapter 2.2):

- Be practical, e.g. easy to construct, assemble and deploy
- Be submerged as much as possible, but still stay at the surface
- Allow for the GPS and RockBLOCK to sit above the waterline
- Be self-righting and tilt as little as possible
- Be bio-degradable

In order to stay practical but keep all advantages of a drogue, without the possibility of loss, an integrated drogue should be used. Following Niiler et al. (1987) and proven by the still prevailing shape, surface floats are spherical to reduce rectification, where the surface waves dominate the behaviour of the drifter. To keep the RockBLOCK and GPS above the water while still preserving the submergence and reduce leeway, an oblate spheroid is suggested. Such a flat float (like a LASER torus without drogue) could easily be flipped (Haza et al., 2018), so more stability is acquired by giving the drifter a large metacentric height, where the centre of the water displacement volume is higher than the centre of gravity (see Motyzhev et al., 2006). This can be achieved by putting the centre of gravity at the lower end of the drifter, e.g. by placing the rather heavy batteries there.

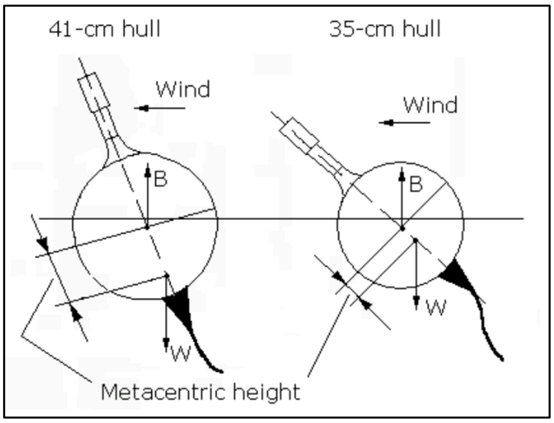


Figure 24 - From Motyzhev et al., (2006) - Two SVP floats, with the centre of the water displacement volume (B) higher than the centre of gravity (W); demonstrating the advantages of a larger metacentric height to reduce tilt.

The resulting design (see figure below) features a 3D-printed buoyant top part, with enough volume to keep everything afloat (ideally immersed up to the rim) and containing the electronics. This is then connected to a 3D-printed container at the bottom, which holds the batteries. The connection is made through the use of four threaded stainless-steel rods, which are cheap while providing a lot of stability, and a thin stainless-steel pipe in the middle, with room for cables to connect the top and bottom parts. Between each of the rods and the centre pipe, a 3D-printed "wing" is fixed. These wings function as the drogue part of the drifter, and through their fixed concave shape should make the drifter turn into the current, but not further, as the wings on opposite sides curve into the same direction. There will most likely be quite some strain on these wings, which could accelerate their degradation, which should be considered for future work. This form should however prevent loss of drogue and be compact enough for easy deployment.

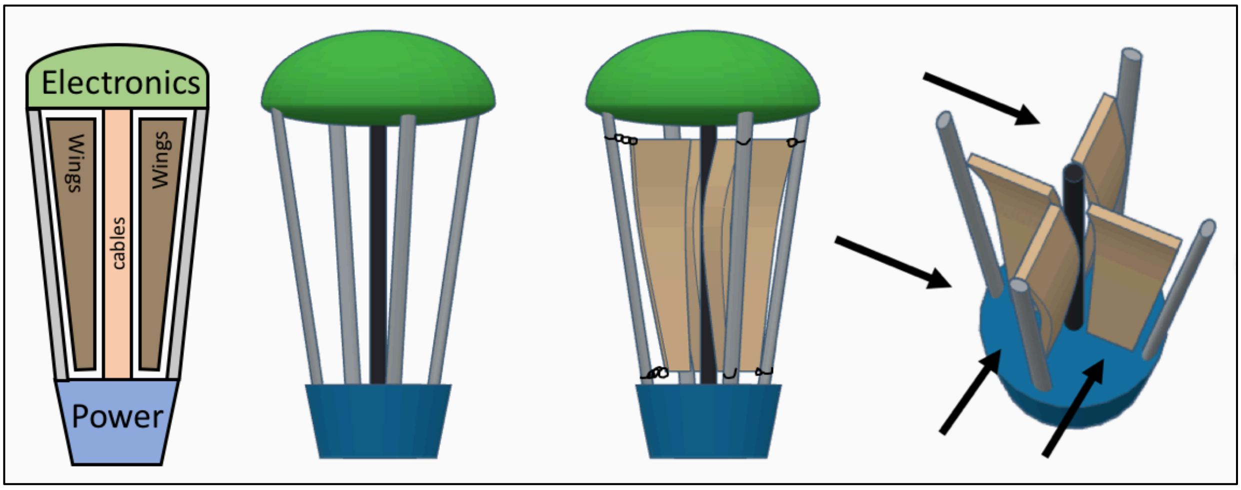


Figure 25 - Design suggestion for the drifter end product using steel and biodegradable 3D printing, the centre of the displaced volume (B) would here be in the green part, the centre of gravity (W) in the blue, giving great vertical stability (made with TinkerCAD, 2018, not to scale).

5.2 Materials

In order to be as environmentally friendly as possible, biodegradable plastic should be used for the components that are neither electric nor metal. Polymers will not block the signal; Rock7 themselves sell the modem as encapsulated waterproof version (RockBLOCK, 2018).

While commercial drifters are usually made via injection-moulding, due to the comparatively low number of drifters needed for this project, 3D-printing is a much more efficient alternative. Biodegradable plastics for 3D-printing are available in either Polyhydroxyalkanoates (PHA), Poly lactic acid (PLA) or a PHA/ PLA blend, to increase the malleability of the material (Greene, 2012).

These materials have been used in bio-engineering and even 3D-printing of tissue without any negative consequences to the organisms (Chiulan et al., 2018). The non-biodegradable parts of this drifter design, like the electrical components, Alkaline batteries and stainless-steel rods/ screws are non-reactive with the environment and will sink to the ocean floor once the degradation of the plastic makes it negatively buoyant, where they will remain.

No actual calculations have been made towards the specific size; the top float will have to be adjusted in size to create enough buoyancy for the entire drifter, while its overall height should be around 50cm, to reach the relevant currents.

5.3 Deployment

For the deployment of the drifter, by helicopter as part of a cluster of ca. 300, the above shape should also proof to be rather efficient. Assuming a height of 50cm, with a ca 20cm wide head tapering off to about 10cm at the bottom, the drifters could be stacked to a volume of ca 6m^3 (width of 2m, height of 1.2m, depth of 2.5m), secured with water-soluble tape. A decelerator (non-personnel parachute) is then attached to the entire package, to prevent damage during deployment.

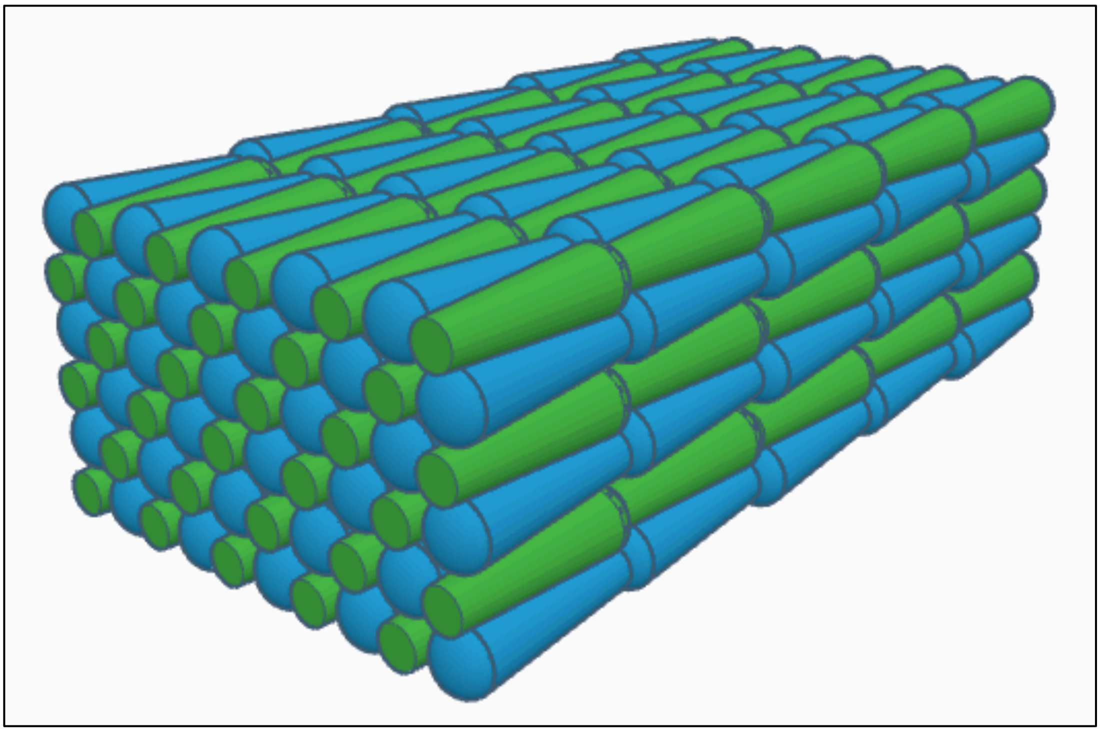


Figure 26 - Drifter placement for deployment (created with TinkerCAD, 2018)

Assuming a cautious average weight of ca 1.5kg per finished drifter, this would give an overall weight of 450kg. Using model-calculations for rocket parachutes (Culp, 2008), the diameter of the decelerator can be calculated as

$$D = \sqrt{\frac{8mg}{\pi \rho_m C_d v^2}},$$

Where m is the mass of the cargo, g is gravitational acceleration, ρ_m is the density of the medium, here air (ca 1.225 kg/m^3), Cd is the drag coefficient of the decelerator (0.75 for a sheet, 1.5 for a dome-shape) and v is the indented final velocity (ideally less than 3m/s). In this case, the decelerator would need a minimum of 27 meters in diameter, if dome shaped.

While the decelerator itself should also be biodegradable to prevent harm to wildlife through tangling or ingestion, Ingram et al. (2015) discovered severe technical problems when trying to create decelerators of the aforementioned materials, to the point where the project had to be aborted due to technical immaturity of the material. The LASER drifter has been announced with a biodegradable decelerator for 2018 (Guigand et al., 2017), but no details are known yet.

6 Cost Evaluation

6.1 Prototype costs

The cost of this prototype was £293.00, excluding extra parts or tools. The main cost factor for the prototype was the RockBLOCK modem at £190 and line rental at £10/ month, as well as a fee of ~ £0.1 per 50 bytes of message (RockBLOCK, 2018), which so far accounted for ~ £38.00. The Adafruit GPS costs £33, with £22 for the Arduino and around £15 for batteries, the lunchbox, wires, and other little parts. Prices for electronics are mainly from coolcomponents.co.uk, or the respective manufacturer if nothing else is stated.

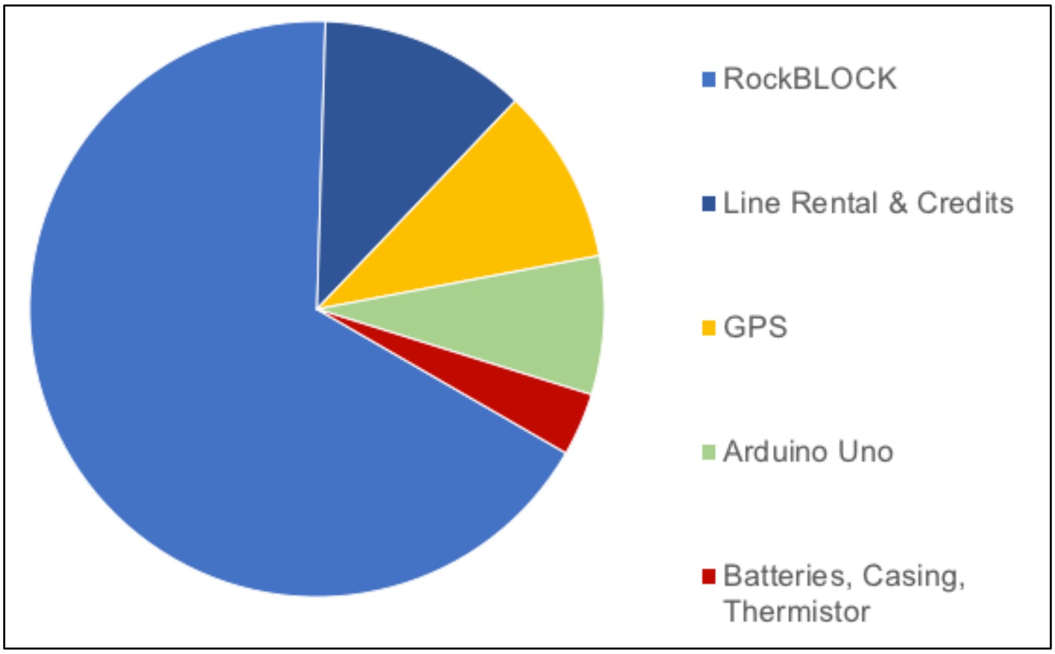


Figure 27 - Cost breakdown prototype

6.2 Alternatives

With the current version of this prototype, the casing cannot be accurately judged. However, PHA/PLA filament costs around £30.00 per 0.75kg (various online shops) and the threaded stainless-steel rods and “straw” that create the inner framework are commonly available in hardware stores and, depending on size, around £2.00/m. The drifter should also include a reed switch, which is available for less than 50p/ piece on various websites. Deployment is still unknown but would be attributed to each drifter with 0.3% of the total cost.

Telemetry

The most expensive component is certainly the Iridium RockBLOCK at £190. However, it is the most reliable option (see Chapter 2.2). As of the writing of this paper, a Globalstar duplex modem costs £348 (GTC, 2018) and a PMT-K (Argos) modem costs £305 (personal correspondence, B. Robert, CLS). If cost efficiency is of utmost important, a Globalstar simplex modems can be used (£116, GTC, 2018). Since all options include line rental and message credits, Iridium remains the cheapest modem for duplex communication. The only real alternative here would be a drifter “network”, instead of individually communication drifters, with a percentage of the drifters acting as “hubs” communicating with the satellite, and the rest connecting over short-wave radio (see Poseidon Project, 2013). However, here we risk loss of data if the hubs get damaged or dispersion is too high. Should more data be available, e.g. to calculate the rate of hub to radio-drifters for a successful study, this could be considered a cost-efficient alternative.

Location tracking

Due to the very rough positioning of the RockBLOCK messages, a GPS modem is essential. The Adafruit GPS board offers some useful features, like the warm start through the battery or the inbuilt data logging capability, however, at £33, it is also rather expensive. As discussed in Chapter 2.4, the CODE Drifters use a Jupiter F2 GPS, which costs around £11, the iSphere a Jupiter 32 chip (discontinued). Contrary to the Adafruit board, the F2 chip is a pure GPS chip without antenna and requires some skill in its implementation, as does the Jupiter SE868-A, which comes with flash storage and antenna at £19 (both roundsolutions.com). However, since data logging can better be achieved by using a SD card module with card (ca £8, Amazon), choosing a Jupiter chip would be a worthwhile switch and should be considered in future iteration.

Temperature

While the current thermistor is cheap, a more accurate thermistor should be used (± 0.1°C, for around £4.00). The scientifically preferred (Chapter 2.2) measurements of ± 0.01° are however not achievable, as such a thermistor costs around £300.00 (both mouser.co.uk).

Batteries

The actual drifter will require more Ah than the prototype has, however in bulk, AA batteries cost around £0.2 each, (mouser.co.uk), so 15 batteries per drifter should cost around £7.50, which is still less than has been spent for the batteries in this drifter. This cost position should not provide any problems.

7 Conclusions and Outlook

The analysis of commercially available drifters (Chapter 2) showed that none of them completely fulfilled the necessary requirements to be used for the main project, which is the observation of Greenland freshwater fluxes in the Labrador Sea through tracking at the surface. In consequence, a conceptual design of an appropriate drifter was created.

Suitable components were identified for the electronics inside the drifter (Chapter 3). The prototype uses an Arduino Uno, which is acceptable for the design-phase, but should be replaced due to power-concerns (see below). For telemetry, the RockBLOCK modem has overall been found to be the most reliable, and also cheapest duplex modem available. GPS tracking should employ a Jupiter chip and SD card, instead of the Adafruit Ultimate used here. The temperature sensor should be exchanged for a more accurate one (±0.1°C), as the scientifically ideal accuracy of ±0.01°C is too expensive for this project.

The drifter has been programmed to locate itself, measure the temperature and transmit the data at remotely changeable intervals, which was undeniably the most complicated part, as, although the RockBLOCK is said to be easy to integrate into hobbyist's projects, anything past the most basic operation requires quite advanced knowledge of electrical engineering and coding.

Power calculations were prepared based on multimeter measurements of the prototype's power consumptions (Chapter 4), and multiples of 5 AA Alkaline cells as a battery have been found to be a suited power source. However, the Arduino Uno most decidedly has to be replaced by a custom-made circuit board to prevent wasting large amounts of power while the drifter sleeps. Further power improvements include the collection of measurements on an SD card, and restricting the satellite communication to once daily. Future work with the drifter should focus on improving the battery life by implementing the suggestions made in chapter 4, especially as cold temperatures can lower battery capacity, so an effective setup is paramount.

The drifter's exterior has then been designed conceptually (Chapter 5), to give a possible shape for the casing, materials to use and a basic design idea on what the finished drifter might look like and how it could be deployed. While these ideas could not be realized and tested, they have been created with the deployment area and task in mind.

Finally, the costs have been analysed (Chapter 6) and possible alternatives for costly products have been discussed. The largest cost position remains the RockBLOCK modem. Possible alternatives such as a drifter network could be explored in the future, but currently, the RockBLOCK cannot be replaced without loss in function.

While there is a large amount of uncertainty about what happens with the freshwater between melting and entering the ocean, and how and where it is released into the ocean, this drifter and its future -improved- versions should be capable of providing valuable information about the freshwater paths off Greenland and hopefully contribute to future clarifications.

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9 Appendices (only electronically)

9.1 Code for Arduino

9.2 Fritzing files

9.3 Data for CEP and power calculation