MPP Marine Robotic Summer School 2023

Ocean Drifter Challenge

Version 1

Introduction:

An ocean drifter is an autonomous, floating instrument used to measure and track ocean surface currents and collect a variety of environmental data. Drifters "drift" passively with the currents, transmitting their position and often other sensor data to satellites in real time.

The goal of this project is to work as a team to design, construct, test, and deploy a custom-built ocean drifter, and to use it as a platform for collecting and analyzing real-world oceanographic data. The project simulates the workflow of professional marine research campaigns — from concept design and engineering, through field deployment, to data analysis and interpretation.

- Develop **engineering and design skills** by constructing a functional, durable, and environmentally responsible surface drifter.
- Gain **practical field experience** with marine deployment procedures, testing methods, and equipment troubleshooting.
- Learn **data acquisition and analysis techniques** by collecting GPS-based trajectory data (and, optionally, environmental sensor data), then comparing observations against oceanographic models and forecasts.
- Understand the **influence of design parameters** — such as buoyancy, drogue depth, and wind exposure — on a drifter's movement.

By the end of the project, teams will have produced a working drifter capable of operating in open-water conditions, gathered real-world data from its journey, and used those data to explore the dynamics of local ocean currents. The experience combines engineering, environmental science, teamwork, and the application of the scientific method, mirroring the interdisciplinary nature of modern oceanographic research.

Project Objective:

- Work as a team to design and construct an ocean drifter that meets specified design and environmental criteria
- Iteratively test, refine and deploy the drifter
- Collect the GPS data from the ocean drifter.
- Compare and analysis the result with oceanographic models and reflect on discrepancies
- Present the methods, results, and future steps

Material & Tools:

Items	Purpose
LandAirSea GPS tracker	Commercial GPS tracker
High Gain LTE Cellular antenna	Alternative antenna for commercial GPS tracker
Lilygo T-sim7000g	Custom GPS cellular development board
18650 Li-ion battery	Custom GPS battery
BMP390 breakout board & Barometric pressure and altimeter	Pressure and altimeter
NTC 3950	Waterproof temperature sensor
Local SIM card	LTE-M Cellular service for Lilygo GO
Cylindrical bamboo containers	Electronic housing
Cotton canvas fabric	Material for drogue
3mm thick jute rope	Material for drogue
Locally sourced cork	Flotation for the drifter
20mm diameter by 1.6m wooden dowel	Material for drogue
Four 8mm diameter by 0.5m wooden dowels	Material for drogue
Iron Fishing weights	Ballast for the drifter
Cylindrical bamboo containers	Electronic housing
Shellac	Coating the bamboo containers for the electronic housing.
Coconut wax	For potting and waterproof electronics
Grommet set and punch	Used for constructing the drifter frame
Hand drill and drill bits	Used for constructing the drifter frame
Hand Saw	Used for constructing the drifter frame

Heavy duty thread & sewing kits	Used for constructing the cotton drogue
Microwave	Used for melting the coconut wax

Timeline:

Week 1 - Preparation, Design, and Testing

Day 1 (2 hours) - Introduction, Drifter Design & Initial Construction
- Short lecture on ocean drifters and examples
- Team formation and brainstorming of design concepts
- Materials review and introduction to tools
- Construction drifter frame and key components

Day 2 (1 hour) - Drifter Test at the Harbor
- Test floatation, balance, and waterproofing integrity
- Verify GPS signal acquisition and data transmission
- Take notes on performance and identify issues to address before deployment

Day 3 (2 hours) - Drifter Refinement & Final Assembly
- Repair leaks, reinforce structure, improvement as needed
- Final waterproof testing of electronics housing
- Document the final design for presentation and reporting

Week 2 - Deployment, Data Collection, and Analysis

Day 1 (2 hours) - Drifter Deployment at the coast of Faial, Azores
- Transport drifters on boat to coastal site
- Review drifter deployment plan
- Record starting coordinates, deployment time
- Release drifters and confirm GPS signal transmission

Day 2 to 4 - Drifter data collection and analysis
- Regularly check drifter GPS upload on web portal
- Compare trajectories to oceanographic model
- Identify anomalies or design effects
- Share team result with the class

Day 5 - Final Presentation
- Compile drifter data and create visualizations
- Compare field results with oceanographic models
- Present final results, challenges faced, and recommendations for design or deployment improvements

Variable Definition:

$V = volume\ of\ drifter$

$m = mass\ of\ drifter$

$v = drifter\ velocity$

$A_w = effective\ cross\ sectional\ area\ in\ water$

$A_a = effective\ cross\ sectional\ area\ in\ air$

$u_a = wind\ velocity$

$u_w = water\ velocity$

$U_w = relative\ speed\ between\ drifter\ and\ water$

$U_a = relative\ speed\ between\ drifter\ and\ wind$

$v_s = steady\ state\ velocity$

$\tau = time\ constant$

$g = gravity = 9.8 m/s^2$

$\rho_w = density\ of\ salt\ water = 1025\ kg/L$

$\rho_a = density\ of\ air = 1.2\ kg/m^3$

$C_{d,w} = estimated\ hydrodynamic\ drag\ coefficient\ with\ water \approx 1.4$ [1]

$C_{d,a} = estimated\ aerodynamic\ drag\ coefficient \approx 0.8$ [1]

$FSPL = Free\ Space\ Path\ Loss$

$EIRP = Effective\ Isotropic\ Radiated\ Power$

$f = transmission\ frequency$

$d = transmission\ distance$

$P_t = transmission\ power\ (db)$

$G_t = transmitter\ antenna\ gain\ (db)$

$P_r = receiver\ sensitivity\ (db)$

$G_r = receiver\ antenna\ gain\ (db)$

Ocean Drifter Design

An ocean drifter is a combination of two parts, the structural water-following frame and the GPS tracking. electronic stack. The water-following frame is primarily influenced by several forces that determine its motion. Understanding these forces is essential for designing a drifter that accurately tracks ocean currents. Below we will showcase an example of an ocean drifter and the assembly process.

Understanding the Effect of Frame Design on Motion

The drifter's frame must be designed to optimize its ability to follow water currents while maintaining structural and electrical integrity. The primary force driving the drifter is the water drag force. To ensure the drifter moves with the local water, the wind drag force must be minimized as it can cause the drifter to diverge from the water's motion. Coriolis force and pressure gradients are the large-scale forces that drive ocean currents, but they have a minimal direct effect on the instantaneous movement of a small, free-floating ocean drifter. [2]

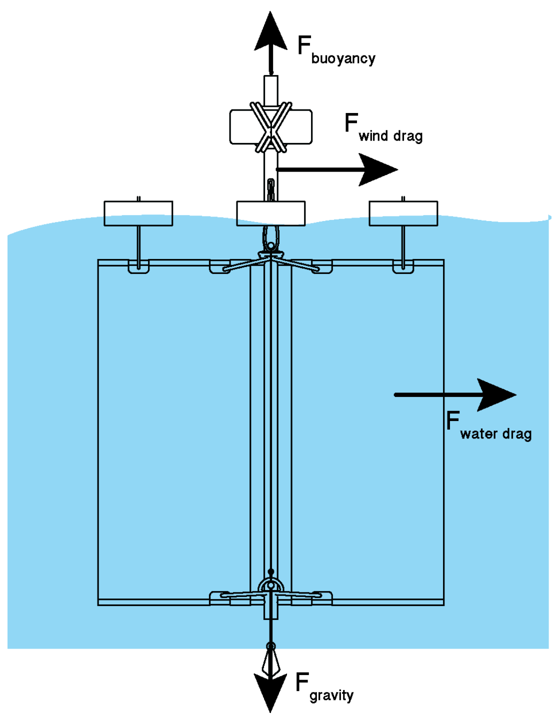


Figure 1 - Simplified free body diagram of the example ocean drifter

$$m\frac{dv}{dt} = F_{current} + F_{drag} + F_{Coriolis} + F_{pressure} + F_{gravity} + F_{buoyancy}$$

$$F_{drag,\ water} = \frac{1}{2}C_{d,w} \cdot \rho_w \cdot A_w \cdot (v - u_w)^2$$

$$F_{drag,\ wind} = \frac{1}{2}C_{d,a} \cdot \rho_a \cdot A_a \cdot (v - u_a)^2$$

The electronic components must be housed above the waterline, which places a constraint on the minimum achievable wind drag force. To survive in the open ocean, the drifter must be slightly positively buoyant, meaning the buoyancy force should be slightly greater than the force of gravity. To ensure the drifter remains upright and self-rights if it capsizes, its center of gravity must be positioned lower than its center of buoyancy. Drag force from the water and the wind are the primary contribution to the ocean drifter.

$$F_{buoyancy} = \rho_w \cdot g \cdot V$$
$$F_{gravity} = m \cdot g$$
$$m\frac{dv}{dt} = F_{wind\ drag} + F_{water\ drag}$$
$$m\frac{dv}{dt} = \frac{1}{2}C_{d,w} \cdot \rho_w \cdot A_w \cdot (v - u_w)^2 + \frac{1}{2}C_{d,a} \cdot \rho_a \cdot A_a \cdot (v - u_a)^2$$

Increasing the ratio of drogue area to surface float area can minimize the wind slip. The recommended minimum ratio of drogue drag area to wind area is 40. Increases in drogue drag result in higher inertial resistance, more stability, require stronger, more robust structure, and potentially more complication deployment due to size.

$$R = \frac{A_{drogue}}{A_{float}}$$
$$U_w = v - u_w$$
$$U_a = u_a - v$$

$$\frac{F_{drag,\ wind}}{F_{drag,\ water}} = \frac{C_{d,a}\cdot\rho_a\cdot A_a\cdot(u_a - v)^2}{C_{d,w}\cdot\rho_w\cdot A_w\cdot(v - u_w)^2} = 6.6 \cdot 10^{-4} \cdot R \cdot \left(\frac{U_a}{U_w}\right)^2$$

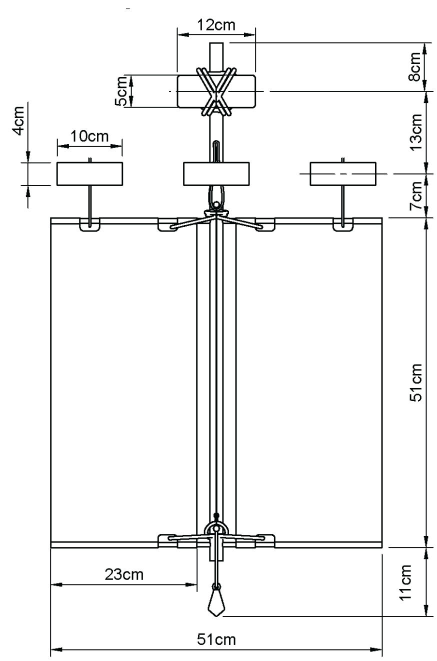


Figure 2 - Size and dimension of the example ocean drifter. The weight of the drifter is around 6kg.

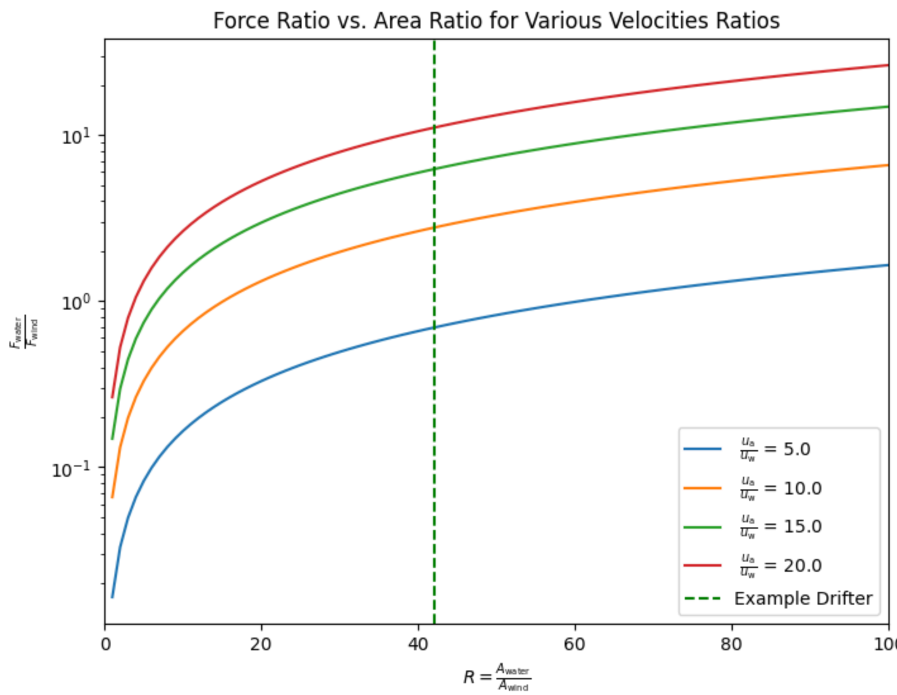


Figure 3 - Relationship between the area-to-drag force ratio at different relative velocities for an ocean surface drifter. As the water drag area increases, the water drag force increases as relative to the wind drag, therefore minimizing wind slippage.

In addition, we can see the effect of drogue design on the response rate of the drifter to water current changes. Assuming the wind drag is minimized, the main driving force is the water drag.

$$m\frac{dv}{dt} = \frac{1}{2}C_{d,w} \cdot \rho_w \cdot A_w \cdot (v - u_w)^2$$

We can linearize the equation of motion at steady state with small slip using Taylor's expansion. Doing so, we have a linearized drifter response rate to small water current change.

$$v \approx u_w$$

$$\delta v = v - u_w$$

$$\Delta_w = v_s - u_w$$

$$(v - u_w)^2 \approx \Delta_w^{\ 2} + 2\Delta_w \delta v$$

$$m\frac{d\delta v}{dt} = \frac{1}{2}C_{d,w} \cdot \rho_w \cdot A_w \cdot (\Delta_w^{\ 2} + 2\Delta_w \delta v)$$

$$\delta v(t) = \delta v(0)e^{-t/\tau}$$

$$\tau \approx \frac{m}{C_{d,w}\rho_w A_w |\Delta_w|}$$

We can see the effect of response time due to drifter structural design. Response time depends on effective mass and drag properties. Increasing mass results in slower response, while increasing drag area results in faster response. Mass and inertia act to slow drifter response to rapid current changes.

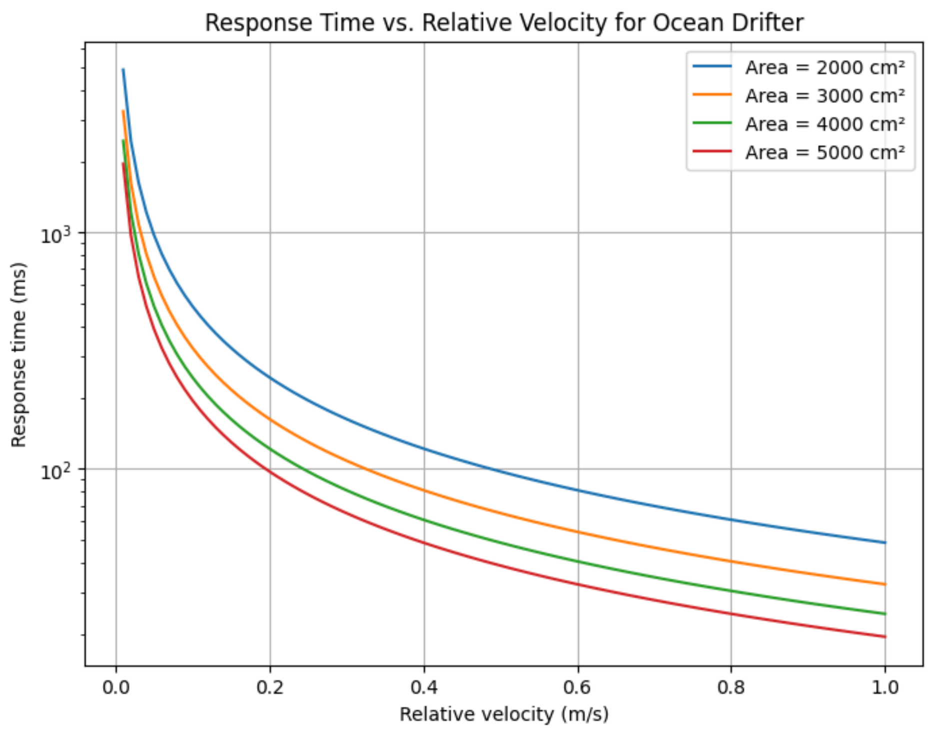


Figure 4 - Relationship between the linearized response time and the relative velocity of the drifter and ocean current with different water drag areas. As the area increases the response time gets faster.

Design your team's drifter, justified your design choice based on the impact on water-following ability, material and deployment constraint.

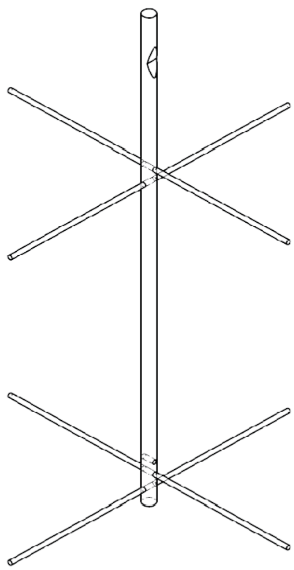
Example Drifter Material & Assembly

Step 1:

Mark the exact positions for drogue rod holes according to the team's measurements. The spacing should match the drogue's final diameter and shape.

Drill perpendicular holes through the center rod. Ensure the hole diameter matches the drogue rod size for a snug fit.

Measure and mark the top end of the rod for the electronics housing attachment. Cut a clean V-notch using a saw.

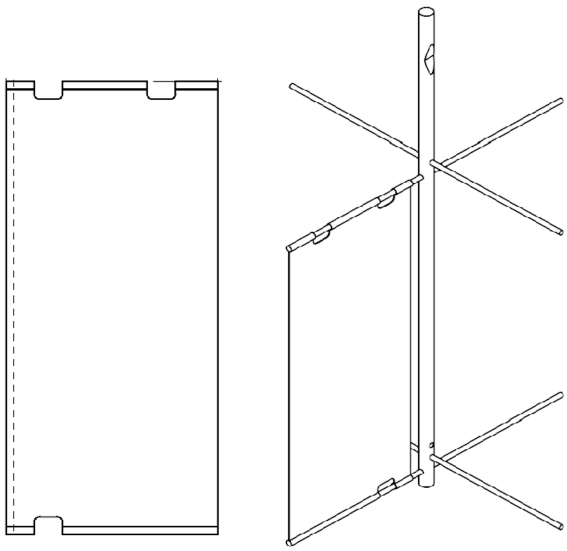


Step 2:

Insert the drogue rods through the previously drilled hole in the center rod.

Press fit them securely; if slack occurs, wrap a thin layer of tape around the rod ends before insertion or use marine-grade adhesive for added hold.

Align rods so they are 90° apart and are centered in both horizontal and vertical planes. Misalignment here will affect drogue symmetry in the water.



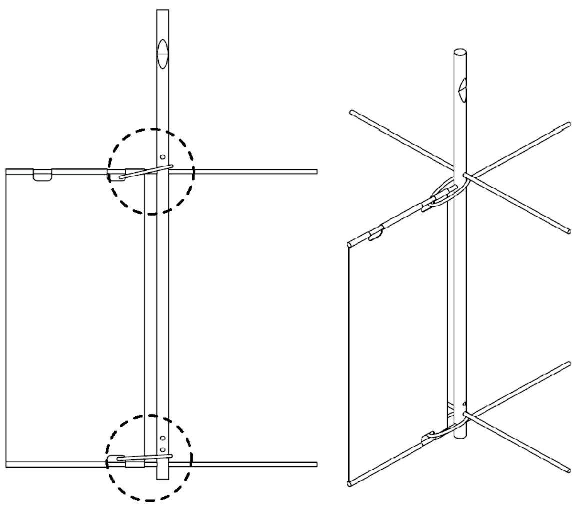
Step 3:

Cut the drogue panels from cotton canvas according to your drogue pattern

Sew the panels with double-stitched seams for strength, optionally reinforcing stress points.

Slide the drogue fabric over the drogue rods so it hangs evenly.

Check: Drogue opening should be uniform all around to avoid asymmetric drag underwater

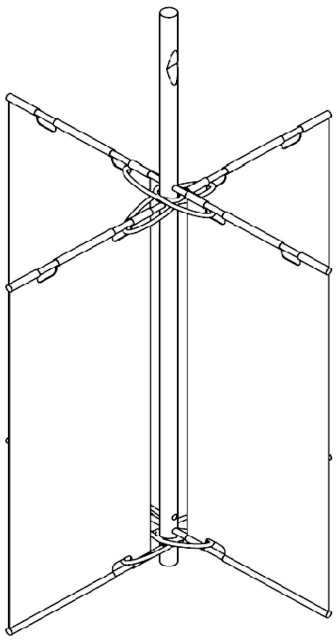


Step 4:

Attach jute rope between the drogue edges and the center rod, pulling evenly to keep the drogue open and centered.

Install grommets at all rope attachment points on the drogue fabric to prevent tearing under drag forces.

Tie using corrosion-resistant knots (e.g., bowline or clove hitch) and ensure knots are secure but adjustable for final tuning.

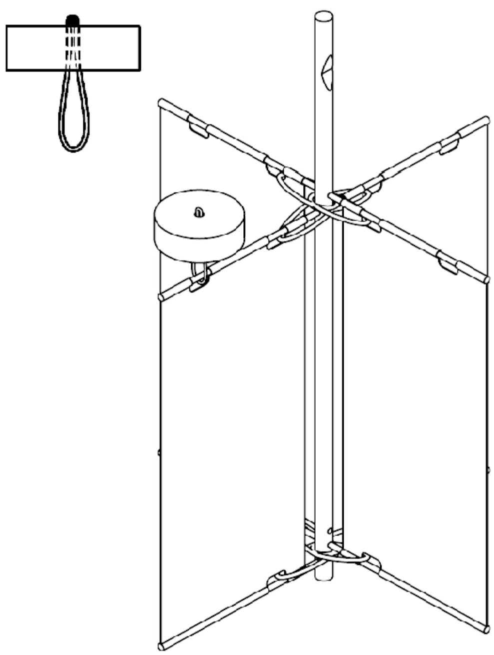


Step 5:

Tension all drogue connection points so the structure is evenly supported and resists twisting.

Double-check rope orientation — avoid any twists that would cause the drogue to deform while deployed.

Trim excess rope ends to prevent fraying.

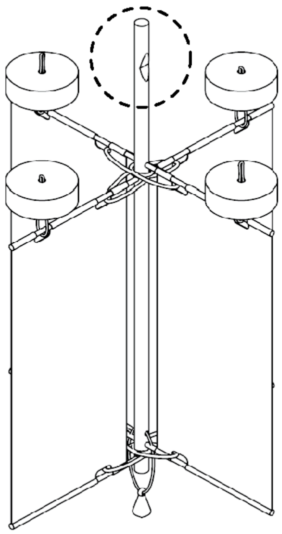


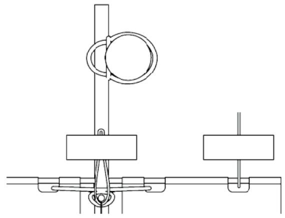
Step 6:

Thread hemp rope through the hole in each cork float.

Securely fasten each float’s rope end to the drogue rod ends or frame using a stopper knot or lashing.

Repeat for all four floats, ensuring they are symmetrically positioned around the frame for balance.



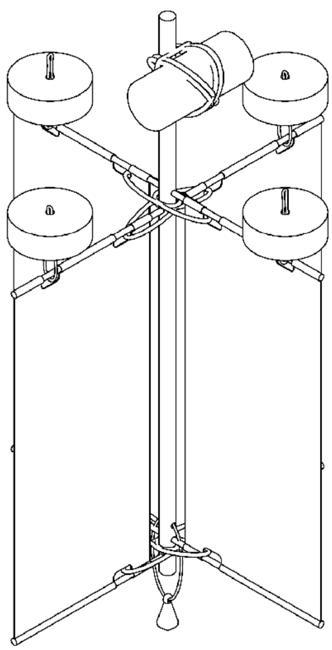


Step 7:

Place the electronics housing into the V-notch at the top of the center rod.

Use a squash lashing to secure it firmly while allowing for easy removal for maintenance.

Check that cables, GPS antenna, and sensor probes are oriented correctly and are not obstructed by the frame or drogue.



Step 8:

Attach ballast weight to the bottom end of the center rod to ensure proper vertical orientation in the water.

Start with light weight, then test the drifter in calm water to check flotation and stability.

Adjust the weight location or amount as needed until the drifter floats upright, with the drogue fully submerged and the electronics above water.

Electrical System

There are two GPS options for the ocean tracker, a commercial tracker and a custom DIY GPS trackers. Both GPS trackers use LTE-M to transmit the data back onshore. The core component is the GPS module to estimate the device's location. The LTE-M cellular module is responsible for transmitting the location data collected by the GPS receiver over cellular networks. A physical activated SIM card is necessary to connect to a mobile network and enable data transmission.

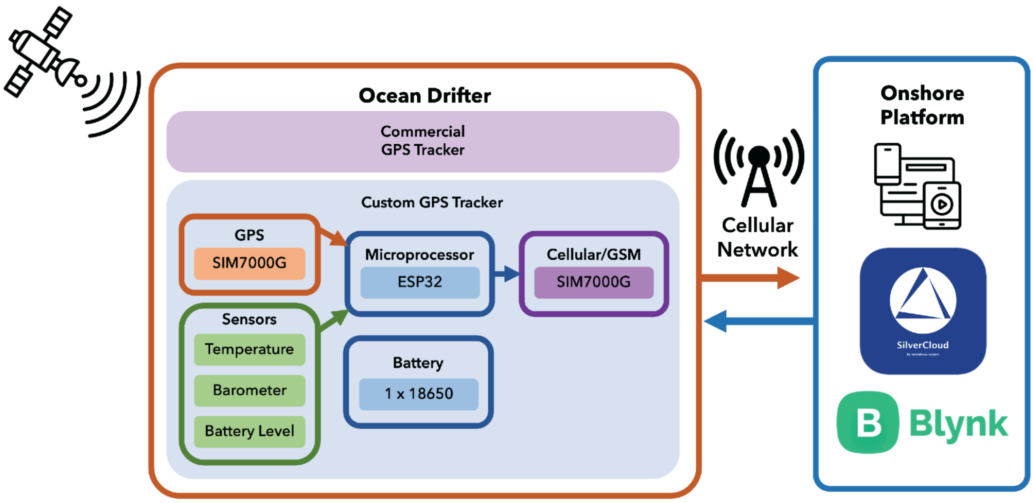


Figure 5 - Block diagram of the Ocean Drifter electronic stack. Two GPS tracker options, commercial and GPS.

Commercial GPS tracker

To set up the commercial drifter, follow the setup instructions and create an account on the SilverCloud web portal. Additionally, you can remove the plastic case and replace the standard GPS antenna with the high-gain directional gain antenna.

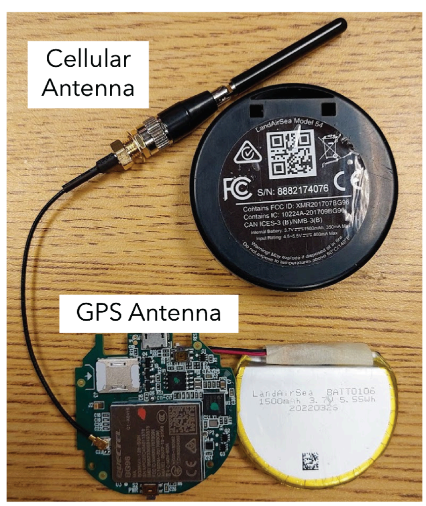


Figure 6 - Setup of the modified commercial GPS tracker with external high-gain cellular antenna.

Custom GPS tracker

The brain of the custom GPS is a ESP32 microcontroller and a SIM7000G GPS Cellular Modem [3]. The MCU manages the SIM7000G module, processing location and sensor data, managing power consumption.

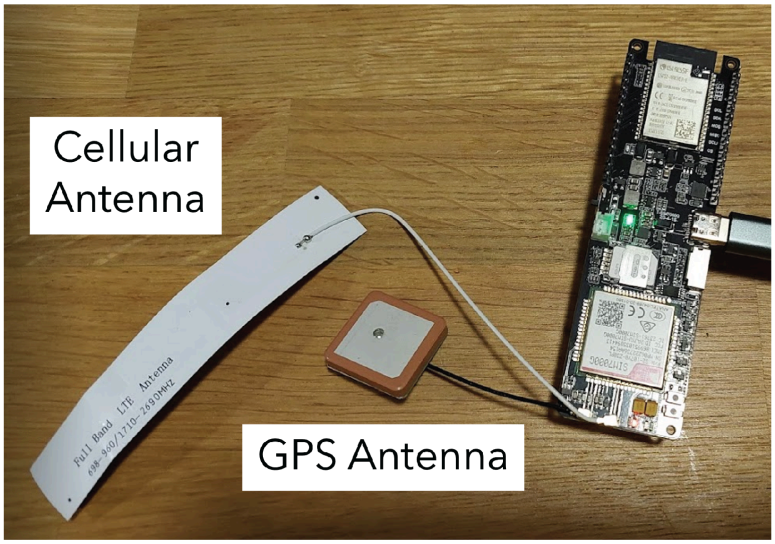


Figure 7 - Setup of the custom GPS tracker with external GPS and cellular antenna

Waterproof Electronic Housing

Shellac is applied as a protective, water-resistant coating on the bamboo electronic housing. Shellac is brushed onto the clean surface. At least 3 thin coats of shellac are applied. The coated housing is tested by submerging in salt water for 1 week. The interior of the coated housing should stay dry after submersion. Add more coating and patches if there is a leak.

Figure 8. (Left) – Application of shellac onto the electronic housing in progress. (Right) – Shellac-coated electronic housing undergoing water resistance testing while fully submerged for a week.

Coconut wax was tested as an biodegradable waterproof potting material for electronics in DIY applications. Coconut wax is hydrophobic, allowing it to fill crevices and coat components, creating a conformal barrier that prevents water ingress and protects against corrosion. The wax is melted and poured over electronics, where it solidifies to encase the circuit. It is suitable for temporary, field-deployable drifter electronics. However, coconut wax has a relatively low melting point compared to industrial epoxies or silicones, so it may soften in high-temperature environments or if the electronics generate significant heat.

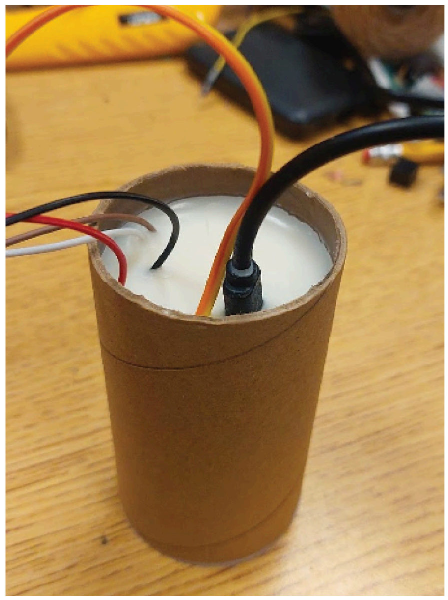


Figure 9 – Testing coconut wax as a water-resistant potting material for electronics. This test evaluates the effectiveness of coconut wax in enhancing water resistance and durability in practical use conditions.

Communication Calculation

The data range of LTE-M can be estimated by calculating the Effective Isotropic Radiated Power (EIRP) and Free Space Path Loss (FSPL) [4]. The LTE-M receiver sensitivity is -110 to -125dBm. For the custom GPS setup, you can select the transmission frequency within LTE-M bands and transmission power. Higher transmission power, longer transmission distance, at the trade off lower battery life.

$$FSPL(db) = 20log_{10}(d) + 20log_{10}(f) + 32.44$$

$$EIRP = P_t + G_t - Cable\ Loss$$

$$P_r = EIRP + G_r - FSPL$$

$$d = 10^{\frac{EIRP + G_r - P_r - 32.44 - 20log_{10}(f)}{20}}$$

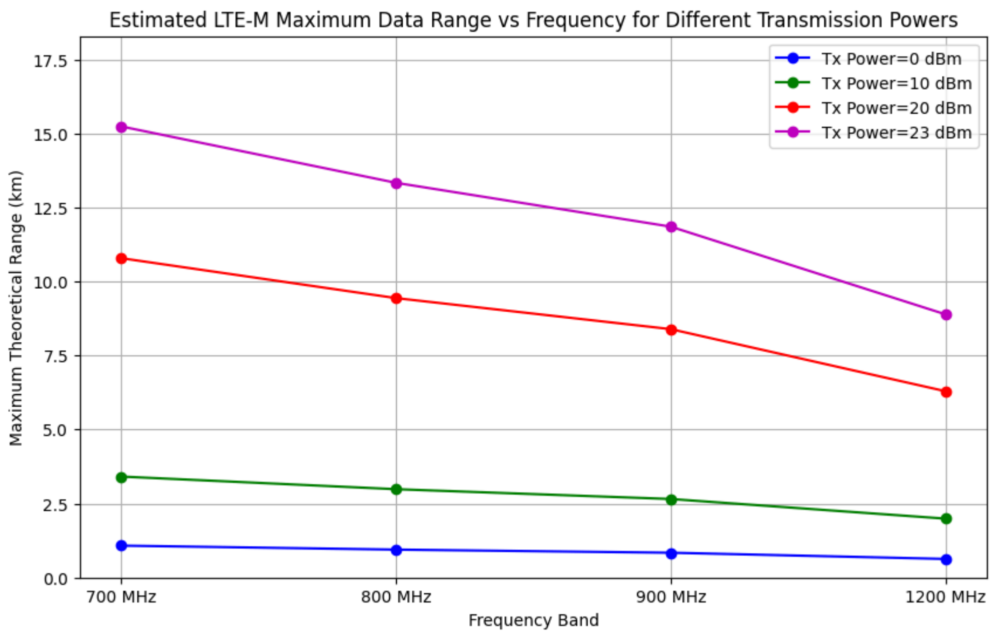


Figure 10 - Relationship between maximum transmission range and various transmission frequencies within the LTE-M bands at different transmission power. As frequency bands increase the transmission range decreases. The receiver antenna gain is set at -100dbm.

Power Management

Understanding the battery life directly determines how long the drifter can reliably collect and transmit oceanographic data, impacting the scientific value of the deployment and ensuring that research missions are completed without premature data loss. Software and hardware design decisions impact battery life by determining the efficiency of power management, sensor operation, data processing, and communication protocols, where optimized components and algorithms reduce energy consumption and extend deployment duration.

Operation	Voltage (V)	Current (mA)	Power (mW)	Notes
SIM7000G Modem [5]				
Power Off	3.8	0.007	0.026	
Power Saving Mode		0.009	0.034	
Sleep		1.7	6.46	
Power On & Idle		11.4	43.42	
GNSS/GPS Operation				
Active Tracking	3.8	30	114	Cold start takes 30 to 60 seconds to locate the initial satellite position. Once located, hot start takes 1 to 5 seconds to location position
Power On & Idle		6	22.8	
LTE-M Cellular Operation				
Sleep	3.8	1.2	4.56	
Power On & Idle		11	41.8	
Transmission		80 (5dBm) -180 (23dBm)	304-684	No minimum Transmission time per operation: 10-15 seconds
ESP32 Microcontroller [6]				
Deep sleep	3.8	0.005	0.019	
Light sleep		0.8	3.04	
Active		20-50	76-190	Depending on the

				operation running on the chip. Additional sensors require more power.

Example Power Management Calculation

$$E_{tx} = P_{tx}^{GPS} t^{GPS} + P_{tx}^{LTE} t^{LTE} = (114mW \cdot 5sec) + (684mW \cdot 15\,sec) = 10.83J = 3.0mWh$$

$$E_{battery} = 3.8V \cdot 1300\,mAh = 17784J = 4940mWh$$

Battery life can be adjusted by modifying the transmission frequency per hour and the duration and depth of the sleep mode. It is useful to note the importance of low power mode for the system. By putting the system in deep sleep when not transmitting, it could in some cases increase operation time by 50%. There are more ways to optimize and increase the operation time. Brainstorm different strategies and understand the trade off.

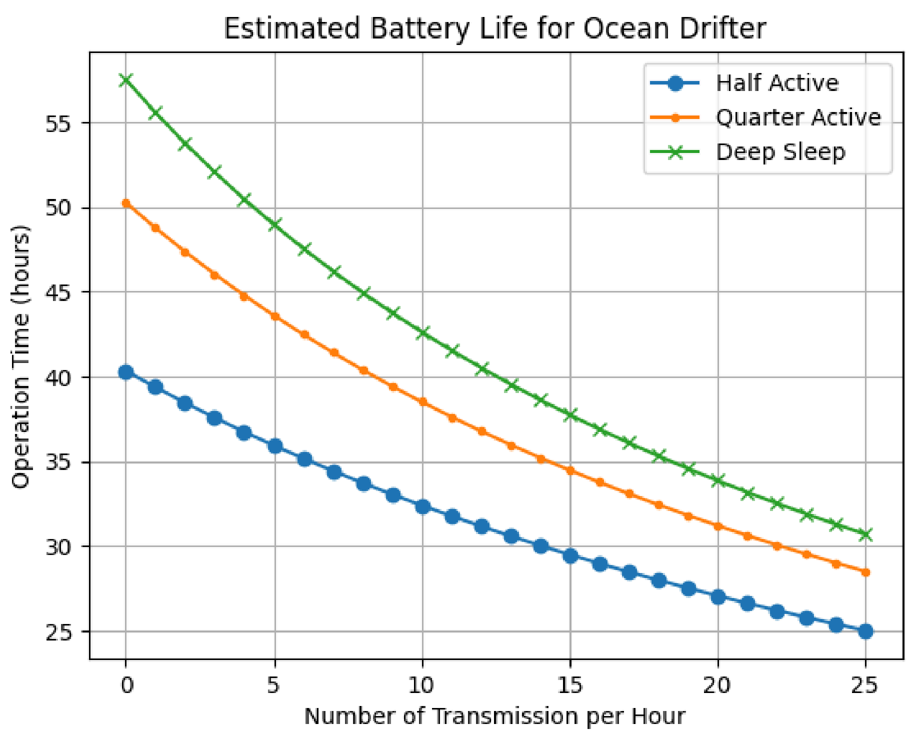
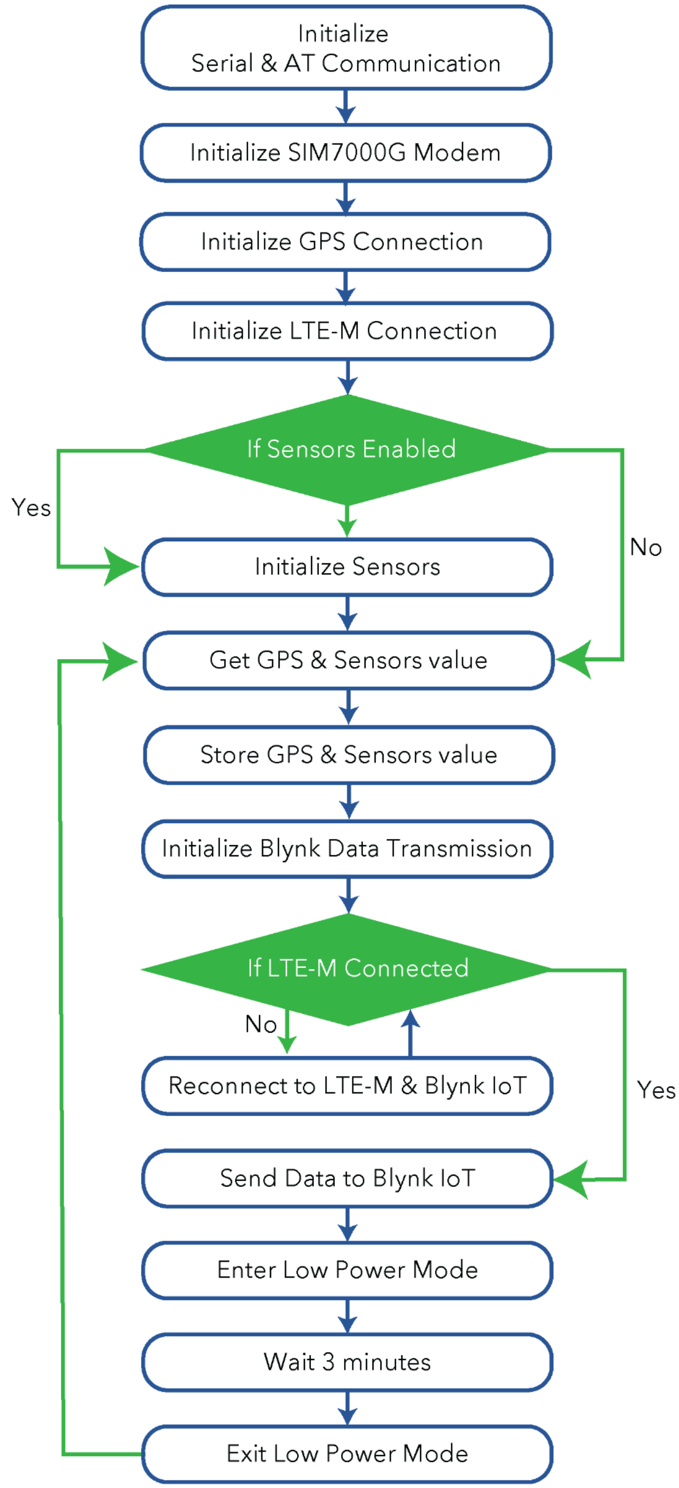


Figure 11 – Relationship between the number of transmissions per hour and the operation time under different system power-saving modes. At 10 transmissions per hour, transmissions occur at 6-minute intervals. The "Half Active" mode indicates that when the system is not transmitting, it spends half the time in a low-power sleep mode and the other half in an active idle state. The "Quarter Active" mode is set only a quarter of the time as active idle. The "Deep Sleep" mode set the esp32 to deep sleep mode and only a quarter active.

Example Custom GPS Software Flow Chart

The example custom GPS software flow chart illustrates the step-by-step operation of the GPS system. It starts with the microcontroller initiating communication with the GPS/cellular modem, followed by the initialization of the GPS modem and sensors. Once the GPS signals are acquired, the software decodes and records location data based on satellite positioning.

Next, the system verifies the LTE-M connection, and if connected to the Blynk IoT network, it transmits the data. If the connection is not established, the system attempts reconnection a set number of times before entering sleep mode until the next GPS logging cycle. This software flow is customizable and serves as a fundamental blueprint for implementation. Users are encouraged to adapt it to suit their specific needs and research objectives.



Deployment Planning

Write up your team's deployment plan and checklist for your drifter. Check in with the instructor and get feedback. An example deployment plan and checklist is as shown.

Pre-Deployment Checklist

Before heading out, make sure the following is done:

- **Inspect the drifter:** Check for any damage to the components and ensure all components are properly secured.
- **Activate the device:** Make sure the drifter is fully charged, powered on.
- **Safety first:** Ensure all teams are aware of the deployment plan. Take sea sick medicine as needed.

Deployment Steps

1. **Maneuver the boat:** The driver will maneuver the boat to the targeted deployment location.
2. **Record data:** Before deployment, record the boat GPS coordinates, date, and time.
3. **Throw the drifter:**Lower the drifter into the sea, from the lowest possible side to minimize the impact on the device.
4. **Monitor Initial Status:** Ensure the drifter is stable in the open water. Check if the GPS signal is live.
5. **Submit data:** After a successful deployment, record and share the GPS data with the team.

References:

[1] Davis, R. E. (1985), Drifter observations of coastal surface currents during CODE: The method and descriptive view, *J. Geophys. Res.*, 90(C3), 4741–4755, doi:10.1029/JC090iC03p04741.

[2] Furnans, J., Imberger, J., & Hodges, B. R. (2008). Including drag and inertia in drifter modelling. *Environmental Modelling & Software*, 23(6), 714–728. https://doi.org/10.1016/j.envsoft.2007.09.010

[3] LILYGO. (2022). *T-SIM7000G – LILYGO®*. Retrieved July 25, 2022, from https://lilygo.cc/products/t-sim7000g

[4] GTE Lenkurt, 1970. *Engineering Considerations for Microwave Communications Systems*, page 35.

[5] SIM7000G Module Datasheet (for LTE CAT-M1/NB-IoT/GPRS):
SIMCom Wireless Solutions. (n.d.). *SIM7000 Series Hardware Design*. Available from SIMCom official documentation websites or vendor repositories.

[6] ESP32-WROVER-B Module Datasheet (ESP32 chip on LILYGO board):
Espressif Systems. (n.d.). *ESP32-WROVER-B Specification*. Retrieved from https://www.espressif.com/en/products/modules/esp32-wrover