The Mini Buoy Handbook

Assessing hydrodynamics in intertidal environments

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Preface

The 'Mini Buoy' is an applied research tool to measure inundation duration, current velocity, and wave orbital velocity in shallow coastal settings using accelerometer technology. As a low cost and open-source solution, Mini Buoys and the associated App are a useful alternative to conventional hydrodynamic sensors.

This guide provides an overview of how the Mini Buoy works, how to configure and deploy them, and how to analyse the data[1].

[1] The MSR145W B4 is a standalone accelerometer with integrated rechargeable lithium ion battery and memory in a waterproof seal. Acceleration is measured along the y-axis.

1 Introduction

There are presently three Mini Buoy designs featured in this handbook, each with their own strengths and limitations:

- **B4** is the original Mini Buoy design featured in Balke et al. (2021) that contains an MSR145 B4 acceleration data logger inside a self-standing centrifuge tube attached to an anchor via a fishing swivel. The B4 measures inundation duration and current velocity only.

- **B4+** is a more durable version of the original Mini Buoy ideal for long term deployments. The B4+ has a UV-resistant casing without the skirt and a metal eye bolt connected to a mooring by crimped fishing line rings. In addition to measuring inundation duration and current velocity, the B4+ has been calibrated to measure wave orbital velocities. Whilst the durability and functionality may be improved, the B4+ requires more effort to assemble.
- **Pendant** is an integrated accelerometer data logger, float, and anchor point, attached to a pole by a fishing swivel. The Pendant is less expensive and easier to assemble than the B4 and B4+, however memory capacity and sampling rates are lower. Because of the low sampling rate, the Pendant is unstable for measuring wave orbital velocity.

Once assembled, Mini Buoys can be used in single, comparative, or multiple deployments for purposes of habitat restoration potential mapping, flood risk monitoring, and citizen science engagement.

Table 1.1: Comparison of each Mini Buoy design.

	B4	B4+	Pendant
Cost	£430	£430	£120
Total weight	42.3 g	60.0 g	19.9 g
Sensing height above bed	16 cm	16 cm	10.5 cm
Deployment duration	1 sec: 25 days	1 sec: 25 days	2 min: **XXX** days
Deployment duration	5 sec: 125 days	5 sec: 125 days	6 min: **XXX** days
Deployment duration	10 sec: 170 days	10 sec: 170 days	10 min: **XXX** days
Currents detection limit	4.3 cm/s	1.8 cm/s	4.9 cm/s
Currents accuracy	±18.9 cm/s	±13.8 cm/s	±2.20 cm/s
Waves detection range	-	0.0 cm/s	-
Waves accuracy	-	**±17.X cm/s**	-
Compatibility	Windows	Windows	Windows and macOS

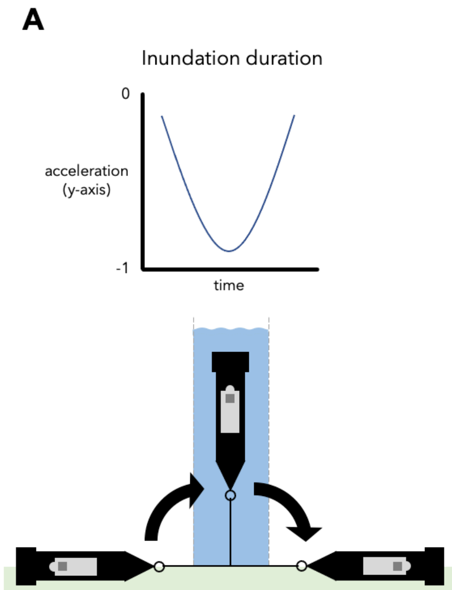
1.1 Operating principles

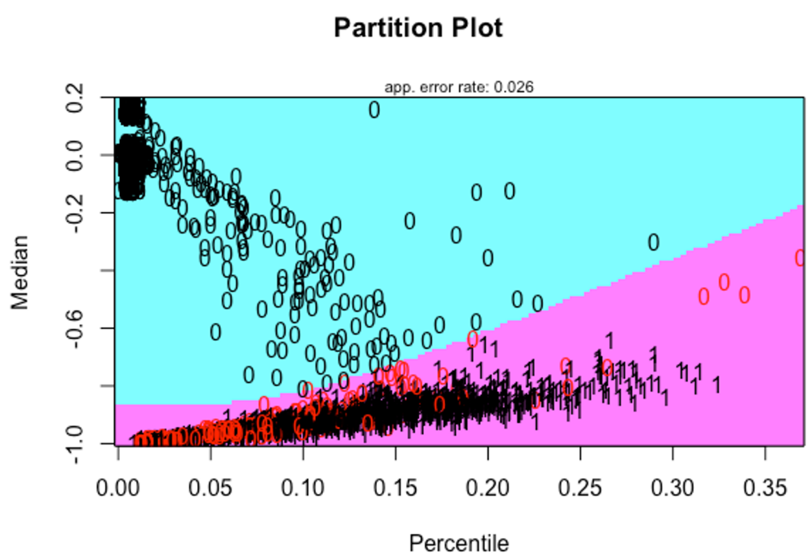
Inundation duration, current velocity, and wave orbital velocity parameters can all be derived from acceleration data.

For an accelerometer mounted in a tethered float, the change in tilt from 0 to 90° indicates a change in the position of the device from lying horizontally on the tidal flat to floating vertically in the water column as the tide comes in. A return of the tilt to 0° indicates the tide has retreated and the Mini Buoy is once again lying flat. The time when the Mini Buoy deviated from the horizontal position gives the inundation duration of the tide (Figure A below). When the Mini Buoy is fully inundated, any tilting away from the vertical position is caused by a current pushing against the buoy. The stronger the current, the stronger the tilt (Figure B below). When waves pass over the Mini Buoy, they cause it to wobble. Moving standard deviation in the tilt over a sufficient time window captures the average wave orbital velocity near the bed. The greater the standard deviation, the greater the wave orbital velocity (Figure C below).

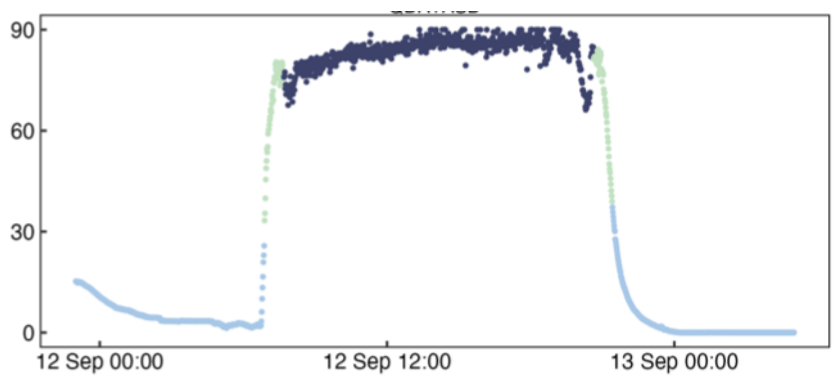
Testing has shown that inundation status is correctly identified at rates of 87-99% across all designs. To identify the inundation status of a Mini Buoy from acceleration data, a classifier algorithm (Quadratic Discriminant Analysis) differentiates inundated and non-inundated cases from the median and standard deviation in tilt; median and standard deviation values are near zero for a Mini Buoy at rest, and are larger when a Mini Buoy is inundated:

Partially inundated cases are then identified using an abrupt shift detection algorithm (Boulton, 2022) that searches for the continuous change in Mini Buoy tilt from 0 to ~90° at the start of


A
Inundation duration
0
acceleration
(y-axis)
-1
time
B
Current velocity
0
acceleration
(y-axis)
-1
time
C
Wave orbital velocity
0
acceleration
(y-axis)
-1
time

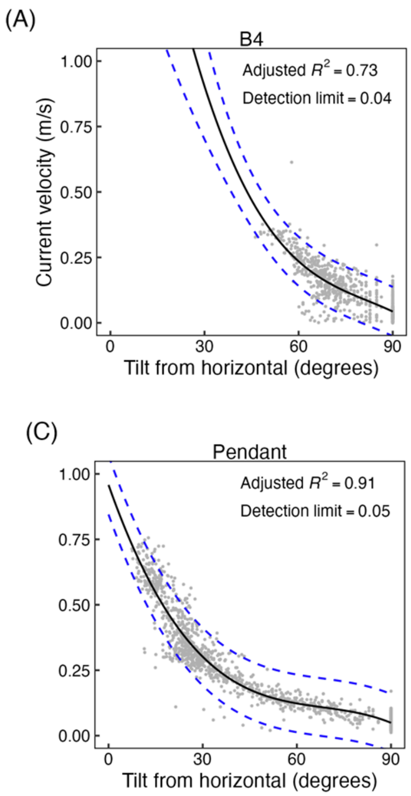

Partition Plot
app. error rate: 0.026
Median
0.2
0.0
-0.2
-0.6
-1.0
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
Percentile

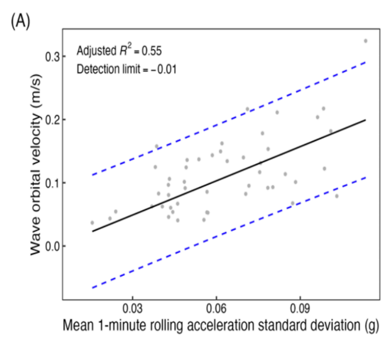
the flood tide and ~90 to 0° at the end of the ebb tide, characteristic of partially inundated cases before/after peak flood/ebb currents:



Conversion from tilt to velocity has been done by deploying each Mini Buoy design adjacent to hydrographic sensors that measure water velocity directly. Current velocities as low as 0.01 m/s and as high as 0.75 m/s can be detected with good accuracy (Figures A-C below). The B4+ is reasonable at measuring wave orbital velocities between 0 and 0.2 m/s (Figure D below).

A comprehensive description of the Mini Buoy calibrations is given in Ladd et al. (2023).


(A)
B4
Adjusted R^2 = 0.73
Detection limit = 0.04
Current velocity (m/s)
1.00
0.75
0.50
0.25
0.00
0
30
60
90
Tilt from horizontal (degrees)
(B)
B4+
Adjusted R^2 = 0.85
Detection limit = 0.02
1.00
0.75
0.50
0.25
0.00
0
30
60
90
Tilt from horizontal (degrees)
(C)
Pendant
Adjusted R^2 = 0.91
Detection limit = 0.05
1.00
0.75
0.50
0.25
0.00
0
30
60
90
Tilt from horizontal (degrees)


(A)
Adjusted R^2 = 0.55
Detection limit = −0.01
Wave orbital velocity (m/s)
0.3
0.2
0.1
0.0
0.03
0.06
0.09
Mean 1-minute rolling acceleration standard deviation (g)

2 Assembly

Depending on their requirements, the user has a choice of three Mini Buoy designs for measuring hydrodynamics (see Chapter ??). In the following steps, we provide instructions for the assembly of each design.

2.1 B4

The B4 is a transparent and self-standing centrifuge tube with an MSR145W B4[1] acceleration logger sealed inside and supported by floral foam. The tube is tethered to an anchor using fishing swivels attached through two holes in the centrifuge tube skirt. To build a B4, first gather the following equipment:

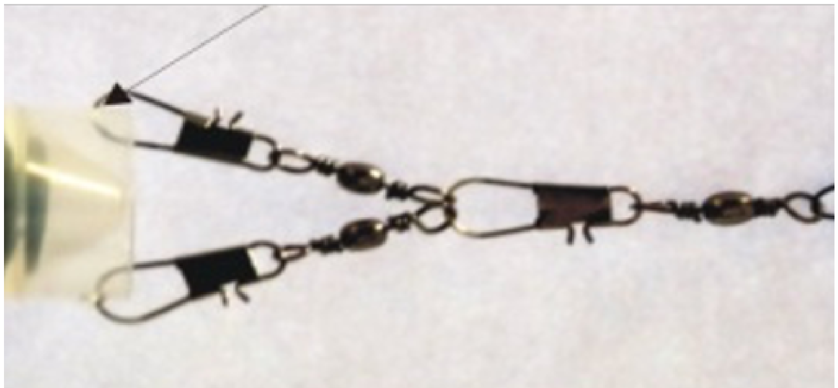
- 50 mL clear self-standing centrifuge tube
- Label
- Floral foam
- MSR145W B4 acceleration data logger
- Silicone sealant
- Drill with a 4 mm dowel bit
- 3 × 5 cm (1.1 g) fishing swivels

To assemble the B4 Mini Buoy:

1. Place a label inside the centrifuge tube, with the text legible through the plastic, indicating the owner, a "do not remove" notice, and contact details
2. Insert a 3 cm cylinder of floral foam into the centrifuge tube. This ensures the logger is positioned at the top of the tube
3. Roughly cut a 5 cm cylinder of floral foam with matching diameter of the centrifuge tube and cut down the middle
4. Place both halves around the configured MSR145W B4 acceleration data logger, then gently push the logger into the centrifuge tube with the PC connector facing outwards. The floral foam will prevent the logger from moving inside the tube
5. Apply silicone sealant around the screw thread of the centrifuge tube and fasten the cap
6. Apply more sealant along the rim of the centrifuge cap if necessary

[1] The MSR145W B4 is a standalone accelerometer with integrated rechargeable lithium ion battery and memory in a waterproof seal. Acceleration is measured along the y-axis.

7. Drill two holes at opposite ends through the centrifuge tube skirt 5 mm from the bottom
8. Fix two fishing swivels through each hole, and connect both to another swivel as shown:



2.2 B4+

The B4+ almost identical in design to the B4, with some modifications: the centrifuge tube is UV-resistant without a skirt, an eye bolt and fishing line rings are fitted to provide more durability, and steel shot is added to the tube to increase sensitivity to current and wave action. Gather the following equipment to assemble the B4+:

- 50 mL UV-blocking centrifuge tube
- Sand paper
- Drill with a 4 mm dowel bit
- M4 Eye bolt and nut
- M4 rubber washer
- M4 long socket
- Epoxy glue
- M32 O-rings
- 20 g lead shot weight
- Floral foam
- Waterproof label
- 250 lb / 113 kg nylon coated 1×7 steel strand fishing line
- Single barrel copper/nickel crimp sleeves (the sleeves should be rated to correctly fit the fishing line)
- Crimp tool with cutter (the tool should be rated to correctly crimp the sleeves)
- MSR145W B4 acceleration data logger
- Silicone sealant

To assemble the B4+ Mini Buoy:

1. Abrade the bottom of the centrifuge tube (this removes any lubricant on the tube and creates a better surface for the epoxy glue to bond with)
2. Drill a 4 mm hole in the bottom of the centrifuge tube
3. Thread the eye bolt through the hole
4. Place the rubber washer over the eye bolt thread from inside the tube
5. Dab some epoxy glue around the eye bolt (inside and out) to seal the hole
6. Secure the nut in place using the long socket

7. To ensure watertightness, install a rubber o-ring around the inside lip of the lid using tweezers as shown:

8. Pour 20 g of steel shot into the tube. The shot reduces the buoyancy of the Mini Buoy, making it less stable in the water column. This has been shown to improve the accelerometer sensitivity
9. Cut a 3 cm length cylinder from the floral foam that will fit comfortably into the tube
10. Insert the floral foam cylinder into the tube. This holds the steel shot in place and ensures the logger is positioned at the top of the tube

11. Attach a waterproof label onto the centrifuge tube indicating the owner, a “do not remove” notice, and contact details
12. Thread the fishing line through a crimp sleeve and loop the fishing line back on itself to form a ring of ~2 cm diameter
13. Crimp the sleeve so it fits tightly around the fishing line
14. Thread another fishing line through a new crimp sleeve, then through the eye bolt and first fishing line ring
15. Adjust the diameter of the ring so the total chain length is 4 cm, then crimp (the B4+ has been calibrated to measure hydrodynamics 4 cm above the tidal flat). The tether should look as follows:

16. Roughly cut a 5 cm cylinder of floral foam with matching diameter of the centrifuge tube and cut down the middle
17. Place both halves around the configured MSR145W B4 acceleration data logger, then gently push the logger into the centrifuge tube with the PC connector facing upright. The floral foam will prevent the logger from moving inside the tube
18. Apply silicone sealant around the screw thread of the centrifuge tube and fasten the tube cap
19. Apply more sealant along the rim of the centrifuge cap