Ocean Bottom Seismometers

Practical consideratio
for deploying seismi
instruments in harsh
environments

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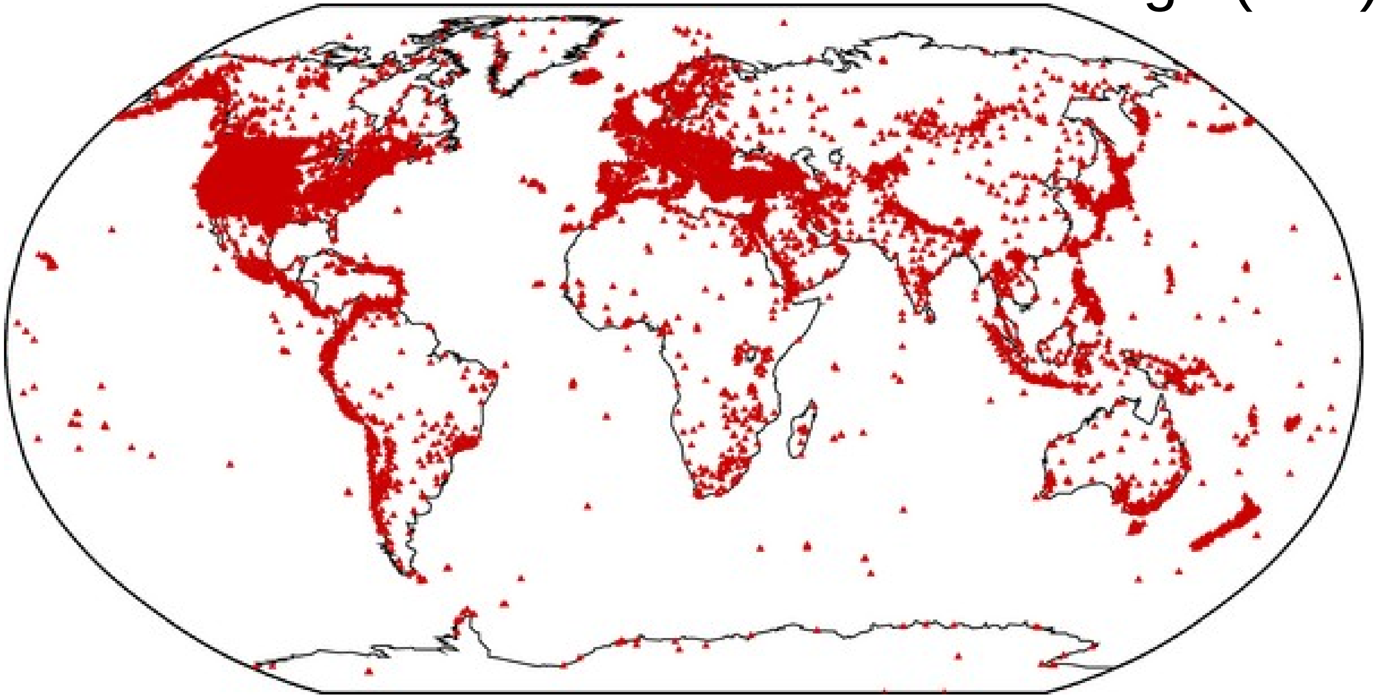
What is an Ocean Bottom Seismometer?

In theory:
It’s a seismic station with the same characteristics as a land station equipped with a comparable instrument.

In practice:
It’s a very sensitive instrument deployed in a harsh, noisy and unpredictable environment.
“A broadband seismometer in a train station.”

Why are they important?

Global Seismic Network Coverage (ISC)



Seismic network coverage is not uniform and specially sparse in the oceans

Let’s build an OBS

What is the main purpose of an OBS?

According to scientists, to provide good seismic data

According to engineers, to reliably come back

How does one start building an OBS?

“From an engineering perspective”

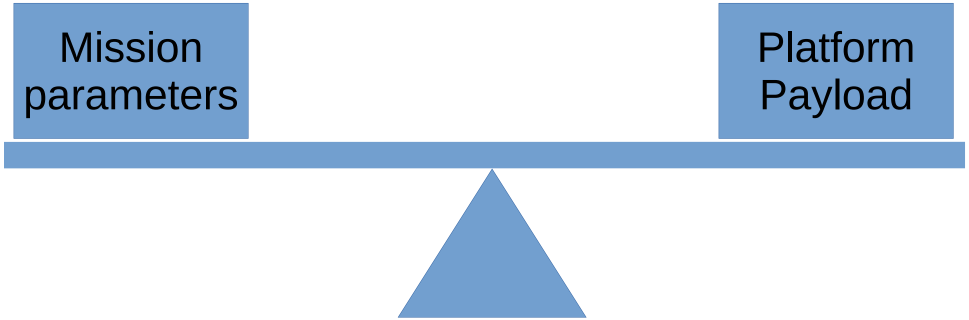
Let's build an OBS

Building an OBS is an exercise of budget balancing

We have to balance energy, weight and data quality requirements

These have a direct impact on:

- Data rate
- Dynamic range
- Endurance
- Retrievability

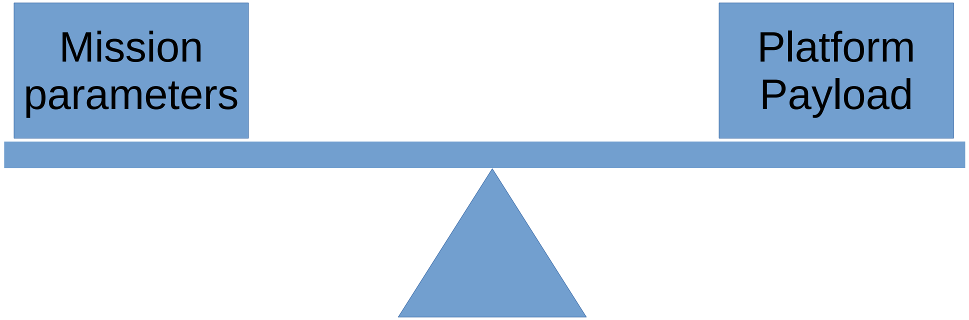


Let's build an OBS

First step – Mission parameters

- Endurance
  - How long is the deployment?
  - How deep is the deployment
- Data quality
  - How many channels?
  - What data rate to use?
  - Dynamic range?
  - How much clock drift is acceptable?
  - Sensor levelling scheme?
- Retrievability

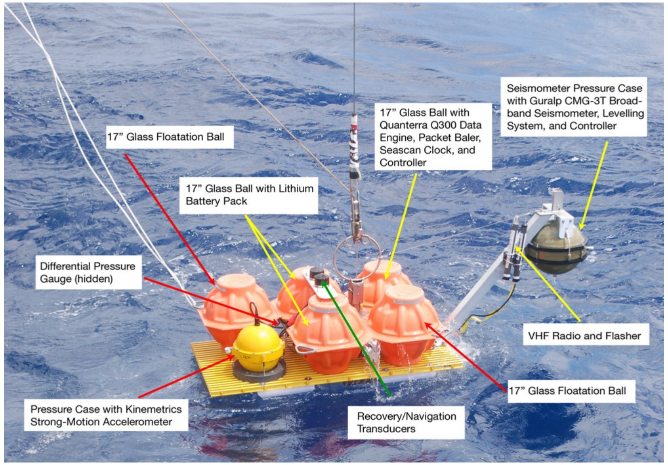
Datalogger



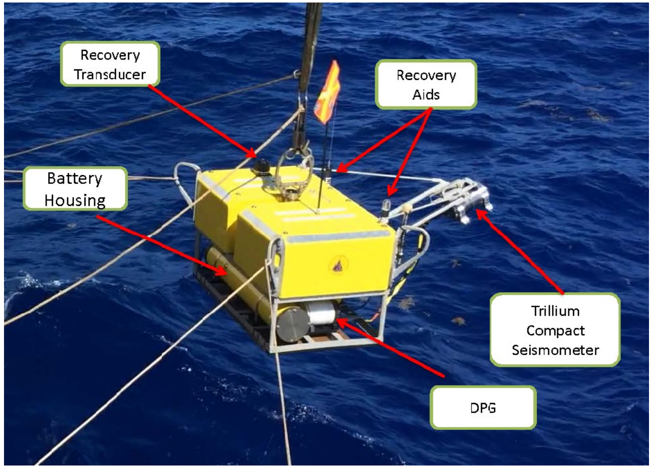
Let’s build an OBS

Second step – Materials for frames and housings

- OBS operate in harsh mechanical and chemical environments
  - extremely high pressures, galvanic corrosion and fouling
    - Glass spheres
    - Titanium tubes
    - Hard-anodized aluminium
    - HDPE
    - Stainless Steel
    - Syntactic foam



KECK OBS (glass spheres)

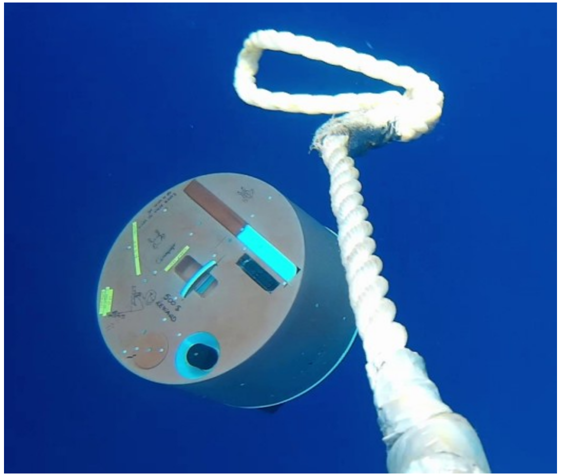


ARRA OBS (aluminium/titanium tubes + syntactic foam)

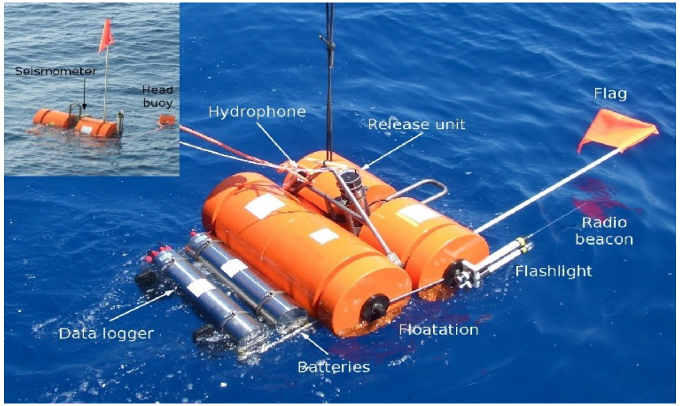
Let’s build an OBS

Second step – Materials for frames and housings

- Glass spheres
  - Provide lots of buoyancy
  - Fragile
  - Cheap
- Titanium/Aluminium tubes
  - Sturdy
  - Provide little buoyancy
  - Expensive
- HDPE
  - Neutrally buoyant
  - Inert and insulating



DUNE (glass spheres + HDPE frame)



LOBSTER (titanium tubes/frame + syntactic foam)

Let’s build an OBS

Third step – Energy budget

- Datalogger power consumption
  - Better clock? More power needed
  - Higher datarates? More power needed
  - Frequent levelling? More power needed
  - Better (...) ? More power needed

There’s a trend here

- Longer deployment? Take into account battery self-discharge
- Battery derating due to low temperatures
- Safety factors?
- Which type of batteries? Alkaline? Lithium? Rechargeable?

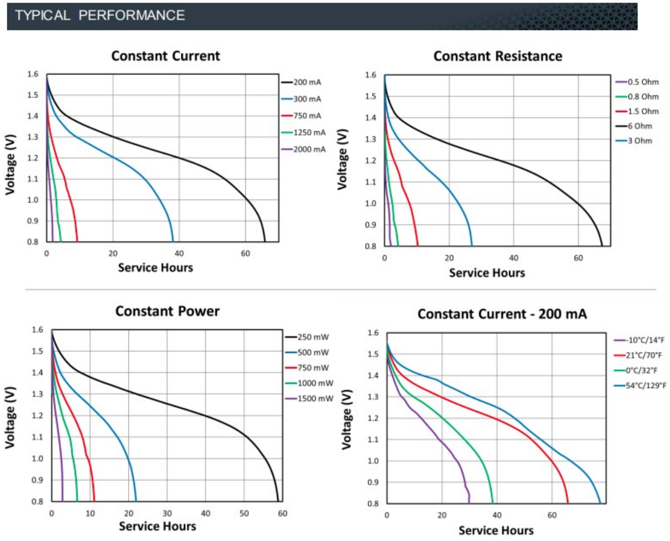
Let's build an OBS

ELECTRICAL CHARACTERISTICS	
Nominal capacity (25 mA Cont., .8V cut-off)	18,600 mAh
Typical Voltage (at + 20 °C)	1.5 V
AC Impedance @ 1kHz	56 mΩ

PHYSICAL CHARACTERISTICS	
Typical weight	140.0 g (5 oz)
Typical volume	56.4 cm³ (3.4 in³)
Terminals	Flat

Example: 6D6 datalogger for 12 months

- 125 mWh ~ 0.08 mAh @1.5v (typical D-cell voltage)
- 12 months deployment
  - 1095 Wh ~ 730000 mAh
- Alkaline D-cell has 18600 mAh capacity
  - 40 batteries ~ 730000 mAh
    assuming no derating
  - 60 batteries, assuming 30% derating



Let’s build an OBS

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Terminals	

Example: 6D6 datalogger

- 60 alkaline D-cells weigh 8.4 kg

  and occupy a minimum volume of 3.4 litres

These two numbers directly influence how the OBS is designed.

“Dry” space is very limited.

Weight must be compensated with additional floats

Let’s build an OBS

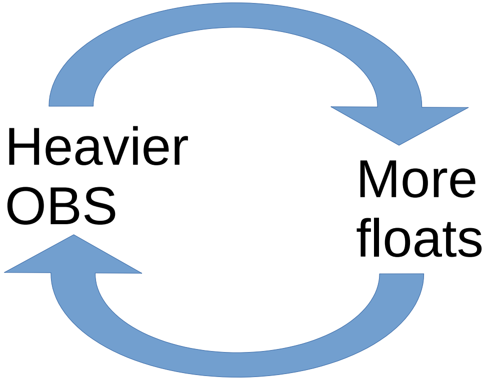
Fourth step – Weight budget and buoyancy (for self ascent OBS)

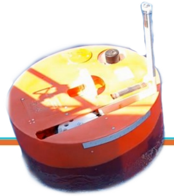
- The primary objective of an OBS is to reach the seafloor and start recording seismic data
- The secondary objective is to resurface when it’s supposed to

If the OBS is too heavy, more floats are required to make it surface.

More floats means more dry weight and larger frames.

It’s an inverted rocket equation.



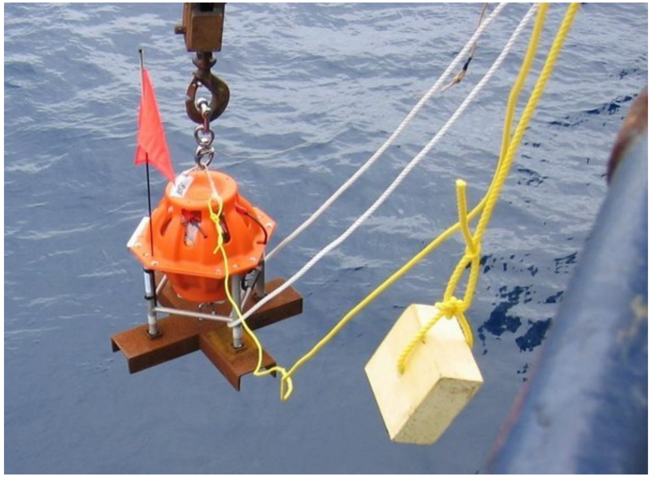


Let’s build an OBS

Three weight definitions

- Dry weight
  - If too heavy, it’s difficult to move on deck
- Anchored wet weight
  - If too heavy, the OBS sinks too fast
  - If not heavy enough, poorly coupled, may drift
- Rising wet weight
  - If not light enough, it rises slowly and drifts
  - If too light, it needs an extra heavy anchor
    - But it is harder to get stuck on the seafloor

LDEO-TRM OBS (~700 kg)

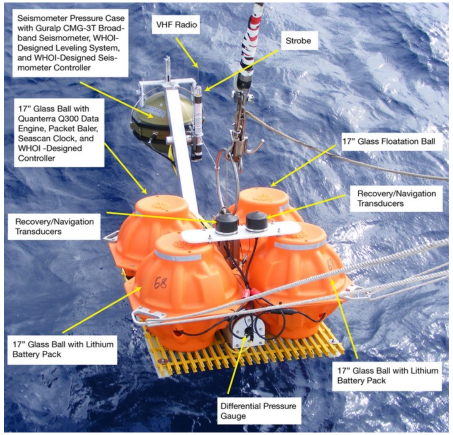


MICROBS (~40 kg)

Let’s build an OBS

Anchor mass is calculated to obtain a reasonable terminal velocity (usually 1m/s) and a good ground coupling

More buoyancy means faster rising times, but larger anchors needed to keep the OBS on the seafloor



WHOI BBOBS (320 kg / 30 kg / -30 kg)
(Dry w. / A. wet / R. wet)

Nammu (205 kg / 30 kg / -13 kg)
(Dry w. / A. wet / R. wet)

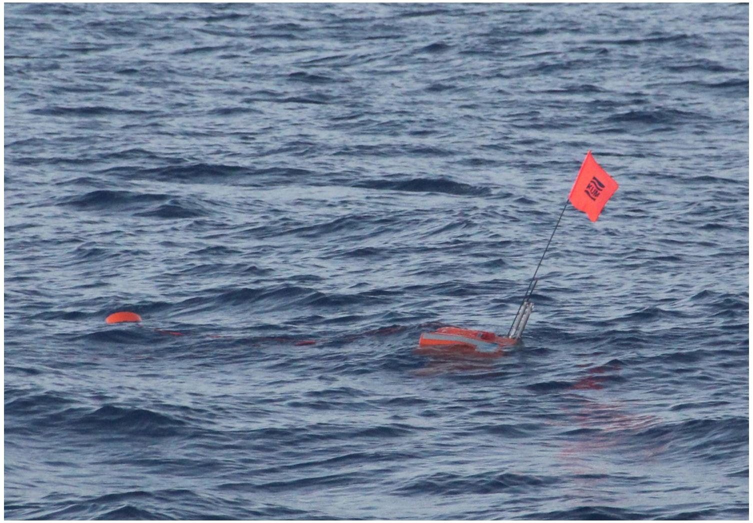
Anecdote

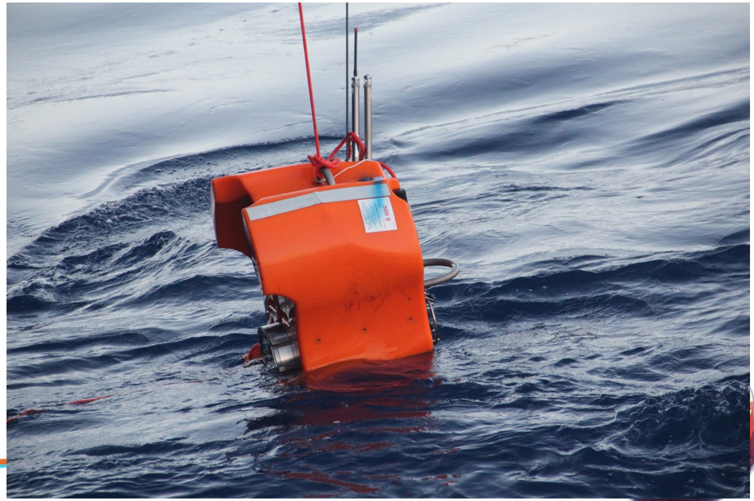
Once upon a time, in the UPFLOW cruise,

there was a Nammu with a “LANGSAM” sticker.

I thought it was an old station name, but it really had too little buoyancy:

- Slooooow ascent
- Faster drop
- No radio or flasher





Let’s build an OBS

Table 1. Buoyancy calculations for all components of Pankun OBS.				
Component	**Main Materials**	**Weight in Air (kg)**	**Buoyancy (kg)**	**Weight in Water (kg)**
Framework	Titanium alloy	9.1	2.7	6.4
Main acoustic releaser	Duplex stainless steel	26	8	18
Sensor releaser	Electrical pure iron	6.8	1.8	5
Sensor module	Titanium alloy (TC4)	17.6	7	10.6
DPG	Engineering plastics	5.5	4.3	1.2
Pressure vessel	Titanium alloy (TC4)	44.3	19.5	24.8
Beacons	Titanium alloy	1.4	0.4	1
Flag etc.	Engineering plastics	0.2	0.2	0
Protective housing	ABS	14.9	14.6	0.4
Cables	-	1	0.2	0.8
Screws	316 stainless steel	2.9	0.8	2.1
Buoyancy module	Syntactic foam	124.4	219.8	−95.4
Anchor	Carbon steel	73	9.3	63.7
Rising	Rising wet weight	NA	NA	−25.2
Sinking	Anchored wet weight	NA	NA	38.5
OBS	Dry weight	327.1	NA	NA

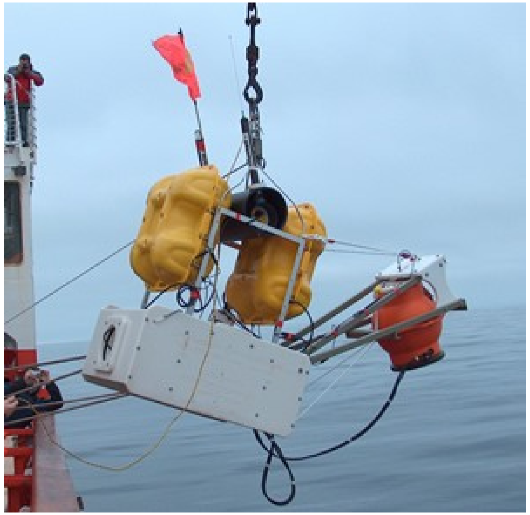
Liu et al. (2023)

Let’s build an OBS

Besides weight, balance is also extremely important

- The OBS must reach the seafloor with the correct attitude
- It must reach the surface in a position suitable for retrieval

- Trawl-resistant shielding or canopies must not become control surfaces
  - LDEO-TRM is only deployable by winch and heave-compensated crane because it behaves like an umbrella



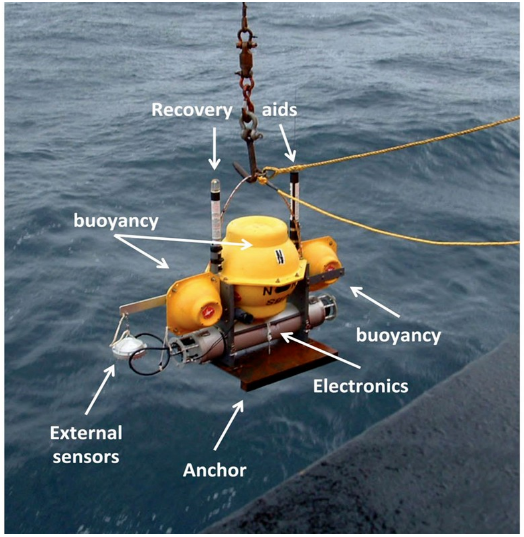
LDEO

LDEO-TRM OBS

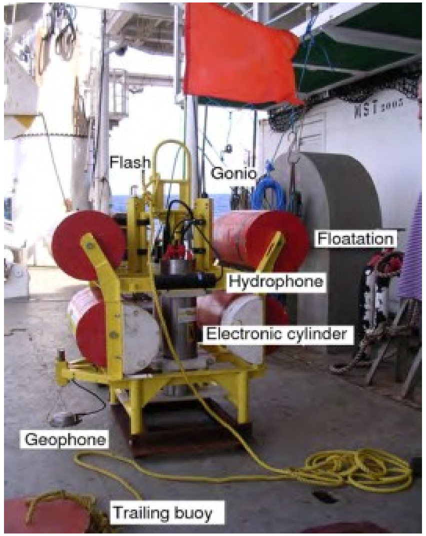
Let's build an OBS

Fifth step: Open or closed frame?

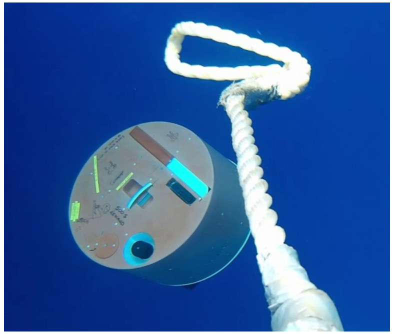
- Open frames
  - Simpler construction
- Closed frames
  - Increase trawl resistance
  - Decrease current noise
  - Increase complexity



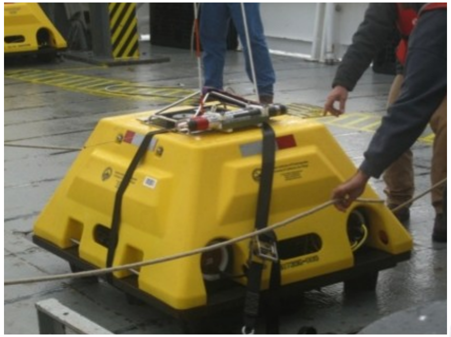
BIO SPOBS



IFREMER OLDOBS



DUNE



ABALONES

Let’s build an OBS

Sixth step: Coupled sensors?

- Coupled sensors

  Increase reliability

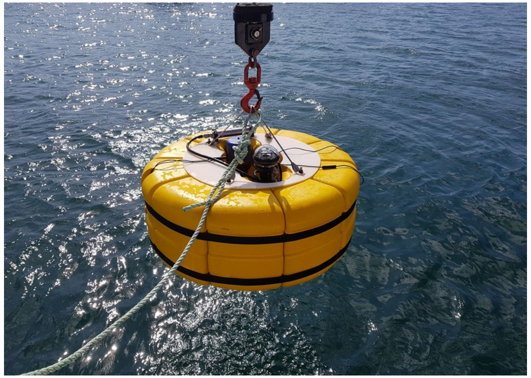
  Degrade signal

- Decoupled sensors

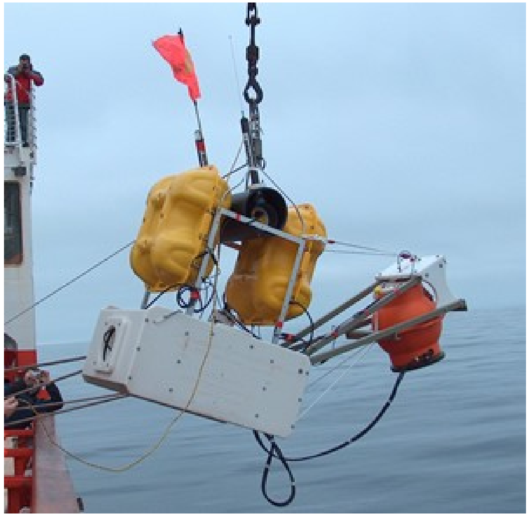
  Increase complexity

  Improve signal

  “Murphy’s law” candidates



AQUARIUS



LDEO

Let’s build an OBS

Last steps: Deployment method

- Free fall

    Simplest

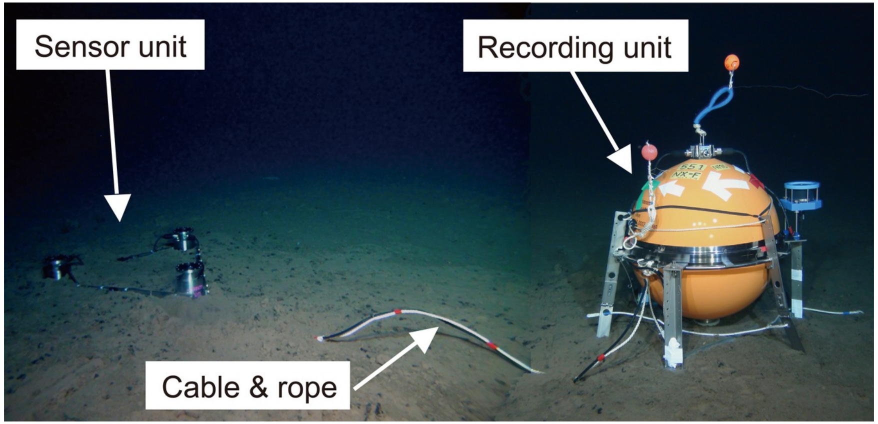
- Wire (+ USBL)

    Heavy / precise positioning

- ROV emplacement

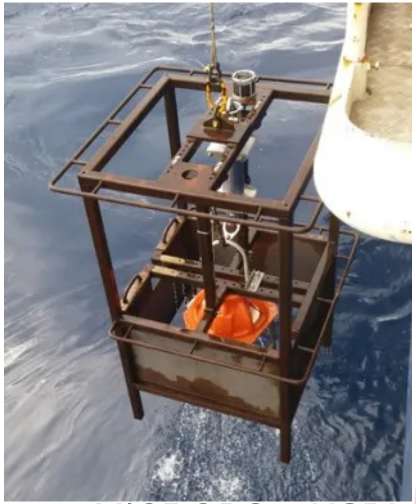
    Heavy / precise positioning

    Sensor burial



U-Tokyo BBOBS + ROV emplacement

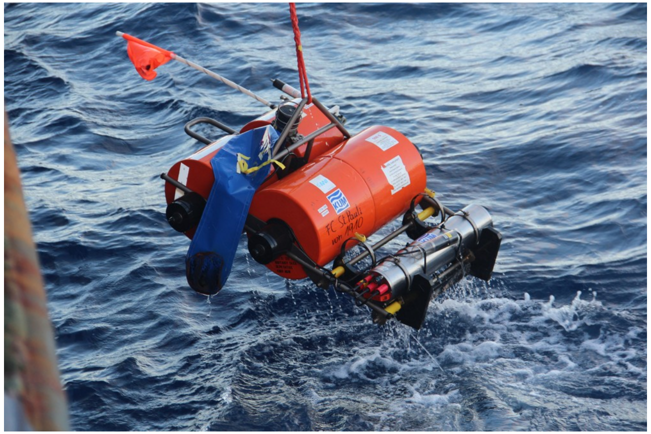

USGS OBS + Free fall


MICROBS + USBL

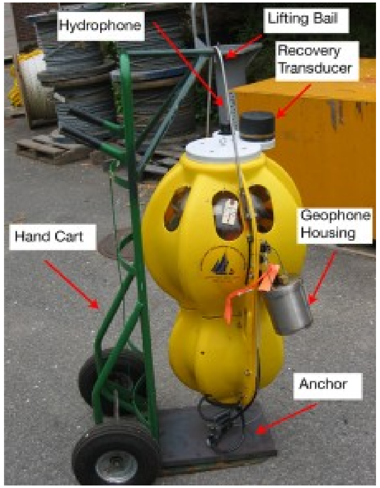
Let’s build an OBS

Last steps: Retrieval method

- Pop-up buoy
  - Easiest
  - Limited to shallow waters
- Self ascent OBS
  - Requires surface-seafloor comms
  - or a timed release
- ROV retrieval
  - Most expensive



LOBSTER



WHOI D2

Let’s use an OBS

So far, we’ve had an engineer’s view of an OBS

We built an instrument to withstand deep ocean environments:

- Extreme pressure
- Chemical and galvanic corrosion
- Inaccurate clocks
- Limited power availability
- Deployment and retrieval

Let's use an OBS

Now, we must regard it as a tool to get good seismic data

What limits the quality of the data when compared to a land station?

- Land stations are usually very well sheltered
- Sites are carefully chosen
- Ground coupling is engineered
- GPS time

Current-induced noise

The structure of the OBS interacts with the moving water

- Generation of vortices
  - Lift and drag effects
- Thin components vibrate
  - Vortex resonance (frequency lock-in)
  - Mechanical strumming
- Larger components suffer tilt and compliance effects
  - The seafloor itself is also compliant

Current-induced noise

We cannot handle the sensor and OBS frame separately

- Frame components oscillations can affect the seismic sensor even if it is detached and lying apart on the seafloor (Kovachev et al 1997)

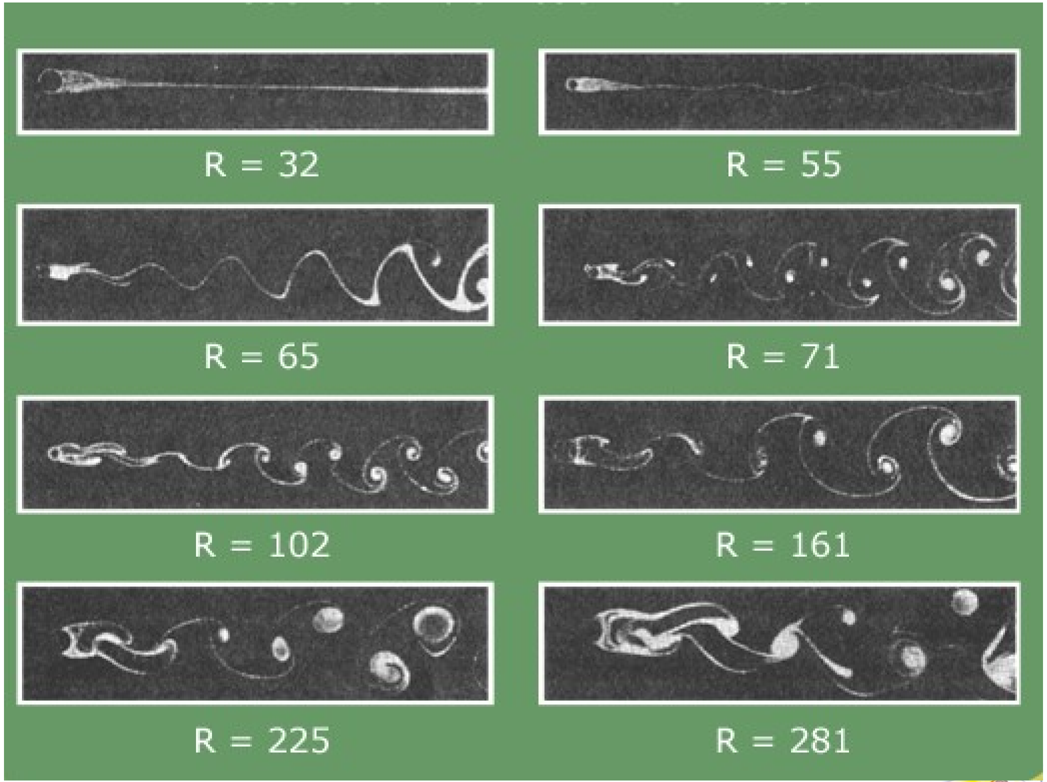
The chosen OBS design affects the noise level of the whole instrument

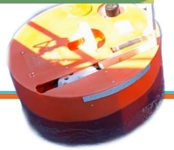
- Compromises are sometimes required

Current-induced noise

von Kármán Vortex shedding

- An object in a moving turbulent fluid generates alternating periodical vortices
- Depends on the Reynolds number (laminar vs turbulent flow)

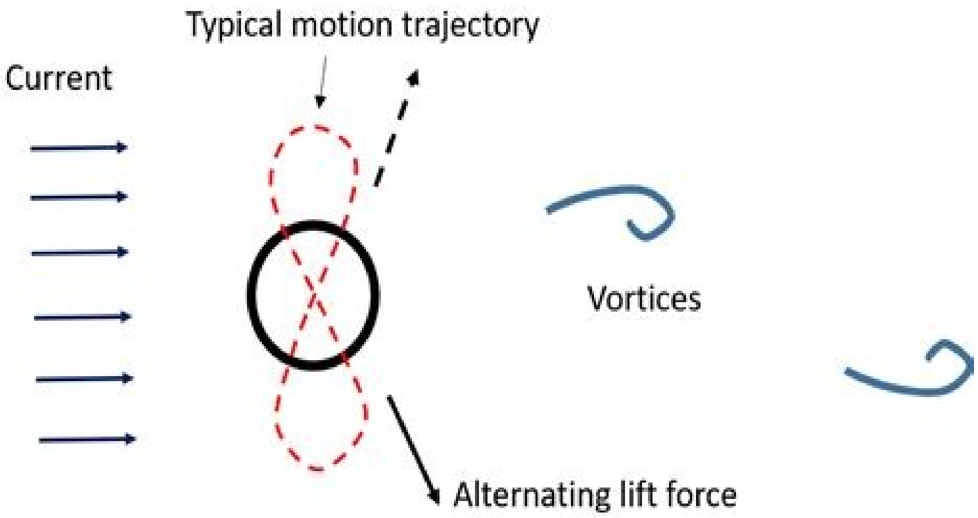




Current-induced noise

von Kármán Vortex shedding

- The current and vortices cause lift and drag effects that move and tilt the OBS



Oscillation frequency depends on current speed and object size (diameter)

Strouhal frequency

$$f_{St} = \frac{St \cdot D}{V} \qquad St \approx 0.22$$

Current-induced noise

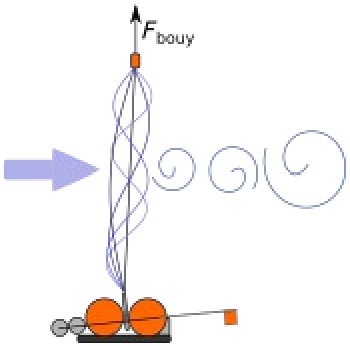
von Kármán Vortex shedding

- This happens to all parts of the OBS that are exposed to the current:
    - Floats
    - Frames
    - Pressure vessels
    - Sensors
    - Anchors

Only used for recovery

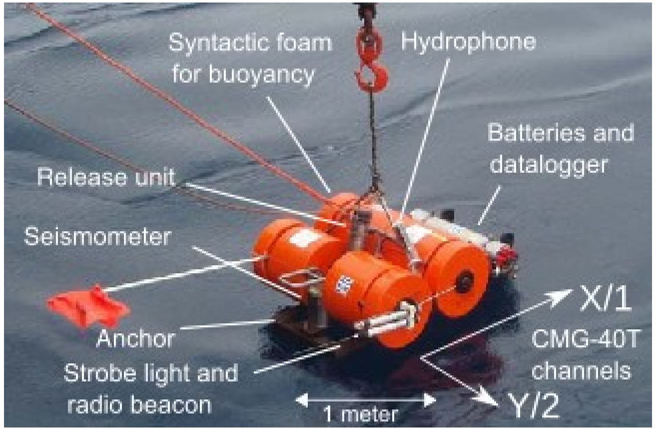
- Antennas
- Flags
- Ropes

Current-induced noise



The LOBSTER is a well studied design in terms of noise.

- Floats, and pressure vessels are cylinders of different diameters → different Strouhal frequencies.
- Large cross-section → increases tilt noise
- Flag and radio antenna vibrate in narrow frequency bands + overtones
- Recent deployments have the rope stowed to reduce noise



Stähler et al. (2018)

Current-induced noise

Strumming and resonance

- If the Strouhal frequency is close to the eigen-frequency of a component, amplification occurs

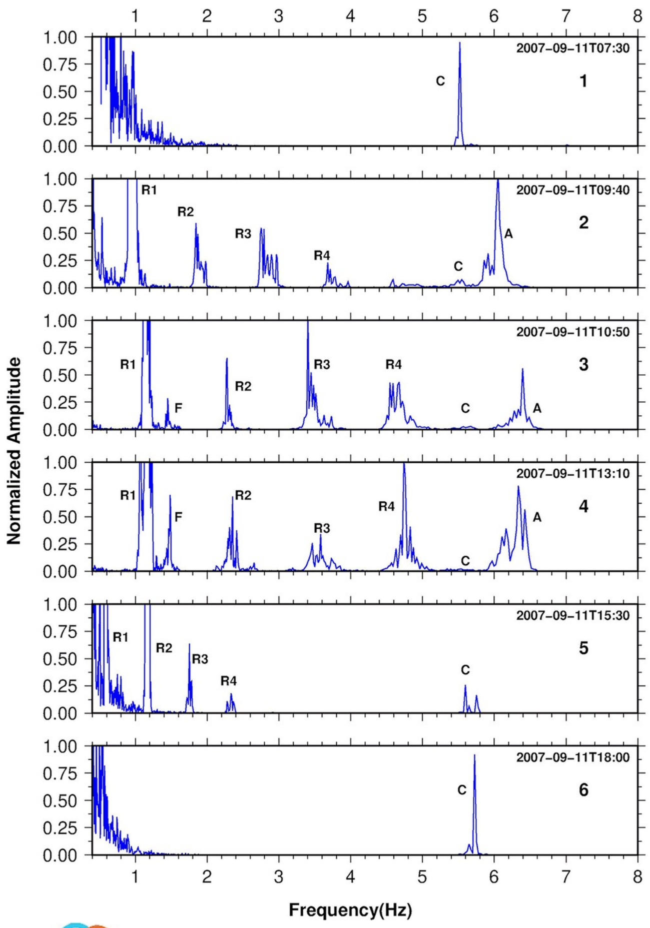
  Frequency lock-in when

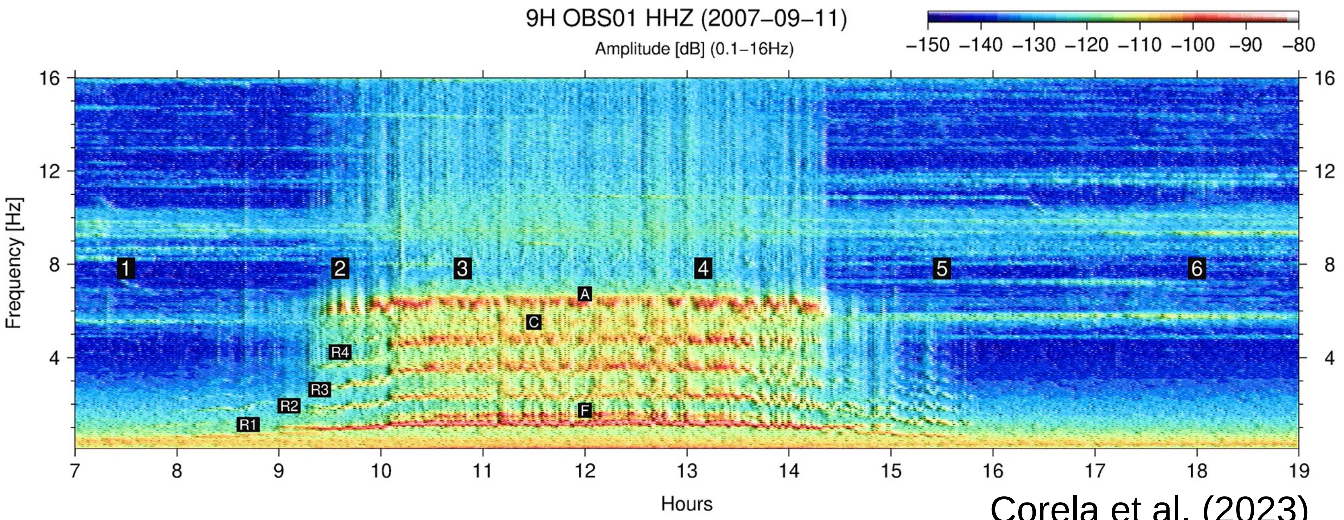
$$0.8\,S_t < f < 1.2\,S_t$$

- Thinner parts can be mechanically excited by the drag of moving water

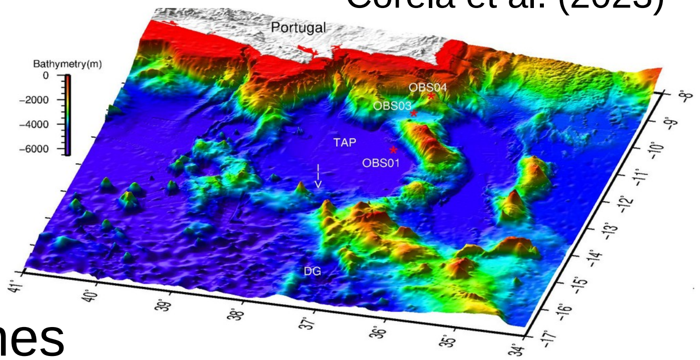
  “Everything is a spring”

Current-induced noise





Corela et al. (2023)

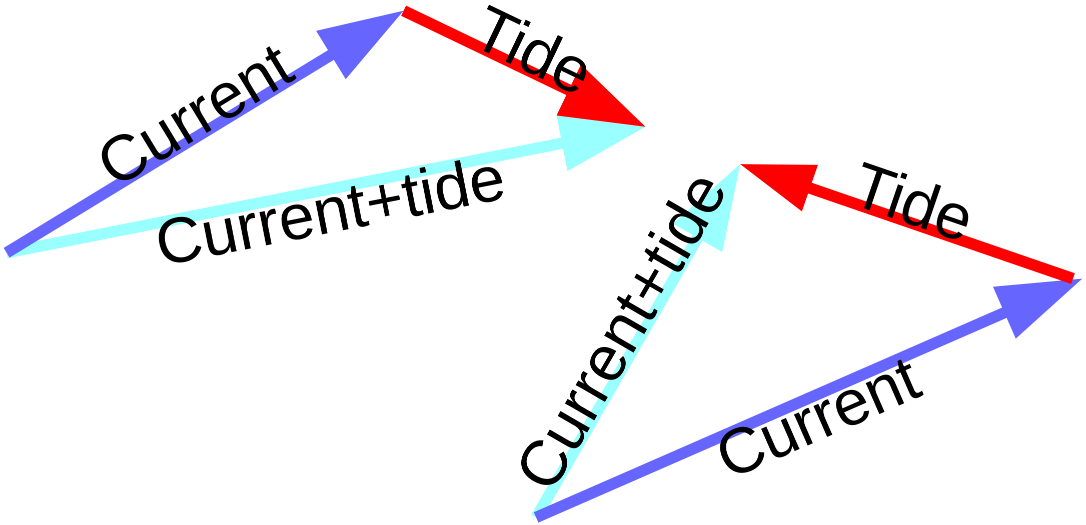


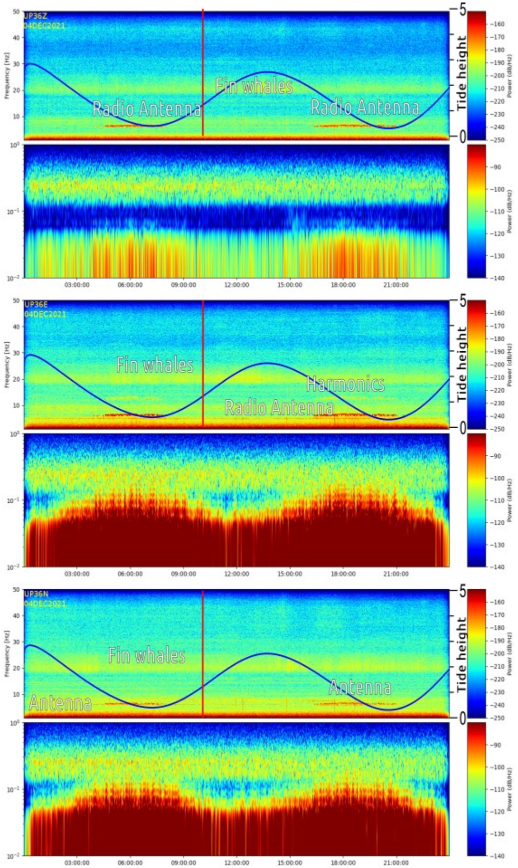
LOBSTER example

A → Radio antenna ~6Hz
F→ Flag pole ~1Hz
R1→ Rope ~1Hz + overtones
C → OBS-sediment coupling ~5Hz

Current-induced noise

Current noise is modulated by tides
Background and tide velocities are summed



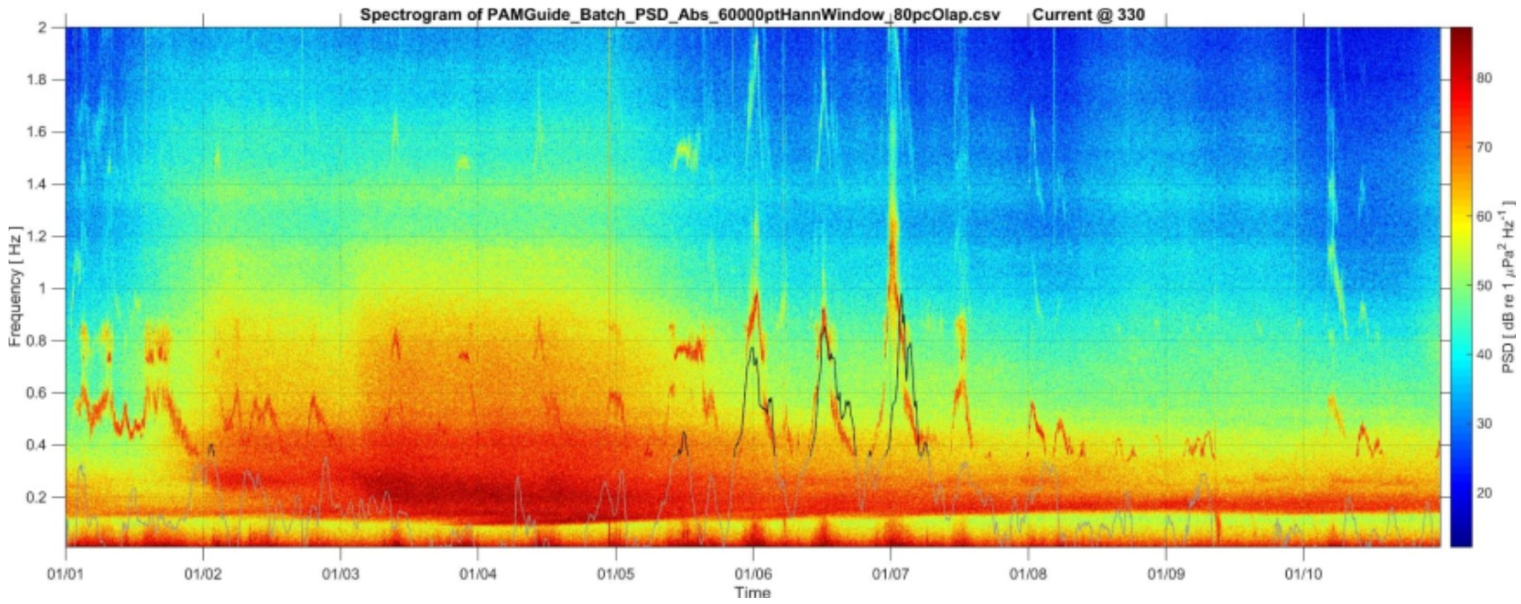


Loureiro et al. (2023)

Interesting fact: outside the lock-in phase, current velocity can be estimated from the Strouhal frequency

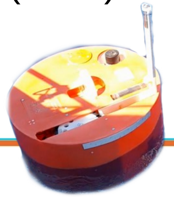
Current-induced noise

- Non-symmetrical OBS have an azimuthal dependency on the current-induced noise



Matias et al. (2020)

GEOSTAR current intensity along azimuth 330º + LOBSTER noise (NEAREST)



Current-induced noise

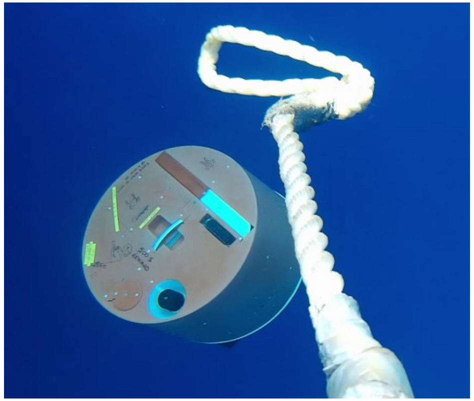
Current-induced noise can be mitigated

- Making instruments more compact
- Enclosing the instrument

    Cowling shape can be fine-tuned for specific Strouhal frequencies (but only for cylinders)

$$f_{St} = \frac{St \cdot D}{V}$$

    Complex shapes need simulations (fluid or fluid + finite element)



DUNE

Current-induced noise

Other approaches

- Having noise models for OBS platforms

  Filter the narrow band events

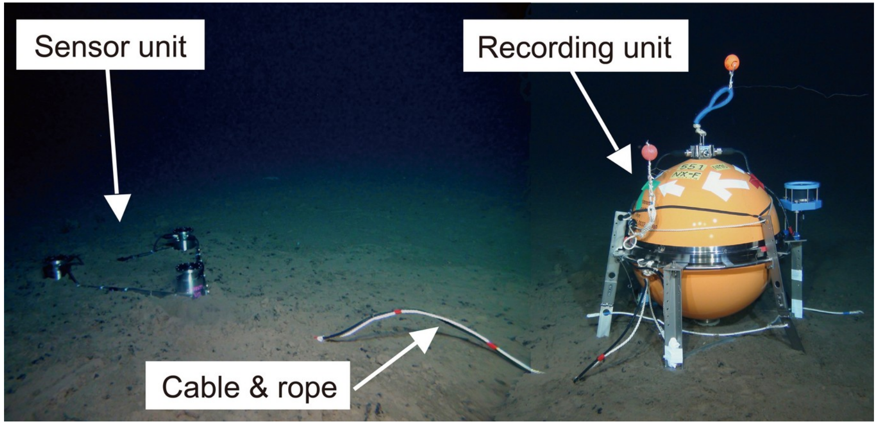
- Decoupling the sensor from the frame

  Tether systems

- Shielding the sensor module

  Buried sensor

  Using a “dirt bag”



U-Tokyo BBOBS + Buried sensor

Take-home messages

- Frames, sensors and ancillary equipment standout from the seafloor,
  offering an irregular profile to the deep oceanic currents
- The interaction of the OBS with ocean bottom currents result in several effects that are recorded by the seismometer:
  - Tilt noise
  - Frequency lock-in
- Current-induced noise depends on instrument type, time and current direction
- Can be mitigated!