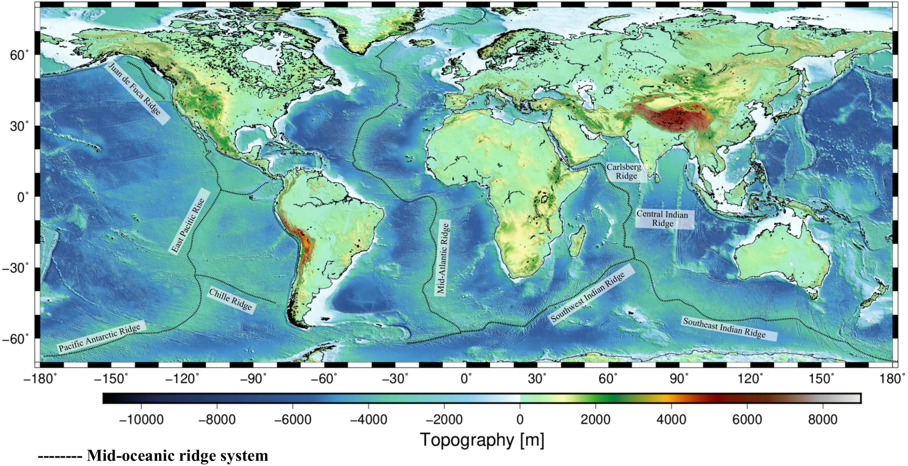
Hydroacoustic observations of a seismic swarm near Melville Fracture Zone along the Southwest Indian Ridge in 2016-17

Vaibhav Vijay INGALE, Sara BAZIN, Jean-Yves ROYER

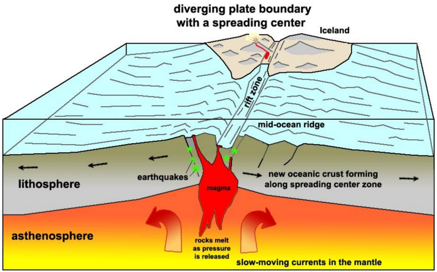
Lab Geo-Ocean
Universities of Brest and Bretagne-Sud, CNRS, Ifremer
Institut Universitaire de la Mer, Plouzane (France)

Introduction: Mid-oceanic ridge



- MOR system is the longest chain of seafloor mountains along the divergent boundaries
- Along them, new ocean floor is created as the Earth's tectonic plates spread apart
- Each MOR has different spreading rates and geometry

Introduction: Mid-oceanic ridge

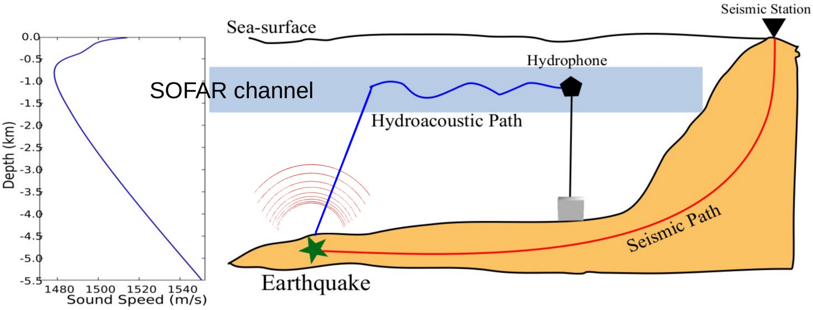


Source: gotbooks.miracosta

- Nature of seismic activity
  - Molten rocks rises due to mantle upwelling
  - Numerous earthquakes (**magmatic nature**)

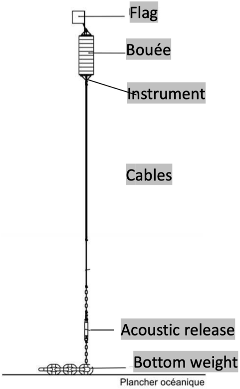
  - Divergence of tectonic plates along MOR
  - Earthquakes (**tectonic nature**)
- This seismicity is
  - Involved in generation of the oceanic crust
  - Associated with seafloor spreading
  - Reflects the thermal and mechanical state of the oceanic lithosphere

Introduction: Hydroacoustic waves

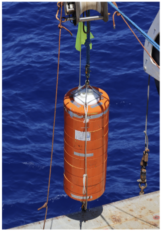


- MOR seismicity comprises small-magnitude earthquakes
  - Not reported in land-based seismic networks due to remoteness and rapid wave attenuation
- Such events produce low-frequency hydroacoustic T-waves
  - By conversion of seismic waves to acoustic waves at sea-bottom
  - Travel through SOFAR channel over long distance with little attenuation

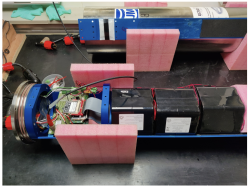
Introduction: Hydrophone Mooring



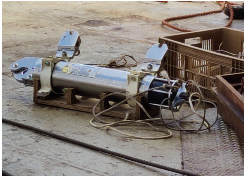
Bouée



Instrument



Weight



Acoustic release

Cables

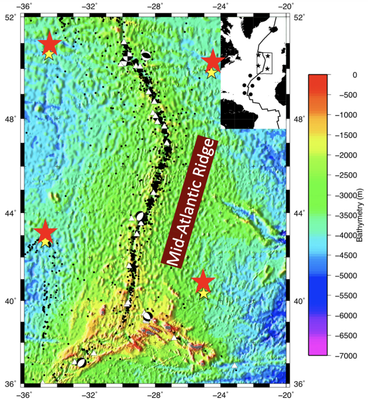
- Hydrophone mooring to record hydroacoustic waves (ocean sound)

Introduction: Hydroacoustic Networks

Previous Study

SIRENA Hydroacoustic Network

Monitoring of Mid-Atlantic Ridge

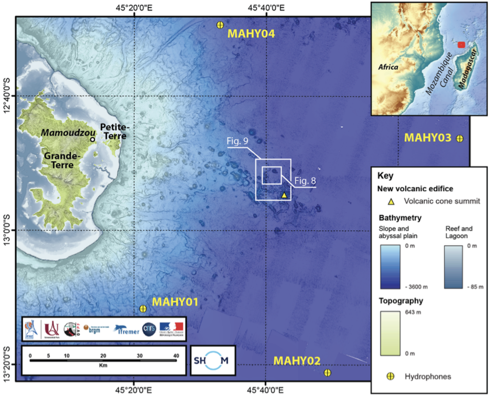


Goslin et al. 2012

Ongoing Study

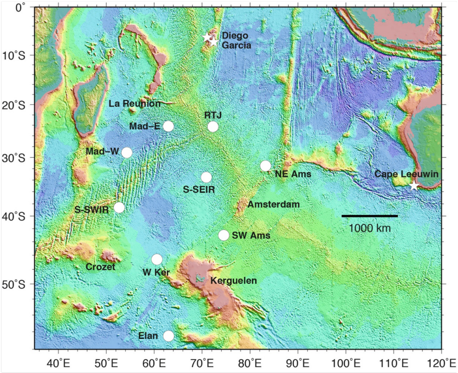
MAHY Hydroacoustic Network

Monitoring of Mayotte Volcano



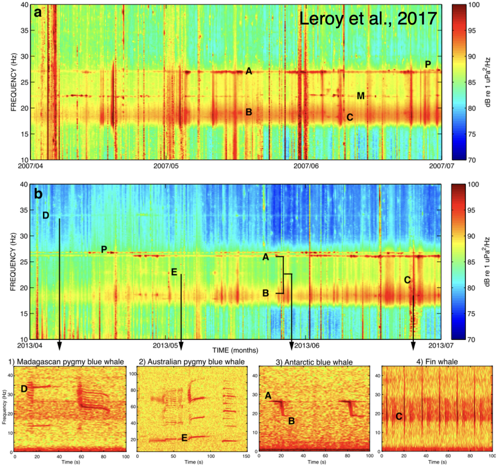
Bazin et al. 2022

Introduction: OHASISBIO Experiment



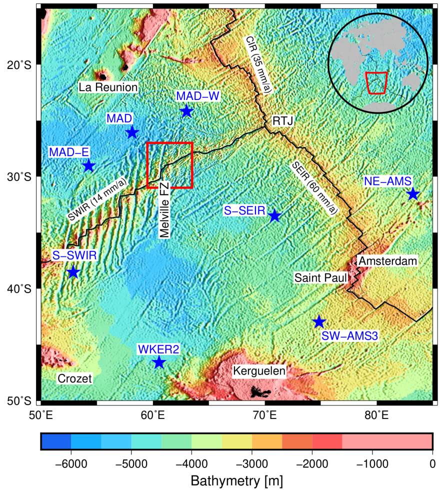
- OHASISBIO (**H**ydroacoustic **O**bservatory of the **Seis**micity and **Bio**diversity in the **I**ndian **O**cean)
  - Led by **Jean-Yves ROYER**
  - Active since: **2010**
  - Area: 3000 x 2000 km
- Deployment of autonomous underwater hydrophones in the Southern Indian Ocean
- To monitor
  - Marine Mammals' activity
  - Seismic activity
  - Cryogenic events
- Along with the International Monitoring Stations of CTBTO (**C**omprehensive Nuclear **T**est-**B**an-**T**reaty **O**rganization)

Introduction: Bio-acoustic Examples



- Long term monitoring of marine mammal activity in the Southern Indian Ocean
- Samaran et al. 2013; Torterotot et al. 2019; Leroy et al. 2018; Tsang-Hin-Sun et al. 2016

Introduction: Seismic Studies



- Three mid-ocean ridges with different spreading rates
  - Ultra-slow: **Southwest Indian Ridge**
  - Slow: **Central Indian Ridge**
  - Intermediate: **Southeast Indian Ridge**
- Monitor seismicity (hydroacoustic **T-waves**) recorded
  - Autonomous hydrophones of **OHASISBIO**
  - Permanent stations of **CTBTO**
- Build up catalogue of hydroacoustic events
  - With their **origin time, location** and **Source Level** (acoustic magnitude)
  - Based on **arrival-times of T-waves** on the hydrophones
- Detected and analysed the hydroacoustic events on
  - **Southwest Indian Ridge** near *Melville FZ*

Method: T-wave Picking

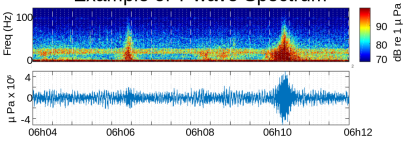
Pick T-wave energy on at least three hydrophones

→ Least square minimization of predicted and calculated arrival times

→ Obtain event's location and origin time

→ Errors in location and origin time obtained from covariance matrix of minimization

Example of T-wave Spectrum



[Royer et al. 2015, 2019]

Pick T-wave energy on at least three hydrophones ↓

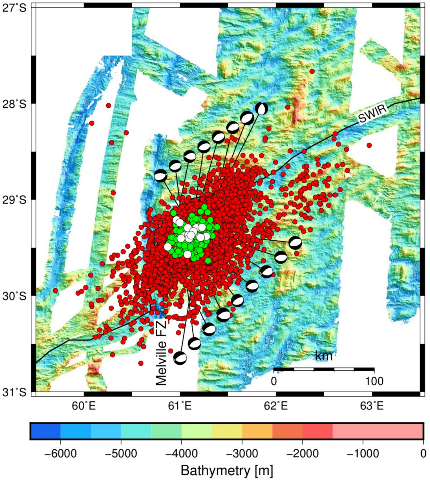
Energy as Received Level (RL) on each hydrophones

→ Correct the RL by transmission loss (TL)

→ Calculate Source Level (acoustic magnitude) by SL = RL + TL

TL comes from cylindrical and spherical sound-spreading between source and station → Correct the RL by transmission loss (TL)

Results: Land-based vs Hydroacoustic events

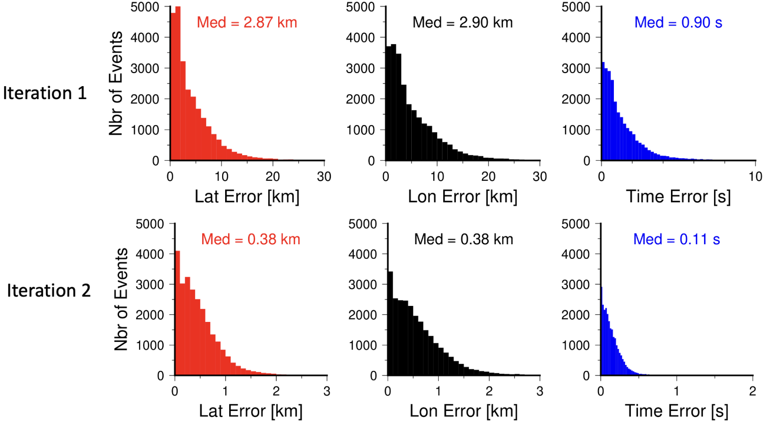


Global CMT

International Seismological Centre

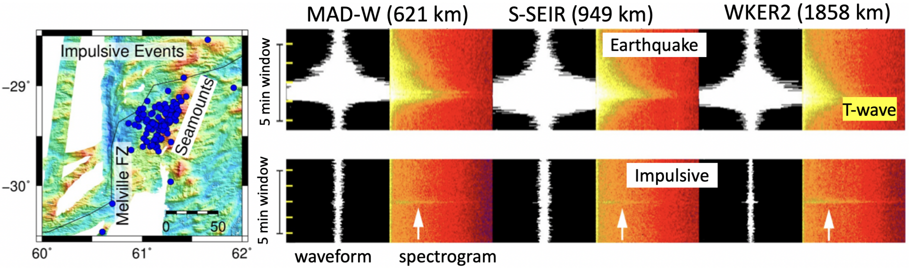
- **Dates Span**: 01 June 2016 to 25 March 2017
  - **298** Julian days
- International Seismological Centre (ISC) catalogue
  - **258 reported events**
  - Maximum $m_B = 5.5$ (16 Sept-18h38)
- Global Centroid Moment Tensor (GCMT) catalogue
  - **17 reported events**
  - Normal faulting mechanisms
  - Azimuths parallel to ridge axis
- Hydroacoustic catalogue
  - Used 3 to 9 hydrophones for detection
  - **27624 detected events**
  - $\sim$**107-fold** increase in event detection
  - $\sim$**93 events** per day (on average)

Results: Improvements in localization errors



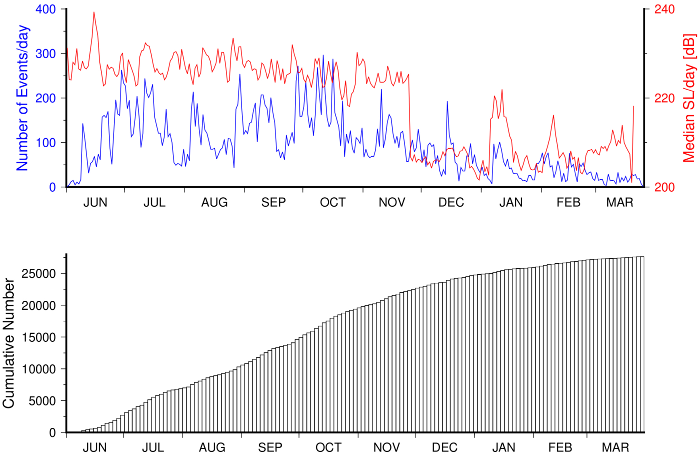
- In iteration 1, build a catalogue of detections with their origin time, location, Source Level and associated errors
- In iteration 2, re-analyse the primary catalogue to improve the errors in location by ∼8-fold
- Errors in latitude/longitude are improved to ∼**400 m** compared with ∼**20 km** in land-based catalogues

Results: Impulsive events



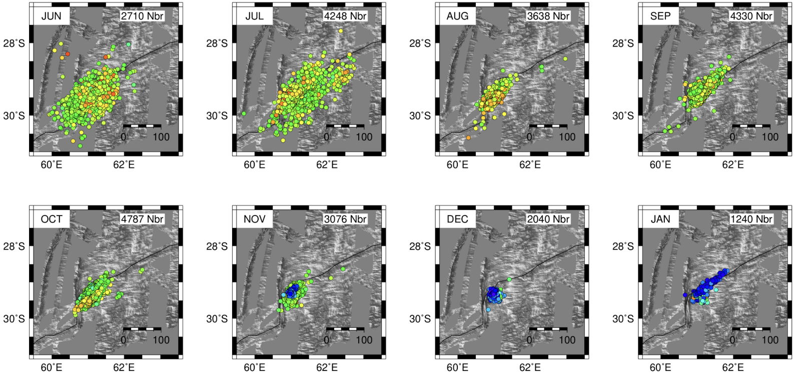
- Occurrence of many **impulsive events** (118 in total)
  - **Short duration** (∼10 s) compared with earthquake events (∼200 s)
  - **Highly energetic**, since detectable 2000 km away (WKER2 site)
- Characteristics
  - Located on the **slopes of seamount** near ridge axis
  - **H-waves** like, with high energy released directly in water column
  - Interpreted as **thermal explosions** due to direct magma supply on the seafloor, as observed in sub-marine volcanic contexts [*Wilcock et al. 2016 (Sci.); Bazin et al. 2022 (C. R. Geosci.)*]

Results: Source Level of events

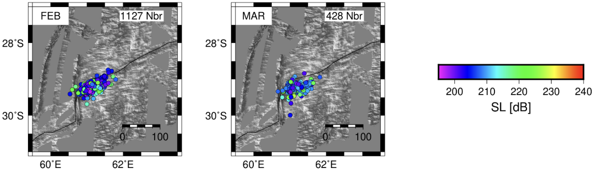


- **Source Level** and **number of events per day** show a sudden drop in seismic activity after 16 November 2016
- Despite of several periods of high activity ($>$ 150 events per day), **cumulative number** of events increases gradually
- Absence of clear mainshock-aftershock sequence (strong events do not govern the seismic rate)

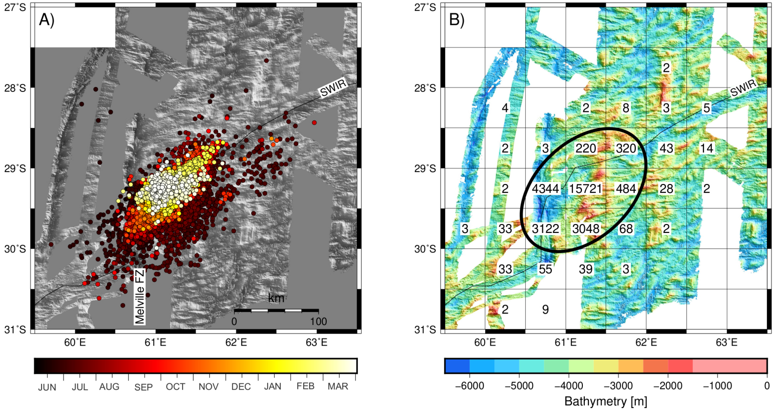
Results: Source Level of events



Events with lower SL are more clustered after mid-November



Results: Spatio-Temporal distribution



- Activity initiated near **Melville FZ** and **spread in N-E direction**; parallel to SWIR axis
- Then, mostly **concentrated near a seamount chain**, east of Melville FZ
- Clustering of events near these seamounts, next to ridge axis, interpreted as **magmatic intrusions**

Summary

- 61°E SWIR swarm comprises **27624 events over 298 days** (93 events per day)
- Hydroacoustic network recorded ∼**100 times more events** than land-based seismological networks
- Acoustic triangulation over 2 iterations shrunk the uncertainties **to 400 m in location and 0.1 s in origin time**
- **Magmatic origin** inferred from :
  - **Absence of mainshock-aftershock** sequences (typical of tectonic events)
  - Characteristic **spatio-temporal distribution** of magmatic intrusions
  - **Impulsive events** focused on the slopes of local seamounts, likely related to active lava flows on the seafloor