The Use of Seismic Nodes and DAS for Monitoring Volcanoes

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Next generation of seismic sensors

- Broadband seismometers
- **Seismic nodes**
  - Many types, emerging market
  - Autonomous
  - Cheap - but software can be expensive
- **Fibre optic cables (DAS)**
- Borehole instruments
- Rotational sensors
  - 6 degrees

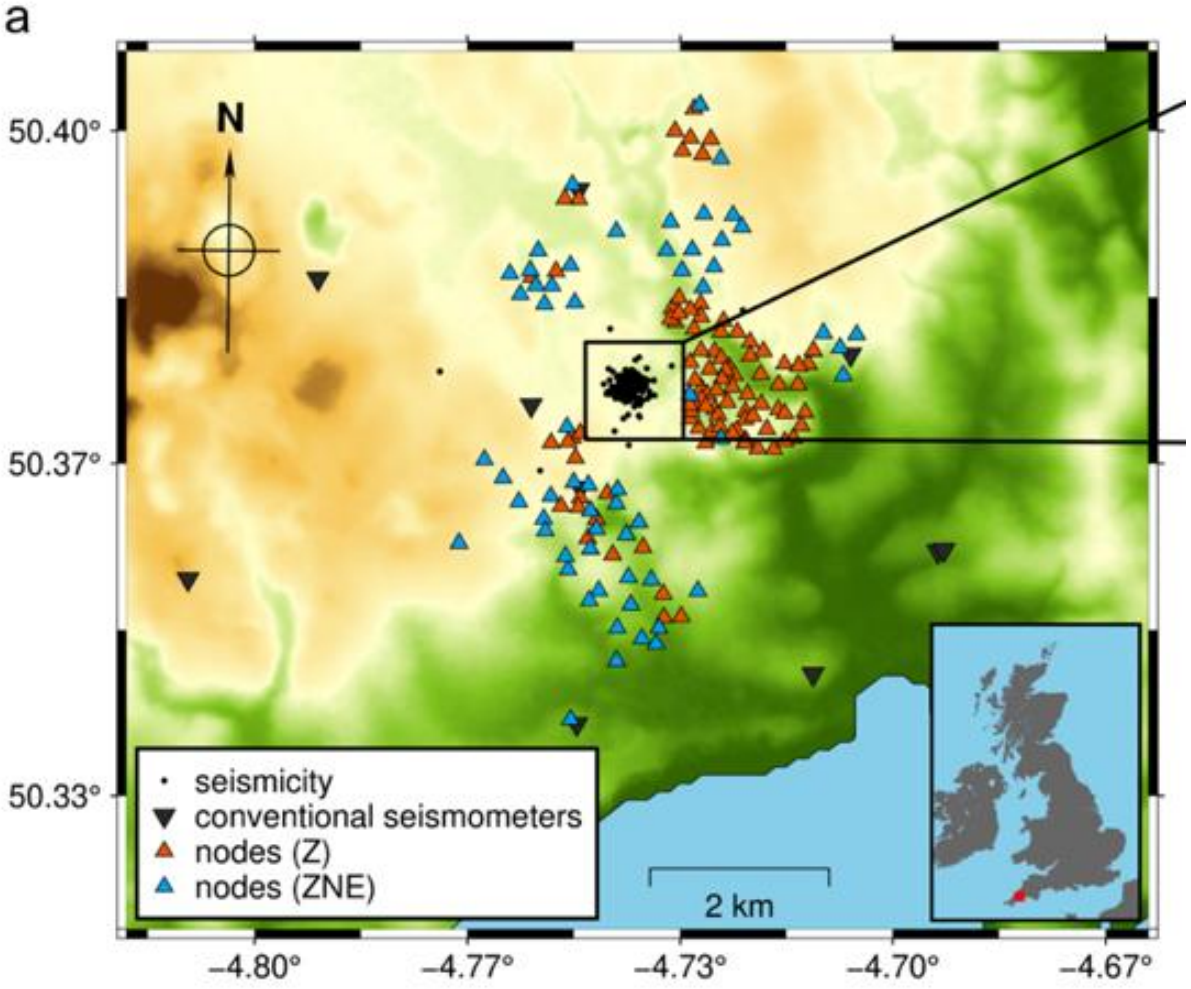
Stryde nodes

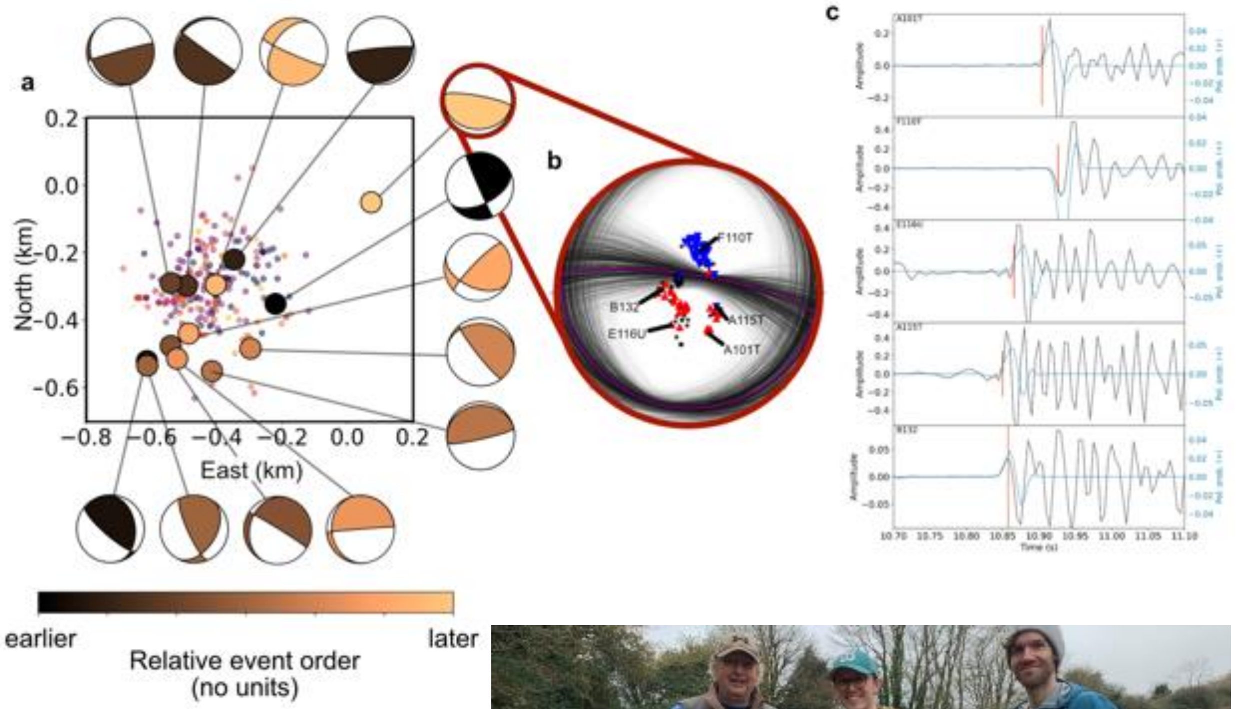
SERCEL WiNG

Smart Solo

A recent example:

Elucidating geothermal systems using dense nodal arrays: An example from Cornwall, UK

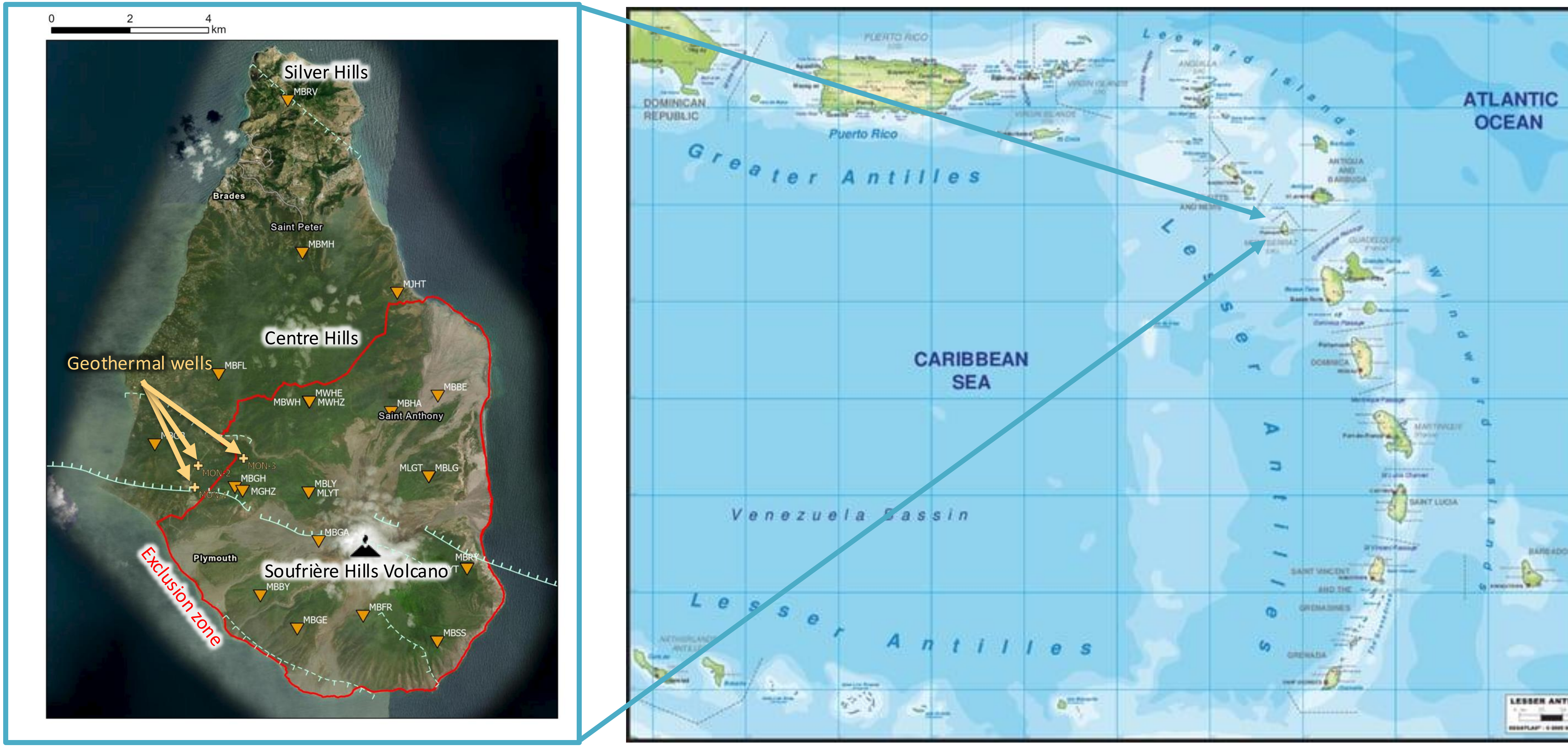




450 Stryde nodes

Hudson, et al., Seismic Record, 2024

Geophysical investigations of Montserrat



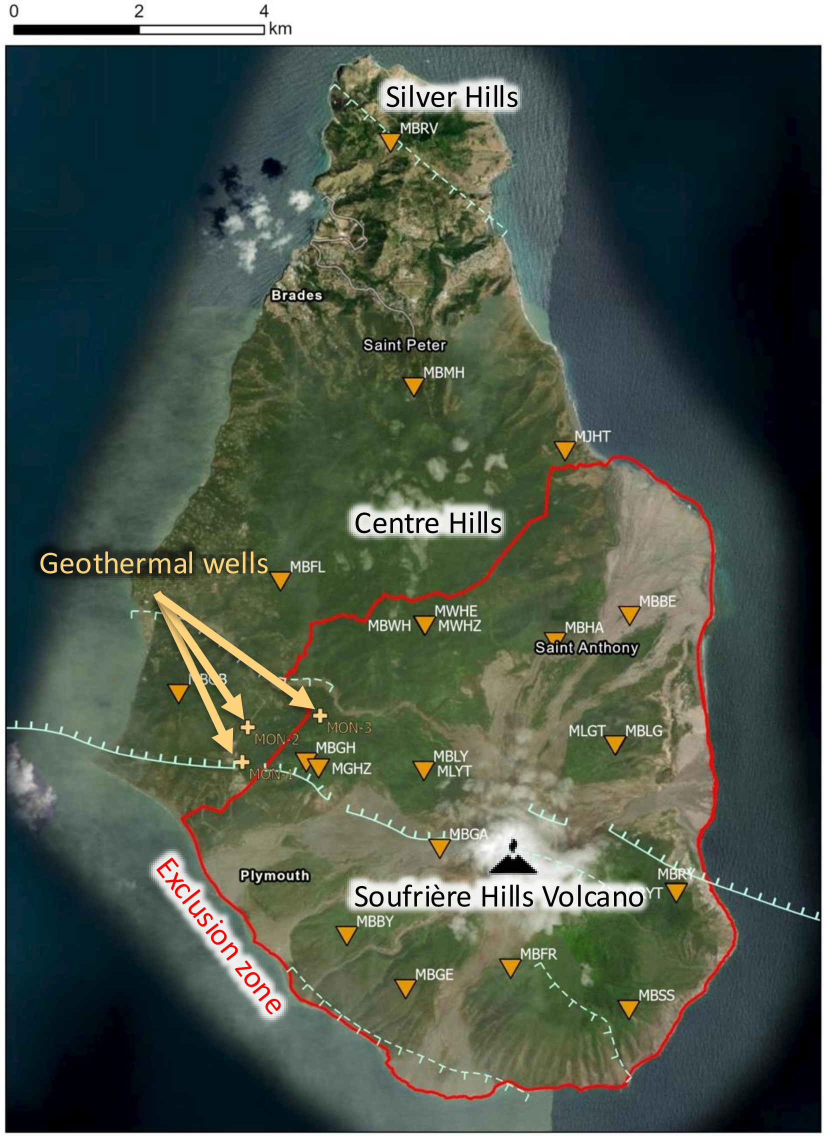
Geophysical investigations of Montserrat

Why important?

Better understanding Volcanic system & Geothermal field:

- Risk management
- Resource development
  - Geothermal energy
  - Mineral exploration
- Better understanding of the volcano and its evolution

Frank Perret



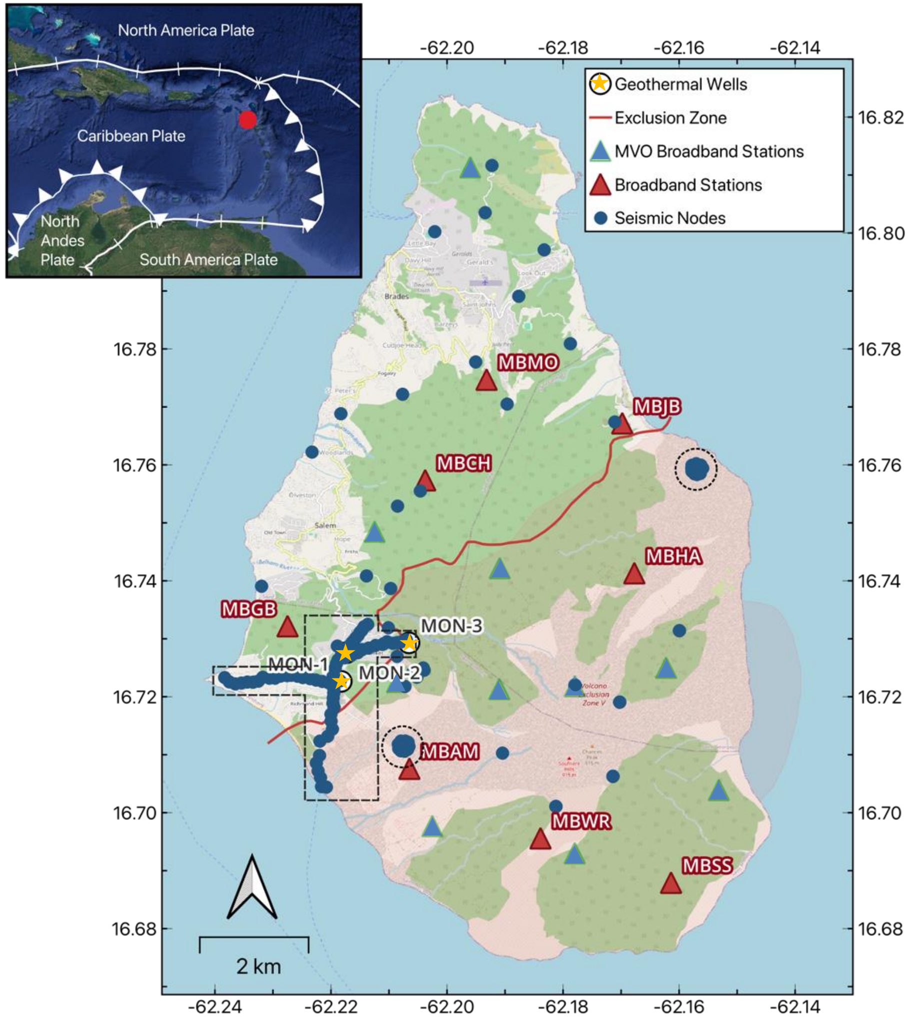
Transition to Geothermal Energy
Recovery of Metals from Brines

OXFORD MARTIN SCHOOL

ReSET: Rethinking Natural Resources

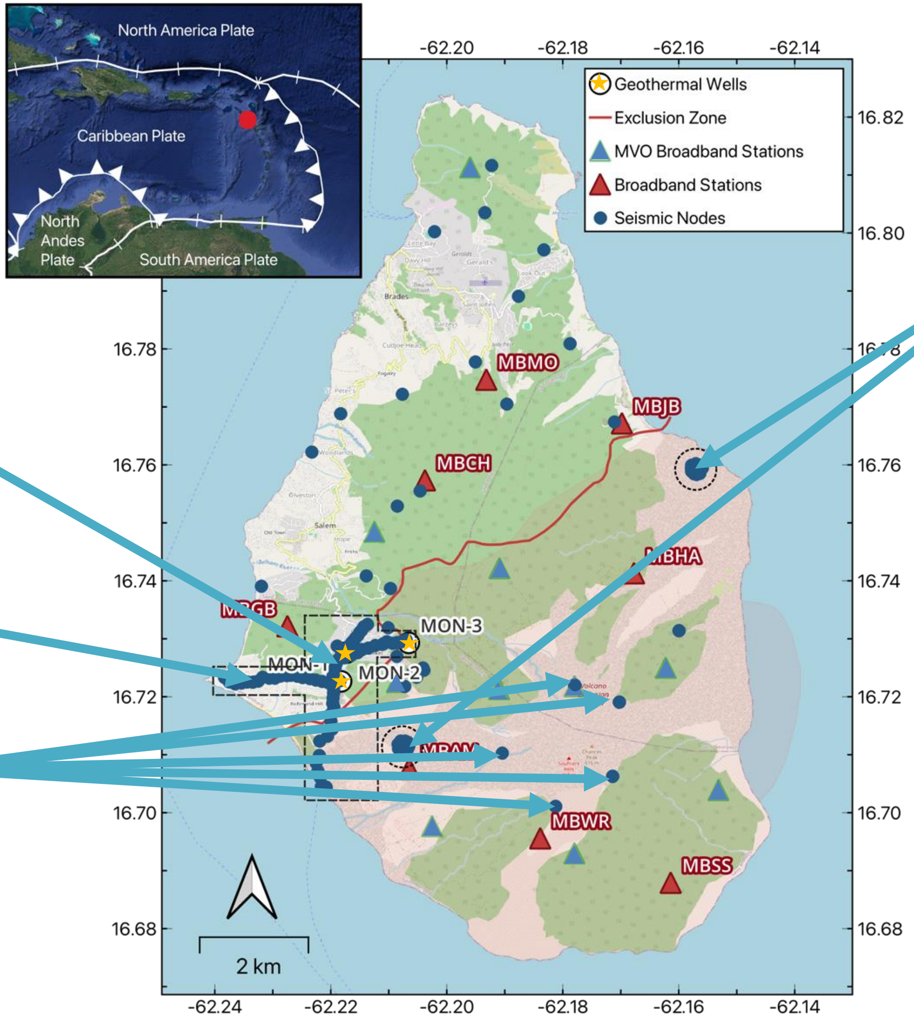
The Seismic Network

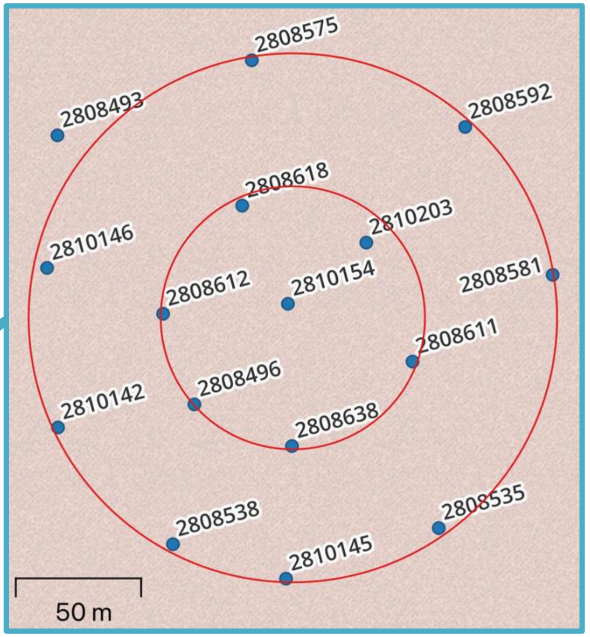
8 Certimus broadband seismometer (3-comp)



120 Sercel nodes (1-comp)

The Seismic Network





- Testing different arrays
- Pushing down detection threshold
- Distal seismicity

Enhanced seismic network

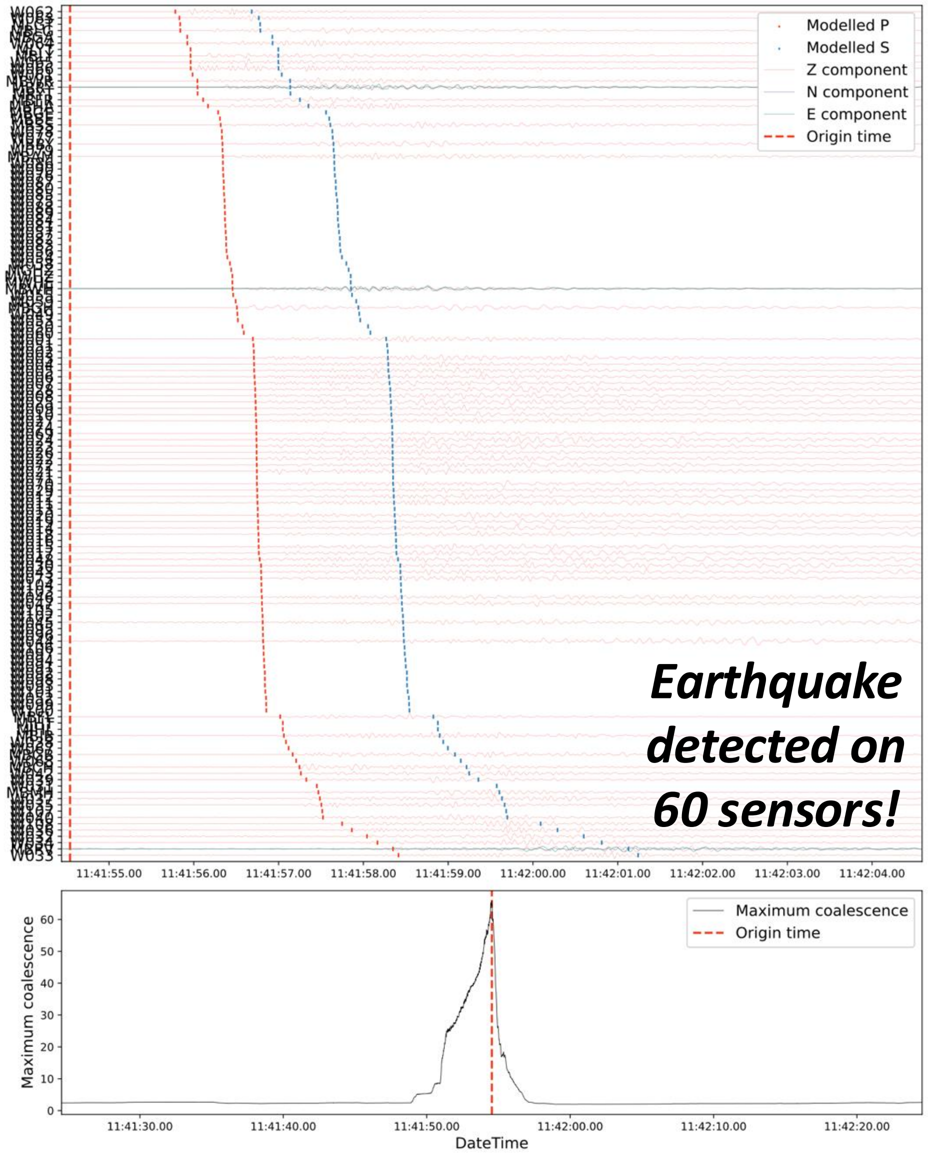
8 broadband seismic stations (£20k)

(Güralp, Certimus)

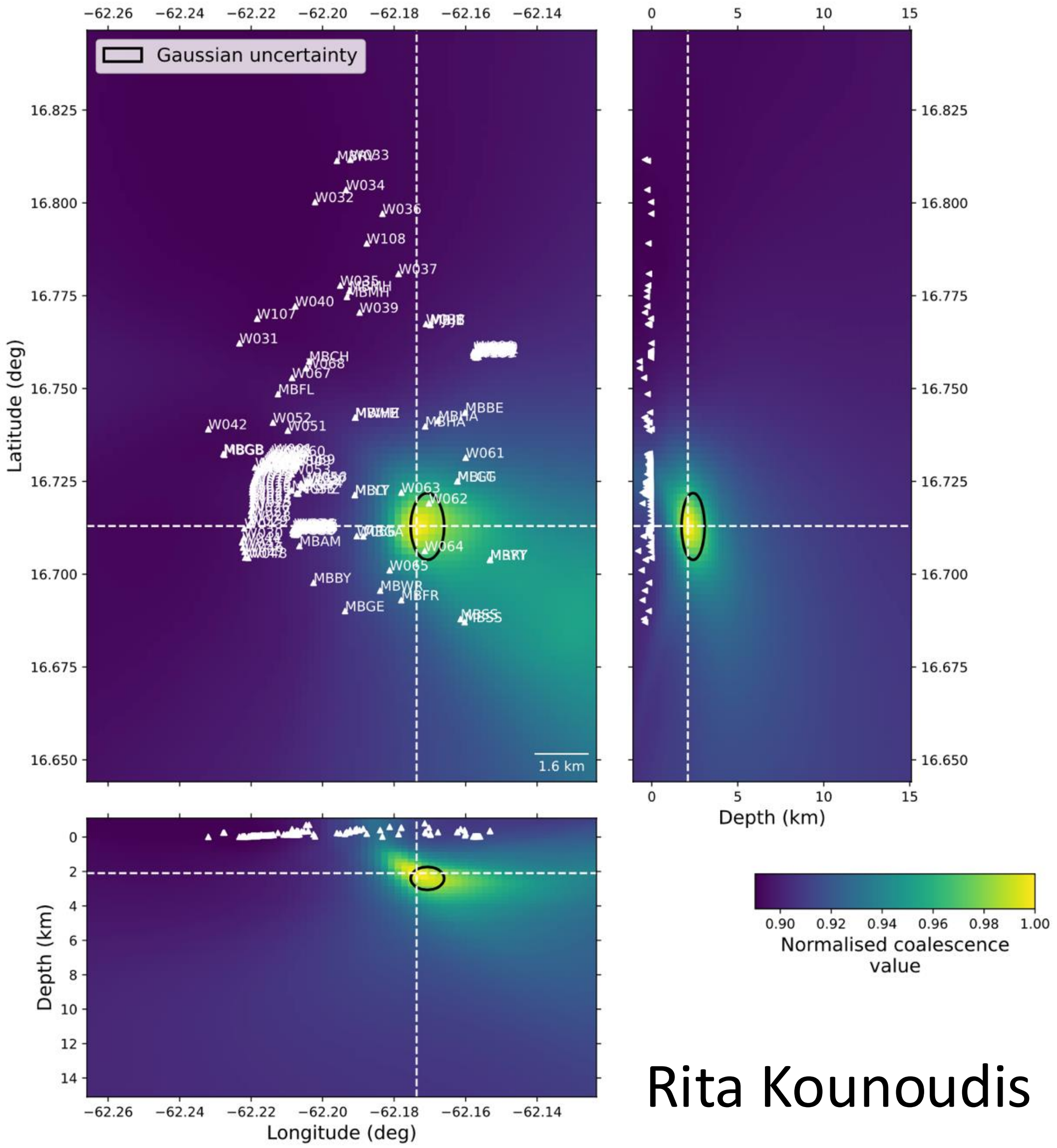
120 autonomous seismic nodes (£0.3k)

(Sercel, WiNG, DFUs)

Locating earthquakes – QuakeMigrate; Machine Learning

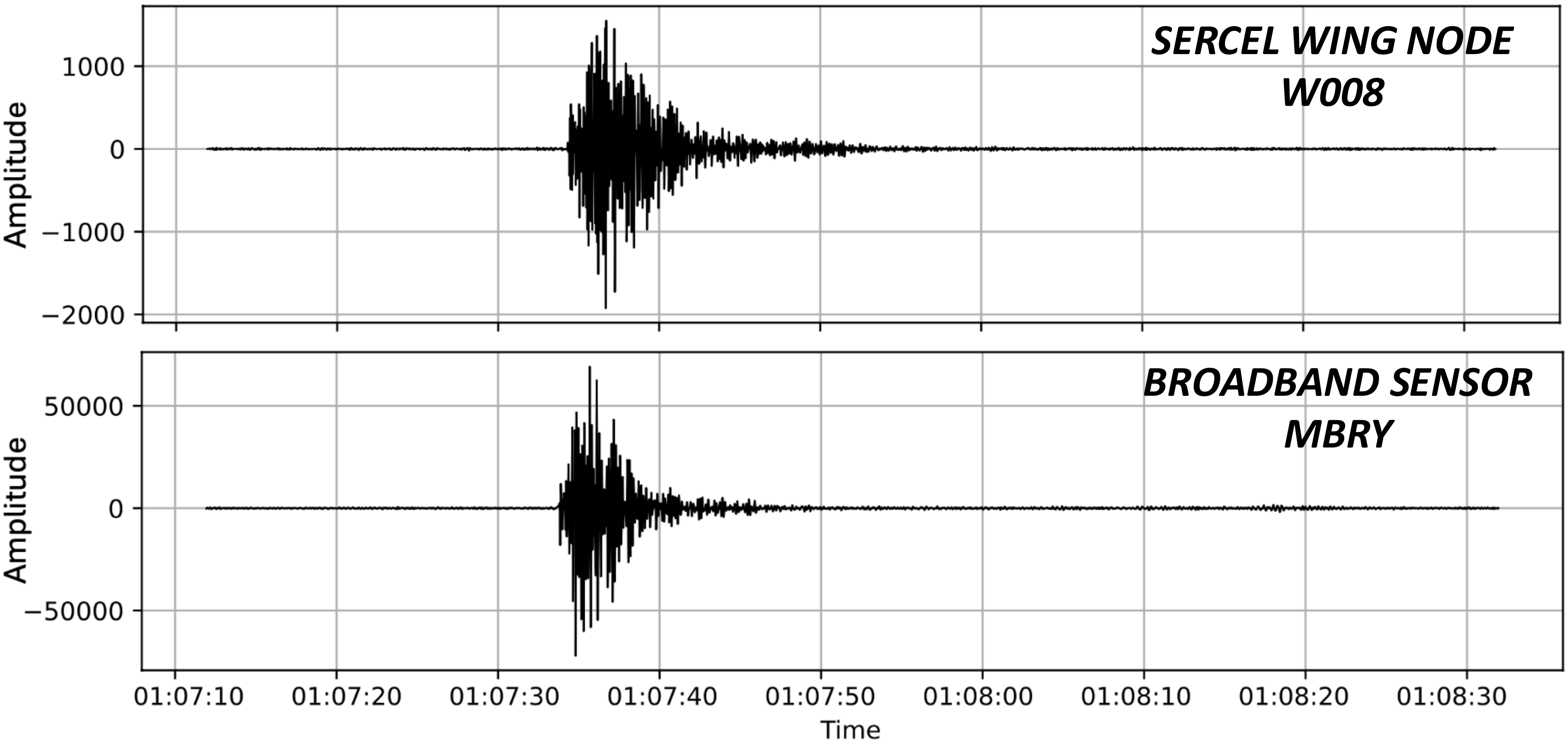


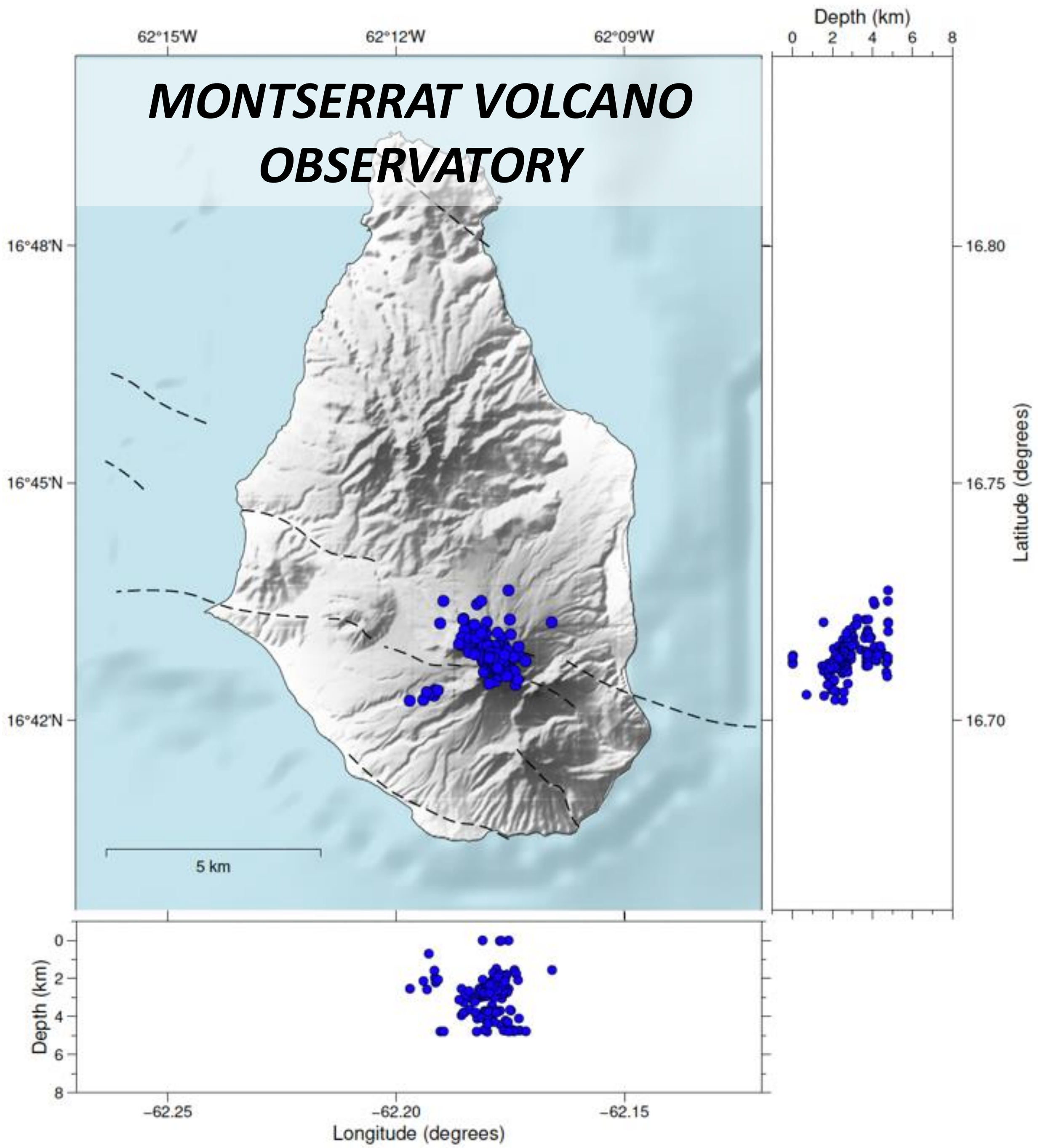
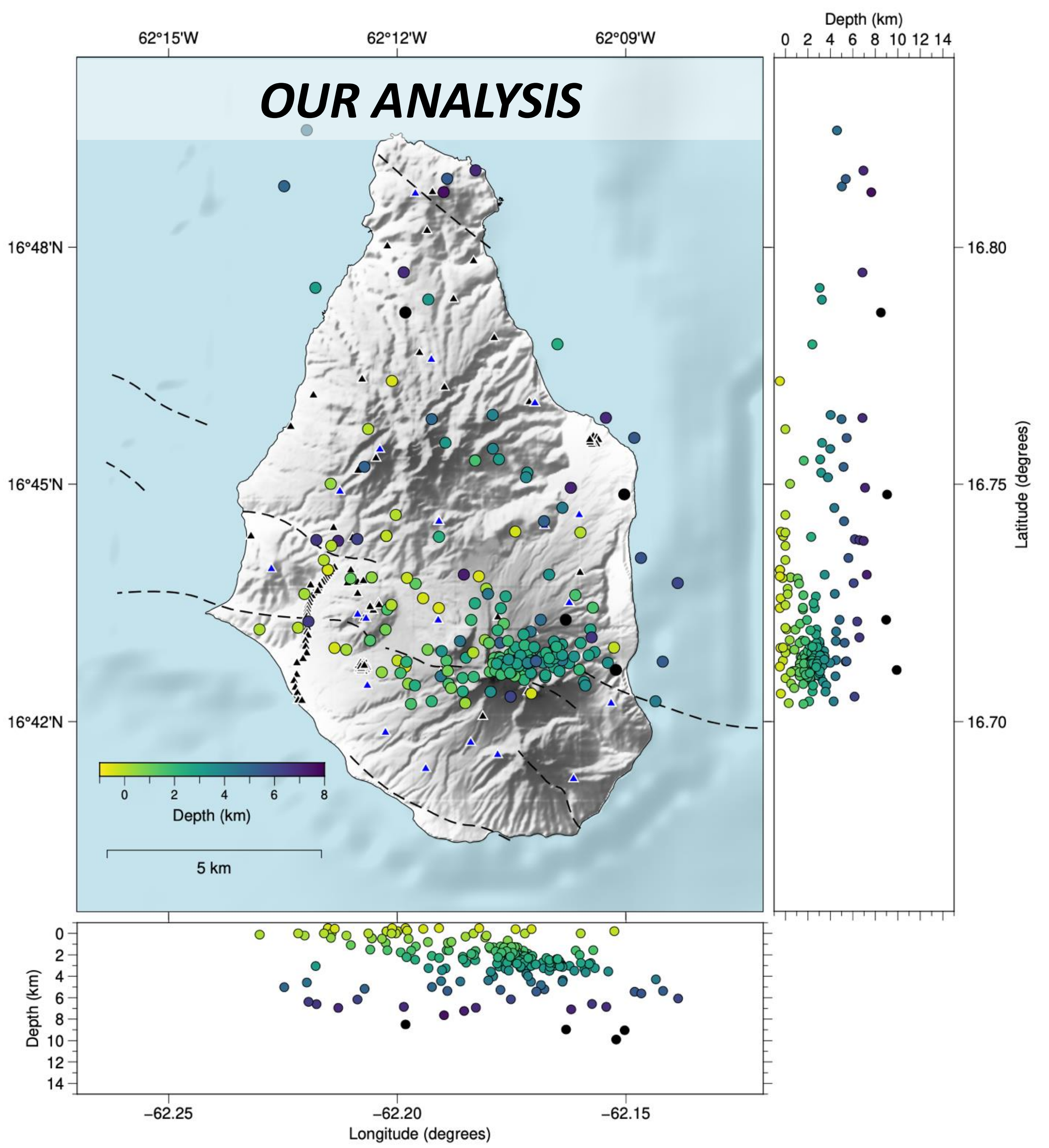
Earthquake detected on 60 sensors!



Rita Kounoudis

Detected earthquakes are clearly visible (high signal-to-noise) in both nodal and broadband sensors




MONTSERRAT VOLCANO OBSERVATORY
Depth (km)
Latitude (degrees)
Longitude (degrees)
5 km
62°15'W
62°12'W
62°09'W
16°48'N
16°45'N
16°42'N
16.80
16.75
16.70
-62.25
-62.20
-62.15

OUR ANALYSIS
Depth (km)
Latitude (degrees)
Longitude (degrees)
5 km
62°15'W
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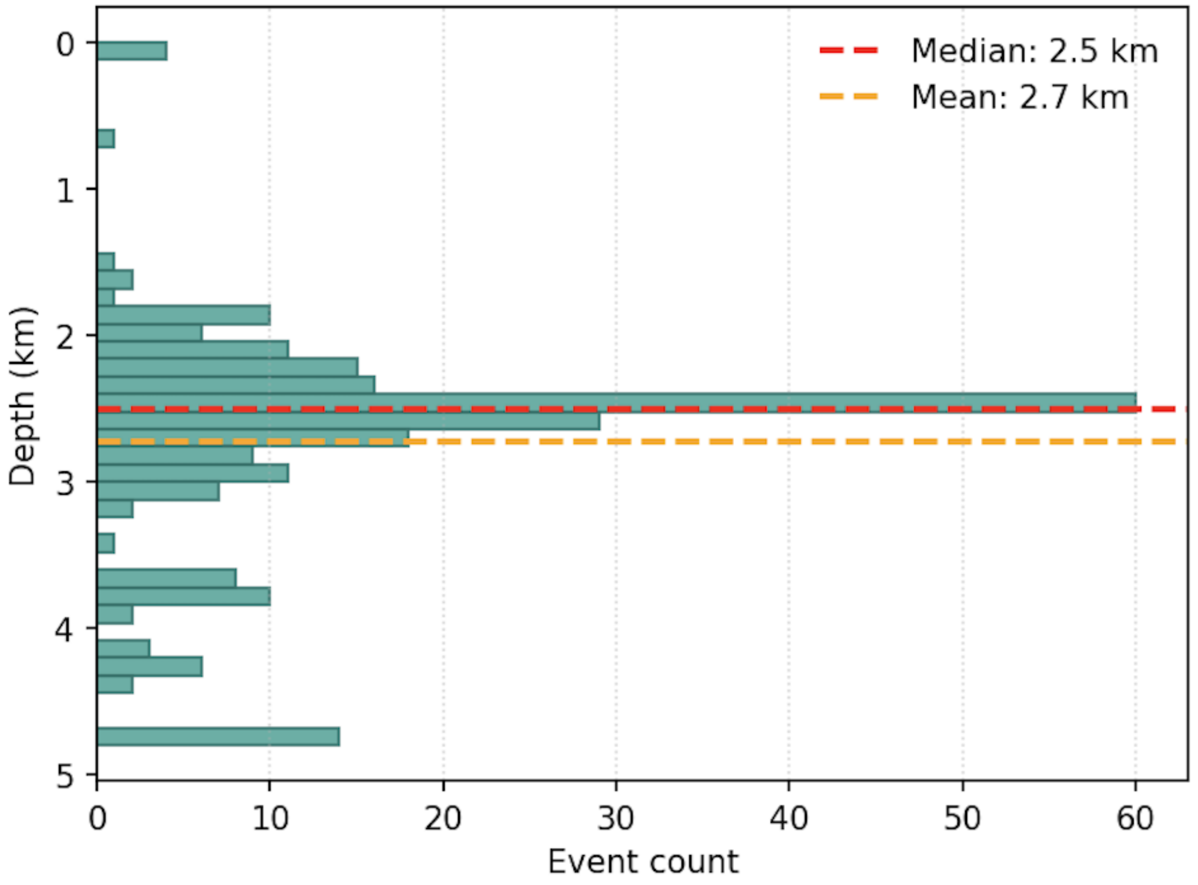
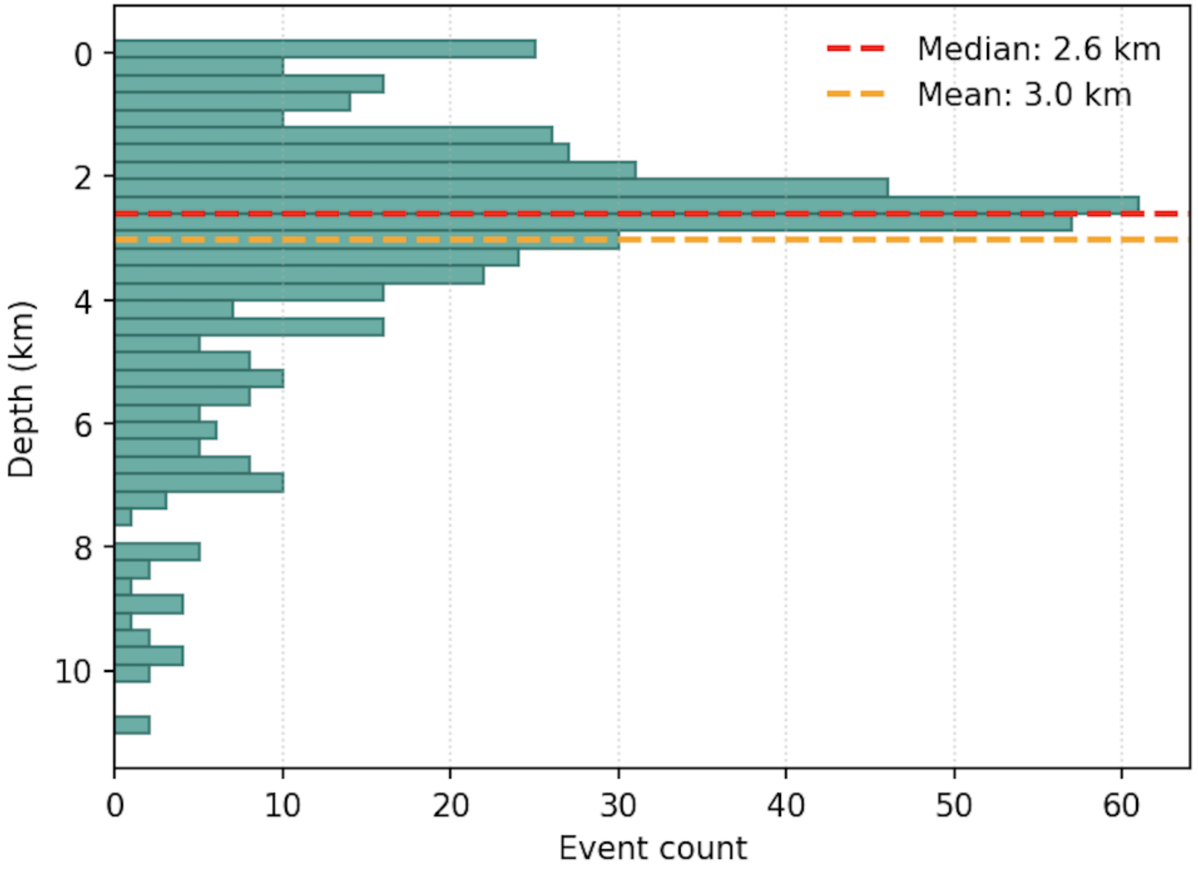
16.80
16.75
16.70
-62.25
-62.20
-62.15

There is improved sensitivity to deeper seismicity, likely due to broader network coverage and a lower detection threshold

MONTSERRAT VOLCANO OBSERVATORY

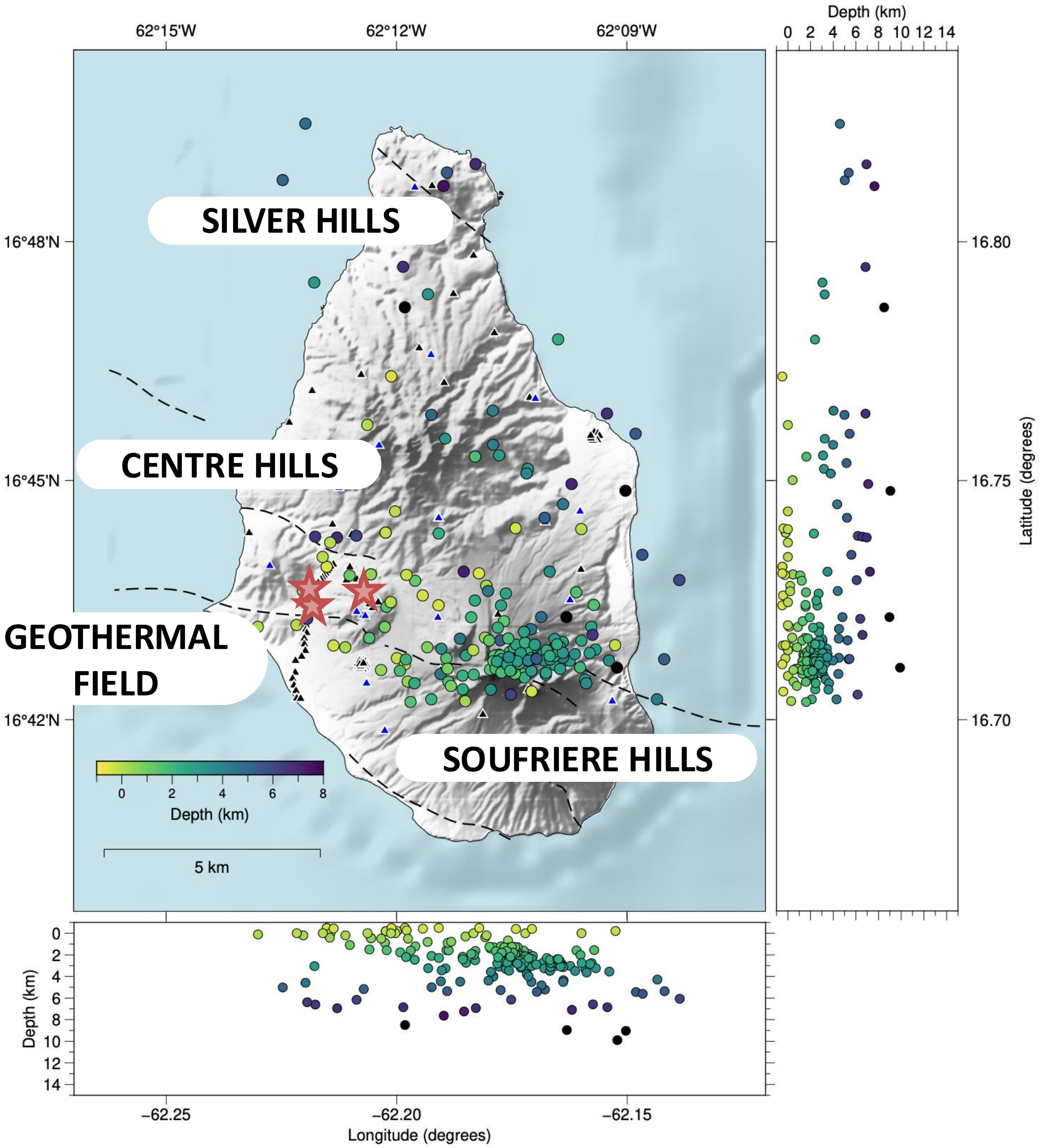


OUR ANALYSIS



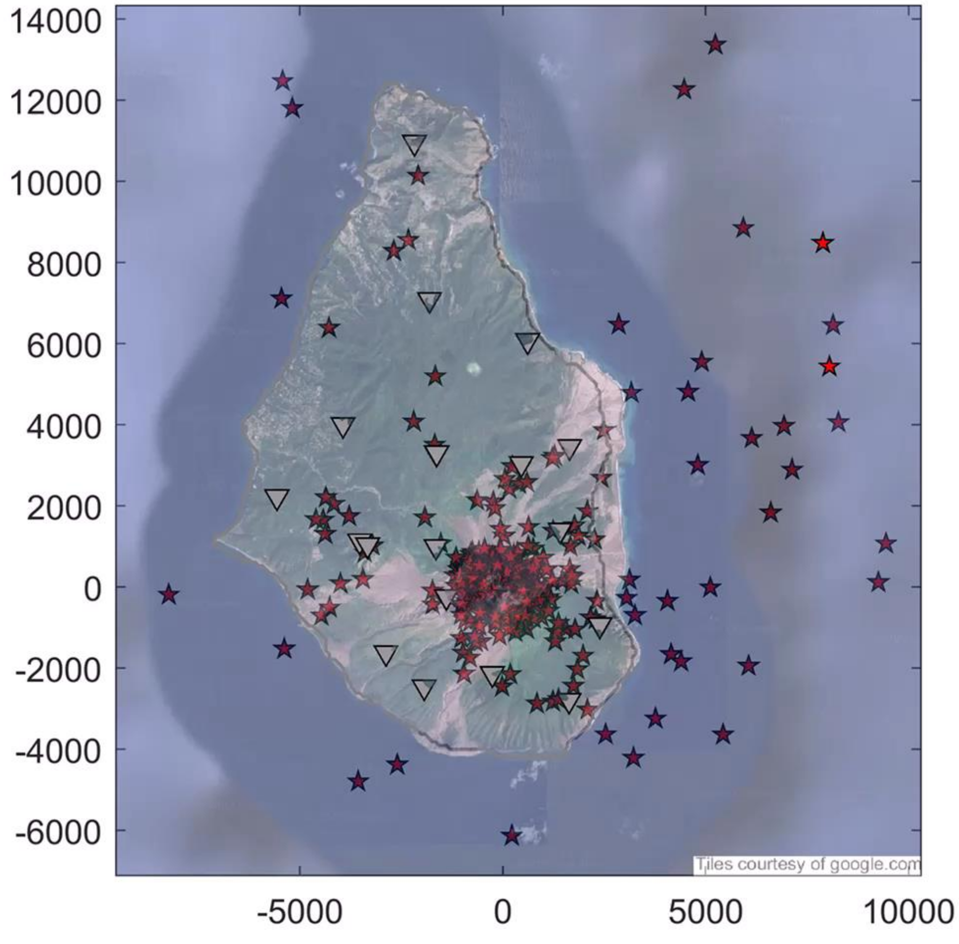
Preliminary earthquake detections point to seismicity in the currently active Soufriere Hills volcano as well as surrounding regions

Some deep (~6-7km) volcano-tectonic earthquakes are present directly below the geothermal area ★



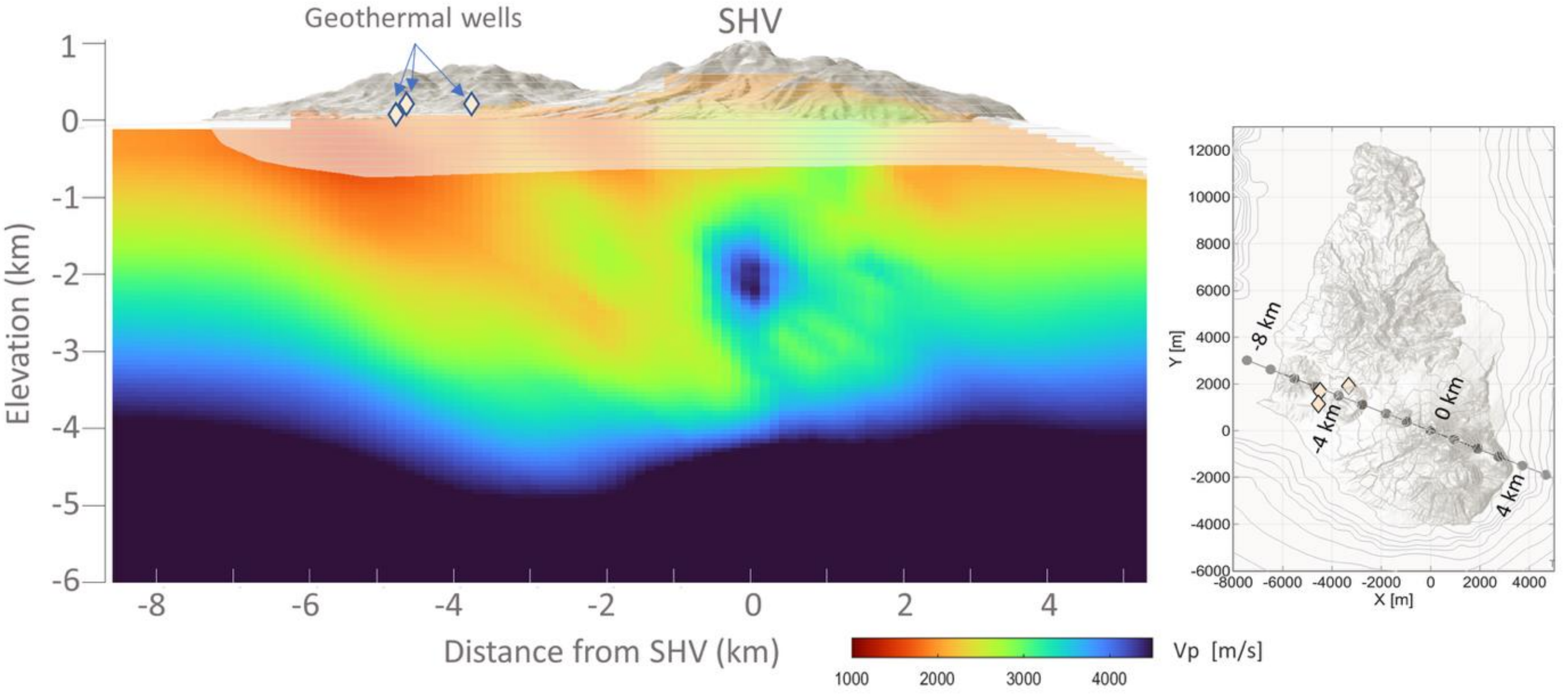
Tomographic Investigation
from the joint inversion of P- and S-wave arrival times

- 1039 located events between 1996 - 2007
- Volcano-Tectonic MVO classification
- 7,112 P-wave arrival times
- 1,376 S-wave arrival times
- 18 MVO stations (triangles)
- Manually re-picked by Baird et al., 2015

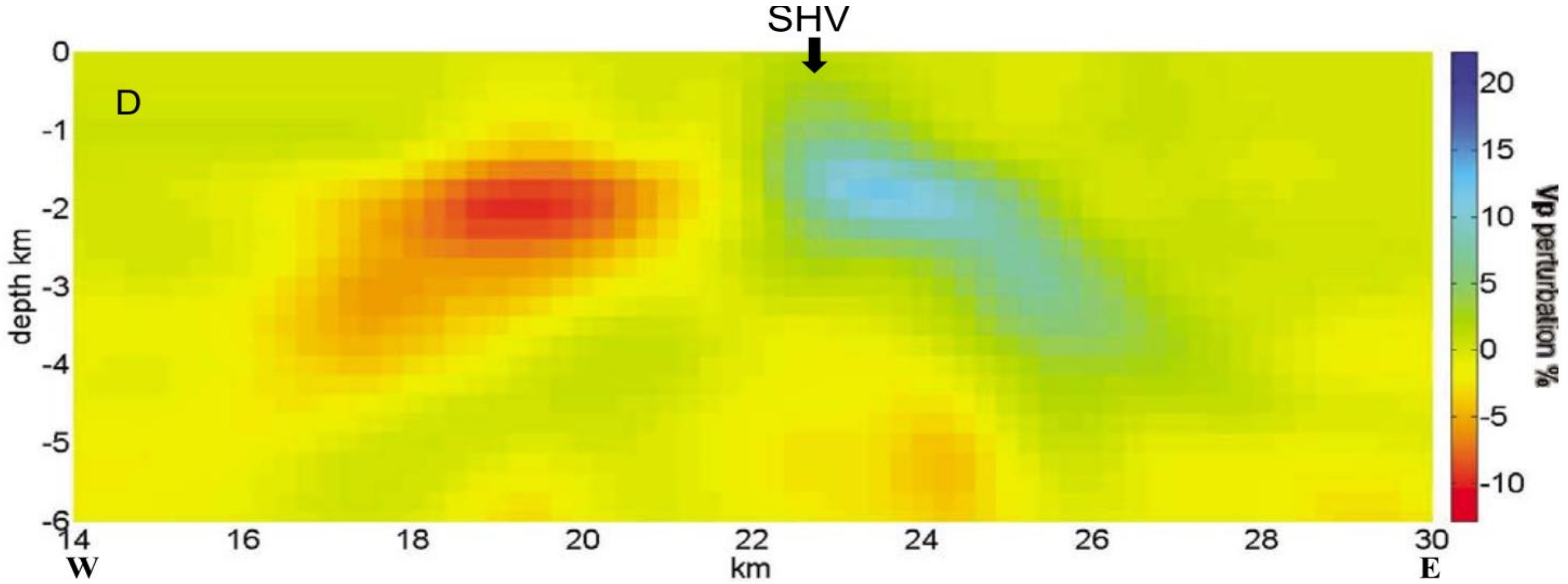


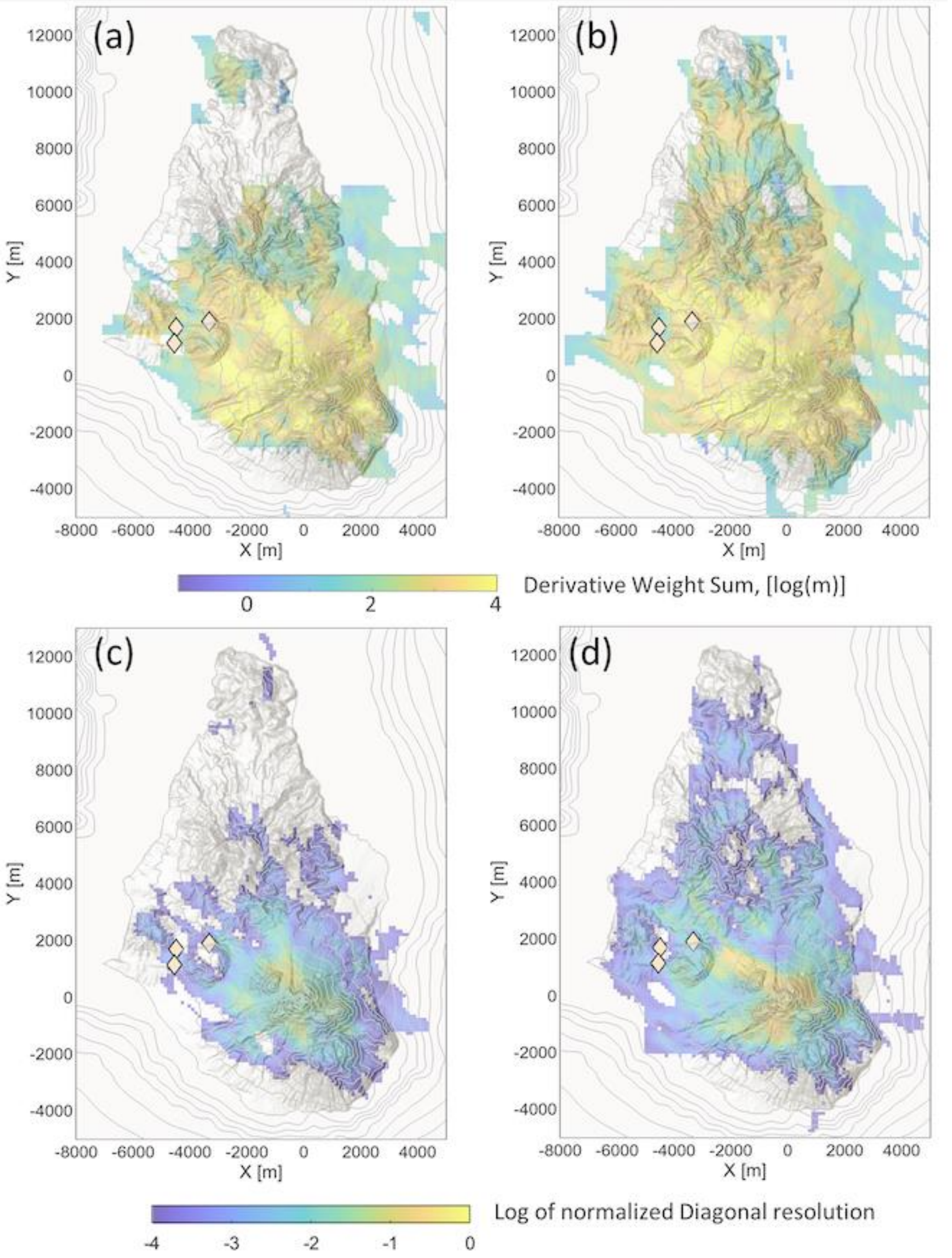
Petros Bogiatzis et al, in prep

This study



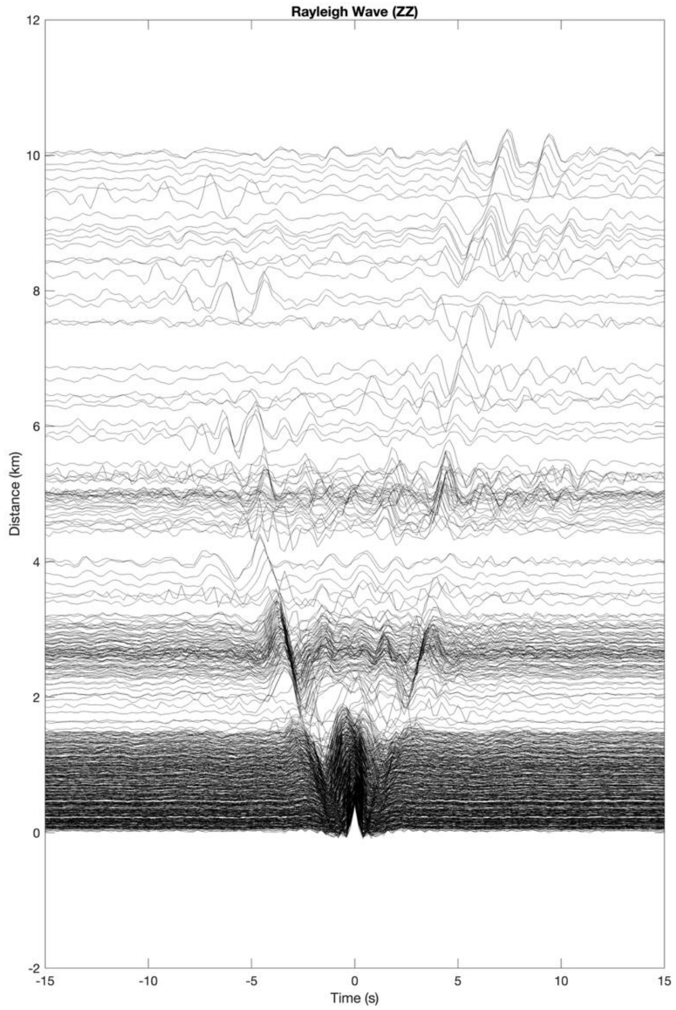
Shalev et al., 2010
(SEA-CALIPSO)





The new network and earthquake catalogue have led to enhanced sensitivity and resolution in seismic tomography (Bogiatzis et al.)

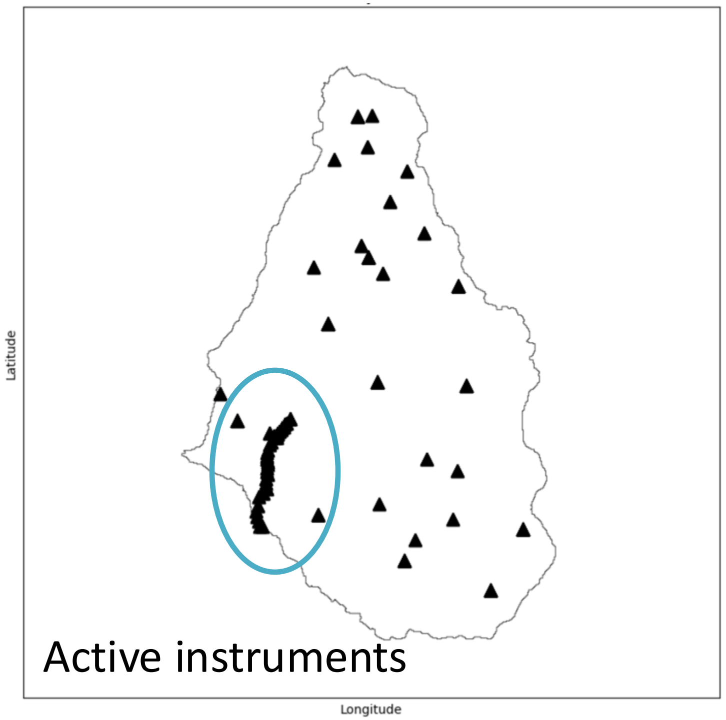
Ambient noise tomography

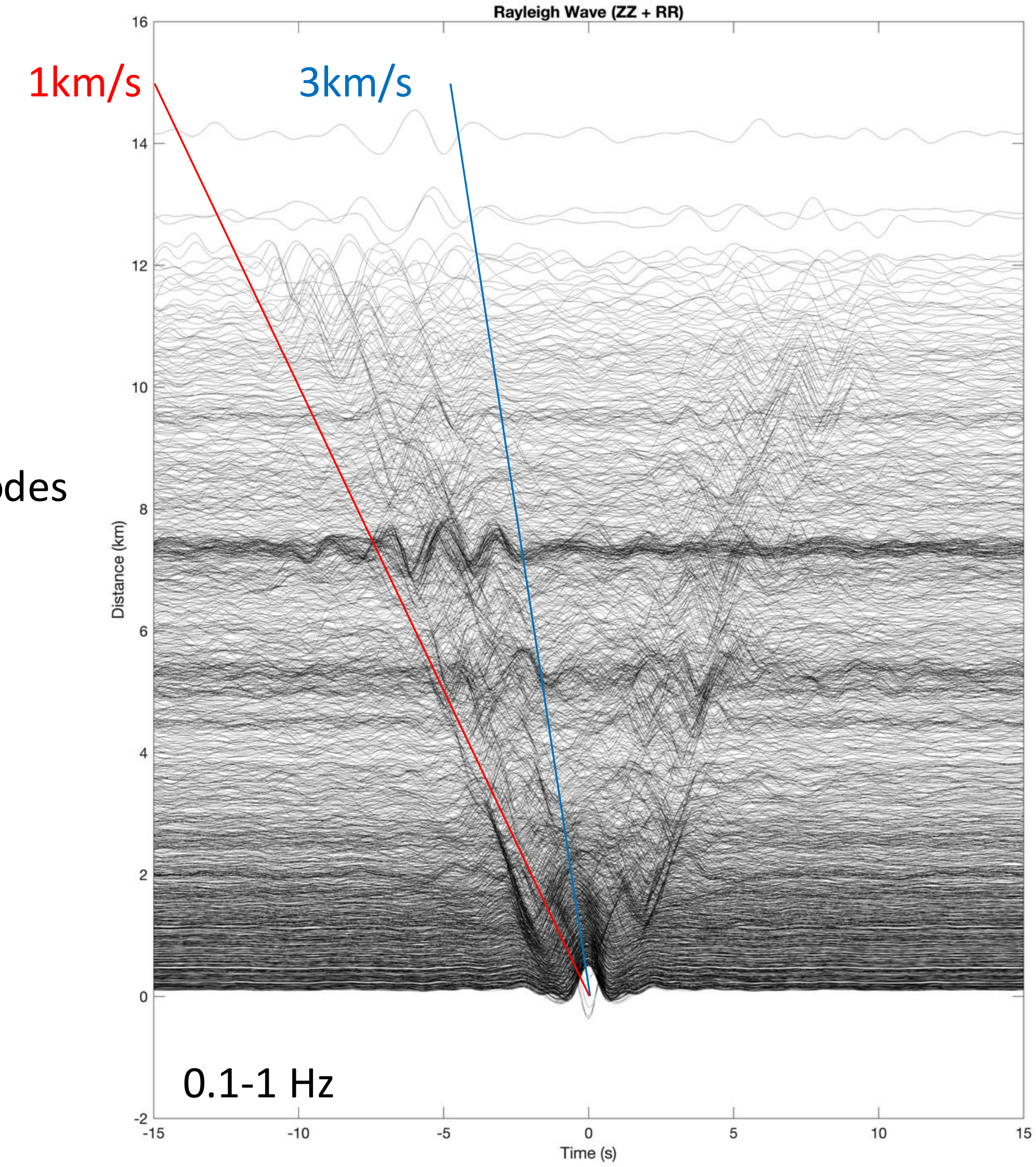


Jamie Chow and Tobermoray Mackay-Chamion

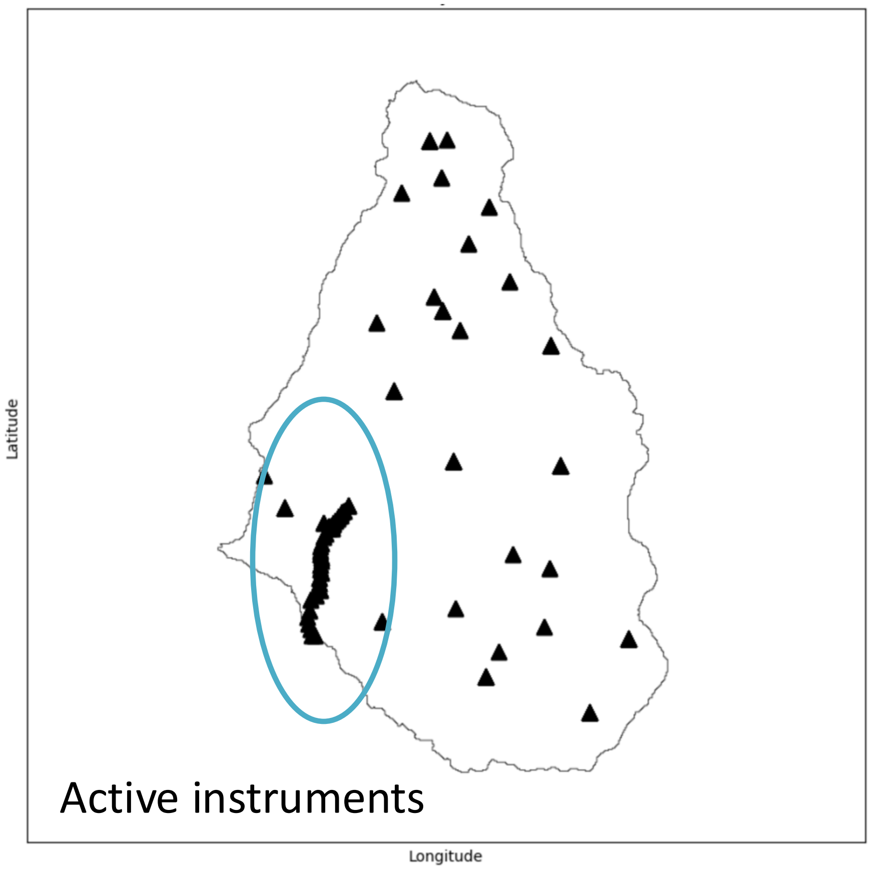
ANT - Cross-Correlation and Stacking (1)

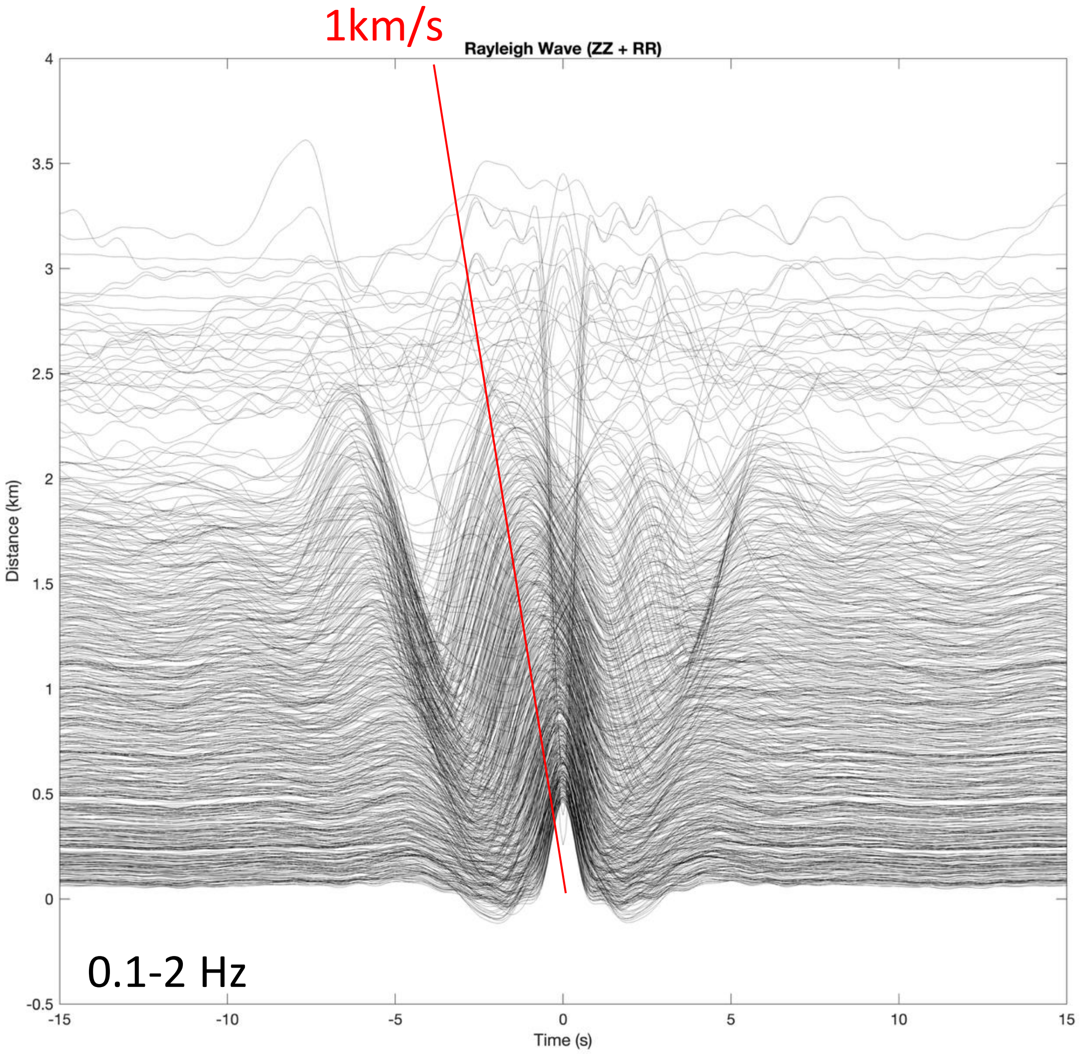
- ~70 days, day traces
- June 2024 – August 2024
- 8 MVO broadbands + 8 Certimus broadbands + ~40 Sercel nodes





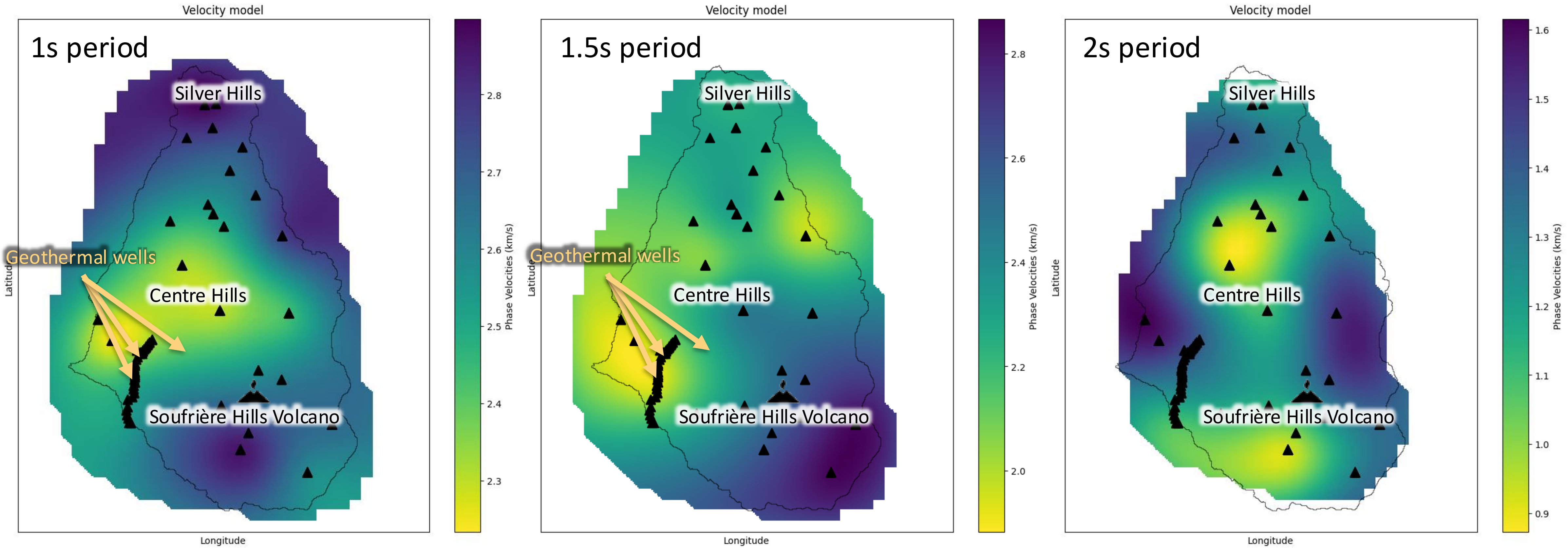
ANT - Cross-Correlation and Stacking (2)





- Positive amplitude at zero offset lag time

ANT - Phase Velocities



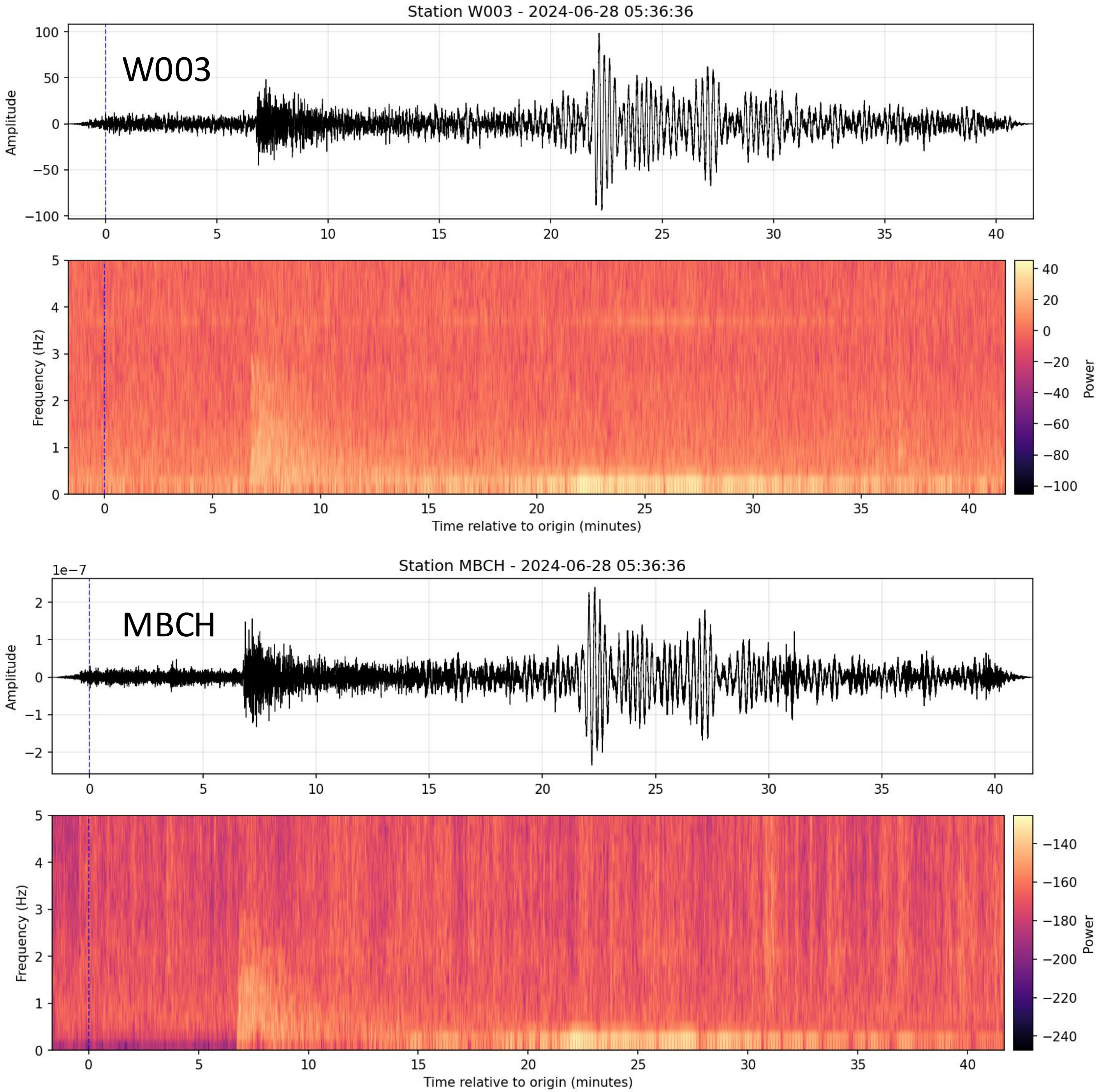
- Low Vs under geothermal field
- High Vs under under SHV

Teleseismic event

Peru Event –
Magnitude: 7.2
Depth: 24km
Time: 2024-06-28 05:36:36 (UTC)
Location: 15.828S 74.454W

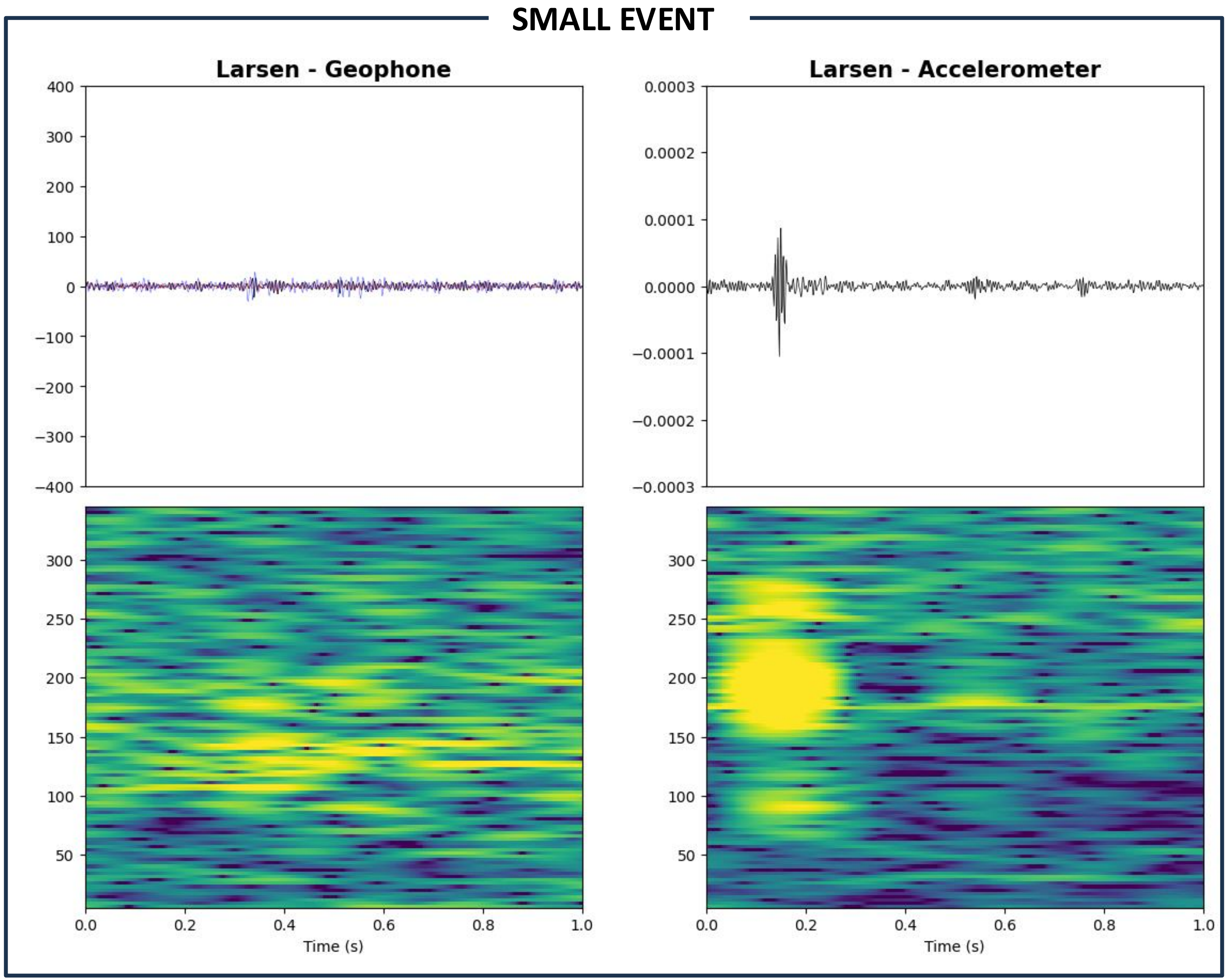
W003 – seismic node

MBCH – BB certimus station



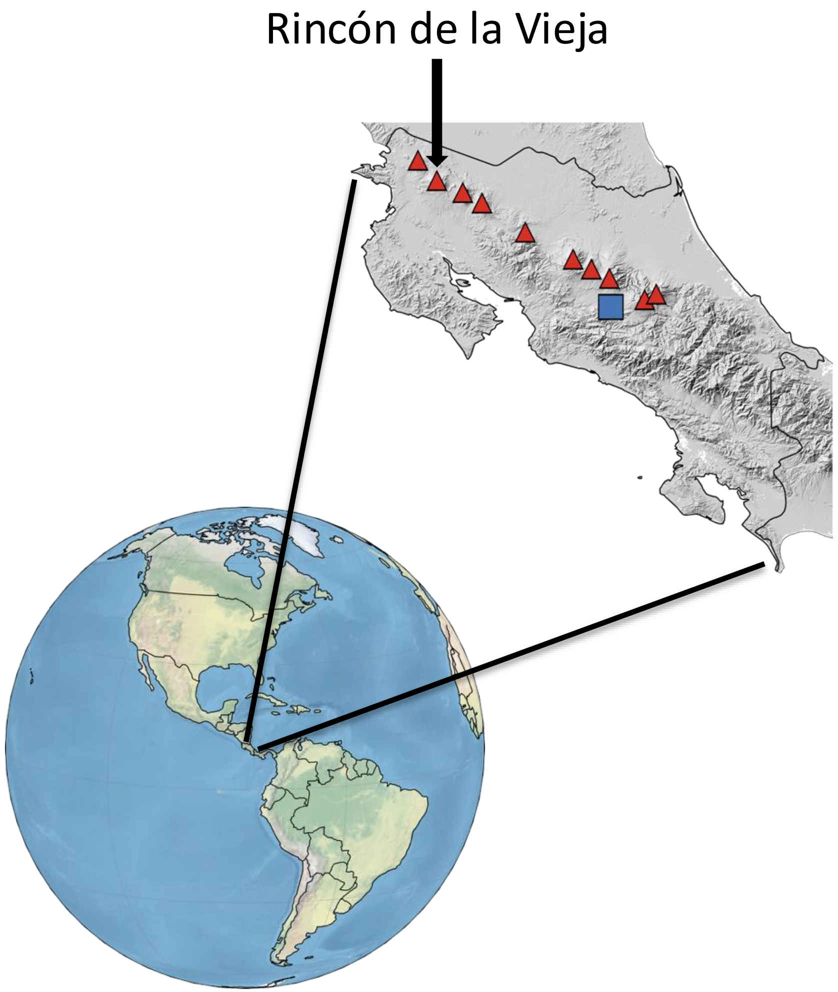
Larsen-C Ice Shelf – Icequake

Very high frequency response

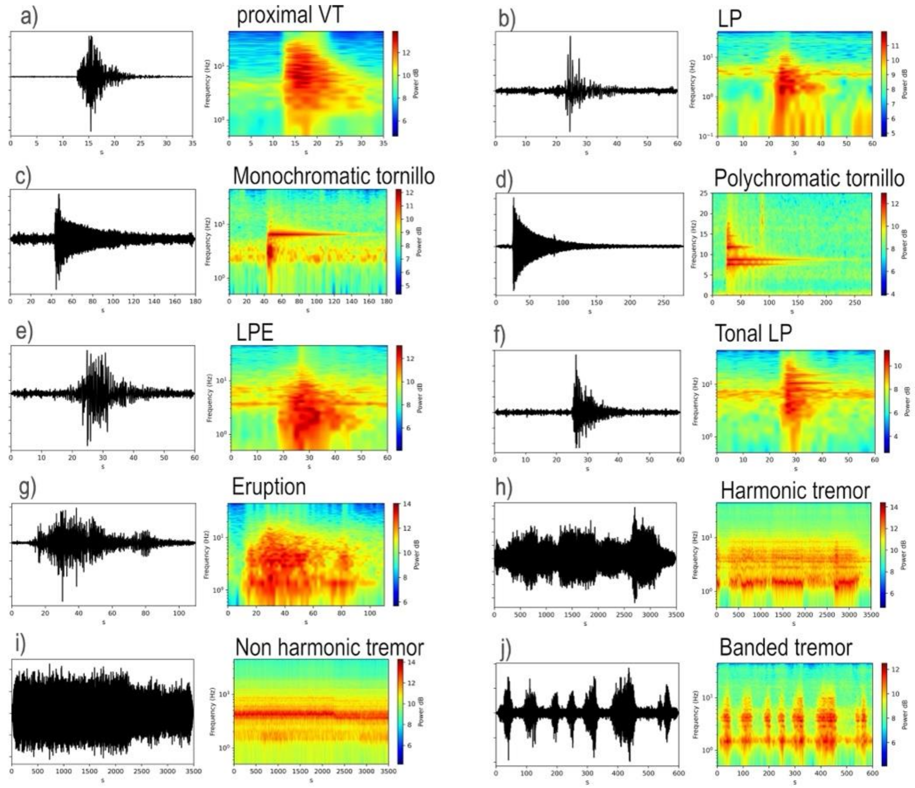


Rincón de la Vieja – one of Costa Rica's most active volcanoes with high geothermal potential

Sacha Lapins – Royal Society DH Fellow



Frequent eruptions

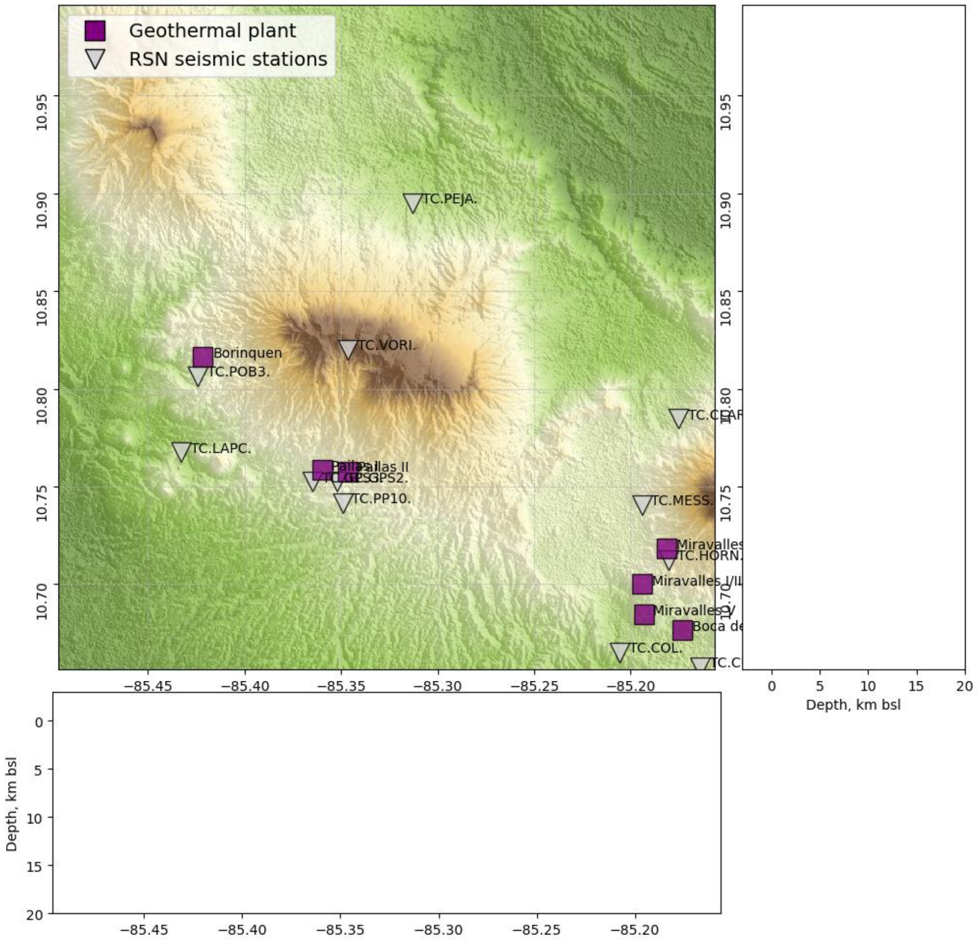


Complex volcanic signals

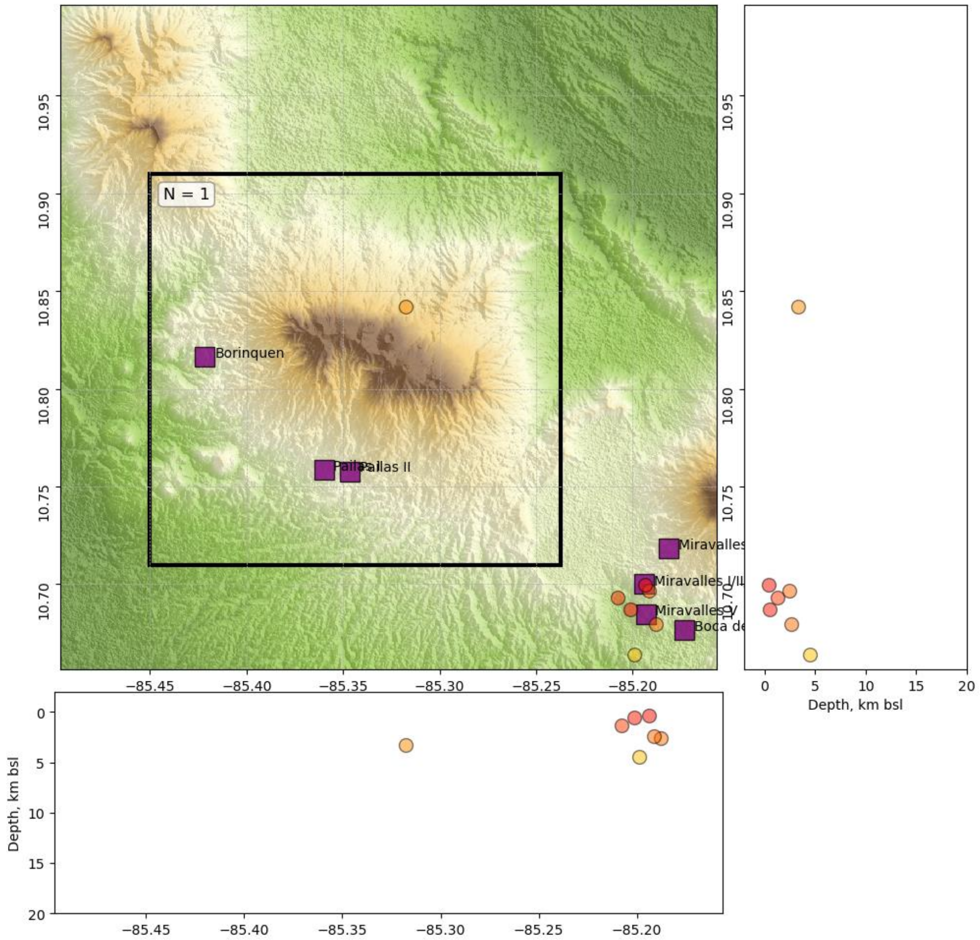
Rincón de la Vieja – node deployment (Jan-Mar ‘24)

Study Aim: Assess potential of nodes to densify network around RDLV to better understand subsurface processes

Existing RSN stations



Existing RSN detections



Rincón de la Vieja – node deployment (Jan-Mar '24)

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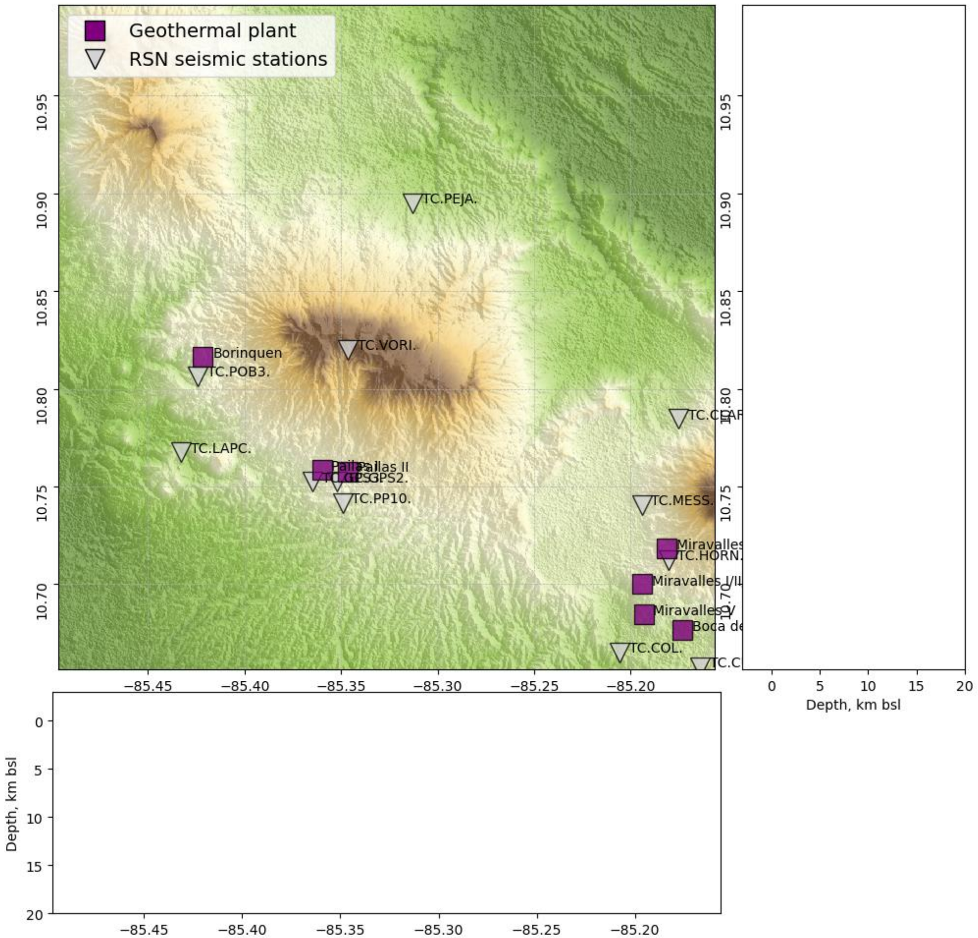
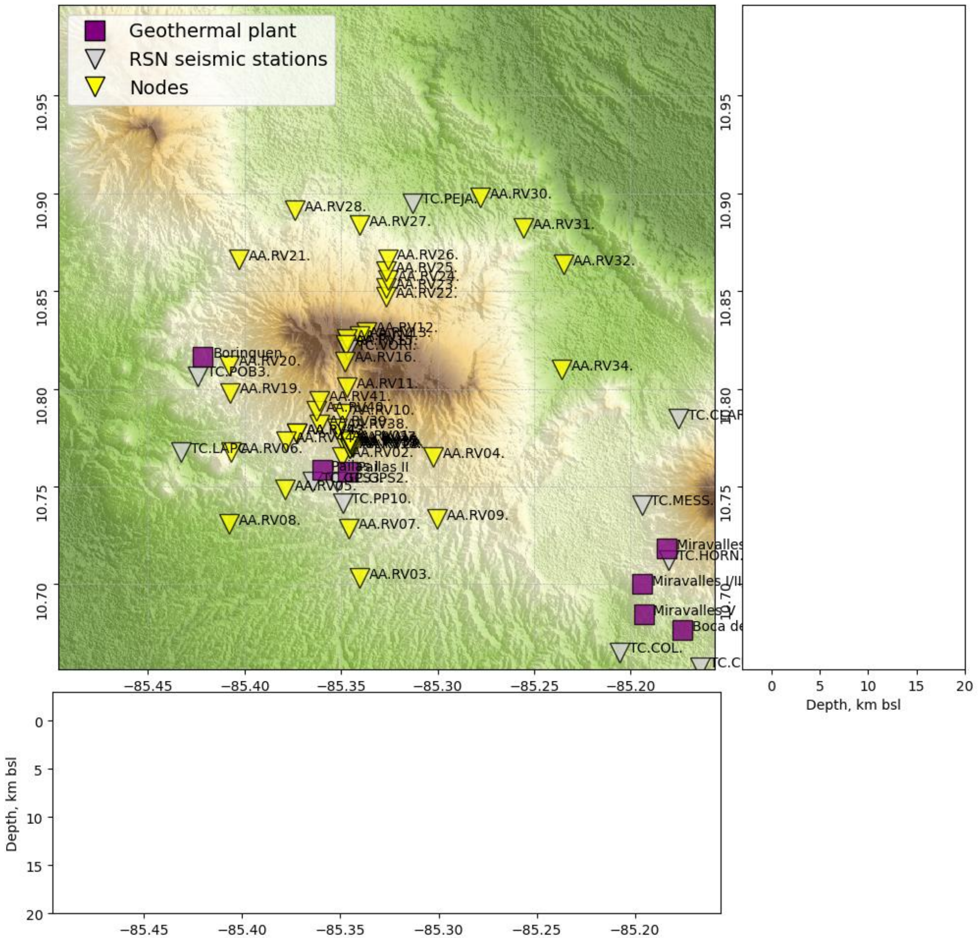
Existing RSN stations



With Nodes (44 sites)



Rincón de la Vieja – node deployment (Jan-Mar ‘24)

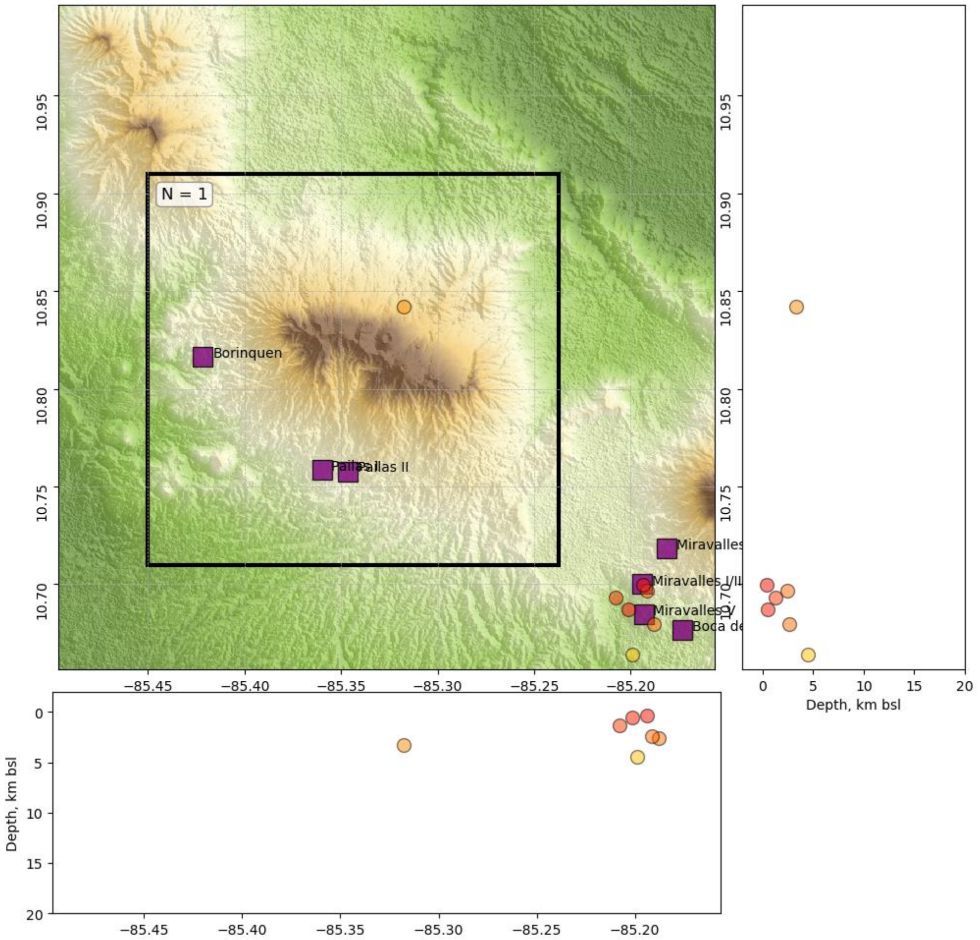
<u>Study Aim</u>: Assess potential of nodes to densify network around RDLV to better understand subsurface processes

34 x 1-component sites

10 x 3-component sites

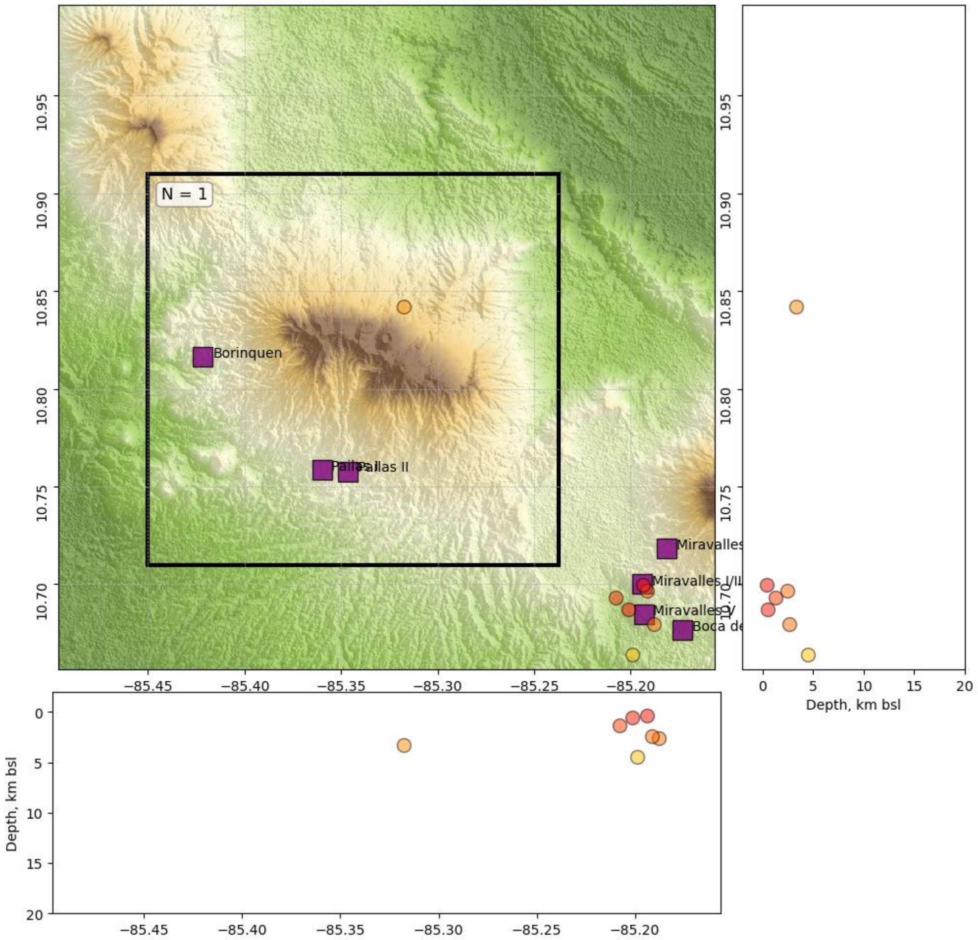
Rincón de la Vieja – node deployment (Jan-Mar '24)

Existing RSN detections

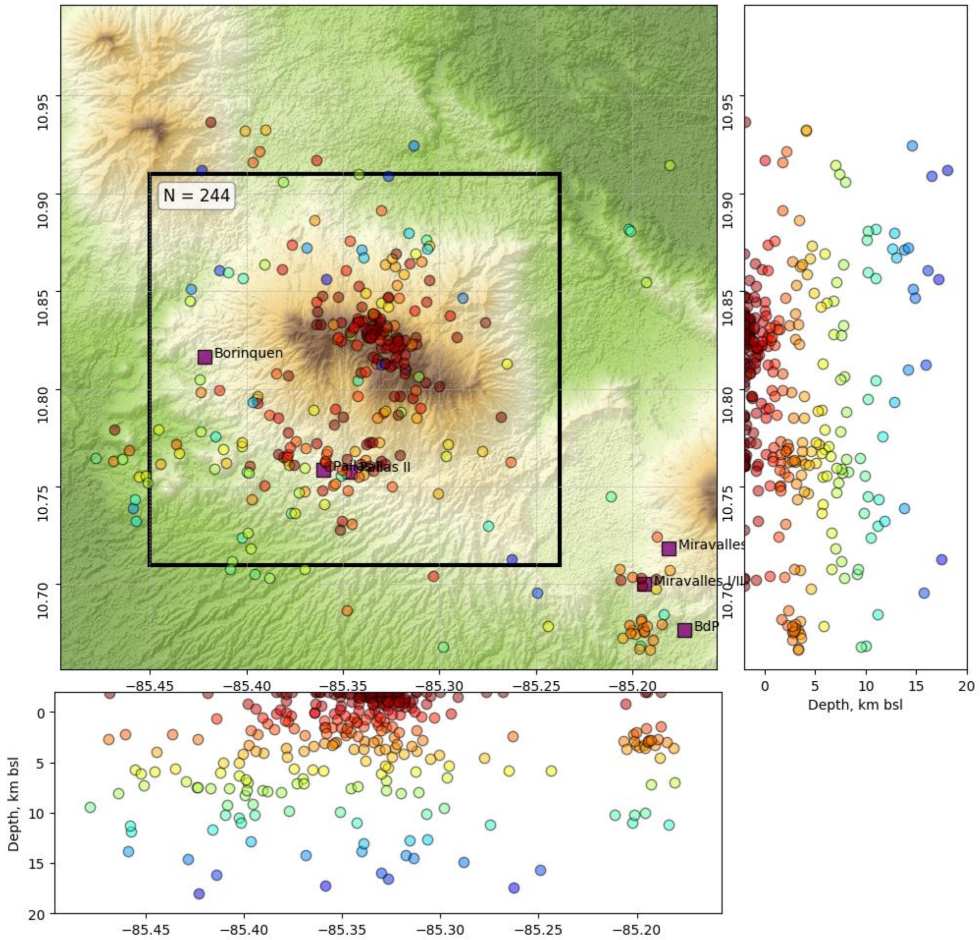


Rincón de la Vieja – node deployment (Jan-Mar '24)

Existing RSN detections

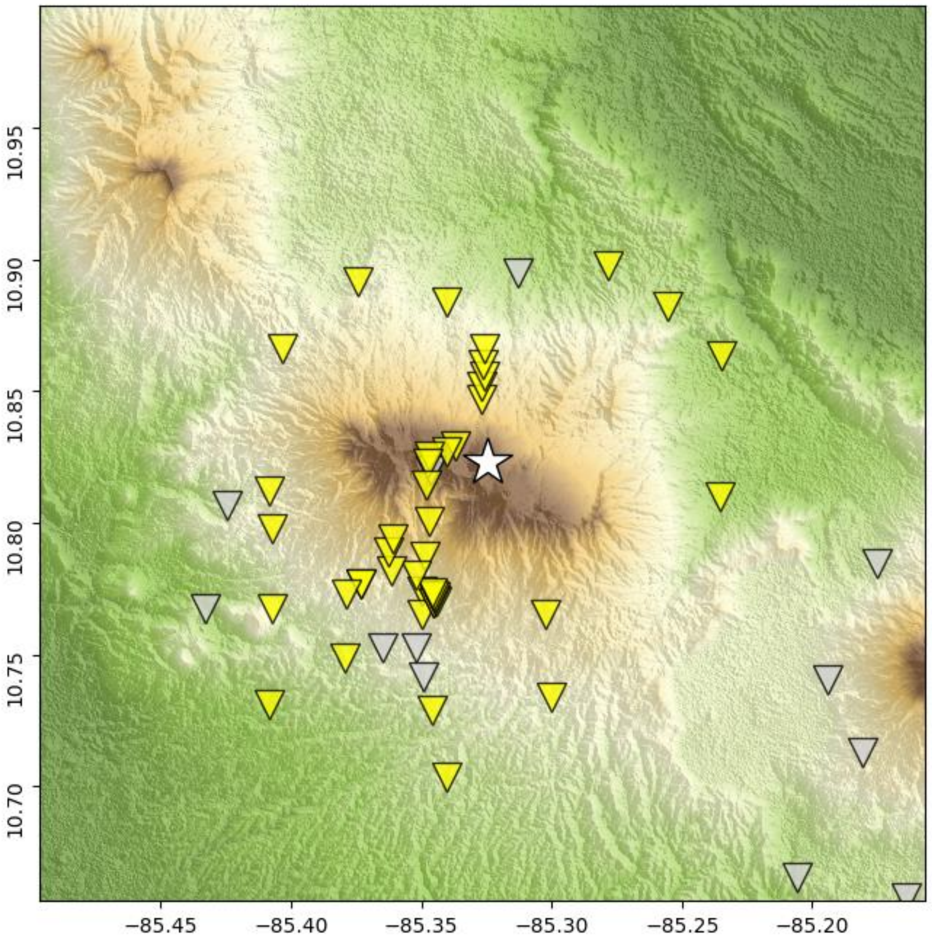


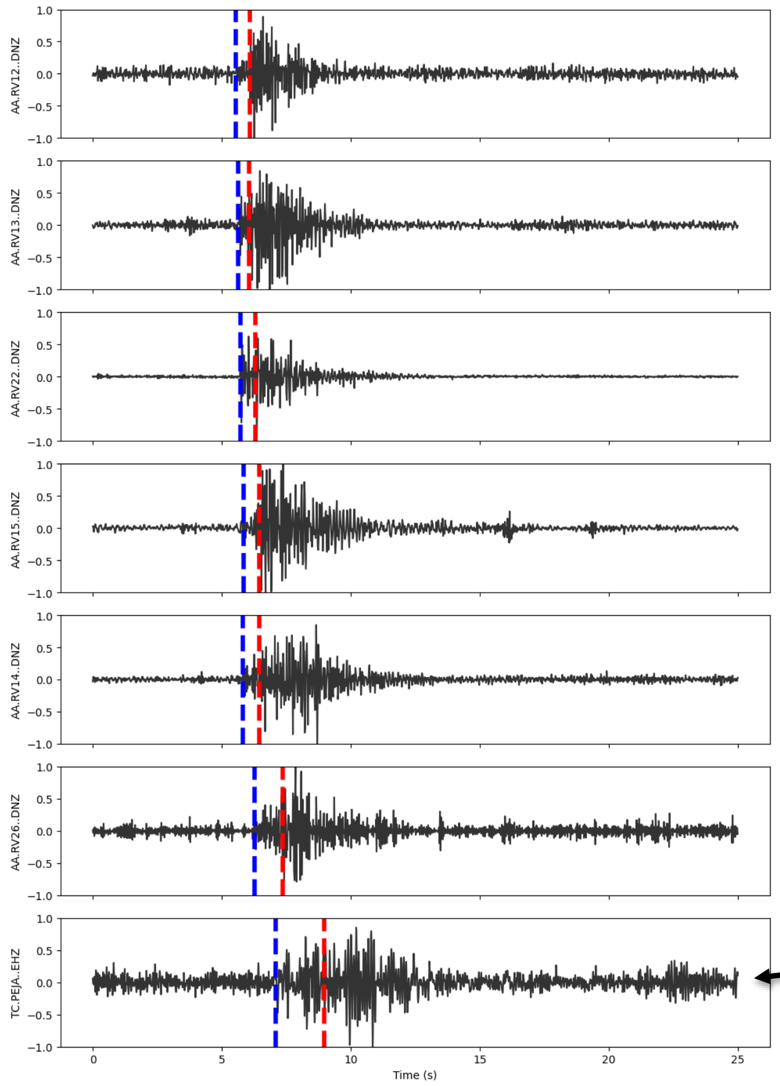
With Nodes
+ PhaseNet-volpick detections
(loc error < 3 km)



"Volpick" models – Zhong & Tan, 2024 (GRL)

Rincón de la Vieja – example event #1

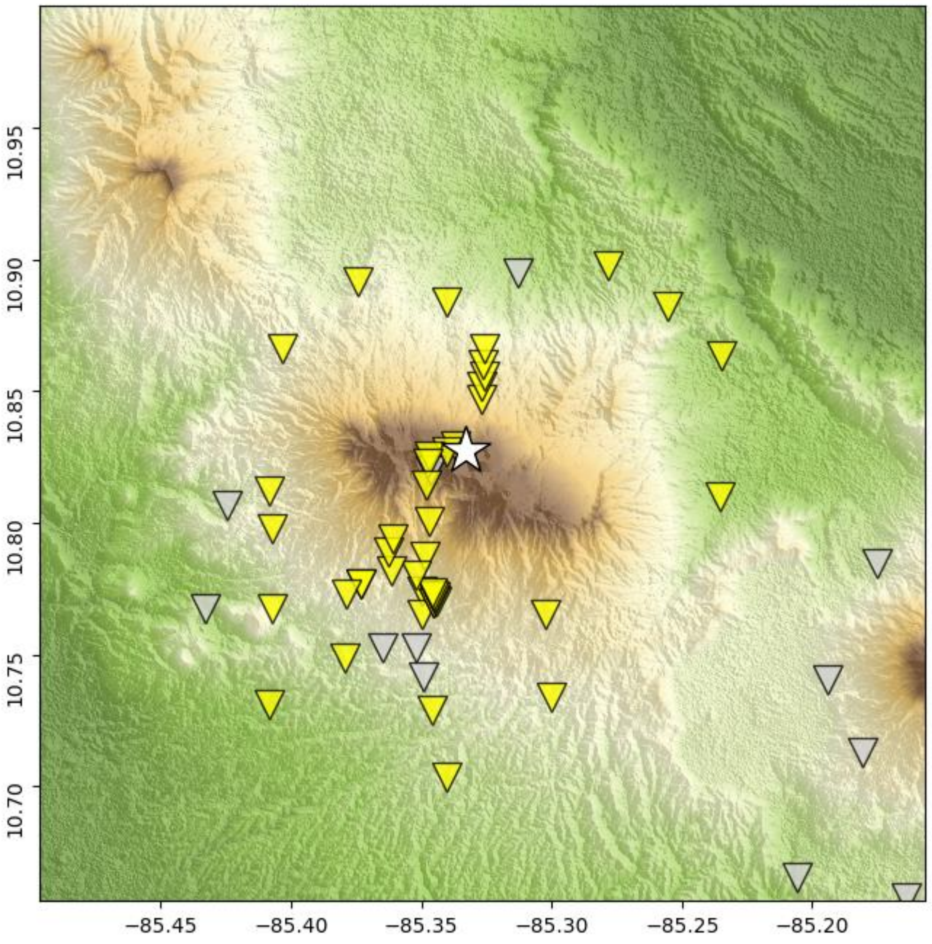


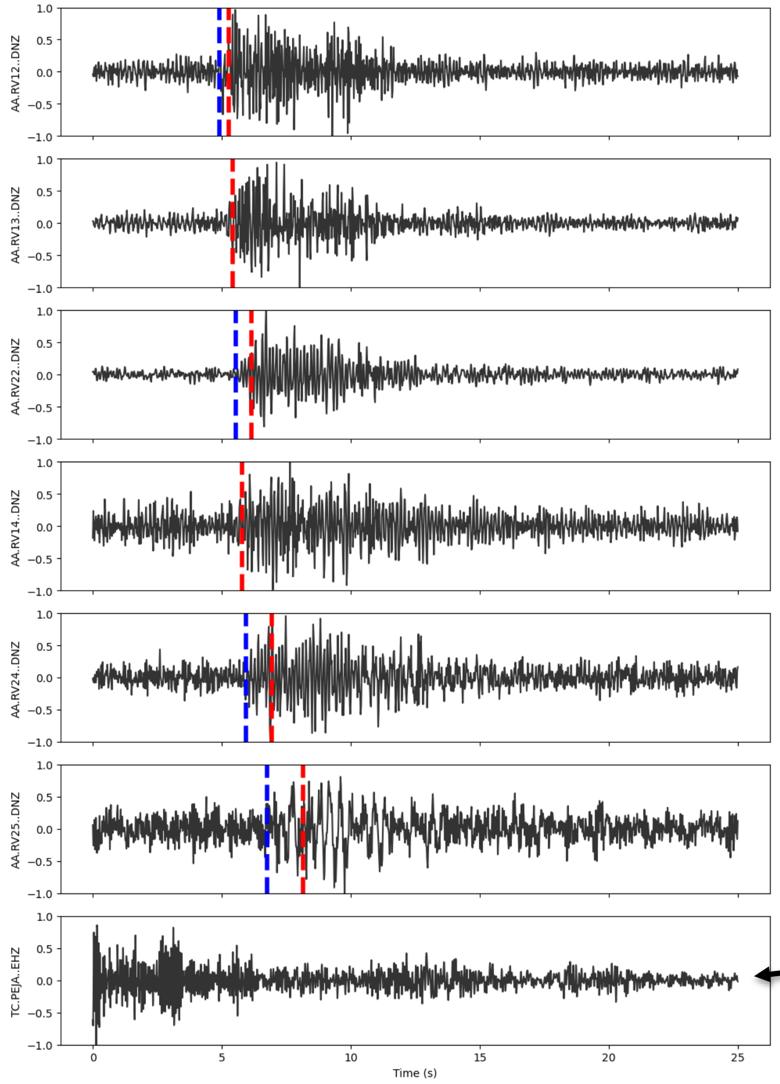


Summit/flank nodes
increasing distance (~ 1.5-4.5 km) from event

Observable on nearest (working) broadband station ~ 7 km away

Rincón de la Vieja – example event #2





Summit/flank nodes

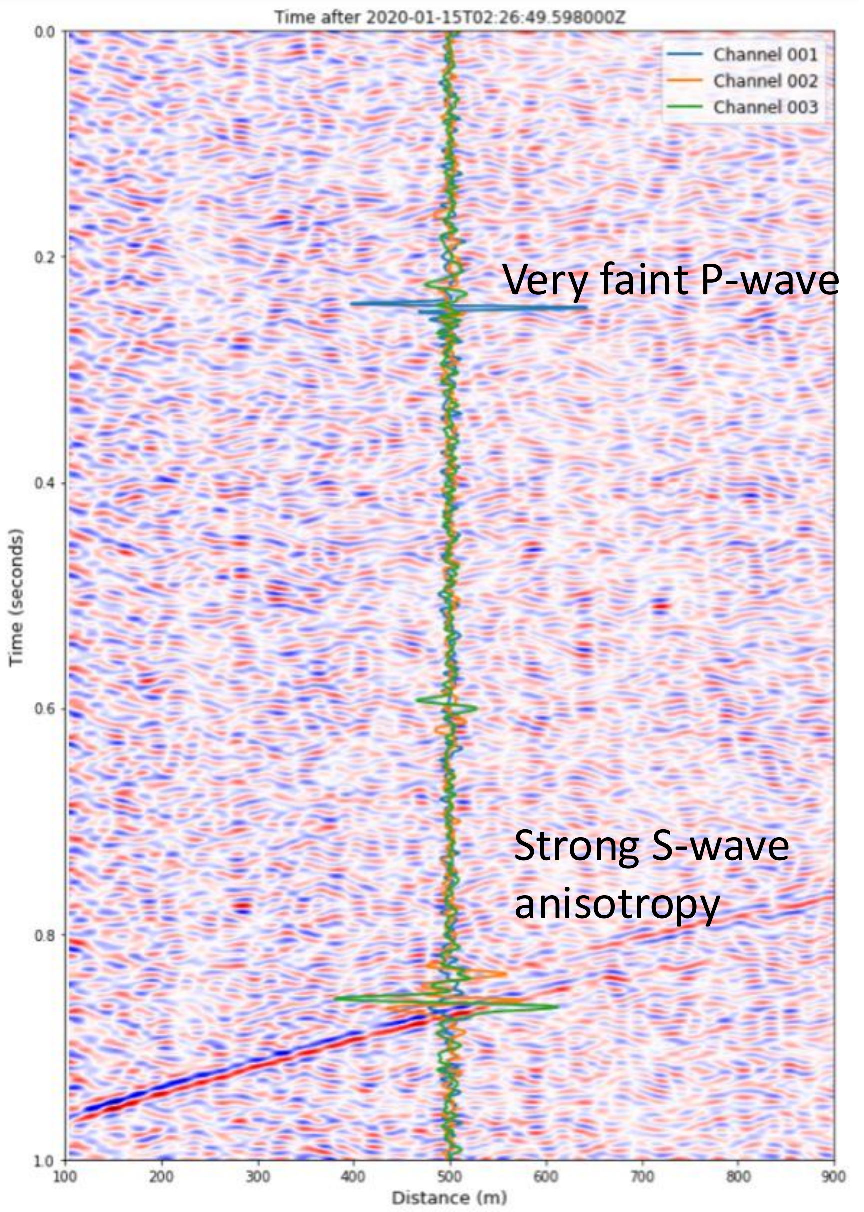
increasing distance (~ 0.3-3 km) from event

Unobservable(?) on nearest (working) broadband station ~ 7 km away

Distributed acoustic sensing (DAS)

Icequakes: DAS vs geophones

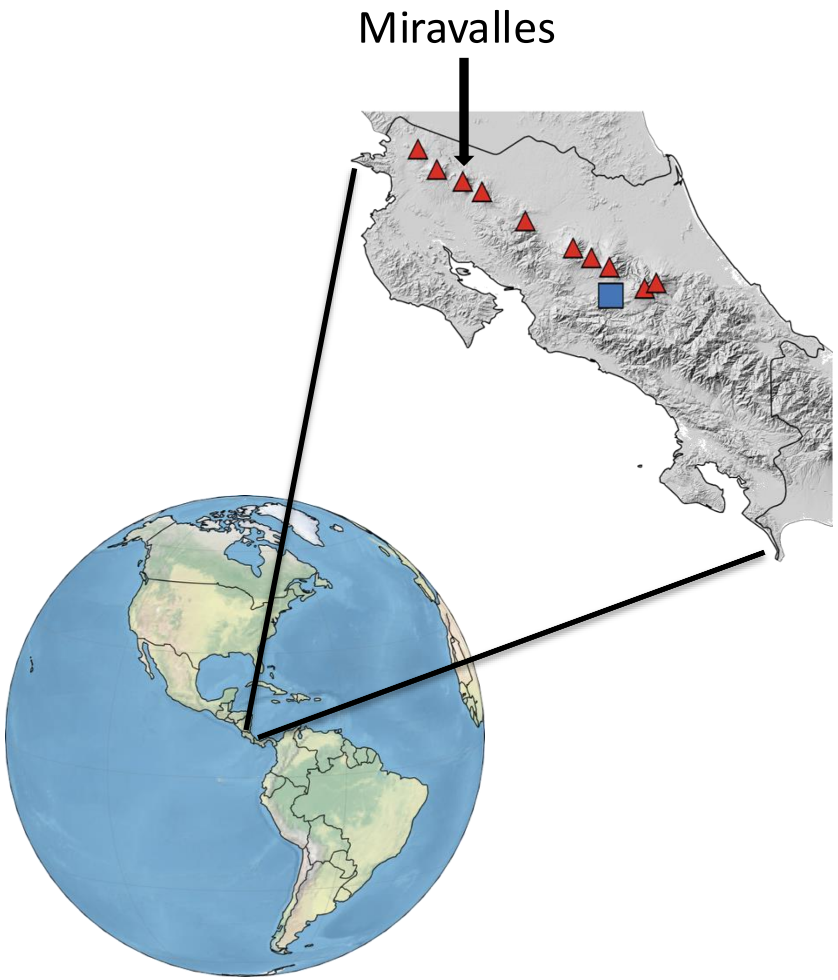
- Geometry is important
- Only S-wave energy visible (slow firn layer)
- 180-degree ambiguity with linear array
- Pick S-wave travel times using QuakeMigrate (CMM) (Hudson et al. 2019)
- Locations using NonLinLoc (Lomax and Vireaux, 2000)
- Determine source mechanisms using full-waveform moment tensor inversion



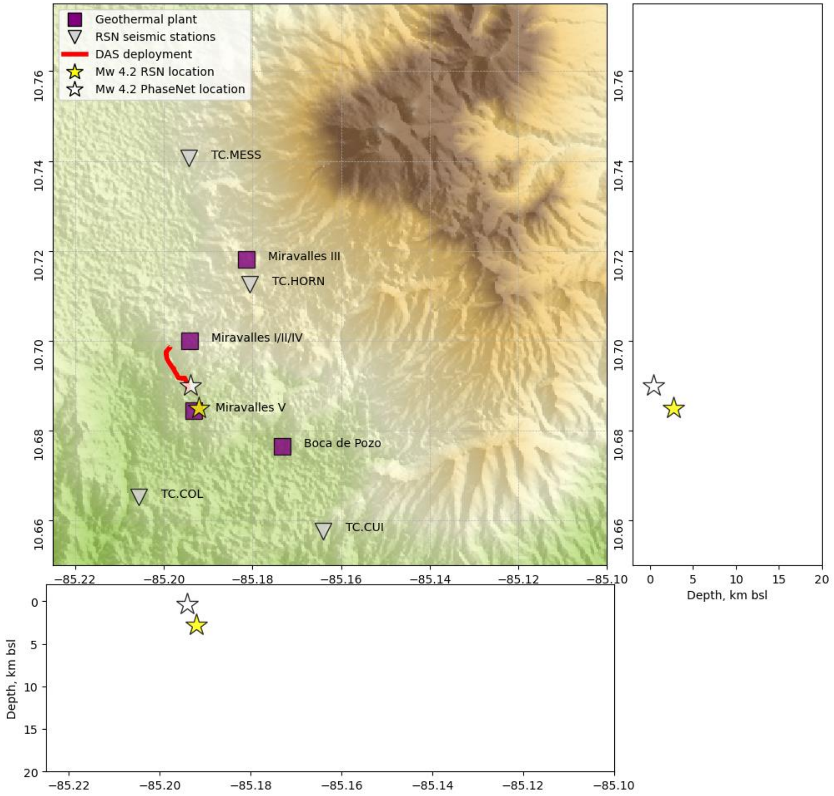
See Hudson et al., 2021

Miravalles geothermal dark fibre DAS (Mar ‘25)

Study aim: To assess feasibility of leveraging dark fibre from local energy infrastructure to densify volcanic network



1.5 km cable running
north -> south between wells

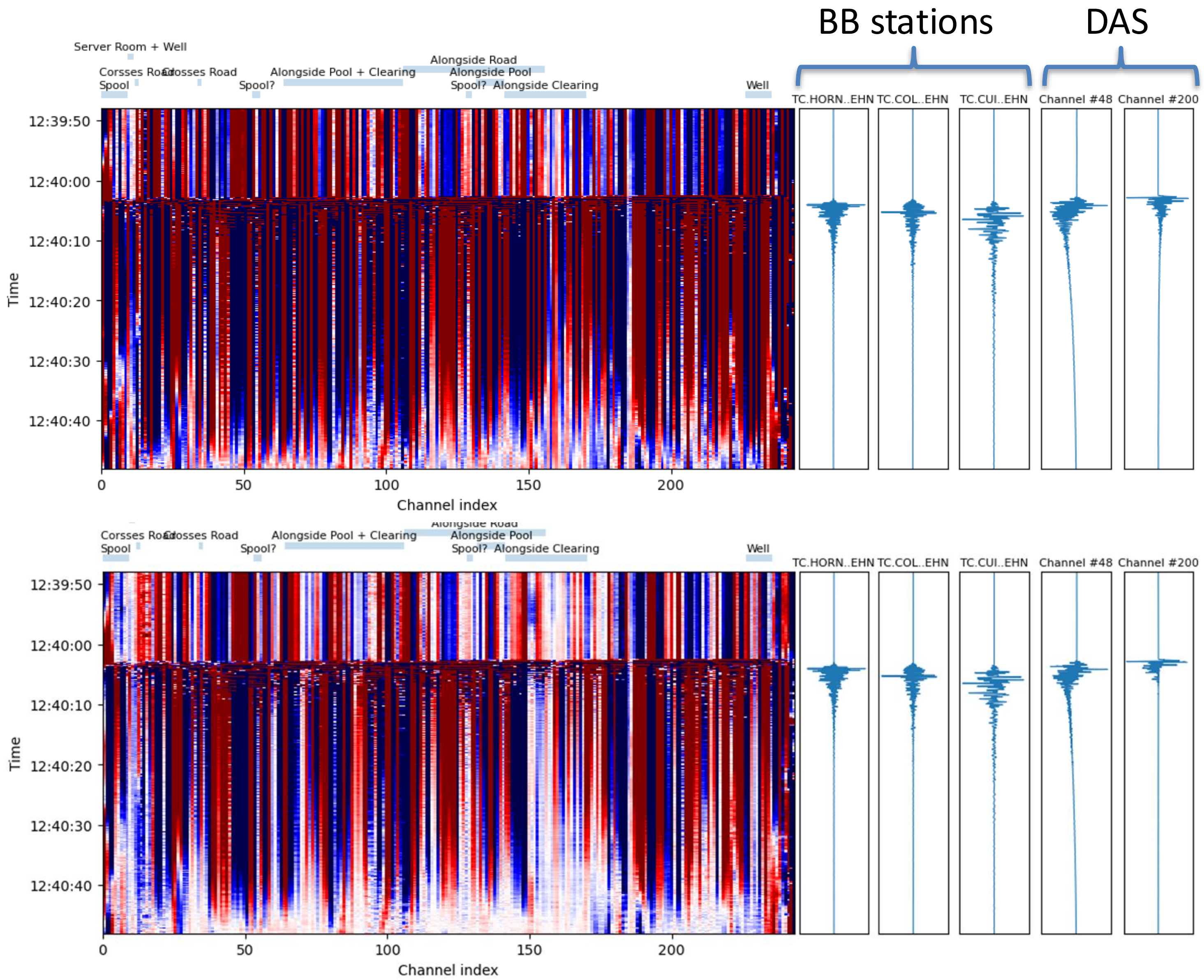


Shallow Mw 4.0 occurred at one end
of fibre during pilot study

Mw 4.0 event on DAS (denoising not needed)

Raw

DAS-N2N Denoised

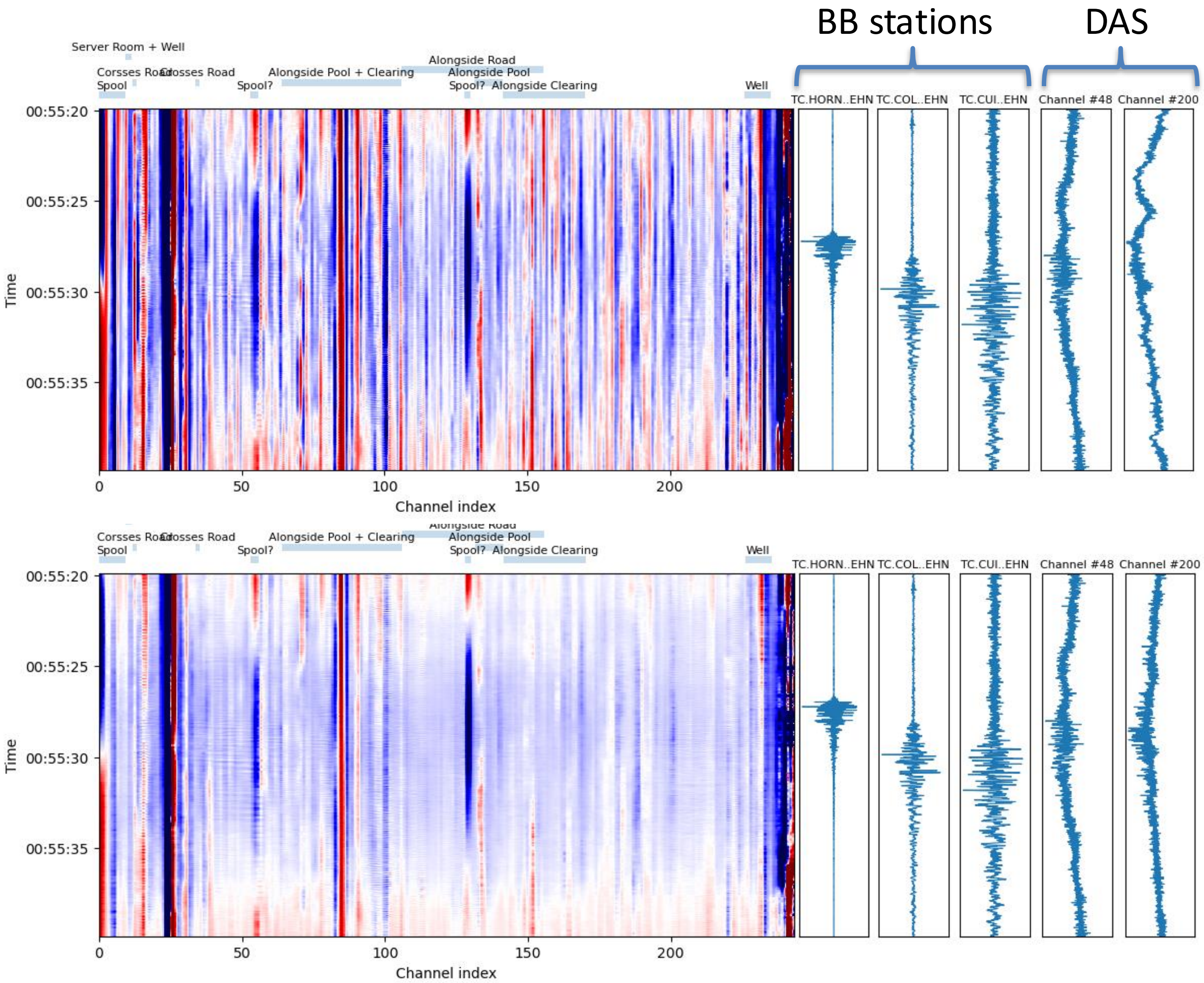


Lapins et al., 2024

Lower magnitude event on DAS

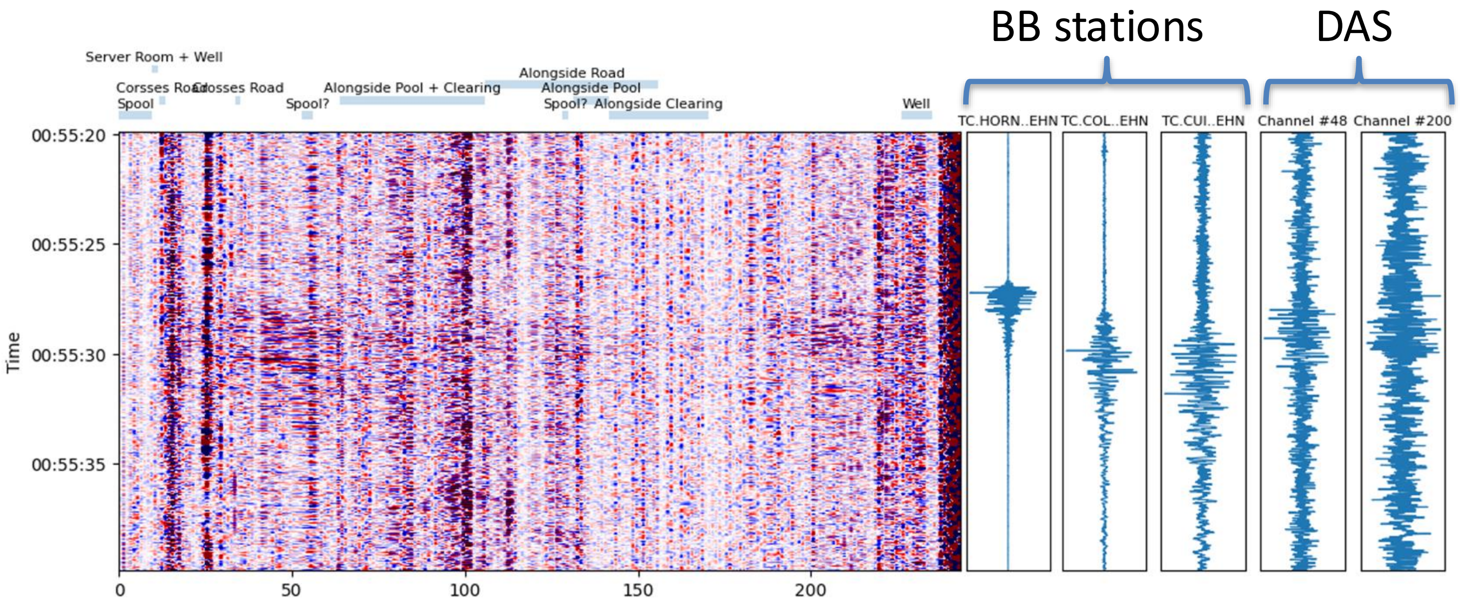
Raw

DAS-N2N Denoised

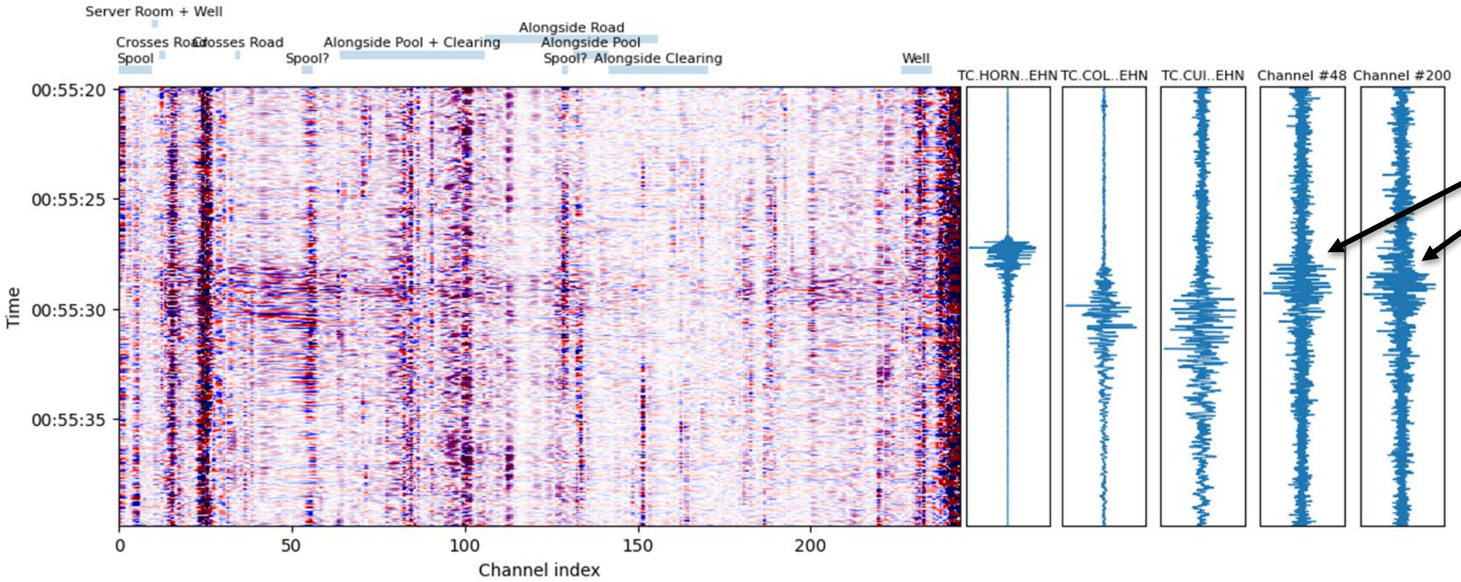


Lower magnitude event on DAS (1 Hz highpass)

From raw

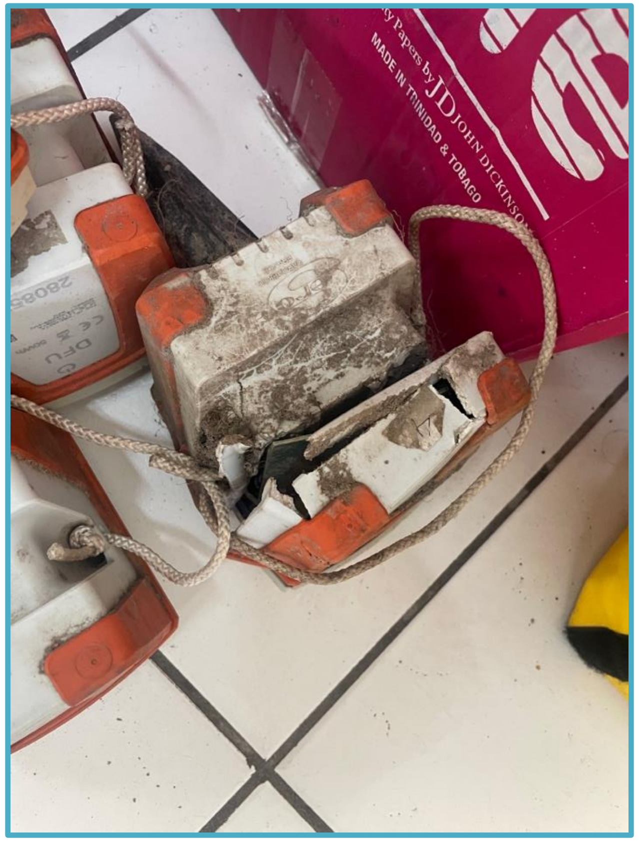


From DAS-N2N denoised



Denoising yields SNR gain but smaller than expected (current work to improve this further)

Challenges



Summary and future work

- Nodes (Montserrat and Rincon) - reduces seismic event detection thresholds; expands spatial coverage.
- Temporary, high-density arrays offer considerable promise for hazard response and geothermal exploration, including metalliferous fluids.
- Machine learning – quick, adds many more events (e.g., Lapins et al., 2021)
- Improved data density from the nodal array enhances resolution and reduces uncertainty in tomographic models.
- Ambient noise tomography (ANT) further complements these analyses by providing detailed imaging of the shallow subsurface (< 3 km).
- Joint inversions of ANT images and travel-time tomographic images allows more comprehensive characterization of volcanic systems; integration with other datatsets (MT, petrology, well loges)
- DAS holds much potential; challenges with coupling; array geometry; lower SNR
- Challenges – huge data volumes; nodes require regular servicing (50 days for WiNGs)

Acknowledgements and Collaborations

- Oxford Martin School; NERC-UKRI
- FCDO
- Government of Montserrat
- Montserrat Volcano Observatory