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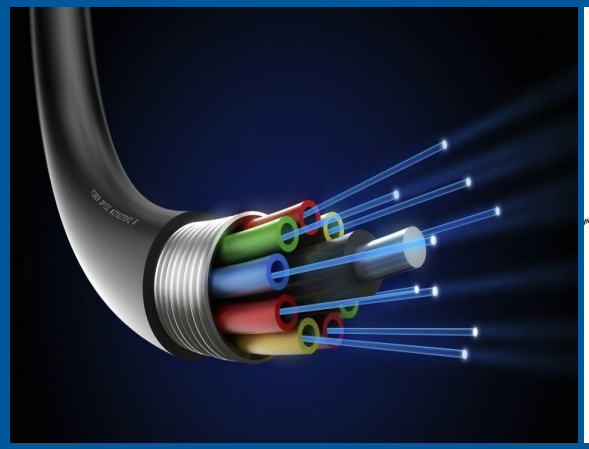
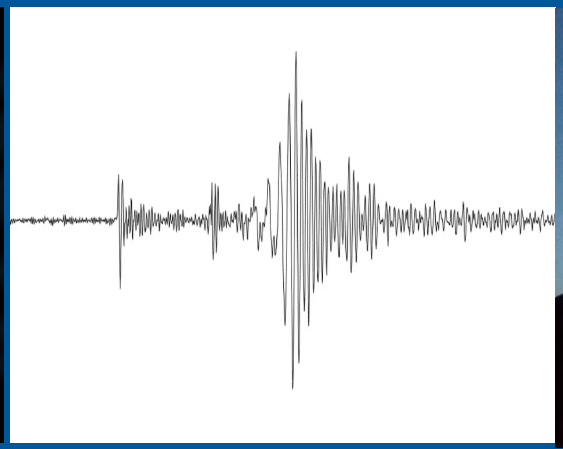
HELMHOLTZ RESEARCH FOR GRAND CHALLENGES

Earthquake detection

Fibre Optic Distributed Sensing: Opportunities for Seismology and Volcanology





Philippe Jousset
and Lotte Krawczyk

GFZ Potsdam,
Germany

Outline

Earthquake detection

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General principles and motivation

- seismology
- optical fibres

Single sensors

Delays in travel time information

Distributed sensing

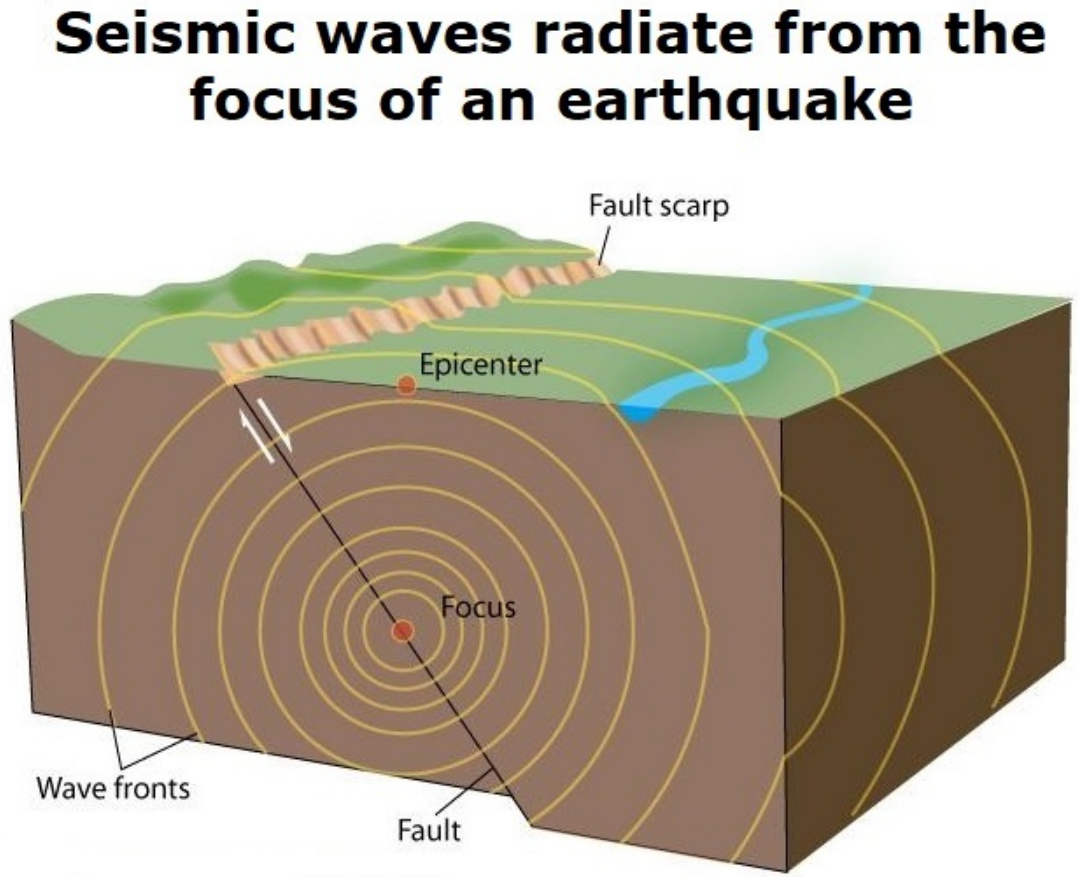
From borehole to surface

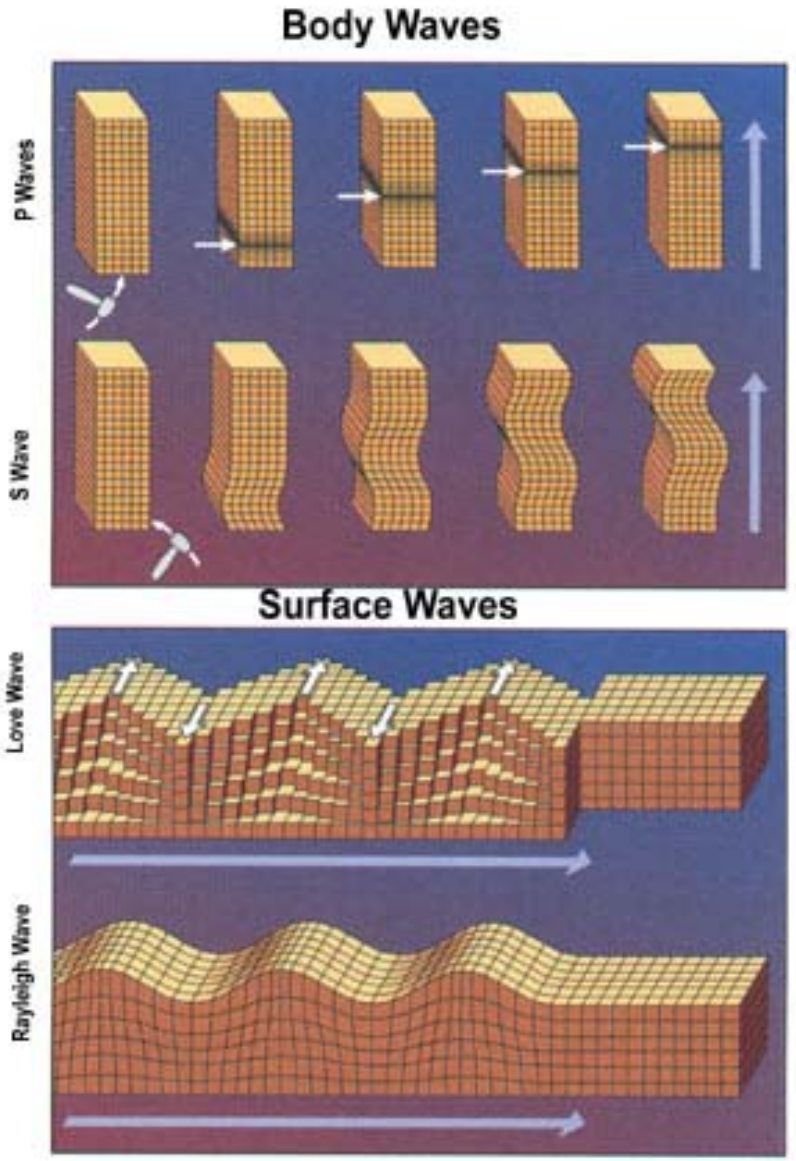
Earthquake and faults: Reykjanes, Iceland

Volcano applications: Etna, Italy

Conclusions, perpectives

Principle of seismology - earthquakes





Motivation

Faults are important

Drivers for generating destructive earthquake

Carry fluids of ore deposit, geothermal resources, etc.

exploration of structure and morphology of the Earth

seismic hazard

volcanic hazard

Unknows within faults

- Detailled structure
- Fault motion
  - What triggers earthquakes?
  - Creeping processes?

Motivation

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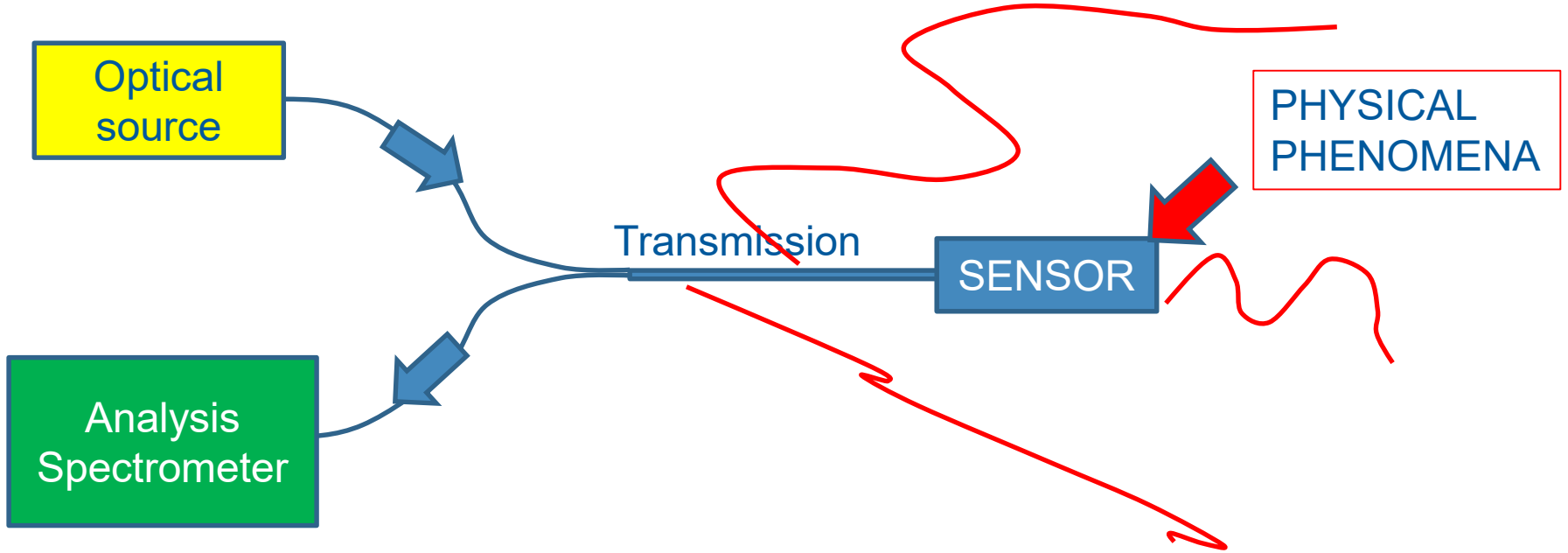
Densification of sensors - Examples:

+ Seismology
    - US Array – 10 years of yearly moving sensors -
    - AlpArray – many stations, several countries...
    - Long Valley - 6500 nodes

+ Volcanoes and Geothermal systems
    - iMUSH - Mount St Helens – 900 nodes
    - VolcArray - Piton de la Fournaise – 300 sensors
    - LABEX g-eauthermie, Strasbourg – 250 nodes
    - IMAGE network – 230 sensors

Fiber Optic Sensing Technologies



Single sensor

Coutant et al. 2015

Delays in phase transmission

Marra et al. 2018

DAS, DSS: the fibre is the sensor

Jousset et al. 2018
Sladen et al., 2019, Walter et al., 2019
Lindsey et al, 2019

Single sensors

Doppler effect of light speed in fibres due to rotation

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Rotational seismometer: measures the rotation of ground motion.

Fiber-optic gyroscope : gives north direction

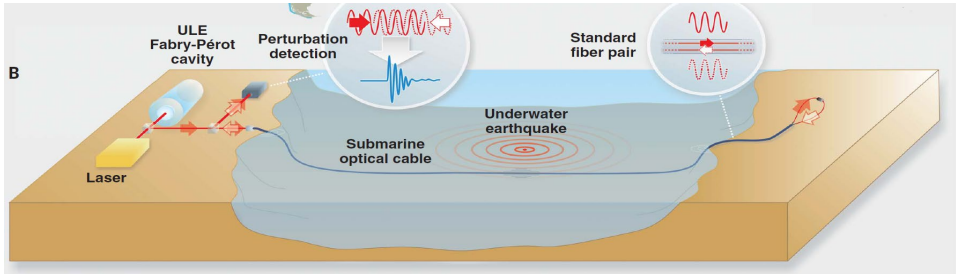
used for many years in marine

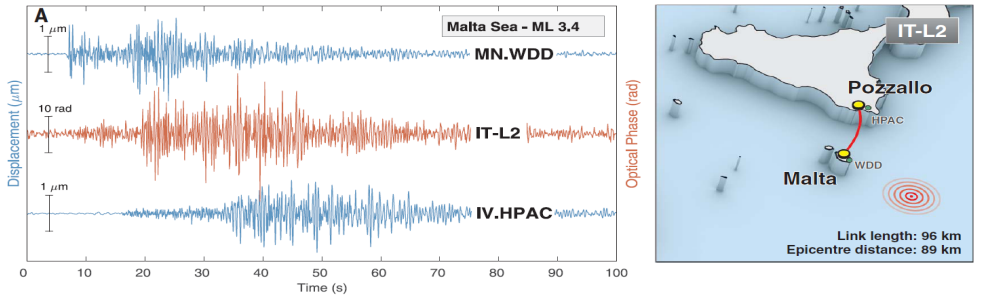
very usefull to find (true) orientation of seismometers

Optical fibre strainmeter: Fabrot-Peret interferometry (Coutant et al,. 2015)

Time delays measurement

- Measure total length change of cable by time-of-flight and F.-P. Interferometry (not DAS)
- Get integrated effect of length change → not the same as seismometer
- Some information on location from comparing timings of length-perturbation at both ends



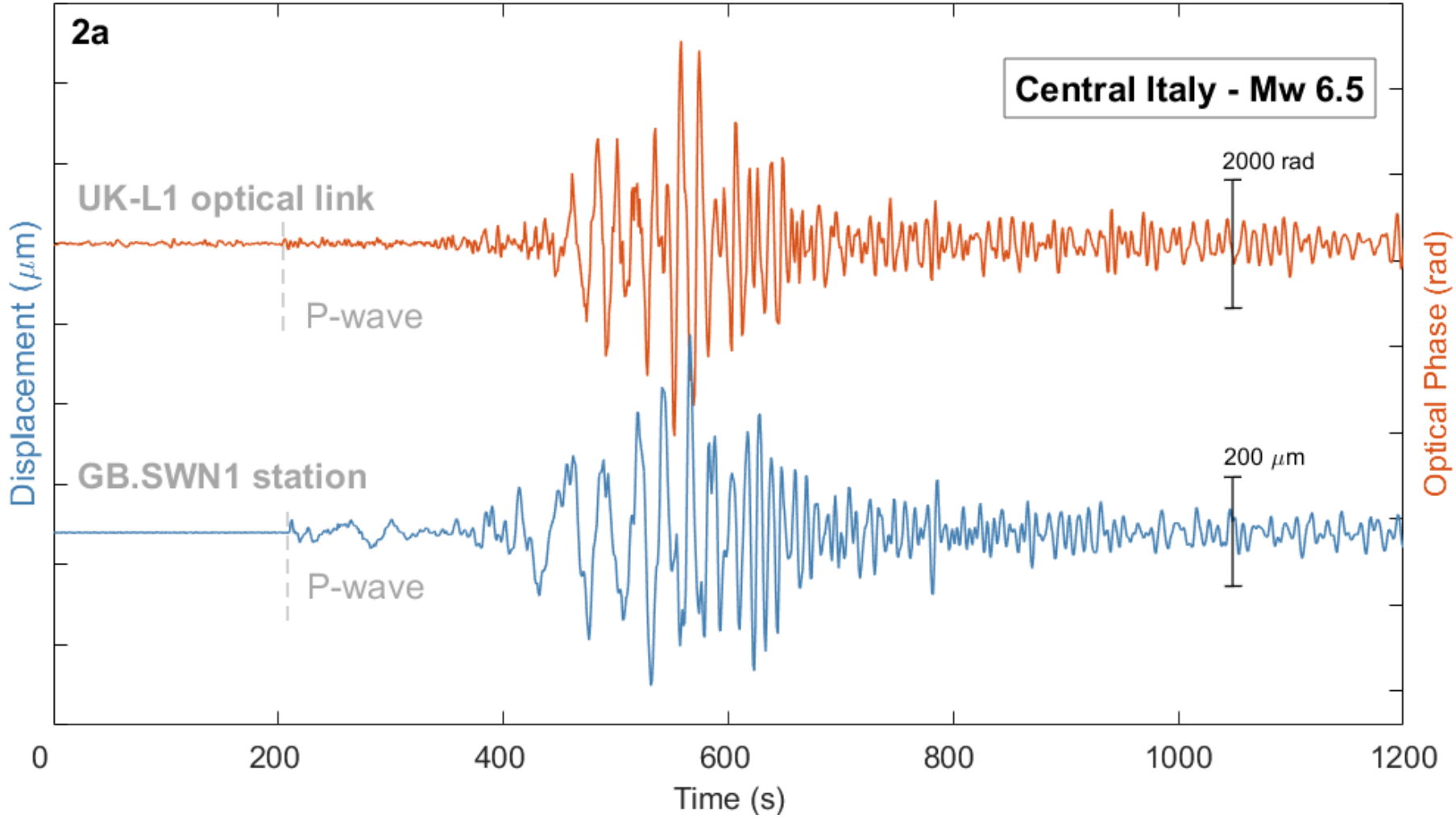


Marra et al, (Science 2018) – concept developed by National Physical Labs in UK, Italy, Malta

Changes in propagation delay (a few femtoseconds…) experienced by the laser light travelling in the fibre, correspond to length changes at the 1 microm-level, over thousands of kilometres of fibre.

Propagation delay changes are caused by environmental perturbations to the fibre, such as vibrations, acoustic noise and temperature fluctuations.

Marra et al. 2018, Science



Tele-seismic events on terrestrial optical links – phase fluctuations match BB record

Marra et al. 2018, Science

Distributed Sensing

- traditional sensors rely on discrete sensors (pre-determined points)
- distributed sensing does not rely upon manufactured sensors but utilises the optical fibre as sensing principle. *Telecom cables already deployed work.*
- continuous, real-time measurements along the entire length of a fibre optic cable.

Temperature – DTS	*Henninges et al., 2014*
Strain – DAS, DSS	*Jousset et al., 2016;* ***Jousset et al., 2018***
borehole measurements	*Reinsch et al, 2016,* ***Götz et al., 2018***
VSP	***Lipus et al, 2018***

DAS – Distributed Acoustic Sensing
The sensor is the fibre itself

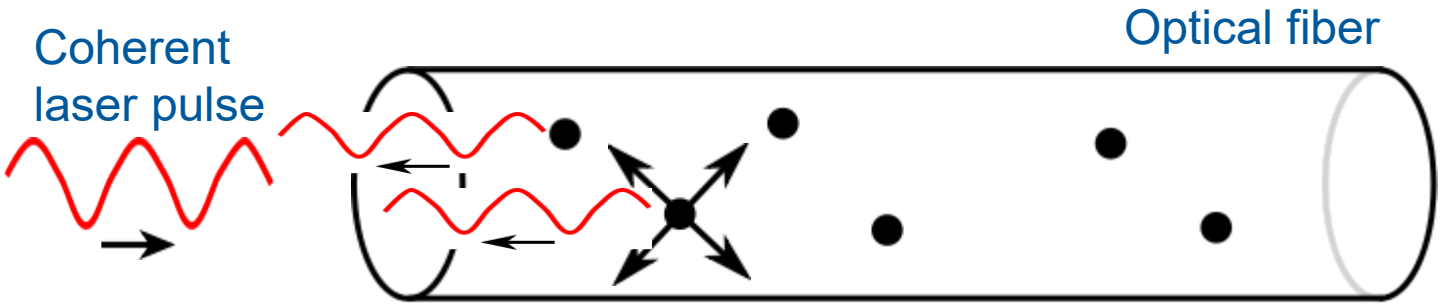
- allow for a simultaneous dense (meter-scale spacing) acquisition of strain along the entire length of the cable (several 10 km)
- can be used under harsh downhole conditions (until 300 °C) (temperature tolerance of the optical fibre)
- read-out unit operated remotely

-> Objective:

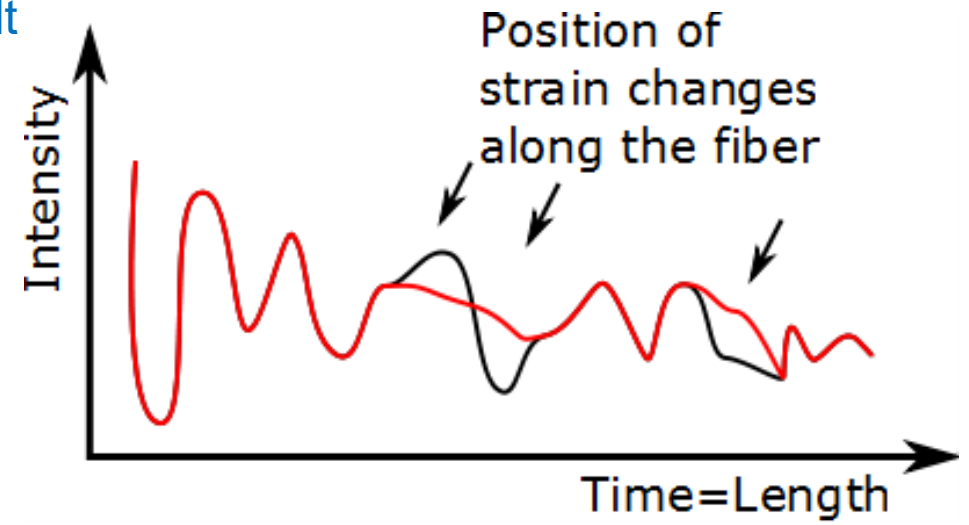
more detailed structural images

more acute understanding of processes

DAS - Measurement principle



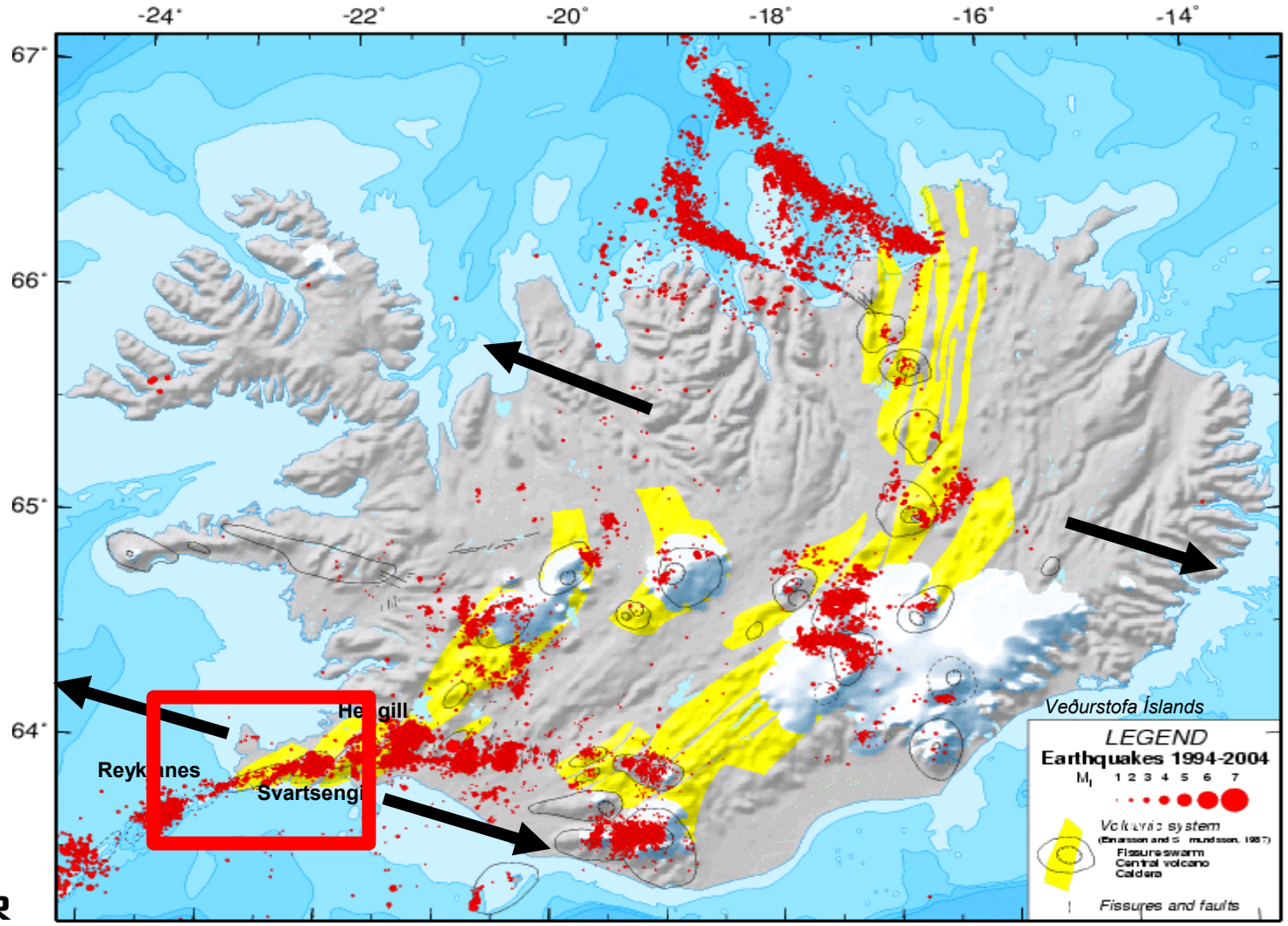
Elastic Rayleigh scattering -> position of the default



→ Change in Intensity/Time = Change in Strain/Time (strain rate)

→ Integration of strain rate = Local strain

Reykjanes experiment



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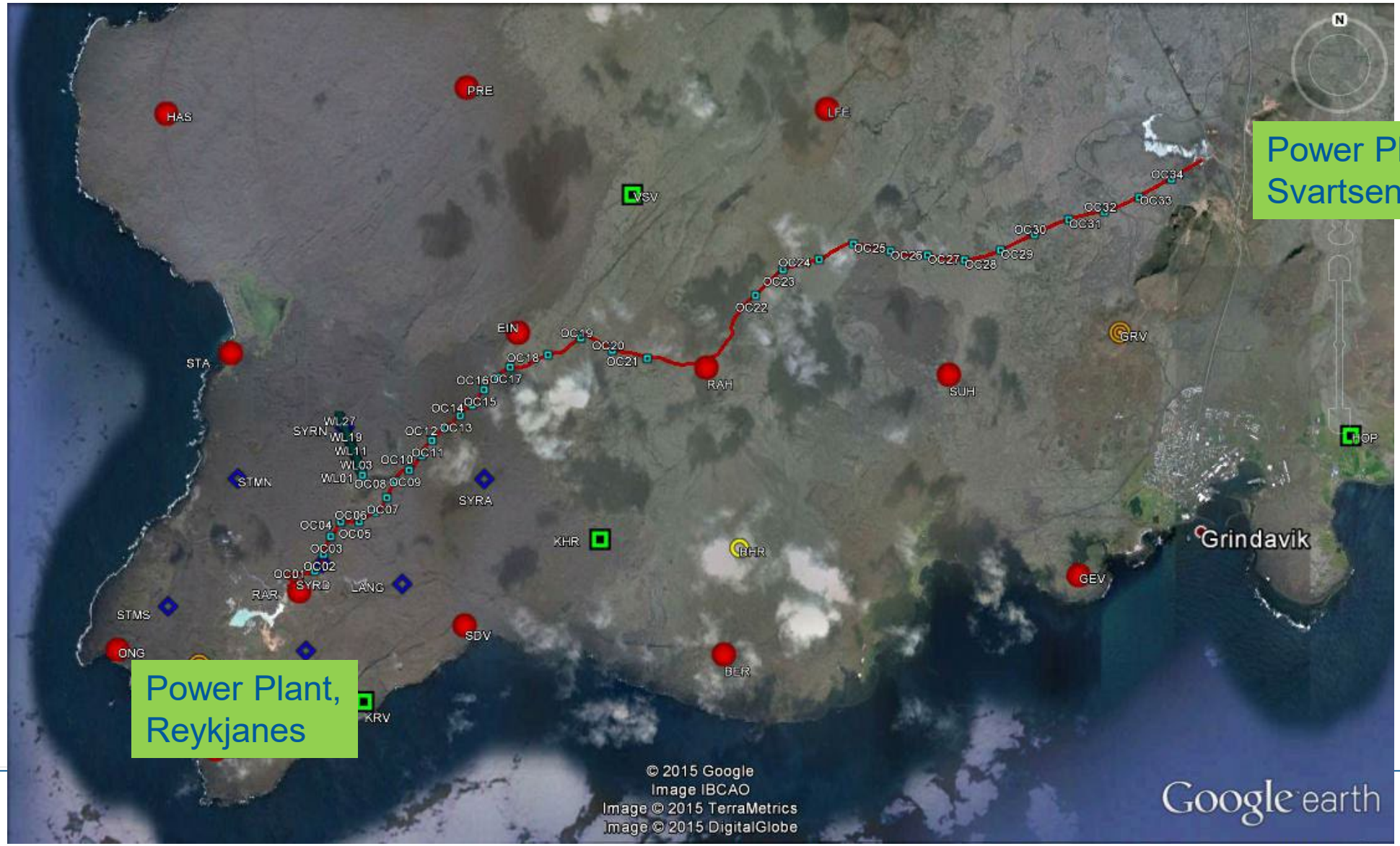
Reykjanes experiment: telecom fibre at surface



Reykjanes experiment: telecom fibre at surface

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Reykjanes experiment: telecom fibre at surface

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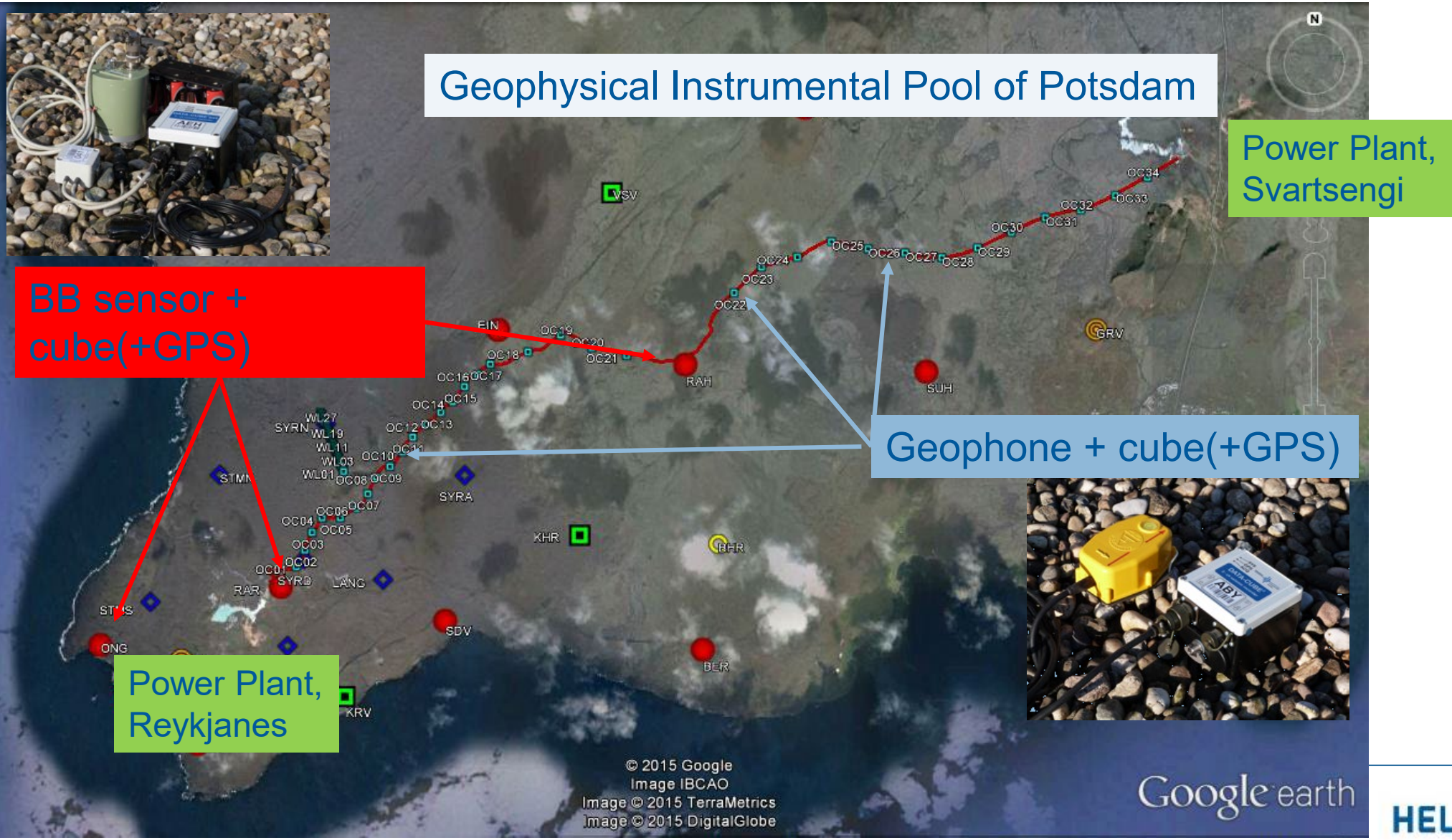

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Reykjanes experiment: telecom fibre at surface

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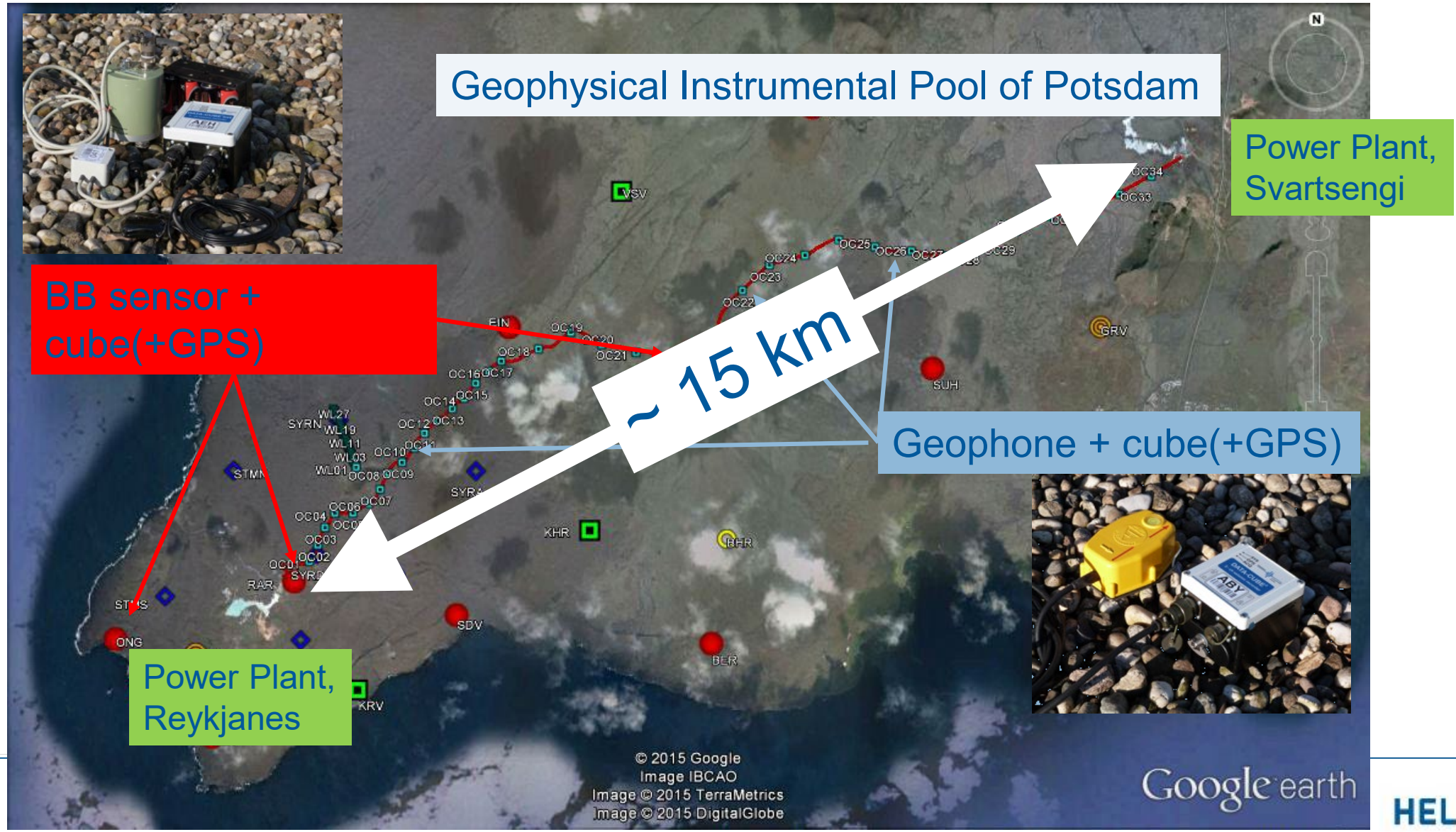

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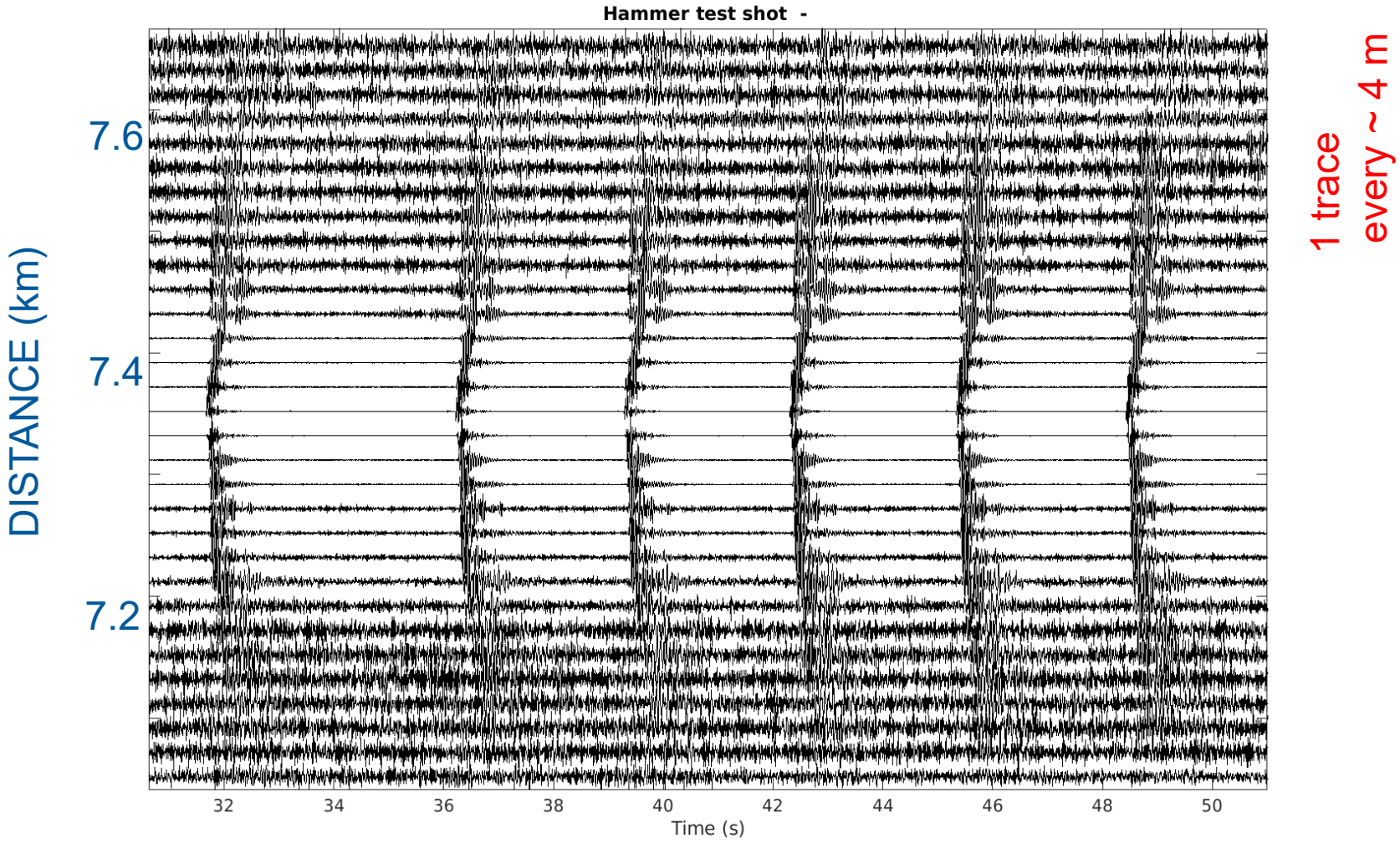
Locating the traces

Locating the traces

Locating the traces

Locating the DAS traces

Comparison with traces from the geophone and its GPS position



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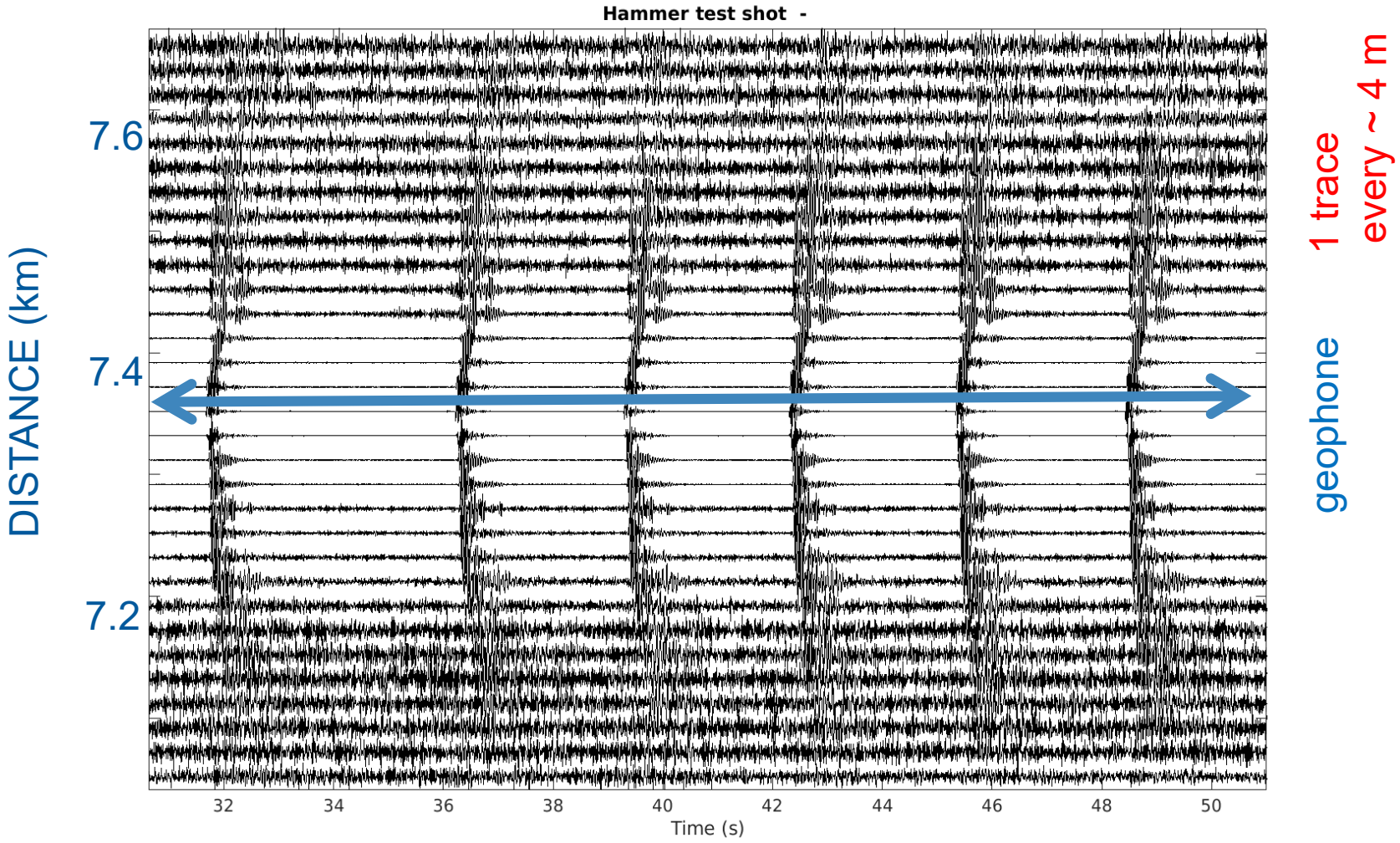
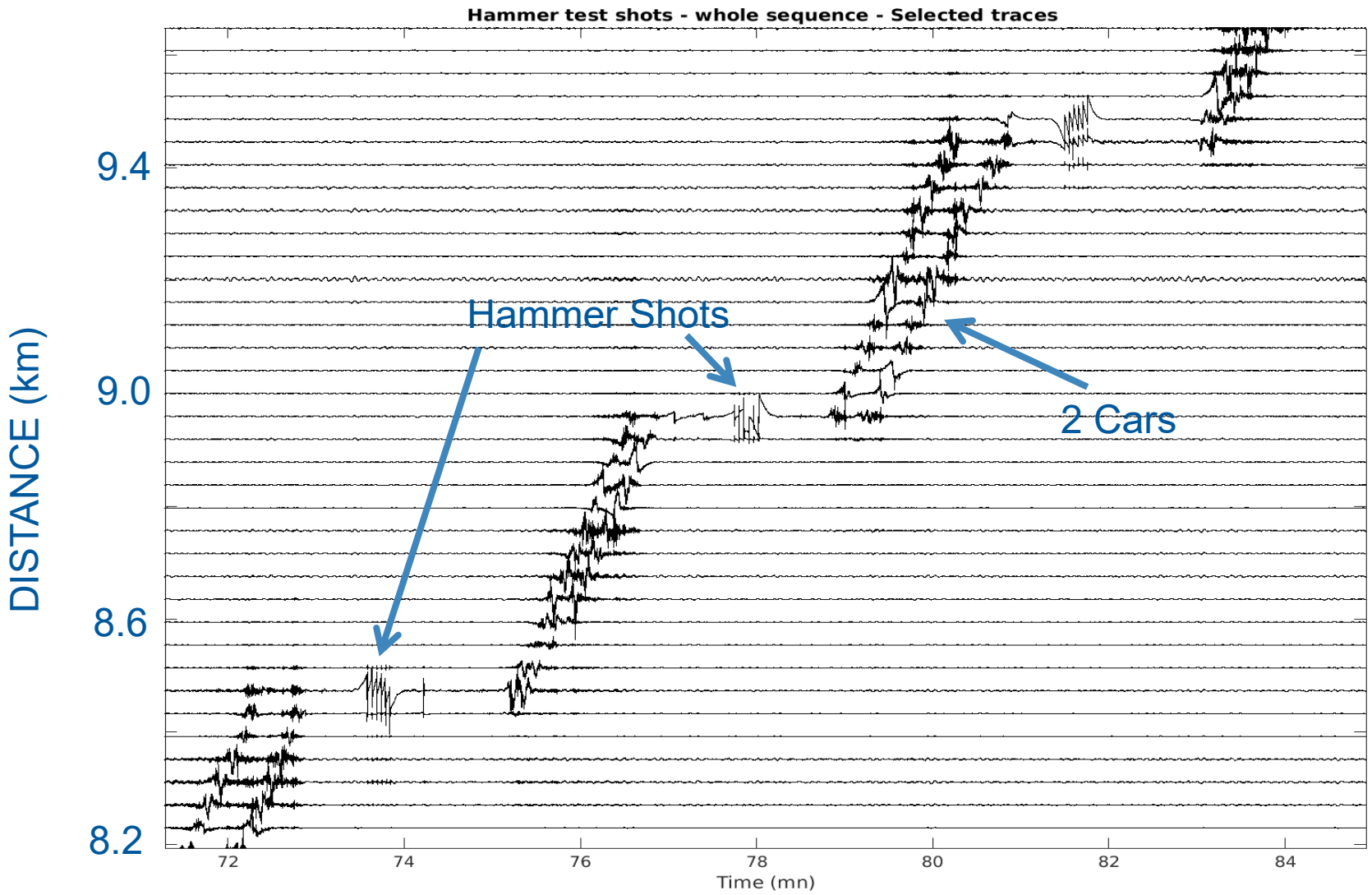


Monitoring our progress...



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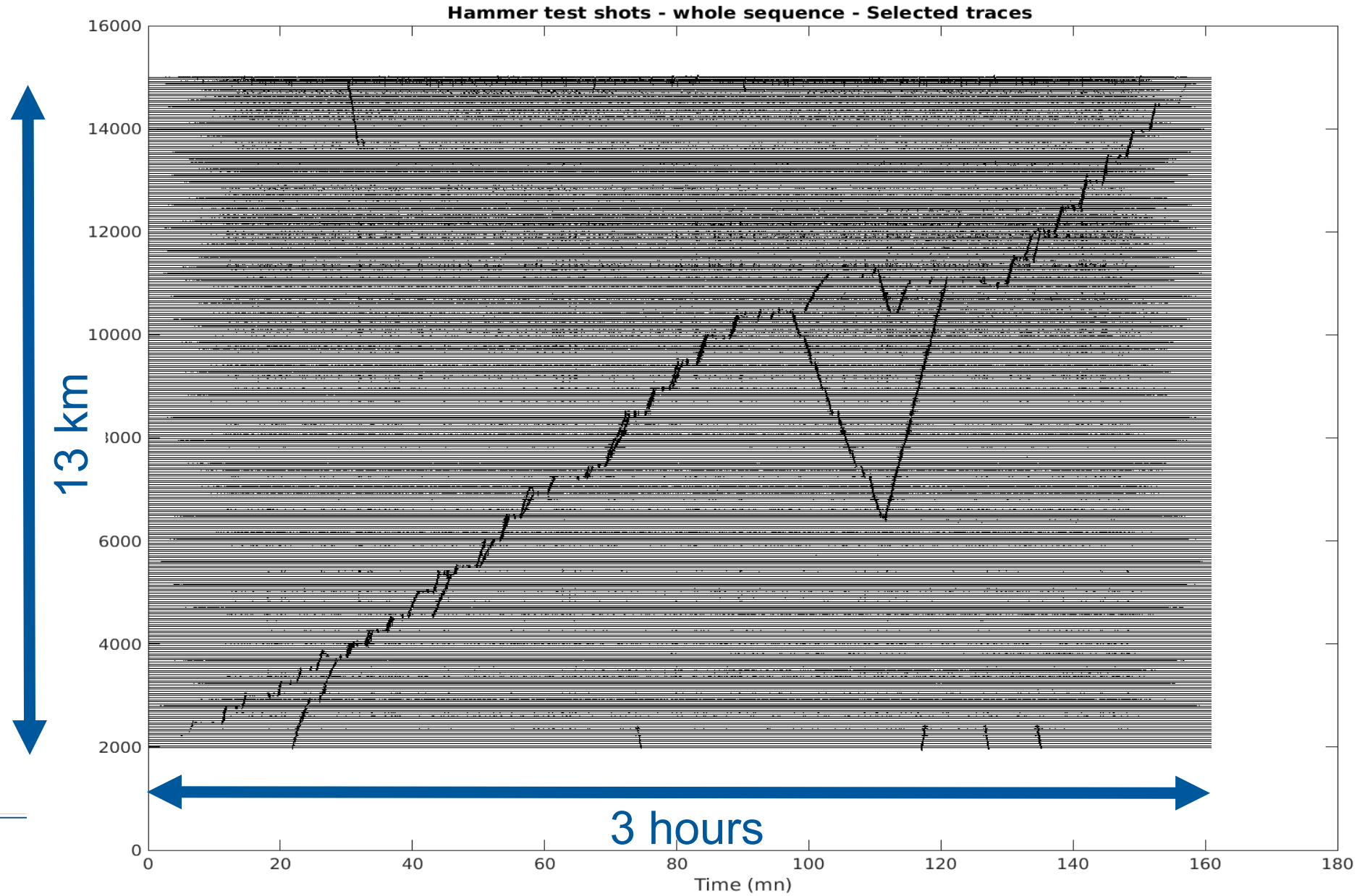

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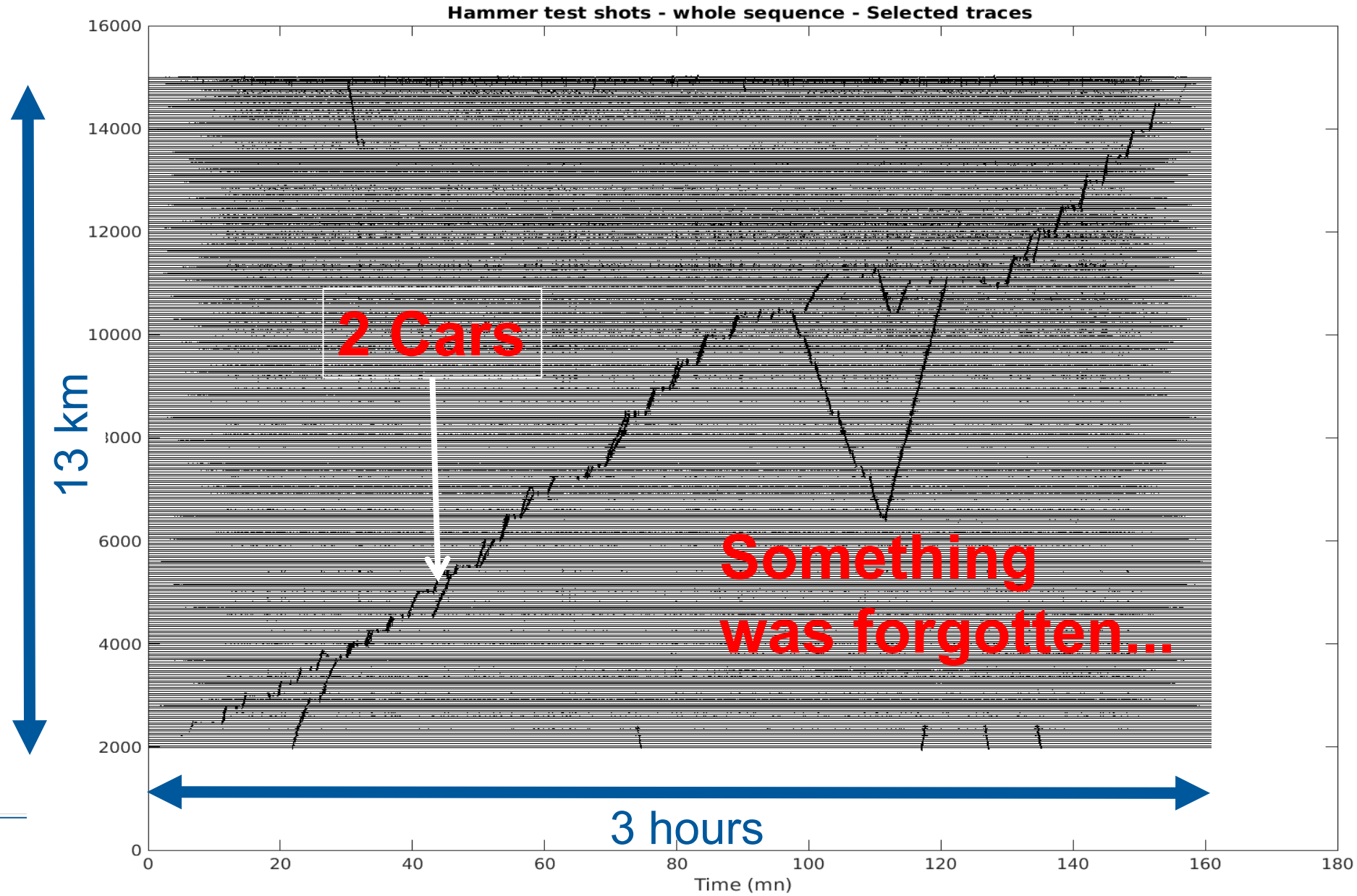

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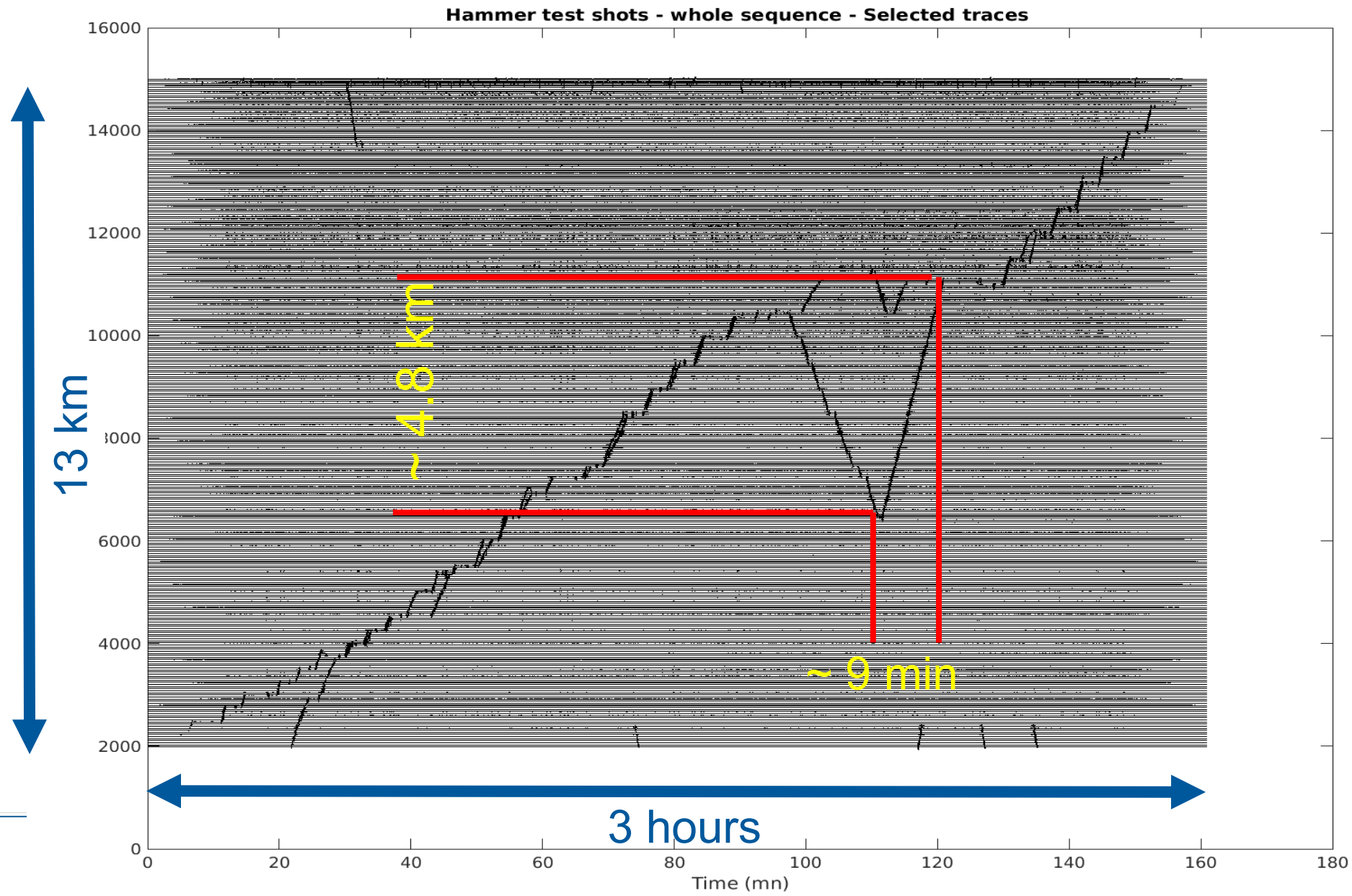

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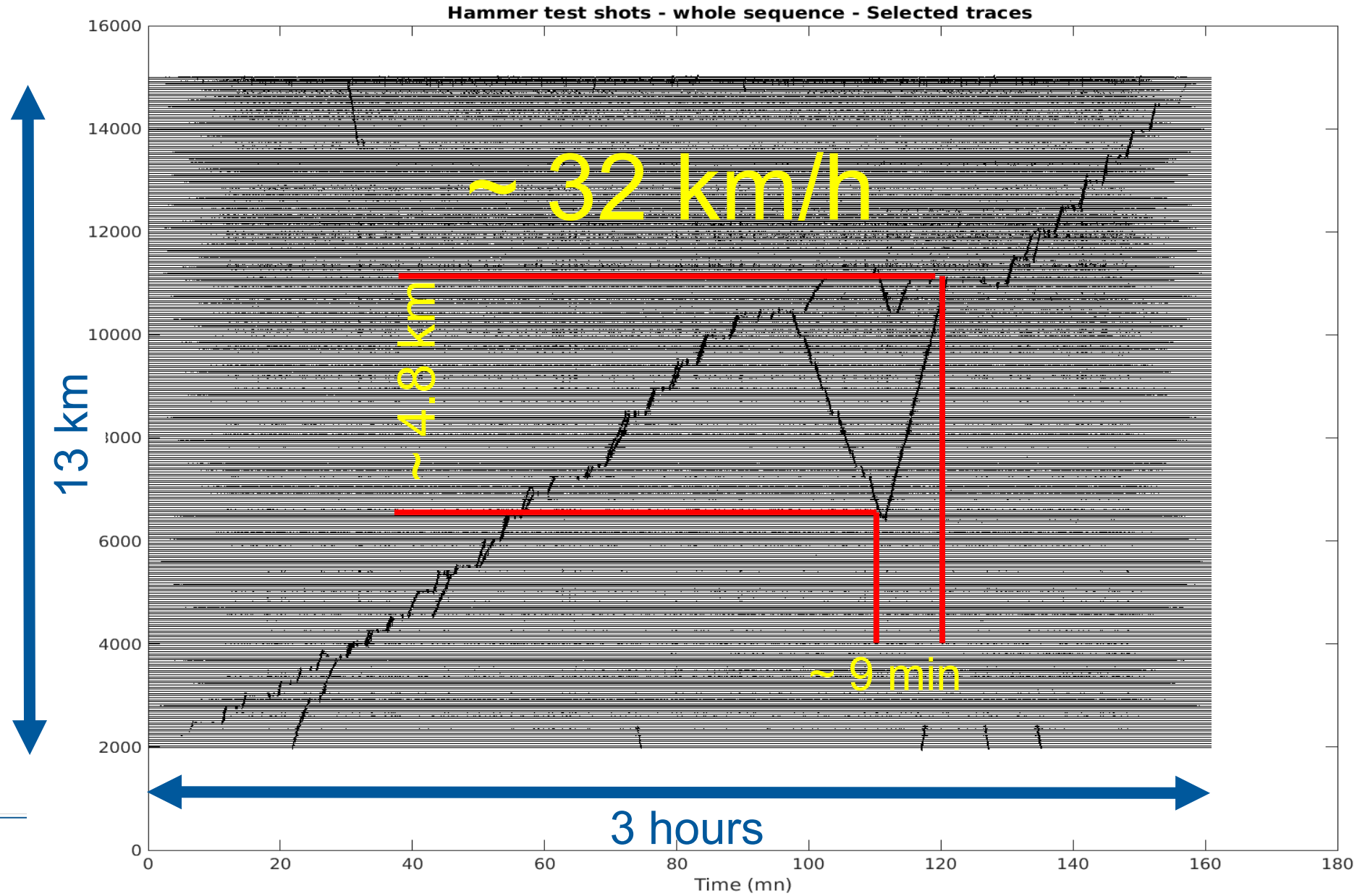
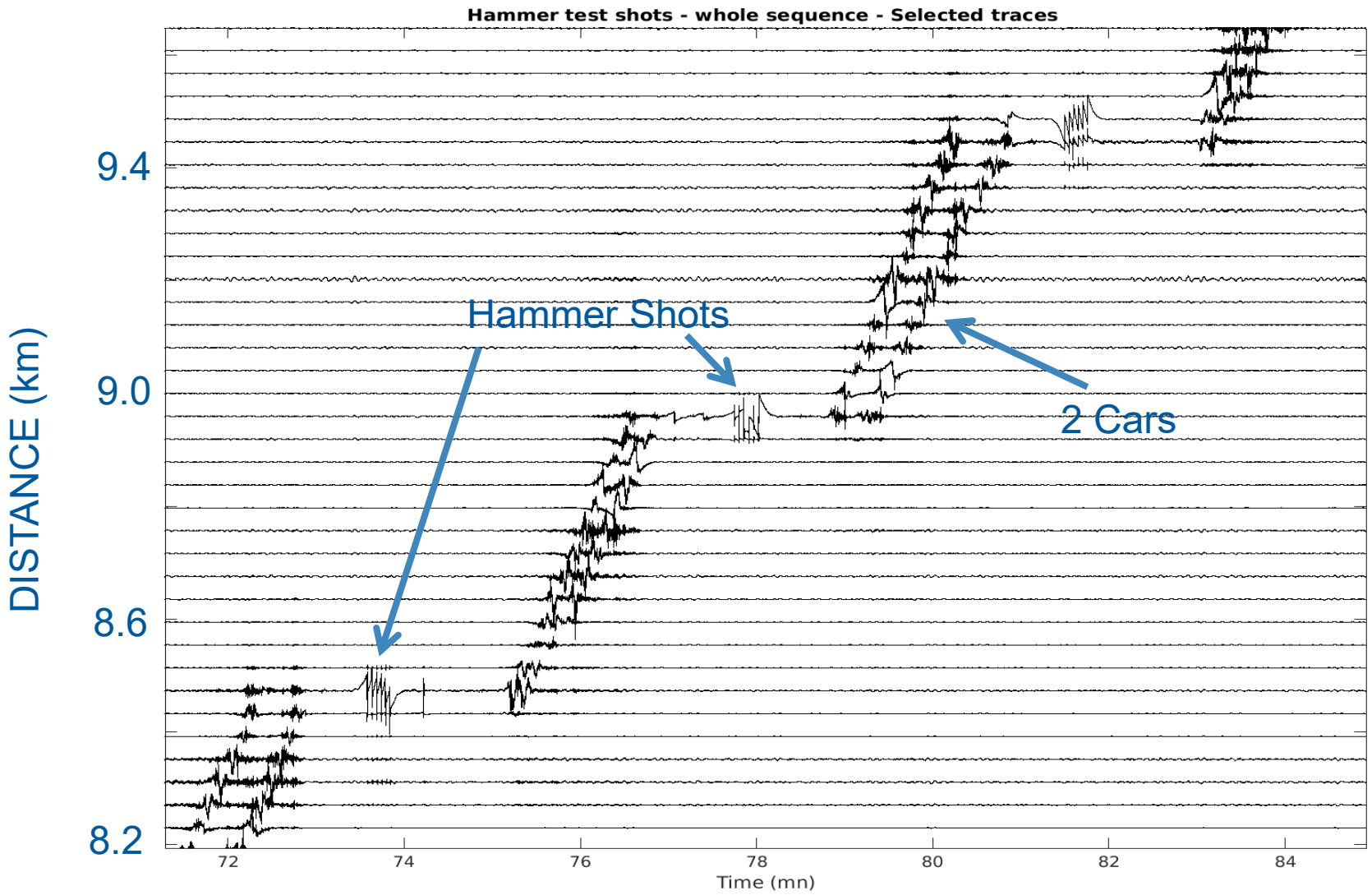


Analysing now the car traces...



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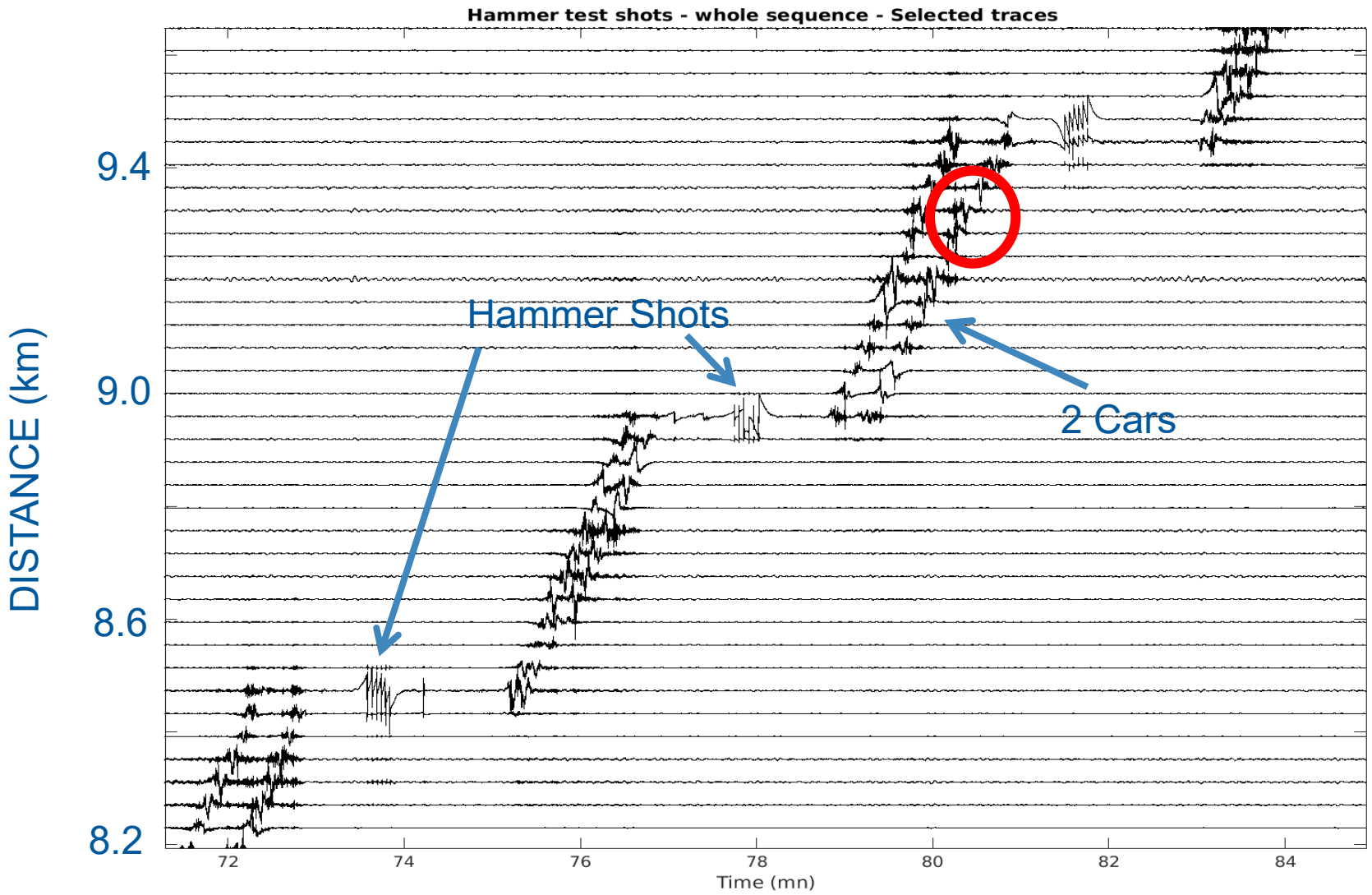
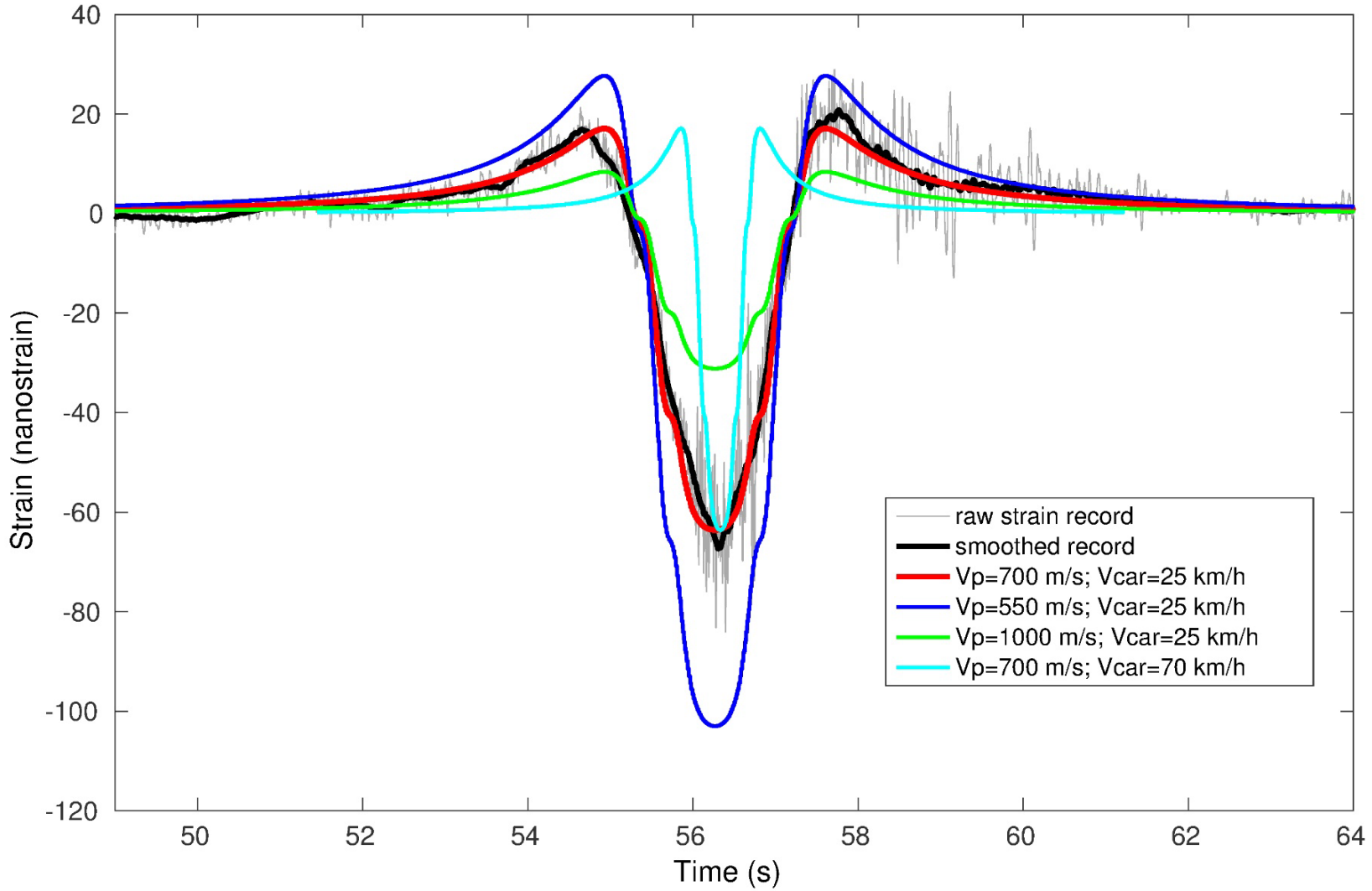


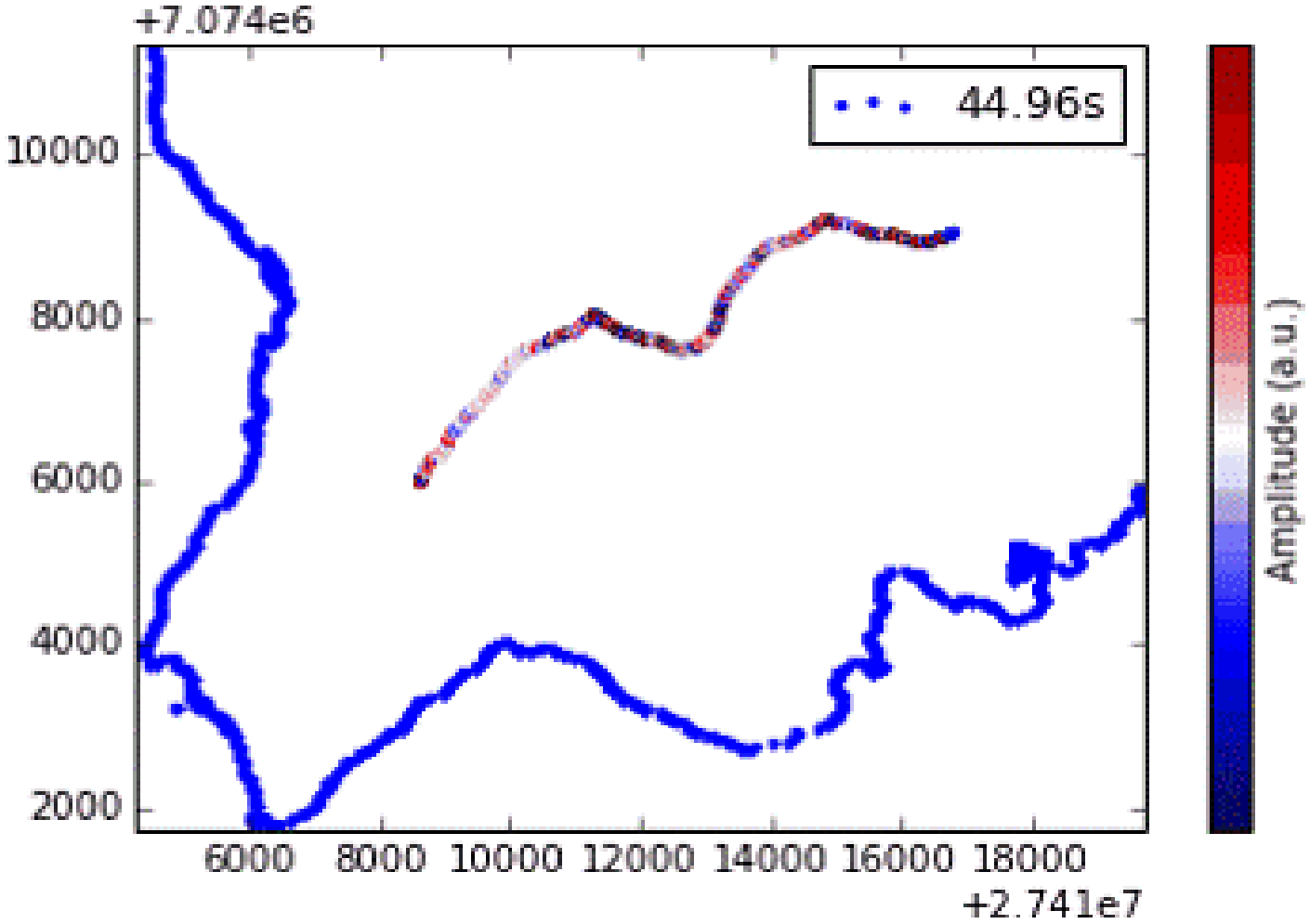
Using a car and a phone cable ...

To explore the underground

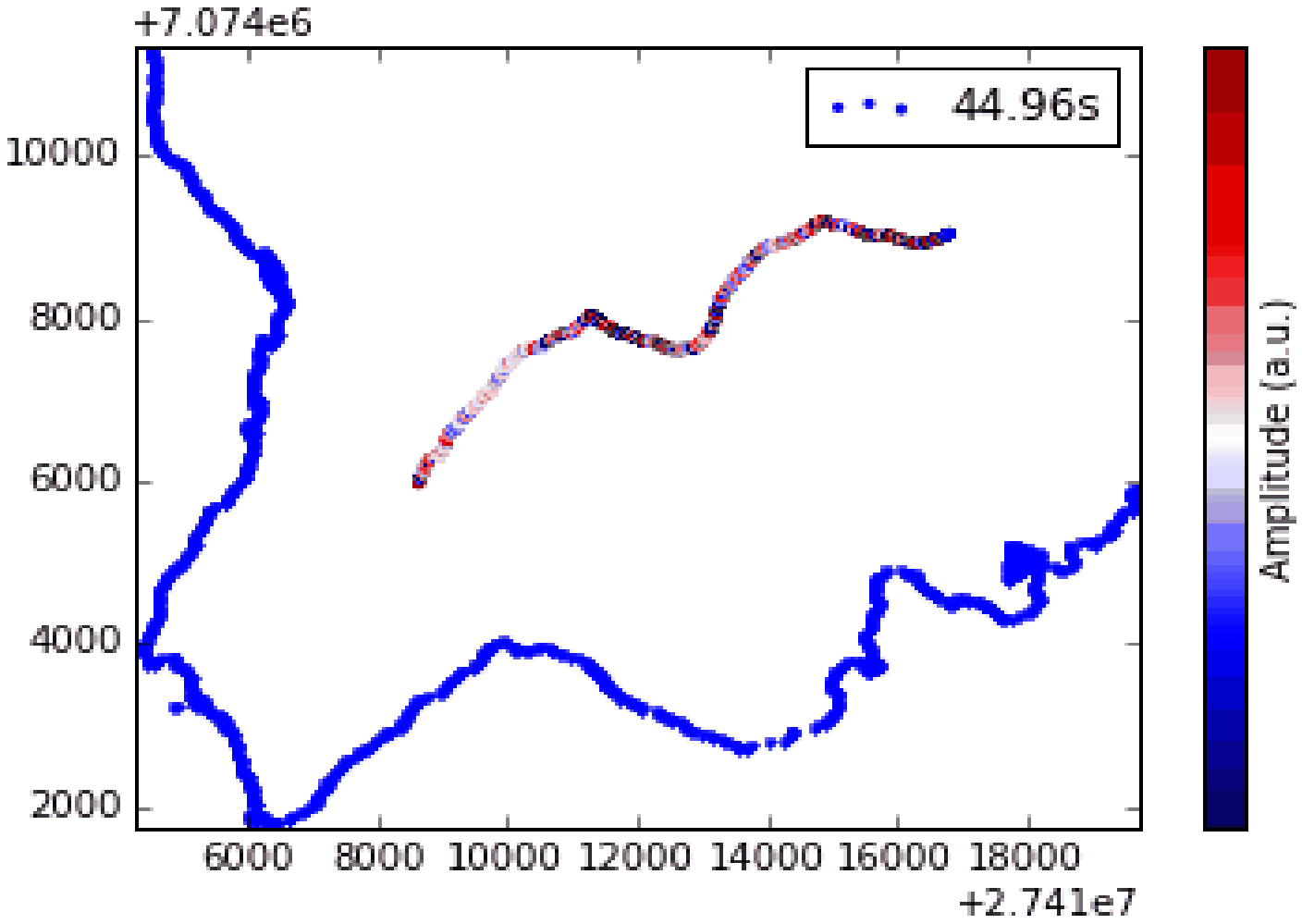


Jousset et al., Nature Communications, 2018

Detecting earthquake

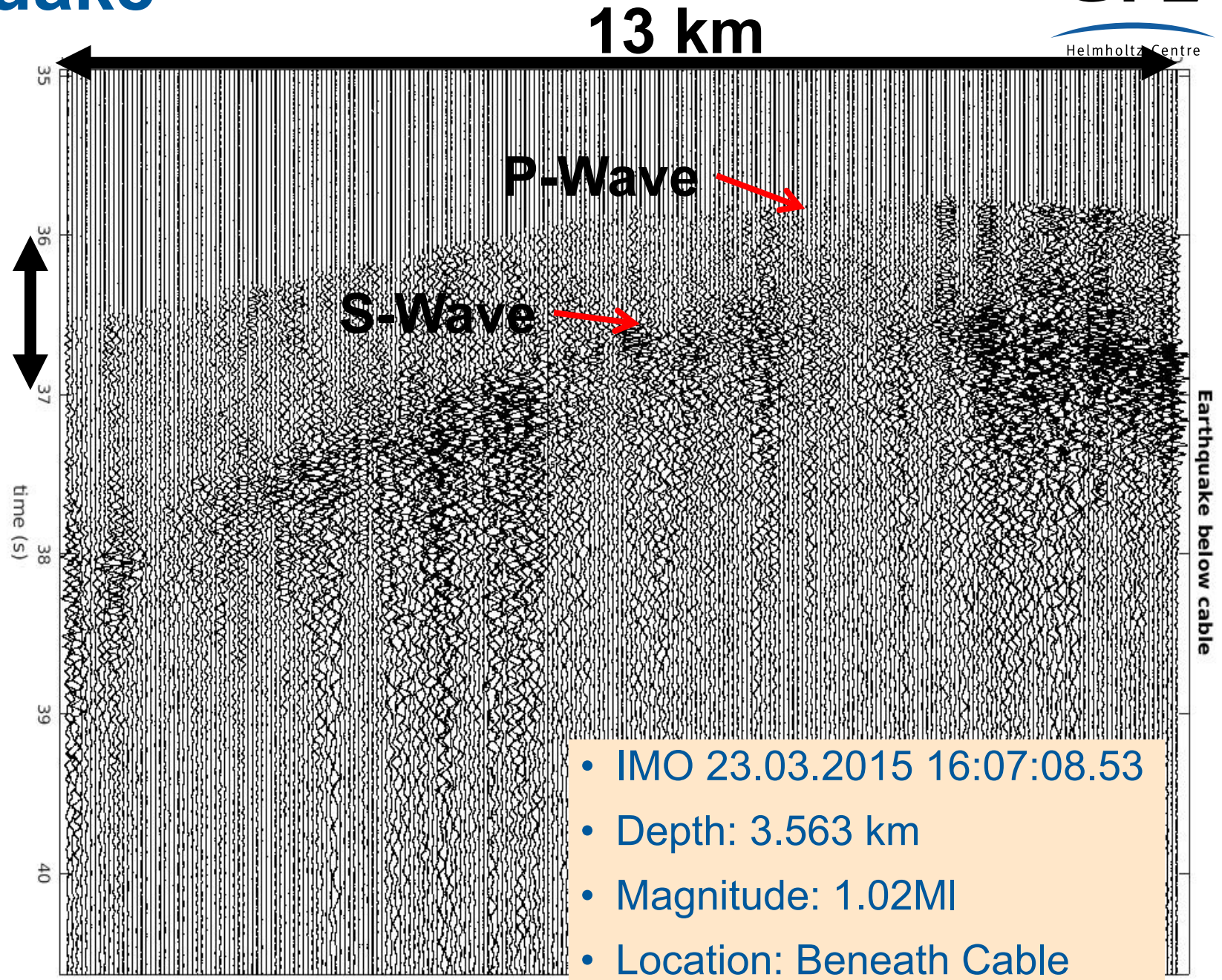


Detecting earthquake



Detecting earthquake

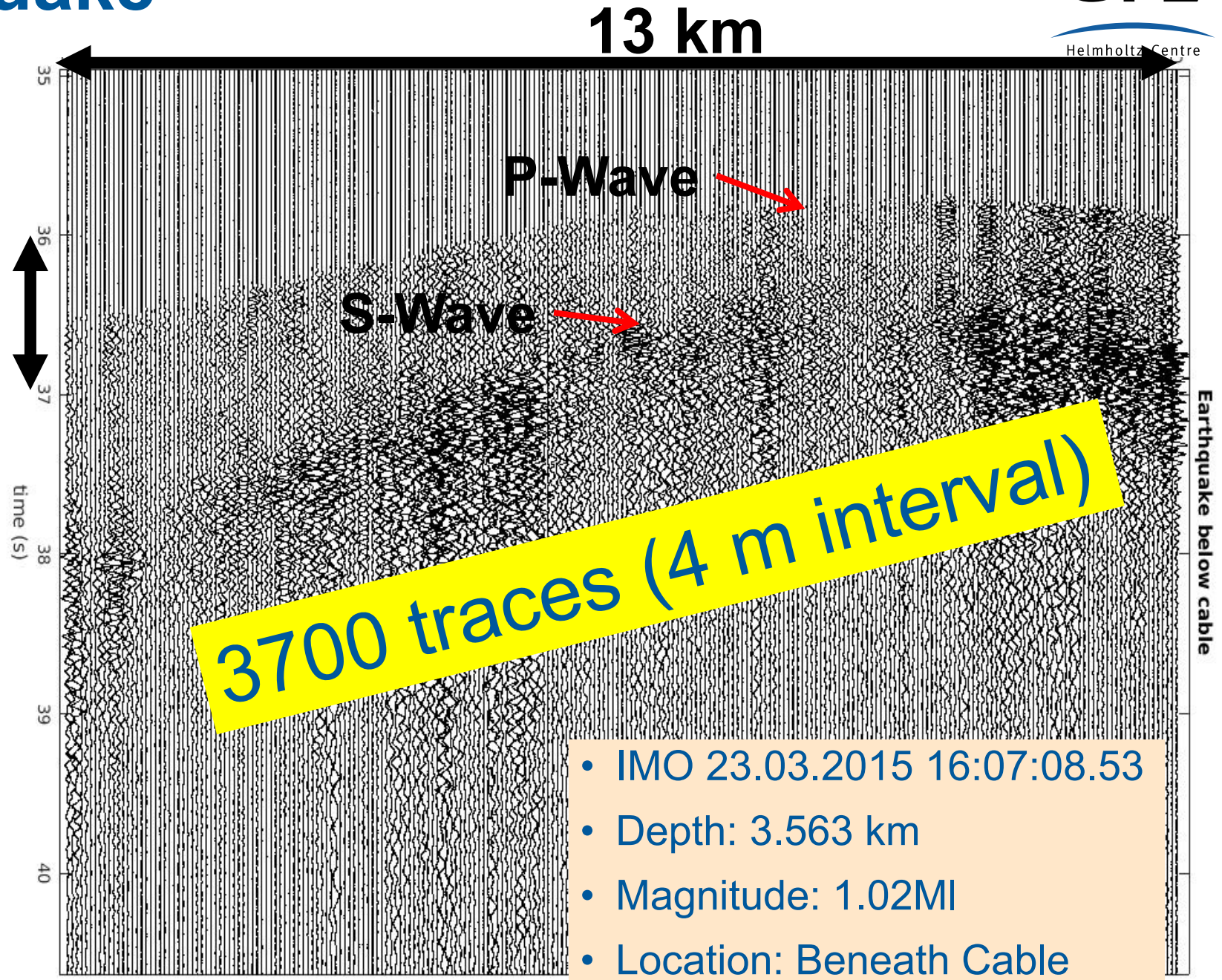
With a telecom cable



- IMO 23.03.2015 16:07:08.53
- Depth: 3.563 km
- Magnitude: 1.02Ml
- Location: Beneath Cable

Detecting earthquake

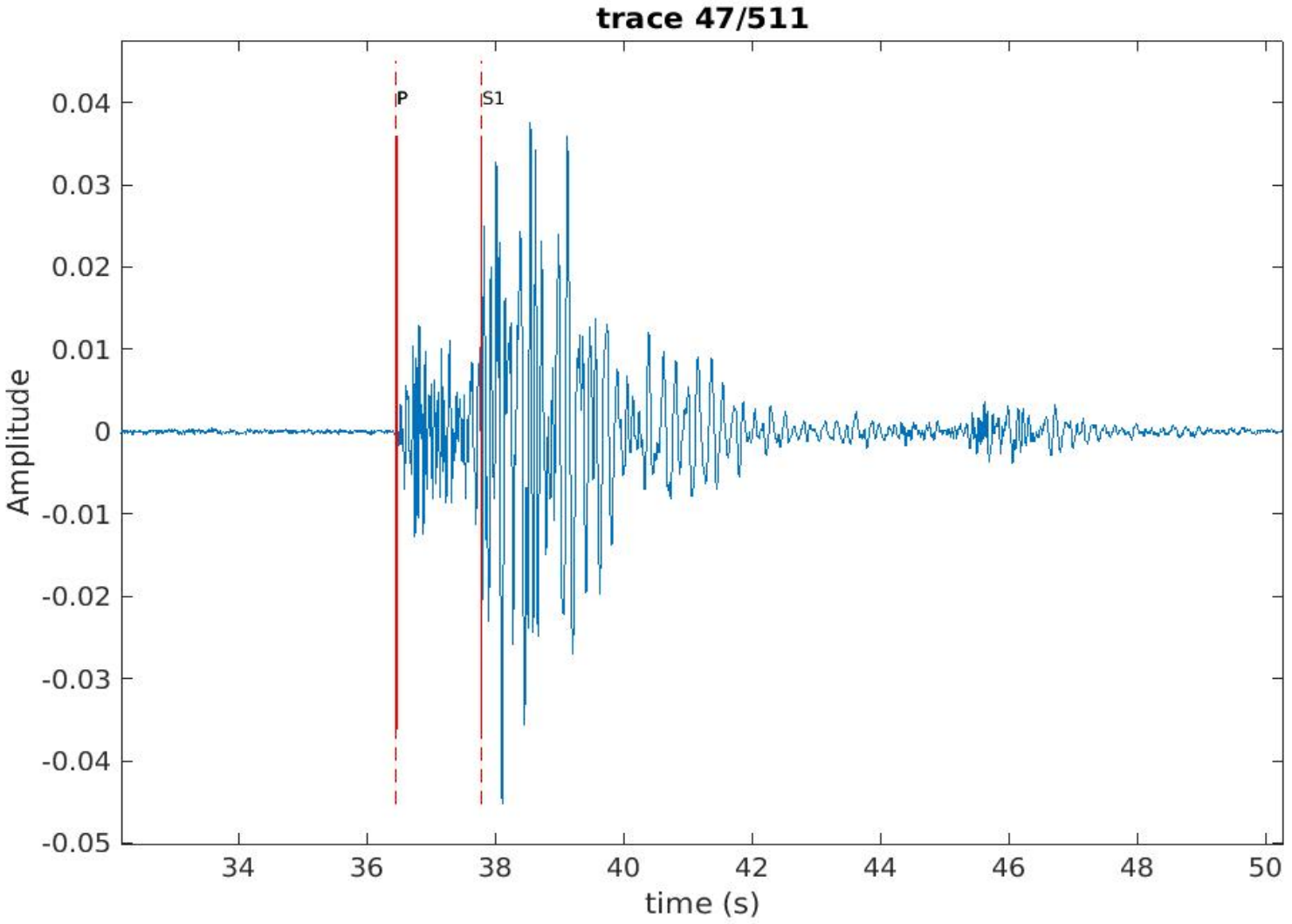
With a telecom cable



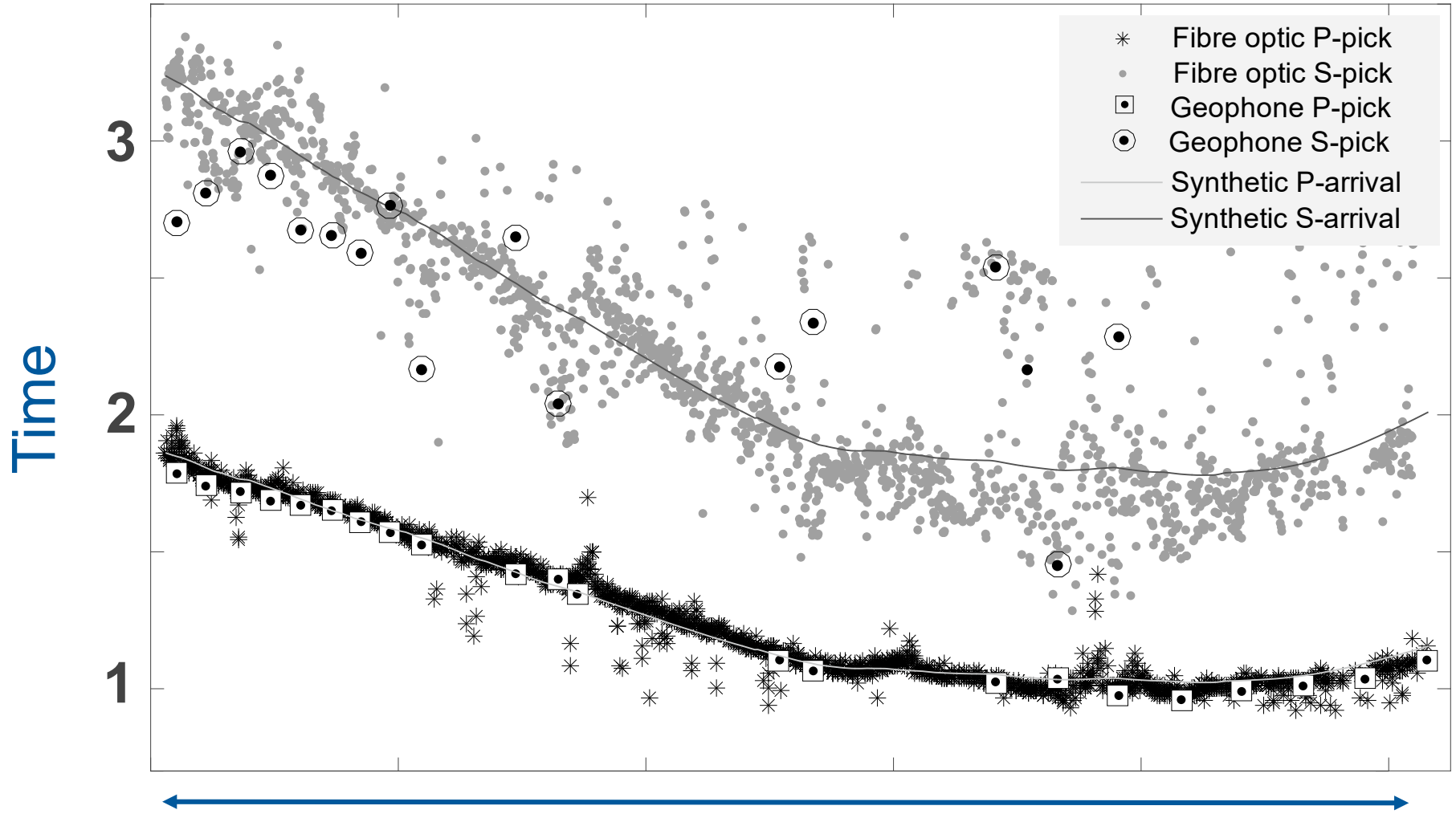
- IMO 23.03.2015 16:07:08.53
- Depth: 3.563 km
- Magnitude: 1.02Ml
- Location: Beneath Cable

Automatic picking required

Akaike Information Criteria picker



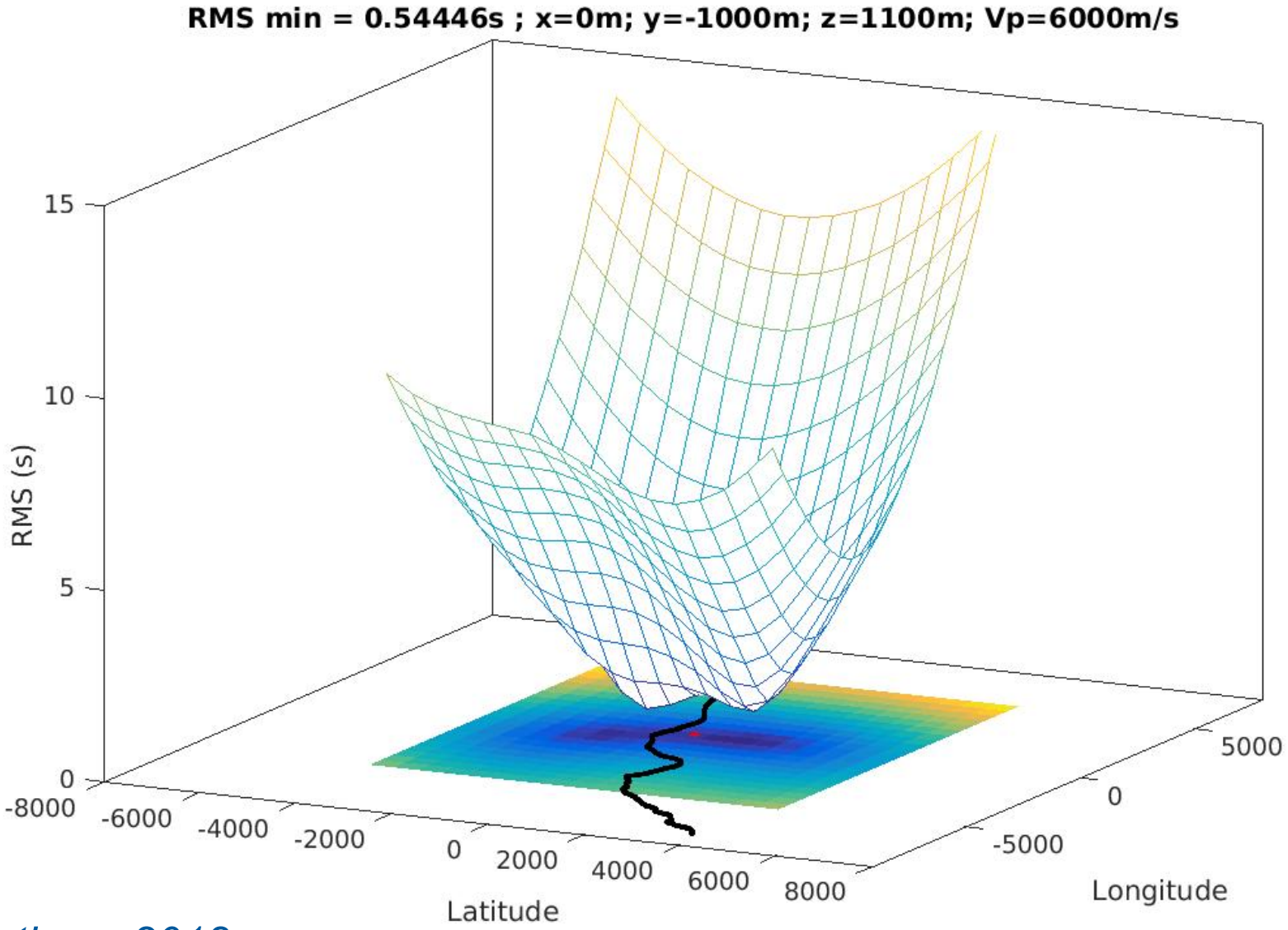
Automatic picking based of AIC picker



Jousset et al., Nature Communications, 2018

Locating the event hypocenter

Grid search, RMS

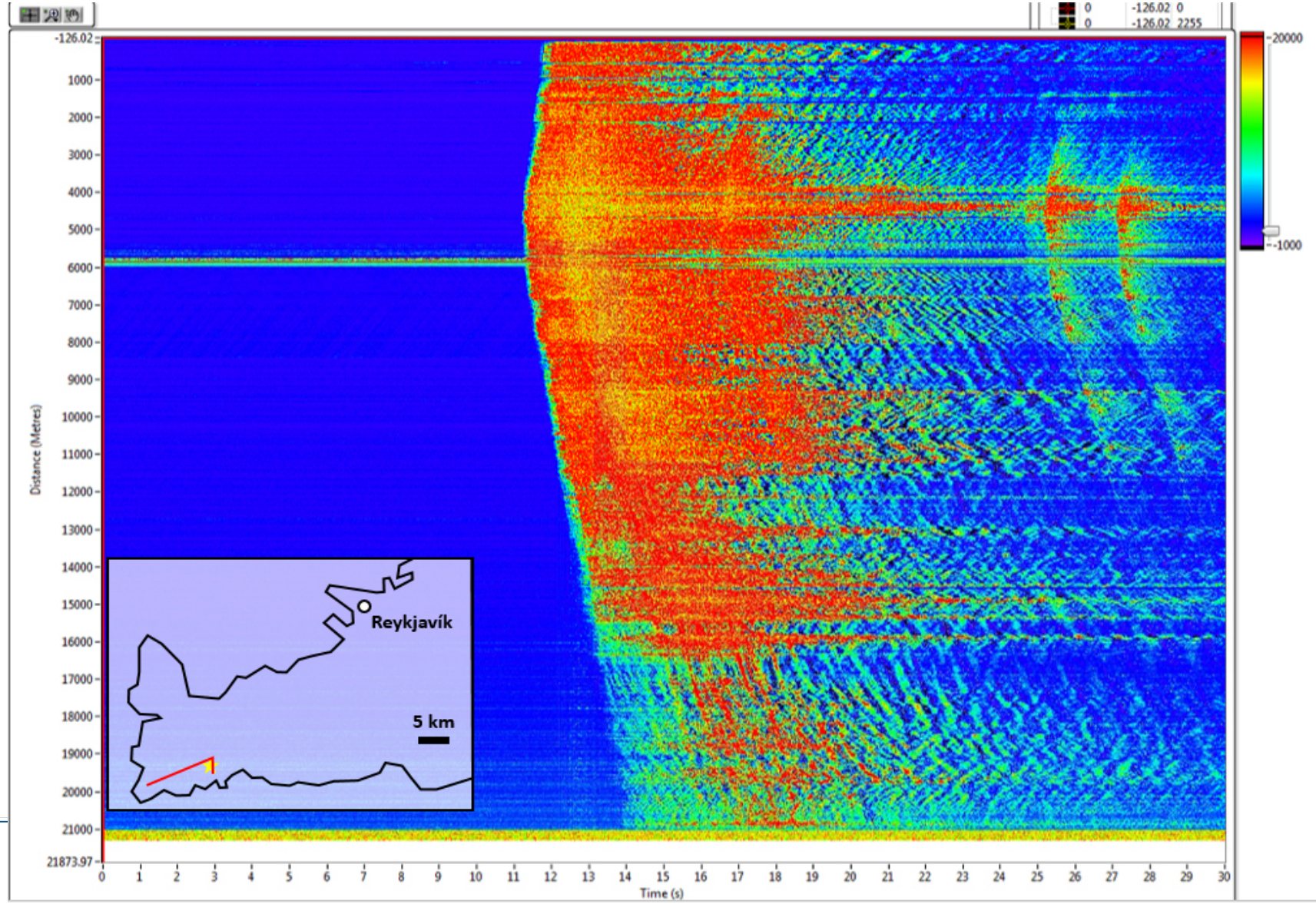


Event found at < 900 m
for the IMO location

Jousset et al., Nature Communications, 2018

a M4.7 earthquake – Prior to Reykjanes eruption

12.03.2020



Press release

https://www.gfz-potsdam.de/en/media-and-communication/news/all/article/earthquake-in-iceland-registered-via-fibre-optic-telephone-cable/

Flovenz et al, accepted, Nature Geosciences

Image fault zones

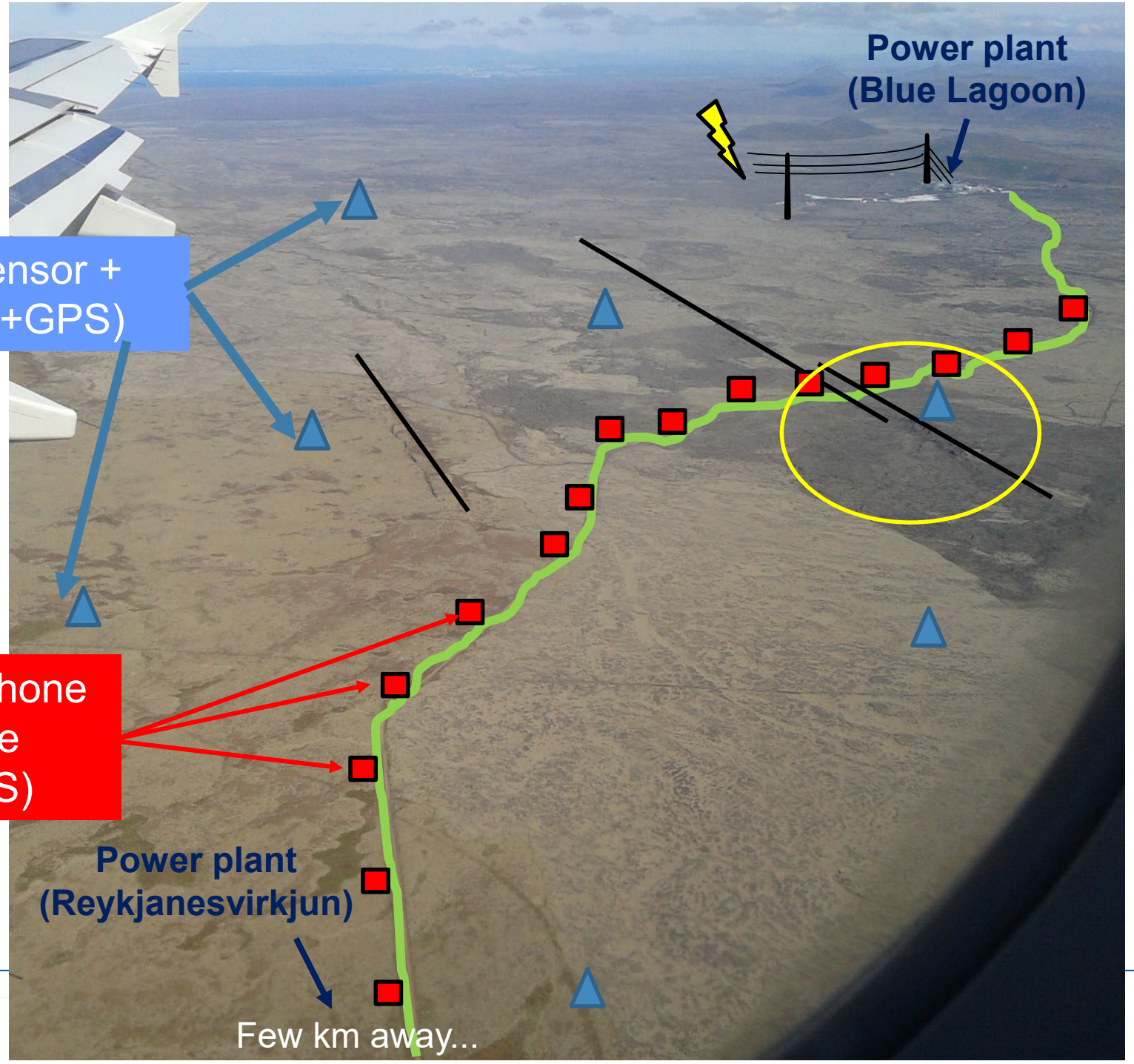


Image fault zones

With optical cable
and an earthquake

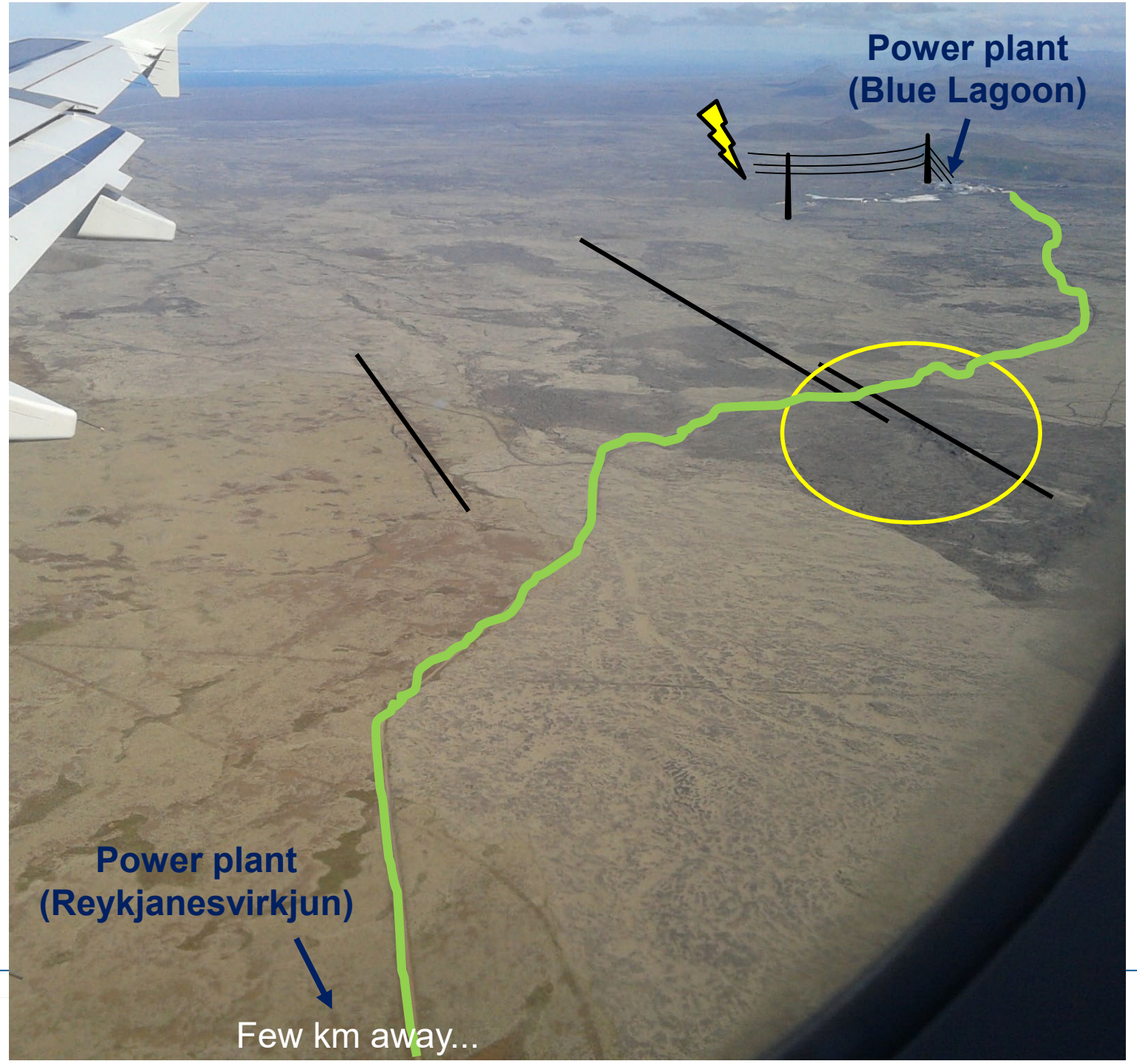
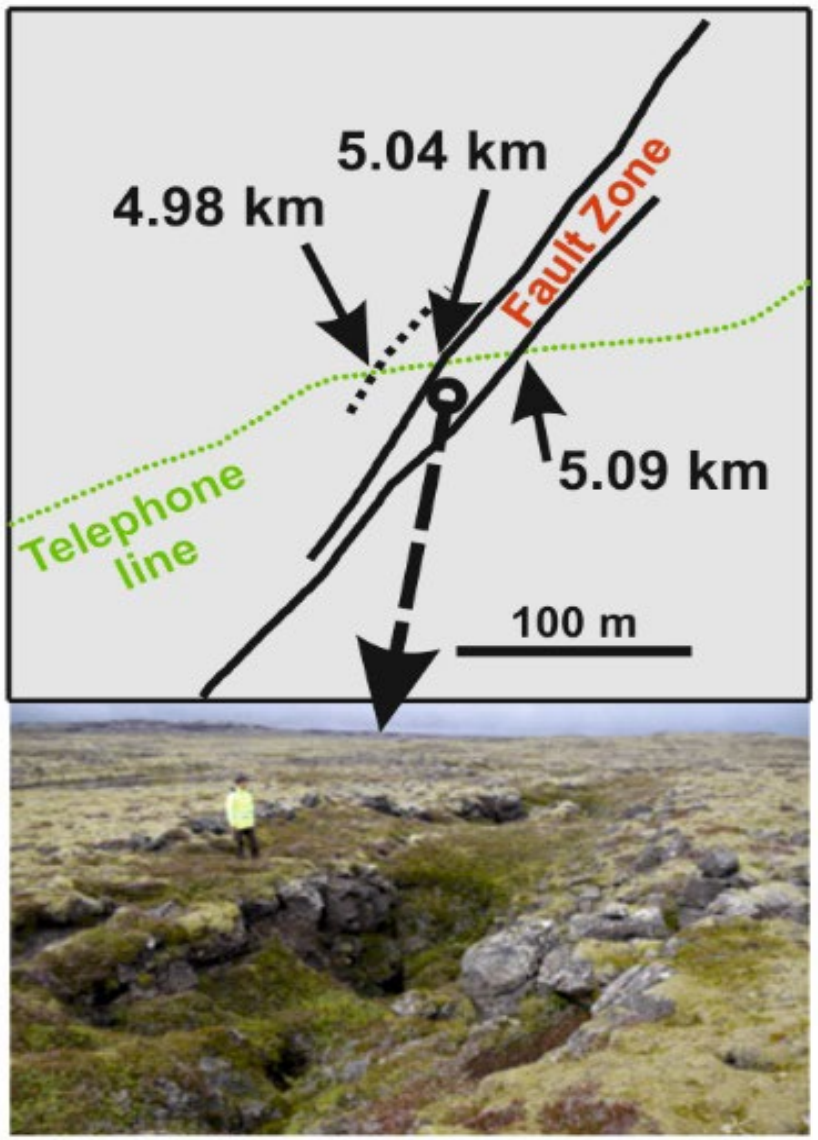
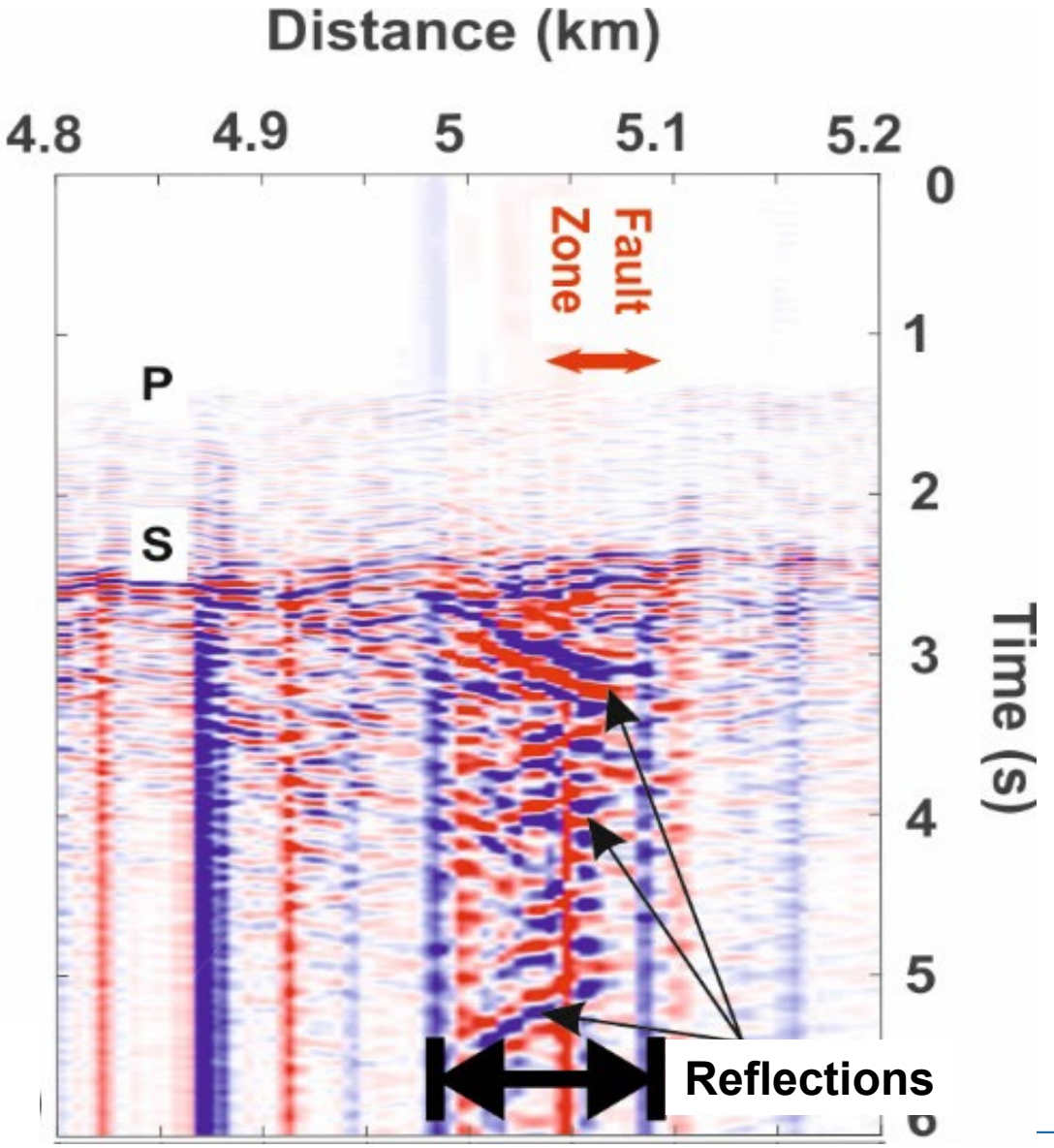


Image fault zones





Jousset et al., Nature Communications, 2018

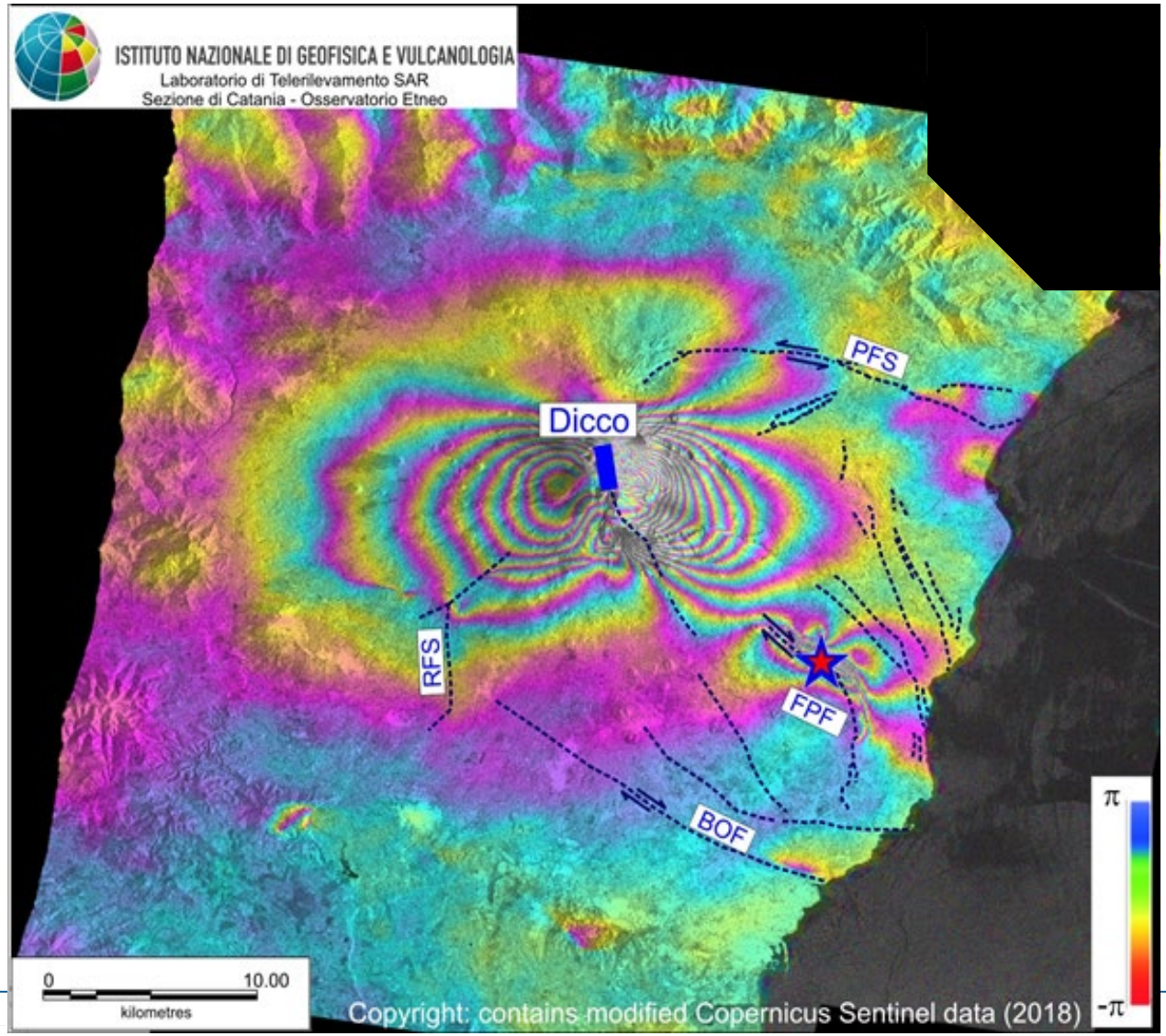
Monitoring of volcanic activity

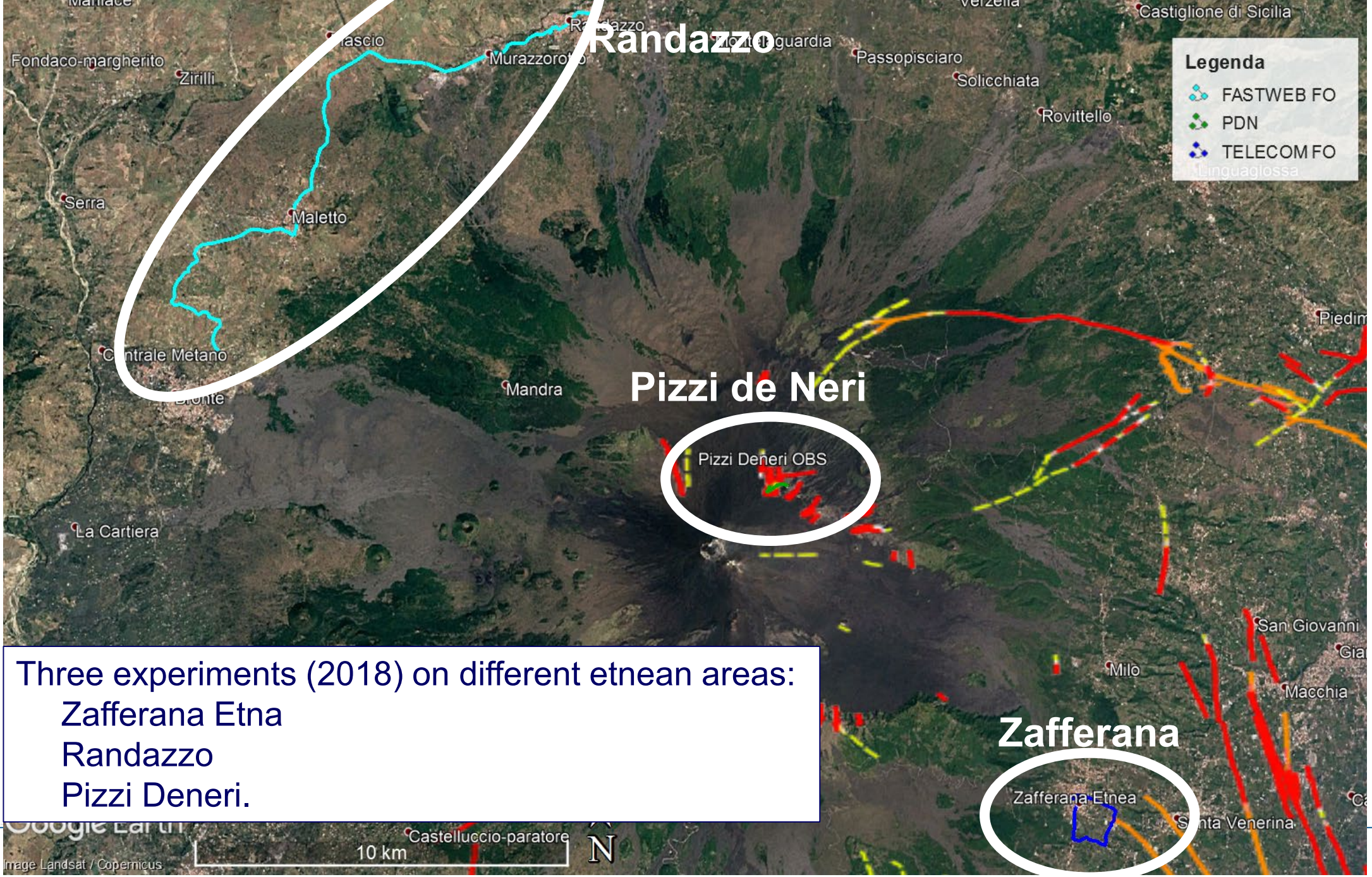
Picture: Mimmo Palano (INGV)

Eruption 24 December 2018

Phenomena questioned: Earthquakes, Faults, Volcanoes, Landslides, Tsunamis, Lava flows, Ash fall, etc.

Does the sliding of the Eastern flank triggers eruptions, or do magma intrusions pushes the flank to the East?





Three experiments (2018) on different etnean areas:

- Zafferana Etna
- Randazzo
- Pizzi Deneri.

August 2018

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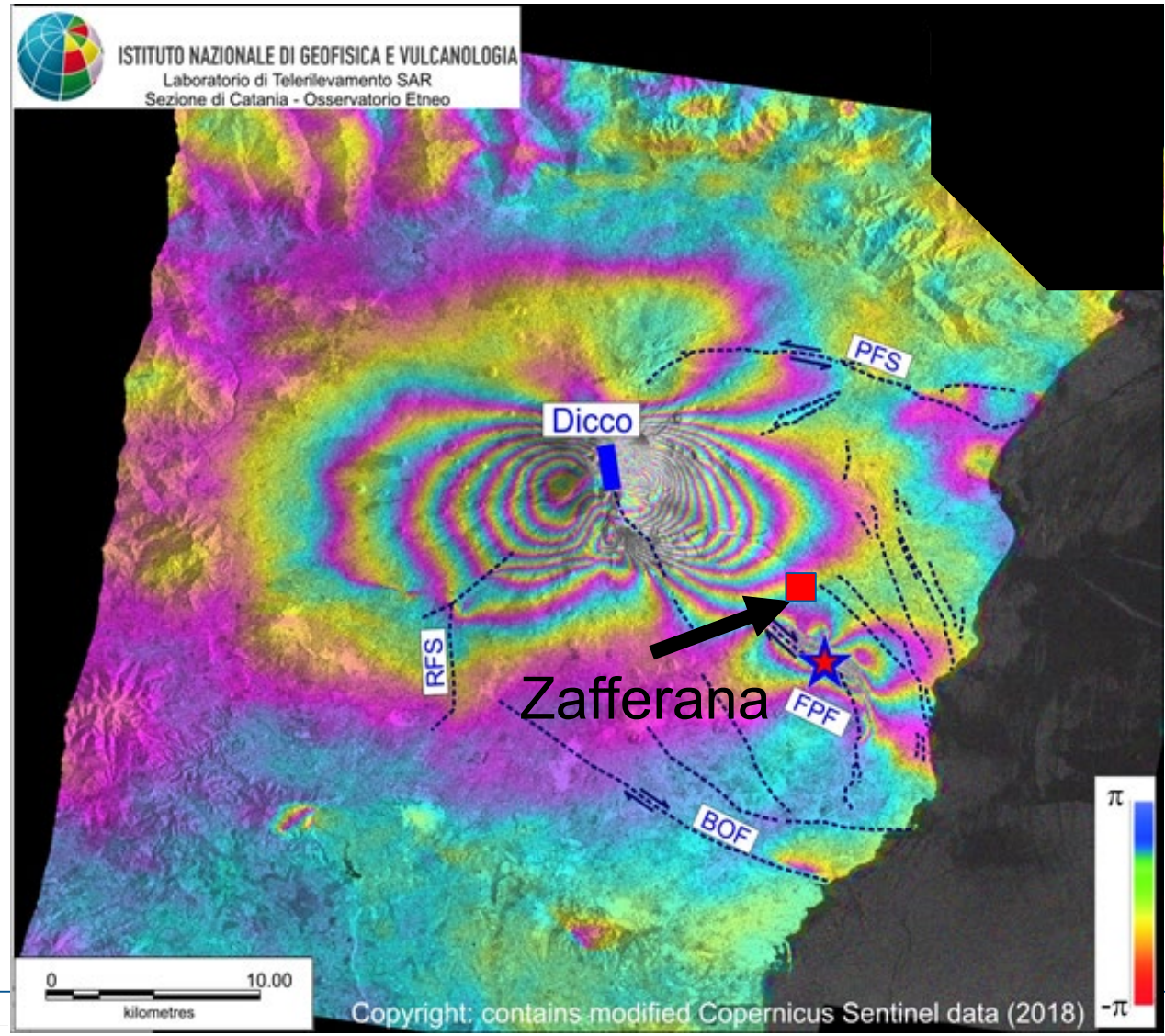
Zafferana Etna: urban seismology

School gave access to its internet connection fibre (August 2018)

Telecom Italia

INGV



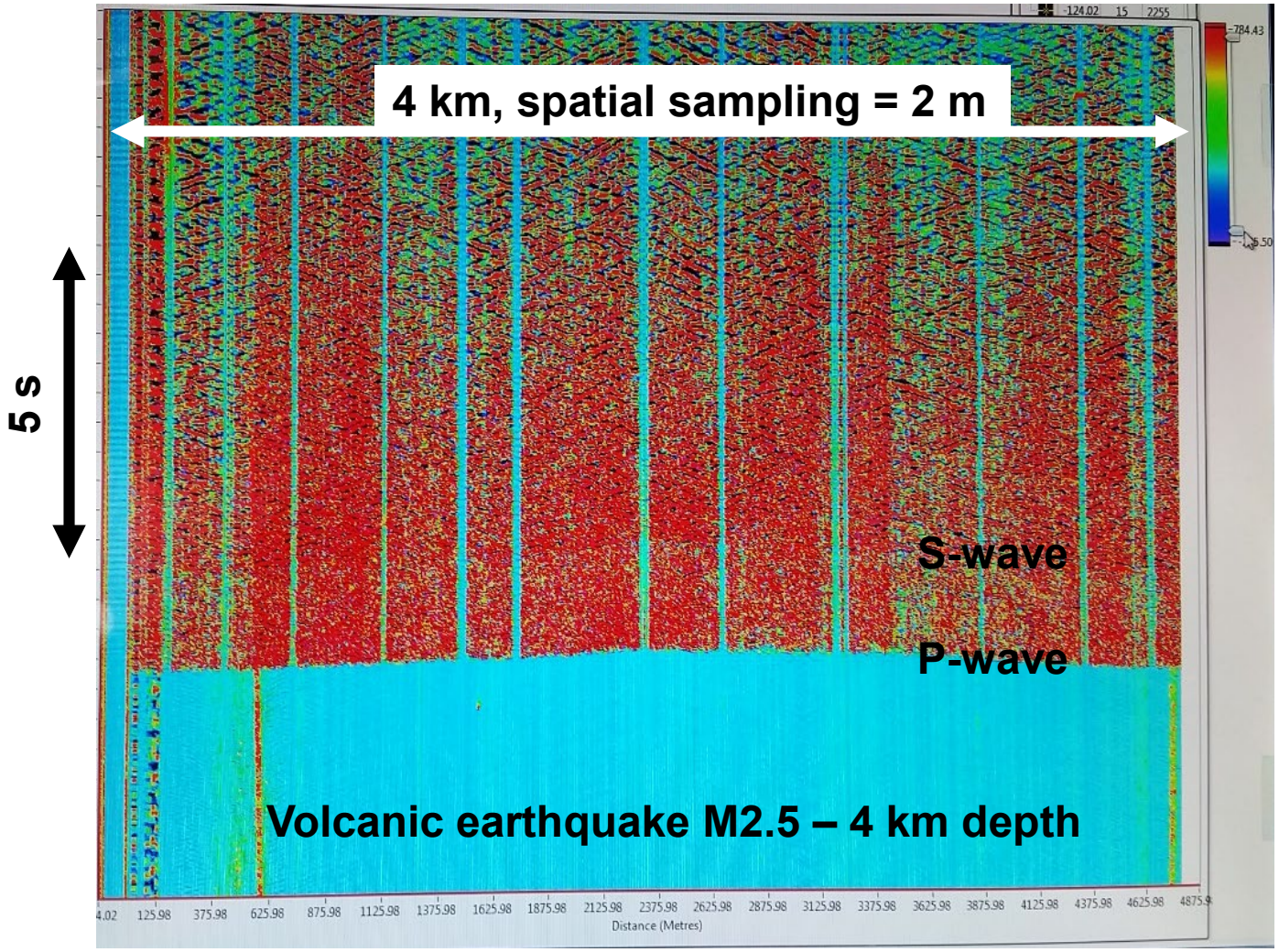
Zafferana Etna: urban seismology

GFZ equipment in a school

Great interest and motivation!

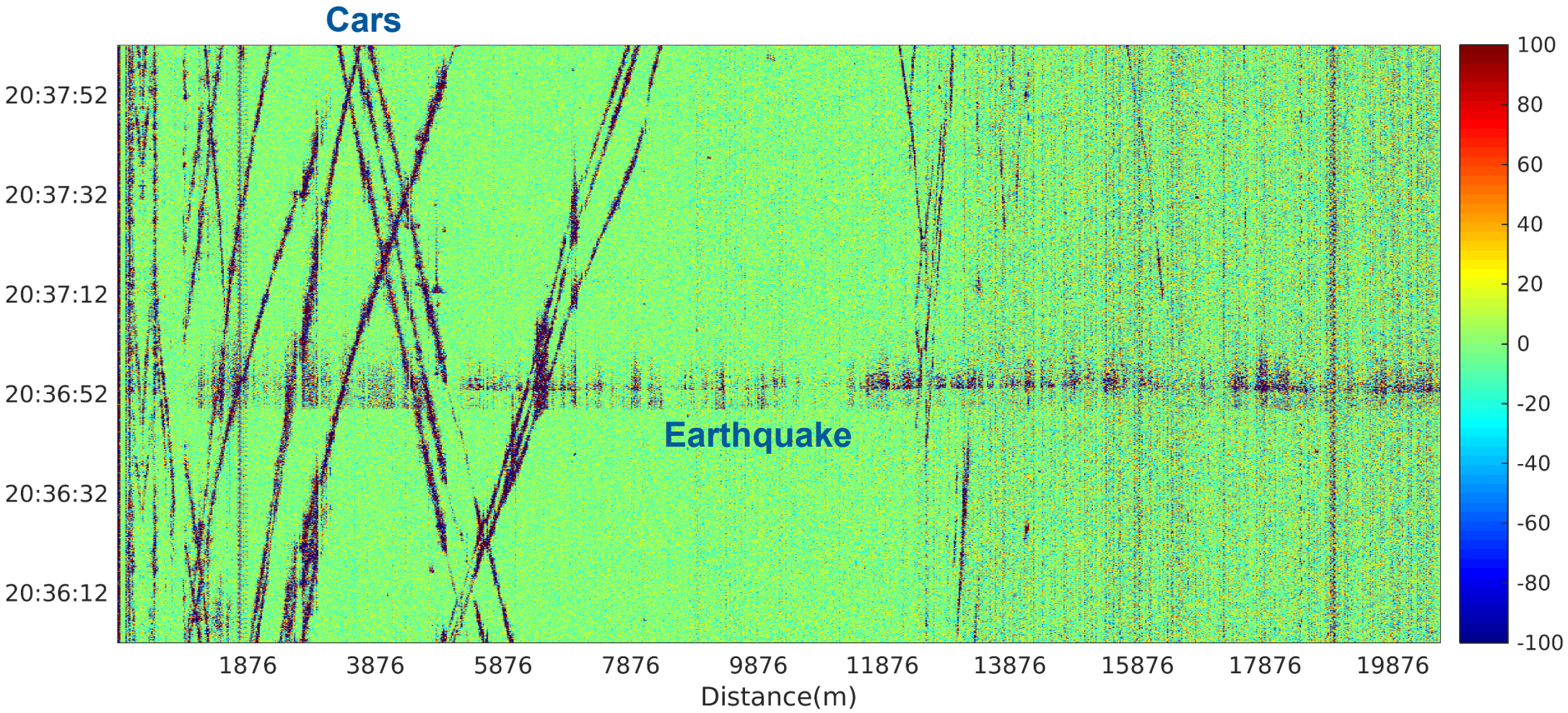
Zafferana Etna: urban seismology

Volcanic earthquake recorded



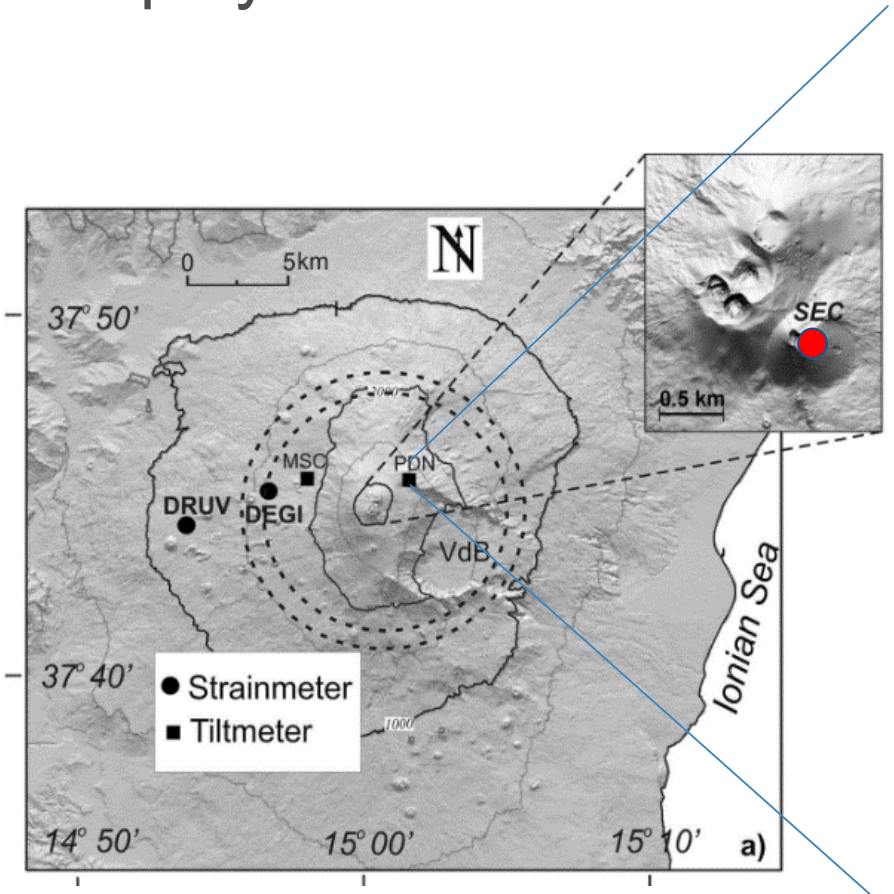
Randazzo: Monitoring of deep seismic activity

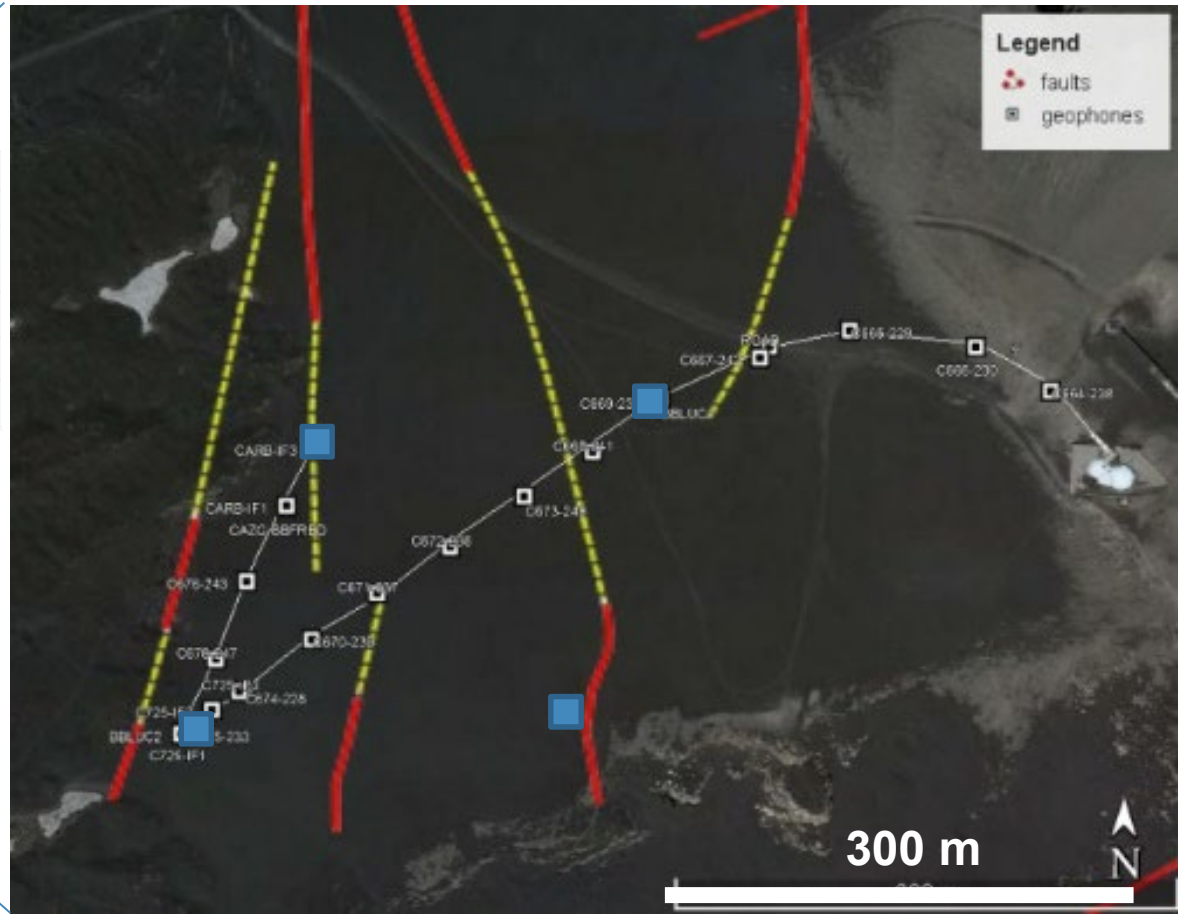
Earthquake observed at 20 km long array



Pizzi Deneri: eruptive activity

Deployment at Etna summit



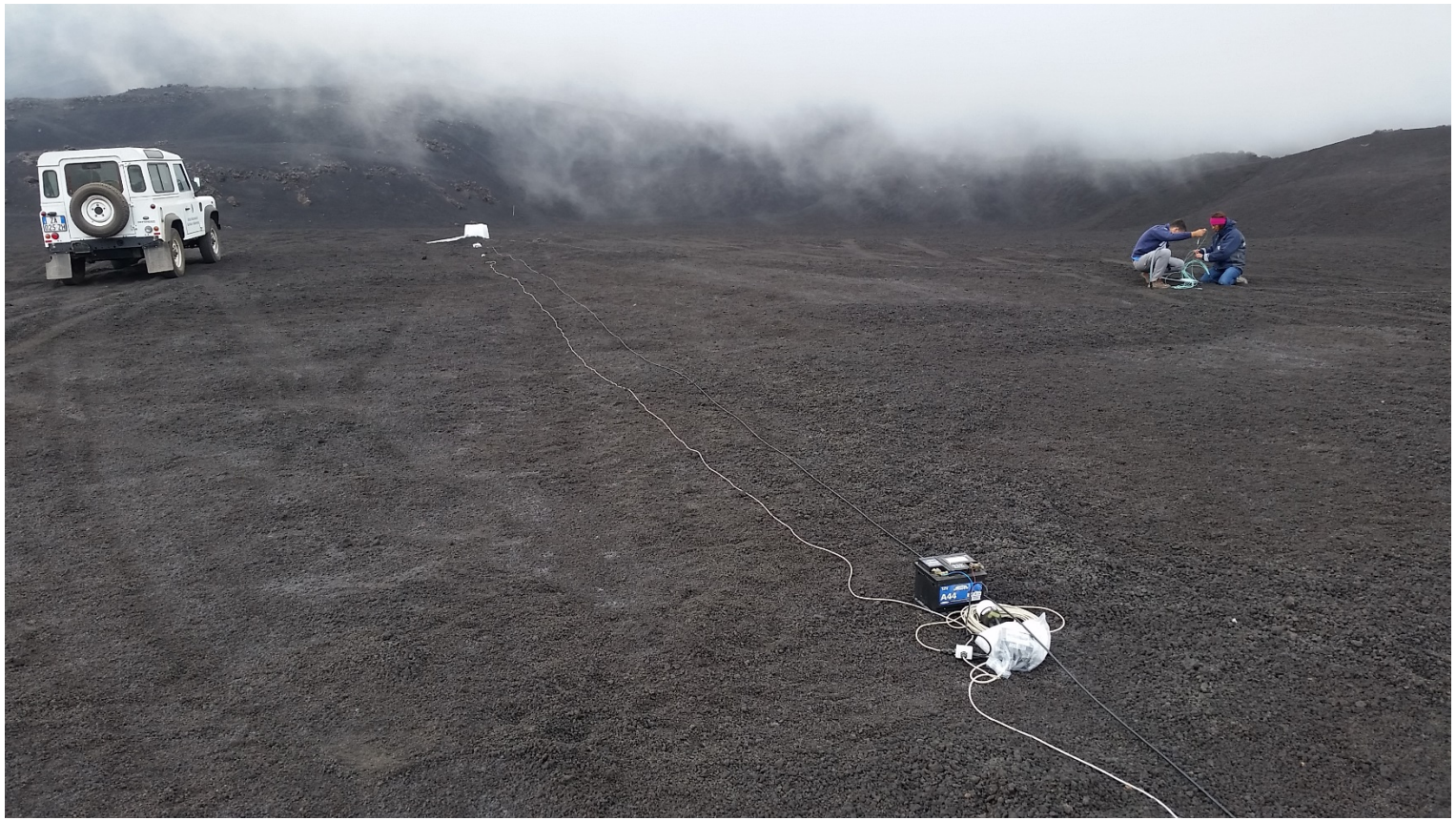


- Broad band station INGV
- Cube and geophone GIPP
- Optical cable : data transmission + DAS

Volcanic processes

Explosion at New-Southeast Crater (NSEC)

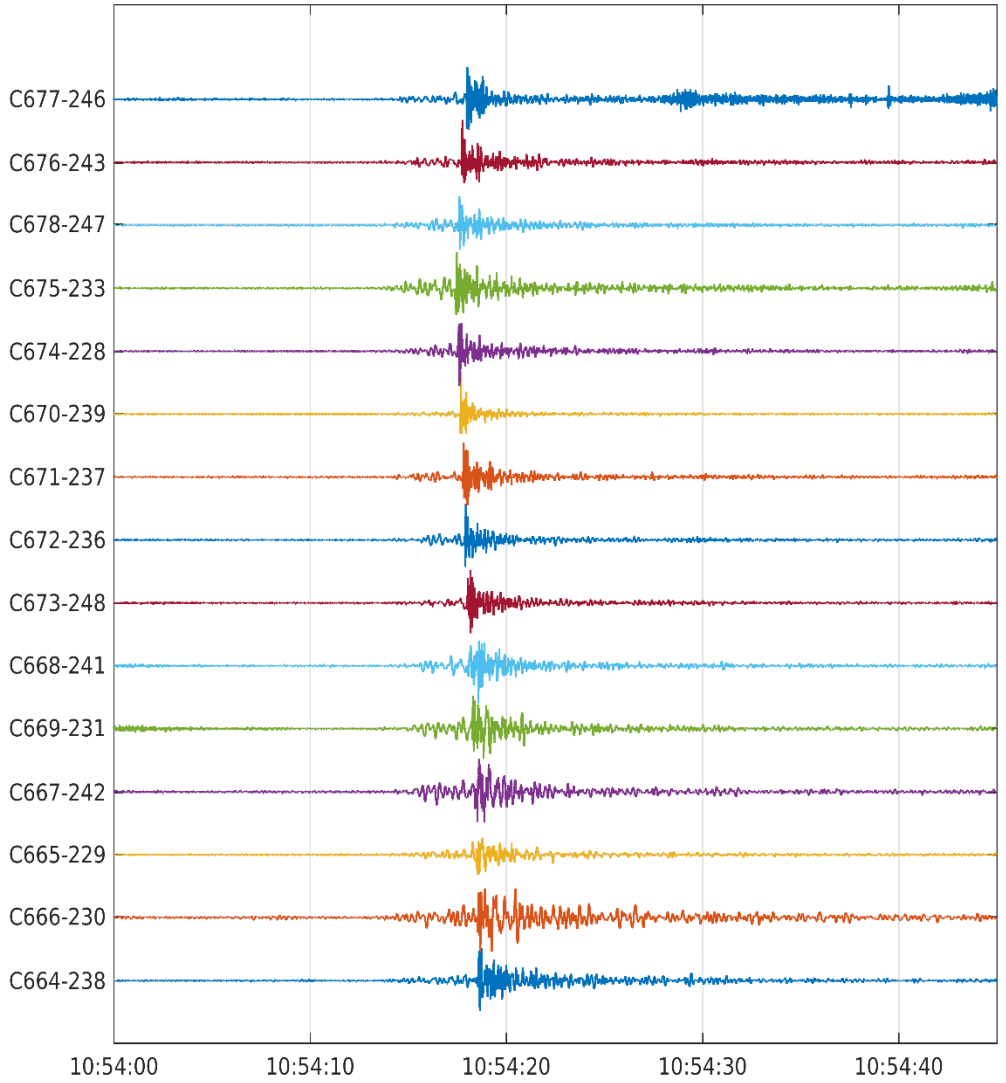
Explosion 05.09.2018

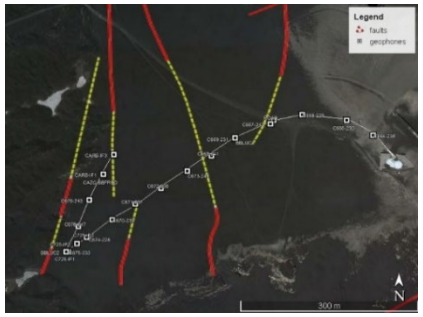


Volcanic processes

Explosion at NSEC

Explosion recorded by collocated infrasound and seismometers





Geophone array

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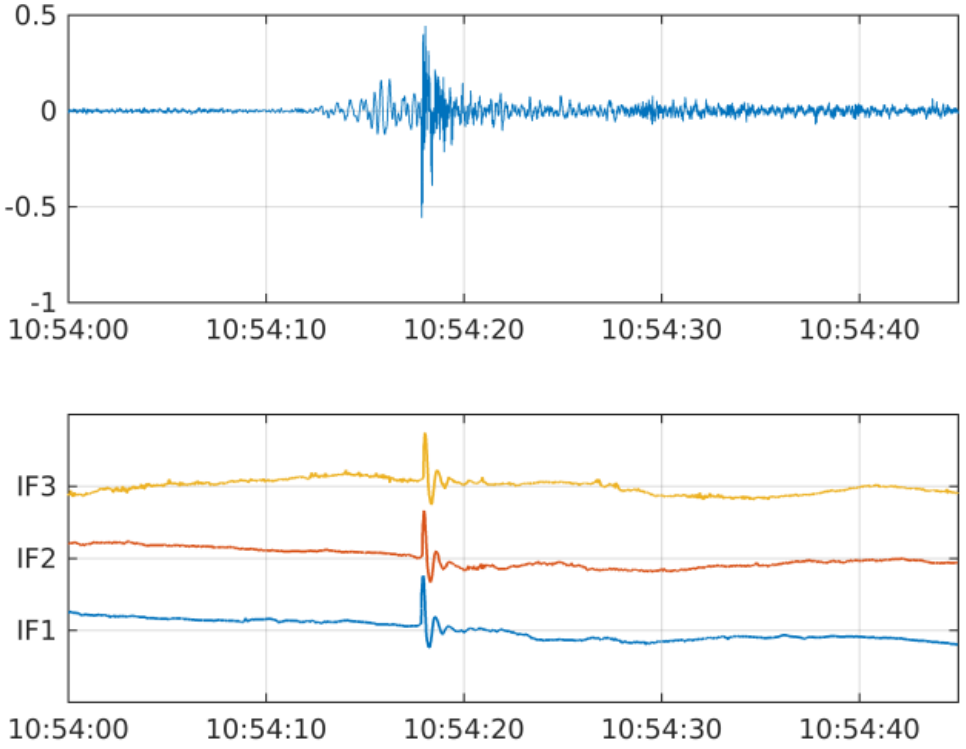
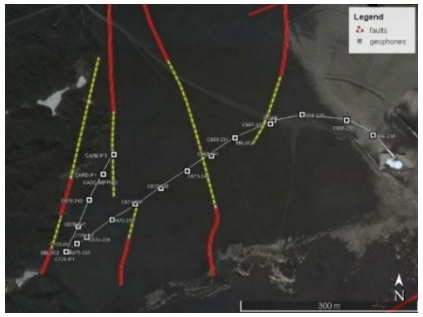
Volcanic processes

Explosion at NSEC



BB sensor

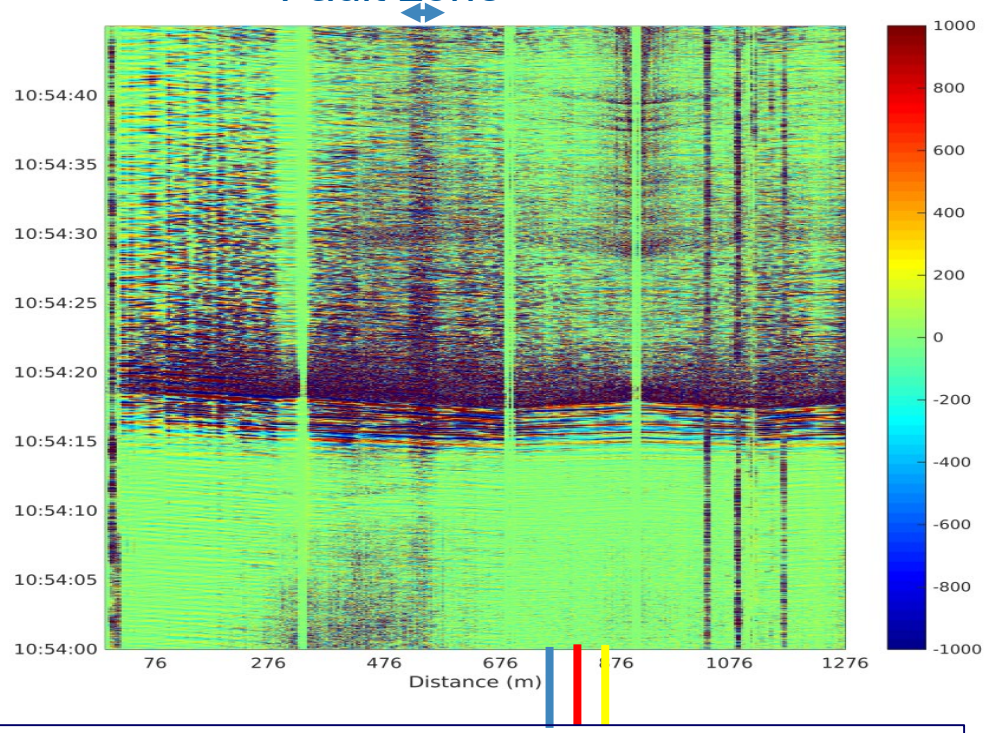


Infrasound array

Explosion recorded by collocated infrasound and seismometers

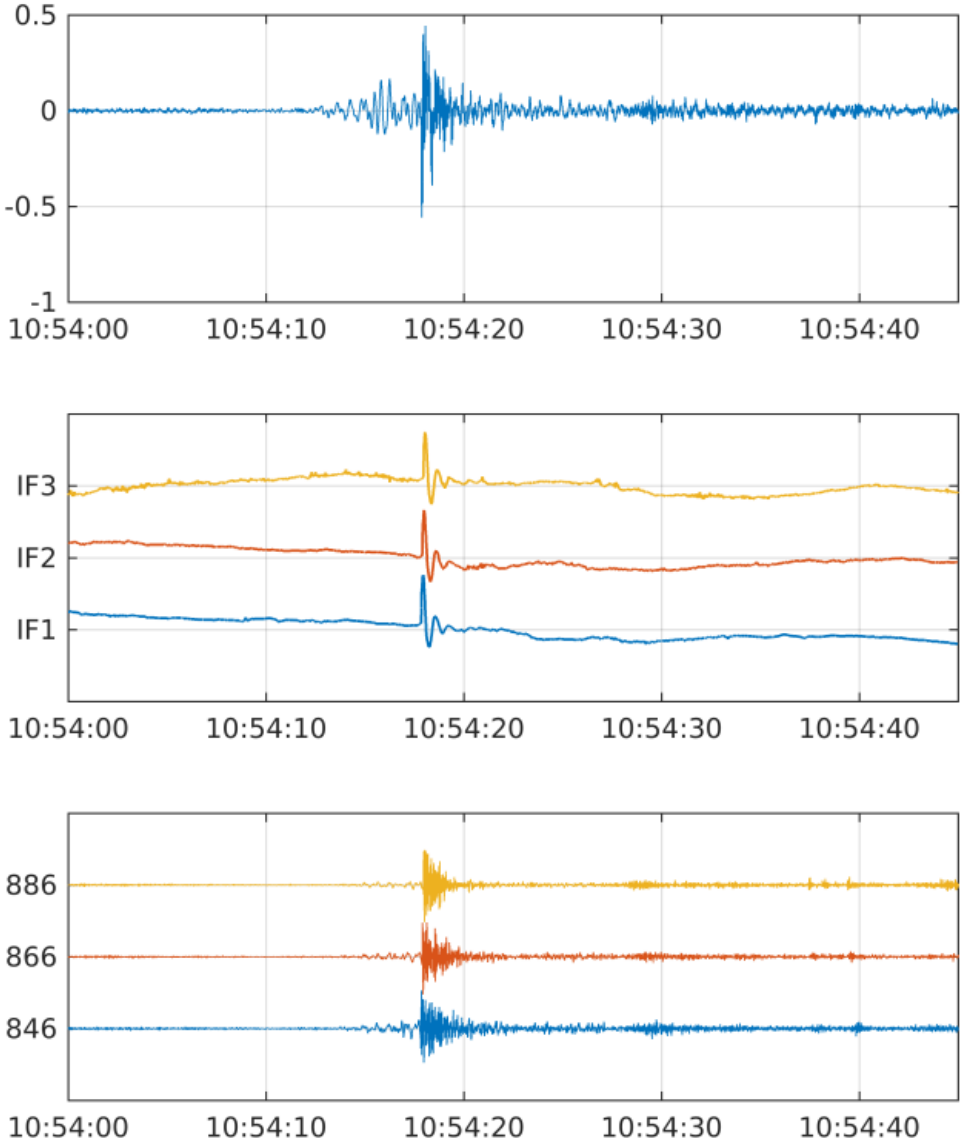
NSEC explosion on 5 Sep 2018

Fault zone

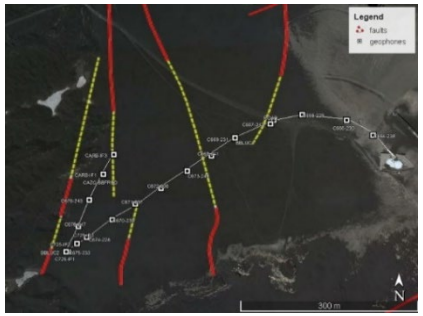


iDAS record during the explosive event at NSEC.

* 0 to 700 m is radially oriented.
* Cable is rotated by 30° from 700 to 900 m.
* From 900 m onward the cable follows the previous path in the opposite direction, at a shallower depth (few cm).
* A fault zone (about 40 m wide) is detected at a distance of about 550 m along the cable in correspondence of the fault trace.



BB sensor



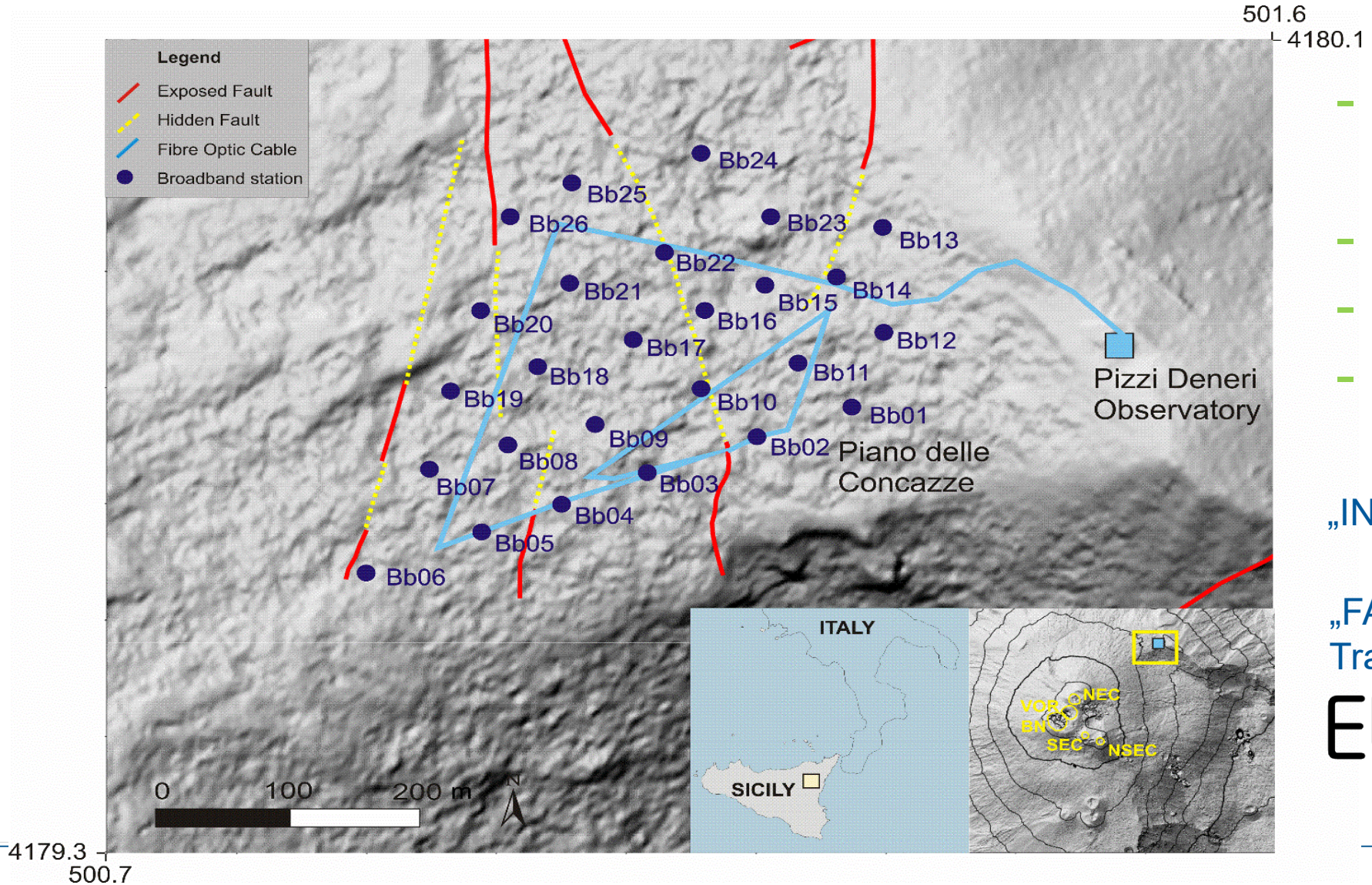
Infrasound array

Idas traces

Jousset et al., accepted, Nature Communication

Multiparameter station deployment (2850 m)

2 km from summital active craters



- 26 BB Trillium (GIPP)
- 3 IF arrays
- 1 Tiltmeter
- Fibre optic cable

„INFRADAS“ GFZ funds

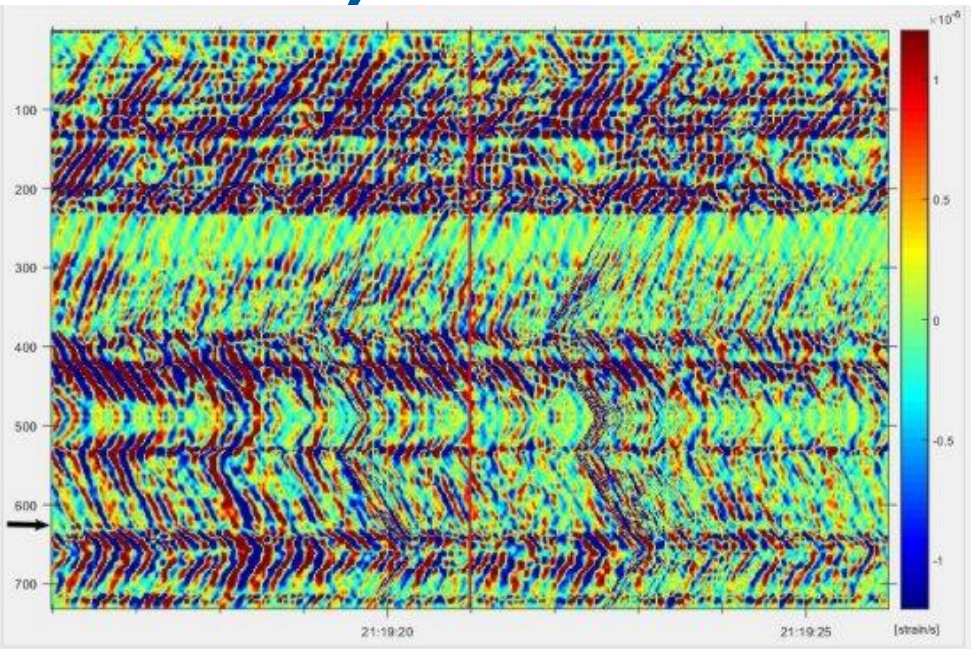
„FAME“
Transnational Access
EUROVOLC

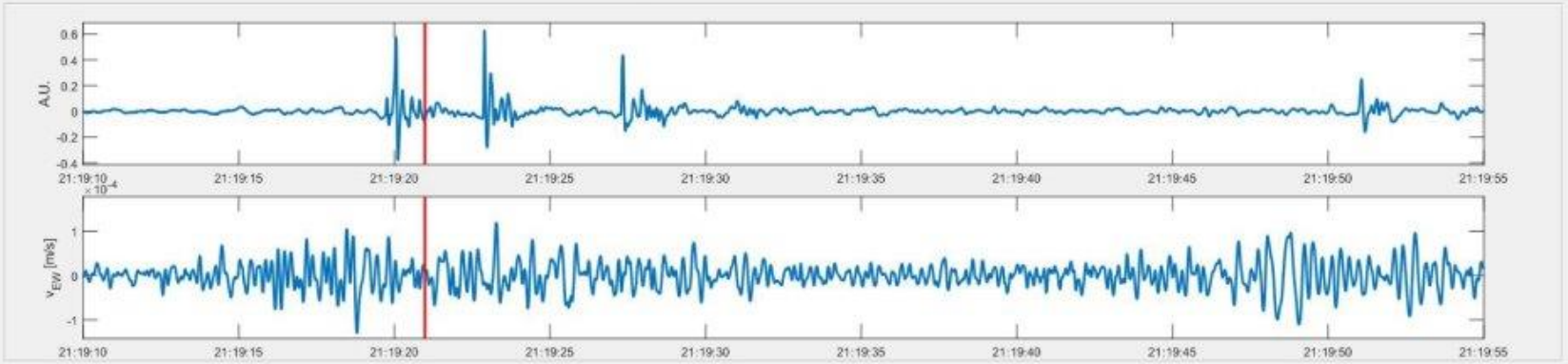
ISTITUTO NAZIONALE
DI GEOFISICA E VULCANOLOGIA

Currenti et al., 2021

Strombolian volcanic activity in Voragine crater (Septembre 2019)

Dario La Scavo Photographer





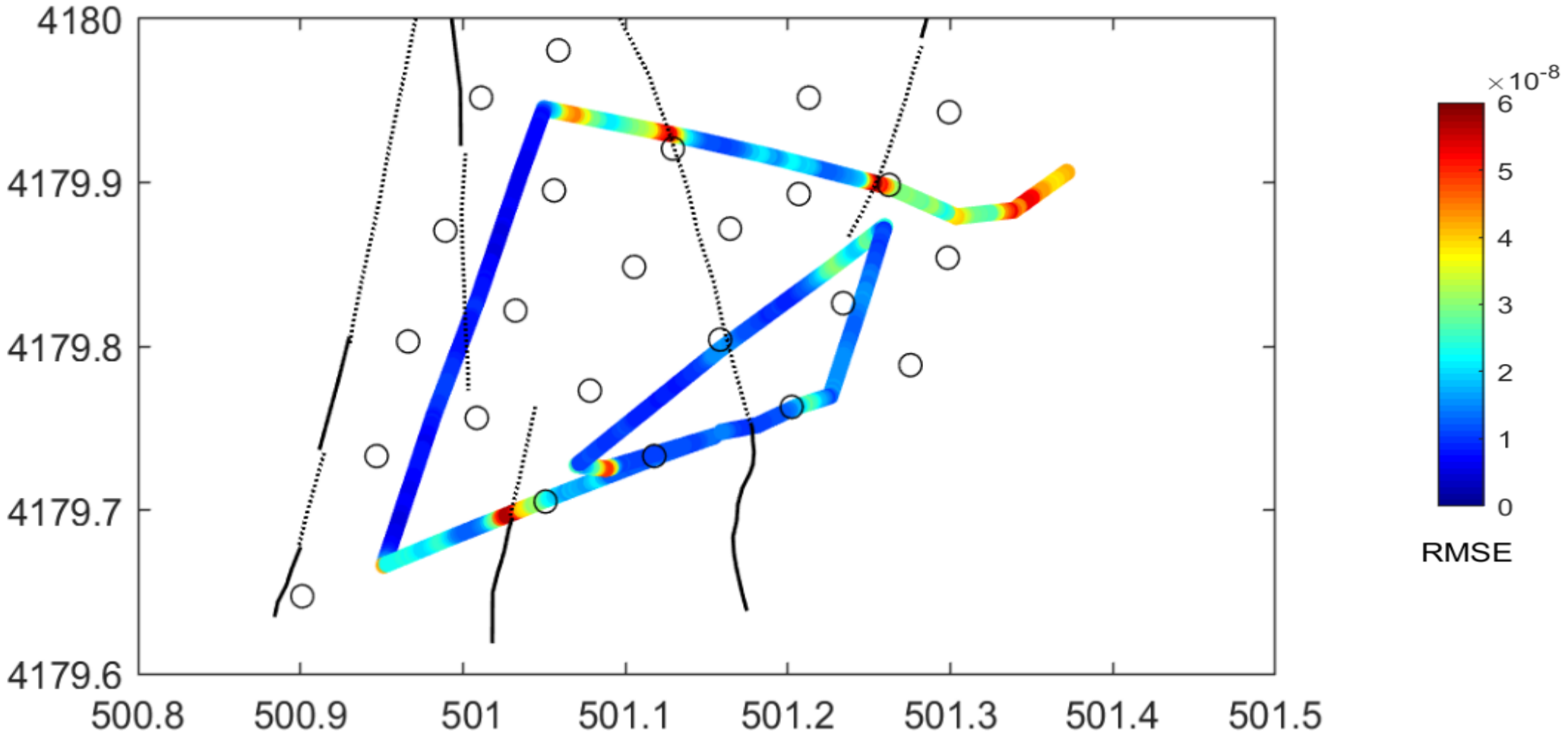
INFRASOUND

SEISMOMETER (BB)

Jousset et al., 2020

Strombolian explosion (06.07.2019)

RMS error between interpolated (large-N) and DAS observations



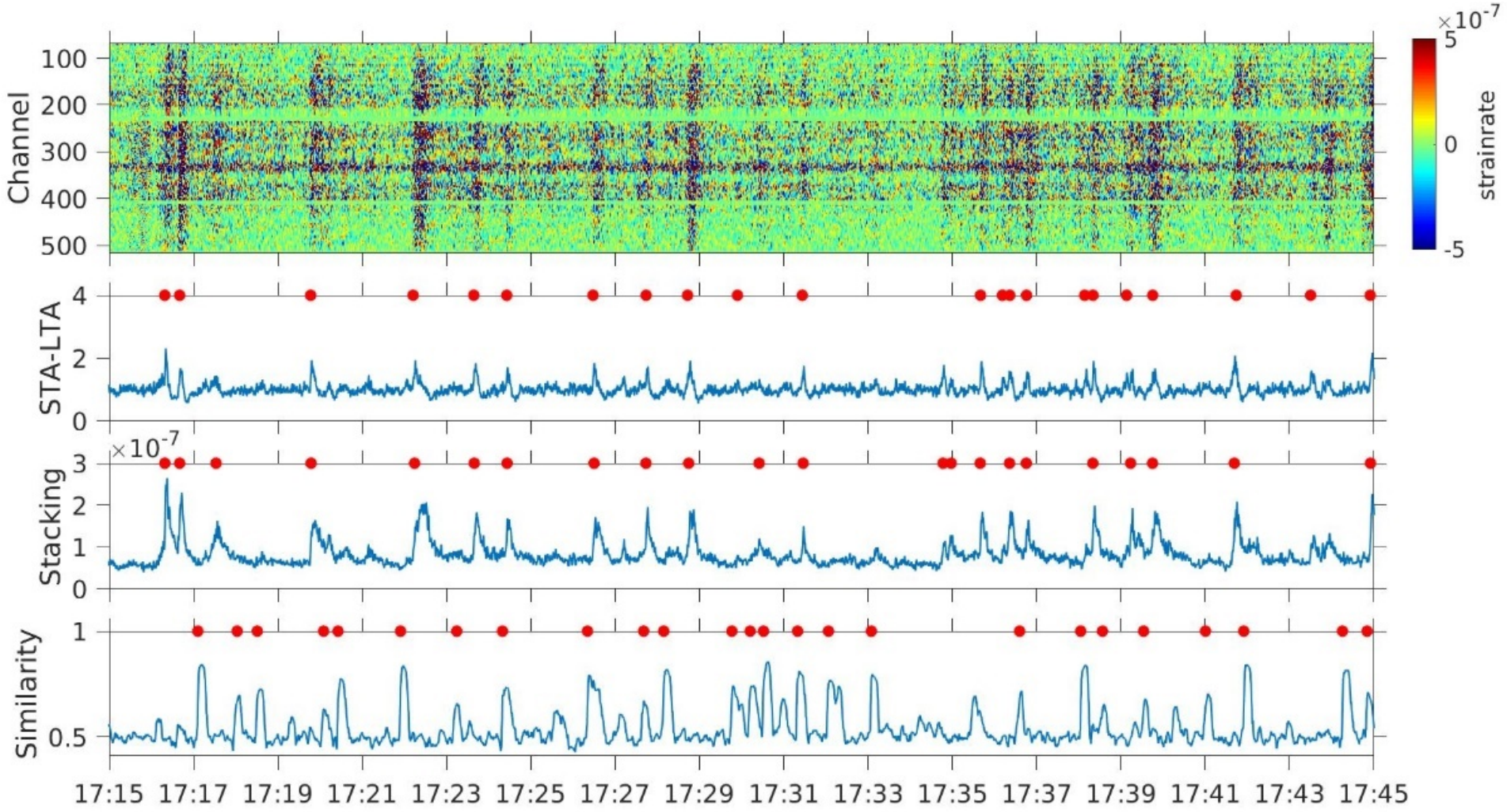
Currenti et al., 2021, Solid Earth: special issue on „Fibre optic sensing in Earth Science“

Degassing events and single tremor pulses

Several methods applied to detect small events

1. STA/LTA
2. Stacking
3. Similarity

Each method detect different event types



Jousset et al., 2020, AGU; Jousset et al., accepted, Nature Communications

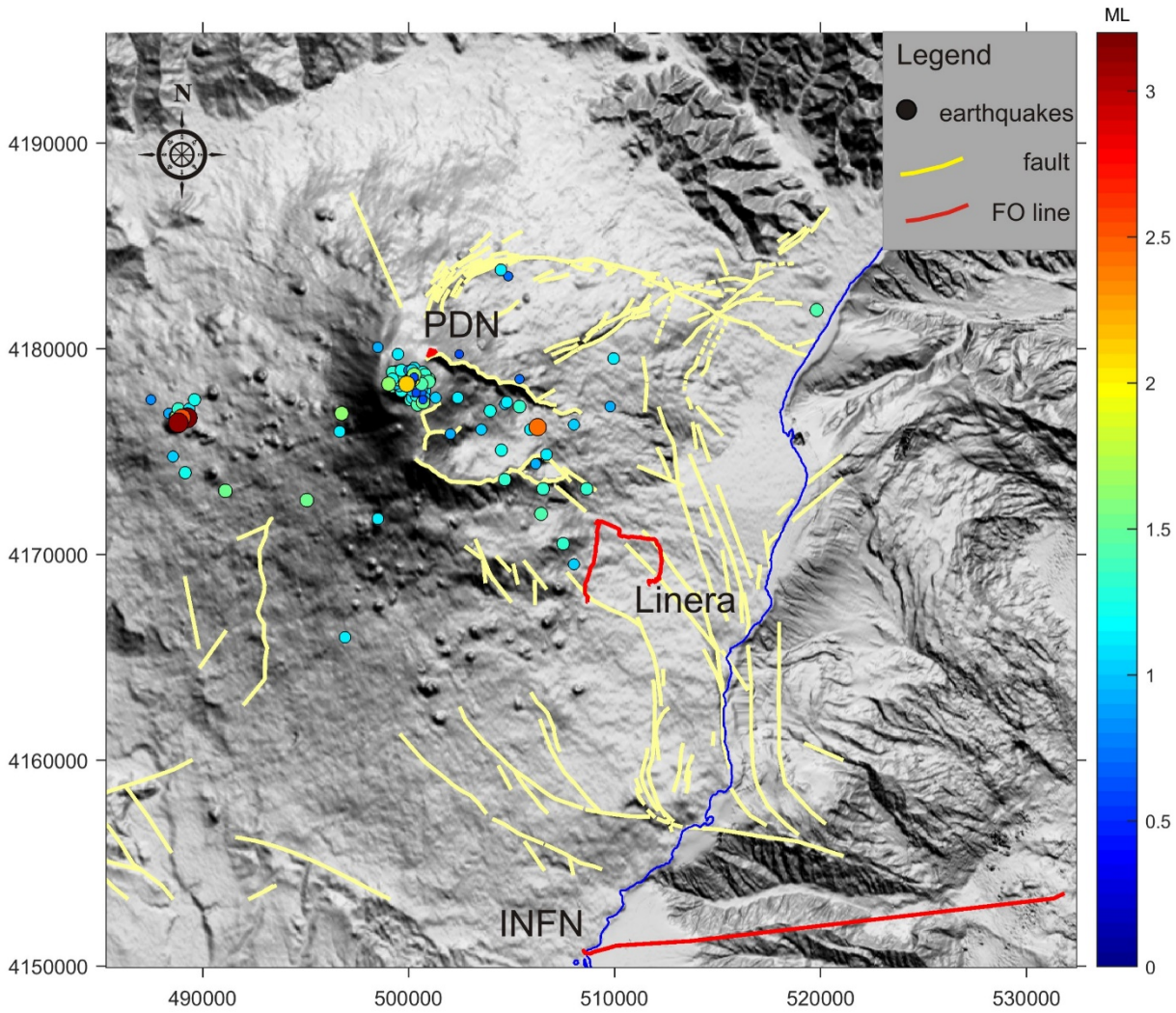
Simultaneous records of 3 iDAS units

PDN - Pizzi Deneri Summit array:
- self-deployed telecom cable (1.5 km)

Linera array:
- TIM internet cable in urban areas (12 km)

INFN-LNS array - ERC FOCUS –
Marc Andre Gutscher (Brest)
- Submarine Observatory (25 km)

The 3 arrays were simultaneously recording from 11 to 23 September 2019, when 134 local seismic events (see map on the right) and 9 regional and teleseismic events (M>=5) occurred.



Krawczyk et al., EGU 2020

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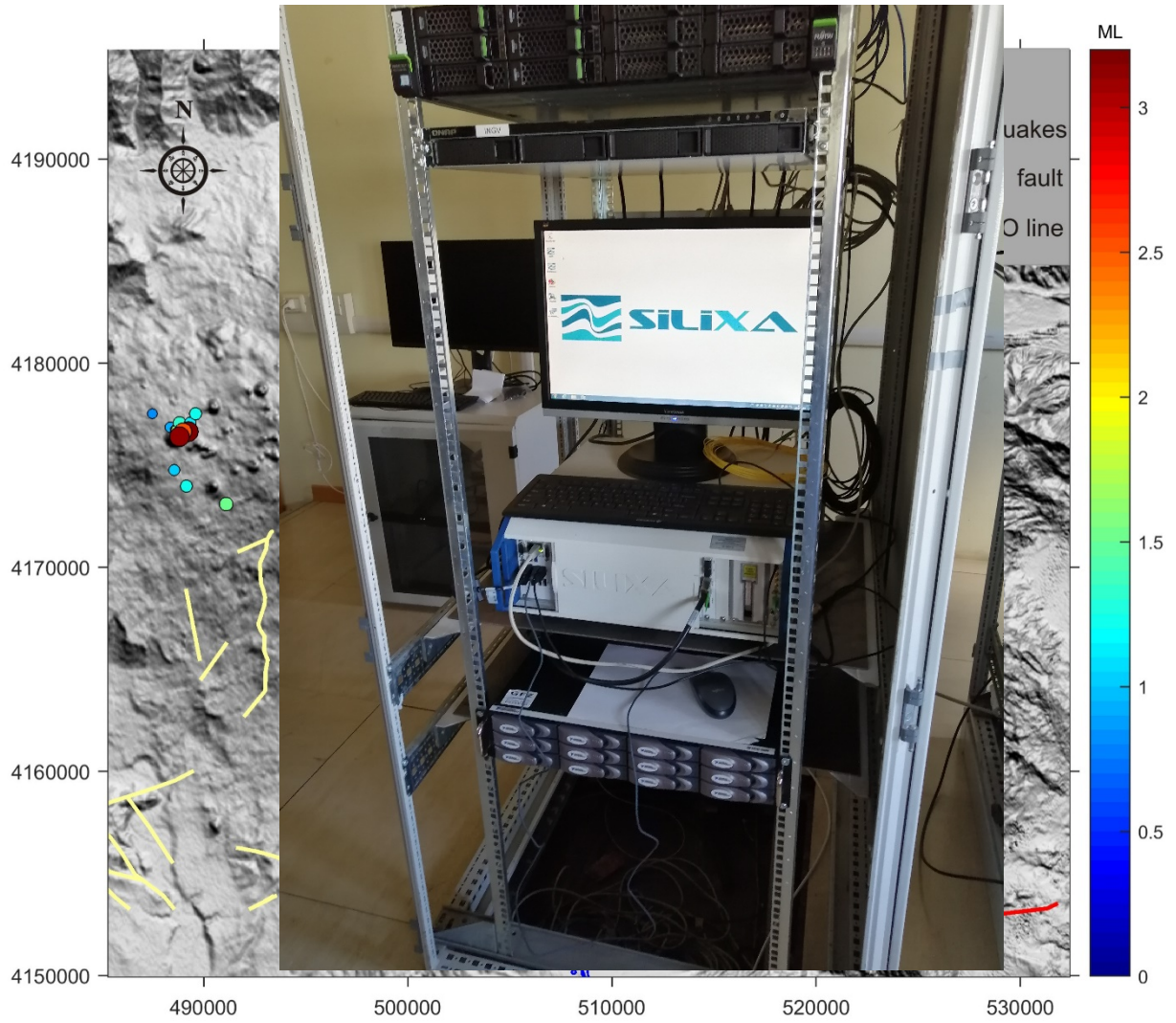
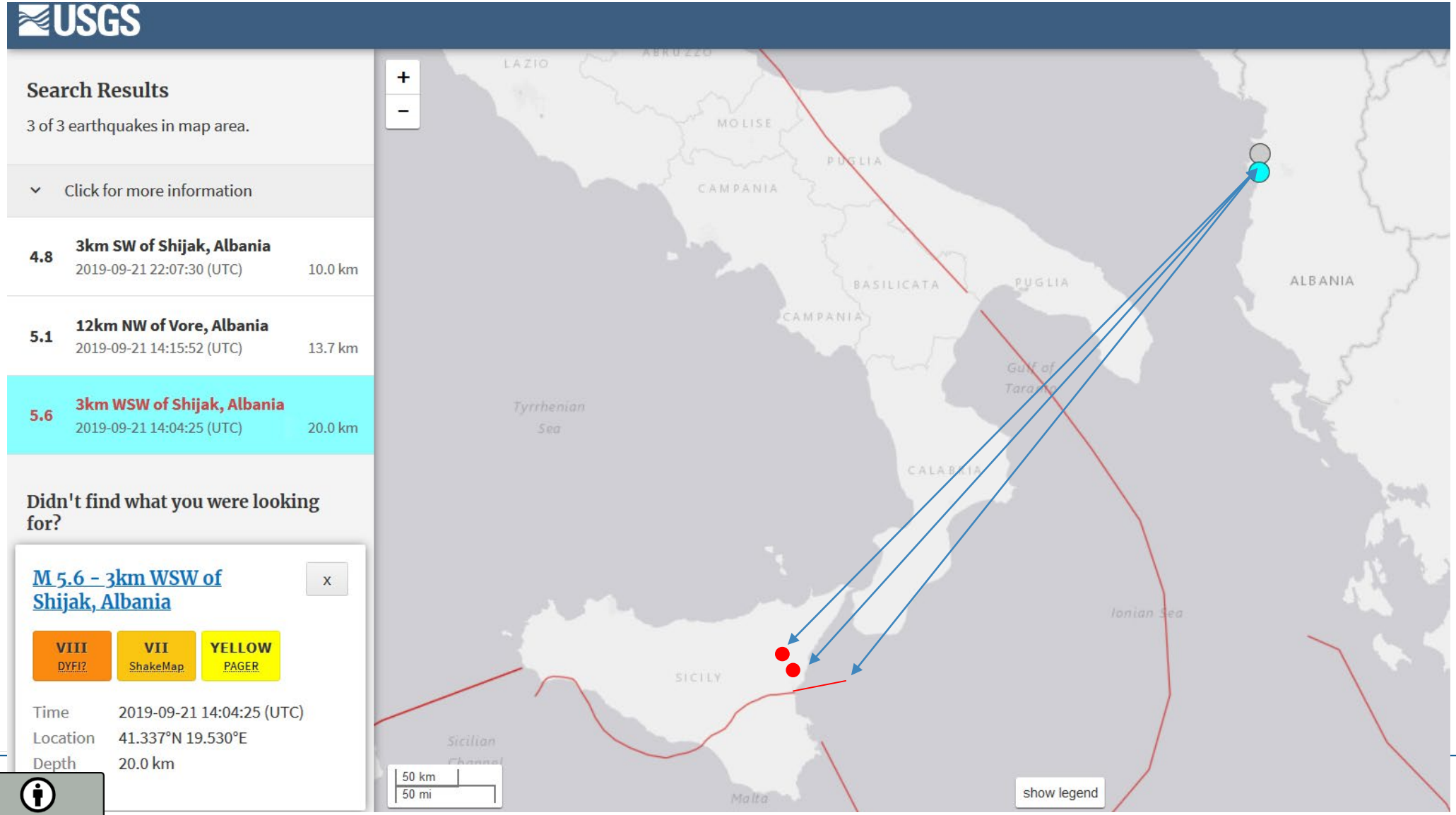


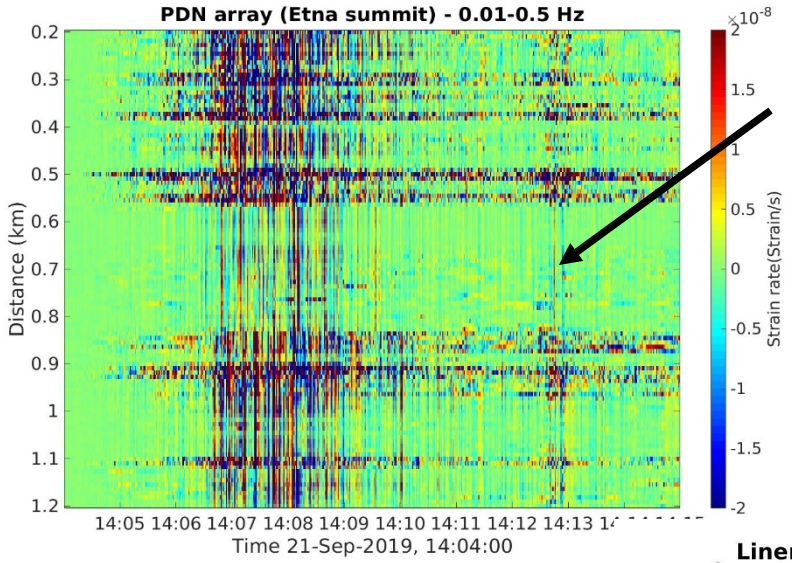
Albania, 21.09.2019

Magnitude 5.6 and 5.1



DAS simultaneous records on 3 arrays

Downsampled (200 Hz) - strainrate

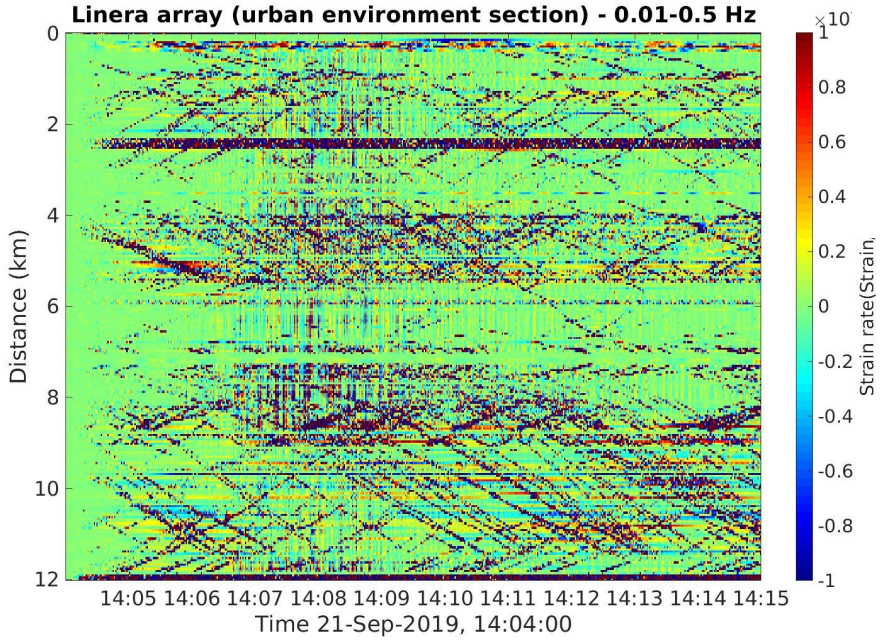


Volcanic event

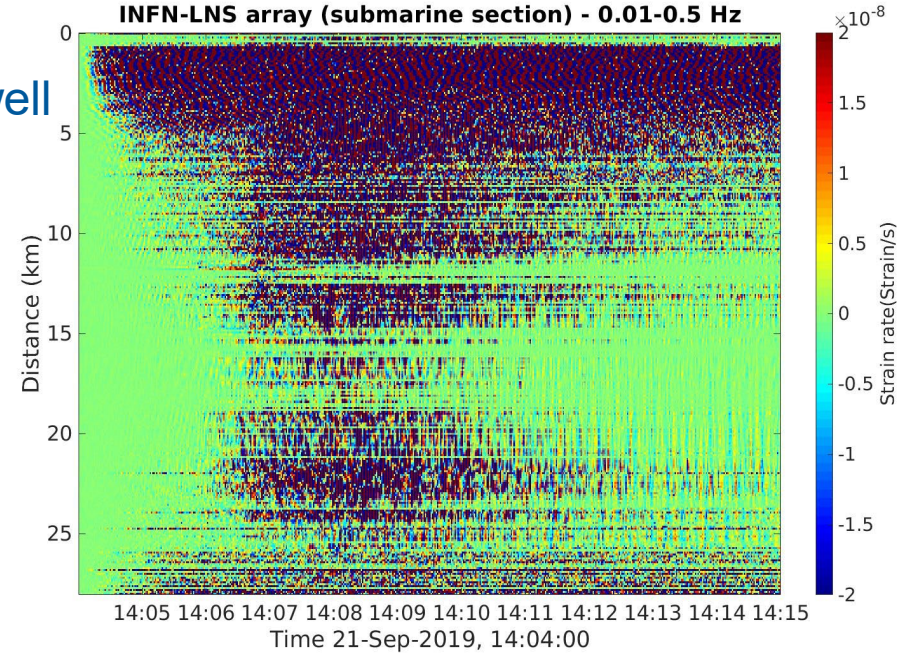
Fault zone

Earthquake

Earthquake



Swell



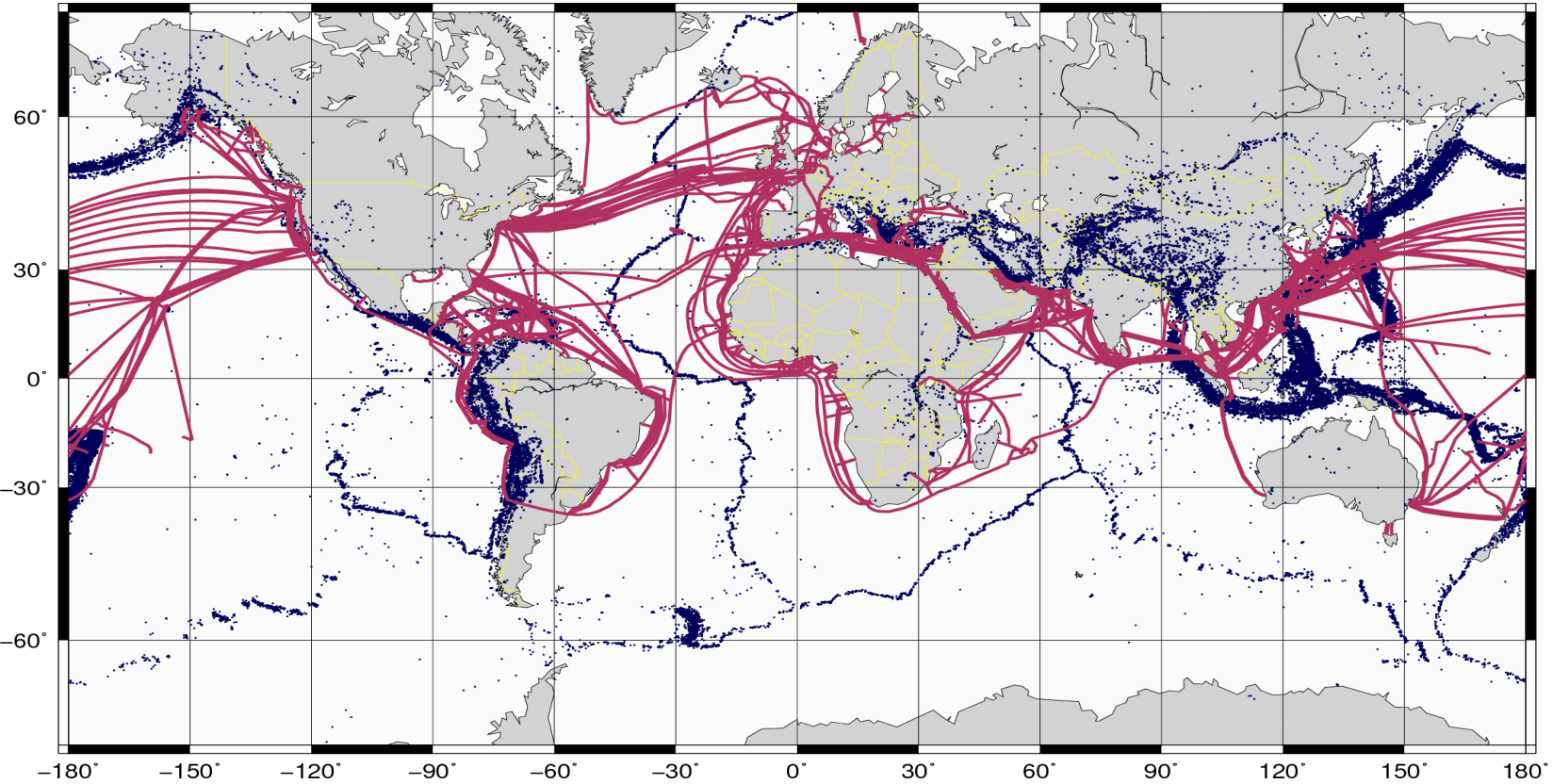
Earthquake

Cars

Krawczyk et al., EGU 2020

Global monitoring in the oceans with telecom cables

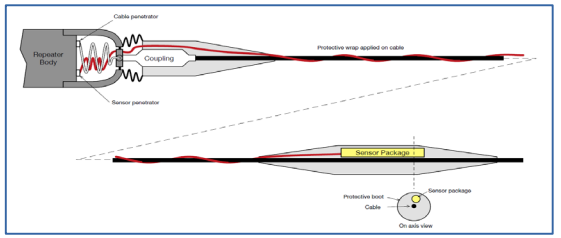
GFZ Helmholtz Centre Potsdam



Joint Task Force
SMART SubSea Cable Systems

SMART Cable concept

Telecom cables offer power and bandwidth. Repeaters every ~50 km offer a possible platform for low power sensors (accelerometer, pressure, temperature).



HELMHOLTZ

Conclusions and perspectives

GFZ Helmholtz Centre Potsdam

Optical fibre technologies:

a new tool for seismic exploration and monitoring

Many opportunities

- Seismic monitoring, Ambient noise tomography, Eq, landslides, volcanoes, tsunamis, faults
- Monitoring of fluids in karsts, offshore seismic monitoring and exploration
- Nuclear waste repositories surveillance
- Monitor of buildings, bridges, dams, boreholes, etc.

Challenges

- Coupling issues (*Reinsch, Thurley and Jousset, 2017)*
- Single component
- Generate a lot of data:
  - Island: 12 Tb/week; Etna 2018: > 20 Tb ~ 1 month; INFN 2019: 60 Tb in 3 weeks
- Processing software to be developped
- Authorization – access to telecom cables