

Terrestrial analogues for seismic site characterization

Marco Olivieri, INGV-Bo, IAPS-INAf
Alessandro Frigeri, IAPS-INAf
Lucia Zaccarelli, INGV-Bo

What terrestrial analogues are?

“Terrestrial analogs are defined as environments on Earth that present one or more geological or environmental conditions similar to those found on the Moon, Mars, or any other extraterrestrial body, either current or past.”

Geological training in terrestrial Moon and Mars analogue environments in **Lanzarote, Spain** to prepares astronauts and space engineers to identify planetary geological features for future missions to the Moon, Mars and asteroids (ESA)



LUNA artificial environment in **Cologne**, (DLR/ESA).



The Desert RATS team evaluates technology, robotic systems and extravehicular equipment for future missions in space. **Arizona**. (NASA)



A half-century of terrestrial analog studies: From craters on the Moon to searching for life on Mars

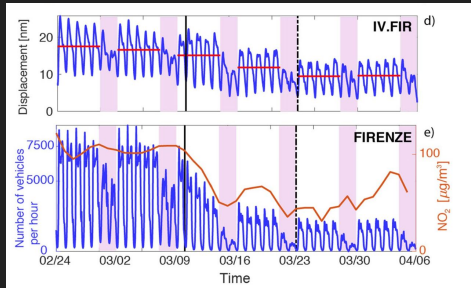
Richard Léveillé  

Seismic noise, what and why

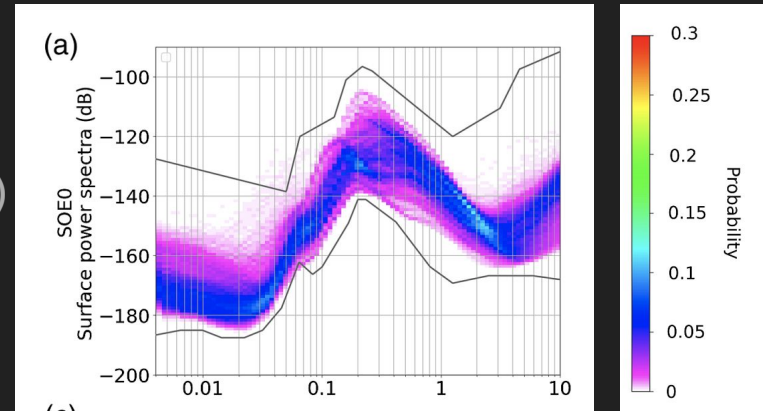
Seismic noise is whole signal that a seismometer records that is not the signal we care about!

- Thermal oscillations
- Microseisms (sea and oceans)
- anthropogenic (industries, wind farms, cars)
- other (wind, tree oscillations)

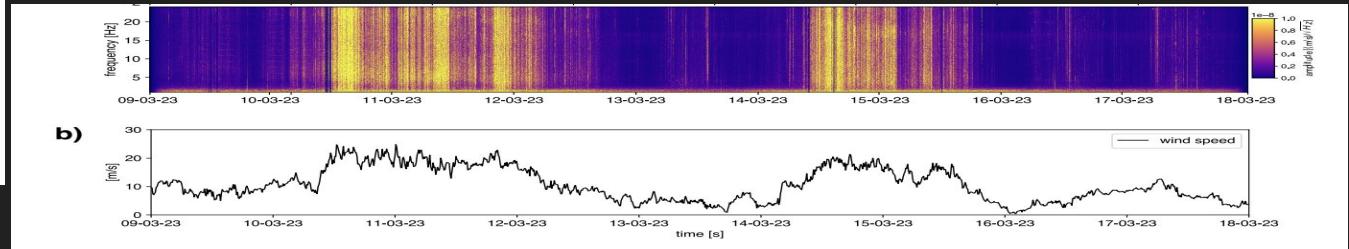
Seismic noise changes over time



Piccinini et al., 2020,
DOI 10.1038/s41598-020-73102-3

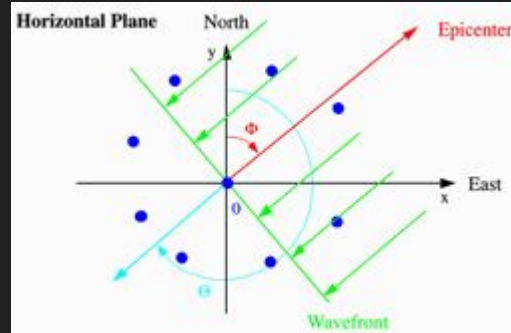
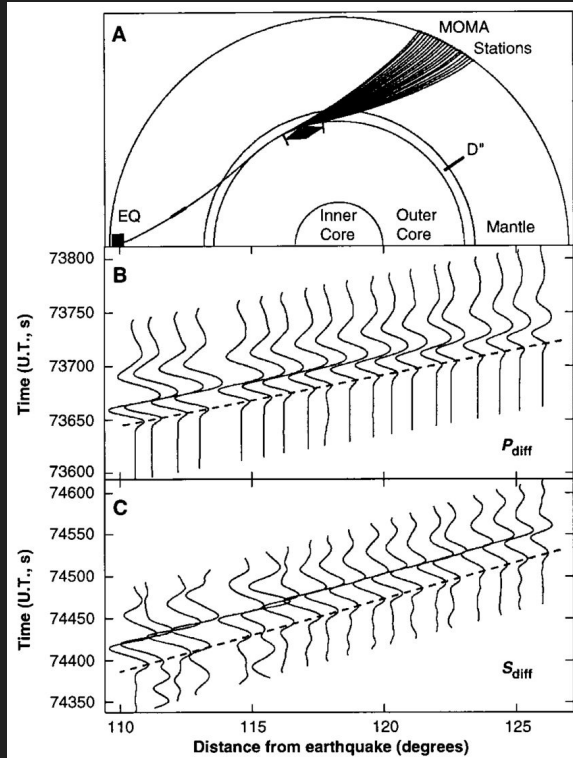


Di Giovanni et al., 2021, doi: 10.1785/0220200186.

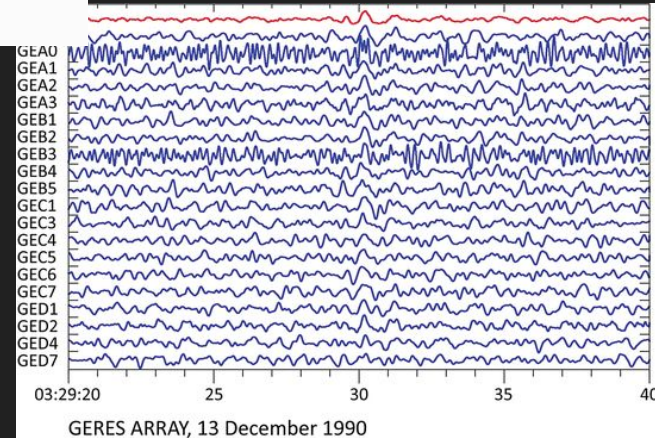


Diaferia et al., in preparation

Traditional “array seismology” approach



- Phase from distant source is correlated.
- The array determine the direction of the wavefront



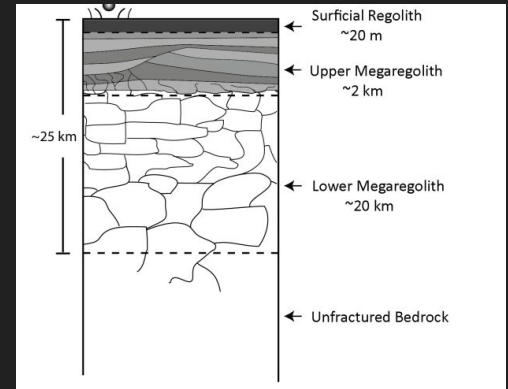
Noise is uncorrelated. it depends...

Seismic noise, on a PSR of the Moon

- ~~Thermal oscillations~~
- ~~Microseisms (sea and oceans)~~
- ~~anthropogenic (industries, wind farms, cars)~~
- ~~other (wind, tree oscillations)~~

but we will look at tiny seismic signals and other disturbances count:

- LGWA itself (power supply, thermal fluctuations, cooling, creeping, soil compaction/perturbation)
- moonquakes
- meteoritic impacts
- solid tide



www.hou.usra.edu/meetings/lpsc2020/pdf/1015.pdf

The plan

To deploy an array of seismic stations in a low noise environment as PSR (Permanent Shadowed Region)

The array will record

- moonquakes
- seismic noise
- moon's vibrations
- gravitational waves
- unexpected signals
- known/recognizable
- unknown
- predictable
- predictable
- unknown

geophysical
complex
problem

GW signature should overcome the background and instrumental noise

PSR are expected to be a quiet place since the daily ~300K temperature fluctuation will be missing.

background seismic noise never measured

Why terrestrial analogue is necessary for LGWA

1. background noise level and its variability

- a. necessary for establishing the capacity of the detector to record the signal with sufficient SNR.
- b. it depends on
 - i. background noise level ← mesh and specfem simulation / soundcheck
 - ii. sensor/soil coupling ← leveling platform deployment

2. noise correlation

- a. necessary for shaping the array properly to achieve good discrimination beGW signals from noise
- b. it depends on
 - i. noise sources ← moonquakes / meteoritic hum
 - ii. shape of the array ← trial and error / on site test **non feasible**

Noise correlation

- Provide further information about the background noise
- Model the shallow structure within the network
- Model the correlation between array nodes and define best array configuration

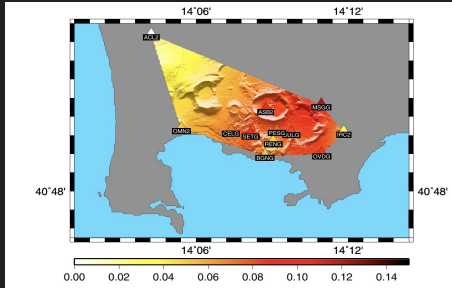
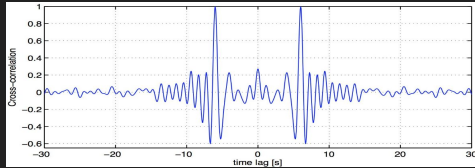
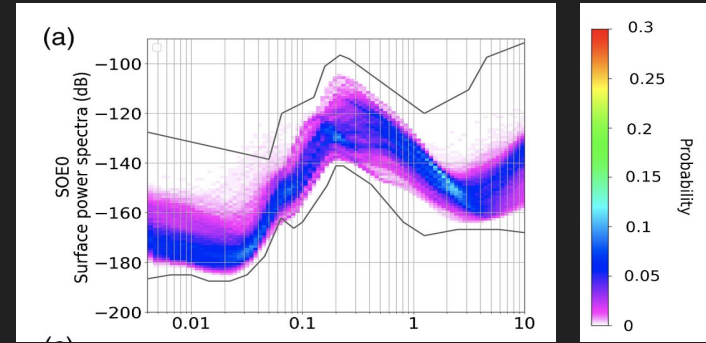
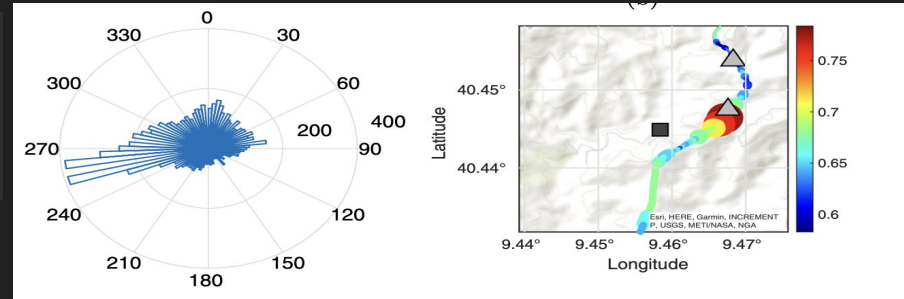
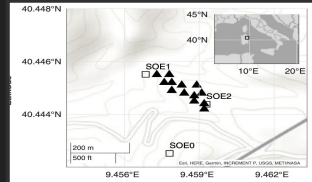


Figure 5. Map of the relative velocity variation drop measured between late August 2012, and beginning of January 2013. The color bar shows the drop values in percentages. The illuminated area is the one enclosed by the seismic network.



Zaccarelli et al., 2017, 10.1002/2016GL072477.

Saccorotti et al., 2023, 10.1140/epj/s13360-023-04395-2

some existing lunar terrestrial analogues



Houghton impact Crater (Canada)

Analogy with Shackleton Crater, a 19-km-wide impact crater at the Moon's South Pole



Svalbard (Arctic)

Red sandstone desert.
Volcanic rocks (basalt)



Rio Tinto (Spain)

Red sandstone desert



Meteor Crater (the United States)

Red sandstone desert and camp site for Apollo mission training



Location of Mt. Etna, Italy.

Soils, rocks, volcanoclastics. Used by ESA and DLR to test rovers and equipments



Teide Volcanic Park

Volcanic rocks (basalt and phonolite)

Selecting the right terrestrial analogues is essential!

Fractured and incoherent soil

Good candidates could be recent lava deposits

- Mt Etna
- Lanzarote
- Hawaii



Logistics count since we are mostly based in Europe

Terrestrial analogue potentials

- test the leveling system
- estimate the background noise correlation
- define best array configuration



Complexities

- Existing analogues never used for seismic studies
- more than one analogue for ensemble approach
- most candidates are remote places.

Thank you