The University of Oxford Department of Earth Sciences

EARTHSCIENCES

UNIVERSITY OF OXFORD

Exploring high-frequency seismic signals: tracking wind and ocean waves or probing shallow lunar structure

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Overview

Seismic stations record low-amplitude high-frequency (>1 Hz) shaking almost continuously. These signals result from a variety of sources: from wind impacting the ground on Earth or Mars, from ocean waves breaking on the shore, and from impacts on the lunar surface. They thus have the potential to teach us about those sources: to determine how wind couples with the ground, where waves collide with the solid earth, and how impacts reverberate around the moon.

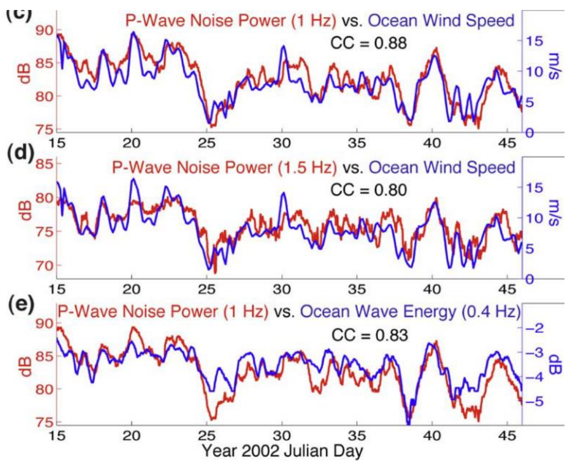
However, continuous seismic signals are challenging to analyse. They are long-duration and complex, so we need sophisticated as well as simple tools to probe the deeper structure. In this project, you will develop some of those tools and use them to probe features of the Earth, Moon, or Mars that interest you.

Option 1: Tracking wind and ocean waves

Wind and ocean waves generate many of the high-frequency signals we observe in seismograms, and observations increasingly see interesting correlations between local wave height and seismic amplitude (Becker et al, 2020). Some evidence of ocean-induced waves can be seen in the figure to the right, by Zhang et al (2009), the seismic amplitude (in red) is roughly proportional to the wind speed in the ocean and to the wave height (in blue).

However, we do not know how often high-frequency seismic signals closely track wave and wind speeds, nor do we know how the signals are generated: from waves that arrive onshore, from direct coupling of wind with the ground, or from waves impact offshore bathymetry? You may answer this question and develop new tools to track waves with one or more of 3 approaches.

First, you may simply compare time-dependent seismic amplitude with observations of wind speed and wave height in a range of locations. You may assess, for instance, whether seismic amplitude is highest when waves arrive at gently sloping bays or when waves arrive at steep cliffs or glacial calving fronts.



Second, you may develop new tools to determine where wave-generated seismic waves originate. We already have some tools to precisely track the locations of complex seismic signals, particularly when we know the location of one signal and want to search for nearby signals (e.g., Hawthorne and Ampuero, 2018). But those tools are somewhat slow and could be dramatically improved. You may wish to develop a template-based neural network in order to rapidly identify and locate wind-induced seismic waves.

Alternatively, you may wish to think more carefully about the generation of seismic waves. How do waves couple with a rough ocean bottom? And how do wind-induced pressure variations generate propagating seismic waves? You may expand on and test the first-order models of, for instance, Gimbert and Tsai (2015).

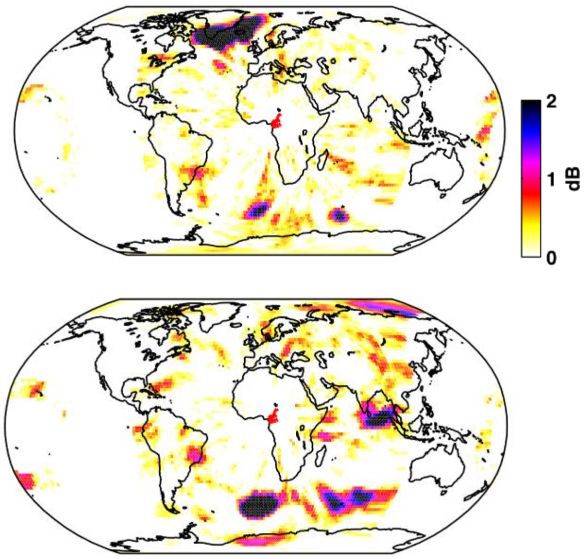
Option 2: Exploring near-surface structure on the Earth, Moon, or Mars

Alternatively, you may choose to focus not on the origin of high-frequency seismic signals, but on what they can tell us about the structure of the shallow crust near observing seismometers. You may develop new approaches to exploit long-duration, high-frequency seismic signals. Such analysis may be particularly useful on the Moon and Mars, where we have just a few seismometers but very significant questions. For instance, we know that the lunar crust has been heavily fractured by colliding meteorites, perhaps even at 10 km depth (Blanchette-Guertin et al, 2015). But how many fractures are there? Is the fracture density significant enough to modify our estimates of crustal thickness?

To learn more about the shallow crust, we need to extract signals from the continuous seismograms, which is created by sources in a wide range of locations. But these seismograms are complex for two reasons: because the sources that generate them are complex and because the seismic waves travel through complex media. To learn from these seismograms, you will likely want to take two steps.

First, you may group the seismograms by their locations: which direction are the waves coming from? You may use a beamforming approach approach, as was used by Euler et al (2014) to show that the microseism energy came from the north Atlantic in January (top) and from the south Atlantic in June (bottom).

Alternatively, you may use a template matching or coherence-based approach to identify signals with similar components, which likely occur in similar locations (e.g., Brown et al, 2009; Hawthorne and Ampuero, 2018). You may even wish to develop a new technique to group seismograms with similar components. You will likely want to test such a technique on Earth, perhaps with data from a remote location where there are relatively few seismic sources at any given time.
Identifying groups of sources will be an interesting result itself. It would be interesting to know, for instance, whether micro-moonquakes migrate around the lunar surface over the lunar month, or whether Martian winds preferentially couple with the ground at particular locations.



But once you have identified groups of sources, you can also do more. You can collect each group of seismograms and attempt to extract their common components: the components that arise from the seismic waves' paths. That path can teach us about crustal structure.

There is no currently existing tool to extract an average path effect from thousands of seismograms, so you will have to develop one. It may be that a very simple approach could work. You might be able to simply average the seismograms and thereby average out the complex sources. Or you may need to do something more complex: you may need a neural network approach just to align the seismograms and extract a signal that's part of many of them.

Finally, once you have extracted the path effect, you may interpret it in the context of crustal structure. For instance, there may be surface waves that could reveal the stiffness and depth of the crust, at >10 km depth, or the nature of the near-surface rocks and regolith, at <1km depth.

Timeline

Years 1-2: initial observations, direct comparisons between seismic amplitude and meterological properties, grouping similar seismograms, initial technique development, identifying specific physical questions

Years 2-3: further analysis and technique development, extraction of key seismogram features, physical modelling

Training & Skills

You will learn a range of seismological techniques, as well as in general time series analysis methods, in order to robustly analyse the seismograms. Depending on your focus, you may also develop your abilities in physical oceanography or in machine learning. You will likely attend classes or summer schools and follow self-developed reading courses or journal clubs with your working groups.

Depending on interest, there are various possibilities for collaborations within Oxford and with researchers at other institutions in the UK, US, and Europe. You will interact with researchers working models and on geological and geophysical observations and will attend conferences and workshops in the UK, Europe, and the US.

Finally, you will develop your ability to write and present your work so that you can have more fruitful interactions your colleagues.

References & Further Reading

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Further Information

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This project would be suited to a student interested in getting the most out of a complex dataset in order to learn about the Earth or other planets. Such a student could have a wide variety of backgrounds, from geology to physics, engineering, or computer science. There will be opportunities to further develop your knowledge in unfamiliar areas. Please get in touch if you're interested in a project along these lines.