Seasonal Variability of Short-Period Ocean Wave Interactions from Seismic Noise.

Introduction

The interaction of ocean gravity waves with the Earth's crust produces continuous ambient seismic noise, especially **in the 1–10 s band known as microseisms**. This persistent noise field, primarily composed of Rayleigh waves, allows for iindirect observation of oceanic processes through seismic interferometry. In coastal regions like the **Southern Pacific of Costa Rica,** where marine and atmospheric systems are tightly coupled, ambient seismic noise provides a window into seasonal and interannual variability of ocean wave energy. This study leverages Costa Rica's dense broadband seismic network to monitor such variability from 2019 to 2023. **The Southern Pacific region** is of particular interest due to its **sensitivity to ENSO phenomena and its biodiversity-dependent coastal communities,** which may be affected by changes in ocean dynamics.

Objectives

The aim of this work is to investigate the temporal evolution of short-period ambient seismic noise in the 1–3 s band and quantify its sensitivity to seasonal and interannual variations in ocean wave activity. This is achieved through the cross-correlation of ambient seismic **wavefields between station pairs to retrieve Green's functions (GFs)**. The degree of similarity between daily and reference GFs is then used to evaluate changes in the noise source field and/or crustal response.

We seek to answer:

- How stable is the ambient wavefield seasonally and across years?
- Are these changes correlated with climatic drivers such as La Niña?
- Can waveform similarity serve as a proxy for oceanic variability?

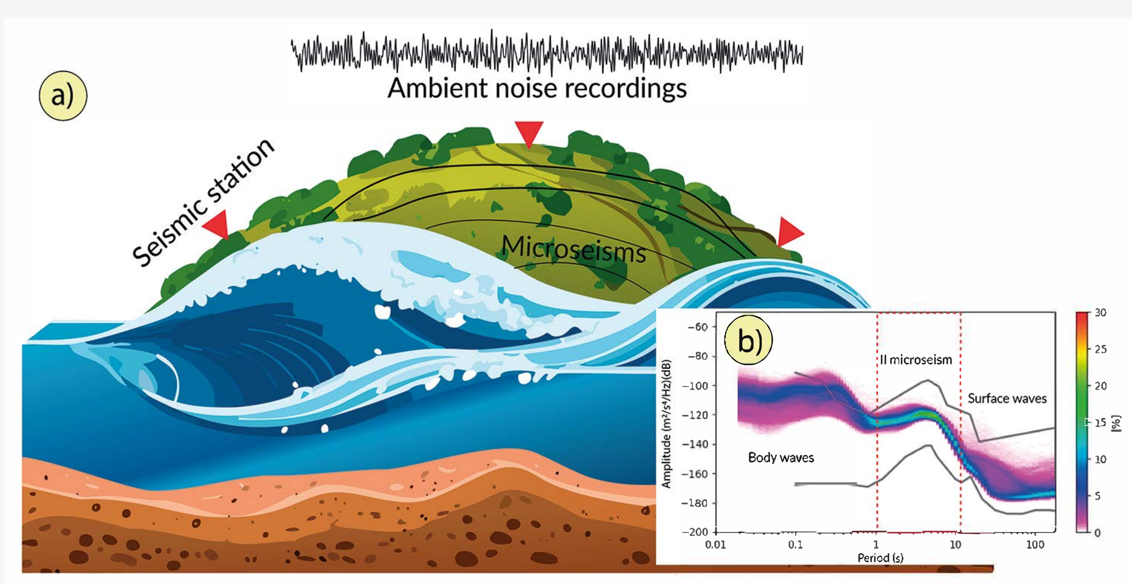
Methodology

We applied seismic interferometry by computing cross-correlations of ambient seismic noise from broadband station pairs spanning the **Southern Pacific region.**

- Data span: 2019–2023, **filtered in the 1–3 s band** (short-period ocean wave sensitivity).
- For each pair, we **retrieved daily empirical Green's functions** (GFs).
- A reference GF was built from the linear average of all daily GFs.
- The correlation coefficient (CC) between each daily GF and the reference GF quantifies decorrelation.
- Decorrelation is interpreted as changes in source strength, wavefield stability, or path effects (**e.g., due to changing water column or crustal properties**). This technique assumes stationarity of the medium but allows temporal variation in the sources, making it ideal for tracking environmental variability.

Figure 1. a)

Illustration showing the generation of ambient seismic noise through the interaction of the oceanic activity with the Earth's crust. The complete **spectrum and frequency-distribution of the seismic energy** recorded daily on a given a seismic station is shown in the panel b). In this figure, the colors indicate intensity in decibels. The upper and lower continuous lines indicate the average upper and lower limits observed globally. The II microseism is found in **the period range of 1 – 10 s,** as marked in the red rectangle.



Results

Clear seasonal decorrelation is observed across the dataset, with a consistent drop in CC from January to April each year. This period coincides with the dry season, when storm frequency and oceanic swell energy are reduced.

Key observations:

- Interferograms show disruptions in coherence during this period.
- CC time series reveal annual cycles with sharp drops each dry season.
- Correlation drops correlate well with regional precipitation minima, supporting a connection between seismic noise variability and atmospheric forcing.

These patterns support the use of ambient seismic noise as a real-time proxy for oceanic and meteorological processes.

Figure 2.

Map showing the spatial distribution of seismological stations (triangles) operated by the Volcanological and **Seismological Observatory of Costa Rica, OVSICORI, in Southern Costa Rica.**

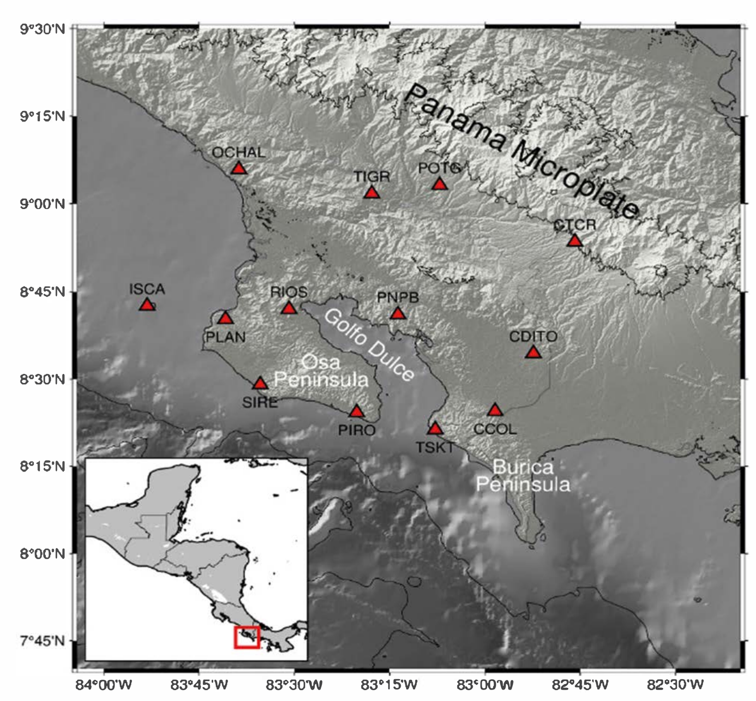


Figure 3.

Description of the Methodology used for computing ambient seismic noise correlations

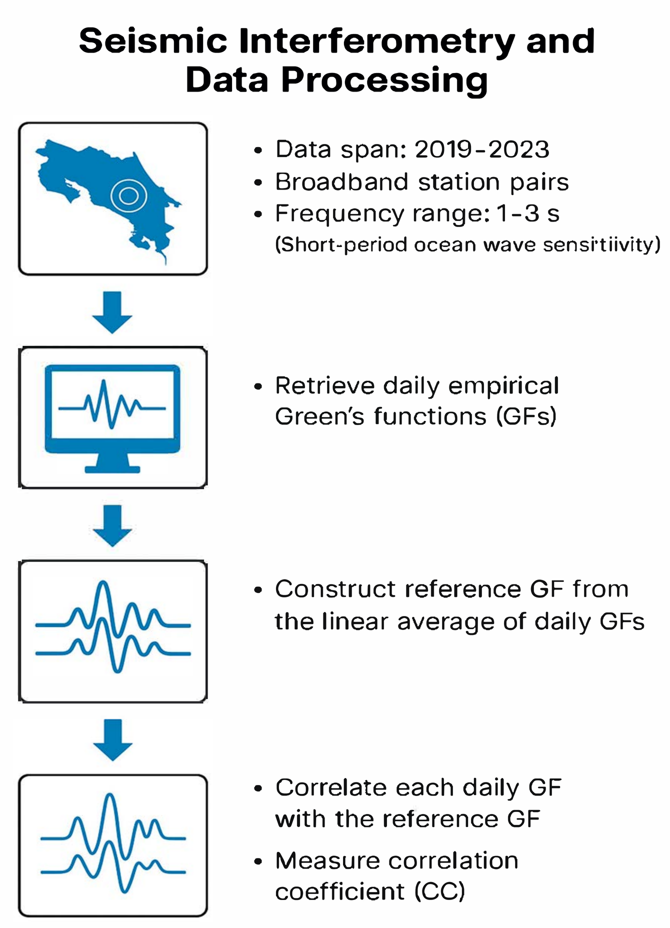


Figure 4.

Empirical Green's function decorrelation with time for a selected number of seismic station pairs (solid color lines) distributed along the **Osa and Burica Peninsulas** in the Southern Pacic of Costa Rica. In the figure, the black thick line represents the mean correlation observed between all station pairs. The horizontal red dashed line highlights **the 30% increase** in decorrelation. The yellow rectangles highlight the period between January and April each year, were decorrelation peaks seasonally. The decorrelation increase observed between the end of June and August 2019 was generated by the **Mw=6.5 Puerto Armuelles** earthquake that occurred on 26 June at **05:23:48 UTC** and the following aftershock sequence.

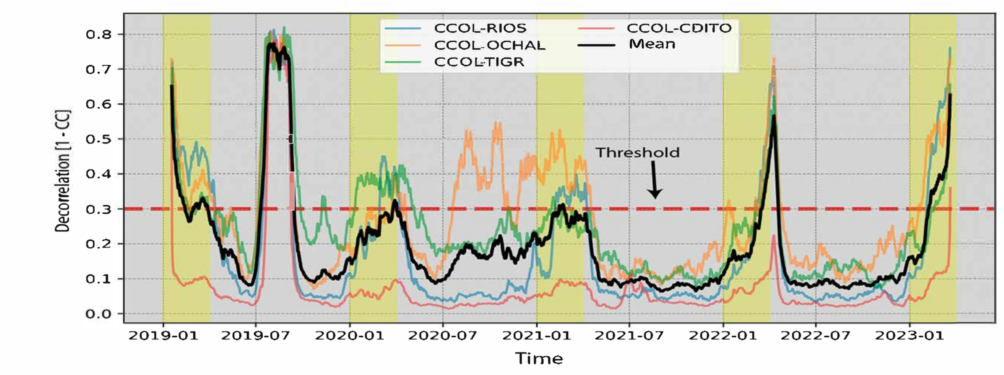


Figure 5.

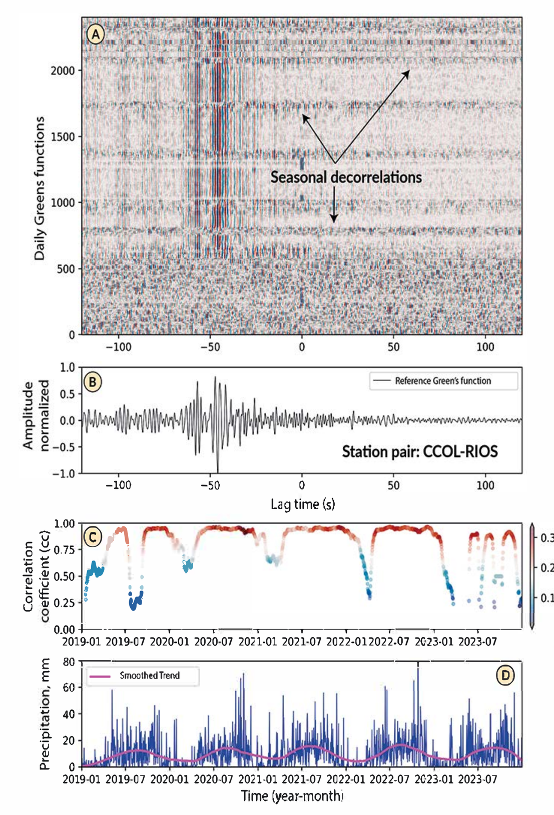
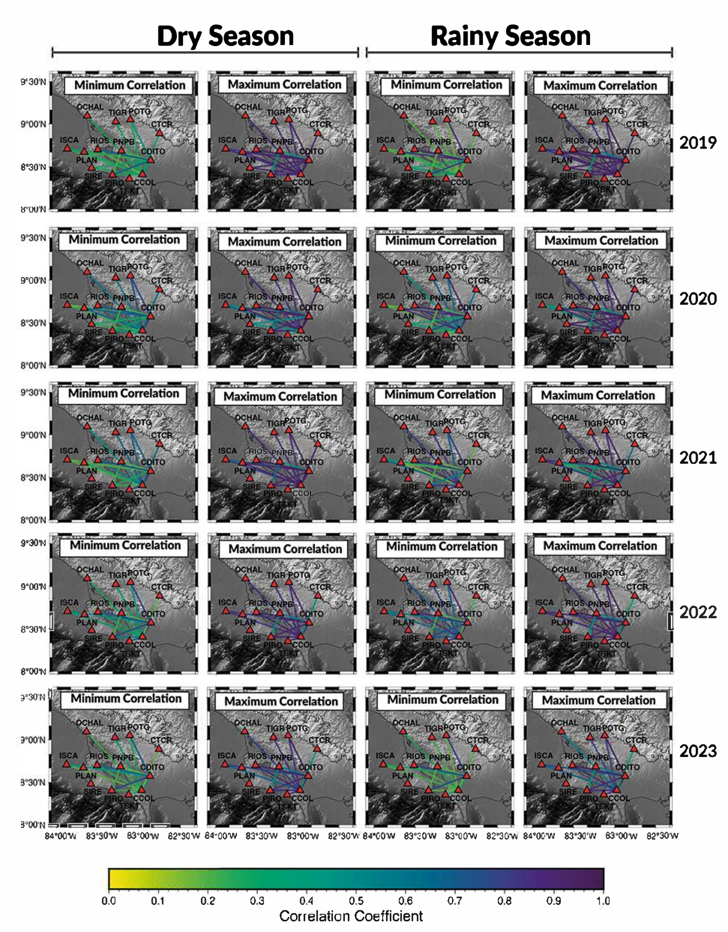


Figure showing the results obtained between the cross correlation of ambient seismic noise between the **stations CCOL and RIOS. Panel A)** displays the interferogram of daily Green's functions. Here, each line represents the daily status of the Earth crust in the period of 1 to 3 s.The appearance of negative interference is clear as it shows as horizontal lines that disrupt the pattern of blue and red colors. Panel B) shows the reference Green's function, obtained after averaging the daily GFs for the entire period of study. Panel C) shows the cross-correlation coecient as a function of time, color coded by standard deviation. Panel D) displays the precipitation table for the same period of analysis. The magenta line highlights the smoothed trend during the rainy and dry seasons.

Figure 6.

Seasonal distribution of minimum and maximum CC values between station pairs in the **Southern Pacic of Costa Rica** obtained through the multi-year cross-correlation of ambient seismic noise. In the AFigure, each raw correspond with the comparison of CC between the dry and the rainy season for years 2019 - 2023 respectively.



Conclusions & Impact

This study confirms that ambient seismic noise interferometry **can effectively track seasonal and climatic variability in ocean wave energy in tropical coastal regions.**

- Seismic waveform similarity (via CC) is sensitive to seasonal oceanic changes, particularly wave energy and storm dynamics.
- Interannual variability, such as La Niña, modulates the stability and coherence of the ambient wavefield.
- The method provides a cost-effective, high-resolution, and continuous alternative to traditional ocean monitoring (e.g., buoys).

Finally, **this study offers early insights into marine ecosystem stressors, enhancing coastal climate resilience assessments**. And it can be integrated into multidisciplinary observatories for real-time environmental monitoring.

OVSICORI-UNA
INSTITUTO DE INVESTIGACIÓN OBSERVATORIO VULCANOLÓGICO Y SISMOLÓGICO DE COSTA RICA

Authors

Esteban J. Chaves, Sonia Hajaji, Nahomy Campos & Evelyn Nuñez-Alpizar

Contacts

Universidad Nacional, Costa Rica (UNA)
Volcanológical and Seismological Observatory of Costa Rica, OVSICORI

esteban.j.chaves@una.cr

ORCID ids:

UNA POR LOS OCÉANOS 2024 - 2025

UNA UNIVERSIDAD NACIONAL COSTA RICA