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Source location of oceanic transform fault earthquakes constrained by IMS hydrophone triplets in the Indian Ocean

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INTRODUCTION AND MAIN RESULTS

Submarine earthquakes cause energy coupling into the ocean. The impact of seafloor relief in the vicinity of the rupture zone and how topography may affect estimates of hydroacoustic source locations remains enigmatic.

Here we study earthquakes at oceanic transform faults rupturing within deep valleys.

Back-projected energy arriving at two IMS hydrophone arrays reveals that the centroid of the source occurs over the deep valleys, suggesting that the topography of the valley walls has little impact on the coupling of energy into the SOFAR channel.

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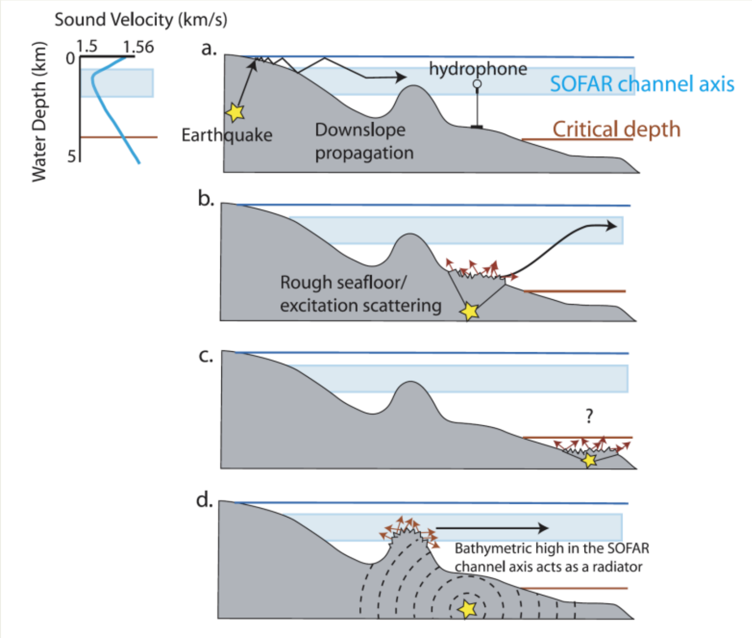
Introduction

T-waves are hydroacoustic waves that propagate as guided waves over long distances through the ocean, representing energy trapped in the Sounding Fixing and Ranging (SOFAR) channel. Natural sources for T-waves are submarine volcanic eruptions or submarine earthquakes. First recognized in the 1950s, T-waves are readily recorded at coastal seismometers or hydrophones moored in the ocean, often thousands of kilometers away from the source area. Today, hydroacoustic energy emerging from earthquakes is routinely used to locate small magnitude seismic events, like mid-ocean ridge earthquakes, using year-long campaigns of autonomous operating hydrophones moored in the SOFAR channel. T-waves resulting from earthquakes have complex waveforms and simulations suggest that their long wavetrains are generated by scattering of upward traveling seismic energy at a rough seafloor and multiple reverberations in the water column. The aim of our study is to reveal whether T-phase locations represent earthquake epicenters. Thus, it has been noted that hydroacoustic source locations might be biased by a complex excitation process. In addition, the conversion of seismic energy into T-waves might be affected by regional seafloor topography and hence may occur tens of kilometers away from the seismic source region if earthquakes occur in the vicinity of submarine ridges, mountains or near seamounts.

Coupling of seismic energy into the ocean



Williams et al. (G-cubed, 2006; figure above) suggested that for earthquakes occurring well below the SOFAR channel topography is an essential feature facilitating the coupling of seismic energy into the SOFAR channel. However, even intraplate earthquakes occurring away from any major topographic relief causes T-wave propagating over long distances through the ocean. Here we study both intraplate earthquakes and events occurring within the deep valleys of oceanic transform faults to reveal the effect of topography on the source location of T-waves.

Methodology I

Seismic energy radiated by an oceanic earthquake excites hydroacoustic T-waves over the focal area. The differential arrival times of the energy approaching a hydrophone array are used to estimate the direction of the earthquake source. The time differences between the hydrophones of a triplet produce three peak delays calculated by cross-correlating the three signal pairs (t_{ij} + t_{jk} + t_{ki}) to each time window of 40 s with a 25% overlap. The sum of the time delay between the three hydrophone pairs is assumed to approach zero for perfectly correlated signals and is expressed by the closure function. Following the 2D plane wave fitting approach, we calculate the back-azimuth of the incoming signal using the slowness vector p = (p_x, p_y) and solving a least-square approach $p = (\Delta x^T \Delta x)^{-1} \Delta x^T t$ (Del Pezzo and Giudicepietro, Computers & Geosciences, 2002). Given that the slowness vector is obtained, we can derived the apparent velocity (v) and back-azimuthal (θ) direction of the T-wave source.

We carry out this procedure for two triplets in the Indian Ocean; namely, HA01W off western Australia and HA08S near Chargos Islands to the south of India. The source location occurs where the energy back-projected along a great circle path meets for both arrays.

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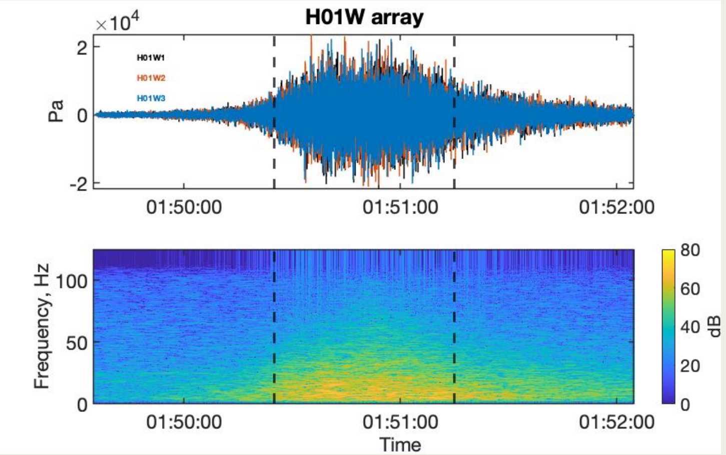
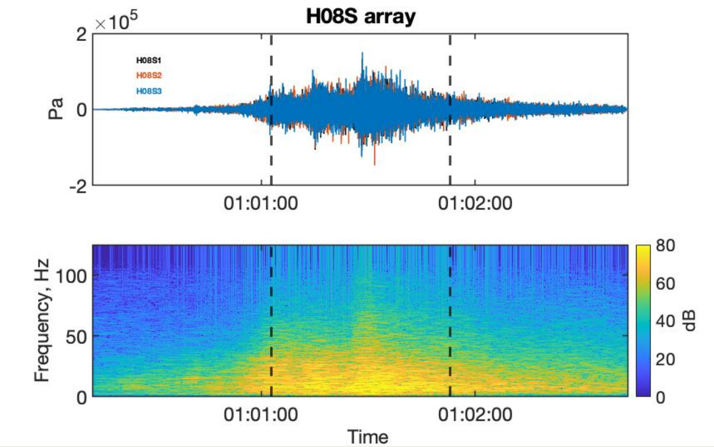
Methodology II

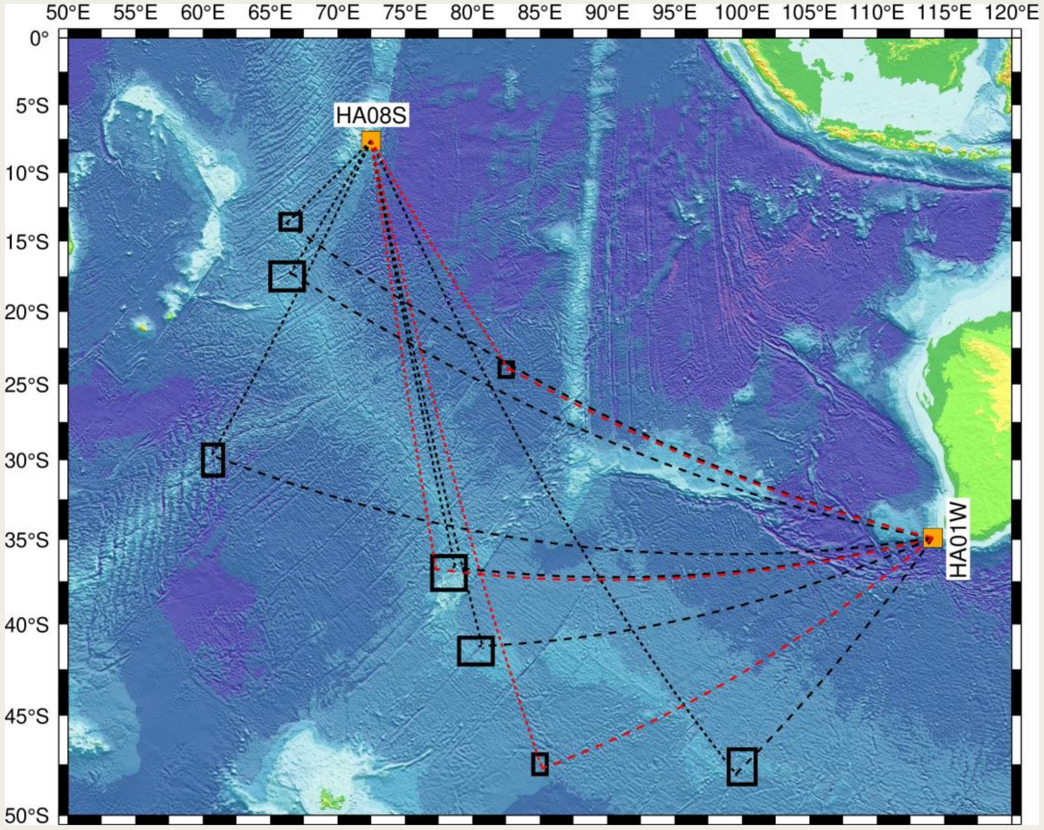
Examples of T-wave energy recorded at HA01W and HA08S on 27/03/2022. The T-waves were generated by a Mw=5.7 earthquake at the Argo transform fault.





Study Area

The CTBTO operates three hydrophone arrays in the Indian Ocean. We use the two arrays HA01 offshore of southwestern Australia and HA08 at the Chargos Islands to the south of India.



We chose in total 17 earthquakes of moment magnitude Mw=5.6 to 7.1 to study earthquakes at oceanic transform faults (Mw=5.6 to 6.4) where we have good coverage of swath-mapping bathymetry to evaluate the seafloor morphology in the vicinity of the transform fault. In addition, we studied five intraplate earthquakes occurring away from any major seamount of ridge-like topography (Mw=5.2 to 7.1). The intraplate settings a chosen to provide a reference to study the efficiency of coupling of seismic energy into the SOFAR channel where seafloor relief is absent. Please note that the intraplate events are generally also the earthquakes with the smallest magnitudes.

Our dataset includes six transform faults with in total twelve earthquakes and additional five intraplate earthquakes rupturing in three different area. All events occurred between 2015 and 2025. We relied on data being open access and were downloaded from IRIS.

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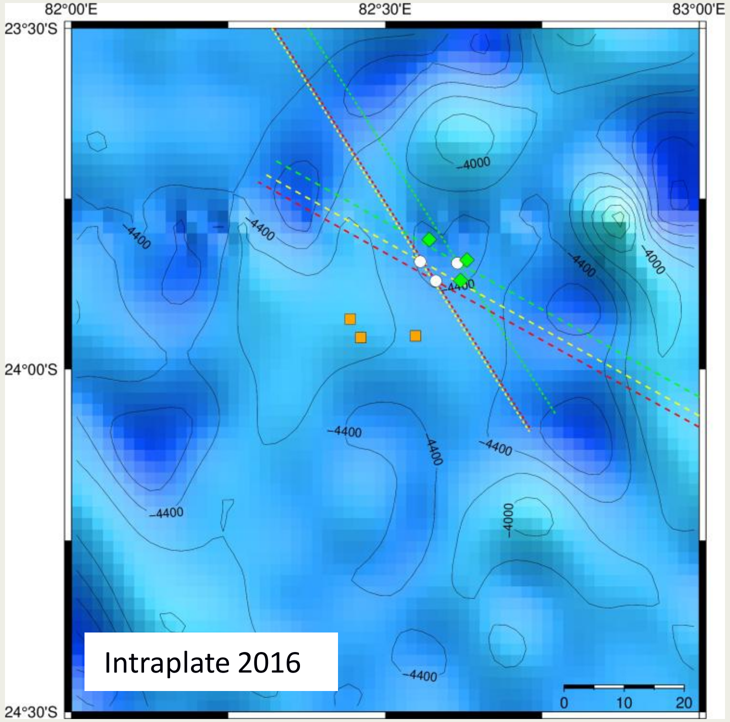
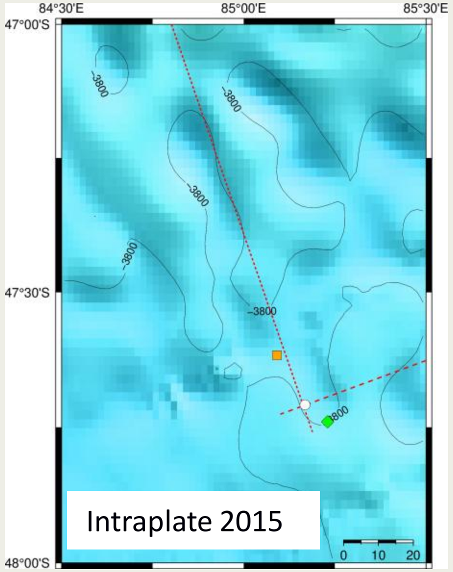
Results I

First, we studied earthquakes occurring in the interior of tectonic plates away from major plate boundaries or topographic features like seamounts or hotspot ridges. We found that those events provide well recorded T-waves even though the seafloor was located well below the SOFAR channel and hence revealing that seismic energy readily converts and couples into the SOFAR channel away from any topography reaching into the velocity minimum zone.

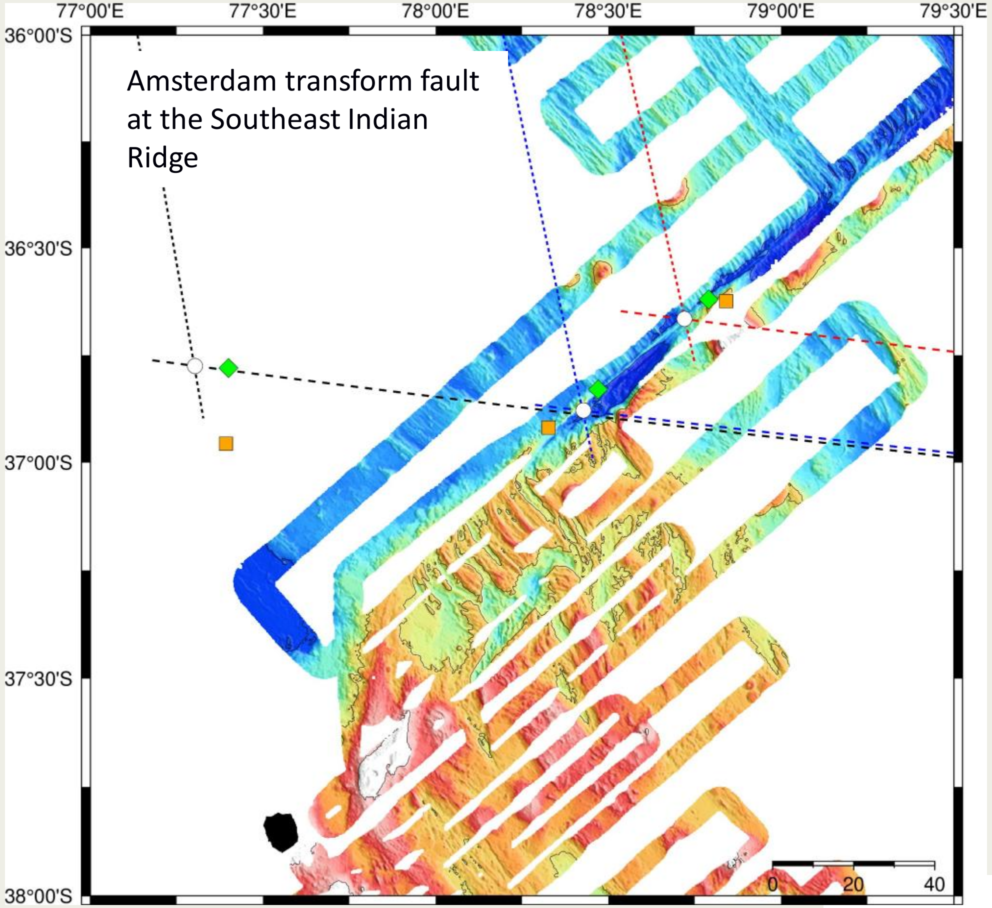


Three intraplate events with magnitudes of 5.1 to 5.6 occurred in 2016 within a few days near 24°S.



A year earlier, a Mw=7.1 event occurred in the Antarctic plate near 48°S. A fifth intraplate earthquake ruptured in the vicinity of the Amsterdam transform fault near 37°S/77°E, but away from the transform itself.

The 2 events at the Amsterdam transform occurred within the well-developed valley of the plate boundary fault.



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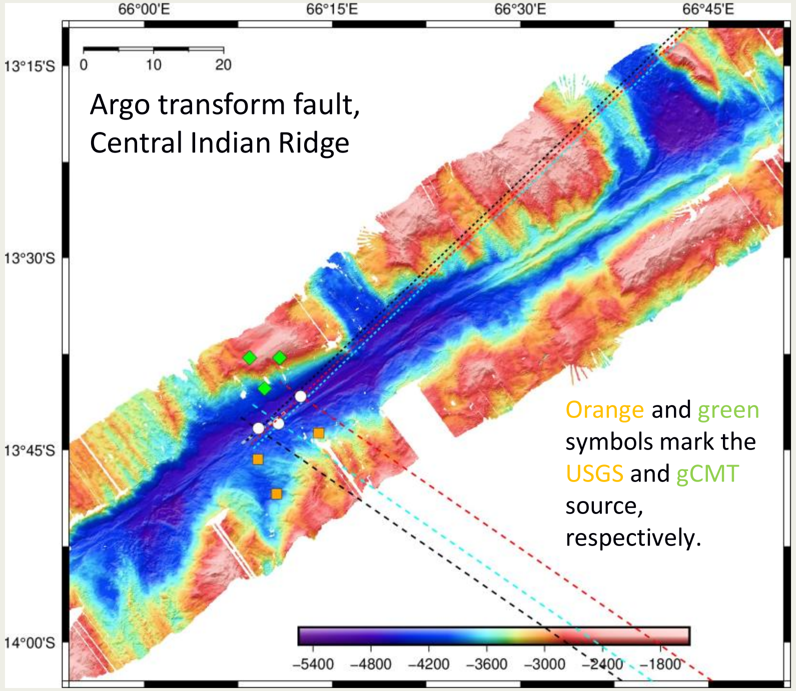
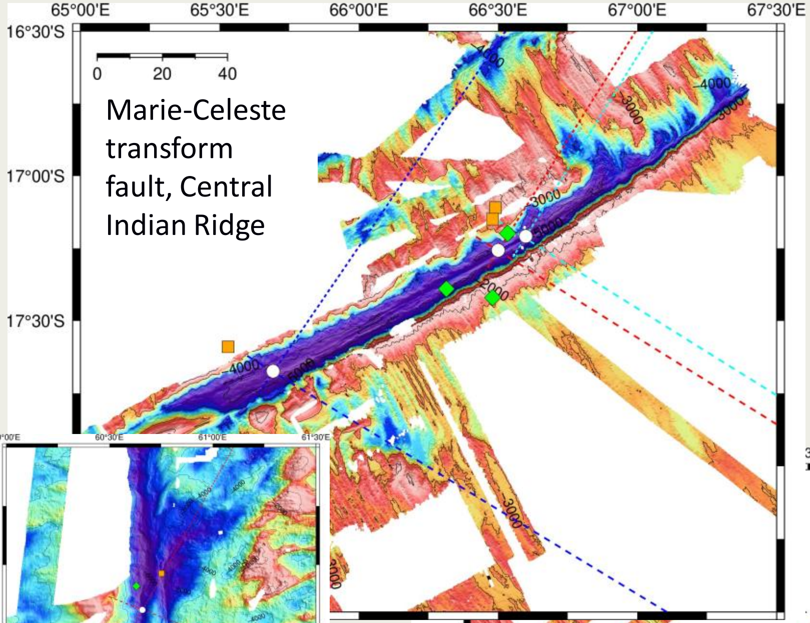
Results II

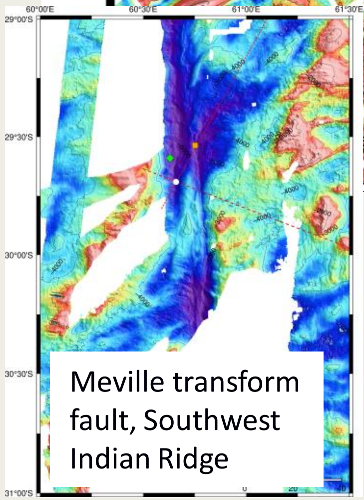
All twelve back-projected earthquakes being associated with oceanic transform faults occurred in the transform valley at water depths well below the axis of the SOFAR channel. Epicentres are located several kilometres from the adjacent walls enclosing the valley and hence away from morphological features reaching into the SOFAR channel. We speculate that seismic energy is trapped within the transform valley and water layer multiples cause energy leaking into the SOFAR channel.

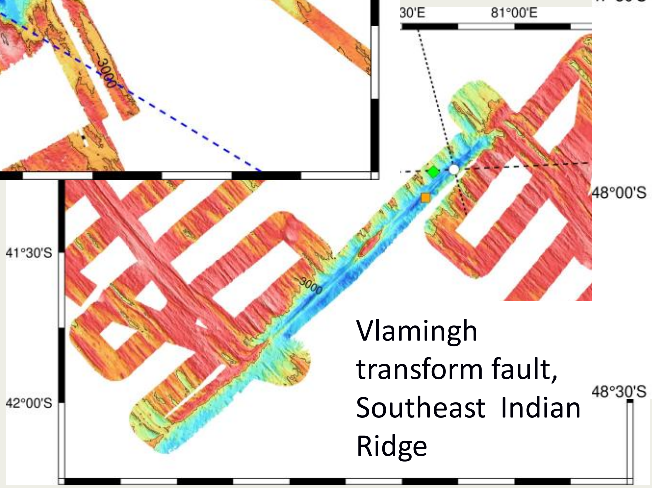


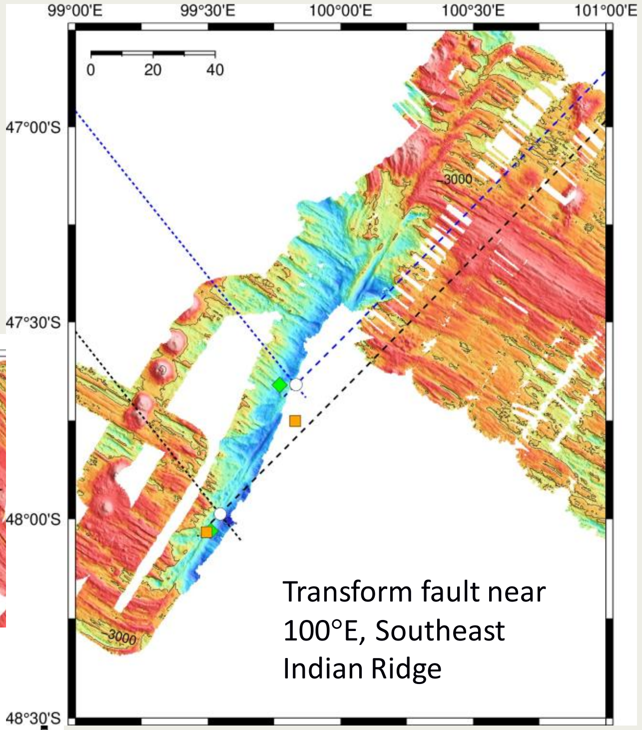
Conclusions

Hydroacoustic estimates of epicenters of transform fault earthquakes suggest that events occur away from bathymetric relief in the deep valleys. Therefore, seismic energy coupling into the SOFAR channel does not require the assistance of any topography reaching into the low velocity channel to cause strong amplitude seismic T-waves. Our T-wave derived epicenters show a much better correction with tectonic plate boundaries than epicenters from global catalogues.









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Acknowledgement

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Our investigations used data recorded at hydroacoustic stations operated in the Indian Ocean under the framework of the International Monitoring System (IMS) operated by the CTBTO.

All data used in this study were obtained from the Incorporated Research Institutions for Seismology (IRIS).

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