Source of the 2023 Morocco Earthquake (Mw6.8) Inferred by analysis of Seismic and Geodetic Data

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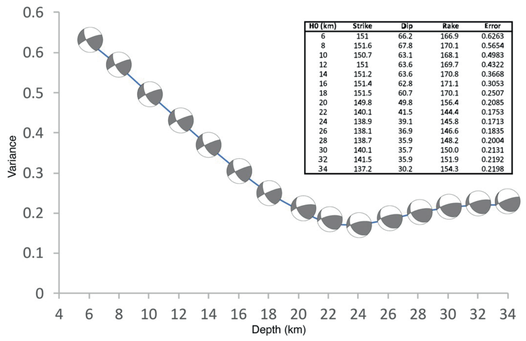
Abstract

On September 8, 2023, at 22:11 UTC, a seismic event of magnitude Mw6.8 (according to the USGS) occurred near the village of Talat N'Yaaqoub, Al Haouz province, in the High Atlas region of Morocco. This earthquake had a profound impact, violently shaking the entire area within a radius of over 70km from the epicentre. More than 78,000 buildings were severely damaged, resulting in approximately 5,600 injuries and around 3,000 fatalities. A considerable portion of the affected population resides in buildings seismically vulnerable and limited access to resources for mitigating such risks.

This incident stands out as a significant earthquake in a region characterized by a low deformation rate and generally considered to have low seismic activity. Testimonies collected by CSEM reveal that the seismic vibrations were felt not only in the High Atlas but also by people in a wider area extending to Algeria, southern Spain, and Portugal.

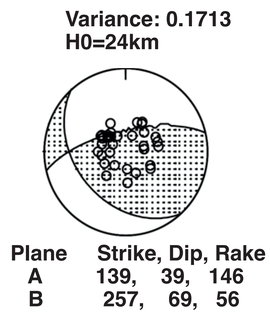
This study presents the preliminary results obtained from a comprehensive investigation of the earthquake's source. The analysis is based on the interpretation of seismic and geodetic data, employing a combination of the following methods: (1) inversion of the seismic moment tensor to determine fault plane geometry and hypocenter depth, (2) waveform inversion using a finite source model to assess spatiotemporal slip distribution, (3) modeling of surface strain field produced by the slip distribution model. The validation of the rupture model was performed by comparing the synthetic surface deformation field with the observed field obtained through the geospatial InSAR method.

Seismic moment tensor solution



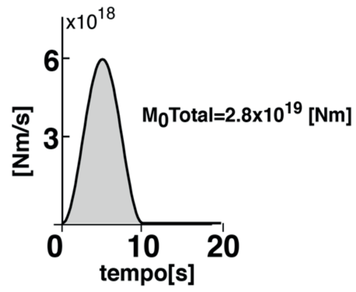
H0 (km)	Strike	Dip	Rake	Error
6	151	66.2	166.9	0.6263
8	151.6	67.8	170.1	0.5654
10	150.7	63.1	168.1	0.4983
12	151	63.6	169.7	0.4322
14	151.2	63.6	170.8	0.3668
16	151.4	62.8	171.1	0.3053
18	151.5	60.7	170.1	0.2507
20	149.8	49.8	156.4	0.2085
22	140.1	41.5	144.4	0.1753
24	138.9	39.1	145.8	0.1713
26	138.1	36.9	146.6	0.1835
28	138.7	35.9	148.2	0.2004
30	140.1	35.7	150.0	0.2131
32	141.5	35.9	151.9	0.2192
34	137.2	30.2	154.3	0.2198

Mechanisms and corresponding Errors (variance) as a function of depth. The mechanisms were calculated by inversion of body wave considering a point source model. The embedded table show the values projected on the graph.



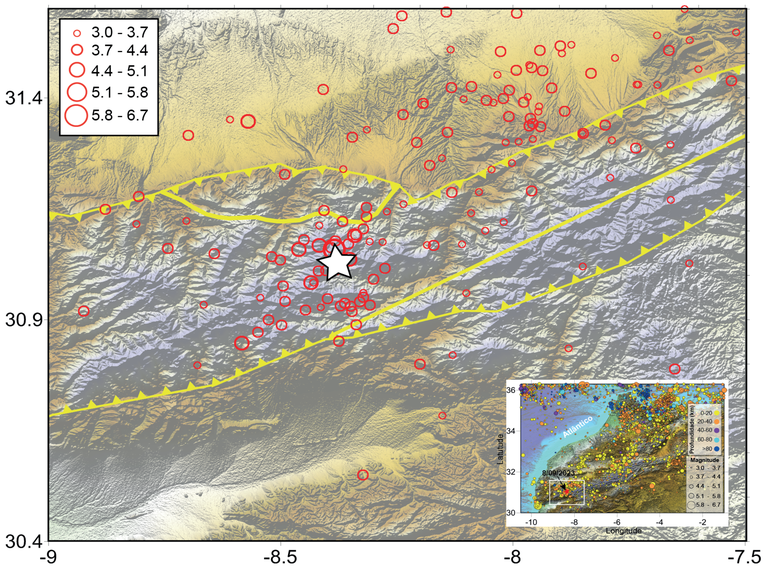
Plane	Strike, Dip, Rake
A	139, 39, 146
B	257, 69, 56

Point source mechanism solution. Average mechanism with location of observation points projected onto the focal sphere.



Seismic moment release: Source Time Function (STF).

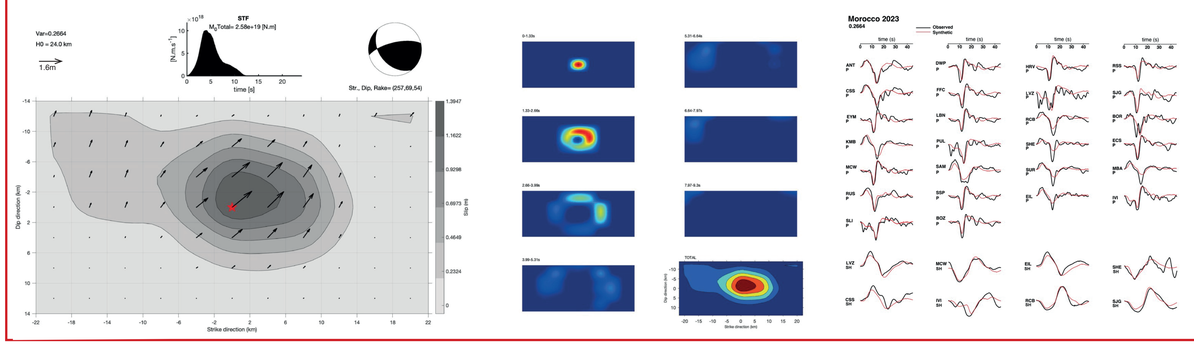
Seismicity in the region



Seismicity of northern Morocco of M>3 to the period 1910-1923, from the International Seismological Center (ISC), Online Bulletin, (small panel map) and zoom of the epicenter area of the September 8, 2023 earthquake (main panel map) in Northh Atlas. Seismotectonic studies indicate that the moderate seismic activity of Morocco is largely explained by the the stress regime of the convergence between Africa and Eurasia (NNW-SSE) sub-horizontal compression axes associated the complex system of thecton ic faults.

Acknowledgement: The work was supported by the Portuguese Foundation for Science and Technology (FCT) project UIDB/04683/2020 - ICT (Institute of Earth Sciences). We also acknowledge: the IRIS Data Management Center for the seismograms used in this study; the International Seismological Center for providing seismicity data; the IPMA for providing the aftershocs and the ESA for the SAR data.

Slip distribution model

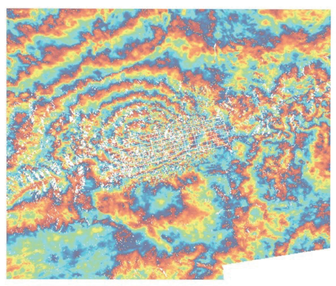


Left panel: Rupture model of the Morocco earthquake. (a) Temporal function of the source; (b) Average mechanism; (c) Distribution of slips on the fault plane; the star represents the nucleation point and the arrows represent the direction and amplitude of the total slip of each sub-fault, whose value can be inferred from the contour lines scale.

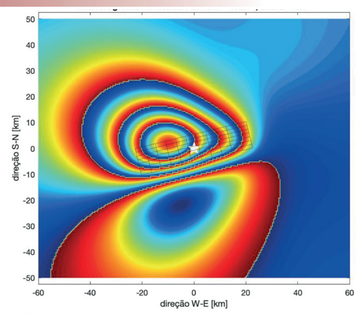
Middle panel: Distribution, in time windows of 1.33s, the seismic moment release. The panel labeled as Total represents the total slip distribution.

Right panel; Comparison the observed (black line) and synthetic (red line) P and SH waveforms used in the inversion.

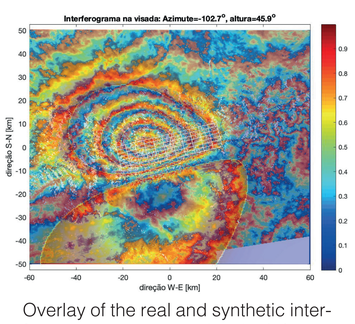
Validation of the model



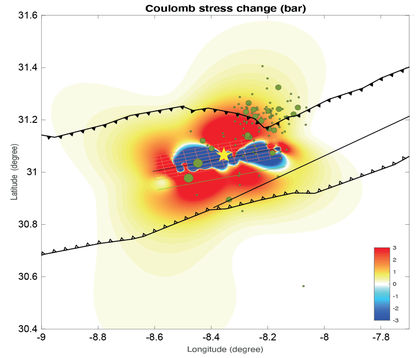
InSAR map containing information of the surface displacement field in the direction of the satellite, due to the 2023 Morocco earthquake, done using the pair of SAR images from the Sentinel-1 Satellite - ascending route 045A_05919_131313 on 3/09/2023 and 15/09/2023.



Synthetic interferogram produced with the calculated surface displacement field using the source model obtained by inversion and subsequently projected in the direction of the satellite.



Overlay of the real and synthetic interferograms represented to the left.



Coulomb stress change at 21 km depth, the average depth of the recorded aftershocks by IPMA (Portugal) between September 8th and November 18th. Where considered the slip distibution model obtained and a receiving fault with geometry compatible with the known tectonics in the region and regional stress state. A friction coefficient of 0.4 was assumed.