Reappraising the Generation Mechanism of the 1755 Lisbon Earthquake:
Constraints from Historical Records and Tsunami Simulation

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The Great Lisbon earthquake (November 1, 1755) with an estimated moment magnitude (Mw) of 8.7, struck Portugal, Spain, and northern Morocco, with tremors felt across most of northwestern Europe. This is the only major earthquake to have occurred far from a major subduction zone in the last ~350 years. The earthquake triggered a devastating trans-oceanic tsunami that swept the nearby Atlantic coast with run-up heights of 5–15 meters. In the Caribbean Islands, run-up heights of 1–5 meters were also reported (Gutscher, 2004). Various tectonic structures have been proposed as the source of this event, based on macro-seismic data, averaged tsunami amplitudes, or comparisons with more recent regional earthquakes. However, these results have led to discrepancies and no single source model has been able to fully explain its seismic moment, tsunami arrival times, and especially, the tsunami run-up heights according to historical records. As a result, the mechanism behind its occurrence remains elusive.

Here we review the full range of phenomenological observations of this earthquake based on historical records such as tsunami run-up heights and arrival times, seismic intensity, and aftershock’s distribution to investigate the source and mechanism that triggered this event. To achieve this, we performed tsunami simulations and compared the obtained run-up heights and arrival times with those reported in historical documents collected at 6 locations. To simulate a tsunami, we used the tsunami simulation code JAGURS (Baba et al., 2015). Bathymetry grids for the simulation were obtained from the General Bathymetric Chart of the Oceans (GEBCO, 2023) with flat resolutions of one arc minute. The time step for calculations was set at 0.5 s to satisfy the stability condition, and the tsunami was simulated for 15 h after the earthquake ensuring that the maximum tsunami height would be obtained, and that the tsunami could travel across the oceans. Manning’s roughness coefficient and rigidity were assumed at 0.025 $m^{-1/3}s$ and 34.3 GPa (Goto and Sato 1993), respectively. We used four different seismic sources from previously published papers by changing the dip, strike, and slip angles of the faults. These sources include the Gorringe Bank Fault (Johnston, 1996); the Marqués de Pombal Fault (Zitellini et al., 2001); the Gulf of Cádiz Fault (Gutscher et al., 2006) and the Horseshoe Abyssal Plain Thrust fault (Barkan et al. 2009; Martínez-Loriente et al., 2021).

The results show that the four modeled earthquake sources were able to somewhat reproduce the historical records. The primary source located at Horseshoe Abyssal Plain Thrust yielded the best correlations between simulations and historical records of run-up heights. The result of seismic intensity analysis shows high intensities (Modified Mercalli Intensity, IX –X) around the Lisbon and Algarve regions. Among all the analyzed epicentral locations, the one closest to Lisbon is approximately 220 km southwest of its end. This suggests that additional factors could have played a role in favoring this shift to longer distances, thus requiring further investigations. Finally, we calculated the static Coulomb stress change from each analyzed source to the location of the Lower Tagus Valley (LTV) fault where most of the aftershocks of the 1755 Great Lisbon earthquake occurred. The results show that LTV may have experienced more than a 0.1 MPa stress increase towards the failure from the Gorringe Bank Fault. In summary, our integrated results suggest that the 1755 Great Lisbon earthquake likely involved multiple ruptures. Therefore, we postulate that this event occurred as a cascading rupture event.

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