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Multiple-rupture earthquakes and hazard assessment – the case of Lisbon 1755

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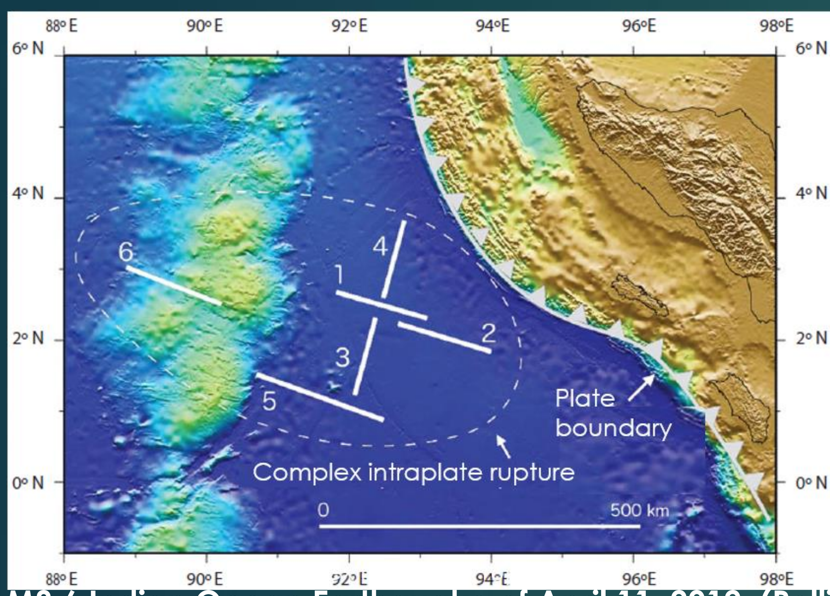
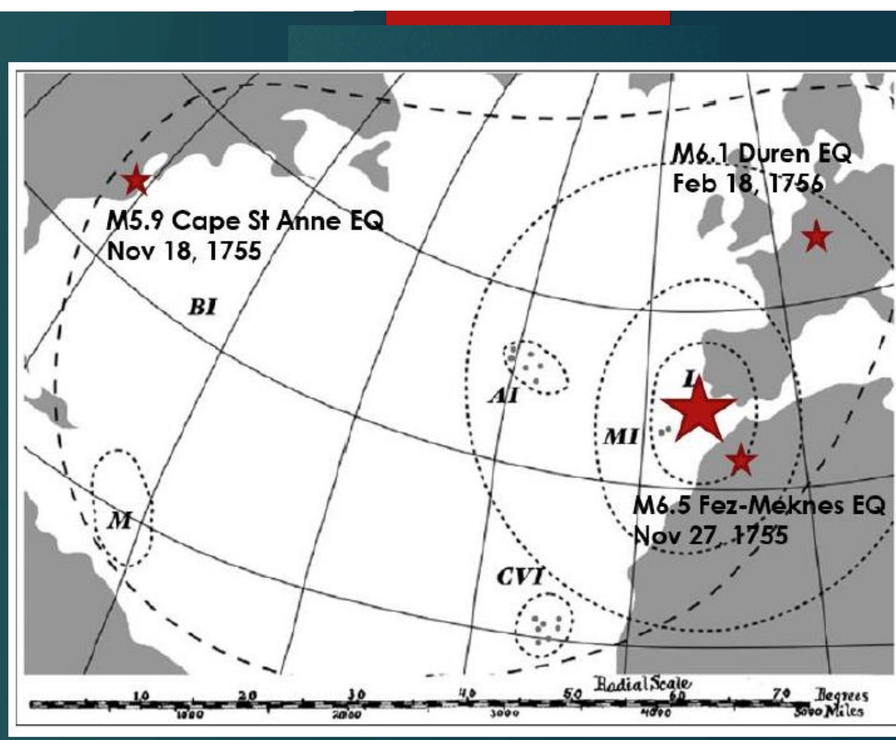
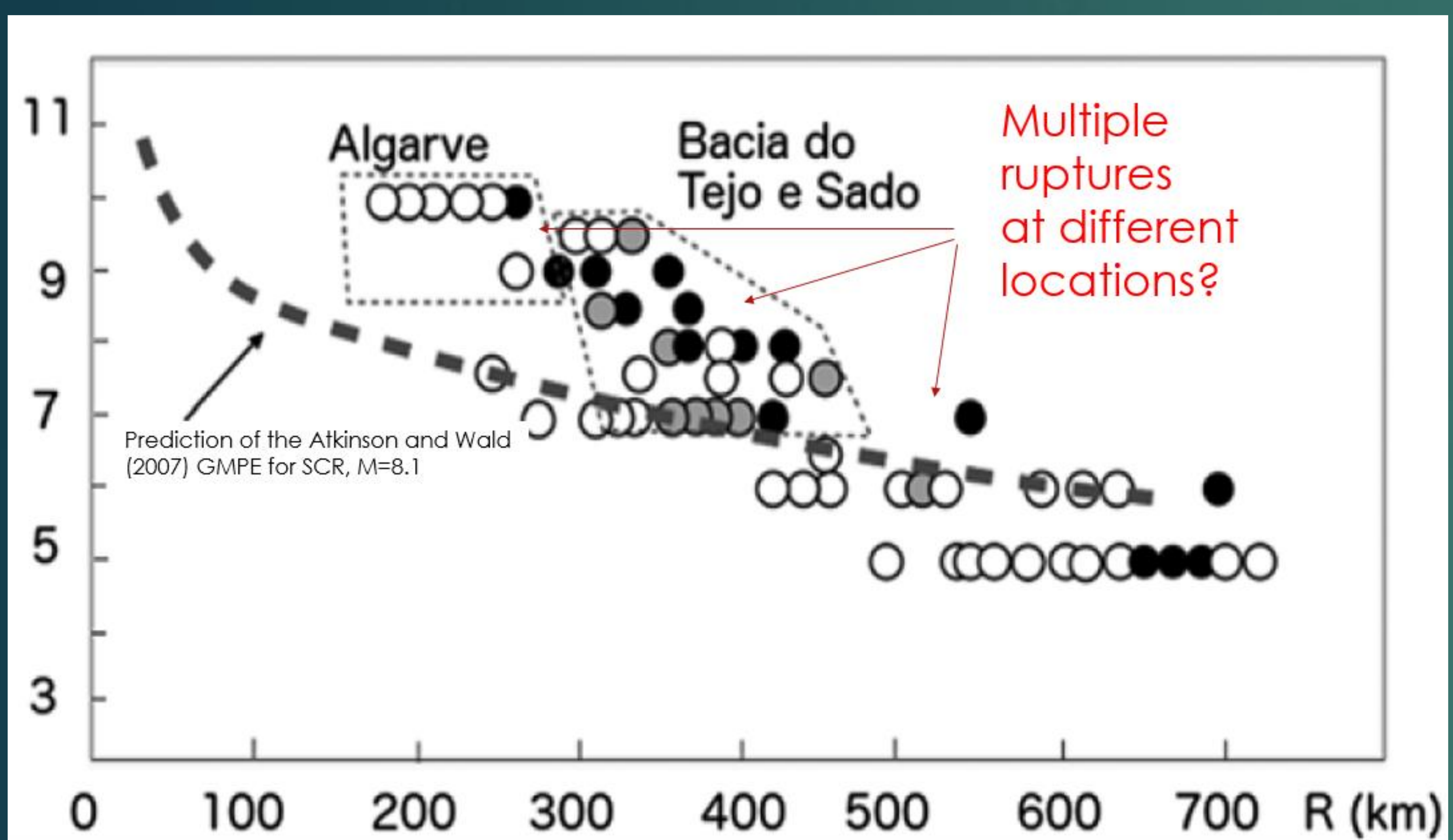


M8.6 Indian Ocean Earthquake of April 11, 2012 (Pollitz et al., 2012). M8.2 rupture not included.

The significant number of M>8.5 earthquakes since the start of the current century provided unprecedented insight into the rupture process of the largest events. In particular, the M8.6 intraplate Indian Ocean earthquake of 2012 (left) was an eye-opener, revealing a complex and disjoint pattern of nearly-simultaneous ruptures with a spatial footprint of ~500km. A close inspection of the coeval accounts of the 1755 earthquake suggests that the two events may have similarities in their rupture processes. They also share the triggering of unusual levels of seismic activity at very large distances (see Pollitz et al., 2012 and Figure on the right).



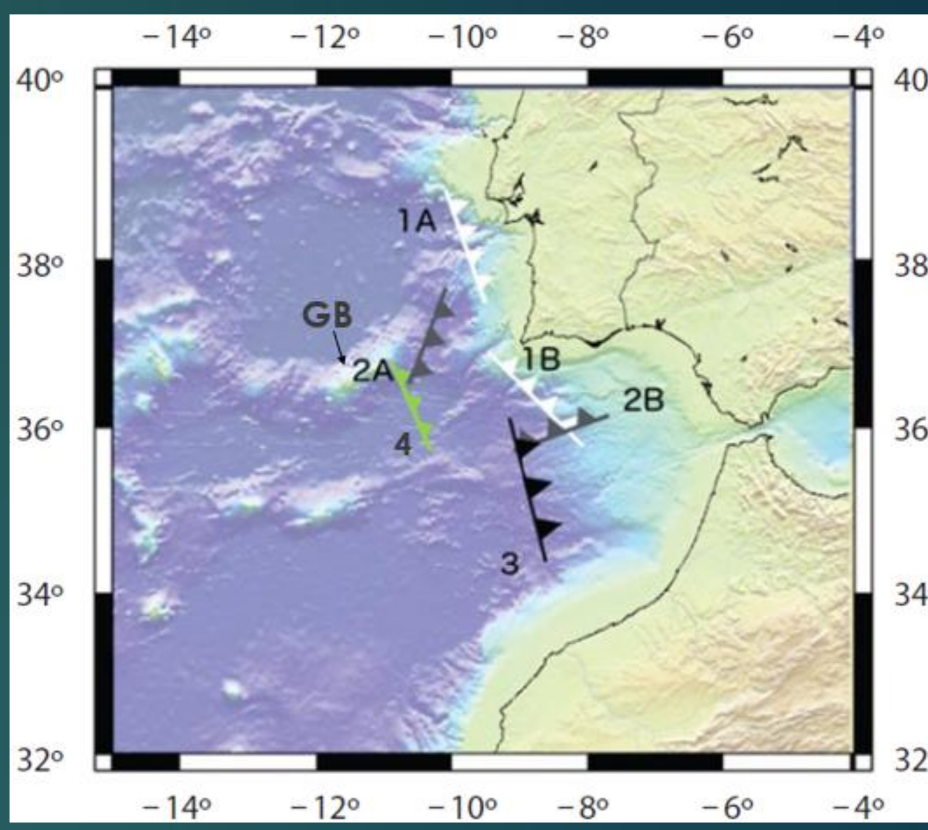
Felt area of the 1755 Cape St Vincent earthquake, according to Reid (1914). Also shown is the unusual intraplate activity in the subsequent months, in different continents.



MM Intensities in Portugal, according to Sousa and Oliveira (1997); open circles are for rocky sites, black circles for unconsolidated soils. Distances are taken from the Gorringe Bank (GB in the figure on the right). Data from the Algarve and Lower Tagus Basin plot above the M8.1 GMPE of Atkinson and Wald (2007), but data at distances larger than 400km do not indicate a higher magnitude.

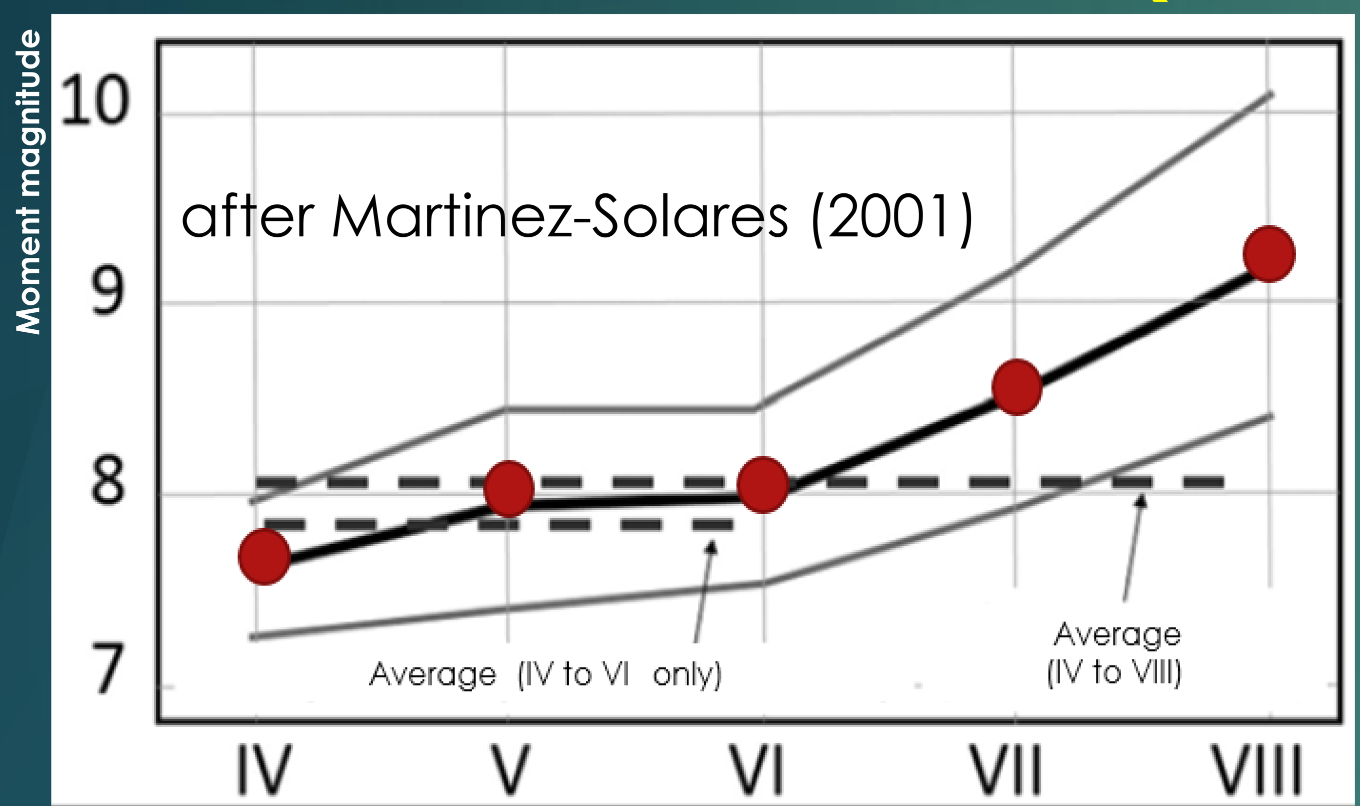
These observations are relevant for hazard assessment because the 1755 EQ has posed a long-standing challenge to PSHA studies, given the difficulty in characterizing the source and estimating its recurrence in a tectonic environment of slow stress build-up (4 to 5 mm/year of convergence). In addition, no published ground motion model can account for the attenuation of intensity with distance (see figure on the left), and attempts to use tsunami traveltime data to identify the source have led to a remarkable scatter in the proposed models (right).

WHICH SOURCE?



Different sources proposed to explain the tsunami travel-times. White: Baptista et al.1996; grey: Baptista et al., 2003; black: Gutscher et al., 2006); green: Barkan et al. (2009; transatlantic data only).

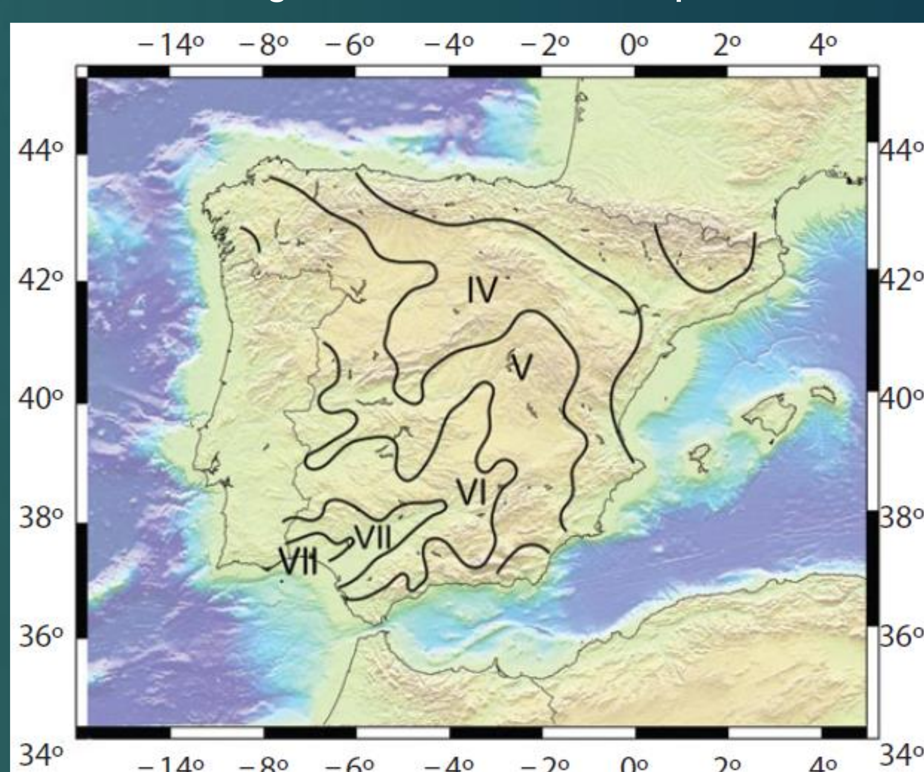
HOW BIG WAS THE EARTHQUAKE?



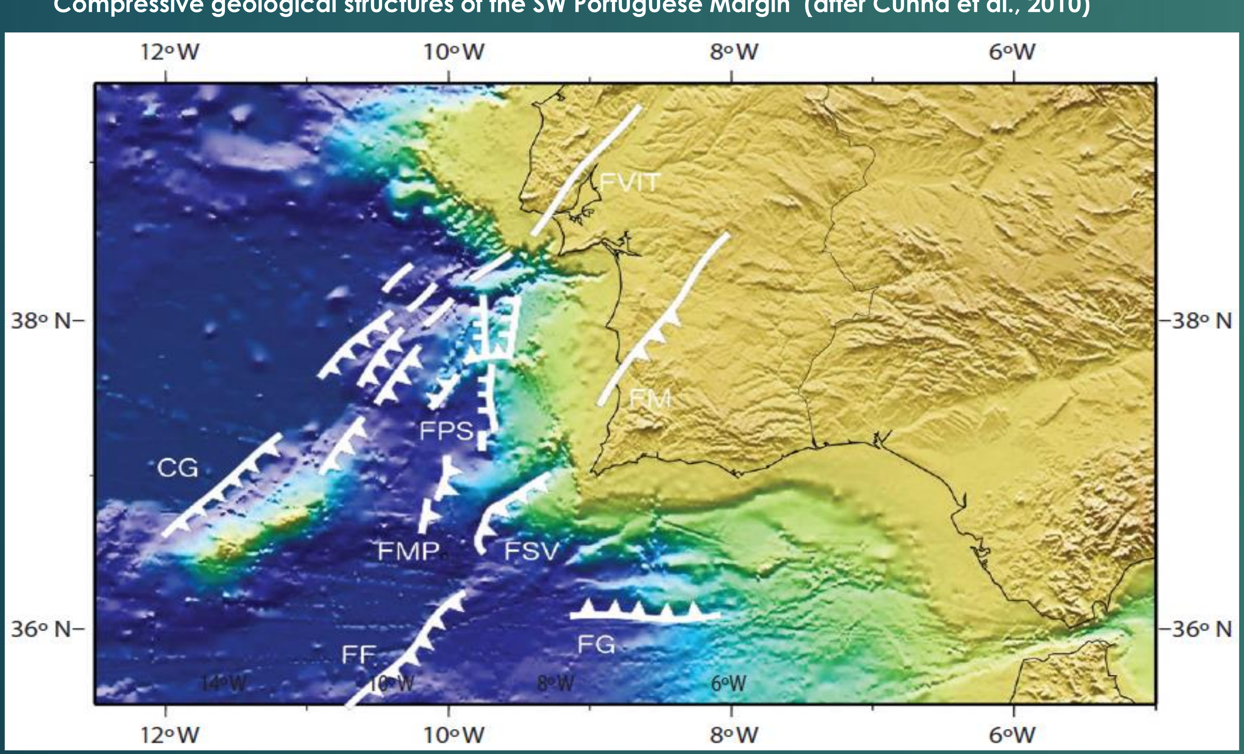
EMS98 Intensity

While early estimates based on (exaggerated) perceptibility areas led to values of 8 ¾ (Gutenberg and Richter, 1958) or 9 (Machado, 1966), the commonly adopted magnitudes range from M8.5 to M8.7, and have been estimated from isoseismal areas for different intensities (Johnston, 1998; Martinez-Solares and Mezcua, 2004). The inherent averaging process has ignored a strong correlation between the chosen intensity and resulting magnitude (figure on the left). "Calibration" corrections of 0.32 and 0.47 were summed to the average by Johnston (1998) and Martinez-Solares and Mezcua (2004).

Isoseismals used by Martinez-Solares and Mezcua (2004) to estimate the magnitude of the 1755 earthquake.



Compressive geological structures of the SW Portuguese Margin (after Cunha et al., 2010)



We posit that the damage distribution, as well as the scatter in tsunami traveltime modeling results, can be better accounted for by multiple rupture of independent faults. This would also explain the abnormal shaking duration: ~8 min with two intervals, according to several coeval accounts (Vilanova et al., 2003). Re-computing the magnitude following Martinez-Solares and Mezcua (2004) but using intensities IV to VI only (and the 0.32 correction of Johnston, 1998), we obtain a moment magnitude of 8.1±0.4 (Fonseca, 2017). We propose that this was the magnitude of the largest sub-event. The task (still ahead) of identifying capable sources whose combined rupture explains the data becomes less challenging (figure in the left).

HOW OFTEN CAN IT RECUR?

While the proposed process of fault rupture is clearly non-Poissonian, the seismic catalog suggests that these faults can, in other occasions, rupture individually. For example, the M7.9 1969 Gorringe Bank Earthquake is a likely recurrence of the leading 1755 rupture, without a "domino-effect". Such a return period is easier to reconcile with the low regional strain rate if the average magnitude is 8 than for the usually adopted magnitudes of M8.5-8.7. The lower magnitude proposed here thus makes the 1755 scenario more relevant at the return period of 475 years adopted by EUROCODE-8. A Poissonian treatment of the (clearly non-Poissonian) multiple ruptures that, according to the model here proposed, compose the 1755 earthquake may be a suitable approach until the implicit fault interaction process is understood and modeled probabilistically. This implies the characterization of the contributing faults and their individual recurrences.

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