Source Rupture Process of the Great Sumatra, Indonesia Earthquake (M_w=8.9) of 26 December 2004
Preliminary Results

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Abstract: *We have study the source rupture process of the great Sumatra (Indonesia) Earthquake (M_w=8.9) of December 26, 2004 using teleseismic broad-band data. The solution obtained shows thrust motion on plane striking on NNW-SSE direction and horizontal pressure axes in NNE-SSW direction. In this preliminary work, we have determined the rupture process using 29 teleseismic broad-band data for rupture directivity study and selected and analysed 14 teleseismic broad-band data for slip distribution study. The results show bilateral rupture with a complex source time function of 210 sec duration and a total scalar seismic moment of 7.25×10^{21} Nm. Due to the long period of the seismic wave the rupture process, presented in this study, is incomplete; we can solve only 25% (M_w=8.5) of the total scalar seismic moment given by the EMSC (M_w=8.9). Soon we will present the complete study of the Sumatra rupture process.*

Introduction

The Indonesian region is one of the most seismically active zones of the earth. On December 26, 2004, a great earthquake occurred at 00:58:50.7 (UTC) (6:58 a.m. local time) off the west coast of northern Sumatra, Indonesia (Fig. 1). The magnitude 8.9 of the seismic event, given by the EMSC, being located nearly Pulau Simeulue Island (3.50^{o}N, 95.72^{o}E, EMSC, Fig. 1), classifies it as the fourth largest earthquake in the world since 1900 (M_w=9.0, 1952, Kamchatka; M_w=9.1, 1957, Andreanof Islands, Alaska; M_w=9.5, 1960, Chile; M_w=9.2, 1964, Prince William Sound, Alaska) and the largest since the 1964 Alaska earthquake.

This megathrus-faulting earthquake occurred on the interface of the India and Burma plates and was caused by the release of stresses that develop as the India plate subducts beneath the overriding Burma plate. The complex tectonics of the region involves several plates: Australia, Sunda, Eurasia, India and Burma (http://earthquake.usgs.gov).

The spatial distribution of the re-locations of larger aftershocks (M>4.5) following the main shock suggests a length and width of the rupture of about 1300 km and 200 km, respectively (see http://iisee.kenken.go.jp).

The earthquake triggered massive tsunamis that affected several countries throughout South and Southeast Asia: Indonesia, Sri Lanka, India, Thailand, Somalia, Myanmar, Malaysia, Maldives, Tanzania, Bangladesh The tsunami crossed into the Pacific Ocean and was recorded along the west coast of South and North America. Tsunamis also took place on the coasts of Cocos Island, Kenya, Mauritius, Reunion and Seychelles. The earthquake was felt (VIII) at Banda Aceh and (V) at Medan, Sumatra. It was also felt in Bangladesh, India, Malaysia, Maldives, Myanmar, Singapore, Sri Lanka and Thailand. As a result of the earthquake the sea floor experienced and uplifted of several meters.

In this preliminary work, we have determined the rupture process of the 2004 Sumatra (M_w=8.9) earthquake using 29 teleseismic broad-band data for rupture directivity study and selected 14 teleseismic broad-band data for slip distribution study.

Data Processing

Source process study has been performed using 29 teleseismic P waveforms data recorded at IRIS-DMC stations retrieved via the Internet. Stations were selected from the standpoint of good azimuthal coverage and correspond to seismograms recorded at distances (30^o<D<90^o) in order to avoid problems with the upper mantle wave triplications, and diffractions by the mantle-core boundary. To perform stable inversion, the records were band-passed and then converted into ground displacement.

Directivity

We determine the rupture direction and velocity from common pulse durations observed in 29 P waveforms using Caldeira (2004) DIRDOP computational code (DIRectivity DOPpler effect). Figure 2 shows the best dominant rupture azimuth ($\varphi = 281^o \pm 12^o$) and the rupture velocity (v_r=1.2±0.2 km/s). This suggests a bilateral rupture with predominant rupture towards the NW. The low value obtained for the rupture velocity denotes, in this method, the bilateral character of the rupture.

Inversion

The modified Kikuchi and Kanamori (2003) method, based on a finite fault inverse algorithm, has been used to carry out the slip distribution. We used a 1D velocity model with 3 km water and the fault plane solution obtained from the moment tensor solution of the HARVARD (strike = 329^o and dip = 8^o and slip = 110^o). For this, we selected and analysed 14 teleseismic broad-band data. In this preliminary work, the inverted total seismic wave used is 240 sec.

Preliminary Results

The solution obtained shows thrust motion on plane striking on NNW-SSE direction and horizontal pressure axes in NNE-SSW direction.

The rupture process can be explained by 3 main subevents distributed between approximately 5 km and 20 km depth (Fig. 3) with time duration of 210 sec. The total scalar seismic moment is 7.25×10^{21} Nm (M_w=8.5) and the maximum slip is about 9m at both extremities of the fault (Fig. 3).

In the first stage the rupture propagated about 200 km to the northwest from hypocenter during the first 45 sec. The two next large ruptures started, respectively, about 80 sec (second rupture) and 135 sec (third rupture) after the initial rupture (Figs 3 and 4). The rupture propagates northwestward with 400 km long and southeastward with 350 km long. The constrained dimension of the fault, in this preliminary work, is nearly 1000 km with a maximum rupture velocity of 3.0 km/sec during 240 sec.

The slip distribution corroborates the bilateral character of the Sumatra rupture process, with a predominant rupture towards the NW, resulting from the directivity study presented above.

Conclusion

The rupture process presented in this study is incomplete (we can solve only 25% of the total scalar seismic moment determined by the EMSC). Our results show the first rupture and a part of the second and third rupture. The period of the seismic wave is too long to analyse the total rupture with this program. We need to adapt the program to analyse the total seismic wave. Soon we will present the complete study of the Sumatra earthquake.

References

- Caldeira B. *Caracterização espaço-temporal da fonte sísmica. Processo de ruptura e directividade*. PhD thesis, University of Évora, Évora, Portugal, 282 p. Submitted in Nov 2004.
- Kikuchi, M. and H. Kanamori, 2003, *Note on Teleseismic Body-Wave Inversion Program*, http://www.eri.u-tokyo.ac.jp/

Related Links

- www.emsc-csem.org/
- http://iisee.kenken.go.jp
- South Asia: Earthquake and Tsunami - Dec 2004
- US Geological Survey
- Tsunamis & Earthquakes at the USGS

- International Tsunami Information Center
- National Tsunami Hazard Mitigation Program
- West Coast & Alaska Tsunami Warning Center
- Tsunami at the University of Southern California
- Tsunami at the University of Washington
- Tsunami Related WWW Sites
- Ministry of Foreign Affairs : Sri Lanka
- Ministry of Foreign Affairs : Thailand

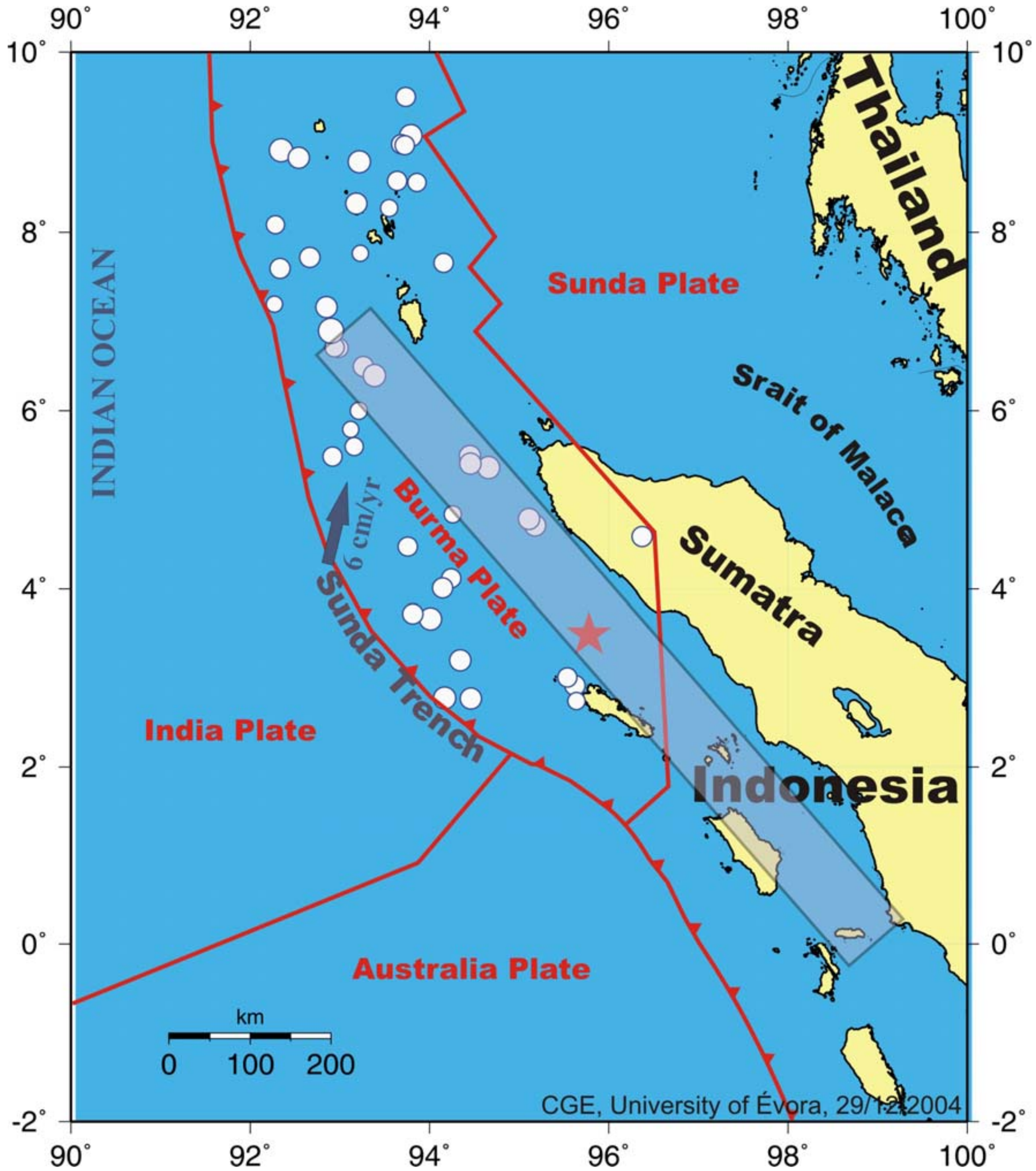

Fig. 1 - Map of the India and Australia plates subduction zone. The India plate moves toward the northeast at a rate of about 6 cm/year relative to the Burma plate. Tectonic background of the epicentral area are plotted together with the large aftershocks (M>4.5, open circle; data compiled from USGS) following the earthquake of December 26th, 2004 (star) located off the west coast of northern Sumatra. The rectangle indicates the extent of the fault plane used in the slip inversion of this study (Fig. 3C).

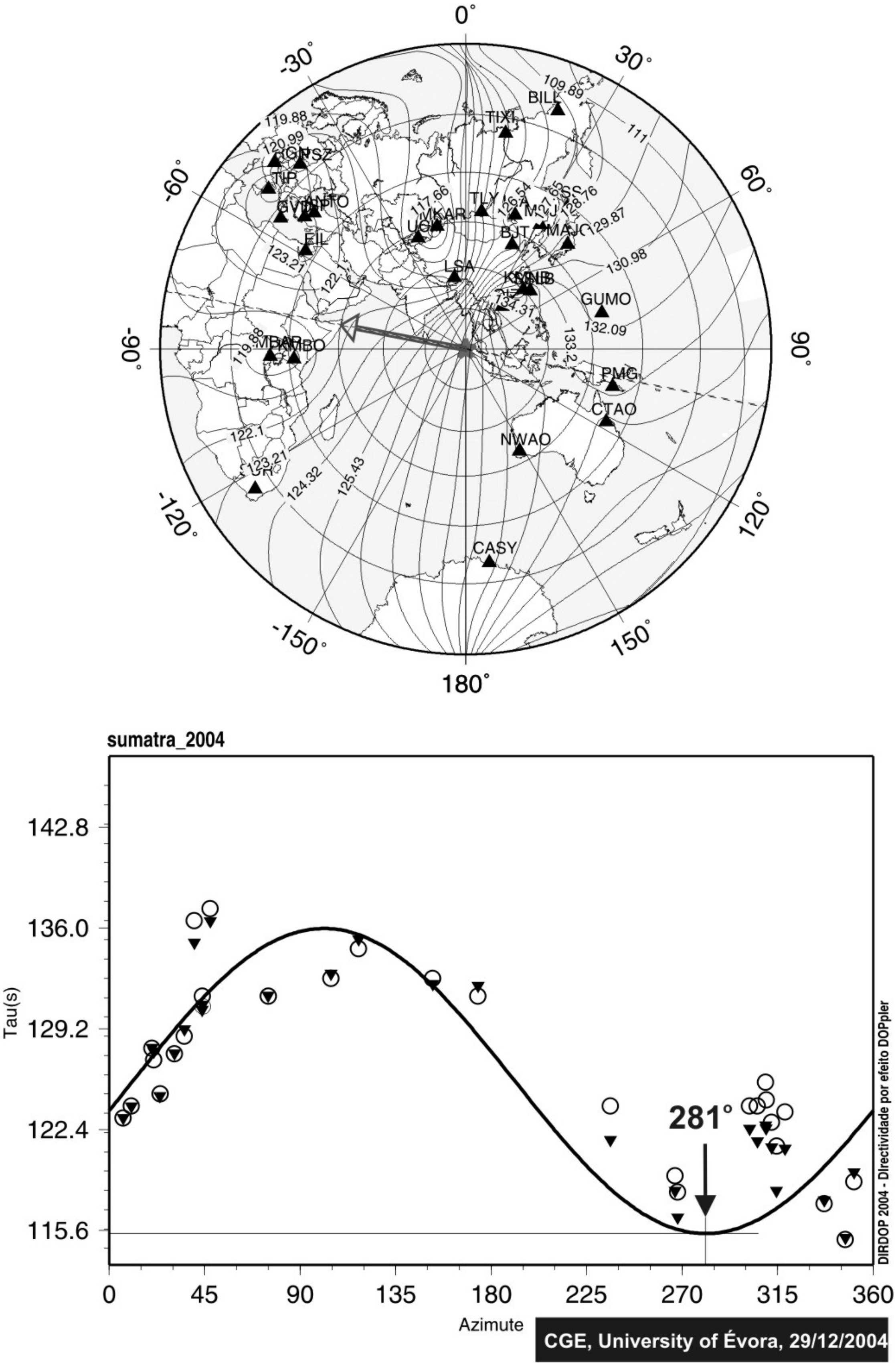

Fig. 2: Results of search for the best rupture azimuth for the Sumatra earthquake using DIRDOP code. Top panel shows the azimuthal distribution (isolines) of common time pulses measured in the observed seismograms. The blue arrow represents the obtained rupture direction. Lower panel shows the phases-delay versus azimuth. Open circles and solid inverted triangles represent measured and normalized time delays, respectively. The solid line represents the predicted time delay obtained by the inversion of the directivity model. Highest correlation coefficient occurred at an azimuth of 281°.

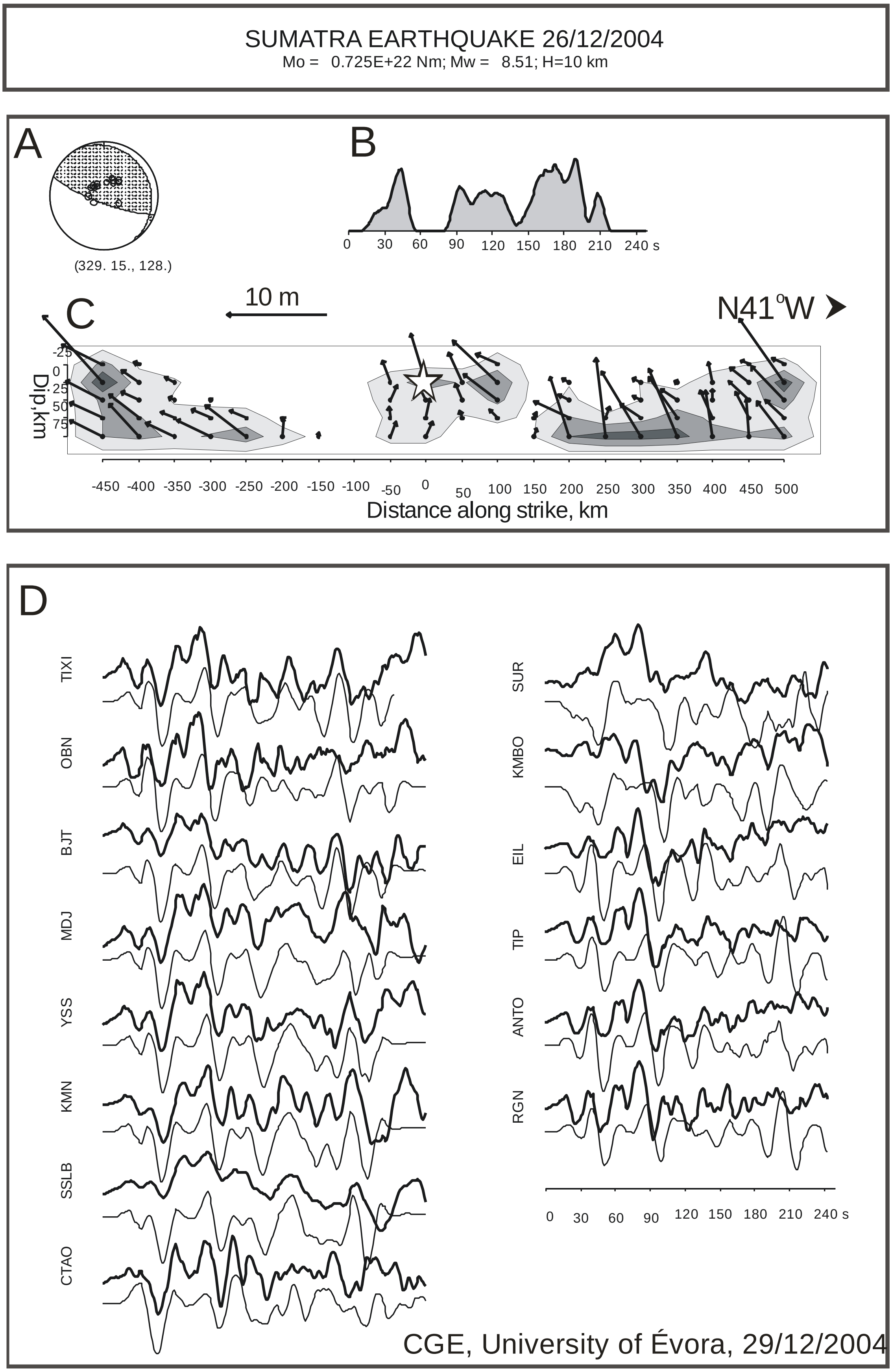

Fig. 3 – Slip distribution model obtained from teleseismic body wave inversion: A) Focal mechanism; B) Source time function; C) Slip distribution along the fault plane; D) P-waveform comparison, solid line represents the observed seismogram and thin line the synthetic seismogram. Star indicates the hypocenter.

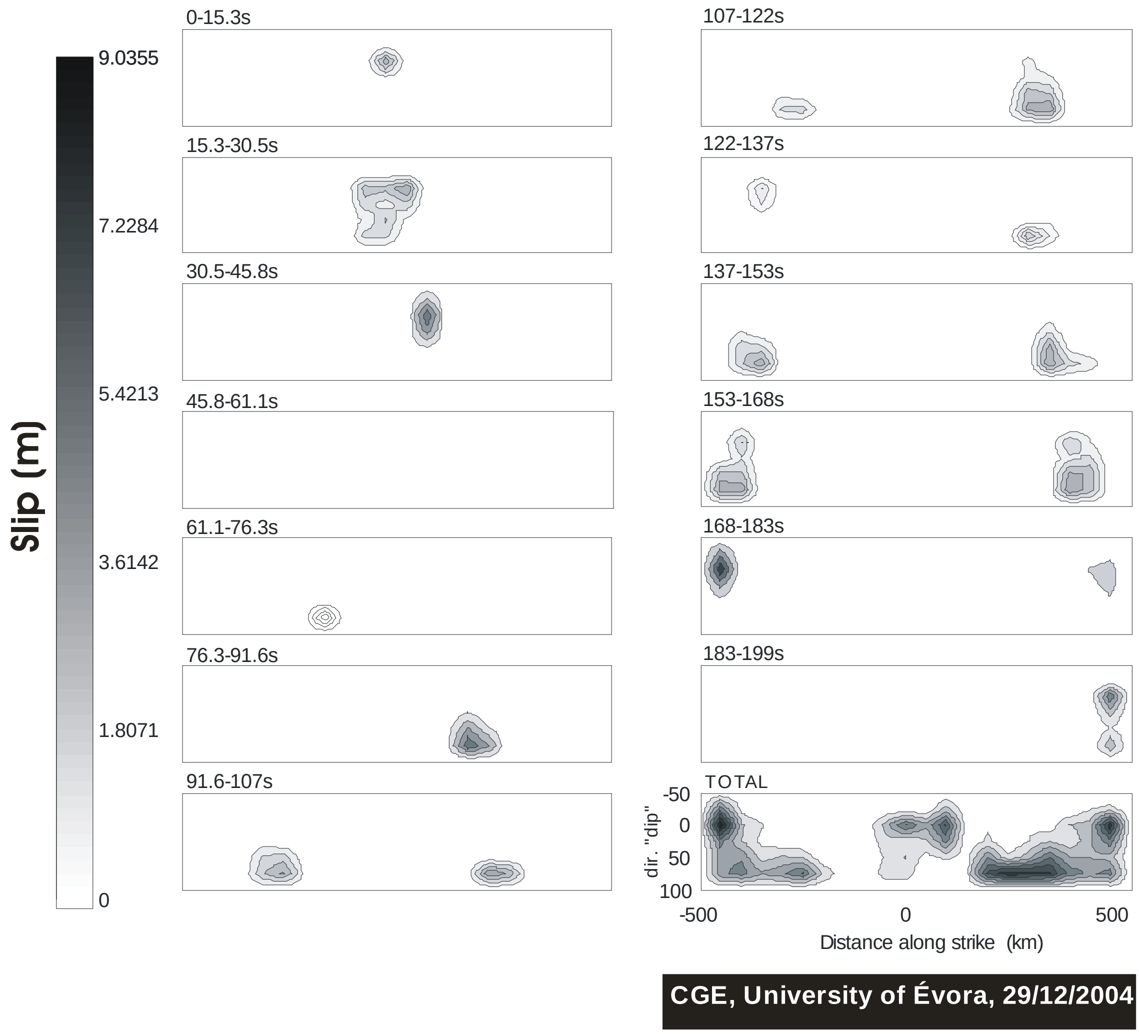

Fig. 4 - Time evolution of the rupture given at intervals of 15.3 sec for our preferred model. See text for details.