Rupture propagation of recent large TsE off-coast Sumatra and Java

Dirk Rößler, Frank Krüger, Matthias Ohrnberger, University of Potsdam
contact: **diroess@uni-potsdam.de**, online at: ***http://www.geo.uni-potsdam.de/forschung/geophysik/gitews/tsunami.htm***

1 Recent TsE earthquakes

Since 2004 three large earthquakes have caused significant tsunamis in the Sunda arc subduction zone: (1) the Mw9.3 megathrust event on 26/12/2004, (2) the Mw8.6 event on 28/03/2005, and (3) the Mw7.7 event on 17/07/2006 (**Figs. 1-3**). Although the magnitude of event (2) (Mw8.6) was much larger than event (3) (Mw7.7) the ruptured areas are similar and the duration of (3) exceeds that of (2). This indicates slow rupturing for event (3). The three events probably started bilaterally or circularly. Event (1) and (3) continued unilaterally.

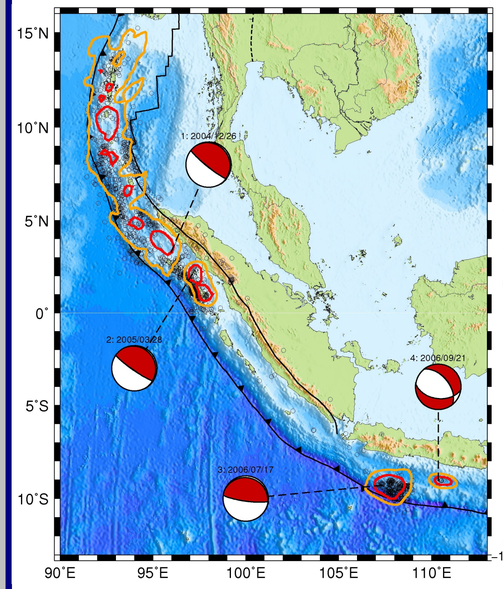
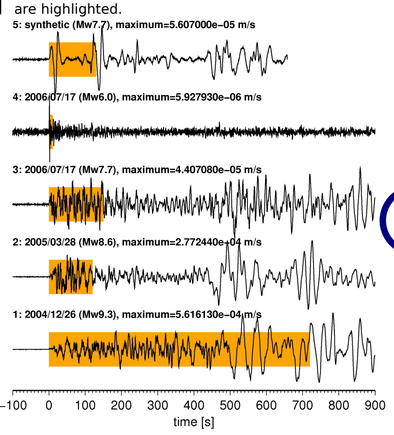


Fig. 1 (left): Epicentres, fault-planes [3], and aftershocks (within 3 days) of events (1)-(3) and, (4), one event (Mw6.0) on 21/09/2006. **Orange** and **red** lines: semblance: **0.5** and **0.75** - approximate ruptured areas.

Fig. 2 (below): Seismograms at station ABU (FNET, Japan) for events (1)-(4) in **Fig. 1** and one synthetic event (see **Sec. 4**). The wavetrains of direct P waves are highlighted.



Rupture times and velocities from semblances (unfiltered)

event (1) on 26/12/2004

Fig. 3a

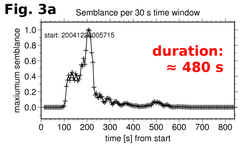
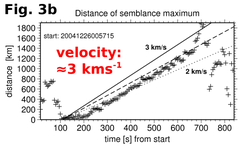


Fig. 3b



event (2) on 28/03/2005

Fig. 3c

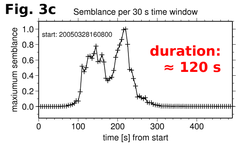
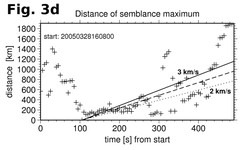


Fig. 3d



event (3) on 17/04/2006

Fig. 3e

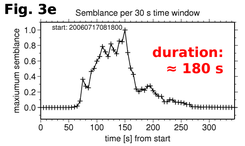
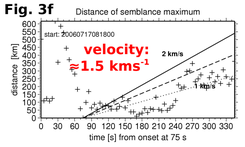


Fig. 3f



Summary

The spatio-temporal evolution of the three recent tsunamogenic earthquakes (**TsE**) off-coast N-Sumatra (Mw9.3), 28/03/2005 (Mw8.5) off-coast Nias, on 17/07/2006 (Mw7.7) off-coast Java. Start time, duration, and propagation of the rupture are retrieved. All parameters can be obtained rapidly after recording of the first-arrival phases in near-real time processing. We exploit semblance analysis, back-propagation and broad-band seismograms within 30°-95° distance:

$$semblance = \frac{1}{M}\frac{\sum_{k=1}^{N}\left(\sum_{i=1}^{M} a_{ik}\right)^2}{\sum_{k=1}^{N}\left(\sum_{i=1}^{M} a_{ik}^2\right)},$$

where a_{ik} is the *k-th* seismogram sample at the *i-th* station. Image enhancement is reached by stacking the semblance of arrays within different directions.
For the three events, the rupture extends over about **1150, 150, and 200km**, respectively (**Sec. 1**,). The events in 2004, 2005, and 2006 had source durations of at least **480s, 120s, and 180s**, respectively. We observe unilateral rupture propagation for all events except for the rupture onset and the Nias event, where there is evidence for a bilateral start of the rupture. Whereas average rupture speed of the events in 2004 and 2005 is in the order of the S-wave speed (**≈2.5-3km/s),** unusually **slow rupturing (≈1.5 km/s)** is indicated for the July 2006 event.
For the July 2006 event (**Sec. 2, 3**) we find rupturing of a **200 x 100 km wide area** in **at least 2 phases** with propagation from **NW to SE**. The event has some characteristics of a **circular rupture followed by unilateral faulting with change in slip rate**. Fault area and aftershock distribution coincide. Spatial and temporal resolution are **frequency dependent**. Studies of a Mw6.0 earthquake on 2006/09/21 and one synthetic source **(Sec. 4)** show a **≈1° limit in resolution**. Retrieved source area, source duration as well as peak values for semblance and beam power generally increase with the size of the earthquake making possible an automatic detection and classification of large and small earthquakes.

2 Frequency-wavenumber analysis at GRSN stations of event (3) on 17/07/2006

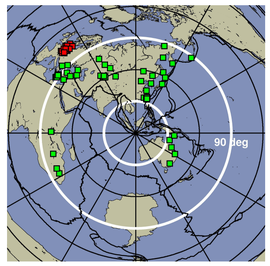


Fig. 4: Green squares: stations for semblance analysis, **red squares**: GRSN stations for F-K and vespagram analysis. **Centre of map:** epicentre of event (3) on 17/07/2006.

Long source duration (>120s) for event (3) on 2006/07/17, Mw7.7, TsE, is indicated by long P wavetrains seen at the German Regional Seismic Network (GRSN), see **Figs. 2, 4, 5a-c**.

Fig. 5a: Vespagram (normalised beam power) for 100s before to 200s after first arrival on station MOX.

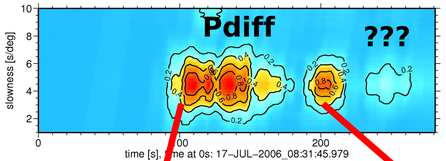


Fig. 5b: F-K-diagram for a time window including 100s before to 20s after the first arrival on station MOX (Pdiff).

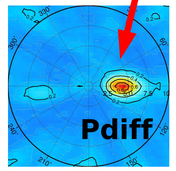
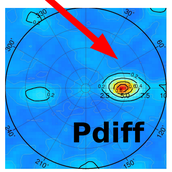
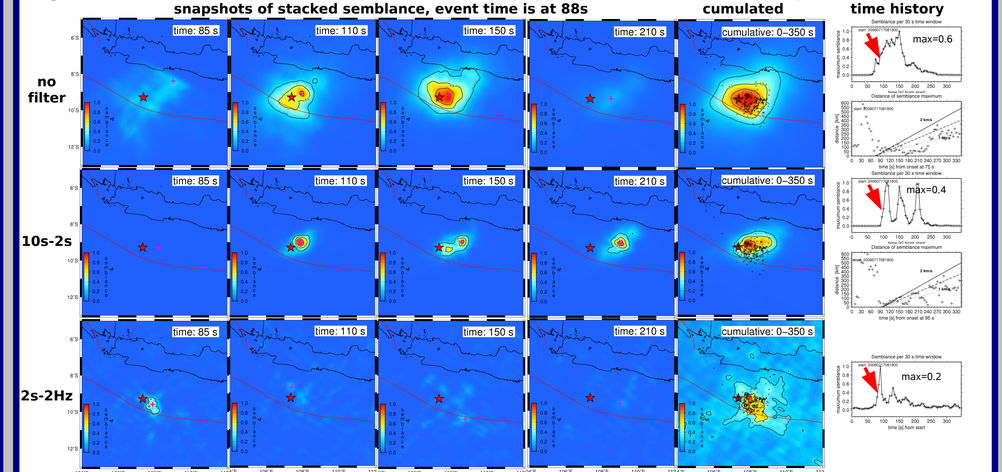


Fig. 5c: F-K-diagram including 100-200s after first arrival on MOX.



3 Rupture propagation of the TsE on 17/07/2006 seen at different frequencies

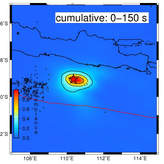
Fig. series 6: Semblance analysis reveals 2-3 peaks – start and stopping phase? **Red arrows**: event time. Rupture velocity: ≈1.5 km/s.



4 Resolution tests (filter: 10s-2s)

Right:
Size, duration, and beam power (not shown) differ clearly between the Mw6.0 event (4), **Fig. 1, a**nd the Mw7.7 event (3), **Secs. 2, 3**.
Below:
Assuming a synthetic source (circular rupture + unilateral Haskell source, area: 200x100km, duration: 130s) shows that only start and stopping phases or fault segments where changes in slip occur can be imaged.

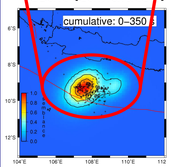
Event (4), Mw6.0, on 2004/09/21



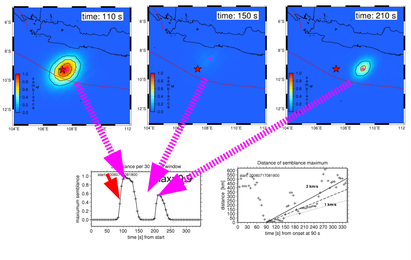
Synthetic source

synthetic model:

result (cumulated)



retrieval: snapshots of stacked semblance
only start/stopping phases are visible, source time at 90s



Acknowledgements / References: Data provision by SZGRF/BGR, IRIS, and FNET are acknowledged.
[1] Krüger, F., Ohrnberger, M., 2005, Tracking the rupture of the Mw=9.3 Sumatra earthquake over 1,150 km at teleseismic distance, Nature, 435
[2] Krüger, F., Ohrnberger, M., 2006, Spatio-temporal source characteristic of the 26 December 2004, Sumatra earthquake as imaged by teleseismic broadband arrays, Geophys. Res. Lett., 32
[3] Global Centroid Moment Tensor Project, online at *http://www.globalcmt.org/*