Automatic near real-time characterisation of large earthquakes

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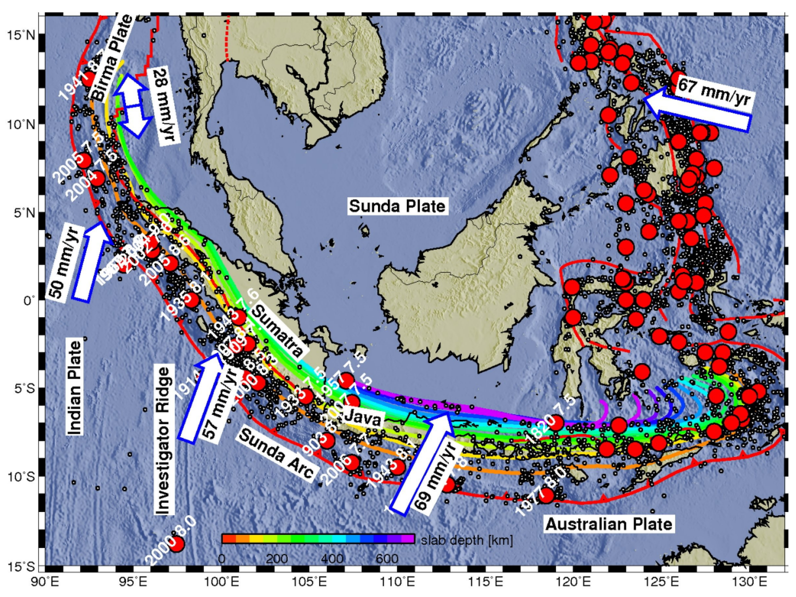
Fig. 1: Map of seismicity and tectonics in the Sunda Arc region. Red cirlcles: major earthquakes, contour lines: slab depth (RUM model). Arrows indicate plate motion.



1. Introduction

We use seismic array methods (semblance analysis) to image areas of seismic energy release in the Sunda Arc region **(Fig. 1)** and world-wide. Broadband seismograms at teleseismic distances (30° ≤ Δ ≤ 100°) are compared at multiple subarrays **(Fig. 2)** which are later combined by multiplication of their semblance maps. High semblance tracked over long time (10s of seconds to minutes) and long distances indicate locations of earthquakes. The method allows **resolution of rupture characteristics for tsunami early warning and hazzard mitigation**:

- **start and duration,**
- **velocity and direction,**
- **length and area.**

The method has been **successfully applied to major recent events in real time (see Sections. 3-5**, Refs. [1], [2], [3]). Results are found shortly after source time, visit `www.geo.uni-potsdam.de/arbeitsgruppen/Geophysik_Seismologie/forschung/ruptrack`.

Fig. 2: Principle of semblance analysis. Waveforms are compared within time windows defined by hypothetical source position and source time. Time and location at source are shifted to obtain resolution in space and time.

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

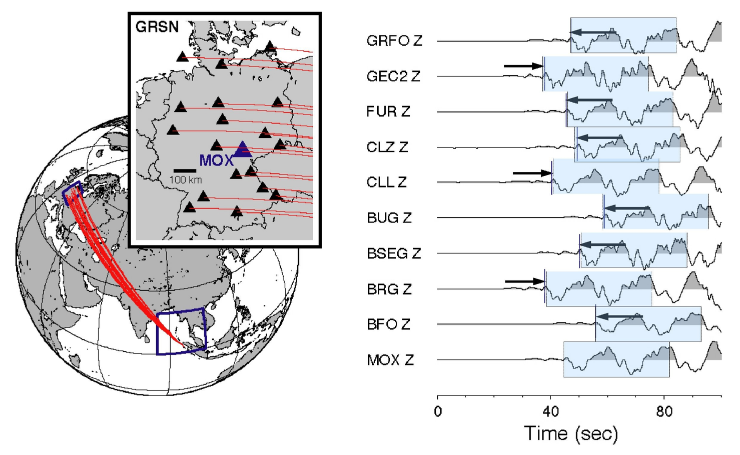
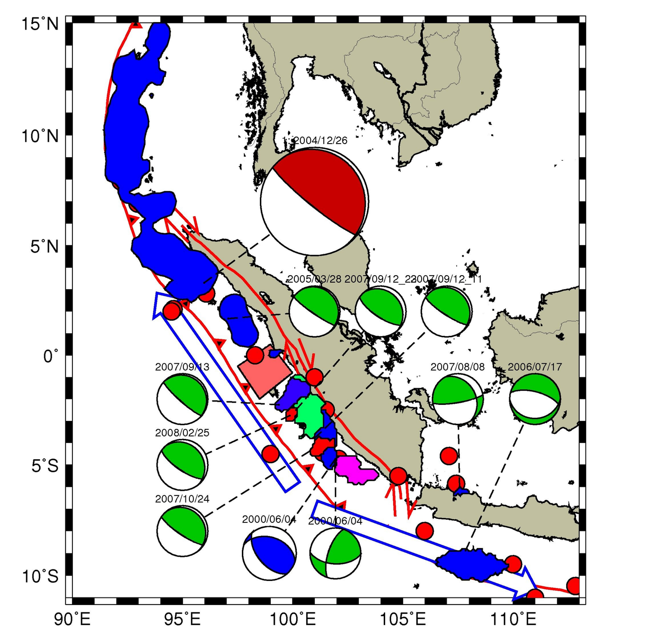
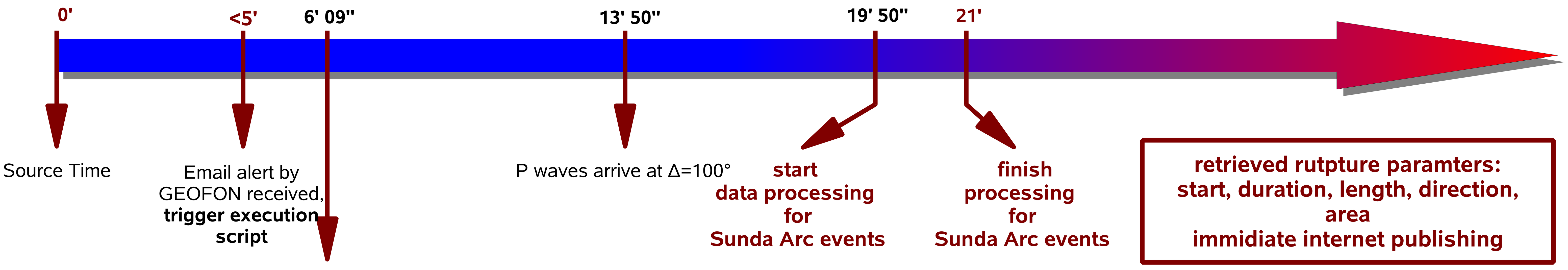


Fig. 3: Rupture areas of major Sunda Arc events since 2000 from semblance analysis. Focal mechanisms by University of Potsdam, [4], and [5].



2. Flow and Timeline of Near Real-Time Processing



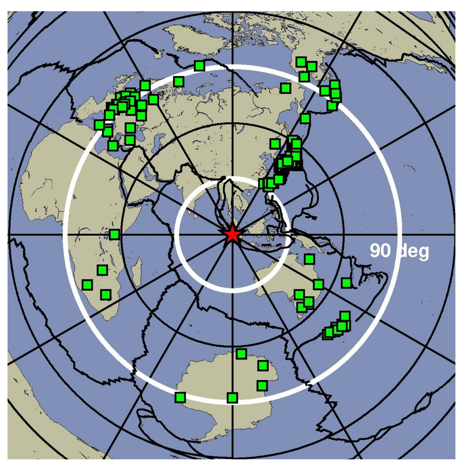
Values / arrows in red indicate times specific for processing.

Flow optimisation and **reduction of processing time** will be reached by including stations closer to the Sunda Arc (≈5') and precalculation of travel-times (≈1').
Resolution of rupture imaging may be increased by including more stations **(Section 3)** such as F-Net or near source seismic arrays and more sophistcated methods such as pattern recognition.

3. Manual vs. Automatic Real-Time Processing

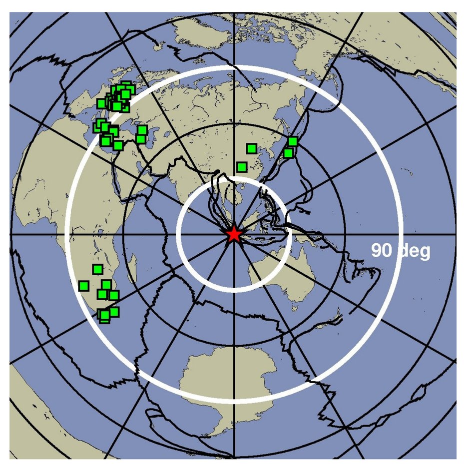
Results from manual and automatic post-processing (equivalent to real-time processing) show striking similarities of major rupture characteristics, e.g. source location, rupture direction, length, area, and velocity. During manual post-processing more than 70 Japanese F-net stations provide high image resolution. They are currently not available in real time. Stations in Australia / New Zealand were not included in automatic processing (likely polarity reversals resulting from source radiation properties).

Manual Data Processing

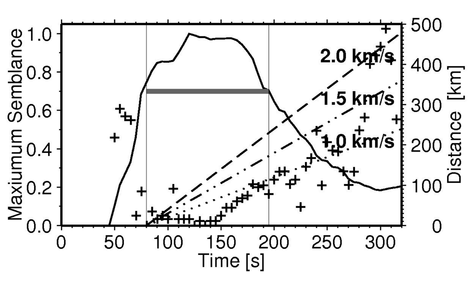


Left / right: Station distribution during manual processing / automatic real-time data processing

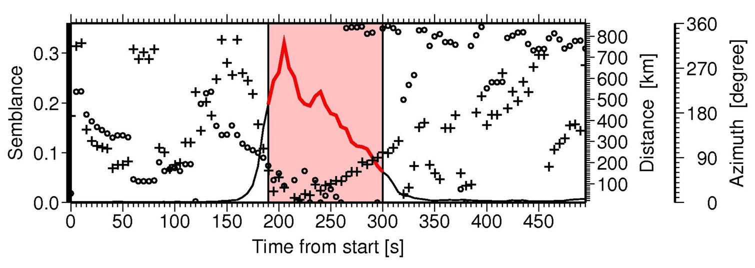
Automatic Processing

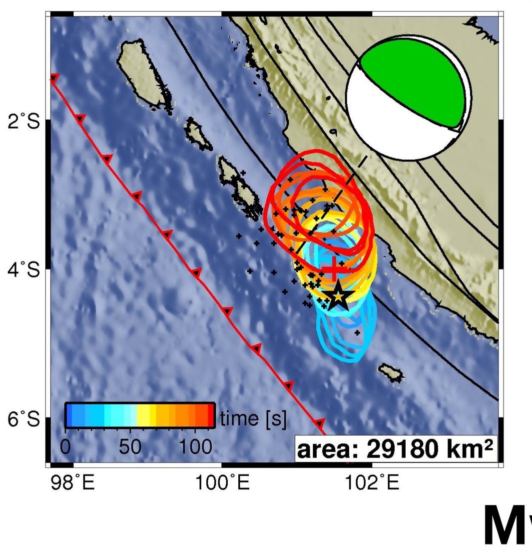


Mw8.0 on 12/09/2007, 11:10

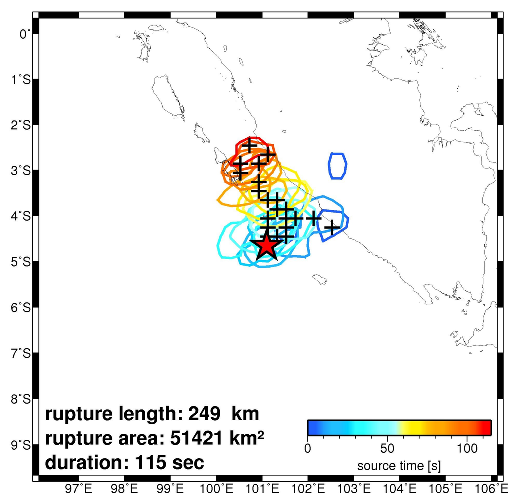


Time series of semblance maxima (SM) and distance of SM to GEOFON location indicating **rupture time ≈ 100 s** and **velocity ≈ 2 km/s. Right:** red line: active trigger, uniform azimuth (circles) indicates N-propagating rupture.

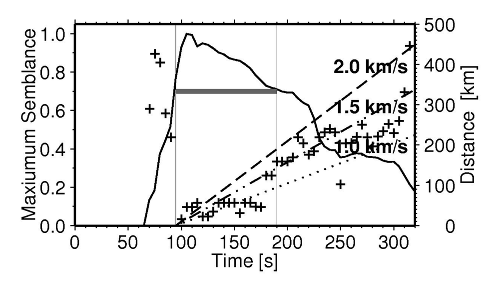




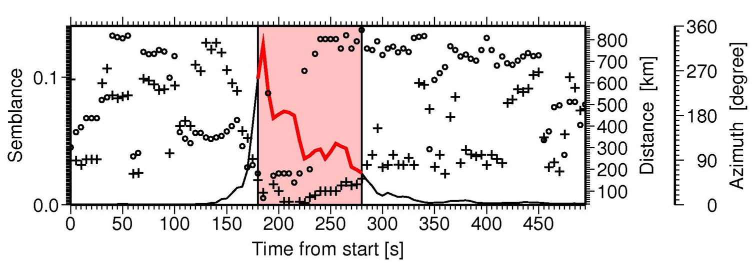
Map of semblance (contour) imaging rupture extent. Star: GEOFON epicentre. Colours represent time from source time. **Right:** Contours for of positive triggering (**red line** in semblance-time plot). Crosses: locations of semblance maxima.

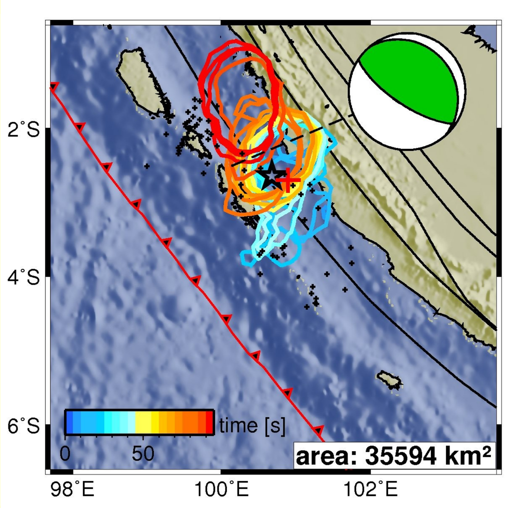


Mw8.0 on 12/09/2007, 23:49



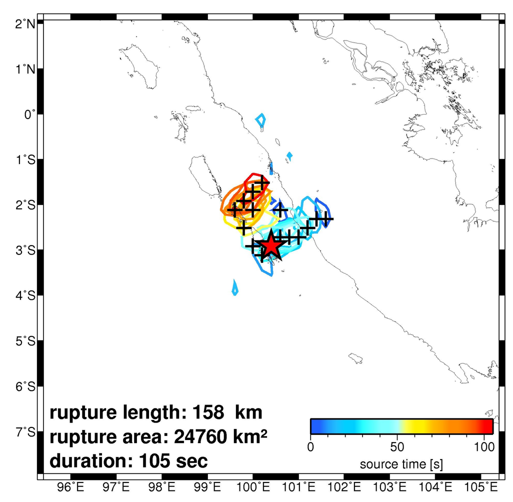
Time series of semblance maxima (SM) and distance of SM to GEOFON location (compare above).
Rupture time ≈ 100 s
rupture velocity ≈ 2 km/s.





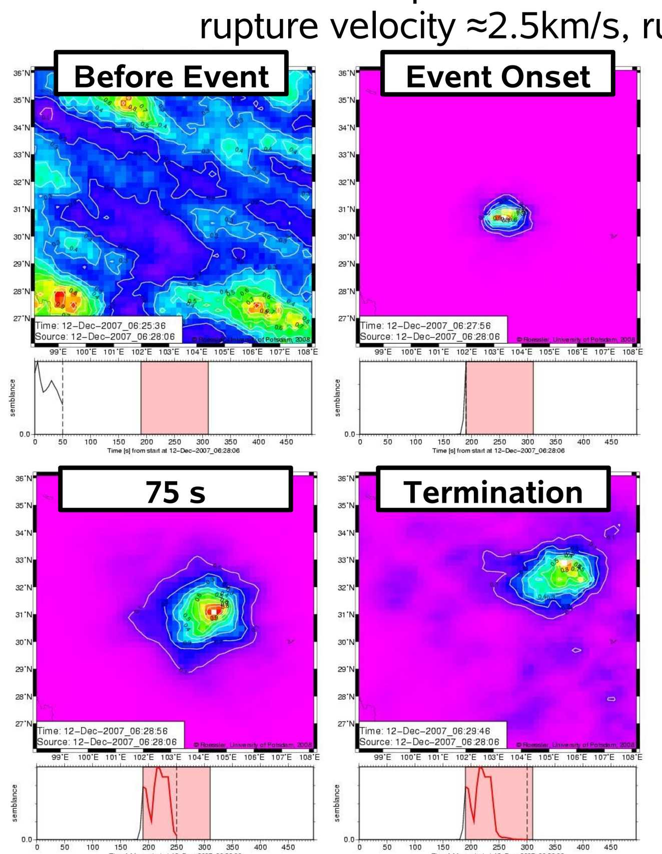
Map of semblance (contour) imaging rupture extent (compare above). Rupturing appears to be smooth. Only start and end phases are clearly resolved.

Rupture lengths are similar for both processing schemes but estimated areas are quiet different.

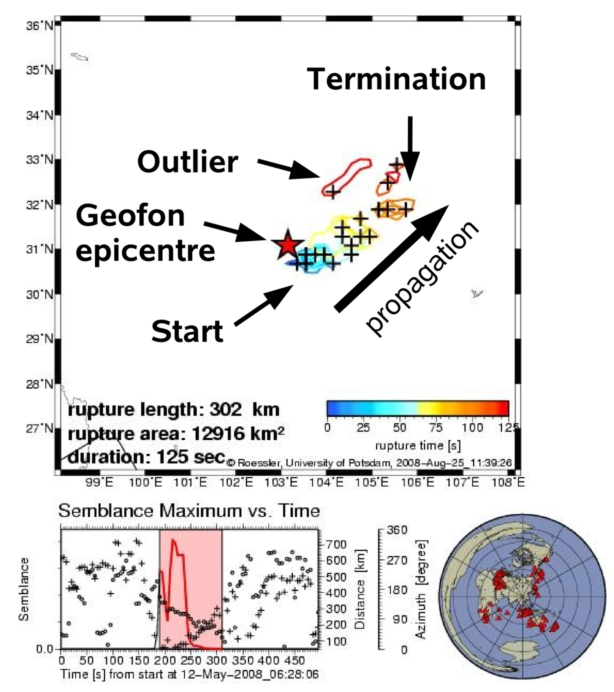


4. Example of Fully Automatic Processing

M8.0 Sichuan, China, Earthquake: 12/05/2008 at 31.1°N, 103.3°E, depth=10 km
Normalised semblance snapshots. Source duration ≈120 s, rupture length ≈300 km, rupture velocity ≈2.5km/s, rupture direction: Northeast .

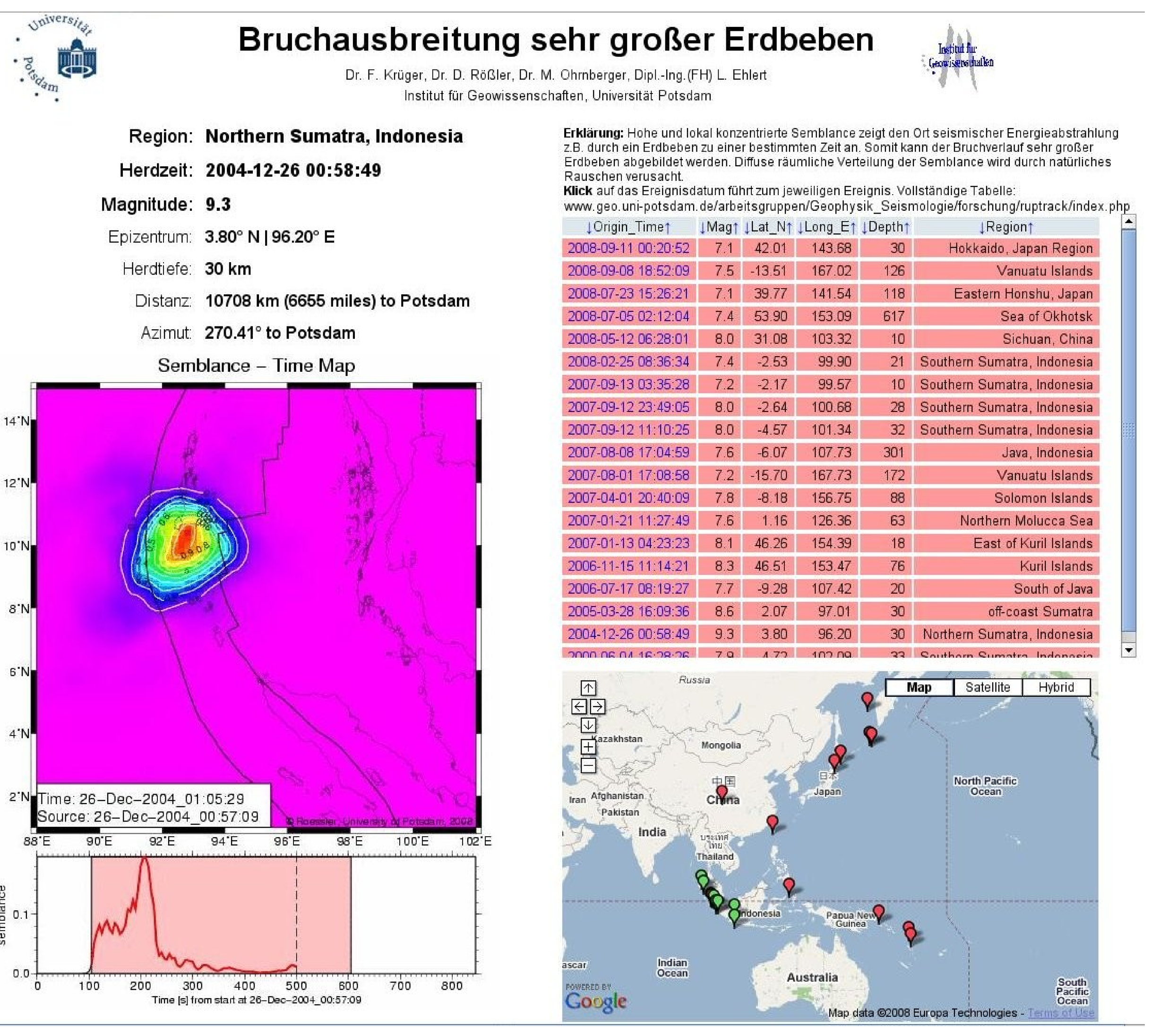


Summary Map
Semblance vs. space and time



5. Online Publishing

For major earthquakes we present our results via internet in real-time:
`www.geo.uni-potsdam.de/arbeitsgruppen/Geophysik_Seismologie/forschung/ruptrack`
Current magnitude threshold for processing is M5.5.



Acknowledgments and References
Data were provided by GEOFON, IRIS, NIED. Seismic Handler and GMT were used for seismogram analysis and plotting, respecitvely.
[1] Krüger, F., Ohrnberger, M., 2005, Tracking the rupture of the *M*w=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] Rößler, D., Krüger, F., Ohrnberger, M., 2008, Rupture properties of the 2006 tsunamogenic Java earthquake seen at teleseismic distances, in review
[4] USGS: www.usgs.org [5] Global CMT Project: www.globalcmt.org