Automatic near real-time characterisation of large earthquakes

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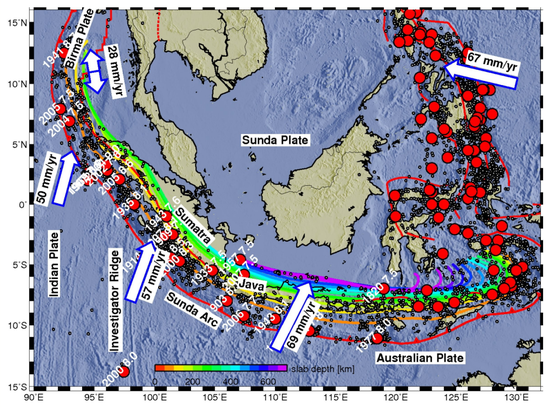
Fig. 1: Map of seismicity and tectonics in the Sunda Arc region.



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 subarrays **(Fig. 2)**. Semblance maps of different subarrays are multiplied. High semblance tracked over long time (10s of second to minutes) and long distances indicate locations of earthquakes. The method allows **resolution of rupture characteristics important for tsunami early warning**:

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

The method has been **successfully applied to recent and historic events (M>6.5**, **Fig. 3**, refs [1], [2]) and is now **operational in real time**. Results are obtained shortly after source time, see http://www.geo.uni-potsdam.de/Forschung/Geophysik/GITEWS/tsunami.htm).

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

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

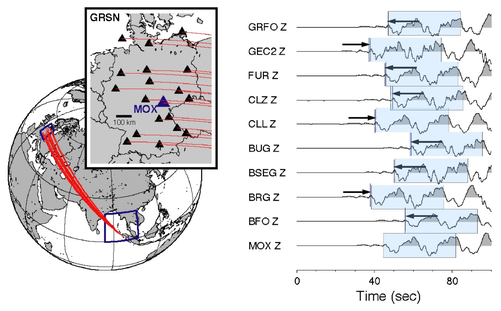
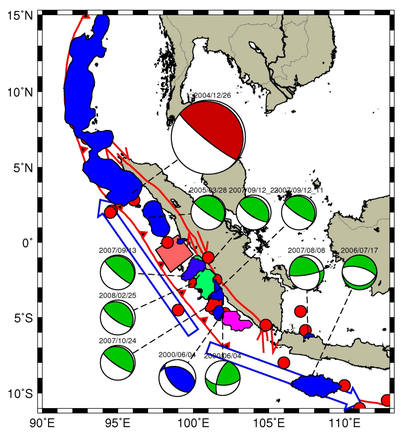
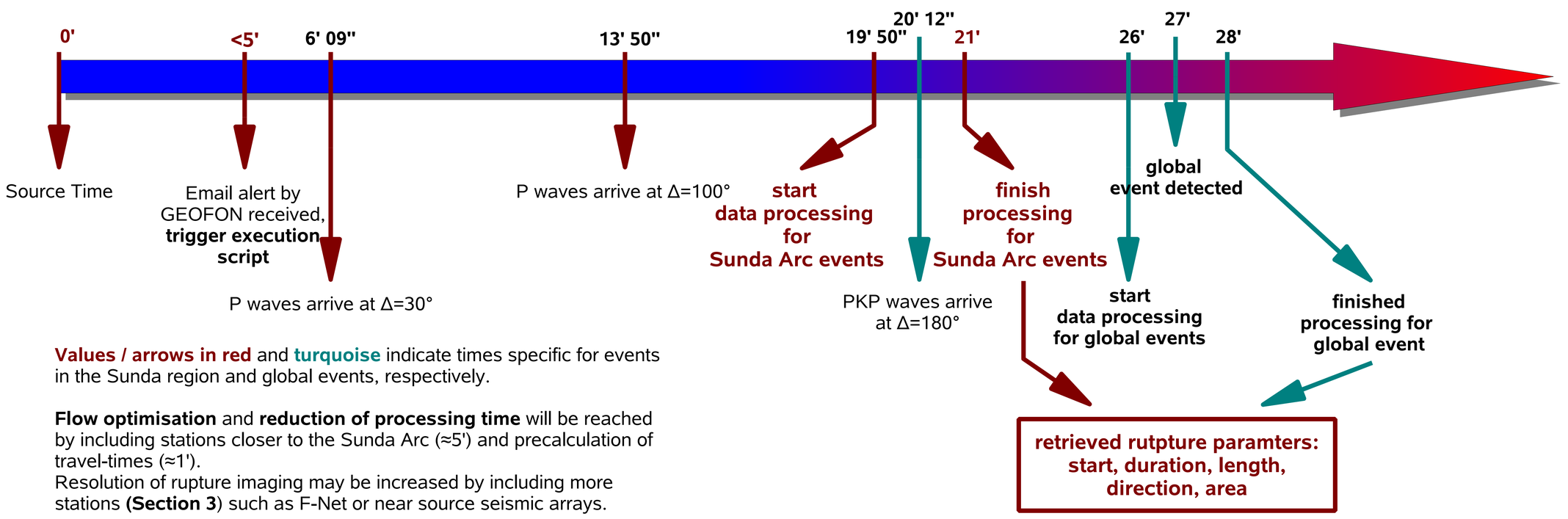


Fig. 3: Rupture areas of major Sunda Arc events since 2000 from semblance analysis. Focal mechanisms by University of Potsdam, [3], and [4].



2. Flow and Timeline of Near Real-Time Processing



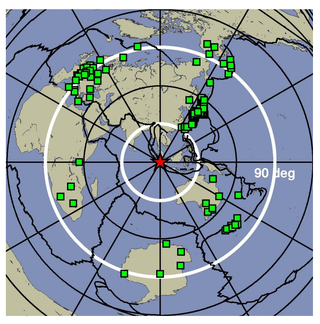
Values / arrows in red and **turquoise** indicate times specific for events in the Sunda region and global events, respectively.

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.

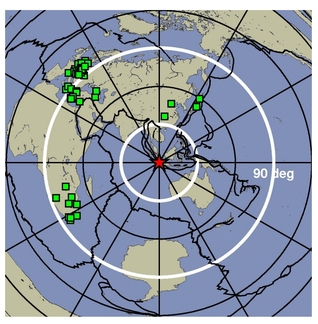
3. Manual vs. Automatic Real-Time Processing

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

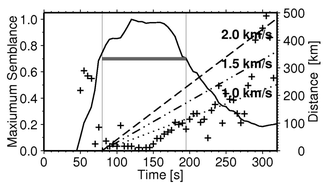


Automatic Processing

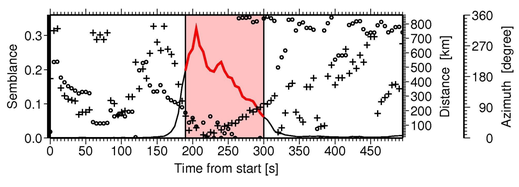


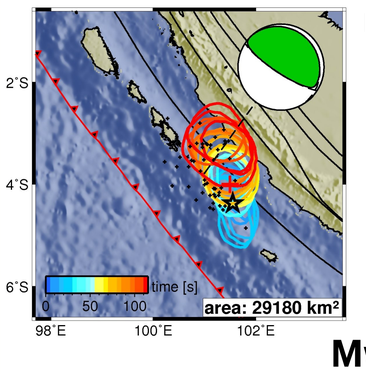
Left / right: Station distribution during manual processing / automatic real-time data processing

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

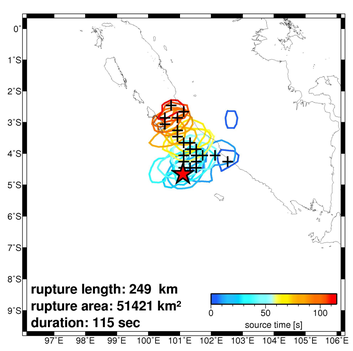


Time series of semblance maxima (SM) and distance of SM to GEOFON location indicating **rupture time ≈ 100 s** and **velocity ≈ 2 km/s**. **Right:** **red line:** active trigger, uniform azimuth (circles) indicates N-propagating rupture.

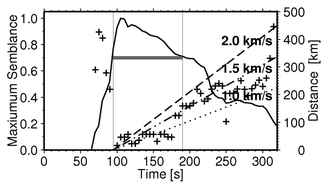




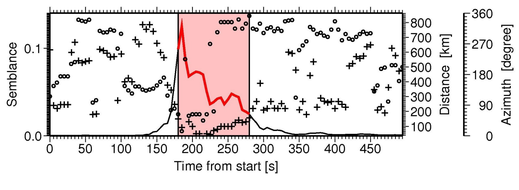
Map of semblance (contour) imaging rupture extent. Star: GEOFON epicentre. Colours represent time from source time. **Right:** Contours for of positive triggering (**red line** in semblance-time plot). Crosses: locations of semblance maxima.



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.

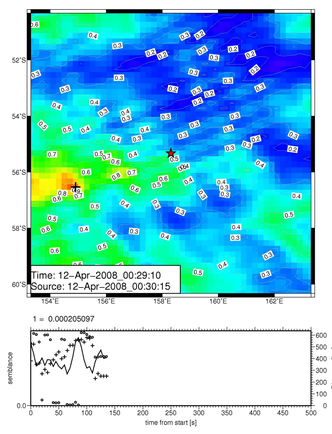
Rupture lengths are similar for both processing schemes but estimated areas are quiet different.

4. Example of Fully Automatic Real-time Processing

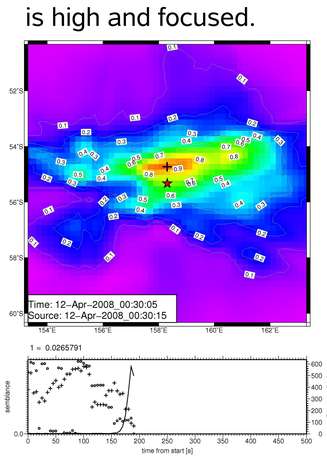
Macquarie Island Region (M7.5) on 12/04/2008 at -55.33°N, 158.31°E, depth=10 km

Figures show normalised semblance at times before and at event onset as well as an event termination. Source duration is about 30 - 50 s. Spatial resolution is low since station selection has been tuned to resolve Sunda Arc events (**compare Section 3**).

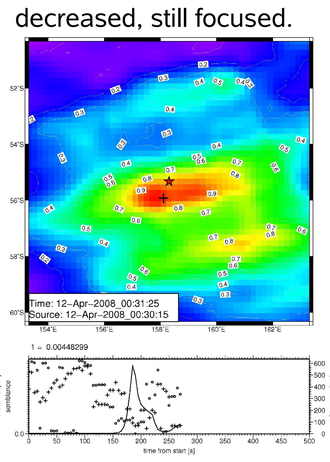
prior to event: semblance is unspecific



event start: semblance is high and focused.

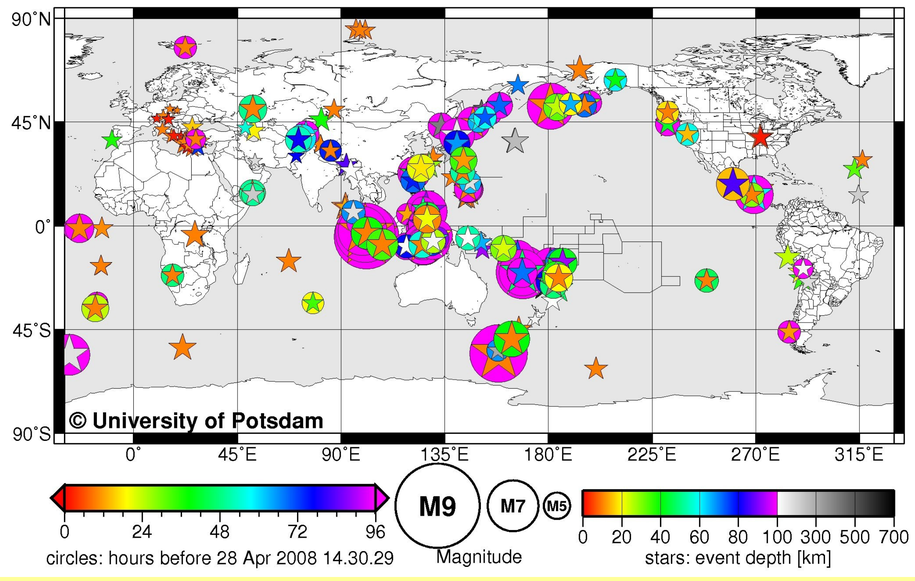


event start: semblance is decreased, still focused.



5. Event Summary Map

Automatically generated global map. Circles show events that were automatically processed in real time or during later post-processing (circles). Stars without circles: unprocessed events. Future magnitude threshold for processing will be around M6. Update: http://www.geo.uni-potsdam.de/Forschung/Geophysik/GITEWS/tsunami.htm



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 *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] USGS: www.usgs.org
[4] Global CMT Project: www.globalcmt.org