



Moment magnitude estimation of large earthquakes using source time function inversion in real-time

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Introduction

- Rapid moment magnitude estimations for large earthquakes to evaluate event sizes
- Estimation of moment magnitudes by instantaneous waveform inversions of broadband recordings at regional distances
- Seismic moment versus time can be determined in real-time
- 2009 Sumatra earthquake $Mw=7.5$
- 2010 Haiti earthquake $Mw=7.1$
- 2010 Chile earthquake $Mw=8.8$
- 2011 Japan earthquake $Mw=9.0$

Procedure

- Response correction of waveform data
- Bandpass filtering
- Compute displacement fk -spectrum for moment tensor source at depth
- Compute synthetics using fk -spectrum
- Estimate the source-time function (STF) by inverting synthetics in the time domain
- Determine the moment magnitude (Mw) by integrating STF in time.

Source time function determination

Non-negative least square fit with smoothing

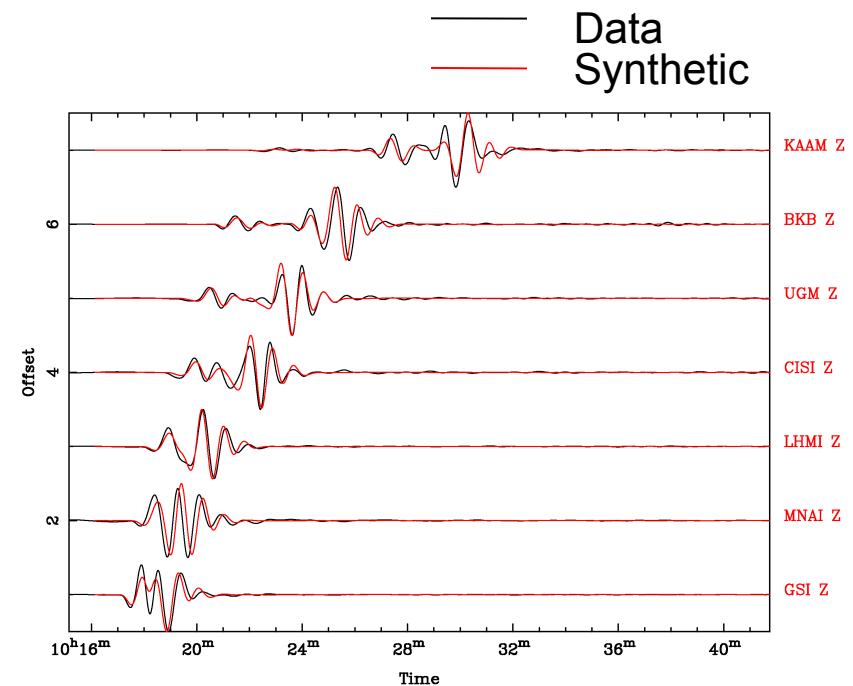
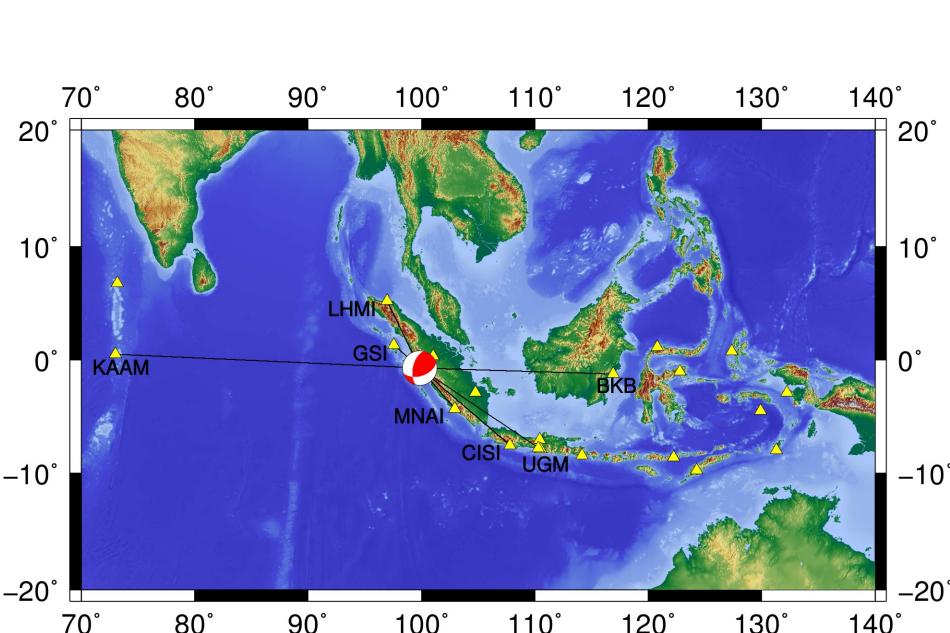
$$s_n(t) = \int_0^{\infty} Q(t - \tau) G_n(\tau) d\tau$$

$$\sum_{n=1}^N \left[\frac{1}{\sigma_n(t)} \left(d_n(t) - \int_0^{\infty} Q(t - \tau) G_n(\tau) d\tau \right) \right]^2 \rightarrow \text{Min}$$

- $G_n(t)$: Green function for impulsive moment rate function
- $Q(t) = dM(t)/dt$: Moment rate function
- $s_n(t)$: synthetic seismogram at receiver n
- $d_n(t)$: recorded seismogram at receiver n

Magnitude 7.5 - SOUTHERN SUMATRA, INDONESIA

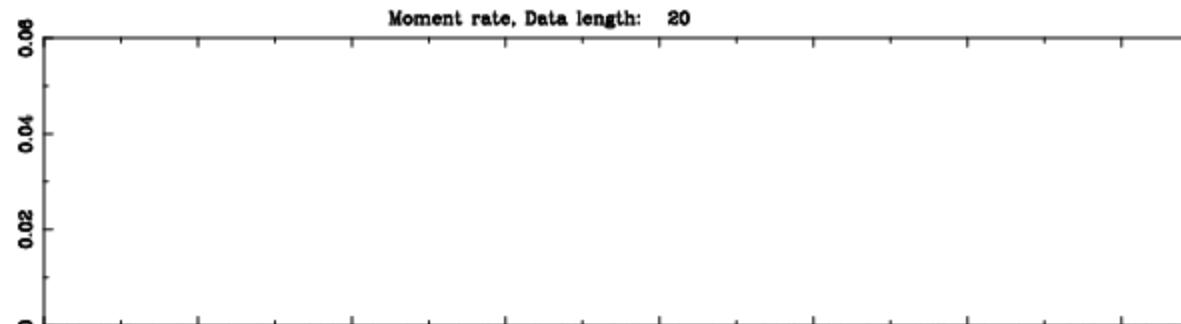
2009 September 30 10:16:09 UTC



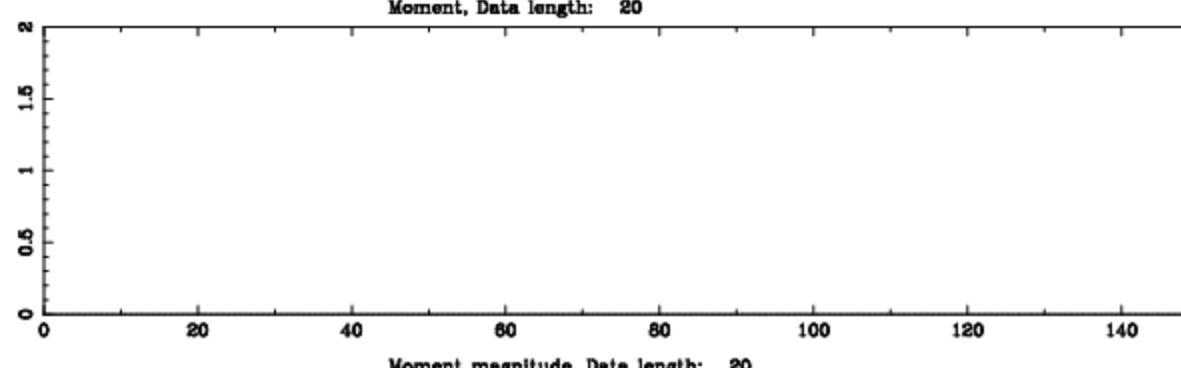
Fit for a 30 s source time function
B.P.: 0.003 – 0.02 Hz
Misfit : 0.54

Moment magnitude estimation

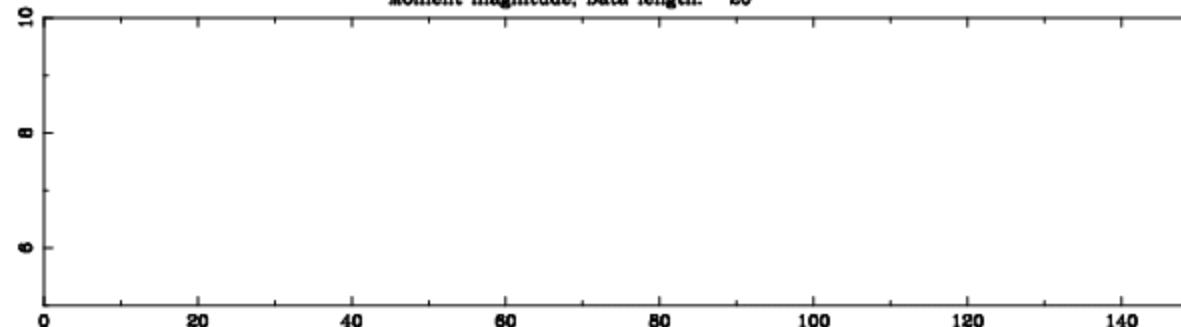
Moment rate function
 $Q(t) = dM(t)/dt$



Seismic moment
 $M(t)$

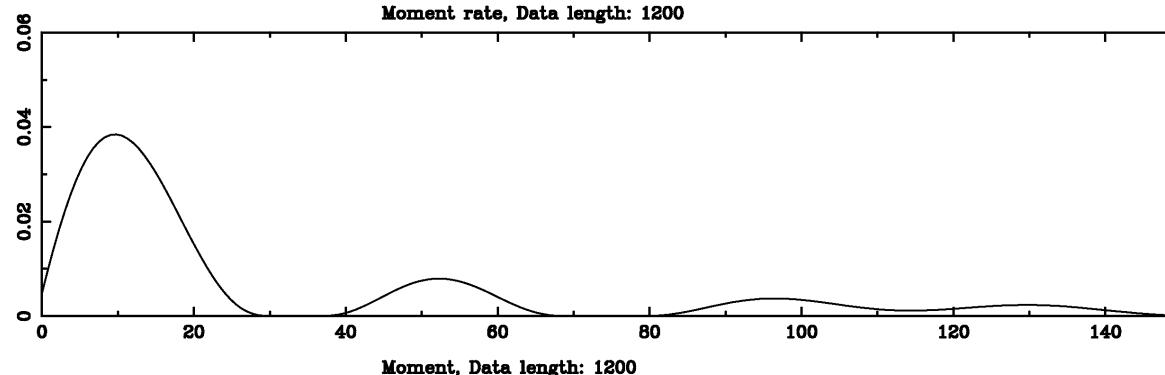


$$M_w = \frac{2}{3} \lg M(t) - 10.7$$

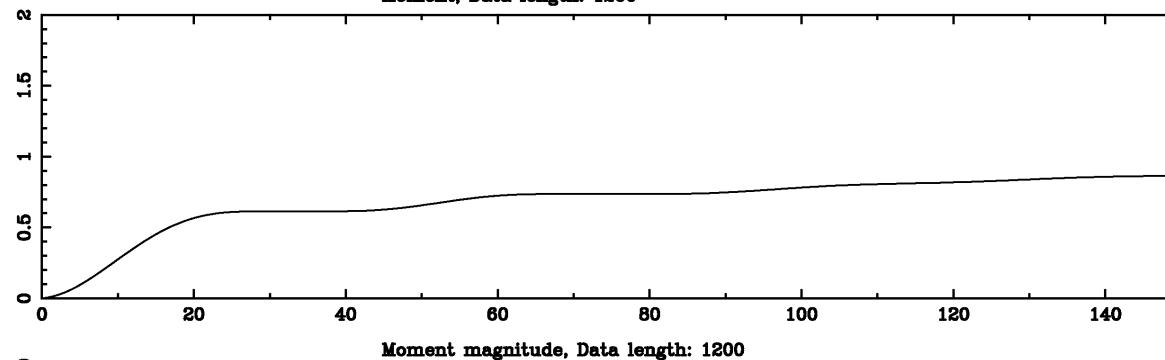


Moment magnitude estimation

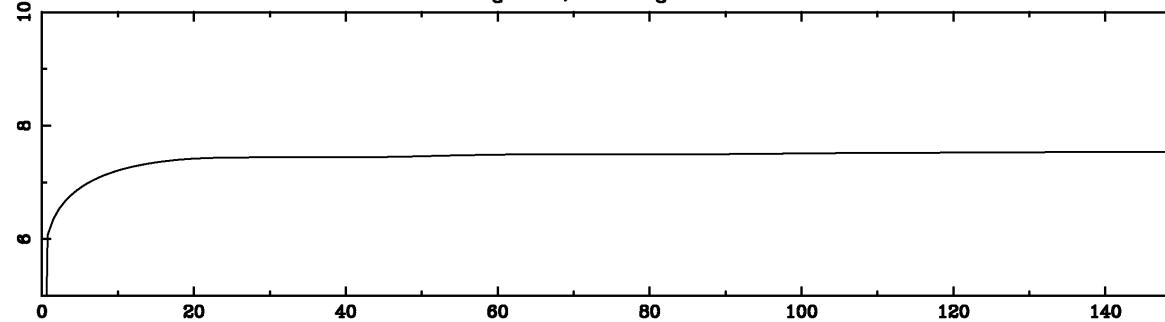
Moment rate function
 $Q(t) = dM(t)/dt$



Seismic moment
 $M(t)$



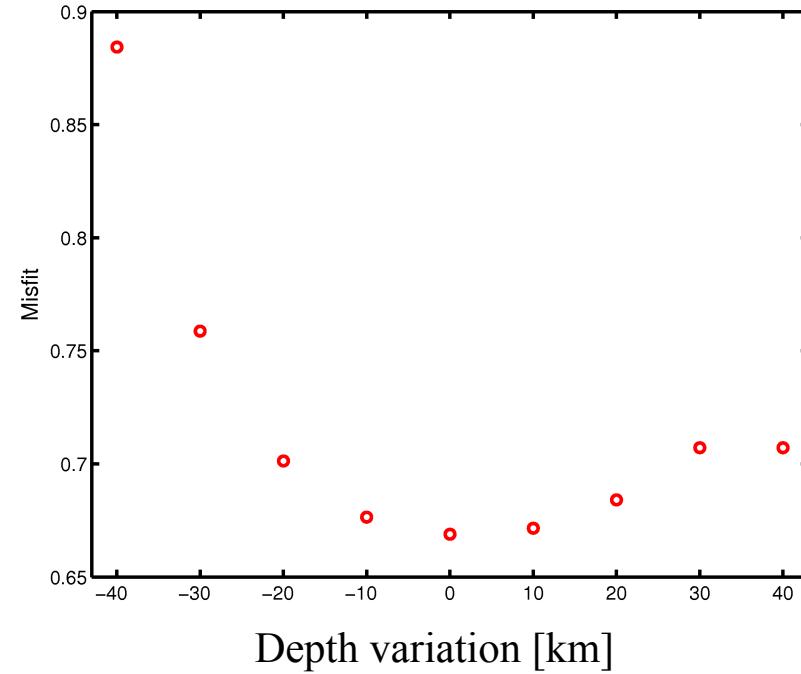
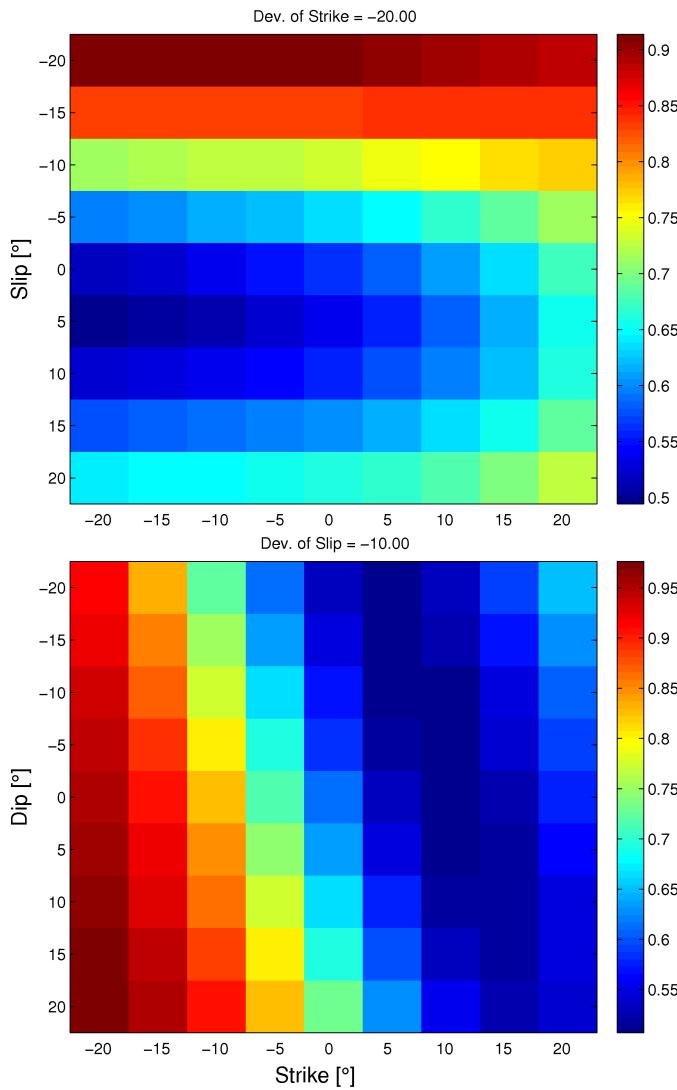
$$M_W = \frac{2}{3} \lg M(t) - 10.7$$



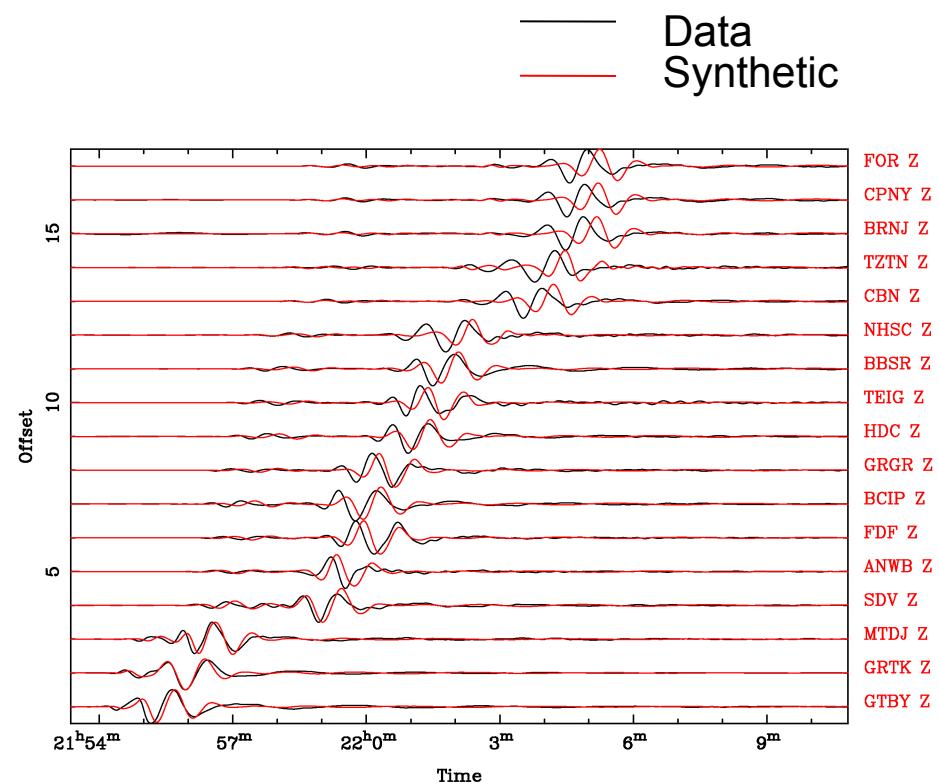
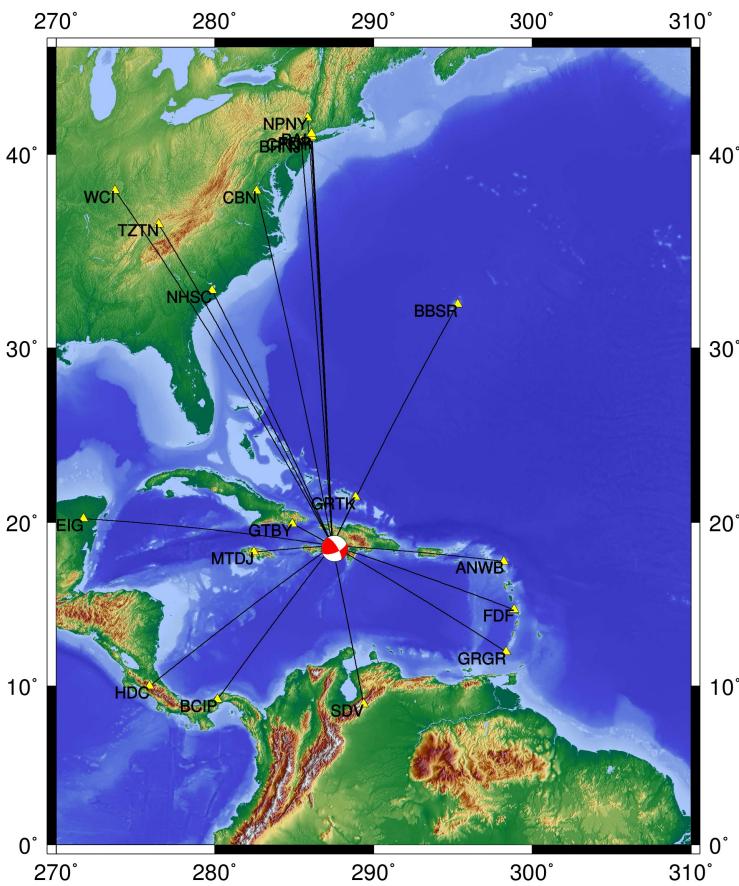
$$M_W = 7.5$$

Sensitivity test of misfit

Strike fixed



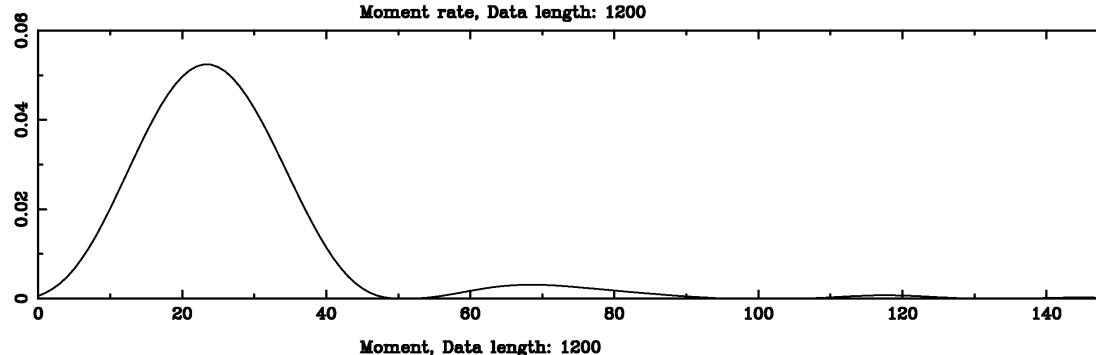
Magnitude 7.0 – HAITI Earthquake 2010 January 12 21:53:10 UTC



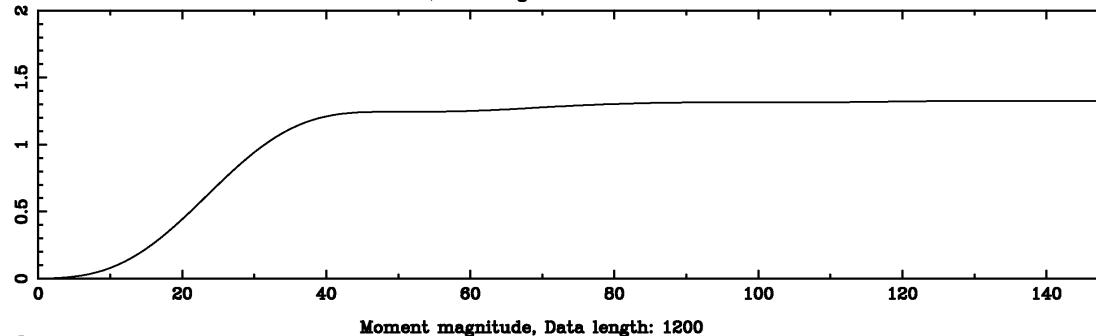
Fit for a 50 s source time function
B.P.: 0.005 – 0.02 Hz
Misfit : 0.48

Moment magnitude estimation

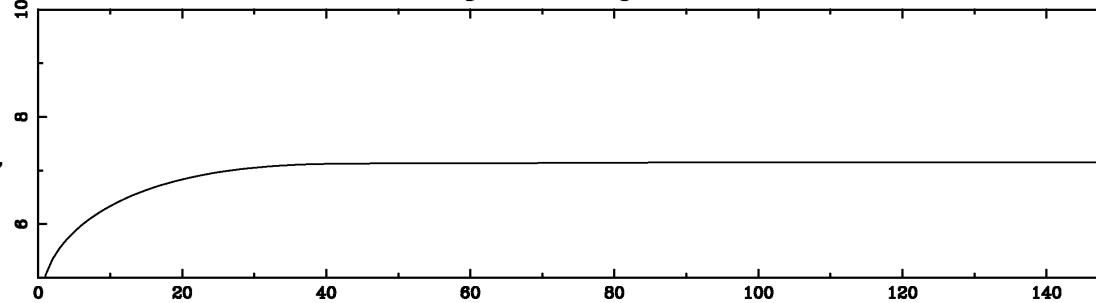
Moment rate function
 $Q(t) = dM(t)/dt$



Seismic moment
 $M(t)$



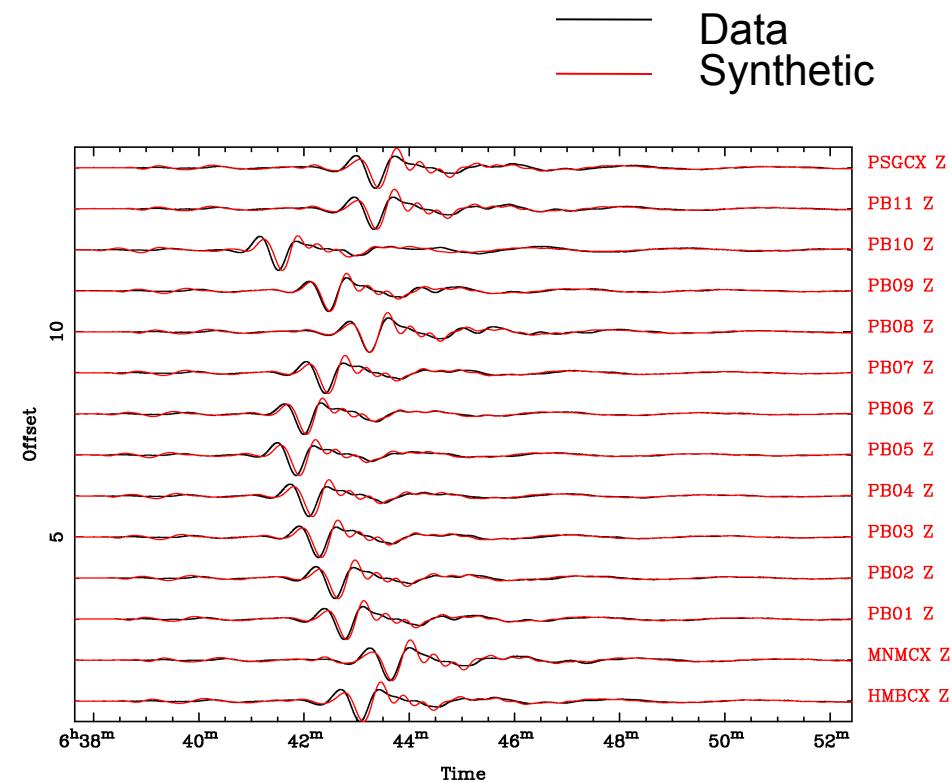
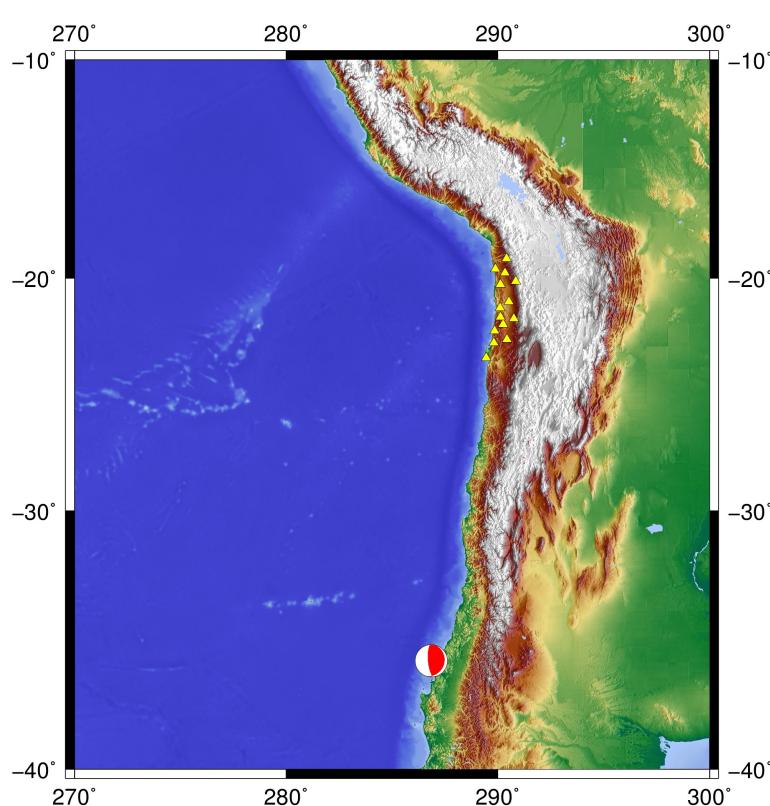
$$M_w = 2/3 \cdot \lg M(t) - 10.7$$



$$M_w = 7.1$$

Magnitude 8.8 - OFFSHORE BIO-BIO, CHILE

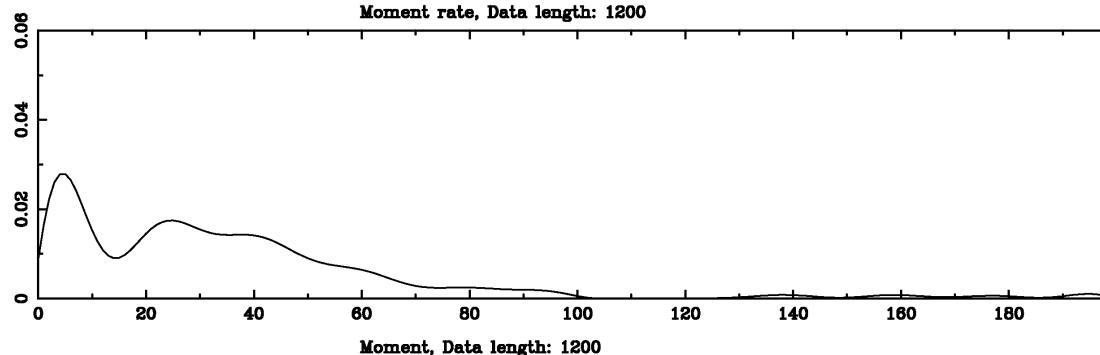
2010 February 27 06:34:14 UTC



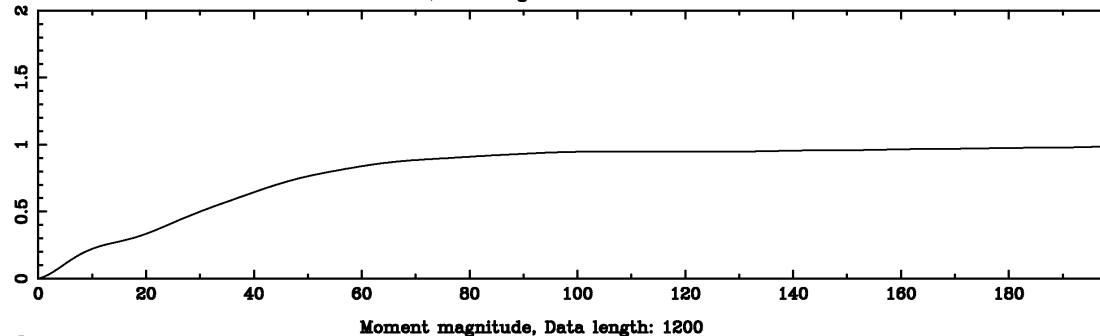
Fit for a 100 s source time function
B.P.: 0.005 – 0.02 Hz
Misfit : 0.24

Moment magnitude estimation

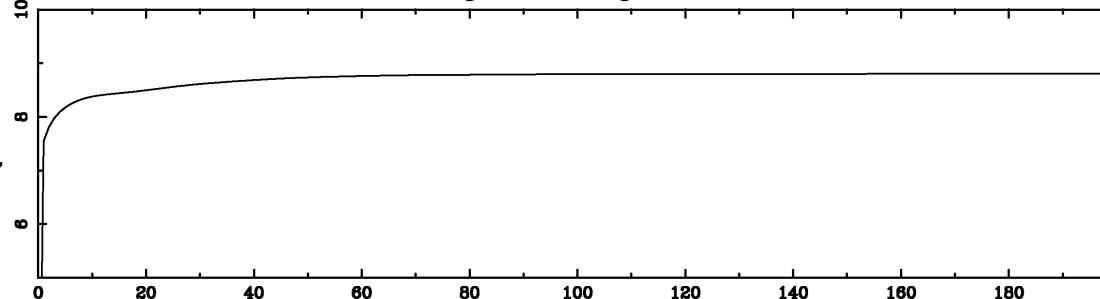
Moment rate function
 $Q(t) = dM(t)/dt$



Seismic moment
 $M(t)$



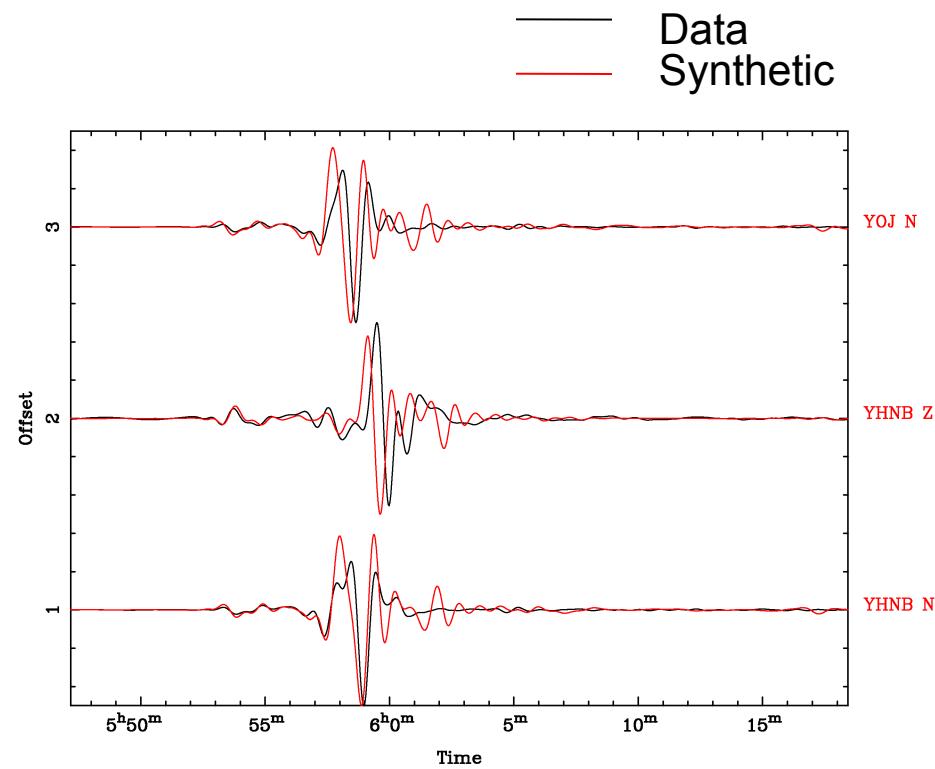
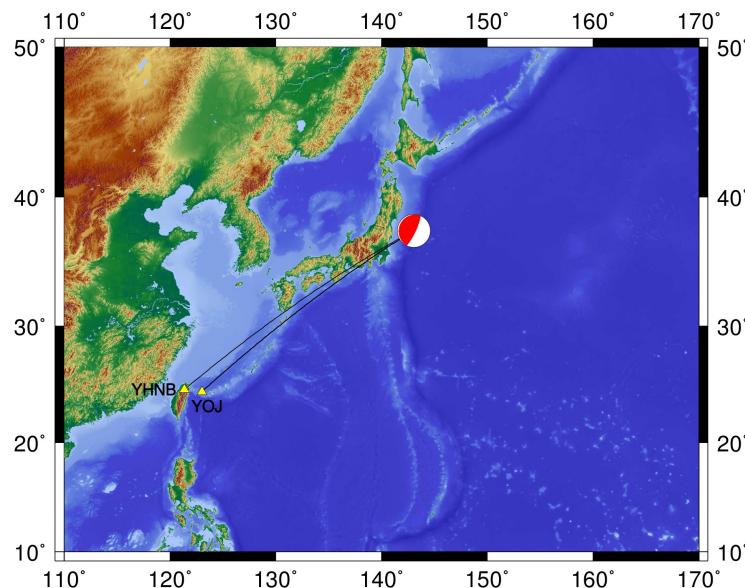
$$M_W = 2/3 \cdot \lg M(t) - 10.7$$



$$M_W = 8.8$$

Magnitude 9.0 - NEAR THE EAST COAST OF HONSHU, JAPAN

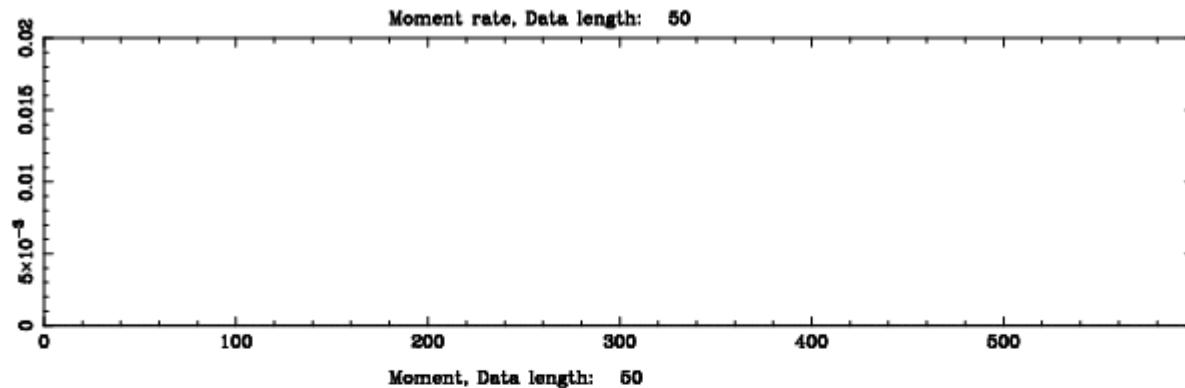
2011 March 11 05:46:23 UTC



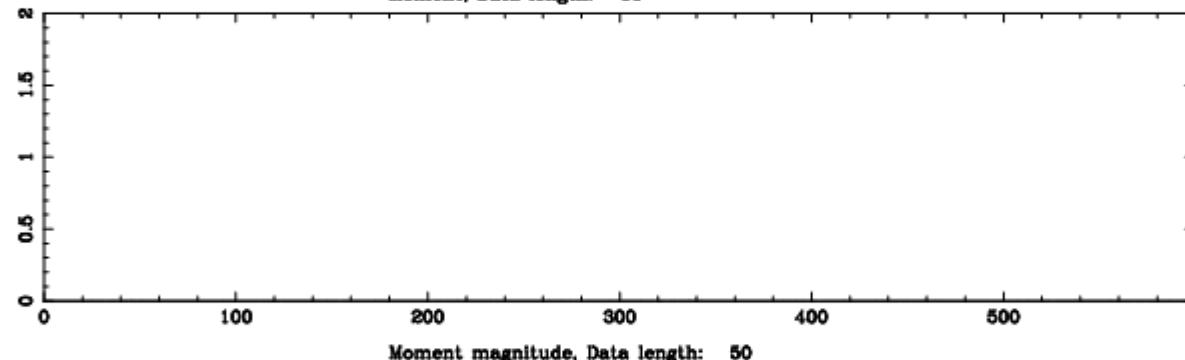
Fit for a 260 s source time function
B.P.: 0.005 – 0.02 Hz
Misfit : 0.24

Moment magnitude estimation

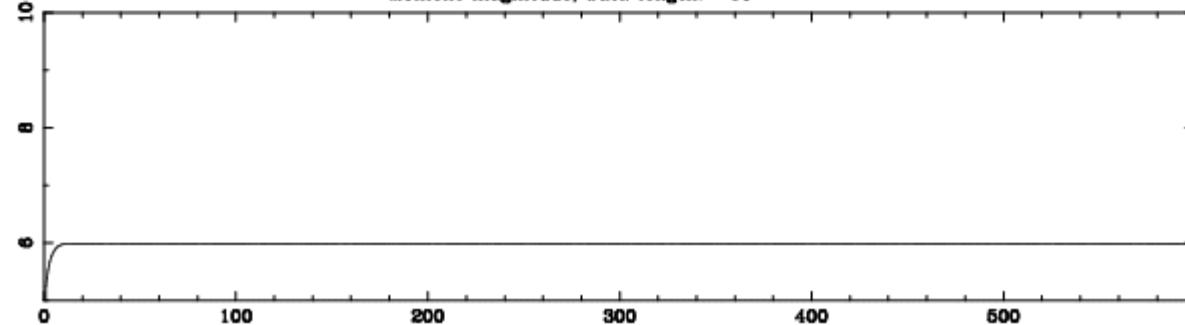
Moment rate function
 $Q(t) = dM(t)/dt$



Seismic moment
 $M(t)$

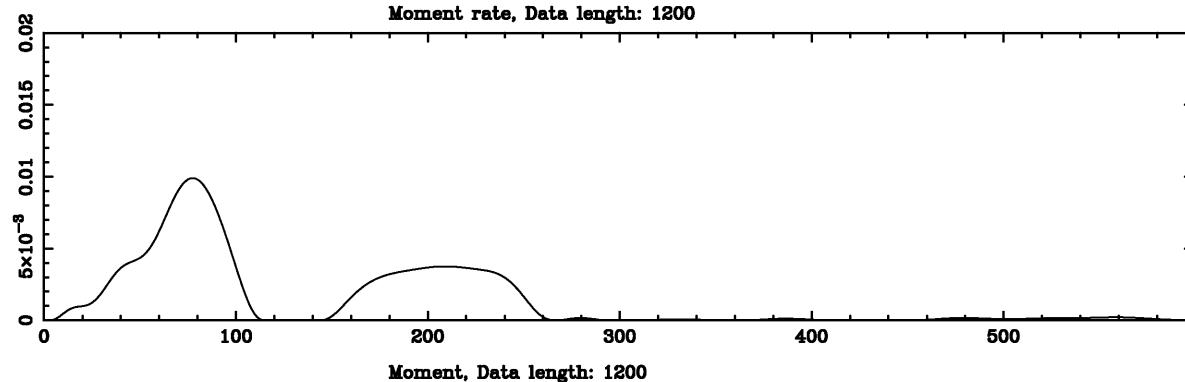


$M_w = 2/3 \cdot \lg M(t) - 10.7$

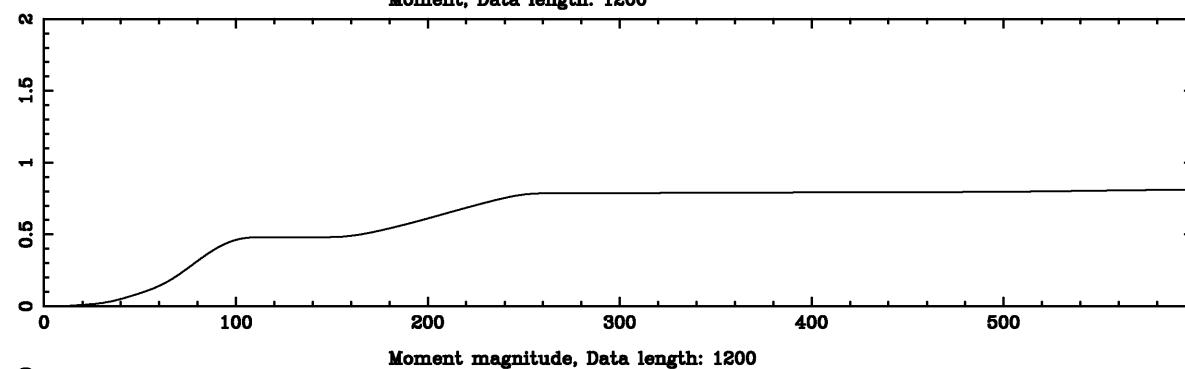


Moment magnitude estimation

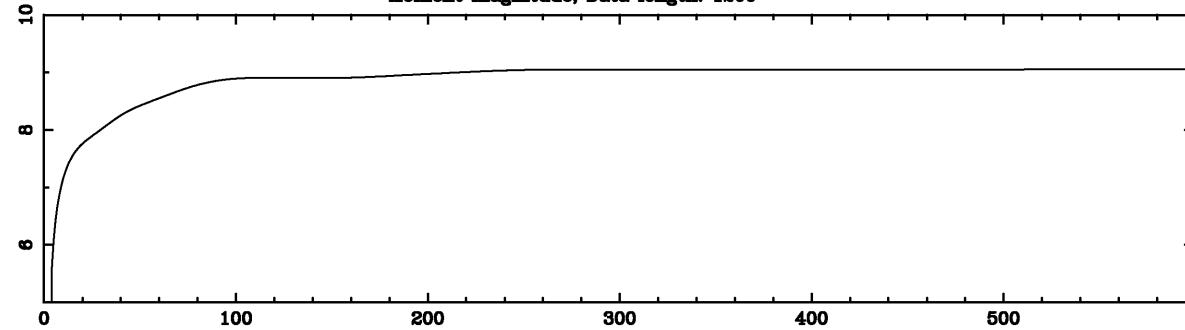
Moment rate function
 $Q(t) = dM(t)/dt$



Seismic moment
 $M(t)$



$$M_w = 2/3 \cdot \lg M(t) - 10.7$$



Conclusions

- Seismic moment and source time function are calculated by full waveform inversion in real-time.
- Moment magnitude is estimated using source time function at regional distance range.
- It is available to alert if threshold of Mw is exceeded.
- Fast estimate is available depending on station distances
- The variation of source moment tensors range between 10 – 20 degree for Mw estimation.
- The depth variation is about +/- 20km for Mw estimation.
- 2009 Sumatra earthquake Mw=7.5 (GCMT: Mw=7.5)
- 2010 Haiti earthquake Mw=7.1 (GCMT: Mw=7.1)
- 2010 Chile earthquake Mw=8.8 (GCMT: Mw=8.8)
- 2011 Japan earthquake Mw=9.0 (GCMT: Mw=9.0)
- Source time function ranges from 50 to 260 s for the earthquakes of Mw = 7.0 – 9.0.