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A Description of the W-phase

Ackonwledgements:

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Motivation: Why is it important to consider yet another method to estimate earthquake magnitude?

- Conventional methods still have difficulty in rapidly identifying ‘giant’ (Mw=9) events.
- This requires us to rely on the perception of strong shaking for near-field tsunami warning, but …
- Tsunami earthquakes can cause large tsunamis but generate only weak shaking. Long-period seismic (or geodetic?) data are required to rapidly detect such earthquakes.

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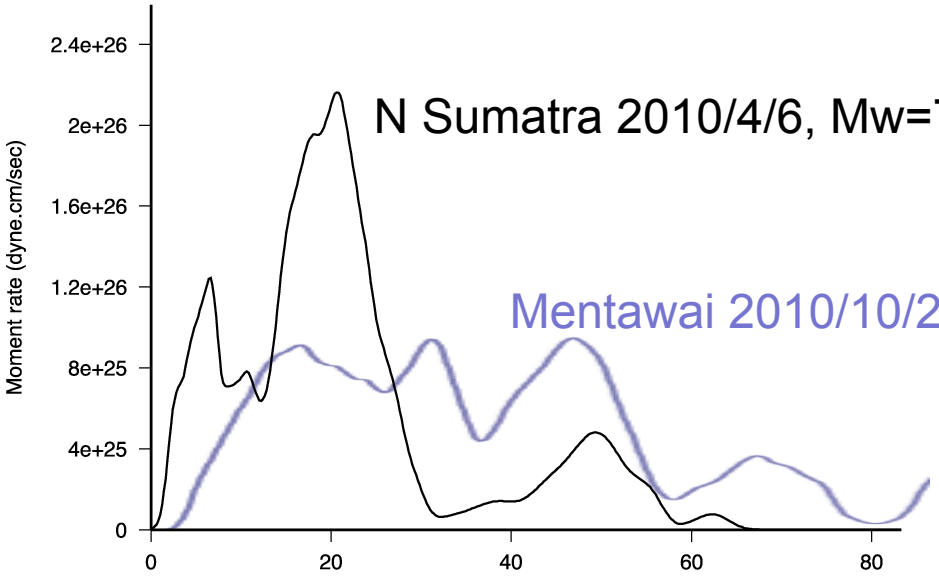
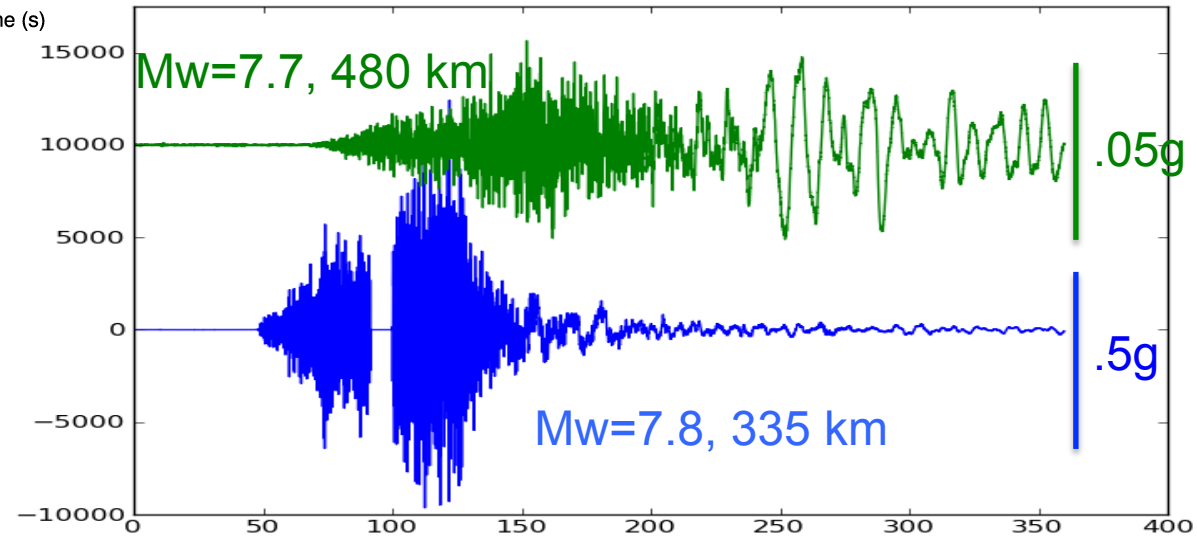
Tsunami vs. 'Normal' Earthquakes



Comparison of estimated earthquake source time functions (source: NEIC)

Comparison of observed accelerograms



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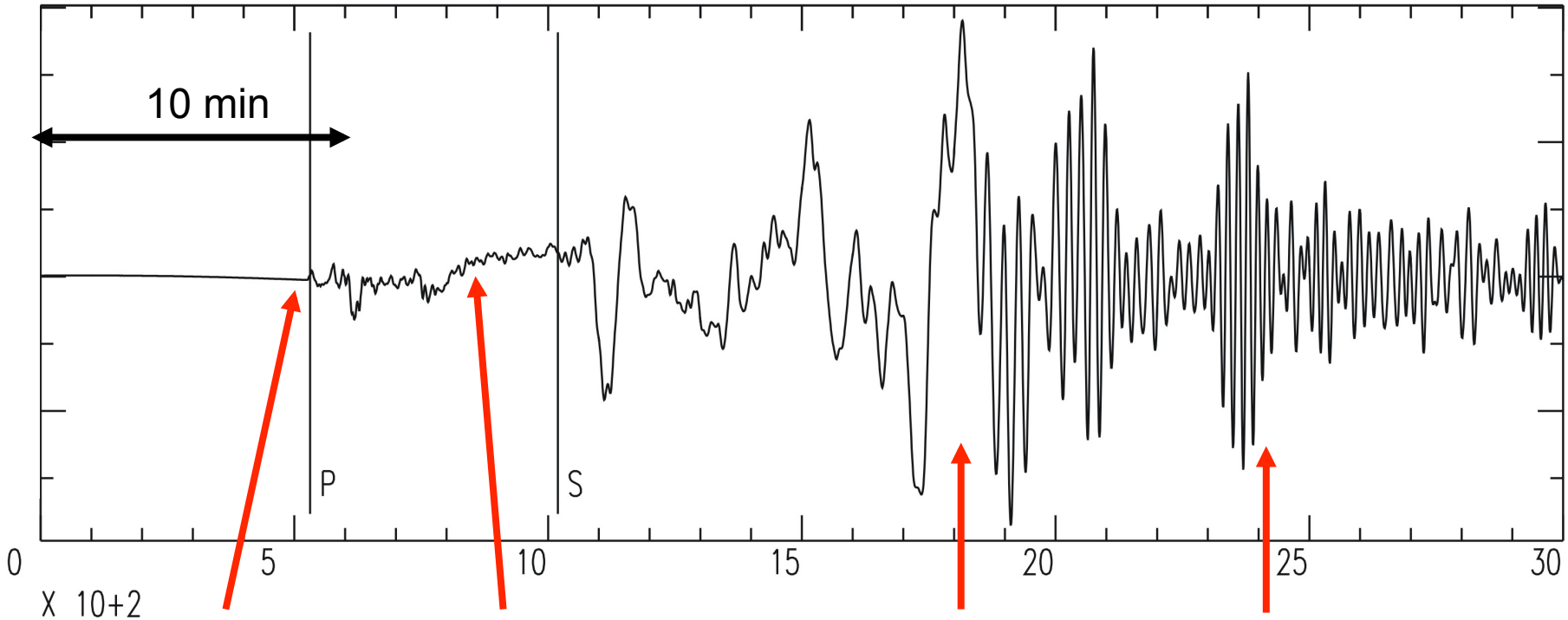
The 'W Phase'

Earthquake Origin Time

W phase? LP (~1000 sec) phase before S



P wave, 10 sec

W phase (~1000 sec)

LP (200 sec) surface wave

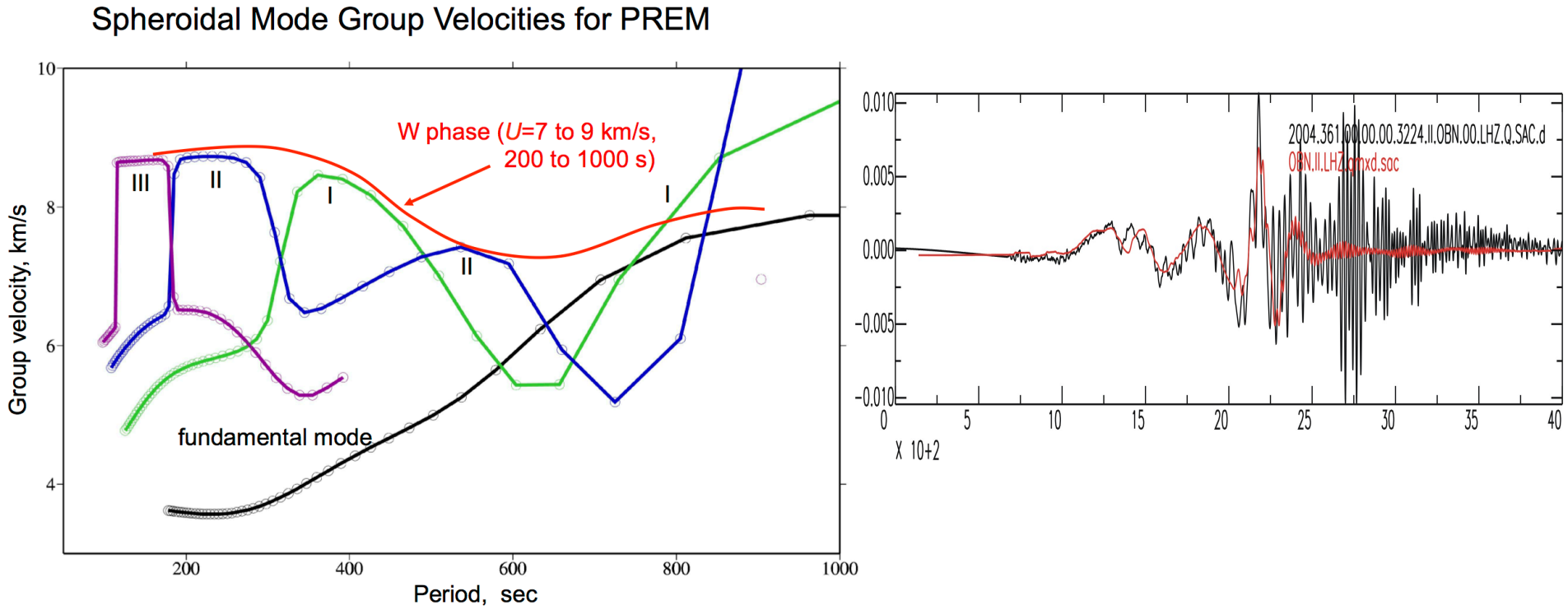
20 sec surface wave

(source: H. Kanamori)

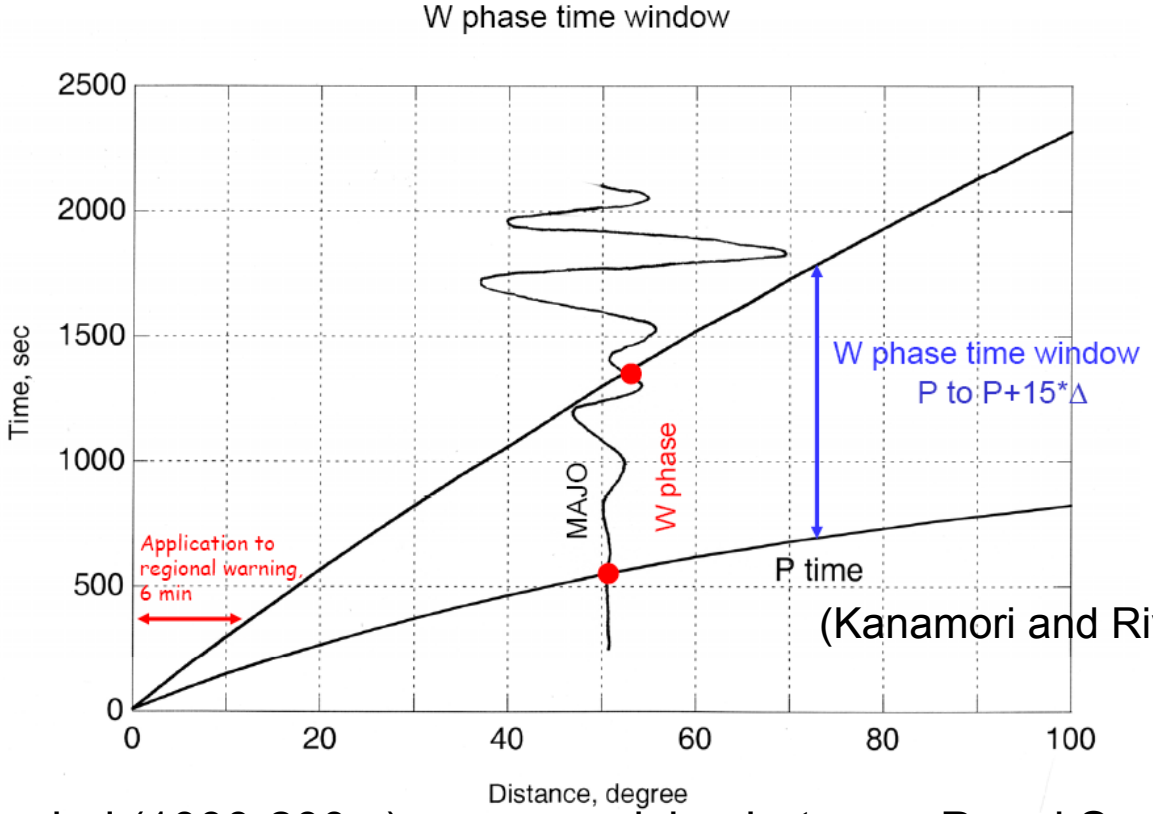
W-Phase synthesis via Normal Modes

W phase can be synthesized by superposition of normal modes.

$$\vec{u}(\vec{r},t) = \sum_{l,m,n} \left[(\mathrm{M}:\varepsilon) \; {}_{\mathrm{n}}\vec{y}_l^m(\vec{r}) \right] \frac{1-\cos {}_n\omega_l^m t}{{}_n c_l^m \; {}_n\omega_l^{m2}}$$



The W-Phase Method



(Kanamori and Rivera, 2008)

Features

- Uses long-period (1000-200 s) energy arriving between P and S waves
- Provides rapid estimate of seismic moment tensor – including Mw

Advantages

- Rapid because it relies on energy arriving prior to S wave
- Less sensitive to clipping because low-amplitude part of waveform is used
- Use of long periods provides unbiased estimate of ‘slow’ earthquake magnitudes

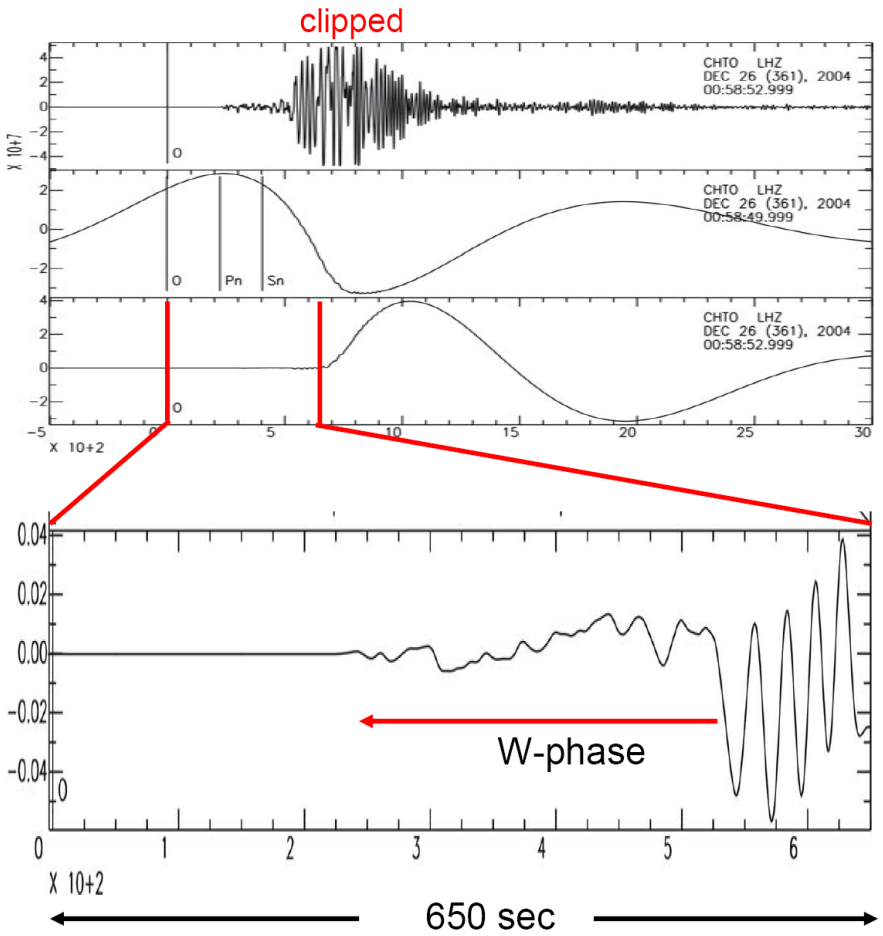
Time-domain Instrument Removal

Use of the beginning of the record from great earthquakes

Original broad-band record (LHZ)

Displacement,
freq.-domain deconvolution

Displacemnet,
time-domain causal deconvolution



(Kanamori and Rivera, 2008)

Advantages

- No need for windowing and FFT
- Avoids clipping of S and Surface waves

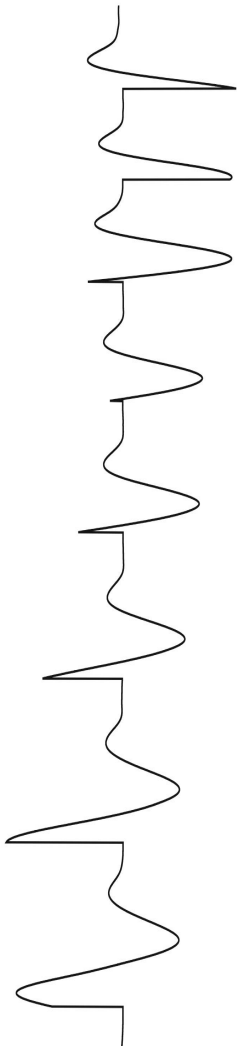
Disadvantage

- Can use up require considerable processing time, especially since long ‘start-up’ time required

Linear Inversion $u_{wn}(t)$: W phase station n

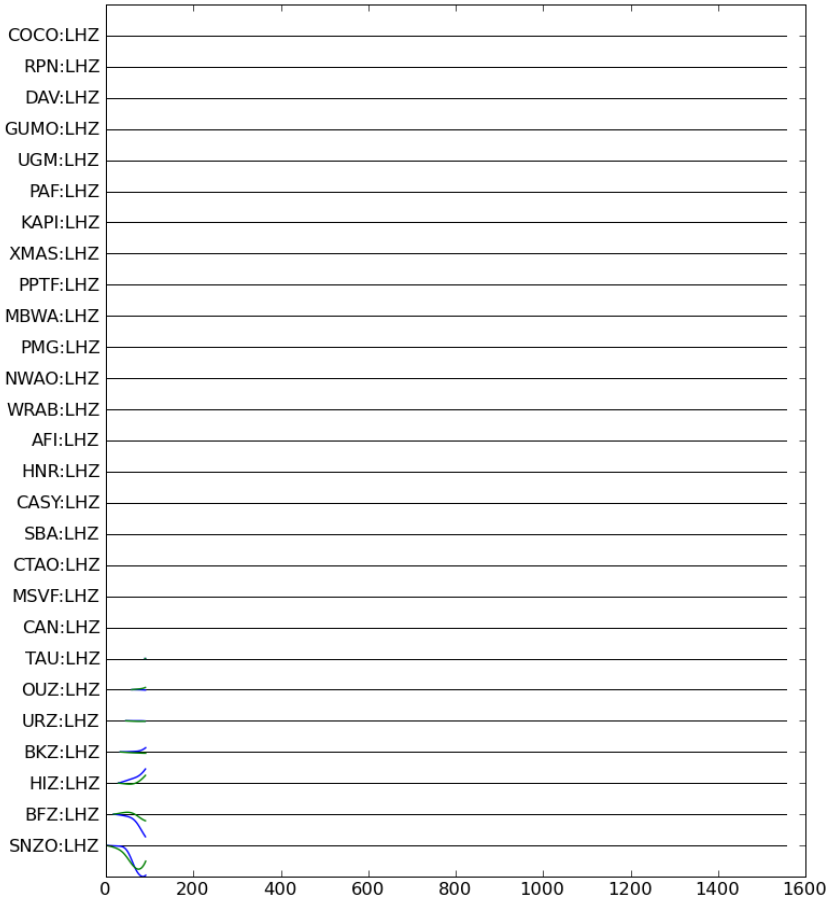
Concatenated unit source functions

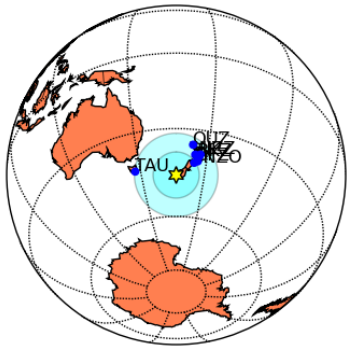
$$\begin{pmatrix} u_{w1}^{1,1} & u_{w1}^{2,2} & * & * & * & u_{w1}^{2,3} \\ u_{w2}^{1,1} & u_{w2}^{2,2} & * & * & * & u_{w2}^{2,3} \\ u_{w3}^{1,1} & u_{w3}^{2,2} & * & * & * & u_{w3}^{2,3} \\ * & * & * & * & * & * \\ * & * & * & * & * & * \\ * & * & * & * & * & * \\ * & * & * & * & * & * \\ * & * & * & * & * & * \\ * & * & * & * & * & * \\ * & * & * & * & * & * \\ * & * & * & * & * & * \\ u_{wN}^{1,1} & u_{wN}^{2,2} & * & * & * & u_{wN}^{2,3} \end{pmatrix} \begin{pmatrix} M_{11} \\ M_{22} \\ M_{33} \\ M_{12} \\ M_{13} \\ M_{23} \end{pmatrix} = \begin{pmatrix} u_{w1} \\ u_{w2} \\ u_{w3} \\ * \\ * \\ * \\ * \\ * \\ * \\ * \\ * \\ u_{wN} \end{pmatrix}$$



Concatenated W-phase for N stations

W-Phase Case Study: 2009 Puysegur earthquake in Simulated Real-time

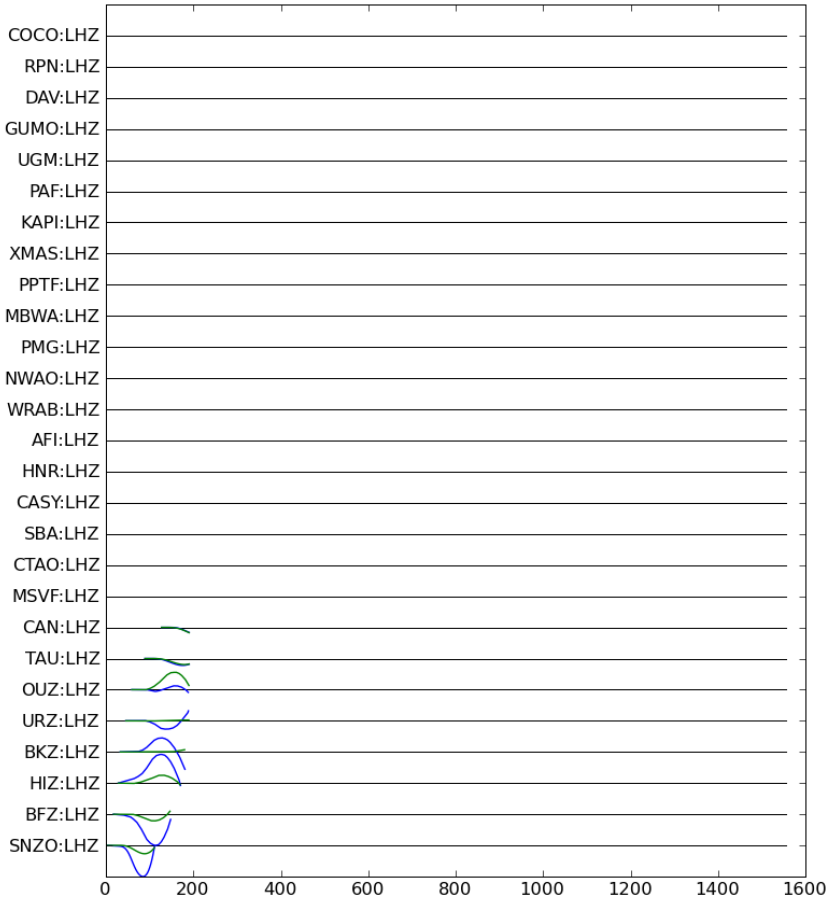


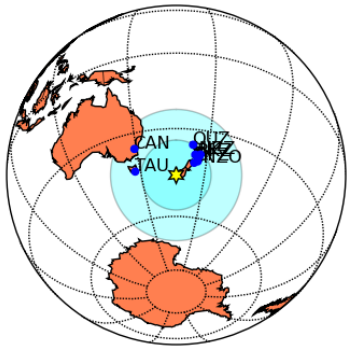


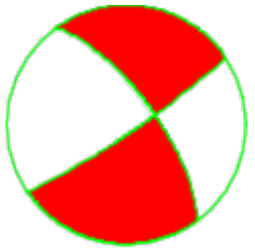
Mw = 8.1

Time = 200 sec

W-Phase Case Study: 2009 Puysegur earthquake in Simulated Real-time



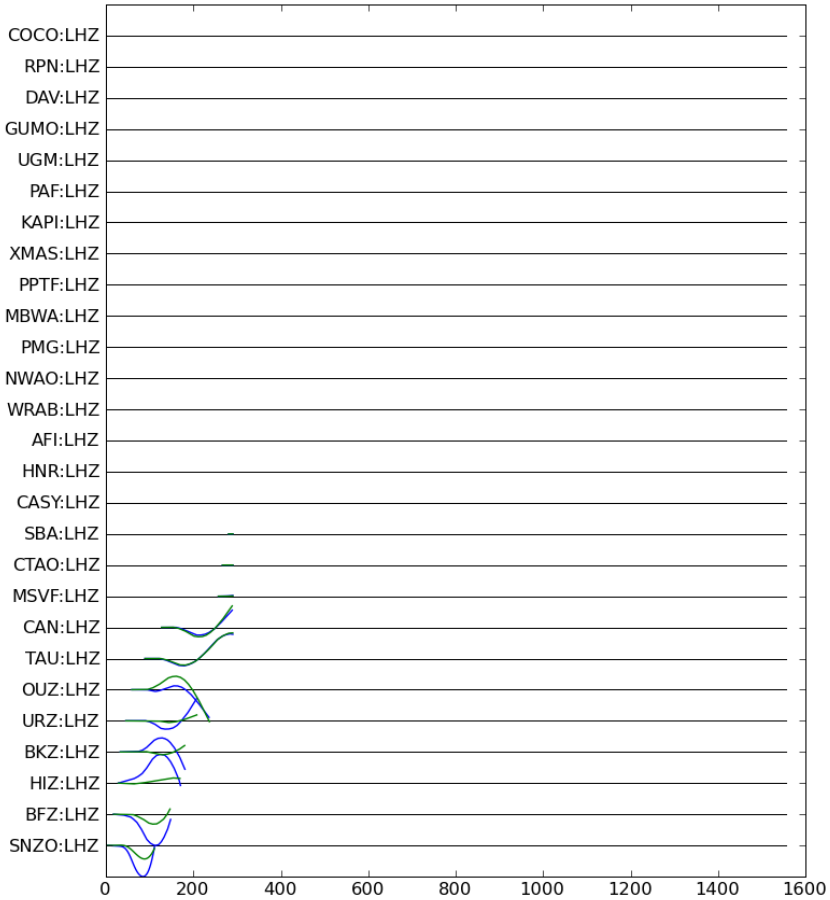


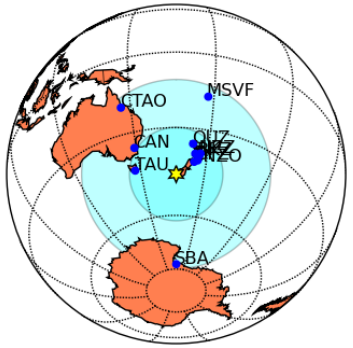


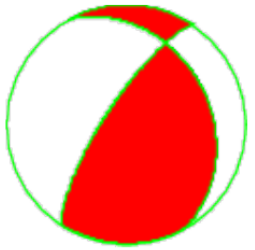
Mw = 7.7

Time = 300 sec

W-Phase Case Study: 2009 Puysegur earthquake in Simulated Real-time



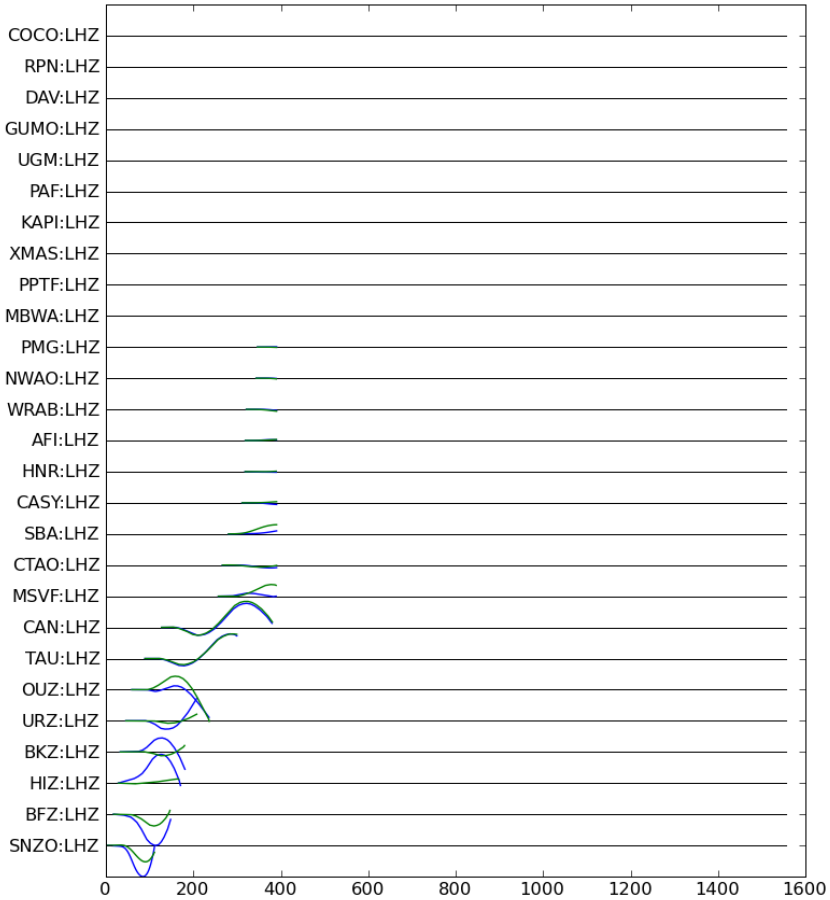


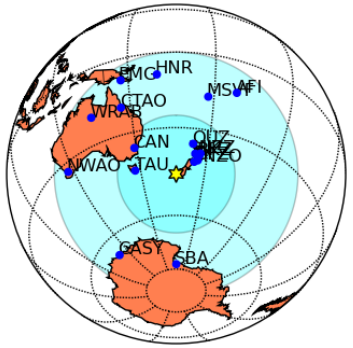


Mw = 7.7

Time = 400 sec

W-Phase Case Study: 2009 Puysegur earthquake in Simulated Real-time





Mw = 7.8

Time = 500 sec

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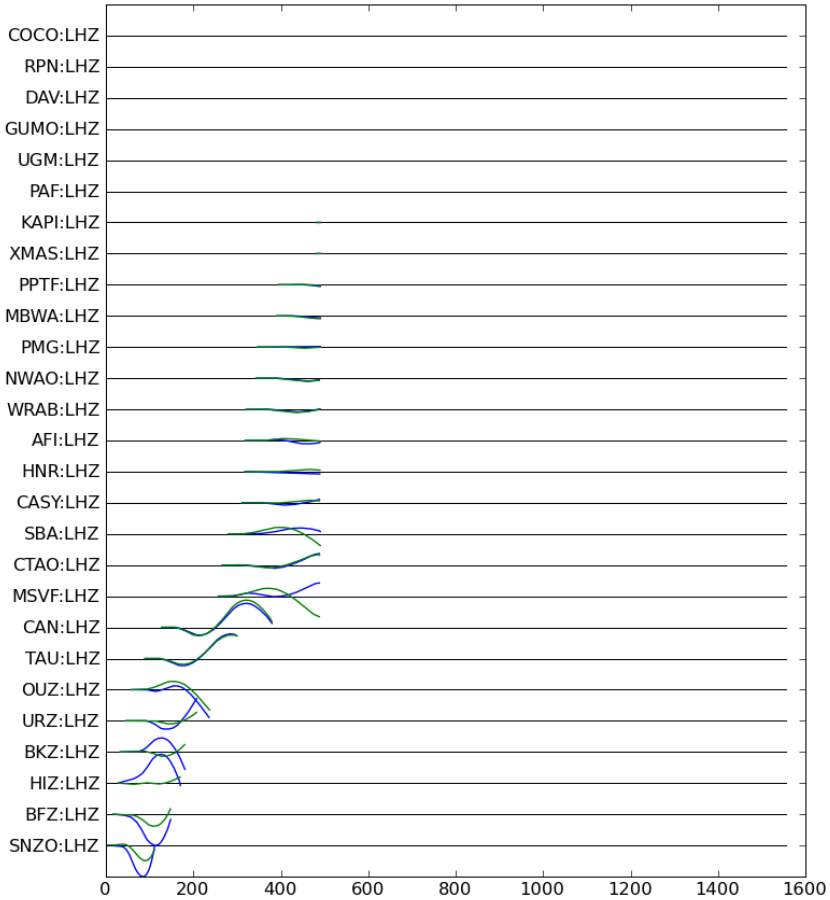
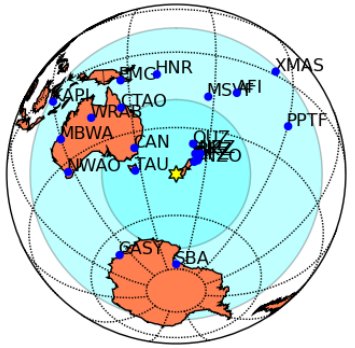
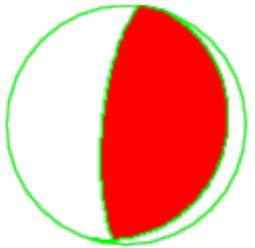
W-Phase Case Study: 2009 Puysegur earthquake in Simulated Real-time



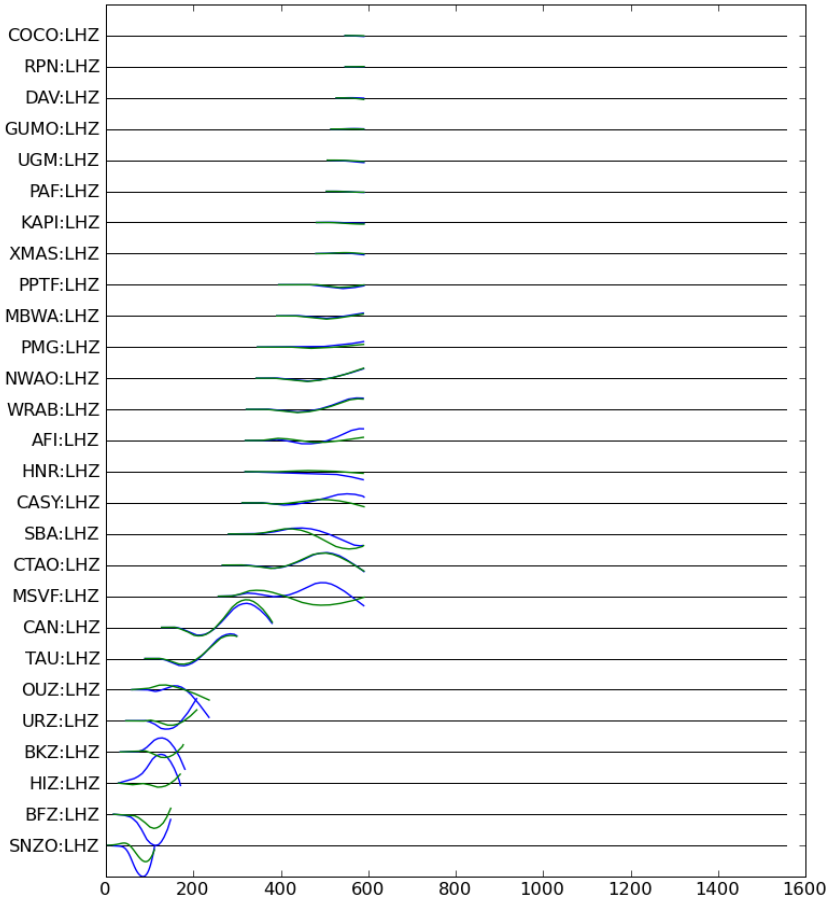


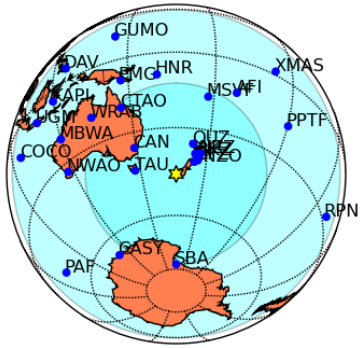


Mw = 7.7

Time = 600 sec

W-Phase Case Study: 2009 Puysegur earthquake in Simulated Real-time

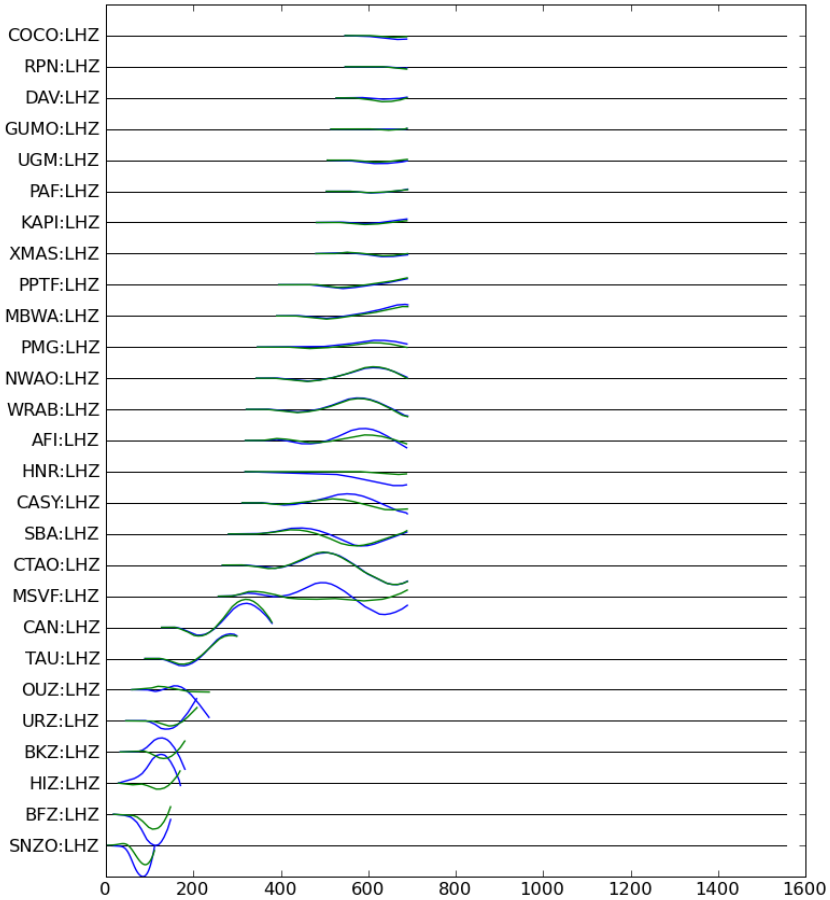


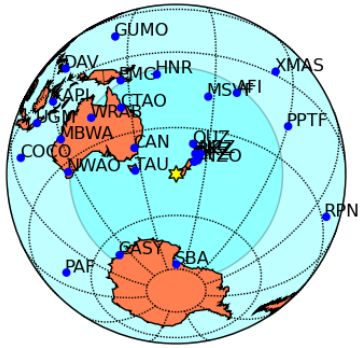


Mw = 7.8

Time = 700 sec

W-Phase Case Study: 2009 Puysegur earthquake in Simulated Real-time

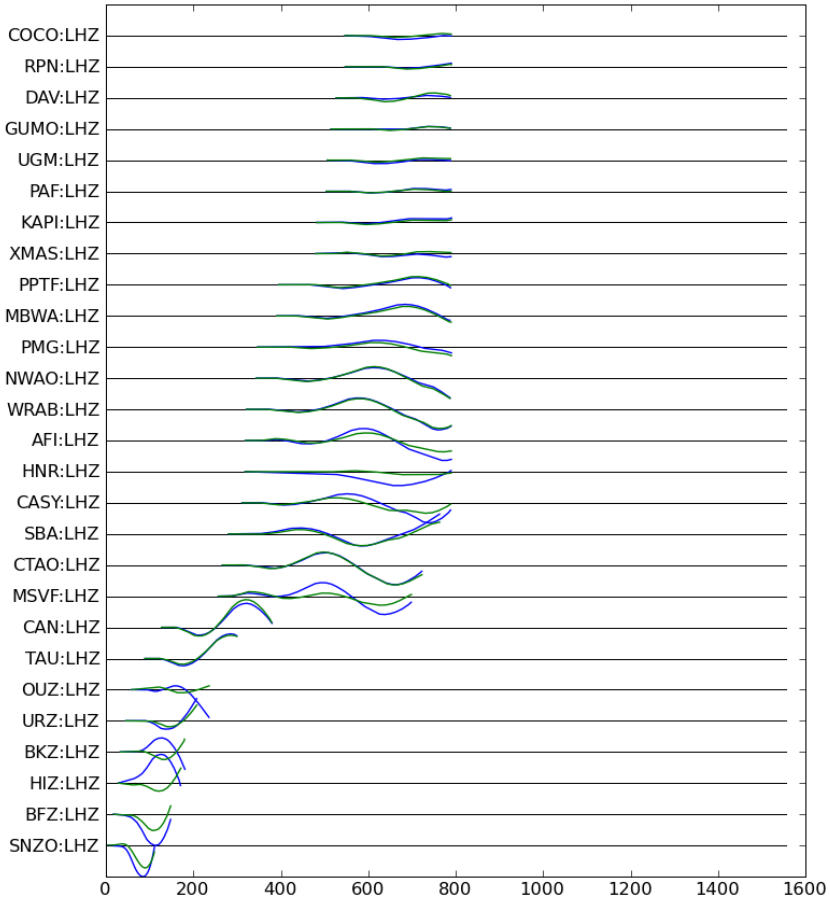


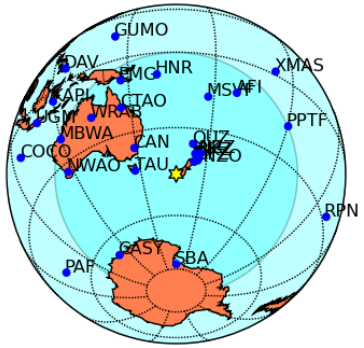


Mw = 7.8

Time = 800 sec

W-Phase Case Study: 2009 Puysegur earthquake in Simulated Real-time

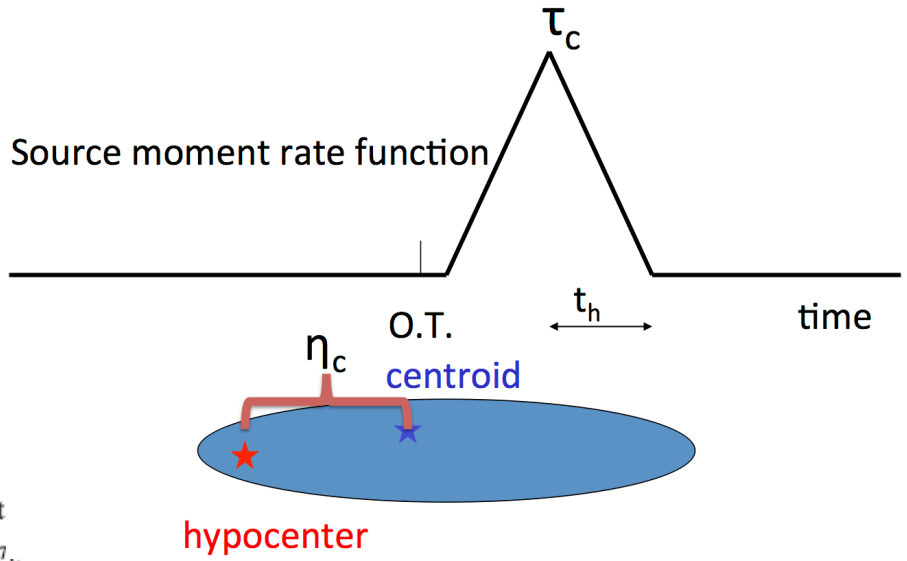


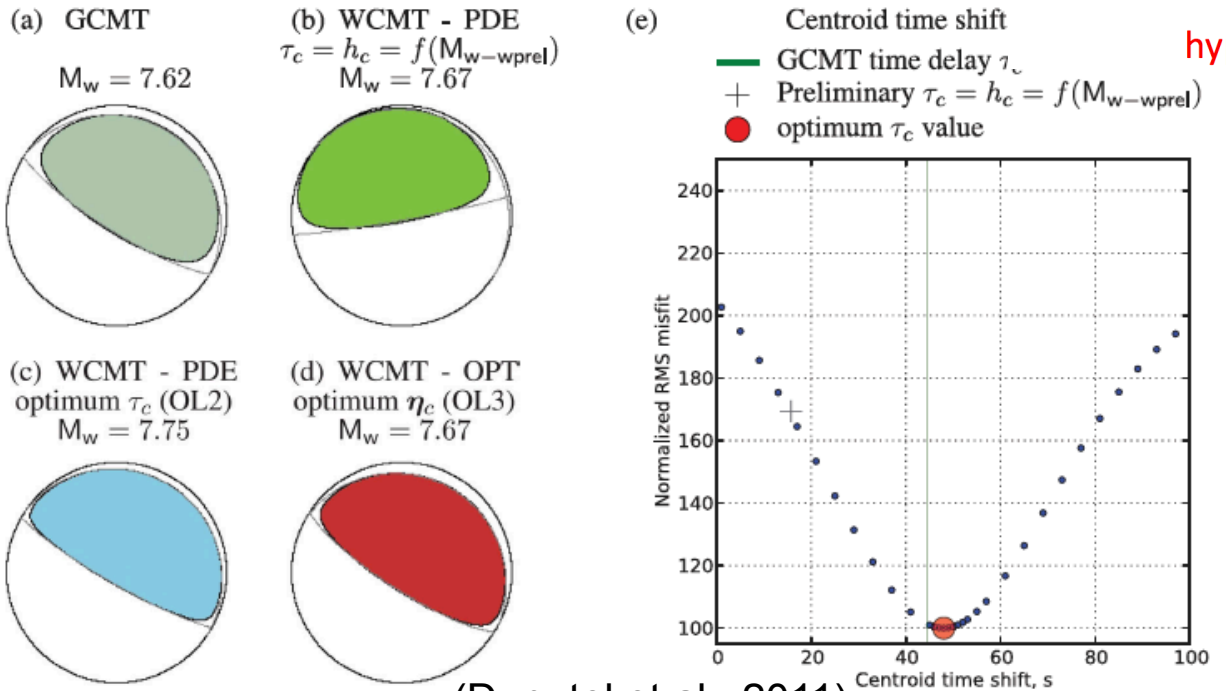


Mw = 7.8

Time = 900 sec

Inversions require the centroid position & time, and half-duration to be specified. Estimates can be based on preliminary magnitude estimates, but the point-source solution is sensitive to errors in these, particularly centroid time.





(Duputel et al., 2011)

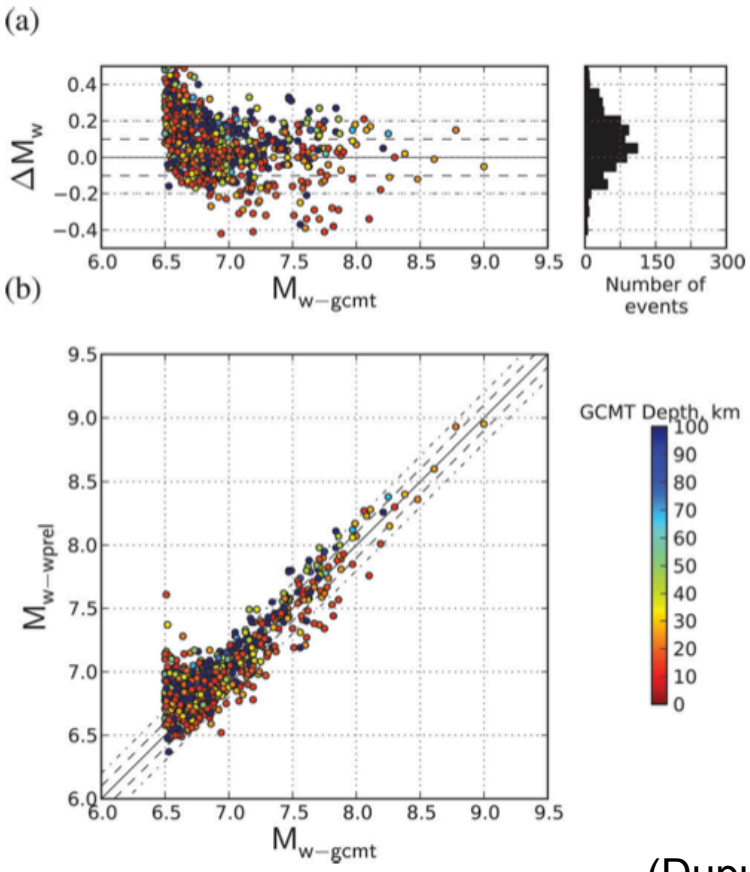
Different levels of solution:

OL1: Uses Preliminary Mw for centroid params

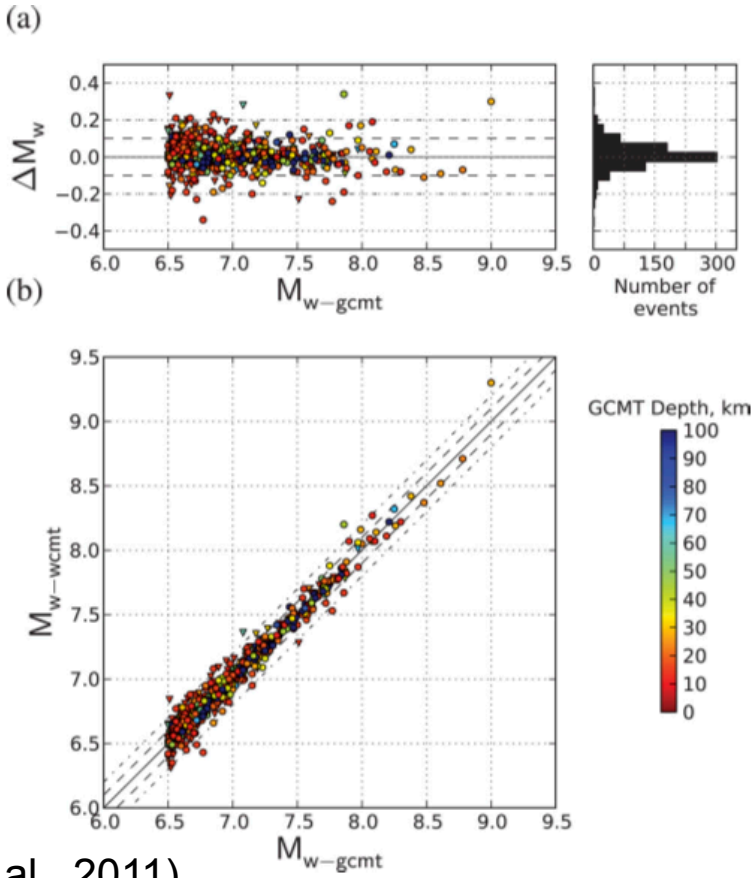
OL2: Optimized centroid delay τ_c

OL3: Uses grid search to optimize centroid location

Preliminary OL1 Mw Estimate



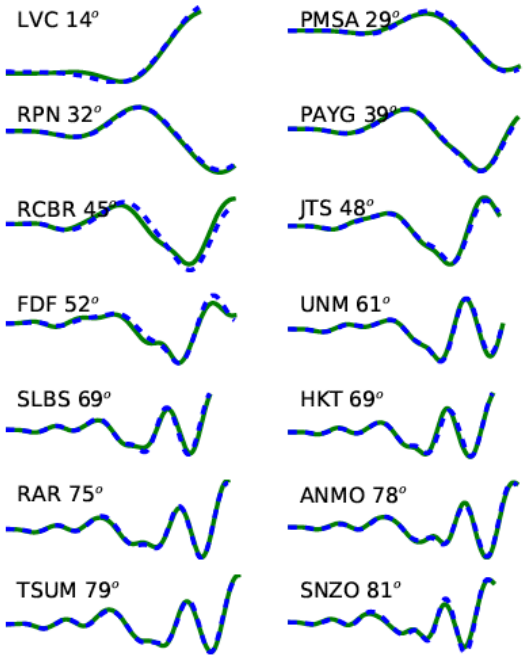
Final OL3 Mw Estimate



(Duputel et al., 2011)

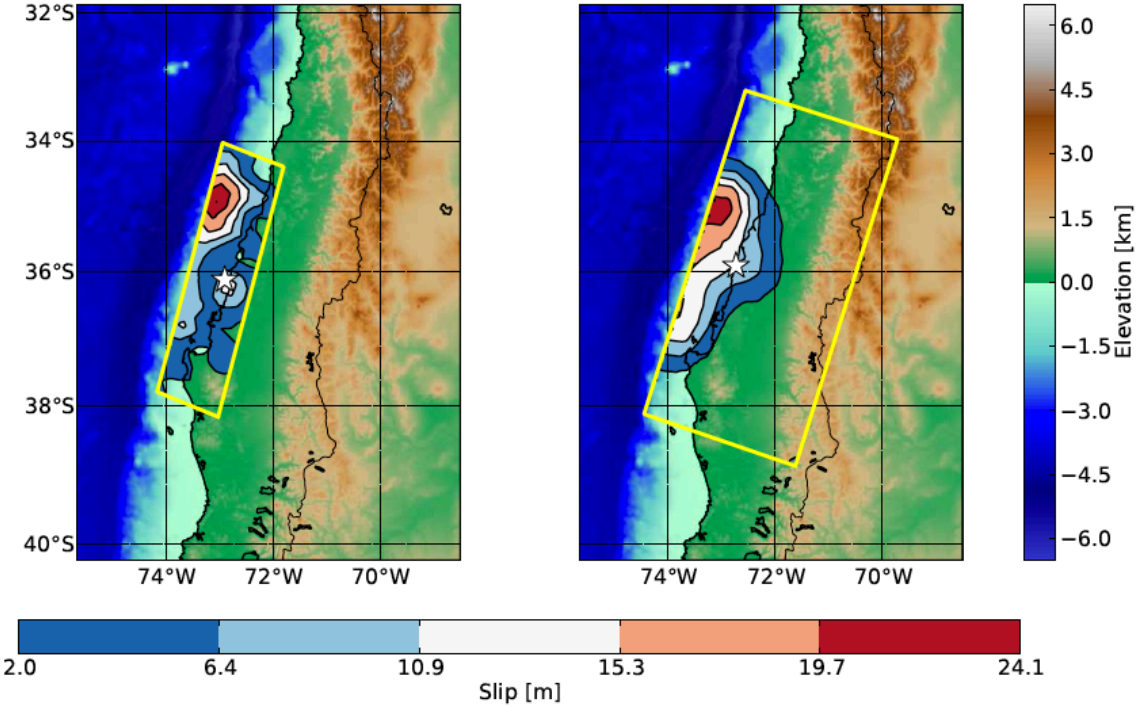
Finite Fault Inversion Using the W-Phase
The 2010 Chile Earthquake

W-phase Waveforms



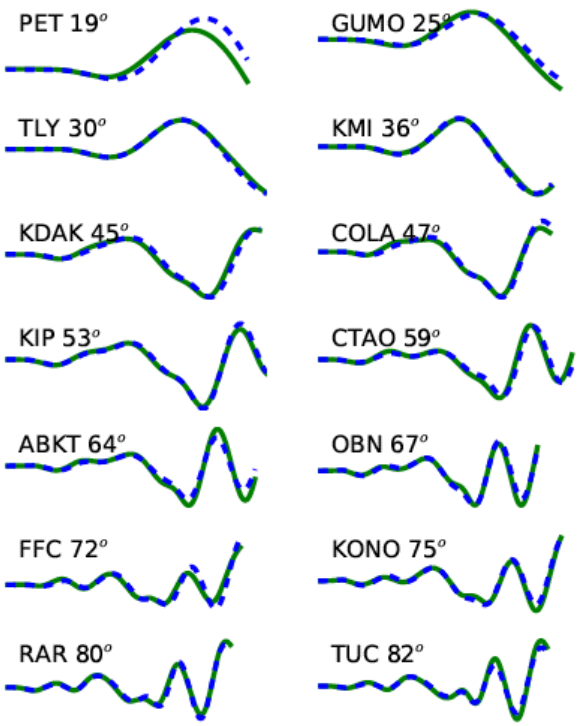
Body & Surface Wave FFI (Lay et al., 2010)

W-phase FFI (Benavente & Cummins, 2013)



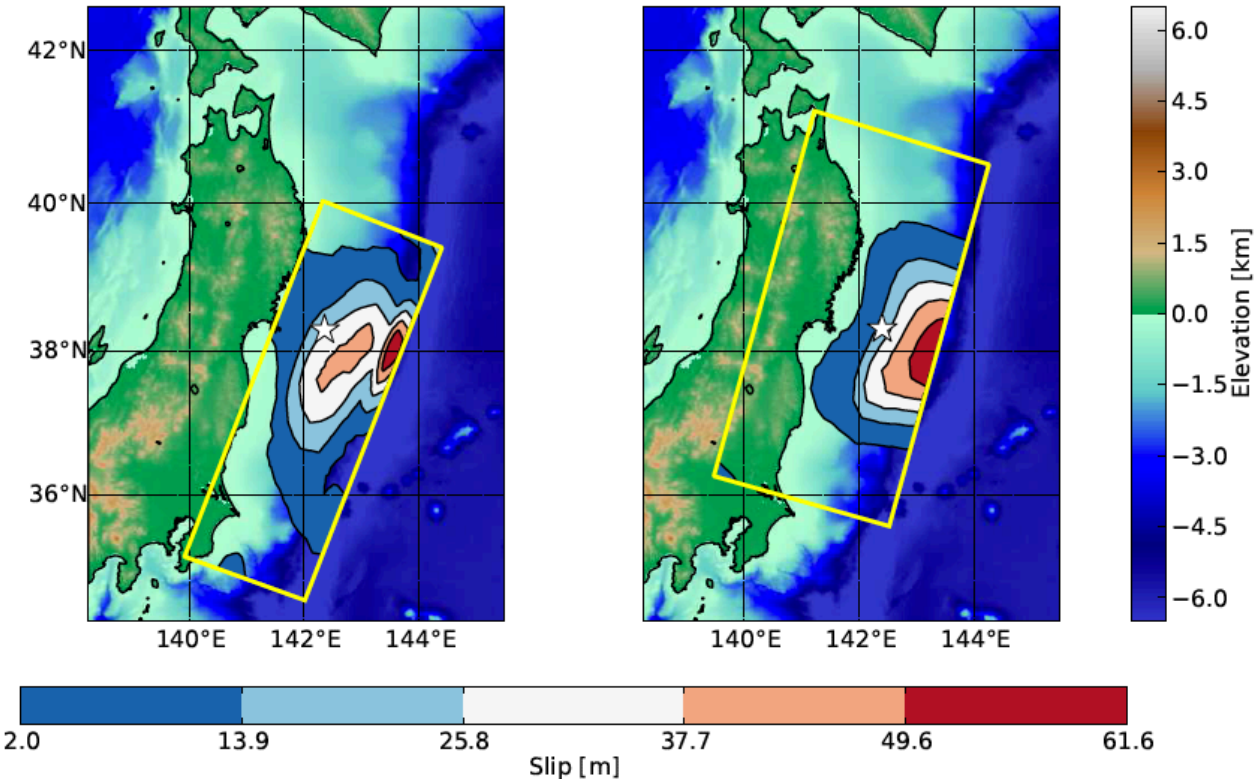
Finite Fault Inversion Using the W-Phase
The 2011 Tohoku Earthquake

W-phase Waveforms



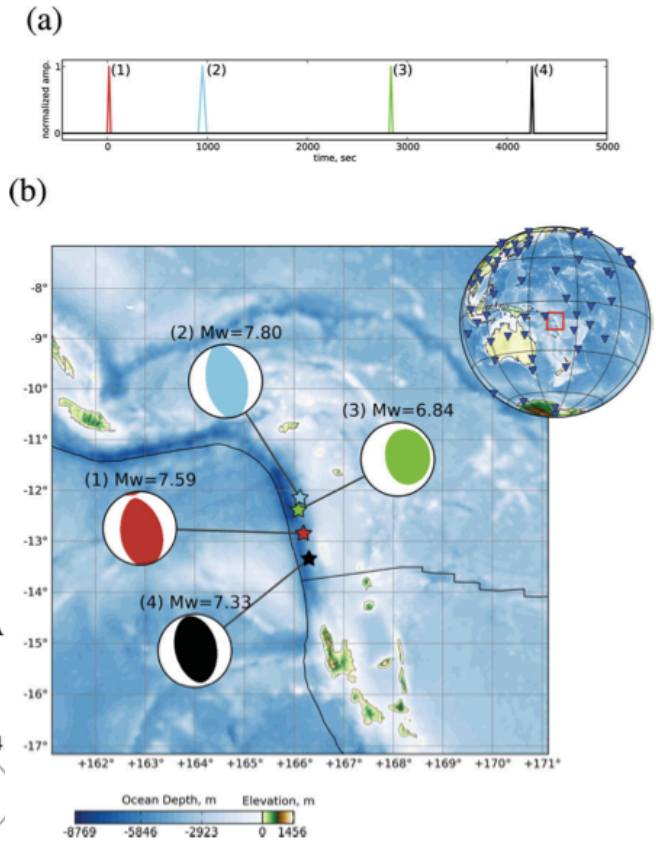
Body & Surface Wave FFI (Koper et al., 2011)

W-phase FFI (Benavente & Cummins, 2013)

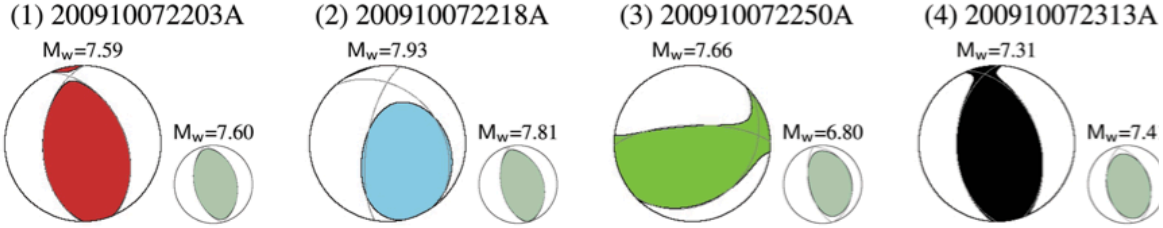


‘Disturbed’ Events

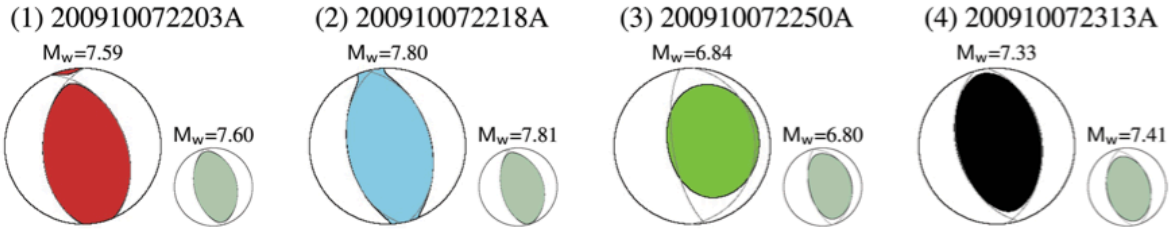
Duputel et al. (2012) showed that a ‘stripping’ technique can be applied that helps resolve magnitudes & mechanisms for compound ruptures.



(a) Standard W phase algorithm



(b) Modified W phase algorithm for *disturbed events*



(Duputel et al., 2012)

Conclusions

- W-phase is well-suited to real-time determination of magnitudes & focal mechanisms for large earthquakes
- Real-time, point-source inversion soon to be operational (?) at ATWS
- Extensions of the w-phase technique, for finite faulting and compound events, may be possible in the near future.

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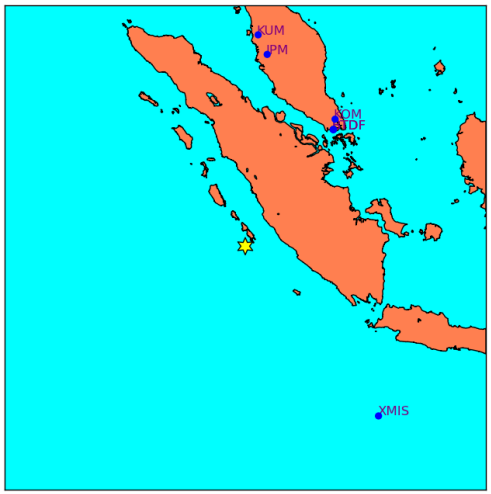
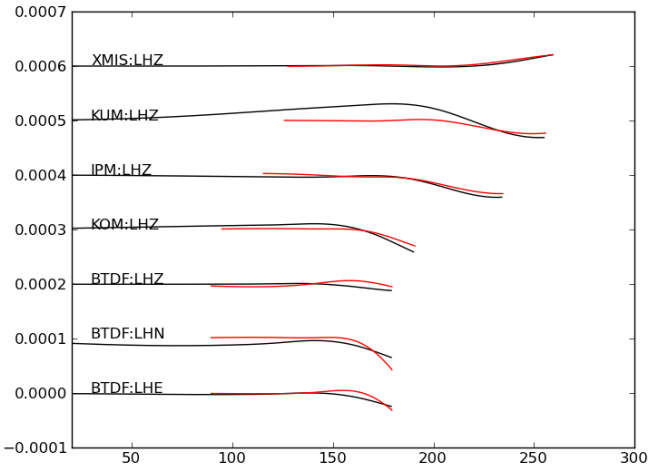
W-Phase closer to the Source:

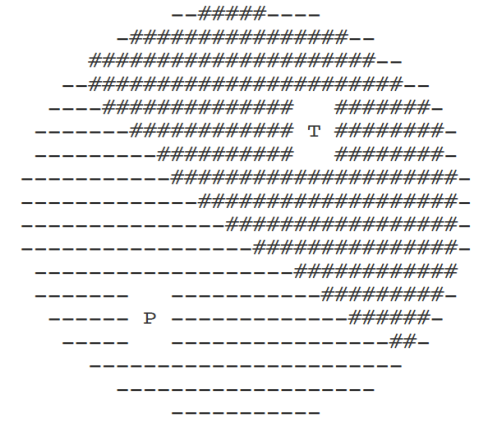
Analysis of the 2010 Mentawai Tsunami Earthqauke



A W-Phase analysis of data available from regional stations within 5 minutes of the earthquake origin time produces a reliable magnitude and focal mechansim estimate.



Global CMT Mw = 7.8
NP1: STRIKE=319;DIP= 7;SLIP= 98
NP2: STRIKE=131;DIP=83;SLIP= 89



W-Phase CMT Mw=7.8
NP1: STRIKE=346.2; DIP=7.7; SLIP=147.2
NP2: STRIKE=108.8; DIP=85.8; SLIP=83.5