W Phase

for *"Whistling"*

or perhaps *"Wisdom"...*

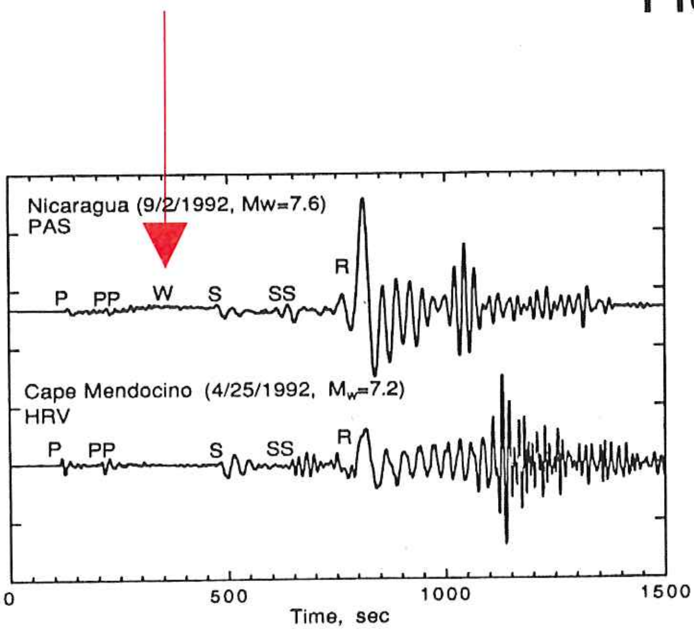
W Phase

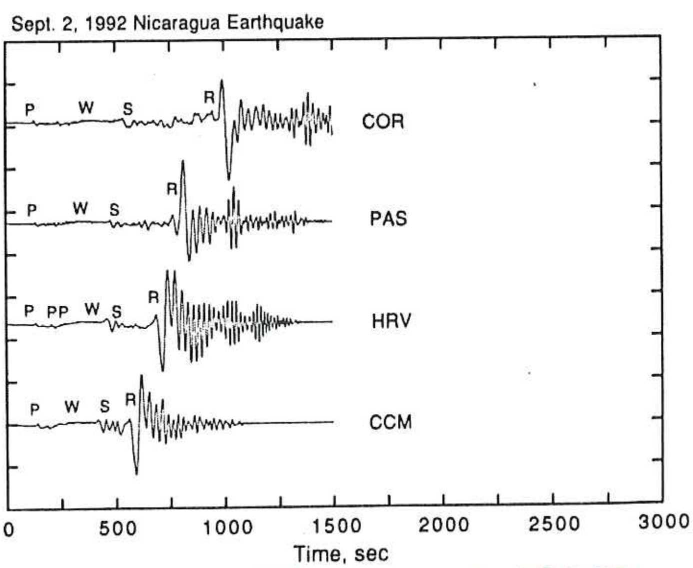
The new, definitive, way of quantifying the low-frequency seismic source in quasi-real time.

[*Kanamori et al.*, 2008]

EAOkal

Geophysical Research Letters





[*Kanamori*, 1993]

AUGUST 20, 1993 Volume 20 Number 16

AMERICAN GEOPHYSICAL UNION

What is the W Phase?

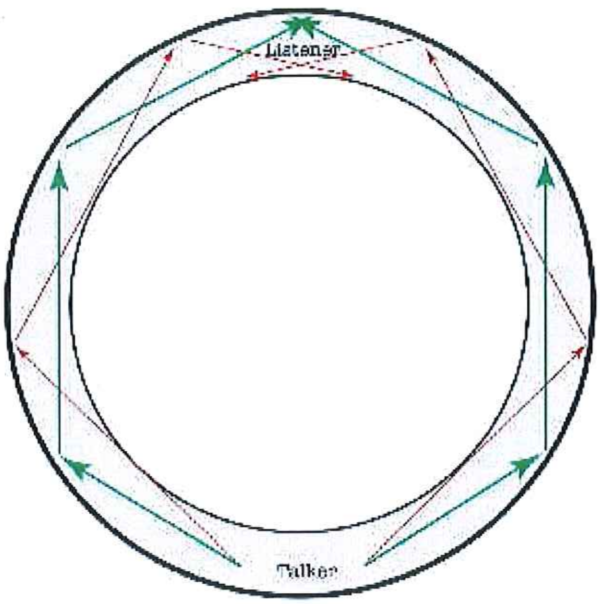
Complex interference of body waves at very long periods.

Arrives between the P- and surface-waves ==> fast.

Travels in the upper mantle ==> stable (unaffected by shallow heterogeneity).

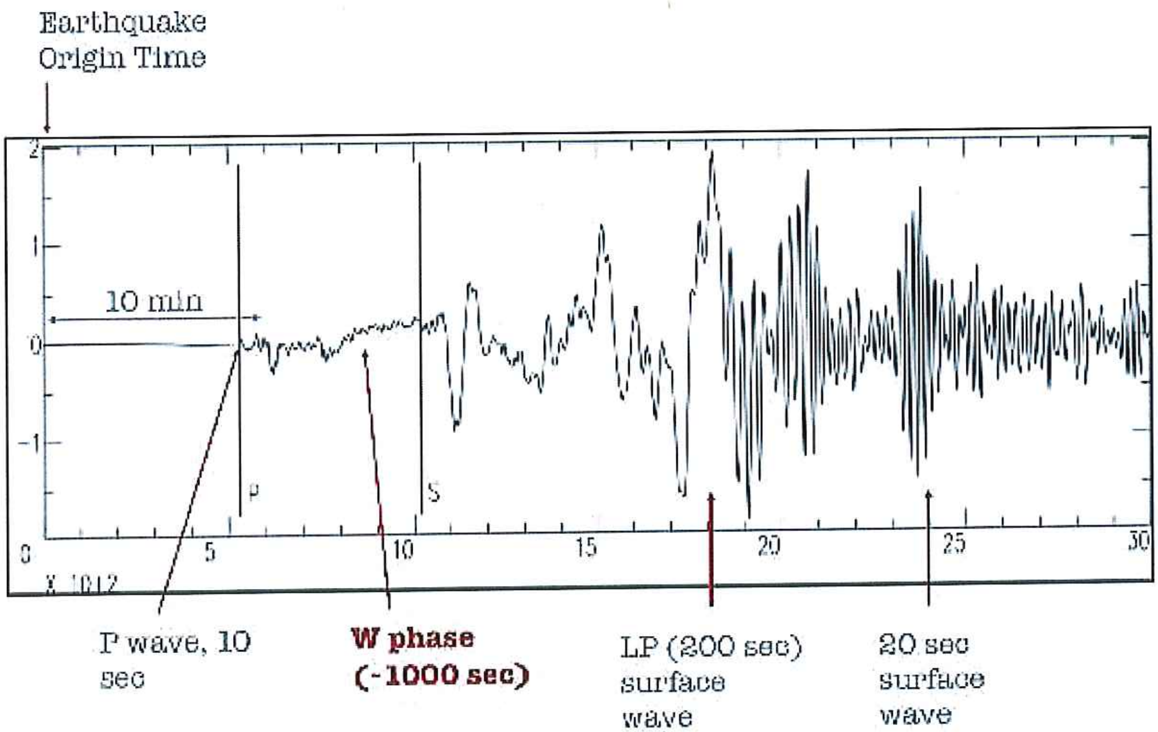
Analogous to a whispering gallery effect - hence 'W' phase.

Can be synthesized by the superposition of normal modes.



What is the W Phase?

[*Gayes,* 2015]

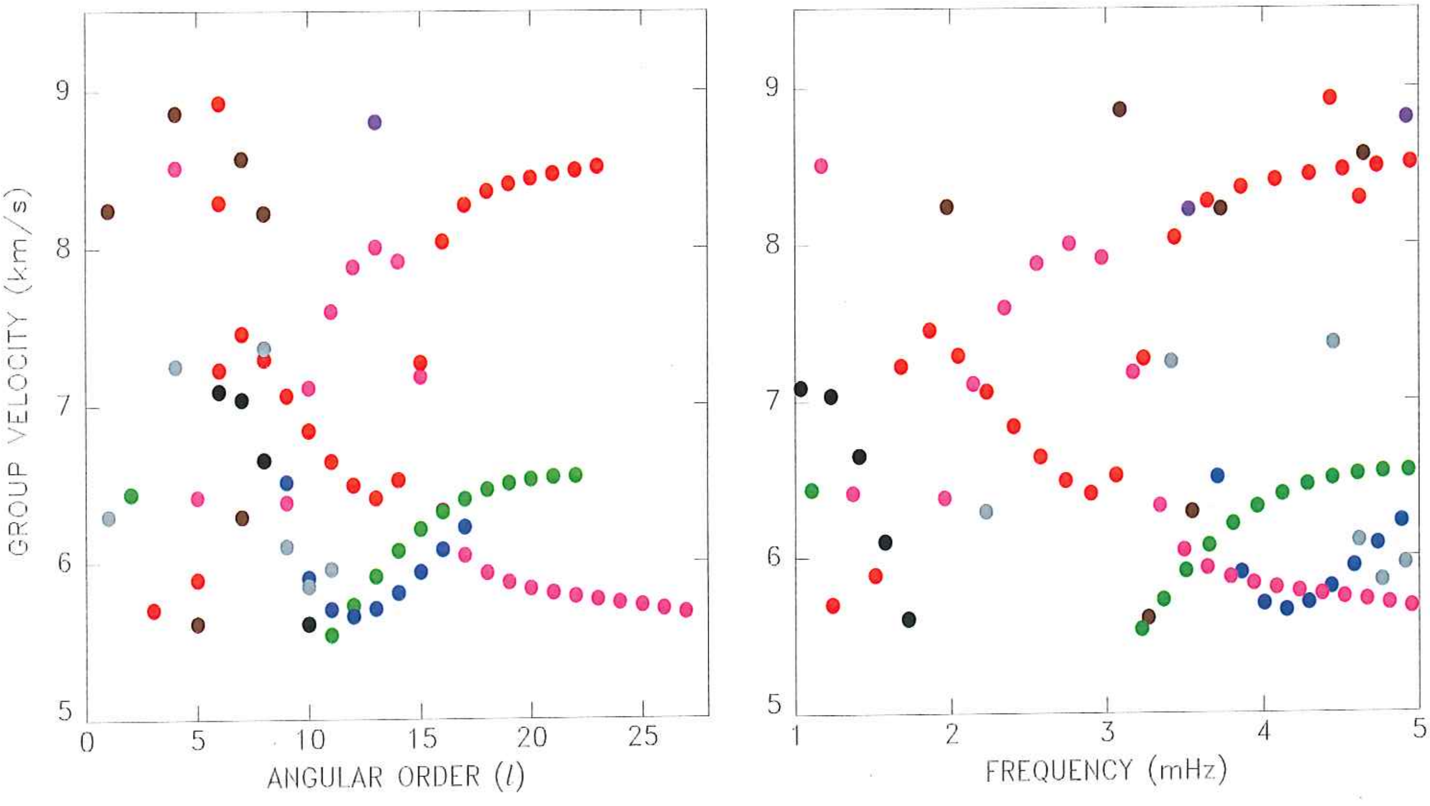


What *IS* the *W* Phase ? (ctd.)

W PHASE as COMBINATION of SPHEROIDAL MODES

→ *It can also be regarded as a superposition of Rayleigh overtones, i.e., of spheroidal modes of the relevant frequencies, with high group velocities ($5.5 < U < 9$ km/s).*

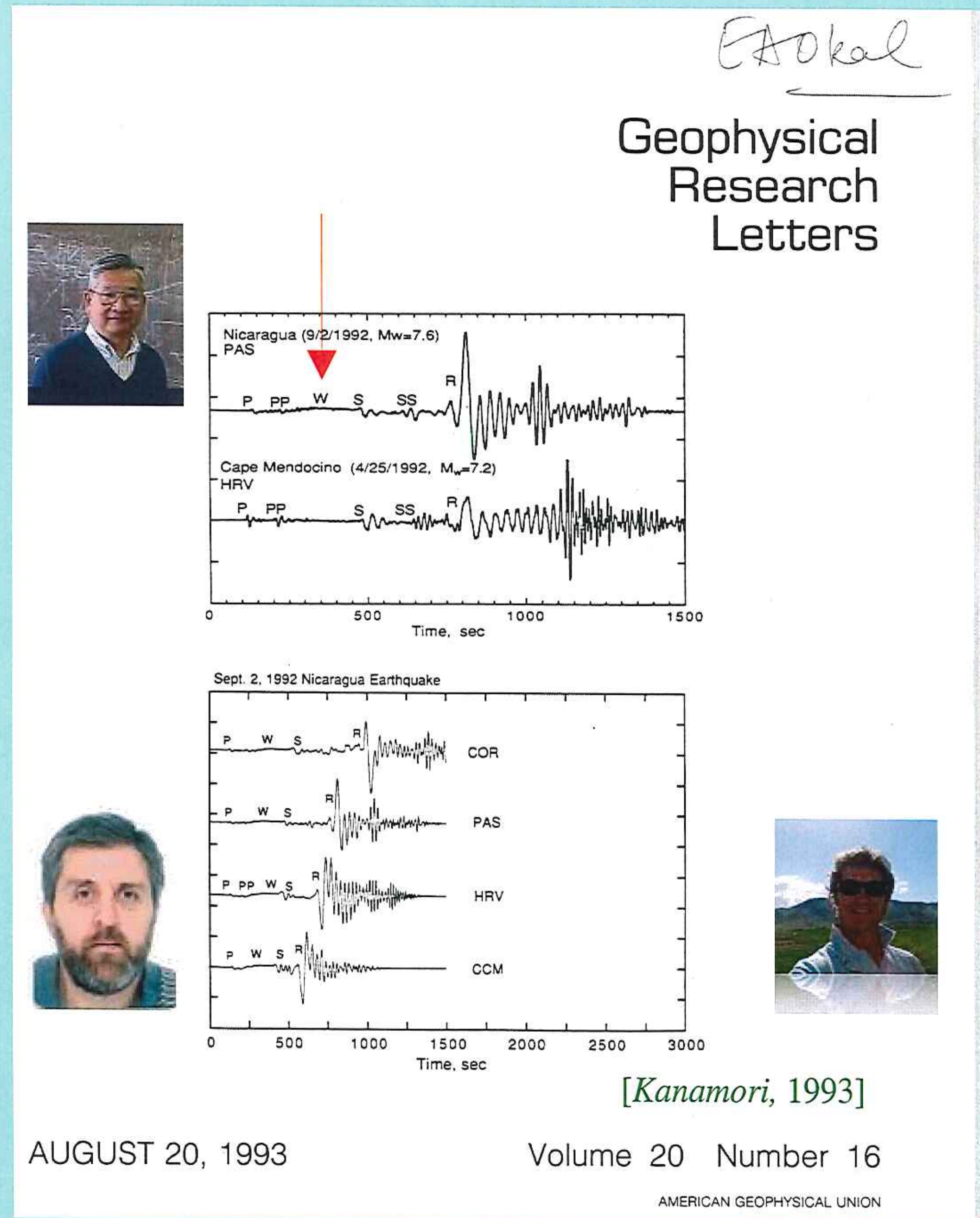
$_0S_l$ $_1S_l$ $_2S_l$ $_3S_l$ $_4S_l$ $_5S_l$ $_6S_l$ $_7S_l$



As such, the W phase may represent the better of two worlds, being both ***Ultra – Long Period*** *and* ***Fast***.

W Phase

The new, definitive, way of quantifying the low-frequency seismic source in quasi real-time



[*Kanamori*, 1993]

[*Kanamori et al.*, 2008]

- The *W* phase is a combination of higher-order Rayleigh overtones (or of reverberated mantle body phases)
- It arrives between *P* and Rayleigh waves
- Originally discovered by *Kanamori* [1993]
- Quantification attempted in the 1990s [*Okal et al.*, 1993]
- Inversion algorithm proposed by *Rivera and Kanamori* [2007]
- Implemented at USGS [*G. Hayes*, 2009] and recently (2010) exported to PTWC

EARLY INVESTIGATIONS (1993–94)

Attempt to retrieve long-period behavior of M_0 from W phase under the *magnitude* concept

1993 FALL MEETING

American Geophysical Union

031B-3 0830h INVITED POSTER

WM_m: An extension of the concept of mantle magnitude to the W phase, with application to real-time assessment of the ultra-long component of the seismic source

Emile A. Okal (Department of Geological Sciences, Northwestern University, Evanston, IL 60208)

Following the recent identification of the so-called W phase by Kanamori, and its recognition as a combination of ultra-low-frequency seismic modes, we have investigated the possibility of using this phase for evaluating in real-time the seismic moment release in the period range 200–1000 s, by adapting the formalism of the mantle magnitude, introduced for conventional surface waves by *Talandier and Okal* [1989].

Because it consists of a superposition of many normal mode branches, the W phase does not lend itself to a simple expression of its spectral amplitude; in particular, source and propagation effects cannot be separated. By computing normal mode synthetics over a grid of distances and frequencies, and averaging their spectral amplitudes over a large number of shallow depths ($h \leq 80$ km), source-receiver and focal geometries, we have produced a theoretical nomogram of the correction $C(\Delta; \omega)$ to be used in the retrieval of the seismic moment M_0 (or equivalently of a mantle magnitude WM_m) from the spectral amplitude of the ground motion $X(\omega)$:

$$WM_m = \log_{10} M_0 - 20 = \log_{10} X(\omega) + C(\Delta, \omega)$$

This algorithm was then used on a dataset comprising at the time of writing 149 IRIS and GEOSCOPE broadband records from 17 large events of the past decade. Our preliminary results show that the method reliably recovers moment information in the range 200–650 s, with a precision comparable to that of the standard M_m algorithm used on traditional mantle Rayleigh waves. The few data points we have obtained at even longer periods are clearly much less robust. A full study will be presented, including a case-by-case comparison of WM_m and M_m values obtained from the same record, and of the influence of using an average over focal mechanism orientation. In the case of the recent tsunamigenic events of 1992 and 1993, the method reliably reproduces the published values of the long-period seismic moment. In particular, in the case of the Nicaraguan earthquake, we have at present no compelling evidence for a continued increase in M_0 with period beyond that reported in the literature, and obtained in real-time from an M_m measurement at Papeete.

SEISMOLOGICAL RESEARCH LETTERS

Volume 65, Number 1, January–March, 1994

SSA 89th Annual Meeting
Pasadena, California • April 5–7, 1994

151.

WM_m: ASSESSING THE POTENTIAL OF THE W PHASE FOR REAL-TIME ASSESSMENT OF THE ULTRA-LONG PERIOD BEHAVIOR OF THE SEISMIC SOURCE.

OKAL, E.A., Department of Geological Sciences, Northwestern University, Evanston, IL 60208; SCHINDELE, F. and REYMOND, D., Laboratoire de Géophysique, Commissariat à l'Energie Atomique, Papeete, Tahiti, French Polynesia.

Following the recent identification of the so-called W phase by Kanamori, and its recognition as a combination of ultra-low-frequency seismic modes, we have investigated the possibility of using this phase for evaluating in real-time the seismic moment release in the period range 200–1000 s, by adapting the formalism of the mantle magnitude, introduced for conventional surface waves by *Talandier and Okal* [1989].

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$$WM_m = \log_{10} M_0 - 20 = \log_{10} X(\omega) + C(\Delta, \omega),$$

for both the vertical and horizontal components of the spheroidal modes' displacements. This algorithm was used on a dataset comprising at the time of writing about 200 IRIS, GEOSCOPE and Papeete broadband records from the large events of the past decade. Our results show that the method reliably recovers moment information in the range 200–650 s, with a precision comparable to that of the standard M_m algorithm used on traditional mantle Rayleigh waves. The few data points we have obtained at even longer periods are clearly much less robust. An estimate of source duration can be obtained by fitting the variation of the WM_m values with frequency to that expected theoretically for a source ramp function. The only recent event clearly requiring a source longer than 50 s is the 1992 Nicaraguan earthquake.

RECENT DEVELOPMENTS

- In the wake of the 2004 Sumatra event, *Lockwood and Kanamori* [2006] showed that the *W* phase was prominently recorded world-wide and that its spectral amplitude could be quantified.

Geochemistry Geophysics Geosystems G3
AN ELECTRONIC JOURNAL OF THE EARTH SCIENCES
Published by AGU and the Geochemical Society

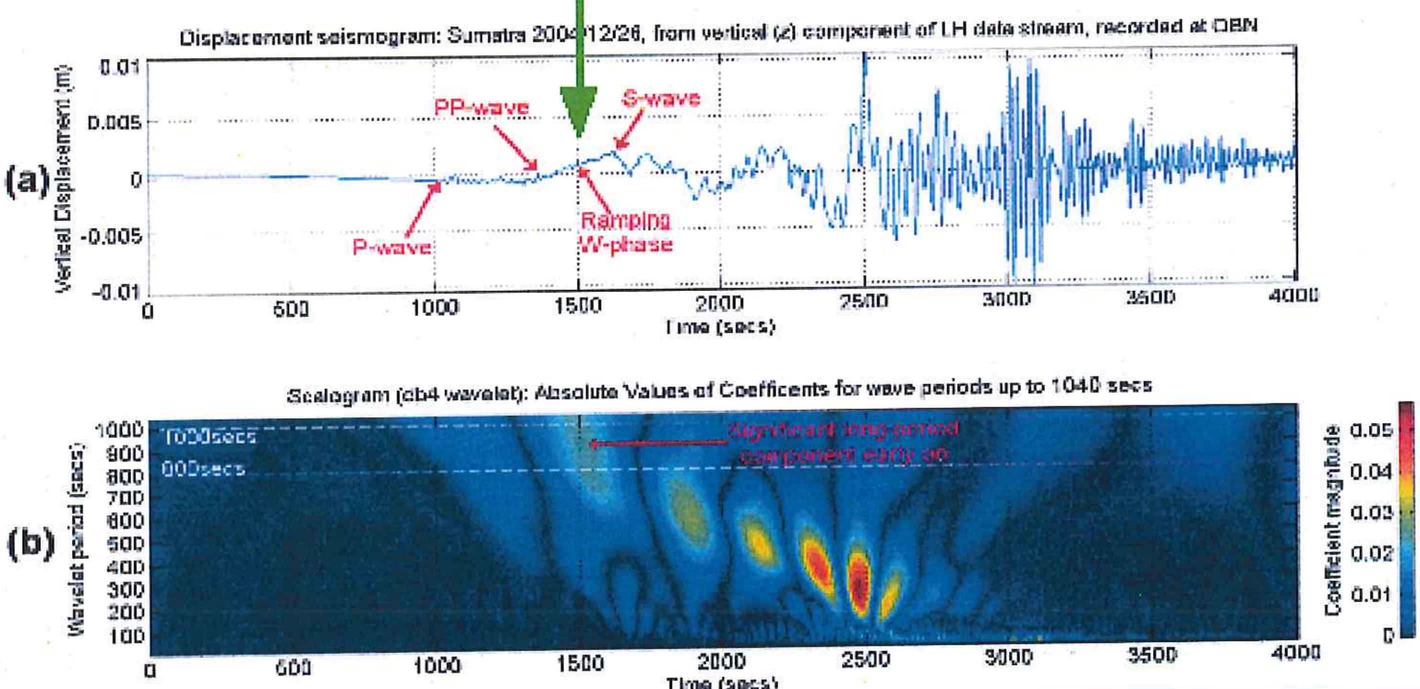
Technical Brief
Volume 7, Number 9
28 September 2006
Q09013, doi:10.1029/2006GC001373
ISSN: 1525-2027

Click Here for Full Article

Wavelet analysis of the seismograms of the 2004 Sumatra-Andaman earthquake and its application to tsunami early warning

Oliver G. Lockwood
Pembroke College, Cambridge University, CB2 1RF Cambridge, UK

Hiroo Kanamori
Seismological Laboratory, California Institute of Technology, 1200 East California Boulevard, Pasadena, California 91125, USA



→ *Rivera and Kanamori* [2007, 2008] later showed that *W* phase signals could be inverted to obtained the ultra-long period focal mechanism of the event.

FULL *W* PHASE INVERSION

Geophys. J. Int. (2008) 175, 222–238

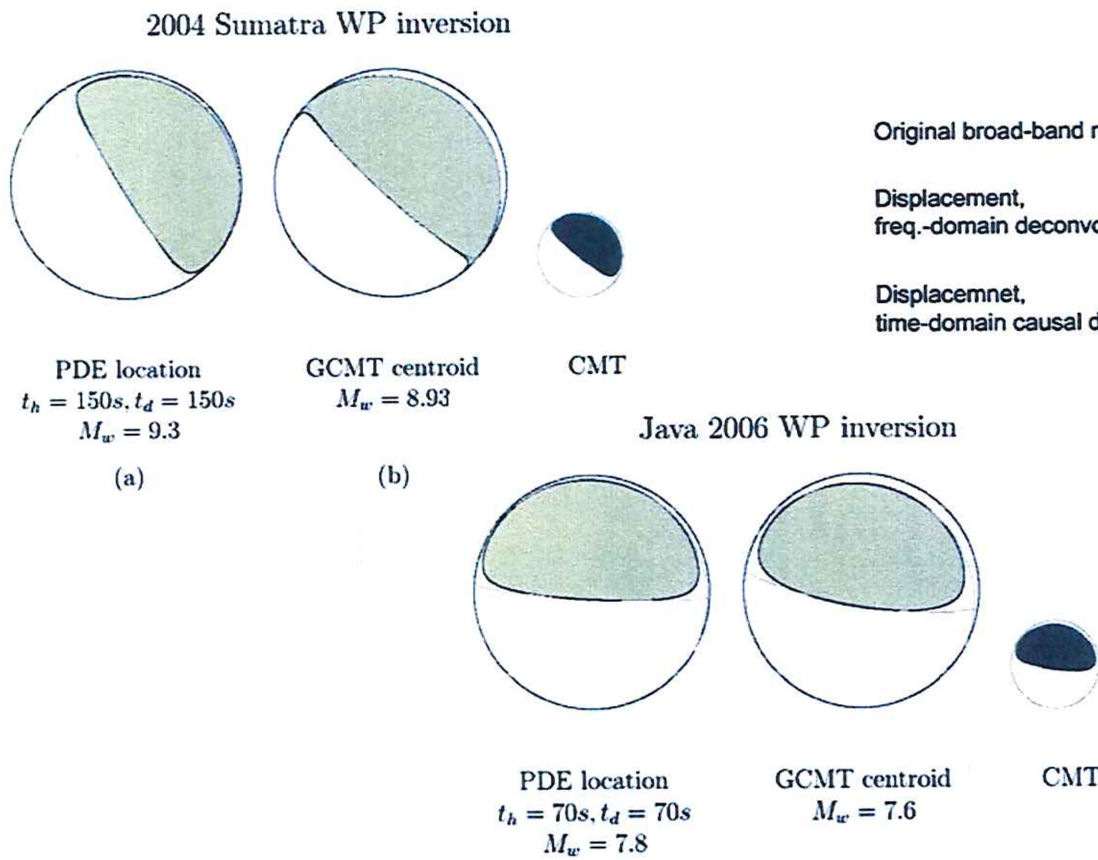
doi: 10.1111/j.1365-246X.2008.03887.x

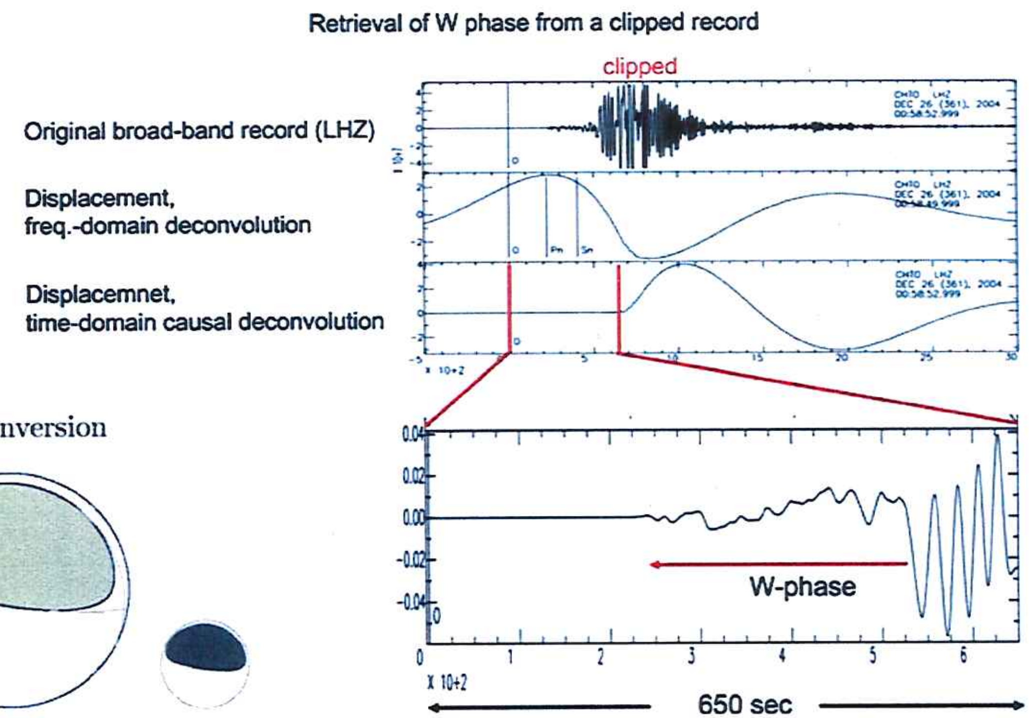
Source inversion of W phase: speeding up seismic tsunami warning

Hiroo Kanamori[1] and Luis Rivera[2]

[1] *Seismological Lab., California Inst. of Technology, Pasadena, CA USA. E-mail: hiroo@gps.caltech.edu*

[2] *Institut de Physique du Globe de Strasbourg, CNRS-ULP, 5 rue René Descartes, Strasbourg Cedex, 67084 France*





Among fundamental results:

Restores the full seismic moment of gigantic (Sumatra 2004) or slow (Java 2006) events.

Geophys. J. Int. (2008) 175, 222–238

doi: 10.1111/j.1365-246X.2008.03887.x

Source inversion of W phase: speeding up seismic tsunami warning

Hiroo Kanamori[1] and Luis Rivera[2]

[1] *Seismological Lab., California Inst. of Technology, Pasadena, CA USA. E-mail: hiroo@gps.caltech.edu*
[2] *Institut de Physique du Globe de Strasbourg, CNRS-ULP, 5 rue René Descartes, Strasbourg Cedex, 67084 France*

The *W* phase also represents the superposition of ultra-long period overtones of Rayleigh modes with fast group velocities.

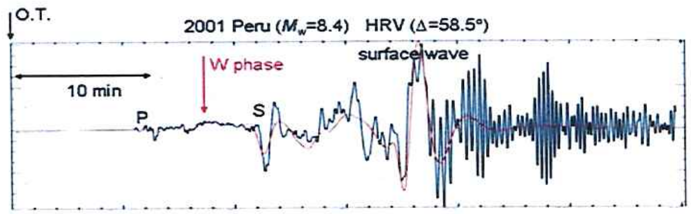


Figure 1. W phase from the 2001 Peruvian earthquake (M_w = 8.4) recorded at HRV, and the synthetic W phase computed by mode summation using the GCMT solution.

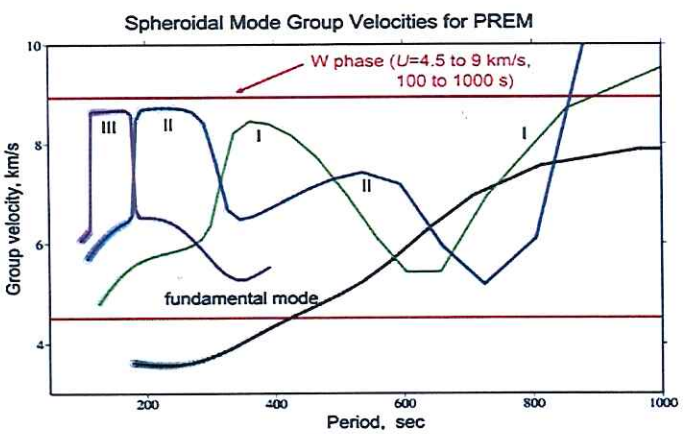


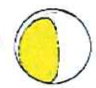
Figure 2. Group velocity dispersion curves of spheroidal modes computed for PREM. Dispersion curves for the fundamental mode (black), the first overtone (green), the second overtone (blue) and the third overtone (magenta) are shown. The horizontal red lines bound the group velocity of W phase.

→ *IT ALLOWS FAST, LOW-FREQUENCY CMT INVERSIONS IN REAL TIME.*

Time Line after 2011 Tohoku Event

M_0 (10^{29} dyn*cm)

T+ 00:20



20min after O.T: USGS Internal W phase solution (6 channels)
Mw=9.0
Centroid loc.: Lat= 36.82N; Lon= 142.87E; Dep= 24.4 km
Time delay = Half duration = 68.7 sec
Best Double Couple: M0=3.941E+29 dyn.cm
NP1: Strike=222.7 ; Dip=16.8 ; Slip=134.6
NP2: Strike=356.8 ; Dip=78.1 ; Slip=78.0

3.9

T+ 00:22

22min after O.T: PTWC Automatic W phase solution (29 channels)
Mw=8.8
Centroid loc.: Lat= 39.00N; Lon= 142.80E; Dep= 83.5 km
Time delay = Half duration = 56.0 sec
Best Double Couple: M0=1.934E+29 dyn.cm
NP1: Strike=165.4 ; Dip=10.3 ; Slip=55.3
NP2: Strike=20.5; Dip=81.6 ; Slip=95.9

1.9

T+00:30

30min after O.T.: PTWC Automatic W phase solution (74 channels)
Mw=8.8
Centroid loc.: Lat= 38.30N; Lon= 143.50E; Dep= 83.5 km
Time delay = Half duration = 68.0 sec
Best Double Couple: M0=1.775E+29 dyn.cm
NP1: Strike=194.3 ; Dip=22.8 ; Slip=81.3
NP2: Strike=23.7 ; Dip=67.5 ; Slip=93.6

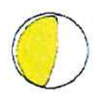
1.8

T+00:40

40min after O.T.: PTWC Manual W phase solution (105 channels)
Mw=9.0
Centroid loc.: Lat= 38.40N; Lon= 142.90E; Dep= 24.4 km
Time delay = Half duration = 69.0 sec
Best Double Couple: M0=4.325E+29 dyn.cm
NP1: Strike=190.6 ; Dip=11.1 ; Slip=76.7
NP2: Strike=24.2 ; Dip=79.1 ; Slip=92.6

4.3

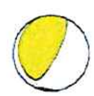
T+00:48



48min after O.T: USGS Internal W phase solution (74 channels)
Mw=8.9
Centroid loc.: Lat= 37.82N; Lon= 142.87E; Dep= 24.4 km
Time delay = Half duration = 72.2 sec
Best Double Couple: M0=3.225E+29 dyn.cm
NP1: Strike=204.4 ; Dip=14.8 ; Slip=104.3
NP2: Strike=9.7 ; Dip=75.7 ; Slip=86.3

3.2

T+01:00



1hour after O.T.: USGS Published W phase solution (89 channels)
Mw=8.9
Centroid loc.: Lat= 38.32N; Lon= 141.77E; Dep= 24.4 km
Time delay = Half duration = 48.0 sec
Best Double Couple: M0=2.836E+29 dyn.cm
NP1: Strike=162.0 ; Dip=16.9 ; Slip=45.1
NP2: Strike=28.2 ; Dip=78.1 ; Slip=102.1

2.8

T +01:30

1hour 30min after O.T.: IPGS W phase solution (146 channels)
Mw=9.0
Centroid loc.: Lat= 38.12N; Lon= 142.97E; Dep= 24.4 km
Time delay = Half duration = 72.0 sec
Best Double Couple: M0=3.507E+29 dyn.cm
NP1: Strike=196.3 ; Dip=14.4 ; Slip=85.1
NP2: Strike=21.4 ; Dip=75.7 ; Slip=91.3

3.5

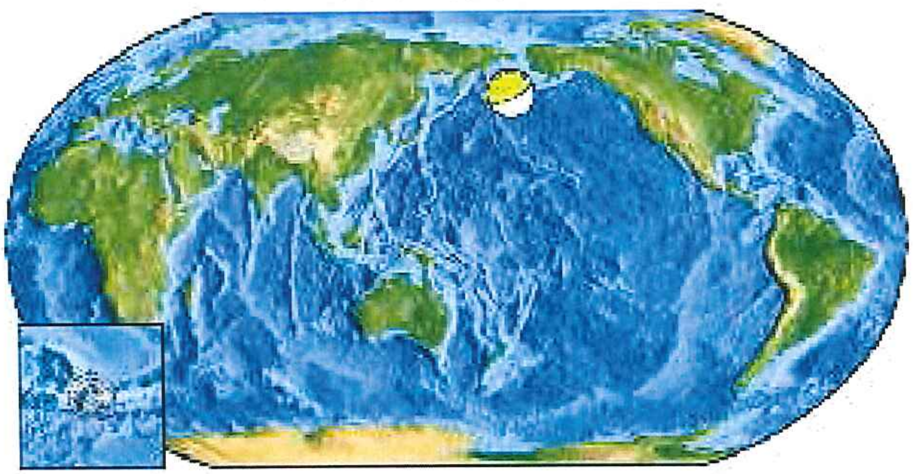
A BIG STEP IN WISDOM !!

2009: IMPLEMENTED AT NEIC – USGS, Golden

[*G. Hayes*, 2009]

W Phase moments are now routinely computed

and fast becoming the authoritative focal solution.



USGS WPhase Moment Solution

```
10/08/04 12:58:27
ANDREANOF ISLANDS, ALEUTIAN IS.
Epicenter:  51.422 -178.573
MW 6.4

USGS/WPHASE CENTROID MOMENT TENSOR
10/08/04 12:58:27.00
Centroid:    51.422 -178.573
Depth  44           No. of sta: 68
Moment Tensor;    Scale 10**18 Nm
  Mrr= 2.52         Mtt=-2.79
  Mpp= 0.27         Mrt= 3.80
  Mrp= 1.99         Mtp=-0.77
 Principal axes:
  T  Val=  4.95  Plg=60  Azm=322
  N        0.30       7       66
  P       -5.25      28      160

Best Double Couple:Mo=5.1*10**18
 NP1:Strike=272 Dip=17 Slip= 116
 NP2:          64     74       81

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