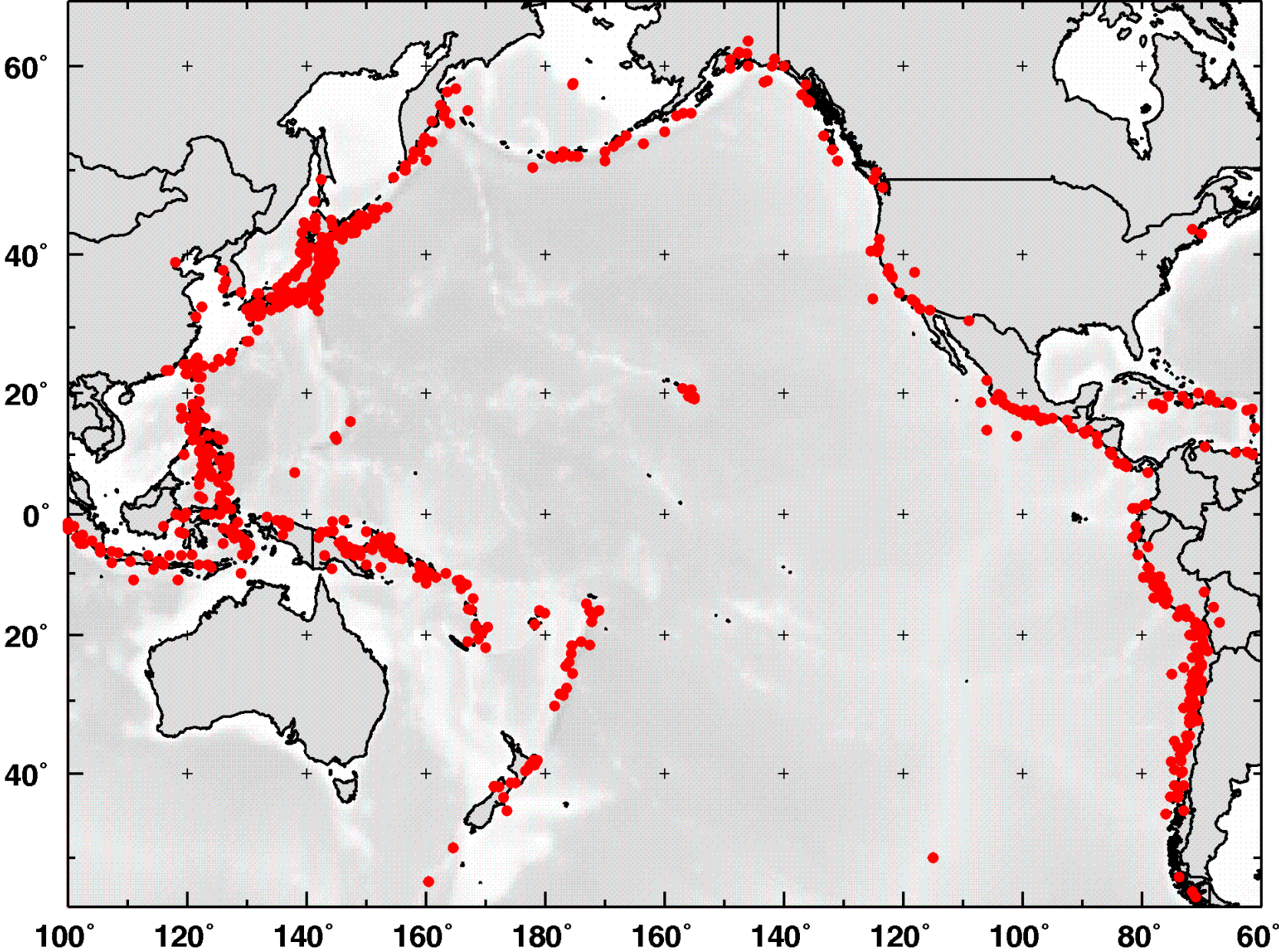# Earthquake source characterization for Tsunami warning
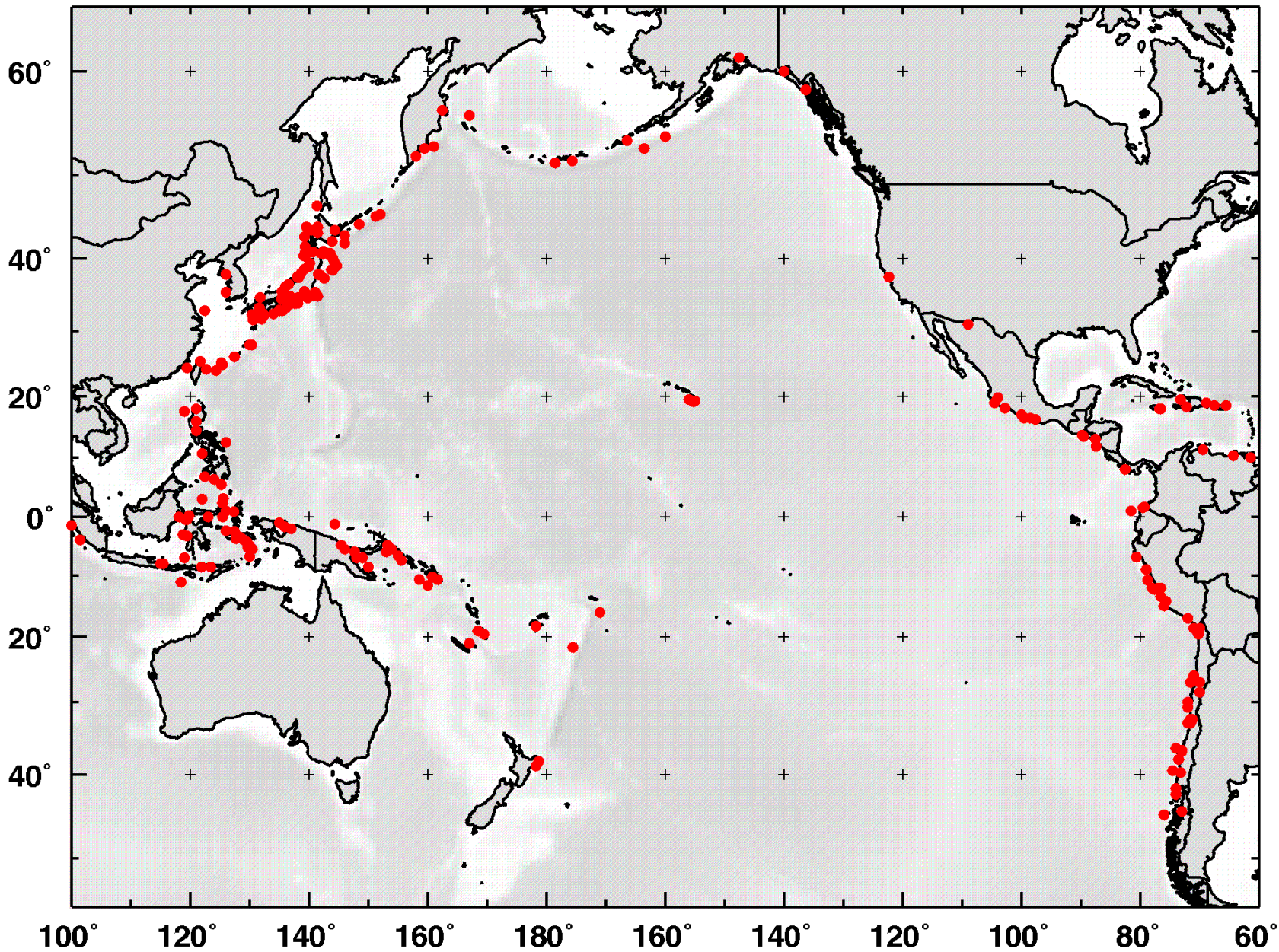
Barry Hirshorn and Stuart Weinstein

NOAA NWS Pacific Tsunami Warning,
Ewa Beach, HI, US A.
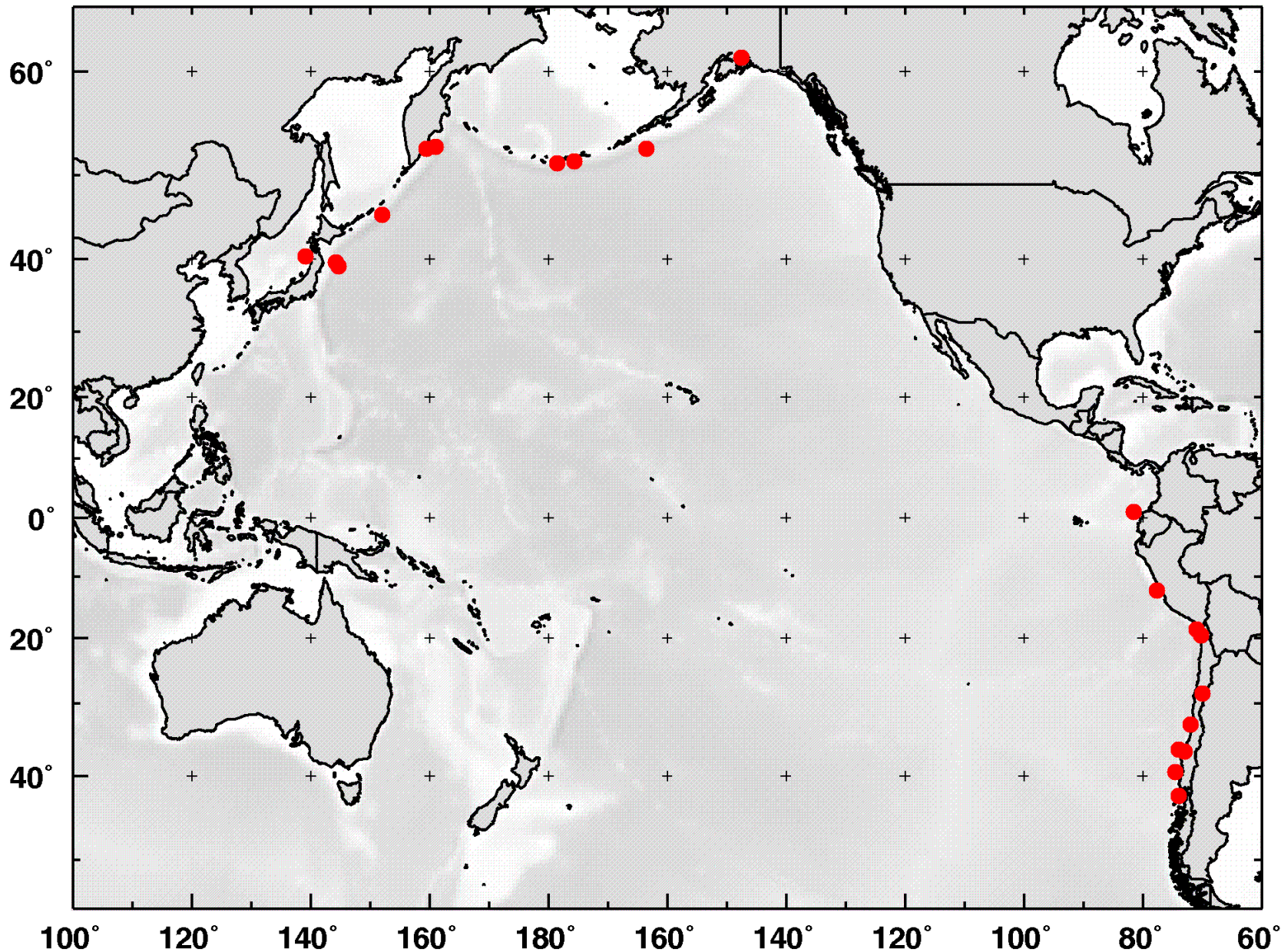
EPICENTERS OF TSUNAMIGENIC EARTHQUAKES

EPICENTERS OF EARTHQUAKES THAT PRODUCED TSUNAMIS CAUSING DAMAGES OR CASUALTIES

EPICENTERS OF EARTHQUAKES THAT PRODUCED TSUNAMIS CAUSING DAMAGES OR CASUALTIES MORE THAN 1000 KM AWAY

Current Practice: Magnitude thresholds.

Mw less than 6.5 (Mw: Moment Magnitude)	**Earthquake Message Only**
Mw 6.5 to 7.5	**Tsunami Information Bulletin**
Mw 7.6 to 7.8	**Regional Tsunami Warning**
Mw > 7.8	**Expanding Warning / Watch**
Confirmed Teletsunami	**Pacific-Wide Warning**

In the NEAR FIELD:

LARGE Earthquakes (aka. Chile 2010)
Move inland if you feel a strong ground shaking and/or see the water recede from the shoreline.

TSUNAMI Earthquakes (aka. Java 2006)
Most people in the areas nailed by the Tsunami felt no eq. Also, many were in homes close the beach but didn't think to look at the water…

==> Local Tsunami Warnings within 5 minutes based on real time data from as dense a seismic network as practical.

In the FAR FIELD:
==> Tsunami Warnings issued within 10 to 15 minutes of EQ origin time.

Case I: A "Large" Earthquake, Chile Mw8.8 2/27/10:

06:34:16   EQ Origin Time.

06:36:54   Scientists PAGED: SOUTH AMERICA (PLCA, del = 5.2 degrees
                                                          TRQA, del = 8.9 degrees)

06:44:01   FIRST MESSAGE:
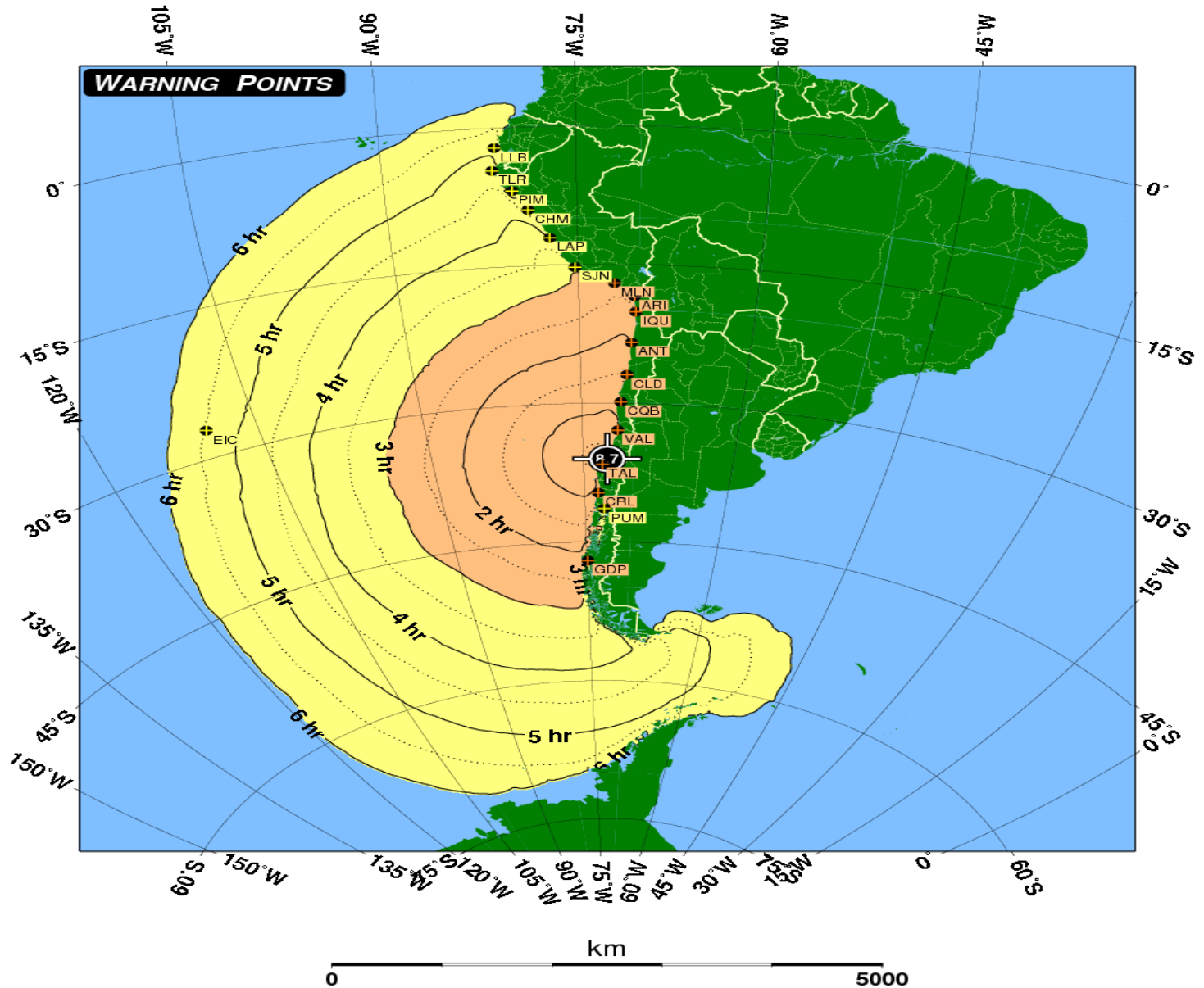   LAT: 36.1S   LON: 72.6W   DEPTH: 55 km. (11 stations) MWP 8.5 (4)

06:44:54   TSUNAMI WARNING FOR CHILE and PERU:

            Estimated Arrival Time of TSUNAMI at   GMT.
            --   --------
            ==> Talcahuno, Chile   07:29
                 Valpariso,   Chile   07:39

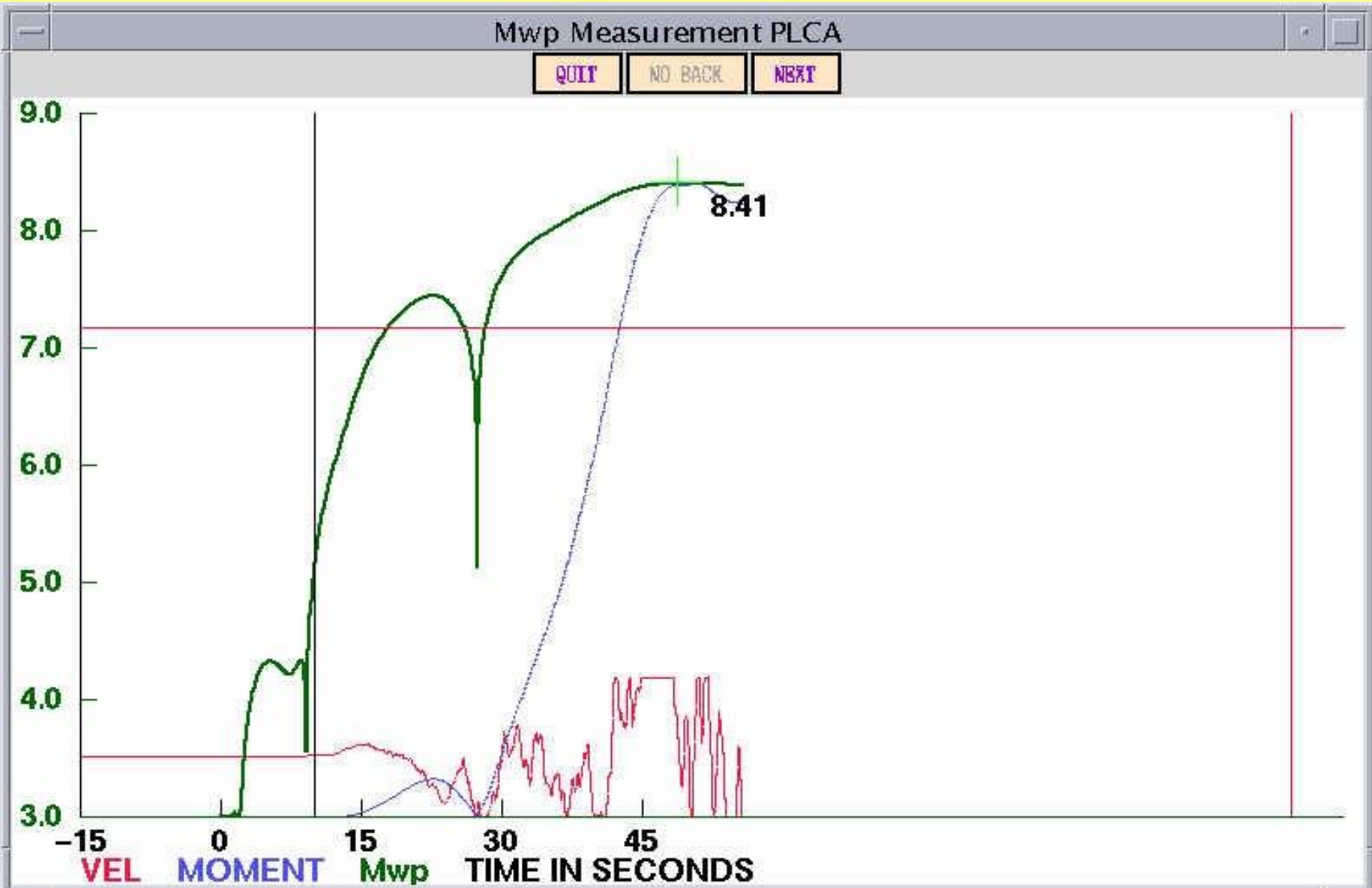07:19:00   First (Automatic) W-Phase solution (16 channels):
            Mww 8.62, BDC: STRIKE:356 / DIP:29 / SLIP ANGLE: 92
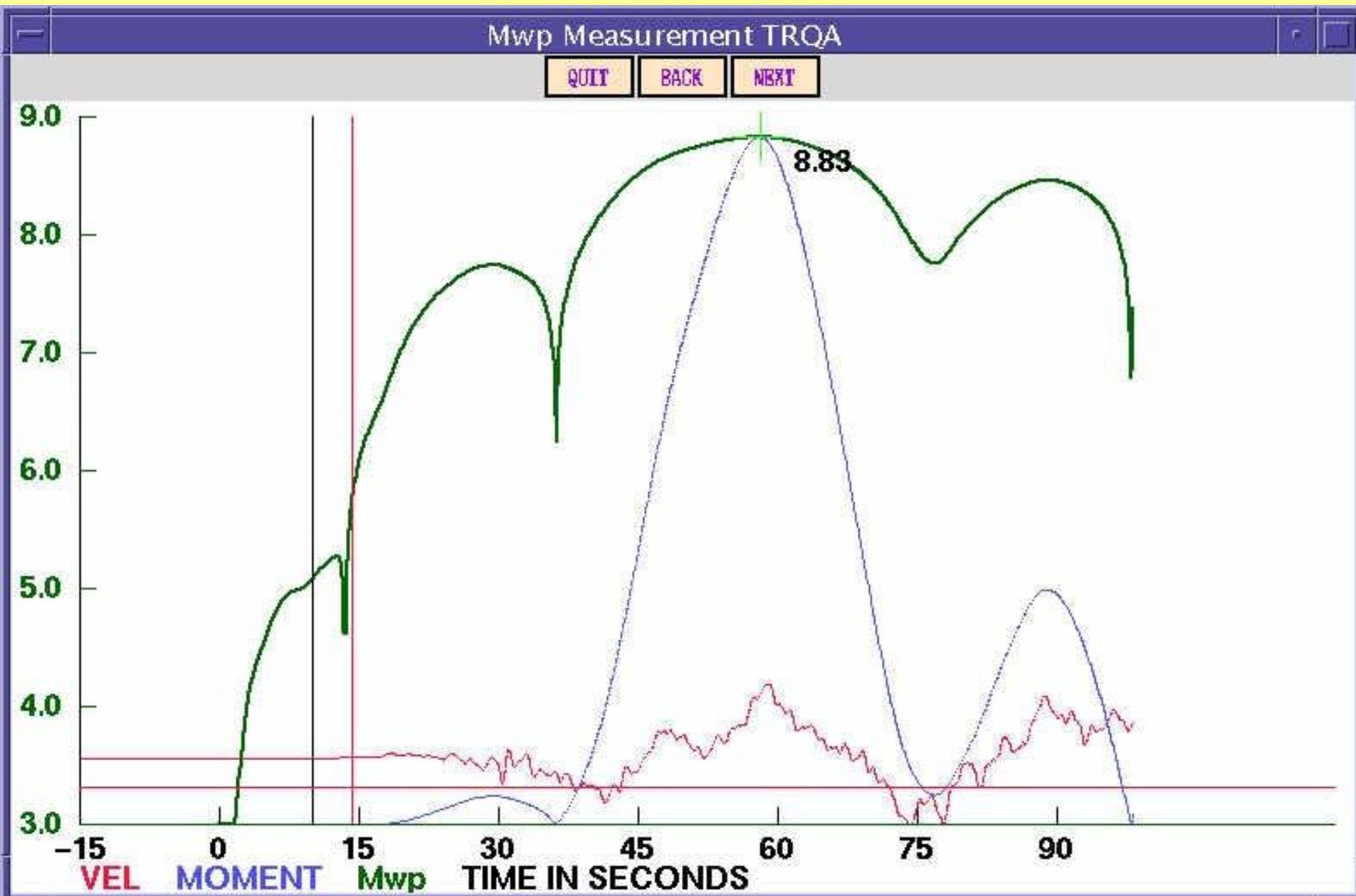   174 /   61 /   89

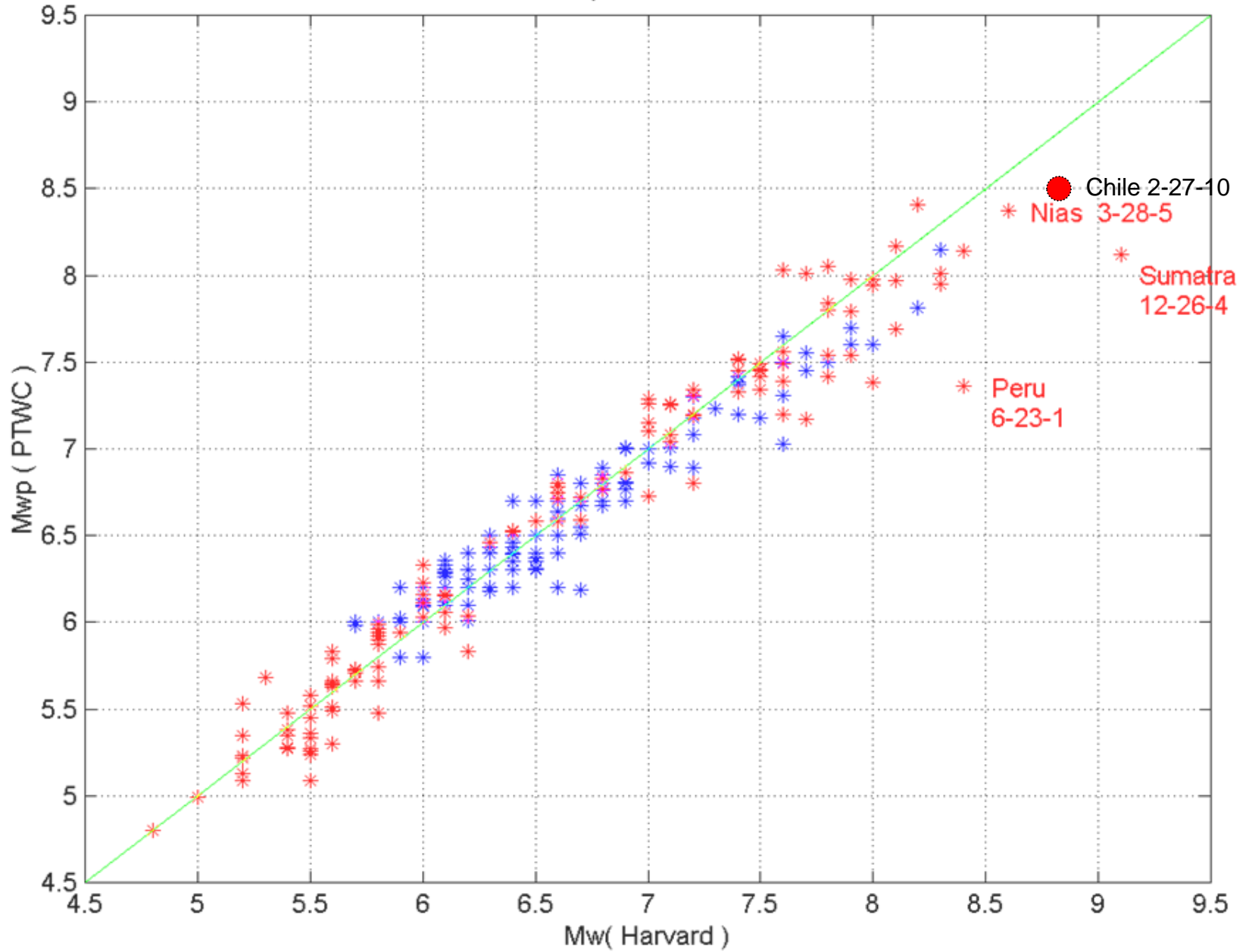08:02:33   Mw(Mm) 8.7 (189 channels)

06:44:54 TSUNAMI WARNING FOR CHILE and PERU:

Mwp from PLCA at 5.2 degrees epicentral distance

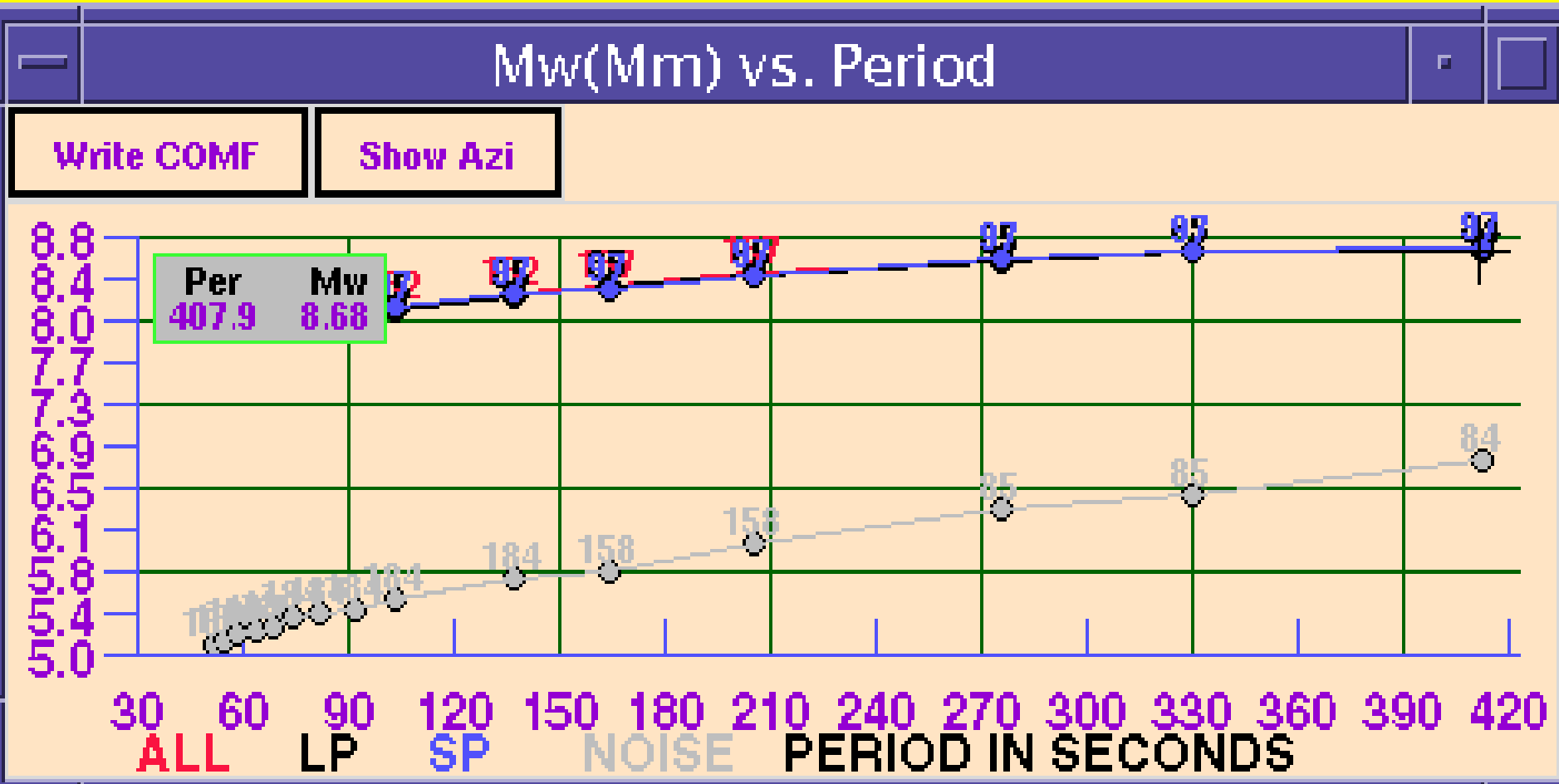# Mwp from TRQA at 8.9 degrees epicentral distance

279 Earthquakes: 1992 - 2008.

Mw(Mm)

The Mantle Magnitude was developed by E.A. Okal and J. Talandier back in 1988. The Mantle Magnitude, abbreviated as Mm, is a variable period magnitude. An Mm is computed for each station at a suite of magnitudes which normally range from 51s to 273s.
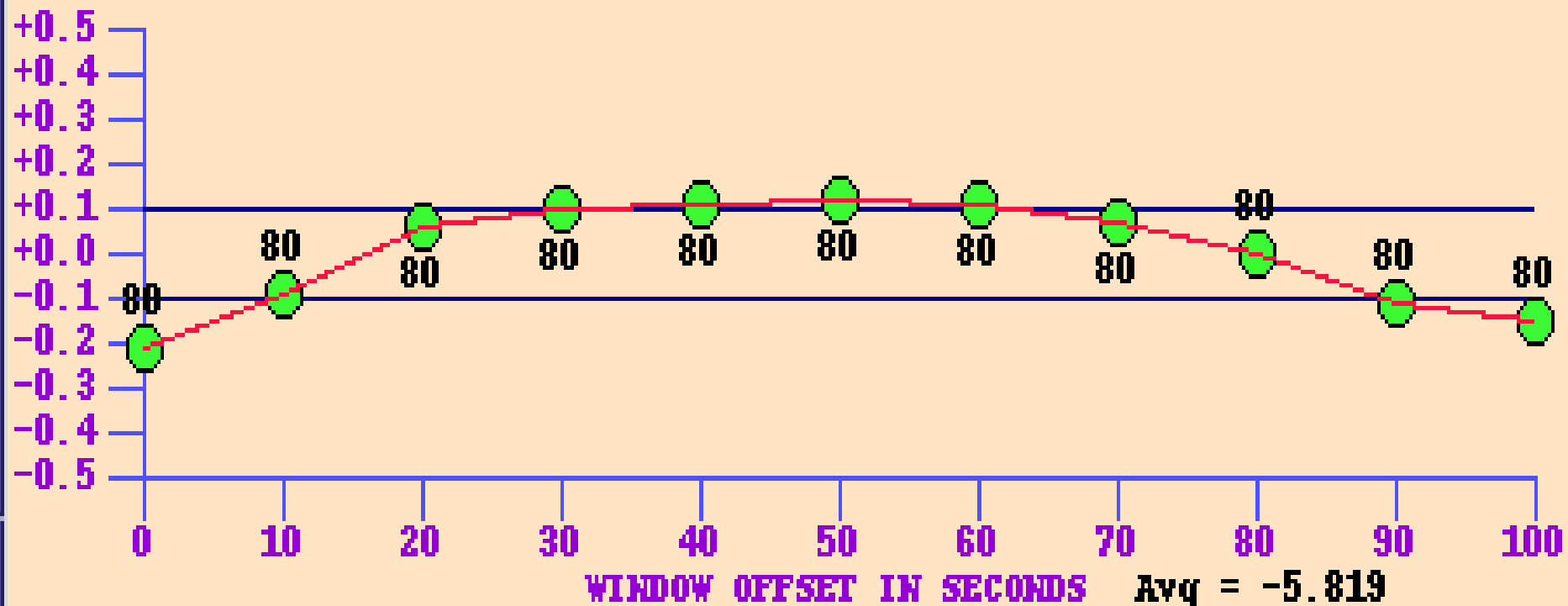
at 420s, Mw(MM) = 8.7.

Theta = log(E/Mo)

Newman and Okal (1998) showed that for tsunami quakes, the value of Θ is usually about -6.0 or less. For a regular or non-slow earthquake, theory suggests that Theta is ~ -4.9.

Theta Window Offset Results

WINDOW OFFSET IN SECONDS   Avg = -5.819

Optimized Centroid, OT + 45 min

QuickTime™ and a
TIFF (Uncompressed) decompressor
are needed to see this picture.

Mw = 8.6
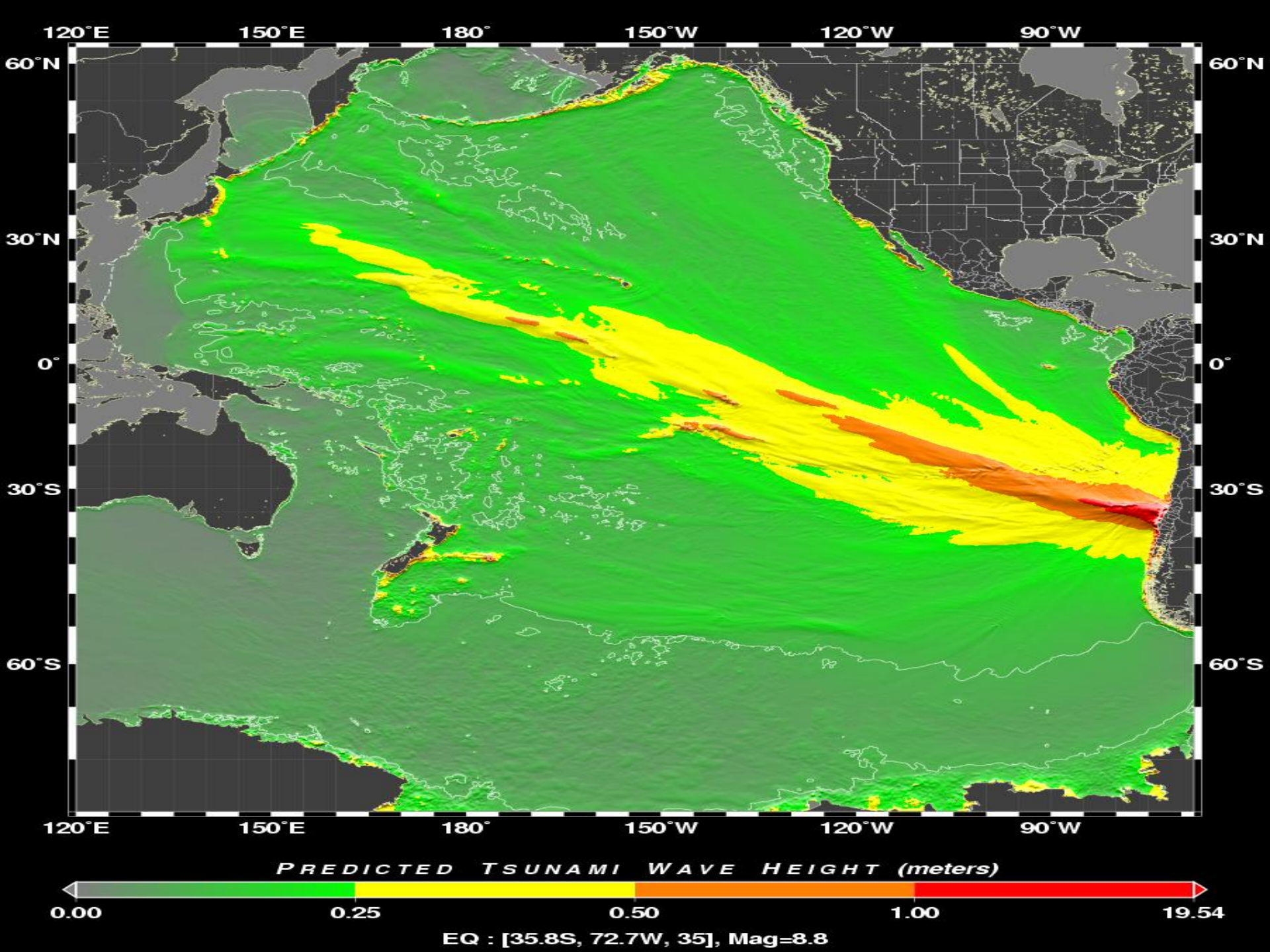Lat 35.5 lon 73.0 h = 55km.
62 sec half duration (from time shift)
Strike = 356, Dip = 29, Rake = 92
Strike = 174, Dip = 61, Rake = 89

USGS WPhase Moment Solution

10/02/27 6:34:17
OFFSHORE MAULE, CHILE
Epicenter: -35.826 -72.668
MW 8.8

USGS/WPHASE CENTROID MOMENT TENSOR
10/02/27 06:34:17.00
Centroid: **-35.826 -72.668**
Depth **35**　　　No. of sta: 28
Moment Tensor; Scale 10**24 Nm
　Mrr= 0.93　　　Mtt= 0.01
　Mpp=-0.94　　　Mrt=-0.01
　Mrp=-1.72　　　Mtp=-0.15
　Principal axes:
　T Val= 1.96 Plg=59 Azm= 86
　N　　0.02　　 3　　 182
　P　　-1.97　　30　　 274

Best Double Couple:Mo=2.0*10**22
　NP1:Strike= 16 Dip=14 Slip= 104
　NP2:　　181　　75　　　86

```
                    ----###
                 --------########-
               ----------##########-
             -----------############--
           ------------#############--
          ------------################--
          ------------################--
         -------------#################--
        ---- -------#######  #######--
        ---- P -------###### T #######--
        ----  -------#######  #######--
         -------------################---
          ------------################--
           ------------##############---
            -----------#############---
             -----------##########---
              --------#########---
               -------######----
                   ###----
```

PREDICTED TSUNAMI WAVE HEIGHT (meters)

| 0.00 | 0.25 | 0.50 | 1.00 | 19.54 |

EQ : [35.8S, 72.7W, 35], Mag=8.8
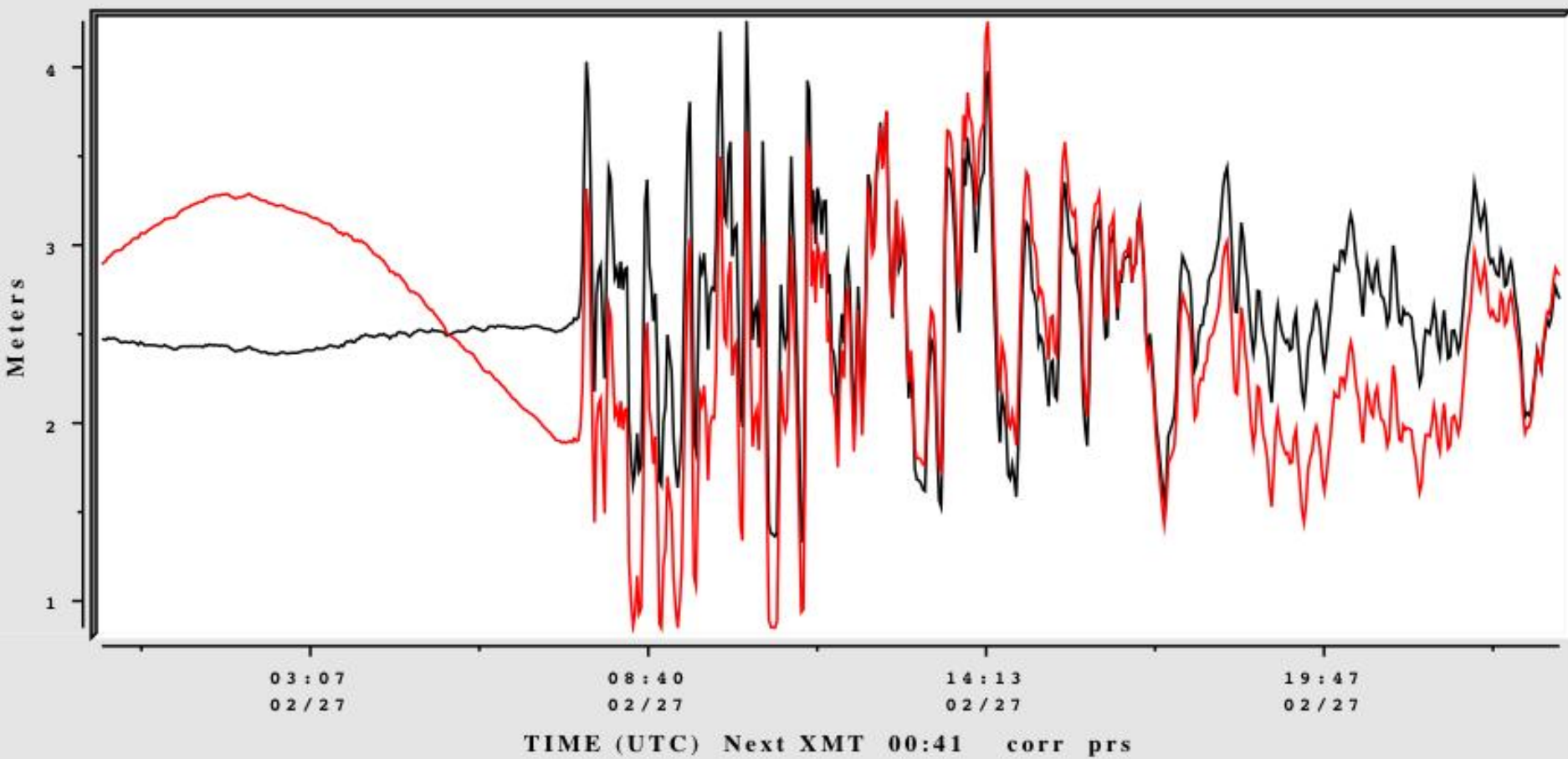
07:44:03   TSUNAMI WARNING SUPPLEMENT:

LAT: 36.1S   LON: 72.6W   DEPTH: 55 km. (11 stations) MWP 8.6 (4)

==> OBSERVATION OF TSUNAMI at   GMT.   AMPL(0-pk)   Period
--   --------   ------------------   ----------
Talcahuno, Chile   (DESTROYED)   6:53   2.3 METERS   20 MIN.

Meters

1

0

-1

00:20   03:07   05:53
02/27   02/27   02/27
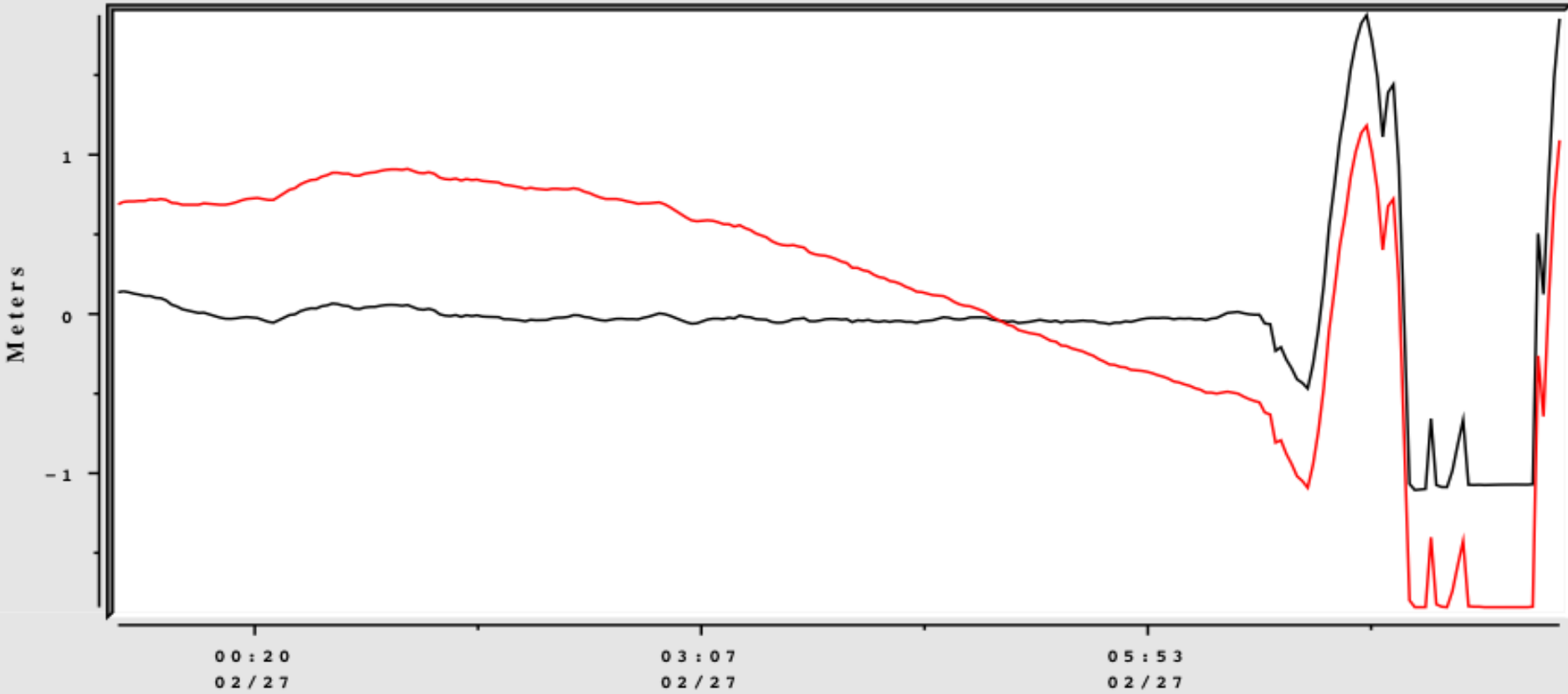
TIME (UTC) Next XMT 09:29   talc prs

LAT: 36.1S   LON: 72.6W   DEPTH: 55 km. (11 stations) MWP 8.6 (4)

==> OBSERVATION OF TSUNAMI at	GMT.	AMPL(0-pk)	Period
Valpariso, Chile	7:08	1.3 METERS	20 MIN.

TIME (UTC) Next XMT 00:41   corr prs

07:44:03   TSUNAMI WARNING SUPPLEMENT:

LAT: 36.1S   LON: 72.6W   DEPTH: 55 km. (11 stations) MWP 8.6 (4)

==> OBSERVATION OF TSUNAMI at   GMT.   AMPL(0-pk)   Period
--   -------   ----------------   ----------
Corral,   Chile   7:39   1.5 METERS   16 MIN.

TIME (UTC) Next XMT 00:41   corr prs
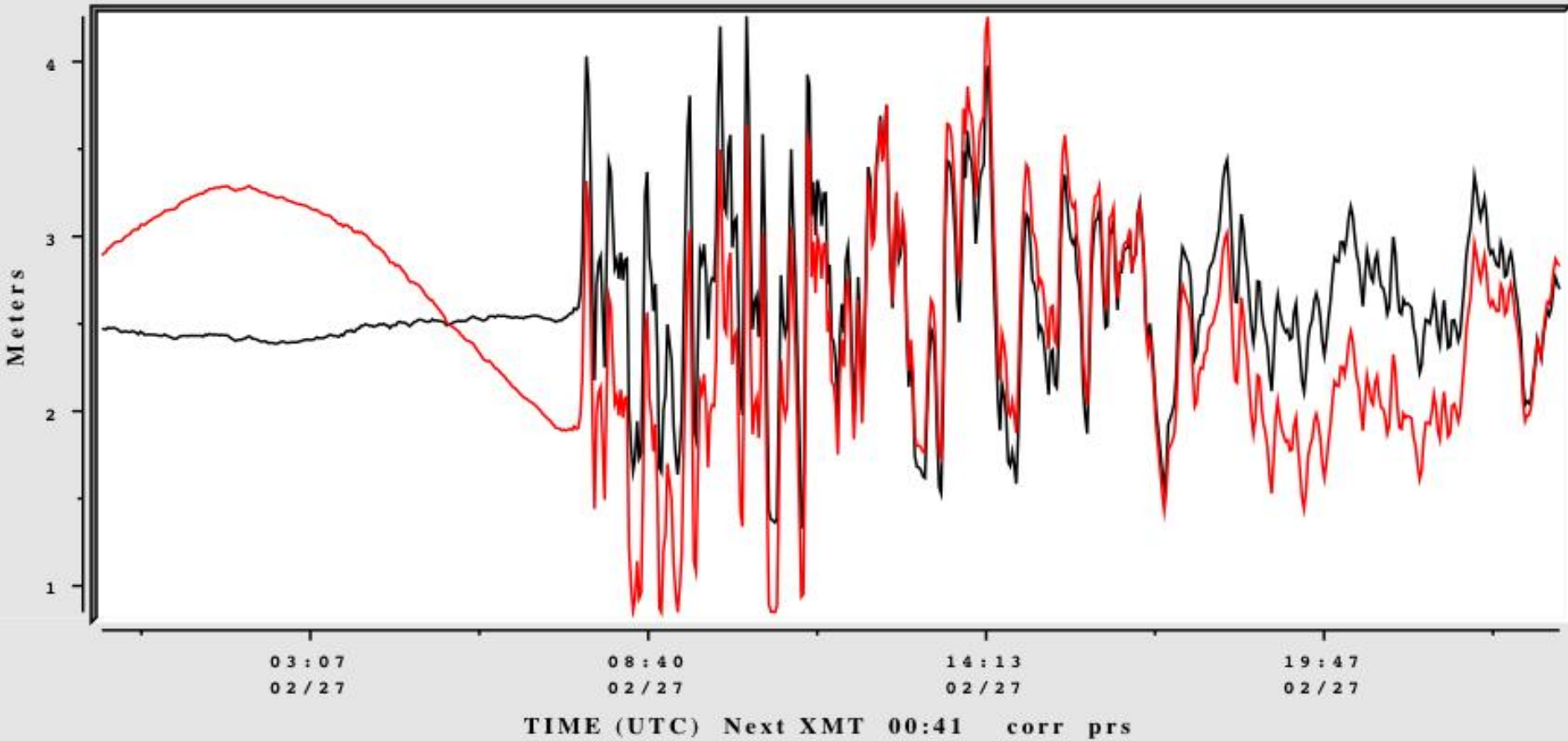
July 17, 2006, Java
First tsunami arrival, 56 min

15:19 Earthquake

~15:30 BMG announces that there is no danger of a tsunami (M6.8)

15: 36 Pacific Tsunami Warning Center issues local watch for Indonesia and Australia (M7.2)

15:46 JMA issued tsunami watch for Indian Ocean (same as PTWC message)

~16:15 Tsunami hit Pangandaran

From Jim Mori (Via Hiroo Kanamori)

QuickTime™ and a
TIFF (Uncompressed) decompressor
are needed to see this picture.

Case II: A "Tsunami" Earthquake (Kanamori, 1972), Java Mw7.7 7/17/06:

08:19z   EQ Origin Time.

08:26z   Scientists PAGED: SOUTH AMERICA (KKM, del = degrees
                                         COCO, del = degrees)

08:31z   PTWC Issues an Observatory Message:
        LAT 9.3S LONG 107.3E MWP 7.3 (6 STATIONS)

08:36z   TSUNAMI WATCH FOR INDONESIA and AUSTRALIA:
        LAT: 9.3S   LON: 107.3W   MWP 7.2

   Estimated Arrival Time of TSUNAMI at   GMT.
           --   --------
           ==> Christmas Island, Australia   08:36z
               Cilacap, Indonesia   09:00z

08:??z   Theta (logE/logMo) = -6.0 (using what Mw? Mwp?)

08:??z   Mw(Mm) ??

09:15z   Tsunami hits Pangandaran

Southern Jawa Earthquake (M_w = 7.7)
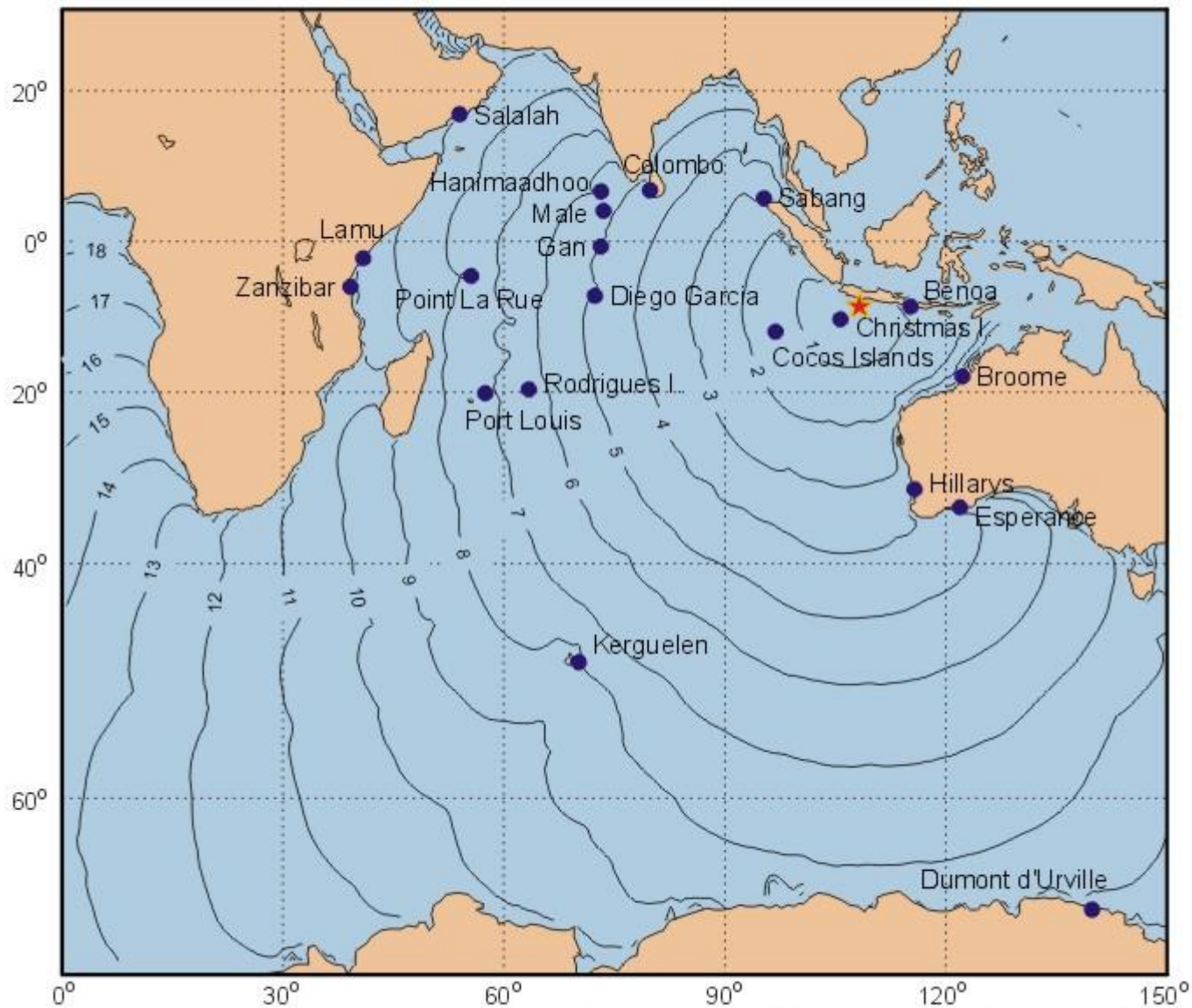
Tsunami travel time computed by Isaac Fine

PGPLOT Window 1

NEXT   EXIT

Move crosshair, left button measures, d key deletes.

——— Mwp   ——— Moment rate   ——— Signal

MWP =   7.3
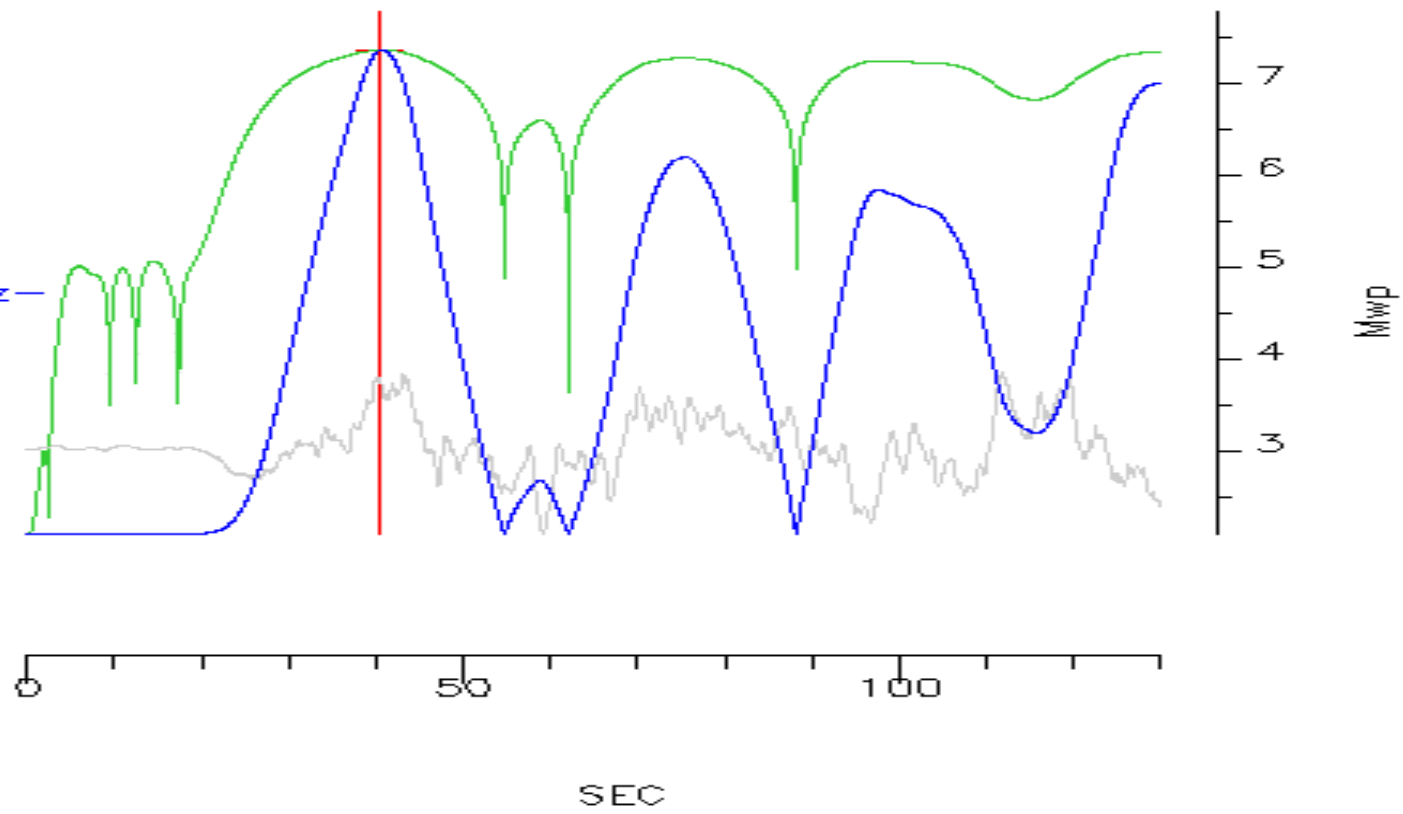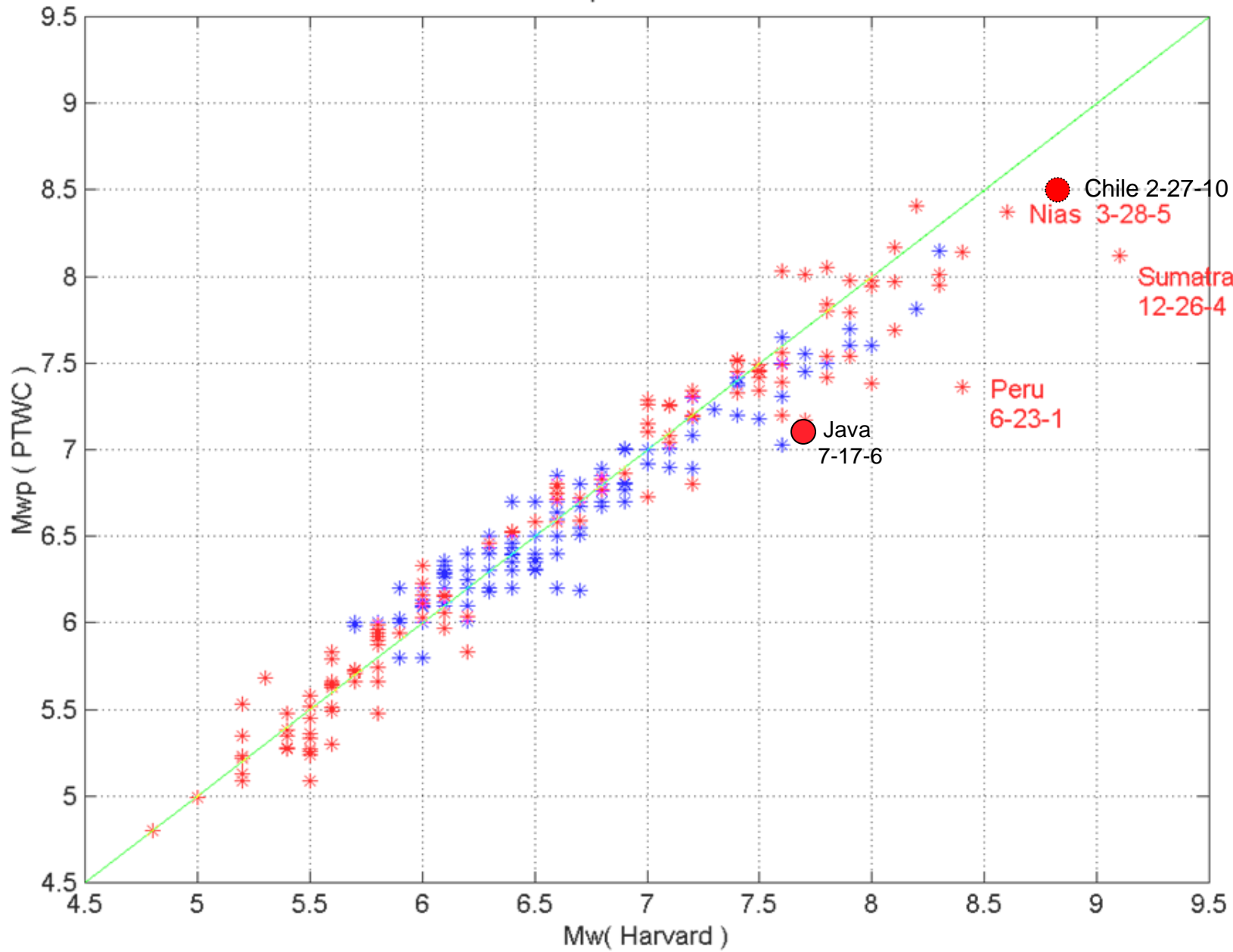
COCO bhz—

SEC

279 Earthquakes: 1992 - 2008.

Chile 2-27-10
Nias 3-28-5
Sumatra 12-26-4
Peru 6-23-1
Java 7-17-6

Mwp (PTWC)

Mw(Harvard)

Theta = Log(E/Mo)

Newman and Okal (1998) showed that for tsunami quakes, the value of Θ is usually about -6.0 or less. For a regular or non-slow earthquake, theory suggests that Theta is ~ -4.9.

"Normal" (Sumatra, 2007. Mw 7.1)
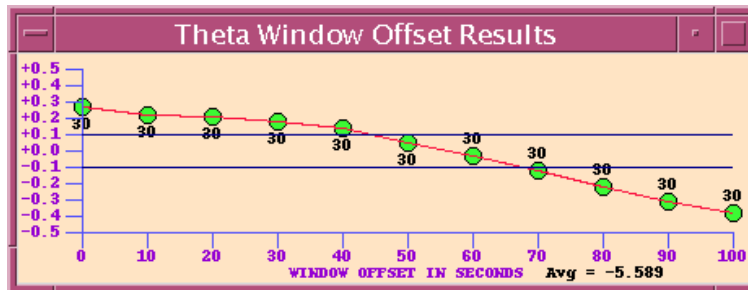
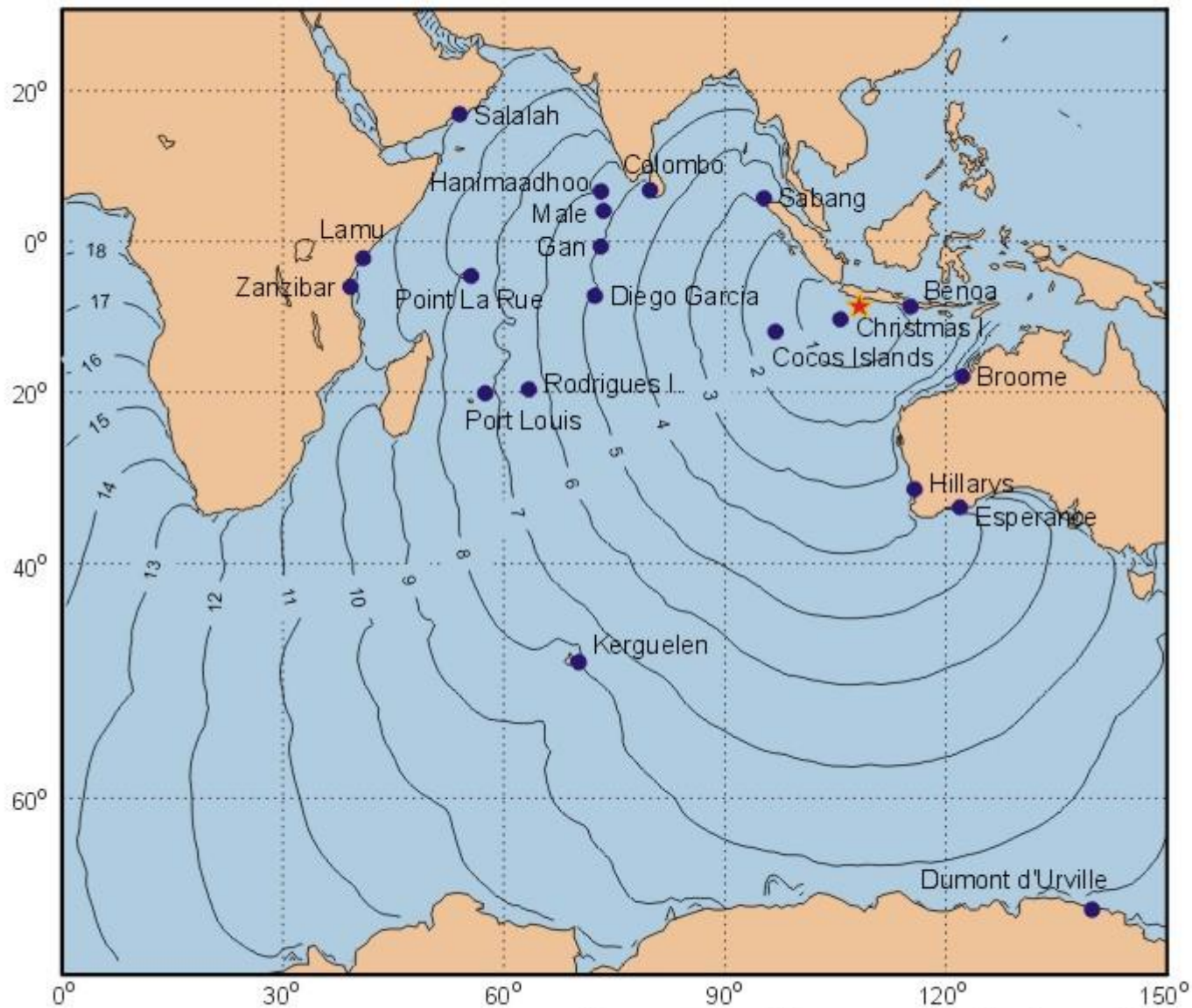Rupture duration > 20 seconds

"slow" (Java, 2006. Mw 7.7)
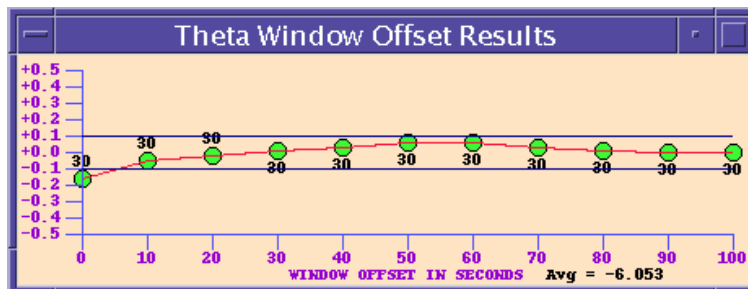
Rupture duration > 100 seconds

Kanamori and Rivera, 2008.

QuickTime™ and a
TIFF (Uncompressed) decompressor
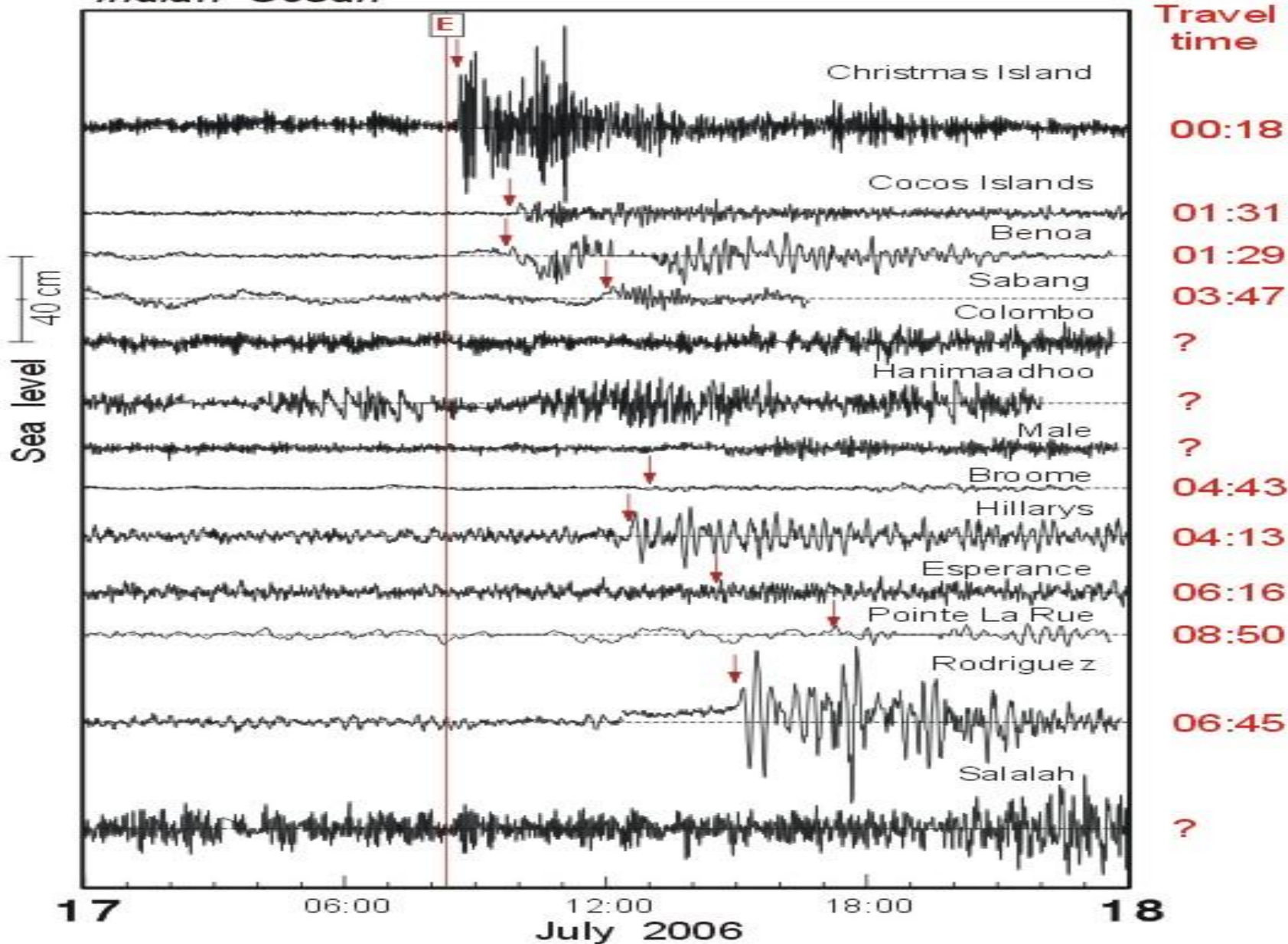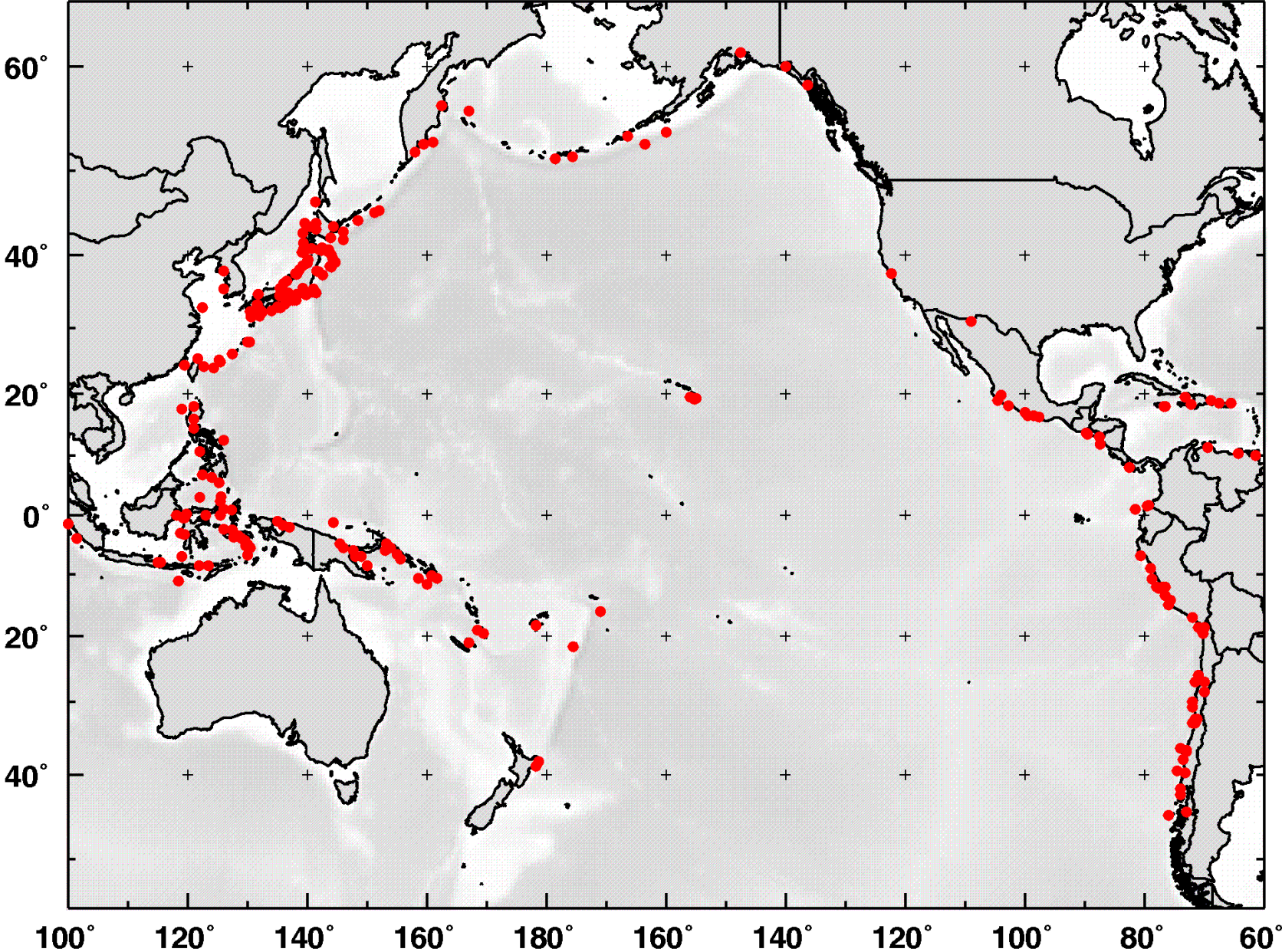are needed to see this picture.

Southern Jawa Earthquake (M_w = 7.7)

Tsunami travel time computed by Isaac Fine

Southern Jawa Earthquake (M_w = 7.7)

Indian Ocean

Travel time

Station	Travel time
Christmas Island	00:18
Cocos Islands	01:31
Benoa	01:29
Sabang	03:47
Colombo	?
Hanimaadhoo	?
Male	?
Broome	04:43
Hillarys	04:13
Esperance	06:16
Pointe La Rue	08:50
Rodriguez	06:45
Salalah	?

Sea level

40 cm

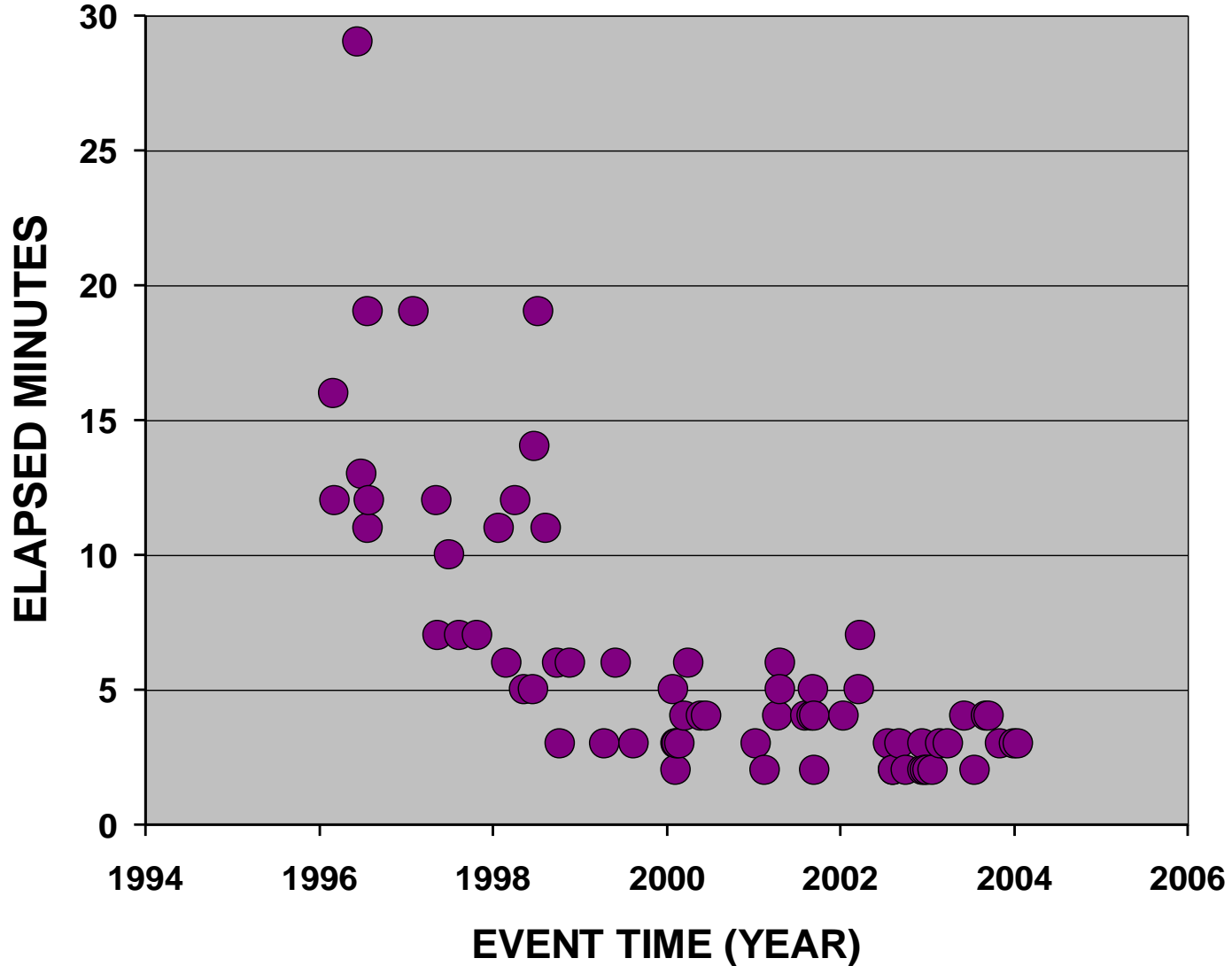17   06:00   12:00   18:00   18

July 2006

EPICENTERS OF EARTHQUAKES THAT PRODUCED TSUNAMIS CAUSING DAMAGES OR CASUALTIES

EPICENTERS OF EARTHQUAKES THAT PRODUCED TSUNAMIS
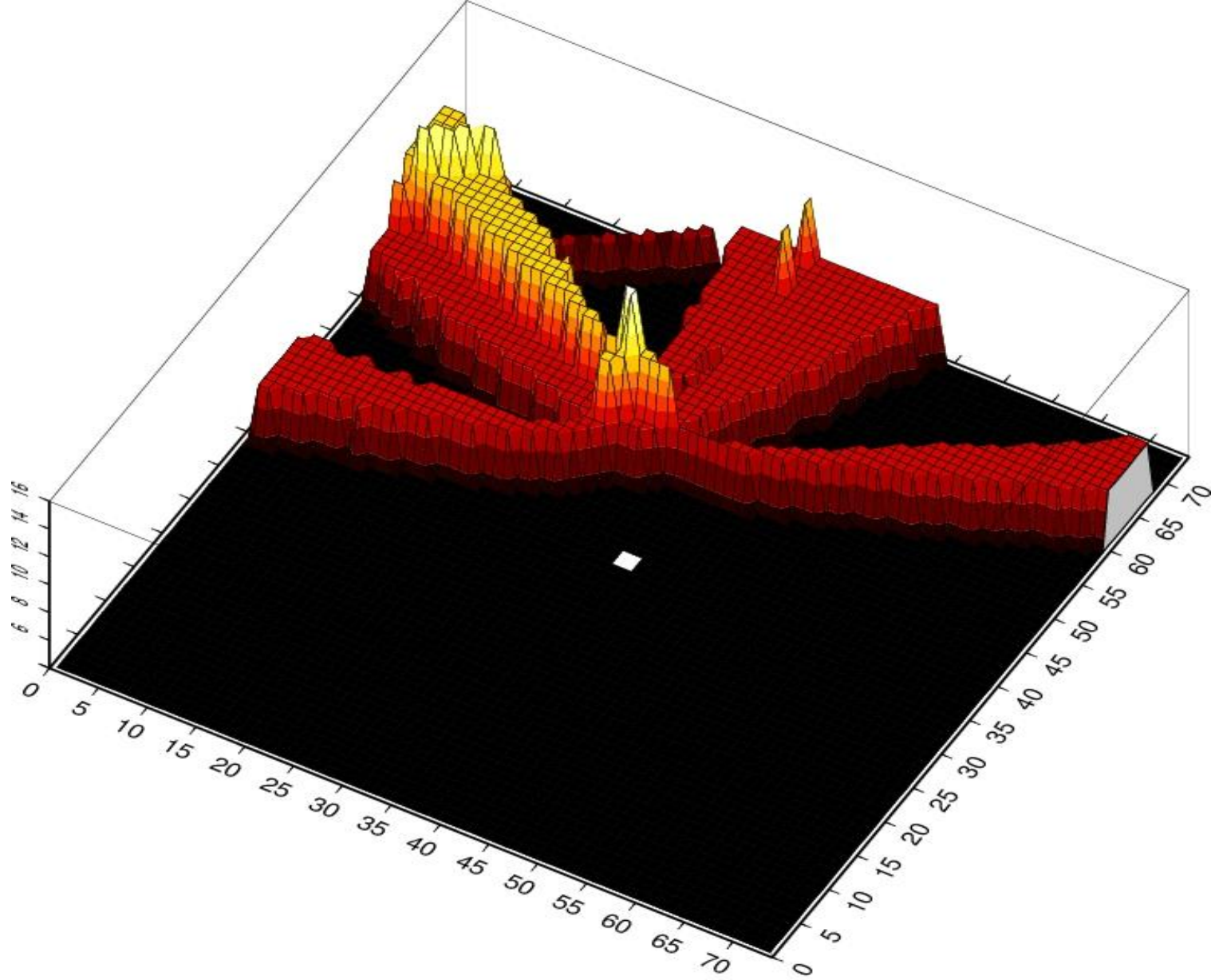CAUSING DAMAGES OR CASUALTIES MORE THAN 1000 KM AWAY
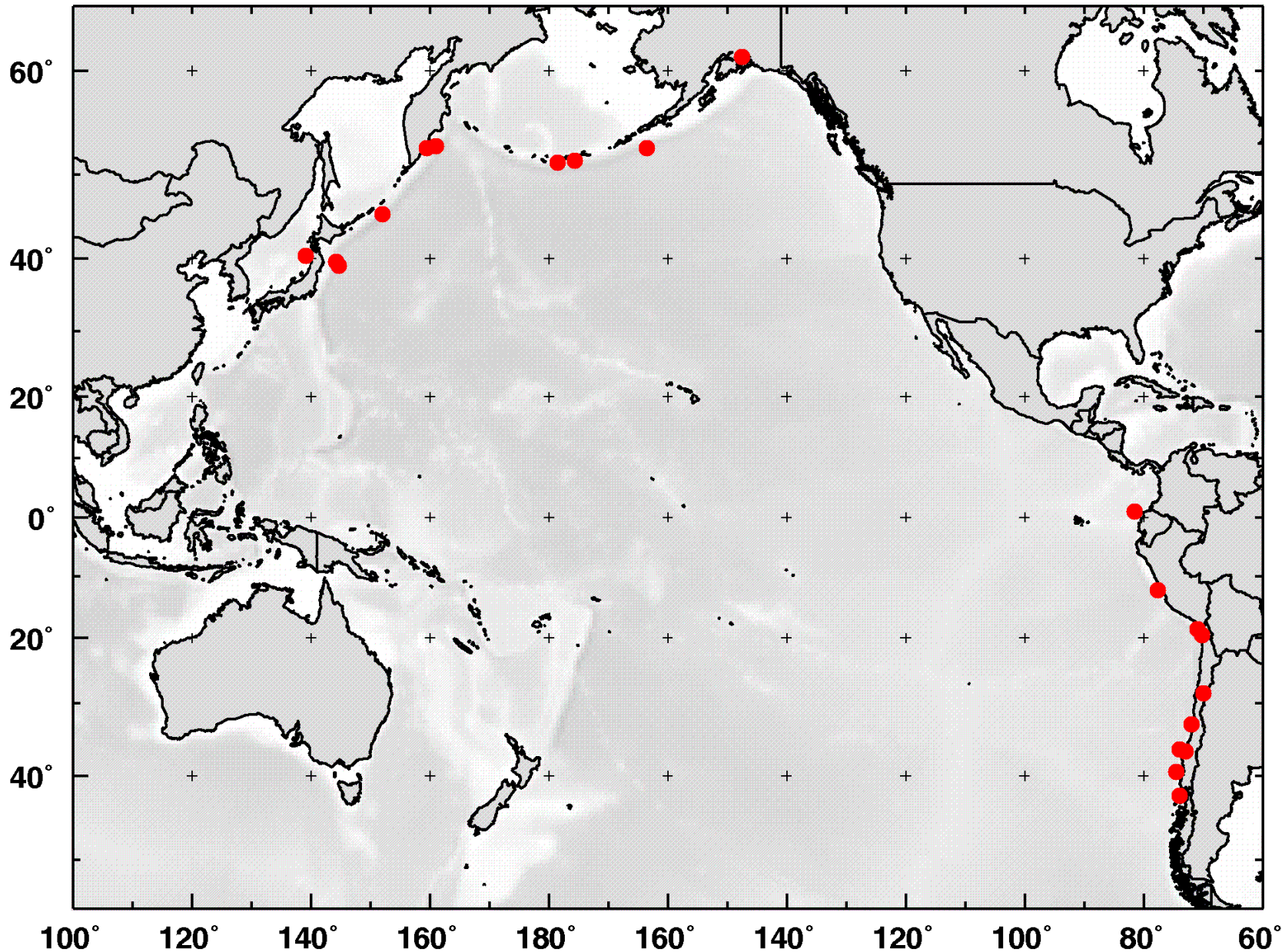
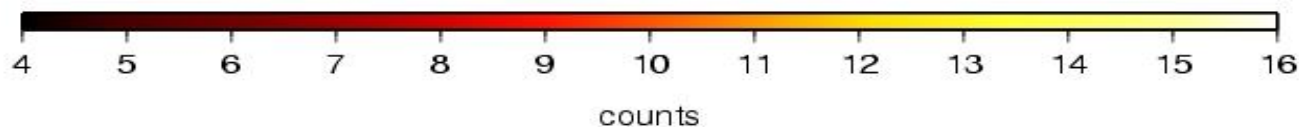# ISSUE TIME OF PTWC BULLETINS FOR HAWAII EVENTS

OT

+ 16 sec.

GMT
3D Image
by
Nathan Becker,
PTWC

counts

4 5 6 7 8 9 10 11 12 13 14 15 16

Harvard CMT.

2006/10/15 17: 7:54.2 GMT   (Centroid time = OT + 6 sec.)

Fault plane: strike=87   dip=42   slip=-151
Fault plane: strike=334   dip=71   slip=-52

Lat= 19.85 Lon=-155.81
    19.8   -155.9   PTWC Location at OT plus 31 seconds.

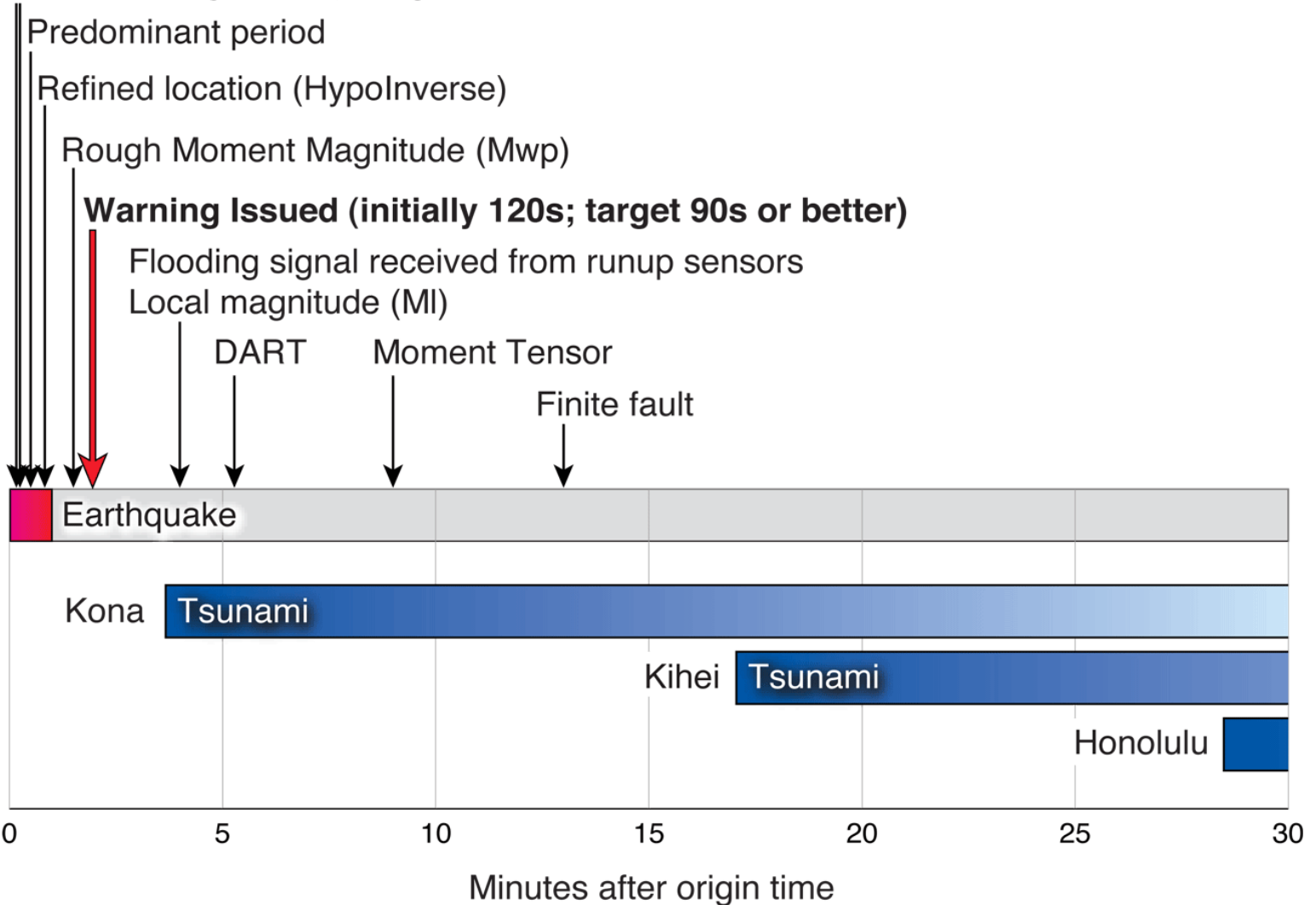Depth= 33.7
    30.0   at OT plus 31 seconds.

Mw = 6.7   mb = 6.3   Ms = 6.3   Scalar Moment = 1.31e+26
Mwp 6.5   at OT plus 2.5 minutes.

Warning timeline after upgrade

Issues/Challanges

- ***Complex Earthquakes:*** (eg. Peu 2001, smaller event followed about

   70 sec later by larger event…)

- ***Multiple Earthquakes:*** (most recent example was Sunday, July 18, 2010

   2 events about 30 min apart, Mw6.9 followed by Mw7.3.

   Lucky this time….because the second was the larger of the 2.

- ***Local Earthquakes:*** More can be done than "*if you feel the ground

   shaking…..*"

   ==> Implement Local/Regional warning systems:

   - Data quality,

   - Network density

   - Network distribution.