Earthquake source characterization for Tsunami warning

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NOAA NWS Pacific Tsunami Warning, Ewa Beach, HI, US A.
EPICENTERS OF EARTHQUAKES THAT PRODUCED TSUNAMIS CAUSING DAMAGES OR CASUALTIES
Current Practice: Magnitude thresholds.

<table>
<thead>
<tr>
<th>Mw less than 6.5</th>
<th>Earthquake Message Only</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mw 6.5 to 7.5</td>
<td>Tsunami Information Bulletin</td>
</tr>
<tr>
<td>Mw 7.6 to 7.8</td>
<td>Regional Tsunami Warning</td>
</tr>
<tr>
<td>Mw &gt; 7.8</td>
<td>Expanding Warning / Watch</td>
</tr>
<tr>
<td>Confirmed Teletsunami</td>
<td>Pacific-Wide Warning</td>
</tr>
</tbody>
</table>
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):
  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
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 \( \Theta \) is usually about -6.0 or less. For a regular or non-slow earthquake, theory suggests that Theta is \( \sim -4.9 \).
Optimized Centroid, OT + 45 min

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

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

===> OBSERVATION OF TSUNAMI at

<table>
<thead>
<tr>
<th>Location</th>
<th>GMT</th>
<th>AMPL(0-pk)</th>
<th>Period</th>
</tr>
</thead>
<tbody>
<tr>
<td>Valpariso, Chile</td>
<td>7:08</td>
<td>1.3 METERS</td>
<td>20 MIN.</td>
</tr>
</tbody>
</table>

![Graph showing tsunami observations over time]
TSUNAMI WARNING SUPPLEMENT:

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

==> OBSERVATION OF TSUNAMI at 7:39 GMT. AMPL(0-pk) 1.5 METERS Period 16 MIN.
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)
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
Move crosshair, left button measures, d key deletes.

MWP = 7.3
Move crosshair, left button measures, d key deletes.

MWP = 7.4

MBWA bhz—
Theta = \log(E/Mo)

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

“Normal” (Sumatra, 2007. Mw 7.1)

Rupture duration > 20 seconds

“slow” (Java, 2006. Mw 7.7)

Rupture duration > 100 seconds
Kanamori and Rivera, 2008.
Southern Jawa Earthquake \( (M_w = 7.7) \)

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

Indian Ocean

- Christmas Island
- Cocos Islands
- Benoa
- Sabang
- Colombo
- Hanimaadhoo
- Male
- Broome
- Hillarys
- Esperance
- Pointe La Rue
- Rodriguez
- Salalah

Travel time
- 00:18
- 01:31
- 01:29
- 03:47
- ?
- ?
- 04:43
- 04:13
- 06:16
- 08:50
- 06:45
- ?

Sea level: 40 cm

July 2006
OT

+ 16 sec.

GMT
3D Image
by
Nathan Becker,
PTWC
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

- Page: pulse width, rough location, minimum magnitude (Pmag)
- Predominant period
- Refined location (HypoInverse)
- Rough Moment Magnitude (Mwp)
- **Warning Issued (initially 120s; target 90s or better)**
  - Flooding signal received from runup sensors
  - Local magnitude (MI)
- DART
- Moment Tensor
- Finite fault

- **Earthquake**
- **Kona** Tsunami
- **Kihei** Tsunami
- **Honolulu**
- **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.