GPS and Tsunami Early Warning
Diego Melgar
Is it reasonable to expect detailed tsunami warning in the shore immediately adjacent to large earthquakes?
The Early Warning System in Japan

THE NEW TSUNAMI WARNING SYSTEM OF
THE JAPAN METEROLOGICAL AGENCY

Hidee Tatchata
Earthquake and Tsunami Observation Division
Seismological and Volcanological Department
Japan Meterological Agency

As an expansion of this theory, the approximation formula does not include only any hypocenters but also magnitude, fault depth and etc. But it is needless to say that a great number of the tsunami simulations are required to make precise forecast for all of the earthquakes and generated tsunamis around Japan like as shown in schematic Fig.4. A white circle denotes a hypocenter for the tsunami simulation.

Specifically, many tsunami simulation output files are fulfilled as in Fig.5. A white circle means a data file related to the tsunami heights for the entire coast in Japan.

Science of Tsunami Hazards, 1998
Near-Field Tsunami Warning: The M9 2011 Tohoku-oki Event

Source: NGDC
Operational Near Source Tsunami Warning Times

Warning updates at:
- OT+28mins
- OT+44mins
- OT+82mins
- OT+240mins
- OT+423mins
- OT+480mins
- OT+740mins

Ozaki, EPS, 2011
Why Were Early Magnitude Estimates so low?

- The EQ source characterization system relies strictly on seismic stations.
- No GPS or off-shore wave gauge information is used.
- Magnitude saturation.

Hoshiba et al, EPS, 2011
Seismic Sensors

Two basic kinds, weak-motion and strong-motion.
Why does Magnitude Saturate or Just how big are big earthquakes?

1989 Loma Prieta M6.9

1992 Landers M7.3

1994 Northridge M6.7

2010 Mexicali M7.2

20 miles
Just how big are big earthquakes?

100 miles

- 2004 M9.0 Sumatra
- 2010 M8.8 Chile
- 2011 M9.0 Japan
Consequences for metrology
Pesky rotations

Melgar et al., 2013, JGR

Pillet & Virieux, 2007
Earthquake Cycle Deformations Recorded with GPS

Bock et al., BSSA, 2011
A regional example, the Mw 8.3 Tokachi-oki event
Teleseismic Data Example: Tohoku-oki EQ from California

Station PIN1

- East (m)
- North (m)
- Up (m)

S-Waves
Surface waves

Seconds after 05:00 (UTC)

Unpublished
One step Further: Seismogeodesy

- GPS
- Kalman Filter

North (m)

East (m)

Up (m)

Seconds after 22:40:00 (GPS)

0.2 m

1 Hz + 100 Hz = 100 Hz

Bock et al., 2011, BSSA
Melgar et al., 2013, JGR
How do we Model the EQ Source?

\[
\min \left\{ \|W G m - W d\| + \lambda \|L m\| \right\}
\]
Slip Inversions

Mw 8.3 2003 Tokachi-oki

Crowell et al., 2012, GRL
Beachballs!

Computing the moment tensor discriminates between types of earthquakes

2003 Mw 8.3 Tokachi-oki

Melgar et al., 2012, GJI
It is Feasible to Compute Rapid Source Models
Can this be Used to Rapidly Estimate a Tsunami Model?
Can this be Used to Rapidly Estimate a Tsunami Model?
The State of Tsunami Modeling

COULWAVE
Patrick Lynett (USC)
Phillip Liu (Cornell)
The State of Tsunami Modeling

Clawpack – Geoclaw
Randal LeVeque et al. (UW)
Validation of the GeoClaw Model

NTHMP MMS Tsunami Inundation Model Validation Workshop

GeoClaw Tsunami Modeling Group, University of Washington.
Frank I. González, Randall J. LeVeque, Paul Chamberlain, Bryant Hirai, Jonathan Varkovitzky and David L. George (USGS)

Figure 3.6.1: Basic geometry and coordinate system. Solid lines represent approximate basin and wavemaker vertical surfaces. Circles along walls and dashed lines represent rolls of wave absorbing material. Note the gaps of approximately 0.38 m between each end of the wavemaker and the adjacent wall. Gauge positions are given in Figure 3.6.2.
How do we Judge Whether a Simulation is Good?

- Good (or at least decent) fits to wave gauges.
- Good prediction of inundation amplitude (survey points).
- Tohoku-oki has a wealth of these types of data.
How do we Judge Whether a Simulation is Good?

3 types of wave gauges
- Ocean bottom pressure (OB)
- GPS buoys (BY)
- Tide gauges (TI)

Melgar & Bock, in review, JGR
How do we Judge Whether a Simulation is Good?

2000+ inundation amplitude survey points (Mori et al, 2012)
How do we Judge Whether a Simulation is Good?

2000+ inundation amplitude survey points (Mori et al, 2012)
Simulation Results with Land Observations

Melgar & Bock, in review, JGR
Land-based Forecast Results

Inundated 956/2250 survey points

Melgar & Bock, in review, JGR

Inundated 956/2250 survey points
Joint Inversion Results

Melgar & Bock, in review, JGR
Joint Inversion Results

Melgar & Bock, in review, JGR
Predicted Tsunami Intensities

Melgar & Bock, in review, JGR
Predicted Tsunami Intensities

<table>
<thead>
<tr>
<th>Time after OT</th>
<th>Wave RMS (m)</th>
<th>Survey Red. (%)</th>
<th>Var.</th>
<th># of Survey Points Inundated</th>
</tr>
</thead>
<tbody>
<tr>
<td>157 s</td>
<td>1.42</td>
<td>85</td>
<td></td>
<td>956/2250</td>
</tr>
<tr>
<td>10 min</td>
<td>0.26</td>
<td>79</td>
<td>60</td>
<td>905/2250</td>
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<tr>
<td>20 min</td>
<td>0.24</td>
<td>79</td>
<td>60</td>
<td>1913/2250</td>
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<td>30 min</td>
<td>0.55</td>
<td>73</td>
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<td>1538/2250</td>
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<td>40 min</td>
<td>0.87</td>
<td>65</td>
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<tr>
<td>50 min</td>
<td>0.85</td>
<td>78</td>
<td>60</td>
<td>1611/2250</td>
</tr>
</tbody>
</table>
On the Importance of Offshore Data

Land-based inversion

Joint inversion

\( t=0.25 \text{ mins} \)
Conclusions

- It is reasonable to expect more complete forecasts of tsunami propagation.
- Land based forecasts are fast but limited.
- Ocean-based data illuminates tsunami complexity.
- Need to relax some physical assumptions.
- Improvements needed in modeling/inversion techniques.
- What do you do with this information?