JMA's response to
Off the Pacific Coast of Tohoku Earthquake
and planned Improvements of Tsunami Warning

Osamu KAMIGAIČHI
Director of Administration Division,
Department of Seismology & Volcanology
Japan Meteorological Agency
Technical Principle of Tsunami Warning

1) Sea surface deformation due to an earthquake fault dislocation under the sea floor

2) Sea wave propagation = TSUNAMI

Tsunami (~10m/sec : near coast)

Tsunami (~200m/sec : far off coast)

Seismic Wave (~5000 m/sec) => **25-500X faster than tsunami**

**Prompt Warning essential to ensure max time for evacuation.**

=> Take advantage of propagation velocity difference between seismic and tsunami waves (25-500x faster).

=> Tsunami ampl forecast based on EQ analysis.

=> Tsunami Warning

Warning should be updated as more seismic & sea level data are available to improved accuracy.

About 40% of near-Japan tsunamigenic earthquakes have caused tsunami that struck coast within 20 minutes.
Tsunami Warning Dissemination

**Establishment of Tsunami Simulation Database**

Conduct Tsunami simulation for various epicenters, depths and magnitudes.

Store the Results in a database.

**Quickly Estimated Hypocenter & Magnitude**

<table>
<thead>
<tr>
<th>Forecast Grade</th>
<th>Levels of Estimated Tsunami Amplitude</th>
</tr>
</thead>
<tbody>
<tr>
<td>Warning</td>
<td>Major Tsunami 3 m, 4 m, 6 m, 8 m, 10 m or greater</td>
</tr>
<tr>
<td></td>
<td>Tsunami 1 m, 2 m</td>
</tr>
<tr>
<td>Advisory</td>
<td>0.5 m</td>
</tr>
</tbody>
</table>

$\Rightarrow$ *Pre-computed Tsunami Database allows 1st warning forecast in 3 minutes*

66 coastal blocks in total (basically, one for a prefecture)
Magnitude estimation: 11th of March and its problem

Calculated Mj (JMA magnitude) = 7.9 in 3 minutes to disseminate 1st tsunami warning by using strong motion data.

Failed to calculate Mw (Moment magnitude) automatically in 15 minutes due to waveform data over-scale for most of domestic broadband seismometers, and consequently, could NOT update warning.

Collected unsaturated oversea broadband waveform data, and calculated Mw = 8.8 in 54 minutes. => That was too late for warning update based on seismic data.

JMA evaluated Mj=7.9 as reasonable because the value was close to that of anticipated “Off the coast of Miyagi Eq.” (7.5 to 8.0), and disseminated the first warning in 3 minutes.

JMA adopts two magnitude calculation methods, Mj and Mw. They are complementary to each other.

Mj : Quick!, but prone to underestimate for gigantic and/or tsunami earthquakes. Mw : Accurate even for gigantic and/or tsunami earthquakes, but a longer time is necessary for calculation.
11 March 2011: Sea Level Monitoring Stations (all collected at JMA in realtime)

- Tide Gauge(172)
  - JMA(76)
  - JCG(20)
  - Port & Harbor Bureau(55)
  - GSI(14)
  - Cabinet Office(1)
  - Municipality, Private sector(6)

- Offshore Tsunami meter
  - GPS type(PHB)(15)
  - Pressure sensor(12)
    - JMA(6)
    - ERI(2)
    - JAMSTEC(4)

As of 2011.Oct.11
11 March 2011
Tsunami Warning Updates
(Aomori to Fukushima Pref.)

JMA updated Tsunami Warning
NOT by EQ magnitude estimation,
but by observed tsunami ampl at
GPS tsunami meters / tide gauges.

3/11 14:46 Eq. Occurrence
1 3/11 14:49 (+3 min) Tsunami Warning Dissemination
Iwate 3m, Miyagi 6m, Fukushima 3m (Major Tsunami),
Pacific coast of Aomori 1m (Tsunami)

2 3/11 15:14 (+28 min) Tsunami Warning Update
Iwate 6m, Miyagi over10m, Fukushima 6m,
Pacific coast of Aomori 3m (Major Tsunami)

3 3/11 15:30 (+30 min) Tsunami Warning Update
Iwate to Boso-peninsula over10m,
Pacific coast of Aomori 8m (Major Tsunami)

---

- Monitored in realtime
- Recovered data by on-site inspection
- Forecast Tsunami amplitude

Mutsu-Sekinehama
Aomori Pref.
Hachinohe
Miyako
Iwate Pref.
Kamaishi (JCG)
GPS Off-Kamaishi (PHB)
Ohfunato
Ishinomaki-Ayukawa
Miyagi Pref.
Sohma
Fukushima Pref.
Iwaki-Onahama

(JST) 14:49 Mj7.9
15:40 Mw8.8
15:43 Mw8.8 reported from PTWC
11 March 2011: Tsunami Warning Problems

---

Tsunami Warning Dissemination:

The first Warning in 3 minutes
Updated warning in 28 minutes

Based on Mj=7.9

- Iwate: 3m
- Miyagi: 6m
- Fukushima: 3m

Based on offshore GPS
Tsunami meter observation

- Iwate: 6m
- Miyagi: over 10m
- Fukushima: 6m

---

Major Problems

Sub.-1 Underestimated EQ magnitude used in 1st tsunami warning in 3 minutes.

Sub.-2 Announced Tsunami Ampl Forecast “3m” (underestimate) led to delays in evacuation.

Sub.-3 No update EQ magn examination (Mw) due to over-scale of domestic BB seismometers, and insufficient warning update technology (For offshore tsunami-meter, Pressure Sensor data that is farther offshore than GPS-type could not be used for update).

Sub.-4 Announced Tsunami Ampl Observation “initial wave ampl 0.2m” gave false perception led to delays/interruptions in evacuation.

---

Investigated measures for Tsunami Warning improvement, in cooperation with intelligent persons, municipalities, broadcasting companies and other relevant organizations.
Principle policy to investigate how to improve Tsunami Warning

1. Early Warning and Update
   • Disseminate the first warning as soon as possible. (as before)
   • Update the warning with improved accuracy by using as many available seismic & sea level data as possible. (as before)
   • Consider a possibility that updated warnings can not reach to residents due to power or communication link failure. → **The first warning is important!**

2. Safe Side Warning
   • Transmit the worst possible case within an uncertainty of tsunami amplitude estimate due to an uncertainty of initial tsunami source estimate.

   • Enable to disseminate proper tsunami warning even to very rare gigantic earthquakes, while making public relations activities on the importance of “self-protection” (run to a high place when you feel a strong shaking (or unusually long) near a coast without confirming JMA’s warning!).

   • At the same time, improve the accuracy of warning for frequent M<8 earthquake to get reliance of residents on the warning.
General flow of planned improved Tsunami Warning Dissemination

1. Quick hypocenter and magnitude (Mj) calculation
   - Possibility of magnitude underestimation
     - No
     - Yes
     - First warning based on Mj
     - Estimated tsunami amplitude in number
     - Mw and CMT calculation
     - Offshore tsunami data analysis
     - Updated warning
     - Estimated tsunami amplitude in number

Example of assumed maximum magnitude

- Off Nemuro-Kushiro (8.3)
- Around the focal area of Off the Pacific Coast of Tohoku Eq. e.g. Tsunami Eq. along the trench (8.6-9.0)
  Outer-rise Eq. (8.3)
- 500 years interval Eq. (8.6)
- Triple of Tokai-Tonankai-Nankai Eq.(9.0)

Sub.-1

Sub.-2

Sub.-3

- Installation of broadband strong motion meters and offshore tsunami meters,
- Analysis method improvement
Example of monitoring method to recognize earthquake magnitude underestimation

2011 Off the Pacific Coast of Tohoku Eq. (M9.0)

2003 Off the coast of Tokachi Eq. (M8.0)

**Rough estimation of magnitude by referring to areal extent of strong motion.**

Dislocation distribution by Yoshida et al. (2011). Contour interval is 5m.

Dislocation distribution by Yoshida (2005). Contour interval is 1m.

Strong motion area extent for M8.0 Eq.

---

by MRI
Deployment of broadband strongmotion meter & offshore tsunami meter

**Domestic Broadband Strong motion meter**
- Present seismic network
- Tsunami Warning (in 3 minutes)
- Examine the adequacy of the first warning by using broadband strongmotion data
- Tsunami Warning Update (in 15 minutes)

**Offshore Tsunami meter**
- 3 buoy-type pressure sensors off the Tohoku coast
- Intensify offshore observation network in cooperation with relevant organizations
- Pressure sensors(Cable-type)(JMA,ERI,JAMSTEC)
- GPS tsunami meter(PHB)
- DONET(Cable-type)(JAMSTEC)

**Ensure** Tsunami Warning update in 15 minutes based on accurate estimation of magnitude even for gigantic earthquake.

**Ensure prompt update of Tsunami Warning with improved accuracy based on offshore sea level data.**
Examination of tsunami warning/advisory criteria and levels of estimated tsunami amplitude

**Points to be considered**

1) Technical issue
   - Scatter of tsunami amplitude (estimated & observed) around mean value (higher, the larger)

2) Difference in disaster severity

3) Feasibility of multiple levels of evacuation

- Reduce the number of levels from 8 to 5.

**Tsunami Amplitude**

- **Warning (Major Tsunami)**
  - 10m
  - Abrupt increase of total destruction/wash-out rate of wooden houses (corresponds to inundation depth 2m)

- **Warning (tsunami)**
  - 5m
  - Lower limit for inundation

- **Advisory**
  - 3m
  - 1m
  - 20cm

**Relation between construction damage and inundation depth**

- **Inundation depth**
  - 0% to 100%
  - Ratio (%)

- **Flow-out**
  - Total destruction

- Significant difference between above and below 2m
Improvements in Warning & Information Statement

- **Warning/Advisory criteria and levels of estimated tsunami amplitude**
  - Present
  - Improved
  - In case of possible magnitude underestimation

<table>
<thead>
<tr>
<th>Forecast Grade</th>
<th>Levels of Estimated Tsunami Amplitude</th>
</tr>
</thead>
<tbody>
<tr>
<td>Warning</td>
<td>Major Tsunami: 3 m, 4 m, 6 m, 8 m, 10 m or greater</td>
</tr>
<tr>
<td></td>
<td>Tsunami: 1 m, 2 m</td>
</tr>
<tr>
<td>Advisory</td>
<td>0.5 m</td>
</tr>
</tbody>
</table>

- **Tsunami observation information**
  - Report the **arrival time** and **initial polarity** of tsunami, because the fact that “tsunami has arrived” is important to urge residents to evacuate.
  - Report the **amplitude** of tsunami **only after** the amplitude grows larger than the criteria amplitude of one grade below the presently valid warning/advisory. (i.e. 1m when the Major Tsunami is valid)
  - While the amplitude is smaller than the threshold above, expression is just “now observing”, not to give residents an underestimating threat.

- **Information on the offshore tsunami observation**
  - Establish a new information on the offshore tsunami observation (independently issued from coastal observation information) to emphasize its importance.
Scenario of Tsunami Warning for a huge Eq. anticipated along the Nankai-trough after the improvement

**Earthquake Early Warning**

**Judgement on gigantic Eq.**

**Detailed Analysis**

- GPS-type
- Pressure-type
- coastal tsunami data watch → **Warning**

Update if necessary

**Mw and CMT Calc.**

**Warning Update if necessary**

** Improvements**

---

**Tsunami Warning for M9.0**

**Cf. Tsunami Warning for M8.0**

---

Judge the possibility of magnitude underestimation, and disseminate the first warning based on the assumed maximum magnitude of the area (9.0).
Other important issues

1. Closer link between Tsunami Warning and Hazard Map

2. Secure warning/information transmission route to residents at risk → cooperation with telecommunication companies and municipalities

3. Education on Tsunami Disaster Mitigation
   • “Self-Protection” is the basis!
   • Physical properties of Tsunami
   • Strikes repeatedly, initial wave is not always the biggest, etc.
   • Philosophy of the “Tsunami Warning”
     o Its meaning (How severe the disaster will be)
     o Not just a forecast, but transmits the worst possible case within an uncertainty
     o (Show reasons why an estimation has an uncertainty)
     o Updated with improved accuracy
The First Warning
- Disseminate in 3 minutes.
- If possibility of magnitude (Mj) underestimation recognized, 1st warning disseminated based on assumed maximum magnitude of area, and estimated tsunami amplitude is mentioned just qualitatively as an emergency message.

Warning Update
- To secure the update of 1st warning in 15 minutes based on Mw (& CMT), broadband strong motion meters are deployed.
- For earlier and more accurate update of warning, offshore tsunami meters are deployed in cooperation with relevant organizations.
- Develop/Improve seismic and sea-level data analysis method for warning update.

Warning/Information statements
- Reduce number of levels of estimated tsunami amplitude from 8 to 5, considering scatter of tsunami amplitude, and for closer linkage of warning to Hazard Map.
- Observed tsunami amplitude is NOT reported in number while amplitude small, not to give underestimating threat to residents.

Disaster Mitigation Education
- Education / Public relations activity very important for more effective disaster mitigation.