2011 Tohoku Earthquake and Tsunami: Application of Remote Sensing

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Contents

• Basics of remote sensing
• The 2011 Tohoku earthquake & tsunami
  ➢ Aerial surveys and damage mapping
  ➢ Satellites employed for damage mapping
  ➢ Tsunami effects detected by SAR images
  ➢ Detection of crustal movements by SAR images
Platforms of Remote Sensing

- **Satellite**: near-polar orbit, geo-stationary, Space Shuttle
- **Airborne platform**: airplane, helicopter, UAV
- **Ground-based**: balloon, tall building, crane, ladder

### Space-borne

- Satellite
  - Optical Sensor/SAR
  - 700-900km
- Space Shuttle
  - 185-575km

### Airborne

- Aerial Photography
  - 1.2-3.5km
- Aerial Television
  - 0.3km
- Airborne SAR
  - 10-12km

### Ground-based

- Balloon, tall building, crane, ladder

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Wavelength of Electromagnetic Waves and Satellite Sensors

- **Reflection**
  - UV
  - Infrared
  - Microwave

- **Radiation**
  - Visible
  - Mid-IR
  - Thermal

- **Active**
  - γ-ray, x-ray
  - NIR
  - Thermal

**Wavelength (μm)**

- LANDSAT/MSS: 0.45-0.90
- LANDSAT/TM: 0.45-1.1
- TERRA/ASTER: 0.45-1.1

**Channels**

- B1: 0.45-0.52
- B2: 0.52-0.60
- B3: 0.63-0.69
- B4: 0.75-0.80
- B5: 1.25-2.5
- B6: 2.14-2.25
- B7: 1.6-1.7
- B8: 2.08-2.35
- B9: 3.7-4.0
- B10: 10.4-12.5
Near-Infrared (NIR) Band to Monitor Vegetation

**QuickBird**

- True color
- False color
- 

\[
\text{NDVI} = \frac{\text{NIR} - R}{\text{NIR} + R}
\]

Chiba Marine Stadium

Manmade Lawn

(M, G, B) = (3, 2, 1) (R, G, B) = (4, 3, 2)

Makuhari Seaside Park

Natural Lawn

SAR: Synthetic Aperture Radar

**Active Microwave Sensor**

Emitting microwave signals, then receiving their reflection from objects on earth’s surface

All Weather, Day and Nighttime

ERS/SAR

- Wave Length: 5.7cm (C-band VV)
- Resolution: 30m
- Recurrent Period: 35 days
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Aerial survey of the tsunami affected area by GSI

**GSI:** Geospatial Information Authority of Japan

Acquisition dates:
- March 12, 13, 19, 27
- April 1, 5

Employing all the major air survey companies in Japan

http://saigai.gsi.go.jp/h23taiheiyo-zort/map/index.html
Aerial photos on GSI web site

http://saigai.gsi.go.jp/h23taiheiyo-ok/photo/photo_dj/index.html

Tsunami Inundation map by GSI and field photos
Digital affected area map produced from visual inspection of GSI’s aerial photos by Association of Japanese Geographers

http://danso.env.nagoya-u.ac.jp/20110311/map/index_e.html

Tsunami run-up and building damage map by Tohoku Univ. (TRM : Tohoku Renovation Mapping) •JPEG, building by building

http://www.tsunami.civil.tohoku.ac.jp/tohoku2011/mapping_damage.htm
Oblique Aerial Photos
Sendai Airport and surrounding area
March 13, 2011
Asia Air Survey Co. Ltd

Kesennuma, Miyagi Pref.
March 12, 2011
Asia Air Survey Co. Ltd
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Satellites images of the 2011 Tohoku earthquake

Optical, Medium Resolution

• ALOS AVNIR-2 (10m)
• Terra ASTER (15m)
• Landsat 7 (30m)

Optical, High Resolution

• FORMOSAT-2 (2.0m)
• THEOS (2.0m)
• RapidEye (2.5m)
• WorldView-1,2 (0.5m)
• QuickBird (0.6m)
• Ikonos (1.0m)
• GeoEye-1 (0.5m)

SAR

• ALOS PALSAR (L-band, 6.25m)
• Radarsat 1, 2 (C-band, 8m)
• TerraSAR-X (X-band, 3m)
• COSMO-SkyMed (X-band, 3m)
Tsunami Flooded area observed by FORMOSAT-2 (Taiwan) on 2011/3/12 under the Sentinel Asia

Sentinel Asia is a voluntary basis initiative led by the Asia-Pacific Regional Space Agency Forum to support disaster management activity in the region.

https://sentinel.tksc.jaxa.jp/sentinel2/topControl.action

http://www.eorc.jaxa.jp/ALOS/img_up/jdis_formosat2_tohokueq_110312.htm

International Charter: Space and Major Disasters

JAPAN Earthquake/Tsunami
Iwaki city, Fukushima

Description:
A huge earthquake of M7.3 occurred at 05:46 UTC on March 11, 2011. The epicenter was located 150 km off the east coast of the Tohoku district, Japan. This earthquake and tsunami caused tremendous damages. Many missing and rescue are reported in Iwaki and Kama districts.

Data Sources:
- RapidEye (0.5 m): March 12, 2011
  © RapidEye AG, 2011
- IKONOS (1 m): March 12, 2011
  © GeoEye

Map Information:
- Map projection: geographic
- Datum: WGS84

Map produced March 16, 2011 by JAXA

http://www.disasterscharter.org/web/charter/activation_details?p_r_p_1415474252_assetId=ACT-359
Flooding area observed by ALOS/AVNIR-2 on 2011/3/14

2011/3/14 2011/2/27

Rikuzentakada
Kesennuma
Minami-sanriku

http://www.eorc.jaxa.jp/ALOS/img_up/jdis_opt_tohokueq_110314.htm

Damage mapping of the affected area by optical satellites

RESTEC
ALOS/AVNIR2 (JAXA)
THEOS (GISTDA, Thailand)

http://www.restec.or.jp/?p=11728
http://alosemergency.restec.or.jp/
Aerial survey was banned over Fukushima Daiichi NPP.

March 12, 2011

March 14, 2011 11:04 am, three minutes after #3 reactor caused hydrogen explosion.

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TerraSAR-X intensity data

Pre-event

UTC: 2010/10/20, 20:43
Japan ST: 2010/10/21, 5:43
Incidence angle: 37.32°

Post-event

UTC: 2011/03/12, 20:43
Japan ST: 2011/03/13, 5:43
Incidence angle: 37.30°

Frame
Image extent
Mode: StripMap
Polarization: HH
Data correction: EEC
Color composite of pre- and post-event SAR intensity images

- Convert DN to $\sigma^0$
- Change pixel size from 1.25m to 3.75m
- Applying the Enhanced Lee filter with 3x3 pixel window

- Higher backscatter for Pre-event
- Flooded areas etc.
- Higher backscatter for post-event
- Debris etc.

**Histograms of pre- and post images**

R: 2011/03/13  G&B: 2010/10/21

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**Natori city**

- Debris carried by tsunami
- Boat

R: 2011/03/13  G&B: 2010/10/21

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2011/03/13  aerial photo by GSI
Difference of Backscattering Coefficients

1. Image matching
2. Speckle noise filtering (Lee Filter)
3. Calculating following indices:

- **Difference** of backscattering coefficients \( d \) (after – before)

\[
d[dB] = \bar{I}_a - \bar{I}_b
\]

- \( d \) values become negative in tsunami flooded areas.
Extracted flooded area in Ishinomaki

Threshold: $\mu \pm 3\sigma$  Tsunami inundation map by AJG

- flooded
- debris

Difficult to extract flooded zone in dense urban areas and sea-side forest

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Crustal movement by GPS measurement of GSI

Geospatial Information Authority of Japan (GSI)

Max: 540cm
Max: -107cm

GPS ground control stations

Yamoto station
Dh=4.07m  Dv=-0.48m

Natori station
Dh=3.18m  Dv=-0.25m

http://www.gsi.go.jp/chibankansi/chikakukansi_tohoku.html
Determination of movement of a building

Area-based matching

\[ R(a, b) = \frac{\sum_{i=0}^{M-1} \sum_{j=0}^{N-1} I_{(a,b)}(i, j) - \bar{T} \{ T(i, j) - \bar{T} \}^1}{\sqrt{\sum_{i=0}^{M-1} \sum_{j=0}^{N-1} I_{(a,b)}(i, j) - \bar{T} \{ T(i, j) - \bar{T} \}^2} \]

\[ \bar{T} = \frac{1}{M \times N} \sum_{i=0}^{M-1} \sum_{j=0}^{N-1} T(i, j) \]

Matrix of correlation

Result of detection (Yamoto in Higashi-Matsushima)

The horizontal movement

<table>
<thead>
<tr>
<th>Length (m)</th>
<th>0</th>
<th>0.5</th>
<th>1</th>
<th>1.5</th>
<th>2</th>
<th>2.5</th>
<th>3</th>
<th>3.5</th>
<th>4</th>
<th>4.5</th>
<th>5</th>
<th>5.5</th>
<th>6</th>
<th>6.5</th>
<th>7</th>
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</thead>
<tbody>
<tr>
<td>Mean</td>
<td>3.65 m</td>
<td>60</td>
<td>40</td>
<td>20</td>
<td>10</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Std</td>
<td>0.47 m</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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</table>

The angle \( \gamma \) of movement

<table>
<thead>
<tr>
<th>Angle (degree)</th>
<th>90</th>
<th>180</th>
<th>270</th>
<th>360</th>
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<tbody>
<tr>
<td>Mean</td>
<td>17.20°</td>
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Movement in easting

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<th>Length (m)</th>
<th>0</th>
<th>0.5</th>
<th>1</th>
<th>1.5</th>
<th>2</th>
<th>2.5</th>
<th>3</th>
<th>3.5</th>
<th>4</th>
<th>4.5</th>
<th>5</th>
<th>5.5</th>
<th>6</th>
<th>6.5</th>
<th>7</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>3.47 m</td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
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<td></td>
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</tbody>
</table>

Movement in southing

<table>
<thead>
<tr>
<th>Length (m)</th>
<th>0</th>
<th>0.5</th>
<th>1</th>
<th>1.5</th>
<th>2</th>
<th>2.5</th>
<th>3</th>
<th>3.5</th>
<th>4</th>
<th>4.5</th>
<th>5</th>
<th>5.5</th>
<th>6</th>
<th>6.5</th>
<th>7</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>1.07 m</td>
<td></td>
<td></td>
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</table>

R: post-event  G&B: pre-event

Easting: 3.75 m, southing 1.00m
Result of detection (Natori)

The horizontal movement

- Mean: 2.99 m
- Std: 0.85 m

The angle of movement

- Mean: 11.01°

Movement in easting

- Mean: 2.92 m

Movement in southing

- Mean: 0.57 m

233 buildings

Verification

Yamoto

- Heading angle: 10.03°
- Incident angle: 37.32°

GPS data

- 3.53 m to east
- 1.12 m to south

Natori

- GPS data

- 2.91 m to east
- 0.64 m to south

\[ \mu_{area} = 3.47 \text{ m}, 1.07 \text{ m} \]

\[ \mu_{area} = 2.95 \text{ m}, 0.57 \text{ m} \]
Summary

Various remote sensing technologies employed after the 2011 Tohoku earthquake were introduced.

✓ Aerial surveys for damage mapping
✓ Satellite images for damage mapping
✓ Tsunami effects detected by SAR images
✓ Detection of crustal movements from SAR

We should prepare for future earthquake events with remote sensing technologies.

Thank you very much!
Muchas Gracias!
ご清聴ありがとうございました.