Utilization of satellite imagery for monitoring disaster damage and environmental change

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   (2) Detection of soil liquefaction in Tokyo bayside areas

1. Satellite Remote Sensing

* Satellite remote sensing is frequently used for monitoring disaster damage or environmental change in wide areas from repeat pass orbits.

* Categories of satellite sensors
  - Optical sensors
  - Radar (Microwave sensors)

(1) Optical sensors

* The most representative is the series of Landsat satellites that have been observing the Earth’s surface since 1972.

* Currently most advanced civilian satellites have a ground resolution as fine as 30"-60 cm (e.g., WorldView-3).

(2) Radar

* Radar is very sensitive to surface changes, such as building damage, ground deformation, and inundation which optical sensors sometimes fail to detect.

* If bad weather conditions prevent the use of optical sensors, radar can serve as an alternative means of observation.

Radar satellites

<table>
<thead>
<tr>
<th>Satellite</th>
<th>County</th>
<th>Year</th>
<th>Band</th>
<th>Frequency [GHz]</th>
<th>Wavelength [mm]</th>
<th>Polarization</th>
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<tbody>
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<td>ALOS-2</td>
<td>Japan</td>
<td>2014</td>
<td>L-band</td>
<td>1.268</td>
<td>24</td>
<td>Single/Dual</td>
</tr>
<tr>
<td>Sentinel-1C</td>
<td>Europe</td>
<td>2013</td>
<td>C-band</td>
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<td>5.6</td>
<td>Single/Dual</td>
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<tr>
<td>Sentinel-1A</td>
<td>Germany</td>
<td>2014</td>
<td>X-band</td>
<td>9.6</td>
<td>3.1</td>
<td>Single/Dual</td>
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</table>
**2. Monitoring environmental change by optical sensors**

Mangroves are unique and important ecosystems.

- Fauna only in inter-tidal zones between the seawater and coastal land
- Support a wide variety of coastal species (shells, crabs, shrimps, fish, etc.)
- Rapidly disappearing due to industrial, agricultural and aquacultural development

Up-to-date information is needed on the extent and distribution of mangroves.

![Yamuna-Hiruyi (Rhizophora stylosa) in Irinomoku island, Japan](image)

**1. Mapping mangrove forests using Landsat imagery and digital elevation model**

**Background**

- Mangrove forests mitigated the impacts of the 2004 Indian Ocean tsunami.
- Reports from India, Sri Lanka, Indonesia and Malaysia show that communities behind mangrove forests suffered less destruction.

Nypa fruticans at Talala, Sri Lanka show damage caused by the tsunami, whereas interior mangrove zones and land areas were largely unaffected.

(F. Dalduh-Guillas et al., Current Biology, vol.15, 2005.)

![World Atlas of Mangroves by FAO](image)

**Currently available information on the extent and distribution of mangroves**

- Vegetation maps composed by each concerned country
- Mangrove distribution maps published by international organizations.

> These maps are not frequently revised and do not necessarily show the current status.

**Research objectives**

Develop a method for extracting mangrove forests using Landsat imagery

- Advantages of using satellite imagery
  - Routine observations
  - Ability to collect data over the places inaccessible from the ground

> Produce a map showing the current status of mangrove distribution in Asian Pacific regions

**Method for mangrove mapping**

Two unique features of mangrove forests are used for extracting their spatial distribution

> Spectral characteristic of mangrove forests in the short-wave-infrared (SWIR) bands (wavelength: 1.5 – 2.5 μm)
  - Band 5 & 7 of Landsat/ETM+ imagery

> Topographic condition of mangrove habitats
  - Digital elevation model (10m grid)
1. Spectral characteristic of mangrove forests

Mangrove forests have lower reflectance than non-mangrove vegetation in the SWIR bands (band 5 & 7 of Landsat/ETM+).

[Image of Landsat/ETM+ image of Ishimote Island, Japan, on 19 November 2003]

2. Difference of spectral characteristics between mangroves and non-mangroves

Mangrove forests along the estuary of the Nakama River (Rb6, Gb5, Bb7)

[Spectral profiles of sample areas]

Seasonal changes of spectral characteristics

- The values of bands 5 & 7 of 13 Landsat images (TM and ETM+) at the sample areas along the estuary of the Nakama River shown in the right figure.

(a) Band 5

(b) Band 7

[Graphs showing seasonal changes of spectral characteristics]

- Why do mangrove forests show lower reflected radiance than ordinary non-mangrove vegetation in the SWIR bands?

- Mangrove leaves have lower reflectance than non-mangrove leaves.

- Satellite image observe mangrove forests as a mixture of mangrove tree-crowns and mud or water at the forest floor.

[Image of Rhizophora stylosa seen from above]

3. Topographic condition of mangrove habitats

Mangroves form forests only in the intertidal zones between the mean and the highest sea levels.

[Diagram showing topographic condition of mangrove habitats]

Red color indicates vegetation with low SWIR radiance

(H. Kayama & T. Miyagi, Coral and Mangroves, Iwami, 2002.)
A digital elevation model can be used to clip coastal zones between the mean and the highest sea levels.
- Tidal amplitude: about 1 m at most around Irinomote Island
- Standard error of the DEM: 2.2 m at flatland
- Potential mangrove habitats: 3 m < altitude < 5 m

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**Results**

Extracted mangrove forests (red parts)

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**Comparison between satellite classifications and ground truth data produced by Ryuku University**

Nakama River

Furumi District

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**Summary**

- A method has been developed for extracting mangrove forests using a spectral characteristic of mangroves and a topographic requirement of mangrove habitats.
- The method was applied for extracting mangrove forests in Irinomote Island, Okinawa, Japan. The results agreed well with ground truth data.
- The method was also applied to observe the changes of mangrove distribution from 1990 to 2010 in southern Vietnam.
3. Monitoring disaster damage by radar

(1) Detection of tsunami damage in Ishinomaki city

(2) Detection of soil liquefaction in Tokyo bayside areas

Horizontal displacement caused by the 2011 East Japan earthquake

[Spatial Information Authority of Japan]

Study site & data

Ishinomaki City (blue line) and the coverage of PALSAR images (black line)

Damage survey map:
Red: Totally destroyed
Blue: Severely destroyed
Green: Partially damaged

Damage was mainly caused by tsunami just after the earthquake.

SAR images

- Repeat-pass PALSAR images:
  5 images (5 pre-seismic and 3 post-seismic)
- Coherence images:
  3 images (2 pre-seismic and 1 co-seismic)
  Same time interval and approximately the same perpendicular baseline
  7 x 3 block averaging and a 3 x 3 moving window

<table>
<thead>
<tr>
<th>Observation dates</th>
<th>Observation dates</th>
<th>Perpendicular baseline (m)</th>
<th>Time interval (day)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10/7/5</td>
<td>10/11/20</td>
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<td>138</td>
</tr>
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<td>2010/7/5</td>
<td>2010/11/20</td>
<td>1093</td>
<td>138</td>
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<tr>
<td>Co-seismic</td>
<td>2010/11/20</td>
<td>1208</td>
<td>138</td>
</tr>
</tbody>
</table>

Method

(1) Calculate the difference of coherence between pre-seismic and pre/co-seismic repeat pass pairs.

\[ \Delta \rho_{\text{pre-co}} = \rho_{\text{pre}} - \rho_{\text{co}} \]

\[ \Delta \rho_{\text{pre}} = \rho_{\text{pre}} - \rho_{\text{pre}} \]

The \( \Delta \rho_{\text{pre-co}} \) image is used to detect changed pixels with a threshold value determined from the \( \Delta \rho_{\text{pre}} \) image.
1. Determine a threshold using the cumulative histogram of $\delta p_{\text{pre-warp}}$ with a prescribed false alarm rate (FAR).

2. Apply the threshold to the $\delta p_{\text{pre-warp}}$ image.

### Numerical investigation of detection rate

* Probability density function of coherence (K. Tzou, et al., 1999)

$$p(p) = \begin{cases} L_1/(L_1-1) & 0 < p < 1 \vspace{0.5em} \\
1 & p = 1 \vspace{0.5em} \\
0 & p = 0 \end{cases}$$

* PDF of coherence change

$$p(\delta p | V_0, V_1) = \begin{cases} \sum_{\delta p} p(p | V_0, V_1) \delta p | p & \delta p > 0 \\
\sum_{\delta p} p(p | V_0, V_1) \delta p | p & \delta p < 0 \end{cases}$$

### Results

* Examples of $p_0(V_0, V_1)$, and detection rate as a function of the initial coherence $V_0$, when the after-the-event coherence $V_1$ is assumed to be 0.

* Detection rate is high enough (>0.8), when $V_0=0.6$ (common value in urban areas) and $L=16$.

* Damage areas detected with FAR=5% (left), and damage survey map overlaid on the detected result (right).

* Detection rate (left) and distribution of $\delta p$ (right) in each damage class.

* Comparison with power-based indices (power correlation & power ratio (db))

* Histograms of difference of power correlation (left) and absolute value of power ratio in dB (right) for each damage class.

* Damage-detection performance of the power-based indices is poorer than that of coherence.
Summary

- Difference of coherence reflects the degree of damage and can be used to detect damaged areas by choosing an appropriate threshold value with a prescribed false alarm rate.
- Numerical examination showed the detection rate of the proposed method is high enough (>90%) when the pre-seismic coherence has a value common in urban areas and a sufficient number of independent looks (>16) is taken.
- Power-based indices (power correlation & power ratio [dB]) showed poorer performance than coherence for the detection of damaged areas, which means changing the SAR observation angle in disaster emergency may lead to unsatisfactory results of damage detection.

(2) Detection of soil liquefaction in Tokyo bayside areas

I. Detection of soil liquefaction areas
II. Detection of land displacement due to liquefaction

I. Detection of soil liquefaction areas

- Soil liquefaction in Urayasu city
- Air photo interpretation in_RINGO city
- Liquefaction areas in the Kantou region due to the Tohoku earthquake on March 11, 2011 (KANTO and KITA) * Based on field investigation and on-site reports * Air photos are also used to extend the coverage of the observation area.

Data

- Footprint of ALOS-PALSAR images covering the Kantou region (Path 403, Frame 770)
- 3 coherence images (2 pre-seismic and 1 co-seismic) with 46-day time interval were generated from 5 ALOS-PALSAR images

Method for detecting liquefaction areas

Coherence change from pre- to co-seismic InSAR data

- Pre-seismic
- Co-seismic
- Mar 11, 2011
- Pre-seismic coherence
- Co-seismic coherence
- Coherence change

Threshold determination

- Threshold was determined using a statistical distribution of coherence change in unchanged urban areas
  - T=0.30 at 1% significance level
- Statistical distribution of coherence change in urban areas obtained from 15 pairs of pre-seismic interferograms
II. Detection of land displacement due to liquefaction

- Co-seismic ALOS-PALSAR HH images
  (Path:405, Frame:700)

<table>
<thead>
<tr>
<th>Observation date</th>
<th>perpendicular baseline</th>
<th>Time interval</th>
</tr>
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<tbody>
<tr>
<td>SLC1 2011/2/19</td>
<td>396 m</td>
<td>46 days</td>
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<tr>
<td>SLC2 2011/4/6</td>
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- Location data from 24 GPS stations run by GSI:
  16 stations within the image
  8 stations around the image

*This map shows the area around Tokyo Bay at the time of the Great East Japan Earthquake.*

Results

Whole image

Tokyo bayside area

Tone river basin

Detected liquefaction areas (upper) and reference survey data by MRIT and JOS (lower)

![Results](image)

Method

PALSAR SLC images

SLC1

SLC2

Interferogram referenced to DEM

GPS data

Displacement in
radial line of sight

Unwrapped phase

Displacement component due to earthquake

\( \phi_{\text{earthquake}} \)

Orbital correction to remove orbital error

Displacement due to liquefaction

\( \phi_{\text{liquefaction}} \)

Interferogram and unwrapped phase

- Components of unwrapped phase

\[ \phi = \phi_{\text{earthquake}} + \phi_{\text{topography}} + \phi_{\text{atmosphere}} + \epsilon \]

\[ \epsilon = \phi_{\text{topography}} + \phi_{\text{atmosphere}} \]

Phase of the interferogram referenced to SRTM DEM

Unwrapped phase

Removal of \( \phi_{\text{earthquake}} \) and orbital correction

1. Removal of \( \phi_{\text{earthquake}} \):

\[ \phi = \phi_{\text{topography}} + \phi_{\text{atmosphere}} + \epsilon \]

2. Orbital correction:

\[ \phi_{\text{orbital}} = \phi_{\text{topography}} + \phi_{\text{atmosphere}} + \epsilon \]

\( \phi_{\text{atmosphere}} \) component has a large spatial scale. This component could be removed using tropospheric delay measured at GPS stations. In a small area, it could be neglected, though it may cause some bias error.

Displacement component due to the earthquake

\( \phi_{\text{earthquake}} \)

Displacements in radial line of sight at GPS stations

\( \phi_{\text{earthquake}} \) generated by spline interpolation

![Method](image)
Results

- Resultant \( \phi \) was rewritten with \( \Delta h = \phi \Delta h / \Delta a \) (\( \Delta a = 1 \) cm).
- The locations of distinctive fringes correspond to the liquefaction areas shown in the lower figure.

Summary

I. Detection of soil liquefaction areas
1. Soil liquefaction areas in the Kanto region caused by the Tohoku Earthquake on March 11, 2011 were detected using InSAR coherence.
2. The detected liquefaction areas agreed well with the field survey data by the MHT and JGS.

II. Detection of land displacement due to liquefaction
1. Land displacement due to liquefaction was detected in Tokyo Bay area by combined use of a co-seismic interferogram and GPS station data.
2. Characteristic fringe patterns showing land displacement were retrieved in the liquefaction areas.