EVALUATION OF TSUNAMI DISASTER BY THE 2011 OFF THE PACIFIC COAST OF TOHOKU EARTHQUAKE IN JAPAN BY USING TIME SERIES SATELLITE IMAGES WITH MULTI RESOLUTION

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ABSTRACT

Extensive damage was caused by a large earthquake and the resulting tidal wave/Tsunami that occurred in the northeast region of Japan on March 11, 2011. Every municipal district, town, and village in the coastal region where Tsunami struck received catastrophic damage. It is essential to be able to understand the extent of Tsunami strike across a wide-ranging area in this type of natural disaster, as rapidly and in as more detail as possible. In addition, it is necessary to monitor the recovery situation of the land cover in the stricken area for a long term after it is struck continuously by using remote sensing. In this study, the change of the stricken area for a long term was investigated from the several kinds of high and middle resolution satellite images by ALOS, LANDSAT, THEOS, Worldview-2 and Quickbird in the time series. The flood generated by the Tsunami over the large area in Sendai coast plains in the southern part of the stricken area and each situation changes in the recovery were evaluated. As a result, it was widely shown that the Tsunami had reached direction of the inland up to about 5km in the coastal plain. The shore protection of the coast collapsed remarkably, and the situation in which an urban artificial structure disappeared almost was investigated in the ria coast region. Additionally, after about from three to four months pass from the disaster, it was considered to cause the delay in the restoration.

KEY WORD: earthquake, tsunami, disaster, multi-resolution, time series

INTRODUCTION

Extensive damage occurred as a consequence of the earthquake in a large area of East Japan on March 11, 2011, which generated a huge tidal wave. Every municipal district town and village in the coastal regions of Iwate Prefecture, Miyagi Prefecture, and Fukushima Prefecture received catastrophic damage due to this tidal wave. It is essential to be able to understand the extent of Tsunami strike across a wide-ranging area in this type of natural disaster, as rapidly and in as more detail as possible. In addition, it is necessary to monitor the recovery situation of the land cover in the stricken area for a long term after it is struck continuously by using remote sensing. The ALOS satellite that Japan operated had excellent performance in emergency observation. The tsunami strike situation on the coastal region of East Japan was widely investigated using multi spectral data of 10m×10m spatial resolution provided by the ALOS/AVNIR-2. The observations of many other satellites were also introduced by a research consortium in which the author participated (Scientific research working group for high resolution satellite remote sensing /RSSJ 2011). The entire image of the strike area and its relationship to known geographical features were examined (Takano et al. 2011, Hashiba et al. 2011). Moreover, the observation for this disaster progresses continuously by other various satellites. There is a possibility of effectively appreciable of the revival situation from the satellite observation.

PURPOSE

In this study, the change of the stricken area for a long term was investigated from the several kinds of high and middle resolution satellite images by Worldview-2, Quickbird, ALOS, Landsat, and THEOS in the time series. The inundation generated by the Tsunami over the large area in Sendai coast plains in the southern part of the stricken area...
and each situation change in the recovery was evaluated. Moreover, the change of detailed land cover and after the disaster had occurred of catastrophic in the ria coast region in Rikuzen-Takada City etc. was investigated by using middle and high resolution satellite images. Thus, the change characteristics of the struck situation were able to be evaluated from the aspect of the multi resolution in time series.

METHOD

Research Area
The wide range in Iwate Prefecture, Miyagi Prefecture, and Fukushima Prefecture that had received the disaster was investigated (Figure 1). The struck situation of the coastal plain (Sendai plains) that stretched from the southern part of Miyagi Prefecture to the Fukushima Prefecture northern part was chiefly investigated here. Additionally, the small-scale coastal plain scattered in the coast region in Fukushima Prefecture was investigated in the time series. The struck situation of a small-scale town in the Yamada-Town, Kamaishi City, etc. located in the ria coast located in the northern part of the stricken area was investigated. Moreover, Rikuzen-Takada City where damage was especially large was surveyed in detail a high-resolution evaluation satellite.

Satellite Images
In this study, several kinds of satellite data that had various spatial resolutions was used overall to investigate a time series change in the stricken area. Data and the observation day, etc. used are indicated in Table -1. The ALOS image data that had been observed on March 14 following the earthquake was used from among the image data that had been observed with the AVNIR-2 sensor. An urgent observation command had been executed by JAXA for continuous monitoring of the disaster beginning on March 13. The image data for the area prior to the strike, as observed with this same sensor, on the 23rd and 27th of February, was used for comparison. The Landsat TM image, the THEOS (Thailand Earth Observation System) image, the Worldview-2 image, and the Quickbird image were used to investigate a time series change since it was struck this time. The image data to which the whole area of the stricken area had been observed on April 21 and June 8 was used by the TM sensor installed in the Landsat-5 satellite. Landsat satellite image data was offered from USGS. The image data to which the Fukushima Prefecture coast region had been observed on July 11 was used with the multispectral sensor installed in the THEOS satellite. Moreover, a high-resolution satellite was used to investigate the struck situation of Rikuzen-Takada City located in the ria coast in detail. The multispectral image data that had been observed high-resolution satellite Worldview-2 on March 20 after February 23 before the disaster and the disaster was used. Moreover, the multispectral image data that had been observed the Quickbird satellite on June 19 was used.

Investigation by Image Interpretation
A positional match was made of the image before and after the strike. In this study, the struck situation was interpreted in case of the strike in the ria coastal area and case of the strike on the coastal plain. The struck situation of the whole area of the stricken area was interpreted by the ALOS image. Chiefly, the struck situation such as floods of the change in the coastline by the tsunami in the coastal plain that stretched to the southern part of the stricken area region and the plains part was clarified. Moreover, the struck situation such as floods of a collapse of the harbor equipment and a small-scale village of the rias coast region in the northern part was clarified. Additionally, it interpreted by using the Landsat satellite and the THEOS satellite image to investigate the change in a time series land cover after it was struck. A time series change in the land cover in the coastal plain scattered in the surrounding of the Sendai airport and Fukushima Prefecture was interpreted. The struck and revival situation since it was struck of Rikuzen-Takada City located in the ria coast part was interpreted high resolution satellite the Worldview-2 and the Quickbird.

Extraction of the Inundated Area by the Tsunami
The whole inundated area by tsunami was extracted by using the ALOS/AVNIR-2 image data with classifying the area of floodwater from the maximum likelihood classification technique. All BAND images of 1-4 bands of the observed object area were used and the results were brought together into one on March 14, immediately after the strike. Training data for classification that showed the floodwater area judged the level of color and brightness on the surface of floodwater from the image interpretation, set five categories in this study.
Field Investigation

A field investigation was executed in the target region on May 3-5, 2011. The examination method included confirmation by direct observation and photography of the strike effects in the target region. The local situation was confirmed from this detailed investigation and validated the actual strike situation with the satellite images and an analytical result of the inundated area.

Figure 1. Research area in this study (Satellite Image: Included©JAXA, Distribution RESTEC).
The Disaster Situation in the Coastal Plain by Image Interpretation

In a wide range of the southern part in Miyagi Prefecture region, many of the coastal plains were flooded by tidal wave/Tsunami, and the area that has changed to a dark brown is shown in the image. Figure 2-a shows the mouth of the Natori River. In this area, the disappearance of the storm surge protection forest due to the tsunami and the disappearance of the shore protection structures are remarkable. Figure 2-b shows the situation of the floodwaters around the Sendai airport. Yamamoto Town, Kodaka City in the southern part was extensively inundated and the shore protection has been violently damaged (Figure 2-c, 2-d). The local photographs after about two months of the tsunami generation were shown in Figure 3. The situation of massive damage in the coastal plain was able to be confirmed as shown in figures.

Extraction of the Inundation in the Coastal Plain

The area of floodwater has been extracted from the satellite image data from March 14 by the maximum likelihood classification method (Figure 4). It was overlapped with the satellite image of area observed on February 23, before the strike. The coastal plain that stretched to the inside southern region was widely inundated, and a remarkably extended area of floodwater was observed in this range. The tsunami reached about 5km inland from the coastline based on the extraction result and the image interpretation in the region around Miyagino-District in Sendai City and the area of around Sendai air

The Disaster Situation in Ria-Coast Region by Image Interpretation

The disaster prevention facilities against storm surges, consisting of an embankment and a protection forest, were violently destroyed along the coastline in Yamada Town (Figure 5-a), Kamaishi City (Figure 5-b), Rikuzen-Takada City (Figure 5-c). These protective features disappeared, and the land cover was remarkably changed. A lot of damage was confirmed in the bays in the ria coastal areas like this. And, the protection forests were planted to protect against storm surges before disaster. A lot of forests and the shore protections against the tsunami were almost destroyed at the coastal line surrounding of Kitakami River (Figure 5-d). The interpretation results of the struck situation in Rikuzen-Takada City by the images observed high-resolution satellite Worldview-2 were shown in Figure 5-e and 5-f. The forest belt and the shore protection facilities, etc. in the coast were admitted to disappear almost as shown in Pont B in Figure 5-f. The artificial structures such as residential quarters were admitted to collapse almost inland area. The division road in the dwelling zone can hardly confirm the prototype with the deposit etc. (Area A in Figure 5-e and f). The situation in which a lot of effluents judged to be toles and pebbles of a collapsing artificial structure piled up was interpreted near the hill ground in the inland. Figure 6 shows a local photograph after about two months of the tsunami generation. The situations of damage in the ria coast region were able to be confirmed as shown in figure.

<table>
<thead>
<tr>
<th>Satellite</th>
<th>Used sensor</th>
<th>Used wave length</th>
<th>Spatial resolution</th>
<th>Used Observation date</th>
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<tr>
<td>ALOS</td>
<td>AVNIR-2</td>
<td>Visible(1,2,3band), Near infra-red(4band)</td>
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<td>TM</td>
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<td>THEOS</td>
<td>Multispectral</td>
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<td>Worldview-2</td>
<td>Multispectral</td>
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<td>2m×2m</td>
<td>2011.2.23, 2011.3.20</td>
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<td>Quickbird</td>
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<td>2.4m×2.4m</td>
<td>2011.6.18</td>
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Figure 2. The interpretation of disaster situation in coastal plain by using the ALOS/AVNIR-2 images (ALOS/AVNIR-2: Included©JAXA, Distribution RESTEC).

Figure 3. The ground photographs of disaster situation in Sendai plain (Date May.5, 2011).
Figure 4. The distribution of floodwater by tsunami on the coastal plane in Miyagi and Fukushima prefecture. (Included©JAXA, Distribution RESTEC).

a) The Classification result of 5 categories of inundated area

b) Merging of the Classification result of the inundated area.
Figure 5. The interpretation of disaster situation in ria coast by using the images (ALOS/AVNIR-2: Included © JAXA, Distribution RESTEC. Worldview-2: Includes copyrighted material of Digital Globe, Inc., All Rights Reserved).
TIME SERIES INVESTIGATION AFTER DISASTER RESTORATION

The Restoration in the Coast Plains
A time series change of three months after it was struck before it was struck around the Sendai airport was interpreted (Figure 7). As shown in figure after about one month after the tsunami was generated. Some partial restorations were interpreted in the area (Point A in Figure 7-c) that was inundated by the tsunami. After three months, the changes thought to be a restoration by an artificial land improvement were interpreted (Point B etc. in Figure 7-d). Figure 8 shows the change of the time series in the coastal plain scattered in the Fukushima Prefecture coast region. As shown in figure, the situation that had been gradually restored to the shape of former land cover was interpreted as well as the change tendency around the Sendai airport (Point A in Figure 8- b, c and d). However, a lot of parts that were the inundated situations were admitted (Point B in Figure 8-b, c and d). In this region, the entry to the stricken area is difficult because of the influence of the radioactivity by struck of the Fukushima Dai-Ichi nuclear power plant. From this, the tendency from which the restoration of the stricken area was not begun still enough was shown. The difference of the restoration by the place was considered in the future remarkably.

The Restoration of the Ria-Coastal Region
The result of interpreting the change by struck of Rikuzen-Takada City observed by high-resolution evaluation satellite Worldview-2 and Quickbird is shown in Figure 9, 10 and 11. The shapes of the division road in the city were admitted to interpret easily compared with immediately after the disaster as shown in the observation image of three months after it was struck (area A in Figure 10, b, and c). This is thought the restoration of the road shape by the progress of the return work of the division road. Additionally, because the removal work of toles and pebbles progressed continuously, it was shown that the distribution of toles and pebbles that had piled up had decreased (area A in Figure 9-b and c). On the other hand, it was interpreted that the coastal region was restored still hardly (Area A in Figure 11 etc.). Especially, the tendency to which the secondary erosion progressed was interpreted in the coast part (B of Figure 11). The movement and the removal work of the deposit by the tsunami were admitted to progress three months of struck after. However, the disaster prevention facilities such as shore protections that disappeared in the coastal area were situations immediately after struck almost. It was considered to the restoration of the land cover to secure safety from a new natural damage such as climax to still take time from this.

Figure 6. The ground photographs of disaster situation in Rikuzen-Takada city (Date: 4 May, 2011).

a) Struck town in ria coast region (point A in Fig.5 c) b) Surrounding of ria coast line (point B in Fig.5 c)
Figure 7. The restoration in coastal plain (Sendai plain) in time series (ALOS/AVNIR-2: Included©JAXA, Distribution RESTEC. Landsat/TM: Courtesy of the U.S. Geological)

Figure 8. The restoration of coastal plain along the coastal line in Fukushima prefecture in time series (ALOS/AVNIR-2: Included©JAXA, Distribution RESTEC. Landsat/TM: Courtesy of the U.S. Geological. THEOS: ©2011 GISTDA. ALL RIGHT RESERVED.)
SUMMARY

In this study, the first investigation of the movement of a tidal wave due to an East Japan great earthquake was monitored using a lot of kind of satellite images. The collapse and inundation in the coastal plain and ria coast area.
caused by the tsunami and the destruction of shore protection could be made out from the interpretation of the ALOS and Worldview-2 satellite image of the area observed three days after the earthquake. The area inundated by the tsunami was investigated by land cover classification processing from the ALOS satellite image observed after it was struck. As a result, it was widely shown that the tsunami had reached direction of the inland up to about 5km in the coastal plain. The shore protection of the coast collapsed remarkably, and the situation in which an urban artificial structure disappeared almost was investigated in the ria coastal region by several kinds of satellite images. Additionally, after about from three to four months pass from the disaster, some places of the inundated region by tsunami has recovered in the coastal plains region and each ria coastal region by using Landsat, THEOS, Quickbird satellite images in time series. However, it was shown that a lot of land covers and social infrastructures were changed compared with before it was struck, and a farmland and urban restoration maintenance were late.

For the support of effective planning following social infrastructure maintenance, the restoration of the land cover is scheduled to be monitored continuously according to many kinds of satellite data in the future.

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REFERENCE


