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Tsunami Damage in the Arahama Coastal Forest Interpreted from ALOS Data

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Abstract: Using ALOS data, this study analyzed the damage to the Arahama coastal forest in Sendai caused by the tsunami that followed the Great East Japan Earthquake on March 11, 2011. The satellite data used was ALOS/AVNIR-2 data and ALOS/PALSAR data. Analysis of the tsunami damage indicated that the NDVI for coastal forest without fallen trees tended to be lower than before the tsunami damage. By comparing NDVI images from before and after the tsunami prepared using AVNIR-2 data, we analyzed the state of fallen trees in the coastal forest. As a result, the area of the standing trees after the tsunami was measured by NDVI images. The backscattering coefficient for the coastal forest tended to be lower overall after the tsunami compared to before. This study found that the NDVI images based on optical satellite data were more effective for assessing tsunami damage to wide areas of coastal forest.

1 Introduction

The Great East Japan Earthquake of March 11, 2011 hit the center area of the Tohoku region of Japan and caused unprecedented damage over a wide area. However, a more significant scale of damage of the coastal forest was caused by the tsunami than the earthquake. In order to take prompt recovery measures following the disaster, it is necessary to assess the overall damage as quickly as possible. However, it is difficult to assess the tsunami damage to coastal forest distributed over a wide area quickly with only a ground survey. Using data from earth observation satellites in space offers a means of assessing the situation on the ground over a wide area. And since the satellite image data is digital, a personal computer can be used to analyze the state of the ground surface in a short time. In addition, recent satellite data allows observation with ground resolution of about 10 m, enabling detailed information to be obtained over a wider area. The satellite data that is currently available to us is optical sensor data and synthetic aperture radar data. Optical sensor data captures the strength of sunlight reflected off the ground in the visible wavelength band, near-infrared wavelength region and so on, so the images obtained are similar to the actual appearance of the ground. This has the merit that the images can be interpreted easily, although there is also the demerit that cloud cover can prevent effective ground observation. Synthetic aperture radar, on the other hand, can be used to observe the ground irrespective of cloud cover, rain or darkness. Using synthetic aperture radar data, we were able to obtain information on backscattering coefficients and levels of ground surface variation, which shows the roughness of the ground surface.

As mentioned, optical sensor and synthetic aperture radar data from earth observation satellites can be used in surveying tsunami damage to coastal forests. It can also be useful for selecting places where more detailed ground damage surveys need to be carried out (Aoyama *et al.*, 2011). In fact, soon after the Great East Japan Earthquake, the Japanese land observation satellite ALOS "Daichi" and foreign-owned earth observation satellites conducted emergency observation. The satellite image data was then made public on the Internet. The data has been used by various organizations as a means to learn more about the overall damage, for example by analyzing the area damaged by tsunami and analysis of crustal movement.

This study is essentially a survey of the tsunami damage to coastal forests using satellite data. AVNIR-2 optical sensor data from the ALOS satellite and PALSAR synthetic aperture radar data for the Arahama coastal forest in Sendai in Miyagi Prefecture, the area damaged by the Great East Japan Earthquake, was analyzed to assess damage to the forest.

2 Study area

As shown in Figure 1, the area surveyed in this study is located in the Miyagino and Wakabayashi districts of Sendai, Miyagi Prefecture in Japan. The coast of this area consists of a Japanese black pine forest with a total of length of 7 km, between the Nanakitagawa River to the north, and the Natorigawa River to the south (Murai *et al.*, 1992). The land cover fronting the sea comprises sandy beach, Japanese black pine forest, a canal and more pine forest. In the tsunami following the Great East Japan Earthquake, this coastal forest suffered damage in the form of fallen trees and trees that were swept away.

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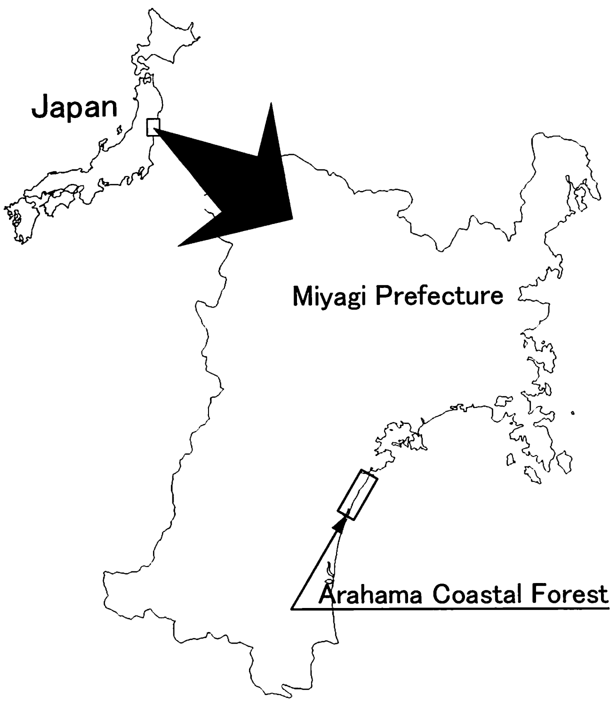


Figure 1: Location of the study area

3 Study method

This study involved interpreting the state of tsunami damage to coastal forest using optical data and synthetic aperture radar data obtained with land observing satellites.

The results of the interpretation were verified by comparison with the actual state of damage. The satellite data used for analysis was ALOS/AVNIR-2 optical data and the synthetic aperture data was ALOS/PALSAR fine beam single-mode data with HH polarization. HH polarization data is a radar wave emitted and received with horizontal polarization. The AVNIR-2 data was taken on February 23, 2011 before the tsunami with relatively low cloud cover, and on March 14, 2011 after the tsunami. The PALSAR data was taken on November 20, 2010 before the tsunami and on March16, 2011 after the tsunami.

The methods used for the study were as follows.

1) Assessment of the actual state of tsunami damage to coastal forest
   We collected aerial photos showing the actual state of tsunami damage to the coastal forest. In addition, we converted digital elevation data into image data in order to visualize the geographical features of the location.
2) Geometric correction of satellite data
   In order to compare the images from before and after the tsunami, we carried out geometric correction to ensure that each image matched a topographic map.
3) Interpretation of tsunami damage to coastal forest using false color images
   We attempted to interpret the state of tsunami damage to coastal forest using false color images created from pre- and post-tsunami AVNIR-2/Band 2,3,4 data.
4) Interpretation of tsunami damage to coastal forest using NDVI images
   We attempted to interpret the state of tsunami damage to coastal forest using NDVI (Normalized Difference Vegetation Index) images created from pre- and post-tsunami AVNIR-2 data.
5) Interpretation of tsunami damage to coastal forest using backscattering coefficient images
   We attempted to interpret the state of tsunami damage to coastal forest using backscattering coefficient images created from pre- and post-tsunami PALSAR data.

4 Assessment of the actual state of tsunami damage to coastal forest

The authors examined the actual damage of the coastal forest using aerial photos of the disaster areas, which had been posted on the Internet by the Geospatial Information Authority of Japan and an aerial survey company.

Photos 1 and 2 are pre- and post-tsunami aerial photos provided by the Geospatial Information Authority of Japan showing the same place on the northern side of the area surveyed. These photos confirm that the pine forest which had grown thickly before the tsunami was largely knocked down by the tsunami. They also show that a part of the coastal forest remains on both sides of the canal as well as a line of trees on the land side of the canal.

Figure 2 shows a pseudo color image of the elevation data for the surveyed area. The elevation data is based on 5 m mesh land elevation data which was taken before the tsunami (provided free of charge by the Geospatial Information Authority of Japan). The elevation is shown sequentially from low to high in black, blue, green, yellow, and red. It shows high elevation of part of the seaward side of the canal and both of its banks, and low elevation of the hinterland of pine forest. It can be seen that pine forest with trees not knocked down by the tsunami tends to be distributed on both banks of the canal with its higher elevation. This suggests that it is desirable to plant Japanese black pine in coastal forests, especially on embankments with high elevation.

Photo 1: Aerial photo of Japanese black pine coastal forest before the tsunami (Courtesy of the Geospatial Information Authority of Japan)

Photo 2: Aerial photo of Japanese black pine coastal forest after the tsunami (Courtesy of the Geospatial Information Authority of Japan)

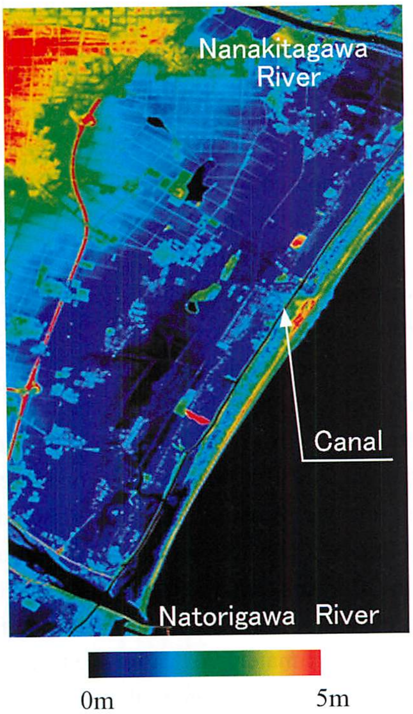


Figure 2: Elevation data image (using 5 m mesh land elevation data)

5 Geometric correction of satellite data

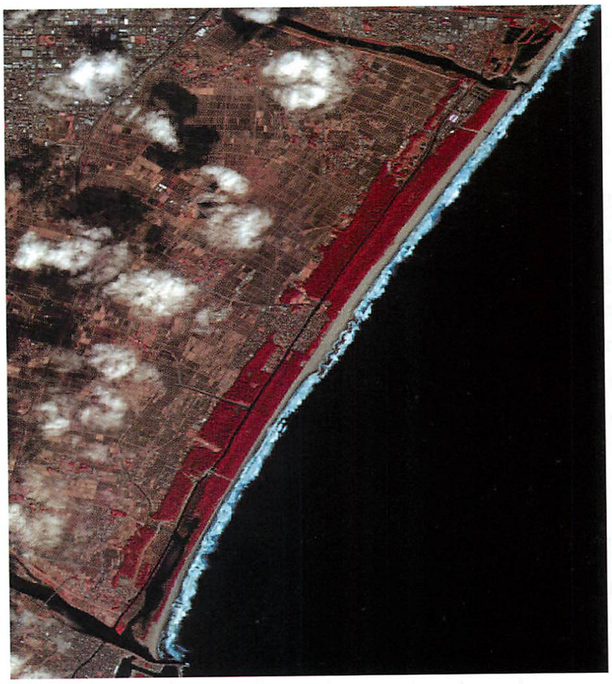
Unlike satellite data for mountainous areas, data for coastal regions is not affected by shadows on sloped surfaces. Therefore it is not necessary to implement geometric slope corrections.

In order to compare the images from before and after the tsunami, we carried out geometric correction to ensure that the pre- and post-tsunami images matched. In the geometric correction process, we matched the AVNIR-2 and PALSAR images against a topographic map with ground resolution of 10 m for the scenes before and after the tsunami.

6 Interpretation of tsunami damage to coastal forest using false color images

We colored channels 2, 3, and 4 of the AVNIR-2 data before and after the tsunami blue, green and red, respectively, to create a false color (infrared color) images. With false color images, vegetation is shown in red. Although all vegetation is shown in red, it is possible to determine the type and condition of the vegetation from differences in the tone of the colors.

Figures 3 and 4 are pre- and post- tsunami false color images, respectively. After the tsunami, the coastal forest hinterland area and a part of the coastal forest are seen as almost solid black. This shows that these areas were inundated by the tsunami.



Black:Waters, White:Clouds and Breaking Waves, Red:Forests, Brown:Paddy Fields, Gray:Structures

Figure 3: False color image before the tsunami

Black:Waters, White:Clouds and Breaking Waves, Red:Forests, Gray:Structures

Figure 4: False color image after the tsunami

When pre- and post-tsunami images are compared, the coastal forest area before the tsunami is a uniform red, but after the tsunami, the area consists of dark red and light red. From the aerial photos, it can be determined that the light red parts are fallen pines. This can be attributed to the reflectance properties of mixed trunks and leaves of fallen pines.

7 Interpretation of tsunami damage to coastal forest using NDVI images

An NDVI image is an index which shows differences in land cover. Where there is vegetation of the same type, a higher NDVI indicates stronger growth (The Remote Sensing Society of Japan, 2011). We prepared NDVI images from AVNIR-2 data using the following equation, with the aim of assessing the conditions of growth in the coastal forest before and after the disaster.

$$NDVI = (NIR - R) / (NIR + R) \qquad (1)$$

Where, R= Reflection coefficient of the red wavelength range (%), NIR= Reflection coefficient of the near-infrared wavelength range (%).

AVNIR-2 data is the digital number of 8 bits corresponding to the earth surface reflectance. The following equation was used to convert the digital numbers to reflection coefficients (Murakami *et al.*, 2007).

$$\rho = L \cdot \pi \cdot d^2/(Fo \cdot \cos\theta) \qquad (2)$$

Where, ρ= Reflection coefficient (%), L= Brightness ($W/m^2/sr/\mu m$), d= Distance between sun and earth (AU), Fo= Spectral solar irradiance ($W/m^2/\mu m$), θ= Solar zenith angle.

The NDVI is shown in a range from -1 to +1, and a higher value indicates vegetation. In addition, where there is vegetation of the same type, a higher NDVI indicates stronger growth. The NDVI value determined the coastal forest 0.30 or more. We then carried out level slicing as follows so that the NDVI images would show differences in the NDVI as different colors. We colored NDVI between 0.30 and 0.35 green, NDVI between 0.35 and 0.40 yellow, and NDVI over 0.40 red.

Figures 5 and 6 show the NDVI level slice images before and after the tsunami. In the post-tsunami NDVI image, the coastal forest hinterland is dark, as are the water areas. This shows that this area was inundated by the tsunami.

When the post-tsunami aerial photos released by the Geospatial Information Authority of Japan are compared with the NDVI images taken after the disaster, the vegetation distribution shown in the NDVI images largely match the distribution of pine forest with no fallen trees. In particular, the distribution of pine forest remaining on both banks of the canal that can be seen in the NDVI image and the distribution of the forest remaining in a line formation at a right angle to the canal on the landward side was the same as the distribution seen in the aerial photo. Therefore, the post-tsunami NDVI image is effective for gauging the damage to the coastal forests.

When the NDVI images taken before and after the tsunami are compared, it is clear that the coastal forest suffered damage after the tsunami over a wide area. Whereas the NDVI of the coastal forest before the tsunami was mostly 0.40 or more, after the tsunami there were hardly any values over 0.40. The post-tsunami NDVI for pine forest with no fallen trees was from 0.30 to 0.40, a lower value than before the tsunami.

We determined from pre- and post-tsunami NDVI images that for NDVI values of 0.30 or more, no trees had fallen, and we measured the area of standing trees. We found that of a coastal forest area of $4.35km^2$ before the tsunami, $0.19km^2$ remained after the tsunami. From this we understood that the area of coastal forest had declined by approximately 96% after the tsunami.

Interpreting tsunami damage to the coastal forest using NDVI images was simpler and more effective than using false color images.

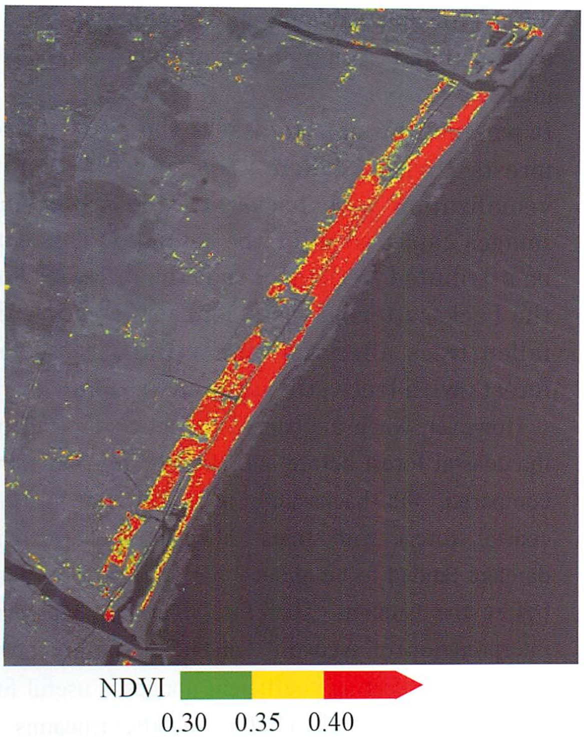


Figure 5: NDVI level slice image before the tsunami

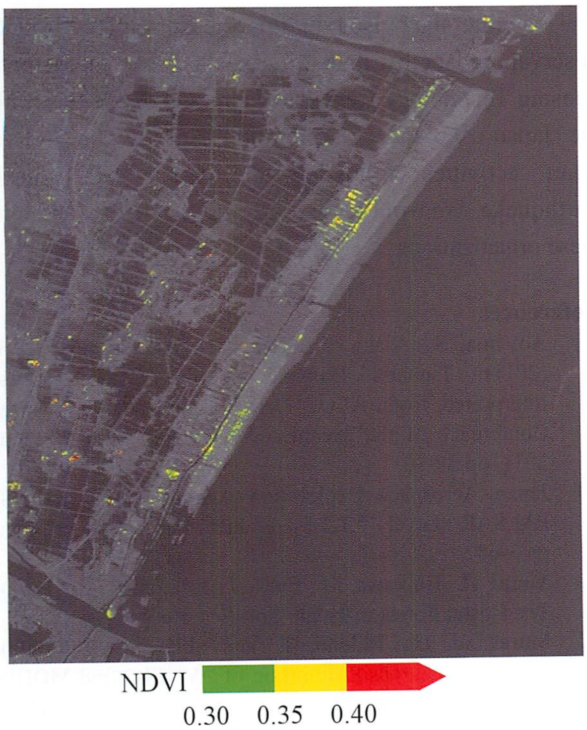


Figure 6: NDVI level slice image after the tsunami

8 Interpretation of tsunami damage to coastal forest using backscattering coefficient images

The backscattering coefficients differ depending on the shape of the features of the ground surface. In this study, we created backscattering coefficient images from before and after the tsunami using PALSAR data to investigate the relationship between the state of the pre- and post-tsunami coastal forest on the one hand, and the backscattering coefficient on the other (Japan Aerospace Exploration Agency, 2009). In addition, in order to visualize the backscattering coefficient values, we created pseudo color images with the backscattering coefficient values colored purple, blue, green, yellow, orange and red from low to high.

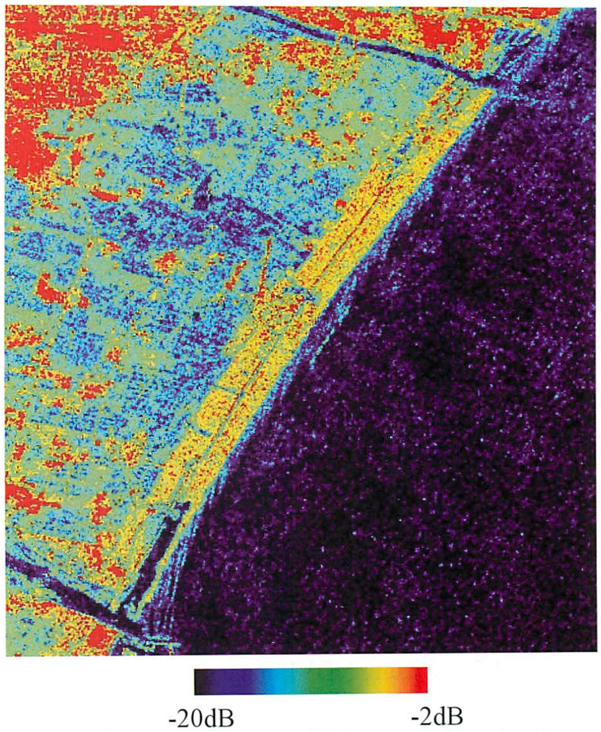


Figure 7: Backscattering coefficient pseudo color image before the tsunami

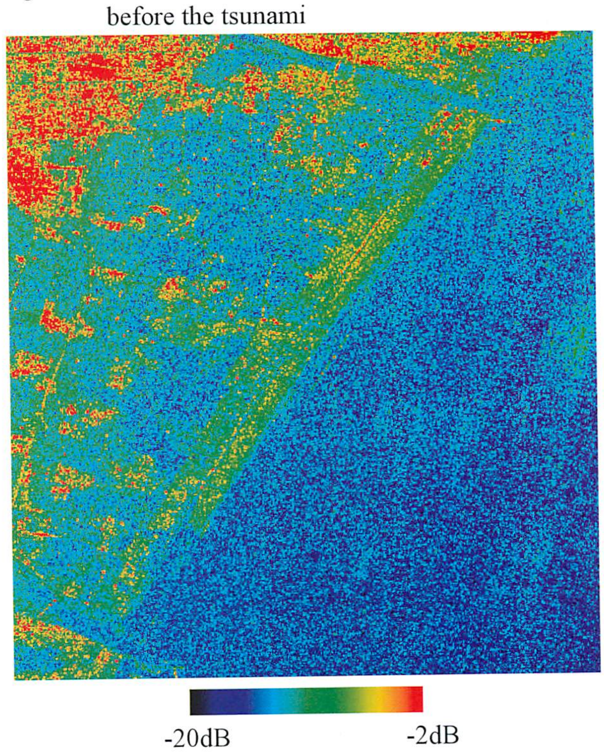


Figure 8: Backscattering coefficient pseudo color image after the tsunami

Figures 7 and 8 show the backscattering coefficient pseudo color images before and after the tsunami. When the backscattering coefficient images before and after the tsunami were compared, the backscattering coefficient for the coastal forest which suffered damage in the tsunami was much lower than before the tsunami due to the influence of scattering from fallen trees, but overall, it tended to be about 2 dB lower overall. Therefore it can be said that for interpretation of tsunami damage to coastal forest using backscattering coefficient images, it is necessary to compare images taken before and after tsunamis.

9 Conclusion

This study attempted to assess tsunami damage to a coastal forest from satellite data. The results obtained should be applicable to other tsunami events and to other regions.

The findings of this study were as follows.

1) Results of interpretation of tsunami damage to coastal forest using false color images
In the false color images, the Japanese black pine forests before the tsunami are dark red, whereas after the tsunami, forests with fallen trees are a light red.
2) Results of interpretation of tsunami damage to coastal forest using NDVI images
Sampling of coastal forest using NDVI images can be done automatically by determining thresholds for NDVI values. We were able to isolate the coastal forest in the surveyed area by taking areas where the NDVI value was 0.30 or more. Using this method, by calculating the area of the coastal forest from the NDVI images taken before and after the tsunami, we established that about 96% of the coastal forest suffered damage in the form of fallen trees and so on. In addition, we obtained results showing that the NDVI for forest that did not suffer fallen trees due to the tsunami had lower values than before the tsunami.
This study found that the NDVI images were more effective for assessing tsunami damage to the coastal forest.
3) Results of interpretation of tsunami damage to coastal forest using backscattering coefficient images
It was not possible to assess the situation of forests with fallen trees using only visualization with backscattering coefficient images captured after the tsunami. This can be attributed to the fact that the difference in the backscattering coefficient for forests with fallen trees after the tsunami and those for forests with trees still standing is small.
However, when the backscattering coefficients of the coastal forest before and after the tsunami were compared, the backscattering coefficient for the coastal forest with trees fallen due to tsunami damage tended to be about 2 dB lower overall than before the tsunami. Therefore it can be said that interpretation of tsunami damage to coastal forest using backscattering coefficient images is useful for comparing images taken before and after tsunamis.

Acknowledgments

The satellite data used in this study was the ALOS observation data distributed free of charge by the Remote Sensing Technology Center of Japan in cooperation with the Japan Aerospace Exploration Agency, for use in relief activities following the Great East Japan Earthquake. We would like to express our appreciation to these organizations.

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