DETECTION OF CATASTROPHIC TSUNAMI DEVASTATION IN JAPAN BY USING OPTICAL AND SAR DATA

Yuzo Suga*[1] and Tomohisa Konishi[2]
[1]Professor, Department of Global Environment Studies, Hiroshima Institute of Technology
2-1-1, Miyake, Saeki-ku, Hiroshima, 731-5193, Japan; Tel: +81-82-922-5204
Email: y.suga.mi@it-hiroshima.ac.jp

[2]Nihon CADIC Co. Ltd.,
5-33-12-102, Inokuchi, Nishi-ku, Hiroshima, 733-0842, Japan,; Tel: +81-82-270-3351;
E-mail: konishi@cadic.co.jp

KEY WORDS: MODIS, AVNIR-2, PRISM, PALSAR, EROS-B, COSMO -SkyMed.

ABSTRACT: The catastrophe of Tsunami disaster has occurred over the wide area in the eastern part of Japan by the earthquake (M9.0) on 11 March, 2011. At that time, we performed the urgent analysis of optical and SAR satellite data for the detection of the catastrophic damaged area by Tsunami devastation. First of all, acquiring MODIS, the wide range devastation was detected regarding the inundated area occurred by Tsunami along the coastline of Miyagi and Fukushima prefectures. The maximum elevation height in the inundated area was identified to be 4 to 5 m and the maximum distance from coastline was 5.0 to 5.5 km according to the results derived from MODIS data. AVNIR-2 images after the earthquake were used for monitoring the inundated area in paddy fields of the damaged area. The inundated areas were detected by means of the difference of ratio of visible and infrared bands derived from AVNIR-2 of before and after the disaster. On the other hand, the change detection of the inundated area was also detected by means of the classified images derived from PALSAR L-band and COSMO -SkyMed X-band high spatial resolution SAR data, and PRISM and EROS-B high spatial resolution optical data taken on multi-temporal observations before and after the disaster. In addition, we have developed 3D viewing system for geospatial visualizing of the damaged area using these satellite image data with digital elevation model. The 3D viewing system has the performance of geographic measurement regarding distance, elevation height, area calculation and cross section drawing including landscape viewing and image layer construction using a mobile personal computer with interactive operation. As the result, it was verified that a quick response for the disaster identification at the initial stage could be performed using optical and SAR satellite data with 3D viewing system.

1. INTRODUCTION

The catastrophe of Tsunami disaster has occurred over the wide area in the eastern part of Japan by the Great East Japan Earthquake (M9.0) on 11 March, 2011. In this study, we performed the urgent analysis of optical and SAR satellite data for the detection of the catastrophic damaged area by Tsunami devastation in the east of Japan base on the contract with ASI for COSMO-SkyMed, ISI for EROS-B and JAXA for ALOS data. This study focused on a quick response for the disaster identification of Tsunami disaster and to develop a 3D viewing system supporting for the disaster monitoring.

At the first time, we acquired MODIS data from NASA web site through the internet, the detection of the wide range damaged area by Tsunami devastation was performed at the initial stage after the disaster. Furthermore, we also acquired high spatial resolution satellite image data, such as ALOS/AVNIR-2, PRISM and EROS-B, the detailed damaged area identification was performed using these multi-temporal satellite data. The optical sensor is often hampered by unfavorable weather conditions. On the other hand, high spatial resolution synthetic aperture radar (SAR) imaging sensor is able to provide effective information regarding the damaged area of the disaster according to their all-weather and day/night time capabilities. In addition, revisit time of the constellation COSMO-SkyMed is within 12 hours (ASI, 2007). These capabilities provide the quick response and reliable disaster monitoring. The rapid impact assessment after the catastrophic disaster is crucial for initiating effective emergency response and disaster mitigation.

2. STUDY AREA AND DATA SET

The total inundated area was approximately 561 km^2 reported by Geospatial Information Authority of Japan (GSI) on 18 April, 2011 (Geospatial Information Authority in Japan, 2011) based on the analysis of aerial photographs including Aomori, Iwate, Miyagi, Fukushima, Ibaraki and Chiba prefecture as shown the red lines in Figure 2. And also, the affected area of the study area in this study was 390 km^2.

The study area in this study is located in the eastern part of Japan as shown in Figure 1. This area was affected by the catastrophic Tsunami. As for low spatial resolution satellite image data, TERRA, AQUA/MODIS data were used with 250 m spatial resolution. As for middle spatial resolution satellite image data, ALOS/AVNIR-2 and PRISM data were used with 10 m and 2.5 m spatial resolution, respectively. As for high spatial resolution satellite image data, EROS-B data were used with 0.7 m spatial resolution and COSMO-SkyMed data were used with 1.0 m of Spotlight-2 mode and 3.0 m of StripMap mode. Table 1 shows the list of satellite image data and acquisition date in this study.

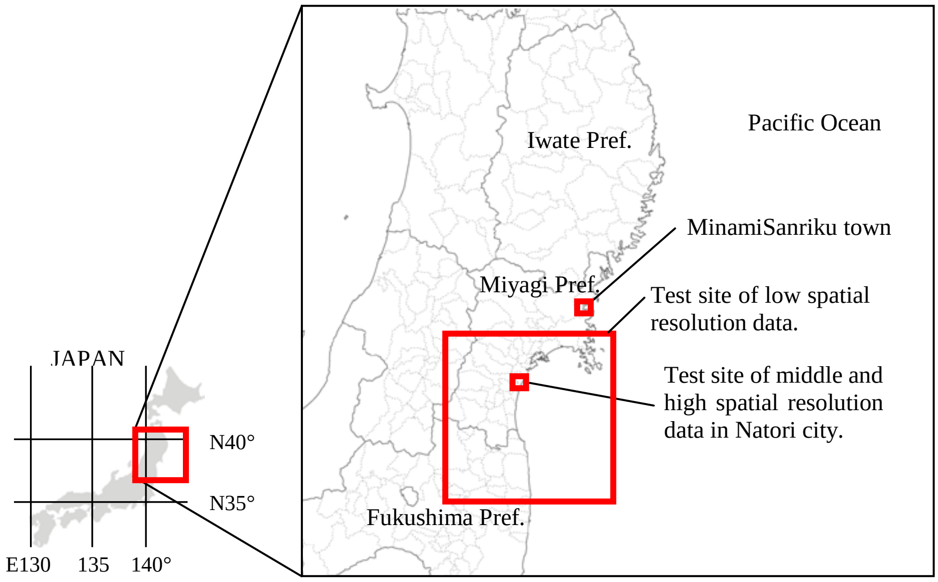

Figure 1 Location of the test site.

Table 1 Used data and acquisition date

Satellite/Sensor	Mode	Acquisition date
TERRA/MODIS		26-Feb-2011
AQUA/MODIS		13-Mar-2011
ALOS/AVNIR-2		27-Feb-2011
ALOS/AVNIR-2		19-Mar-2011
ALOS/AVNIR-2		28-Mar-2011
ALOS/PALSAR		29-Sep-2010
ALOS/PRISM		23-Aug-2010
COSMO-SkyMed	Spotlight-2	13-Mar-2011
COSMO-SkyMed	Stripmap	16-Mar-2011
EROS-B	Basic scene	02-Apr-2011

3. ANALYSIS IN TSUNAMI AFFECTED AREAS

3.1 Analysis using low spatial resolution data

We attempted the analysis for the extraction of inundated area in wide range regions using TERRA and AQUA MODIS data. MODIS data can be used for monitoring of global disasters to download from NASA web site through the internet. The MODIS images were acquired on before (26 March, 2011) and after (13 March, 2011) the disaster. The images were composed by three bands which are band 7 (short-wave infrared band), band 2 (near-infrared band) and band 1 (red band). The value of near-infrared band in water region is lower than that of dry surface due to water absorption occurs in near-infrared. Therefore, water and non-water region can be discriminated by image classification algorithms. The inundated area was extracted by means of the maximum likelihood classifier using the above MODIS data. Figure 2 shows the inundated area as indicated in yellow color along the coastline derived from multi-temporal MODIS data. The inundated area was approximately 211 km^2 located in the pacific coastal region of Miyagi and Fukushima prefectures of Tohoku district in Japan. The maximum distance from the coastline is approximately 5.2 km and the maximum elevation height of inundated area is approximately 3 to 4 m in reference to 10 m mesh digital elevation model (DEM) data produced by GSI. The inundated area derived from multi-temporal

MODIS data was almost coincided with the estimation line derived from aerial photographs. The inundated area was under estimated because aerial photographs detected piles of rubbles including the inundated area caused by the disaster, however, MODIS data detected only the inundated area after the Tsunami. And also, some surfaces were not inundated due to the acquisition date of MODIS, two days after the Tsunami.

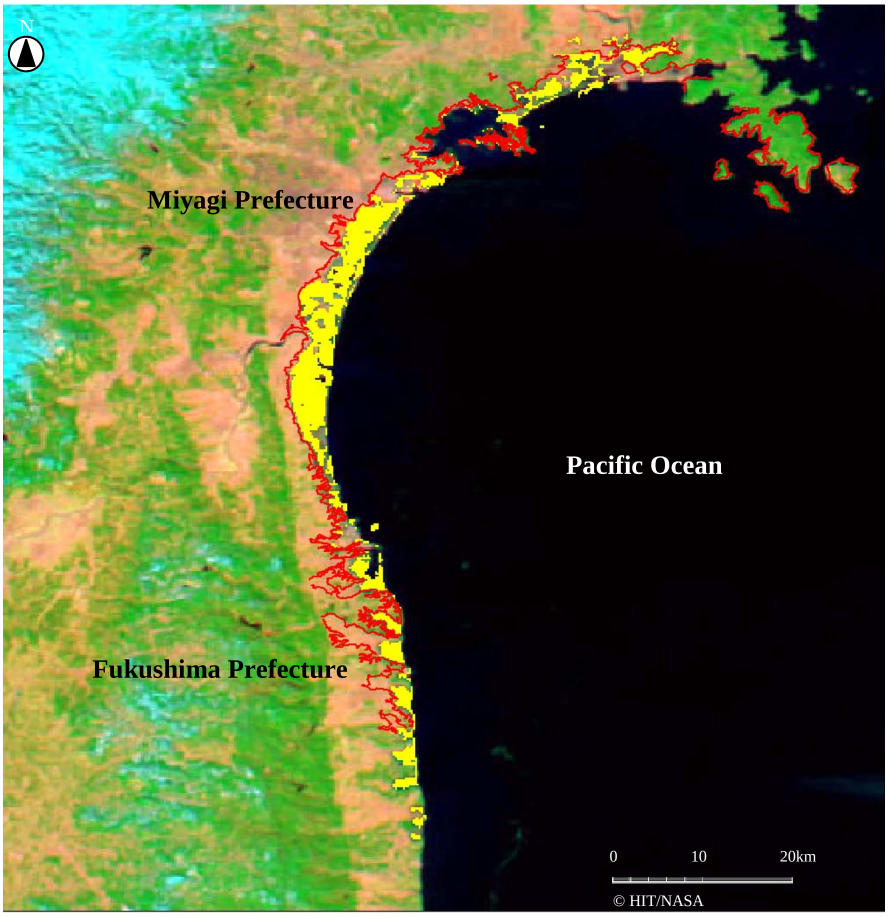

Figure 2 Detection image of the inundated area along the pacific coastal region using multi-temporal MODIS data. (Yellow: Detected inundated area, Red: Estimation line of inundated area using aerial photographs)

3.2 Analysis using middle and high spatial resolution data

We performed the extraction of inundated area in plain region of Natori city, Miyagi prefecture using middle and high spatial resolution SAR and optical data. This area was inundated for a long time due to Tsunami and land subsidence by the earthquake. The study area is 10 x 10 km, which is the same area acquired on different date as shown in Figure 3 to 6.

As for radar data, ALOS/PALSAR was acquired on 29 August, 2010 before the disaster, and COSMO-SkyMed was acquired on 13 March and 16 March, 2011 after the disaster. According to a past study regarding the flooding of paddy fields, it was shown that the backscattering coefficient (σ^0) decreased more than 3 dB when paddy fields were inundated by flooding (Takeuchi et al., 1996). In addition, SAR backscatter on calm water surface with no wind was basically the lowest level among various land cover types. Therefore, the flooding detection by SAR data can be performed by extracting the pixels in SAR image of damaged area that were decreased between before and after the disaster.

SAR is contaminated with coherent speckle noise, which disturbs the homogeneous area identification. The processing of 7x7 mean filter was adopted to SAR images. Then, amplitude SAR images were converted into σ^0 in dB for image calibration. The object based classification technique was adopted for identifying the inundated areas on SAR image. In comparison with traditional pixel based classification techniques, it is able to perform the extraction of homogeneous segments in SAR image. The mean and standard deviation values of segments after segmentation processing were used for sample-based nearest neighbor classification. Figure 3 shows the extraction of inundated area as indicated in yellow color using PALSAR acquired on 29 September, 2010 and COSMO-SkyMed acquired on

13 March, 2011. Figure 4 shows the extraction of inundated area as indicated in yellow color using PALSAR acquired on 29 September, 2010 and COSMO-SkyMed acquired on 16 March, 2011.

As for multi-spectral optical sensor data, the inundated area is generally detected by using near-infrared (NIR) band data because NIR value on the inundated surface is much lower than other land cover types. However, actual data values in visible and near-infrared bands on the inundated surface are easily affected by atmospheric conditions, surface reflection of sun light, and water turbidity, it is difficult to set a common threshold value for flooding detection among different dated data. Therefore, we adopted Normalized Difference Vegetation Index (NDVI) derived from visible band (Band-3) and NIR band (Band-4) data of AVNIR-2 by the following reasons (Takeuchi et al., 1999);

(1) NDVI values of the inundated surface are more stable for the differences of atmospheric condition, the reflection of sun light, and water turbidity compared with original band data.
(2) NDVI for the inundated surface is lower than that of non-vegetated land surface such as bare soil or concrete surface as well as than that of vegetation among various land cover types.

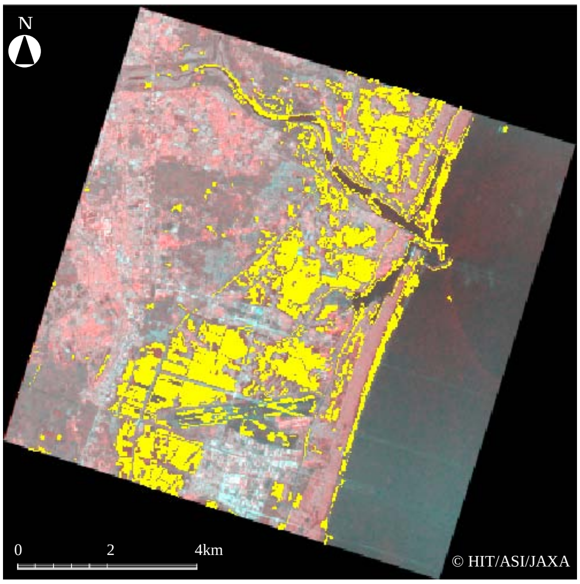

Figure 3 Extraction of inundated area using PALSAR acquired on 29 September, 2010 and COSMO-SkyMed acquired on 13 March.

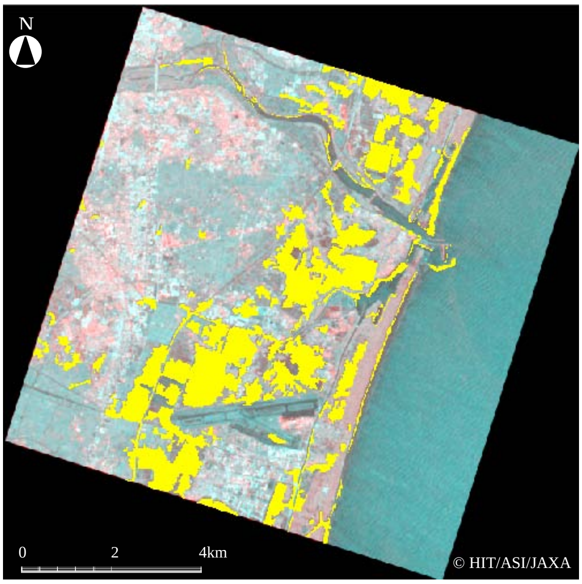

Figure 4 Extraction of inundated area using PALSAR acquired on 29 September, 2010 and COSMO-SkyMed acquired on 16 March.

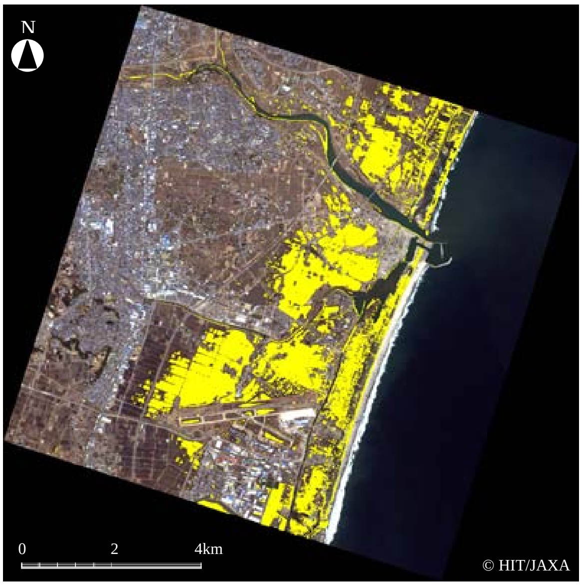

Figure 5 Extraction of inundated area using ALOS/AVNIR-2 acquired on 27 February and 19 March, 2011.

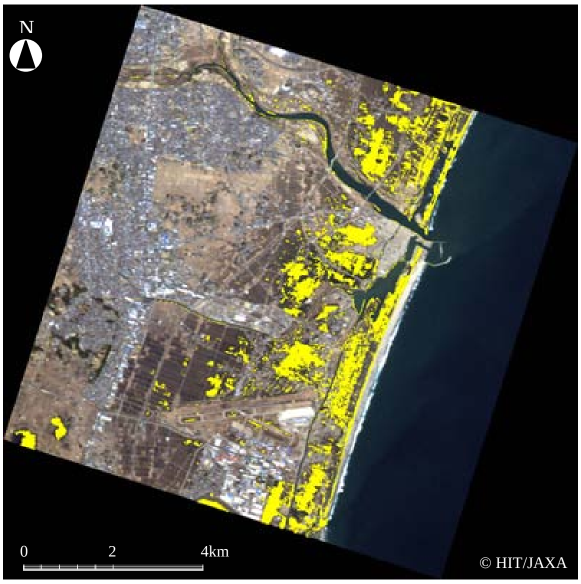

Figure 6 Extraction of inundated area using ALOS/AVNIR-2 acquired on 27 February and 28 March, 2011.

Therefore, the threshold value of NDVI was derived from the following condition for the extraction of inundated areas by Tsunami;

$$NDVI_B - NDVI_A \geqq T_C \tag{1}$$

where, $NDVI_B$ and $NDVI_A$ are derived from the data before and after Tsunami, respectively. T_C is the threshold value to detect the decrease of NDVI by Tsunami. Actual value of T_C was defined by inspecting histograms of the data by the difference of $NDVI_B$ - $NDVI_A$. T_C was set to 0.1 in this study. Figure 5 shows the extraction of inundated area as indicated in yellow color using ALOS/AVNIR-2 acquired on 27 February and 19 March, 2011. Figure 6 shows the extraction of inundated area as indicated in yellow color using ALOS/AVNIR-2 acquired on 27 February and 28 March, 2011.

As the results, the estimated inundated area using those satellite image data were 15.2 km^2 in 13 March, 14.0 km^2 in 16 March, 12.7 km^2 in 19 March and 7.6 km^2 in 28 March, respectively. The inundated areas were reduced after Tsunami. This result shows the availability of the inundated area monitoring by using SAR and optical images.

As for high spatial resolution panchromatic optical sensor data, it generally includes the spectral band from visible to near-infrared. The spectral band of ALOS/PRISM is from 0.52 to 0.77 μm and that of EROS-B is from 0.50 to 0.90 μm. In the case of Tsunami disaster, seawater and sludge covered over the damaged area. It is difficult to discriminate between the inundated area and the sludge covered area using satellite image data before and after Tsunami. Figure 7 shows the composite panchromatic image of before and after Tsunami in Natori city. Red color shows the inundated area covered with seawater and/or dark sludge by Tsunami. The estimated area covered by sludge was approximately 7.1 km^2 in the composite image. In addition, red color portions along the coastline show disappearance of beach caused by the earthquake and Tsunami disaster.

Figure 7 Detection of the inundated and disappearance of beach in Natori city caused by the earthquake and Tsunami.
(R: ALOS/PRISM acquired on 23 August, 2010, G & B: EROS-B acquired on 2 April, 2011)

3.3 Development of 3-D viewing system for the disaster monitoring

Furthermore, we attempted a development of an user-friendly 3-D viewing system to apply disaster and environmental monitoring .This 3-D viewing system has a capability of the bird's eyes viewing by using satellite image data and DEM dataset, in addition, geographical features can be calculated on the 3-D image such as the distance and the height of selected points, the area of interest, the cross section drawing, and the estimation of disaster damaged area including landscape viewing and image layer construction using a mobile personal computer with interactive operations.

Figure 8 shows the 3-D image of Minami Sanriku town damaged by Tsunami using EROS-B acquired on 2 April, 2011. The central part of the image was built-up and residential area and bottom right part of the image was bay area. This image clearly shows the whole area of the town excluded some hilly regions was completely destroyed by Tsunami as shown in the light blue colored area. It is declared by using 3-D viewing system that the maximum distance of the range from coastline was approximately 3.0 km and the maximum elevation height of inundated area was approximately 14 to 15 m, respectively. This 3-D viewing system has a capability to effectively utilize for the disaster assessment.

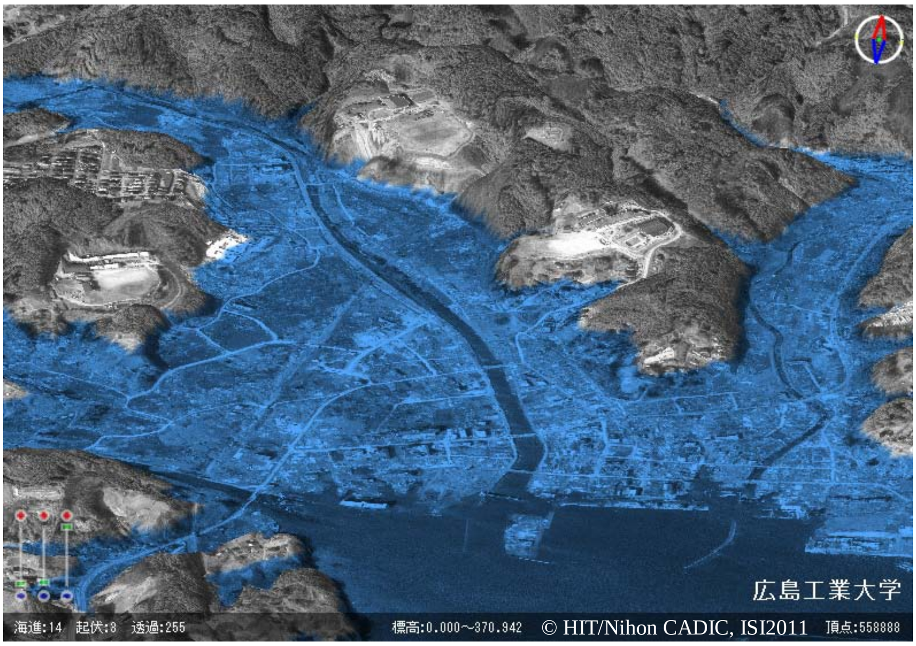

Figure 8 3-D image of Minami Sanriku town damaged by Tsunami using EROS-B acquired on 2 April, 2011.

4. CONCLUSION

The multiple spatial resolution satellite image data were used for the detection of inundated area caused by Tsunami disaster in Japan. This study performed the extraction of inundated area along the coastline from Miyagi to Fukushima prefectures using MODIS data of before and after Tsunami. As for middle and high spatial resolution optical and SAR satellite image data such as ALOS/AVNIR-2, PRISM, PALSAR, EROS-B and COSMO-SkyMed, the extraction of inundated area was estimated in the study area, Natori city. The change pattern of the inundated area after Tsunami disaster was detected by using the multi-temporal optical and SAR satellite image data. In addition, we have developed a user-friendly 3-D viewing system to produce the bird’s eyes viewing image using satellite image data and DEM. The 3-D viewing system is useful for the disaster assessment.

As the result of this study, it was verified that a quick response for the disaster identification at the initial stage could be effectively performed by using optical and SAR satellite data with 3D viewing system for Tsunami disaster.

Acknowledgement

This study was conducted as a part of Strategic Research Infra-structure Construction Project in Hiroshima Institute of Technology, entitled on “Generation of time-spatial image information using earth observation satellite remote sensing”, supported by the Ministry of Education, Culture, Sports, Science and Technology, Japan.
COSMO-SkyMed data used in this study were provided through COSMO-SkyMed AO PI Account based on the contract with ASI.
ALOS data used in this study were provided through AUIG (Alos UserInterface Gateway) based on the contract with JAXA.

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