Chapter 13

Development and Future Perspectives of Tsunami Damage Assessment Technology

Field of expertise: Wide-area damage assessment research

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Summary

This paper outlines the current status and prospects of research on the use of remote sensing for understanding the wide-area damage caused by tsunamis, focusing on the following issues: understanding the inundation area and run-up characteristics, extracting building damage, understanding debris, and searching for victims.

Keywords: tsunami disaster, wide-area damage assessment, remote sensing, geo-informatics, disaster response

Introduction

Remote sensing is a crucial technology to assess damage in a wide area during a major disaster. Remote sensing was also used effectively in the 2011 Great East Japan Earthquake and made contributions to assessing damage and monitoring recovery in the affected areas. In ten years since then, significant changes and advances have been achieved in sensor performance, diversification of platforms, and sophistication of analysis technology.

1: Problems Revealed by the Great East Japan Earthquake

What happened?

One of the most critical issues in disaster response and relief activities in the affected areas is understanding the full extent of the impacts. In the aftermath of a disaster, information from the severely affected areas is fragmented, making it extremely difficult to assess the full extent of the damage, and relief and recovery activities in the affected areas would be challenging. After the 2011 Great East Japan Earthquake disaster, the affected areas were vast, and it was tough to quickly determine where the severely damaged areas were. The survey's duration and human resources for damage assessment efforts were restricted, so it was necessary to assess the situation from outside the affected areas.

The reality of the damage

Immediately after the 2011 Great East Japan Earthquake, several organizations conducted emergency observations. For instance, Japan Aerospace Exploration Agency (JAXA) was operating the Advanced Land Observing Satellite "Daichi" during the 2011 event. The satellite contained three observation sensors: the Panchromatic Remote-sensing Instrument for Stereo Mapping (PRISM) to generate topographic data with its optical stereoscopic observation, the Advanced Visible and Near Infrared Radiometer type 2 (AVNIR-2) to monitor land cover and land use, and the Phased Array type L-band Synthetic Aperture Radar (PALSAR). The AVNIR-2 sensor has three bands of visible light (RGB) and near-infrared light (NIR), and its ground resolution is 10 meters in the nadir direction. Figure 13-1 shows the inundation area map using the ALOS AVNIR-2 image on March 14, 2011. The inundation area was identified by focusing on the spectral reflectance characteristics of water with the threshold values.

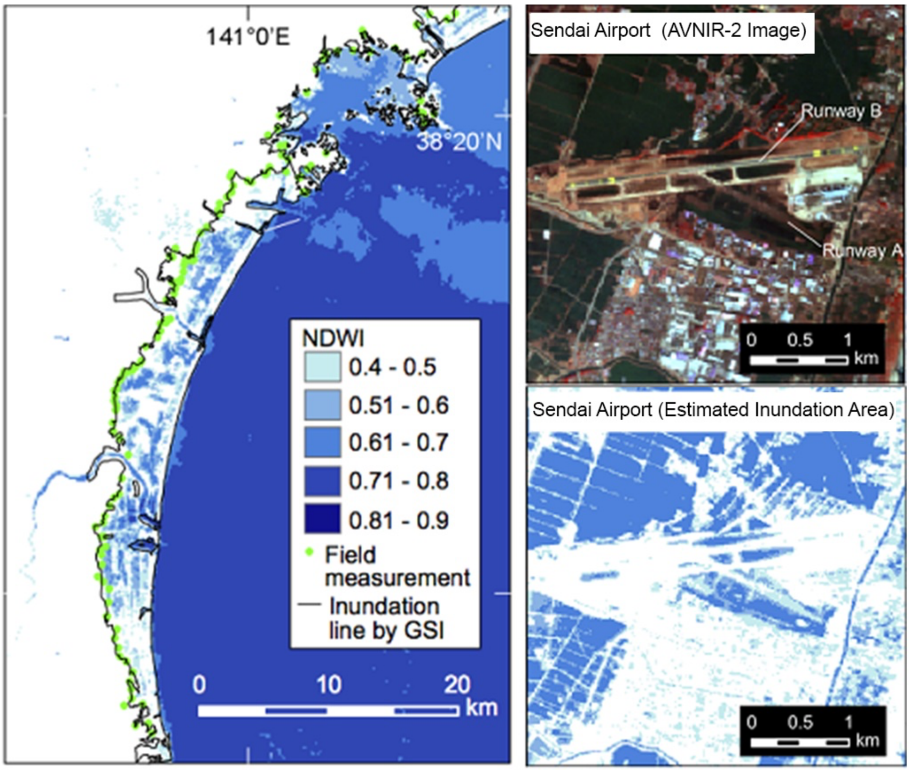

Figure 13-1. The tsunami inundation area (blue area) extracted using ALOS AVNIR-2 imagery. The black solid line is the inundation line extracted from aerial photographs by the Geospatial Information Authority of Japan, and the green dots are the results of field surveys pointing out the tsunami inundation limits.

In addition, aerial photographs were widely used to assess building damage. In fact, aerial photographs taken by the Geospatial Information Authority of Japan (GSI) made significant contributions to understanding building damage levels by visual interpretation. The authors used these aerial photographs of the disaster area in Miyagi Prefecture to extract damage information of 160,000 buildings. One drawback of this effort was the time requirement because it is interpreted and deciphered by human eyes. This problem will soon be solved with advances of machine learning (AI) which have been developing rapidly in recent years.

2: Paradigms Destroyed by the Earthquake

Conventional wisdom and necessary responses (Recognition, knowledge, dogma)

Table 13-1 summarizes the sensor platforms and analysis methods used for assessing wide-area damage in research efforts conducted immediately after the 2011 Great East Japan earthquake disaster. There is now a wide range of platforms used for remote sensing including satellites, aircraft, and unmanned aerial vehicles (UAVs). Optical sensors that capture visible and near-infrared light, synthetic aperture radar (SAR), and LiDAR (Light Detection and Ranging) are mainly used. It is necessary to use diverse sensors and platforms, considering these needs.

Table 13-1. Sensor platforms for tsunami wide-area damage assessment

Extraction details	Sensor/Platform	Analysis method
Tsunami inland penetration and run-up	Aircraft, UAV/ Optical sensor, Video	Visual inspection, edge extraction
Tsunami inundation zone	Satellite, Aircraft, UAV/ Optical and infrared sensor, Synthetic Aperture Radar (SAR)	Visual inspection, Image filter, Change detection
Building damage	Satellite, Aircraft, UAV/ High-resolution optical sensor, Synthetic Aperture Radar (SAR)	Visual inspection, Image filter, Change detection, Machine learning
	Satellite, Aircraft, UAV/ High-resolution optical sensor, Synthetic Aperture Radar (SAR), (Light Detection and Ranging (LiDAR)	Supervised and unsupervised classification, Machine learning, 3D measurement, and mapping
Searching for Victims	Aircraft, UAV/ High-resolution optical sensor, Video	Image recognition, Machine learning

3: A New Approach

In particular, the analysis methods aiming at a quantitative understanding of building damage have been developed using synthetic aperture radar, which can observe day and night, regardless of weather conditions. The method that has been the most widely applied is the change detection method. It is common to relate changes in pre- and post-event datasets to the degree of damage to determine thresholds and construct damage classifiers. Figure 13-2 shows an example of building damage extraction in the tsunami-affected area using TerraSAR-X images by applying a two-step method; first extracting the building area, then constructing a classifier based on the Decision Tree method. It has been demonstrated that 80% accuracy was achieved to extract washed-away buildings. This change detection method can show excellent results only when the data before and after the disaster are obtained under the same acquisition conditions. Besides, this method cannot be utilized in the case where only post-disaster images are available.

Machine learning methods can overcome this drawback. Advanced methods are being developed to extract building damage only from post-disaster data, by applying machine learning methods with training data on building damage prepared in advance. For instance, Figure 13-3 shows the results of extracting building areas using Deep Neural Network (DNN) called SqueezeNet and then classifying the damage using a convolutional neural network architecture called wide residual networks (Wide ResNet). The results are consistent with conventional change detection methods (total accuracy of about 75%). This implies that by preparing appropriate training data, AI can perform rapid damage assessment.

The characteristics and advantages of remote sensing include wide coverage, periodicity (the ability to observe the same place at a specific time interval), and continuity (the ability to continue observation for an extended time). In other words, it is possible to monitor not only wide-area damage immediately after the occurrence of a disaster but also continuously monitor it. In the 2011 Great East Japan earthquake, it was estimated that more than 23 million tons of debris were caused in the three prefectures of Tohoku. The rapid removal of debris was an important and urgent issue in accelerating disaster recovery, and for this purpose quantitative monitoring of debris removal activity was crucial. We have developed a method to quantitatively monitor the accumulation and distribution of debris in three-dimensional form using aerial photographs and LiDAR data. Figure 13-4 shows the results of the 3D extraction of debris in Onagawa Town, Miyagi Prefecture. The total volume of debris in this area was estimated to be 238,000m^3, and considering the bulk density of debris of 1.2t/m (based on the National Institute for Environmental Studies), the total weight was estimated to be 286,000t. Despite the difficulty to measure and monitor the debris directly on-site regularly and continuously, the remote sensing results show that the amount of debris could be determined quickly and quantitatively by integrated analysis of aerial photographs and LiDAR data.

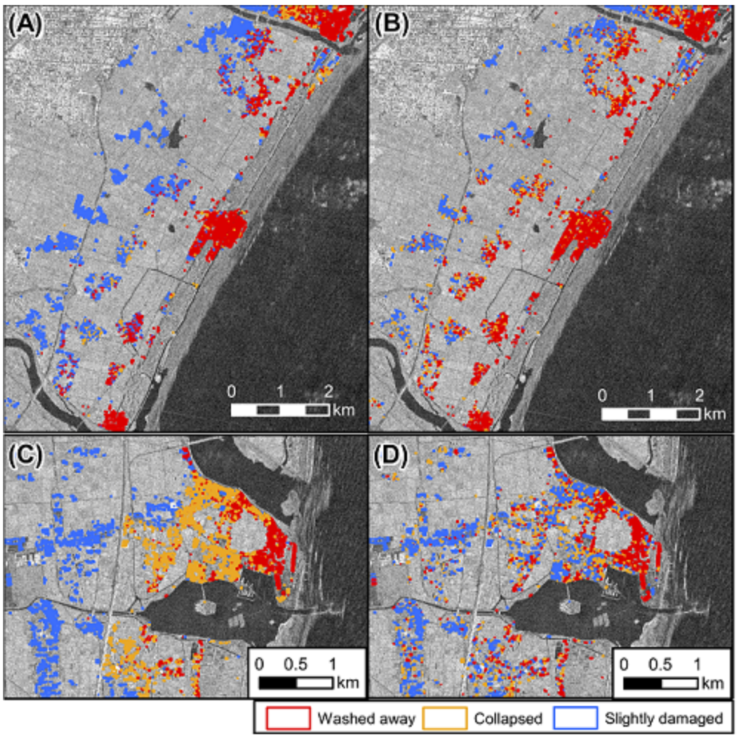

Figure 13-2. Extraction results of tsunami-induced building damage in Sendai City and Watari Town, Miyagi Prefecture. (A) and (C) are the results of the survey, and (B) and (C) are the results of damage extraction from TerraSAR-X images.

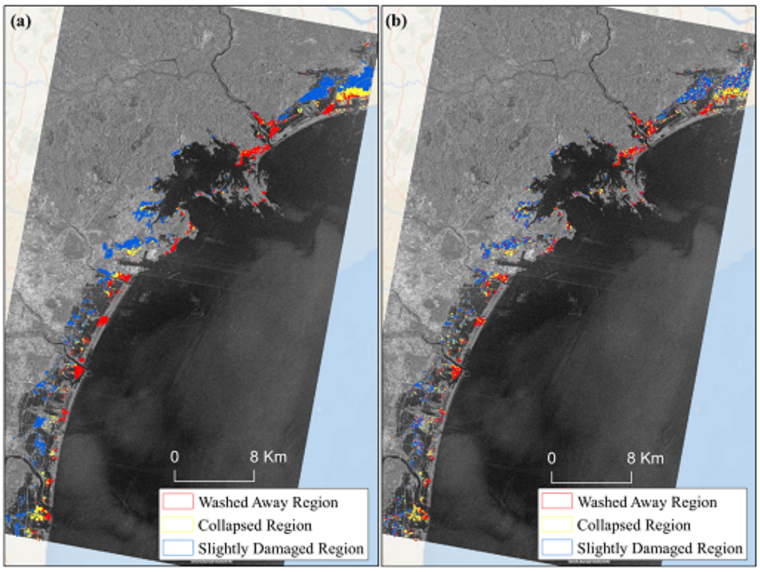

Figure 13-3. Building damage extraction results obtained by deep learning only from post-event TerraSAR-X data. (a) Building damage survey result, (b) Damage extraction result by deep learning

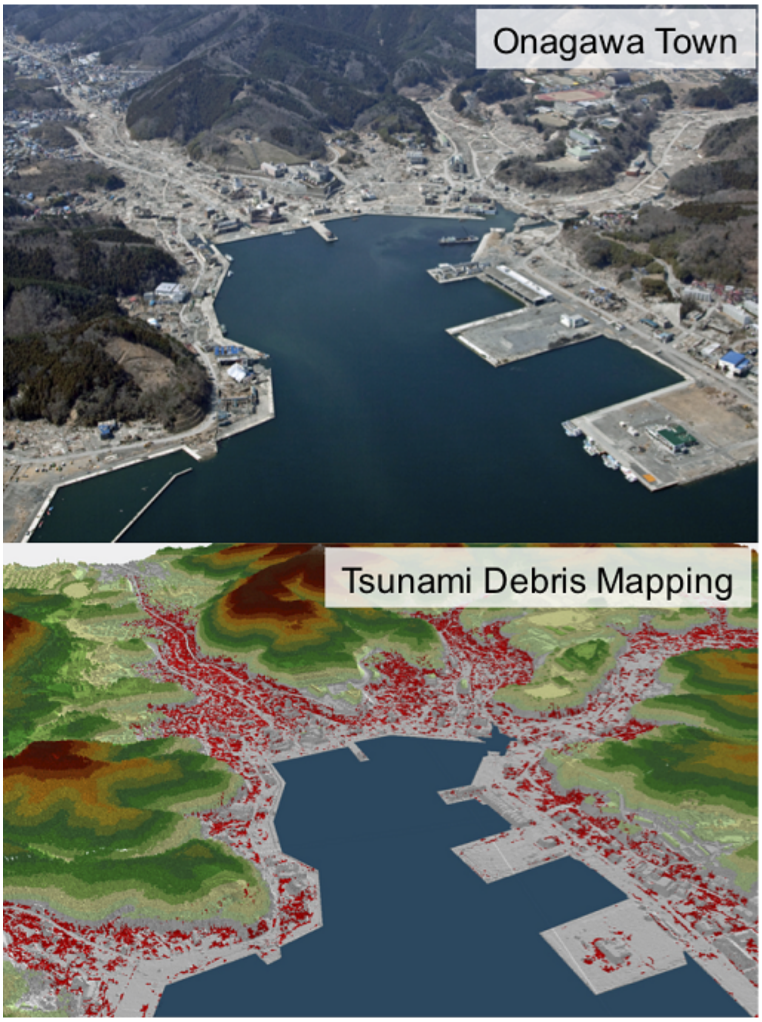

Figure 13-4. Three-dimensional mapping of debris in Onagawa town, Miyagi Prefecture. The upper figure shows a bird's eye view of the urban area of Onagawa, and the lower figure shows the estimated distribution of the debris.

4: Achievements and the Future

A new approach to disaster science

Remote sensing technology is expected to make great advances in the future, thanks to the use of a variety of platforms, improvements in sensor performance and resolution, progress in information and communication technology, and the use of AI for image recognition through machine learning. The challenge will be to ensure the rapidity of observation and satellite constellation for emergency observation. Thus, international cooperation, coordination and standardization of sensing and analysis technologies are necessary.

Unmanned aerial vehicles (UAVs) also need to improve mobility in tough conditions. The development of hardware, sensors, analysis technologies, and interpretation methods must be carried out in a coordinated manner, and the capabilities of urgent operations of monitoring disaster affected areas must be proved at various disaster sites while meeting the most critical user needs.

Conclusion - from the authors

More detailed technical explanations and examples can be found in our publications.

References

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