Contributions of the Remote Sensing by Earth Observation Satellites on Engineering Geology

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Abstract

Many natural disasters including landslides are depending on terrain conditions i.e. topography, land-cover, land-use, soil composition, which are a kind of geospatial information and some of them can be observed by earth observation satellites. In addition, surface deformations may also be able to measure by satellites applying some processing techniques. This study is described some usage examples to derive geospatial information related to geology from satellite data, which is discussed how to contribute the satellite remote sensing techniques for prevention and response to natural disasters.

The Japan Aerospace Exploration Agency is developing and operating earth observation satellites. The Advanced Land Observing Satellite (ALOS, nicknamed “Daichi”) and ALOS-2 satellites are major contributors for monitoring land regions based on their characteristics. The former was launched in 2006, and unfortunately completed the mission life on May, 2011 that is after the 2011 off the Pacific coast of Tohoku Earthquake. The later was launched on May, 2014, and is currently operating very well. In this paper, some application examples will be showed using data acquired by ALOS and ALOS-2.

Keywords: remote sensing, ALOS, ALOS-2, geospatial information

1. Introduction

Many natural geohazards including landslide are depend on terrain conditions i.e. topography, land-cover, land-use, which are a kind of geospatial information and some of them can be observed by earth observation satellites. This study is described how to contribute the satellite remote sensing techniques for prevention and response to such natural disasters, and show practical usage examples.

Topography is fundamental information for any geospatial applications including geology. The Japan Aerospace Exploration Agency (JAXA) is providing the precise global digital 3D map called “ALOS World 3D” (AW3D) that is processed using some 3 million images acquired by the Panchromatic Remote sensing Instrument for Stereo Mapping (PRISM) onboard the Advanced Land Observing Satellite “Daichi” (ALOS) (Tadono et al., 2014). The digital 3D map consists of a 5 m mesh digital surface model (DSM), and a 2.5 m resolution of ortho-rectified images (ORI), which enables us to express land terrain over the world. It can contribute to make hazard map in prevention phase as well.

“Daichi-2” (ALOS-2) has been launched on May 24, 2014, and is now operating very well. ALOS-2 carries on an L-band Synthetic Aperture Radar (PALSAR-2) and be able to obtain precise surface information in not only daytime but also nighttime even under bad weather conditions (Shimada, 2013). An advantage of PALSAR-2 is gives us subsidence information by interferometry due to use its longer wavelength of microwave as L-band. JAXA is conducted the emergency observations for assessing damaged areas when natural disasters are happened. An example of actual landslides monitoring occurred by the earthquake in Nepal 2015 is shown.

2. ALOS and ALOS-2

ALOS was launched on Jan. 24, 2006, and has operated very well over the mission target life of five years (Shimada et al., 2010). However, its operation was official termination on May 12, 2011 due to a power generation anomaly. Notwithstanding, approx. 6.5 million-scenes of archived data by three instruments covering the entire globe are available to users. Fig. 1 shows an overview of ALOS, which

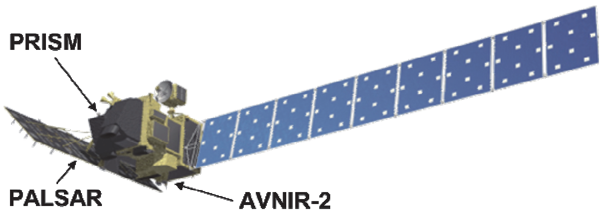


Fig. 1 Overview of “Daichi” (ALOS).

curried on two optical instruments called PRISM and AVNIR-2, and an L-band synthetic aperture radar called PALSAR. PRISM image has a 2.5 m spatial resolution with a 35 km swath width in triplet mode. It performs along-track triplet stereo observation to generate precise DSM. AVNIR-2 stands for the Advanced Visible and Near-infrared Radiometer type-2, which has four radiometric bands of a 10 m resolution. A color image with a 2.5 m resolution can be created using images of PRISM and AVNIR-2 as a pan-sharpened image.

ALOS-2/PALSAR-2 is followed on mission of the ALOS/PALSAR with some improved functions. PALSAR-2 can provide 1-3-m high-resolution Spotlight and Strip map with multiple polarizations with an imaging swath of 25/50/70 km, ScanSAR with dual polarizations with a 350/490 km swath, a shorter temporal baseline of 14 days and spatial baseline of within 1 km, emergency observation service within a 12-h delay for any global target and especially within a 72-h (74 h in the worst case) delay as synchronized observation with the archives, i.e. same off-nadir and observation mode, and ScanSAR interferometry with more than 90% global beam synchronization. Such function will be suitable a natural disaster monitoring and mitigation. Fig. 2 shows an overview of ALOS-2 in orbit.

3. Global Digital 3D Map by PRISM

PRISM global 3D map dataset processed in AW3D project consists of the precise DSM in 1 degree tiles of lat/long frame units, and ORI of nadir-looking image of PRISM in scene bases. The precise DSM has 0.15 arcsec (approx. 5 m) horizontal spacing with 5 m height accuracy (root mean square error, RMSE) as the target accuracy. This is achieved by stacking and mosaicking processing using multi-temporal acquired scenes of DSM. The ORI has 0.075 arcsec horizontal spacing, which corresponds to approx. 2.5 m original resolution. The correlation coefficient image (CCI) is an intermediate product of the image matching processing in DSM generation. A summary of CCI is given in the quality assessment information (QAI) that is attached in the product. An overview and technical challenging were summarized by Tadono et al. (2014) and Takaku et al. (2014).

The AW3D dataset was released from March 2014 in commercial bases, and is scheduled to be

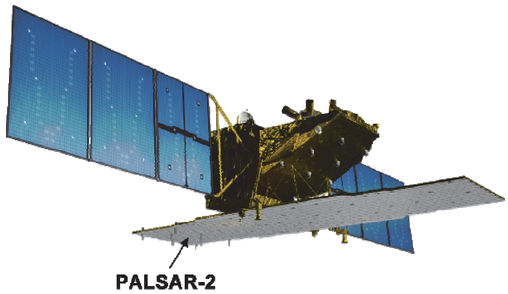


Fig. 2 Overview of “Daichi-2” (ALOS-2).

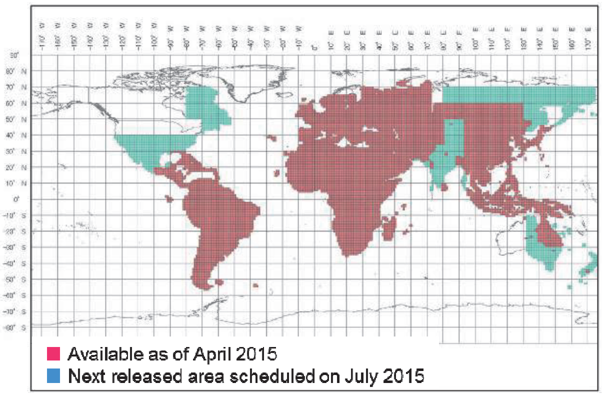
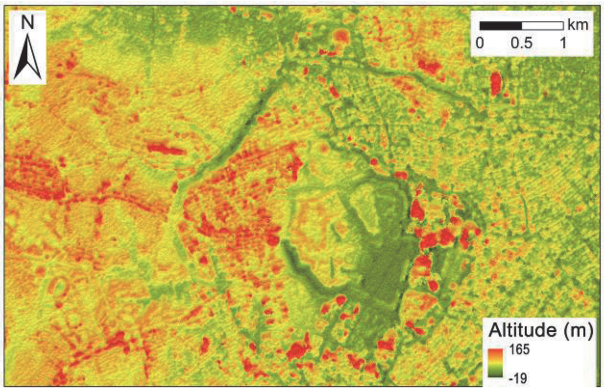


Fig. 3 Processing status and next released plan of AW3D dataset tiles as of April 2015.

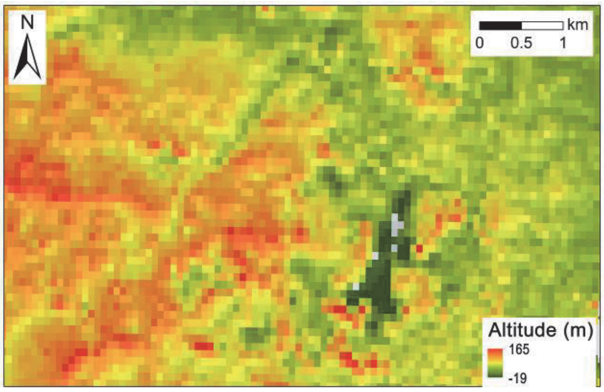
complete the global dataset by March 2016. Fig. 3 shows the AW3D dataset processing status as well as next released plan as of April 2015. Approximately 11,000 tiles of the dataset out of 22,000 tiles have been completed as of April 2015, which is corresponding to 60% in aerial fraction coverage of the global terrestrial regions. Priority of the data processing areas is determined based on the user needs and requirements. Therefore, North America, Greenland, and Antarctica have relatively lower processing priorities, and are processing soon. Even available PRISM archived data are used in AW3D as much as possible, the masks due to clouds are still remaining in the first version of the dataset.

Fig. 4 shows an example of DSM/DEM image comparison between (a) AW3D DSM in 5 m mesh and (b) version 2 of the Shuttle Radar Topography Mission (SRTM) in 90 m mesh as existing global DEM in Tokyo, Japan. The color assignments of both DSM/DEM are same, therefore they are clearly seeing that AW3D DSM can identify more detail textures and large buildings.

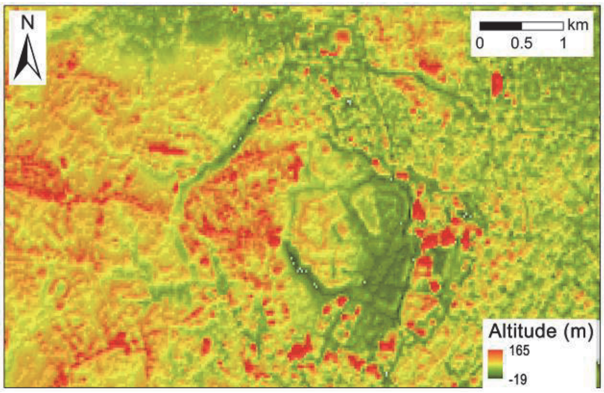
The aim of AW3D dataset generation is to provide the global digital elevation data with precise accuracy, therefore validations for widespread areas are important. Two validation procedures are applied operationally; (a) comparison between AW3D DSM and existing global DEM i.e. SRTM version 3 (v.3) to identify systematic errors and masks status in widespread areas as a relative validation, and (b) evaluation using ground-based check points (CPs) as



(a) AW3D DSM (5 m mesh).



(b) SRTM version 2 DEM (90 m mesh).



(c) AW3D30 DSM (30 m mesh).

Fig. 4 Comparison among (a) AW3D DSM (5m mesh), (b) SRTM version 2 (90m mesh), and (c) AW3D30 DSM (30m mesh) in Tokyo, Japan.

an absolute validation.

The absolute height validation of AW3D DSM dataset was conducted using 4,662 CPs distributed in 103 tiles as an initial validation that located in not only Japan area but also foreign countries. Fig. 5 shows the histogram of height error evaluated by 4,662 CPs, where red bars are the results for AW3D DSM, and green bars are for SRTM v.3 as just reference. The shapes of histograms look Gaussian distribution with almost zero peaks, but AW3D's one is much sharp than SRTM's one. Table 1 summarizes statics of evaluation of AW3D DSM and SRTM as

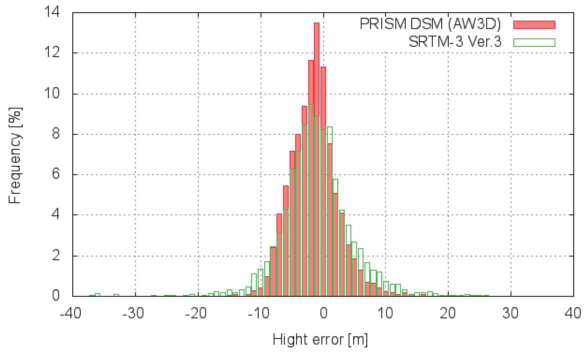


Fig. 5 Histogram of height error evaluated by 4,622 CPs in 103 tiles (red: AW3D DSM, and green: SRTM version 3 as a reference).

Table 1 Validation results by 4,622 CPs.

Dataset	Ave. (m)	STDEV (m)	RMSE (m)
AW3D	-1.51	3.81	4.10
Ref) SRTM v.3	-1.11	6.13	6.23

*Ave.: average, STDEV: standard deviation, Ref: reference

just a reference. It was confirmed 3.81 m (standard deviation, STDEV) and 4.10 m (RMSE) of height accuracy for AW3D DSM, which was gained the target accuracy of 5 m (RMSE). Similar evaluations will be continued when new tiles are available.

An example of practical usage of AW3D in geology, Fig. 6 shows the landslide volume estimation in Koslanda, Sri Lanka, which was occurred on October 29, 2014. It affected more than 1,000 peoples (320 families) and over one hundred were estimated to be missing based on the report. The Japan International Cooperation Agency (JICA) Sri Lanka office was conducted the aerial survey on November 5, 2014, and analyzed terrain height after the landslide (JICA, 2014). As the results, the landslide was approx. 100 m in width and 260 m in length with an average depth of about 15 m, and the mass was roughly estimated about 260,000 m^3 and half remained on the upper slope.

Addition to AW3D DSM 5 m mesh dataset, JAXA is started to publish a lower resolution version free of charge for any users, which has a 1 arcsec (approx. 30 m) resolution of AW3D DSM (AW3D30) dataset that is created based on original 5 m mesh DSM dataset. Two resampling methods are applied to calculate AW3D30 i.e. averaging and median resampling. The nearest neighbor resampling will be added in next release. Fig. 4 (c) shows an example of AW3D30 DSM, and can be seen that still remaining terrain feature details. AW3D30 DSM should have 5 m height accuracy as target, and similar validation will be conducted. The first release of AW3D30 was offered East Asia, including Japan, and South East Asia regions since May 18, 2015, and will expand the areas to all over the world. AW3D30 dataset is expected to be useful for scientific research, education, as well as for the private service sector that uses geospatial information (JAXA EORC, 2015).

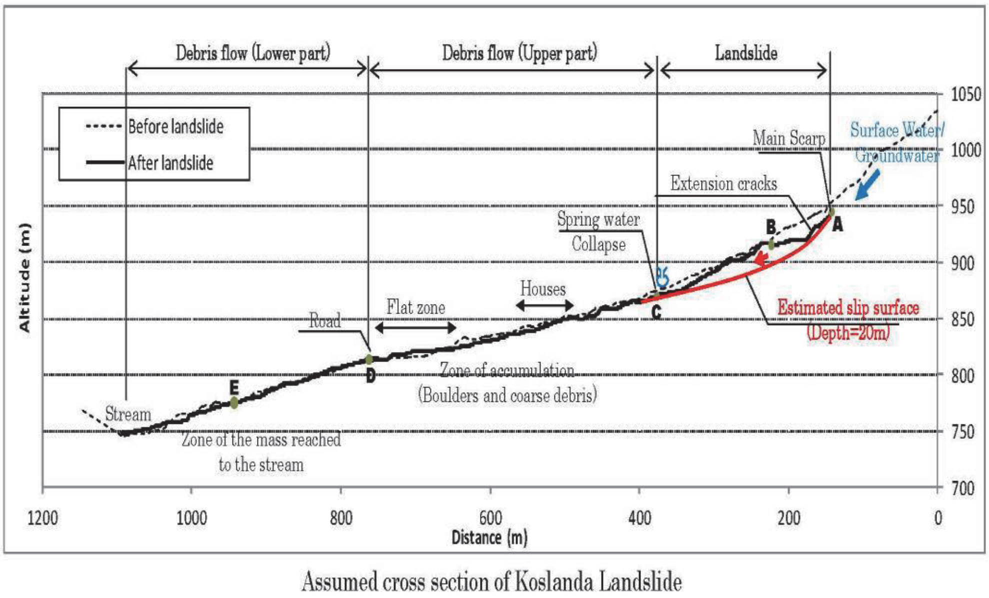


Fig. 6 Example of landslide volume estimation in Koslanda, Sri Lanka. This shows slope profiles change compared AW3D DSM (dash line as before event) and the analyzed by aerial survey (the red line) after the event (©JICA).

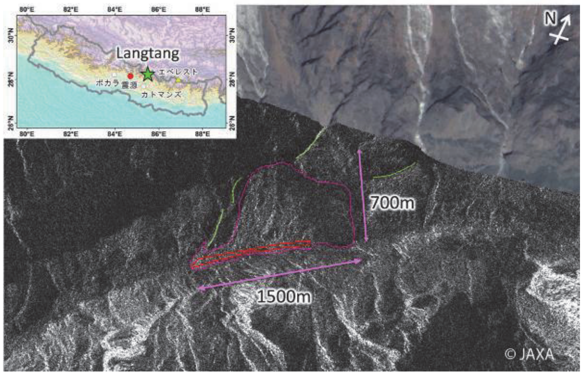


Fig. 7 PALSAR-2 image observed on April 26, 2015 acquired by the emergency observation. Green lines are identifiable ridges (as markings of terrain), a red polygon is showed the debris covered riverbed area, and a pink polygon is the estimated damaged area. The background image is an ALOS pan-sharpened image.

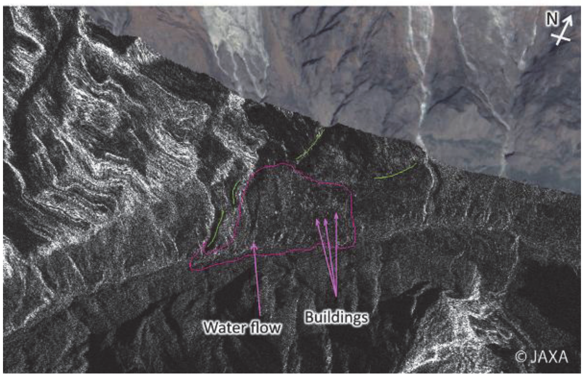


Fig. 8 PALSAR-2 image observed on Dec. 28, 2014 as before the earthquake. Green lines, a pink polygon, and the background image are same with Fig. 7.

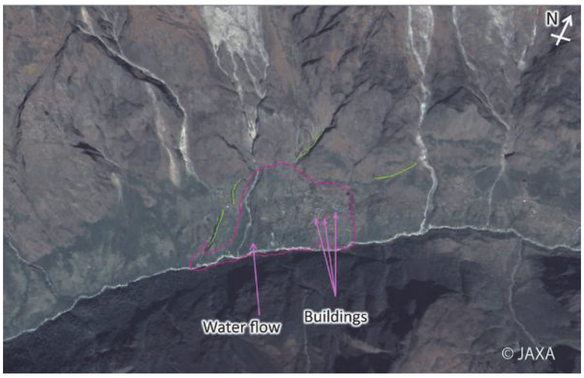


Fig. 9 ALOS pan-sharpened image acquired on Oct. 12, 2008. Green lines and a pink polygon are same with Fig. 7.

4. Natural Disaster Monitoring by ALOS-2

As an example of emergency observation result by ALOS-2, the earthquake occurred in Nepal on April 2015 is summarized.

Corresponding to the emergency requests from "Sentinel Asia" and the "International Charter" related to the earthquake occurred in Nepal on April 25, 2015, JAXA performed an emergency observation at 7:02 (GMT) on April 26, 2015 by PALSAR-2 onboard ALOS-2. Fig. 7 is a close-up image acquired by the PALSAR-2 Ultra Fine mode (3 m resolution, HH polarization). It shows a post-quake situation around Langtang village, Nepal, which is located on a famous trekking route in the Nepal Himalayas. The brightness of the image represents the signal received by PALSAR-2, which is the amplitude of the backscattering microwave from the ground. Comparison between this image and pre-

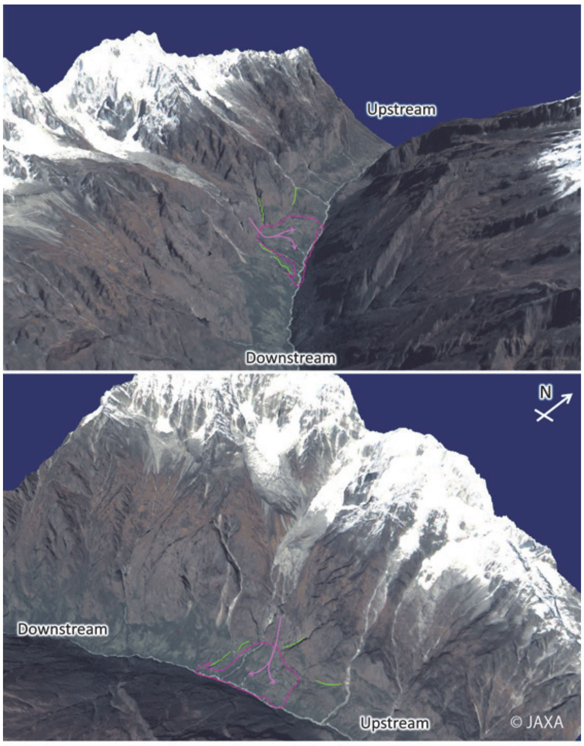


Fig. 10 Birds-eye view of pan-sharpened image taken by PRISM and AVNIR-2 on Oct. 12 2008. Green lines and a pink polygon are same with Fig. 7.

quake image suggests a large displacement of avalanche and/or landslide covering the river bed. For comparison, a close-up image acquired before the earthquake, December 28, 2014, is shown in Fig. 8. A great change can be identified on the surface. Fig. 9 is a pan-sharpened image obtained by ALOS PRISM and AVNIR-2 on October 12, 2008 as a reference. The bright points and a valley-shaped feature denoted in Fig. 8 correspond to buildings and water flow, respectively. Damaged area is estimated to be the pink polygon because of their disappearances.

Fig. 10 shows birds-eye views around the damaged area from two angles, in which the ALOS pan-sharpened image is overlaid on PRISM DSM. The damaged area is located on the bottom of a U-shaped valley, above which several glaciers are distributed. A large displacement induced by the earthquake is implied here.

An emergency observation with ALOS-2 estimated that the damaged area affected by a displacement in Langtang village ranges approx. 1,500 m in width and 700 m in length as shown in Fig. 7. These results have been reported to the concerned authorities immediately to support their rescue and recover activities. JAXA will continue the observation in Nepal in cooperation with them.

As seen from the above example, the images acquired both pre- and post-event are most important to response natural disasters because change detection is a fundamental approach. Therefore, both ALOS and ALOS-2 introduce the basic observation scenario, which is acquired the data systematically as foreground mission operation plan. This is an advantage JAXA's land observation mission to contribute disaster monitoring as well as preventions.

5. Conclusions

In this paper, contributions of the satellite remote sensing for response and prevention to natural disasters, which includes practical examples to monitor landslides were described.

Topography is a fundamental information not only geology but also any geospatial applications. Although PRISM data were acquired from 2006 to 2011, derived DSMs has the best height accuracy in the global digital elevation dataset, therefore AW3D project have particularly large expectations for many users. It can also be used as base map in the disaster monitoring and mitigations. Also, AW3D30 DSM dataset was introduced that now freely available.

ALOS-2 is now operating that carried on PALSAR-2 and can be observed not only daytime but also nighttime even under bad weather conditions. A practical example to monitor landslide caused by the earthquake in Nepal 2015 was introduced, which analyzed only amplitude image. PALSAR-2 has a big potential to apply the interferometry to measure subsidence caused by earthquake, volcanic activity as well as potential dangerous landslides. This will also contribute to monitor natural disasters.

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