

## GEOMORPHOLOGICAL ANALYSIS ASSOCIATED WITH THE 2007 NOTO HANTO EARTHQUAKE BY LIDAR DEM

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### ABSTRACT

On 25 March 2007, the Noto Hanto earthquake (Mw 6.9, 37.3°N, 136.5°E) struck the Hokuriku region facing the Sea of Japan. The earthquake caused severe damage and uplift about a few 10cm around the coastal area. Hokuriku Electric Power Co. had already had airborne LiDAR data (Oct. – Dec. 2006), so acquired struck area again (Mar. – Apr. 2007). Hokuriku Electric Power Co. and Asia Air Survey Co., Ltd. are trying to develop practical methods for geomorphological/geological analysis using before and after LiDAR DEM. First, change detection method was developed less subject to errors such as misregistration, filtering operation, seasonal vegetation changes, etc. Because DEM accuracy became higher in order to detect a little elevation change. We only used data on roads, then interpolate and averaged whole area. Extracted deformation pattern by this method corresponds to the results of levelling, GPS, and differential SAR interferometry. Next, semi-automatic approach of land surface recognition, especially marine terraces classification, was examined. Several terraces widely distributed in Noto Peninsula, and these marine terraces are very important for studying historical uplift caused by earthquake. We applied supervised classification method to DEM-derived terrain parameters and made a detailed geomorphological map. This study was the first attempt in the world to analyze geomorphological phenomena associated with an earthquake using airborne LiDAR.

### 1. INTRODUCTION

At 9:51 A.M. local time on 25 March 2007, the Noto Hanto (Hanto means Peninsula in Japanese) earthquake struck the Hokuriku region facing the Sea of Japan. The epicenter located in the west of the Noto Peninsula in the sea (37.3°N, 136.5°E) with magnitude Mw 6.9 by Japan Meteorological Agency. Especially in Monzen district in Wajima city, where northwest of Noto peninsula, the earthquake caused severe damages such as landslides, rockfalls and collapses of old wood-frame houses, but fortunately causality produced minimum.

The seismic activity of the submarine earthquake source faults uplifted coastal area about a few tens of centimeters. After the earthquake, however, there still remain unrevealed whether surface ruptures associated with earthquake surface faults emerged or not. Moreover, local tectonic deformation in hilly inland where followed aftershocks had not investigated yet.

Hokuriku Electric Power Co. had continued to investigate geology and geomorphology in service area, and had already acquired the airborne light detection and ranging (LiDAR) data before earthquake. Therefore, Hokuriku Electric Power Co. and Asia Air Survey Co., Ltd. tried to acquire earthquake-affected area again in order to analyze crustal deformation by comparison with before and after digital terrain model (DEM).

The purpose of this study is to develop practical methods for geomorphological/geological analysis using before and after LiDAR DEM.

## 2. STUDY AREA

Noto Peninsula is projected north at Hokuriku region into the Sea of Japan (Fig. 1). Most part of peninsula is covered hilly mountains with 400-200m height. These mountains are divided into tilting blocks by active faults. Several levels of marine terraces are widely distributed around coastal area, and thin coastal plain are fringed. Bedrocks consist of tertiary volcanic and sedimentary rocks, so they tend to generate many landslides.

Noto Peninsula's geomorphological settings are determined by complex interaction of seismic uplifting and landslide's dissection. So it is important to investigate geomorphology and geology for future earthquake disasters.

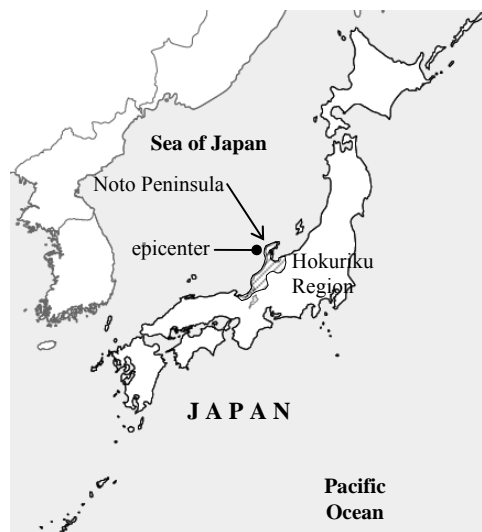
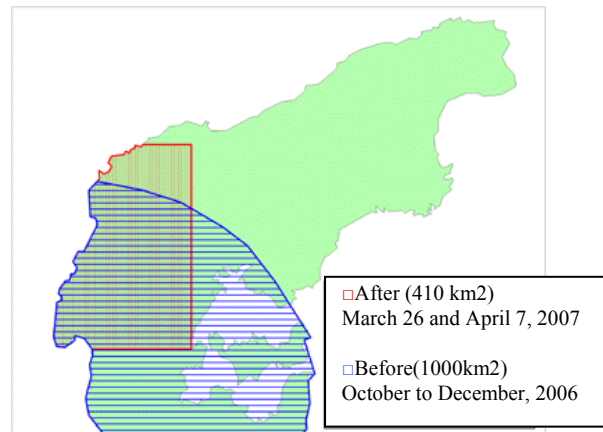


Figure 1. Study Area

## 3. LIDAR DATA ACQUISITION AND PROCESSING

LiDAR is a technology that uses a transmitted laser pulse to measure point coordinates (x, y, z) on the terrain surface. Airborne LiDAR mapping system is a combination with global positioning system (GPS) and inertial measurement unit (IMU) onboard the aircraft. All point clouds data obtained by LiDAR are processed with classification and filtering to remove vegetation and building. Extract bare earth points data are interpolated by irregular triangulation (TIN) and arranged to 1m-grid DEM datasets in JGD2000 plane coordinate system zone 7.

Before the earthquake, LiDAR survey had held from October 2006 to December, in the south central part of the Noto Peninsula, about 1000km<sup>2</sup>. After the earthquake, LiDAR and digital photography survey had carried out on March 26 and April 7 in the epicentral area, about 410 km<sup>2</sup>. The survey specification and coverage map shows below (Table 1, Figure 2).



**Figure 1. Acquisition area of airborne LiDAR data**

**Table 1. Airborne LiDAR survey specification**

Items	Parameter (Average)	
	Platform (AirPlane)	C207
Laster Scanner	Optech ALTM3100	Leica ALS50
Measurement Height	1,200m	
Airplane Velocity	65m/sec	
Frequency	70,000Hz	
Distance between courses	About 385m	
Lap ratio between courses	35%	
Distance between Points	About 0.7m	
Numebr of courses	Before 174, After 56	

### 3.1. Accuracy assessment and improvement

Generally, the high-resolution DEM data from LiDAR seems to enable automatic and quantitative analysis effectively, however it is not easy to remove errors and refine data toward the level of advanced analysis. The datasets are obtained over some a long operation period, so they have errors arise from airplane condition, like gaps in overlapped area of courses. And more, the survey area is covered with dense forest from defoliating to foliating period.

But this mission aims to extract changes of land surface in sub-meter order, because maximum vertical displacement are 41 centimeters with ground surveyed. So we need extra-high quality DEM by one meter horizontal resolution and a few tens centimeters vertical accuracy in minimal level.

In order to minimize those errors, we had performed calibration more accurately than official laser mapping criteria of Geographical Survey Institute of Japan. Extra validation point of the difference between the courses and known ground control points were added. In the result of these adjustments, an average of gaps between courses is cancelled, and vertical absolute accuracy within 14 centimeters (before) and 9 centimeters (after).

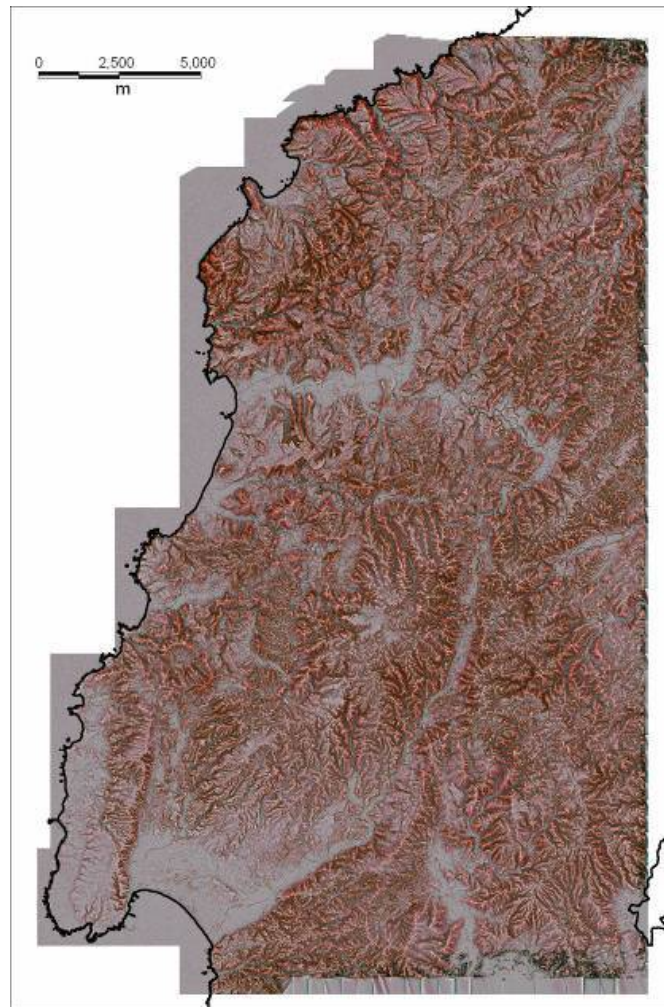
Furthermore, in order to check remaining error such as trees or buildings in the generated DEM data, we performed visual inspection of RRIM in following section.

### 3.2. Data Check with Visualization Technique

We utilize Red Relief Image Map (RRIM) in error check process and landform interpretation (figure 2). This pseude-3D visualization technique for digital elevation model are invented by Chiba(2000). This impressive RRIM image is made by just image processing of DEM and very useful for comprehensive cognition of geomorphological features in multi-scale. RRIM is made

from three landform elements values, which are slope, positive openness, and negative openness. Positive and negative openness were devised by Yokoyama et., al. (1998). Openness values can be calculated by large image window and difference between inverted negative openness and positive openness are corresponding to concavity and convexity. And overlaying red-colored gradient layer enhances three dimensional visual effects.

Red Relief Image Map overcomes some shortcoming of existing terrain visualization method, for instance, a dependency on sun direction of shaded relief, or a performance limitation of representation by contour map.



**Figure 2. Red Relief Image Map (RRIM) of after the earthquake LiDAR DEM**

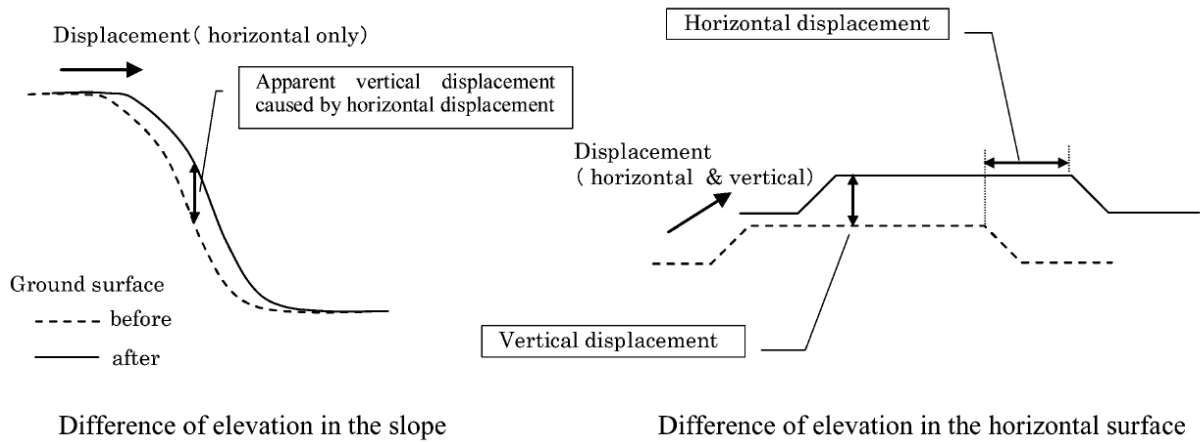
## **4. CHANGE DETECTION**

### **4.1. Avoidance of apparent displacement caused by misregistration**

At first, we tried to estimate tectonic displacement associated with the earthquake using a simple raster difference approach between before (from October to December, 2006) and after (from March to April, 2007) DEMs. Mentioned above, however, difference value between DEMs contains many errors due to flight course, spatial misregistration, filtering operation, seasonal vegetation changes, etc. Especially, spatial horizontal misregistration errors are sensitive to calculating vertical apparent difference values on steep sloping area (figure 3).

To avoid these problems, change detection method is applied only on road surfaces, and hilly vegetated area prone to the error is excluded. The traverse line data are digitized by tracing

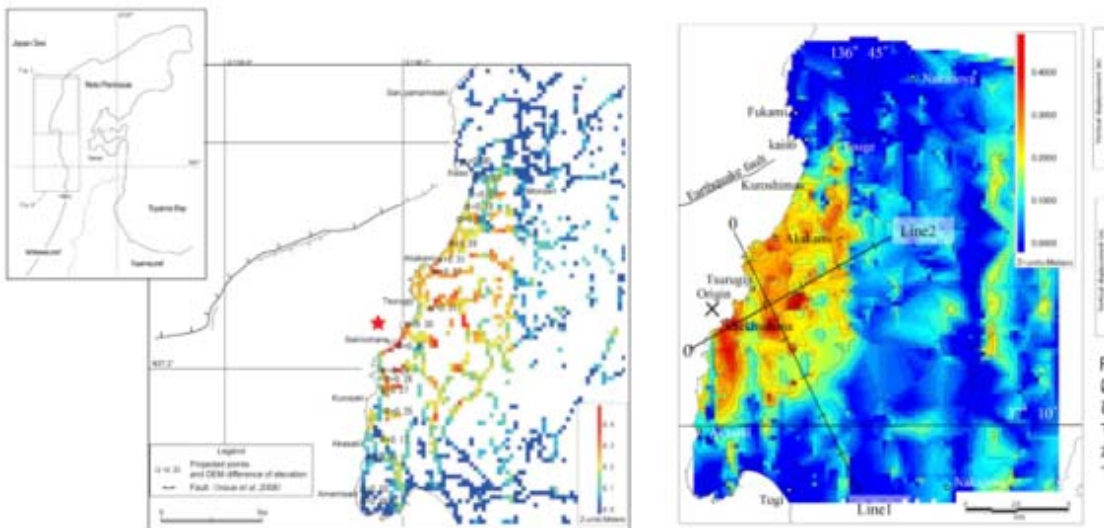
orthophoto manually on road surface, keeping from landslide area or collapsed road. The traverse line of roads are total length of 320km.



**Figure 3. Apparent vertical displacement and actual net slip**

#### 4.2. Difference distribution mapping

First, measuring points are generated on traverse lines at every one-meter interval. Then, calculate the difference of elevation between before and after on the same measuring points. Next, to cancel the effects of error factors such as fallen rocks or vegetation on the surface, the value of the difference was aggregated and calculated mode value in each 200m mesh. Finally, excluded area are interpolated from difference data on road surface, and create a vertical surface displacement distribution map in whole area (figure 4). As a result, deformation pattern became recognizable clearly, but deserve attention to an interpolated map.



**Figure 4. The vertical displacement map (left: only on road mesh right: interpolated map)**

#### 4.3. Detection of Deformation Pattern from LiDAR DEM

Extent of the vertical displacement spread along coastal area near earthquake source fault, and bounded about three kilometer form coast, and more inland area seems not to be affected. Maximum vertical displacement observed 0.45m in Sekinohana, Shika town, and averaging 30 centimeters in uplifted area. Higher values in eastern area seem to be error result from flight course

gap. These errors are already optimized to zero in each overlapped area, but slight value spatial irregularity emerged in the analysis result.

#### **4.4. Comparison with other Geodetic Data**

The displacement pattern by LiDAR were compared with levelling, GPS, and differential SAR interferometry.

Bench marks in uplifted area are levelled by Geographical Survey Institute. Their reported vertical displacement of bench mark reported are almost close to LiDAR's one. Some points records below slightly due to subsidence of road embankment.

GPS based control station (GEONET) are put five points into surveyed area. Their vertical displacement are also well accorded with result of LiDAR data within 10 centimeters.

Differential interferometry (DInSAR) using ALOS PALSAR data are reported by Ozawa et al. (2008). Extent of the displacement calculated by DInSAR is slightly larger than LiDAR's one, and area's shape is concentric circle. These difference between DInSAR and LiDAR are explained by data acquisition system, DInSAR's value are increase or decrease from ground to the satellite which incident angle are oblique, so its value is neither vertical displacement nor horizontal displacement.

### **5. GEOMORPHOLOGICAL ANALYSIS AND INTERPRETATION**

The Noto Hanto earthquake caused uplifting in the epicentral area, where several marine terraces are widely distributed. These marine terraces are very important for studying uplift caused by historical earthquakes. To reveal the long-term activity of the earthquake source fault, we compared the altitude distribution of the former shorelines on coastal terraces and Holocene emerged shoreline with co-seismic uplifts associated with the Noto Hanto earthquake.

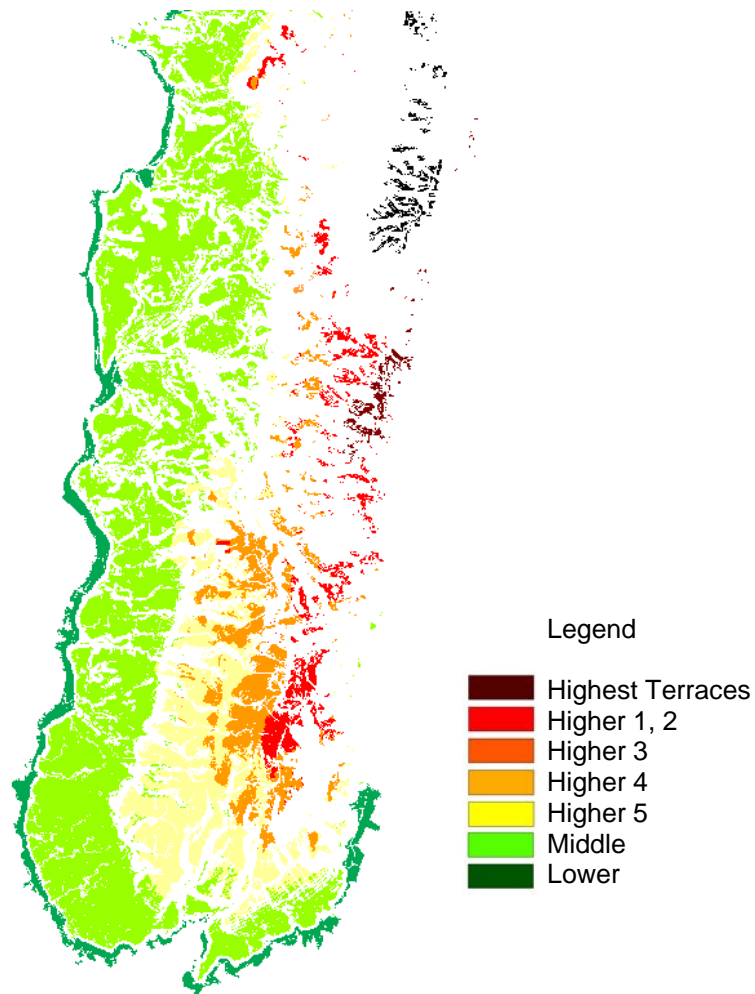
#### **5.1. Terraces classification**

Semi-automatic approach of land surface recognition, especially marine terraces classification, was examined. We applied supervised classification method to DEM-derived terrain parameters and made a detailed geomorphological map.

Training area polygons are digitized with manually interpretation of RRIM. The polygon data are overlaid on DEM and DEM-derived terrain parameter datasets. DEM-derived terrain parameters are chosen statistically tested, result in elevation, distance from coastline, slope, variance of elevation, profile curvature, planimetric curvature.

These parameters raster datasets are classified with maximum likelihood classifier in terrace classification map (figure 5) Seven terraces are able to recognise from DEM dataset, and ther land surface, such a alluvial fan or fluvial terraces are excepted.

Accuracy validation in training area shows good performance in middle terrace and higher V and III. By contrast, Lower terraces are not extracted successfully due to colluviums and sand dune.

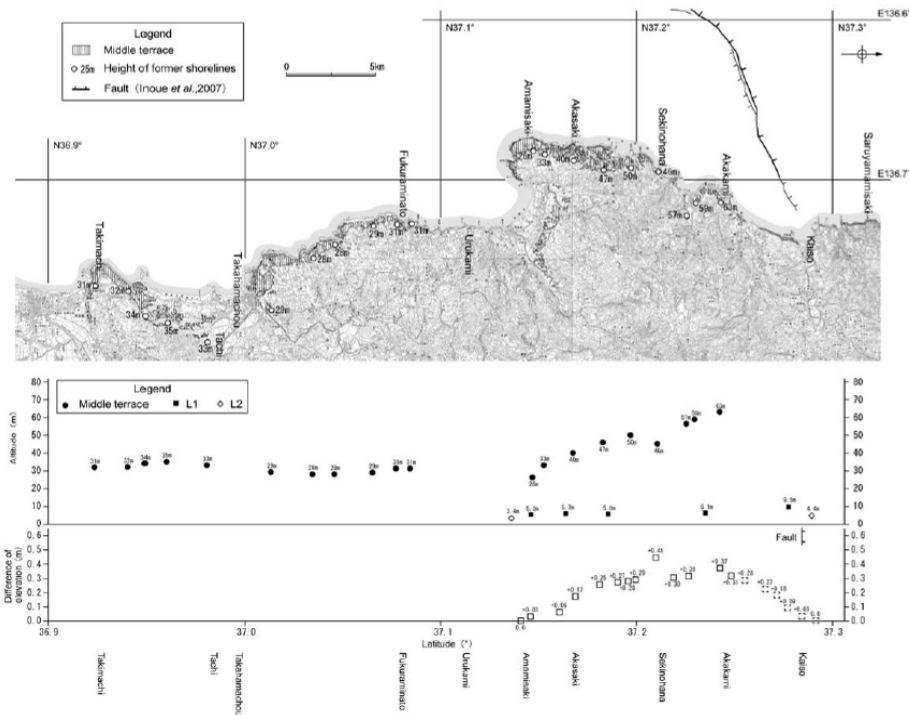


**Figure 5. Terrace Classification map from one meter LiDAR DEM**

## 5.2. Terraces classification

The one meter DEM generated from LiDAR of before earthquake is used for identifying of the former shorelines and evaluating the altitude of coastal terraces (figure 6). Under the assumption that the coastal uplift represents the cumulative crustal deformation produced by similar earthquake events to the 2007 one, the average recurrence interval of earthquake events is estimated to be 1500 years.

The altitude pattern of the paleo-shoreline angle on the middle coastal terrace, which corresponds to sea level of 120 ka (MIS5e), is concordant with the crustal deformation associated with the 2007 Noto Hanto earthquake.



**Figure 6. Height distribution and paleo-shoreline angle**

## 6. CONCLUSIONS

Using airborne LiDAR data acquired just before and after of the Noto Hanto earthquake, we created 1m-DEM and developed practical methods of geomorphological analysis. Tectonic deformation estimated with an approach of difference derived between two raster DEMs. Difference distribution map represents co-seismic surface deformation pattern in epicentral area. Despite the presence of a number of errors caused by airborne LiDAR survey, the extent of deformation and the value of vertical displacement are corresponding to the results of ground levelling, GPS, and differential SAR interferometry. The high-resolution DEM data are applied for semi-automatic cognition and delineation of marine terraces. Objectively-measured terrain attribute data are useful for refinement of landform classification map.

Paleo-shoreline angle elevation is measured in one meter DEM datasets, and elevation distribution of this coseismic uplifting and older uplifted landforms are compared. Both pattern is similar with each other, that means that a number of this type's co-seismic deformation repeated and cumulatively build up the topography in this area. Amount of uplift of the Noto Peninsula earthquake in 2007 was 0.45cm. Meanwhile, average elevation of paleo-shoreline angle of middle terrace which formed in MIS 5e (12.5) age lies at 37 meters at the present day. On the bases on hypothesis that co-seismic deformation pattern are unchanged and cumulative, in order to uplift middle terraces to modern level, same type earthquakes occur 83 times every about 1500 years interval.

This is the first attempt in the world to detect crustal deformation between before and after earthquake using airborne LiDAR. We continue to analyse this valuable data in the future work.

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