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GEOMORPHOLOGIC RESEARCH USING LIDAR DATA

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KEYWORDS

DTM, LIDAR, Remote Sensing

ABSTRACT

The airborne laser survey (LIDAR Survey) is a new survey technology, and is very useful for geomorphologic research such as disaster prevention. Because LIDAR survey can provide detailed DEM (Digital Elevation Model) with high resolution and high density, it is used for flood simulation in plain area. Because with LIDAR data, it is also possible to detect micro landform under forest area using last pulse data in autumn or winter season, it is useful for research of landslides in forest areas. Using detailed DEM, landform classification has been done by automatic landform classification method (Iwahashi and Pike, 2008) combining three categories, such as slope, texture (roughness) and convexity. As the vertical accuracy of LIDAR data is about 15cm, it is possible to detect deformation or displacement which are over 50cm by comparing two DEMs before and after earthquake or volcanic activity. In the case of Usu Volcano Eruption in 2000, LIDAR data showed the crustal deformation by the growth of lava dome under ground. In the case of Miyake-jima Volcano Eruption in 2000, LIDAR data of several periods showed topographic change of bottom of the crater. In the case of Niigata Prefecture Chuetsu Earthquake in 2004, the comparison between DEMs before earthquake and after earthquake showed crustal deformation with sub meter class by the growth of active fold. In the case of Niigata Prefecture Chuetsu-oki Earthquake in 2007, however, the small crustal deformation with 10cm by the growth of active fold in Nishiyama Hill is detected using InSAR technology. Information of refraction intensity of LIDAR data is also useful to detect disaster damage. Refraction intensity of LIDAR data is high on glass area, middle on soil or sand, and low on asphalt. In the case of Niigata Prefecture Chuetsu-oki Earthquake in 2007, it is easy to interpret sand volcano by liquefaction on glass area in park or on road using LIDAR intensity imagery. In this oral presentation, the authors show some kinds of geomorphic research results using LIDAR data in the case of the 2004 Chuetsu Earthquake and the 2007 Chuetsu-oki Earthquake. In this study, they try to produce the cross section profile of river terrace and river bed along small rivers using LIDAR data. The part of this research is supported by Grant-in-Aid for Scientific Research (C).

1. INTRODUCTION

Geospatial Information Authority of Japan (GSI) has been publishing various elevation data in a digital format, such as “Digital map 10m grid (elevation of volcanic area)”, “Digital map 10m grid (elevation)”, “Digital map 50m grid (elevation)”, and “Digital map 250m grid (elevation)”. These are made from the contour lines of 1/5,000 or 1/10,000 volcanic basic maps and 1/25,000 topographical maps. Since the beginning of provision of those products, demands for more detailed elevation data has been considerably increased. Fortunately, with the advent of improved measurement technologies, these have become more freely available. One of the technologies is airborne laser scanning (LIDAR: Light Detection and Ranging). GSI began publishing a “Digital map 5m grid (elevation)” using LIDAR data from 2003, as a basic resource for disaster prevention, land protection and land use planning in the public and the private sector.

LIDAR Survey is very useful for disaster prevention, as it is possible to get detailed DEM (Digital Elevation Model) which have high resolution and high density. In this paper, the authors introduce the example of utilization of LIDAR data for geomorphologic and environmental research field such as analysis of relationship between landform and disaster, landform and vegetation, and so on.

2. AIRBORNE LASER (LIDAR) SURVEY

LIDAR is an active measurement method in which the distance from the sensor to the ground is measured by processing the laser beam emitted from the onboard scanner and reflected on the ground. Aircraft positions are calculated using combinations of GPS data, both on the aircraft and on the ground. Aircraft acceleration and three-axial attitude data measured by an IMU (Inertial Measurement Unit) are also used for the calculation. Furthermore, the direction data of the laser beams are measured by an onboard sensor. These data are combined to calculate the three dimensional position (X, Y, Z) on the ground (Fig.1).

Akutsu et al. (2005) shows vertical accuracy of LIDAR survey. The sites which were selected as points for accuracy verification were flat ground surfaces such as parks. Coordinates of verification points acquired by LIDAR were compared with those derived from the ground survey using GPS and leveling. The results of comparison with the altitude value of leveling, was 0.03m on average (maximum +0.42m minimum -0.32m) and the standard deviation was 0.16m.

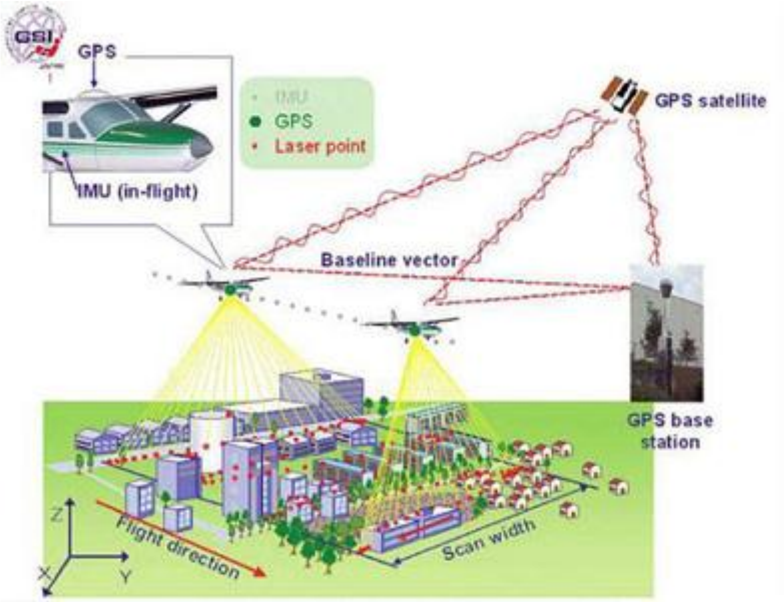

Fig.1 Image of airborne laser scanning (Akutsu et al., 2005)

3. UTILIZATION OF LIDAR DATA FOR FLOOD DISASTER PREVENTION

Disasters caused by heavy rainfall in urban areas bring damages such as chaos in the roads and railway transport systems, power failures, breakdown of the telephone systems and submersion of built up areas, subways and underground shopping arcades etc. It is important to obtain high precision elevation data which show the detailed landform as a slight height difference increases a possibility of damaging by flood very considerably. Therefore, the GSI is preparing 5 m grid DEM based on precise ground elevation data acquired by LIDAR.

Fig.2 shows the relationship between elevation and flooded area close to Fukuoka Station of the 2003 Fukuoka Heavy Rainfall （Kadowaki, 2007）. Shadowed area is flooded area, the left image shows elevation using 50m grid DEM, and the right image shows elevation using 5m grid LIDAR DEM. Although it is difficult to understand the relationship between elevation and flooded area in the left image, it is easy to understand that flooded area always correspond with relatively low elevation area in the right image. Fig.3 shows the relationship between elevation and flooded area on Sanjo City of the 2004 Niigata Fukushima Heavy Rainfall. The left image shows the simulated flooded area by 2m grid LIDAR DEM, and the right image shows actual flooded area of the 2004 Niigata Fukushima Heavy Rainfall, and this area correspond with the simulated area (Ando and Akutsu, 2006).

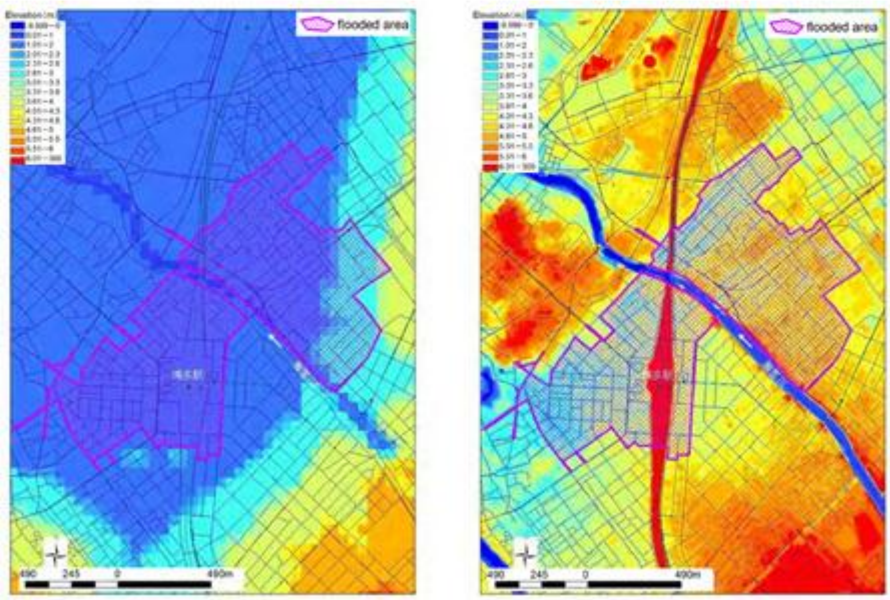

Fig.2 Relationship between elevation and flooded area of the 2003 Fukuoka Heavy Rainfall (Kadowaki, 2007)

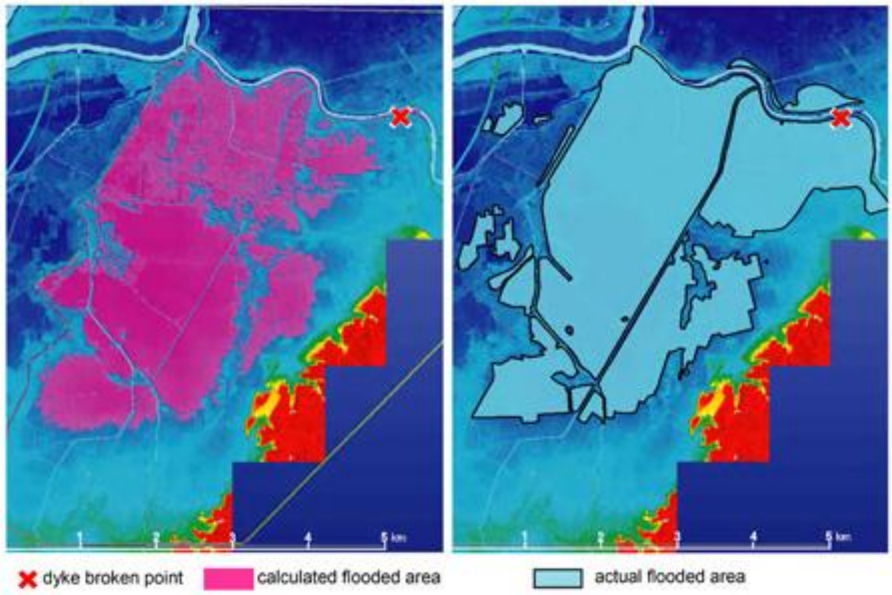

Fig.3 Relationship between elevation and flooded area of the 2004 Niigata Fukushima Heavy Rainfall (Kadowaki, 2007)

4. UTILIZATION OF LIDAR DATA FOR PREVENTION OF LANDSLIDES ON MOUNTAIN AREA

As LIDAR data are also possible to detect a micro landform under a forest area using the last pulse data in autumn or winter season, it is useful for research of landslides in forest areas. Fig.4 shows digital photo and LIDAR height data image of the mountains of Tertiary sedimentary rocks distributed from Izumozaki town to Nagaoka city in Niigata Prefecture. In this area, there are many slope collapses caused by the 1961 Niigata Heavy Rainfall and the 2004 Niigata Fukushima Heavy Rainfall. It is possible to interpreter slope collapse by aerial photo interpretation, however, it is easy to interpreter many slope collapses using LIDAR height data image compared withy aerial photo.

Iwahashi et al, (2009) had estimated the most suitable window size for the assessment of shallow landslides caused by heavy rainfalls using 2m resolution LIDAR DEM on this study area by the linear discriminant analysis. As the results, the most suitable window size for the study area is around 30m, and the most suitable window size is essentially proportional to the mean size of target landslides. Moreover, to obtain the most effective window, it is ascertained that the expansion of kernel size is better than the resolution-reduction of DEM.

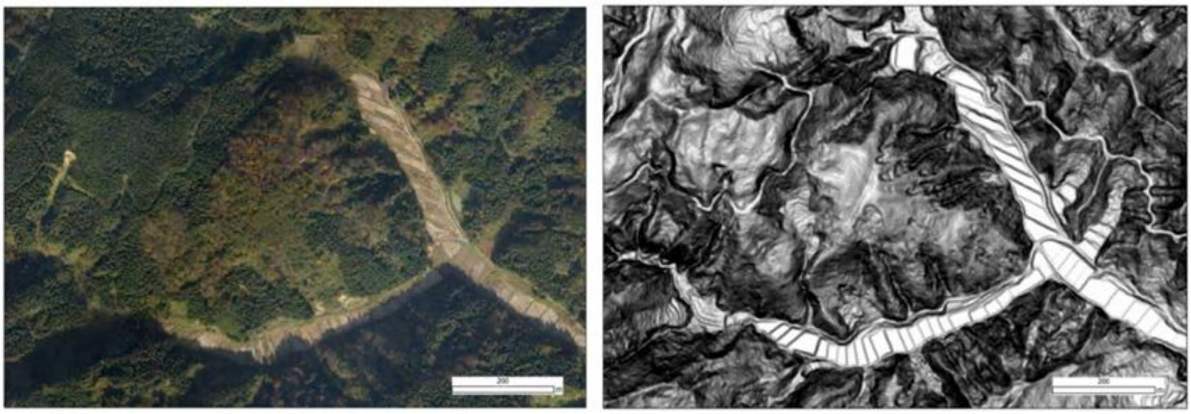

Fig.4 Digital photo (left) and LIDAR height data image (right) of Izumozaki Town (Iwahashi et al, 2009)

5. CRUSTAL DEFORMATION BY VOLCANIC ACTIVITY FOR COMPARISON BETWEEN TWO DEMS

As the vertical accuracy of LIDAR data is about 15cm, it is possible to detect crustal deformation or non tectonic displacement with more than 50cm by comparing two DEMs before and after earthquake or volcanic activity.

In the case of the Usu Volcano Eruption in 2000, LIDAR data showed the crustal deformation by the growth of lava dome under ground. GSI had repetitively monitored the surface displacement in and around Usu volcano by digital photogrammetric method using stereo aerial photos (Koarai et al., 2002). The advantage of this method is that it can map the spatial distribution of deformation even in the area where instruments commonly used such as GPS cannot be applied. As a result of the analysis, it was found that; before the eruption of March 31, the uplifted area was concentrated around the cinder cone of Usu volcano. After the eruption began, the uplifted area shifted to Konpira-yama and Nishi-yama area. After April 3, the uplifted area was limited in the area around Nishi-yama.

In the case of Miyakejima Volcano Eruption in 2000, LIDAR data of several periods shows topographic change of bottom of creator (Hasegawa et al., 2007). The study investigated the evolvement of the caldera at Miyakejima volcano between February 2001 and September 2003. Hill shade image of Miyakejima volcano acquired in September 2003 is shown in Fig.5. DEMs acquired with LIDAR surveys were used for analysis. Topographic changes for each surface category were examined and the change in shape was analyzed. Results showed that the caldera floor had risen more than 10 m because of secondary sediment caused by collapse of the caldera wall. However, topographic changes on slope surfaces were limited to gullies. The caldera wall height was 450m at its maximum with a steep slope. Analysis of the shape change revealed that the volume of the caldera increased by 10.0 million volume meters. Lost substance in the new crater and around it reached 8.6 million volume meters , whereas volume expansion of other areas was only 1.7 million volume meters. These facts indicate that the main cause of caldera expansion was the formation of a new crater. As a whole, the caldera volume has continued to increase. Additionally, the caldera wall slope is steeper than the angle of repose. These facts imply that enlargement of the caldera area will continue for the time being.

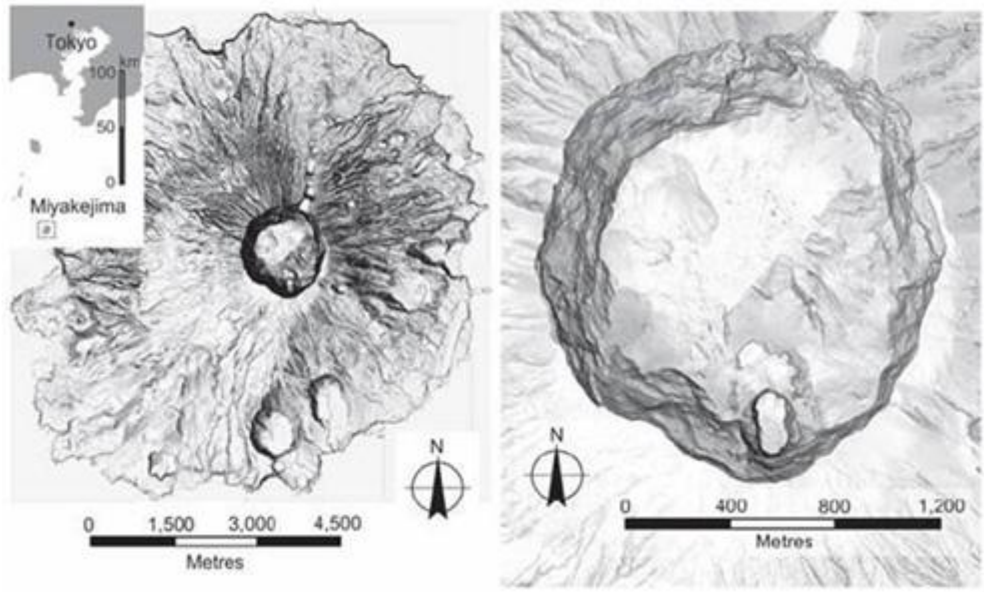

Fig. 5 Hill shade image of Miyakejima volcano. Original DEM was acquired on September 2003. (Hasegawa et. al., 2007)

6. LANDSCAPE ECOLOGICAL STUDY USING LIDAR DATA

Koarai et al. (2010a) tried to produce landscape ecological map for estimation of biodiversity using LIDAR data. Study areas are Mt. Rausu of Siretoko Peninsula, Hokkaido Island for World Natural Heritage Area of Japan and Mt. Dougo of Chugoku Mountain area for Satoyama rural region.

Basic legend of landscape ecological map consists of the combination of three dimensional vegetation structure classification using detailed DSM (Digital Surface Model) and micro landform classification using detailed DEM. By the LIDAR Survey in summer and autumn seasons, the authors got 0.5m grid DSM and DEM in summer and 1m grid DSM and DEM in autumn.

Vegetation classification was done using three dimensional vegetation structure detected by the difference between LIDAR data in two seasons. The legend of three dimensional vegetation structure maps consists of the combination of vegetation height, thickness of crown and difference in two seasons (deciduous single layer forest, deciduous multi layer forest and evergreen forest). Fig.6 shows LIDAR vegetation classification map of the north foot of Mt.Dougo.

Landform classification had been done by automatic landform classification method (Iwahashi and Pike, 2007) using detailed autumn season DEM, combined three categories, such as slope degree, convexity and roughness (texture). Fig.7 shows automated landform classification map of the north foot of Mt.Dougo.

The results of overlay analysis between vegetation classification and landform classification are as follows: On the Mt. Rausu, three dimensional vegetation structures are dominated by site elevation compared with micro landform classification. On the Mt. Dougo, some early deciduous high think crown trees (a kind of nut) are concentrated in historical mining sites (Kanna-Nagashi) with following micro landform categories such as gentle slope, concave and rough texture. Typical historical mining sites are shown as A and B in Fig.7.

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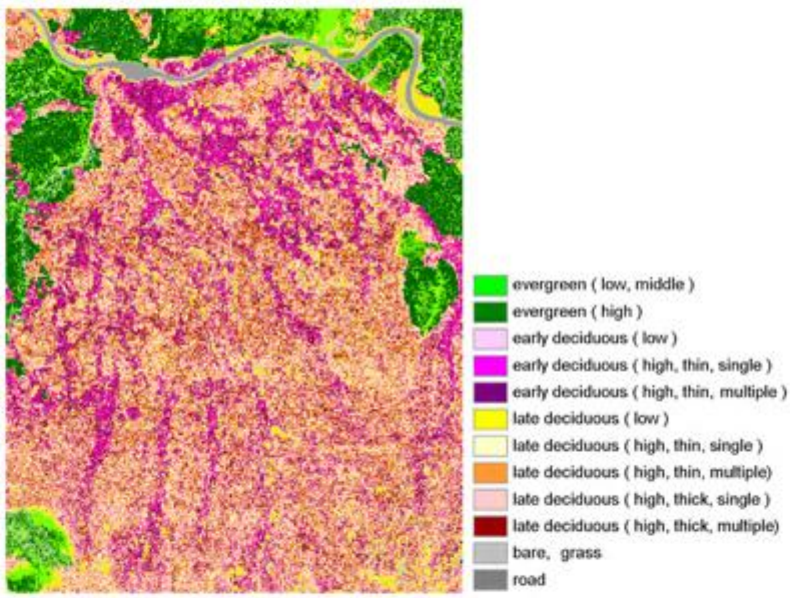

Fig.6 LIDAR vegetation classification map of the north foot of Mt.Dougo in Satoyama rural region (Koarai et al., 2010a)

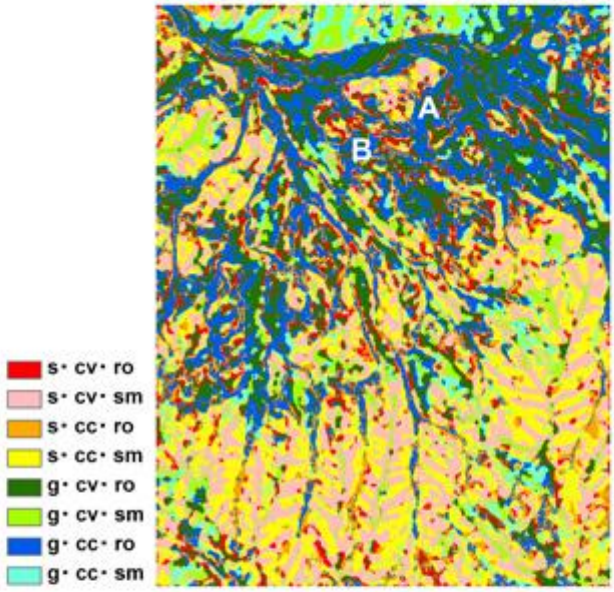

Fig.7 Automated landform classification of the north foot of Mt.Dougo in Satoyama rural region

7. REFRACTION INTENSITY OF LIDAR DATA FOR DETECTING DISASTER DAMAGE

LIDAR data is useful to detect a damage situation just after a catastrophic disaster occurred. In this chapter, the case of the 2007 Niigata Prefecture Chuetsu-oki Earthquake is introduced (Koarai et al. 2008).

Fig.8 is LIDAR height data image of the Sabaishi River Memorial Park in Kashiwazaki City. Line A-A' and B-B' shows ground deformation with northeast – southwest direction fracture. On field survey, tension cracks with 40cm vertical displacement were recognized. Around C area, the land subsidence by liquefaction was recognized.

Information of refraction intensity of LIDAR data is also useful to detect disaster damage. Refraction intensity of LIDAR data is high on glass area, middle on soil or sand, and low on asphalt (Hasegawa, 2006). In the case of the Chuetsu-oki Earthquake, it is easy to interpret sand volcano by liquefaction on glass area in park or on road using LIDAR intensity imagery. Fig.9 is LIDAR intensity data image of same area of Fig.8. Dark area in circle A and B shows sand volcanoes in grass, and bright area in circle C and D shows sand volcanoes in road and parking.

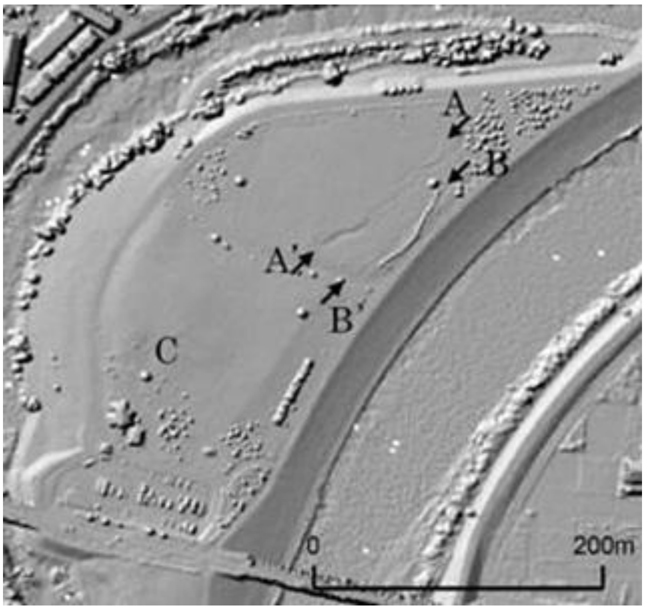

Fig.8 LIDAR height data image of Sabaishi River Memorial Park in Kashiwazaki City (Koarai et al., 2008)

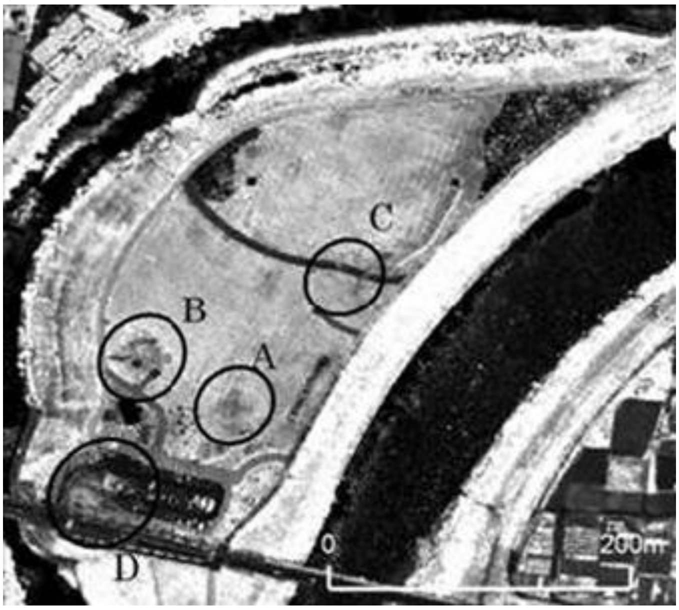

Fig.9 LIDAR intensity data image of Sabaishi River Memorial Park in Kashiwazaki City (Koarai et al., 2008)

8. RELATIONSHIP BETWEEN SLOPE COLLAPSE AND LANDFORM EVOLUTION OF ACTIVE FOLD ZONE

Large earthquakes occurred in Chuetsu District, such as the 2004 Niigata Prefecture Chuetsu Earthquake and the 2007 Niigata Prefecture Chuetsu-oki Earthquake. There are many active folds in Chuetsu District.

In the case of the 2007 Chuetsu-oki Earthquake, the small crustal deformation with less than 10cm uplift by the growth of active fold in Nishiyama Hill was detected using InSAR technology (Koarai et al., 2010b), and several slope collapses occurred in Nishiyama Hills.

In the case of the 2004 Chuetsu Earthquake, 0.5-1.5m uplift by the Earthquake was detected by difference between the DEM measured by photogrammetry using aerial photos taken before earthquake and the DEM by LIDAR data measured after earthquake (Konagai et al., 2007), and many slope collapses and landslides by earthquake are concentrated in Imokawa-River region.

The authors try to survey the relationship between the growth of active fold by earthquake and the concentration of slope collapses by earthquake. In this presentation, the authors show some kinds of geomorphic research results using LIDAR data in the case of the 2004 Chuetsu Earthquake and the 2007

Chuetsu-oki Earthquake. Fig.10 is the cross section profile of river terrace and river bed along small rivers using LIDAR data.

There is Asama-Kusatsu tephra which erupted from Asama Volcano on 15ka, on upper terrace only in Imokawa River region. Then, there is no terrace which is older than 15ka along Imokawa-River, and it means that uplifting ratio of Imokawa-River region is large. As the relative elevation between oldest terrace and river bed is 20m in downstream and 30m in upstream, uplift ratio is 1.3-2 mm/year. If amount of uplift of the Chuetsu Earthquake is about 1m, the cycle of one earthquake would be 500-770 years. Other way, Koarai et al. (2010b) estimated uplift ratio of Nishiyama hills is 0.8mm/year (1000m uplift for 1.2 million years).

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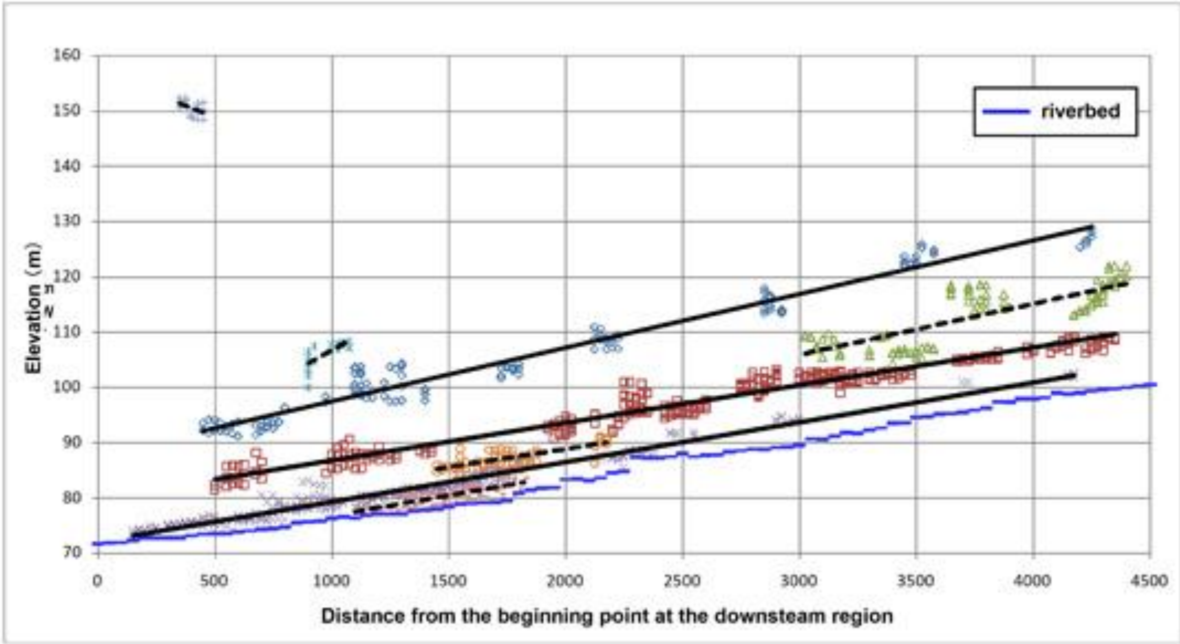

Fig.10 Cross section profile of river terrace and river bed along Imokawa River, Niigata Prefecture using LIDAR data

9. CONCLUSION

In this paper, the authors introduced example of application of LIDAR Data for geomorphologic research field such as disaster prevention and environmental protection. Detailed DEM by LIDAR was used for flood simulations in plain areas, detection of micro landforms such as slope collapses and landslides under forests. It is possible to detect deformation or displacement with more than 50cm by comparing two DEMs before and after the disaster. It is possible for landscape ecological analysis to combine automated landform classification by detailed DEM and three dimensional vegetation structure classification by detailed DSM. Information of refraction intensity of LIDAR data is also useful to detect disaster damage. Finally, the authors showed the geomorphic consideration using the cross section profile of river terrace and river bed using LIDAR data in the case of the 2004 Chuetsu Earthquake and the 2007 Chuetsu-oki Earthquake.

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In this paper, the authors introduced geomorphic research using LIDAR, not only our research division's results but also other results such as the results of Geographical Department of GSI, and the results of former division stuffs who are Dr. Hiroshi P. Sato, Mr. Hiroyuki Hasegawa and Dr. Junko Iwahashi.

REFERENCES

Akutsu, O., M. Ohta, T. Isobe, H. Ando, T. Noguchi and M. Shimizu, Development and Utilization of High Precision Digital Elevation Data taken by Airborne Laser Scanner. Bulletin of the GSI, 52, 13-21, 2005

Ando, H. and O. Akutsu, Compilation of a Disaster Information Map of Lower Stream of Shinano River Damaged by Niigata and Fukushima Heavy Rain in July 2004, Using Airborne Laser Survey. Reports of GSI, 110, 55-63, 2006 (in Japanese with English abstract)

Hasegawa, H., Evaluations of LIDAR reflectance amplitude sensitivity towards land cover conditions. Bulletin of the GSI, 53, 43-50, 2006

Hasegawa, H., H. P. Sato and J. Iwahashi, Continuous Caldera Changes in Miyakejima Volcano after 2001. Bulletin of the GSI, 54, 60-64, 2007

Iwahashi, J., I. Kamiya and H. Yamagishi, Estimation of the Most Suitable Window Size of the Slope Gradient and Convexo-Concave Index for the Assessment of Shallow Landslides Using High-Resolution LiDAR DEM. Transactions, Japanese Geomorphological Union, 30(1), 15-27, 2009 (in Japanese with English abstract)

Iwahashi, J. and R. J. Pike, Automated classifications of topography from DEMs by an unsupervised nested-means algorithm and a three-part geometric signature. Geomorphology, 86, 409-440, 2007

Kadowaki, T., Provision and application of detailed three dimensional digital fundamental information, Reports of the 36 th GSI presentation meeting, 57-66, 2007 (in Japanese)

Koarai, M., H. Hasegawa, Y. Iida, K. Matsuo, N. Watanabe and H. Suzuki, Monitoring Surface Deformation of Usu Volcano Using Digital Photogrammetry. Volcano, 47(3), 139-150, 2002 (in Japanese with English abstract)

Koarai, M., H. Hasegawa, H. P. Sato and H. Une, Relationship between building damage and ground deformation caused by the Niigata-ken Chuetsu-Oki Earthquake in 2007 –Detection of ground deformation using LIDAR data-. Geo-pollution Science, Medical Geology and Urban Geology, 4(2), 17-28, 2008 (in Japanese with English abstract)

Koarai, M., T. Nakano, H. P. Sato, T. Yoshida, A. Yamashita, R. Nagasawa and Y. Hioki, LANDSCAPE-ECOLOGICAL MAPPING USING LIDAR DATA FOR BIODIVERSITY EVALUATION. Proceedings of ISPRS Symposium 8, 2010a

Koarai, M., H. Une, T. Nishimura, H. Yarai, M. Tobita and H. P. Sato, Detection of surface deformation and growth of an active fold induced by the 2007 Niigataken Chuetsu-oki Earthquake using SAR interferometry. Journal of Geology, 116(11), 602-614, 2010b

Konagai, K., T. Ikeda, S. Takatsu and T. Fujita, Scientific Detection of Landform Changes in Active Folding Zones. Lecture abstracts of symposium for disaster prevention in active-folding areas, Japan Society of Civil Engineers, 4-14. 2007 (in Japanese with English abstract)