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How the NGIA of Japan responded to the Great East Japan Earthquake*

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Key words: natural disaster, earthquake, tsunami, Japan, national geospatial information authority

SUMMARY

This paper summarizes the activities of Geospatial Information Authority of Japan (GSI), the national geospatial information authority in the Japanese Government on its disaster response to the Great East Japan Earthquake in 2011 and identifies major achievements and challenges.

Since the massive Earthquake took place on 11 March 2011, GSI has played a major role in disaster response activities in the Japanese Government. Out of these activities, this paper focuses on prominent ones including: detection and analysis of ground surface movements; aerial photo survey; tsunami inundation mapping; and provision of base maps. Its follow-up activities for reconstruction support of damage areas are also included.

In addition, outstanding achievements of GSI in these activities are addressed, including quick gathering, processing and provision of data; new arrangements for effective and efficient data delivery to the users; and wider use of its products, particularly in rescue and recovery operations.

Lastly, the challenges for further improvement are identified. They include: ensuring resiliency and redundancy of communication, energy and other important facilities in GSI against disasters; further rapid data development; and data provision that meets a variety of user needs.

1. INTRODUCTION

The Great East Japan Earthquake has brought enormous loss of lives and damages of properties to the people and lands of Japan. As soon as the main shock occurred on 11 March 2011, Geospatial Information Authority of Japan (GSI), the national geospatial information authority in the Japanese government, established emergency headquarters in order to gather, develop, and provide relevant geospatial information for responding organizations and the people. While initial emergency activities have been finished, follow-up activities are still continuing as of March 2012.

This paper first shortly summarizes the disaster. Following, GSI's response to the disaster and achievements and challenges recognized are given ending with conclusion.

2. GSI's commitments to disaster measures

Since Japan is vulnerable to large-scale natural disasters such as earthquakes, tsunamis, volcanic eruptions, typhoons, protecting citizens and properties from disasters has always been an important subject. To this end, the Disaster Measures Basic Law was enacted in 1961 as a national framework for measures against disasters. GSI has served as one of the designated administrative organs, designated by the Prime Minister under the Law since 2001.

GSI develops its Disaster Management Operation Plan, by stipulation of the Law. The Plan describes the principles of measures and activities in disaster operation cycle. It also defines GSI's two missions in disaster management operation: 1) providing information on natural phenomena including crustal movements, and 2) providing topographic and land condition information of the country. Under the Plan, GSI maintains Disaster Management Operation Manual which prescribes the organization and resource mobilization in disaster response phase. Departments within GSI further establish their operation manuals.

However established rules and procedures by itself do not assure good performance during disaster. A number of drills have been regularly exercised in Japan at all levels to maintain quick responsiveness and resource

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mobilization. GSI also conducts such drills organized by central government and by itself at least several times a year.

Major GSI's disaster response experiences in recent decades includes: Great Hanshin-Awaji Earthquake (1995), Mt. Usu volcanic eruption (2000) and Niigata-ken-Chuetsu earthquake (2004). Notably Mt. Shinmoe volcanic eruption and Typhoon No. 12 (Talas) were also experienced by GSI in 2011, in addition to that of Great East Japan Earthquake.

3. GREAT EAST JAPAN EARTHQUAKE, SUMMARY

3.1 The main shock

The main shock of the 2011 off the Pacific coast of Tohoku Earthquake, , occurred at 14:46(JST) 11 March 2011. The epicenter was located about 130km ESE from Osika peninsula, Miyagi prefecture and 24 km in depth (JMA, 2012). The hypocentral area of the earthquake in the boundary between two plates extended 400km in N-S and 150km in E-W directions. Moment magnitude (Mw) of the earthquake is 9.0. It was the largest in Japan's recorded history and was the fourth largest one since 1900 (USGS, 2012). A massive shake (more than 6+ in Japanese seismic intensity scale) was detected in Miyagi, Fukushima, Ibaraki and Tochigi prefectures during the main shock. The main shock generated the huge tsunami which was more than 10 meters in height and 40m at maximum in run-up height, devastated the wide range of Pacific coast of Tohoku province (JMA, 2012) (TETJSG, 2012).

3.2 Major damages

The huge tsunami washed away many lives and properties in the coastal areas. The number of dead and missing as of March 2012 amounted to 19,125 (NPA, 2012). Most victims were in Iwate, Miyagi and Fukushima prefectures. More than 90% of casualties were caused by the tsunami. Many of the buildings and infrastructure were damaged by the tsunami. Some areas have been permanently inundated since the tsunami, due to the land subsidence up to one meter caused by the earthquake (see 4.2).

Fluvial plain and reclaimed areas in Chiba and Ibaraki prefecture, close to Tokyo metropolis were struck by the land liquefaction due to the strong shakes. These areas were suffered from inclination of building, disconnection of water and gas pipes, inundation of rice paddies with the deposition of naturally pumped sands.

The earthquake and the tsunami also triggered a severe accident of Fukushima Daiichi Nuclear Power Plant. Because the ECCS, or emergency core cooling system of the Plant got damaged it did not work. Nuclear reactor was broken by the melted nuclear fuel, causing the emission of radioactive materials into the air. Many residents around the Plant had to evacuate to avoid radioactivity contamination and have to endure a severe life since then.

3.3 Damages of GSI properties

Thanks to the completion of base isolation (earthquake free) system in December 2010, the main building of GSI headquarters were all safe, despite of the severe shake. Damages of other structures were not serious, however office furniture including map lockers was broken and documents were scattered on the floor after the earthquake. It was fortunate that there were no human damages within the organization.

Meanwhile geodetic observation facilities in the field were damaged. One GNSS based station was totally washed away and two stations were partly damaged by the tsunami. Soma tidal station in Fukushima prefecture was totally devastated by the tsunami.

4. RESPONSE OF GSI TO THE GREAT EAST JAPAN EARTHQUAKE

4.1 Management

Following its Disaster Management Operation Manual, GSI entered into emergency status and set up emergency headquarters (EHQs) immediately after the main shock. EHQs served as the decision making body in disaster operation. The first EHQs meeting was held 15:10, 11 March (JST), within thirty minutes after the main shock. Subsequent two EHQs meetings were held on the same day. Chaired by the Director General of GSI, executives identified the damages of the facilities and status of staff and discussed initial actions to be taken. The EHQs meetings were held twice to four times a day during the first week, once a day in the rest days of March. Figure 1 shows the summary of GSI disaster response activities.

As a government organ, GSI also dispatched its liaisons on 24 hour per day basis for two months to relevant organizations in order to identify geospatial needs and inform and provide GSI's products for response activities. Cabinet Secretariat's emergency operation center was one of them. The other was Disaster Response Headquarters of Ministry of Land, Infrastructure, Transport and Tourism (MLIT), to which GSI belongs.

Further, GSI sent its liaisons to local disaster operation centers in Miyagi, Iwate and Fukushima prefectures. The liaisons consisted of special team (called "TEC-FORCE") and staff of Tohoku Regional Survey Department of GSI. They introduced GSI's products to related organizations and provided the products for the use in field operation.

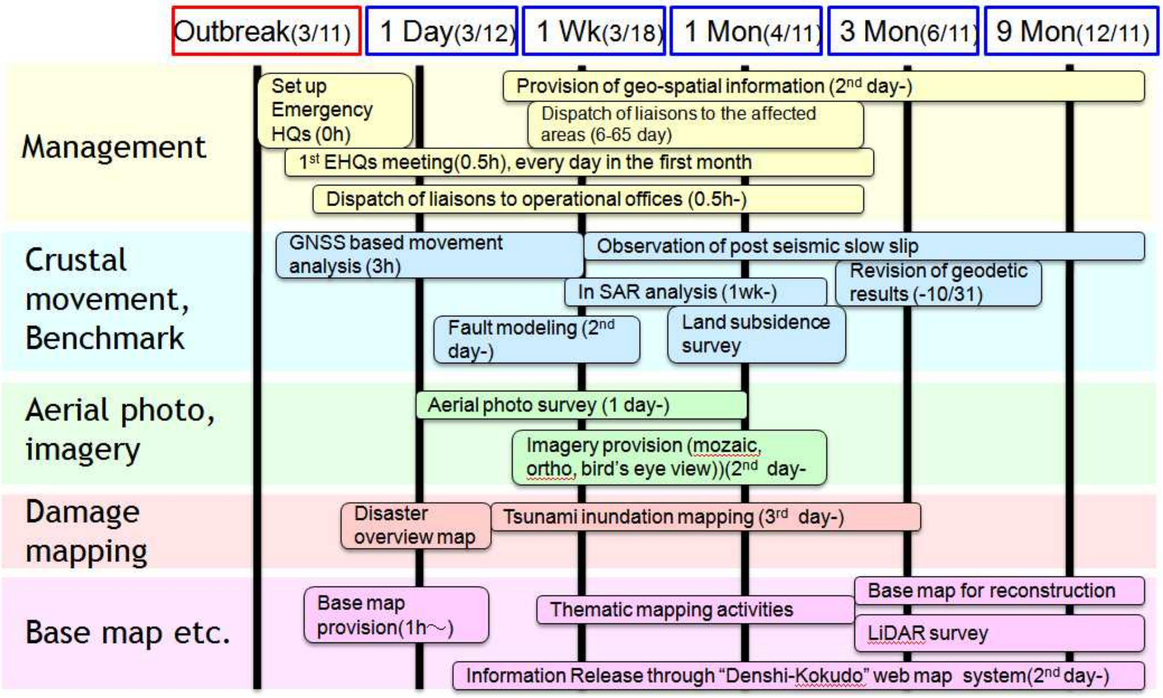

Figure 1 Summary of GSI disaster response activities

4.2 Ground surface movements

Since 1995, GSI has installed the GEONET system, with 1,200 GNSS continuous observation stations throughout the country for location reference services and detection of crustal deformation. After the main shock, GSI made its best efforts to get initial results of ground surface movements while struggling with power outage and unstable communication line. On the same day, GSI disclosed that 4m eastward movement and 70cm subsidence occurred at Kahoku GNSS based station. After a week, analysis of salvaged station data further revealed that Osika station, closed to the epicenter of the main shock, moved 5.3m eastward and subsided 1.2m. This movement was the largest one in the GEONET observation history (Figure 2 and 3).

A fault surface slip distribution model was derived from the GEONET observation data (Figure 4). According to the mode, the extent of slipping area was 450km (long axis) and 200km (short axis) with the maximum dislocation of 27 meters. This magnitude of slipping and accompanying post seismic dislocation can be compared with the release of stress of plate boundary accumulated 350 – 700 years (Ozawa et al., 2011).

It is notable that a large post seismic slipping movement occurred even after the main shock. This post seismic movement amounted to 88cm at Yamada GNSS-based station in Iwate prefecture by February 2012. The total energy released during the movements was estimated to be 8.58 at the scale of moment magnitude (GSI, 2011b). This movement posed a difficult decision making in justifying the timing of determination and announcement of new geodetic results in affected areas (Yamagiwa et al., 2012).

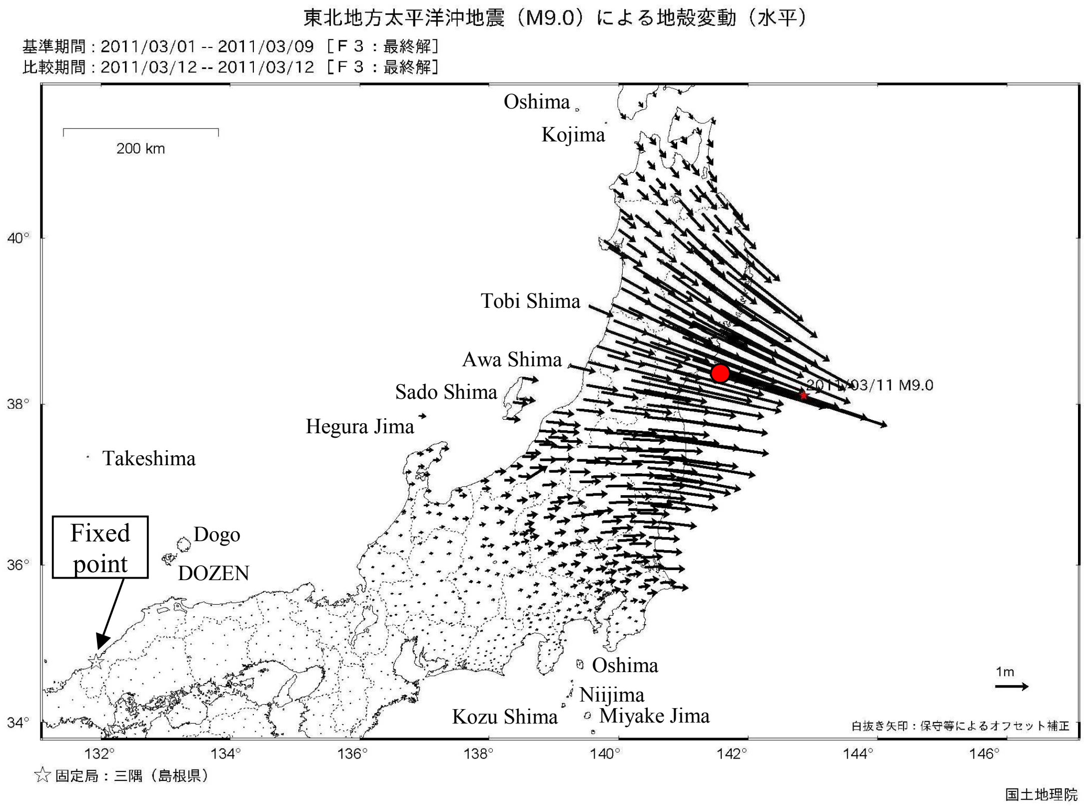

Figure 2 Horizontal displacements by the main shock

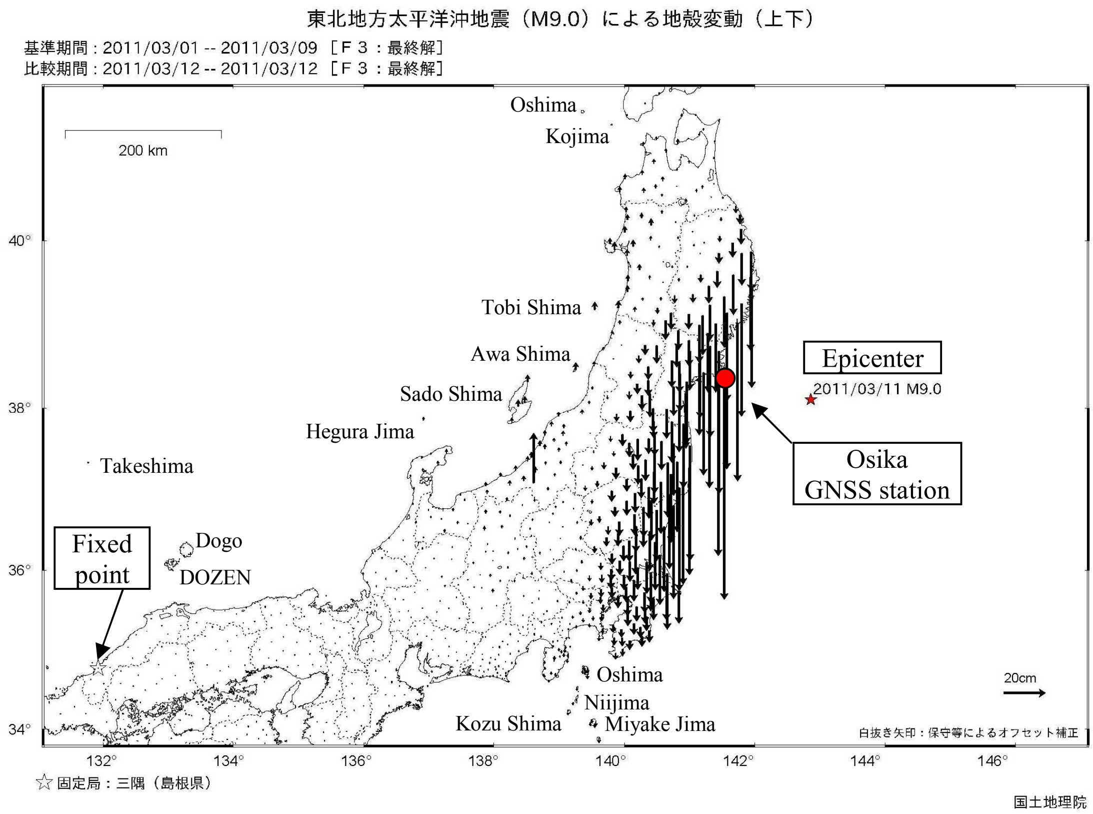

Figure 3 Vertical displacements by the main shock

GSI also detected surface movements by exploiting SAR (Synthetic Aperture Radar) interferometry (In SAR) method. Original data were captured by PALSAR sensor loaded on ALOS (Advanced Land Observation Satellite) by JAXA (Japan Aerospace Exploration Agency). Several batches of data observed from March to April 2011 were analyzed. Figure 5 shows the result. The results of surface movements estimated by InSAR analysis were concordant with that of GNSS observation. The areas moved extended 600km N-S and 200 km E-W directions. The largest movement (in the sense of difference in distances between pre- and post- earthquake from the sensor on board in the orientation of radar beam emitted) was 4 meters. Figure 5 also shows the local displacements caused by aftershocks during March and April (GSI, 2011c).

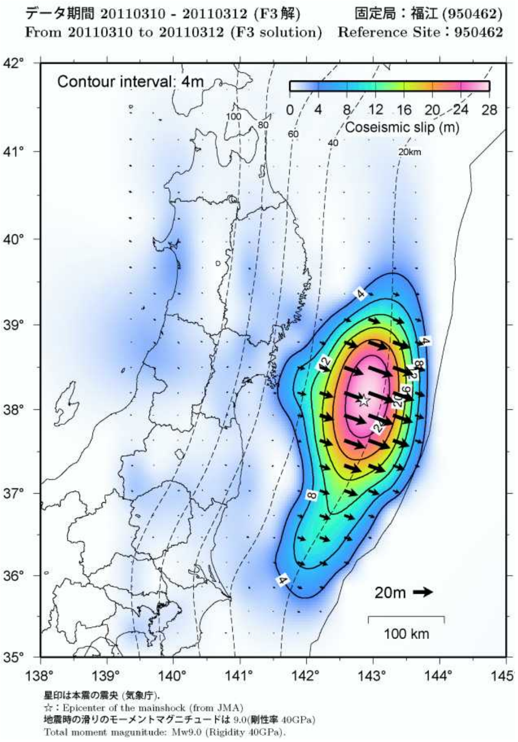

Figure 4 Estimated slip distribution on the earthquake fault plane (GSI 2011a)

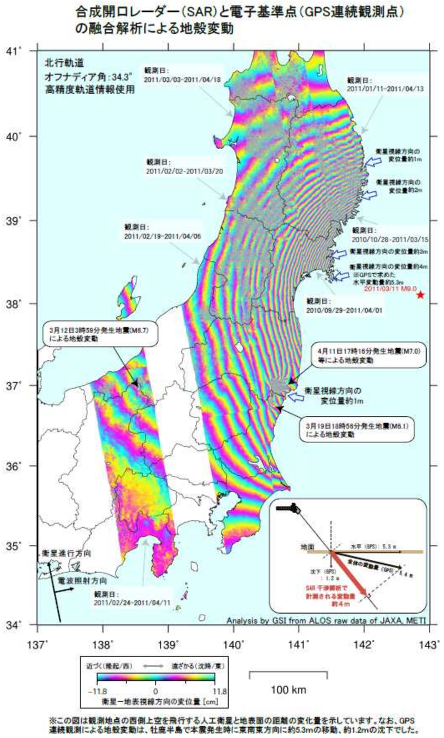

Figure 5 Surface movement distribution estimated by In SAR analysis (GSI 2011c)

4.3 Aerial photo survey

It is imperative for geospatial information organizations to take a quick action of acquiring imagery for damage reconnaissance in any circumstances. When the main shock occurred, GSI's survey aircraft "Kunikaze III" had been in process of periodical mechanical check till 31 March 2011. Therefore GSI aerial survey team took initial action by checking the availability of survey aircrafts of private companies, based on the Memorandum of Understanding between GSI and APA (Association of Precise Survey and Applied Technology) on the mobilization of survey companies' aircrafts in emergency cases. Six companies responded to the emergency request by GSI on that day. In parallel, GSI asked the MLIT and its regional bureau for their areas of interest for aerial photo survey. In spite of confusion and insufficient information due to the main shock, GSI compiled their requests and other information for the completion of survey plan, delegated to air crew teams.

Clear weather enabled the air crew teams to take aerial photos of major damaged areas on 12 and 13 March. The remaining areas were taken in the following survey missions. Final aerial photo coverage is shown in blue in Figure 6. Acquired data were duly processed as quickly as possible, mobilizing resources throughout the night. In general, the data were delivered to major government organizations and uploaded to GSI's website on the next day. When the first photograph appeared on GSI's website on 14 March, the access by the public suddenly increased. Some people gratefully reported that they were relieved to make sure that their friends' house was not damaged nor broken by the tsunami by viewing the photographs on the website.

Aerial photo products were produced in order series. Firstly, simple photos were made. Then photos were orthorectified using GPS/IMU data on the aircraft. Accordingly orthophotos and orthophotomap (Figure 7) (orthophoto overlain by line map with locality names and symbols) were produced. Orthophoto pairs were also made to show the difference of landscape before and after the earthquake in specific areas (Figure 8). Later bird's eye view (oblique view) aerial photos were also taken in additional aerial survey missions and released to the public.

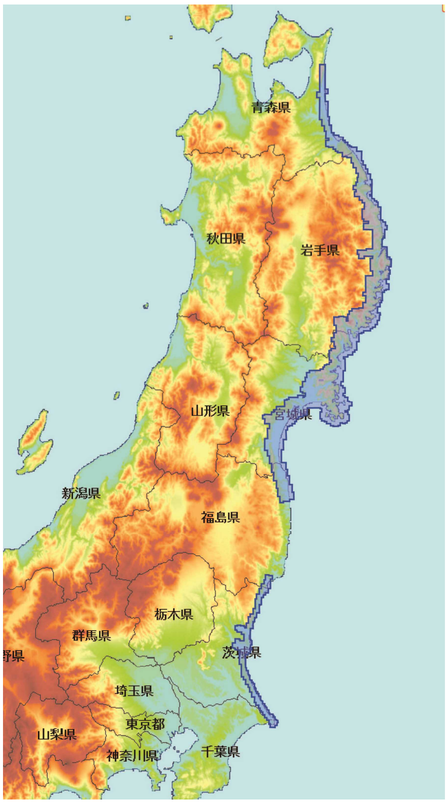

Figure 6 Aerial photo coverage (GSI 2011d)

Figure 7 An example of orthophoto map (10NF671), Rikuzen takada city (GSI 2011e)

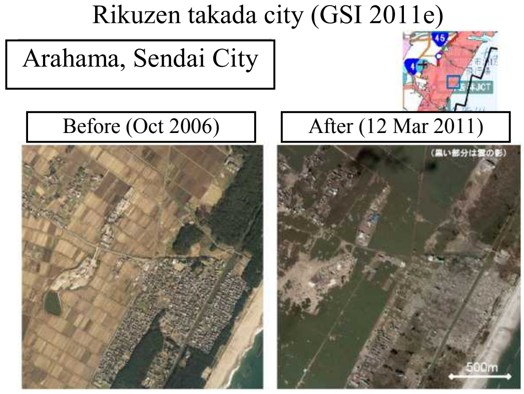

Figure 8 Landscape difference, before and after the earthquake (GSI 2011f)

4.4 Tsunami inundation mapping

Because it became clear that most damages were caused by the huge tsunami, identification of tsunami inundation areas became so important that various organizations including Cabinet Secretariat requested GSI to conduct it. Responding to their requests, GSI organized a working team consisting of staff members who has expertise in aerial photo interpretation.

When the first aerial photographs were delivered in the afternoon of 13 March, the team interpreted them to delineate the inundation areas by the tsunami. One thousand nine hundred aerial photos were interpreted to make the first version of inundation map for the delivery to the Cabinet Secretariat and major institutions on 14 March. No sooner had additional aerial photographs of damaged areas arrived, the team interpreted and delineated additional areas. Finally it was found that 561km^2 was inundated by the tsunami. Half of inundated areas were located in Miyagi prefecture (327km^2). Land use map series of inundated areas were also produced to show the character of land use pattern of inundation areas. The index map is shown in Figure 9. Inundation area map is shown in Figure 10. Land use of inundated area is in Figure 11.

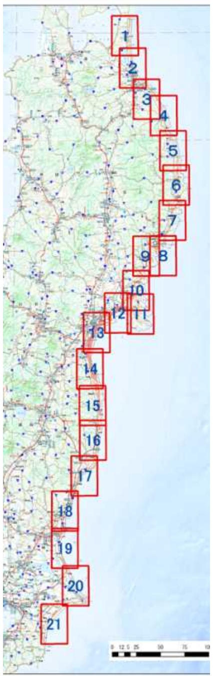

Figure 9 Index of inundation area map (GSI 2011g)

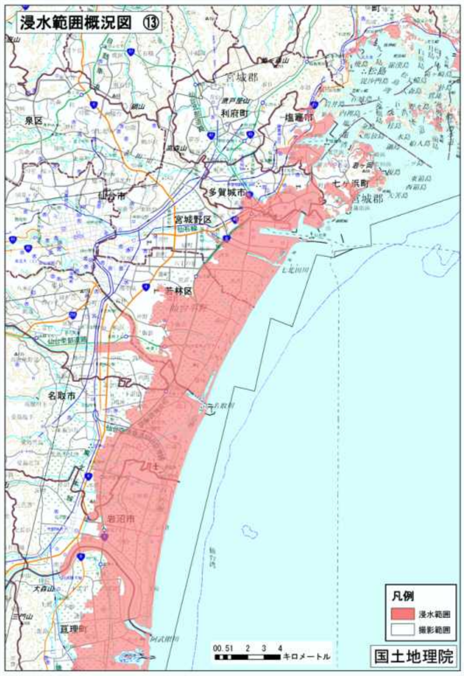

Figure 10 An example of inundation area map, Sendai area (GSI 2011g)

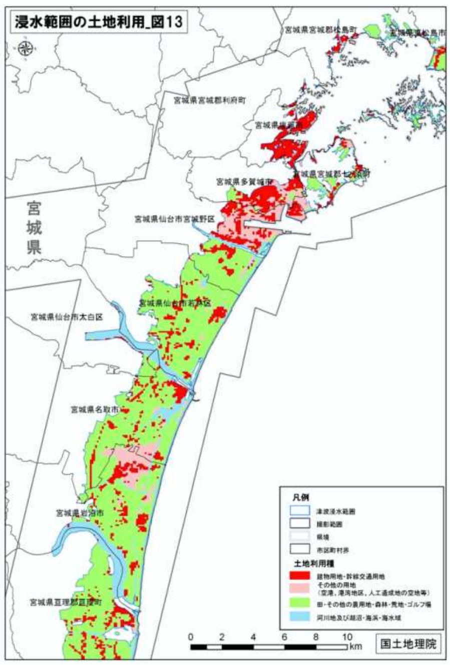

Figure 11 An example of inundation area land use map, Sendai area (GSI 2011h)

4.5 Provision of base maps and other activities

Responding to the high needs of base maps (topographic maps etc.) for disaster operation management, GSI also delivered them to the requesting organizations. On the day of the main shock, Japan Map Center (a public organization associated with GSI) delivered paper maps at various scales to major government bodies on behalf of GSI. Electric data of base maps became available from the GSI's the website accordingly.

Several kinds of thematic maps were also produced. One example is the recovery progress map (Figure 12). The purpose of the map is to show the status of recovery of major transport infrastructure (road, railway, port and airport) on a regular update basis. This map, which was developed collaboratively with GSI and relevant bureaux of MLIT, got publicity in a certain period. Another example is the evacuation zoning map (Figure 13). The government designated evacuation zoning areas around Fukushina nuclear power plant on 22 April 2011. Accordingly, GSI produced the map in collaboration with Cabinet Secretariat operation center and made it public. Geospatial information analysis and cartographic capability of GSI was effectively utilized to ensure information accessibility of the public.

Figure 12 Recovery progress map (GSI 2011i)

Figure 13 Evacuation zoning map (GSI 2011j)

4.6 Provision of geospatial information

GSI's disaster related products were mainly delivered by four methods. The first method was to use in the humanitarian relief transportation system operated by JSDF (Japanese Self-Defense Force). This method was applied to deliver necessary geospatial products in poor transport environment to support malfunctioning local governments by the disaster. The second method was providing information through GSI liaisons (TEC-FORCE) attached to local disaster headquarters. The third method was provision through the Geospatial Information Support Team. This team was set up for the first time in EHQs, acting as the one-stop center of provision of products to meet high demands of geospatial information from public organizations. The forth method was provision through the website (www.gsi.go.jp) mainly targeting the general public.

Table 1 shows the numbers of cases of provisions by the second and the third methods. Totally 1,491 cases were handled (Nakai et al., 2012). 90% of requests were received from central and local government organizations.

Table 1 Numbers of cases of GSI products provision (as of 25 November 2011)

Product		GSI intiative based cases	Request based cases	Total
Geodetic	Geodetic results of reference points	0	7	7
	Crustal movement data	0	6	6
Aerial Photos	Areal photographs	234	73	307
	Orthophotos	195	81	276
	Bird's eye view photos	0	6	6
	Ortho photo maps	161	59	220
Tsunami inundation map		167	175	342
Basemap	Small scale maps	38	1	39
	1:200,000 scale regional maps	8	0	8
	1:50,000 scale topographic maps	33	8	41
	1:25,000 scale topographic maps	1	11	12
	Print outs of web based basic maps	3	17	20
	Historical topographic maps	0	2	2
	Wide area base map for disaster operation	6	28	34
Thematic maps and Others	Transport recovery progress map	2	0	2
	Base map for recovery and reconstruction	4	12	16
	Digital elevation map	1	7	8
	Concentric circle map around the nuclear power plants	2	15	17
	DEM at 5 m resolution	0	30	30
	Images captured by mobile mapping system (MMS)	0	2	2
	Homepage service with rectricted access	26	2	28
	Order made map	5	20	25
	Others	16	27	43
Total		902	589	1491

In addition to the cases summarized in Table 1, many other products were browsed and downloaded from the website. The number of access to GSI website in the following several months after the earthquake doubled compared to that in the previous year.

4.7 Use of geospatial information

Major purposes of use of geospatial information for disaster response provided by GSI were as follows (Nakai et al., 2012): damage identification; information sharing; reconstruction activities; spatial analysis; recovery activities; and field operations. The following list shows some cases that geospatial information was used by the relevant organizations.

- Damage identification, issuance of building damage certification to citizens (local governments)
- Operation of searching for dead bodies (police, Self-Defense Force)
- Facility damage identification (MLIT)
- Evaluation of property taxation in damaged areas (Ministry of Internal Affairs and Communications)
- Inundation of farm lands, damage mapping of national forests (Ministry of Agriculture, Forestry and Fisheries)
- Cultural properties' damage mapping, radioactive distribution mapping (Ministry of Education, Culture, Sports, Science and Technology)
- Articles describing damage situation by the disaster (news paper companies)
- Redistributing geospatial products through web mapping sites in support of damaged areas (IT companies and volunteer groups)
- Enterprise affection evaluation (corporate analysis consultants)

The magnitude and the significance of the disaster made the GSI's geospatial information product applied for various purposes in a wide variety of fields beyond expectations. This situation has never happened in previous disaster responses.

4.8 Reconstruction support activities

GSI does not only conduct disaster response activities but also supports reconstruction activities. Because the positional reference framework and basic geospatial information are always indispensable for recovery and reconstruction works which would take at least several years in damaged areas, GSI developed such information base to support reconstruction activities in the areas, utilizing supplemental national budget for reconstruction for the fiscal year 2011.

The first area is the revision of geodetic framework. A large ground surface movements by the earthquake required total revision of coordinates of ground control points in the area. First, the results of GNSS based stations were revised by the end of May 2011. In succession resurvey of 1,900 triangulation points and 1,900 bench marks was implemented, resulting in the new coordinate results announced in the end of October 2011, including correction parameters for the unsurveyed 40,000 triangulation stations. The detailed aspects of this work are precisely reported in Yamagiwa et al. (2012).

The second area is the development of 1:2,500 base map in support of reconstruction planning. The damaged areas of 4,200km^2 were photographed from May 2011. The cartographic works for base maps included features recognized both before and after the earthquake to facilitate map reading. The early delivery of draft map to local governments has started from August 2011, followed by the start of delivery of the final map in January 2012.

The third area is developing DEM by airborne LiDAR survey. 10,876km^2 of coastal areas affected by the tsunami and mountain areas vulnerable to landslides were covered by the survey. Acquired raw data were processed into DEM at 5 meter (partly 2 meter) resolution for the use of national and local governments to formulate measures against land subsidence, inundation and landslides. Using the DEM, detailed elevation cartography was also produced to ease the visual understanding of local/regional elevation settings in subject areas.

5. ACHIEVEMENTS AND CHALLANGES

The following achievements were identified as a result of GSI's disaster response activities.

- A chain of quick actions of data gathering and development enabled GSI to release its products in early period of disaster response. This is the result of experiences accumulated among the staff, regular drilling and necessary provision of equipment beforehand.
- Devising new arrangements for efficient data delivery: Geospatial Information Support Team performed well in providing data, interacting with requesters on their needs. Collaborations with other government organs for data delivery to difficult areas were also successful. Posting liaison to disaster operation offices was also effective to catch-up with rapidly changing needs of organizations according to post disaster development phase.
- A wide range of usage of GSI geospatial information products were recognized quantitatively and qualitatively. In fact, this large disaster gave GSI an opportunity to demonstrate the capability of national geospatial information authority for damage reconnaissance and supporting reconstruction activities.

While appreciating the achievements above, following challenges were also recognized and urge GSI to further improve its disaster response capabilities.

- Resiliency and redundancy of energy, communication and facilities: Some data from GNSS based station were lost or unable to send due to destruction of communication and power lines. Supplementary battery did not allow the stations to work more than 72 hours after power outage. By external failures, GSI headquarters were also struck by power outage and internet disconnection. Although it did not cause serious consequences, it urged GSI to reinforce its back up equipment such as auto generator, water storage and other facilities.
- Although the performance of geospatial information development and provision were appreciative, there are still rooms for further improvement. After the disaster, GSI reviewed its response activities, found problems and proposed solutions for further improvement. Some of the solutions were tested in disaster response drills thereafter.
- Actually, not all the users are satisfied with GSI's data provision. Particularly, volunteer mapping community, which emerged in recent years for disaster response, are not satisfied with technical and policy aspects of GSI's data provision. Their claim reflects the GSI's emphasis on products provision to rescue and recovery organization (mostly public) and non-professional general public through its web site. GSI needs to optimize its performance to satisfy diversified data needs in emergency through establishing public relations with various stakeholders during inter-disaster periods.

GSI is now reviewing its Disaster Management Operation Plan and Manual to align organizational efforts in responding to the above challenges.

6. CONCLUSION

According to its missions, GSI conducted response activities at full strength against the tragic East Japan Great Earthquake. Geospatial information products developed and provided by GSI were well utilized and applied by peoples and organizations during rescue, recovery and reconstruction phases. Although achievements were obvious, new challenges were recognized through the experience, prompting continuous improvement of disaster response capabilities. As occurrence of natural disasters never ends in Japan, GSI will make its best efforts to provide geospatial information products to those who need them in a timely manner, fully recognizing the expected role as the national geospatial information authority in changing societal context.

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