2.1.7 Field survey results

2.1.7.1 Field surveys

The M9.0 Great East Japan Earthquake － the world's fourth largest in recorded history － triggered massive tsunamis and caused widespread damage typical of such waves, including flooding to a depth of several tens of meters, submergence of coastal lowlands under sea/flood water, tsunami runups, damage to tsunami protection walls, urban devastation and bridge collapse. JAXA conducted a field survey between August 2011 and March 2012 to evaluate emergency observations and analysis performed in response to the disaster. The survey involved investigation of field survey results and satellite images in order to collect data for use in verifying the suitability of using satellite images to analyze such damage.

Damage is divided into the three categories of flooding, crustal movement/ground deformation and damage to artificial structures, and is further classified into three levels: a. clearly identifiable; b. identifiable from the surrounding conditions; c. not identifiable using satellite data. Due to the time that has passed since the disaster, damage that cannot be identified using satellite data must be investigated based on data provided by the national government and affected prefectures/municipalities and on results made public by organizations involved in such surveying. Against this background, candidate survey areas were chosen in consideration of data availability. However, areas that cannot be fully observed must be replaced with other candidate areas with similar conditions.

Clarifying how satellite images are actually used in disaster countermeasures and pinpointing factors that prevented such data from being used in this case will help to enhance satellite information usage in the future. Accordingly, relevant considerations for promoting the use of such information will be identified through interviews with a variety of businesses. Specifically, efforts will be made to clarify and summarize the purposes of its usage by commercial enterprises and organizations, appropriate timing for the provision of image information, the effects of actual satellite information usage, and related concerns and problems.

(1) Flood surveys

Flooded areas were selected as typical sites of tsunami damage based on the conditions and reasons shown below. For each condition, one or two sites will be observed to verify the accuracy of satellite image interpretation.

Table 2.1-9 Selection of survey sites (flooding)

Sites to be selected	Reason	Site
1. Areas that were flooded despite the construction of strong harbor breakwaters at bay mouths in preparation for a tsunami	Harbor breakwaters expected to protect against a big tsunami were destroyed.	Kamaishi City, Iwate Ofunato City, Iwate
2. Areas that were flooded despite the construction of sturdy harbor breakwaters or coastal levees in preparation for a tsunami	Some districts where locals prided themselves on the safety of coastal levees built in preparation for a tsunami along the Sanriku shoreline sustained serious damage.	Taro district, Miyako City, Iwate Kamaishi City, Iwate
3. Normal flooding at harbors	Harbor facilities with breakwaters (to absorb the force of waves) and wharves	Kesennuma City, Miyagi Kitaibaraki City, Ibaraki

Sites to be selected	Reason	Site
4. Flooding at large-scale harbors built using modern techniques	Harbor facilities considered to have been built with all possible disaster countermeasures	Sendai Shinko, Miyagi Sendai Airport, Natori City, Miyagi
5. Flooding in urban areas with no harbor breakwaters or coastal levees	Severe damage in districts with no tsunami protection facilities	Yuriage district, Natori City, Miyagi Asahi City, Chiba
6. Running of water along relatively steep geographical features (villages experiencing fast running tsunami)	The northern coast of the Sanriku shoreline is dotted with communities stretching along rivers on the breaks of cliffs. The tsunami ran up these narrow areas and reached upper zones.	Settai district, Miyako City, Iwate Ryori district, Ofunato City, Iwate
7. Running of water over gently sloping fields (area sustaining severe damage from the tsunami running up the river)	The tsunami ran up relatively low-level wide rivers, causing severe damage to the area.	Ishinomaki City, Miyagi (Kitakami River) Natori City, Miyagi (Natori River)
8. Coastal forests	Coastal forests cultivated since the Edo period were destroyed by the tsunami.	Fudai district, Fudai Village, Iwate Nobiru Beach, Higashimatsushima City, Miyagi
9. Reclaimed land, landfill development	Areas developed by reclaiming land	Ishinomaki City, Miyagi
10. Tideland	Areas where natural geographical features were protected for environmental preservation were damaged by the tsunami.	Sendai City, Miyagi (Gamo Tideland)

Figure 2.1-67 Settai district, Miyako City, Iwate
The site of a village and a bridge claimed by the tsunami
(Photo courtesy of Mr. Hiroshi Sasaki)

Figure 2.1-68 Taro district, Miyako City, Iwate
Damage to an area with tsunami barriers
(Photo courtesy of Asia Air Survey Co., Ltd.)

(2) Crustal movement/ground deformation surveys

Sites where typical crustal movement and ground deformation occurred in the earthquake were selected based on the conditions and reasons shown below. For each condition, one or two sites will be observed to verify the accuracy of satellite image interpretation.

Table 2.1-10 Selection of survey areas (crustal movement/ground deformation)

Sites to be selected	Reason	Site
1. Residential areas affected by subsidence	Residential areas experiencing subsidence due to the earthquake	Kesen district, Rikuzentakata City, Iwate Watanoha district, Ishinomaki City, Miyagi
2. Harbor facilities affected by subsidence (industrial and fishing ports)	Harbor facilities experiencing subsidence due to the earthquake	Hachinohe City, Aomori (industrial and fishing ports) Kamaishi City, Iwate (industrial and fishing ports) Kesennuma City, Miyagi (industrial and fishing ports)
3. Previous beach sites	Popular bathing beaches were washed away.	Nehama Beach (Kamaishi City, Iwate) Yuriage Beach (Natori City, Miyagi)
4. Previous scenic and historic spots	Popular scenic and historic spots were washed away.	Takatamatsubara (Rikuzentakata City, Iwate) Remains of Nobiru Harbor (Higashimatsushima City, Miyagi)
5. Diastrophism caused by earthquake vibration (new residential area)	Crustal movement related to the earthquake caused extensive damage in new hillside residential areas.	Aoba Ward, Sendai City, Miyagi (Midorigaoka district) Yamamoto Town, Miyagi (Taiyo New Town)
6. Sediment damage (landslides, landslips, etc.)	The earthquake caused landslides and landslips.	Marumori Town, Miyagi Shirakawa City, Fukushima
7. Liquefaction (residential areas)	Residential areas were heavily damaged due to liquefaction caused by the earthquake.	Itako City, Ibaraki Urayasu City, Chiba
8. Liquefaction (common land)	Common land was damaged due to liquefaction caused by the earthquake.	Mihama Ward, Chiba City, Chiba (Inage Seaside Park)
9. Movement of the earth's surface (horizontal and vertical)	The surface of the earth moved (horizontal motion, uplift and subsidence) due to the earthquake.	Document analysis

Figure 2.1-69 Harbor affected by subsidence in Kesennuma City, Miyagi

(Photo courtesy of Asia Air Survey Co., Ltd.)

(3) Artificial-structure damage surveys

Damaged artificial structures were selected as typical sites of devastation caused by earthquakes and tsunamis based on the conditions and reasons shown below. For each condition, two or more sites will be observed to verify the accuracy of satellite image interpretation.

Table 2.1-11 Selection of survey areas (damaged artificial structures)

Sites to be selected	Reason	Site
1. Bay-mouth breakwaters	Although significant amounts of time and money were spent constructing breakwaters in preparation for massive waves, these structures were destroyed by the tsunami.	Breakwaters at the mouth of Kamaishi Bay in Iwate Breakwaters at the mouth of Ofunato Bay in Iwate
2. Coastal levees	Many coastal levees built to protect residential areas from tsunami were destroyed and washed away, resulting in extensive damage.	Otsuchi Town, Iwate Ofunato City, Iwate
3. Floodgates	Floodgates built to protect urban areas from tsunami were destroyed and washed away, resulting in extensive damage.	Iwaizumi Town, Iwate (floodgate at the mouth of the Omoto River) Miyako City, Iwate (floodgate at the mouth of the Tsugaruishi River)
4. Breakwaters and quays at industrial ports	Many local facilities of pivotal industries were washed away.	Kuji Port in Kuji City, Iwate Sendai Shinko in Sendai City, Miyagi
5. Breakwaters and quays at fishing ports	Many facilities related to the region's major industry of fisheries were destroyed and washed away.	Kuwagasaki fishing port in Miyako City, Iwate Kesennuma fishing port in Kesennuma City, Miyagi
6. River banks	River banks were destroyed by the tsunami running along rivers.	Rikuzentakata City, Iwate (Kesen River) Ishinomaki City, Miyagi (Kitakami River) Watari Town, Miyagi (Abukuma River)
7. Roads	Many roads were closed due to flooding and landslides caused by the tsunami.	National Route 45 (Miyagino Ward, Sendai City — Tagajo City) Joban Expressway (Mito IC — Naka IC)
8. Bridges	Many bridges located at the mouths of rivers were washed away by the tsunami.	Kesen Bridge (Rikuzentakata City, Iwate) Rokko Bridge (Namegata City, Ibaraki — Hokota City)
9. Railroads	Many railroads and stations were washed away by the tsunami.	Rikuzentakata Station (JR Ofunato Line) Higashimatsushima City (JR Sengoku Line)
10. Aquaculture facilities	Many aquaculture facilities (fish preserves, rafts, longlines, etc.) established in bays along the coast were destroyed and washed away by the tsunami.	Yamada Bay, Iwate Ofunato Bay, Iwate Kesennuma Bay, Miyagi
11. Municipal government buildings	Municipal government buildings serving as bases for local government were damaged.	Otsuchi Town Hall in Iwate Rikuzentakata City Hall in Iwate Minamisanriku Town Hall in Miyagi
12. Other public facilities	Public facilities such as prefectural hospitals and fire stations were damaged.	Takata, Iwate Prefectural Hospital Iwate Prefectural Otsuchi Fire Station
13. Large-scale retail facilities	Large-scale retail facilities serving an unspecified number of customers were damaged.	Sendai Airport (Natori City, Miyagi)
14. Facilities for people requiring support in the event of a disaster	People requiring support in the event of a disaster were particularly affected.	Sanriku no Sono special nursing home for the elderly (Ofunato City, Iwate)
15. Fire damage in urban areas	Urban areas were destroyed due to fires caused by the earthquake.	Kesennuma City, Miyagi (residential areas) Ichihara City, Chiba (complexes)
16. Other wooden structures	An old dam was destroyed by the earthquake, and the community in the lower reaches of the river was damaged.	Sukagawa City, Fukushima (Fujinuma Dam)

Figure 2.1-70 Minamisanriku Town, Miyagi

Damaged town hall

(Photo courtesy of Asia Air Survey Co., Ltd.)

Figure 2.1-71 Natori City, Miyagi

Overview of flooding at Sendai Airport

(Photo courtesy of Asia Air Survey Co., Ltd.)

(4) Satellite image usage survey

Organizations that actually utilized satellite images will be interviewed to clarify how they were used and what benefits they brought. Based on the results, a summary of user opinions regarding ideal image provision channels, timing, continuity and analysis support in addition to data usage will be made. Organizations to be interviewed include municipalities, universities and research institutions, fisheries/agricultural cooperatives and other associations, private corporations and NPOs.

(5) Identification of problems

The results of the surveys will be used to determine objects/conditions that are easy or difficult to identify in images, and to clarify optimal methods of satellite image provision to users. Based on this, current problems will be pinpointed and countermeasures for them formulated.

2.1.7.2 Evaluation of image analysis results

(1) Analysis of flooded areas using PALSAR data

Immediately after the disaster, intensive observation using the PALSAR satellite was started in light of its ability to perform observations in any weather conditions. Based on the data obtained (listed in Table 2.1-12), ongoing analysis of flooded areas was carried out.

Table 2.1-12 List of PALSAR data used for flood zone analysis

No.	Observation date	Incidence angle /orbit	Date of previous data	Incidence angle /orbit
1	2011.3.13	46.6 / Asc	2008.6.21	47.8 / Asc
2	2011.3.23	50.0 / Dsc	2009.11.12	41.5 / Dsc
3	2011.3.26	28.8 / Asc	2010.11.20	34.3 / Asc
4	2011.4.1	34.3 / Asc	2010.9.20	34.3 / Asc
5	2011.4.7	34.3 / Asc	2010.11.20	34.3 / Asc
6	2011.4.18	34.3 / Dsc	2011.3.3	34.3 / Dsc

The results indicated that PALSAR had the capacity for successful analysis of flooded areas if appropriate observation conditions were provided. Ortho-/gradient-corrected SAR intensity images, normalized difference images and GoogleEarth images from before the earthquake were used to identify flooded areas. Here, normalized difference images can be found using the following equation:

$$NDIF = (DN_1 - DN_2) / (DN_1 + DN_2)$$

Where NDIF is a normalized difference image, DN_2 is a DN value for a pre-disaster PALSAR image, and DN_1 is a post-disaster DN value. The normalized difference allowed identification of flood zones and facilitated analysis of areas that were difficult to deal with using SAR intensity images alone. GoogleEarth images from before the earthquake were also used to check pre-disaster land cover and support the identification of flooded areas.

A number of findings were obtained from the image analysis. First, it was learned that the use of images of paddy fields taken during the planting and growing seasons (around from May to July) should be avoided. This is because many tsunami-hit areas are located on plains where paddy fields grow, and when PALSAR data obtained during the rice planting and growing seasons are used for pre-disaster images, it is difficult to discriminate between tsunami-flooded areas and land covered with water used to irrigate paddy fields. Rain that fell during or immediately before observations created puddles in areas from which floodwaters had receded, and these were misidentified as flooding. In terms of PALSAR observation conditions, it was found that a large incidence angle could cause reduced accuracy in image analysis due to the influence of range ambiguity, and that a small incidence angle could also impair accuracy due to low spatial resolution. Figure 2.1-72 shows a flooded-area identification image and a normalized difference image as examples of PALSAR data.

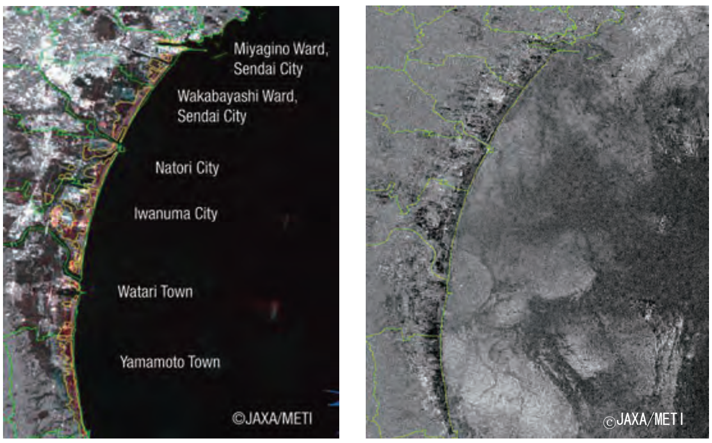

Figure 2.1-72 Examples of results from PALSAR-based flood analysis
(left: identification image; right: normalized difference image)