Report on JAXA's Response to the Great East Japan Earthquake

– Assistance using earth observation satellites and communication satellites –

March 2012

Japan Aerospace Exploration Agency

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1. Preface

A 9.0-magnitude earthquake — the strongest ever to strike Japan — occurred in the Pacific Ocean near the Tohoku region of the country at 14:46 JST on March 11, 2011.[1] The epicenter was off the Tohoku coast (38.32°N, 142.37°E) [2], and the hypocenter was 32 km below the earth's surface. The quake was considered to have a long-angle reverse fault mechanism with a pressure axis extending from west-northwest to east-southeast, and occurred between the Pacific plate and the North American plate. After the tremor, a massive tsunami struck coastal areas from Tohoku to Kanto, with an 11.8-meter-high wave[3] causing widespread damage to the coastal district of Ofunato in Iwate Prefecture. The earthquake was the fourth largest on record in the world, and caused massive destruction along the Tohoku-Kanto Pacific coast. The disaster was named the Tohoku Region Pacific Ocean Coastal Earthquake, and later became known as the Great East Japan Earthquake — a collective term whose meaning also includes the subsequent tsunami and the accident at the Fukushima Dai-ichi Nuclear Power Station.

A total of 15,783 people were killed, 4,086 were left missing and 5,932 were injured.[4] In terms of major material effects, many houses were washed away or flooded, and there was widespread damage to roads in affected areas. More than 115,000 houses were completely destroyed and over 795,000 sustained significant damage.[4] Frequent aftershocks were felt since March 12, as of September 12, more than 550 of which were magnitude 5 or over, and five were magnitude 7 or over (three on the day of the main quake).

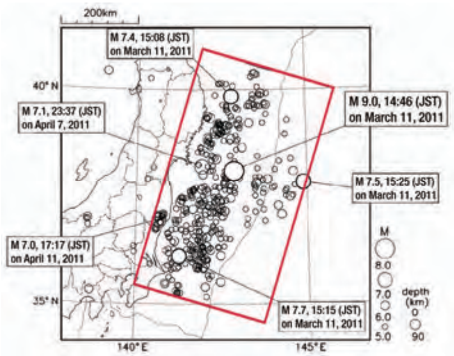

Figure 1-1: The Tohoku Region Pacific Ocean Coastal Earthquake and aftershocks

(Japan Meteorological Agency/the Great East Japan Earthquake — the Tohoku Region Pacific Ocean Coastal Earthquake — related portal site: http://www.jma.go.jp/jma/en/2011_Earthquake.html)

This report details various activities conducted by the Japan Aerospace Exploration Agency (JAXA) involving earth observation satellites and communication satellites in collaboration with domestic and overseas institutions in the wake of the Great East Japan Earthquake.

The names of the organizations and departments included here are those applicable at the time the activities were carried out. This report is also provided on the website of JAXA's Satellite Applications and Promotion Center at http://www.sapc.jaxa.jp/antidisaster/index.html.

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[1] The magnitude of the quake was originally announced as 7.9, but this was revised to 9.0 on March 13.
[2] Intensity and epicenter information based on data from the United States Geological Survey (USGS)
[3] Based on data from the Japan Meteorological Agency
[4] Based on data from the Metropolitan Police Department as of Sept. 12, 2011

2. JAXA activities

2.1 Activities involving earth observation satellites

2.1.1 Satellite image utilization in disaster management

JAXA established the Disaster Management Support Systems Office (in the Satellite Applications and Promotion Center) to support disaster countermeasure activities involving the Advanced Land Observing Satellite “Daichi” as well as observation data acquired by overseas satellites. JAXA also plans the utilization of Daichi and related developments based on experience of operating the satellite.

Domestically, JAXA strives to highlight the role of earth observation satellites in disaster prevention in conjunction with related institutions, including national government ministries, agencies and local governments. Internationally, JAXA is a member of the International Charter, Space and Major Disaster (Disaster Charter), which provides satellite data to users in the event of large-scale disasters, play a particular roleas the secretariat of Sentinel Asia － an international collaborative project organized to observe natural disasters in the Asia-Pacific region.

The ALOS Analysis Research Team of the Earth Observation Research Center in Tsukuba analyzes satellite data in conjunction with the Disaster Management Support Systems Office in the event of a disaster in addition to implementing earth observation data analyses at operational basis.

When the Great East Japan Earthquake struck, JAXA immediately planned emergency observations using the Daichi, and asked the Disaster Charter and Sentinel Asia to conduct intensive emergency observation of the affected meas occured. The huge amounts of data collected and the results of related analysis provided a comprehensive overview of the massive disaster area and the damage sustained of the massive disaster area.

The observations conducted by Daichi, the Disaster Charter and Sentinel Asia are summarized in Table 2.1-1.

Table 2.1-1 Observations conducted by Daichi, the Disaster Charter and Sentinel Asia (March 12, 2011, to March 24, 2011)

Observation date	JAXA/ overseas satellites	Miyako	Kamaishi	Minamisanriku	Onagawa, Oshika Peninsula	Ishinomaki, Shiogama, Higashimatsushima	Sendai	Sendai Airport	Watari, Torinoumi	Soma	Fukushima nuclear plant
March 12	**Japan (JAXA)**						**AVNIR-2 PRISM**	**AVNIR-2 PRISM**			
	Overseas	LANDSAT-7 WorldView-2	LANDSAT-7 WorldView-2 RADARSAT IKONOS	LANDSAT-7 SPOT-5 WorldView-1 WorldView-2 FORMOSAT-2	LANDSAT-7 SPOT-5 GeoEye RapidEye WorldView-2 FORMOSAT-2 THEOS	LANDSAT-7 SPOT-5 GeoEye RapidEye WorldView-1 WorldView-2 FORMOSAT-2 TerraSAR-X IKONOS THEOS	LANDSAT-7 SPOT-5 WorldView-2 FORMOSAT-2 TerraSAR-X RADARSAT IKONOS THEOS	LANDSAT-7 SPOT-5 WorldView-2 IKONOS TerraSAR-X RADARSAT THEOS	LANDSAT-7 SPOT-5 WorldView-2 FORMOSAT-2 TerraSAR-X RapidEye TerraSAR-X THEOS	LANDSAT-7 SPOT-5 IKONOS WorldView-1 WorldView-2 TerraSAR-X RapidEye RADARSAT THEOS	LANDSAT-7 SPOT-5 IKONOS WorldView-1 WorldView-2 FORMOSAT-2 TerraSAR-X RapidEye Quickbird
March 13	**Japan (JAXA)**						**PALSAR**	**PALSAR**	**PALSAR**	**PALSAR**	**PALSAR**
	Overseas	SPOT-5 RapidEye LANDSAT-5 THEOS	SPOT-5 RapidEye LANDSAT-5 THEOS	SPOT-5 RapidEye LANDSAT-5 EO-1 FORMOSAT-2 THEOS GeoEye	SPOT-5 RapidEye LANDSAT-5 EO-1 FORMOSAT-2 THEOS	SPOT-5 TerraSAR-X RapidEye LANDSAT-5 WorldView-2 EO-1 FORMOSAT-2 THEOS	SPOT-5 RapidEye LANDSAT-5 EO-1 FORMOSAT-2 THEOS WorldView-2	SPOT-5 RapidEye LANDSAT-5 EO-1 THEOS WorldView-2	SPOT-5 RapidEye FORMOSAT-2 LANDSAT-5 EO-1 THEOS	SPOT-5 LANDSAT-5 EO-1 FORMOSAT-2 THEOS	LANDSAT-5 WorldView-2 FORMOSAT-2 THEOS Quickbird
March 14	**Japan (JAXA)**	**AVNIR-2 PALSAR**	**AVNIR-2 PALSAR**	**AVNIR-2 PALSAR**	**AVNIR-2 PALSAR**	**AVNIR-2 PALSAR**	**AVNIR-2 PALSAR**	**AVNIR-2 PALSAR**	**AVNIR-2 PALSAR**	**AVNIR-2 PALSAR**	**AVNIR-2 PALSAR**
	Overseas	RapidEye SPOT-5 FORMOSAT-2	RapidEye SPOT-5 FORMOSAT-2 WorldView-1	RapidEye SPOT-5 FORMOSAT-2 TerraSAR-X WorldView-1	RapidEye SPOT-5 FORMOSAT-2	RapidEye SPOT-5 FORMOSAT-2 HJ	RapidEye SPOT-5 FORMOSAT-2 KOMPSAT-2 CARTSAT-2 WorldView-2	RapidEye SPOT-5 KOMPSAT-2 WorldView-2	RapidEye FORMOSAT-2 WorldView-2	KOMPSAT-2 FORMOSAT2 WorldView-2	KOMPSAT-2 GeoEye WorldView-1 WorldView-2
March 15	**Japan (JAXA)**	**AVNIR-2**	**AVNIR-2**	**AVNIR-2 PALSAR**	**AVNIR-2 PALSAR**	**AVNIR-2**	**AVNIR-2**	**AVNIR-2**	**AVNIR-2**	**AVNIR-2**	**AVNIR-2**
	Overseas					FORMOSAT-2	SPOT-4 FORMOSAT-2 DubaiSat-1	SPOT-4 DubaiSat-1	FORMOSAT-2 DubaiSat-1	SPOT-4	DubaiSat-1
March 16	**Japan (JAXA)**	**AVNIR-2**	**AVNIR-2**	**AVNIR-2**	**AVNIR-2**	**AVNIR-2 PALSAR**	**AVNIR-2 PALSAR**	**AVNIR-2 PALSAR**	**AVNIR-2 PALSAR**	**AVNIR-2 PALSAR**	**AVNIR-2 PALSAR**
	Overseas	FORMOSAT-2	FORMOSAT-2	FORMOSAT-2	FORMOSAT-2	FORMOSAT-2 WorldView-2	FORMOSAT-2 WorldView-2	FORMOSAT-2 WorldView-2	FORMOSAT-2 WorldView-2	FORMOSAT-2 WorldView-2	FORMOSAT-2 QuickBird-1 QuickBird-2 GeoEye WorldView-1 WorldView-2

Observation date	JAXA/ overseas satellites	Miyako	Kamaishi	Minamisanriku	Onagawa, Oshika Peninsula	Ishinomaki, Shiogama, Higashimatsushima	Sendai	Sendai Airport	Watari, Torinoumi	Soma	Fukushima nuclear plant
March 17	**Japan (JAXA)**	**AVNIR-2 PALSAR**	**AVNIR-2 PALSAR**	**AVNIR-2**	**AVNIR-2**	**AVNIR-2**	**AVNIR-2**	**AVNIR-2**	**AVNIR-2**	**AVNIR-2**	**AVNIR-2**
	Overseas	SPOT-5 FORMOSAT-2	SPOT-5 FORMOSAT-2	SPOT-5 FORMOSAT-2	SPOT-5 FORMOSAT-2	SPOT-5 FORMOSAT-2 WorldView-2	SPOT-5 SPOT-4 FORMOSAT-2 TerraSAR-X WorldView-2	SPOT-5 SPOT-4 FORMOSAT-2 TerraSAR-X WorldView-2	SPOT-5 SPOT-4 FORMOSAT-2 WorldView-2	SPOT-5 SPOT-4 FORMOSAT-2 WorldView-2	SPOT-5 SPOT-4 FORMOSAT-2 WorldView-1 WorldView-2 IKONOS
March 18	**Japan (JAXA)**						**PALSAR**	**PALSAR**	**PALSAR**	**PALSAR**	**PALSAR**
	Overseas	SPOT-5	SPOT-5 FORMOSAT-2	SPOT-5 FORMOSAT-2	SPOT-5 FORMOSAT-2	SPOT-5 FORMOSAT-2 EO-1 DEIMOS-1 QuickBird	SPOT-5 FORMOSAT-2 EO-1 DEIMOS-1 QuickBird	SPOT-5 FORMOSAT-2 DEIMOS-1 QuickBird	SPOT-5 FORMOSAT-2 DEIMOS-1	SPOT-5 FORMOSAT-2	SPOT-5 FORMOSAT-2
March 19	**Japan (JAXA)**	**AVNIR-2**	**AVNIR-2**	**AVNIR-2 PALSAR**	**AVNIR-2 PALSAR**	**AVNIR-2 PALSAR**	**AVNIR-2 PALSAR**	**AVNIR-2 PALSAR**	**AVNIR-2 PALSAR**	**AVNIR-2 PALSAR**	**AVNIR-2 PALSAR**
	Overseas	FORMOSAT-2 Worldview-1	Resurs-DK FORMOSAT-2	FORMOSAT-2 GeoEye	FORMOSAT-2 GeoEye	FORMOSAT-2 GeoEye Worldview-2	FORMOSAT-2 GeoEye Worldview-1 Worldview-2 KOMPSAT-2	FORMOSAT-2 GeoEye Worldview-1 Worldview-2 KOMPSAT-2	FORMOSAT-2 GeoEye Worldview-1 Worldview-2	FORMOSAT-2 GeoEye Worldview-1 Worldview-2	FORMOSAT-2 GeoEye Worldview-1 Worldview-2
March 20	**Japan (JAXA)**	**AVNIR-2**	**AVNIR-2**	**AVNIR-2**	**AVNIR-2**	**AVNIR-2**	**AVNIR-2**	**AVNIR-2**	**AVNIR-2**	**AVNIR-2**	**AVNIR-2**
	Overseas	FORMOSAT-2 IKONOS LANDSAT-5 ENVISAT	FORMOSAT-2 LANDSAT-5 ENVISAT	FORMOSAT-2 LANDSAT-5 ENVISAT IKONOS	FORMOSAT-2 LANDSAT-5 Worldview-2 ENVISAT QuickBird	FORMOSAT-2 IKONOS LANDSAT-5 Worldview-2 ENVISAT	Resurs-DK FORMOSAT-2 LANDSAT-5 Worldview-2 ENVISAT	Resurs-DK FORMOSAT-2 LANDSAT-5 Worldview-2 ENVISAT	Resurs-DK FORMOSAT-2 LANDSAT-5 Worldview-2 IKONOS ENVISAT	Resurs-DK FORMOSAT-2 LANDSAT-5 Worldview-2 ENVISAT	FORMOSAT-2 LANDSAT-5 IKONOS Worldview-2 ENVISAT
March 21	**Japan (JAXA)**	**AVNIR-2 PALSAR**	**AVNIR-2 PALSAR**	**AVNIR-2**	**AVNIR-2 PALSAR**	**AVNIR-2**	**AVNIR-2**	**AVNIR-2**	**AVNIR-2**	**AVNIR-2**	**AVNIR-2**
	Overseas	FORMOSAT-2	FORMOSAT-2	FORMOSAT-2	FORMOSAT-2	FORMOSAT-2	FORMOSAT-2	FORMOSAT-2	FORMOSAT-2	FORMOSAT-2	FORMOSAT-2
March 22	**Japan (JAXA)**	**AVNIR-2**	**AVNIR-2**	**AVNIR-2**	**AVNIR-2**	**AVNIR-2**	**AVNIR-2 PALSAR**	**AVNIR-2 PALSAR**	**AVNIR-2 PALSAR**	**AVNIR-2 PALSAR**	**AVNIR-2 PALSAR**
	Overseas	FORMOSAT-2	FORMOSAT-2	FORMOSAT-2	FORMOSAT-2	FORMOSAT-2	FORMOSAT-2	FORMOSAT-2	FORMOSAT-2	FORMOSAT-2	FORMOSAT-2
March 23	**Japan (JAXA)**			**PALSAR**		**PALSAR**	**PALSAR**	**PALSAR**	**PALSAR**	**PALSAR**	**PALSAR**
	Overseas	FORMOSAT-2 ENVISAT	FORMOSAT-2 ENVISAT	FORMOSAT-2 ENVISAT QuickBird	FORMOSAT-2 ENVISAT	FORMOSAT-2 ENVISAT	FORMOSAT-2 ENVISAT	FORMOSAT-2 ENVISAT	FORMOSAT-2 ENVISAT	FORMOSAT-2 RADARSAT-2 ENVISAT	FORMOSAT-2 Worldview-2 ENVISAT
March 24	**Japan (JAXA)**	**AVNIR-2 PRISM**	**AVNIR-2 PRISM**	**AVNIR-2 PRISM**	**AVNIR-2 PRISM**						**AVNIR-2 PRISM**
	Overseas	FORMOSAT-2	FORMOSAT-2	FORMOSAT-2	FORMOSAT-2	FORMOSAT-2	FORMOSAT-2	FORMOSAT-2	FORMOSAT-2	FORMOSAT-2	FORMOSAT-2

2.1.2 Details of emergency observations by Daichi

The details of emergency observations conducted by Daichi are shown in Table 2.1-2. Although observations could not be conducted on the day of the disaster, on March 12 (the day after the earthquake), the Tohoku inland area and the Sendai district were observed using AVNIR-2 and PRISM. On March 13, PALSAR observed Sendai and other areas along the coast of Miyagi and Fukushima prefectures, and AVNIR-2 observed wider areas along the Pacific coast from Tohoku to Chiba on March 14. Observations were continued until April 20, and a total of 643 scenes were observed (see Table 2.1-3).

Daichi could not be used for observations after April 22 due to an electrical power system fault, and its operations were halted on May 12. Its final observation in relation to the Great East Japan Earthquake was on April 20.

Table 2.1-2 Details of emergency observations by Daichi

Observation date	Descending orbit	Ascending orbit	Sensor	AVNIR: pointing angle PALSAR: incidence angle	Observation area
March 12, 2011	○		PRISM	0	Inland Tohoku (Aomori to Fukushima), Sendai area
	○		AVNIR-2	0	Inland Tohoku (Aomori to Fukushima), Sendai area
March 13	○		AVNIR-2	44	Niigata, Nagano, Gifu
		○	PALSAR	46.6	Tsugaru Peninsula from the Miyagi/Fukushima coast through inland areas
March 14	○		AVNIR-2	-23	Pacific coast (Tohoku to Chiba)
	○		PALSAR	27.1	Hokkaido to the Tohoku, Kanto and Tokai regions
March 15	○		AVNIR-2	37	Pacific coast and inland from Aomori to Fukushima
		○	PALSAR	34.3	Iwate coast and the Shimokita Peninsula
March 16	○		AVNIR-2	-42	Pacific coast and inland from Aomori to Fukushima
	○		PALSAR	43.4	Miyagi, Fukushima and Ibaraki coast from the Shimokita Peninsula through inland Iwate
March 17	○		AVNIR-2	16	Pacific coast (Tohoku to Ibaraki)
		○	PALSAR	14	Pacific coast (Iwate to Aomori)
March 18		○	PALSAR	50	Tsugaru Peninsula from the Miyagi/Fukushima coast through inland Akita
March 19	○		AVNIR-2	-12.8	Pacific coast (Tohoku to Ibaraki)
	○		PALSAR	14	Pacific coast (Tohoku to Ibaraki)
March 20	○		AVNIR-2	42	Pacific coast and inland from Aomori to Fukushima
		○	PALSAR	34.3	Akita coast from the Ibaraki coast through inland areas
March 21	○		AVNIR-2	-36.5	Pacific coast and inland from Aomori to Fukushima
	○		PALSAR	34.3	Iwate coast
March 22	○		AVNIR-2	25	Pacific coast (Tohoku to Ibaraki)
		○	PALSAR	14	Akita coast from the Miyagi/Fukushima coast through inland areas
March 23	○		PALSAR	50	Miyagi/Fukushima coast from the Aomori coast through inland Iwate
March 24	○		PRISM	0	Pacific coast (Tohoku to Ibaraki)
	○		AVNIR-2	0	Pacific coast (Tohoku to Ibaraki)
March 25	○		AVNIR-2	44	Inland Tohoku, Sea of Japan coast and areas near Sendai
		○	PALSAR	43.4	Tsugaru Peninsula from the Miyagi/Fukushima coast through inland Akita
March 26	○		AVNIR-2	-28.5	Pacific coast (Tohoku to Ibaraki)
	○		PALSAR	28.8	Pacific coast (Tohoku to Ibaraki)
March 27	○		AVNIR-2	32.5	Pacific coast (Tohoku to Ibaraki)
		○	PALSAR	25.8	Tsugaru Peninsula from the Miyagi/Fukushima coast through inland Akita
March 28	○		AVNIR-2	-44	Pacific coast (Tohoku to Fukushima)

Observation date	Descending orbit	Ascending orbit	Sensor	AVNIR: pointing angle PALSAR: incidence angle	Observation area
March 29	○		AVNIR-2	1.9	Kanagawa coast from the Shimokita Peninsula through inland Tohoku and Kanto
March 30		○	PALSAR	47.8	Tsugaru Peninsula from the Miyagi/Fukushima coast through inland Akita
March 31	○		AVNIR-2	-25	Kanagawa coast from the Shimokita Peninsula through inland Tohoku and Kanto
	○		PALSAR	27.1	Tohoku to Chubu
April 1	○		AVNIR-2	38	Pacific coast and inland areas between Aomori and Chiba/Kanagawa
		○	PALSAR	34.3	Tsugaru Peninsula from the Miyagi/Fukushima coast through inland Akita
April 2	○		AVNIR-2	-41	Pacific coast and inland areas between Aomori and Chiba
	○		PALSAR	41.5	Pacific coast (Miyagi to Chiba) from the Pacific coast near Aomori through inland Iwate
April 3	○		AVNIR-2	14	Inland areas from Aomori to Tokyo/Kanagawa
April 5	○		AVNIR-2	-9	Pacific coast (Tohoku to Chiba)
	○		PALSAR	27.1	Sea of Japan coast in Tohoku to the Hokuriku and Chubu regions
April 6	○		AVNIR-2	43	Pacific coast and inland areas from Aomori to Chiba
April 7	○		AVNIR-2	-34	Pacific coast (Tohoku to Chiba)
	○		PALSAR	34.3	Pacific coast (Tohoku to Chiba)
April 8	○		ANVIR-2	28	Pacific coast (Tohoku to Chiba)
		○	PALSAR	21.5	Ou mountains to Sendai
April 10	○		AVNIR-2	0	Pacific coast (Tohoku to Chiba)
	○		PRISM	1.2	Hokkaido to the Pacific coast (Tohoku to Chiba)
April 11	○		AVNIR-2	44	Hokkaido to the Tohoku region along the Sea of Japan
April 12	○		AVNIR-2	-26	Pacific coast (Tohoku to Chiba)
	○		PALSAR	34.3	Tohoku region along the Sea of Japan
April 13	○		AVNIR-2	35.3	Pacific coast (Tohoku to Chiba)
		○	PALSAR	34.3	Miyagi and Iwate coast
April 14	○		AVNIR-2	-44	Pacific coast (Tohoku to Chiba) and inland Tohoku
April 15	○		AVNIR-2	12.5	Pacific coast (Tohoku to Chiba)
April 17	○		AVNIR-2	-16	Pacific coast (Tohoku to Chiba)
	○		PALSAR	27.1	From Tohoku to Chubu
April 18	○		AVNIR-2	41	Pacific coast (Tohoku to Ibaraki and southern Chiba)
		○	PALSAR	34.3	Miyagi and Fukushima to Akita and the Sea of Japan coast in Aomori
April 19	○		AVNIR-2	-39	Pacific coast (Tohoku to Chiba) and inland Tohoku
April 20	○		AVNIR-2	22.5	Pacific coast (Tohoku to Chiba)

Table 2.1-3 Number of scenes observed according to sensors (March 12, 2011－April 20, 2011)

Sensor		Number of observation scenes		
		3/12-3/31	4/1-4/20	3/12-4/20
AVNIR-2		162	217	379
PRISM	OB1	0	25	25
	OB2	32	0	32
PALSAR	FBS	111	74	185
	FBD	8	0	8
	WB1	8	6	14
Total		321	322	643

※Observation period: March 12 to April 20, 2011

2.1.3 Image analysis by JAXA

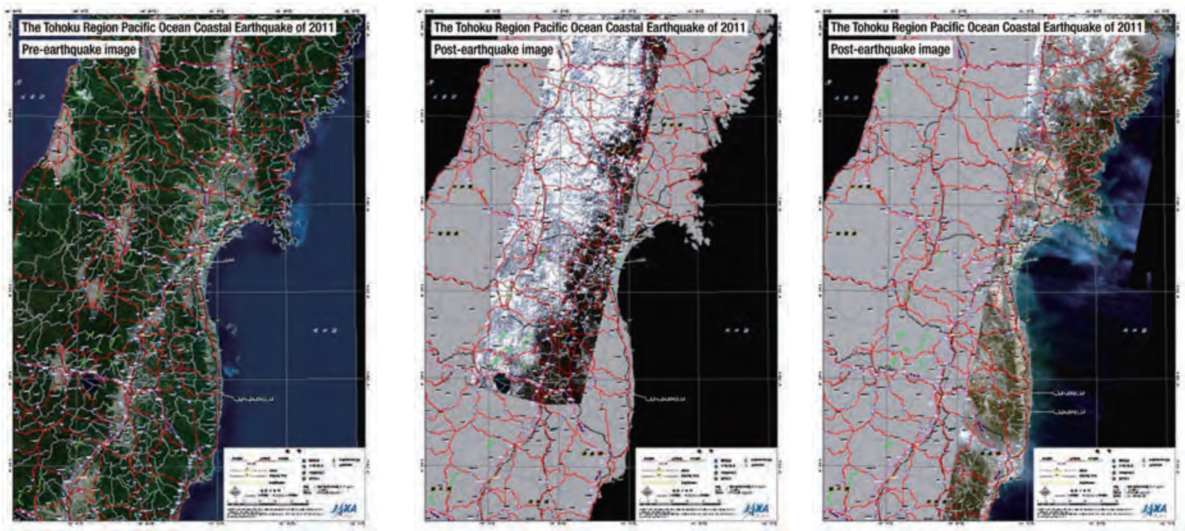
JAXA conducted ongoing emergency observations using Daichi in the wake of the Great East Japan Earthquake, releasing reporting of its analysis of eastern Japan and Hokkaido to government ministries and agencies related to disaster management, including the Cabinet Office and local municipalities. The satellite images collected through the Disater Charter and Sentinel Asia were also analyzed for report to relevant organizations.

The results of the image analysis conducted by JAXA immediately after and after the disaster are outlined here. Support provided by overseas institutions is detailed in Section 2.1.4.

2.1.3.1 Overview of the damage

In view of the difficulty of under standing the extent of the damage from the ground immediately after the disaster, satellite images collected from extensive observations were used to clarify the situation.

JAXA created satellite topographical maps using the data acquired from its emergency observations and previously archived data by superimposing geographical data, and analyzed the disaster areas. The image on the left of Figure 2.1-1 shows a pre-earthquake satellite topographical map based on archived data, while those in the center and on the right show post-earthquake equivalents created by scattering mosaic patterns on AVNIR-2 images taken during emergency observations at around 10:25 JST on March 12 and 10:11 JST on March 14. Figure 2.1-2 shows a disaster area overview produced by AVNIR-2 on March 14.



Pre-earthquake image compiled from archive data
Immediately after the earthquake
(Created and published on March 11, 2011)

Inland Tohoku area observed by AVNIR-2
The day after the earthquake
(March 12, 2011)
(Created and published on March 12, 2011)

Northeastern coastal area observed by AVNIR-2
Three days after the earthquake
(March 14, 2011)
(Created and published on March 14, 2011)

Figure 2.1-1 Pre- and post-disaster satellite topographical maps

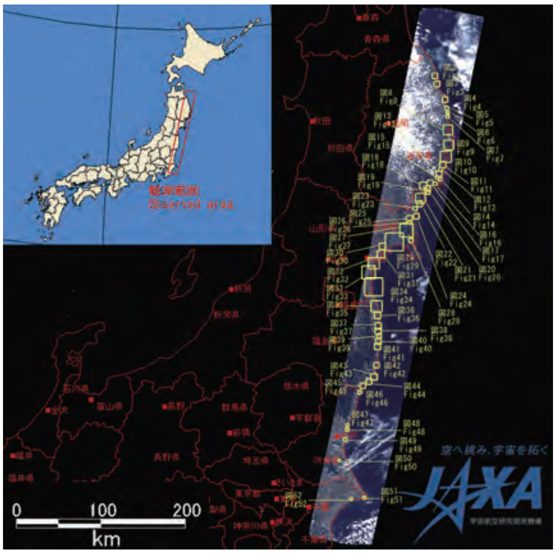


Figure 2.1-2 Overview of the disaster area observed on March 14

2.1.3.2 Analysis of local damage

AVNIR-2 acquired images with minimal cloud on March 14, three days after the disaster, thereby helping to clarify the extent of the damage in Iwate and Miyagi prefectures (the yellow-framed areas in Figure 2.1-2). For example, Figure 2.1-3 shows images of the Omoto area of Iwaizumi Town in Iwate Prefecture enlarged from false-color images produced from a composite of AVNIR-2 band 4, 3 and 2 images from March 14 (after the earthquake) and March 10 (before the earthquake). The clear contrast of areas of vegetation (shown in red) and cloud (white) help to clarify the conditions on the ground. Rice and crop fields are flooded (areas of dark blue after the disaster), and landslides can be seen at the mouth of the river.

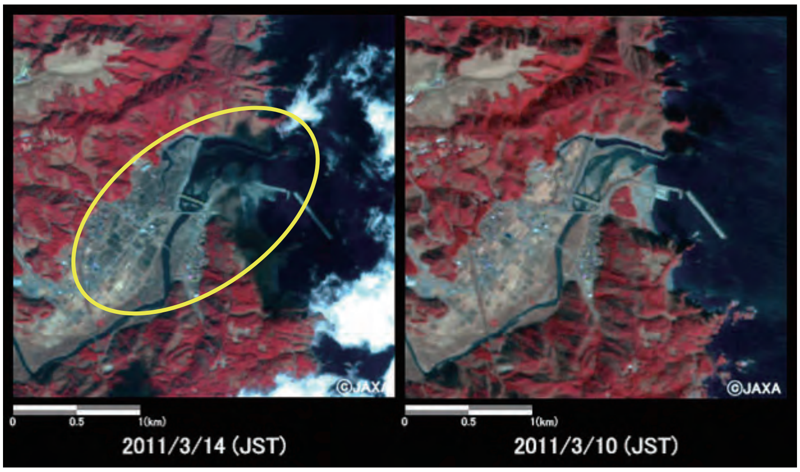


Figure 2.1-3 Flooding in the Omoto area of Iwaizumi Town in Iwate Prefecture (same 3 × 3 km area)
Left: after the earthquake (March 14, 2011); right: before the earthquake (March 10, 2011)

Figure 2.1-4 shows enlarged pre- and post-disaster images of Kitaibaraki City in Ibaraki. Clear damage to the sea wall can be seen in the area enclosed in yellow.

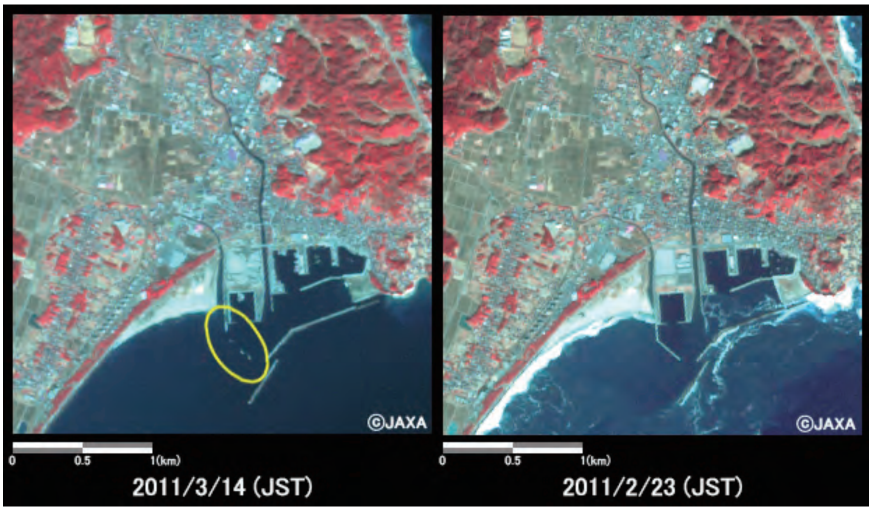


Figure 2.1-4 Kitaibaraki City, Ibaraki (same 3 × 3 km area)

Figure 2.1-5 shows enlarged images of Rokko Bridge in Ibaraki. It can be seen that the middle part of the bridge has collapsed. (Upper part: new bridge under construction)

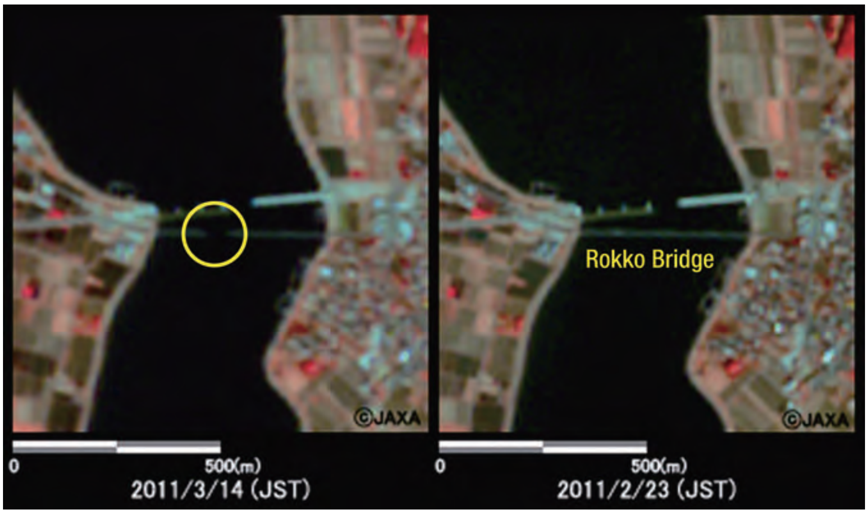


Figure 2.1-5 Area around Rokko Bridge in Ibaraki (same 1 × 1 km area)

Figure 2.1-6 shows enlarged images of Yawata Town, Iwaki City, Fukushima. Collapsed buildings and other large-scale changes can be seen in the area enclosed in yellow.

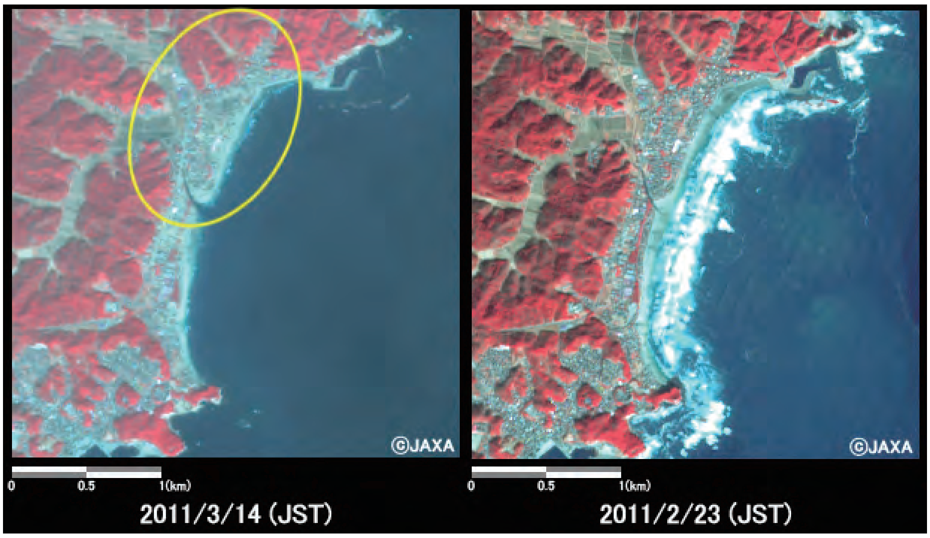


Figure 2.1-6 Yawata Town, Iwaki City, Fukushima (same 3 × 3 km area)

Figures 2.1-7 to 2.1-9 show pre- and post-earthquake bird's-eye views of Rikuzentakata City and Otsuchi Town in the Kamihei area of Iwate created by merging pan-sharpened images from AVNIR-2 and PRISM acquired on March 24, 2011, and November 6, 2010 with Digital Surface Model (DSM) images from PRISM. The images provide a three-dimensional view of the extensive destruction caused by the tsunami to bridges, embankments, urban areas and vegetation.

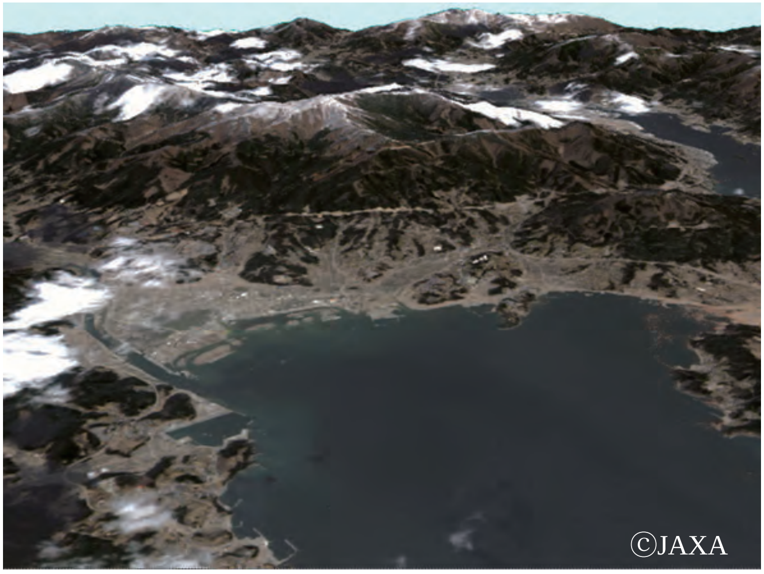


Figure 2.1-7 Post-quake bird's-eye view of the area around Rikuzentakata City, Iwate

(White areas: clouds and snow)

Figure 2.1-8 Pre-quake bird's-eye view of the area around Rikuzentakata City, Iwate

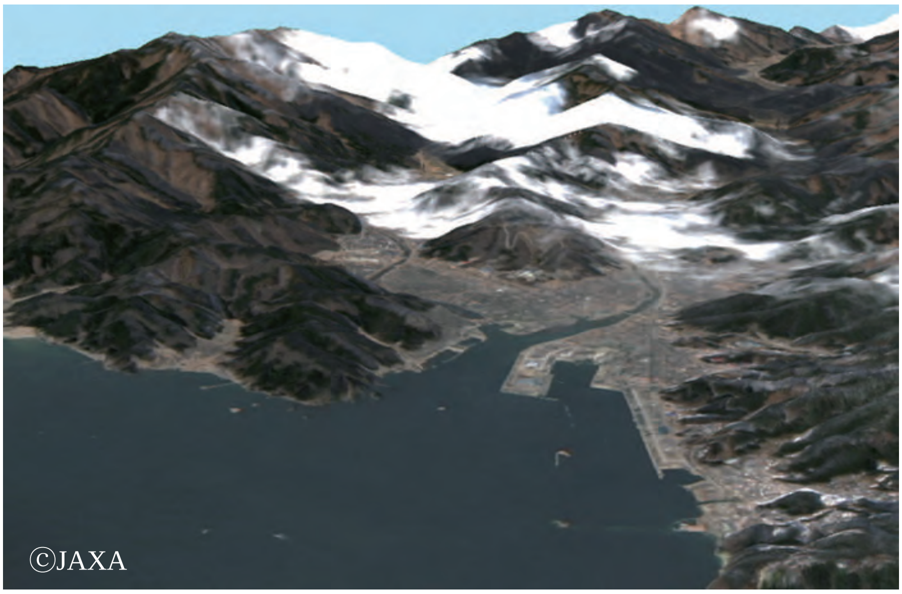


Figure 2.1-9 Post-quake bird's-eye view of the area around Otsuchi Town, Kamihei, Iwate

(White areas: clouds and snow)

2.1.3.3 Landslides

Figure 2.1-10 shows enlarged images of the Oshino district of Nakagawa Town in Tochigi acquired from AVNIR-2 images observed after the earthquake on March 29, 2011 (left), before it on February 27, 2011 (center), and on December 4, 2008 (right). In the area enclosed in yellow, it can be seen that landslides destroyed areas of vegetation and approached buildings to the north.

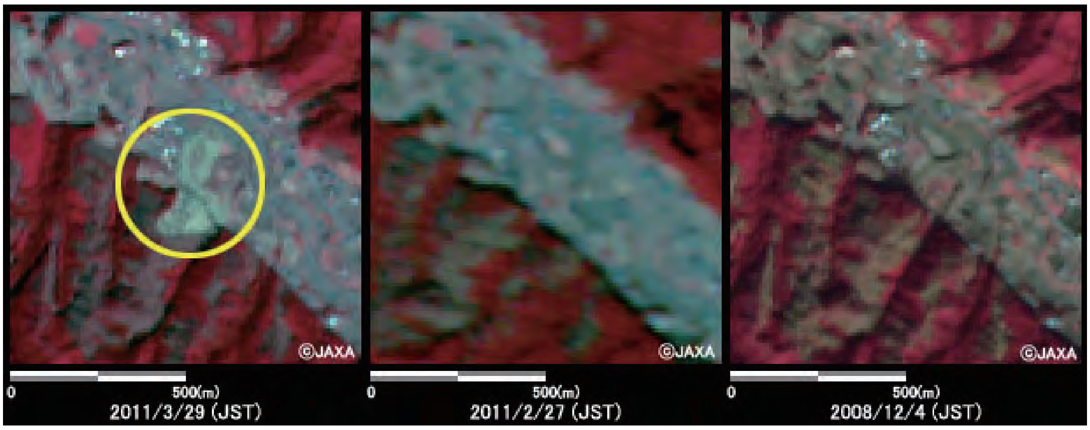


Figure 2.1-10 Oshino district of Nakagawa Town, Tochigi (same 1 × 1 km area)

Figure 2.1-11 shows enlarged images from AVNIR-2 of the area near Lake Fujinuma in Sukagawa City, Fukushima, after the earthquake on March 12 and 29, 2011, and before it on December 4, 2008. In the area enclosed in yellow, it can be seen that the lake burst, sending water into the Taki and Naganuma districts in the lower reaches of the river. It can also be seen that less water was remained in the lake.

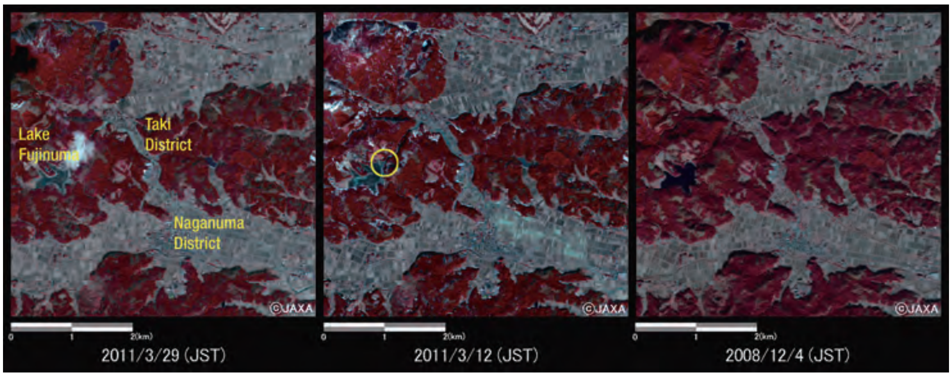


Figure 2.1-11 Area around Lake Fujinuma in Sukagawa City, Fukushima (same 5 × 5 km area)
Left: after the earthquake on March 29, 2011; center: after the earthquake on March 12, 2011; right: before the earthquake on December 4, 2008

Magnitude 7.1 and 6.0 aftershocks occurred in Hamadori, Fukushima, at 17:17 on April 11, triggering landslides at various locations around Iwaki City. Figure 2.1-12 shows enlarged images of a landslide between Iwaki Nakoso IC and Iwaki Yumoto IC on the Joban Expressway taken after the aftershocks on April 12, 2011, and before the aftershocks on April 10, 2011. In the area enclosed in yellow, it can be seen that the landslide reached the expressway.

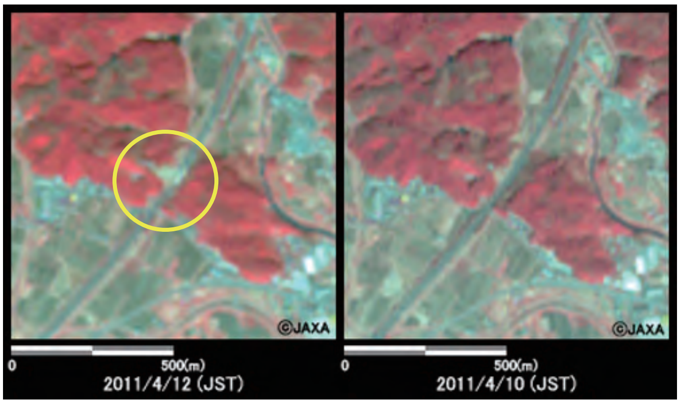


Figure 2.1-12 Joban Expressway in Iwaki City, Fukushima (same 1 × 1 km area)

Left: after the earthquake on April 12, 2011; right: before the earthquake on April 10, 2011

2.1.3.4 Marine debris

Figure 2.1-13 shows enlarged images from AVNIR-2 taken after the earthquake on March 14, 2011 and before it on February 27, 2011, around Aburasaki, Rikuzentakata City, Iwate. It can be seen that a large amount of marine debris washed into the bay and that plains were flooded.

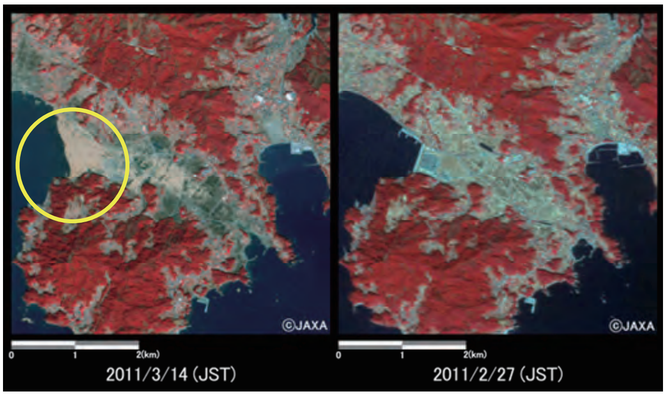


Figure 2.1-13 Aburasaki, Rikuzentakata City, Iwate (same 5 × 5 km area)

Left: after the earthquake on March 14, 2011; right: before the earthquake on February 27, 2011

Figure 2.1-14 shows an image from PALSAR observed around Sendai Bay on March 13. The green circles show debris; roughly 30 objects can be seen. The many white lines extending from north to south are caused by a phenomenon called ambiguity, in which bright land reflects on the dark surface of the sea.

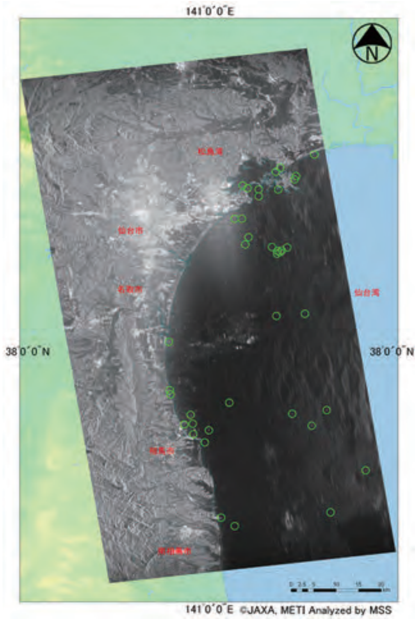


Figure 2.1-14 Marine debris observed by PALSAR (near Sendai Bay)

(around 22:11 on March 13, 2011)

2.1.3.5 Flood damage

Satellite observations are effective in determining the extent of tsunami-related flooding. Figure 2.1-15 shows enlarged pre- and post-earthquake images of the area around the Odaka district of Soma City in Fukushima taken by AVNIR-2 on March 14 and February 23. Areas of vegetation (shown in red) are still present, but extensive flooding is seen in rice fields and other areas of arable fields (shown in dark blue).

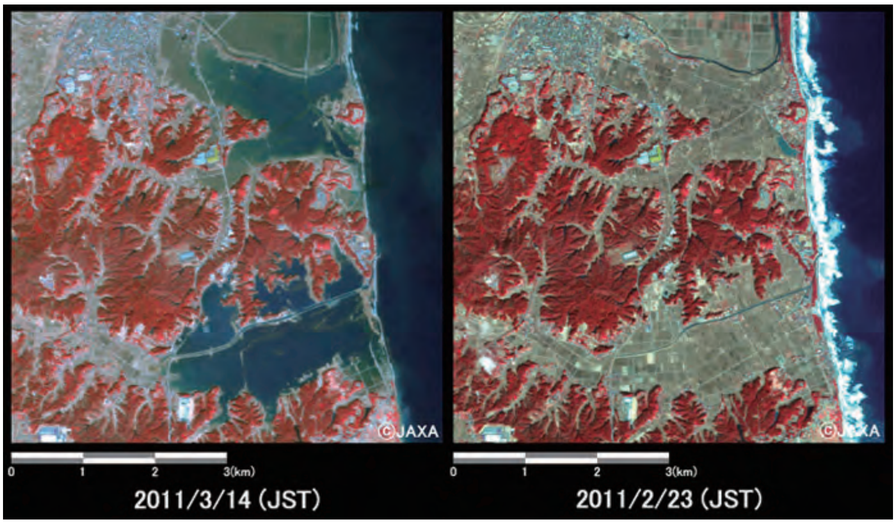


Figure 2.1-15 Flooding around Odaka, Minamisoma City, Fukushima (same 6 × 6 km area)

Observations using PALSAR also help to identify areas of flooding based on the properties of reflection. As shown in Figure 2.1-16, most signals transmitted from the satellite bounce off water when flooding is present, which results in less reflection back toward the satellite and makes terrain appear darker (left). After the floodwater dissipates, signal reflection back to the satellite is increased, making terrain appear lighter (right).

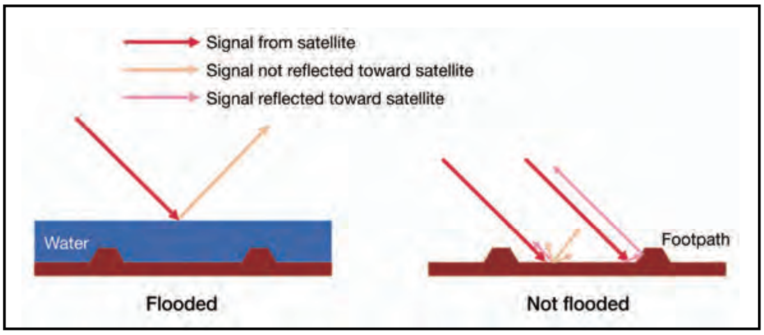


Figure 2.1-16 Difference in signal reflection with and without floodwater

Based on this characteristic, Figure 2.1-7 shows a pseudo-color image from PALSAR consisting of images observed on April 2 (red, incidence angle: 41.4°) and March 16, 2011 (green and blue, incidence angle: 43.4°). The images are merged to highlight changes along the Pacific coast from the Shimokita Peninsula to Chiba.

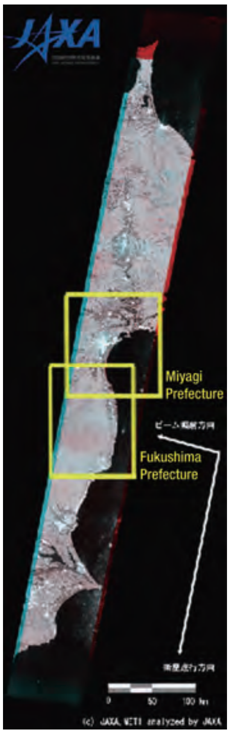


Figure 2.1-17 Pseudo-color PALSAR image

(R: observation on April 2 (incidence angle: 41.4°); G, B: observation on March 16 (incidence angle: 43.4°))

The geographical features of the two pseudo-color images were adjusted to compensate for their different incidence angles. The coastal areas of Miyagi and Fukushima shown in Figure 2.1-17 are enlarged in Figure 2.1-18.

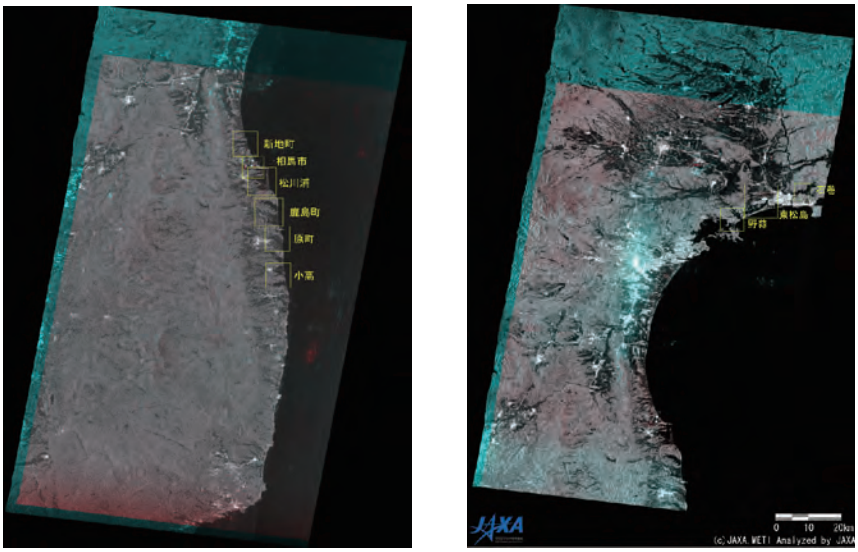


Figure 2.1-18 Enlarged images of coastal areas in Fukushima and Miyagi

Left: coastal area of Fukushima; right: coastal area of Miyagi

Figure 2.1-19 shows an enlarged image of the Ishinomaki area from Figure 2.1-18, which is a part of areas where changes can be seen between the two pseudo-color images shown in Figure 2.1-18 for March 16 and April 2. Areas that are lighter in the former (i.e., those with higher levels of reflection) than in the latter are indicated in blue, while those that are lighter in the latter are shown in red.

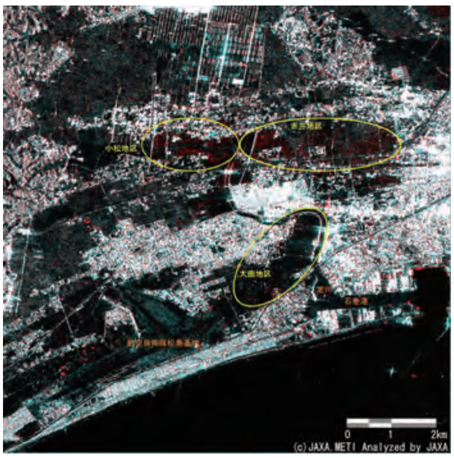


Figure 2.1-19 Enlarged image of the area around Ishinomaki

The rice fields along the Mano River (including those in the districts of Ouri, Negishi and Takaki) look dark due to floodwater, but are all lighter in the April image. This is because the ground surface was exposed as the floodwater dissipated, resulting in increased signal reflection.

Flooded parts of disaster-stricken areas were also detected using AVNIR-2 and PALSAR.

The total area of flooding in each prefecture was determined using pre- and post-earthquake images from AVNIR-2, and the results are shown in Table 2.1-4. Zero is shown for areas where observation was not possible due to clouds and for those where no flooding occurred. The results, classified into municipal government areas, were provided to central government ministries and agencies. By way of example, Figure 2.1-20 shows the results for the cities of Soma and Minamisoma. It can be seen that coastal areas were extensively flooded just after the disaster on March 14, and that the floodwater dissipated over time. Similar analysis was also conducted with images from PALSAR (see Section 2.1.7.2 for the analysis results).

Table 2.1-4 Total areas of flooding by prefecture as observed by AVNIR-2

Name of prefecture	Flooded area [km^2]						
	As of March 14	As of March 19	As of April 5	As of April 12	As of April 17	As of April 20	
	Observation on March 14	Observation on March 19	Observation on April 5	Observation on April 12	Observation on April 17	Observation on April 18	Observation on April 20
Iwate Prefecture	2.74	1.96	1.10	1.03	0.75	0.69	0
Miyagi Prefecture	109.09	64.68	22.28	14.21	7.61	4.28	0
Fukushima Prefecture	25.90	21.52	13.94	11.03	5.85	0	0.09
Ibaraki Prefecture	2.62	0.05	0.10	0.09	0.04	0	0.02
Chiba Prefecture	1.07	0.16	0.02	0	0	0	0.00

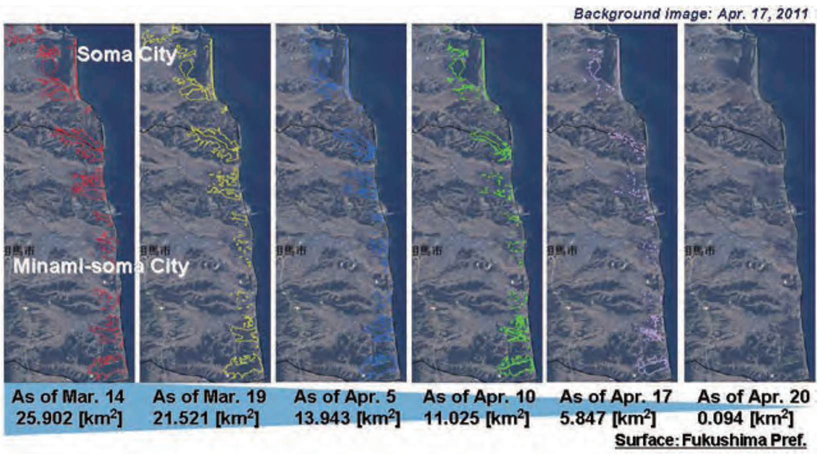


Figure 2.1-20 Results of observation by AVNIR-2 to determine total areas of flooding in the Fukushima cities of Soma and Minamisoma

2.1.3.6 Crustal movement

(a) Detection of crustal movement

Differential interferometric synthetic aperture radar (DInSAR) analysis was performed to detect crustal movement in relation to the Great East Japan Earthquake by comparing pre- and post-earthquake images acquired from the same orbit on April 18 and March 3, 2011.

Crustal deformation considered to have been caused by the M-7.0 earthquake centered on Hamadori in Fukushima on April 11, 2011, was also detected.

Figure 2.1-21 Range of PALSAR observation to detect crustal movement

SRTM3 data were used to provide digital elevation models. The red star shows the epicenter of the Great East Japan Earthquake.

The image on the left of Figure 2.1-22 was generated from PALSAR data acquired before the disaster (on March 3) and after it (on April 18) using differential interferometric SAR (DInSAR), and the image on the right is from PALSAR observation after the earthquake. Interference fringes (rainbow-color stripes) are seen in most parts of the left DInSAR image, indicating extensive crustal deformation typical of a massive earthquake. Diastrophism resulting in movement of around 2.6 m away from the satellite (including the gaps toward the east) is also seen in coastal areas of Sendai City in the vicinity of the epicenter.

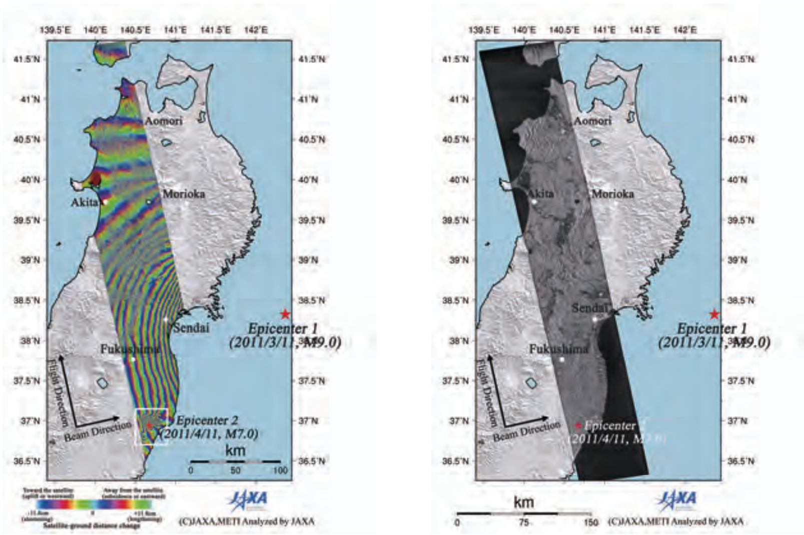


Figure 2.1-22 DInSAR images from PALSAR showing crustal deformation

Left: DInSAR image from PALSAR (crustal deformation). The section in the white frame is enlarged in Figure 2.1-23.

Right: PALSAR image taken after the earthquake. The Epicenter 1 star shows the focal point of the Great East Japan Earthquake (M 9.0), and the Epicenter 2 star shows that of the earthquake centered on Hamadori in Fukushima on April 11, 2011 (M 7.0). (Epicenter 2 data courtesy of the Japan Meteorological Agency)

In Figure 2.1-23, regional interference fringes that differ significantly from those around them can be seen. This is considered to stem from crustal deformation associated with the April 11 2011 Fukushima Hamadori earthquake (M 7.0), which is thought to have caused crustal movement of 2 m or more around the epicenter.

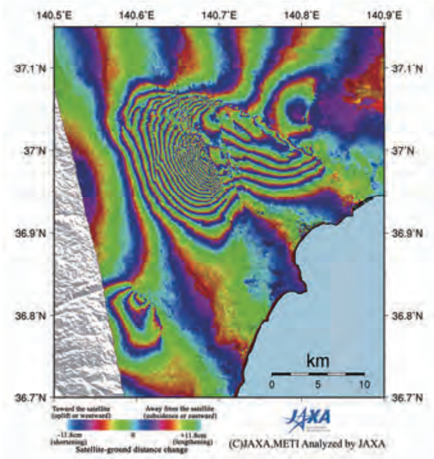


Figure 2.1-23 Enlarged DInSAR image from PALSAR (crustal movement)
(area shown in the white frame in Figure 2.1-22)

2.1.3.7 Liquefaction

Figure 2.1-24 shows enlarged images of the area around Kaihin-Makuhari Station on the Keiyo Line in Chiba based on AVNIR-2 data acquired after the earthquake on March 17, 2011 (left) and before the earthquake on February 23, 2011 (right). The areas circled in yellow show a lighter shade of gray after the earthquake due to liquefaction, which brought moist sand up to the ground surface. An example of this phenomenon is shown in the photo in Figure 2.1-25, taken on March 18, 2011.

Figure 2.1-24 Kaihin-Makuhari Station in Chiba (same 3 × 3 km area)

Figure 2.1-25 Liquefaction in Makuhari Kaihin Park (photo taken on March 18)

Figure 2.1-26 shows the results of liquefaction detection in a high-resolution image of the coastal area between Makuhari Hongo and Makuhari stations taken at 10:57 JST on March 17 2011 by the United States' WorldView-2 satellite, whose data is provided through Disaster Charter.

Figure 2.1-26 Areas of liquefaction between Makuhari Hongo and Makuhari stations

Left: overview; right: enlargement

2.1.3.8 Fire

Figure 2.1-27 shows enlarged pre- and post-earthquake images of the area around an oil refinery in Ichihara City, Chiba, observed by AVNIR-2 on March 17, 2011 (left) and on February 23, 2011 (right).

The black area circled in yellow is the site of a fire caused by the Earthquake.

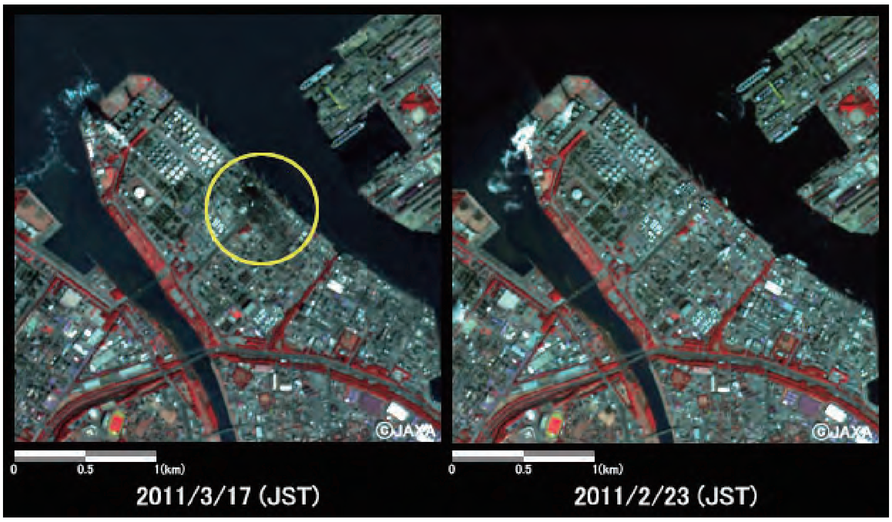


Figure 2.1-27 Oil refinery in Ichihara City, Chiba (same 3 × 3 km area)

Figure 2.1-28 shows a satellite topographical image in which the area of the fire at the oil refinery can be seen.　This is based on an image observed by FORMOSAT-2 on March 13 2011 through Sentinel Asia.

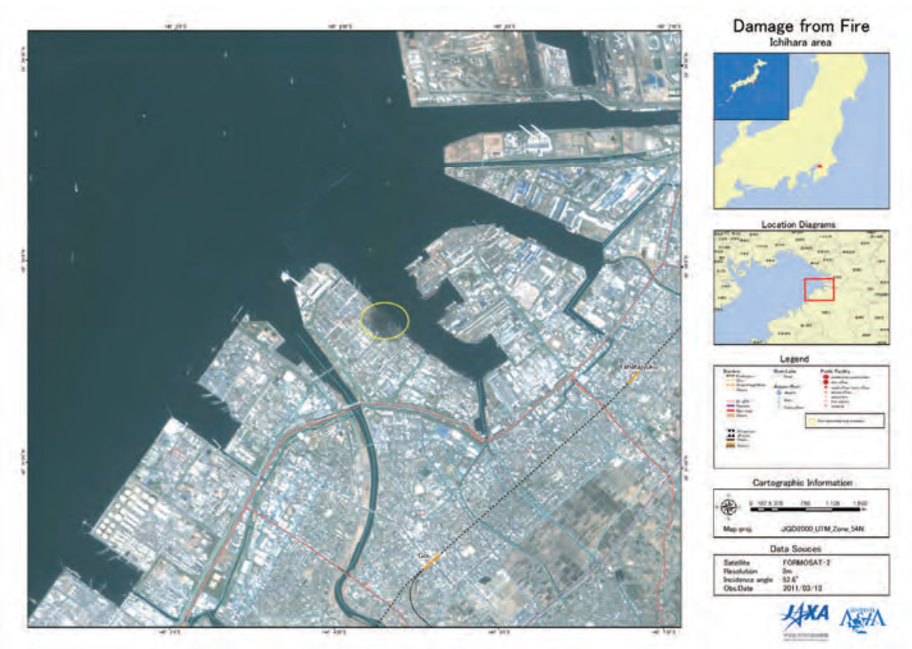


Figure 2.1-28 Satellite topographical image showing the area of the oil refinery fire in Ichihara City, Chiba

2.1.4 Cooperation with from overseas institutions

JAXA asked Sentinel Asia and, on behalf of the Cabinet Office, the Disaster Charter to carry out emergency observations immediately after the earthquake struck at 14:46 on March 11 2011 for (request time: 15:24).

2.1.4.1 Response by the Disaster Charter and others

In response to the request made to the Disaster Charter for emergency observations, earth observation satellites managed by space-related institutions worldwide observed more than 5,000 images and provided them to Japan. Table 2.1-5 shows a list of satellites and contributing institutions that conducted observations at the disaster areas as members of the Disaster Charter and others (except Daichi). In addition, footprints (observation areas) monitored by the Disaster Charter are also listed in Figure 2.1-29.

Table 2.1-5 Satellites used for observations by members of the Disaster Charter and others (except Daichi)

Sensor type	Satellite name	Organization name	Country
SAR data	TerraSAR-X	（Deutsches Zentrum für Luft- und Raumfahrt：DLR）	Germany
	RADARSAT-1, 2	（Canadian Space Agency：CSA）	Canada
	ENVISAT	（European Space Agency：ESA）	EU
	COSMO-SkyMed ※Provided by non-Chater member	（Agenzia Spaziale Italiana：ASI）	Italy
Optical sensor data	IKONOS-2	（U.S. Geological Survey：USGS）	USA
	GeoEye-1	USGS	USA
	QuickBird-2	USGS	USA
	WorldView-1, 2	USGS	USA
	SPOT-4, 5	（Centre National d'Etudes Spatiales：CNES）	France
	Kompsat-2	（Korea Aerospace Research Institute：KARI）	South Korea
	RapidEye	DLR	Germany
	HJ	（China National Space Administration：CNSA）	China
	LANDSAT-5, 7	USGS	USA
	EO-1	USGS	USA
	Cartosat	（Indian Space Research Organization：ISRO）	India
	Dubaisat ※Provided by non-Chater member	EIAST(Emirates Institution for Advanced Science and Technology）	UAE

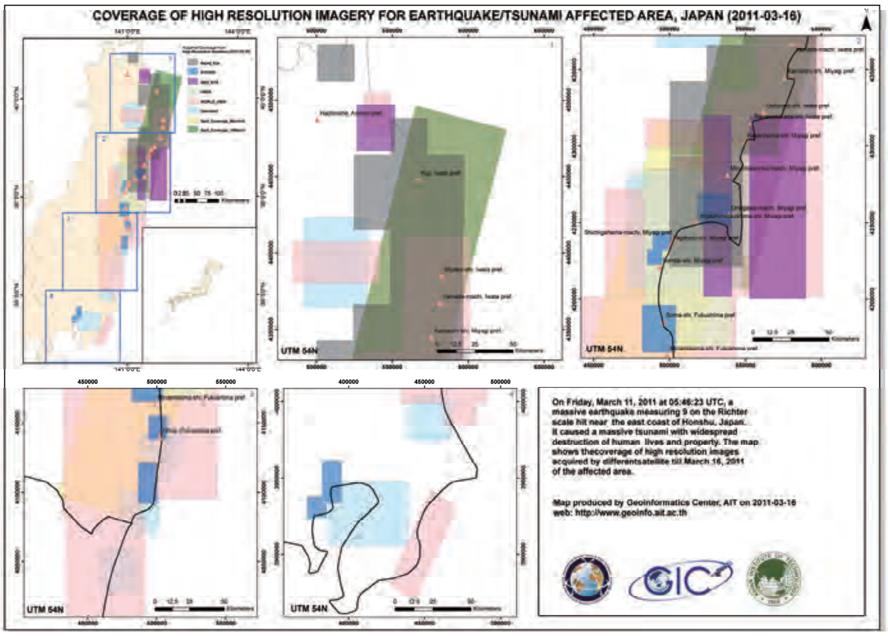


Figure 2.1-29 Overview of observations by Disaster Charter members

The images of the disaster areas provided by the Disaster Charter were processed and analyzed by JAXA, the Asian Institute of Technology (AIT), and other institutions across the world that were approved by the Disaster Charter. These organizations produced over 90 useful data sets and created related analysis products, which were made available to the public on the Disaster Charter website (Figure 2.1-30).

Figure 2.1-30 Image analysis products released on the Disaster Charter website
(http://www.disasterscharter.org/web/charter/home)

The institutes produce analysis products for the disaster-area images are listed in Table 2.1-6, and examples of products themselves are shown in Figures 2.1-31 to 2.1-41.

Table 2.1-6 Overseas institutions creating image analysis products for the Disaster Charter

Origin	Institution providing product	Satellite using data	Example of product
United Nations (UN)	United Nations Institute for Training and Research (UNITAR) / UNITAR's Operational Satellite Application Programme (UNOSAT)	RADARSAT-1 RADARSAT-2	Figure 2.1-31
USA	Clark Labs, Clark University	GeoEye-1, WorldView	Figure 2.1-32
	Earthquake Data Enhanced Cyber-Infrastructure for Disaster Evaluation and Response (E-DECIDER)	WorldView, QuickBird-2	Figure 2.1-33
	Rochester Institute of Technology (RIT)	GeoEye-1, WorldView	Figure 2.1-34
	USGS	WorldView-1	Figure 2.1-35
	George Mason University	WorldView-2	Figure 2.1-36
	GISCorps, Auburn University	WorldView-1	Figure 2.1-37
	ImageCat inc.	GeoEye-1	Figure 2.1-38
	Pennsylvania State University	WorldView-2	Figure 2.1-39
Germany	DLR / Center for Satellite Based Crisis Information (ZKI)	RapidEye TerraSAR-X	Figure 2.1-40
France	Regional Service of Image Treatment and Remote Sensing (SERTIT)	WorldView-1, 2 IKONOS-2 SPOT-5 Landsat-7	Figure 2.1-41

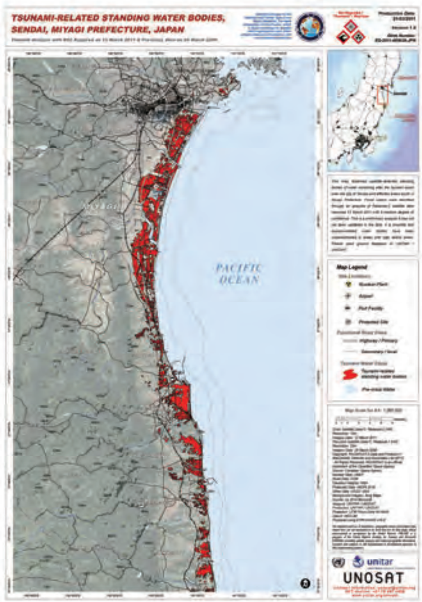


Figure 2.1-31 Example of image analysis products produced by overseas institutions (United Nations Instiute for Traing and Research (UNITAR) / UNITAR’s Operational Satellite Application Programme (UNOSAT))

Identification of tsunami-hit areas from Sendai to southern Miyagi using pre- and post-disaster SAR images
Images used: RADARSAT-1 (observation after disaster on March 12, 2011), RADARSAT-2 (observation before disaster on March 26, 2006)

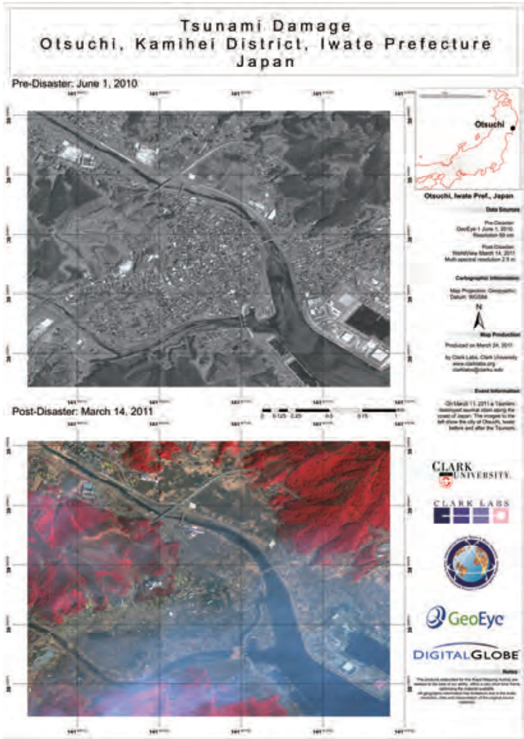


Figure 2.1-32 Example of image analysis products produced by overseas institutions (Clark Labs, Clark University.)

Pre- and post-disaster images of Otsuchi Town, Iwate, taken using a high-resolution optical sensor
Images used: top: GeoEye-1 (observation before disaster on June 1, 2010); bottom: WorldView (observation after disaster on March 14, 2011)

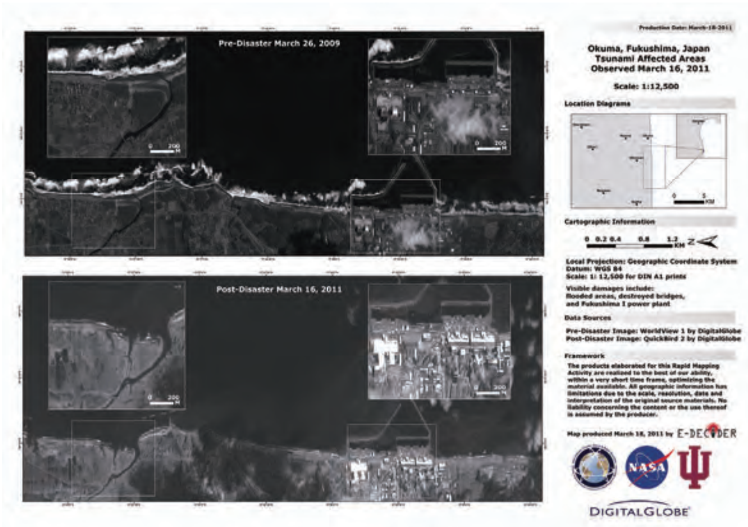


Figure 2.1-33 Example of image analysis products produced by overseas institutions (Earth quake Date Enhanced Cyber-Infrastructure for Disaster Evaluation and Response(E-DECIDER))

Pre- and post-disaster images of the Fukushima Dai-ichi Nuclear Power Station taken using a high-resolution optical sensor
Images used: top: WorldView-1 (observation before disaster on March 26, 2009): bottom: QuickBird-2 (observation after disaster on March 16, 2011)

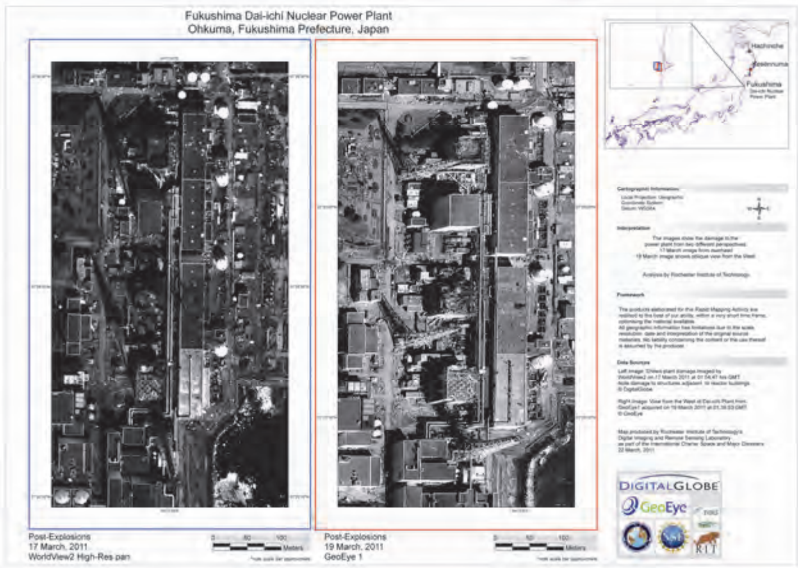


Figure 2.1-34 Example of image analysis products produced by overseas institutions Rochester Institute of Technology (RIT)

Post-disaster images of the Fukushima Dai-ichi Nuclear Power Station taken using a high-resolution optical sensor after the hydrogen explosion

Images used: left: WorldView-2 (observation on March 17, 2011); right: GeoEye-1 (observation on March 19, 2011)

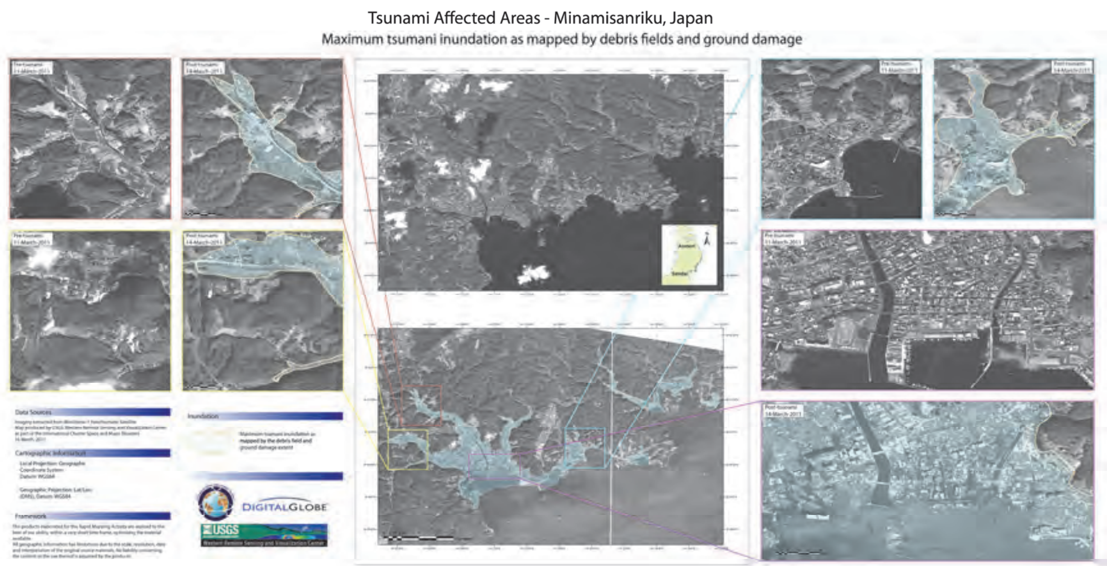


Figure 2.1-35 Example of image analysis products produced by overseas institutions United States Geological Survey (USGS)

Pre- and post-disaster images of tsunami-affected areas in Minamisanriku Town, Miyagi, taken using a high-resolution optical sensor

Images used: Worldview-1 (observation before disaster on March 11, 2011; observation after disaster on March 14, 2011)

Figure 2.1-36 Example of image analysis products produced by overseas institutions (George Mason University.)

Pre- and post-disaster images of tsunami-affected areas in Tagajo City, Miyagi, taken using a high-resolution optical sensor
Images used: Worldview-2 (top: observation before disaster on August 4, 2010; below: observation after disaster on March 14, 2011)

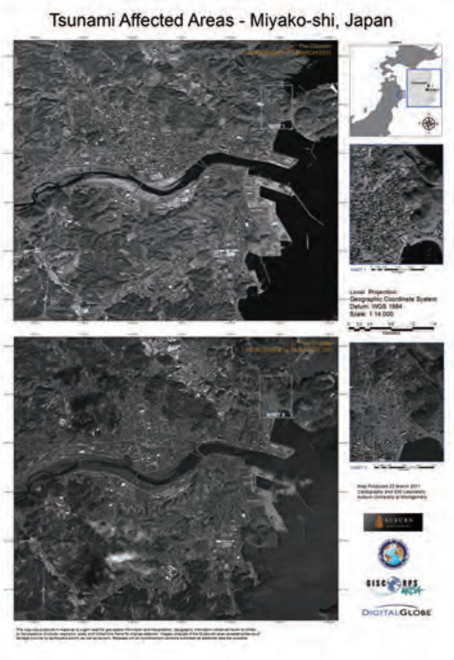


Figure 2.1-37 Example of image analysis products produced by overseas institutions (GISCorps, Aubum University.)

Pre- and post-disaster images of tsunami-affected areas in Miyako City, Iwate, taken using a high-resolution optical sensor
Images used: Worldview-1 (top: observation before disaster on March 11, 2011; bottom: observation after disaster on March 19, 2011)

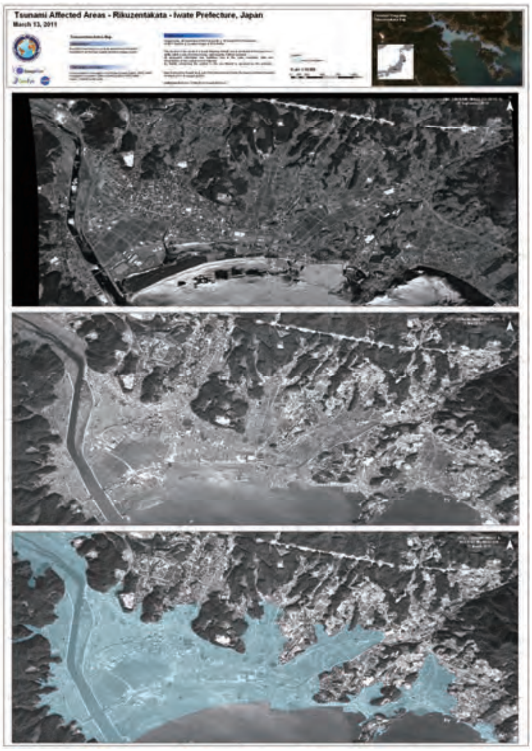


Figure 2.1-38 Example of image analysis products produced by overseas institutions (Image Cat Inc,)

Pre- and post-disaster images of tsunami-affected areas in Rikuzentakata City, Iwate, taken using a high-resolution optical sensor

Images used: GeoEye-1 (top: observation before disaster on September 29, 2010; center: observation after disaster on March 13, 2011; bottom: post-disaster image of tsunami-affected areas)

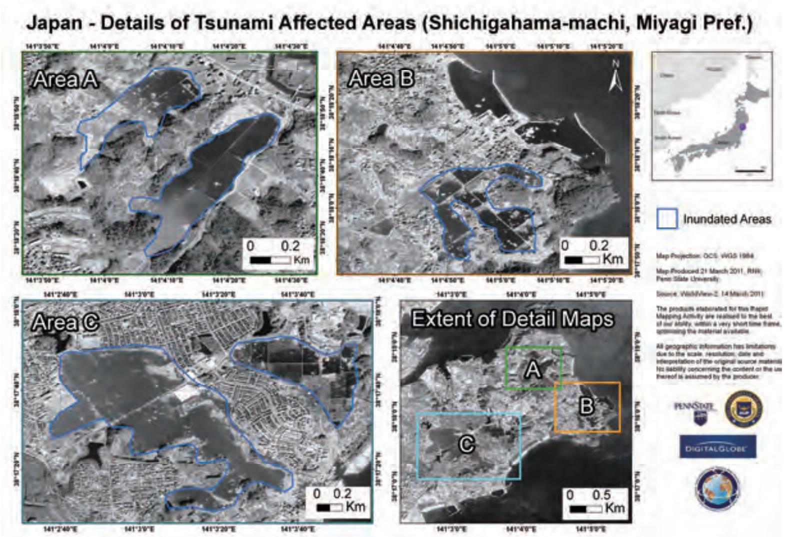


Figure 2.1-39 Example of image analysis products produced by overseas institutions (Pennsylvania State University.)

Post-disaster images of tsunami-affected areas in Shichigahama Town, Miyagi, taken using a high-resolution optical sensor

Images used: Worldview-2 (observation after disaster on March 14, 2011)

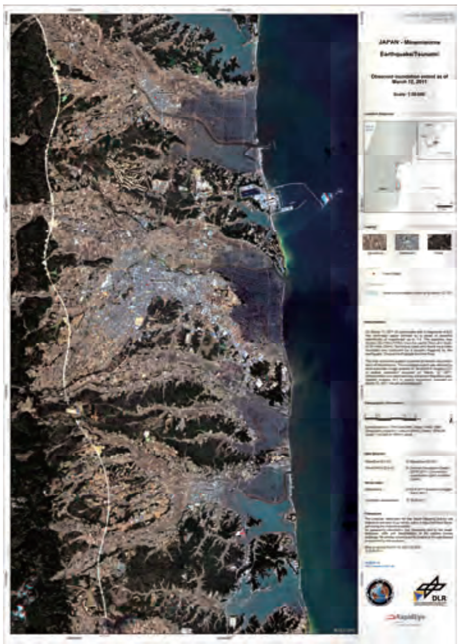


Figure 2.1-40 Example of image analysis products produced by overseas institutions (Deutsches Zentrum für Luft-und Raumfahrt (DLR) / Center for Satellite Based Crisis Information (ZKI))

Superimposition of a SAR image showing tsunami-affected areas in Minamisoma City, Fukushima, onto one taken using a high-resolution optical sensor

Images used: SAR/Terra SAR-X (observation after disaster on March 12, 2011), optics/RapidEye (observation after disaster on March 12, 2011)

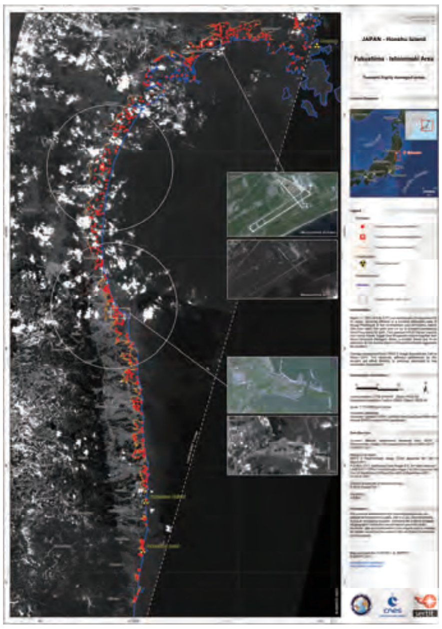


Figure 2.1-41 Example of image analysis products produced by overseas institutions (Service Régional de Traitement d'Image et de Télédétection (SERTIT))

Superimposition of pre-disaster wide-range images of the area encompassing Ishinomaki City, Miyagi, and Okuma Town, Fukushima, taken using an optical sensor, onto an image of the tsunami-affected areas, and post-tsunami enlarged images taken using a high-resolution optical sensor

Images used: broad-swath images/Landsat-7 (observations before disaster on September 21, 2000 and September 24, 2001), enlarged images/SPOT-5 (observation after disaster on March 12, 2011)

2.1.4.2 Response by Sentinel Asia

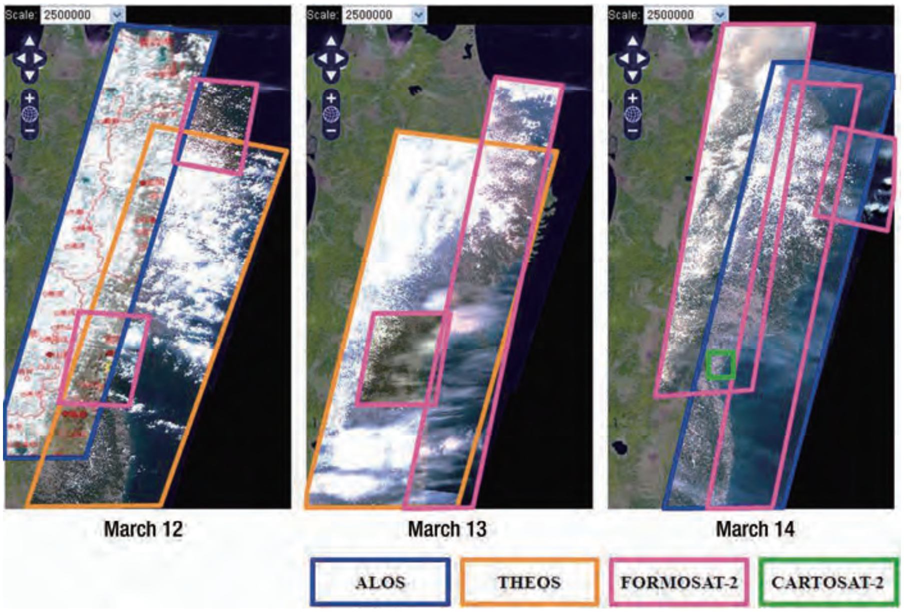
JAXA asked Sentinel Asia observations along the Tohoku coast to supplement the observation areas of Daichi on March 11, because PRISM and AVNIR-2 observations using Daichi were scheduled for inland Tohoku on the day after the earthquake (March 12) and the tsunami was thought to have affected a wide area.

In response, Taiwan's National Space Organization (NSPO) of the National Applied Research Laboratory (NARL) and Thailand's Geo-Informatics and Space Technology Development Agency (GISTDA) conducted observations along the coast using FORMOSAT-2 and THEOS on March 12. The activities were continued on March 13, and the Indian Space Research Organization (ISRO) also observed the Sendai area using CARTOSAT-2 on March 14 after the FORMOSAT-2 survey.

FORMOSAT-2 has the particular characteristic of following the same orbit every day and making three observations of Japan with each flight over the country by shifting the pitch of its axis from north to south. It continuously observed the disaster areas between March 12 and 24 every day.

Table 2.1-7 Emergency observations by Sentinel Asia satellites (except Daichi)

Date	Time	Major events
March 11	14:46	Earthquake occurrence
	15:24	Emergency observation requested
March 12	Approx. 9:12	Observation by FORMOSAT-2
	Approx. 10:07	Observation by THEOS
	Approx. 13:00	FORMOSAT-2 data provided (observation on March 12)
March 13	Approx. 9:12	Observation by FORMOSAT-2
	Approx. 9:47	Observation by THEOS
	Approx. 15:00	FORMOSAT-2 data provided (observation on March 13)
March 14	Approx. 9:12	Observation by FORMOSAT-2
	Approx. 10:30	Observation by CARTOSAT-2
	Approx. 15:00	FORMOSAT-2 data provided (observation on March 14)
	Approx. 17:09	THEOS data provided (observation on March 12)
	Approx. 23:04	THEOS data provided (observation on March 13)
March 15	Approx. 9:12	Observation by FORMOSAT-2
	Approx. 15:00	FORMOSAT-2 data provided (observation on March 15)
March 16	Approx. 9:12	Observation by FORMOSAT-2
	Approx. 15:00	FORMOSAT-2 data provided (observation on March 16) CARTOSAT-2 data provided (observation on March 14)
March 17 – 24	Approx. 9:12	Observation by FORMOSAT-2
	Approx. 15:00	FORMOSAT-2 data provided (observation on the day)



*FORMOSAT-2 observed the same area between March 14 and 24 every day.
Background images: acquired by LANDSAT, NASA

Figure 2.1-42 Observation areas covered by each satellite

(1) Quick gathering of data on the affected areas

Satellite images covering all the affected areas, including inland regions, had been taken on March 12 (the day after the earthquake) through cooperation with Sentinel Asia using the FORMOSAT-2, THEOS and CARTOSAT-2 satellites in combination with observations made by Daichi. By March 14, cloud-free images had been obtained for almost all coastal areas, including zones where local conditions could not be determined from images obtained on March 12 due to the presence of clouds.

Immediately after observation, FORMOSAT-2 data were initially sent to Taiwan due to the geographical situation of the receiving station. The observation data were made available on the afternoon of the same day. The images taken on March 12 were provided at around 13:00 together with those taken on March 11 before the earthquake struck. On the following day (March 13), the results of image analysis were also provided to enable comparison of conditions before and after the disaster (Figures 2.1-43 and 2.1-44), and proved helpful in promptly determining the extent of the damage.

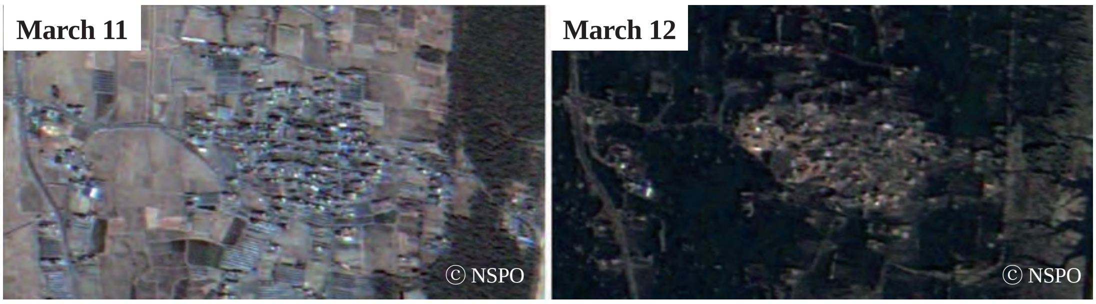


Figure 2.1-43 FORMOSAT-2 images (Watari Town and surrounding areas, Miyagi)

Figure 2.1-44 FORMOSAT-2 images (Watari Town and surrounding areas, Iwanuma City, Miyagi)

Figure 2.1-45 FORMOSAT-2 image (Miyagino Ward and surrounding areas, Sendai, Miyagi)

Figure 2.1-46 THEOS image (Higashimatsushima City and surrounding areas, Miyagi)

Figure 2.1-47 CARTOSAT-2 image (Shiogama Port and surrounding areas, Sendai)

(2) Continuous observation for determination of changes in the affected areas

Sentinel Asia continuously observed all the affected areas immediately after the earthquake and for a period of two weeks in collaboration with FORMOSAT-2.

Comparison of daily data observed under the same conditions enabled identification of developments in the affected areas, such as changes in flood areas, fire outbreaks, fire control, snowfall and other weather considerations.

Figure 2.1-48 FORMOSAT-2 images (Shiogama Port area, Sendai)

(3) Provision of satellite data to organizations in Japan

Satellite data from Sentinel Asia which can be used for analyasis is usually provided exclusively to member organizations operating as Data Provider Nodes and Data Analysis Nodes. However, it was decided to distribute the data freely to organizations in Japan in response to the Great East Japan Earthquake in conjunction with the National Applied Research Laboratory (NARL) and the National Space Organization (NSPO).

As a result, FORMOSAT-2 data were provided to six universities and one private company on request, and were utilized by a variety of organizations in activities to support the affected areas.

2.1.5 Product provision and utilization by users for disaster management

2.1.5.1 Product provision

JAXA created over 1,700 products using satellite data from Daichi and data provided by the International Disaster Charter and Sentinel Asia. These were distributed to government ministries involved in disaster risk management as well as to local governments and other disaster prevention institutions.

Standard processed data from Daichi were also provided to users involved in disaster management for analysis purposes, and were utilized by various organizations.

Table 2.1-8 Major analysis products provided by JAXA

Main type	Details	Satellite data used	Forms
Daichi satellite image Map	Geographical information is superimposed on images acquired by Daichi with several reduced-scale. Daichi satellite image maps are arranged as standard.	Daichi (emergency observation data) Daichi (archive)	Geo PDF Geo TIFF JPEG (low resolution) JPEG (high resolution) PDF Online delivery Shape file PowerPoint Large printed paper Excel (numerical data)
Mapping product	Geographical information is superimposed on data acquired by overseas satellite images with several reduced-scale.	Provide by the Disaster Charter and Sentinel Asia	
Area damage analysis	Production of images for areas where there is a need, and processing of already-acquired images Identification of changes between pre- and post-disaster images Stereoscopic images from disaster areas Interferograms generated from ALOS/PALSAR data using the differential interferometric SAR (DInSAR) technique	Daichi (emergency observation data) Daichi (archive) Provided by the Disaster Charter Provided by Sentinel Asia	
Flood damage analysis	Time series analysis for areas of tsunami flooding Calculation the overall flooded area Interpretation of liquefaction	Daichi (emergency observation data) Daichi (archive) Provided by the Disaster Charter	
Nuclear power plant	Images of facilities and buildings of the Fukushima Dai-ichi Nuclear Power Station Superimposition of images showing the plant's range scales and nuclear evacuation zones Comparison of before-/after-earthquake images showing the plant's facilities and buildings Comparison of before-/after-earthquake images showing other nuclear power plants, e.g., the Onagawa facility	Daichi (emergency observation data) Daichi (archive) Provided by the Disaster Charter	
Accident analysis	Identification of changes in marine debris/flotsam and related analysis Analysis of fires (in mountainous areas and complexes) Analysis of sediment damage	Daichi (emergency observation data) Daichi (archive) Provided by the Disaster Charter Provided by Sentinel Asia	

2.1.5.2 Utilization by parties involved in disaster management

Feedback from users of products provided by JAXA is summarized below.

(1) Cabinet Secretariat (in charge of security and risk management)

In response to a request from the Crisis Management Center of the Prime Minister's Office to take initial action immediately after the earthquake, Daichi images and satellite data provided through the Disaster Charter were used to create mapping products for comparison of pre- and post-disaster conditions at the Japan Air Self-Defense Force's Matsushima Airbase and Sendai Airport (as potential bases for the transport of patients and goods), for determination of changes in the status of buildings at the Fukushima Dai-ichi Nuclear Power Station, and for monitoring of the expanded evacuation zone and stay-indoors zone around the plant. In addition, in response to a request for data to be used in identifying an area in which evacuees would be allowed to return home for a limited period of time, the results of satellite data analysis for tsunami-flooded areas were provided. On March 15, a flight restriction was issued for areas within 30 km of the Fukushima Dai-ichi Nuclear Power Station, making it difficult to determine local conditions using aircraft. Against this background, optical images of the power plant and surrounding areas (including high-resolution data from the

Disaster Charter) were provided almost every day until April 19, and were utilized to identify changes in the status of buildings at the plant.

It was difficult to obtain an overall picture of local damage immediately after the earthquake, and these images from Daichi and other satellites were the first post-disaster data provided. They enabled direct and uniform determination of local conditions over wide areas, and were the most utilized geospatial information products during the early stages of post-disaster response. To meet a variety of needs, particularly from the Prime Minister's Official Residence, the products were flexibly made according to the scale of the area of interest (i.e., from individual buildings to whole regions) and presented for comparison with relatively recent pre-disaster images. They were also frequently utilized in combination with aerial photos provided later.

Figure 2.1-49 Pre- and post-disaster images of Sendai Airport from Daichi (left) and satellite images of the Fukushima Dai-ichi Nuclear Power Station provided by the Disaster Charter (right)

(2) Cabinet Office (disaster management)

After the disaster, a contact system between the Cabinet Office and JAXA was promptly established. Based on this setup, emergency observation plans to support the selection of disaster zones for observation and for other purposes, and the details of the products to be created were discussed in the Cabinet Office.

Immediately after the earthquake, a set of Daichi satellite image maps (57 maps; 46 on a scale of 1:50,000 and 11 on a scale of 1:200,000) created using Daichi data collected from Pacific coastal areas in the Tohoku region before the disaster were printed in wide format and hand-carried by JAXA staff to the Cabinet Office because transportation services in the Tokyo metropolitan area were suspended. On March 12, the day after the earthquake, 19 maps were added as requested, and totally 76 pre-disaster Daichi satellite image maps were provided and distributed to the disaster countermeasures offices of individual prefectures via the Cabinet Office.

Daichi emergency observation results and pre-disaster archive data were continuously provided in GeoTIFF, orthorectified or standard processed data format. Geographical information of various types was merged with onto Daichi data to create a range of map products, which were provided as digital data or printed in large format. These data were utilized by the Crisis Management Center of the Prime Minister's Office and by other organizations.

In response to a request for provision of information on flooded areas ranging from Hokkaido to Chiba in order to support determination of the extent of tsunami damage across the affected areas, the results of data analysis for the entire disaster-stricken region (together with those for the Tohoku and northern Kanto regions provided in line with requests from other institutions) were made available to the public. Products from the Disaster Charter were also provided as needed.

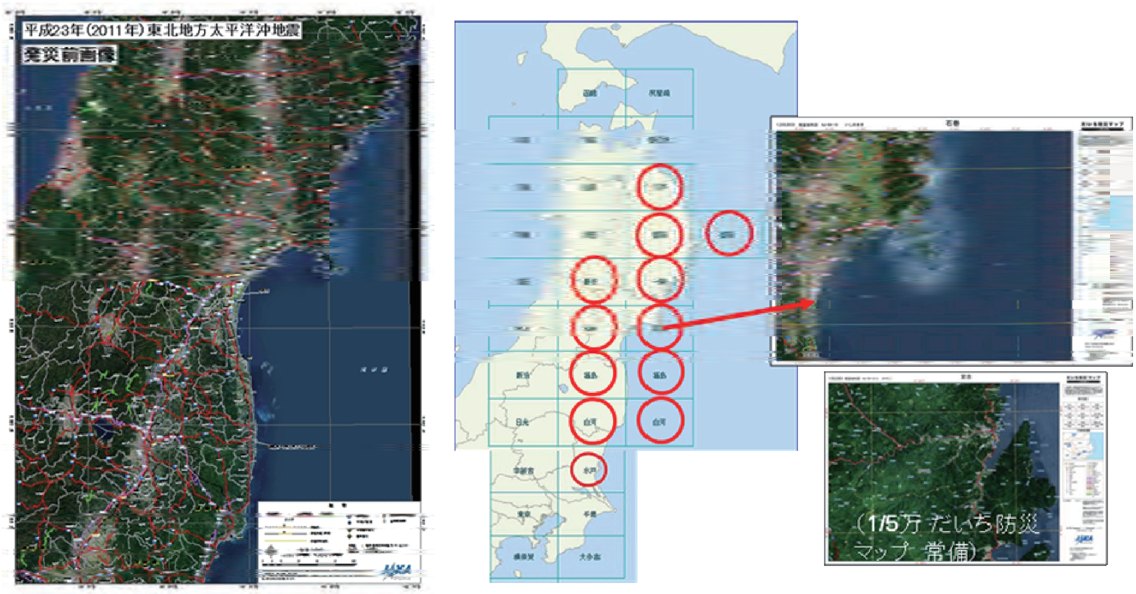


Figure 2.1-50 Daichi satellite image maps: special scale (1:400,000) (left) and regular scale (1:200,000) (right)

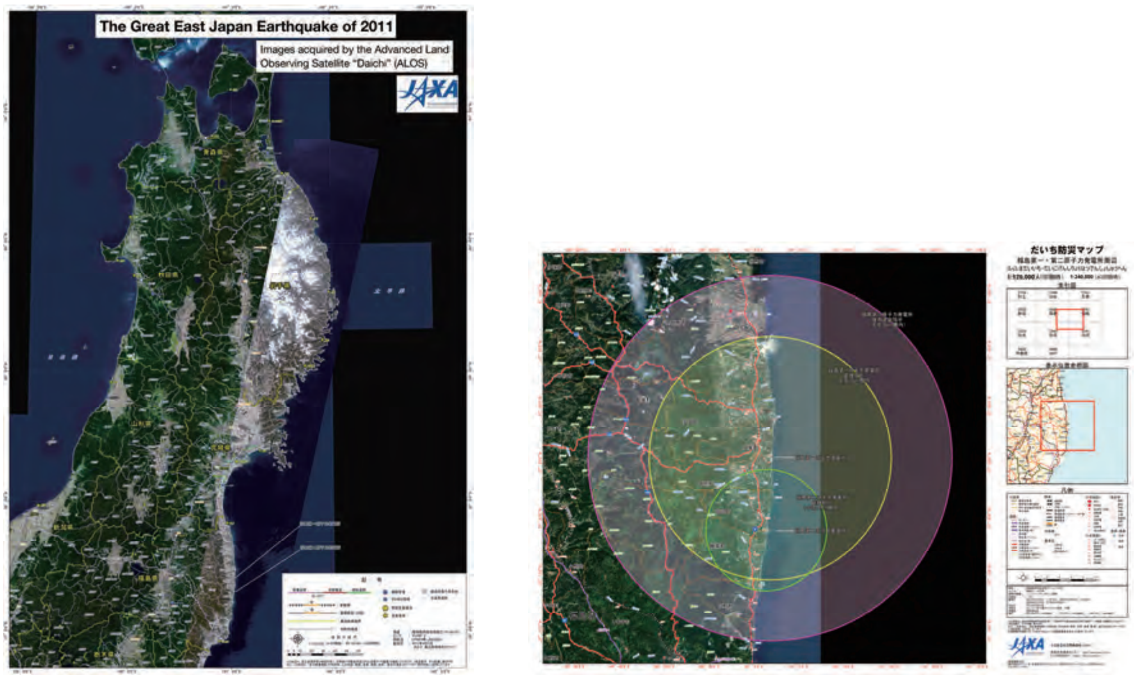


Figure 2.1-51 Daichi satellite image maps: with a post-disaster Daichi image merged with onto a pre-disaster one (left), and with information on distances from the Fukushima Dai-ichi Nuclear Power Station superimposed onto a pre-disaster one (right)

(3) National Police Agency

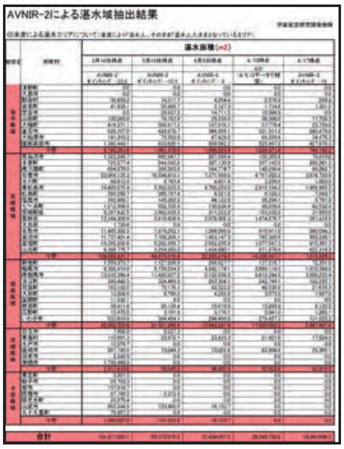
Observation images posted on Daichi Bosai WEB were downloaded by the National Police Agency, and a range of related products were created. These were printed in large format and sent to on-site disaster countermeasures offices in individual disaster-affected prefectures.

(4) Ministry of Land, Infrastructure, Transport and Tourism

(a) River Bureau, City and Regional Development Bureau, Housing Bureau, Kanto and Kinki Regional Development Bureaus

In response to a request for provision of Daichi emergency observation data immediately after the disaster, information on plans for observation of coastal Tohoku and on cloud coverage information in AVNIR-2 images was provided. In line with a further request for provision of information on flooding in tsunami-hit areas to help clarify the growing tsunami damage, information on flood areas as determined from data interpretation and from calculation using the output of PALSAR and AVNIR-2 was provided from March 21 through April 22. These results were used for comparative verification with other information.

Another request was also received for provision of satellite data to be used in determining the extent of the damage and detecting wildfires in Pacific coastal areas of eastern Japan. In response, information extracted from Daichi images of the Sanriku coast in Iwate and satellite images of liquefaction areas in Chiba from the Disaster Charter were provided.


AVNIR-2による湛水域抽出結果

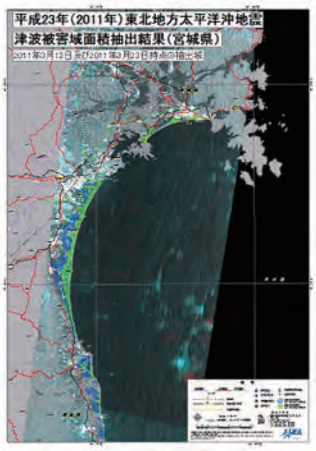
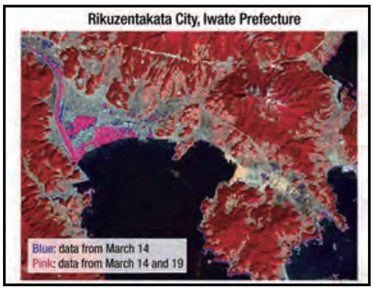


Figure 2.1-52 List of flooded areas (m^2) extracted from AVNIR-2 data (left) and an image of flooded areas extracted from PALSAR data (right)



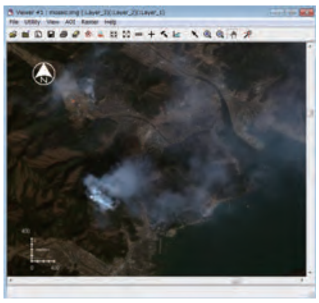


Figure 2.1-53 Image of flooded areas extracted from AVNIR-2 data (left), identification of liquefaction areas (middle) and identification of a wildfire (Otsuchi Town, Iwate) (right)

(b) National Institute for Land and Infrastructure Management

Prompt investigations were needed in light of the high risk of landslides in the 40,000 km^2 area where a seismic intensity of 5-upper was experienced. There were also fears that extensive collapses might trigger secondary landslides due to aftershocks and rainfall. In response to a request from the National Institute for Land and Infrastructure Management, JAXA performed emergency observation using Daichi. The images collected (AVNIR-2, PRISM, pan-sharpened and forward view) were provided to the institute, where they were interpreted by specialists, and automatic landslide identification was performed. As a result, approximately 200 actual and potential landslides were pinpointed. It was also confirmed that no major rivers had been blocked by landslides, and that no intensive landslides had occurred.

It was impossible to survey every hazard event based only on visual observation from helicopters. In addition, as only satellite-based observation could be conducted in the no-fly zone (within 30 km of the nuclear power plant), images captured by Daichi proved very effective.

These results were reported to the Sabo (Erosion and Sediment Control) Department of the Ministry of Land, Infrastructure, Transport and Tourism and released as emergency inspection results.

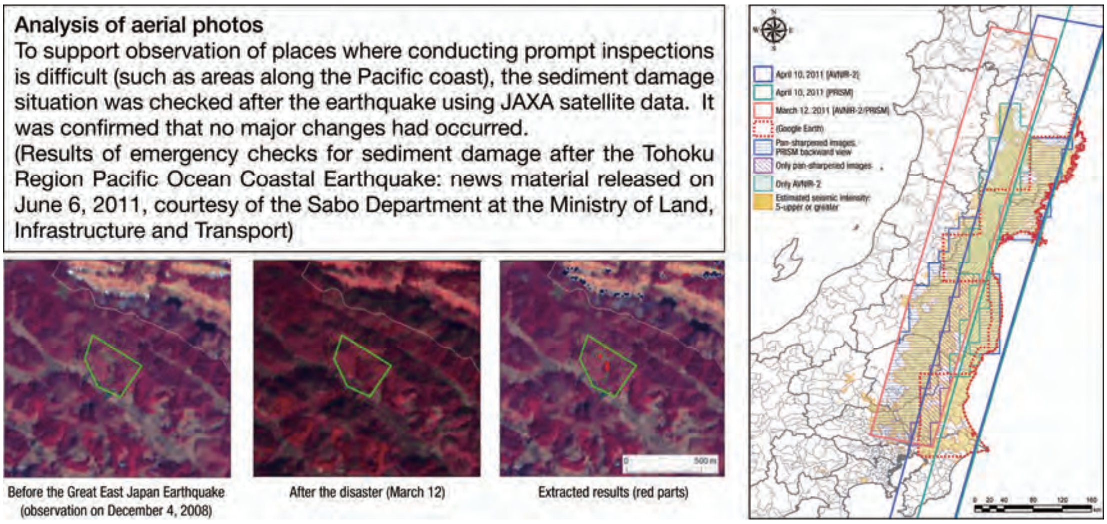


Figure 2.1-54 Satellite image interpretation

(5) Ministry of Agriculture, Forestry and Fisheries

The Ministry of Agriculture, Forestry and Fisheries asked JAXA to provide Daichi data for prompt determination of the extent of damage to farmland in tsunami-hit areas. In response, JAXA analyzed tsunami-related flooding using PALSAR and other satellite data and provided the results to the ministry. These data were utilized to clarify the situation on farmland and as information to be taken into consideration together with later information when devising methods of related restoration.

Daichi images from Daichi Bosai WEB were also downloaded by the Ministry of Agriculture, Forestry and Fisheries and used as base maps. These images were further used to assess damage and current conditions at Ogaki irrigation dam, which could not be observed directly because it was located within 20 km of the Fukushima Dai-ichi Nuclear Power Station.

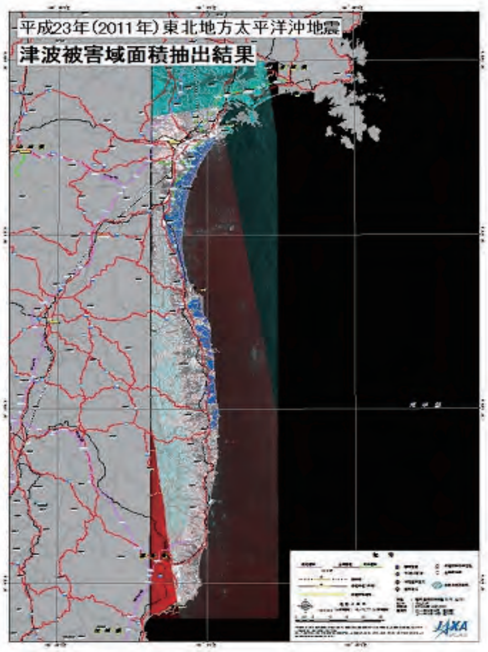


Figure 2.1-55 Results of flooding analysis using PALSAR data provided to the Ministry of Agriculture, Forestry and Fisheries

(6) Fisheries Agency

As reference information to support the assessment of damage to aquaculture rafts, Daichi images of Yamada Bay in Iwate and coastal areas of Kesennuma City in Miyagi were provided to the Fisheries Agency's Fish Ranching and Aquaculture Division.

JAXA contacted the Resource Management Department to offer data for use in searching for fishing boats, but the information was not needed due to the constantly changing nature of the situation.

Figure 2.1-56 Floating debris in the sea as captured in a Daichi image provided to the Fisheries Agency

(7) Japan Coast Guard

The Japan Coast Guard's Navigation Guidance Office (part of the Maritime Traffic Department's Navigation Safety Division) requested information covering a wide area to support the tracking of Marine debris off the coast of Miyagi. Daichi data collected on April 18 were analyzed and provided, although further scheduled data provision was canceled due to the suspension of Daichi's observations. Data were also provided as reference information to the Japan Coast Guard's Guard and Rescue Department.

(8) Ministry of the Environment

In response to a request for satellite data analysis from the Ministry of the Environment to support investigation of floating debris distribution along the Sanriku coast, changes between pre- and post-disaster observation data (November 16, 2010 vs. March 14, 2011) were identified. As a result, the presence of floating debris over an area of approximately 560,000 m^2 in the Rikuzentakata region alone was determined. This result was largely consistent with that of a study by the Ministry of the Environment, and provided useful data to determine the amount of floating debris and matter washed up on beaches where access was not possible and along coasts and on beaches where evaluation was difficult. The results were also provided to the Japan Coast Guard.

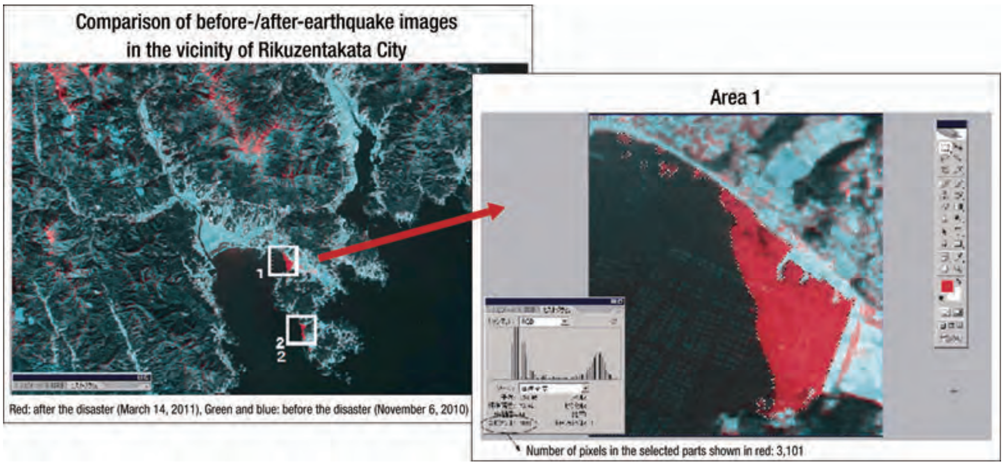


Figure 2.1-57 Daichi image of debris washed up along the coastline

(9) Ministry of Education, Culture, Sports, Science and Technology

In line with a request from the Nuclear Damage Compensation Office (part of the Research and Development Bureau at the Ministry of Education, Culture, Sports, Science and Technology), a product in which range indications and nuclear evacuation zones for the Fukushima Dai-ichi Nuclear Power Station were merged with onto Daichi images and a variety of other products related to the plant were created, printed on a large scale and provided to the office.

Figure 2.1-58 Fukushima Dai-ichi Nuclear Power Station range scales

(10) National Research Institute for Earth Science and Disaster Prevention

In response to a request from the Disaster Risk Research Unit of the National Research Institute for Earth Science and Disaster Prevention to release Daichi images, related data covering the Tohoku region and Niigata and Nagano prefectures were provided. Based on WMS (ISO 19128 — an international standard for geospatial information distribution), these Daichi images were distributed by the institute as a matter of urgency for use at volunteer centers and other facilities in the affected areas via the ALL311 Great East Japan Earthquake Information Platform website, and were also transmitted as information to support disaster response and recovery in affected areas.

Figure 2.1-59 Web page with information on Daichi image distribution (left) and WMS distribution of Daichi images (right)

(http://bosai-drip.jp/alos/wms.htm)

(11) Geospatial Information Authority of Japan and Earthquake Working Group

At the Geospatial Information Authority of Japan and the Earthquake Working Group, SAR interferometry was performed using data acquired by Daichi before and after the disaster, and the results were released. The data identified crustal deformation of up to 4 m near the Oshika Peninsula — a result that corresponded with the outcomes of continuous GPS observations (movement of approximately 5.3 m in an east-southeast direction and subsidence of approximately 1.2 m). Local crustal deformation resulting from inland earthquakes triggered by the main shock (M 9.0) of March 11 was also seen in several locations.

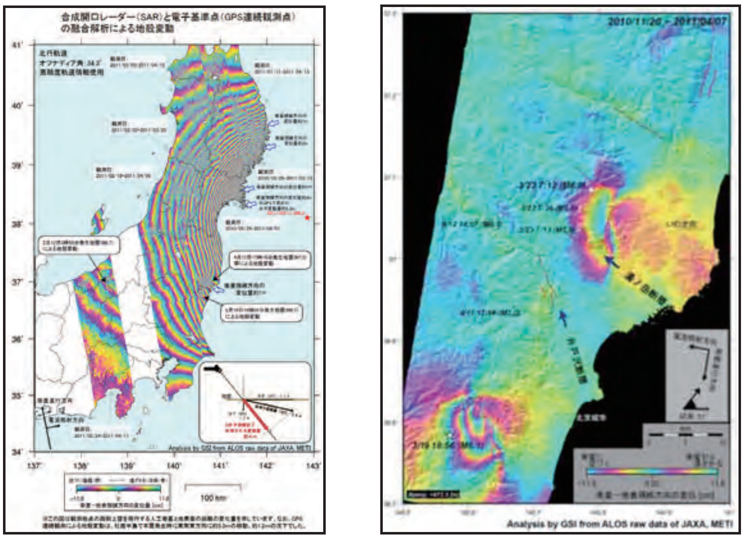


Figure 2.1-60 Analysis of crustal deformation caused by the main shock (left) and identification of crustal deformations caused by aftershocks (right)

(12) Iwate and Fukushima Prefectural Disaster Countermeasures Offices, on-site technical emergency control forces, government agency regional bureaus and departments

In cooperation with Professor Yokoyama from the Laboratory of Remote Sensing Data Analysis at Iwate University, Daichi data provided by JAXA were analyzed by the university, and products were created and printed in long format. Professor Yokoyama visited local organizations in Iwate and other prefectures to distribute the results. Related local organizations faced extreme difficulties in determining the extent of the damage because communications networks were disrupted and gasoline shortages restricted the sphere of activity. Against this background, Daichi images were utilized in various ways by local organizations involved in disaster response.

(a) List of Daichi image products created

① AVNIR-2 images taken on Mar. 14, 2011
② Pan-sharpened (PS) images taken on Mar. 24, 2011
③ PS images and PS stereoscopic images taken on Apr. 10, 2011
④ PS images from before the disaster

(b) Major organizations receiving data

① Iwate Prefecture Disaster Countermeasures Office and Iwate Air Rescue Team
■ Daichi images of coastal Iwate on a scale of 1:30,000 taken before and after the disaster and printed on

paper measuring 7 m in length were provided.

- ■ The print gave an overall picture of the affected areas, and was posted in the control center and used to share information with relevant parties.

② Ground Self-Defense Force Iwate and Miyagi Disaster Relief Headquarters

The same 7-m printout was provided in response to a request from the Ground Self-Defense Force for use in rescue operations in the affected areas.

- ■ Daichi images of coastal Iwate on a scale of 1:30,000 taken before and after the disaster and printed on paper measuring 7 m in length were provided.
- ■ Daichi images of coastal Miyagi on a scale of 1:30,000 taken before and after the disaster and printed on paper measuring 6 m in length were provided.

③ Fukushima Prefecture Disaster Countermeasures Office

- ■ PS stereoscopic images of coastal Fukushima on a scale of 1:30,000 taken on Apr. 10, 2011, were provided.
- ■ The print gave an overall picture of the affected areas, and was posted in the control center and used to share information with relevant parties.

⑤ Tohoku Construction Association

- ■ Daichi images of coastal areas from Hachinohe City, Aomori, to Iwaki City, Fukushima, on a scale of 1:30,000 taken before and after the disaster and printed on paper measuring 17.5 m in length were provided.

⑥ Tohoku Regional Bureau, Ministry of Land, Infrastructure, Transport and Tourism (provision through the Tohoku Construction Association)

- ■ Daichi images of coastal areas from Hachinohe City, Aomori, to Iwaki City, Fukushima, on a scale of 1:30,000 taken before and after the disaster and printed on paper measuring 17.5 m in length were provided.

⑦ Tohoku Regional Agricultural Administration Office, Ministry of Agriculture, Forestry and Fisheries

- ■ Pre-disaster PS images (covering the area from Hachinohe City, Aomori, to Iwaki City, Fukushima) printed on a scale of 1:25,000 were provided.
- ■ Post-disaster AVNIR-2 images (observed on Mar. 14, 2011, covering the area from Hachinohe City, Aomori, to Iwaki City, Fukushima) printed on a scale of 1:25,000 were provided.
- ■ PS stereoscopic images of coastal Fukushima taken on Apr. 10, 2011, printed on a scale of 1:30,000 were provided.
- ■ AVNIR-2 images taken on Apr. 14, 2011 were used.
- ➢ Data on Tohoku areas hit by the tsunami were analyzed, and the extent of the damage was determined to provide information in the early stages. AVNIR-2 images supported damage evaluation even in areas for which aerial photos were unavailable. This type of support was not taken into consideration on many other flood maps.
- ➢ Images and analysis results were shared within the office and used in explanations given to visitors.

- ■ PS stereoscopic images acquired on Apr. 10, 2011 were used.
- ➢ Satellite images were used to identify massive landslides in coastal areas of Fukushima where aerial photos were unavailable after the earthquake.
- ➢ Satellite images were used to identify geographical features, areas of greenery and other characteristic areas. Field reconnaissance of landslides was then conducted in Iwaki City and the surrounding areas, and an earthquake fault in Iwaki City forming as a result of an aftershock on April 11 was surveyed.
- ➢ These images were useful in identifying geographical conditions over a wide area.

Figure 2.1-61 PS stereoscopic image of an affected area (created by Prof. Yokoyama)

⑧ Tohoku Regional Environment Office, Ministry of the Environment

Daichi images of Pacific coastal areas from Hachinohe City, Aomori, to Iwaki City, Fukushima, taken at six different times after the disaster and before it were provided (see Section 3.2.1.2 for details).

⑨ Yamada Cho, Iwate prefecture

Pan-sharpened images taken by Daichi on Sep. 10, 2006, were provided in response to a request for data to be used in confirming locations where aquaculture facilities were installed before the earthquake, and in supporting the identification of borders within which such facilities washed away by the tsunami could be re-established in Yamada Bay.

⑩ Hachinohe City, Aomori prefecture

Comment from a city official in charge: The Daichi Bosai map covering Hachinohe City (provided as a result of the Cooperation for Joint Exercises of Aomori and Iwate for Citizen Protection in 2010 project) provided very useful data to which information on flooded areas could be added, and was very helpful in explaining disaster-related matters to local residents.

(13) Wakayama Prefecture

Wakayama Prefecture promotes activities to demonstrate experimental disaster management applications under an agreement with JAXA. Before prefectural government employees were dispatched to Iwate Prefecture as part of the activities of the Union of Kansai Governments in response to the earthquake, it was necessary to consider how to ensure their safety and clarify the local situation, as the relevant personnel were unfamiliar with the affected areas and had little information on the situation there. In response to a request for information from Wakayama Prefecture on March 14, JAXA conducted emergency observations and also provided a Daichi Bosai map showing Iwate Prefecture before the earthquake as well as products created after it. A number of large prints of these products were created by Wakayama Prefecture in advance, and were brought to Iwate Prefecture along with a CD-R at the time of the dispatch at the end of April. These resources were utilized to check routes to the affected areas and shed light on the situation there. Wakayama Prefecture also provided the CD-R to the Tohoku Regional Bureau of the Ministry of Land, Infrastructure, Transport and Tourism.

The activities carried out in Wakayama Prefecture to support Iwate Prefecture are a typical example of inter-regional and wide-ranging collaborative initiatives implemented when major disasters occur. The continuous efforts of Wakayama Prefecture and JAXA to demonstrate disaster management applications enabled the prefecture to utilize information on other prefectures with the help of the Agency.

(14) Miyagi Prefecture

Based on a report from the United States Geological Survey (USGS; a member of the Disaster Charter), an SOS signal in Onagawa Sports Park in Onagawa City, Miyagi, was identified in satellite imagery on March 19. The matter was promptly reported to Miyagi Prefecture, and it was confirmed a few hours later that the park had been used as an evacuation shelter and the situation had been resolved, thereby allaying fears that access to the village had been cut off.

Figure 2.1-62 SOS signal identified in satellite imagery

(15) Disaster Prevention Research Institute, Kyoto University

After the disaster, an Emergency Mapping Team (EMT) was launched, and Daichi images were provided and utilized for mapping in response to a request to JAXA for collaboration (see Section 3.2.1.1 for details).

(16) Other organizations

Flood analysis results (for the prefectures of Iwate, Miyagi, Fukushima and Ibaraki) obtained using the AVNIR-2 and PALSAR satellites were provided to the Ministry of Defense and utilized to identify costs and plan searches for missing people in the evacuation zone of the Fukushima Dai-ichi Nuclear Power Station.

2.1.5.3 Web-based information provision

(1) Daichi Bousai WEB (https://bousai.jaxa.jp/)

To support the prompt provision of information to users involved in disaster management, a page for the Great East Japan Earthquake was established on the Daichi Bosai WEB site. This enabled the posting of Daichi emergency observation plans and results in addition to various products created using Daichi data and output developed by the Disaster Charter, Sentinel Asia and other overseas institutions. Providing this data to users around the clock, the website received totally more than 1,500 hits from central government ministries/agencies, local governments and other organizations.

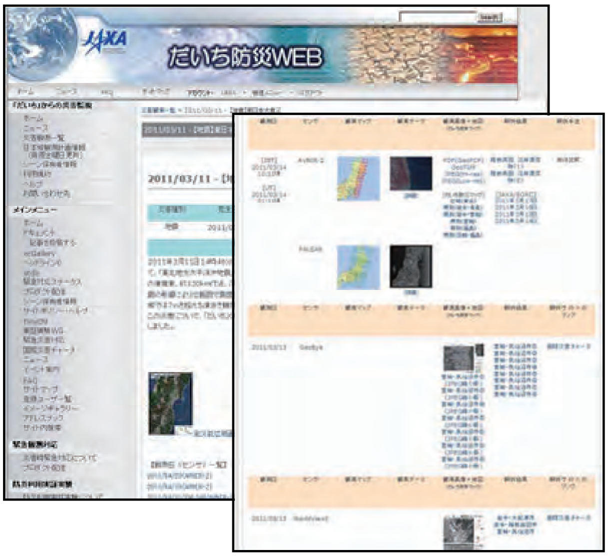


Figure 2.1-63 Great East Japan Earthquake page on Daichi Bosai WEB

(2) EORC ALOS website (http://www.eorc.jaxa.jp/ALOS/en/index_j.htm)

Satellite data analysis results were regularly updated on JAXA's Earth Observation Research Center (EORC) website, which received up to 20,000 visits per day after the quake. The site is usually accessed by between 100,000 and 200,000 hits monthly, but received 550,000 hits in March and 340,000 in April. Inquiries were fielded from people in the affected area who had viewed the analysis results, and requests were received from individuals involved in the operation of ships in affected sea areas for updated information on driftage at any time.

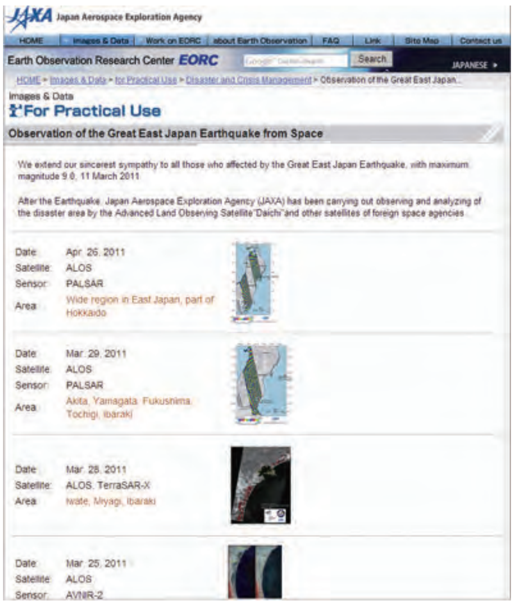


Figure 2.1-64 EORC ALOS website

2.1.6 Aerial SAR observation

2.1.6.1 Overview

Pi-SAR-L (Polarimetric Interferometric Synthetic Aperture Radar in L-band) is an airborne L-band synthetic aperture radar developed by JAXA and completed in 1996. It is mounted on a Gulfstream II jet airplane and observes a zone with a width of approximately 15 km to the left of the direction of travel from an altitude of around 10,000 m. With transmission power as high as 3,500 W (almost a little less than twice that for satellite-borne SAR) and closer proximity to the targets of observations, Pi-SAR-L is capable of capturing images of exceptional quality. Accordingly, this type of SAR was developed with an eye on future SAR evolution and expansion of the study area. It offers the following advantages: 1) the range resolution is twice as high as that of PALSAR, and the azimuth resolution is five times as high; 2) the noise level is -45 dB (approximately 10 dB lower than that for PALSAR), and 3) polarimetric observation can be made at any time. Pi-SAR-L was put into operation to support the identification of changes in the collapsed crater of Murakoshi Village (2004), Miyake Island's Mt. Oyama (July 2000), Mt. Usu (September 2000) and other disasters. As it is difficult for aircraft to fly as straight as satellites, high-resolution images can be obtained only with highly accurate analysis of data from an inertia navigator on board. For analysis relating to the Great East Japan Earthquake, observations were made on April 4 and April 13, 2011. On April 4, the inertia navigator failed to operate properly, but on April 13, normal images for some areas were obtained and used for analysis as shown below. Figure 2.1-65 gives an overview of an evaluation area encompassing the damaged cities of Higashimatsushima, Sendai and Natori.

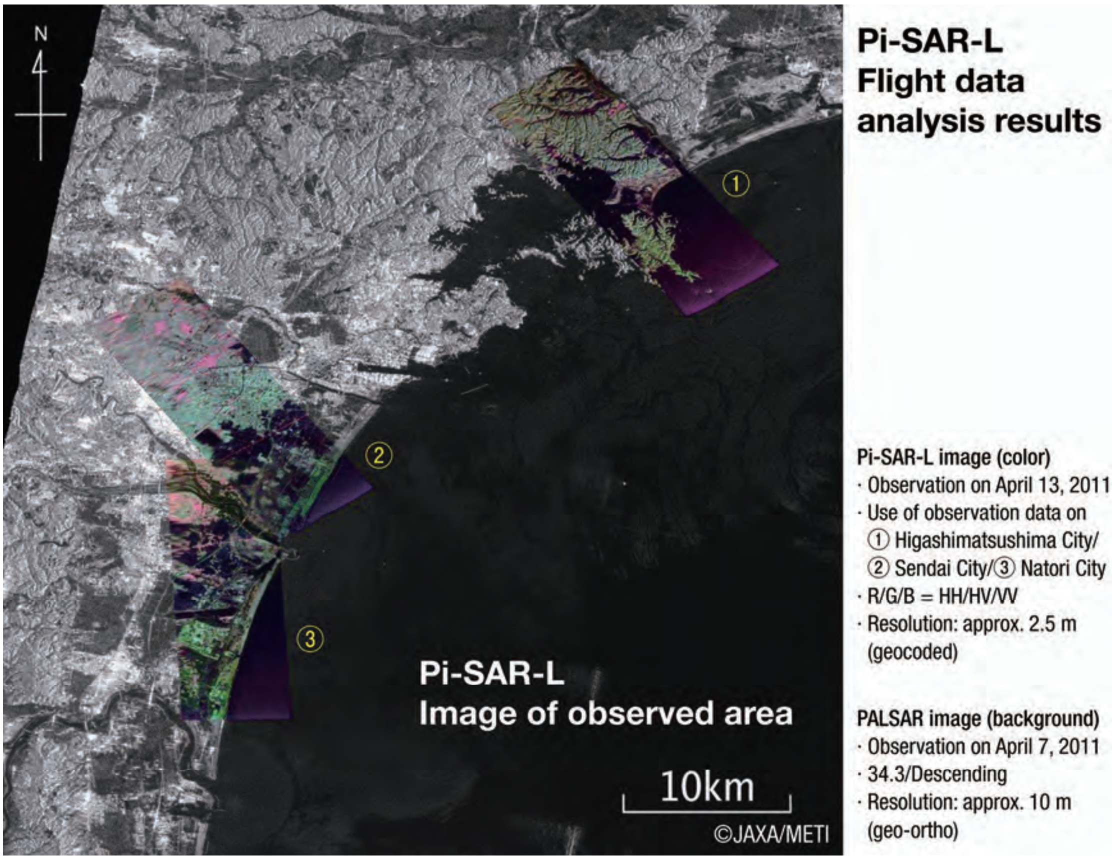


Figure 2.1-65 Pi-SAR-L observation area (PALSAR image in the background, Pi-SAR-L observation zone with a width of 15 km)

2.1.6.2 Analysis of single images

A lack of imagery for April 4 made it impossible to identify changes that had taken place over a period of eight days. Pi-SAR-L images ① and ② were taken by the satellite from a trajectory along the coastline, and image ③ was taken as it moved eastward (see Figure 2.1-65). An enlarged picture of image ③ together with WorldView-2 images is shown in Figure 2.1-66. Although the quality of these images varies greatly (as the resolution of Pi-SAR-L is approximately 3 m while that of WorldView-2 is approximately 50 cm), both satellites captured clear images showing scattered debris. Pi-SAR-L has a full-polarimetric function, and pseudo-natural color images (as shown in Figure 2.1-66 (left)) can be created by converting R-G-B to received signals HH-HV-VV (HV means that horizontally-polarized waves (H) are transmitted and vertically-polarized (V) waves are received), and visibility is improved as a result. Areas shown in green represent piled up objects (volume scattering), while those in purple are solid masses (surface scattering). The images are mostly dark-bluish purple, meaning that the majority of areas were flat. (Scattering intensity is generally higher for VV than for HH on flat surfaces.) With the resolution of Pi-SAR-L, roads, urban areas and buildings can be clearly seen, and close agreement with WorldView-2 images is confirmed. The next-generation Pi-SAR-L (Pi-SAR-L2) is currently being developed with the aim of achieving better resolution with greater stability. It is scheduled to enter full operation in April 2012, and is expected to make high-resolution observations in relation to disasters.

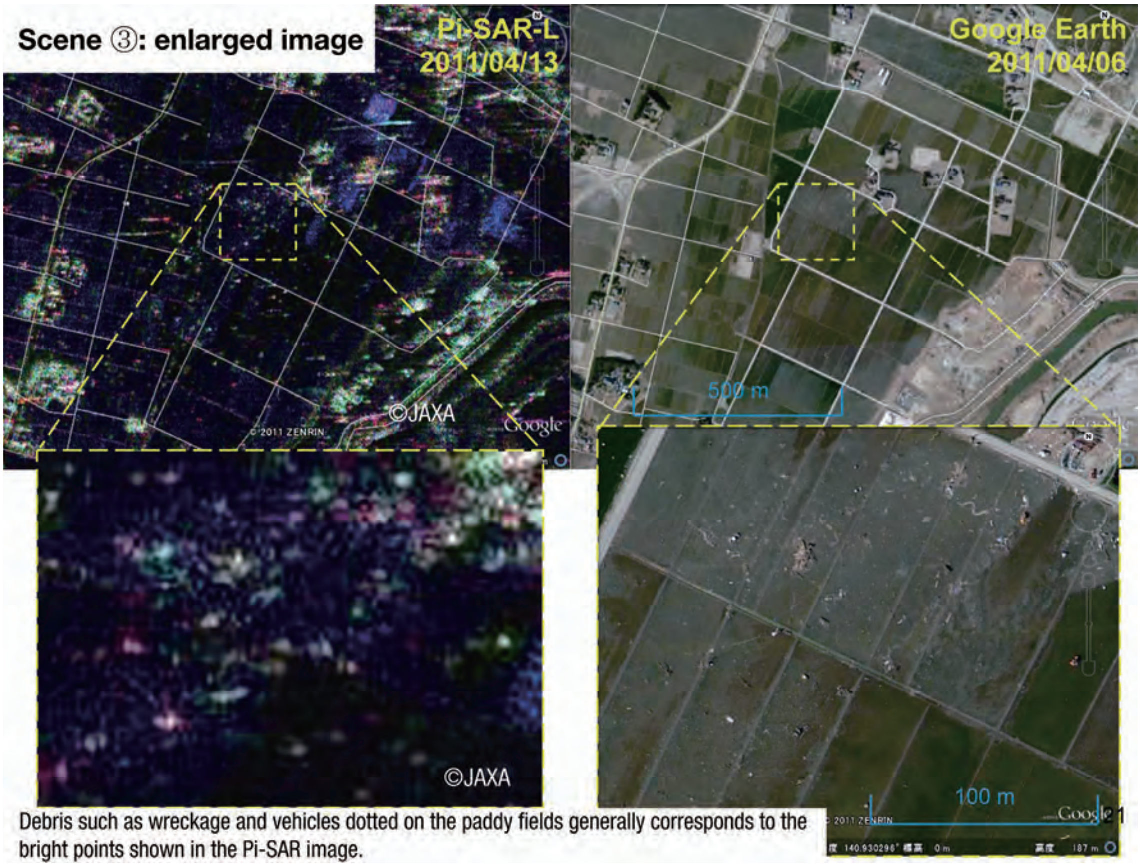


Figure 2.1-66 Comparison of Pi-SAR-L and WorldView-2 images of an affected area in Natori City
Despite a one-week difference between the observation dates, similar patterns of scattered debris are seen in both the radar and the optical images.

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.

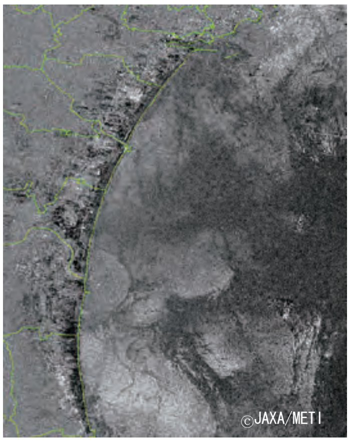
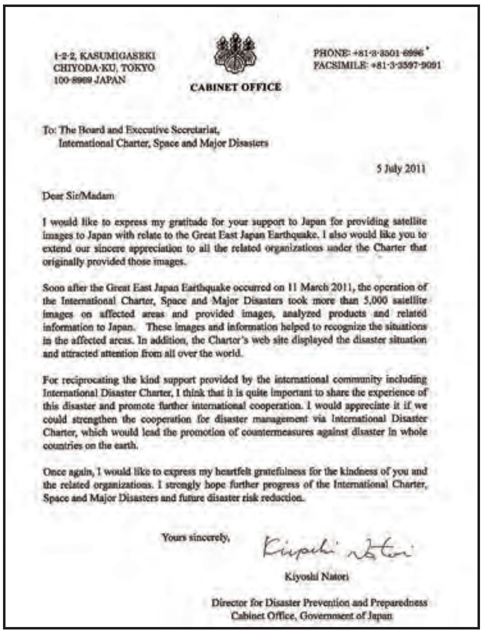


Figure 2.1-72 Examples of results from PALSAR-based flood analysis
(left: identification image; right: normalized difference image)

2.1.8 Summary

After the Great East Japan Earthquake, JAXA conducted disaster monitoring using the Advanced Land Observing Satellite “Daichi” and enlisted the help of international organizations involved in disaster monitoring (such as the Disaster Charter and Sentinel Asia), thereby contributing to efforts made by national/local government bodies to collect information and support relief operations.

- Top priority was given to emergency observation of affected areas using Daichi, and 643 satellite images were obtained.
- In reciprocation for Daichi’s active international contribution to relief efforts in previous major disasters elsewhere, intensive observation was conducted in response to the Great East Japan Earthquake by 14 countries and regions using 27 satellites through the framework of international cooperation, which includes organizations such as the Disaster Charter and Sentinel Asia. As a result, approximately 5,700 satellite images were provided.
- These images were processed and analyzed by JAXA to facilitate usage by disaster management organizations, and were provided to ten ministries, agencies, organizations and municipalities, including the Cabinet Secretariat and the Cabinet Office for disaster management.
- The images were analyzed in various ways by institutions and researchers around the world, and the information obtained was shared extensively through the framework of the Disaster Charter, Sentinel Asia, Geo-Supersite and other organizations.
- The images were utilized to determine the extent of damage over wide areas that could not be viewed from the ground or from aircraft, and to plan disaster countermeasures.
- Approximately 80 analyzed images were provided to various organizations after the Great East Japan Earthquake. The Daichi Bosai WEB site received as many as 1,500 hits from central government ministries/agencies and local governments.
- The Cabinet Office sent letters of thanks to the Disaster Charter and Sentinel Asia.



1-2-2, KASUMIGASEKI
CHIYODA-KU, TOKYO
100-8969 JAPAN

CABINET OFFICE

PHONE: +81-3-3501-6996
FACSIMILE: +81-3-3597-9091

To: The Board and Executive Secretariat,
International Charter, Space and Major Disasters

5 July 2011

Dear Sir/Madam

I would like to express my gratitude for your support to Japan for providing satellite images to Japan with relate to the Great East Japan Earthquake. I also would like you to extend our sincere appreciation to all the related organizations under the Charter that originally provided those images.

Soon after the Great East Japan Earthquake occurred on 11 March 2011, the operation of the International Charter, Space and Major Disasters took more than 5,000 satellite images on affected areas and provided images, analyzed products and related information to Japan. These images and information helped to recognize the situations in the affected areas. In addition, the Charter’s web site displayed the disaster situation and attracted attention from all over the world.

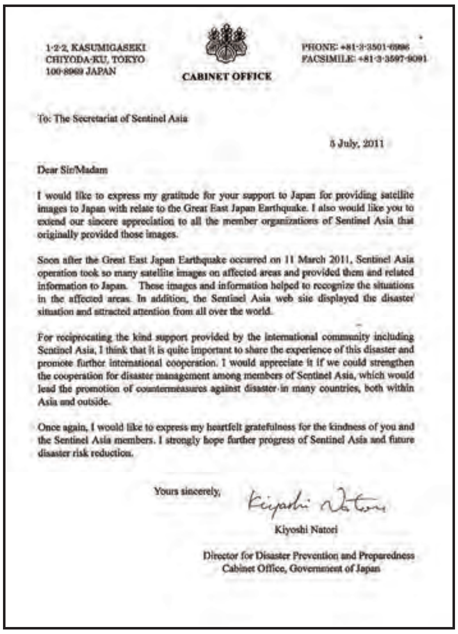
For reciprocating the kind support provided by the international community including International Disaster Charter, I think that it is quite important to share the experience of this disaster and promote farther international cooperation. I would appreciate it if we could strengthen the cooperation for disaster management via International Disaster Charter, which would lead the promotion of countermeasures against disaster in whole countries on the earth.

Once again, I would like to express my heartfelt gratefulness for the kindness of you and the related organizations. I strongly hope further progress of the International Charter, Space and Major Disasters and future disaster risk reduction.

Yours sincerely,

Kiyoshi Natori

Director for Disaster Prevention and Preparedness
Cabinet Office, Government of Japan



1-2-2, KASUMIGASEKI
CHIYODA-KU, TOKYO
100-8969 JAPAN

CABINET OFFICE

PHONE: +81-3-3501-6996
FACSIMILE: +81-3-3597-9091

To: The Secretariat of Sentinel Asia

5 July, 2011

Dear Sir/Madam

I would like to express my gratitude for your support to Japan for providing satellite images to Japan with relate to the Great East Japan Earthquake. I also would like you to extend our sincere appreciation to all the member organizations of Sentinel Asia that originally provided those images.

Soon after the Great East Japan Earthquake occurred on 11 March 2011, Sentinel Asia operation took so many satellite images on affected areas and provided them and related information to Japan. These images and information helped to recognize the situations in the affected areas. In addition, the Sentinel Asia web site displayed the disaster situation and attracted attention from all over the world.

For reciprocating the kind support provided by the international community including Sentinel Asia, I think that it is quite important to share the experience of this disaster and promote further international cooperation. I would appreciate it if we could strengthen the cooperation for disaster management among members of Sentinel Asia, which would lead the promotion of countermeasures against disaster in many countries, both within Asia and outside.

Once again, I would like to express my heartfelt gratefulness for the kindness of you and the Sentinel Asia members. I strongly hope further progress of Sentinel Asia and future disaster risk reduction.

Yours sincerely,

Kiyoshi Natori

Director for Disaster Prevention and Preparedness
Cabinet Office, Government of Japan

Figure 2.1-73 Letters of thanks from the Cabinet Office to the Disaster Charter and Sentinel Asia

Based on the provision of disaster images, the following observations were made:

- When large-scale disasters like the Great East Japan Earthquake strike, satellite image products comparing pre- and post-disaster conditions are very useful primary information sources in the initial stages of response to determine the extent of the damage. Superimposing geospatial information (e.g., place and street names) onto satellite images and recent images taken in the months before the disaster in particular enhances the usefulness of such data.
- Daichi images provided useful extensive aerial views to support information collection immediately after the disaster.
- In terms of the division of roles, airplanes and helicopters were intensively used to observe tsunami-damaged coastal areas, while nadir observations by Daichi over extensive inland areas significantly contributed to the surveying of landslide-related damage.
- In response to the nuclear power plant accident triggered by the tsunami, satellite observation was useful in enabling ongoing unmanned monitoring of areas affected by high radiation levels.
- Planar crustal movement and inland areas at high risk of landslides could be determined using only data from Daichi, which is equipped with L-band SAR and optical sensors and is capable of observing extensive areas.
- Interferometric SAR images enabled identification of changes over the entire Tohoku region and helped to clarify that the cause of subsidence along the Pacific coast was not local surface ground contraction but extensive settlement resulting from the sliding of the earthquake source fault along the plate boundary.
- In addition to the monitoring of crustal movement triggered by inland active faults and volcanic activity resulting from earthquake-related changes in stress, local crustal movement stemming from inland aftershocks was also identified. In this way, observation data helped to clarify the fault mechanisms of several aftershocks.
- A combination of SAR and optical images was needed to improve data interpretation accuracy. As stereoscopic observation is also effective, stereovision was used to investigate damage from landslides.
- Repeated satellite observation over a long period of time was important in identifying changes in the affected areas. Japan's satellites play an important role in this regard.
- International organizations such as the Disaster Charter and Sentinel Asia serve to increase observation frequency. In particular, the European Space Agency (ESA) highlighted the activities of the Disaster Charter and GEO in response to the Great East Japan Earthquake.
- Through the Disaster Charter, commercial high-resolution satellites were used to assess the conditions of collapsed buildings, determine the extent of damage to roads and railways and carefully monitor the situation at the nuclear power plant.
- As it was impossible to determine conditions after the nuclear power plant accident using visible light and SAR images alone, infrared radiation sensor and other temperature detection data were needed.

2.2 Communications satellite-based activities

2.2.1 KIZUNA (WINDS)

2.2.1.1 Overview and characteristics of KIZUNA

The KIZUNA Wideband InterNetworking engineering test and Demonstration Satellite (WINDS) was jointly developed by JAXA and the National Institute of Information and Communications Technology (NICT) and launched on February 23, 2008. It is designed to support the development and demonstration of technologies and to perform related demonstration testing, thereby contributing to the formation of an advanced information and communications network society without disparities in data availability through operation in conjunction with ground-based infrastructure.

KIZUNA follows an orbit above the equator at 143 degrees east longitude, and is equipped with multi-beam antennas (MBAs) featuring fixed multi-spot beams covering Japan and Southeast Asia and an active phased array antenna (APAA) that covers a wide area with scanning beams (see Figure 2.2-1). Its switching equipment enables signal switching on board the satellite itself.

KIZUNA features the following characteristics of ordinary geostationary communications satellites:

- Wide coverage area: Covers almost a third of the earth's surface without geographical restriction.
- Broadcast: Information is simultaneously received within the coverage area.
- Disaster resistance: Networks are not affected by disasters, and line setting is easy.

KIZUNA also has the following characteristics that make it superior to conventional communications satellites:

- Ultra-high-speed satellite communications (155 Mbps for the 45 cm ϕ small antenna and 1.2 Gbps for the 5 m ϕ antenna):
  Its small antennas supporting ultra-high-speed communications are especially useful in setting up temporary lines. For this purpose, JAXA operates portable VSAT and portable USAT user terminals (see Figure 2.2-2).
- Communications without links to a hub station with half the conventional delay time:
  By halving the delay time of conventional satellites that use a hub station for communications, KIZUNA allows videoconferences to be conducted with minimal interference.
- IP (Internet Protocol) interface highly compatible with ground equipment:
  The interface with the earth station is IP-based, and the ability to use commercially available devices as ground equipment allows the adoption of inexpensive modern instruments. By way of example, videoconferences, wireless LAN, IP telephones and PCs can be connected with no special interface arrangement.
- KIZUNA's own communication specifications provide outstanding data security and make interception difficult:
  Existing communications satellites frequently use the Ku band or lower, whereas KIZUNA uses the high-frequency Ka band. The unique communication protocol specifications used provide outstanding data security.

JAXA utilized these characteristics and conducted basic experiments to analyze the fundamental performance of the communication network system and on-board equipment and to perform demonstration tests. The results indicated that KIZUNA is suitable for use in a variety of fields such as emergency communications, the bridging of digital divides, distance learning and telemedical services.

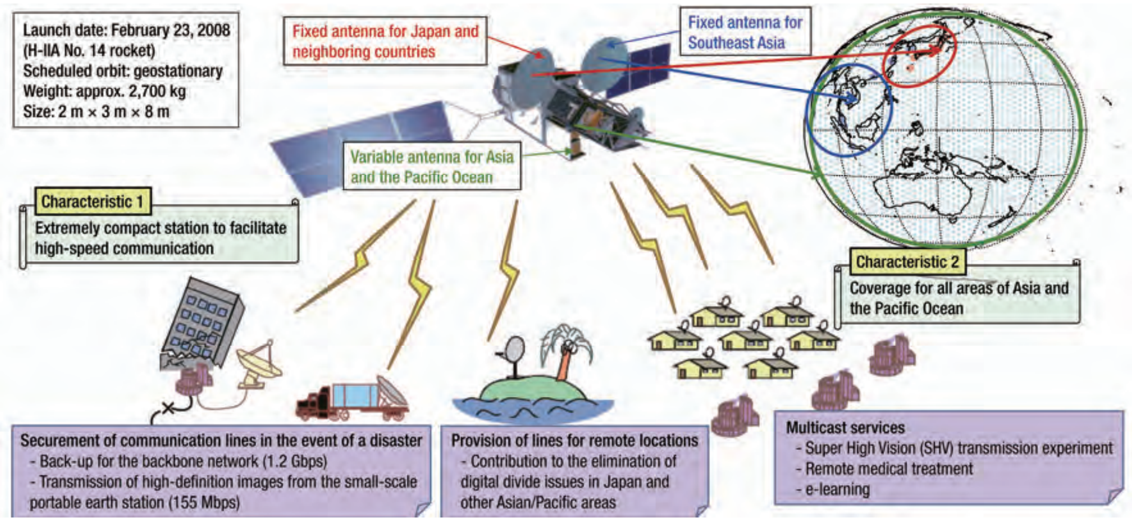


Figure 2.2-1 Image of KIZUNA in orbit and coverage areas

Earth station equipment	HDR-VSAT	Portable very-small-aperture terminal (VSAT)	1.2-m portable VSAT	Portable USAT
Antenna diameter	1.2m	1.0m	1.2m	45cm
Output from transmitter (Rated capacity)	250W (TWTA)	40W (SSPA)	40W (SSPA)	10W (SSPA)
Data transfer rate Upload	1.5/6/24/51/ 155Mbps	1.5/6/24/51 Mbps	1.5/6/24/51 Mbps	1.5/6 Mbps
Download	155Mbps	155Mbps	155Mbps	155Mbps
Service areas (MBA or APAA)	MBA/APAA	MBA	MBA/APAA	MBA
Weight (standard)	442kg	97kg	More than 90kg	53kg
Images				

Figure 2.2-2 Examples of KIZUNA experimental stations

2.2.1.2 Background to the provision of communication lines in affected areas

- March 11, 2011: JAXA scheduled disaster drills involving the use of KIZUNA on March 12 and 13 on Sado Island in Niigata along with NPO Aichi Net, Ibaraki Rescue Support Bike and Kanagawa Rescue Support Bike in conjunction with Sado City. The Great East Japan Earthquake hit when JAXA staff were near the ferry terminal in Niigata on the way to Sado Island, and the drills were cancelled.
- March 12: In response to an earthquake with a seismic intensity of 6 upper in the Chuetsu area of Niigata, an arrangement for the provision of communication lines using KIZUNA was discussed with the prefectural staff in charge of disaster management at the Niigata Prefecture Disaster Countermeasures Office (Niigata Prefectural Government Disaster Prevention Center). However, it was found that no areas had been left without communication lines in the prefecture, and JAXA asked them to contact municipalities in coastal Tohoku instead. It was possible to reach the Fukushima Prefecture Disaster Countermeasures Office, but not the corresponding offices in the prefectures of Iwate and Miyagi. Plans to provide communication lines to Fukushima Prefecture were abandoned due to the unpredictable safety situation brought about by the nuclear power plant accident in the region.
- March 15: A request was received from the Iwate Prefecture Disaster Countermeasures Office (Morioka) for the provision of communication lines using KIZUNA to support information sharing and Internet usage, as telephone and other communication systems were congested at the Kamaishi on-site disaster countermeasures office (Wide-area Coastal Promotion Bureau). After consultation with JAXA and the Ministry of Education, Culture, Sports, Science and Technology (MEXT), the Chief of the Disaster Management Office at the Department of General Affairs in Iwate Prefecture asked the Director-General of MEXT's Research and Development Bureau to support the securement of communication lines using KIZUNA.
- March 15: The Director-General of MEXT asked the President of JAXA to fulfill this request. In response, safety in field activities was confirmed with the staff in charge from the Disaster Management Office of the Department of General Affairs at the Iwate Prefecture Disaster Countermeasures Office, and the Tsukuba City Disaster Countermeasures Office was asked to issue emergency passes because the Tohoku Expressway was closed to the public. JAXA also asked Iwate Prefecture to secure accommodation, provide official vehicles and issue certificates that would give the Agency priority in purchasing gasoline.
- March 16: At a meeting of JAXA's Disaster Countermeasures Office, a decision was made to provide KIZUNA services to Iwate Prefecture.
- March 17: Communications equipment and five staff members were dispatched to the field.
- March 18: Equipment was transported to the Prefecture Disaster Countermeasures Office (Morioka), and earth station facilities and communications equipment were installed.
- March 19: Earth station facilities and communications equipment were installed at the on-site disaster countermeasures office (Kamaishi). Connection between the two offices was confirmed.
- March 20: Communication service was started using the line of communication between the Prefecture Disaster Countermeasures Office (Morioka) and the on-site disaster countermeasures office (Kamaishi).
- March 22: Due to problems with communication lines for the on-site disaster countermeasures office (Wide-area Coastal Promotion Bureau) in Ofunato City, the Prefecture Disaster Countermeasures Office asked JAXA to provide communication lines using KIZUNA in order to support information sharing and Internet usage. After consultation with JAXA and MEXT, Chief of the Disaster Management Office of the Department of General Affairs in Iwate Prefecture asked the Director-General of MEXT's Research and Development Bureau to support the securement of communication lines using KIZUNA.
- March 22: The Director-General of MEXT asked the President of JAXA to fulfill this request.
- March 23: Communications equipment and one staff member were dispatched to the on-site disaster countermeasures office (Wide-area Coastal Promotion Bureau) in Ofunato City.

- March 24: The staff member dispatched to provide communication lines in Kamaishi joined in with work at the on-site disaster countermeasures office (Wide-area Coastal Promotion Bureau) in Ofunato City, installing earth station facilities and communications equipment. The provision of communication lines to connect the three offices started.
- April 24: As business communication lines for the on-site disaster countermeasures offices (Wide-area Coastal Promotion Bureaus) in the cities of Kamaishi and Ofunato were mostly restored, the provision of communication lines using KIZUNA was ended in coordination with the Prefecture Disaster Countermeasures Office and MEXT.
- April 25: Earth station facilities and communications equipment were removed from the three offices.

2.2.1.3 Communication modality and results of communication line usage

Figure 2.2-3 shows a schematic representation of support offered by JAXA to disaster areas in Iwate Prefecture through the provision of communication lines using KIZUNA. A portable VSAT unit installed at the Iwate Prefecture Disaster Countermeasures Office (part of the Iwate Governor's Office) was connected using KIZUNA with portable USAT and VSAT units installed at the local disaster countermeasures offices in the cities of Kamaishi and Ofunato. Additionally, the High Data Rate VSAT (HDR-VSAT) at the Tsukuba Space Center was designed to connect with public Internet networks, and connections were established from these support bases.

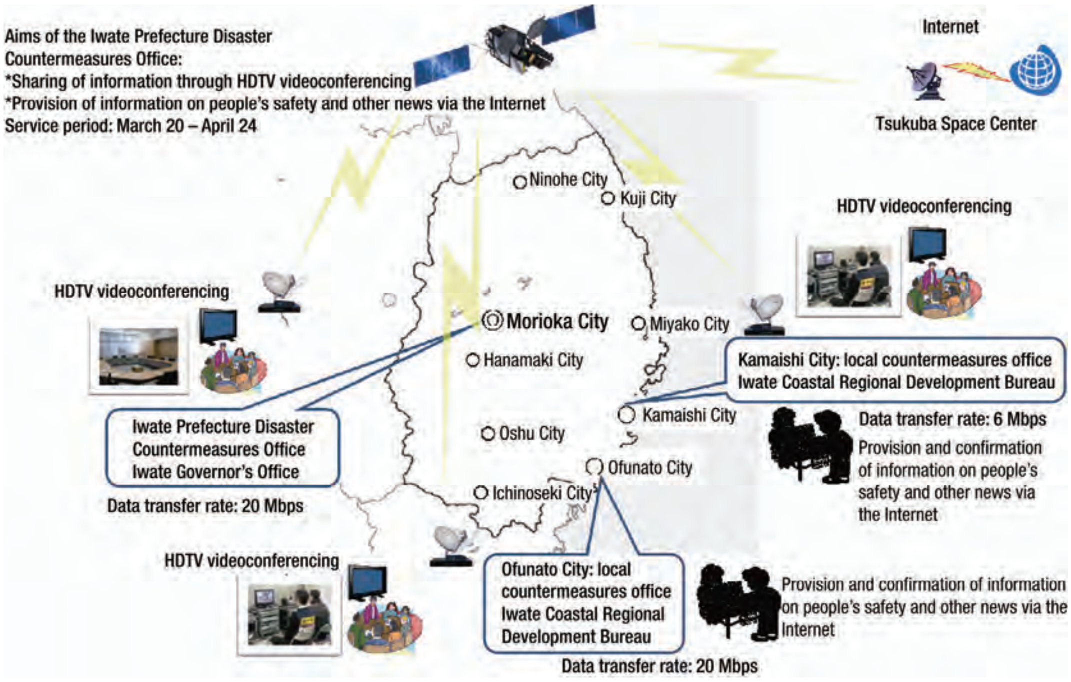


Figure 2.2-3 Schematic representation of support offered by JAXA to disaster areas in Iwate Prefecture through the provision of communication lines using KIZUNA

In addition to the portable VSAT/USAT experimental stations, the support bases were also equipped with an all-in-one unit of disaster-related equipment and supplies (peripheral communication equipment, including an L3 switch and a TCP accelerator, housed in a general-purpose rack), a videoconferencing system, application equipment for wireless LAN access points and other items. These were used for videoconferencing, Internet services and other purposes. Photos and schematic representations of antenna installation locations at the support bases are shown below.

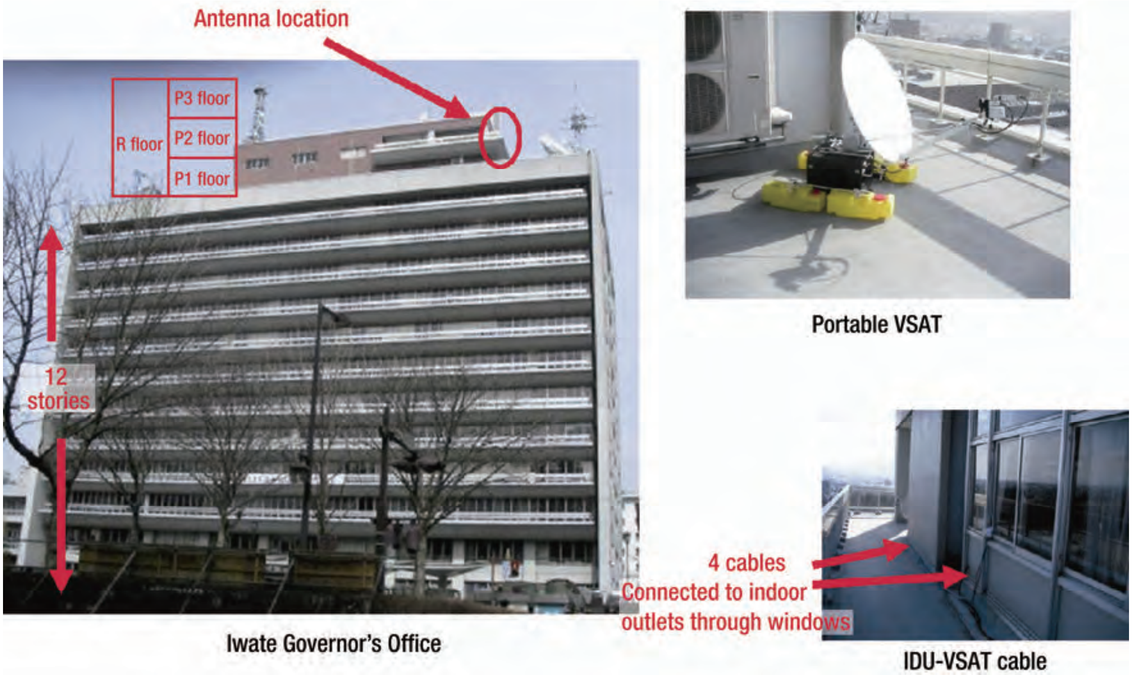


Figure 2.2-4 Outdoor unit (ODU) installed at the Iwate Governor's Office

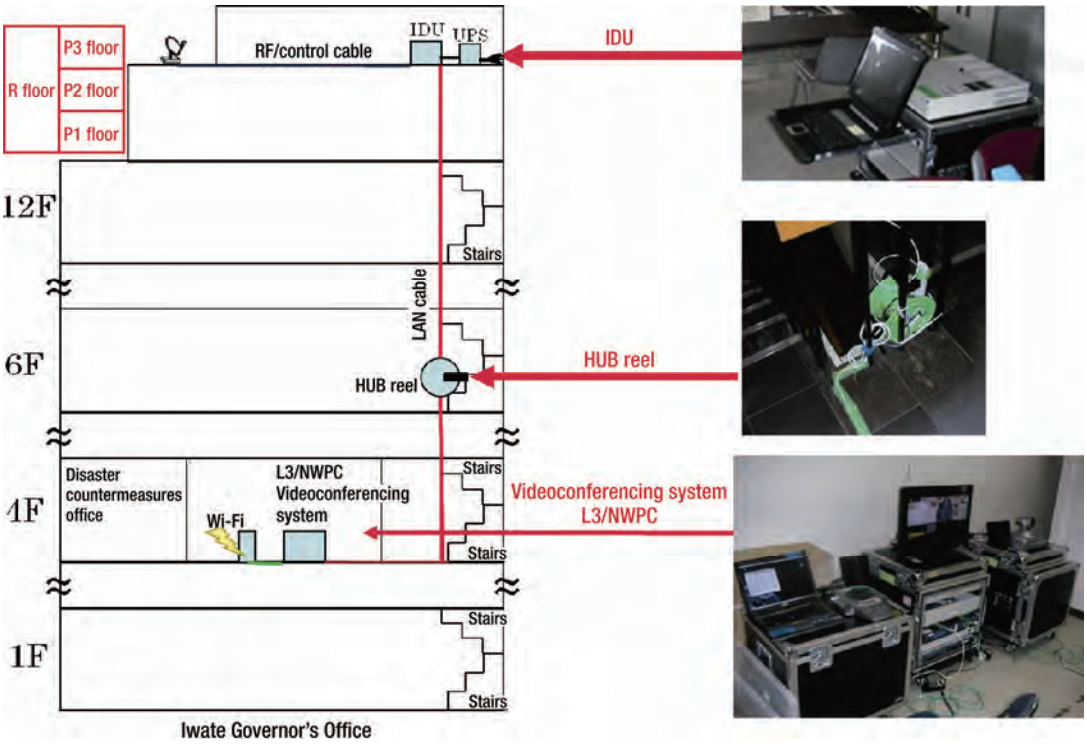


Figure 2.2-5 Schematic representation of equipment installed at the Iwate Governor's Office

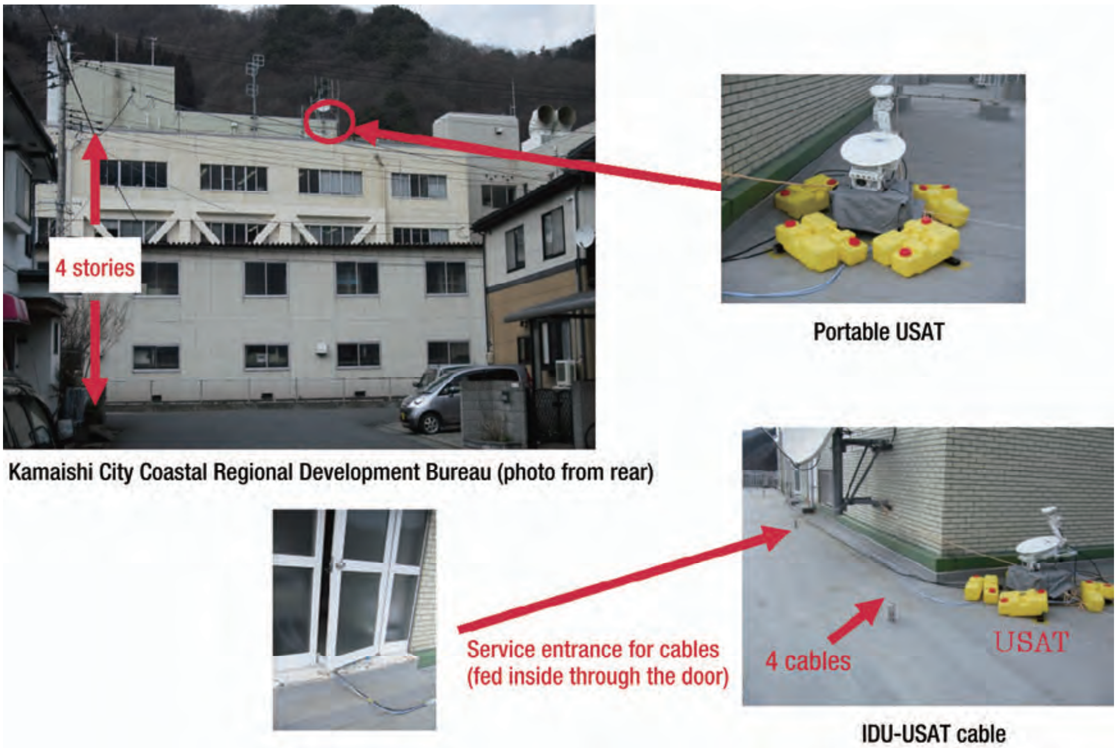


Figure 2.2-6 Outdoor unit (ODU) installed at the Kamaishi Coastal Regional Development Bureau

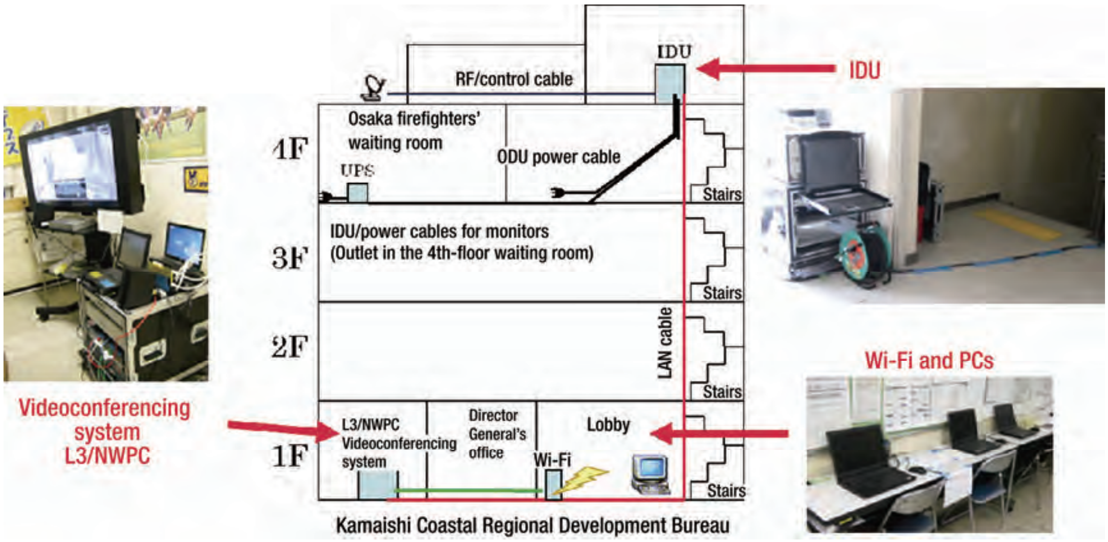


Figure 2.2-7 Schematic representation of equipment installed
at the Kamaishi Coastal Regional Development Bureau

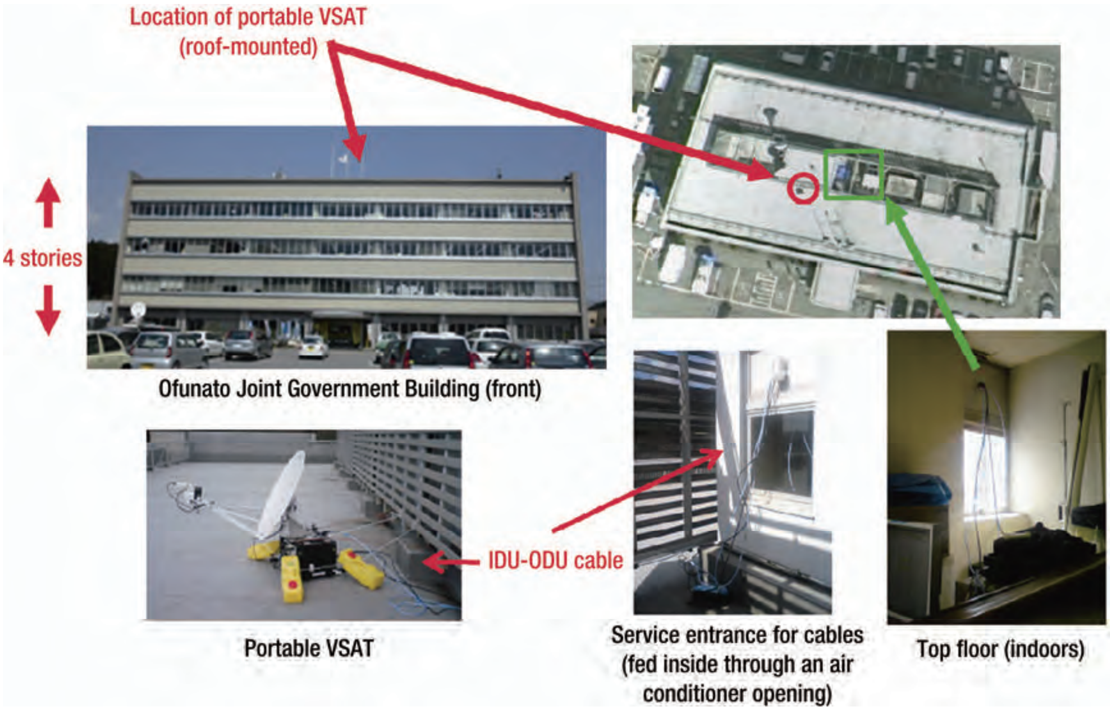


Figure 2.2-8 Outdoor unit (ODU) installed at the Ofunato Coastal Regional Development Bureau

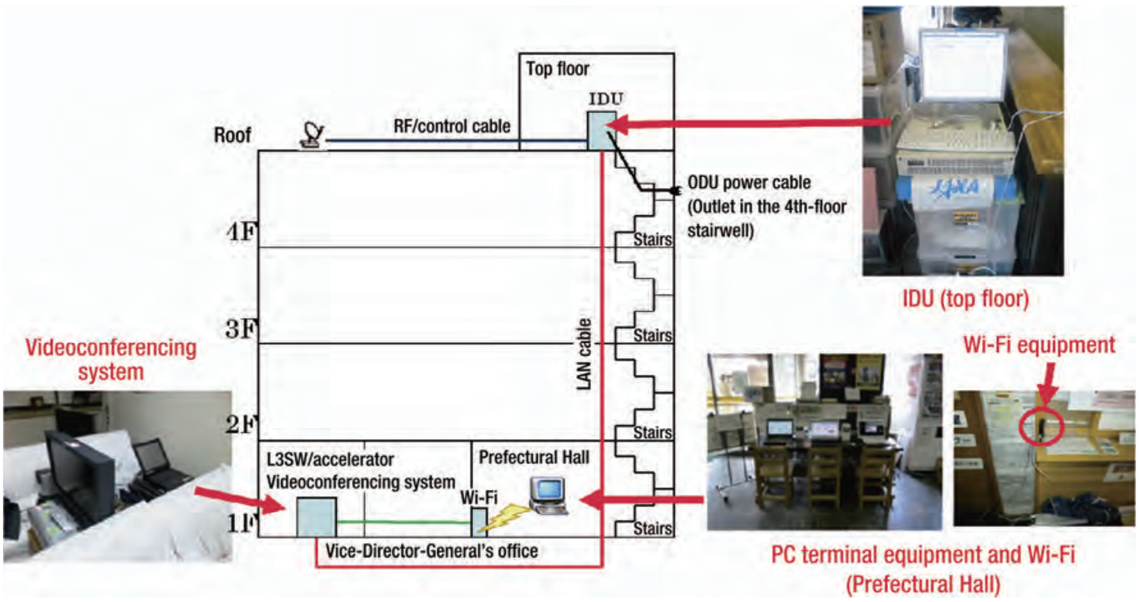


Figure 2.2-9 Schematic representation of equipment installed
at the Ofunato Coastal Regional Development Bureau

Videoconferencing

As part of JAXA's support activities, the videoconferencing systems installed at the support bases were used for information sharing by disaster countermeasures offices. The details of their usage are outlined below.

At the Prefecture Disaster Countermeasures Office, support activities were engaged in not only by prefectural government employees but also by staff dispatched from other prefectural governments, government ministries and agencies (e.g., the Cabinet Office, the Ministry of Health, Labour and Welfare, the Ministry of Land, Infrastructure, Transport and Tourism, the Ministry of Internal Affairs and Communications, the Fire and Disaster Management Agency, and the Japan Self-Defense Forces (JSDF)) and other organizations. Accordingly, liaison and coordination meetings were held almost daily at the Prefecture Disaster Countermeasures Office for two purposes: 1. to share information on sanitary conditions at evacuation sites, the living conditions and needs of disaster victims, the status of search operations for missing people, and other considerations; and 2. to solve problems toward expedited recovery and reconstruction efforts. The information shared and the decisions made by the prefectural government at these meetings and other gatherings took time to reach local disaster countermeasures offices in coastal areas, and much more time was needed until the information was shared with smaller local countermeasures offices.

To address this delay issue, local disaster countermeasures offices and the Prefecture Disaster Countermeasures Office were connected by a videoconferencing system via KIZUNA so that local office representatives could participate in the liaison and coordination meetings held by the prefectural government from their own offices. In this way, the videoconferencing system supported real-time information sharing and opinion exchanges with the prefectural government.

The system was well received by staff at local disaster countermeasures offices, who highlighted its usefulness for promptly communicating the state of devastation in coastal areas to the prefectural government. Specific advantages mentioned include superior voice and image clarity (of a level that allowed small print on the screen to be read) compared to the web conference system previously used by the Iwate Prefectural Government, and the capacity for real-time transmission of videos captured from helicopters above coastal areas and other resources.

Figure 2.2-10 Liaison and coordination meeting held by the prefectural government (center: videoconferencing system)

Internet services

As part of JAXA's support activities, wireless LAN access points were set up at support bases to connect to public Internet lines by linking to HDR-VSAT installed/operated in Tsukuba using KIZUNA. At the Prefecture Disaster Countermeasures Office in Morioka City, a wireless LAN access point was set up in the room next to the disaster countermeasures office (where the videoconferencing system was installed) for use by staff dispatched from supporting organizations. In particular, pre- and post-earthquake images from the Daichi satellite (PALSAR and AVNIR) showing coastal areas of Iwate were downloaded at high speed from the Daichi Bousai WEB via KIZUNA for use in planning debris removal work and to help visualize the status of removal progress.

At the local disaster countermeasures offices in Kamaishi and Ofunato, a wireless LAN access point and three Internet-enabled laptops were installed in the entrance lobby, which was open to the public. These units were used by disaster victims and individuals dispatched to coastal areas by various organizations to assist with support activities.

During the period of provision from March 20 to April 24, these Internet services were used by 538 people at the disaster countermeasures office in Kamaishi and by 1,252 in Ofunato. Changes in the number of Internet users are shown in Figure 2.2-11. On average, 18.6 people per day used the services in Kamaishi, and 43.1 in Ofunato. The laptop usage rates at the support bases exceeded 50 percent almost all day long, indicating high demand for Internet services.

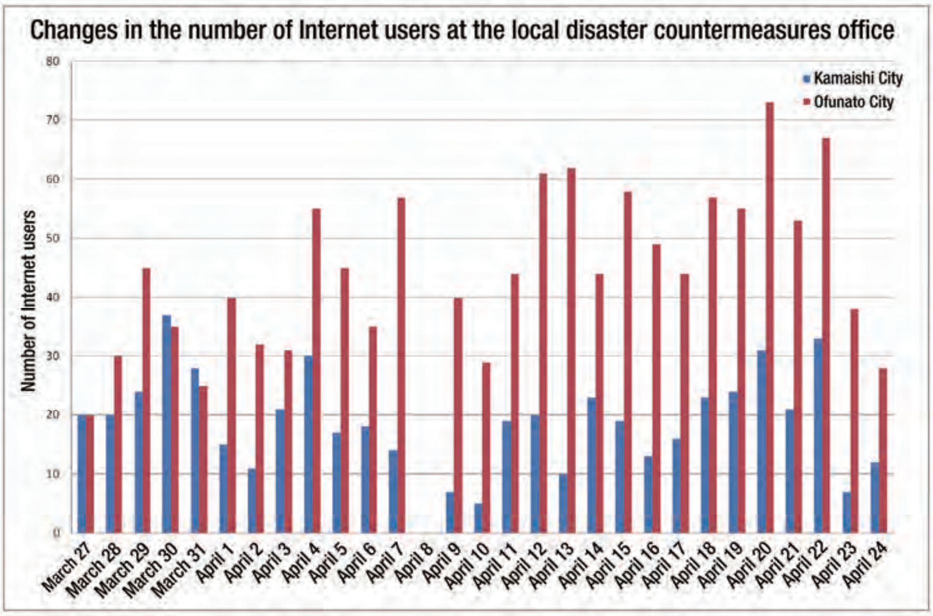


Figure 2.2-11 Changes in the number of Internet users

Usage of the Internet services by staff who were dispatched by organizations to coastal areas to assist in support activities included accessing web-based e-mail to report to their organizations and checking restoration conditions of available means of transportation and roads to destination, and routes to take. Usage by the general public until about two weeks after the disaster was generally to check people's safety and obtain information on disaster-related matters such as evacuation sites, evacuees and the extent of the devastation. In particular, city government website lists showing the names of those affected by the disaster were heavily accessed every day, despite the availability of the same lists in paper form. The prompt information updates and powerful search capabilities of the Internet are believed to have been behind the large user numbers seen. Two weeks after the disaster onwards, Internet usage was more to collect information on everyday living, such as that relating to the issuance of disaster victim certificates, the status of restoration efforts for daily utilities like electricity, gas and telephone lines, applications for temporary housing, housing units for rent, used cars, hospitals/schools and job openings. This usage demonstrates how the type of information sought by disaster victims changes with time from matters relating to the disaster itself to those concerning living environments.

Figure 2.2-12 Internet provision to the general public (left: Kamaishi City; right: Ofunato City)

2.2.2 KIKU No. 8 (ETS-VIII)

2.2.2.1 Outline and characteristics of KIKU No. 8

The KIKU No. 8 Engineering Test Satellite VIII (ETS-VIII) is Japan's largest geostationary satellite. Its purpose is to contribute to today's increasingly networked information society through the development of state-of-the-art satellite common base technologies and technological development of satellite communication systems for future space activities. It was launched using an H-IIA rocket on December 18, 2006.

The satellite's primary mission is to support verification of the following new developments:

1. Technology for an advanced 3-ton-class spacecraft bus in geostationary orbit
2. Technology for large deployment antennas (size: 19 m × 17m)
3. Technology for a mobile satellite communication system using mobile terminals, and for a mobile satellite digital multimedia broadcasting/communication system enabling transmission of images and high-quality voice data
4. Basic technology for a geostationary satellite positioning system

The satellite has the characteristics outlined below.

■ Installation of two tennis-court-sized (19 m × 17 m) large deployment antennas (reflectors)

JAXA verified the technologies for deploying a large deployable structure on orbit and using large deployment antennas. Currently, only Japan and the U.S. have these technologies.

■ Mobile satellite communication technology

Large deployment antennas enable the establishment of communication links with small-scale ground communication terminals. Such satellite communication terminal equipment is highly portable, meaning that communication lines can be easily set up even if land-based communication networks are disrupted.

This portable equipment uses a TCP/IP interface, and is therefore compatible with commercially available network devices. Ultra-small mobile terminals allow direct communication with KIKU No. 8 with the functionality of transmitting and receiving positioning data and transmitting messages, making it an effective tool in times of disaster. It can also serve as terminal equipment to transmit and receive sensor information relating to remote locations.

* With regard to the verification of mobile satellite communication technology, an abnormality in the low noise amplifier (LNA) in the S-band receiving system for mobile communication made the experiment using large deployment antennas on the receiving side difficult. Accordingly, the originally planned experiment was continued by increasing the output of ground communication terminal equipment, connecting to an external antenna, and using an alternative antenna on the satellite side for reception.

■ Technology for one of the world's largest geostationary satellites and common bus technology

KIKU No. 8 is a 3-ton-class satellite — one of the world's largest — in geostationary orbit, and the common satellite bus technology for it was verified. The DS2000 bus system used for KIKU No. 8 has also been adopted for the First Quasi-Zenith Satellite MICHIBIKI, the Meteorological Satellite HIMAWARI and other overseas commercial satellites.

■ Technology for geostationary satellite positioning technology systems

The basic technology for a geostationary satellite positioning system using an atomic clock was verified. The results were also used for the Quasi-Zenith Satellite System (QZSS).

JAXA verified that the mobile satellite communication technologies of KIKU No. 8 could be applied in a variety of fields through in-orbit technical evaluation efforts (such as experiments to clarify the characteristics of large deployment antennas) and various experiments in mobile satellite communication. These included verification testing for disaster preparation training using portable communication terminal equipment and ultra-small mobile terminals, and experiments involving the transmission and receipt of medical information in preparation for disaster situations.

Figure 2.2-13 shows a conceptual diagram of mobile communication and positioning systems that use KIKU No. 8.

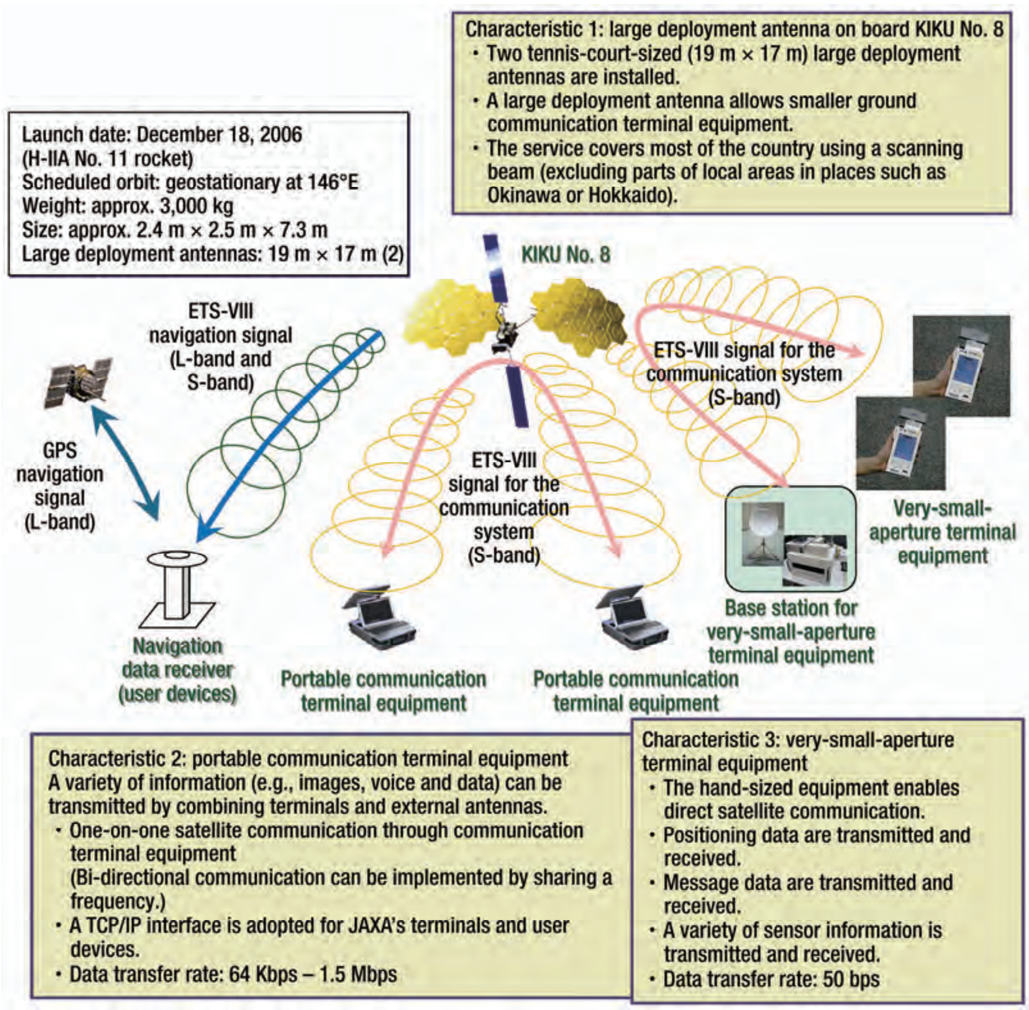


Figure 2.2-13 Conceptual diagram of mobile communication and positioning systems using KIKU No. 8

2.2.2.2 Chronicle of events in the provision of communication lines to disaster areas

The following is a chronicle of events in the provision of communication lines to disaster areas following the Great East Japan Earthquake.

- March 15: In response to the quake of March 11, 2011, JAXA began studying the possibility of providing disaster areas with communication lines using communication terminal equipment for KIKU No. 8, whose operation had been suspended. Concurrently, the Agency began coordinating with partner businesses toward securing sufficient staff to confirm the integrity of this equipment, and with other institutions involved in experiments using KIKU No. 8 to secure satellite lines on an ad hoc basis.
- March 16—18: Tests to confirm the integrity of communication terminal equipment were implemented. The dispatch of personnel by partner businesses and the securement of communication lines using KIKU No. 8 were coordinated.
- March 18: The integrity tests showed that the equipment would function properly, thereby paving the way for the provision of satellite channels in disaster areas.
- On the same day, preparations were made to move into action with a complete set of communication equipment and supplies. A support system was put in place through coordination to dispatch staff from JAXA and partner businesses and by securing satellite channels on an ad hoc basis.
- March 19: JAXA attempted to contact municipalities in Miyagi Prefecture that had sustained heavy damage, but with little success. No requests for communication line support were made because communication disruption was minimal in the few municipalities the Agency was able to contact.
- On the same day, the difficulty of communicating information on the effective use of KIKU No. 8 to disaster areas prompted JAXA to make inquiries to NPO Aichi Net, with which it enjoys collaborative relationships in regard to KIZUNA, disaster prevention drills and other matters.
- March 20: Via NPO Aichi Net staff who were dispatched to Ofunato City in Iwate Prefecture, JAXA received a request from Ofunato City Hall to use KIKU No. 8.
- March 22: Ofunato City Hall asked the Ministry of Education, Culture, Sports, Science and Technology (MEXT) to secure a means of communication using the KIKU No. 8 Engineering Test Satellite VIII. On the same day, MEXT asked JAXA to provide support to secure a means of communication using the satellite based on this request.
- March 23: JAXA dispatched two staff to Ofunato along with communication equipment and supplies.
- March 24: In the morning, equipment and supplies were delivered to Ofunato City Hall, ETS-VIII portable communication terminal equipment and antennas were installed, and satellite channels between Ofunato and the Tsukuba Space Center were established. Communication lines were opened in the afternoon, and were used to provide the disaster countermeasures office with a way of collecting information via the Internet and IP phone for business use.
- April 2: JAXA received a similar request for communication lines from Iwate's Otsuchi Town Central Public Hall, which served as the disaster countermeasures office and as an evacuation site. Late in the afternoon on the same day, equipment, supplies and two staff members were dispatched to the site.
- April 3: Equipment and supplies were installed at Otsuchi Town Central Public Hall, and communication conditions were checked.
- April 4: Satellite channel provision began in Otsuchi Town, with lines mainly being used for two purposes: 1. allowing evacuees to collect information on people's safety over the Internet; and 2. enabling disaster countermeasures office staff to perform their duties.
- Midnight, April 7: One of the largest aftershocks since March 11 struck (seismic intensity: upper 6).

- April 8: Aftershocks caused power failures in Ofunato City and Otsuchi Town, and mobile phones also became temporarily unusable. JAXA provided Internet service via KIKU No. 8 using portable generators.
- April 10: In response to the recovery of most Internet connections at the disaster countermeasures office in Ofunato, JAXA ended support via KIKU No. 8 after discussions between the disaster countermeasures office and MEXT.
- April 21: The provision of communication lines using KIKU No. 8 was ended at Otsuchi Town Central Public Hall after Nippon Telegraph and Telephone Corporation (NTT) set up temporary Internet connections.
- April 22: JAXA received a request from the Onagawa Town Disaster Countermeasure Office in Miyagi Prefecture to use communication lines provided via KIKU No. 8.
- April 25: Three staff members were dispatched to the site along with communication equipment and supplies.
- April 26: Equipment and supplies were installed at the Kaisenkaku evacuation site in Onagawa Town's Takashirohama district in the morning, and communication lines via KIKU No. 8 were opened in the afternoon. The facilities were used primarily by evacuees to collect information on everyday living via the Internet.
- May 12: The provision of communication lines using KIKU No. 8 in Onagawa's Takashirohama district was ended after the Widely Integrated Distributed Environment (WIDE) Project began providing IPSTAR broadband satellite Internet services at the evacuation site.
- May 13: The equipment and supplies in Onagawa were removed.

2.2.2.3 Communication modality and results of communication line usage

To confirm the integrity of communication terminal equipment, interfaces were inspected using the video transmission system (a setup with a proven track record for peer-to-peer transmission of image and voice data using KIKU No. 8) to evaluate the overall performance of related equipment in addition to checking of in dividnal terminal. Initially, JAXA examined the idea of offering support by providing communication lines using the proven video transmission system. However, the feasibility of providing Internet connections was also checked to maximize the benefits of using KIKU No. 8 in disaster areas. This approach was taken in response to the lack of information about needs in these areas and the limited availability of resources in terms of capacity to operate the video transmission system, equipment and supplies, staff numbers and communication lines to be provided.

Although JAXA had no experience of Internet connection trials using KIKU No. 8 communication terminal equipment, such lines were found to offer the advantages of enabling Internet and IP phone usage from multiple PCs despite limited data transfer rates. The simplicity of operation compared to that of the video transmission system was also considered an advantage. As the first attempt confirmed that KIKU No. 8's communication terminal equipment could also be used to provide Internet connections, two modality types were set up to enable the use of the video transmission system and Internet connections. Ultimately, JAXA provided Internet connections using KIKU No. 8 in line with disaster-area needs for information gathering over the Internet. The details of preparations made in Tsukuba are outlined in Figure 2.2-14.

Preparation, materials, etc.	Amount, data transfer rate, etc.
Period for function confirmation	March 16 – 18
ETS-VIII portable communication terminal equipment	Number of available terminal units: 6
20-W amplifier	Number of available amplifiers: 4
90-cm antenna	Preparation of three sets for disaster areas
1.2-m antenna	Preparation of three sets for Tsukuba
Data transfer rate	Upload rate: up to 768 Kbps Download rate: up to 768 Kbps
Number of communication lines available	Number of lines: up to 3 (if no extra lines are provided)
Attached equipment	PC for Internet IP phone FOMA mobile card Transmission system for images, etc.
Others	Required number of LAN cables Required number of RF cables Preparation of power generation, etc.
Utilization form	Internet service provision Flexible response to user requests

Confirmation of functions in Tsukuba / preparation

Figure 2.2-14 Preparation details

Figure 2.2-15 shows a schematic representation of support provided for disaster areas via communication lines using KIKU No. 8 in the prefectures of Iwate and Miyagi, and Figure 2.2-16 outlines the Internet connections provided using the satellite.

ETS-VIII portable communication terminal equipment, antennas, laptops and other equipment were provided to Ofunato City and Otsuchi Town in Iwate Prefecture and Onagawa Town in Miyagi Prefecture, while ETS-VIII portable communication terminal equipment for disaster areas connected to Internet networks was set up at the Tsukuba Space Center. Internet service was made available to disaster areas by connecting them with Tsukuba via KIKU No. 8.

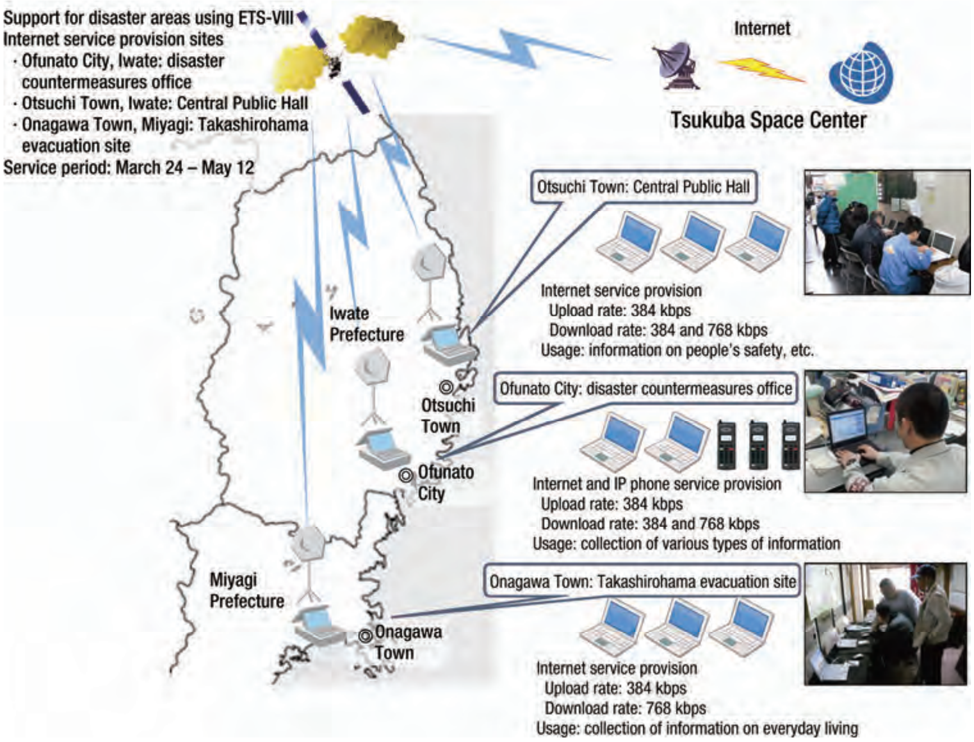


Figure 2.2-15 Outline of support for disaster areas via the provision of communication lines using KIKU No. 8 in the wake of the Great East Japan Earthquake

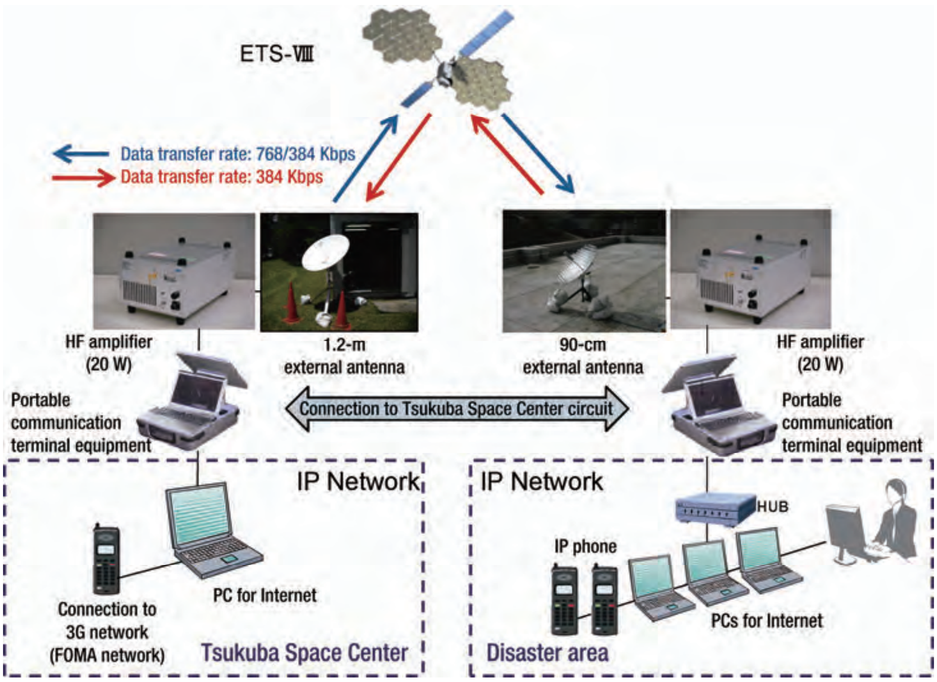


Figure 2.2-16 Outline of Internet connection provision using KIKU No. 8

(1) Usage at Ofunato City Hall in Iwate Prefecture

Communication lines were used at Ofunato City Hall's disaster countermeasures office for the provision of Internet and IP phone services. Two PCs and three IP phones were installed for this purpose.

In terms of communication infrastructure, Ofunato City Hall had only a few voice lines as of March 24 when JAXA offered communication support, and needed Internet connections to enable information gathering.

The Internet service provided at the disaster countermeasures office was widely used, and the office informed JAXA that the connections provided enabled information collection and were therefore very useful. As the IP phones also had less delay than satellite-based mobile phones, they were considered easy to use.

While satellite-based mobile phones use the double-hop system, KIKU No. 8 allows direct IP communication using the single-hop method, and this is considered to be a factor behind the reduced delay.

On March 25, the establishment of Internet connections using KIKU No. 8 was announced at a regular Ofunato City Government press conference.

Late at night on April 7, one of the largest aftershocks since March 11 struck (seismic intensity: upper 6), disrupting the restored power and communication infrastructure until April 8. While power supplies were cut off and mobile phones and other appliances were unavailable, JAXA provided Internet connections using the previously arranged portable generators. This service enabled information collection at the disaster countermeasures office.

The installation and usage of communication terminal equipment in Ofunato City are described below.

Table 2.2-1 Installation and usage of communication terminal equipment in Ofunato City

Support site	Support period	Service line, etc.	Usage:	Notes
Ofunato City, Iwate Disaster countermeasures office	March 24 ― April 10 (18 days)	Upload rate: 384 Kbps Download rate: 768/384 Kbps (*) *Downloads provided at 384 Kbps between April 4 and 10 thanks to frequency sharing with Otsuchi Town, Iwate.	collection of information by the disaster countermeasures office ・Collection of information released by the Japan Meteorological Agency ・Collection of information using aerial photography released by the Geospatial Information Authority of Japan ・Simulated tsunami information (existing) → Comparison of hazard maps and actual damage from the disaster ・Searching of disaster-related ordinances ・Reading of news and use of e-mail function	・Two notebook computers available ・Three IP phones available

Network situation on the first day of support in Ofunato City Hall (March 24)
・Fixed-line telephone and Internet services: not available (date of re-installation was unknown)
・Satellite mobile telephone lines: 3 (provided by NTT)
・Telephone and fax for disaster use only: 1 (connections were limited)
・Mobile phone lines: Only NTT Docomo was available thanks to its special base station (frequent congestion)
・Radio communications for communicating with the fire service and police, radio communications for police, and radio communications for the Self-Defense Forces were introduced.

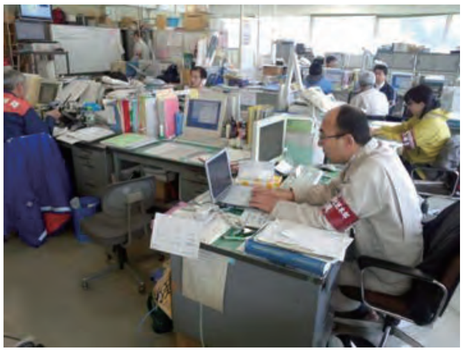


Figure 2.2-17 Ofunato City Hall (left: outside; right: local countermeasures office)

(Installation on the roof of City Hall)

(Access to the roof)

(Generators used during power failure on April 8)

Figure 2.2-18 Communication equipment installed (left: 90 cm ϕ portable antenna; center: portable communication terminal equipment; right: portable generators)

Figure 2.2-19 Usage at the countermeasures office

Figure 2.2-20 Use of communication lines during power failure on April 8
(rooftop generator operation due to power failure in the office)

Figure 2.2-21 Tsunami damage (near Rikuzentakata City)

Figure 2.2-22 Urban area of Ofunato City

(2) Usage at Otsuchi Town Central Public Hall in Iwate Prefecture

In Otsuchi Town, communication lines were provided at the disaster countermeasures office, which doubled as an evacuation site, and were primarily used to offer Internet services to disaster victims. As of April 4 (the day when communication lines were first opened), five special NTT satellite telephone lines were provided at the town's Central Public Hall as communication infrastructure for the general public. In conjunction, JAXA provided communication lines exclusively for Internet access and installed three PCs.

The facilities were primarily used by disaster victims and disaster relief support staff to collect information on people's safety, research disaster-related matters (such as the issuance of disaster victim certificates), browse the web and send e-mail.

On April 8, the day after one of the largest aftershocks since March 11 struck, satellite channels were provided using portable generators.

The installation and usage of communication terminal equipment are described below.

Table 2.2-2 Installation and usage of communication terminal equipment in Otsuchi Town

Support site	Support period	Service line, etc.	Usage:	Notes
Otsuchi Town, Iwate Central Public Hall	April 4 — April 21 (17 days)	Upload rate: 384 Kbps Download rate: 768/384 Kbps (*) *Downloads provided at 384 Kbps between April 4 and 10 thanks to frequency sharing with Ofunato City, Iwate. Downloads from April 11 provided at 768 Kbps.	provision of Internet service for evacuees ・Collection of information on people's safety and evacuees ・Collection of information on evacuation sites ・Collection of disaster information and news browsing ・Confirmation of disaster victim certificates and insurance details ・Cancellation of electricity, telephone, gas services, etc. ・Utilization of e-mail function	・Three notebook computers available An average of 20 — 30 users per day utilized the service.

Network situation on the first day of support at Otsuchi Town Central Public Hall (April 4)
・Special satellite telephone lines provided by NTT: 5
・Mobile phone lines: available (service limitations due to line congestion and access failure)
・Internet service for evacuees: not available

Central Public Hall roof

Access to the roof

Figure 2.2-23 Communication equipment and other devices installed (left: antenna; right: equipment and supplies)

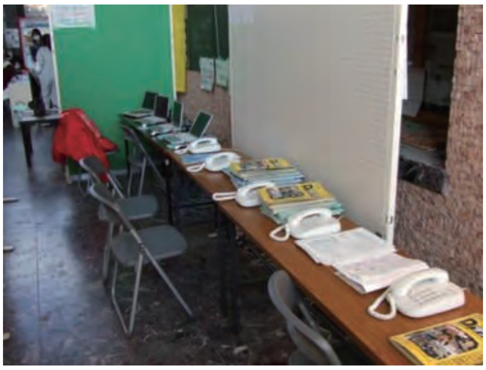


Figure 2.2-24 JAXA PCs for Internet access and special NTT telephone lines installed in the lobby of Central Public Hall

Figure 2.2-25 Internet users

(3) Takashirohama Evacuation Site in Onagawa Town, Miyagi Prefecture

Communication lines were provided at the evacuation site in Onagawa Town so that evacuees could access the Internet. As of April 25, general subscriber telephone lines in the town remained cut off, although mobile phone networks had been restored. Mobile phone connectivity at the Takashirohama evacuation site where JAXA provided communication lines was poor due to its geographical location.

In the same way as for Otsuchi Town, Internet connections for public use were provided in Onagawa. The service at the evacuation site was used to collect disaster-related information on matters such as the issuance of disaster victim certificates, and on everyday considerations such as used cars, second-hand boats and ships, mail-order services for clothes and other commodities, and job openings. People also used the Internet to collect information specific to the area such as daily tide times, as earthquake-related subsidence caused urban areas to flood during high tide. The installation and usage of communication terminal equipment are described below.

Table 2.2-3 Installation and usage of communication terminal equipment in Onagawa Town

Support site	Support period	Service line, etc.	Usage:	Notes
Onagawa Town, Miyagi Takashirohama evacuation site, Kaisenkaku	April 26 — May 12 (18 days)	Upload rate: 384 Kbps Download rate: 768 Kbps	provision of Internet service for evacuees ・Collection of information on temporary housing and mail-order (clothes and furniture) ・Collection of information on tide tables/post-disaster situations and news browsing ・Collection of information on used cars, boats and ships ・Confirmation of employment opportunities and information on hospitals and schools ・Cell-phone subscriptions and other general information on everyday living In response to a request from the evacuation site, the service is available between 14:00 and 21:00.	・Three notebook computers available An average of 20 users per day utilized the service.

Network situation on the first day of support in Onagawa Town and at the Takashirohama evacuation site (April 26)
・Fixed-line telephone and Internet services: not available (re-installation in May)
・Mobile phone lines: available (instability of radio wave environment)
・Rental cell-phones available for evacuees

Figure 2.2-26 Communication equipment and other devices installed (left: antenna; right: equipment and supplies)

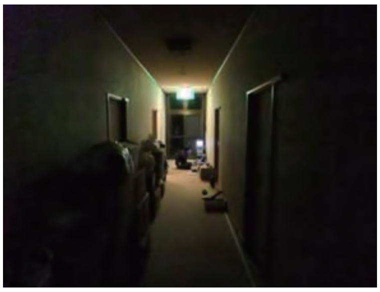


Figure 2.2-27 Nighttime Internet service

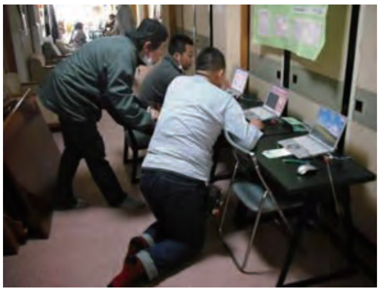


Figure 2.2-28 Internet users

Figure 2.2-29 Onagawa Town (left: downtown area; right: commuter road (during high tide))

(4) Support results

A total of 15 staff from JAXA and partner businesses worked in rotation over a period of about two months from March 16 (when it was confirmed that communication equipment was working) to May 13 (when the equipment and supplies were removed), providing satellite channels in Tsukuba Space Center, Ofunato and Otsuchi in Iwate Prefecture and Onagawa in Miyagi Prefecture.

These channels were used to collect a variety of information in line with the requirements of the disaster areas, which ranged from governmental needs (such as the capacity for information gathering by disaster countermeasures offices) to those of the general public (such as the capacity for information collection to confirm people's safety at evacuation sites). JAXA offered flexibility in response to requests for the hours of communication line provision to be extended.

Although the data transfer rates of KIKU No. 8 are limited, the high mobility and operability of related communication terminal equipment highlighted the satellite's important role in securing post-disaster communication lines as part of initial response efforts. It was also clarified that the top priority for people in disaster areas was the provision of telephone and Internet functions rather than disaster-management application. The provision of Internet connections over a long period further highlighted that usage patterns shifted over time from operation to collect information on damage in the immediate aftermath of the disaster to gathering daily living information toward recovery.

The provision of communication lines using KIKU No. 8 (an R&D satellite) went smoothly even though this was the first time it had been used to support disaster-related measures. It enabled the provision of ongoing stable communication environments, except when operations were interrupted by bad weather (strong winds), over a period of approximately two months with almost daily aftershocks. There were no personnel accidents or major issues with the satellite and related communication equipment/supplies during this period.

The support sites fully tested the functions and performance of KIKU No. 8, and its high potential was demonstrated and utilized at the support sites as a result.

2.2.3 Summary

A digital divide issue emerged in northeastern coastal areas in the immediate aftermath of the Great East Japan Earthquake. To help bridge this divide, JAXA provided the disaster countermeasures offices in Iwate Prefecture and Onagawa Town in Miyagi Prefecture with communication lines using KIZUNA and KIKU No. 8. Changes in the overall state of damage to commercial communication lines and findings gained through JAXA's support activities for disaster areas and other matters are summarized below.

2.2.3.1 Communication infrastructure damage caused by the Great East Japan Earthquake

Communication infrastructure damage and related influences are summarized in Damage to Information and Communications Infrastructure Caused by the Great East Japan Earthquake and the Present Status of Restoration (Reference Material No. 37-1-10) in the handout given at the 37th meeting of the Information and Communications Council's Information and Communications Policy Committee under the Ministry of Internal Affairs and Communications. The statistics below are from this source.

Figure 2.2-30 shows the status of damage and congestion relating to fixed-line and mobile communications. A total of 1.9 million landlines and 15,000 mobile phone base stations were damaged.

Figure 2.2-31 shows changes in the numbers of disconnected landlines and suspended mobile phone base stations between March 11 and May 6. It can be seen that immediately after the quake, both landline and mobile phone communications were possible in many areas. However, the problem worsened thereafter because private generators at relay and base stations (i.e., control stations) were used due to power failures after the quake, and disruption to landlines and base stations peaked once these units ran out of fuel (see

Figure 2.2-32).

Figure 2.2-33 shows changes in the status of damage to communication lines in Iwate Prefecture 2 weeks, 1 month and 1.5 months after the disaster. At the two-week stage, lines were yet to be restored in 10 municipalities, including Kamaishi, Ofunato and Otsuchi, where JAXA provided communication facilities. A month after the disaster, recovery still had not been achieved in parts of five municipalities, including Kamaishi, Ofunato and Otsuchi Town. All lines were finally restored 1.5 months after the disaster.

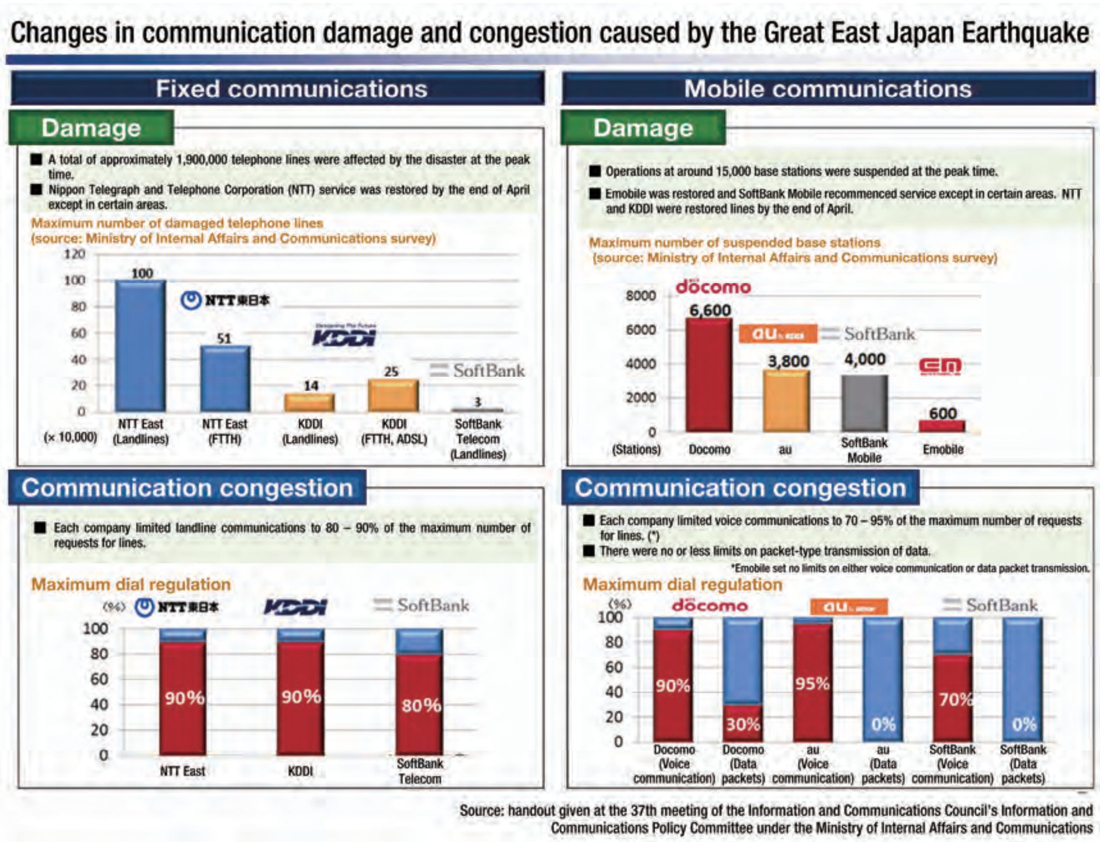
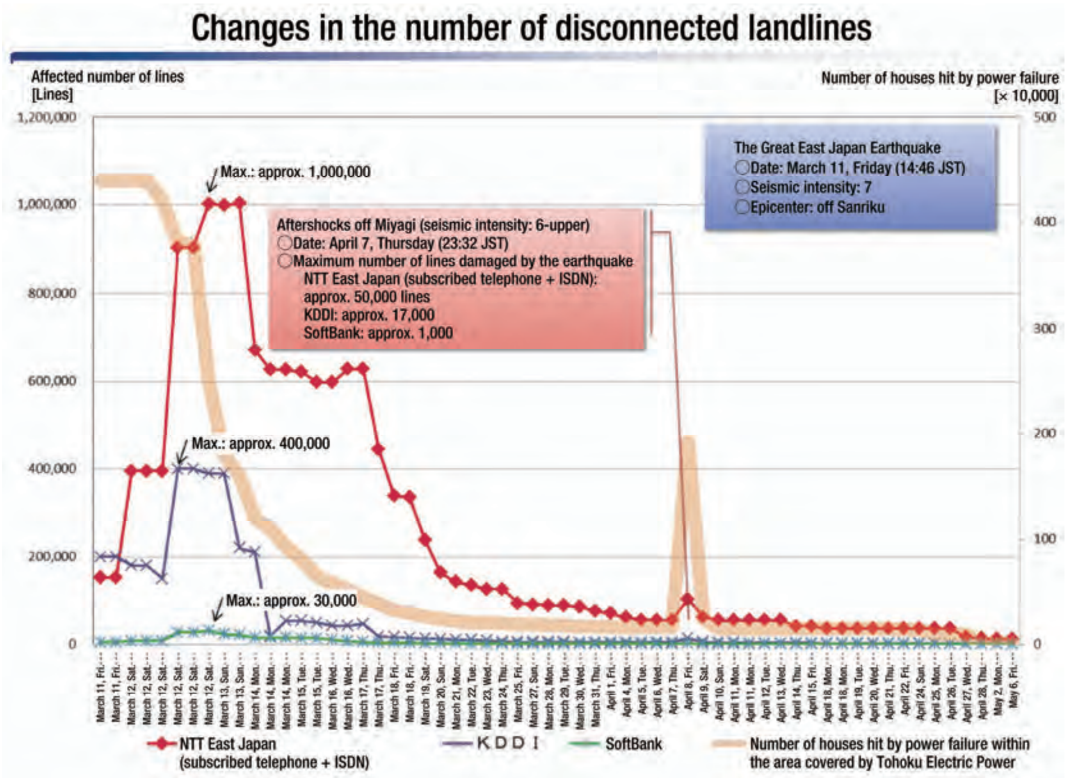


Figure 2.2-30 Changes in communication damage and congestion caused by the Great East Japan Earthquake



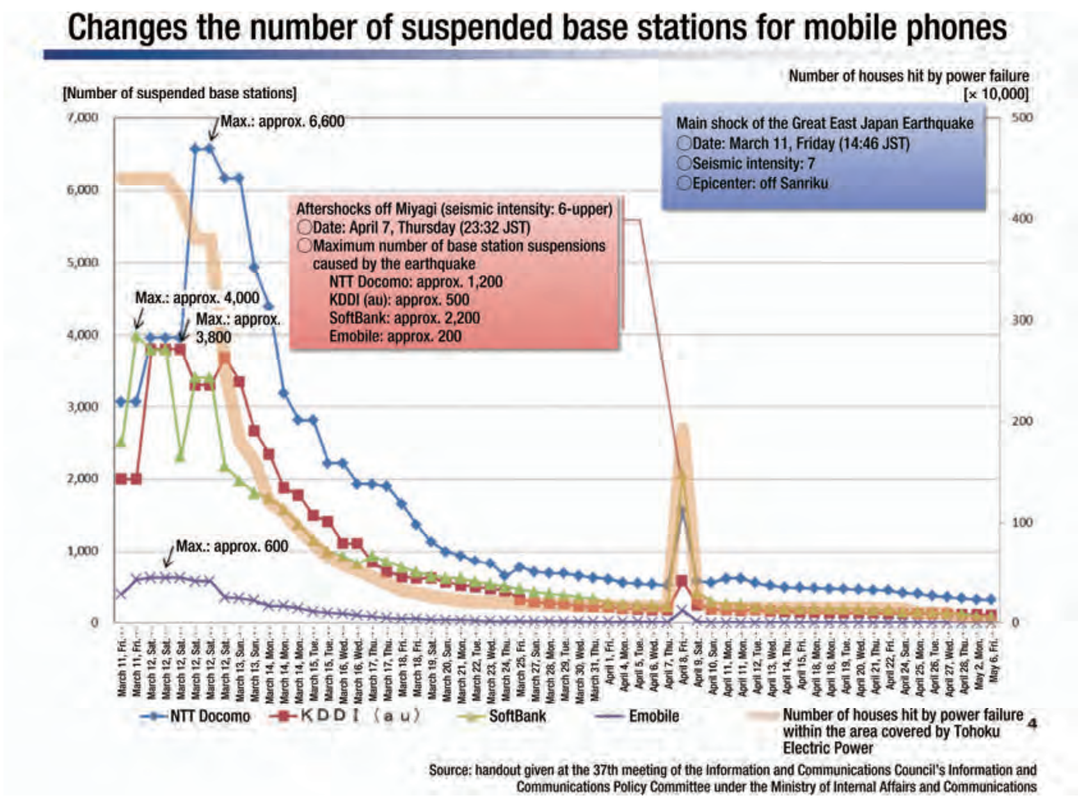


Figure 2.2-31 Changes in numbers of disconnected landlines and suspended mobile phone base stations

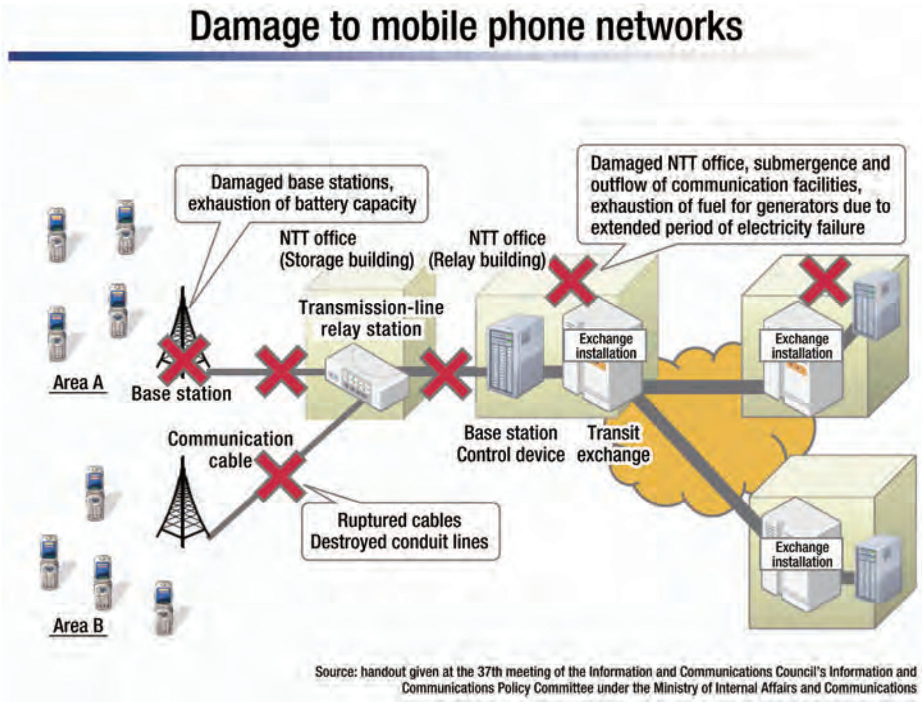


Figure 2.2-32 Locations of damage to mobile phone networks

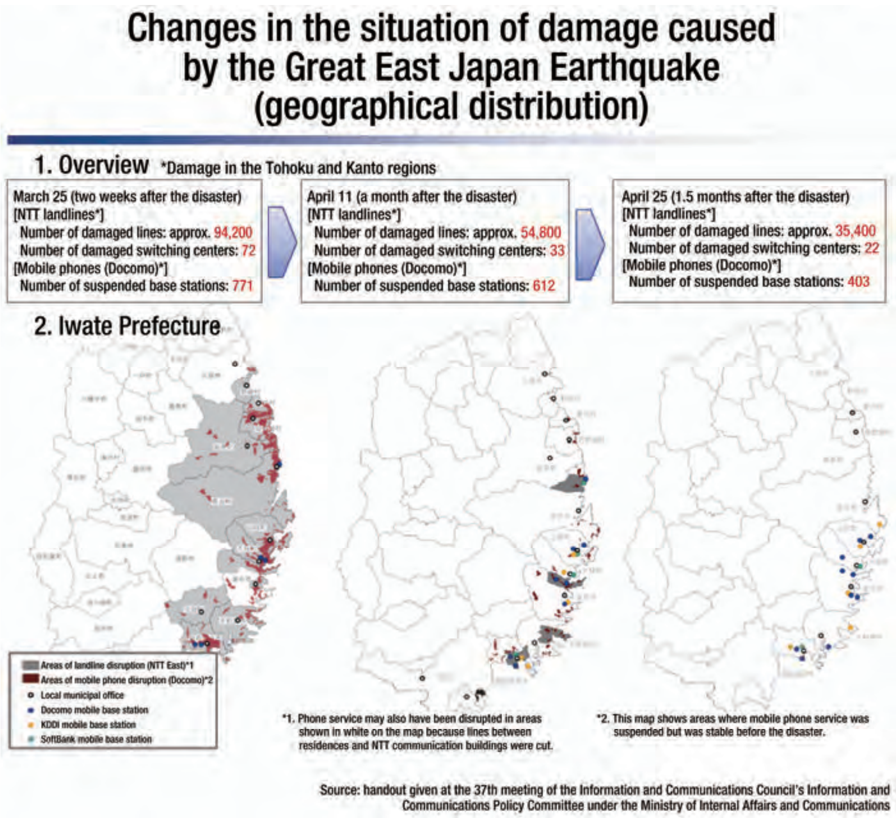


Figure 2.2-33 Changes in damage to communication lines in Iwate Prefecture

2.2.3.2 Findings from communication line provision work in disaster areas

Findings made through direct interaction with representatives of prefectural/local disaster countermeasures offices, disaster victims at these offices and staff dispatched from national/local government bodies are summarized below.

- Ideally, the quality of telephone and Internet services provided should match that of pre-disaster levels.
  - Immediately after the disaster, facilities to communicate the need for emergency medical assistance and to request help were considered more important than food, gas and water.
  - In Iwate Prefecture, a lack of communication facilities delayed rescue work.
  - Many survivors had mobile phones on their person, but PCs were mostly located in washed-away/damaged houses and buildings. As a result, electronic communications were difficult regardless of the status of Internet service recovery. In Kamaishi and Otsuchi in Iwate Prefecture and Onagawa in Miyagi Prefecture, government buildings sustained tsunami damage, and the number of PCs available was limited as a result.
- In tsunami-ravaged coastal areas, damage to base stations and overland cables caused an immediate digital divide. In this regard, it is important for local governments to share information and broadcast prompt reports on aftershocks, tsunamis and similar.
  - Municipalities that could not be contacted immediately after the earthquake and tsunami had suffered serious damage, and faced the worst conditions.
  - In coastal areas of Iwate Prefecture, information on aftershocks and accompanying tsunami could not be broadcast to local residents after the initial tsunami damage.
- Information and communication lines in various forms are required depending on time, place and usage. Generally, disaster victims and local government staff used telephones for different purposes. Meanwhile, disaster victims used the Internet mainly to download information, while local government staff used it to upload information from disaster areas.
  - Earthquake/tsunami – 2nd week: Phone and Internet lines were disrupted.
    - ✓ Disaster victims

      Used phone services to let people know they were safe and accessed the Internet to e-mail, locate other affected people and obtain information on the extent of the devastation. The phone line capacity provided approximately matched the demand for the service.
    - ✓ Teams dispatched from municipalities and other organizations outside disaster areas

      Used phone services to communicate with their activity bases and accessed the Internet to send images of disaster areas to their home organizations and to check maps and road conditions at their dispatch destinations.
    - ✓ Local government staff in disaster areas

      Used phone services and the Internet to clarify situations and share information. Communication lines were also used for videoconferencing between prefectural and local disaster countermeasures offices. KIZUNA provided upload speeds of up to about 6 Mbps at Kamaishi's local countermeasures office (Iwate Coastal Regional Development Bureau).
  - 2nd week after the disaster onward: Most phone networks were restored. Internet connections with speeds matching those of communication cards provided by telecommunications carriers (i.e., several hundred Kbps or more) were achieved.
    - ✓ Disaster victims and evacuation sites

Used Internet services to collect information on everyday living (e.g., procedures for disaster victim certificate issuance, evacuation sites, insurance coverage, cancellation of contracts for essential utilities, job openings, schools and used cars). KIKU No. 8 provided connection speeds of up to about 768 Mbps at the evacuation site in Onagawa.

- ✓ Teams dispatched from municipalities and other organizations outside disaster areas
  Used phone services to communicate with their activity bases and accessed the Internet to send images of disaster areas to their home organizations and to check maps and road conditions at their dispatch destinations.
- ✓ Local government staff in disaster areas
  Used phone services and the Internet to clarify situations and share information. Communication lines were also used for videoconferencing between prefectural and local disaster countermeasures offices. KIZUNA provided upload speeds of up to about 6 Mbps at Kamaishi's local countermeasures office (Iwate Coastal Regional Development Bureau).

These usage details are summarized in Table 2.2-4 below.

Table 2.2-4 Summary of communication line usage in disaster areas

Target	Details	Purpose	Circuit capacity	Notes
Victims		Phone calls and e-mails to support confirmation of people's safety	Double-digit kbps upward (upload and download)	Phone service is essential for victims to confirm people's safety and make emergency calls.
Evacuation sites		Phone calls and Internet service to support confirmation of people's safety and collection of information on damage and everyday living	KIKU No. 8 provision: 768 kbps upward	Evacuation sites in Otsuchi Town, Iwate and Onagawa Town, Miyagi
Dispatched teams		Release of local information and sharing with organizations dispatching teams, delivery of images and collection of map information	Several Mbps upward	The circuit capacity between evacuation sites and local municipalities is used to deliver local images.
Municipalities in disaster areas	Local disaster countermeasures office organized	Internet service to collect, share and release information, videoconferencing to share information	KIZUNA provision: 6 Mbps upward	Iwate Prefecture Disaster Countermeasures Office and local countermeasures offices in Kamaishi and Ofunato (Coastal Regional Development Bureau)
	No local disaster countermeasures office organized	Internet service to collect, share and release information	KIKU No. 8 provision: 768 kbps upward	Ofunato City Hall, Iwate

The successful provision of communication lines using KIZUNA and KIKU No. 8 demonstrated the direct applicability of results from previous related JAXA experiments and training programs. The satellite network provided by KIZUNA and KIKU No. 8 along with commercial communications satellites served government bodies and other organizations in disaster areas. This is a clear indication that satellite networks are a necessary supplement to terrestrial lines, which by themselves may be inadequate. Terrestrial networks are vulnerable to major disasters like the March 11 calamity due to possible disconnection of communication cables and destruction of base stations. To protect human life and property, satellite network systems and the supplementary connections they provide are essential. In light of the serious damage and extreme hardships suffered in areas where communications were cut off immediately after the disaster, there is an urgent need to examine the future of information and communications technologies for improved disaster-preparedness in Japan.

3. JAXA activities as viewed by other institutions

3.1 JAXA-related media coverage

JAXA's response to the Great East Japan Earthquake (including emergency observation of afflicted areas using the Daichi satellite and provision of communication facilities using KIZUNA and KIKU No. 8) was widely covered in the media, as outlined in Table 3.1-1.

Table 3.1-1 Media coverage of JAXA activities

Date published		Media published	Type	Page no.	Headline/content	Satellite
March 2011	15	Yahoo News	Web	-	Earthquake images of damaged areas from JAXA's Advanced Land Observing Satellite "Daichi" released	Daichi image provision
	16	goo News	Web	-	Additional emergency observations in the Tohoku region conducted using JAXA's Advanced Land Observing Satellite "Daichi"	Daichi image provision
		Yomiuri Online	Web	-	Tsunami-hit house drifts 20 km out to sea	Daichi image provision
		Yomiuri Shimbun	Newspaper/morning	7	Drifting caused by the Great East Japan Earthquake extends as far as 20 km out to sea	Daichi image provision
		goo News	Web	-	Great East Japan Earthquake: JAXA emergency observation shows crust shifted 3 m	Daichi image provision
	17	Nikkei BPnet ITpro	Web	-	JAXA releases online results of disaster-area crustal movement observation conducted using the Advanced Land Observing Satellite	Daichi image provision
		NHK News	Web	-	Trial satellite provides disaster-area news	KIZUNA disaster-area news provision
		Nihon Keizai Shimbun	Newspaper/evening	10	JAXA uses high-speed-data communication satellite for damaged areas	KIZUNA disaster-area news provision
		Kahoku Shimpo	Newspaper/morning	1	Daichi satellite captures Rikuzentakata's lost scenic site of Matsubara	Daichi image provision
	18	Nihon Keizai Shimbun	Newspaper/morning	30	Specialist analysis of satellite images reveals changes in Pacific coastline	Daichi image provision
		Iwate Nippo	Newspaper		Iwate University team identifies clear collapse and flooding in satellite images	Daichi image provision
		Iwate Nippo	Newspaper	4	Great East Japan Earthquake: Japan Aerospace Exploration Agency supports communications between Kamaishi City and prefectural government by satellite	KIZUNA disaster-area news provision
		Yahoo News	Web	-	Great East Japan Earthquake: JAXA opens KIZUNA communication system to damaged areas	KIZUNA disaster-area news provision
		Nikkan Kogyo Shimbun	Newspaper		Great East Japan Earthquake: JAXA installs antennas in Iwate to allow use of KIZUNA (internetworking satellite)	KIZUNA disaster-area news provision
		response.jp	Web	-	Great East Japan Earthquake: JAXA opens KIZUNA communication system to damaged areas	KIZUNA disaster-area news provision
		asahi.com	Web	-	Daichi satellite images show aftermath of tsunami along Fukushima coast	Daichi image provision
		Mainichi Newspaper	Newspaper/evening		Great East Japan Earthquake: Daichi satellite data show Oshika Peninsula shifted 3.5 m eastward	Daichi image provision
		Nikkan Kogyo Shimbun	Newspaper	19	Great East Japan Earthquake: JAXA dispatches five staff to install antennas in Iwate for KIZUNA (internetworking satellite)	KIZUNA disaster-area news provision
		Fuji Sankei Business i.	Newspaper	6	Great East Japan Earthquake: tsunami leaves mark over a wide area	Daichi image provision
		Denkei Shimbun	Newspaper	3	Ministry of Internal Affairs and Communications asks NTT Docomo and KDDI for 324 and 144 rental satellite phones	KIZUNA disaster-area news provision
	23	Nihon Keizai Shimbun	Web	-	JAXA uses KIZUNA (high-speed-data communication satellite) for damaged areas	KIZUNA disaster-area news provision
	27	TV Asahi's Sunday Front Line	TV	-	Massive tsunami engulfs huge embankment	Daichi image provision
	28	Nihon Joho Sangyo Shimbun	Newspaper	2	NICT provides broadband lines to support disaster countermeasures	KIZUNA disaster-area news provision
		Denkei Shimbun	Newspaper	3	Tohoku Region Pacific Ocean Coastal Earthquake: JAXA supports damaged areas by providing engineering test satellite, terminal equipment for KIKU No. 8, to Ofunato City	KIKU No. 8 disaster-area news provision

Date published		Media published	Type	Page no.	Headline/content	Satellite
	29	Ibaraki Shimbun	Newspaper	18	Land shifts 3.5 m eastward	Daichi image provision
		Fukushima Minyu Shimbun	Newspaper	3	Tohoku shifts up to 3.5 m eastward; Date area moves 1 m	Daichi image provision
		TV Asahi, Yajiuma TV!	TV	-	Victims' beacon of hope: single pine tree survives	Daichi image provision
	30	Nikkan Kogyo Shimbun	Newspaper	25	Ofunato Internet service restored with JAXA's KIKU No. 8.	KIKU No. 8 disaster-area news provision
	31	Nihon Keizai Shimbun website	Web	-	Nikkei Shimbun homepage displays animated images taken by Daichi satellite	Daichi image provision
April 2011	1	Tokai Shimpo	Newspaper	3	JAXA supplies 3 PCs to joint government with ultra-high-speed network service free of charge	KIZUNA disaster-area news provision
	3	Jiji.com	Web	-	Underutilized data with overly tight secrecy; specialists request release and use of information	Daichi image provision
	8	Yomiuri Shimbun	Newspaper/morning	11	Immediate relief for communication-network protection requested	KIZUNA disaster-area news provision
	19	Nikkei Sangyo Shimbun	Newspaper	1	Toward disaster recovery: on-site research and efforts by stronger universities required	Daichi image provision
	21	Space News (TV Tokyo)	TV	-	JAXA HQ supports Great East Japan Earthquake recovery, astronaut Furukawa reveals details of space training (appearance by Futoshi Takiguchi, Manager, Disaster Management Support Systems Office)	Daichi, KIZUNA and KIKU No. 8
	22	MYCOM Journal	Web	-	Electrical abnormality found on Advanced Land Observing Satellite "Daichi" — an important part of efforts to analyze damaged areas after the Great East Japan Earthquake	Daichi, KIZUNA and KIKU No. 8
	29	Friday	Magazine	-	Observing Satellite Daichi captures earthquake's effects — shocking images of land sliced off	Daichi image provision
May 2011	15	Space News (TV Tokyo)	TV	-	Daichi after the Great East Japan Earthquake; last shot to finish operations	Daichi image provision
	18	Nikkei BP Online	Web	-	JAXA team operates KIZUNA (high-speed-data satellite) to support Internet services from space	KIZUNA disaster-area news provision
	24	Yomiuri Shimbun	Newspaper/morning	11	Great earthquake and space technology — a practically invisible Japanese satellite; secrecy constitutes a barrier to Daichi's provision of rough images	Daichi image provision
June 2011	12	Nihon Keizai Shimbun	Newspaper/morning	12	Daichi, KIZUNA and KIKU No. 8 contribute to GPS and other types of private use	Daichi, KIZUNA and KIKU No. 8
	15	Fuji TV's Mezamashi TV	TV	-	Daichi observation images show geomorphic changes and subsidence after March 11 earthquake	Daichi image provision
	30	Kahoku Shimpo	Newspaper/morning	4	Daichi before/after disaster photos to be released on the Internet tomorrow	Daichi image provision
July 2011	2	Asahi Shimbun	Newspaper/morning		Space School, do you support earthquake disaster reconstruction even from space?	Daichi, KIZUNA and KIKU No. 8
	28	Weekly Shincho	Magazine	-	Science Delivery Service — an unseen rising sun; hidden space development	Daichi, KIZUNA and KIKU No. 8
August 2011	2	Wirelesswire News	Web	-	ICT specialists from a range of fields publish report entitled The Great Earthquake and Information Communication, its Roles and its Future	Daichi, KIZUNA and KIKU No. 8
	25	Japanese Government Internet TV	Web	-	Tokumitsu & Kisa's Learn about Japan! Saving the earth — space science technology to save lives	Daichi image provision

3.2 Usage of JAXA satellite by other institutions

Images of disaster-stricken areas captured by Daichi were also used by institutions other than JAXA in response to the disaster. Examples of Daichi observation data usage by non-JAXA institutions are outlined below.

3.2.1 Earth observation satellite-based activities

3.2.1.1 Tohoku Region Pacific Ocean Coastal Earthquake Emergency Mapping Team (EMT)

To promote uniform understanding of the situation nationwide, a group of volunteers from the Research

Center for Disaster Reduction Systems at Kyoto University's Disaster Prevention Research Institute and others formed the Emergency Mapping Team (EMT) and began mapping activities in collaboration with officials in charge of disaster management at the government's Cabinet Office. The maps were made available on the EMT website (Figure 3.2-1).

The EMT engaged in the activities outlined below to promote uniform understanding of various types of damage and responses nationwide.

- Visualization of the situation over a wide area based on information mapping
- Visualization based on information mapping for prefectural coordination of related activities
- Visualization based on information mapping to support activities at major disaster sites requiring immediate response

As part of its activities, the EMT developed and published maps based on images captured by Daichi.

Figure 3.2-1 EMT map-distribution website
(http://www.drs.dpri.kyoto-u.ac.jp/emt/)

3.2.1.2 Tohoku Regional Environmental Office (Ministry of the Environment) and Yokoyama Spatial Information Research Center

From July 1, 2011, to March 31, 2012, the Ministry of the Environment's Tohoku Regional Environmental Office used its website to publish post-disaster images taken by Daichi during six individual periods after the Great East Japan Earthquake and pre-disaster images in collaboration with partner institutions on an industry-academia-government program to support the use of Daichi images in the Tohoku region. This initiative was coordinated by the Tohoku Regional Environmental Office with the Yokoyama Spatial Information Research Center in charge of planning and project management, and enjoyed the collaboration and partnership of the Ministry of the Environment, JAXA, the Tohoku Construction Association, the Iwate University Center for Regional Collaboration in Research and Education, and NEC Software Tohoku, Ltd.

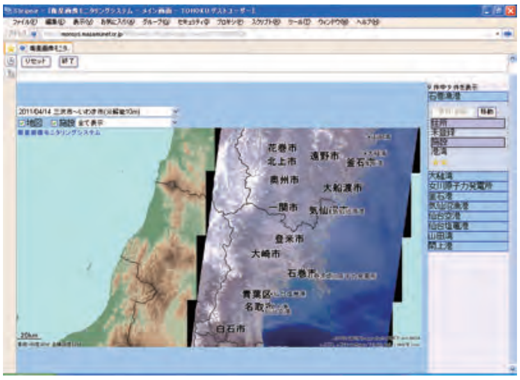


Figure 3.2-2 Tohoku Regional Environmental Office website showing images of disaster areas

(Access requires guest login from http://tohoku.env.go.jp/to_2011/0701a.html.)

3.2.1.3 Sinsai Info

Sinsai.info is a collaborative platform developed to support reconstruction in the aftermath of the Great East Japan Earthquake. The website was built using Ushahidi (a crowdsourcing tool also adopted in a variety of fields when a major earthquake struck New Zealand in 2011), and is managed by volunteer developers, data managers and contributors from OpenStreetMap Japan and OpenStreetMap Foundation Japan.

Moderators in charge of incident report content received via the web, e-mail and Twitter check submissions and post them to the site.

When a request for help with printing satellite image maps created from Daichi data on A0-size paper was posted on the sinsai.info website, Hewlett-Packard Japan Ltd. and Tezukayama Gakuin University's Faculty of Liberal Arts provided support.

Figure 3.2-3 The Sinsai Info website

(http://www.sinsai.info/)

Figure 3.2-4 Report on large-format printing of satellite image maps made from Daichi data on the sinsai.info website

3.2.1.4 NTT Data Corporation and RESTEC

NTT Data Corporation and the Remote Sensing Technology Center of Japan (RESTEC) collaborated on the creation of satellite image maps of Iwate, Miyagi and Fukushima prefectures to help reconstruct areas devastated by the Tohoku Region Pacific Ocean Coastal Earthquake. The maps have been published on websites and elsewhere since March 31, 2011 (shown on the left of Figure 3.2-5).

The satellite image maps created using pre- and post-disaster images captured by Daichi and the Thailand Earth Observation Satellite (THEOS) consist of coordinate data in Geo PDF format, and were developed by laying map information showing roads, public facilities and other data over satellite images (shown on the right of Figure 3.2-5).

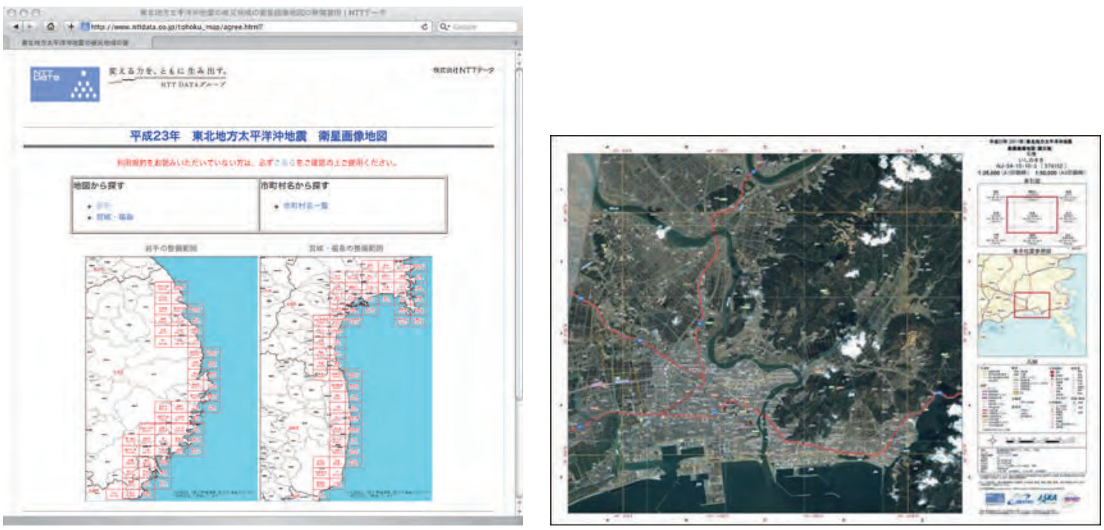


Figure 3.2-5 Satellite image map website (left) and one of the satellite image maps published (right)
(http://www.nttdata.co.jp/tohoku_map/index.html)

3.2.1.5 PASCO Corporation

Immediately after the March 11 earthquake, PASCO Corporation began work to clarify the nature and extent of the devastation and provide related information. To achieve this, it engaged in multi-platform observation using various resources including TerraSAR-X (an earth observation satellite with an X-band SAR antenna), an optical satellite, airplanes and vehicles for ground-based evaluation (Figure 3.2-6). For the optical satellite platform, emergency observation images captured by Daichi were used.

Figure 3.2-6 Multi-platform response

(1) Use of pre-disaster images

(a) Use of pre-disaster images as a base for superimposition of analysis results

PASCO superimposed the outcomes of analysis for various satellite images onto pan-sharpened ortho images developed using Daichi data, and provided the results to disaster countermeasures organizations and other institutions (shown on the left of Figure 3.2-7).

(2) Use of post-disaster images

(a) Use of post-disaster images to draw up detailed tsunami flood hazard maps

PASCO drew up detailed tsunami flood hazard maps for wide areas stretching from Aomori down to Ibaraki using satellite images, including data captured by TerraSAR-X and Daichi, aerial photographs and other resources. The results were provided to the Prime Minister’s Official Residence, the Ministry of Land, Infrastructure, Transport and Tourism, the Ministry of Agriculture, Forestry and Fisheries and other disaster countermeasures organizations, research institutions, academic societies, private enterprises, media and other organizations (shown on the right of Figure 3.2-7).

(b) Use of images to clarify changes in coastal forests

Using AVNIR-2 images captured before the earthquake on February 27, 2011, and after it on March 14, 2011, PASCO confirmed that the earthquake-triggered tsunami had exerted a significant adverse effect on coastal forests in terms of both activity and density/area. The results were publicized at a meeting of the Japan Society of Erosion Control Engineering held from May 18, 2011.

(c) Use of images in materials showing examples of satellite use

PASCO developed large-format images (up to 2.8 m wide) by superimposing the flood hazard maps described above onto ALOS (Daichi) data captured on March 14, 2011, (showing areas from southern Aomori to northern Ibaraki) for distribution. The Daichi images in the materials showed the extent of tsunami damage, sea surface turbidity, tsunami-related flotsam and other features. The product was well received by various groups, including disaster countermeasure organizations within the national government and elsewhere and the news media.

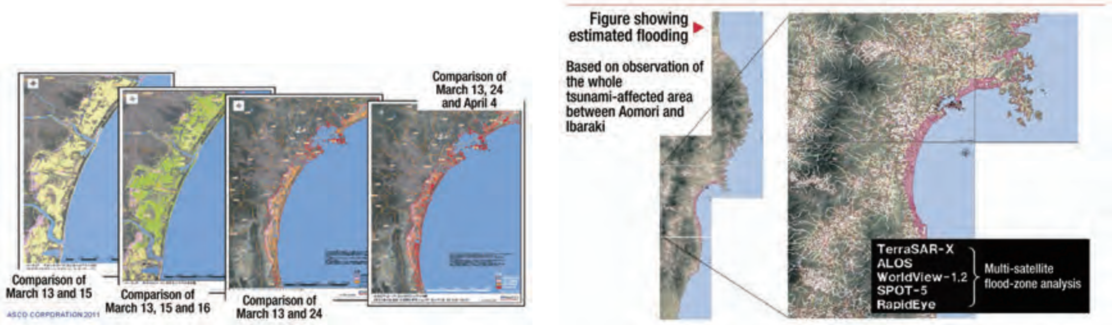


Figure 3.2-7 Use of pre-disaster images (left), flood hazard map (right)

3.2.2 Communication satellite-based activities

3.2.2.1 National Institute of Information and Communications Technology (NICT)

In response to a request for assistance from the Tokyo Fire Department on March 13, the National Institute of Information and Communications Technology (NICT) transported equipment and supplies, including a portable Very Small Aperture Terminal (VSAT), to Kesennuma City on March 14. Using KIZUNA, it subsequently began providing broadband network connections between the Emergency Fire Response Team Command Support HQ (local headquarters) in Kesennuma and the Tokyo Fire Department's Earthquake Preparation Section in Tokyo's Otemachi area on March 15. This allowed real-time two-way transmission of high-quality images, communication of information on the state of the devastation using high-definition images and so forth between the two groups. As a further advantage over telephone usage, the provision also supported the inspection of visual resources such as images and maps, thereby contributing to efficient sharing of information between the sites.

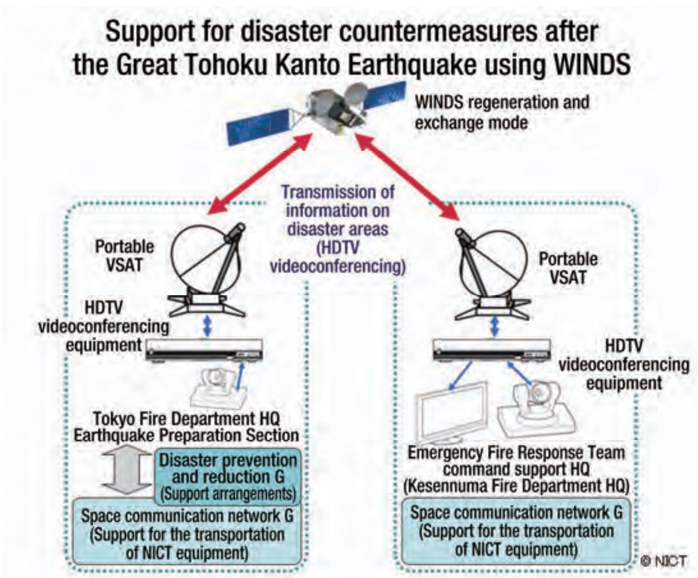


Figure 3.2-8 NICT support for disaster response activities using KIZUNA
(http://www2.nict.go.jp/pub/whatsnew/press/h22/announce110316/index.html)

4. Challenges and future tasks

4.1 Challenges

Since JAXA's 2005 announcement of its long-term vision, the organization has promoted satellite application to disaster management and verified related technologies in its role as Japan's Space Applications Mission Directorate for pursuing the innovative utilization of space resources. Against this backdrop, the Agency reviewed the current situation and related challenges in the context of the March 2011 earthquake and tsunami ― a disaster on a scale never before experienced in the country.

4.1.1 Challenges concerning satellite image provision

JAXA discussed its provision of satellite images in relation to data captured by Daichi based on feedback regarding their use by government ministries and agencies involved in disaster response and other organizations. As a result, the tasks outlined below were identified as challenges to be addressed.

1) Reinforcement of systems for image processing, analysis and other tasks to respond to the government's information collection requirements

JAXA's activities to verify the feasibility of using ALOS in disaster management work are focused on the provision of information to the Cabinet Office and other government ministries and agencies, and its work following the March 11 disaster yielded concrete results. Close collaboration between the Disaster Management Support Systems Office (DMSSO) and the Earth Observation Research Center (EORC) enabled the provision of information that met both the requirements of JAXA's data users and new needs, such as that for the identification of flooded areas and tsunami flotsam.

However, both DMSSO and EORC have manpower-related limitations in terms of processing, analyzing and providing such enormous numbers of images. To support a more timely supply of a wider range of information in the future, it is necessary to establish a structure for image processing, analysis and provision involving not only DMSSO and EORC but also external institutions.

2) Establishment of activity bases to help disaster-stricken local governments

JAXA's activities to help disaster-stricken local governments in the Tohoku region were supported by Iwate University Professor Emeritus Ryuzo Yokoyama, with whom JAXA had built a collaborative relationship over the five years prior to the disaster. In future work, JAXA needs to establish similar activity bases in other regions, and particularly in Kyushu, where it currently has no such facilities.

3) Responses during the blank period until the launch of Daichi's successors

Experience gained from disaster drills and satellite image usage in non-disaster times supported the smooth provision and use of information in the aftermath of the March 11 catastrophe. Now that Daichi's operations are complete, it is imperative to examine responses to user needs during the period until the launch of its successor satellites. It is important for people to use satellite images in non-disaster times, and it is essential for JAXA to maintain its relationships with users based on timely and specific steps for collaboration with overseas institutions, the utilization of airplanes and other related efforts.

4.1.2 Challenges concerning support for disaster areas based on communication line provision

JAXA provided communication lines in disaster areas using KIZUNA and KIKU No. 8 for use by local government bodies, local residents and people from disaster-related institutions elsewhere. The challenges and lessons outlined below were identified from these activities.

1) Prompt provision of communication lines immediately after the disaster

- ■ Clarification of the basic idea behind the provision of support and criteria for taking action
- ■ Securement of a means of quickly transporting personnel, equipment and supplies to disaster areas
- ■ Establishment of preliminary systems necessary for the above two points and partnerships with disaster and crisis management organizations
- ■ Sharing of information with staff dispatched to disaster areas and clarification of the chain-of-command structure/operational flow

2) Information services in disaster areas

- ■ Ideally, the quality of telephone and Internet services provided should match that of pre-disaster levels.
- ■ As coastal areas suffering tsunami damage experience an immediate digital divide, broadcast communication is important for checking the safety of local residents, sending prompt reports on earthquakes/tsunami, and engaging in other related activities.
- ■ Information and communication lines with different capacities are necessary for different locations and situations.
  - ・Small capacity for disaster victims and evacuation sites
    Phone and Internet environments to enable checking of people's safety
  - ・Medium capacity for dispatched teams
    Dispatch of Disaster Medical Assistance Team (DMAT) members after 100 minutes of the disaster; provision of Internet connections for communication between DMT headquarters or dispatched teams or others and the Emergency Medical Information System (EMIS)
  - ・Large capacity for local governments in disaster areas
    Communication environments for phone calls, Internet access and videoconferencing

3) Autonomous communication equipment

- ■ Communication equipment for quick installation in disaster areas (minimized weight and size)
- ■ Improved ease of installation and operability
- ■ Lower communication equipment prices

4.1.3 Challenges concerning the dispatch of information

The challenges outlined below were clarified in regard to the lack of public awareness of JAXA's activities in the aftermath of the Great East Japan Earthquake.

1) Need for provision of information on JAXA's disaster response efforts as part of its voluntary Corporate Social Responsibility (CSR) initiatives

- JAXA concentrated its efforts on business continuity, including responses to disaster management organizations. On the whole, it is considered that the Agency had only a shallow awareness of the need for active dispatch of information on its responses to the disaster.

2) Securement of adequate manpower and accumulation of knowledge on specific facilities and equipment

- It is necessary to secure sufficient manpower to analyze images, post data and explanations on websites, respond to the media and more. There is also a need to share information regarding image analysis and the dispatch of data.
- Knowledge must be enhanced in relation to image analysis for secondary disasters such as damage to major facilities like nuclear power plants and industrial complexes.

3) Enhancement of information services for stakeholders

- Little information on JAXA's responses to the disaster was dispatched to stakeholders.

4) Reinforced, faster dispatch of information to the media

- On March 12, the day after the disaster, there was high demand for satellite images showing the extent of the devastation caused by the earthquake and tsunami. However, these resources could not be provided on the day.
- The nuclear power plant issues that surfaced in the evening of March 12 gave rise to high demand for nuclear power plant images. Although JAXA's PR staff released images captured by Daichi to the press, the demand was specifically for pictures of the nuclear power plant, regardless of whether or not they were captured by Daichi.
- There was low awareness of the division of roles by which Daichi observed wider areas while overseas high-resolution satellites and airplanes engaged in focused observation.

5) Enhanced collaboration with institutional users and external organizations (dispatch of information, data analysis)

- The Geospatial Information Authority of Japan immediately dispatched information on its utilization of images captured by Daichi after the Great East Japan Earthquake, but such dispatch by other institutional users collaborating regularly with JAXA took time in line with their individual situations.

4.2 Future tasks

4.2.1 Basic idea behind the provision of support for disaster areas

4.2.1.1 Basic stance

In its role as an institution implementing R&D to enhance people's safety and security, JAXA makes constant efforts in non-disaster times to leverage its resources so that the necessary support can be provided when disasters strike.

4.2.1.2 Responses to requests from the government and other institutions

As JAXA is not a designated public institution, it contributes by providing research and development results and other relevant information within the bounds of such institutions' social obligations. It remains committed to its best efforts to engage in support activities in disaster zones once the safety of these areas and the feasibility of such work has been confirmed.

4.2.2 Improvements to be made for satellite image provision

Daichi's observations were unfortunately halted by a power issue on April 22, 2011, and its operation was ended on May 12, 2011. The land-observing satellite had been operated beyond its design lifetime of three years and its target lifetime of five years, and its period of service ended after its important work in observing disaster-stricken areas following the Great East Japan Earthquake. As natural disasters will continue to occur, JAXA plans to take the steps outlined below in order to strengthen its response capabilities based on lessons learned from the March 11 disaster.

- Early launch of Daichi's successors (the Advanced Land Observing Satellite-2 (ALOS-2) with Synthetic Aperture Radar (SAR) and the Advanced Land Observing Satellite-3 (ALOS-3) with optical sensors) for the use of improved wide-ranging and high-resolution observation technologies found to be effective after the March 11 disaster. This is expected to enable greater accuracy in determining the extent of devastation via a combination of SAR and optical data, and in particular to enhance mobility and facilitate detailed JAXA observation over wide regions on the day a disaster strikes — a task that was not possible with the Great East Japan Earthquake.
- Achievement of the following specifications as requested by a disaster management-related goverment organization (at the Space Activites Commission (SAC) on August 17, 2011)
  - ・Observation width of 30—50 km to allow collection of images over the entire disaster zone for monitoring of flooded areas
  - ・Resolution of 1 m to support identification of passable routes
  - ・Resolution of less than 1 m to enable observation of damage to embankments, bridges and houses
  - ・Wide observation width of 40—70 km for monitoring of crustal movement (e.g., earthquakes, volcanic activity, subsidence and landslides) using InSAR analysis
- Continuation of efforts relating to the Data Relay Test Satellite (DRTS) in light of its capacity to support instantaneous observation and data provision

- Promotion of R&D on new earth observation sensors in addition to optical sensors and radars to meet new needs identified through response to the March 11 disaster (e.g., thermal change monitoring and tsunami observation)

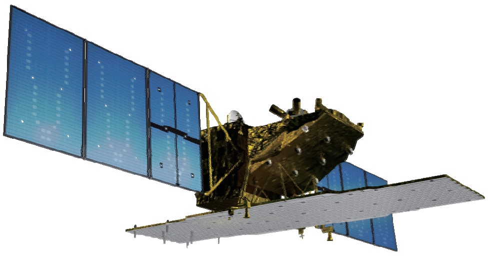



Figure 4.2.1 Successors to Daichi (left: ALOS-2; right: ALOS-3)

The information JAXA provides to disaster areas and other sites using observation satellites must serve the disaster countermeasure efforts of local governments and other organizations, who must be able to interpret and analyze it together with local information. Accordingly, JAXA plans to establish regional bases (at universities and other institutions) in addition to promoting joint efforts with local governments and other organizations.

JAXA will also provide as much information as possible in disaster areas where such bases are not established.

- Development of strategic ties with the Geospatial Information Authority of Japan, the National Research Institute for Earth Science and Disaster Prevention (NIED) and other nationally designated disaster management organizations, and establishment of a structure incorporating private enterprises and universities for a reinforced system of post-disaster work ranging from image processing to image provision
- Establishment of regional bases with Kyoto University (Kinki region), Hiroshima Institute of Technology (Chugoku region) and other institutions similar to the base set up with JAXA collaborative partner Iwate University (northern Tohoku region) toward the launches of ALOS-2 and ALOS-3. Until such bases are established, JAXA will work in disaster areas in response to requests from local governments while ensuring synergies between the operations of earth observation and communications.

It is also important for JAXA to effectively collaborate with overseas satellite operators rather than relying solely on observations by ALOS-2 and ALOS-3, particularly in the event of catastrophic disasters over wide areas.

- Close work with disaster management and related organizations for increased use of the Disaster Charter and Sentinel Asia in the event of domestic disasters. In this regard, JAXA will actively request the activation of related initiatives when disasters strike Japan, and will coordinate with institutions concerned on related matters, including criteria for activation and schemes for image utilization. The Agency will also use airplanes with Polarimetric and Interferometric Airborne Synthetic Aperture Radar (Pi-SAR) and other systems. To support the use of airplanes, a structure of operational planning and management will be established.

4.2.3 Improvements to be made in the provision of communication lines

Outlined below are improvements to be made in providing disaster areas with support using communication satellites. Particular focus is placed on areas to be strengthened in terms of partnerships with local governments and other organizations and requirements to be addressed in the next generation of information and communication satellites. The criteria for the provision of support and the establishment of related systems are described in Section 4.2.5.

- Strengthening of partnerships
  - Further promotion of the benefits of satellite communication line usage to local governments in recognition of the fact that pre-arrangements regarding such provision in affected areas enables smooth action in times of disaster
  - Consideration for the idea of lending communication equipment to nonprofit and other organizations where radiotelephone operator license holders are present to ensure continuous provision of communication lines
  - Advance explanation of criteria and other guidelines for providing support to the Ministry of Education, Culture, Sports, Science and Technology (MEXT) and the Ministry of Internal Affairs and Communications. This is based on the fact that JAXA will offer support to institutions with which it has not concluded collaboration agreements upon receipt of requests for assistance from MEXT (as was the case with the March 11 disaster).

- Fulfillment of requirements in the next generation of information and communication satellites

  Requirements clarified as a result of support provision are outlined below. It is important to incorporate solutions into the next generation of information and communication satellites. Figure 4.2.2 shows a conceptual image of how such satellites might work.

  - Portable terminals that can be installed by one person
    - ✓ Wireless LAN-capable, portable in a backpack or briefcase
    - ✓ Assembly-free
    - ✓ Capable of automatic satellite alignment and establishment of Internet connection when power is turned on
    - ✓ Compatible with existing terminals (e.g., mobile phones and commercial earth stations)
    - ✓ Unaffected by communication outages
  - Situation-based link capacity
    - ✓ Disaster victims, evacuation sites: best-effort capacity (KIKU No. 8: 768 kbps or more)
    - ✓ Local governments, dispatched-team activity bases: achievements (KIZUNA: 20 Mbps or more)
  - Terminals with specifications appropriate for disaster areas
    - ✓ Ultra-low power consumption and operability with home-use batteries, onboard AC power source or similar
    - ✓ Integrated power supply using solar cells and storage batteries
    - ✓ Durable outdoor equipment protected from water and wind erosion
  - No need for operators
    - ✓ No need for radiotelephone operator license holders
    - ✓ Management and control of terminals at related reference stations

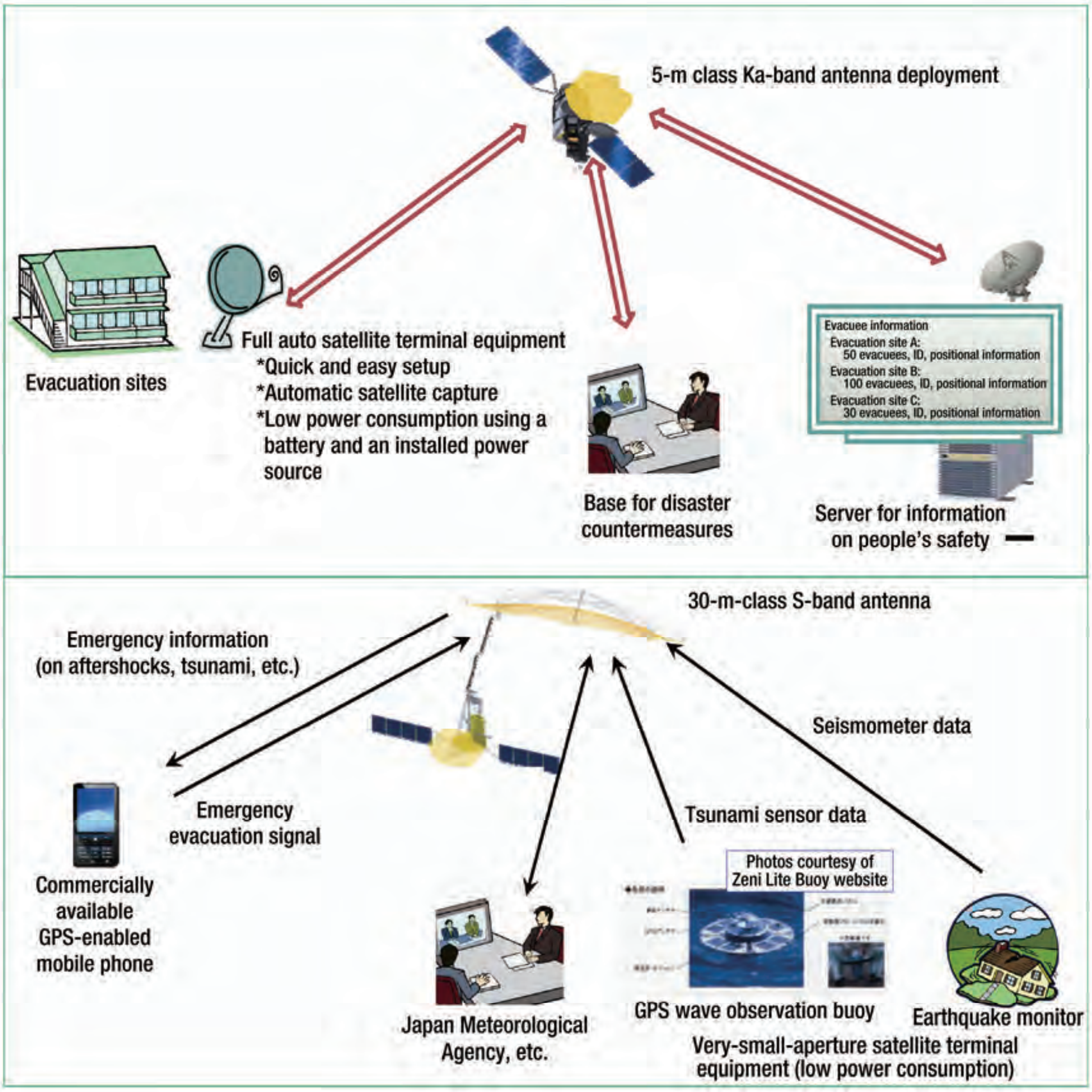


Figure 4.2-2 Conceptual representation of next-generation information and communication satellites

- Coordination of satellite positioning systems

At times of disaster, information on the geographical locations of those who send data is essential. In the next generation of information and communication satellites, equipment and terminals should be able to receive/use satellite positioning signals. Accordingly, the feasibility of transmitting such information using advanced positioning signals should be examined in line with the direction of plans involving quasi-zenith satellites.

Satellite communication and satellite positioning will play important roles in efforts to upgrade terrestrial sensor networks and improve their robustness. By way of example, ocean-monitoring sensors such as GPS wave meters (buoys) and water-pressure gauges will be upgraded for the establishment of tsunami early warning systems. However, to allow the detection of displacement and changes via installed offshore sensors, satellite communication and satellite positioning capability should be upgraded to support related infrastructure.

4.2.4 Improvements to be made concerning information dispatch

- Public provision of appropriate and timely news on JAXA's social contribution activities in response to disasters as part of its obligations to society. The Agency firmly positions such public communication (including development of the related organizational climate) as part of its CSR.
- Prompt and widespread dispatch of information following large-scale disasters. For such provision, staff in charge assemble in a dedicated disaster response control room immediately after the disaster and share information.
- Securement of sufficient manpower (including backup personnel) for data analysis and website posting/updating
- Close collaboration with the Ministry of Education, Culture, Sports, Science and Technology (MEXT) — particularly concerning nuclear power stations
- Enhancement of knowledge regarding possible disasters that could cause large-scale damage to facilities and the like, and examination of possible simulations and other related matters
- Examination of steps for dispatching information to stakeholders
- Enhancement of interest in and understanding of JAXA disaster response activities among journalists through provision of regular lectures. (At times of large-scale disasters, presentations will be provided frequently to support the active dispatch of information.)
- Active dispatch of information on activities such as those implemented after the March 11 disaster using KIZUNA, KIKU No. 8, airplanes and the like, as opposed to simple provision of satellite observation results
- Implementation of arrangements for media communications (e.g., notices on information posted on websites) to enable the immediate dispatch of information, such as allowing the provision of data through simple procedures or with ex post facto reports at times of large-scale disasters
- Efforts to encourage JAXA's institutional users to raise public awareness of their work with the Agency so that partnerships with such users will further develop into sustainable activities (with focus on the successors to Daichi and KIZUNA)
- Examination of the following considerations as efforts to collaborate with external organizations for faster image analysis and speedier/wider provision of information:
  - Establishment of a structure to support the mobilization of personnel for data analysis from academic societies, universities and other organizations based on agreements and similar arrangements. Anticipated effects include the development of high-quality information products that cannot be produced by JAXA alone, further expansion of the satellite data user base, and the dispatch of information from researchers.
  - Reinforcement of the structure for online delivery of emergency observation results to further promote the dispatch of data in conjunction with private information providers based on confirmation of the effectiveness of web-based provision
  - Requests for Japanese and international image analysis organizations to perform analysis for JAXA on a chargeable basis

4.2.5 Development of disaster response manuals

JAXA plans to clarify the criteria for triggering disaster response activities in consideration of the scope of large-scale disasters and the extent of damage to its own facilities. Disaster response manuals will then be developed with patterns tailored to suit levels of devastation (including plans to secure manpower) based on the examination of disaster operation reinforcement efforts (such as the provision of satellite image data and communication lines) and systems to ensure appropriate and timely dispatch of related information.

5. Summary

Following the Great East Japan Earthquake of March 11, 2011, JAXA assisted the government's Emergency Disaster Response Headquarters, central government ministries and agencies, local governments and other related institutions in producing a full picture of the disaster. It also facilitated recovery efforts by providing these organizations with images captured by Daichi and overseas satellites, and supplied related analysis results as needed. The Agency further provided satellite communication lines using KIZUNA and KIKU No. 8 at disaster countermeasures offices and other places in Iwate Prefecture and Miyagi Prefecture's Onagawa Town as a temporary replacement for damaged terrestrial networks. Through these communication lines, it provided disaster areas with logistics support based on the temporary restoration of Internet connections and IP phones, thereby allowing people to check the safety of others and collect a variety of information. These activities were made possible by years of effort on JAXA's part to promote satellite application to disaster management, routine communication with disaster management organizations and other institutions, and participation in disaster prevention drills and other related events.

Six months after the Great East Japan Earthquake, many reports had been published by government agencies. One issued by the Headquarters for the Reconstruction from the Great East Japan Earthquake (Basic Policy on Reconstruction from the Great East Japan Earthquake; July 29, 2011) recognized once again the effectiveness of satellite application in wide-area disasters, and highlighted the need to strengthen satellite communication capabilities and utilize satellite systems for various purposes, including clarification of the extent of damage.

Reports published by the Central Disaster Prevention Council and the Japan Meteorological Agency also pointed out the need to reinforce tsunami observation and improve tsunami warning systems. In this regard, JAXA sees a need to upgrade its satellite communication and satellite positioning technologies and to partner with parties involved in the monitoring of GPS buoys and water-pressure gauges.

In the government's science and technology policy, reconstruction and recovery from the March 11 disaster and improved safety during future calamities were identified as key areas for attention. With the development of ALOS-2 and next-generation of information and communication engineering test satellites positioned as specific policy measures, there are high expectations for satellites in the future.

The completion of Daichi's operations as its service lifetime was exceeded has created a significant need in various fields for the early launch of its successors (ALOS-2 and ALOS-3). Moves toward the development of systems and structures based on the use of images captured by Daichi have also begun.

In this way, satellites have become indispensable tools for supporting safety and security in Japan. However, they do not represent a silver-bullet solution, and their operation requires terrestrial equipment as well as work by organizations and personnel. For satellites to become essential as a system in their own right, JAXA must continue its close collaboration with disaster management organizations and overcome challenges yet to be identified rather than simply implementing ongoing technological upgrades.

Finally, we at JAXA offer our sincere condolences to the families of those who perished in the disaster and our deepest sympathies to everyone affected. We would also like to express our sincere appreciation to all staff of the organizations concerned as well as to the Disaster Charter and Sentinel Asia for their guidance, support and cooperation in JAXA's responses to the disaster.

Report on JAXA's Response to the Great East Japan Earthquake
－Assistance using earth observation satellites and communication satellites－

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