



Satellite Contributions to Disaster Monitoring

- Japanese Earthquake and Tsunami Case in 2011 -

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The University of Tokyo

We express sincere condolences to those who have suffered from the 2011 Tohoku Earthquake and subsequent tsunami.

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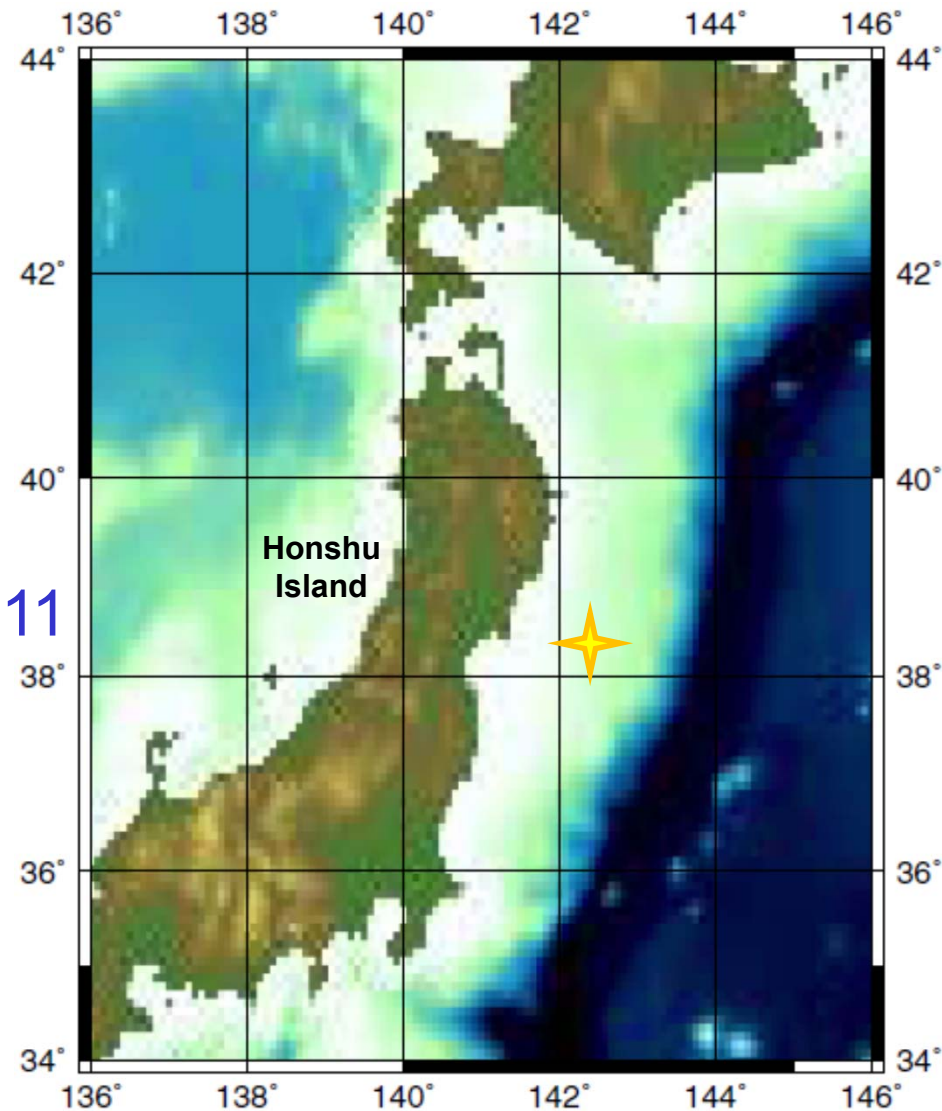
1. What happened on March 11, 2011?
 - Earthquake and Tsunami
 - Nuclear Power Plant

2. Observation Activities
 - Satellite Observation
 - Other Methods

3. What is needed for Small Satellites?

Epicenter of Main Shock

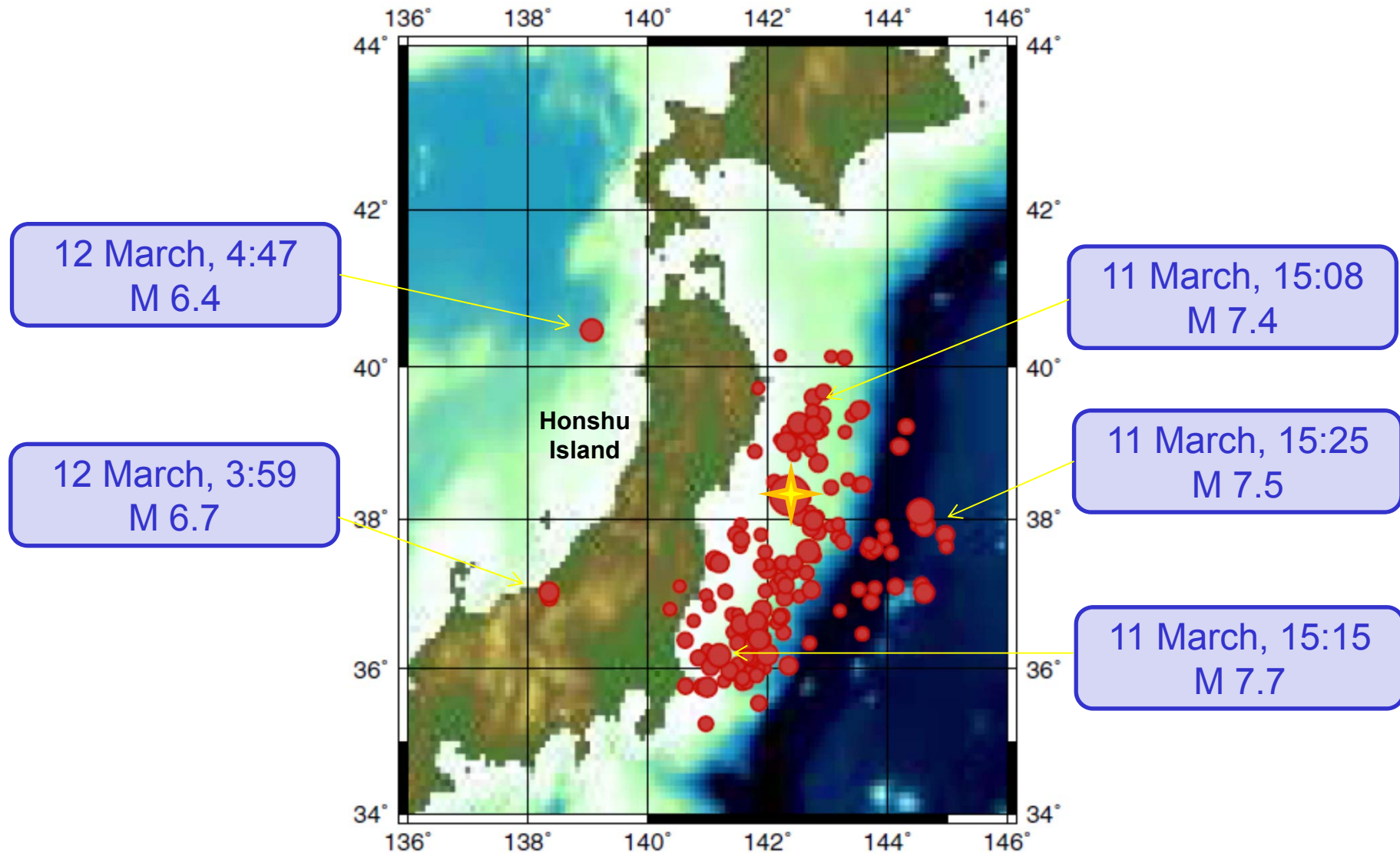
Main shock
at 14:46 (JST)
on 11 March, 2011
Mw 9.0



1960 Chile	9.5
1964 Alaska	9.2
2004 Indonesia	9.1

Thanks to GMT

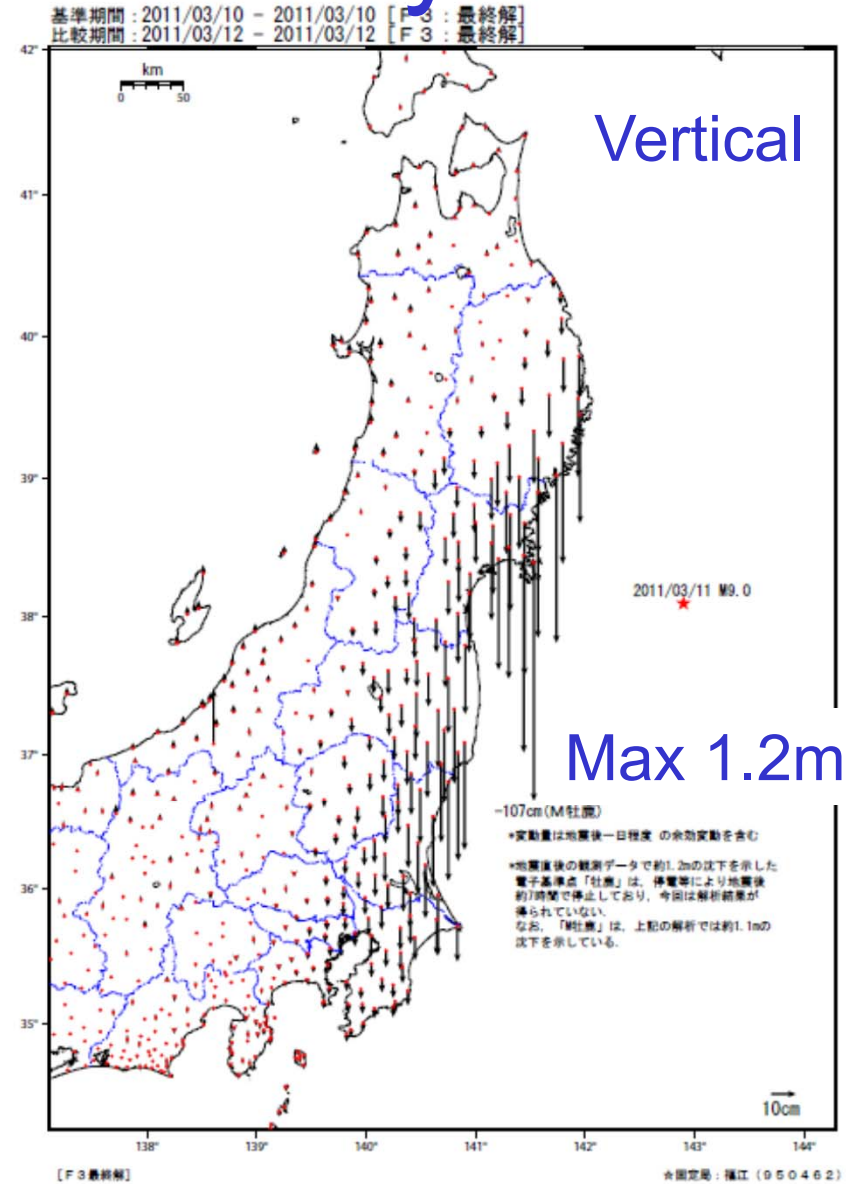
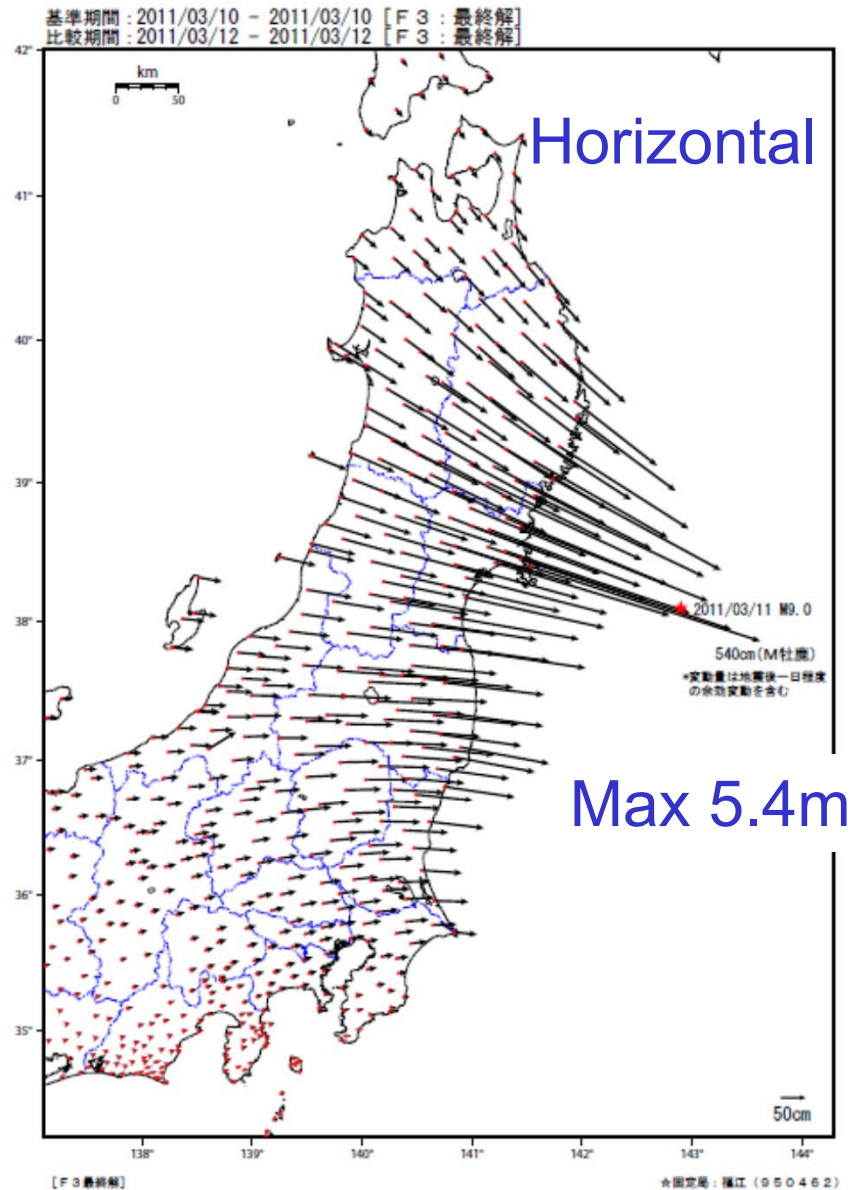
Epiceenters on First Day



Thanks to GMT

M > 5 145 times

Crustal Deformation by GPS



Tsunami

<http://www.rssj.or.jp/sinntyakujiyouhou/pdf/report-ajiko2.pdf>

To see more data, please try, or example, http://www.ajiko.co.jp/bousai/touhoku2011/touhoku_naname.htm.

The 2011 Tohoku Earthquake Tsunami Joint Survey Group (<http://www.coastal.jp/tsunami2011/>).

Damage Quantities

Human	
Killed	15,868
Missing	2,848
Injured	6,109
House	
All destroyed	129,316
Half destroyed	263,845
Infrastructure	
Broken road	4,200
Broken bridge	116
Landslide	208

As of 8 August, 2012,
by National Police Agency of Japan

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 - Earthquake and Tsunami
 - **Nuclear Power Plant**

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National Diet of Japan Fukushima Nuclear Accident Independent Investigation

National Diet of Japan Fukushima Nuclear Accident Independent Investigation.

**Commission was established in the Diet with the
following objectives.**



- ① To elucidate the background and causes of the accident at the Fukushima nuclear power plants of the Tokyo Electric Power Company that occurred after the Tohoku Pacific Earthquake of 2011.
- ② To make proposals concerning policies and measures to prevent future accidents at nuclear power plants and to reduce the damage occurring in the event of an accident.

The Commission is scheduled to draw up a report recording the results of the investigation and its proposals six months from the date of the appointment of the Chairman and members of the Commission.

National Diet of Japan

Fukushima Nuclear Accident Independent Investigation

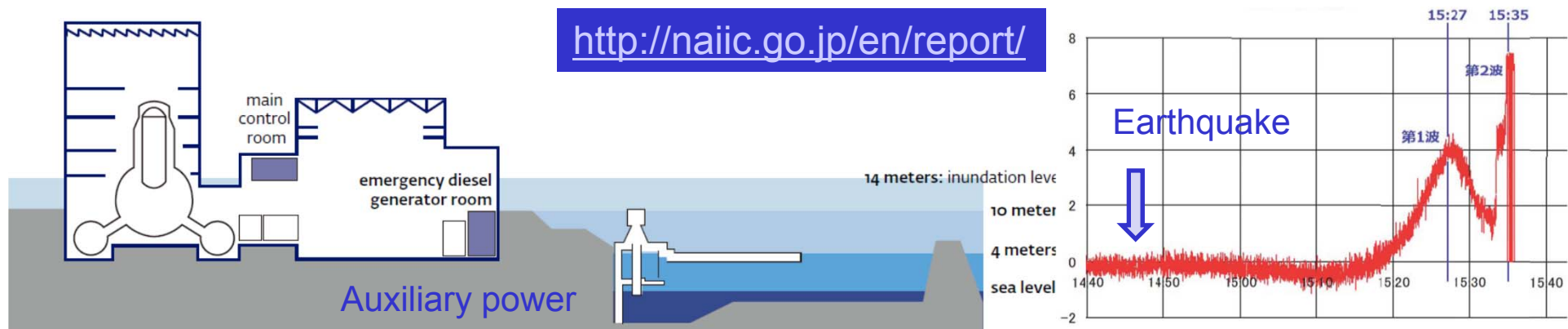
Concluded as “Man-made disaster”.

No preparation for severe accidents.

- Large acceleration of 550 gal was applied.
- Nuclear power plant shut down.
- Auxiliary power generator sank due to tsunami.
- Power line from other area was lost.
- No electric power to cool reactor was obtained.



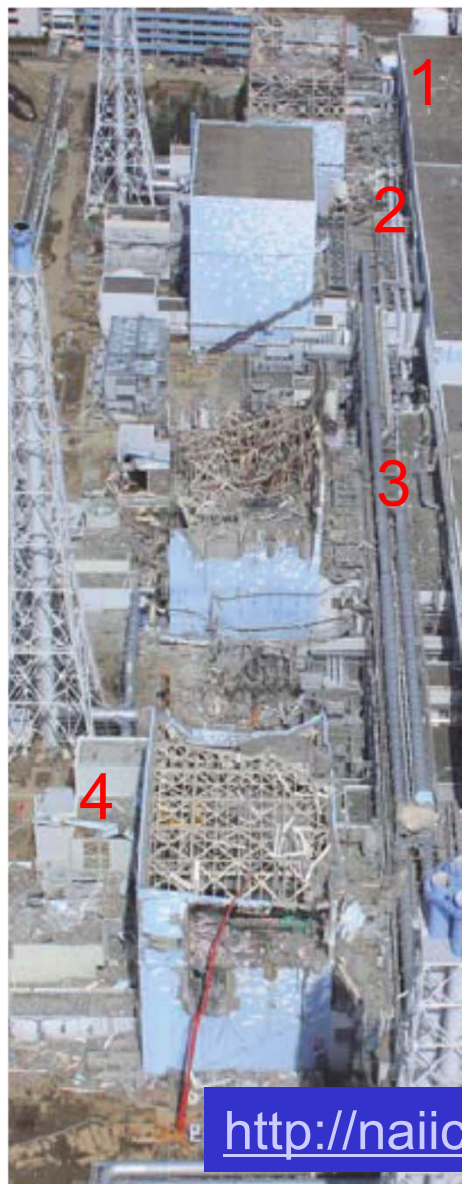
- Unit 1 and Unit 3 plants exploded by hydrogen gas.
- Level 7 (major accident) of International Nuclear Event Scale.



National Diet of Japan

Fukushima Nuclear Accident Independent Investigation

Due to vent and hydrogen explosion, nuclear materials were scattered in wide area.



<http://naiic.go.jp/en/report/>

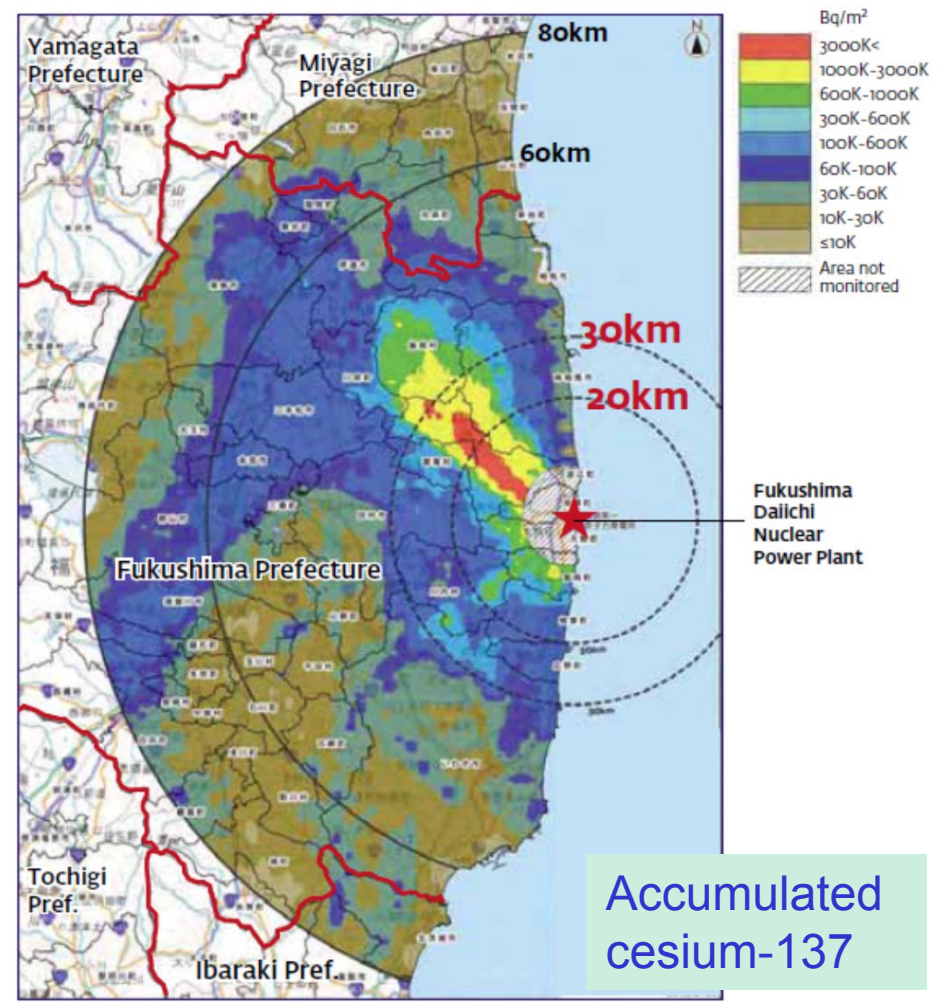


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International Charter



INTERNATIONAL CHARTER
SPACE AND MAJOR DISASTERS

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Charter Activations

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Earthquake in Japan

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Type of Event	Earthquake/Tsunami
Location of Event	Japan
Date of Charter Activation	11/03/2011
Charter Requestor	JAXA - Cabinet Office JAPAN
Project Management	Asian Institute of Technology (AIT)

Description of the Event

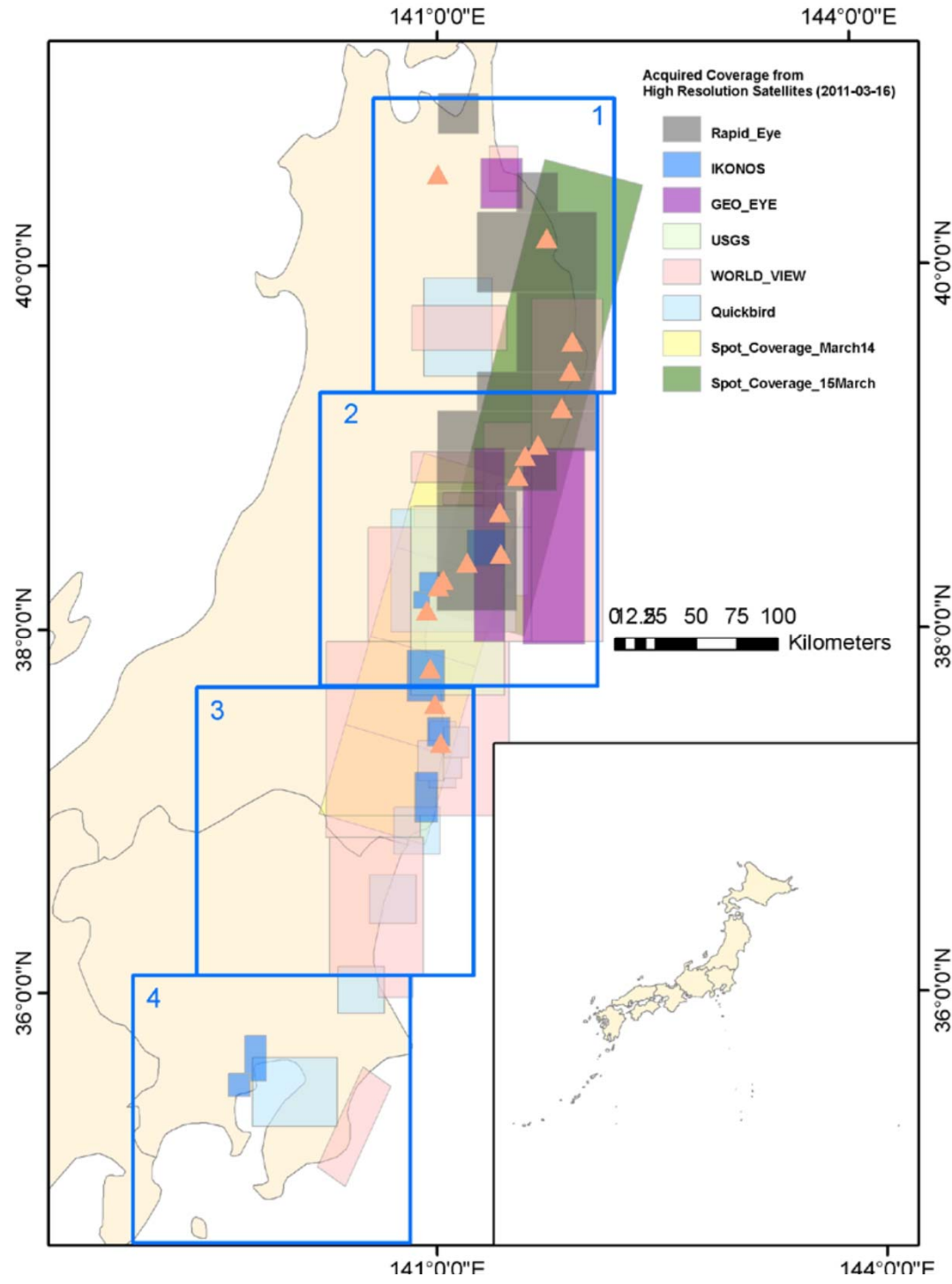
Earthquake hits north-east of Japan causing extensive damage, triggering a tsunami. The earthquake scaled at a magnitude of 8.9 which sparked fires in Tokyo. Many casualties are also feared.

[View the NGA Urban Search and Rescue Atlas for products related to this event](#)

International Charter 'Space and Major Disasters' was activated at 15:24 (JST), less than an hour after the earthquake, by JAXA / Cabinet Office.

Data Coverage

As of 16 March, 2011



<http://www.disasterscharter.org>



Earth Observation Satellite in First 5 Days

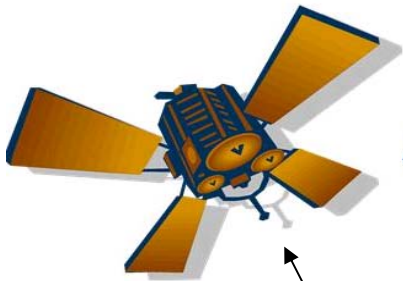
Day	2011/3/11	2011/3/12	2011/3/13	2011/3/14	2011/3/15
Optical	EarthQuake 14:46:18	ALOS/AVNIR-2 ALOS/PRISM FORMOSAT-2 RapidEye*2 LANDSAT-7 IKONOS SPOT-5 WorldView-2 ASTER (TIR)	FORMOSAT-2 RapidEye LANDSAT-5 GeoEye-1 SPOT-5 QuickBird EO-1	ALOS/AVNIR-2 FORMOSAT-2 RapidEye*2 GeoEye-1 SPOT-5 WorldView-1, 2 ASTER HJ KOMPSAT-2 CARTSAT-2 EROS-B	ALOS/AVNIR-2 FORMOSAT-2 IKONOS SPOT-4 WorldView-1,2 EROS-B
SAR			DMC*2 ALOS/PALSAR CosmoSkymed*4 TerraSAR-X RADARSAT-2	ALOS/PALSAR CosmoSkymed TerraSAR-X	ALOS/PALSAR CosmoSkymed*3 TerraSAR-X RADARSAT-2

No satellite image

*2 means two times observation was carried out using constellation.

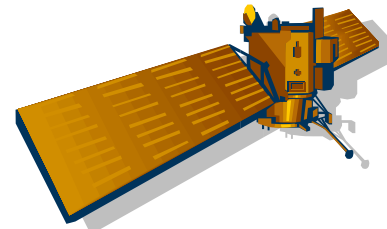
Optical & SAR

Optical Sensor



Low power
Small instrument
Weak to cloud

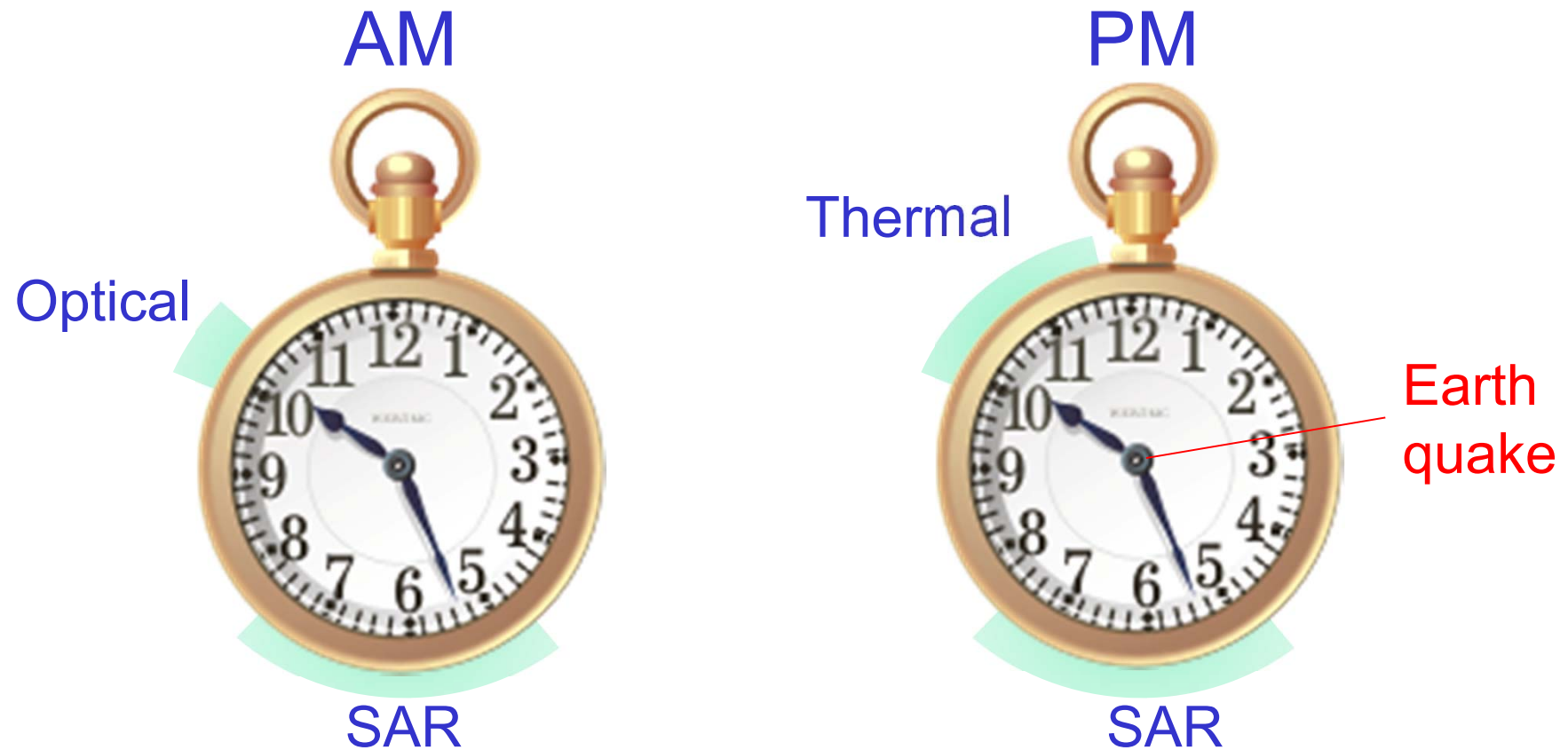
Synthetic Aperture Radar (SAR)



Need power
Relatively large instrument
All weather, Day & Night



Observation Time of Satellite

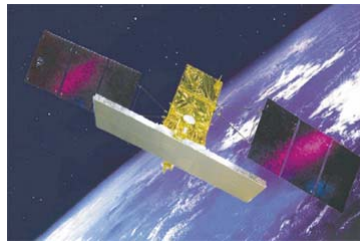


COSMO-SkyMed (3/12 08:27)

SAR constellation composed of 4 satellites.

About 5-6 times/day observation of the same target is possible.

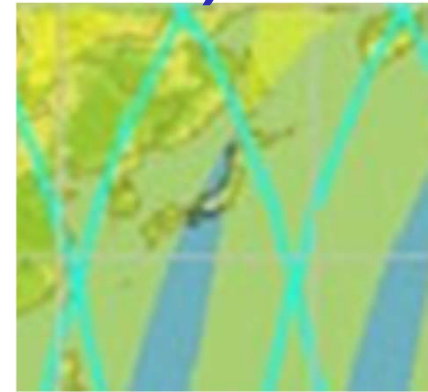
4 times observation was carried out (08:28 CSM-3, 08:45 CSM-2, 09:09 CSM-4, 09:33 CSM-1).



http://www.spaceimaging.co.jp/EastJapanEarthquake/record_collection/continuation/cosmo_skymed/tabid/592/Default.aspx
http://www.spaceimaging.co.jp/EastJapanEarthquake/record_imagery/fukusima/souma/tabid/607/Default.aspx

FORMOSAT-2 (3/12 09:15)

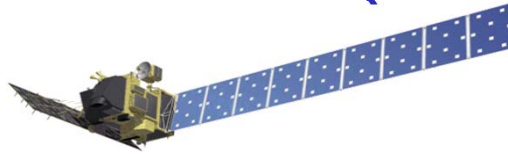
- No path for nadir observation of Japan
- Oblique observation
- Fastest observation among optical sensors



http://www.eorc.jaxa.jp/ALOS/img_up/jdis_formosat2_tohokueq_110312.htm

ALOS/AVNIR-2 (3/12 10:28)

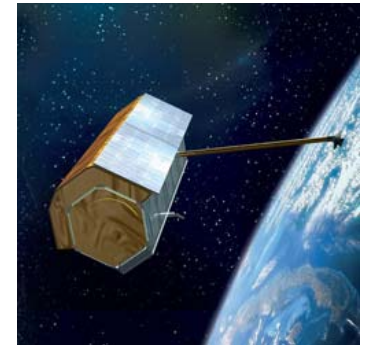
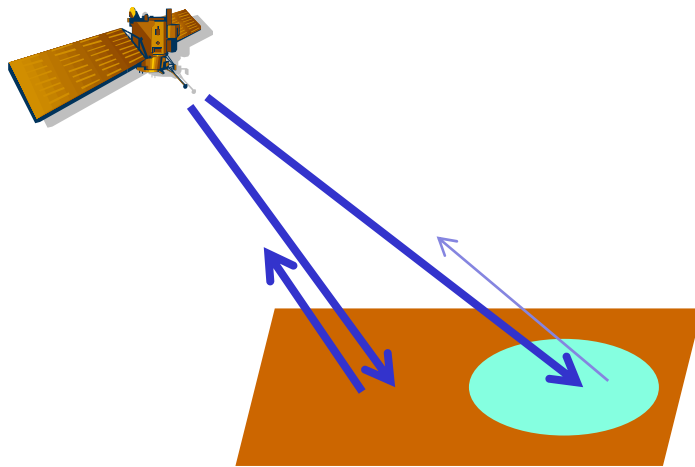
Inland area was
observed to check
landslides and dam
burst.



http://www.eorc.jaxa.jp/ALOS/img_up/jdis_opt_tohokueq_110312.htm

TerraSAR-X (3/13 05:43)

No influence of cloud.
Composite of data before
and after the earthquake.
Small backscatter for
water-area.



http://www.eorc.jaxa.jp/ALOS/img_up/jdis_pal_tohokueq_110313.htm

Inundated Map

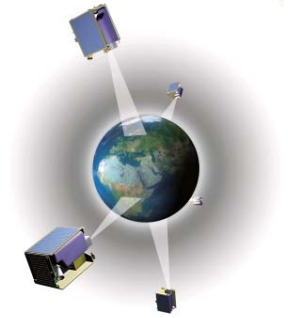
Saw-toothed (ria) coastline
was weak to tsunami
because tsunami height
increases in interior.

Debris on the sea is
observed.

http://www.eorc.jaxa.jp/ALOS/img_up/jdis_terrasarx_tohokueq_110313.htm

RapidEye (3/13 11:20)

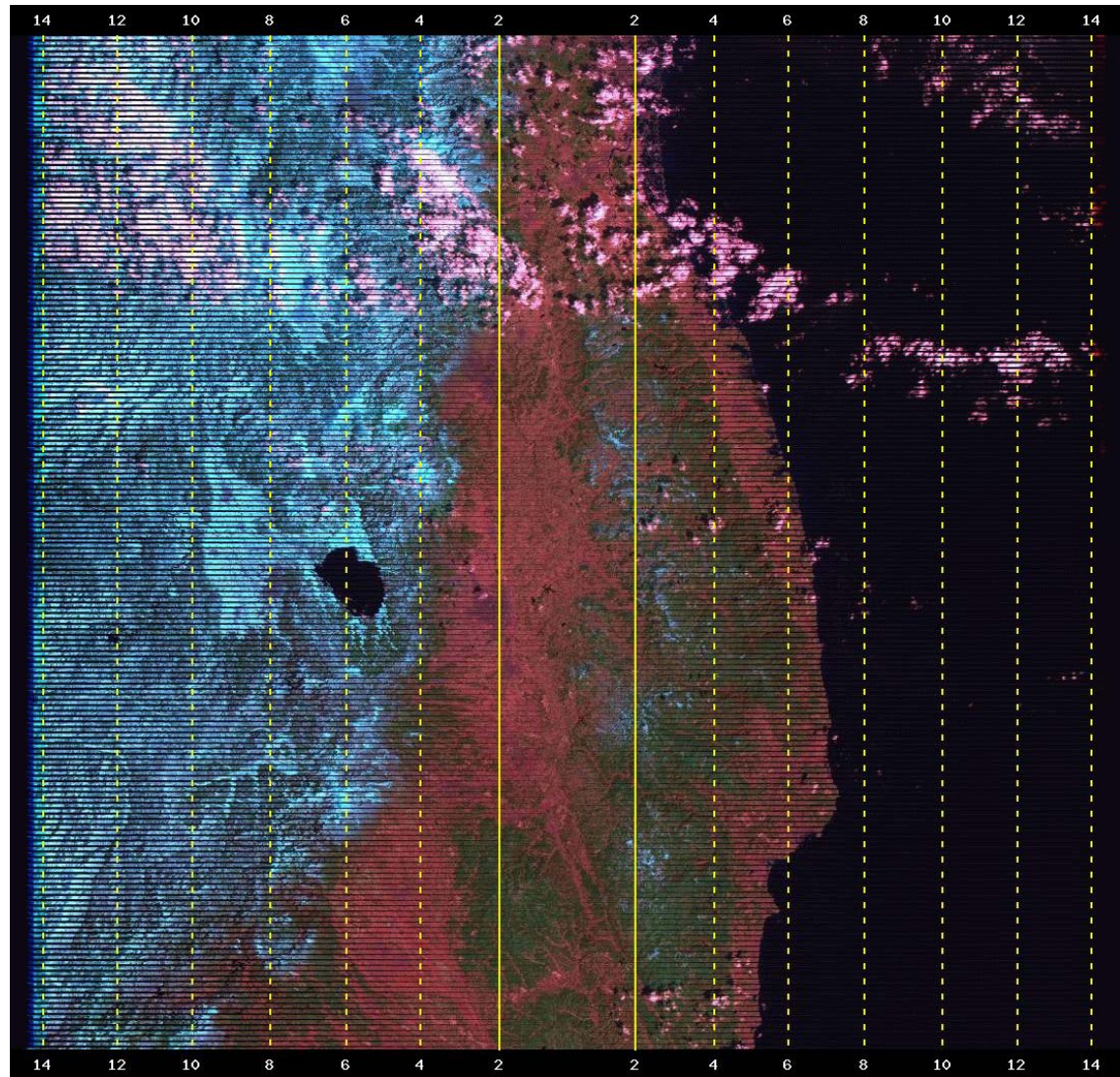
Fire and debris on the sea were observed.



Japan Earthquake and Tsunami Support
<http://www.rapideye.com/upload/japan.pdf>

Landsat-7 (3/12)

Operational observation
No parameter setting



Day 1

ASTER (3/14 and 3/12)



Pointing operation was late on first day.

Night time observation

Day 3 | Day 1

ALOS/PALSAR (3/13 22:11)

Night time observation.
(Ascending Orbit)

http://www.eorc.jaxa.jp/ALOS/img_up/jdis_pal_tohokueq_110313.htm

ALOS/AVNIR-2 (4/05 10:18)

http://www.eorc.jaxa.jp/ALOS/img_up/jdis_opt_tohokueq_110405.htm

Long term observation is suitable for satellite.

Day 25

Day 3

AVNIR-2 (4/12 10:08)

2011/04/11 17:16

Mw 7

Inland earthquake: no tsunami but landslide



http://www.eorc.jaxa.jp/ALOS/img_up/jdis_opt_tohokueq_110412.htm

Power Plant Calendar

GeoEye group

http://www.spaceimaging.co.jp/EastJapanEarthquake/record_collection/continuation/geoeye1/tabid/591/Default.aspx

High Resolution Satellite Remote Sensing Concerning the 2011 off the Pacific Coast of Tohoku Earthquake and Tsunami Disaster, Scientific Research Working Group for High Resolution Satellite Remote Sensing, Remote Sensing Society of Japan, Journal of RSSJ, Vol.3, 2011, pp. 344-367.

https://www.jstage.jst.go.jp/article/rssj/31/3/31_3_344/_pdf

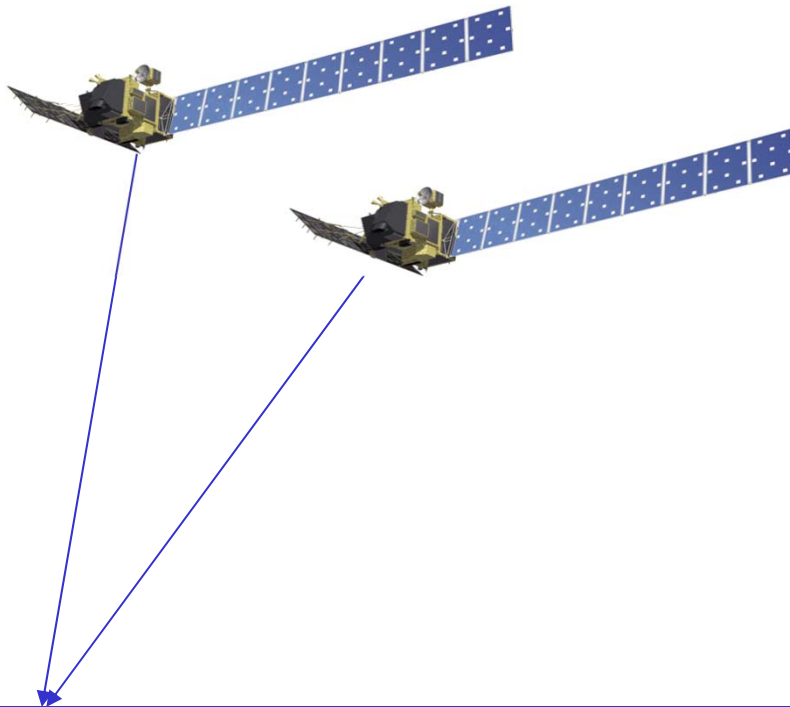
WorldView

High Resolution Satellite Remote Sensing Concerning the 2011 off the Pacific Coast of Tohoku Earthquake and Tsunami Disaster, Scientific Research Working Group for High Resolution Satellite Remote Sensing, Remote Sensing Society of Japan, Journal of RSSJ, Vol.3, 2011, pp. 344-367.

https://www.jstage.jst.go.jp/article/rssj/31/3/31_3_344/_pdf

Interferometric SAR (ISAR)

Interference before and after earthquake
→ Crustal motion detection



http://www.eorc.jaxa.jp/ALOS/img_up/jdis_pal_tohokueq_110418.htm

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Airplane Data Acquisition

Geospatial Information Authority of Japan (GSI)
Agreement for urgent observation in disaster.

Aerial Survey Companies in Japan

- Asia Air Survey Co., Ltd.
- PASCO Corporation
- Kokusai Kogyo Co., Ltd.
- Aero Asahi Corporation
- Hasshu Co., Ltd.
- A-TEC Co. Ltd.
- Nakanihon Air Service Co.,Ltd.

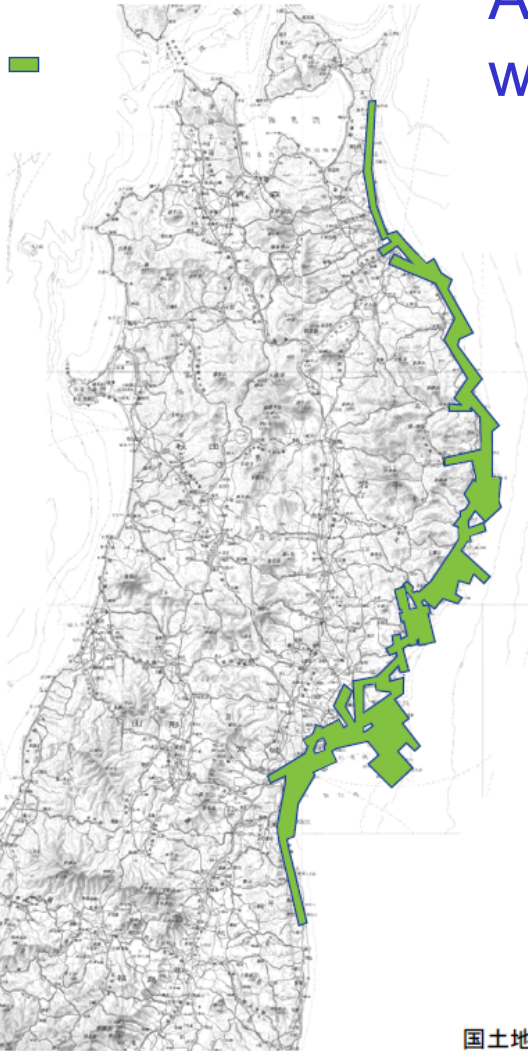
Observation areas were divided to cover wide region
up to 700 km N-S.

Many air photos have been acquired since 12 March.

Urgent Airplane Picture

東北地方太平洋沖地震

空中写真撮影地域

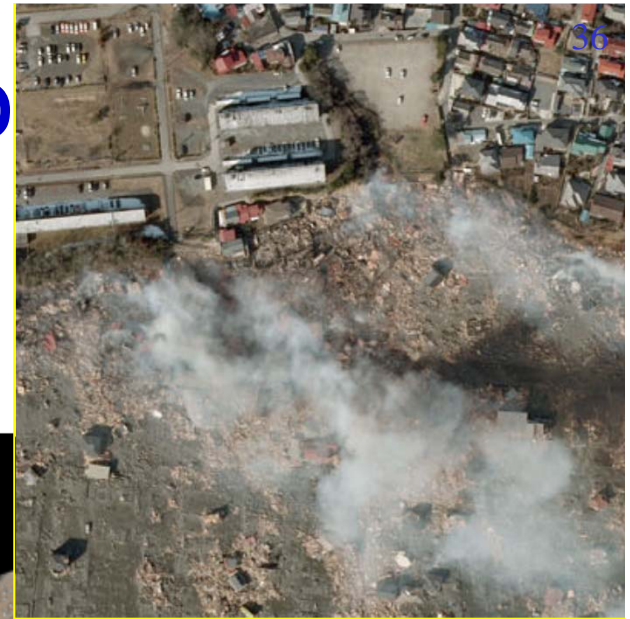


国土地理院

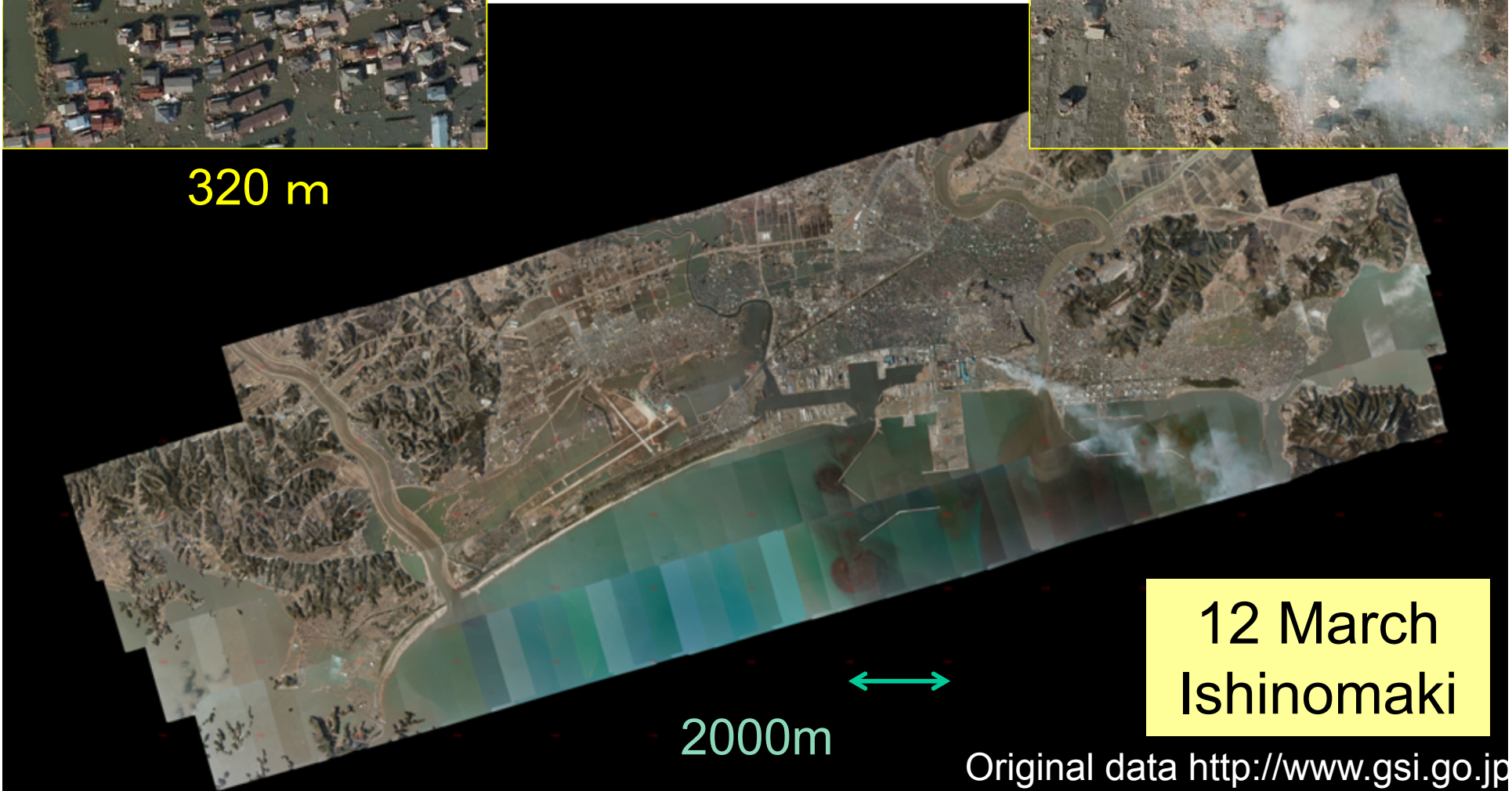
Area up to 4,018 km² was covered within 1 week with high resolution photo.

➤ All data including oblique photo were on the web and freely available.

Airplane Photo



320 m



2000m

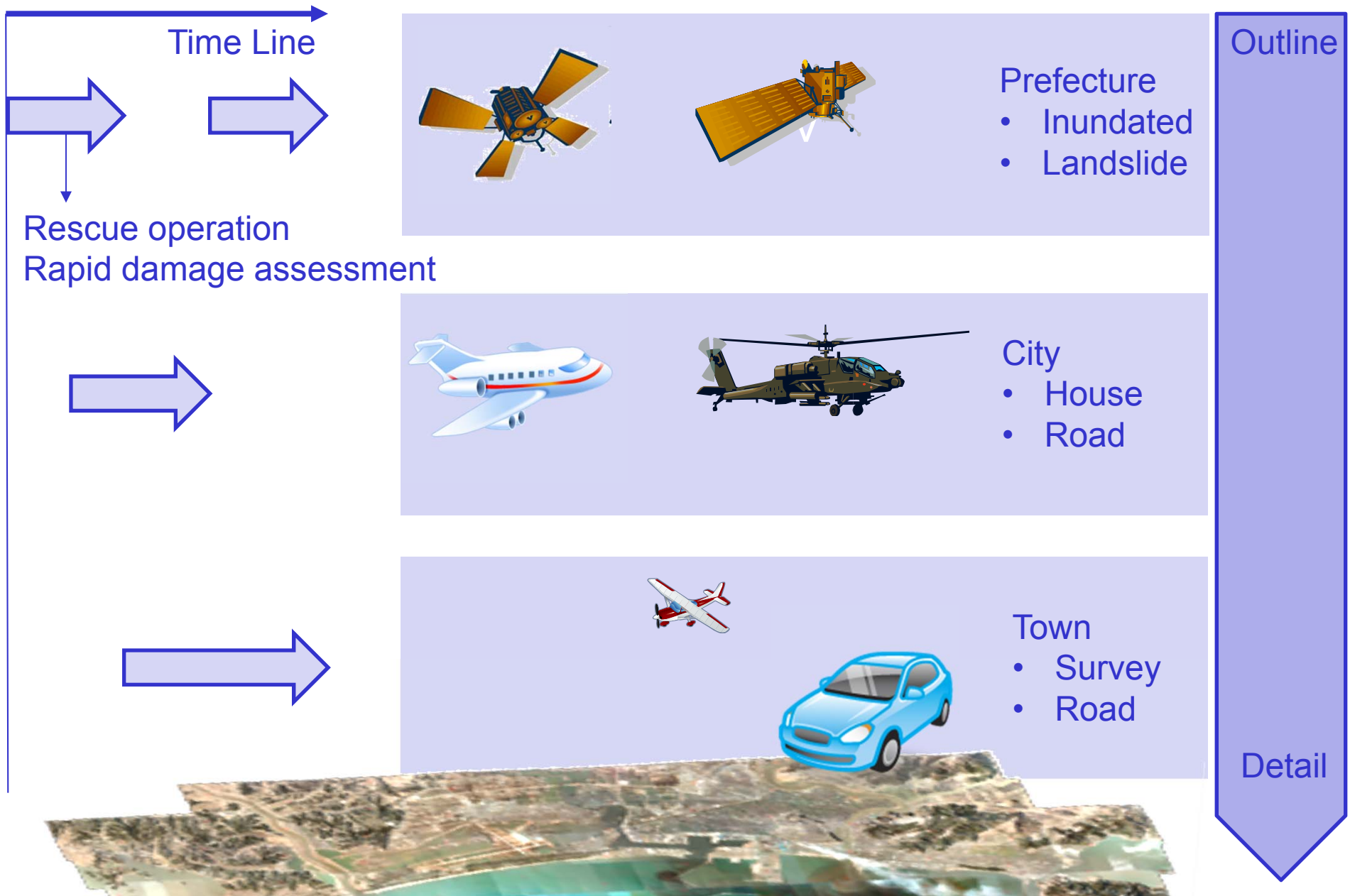
12 March
Ishinomaki

Original data <http://www.gsi.go.jp>

Unmanned Air Vehicle (UAV)



Remote Sensing Strategy



Urgent Plan of Survey Company

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Various Satellite Sensor

Information Integration

Short Summary

- Many satellites took part in the observation activity.
- Coastal line attacked by tsunami was along satellite path.
- The closer time after disaster, the coarser image was accepted.
- Many man power was needed to analyze amount of disaster.
- Data archive before disaster is important for change detection.
- Another information was also needed for rescue team.
- Nuclear power plant showed another view.
- There is a task on cooperation for huge disaster.
- Satellite data acquisition time is limited.



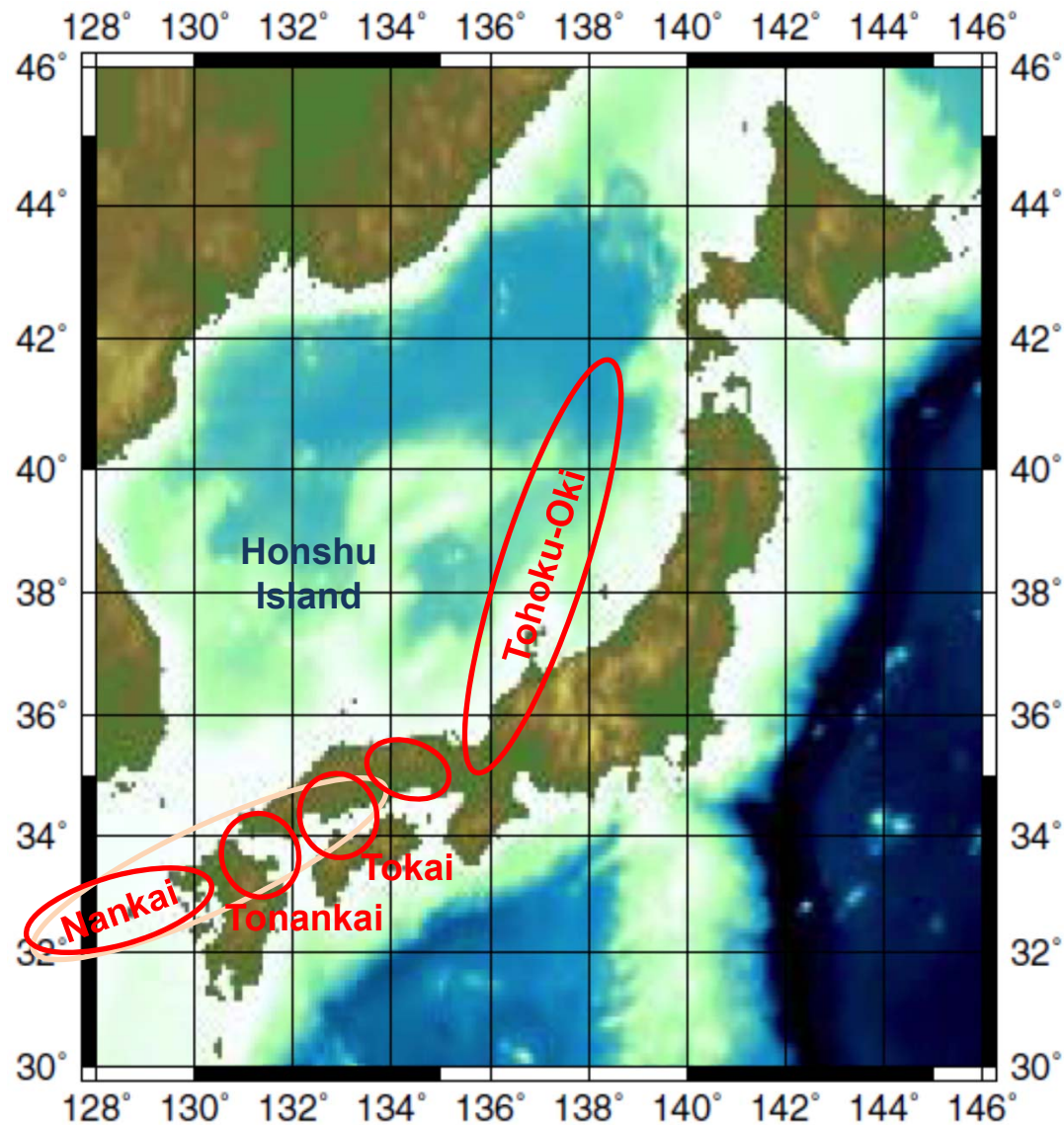
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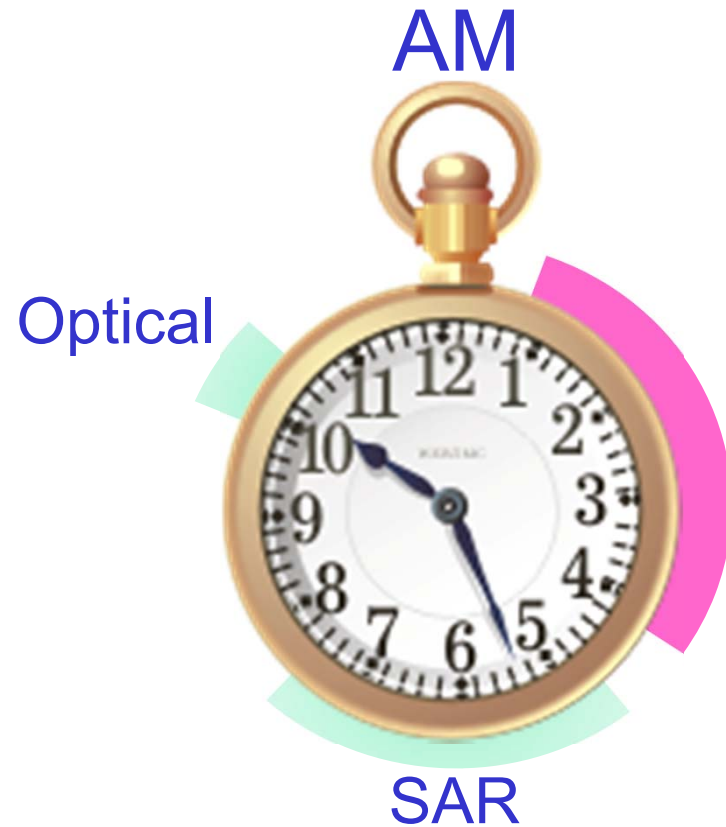
3. What is needed for Small Satellites?

Predicted Earthquake Area



Thanks to GMT

Observation Time of Satellite



Governmental “First” Program

”Hodoyoshi-project” (2010-2015)

Leader: Prof. Nakasuka

- Reliability concept for micro/nano/pico-satellites
 - “So-so and not expensive (Hodoyoshi)” reliability
(compromise between cost (workload) vs. reliability)
- Component technology development
 - Should solve “size and power problem”
- Development process innovation
 - Software architecture
 - Ground test, etc.
- Create novel applications and use communities
 - Non-government users as individuals, companies, local government, research institute can seek for their interest

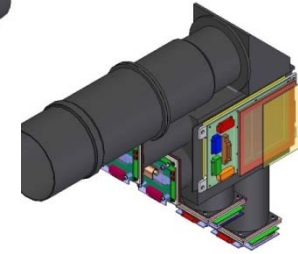
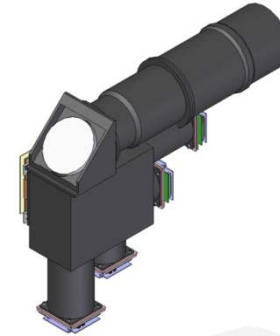
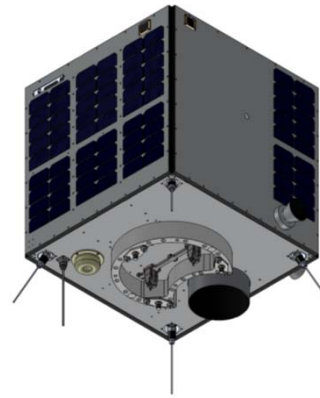
Satellite Development Plan

(4 satellites in 4 years, 50 kg/satellite)

#1 : 6.7m GSD 4 band remote sensing

- *Data is open to private users so that they can test their utilizations*

(developed by AXELSPACE)

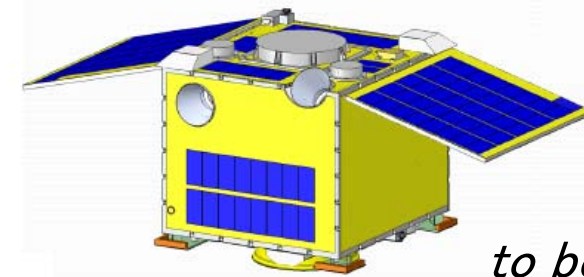


Dnepr launch in 12/2012

#2 : Foreign space science mission

- *5 Mission payloads will be onboard (from foreign research institutes)*

(developed by Tohoku University)

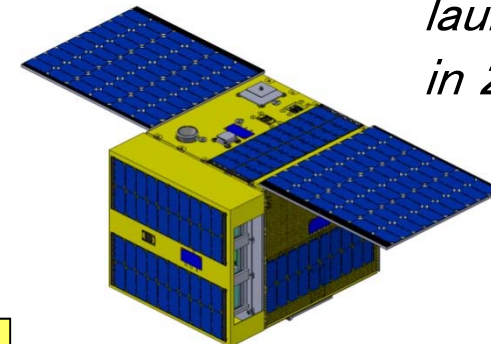


to be launched in 2013

#3 : Constellation of 2 satellites

- *5, 40, 200m GSD, rental space, Store and forward missions*

(developed by Univ. Tokyo and NESTRA)



Telescope and Image Data Processing

Spaceborne Optical Telescope

Optics robust to temperature change
Swath of 27.8km, GSD of 6.7m, S/N > 100
4 bands in Visible and Near Infrared

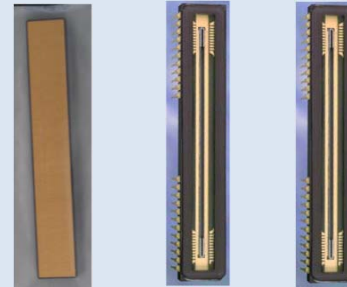


Flight model of telescope

Focal Plane System

Linear CCD with high precision filters
Pushbroom scan using small satellites
Super-resolution for NIR band

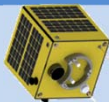
NIR Filter RGB Mono
 CCD CCD



Optical filter and
CCD detectors



Focal plane
for
4 bands
observation



Optical telescope will be launched in December 2012.

Merit of Small Satellite: Constellation

Design of Constellation

1. Walker

Satellites evenly spaced on circular orbits

2. Rider

Analytic design based on street-of-coverage

3. Genetic Algorithm-Based Optimization

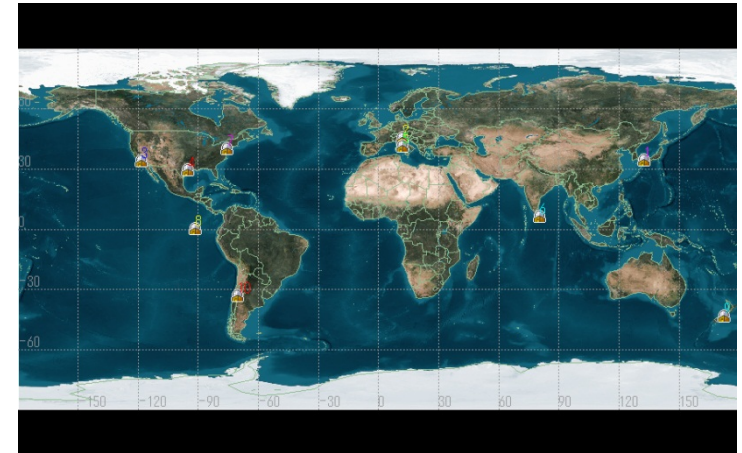


Maneuverability

How can we optimize constellation?

Simulation Procedure 1

1. Disaster area
 - Ten target points
 - Time of disaster: random
2. Off-nadir angle



$$\theta = \sin^{-1} \left(\frac{h + r_e}{r_e} \sin \alpha \right) - \alpha$$

3. Satellite position
 - Walker's Method (T/P/F)
 - Initial orbit = Sun-synchronized

$$(MN \pm 1)(\omega_E - \dot{\Omega})T = 2\pi M$$

Simulation Procedure 2

4. Orbit Transfer

– Impulse of ΔV

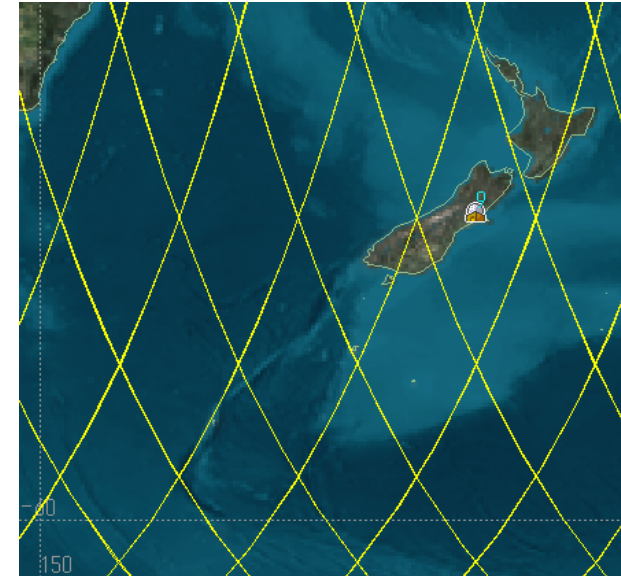
$$\frac{\Delta V}{V_{c1}} = 2 \sin \frac{\theta}{2}$$

– Perturbation by J_2

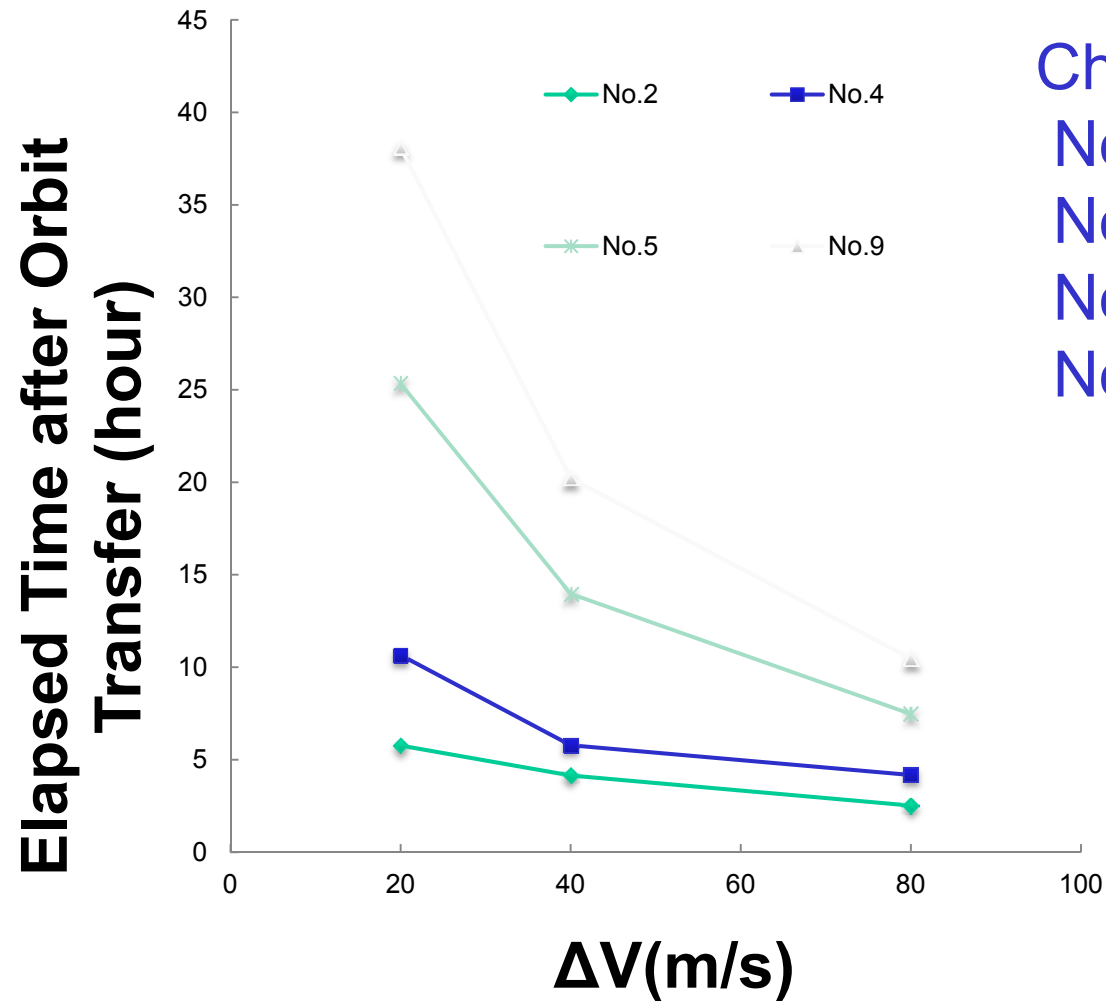
$$\frac{\partial \Omega}{\partial t} = -\frac{3}{2} J_2 \left(\frac{Re}{p} \right)^2 n \cos i$$

$$\frac{\partial \omega}{\partial t} = \frac{3}{4} J_2 \left(\frac{Re}{p} \right)^2 n (5 \cos^2 i - 1)$$

$$\frac{\partial \sigma}{\partial t} = \frac{3}{4} J_2 \left(\frac{Re}{p} \right)^2 n \eta (3 \cos^2 i - 1)$$



Simulation Result



Change in equatorial plane

No.2 -0.36 degree

No.4 -0.66 degree

No.5 -1.54 degree

No.9 2.28 degree

Concluding Remarks

Small satellites' merit for disaster monitoring would be much larger when the number of them increases. But, in the 2011 Tohoku Earthquake, the contribution of them are limited.

It takes time to make sufficient constellation of small satellites for infrastructure of disaster monitoring.

But before making such infrastructure, we should demonstrate merits of small satellites utilizing constellation of low-cost micro-satellites.

Maneuverability is another method to operate small satellite network for the time being.

It is important to appeal merits of small satellites to the society.

Acknowledgements

Thank you very much for your support.

I am deeply grateful to these organizations, companies, and people, who provide the images, pictures, data, and slides of this presentation;

National Diet of Japan, International Charter,
Japan Aerospace Exploration Agency, National Police Agency of Japan,
Earth Remote Sensing Data Analysis Center, U.S. Geological Survey,
Japan Meteorological Agency, Geospatial Information Authority of Japan,
The 2011 Tohoku Earthquake Tsunami Joint Survey Group,
Asia Air Survey Co., Ltd., PASCO Corporation, Infoterra GmbH,
Japan Space Imaging Corporation, GeoEye, Inc.,
Hitachi Solutions, Ltd., Digital Globe, Inc., ESRI Japan Corporation,
RapidEye AG., National Space Organization, Taiwan,
ImageONE Co., Ltd., MacDonald, Dettwiler and Associates Ltd.,
Air Photo Service Co. Ltd.,
Remote Sensing Society of Japan

Activities of small satellites
are not limited to imager.

The support of the Cabinet Office, Government of Japan for funding under the "FIRST" (Funding Program for World-Leading Innovative R&D on Science and Technology) program.