Case Study of Japan: Crustal deformation monitoring with GNSS and InSAR

Basara Miyahara

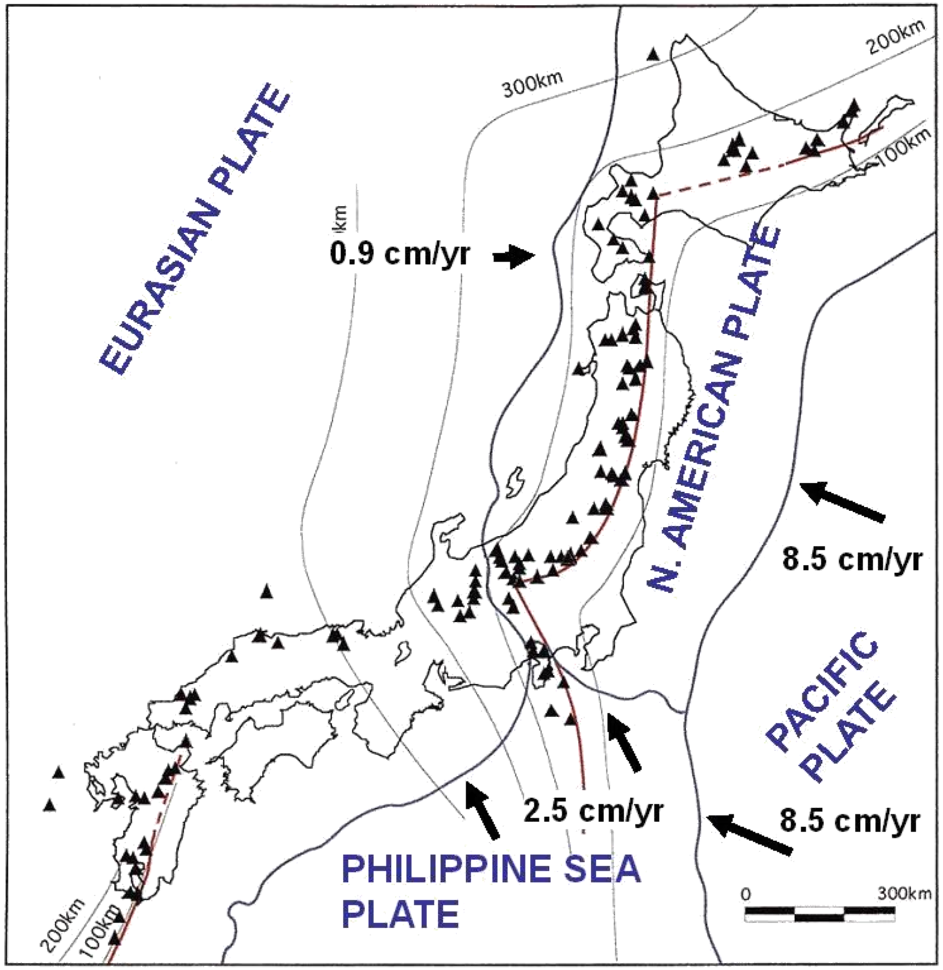
miyahara-b96ip@milt.go.jp

Geospatial Information Authority of Japan

Outline

- Introduction
  - Tectonic background in Japan.
- Two main techniques for monitoring crustal deformation: GNSS CORS and InSAR
- Monitoring consecutive deformation with GNSS CORS
- Semi-Dynamic geodetic reference frame of Japan
- Detecting coseismic displacement with InSAR
- An example: the 2016 Kumamoto Earthquakes
  - Detection of displacement, Source fault modeling

Tectonic background in Japan



Martin et al. (2012)

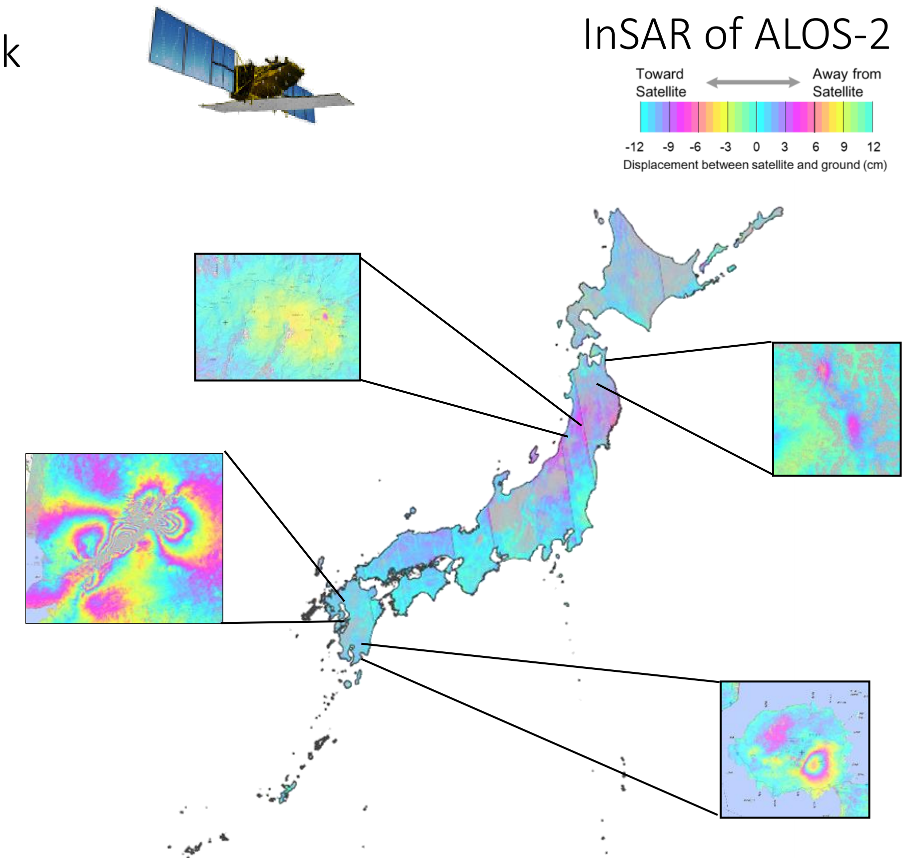
- Japan is located on an area where four active plates are colliding.
- Subduction rates are 8.5 cm/yr for Pacific plate, 2.5 cm/yr for Philippine sea plate, and 0.9 cm/yr for Eurasian plate relative to North American plate.
- Such active plane tectonics makes the country continuously deforming and prone to earthquakes and volcanic activities.
- Crustal deformation monitoring is essential to maintain geodetic reference frame.

Two techniques for monitoring

- GSI of Japan is monitoring crustal deformation of Japan with two techniques; GNSS CORS network (GEONET) and SAR interferometry (InSAR) of ALOS-2.

GNSS CORS network
- GEONET -

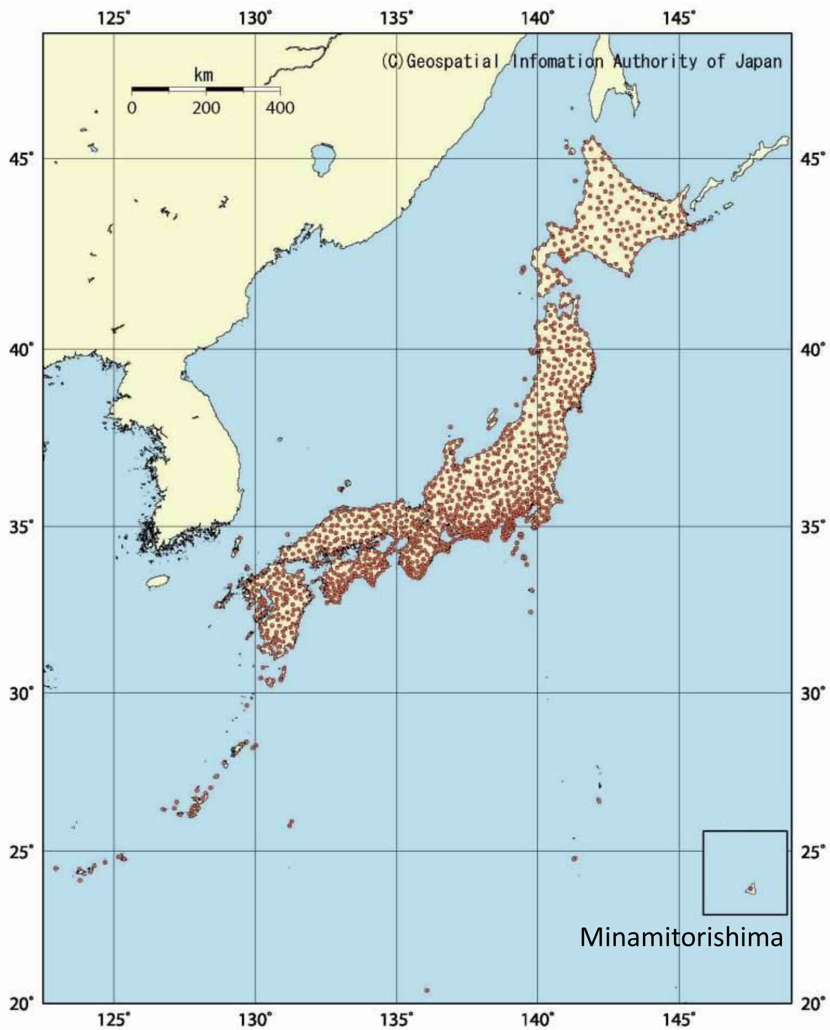
InSAR of ALOS-2



Analysis by GSI from ALOS-2 raw data of JAXA

GEONET

GNSS Earth Observation Network System



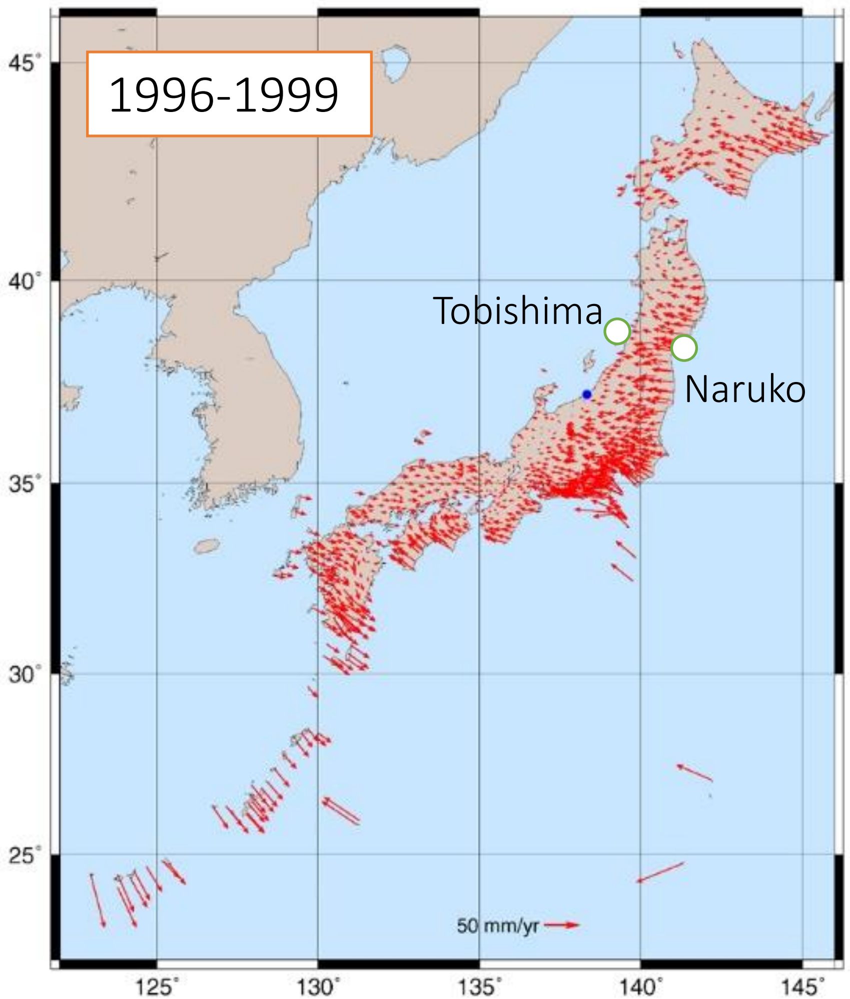
- GNSS continuously operating reference stations (CORS) covering Japanese archipelago for surveying and crustal deformation monitoring.
- Founded in 1994.
- 1318 stations (As of July 2017).
- Average spacing between stations about 20 km.
- Precise coordinate time series at each CORS station.
- Powerful tool for both monitoring secular crustal deformation and episodic coseismic displacement.

GEONET station

GEONET station “Tsukuba” at GSI headquarters and an antenna and equipment

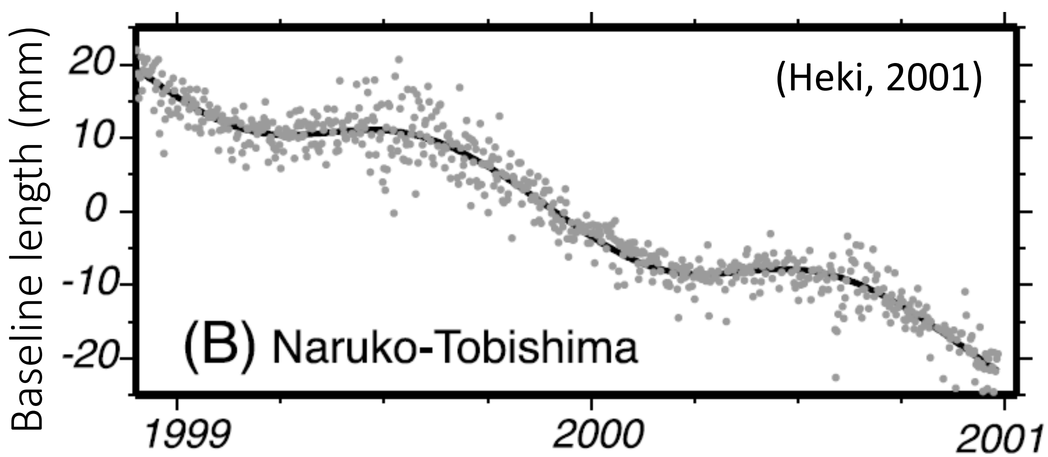
- Stainless steel pillar (5m tall)
- Chokering Antenna
- Clinometer and thermometer
- Dual frequency receiver (GPS, QZS, Galileo, Glonass)
- 24-hr observation
- 1-sec and 30-sec sampling
- 1-Hz real-time data transfer for crustal deformation monitoring and N-RTK services
- Both IP/VPN real-time and mobile phone communication

Secular deformation by plate tectonics

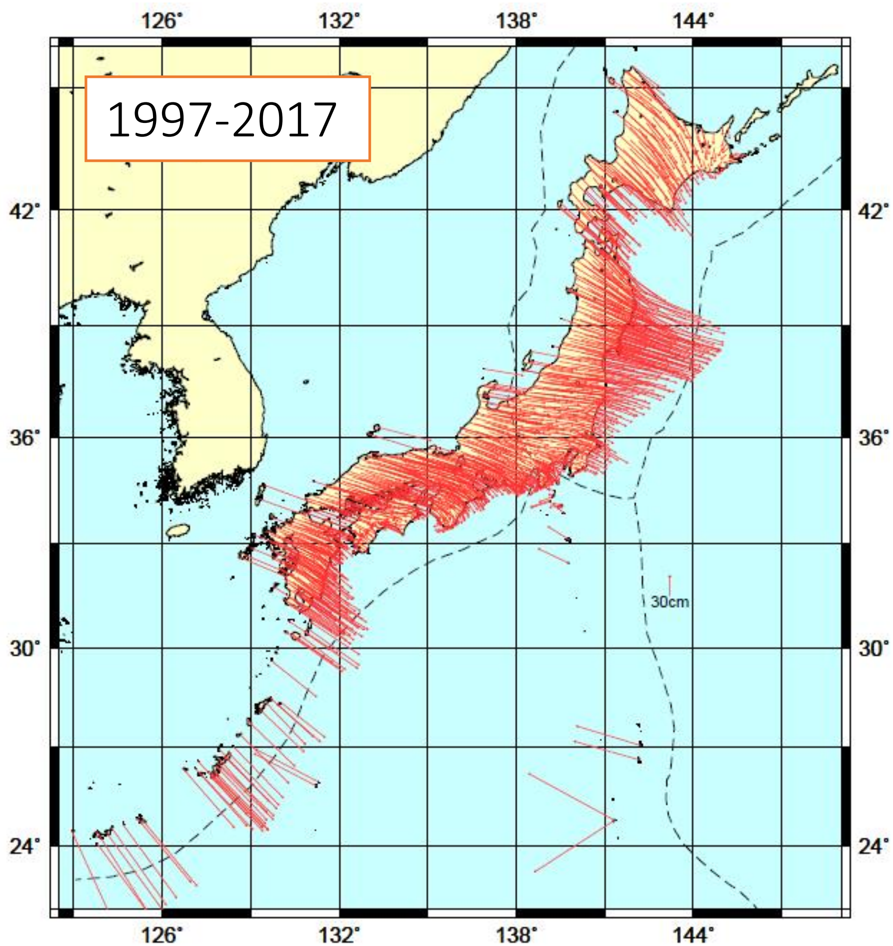


Horizontal displacement vector map detected by GEONET coordinate time series

- Secular crustal deformations have been observed by GEONET.
- Length of a baseline between east and west coast regions is decreasing at the rate of about 10-20 mm/yr.
- The pattern of deformation is not simple because of complicated tectonics.



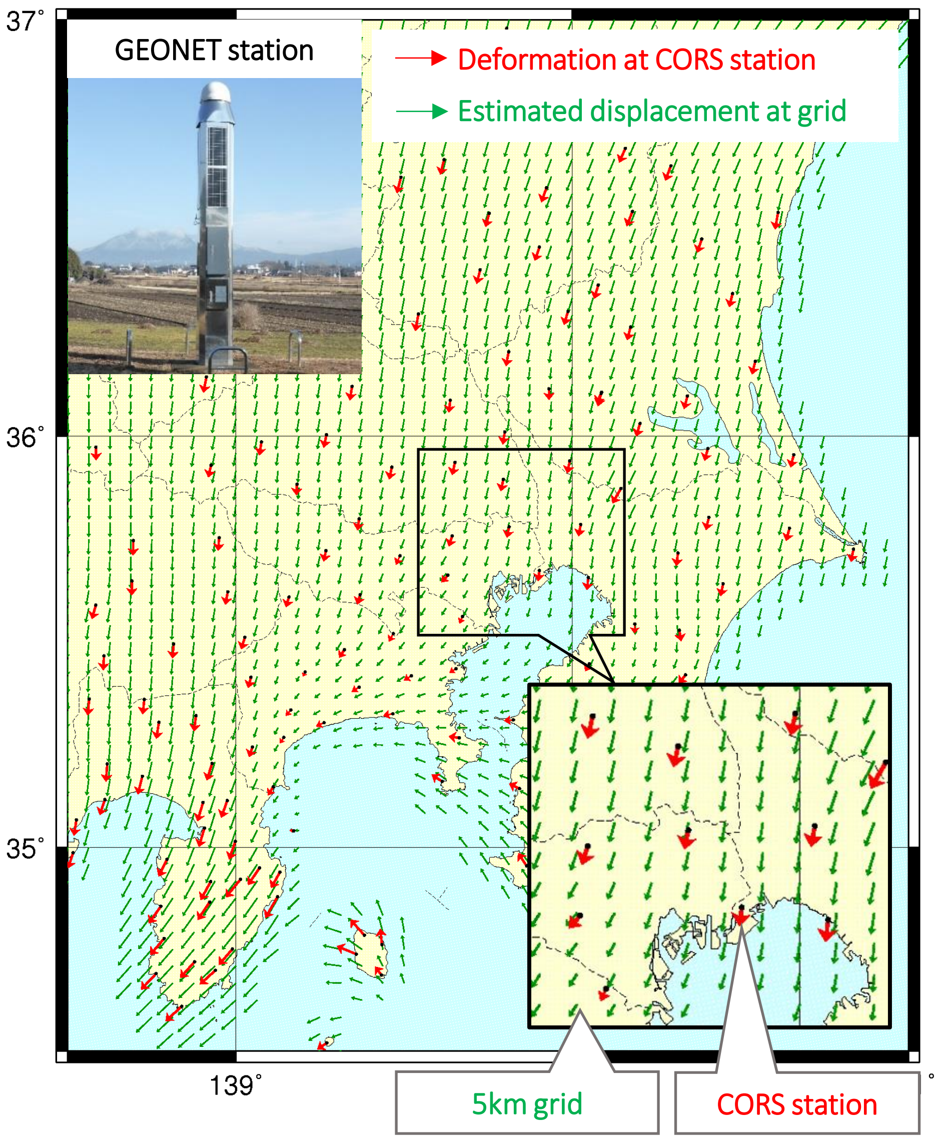
Monitoring with GEONET



Horizontal absolute displacement vector map detected by GEONET coordinate time series from 1997 to 2017

- GNSS CORS offers precise coordinate time series at each station.
- Dense GNSS CORS network provides precise displacement field.
- GEONET covers the whole area of Japan with 20km average spacing.
- Precise displacement field of Japan has been monitored monitored with GEONET since 1994.

How to model crustal deformation



1) Cumulative crustal deformation is calculated from coordinate time series at each CORS station (average spacing 20km)

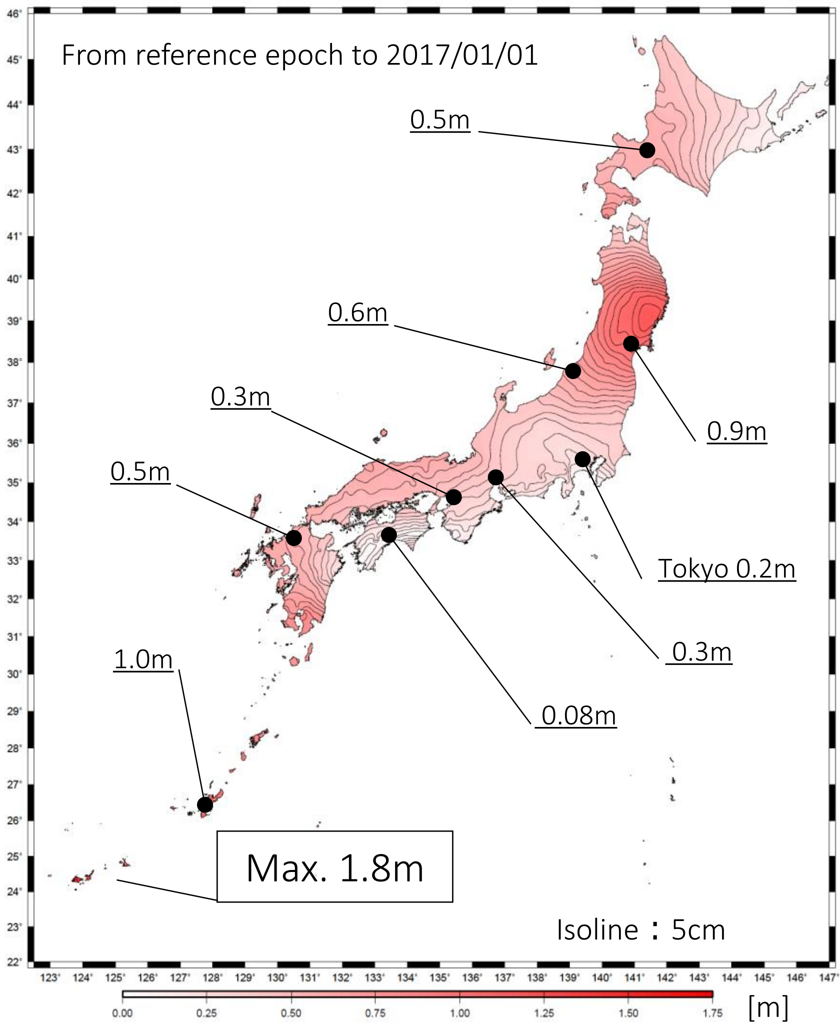
2) Deformation is estimated for each 5km grid by interpolating the deformation at each CORS station.

3) Users can estimate crustal deformation anywhere in the country by interpolating the estimated deformation at the grids.

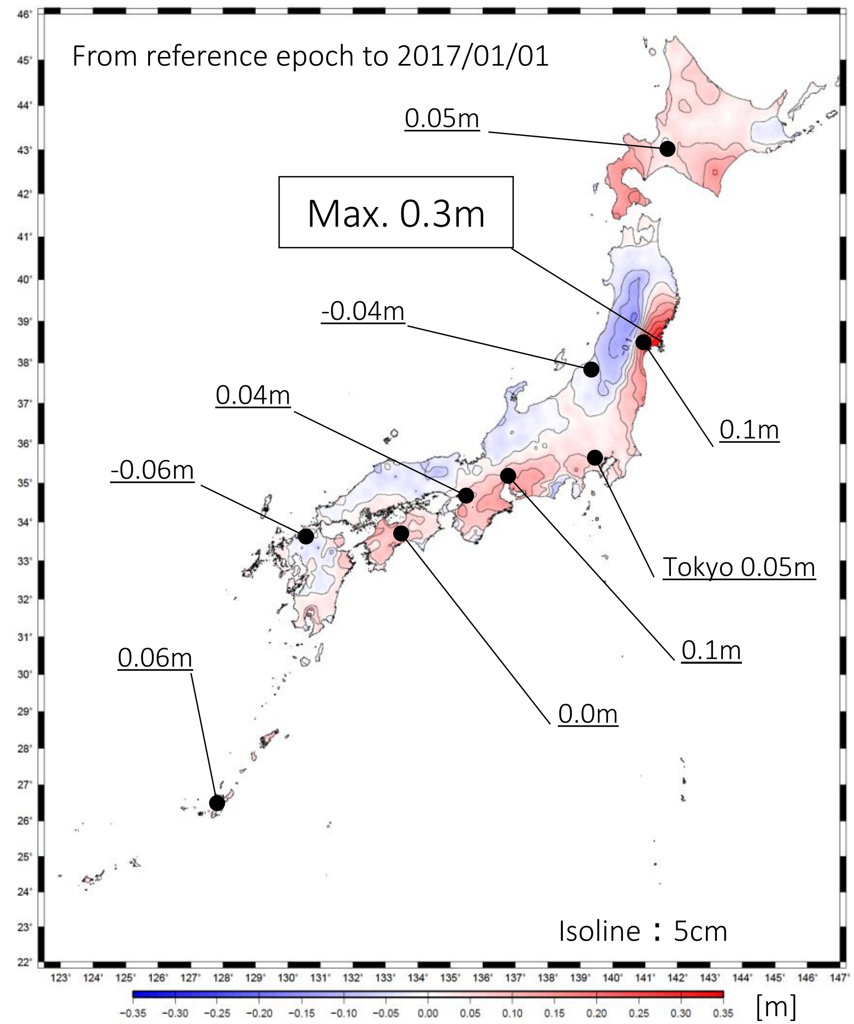
4) The cumulative crustal deformation is updated once a year.

Cumulative deformation from GEONET

Horizontal Displacement



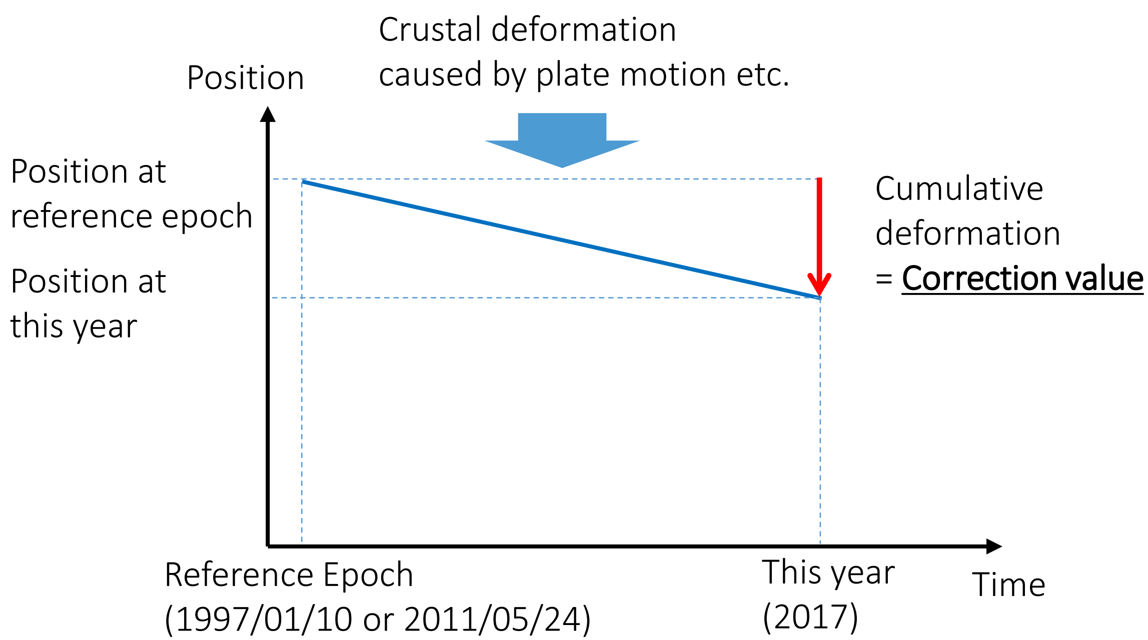
Vertical Displacement



※Reference epoch：1997/01/01(Hokkaido and West Japan)
2011/05/24（West Japan）

Semi-Dynamic datum of Japan

- GSI has developed cumulative crustal deformation model from GEONET and utilized it for maintenance of geodetic reference frame of Japan.
- Geodetic reference frame of Japan is Semi-Dynamic datum.
- All positions are described as positions at reference epoch.
- Reference epoch is 1997/01/01 (Hokkaido and West Japan) and 2011/05/24 （West Japan） .
- Semi-Dynamic correction is a method to align epoch of surveying to reference epoch. (Correction values are updated once a year)



Flow of Semi-Dynamic correction

Positions of CORS at reference epoch

↓ Add correction value to positions of CORS

Positions at CORS at this year

↓

GNSS positioning of new points

↓

Positions of new points at this year

↓ Remove correction value from positions of new points

Positions of new points at reference epoch

Detection of Coseismic displacements

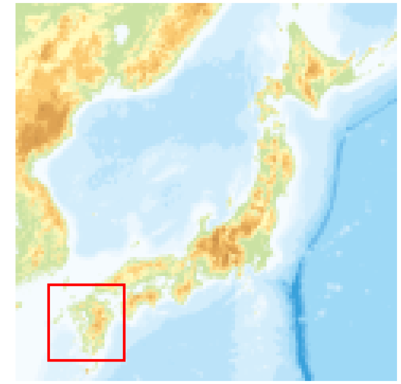
List of large earthquakes in Japan caused large crustal displacements

1995.1.17	Kobe EQ (M7.2)
2000.10.6	Tottori EQ (M7.3)
2003.9.26	Off-Tokachi EQ (M8.0)
2004.10.12	Niigata-Chuetsu EQ (M6.8)
2007.3.25	Noto peninsula EQ (M6.8)
2007.7.16	Off-Chuetsu EQ (M6.8)
2008.6.14	Iwate-Miyagi EQ (M7.2)
2011.3.11	**Off-Tohoku EQ (M9.0)**
2014.11.22	Nagano EQ (M6.7)
2016.4.16	Kumamoto EQ (M7.3)

- Japan has experienced a number of large earthquakes.
- Some of the earthquakes caused large coseismic and postseismic displacements up to several meters.
- Positions of control points need to be revised as prompt as possible in order to support rehabilitation and reconstruction.
- GSI detected the displacement with GEONET and InSAR and revised positions of control points as soon as possible.

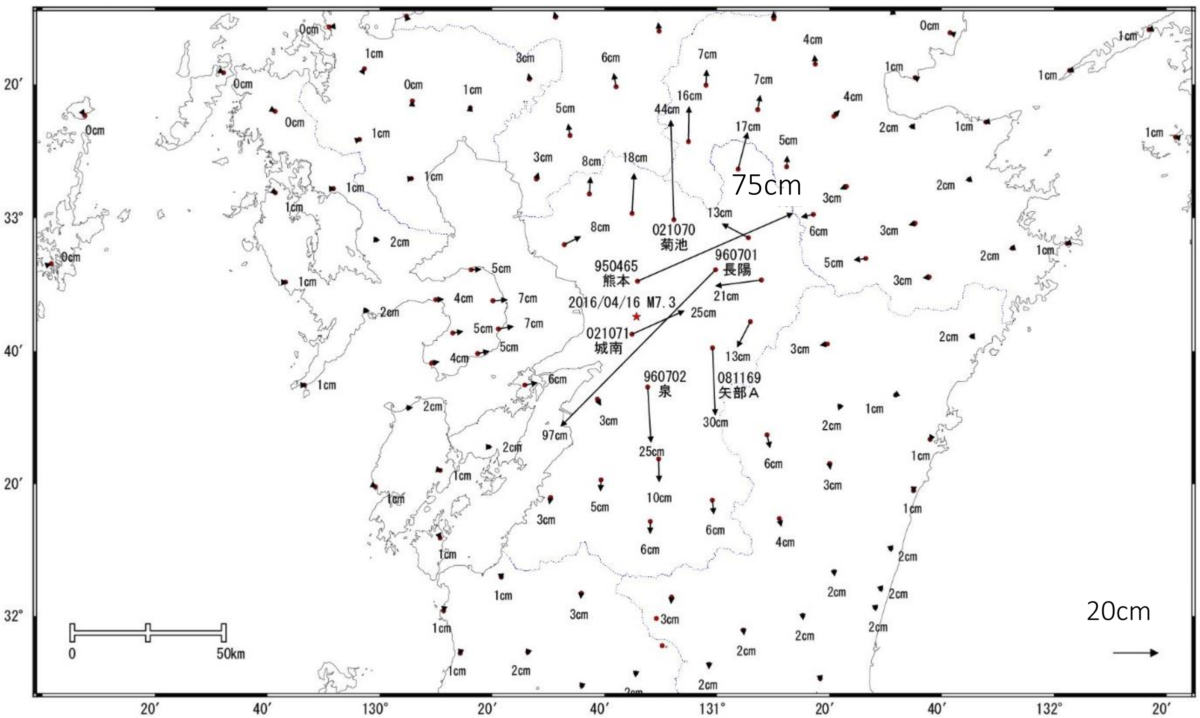
Example: Coseismic displacement

The 2016 Kumamoto EQ (M7.3)

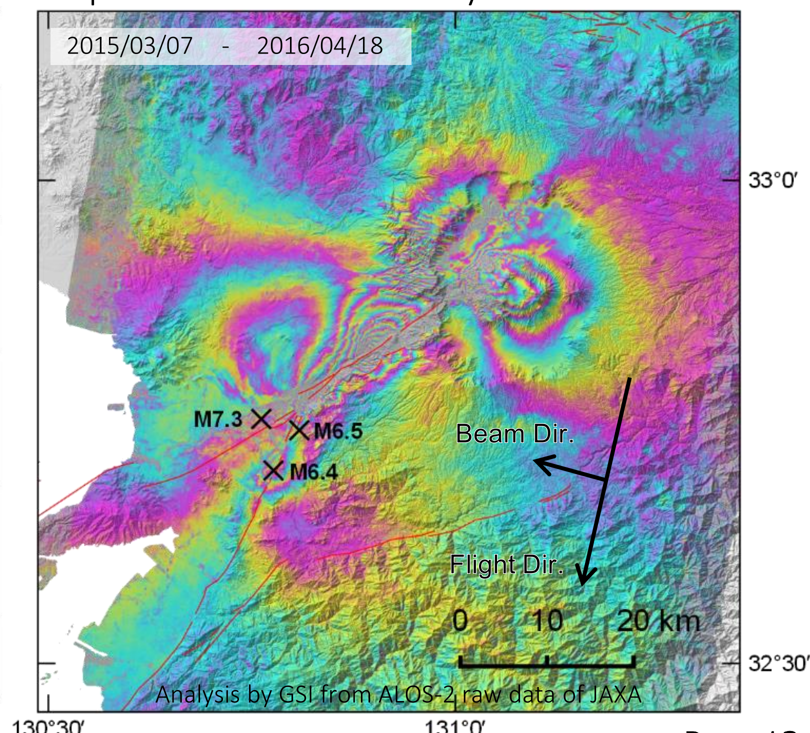


- The sequence of strike-slip earthquakes occurred in Kumamoto prefecture on 14-16 April 2016.
- GSI promptly calculated coseisimic displacement from GEONET.
- In addition, GSI conducted InSAR analysis of SAR satellite of Japan, ALOS-2.

Horizontal displacement detected by GEONET



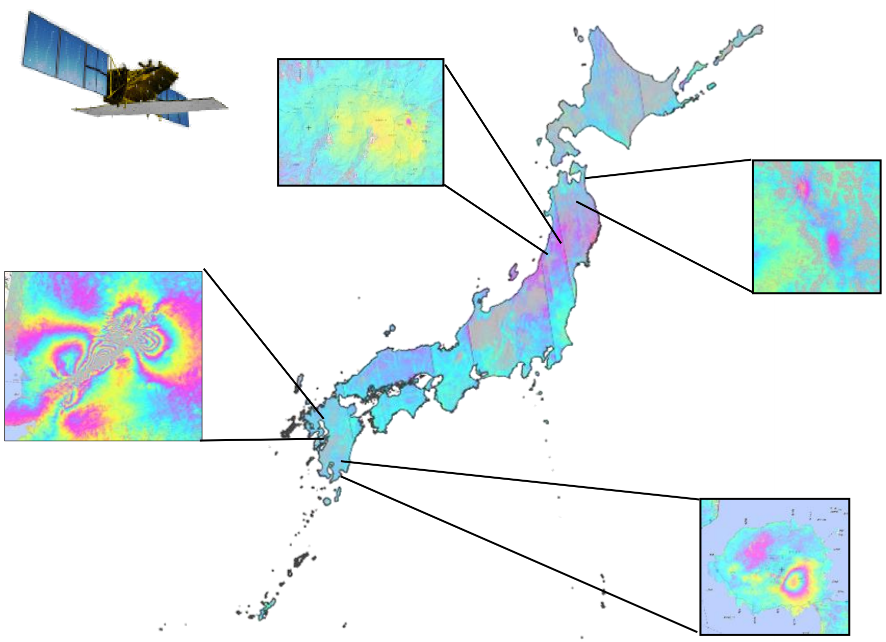
Displacement detected by ALOS-2 InSAR



× Epicenters of the two foreshocks and mainshock
— Estimated active faults (HERP, 2013)

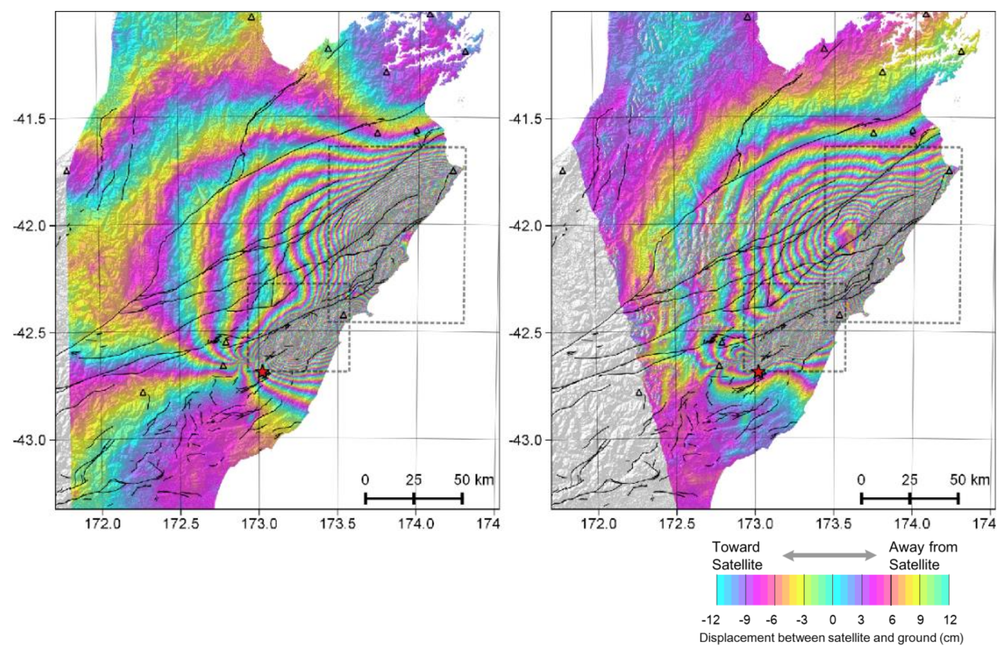
Monitoring by InSAR

- GNSS CORS are powerful tool to detect precise displacement at stations.
- InSAR is also powerful tool to detect detailed special distribution of displacement even in the area without CORS.
- GSI is monitoring ground surface with InSAR images of ALOS routinely (4~6 a year).
- GSI also conducts emergency InSAR analysis of ALOS-2 once events occur.



Analysis by GSI from ALOS-2 raw data of JAXA

Routine analysis covering the whole country

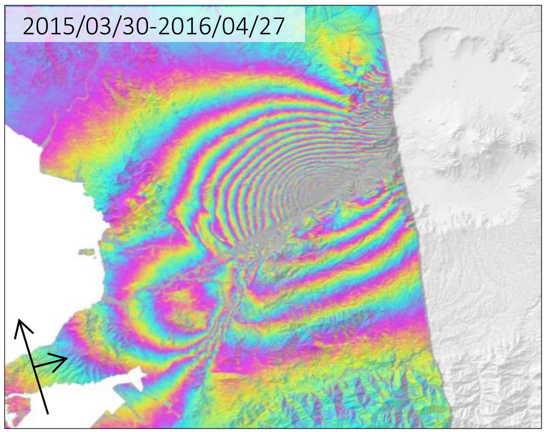


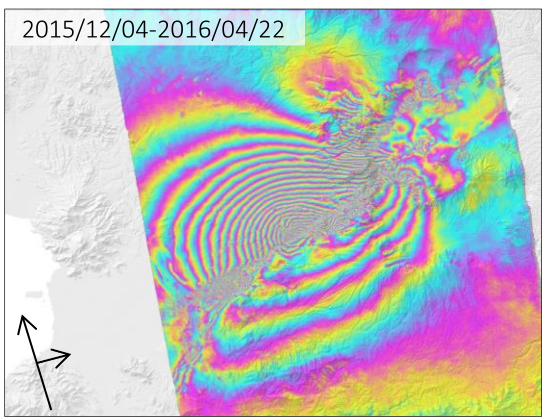
Kaikoura Earthquake (New Zealand)

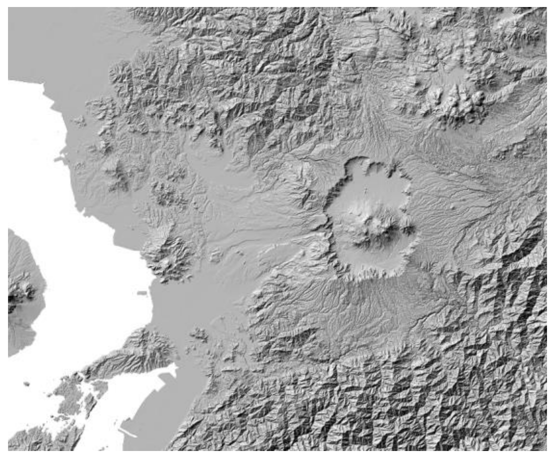
Emergency analysis for catastrophic events

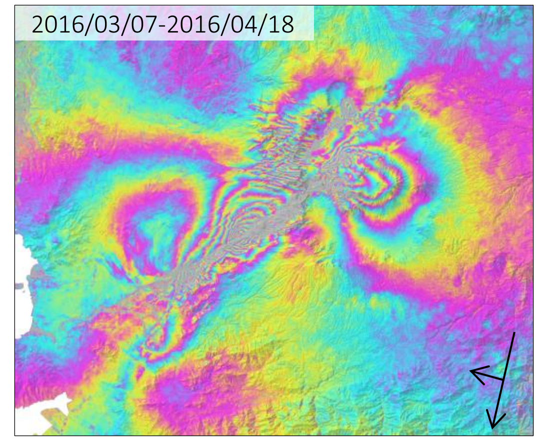
Coseismic displacement by InSAR

- ALOS-2 has left and right looking observation capability and can observe ground surface from multi directions.
- 3-D displacement field can be retrieved by combining observation from multi directions.
- For Kumamoto EQs, 3-D coseismic displacement filed was retrieved from SAR pixel offset analysis of three independent SAR images.

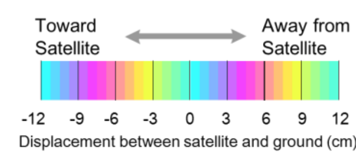








Analysis by GSI from ALOS-2 raw data of JAXA



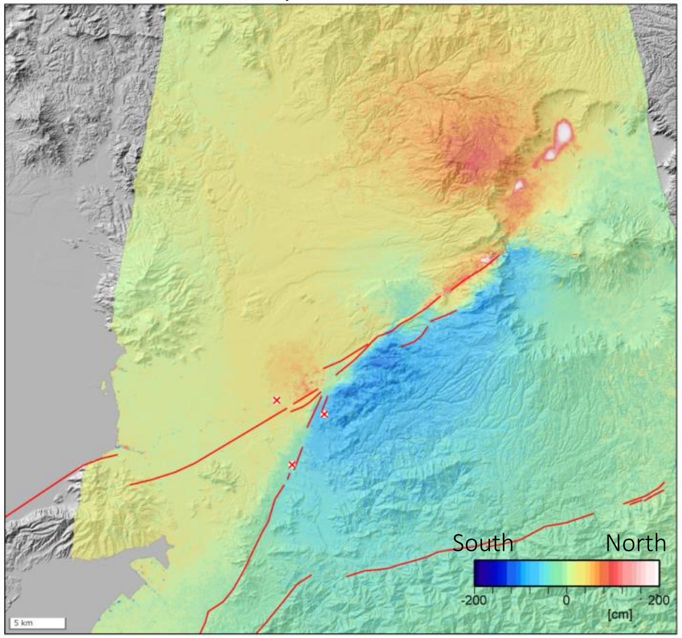
3-D coseismic displacement field

3-D displacement detected by SAR

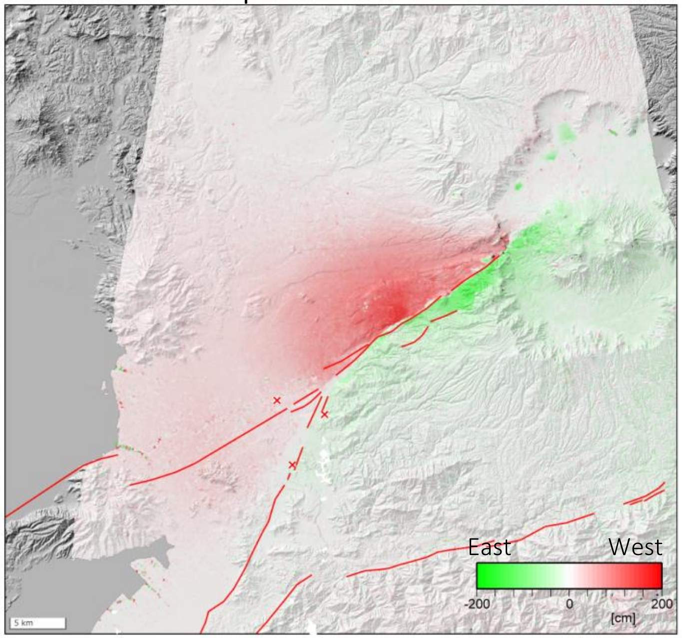
- 3-D coseismic displacement field is retrieved from SAR pixel offset analysis of ALOS-2.
- The field reveals detailed spatial distribution of coseismic displacement.
- Although maximum displacement detected by GEONET is 75cm, the maximum revealed by ALOS-2 is over 2m in horizontal and over 1m in vertical.
- An area of revision was identified from the 3-D displacement field.

3-D coseismic displacement field retrieved by ALOS-2 analysis

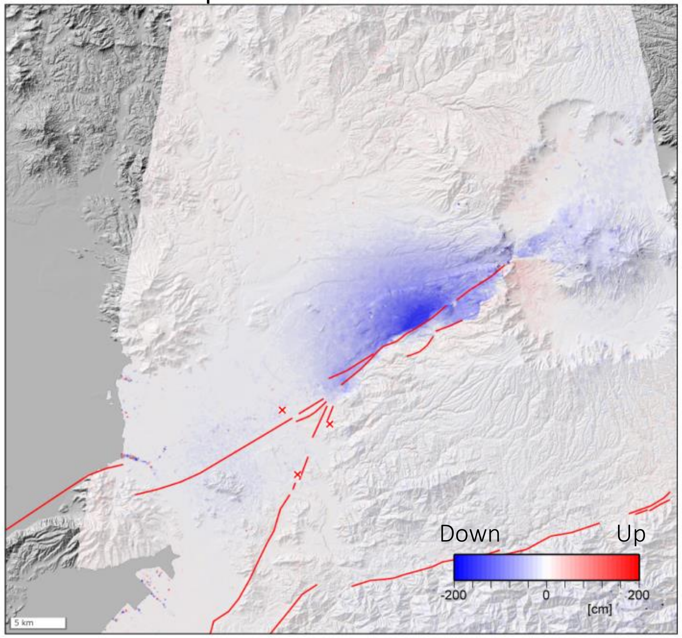
North-South Displacement



East-West Displacement



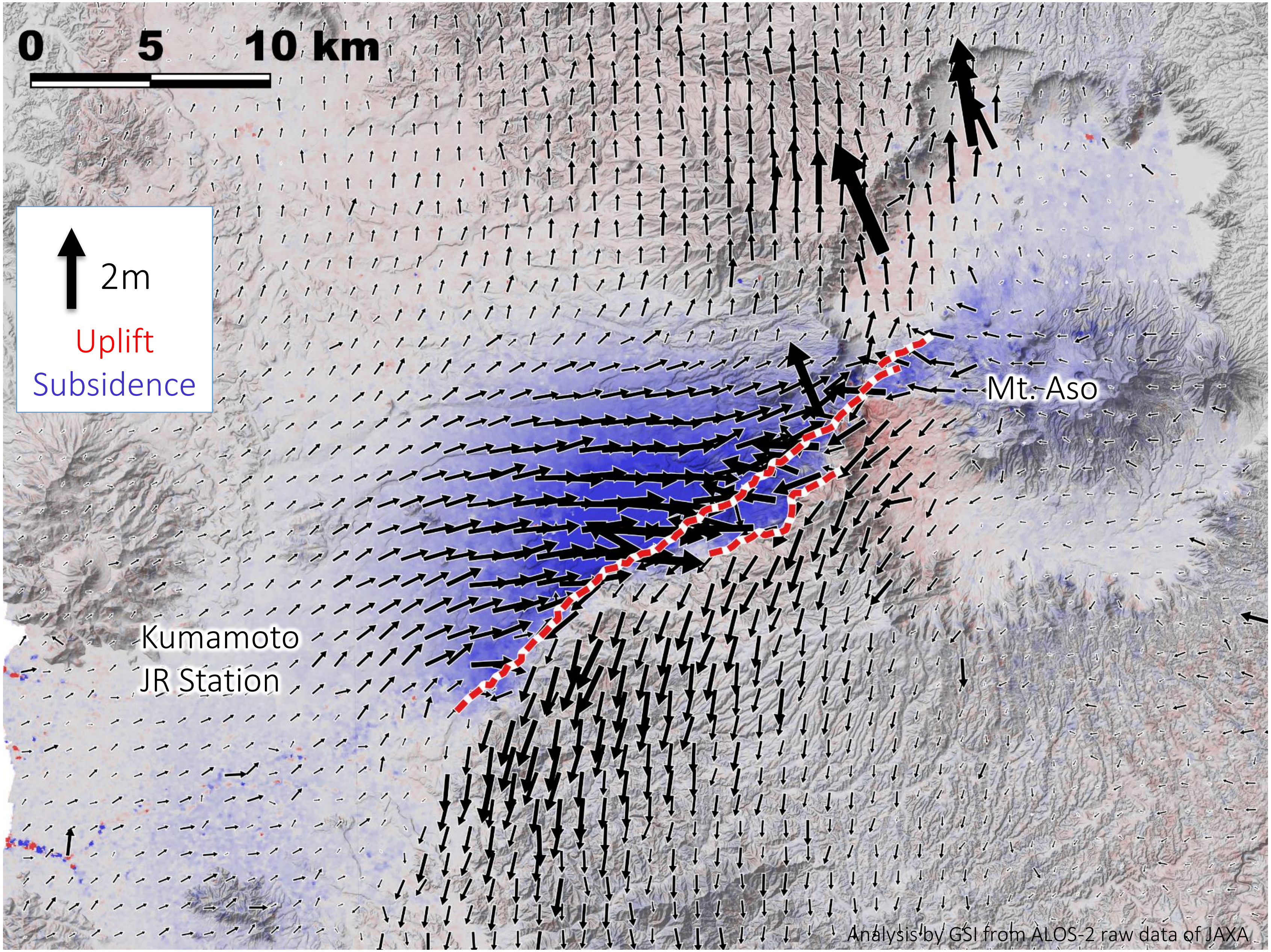
Vertical Displacement



× Epicenters of the two foreshocks and mainshock
— Estimated active faults (HERP, 2013)

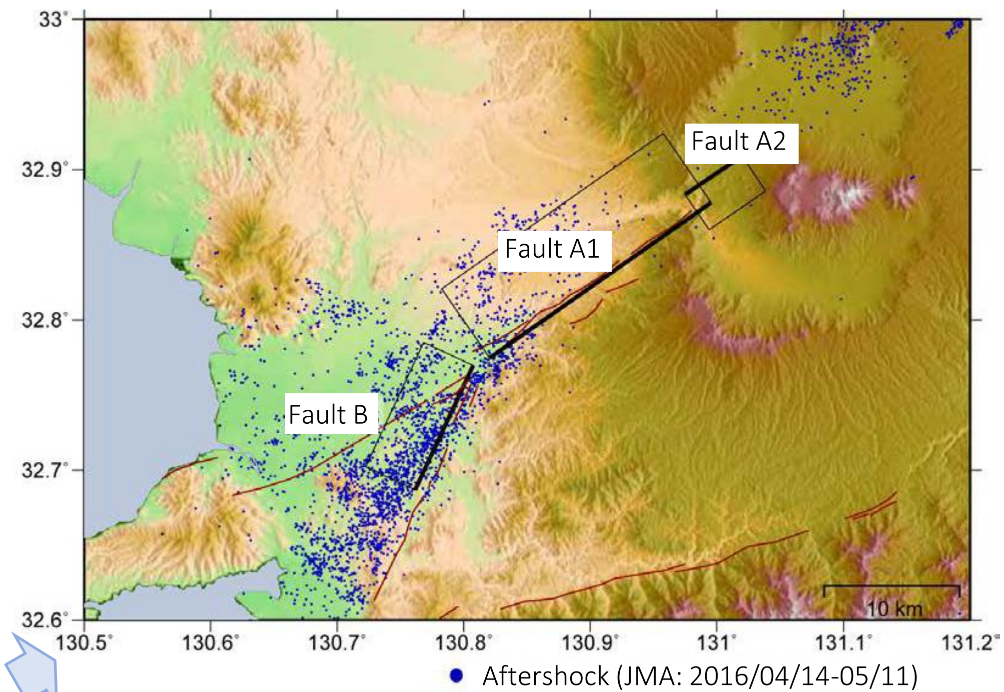
Analysis by GSI from ALOS-2 raw data of JAXA

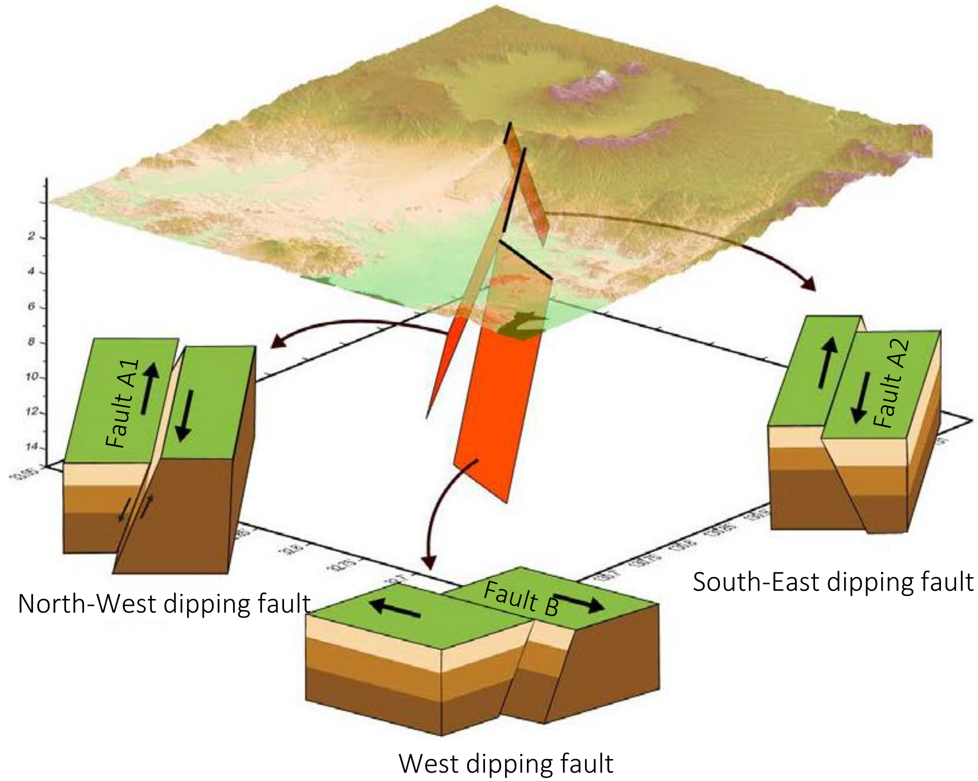
3-D displacement detected by SAR



Source fault model

- GSI developed earthquake source fault model from coseimic displacement field constructed from GEONET and SAR analysis.
- Three source faults were estimated and consistently explain observed displacement.





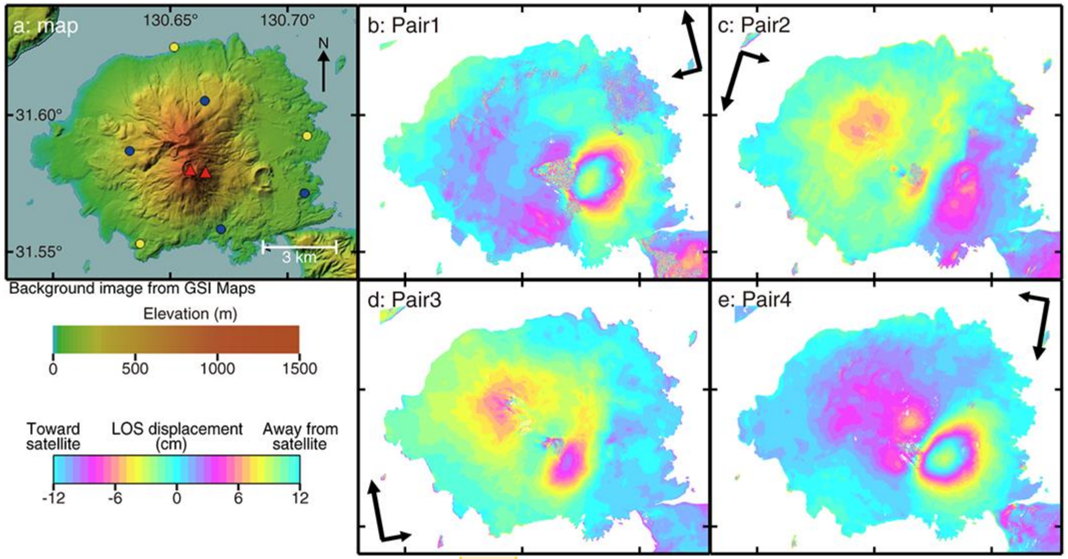
3D View

	longitude [°]	latitude [°]	upper depth [km]	length [km]	width [km]	strike [°]	dip [°]	slip angle [°]	slip amount [m]	M_w
Fault A1	130.996	32.878	0.6	20.0	12.5	235	60	209	4.1	6.96
Fault A2	130.975	32.883	0.2	5.1	6.6	56	62	178	3.8	6.36
Fault B	130.807	32.770	0.8	10.2	13.0	205	72	176	2.7	6.65

3-D displacement retrieved from InSAR

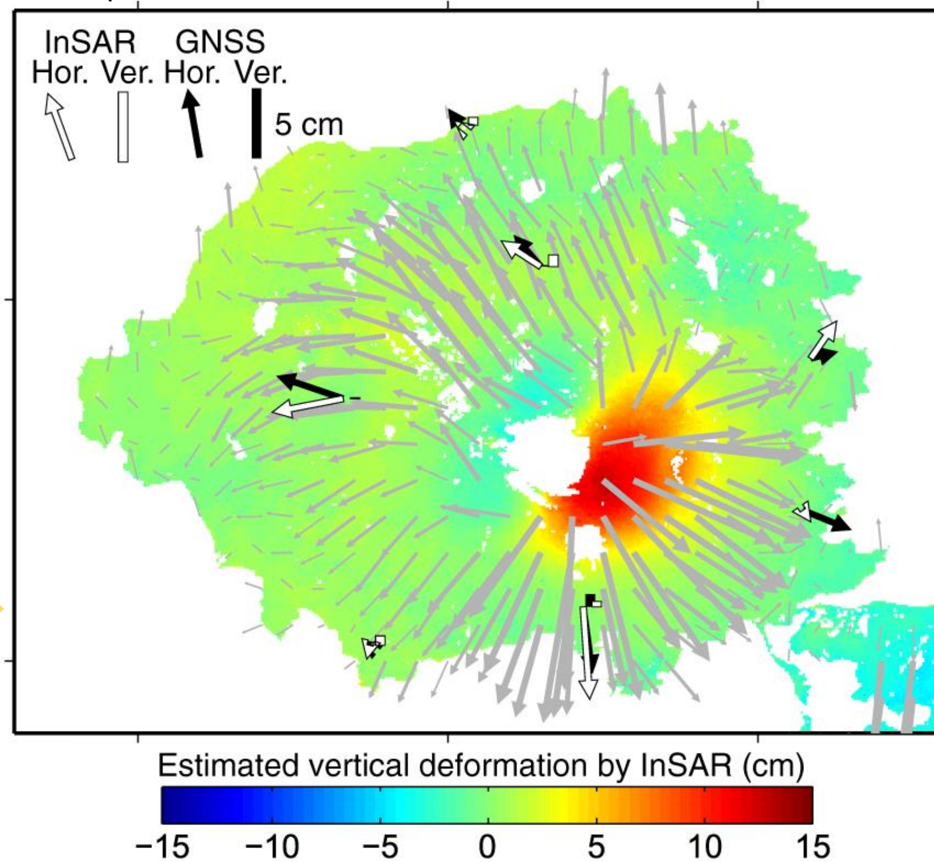
- Volcanic activity caused displacement at Sakurajima volcano in 2015.
- GSI retrieve 3-D displacement from four InSAR images from different observation directions.

InSAR images from four observation directions



Morishita et al. (2016)

3-D displacement field retrieved from InSAR and comparison between InSAR and GNSS



Estimation of 3-D deformation at each pixel from four independent SAR images observed from different observing directions.

Summary

- GSI is monitoring crustal deformation in Japan by utilizing GNSS CORS network (GEONET) and InSAR.
- Secular deformation mainly caused by plate motions is monitored and deformation model is developed from GEONET coordinate time series.
- Displacements caused by earthquakes are also detected by GEONET and InSAR and source fault models are developed from detected displacement.
- Crustal deformation field is utilized for maintenance of geodetic reference frame.
- Secular deformation model is utilized for Semi-Dynamic Correction of geodetic coordinates.
- Coseismic displacement is utilized for revision of geodetic coordinates of control points.