The 2011 Great East Japan Earthquake and Tsunami
- What we did and what we learned -

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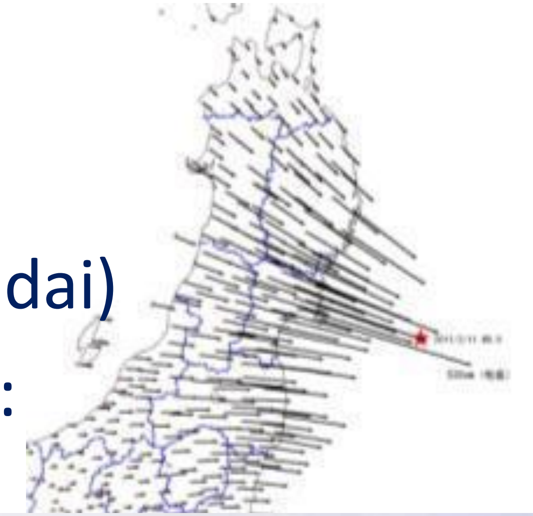
Outline

1. Great East Japan Earthquake in 2011
2. Immediate Response
3. Recovery/Reconstruction
4. Improved Preparedness
5. Kumamoto Earthquakes (14-16 April 2016)
6. Summary (What we learned)

Great East Japan Earthquake in 2011

Disaster caused by the Great East Japan Earthquake on 11 March 2011



- Earthquake:
  - Mw: 9.0 (Epicenter: 70km east of Sendai)
  - Co-seismic crustal deformation (max): 5.3m (horizontal), -1.2m (vertical)

- Tsunami:
  - Highest elevation reached: 43m
  - Inundated areas: 561 square km (approx. 10 times the Manhattan Island in New York)

- Nuclear meltdown:
  - 3 reactors in Fukushima

Disaster caused by the Great East Japan Earthquake on 11 March 2011

- Casualties (as of 10 March 2016)
  - Death: 15,894 (>90% by Tsunami)
  - Missing: 2,561
  - Injured: 6,152
- Liquefaction (as of 27 September 2011)
  - Damaged houses: 26,914
- Economy
  - Estimated economic loss: > 200B US$

Immediate Response

What we did after the Earthquake

- Detection of co-seismic crustal deformation using CORS network
- Aerial survey (Aerial photos + Ortho images)
- Photo interpretation (Inundated areas)
- :

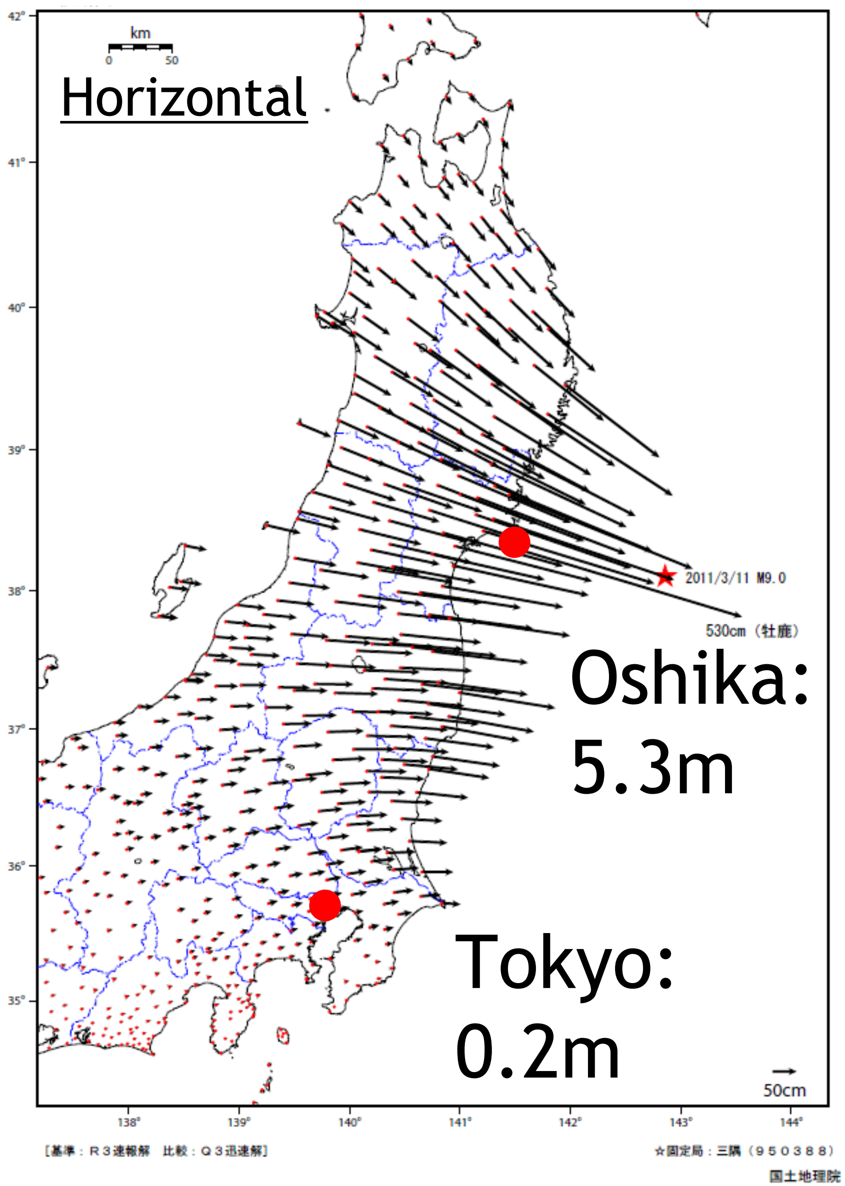
Co-seismic Crustal Deformation

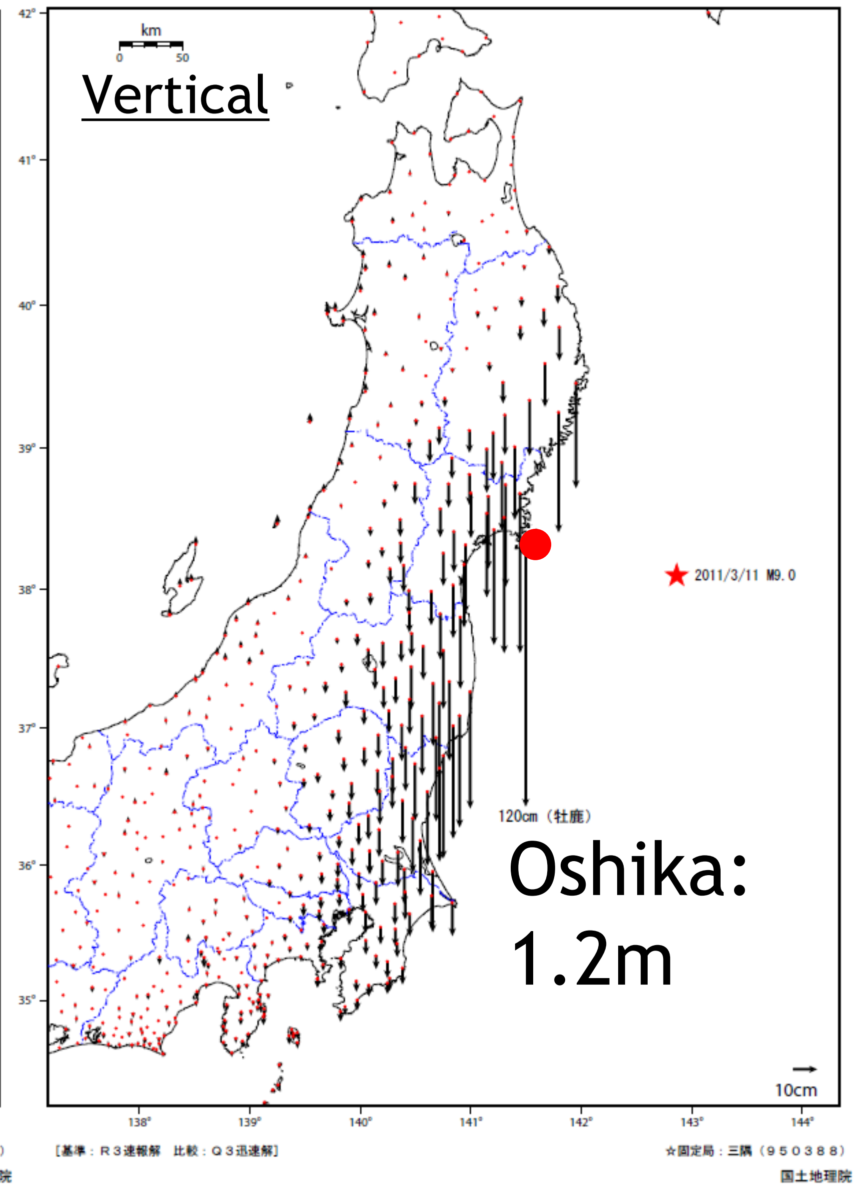
CORS Network in Japan

1,300 stations

(Ave. 20km interval)

Co-seismic Crustal Deformation





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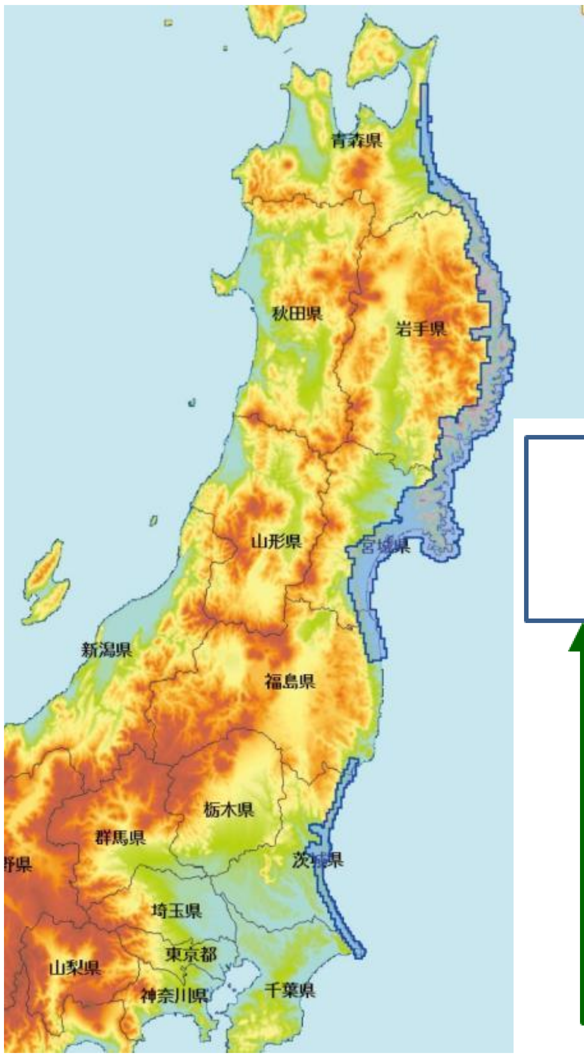
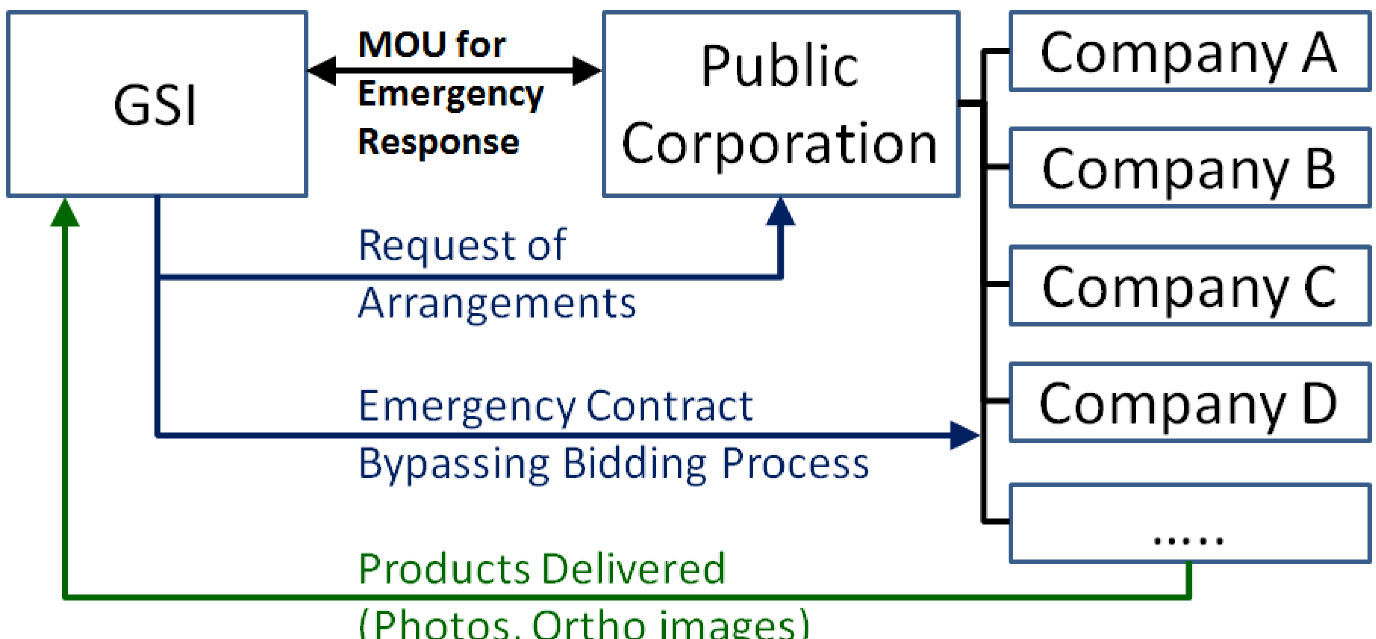
Aerial Survey

Seven airplanes were mobilized, based on an MOU with private companies, to take aerial photos covering approx. 7,000 square km starting from the next day.





Aerial Survey

Photo Interpretation (Inundated Areas)

Recovery/Reconstruction

Resurveying of Control Points

- The deformation caused by the earthquake was too large to start surveying for reconstruction without revising the control points coordinates.
- Two questions:
  - When should the resurveying be conducted?
    - Large post-seismic deformation required a careful analysis to find the right time for revising the datum.
  - Which control points' coordinates are to be revised?
    - The extent of deformed areas were to be identified before surveying.

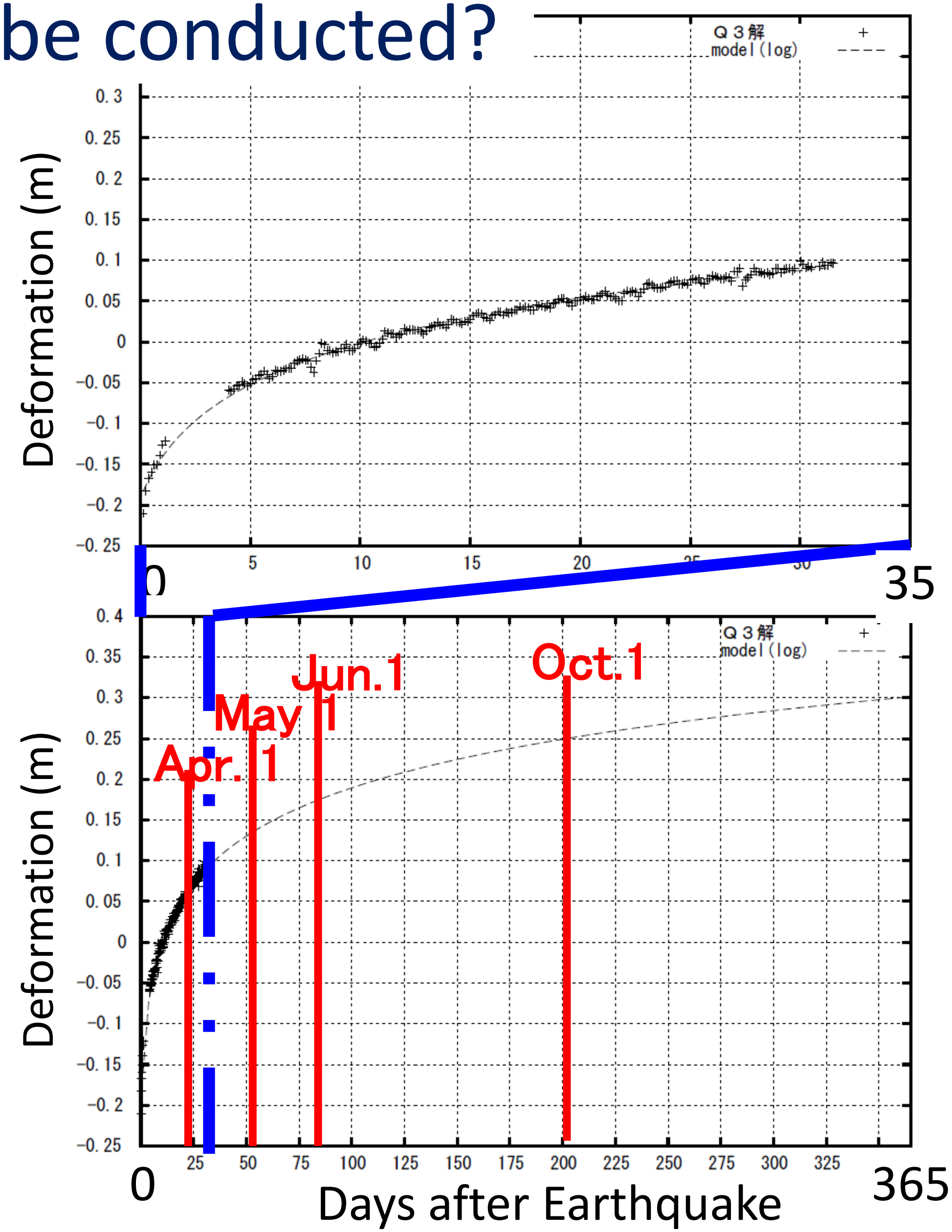
When the revision should be conducted?

Logarithmic function is adopted to estimate the future trend of post-seismic deformation by using CORS data.

$$y(t) = c + a \ln\left(1 + \frac{t}{\tau_{log}}\right)$$

(c, a:constant, τ_{log}: constant(time), t: time)

The **<u>end of May</u>** was set as the date for fixing the coordinates given that the deformation trend is estimated to become moderate after that.

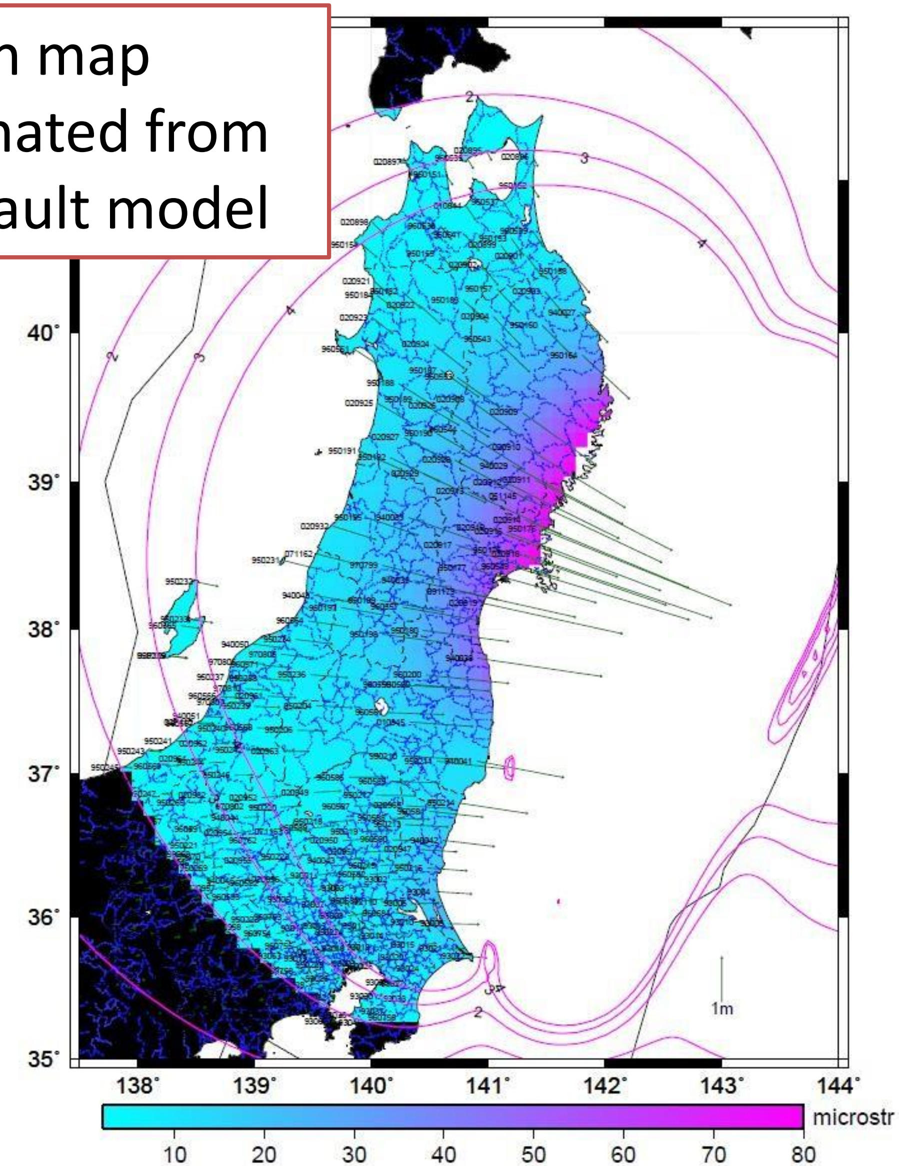


Estimated deformation at “Yamada”(#950167) Station

Areal Extent of New Datum

The area where estimated strain was over 2ppm was identified for revision.

Strain map estimated from the fault model



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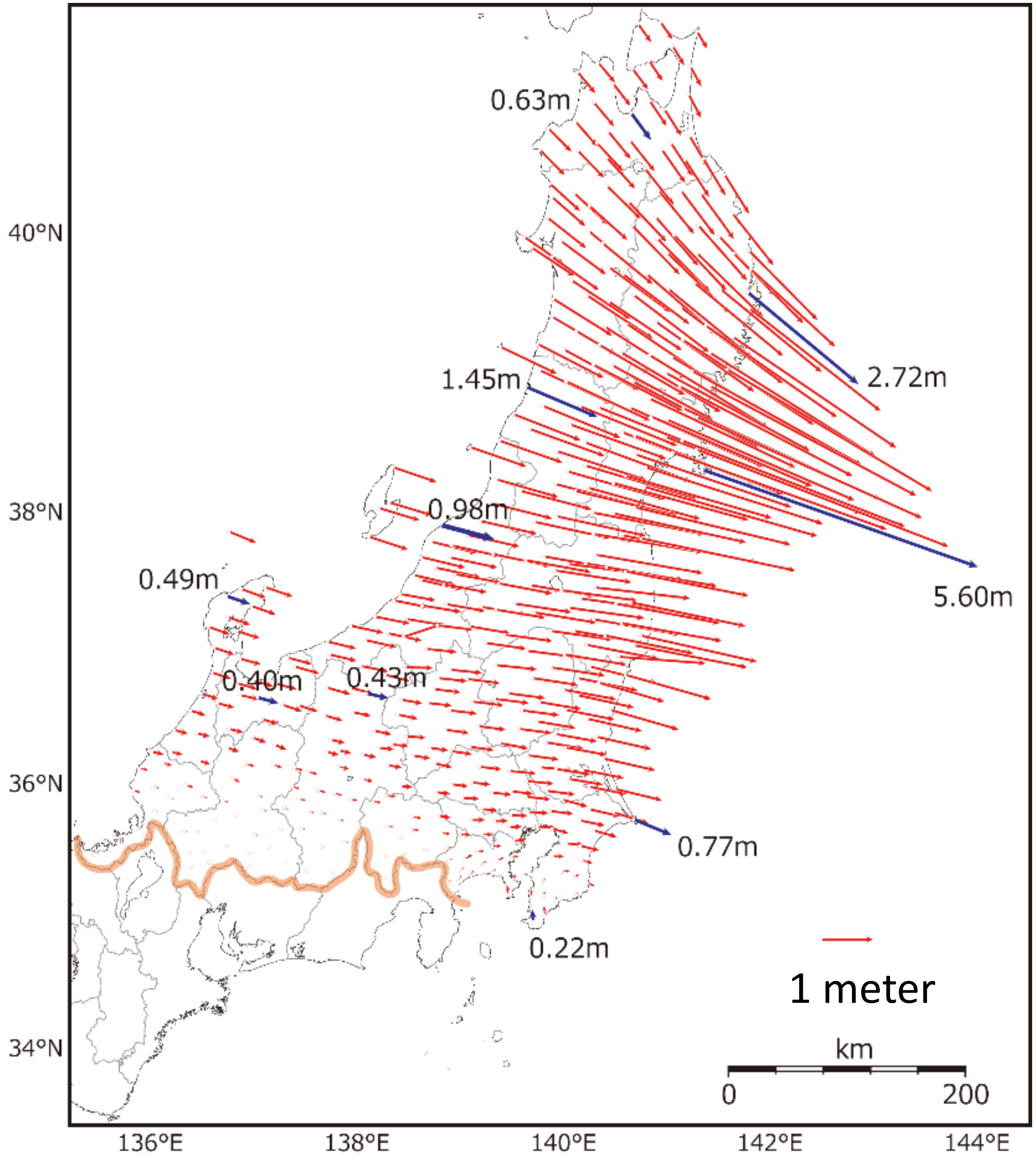
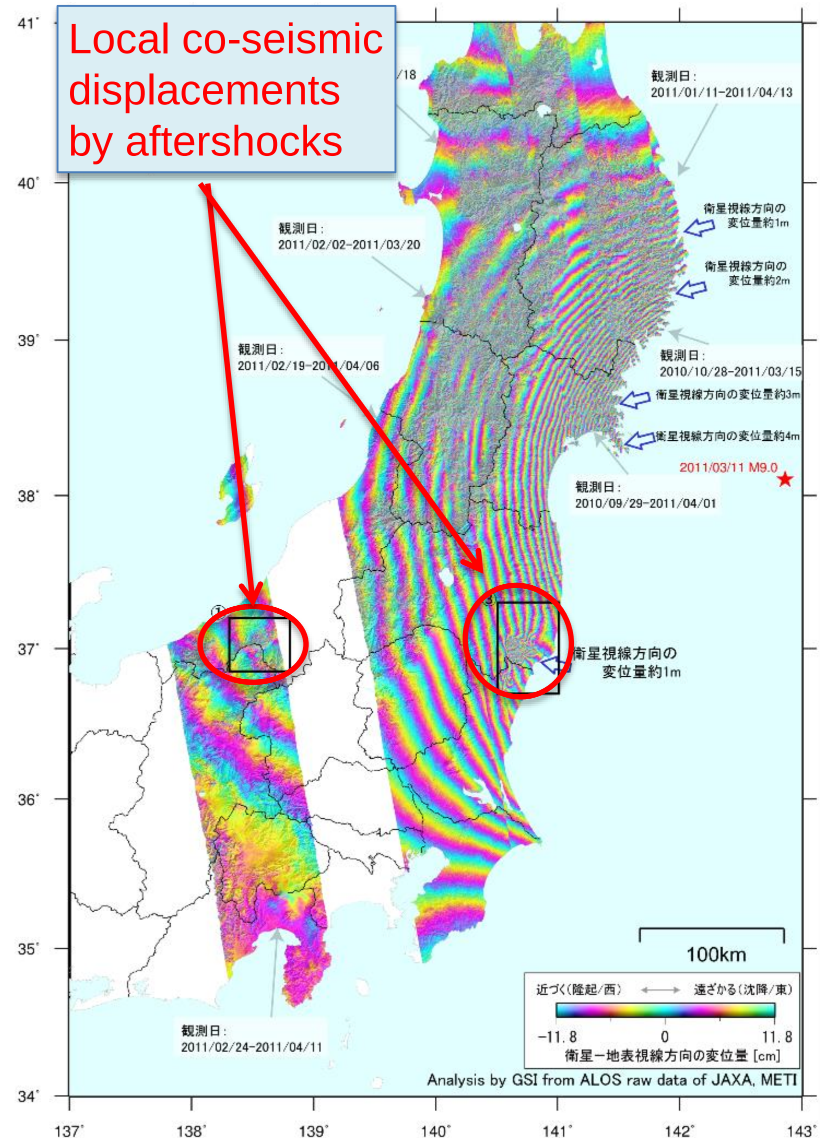
Coordinate Differences

Coordinate differences between old and new datums derived from CORS.



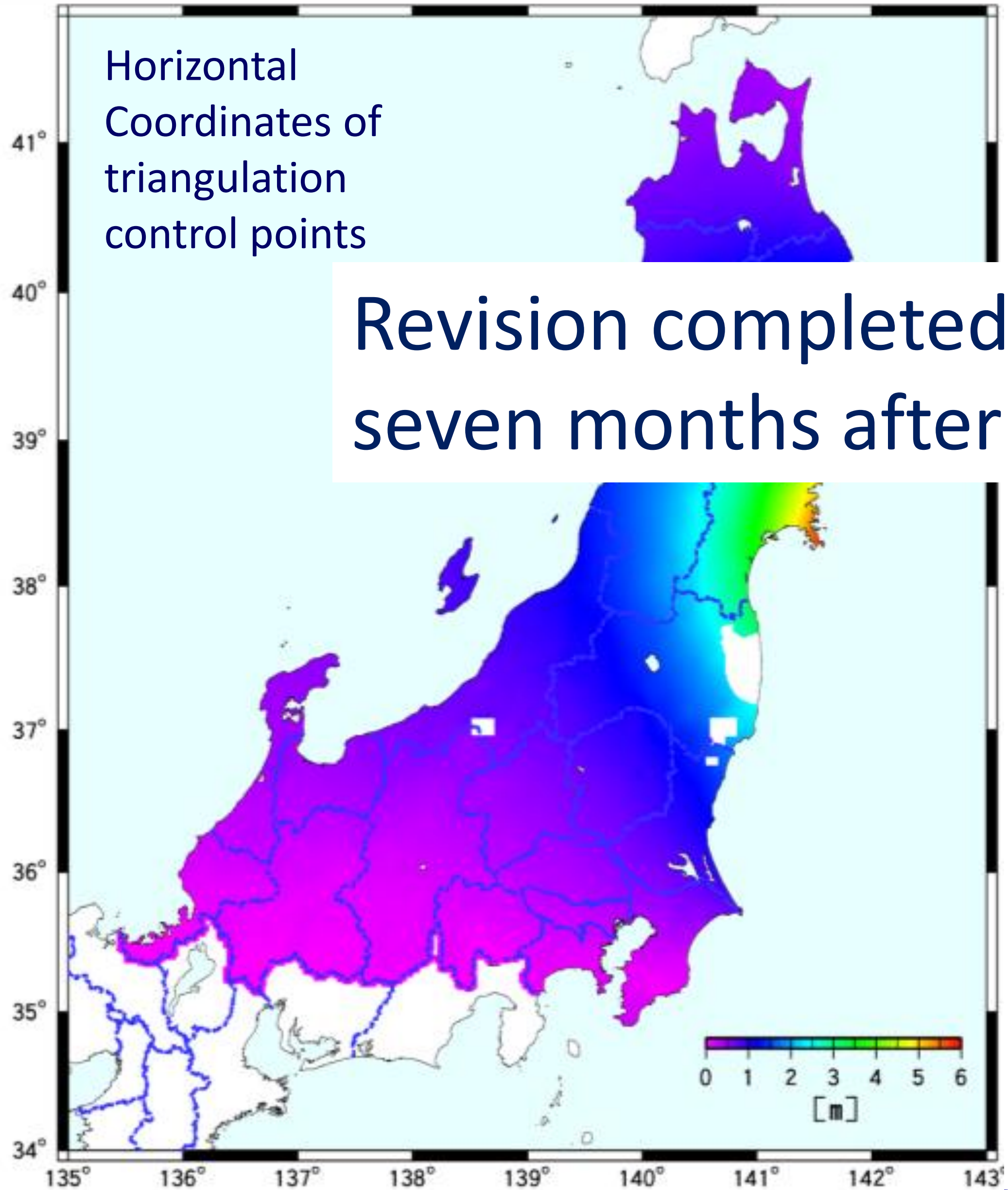
Areas Excluded from Applying Transformations with Parameters

- Large aftershocks made some areas unsuitable for applying coordinate transformations with parameters.
- InSAR analysis was employed to quickly identify the extent of the areas that should be excluded from the coordinate transformations.

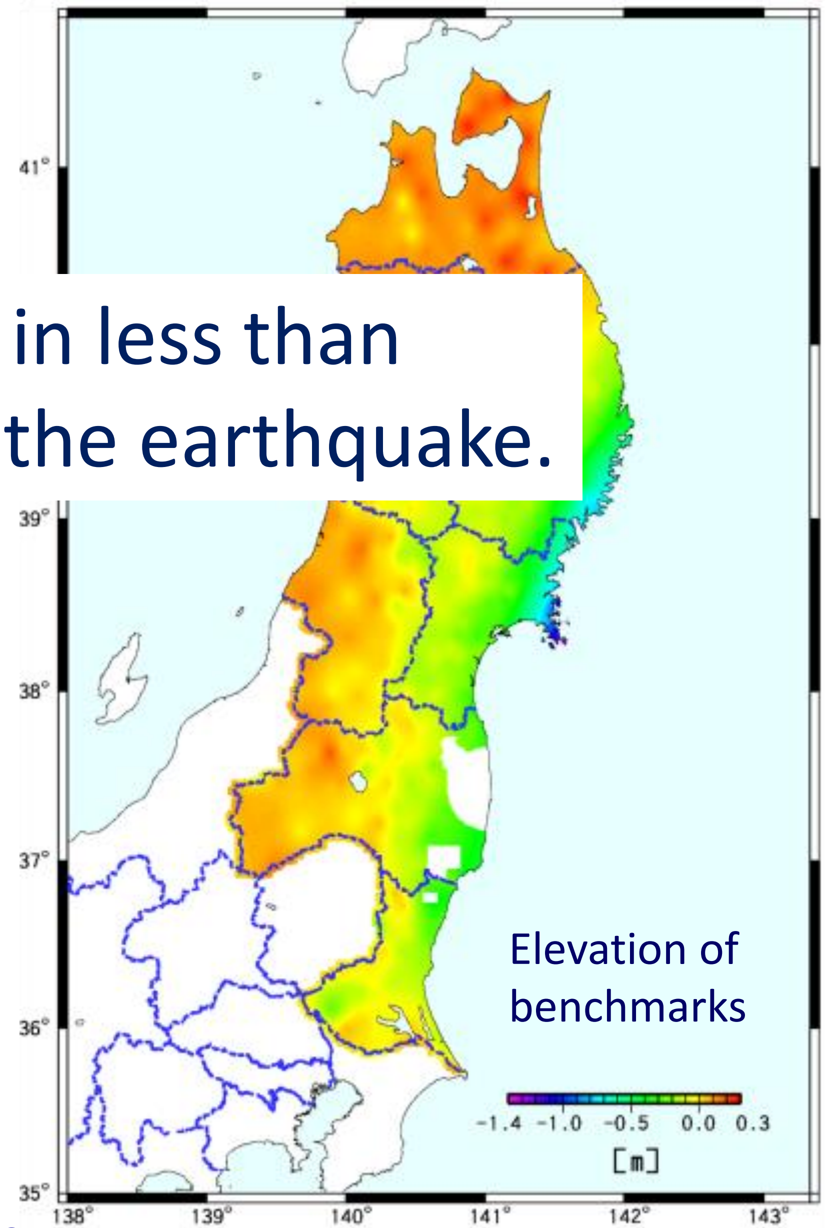


Correction Parameters for control points

Horizontal Coordinates of triangulation control points

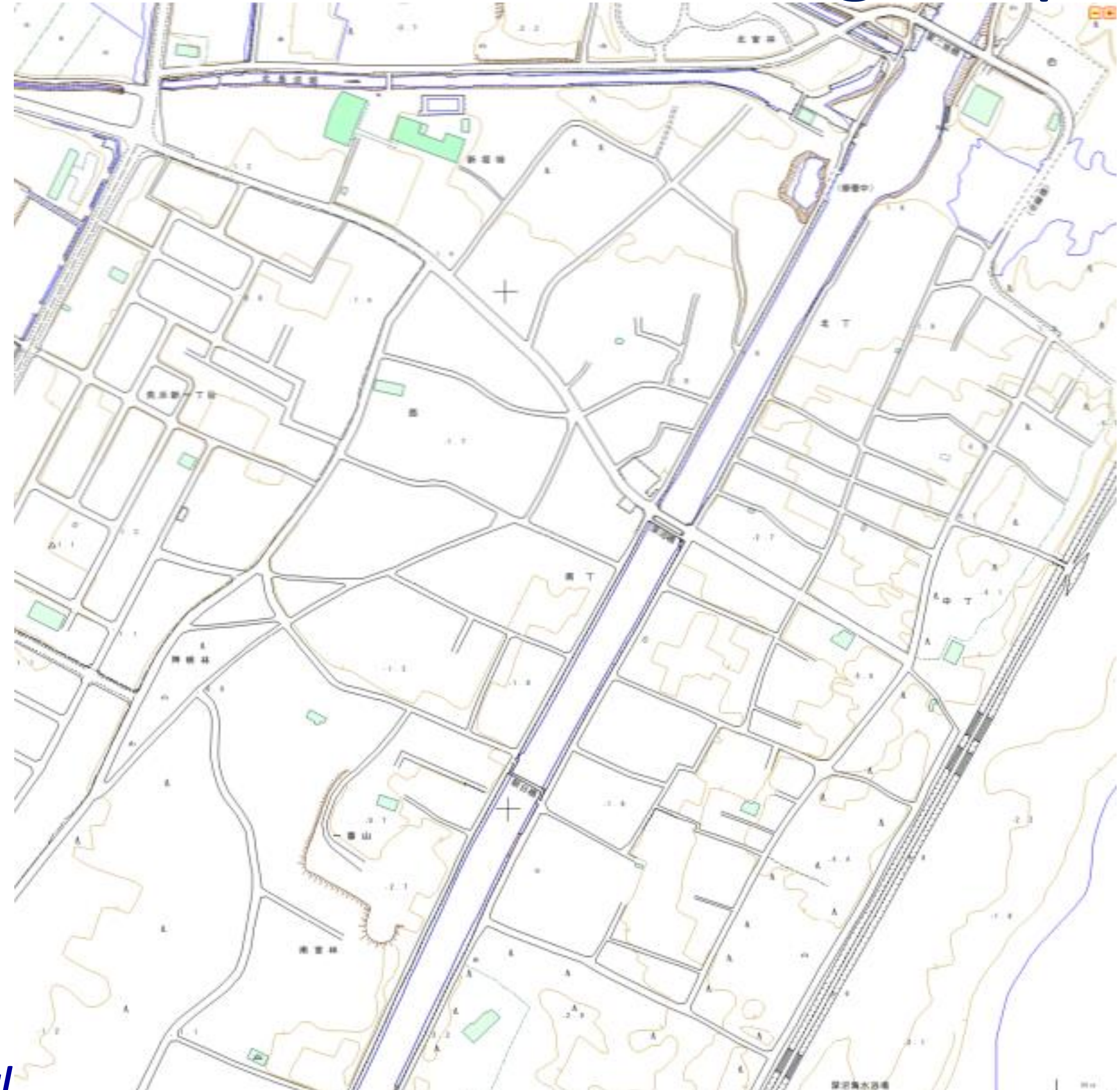


Revision completed in less than seven months after the earthquake.



Elevation of benchmarks

Reconstruction Planning Map



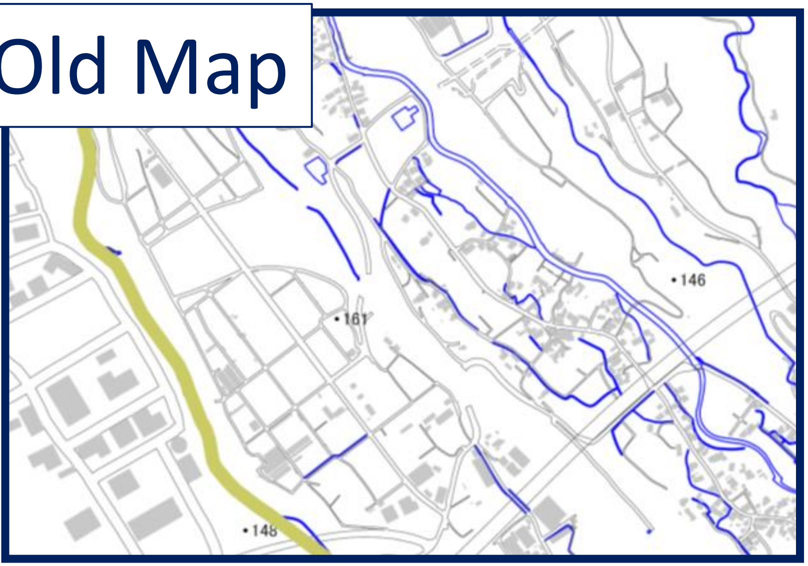
Geospatial

Improved Preparedness

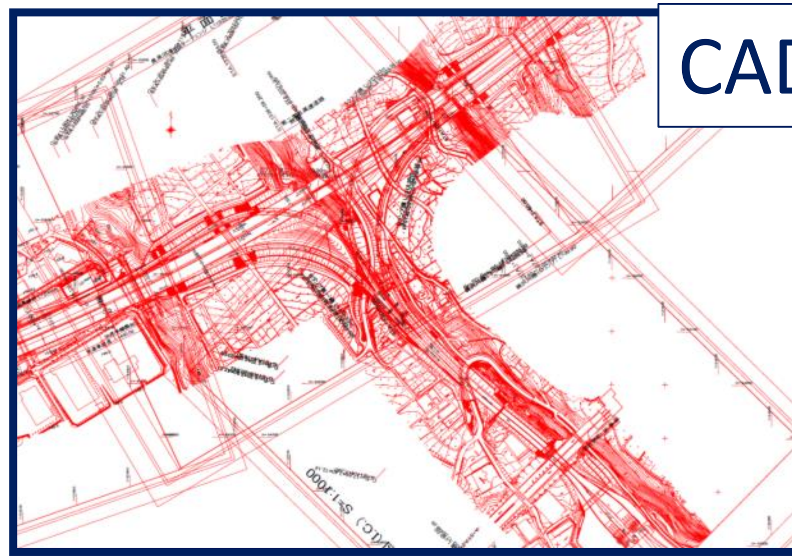
Digital Archives of Maps and Photos

Map Revision

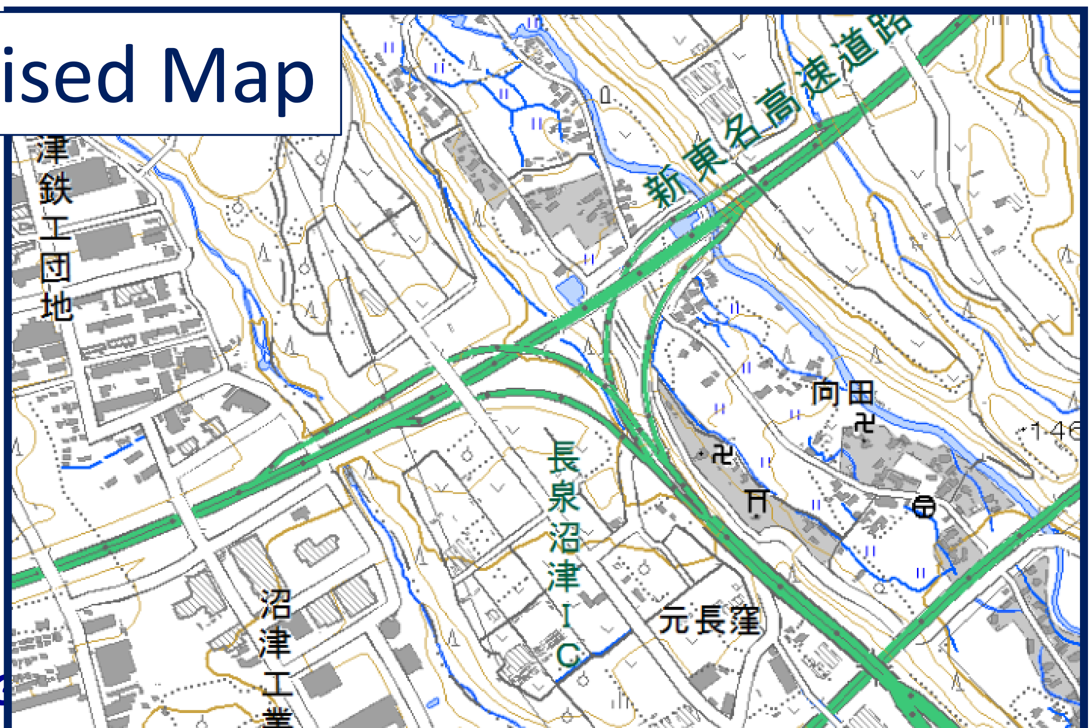
Old Map



CAD



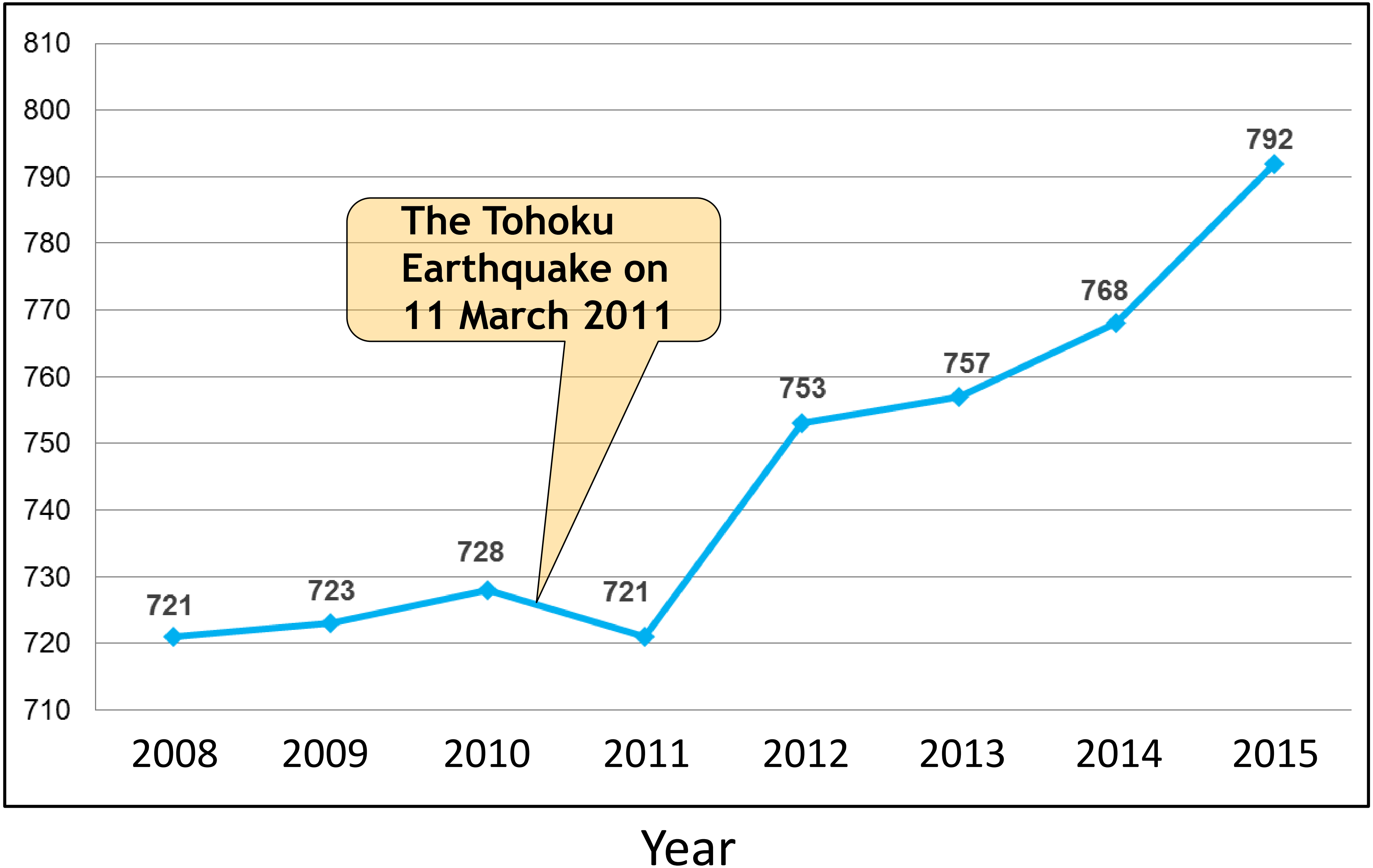
Revised Map



Web Map

The revised map is made available on the web on the same day the road is made available to the public.

Number of Municipalities Conducting Cadastral Survey



* The data of end of 2014 and end of 2015 are estimated values

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Completed Cadastre Facilitates Reconstruction

Coastal Areas

Relocation

Inland Areas of Higher Elevation

Benefits of Cadastral Survey

With pre-existing cadastral data

\12 M,
0.7 year

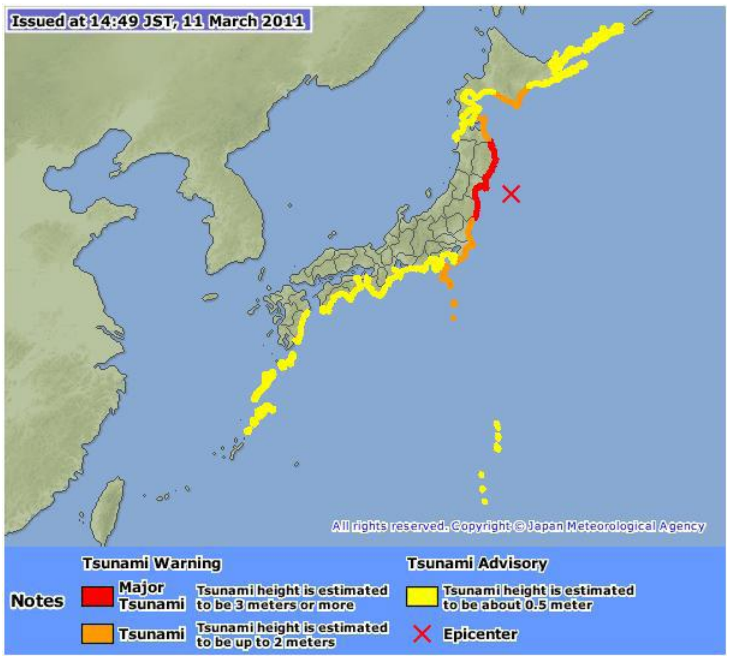
Saved : \10 M
0.5-1 year

\22 M,
1～1.5 year (estimated)

Without pre-existing cadastral data

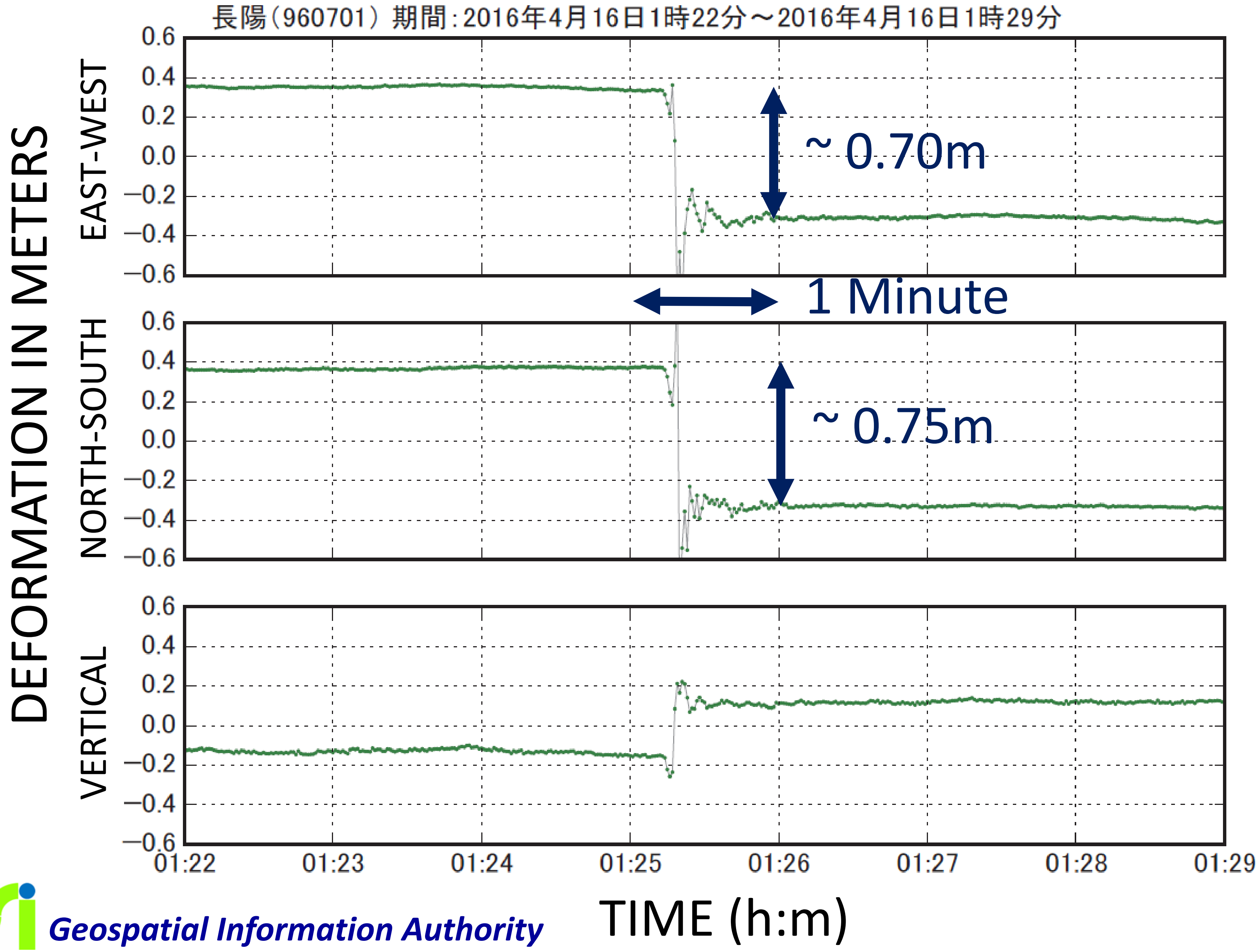
The cost for relocation was reduced by \10 M and the time cut by 0.5-1 year.

Real-time Analysis of CORS Network for More Accurate Tsunami Warning



- Initial tsunami warning (**up to 6m** in wave height) issued by the Meteorological Agency was too low due to the saturated seismic wave data by seismometers.
  - Real height was **up to 15m**.
  - Highest elevation reached by tsunami was 43m.
- Real-time analysis of CORS network to estimate the magnitude of large earthquakes can estimate tsunami wave height without saturation in a few minutes.

Real-time CORS Analysis of Kumamoto Earthquakes



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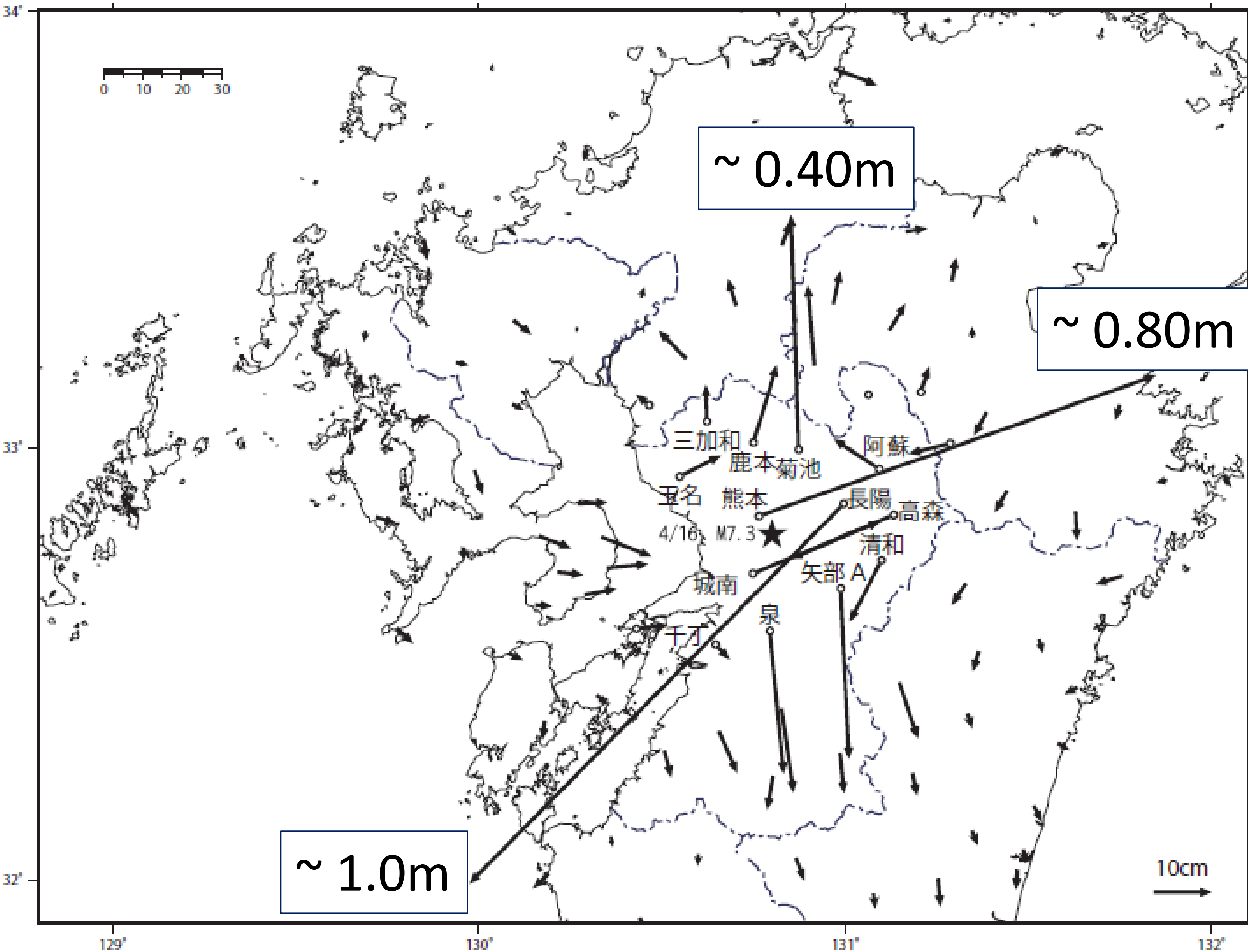
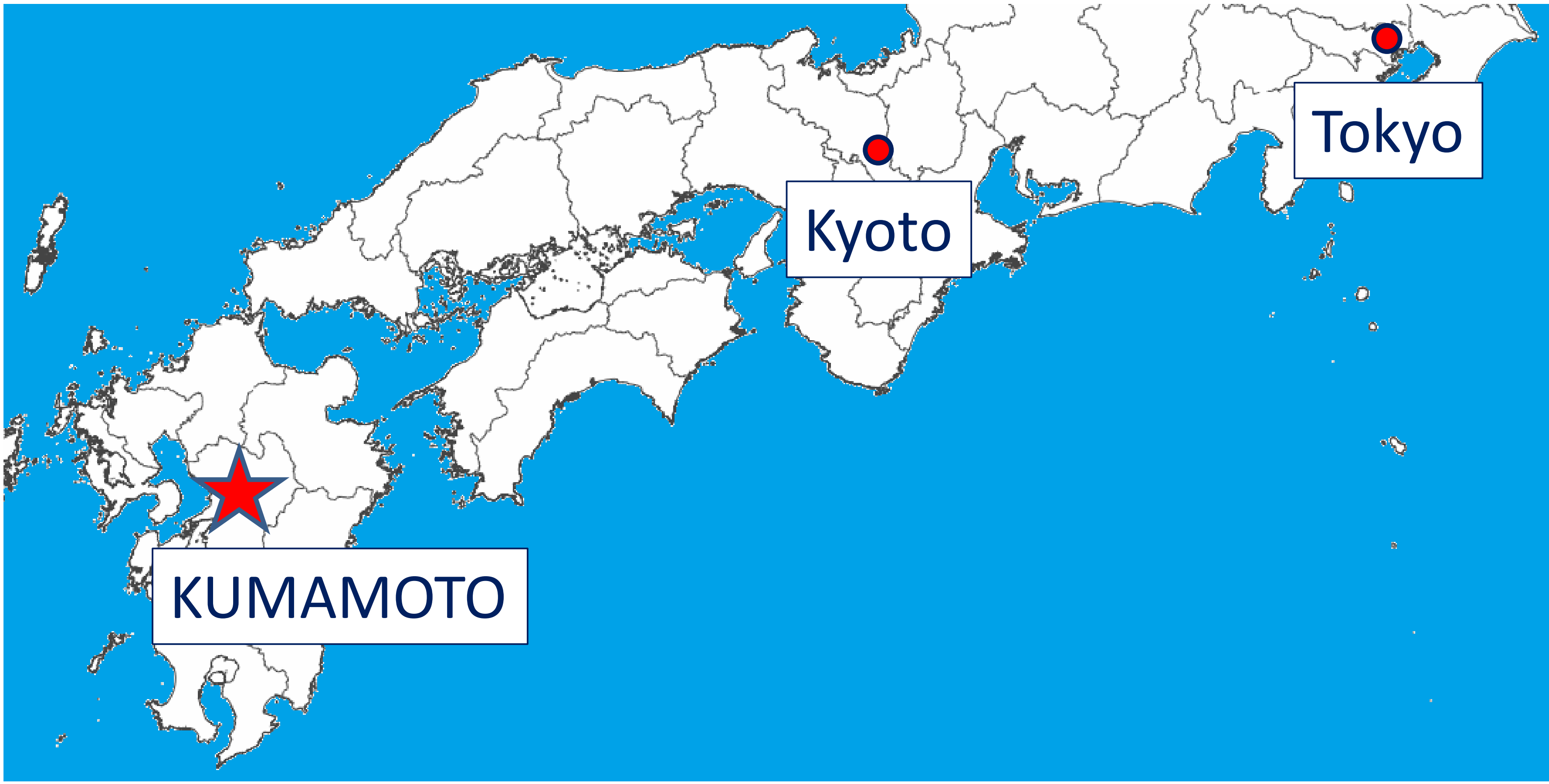
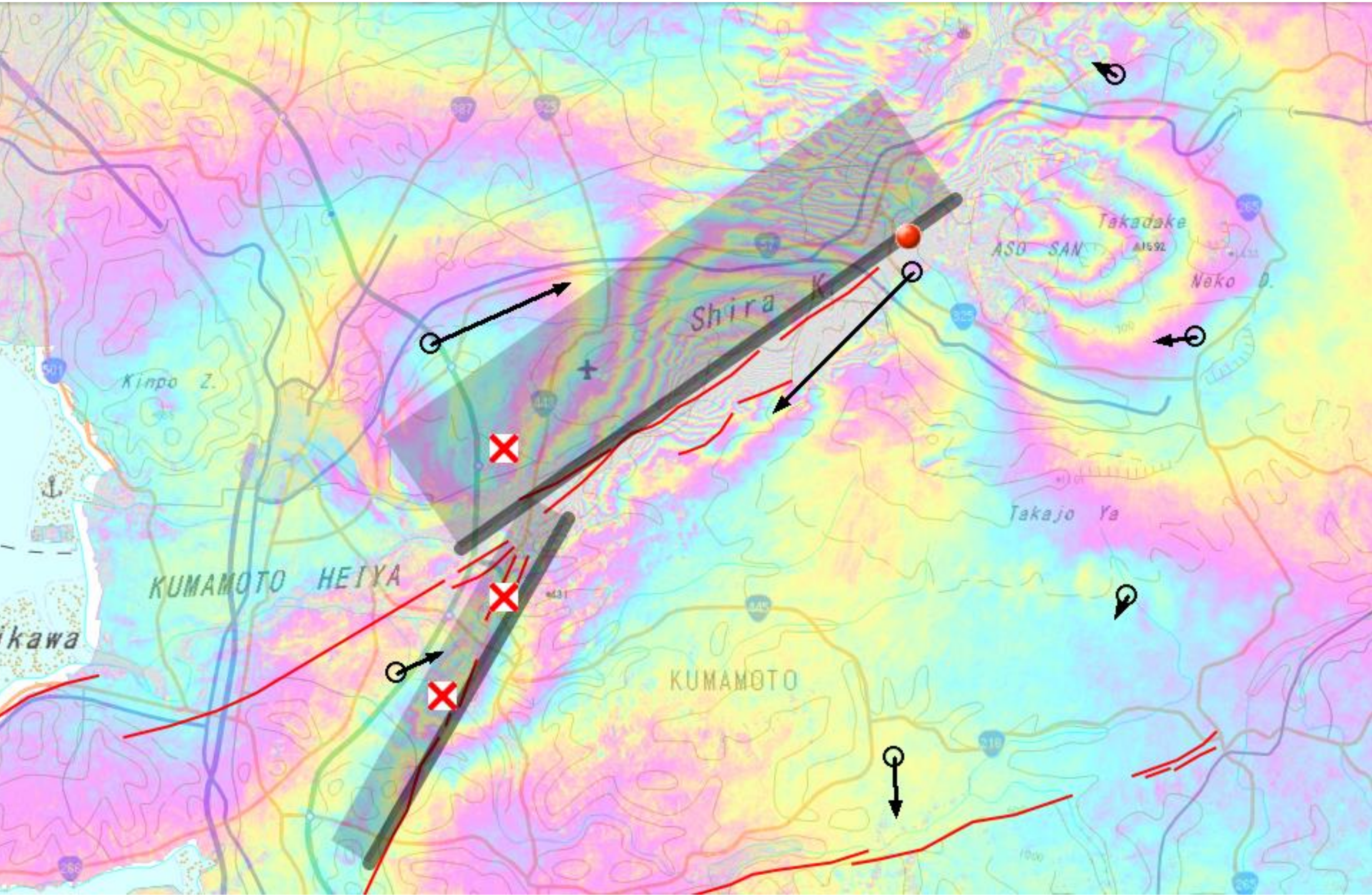
Real-time CORS Analysis of Kumamoto Earthquakes



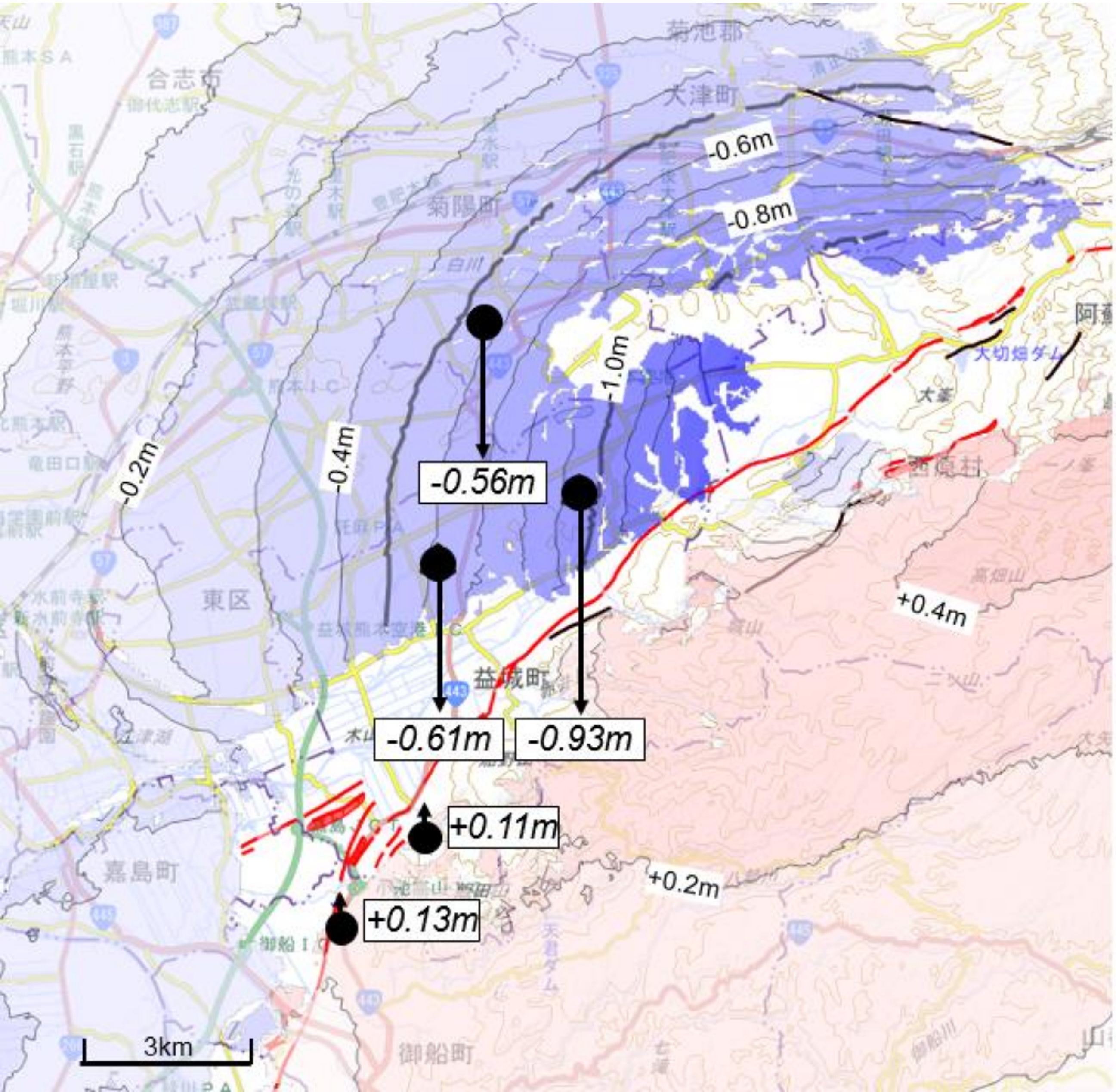
Kumamoto Earthquakes (14-16 April 2016)



CORS Data Analysis/Modeling and ALOS-2 InSAR Analysis



InSAR (ALOS-2) Analysis in 2.5 Dimensions



- InSAR data from two different directions were used to estimate near vertical deformation.
- The result was compatible with GNSS survey on the ground.

Summary (What we learned)

Summary: What We Learned

- **CORS network** has crucial roles in:
  - Assessing the magnitude and extent of co-seismic and post-seismic deformation for efficient resurveying and modeling of the earthquake, particularly **when combined with InSAR analyses**.
  - Providing accurate control for aerial surveys.
  - Estimating the magnitude of large earthquakes and tsunami wave height near real-time.

Summary: What We Learned

- Cooperation with private aerial survey companies provides emergency aerial survey activities in large-scale disasters.
- Digital archives of past aerial photos and maps help quickly assess the magnitude and extent of disaster damage.
- Maps need to be updated, particularly for transport information, to facilitate emergency responses.
- Completed cadastre helps streamline post-disaster reconstruction processes.

Thank you.