Recent Advances in Prediction of Earthquakes

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GIC/AIT
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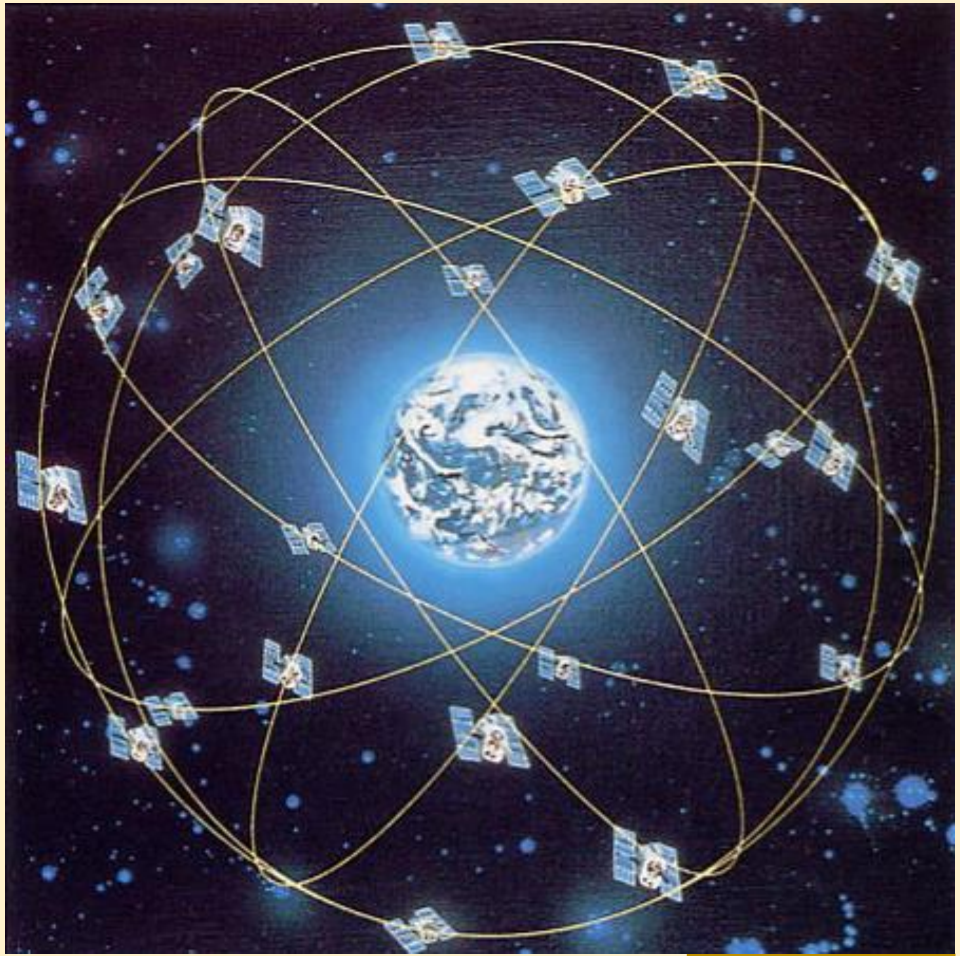


+ Introduction
+ Part 1: Review of prediction
+ Part 2: Flow of prediction with GNSS data
+ Part 3: Additional RS &GIS techniques for prediction
+ Part 4: Mini-plate theory
+ Conclusions

Introduction

+ I started research on the prediction of earthquakes since 2002 with my partner; Dr. Harumi Araki.
+ The basic prediction method depends on multi-temporal GNSS data in which abnormal signals or pre-cursors must be involved.
+ In Japan free access is available to daily GNSS data of 1,300 CORSs all over Japan.
+ I did realized very abnormal signals just before the East Japan Great EQ occurred on the 11th March 2011 with 18,000 victims mainly due to Tsunami.
+ In order to rescue human lives I invested to establish a private company namely JESEA in 2013.

Part 1: Review of Prediction of Earthquakes

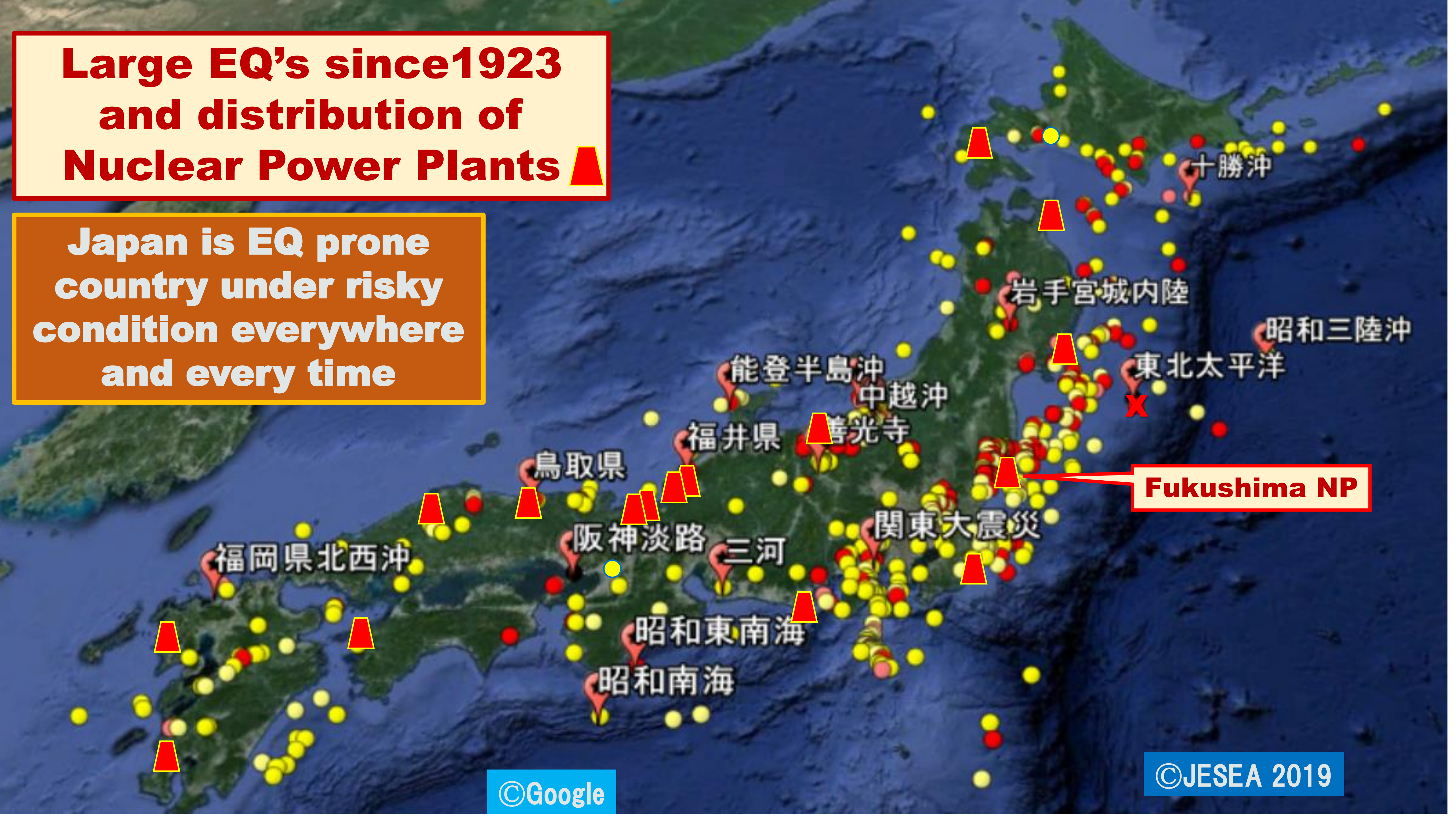
- **No 1**: Nobody has succeeded the prediction of earthquakes in the human history. It is a challenging theme in the latter half of my life.

- **No 2**: Though so many people died in the past history of Japan due to huge earthquakes; 30 times with more than one thousand victims in the past 400 years, Japanese government and seismic scientists gave up the prediction of earthquakes in 2012 after many unreliable trials spending huge budget.

- **No 3**: Conventional prediction method in Japan only relies on information about seismographs, active faults and the past record of giant earthquakes, which are analyzed with statistical and provability model. The method is unreliable!

Large EQ's since1923 and distribution of Nuclear Power Plants

Japan is EQ prone country under risky condition everywhere and every time



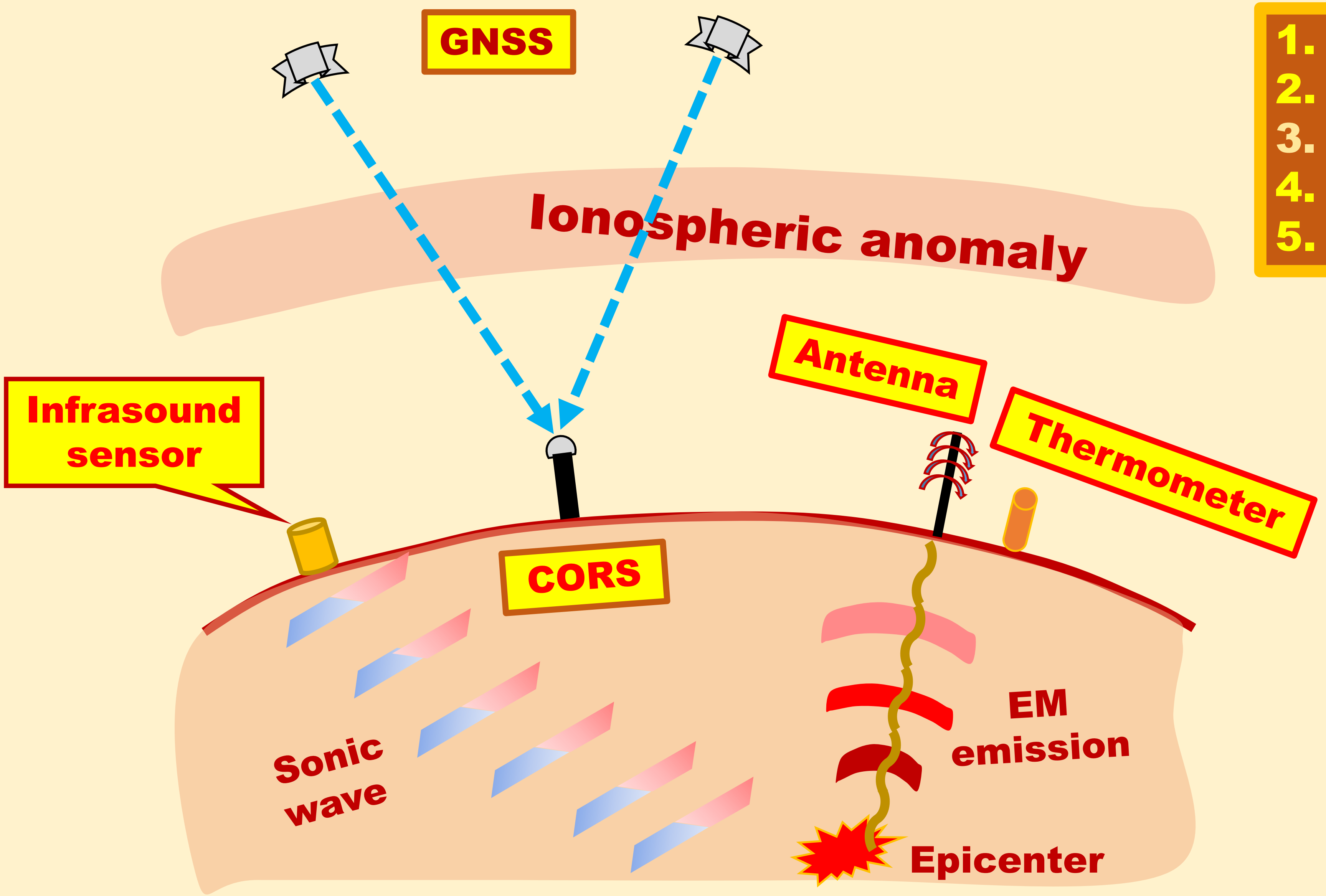
What should be the key for prediction?

- No.1: Remote sensing method should be applied to detect macroscopic anomalies or pre-signals in advance to occurrence of earthquakes. We need time series of scientific observation data covering whole area. The existence of the pre-signals has been verified by my research in 2007.

- No.2: Quantitative correlation between anomalies of observation data and the occurrence of earthquakes should be developed.

- No.3: The anomalies should be analyzed and visualized using GIS techniques and artificial intelligence for better understanding for risky areas.

Macroscopic Phenomena before earthquakes



1. Crustal Change
2. Infrasound anomaly
3. ELF emission anomaly
4. Temperature anomaly
5. Ionospheric anomaly

Part 2: Flow of prediction with GNSS data

Download of GNSS data from GSI database

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Data filing in EXCEL and graphic representation

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Detection of anomalies

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Visualization of anomalies

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Judgement and mapping of risky areas

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Preparation of documents

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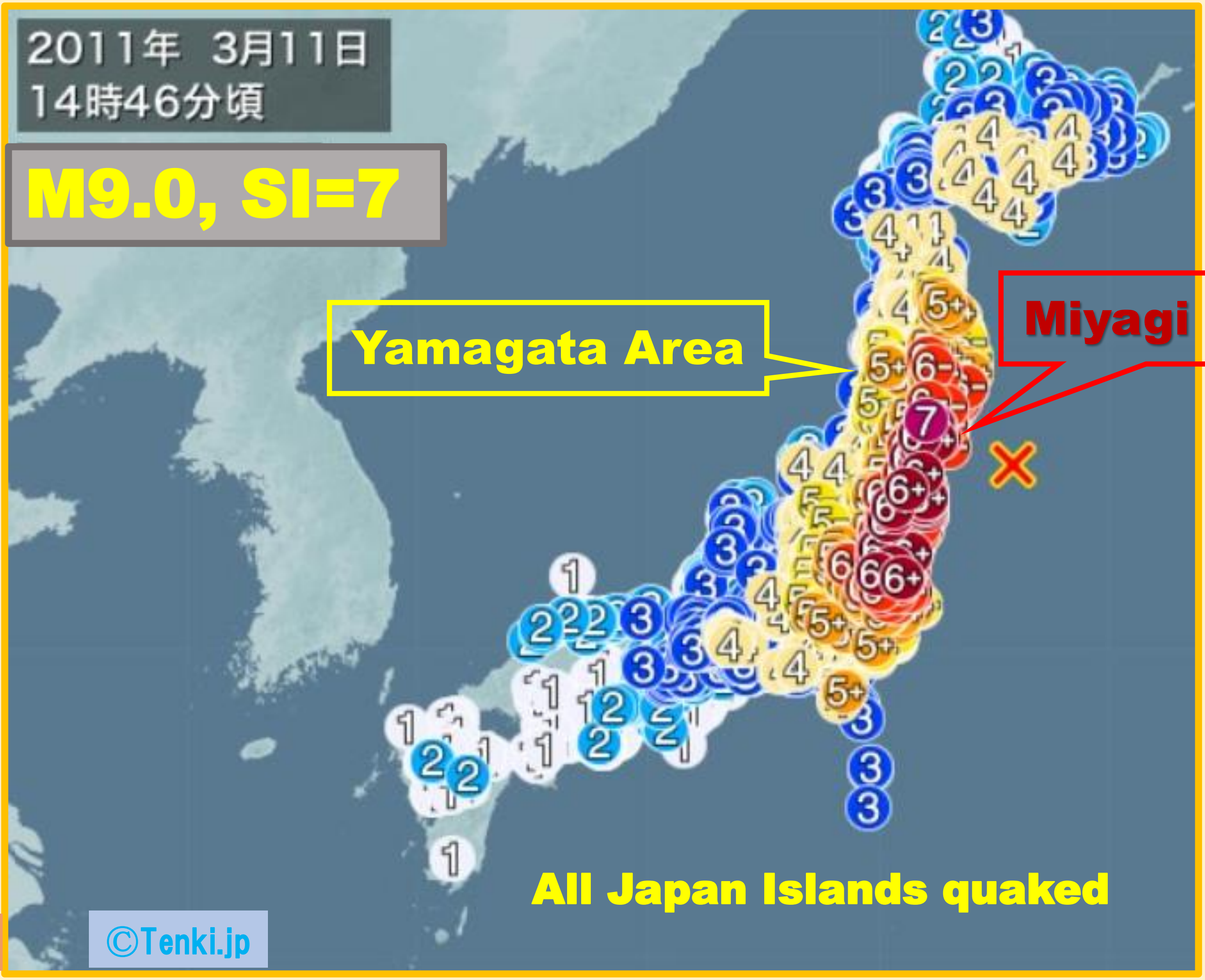
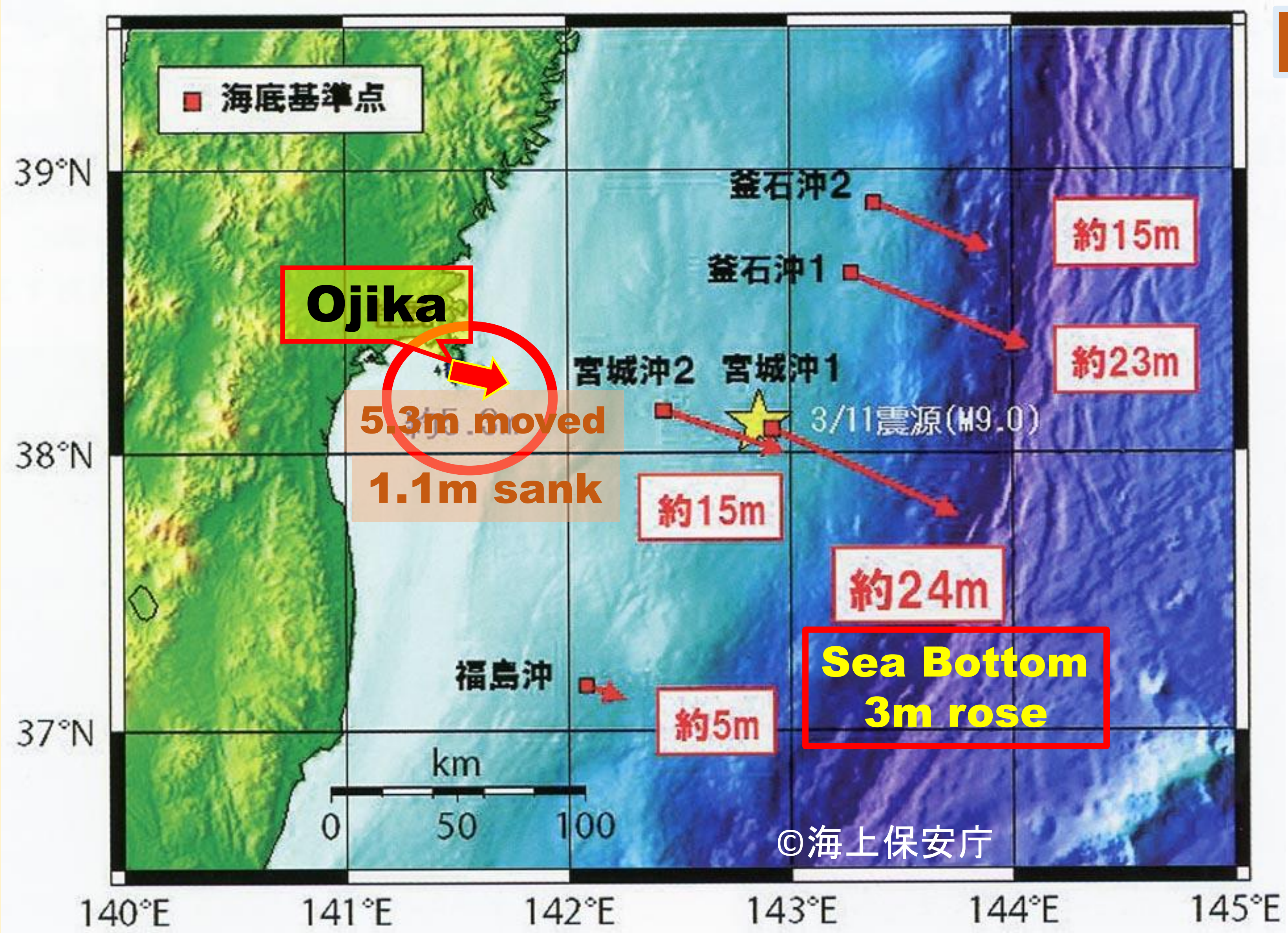
Dissemination of MEGA EQ Prediction

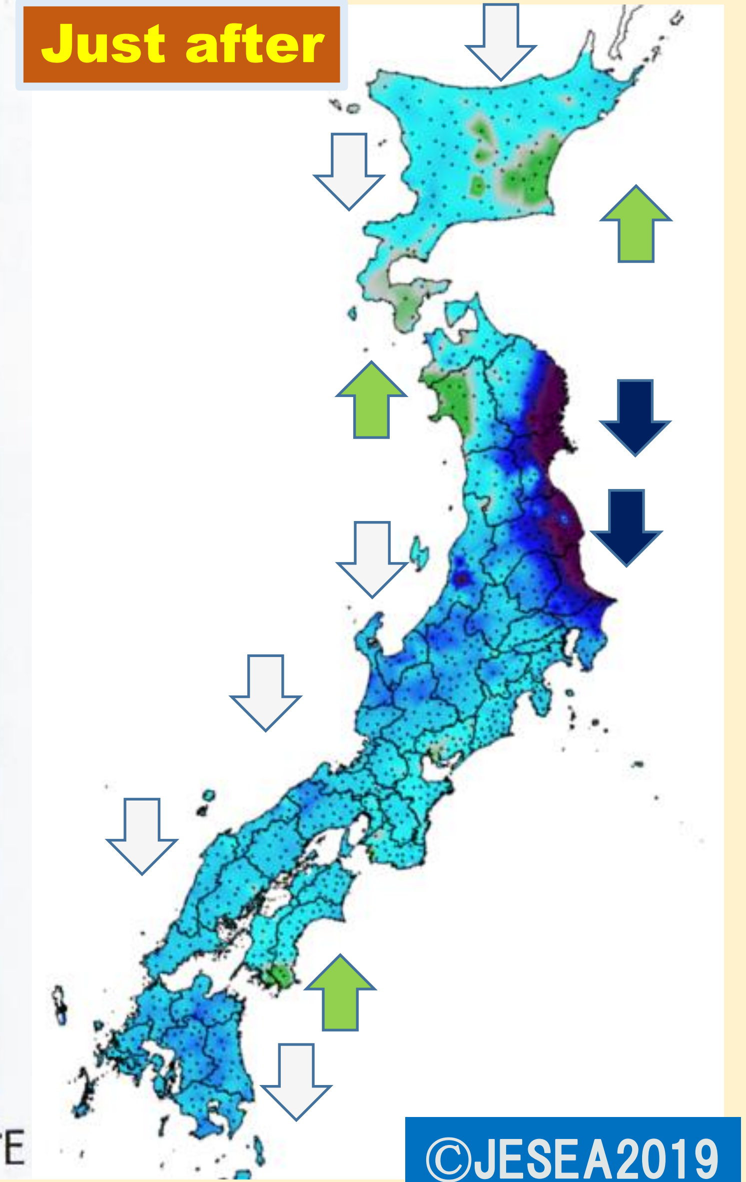
East Japan Great EQ: 2011/3/11 M9.0, SI=7

Damage due to Tsunami

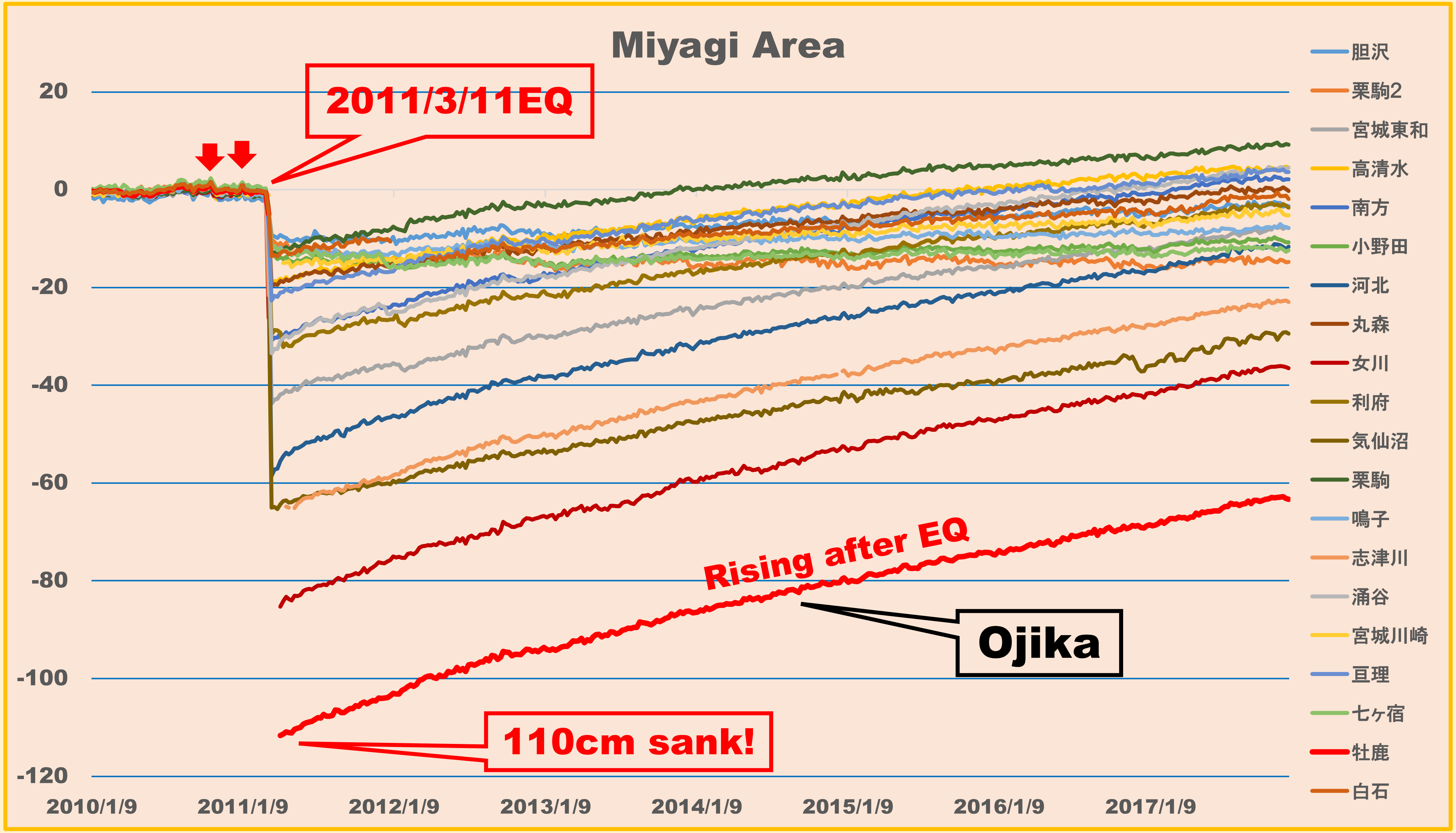


What were the movements at 2011/3/11 EQ？

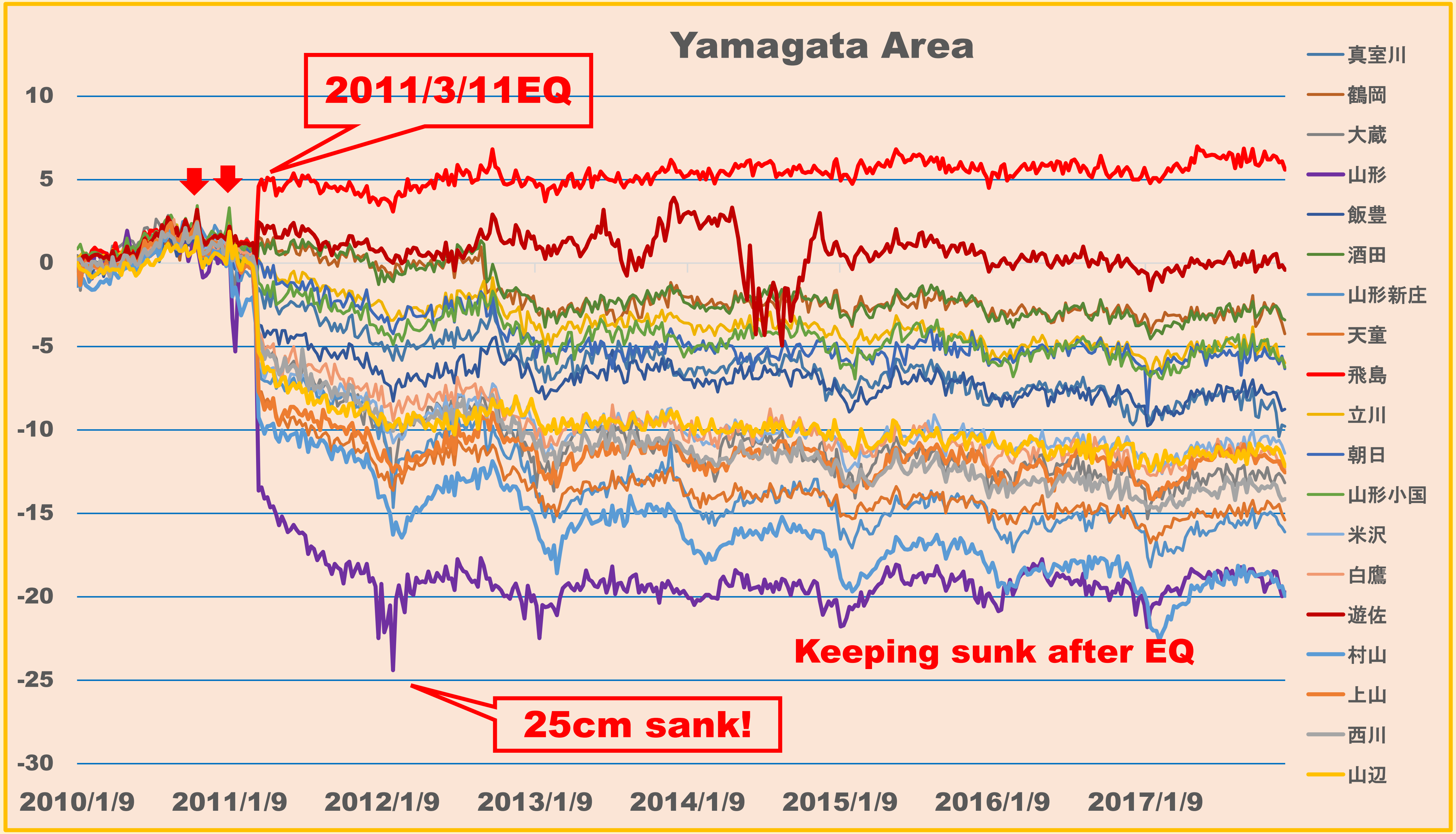




Height Change in Miyagi Area, Tsunami hit area: 2010-2017



Height Change in Yamagata Area near Japan Sea: 2010-2017



Scientific findings for prediction with GNSS data

+No.1: The Earth is moving always about 5mm to 1cm vertically and horizontally in normal condition but moves abnormally in advance to large earthquake without knowing the reason.

+No.2: Abnormal movement and variation will not be only one pattern but vary case by case. Earthquake is very complicate phenomenon.

+No.3: Sinking tendency would be more risky than rising tendency to induce earthquakes.

+No.4: The time span between pre-signal abnormality and actual occurrence of earthquake ranges a few weeks to few months.

Prediction method by crustal change with GNSS data

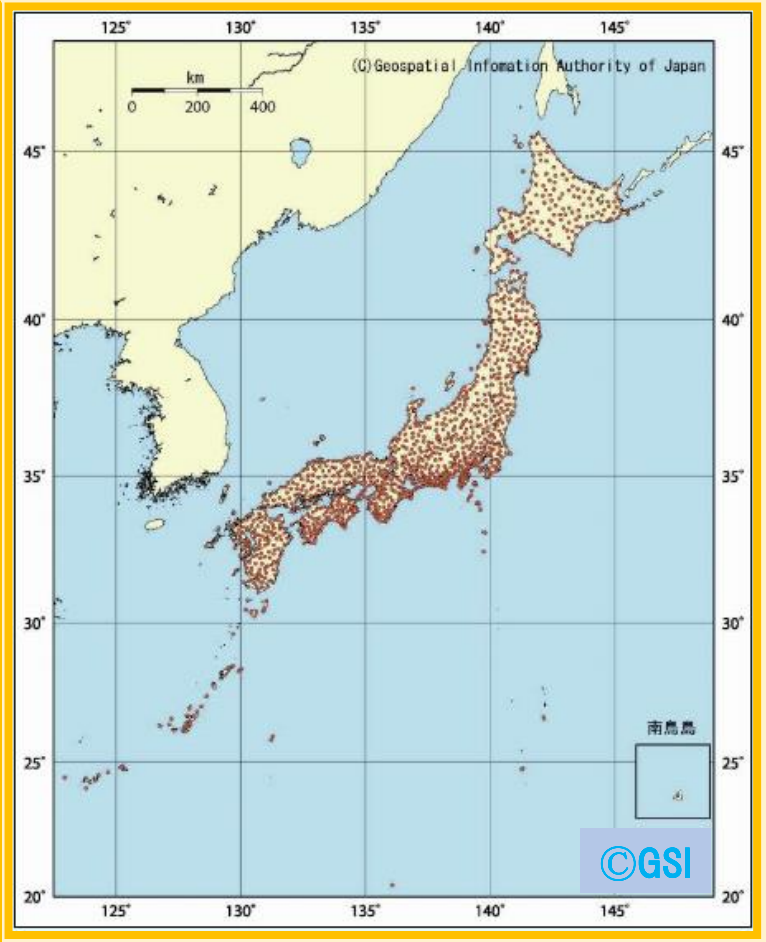
GSI's CORS: Daily XYZH

+ **Short term anomaly**
  - **# Weekly vertical change**
  - **# Monthly horizontal change**
+ **Long term anomaly**
  - **# Two year up-down tendency**
  - **# Accumulated stress**

JESEA's own CORS

+ **Real time anomaly**
  - **# hourly XYZH change**

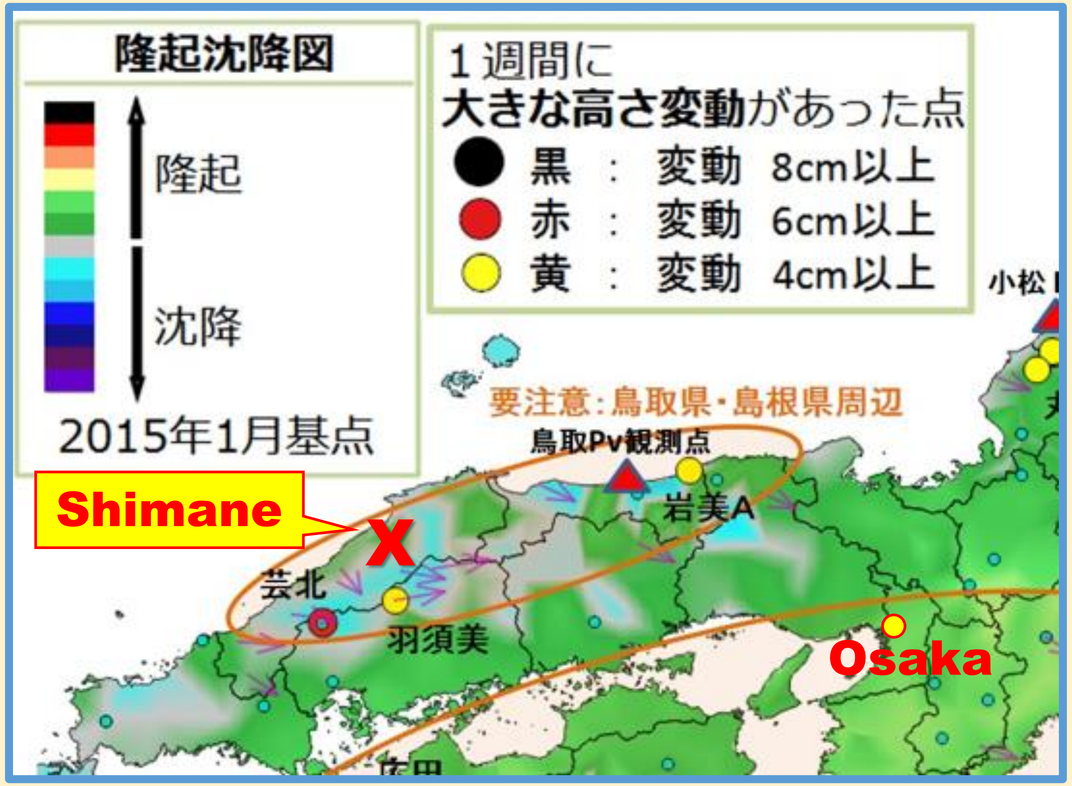
GSI CORS



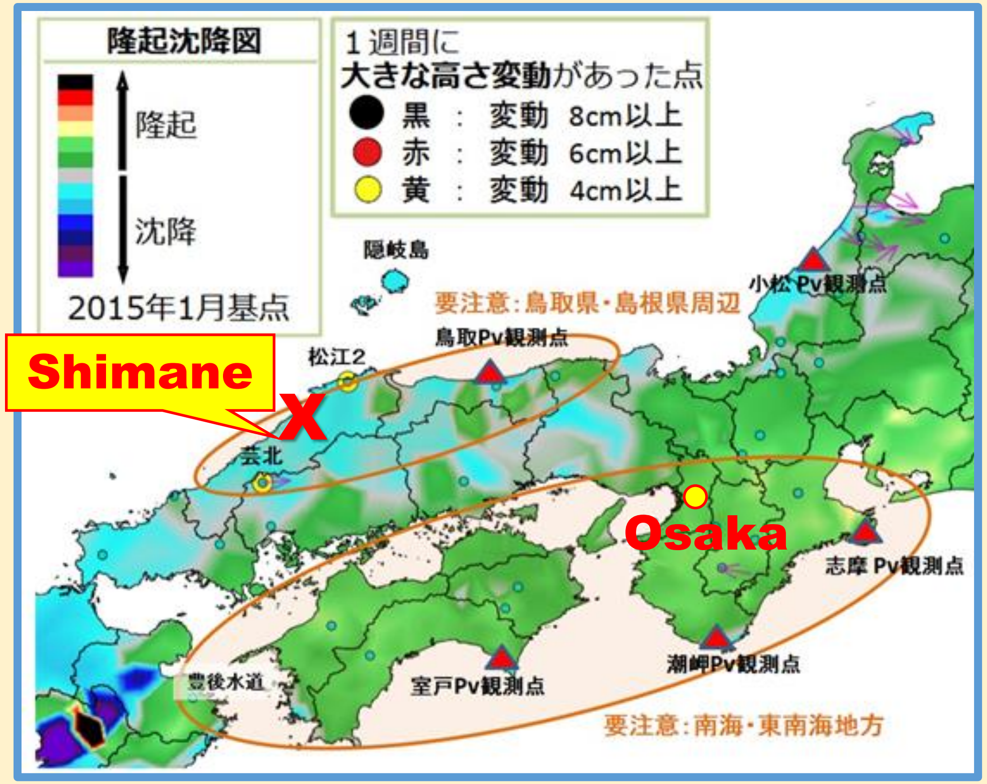
Distribution of CORS

Prediction examples with correct judges

Example 1: West Shimane Pref. 2018/4/9 M6.1 SI=5+



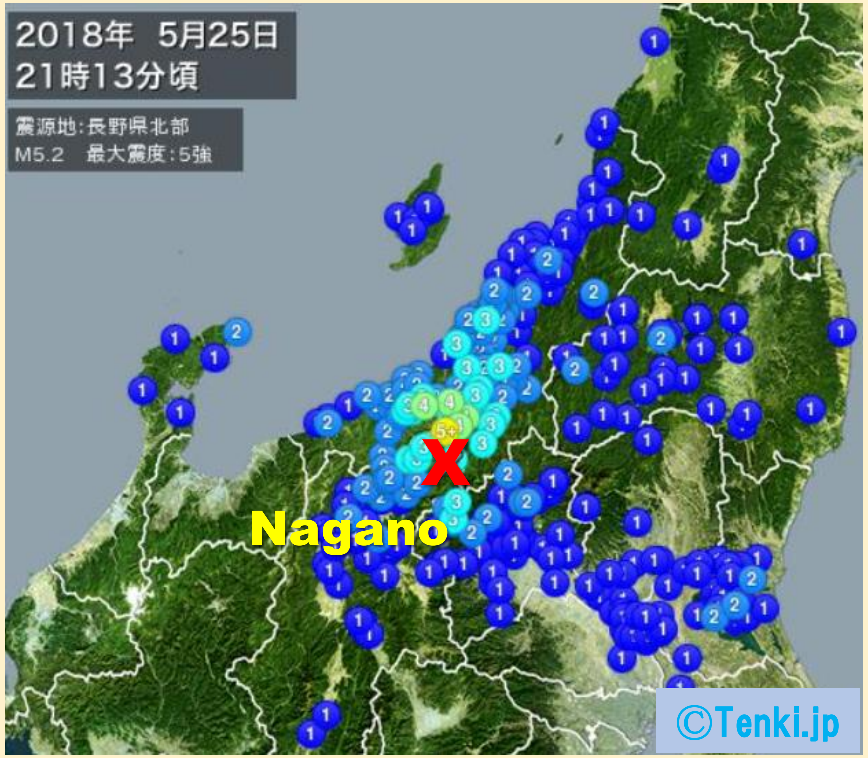
2 months before:
Weekly vertical anomaly



1 month before:
Weekly vertical anomaly

Prediction examples with correct judges

Example 2: North Nagano Pref. 2018/5/25 M5.2 SI=5+

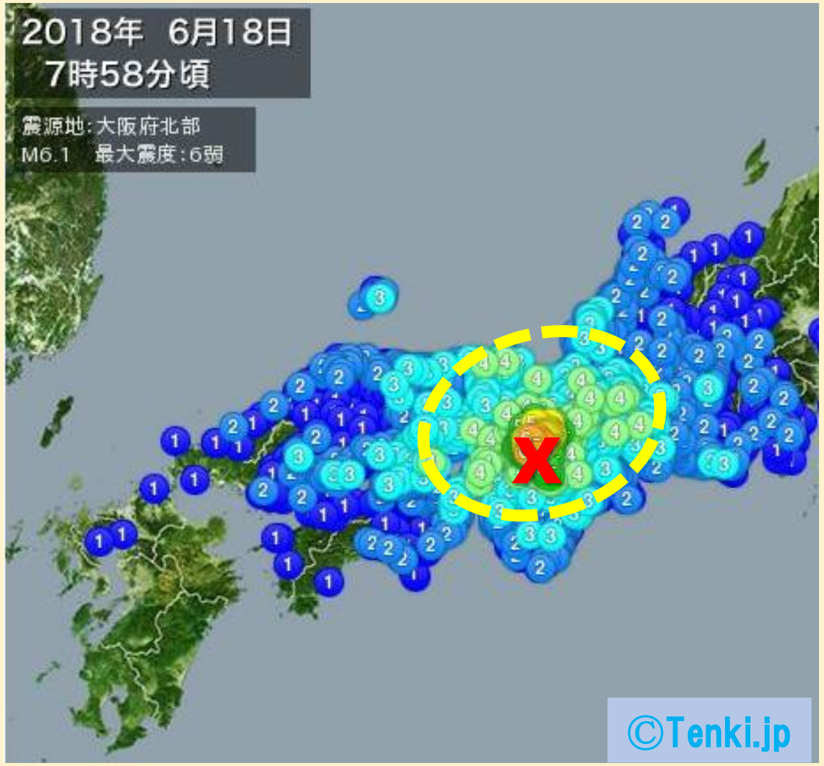


Japanese SI= 5+

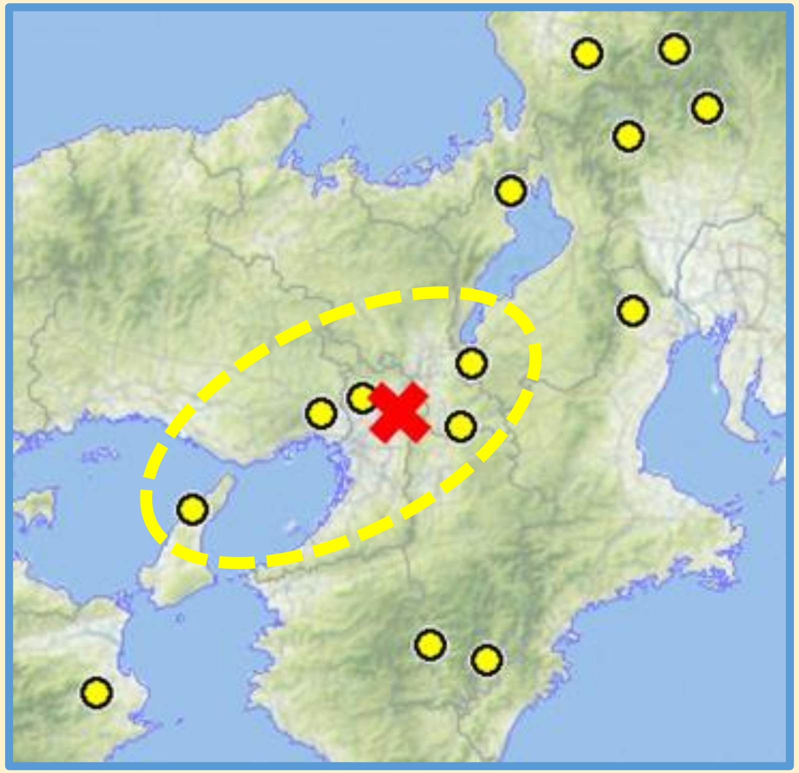
3 months before:
Weekly vertical anomaly with more than 6cm

Prediction examples with incorrect judges

Example 3: North Osaka 2018/6/18 M6.1 SI=6-



Japanese SI= 6-

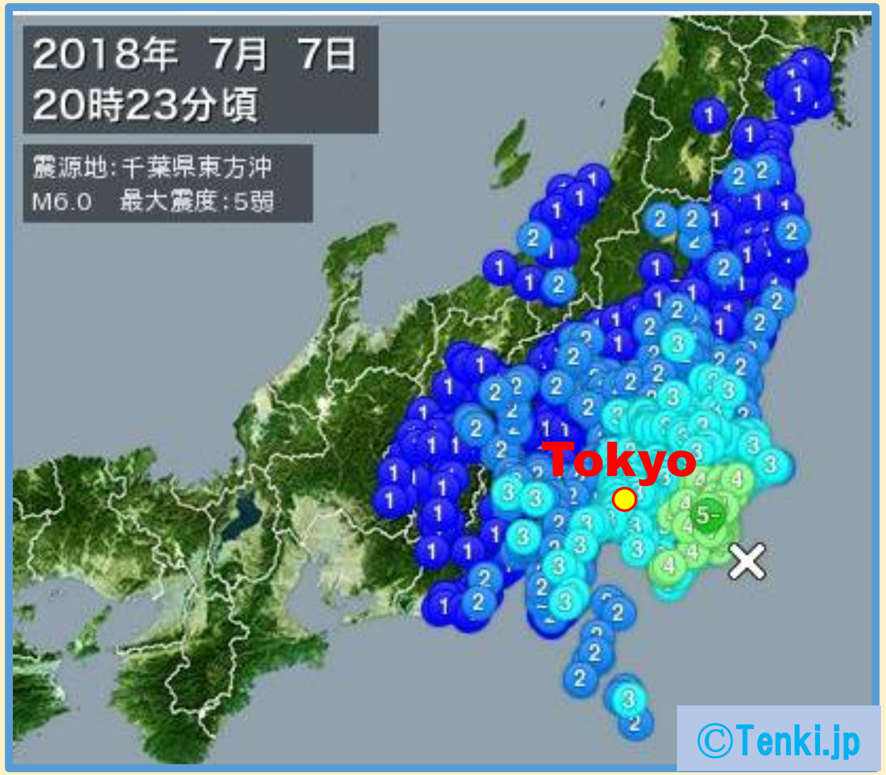


2 weeks before:
Weekly vertical anomaly with more than 4cm

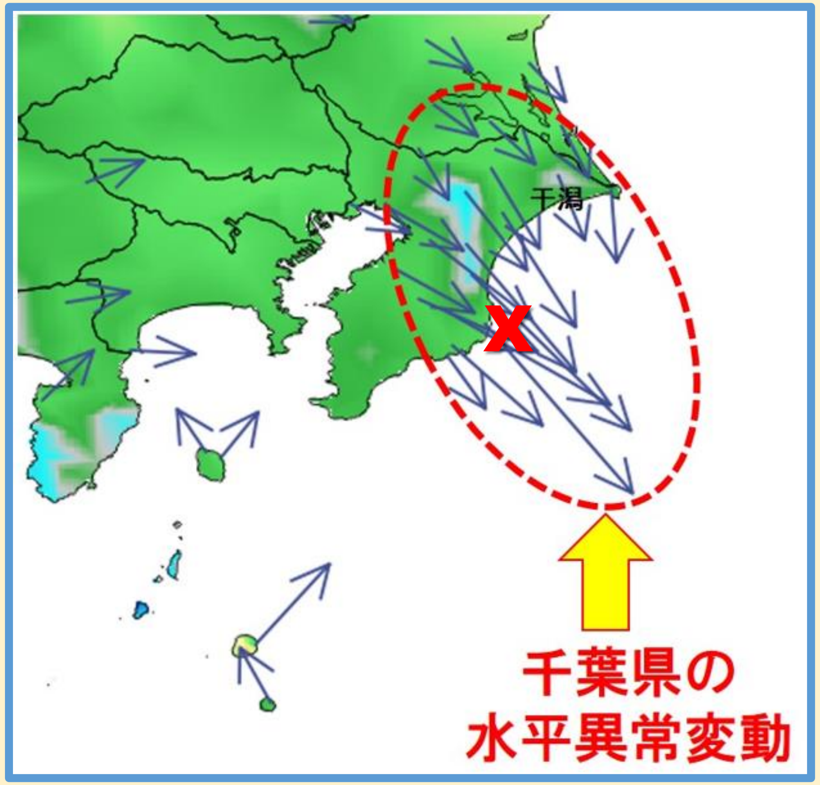
Weekly vertical anomaly with more than 4cm was recognized but data were released just on the day of occurrence. As the result the prediction was unable in time.

Prediction examples with correct judges

Example 4: East Chiba 2018/7/7 M6.0 SI=5-



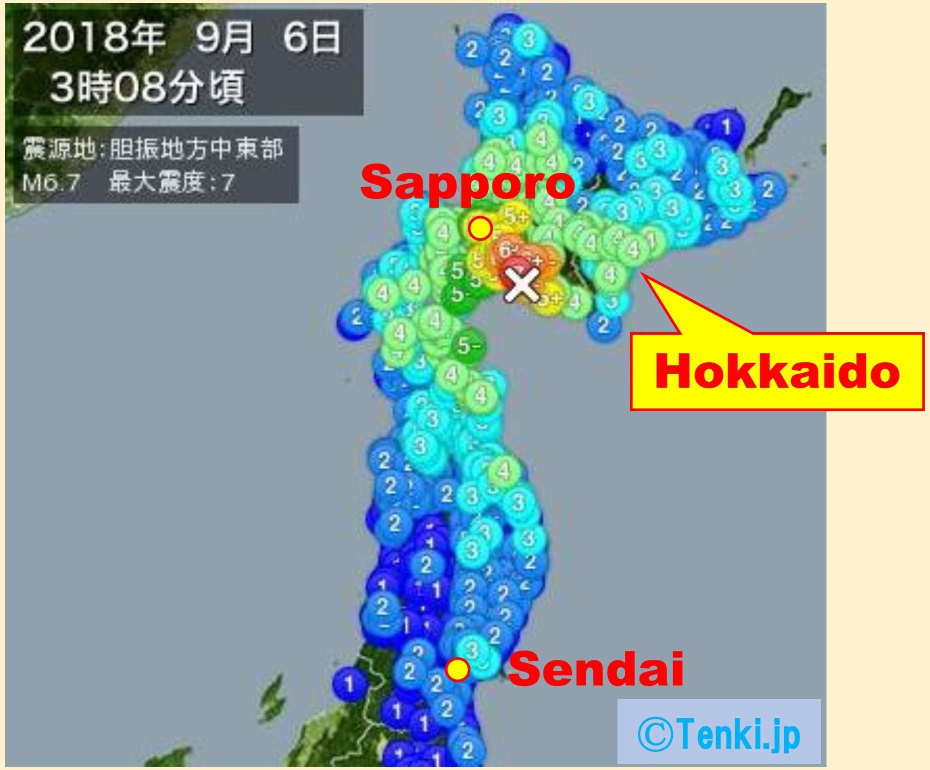
Japanese SI= 5-



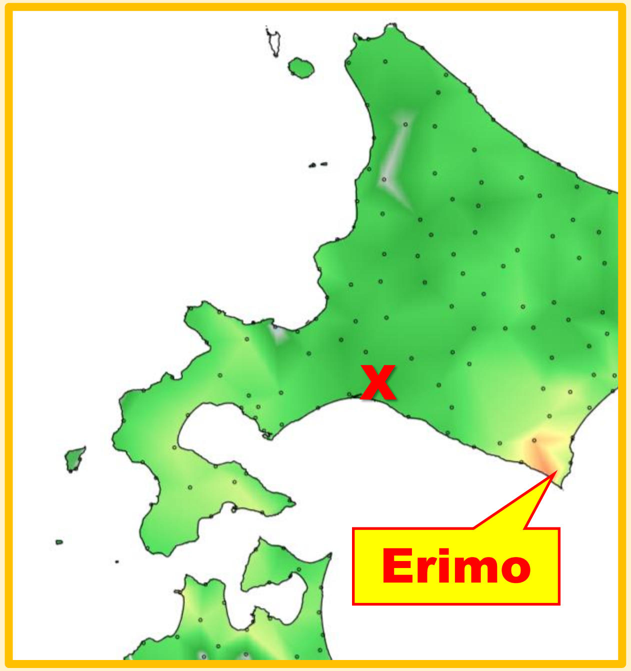
10 days before:
Weekly horizontal anomalies were concentrated

Prediction examples with correct judges

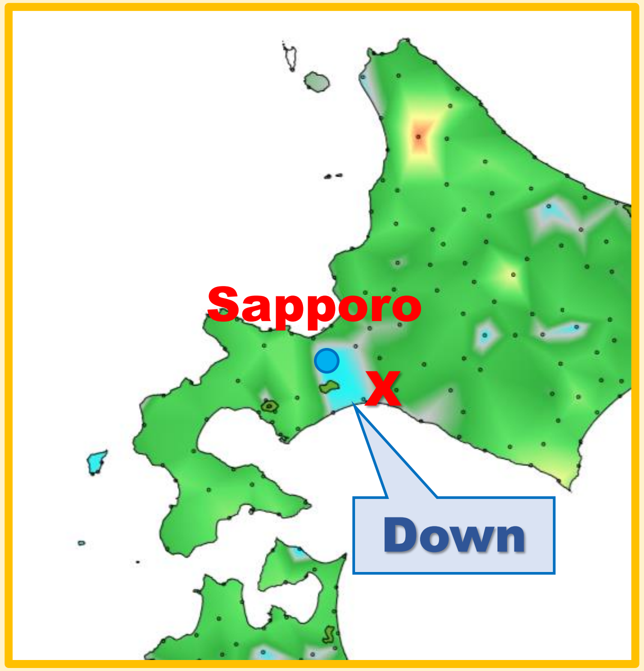
Example 5: Hokkaido 2018/9/6 M6.7 SI=7



Japanese SI= 7



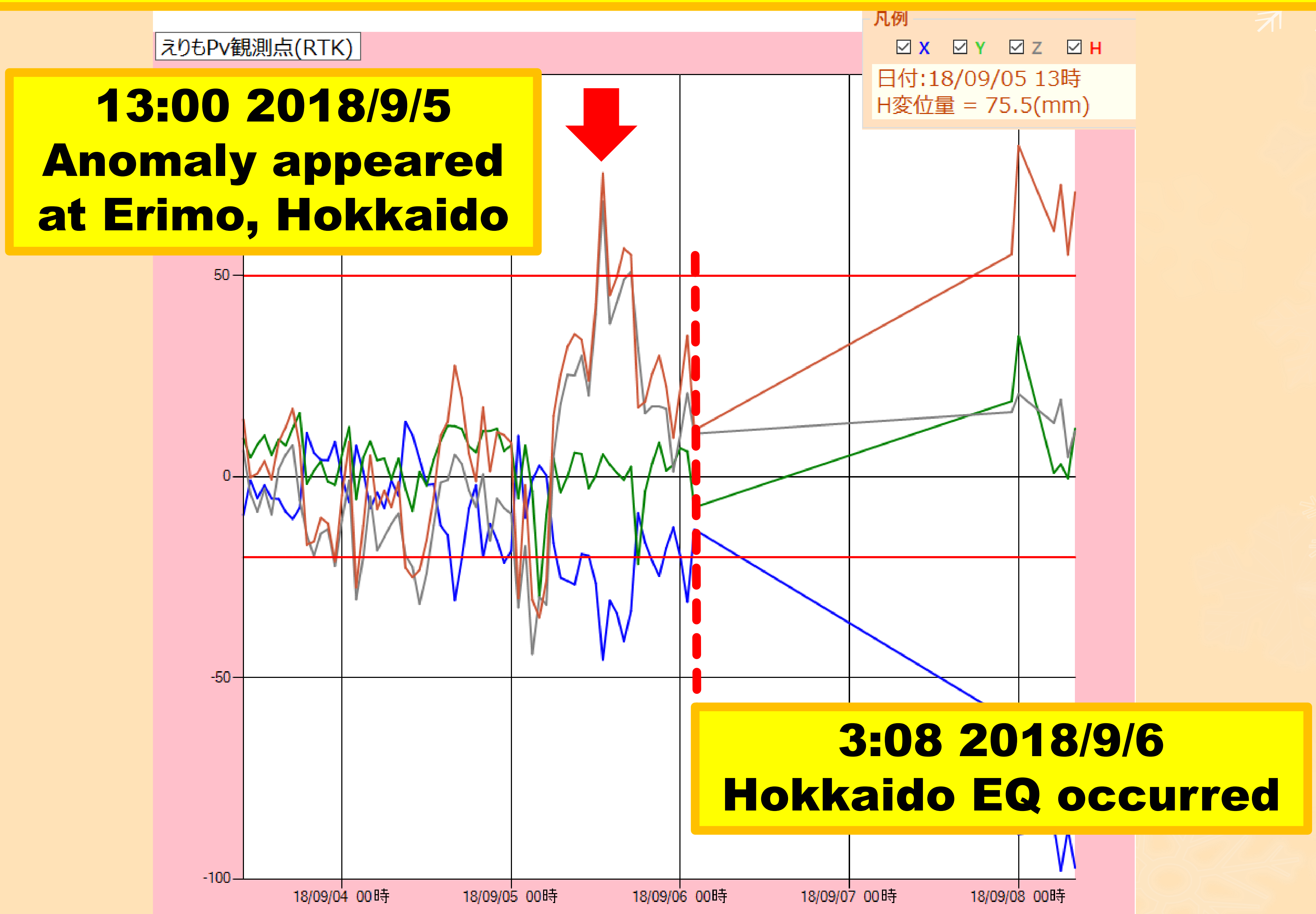
6 months before



1 month before

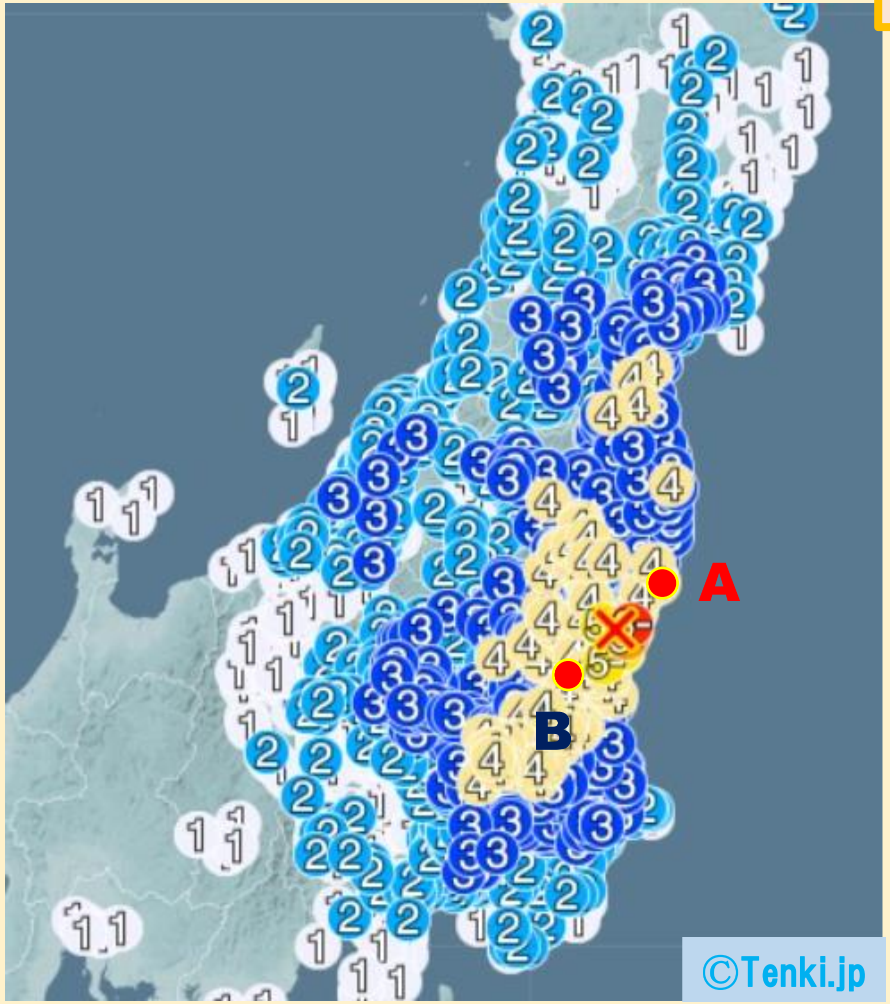
1 month before:
Monthly vertical anomalies of down tendency

Anomaly appeared on the 5th September, 14 hours before EQ!

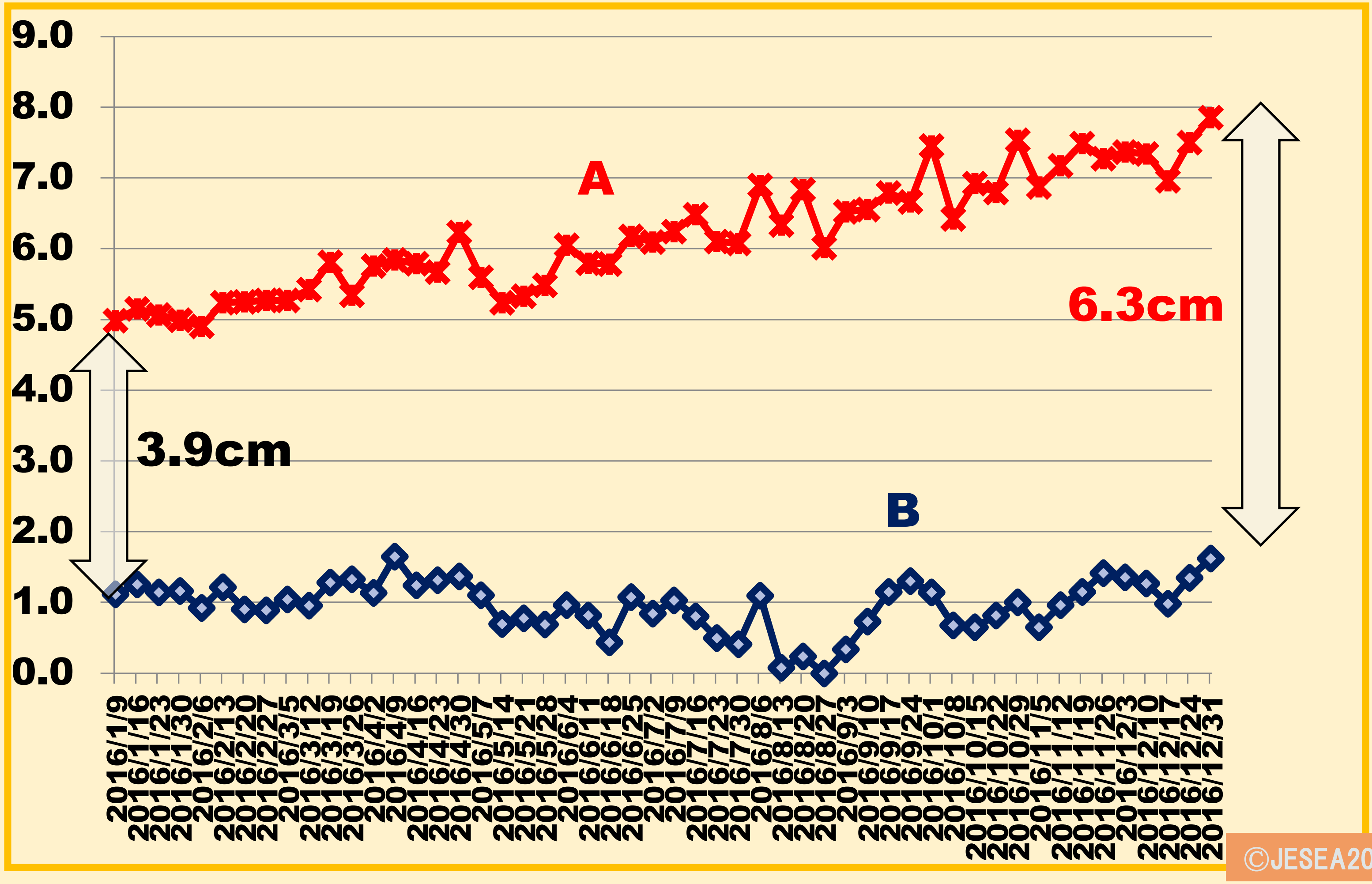


Prediction examples with correct judges

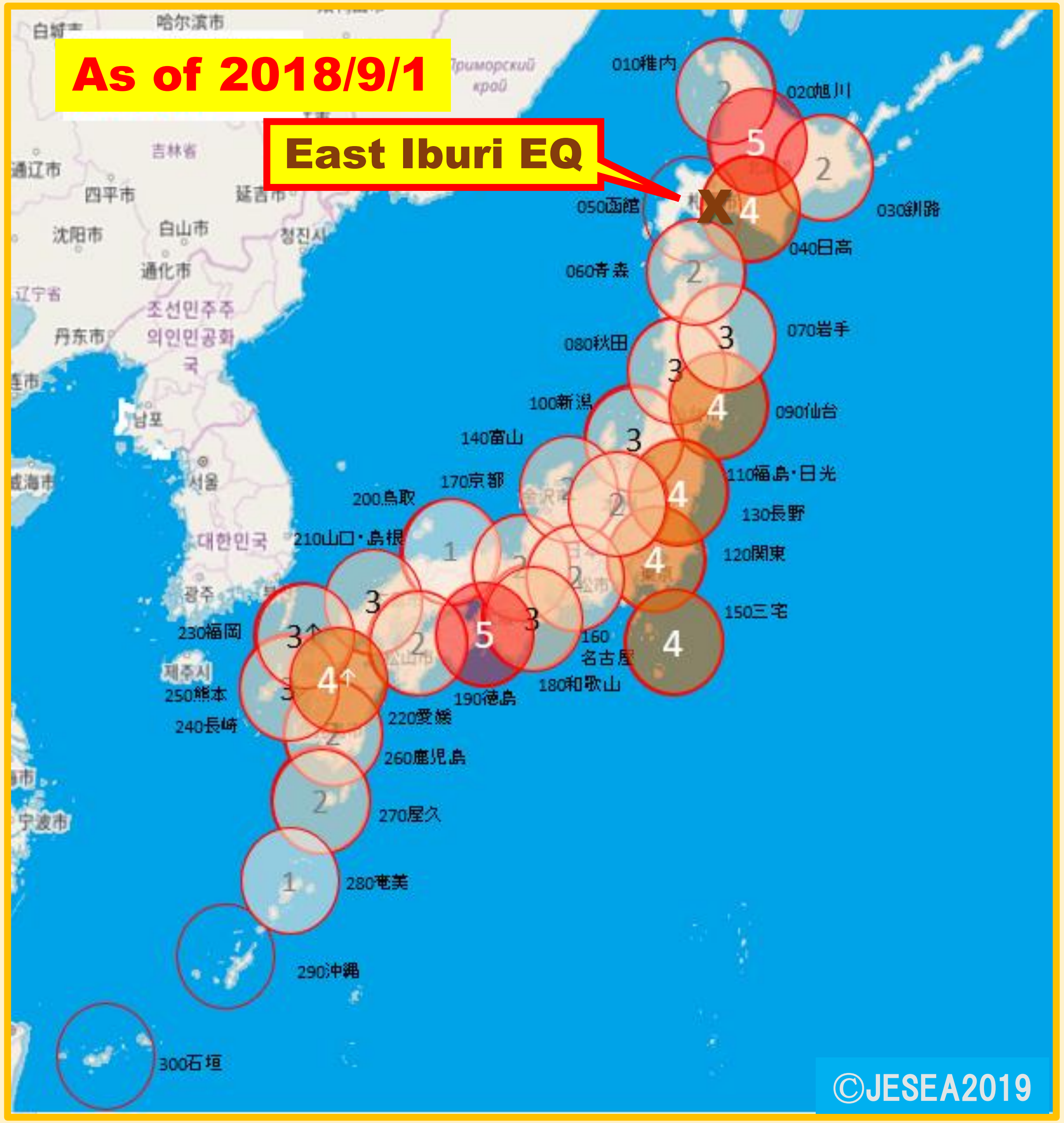
Example 6: North Ibaragi 2016/12/28 M6.3 SI=6-



It is risky if height difference exceeds 6cm



Sample of AI based risk map



Hokkaido East Iburi EQ occurred on 2018/9/6 (M6.7, SI=7) in the risky level 4 of AI risk map

Ratio of correct prediction of earthquakes 2013-2018

	2013年	2014年	2015年	2016年	2017年	2018年	Total
Correct ○	3/9=33.3%	5/8=62.5%	5/10=50.0%	6/10=60.0%	5/8=62.5%	5/9=55.5%	29/54=53.7%
Almost △	5/9=55.5%	2/8=15.0%	4/10=40.0%	4/10=40.0%	2/8=25.0%	0/9=0%	17/54=31.5%
Incorrect ×	1/9=11.1%	1/8=12.5%	1/10=10.0%	0/10=0.0%	1/8=12.5%	4/9=44.4%	8/54=14.8%

Definition

Correct: Within 3 months from anomality, EQ occurred

Almost: Within 6 months from anomaly, EQ occurred

Incorrect: In spite of anomality, EQ did not occur

Correct	=	29/54=	53.7%
Almost	=	17/54=	31.5%
Not correct	=	8/54=	14.8%

> 85.2%

Part 3: Additional RS &GIS techniques for prediction

+ New findings for prediction with RS data
  - # Infrasound sensor: abnormal wave pattern
  - # Thermometer: pseudo temperature change
  - # Disturbance of ionosphere: time delay of GNSS
  - # Atmospheric low pressure: sudden fall

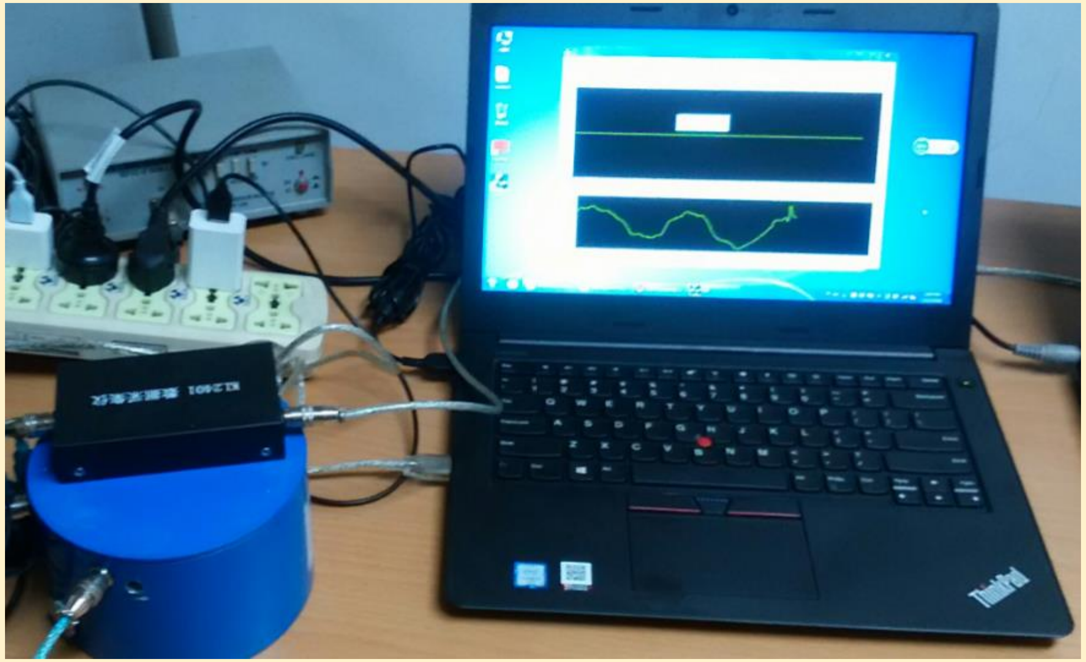
+ My policy

All possible geosphere phenomena should be scientifically validated on correlation between the phenomena and occurrence of earthquakes.

Above phenomena have been already validated and can be used as supplemental tools for prediction.

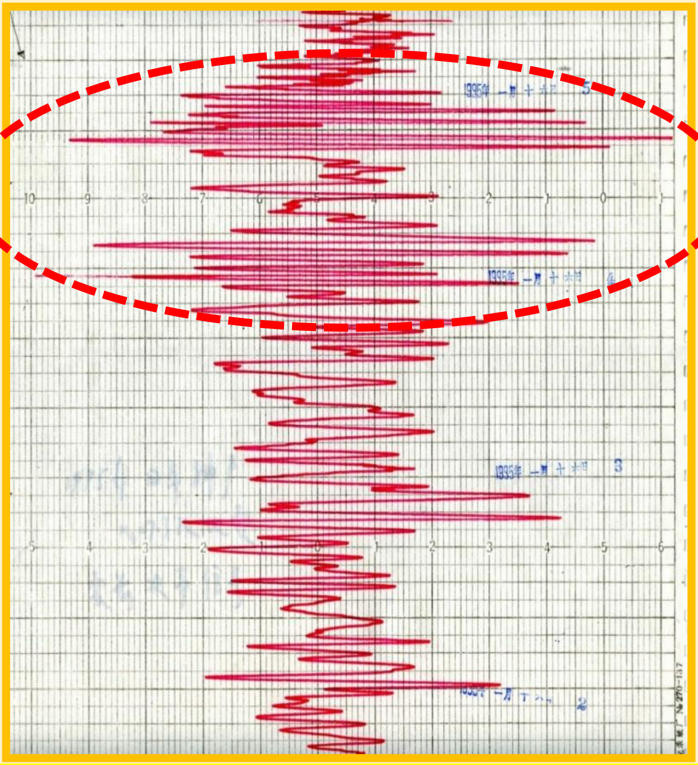
Prediction method by infrasound anomaly

Ultra low frequency sound: 0.0004～0.001Hz

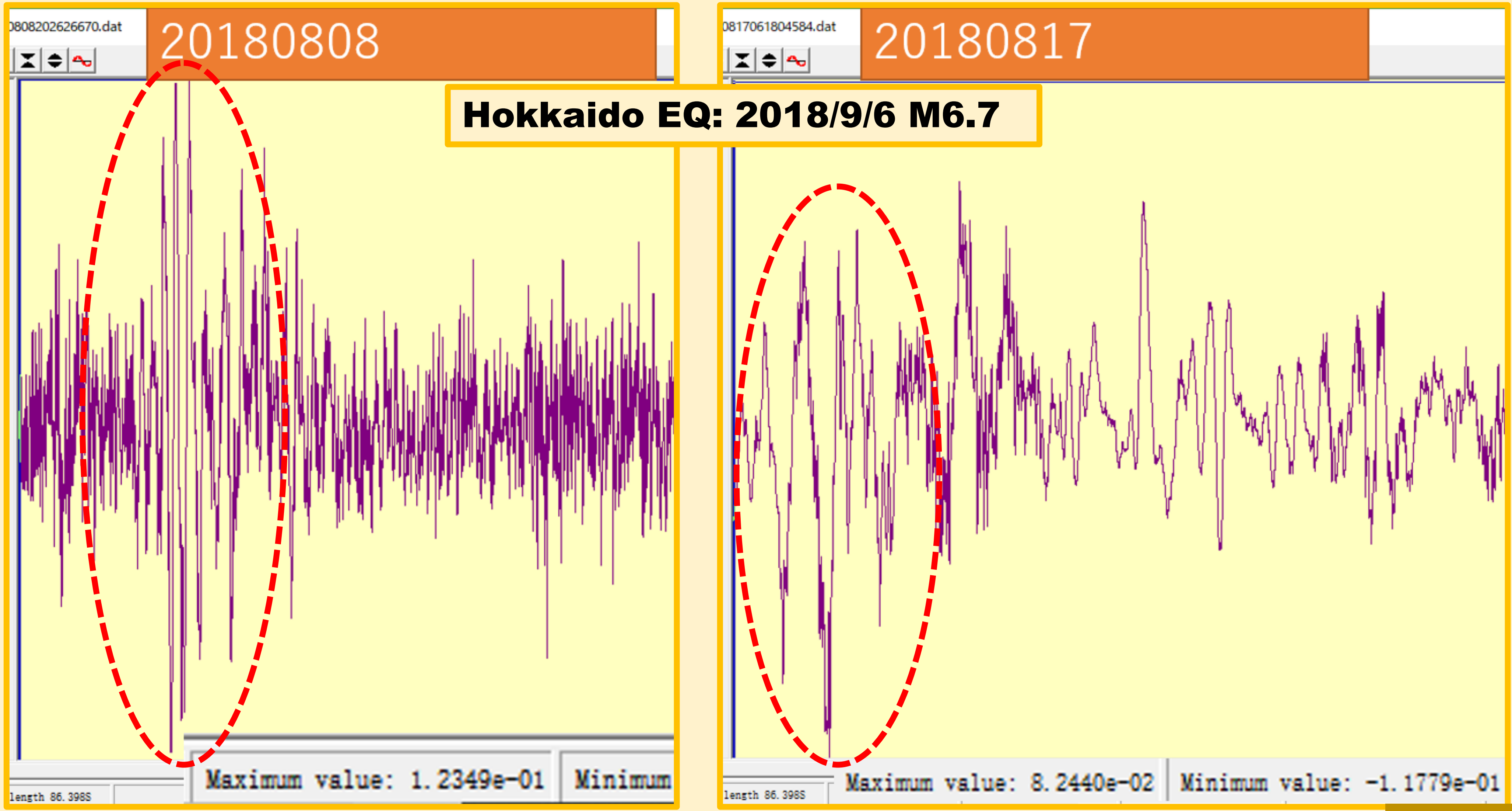


Infrasound sensor made in China

Anomaly was recognized 2 days before Kobe EQ 1995/1/17 M7.3, 6400 victims

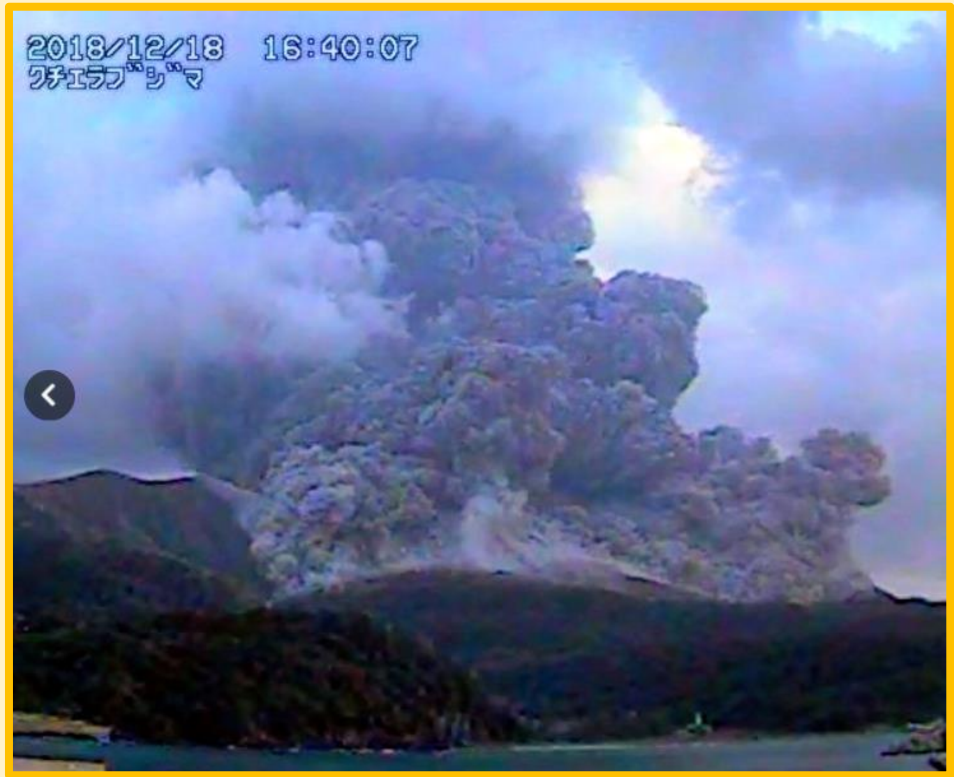


Prediction example: Hokkaido EQ with provable judges



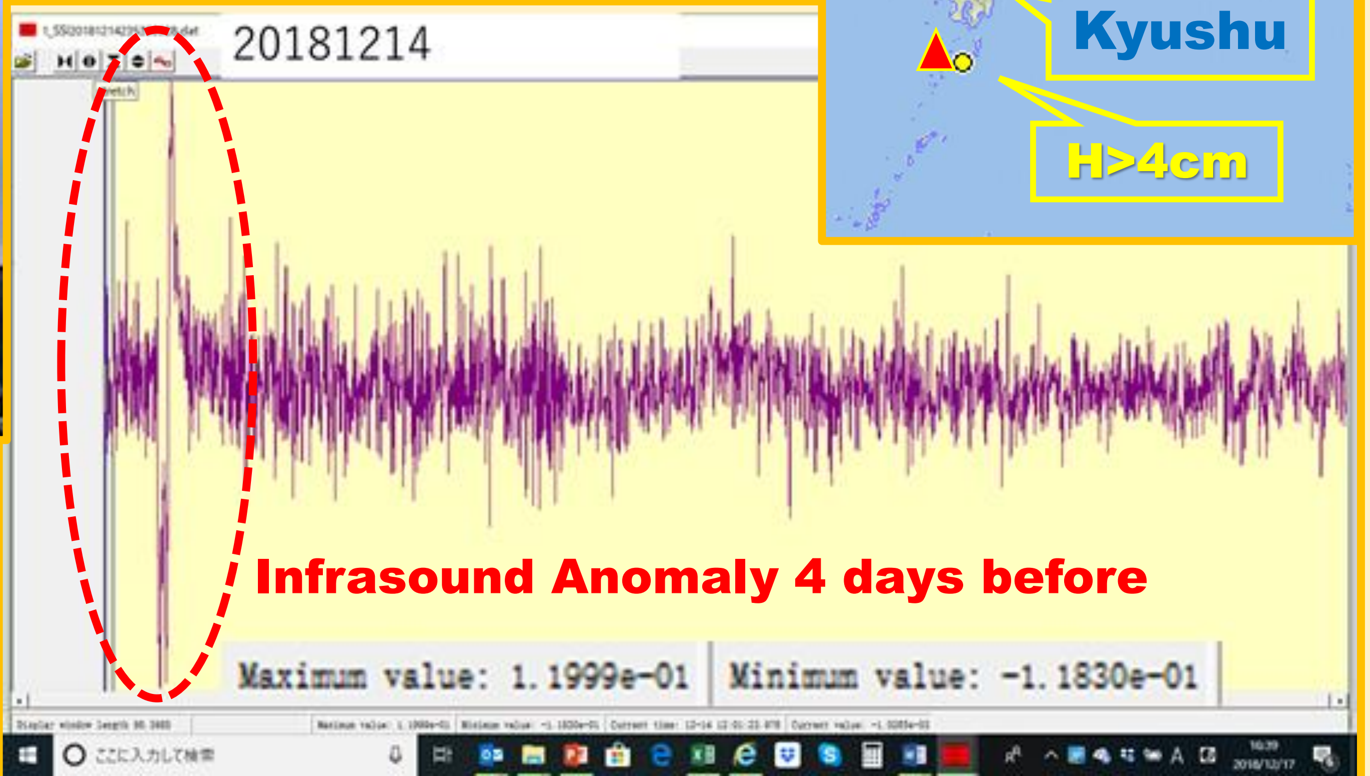
About 1 month before **About 20 days before**

Prediction example: Kuichi-no-Erabu Volcano 2019/12/18



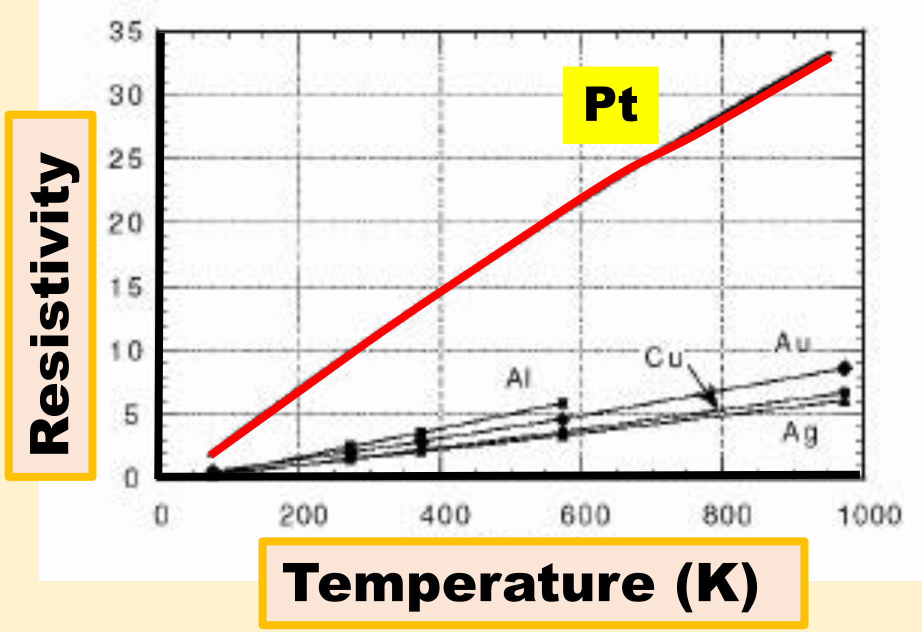
Volcanic Eruption at Kuchi-no-Erabu Island

GNSS H Anomaly: 10 days before



Prediction method by temperature anomaly

Temperature is measured with platinum resistance sensor by detecting electric resistivity from weak electric current

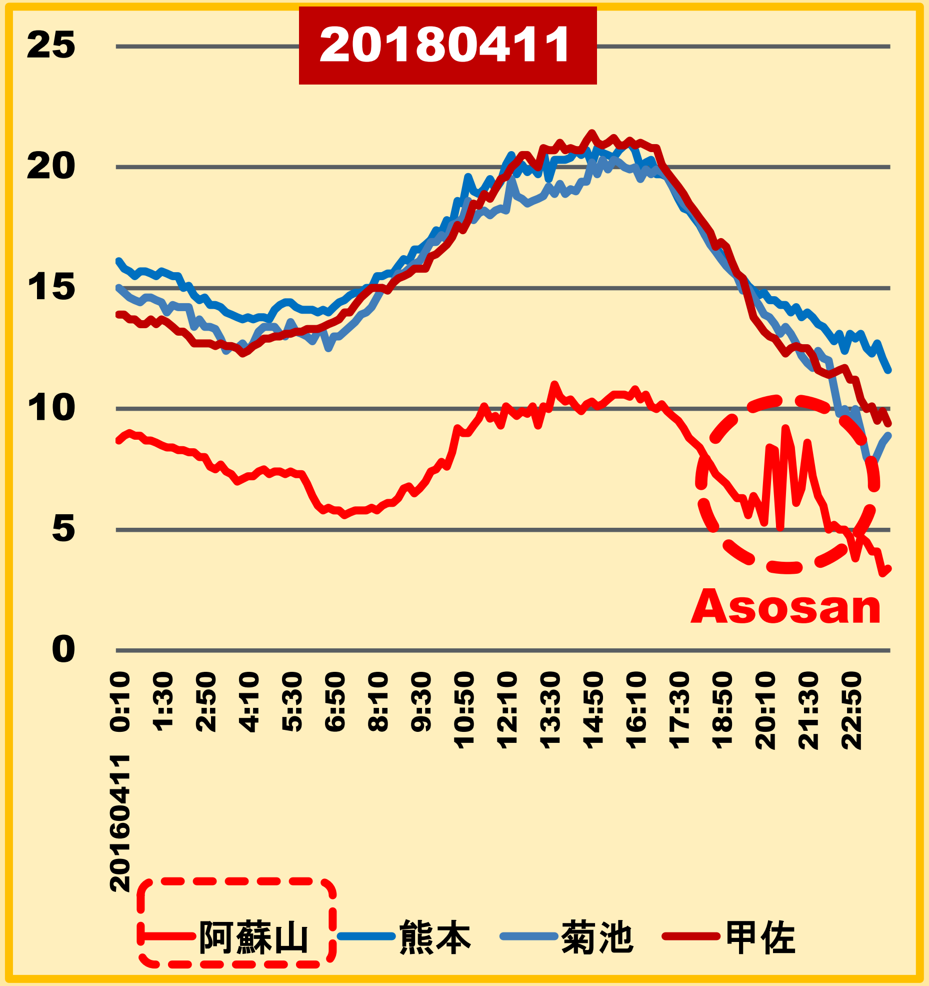


Platinum resistance thermometer

Anomaly will be recognized about within a month before EQ due to EM emission

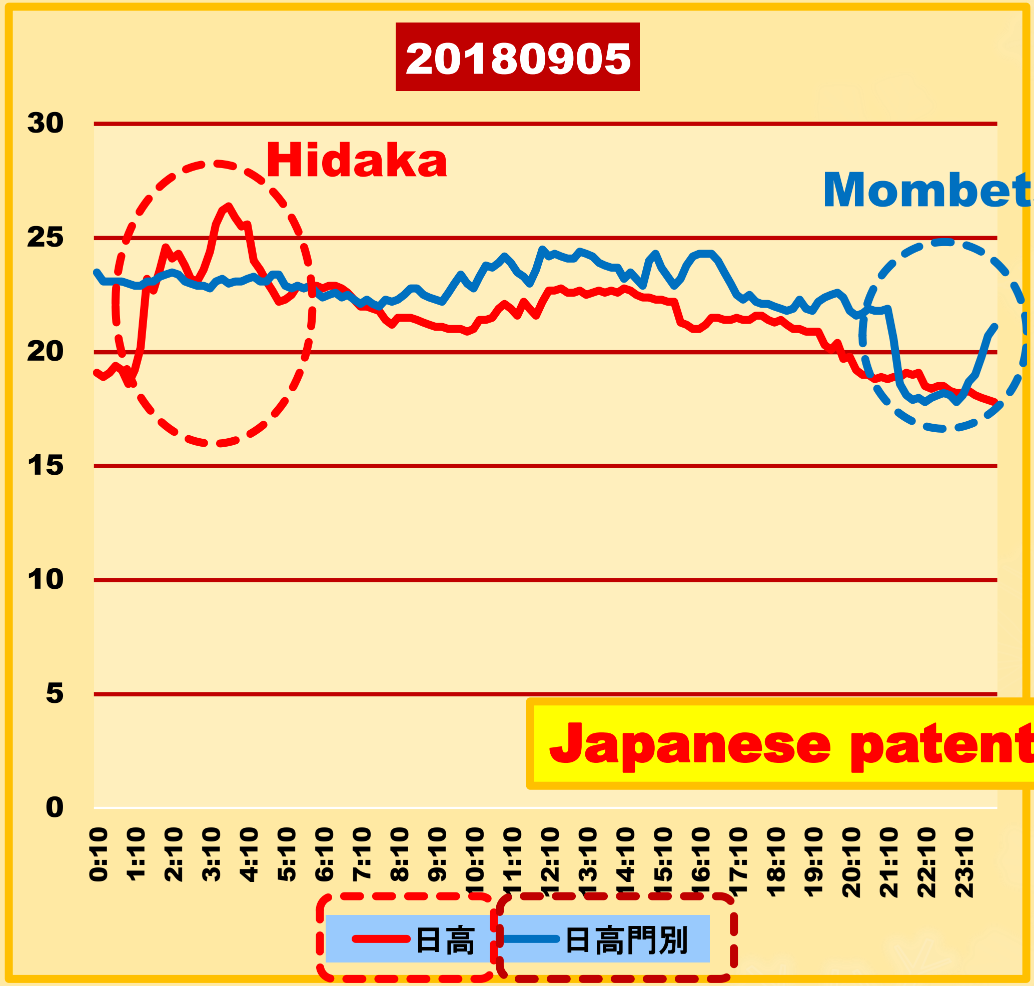
Validation example: Kumamoto and Hokkaido EQ

Kumamoto EQ(2016/04/16)



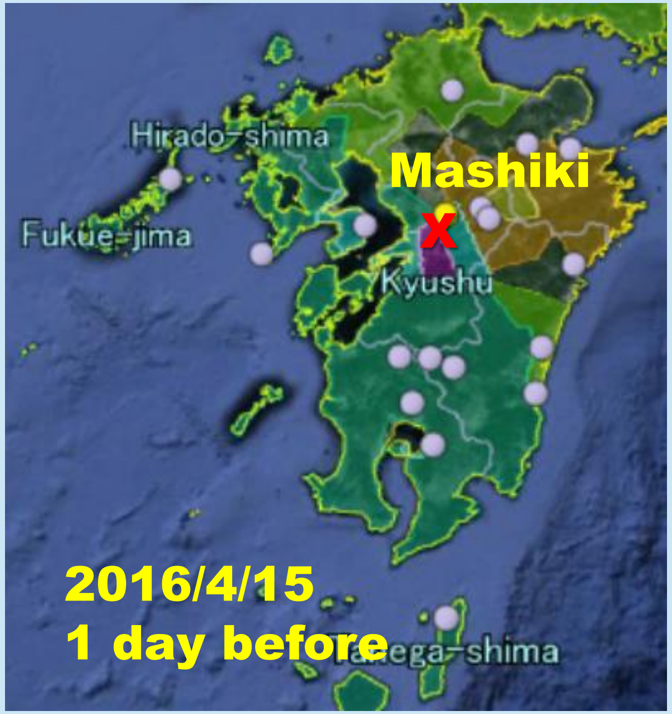
Anomaly detected 5 days before

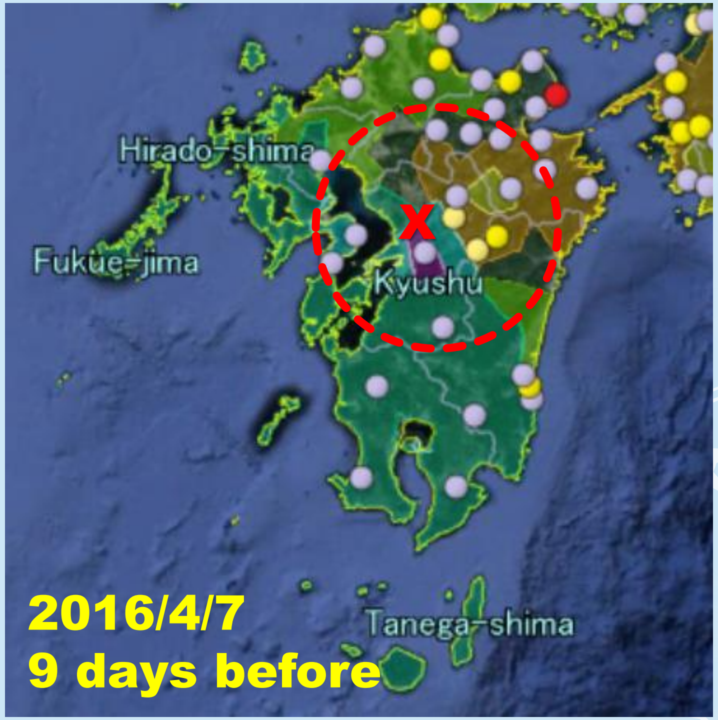
Hokkaido EQ(2018/9/6)



Japanese patent approved

Anomaly detected 1 day before



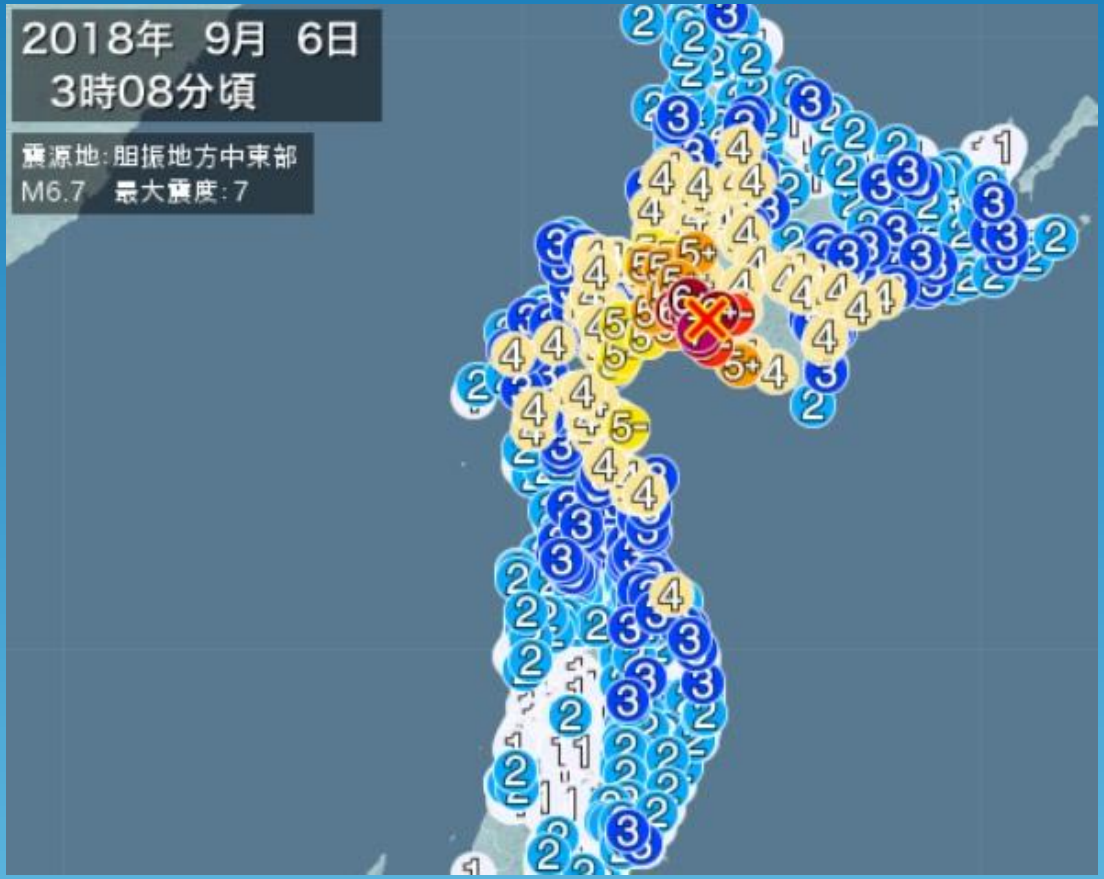


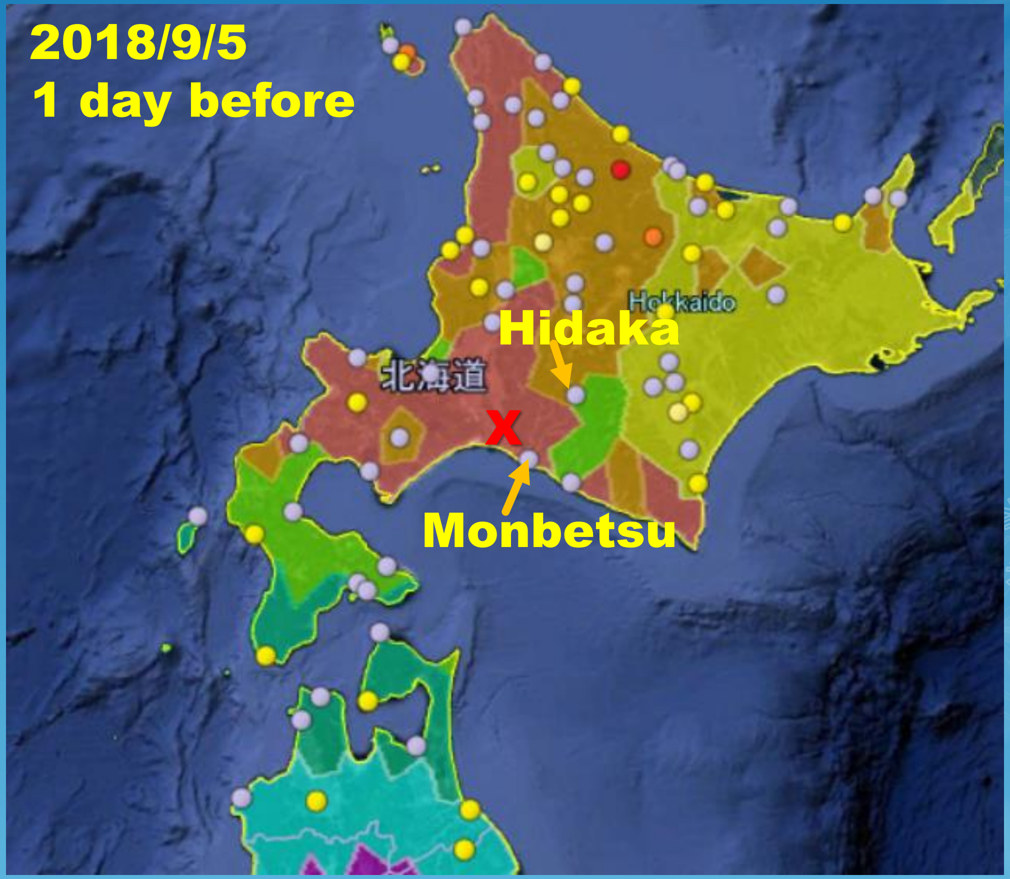
Kumamoto EQ
（2016/04/16: M7.3）

From 2 weeks before anomaly is observed at Mashiki & Asosan near the epi-center

Hokkaido EQ

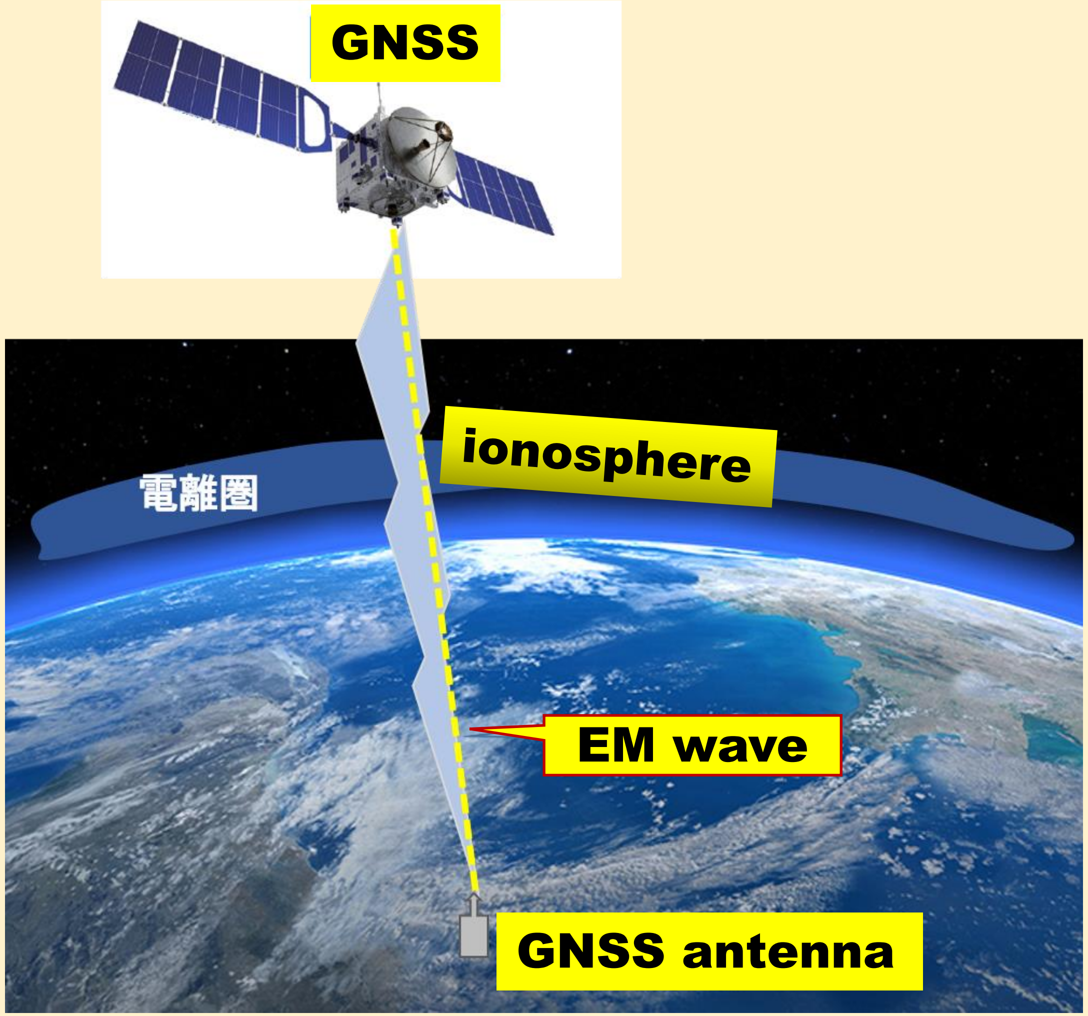
2018/9/6：M6.7, SI=7





Prediction method by ionospheric anomaly

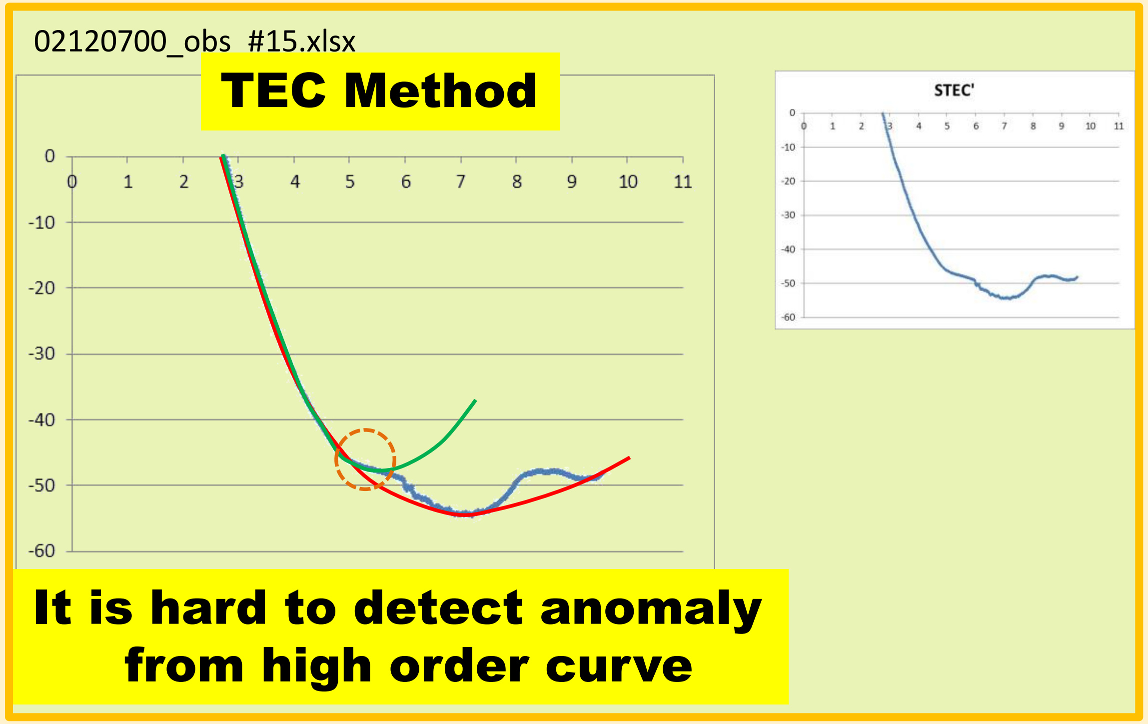
Very new innovation **Japanese patent approved**

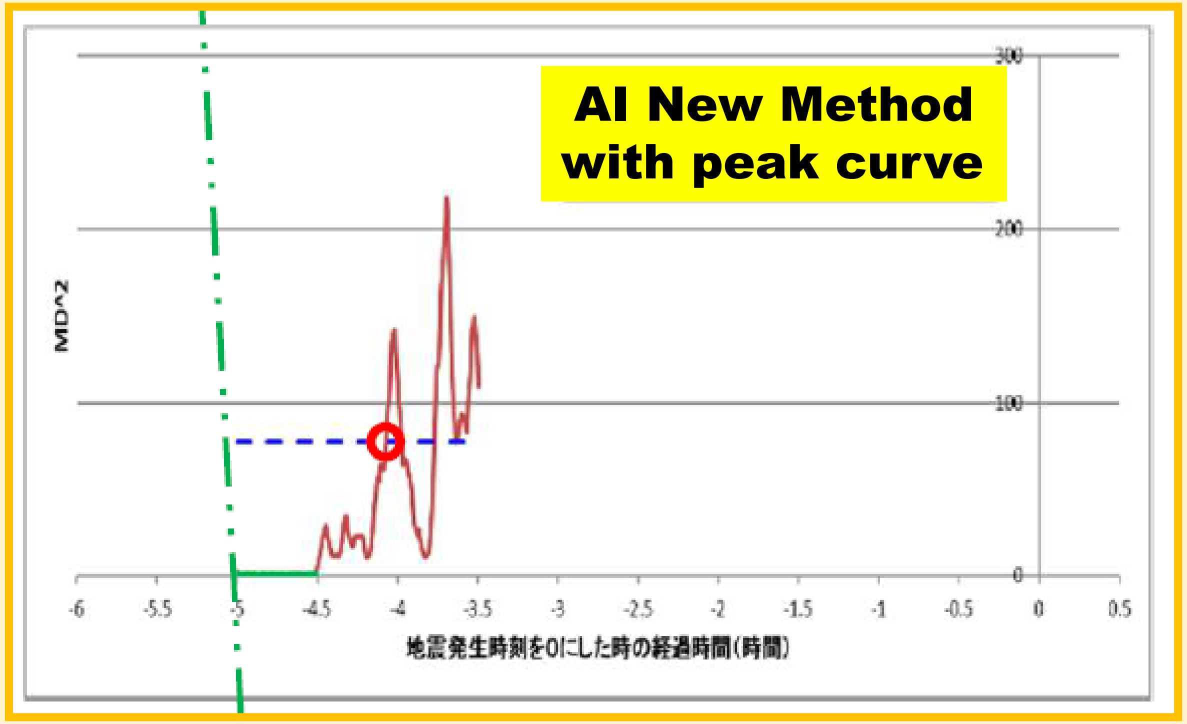


·Electric magnetic wave transmitted from GNSS to GNSS antenna will be delayed unusually due to ionospheric anomaly before EQ.

·**Artificial intelligence technique** is applied to detect anomalies a few hours before EQ. in real time.
· The exist TEC method will be hard to detect the anomaly in real time base.

Comparison between the exist and new AI method

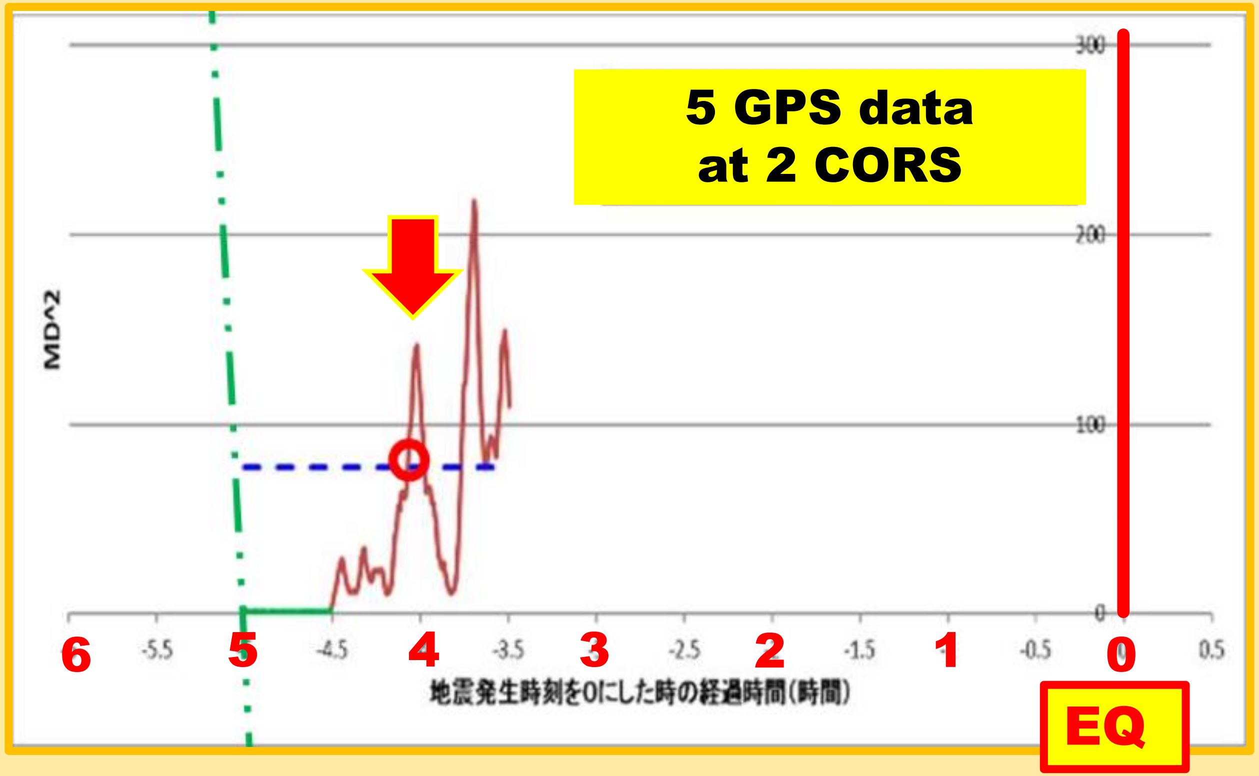




This prediction method would be my final goal to enable early warning a few hours in advance to the occurrence of huge earthquake.

Validation example: East Japan Great EQ

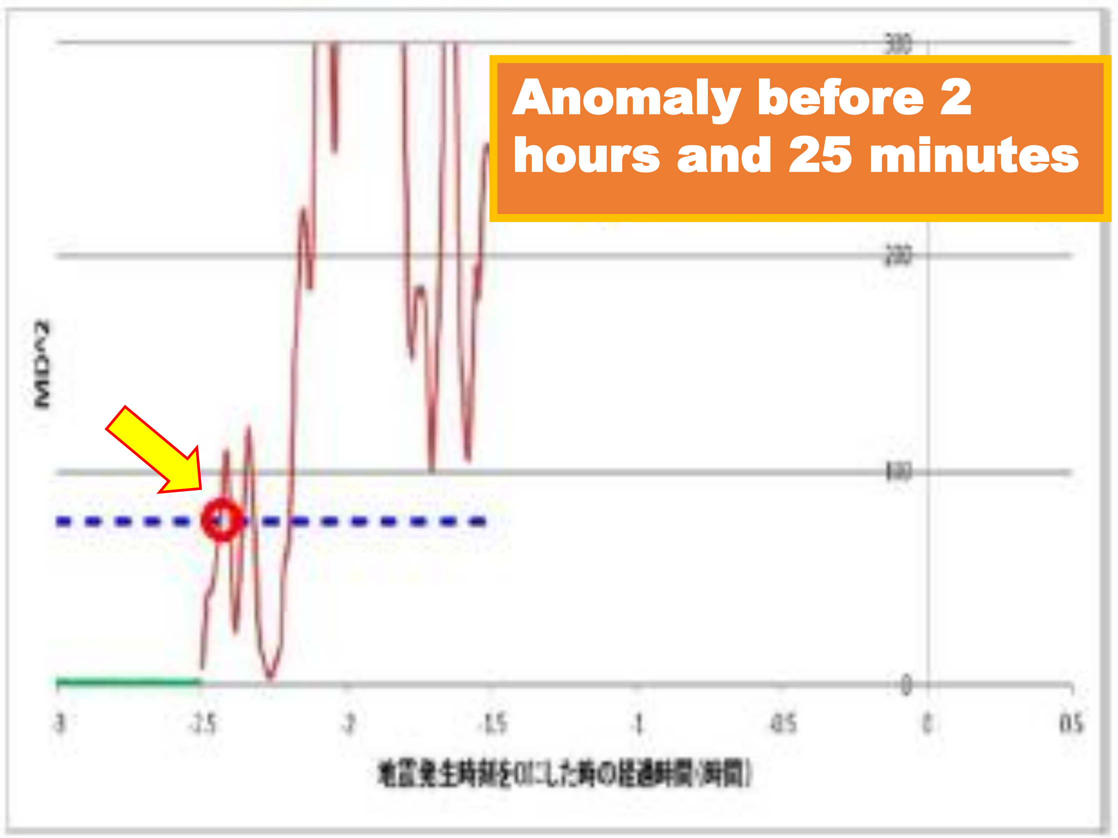
East Japan EQ(2011/03/11）



Anomaly just about 4 hours before

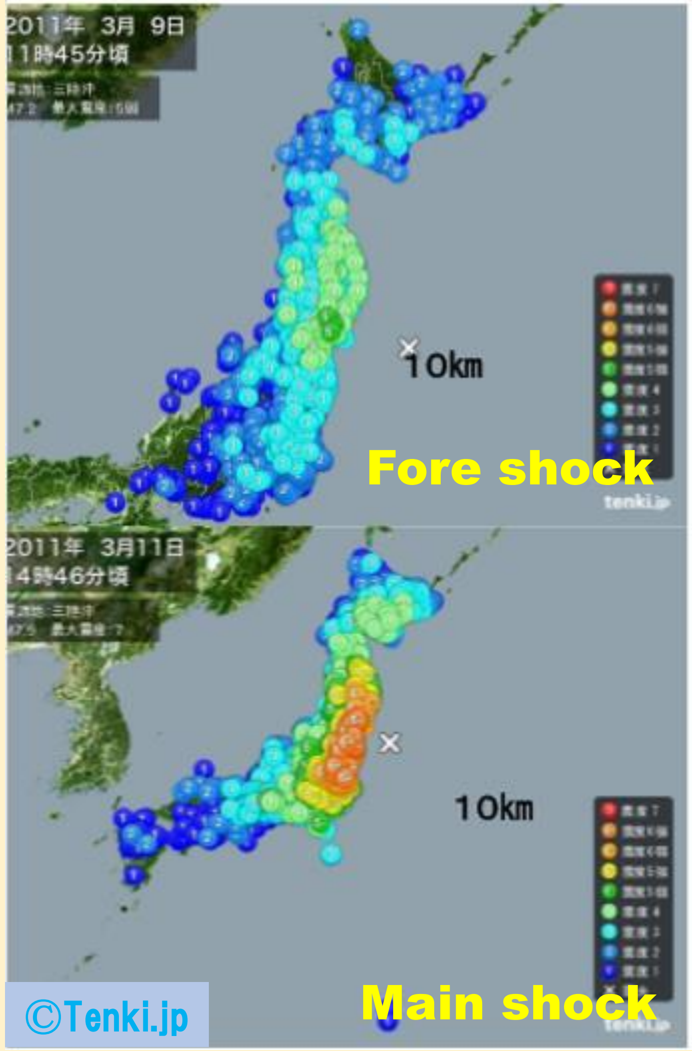
Validation example: Kumamoto EQ

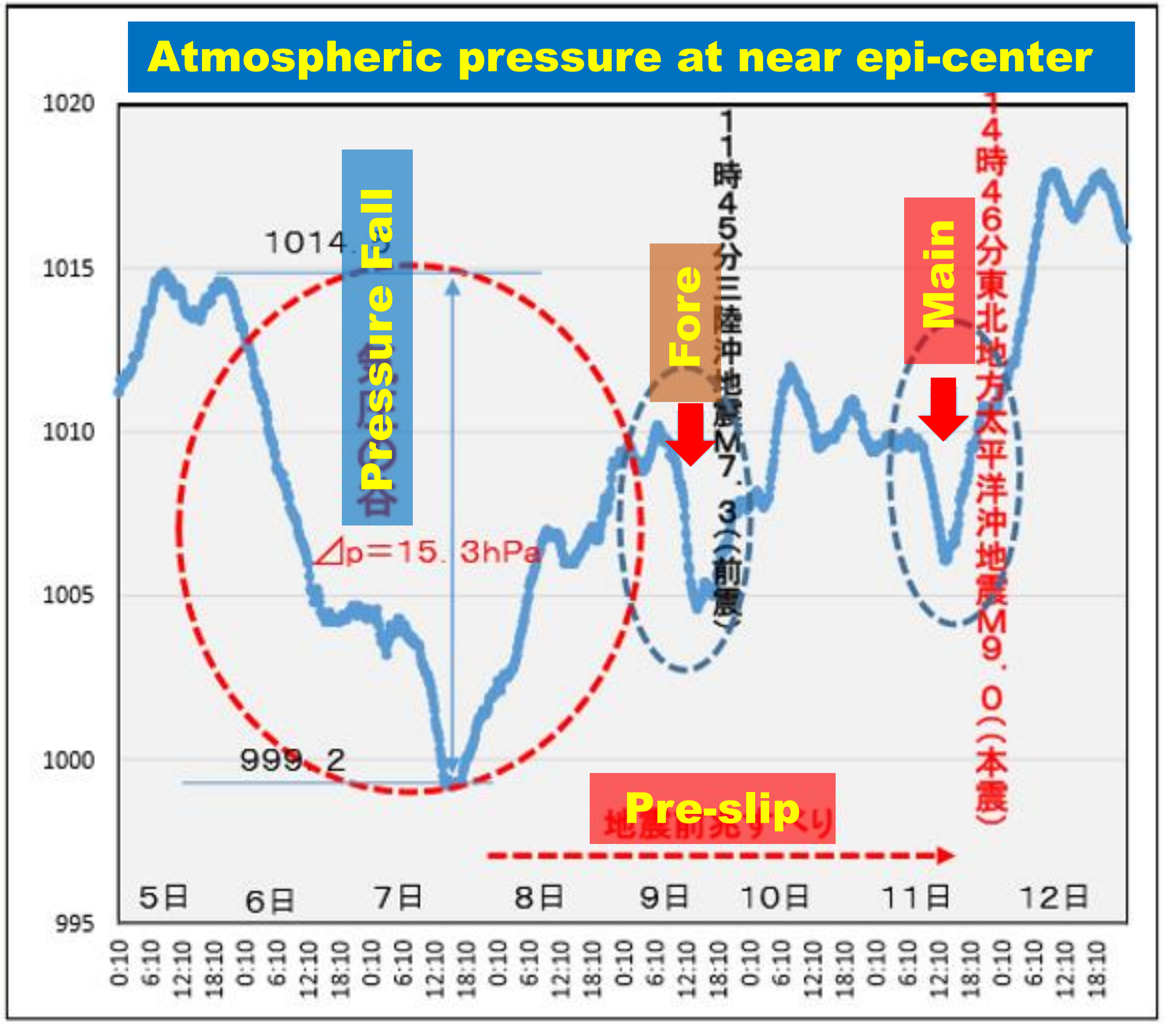
Kumamoto EQ, Fore shock
M6.5, SI=7 2016.04.14



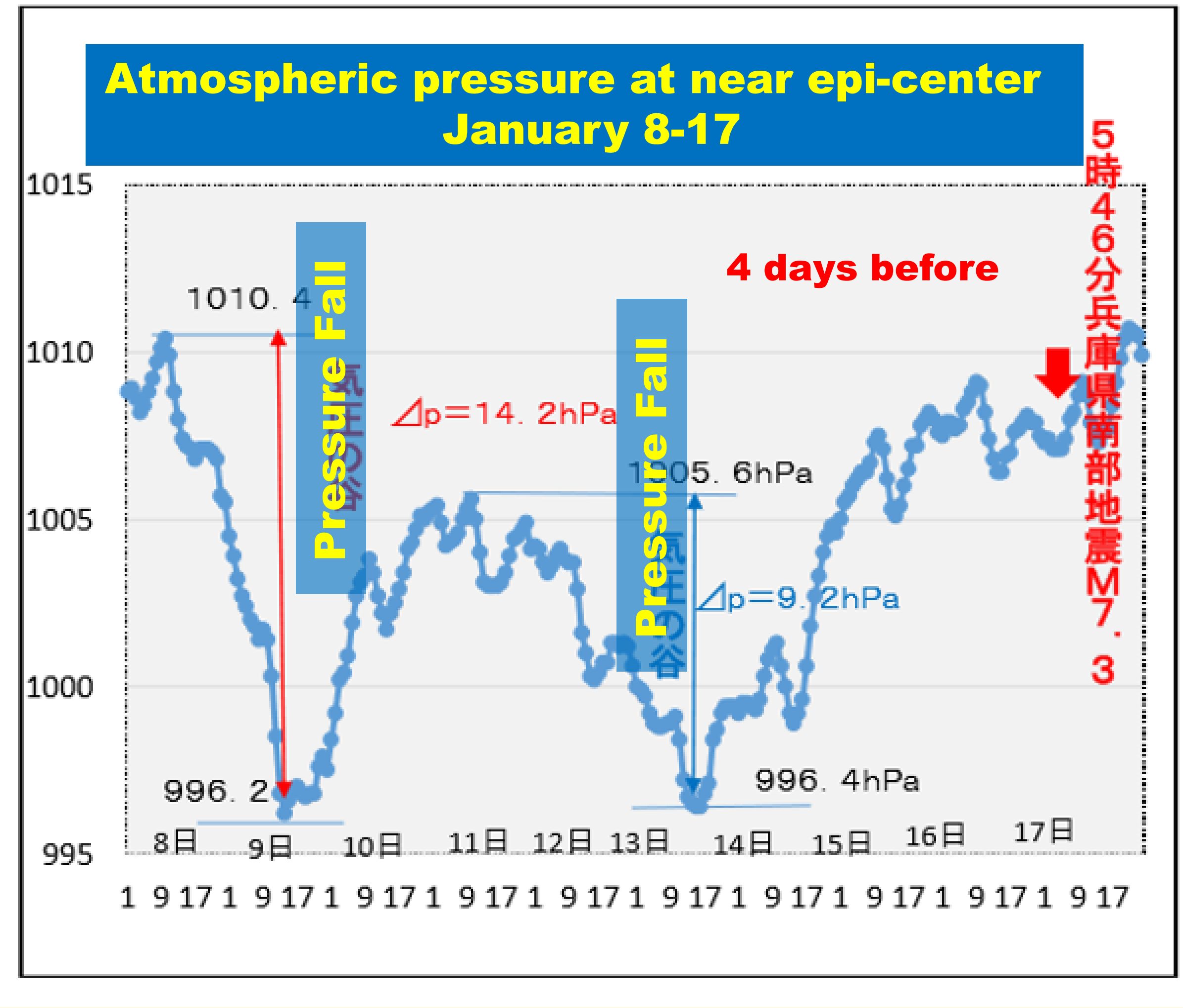
Kumamoto major EQ
M7.3, SI=7 2016.04.16

Validation of low pressure: East Japan Great EQ
Fore shock(M7.3):2011/3/9: Main shock(M9.0):2011/3/11

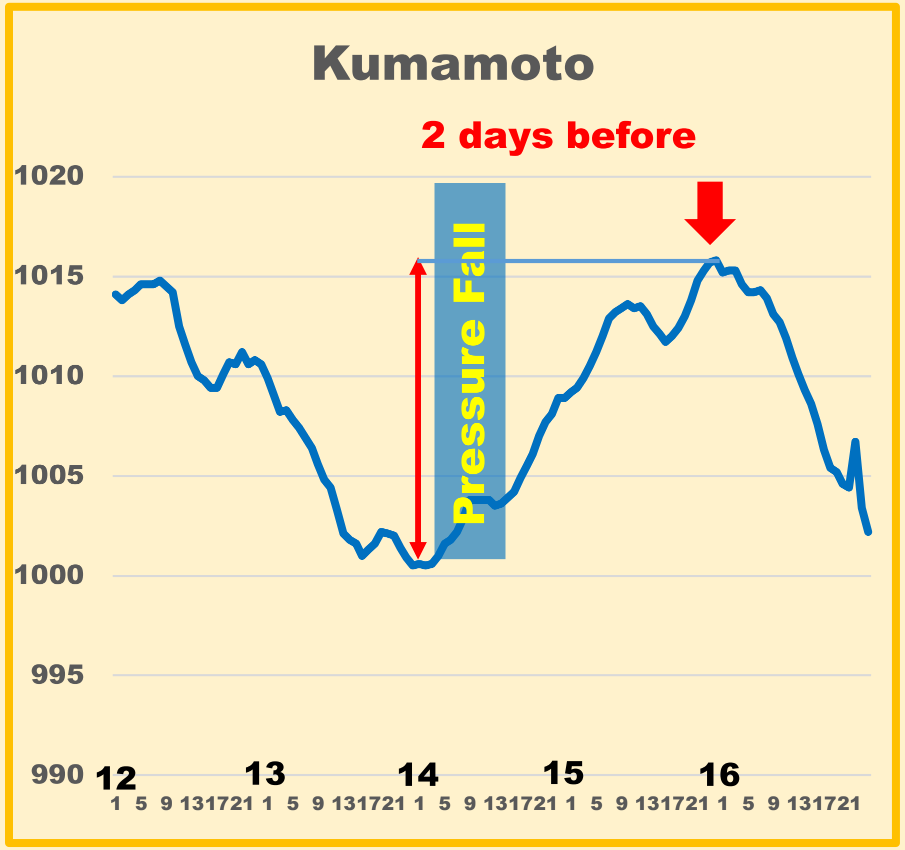




Validation of low pressure Kobe Great EQ 1995/1/17(M7.3)



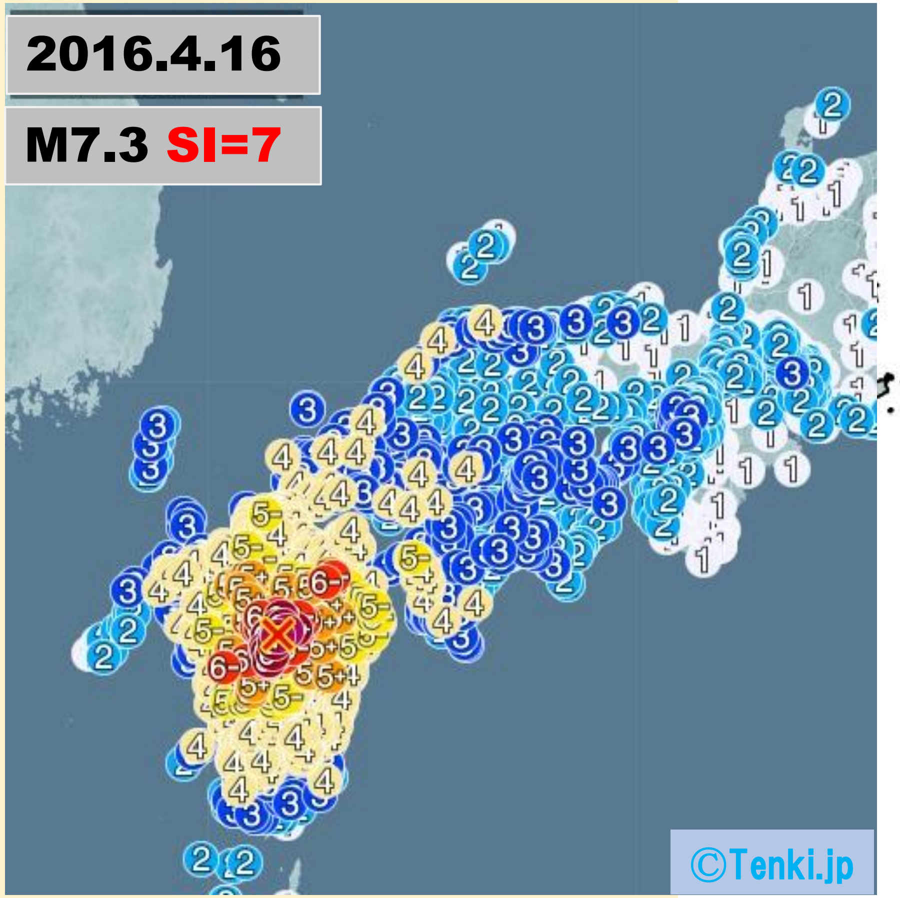
Validation of low pressure Kumamoto EQ 2016/4/16(M7.3)

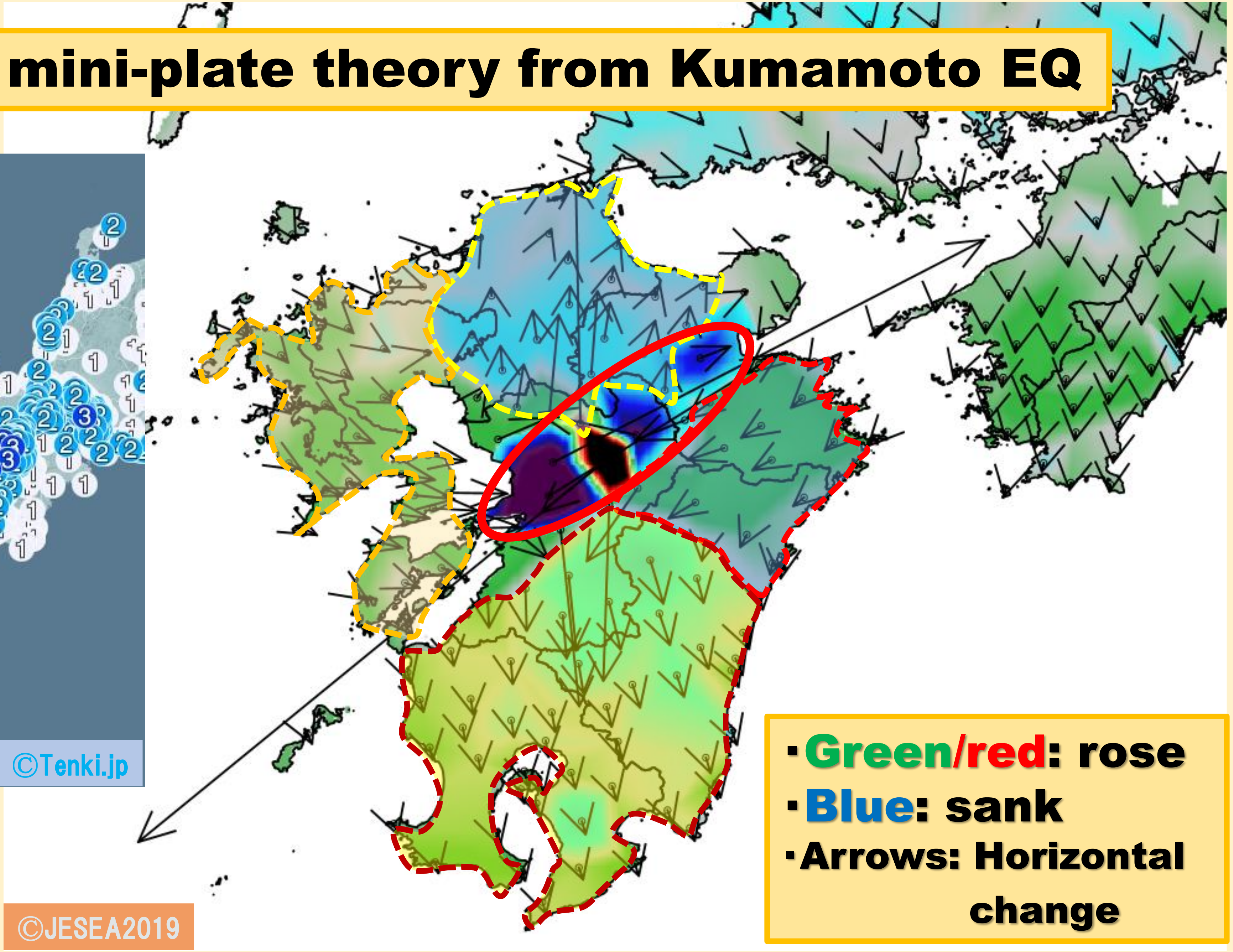


Part 4: Mini-plate theory

+ **New findings of mini-plates**
  - # The hint of mini-plate theory was obtained from the change analysis of Kumamoto EQ occurred 2016/4/16
  - # Mini-plates was clustered with time sequence GNSS data variation in 2016
  - # Mini-plates are more related to occurrence of EQs rather than faults or geotectonic map
  - # About 70% of large Eqs are located near the boundary of mini-plates
  - # Mini-plates are useful for understanding geodynamic characteristics of the moving Earth

The hint of mini-plate theory from Kumamoto EQ





- Green/red: rose
- Blue: sank
- Arrows: Horizontal change

Clustering of mini-plates with GNSS data

GNSS data (XYZ) in 2016

↓

Convert to (NEU)

↓

PCA analysis（PC1,PC2)

↓

Eliminate errors/noises

↓

Select cluster number

↓

PCA analysis（PC1,PC2)

↓

Pointwise cluster map

↓

Nearest neighbor interpolation for image map

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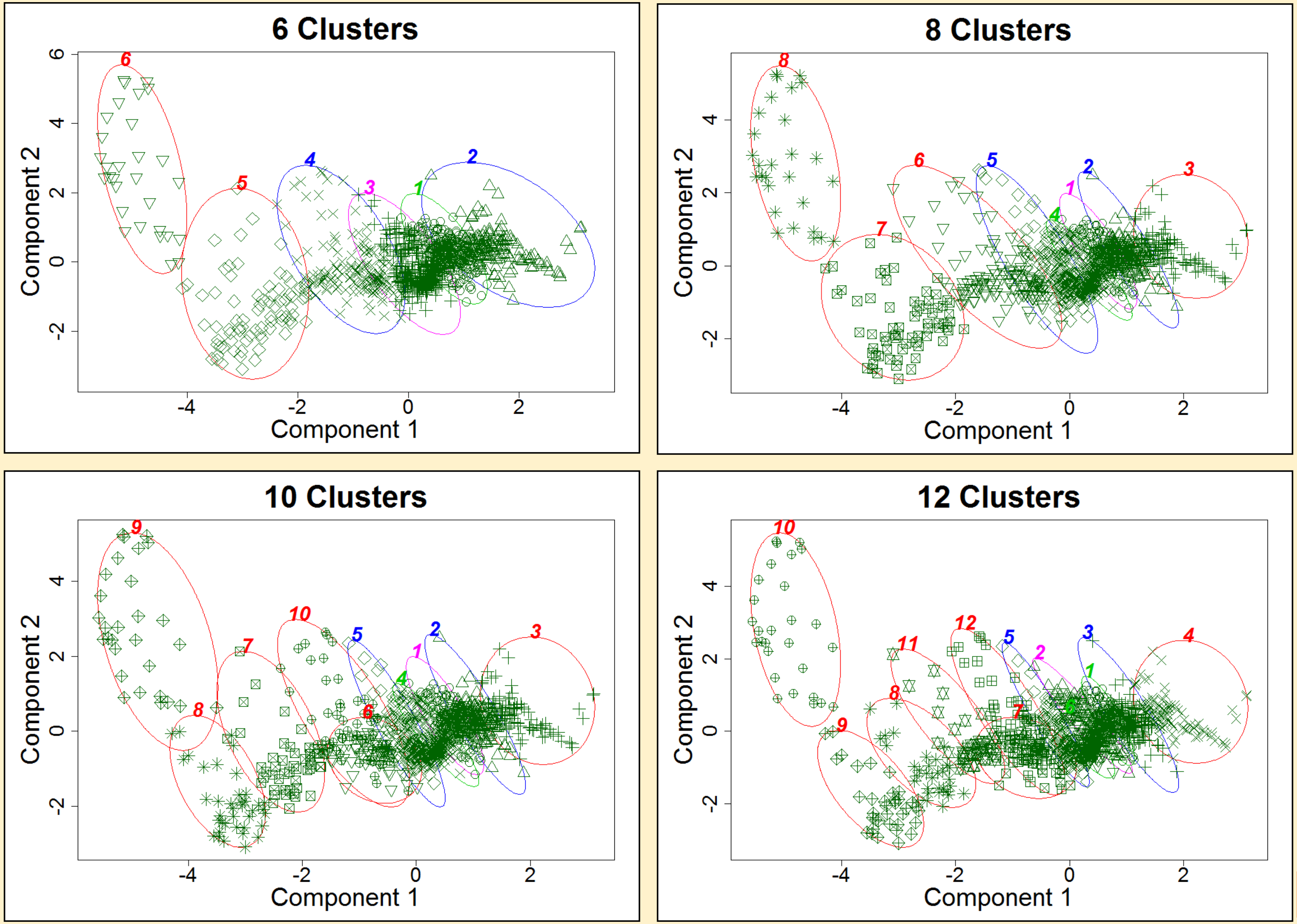
Comparison with geotectonic map

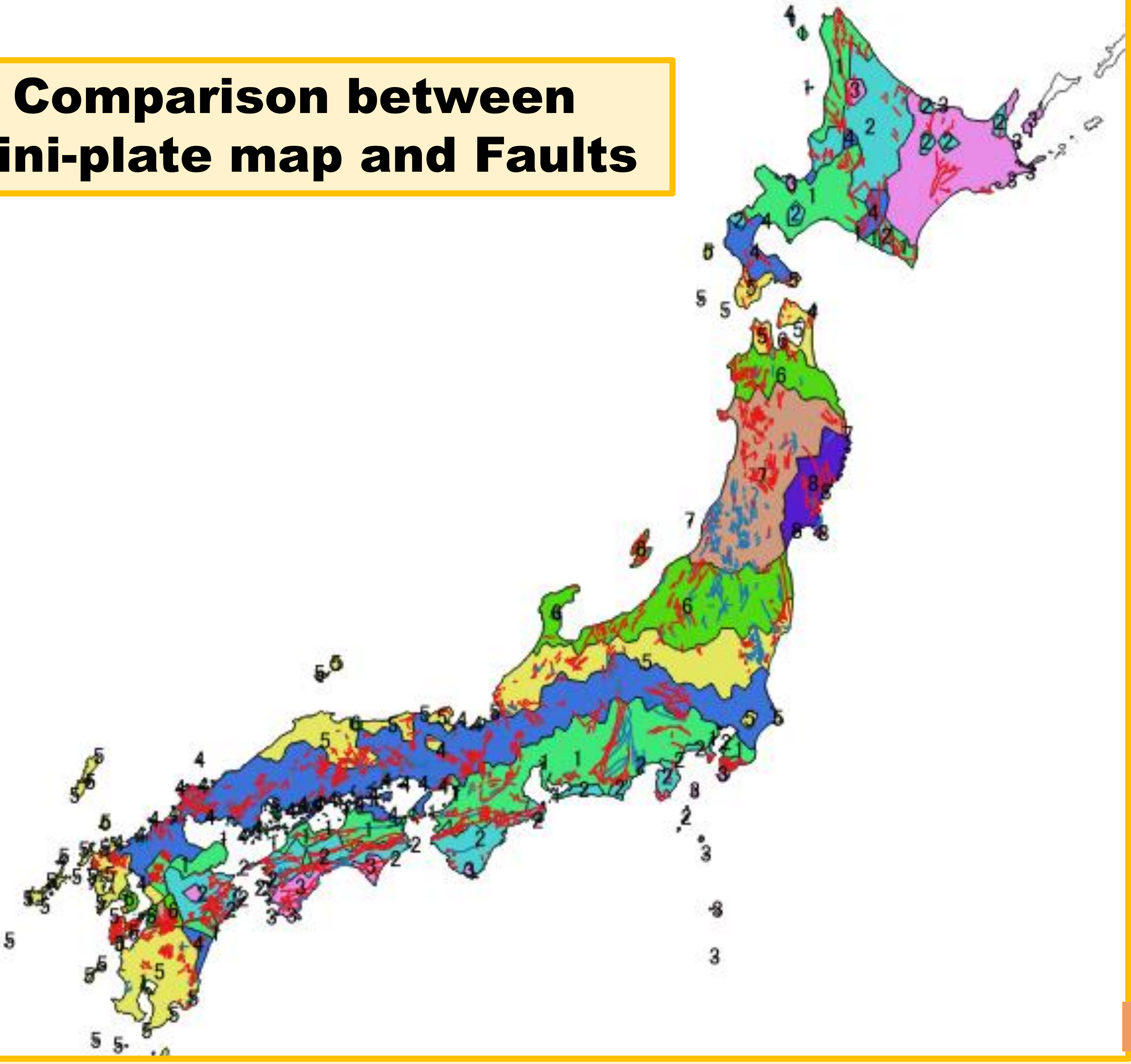
↓

Correlation with earthquakes → Determine Cluster Number

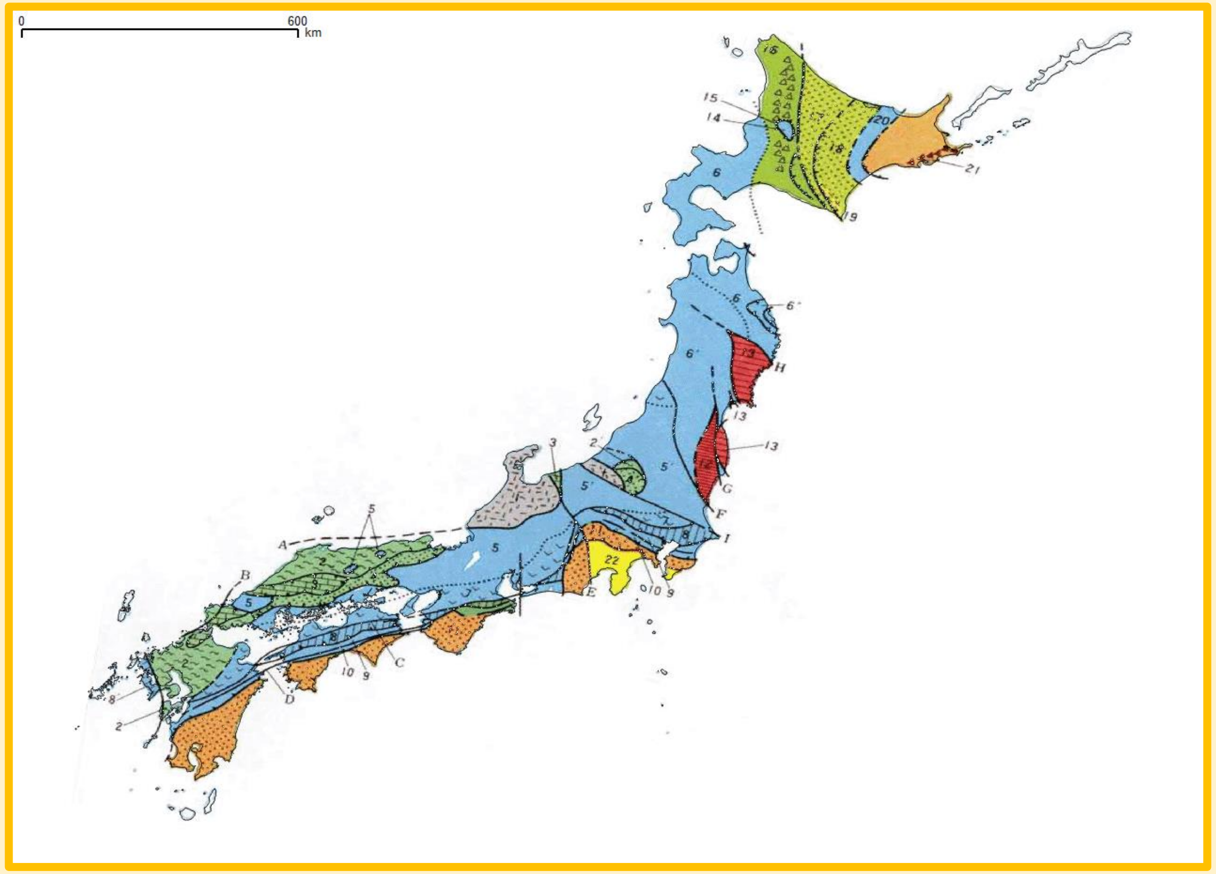
Clustering of PC1 and PC2 domain



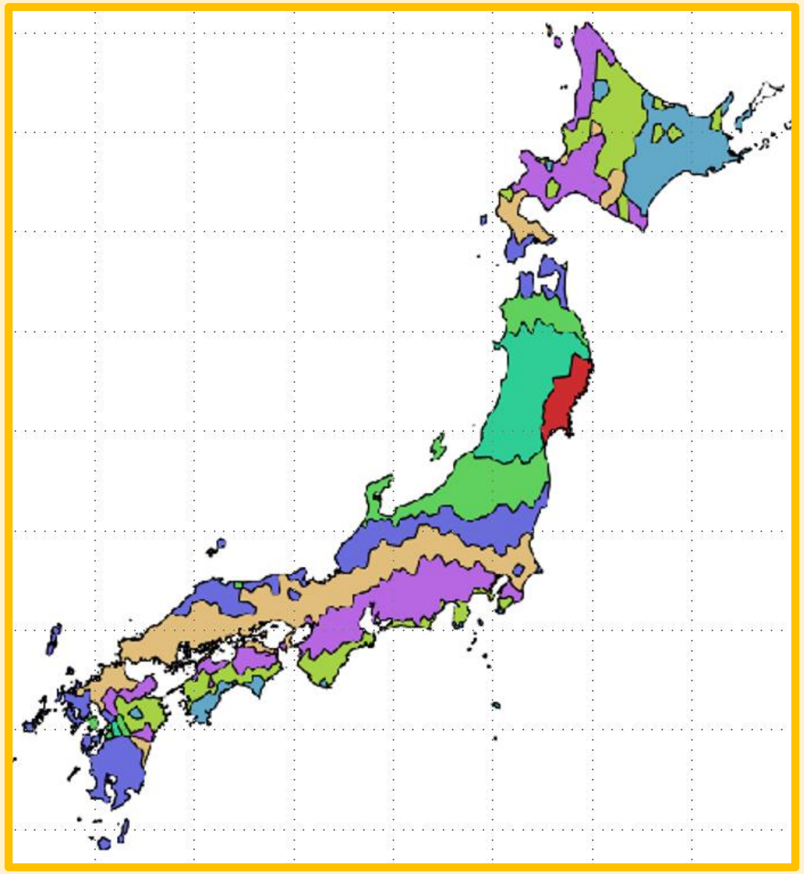
Comparison between Mini-plate map and Faults



Comparison between geotectonic map and mini-plate map

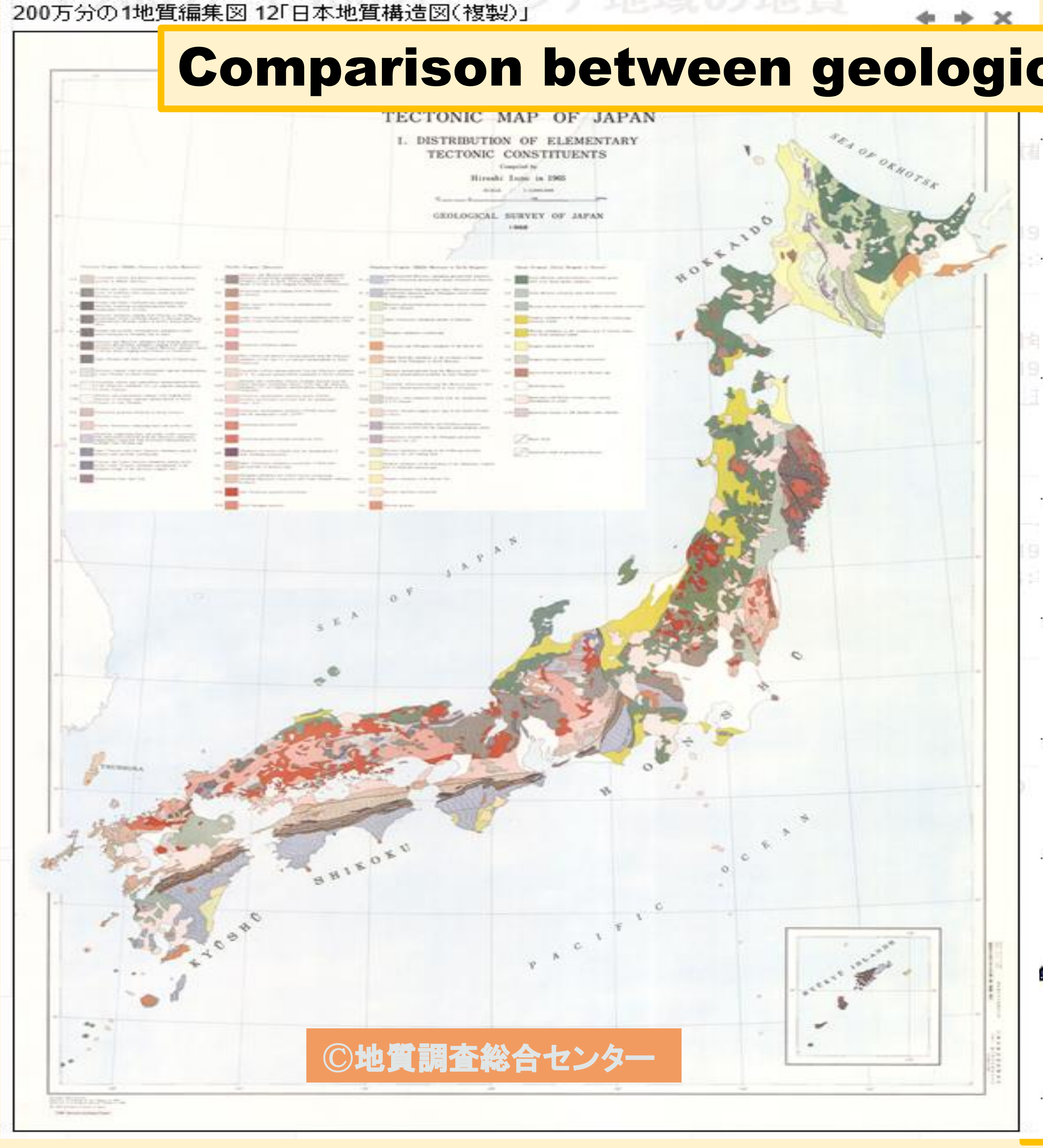


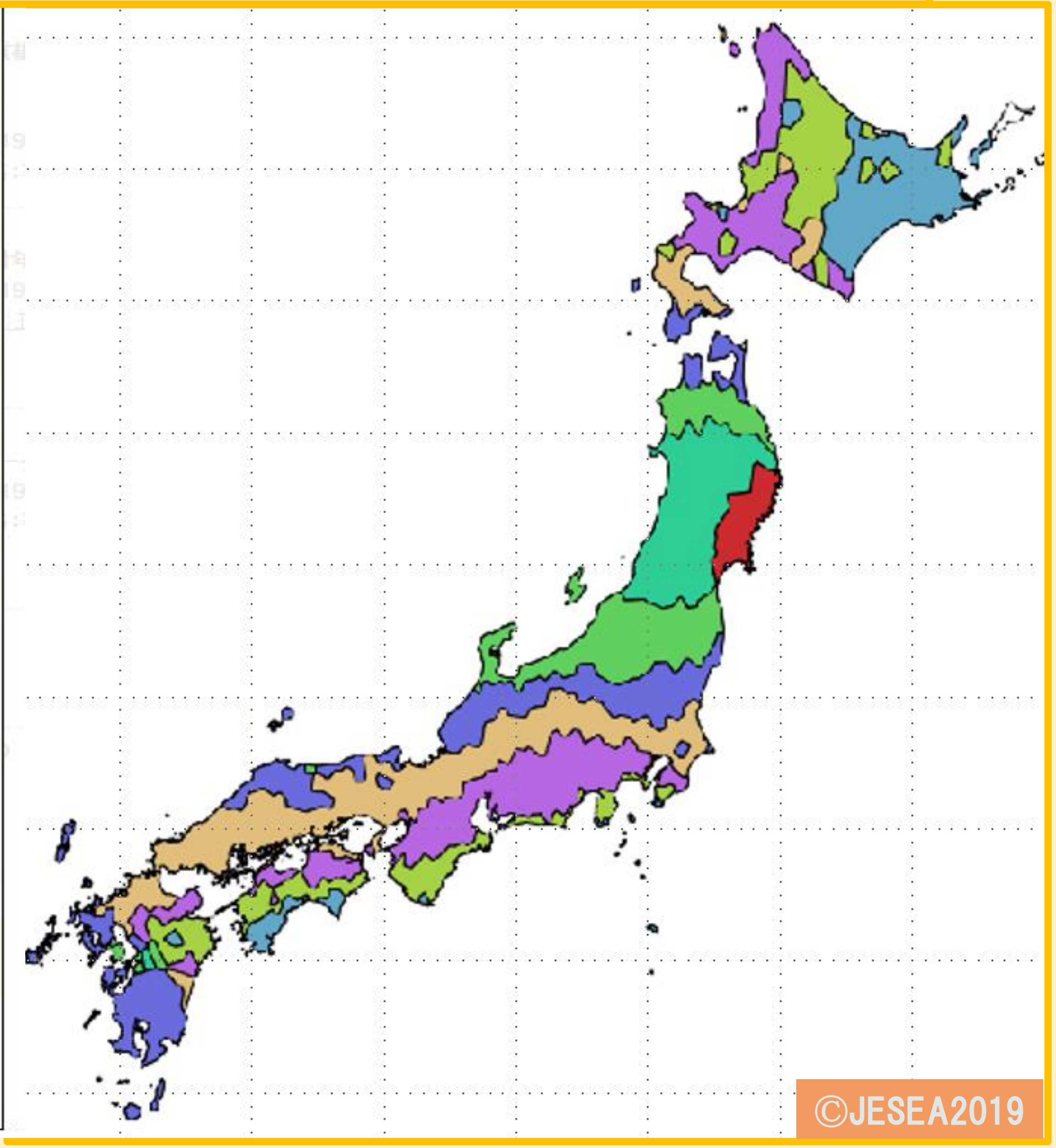
a) National Atlas: Geotectonic Map

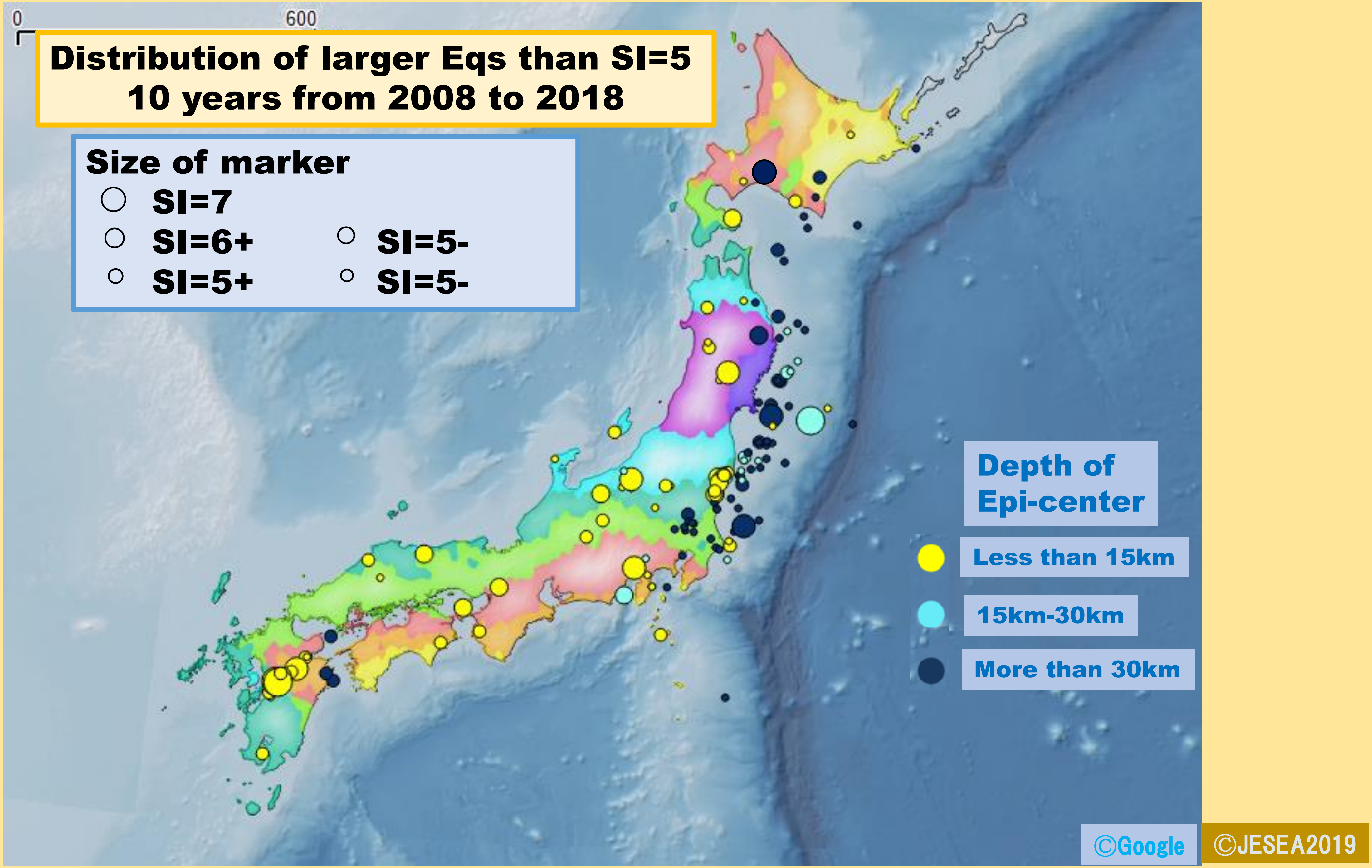


b) Clustering Map

Comparison between geological map and mini-plate map






0
600
Distribution of larger Eqs than SI=5
10 years from 2008 to 2018
Size of marker
SI=7
SI=6+
SI=5-
SI=5+
SI=5-
Depth of Epi-center
Less than 15km
15km-30km
More than 30km
©Google
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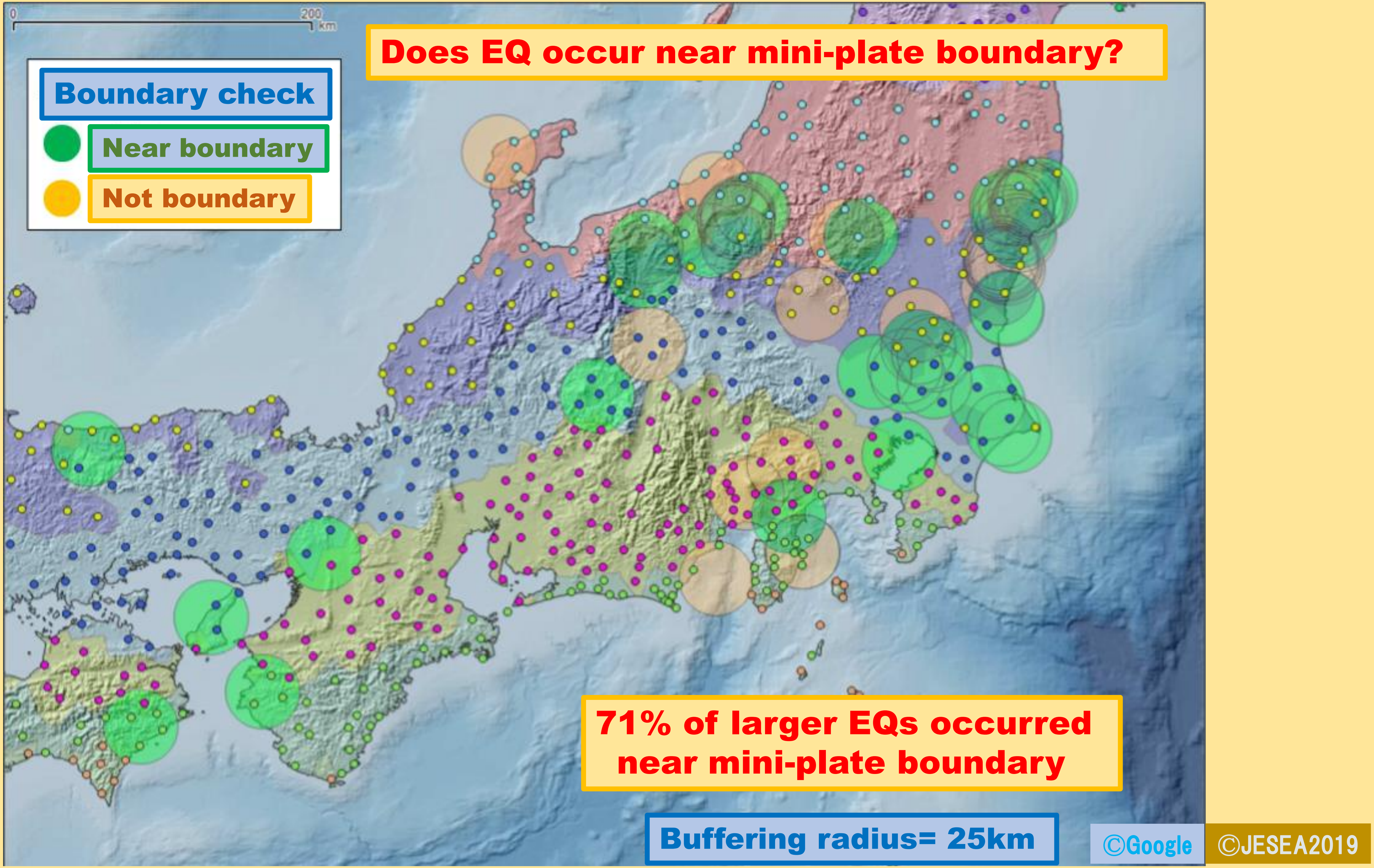
0
200
km
Does EQ occur near mini-plate boundary?
Boundary check
Near boundary
Not boundary
71% of larger EQs occurred near mini-plate boundary
Buffering radius= 25km
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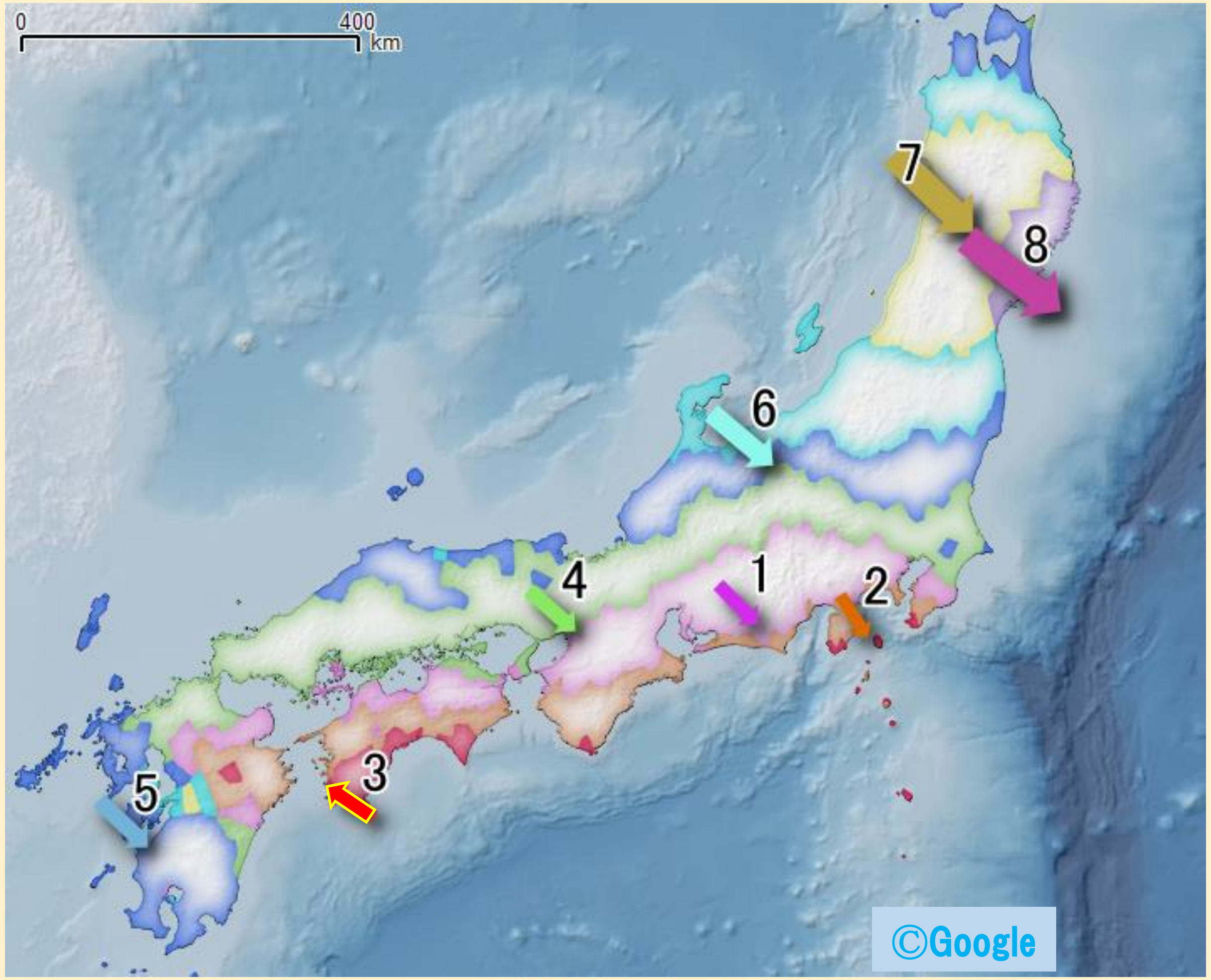
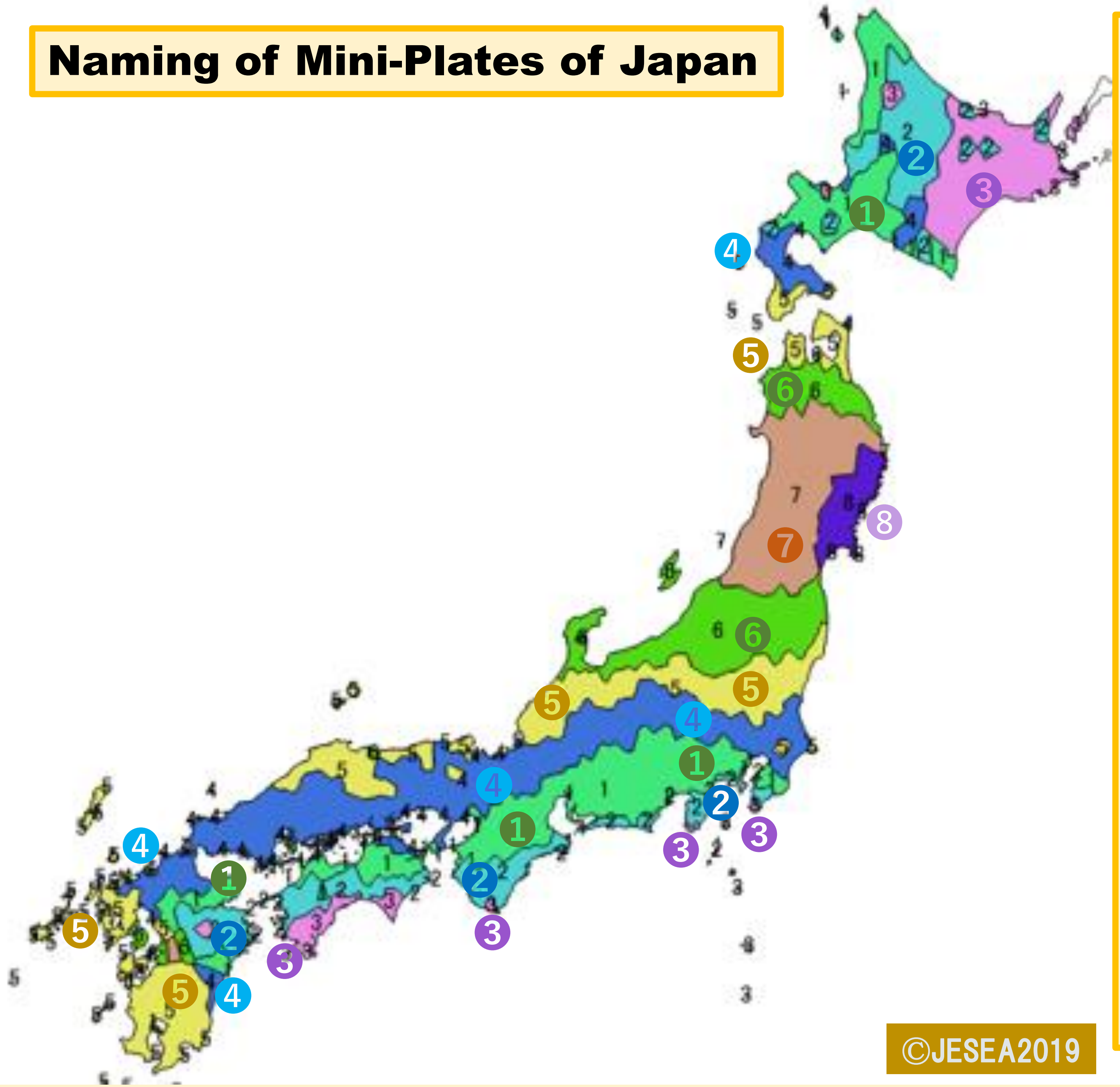
Geo-dynamism of mini-plates with GNSS data



No.	dN N-S	dE E-W	dU H	dNEU Move	azNEU Azimuth	Hori./Vert. move
1	-4.01	3.966	0.815	5.698	135.32	SE+: Down - -
2	-2.137	1.361	0.311	2.553	147.5	SE+: Down -
3	1.378	-2.117	0.152	2.531	303.06	NW-: UP/Down -
4	-6.044	6.927	-0.301	9.199	131.1	SE ++: Down -
5	-8.802	9.17	-0.052	12.711	133.83	SE++: UP/Down-
6	-13.336	15.733	0.193	20.626	130.28	SE++:Up/Down -
7	-26.764	27.556	-0.487	38.417	134.17	SE+++* Down - -
8	-25.265	32.97	11.144	43.006	127.46	SE+++: UP+++

Naming of Mini-Plates of Japan



Name of Mini-Plate

1： Central belt MP
with SE moves/rising

2： Southern central belt MP
with SE moves/little up/down

3： South coast MP
with NW moves/little sinking

4： Northern central belt MP
with SE moves/little up/down

5： Wet to East central belt MP
with SE moves/little up/down

6： West to East northern belt MP
with SE moves/little up/down

7： West Tohoku MP
with big SE moves/sinking

8： East Tohoku MP
with SE big moves /rising

Comparison between existing geo-tectonics map and mini-plate map with GNSS data

	Existing geo-tectonics map	Mini-plate map
Information	Analog and Qualitative	Digital and Quantitative
Status	Static and Time independent	Dynamic and Time dependent
Productivity	Professional and Not reproductive (geological survey needed)	Reproductive and Repeatable (clustering needed)
Relation to Earthquakes	Weakly related	Strongly related

Conclusions

+ I realized that the main stream of the prediction of earthquakes should be along with remote sensing but not seismic science.
+ Geospatial techniques and artificial intelligence are strong tools to support advanced data analysis and prediction.
+ All possible macroscopic phenomena should be used or supplemented in order to increase the accuracy.
+ Alert level prediction would be possible with ionospheric anomalies in a few years after validation and verification are to be implemented.
+ Mini-plate theory would be an innovation principle for better understanding and predicting earthquakes.
+ I hope that collaboration with GIC/AIT and UN will contribute to the reduction of earthquake disasters in Asian region.

Thank you for your attention