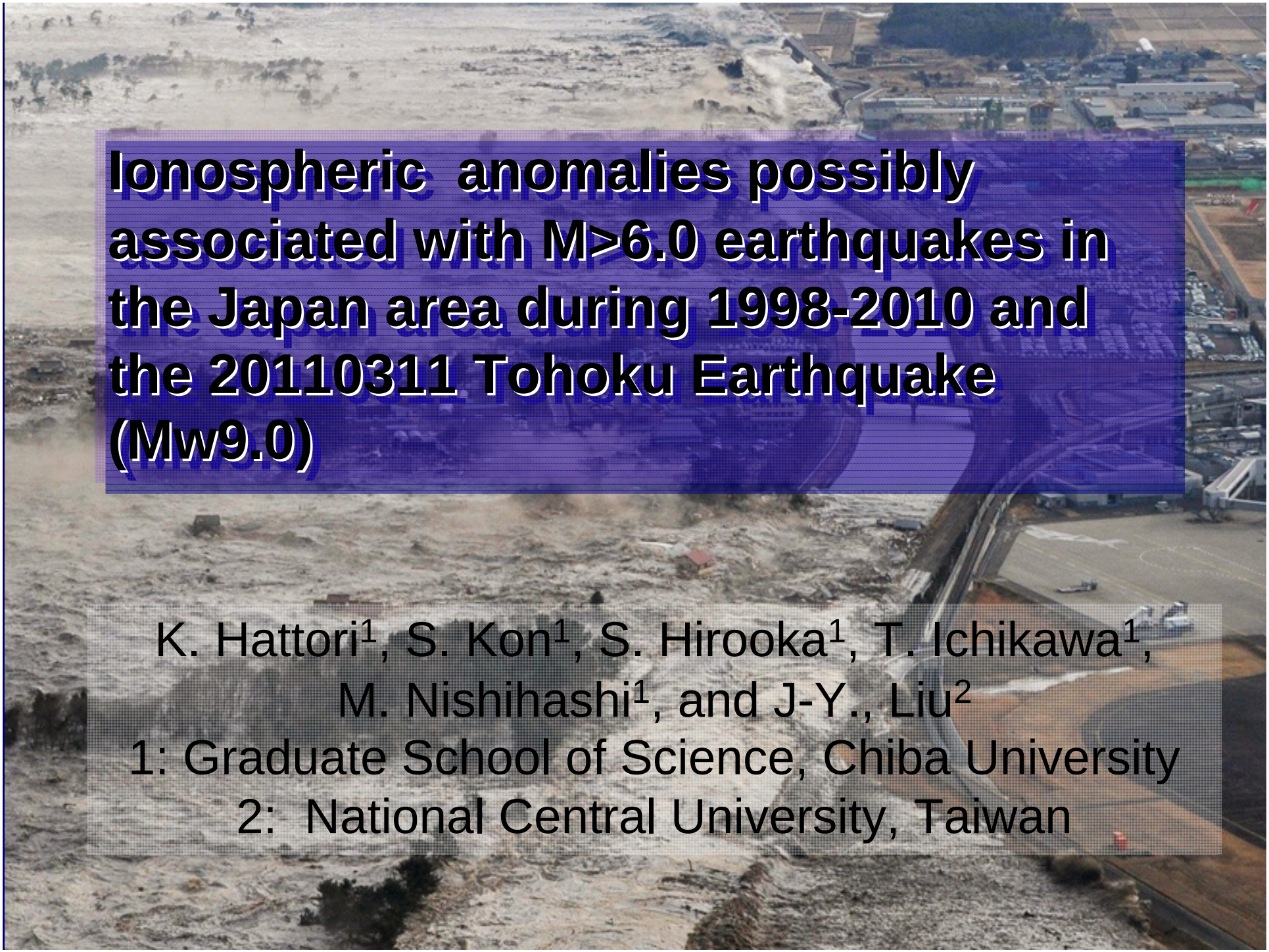


Ionospheric anomalies possibly associated with M>6.0 earthquakes in the Japan area during 1998-2010 and the 20110311 Tohoku Earthquake (Mw9.0)

K. Hattori[1], S. Kon[1], S. Hirooka[1], T. Ichikawa[1], M. Nishihashi[1], and J-Y., Liu[2]
1: Graduate School of Science, Chiba University
2: National Central University, Taiwan

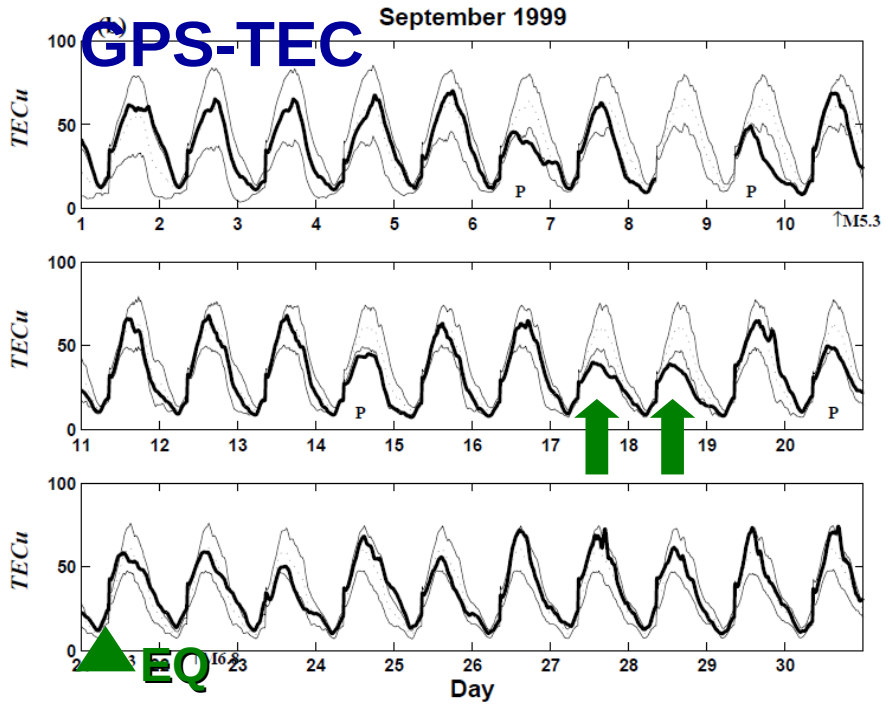
Outline

- Introduction
- Data processing
- Case studies
- Statistical study during 1998-2010
- Summary
- 20110311 M9 EQ

Introduction
Preseismic TEC change

The 1999 Chi-Chi EQ

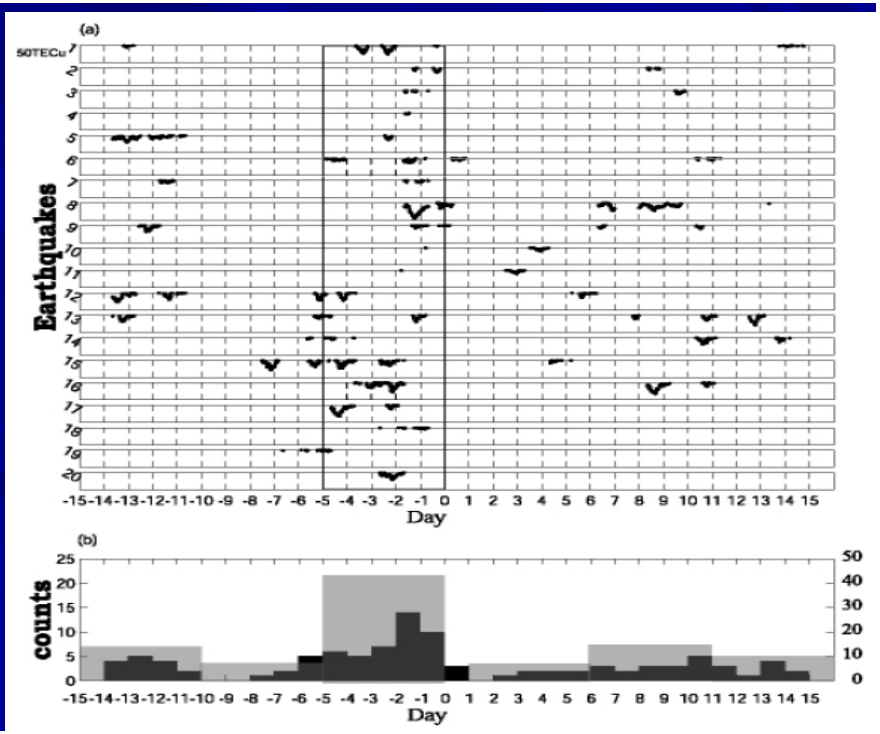
GPS-TEC decreased significantly 3, 4 days before EQ. (Liu et al., 2001, 2004)



Statistical Analysis in Taiwan

From statistical analysis, the ionospheric anomalies appeared 1 - 5 days before M.5.0 earthquakes in Taiwan.

(Liu et al., 2004, 2006)



Introduction

- We investigate the temporal & spatial extent of the Total Electron Content (TEC) anomalies prior to large EQs in Japan area (GPS-TEC and GIM-TEC).

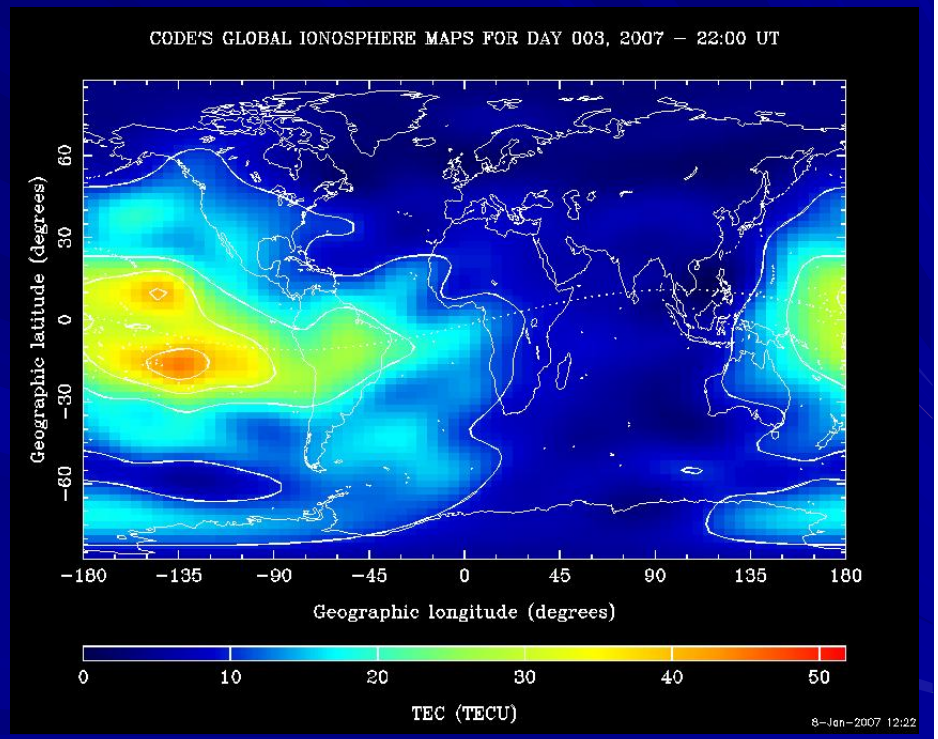
- In order to clarify the association between EQ activity and TEC anomalies, we conduct case and the statistical analysis using GIM data during 1998- 2010.

- We investigate possible anomalies associated with the 20110311 Mw9.0 EQ.

Global Ionosphere Maps (GIM)

We use global TEC data-set produced by the Center for Orbit Determination in Europe (CODE).

Spatial resolution :
2.5 degrees in latitude
5 degrees in longitude
Time resolution : 2 hours

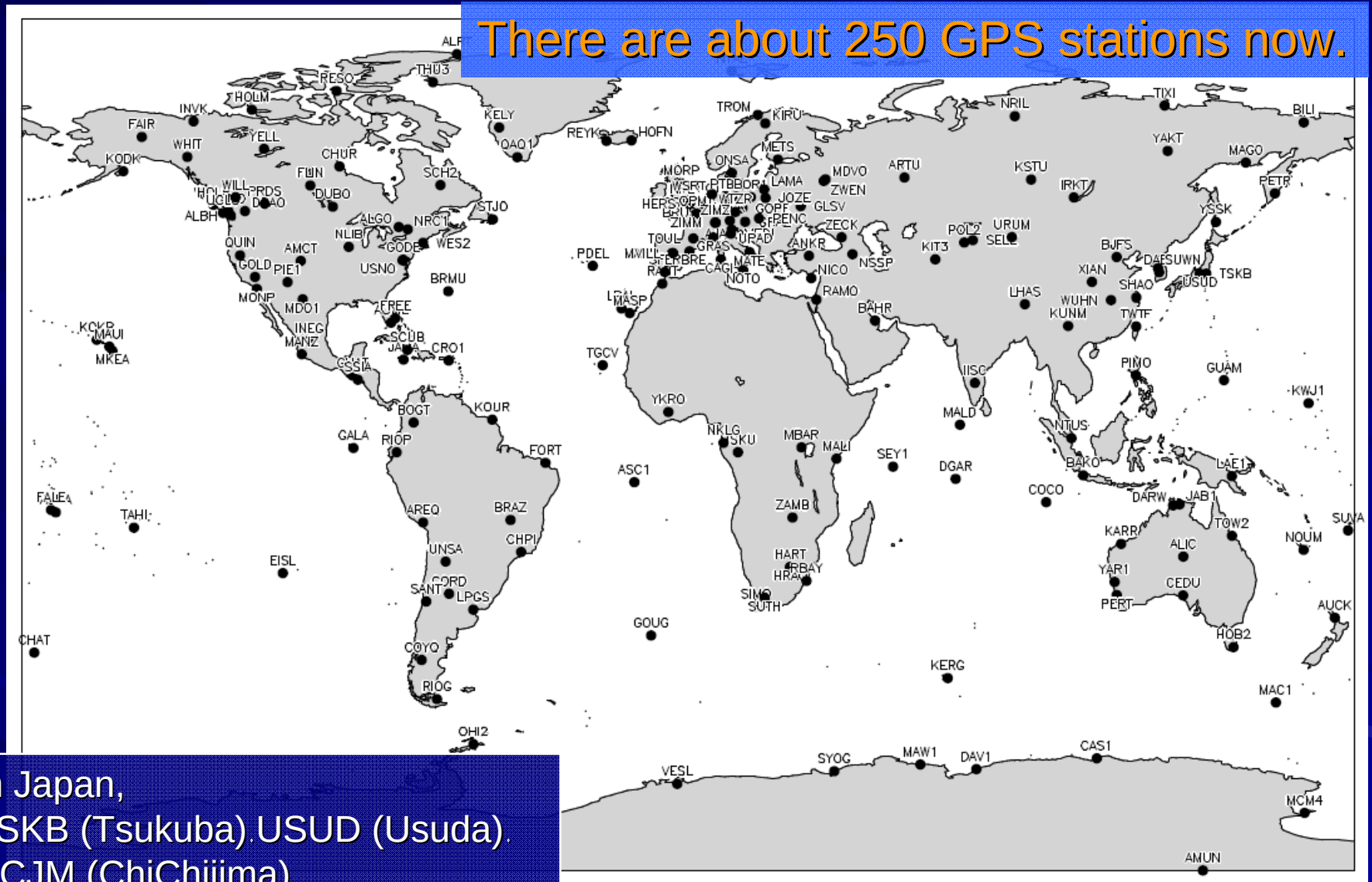


Example of GIM data (22UT, Jan. 3, 2007)

In order to be able to observe TEC values at a certain location, we extracted data from the GIM and linearly interpolated to yield a 15-min resolution and 1 degree resolution.

GPS stations for GIM computation

There are about 250 GPS stations now.



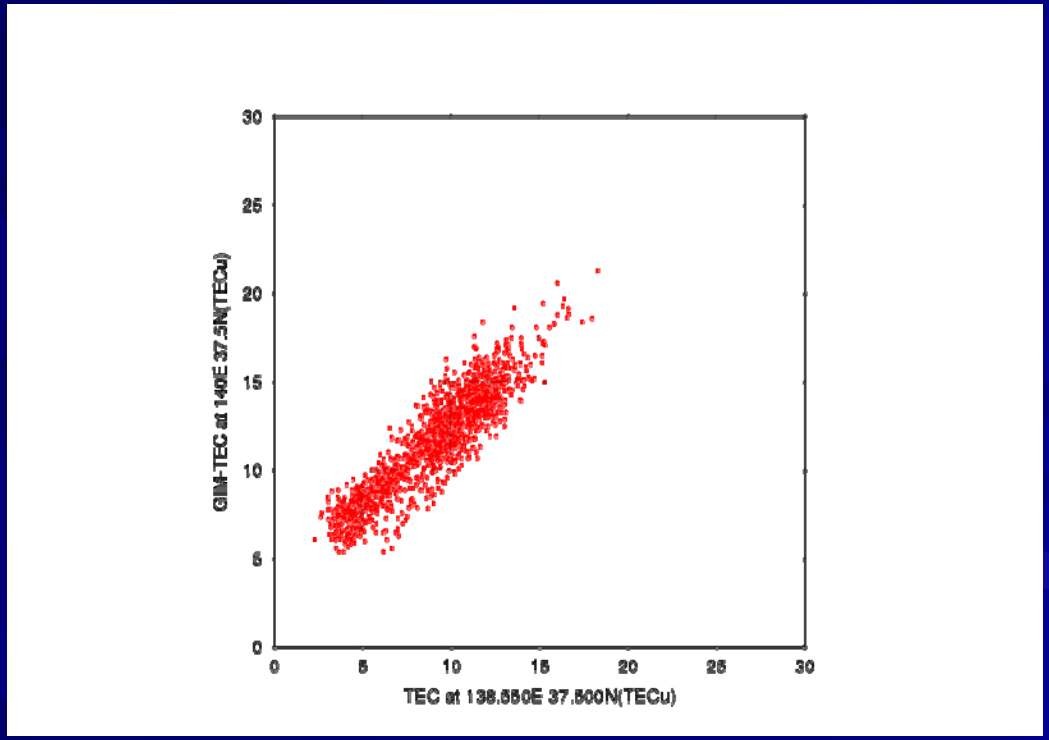
In Japan,
TSKB (Tsukuba), USUD (Usuda),
CCJM (ChiChijima),
MIZU (Mizusawa), MTKA (Chofu)

http://aiuws.unibe.ch/ionosphere/codnet_abbr.pdf

Correlation between TEC & GIM-TEC

(2004/09.2004/12)

TEC: (37.50°N, 138.55°E)
GIM-TEC: (37.50°N, 140.00°E)



R=

(Unit: TECU)

Correlation between TEC and GIM-TEC is high not concerned the geomagnetic activity.

Advantage & disadvantage of GIM

Advantage

- We can see global TEC variation easily & efficiently.
- We can process TEC data without GPS analysis software like the GAMIT.
- We can analyze TEC variation in the area of lack of GPS stations.
- GIM is no missing data for 12 years (1998~).

Disadvantage

- GIM is interpolated using the spherical harmonics.
- Spatial-temporal resolution of the GIM is low. (However, EIA can be identified.)

Computation of TEC* & GIM-TEC*

To remove daily variation of TEC
and identify abnormal signals associated with EQs

We computed the 15 days backward mean values,
and the associated standard deviation (σ)
as a reference at specific times.
Then, we derived the normalized ΔTEC (TEC*).

$$TEC^*(t) = \frac{TEC(t) - \overline{TEC(t)}}{\sigma\,(t)}$$

(computed using RINEX files)

$$GIM\text{-}TEC^*(t) = \frac{GIM\text{-}TEC(t) - \overline{GIM\text{-}TEC(t)}}{\sigma\,(t)}$$

Removal of geomagnetic storm effect

To remove geomagnetic storm effect,
we defined a criterion as follows;

Dst index < -60 nT : geomagnetic storm

TEC could depress about a few hours
to 2 days after geomagnetic storm onsets.
(Kelley, 1989; Davies, 1990)

We removed the TEC data of geomagnetic storm period for 2 days after storm onset.

Japan region

- Case study
  1. The 20041023 Chuetsu EQ (M6.8) and the its aftershock (M6.1).
  2. The 20070716 Chuetsu-Oki EQ (M6.8)

(Kon, Nishihashi, and Hattori, *J. Asian Earth Sciences*, 41, 410-420,2011)

- Statistical study

  EQs from1998 to 2010 (12 years)

(Kon, Nishihashi, and Hattori, *J. Asian Earth Sciences*, 41, 410-420,2011)

- Validation

  The 20110311 Tohoku EQ (Mw9.0)

- Tomography

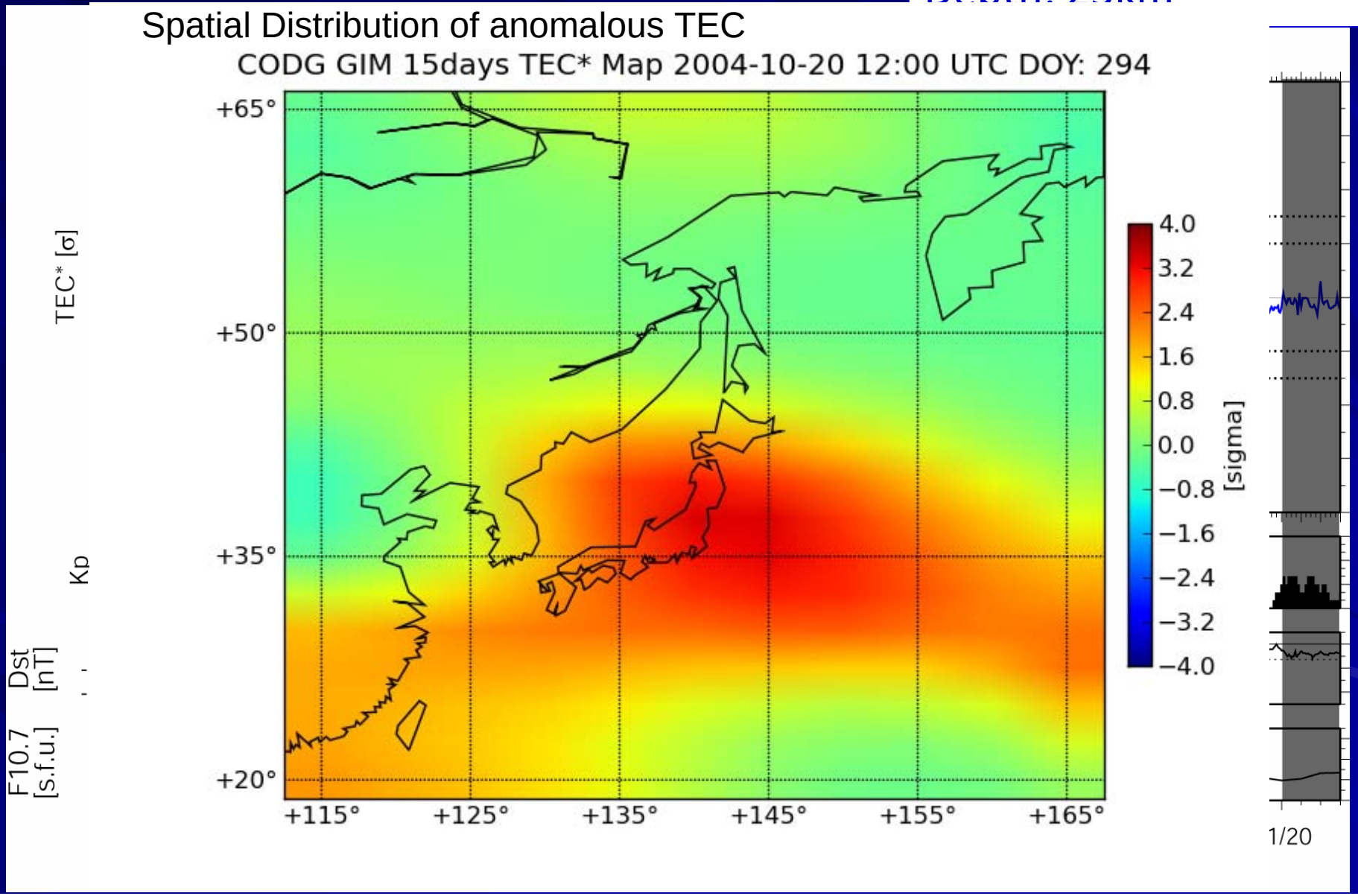
(Hirooka, Hattori, and Takeda, *Radio Science*, 2011 in press)
(Hirooka, Hattori, and .Takeda, *NHESS*, 2011)

Case Study 1

The 20041023 Chuetsu EQ

2004/10/23 08:56UT
M: 6.8
Depth: 23km

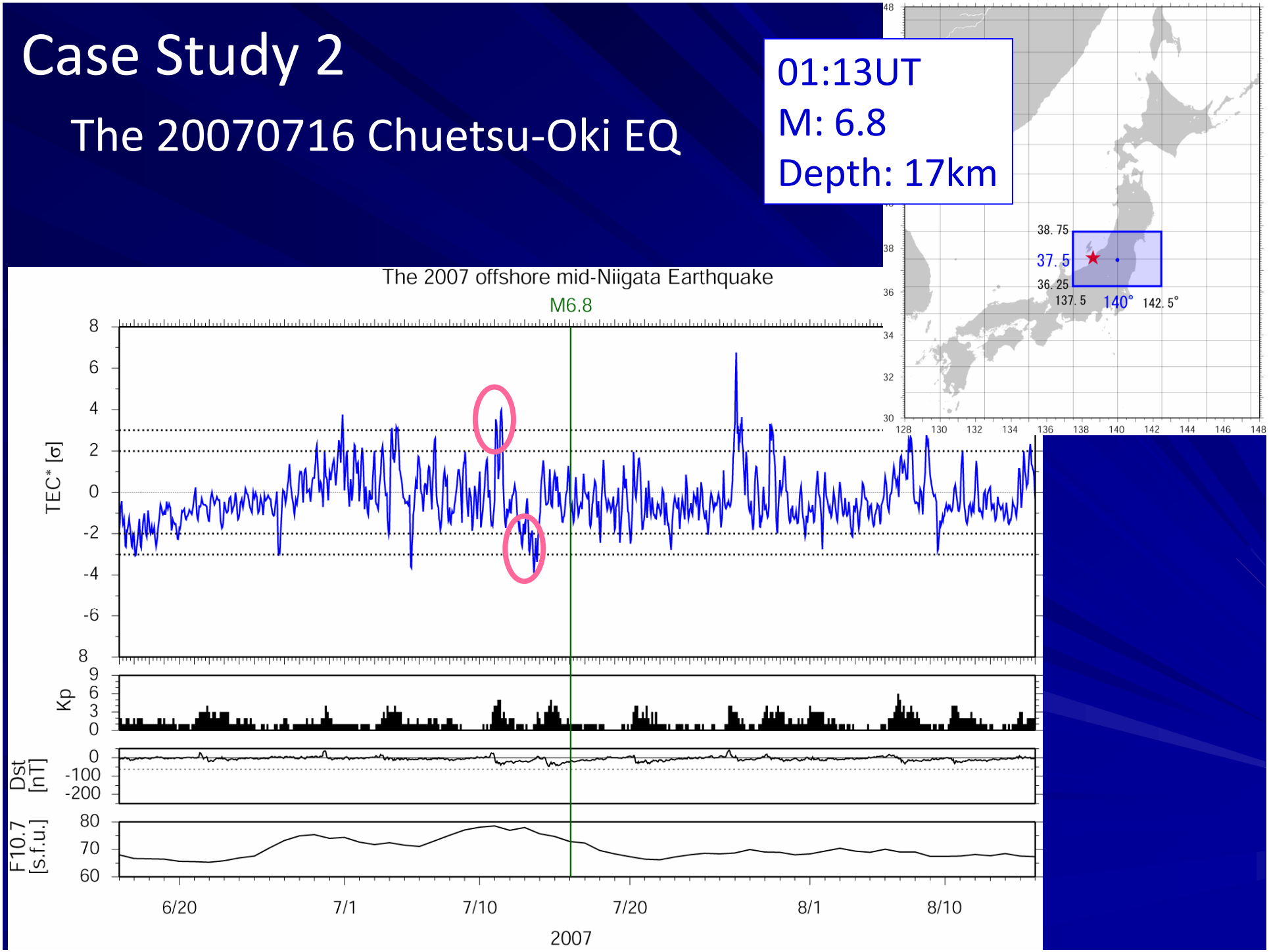
Spatial Distribution of anomalous TEC



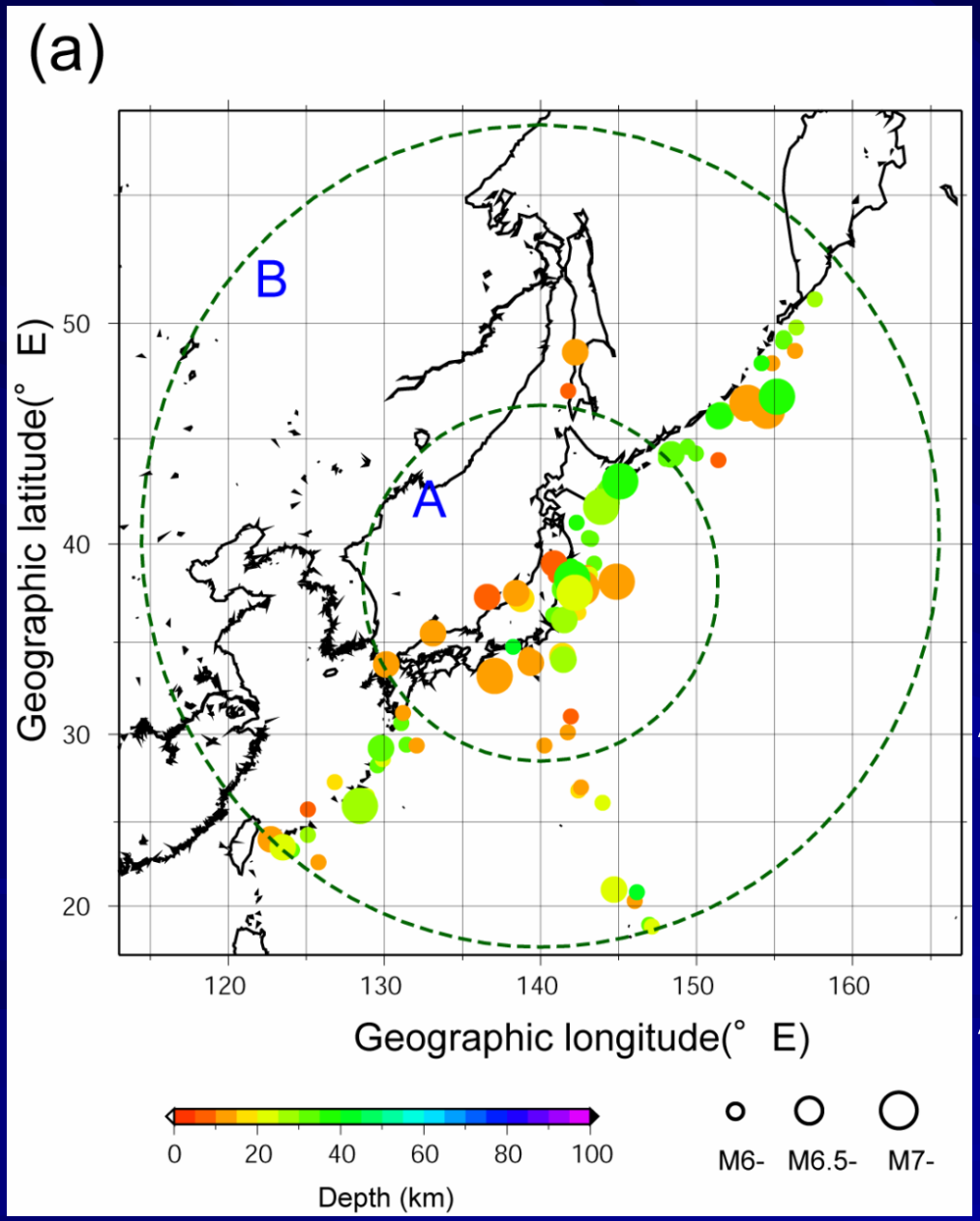
Case Study 2

The 20070716 Chuetsu-Oki EQ

01:13UT
M: 6.8
Depth: 17km



Statistical analysis of GIM-TEC* anomalies



GIM-TEC* data:

37.5° N, 140° E (Niigata Prefecture)

May 1998 – May 2010

12 years

Earthquake data:

USGS

Analyzed earthquakes:

M ≥ 6.0, Depth ≤ 40 km

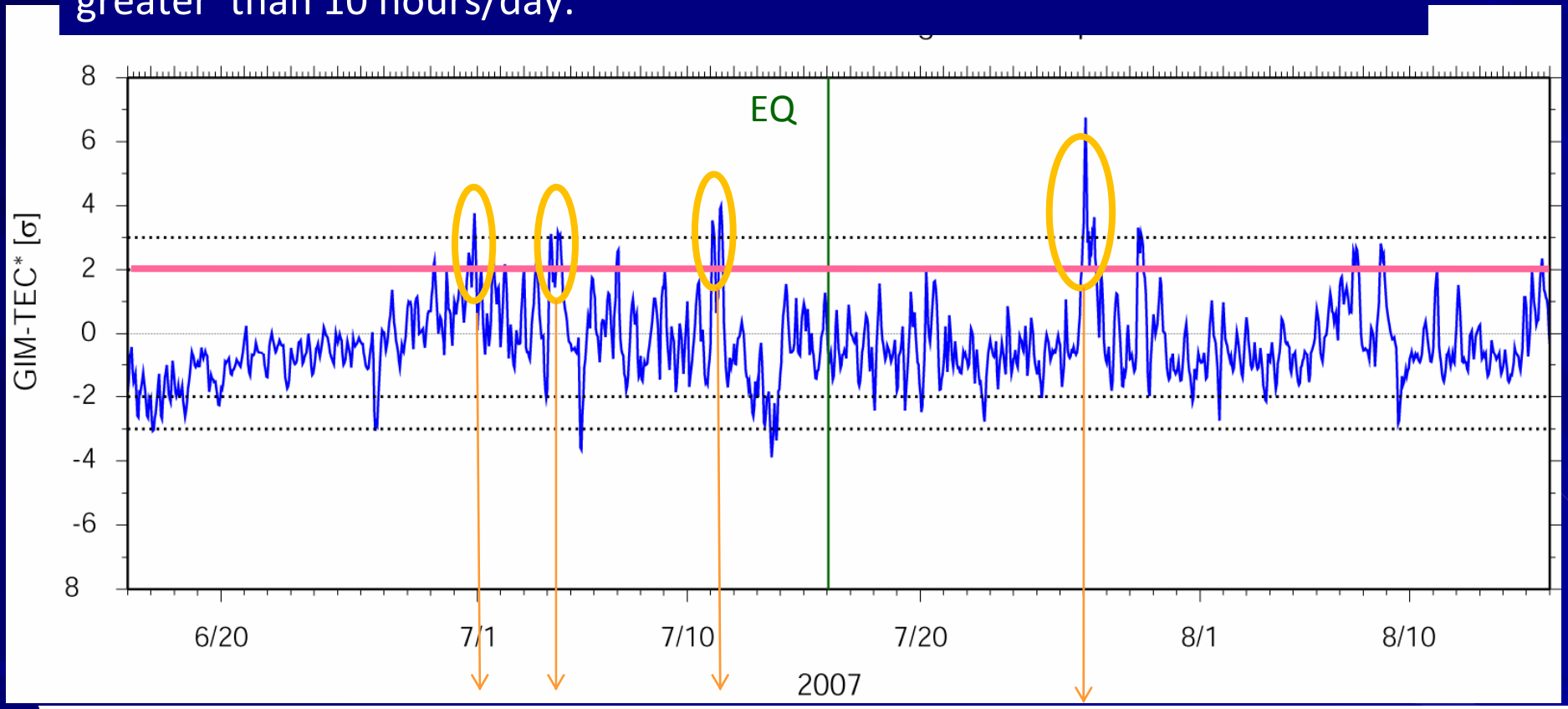
From 37.5° N, 140° E ,

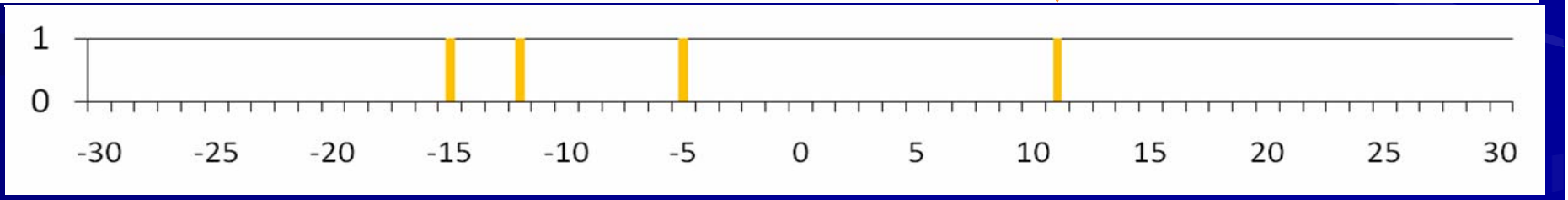
A. 0≤R≤1,000km (52 EQs)

B. 1,000≤R≤2,224km (52 EQs)

Superposed Epoch Analysis . . .

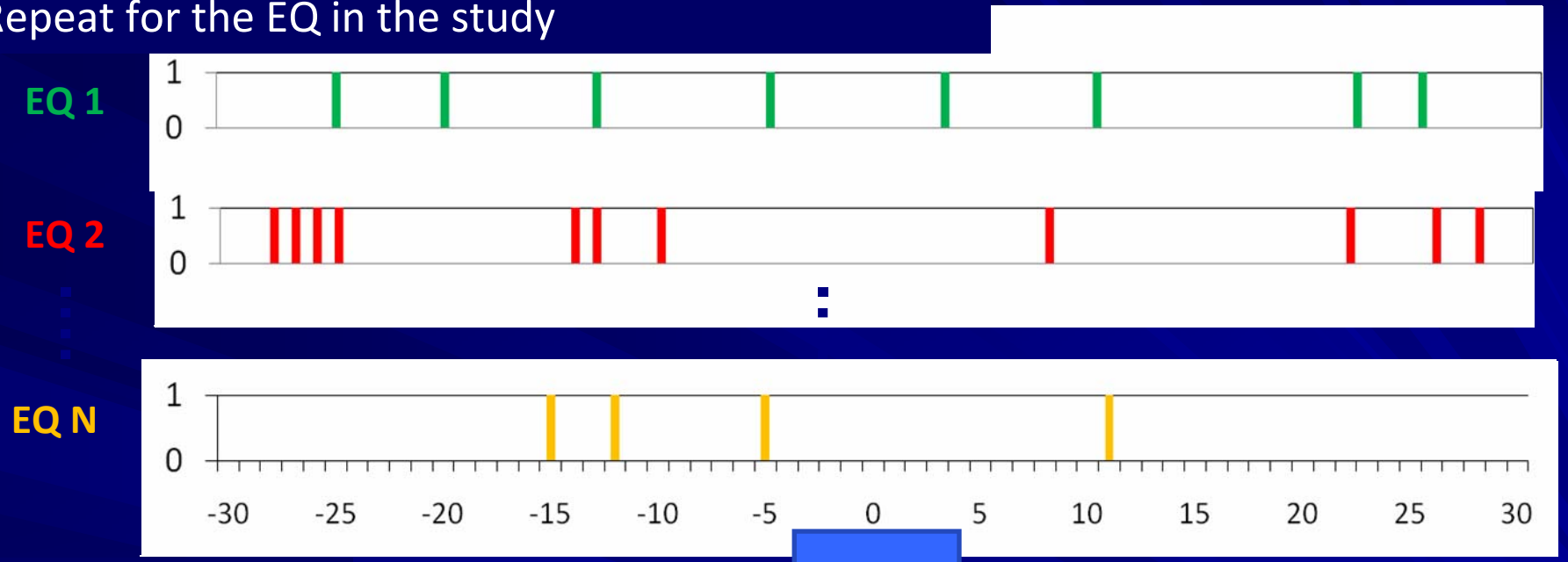
Definition of Anomaly: Count 1 when GIM-TEC* exceeds 2.(-2.) criterion greater than 10 hours/day.



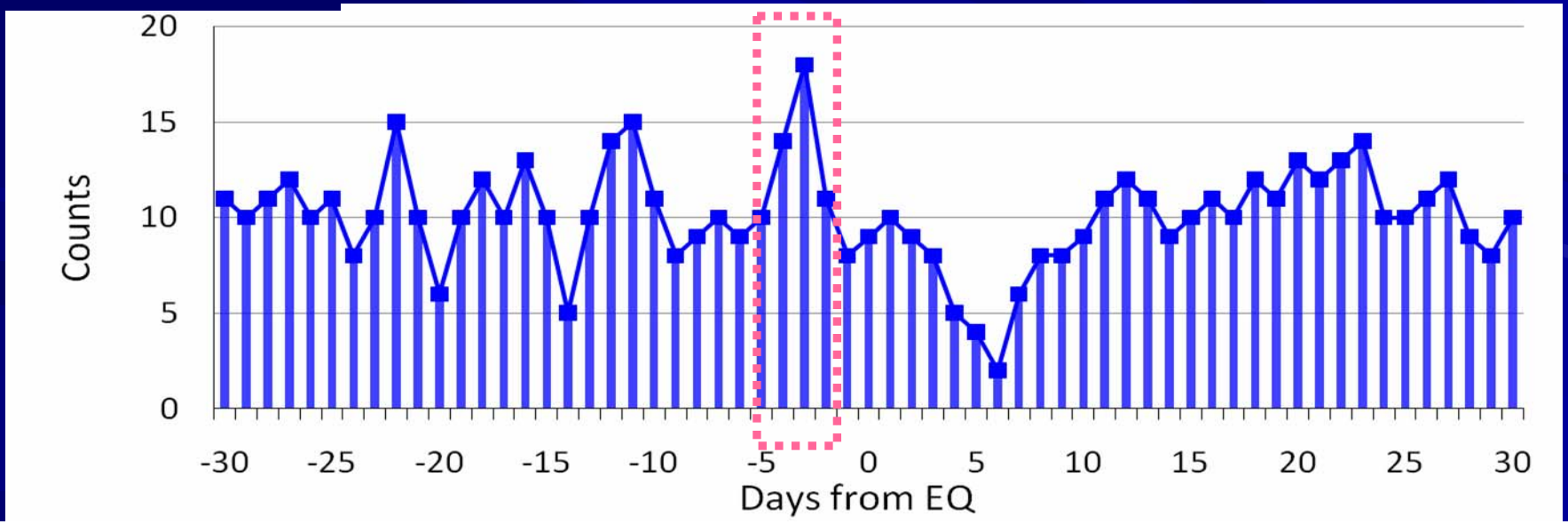


Superposed Epoch Analysis 2

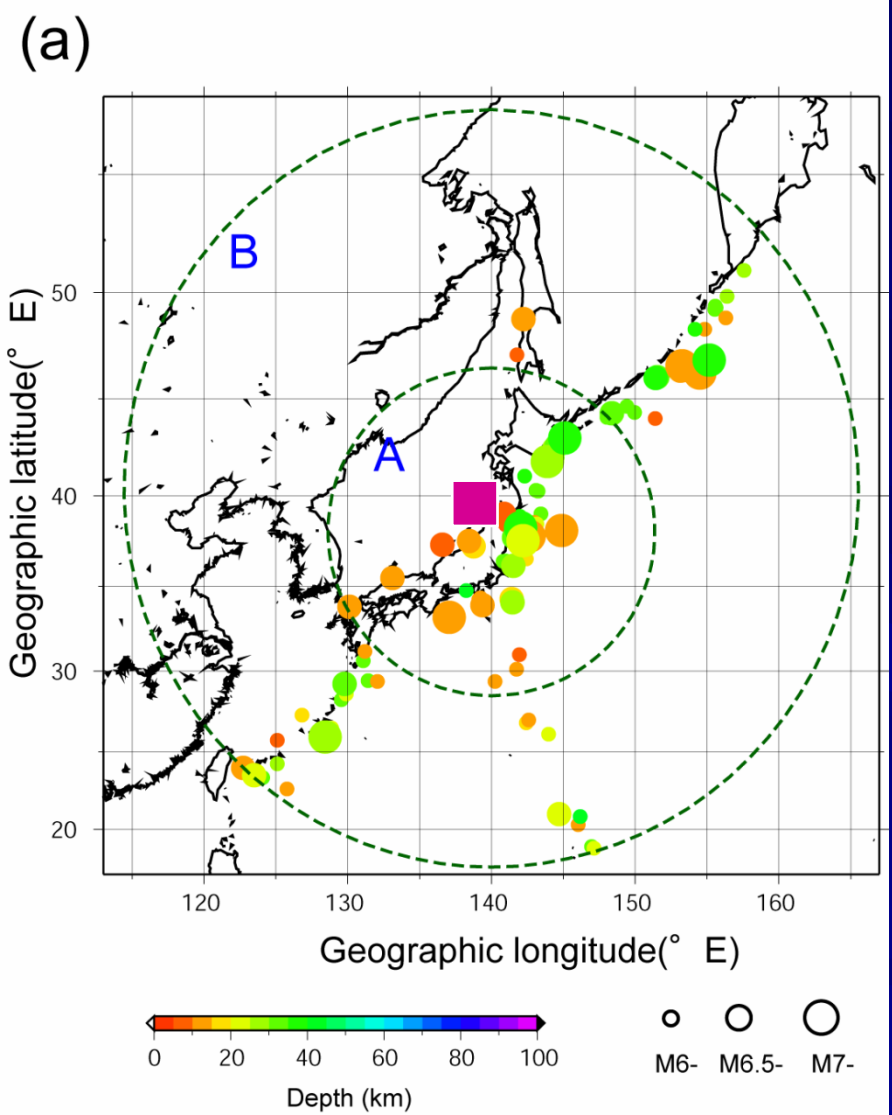
Repeat for the EQ in the study



Summation



Superposed Epoch Analysis 3



EQ with M>6.0 around Japan

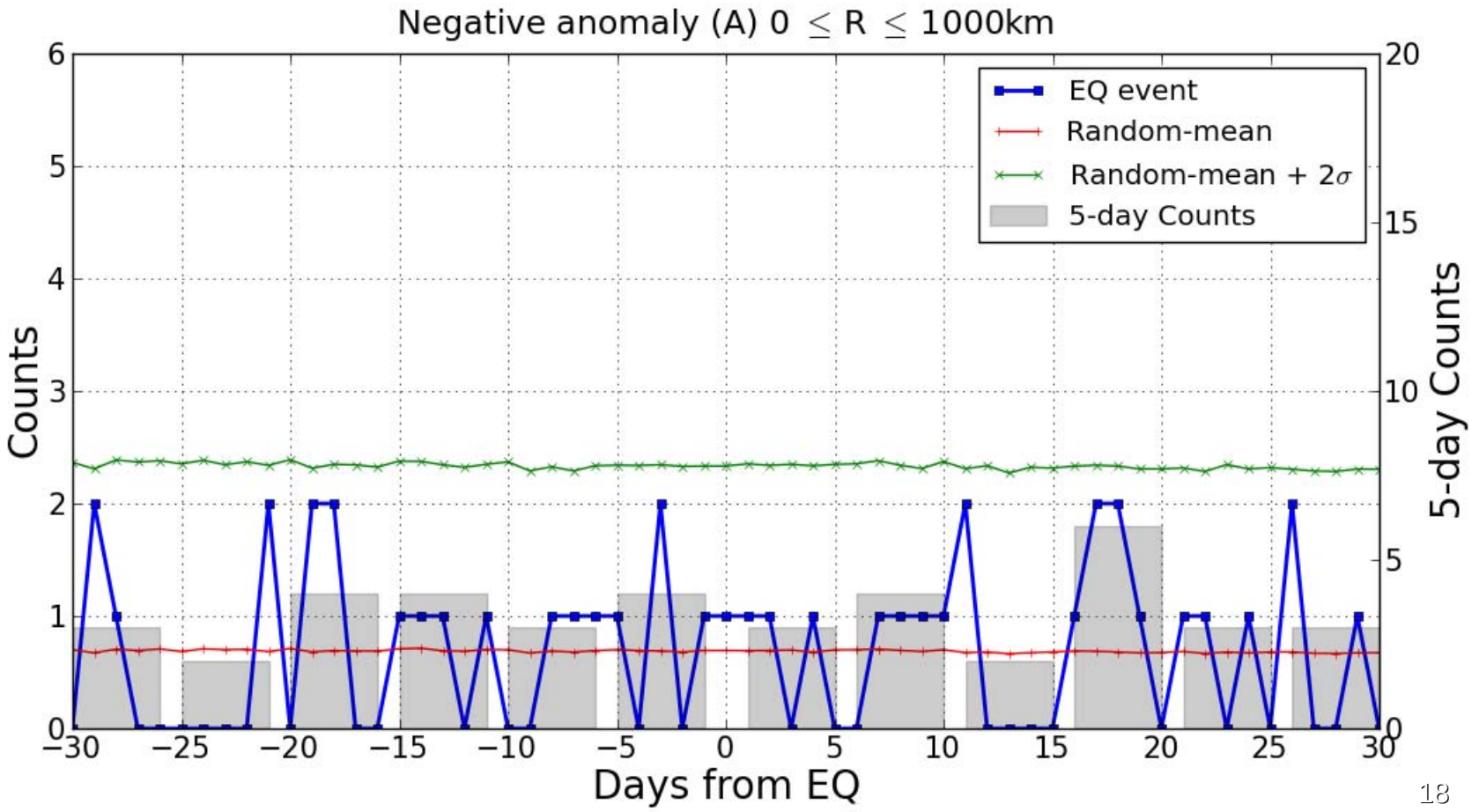
M>=6.0, D<40km
37.5°N, 140°E
A. 0≦R≦1000 km (52 EQs)
B. 1000≦R≦2224 km (52 EQs)

[Evaluation of significanse]

- Random-mean
  - "Choose 52 days over 12 years data randomly and perform SEA. Repeat above process 10,000 times and take average.
- Random-mean+2σ

Results of Superposed Epoch Analysis 1.

Negative GIM-TEC* anomaly | 0≤R≤1000km 52EQs.

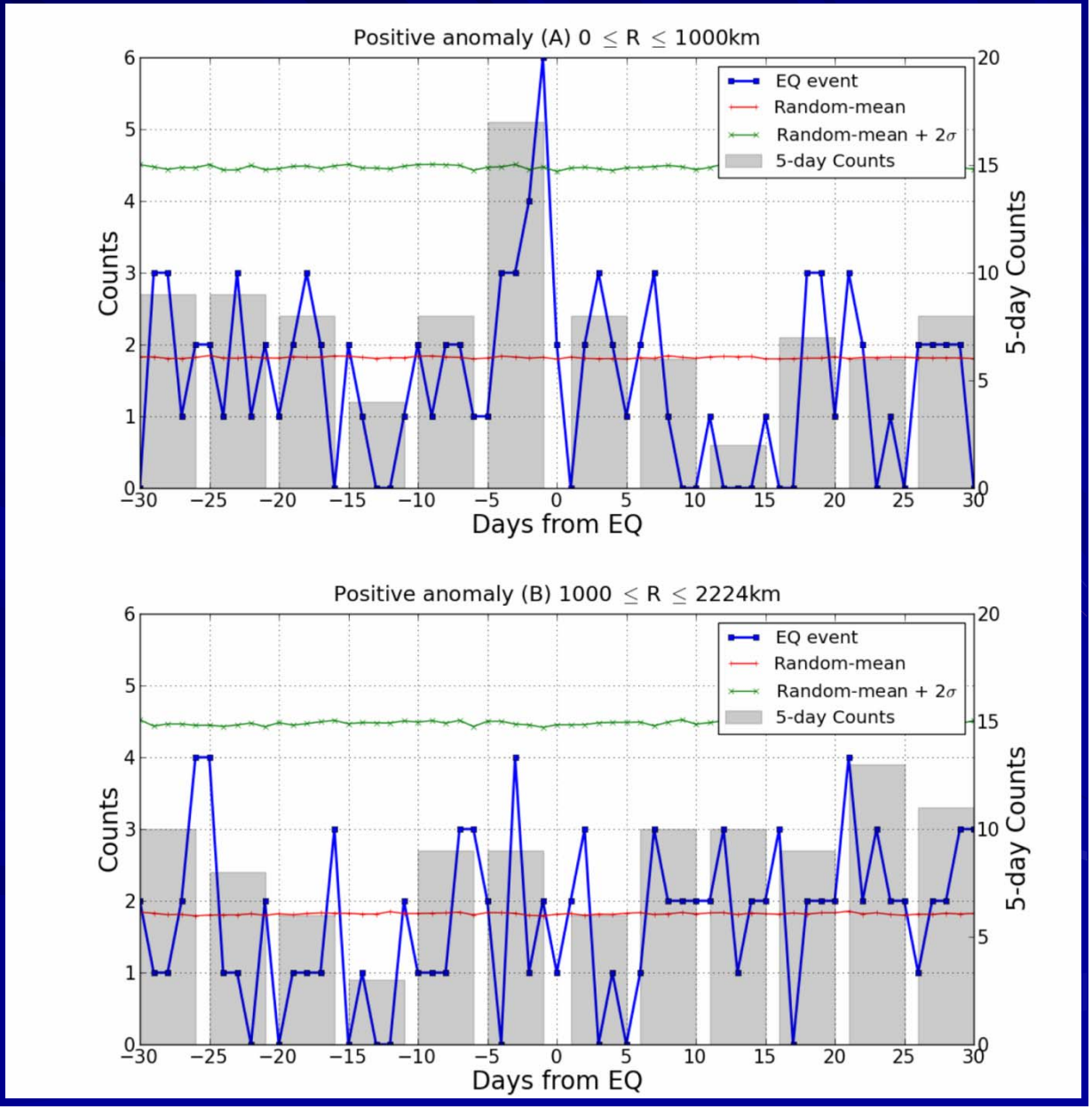


Results of Superposed Epoch Analysis 2

Positive GIM-TEC* anomaly

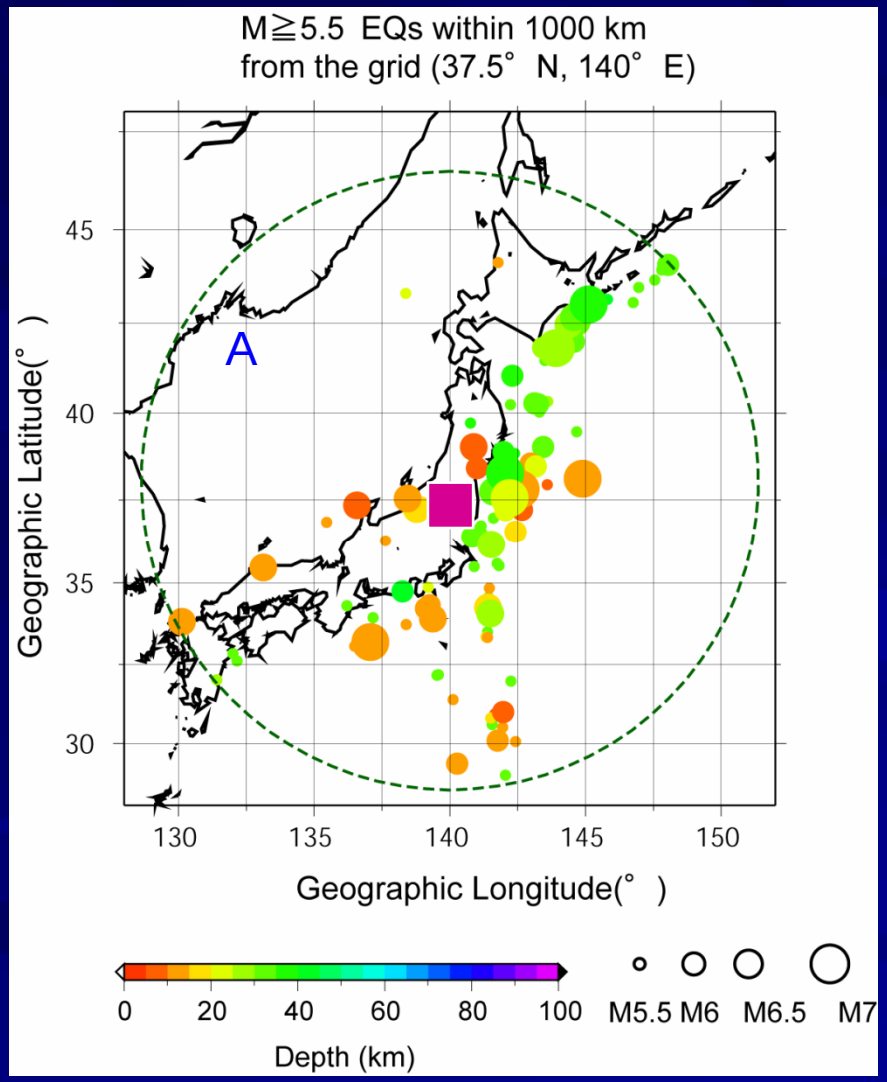
[Region A]
0< R <1000 km
52 EQs M>= 6.0

[Region B]
1000 < R 2224 km
52 EQs M>=6.0



Results of Superposed Epoch Analysis 3

Magnitude dependence



Target : Region A

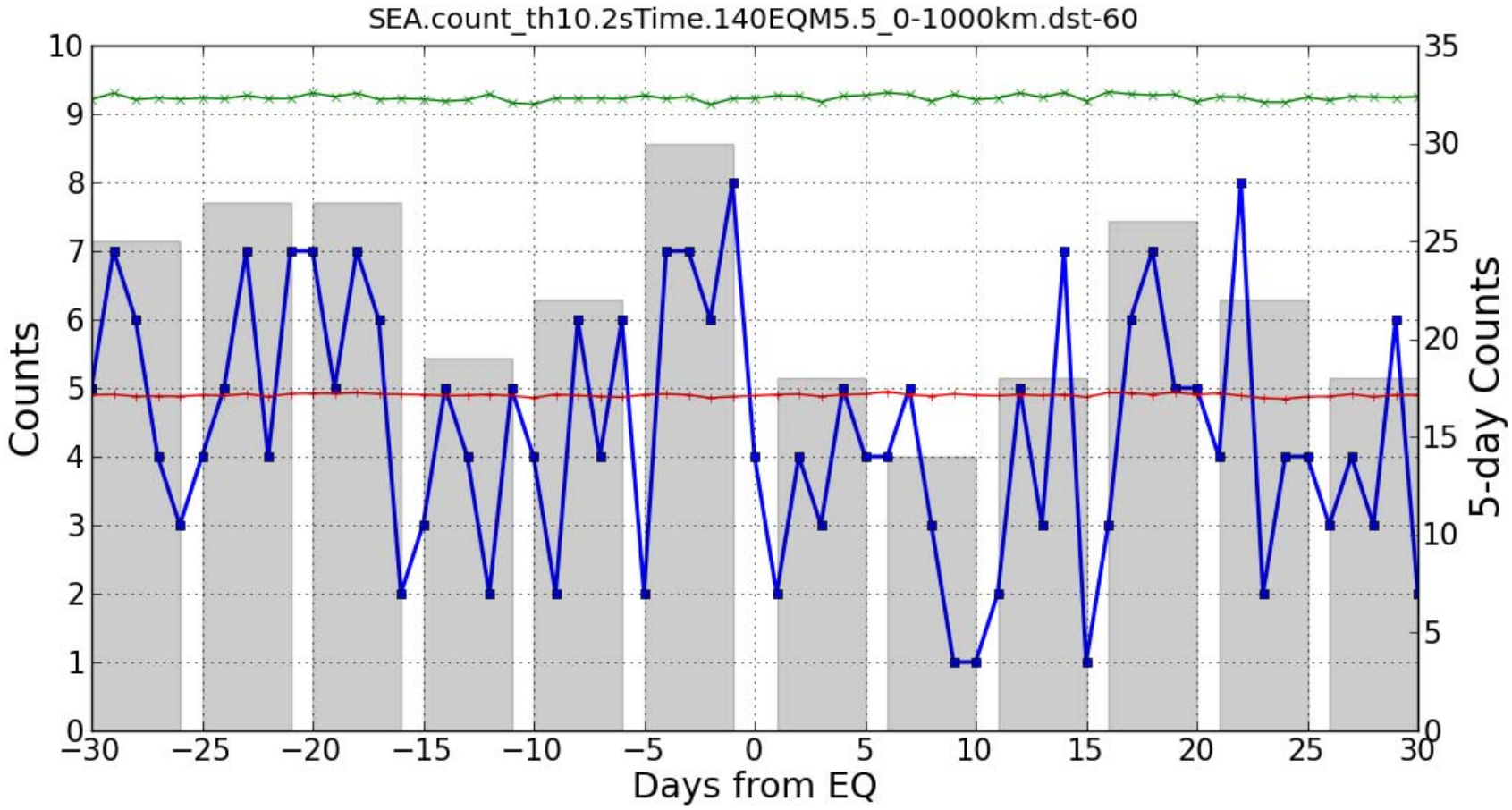
[Number of EQs and M]
Region A: Depth < 40 km
(a). M>=5.5, 140 EQs
(b). M>=5.6, 119 EQs
(c). M>=5.7, 98 EQs
(d). M>=5.8, 79 EQs
(e). M>=5.9, 66 EQs
(f). M>=6.0, 52 EQs

EQ map for Region A : EQ >= M5.5

Results of Superposed Epoch Analysis 2

Positive GIM-TEC* anomaly

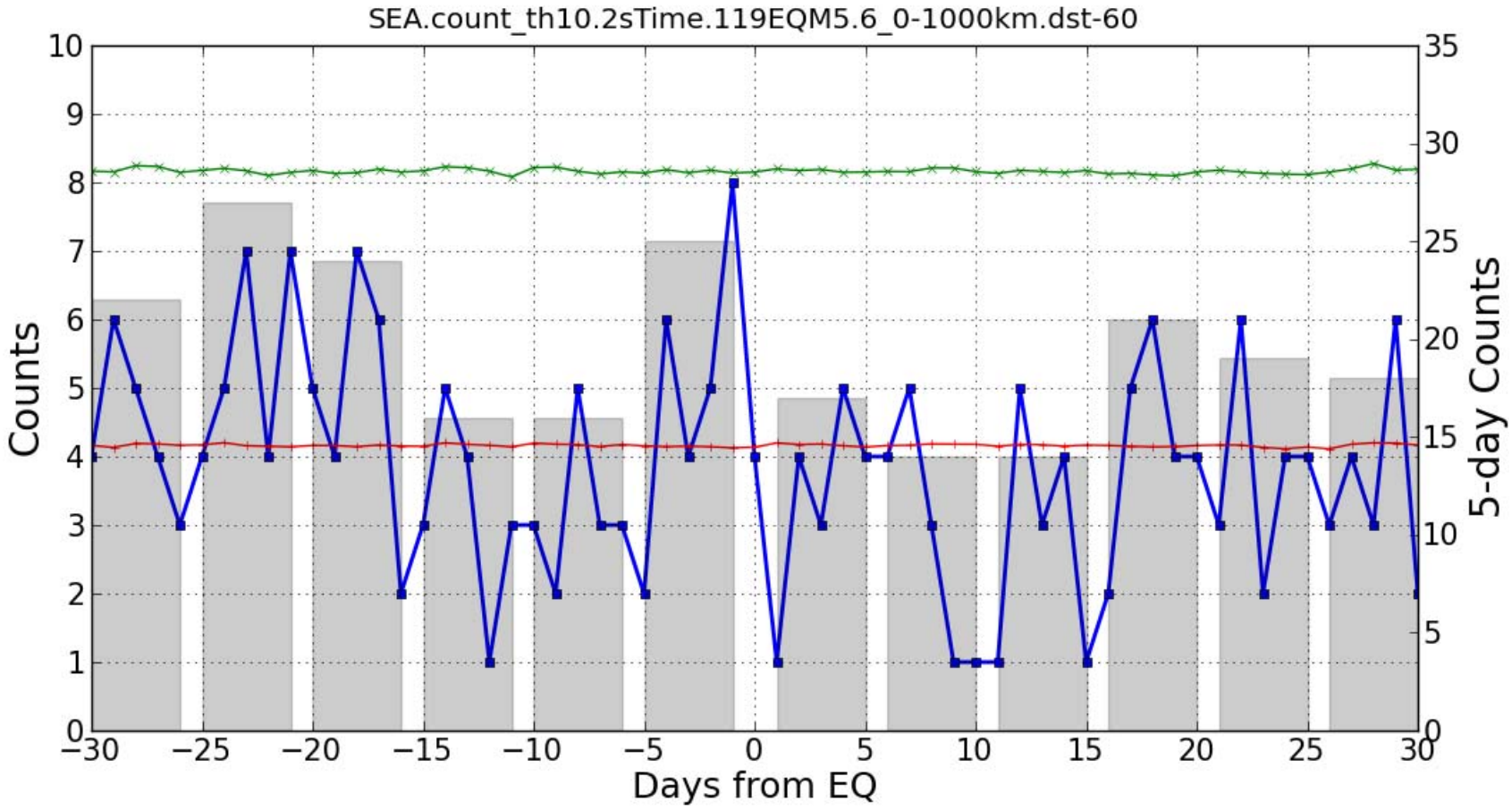
M >=5.5 140EQs
(Region A: 0<R 1000 km)



Results of Superposed Epoch Analysis 4

Positive GIM-TEC* anomaly

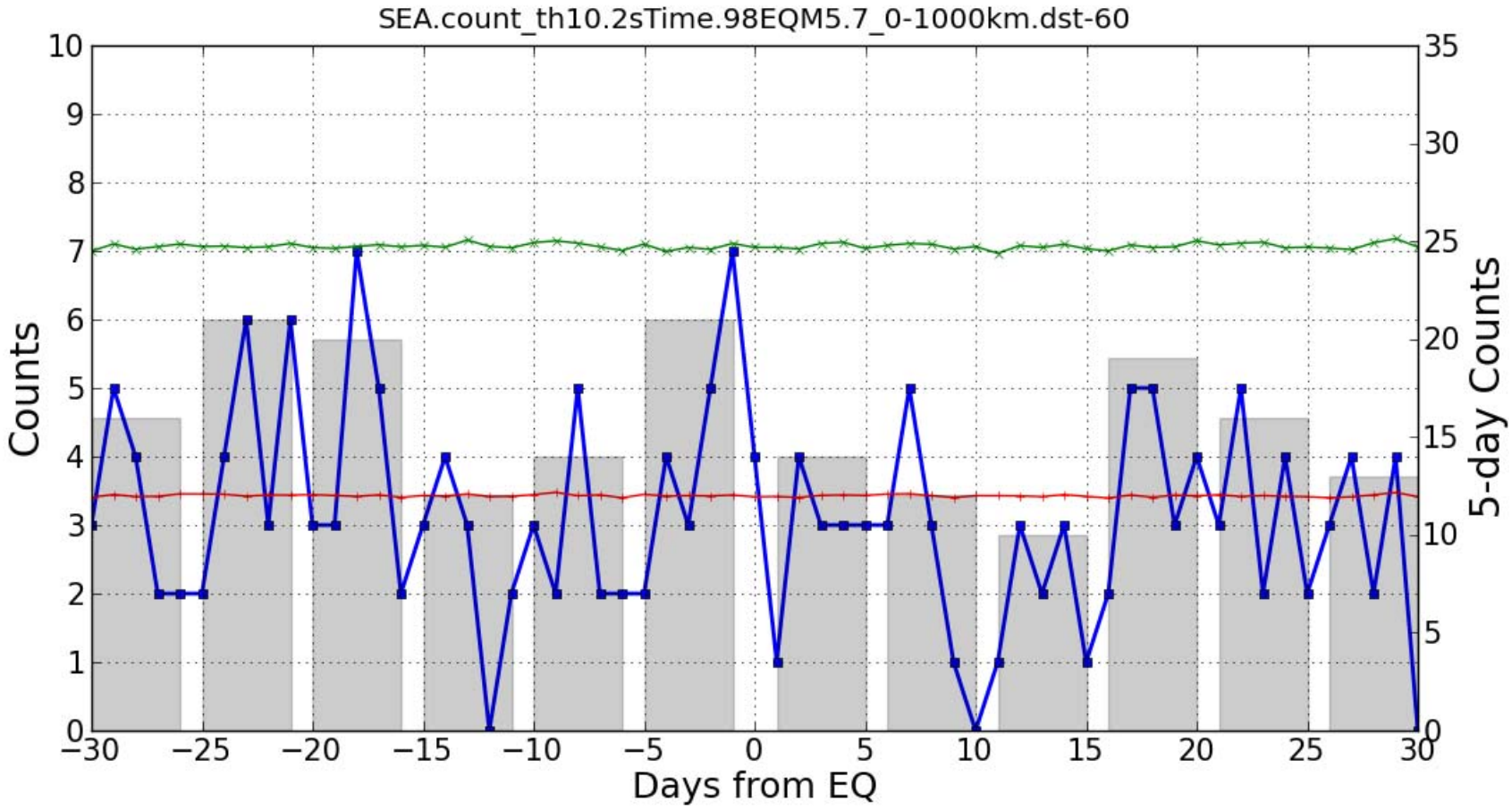
M >=5.6 140EQs
(Region A: 0<R 1000 km)



Results of Superposed Epoch Analysis 4

Positive GIM-TEC* anomaly

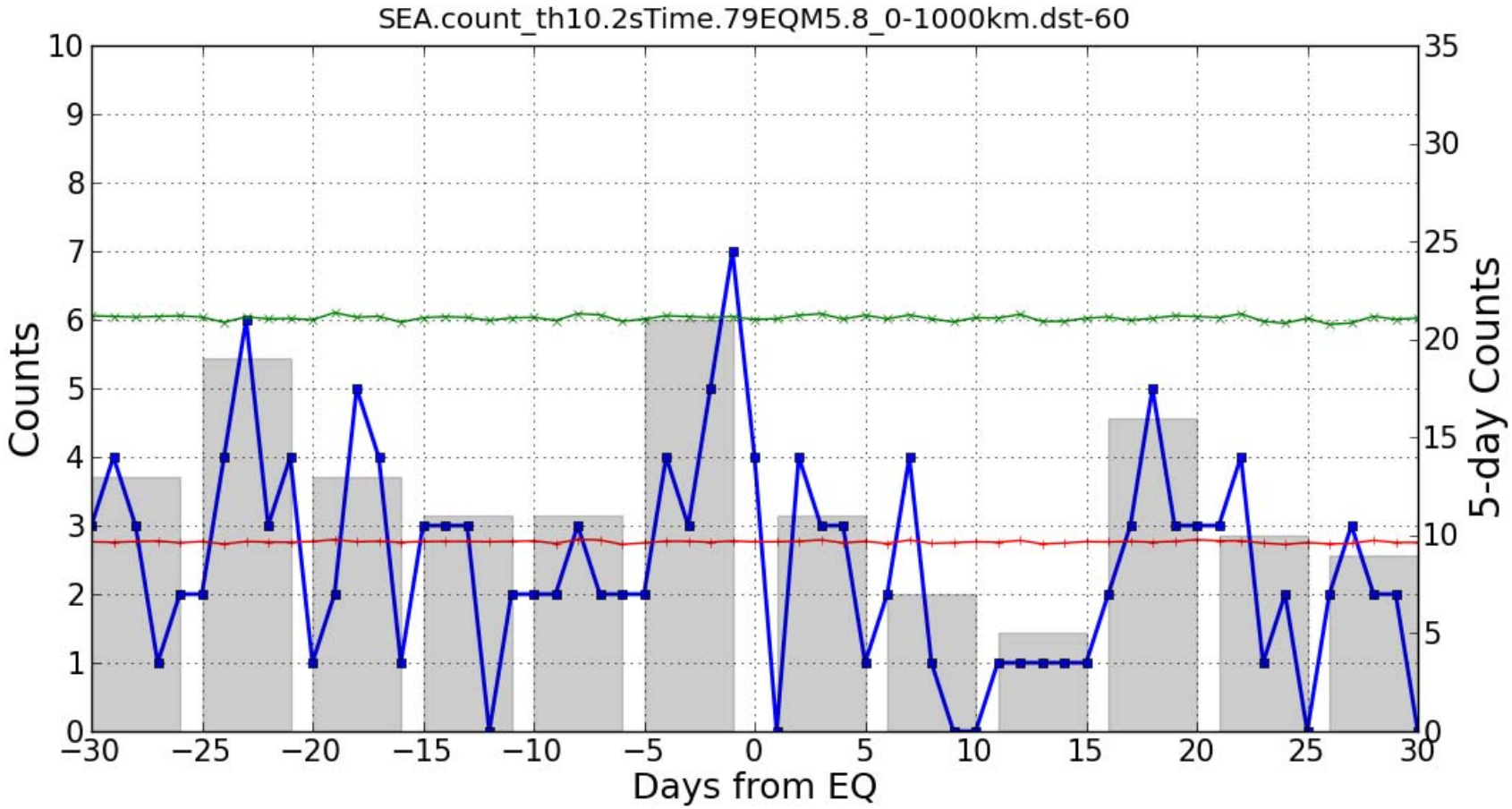
M >=5.7 140EQs
(Region A: 0<R 1000 km)



Results of Superposed Epoch Analysis 4

Positive GIM-TEC* anomaly

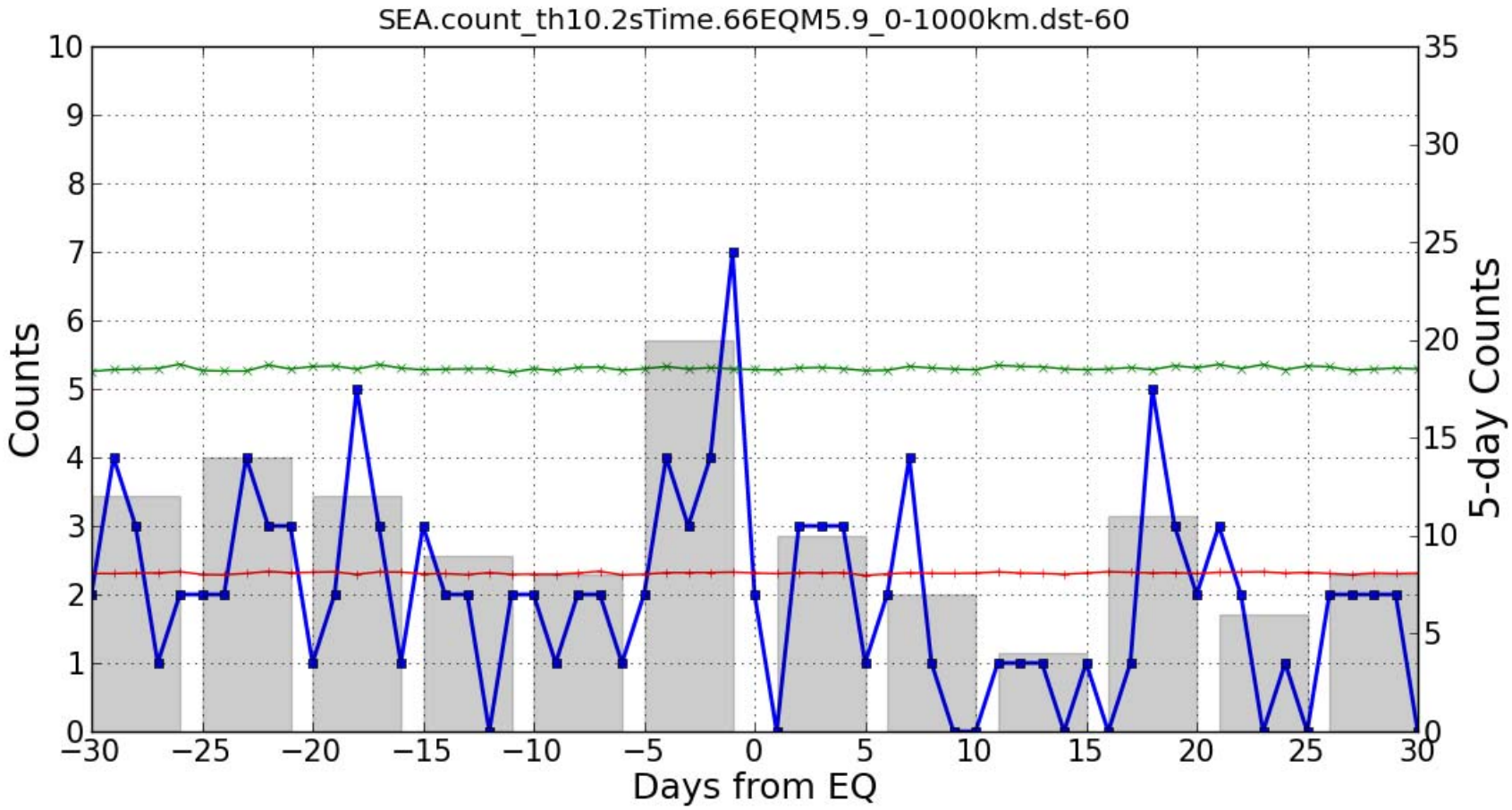
M >=5.8 140EQs
(Region A: 0<R 1000 km)



Results of Superposed Epoch Analysis 4

Positive GIM-TEC* anomaly

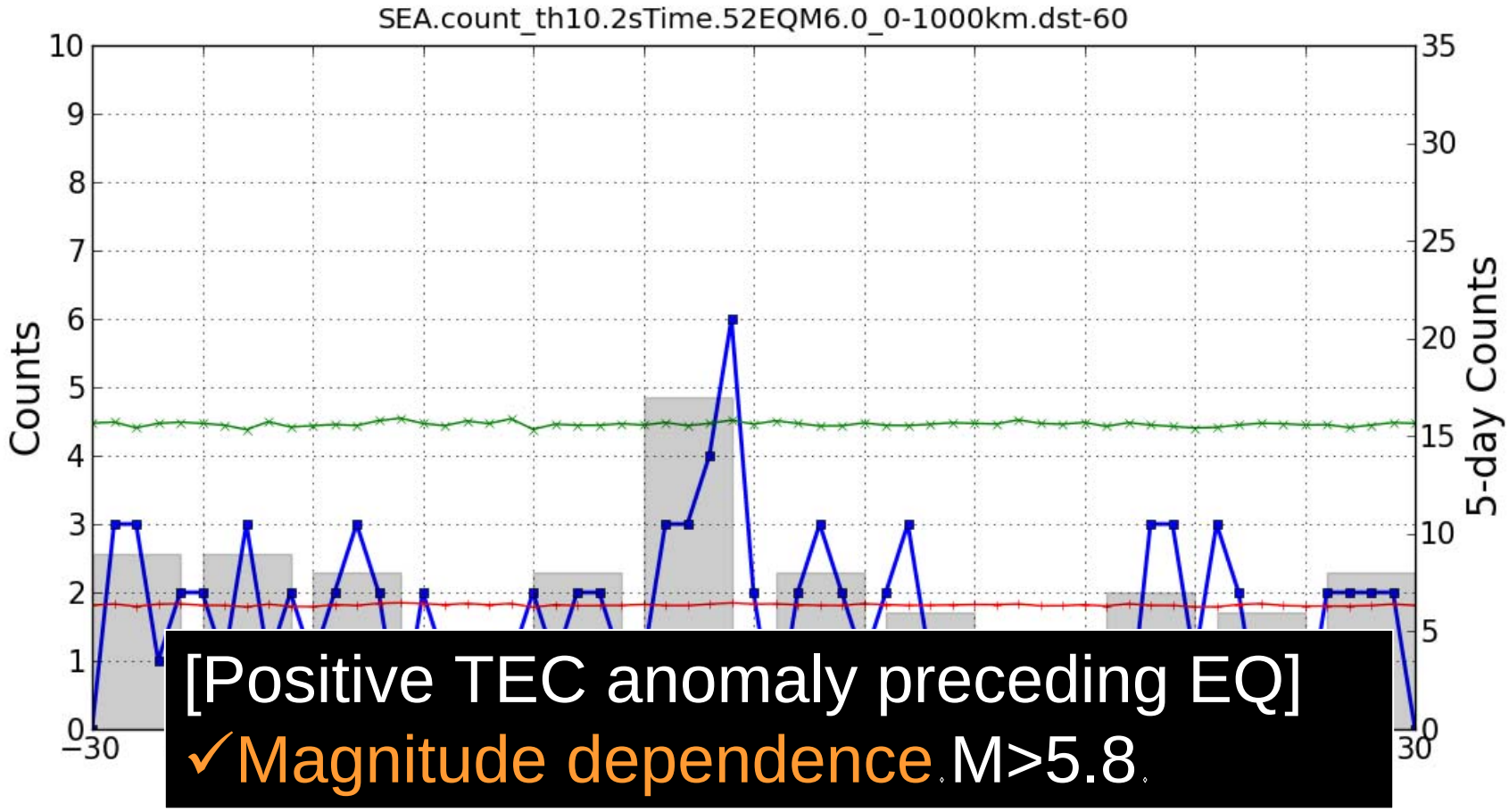
M >=5.9 140EQs
(Region A: 0<R 1000 km)



Results of Superposed Epoch Analysis 4

Positive GIM-TEC* anomaly

M >=6.0 140EQs
(Region A: 0<R 1000 km)



[Positive TEC anomaly preceding EQ]
✓Magnitude dependence M>5.8

SEA for TEC anomaly

Statistical Analysis of Seismic Activities based on TEC Anomalies

- Validation of SEA of TEC anomaly based on Seismic events
- Validation for practical earthquake forecast

SEA of seismic activities based on TEC anomaly

The number of days of positive GIM-TEC* anomaly: 155 days
(May 1998/ – May 2010 (12 years) at (37.5N, 140E) for GIM)

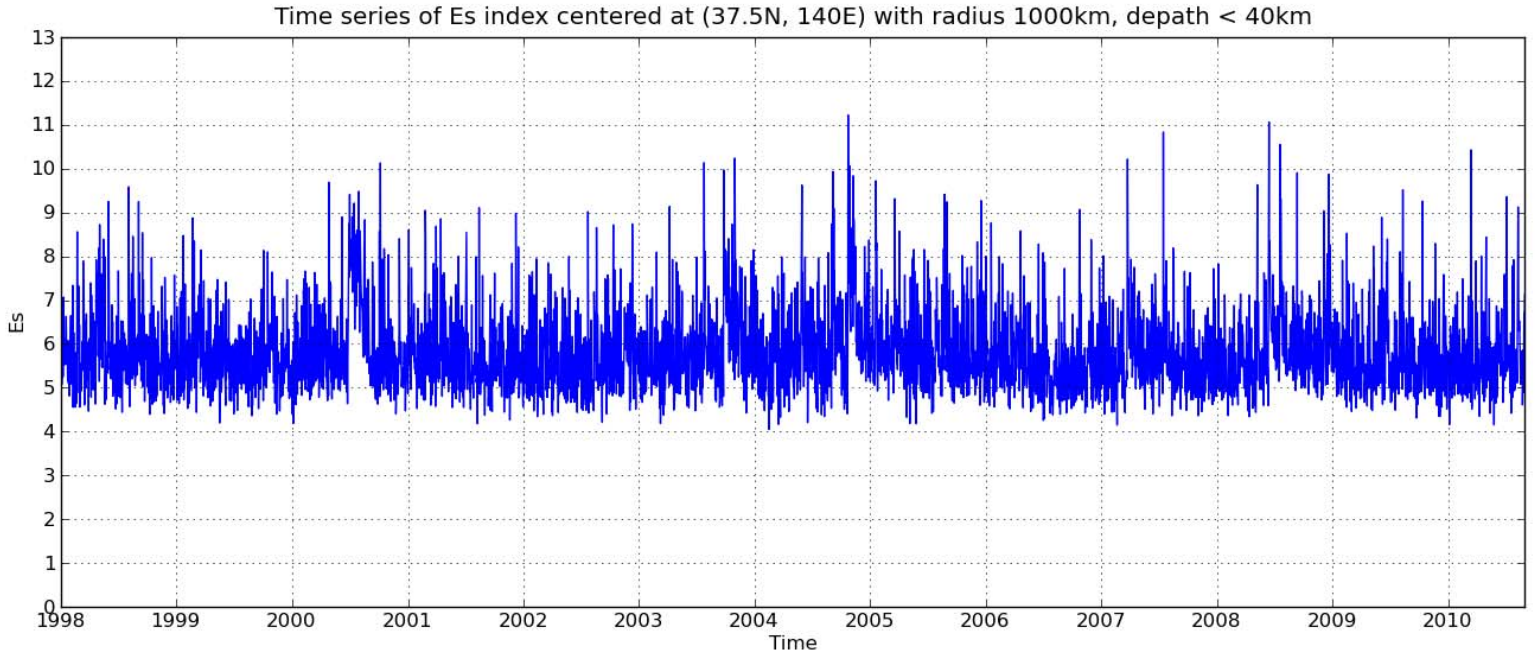
Definition of seismic activity for SEA

Es index

$$Es = \log \sum_{1\mathrm{day}} \frac{10^{4.8+1.5M}}{r^2}$$

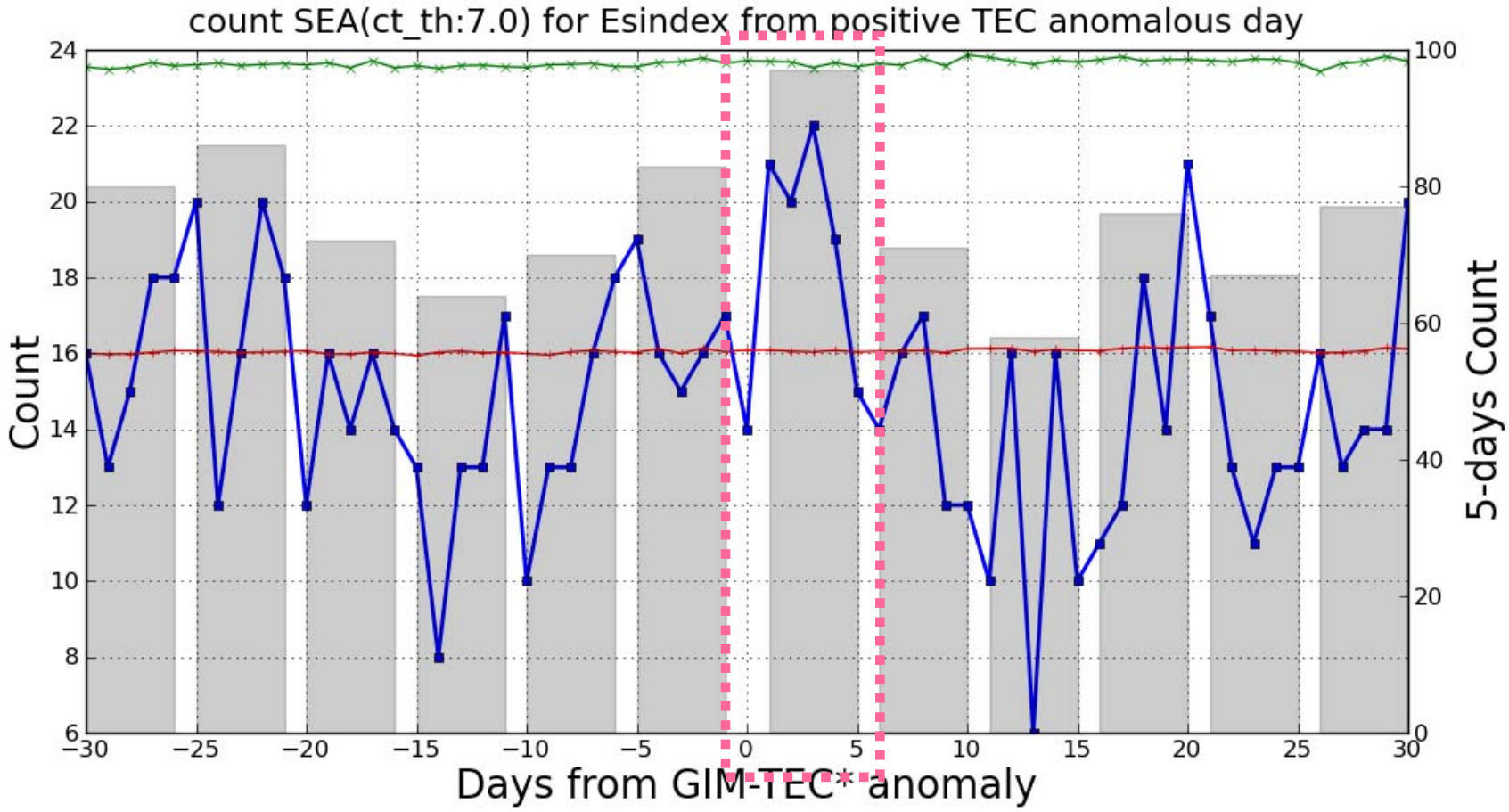
Daily sum of the seismic energy at the site
r : hypocenter distance

Hirano and Hattori., JAES, 2011



Results of SEA for Seismic Activity

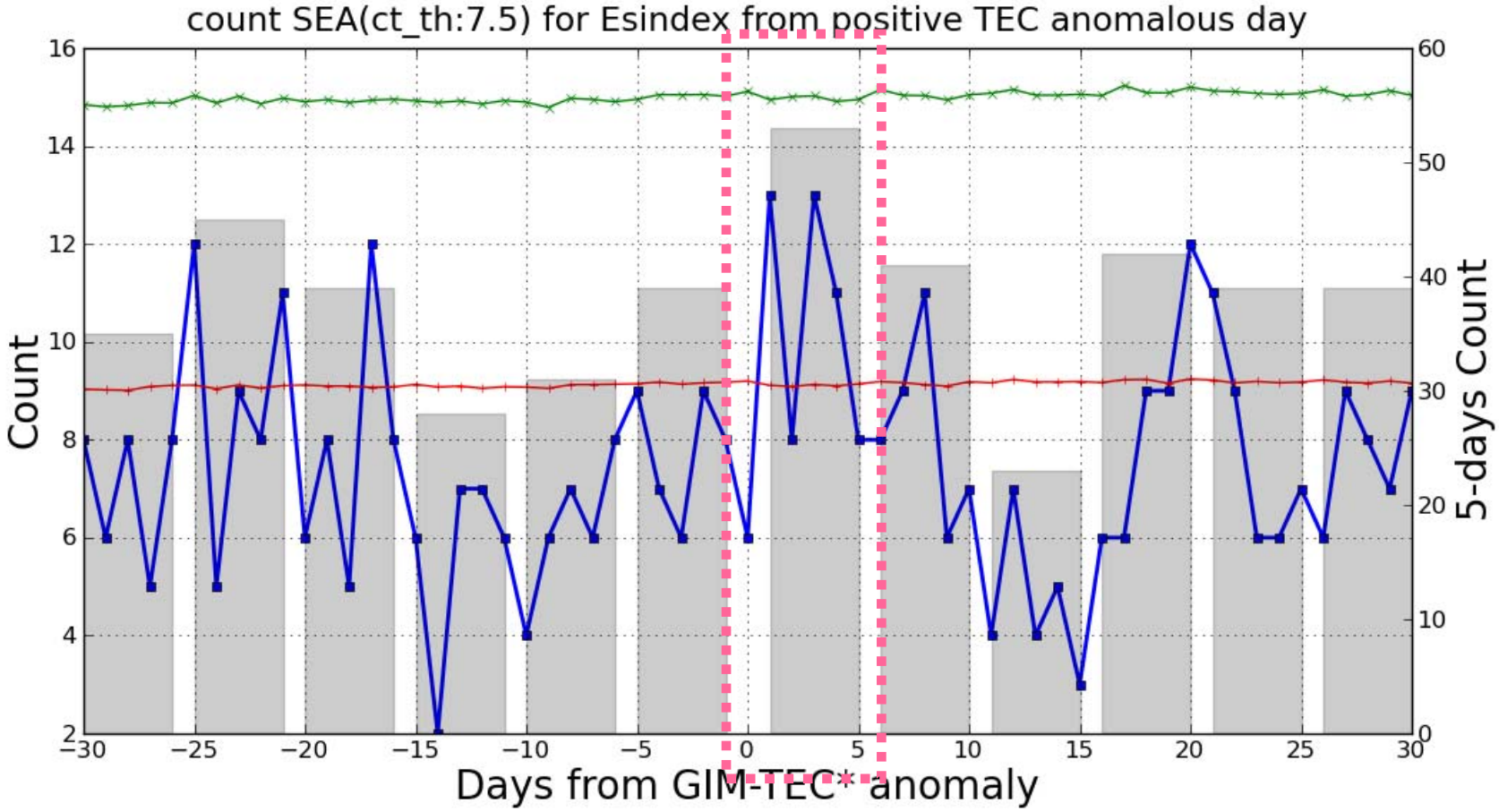
Count for Es index 7.0



The day of positive GIM-TEC* anomaly

Results of SEA for Seismic Activity

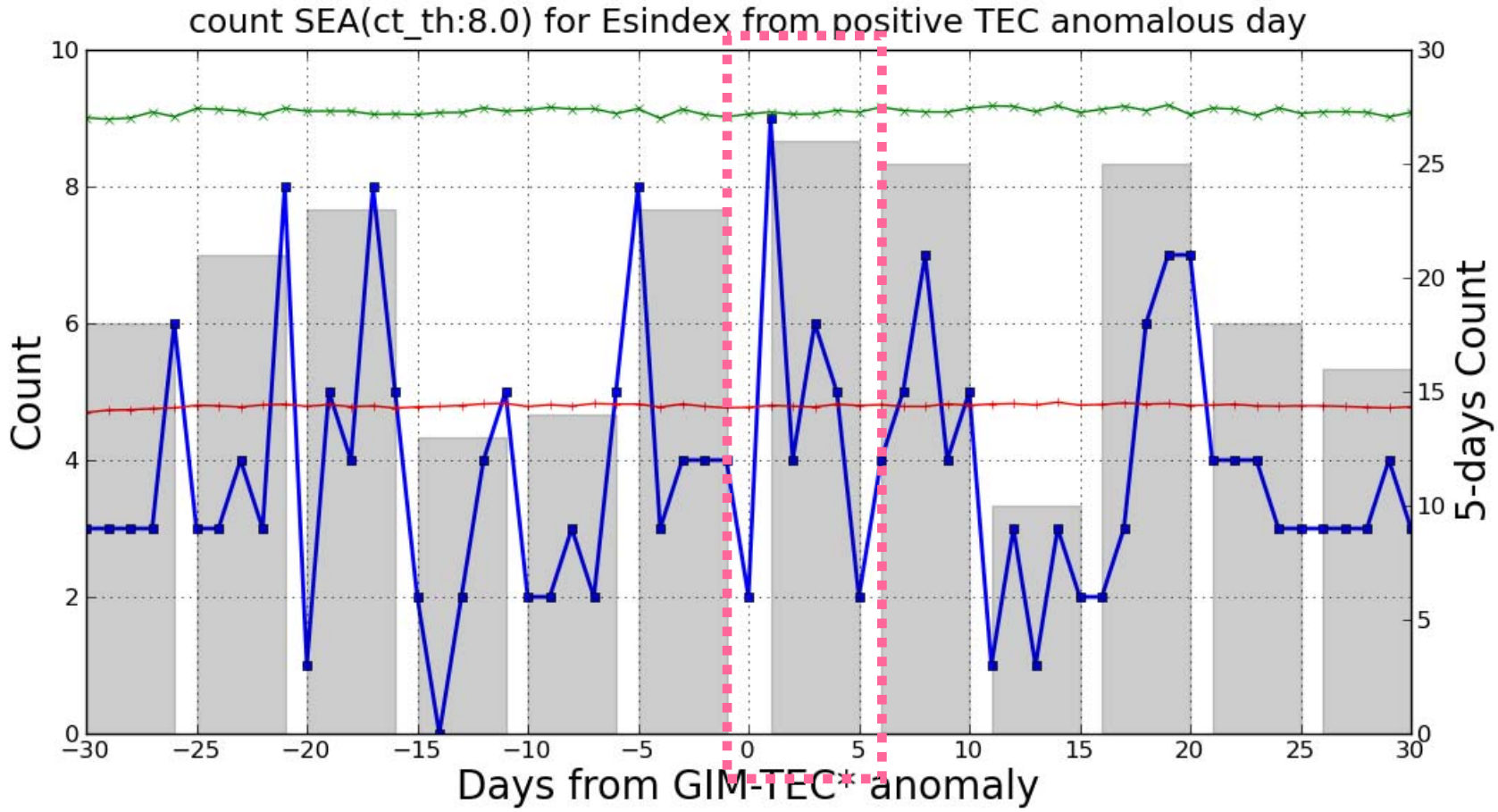
Count for Es index 7.5



The day of positive GIM-TEC* anomaly

Results of SEA for Seismic Activity

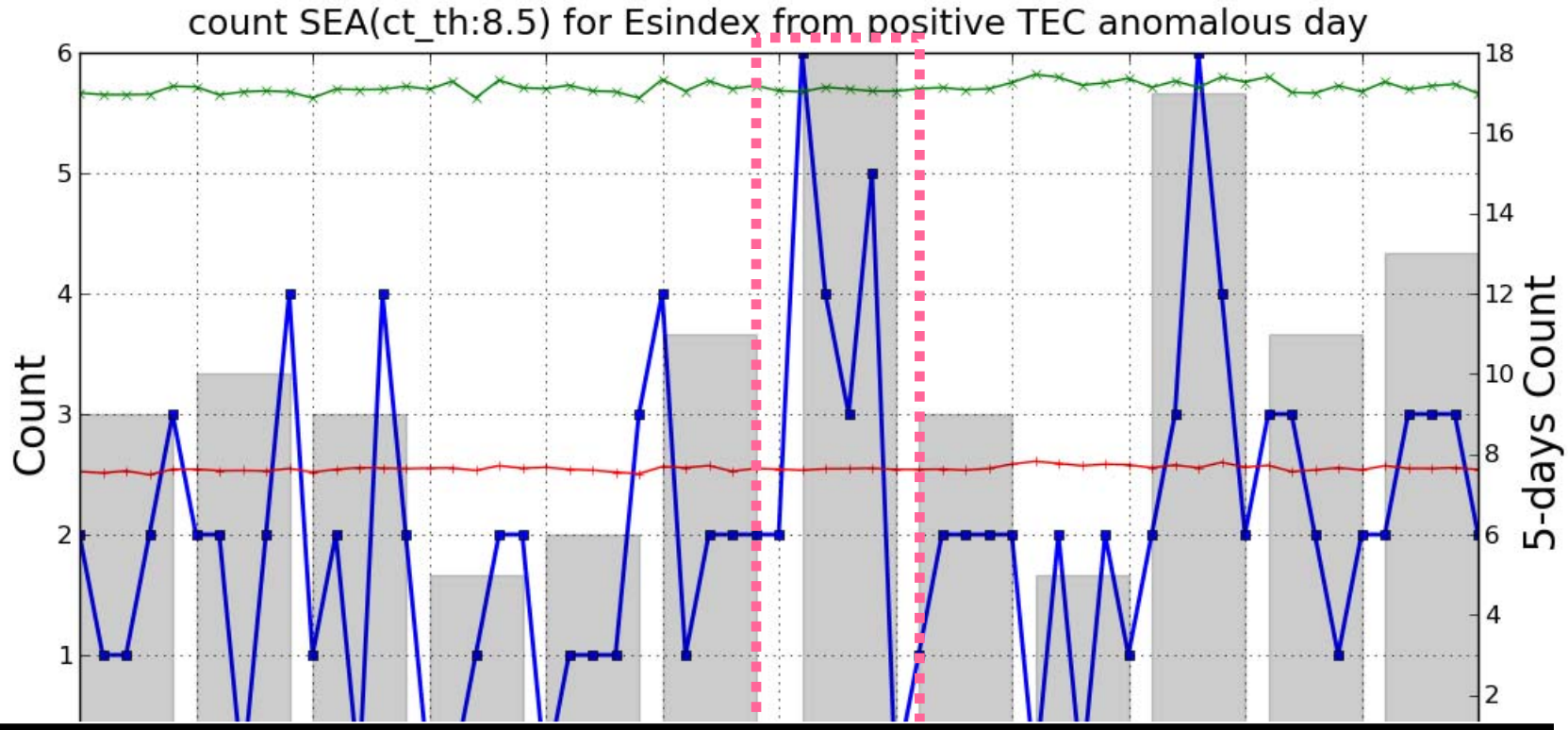
Count for Es index 8.0



The day of positive GIM-TEC* anomaly

Results of SEA for Seismic Activity

Count for Es index ≥ 8.5



Regional seismic activity seems to be activated 1-5 days after the appearance of positive TEC anomaly

➔ Good agreement with results of SEA for TEC anomaly

Summary

- EQ-based SEA analysis

EQ with M >= 6.0, D =< 40 km around Japan
Increase of positive TEC anomalies 1-5 days before the EQ (Especially, 1 days before)

✓Epicentral distanse dependence
✓Magnitude dependence M >=5.8

Consistent results

- TEC-based SEA analysis

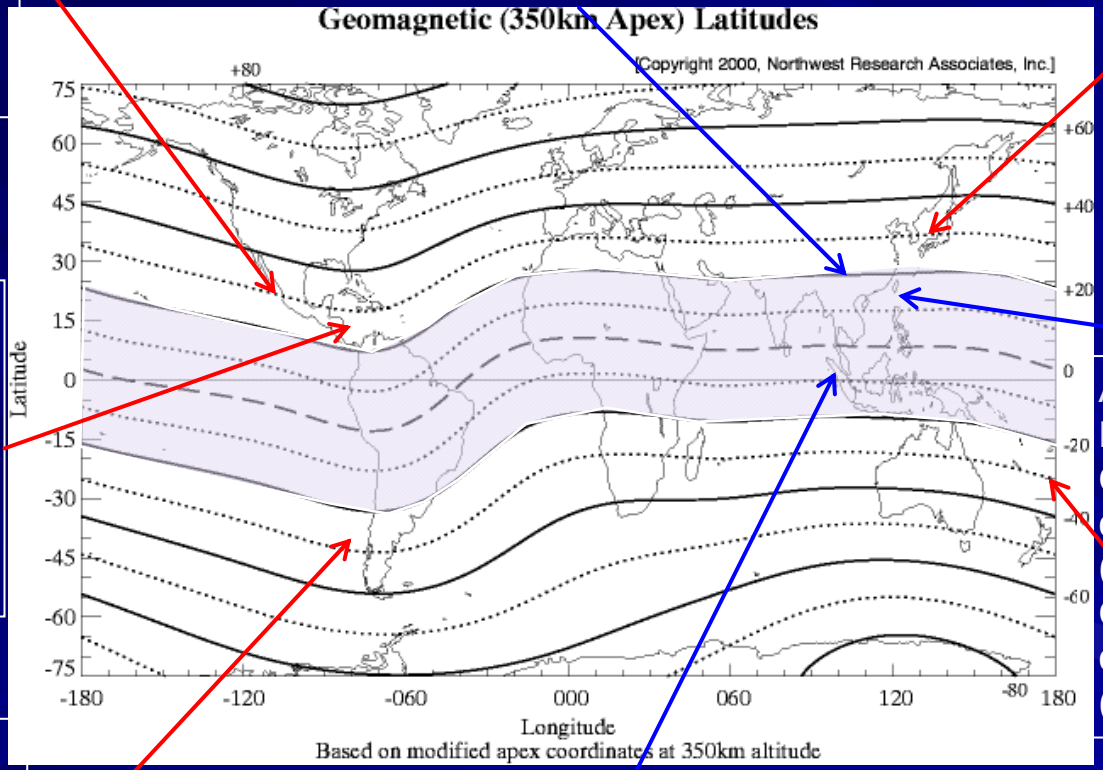
1-5 days after the positive anomaly
Tendendcy of increase of the EQ activity

Regions for SEA

Around Maxico
....Geographical coordinate
(105˚W, 20˚N)
Geomagnetic coordinate
(35.28˚W, 28.16˚N)

Around China .Sichuan, Qinghai EQs.
Geographical coordinate
(103.6˚E, 31.0˚N)
Geomagnetic coordinate
(176.16˚E, 20.88˚N)

Around Japan
Geographical coordinate
(140˚E, 37.5˚N)
Geomagnetic coordinate
(151.09˚W, 28.71˚N)



Around Haiti
Geographical coordinate
(80˚W, 15˚N)
Geomagnetic coordinate
(8.29˚W, 24.79˚N)

Around Taiwan.Chi-Chi EQ.
Geographical coordinate
(120.8 ˚E, 23.9 ˚N)
Geomagnetic coordinate
(168.0 ˚W, 14.0 ˚N)

Around Chile
Geographical coordinate
(75˚W, 37.5˚S)
Geomagnetic coordinate
(2.49˚W, 27.34˚S)

Around Indonesia (Sumatra EQs)
Geographical coordinate
(95.8˚E, 3.3˚N)
Geomagnetic coordinate
(168.0˚E, 6.49˚S)

Around NZ
Geographical coordinate
(180˚E, 25˚S)
Geomagnetic coordinate
(103.03˚W, 27.52˚S)

Summary & Discussion

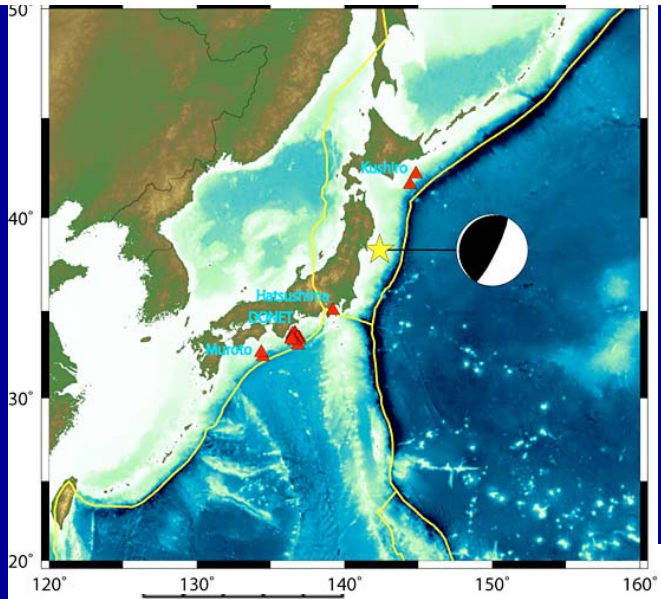
Latitude dependence of EQ-related TEC anomaly (Kon, Master thesis 2011)

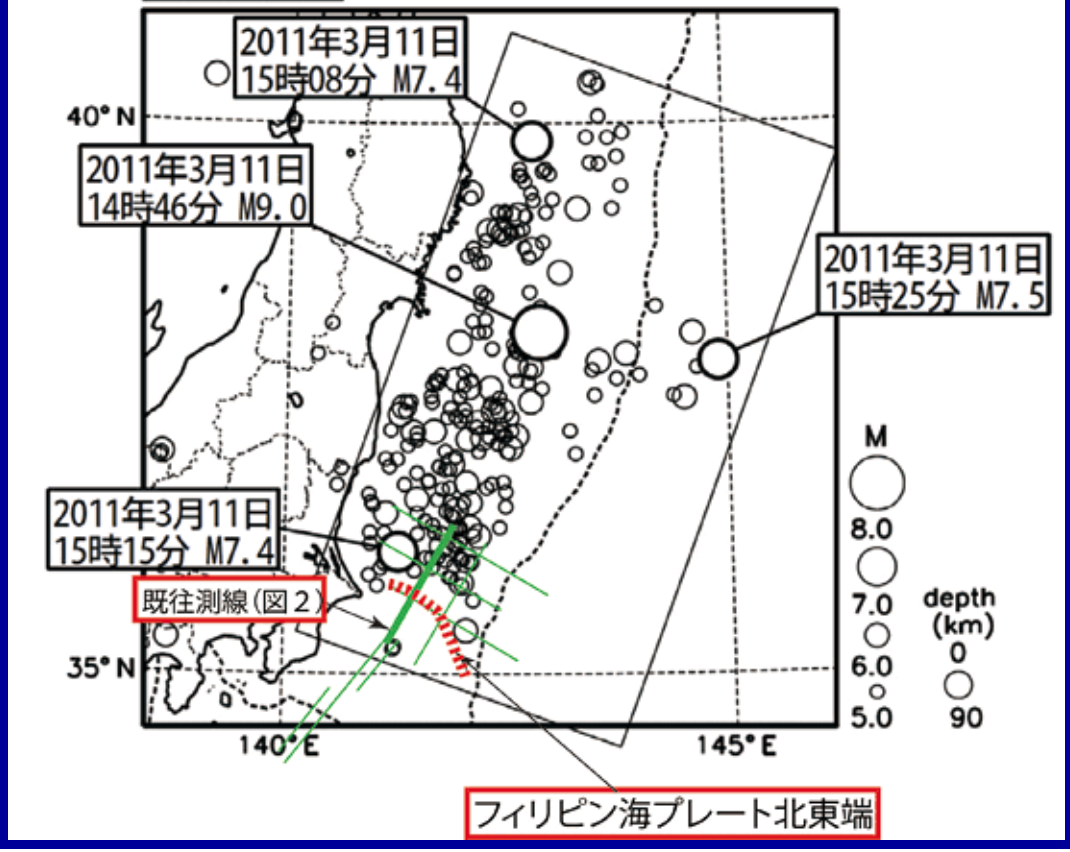
	Study Area	Positive GIM-TEC* Anomaly	GIM-TEC* Negative Anomaly
Low Latitude	Taiwan.M>=6.0.	X	1 - 5 days before
	Southern China.M>=6.0.	X	4 – 6days before
	Indon		days before
Mid-latitude			
	Mex		X
	Haiti.M>=6.0.	1.5days before	X
	Chile.M>=5.5.	11.15.26.25 days before	21.25 days before
	NZ.M>=6.0.	6.15 days before	X

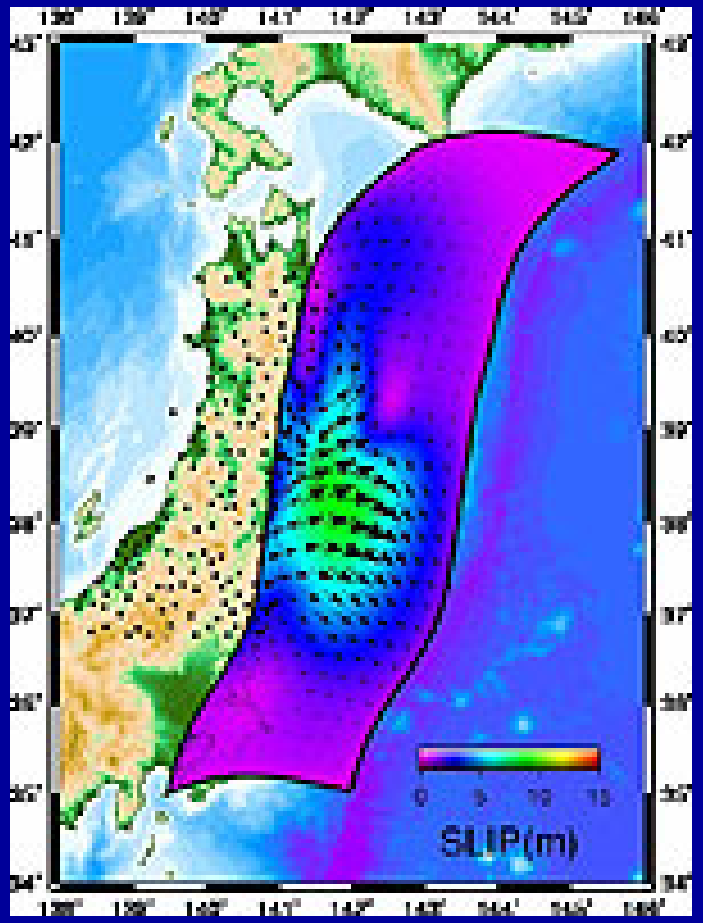
Mechanism of EQ-related Ionsopheric Anomalies

The 20110311 Tohoku EQ

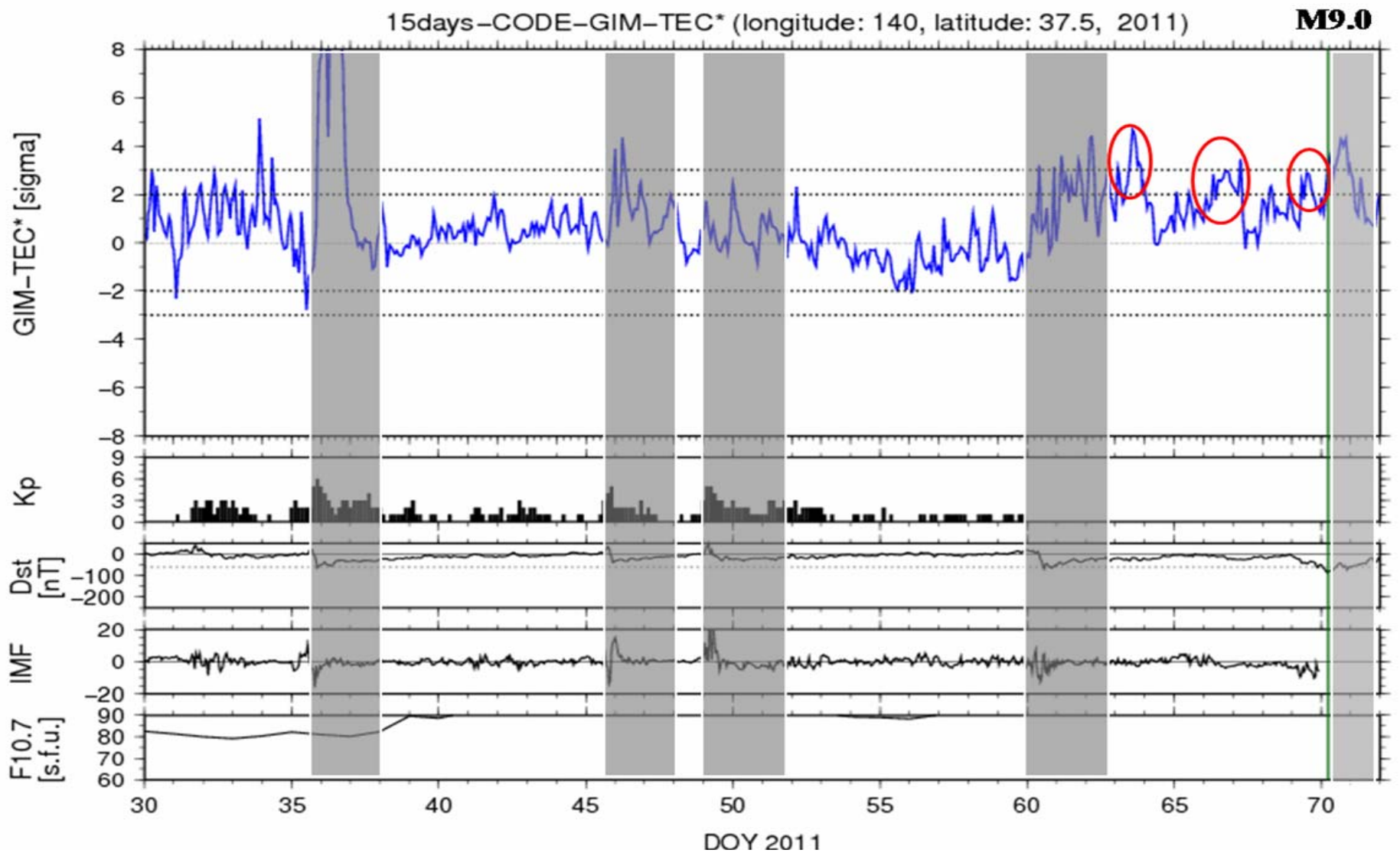
2011/03/11 14:36UT
M: 9.0
Depth: 24km



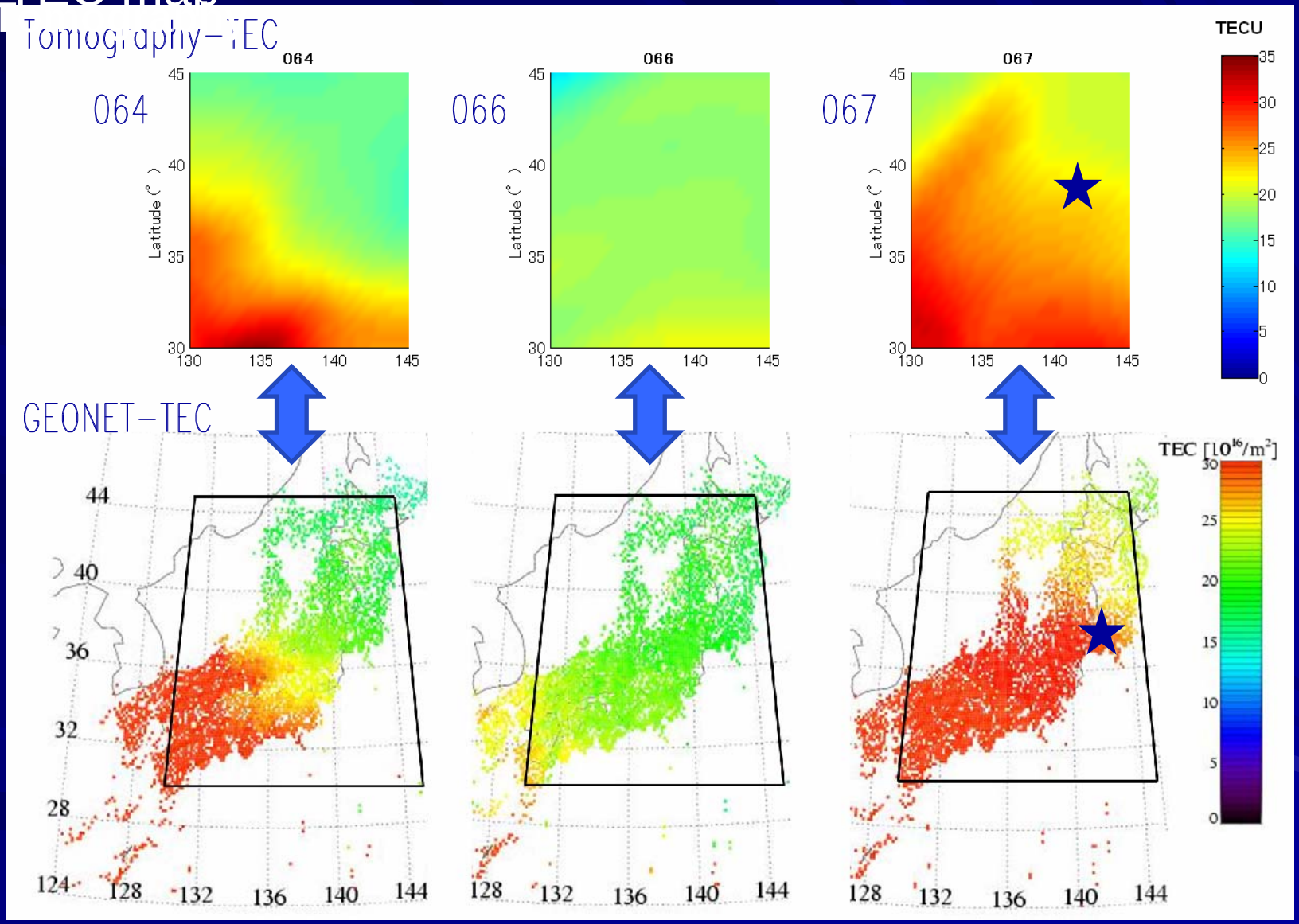




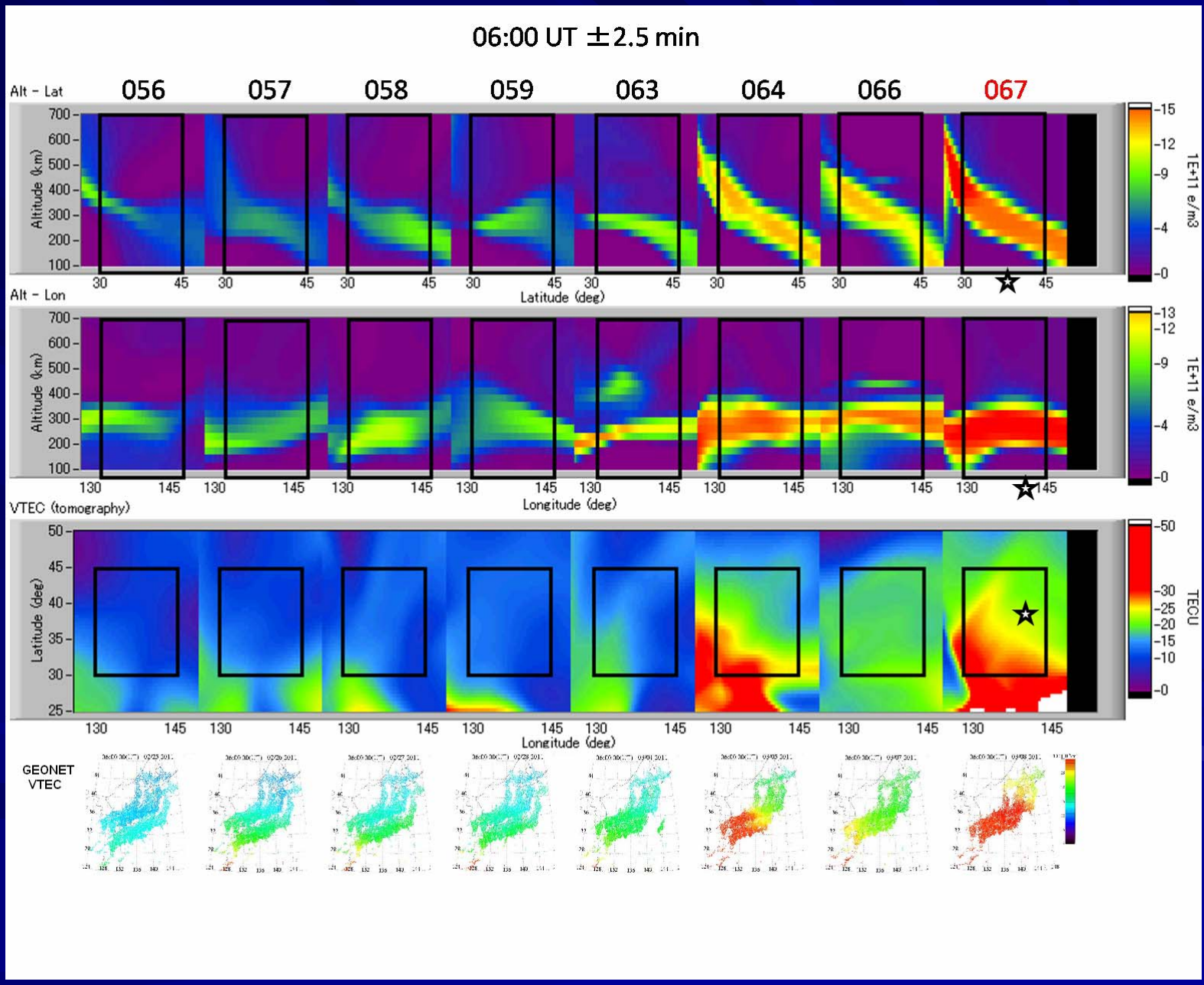
The 20110311 M9.0 Tohoku EQ GIM-TEC*



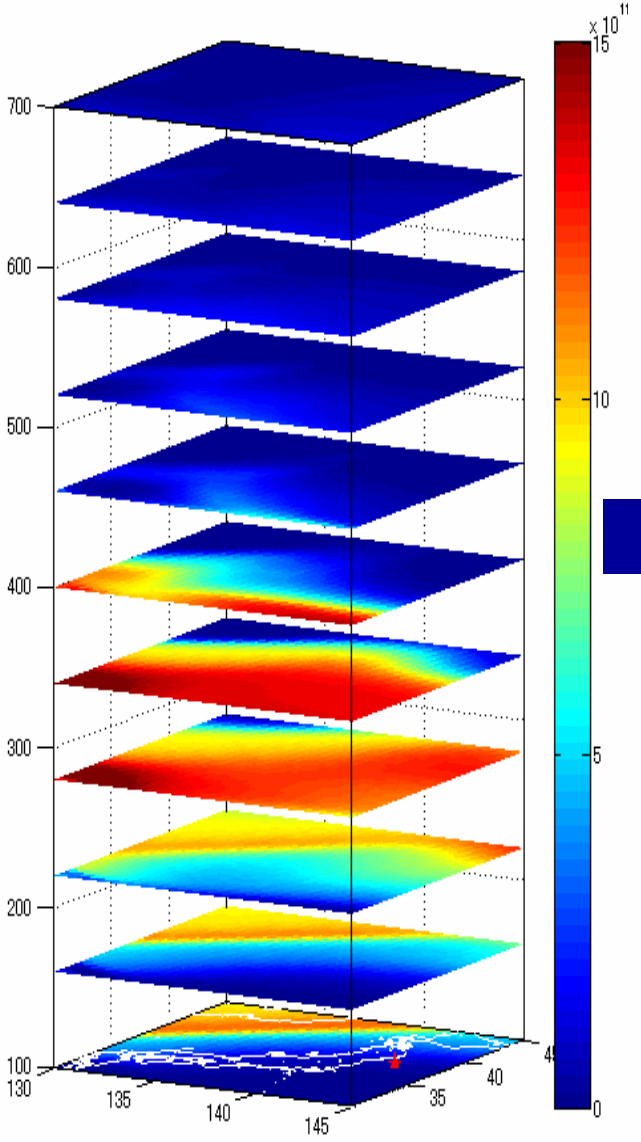
Comparison of integrated images (100 – 700 km) with GEONET-TEC map

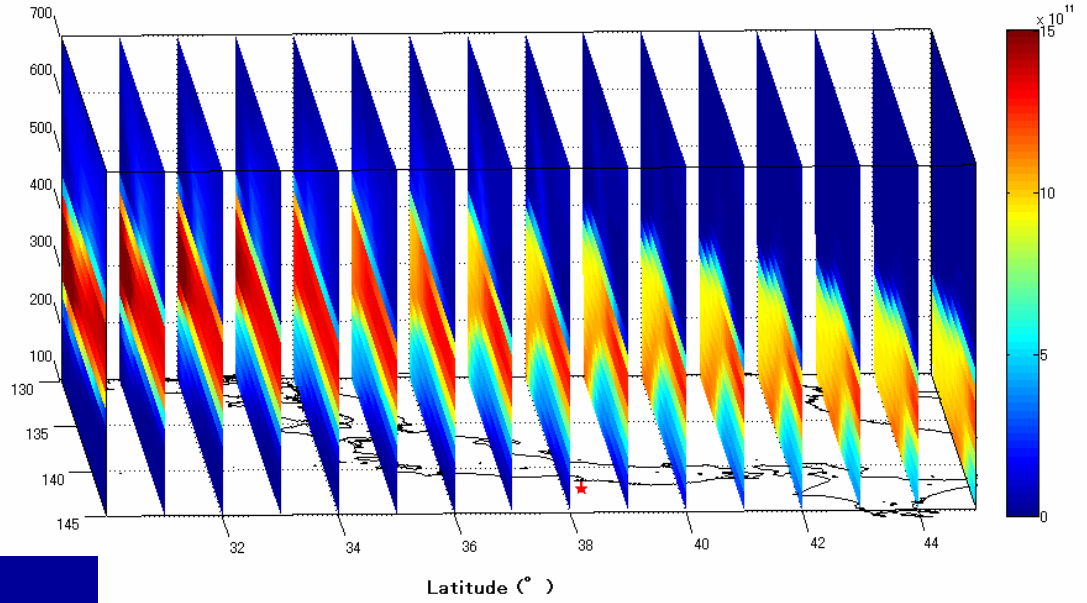


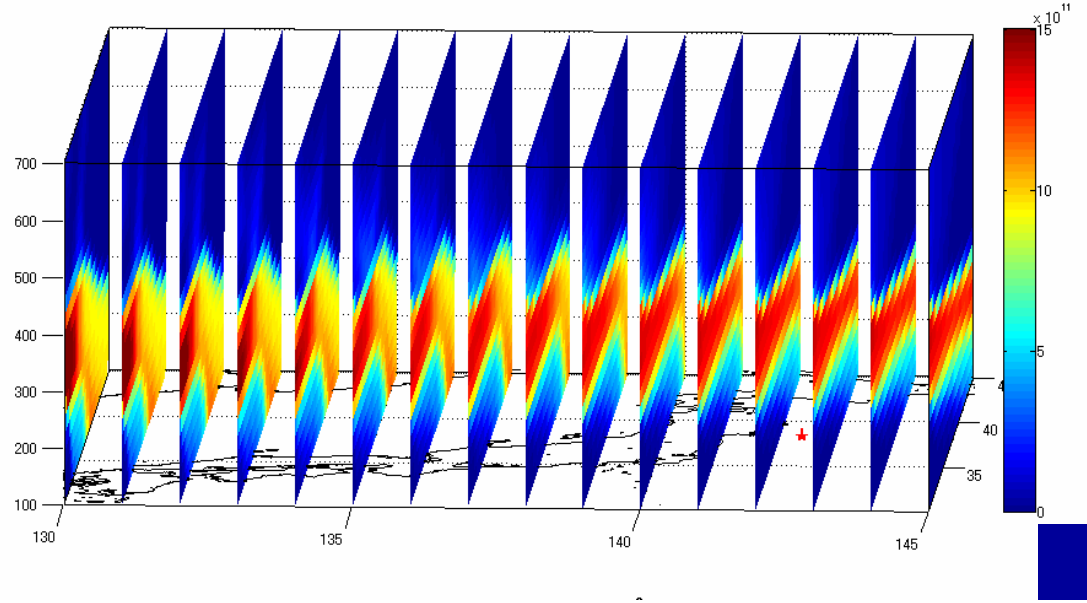
Good agreement with GEONET-TEC map


06:00 UT ±2.5 min
Alt - Lat
056
057
058
059
063
064
066
067
Altitude (km)
Latitude (deg)
1E+11 e/m3
Alt - Lon
Longitude (deg)
VTEC (tomography)
Latitude (deg)
TECU
GEONET
VTEC

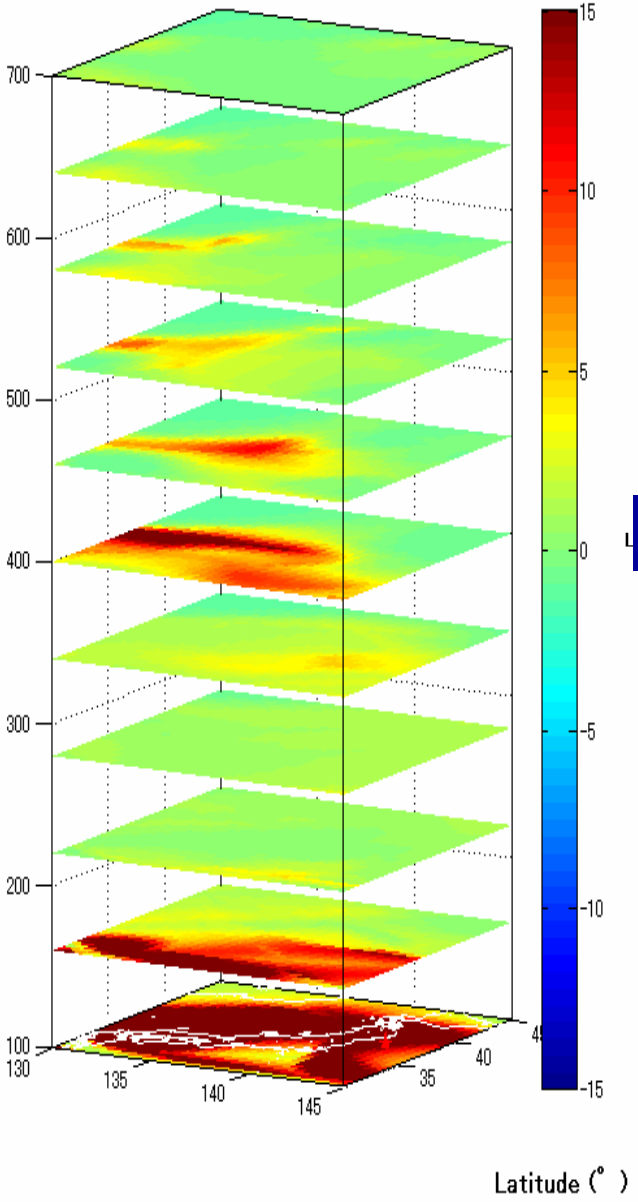
Result of tomographic analysis (absolute)

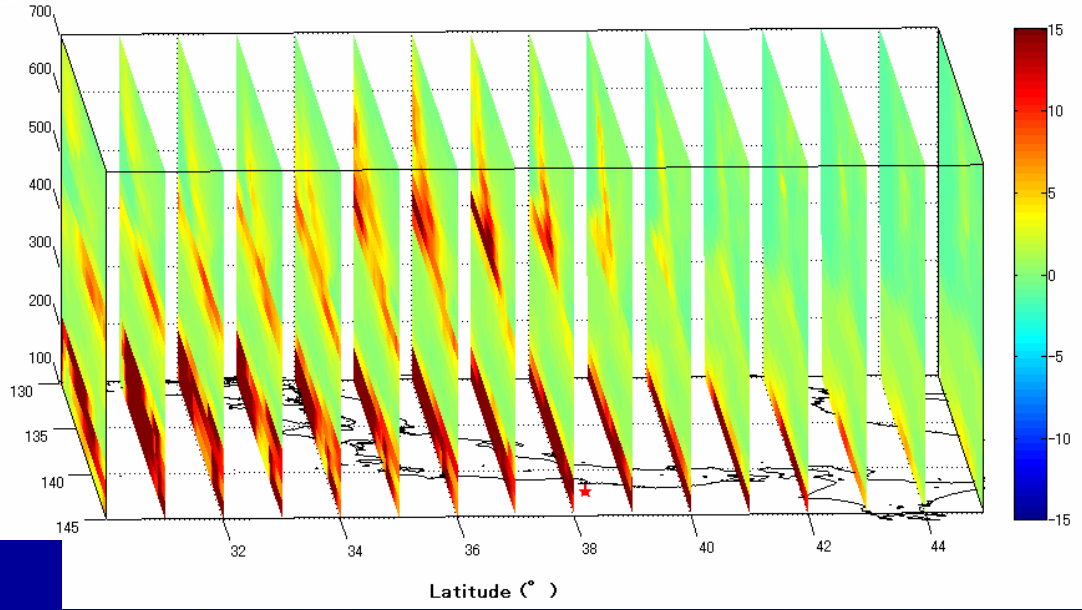


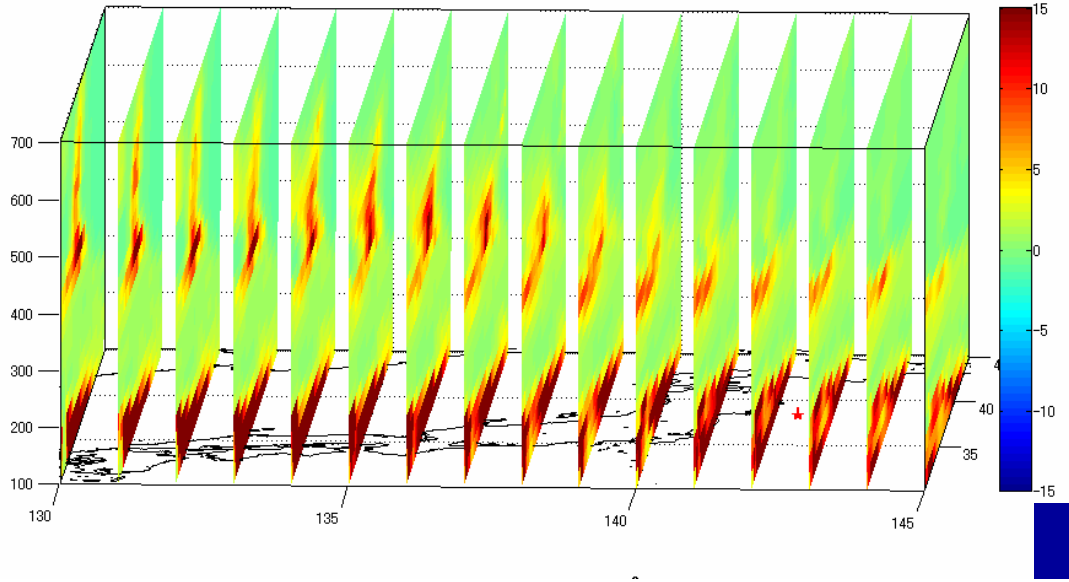




Result of tomographic analysis (normalized)

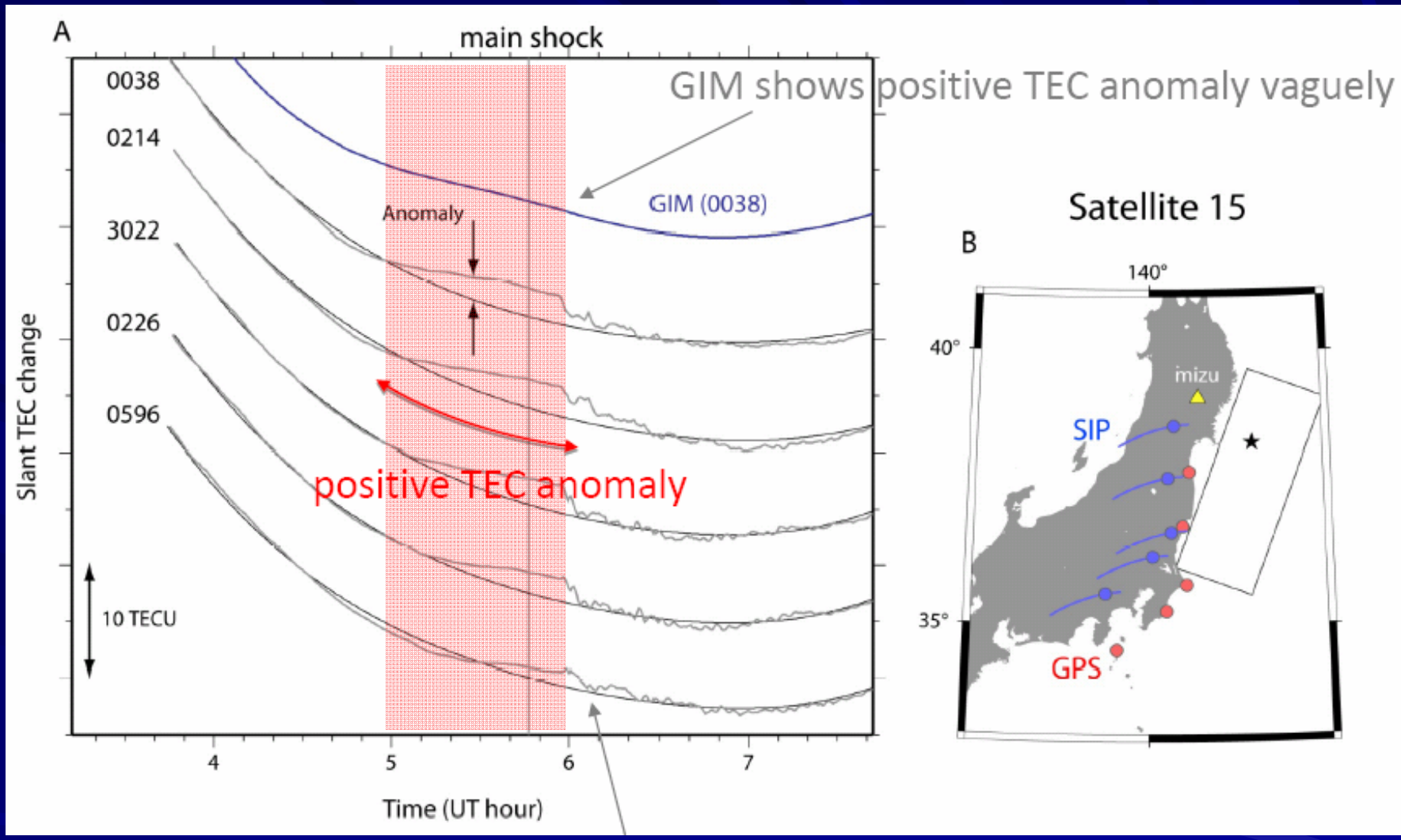






Anomaly 40 min before the main shock

reported by Heki 2011



Heki, 2011

-Appearance of 40 min before EQs (~M9)

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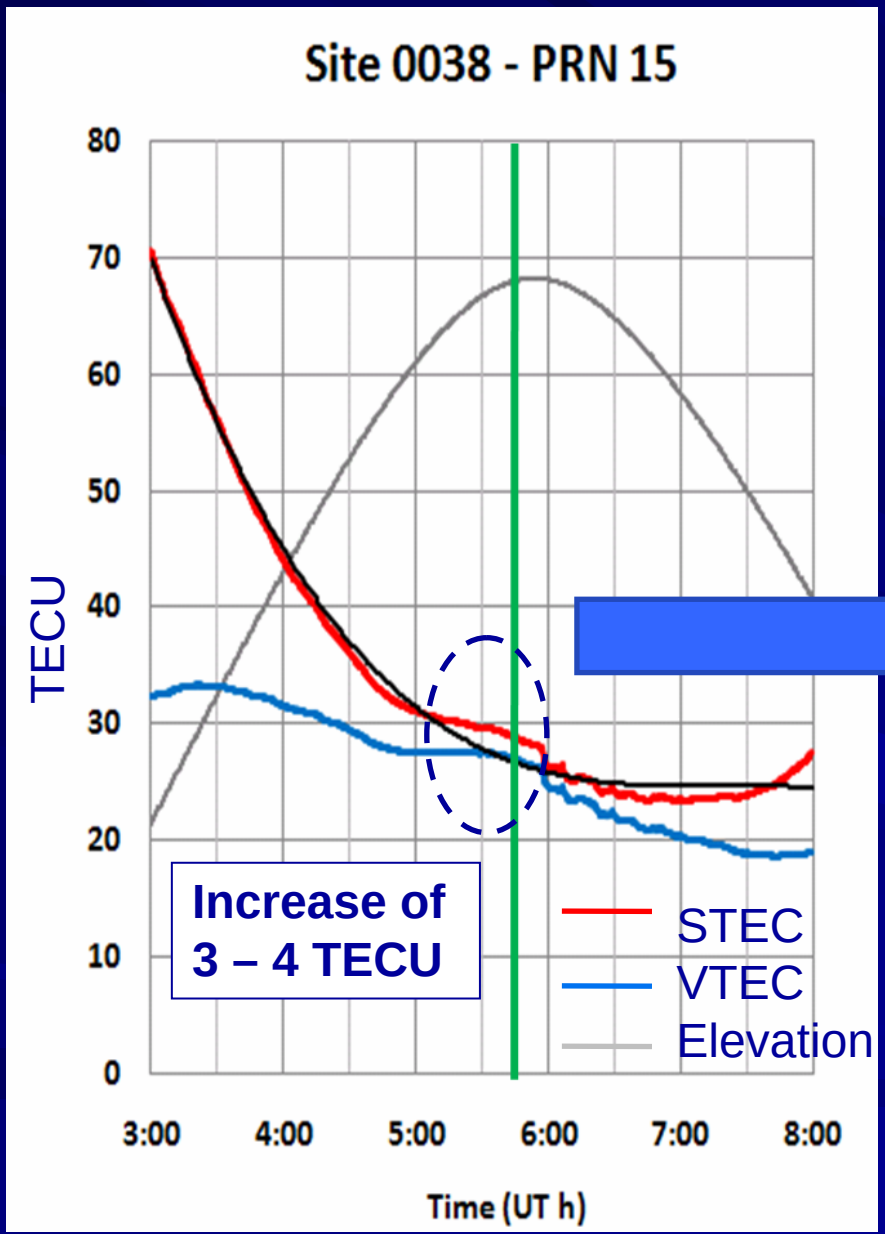
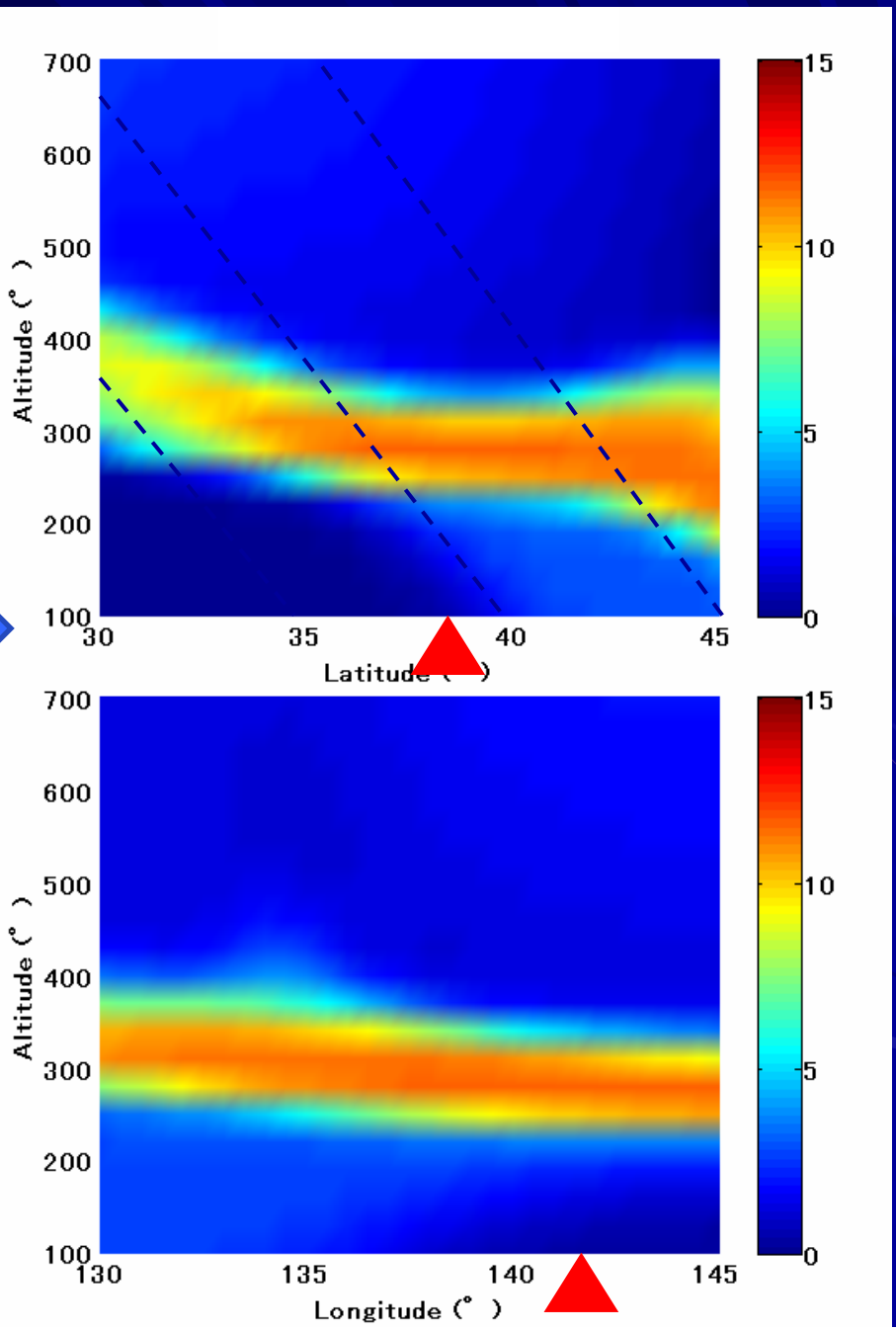
...STEC, VTEC.....

Tomography 05:45UT ±5min, (1 min before EQ.





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Future problem for tomography

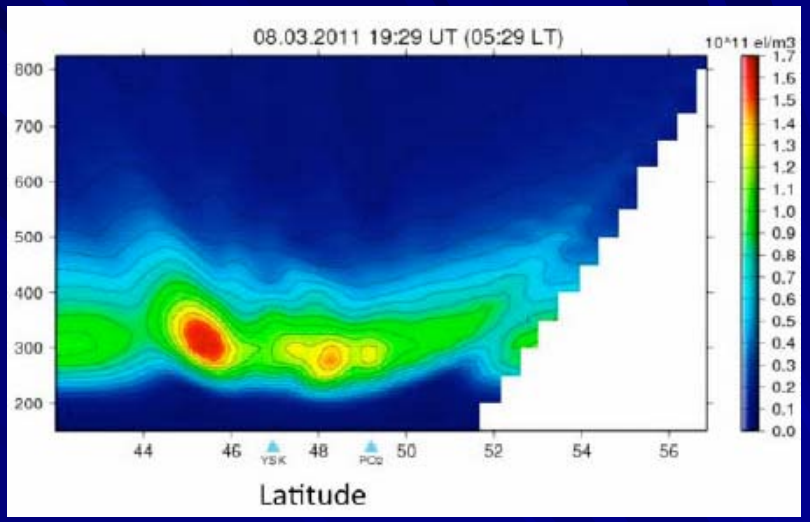
.**Improvement of electron density reconstruction for lower Ionosphere**

.**Joint inversion with LEO data/ Ionosonde data etc.**

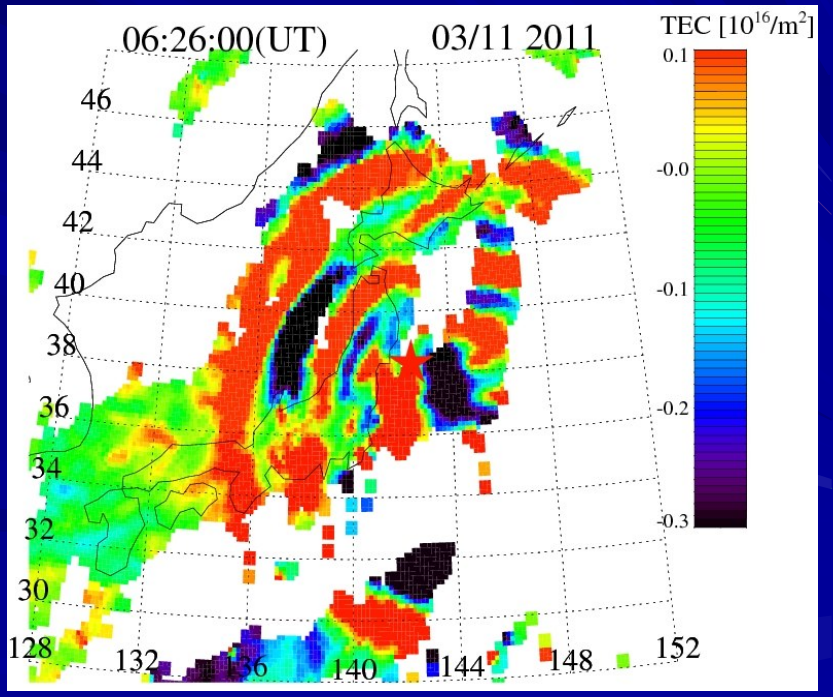
.**Time series analysis**

.**visualization of Plasma flow and electric fields**.

.Reconstruction of co-seismic changes



***Ouzounov** et al*, 2011



... GPS.....

Thank you for your attention.