DAVOS ◆ SENDAI WORLD BOSAI FORUM

Beware Back Before

-Aware One Hour Before (OHB) Earthquake and a Physicist View on Sendai Framework Vision: Build Back Better-

Ken Umeno, Ph.D

Master of Chaos (ChaosKen)

Professor

Kyoto University

Huge Complexity After Tsunami

Time Series (on March 11,2011)

- 14:46 (05:46 UTC) The great East Japan Earthquake Occurred.

- 14:46 Earthquake Early Warning Broadcasting
- 14:49 Tsunami Warning
- 14:54 Tsunami Came [to Kesennuma]

8 minutes are too short for evacuation!

Basic Question

Why Too Short?

Simple Answer

We cannot evacuate in 8 minutes

Imagine Expected Time Series (on X.Y,201Z)

- 13:46 (04:46 UTC) **Pre-Warning** Broadcasted by Precursor
- 14:46 (05:46 UTC) Earthquake Occurred

- 14:46 Earthquake Early Warning Broadcasted
- 14:49 Tsunami Warning Broadcasted
- 14:54 Tsunami Came

One hour (lead time) are not enough but can reduce and minimize damages caused by earthquake, especially human damages. Save Lives

My Question to Myself

How?

Back to My Memory Inside a Refugee Bus at Fukushima on March 11, 2011

My Question to Myself (As a Physicist) on 311:

- Why did I not get any *precursor* of the great east Japan earthquake at all?
- It is strange that such a great earthquake with huge power emission had shown no precursor signals to us.

Fundamental Physical Principle (The First Law of Thermodynamics):

- Energy Must Conserve
  (Energy Conservation Law)
- Energy Before Earthquake = Energy After Earthquake.
- Just Change (Convert) :
  From Potential Energy to Kinetic Energy

Common Sense (Few Mentioned)

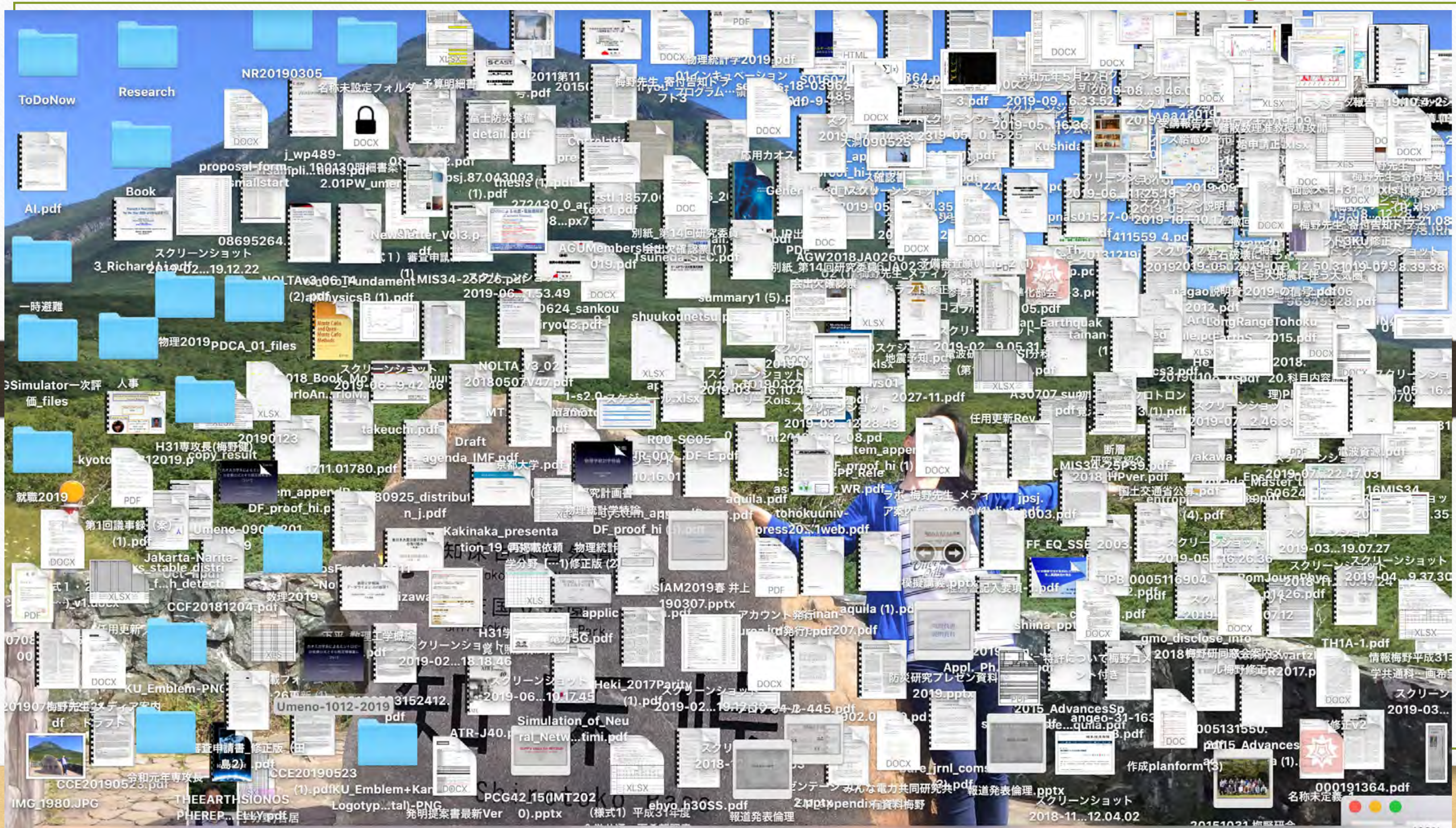
- Every energy change in a physical process must have a signal emission to be detected.
- Example: Electro-magnetic Signal:

Fundamental Physical Principle 2 (The Second Law of Thermodynamics):

Complexity Is Growing.

Desktop One Year Before

Desktop Now (Complexity is Still Growing)



General Physical Principle:

Complexity Is Growing

-This physical principle supersede my personal feeling-

Fundamental Physical Principle 2 (The Second Law of Thermodynamics):

- Complexity Is Growing.
- Complexity Before Earthquake

<

Complexity After Earthquake.

Question Again:

What Does It Mean?

Cost Efficiency According to the Physical Principle

When	Complexity	Investment (Back) Cost
Before	Small	Relatively Small
After	Huge	Dramatically Huge

Truth

- Earthquake must occur.

(we cannot avoid it)

Real Question:
-How To Invest Before-

- Can we detect earthquake precursor?

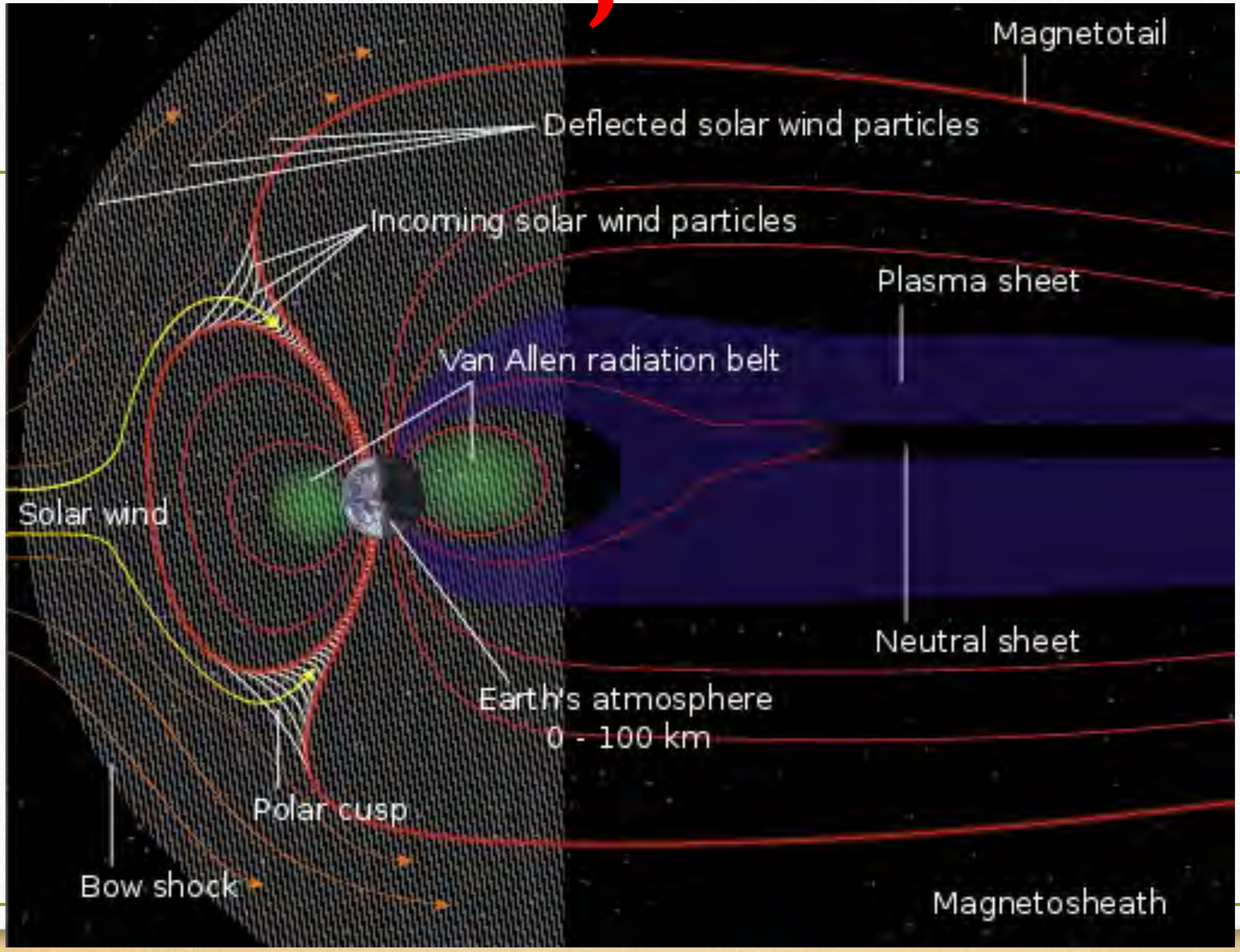
Our View (as a physicist):

- Every physical phenomena have their signals to be detected. →Precursors must exist and can be detected in principle.

Question (Again)

How?

Earth is an electro-magnetic object.



GNSS –Global Navigation Satellite System-

GEONET

(GNSS Earth Observation Network)

# of Stations is about 1300.

Our GNSS Sensor Set at Wakayama Shionomisaki (DPRI, Kyoto U.)Build Before ..

Calculation of Slant TEC
(TEC: Total Electron Contents)

$$L_1 = \rho + \sigma - \frac{I}{f_1^2} + \lambda_1 n_1 + \epsilon_1 + \tau_1$$

$$L_2 = \rho + \sigma - \frac{I}{f_2^2} + \lambda_2 n_2 + \epsilon_2 + \tau_2$$

L : the carrier phase measurement

ϱ : the true distance between the GNSS satellite and receiver

σ : the tropospheric delay

f : carrier frequency

λ : carrier wavelength

ε : satellite bias

τ : receiver bias

Calculation of Slant TEC

$$L_1 = \rho + \sigma - \frac{I}{f_1^2} + \lambda_1 n_1 + \epsilon_1 + \tau_1$$

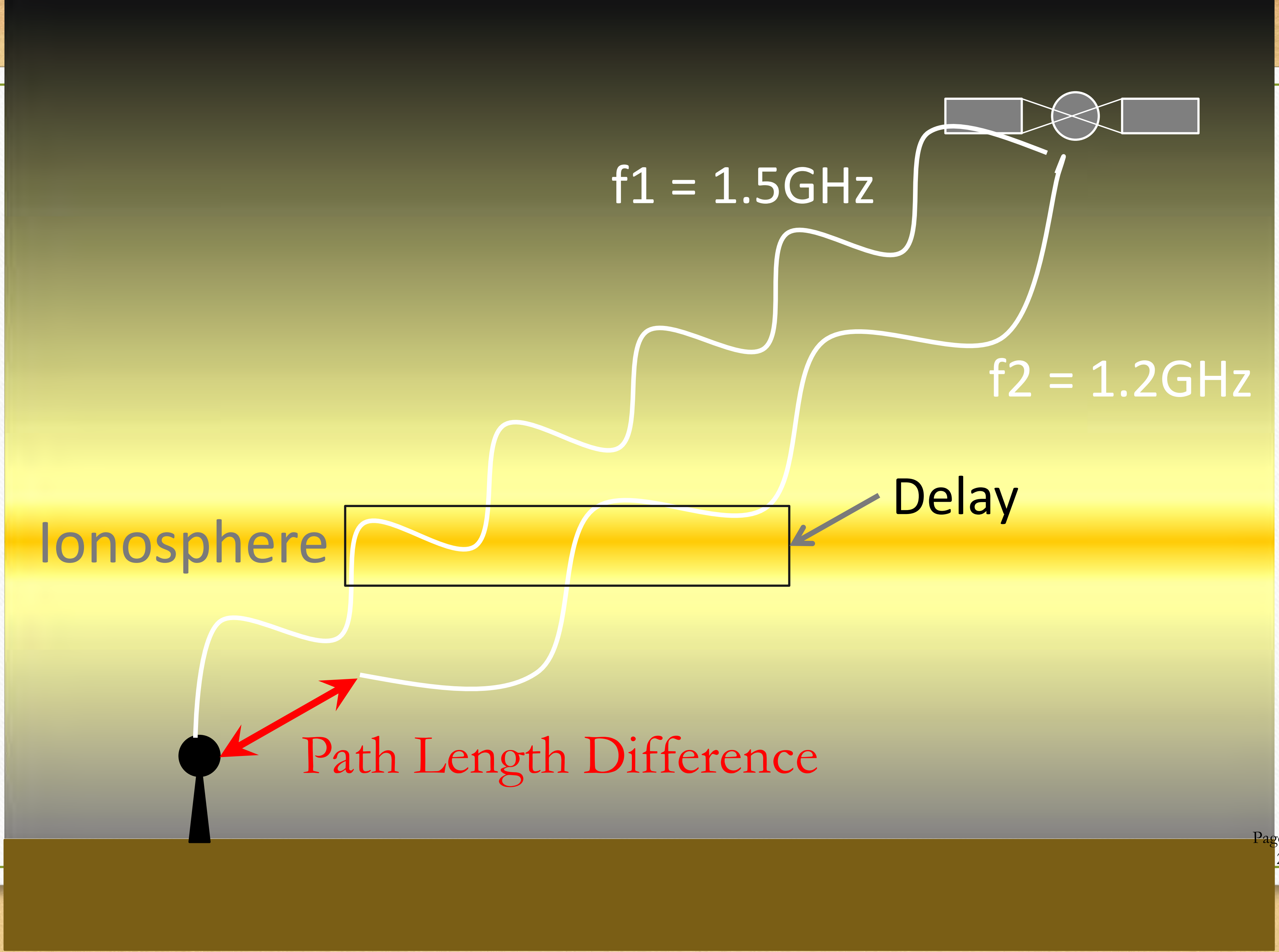
$$-) \qquad L_2 = \rho + \sigma - \frac{I}{f_2^2} + \lambda_2 n_2 + \epsilon_2 + \tau_2$$

$$L_1 - L_2 = -I\left(\frac{1}{f_1^2} - \frac{1}{f_2^2}\right) + \text{Const.}$$

Calculation of Slant TEC

$$\mathrm{TEC} = \frac{1}{40.308}\frac{f_1^2 f_2^2}{f_1^2 - f_2^2}(L_1 - L_2) + \mathrm{Const.}$$

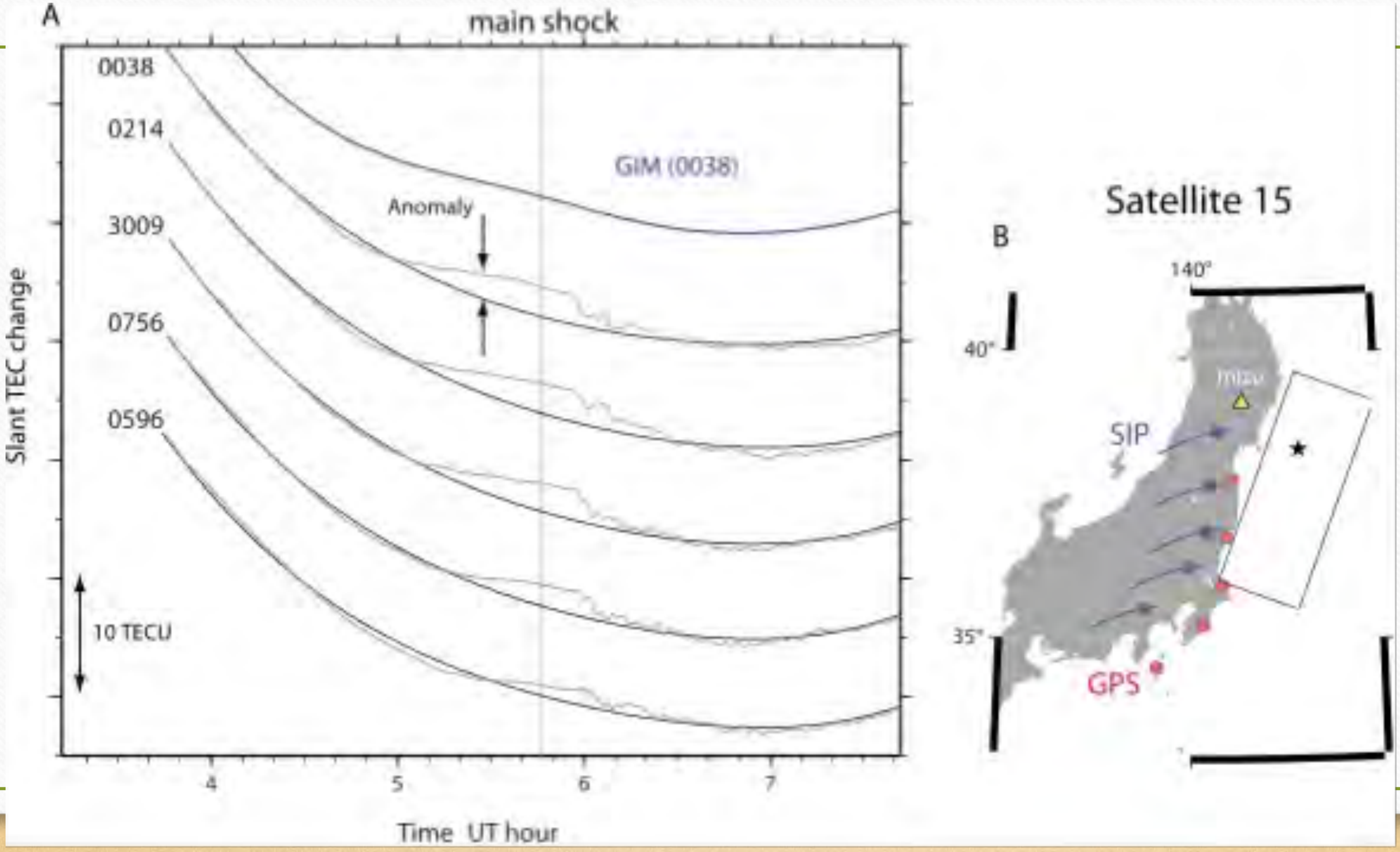
$$\Delta\mathrm{TEC} = \frac{1}{40.308}\frac{f_1^2 f_2^2}{f_1^2 - f_2^2}\Delta(L_1 - L_2)$$


f1 = 1.5GHz
f2 = 1.2GHz
Delay
Ionosphere
Path Length Difference

Reference

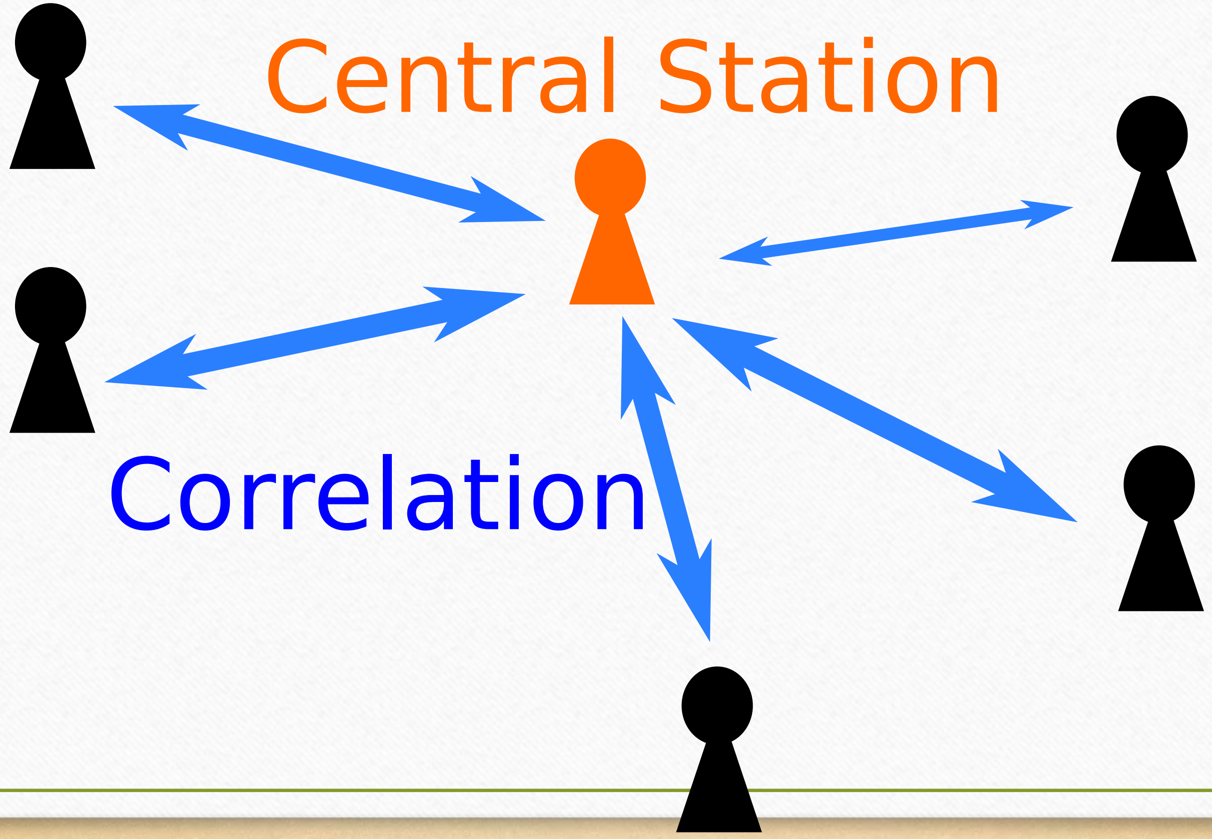
Heki Hokkaido Univ. (2011)

“Ionospheric electron enhancement preceding the 2011 Tohoku-Oki earthquake” GRL



Method: Correlation Analysis

My Key Idea : Take Simultaneous Correlations of GNSS TEC data(Correlation) for Increasing SNR like VLBI

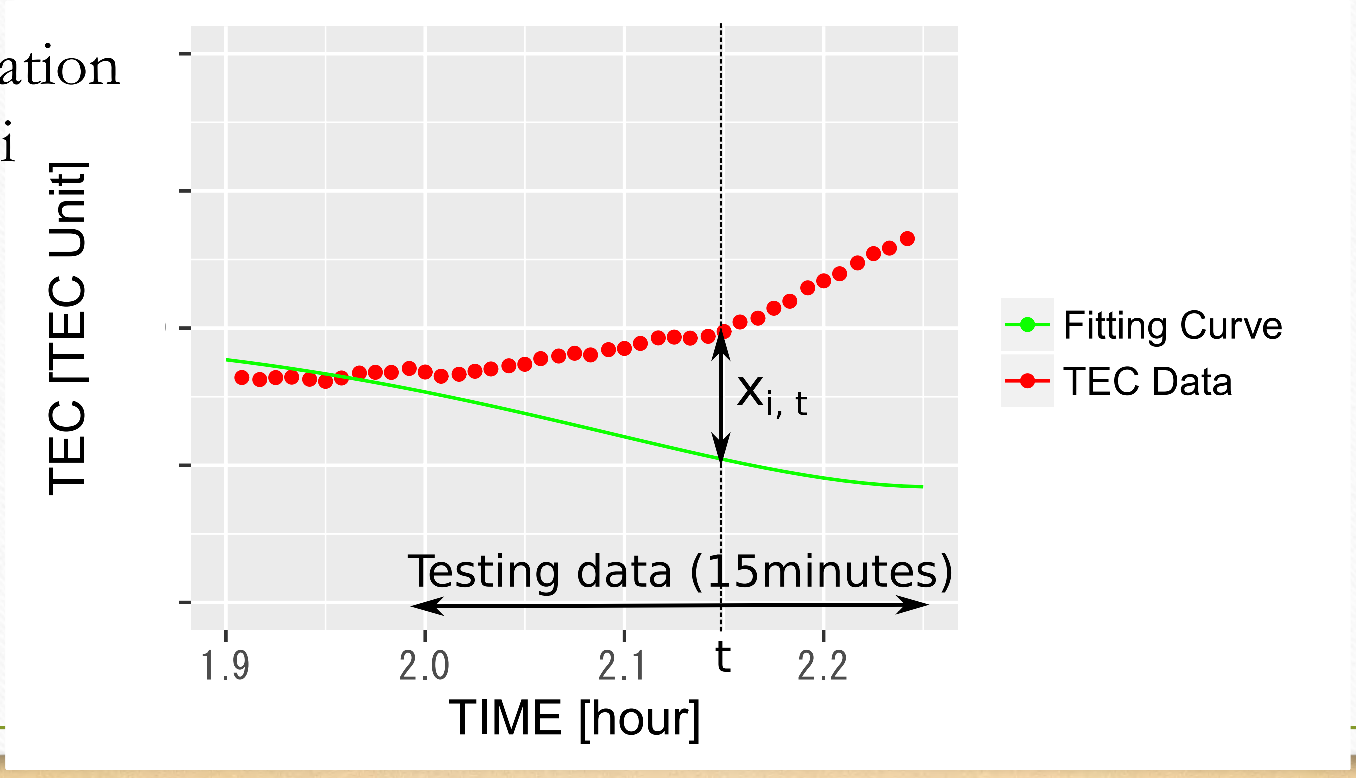


Correlation Analysis (Iwata and Umeno, *JGR*, 2016)

STEP1 Fitting TEC Training data(2 hours) by a certain curve.

STEP2 Measure Fitting Error as the Difference between Observed TEC Data (Testing Data for 15 minutes)

Observation Station i



Take Correlations as follows

STEP3

Correlation analysis II (Iwata and Umeno, JGR, 2016)

Learning Data for Fitting (2hours)+Testing Data (15 minutes)

$$C(T+2.25) = \frac{1}{M \times N} \sum_{i=1}^{M} \sum_{t \in [T+2.0, T+2.25]} x_{0,t} x_{i,t}$$

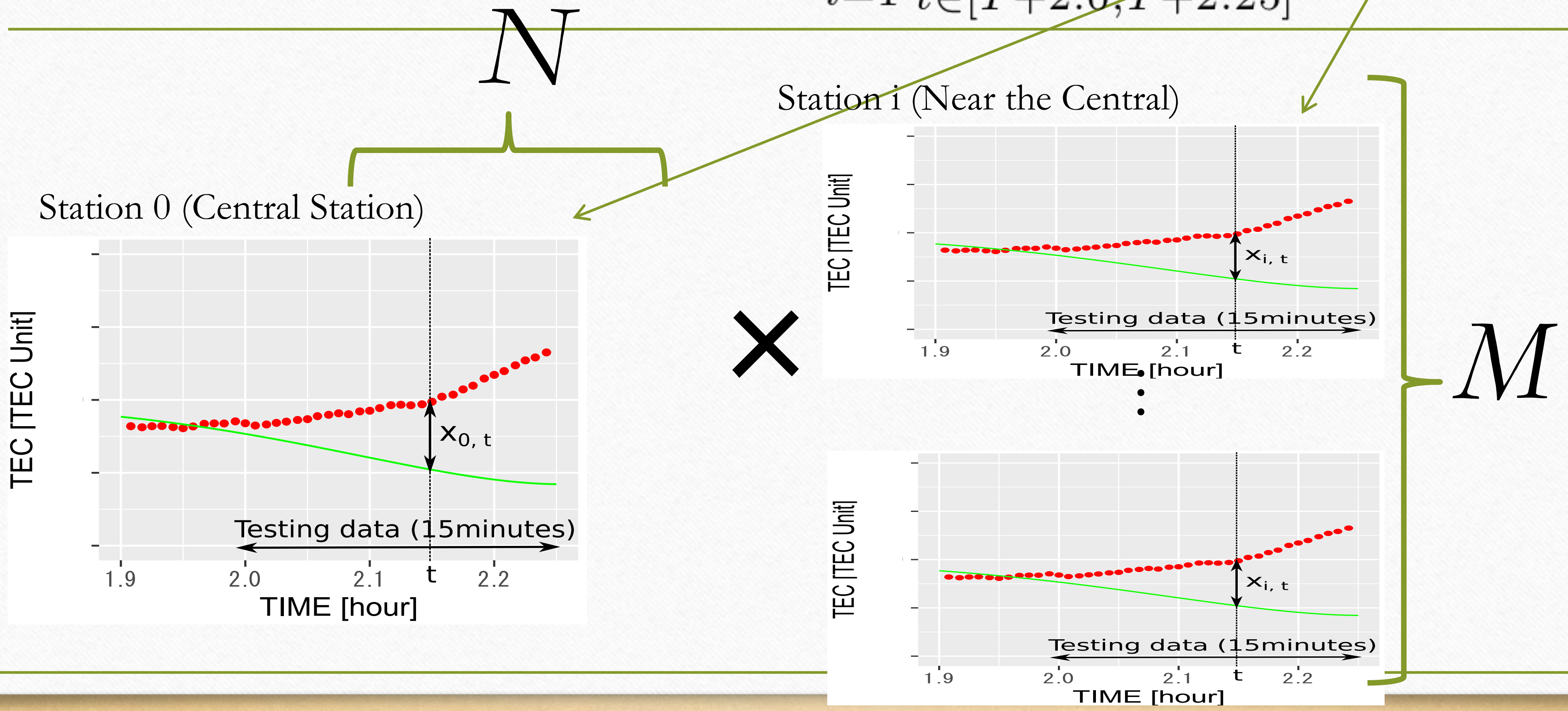
Stations Near the Central Station

Central Station

M : # of Stations Used for Correlation , N : # of Data Sampling

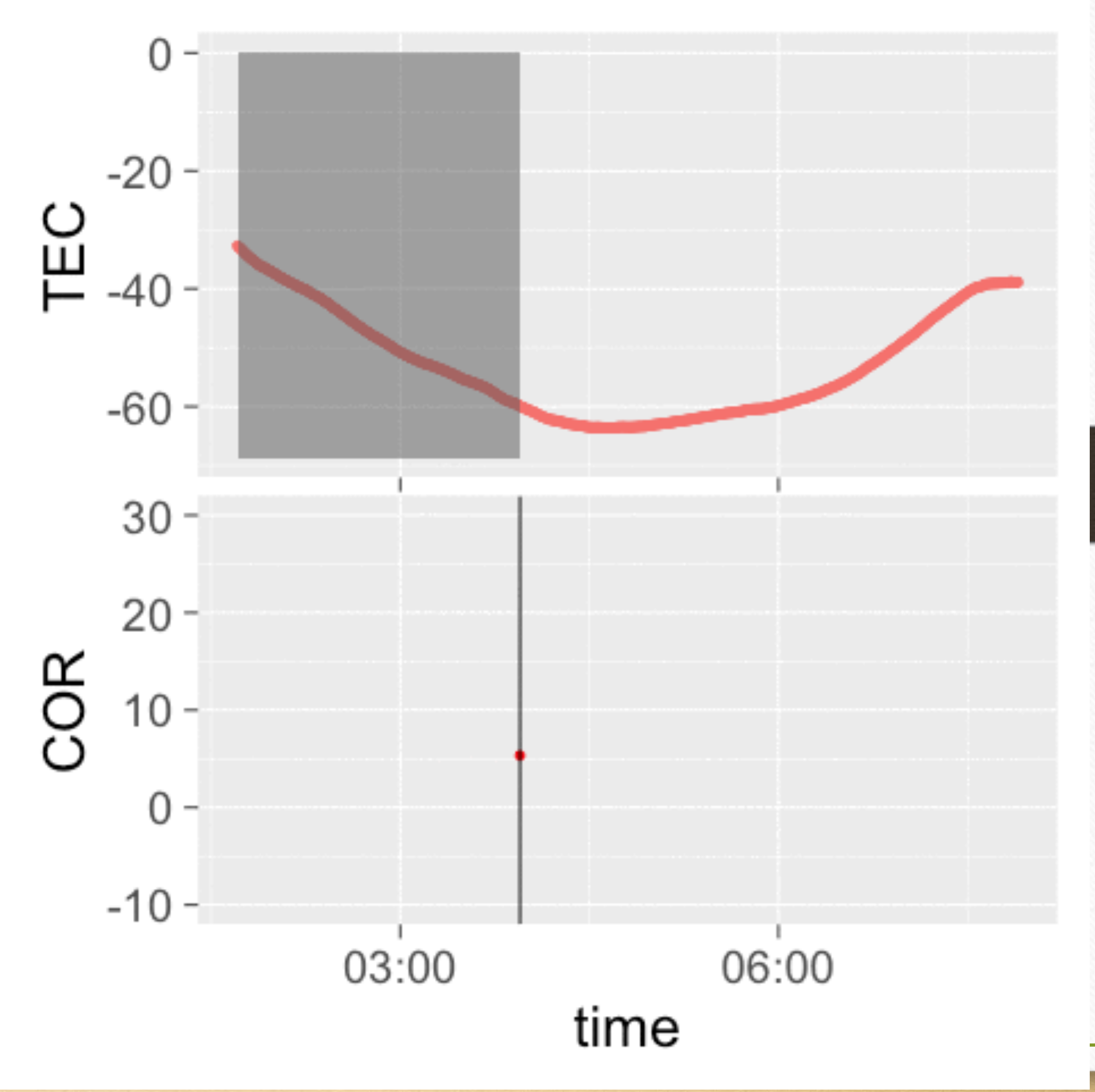
Correlation Method III

$$C(T+2.25) = \frac{1}{M \times N} \sum_{i=1}^{M} \sum_{t \in [T+2.0, T+2.25]} x_{0,t} x_{i,t}$$



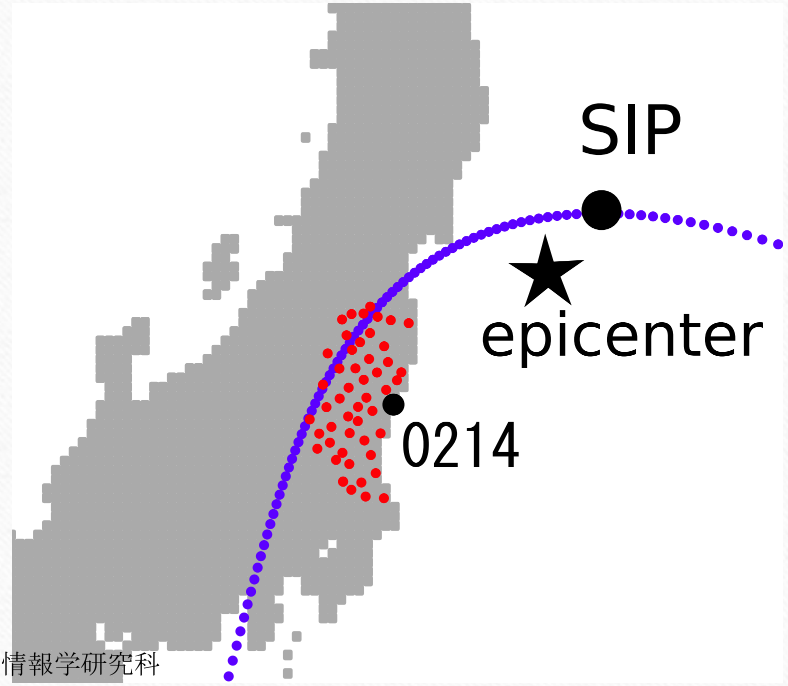
Correlation Method IV

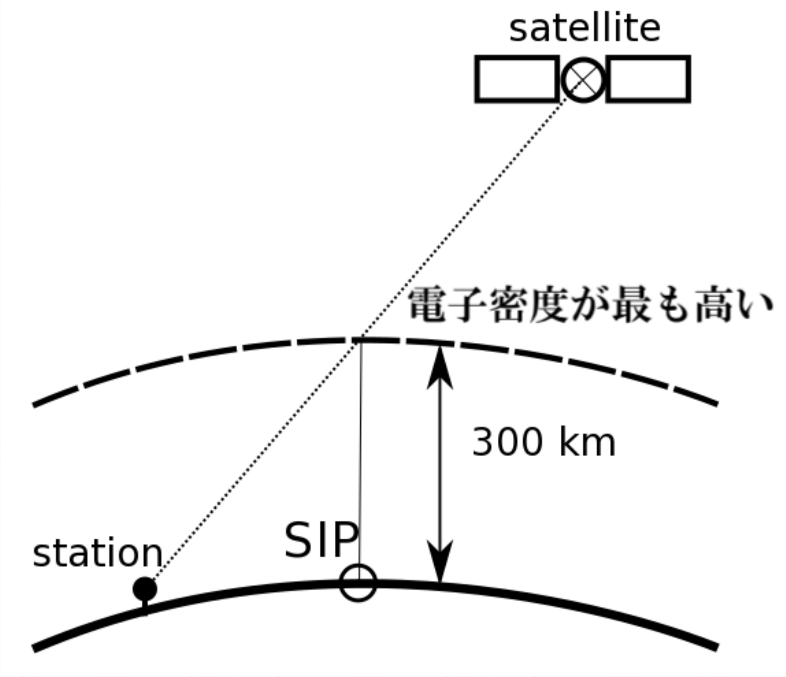
• • •135minutes' time window (Training Data (2hours) + Testing Data (15 minutes))



2011 Tohoku Oki Earthquake

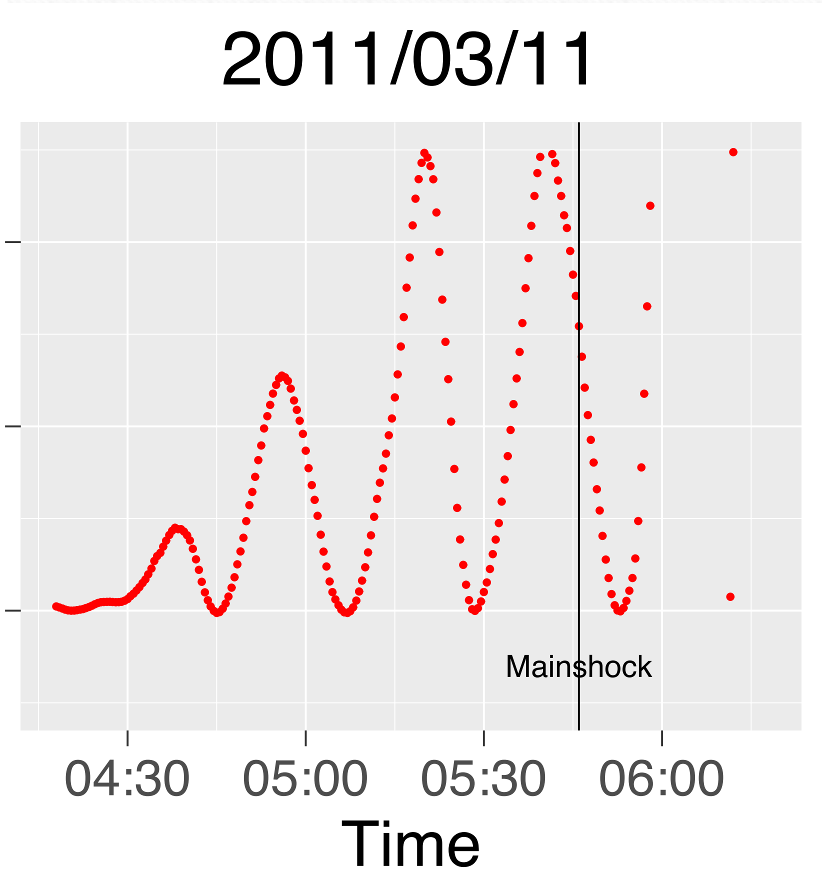
- Mainshock : 2011/03/11 05:46 [UTC]
- Mw : 9.0



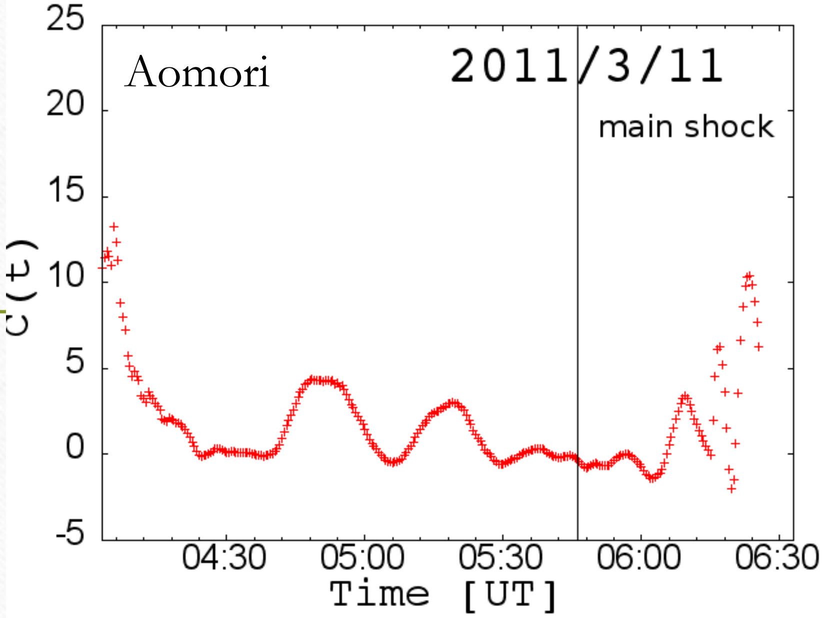


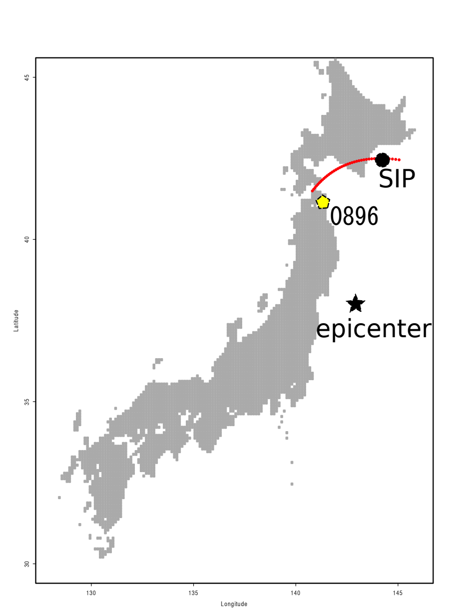
2011 Tohoku Oki Earthquake

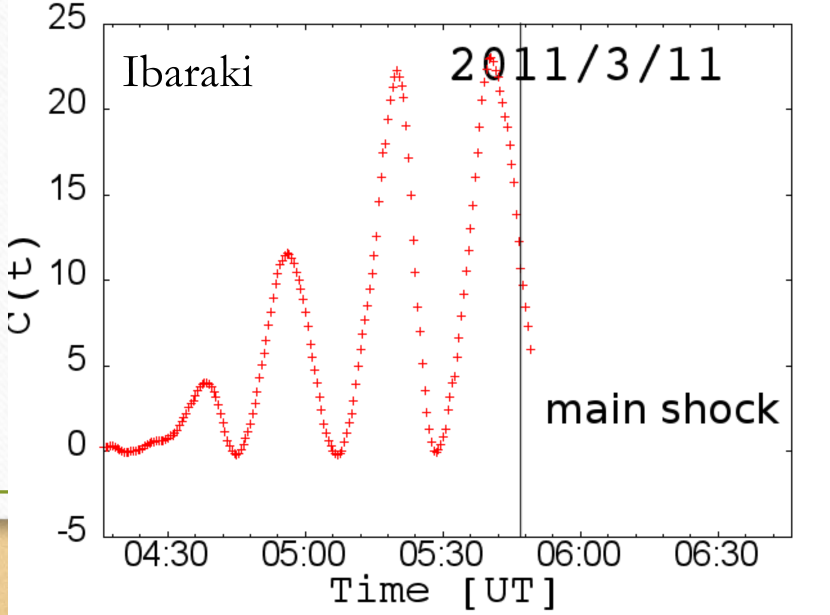
Ref: Takuya Iwata and Ken Umeno (2016)
Journal of Geophysical Research –Space Physics

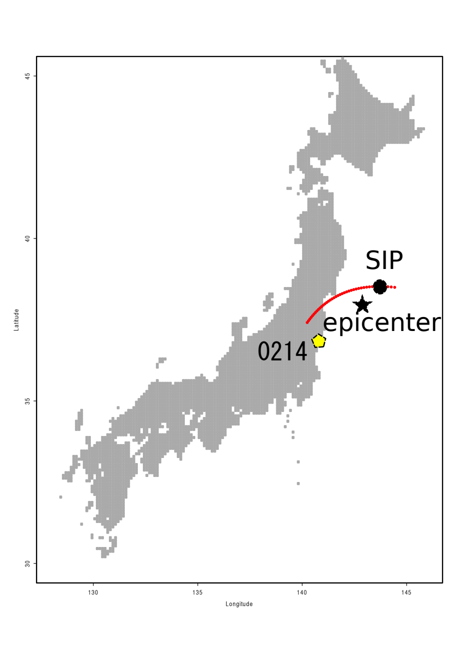


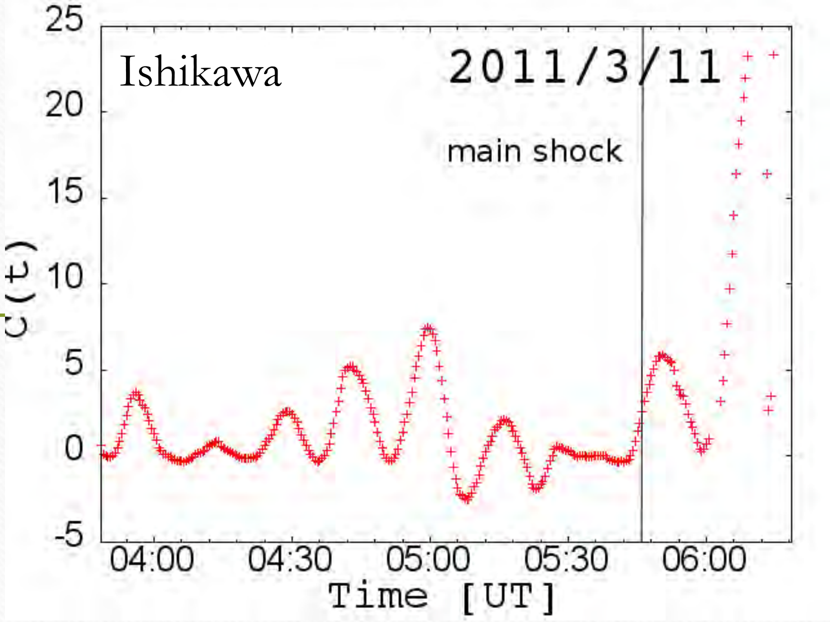
Other regions



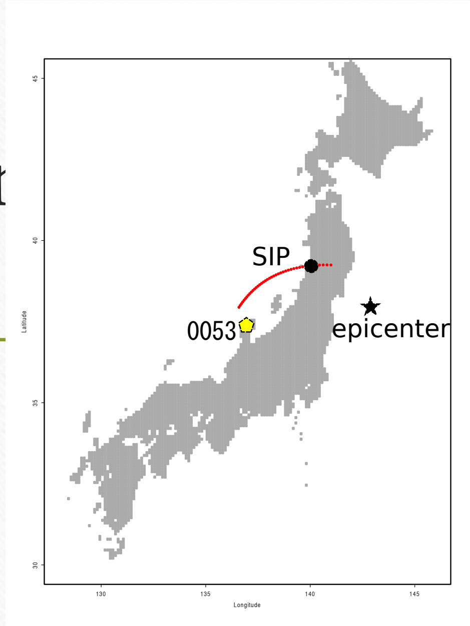


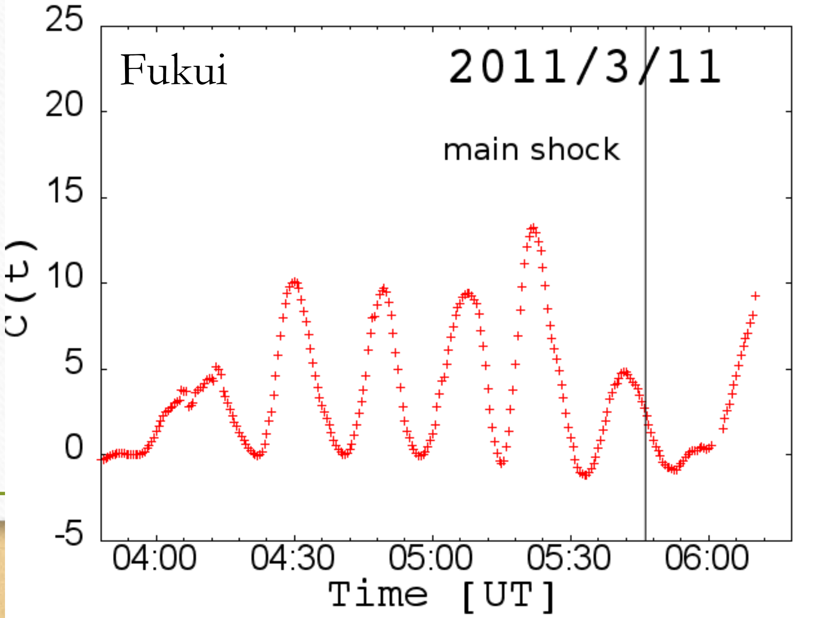


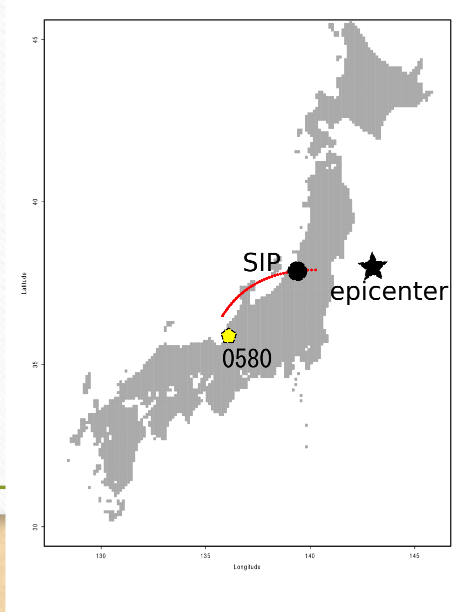



Ishikawa
2011/3/11
main shock
C(t)
25
20
15
10
5
0
-5
04:00
04:30
05:00
05:30
06:00
Time [UT]

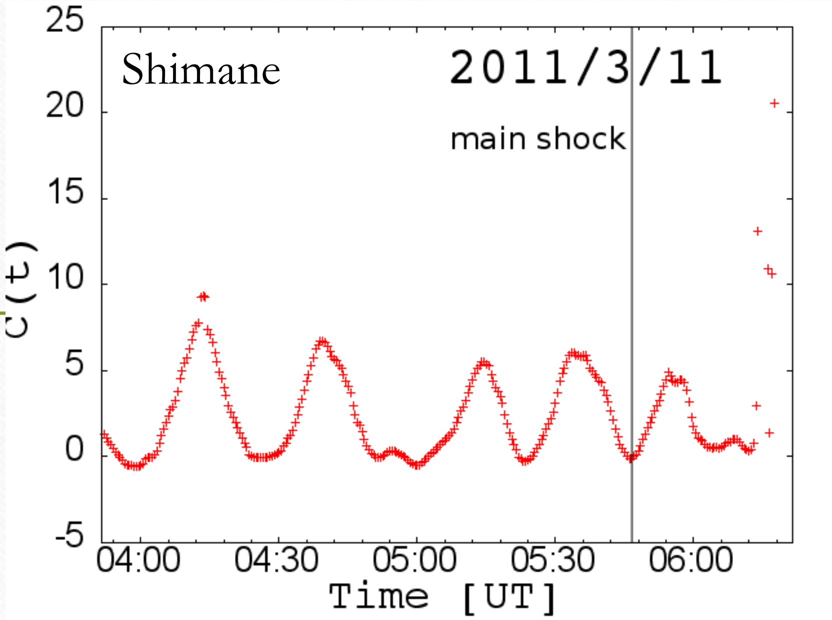
Ot

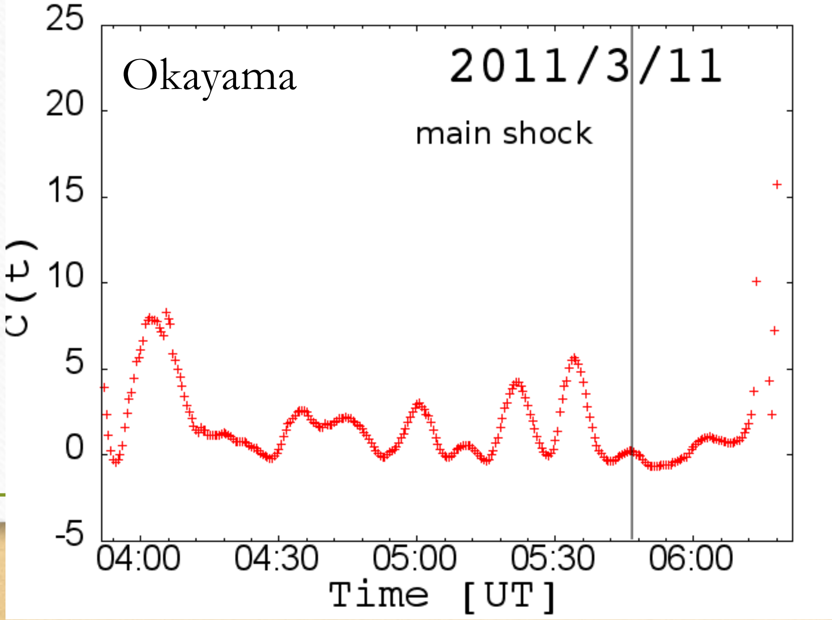

SIP
0053
epicenter

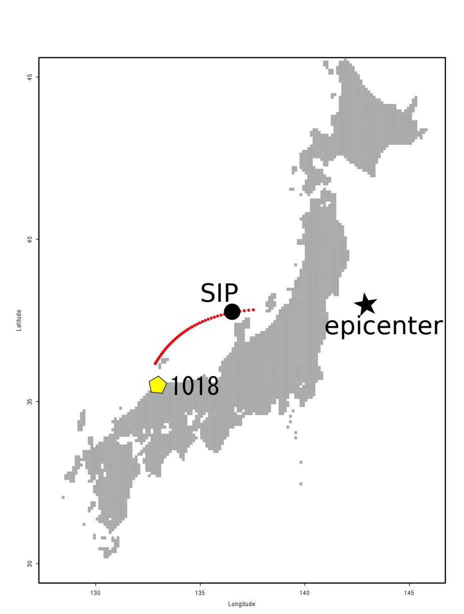

Fukui
2011/3/11
main shock
C(t)
25
20
15
10
5
0
-5
04:00
04:30
05:00
05:30
06:00
Time [UT]

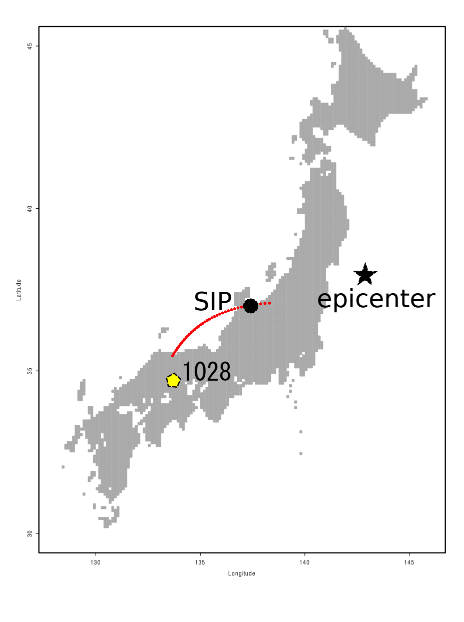

SIP
epicenter
0580

or


Shimane
2011/3/11
main shock
C(t)
25
20
15
10
5
0
-5
04:00
04:30
05:00
05:30
06:00
Time [UT]


Okayama
2011/3/11
main shock
C(t)
25
20
15
10
5
0
-5
04:00
04:30
05:00
05:30
06:00
Time [UT]

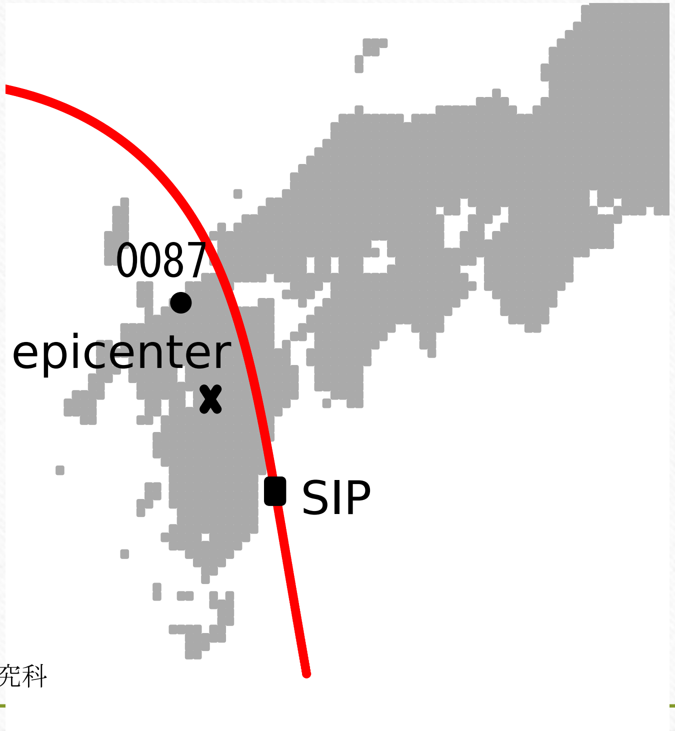

SIP
epicenter
1018

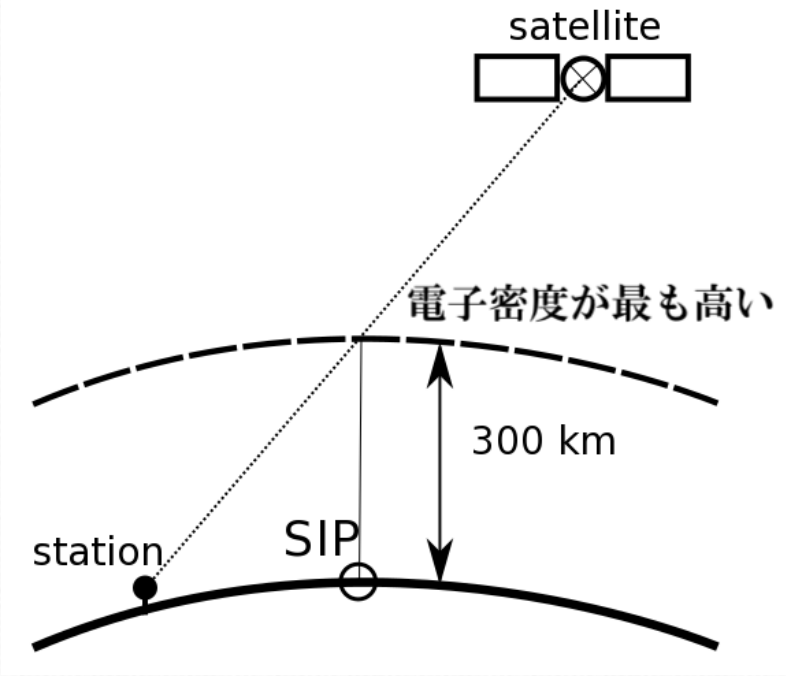

SIP
epicenter
1028

2016 Kumamoto Earthquake

Ref: Takuya Iwata and Ken Umeno, Journal of Geophysical Research (2017)

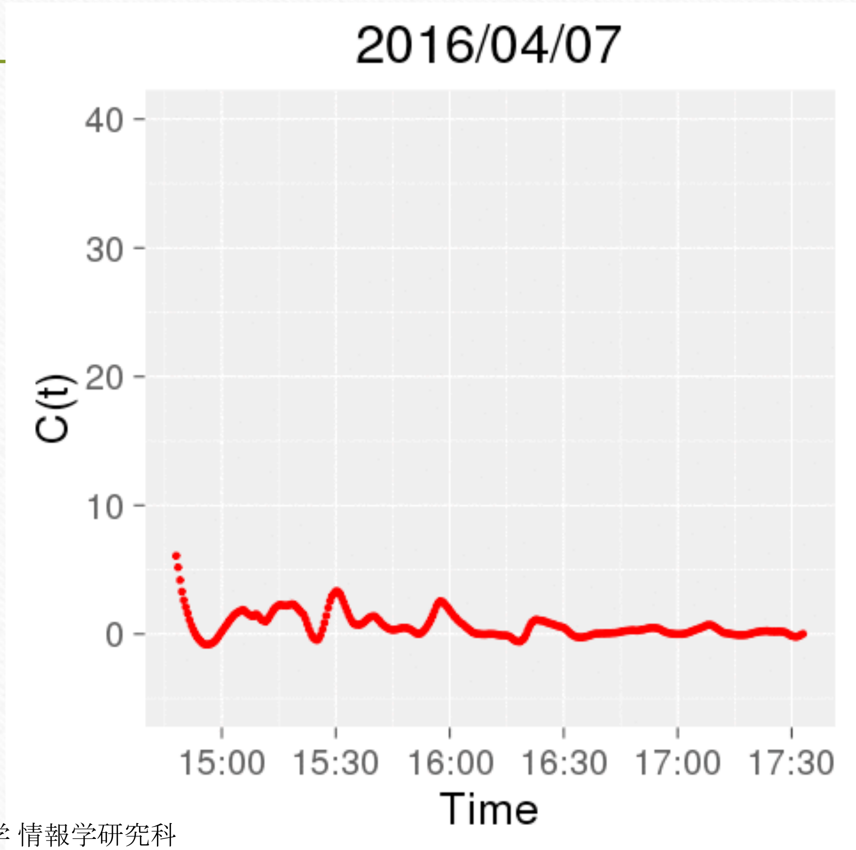
- Main Shock : 2016/04/15 16:25 [UTC]
- Mw : 7.3

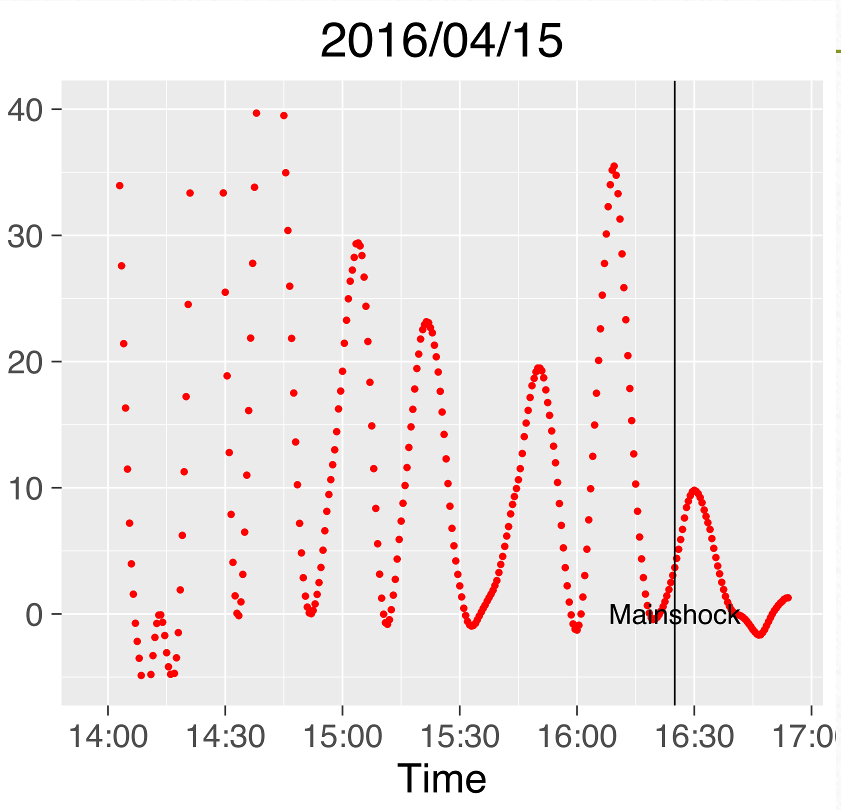




2016 Kumamoto Earthquake

Takuya Iwata and Ken Umeno, published in
Journal of Geophysical Research (2017 March)





Recent Publication (JGR, published on Nov. 7, 2019) shows that electro-magnetic Eq. precursor (OHB:1 hour before) certainly exists can be detected.

AGU100 ADVANCING EARTH AND SPACE SCIENCE

JGR Space Physics

RESEARCH ARTICLE

10.1029/2019JA026640

Preseismic Ionospheric Anomalies Detected Before the 2016 Taiwan Earthquake

Shin-itiro Goto[1], Ryoma Uchida[1], Kiyoshi Igarashi[1], Chia-Hung Chen[2], Minghui Kao[1], and Ken Umeno[1]

[1]Department of Applied Mathematics and Physics, Graduate School of Informatics, Kyoto University, Kyoto, Japan, [2]Department of Earth Sciences, National Cheng Kung University, Tainan, Taiwan

Key Points:
- This shows first clear preseismic ionospheric anomalies 40 min before the 2016 Taiwan earthquake which is an intraplate one with M_w 6.4
- These anomalies were detected by applying our correlation analysis to total electron content (TEC) data obtained from the GNSS stations
- Our finding cannot be explained by some existing phenomenology

Correspondence to:
K. Umeno,
umeno.ken.8z@kyoto-u.ac.jp

Citation:
Goto, S.-I., Uchida, R., Igarashi, K., Chen, C.-H., Kao, M., & Umeno, K. (2019). Preseismic ionospheric anomalies detected before the 2016 Taiwan earthquake. *Journal of Geophysical Research: Space Physics, 124*. https://doi.org/10.1029/2019JA026640

Received 25 FEB 2019
Accepted 12 SEP 2019
Accepted article online 14 OCT 2019

Abstract On 5 February 2016 (UTC), an earthquake with moment magnitude 6.4 occurred in southern Taiwan, known as the 2016 (Southern) Taiwan earthquake and 2016 Meinong earthquake. In this study, evidences of seismic earthquake precursors for this earthquake event are investigated. Results show that ionospheric anomalies in total electron content (TEC) can be observed before the earthquake. These anomalies were obtained by processing TEC data, where such TEC data are calculated from phase delays of signals observed at densely arranged ground-based stations in Taiwan for Global Navigation Satellite Systems. This shows that such anomalies were detected within 1 hr before the event.

1. Introduction

The ionosphere is an ionized medium, which can affect the radio communications. The electron density in the ionosphere is disturbed by various phenomena such as solar flares (Donnelly, 1976), volcanic eruptions (Igarashi et al., 1994), flying objects (Mendillo et al., 1975), earthquakes (Ogawa et al., 2012), and so on. These electron density disturbances are observed with total electron contents (TECs) at ground-based Global Navigation Satellite Systems (GNSS) receivers. With GNSS that can monitor variations of TEC, it has been reported (Heki, 2011; Heki & Enomoto, 2015; Kelly et al., 2017) that preseismic ionospheric electron density anomalies appeared frequently before large earthquakes, which could be caused by the earthquake-induced electromagnetic process before such earthquakes. Furthermore, such TEC anomalies were found in the 2016

Another Case in Taiwan

2016 Taiwan Earthquake

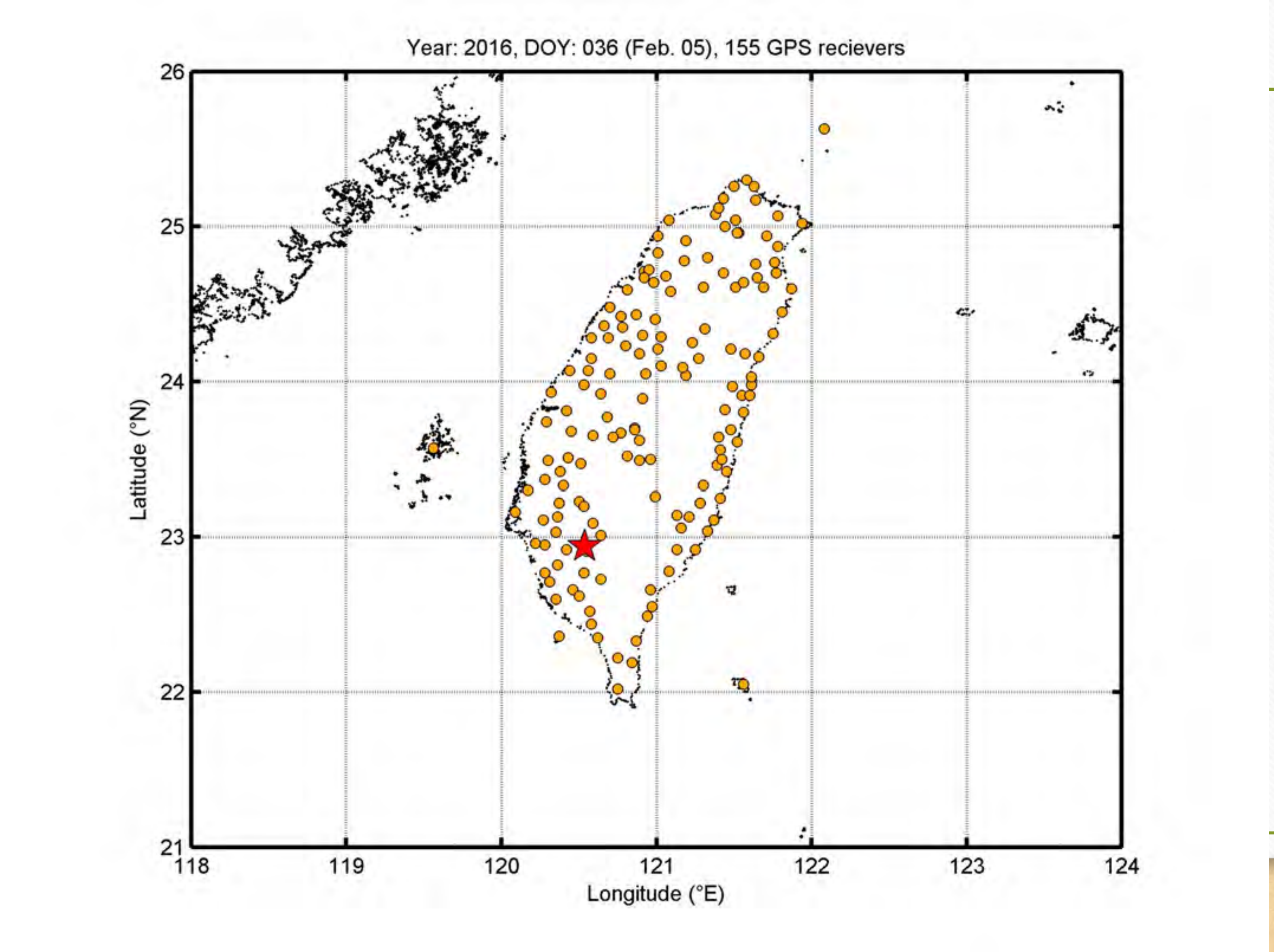
Occurrence Time：2016/02/05 19:57
（UTC=Taiwan Time – 8.0）

Epicenter：South Part of Taiwan

Magnitude：M6.4

Our Recent Detection: M6.4 Taiwan Earthquake

Taiwan GNSS 155 stations(Taiwan Central Weather Bureau)



Ionospheric Anomaly Area

Journal of Geophysical Research: Space Physics 10.1029/2019JA026640

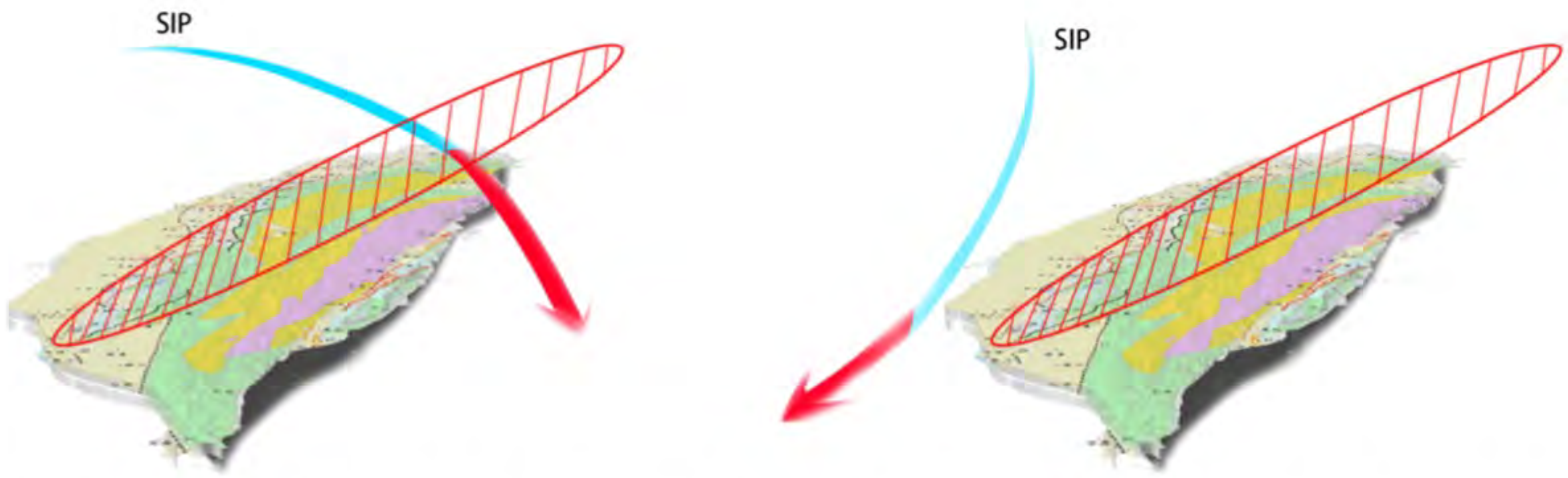


Figure 1. (left) When a subionospheric point (SIP) track crosses the projection of an assumed ionospheric anomaly area (shaded in red). (right) When a SIP track does not cross the projection of the anomaly area.

Precursor Detected !

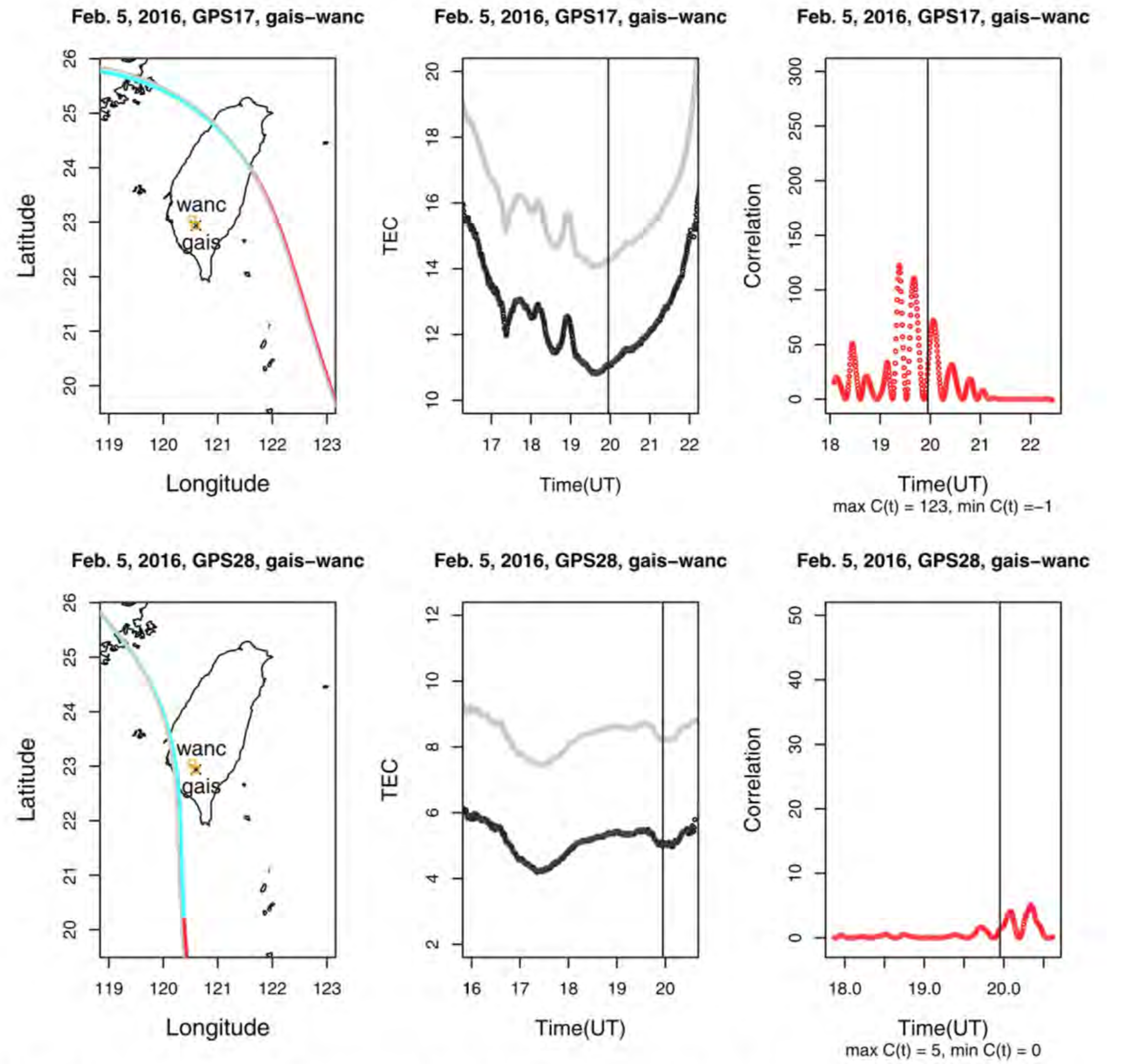


Figure 2. (left) Subionospheric point tracks for Global Positioning System (GPS) satellites 17 and 28. Red: Track for "gais" after the event, Cyan: Track for "gais" before the event, Gray: Track for "wanc," ×: Epicenter. (middle) Time series of total electron content (TEC), the vertical lines indicate the time (UT) when the event occurred. Black: TEC obtained at "gais," Gray: TEC obtained at "wanc," where the TEC values were shifted by hand for the guide of eyes. (right) Time series of correlations obtained with CoRelation Analysis.

Precursor Diary

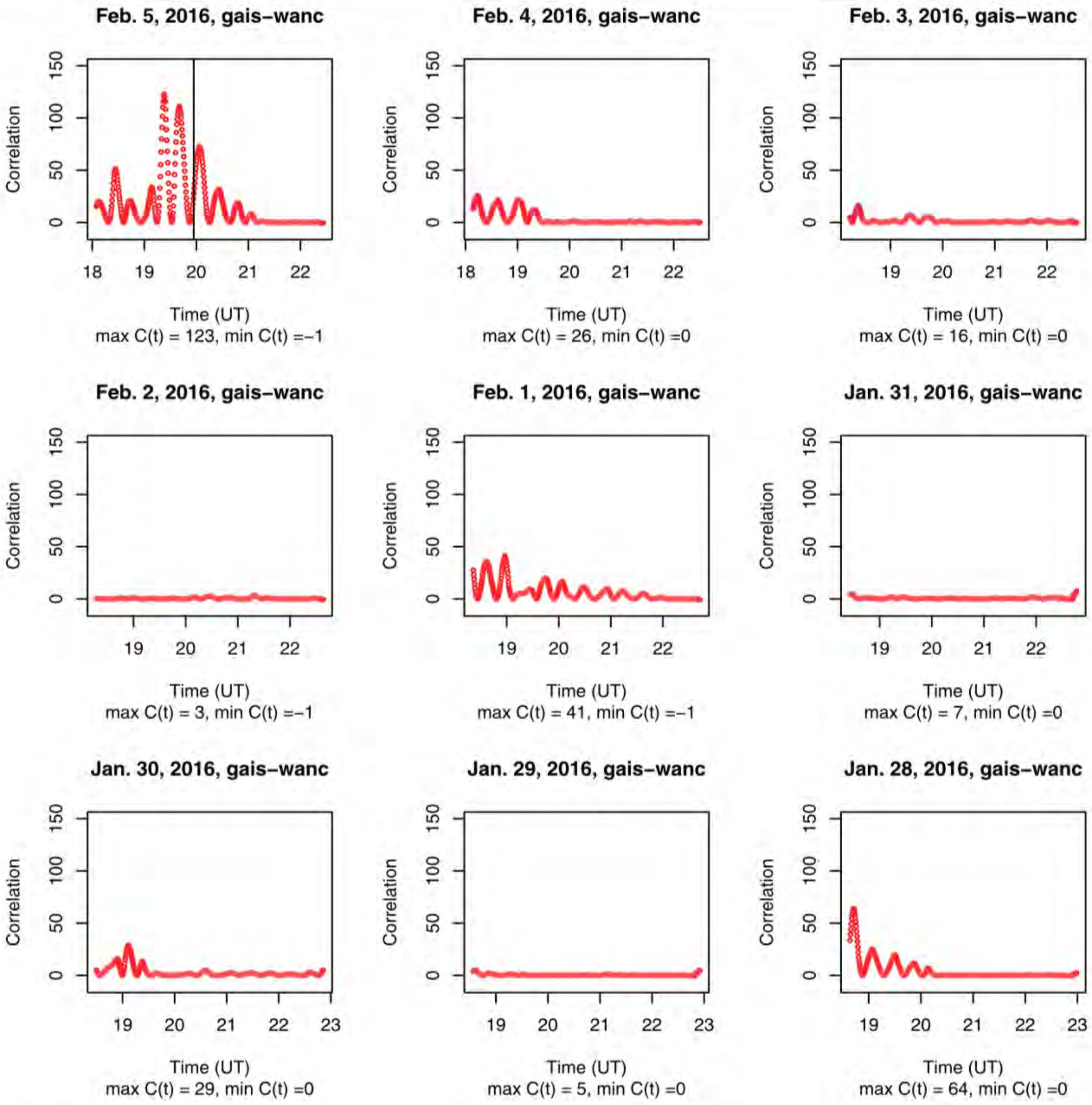


Figure 7. Time series of correlations obtained by CoRelation Analysis with $M = 1$, where total electron content (TEC) data were observed at the stations "gais" and "wanc" for the period from 28 January to 5 February in 2016. Global Positioning System satellite 17 was used. The vertical line on 5 February indicates the time when the event occurred.

Conclusion (Scientific Part)

- Importance of Physical Law (Energy Conservation and Complexity Growing) to Invest Against Future Disasters.
- Predicting earthquake here is Not a gambling (probabilistic game) but a totally deterministic procedure with big data analysis.
- Similar definite precursor signals detected for different type of earthquakes in different countries. (Low Error Rate)
- Earthquake precursor "One Hour Before" earthquake can possibly prevent or definitely mitigate disasters all over the world.

In other words,

- There is what we can do before earthquakes and we must do it before earthquake to save our lives.
- That is really a smart investment strategy.

Sendai Framework Preamble (2015, Here in Sendai)

14. Against this background, and in order to reduce disaster risk, there is a need to address existing challenges and prepare for future ones by focusing on monitoring, assessing and understanding disaster risk and sharing such information and on how it is created; strengthening disaster risk governance and coordination across relevant institutions and sectors and the full and meaningful participation of relevant stakeholders at appropriate levels; investing in

Cost Efficiency According to the Physical Principle

When	Complexity	Investment (Back) Cost
Before	Small	Relatively Small
After	Huge	Dramatically Huge

Main Message:

Beware Back <u>Before</u>

Then,

Build Back Better

Thank you very much.

Acknowledgements: The work published in JGR (2019) is based on Kyoto-U.-Optage Collaborative Research (2017-2020).

Discussions with Ohno(Optage), M.H. Kao and N. Ohora (Kyoto University)

Are Also Greatly Appreciated to sharpen our view.