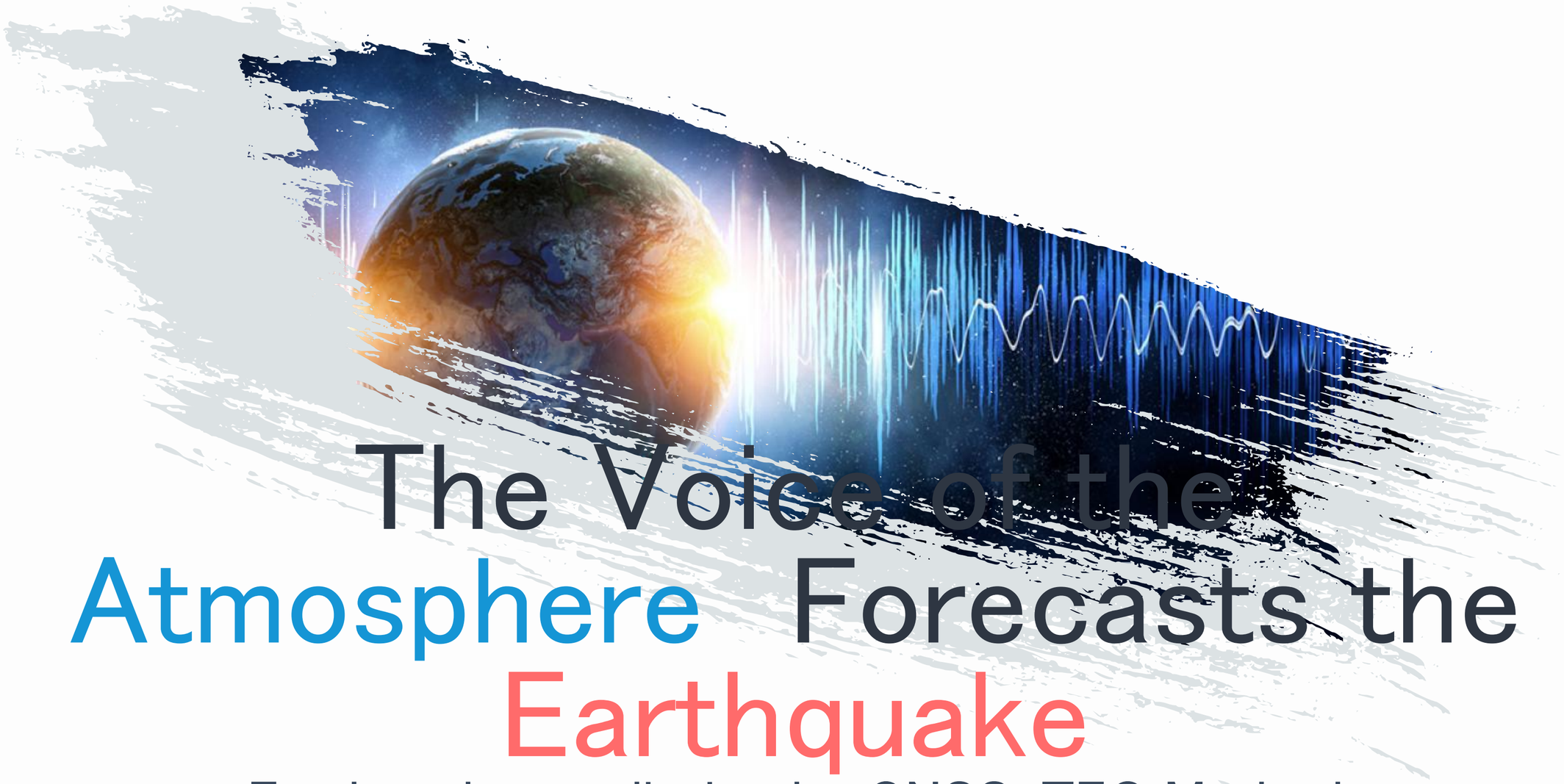


The Voice of the Atmosphere Forecasts the Earthquake

Earthquake prediction by GNSS-TEC Method

TABLE OF CONTENTS

SECTION 1

INTRODUCTION


The video material by Cabinet Office, Reference 1


最大震度
7
9日15時 00分ごろ
M8.3
what if:
IN the near future
This is an fake image of the news that Nankai Megathrust Earthquake has happened,
based on the prediction by a committee inside Japanese Cabinet Office.
Made by Bye Bye Plastic Bags Kyoto(BBPB Kyoto), https://newscast.jp/news/2201536

Nankai TROUGH EARTHQUAKEs

SINCE 1361 (the oldest one is OBSERVed in 684)

1361 — 137 years — 1498 — 107 years — 1605 — 102 years

SHOHEI/Koan M8.5

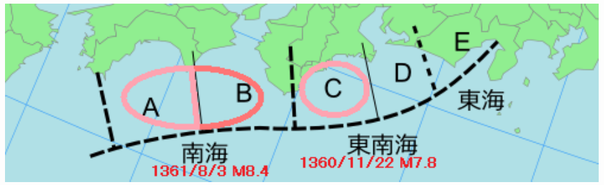
NANKAI

8.3.1361 (Shohei 16) M8.2 – 8.5

↑ 0.7 years

TONANKAI

11.22.1360 (Shohei 15) M7.8



MEIOH M8.4

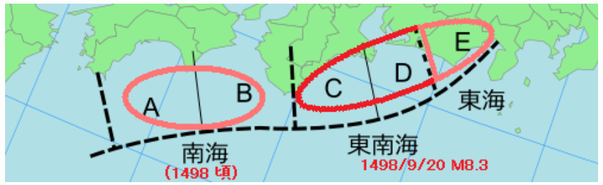
NANKAI

7.9.1498 (Meioh 7)

↓ 0.2 years

TOKAI & TONANKAI

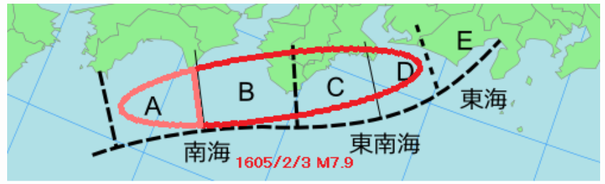
9.20.1498 (Meioh 7) M8.2 – 8.4



KEICHO M8.0

NANKAI & TONANKAI

2.3.1605 (Keicho 9) M7.9 – 8.0

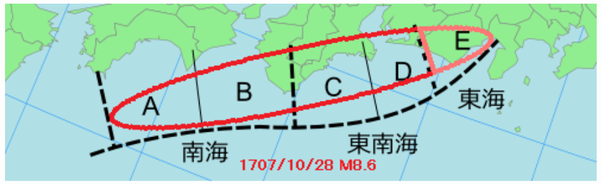


1707 147 years 1854 92 years 1946 76 years

HOuEI M8.6

TOKAI & TONANKAI & NANKAI

10.28.1707 (Houei 4) M8.6



Ansei M8.4

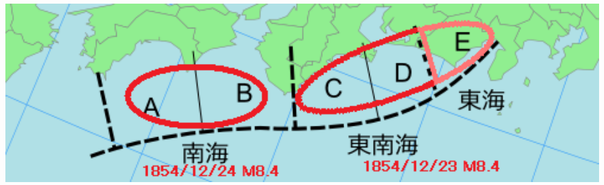
NANKAI

12.24.1854 (Kaei 7) M8.4

↑ 32 hours

TOKAI & TONANKAI

12.23.1854 (Kaei 7) M8.4



SHOWA M8.0

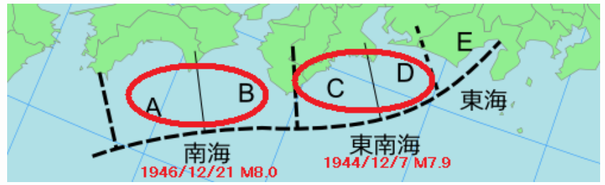
NANKAI

12.21.1946 (Showa 21) M8.0

↑ 2 years

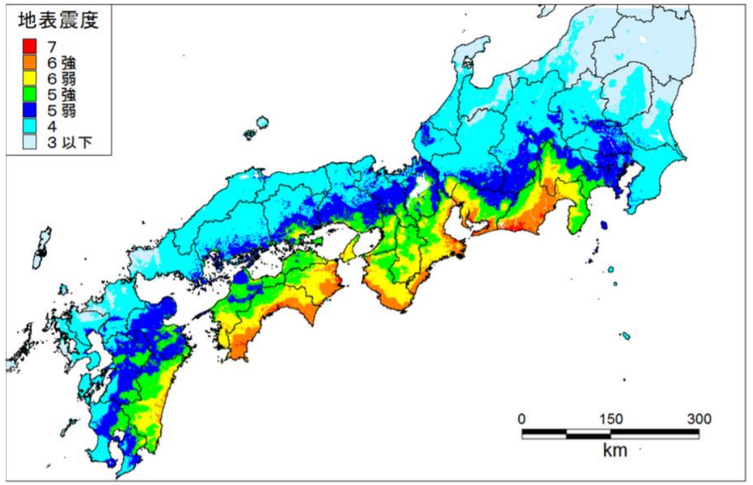
TONANKAI

12.7.1944 (Showa 19) M7.9



Within 10 years: about 30%
Within 30 years: 70% ~ 80%
Within 50 years: 90% or more

Predicted by Government of Japan, Reference 2



Made by Cabinet Office, Reference 3

2022 → 20XX

NOW

Most recent earthquakes of intensity over 5 lower

2021/12/09 M6.1 Tokara Islands

2022/01/04 M6.1 Chichijima Island

2022/01/22 M6.6 Hyuga-nada

We can change the wotst future

NANKAI MEGATHRUST EARTHQUAKE

- **185,000 people can be killed**
  (Case that Tokai region would be largely damaged, Midnight in winter, Average wind speed)
- By Tsunami account for About 83%
- **9,500,000 people would have to take refuge in a week**

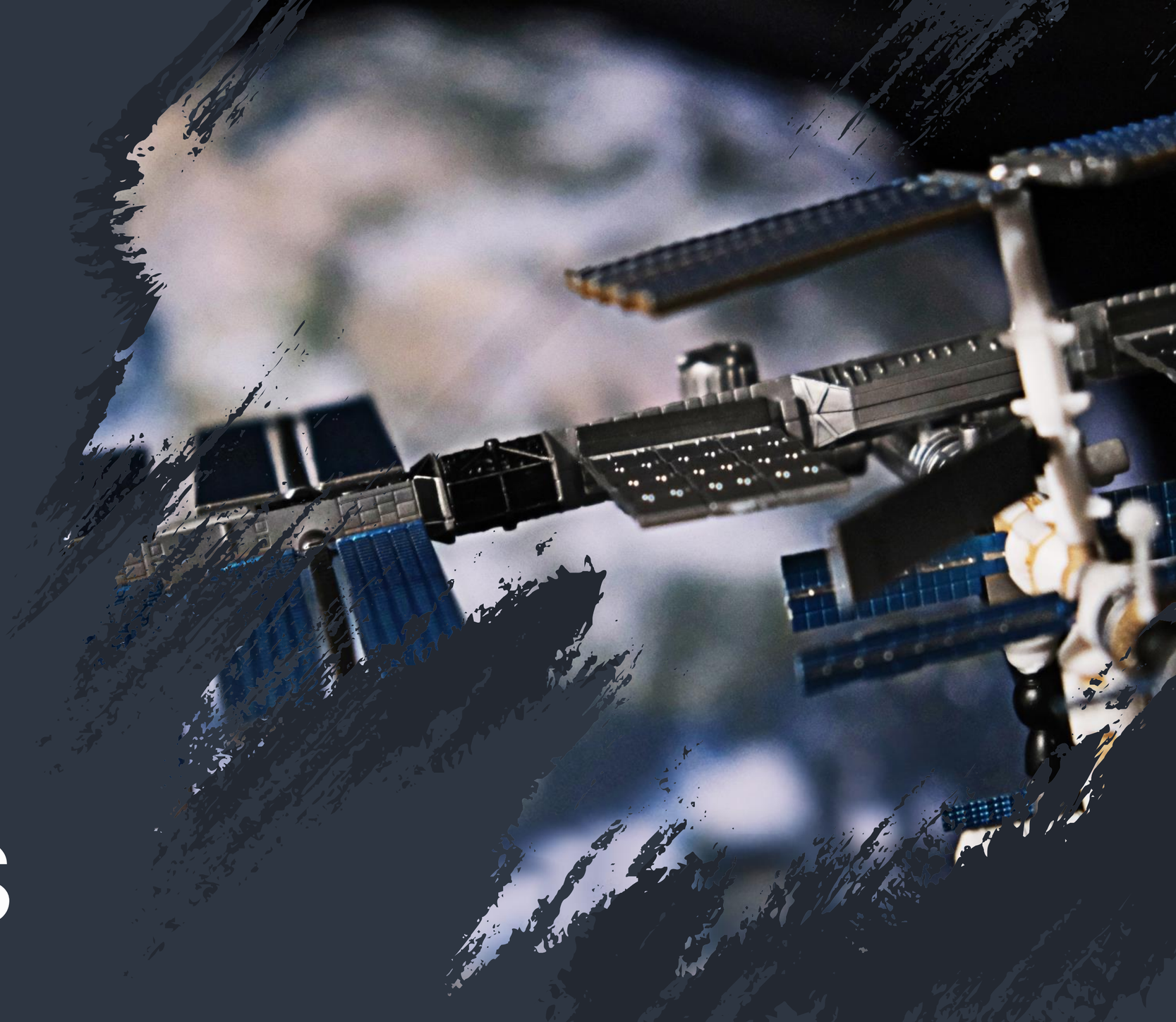
Reference 3

How can we save our lives?

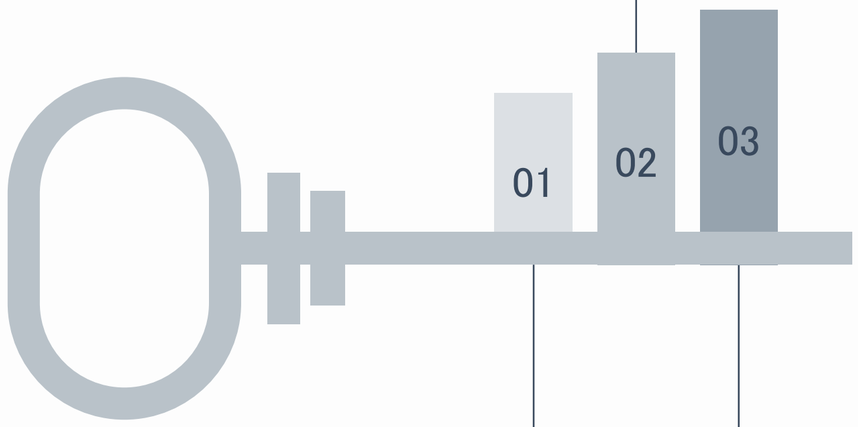
IS it possible to PREDICT earthquakeS ACCURATELY?

SECTION 2

METHODS



3 KEY POINTS to predict



OBSERVABLENESS

Using the observation device which meets the following conditions:

1. **Already available now**
2. **Exist all over Japan**

There's no time to equip new devices.

SENSIBILITY

How minutely can we predict the earthquake?

How large (magnitude)

Where it happens

How early can we know

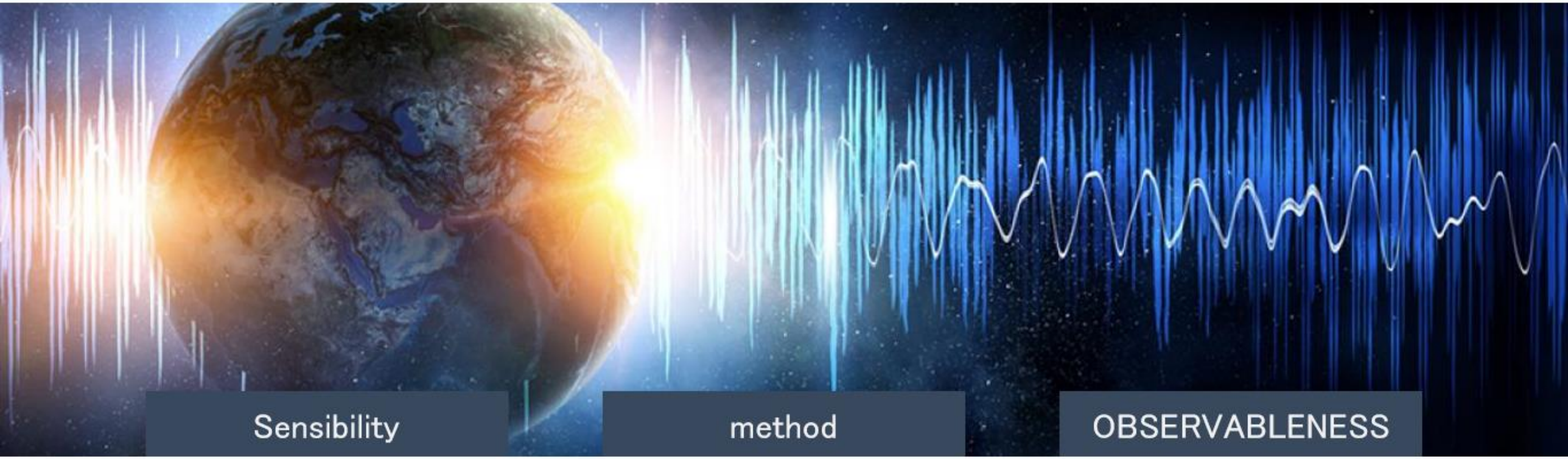
How small earthquake can we know

ACCURACY

Most important point

If an earthquake forecast was wrong, the whole society would go into a panic.

GNSS-TEC Method FEATURES



Sensibility

This method is intend to predict

- In 30 mins ~ 1 hour
- Over magnitude 7

method

Calculate TEC (total electron content, the number of electrons in the ionosphere) and find the phenomenon that TEC increases about 30 mins ~ 1 hour before the earthquake.

OBSERVABLENESS

1,300 observation stations all over Japan are available now, using GEONET (GNSS Earth Observation Network System) data

GNSS-TEC Method FEATURES

GNSS =
Global Navigation Satellite System

A System which uses satellites to let us know our position
Ex. GPS, QZSS (Michibiki in Japan), GLONASS

Sensibility

This method is intend to predict

- In 30 mins ~ 1 hour
- Over magnitude 7

method

Calculate TEC **(total electron content, the number of electrons in the ionosphere)** and find the phenomenon that TEC increases about 30 mins ~ 1 hour before the earthquake.

OBSERVABLENESS

1,300 observation stations all over Japan are available now, using **GEONET (GNSS Earth Observation Network System)** data

GNSS-TEC Method FEATURES

TEC = Total Electron Content

The number of electrons in the ionosphere

Sensibility

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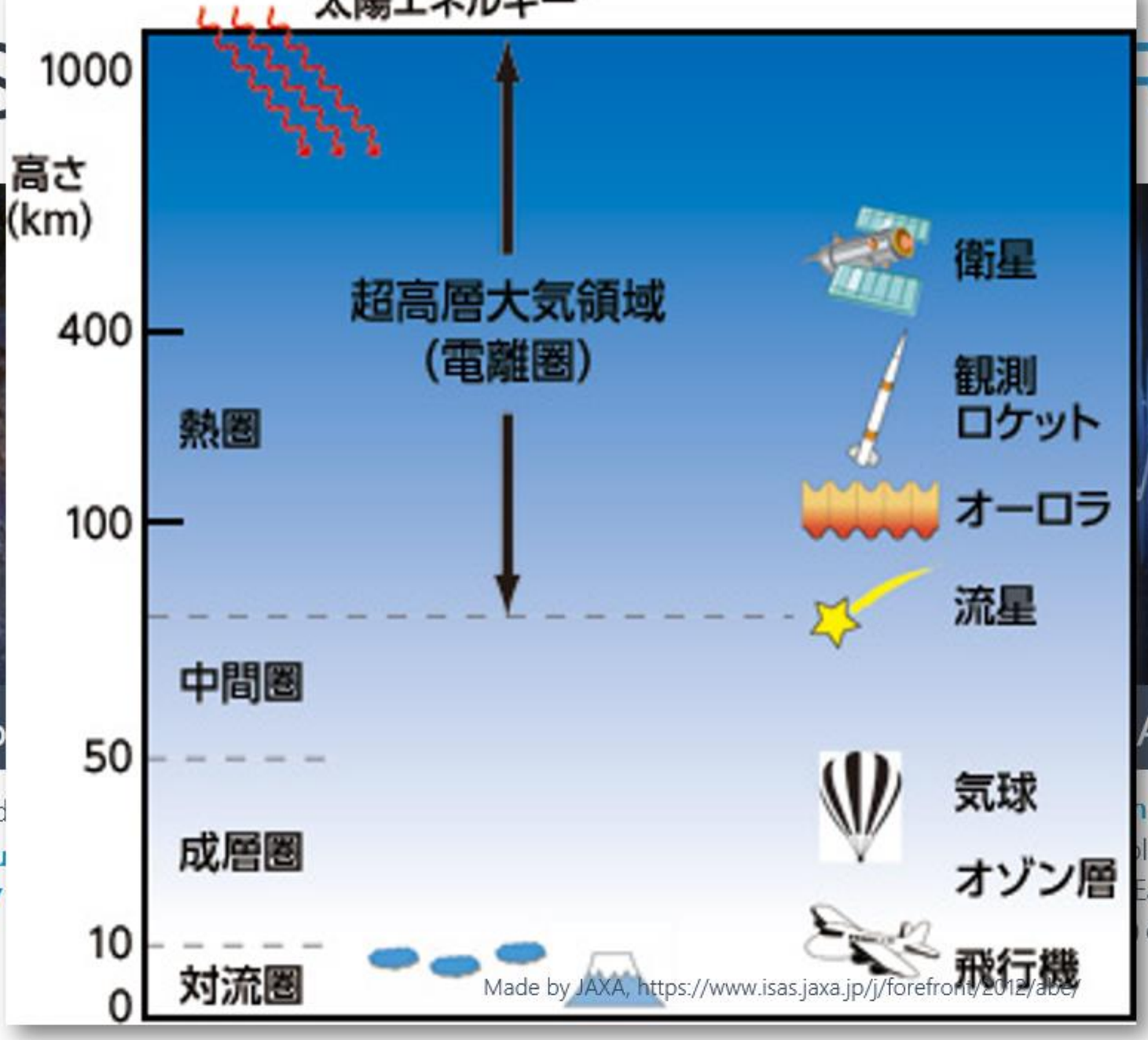
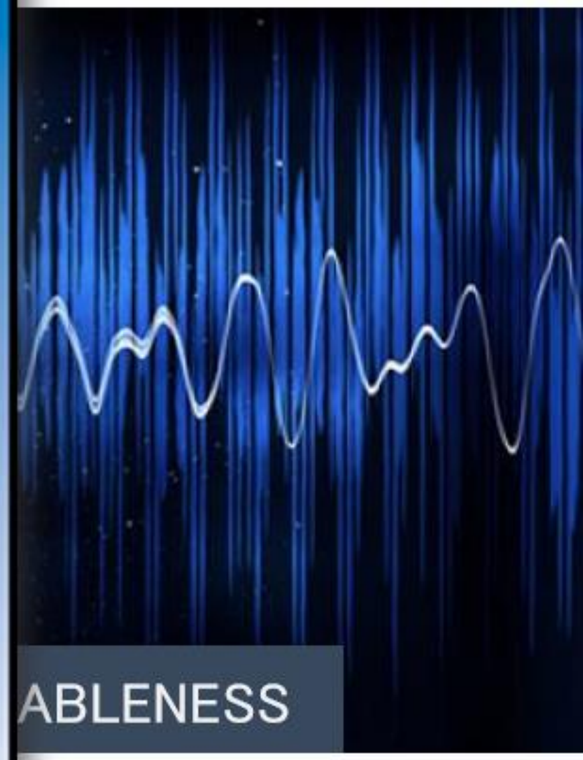
GNS RES

Sensib





ABLENESS

This method is intend
- In 30 mins ~ 1 hou
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n stations all over
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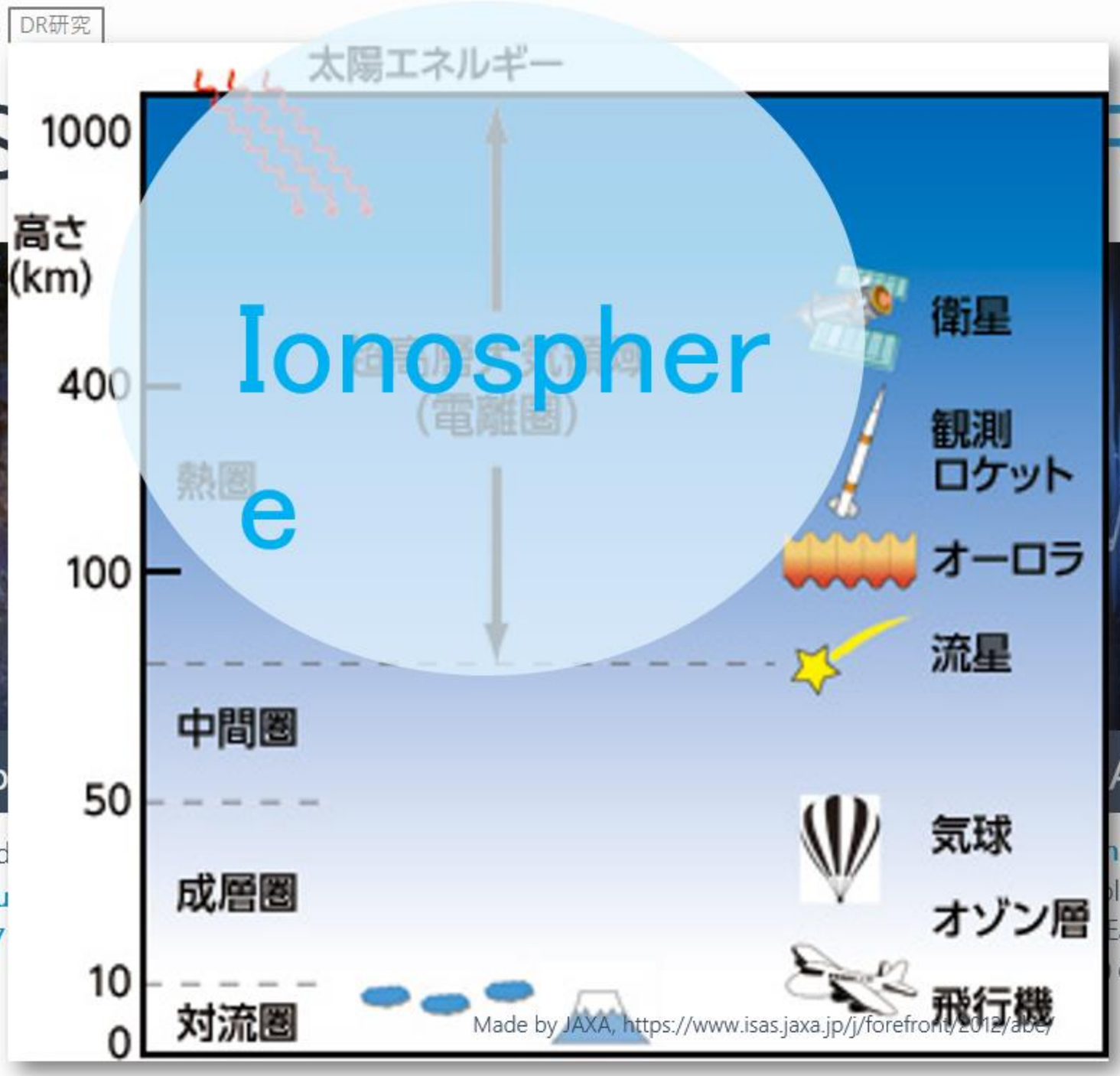
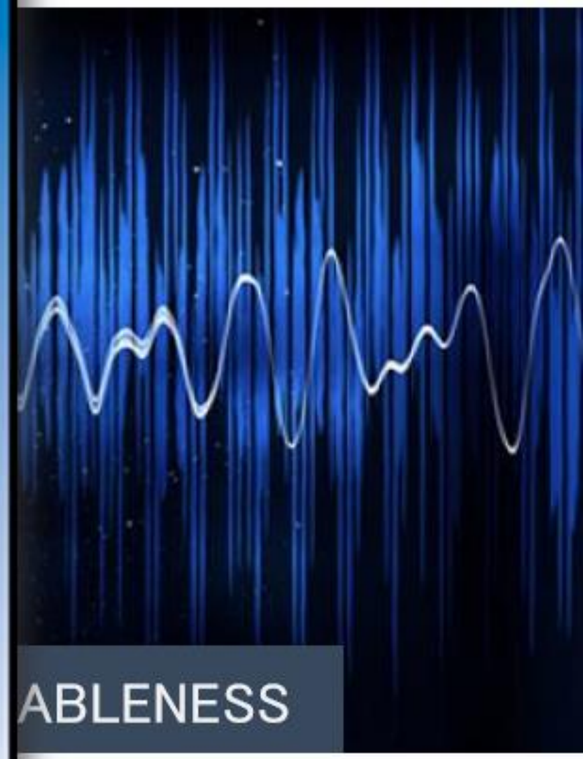
Earth Observation
data

GNS RES

Sensib





ABLENESS

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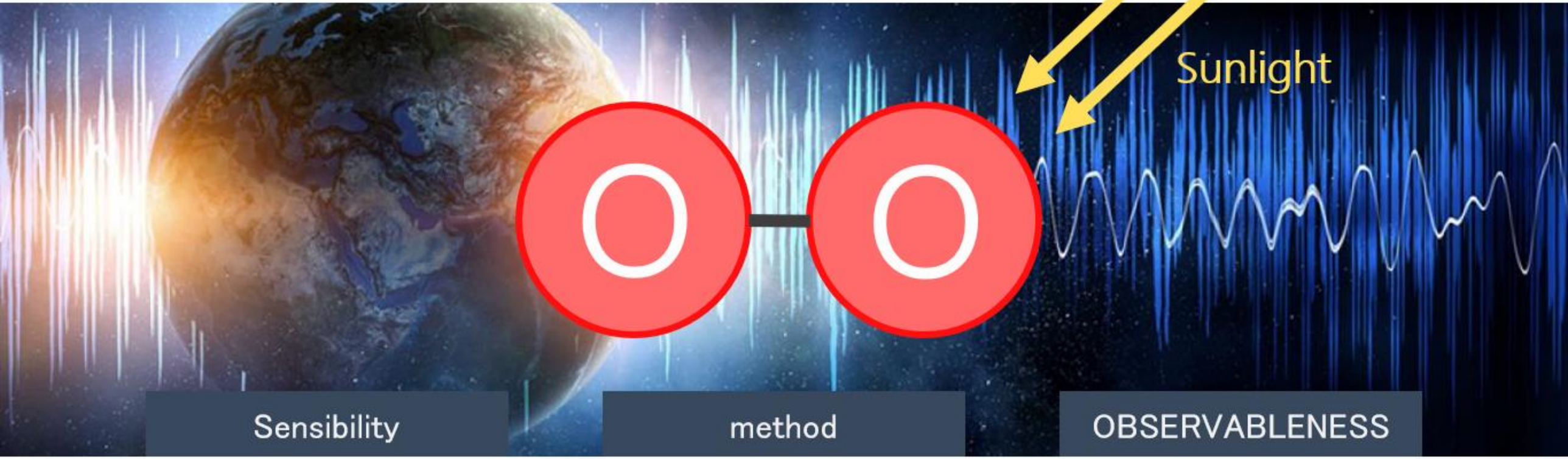
GNSS-TEC Method FEATURES



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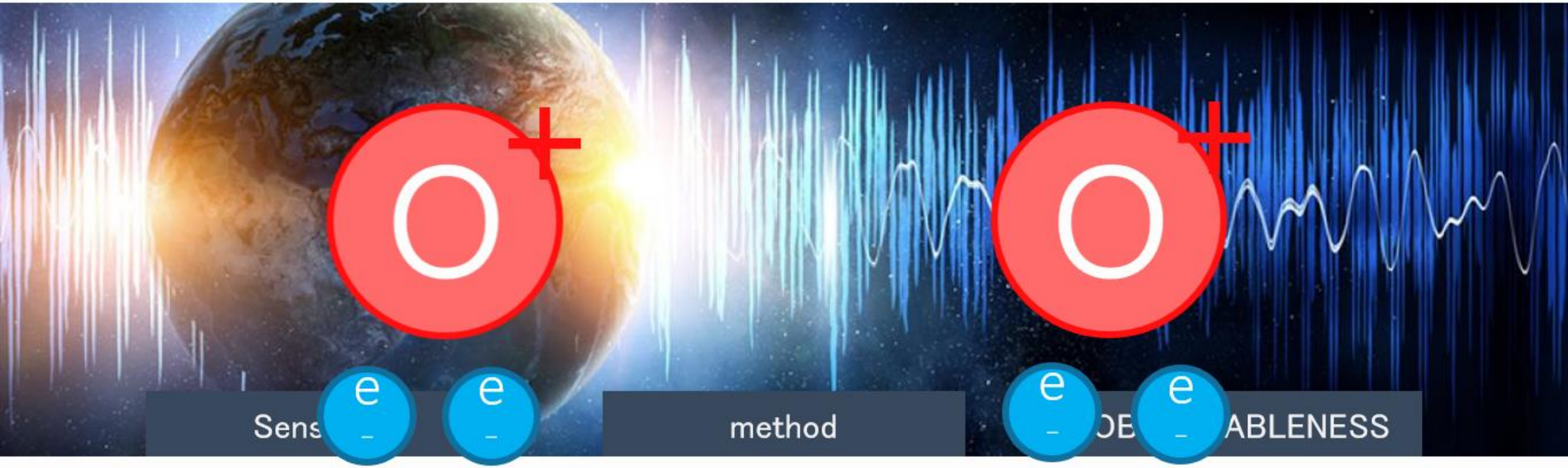
GNSS-TEC Method FEATURES



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Calculate TEC (total electron content, the number of electrons in the ionosphere) and find the phenomenon that TEC increases about 30 mins ~ 1 hour before the earthquake.

1,300 observation stations all over Japan are available now, using GEONET (GNSS Earth Observation Network System) data

Researching PROCESS

01

hypothesis

We can observe increase in TEC in all the earthquakes of magnitude over 7

02

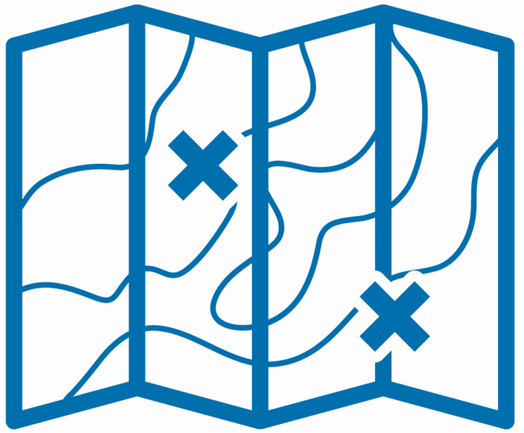
Collect primary Data

1. Make the list of the earthquakes which occurred in Japanese territory (Unite data of magnitude, intensity, seismic center, etc.)
2. Get GNSS data from 2 hours before the earthquake to right before the earthquake from GEONET

03

Convert GNSS data to TEC data (later discussed in detail).

Convert to TEC data



04

Observe tEC anomaly

Make sure of the fact that the anomalies before the earthquake really exist.

TODAY’s presentation

See if the anomaly as the sign of earthquakes before the Great East Japan Earthquake

SECTION 3

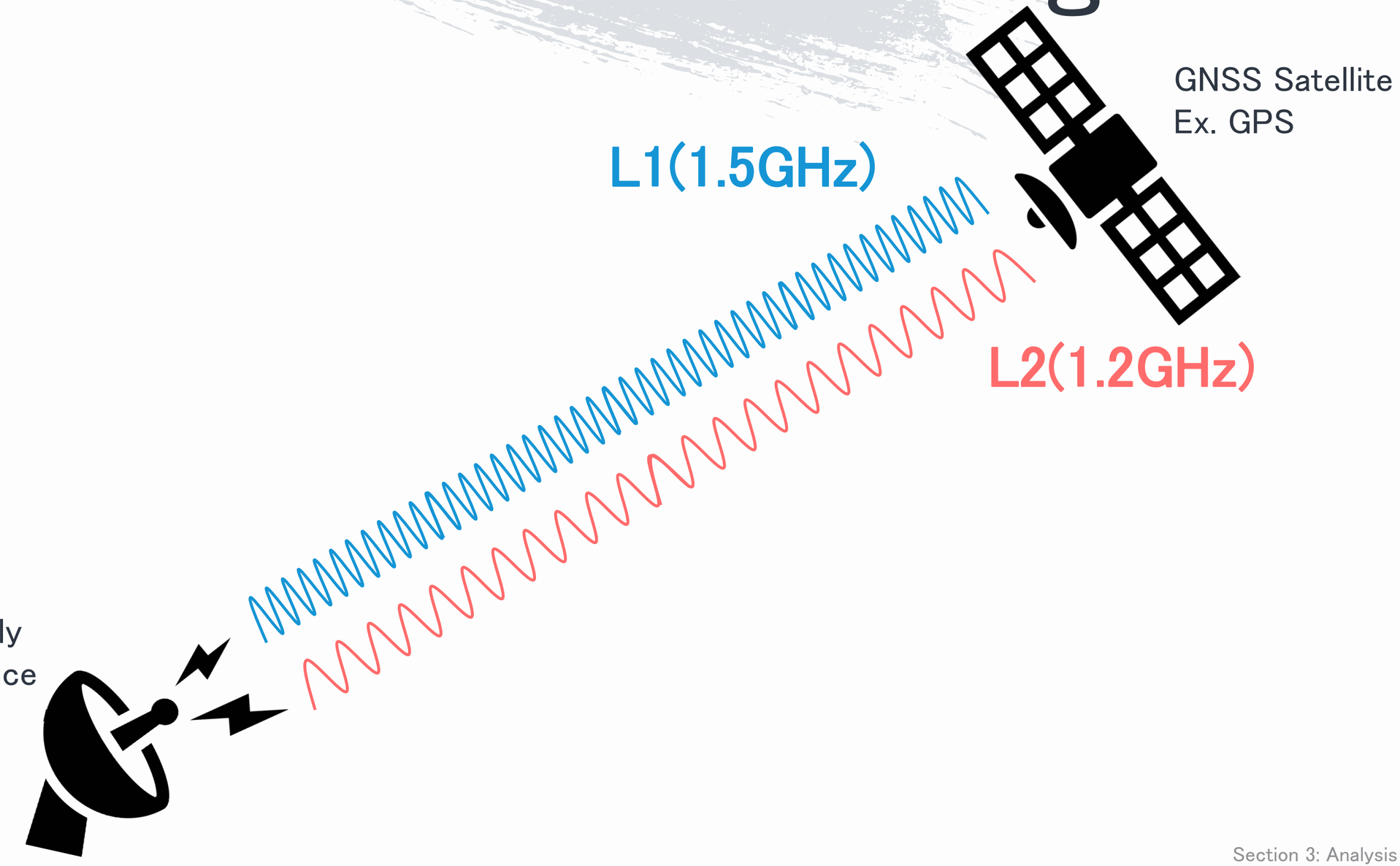
ANALYSIS

WARNING

Image: designed by starline / Freepik
Sound: made by OtoLogic

If you have an allergy to math,
you should skip this section

Mechanism of calculating TEC



Mechanism of calculating TEC

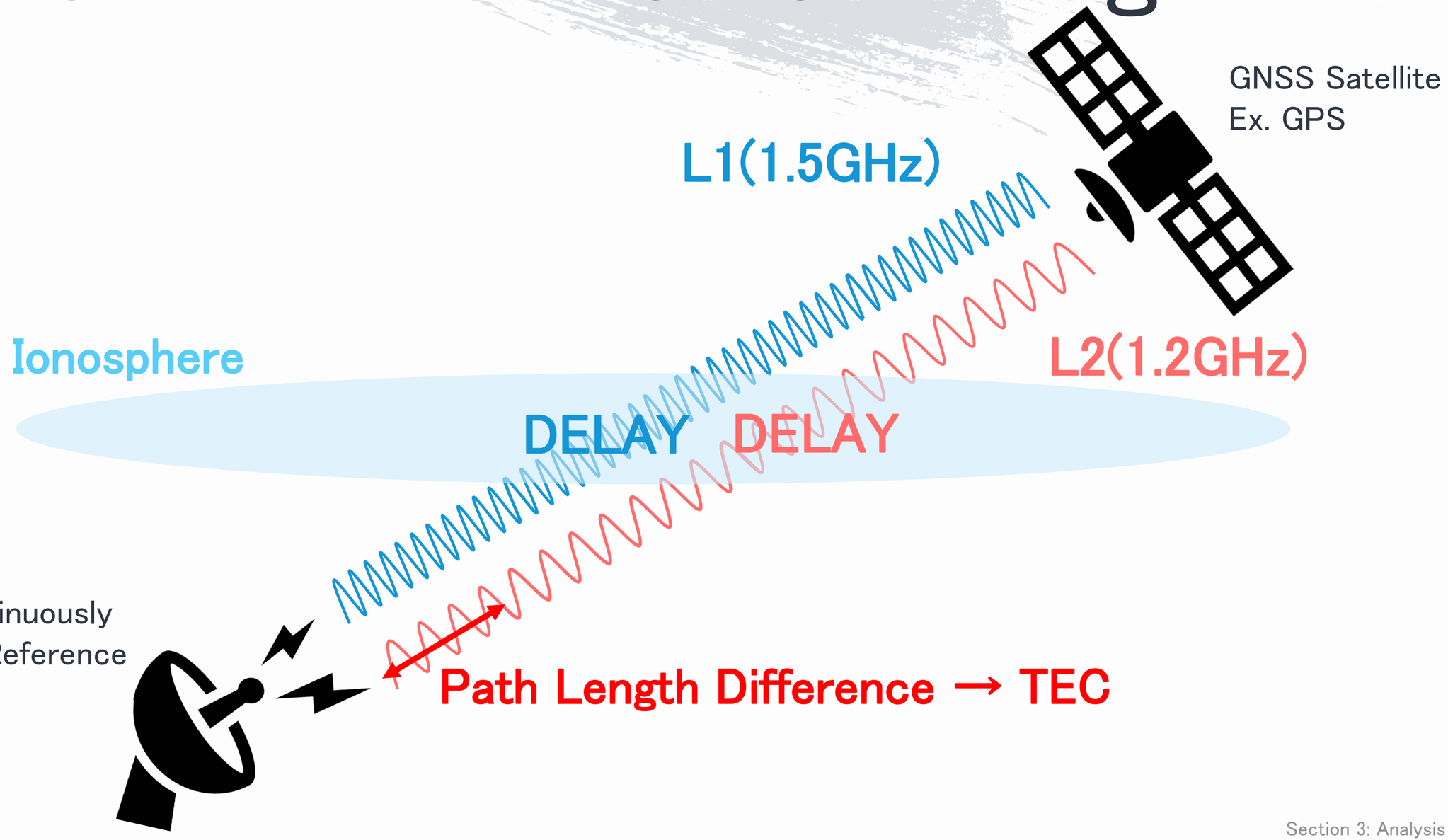
$$D_{iono} = \frac{40.3N_e}{f^2}$$

- D_{iono} : Ionospheric delay
- f : Frequency
- N_e : Number of the electrons in the ionosphere
  = TEC (total electron content)

1. The lower frequency
2. The more electrons in the ionosphere

→ The electric wave will be delayed longer

Mechanism of calculating TEC



Mechanism of calculating TEC

$$L = \lambda\phi = \rho - D_{iono} + D_{tropo} + \lambda n + \varepsilon + \tau$$

Reference 4

- L : Carrier phase measurement
- λ : Carrier wavelength
- ϕ : Carrier phase
- f : Frequency
- D_{iono} : Ionospheric delay
- [illegible]pospheric delay
- [illegible]ellite Bias
- [illegible]eiver Bias

$$D_{iono} = \frac{40.3N_e}{f^2}$$

$$L = \lambda\phi = \rho - \frac{40.3N_e}{f^2} + D_{tropo} + \lambda n + \varepsilon + \tau$$

- N_e : TEC (total electron content)

Mechanism of calculating TEC

$$L_1 = \rho - \frac{40.3N_e}{{f_1}^2} + D_{tropo} + \lambda_1 n_1 + \varepsilon_1 + \tau_1$$

$$-) \quad L_2 = \rho - \frac{40.3N_e}{{f_2}^2} + D_{t} \qquad - \tau_2$$

The equation with only TEC, L, constant numbers
You can find these values in the GNSS data

$$L_1 - L_2 = -40.3N_e\left(\frac{1}{{f_1}^2} - \frac{1}{{f_2}^2}\right) + Const.$$

Now I'm calculating N_e (=TEC)

Reference 5, 6

Mechanism of calculating TEC

$$N_e = -\frac{1}{40.3}\frac{L_1 - L_2}{\frac{1}{{f_1}^2} - \frac{1}{{f_2}^2}} + Const.$$

$$TEC = N_e = \frac{1}{40.3}\frac{{f_1}^2 {f_2}^2}{{f_1}^2 - {f_2}^2}(L_1 - L_2) + Const.$$

Mechanism of calculating TEC

$$\Delta TEC = \frac{1}{40.3}\frac{{f_1}^2 {f_2}^2}{{f_1}^2 - {f_2}^2}\Delta(L_1 - L_2)$$

Reference 5, 6

```
8   cm = plt.get_cmap("seis
9
10  for i in range(20):
11      # 地図データ読み込み
12      df = gpd.read_file
13
14      # 表示
15
16
17      with plt.style.con
18          df.plot(figsiz                    44', facecolor='white', linew
19
20          # リストを読み
21          # csvファイル
22          f = open("{:.2f}Si                .05 + 14.00), "r")
23          # リスト形式
24          reader = csv.reader(f)
```

PythOn 3.10.2

- Easy to make graphs
- Has a lot of modules of various functions

```
 3   33.095781854355323                  137.13332653906626
 6   33.63846255                         138.16456165635378
13   40.89012135                         132.37854966788186
16   35.97729925                         138.20788093658641
19   28.54937413                         134.14814544234187
21   35.07688962                         4.54217496234480
23   35.91275995                         5.04227733622409
30   36.02350954                         9.63627699703287
31   33.70191124                         1.10973912378580
 3   32.89607156                         7.06577863023017
 6   33.43618549                         8.08959669398197
13   40.71189338                         2.27837492156982
16   35.77258735                         8.12653372849803
19   28.40248431                         4.12740228866124
21   34.8779793355                       44.455762162230
```

- Runs much faster than Python
- Can be written in its very simple syntax

Fortran 95

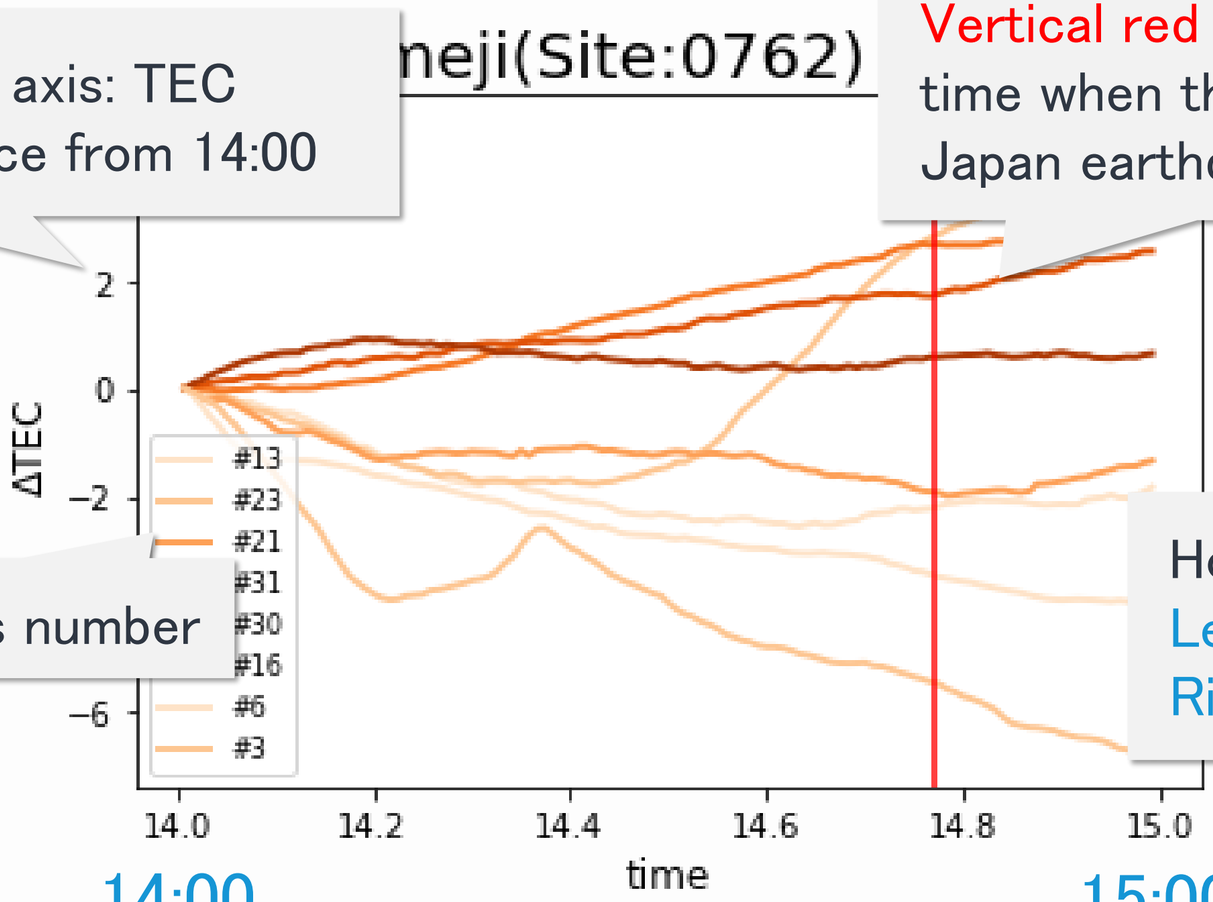
SECTION 4

RESULTS

Comparison between 3.10 & 3.11

Vertical axis: TEC difference from 14:00

Vertical red line shows the time when the Great East Japan earthquake occurred



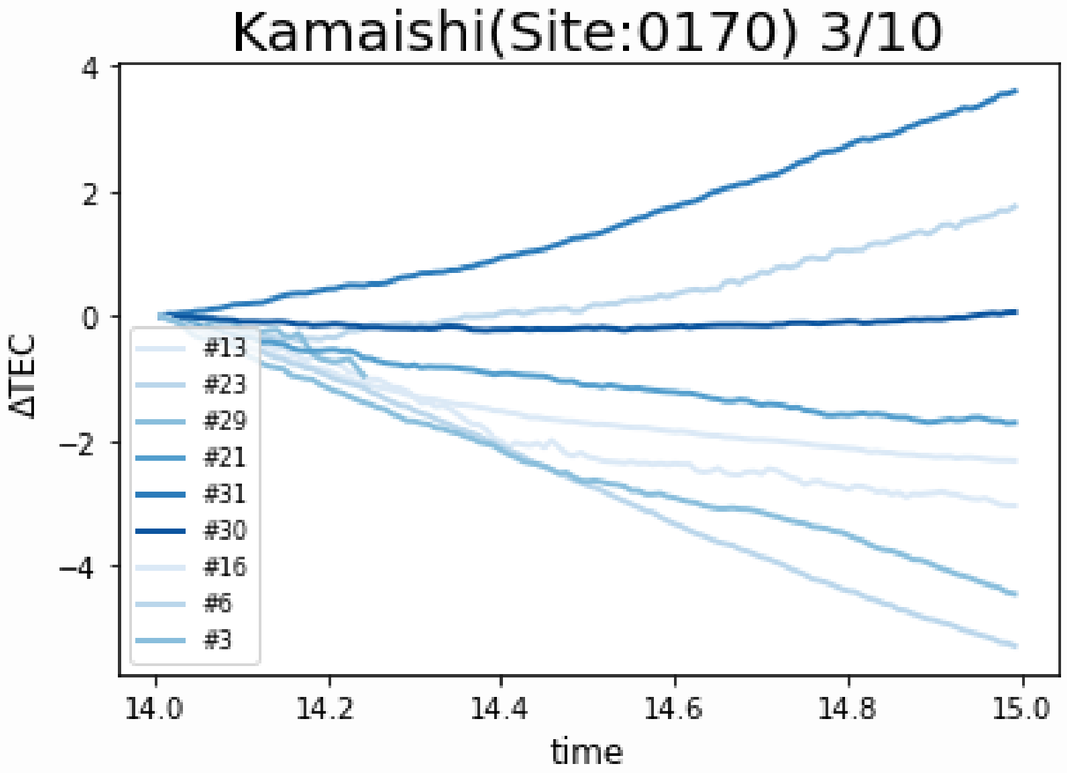
Satellite's number

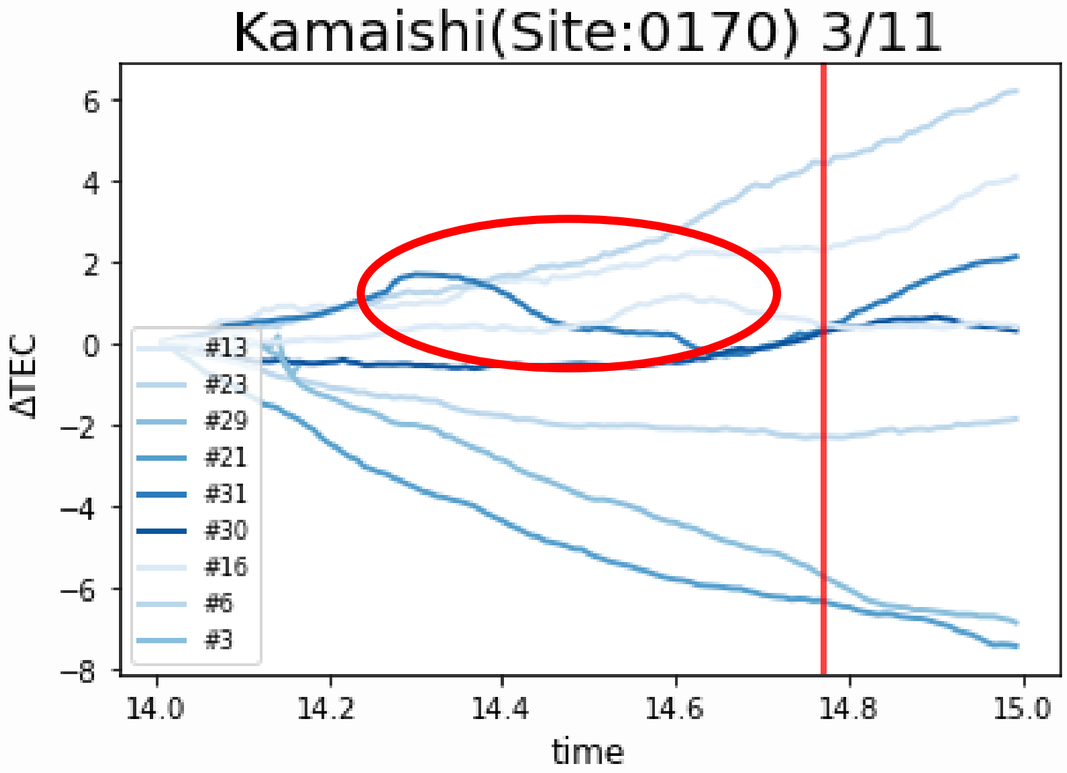
Horizontal axis: time
Left end 14:00
Right end 15:00

14:00

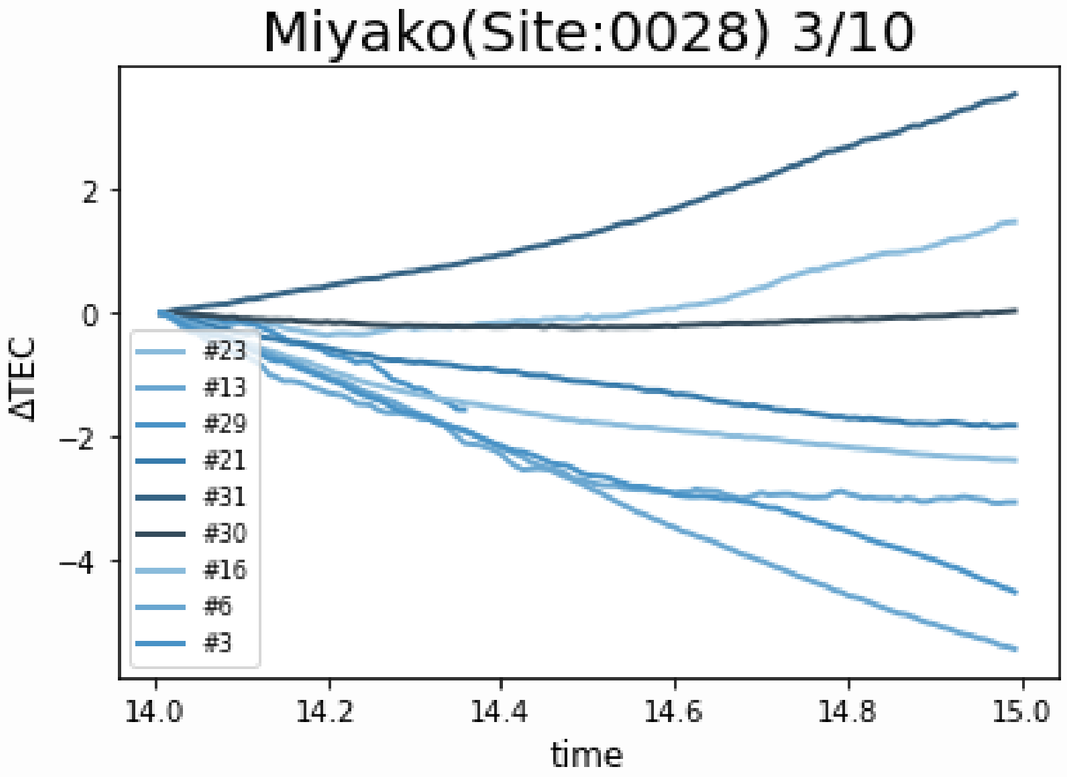
15:00

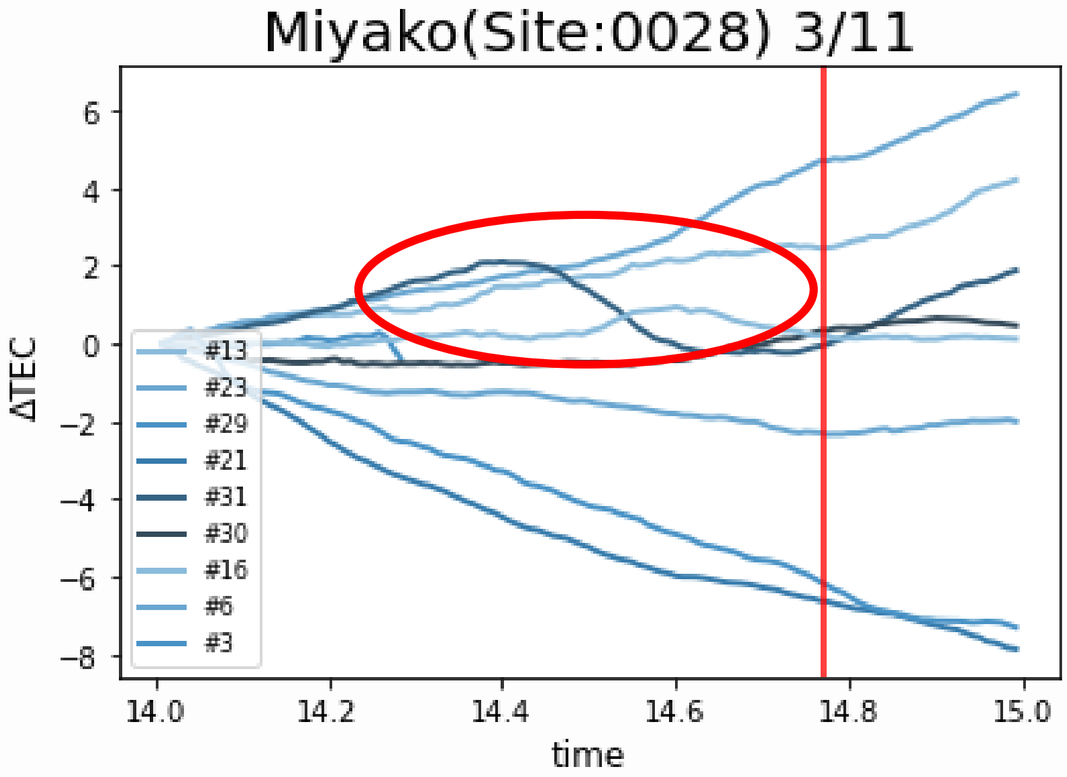
Kamaishi, Iwate pref.



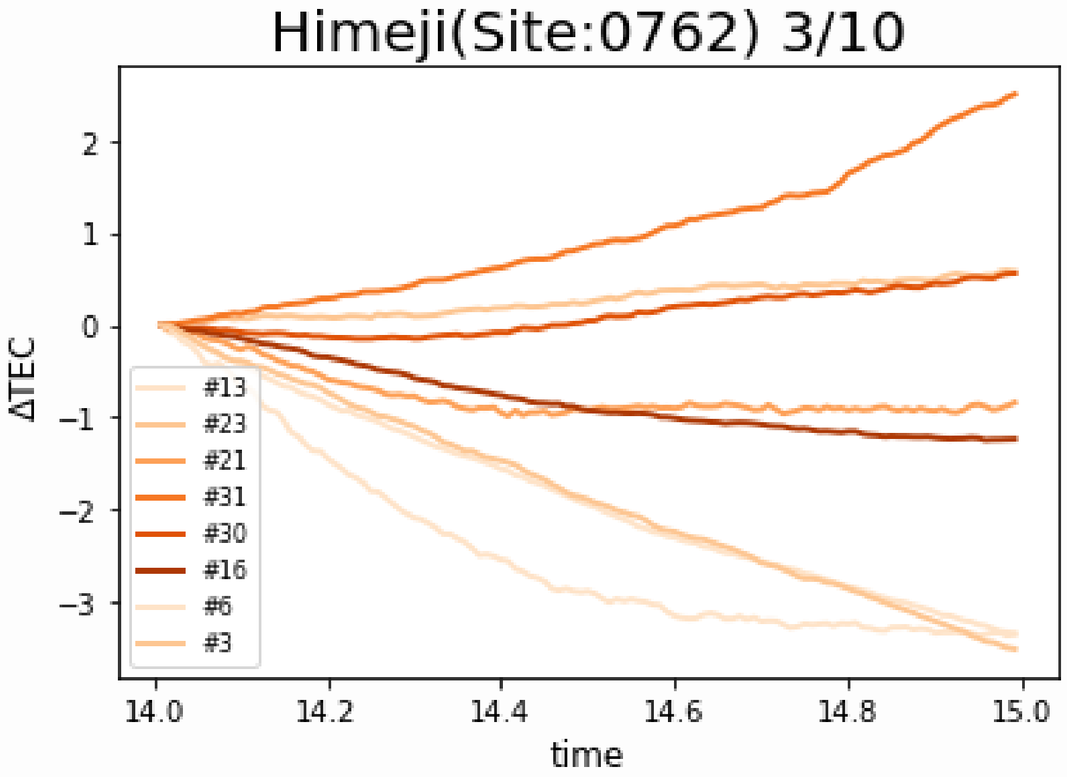


Miyako, Iwate pref.

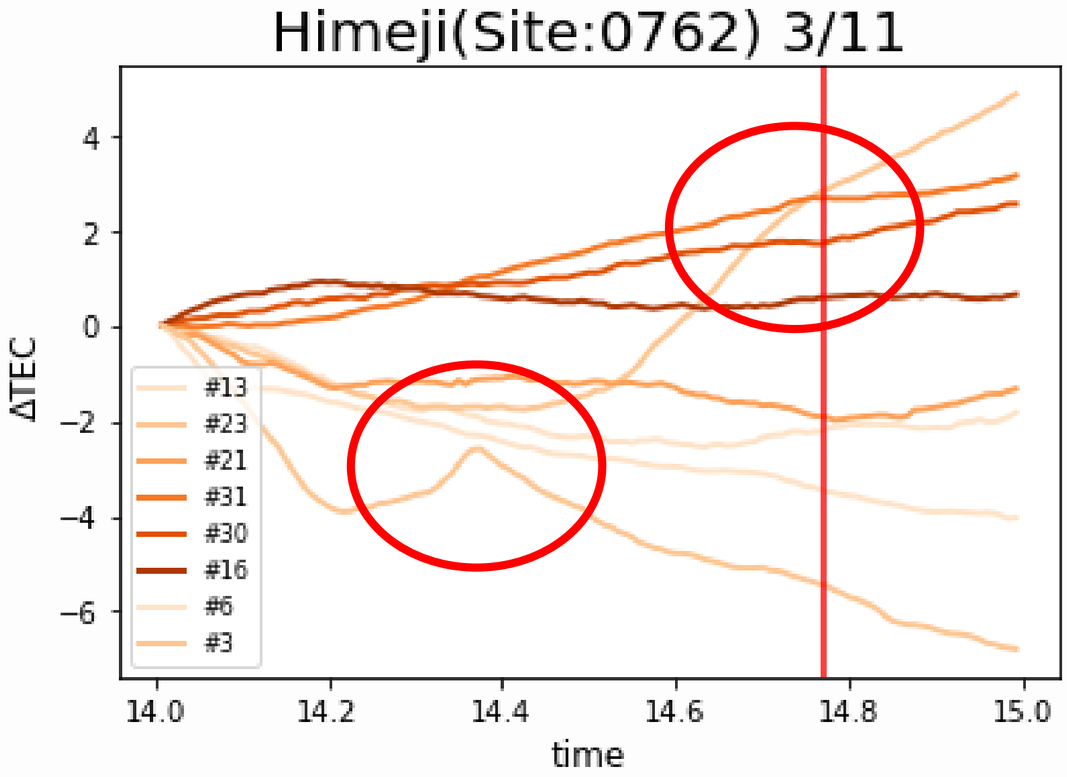


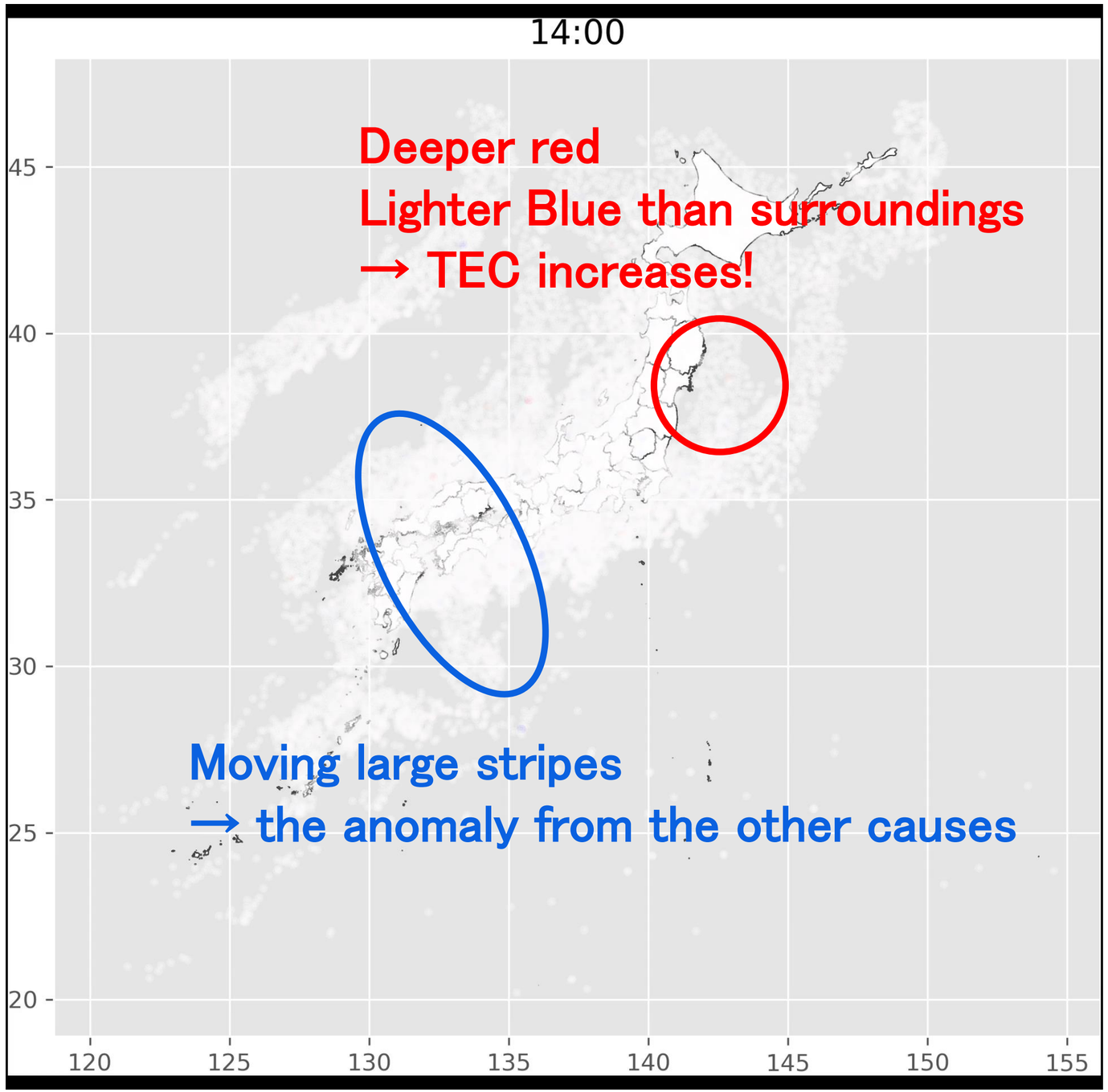


Himeji, Hyogo pref.



Is this the sign?





TEC difference From 14:00 on 3.11

Decreased TEC in 14:00 **Increased**

The earthquake happened at 14:46

Results

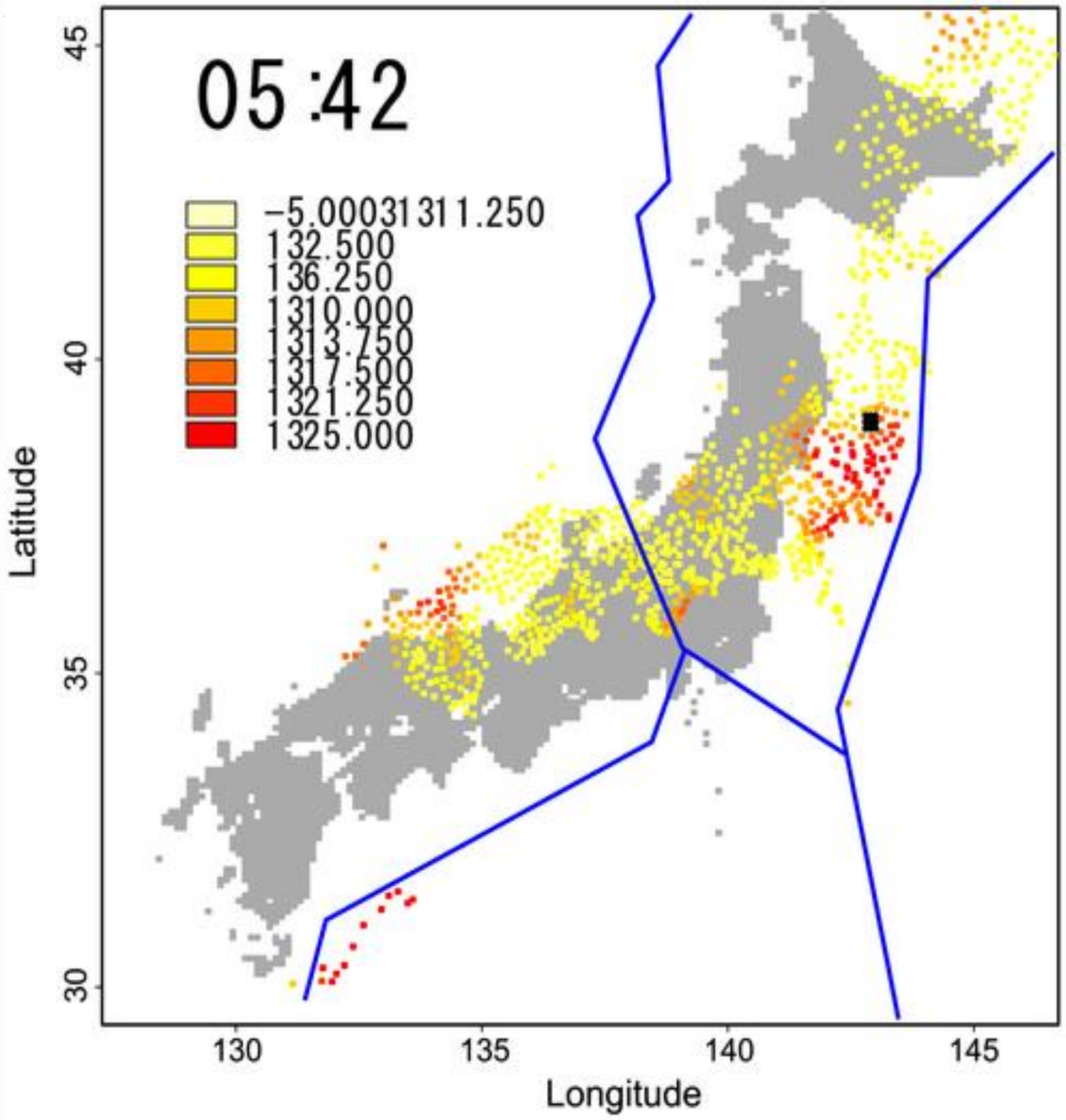
- Successfully managed to observe increase in TEC before the Great East Japan earthquake occurred
- I'm unable to distinguish only the sign of the earthquake from the other accurately so far

SECTION 5

PROSPECTS

Develop the new way to predict earthquakes

- Introduce Deep Learning to GNSS-TEC method
- Deep learning can learn what kind of anomalies is the sign of the earthquake in itself, so we can distinguish the sign from anomalies from the other causes more accurately.
- This idea leads to automatic prediction



Correlation analysis

More developed GNSS-TEC method

can remove noises and emphasize the sign of the earthquake, **using large TEC data of observation stations around the considered station** to calculate.

There were no signs in Himeji

The anomaly I wondered if it was the sign of the earthquake in Himeji on 3.11 was likely to be a noise or a fluctuation from another causes.

"Correlation analysis for preseismic total electron content anomalies around the 2011 Tohoku-Oki earthquake" by Ken Umeno and Takuya Iwata, Reference 7

References

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Tomoji Takasu

Published on 2005/6/13

5. Geophysics with GPS-TEC

https://eprints.lib.hokudai.ac.jp/dspace/bitstream/2115/45003/1/Heki_etal_JGSJ2010.pdf

Kosuke Heki, Mamoru Sugawara, Masaru Ozeki & Ikuya Okazaki

Published on 2011/2/25

6. The Analysis of ionospheric anomalies the Megathrust earthquake and its mechanism to occur

Ken Umeno

Presented in IEEE Nagoya LMAG Symposium on 2019/8/31

References

7. Correlation analysis for preseismic total electron content anomalies around the 2011 Tohoku-Oki earthquake
https://agupubs.onlinelibrary.wiley.com/doi/full/10.1002/2016JA023036
Ken Umeno, Takuya Iwata
Published on 2016/8/22

Preseismic ionospheric anomalies detected before the 2016 Kumamoto earthquake
https://agupubs.onlinelibrary.wiley.com/doi/full/10.1002/2017JA023921
Ken Umeno, Takuya Iwata
Published on 2017/2/24

Programs I used to convert gnss data (based on rinex format) to TEC Data
http://www.ep.sci.hokudai.ac.jp/~heki/software.htm
Kosuke Heki
Downloaded on 2021/10/30


THE FUTURE STARTS TODAY, NOT TOMORROW.

THANK YOU!

ANY QUESTIONS?

Presented by Sota Kashiwagi (Leader’s Number: 2711)

Used the template “pollux” designed by Jun Akizaki