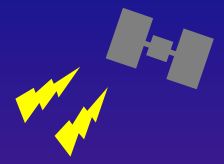
IUGONET workshop
(18 Aug. 2015)



GNSS-TECで見る、最近の火山噴火に伴う電離圏擾乱

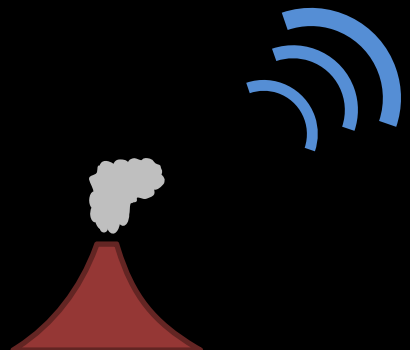
北海道大学 宇宙測地学研究室
中島 悠貴、日置幸介

Disturbances made by Volcanos

Acoustic/gravity wave

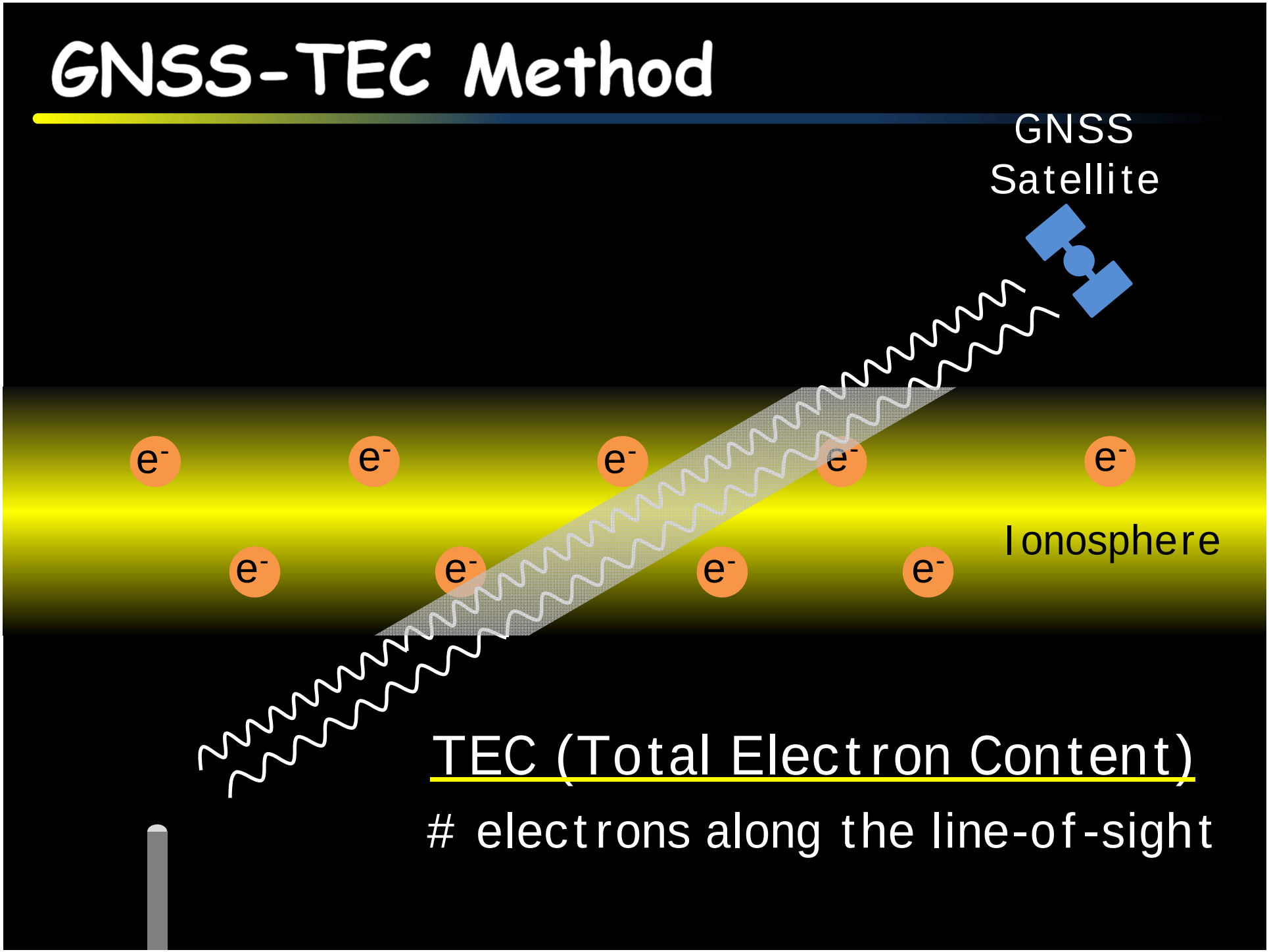
Ionosphere

How does an eruption disturb the ionosphere?



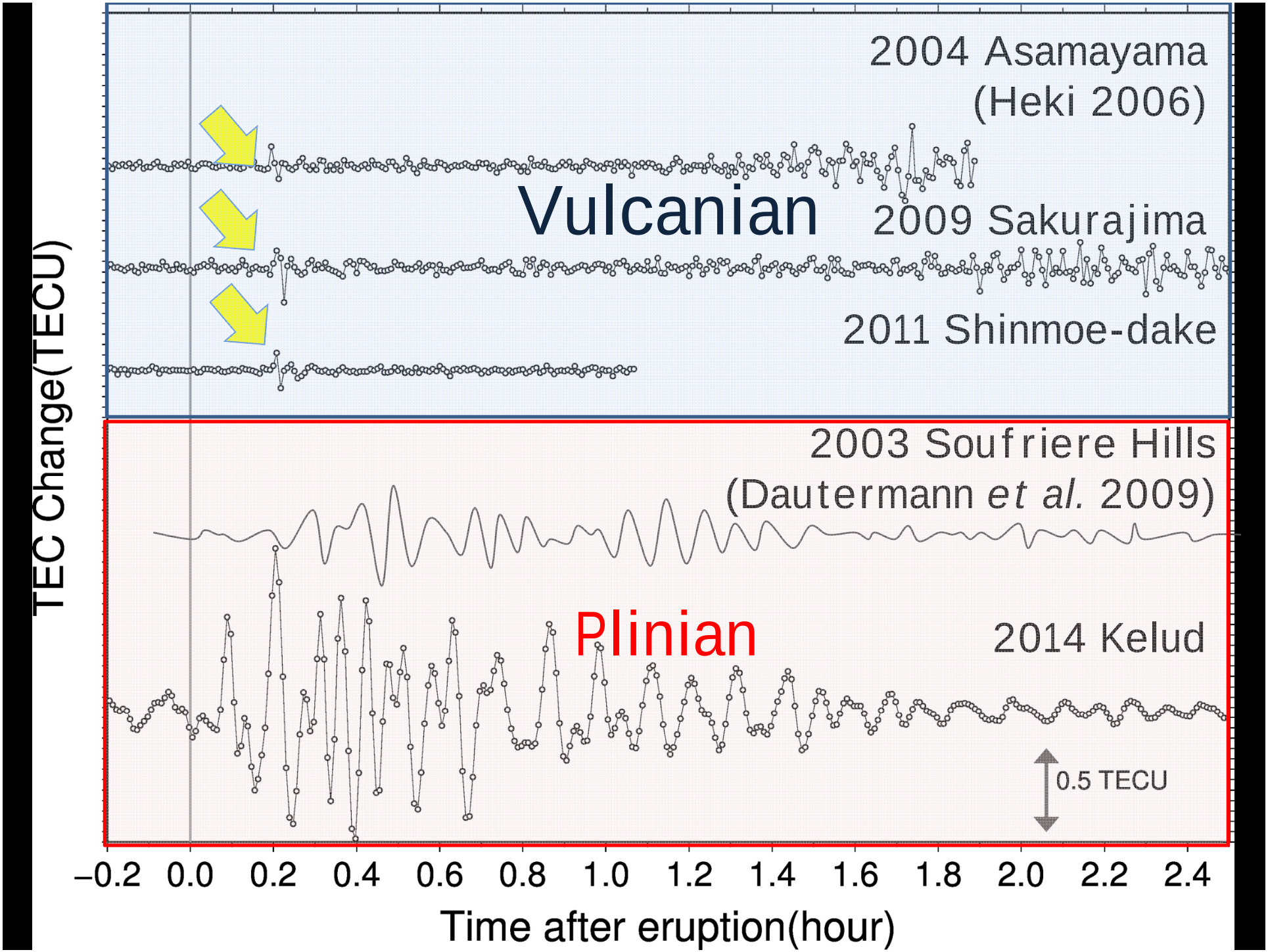
Troposphere
(Neutral atmosphere)

GNSS-TEC Method

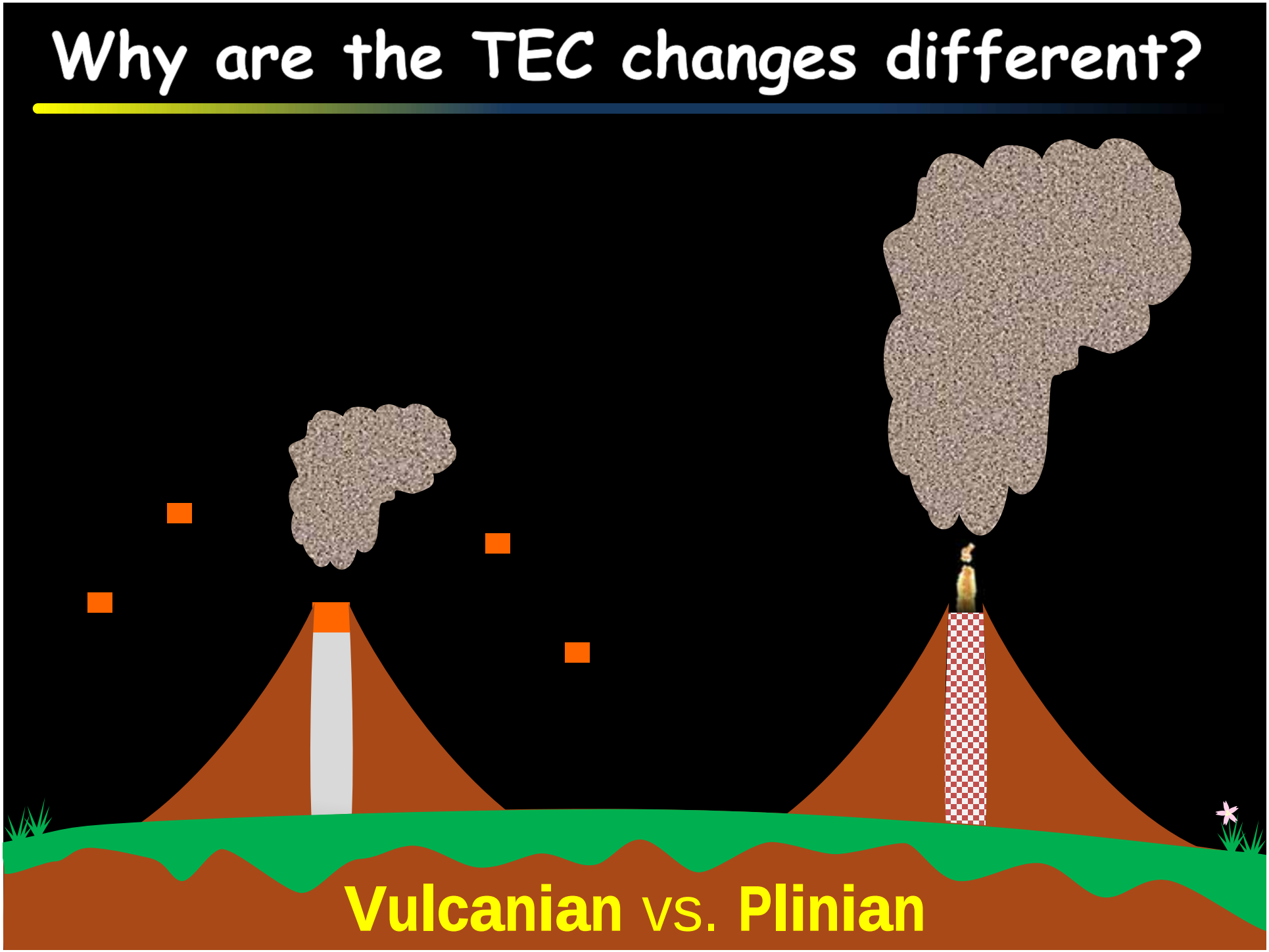


TEC (Total Electron Content)

electrons along the line-of-sight


2004 Asamayama
(Heki 2006)
Vulcanian
2009 Sakurajima
2011 Shinmoe-dake
2003 Soufriere Hills
(Dautermann et al. 2009)
Plinian
2014 Kelud
0.5 TECU
TEC Change(TECU)
–0.2
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
2.2
2.4
Time after eruption(hour)

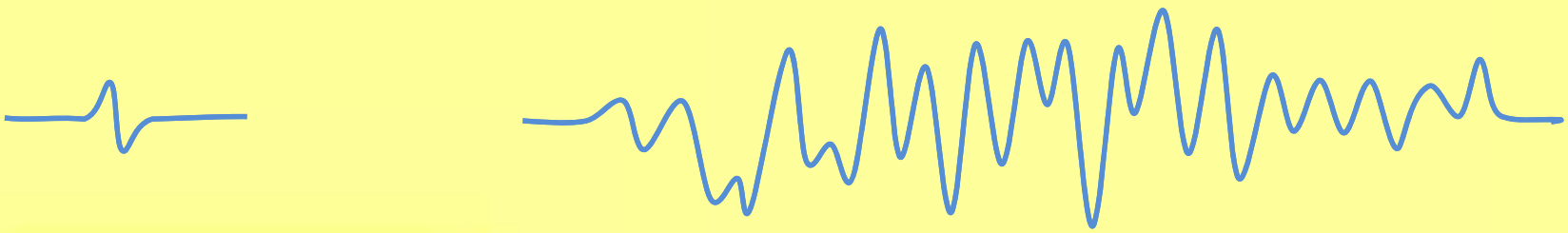
Why are the TEC changes different?



TEC signatures: Vulcanian vs. Plinian

Type 1

Type 2

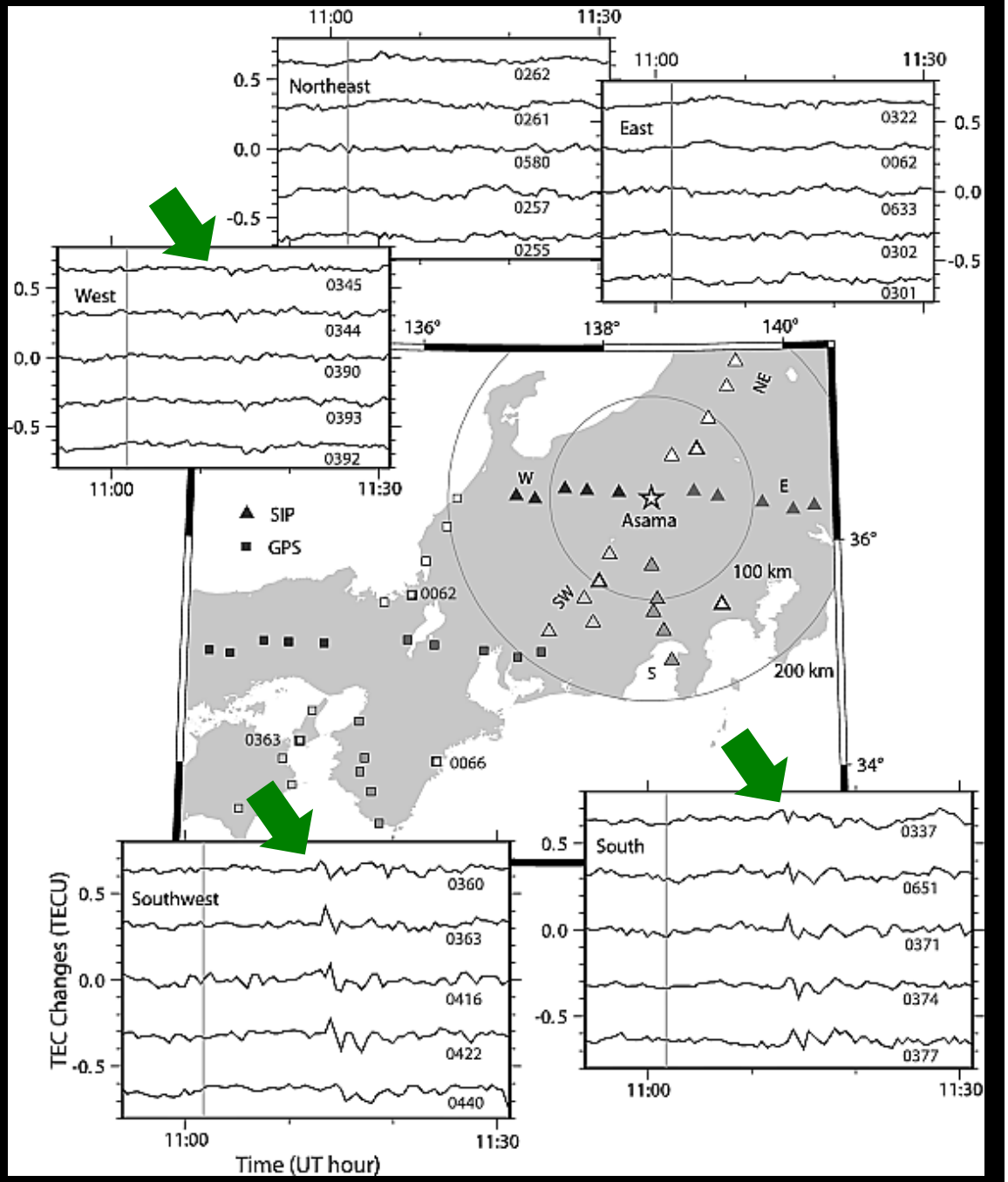


Plinian eruptions excite atmospheric resonance

Summary: Plinian vs. Vulcanian

	Plinian	Vulcanian
TEC Waveform	Harmonic oscillation (~250sec)	N-shaped pulse (~120sec)
Propagation Velocity	Acoustic	Acoustic
Origin	Resonance excited by turbulence	Pressure pulse by explosion

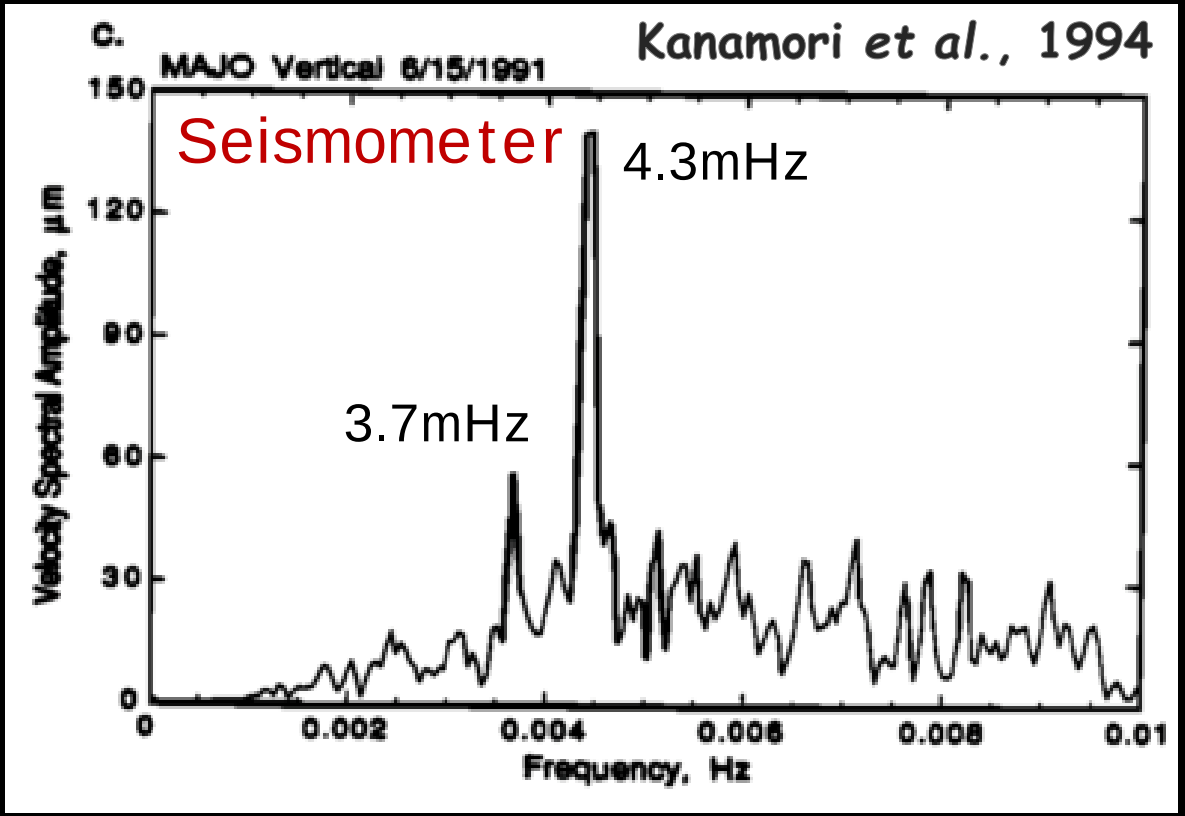
The 2004 Asama volcano Eruption



SIP
(Sub Ionospheric Points)

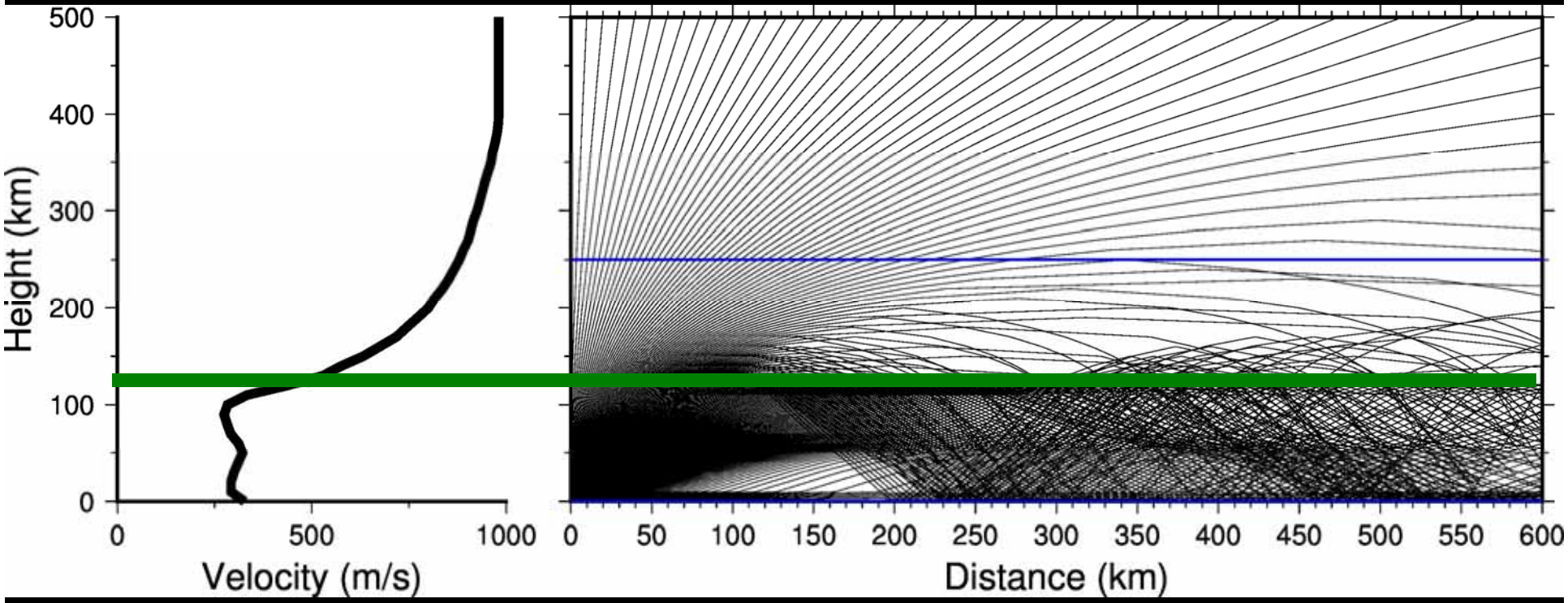
Station

The 1991 Pinatubo eruption



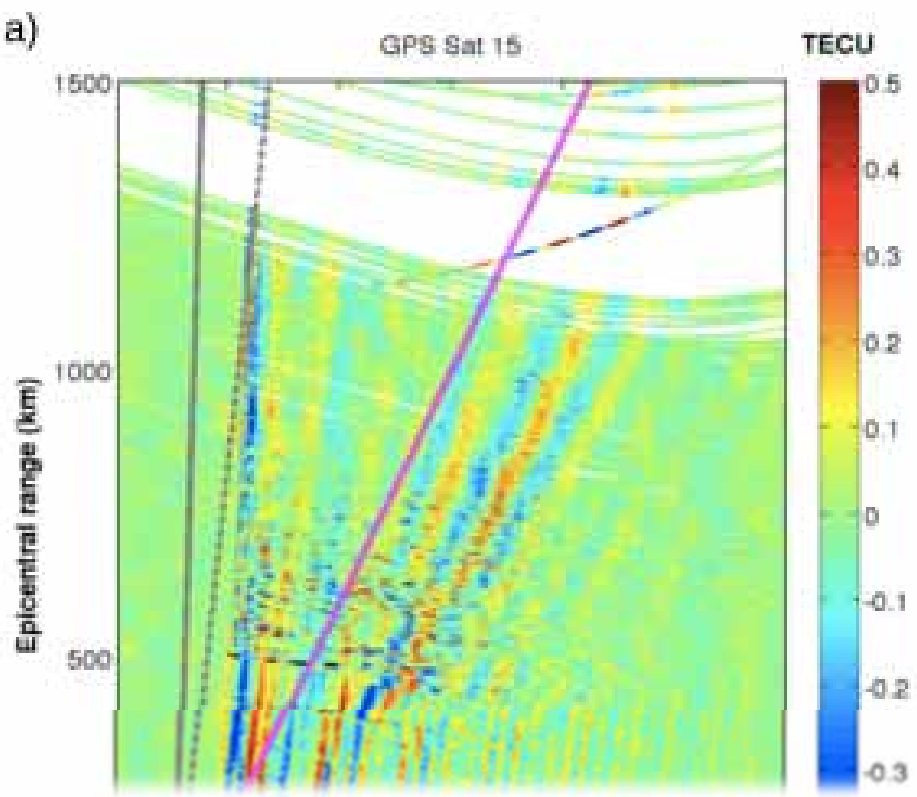
Two frequency peaks: 270 sec (3.7 mHz)
230 sec (4.3 mHz)

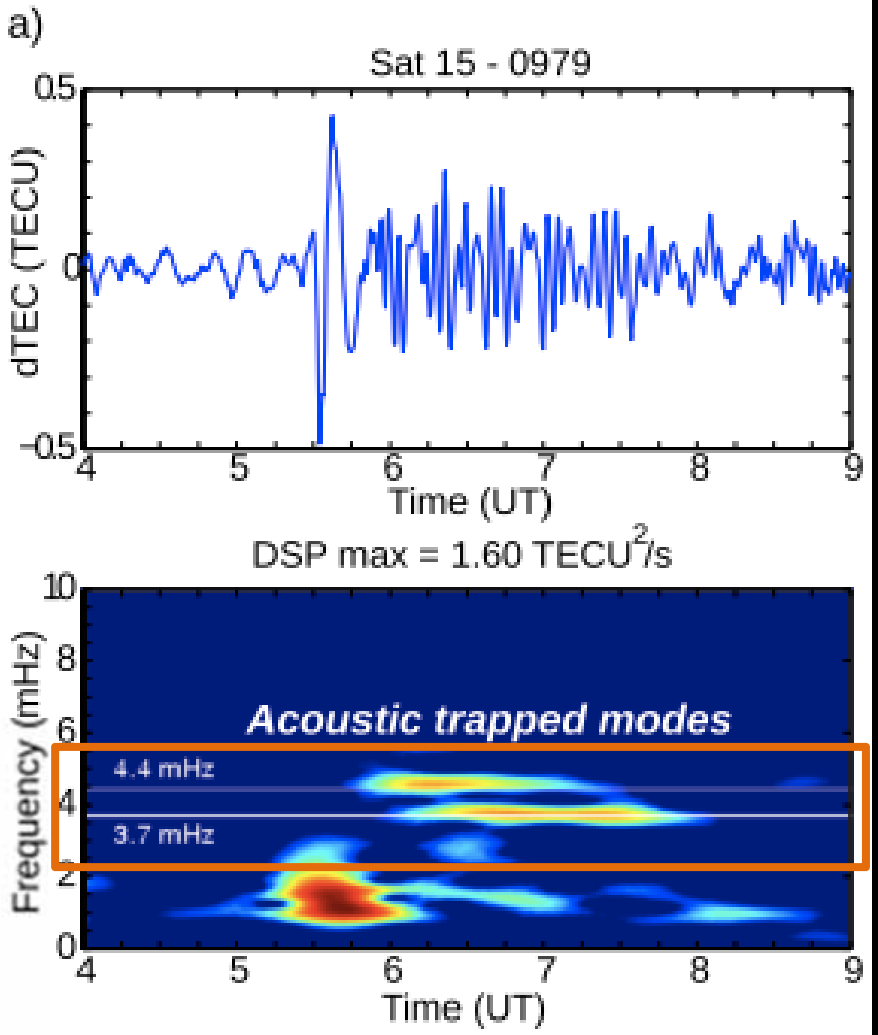
The 1991 Pinatubo eruption excited bichromatic oscillation.



Excited Acoustic Trap Mode Between Surface and Thermopause!

2011 Tohoku-Oki Earthquake

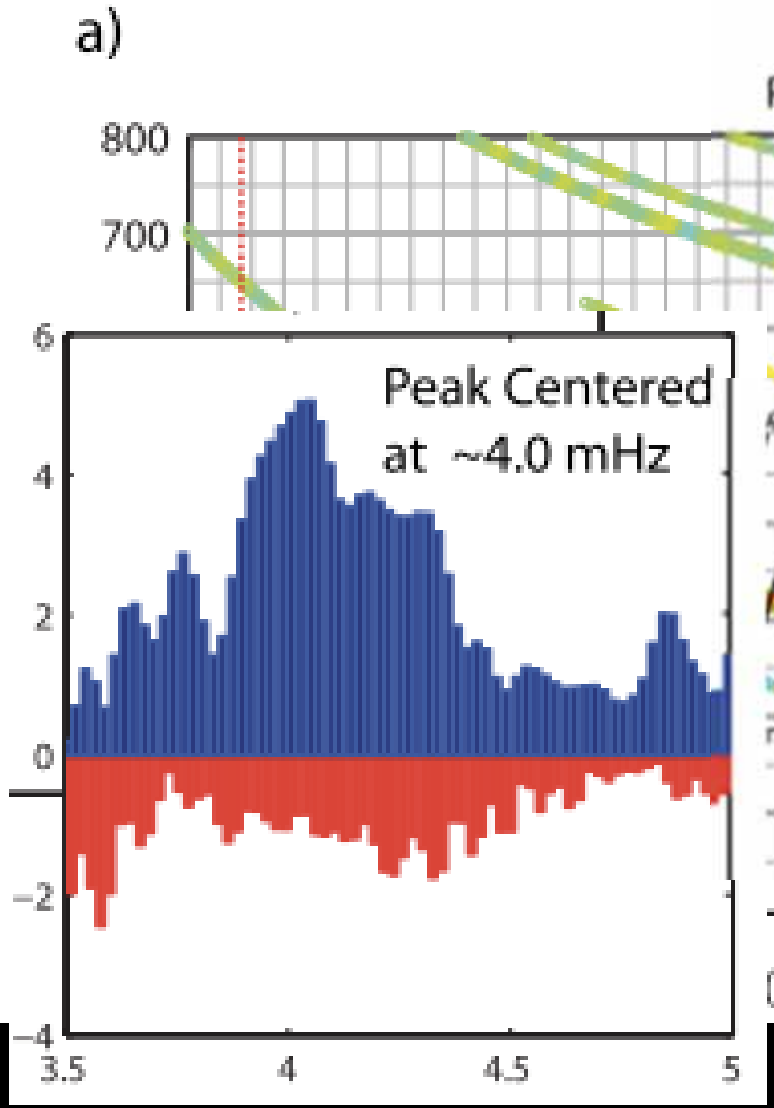




Bichromatic wave can propagate to the ionosphere!

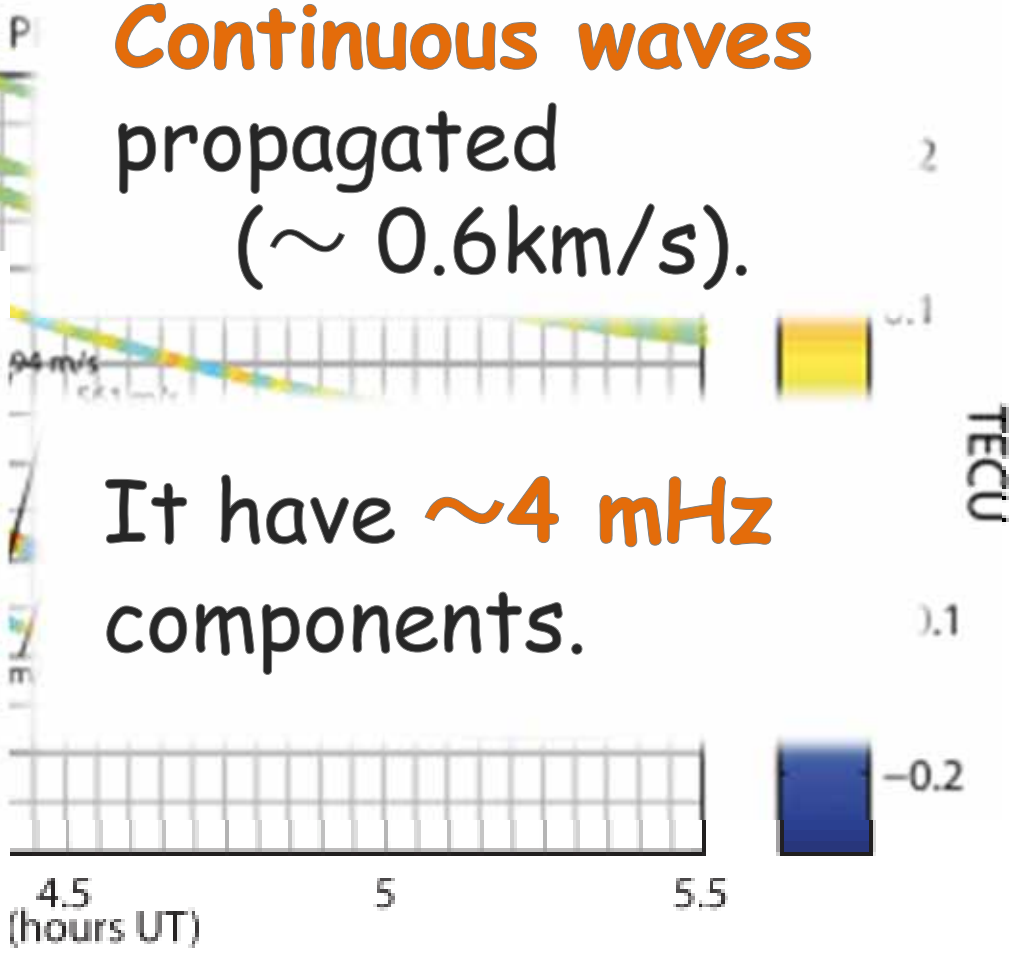
Rolland *et al.* (2011, EPS)

The 2003 Soufriere Hills volcano



Continuous waves propagated (~ 0.6km/s).

It have **~4 mHz** components.



Dautermann *et al.* (2009, JGR)

Contents

The 2014 Kelud Volcano eruption

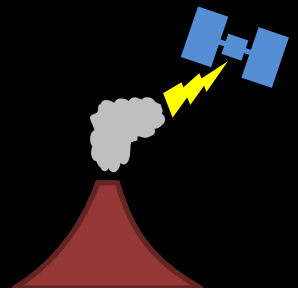
The 2015 Calbuco Volcano eruption

The 2015 Kuchinoerabujima eruption

Near Field Ionospheric Disturbance by the Eruption of the Kelud Volcano, Indonesia, in February 2014 Observed by GNSS-TEC

Y. Nakashima[1#], K. Heki[1], A. Takeo[1],
M. N. Cahyadi[2], A. Aditiya[3]

1: Hokkaido University, Sapporo, Japan
2: Sepuluh Nopember Institute of Technology, Surabaya, Indonesia
3: Geospatial Information Agency, Bogor, Indonesia



The Kelud volcano, Java Island, Indonesia

- Kelud Volcano eruption in 2014
  Java, Indonesia

VEI (Volcanic Explosivity Index) : 4

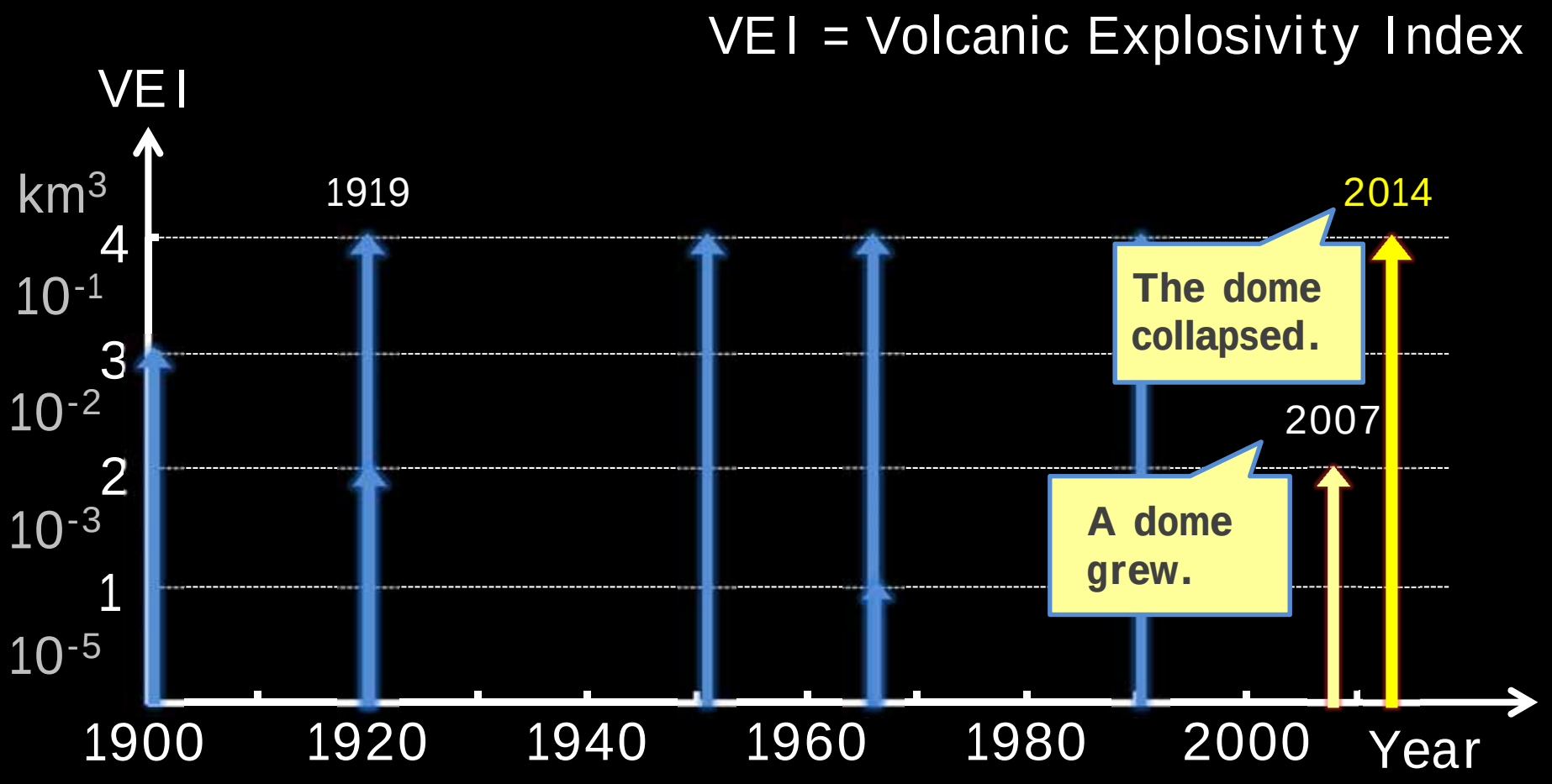
http://guardianlv.com/2014/02/indonesia-volcano-culture/

Trip to the Kelud (1 Aug.)

Prof. Heki Dr. Cahyadi

Trip to the Kelud (1 Aug.)

Eruption History of Kelud



The Smithsonian Institution's Global Volcanism Program

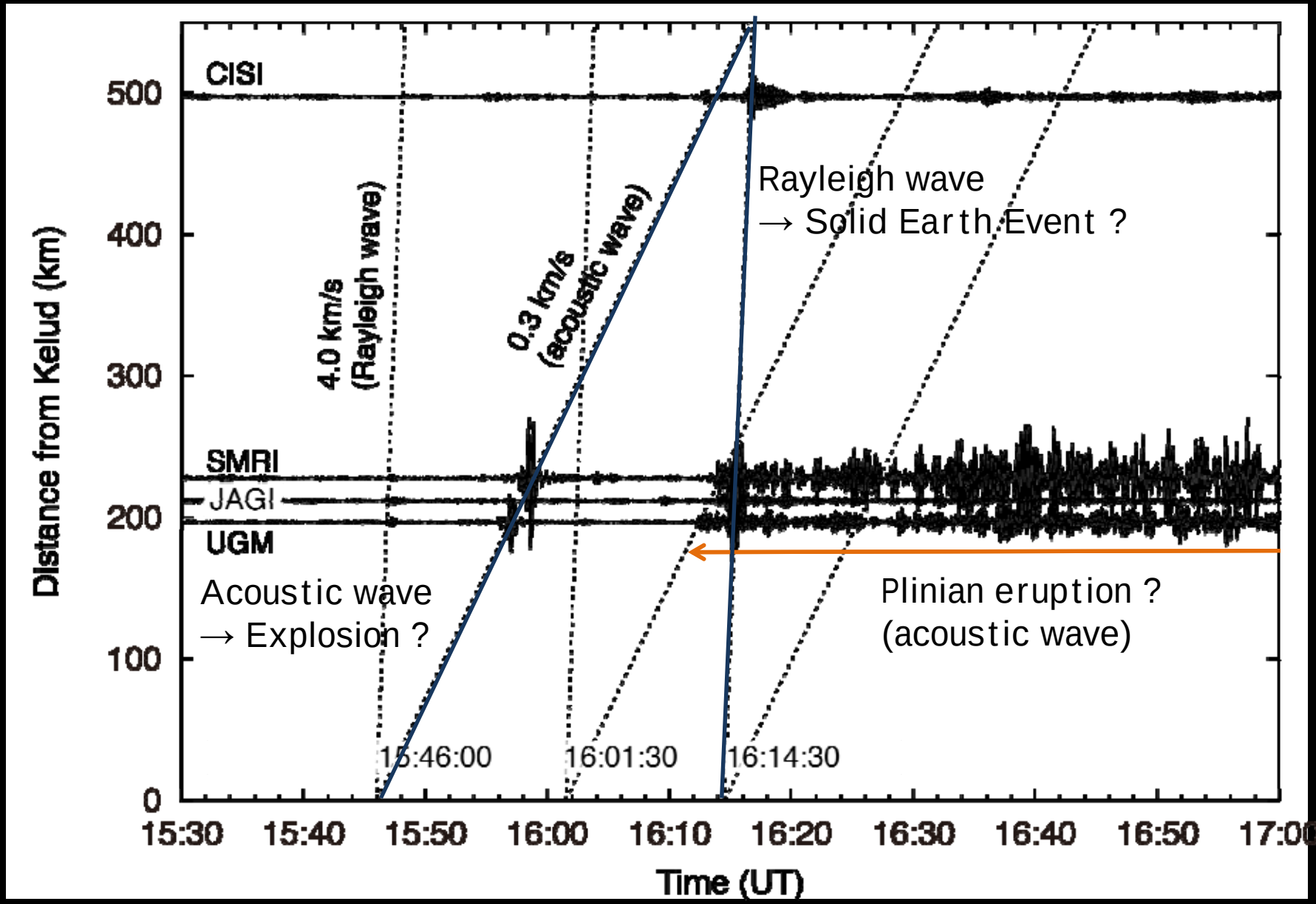
Kelud Volcano Feb 13, 2014 Explosion

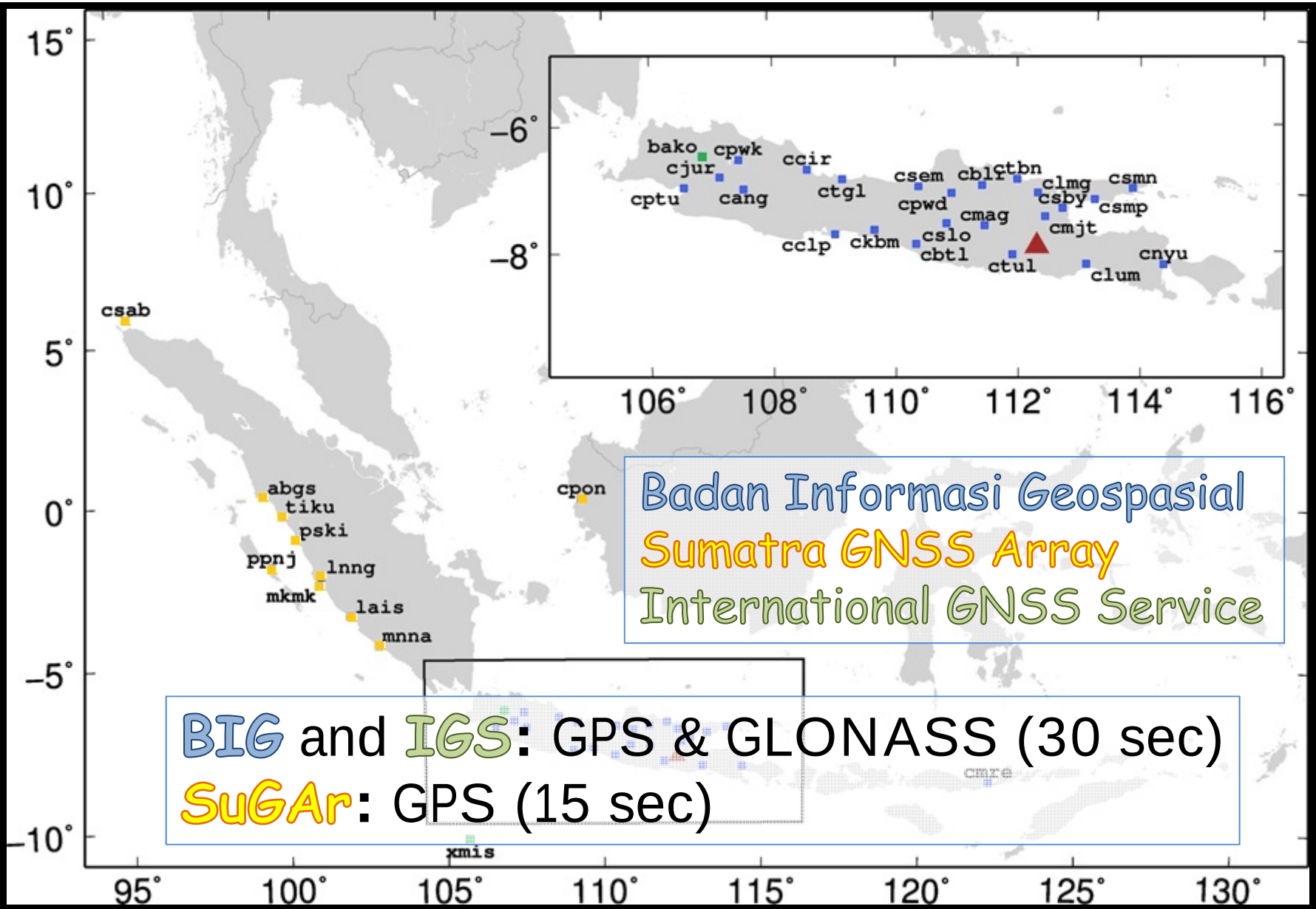
Before **After**

30/10/2011 **Kelud-Volcano** **18/02/2014 (?)**

http://www.wired.com/2014/02/kelud-eruption/

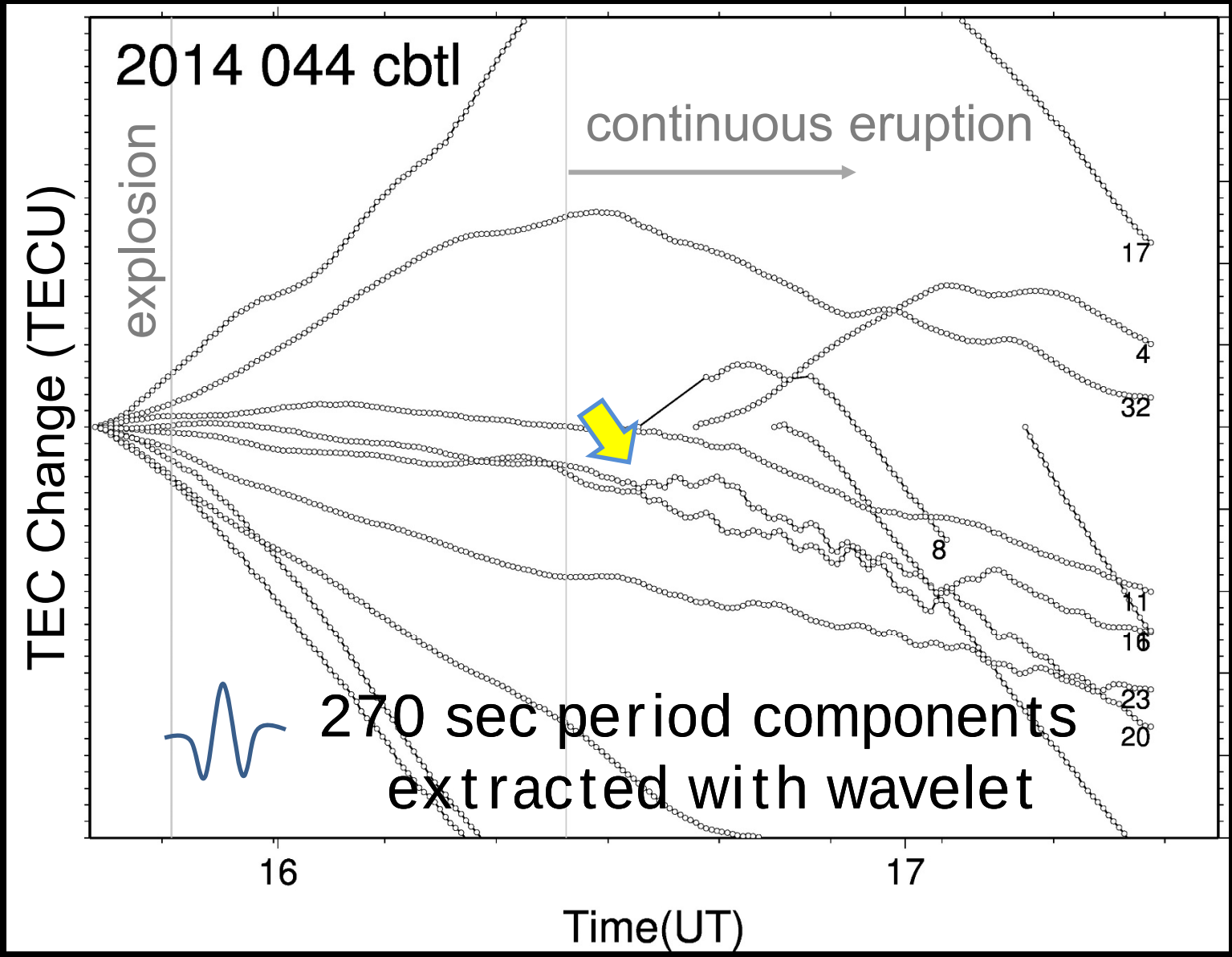
Analysis of Seismograms

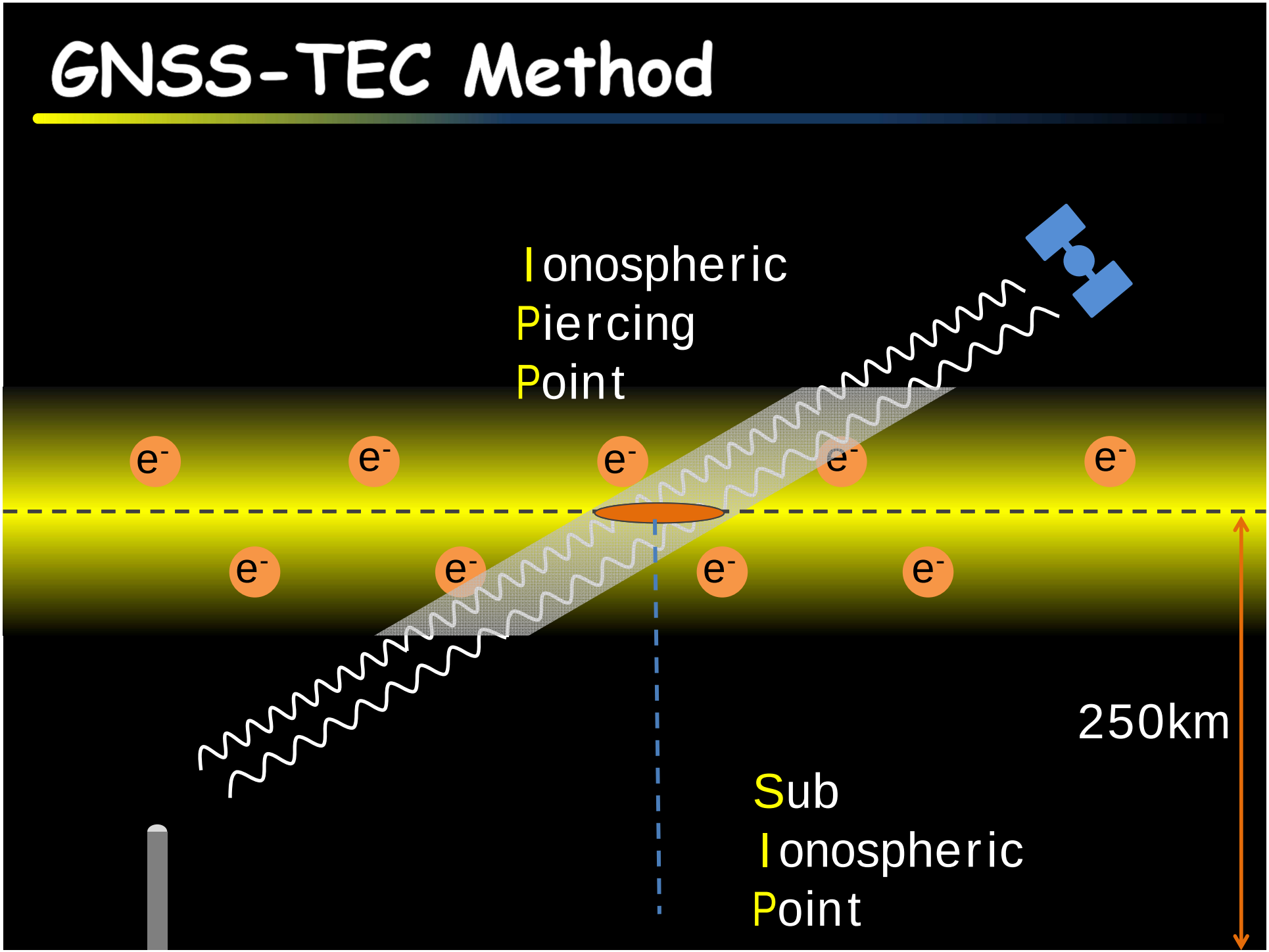




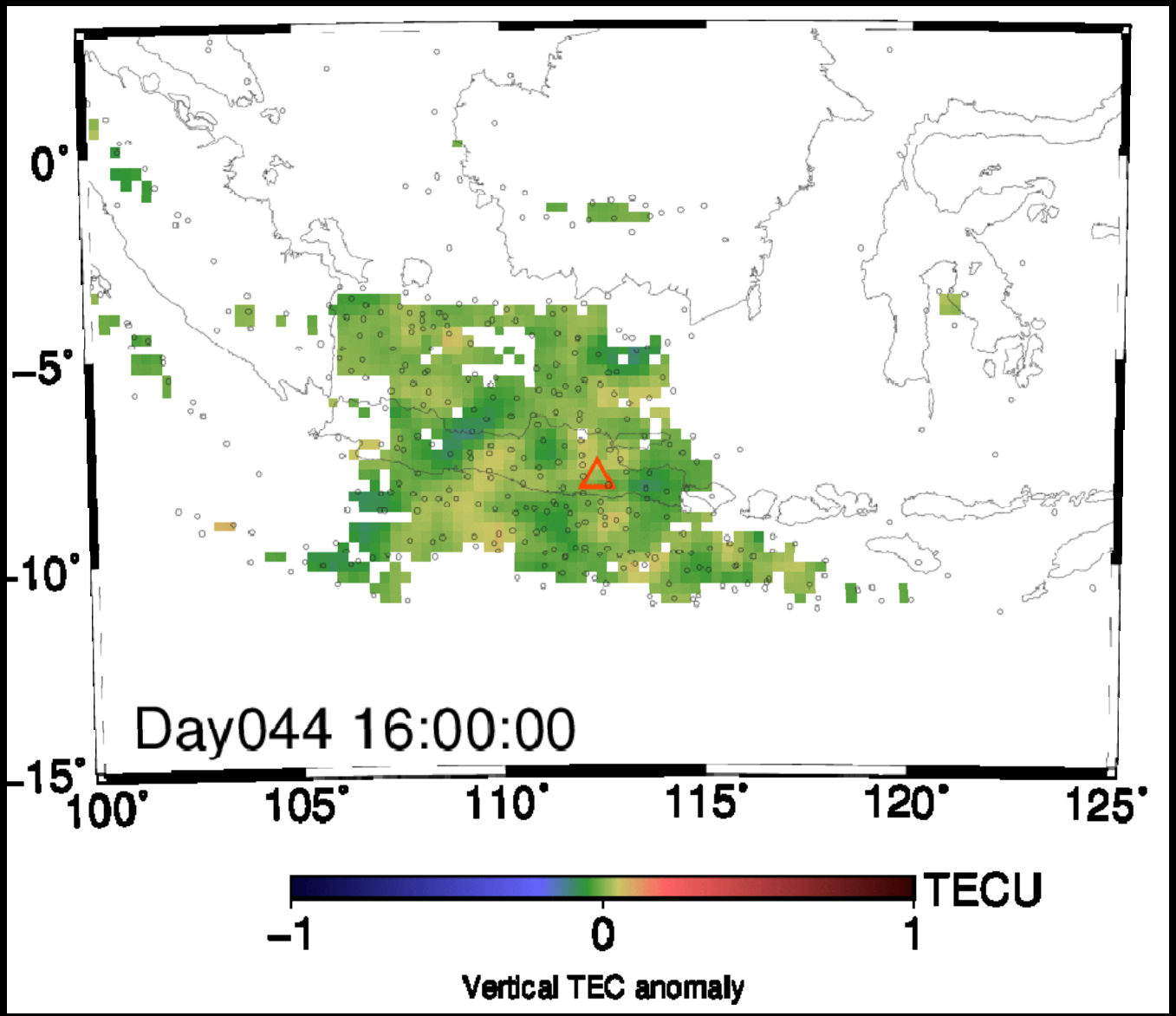
GNSS Stations

TEC oscillation by the Kelud eruption

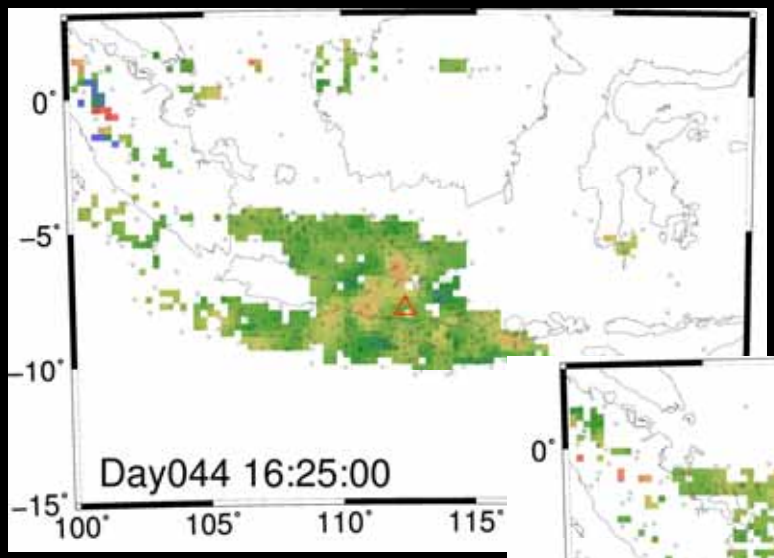


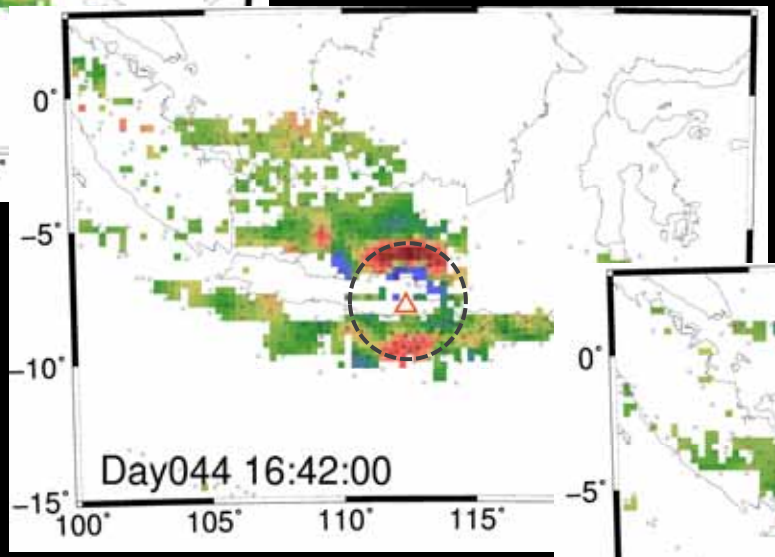

GNSS-TEC Method
Ionospheric
Piercing
Point
e-
e-
e-
e-
e-
e-
e-
e-
250km
Sub
Ionospheric
Point

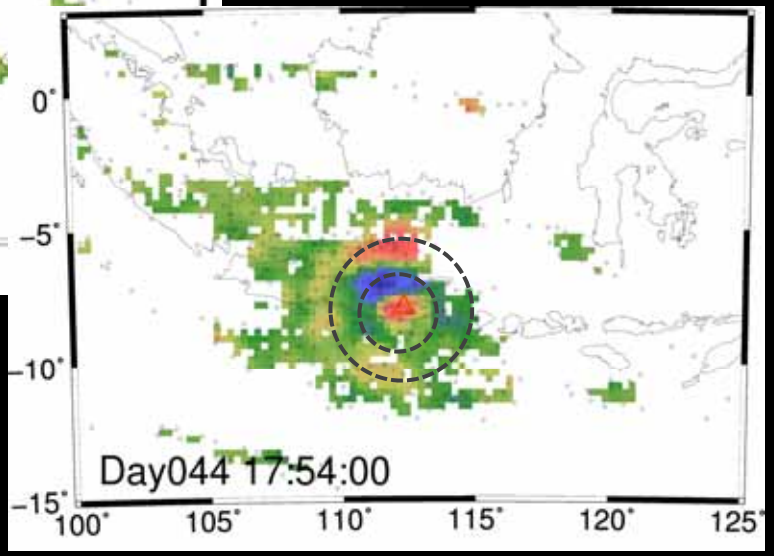
Spatial Distribution of the anomaly

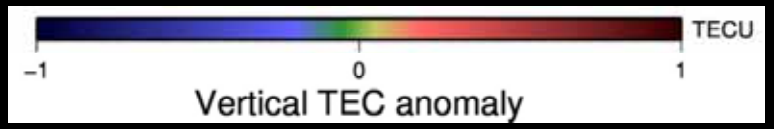


Propagation of TEC anomaly

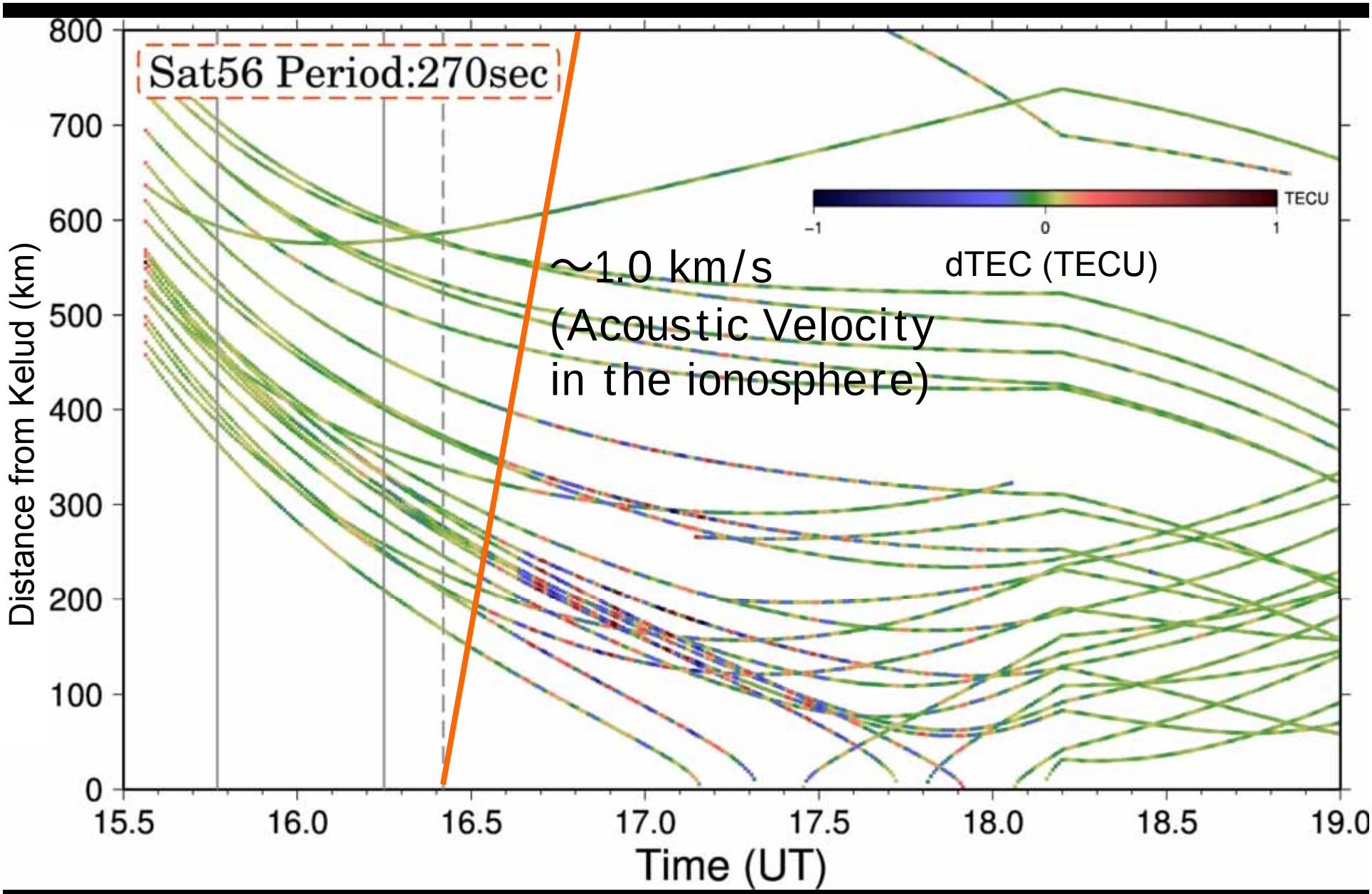






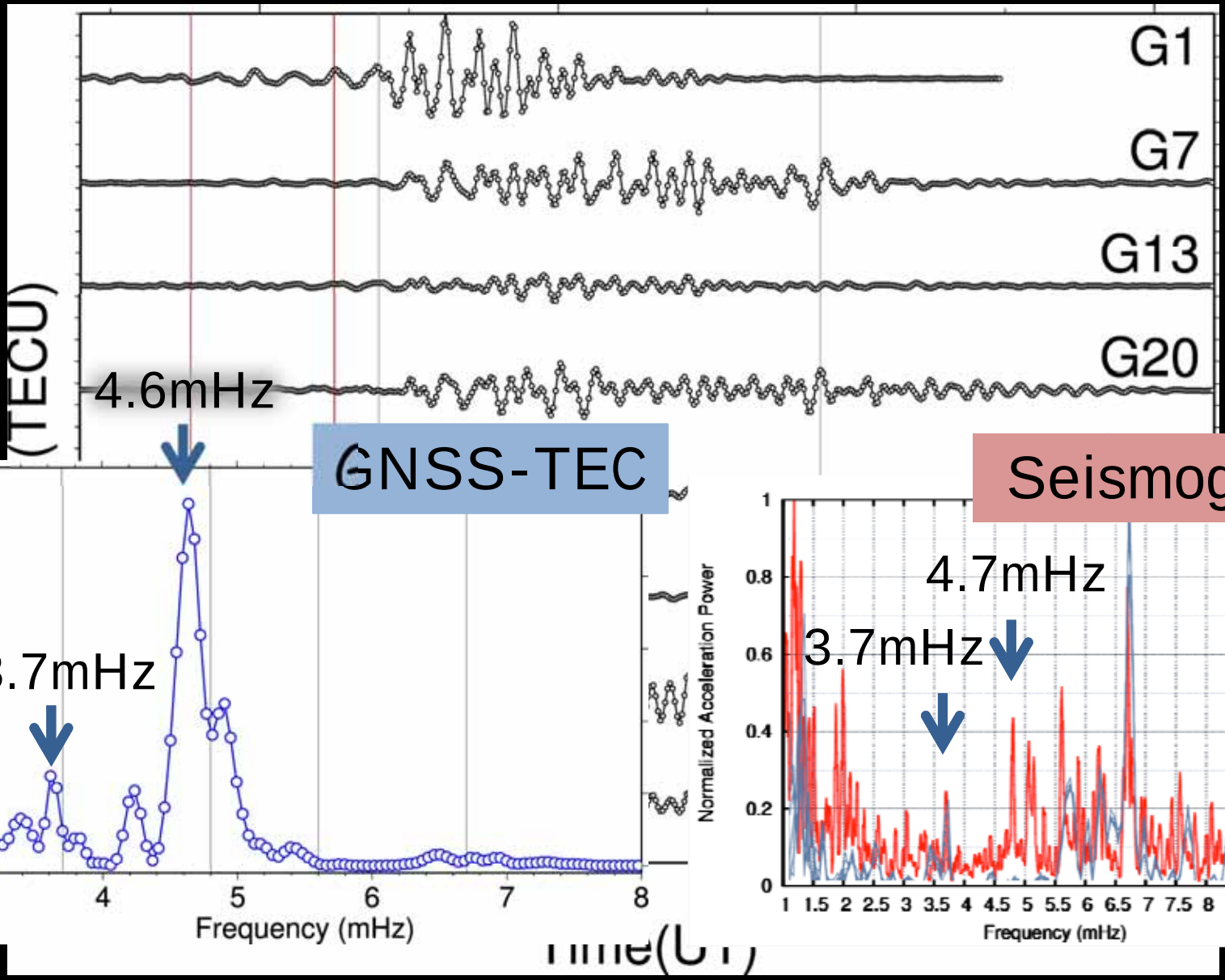


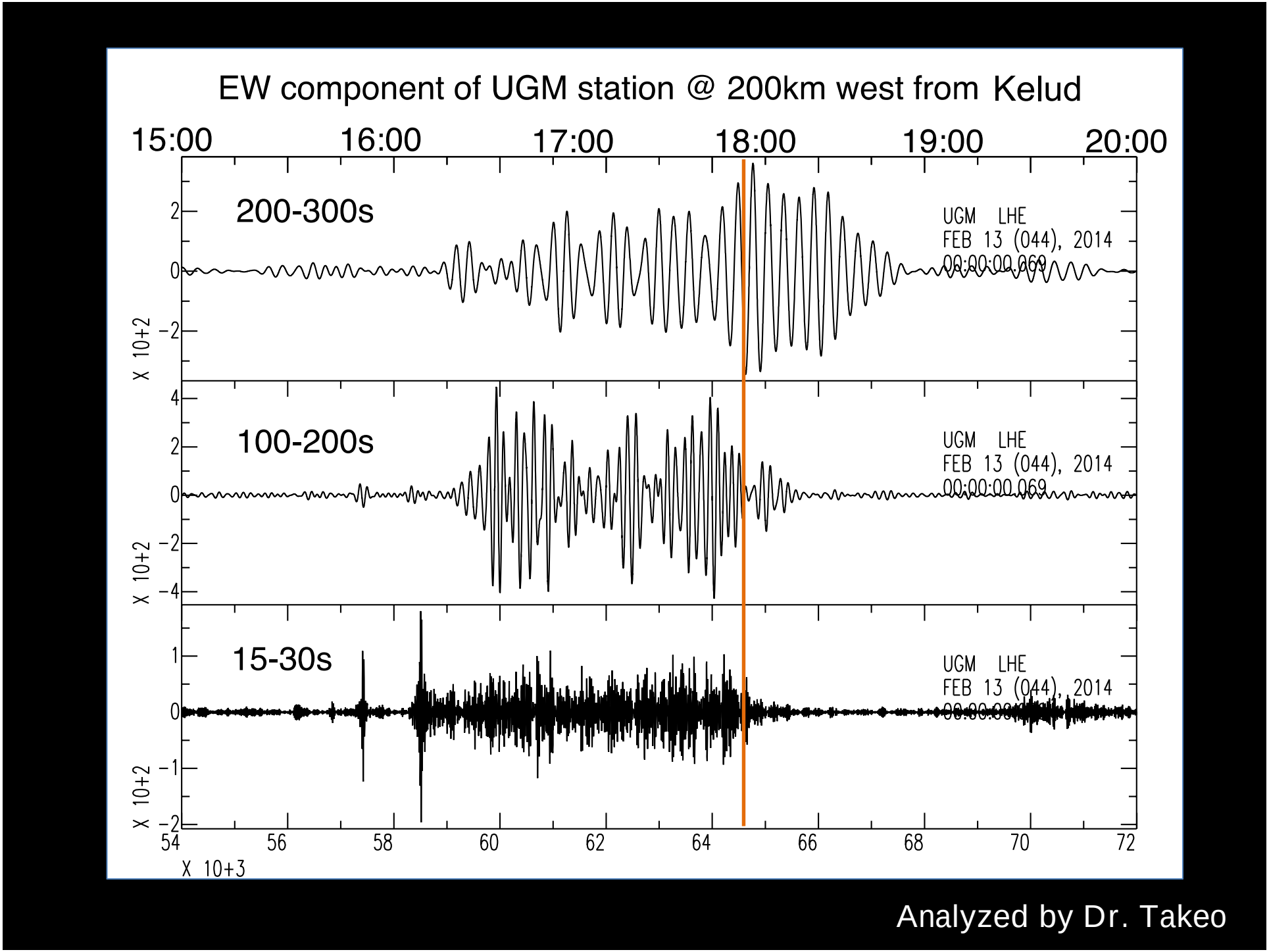
Concentric wave is clearer on the **northern** side.
(interaction with geomagnetism)

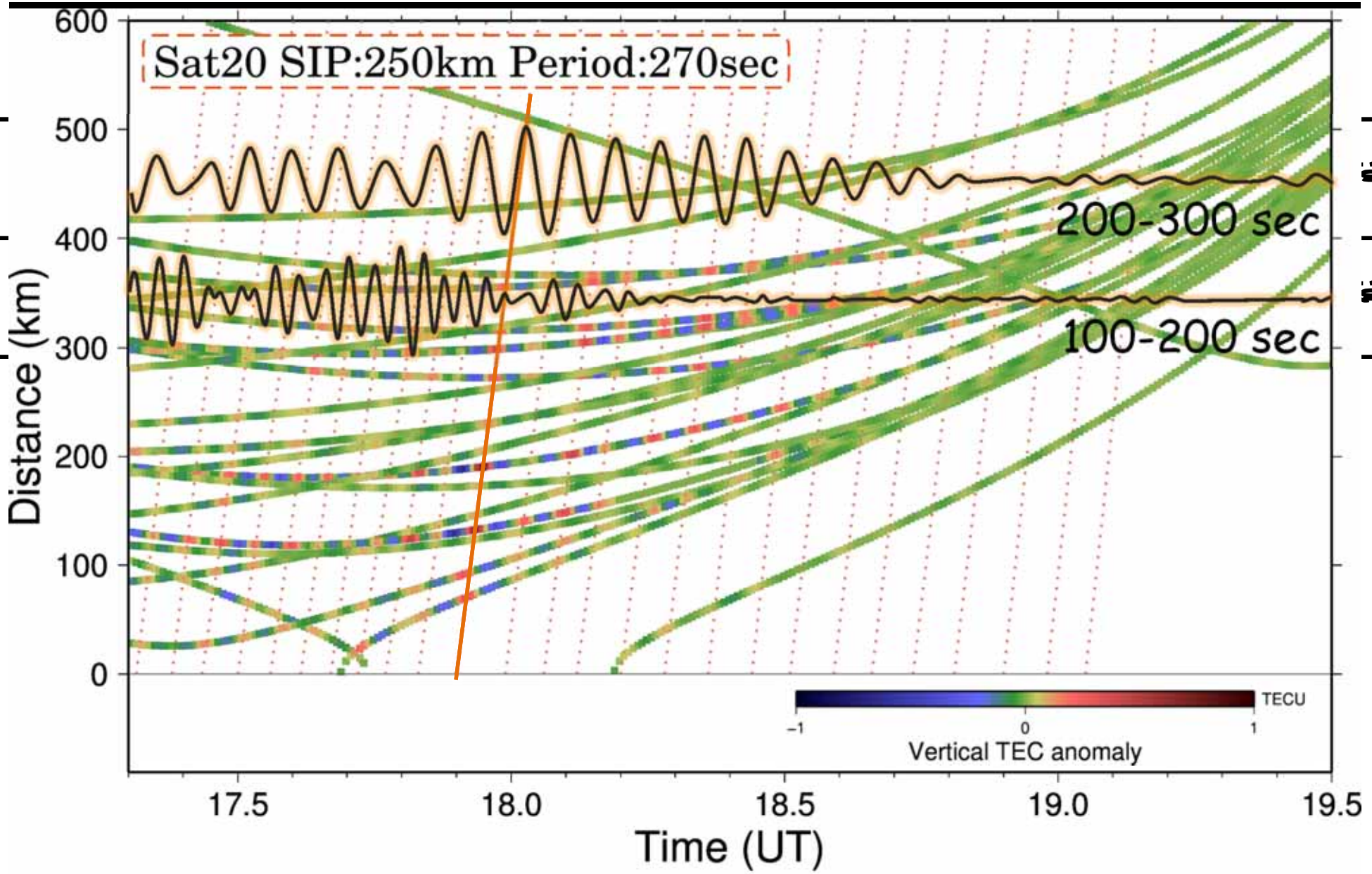


GLONASS Satellite #16

Kelud volcano – Stacked Wave Form

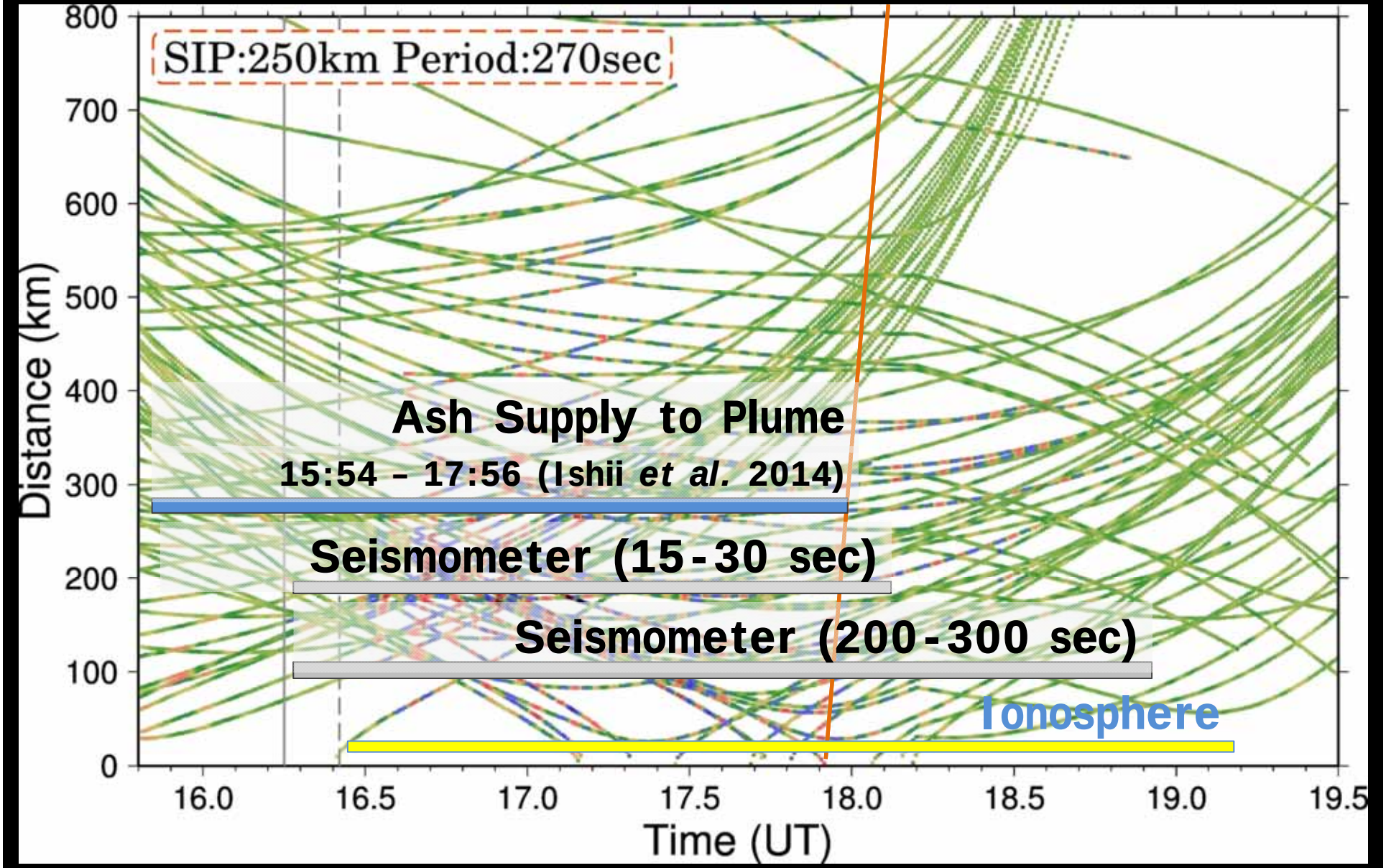



EW component of UGM station @ 200km west from Kelud
15:00
16:00
17:00
18:00
19:00
20:00
200-300s
100-200s
15-30s
UGM LHE
FEB 13 (044), 2014
00:00:00.069
X 10+2
X 10+3
54
56
58
60
62
64
66
68
70
72
Analyzed by Dr. Takeo

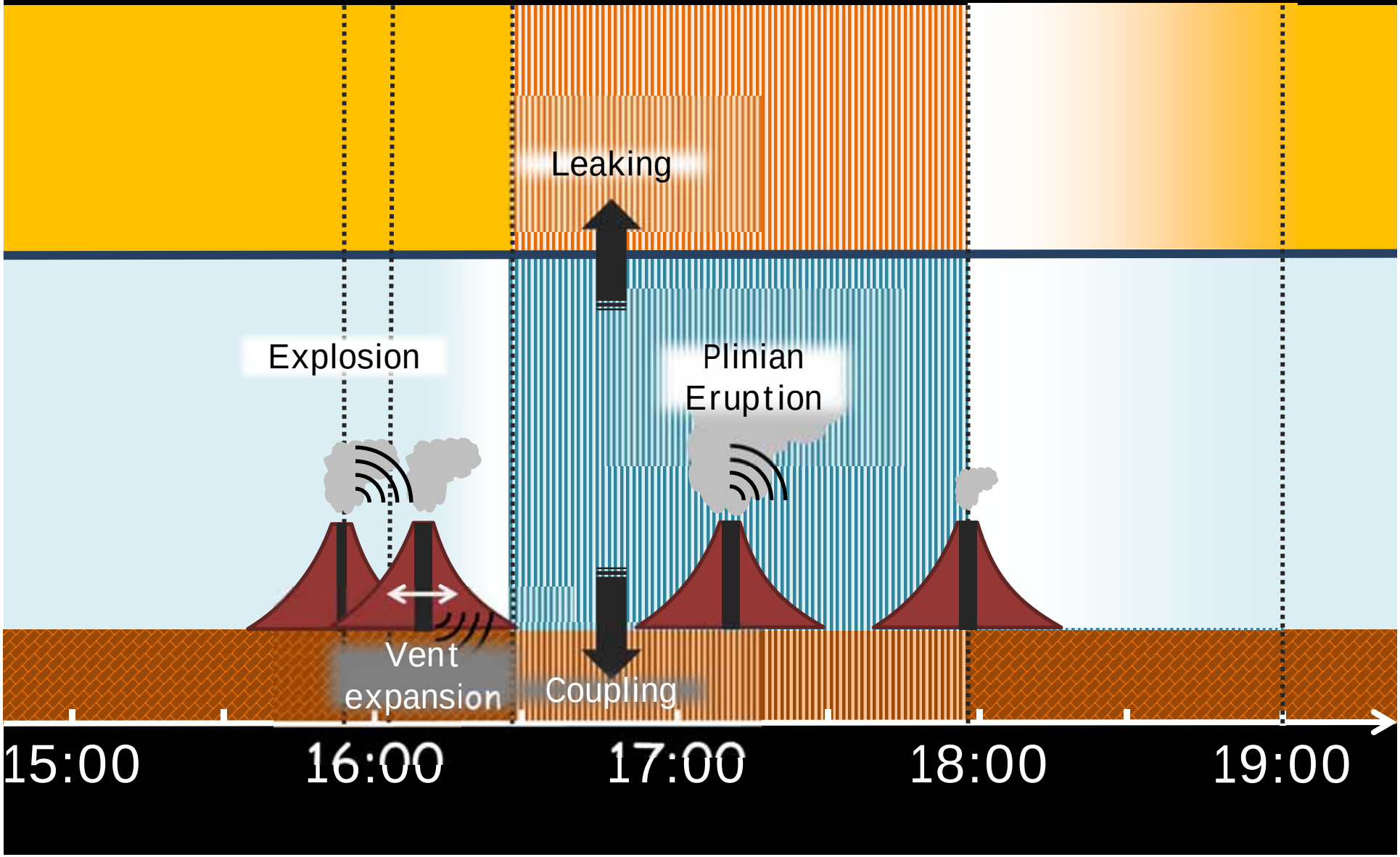


Two-stage excitation?

Time Sequence of the Eruption



Excitation Scenario



Summary: 2014 Kelud case

- GNSS-TEC detected ionospheric disturbances by the 2014 Kelud eruption.
- Concentric waves propagated outward with acoustic wave velocity (0.8-1.3 km/s).
- Kelud eruptions excited an atmospheric resonance.
- The resonance excited solid earth - atmosphere coupling.

Contents

The 2014 Kelud Volcano eruption

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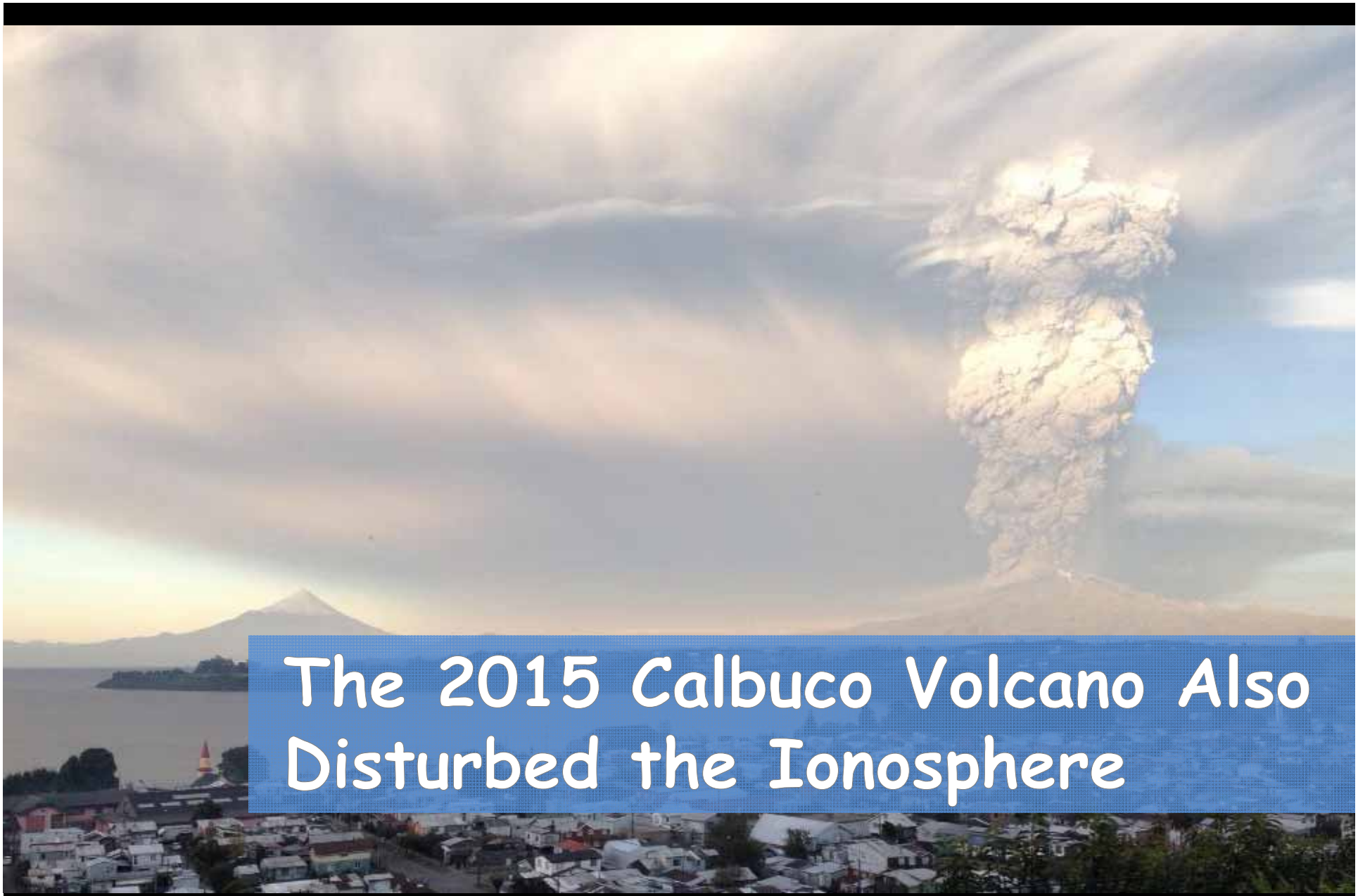
The 2015 Kuchinoerabujima eruption



The 2015 Calbuco Volcano Also Disturbed the Ionosphere

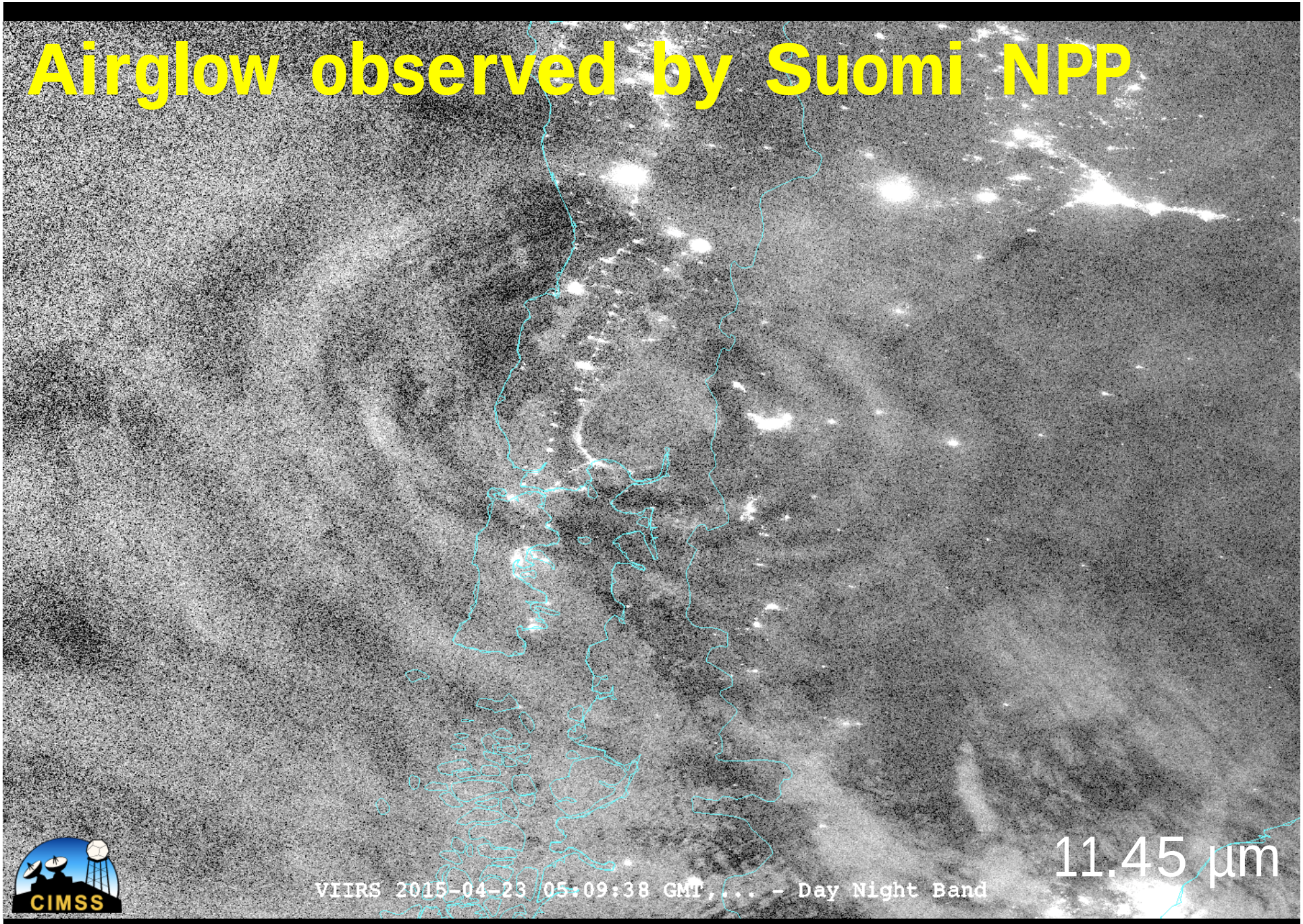
http://www.wired.com/2015/04/chiles-calbuco-unleashes-dramatic-explosive-eruption/
Photo by JULIO DEL RIO C.

- An eruption from Calbuco began at 21:04 UT on 22 April. […] After a Large seismic event detected at 20:35 UT, a 90 minute eruption generated a sub-Plinian, gray ash plume that rose 15 km above the main crater….

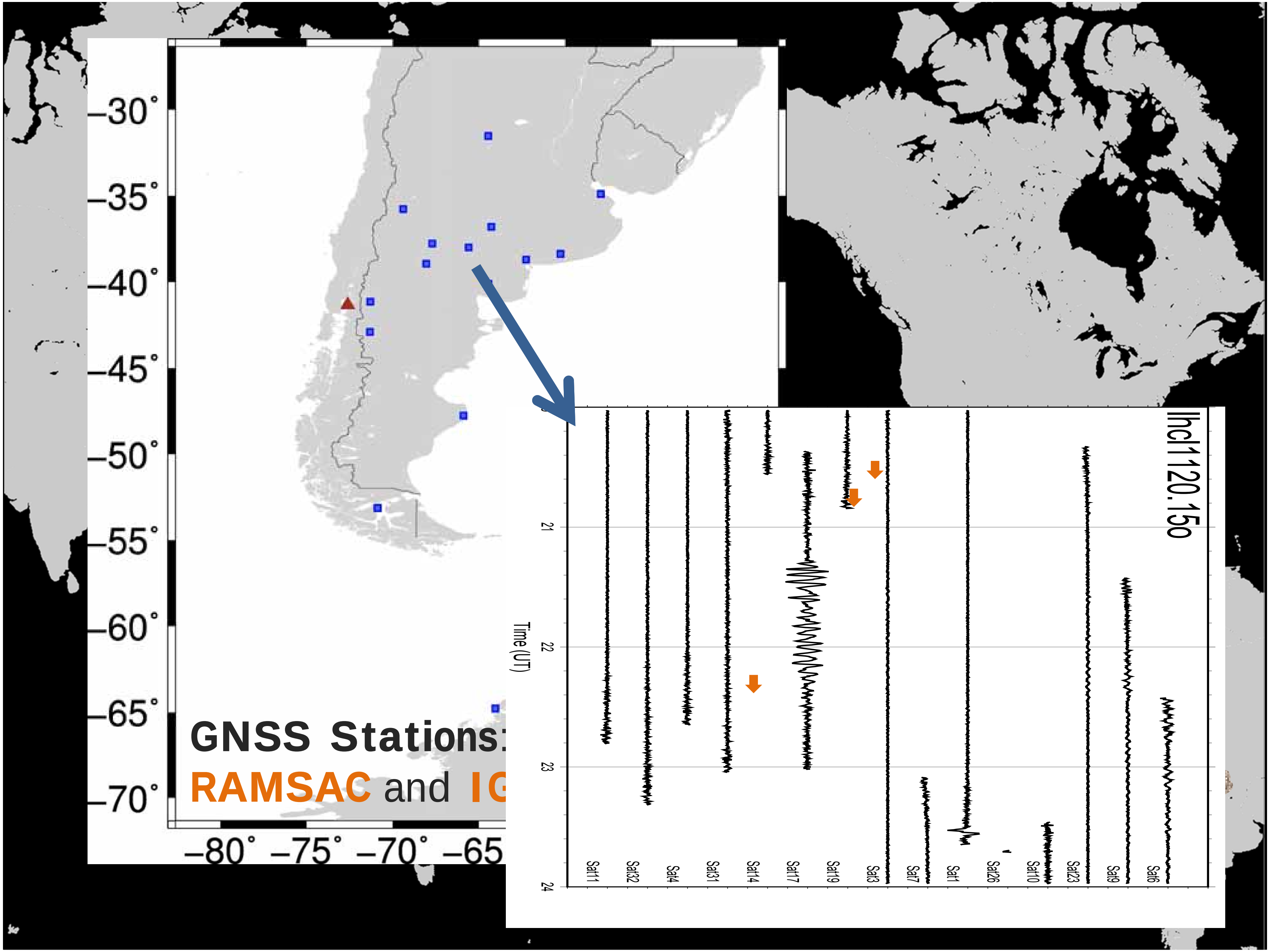
- A large second event on 23 April began at 4:00 UT, lasted six hours, and also generated a sub-Plinian ash plume that rose higher than 15 km….

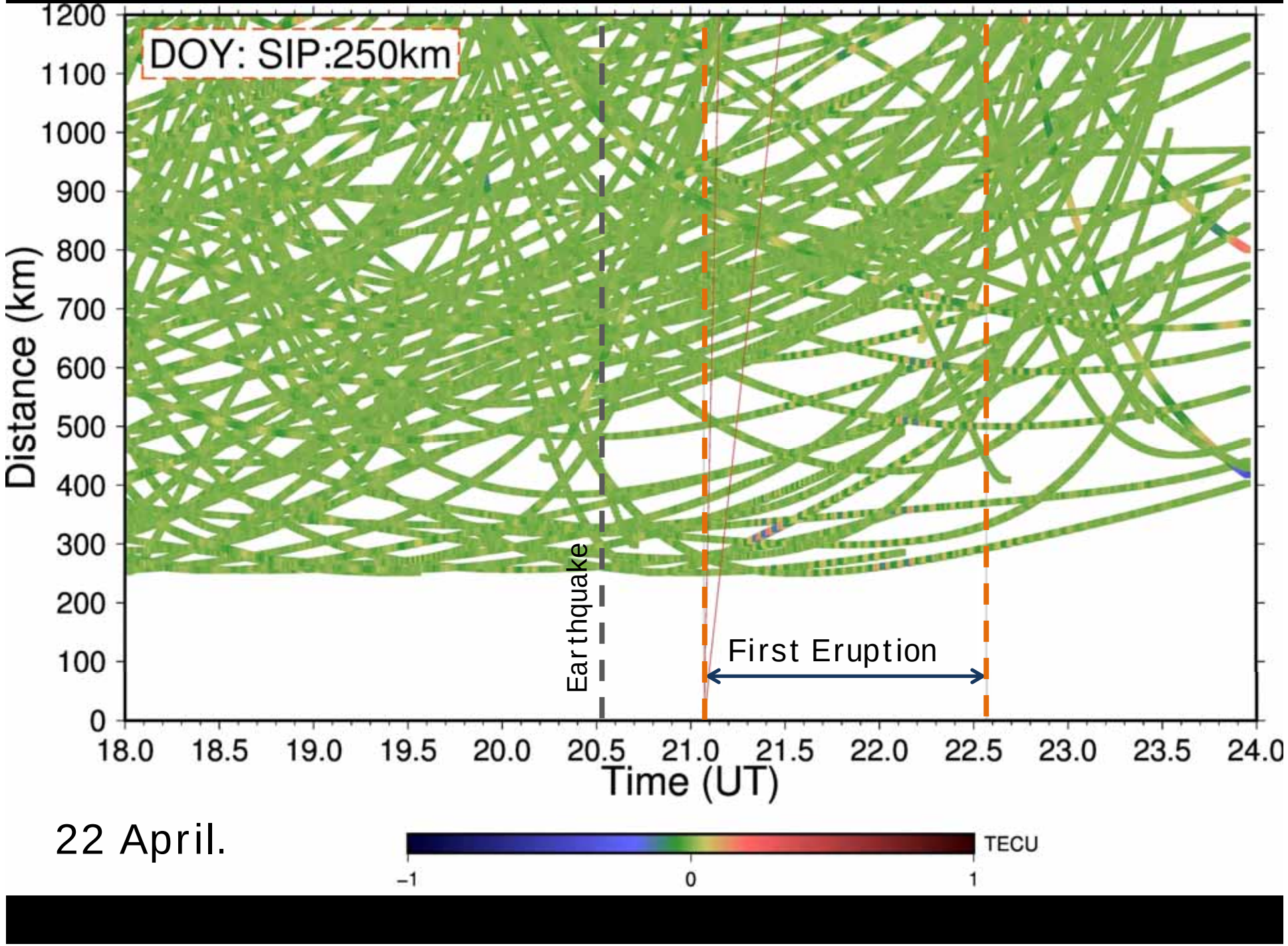
The Smithsonian Institution's Global Volcanism Program –Weekly Reports
http://www.volcano.si.edu/volcano.cfm?vn=358020

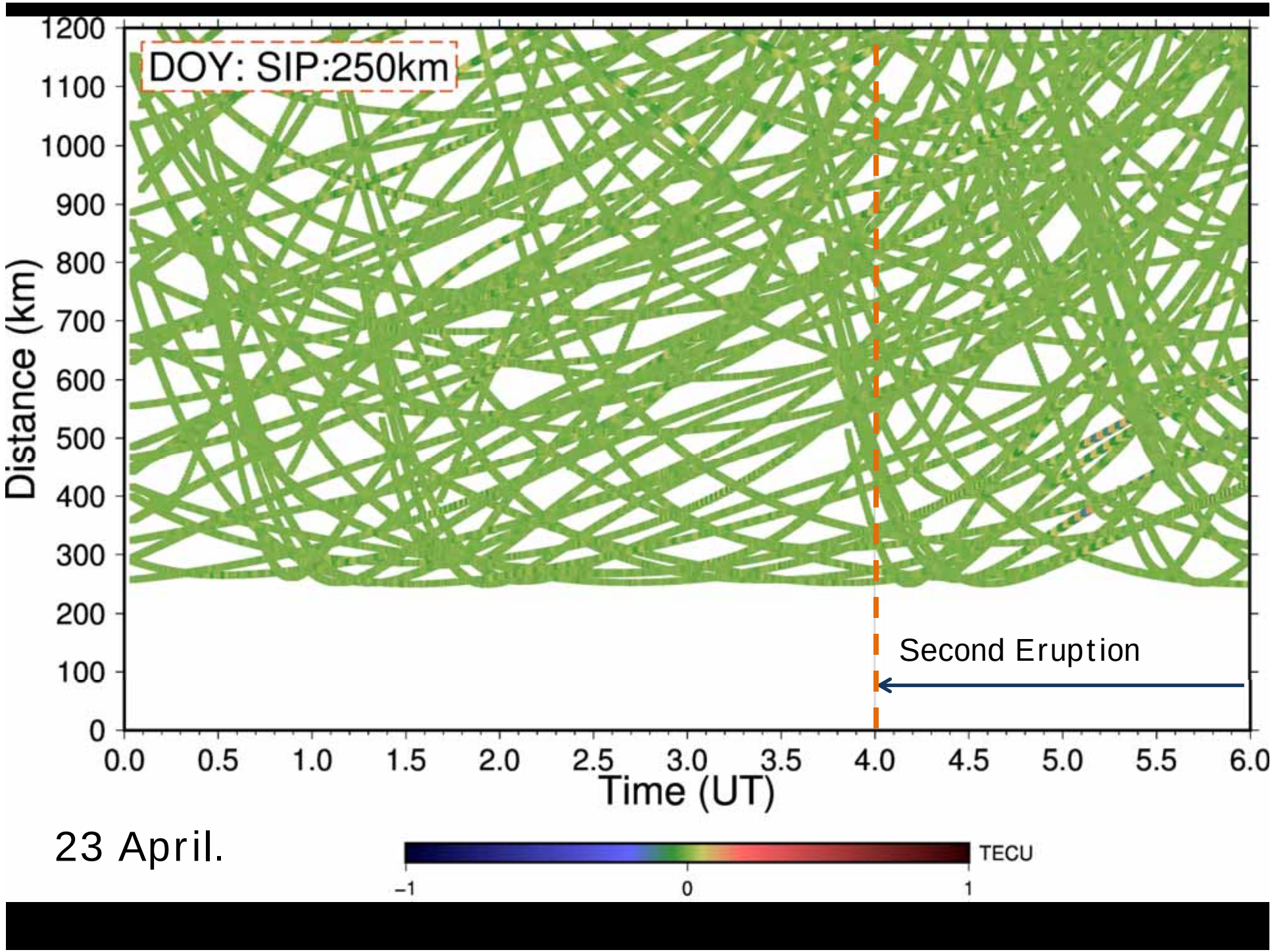
Airglow observed by Suomi NPP

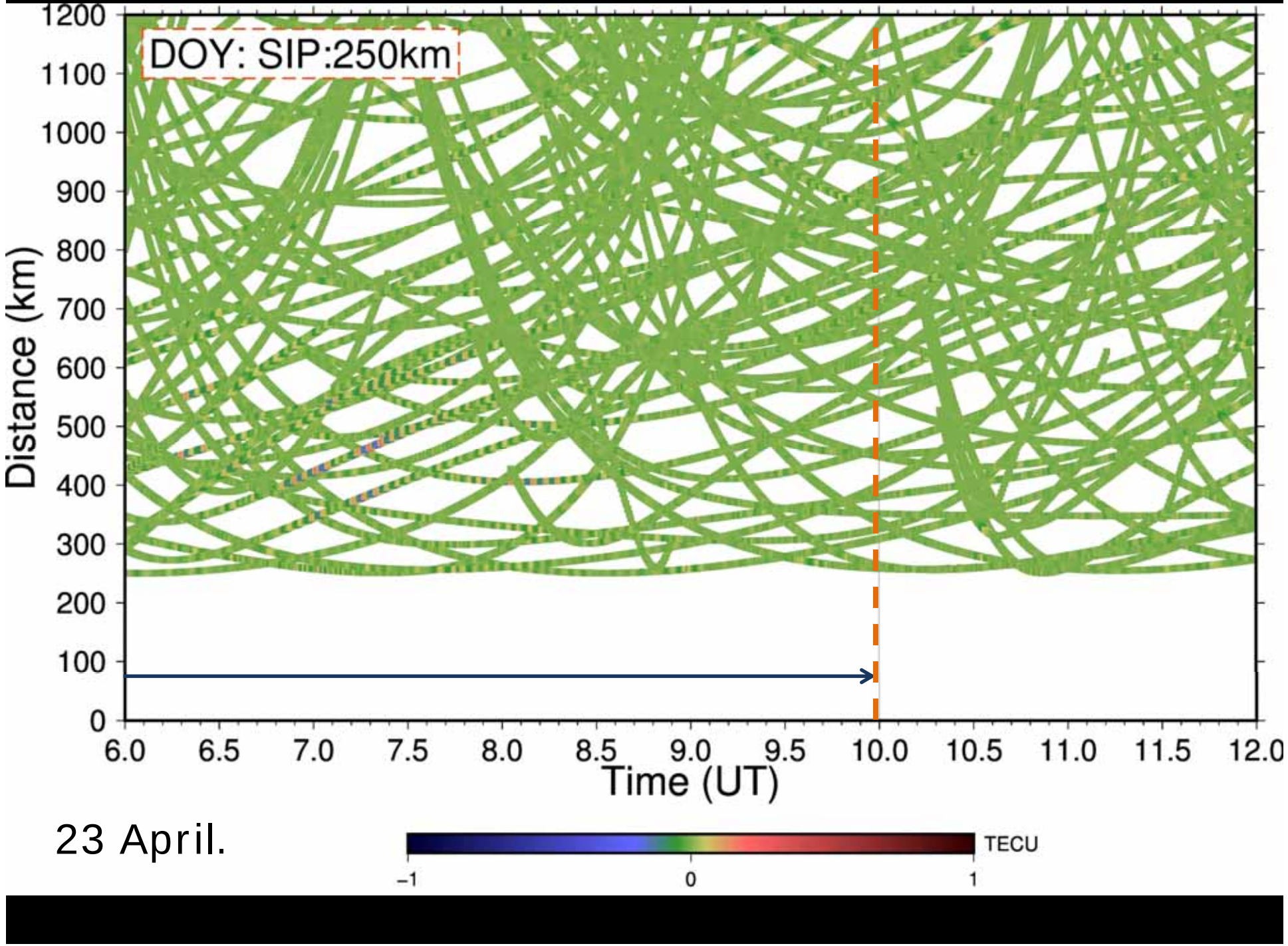


https://cimss.ssec.wisc.edu/goes/blog/archives/1817

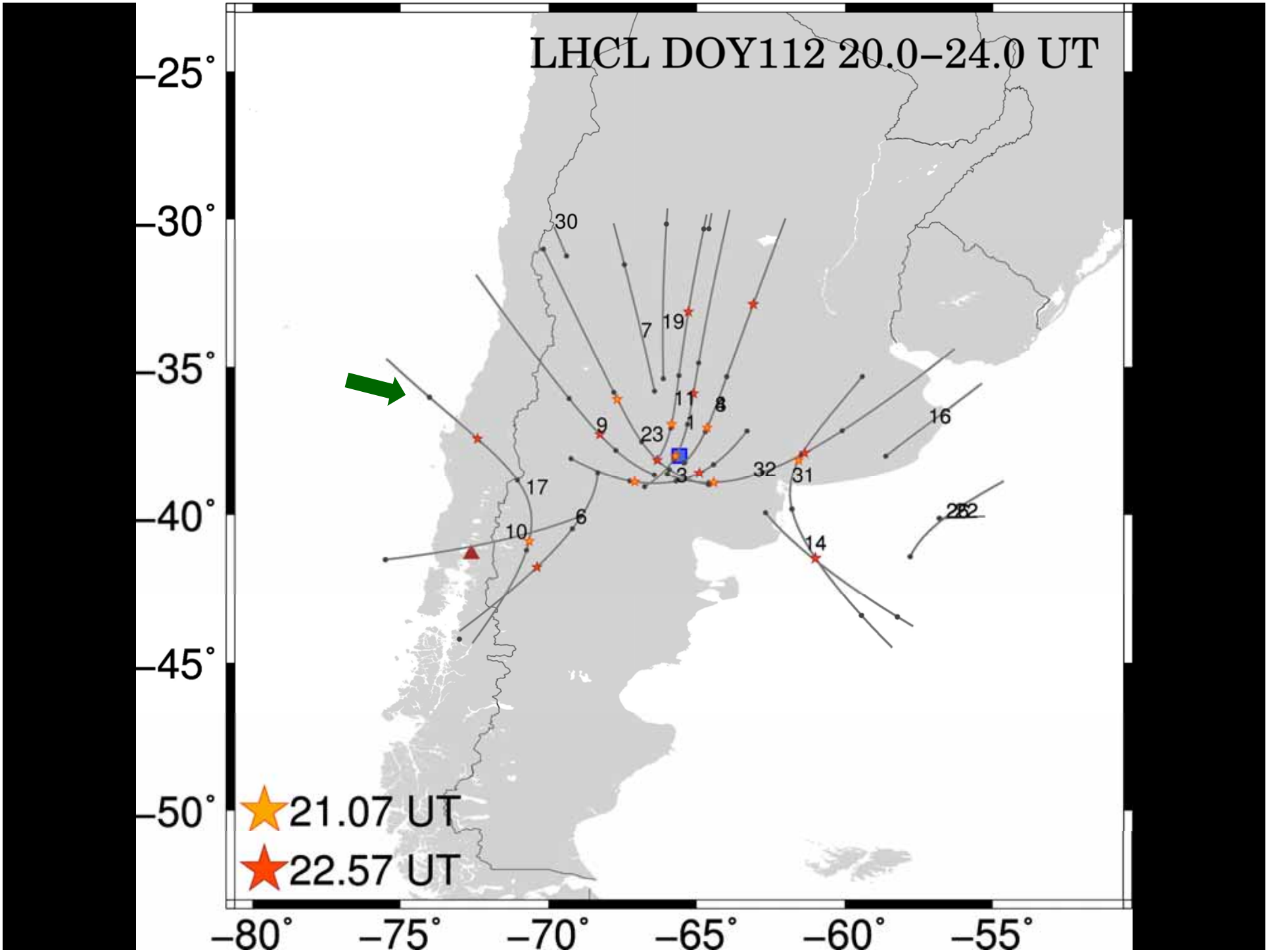

GNSS Stations:
RAMSAC and IG
–30°
–35°
–40°
–45°
–50°
–55°
–60°
–65°
–70°
–80°
–75°
–70°
–65
lhcl1120.15o
Time (UT)
21
22
23
24
Sat11
Sat32
Sat4
Sat31
Sat14
Sat17
Sat19
Sat3
Sat7
Sat1
Sat26
Sat10
Sat23
Sat9
Sat6

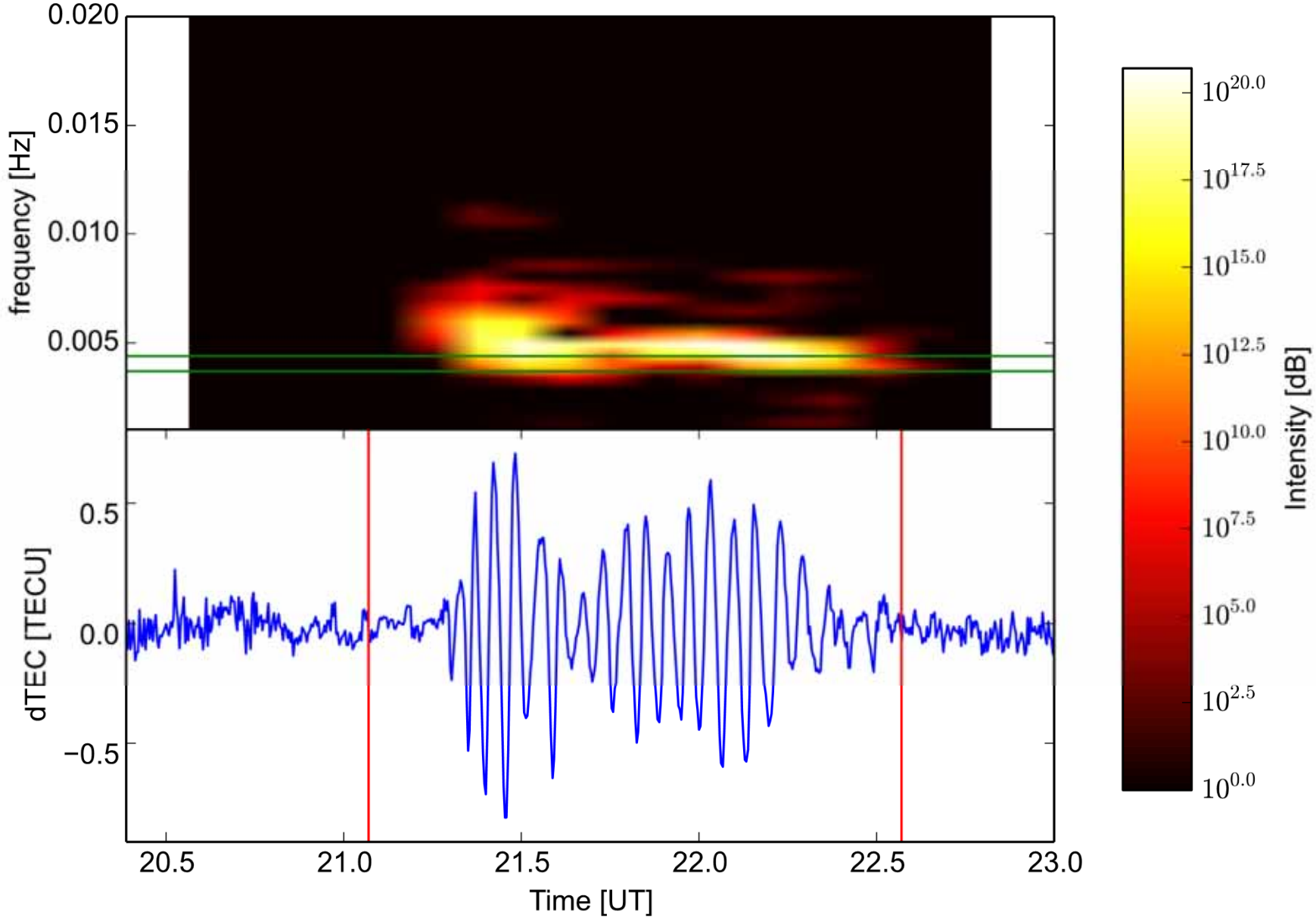

DOY: SIP:250km
Distance (km)
1200
1100
1000
900
800
700
600
500
400
300
200
100
0
18.0
18.5
19.0
19.5
20.0
20.5
21.0
21.5
22.0
22.5
23.0
23.5
24.0
Time (UT)
Earthquake
First Eruption
22 April.
TECU
−1
0
1

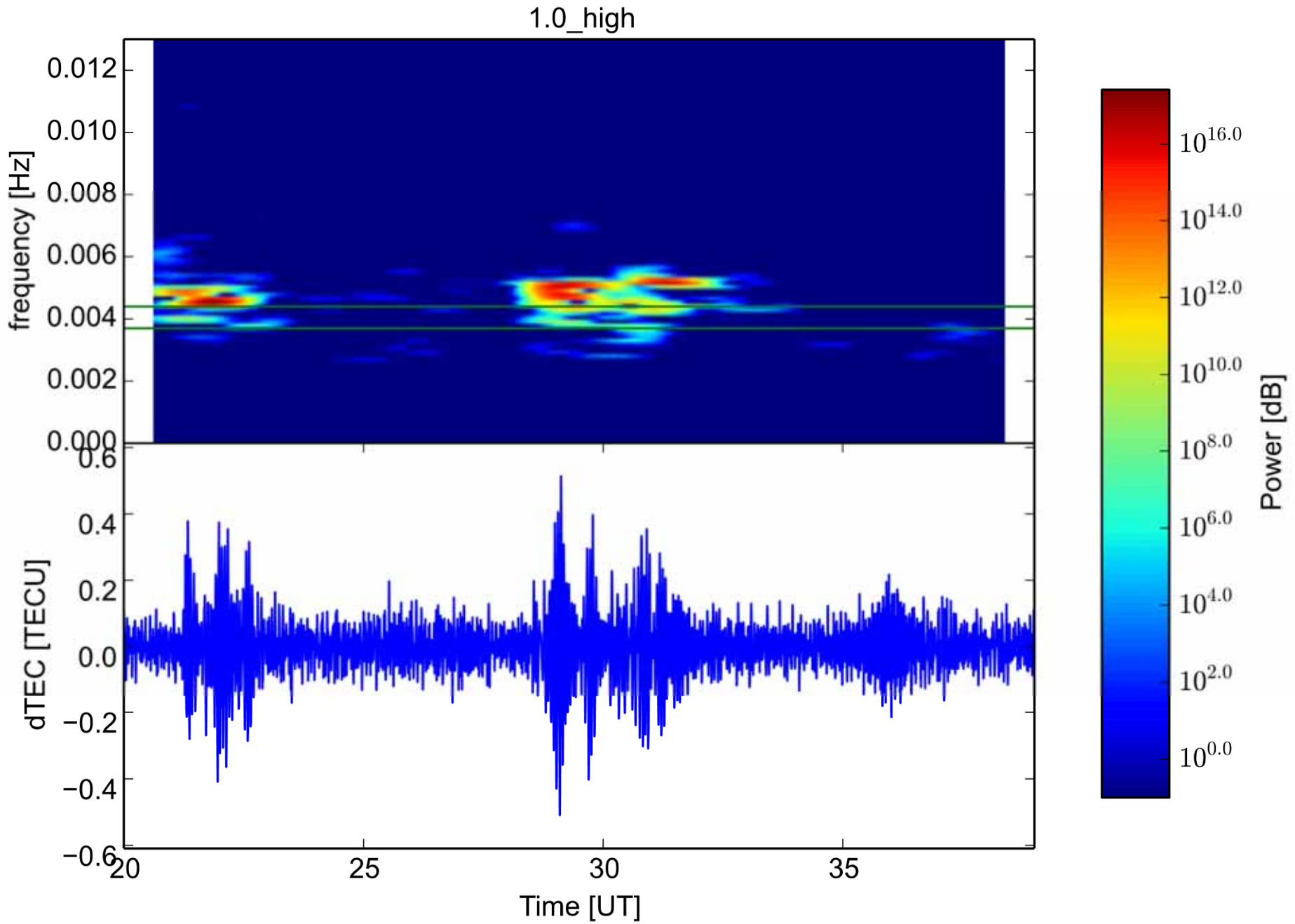

DOY: SIP:250km
Distance (km)
1200
1100
1000
900
800
700
600
500
400
300
200
100
0
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
5.5
6.0
Time (UT)
Second Eruption
23 April.
TECU
−1
0
1


DOY: SIP:250km
Distance (km)
1200
1100
1000
900
800
700
600
500
400
300
200
100
0
6.0
6.5
7.0
7.5
8.0
8.5
9.0
9.5
10.0
10.5
11.0
11.5
12.0
Time (UT)
TECU
−1
0
1

23 April.


LHCL DOY112 20.0–24.0 UT
–25°
–30°
–35°
–40°
–45°
–50°
–80°
–75°
–70°
–65°
–60°
–55°
30
7
19
11
8
9
23
1
16
32
31
3
17
6
10
14
21.07 UT
22.57 UT


0.020
0.015
0.010
0.005
frequency [Hz]
0.5
0.0
−0.5
dTEC [TECU]
20.5
21.0
21.5
22.0
22.5
23.0
Time [UT]
$10^{20.0}$
$10^{17.5}$
$10^{15.0}$
$10^{12.5}$
$10^{10.0}$
$10^{7.5}$
$10^{5.0}$
$10^{2.5}$
$10^{0.0}$
Intensity [dB]


1.0_high
frequency [Hz]
0.012
0.010
0.008
0.006
0.004
0.002
0.000
dTEC [TECU]
0.6
0.4
0.2
0.0
−0.2
−0.4
−0.6
20
25
30
35
Time [UT]
$10^{16.0}$
$10^{14.0}$
$10^{12.0}$
$10^{10.0}$
$10^{8.0}$
$10^{6.0}$
$10^{4.0}$
$10^{2.0}$
$10^{0.0}$
Power [dB]

Summary: the 2015 Calbuco case

- Ionospheric disturbances are detected near the Calbuco volcano after the eruptions.
- These excitations correspond to the two eruptions.
- Second excitation continued for more than 5 hours.
- Frequency components have atmospheric eigenfrequency components.

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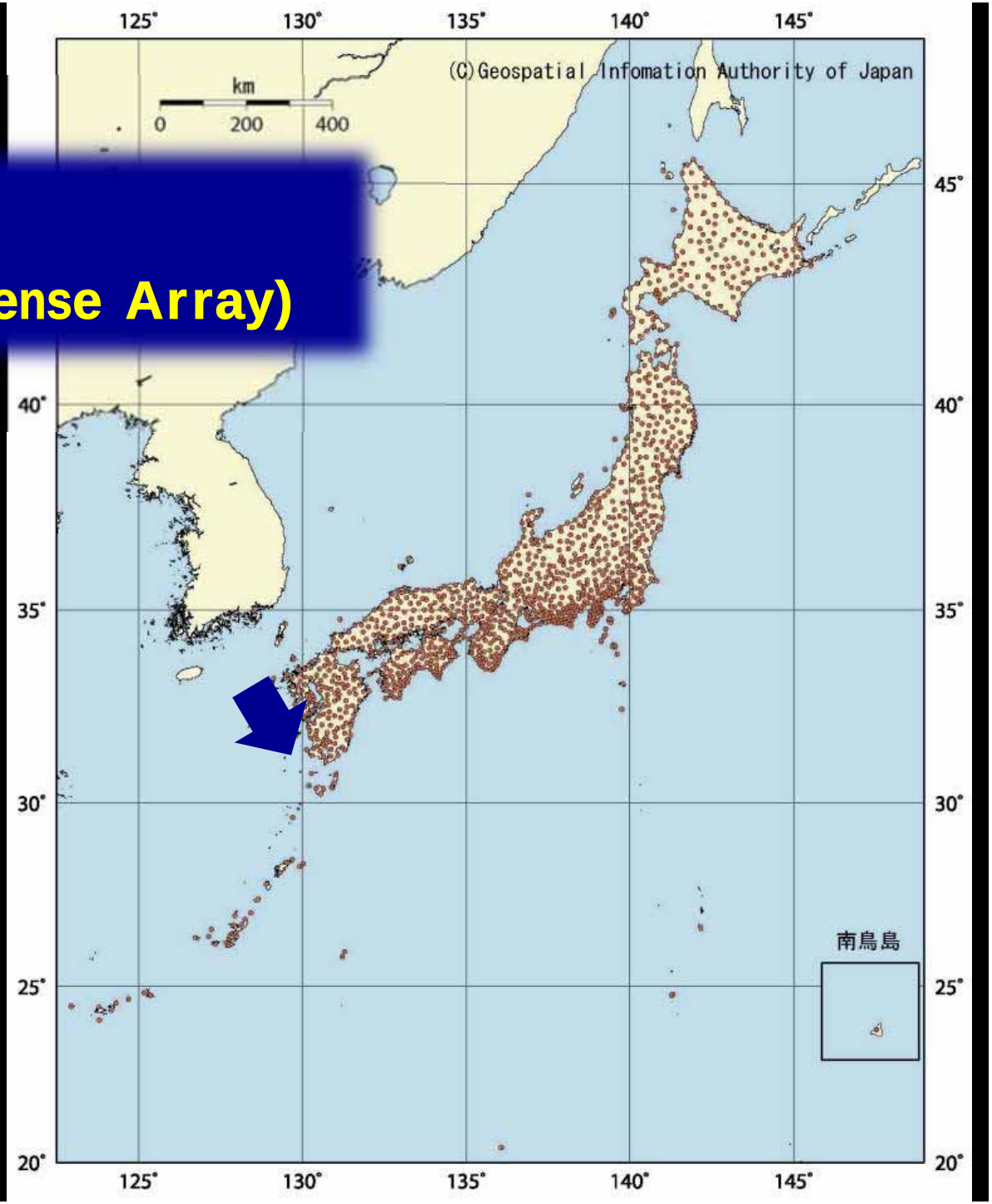
The 2015 Kuchinoerabujima eruption

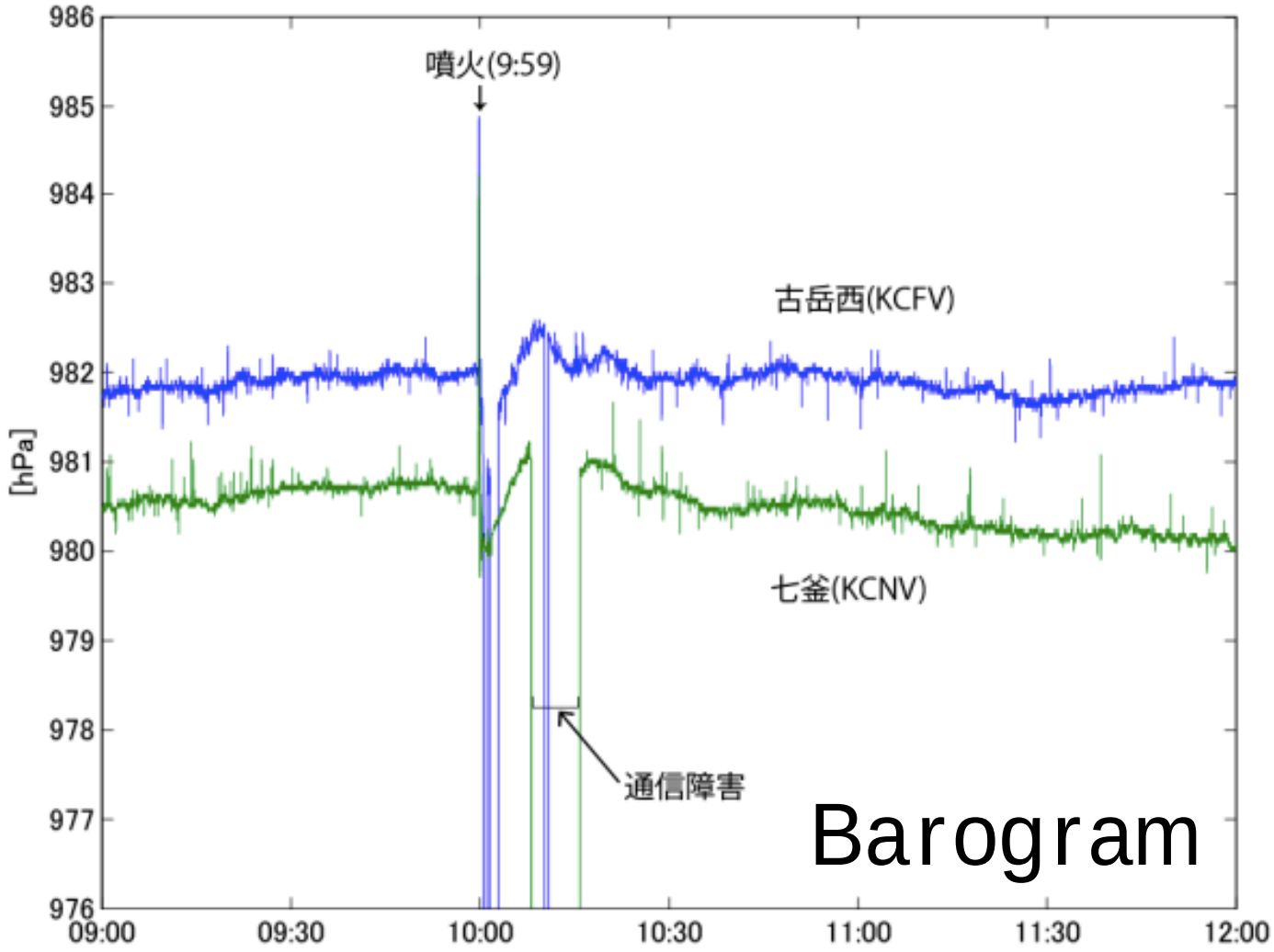
The 2015 Kuchinoerabujima Volcano

毎日新聞 (撮影: 高久 至)
http://mainichi.jp/select/news/20150529k0000e040264000c.h

GEONET

(Japanese GNSS Dense Array)

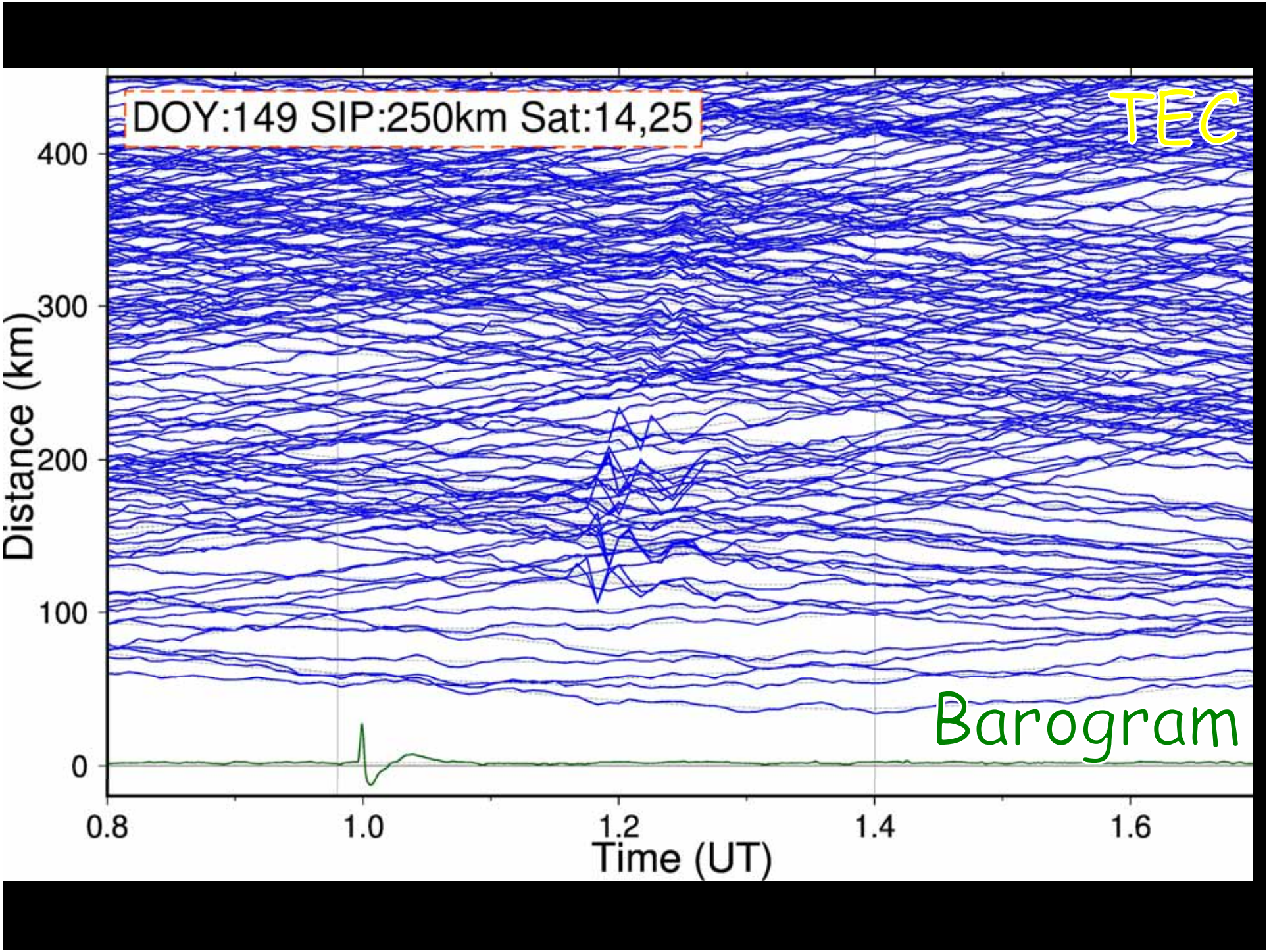




Barogram

図 3. KCNV と KCFV の 5 月 29 日 9 時から 12 時までの気圧計データ。噴火発生時に空振による気圧変化が観測されている。

KCFV=地震計（短周期・広帯域）、気圧計、雨量計、GNSS


DOY:149 SIP:250km Sat:14,25
TEC
Barogram
Distance (km)
400
300
200
100
0
0.8
1.0
1.2
1.4
1.6
Time (UT)

Conclusion

- Plinian ionospheric disturbances seem to be excited by lower atmospheric resonance.
- Vulcanian ionospheric disturbances directly shake the ionosphere
- We detect, for the first time, spatial distribution of Plinian ionospheric disturbance, and bichromatic oscillation in the ionosphere from Plinian eruption about the Kelud case.