卓越計畫

iSTEP

integrated Search for Taiwan Precursor

Precursors and Co-seismic signatures in the ionosphere during the 26 December 2004 M9.3 Sumatra Earthquake

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- Seismo-ionospheric Precursors
  - (1) Temporal variations
  - (2) Spatial variations
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  - (2) Acoustic Gravity Wave
  - (3) Tsunami Wave
- Conclusion

Introduction

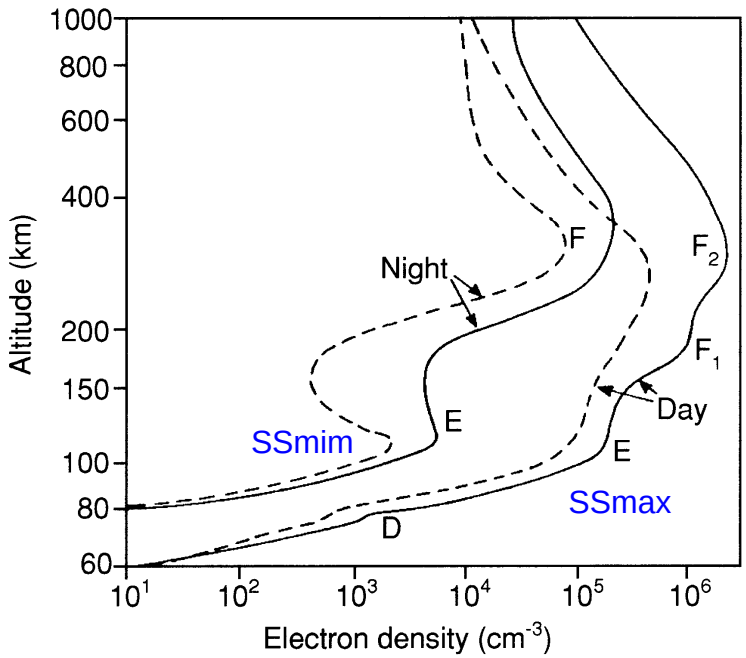
Ionosphere

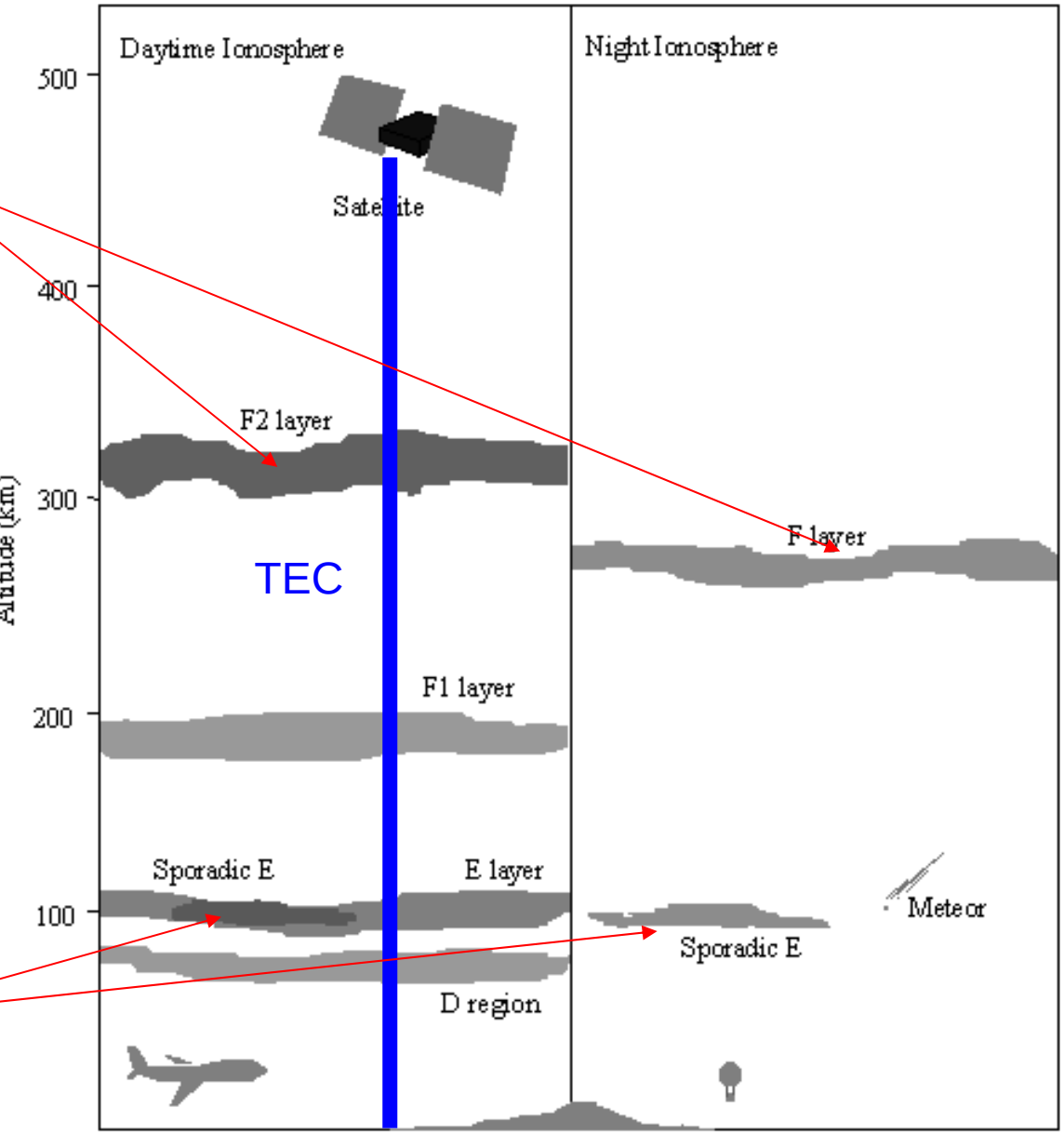
Ionosonde

GPS Receiver

Doppler Sounding System

Ionospheric Layers





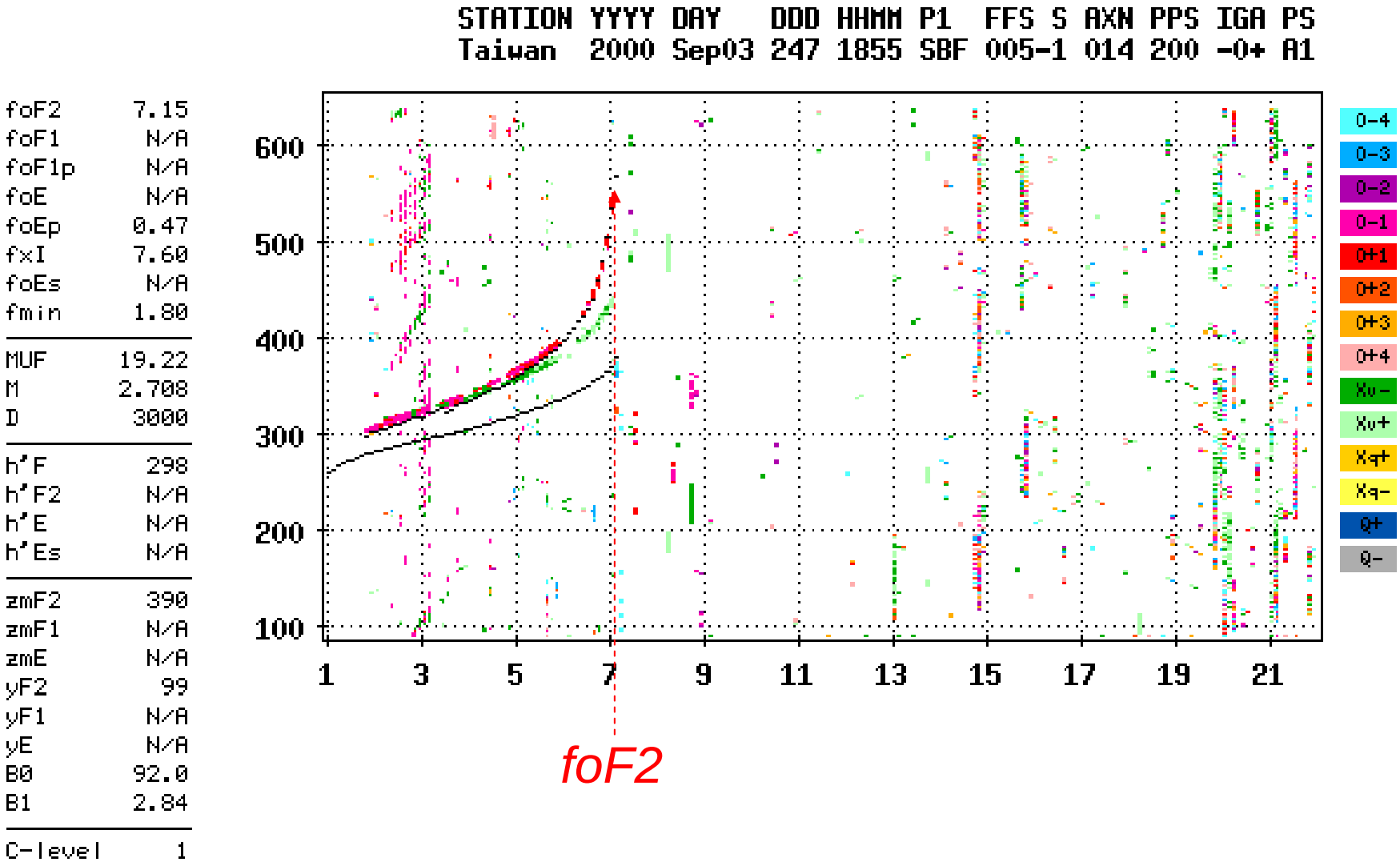
NCU Digisonde Portable Sounder

觀測站全景

觀測天線

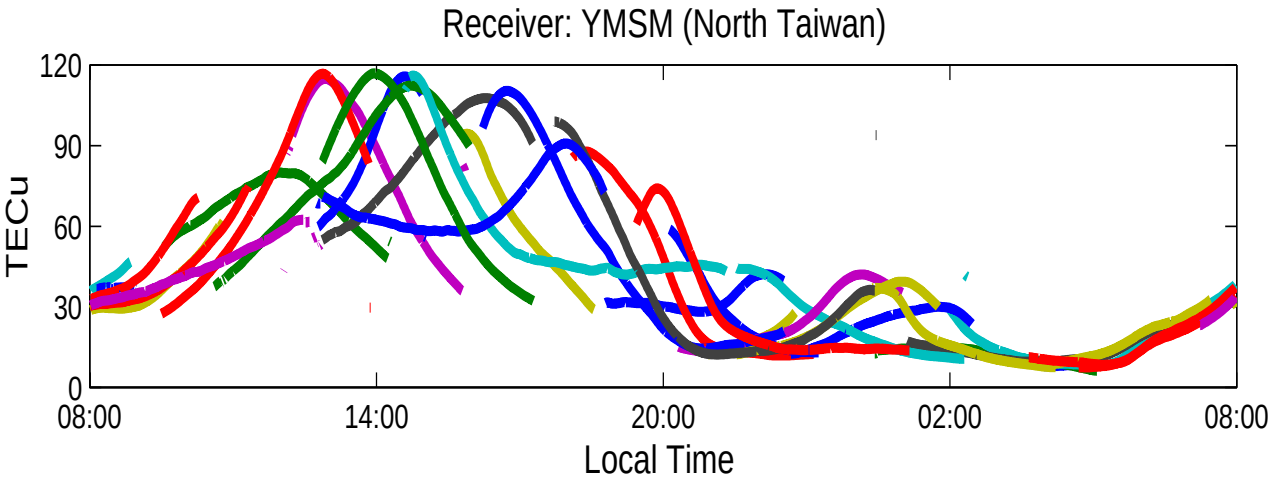
觀測站

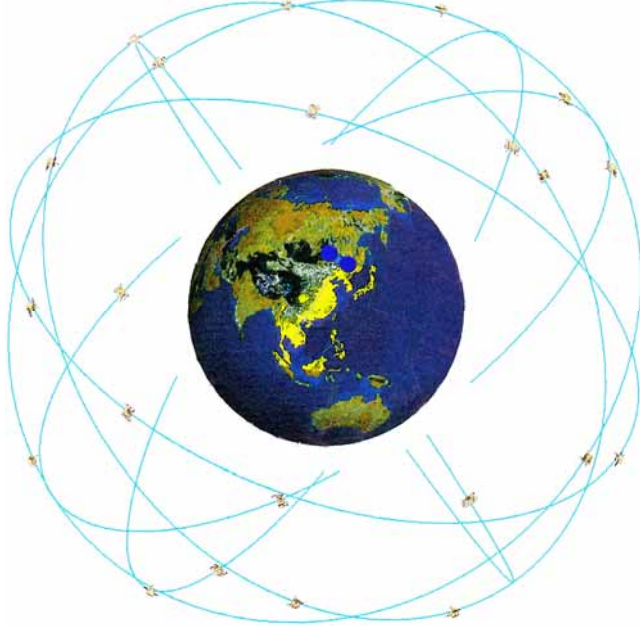
觀測資料分析



CL424_2000247185500+SBF / 210fx256h 100 kHz 2+5 km 2x1 / DPS-1 (125-125) 25+0 N 121+2 E

Ionospheric total electron content (TEC) derived from GPS





TEC (total electron content)

unit: TECu (10^{16} ele/m^2)

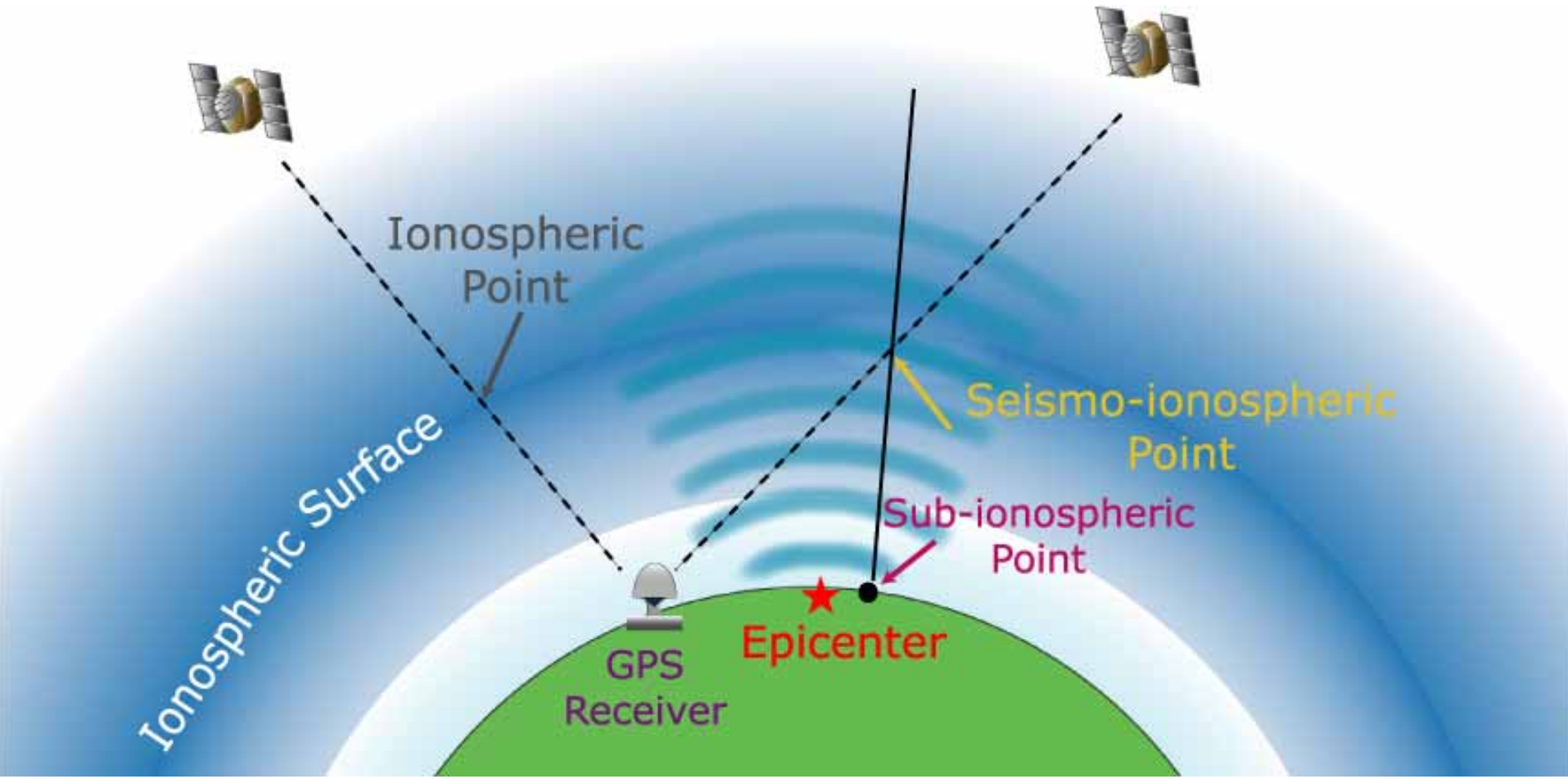
ionosphere

Line-of-sight

$S_o=[(x^i-x_j)^2+(y^i-y_j)^2+(z^i-z_j)^2]^{1/2}$

(x_j, y_j, z_j)

SIP observed by GPS TEC



Seismo-Ionospheric Precursors (SIP) - foF2

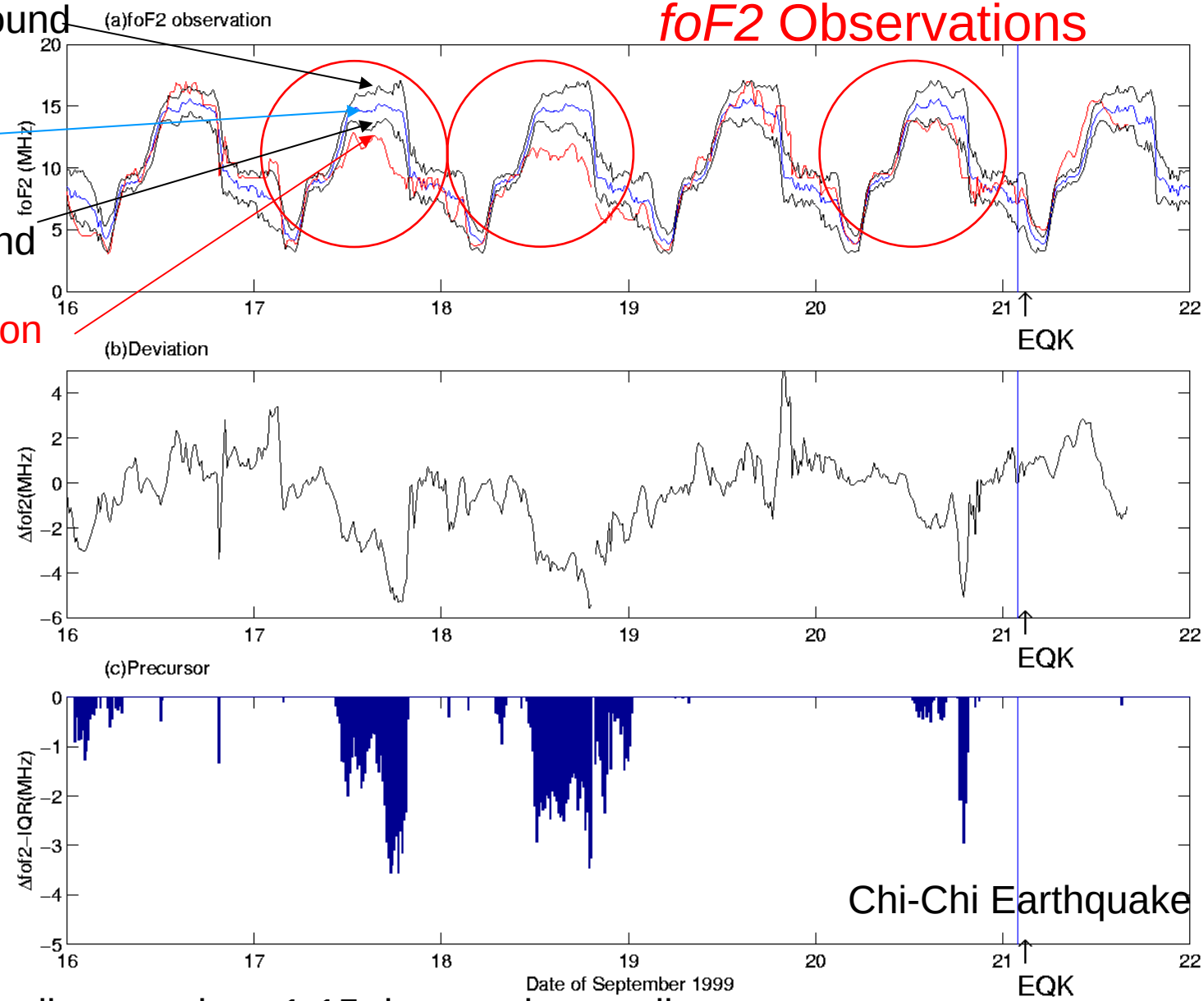
foF2 Observations

Upper Bound

Median

Low Bound

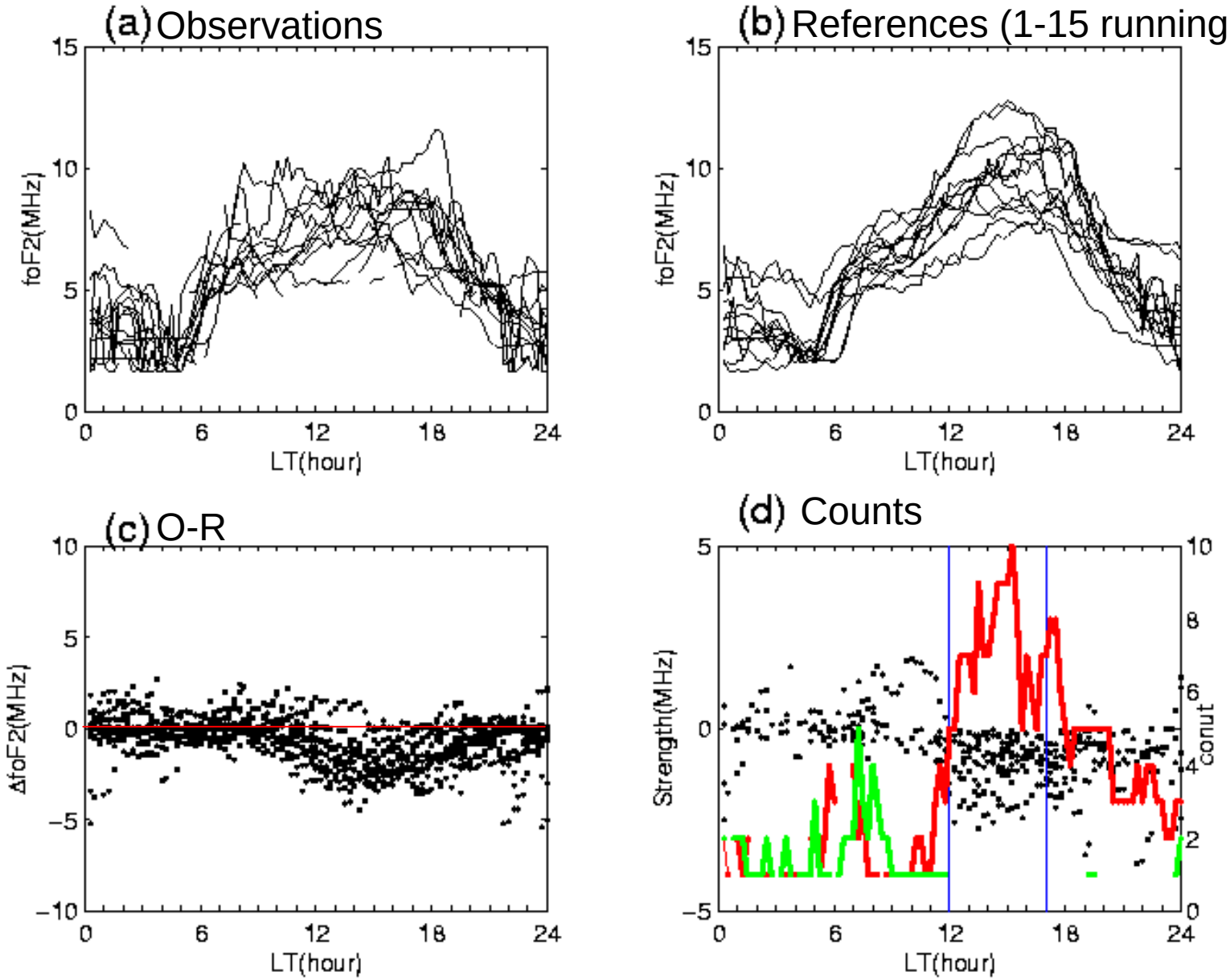
Observation



Median: previous 1-15 day running median

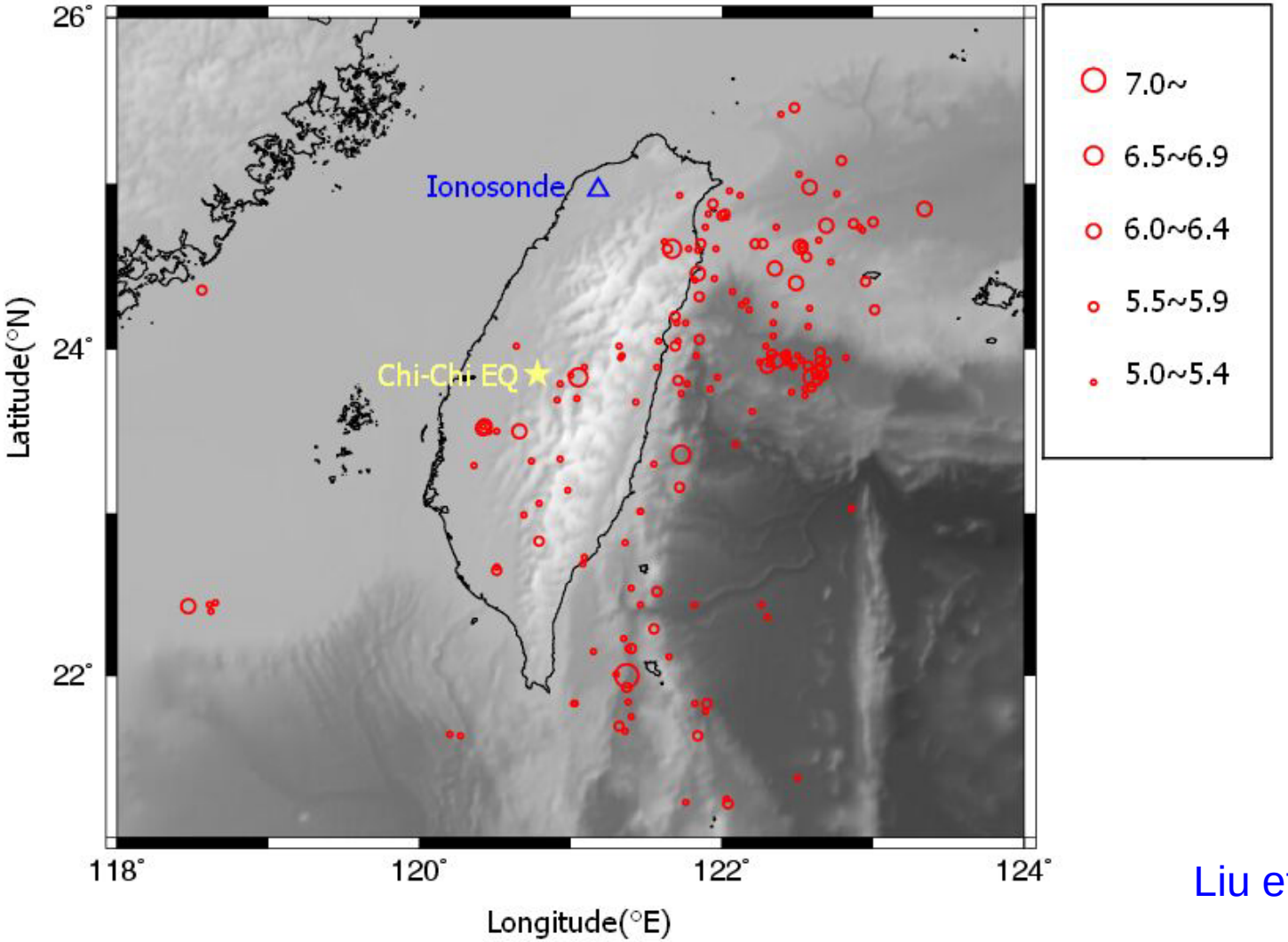
UB=M+IQR LB=M-IQR IQR=UQ-LQ

Liu et al. [GRL, 2000]

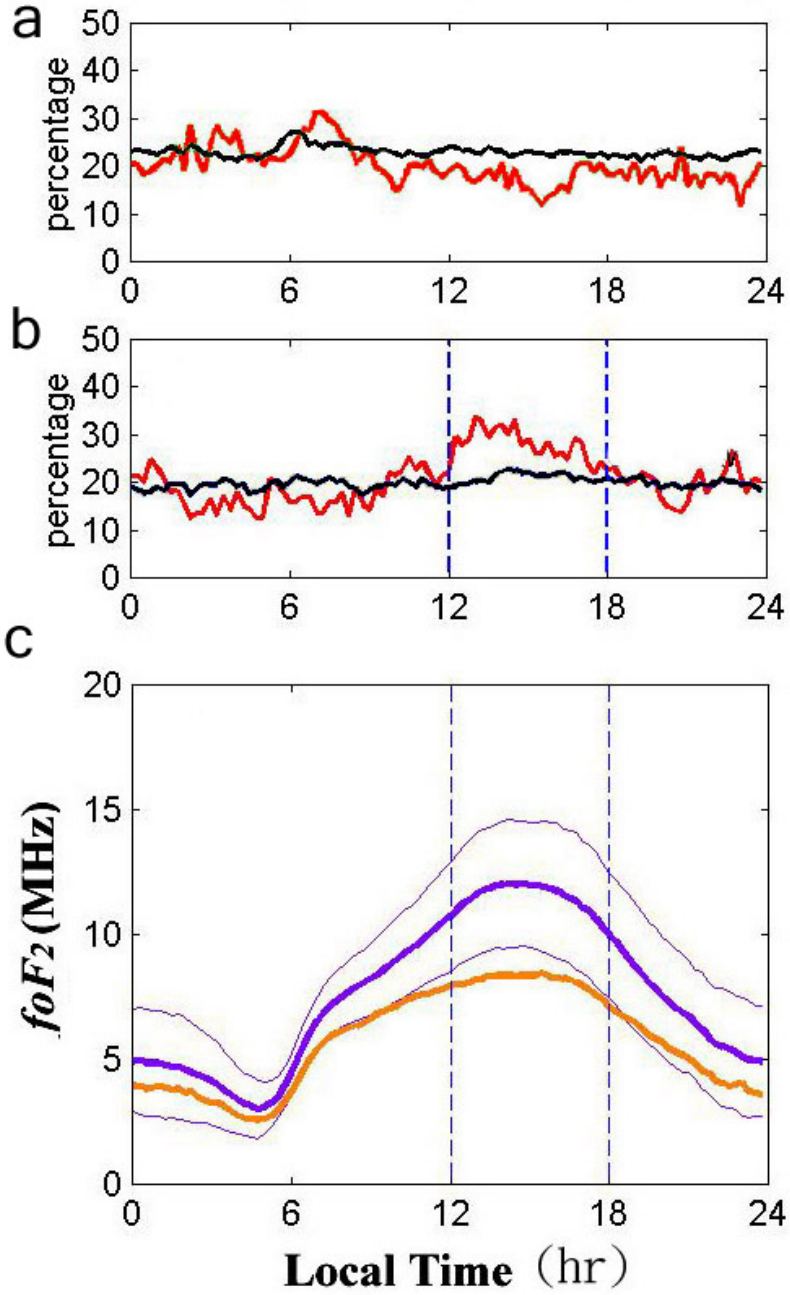


13 M ≥ 6.0 earthquakes during 1994/1-1999/9 Liu et al. [GRL, 2000]

1994-1999
M≥5.0 184 EQKs



Liu et al. [JGR, 2006]



Precursor Shape

1994-1999: 2191 days

M≥5.0 EQK: 184 (170days)

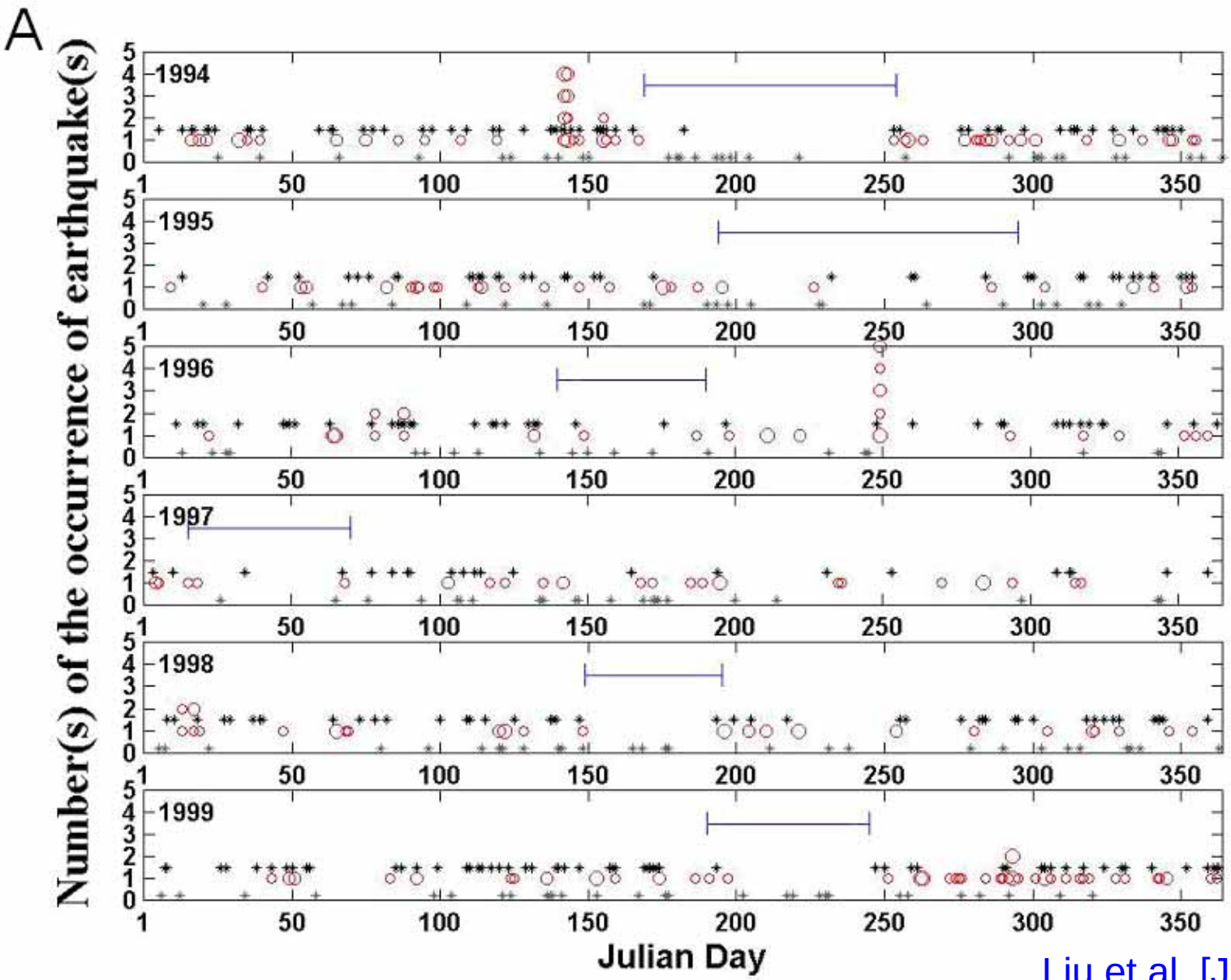
Ref: 15-day running MED & SIQR

Below Lower Bound:1200-1800 LT

Precursor Shape

Liu et al. [JGR, 2006]

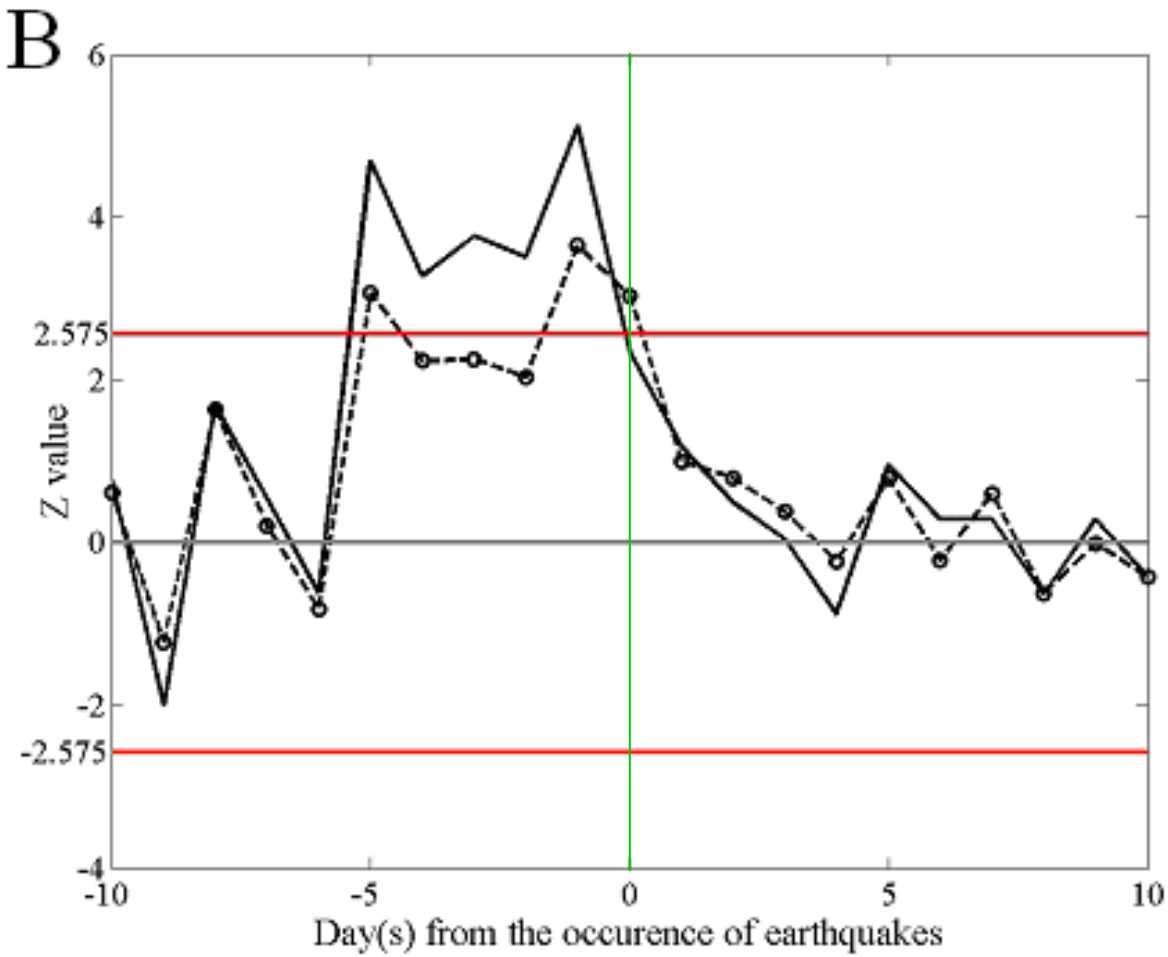
170 EQKdays, 307 Pdays, 109 storm_days, Es -- > Ps: 74.1%; Ps -- > Es: 50.2%



Liu et al. [JGR, 2006]

Precursor Lead Time

416 Anomalies
307 Precursors
Lead Time: 0-5 days



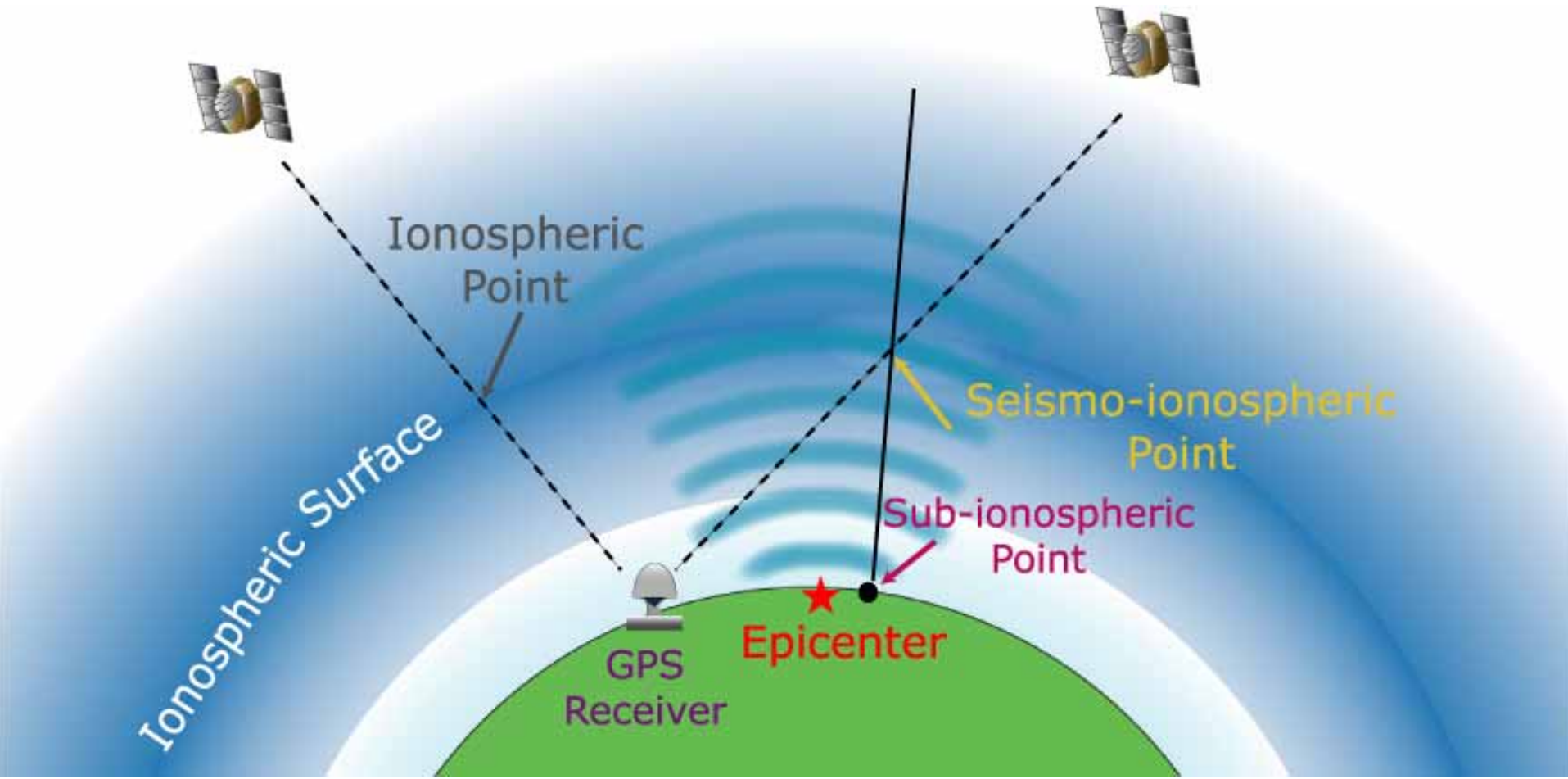
Liu et al. [JGR, 2006]

Remark-1

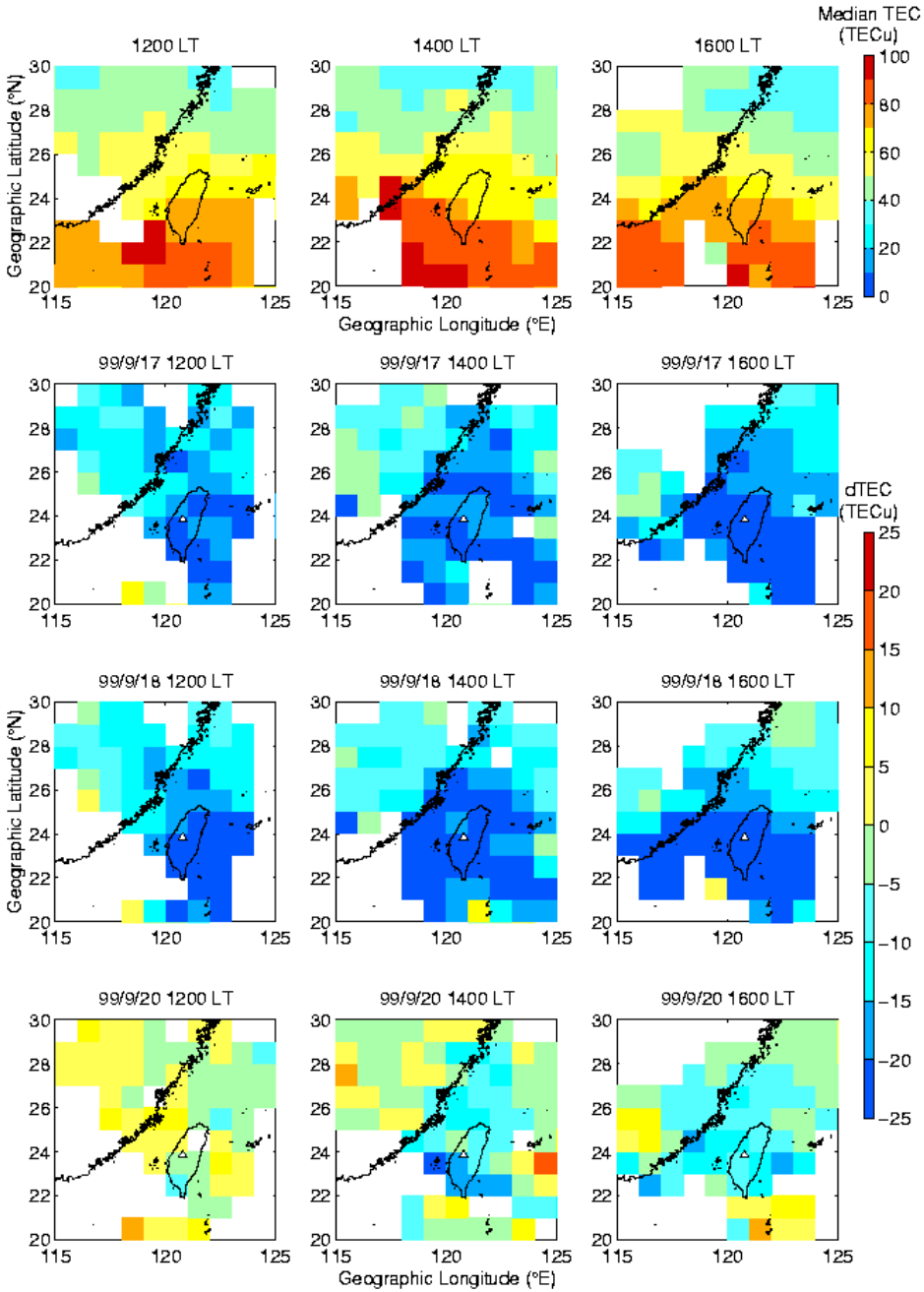
- The SIP, defined as the abnormal decrease in the ionospheric electron density during the afternoon period, 1200-1800 LT, significantly occurs within 5 days before the earthquakes.
- The odds of the earthquakes with the SIP increasing with the earthquake magnitude but decreasing with the distance between the epicenter and the ionosonde station indicate that the SIP may be energy related.
- The probability of observing the SIP seems to be related to the conductivity of the solid Earth.

Seismo Ionospheric Precursor (SIP)
-GPS TEC

SIP observed by GPS TEC

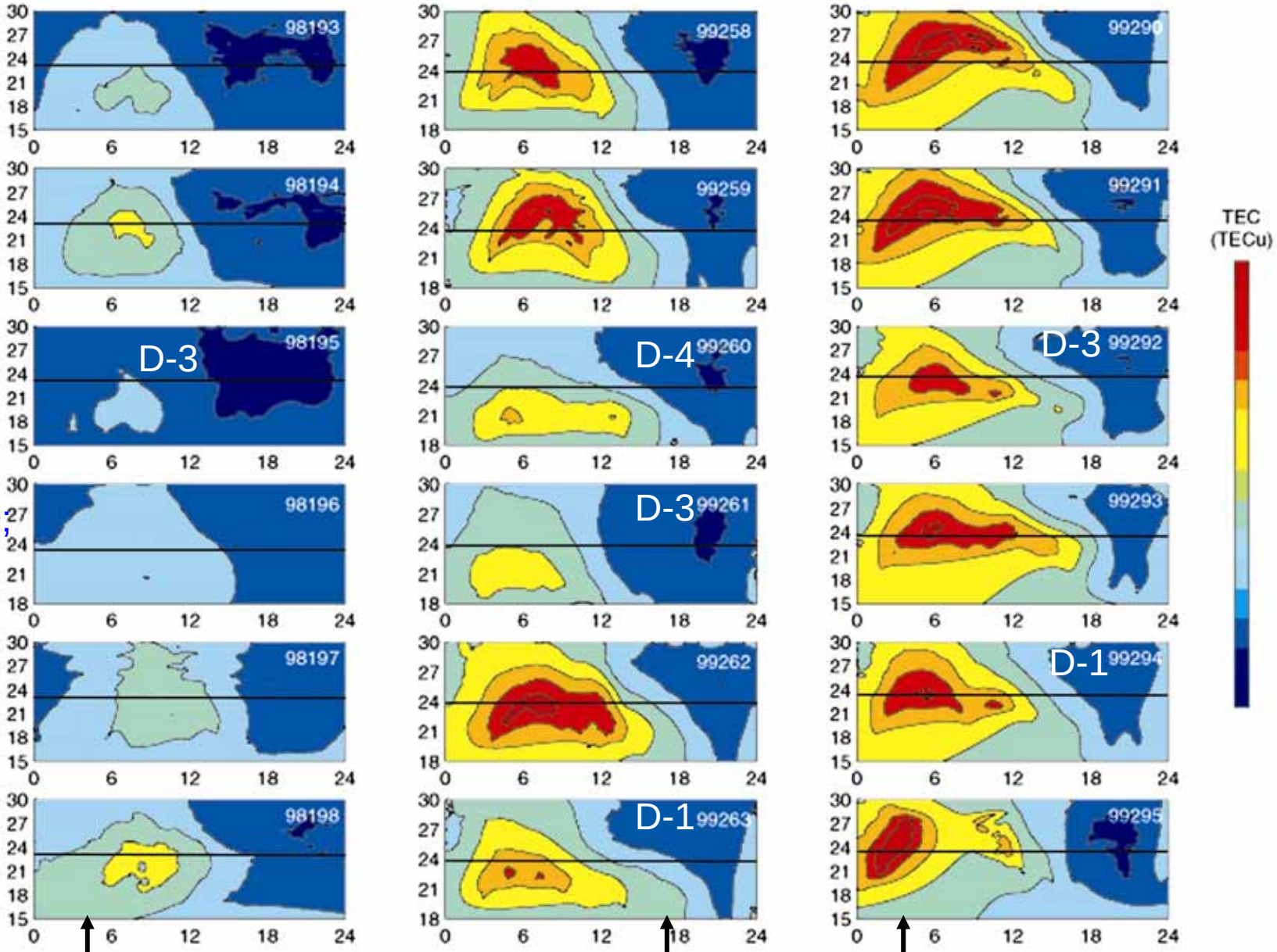


LLT maps



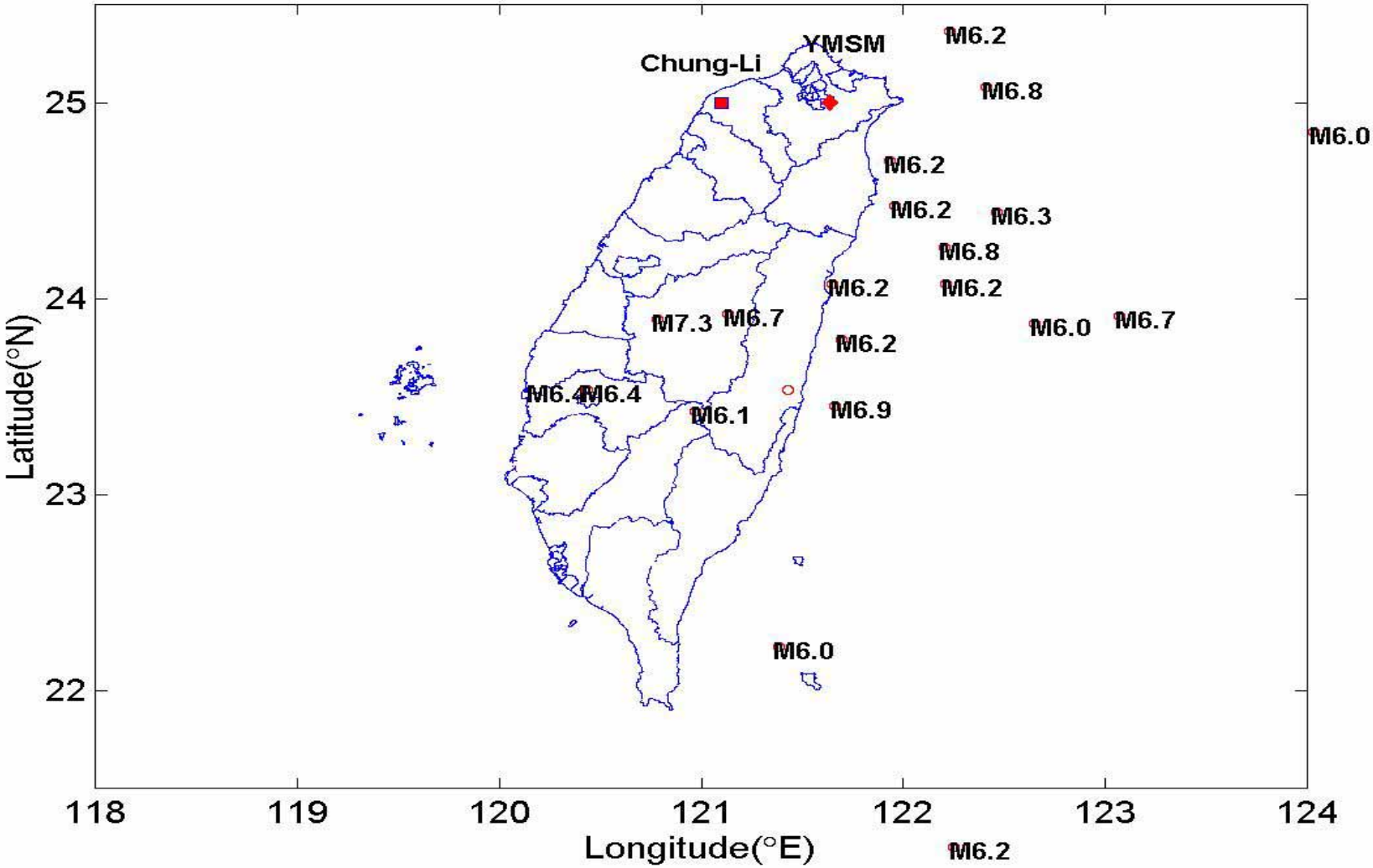
Liu et al. [GRL, 2001]

LTT plot

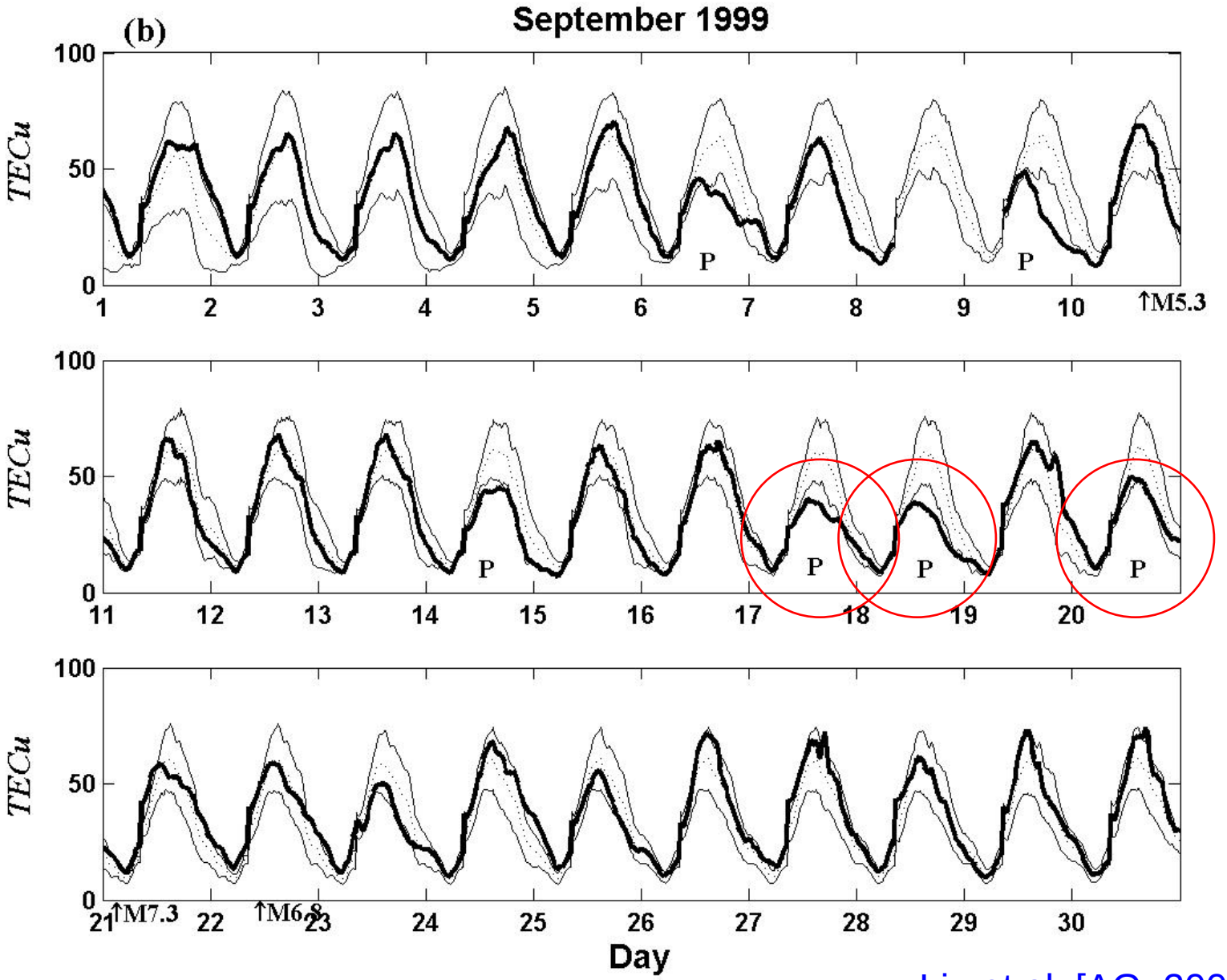


Liu et al. [IWSE,2000; SEM, 2002]

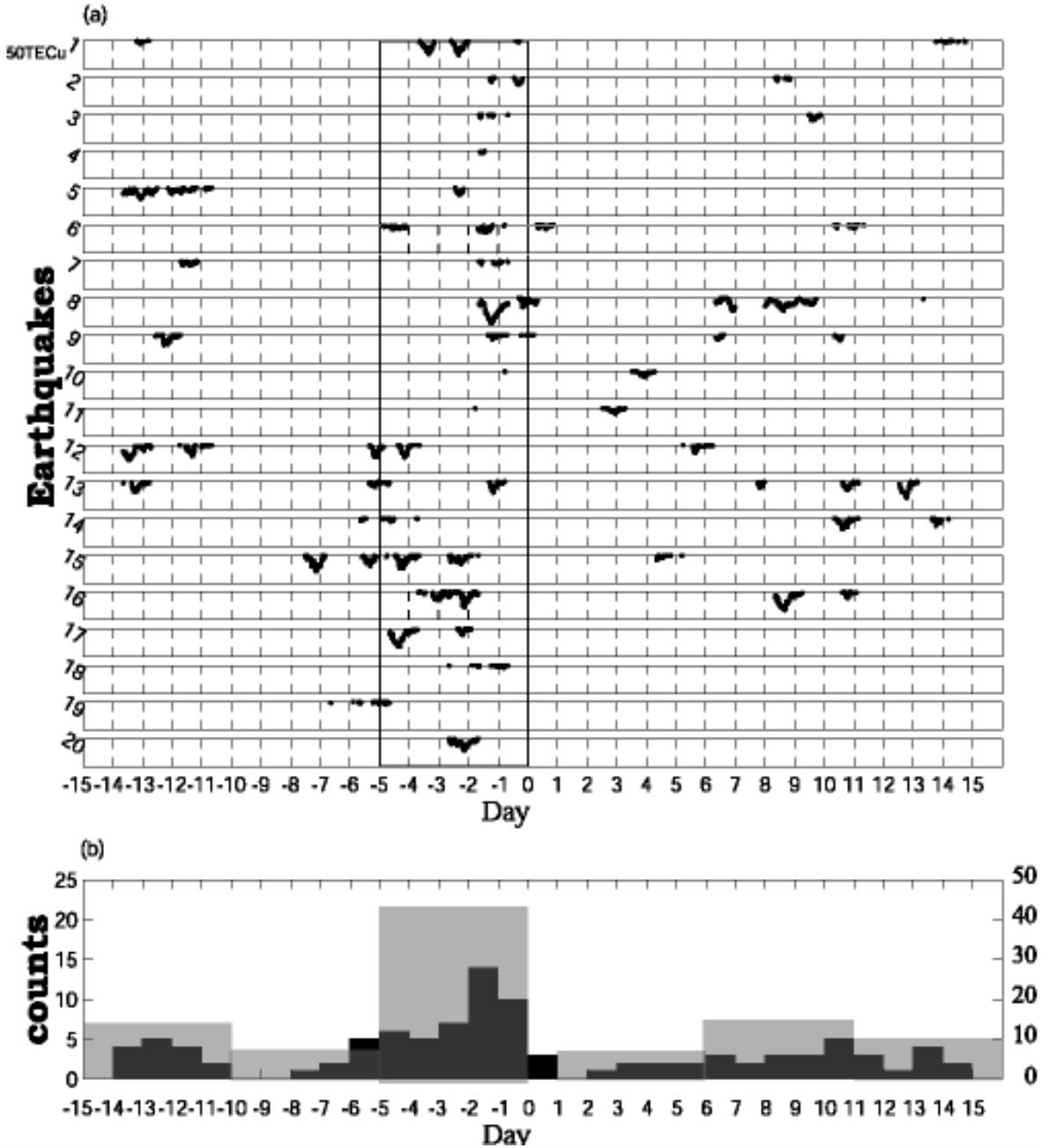
20 M≥6.0 Earthquakes, 9/21 1999-12/31 2002



Liu et al. [AG highlight, 2004]



Liu et al. [AG, 2004]



Liu et al. [AG, 2004]

Remark-2

- The maps reveal that the GPS TEC significantly decreases around the Chi-Chi epicenter when the SIP appears.
- The crest of equatorial ionization anomaly (EIA) reduces and/or moves equatorward during the SIP appearance.
- GPS TEC can be used to detect the SIP.
- Results demonstrate that GPSTEC significantly decreases within 1-5 days before the earthquakes.

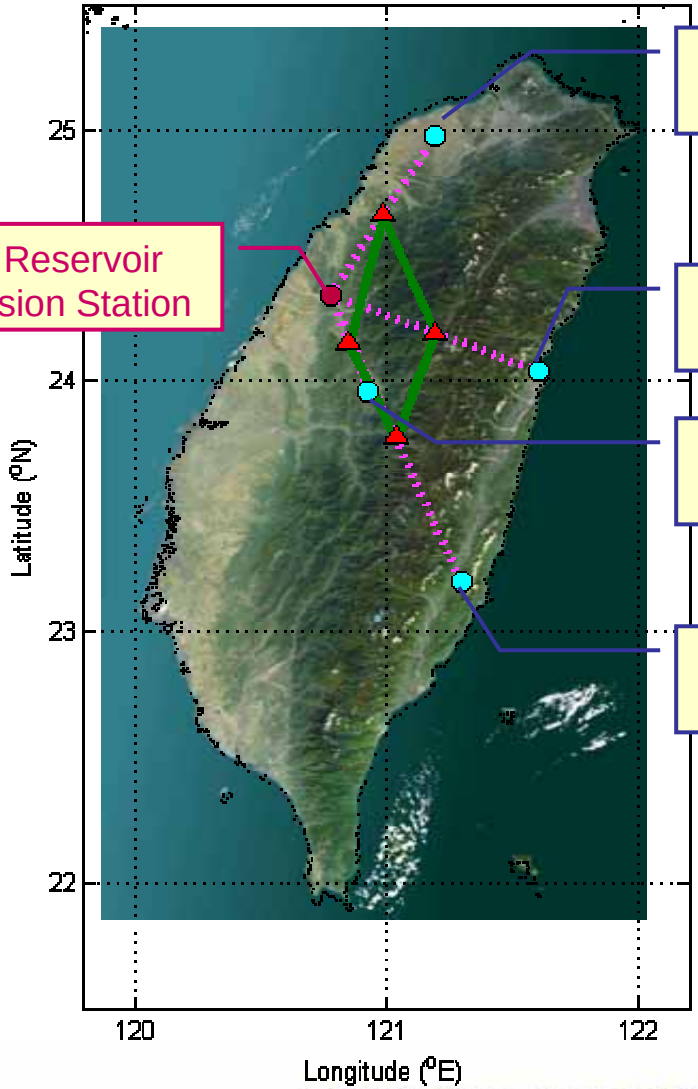
Remark-3

- The seismo-ionospheric seems to be that the GPS TEC around the epicenter significantly decreases in the afternoon of 21 December 2004, 5 days prior to the earthquake occurrence.
- The temporal and spatial variations of the precursor show that the equatorial ionization anomaly (EIA) plays an important role.

Co-seismo-ionospheric Disturbances

Doppler Sounding System

Probing frequency:5.26 MHz



National Central University
Receiver Station

Liyutan Reservoir
Transmission Station

Da-Han Institute of Technology
Receiver Station

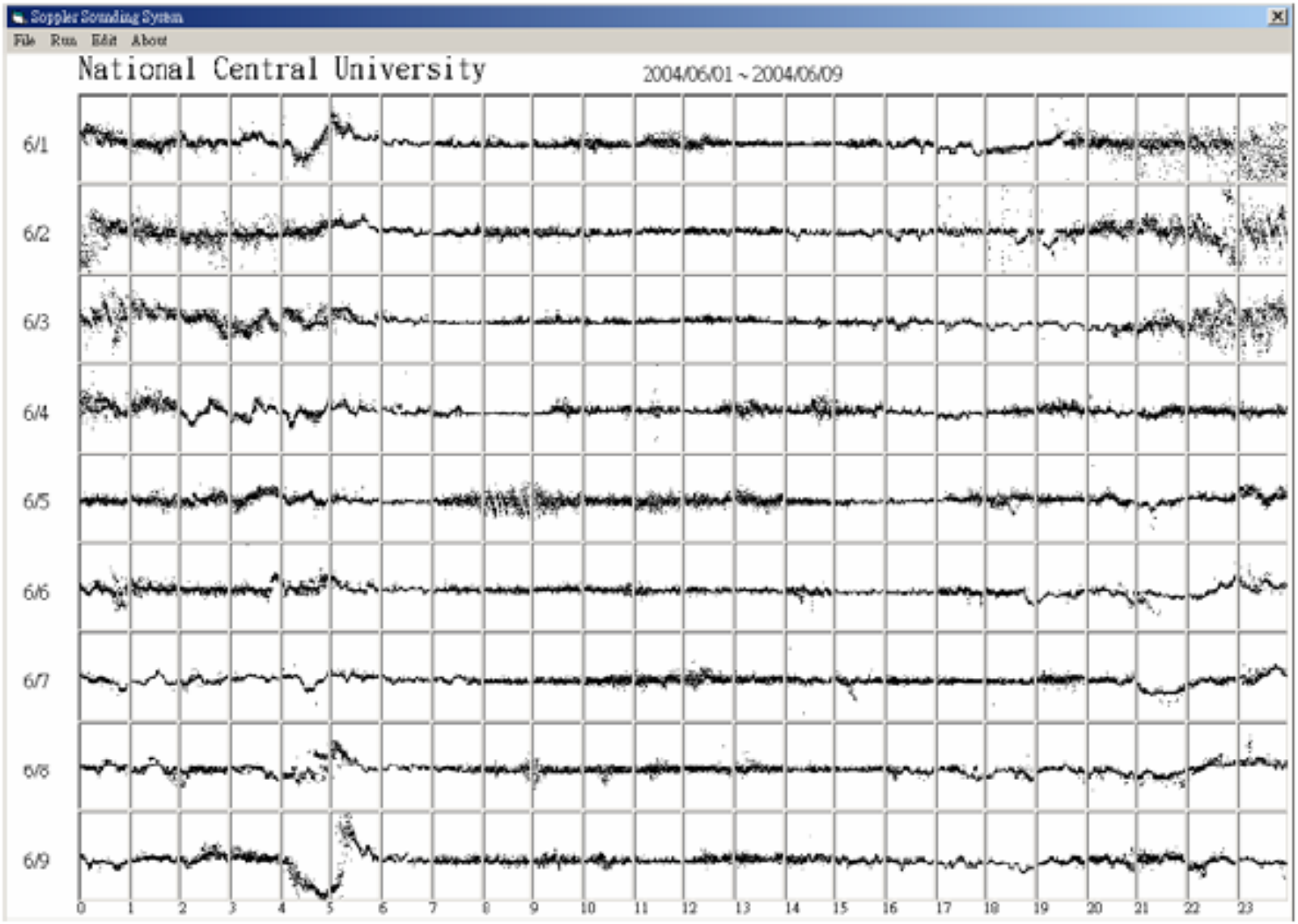
National Chi-Nan University
Receiver Station

Fuli Township, Hualien
Receiver Station

Reflection Point

Wave propagate path

Routine Observation 例行性觀測資料



Date in 2004

Local Time (hr)

Amplification

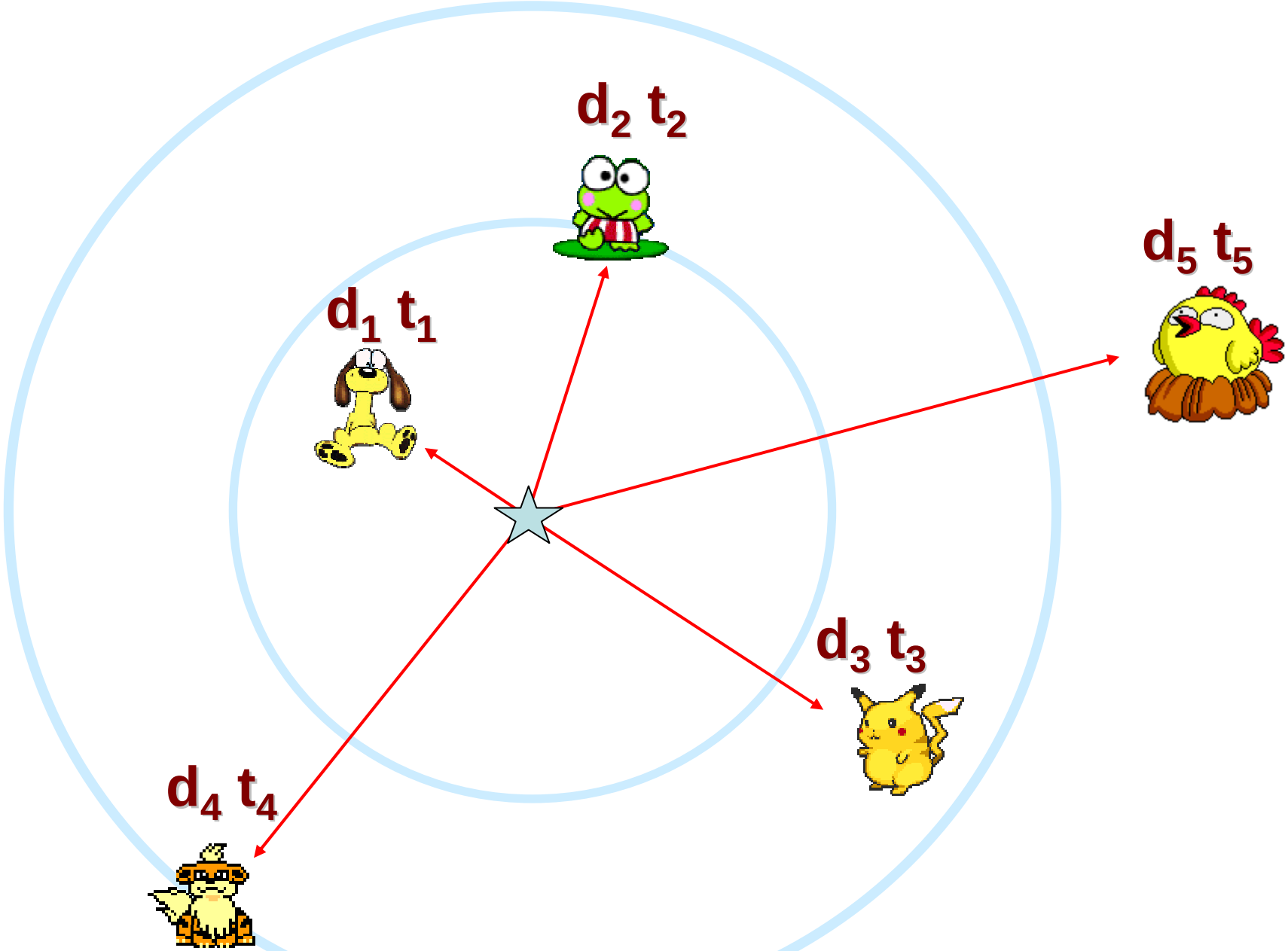
- $\kappa = 1/2\,\rho_g V_{gm}^2 = 1/2\,\rho_a V_{am}^2$
- $V_m = A\omega$
- $A_a/A_g = (\rho_g/\rho_a)^{1/2} \sim 10^6$

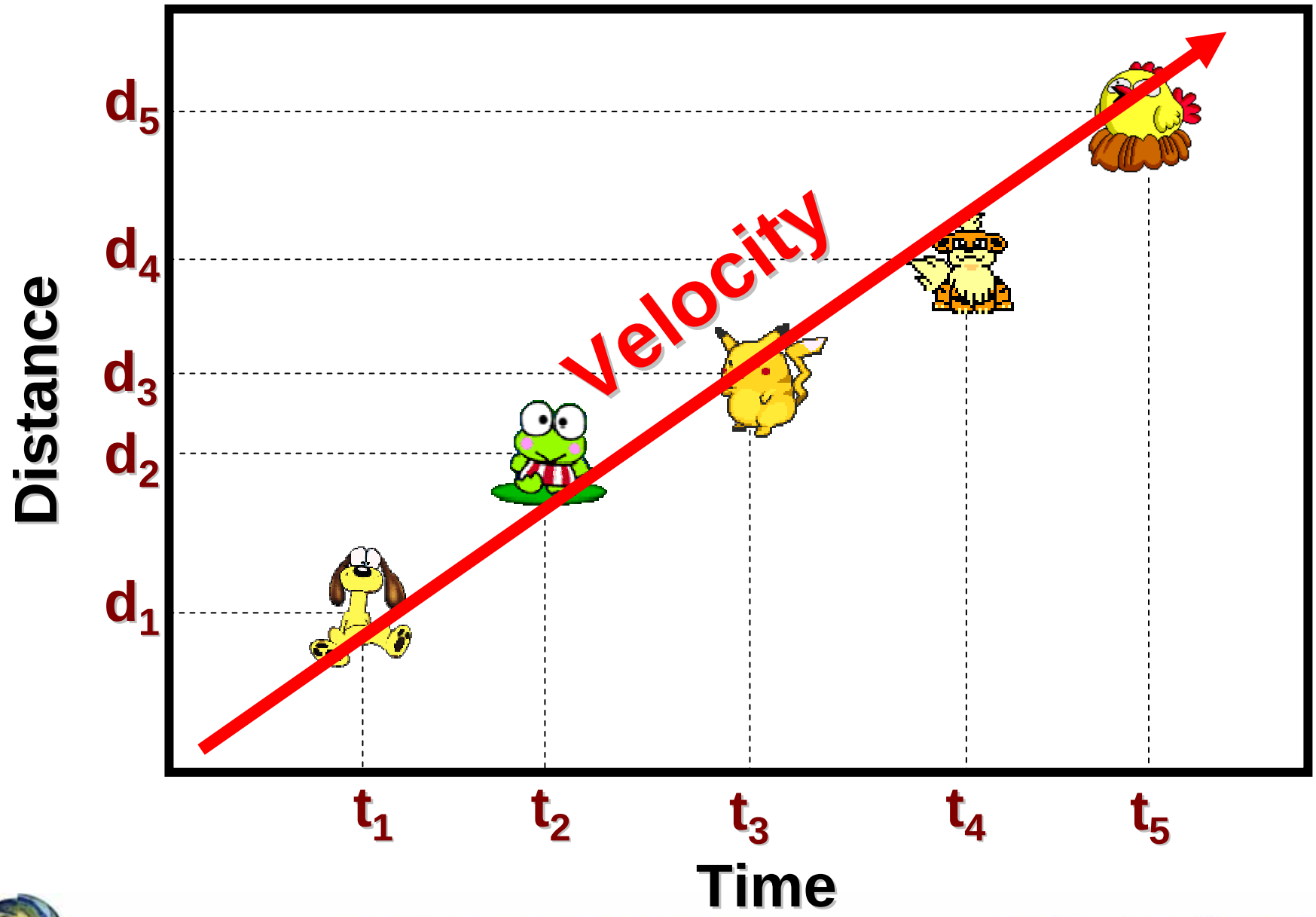
Locate sources of atmospheric and ionospheric disturbances triggered by an earthquake

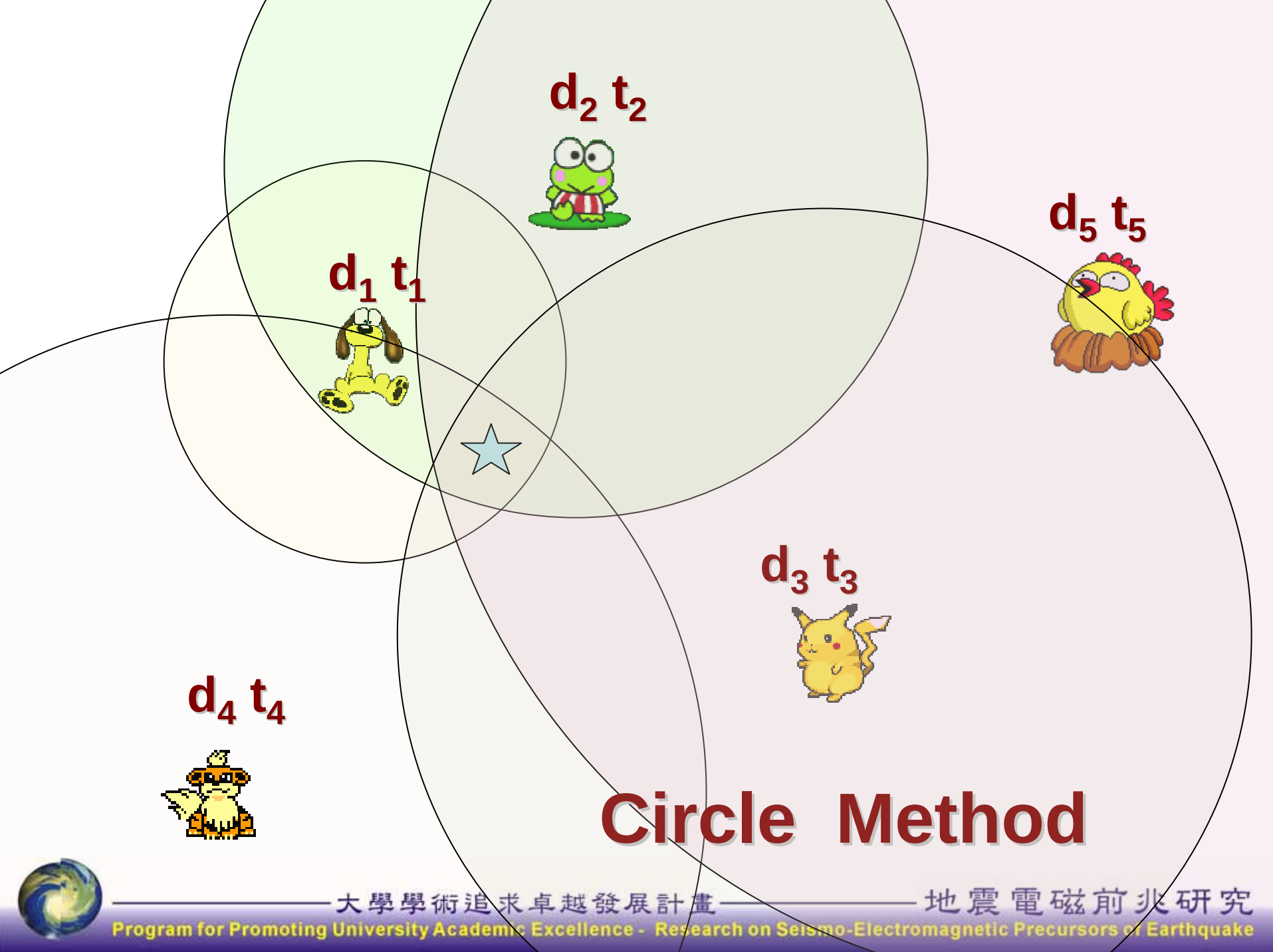
- Circle Method
- Ray Tracing Technique
- Beam Forming Technique





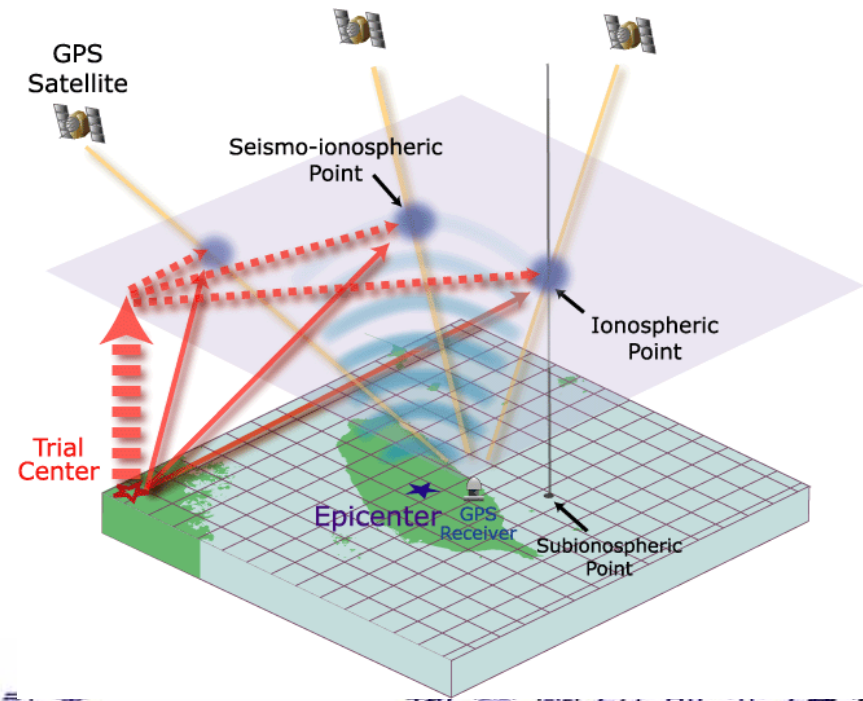


$d_2\ t_2$
$d_1\ t_1$
$d_5\ t_5$
$d_3\ t_3$
$d_4\ t_4$


Distance
d_5
d_4
d_3
d_2
d_1
Velocity
t_1
t_2
t_3
t_4
t_5
Time


d_2 t_2
d_1 t_1
d_5 t_5
d_3 t_3
d_4 t_4
Circle Method

Grid Search

- Hamilton's Variational Principle of Lagrangian Mechanics (assume that there are numerous paths between the CID origin or trial center and the SIP.
- Global Grid Search (the Ray Tracing Technique and Beam Forming Technique)



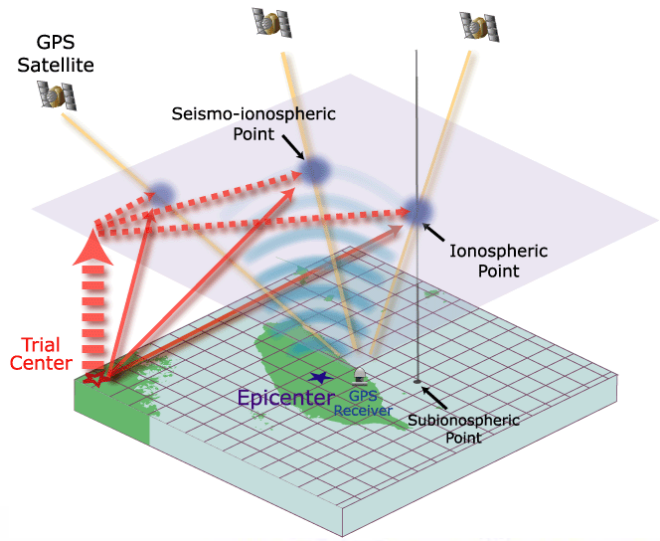
The Ray Tracing Technique

- The two-segment path

  $T_{Ck} = T_{Ak} - (D_{Vk}/V_V + D_{Hk}/V_H)$

- The great circle (radial) path

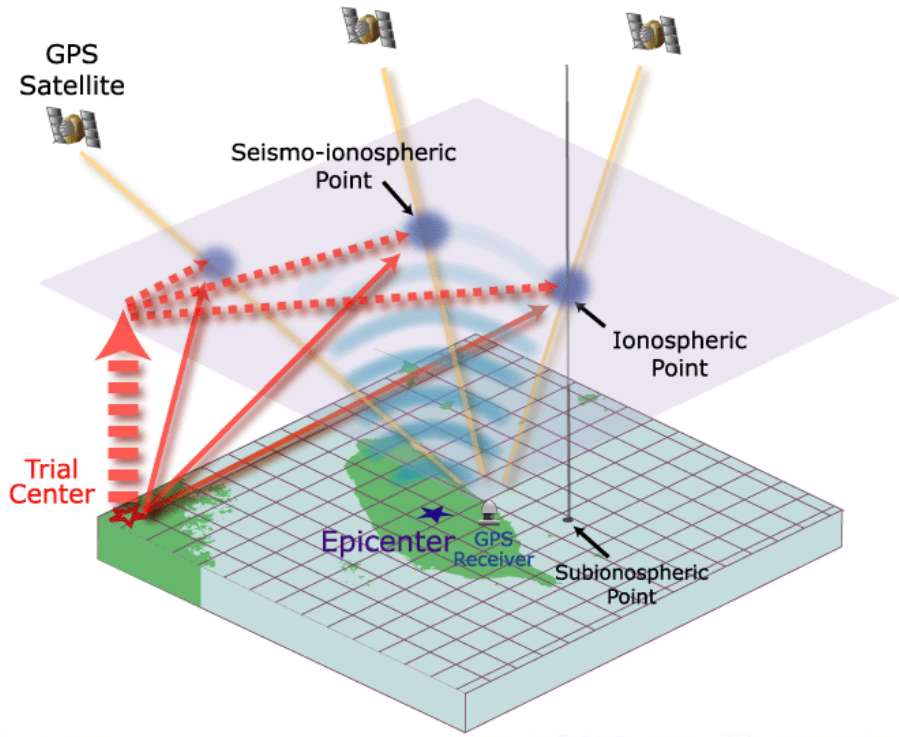
  $T_{Ck} = T_{Ak} - (D_{Rk}/V_R)$



The Beam Forming Technique

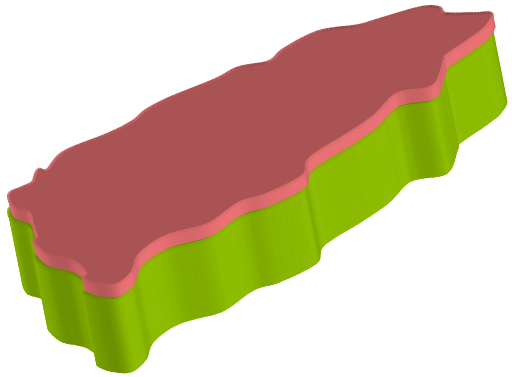
- The great circle (radial) path

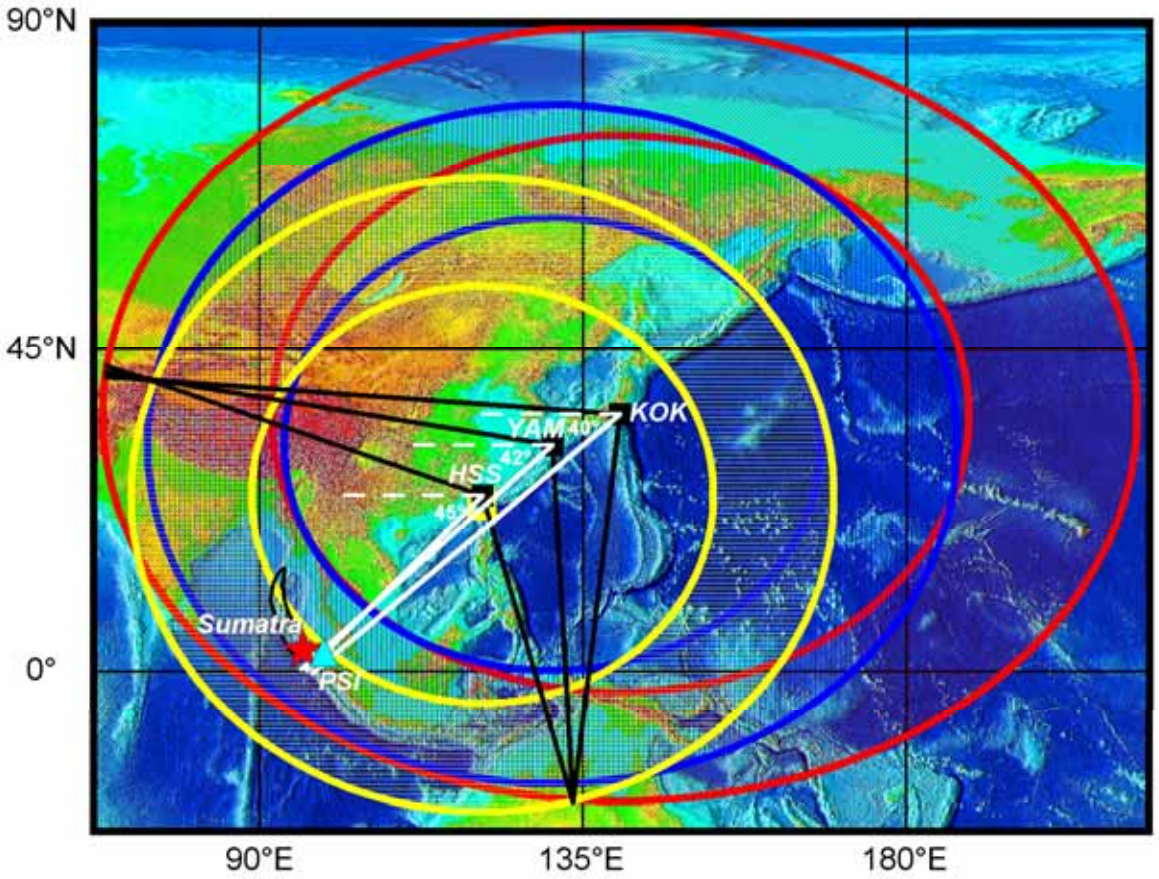
  $R_{Rk} = D_{Rk}/(T_{Ak} - T_o)$

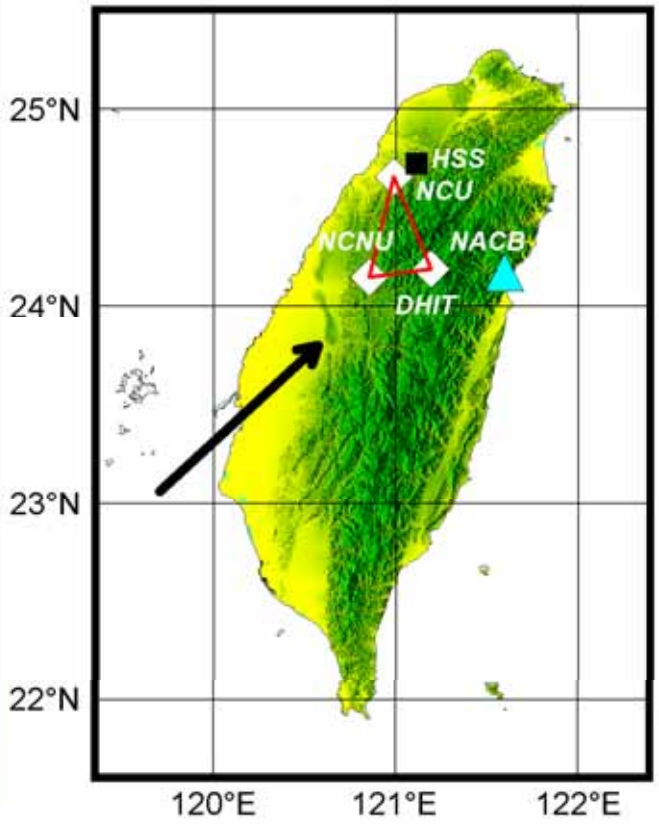


Ionosphere

AGW







M9.3 off the west coast of northern Sumatra (3.244°N, 95.825°E)
26 December 2004 00:58:49 UTC

Liu et al. [GRL, 2006]

Rayleigh Wave 3.5 km/s AGW 360±70m/s

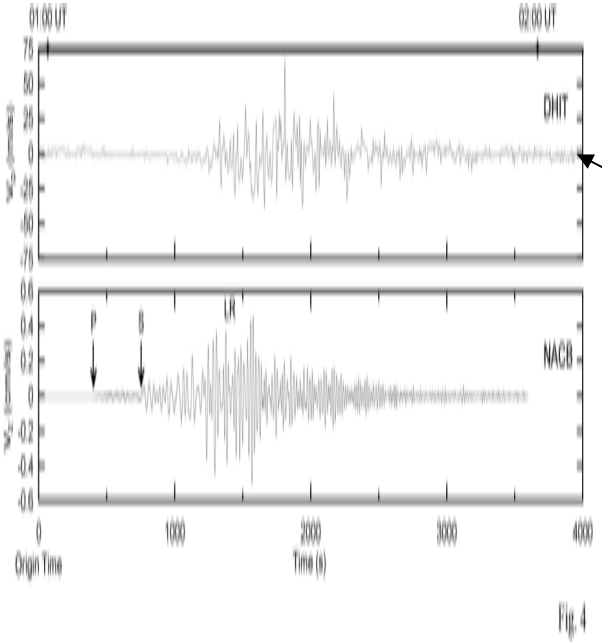
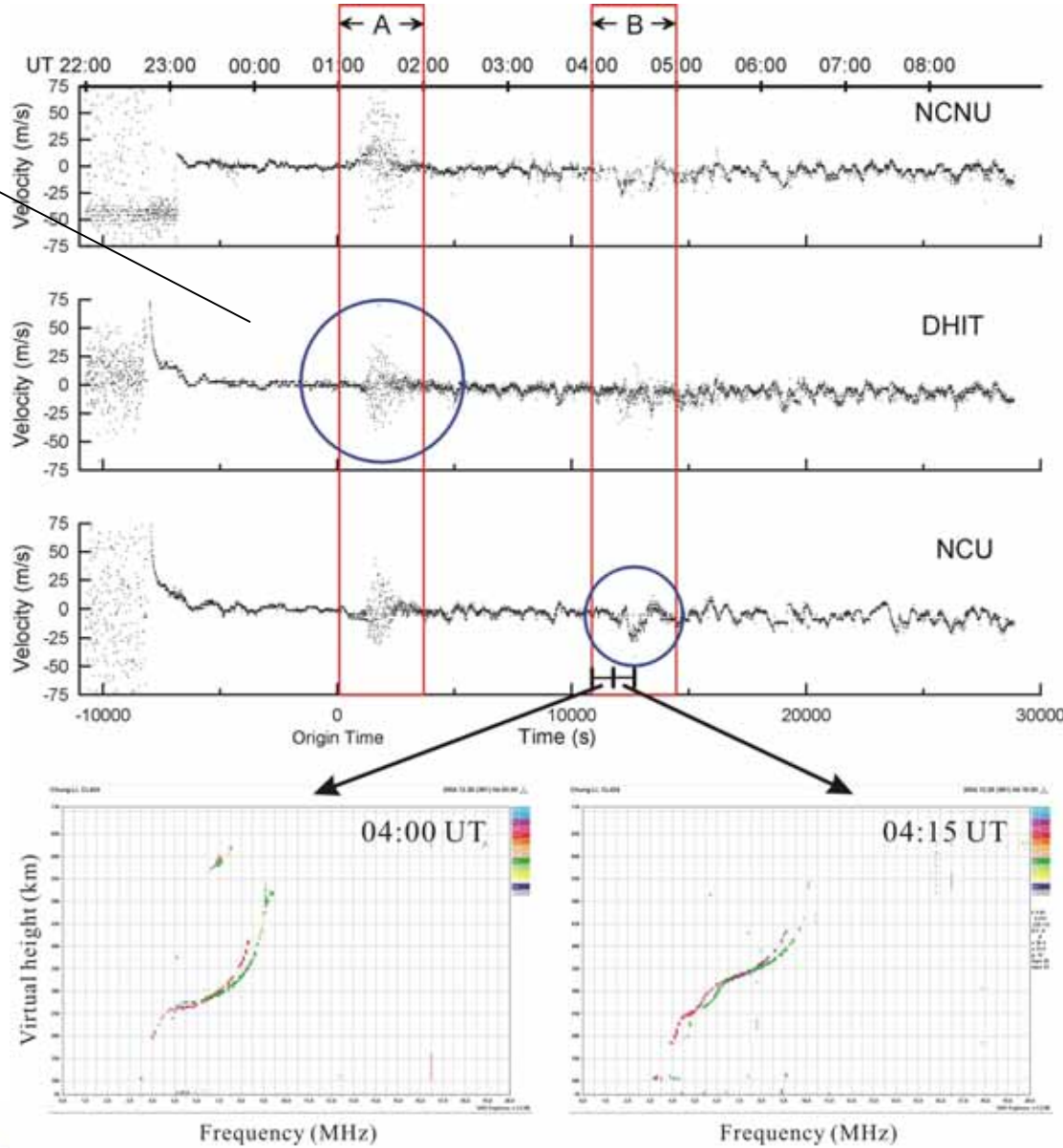
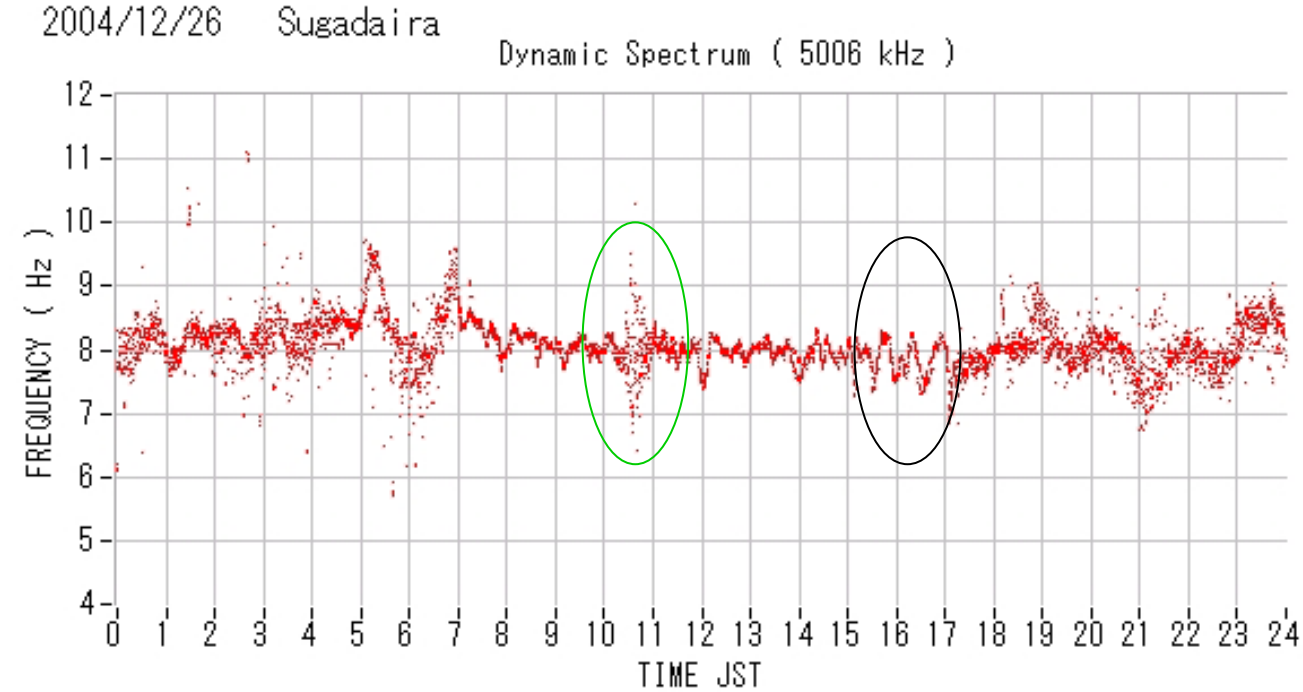


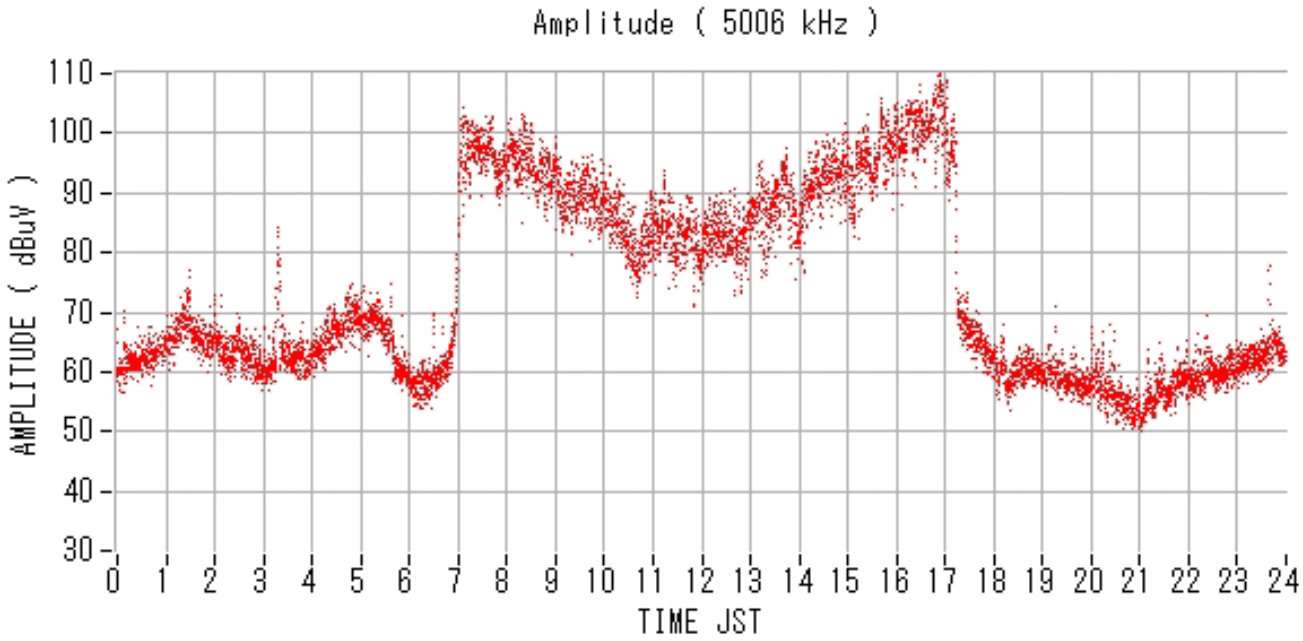
Fig. 4

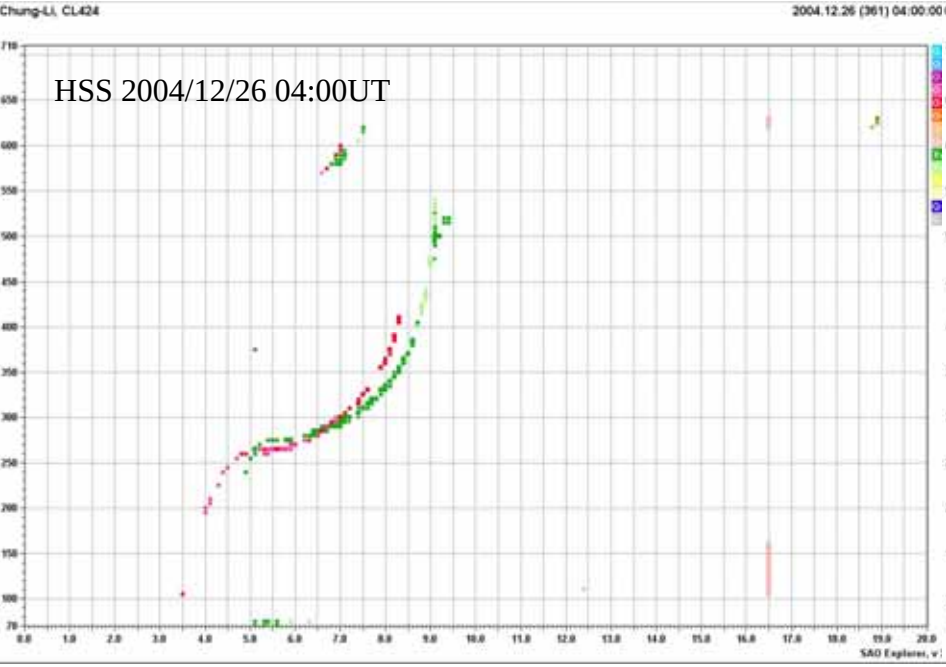


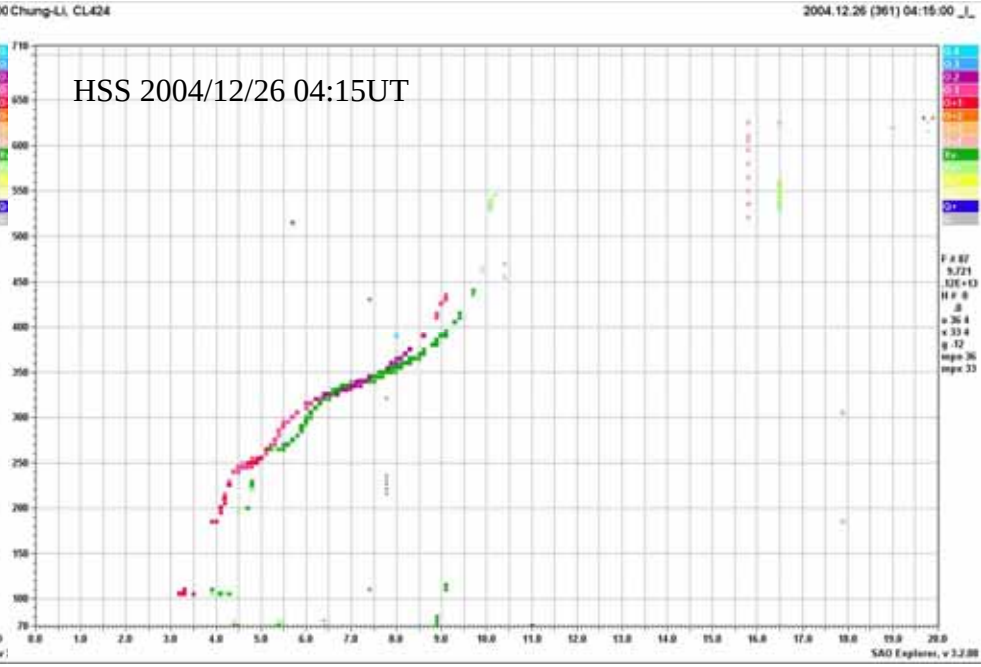
Liu et al. [GRL, 2006]

Fig. 2


2004/12/26 Sugadaira
Dynamic Spectrum (5006 kHz)
FREQUENCY (Hz)
TIME JST


Amplitude (5006 kHz)
AMPLITUDE (dBuV)
TIME JST


Chung-Li, CL424
2004.12.26 (361) 04:00:00
HSS 2004/12/26 04:00UT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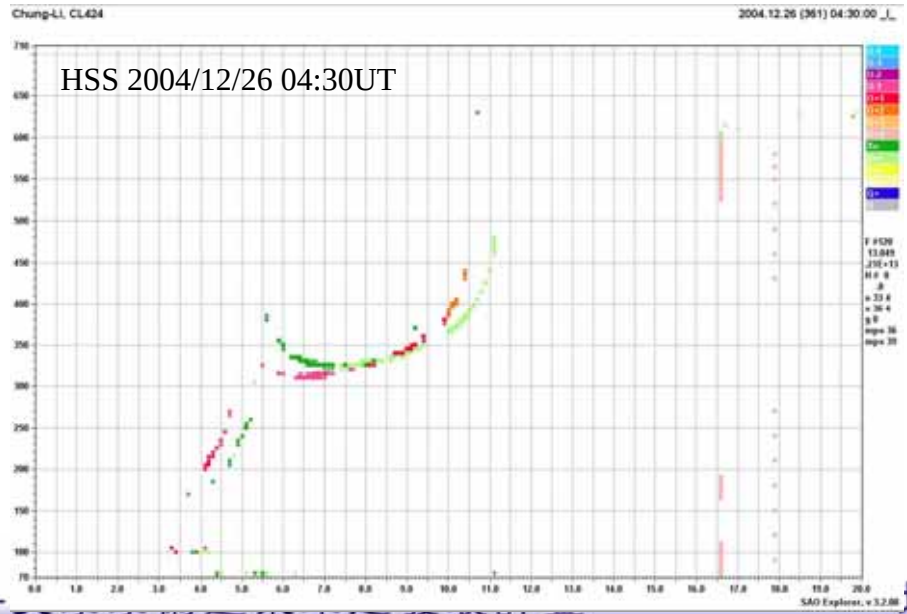
Chung-Li, CL424
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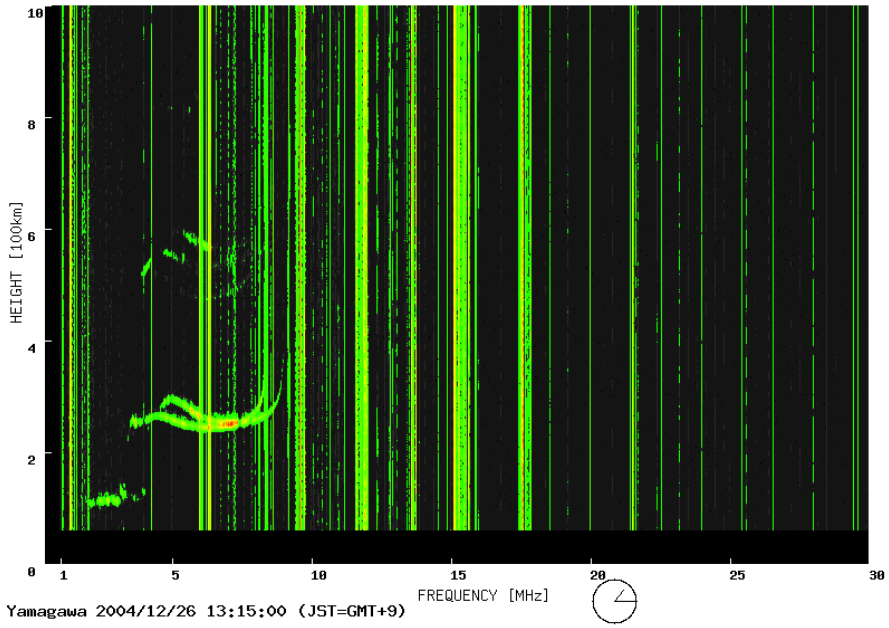
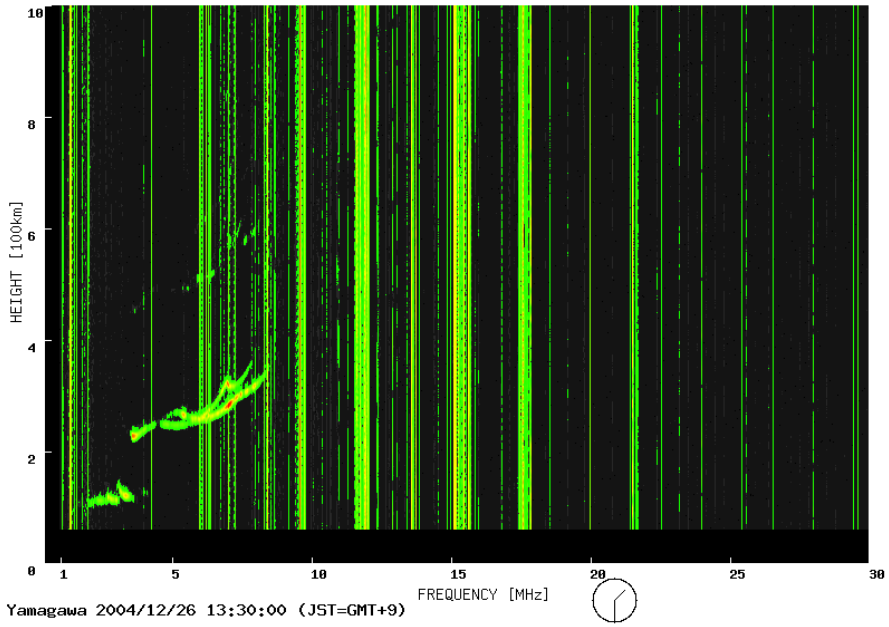
YAM 2004/12/26 04:15UT



YAM 2004/12/26 04:30UT



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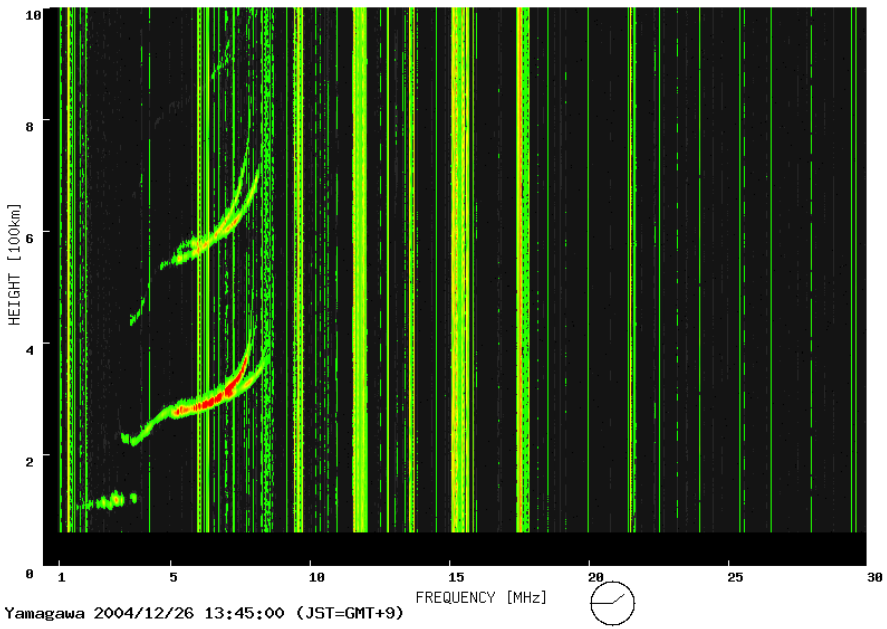
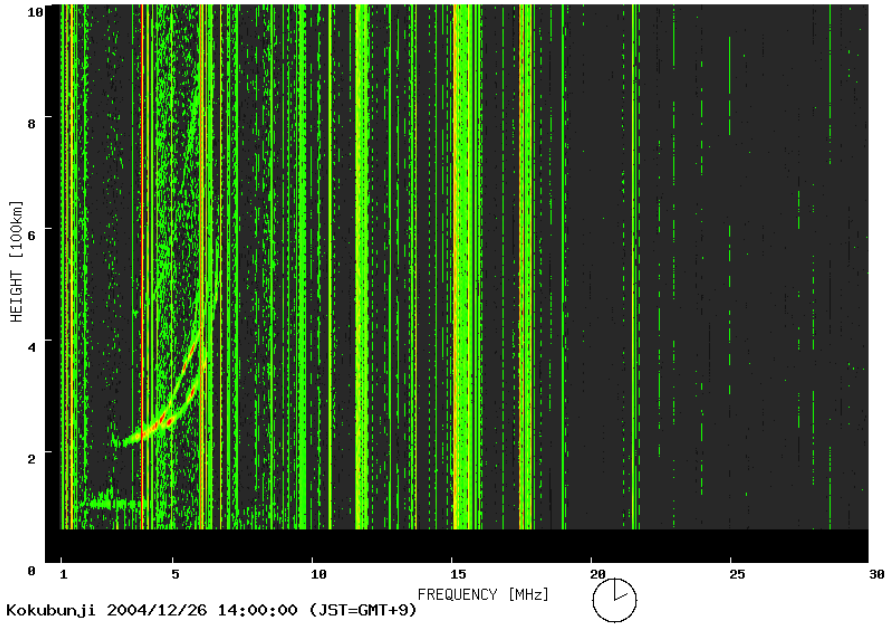
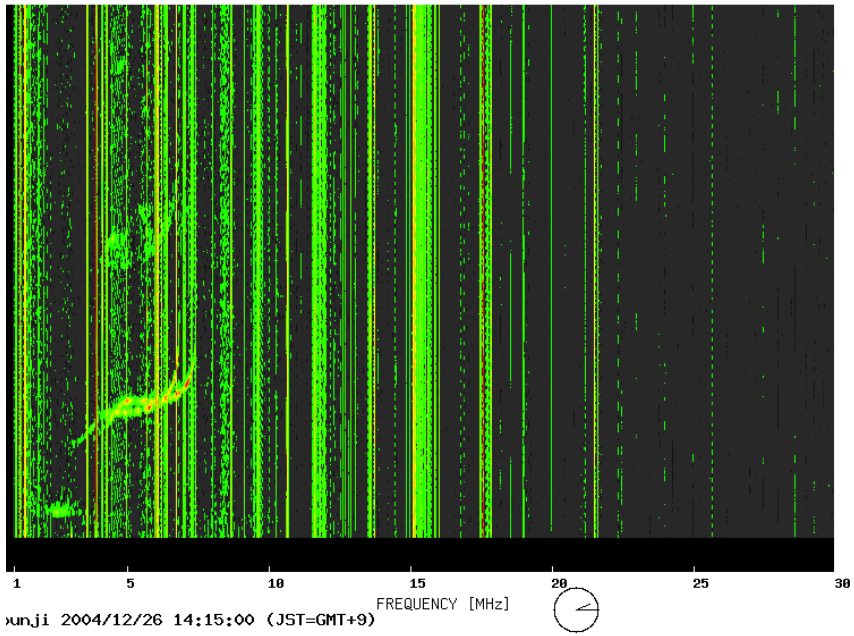


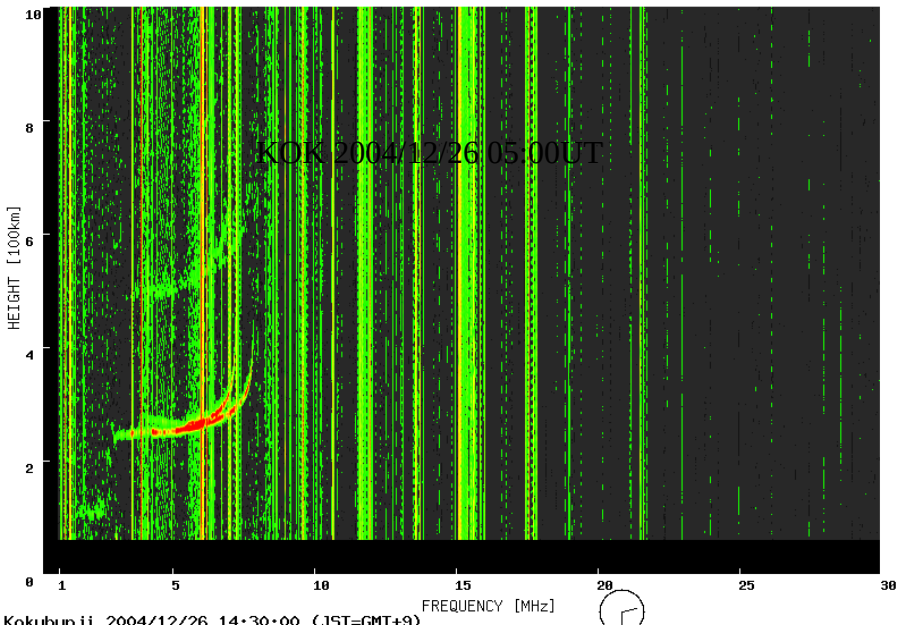
KOK 2004/12/26 05:00UT

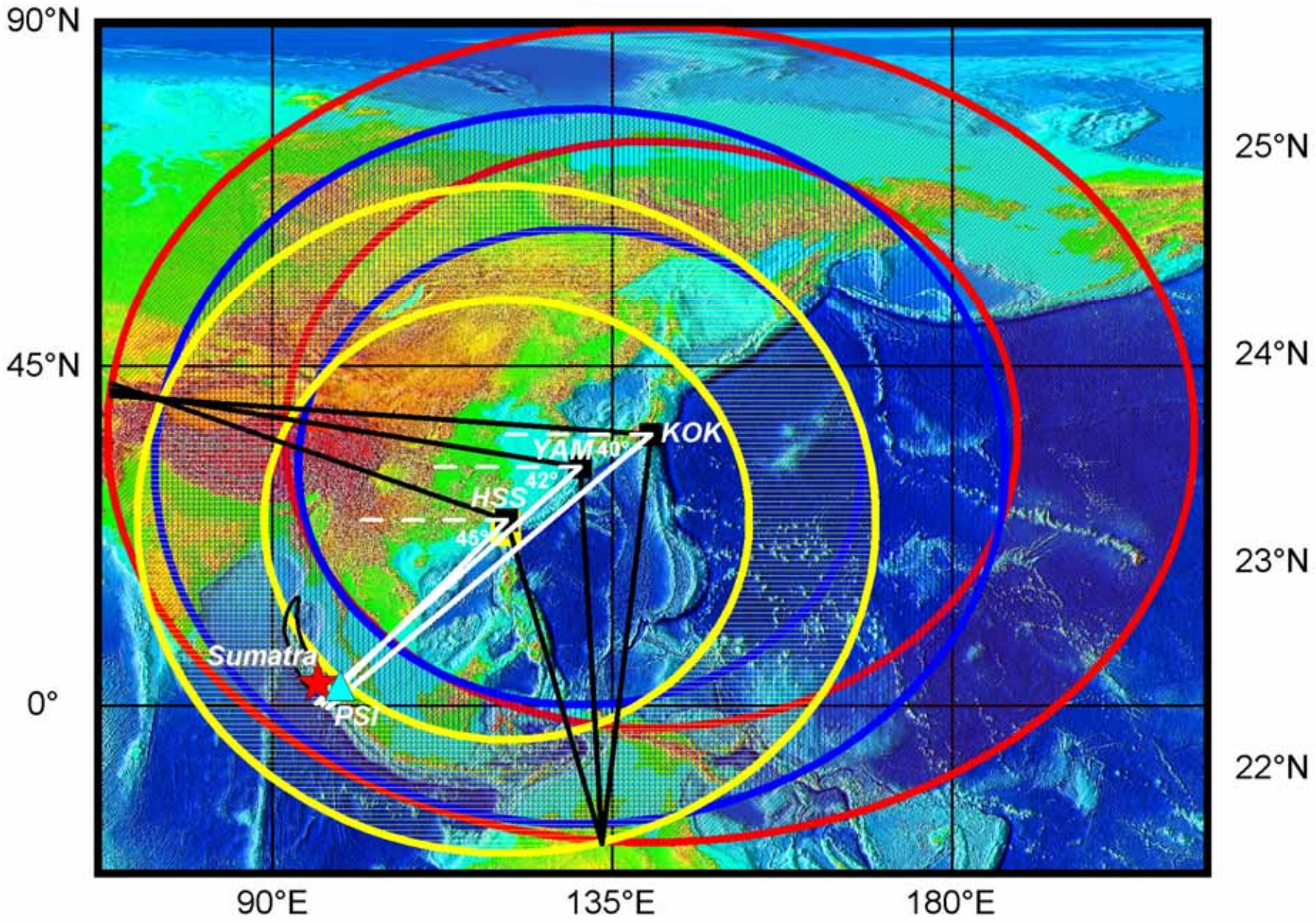


KOK 2004/12/26 05:15UT



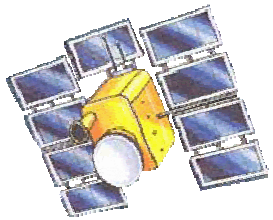
KOK 2004/12/26 05:30UT



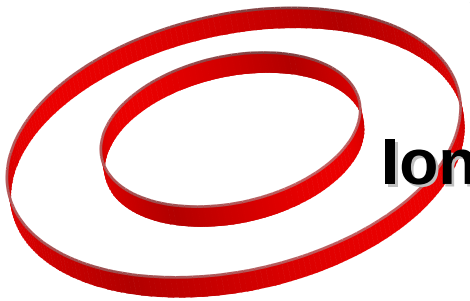

90°N
45°N
0°
90°E
135°E
180°E
25°N
24°N
23°N
22°N
KOK
YAM
40°
42°
HSS
45°
Sumatra
PSI

Remark-4

- The disturbance excited by the Rayleigh waves results in the induced atmospheric disturbances traveling away from the earth's surface 833 m/s upward into the ionospheric and there causing the vertical fluctuations with a maximum Doppler velocity of about 70 m/s and displacement of about 200 m (amplification 50,000).
- The disturbance propagating at a horizontal speed of 360±70 m/s, is attributable to coupling of the atmospheric gravity waves excited by broad crustal uplift together with the following big tsunami waves around the earthquake source zone.

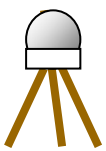


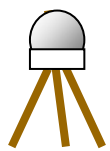
GPS Satellite

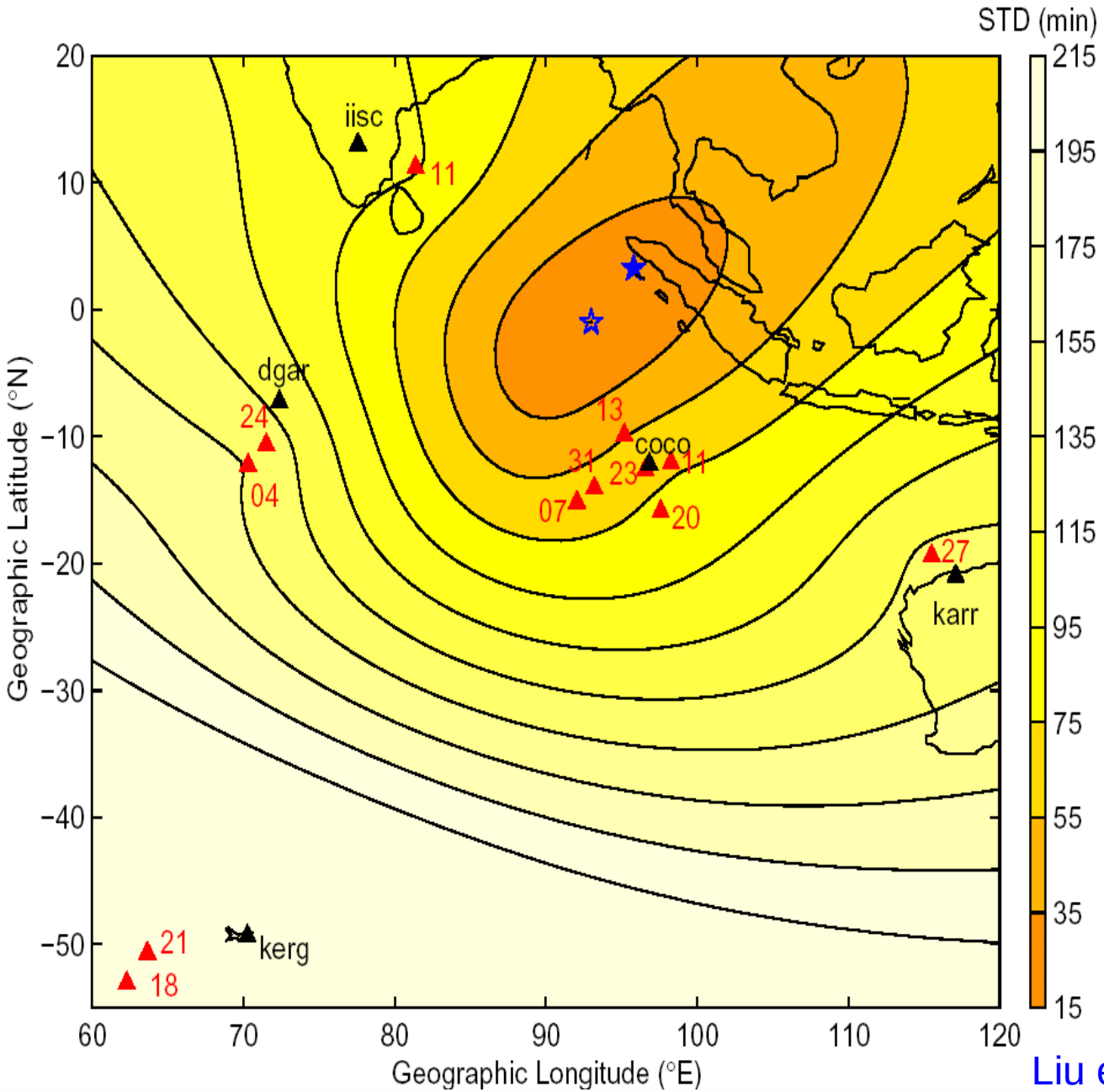


Ionosphere

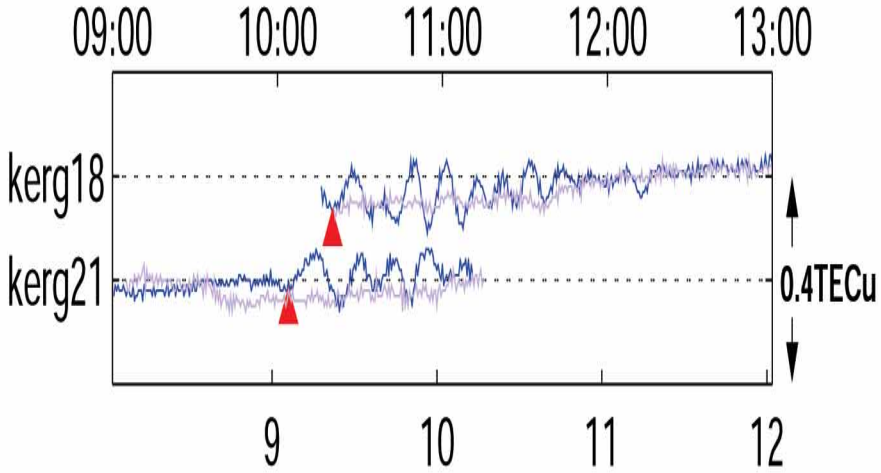
Tsunami







Liu et al. [JGR, 2006]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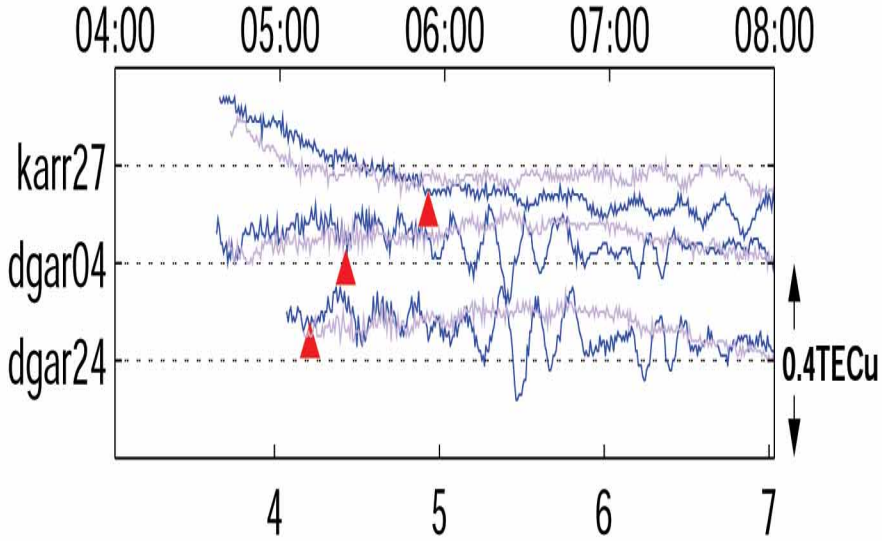
10:00
11:00
12:00
13:00
kerg18
kerg21
0.4TECu
9
10
11
12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05:00
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07:00
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karr27
dgar04
dgar24
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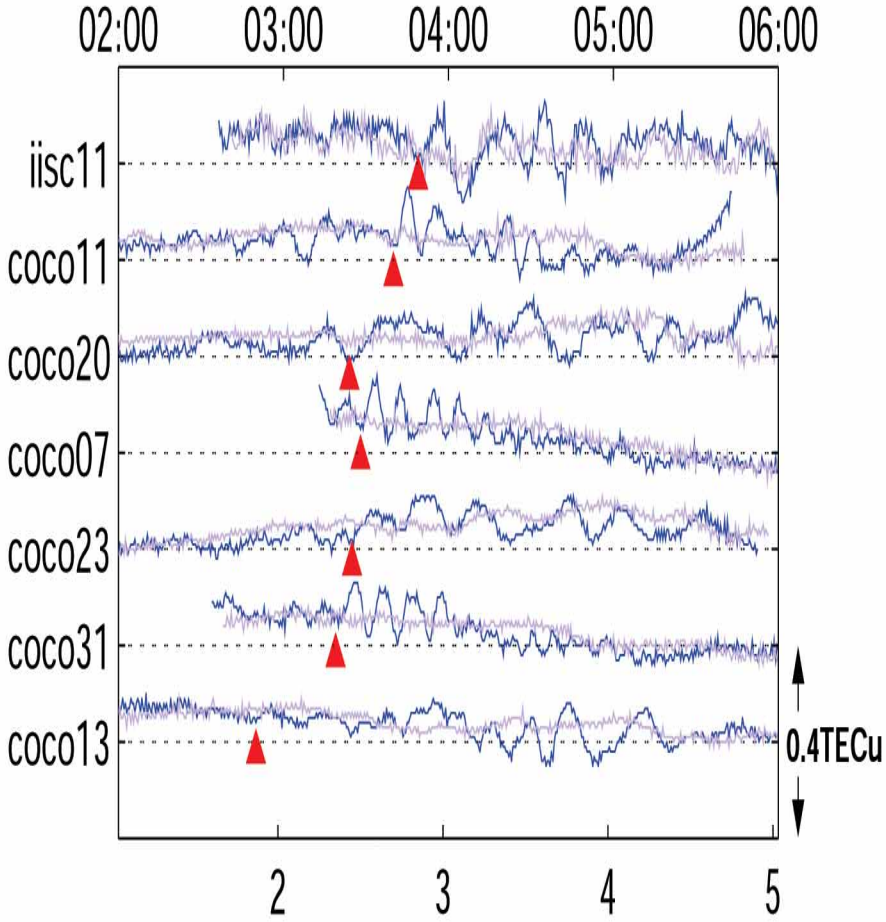
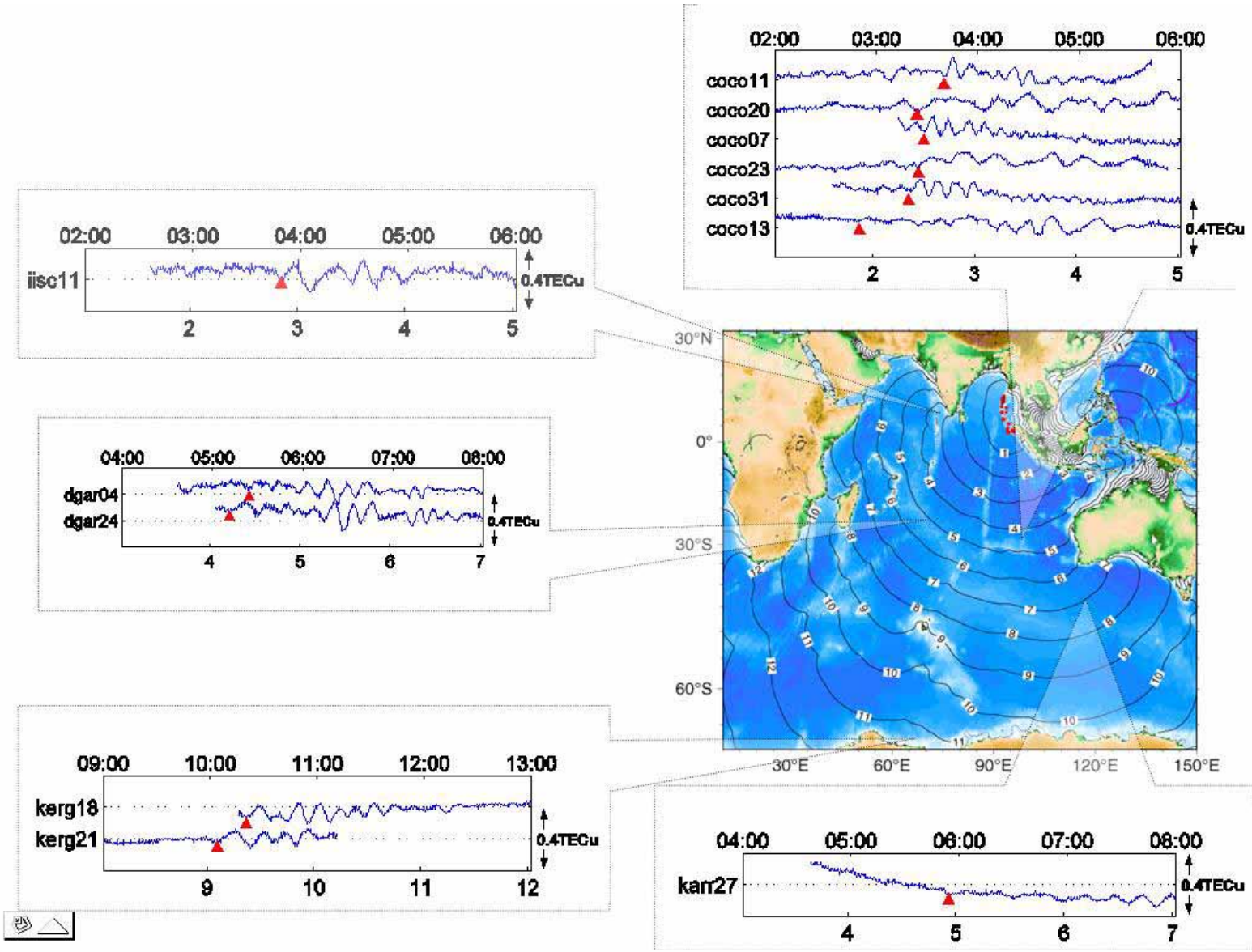
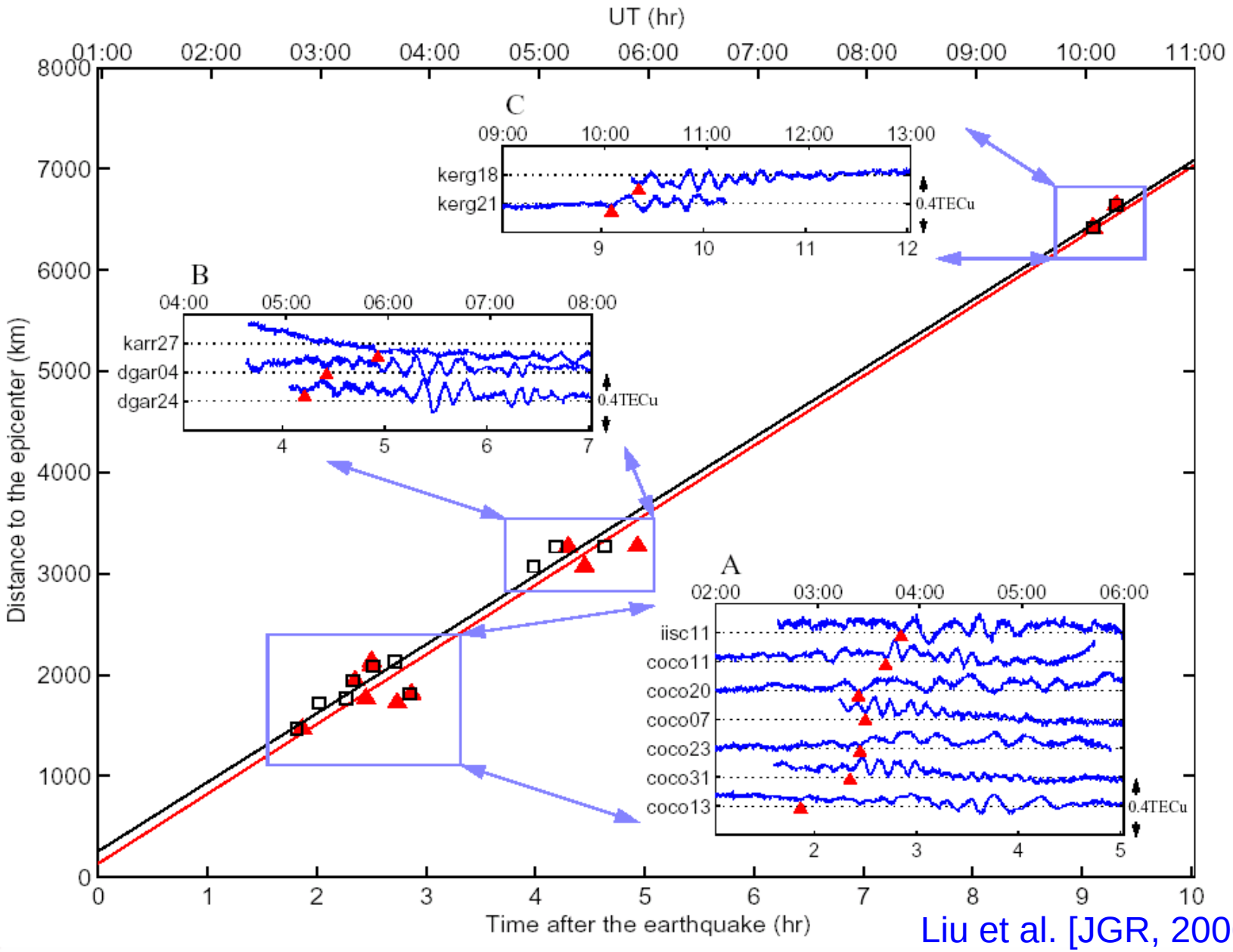
4
5
6
7

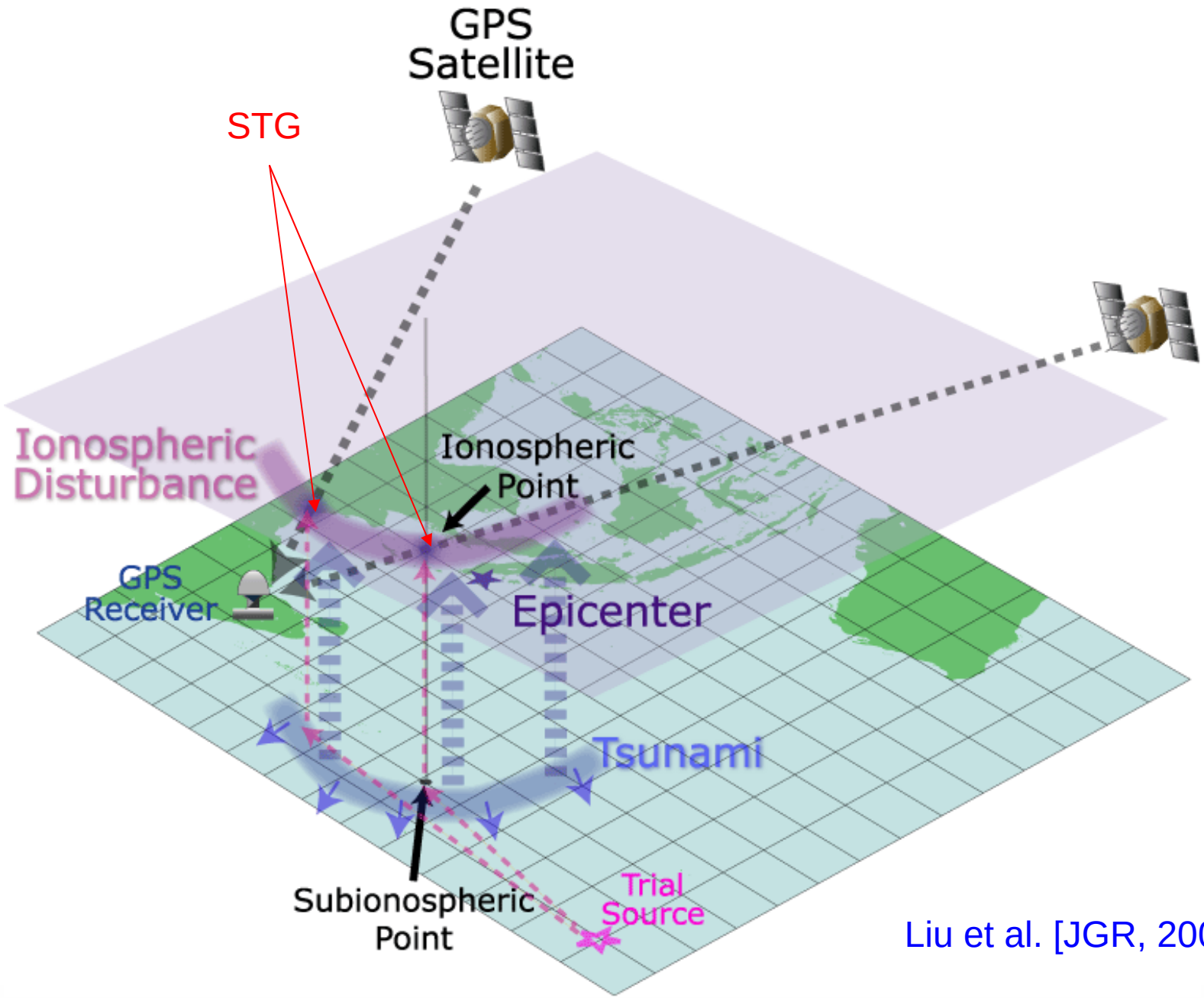

02:00
03:00
04:00
05:00
06:00
iisc11
coco11
coco20
coco07
coco23
coco31
coco13
0.4TECu
2
3
4
5

The two arrival times have good agreements accordingly.

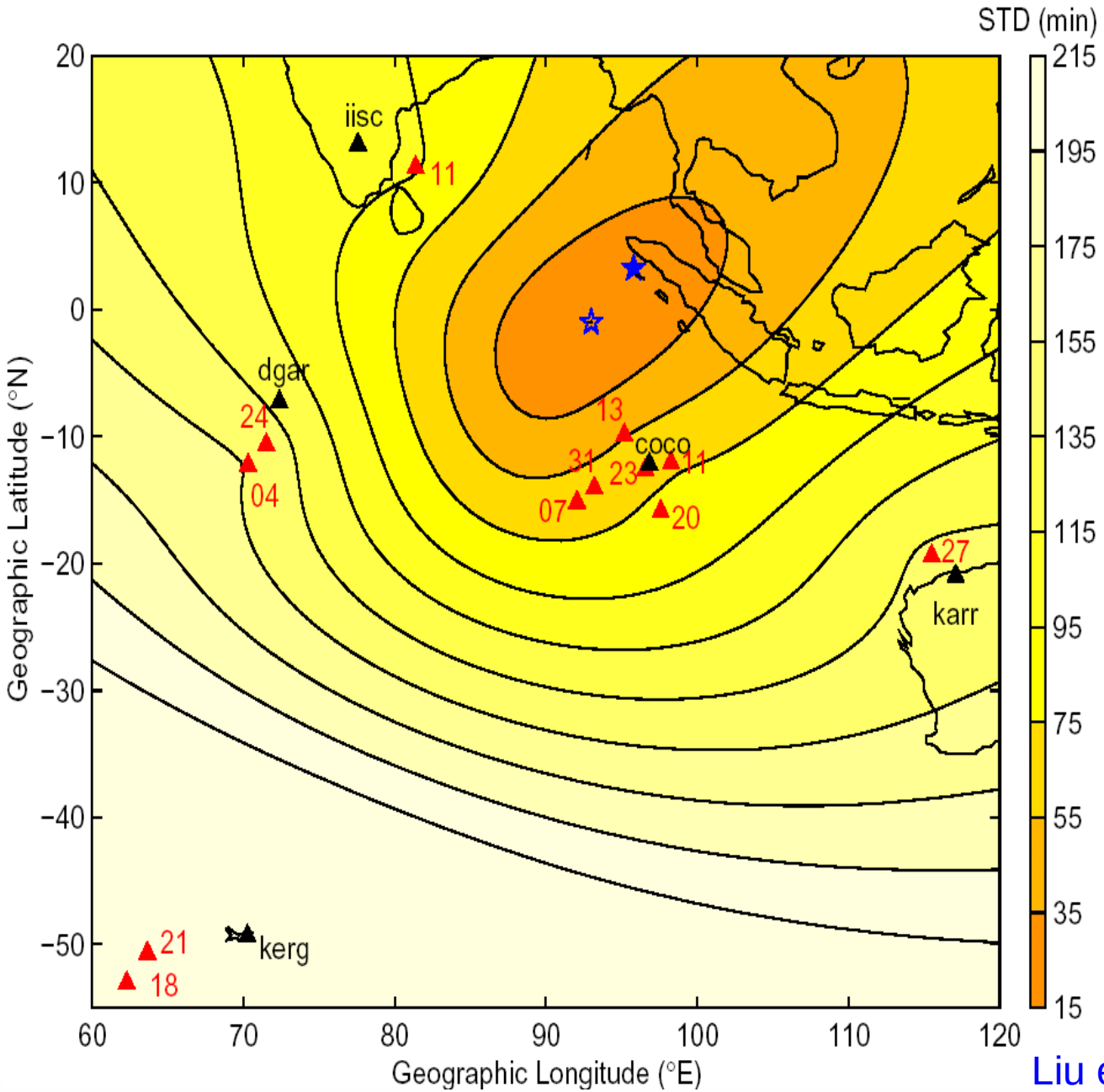




Liu et al. [JGR, 2006]



Liu et al. [JGR, 2006]

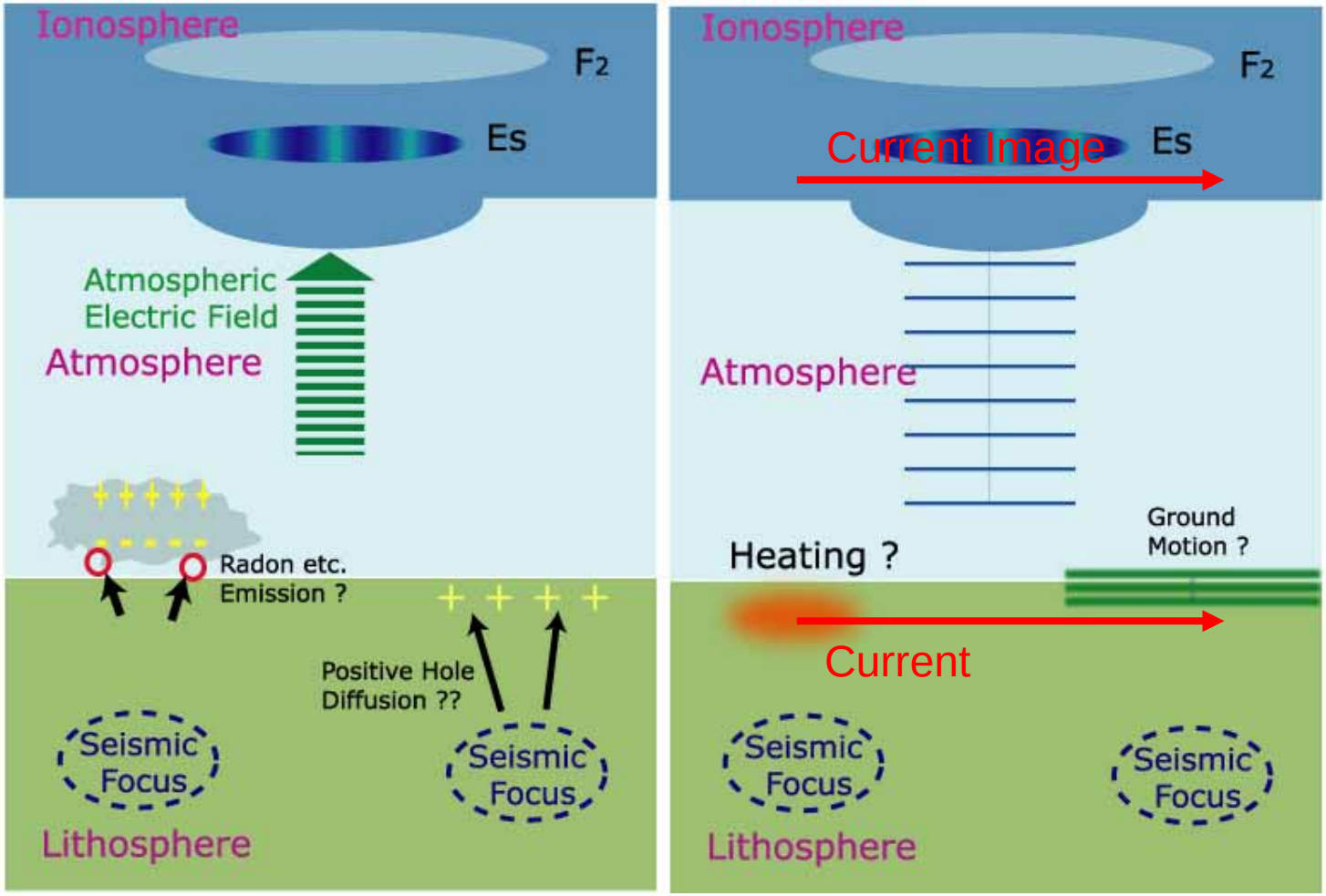


Liu et al. [JGR, 2006]

Remark-5

- It is found that the tsunami waves triggered acoustic gravity waves near the sea surface, which then traveled upward with an average velocity of about 730m/s into the ionosphere and significantly disturbed the GPS TEC (or ionospheric electron density) within it.
- The giant iononamis which have maximum heights of about 8.6-17.2 km (amplification 1300-20,000), periods of 10-20 minutes, and horizontal wavelengths of about 120-240 km, travel away from the epicenter with an average horizontal speed of about 700 km/hr.

Mechanisms of Seismo-Ionospheric Variations



Conclusion

- Seismo-ionospheric precursors might mainly be resulted from the EM processes in the lithosphere.
- Co-seismo-ionospheric disturbances is most likely triggered by the vertical motions (mechanical processes) of the Earth's surface.

敬請批評指教 Thank you!!!

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