Temporal and spatial anomalies of seismo-ionospheric GPS TEC

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Forecast Summary Questions

1. Describe a typical forecast:
   a. What area do they cover? Regional toward global area.
   b. What is the magnitude range? M≧5.5.
   c. How long is the time period? 1-6 day.
   d. Do you include a probability of an event during the forecast? Yes, in Taiwan and not yet for the globe.
   e. Do you include a confidence level in the forecast? Not yet but working on it.

2. Describe the process for making a forecast:
   a. Is it automatic or manual? Automatic for temporal and semi- automatic for spatial SIPs.
   b. What data are used? GPS TEC (local GPS and public GIM) + electrode, magnetometer, surface deformation , wall water level, infrasonic, atomistic E-filed, HF Doppler frequency shift, ionosonde, satellite sounding, etc.

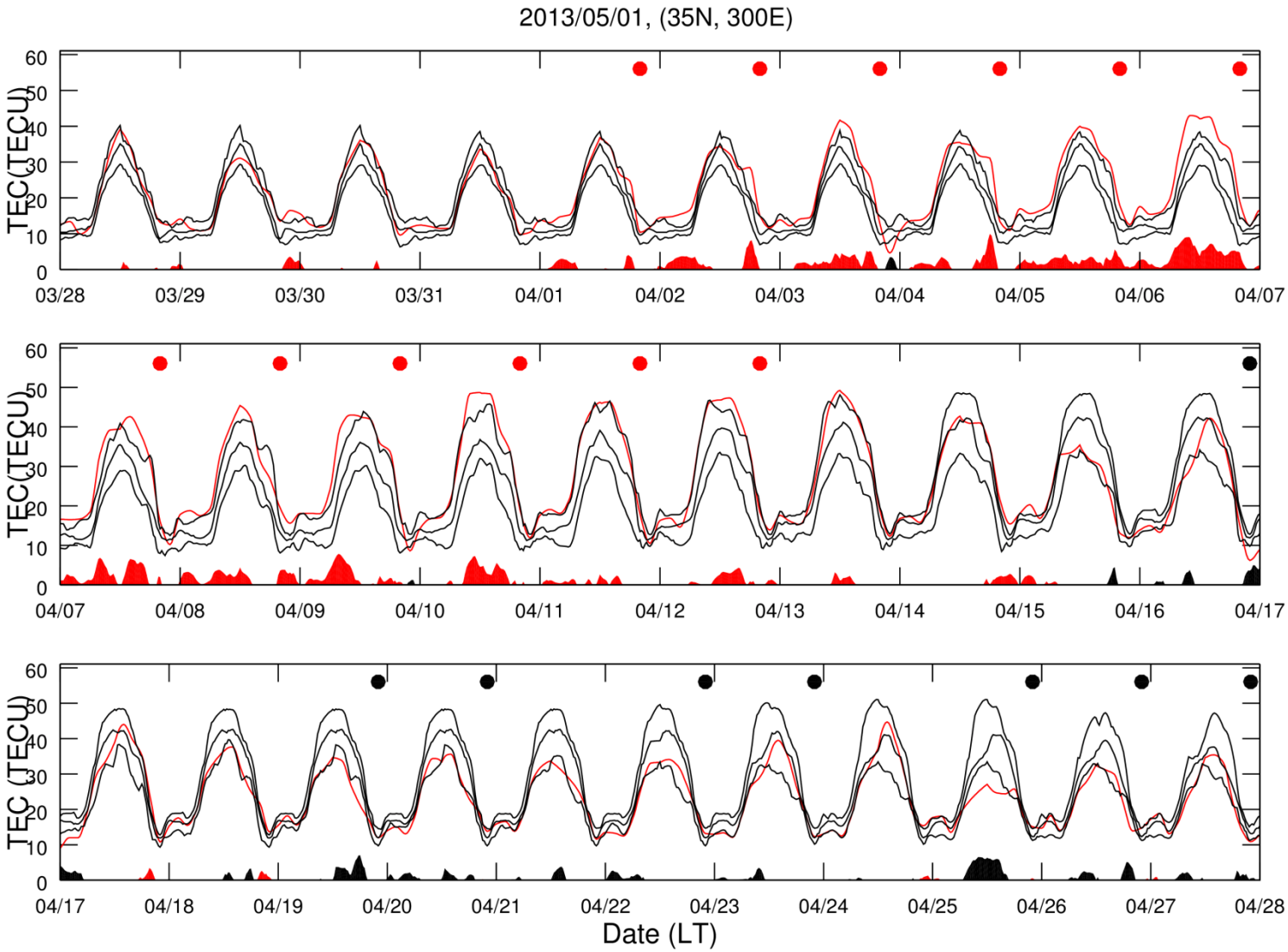
3. Do you have a preference for which earthquake data should be used to test your forecasts? Regional + USGS earthquake catalogs.

4. Do you have a preferred testing method? Statistical analyses and ionospheric model.

5. What physical hypotheses about earthquake predictability have motivated your research? Lithosphere-Atmosphere-Ionosphere Coupling.

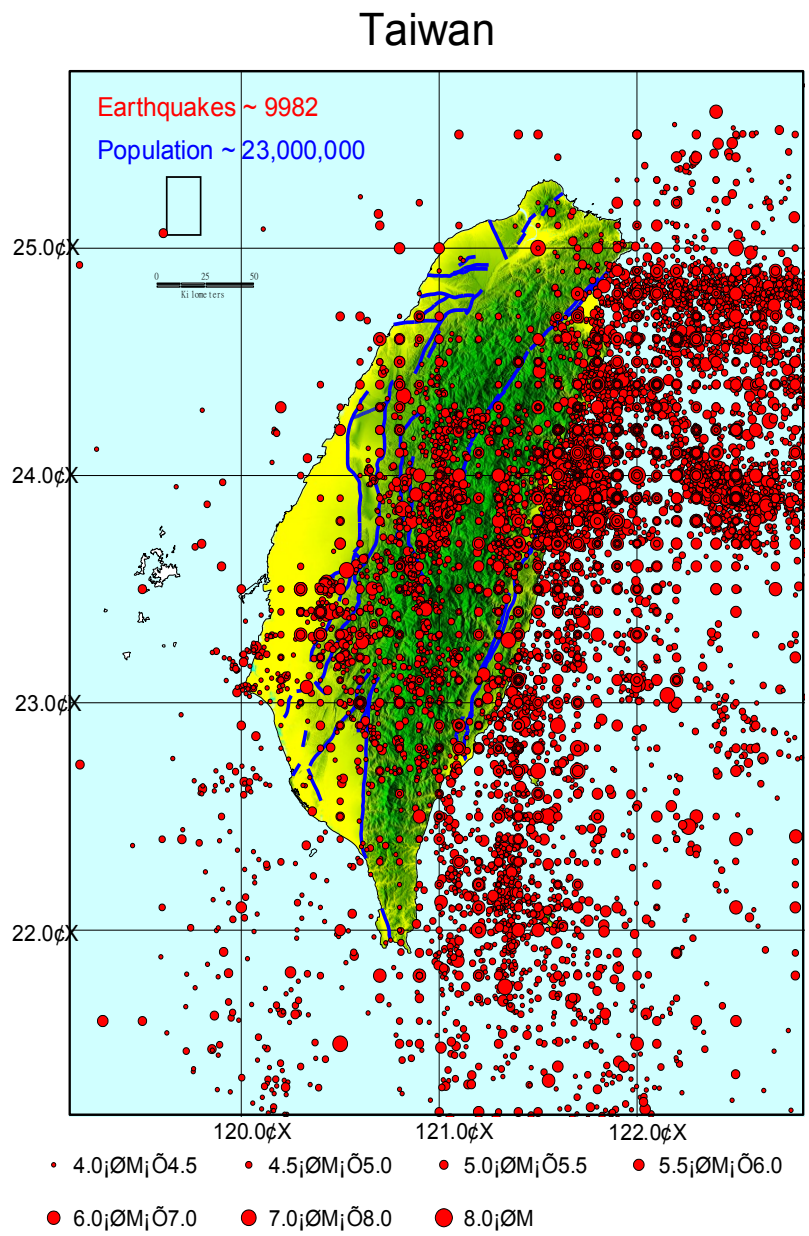
Content

- Introduction
  - iSTEP (integrate Search for Taiwan Earthquake Precursors)
- Seismo-ionospheric Precursors
  - Statistical results of M≧5.0 earthquakes in Taiwan
  - World Devastating Earthquake
  - the 16 October1999 Mw7.1 Hector Mine earthquake
- Conclusion
- FORMOSAT-7 (lithosphere weather)
- SIP monitoring routine



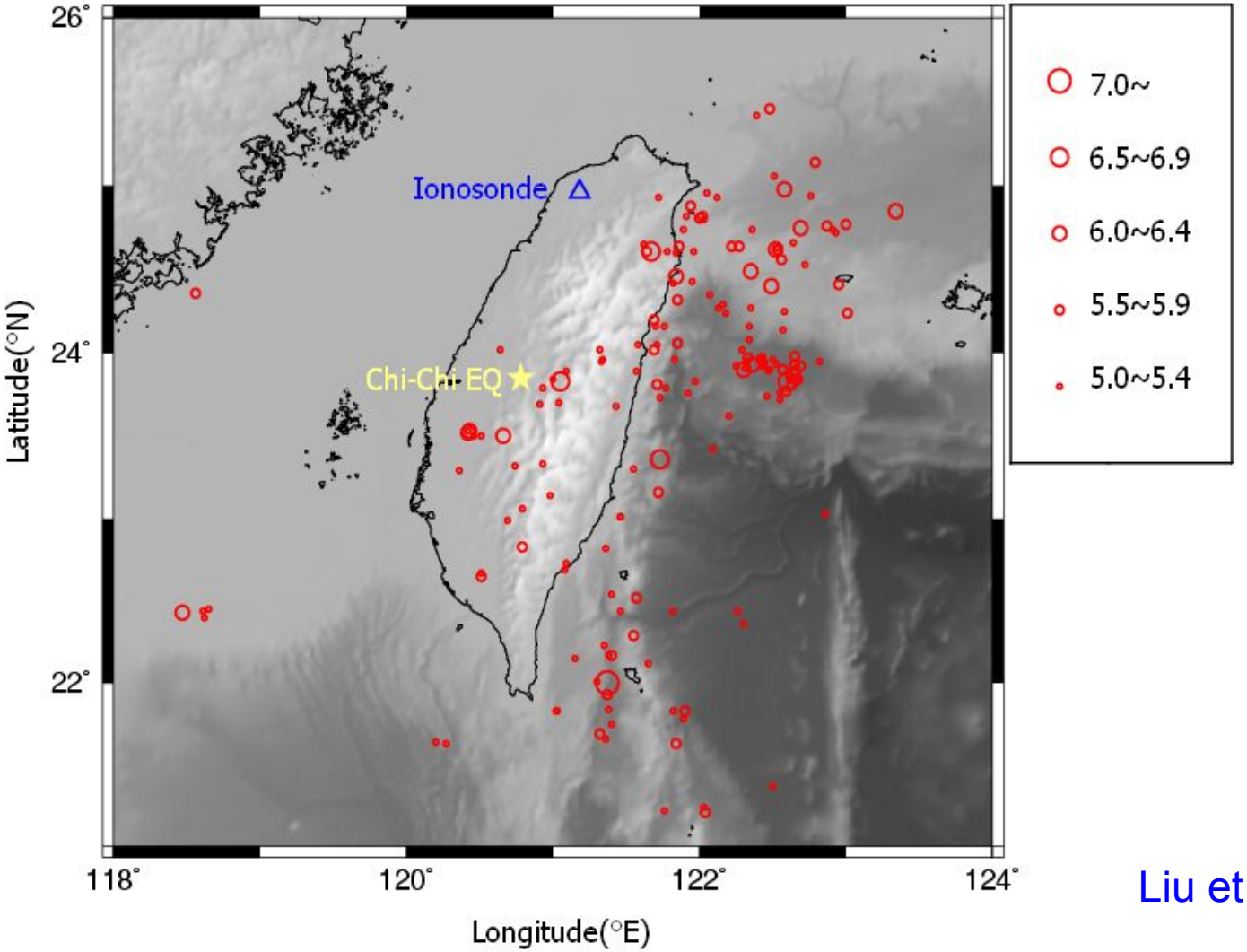
Seismo-ionospheric anomalies in the GIM TEC at LA in April 2013.

M>=4. 0 earthquakes in Taiwan 1900-2001.

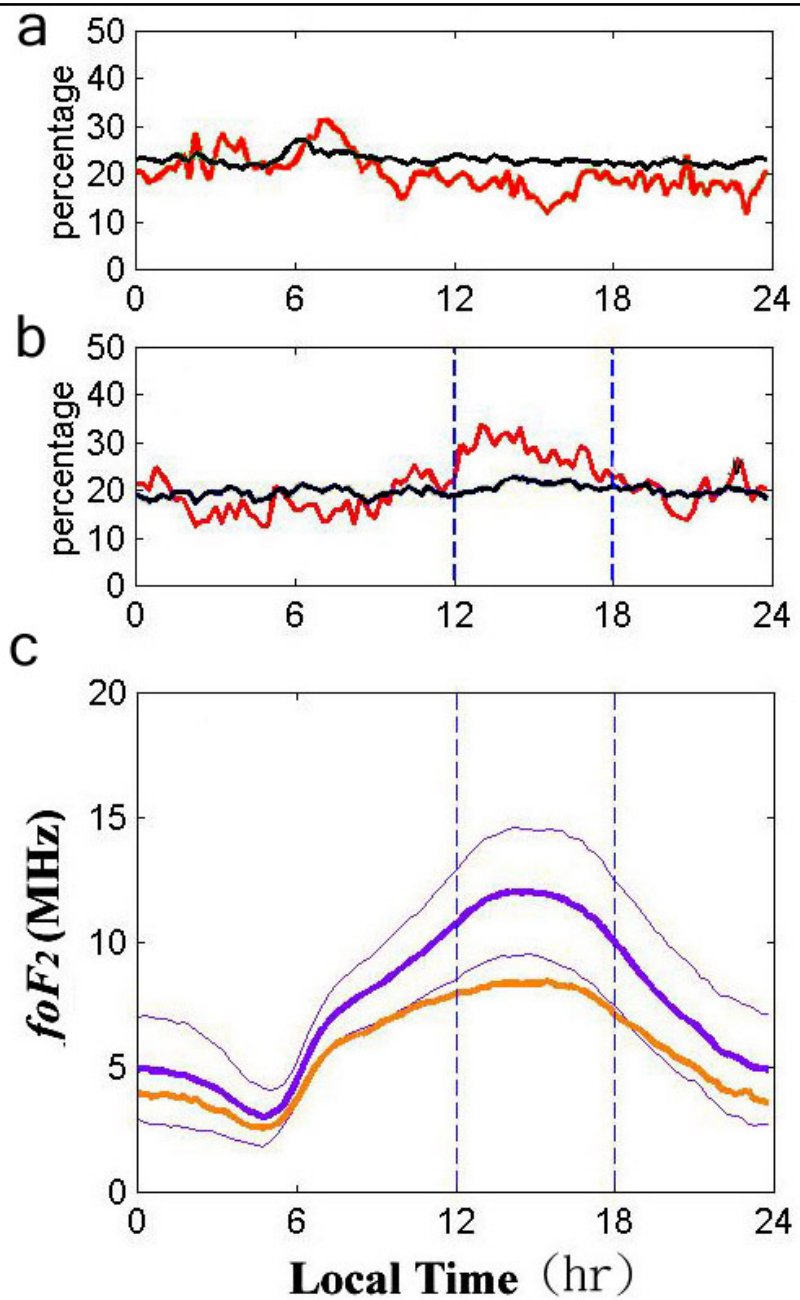


1900至2001年規模4以上的地震分布圖

1994-1999 M≥5.0 184 EQKs



Liu et al. [JGR, 2006]



Precursor Shape

1994-1999: 2191 days

M≥5.0 EQK: 184 (170days)

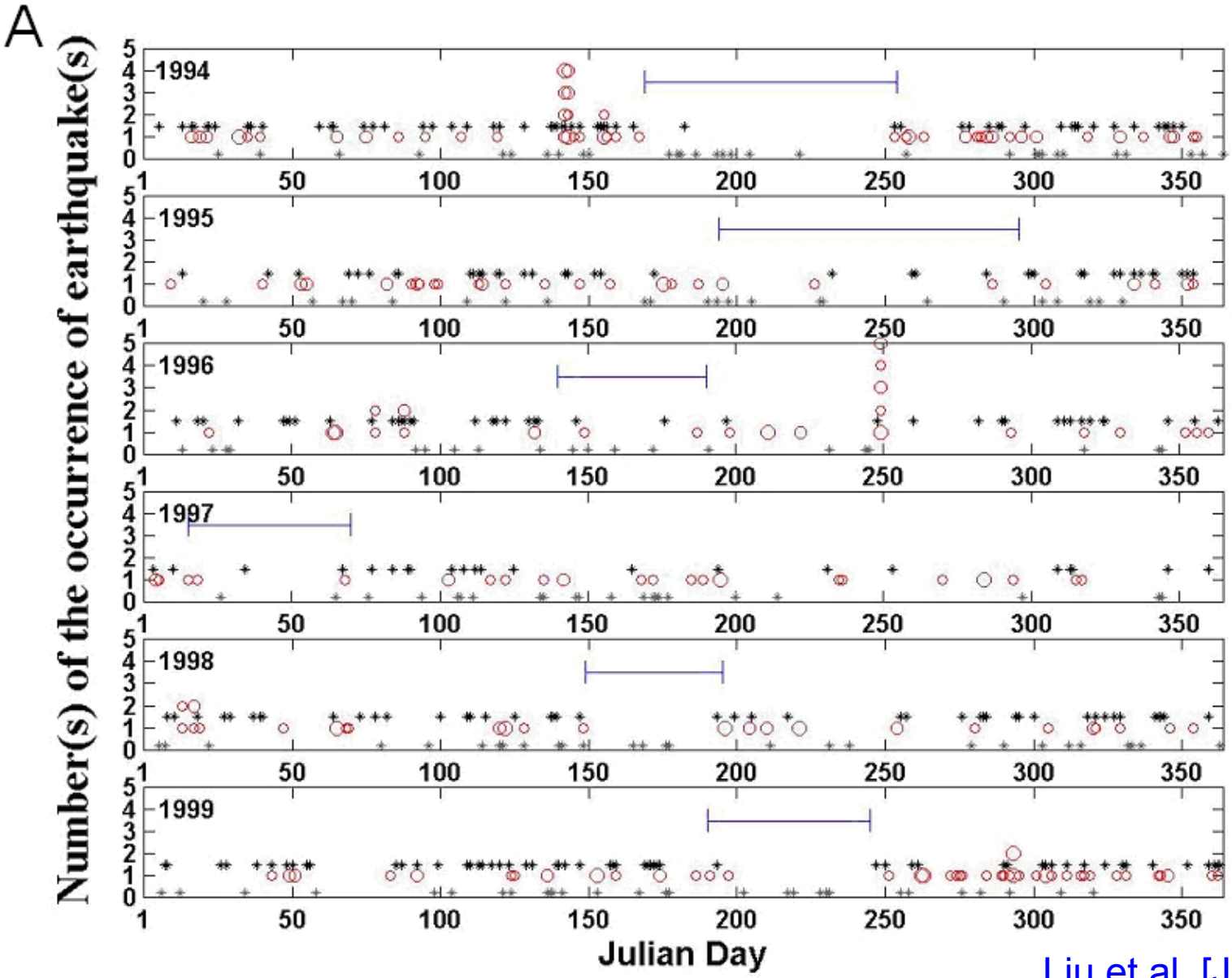
Ref: 15-day running MED & IQR

Below Lower Bound:1200-1800 LT

Precursor Shape

Liu et al. [JGR, 2006]

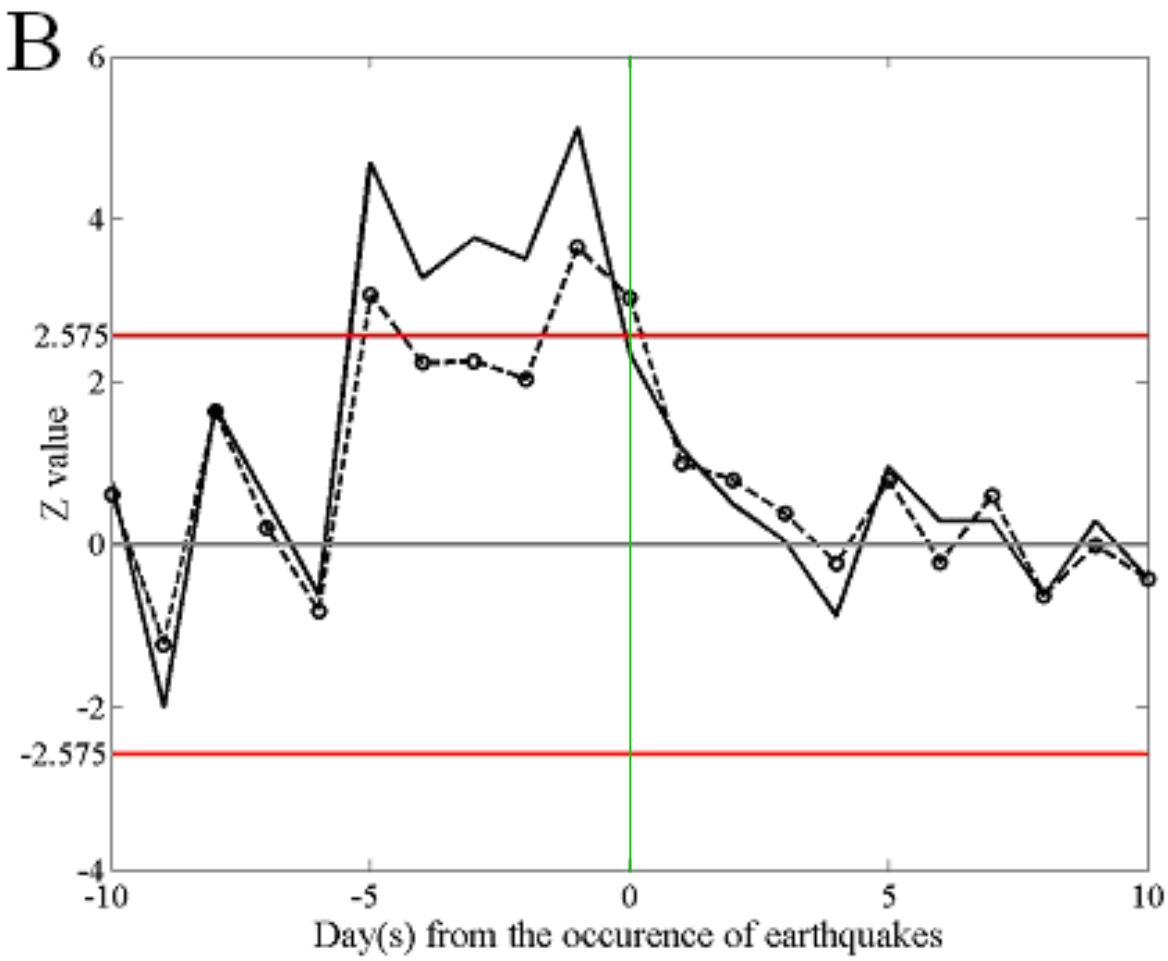
170 EQKdays, 307 Pdays, 109 storm_days, Es -- > Ps: 74.1%; Ps -- > Es: 50.2%



Liu et al. [JGR, 2006]

Precursor Lead Time

416 Anomalies
307 Precursors
Lead Time: 0-5 days

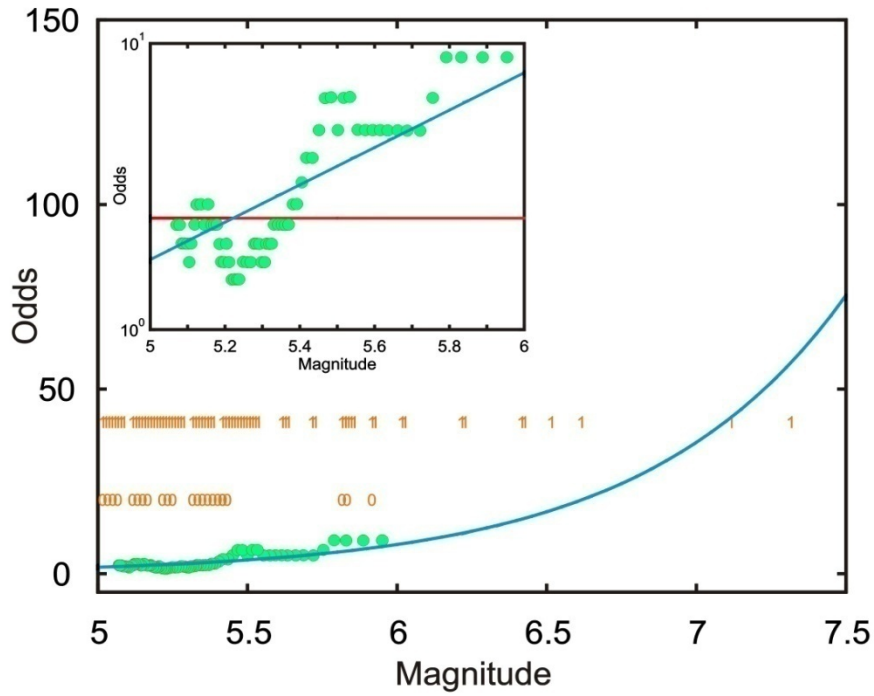


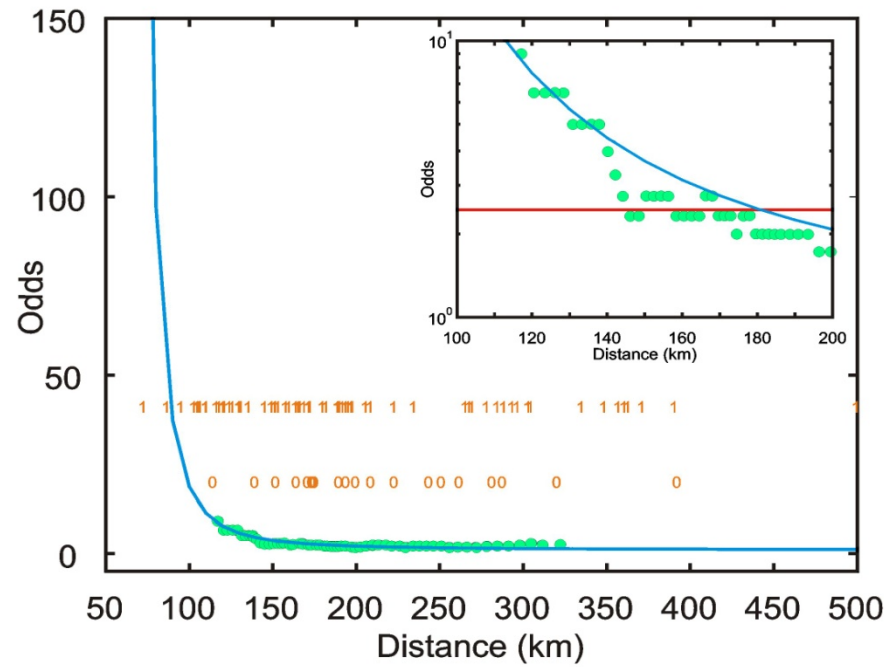
Liu et al. [JGR, 2006]

$\log_{10} E \sim 1.4M + \text{constant}$

(a) $\ln\{p/(1-p)\} = 1.50M - 6.96$

(b) $\ln\{p/(1-p)\} = 29281.84/d^2$





Relation between the odds of M≥5.0 earthquakes with the foF2 PEIA in 5 days and the related magnitude and distance. D≤40 km, 93 EQK days.

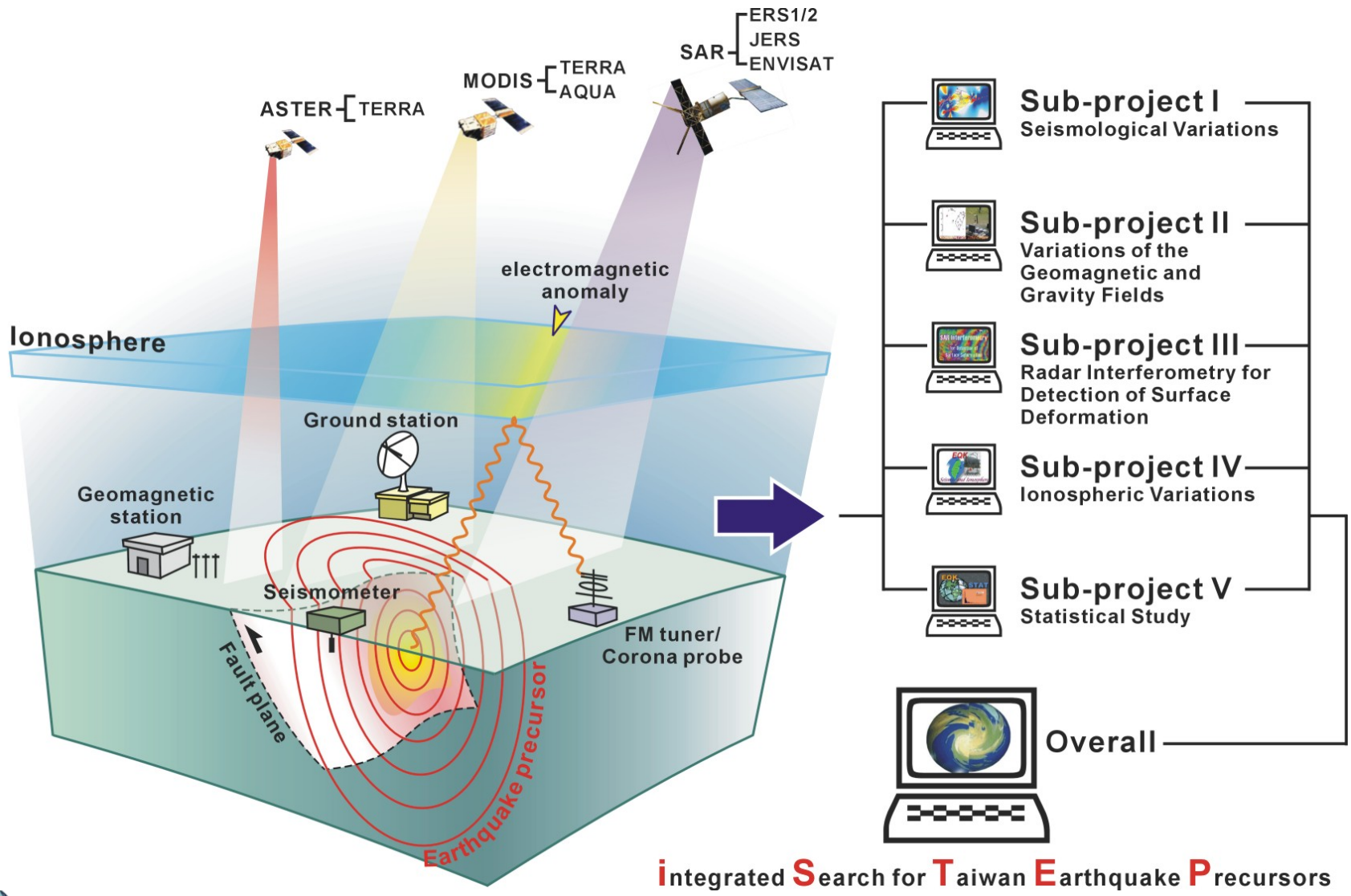
Liu et al. [JGR, 2006]

Statistical results

- The inter event time of M≧5.0 earthquakes in Taiwan is about 14 days. This implies the chance of observing an M≧5.0 earthquakes within next 1-5 days is about 35.7%.
- The chance of the 5.0 earthquakes being led by the SIPs within next 1-5 days is 74.1%.
- The chance of the SIPs being followed by the earthquakes within next 1-5 days is 50.2%.

Chen et al. [TAO, 2004]

iSTEP-1 (2003/4-2007/3)

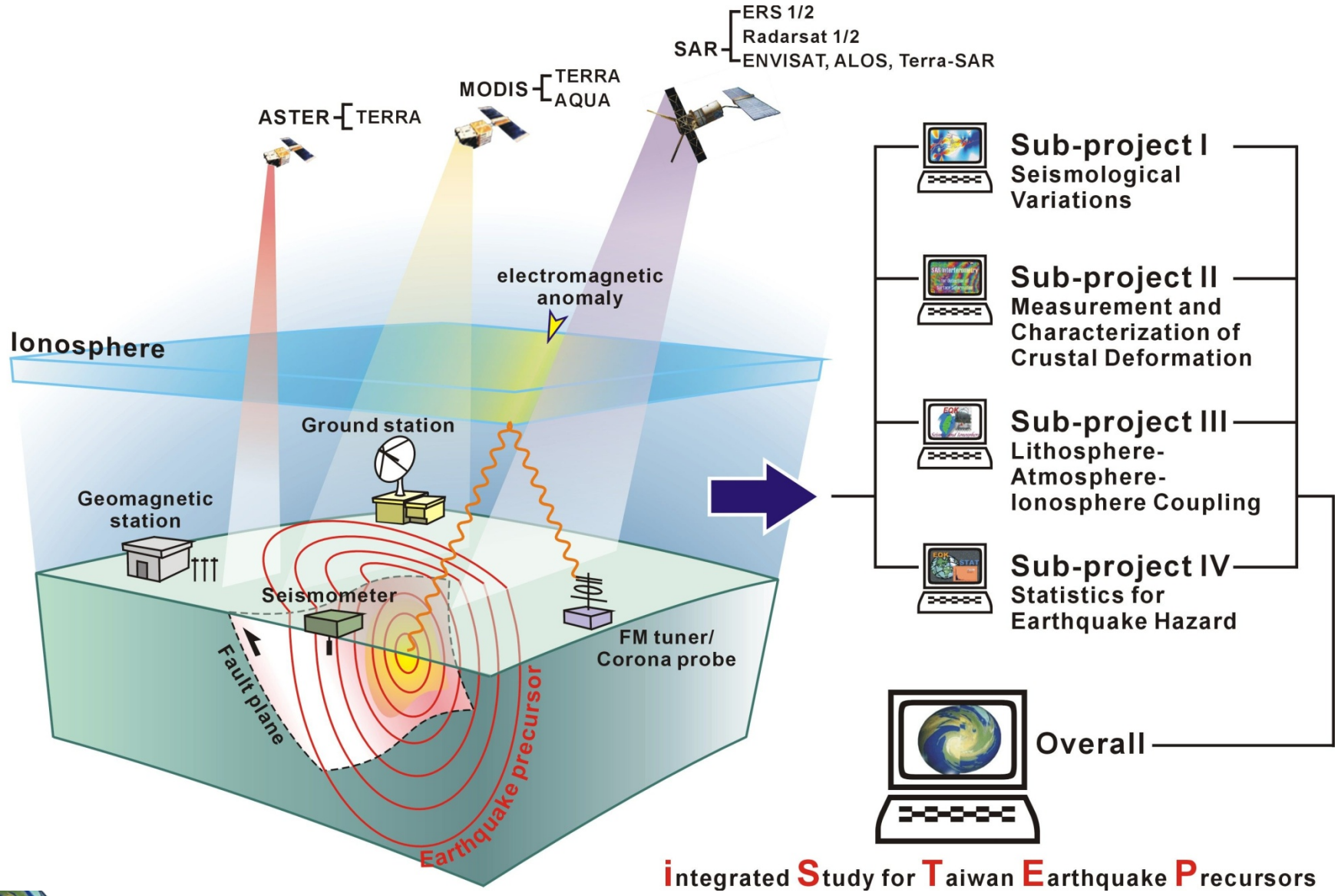


integrated **S**earch for **T**aiwan **E**arthquake **P**recursors

大學學術追求卓越發展計畫 地震電磁前兆研究

Program for Promoting University Academic Excellence - Research on Seismo-Electromagnetic Precursors of Earthquake

iSTEP-2 (2008/8-2012/7)



integrated **S**tudy for **T**aiwan **E**arthquake **P**recursors

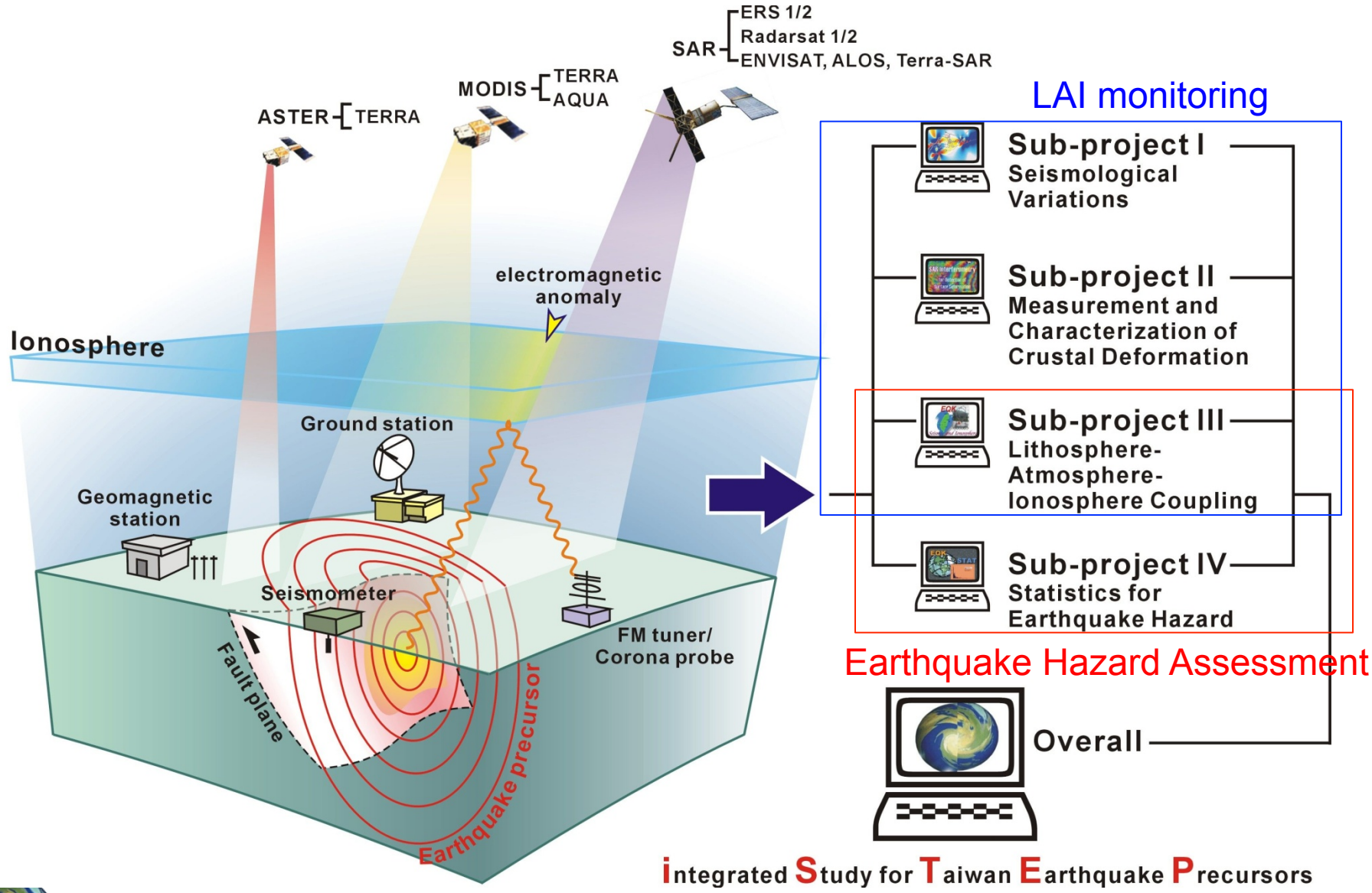
大學學術追求卓越發展計畫 地震電磁前兆研究

Program for Promoting University Academic Excellence - Research on Seismo-Electromagnetic Precursors of Earthquake

iSTEP-2 (2008/8-2012/7)

- Seismo-ionospheric Temporal and Spatial Precursors
- LAI Anomaly Monitoring (seismo-magnetic field, GPS surface deformation)
- Seismo-ionospheric Modeling

iSTEP-3 (2012/8-2016/7)



integrated **S**tudy for **T**aiwan **E**arthquake **P**recursors

大學學術追求卓越發展計畫 地震電磁前兆研究

Program for Promoting University Academic Excellence - Research on Seismo-Electromagnetic Precursors of Earthquake

iSTEP-3 (20012/8-2016/7)

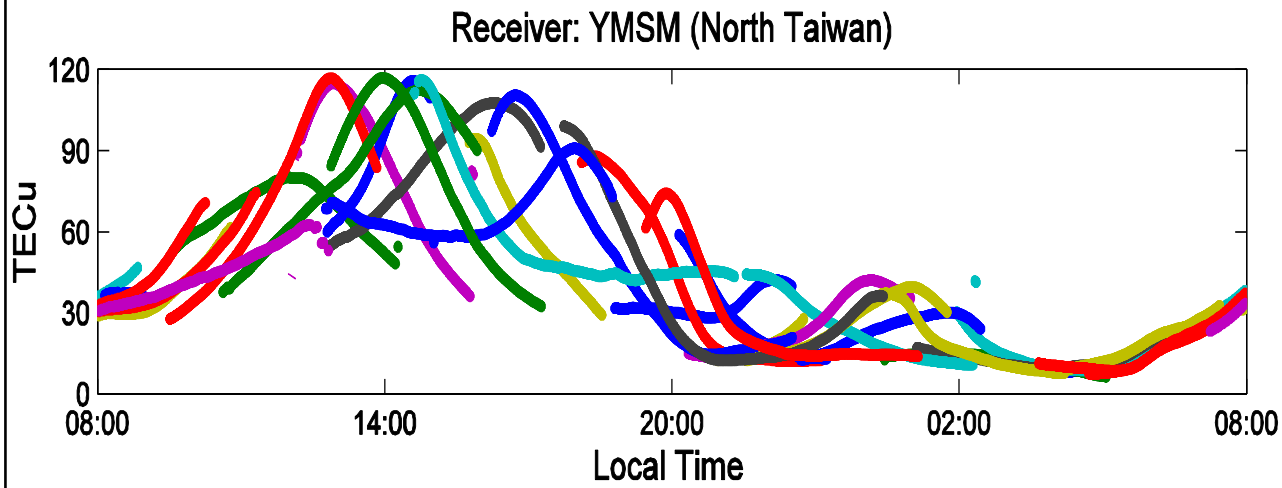
- SAS (seismo-ionospheric, atmospheric, and lithospheric anomalous signals) observations
- LAIC model development
- Temporal/spatial SIP (seismo-ionospheric precursor) monitoring system
- Earthquake hazard statistics

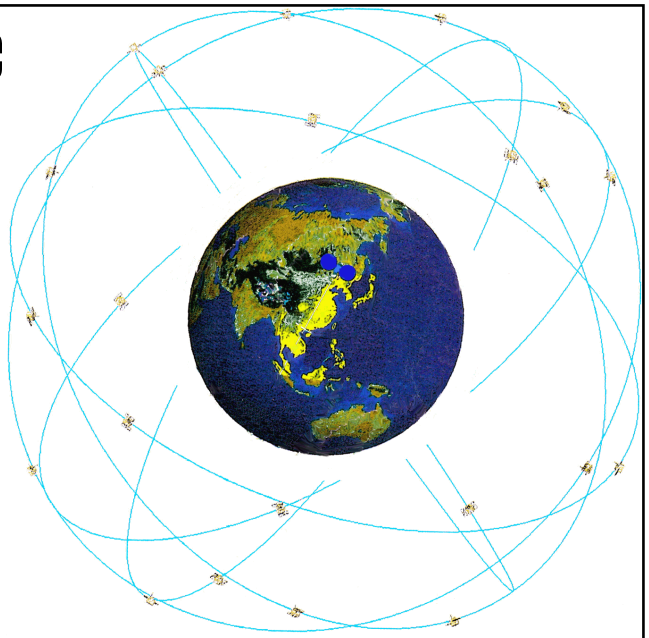
iSTEP-3 (2012/8-2016/7)

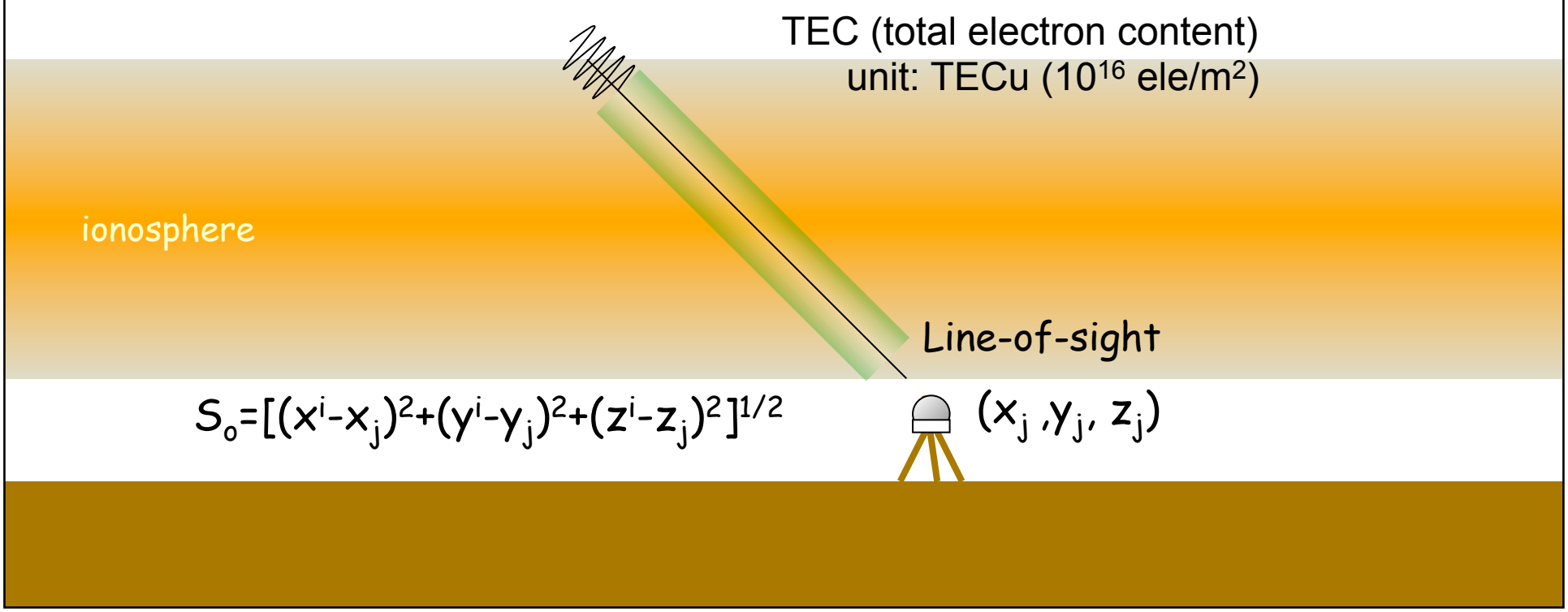
- International Cooperation (Russia, Japan, USA, China, France, etc.)
- Ground-based LAI observation networks (Electrode, Infrasounder, Atmospheric E-field, FM tuner, Doppler Sounder, ionosonde, magnetometer, GPS receiver), etc. 11 stations, 52 instruments
- Satellite: FORMOSAT-3, -5, -7
- Model Simulation
- Tsunami Early Warning

Seismo-ionospheric Precursors

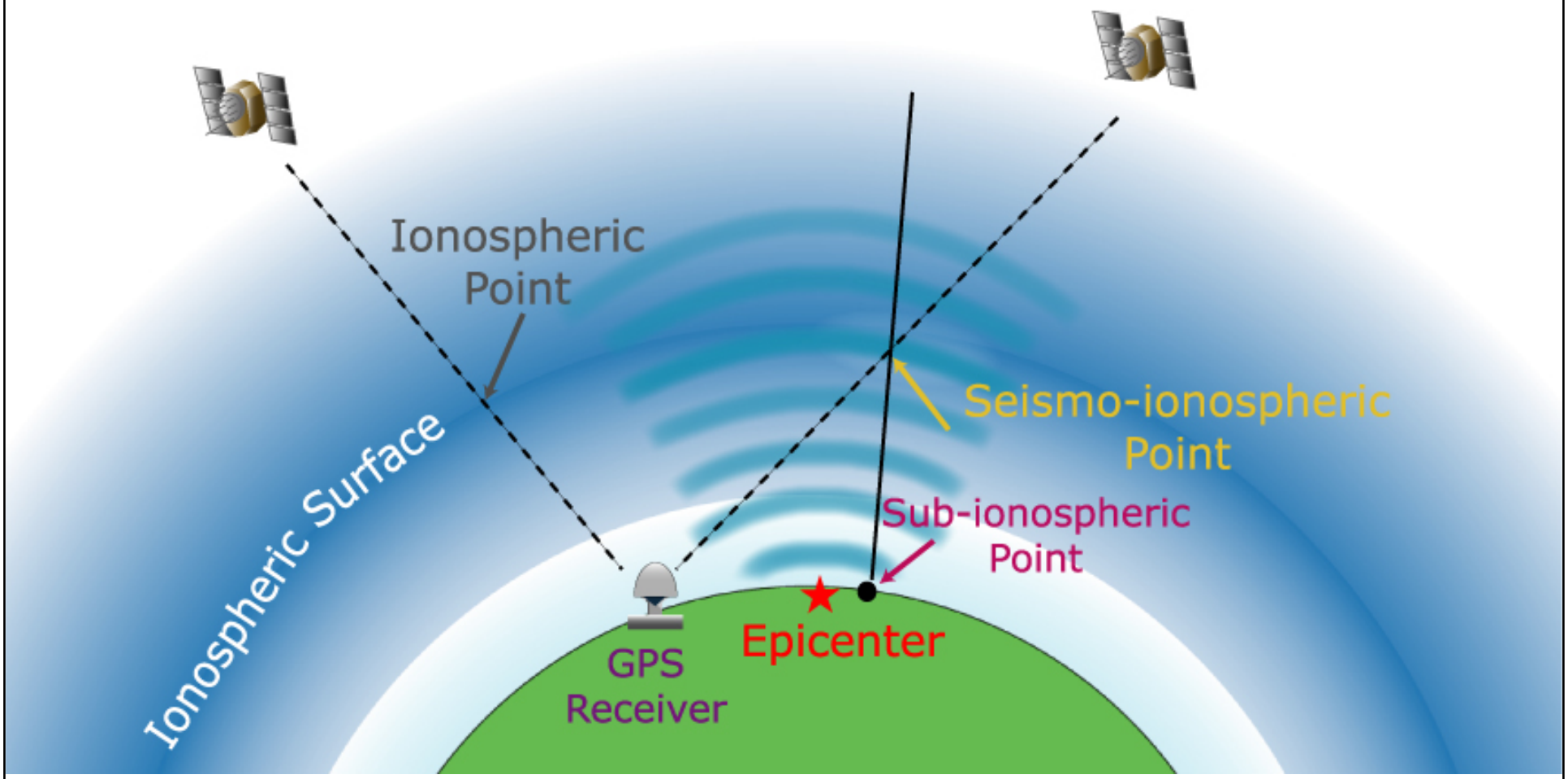
Ionospheric total electron content (TEC derived from GPS



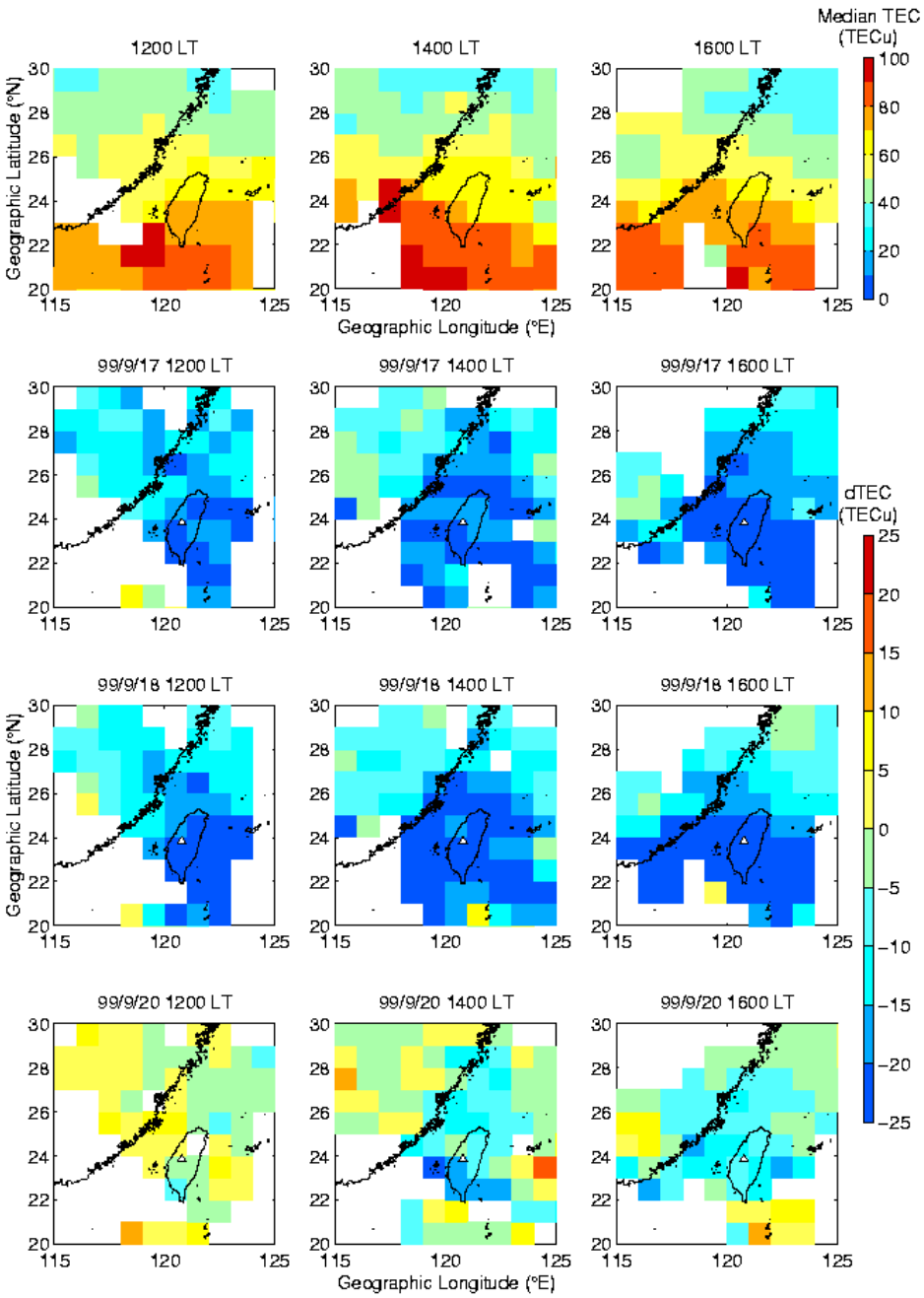




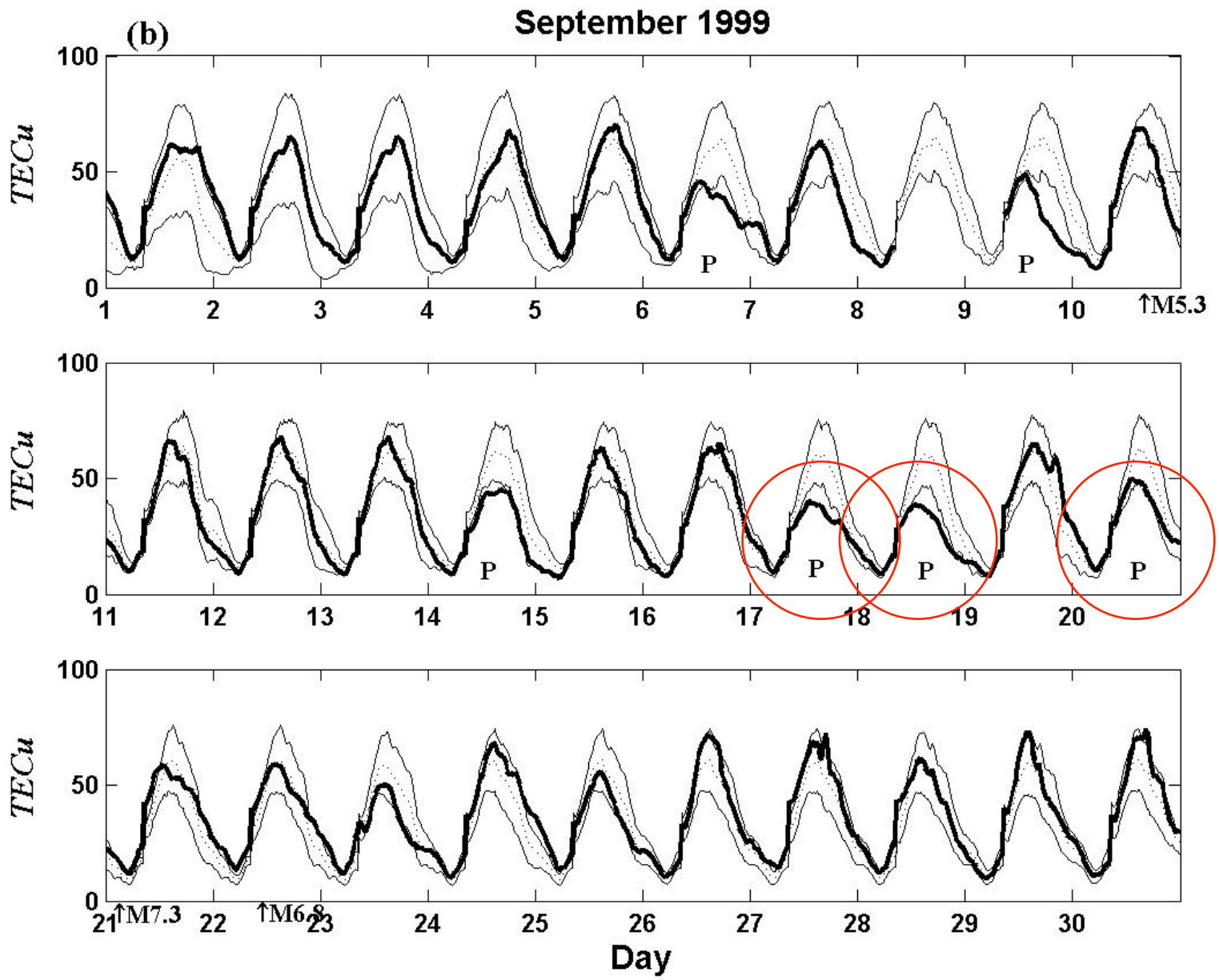
SIP observed by GPS TEC



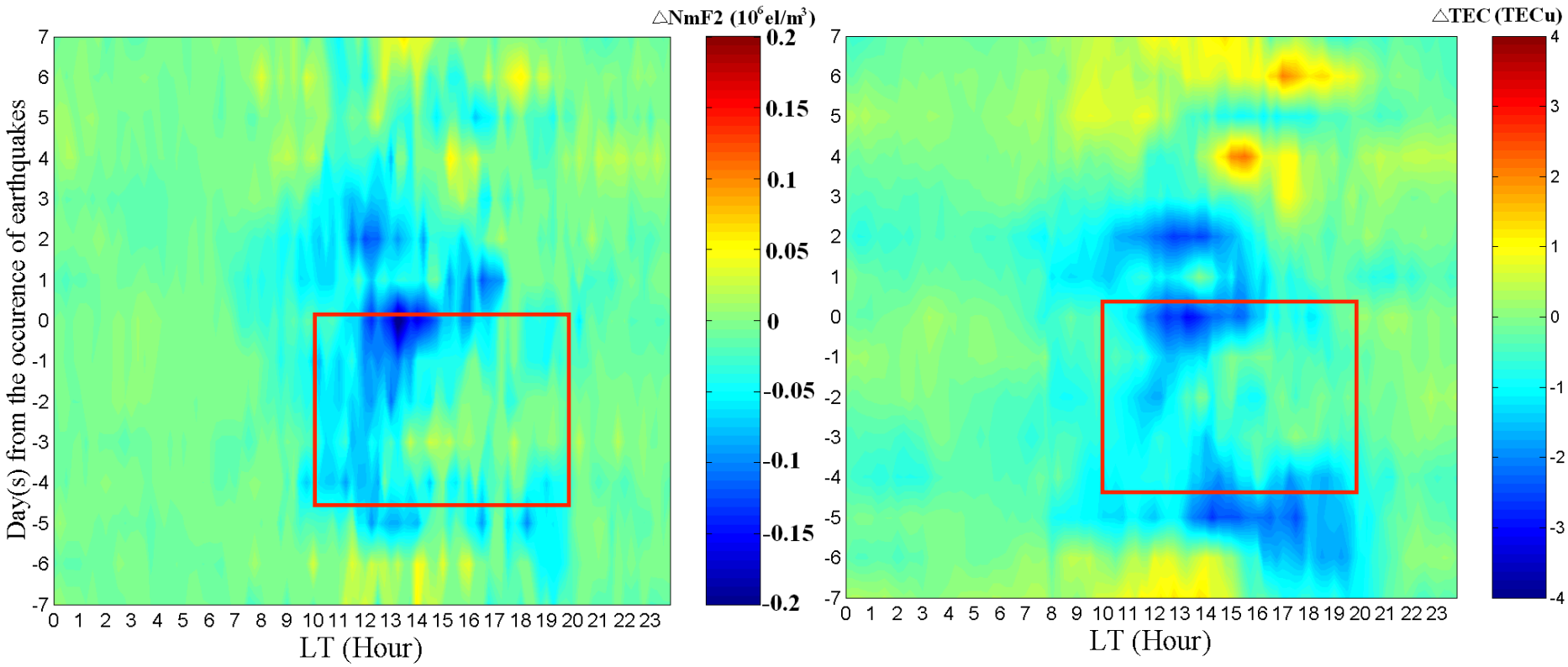
LLT maps



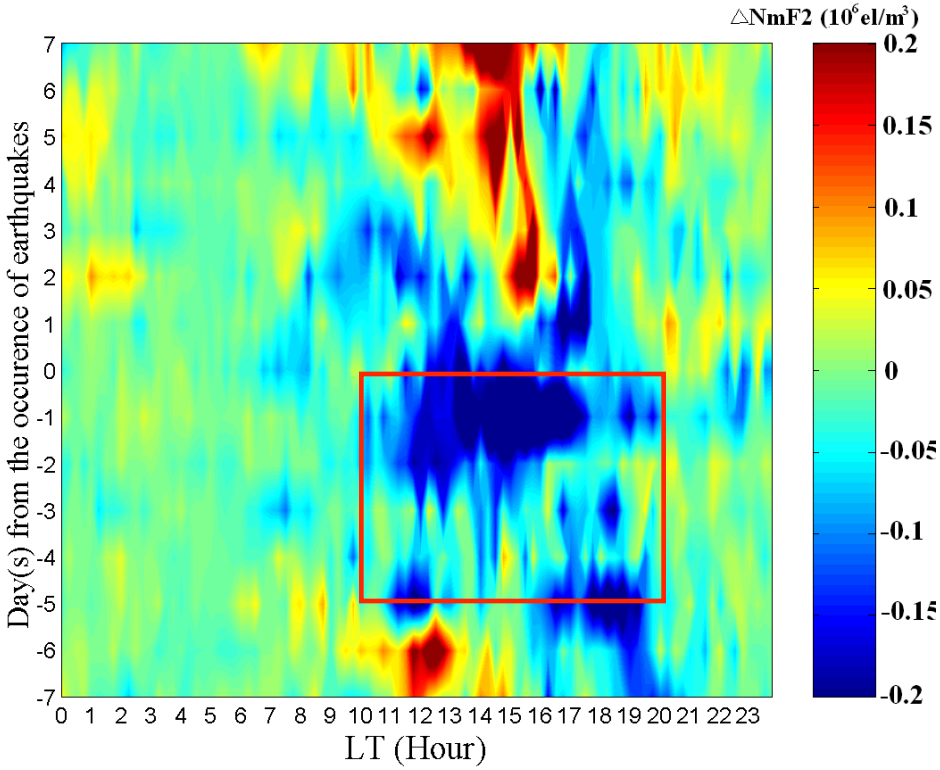
Liu et al. [GRL, 2001]

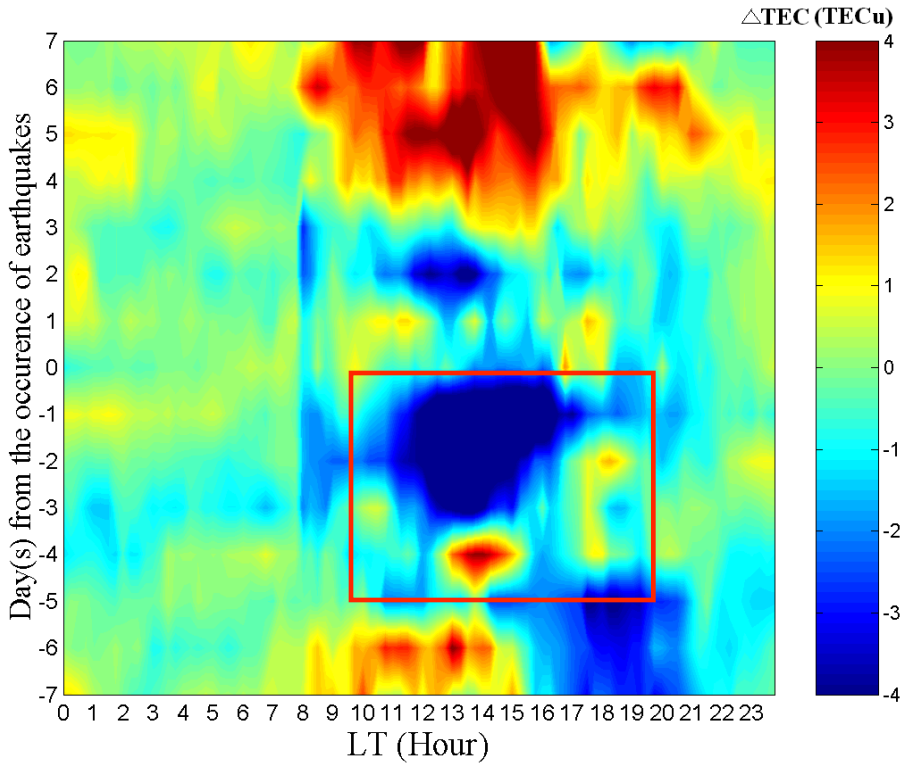

(b)
September 1999
TECu
100
50
0
P
↑M5.3
↑M7.3
↑M6.8
Day

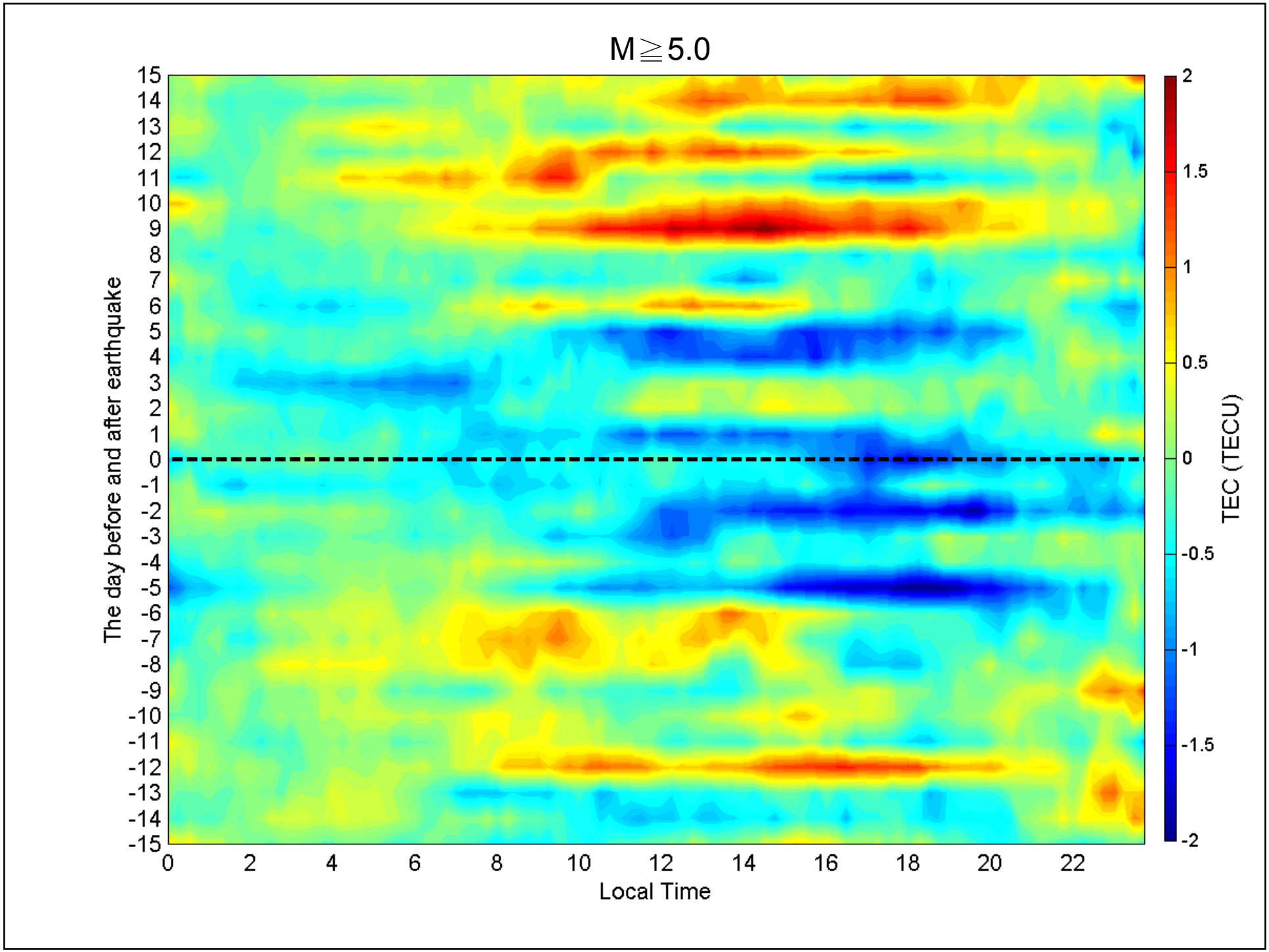
Difference between Observations and the Median of NmF2 and GPSTEC for $M_L \geqq 5.0$ Earthquakes

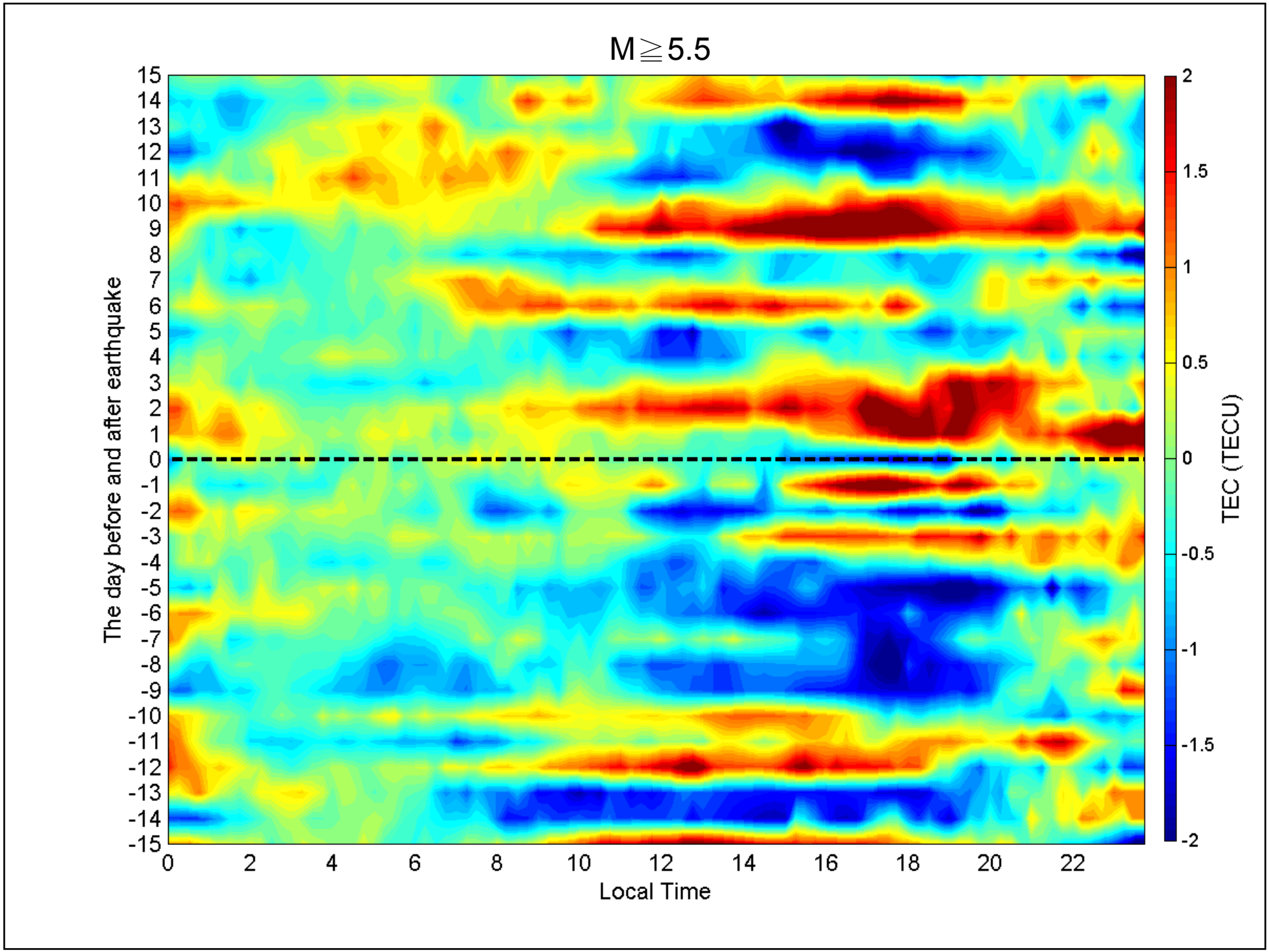


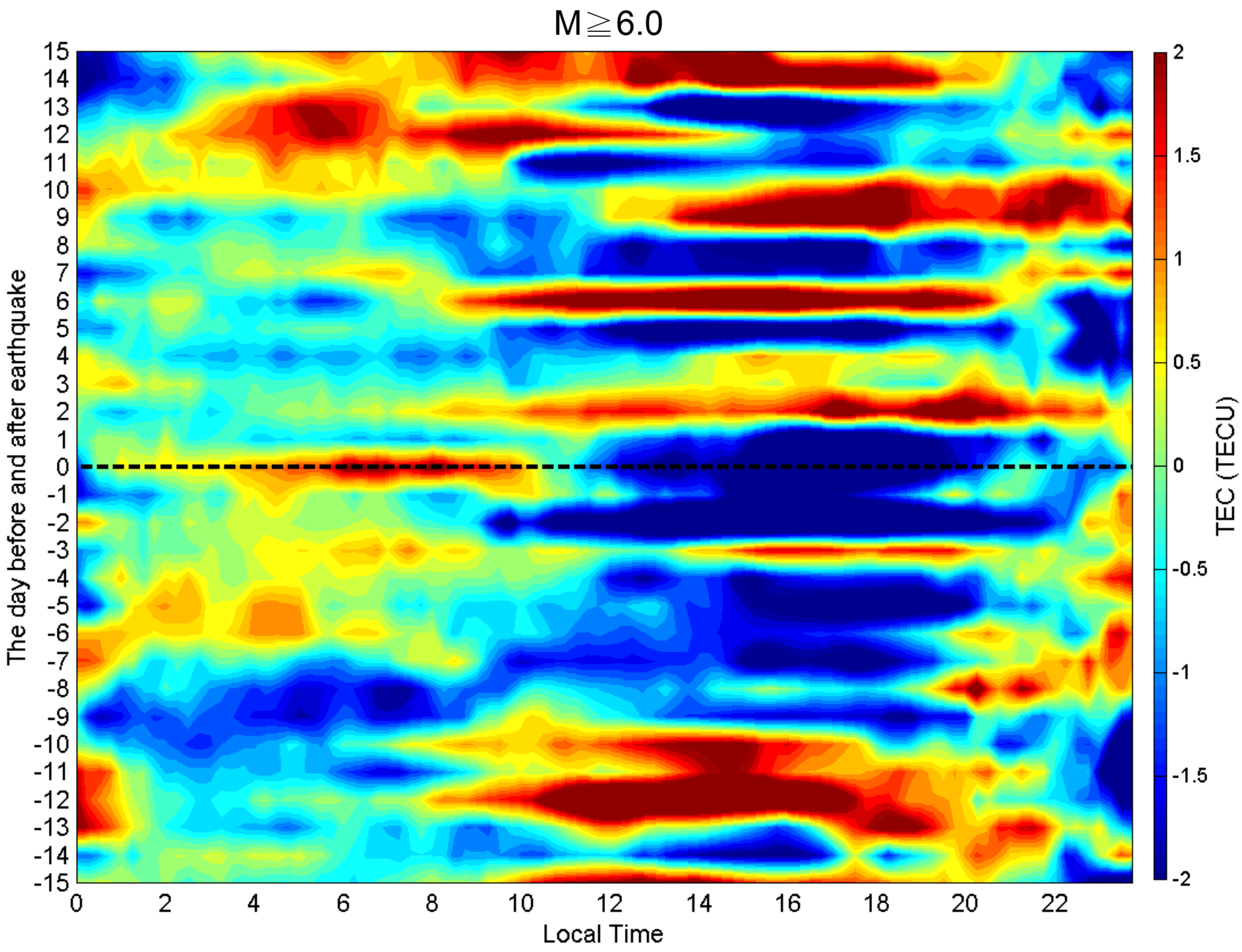
Difference between Observations and the Median of NmF2 and GPSTEC for $M_L \geqq 6.0$ Earthquakes

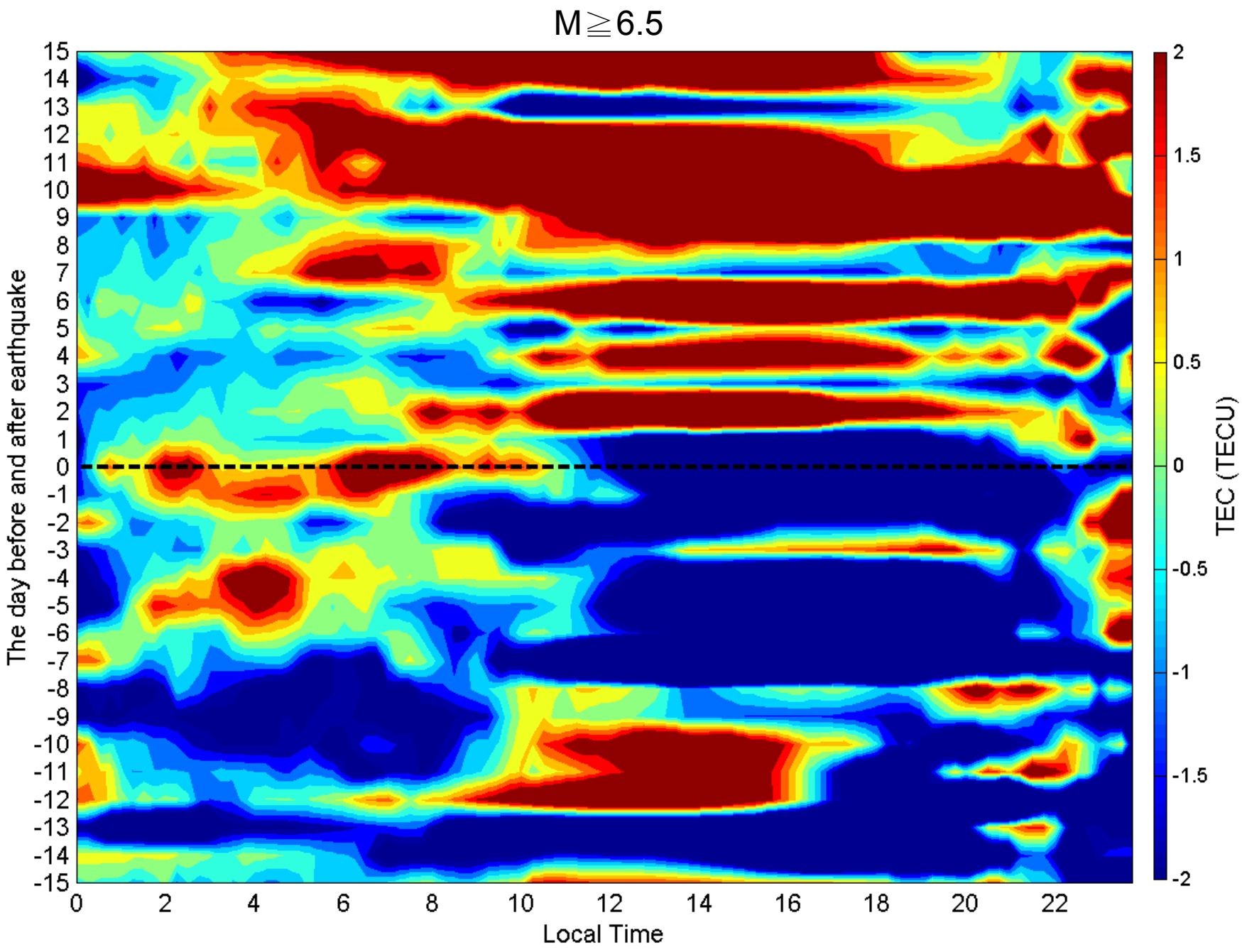





M≧5.0
The day before and after earthquake
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
-1
-2
-3
-4
-5
-6
-7
-8
-9
-10
-11
-12
-13
-14
-15
0
2
4
6
8
10
12
14
16
18
20
22
Local Time
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
TEC (TECU)


M≧5.5
The day before and after earthquake
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
-1
-2
-3
-4
-5
-6
-7
-8
-9
-10
-11
-12
-13
-14
-15
0
2
4
6
8
10
12
14
16
18
20
22
Local Time
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
TEC (TECU)


M≧6.0
The day before and after earthquake
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
-1
-2
-3
-4
-5
-6
-7
-8
-9
-10
-11
-12
-13
-14
-15
0
2
4
6
8
10
12
14
16
18
20
22
Local Time
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
TEC (TECU)

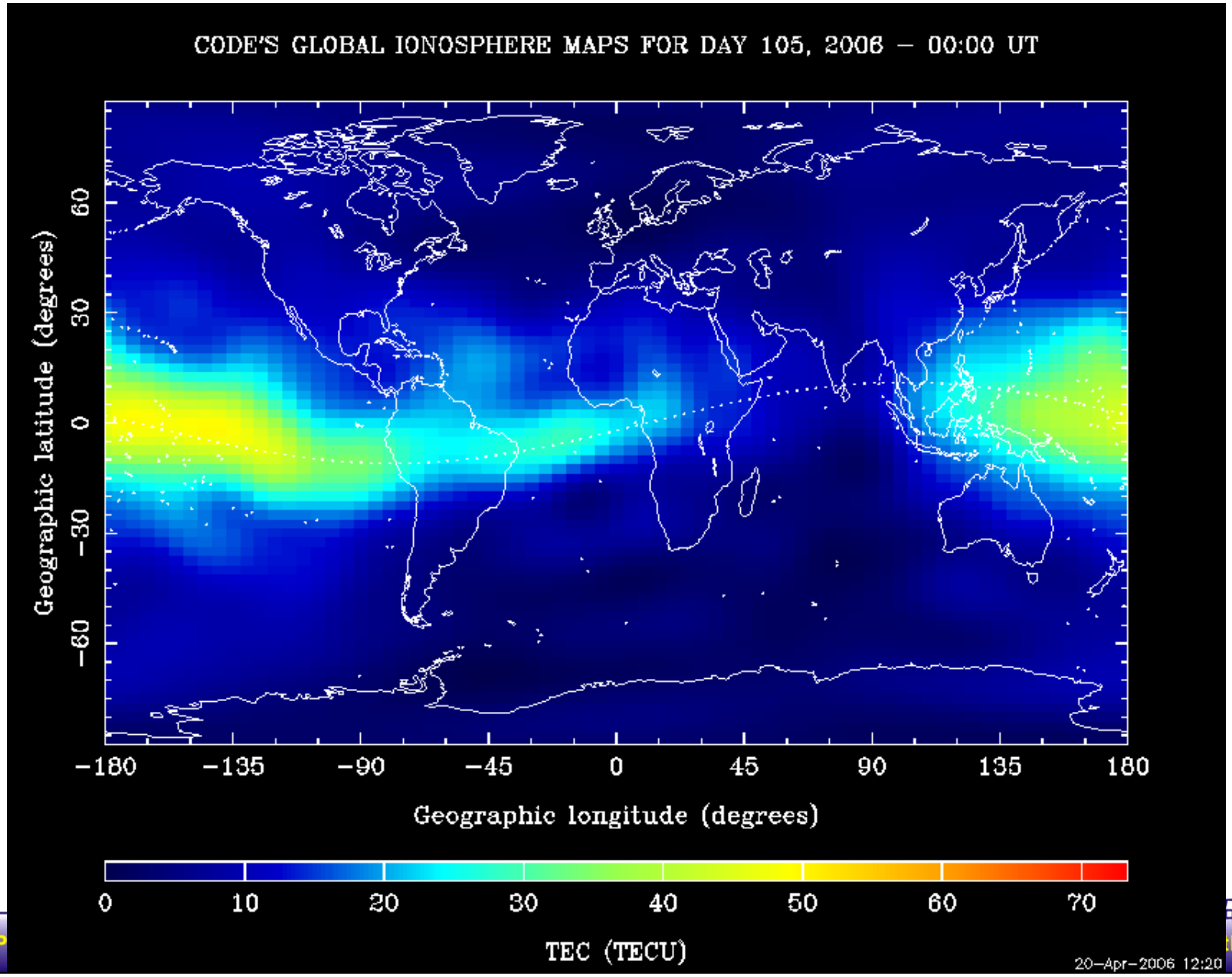

M≧6.5
The day before and after earthquake
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
-1
-2
-3
-4
-5
-6
-7
-8
-9
-10
-11
-12
-13
-14
-15
0
2
4
6
8
10
12
14
16
18
20
22
Local Time
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
TEC (TECU)

World Devastating Earthquake

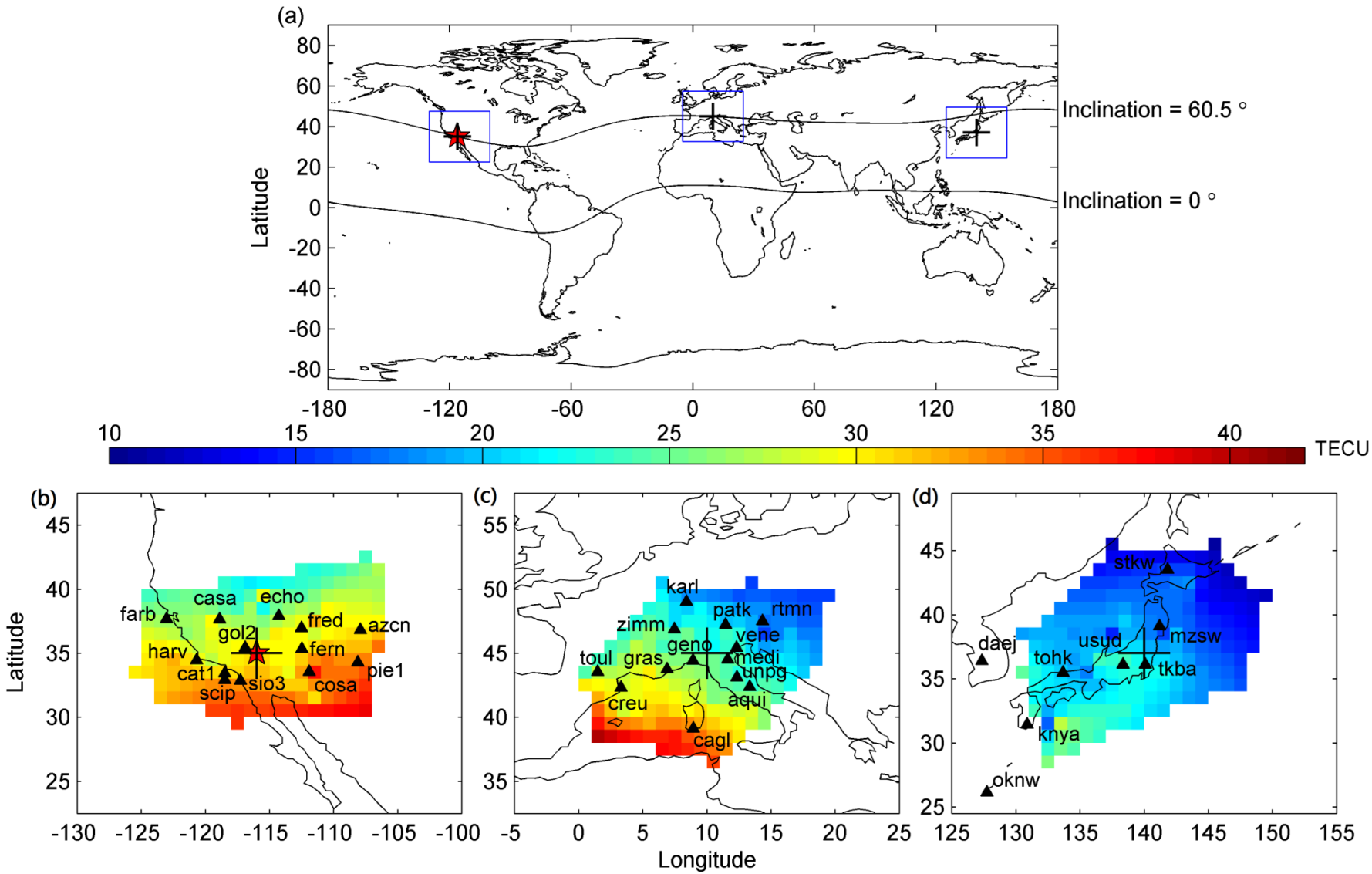
- 1999 M7.6 Chi-Chi earthquake (Ne+TEC)

  Liu et al.(GRL 2000, GRL 2001)
- 2004 M9.3 Sumatra Earthquake (Stochastic test) Liu et al.(JGR 2010)
- 2008 M8.0 Wenchuan Earthquake (FORMOSAT-3 observation) Liu et al.(JGR 2009)
- 2010 M7.0 Haiti Earthquake (Model simulation) Liu et al.(JGR 2011)
- 2011 M9.0 Tohoku Earthquake (????)

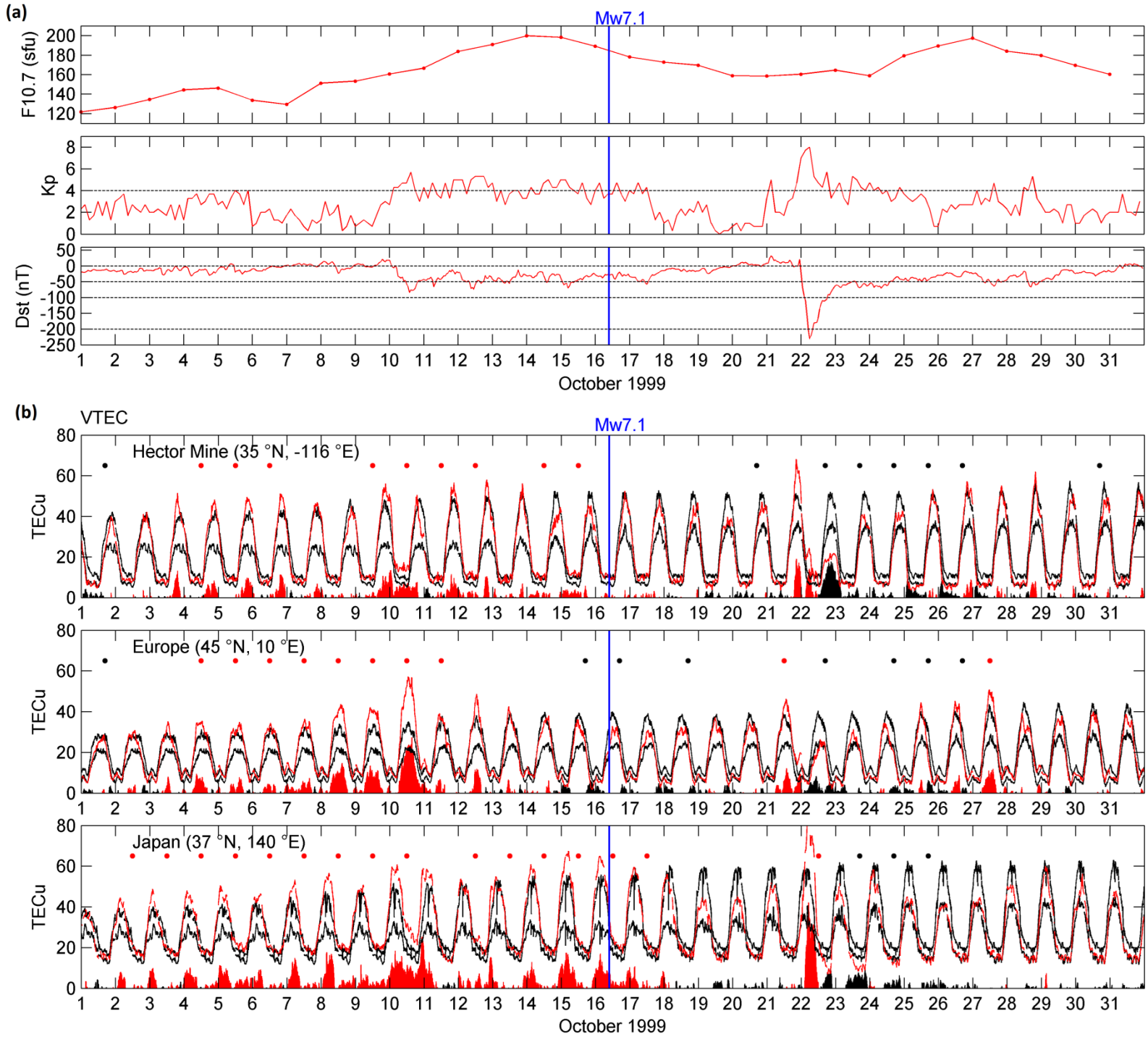
Global Ionosphere Map of the GPS TEC



16 October 1999 M7.1 Hector Mine earthquake



The Hector Mine area and two reference areas.


(a)
Mw7.1
F10.7 (sfu)
Kp
Dst (nT)
October 1999
(b)
VTEC
Mw7.1
Hector Mine (35 °N, -116 °E)
Europe (45 °N, 10 °E)
Japan (37 °N, 140 °E)
TECu
October 1999

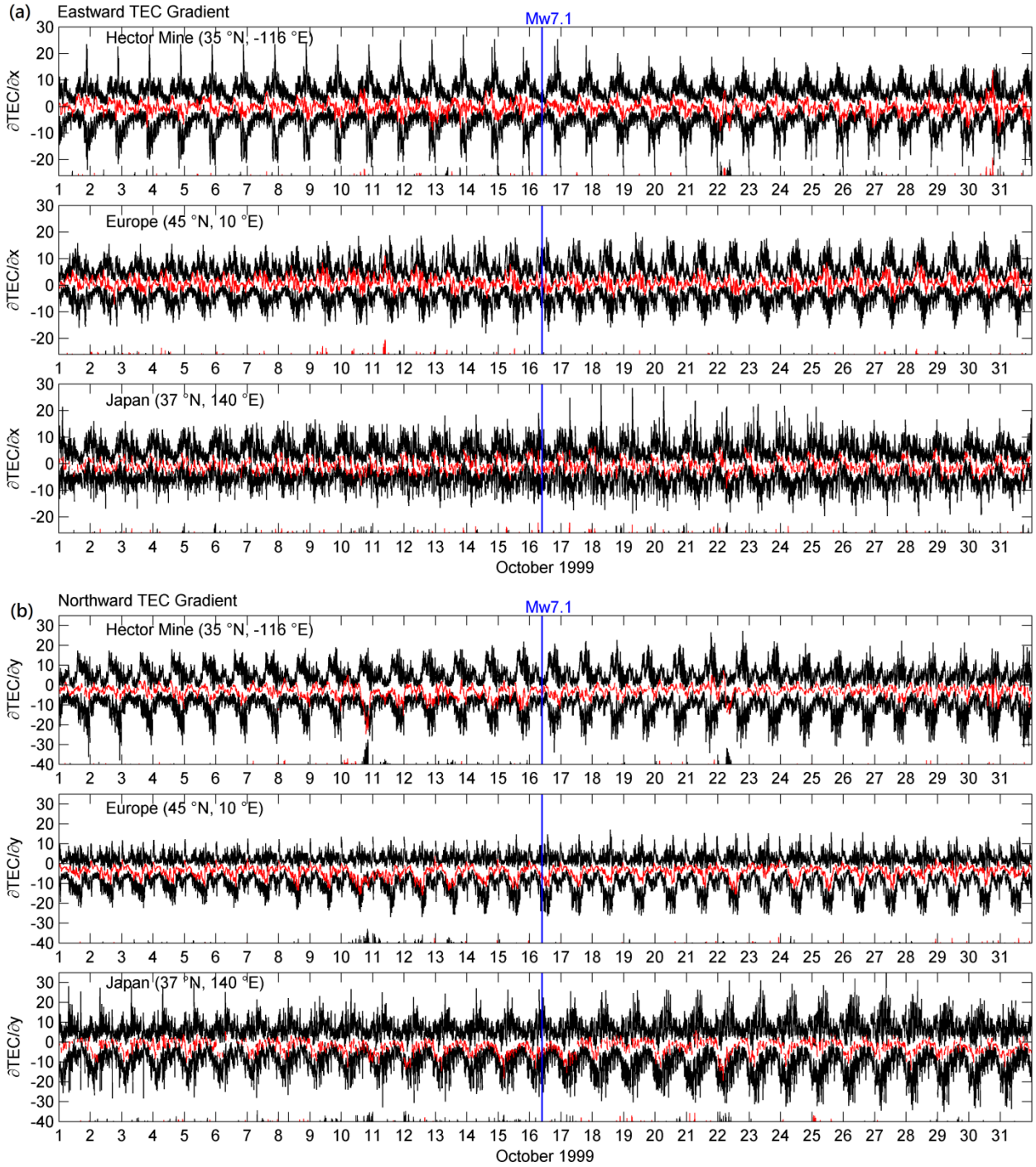

(a)
Eastward TEC Gradient
Mw7.1
Hector Mine (35 °N, -116 °E)
Europe (45 °N, 10 °E)
Japan (37 °N, 140 °E)
∂TEC/∂x
October 1999
(b)
Northward TEC Gradient
Mw7.1
Hector Mine (35 °N, -116 °E)
Europe (45 °N, 10 °E)
Japan (37 °N, 140 °E)
∂TEC/∂y
October 1999

Figure 3.

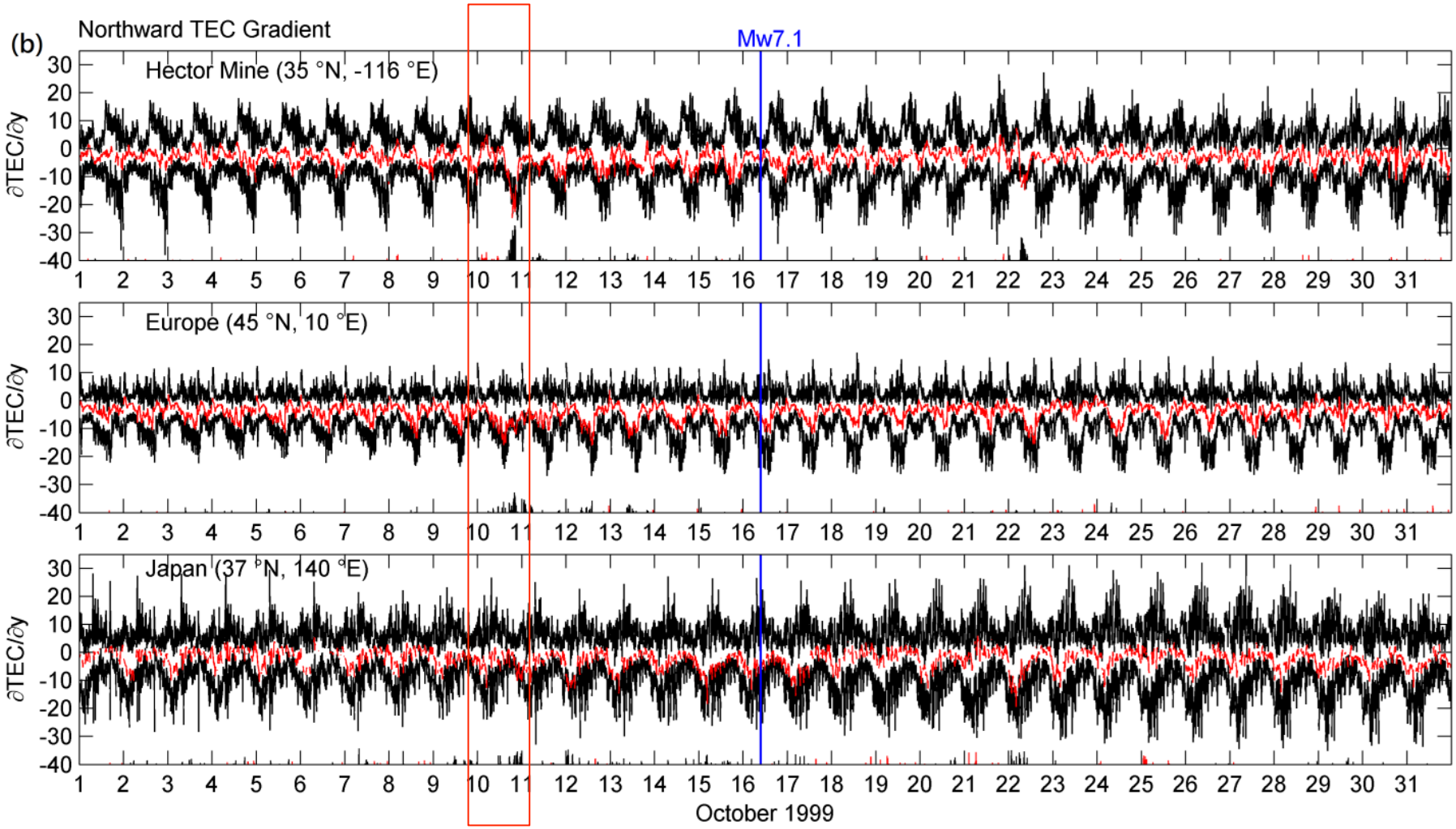
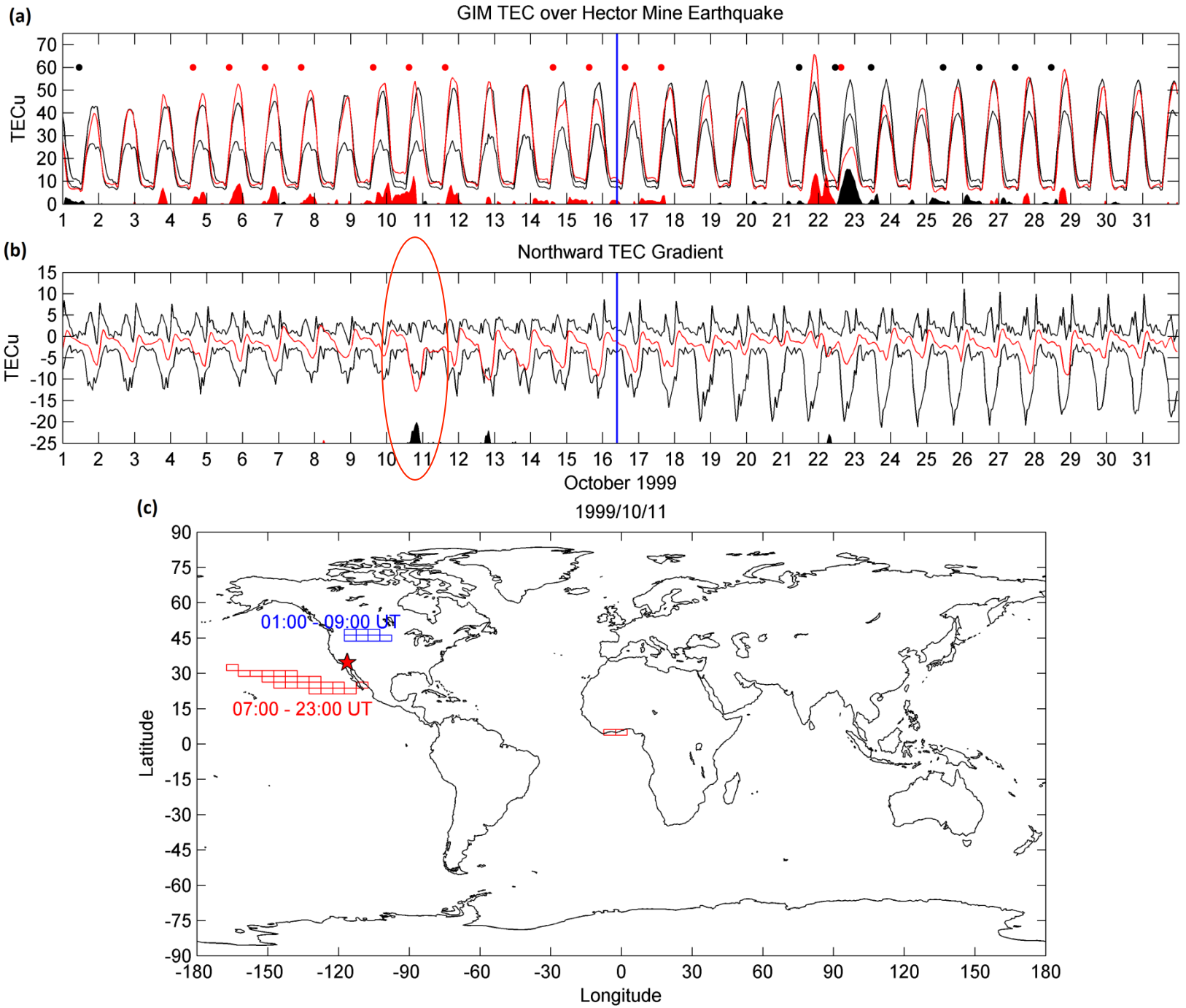
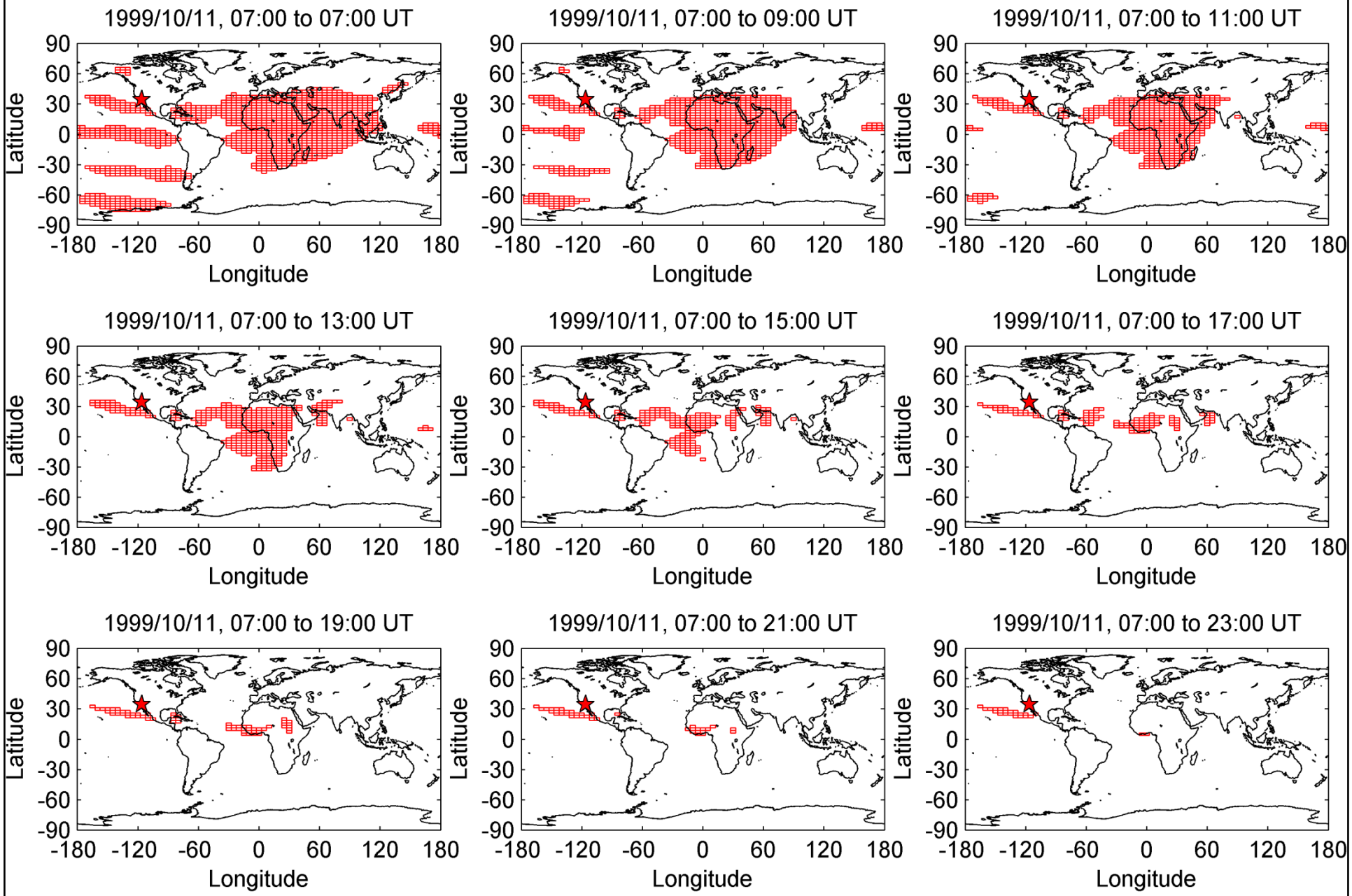

(b)
Northward TEC Gradient
Mw7.1
Hector Mine (35 °N, -116 °E)
Europe (45 °N, 10 °E)
Japan (37 °N, 140 °E)
∂TEC/∂y
30
20
10
0
-10
-20
-30
-40
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31
October 1999

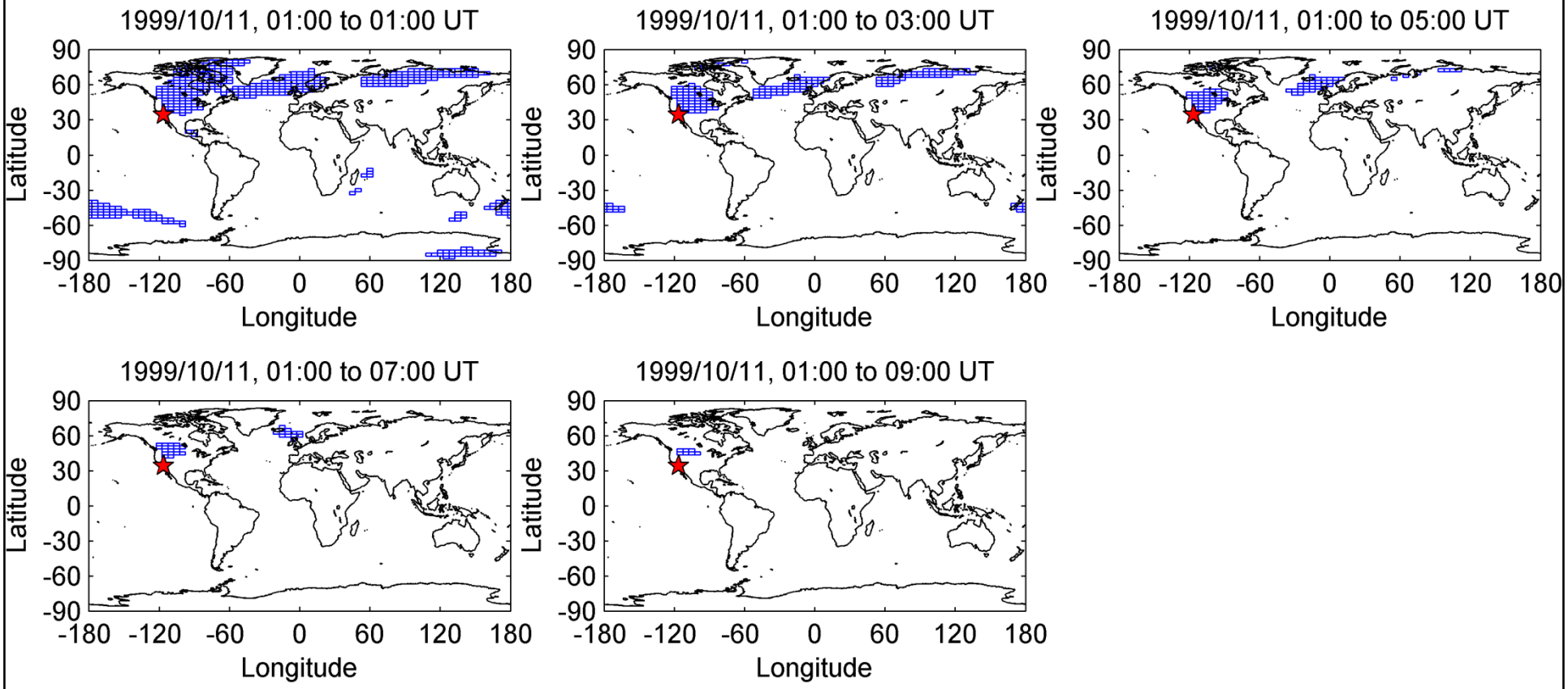
Figure 3.


(a)
GIM TEC over Hector Mine Earthquake
TECu
(b)
Northward TEC Gradient
TECu
October 1999
(c)
1999/10/11
01:00 - 09:00 UT
07:00 - 23:00 UT
Latitude
Longitude

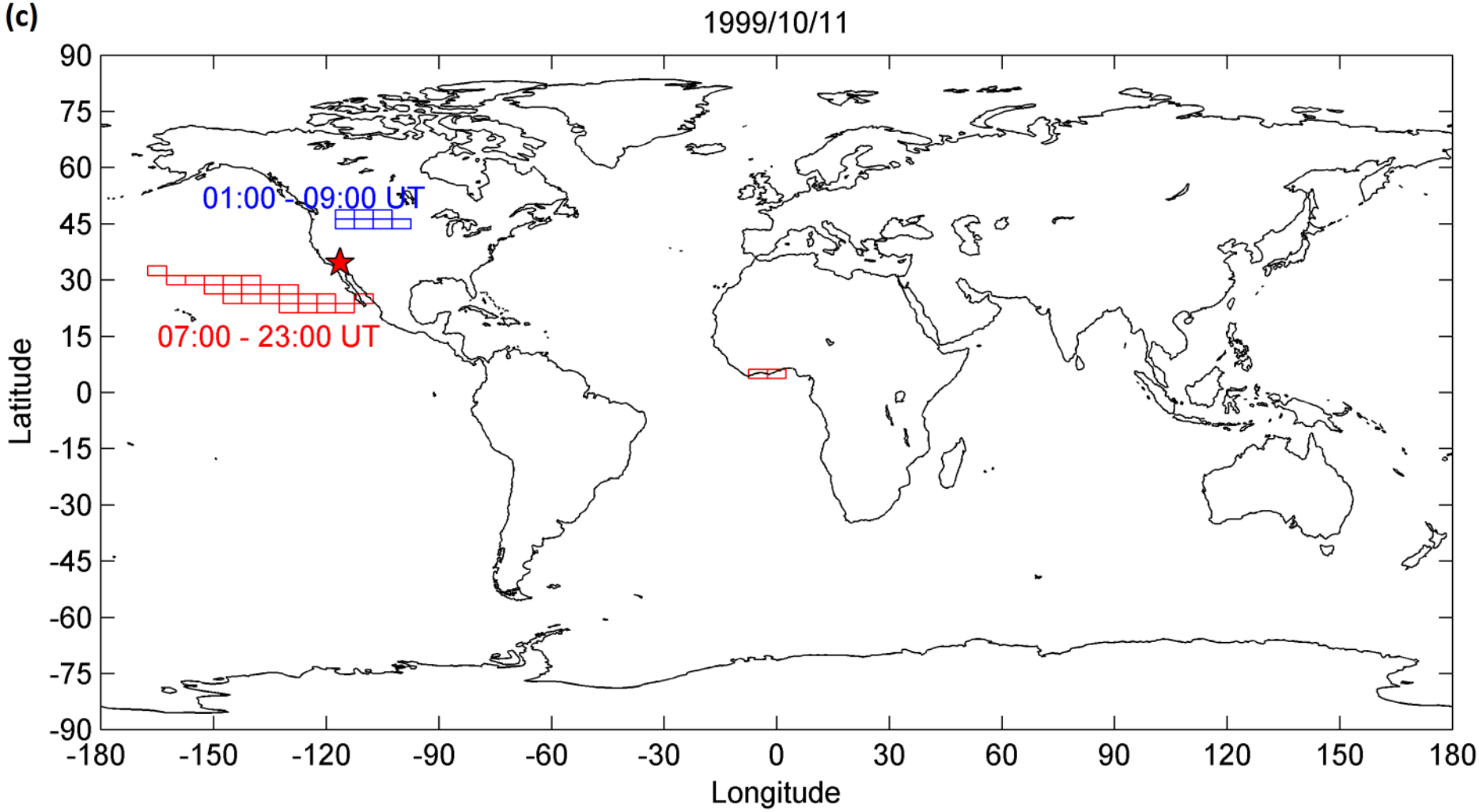
Increase anomaly



Decrease anomaly



(c)


1999/10/11
01:00 - 09:00 UT
07:00 - 23:00 UT
Latitude
Longitude
90
75
60
45
30
15
0
-15
-30
-45
-60
-75
-90
-180
-150
-120
-90
-60
-30
0
30
60
90
120
150
180

Conclusion

- To discriminate anomalies caused by global effects, such as solar radiations, magnetic storms, etc., and local effects, such as earthquake both temporal and spatial anomaly analyses are required.
- A global search by using the TEC of GIM (global ionosphere map) shows that the TEC increase and decrease anomalies continuously and specifically appear around the epicenter day 5 before 1999 Mw7.1 Hector Mine the earthquake.
- A region index, spatial gradient seems to be helpful/useful to discriminate global and local effects.
- Temporal anomalies – Forecast, spatial anomalies – Prediction.
- CSEP-Taiwan???

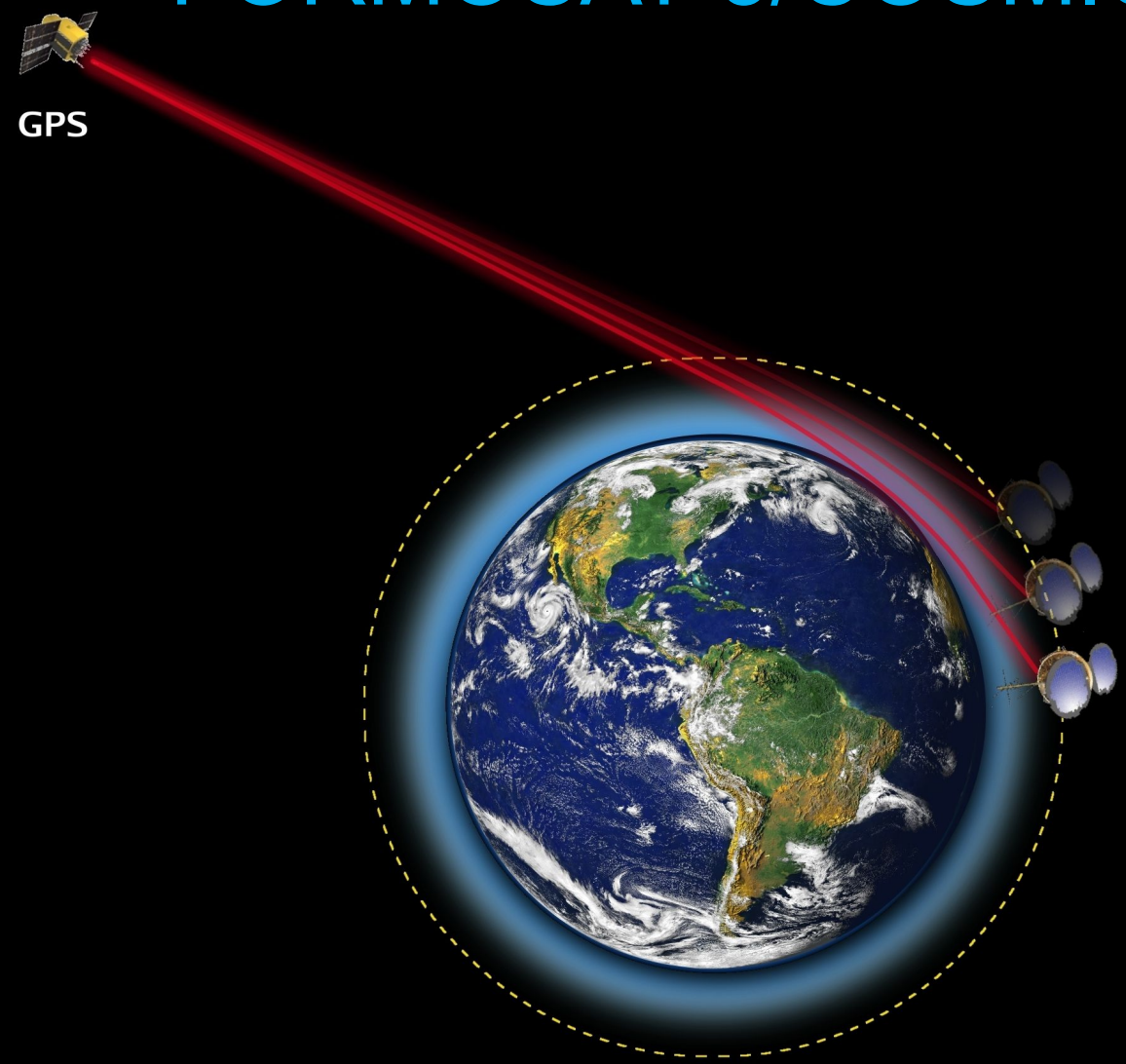
FORMOSAT-3/COSMIC

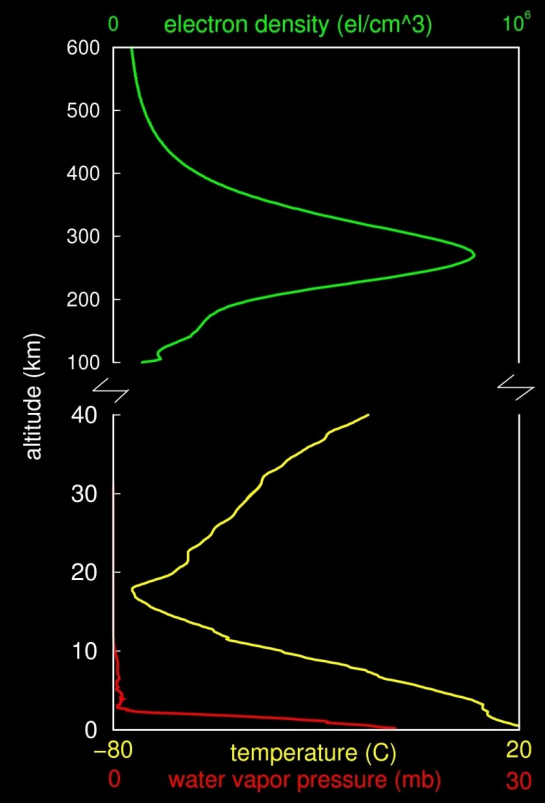
- ***FORMOSAT-3/COSMIC Constellation was launch at 01:40 UTC, April 14, 2006 (Taiwan Time: April 15 2006) at Vandenberg Air Force Base, CA.*** *Minotaur Launch*

- ***Maneuvered into six different orbital planes (inclination ~72°) for optimal global coverage (at ~800 km altitude).***

- ***5 out of 6 satellites are in good health and providing science data.***

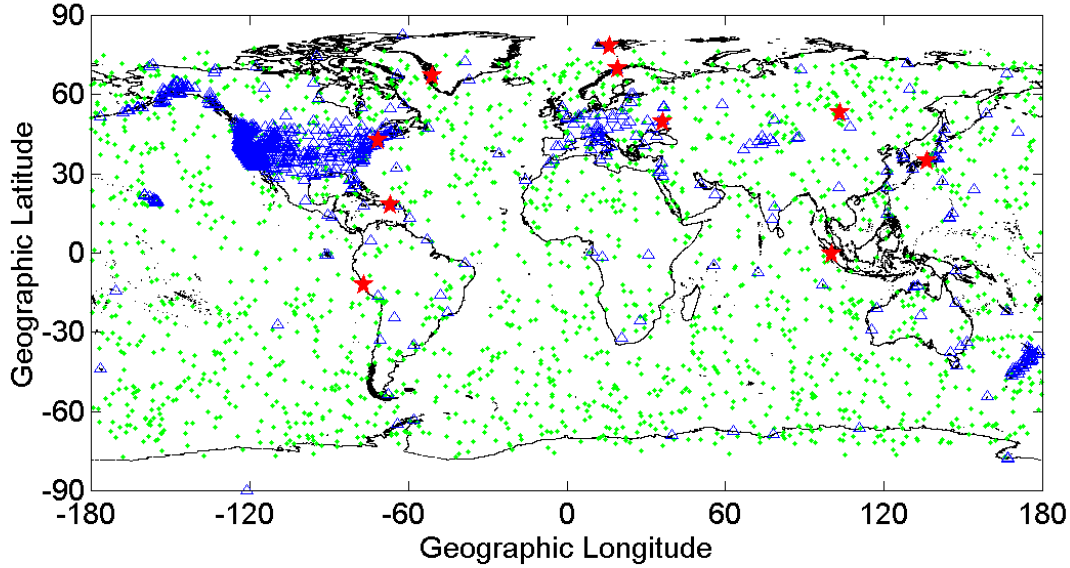
FORMOSAT-3/COSMIC

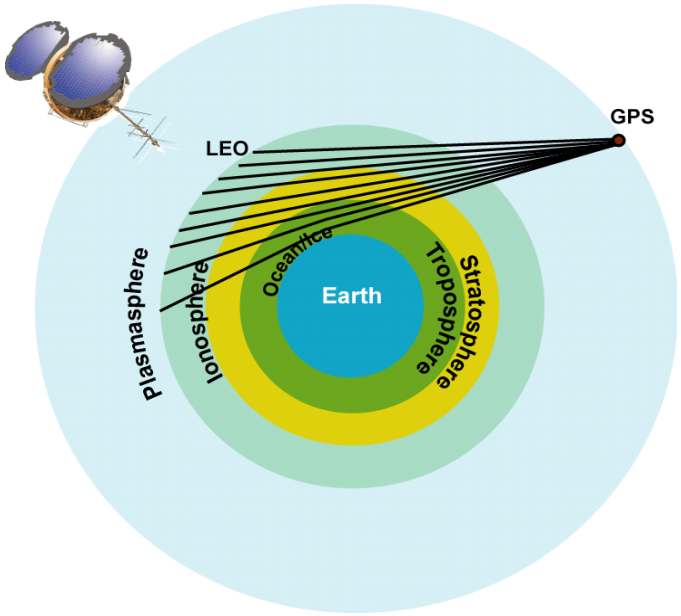


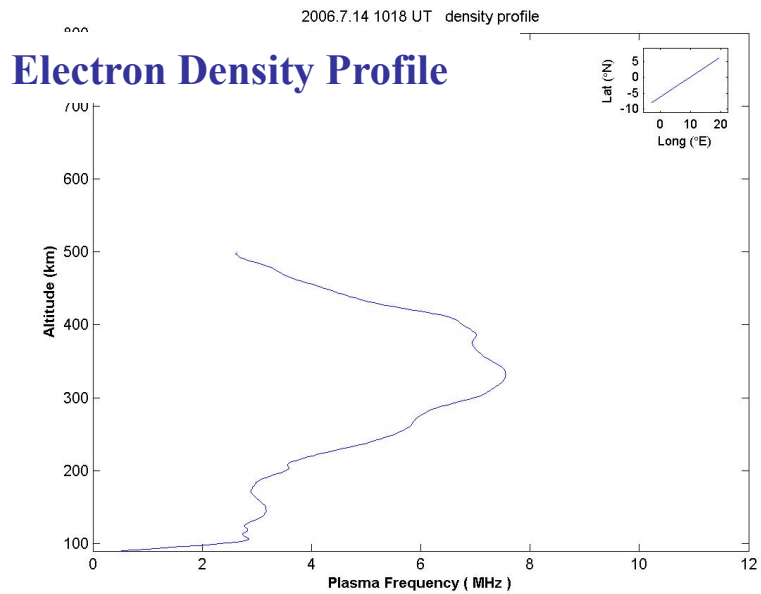


Profiling the Troposphere, Stratosphere and Ionosphere by Radio Occultation

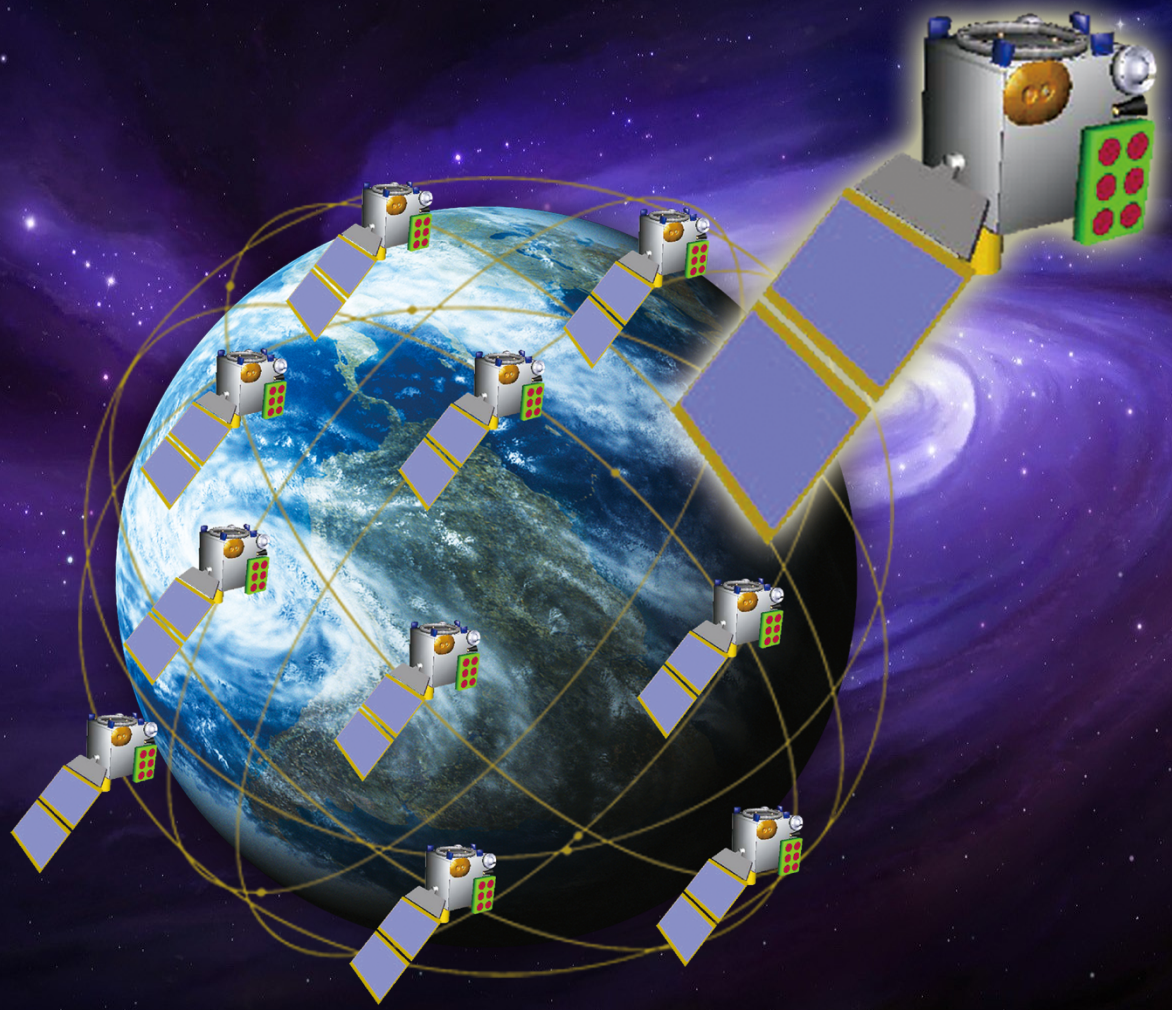
GOX


Geographic Latitude
Geographic Longitude
90
60
30
0
-30
-60
-90
-180
-120
-60
0
60
120
180

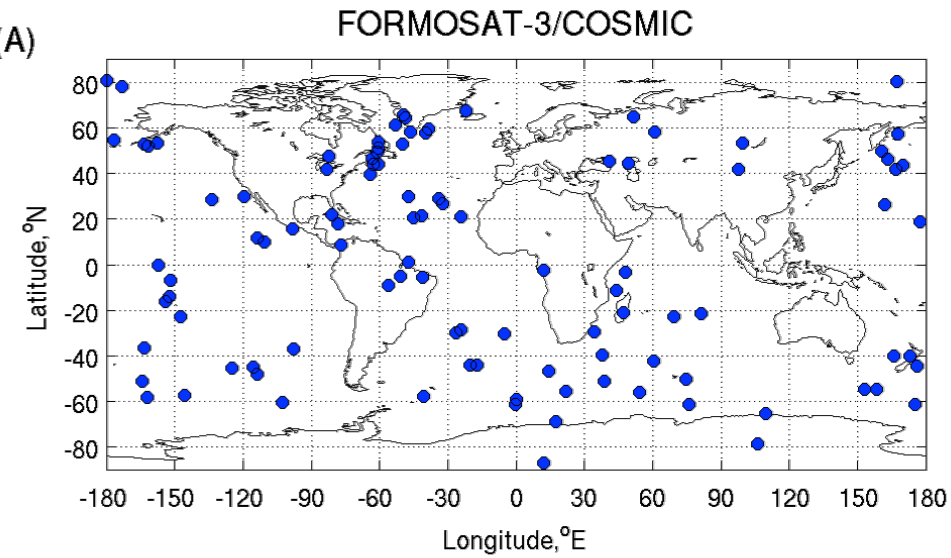

GPS
LEO
Plasmasphere
Ionosphere
Oceanice
Earth
Troposphere
Stratosphere


2006.7.14 1018 UT density profile
Electron Density Profile
Altitude (km)
Plasma Frequency (MHz)
Lat (°N)
Long (°E)

FORMOSAT-7



(A)

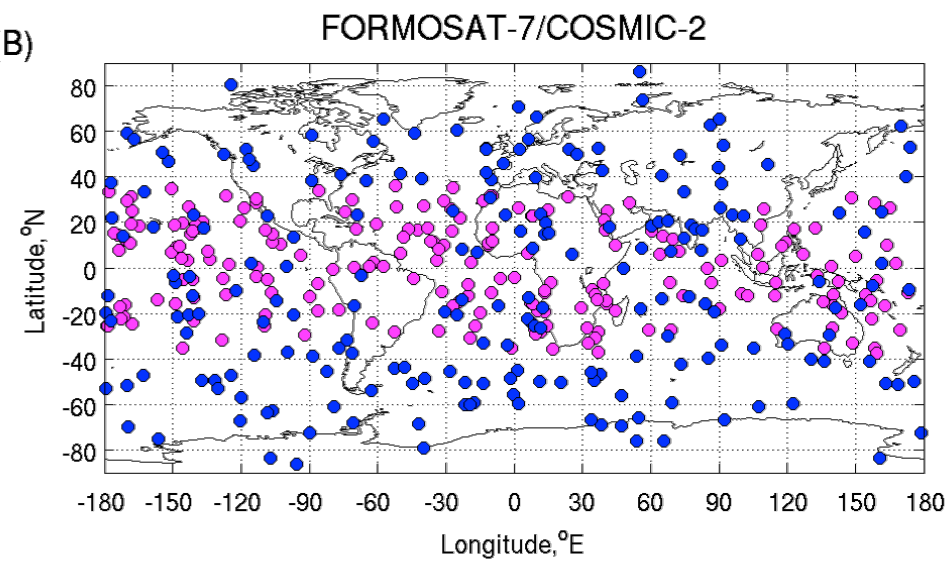


With 6 satellites + GPS, 60 minutes

About 80-100 profiles per hour

F3/C

(B)



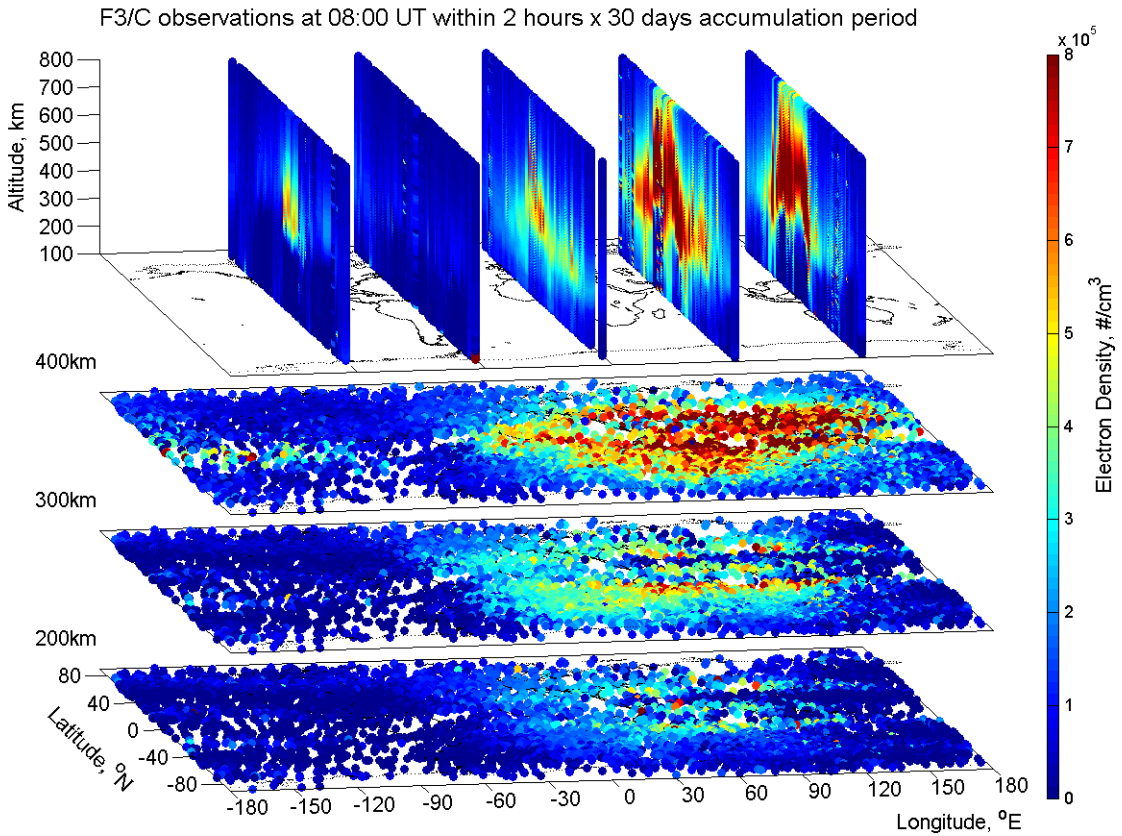
With 12 satellites + GPS, 60 minutes

About 400 <u>profiles</u> per hour

1 st

2 nd

What is future impact of F7/C2 on ionospheric research?

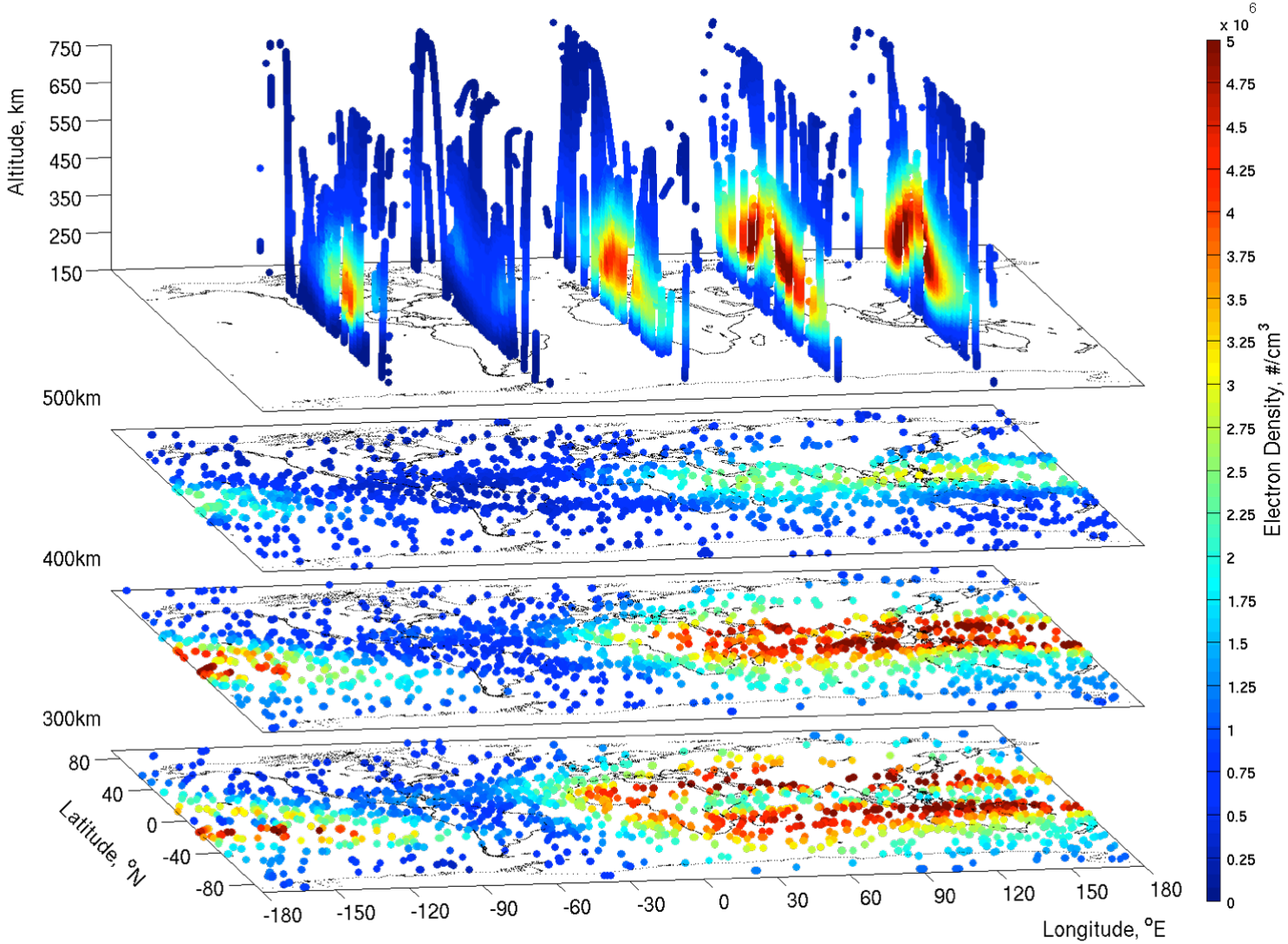


- Solar activity variations
- Seasonal variations
- Monthly variations
- Tidal effects
- Diurnal variations
- Semi-diurnal variations
- Disturbed period effects
- Other temporal variations
- Irregularities

Could it be advanced by F7/C2 ?

Simulated F7/C2 observations at 08:00 UT within 1 hour x 1 day accumulation period

12 satellites, 28 GPS and 24 GLONAAA



Lee et al. submitted [2012, JGR]

敬請批評指教 Thank you!!!