# Effect of the ionospheric irregularities occurring before earthquakes on the signal parameters of GNSS

S.A. Pulinets[1,2], D.V. Davidenko[1,3]

[1]Space Research Institute, Russian Academy of Sciences, Moscow

[2]JSC "Russian Space Systems", Moscow

[3]S.P. Korolev Rocket and Space Corporation «Energia», Korolev

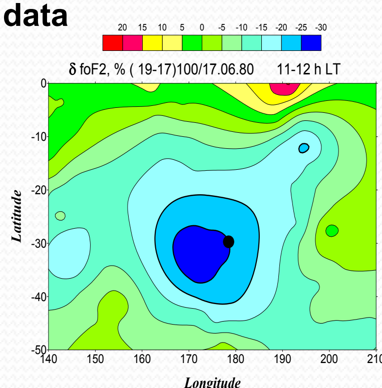
United Nations/ICTP Workshop on the Use of Global Navigation Satellite Systems (GNSS) for Scientific Applications, 1-5 December 2014, Trieste, Italy

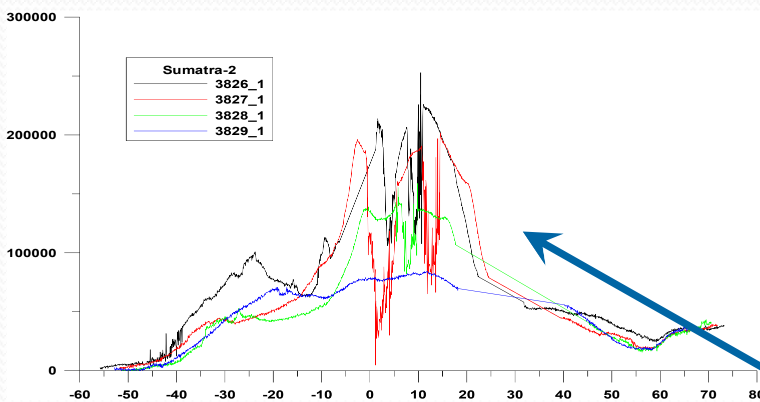
# Outline

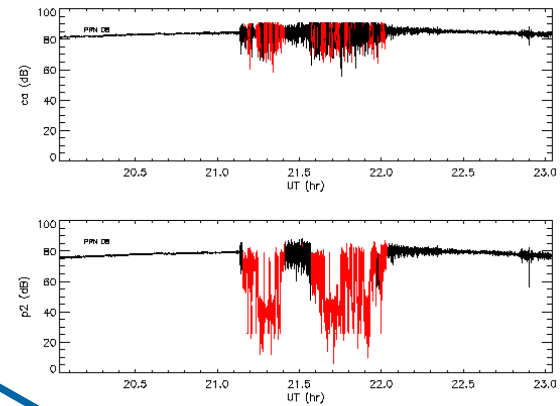
- Introduction
- Seismo-ionospheric anomalies – unpredictable threats for the satellite navigation and communication
- The types of seismo-ionospheric anomalies
- Multi-parameter monitoring – the way to anticipate the seismo-ionospheric anomalies in advance
- Local character and self-similarity of the ionospheric precursors – the way to their automatic recognition
- Conclusions

# Seismo-ionospheric anomalies and radio waves propagation

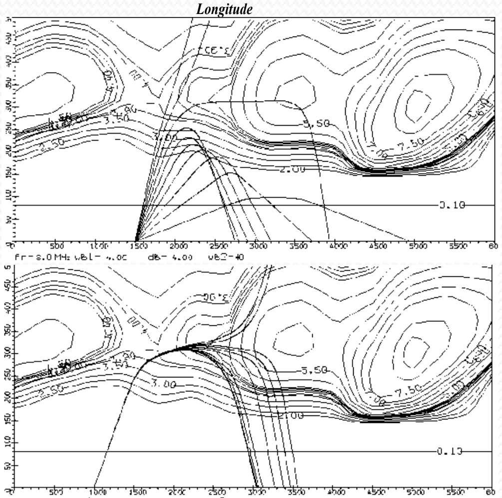
**The «hole» in the ionosphere over the earthquake preparation zone in New Zealand region by Intercosmos-19 data**



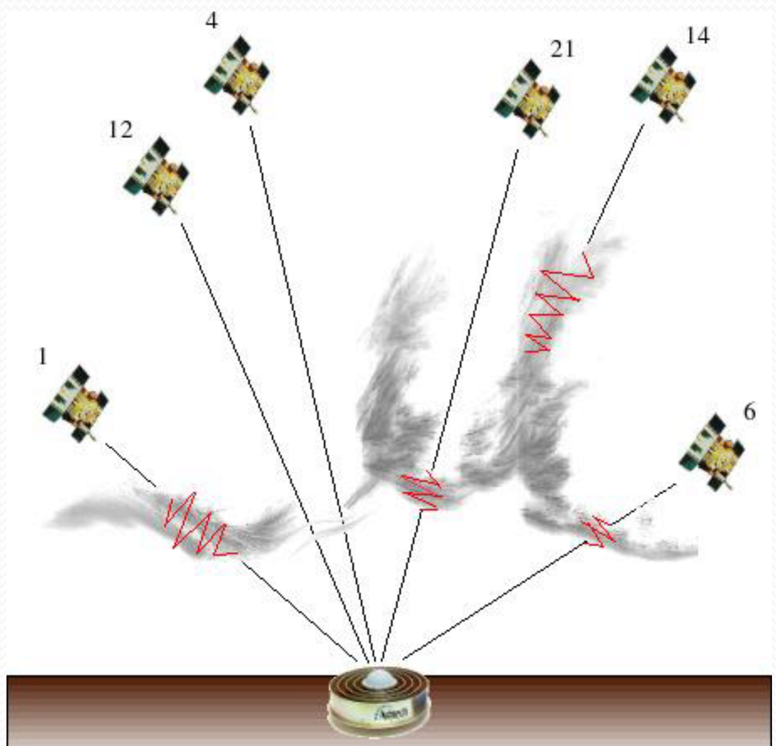




**Plasma bubbles formation before the M8.6 Sumatra earthquake 27 March 2005 by the DEMETER satellite data**

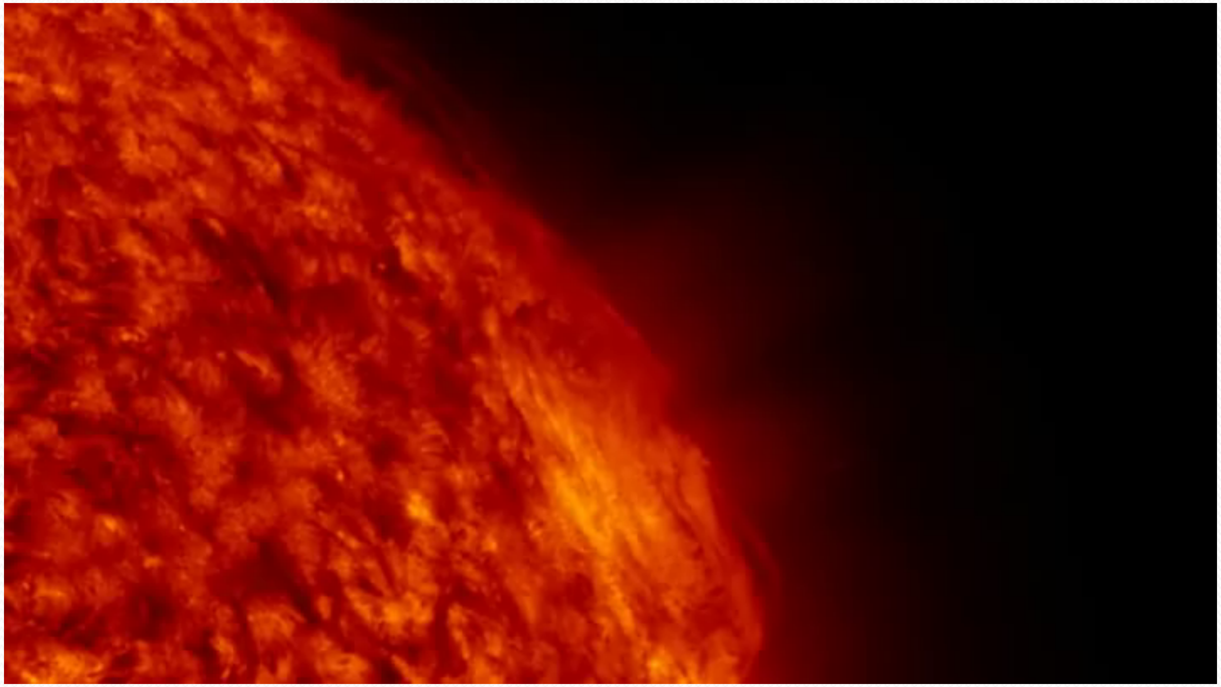


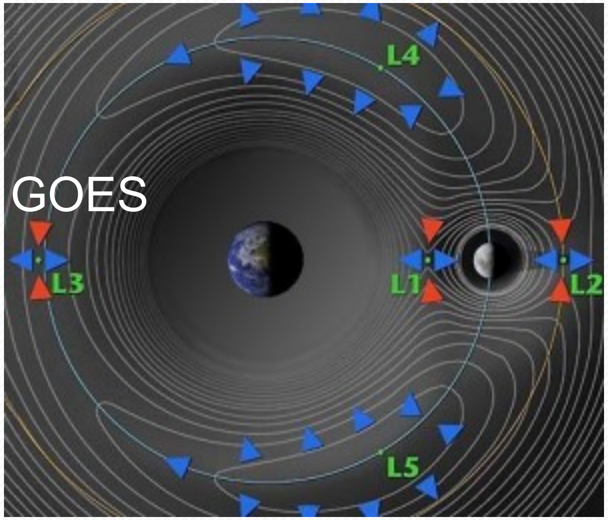
**Anomalous trajectories of HF waves propagation under different under different incidence angles on the modified area**




**Plasma bubbles effect is the signal scintillation up to complete loss of tracking the GPS signal сигнала (tracking)**

# unpredictable threats for the satellite navigation and communication

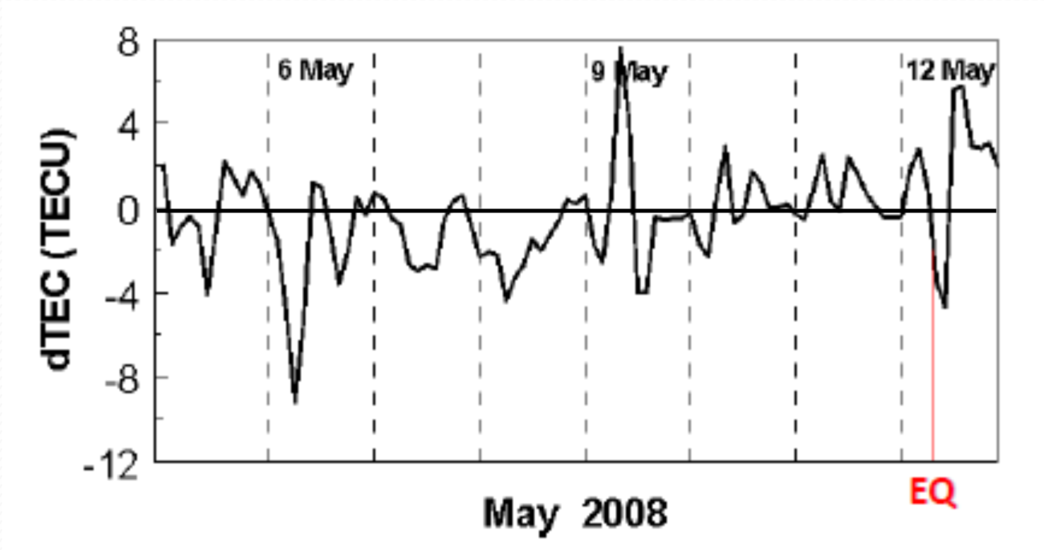




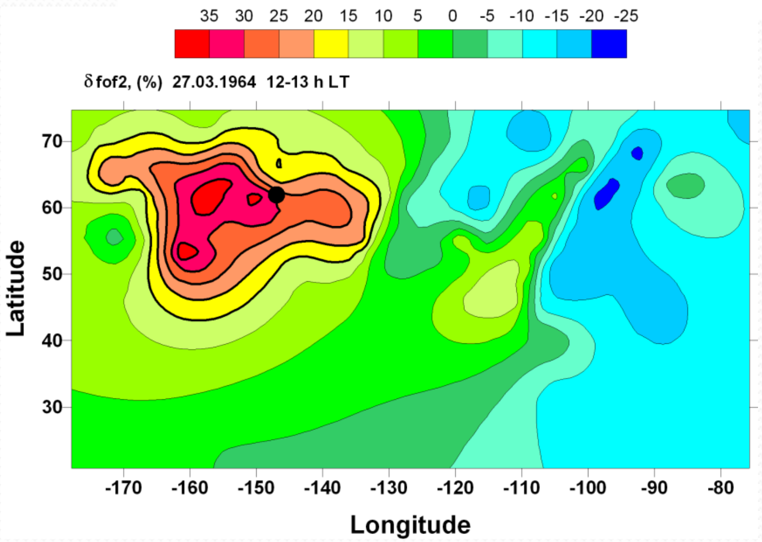

Solar flare – 8.3 min
X-rays – few hours
CMEs – 2-3 days

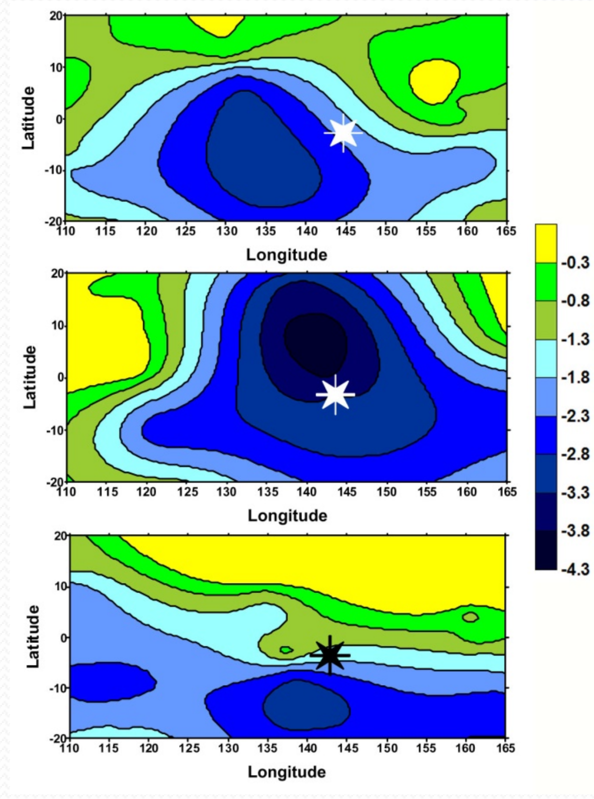
**Nobody knows where and when the next earthquake will happen and seismo-ionospheric anomaly will form**

# How look like the seismo-ionospheric anomalies

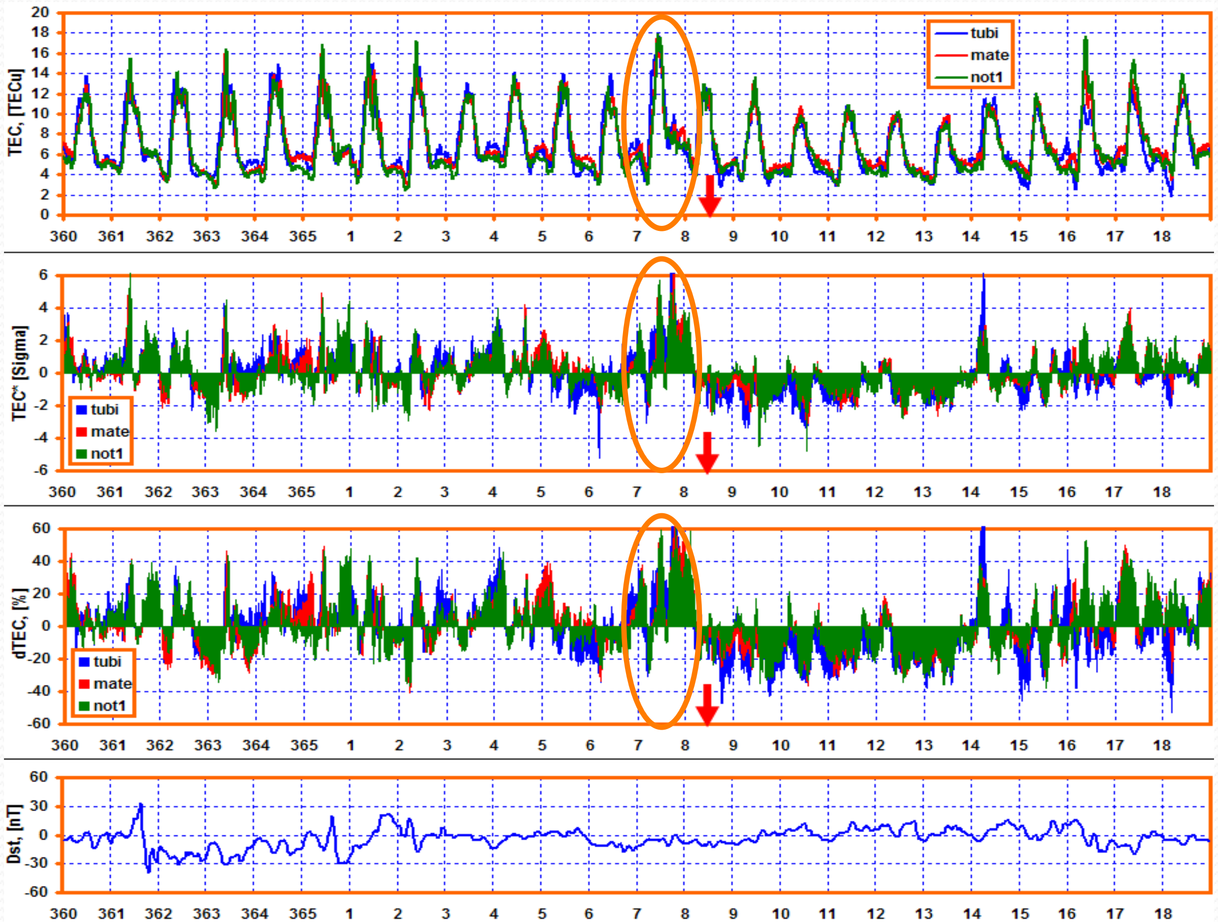


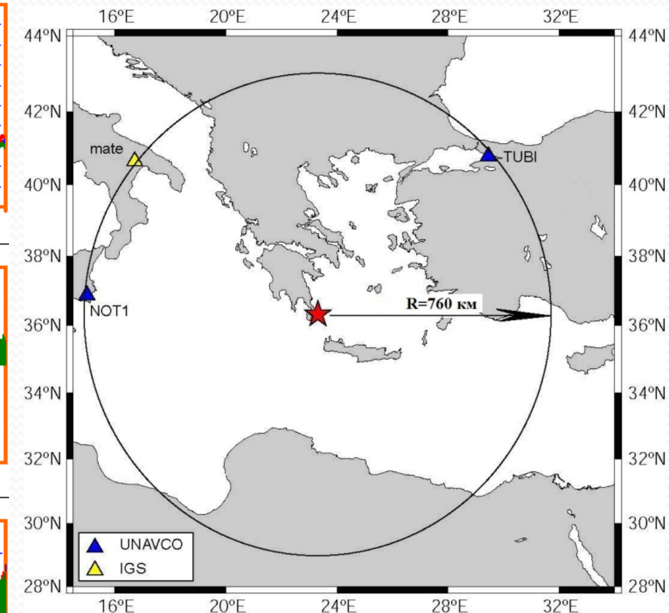

Positive and negative deviations are possible



# In GPS TEC language for GPS receivers located inside of the earthquake preparation zone



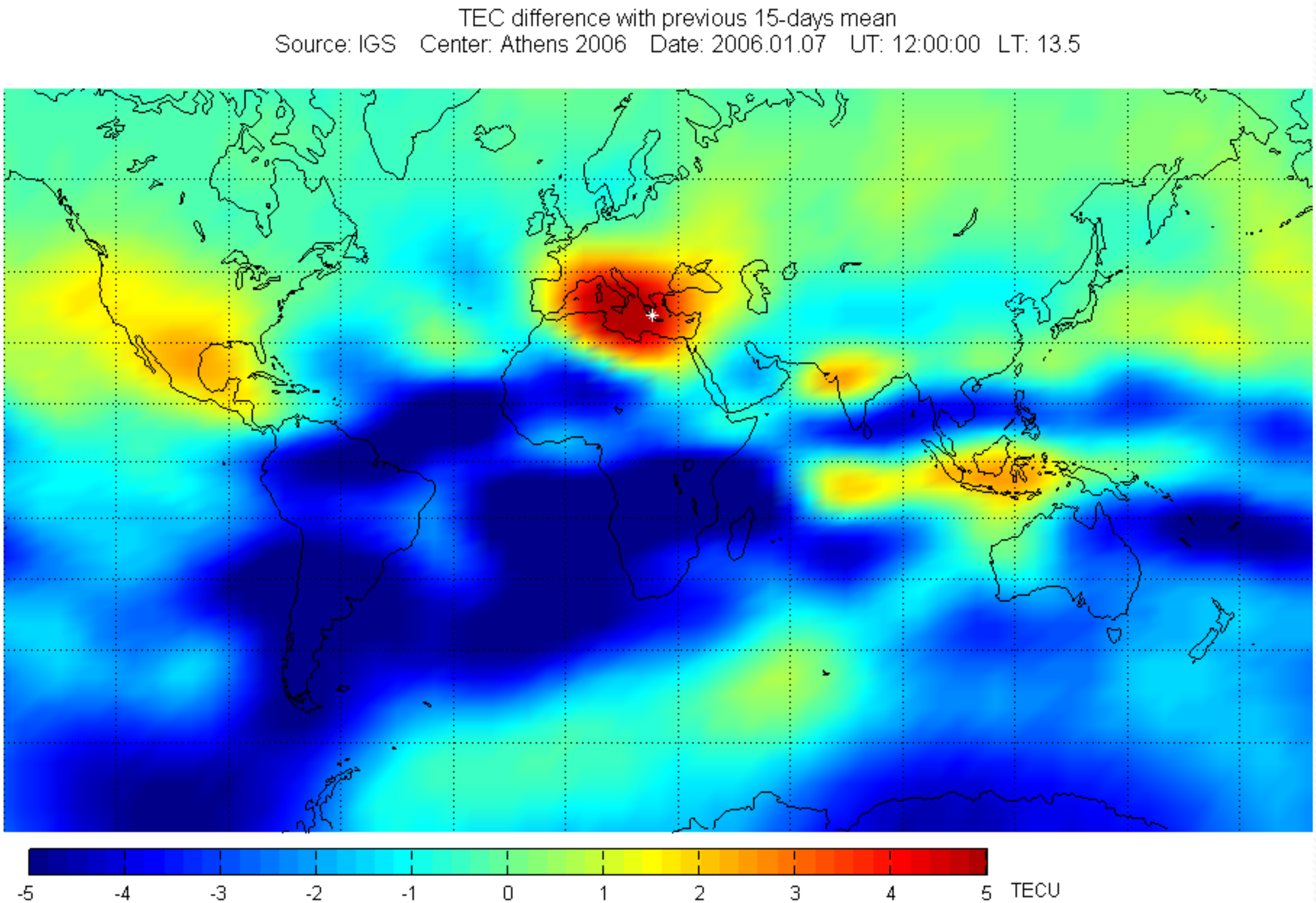

- ***dTEC=100·(TEC-TEC$_{CP}$)/TEC$_{CP}$***

**TEC, [TECu] – value of TEC for given time;**

**$TEC_{CP}$ , [TECu] – running average value of TEC calculated for 15 previous values TEC for given time;**

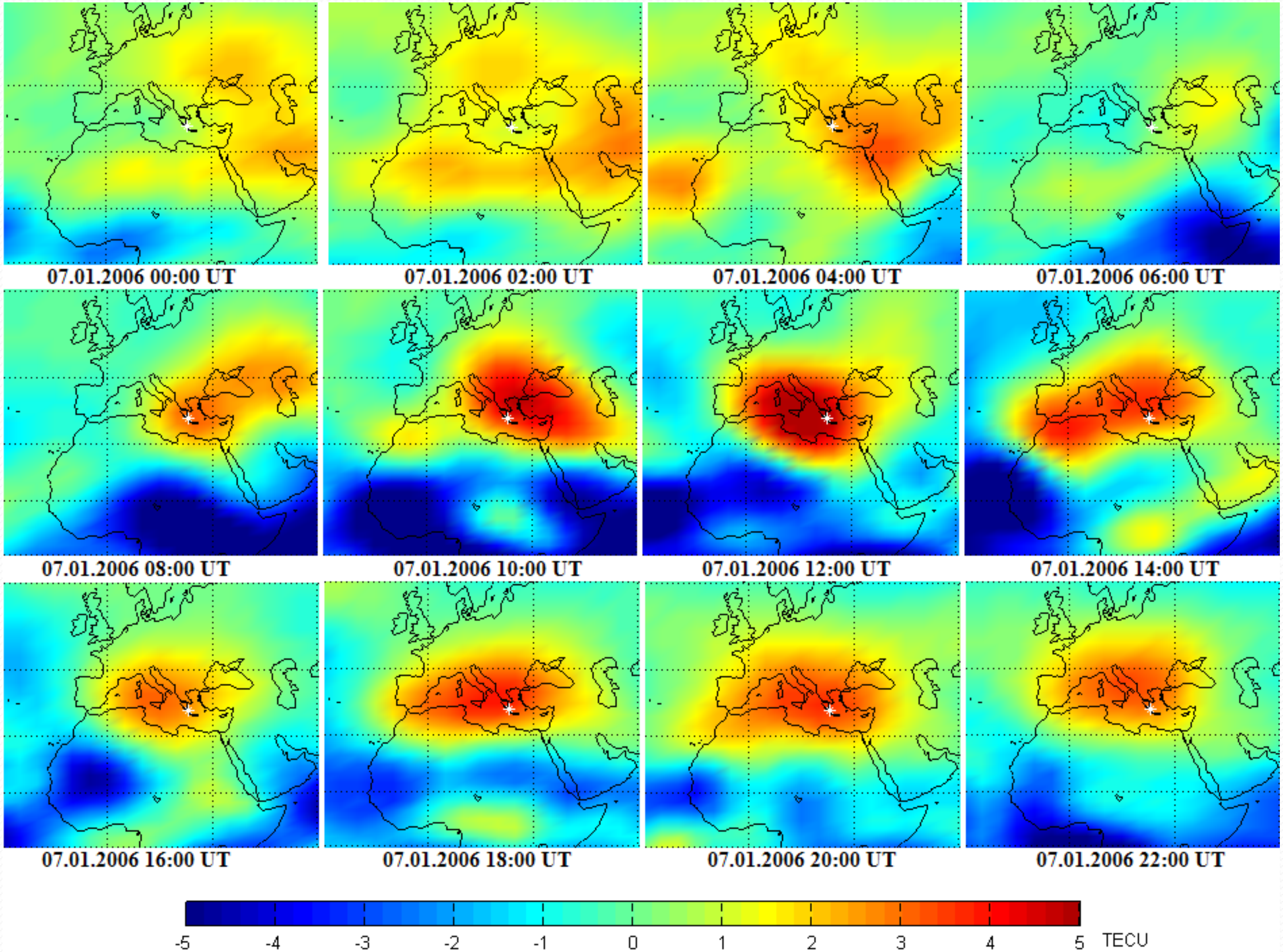
**σ – standard deviation calculated for 15 previous values of TEC for given time.**

# How it looks at GIM map




**Region with considerable increase of TEC over the epicenter 24 h before the earthquake M6.7.**

# How long it can exist

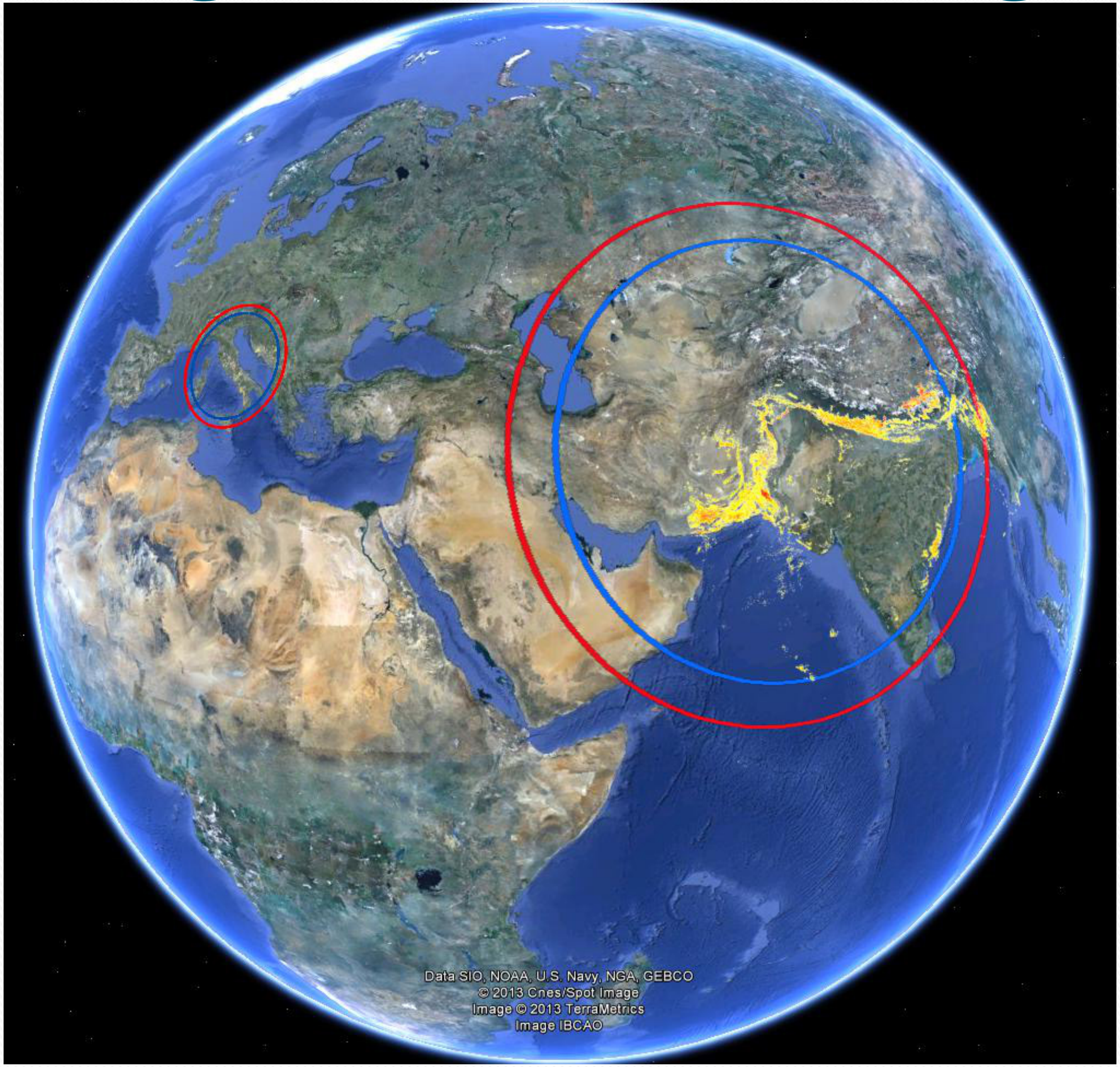



# How large

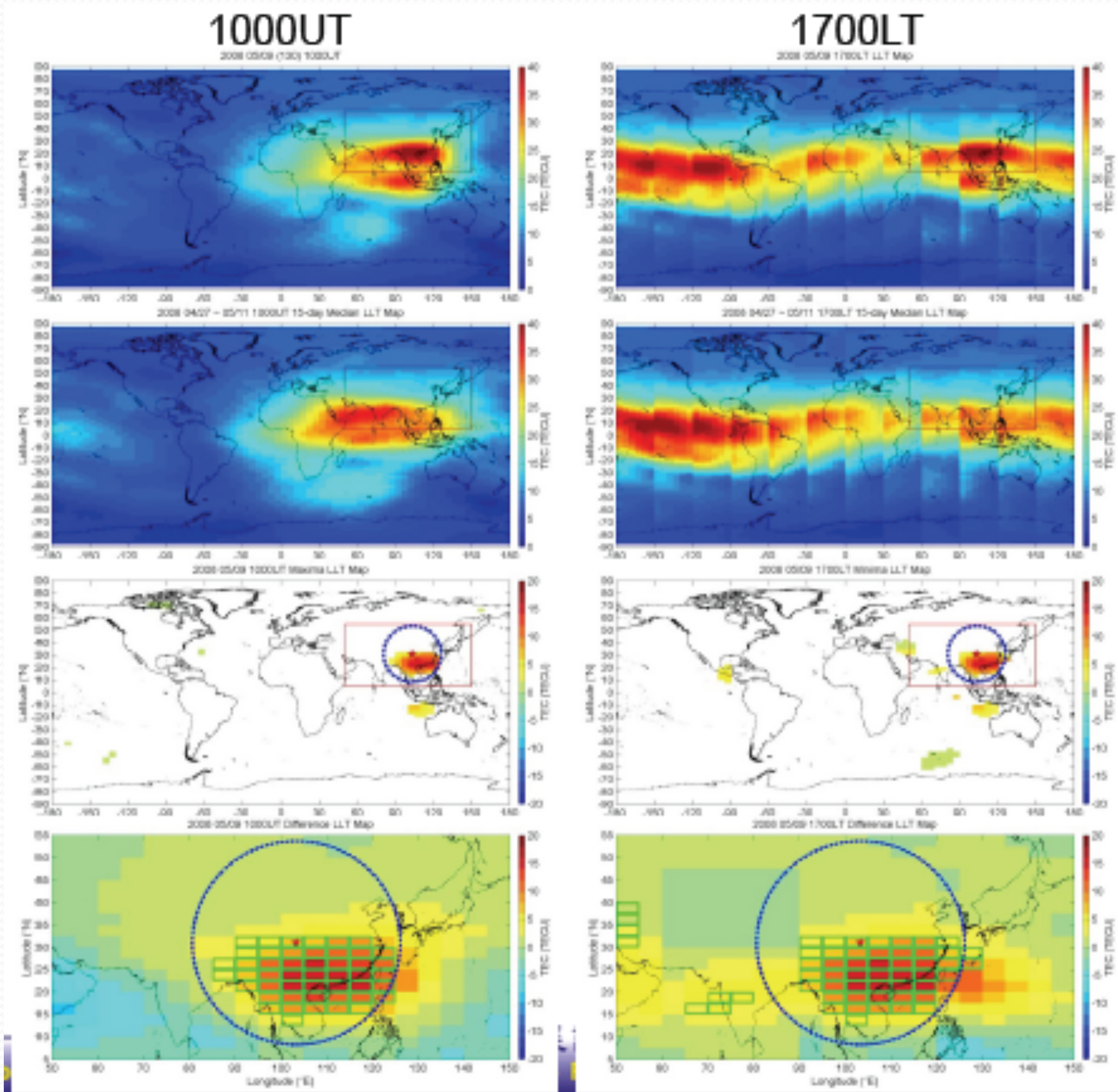
$R = 10^{0.43M}$ km ~ 511 km

| Magnitude | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|
| Earthquake preparation zone radius ρ (km) | 19.5 | 52.5 | 141 | 380 | 1022 | 2754 | 7413 |

# Magnitude scaling



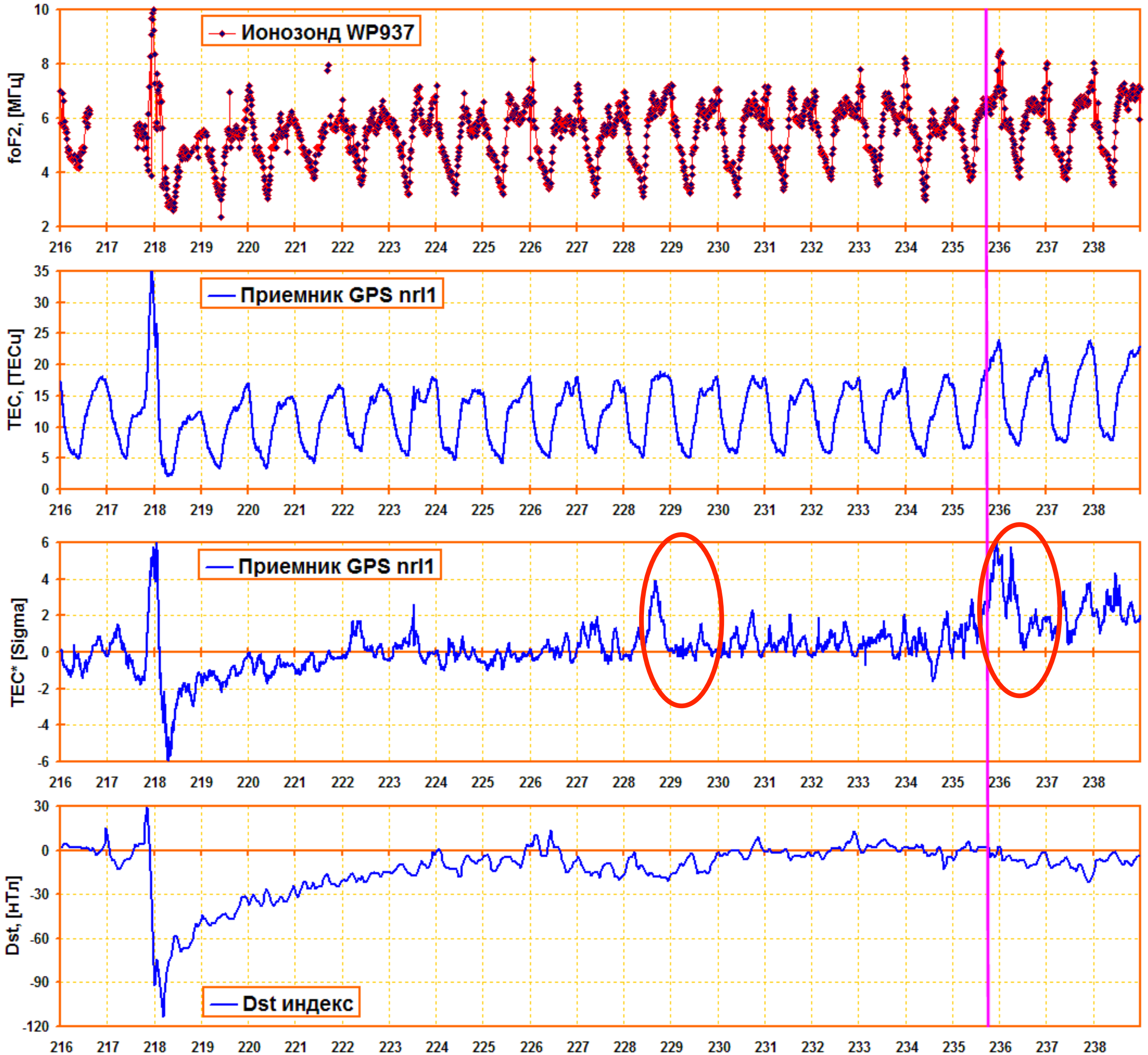
# Wenchuan earthquake



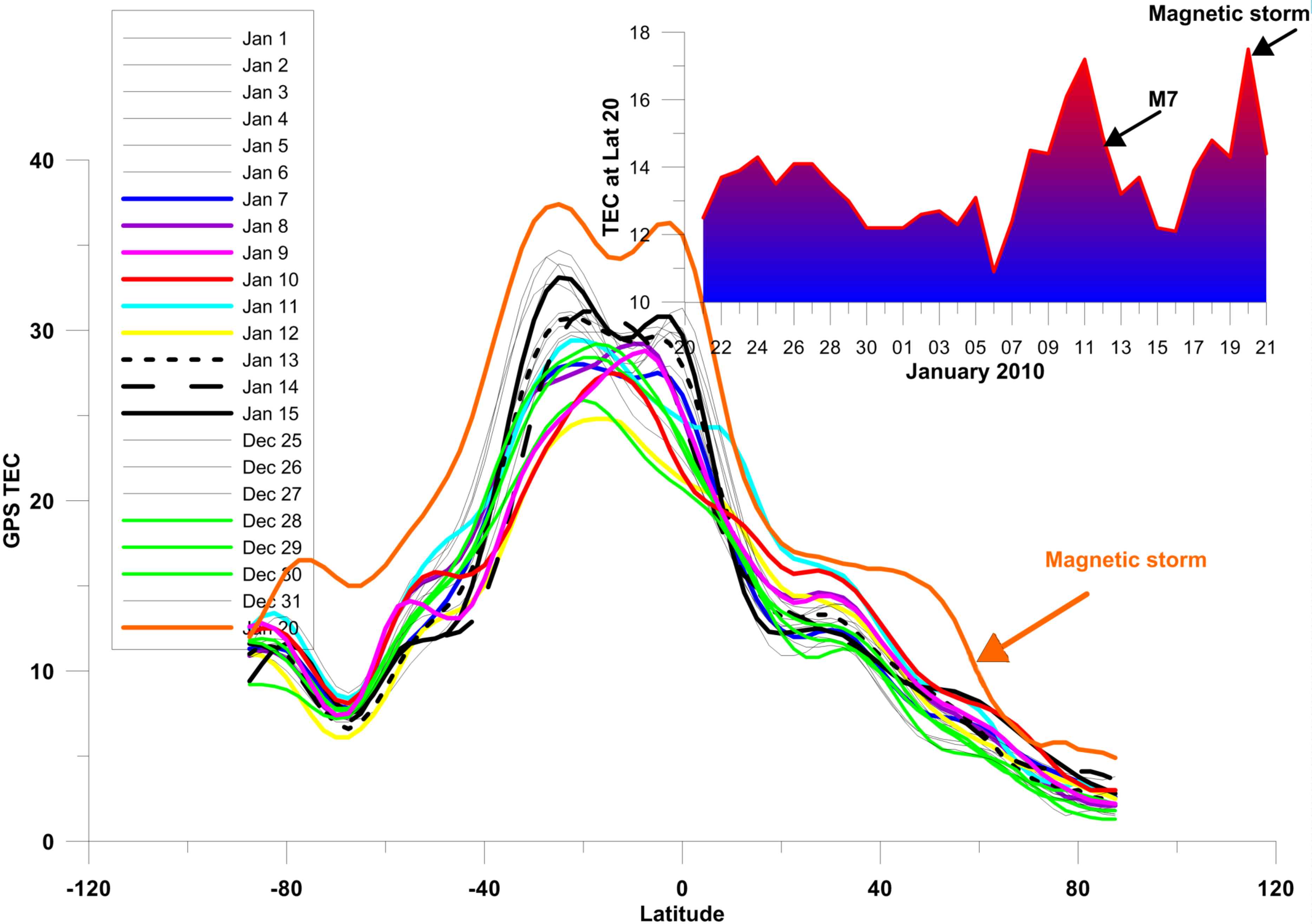

The GIMs observed at 08:00UT and global fixed 15:00 LT on day 3 before the 2008 Mw7.9 Sichuan Earthquake.

Liu et al., 2013

# Magnetic storm and earthquake



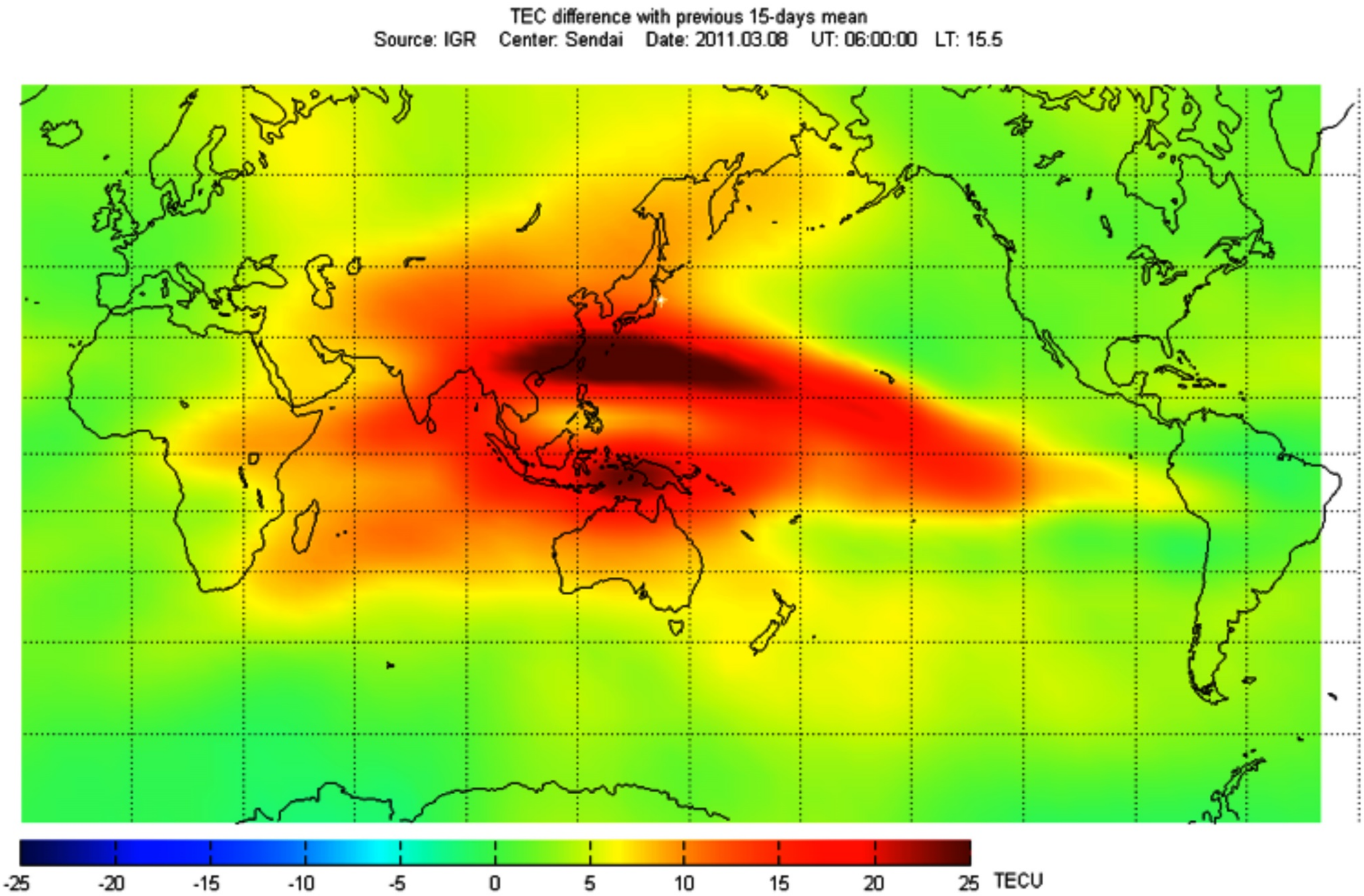

Virginia M5.8 earthquake
23 August 2011



Magnetic storm
Jan 1
Jan 2
Jan 3
Jan 4
Jan 5
Jan 6
Jan 7
Jan 8
Jan 9
Jan 10
Jan 11
Jan 12
Jan 13
Jan 14
Jan 15
Dec 25
Dec 26
Dec 27
Dec 28
Dec 29
Dec 30
Dec 31
Jan 20
TEC at Lat 20
M7
January 2010
GPS TEC
Magnetic storm
Latitude

# Tohoku earthquake

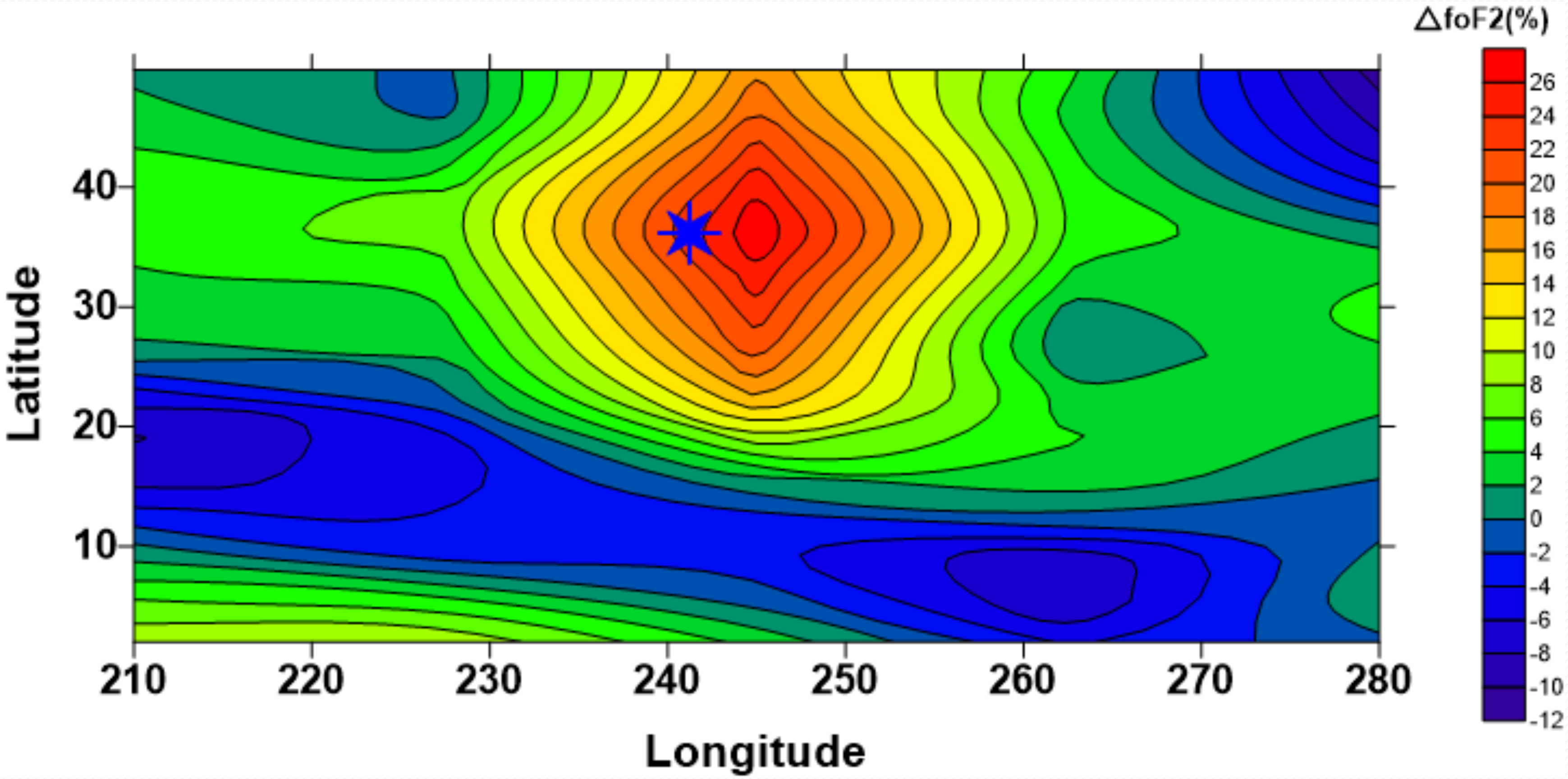
38.3 N
142.4 E



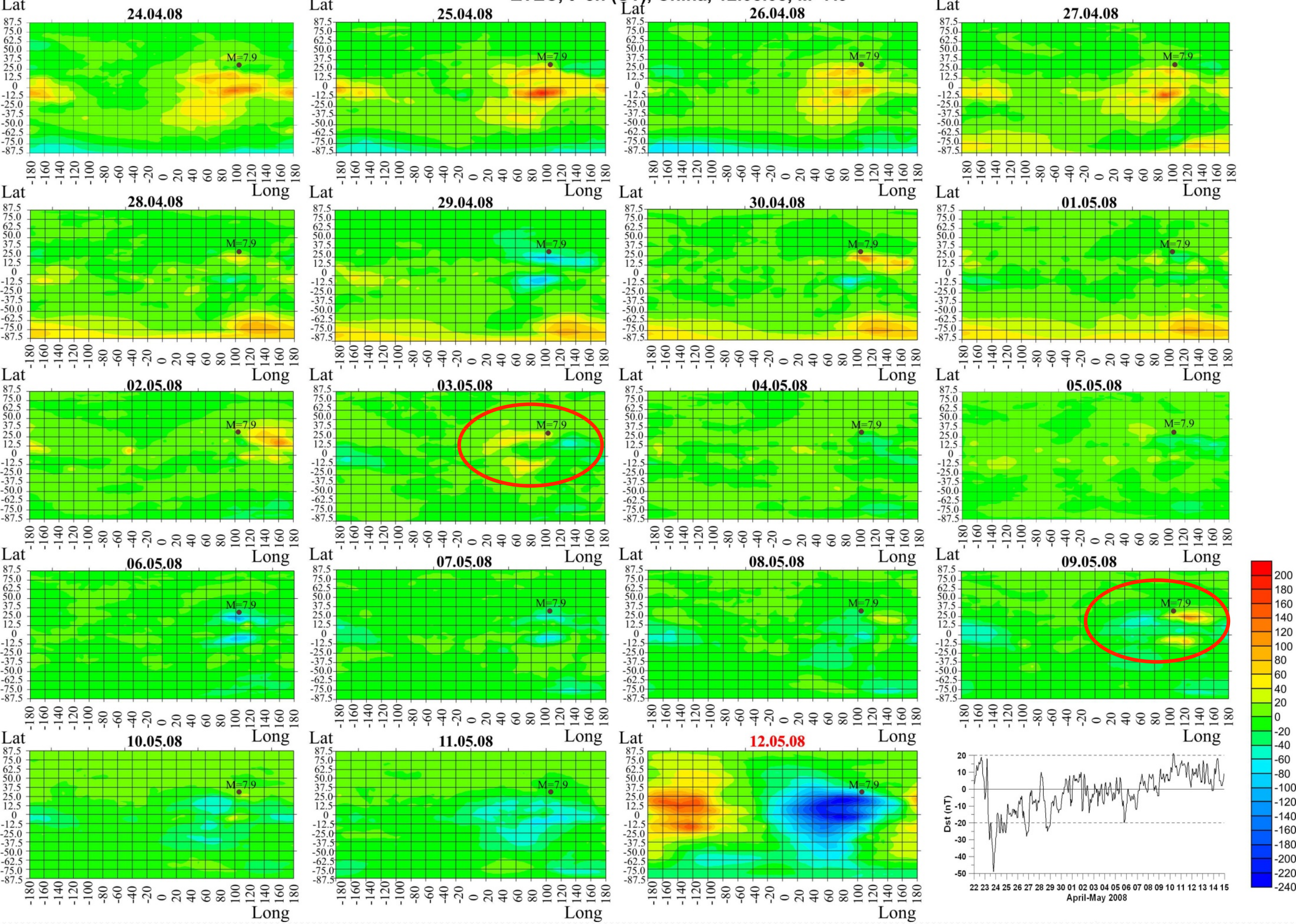
# Equatorial anomaly reaction on the middle latitude earthquakes

Mammoth Lake seismic swarm,
May 25-27, 1980, 4 shocks M>6

37.5 N
118.8 W

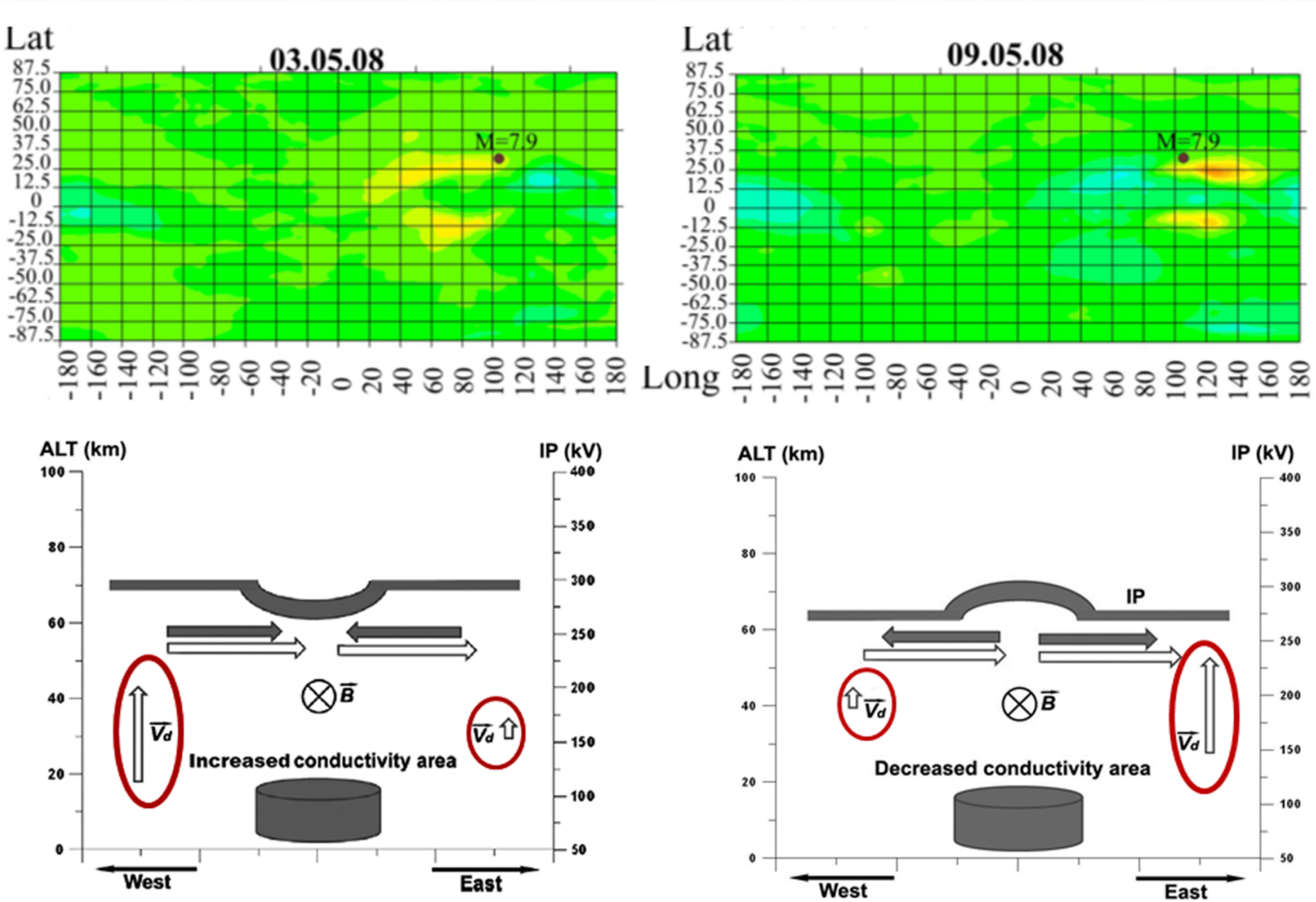


ΔTEC, t=8h (UT), China, 12.05.08, M=7.9



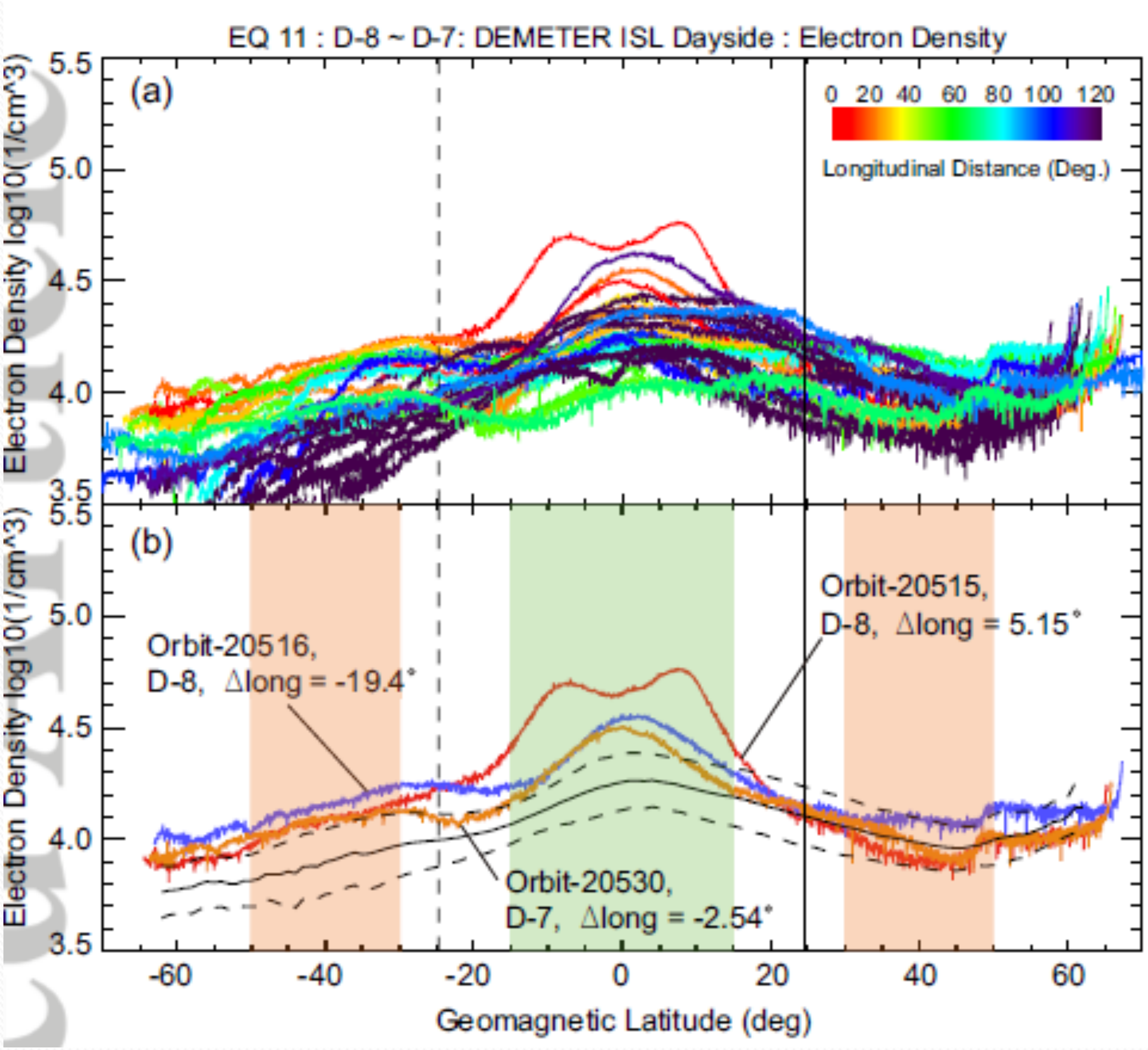
# Ionospheric potential variations

Pulinets and Davidenko, 2014

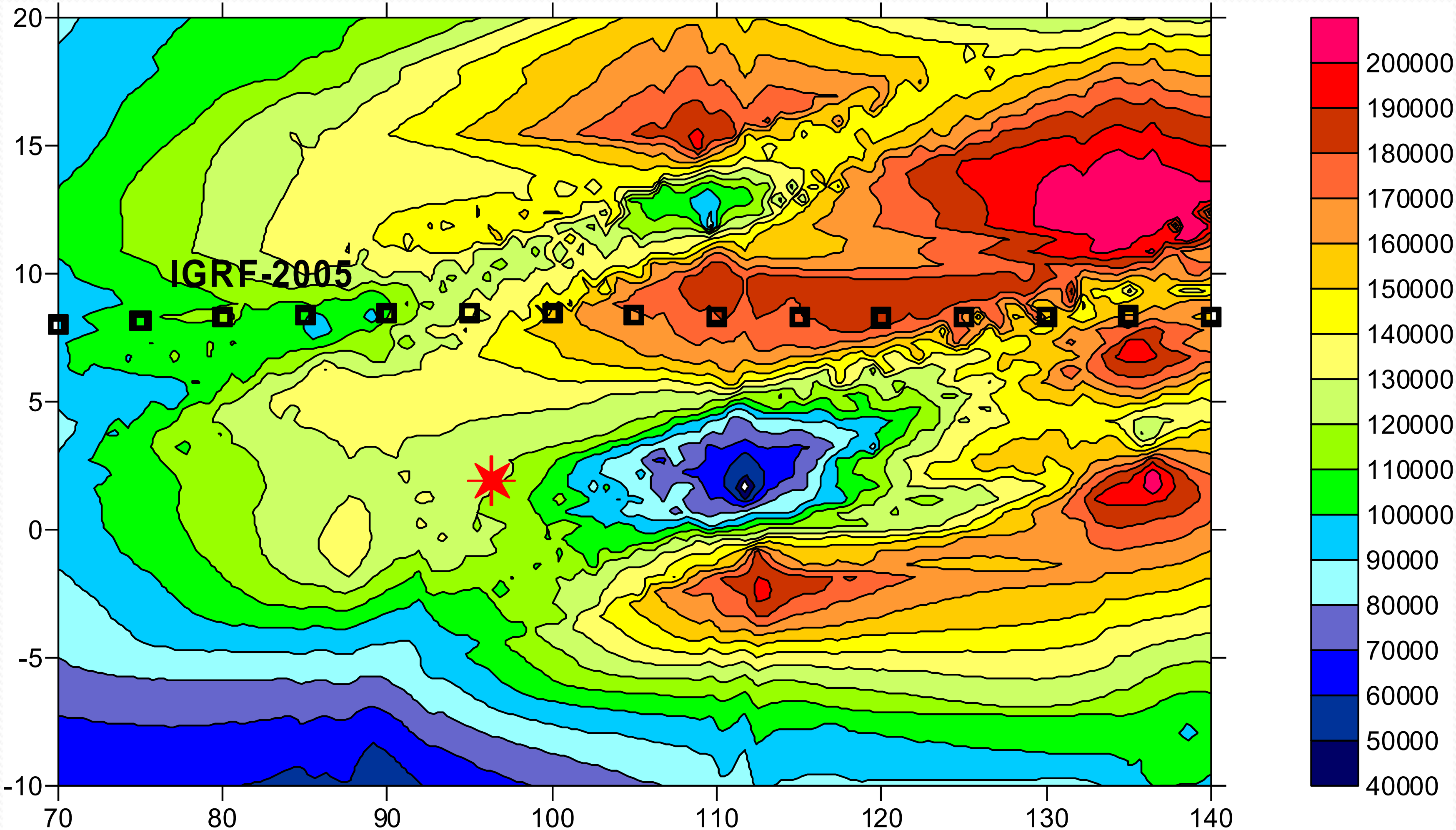


# Pure anomalous electric field effect

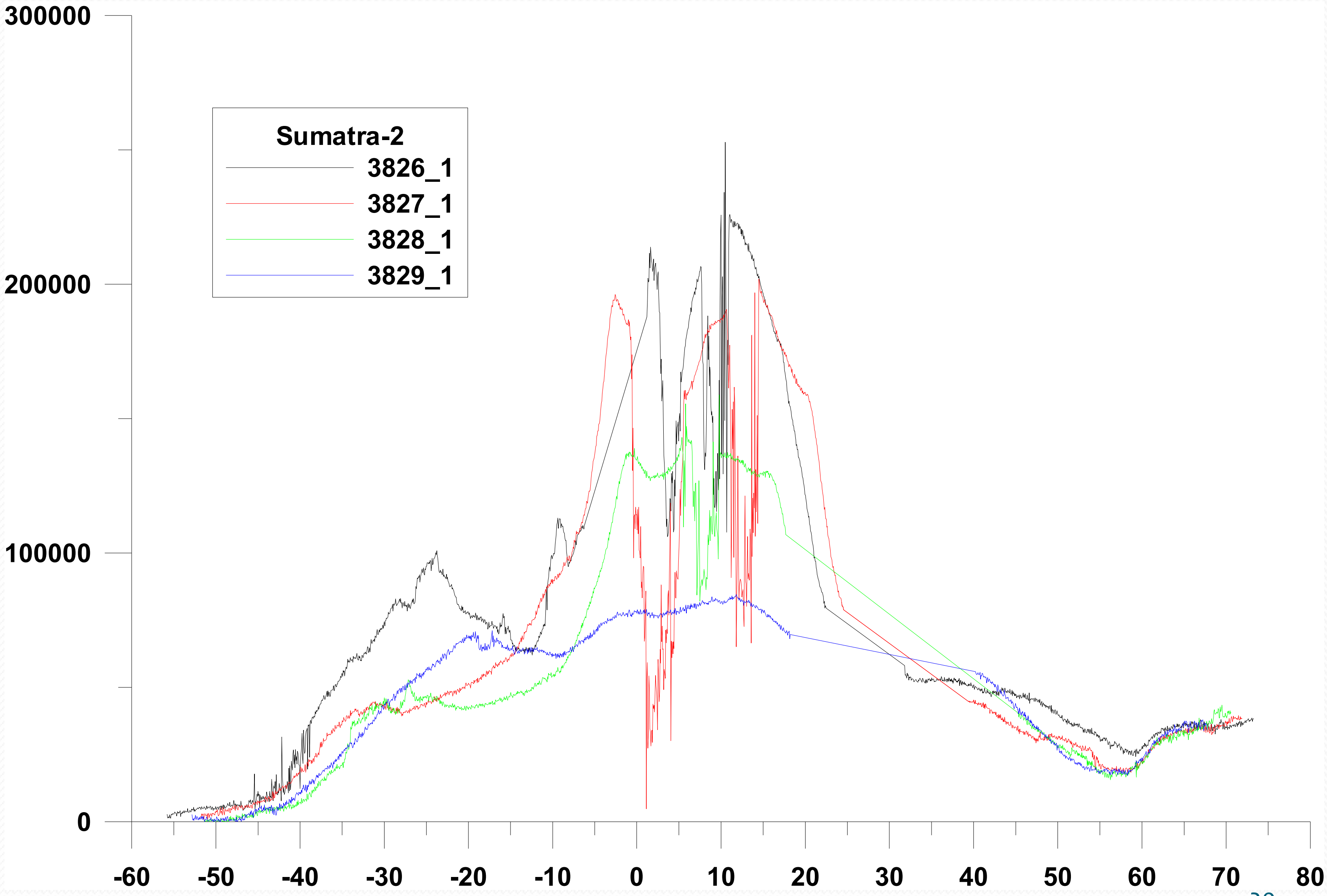
Ryu et al, JGR, 2014, accepted



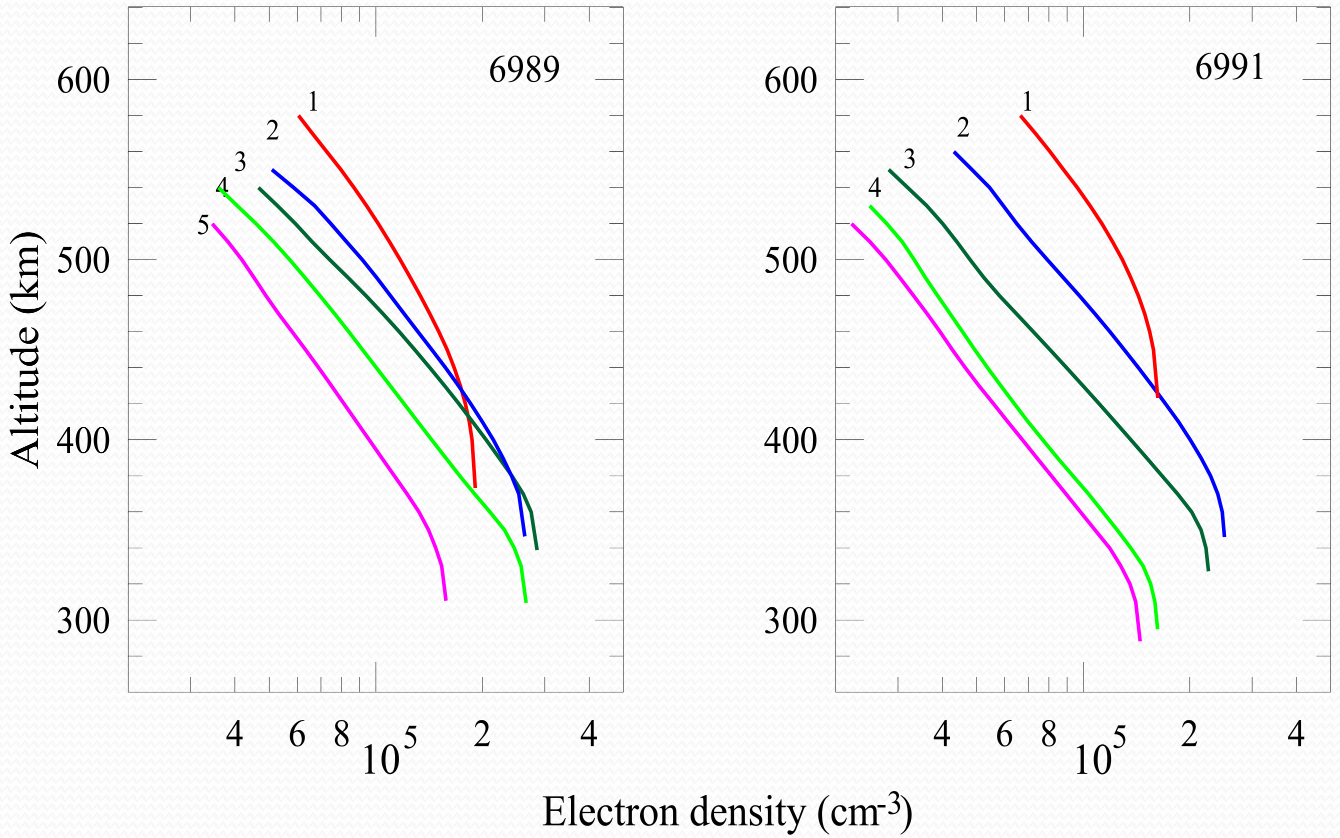
# Ion concentration distribution before Sumatra M8.7 EQ of 27 March 2005



# Plasma bubbles



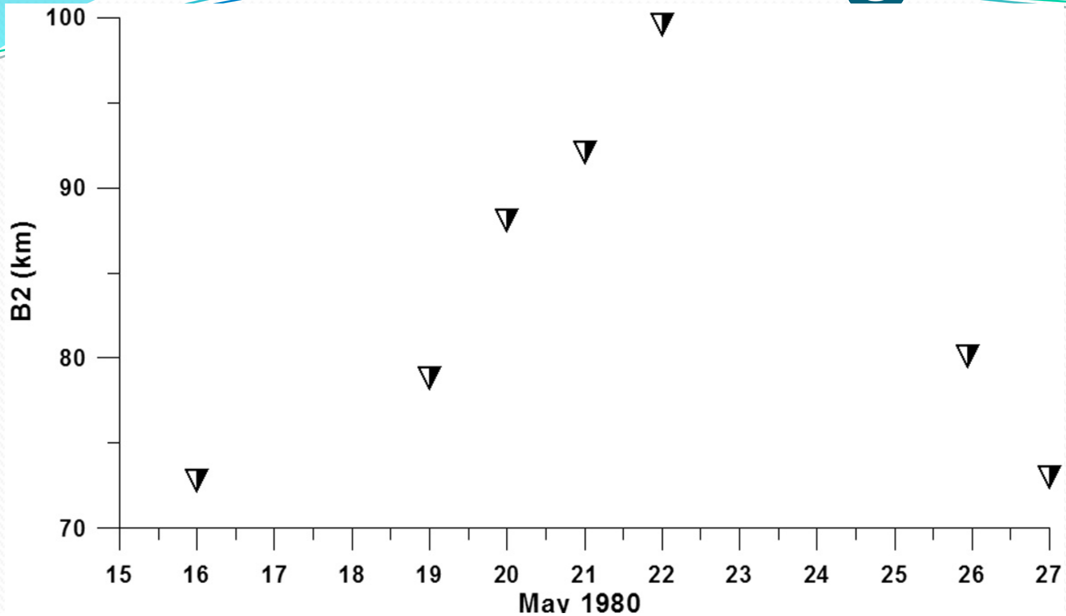
# Vertical profiles modification



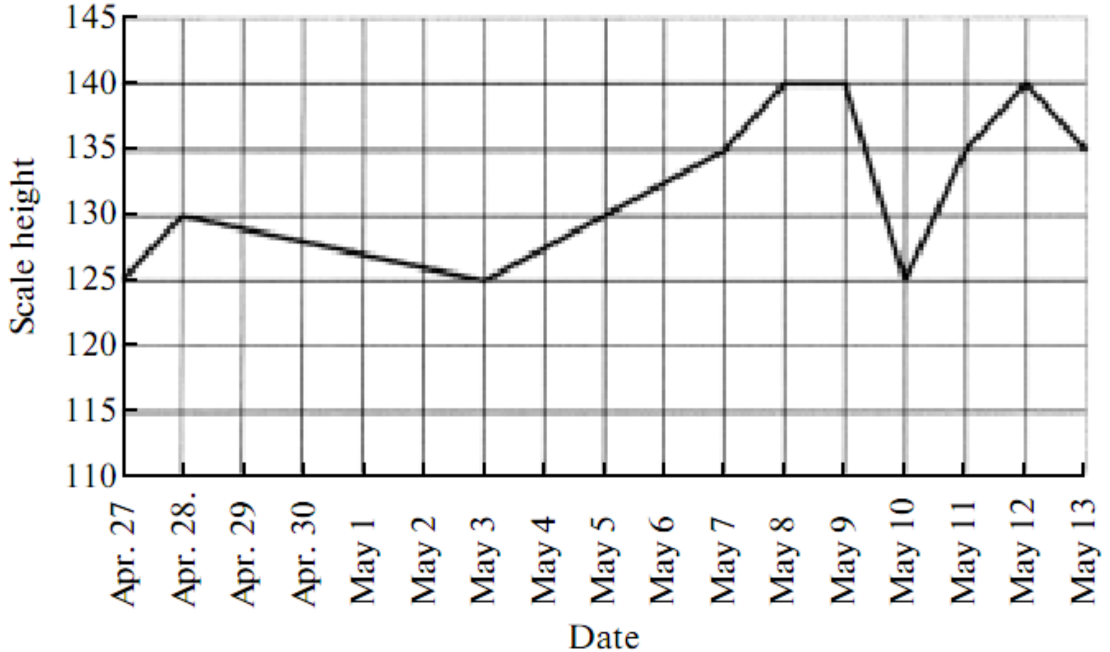

| | lat | hmF2 | foF2 | B2u | k2u |
|---|---|---|---|---|---|
| 1. | 8.4 | 375 | 12.4 | 75.8 | 0.02 |
| 2. | 0.6 | 345 | 14.6 | 47.1 | 0.14 |
| 3. | -3.3 | 340 | 15.2 | 43.3 | 0.13 |
| 4. | -7.2 | 310 | 14.6 | 44.4 | 0.12 |
| 5. | -15.1 | 310 | 11.3 | 46.5 | 0.15 |

| | lat | hmF2 | foF2 | B2u | k2u |
|---|---|---|---|---|---|
| 1. | 9.6 | 425 | 11.5 | 61.7 | 0.17 |
| 2. | 1.8 | 345 | 14.2 | 47.5 | 0.12 |
| 3. | -2.2 | 325 | 13.5 | 40.6 | 0.12 |
| 4. | -10.0 | 295 | 11.4 | 44.6 | 0.13 |
| 5. | -14.0 | 290 | 10.8 | 48.4 | 0.11 |

# Scale Height variations

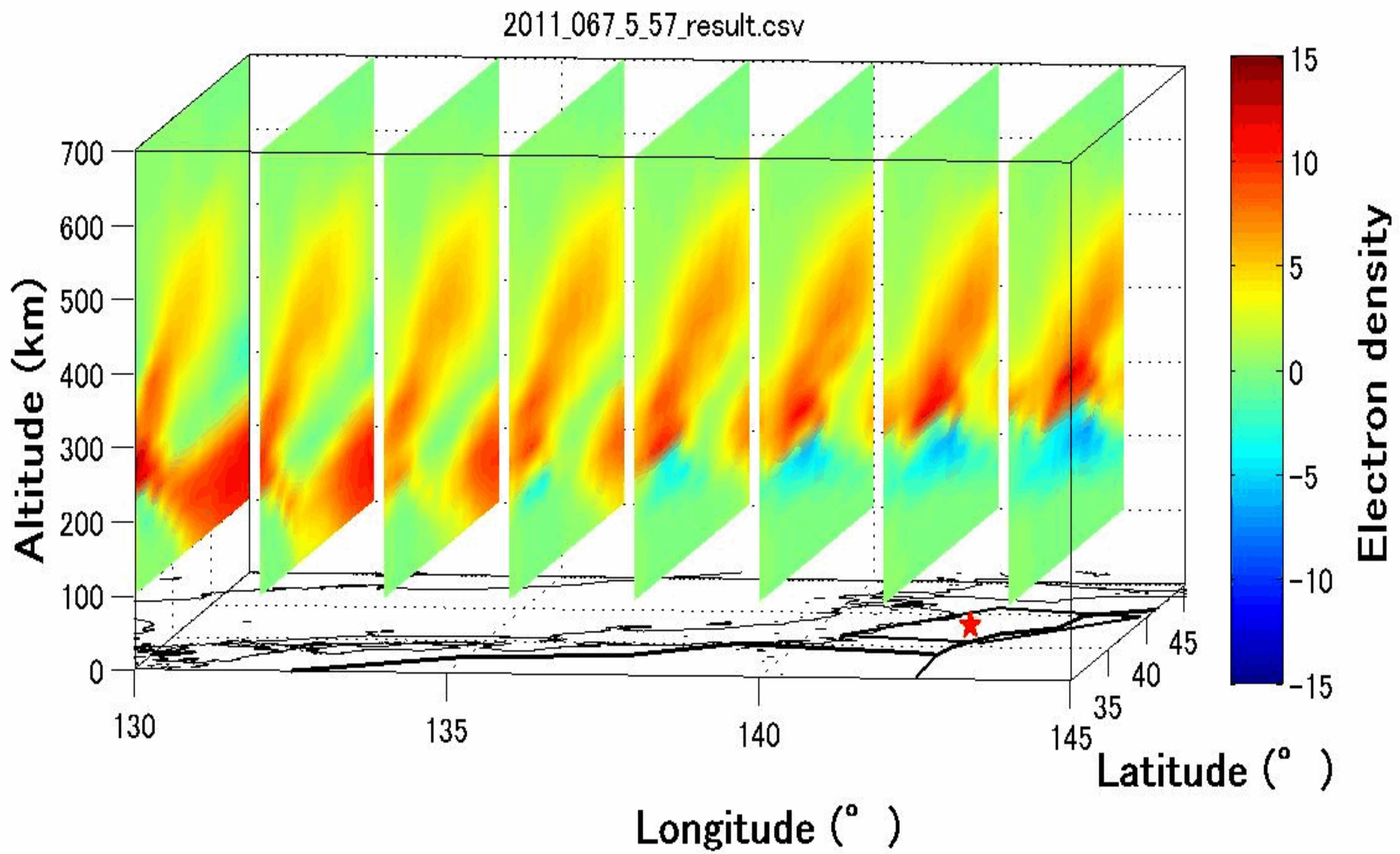



Mammoth Lake
May 1980, USA




Wenchuan
May 2008, China

# Tohoku, 2011, tomography




Hattori et al., 2014

# Self similarity of earthquake precursors

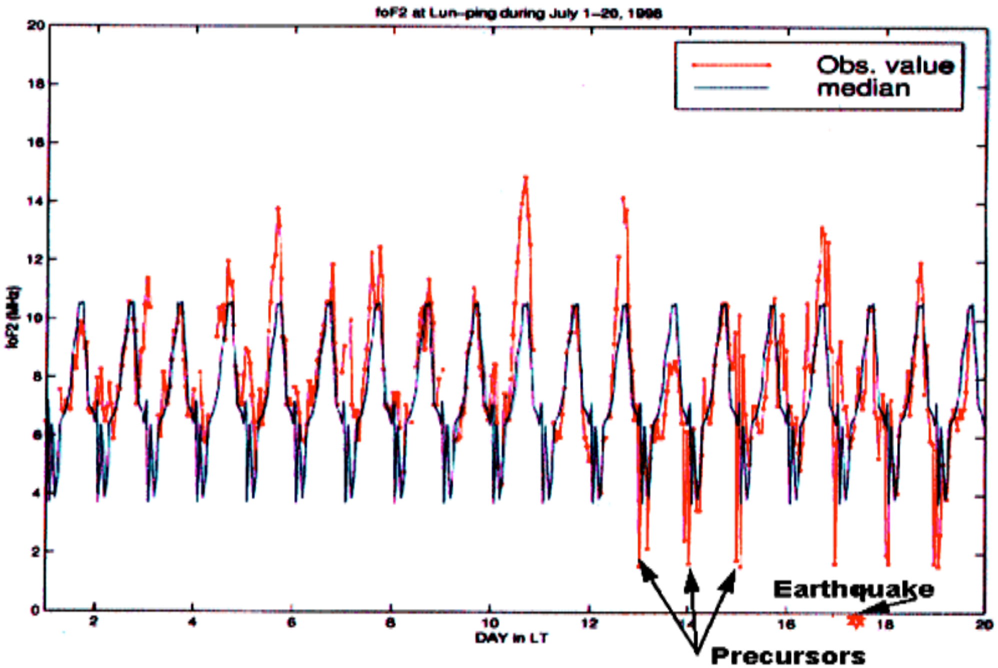
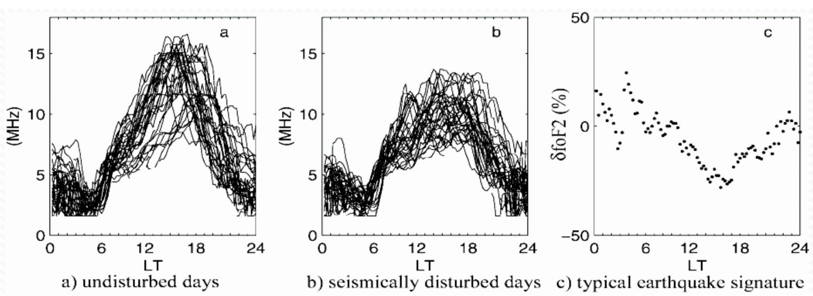
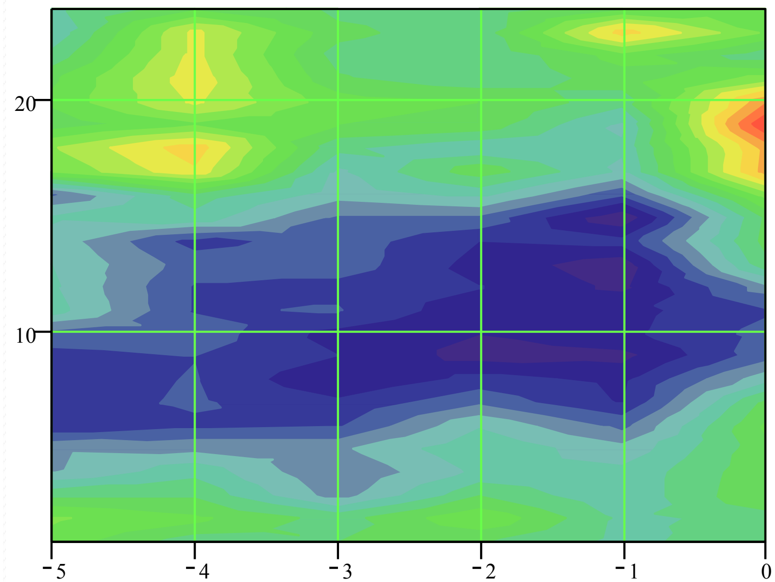
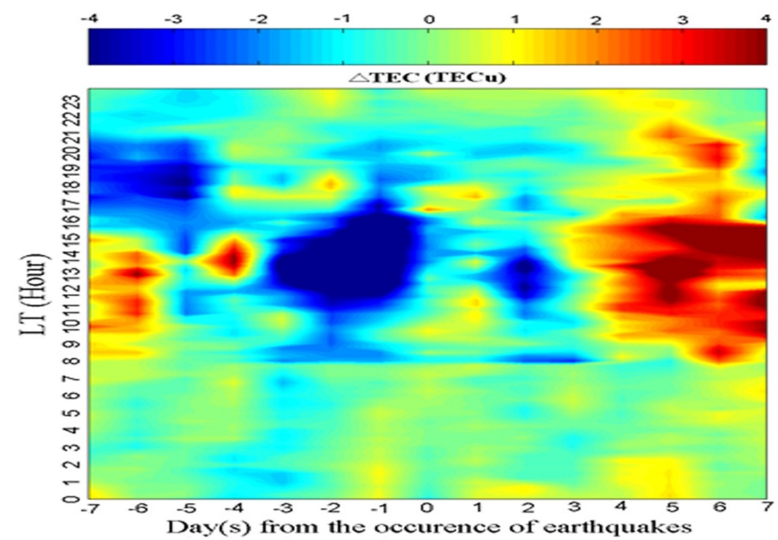



Figure 3 The hourly foF2 and their medium value during the Earthquake





# Formal determination of self similarity

We represent the state of the ionosphere prior to the event in the form of an $A_{ij}$ matrix whose columns contain the hourly deviations of *foF*2 from its median value. The number of columns in the matrix is determined by an expected time interval between a precursor and an event. In this paper, we assume that this interval does not exceed six days and, respectively, the dimension of the $A_{ij}$ matrix is $24 \times 6$, i.e., $i = 1 \ldots 24$, $j = 1 \ldots 6$.

For all events we form matrices in the same manner and obtain an $A_{ij}^{(n)}$ series, where $n$ is the ordinal number of an event. We now introduce the value

$$S_n = \frac{\sum_{i,j} \langle A_{ij}^{(n)} \rangle_n^2}{\langle \sum_{i,j} (A_{ij}^{(n)})^2 \rangle_n},$$

where $\langle \ldots \rangle_n$ means averaging over an ensemble of $n$ events. $S_n$ is the dispersion normalized so that $S_1 = 1$.

With the help of $S_n$, it is convenient to characterize the degree of $A_{ij}^{(n)}$ similarity at various $n$. For example, if $A_{ij}^{(n)}$ values for various events do not correlate with one another, the $S_n$ series tends to unity at $n \longrightarrow \infty$. In the other extreme case, when the states of the ionosphere prior to all events are completely identical, $S_n$ increases: $S_n \sim n$ at $n \longrightarrow \infty$.

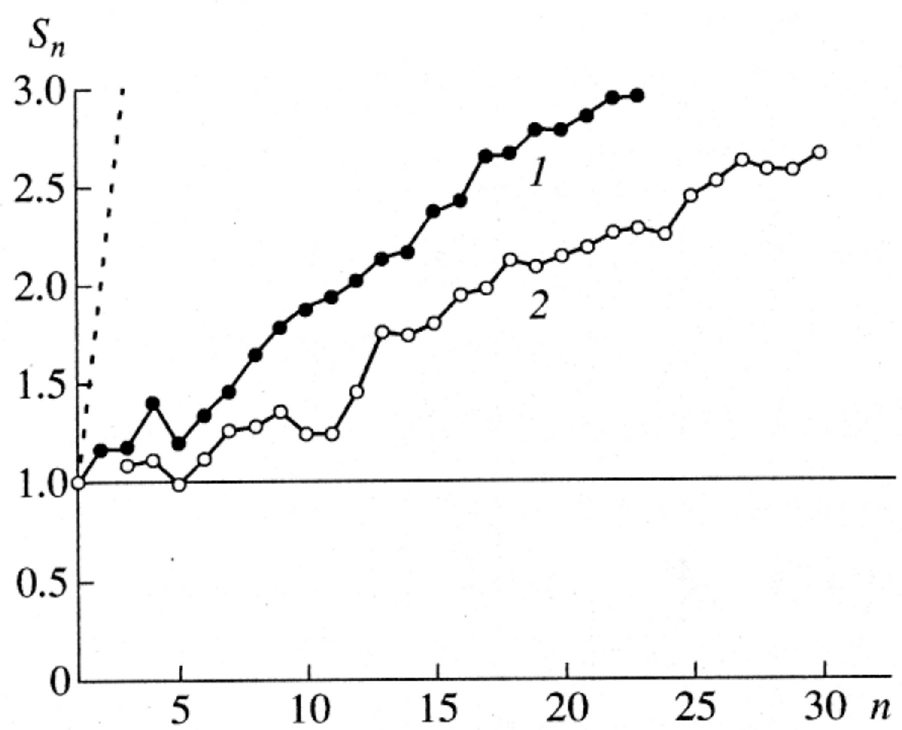
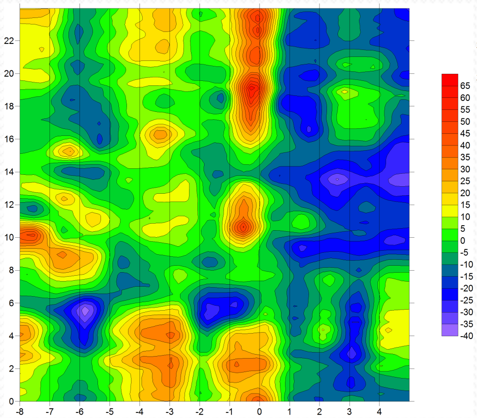
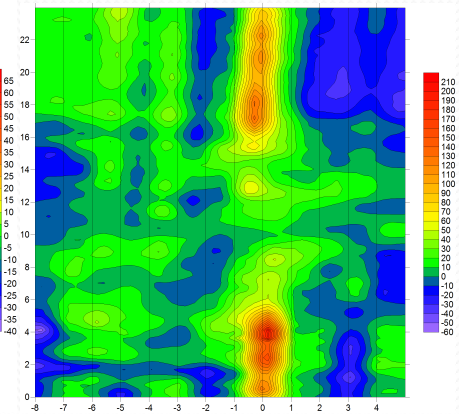



**Fig. 2.** Behavior of the $S_n$ parameter for two groups of deep-focus earthquakes: a series of 23 (curve *1*) and 30 (curve *2*) events. Dashed and solid curves: theoretical curves for a similar state and noncorrelated states of the ionosphere prior to any earthquake in the series, respectively.

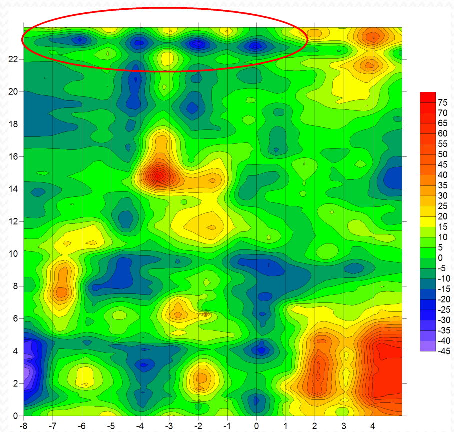
# Characteristic patterns of the ionospheric precursor



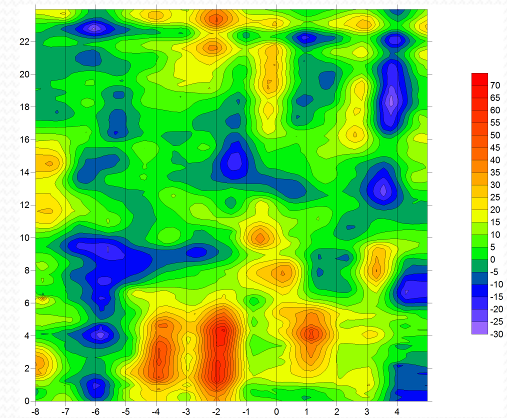
EQ G1



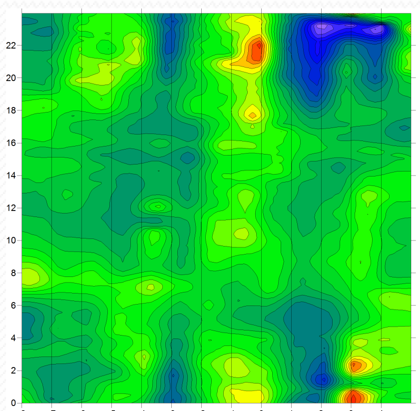
EQ G2



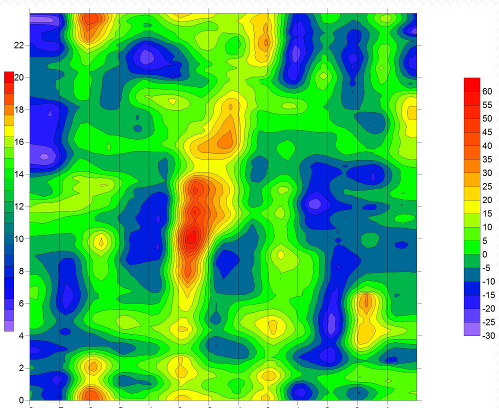
EQ G3



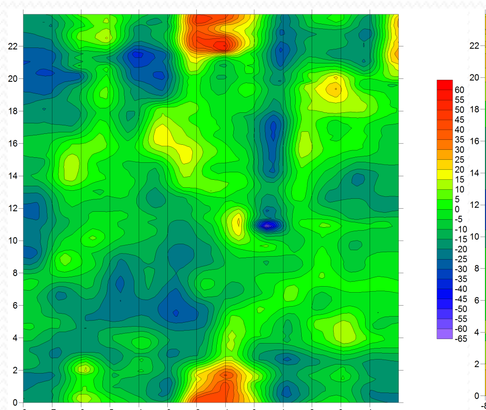
EQ G4



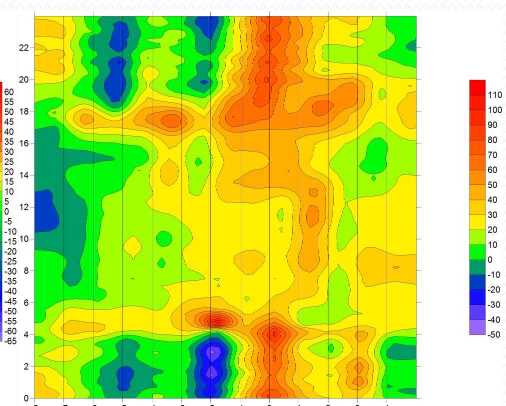
EQ G5



EQ G6

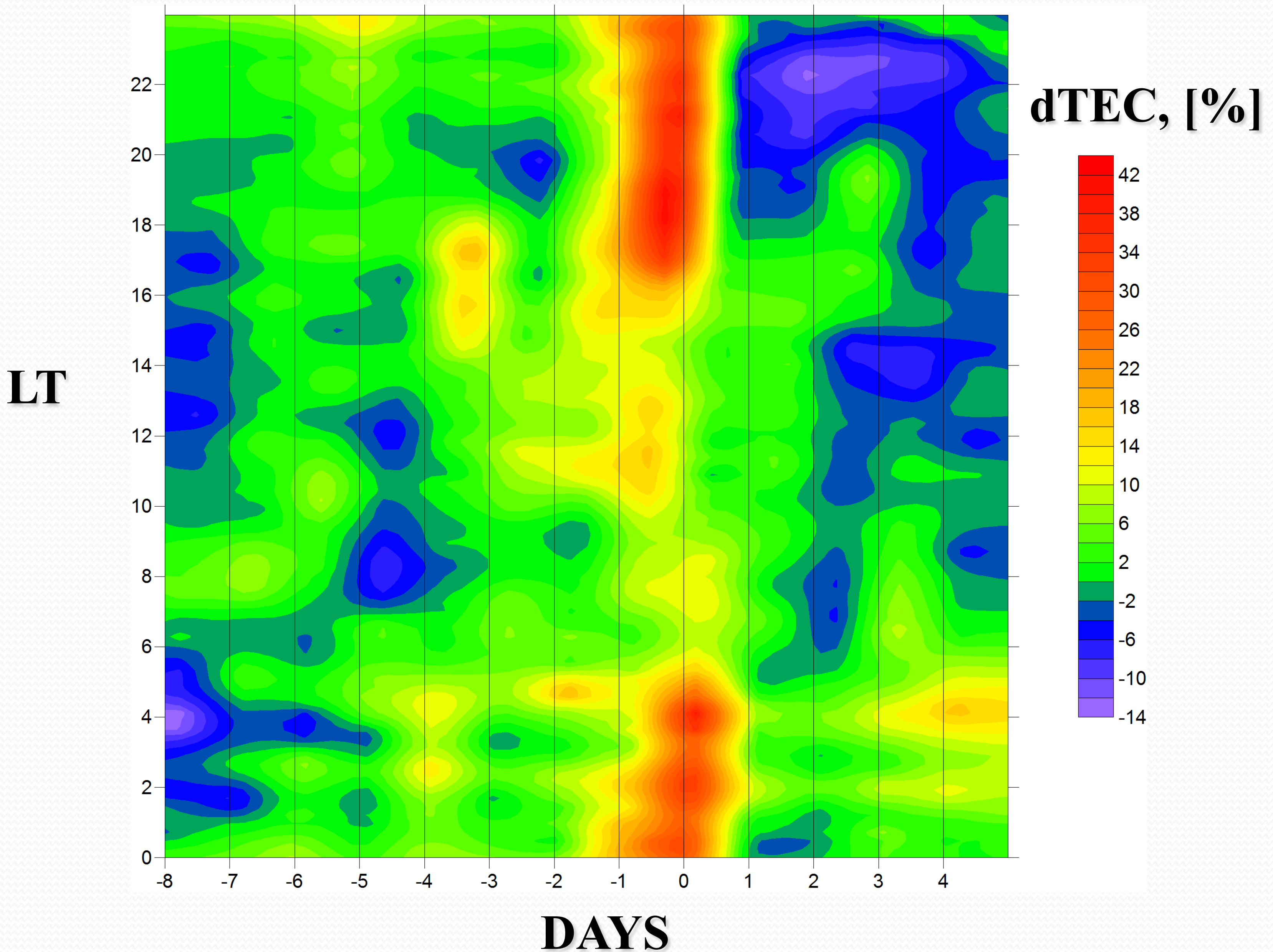


EQ G7

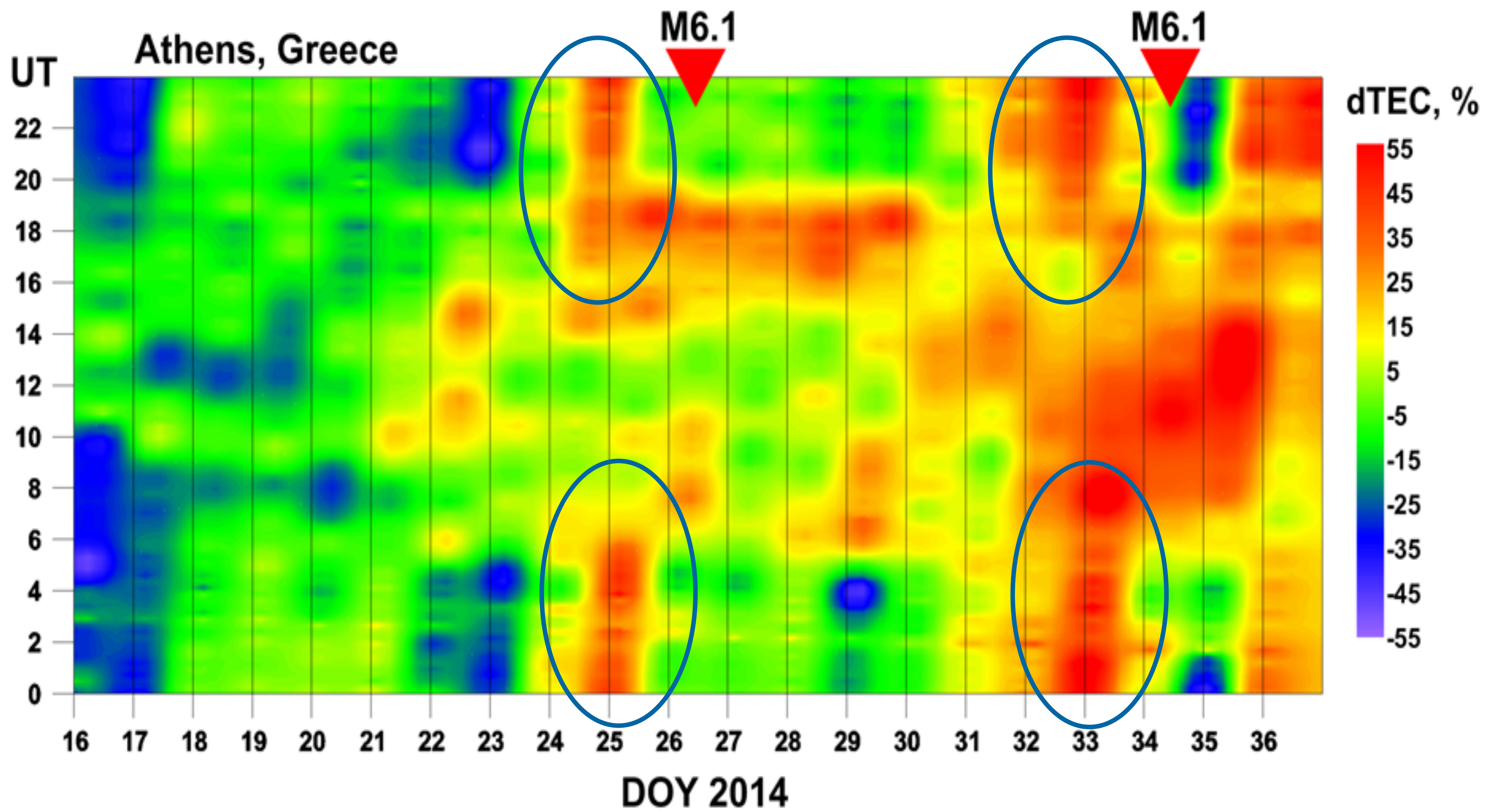


EQ G8

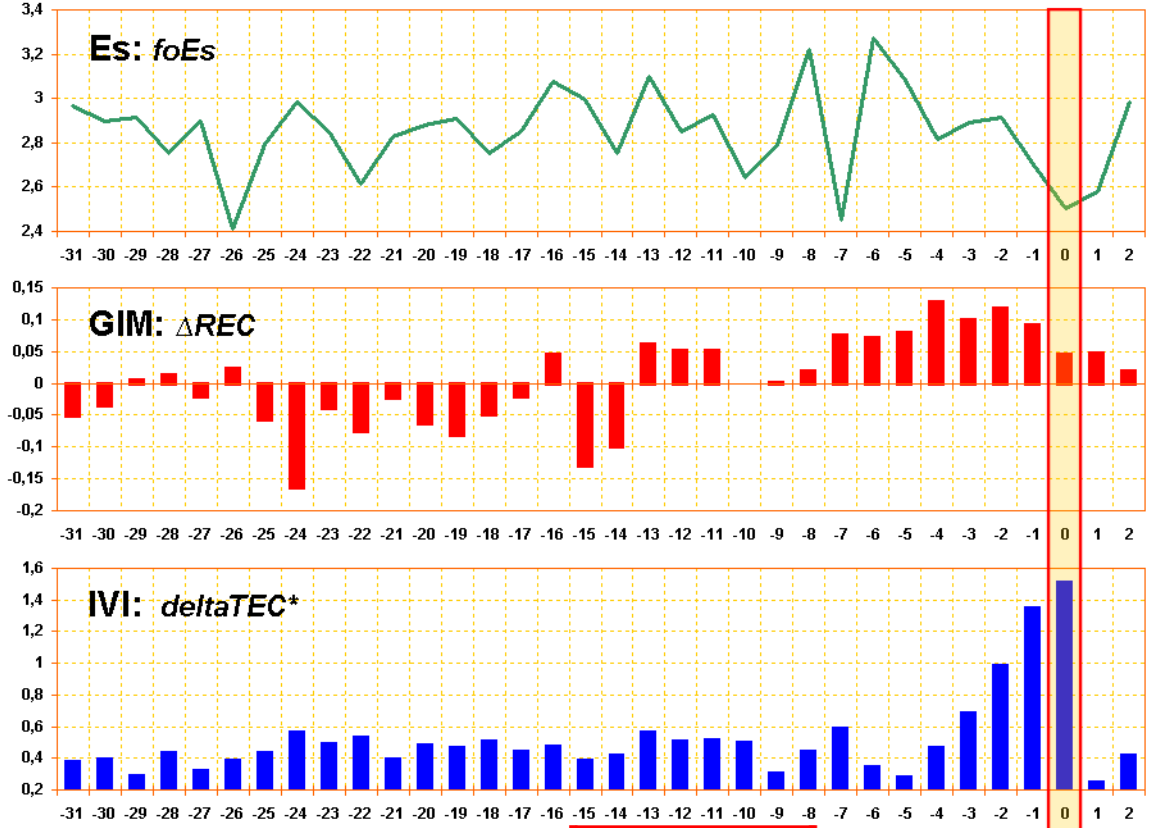
# Ionospheric precursor mask for Greece earthquakes with M≥6.0

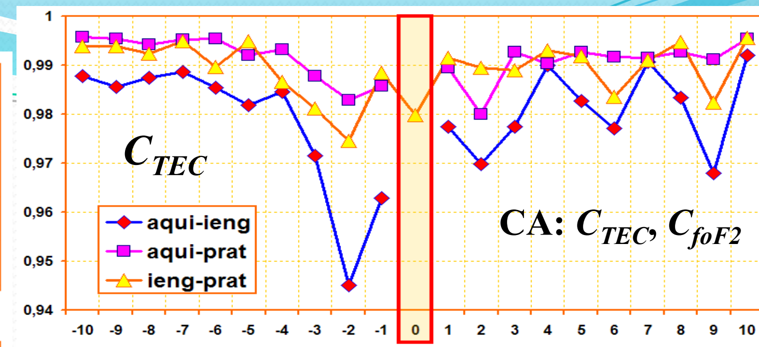


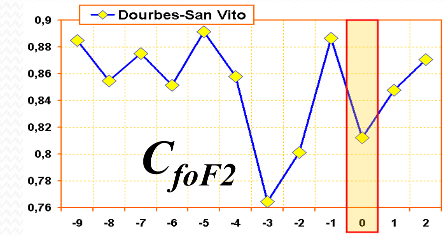
# Real time alarms for Greece

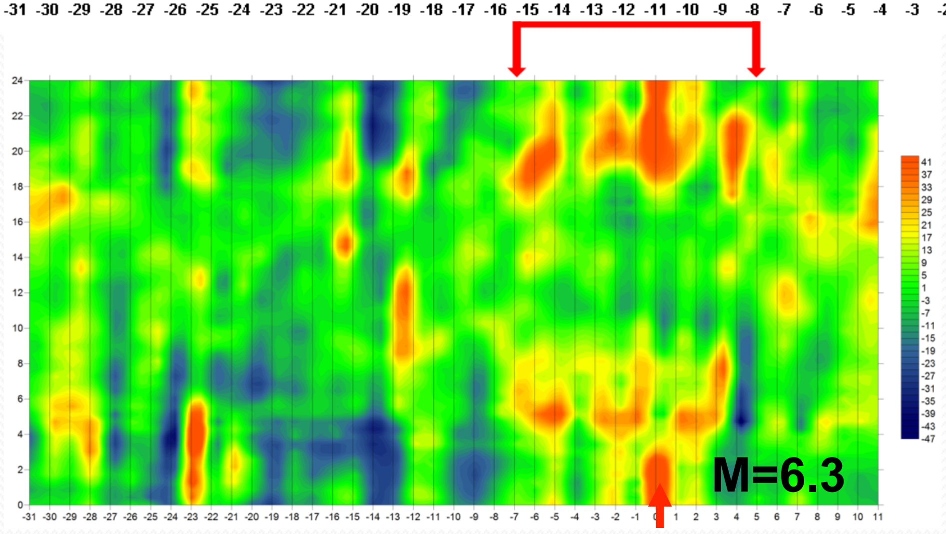


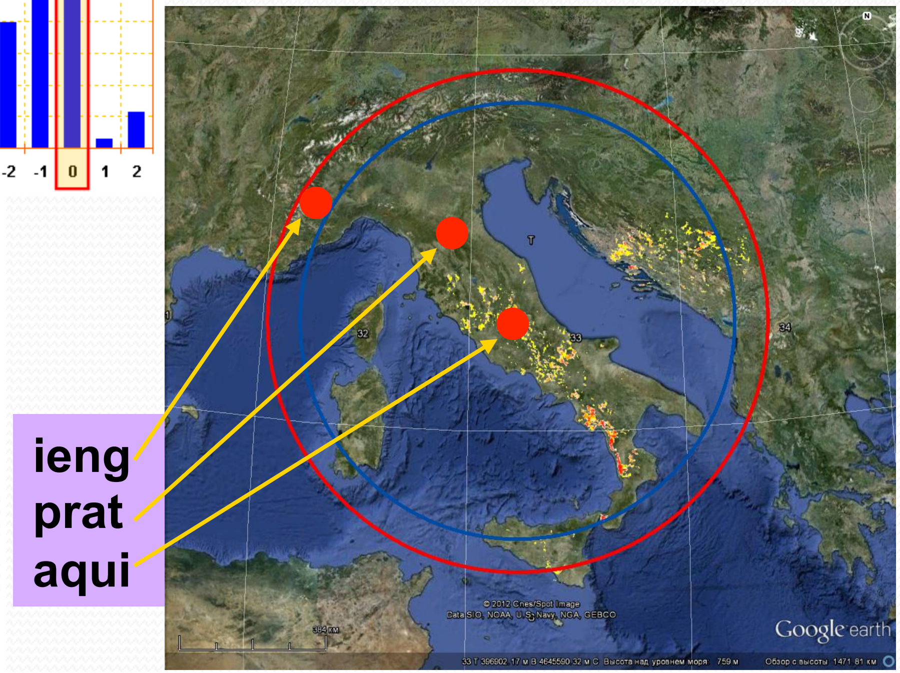
# L'Aquila, 6 April 2009



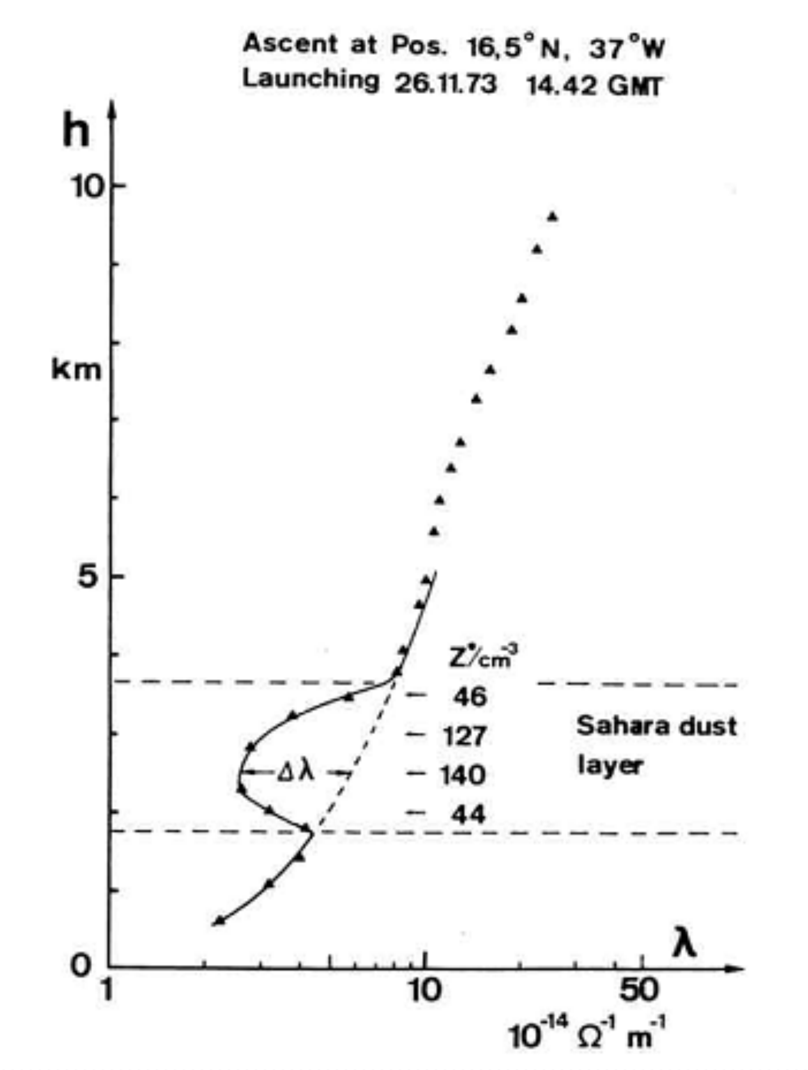



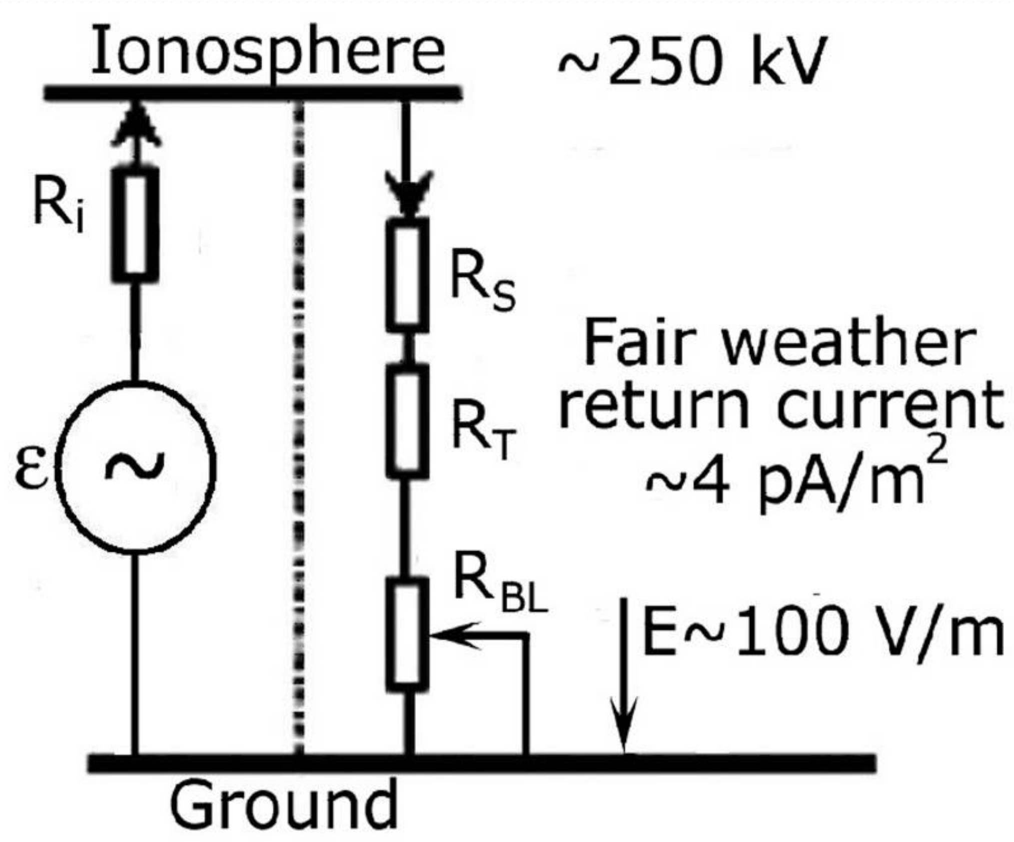



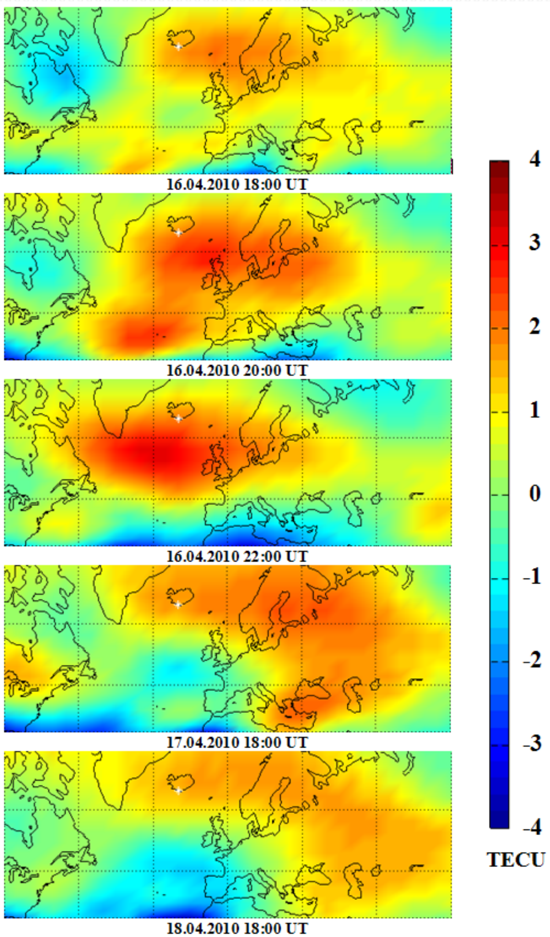
# Few words on the physical mechanism



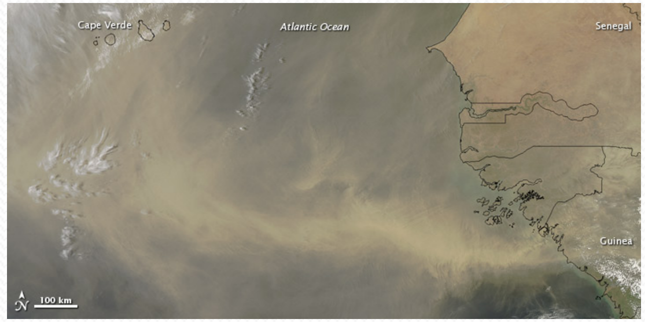



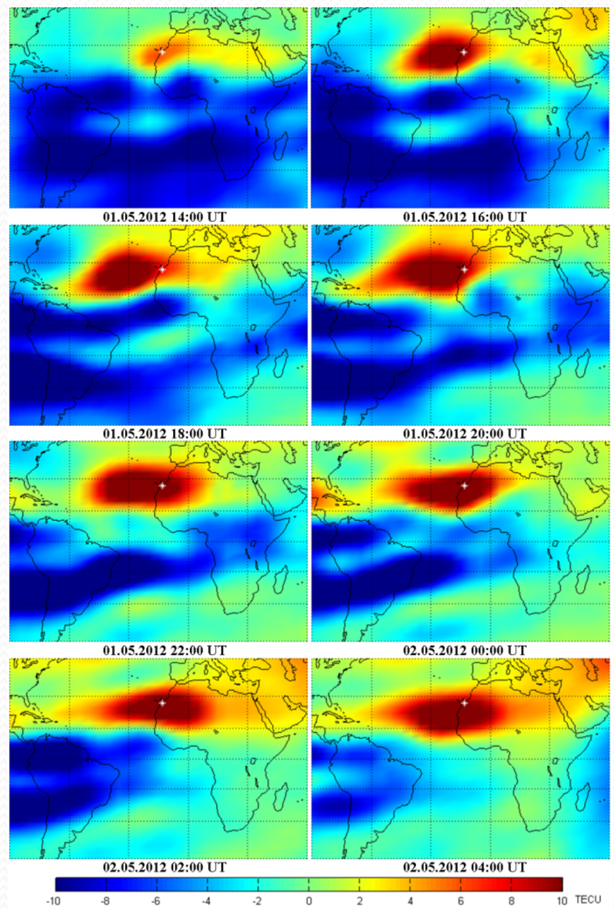

Harrison, 2002

# Volcano eruption

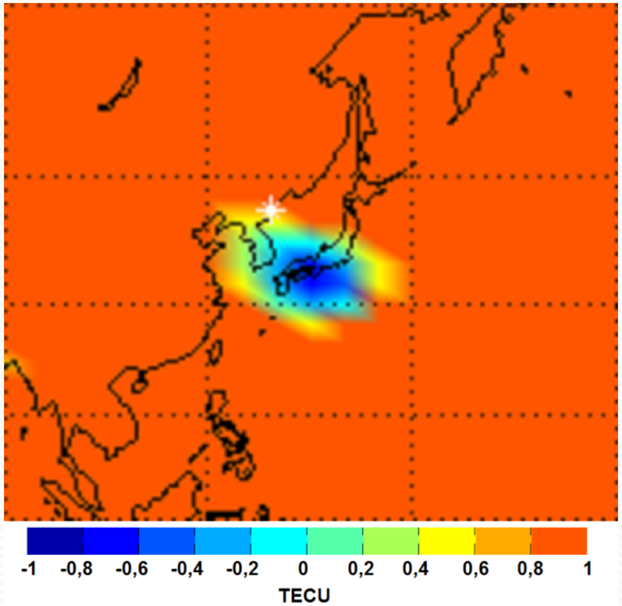




# Sand storm

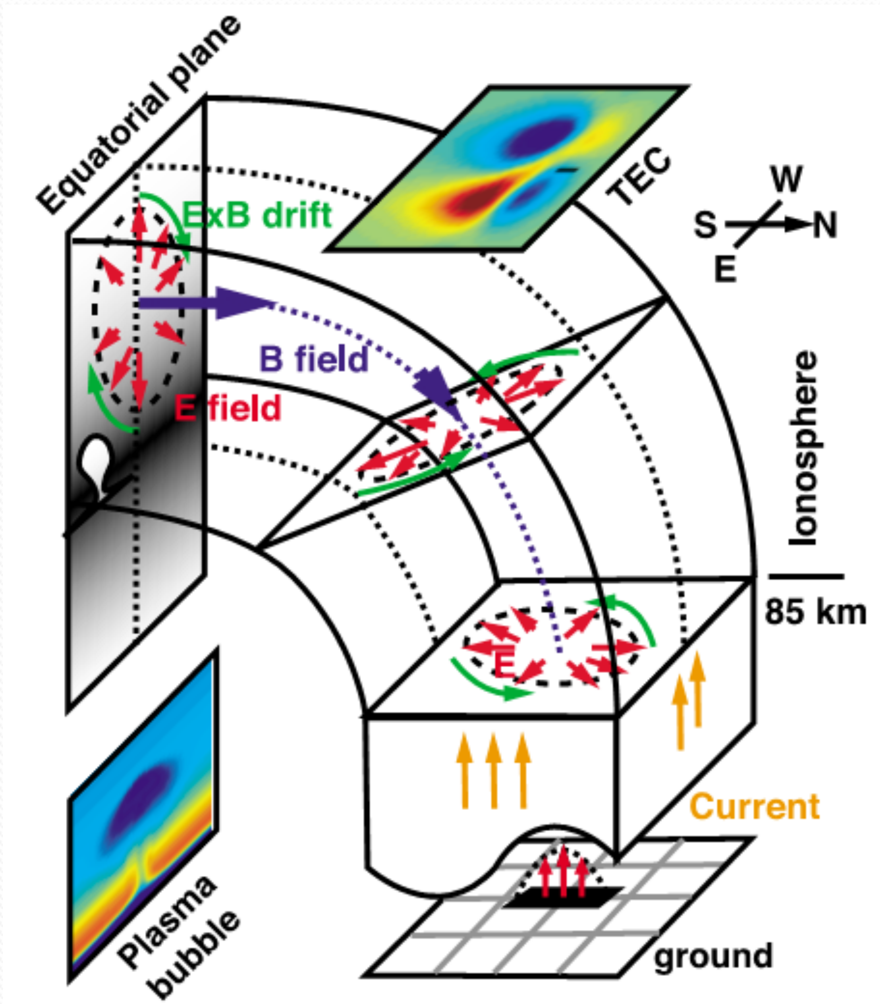


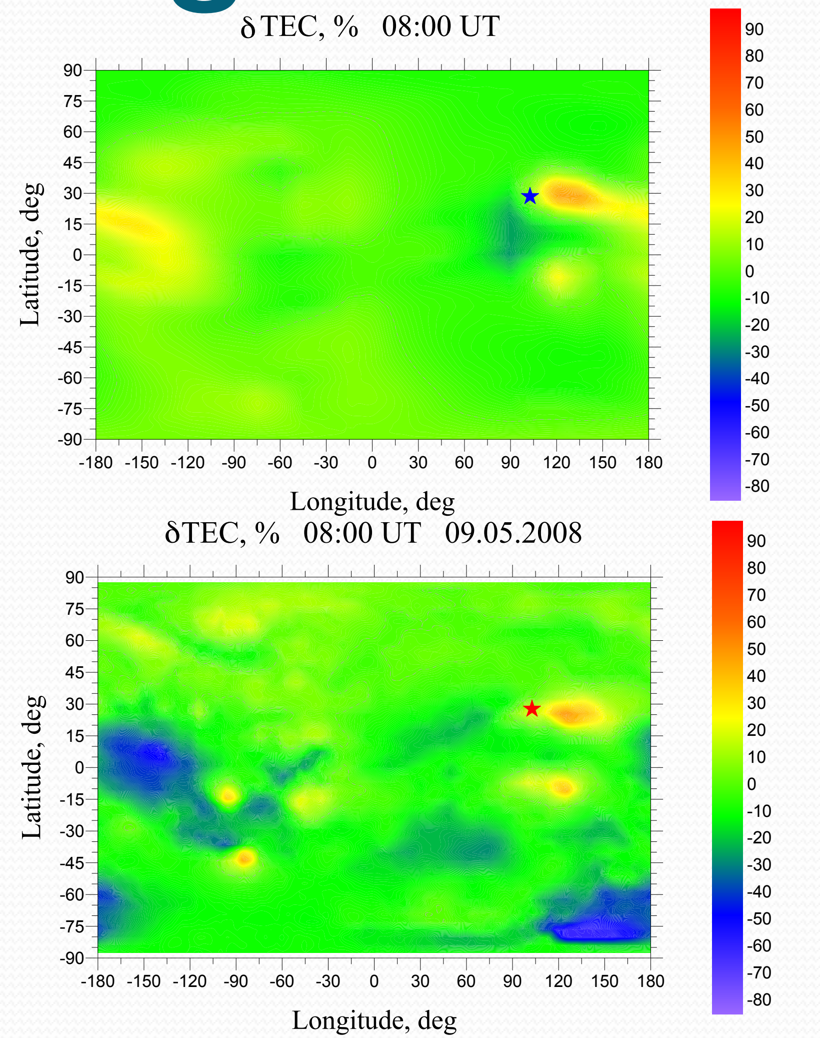

# Nuclear explosion



# Modeling




Kuo et al., JGR, 2011




Klimenko et al., ASR, 2011

3 most comprehensive ionospheric first principal ionospheric models (Huba, Namgaladze, Klimenko) show ionospheric anomalies are of electric field origin

# Conclusions

- Seismically induced ionospheric variability is unpredictable from the point of view of ionosphere modeling
- Using the mask conception gives opportunity to automatically identify the regular component of the ionospheric variability associated with seismic activity
- Multiparameter precursors monitoring and precursors synergy permits using the temporal sequence of precursors anticipate ionospheric anomalies using precursors apearing earlier

# Thanks for your attention