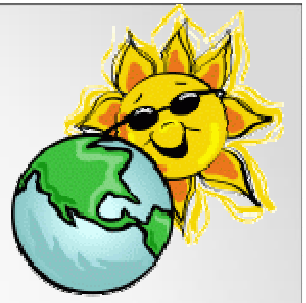

Observed Changes in Ionospheric foF2 Critical Frequency before the Earthquakes

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The Organization Of This Work As Follows:

A. Ionosphere and Its Solar-Geomagnetic Connections

B. What is the Earthquake? Relationship between Ionosphere and Earthquakes?

C. Material

- Earthquake Data
- Ionosonde Data

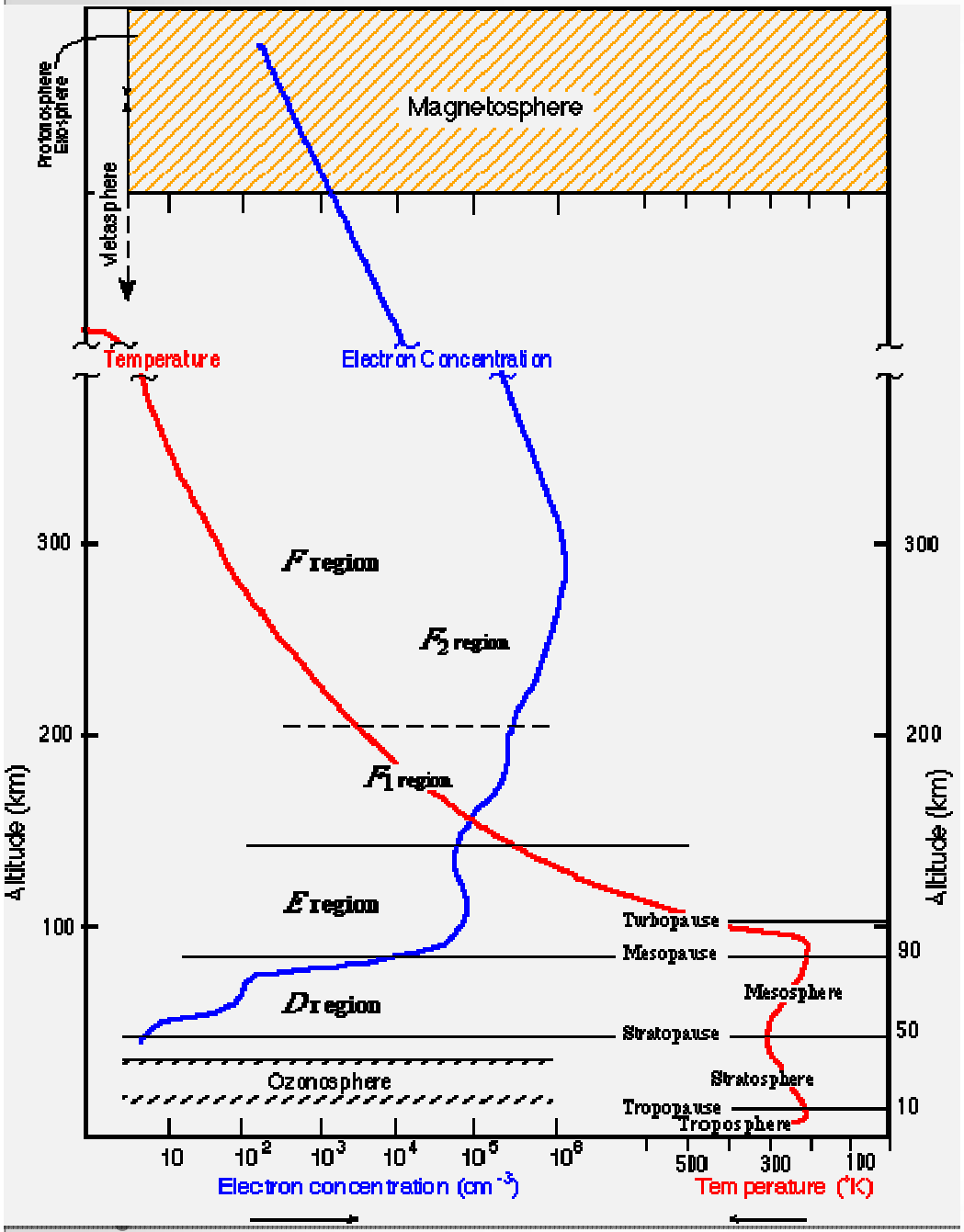
D. Methods

- Standard Deviation
- Inter-Quartile Range (IQR)

E. Results

F. Conclusions

A. IONOSPHERE AND IT'S SOLAR-GEOMAGNETİC CONNECTİONS



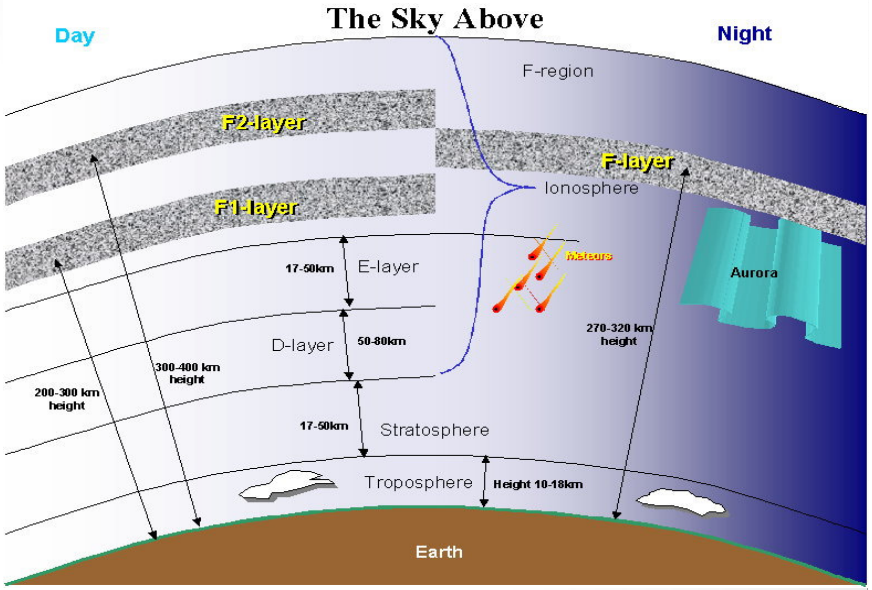
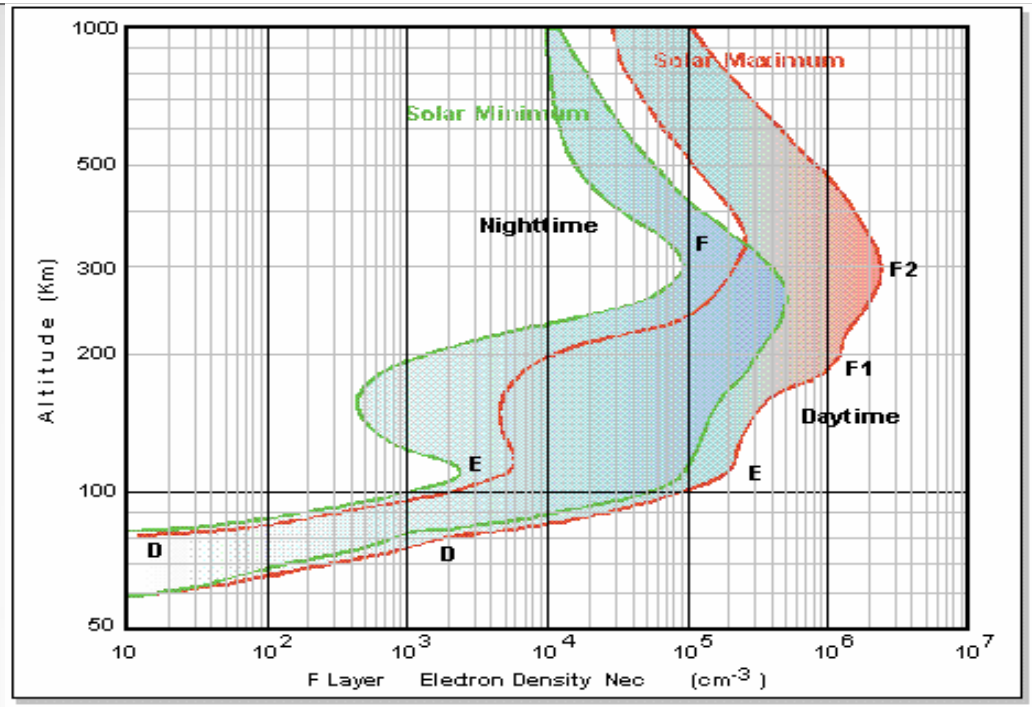


Figure 1. Ionospheric electron densities and temperature.

Figure 2. Ionospheric regions

Table 1. Ionospheric regions

Region	Altitude	Electron Density (Day Time, m^3)
D	50-90	10^8-10^{10}
E	90-160	10^{11}
Es	110-120	Vary
F	140-400	10^{11}-10^{12}
F1	140-200	$2x10^{11}$
F2	200-400	10^{12}



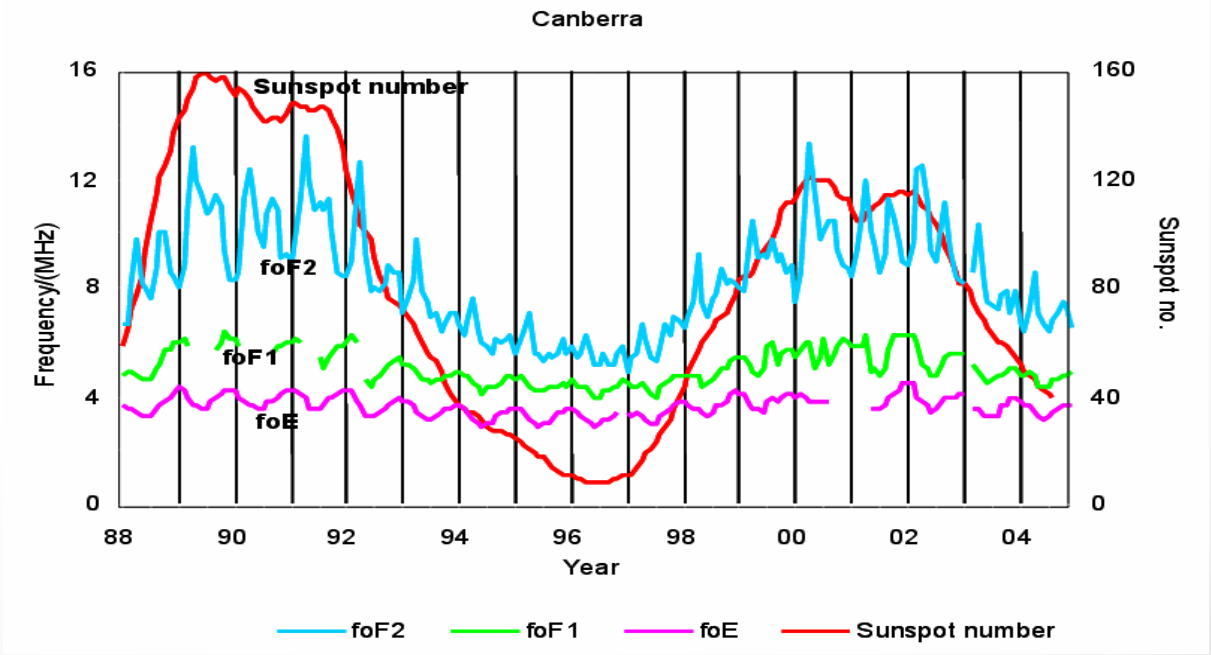


Figure 3. Solar effects on ionospheric paramethers**.**

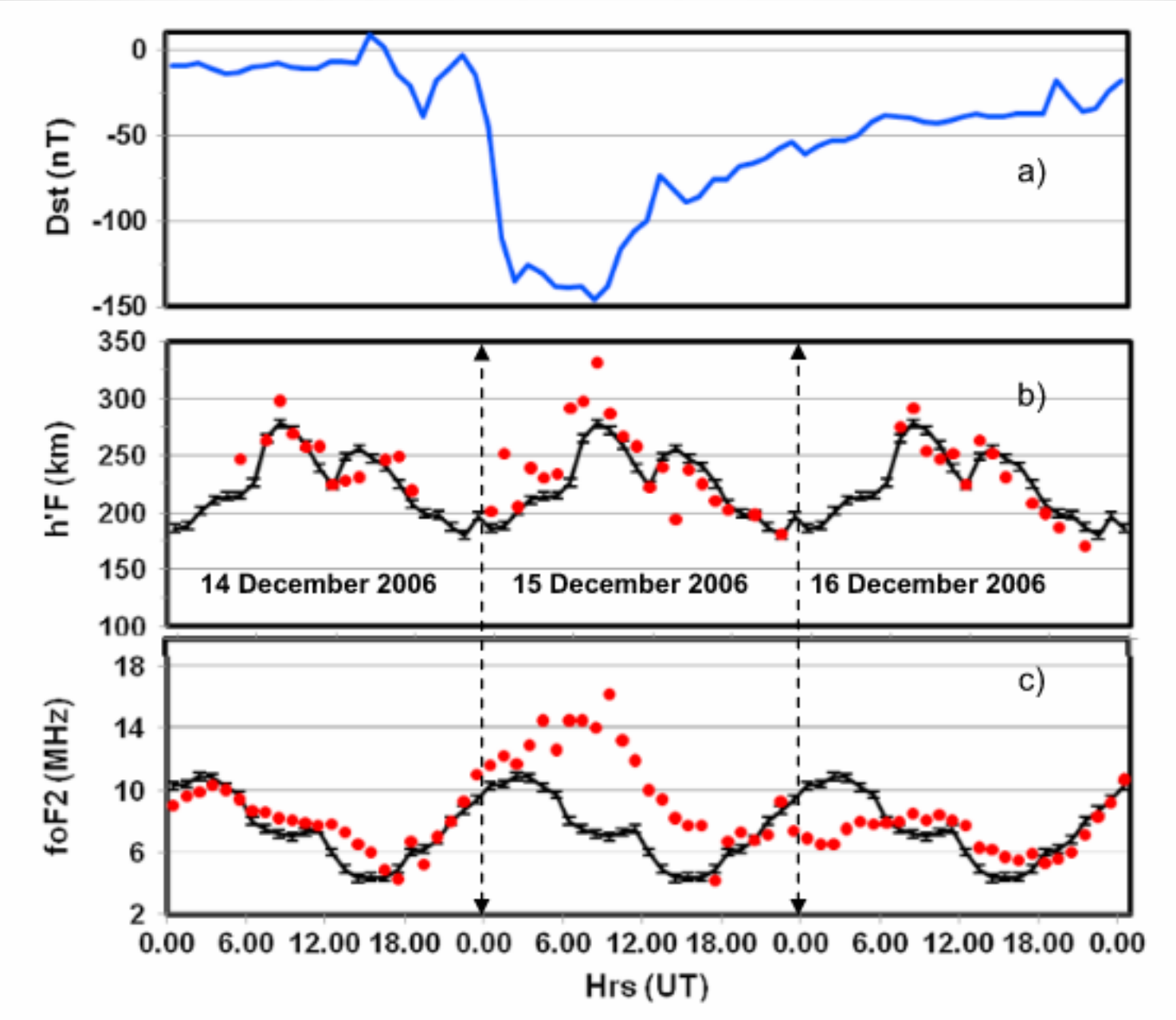


Figure 4. 14-16 December 2006 geomagnetic storms a) Dst index b) hourly h'F2 c) foF2

B. What is the Earthquake? Relationship between Ionosphere and Earthquakes?

- **Now, it's well known that the ionosphere is very sensitive to natural events.**

- **There are many reports of possible links between ionospheric phenomena and events at lower levels, e.g., earthquakes, volcanic explosions and thunderstorms.**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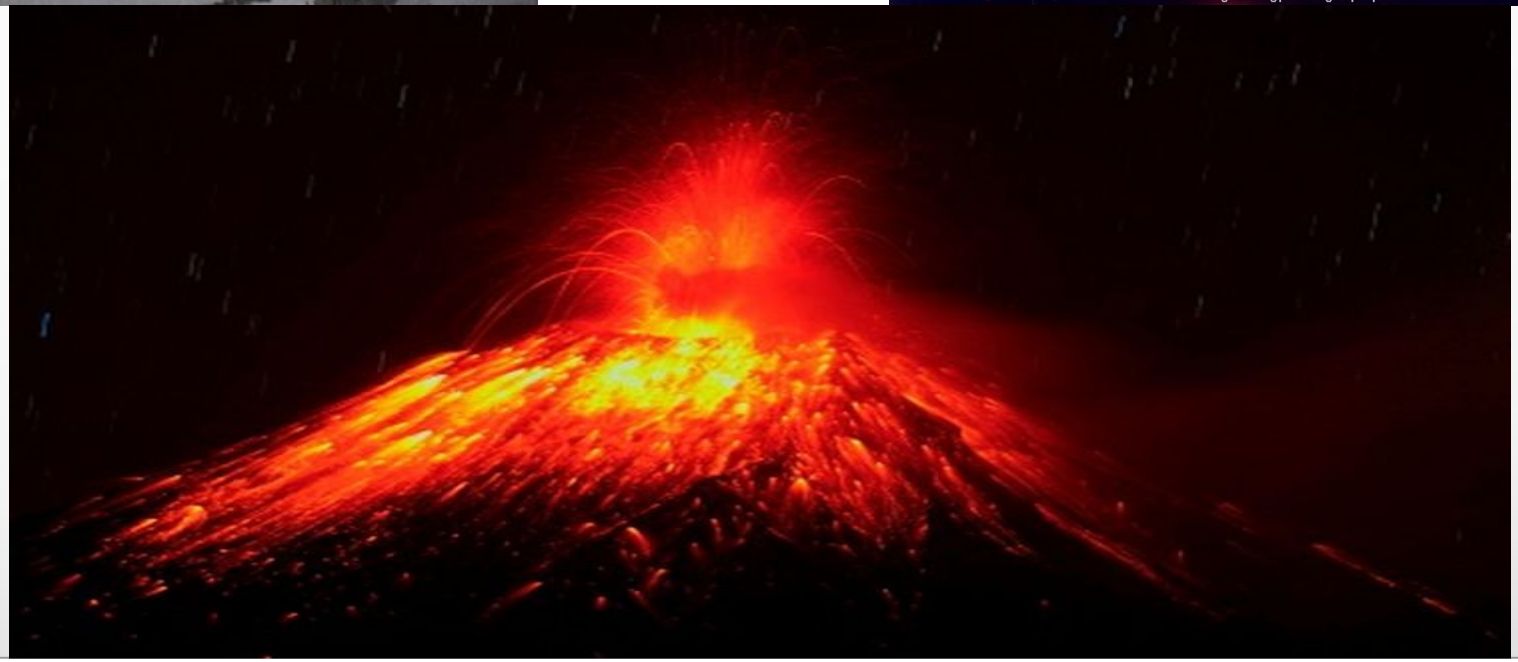
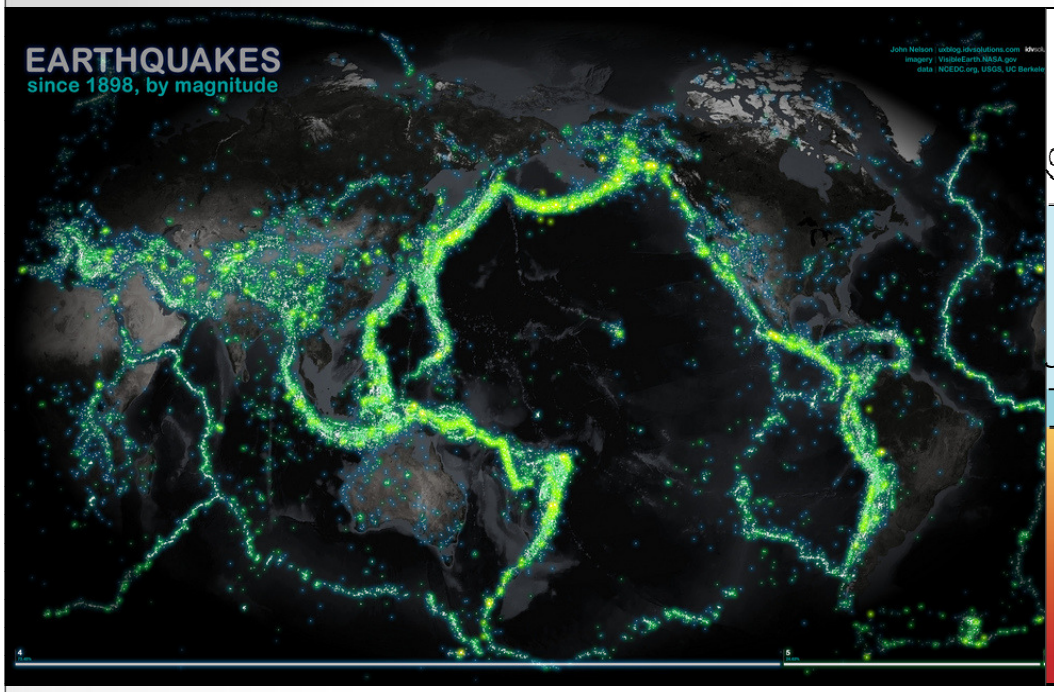
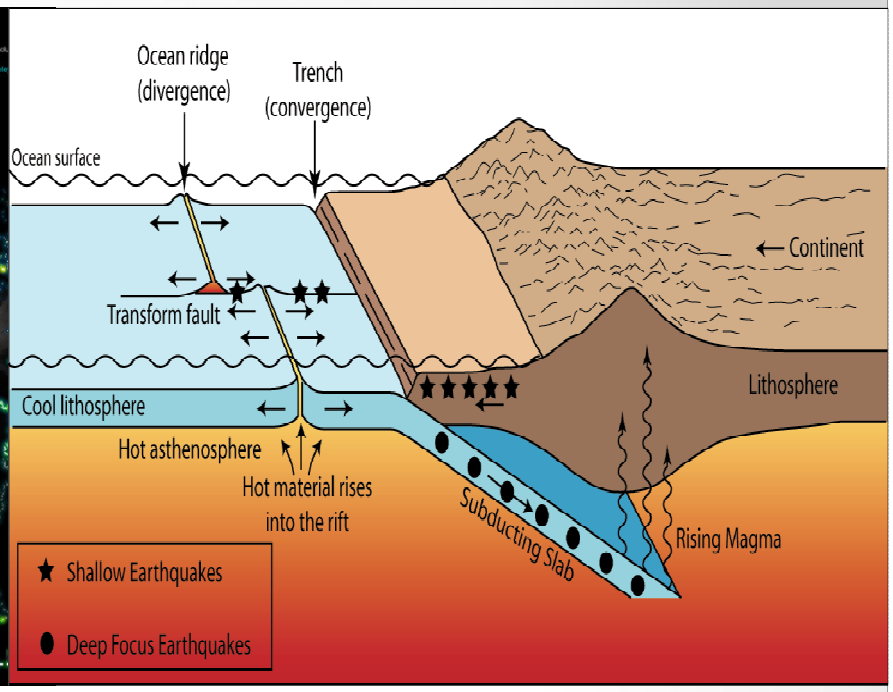


- **Earthquake is a result of sudden fault movement and a sudden release of energy in the Earth's crust that creates *seismic waves***
- **Earthquakes are one of the most destructive and harmful natural disasters causing fatalities in human life.**
- **Because of this, earthquake forecasting is quite important for humanity and one of the major unsolved tasks of modern geophysics.**





- During the last 20 years the geophysical phenomena which appear prior to a seismic event is the subject of research of many scientists from different disciplines.

- Recent field workings and simultaneously satellite observations have showed that seismic activities caused variations not only lithosphere, but also atmosphere and ionosphere.

- **This means that earthquake can excite atmospheric and ionospheric perturbations with directly or indirectly interactions.**
- **This relationship is called "Lithosphere-Atmosphere-Ionosphere Coupling (LIAC)".**
- **These variations of lithosphere–atmosphere-ionosphere parameters occurred prior earthquakes are considered as earthquake precursors.**

- To predict earthquakes accurately, many researchers have developed new earthquake monitoring and prediction methods.
- They have tried to explain the physical mechanism behind the Lithosphere-Atmosphere-Ionosphere Coupling (LIAC).
- And also, these researches are imporant to explain chemical and physical processes in ionosphere during the earthquake.

C. Material

Earthquake Data:

- In the seismo-ionospheric studies, the *earthquake preparation zone* term is frequently used.
- This is an area where the local deformations connected with the source of the future earthquake are observed.
- The size of modified area in ionosphere is of the same order of magnitude as the size of the earthquake preparation area on the ground surface.

- The radius of earthquake preparation zone was estimated by Dobrovolsky et al., (1979) and was calculated for each earthquake by using following formula

$$\rho = 10^{0,43M}\ km$$

- Here ρ and M are radius of earthquake preparation zone the observed magnitude in Richter scale respectively.

- **Ionosonde Data:**

- **Ionosphere affects radio propagation of electromagnetic waves. Ionospheric critical frequency is a parameter used in the ionospheric physics.**

- **F2 region critical frequency (f_oF2) is the electromagnetic wave that has maximum frequency that could be reflected from F2 region at vertical incidence.**

- **Proportional to the square root of maximum electron density of the ionospheric F2 layer.**

- It is approximately,

$$f_o\mathrm{F2} = 9\sqrt{N_e}$$

- Here, *Ne* is F2 region maximum electron density in el/m^3 and f_oF2 is in MHz.

- In this work hourly values of f_oF2 data were obtained from ionosonde stations Kokubunji (K) (35.71 ^{o}N, 139.49 ^{o}E).

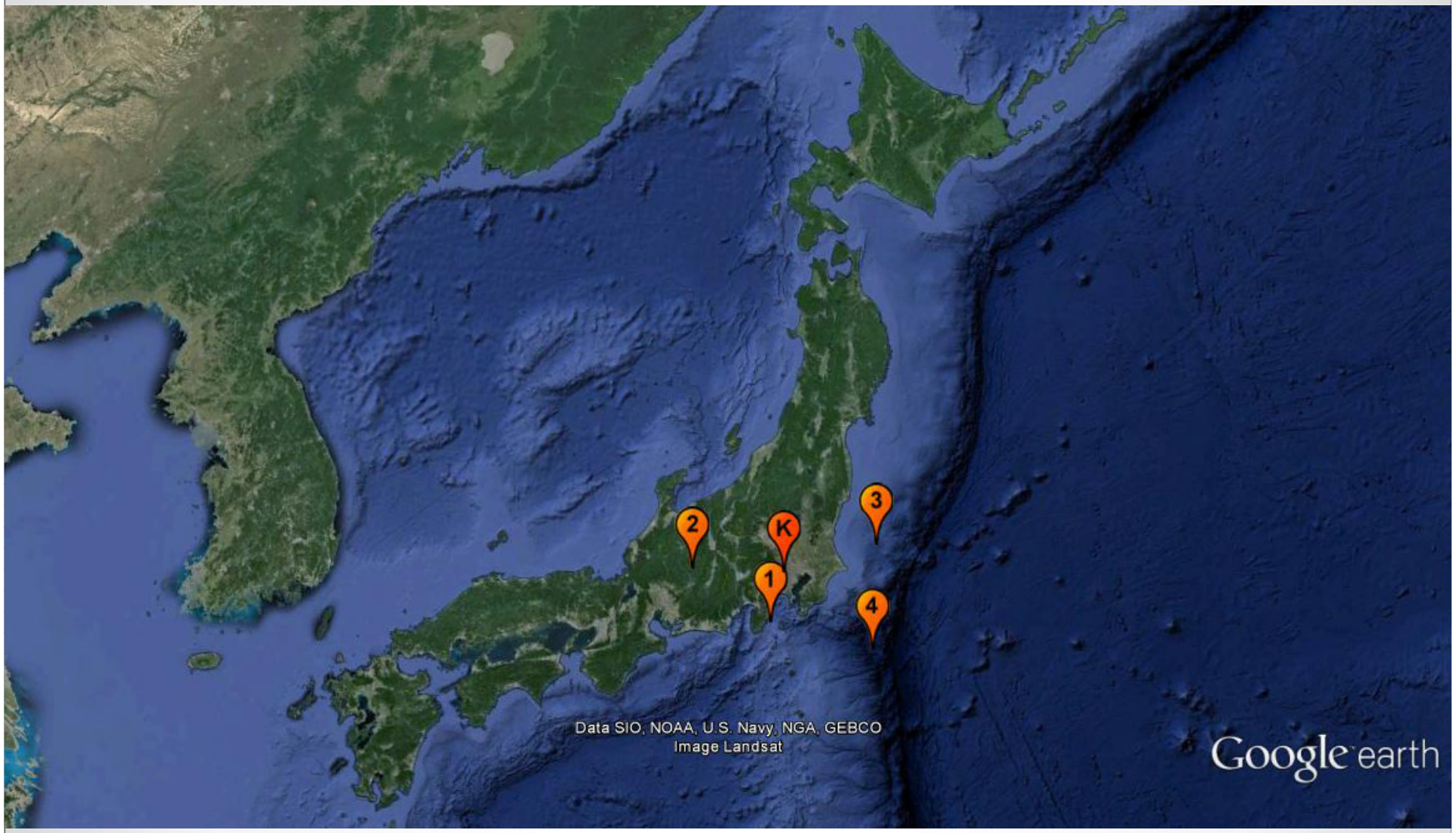
- **In Table 2, earthquake information (their onset date and time, epicenter latitude/longitude, focal depth and distance from earthquake preparation zone) is given. (LT = UT + 9.0).**

- **In figure, earthquakes and ionosonde stations' location are given.**

Table 2. Characteristics of earthquakes which are studied in this work.

S.N.	Location Name	Epicenter	Date	Time (LT)	Magnitude (M)	Depth (D)	Distance from Station	Radius of Earthquake Preparation Zone (ρ)
1	South Coast of Honshu	34.808ºN 139.181ºE	29.06.1980	16:20:05	6.2	15	103.950	463.5
2	Center of Honshu, MT Ontake	35.789ºN 137.488ºE	14.09.1984	08:48:49	6.1	10	181.290	419.8
3	Near Eastern Coast of Honshu	36.141ºN 141.54ºE	08.05.2008	01:45:19	6.8	36.6	191.09	839.46
4	Far Eastern Coast of Honshu	34.256ºN 141.385ºE	30.05.2004	05:56:12	6.5	38.1	236.54	623.73

Figure. Visual exhibition of earthquakes by numbers and ionosonde stations by letters.



- Although in the literature, interrelation between the dynamics of lithospheric process and variation of ionospheric parameters is verified, it's known that solar and geomagnetic activities have a major effect on ionosphere and many kind of perturbations on ionospheric parameters are connected with them.

- It is quite difficult to separate these variations whether they are related to seismic activities, because of solar and geomagnetic effects on ionosphere.

- Therefore, to distinguish these disturbances from geomagnetic activities, solar and geomagnetic conditions will be considered during this work.

D. METHODS

➢ Standard Deviation

- **In this technique, to identify anomalous variations, we determined upper bound (UB) and lower bound (LB), we computed hourly 15 days means ($\bar{X}$) and standard deviation (σ) over the period before the main shock.**

$$\textbf{Upper Bound } (UB) = \bar{X} + 2\sigma$$

$$\textbf{Lower Bound } (LB) = \bar{X} - 2\sigma$$

➢ Inter-Quartile Range (IQR)

- **We achieved a similar method using median, but defined upper and lower bounds using hourly Inter – Quartile – Range (IQR) instead of standard deviation.**

$$Upper\ Bound\ (UB) = \hat{X} + IQR$$

$$Lower\ Bound\ (LB) = \hat{X} - IQR$$

E. RESULTS

1. South Coast of Honshu

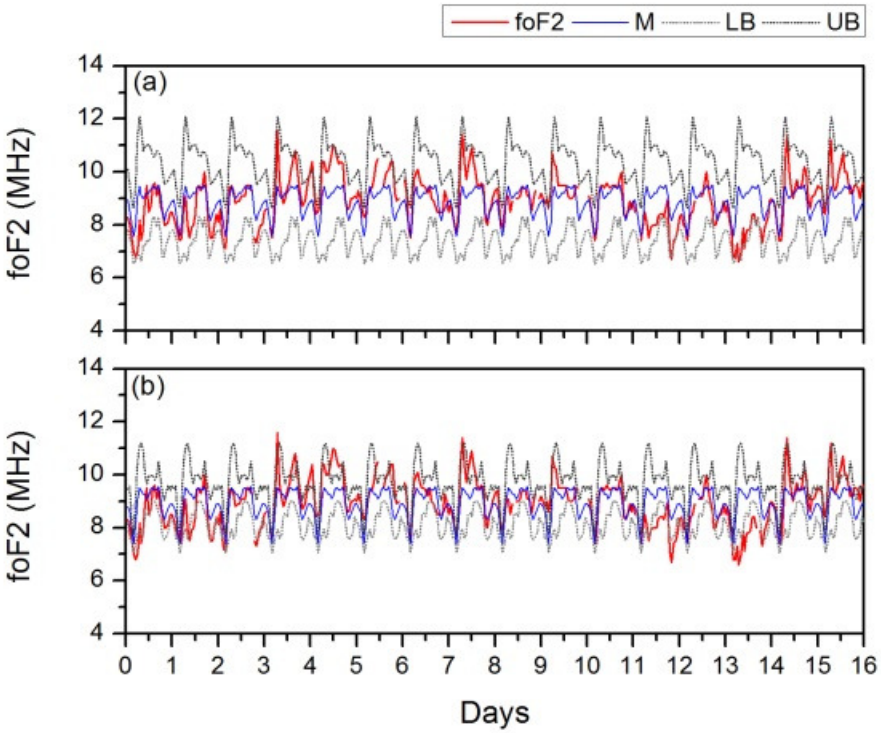


Figure 1a. Variations of daily foF2 (red line) for the earthquakes given in order in Table 1 .(a) Standard deviation, (b) Inter quartile range. Blue, green and grey lines indicate (M) - median, (UB) - upper bound and (LB) - lower bound respectively.

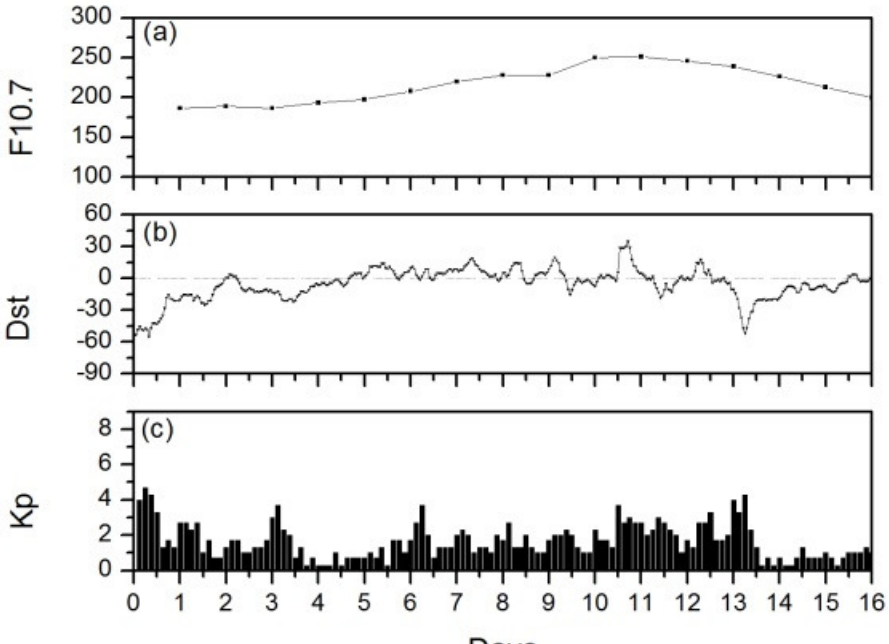


Figure 1b. Solar and geomagnetic activities

2. Center of Honshu, MT OntakeEarthquake

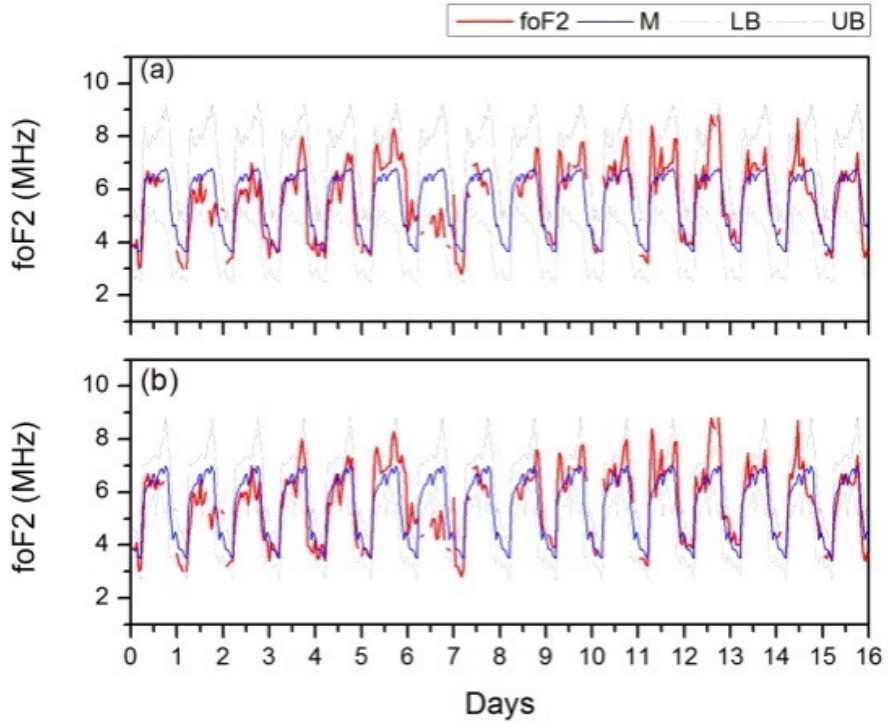


Figure 2a. Variations of daily foF2 (red line) for the earthquakes given in order in Table 1 .(a) Standard deviation, (b) Inter quartile range. Blue, green and grey lines indicate (M) - median, (UB) - upper bound and (LB) - lower bound respectively.

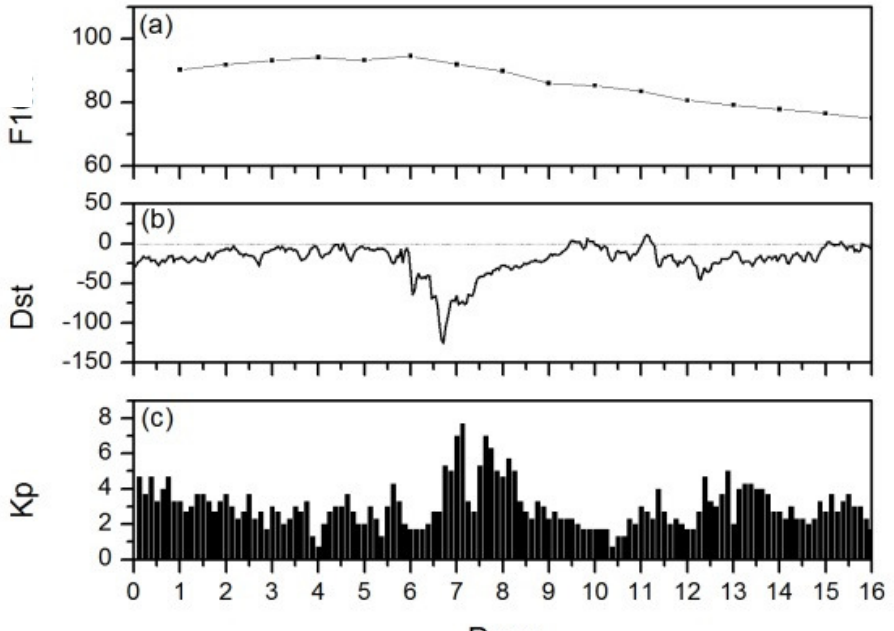


Figure 2b. Solar and geomagnetic activities

3. Near Eastern Coast of Honshu Earthquake

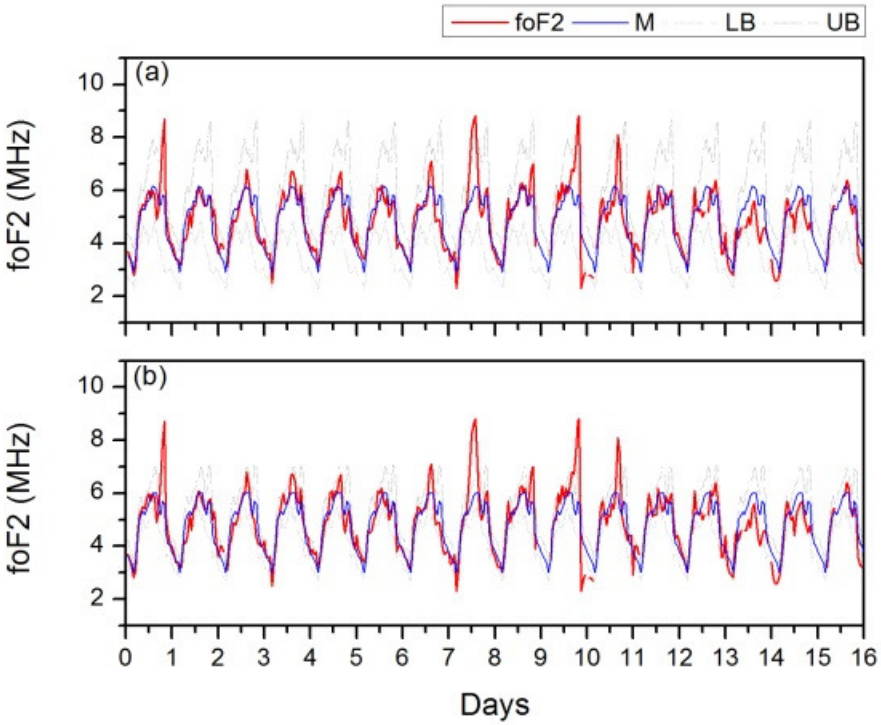


Figure 3a. Variations of daily foF2 (red line) for the earthquakes given in order in Table 1 .(a) Standard deviation, (b) Inter quartile range. Blue, green and grey lines indicate (M) - median, (UB) - upper bound and (LB) - lower bound respectively.

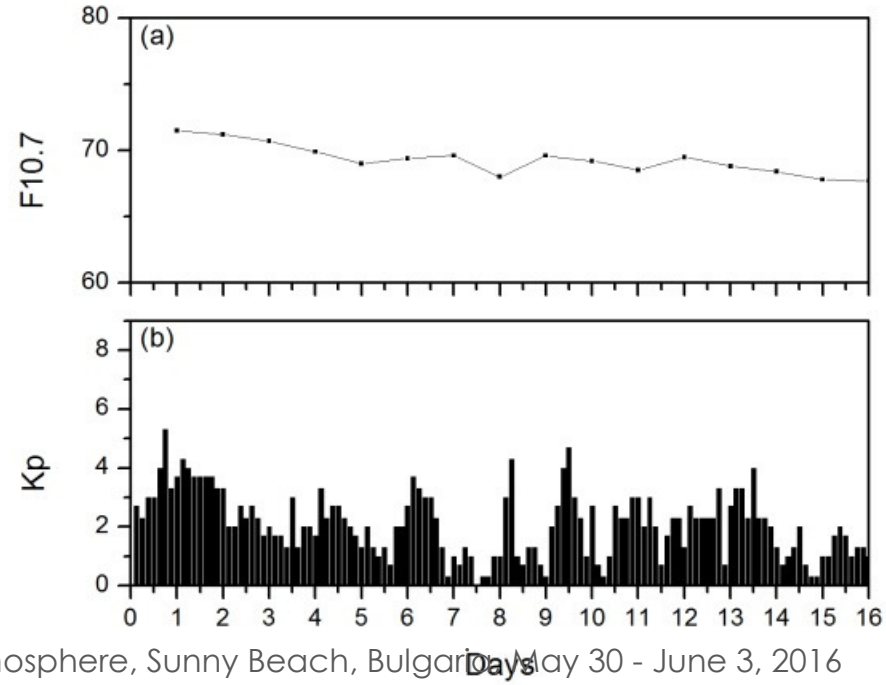


Figure 3b. Solar and geomagnetic activities

4. Far Eastern Coast of Honshu

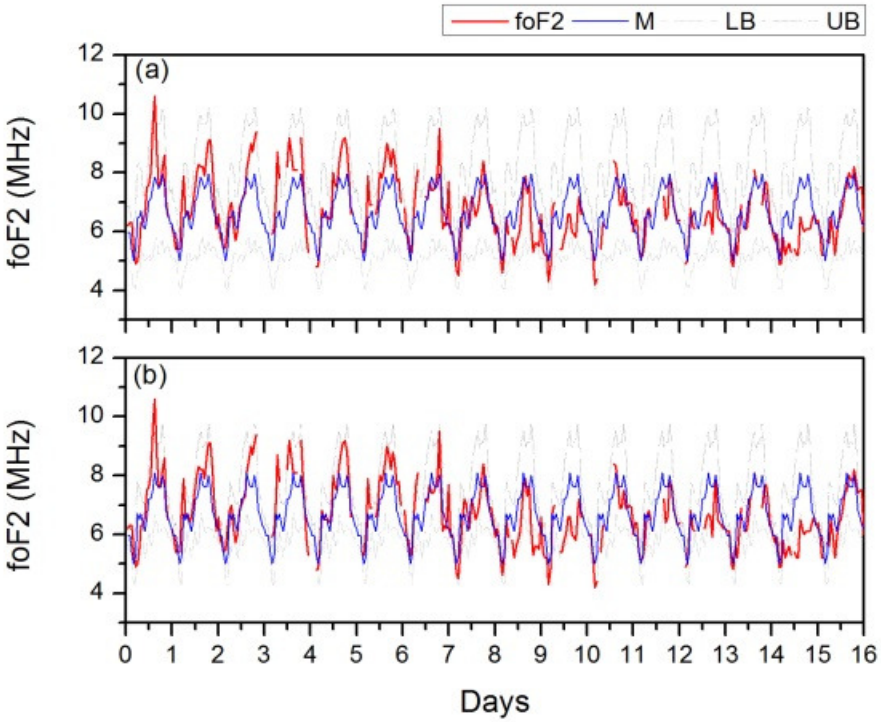


Figure 4a. Variations of daily foF2 (red line) for the earthquakes given in order in Table 1 .(a) Standard deviation, (b) Inter quartile range. Blue, green and grey lines indicate (M) - median, (UB) - upper bound and (LB) - lower bound respectively.

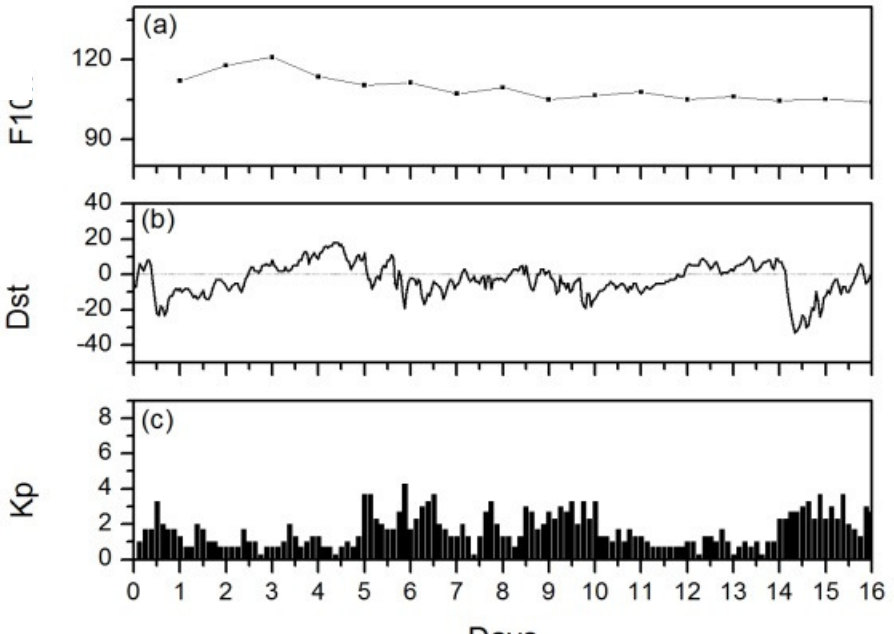


Figure 4b. Solar and geomagnetic activities

- **We have seen that for the all earthquakes, *f*oF2 variations were very close to upper and lower bounds and in some days *f*oF2 passed either upper or lower bounds in the earthquake day and before five day from main shock.**

- **In the most of cases, the formation time of *f*oF2 variations before earthquake tended to occur on the same or similar time of the day.**

- **For both methods results present that all the earthquakes show both positive and negative prominent variations before earthquakes but the crossings for both bounds are more pronounced in the IQR**

- **According to the results obtained, the method defined with IQR gives us more sensible results than standard deviations for identifying earthquake precursors.**

F. Conclusion

- **Earthquakes as a geophysical phenomenon involve processes which are irregular, nonlinear and complicated. These events are so sophisticated that the dynamic relations between their parameters result in high uncertainties.**

- **Earthquake precursors are difficult to identify because of the complexity of the earth's crust, various types of the earthquake mechanisms and the absence of widespread geophysical, geochemical and ionospheric data and observing in most regions, as well as there are a lot of factors affected on day to day variability on ionosphere like especially geomagnetic and solar activities.**

- **Although some seismologists have made successful earthquake prediction, especially in short term (few hours and a few days before earthquakes), it's still in discovery stage.**

- **Moreover, mechanism of seismo-ionospheric coupling is still not fully understood.**

- **To make short-term earthquake prediction more accurately, further investigation is required together with other areas like geophysics, geomagnetism, geochemistry, seismology, and atmospheric physics and integration of different kinds of precursors from different experiment.**

Acknowledgments

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THANK YOU
FOR YOUR ATTENTION