Analysis of Ionospheric Disturbance Associated With Earth Quakes In Papua New Guinea

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Analysis of Ionospheric Disturbance associated with Earth quakes in Papua New Guinea

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Abstract

An analysis of the perturbations in the electron content up to the ionospheric F_2 layer peak and F2 layer peak height (h_mF2) variations during earthquake time has been done using ionosonde data observed in the equatorial station Vanimo, Papua New Guinea. Two earth quakes occurred, one of magnitude 7.1 in Sissano in 1998 and the other of magnitude 6.7 in Aitape in 2002 in the western province of Papua New Guinea, have been studied. A decrease in electron content was observed in both the cases a few days prior to the earthquakes. An increase in height of h_mF2 during night time was also observed during this period. This can be explained in terms of the lithosphere- atmosphere-ionosphere coupling prior to earthquake period.

Key words: Ionospheric F2 layer, Earthquake, Ionosonde

1. Introduction

Prediction of occurrence of strong earth quakes is a great concern nowadays and a lot of studies using different physical parameters are going on in this area. Seismo-ionospheric study is one among them [Pulinets, 2004; Liu et al., 2011]. Ionosphere is a region of the atmosphere which contains weakly ionized plasma. Changes in the ionosphere are often disturbed by natural phenomena such as volcanic eruptions [Heki, 2006], earth quakes [Liu et al., 2009], solar flares [Krecht and Davis, 1961] and so on. Underground nuclear explosions affect the electron density of the ionosphere [Park et al., 2011]. Total Electron Content (TEC) of the ionosphere is one of the parameters used to study and monitor the ionosphere. TEC is sensitive to strong earth quakes. TEC disturbances increase with earth quake magnitude but decrease with distance from the epicenter [Liu et al., 2006; Zolotov et al, 2012].

In this paper, we have studied the ionospheric disturbances that occurred prior to earth quake in Sissano in 1998 and in Aitape in 2002 in Sandaun province of Papua New Guinea. We have used the critical frequency corresponding to the maximum electron content of F2 layer (f_0F2) and the F layer heights (h_mF2) of the ionospheric data measured in Vanimo station in Sandaun province of Papua New Guinea. Vanimo station is situated very close to these places. We have also analyzed the geomagnetic activity during this period.

2. Data Analysis

We have studied the ionospheric properties during two earth quakes which occurred one in Sissano in 1998 and the other in Aitape in 2002 in Sandaun province in Papua New Guinea. The location of Sissano is -2.943N, 142.582E and that of Aitape is -3.212N, 142.427E. We have used ionosonde data measured in Vanimo (-2.7N, 141.3E) which is close to the epicentre of the earth quakes. Fig. 1 shows the locations of earth quakes and Vanimo ionospheric station. The earth quake which occurred in Sissano was a shallow earth quake and was associated with fault rupture of a dipping fault (McCue, 1998). About 600 km^2 of sea floor was moved through the dipping fault to the Wewak Trench (McSavney et al., 1998; Goldsmith et al., 1999). Table 1 summarizes the date of occurrence, epicentre, depth and magnitude of the earth quakes considered. The epicentre of the 1998 earth quake observed on 17^{th} July in Sissano is at a distance of 91 km and that of the 2002 earth quake observed on 10^{th} January is at a distance of 129 km from Vanimo equatorial station.

F2 region is the most ionized region in the ionosphere. The minimum frequency below which a radio wave is reflected by the ionospheric layer is called the critical frequency. The peak electron density associated with each layer of the ionosphere is associated with a critical frequency. Ionospheric observations can be made using ionosondes (Cooper, et al., 2018). Total electron content (TEC) is derived from ionospheric electron density N(h) as $TEC = \int_0^h N(h)dh$ and is measured in TEC units (10^{16} electrons/m^2). In ionosonde, high frequency radio wave pulses are transmitted and after reflection from the ionosphere are received in a receiver. From the reflected time series of plasma frequency, electron density can be derived (Huang and Reinisch, 2001). The received frequency f_0F2 corresponds to the maximum electron density (N_mF2) in the ionosphere. The peak electron density associated with critical frequency f_0F2 is given by $N_mF2 = 1.24 \times 10^{10}(f0F2)^2$(Spalla and Ciraola, 1994). The TEC is related to N_mF2 as $TEC = \tau \times N_mF2$ where τ is called the slab thickness which provides an estimation of the width of the vertical electron density profile. $TEC = 1.24 \times 10^{-6}\tau(f_0F2)^2$ (Davies, 1990). Ionosonde gives an estimation of vertical TEC up to the peak electron density N_mF_2. TEC is highly correlated with f_0F2 and the correlation coefficient can reach a value of 0.9 (Houminer and Soicher, 1996). The ionospheric region above the N_mF2 region cannot be measured by ionosonde.

2.1 Magnetic Storm effects

In our analysis, we have used f_0F2 values of the ionosonde data published by Australian Meteorological Society (https://www.sws.bom.gov.au). Ionospheric parameters are affected by magnetic storms. D_{st} index data published by NASA (https://omniweb.gsfc.nasa.gov) is used to study the effect of magnetic activity during this period. The Daily average $(foF_2)^2$ (proportional to electron content) variation and D_{st} index variation for Sissano and Aitape earthquakes are shown in Fig. 2a and 2b respectively. A decrease in $(f_0F2)^2$ variation is observed prior to both the quakes. No intense magnetic storms occurred during these periods. Usually decrease in electron content of the equatorial ionosphere is observed during the main phase of intense magnetic storms (Rakhee Malik et al., 2010; Balan et al., 2013). Magnetic storms are categorized as intense (Dst <-100nT), strong (-100nT> Dst >-80nT), moderate (-80nT> Dst> -60nT) and mild (-60> Ds t>-40nT). Only strong and intense magnetic storms produce TEC fluctuations lasting for one to several days. Moderate and mild magnetic storms, if at all, produce only weak ionospheric perturbations lasting for a day or so. Only a mild magnetic storm occurred on 17th of July 1998 and the earthquake happened just after the main phase (MP) peak (Figure 2a). Because it was a mild magnetic storm, no major decrease in $(foF_2)^2$ is expected during its MP. Prior to this earthquake the magnetic activity was quiet for ~15 days. However, a large decrease in $(foF_2)^2$ happened well before the earth quake. In short, the observed decrease in $(foF_2)^2$ could most probably be related to the earth quake. The Dst index variation from December 26th 2001 to January 25th 2002 is plotted in Fig. 2b. Prior to Aitape earth quake on 10th January, the geomagnetic activity was quiet. The recovery phase of a mild magnetic storm was in progress prior to the quiet period, when usually an increase in $(foF_2)^2$ was expected at equatorial latitudes (Balan et al., 2013). Contrary to the expectation, a large decrease in $(foF_2)^2$ was observed prior to the Aitape earth quake. In short, the decreases in $(foF_2)^2$ observed prior to both the earth quakes seem to be related to the quakes.

A detailed study is conducted using hourly values of $(f_0F2)^2$ variations during the two periods. The mean value and standard deviation of $(f_0F2)^2$ are calculated in every hour for 31 days and $(\bar{x} \pm \sigma)$ are calculated for 24 hours. A graph is plotted with hourly variation of $(f_0F2)^2$

along with $(\bar{x}+\sigma)$ and $(\bar{x}-\sigma)$ for 31 days around the earth quake day. If the $(f_0F2)^2$ variation is outside the range of $(\bar{x}\pm\sigma)$, it is considered as a fluctuation. Fig. 3a represents the variation of $(f_0F2)^2$ during Sissano earth quake and Fig.3b shows that during Aitape earth quake. During Sissano earthquake (Fig. 3a), $(\bar{x}\pm\sigma)$ during daytime varies from 95X10^{12} $(\bar{x}-\sigma)$ to 157X10^{12} $(\bar{x}+\sigma)$. An unusual decrease of $(f_0F2)^2$ is observed on 14th, 16th and 18th of July and their values decrease below 80X10^{12}. During Aitape earthquake (Fig.3b), $(\bar{x}\pm\sigma)$ during daytime varies from 140X10^{12} $(\bar{x}-\sigma)$ to 180X10^{12}$(\bar{x}+\sigma)$. We could observe that the $(f_0F2)^2$ values decrease below 140X10^{12} on 31st December, 4th, 6th and 8th January, during daytime.

Anomaly in TEC is defined as

$$Anomaly = \frac{TEC_{obs.} - TEC_{mean}}{TEC_{mean}} \times 100\% ,$$

where $TEC_{obs.}$ is the daily average of observed value of TEC and TEC_{mean} is the mean value of TEC for one month. TEC anomaly is calculated during both the earthquake periods and plotted in Fig. 4. Fig. 4a represents the daily TEC anomaly for 21 days; ten days prior to and ten days after the Sissano earthquake. A negative TEC anomaly of 34% on 4th, 28% on 16th and 30% on 18th of July 1998 were observed associated with Sissano earthquake. During Aitape earthquake (Fig. 4b), a negative anomaly of 24% on 31st December, 15% on 4th and 17% on 5th of January 2002 were observed. You can observe a slight decrease of TEC anomaly magnitude for Aitape earthquake compared to Sissano earthquake. This may be because Aitape is far away from Vanimo than Sissano.

The hourly values of height (hmF_2) corresponding to the peak electron density (N_mF_2) of F2 layer for 13/07/1998 to 17/7/1998 from 22:00 to 06:00 hours UT are plotted in Fig. 5. We can notice an increase in h_mF2 on 14th and 16th of July whose values are above 350 km compared to other days in which dates the $(f_0F2)^2$ values were also observed to be less. The h_mF2 data during January 2002 is not available.

Results and Discussion

A decrease in daily average $(f_0F2)^2$ is observed prior to the earthquakes (Fig. 2). No intense magnetic storms were observed during these periods of study. The TEC anomaly on 14th, 16th and 18th of July 1998 Sissano earthquake showed values more than 30% in the negative direction. But during Aitape earthquake, the TEC anomaly was found to be less than that in Sissano earthquake. This could be because; Aitape is slightly away from Vanimo station than Sissano. Fluctuations in ionosphere are observed about 150 km around the epicenter of the earthquake.

A decrease in peak electron density is observed on 14th, 16th, 18th and 21st of July 1998. A decrease in electron density is observed three days prior to the Sissano earth quake day (Fig. 3a). A decrease in peak electron density is observed on 3rd, 5th, 7th and 9th of January 2002 prior to the 10th January earth quake in Aitape (Fig. 3b). An increase in electron density is observed on 7th, 11th, 12th, 22nd, 23rd and 25th July during Sissano earth quake and on 10th and 12th January in Aitape earth quake.

The height of the peak electron density region reaches a maximum at around 2-3 hours UT and attains a height of about 300-350 km on normal days. On 14th and 16th of July 1998, it rises above 350 km and remains at this height for more than four hours. The decrease in electron density during these days might be due to this unusual rise of F2 layer. This unusual rise in F2 layer can happen if the Hall current is higher during this period.

The location of Papua New Guinea is in one of the most seismic active regions (Pegler et al., 1995). It is a region consisting of an array of tectonic boundaries (Mc Clusky et al., 1994; Tregoning et al., 1998; Wallace et al., 2004).The location of PNG is where the Australian and Pacific plates converge. The Pacific plate is moving west-southwest direction at 110 mm/year relative to Australian plate (DeMets et al., 2010). In addition, there are at least two more minor plates. The models of GPS velocities and earthquake slip vectors suggest that there are six plates namely the Australian, Pacific, South Bismarck, Woodlark and the New Guinea Highland plates. A fault is considered as a discontinuity in a continuous elastic medium. In such cases deformation can be in different ways by the application of a force. If the deforming force is greater than the applied force, the elastic medium bounces back to static equilibrium.

Earth quake occurs in various areas of the earth in which the tectonic plates move side past or collide with or diverge away from each other. These tectonic activities induce electric and magnetic fields in the near surface. During pre-earth quake period, gases like radon are expelled from the ground. These gases ionize the neutral air and a large quantity of ions was produced during this time. Moreover, during the earth quake preparation time, the rocks will be under stress and creates charges, which spreads over the surface near the earth quake region. These charges also ionize the lower layers of the atmosphere. As the gravity wave moves towards the east direction, with the earth's magnetic field towards the north direction, the Lorentz force forces the positive ions in the upward direction. There is a greater concentration of positive ions in the lower ionosphere. One possibility is that some of the positive ions neutralize some of the electrons in the ionosphere thus reduces the total electron content in the ionosphere. Another possibility is that the F2 layer height increases and thus reduces the electron density in the equatorial ionosphere.

Conclusion

Papua New Guinea is a country that falls in the 'ring of fire' region where frequent earthquakes are common. There are many studies around the globe that relate earthquakes and ionospheric disturbances. In our paper, we studied the ionospheric F2 region fluctuations related to Sissano earthquake (magnitude 7.1) which occurred in July 17th 1998 and Aitape earthquake (magnitude 6.7) which occurred in January 2002 using the critical frequency data observed in Vanimo station, Papua New Guinea. A decrease in electron density was observed in both cases a few days prior to the earthquake day. In these days, the ionospheric peak height has risen to greater heights. During the earthquake preparation period, a large amount of radioactive gases like radon are expelled from the fault region, which ionize the lower atmosphere and these ions are lifted up to the ionospheric heights. Also, the stress developed during tectonic plate movement generates electric field on the surface of the active region. Further study is required with regard to the electric field created on the surface of the earth to accurately predict the earthquake.

DECLARATIONS

Availability of Data materials

1. Ionosonde data published by Australian Meteorological Society (https://www.sws.bom.gov.au)
2. Dst index data published by NASA (https://omniweb.gsfc.nasa.gov)

Competing Interest

The authors declare that they have no competing interests.

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Author's contributions

JS analyzed the data. FP interpreted and prepared the paper. All authors read and finalized the manuscript.

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Table

Table 1: The locations, magnitudes and depths of Sissano and Aitape earthquakes

Date	Place	Latitude	Longitude	Depth	Magnitude
17/07/1998	Sissano	-2.943	142.582	25 km	7.1 Mw
10/01/2002	Aitape	-3.212	142.427	11 km	6.7 Mw

Figure Captions

Fig. 1: Map showing the locations of earthquakes and the ionospheric station in Papua New Guinea.

Fig. 2: a) Variation of Dst index (Top) and daily average $(f_0F2)^2$ (Bottom) fifteen days prior to and fifteen days after the Sissano earth quake and b) that after the Aitape earth quake. Vertical dashed lines indicate the earth quake times.

Fig. 3: Hourly variation of $(f_0F2)^2$ (Blue) along with $(\bar{x} + \sigma)$ (Red) and $(\bar{x} - \sigma)$ (Green) fifteen days prior to and fifteen days after (a) the Sissano earth quake and (b) the Aitape earth quake. The vertical dotted line represents the earth quake day.

Fig 4: a) Daily TEC anomaly from 7^{th} July to 27^{th} July 1998 associated with earthquake in Sissano and b) daily TEC anomaly from 27^{th} December 2001 to 25^{th} January 2002 associated with Aitape earthquake.

Fig. 5: Variation of height (hmF_2) of peak electron density (N_mF_2) of F_2 layer of the ionosphere for days from 13 to 17 of July 1998.

Figures

Figure 1

Map showing the locations of earthquakes and the ionospheric station in Papua New Guinea.

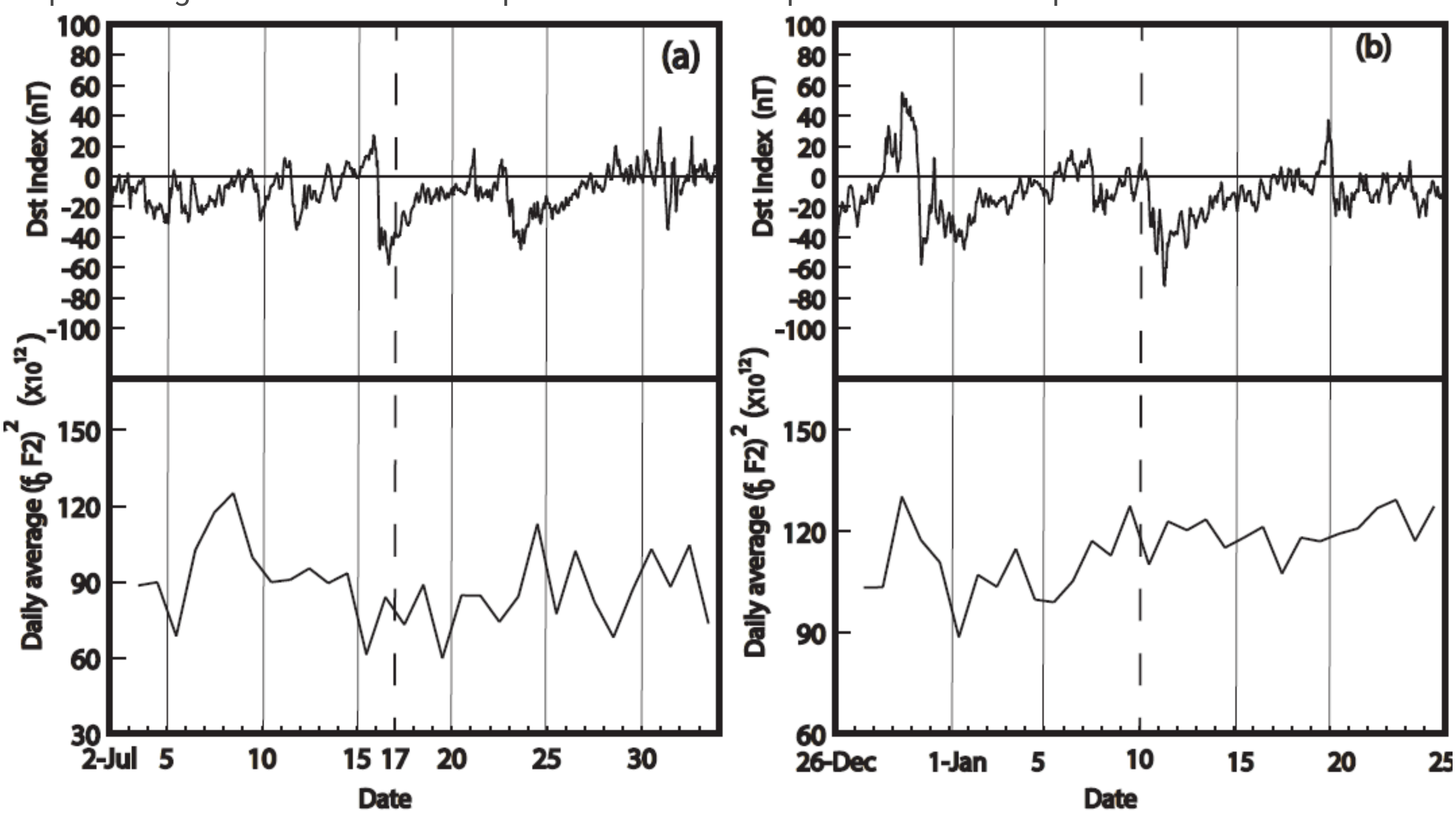

Figure 2

a) Variation of Dst index (Top) and daily average (f0F2)2 (Bottom) fifteen days prior to and fifteen days after the Sissano earth quake and b) that after the Aitape earth quake. Vertical dashed lines indicate the earth quake times.

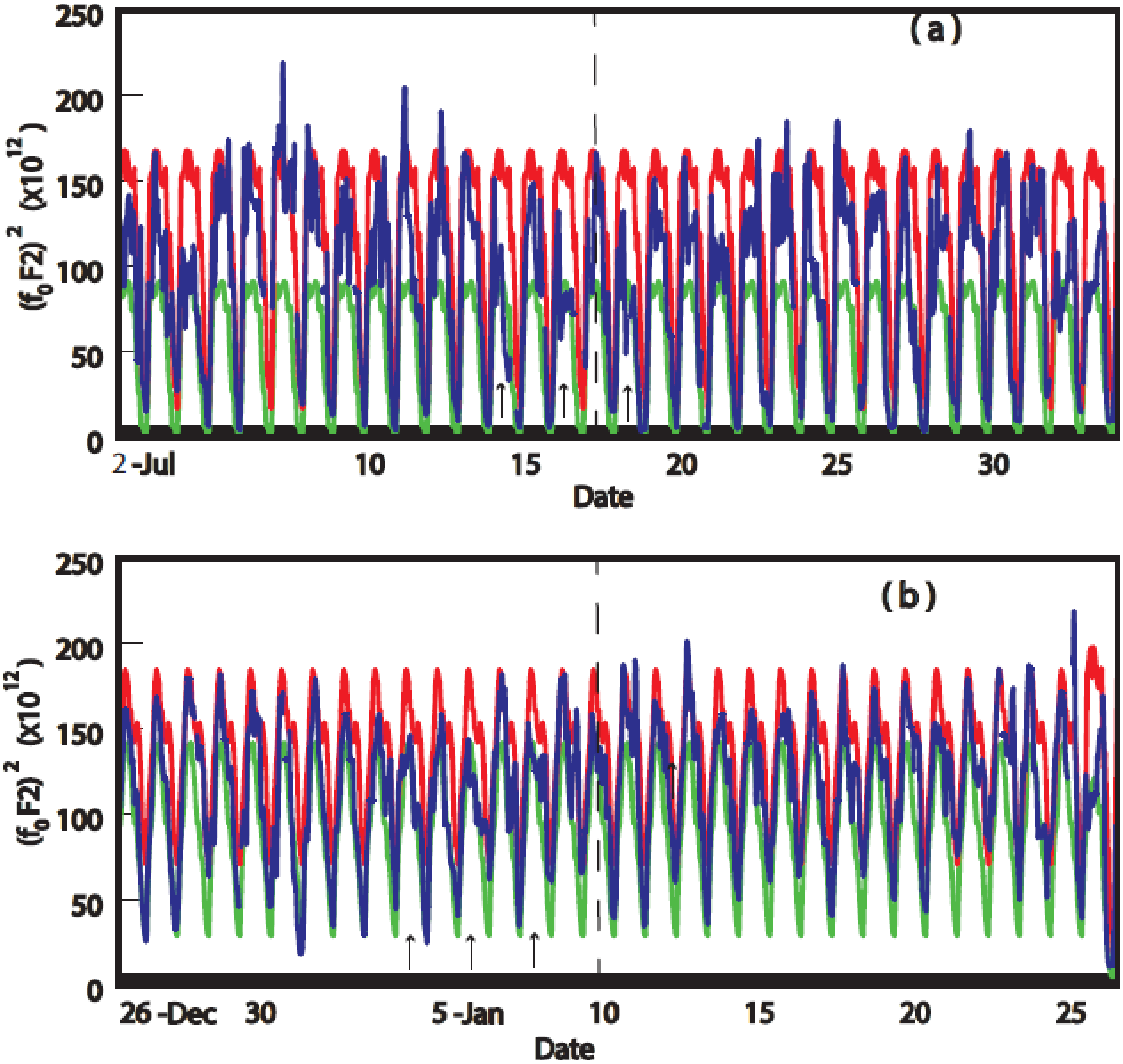

Figure 3

Hourly variation of (f0F2)2 (Blue) along with (Red) and (Green) fifteen days prior to and fifteen days after (a) the Sissano earth quake and (b) the Aitape earth quake. The vertical dotted line represents the earth quake day.

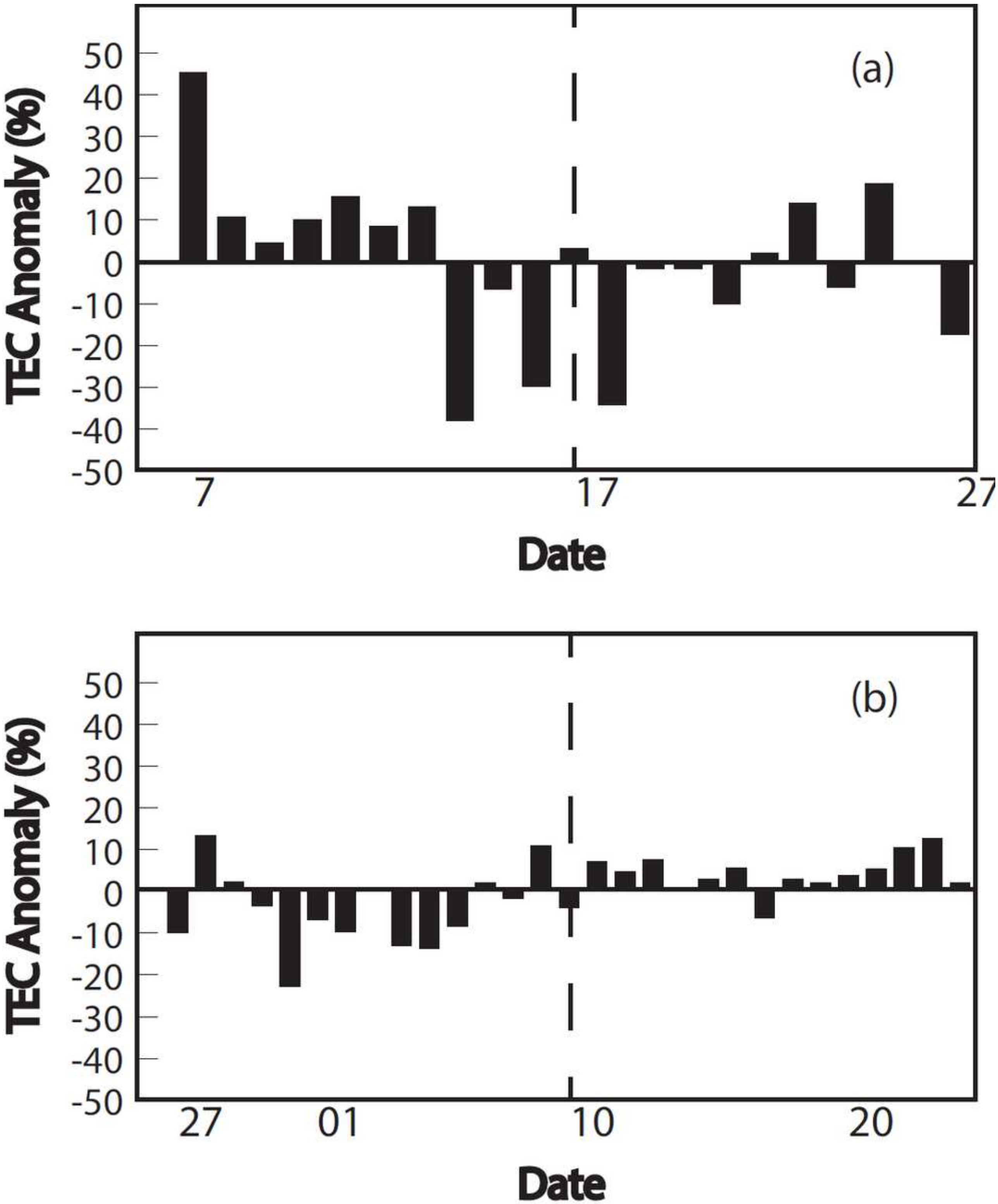

Figure 4

a) Daily TEC anomaly from 7th July to 27th July 1998 associated with earthquake in Sissano and b) daily TEC anomaly from 27th December 2001 to 25th January 2002 associated with Aitape earthquake.

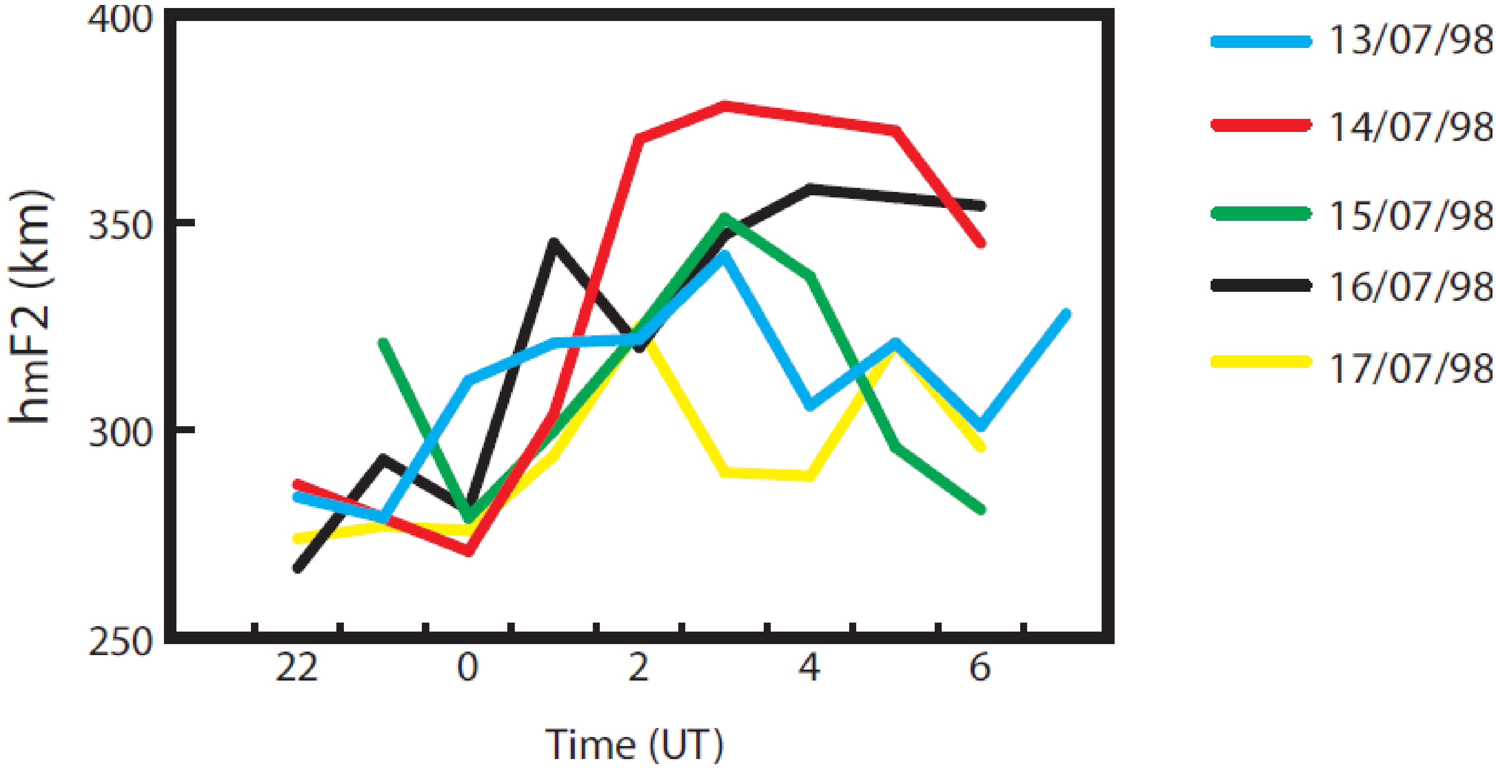

Figure 5

Variation of height (hmF2) of peak electron density (NmF2) of F2 layer of the ionosphere for days from 13 to 17 of July 1998.

Supplementary Files

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