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HF Propagation during geomagnetic storms at a low latitude station

Abstract

The variations in the ionosphere affect the radio wave propagation. These variations become more pronounced as a result of geomagnetic storms. The data from a Digitonide installed at Guam station (Lat. 13.62°N and Long. 144.86°E) during geomagnetic events was scaled for an ionogram, which shows the heights of different layers in the ionosphere at different frequencies. The ionogram was then analysed and interpreted. Results showed that virtual heights steadily increased as frequency increased. The splitting of waves into ordinary and extraordinary waves as they enter the ionosphere was an indication that waves divide on entering the ionosphere. The extraordinary was consistently higher than the ordinary wave. The highest frequency the ionosphere above the station could refract signal at 180° was 12.625 MHz. This is the frequency at which communication was to be made from one location to another location within the location of the station. Comparative results between the iongrams of disturbed and undisturbed ionosphere showed that geomagnetic storms lead to increased foF2, MUF values and NmF2. The results also revealed that the strength of the refracted signals were particularly good, strong enough to rebound from the earth and refract again.

Keywords: ionosphere, HF propagation, F2 layer, MUF, foF2

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Abbreviations: GIRO, global ionospheric radiosonde observatory; ARTIST, Automatic Real-time Ionogram Scaling with True-height; MUF, maximum usable frequency; F2, F2-layer

Introduction

The ionosphere is the part of the atmosphere in which free ions exist in sufficient quantities to affect the propagation of radio waves. There are three commonly known sections of the ionosphere, the D, E and F regions occurring at heights of 50 to 90 km, 90 to 140 km and above 120 km respectively. The F2 layer peaks between 200 and 600 km, depending on factors such as time of day, season, phase of solar cycle, neutral winds, ion composition, etc. Due to the low densities of these altitudes, recombination is very slow; the ionisation exists for many hours following sunset. The F2 layer is the most important layer for radio communications,[1] since it generally has the largest electron densities and, therefore, reflects the highest frequencies. It is found at the greatest height and, therefore, results in the largest possible 1-hop distance. Some claims have been made for the existence of two other regions: C and G. The C region is thought to exist at the bottom edge of the D region, approximately 60 km up, and is formed by cosmic rays and is therefore always present (since impinging cosmic rays are always present). The G region appears on ionograms as a little kink during a storm when the critical frequency of the F2 layer is greatly diminished. It's possibly not a distinct region but rather a phenomenon that occurs only at special times.[2] The ionograms show the heights of different layers in the ionosphere at different frequencies, measured using ionospheric sounding techniques. The HF radar and ionospheric sounders use the same basic echo principles, the main differences between then are range and type of object detected. With digital ionosondes (Digisondes), the information provided by sounders enables communicators to design radio systems, choosing frequencies and times of operation more effectively.

Methodology

The digisonde DPS-4D installed at the observatory of Guam (Lat. 13.62°N and Long. 144.86°E) was used to monitor the ionosphere with the regular interval of 15 minutes.[3] This was obtained from Global Ionospheric Radiosonde Observatory (GIRO) to investigate the responses of ionospheric parameters to geomagnetic activities. The data obtained included ionogram plots at regular interval of 15 minutes, which has been scaled automatically by Automatic Real-time Ionogram Scaling with True-height (ARTIST). Some of the parameters from the ionogram include critical frequency of F2-layer (foF2), maximum usable frequency (MUF), E region critical frequency, virtual height and so on.

Results

The ionogram for both disturbed and undisturbed periods, with their respective Maximum Usable Frequency (MUF) tables are hereby presented (Table 1 & 2).

Table 1 MUF Values at given distances for 1 October 2012 storm event during 05:00 – 05:45 Hour

D	100	200	400	600	800	1000	1500	3000 (km)
MUF	13.1	13.2	13.8	14.6	15.8	17.6	22.8	35.9 (MHz)
D	100	200	400	600	800	1000	1500	3000 (km)
MUF	13.0	13.1	13.6	14.5	15.7	17.5	22.6	35.7 (MHz)
D	100	200	400	600	800	1000	1500	3000 (km)
MUF	12.9	13.1	13.6	14.4	15.6	17.3	22.3	34.9 (MHz)
D	100	200	400	600	800	1000	1500	3000 (km)
MUF	12.7	12.8	13.3	14.2	15.3	17.0	21.8	34.1 (MHz)

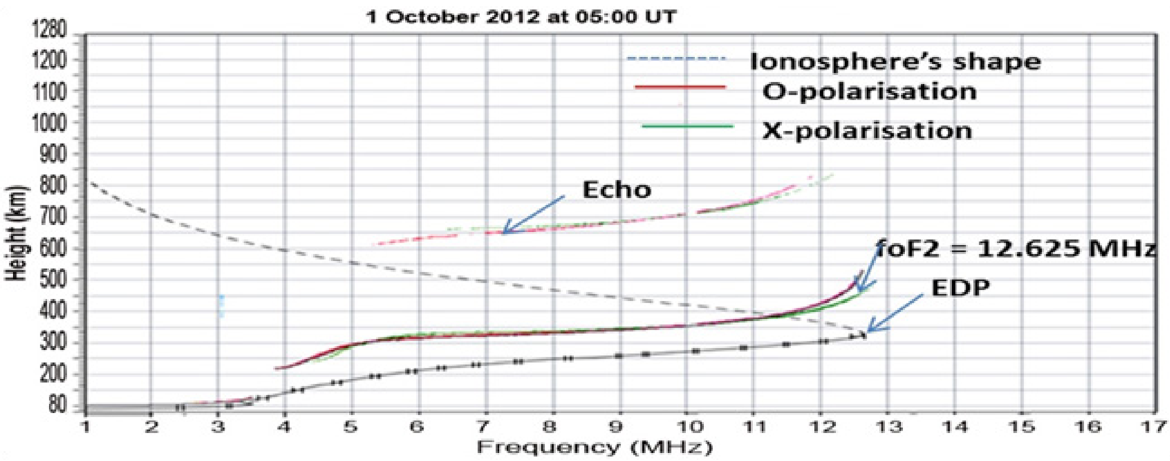
Table 2 MUF Values at given distances for 29 August 2012 Quiet period from period 00:00 to 00:45 hour

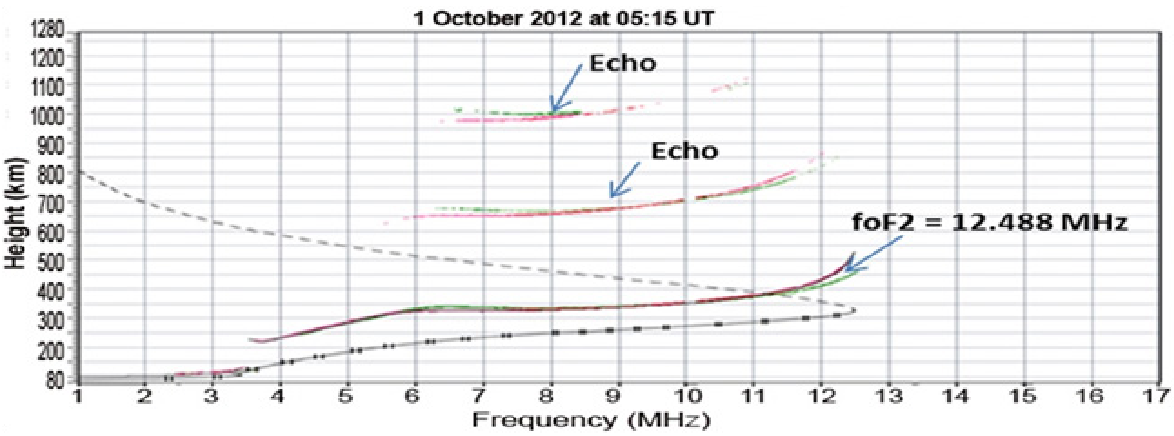
D	100	200	400	600	800	1000	1500	3000 (km)
MUF	10.1	10.2	10.6	11.2	12.1	13.4	17.0	26.3 (MHz)
D	100	200	400	600	800	1000	1500	3000 (km)
MUF	10.4	10.5	10.8	11.5	12.3	13.6	17.2	26.5 (MHz)
D	100	200	400	600	800	1000	1500	3000 (km)
MUF	10.5	10.6	11.0	11.6	12.5	13.8	17.6	27.0 (MHz)
D	100	200	400	600	800	1000	1500	3000 (km)
MUF	10.9	11.0	11.4	12.1	12.9	14.2	18.0	27.5 (MHz)

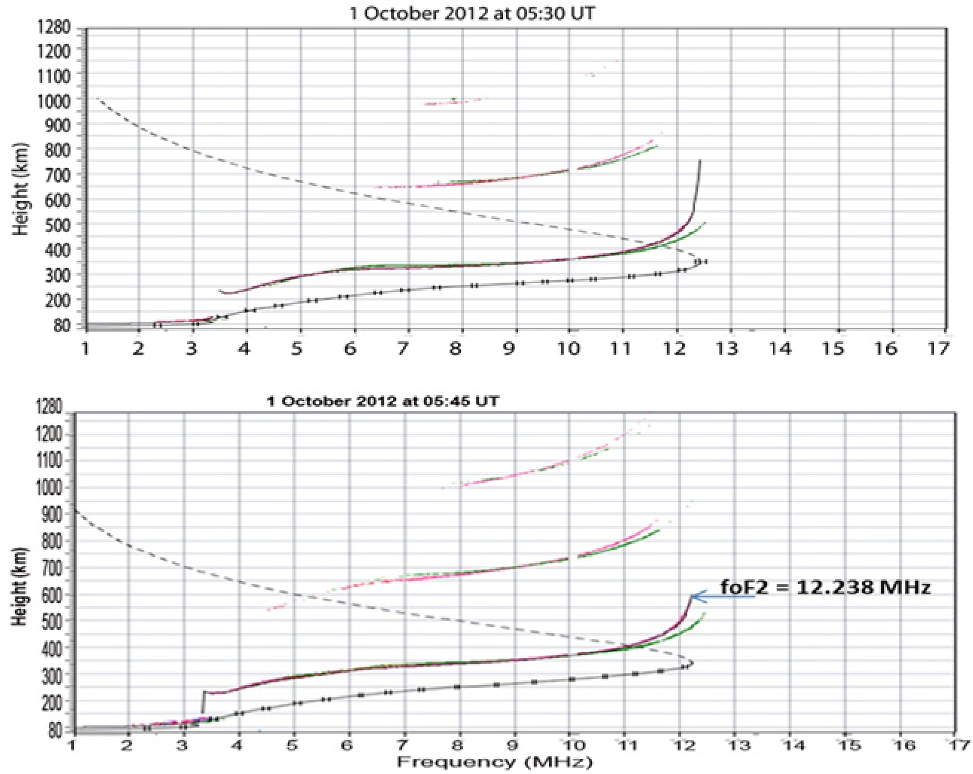
Discussion

Ionogram interpretation

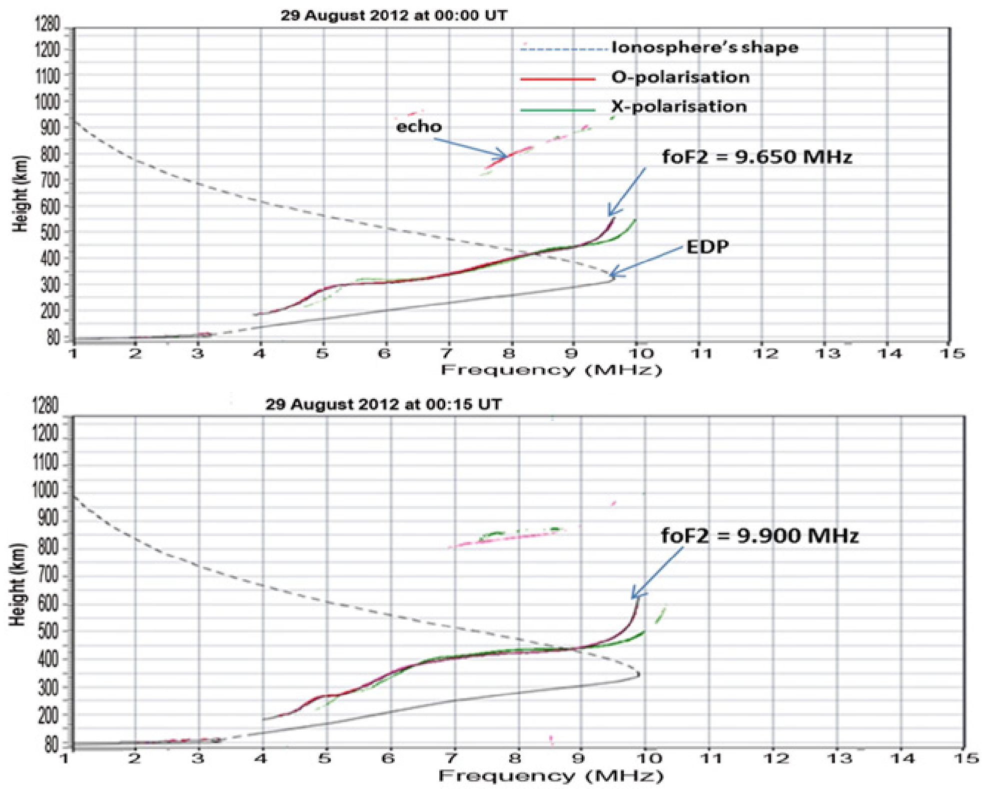
Ionogram presents a plot of virtual height (km) against frequency (MHz) and indicates signals reflected from the ionosphere depicted by colours. The red (green) colours indicate vertical echoes with O-polarization or ordinary wave (X-polarization or extra ordinary). It also consists of sections of the ionosphere – D, E and F regions, with each having some sub-divisions. ARTIST software scaled the ionogram and calculates the vertical Electron Density Profile (EDP) in real time. The electron density profile (EDP) shown in all ionogram Figures is comprised by the bottom side part which is measured by the digisonde (continuous line with uncertainty bars) and a topside part (dashed line) which is modelled.[4] The EDP chart in the ionogram depicts the ionosphere's shape, making the ionospheric density easier to visualise. The two lines that accompanied every ionogram, show the Maximum Usable Frequency (MUF) values in MHz at the given distances D in km. The MUF represents the statistical frequency during which 3000 km single hop refraction via the F2-layer is generally open 50% of the time, thus a median value. It is used to define the uppermost frequency that is reflected by the F-layer at a distance of 3000 km from the transmitter.







Ionogram Data during Magnetic Storm of 1 October 2012, from Period 05:00 to 05:45 Hour.



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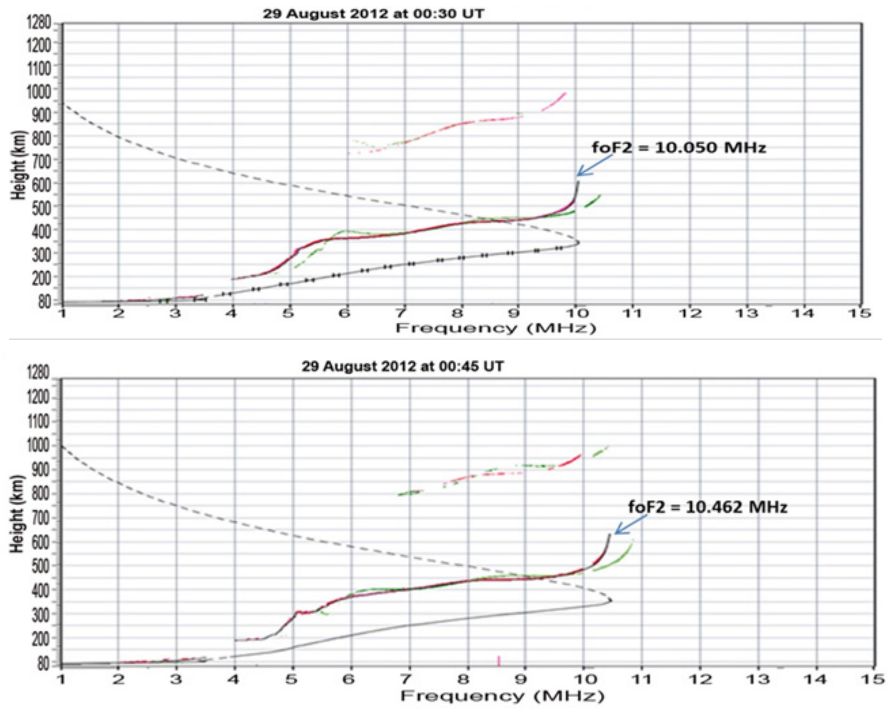

Ionogram Data During Quiet Day of 29 August 2012, from Period 00:00 to 00:45 Hour.

Ionogram interpretation on 1 October and 29 August, 2012 geomagnetic events

Figure 1 shows ionogram on 1 October, 2012, which represent intense (Dst=-119 nT) storm event. From the Figure, beginning with frequency of about 2.7 MHz, it was observed that the virtual height steadily increases as frequency increases. Just after the 3 MHz, the virtual height increases steeply, this was the E region critical frequency (foE), which has the value of 3.51 MHz. This indicates that the E region electron density at this frequency is not dense enough to turn the pulse back to Earth. There was another steep increase in the virtual height around 12.625 MHz. This is the F2 region critical frequency (foF2). Also observed were two traces showing up beginning just after 4 MHz. The two traces are the ordinary and the extraordinary waves. The ordinary wave is indicated on red line while the extraordinary wave is indicated on green line. The splitting into the two waves indicates that the up-going wave divides on entering the ionosphere. The difference in the refraction between the ordinary and extraordinary waves was quite obvious. The extraordinary wave F2 region critical frequency (FXI), 13.07 MHz was higher than the ordinary wave F2 region critical frequency (foF2), 12.625 MHz.

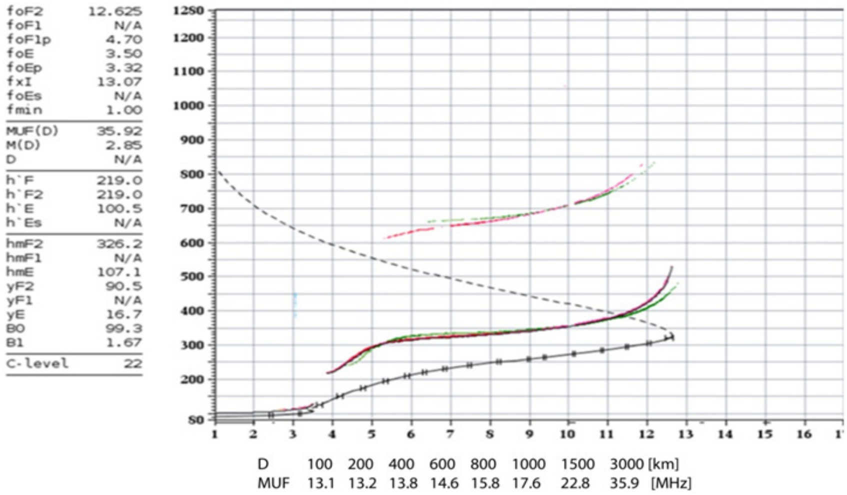

Figure 1 The Intense Storm Event on 1 October 2012.

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The ionogram data during quiet condition on 29 August, 2012 (Figure 2) for the same station was also examined to determine the contribution of geomagnetic storms on low latitude ionosphere. These ionograms are shown in Figure 2. They are of the same patterns of figures as described in Figure 1. The observation showed that the F2 critical frequency was reduced, as well as the virtual height. Also reduced were MUF values at different distances, ranging from 100 to 3000 km. Hence, geomagnetic storm on 1 October lead to increased foF2 and MUF values compared to their values during quiet condition on 29 August 2012. A good interpretation of ionogram leads to the understanding of HF propagation. Now, interpreting the ionogram in Guam station using that at 05:00 UT as an example, the red line extending just before 6 MHz to around 10 MHz shows that the ionosphere above the station was refracting radio signals in that frequency range straight back down again (i.e. at an angle 180°). It was acting like a mirror for radio frequencies in this range. As the frequency goes above 10 MHz, the line bends upwards until eventually it goes off the top of the chart. At this point, the ionosphere stops refracting signals back down (at 180°), however it will continue to refract signals at higher frequencies which hit it at lower angles (less than 180°).

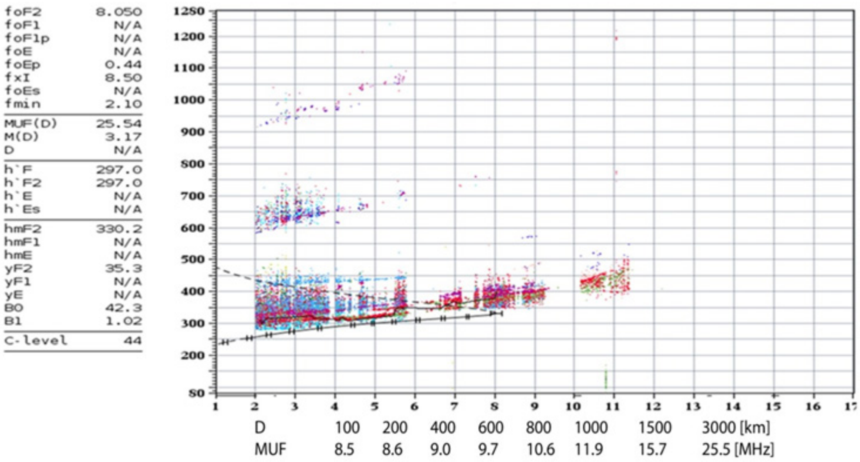

Figure 2 The Moderate Storm Event on 3 September 2012

Using the parameters in the interpretation, firstly the MUF (Table 1), which is the highest frequency the ionosphere will reliably reflect radio signals and also the one with lowest refraction angle, it simply means that the signals at this frequency will be refracted by the ionosphere (above the station) but only where the path between the ends of the link hits it at a low angle. This equates to a path length of around 3000 km. This implies that two stations, each 1500 km away from the station, the centre of whose path is above the station, will therefore be able to communicate at a frequency of 35.9 MHz. The second useful frequency shown in the figure was foF2. In this particular example, it has the value of 12.625 MHz. This is the highest frequency at which the ionosphere above the station will refract signals at an angle of 180°. It is the highest frequency at which a communication is to be made from one location to another location all situated in the location of the station. This was buttressed by the interpolations between foF2 and the MUF shown under the ionogram, under the various distances (from 100 to 3000 km). These are the maximum frequencies that can be used to communicate over the distance shown. The splitting of the waves into O- and X-waves was very visible in the plots. The two waves travel at independent path through the ionosphere, resulting in different refractive indices. The different in the magnitude of the waves results in gyrofrequency as $\frac{1}{2} f_H = \left(f_x - f_o\right)$. The critical frequency of the extra ordinary wave $\left(f_x\right)$ is $\frac{1}{2} f_H$ higher than the critical frequency of the ordinary wave $\left(f_0\right)$. Both waves have their MUF and that of X-wave will always be higher.

Also, an assessment on how strong the ionosphere is refracting can be made from the figures. The phantom reflections shown at around 600 km and 700 km height for Figure 1 and Figure 2 respectively are signals which were refracted from the ionosphere, then reflected by the earth and then refracted again by the ionosphere. These phantom reflections would tend to suggest that the strength of refracted signals is particularly good, as it has been strong enough to rebound from the earth and refract again.

NmF2 derived from ionogram plots

The electron density, especially the maximum electron density of the F2 layer in the ionosphere (NmF2) is an important parameter of the ionosphere. From the Figure 1, representing daytime ionogram during storm on 1 October 2012 from 05:00–05:45 UT, the maximum electron densities of the F2 layer are found to be $1.98\times10^{12}\,m^{-3}$, $1.93\times10^{12}\,m^{-3}$, $1.92\times10^{12}\,m^{-3}$ and $1.86\times10^{12}\,m^{-3}$ during the period of 05:00, 05:15, 05:30 and 05:45 UT respectively. Comparatively, the maximum electron density during the quiet period of 29 August 2012 showed reduced values of $1.15\times10^{12}\,m^{-3}$, $1.22\times10^{12}\,m^{-3}$, $1.25\times10^{12}\,m^{-3}$ and $1.36\times10^{12}\,m^{-3}$ during the period of 00:00, 00:15, 00:30 and 00:45 respectively.

The obtained NmF2 is related to the critical frequency of F2 layer (foF2), which is of particular interest in HF radio communication applications. A HF signal transmission can be interrupted or even lost due to regular and irregular variations of the side plasma density including theNmF2. The knowledge of NmF2is required to mitigate higher-order ionospheric propagation effects such as ray path bending errors in precise positioning[5] using Global Navigation Satellite System (GNSS). It is also important in deriving the slab thickness of the ionosphere, a parameter which provides information about the nature of the distribution of ionization at a specific location. Slab thickness measurements offer substantial information on the shape of the electron density profile, the neutral and ionospheric temperatures/gradients and on the ionospheric composition and dynamics.[6] It is therefore particularly employed in modelling the ionosphere, such as the International Reference Ionosphere (IRI).[1,7,8]

Conclusion

The results from the analyses of storm time and quiet period ionograms showed that foF2, NmF2 and MUF were enhanced during the geomagnetic storm event. When linked to HF propagation, the ionosphere above the station on 1 October, 2012 was refracting radio signals in the frequency between 6–10 MHz at about 05:00 UT. With MUF value of 3000 km, the implication was that two stations each 1500 km away from the station, the center of whose path was above the station, was able to communicate at a frequency of 35.9 MHz. With foF2 value of 12.625 MHz, it meant the highest frequency at which the ionosphere above that station was refracting signal at 180°.

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Conflicts of interest

The author declares there is no conflict of interest.

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