URSI - RCRS 2022, IIT (Indore), India, 1 - 4 December, 2022

Study of Y-forking signatures in Ionogram traces observed at low-mid latitude Indian station, New Delhi: Ionosonde Observations.

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Abstract

In this study, we examined the pre- and post- signatures of earthquake events during the year 2020 that occurred over the vicinity of New Delhi, India ((28.6°N, 77.2°E, 19.2°N geomagnetic latitude, 42.4°N dip). Earthquakes with Richter scale magnitude of less than 4 is considered. We examined the manually scaled ionogram records and found a distortion of ionogram trace in the form of Y-forking i.e., 'Type A' anomaly of the trace at F-layer penetration frequency. This anomaly appeared over the station from 30 minutes to a few hours after the earthquake events. We also found notable characteristic signatures of travelling ionospheric disturbances (TIDs) following the earthquake events. Precursory signatures to earthquake were also observed atleast a week before these earthquake events where a maximum enhancement in deviation of F2 layer critical frequency (ΔfoF2) from quiet time ionospheric behaviour was found to be 5.16 MHz, observed 7 days before earthquake event and maximum enhancement in electron density was found to be more than 250%.

1. Introduction

Coupling between Lithospheric and ionospheric variations is mainly associated to Pre-Earthquake Ionospheric Anomalies (PEIAs). PEIAs are considered as Earthquake precursors mainly on the basis of Lithosphere Atmosphere Ionospheric Coupling (LAIC) models. The seismo-ionospheric effects in the F-layer of the ionosphere have been extensively studied in last two decade [1]. It has been reported that before the main shock of the earthquake, its effect can be observed over the preparing earthquake region (~1000 Km diameter) [2] from a few days to up to several minutes and the effects on ionosphere could be enhancing/depressing electron density increasing/diminishing of critical frequency (foF2), increasing electron temperature, changing total electron content (TEC) based on various parameters like earthquake's depth, location, magnitude and distance between its epicentre and ionosphere monitoring station [3, 4]. The ionospheric anomaly exhibits a characteristic of traveling ionospheric disturbances and is seen as a distortion of ionogram trace (Y-forking) [5].

2. Methodology

To examine the ionospheric response pre- and post- to earthquakes, we studied manually scaled data of F2 layer critical frequency (foF2) and F layer height (h'F) and ionogram traces from low-mid latitude Indian station, Delhi (28.6°N, 77.2°E, 19.2°N geomagnetic latitude, 42.4°N dip) to examine the ionospheric response pre- and post-earthquakes. These results were obtained utilising the Digisonde System which is located at CSIR-NPL in Delhi. The regular vertical sounding is carried out every 5 min round the clock, for a frequency range of 0.5–30 MHz and start, stop, and step size selectable to 1 kHz. The data are manually scaled using SAO-X software, to obtain foF2 and hmF2 values. To separate anomalous ionospheric variability from its day-to-day variability, we estimated the difference in F2 layer critical frequency and peak height from that of normal quiet time behaviour to obtain deviation in these parameters (foF2, hmF2. The whole analysis is done in Universal Time (UT). The software SAO explorer is used to extract a recorded ionogram trace every 5 minutes round the clock. Indices such as the geomagnetic storm index (Kp), and solar radio F10.7 flux were obtained from the NASA/Goddard website http://omniweb.gsfc.nasa.gov/form/dx1.html to investigate the background space weather conditions.

3. Observations and Analysis

We have examined ionospheric response to the following seven earthquake events with magnitude less than 4 on Richter scale, affecting low-mid latitude Indian station, Delhi, during the year 2020: (1) 10 May 2020 and 28 May 2020, (4) 18 June 2020, (5) 20 June 2020, (6) 24 June 2020, (7) 26 June 2020 (8) 08 and 25 December 2020. With similar month events grouped into one section as is discussed below in section 3.1 for June (18, 20, 24, 26 June events) and section 3.3 for May (10 and 28 May events).

3.1. Earthquake Event of 08 and 25 December 2020

Pre-Earthquake Analysis: On December 8, 2020, at 1857 UT, a magnitude 3.3 earthquake struck 38 kilometres east

of Rohtak, Haryana, India. The distance of the observing station, Delhi (62 km), was well within the radius of the earthquake preparation zone (26 km) for this earthquake and another earthquake of magnitude 2.3 happened with epicentre in New Delhi itself on 25 December 2020, as shown in Table 1. The earthquake occurred on 8 December at 0027 LT (1857 UT of 07th December) and on 25 December 2020 at 0502 LT (2332 UT of 24th December). Figures 1a–1d show the background space weather conditions as well as ionospheric F2 region variations during this event. Figure 1a shows the interplanetary

Table 1. Details of Earthquake Events Affecting Low-Mid Latitude Indian Station, Delhi, During the Year 2020 along with the ionogram records post-earthquake.

Date (LT)	Earthquake (UT)	Lat. (°N), Lon. (°E)	Magnitude (M)	Depth	Location	Y-forked Ionogram (UT)
14-01-2020 23:35	17:05:20	29.6,76.4	3	10	kurukshetra, Haryana	15-01-2020 14:45-15:00
10-05-2020 13:45	08:15:29	28.8,77.2	3.4	5	New Delhi	16:55 - 17:10
28-05-2020 16:24	10:54:30	28.4,77.4	2.5	10	Faridabad, Haryana	00:50-01:05
18-06-2020 04:18	17-06-2020 22:48:30	28.81,76.73	2.1	5	Rohtak, Haryana	16:35-16:50, 23:45-00:05
20-06-2020 01:52	19-06-2020 20:22:15	28.76,76.81	1.8	10	Rohtak, Haryana	17:00- 17:25
24-06-2020 12:58	07:28:13	28.83,76.75	2.8	5	Rohtak, Haryana	08:10-08:45
26-06-2020 15:32	10:02:36	28.83,76.77	2.8	10	Rohtak, Haryana	16:55-17:10
08-08-2020 16:48	11:18:37	28.16,77.24	2.1	5	Faridabad, Haryana	09-08-2020 00:00-00:15
06-11-2020 16:39	11:09:18	28.78,76.78	2.1	5	Rohtak, Haryana	18:45-19:00
08-12-2020 00:27	07-12-2020 18:57:44	28.96,76.99	3.3	14	Rohtak, Haryana	01:00-01:15, 21:45-22:05
25-12-2020 05:02	24-12-2020 23:32:19	28.70,77.04	2.3	5	New Delhi	14:30-14:45

[a]Observing station lies inside the earthquake preparation zone as given by Dobrovolsky et al. [1979].

magnetic field's Z component (BZ) ≥ -6.8 nanotesla and solar wind speed (VSW) under 634 km/s marked in blue, while Figure 1b shows the global geomagnetic storm index (Kp) < 4 and F10.7 flux in sfu (solar flux unit, 1 SFU = 1022 W/m2 /Hz) well within 77 – 113 sfu, marked in blue from November 24 to January 01, 2021. (14 days before first event and 7 days after second earthquake event marked by red line). The solar and geomagnetic disturbances in Figures 1a and 1b are quiet and steady before to the earthquake, providing a perfect scenario for investigating any unusual ionospheric variation caused by this event.

To examine the ionospheric response of this earthquake event, we present in Figure 1c, the F2 layer critical frequency (foF2) for 39 days, covering the 14 days before and 7 days after period for the occurrence of both earthquake events, i.e., from 24 November to 01 January 2021, as a function of time (UT). It can be noticed that enhanced foF2 values are seen around 03 to 06 UT followed by more pronounced foF2 values (~10MHz) lasting for nearly 2 h at around 04 to 6 UT on 2 December 2020, the precursor day (marked by circle), 6 days prior the 8th December earthquake and around 04 to 08 UT for 25 December earthquake with pronounced foF2 values 9.2 MHz on 24 December (Precursor day) and ~9 MHz on 22 and 20 December (Precursor day) i.e., 1, 3 and 5 days prior the event, marked by circle. This enhanced foF2 variation, to contemplate as anomalous, requires the ionospheric day-to-day variability to be removed from the observed foF2 values. In view of this, in **Figure 1d**, we present the plot of deviation of F2 layer critical frequency (ΔfoF2) from quiet time ionospheric behaviour during this period. It can be seen from this figure that a prominent enhancement, as large as ~3 MHz, is noticed on 2 December between 04 to 06 UT and 12 UT, leading to ~104% increase in the peak electron density at these times. and 2.5 MHz as noticed at 07 to 09 UT on 22 and 20 December, lead to 93% and 113% increase in electron density. The most enhancement and depression in electron density during this period was 127% and 63% respectively. The maximum foF2 variation during this period was ~10 MHz as was seen in Figure 1c. It can also be seen that enhancements not as prominent as on 2 December are also observed on 28 and 30 November, 4, 6, 11, 13 and 31 December. It is to be pointed out that there was a 4.2 magnitude earthquake on 17 December 2020 with epicenter at Gurugram Haryana, 31.5 Km distant from the observing station Delhi. Since the background space weather conditions as shown in Figures 1a and 1b were quiet during these periods of foF2 variations, they could be due to this 4.2 magnitude impending earthquake. It is to be observed that prominent variations in foF2 are observed a week prior to the earthquake event of 8 and 25 December 2020.

To better identify, visualize, and for keeping analogy with other reports, in Figure 2, we present (a) hourly Dst variation, (b) ΔfoF2 variation (c) variation in F layer height (Δh'F) from quiet time median and (d) percentage change in electron density from 24 November to 31 December 2020. It can be seen that the minimum Dst index was -13 nT at 10 UT on 8 December and -22 nT at 09 UT on 22 December, indicating quiet geomagnetic condition during this period. It can be clearly seen from the ΔfoF2 plot in Figure 2b that the prominent enhancement of 3 MHz took place on 2 December (0400 UT) and 2.8 MHz on 20 December (0605 UT), as also observed in Figure 1d. This enhanced ionospheric F2 layer behaviour indicates toward a precursory signal to the earthquake which appeared at ionospheric height 6 days prior, resulting in a corresponding increase in electron density as high as ~127% as can be seen in Figure 2d. A little variation of 2.6 MHz as compared to 2 December was also observed on 6 December and -2.17 MHz depression was observed on 21 December, as is also depicted in Figure 2b.

Further, instances of foF2 variations were also observed after the earthquake events, enhancements (maximum of ~43%) and depressions (maximum of ~41%) on 9 December and depressions (maximum of ~55%) on 27 December. It is seen that at times when there was a maximum enhancement in ΔfoF2 (on 2 December), when precursor is seen, no prominent variation (±50 km) in Δh'F was noticed while a ~133 Km variation in height is observed on 24 December (precursor day) for 25 December earthquake as can be seen in Figure 2c. However, enhancements of the order ~117 km were observed in the evening time of 3 December and depression of the order of ~117 Km were observed on a few occasions (e.g., in the evening time of 4, 5 and 7 December) which were not

followed by significant variations in ΔfoF2. Further, observations a week after the 25 December event contains only six days data due to lack of availability of data for 1 January 2021.

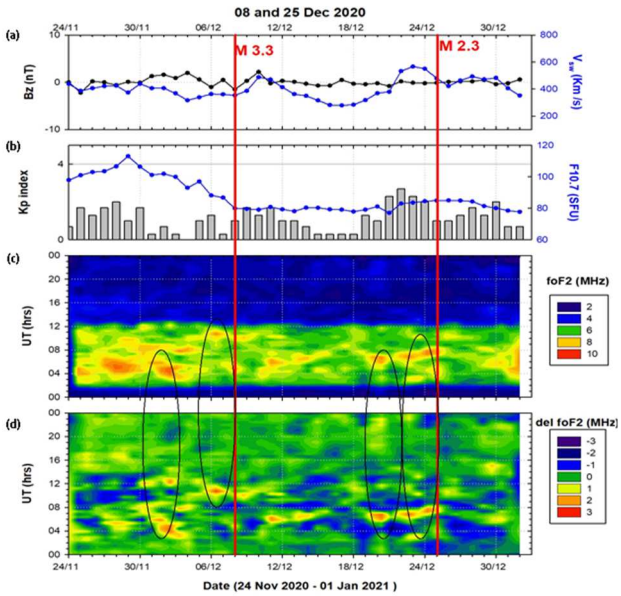

Figure 1. Plots of solar, geomagnetic, and ionospheric parameters from 24 November to 01 January 2021, 14 days before and 07 days after the earthquake event of 8 and 25 December 2020, showing (a) daily interplanetary magnetic field's Z component (B_z) in nanotesla and solar wind speed (VSW) in km/s in blue; (b) daily global geomagnetic storm index (Kp) and solar F10.7 flux in sfu (solar flux unit, 1 sfu = 10^22 W/m2 /Hz) given in blue; (c) variation in F2 layer critical frequency (foF2) in MHz at low-mid latitude Indian station, Delhi, observed every 5 min; and (d) deviation (ΔfoF2) in MHz obtained by subtracting foF2 values from the median of 10 quiet days.

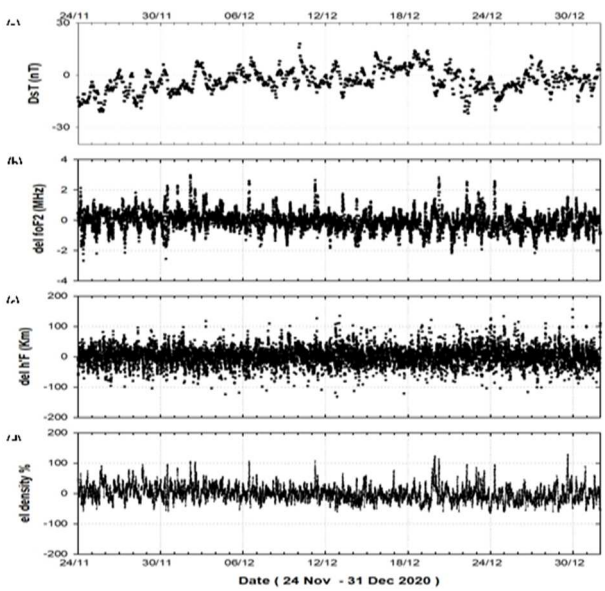

Figure 2. Plots of (a) hourly variation of disturbance storm time index (Dst) in nanotesla from 2 to 8 December 2020 and from 19 to 25 December 2020; (b) deviation in F2 layer critical frequency (ΔfoF2) from its quiet day median in megahertz from 2 to 8 December 2020 and from 19 to 25 December 2020; (c) deviation in F layer peak height (Δh'F) from its quiet day median in kilometer, from 2 to 8 December 2020 and from 19 to 25 December 2020; and (d) percentage variation in electron density from 2 to 8 December 2020 and from 19 to 25 December 2020.

Post-Earthquake Analysis: To check Post-earthquake Ionospheric Anomalies, we have considered ionogram traces and distortion seen in the trace. Figure 3 shows tracing of ionogram records post-earthquake event of 08 December 2020. The Disturbances in the ionospheric plasma associated with the earthquake events mostly (but not always) manifested themselves in the data as a distinct Y-forking of the ionogram traces.

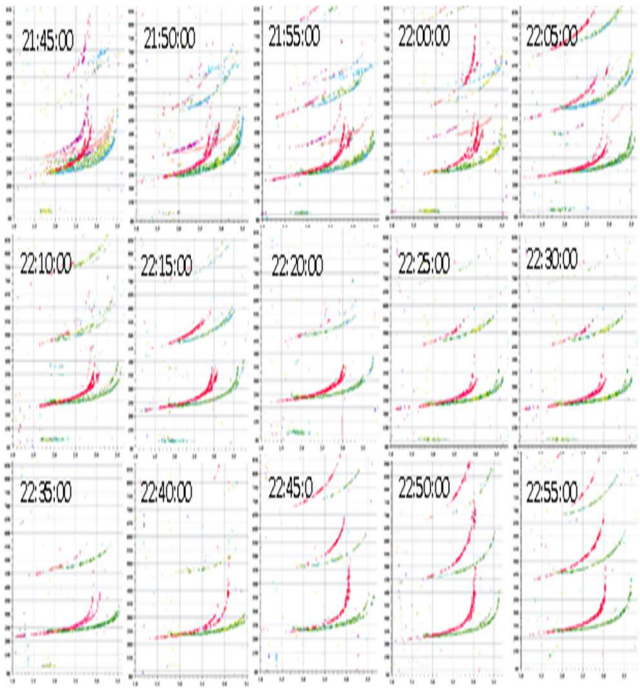

Figure 3. Sequential Y- forked Ionograms (2145 – 2255 UT) at the NPL, Delhi station, post the earthquake event of 08 December 2020 at 0027 UT. In all of the above ionograms, the x axis is the sounding frequency (MHz), and the y axis is the virtual height (km). The ionogram traces in red color are those of O-mode polarization, and the traces in green color are those of X-mode polarization.

Similar observations were also found for other event dates as shown in Table 2.

Table 2. Summary of the Observations of a Week Prior to the Six Earthquake Events During the Year 2020 at Low-Mid Latitude Indian Station, Delhi.

		f_oF_2 (MHz)		ΔfoF2 (MHz)			Electron Density Variation (%)	
S.No.	Earthquake Event	Max	Min	Max	Min	Anomaly seen prior to the Event (Days)	Max Enhancement	Max Depression
1	14 January	7.87	1.47	2.9	1.35	3,5	165	66
2	10 and 28 May	10.45	1.62	4.9	3.82	9 and 3	266	75
3	18, 20, 24 and 26 June	9.47	1.87	3.9	3.02	2, 2, 4 and 2	196	64
4	08 August	10.575	2.55	3.33	3.18	2,4	132	76
5	06 November	12.01	2	5.16	2.8	2,7	229	55
6	08 and 25 Dec	9.9	1.57	2.9	2.54	2 & 6 and 1 & 3	122	64

5. Results

There are perceptible ionospheric perturbations before the earthquake events, indicating the possibility of seismo-ionospheric coupling. These perturbations appear as enhancement and depression in foF2, consequential to the maximum peak electron density variation of ~266%.
Significant enhancement in the F2 region critical frequency was observed 3–4 days before the earthquake. These observations are in accordance with the earlier results reported at the same station by Gupta et al. [2017] for five major earthquakes affecting the Indian region ionosphere. As far as the F layer height (h'F) is concerned, there are neither prominent variations nor no well-defined structured patterns in F layer height that can be considered a signature for precursor to earthquake events.
Perturbed ionogram traces varies from 15 minutes to about 35 minutes in duration. These perturbations are seemed to be brought about by TID's.
Similar perturbed ionogram traces were observed at other Ionospheric monitoring stations, Ahemdabad and Trivandrum.

6. Acknowledgements

The authors are thankful to Dr Chhemendra Sharma and Dr T. K. Mandal, Head, Environmental Sciences and Biomedical Metrology Division, CSIR-NPL, for supporting this work. One of the authors, Arti Bhardwaj, is thankful to UGC for granting Senior Research Fellowship. Delhi Digisonde data can be obtained from the authors. Authors are thankful to NASA Goddard Data centre for making background space weather conditions and National Centre for Seismology for making Earthquake data available. The authors are grateful to CSIR for providing the facilities.

7. References

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