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Sources of Ionospheric F_2 region variability at low-mid latitude Indian station, Delhi

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Abstract

Analysis of ionospheric F_2 region critical frequency (f_oF_2) obtained by using Digisonde at low-mid latitude Indian station, Delhi (28.6°N, 77.2°E), is carried out for the period of January 2015 to April 2018 to examine the effect of space weather, meteorological and lithospheric events. Total 27 cases are identified such that deviation of f_oF_2 from quiet median, $|\Delta f_oF_2| \geq 5$ MHz. Such large anomalous variations are found when it can/cannot be attributed to a known phenomenon either exclusively or in coalesce. Comparable electron density variations are observed for events originated both from "above" and "below" the ionosphere, thus suggesting inclusion of contribution of sudden stratospheric warming and earthquake, apart from space weather agents, to the ionospheric models. Two out of 27 cases exhibit large f_oF_2 variations that are not attributed to any event, indicating towards possibility of an unidentifiable source and further adding to the complexity to predict ionosphere. Simultaneity between earthquake and geomagnetic storm indicates towards possibility of solar-terrestrial triggering of earthquakes. Perceptible pre-earthquake f_oF_2 perturbations 3-4 days prior were observed, however, as no two earthquake events are same but are a function of earthquake strength, depth and distance from the epicenter, the dominating factor in deciding the response can only be identified if their individual effect can separately be simulated.

1 Introduction

With our ever-growing technological dependence on satellites for many applications and the growing complexity and interdependence of the electrical grids, it is becoming increasingly important to understand the solar, ionospheric and atmospheric processes that affect the performance of these vital technical installations and services. The largest contributions to signal delays and GPS inaccuracies are caused by variations in the distribution and concentration of free electrons and ions in the ionosphere. Improving our understanding of this complex and highly variable ionized medium is of great importance. Decades of research have established ionosphere's complex and often elusive nature. It is influenced from above by solar flares, geomagnetic storms, coronal mass ejections, etc. [1], and from below by meteorological processes like Sudden Stratospheric Warming (SSW) [2] and lithospheric processes like earthquake [3]. The ionospheric response to each of these events individually has been reported from time to time, however, there are a very few studies which examine the combined effect of these events on ionosphere. For examining ionospheric variability and its effects at a particular latitude/longitude, it will be important to examine its plausible sources like solar driven, meteorological and lithospheric phenomena, either in coalesce or exclusively. In this study, we address (a) whether observed large ionospheric variability can be attributed to a known phenomenon, (b) what are the efficacies of solar driven and lower atmospheric phenomena, and (c) whether ionospheric variability observed before earthquake can be used as a precursory signature.

2 Methodology

The ionospheric variability is manifested in F_2 region response and is reflected in perturbations of F_2 layer critical frequency, f_oF_2. Manually scaled f_oF_2 data obtained from Digisonde System (Lowell Digisonde International, Lowell, USA) installed at low-mid latitude Indian station, Delhi (28.6°N, 77.2°E, 19.2°N geomagnetic latitude, 42.4°N dip) is used for the period of 3 years and 4 months (January 2015 to April 2018). To segregate anomalous ionospheric variability from its day-to-day variability, the difference of f_oF_2 from normal quiet time behavior, characterized by averaging 10 international quiet days (IQDs) of that particular month, is calculated to obtain Δf_oF_2. The variations in Δf_oF_2 are considered anomalous if $|\Delta f_oF_2| \geq 5$ MHz. The instances of such enhancements/depressions are checked for coinciding in concurrence with any event, be it space weather, meteorological or lithospheric event.

To examine the solar and space weather conditions, daily $F_{10.7}$ flux and hourly D_{st} have been taken from NASA/Goddard website http://omniweb.gsfc.nasa.gov/form/dx1.html. To check the occurrence of solar flares, the information about real time X-ray solar flux is taken from http://www.tesis.lebedev.ru/en/sun_flares.html?m=7&d=28&y=2014. The stratospheric summary is provided by http://acdb-ext.gsfc.nasa.gov/Data_services/met/ann_data.html, while earthquake information is taken from http://www.imd.gov.in/pages/earthquake_prelim.php. For this study, strong geomagnetic storms ($D_{st} \leq$ -90 nT) with the main or the recovery phase coinciding with f_oF_2

variations are considered. Those X and M class solar flares are taken into account that occur on the day of anomalous f_oF_2 variation. Earthquake events with Delhi in the earthquake preparation zone and occurring within one week after the variation are considered. The ionospheric variability is quantified as a percentage change in electron density, which is calculated as,

$$N_e = \left(\frac{{(f_0F_2)_{obs}}^2 - {(f_0F_2)_{quiet}}^2}{{(f_0F_2)_{quiet}}^2}\right) \times 100 \qquad (1)$$

where, $(f_oF_2)_{obs}$ is the f_oF_2 values observed every 15 minutes and $(f_oF_2)_{quiet}$ is the quiet median for each UT.

3 Observation

Out of 1209 days from January 2015 to April 2018, a total of 27 days are found with $\Delta f_oF_2 \geq 5$ MHz or $\Delta f_oF_2 \leq -5$ MHz. This comprises of 2.2% of the total days. It is to be noted that the solar activity decreases from 2015 to 2018. Coinciding with all such variations, the time of occurrence of concurrent geomagnetic storm, solar flare, earthquake, sudden stratospheric warming period, total lunar eclipse, if any, is noted. We find that these ionospheric variations are or can be linked with three (earthquake, SSW and flare, or earthquake, flare and storm), two (earthquake SSW, earthquake storm, earthquake flare, SSW flare, flare storm), one (SSW or earthquake) or with no event, as shown in Table 1. Maximum enhancement in electron density is observed to be 626.8% when two events (storm and earthquake) occurred and minimum enhancement of 126.6% in electron density is observed to be during SSW period of 2015. However, there is only one instance when f_oF_2 showed depression corresponding to 66.8% decrease in electron density. This is observed for the first superstorm of 24th solar cycle, St. Patrick's Day storm. For each of the three categories in Table 1, the maximum electron density enhancement is observed when an earthquake event is impending.

4 Discussion

A feature to be noted in this study is anomalous Δf_oF_2 variations resulting in electron density enhancements during two of these 27 cases which were not influenced by any event, with variations that are comparable with variations that are attributed to one or more events. This indicates towards possibility of an "unknown phenomena" and further add to the complexity depicted by ionosphere. Analysis of coalesce and individual effect of these events have shown that the variability is not generally higher when conjunction of event occurred which is normally expected as the effect due to individual phenomena showed an enhancement. That is, depression is not normally observed which can counteract the effect. Apart from the two cases of January 20, 2016 and April 11, 2001, electron density variations observed for individual events originated both from "above" and "below" are found to be comparable, i.e., maximum enhancement prior to an earthquake event is observed to be ~298%, during SSW is ~273%, while during space weather events (storm and flare) is ~220%. As large variabilities in ionospheric F_2 region are observed because of meteorological phenomena of SSW and lithospheric phenomena of earthquake, it is suggested that the effect of these variabilities should be included in the models used to predict ionospheric conditions. Above analysis is carried out by way of establishing and attributing an event/s to cases where ionospheric variability was high ($|\Delta f_oF_2| \geq 5$ MHz). Considering holistic approach, cases are examined when major event/s occurred and were known, however, with no to little accountable f_oF_2 variations, such that Δf_oF_2 remain less than ±5 MHz, and therefore are not included in 27 cases of Table 1. A total of 41 such cases are identified during the period of our analysis. It is suggested that the occurrence of large F_2 region variability is not definite even in the presence of an event, nor the occurrence of such events warrant the F_2 region to exhibit large variations. This further suggests ionosphere to be complex and elusive.

Earthquake event seems to be associated with both storm and SSW events for the cases when $|\Delta f_oF_2| \geq 5$ MHz. This association of earthquake event with storm points towards the possibility of solar – terrestrial triggering of earthquakes. However, it is new and interesting to note a large occurrence simultaneity between SSW event and seismicity as it is generally believed that there is a vertical coupling between the lower and upper atmosphere during SSW event and this coupling is thought to be due to nonlinear interaction of quasi-stationary planetary waves and migrating tides [5]. The maximum electron density enhancement was observed for the cases where an earthquake event was associated, particularly 3-4 days prior to seismic activity, e.g. as shown in Figure 1. We are of the notion that the observed variations in f_oF_2 due to earthquake is a function of earthquake strength, depth and the distance from the epicenter [3]. As no two earthquake events are same, the dominating factor in deciding the ionospheric response to these earthquake events can only be identified if the individual effect of each parameter can separately be simulated.

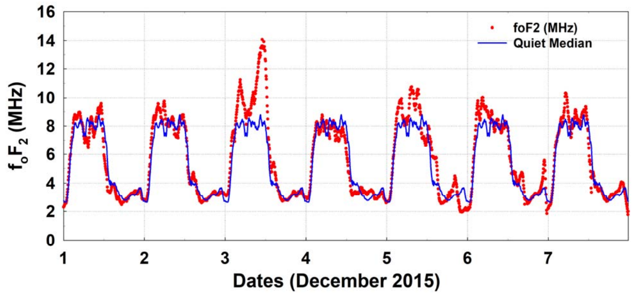

Figure 1. f_oF_2 variability resulting in ~207% enhancement in electron density is observed at ionospheric observing station Delhi on December 3, 2015, 4 days prior to earthquake event of December 7, 2015.

Unlike solar and geomagnetic conditions, there are no indices to represent daily changes in neutral atmosphere to explain day-to-day and hour-to-hour variability of the

Table 1. Summary of $|\Delta f_oF_2| \geq 5$ MHz variation in concurrence with various events.

S.No.	Date	Duration (UT)	Max Δf_oF_2 (MHz)	Min Δf_oF_2 (MHz)	Event	Change in electron density (%)
THREE EVENTS						
1.	21.12.15	04:25 – 04:30	5.1	-	Storm (D_{st} = -155 nT – 20 Dec – 23:00) Flare (M2.8 – 01:03) Earthquake (M6.5 Hindukush – 25 Dec – 19:14, 186 km, 1005 km)	169.6
2.	22.12.15	11:20 – 12:25	5.8	5	Storm (D_{st} = -155 nT – 20 Dec – 23:00) Flare (M1.6 – 03:34) Earthquake (M6.5 Hindukush – 25 Dec – 19:14, 186 km, 1005 km)	226.2
3.	14.2.16	11:15 – 13:45	8.4	5.2	SSW Period (ΔT = 1.6 K) Flare (M1.0 – 19:26) Earthquake (M5.7 Hindukush – 21 Feb – 09:12, 177 km, 1005 km)	358.9
TWO EVENTS						
1.	10.1.15	07:30 – 11:25	6.6	5	SSW Period (ΔT = 6.5 K) Earthquake (M3.3 Sonipat – 14 Jan – 15:49, 5 km, 33 km)	209.4
2.	12.1.15	07:25 – 10:10	6.3	5	SSW Period (ΔT = 7.4 K) Earthquake (M3.3 Sonipat – 14 Jan – 15:49, 5 km, 33 km)	199.0
3.	29.1.15	13:00	5.03	-	SSW Period (ΔT = 3.1 K) Flare (M2.1 – 11:42)	242.9
4.	18.3.15	10:00 – 10:45 13:40	-5.5	-5.1	Storm (D_{st} = -222 nT – 17 Mar – 23:00) Earthquake (M5.1 Hindukush – 21 Mar – 17:44, 86 km, 1005 km)	-66.8
5.	17.8.15	09:10	5	-	Storm (D_{st} = -84 nT – 16 Aug – 08:00) Earthquake (M5.0 Nepal – 23 Aug – 09:02, 10 km, 875 km)	131.9
6.	8.11.15	09:05 – 09:35	5.3	5	Storm (D_{st} = -89 nT – 7 Nov – 07:00) Earthquake (M6.0 Nicobar – 8 Nov – 16:47, 10 km, 2166 km; M3.0 Pithoragarh – 13 Nov – 07:44, 10 km, 318 km)	151.1
7.	20.1.16	13:15 – 15:00	7	5.3	Storm (D_{st} = -93 nT – 20 Jan – 17:00) Earthquake (M5.1 Hindukush – 23 Jan – 04:54, 50 km, 1005 km; M5.4 Hindukush – 26 Jan – 23:19, 250 km, 1005 km)	626.8
8.	14.10.16	04:30 – 05:00	6.3	5.3	Storm (D_{st} = -104 nT – 13 Oct – 23:00) Earthquake (M3.3 Pithoragarh – 14 Oct – 02:01, 10 km, 318 km; M4.0 India Nepal Border – 17 Oct – 00:30, 10 km, 875 km; M5.4 Afghan Taji Border – 20 Oct – 00:39, 102 km, 1105 km)	245.9
9.	7.9.17	11:15	5.4	-	Flare (X1.3 – 14:36) Earthquake (M5.0 Afghan Taji Border – 7 Sept - 11:10, 65 km, 1105 km)	170.8
*10.	9.9.17	04:15	5.3	-	Storm (D_{st} = -124 nT – 8 Sept – 02:00) Flare (M3.7 – 11:04; X8.2 – 10 Sept)	220.4
ONE EVENT						
1.	5.1.15	03:45 – 03:50	5.09	5.04	SSW Period (ΔT = 22.8 K)	154.0
2.	8.2.15	09:50 – 10:50	5.4	5.1	SSW Period (ΔT = 11 K)	126.6
3.	15.5.15	08:35 – 12:10	5.3	5	Earthquake (M5.0 Nepal -15 May - 01:42, 10 km, 875km; M5.7 Nepal - 16 May - 11:34, 10 km, 875km; M5.3 Taji – Afghan Border - 20 May –03:31, 9 km, 1105 km)	141.0
4.	19.11.15	12:25	5.1	-	Earthquake (M6.0 Hindukush – 22 Nov – 18:16, 80 km, 1005 km)	178.7

*5.	3.12.15	10:40 – 11:50	6	5.1	Earthquake (M2.9 Rohtak – 6 Dec – 12:35, 5 km, 52 km; M7.0 Tajikistan – 7 Dec – 07:50, 25 km, 1105 km)	207.2
6.	12.1.16	10:30	5.4	-	Earthquake (M5.8 Hindukush - 12 Jan - 20:04, 220 km, 1005 km)	207.2
7.	23.2.16	08:15 – 09:00	5.9	5.01	SSW Period (ΔT = 9.7 K)	178.1
8.	4.9.16	08:45 – 09:00	5.1	5	Earthquake (M4.1 Jhajjar – 10 Sept – 15:27, 10 km, 41km	160.4
9.	2.7.17	09:30 – 11:15	6	5	Earthquake (M5.2 J&K – 8 July – 10:12, 10 km, 686 km)	298.2
10.	14.10.17	03:15 – 03:30	5.6	5.5	Earthquake (M4.7 J&K – 19 Oct – 01:10, 10 km, 645 km)	219.2
11.	15.2.18	07:45 – 08:15	5.5	5.1	SSW Period (ΔT = 24.7 K)	243.6
*12.	21.2.18	07:30 – 09:00	6.1	5.1	SSW Period (ΔT = 15.7 K)	273.5
NO EVENT						
1.	28.7.17	11:15	5.4	-	-	313.5
2.	3.101.17	13:45	5.1	-	-	398.1

*International Quiet Day (IQD)
Note: Earthquake (Magnitude, Epicentre, Date, Time, Depth, Distance from Delhi), SSW period (Stratospheric Temperature Anomaly), storm (D_{st}, Date, Time), Flare (Class, Time).

ionospheric F_2 region. Further, no two naturally occurring phenomena are same (of same strength). The problem further gets complicated owing to simultaneity of these events. These problems of multi-variants can only be tackled by simulating lab models and artefacts, and analysing each parameter in a controlled environment.

5 Conclusion

The conclusions of our analysis of f_oF_2 variations obtained from Digisonde installed at low-mid latitude Indian station Delhi, during the period of January 2015 to April 2018, are:

i. Instances of large ionospheric variabilities is observed where we can't associate an event. This suggests ionosphere to be quite complex and elusive.
ii. Comparable electron density variations due to events originating both from below (SSW and earthquake) and above (space weather), suggesting inclusion of their contributions in ionospheric models.
iii. Simultaneity between SSW and earthquake events is "new" and worth reporting. Simultaneity between earthquake and geomagnetic storm point towards the possibility of solar-terrestrial triggering of earthquakes. Considering all events with no constraint on $|\Delta f_oF_2|$ indicates towards non-simultaneity in events.
iv. Perceptible pre-earthquake f_oF_2 perturbations 3-4 days prior were observed, however, as no two earthquake events are same but are a function of earthquake strength, depth and distance from the epicenter, the dominating factor in deciding the response can only be identified if their individual effect can separately be simulated.

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