F2 Region Response to the Magnetic Storm of January 10, 1976 at American Sector

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This paper attempts to study the F2 region response to an intense (Dst = -158nT) geomagnetic storm of January 10, 1976 using the critical frequency foF2 and using the data obtained from ionosonde stations in the American sector of the world. The stations were classified into high, middle and low latitudes, respectively. To analyze the behaviour of the F2 region, we employed the parameter D(foF2), which is the normalized deviation of the critical frequency foF2 from the reference. From our analysis, it was observed that (i) there is an absence of the positive ionospheric storm effects at high and mid latitudes on the dayside during the initial phase of the storm, (ii) there is a simultaneous existence of the negative storm at the high and the middle latitudes, and (iii) there is an occurrence of strong positive phase at the low latitude station.

However, this observed simultaneous depletion of foF2 at high and middle latitudes revealed that the depletion of the F2 region plasma density is due to changes in the neutral wind produced predominantly by the Joule heating in the aurora zone. Hence the F2 region response during the magnetic activity of January 10, 1976 at the American sector of the world lacked simultaneity as the depression does not extend to low latitude.

1. Introduction

According to [1], the F2 region response to a geomagnetic storm, usually called an ionospheric storm, is rather a complicated event. This is because of its so called positive and negative phases, which have very complicated spatial and temporal behaviour. However, a significant progress in understanding this behaviour has shown that during a geomagnetic disturbance, there is an input of energy into the polar ionosphere that changes the thermospheric concentration of the F2 region. The conflict between the storm-induced circulation and the regular one determines the spatial distribution of negative and positive phases in various seasons [2, 3]. Meanwhile, there are still some unsolved problems. According to [1], two of the acute problems are the appearance of positive storm before the beginning of a geomagnetic disturbance in the mid-latitudes and the strong negative phase experienced at the equator. To study these phenomena, we have analyzed the data made available to us from the global network of ionosonde stations obtained during the intense geomagnetic storm event of January 10, 1976 at the American sector of the world.

Moreover, while negative phases are almost always observed at high latitudes and nearly as often as positive phases at middle latitudes, positive phases tend to occur at middle and low latitudes. As for the seasonal preference, negative phases dominate in all seasons except in the winter when positive phases are more possible. However, according to [4] and [5], the positive phase in most cases (90%) is observed at equatorial latitudes during magnetic disturbances. But during prominent disturbances, negative phase may also be observed [5, 6].

Huang [7] emphasized in his work that Ionospheric plasma density is determined mainly by solar photo-ionization, neutral composition and winds, and plasma diffusion during magnetic quiet periods, which in its turn causes large disturbances in the F2 region plasma parameters. These electron densities can significantly be increased or decreased, which are termed positive or negative storm effects, respectively.

2. Data and method of analysis

The ionospheric data used in this study consists of hourly values of the F layer critical frequency foF2 obtained from some of the National Geophysical Data Center's SPIDR (Space Physics Interactive Data Research), a network of ionosonde stations located in the American sector of the world: Argentine Island (65.2^0N), Churchill (59.0^0N), Rostov (47.2^0N), Ottawa (45.4^0N), Boulder (40.0^0N) and Huancayo (12.0^0N). These stations are listed in Table 1.

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Table 1: American Sector Ionosonde Stations

STATION	GEOGRAPHIC LATITUDE (ϕ)	CO-ORDINATE LONGITUDE (λ)
Argentine Island	65.2^0N	295.7^0E
Churchill	59.0^0N	265.8^0E
Rostov	47.2^0N	269.6^0E
Ottawa	45.4^0N	284.1^0E
Boulder	40.0^0N	254.7^0E
Huancayo	12.0^0N	284.4^0E

The F layer critical frequency foF2 is used because of its direct relationship with the F layer peak electron density NmF2 (which is a measure of positive or negative storm effects through its significant increases or decreases about the mean value respectively), i.e.,

$$foF2\ (Hz) = 9.0 \times \sqrt{[NmF2]}\ (m^{-3}) \qquad (1)$$

The present study is concerned with variations in foF2 due to the intense geomagnetic storm of January 10, 1976 at all latitudes (i.e., high, middle and low). However, the F2 region response to a geomagnetic storm is most conveniently described in terms of the normalized deviations of the critical frequency foF2 from the reference, D(foF2) [8], where

$$D(foF2) = [foF2 - (foF2)ave] / (foF2)ave \qquad (2)$$

Hence the data under analysis consists of D(foF2) of respective hourly values of foF2 on January 5-12, 1976. The reference for each hour is the average value of foF2 for that hour calculated from the five quiet days in January 5-9, 1976, preceding the storm, i.e.,

$$\left.\begin{aligned} D(foF2)_1 &= \frac{(foF2)\text{ on Jan. 10} - (foF2)\text{ave. of Jan. 5-9 values}}{(foF2)\text{ave. of Jan. 5-9 values}} \\ D(foF2)_2 &= \frac{(foF2)\text{ on Jan. 11} - (foF2)\text{ave. of Jan. 5-9 values}}{(foF2)\text{ave. of Jan. 5-9 values}} \\ D(foF2)_3 &= \frac{(foF2)\text{ on Jan. 12} - (foF2)\text{ave. of Jan. 5-9 values}}{(foF2)\text{ave. of Jan. 5-9 values}} \end{aligned}\right\} \qquad (3)$$

All values are on hourly basis, as summarized in Table 2. The use of D(foF2), the normalized deviations of the critical frequency rather than the critical frequency foF2 itself, provides a first-order correction for temporal, seasonal and solar cycle variations, so that geomagnetic storm effects are better identified. However, it should be noted that in the present analysis of D(foF2) variations, any change of more than 10% in amplitude indicates a variation [1], while a change of -30% and above would be regarded as intense or large ([7] and references therein).

3. Ionospheric response

Ionospheric F region electron density is determined mainly by photo-ionization, neutral composition and winds during geomagnetic quiet periods. However, during geomagnetic storms, ionospheric F region plasma parameters experience disturbances and in response, the electron density is either significantly enhanced or depleted resulting in a positive or negative ionospheric storm, respectively. In this paper, our primary interest lies, in part, in explaining the response of the F2 layer to the intense (Dst = -158nT) geomagnetic storm of January 10, 1976 (See Fig. 2 for Dst plot) mainly by considering its remarkable features.

Table 2: Computed normalized deviations of the critical frequency D(foF2) from the reference for January 10-12, 1976. [i.e., $D(foF2)_1$, $D(foF2)_2$ and $D(foF2)_3$ values for Jan. 10, 11 & 12, 1976 respectively] at American sector of the world.

Date	Time	Argentine Is.	Churchill	Rostov	Ottawa	Boulder	Huancayo
10-Jan.	0:00	-0.14	-0.20	0.20	-0.23	-0.15	0.07
10-Jan.	1:00	-0.15	-0.05	0.05	-0.22	-0.18	0.05
10-Jan.	2:00	-0.09	-0.16	0.14	-0.10	-0.05	0.26
10-Jan.	3:00	-0.12	-0.17	0.01	-0.08	-0.09	0.47
10-Jan.	4:00	-0.14	-0.13	-0.20	-0.06	-0.21	0.63
10-Jan.	5:00	-0.13	-0.13	-0.01	-0.01	-0.26	0.76
10-Jan.	6:00	-0.08	-0.07	-0.02	-0.02	-0.26	0.99
10-Jan.	7:00	-0.02	0.10	-0.16	-0.01	-0.32	
10-Jan.	8:00	0.03	0.10	-0.10	-0.08	0.05	
10-Jan.	9:00	0.10	-0.16	-0.16	-0.10	-0.34	-0.54
10-Jan.	10:00	0.13	-0.16	-0.10	-0.17	-0.36	-0.51
10-Jan.	11:00	-0.10	0.23	0.06	-0.14	-0.13	-0.04
10-Jan.	12:00	-0.05	0.06	-0.10	-0.18	-0.05	-0.03
10-Jan.	13:00	-0.04	0.06	-0.03	-0.12	-0.02	-0.06
10-Jan.	14:00	0.03	0.23	0.11	-0.12	0.07	0.04
10-Jan.	15:00	0.28	-0.18	0.01	-0.14	-0.03	-0.08
10-Jan.	16:00	0.23	-0.31	-0.17	0.02	0.12	-0.25
10-Jan.	17:00	0.37	-0.33	0.14	0.21	0.05	-0.13
10-Jan.	18:00	0.75	0.03	0.07	0.47	0.05	-0.04
10-Jan.	19:00	0.98	0.08	0.06	0.37	0.04	0.14
10-Jan.	20:00		0.12	0.04	0.31	0.03	0.02
10-Jan.	21:00		-0.28	-0.17	0.44	-0.05	-0.04
10-Jan.	22:00	0.37	-0.49	-0.21	0.55	-0.20	0.02
10-Jan.	23:00	-0.24	-0.28	-0.34	0.99	-0.01	-0.08
11-Jan.	0:00	-0.48	-0.26	-0.08		0.11	0.01
11-Jan.	1:00	-0.58	-0.28	-0.21		0.49	0.00
11-Jan.	2:00	-0.63	-0.24	-0.29			0.25
11-Jan.	3:00	-0.64	-0.25	-0.15	0.36	0.43	0.58
11-Jan.	4:00	-0.63	-0.22	0.07	0.44	0.58	0.61
11-Jan.	5:00	-0.60	-0.22	0.35	0.30	0.86	0.39
11-Jan.	6:00	-0.53	-0.33	-0.13	0.08	0.24	0.39
11-Jan.	7:00	-0.49	-0.21	0.25	-0.01	0.23	0.29
11-Jan.	8:00	-0.34	-0.21	0.31	-0.08	0.14	0.29
11-Jan.	9:00	-0.28	-0.19	0.12	-0.10	0.09	0.29
11-Jan.	10:00	-0.30	-0.19	0.24	-0.17	0.21	0.29
11-Jan.	11:00	-0.31	-0.17	0.02	-0.14	0.11	-0.04
11-Jan.	12:00	-0.20	-0.29	-0.04	0.47	-0.02	0.02
11-Jan.	13:00	-0.21	-0.29	-0.03	0.57	0.14	0.05
11-Jan.	14:00	-0.16	-0.17	-0.11	0.31	0.07	0.12
11-Jan.	15:00	-0.13	-0.18	0.40	0.14	0.06	0.18
11-Jan.	16:00	-0.14	-0.22	0.32	-0.02	0.16	0.05
11-Jan.	17:00	-0.14	-0.29	0.61	-0.03	0.31	0.02
11-Jan.	18:00	-0.01	-0.13	0.56	0.04	0.08	0.06
11-Jan.	19:00	-0.01	-0.15	0.44	-0.10	0.07	0.10
11-Jan.	20:00	-0.03	-0.20	0.36	-0.01	-0.10	0.00
11-Jan.	21:00	0.11	-0.10	0.38	-0.13	0.12	0.02
11-Jan.	22:00	0.02	0.00	0.31	-0.13	0.09	-0.07
11-Jan.	23:00	0.03	0.18	0.31	-0.26	0.13	-0.04
12-Jan.	0:00	-0.06			-0.16	0.06	0.00
12-Jan.	1:00	-0.18	-0.02	-0.35	-0.06	0.33	0.03
12-Jan.	2:00	-0.23	0.03	-0.29	0.00	-0.01	0.09
12-Jan.	3:00	-0.38	0.02	-0.27	0.07	0.04	0.31
12-Jan.	4:00	-0.51	0.06	-0.20	0.09	-0.17	0.09
12-Jan.	5:00	-0.50	0.06	0.13	0.15	-0.21	0.15
12-Jan.	6:00	-0.44	-0.10	0.11	0.13	-0.26	0.08
12-Jan.	7:00	-0.42	0.07	-0.08	0.15	-0.35	0.04
12-Jan.	8:00	-0.34	0.07	0.41	0.07	-0.38	0.04
12-Jan.	9:00	-0.30	0.10	0.01	0.04	-0.44	-0.05
12-Jan.	10:00	-0.33	0.10	0.08	-0.04	-0.36	-0.23
12-Jan.	11:00	-0.24	0.09	0.25	-0.01	-0.31	0.03
12-Jan.	12:00	-0.11	-0.06	0.00	0.16	-0.24	-0.02
12-Jan.	13:00	-0.13	-0.06	-0.05	0.02	-0.28	-0.08
12-Jan.	14:00	-0.12	0.09	-0.16	-0.03	-0.20	0.00
12-Jan.	15:00	-0.09	0.08	0.01	-0.12	0.00	-0.08
12-Jan.	16:00	-0.09	-0.17	0.01	-0.08	-0.03	-0.12
12-Jan.	17:00	-0.12	-0.24	0.23	-0.09	0.08	-0.06
12-Jan.	18:00	0.01	-0.11	-0.30	-0.07	0.02	0.05
12-Jan.	19:00	-0.03	-0.06	-0.24	-0.23	-0.04	0.10
12-Jan.	20:00	-0.03	-0.05	-0.25	-0.12	0.11	0.00
12-Jan.	21:00	0.00	-0.10	-0.20	-0.11	0.18	0.02
12-Jan.	22:00	-0.06	-0.10	-0.14	-0.07	-0.04	0.02
12-Jan.	23:00	-0.18	0.06	-0.14	-0.15	-0.09	0.07

The D(foF2) variations at the American sector are shown in Fig. 1 and the stations are listed in Table 1.

It should be noted that in Fig. 1, the plot of the first January 10 to the second January 10 represents 1200UT hours, from second January 10 to the first January 11 represents another 12 hours thus making it 2400UT hours so that first January 10 to first January 11 stands for 2400UT hours and so on for the remaining part of the plot. Also, the maximum percentage value (100%) of D(foF2) is 1, so that an enhancement of 0.40 will be 40% rise from the reference level.

From the plots of Fig. 1(a), (b), and (c), it was observed that with the exception of Huancayo, a low latitude station, which experienced an enhancement in the D(foF2) variation, all other stations recorded a depletion between 0000UT and 1200 on January 10. It was also observed that at all high and middle latitude stations (except Huancayo), there was no immediate effect on foF2 in the ionosphere following storm commencement between 0000UT and 0600UT on January 10. This is because the depletion level from the reference is not up to 20%. However, between 1400UT and 1800UT on January 10, there was an enhancement at the high latitude station of Yakutsk (Fig. 1(a)) to about 98% from the reference and thereafter, the response drops to about 65% depression and maintains these negative phase characteristics throughout January 11-12. The enhancement do not come as a surprise, this is because at high latitudes it is very difficult to establish a definite pattern due to an increased auroral activity during geomagnetic storm [10].

The corresponding plot at Churchill (Fig. 1(a)), however, revealed a negative phase storm throughout January 10-12. The case was the same at Ottawa, a middle latitude station (Fig. 1(b)). Note that the peak depletion (50% of the reference) occurred at 2300UT on January 10. The F2 layer response at Rostov (Fig. 1(b)) did not record any meaningful positive phase storm until around 0300UT on January 11 and lasted through 2300UT on the same day. It thereafter drops and then rises again through January 12, thus creating pattern that is irregular, but more typical of the positive phase event. Note that the peak value was reached around 1600UT on January 11 to an enhancement value of 67%. It should be observed that this time corresponds to the period when Dst value drops sharply to its minimum peak value (Fig. 2).

Meanwhile, the D(foF2) plot for Boulder (Fig. 1(c)) shows a rather weak ionospheric F2 region response to the first depletion of solar wind density throughout January 10. But, beginning from 0000UT on January 11, this station started recording a positive storm with foF2 increasing rather sharply to 87%. It thereafter droped for a while, but still maintaining a positive phase through 0100UT on January 12, from where it decreased abruptly again maintaining a negative phase through 1400UT on January 12 and then turned positive again rather weakly.

The corresponding D(foF2) plot for Huancayo (Fig. 1(c)) shows a strong positive ionospheric response in the period 0000UT - 0700UT on January 10. Thereafter, foF2 revealed a negative phase between 0900UT and 1800UT on the same day. The foF2, however, recovered to an intense positive storm at 0400UT on January 11. The D(foF2) plot shows that the ionosphere at Huancayo is mostly characterized by positive storm during the period under investigation. The plot further shows negative phase at 2200UT on January 12 with a 20% depletion level.

4. Discussion

The analysis of the D(foF2) plots (Fig. 1) appear to reveal these significant features: (a) an absence of positive ionospheric storm effects at high and mid latitudes on the dayside during the initial phase of the storm (i.e., between 0000UT and 1000UT on January 10); (b) simultaneous existence of the negative storm at high and middle latitudes during the storm event; (c) presence of positive phase storm at mid latitudes between 0400UT and 2300UT after storm commencement on January 11; (d) the appearance of negative storm at the low latitude station of Huancayo between the period 1000UT – 1800UT on January 10; (e) the occurrence of strong positive phase at the low latitude station of Huancayo before storm commencement.

Danilov [1] had proposed that a significant feature of the negative storm is its equator-ward shift during the storm from auroral latitudes to middle latitudes with the amplitude of the effect decreasing during the shift. Hence the D(foF2) plots appear to reveal the aforementioned feature of the negative phase. Presently, this study has revealed the appearance of a negative storm before the beginning of a geomagnetic disturbance, in the mid and high latitudes (i.e., between 0000UT – 1200UT on January 10), as well as the occurrence of strong positive phase at a low latitude station.

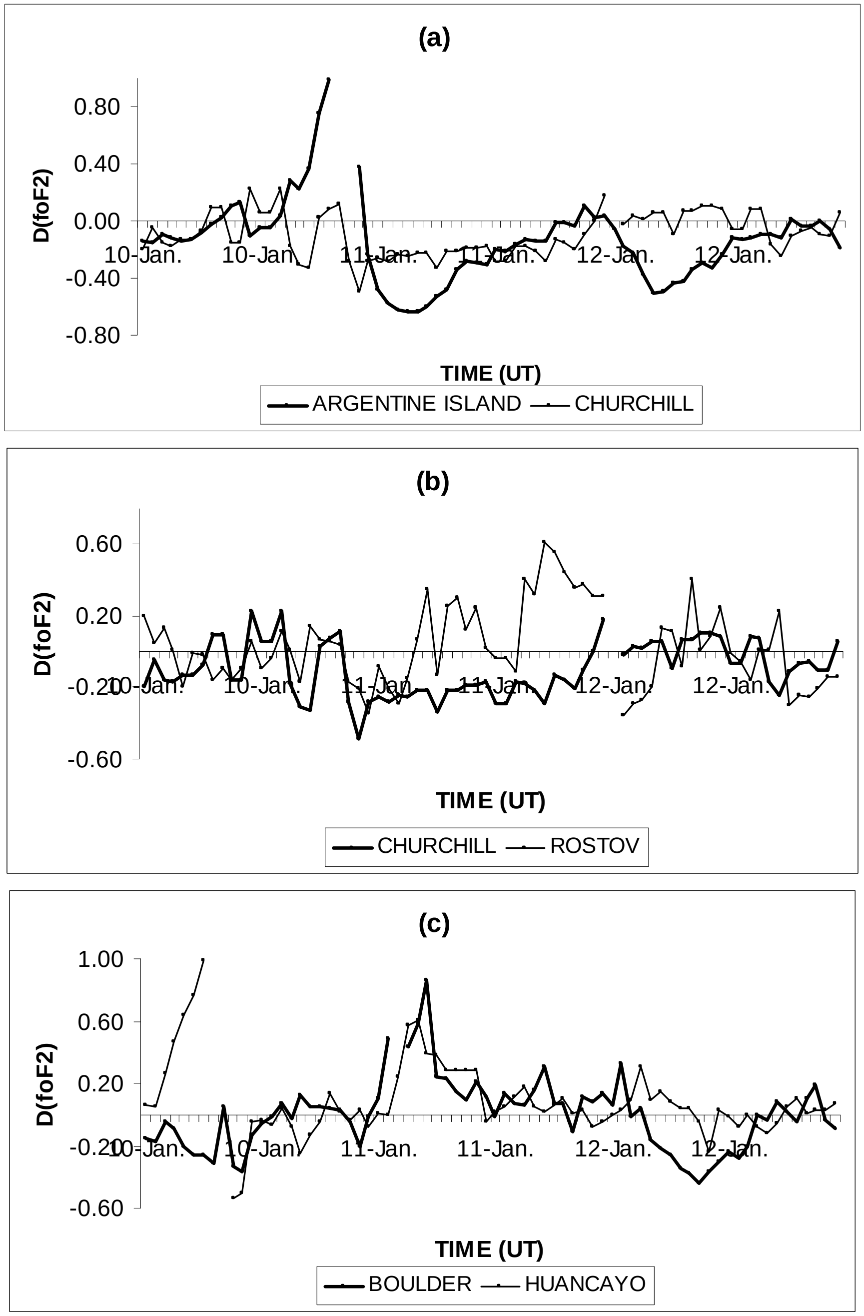

FIG. 1: Plot of normalized deviations of the critical frequency D(foF2) from the reference in American sector of the world for January 10-12, 1976.

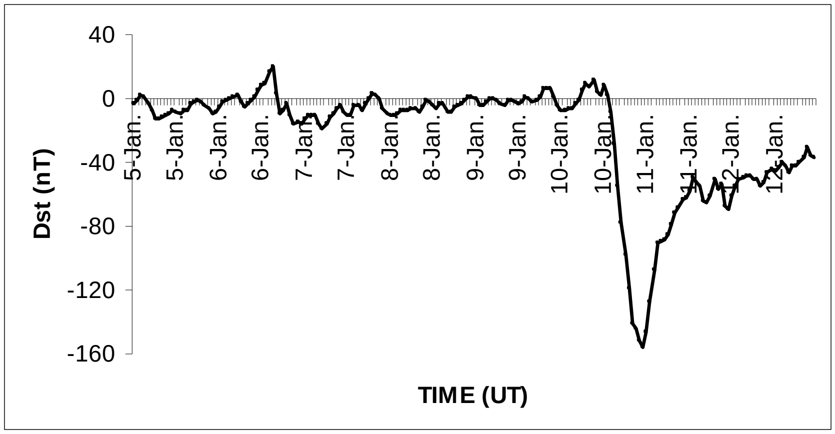

FIG. 2: Dst plot for January 5-12, 1976 showing five quiet days before storm commencement of January 10, 1976.

However, the simultaneous intense depletion of foF2 at the high and mid latitudes appear to suggest that during the intense geomagnetic storm of January 10, 1976, the foF2 depletion may be due mainly to changes in neutral composition resulting from neutral wind produced in the aurora zone. According to [11] and reference therein, during very intense geomagnetic activity, soft particle precipitation will increase the vibrational excitation of molecular nitrogen, which will in turn increase the loss of ionization at F2 region heights.

5. Conclusion

The studies of the intense (Dst = -158nT) geomagnetic storm of January 10, 1976 and its corresponding F2 region response had been clearly analyzed using the critical frequency foF2 data obtained from ionosonde stations in the American sector of the world. It was found that the leading single magnetospheric process responsible for the Dst decrease was the enhancement of the plasma sheet.

However, the F2 region response appears to show the following significant features: (i) an absence of positive ionospheric storm effects at high and mid latitudes on the dayside during the initial phase of the storm; (ii) the simultaneous existence of negative storm at high and middle latitudes during the storm event; (iii) the presence of positive phase storm at mid latitude stations of Rostov and Boulder after storm commencement on January 11; (iv) the occurrence of strong positive phase at the low latitude station (except for the period 1000UT – 1800UT on January 10 that experiences a little depression).

Moreover, the observed simultaneous depletion of foF2 at the high and mid latitudes only appears to support the notion that the depletion of F2 region plasma density is due to changes in neutral wind produced predominantly by the Joule heating in the aurora zone. Hence it could be said that the F2 region response lacked simultaneity during the intense storm of January 10, 1976 at the American sector of the world since the total depression in foF2 does not extend to low latitudes.

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Received: 17 December, 2007
Accepted: 3 October, 2008