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On the Geomagnetic Storm of January 10-11, 1976

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Abstract: This study investigates the intense (Dst = -158 nT) magnetic storm of January 10-11, 1976; in regards to the appearance of positive storm before the beginning of a geomagnetic storm in the mid latitudes and the occurrence of strong negative phase at the equator and also to confirm whether the storm event will agree with earlier results of the very intense geomagnetic storm (D_{st} = -600nT) of March 12-14, 1989 and April 12-14, 1981 (D_{st} = -311nT), which shows that the depletion of foF2 was simultaneously worldwide and extended to very low latitudes The analysis of the D (foF2) plots appear to show that the storm event is characterized by the occurrence of positive ionospheric storm at the high latitudes and mid latitude stations of Khabarovsk, Yamagawa and Okinawa stations before the beginning of the storm event Presence of strong negative phase at Manila, a low latitude station before the beginning of a geomagnetic storm. Simultaneous existence of negative storm at all latitudes during January 10-11, 1976 storm event between 0600UT-0900UT, January 10, before storm commencement; as well as between 1200UT-1400UT during storm main phase on January 10 and appearance of strong positive storm at the mid latitude stations of Kokubunji and Yamagawa between 0000UT-2200UT, January 11 and Okinawa between 1200UT-2300UT, January 11. The simultaneous depletion of foF2 during the storm event occurs at all latitudes between the time intervals in above. This shows that the F2 regional structure response is simultaneous and in agreement with the aforementioned intense storm events. However, this observed simultaneous depletion of fosF2 at all latitudes revealed that the depletion of F2 region plasma density is due to particle precipitation and not only changes in neutral composition resulting from neutral wind. Moreover, it was observed that this storm event is caused as a result of shock generated by magnetic clouds which are characterized by low beta plasma, high IMF magnitude and large scale coherent field rotations often including large and steady north-south components. Also, the positive storm experienced at some of the high and mid latitude stations after storm commencement appear to be caused by the short duration southward turning of Bz giving δBz = -12nT between 0600 and 0800UT on January 10.

Key words: Geomagnetic storm, beta plasma, Depletion of foF2, plasma density, magnetic clouds

INTRODUCTION

The principal features of the positive and negative phase distribution and variables have been explained on the basis of the principal concepts: during a geomagnetic disturbance there is an input of energy into the polar ionosphere, which changes thermosphere parameters, such as composition, temperature and circulation. Composition changes directly influence the electron concentration in the F2 region. The circulation spreads the heated gas to lower latitude. The conflict between the storm-induced circulation and the regular one determines the spatial distribution of the negative and positive phases in various seasons (Danilov, 2001)

In a recent research by Adebesin *et al.* (2007) in studying the interplanetary magnetic field (Bz) and Ionospheric variation during Magnetic activities at low latitude with particular reference to the East Asian station of Manila (14.7°N), it was observed that there is homogeneity in the response of F2 region at low latitude stations (i.e., foF2 enhancement) irrespective of the period of storm event, but more pronounce during intense storms which was in agreement with the results of Danilov (2001). It was also noted that a southward turning with change in Bz of δBz > 11.5nT results in foF2 showing a marked decrease in amplitude reaching a minimum value of 20 h after the southward turning (Chukwuma, 2007). Moreover, according to Adebesin and Chukwuma (2008), their study reveals that 'very intense' (-250nT = peak Dst <-100nT) storms are more likely to experience shock in the interplanetary magnetic field region faster than 'intense' (peak Dst <-250nT) storms with a plasma flow speed > 400 km s^{-1}, thereby enhancing changes observed at different ionospheric regions of the world.

Also, recent results of the study of the very intense geomagnetic storm (D_{st} = -600nT) of March 12-14, 1989

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(Chukwuma, 2003a) and April 12-14, 1981 (D_{st} = -311nT) (Chukwuma and Bakare, 2006) show that the depletion of foF2 was simultaneously worldwide and extended to very low latitudes while the October 20-21, 1989 intense geomagnetic storm (D_{st} = -268nT) observed by Chukwuma (2003b) show that the depletion of foF2 was restricted to the high and middle latitudes and lacked simultaneity. In this light, this study attempts to investigate the intense magnetic storm of January 10-11, 1976; in regards to the appearance of positive storm before the beginning of a geomagnetic storm in the mid latitudes and the occurrence of strong negative phase at the equator and also to confirm whether the storm event will agree with earlier results and to also investigate the likely source of energy injection into the magnetosphere of this storm.

Interplanetary and geomagnetic observations: The data used in this study consists of hourly averaged interplanetary parameters: low latitude magnetic flux Dst, interplanetary magnetic field Bz component, ion density, solar wind flow speed, plasma beta and plasma temperature for the period January 5-12, 1976. January 5-9 are the five quiet days before the storm. These hourly observations are from the NSSDC's OMNI database. Figure 1 shows the interplanetary and geomagnetic plot for January 10-12, 1976, in which the Storm sudden commencement (SSC) was experienced around 0900UT on January 10 as indicated on the Dst plot.

The Bz plot shows Bz was northward from 0000UT-0300UT, January 10, but rotated southward briefly between 0300 and 0800UT and then northward again up till 1000UT to a value of 5nT on the same day. It then rotates southward and oscillated weakly northward at 1200UT. Thereafter, Bz rotated southward again at 1300UT, reaching a minimum peak value of-18nT around 2000UT, January 10. Bz then begins to decrease southwardly in magnitude up till around 0500UT, January 11 to the reference level and then experiences a strong northward rotation through 1200UT on January 11 to a value of 11.5nT. However, non availability of data from this point forward would not make us comment on the remaining part of the Bz plot.

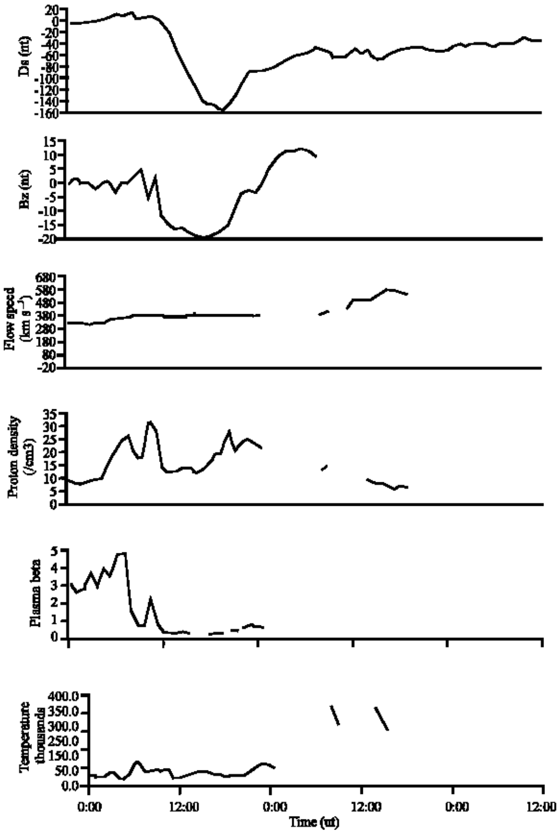

Fig. 1: Composition of interplanetary and geomagnetic observations for January 10-12, 1976

The low latitude magnetic index Dst plot is shown in the top panel of Fig. 1. Storms are classified as weak (Dst >-50nT), moderate (-50nT < Dst <-100nT) and intense (Dst <-100 nT) [Veira *et al.*, 2001]. Beginning from 1400UT on January 10, Dst decreased sharply getting to its minimum peak value of-158 nT at 2300UT indicating an intense storm (Dst <-100 nT), thereafter, Dst recovers gradually getting to a value of-62 nT around 1300UT on January 11 and continue in this recovery manner through January 12. Note that the Dst value begins to decrease sharply at the instant the Bz component turns sharply southwardly, reaching a minimum peak value of-20 nT on January 10, thereby indicating the arrival of a shock in the interplanetary medium. The long duration of Bz in the southward direction for over 7 hours is an indication that the storm event is intense in nature. According to Danilov (2001), the IMF structures leading to intense magnetic storms have intense (>10nT) and long duration (>3 hr) southward component. The Dst profile for this storm event also appears to present a single step intense geomagnetic storm.

The proton density plot shows a large increase in the proton density around 1200UT on January 10, which coincides with increase in plasma flow speed. This signals the arrival of a shock at this time. As a consequence, the enhanced solar proton density drove the plasma sheet density leading to the injection of the ring current and thus caused the sharp depression in Dst within this same time interval. This assertion derives from the fact that plasma sheet density is found to correlate well with high solar wind density, with the source of the ring current particles being the plasma sheet (Borovsky *et al*., 1998). Moreover, the rapid increase in proton density between 0000UT and mid January 10 appears to indicate the presence of a magnetic cloud.

Moreover, from the flow speed plot of Fig. 1, it was observed that the relatively slow rising stream on January 10 to a value less than 400 km s^{-1} indicates that the arrival of shocks in the interplanetary medium is not caused by CME ejecta. This is because according to Kamide *et al.* (1998), it was observed that the precise form of solar wind energy input into the magnetosphere is the solar wind dawn-to-dusk electric fields. These electric fields are caused by a combination of solar wind velocity and southward IMF Bz, but with the southward field playing the more important role because of its far greater variability. Hence, since the flow speed value of $Vsw < 400$ km s^{-1} was observed at the instant Dst attains its minimum peak value, then the shock experienced could be attributed to the intense nature of Bz (i.e. $Bz > -10$nT) coupled with increase in proton density, thus not conforming to the statement of Gonzalez *et al.* (2001, 2002), that intense magnetic storms occur when the solar flow speed is substantially higher than the average speed of 400 km s^{-1}.

From the Bz plot in Fig. 1, a change in Bz of $\delta Bz = -12$nT [i.e. (-7-(5)] nT was observed between 0600 and 0800UT on January 10 which appear to coincide with increases in both plasma density and flow speed. This change in Bz could lead to the explanation of ionospheric responses observed at some stations hours after it occurred. This is because it has been shown that a southward turning with a change in Bz of $\delta Bz = -11.5$nT results in foF2 showing a marked decrease in amplitude, reaching a minimum value few hours after the southward turning (Chukwuma, 2007). It thus appear that this southward turning with $\delta Bz = -12$nT may have been accompanied by an increase in solar wind dynamic pressure which led to an enhanced coupling between the solar wind and the terrestrial magnetosphere that significantly increased the geoeffectiveness of the solar wind (Chukwuma, 2007).

The structure of this geomagnetic storm event is made clearer by the plasma beta and plasma temperature plot in Fig. 1. The plasma beta plot shows a relatively build up value in plasma beta between 0000UT-0800UT, January 10, but just before SSC it reduces sharply to a value less than 1.0 around 1000UT of same day. It thereafter begins to rise and then falls again maintaining a very low value coinciding with Dst minimum peak value. Paucity of data would not allow comment for the period 0600UT on January 11 through the whole of January 12.

The plasma temperature plot shows a relatively low temperature profile throughout the whole event days except for around 1400 and 2300 UT on January 12 which experiences high temperature profile of about 350000 K. However, the temperature was low at Dst minimum peak value.

Given this low values of plasma beta and temperature which is coincident with an enhanced plasma flow speed between January 10 and January 11, the profile of the plasma beta appears to present a criterion for magnetic clouds. Hence, it can be stated that the storm of January 10, 1976 is generated by shocks from magnetic cloud origin which is characterized by low beta plasma, high IMF magnitude and large scale coherent field rotations often including large and steady north-south components. Given the variations of the solar wind parameters under investigation, it is safe to suggest that the same magnetospheric process played the leading role in the enhancement in the ring current

Moreover, according to Tsurutani *et al.* (2003), magnetic clouds that are geoeffective have a southward and then northward (or vice versa) magnetic field directional variation. When the magnetic cloud has a very high velocity, it compresses the plasma ahead of it and forms a collissionless shock (Chukwuma, 2007). Behind this shock is a sheath, which contains heated plasma and compressed magnetic fields. These intense sheath magnetic fields in turn, can also cause magnetic storms.

MATERIALS AND METHODS

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 East Asian sector of the world: 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 position, respectively). i.e

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

The present study is concerned with variations in foF2 due to the intense geomagnetic storm of January 10-11, 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) (Chukwuma 2003b), 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. 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 (Chukwuma, 2003b). However, it should be noted that in the present analysis of D (foF2) variations, any changes of more than 10% in amplitude indicates a variation while a change of-30% and above would be regarded as intense or large (Chukwuma, 2007).

RESULTS

Figure 2 and 3 show D (foF2) vs UT throughout January 10-12, 1976 for the nine, East Asian sector ionosonde stations listed in Table 1. These stations in order of decreasing latitude are Yakutsk (62.0°N), Magadan (60.0°N), Khabarovsk (48.5°N), Wakkanai (45.4°N), Akita (39.7°N), Kokunbunji (35.7°N), Yamagawa (31.2°N), Okinawa (26.3°N) and Manila (14.7°N). Ionospheric F region electron density is determined mainly by photoionisation, neutral composition and winds during geomagnetic quiet periods. However, in this analysis, our main interest shall be in explaining the response of the ionosphere to the intense geomagnetic storm of January 10-11, 1976 mainly by considering its remarkable features.

The D (foF2) plot at Yakutsk shows that there was an enhancement in the F2 layer from 0000UT to 0600UT, January 10, just before storm sudden commencement. However, a negative storm event was observed right from this period till the early pre-noon hours up till about 30% depletion from the reference. Thereafter, an increasing positive phase storm was observed between 1200 and 2300UT on January 10. This is coincident with the observed minimum peak value of-158nT about the same period. With effect from 0300UT, January11, the D (foF2) variation shows a predominantly negative storm through January 12. Note that the peak depletion occurred at 0300UT on January 11 followed the large increase in the proton number density at 0000UT on January 11.

The F2 region response at Magadan (Fig. 2), also shows a positive storm between 0000 and 0600UT on January 10 before Storm sudden commencement (SSC). But just immediately after the storm commencement on January 10, the foF2 response shows a 30% depletion at 0600UT, an abrupt recovery to the reference level and then a negative phase rotation again till the after noon hours on January 10. However, with effect from 2000 UT on January 10, a major 43% depletion level was observed, indicating the commencement of an intense negative storm which lasted throughout the period under investigation, except between 0000 and 0900UT, January 12, that recorded a weak positive storm. Note also that these large decreases in foF2 between 0000UT and 2300UT. January 11 followed the sharp increase in proton density at 0000UT on January 11.

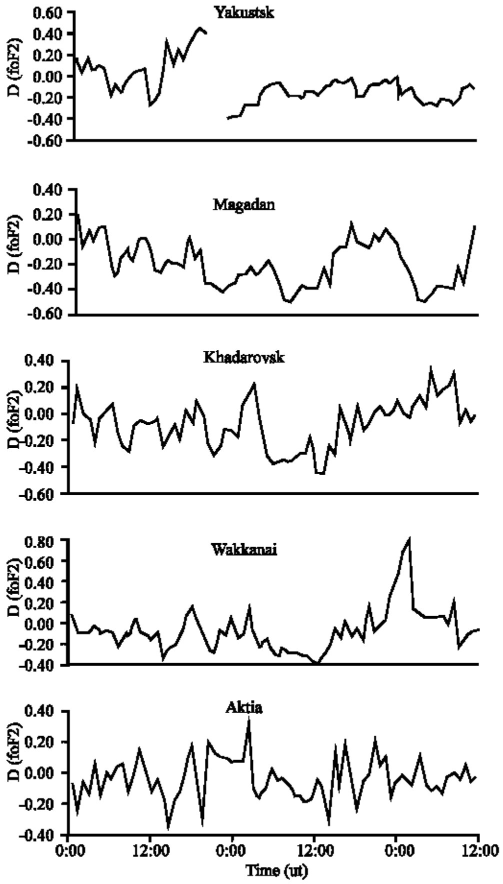

Fig. 2: Variations in D (foF2) for high latitude stations of Yakutsk and Magadan and the mid latitude stations of Khabarovsk, Wakkanai and Akita for January 10-12, 1976

The D (foF2) plot at Khabarovsk also shows a positive storm between 0000 and 0300UT on January 10. Observe the D (foF2) variations show the ionosphere developing a negative storm at 0800UT and attaining a 28% depletion level from the reference. it should also be observed that the peak depletion in foF2 at 0800, 1500, January 10 and 0000UT and 1000UT, January 11 coincides with the large increases in proton number density at this

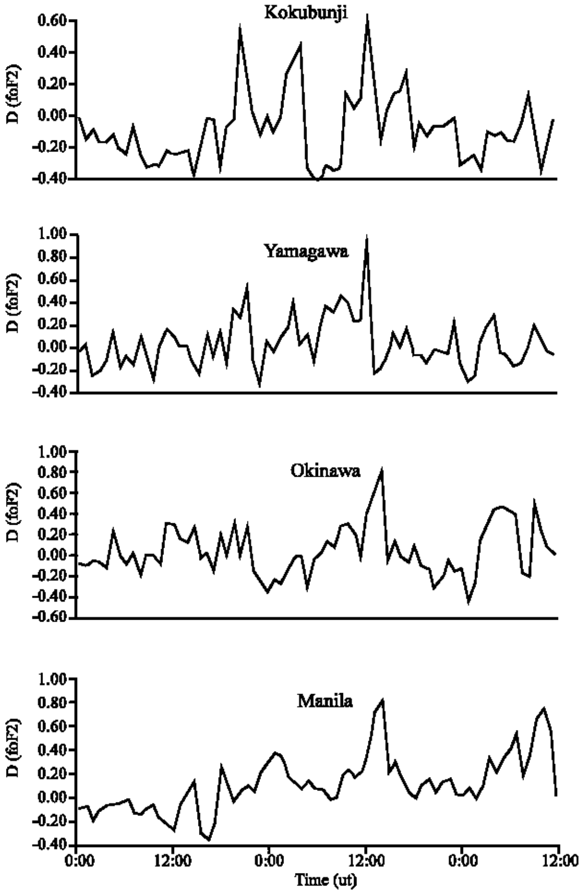

Fig. 3: Variations in D (foF2) for the mid latitude stations of Kokubunji, Yamagawa and Okinawa and the low latitude of Manila for January 10-12, 1976

Table 1: Ionosonde stations

	Geographic co-ordinates		Geomagnetic co-ordinates		
Stations	Φ(°N)	λ(°E)	Φ(°N)	λ(°E)	Difference btw Last and ut (h)
Yakutsk	62.00	129.60	50.90	206.9	+9
Magadan	60.00	151.00	51.90	213.4	+10
Khabarovsk	48.50	135.10	37.80	200.00	+9
Wakkanai	45.40	141.70	35.30	206.00	+9
Akita	39.70	140.10	30.20	207.50	+9
Kokunbunji	35.70	139.50	26.17	207.50	+9
Yamagawa	31.20	139.50	22.30	208.70	+9
Okinawa	26.30	127.30	15.30	197.90	+8
Manila	14.70	121.00	4.05	191.90	+8

same points, which indicate the arrival of a shock in the interplanetary medium. However, between 0600 and 0900UT, January 11, a positive storm was observed, which thereafter depletes, reaching a 50% depletion level on January 11 and then begins rotating northward through January 12. Between 0600 and 2100UT, January 12, a positive phase storm with 30% enhancement level was observed.

The ionospheric response at Wakkanai shows that there were no immediate response between 0000 and 0700UT, January 10. With effect from 0700UT, January 10, the ionosphere recorded a negative phase storm through 0300UT, January 12. However, a brief positive storm was observed between 1900 and 2100UT, January 10 and 0600UT, January 11. Furthermore, negative storm observed at this station also preceeded the intense magnetic storm. Note the 80% ionospheric response enhancement at 2300UT, January 12, before a gradual decrease resulting in negative phase again through 2000UT, January 12. The D (foF2) plot at Akita shows a predominantly negative phase storm between 0000 and 1000UT, January 10. However, the foF2 pattern observed at this station is irregular showing a 50% ratio apiece for both positive and negative phase storms. Note the enhancement between 0000 and 0900UT, January 11, having a 37% peak enhancement value.

Available foF2 data at Kokubunji [Fig. 3] is similar to the D (foF2) plot at Akita except that a negative phase storm was observable between 0000 and 2300UT, January 10. Thereafter, a positive phase storm was imminent up till pre noon hours of January 11, when it experiences a southward rotation resulting in negative phase storm which lasted till 1600UT before another enhancement to a peak value of 59% was observed. It thereafter begins to recover and maintains a negative phase storm between 0300 and 2300UT, January 12. The plot of the ionospheric response at Yamagawa as seen from Fig. 3, indicates a rather irregular pattern between 0000 and 1800UT, January 10, but more of negative storm. Note the enhancement between 0000 and 2100UT, January 11. The irregular pattern thereafter continues through January 12. it should also be noted that the 31% peak depletion value observed at 0300UT, January 11 is preceeded by an increase in proton density about the same time which also coincides with the minimum peak value of Dst, thus indicating the presence of an intense storm.

The situation at Okinawa is not different, an existing positive phase storm was observed between 0500UT, January 10 and 0200UT, January 11. Note the depletion in foF2 observed between 0200 and 2200UT, January 11 and 0300UT and 1200UT, January 12. Apart from these two points, the F2 response is predominantly positive. Also, the D (foF2) plot for Manila, a low latitude station is mostly characterized by positive storm during the period under investigation. However, the plot shows a weak negative storm between 0000UT and 1200UT, January 10. The plot further shows a negative phase at 1800UT, January 10 with a 32% depletion value from the reference.

DISCUSSION

It is well established that the Bz component of the IMF is the most important influence on the magnetosphere and high and mid-latitude ionosphere as it controls the fraction of the energy in the solar wind which is extracted by the magnetosphere.Hence, the positive storm experienced at some of the high and mid latitude stations after storm commencement appear to be caused by the short duration southward turning of Bz giving $\delta Bz = -12nT$ between 0600 and 0800UT on January 10. It thus appear that this southward turning with $\delta Bz = -12nT$ may have been accompanied by an increase in solar wind dynamic pressure which led to an enhanced coupling between the solar wind and the terrestrial magnetosphere that significantly increased the geoeffectiveness of the solar wind (Chukwuma, 2007).

The analysis of the D (foF2) plots appear to show the following characteristics for the January 10-11 geomagnetic storm event:

- The occurrence of positive ionospheric storm at the high latitudes and mid latitude stations of Khabarovsk, Yamagawa and Okinawa stations before the beginning of the storm event.
- Presence of strong negative phase at Manila, a low latitude station before the beginning of a geomagnetic storm (i.e. between 0000 and 2000UT, January 10).
- Simultaneous existence of negative storm at all latitudes during January 10-11, 1976 storm event; between 0600UT-0900UT, January 10.
- Presence of positive ionospheric storm effects at high latitude station of Yakutsk and mid latitude stations of Akita, Yamagawa and Okinawa during the initial phase of the storm.
- Appearance of strong positive storm at the mid latitude stations of Kokubunji and Yamagawa between 0000UT-2200UT, January 11 and Okinawa between 1200UT-2300UT, January 11.
- Appearance of positive phase storm at mid latitude stations of Khabarovsk, Wakkanai, Akita and Okinawa during recovery phase of the geomagnetic activity.

Danilov (2001) had proposed that a significant feature of the negative storm is its equatorward 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 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 low latitude station. However, the simultaneous intense depletion of foF2 at all latitudes appear to suggest that during the intense geomagnetic storm of January 10, 1976, the foF2 depletion is due to particle precipitation at all latitudes during intense magnetic storms. According to Prolls (1995) 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.

The appearance of the positive storms at the high latitude stations under investigation is as a result of energy being injected into the polar upper atmosphere as the solar wind become geoeffective; which in turn launches a traveling atmospheric disturbance (TAD) which propagates with high velocity. This TAD carries along equatorward-directed winds of moderate magnitude. At high latitudes, these meridional winds drive ionization up inclined magnetic field lines and cause uplifting of the F layer, leading to an increase in the ionization density i.e. positive storm. The observed decrease in foF2 during the storm is related to the neutral composition disturbances. Heating at auroral and high latitudes causes expansion of the neutral atmosphere and enhanced neutral winds carry disturbed composition. However, enhancement in the mean molecular mass in the neutral composition disturbance zone leads to an increase in the loss rate of ions, resulting in a decrease of the ionospheric plasma density and thus a negative storm.

CONCLUSION

In this research, we have presented an interplanetary phenomenon, a geomagnetic and Ionospheric response associated with the storm of January 10-11, 1976. The study was based on measured parameters of solar wind plasma, the Bz and the corresponding Dst variations for the period of January 6-12, 1976 and foF2 data obtained from a global network of ionosonde stations in the East Asian sector of the world. Analysis into the interplanetary and geomagnetic parameters of the storm showed an intense ($Dst = -158nT$), Type 1 storm, whose shock arrival in the interplanetary medium is indicated by the large southward turning of Bz, which in turn leads to increase geomagnetic activity resulting in negative storms. It was found that the leading single magnetospheric process responsible for the Dst decrease was the enhancement of the plasma sheet. However, the analysis of the D (foF2) plots appear to show the following characteristics for the storm event:

- The occurrence of positive ionospheric storm at the high latitudes and mid latitude stations of Khabarovsk, Yamagawa and Okinawa stations before the beginning of the storm event.
- Presence of strong negative phase at Manila, a low latitude station before the beginning of a geomagnetic storm (i.e. between 0000 and 2000UT, January 10).
- Simultaneous existence of negative storm at all latitudes during January 10-11, 1976 storm event; between 0600UT-0900UT, January 10.
- Presence of positive ionospheric storm effects at high latitude station of Yakutsk and mid latitude stations of Akita, Yamagawa and Okinawa during the initial phase of the storm.
- Appearance of strong positive storm at the mid latitude stations of Kokubunji and Yamagawa between 0000UT-2200UT, January 11 and Okinawa between 1200UT-2300UT, January 11.

The simultaneous depletion of foF2 during the storm event occurs at all latitudes. This shows that the F2 regional structure response is simultaneous. This is in agreement with the results of Chukwuma (2003a) of the intense storm of March 13-14, 1989 and Chukwuma and Bakare (2006) of the intense storm event of April 12-14, 1981. However, this observed simultaneous depletion of foF2 at all latitudes revealed that the depletion of F2 region plasma density is not due to changes in neutral wind produced predominantly by Joule heating in the aurora zone alone, but also by particle precipitation Moreover, it was observed that this storm event is caused as a result of shock generated by magnetic clouds which are characterized by low beta plasma, high IMF magnitude and large scale coherent field rotations often including large and steady north-south components. Also, the positive storm experienced at some of the high and mid latitude stations after storm commencement appear to be caused by the short duration southward turning of Bz giving $\delta Bz = -12nT$ between 0600 and 0800UT on January 10.

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