AN INVESTIGATION INTO GEOMAGNETIC AND IONOSPHERIC RESPONSE ASSOCIATED WITH THE STORM OF APRIL 12-14, 1981

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Abstract

An investigation is made of the intense storms of April 12- 14, 1981(Dst =-311nT) in an attempt to contribute to the current understanding of solar wind structures and magnetospheric processes that generate intense magnetic storms, as well as explain the F2 region response associated with these interplanetary structures and magnetospheric processes. The interplanetary and geomagnetic data used in this study consists of hourly values of proton density, solar wind flow speed, interplanetary magnetic field B_z component, and the low-latitude magnetic index, Dst. The ionospheric data are hourly values of foF2 obtained from a network of ionosonde stations located in the East Asian sector: Yakutsk, Magadan, Khabarovsk, Wakkanai, Akita, Kokubunji, Okinawa and Manila. The study shows that the present storm is double step, and the leading single magnetospheric process that was responsible for both the first and second Dst decrease is the enhancement of the plasma sheet. An enhanced solar wind density drove, under southward B_Z conditions, the plasma sheet density leading to the injection of the ring current. In regards to the F2-region response, it appears the ionosphere in the East Asian zone is characterized by the occurrence of strong negative phase at the low latitude station of Manila before the beginning of the geomagnetic storm, absence of positive ionospheric storm effects at high and mid latitudes on the dayside during the initial phase of the magnetic storm, and simultaneous intense depletion of foF2 at all latitudes at ~ 20:00 UT, April 12. The simultaneous depletion of foF2 at all latitudes does not appear to support the previously held notion that the depletion of F2-region plasma density is due to changes in neutral composition resulting from neutral wind produced predominantly by Joule heating in the aurora zone, but rather suggests that particle precipitation does contribute to depletion of foF2 at all latitudes during intense magnetic storms.

Keywords: *Geomagneticstorm, ionospheric Fz region, negative storm, plasma sheet density and ring current*

Introduction

The term "Space weather" refers to conditions on the sun and in the solar wind, magnetosphere, ionosphere, and thermosphere that can influence the performance and reliability of space-borne and ground-based technological systems and can endanger human life or health. Adverse conditions in the space environment can cause disruption of satellite operations, communications, navigation, and electric power distribution grids, leading to a variety of socioeconomic losses (United States of America's National Space Weather Program Strategic Plan, FCM-P30-1995).

The above-mentioned statement underscores the increasingly worldwide recognition of the importance of "space weather" research which has lead, in recent years, to the intensification of investigations of geomagnetic storms. The main objective of space weather studies is to understand the solar and interplanetary causes of magnetic storms, and the ionospheric phenomena associated with these magnetic storms.

In the main, the principal defining property of a magnetic storm is the creation of an enhanced ring current. The ring current is a westward current that flows in the Earth's magnetosphere between 2 and 7 Earth radii (R_E) and produces a magnetic field disturbance which, at the equator, is opposite in direction to the Earth's dipole field (Gonzalez et al., 1994), thereby causes a diamagnetic decrease in the Earth's magnetic field measured at near-equatorial magnetic stations as low-latitude magnetic index, *Dst* (Buonsanto and Fuller-Rowell, 1997). The *Dst* while directly measuring the magnetic field of the ring current flowing in the magnetosphere, is also a measure of the kinetic energy, *E(t)*, of the particles that make up the ring current. This is stated formally in the Dessler-Parker-Sckopke relation (Dressler and Parker, 1959; Sckopke, 1966):

$$\frac{Dst^*(t)}{B_o} = \frac{2E(t)}{3E_m} \qquad (1)$$

Here $Dst^*(t)$ is the measured *Dst* value after a correction due to magnetopause currents is made. B_o is the average equatorial surface field. and E_m is the total magnetic energy of the geomagnetic field outside the Earth. Hence. the *Dst* index is an important defining parameter of a magnetic storm. Magnetic storms can be classified as follows: weak (-30nT > Dst_{min} >-50 nT). moderate (-50 nT > Dst_{min} > - 100 nT) and intense (Dst_{min} < - 100 nT) (Gonzalez et al., 1994, Kamide et al.. 1998; Viera et al., 2001). However, within the scientific community, investigations into intense storms have generated extensive interest because of their profound effects on satellite navigation, communication, and power systems. According to Kamide et al. (1998a) and Viera et al. (2001), intense storms are classified into two types: Type 1 and Type 2, according to how *Dst* reaches the minimum of the main phase. Type 1 represents a "normal" magnetic storm that consists of a main phase and a subsequent recovery. During the main phase. the Earth's geomagnetic field is significantly depressed by the storm time ring current. This sequence is at times preceded by an initial phase during which *Dst* shows a positive change responding to ram pressure increase in the solar wind. On the other hand. Type 2 storms are storms which have a two-step decrease in *Dst* in the main phase (Kamide et al., 1998a).

In this work, we present the results of an investigation into geomagnetic and ionospheric storms associated with solar wind structures during April 12-14, 1981. This paper attempts to contribute to the current understanding of solar wind structures and magnetospheric processes that generate intense magnetic storms, and F2 region response to the interaction between the interplanetary structures and the Earth's magnetosphere. The present study is informed by the fact that despite the works available in literature, geomagnetic storms still are not fully understood.

2. Data and Method of Analysis

The data used in this study consists of:

1. OMNI hourly averaged definitive multi-spacecraft interplanetary parameters data: proton density, solar wind flow speed, and interplanetary magnetic field B_z component. These data were obtained from NSSDC's OMNIWebServic(http://nssdc.gsfc.nasa. Gov/omniweb).

2. Hourly values of the low-latitude magnetic index. *Dst.* These data were also obtained from NSSDC's OMNIWeb Service (http://nssdc.gsfc.nasa.gov/omniweb).

3. The Ionospheric data used in this study consists of hourly values of *foF2* obtained from some of the National Geophysical Data Centre's SPIDR Space Physics Interactive Data Resource) a network of ionosonde stations located in the East Asian sector: Yakutsk, Magadan, Khabarovsk, Wakkanai, Akita, Kokubunji, Okinawa and Manila. These stations are listed in Table 1. The present study is concerned with variations in *foF2* due to the intense geomagnetic storm of April 12-14, 1981. However, the F2 region response to geomagnetic storms is most conveniently described in terms of *D(foF2)*, that is the normalized deviations of the critical frequency *foF2* from the reference (Chukwuma, 2003b):

$$D(f_oF2) = \frac{f_oF2 - (f_oF2)_{ave}}{(f_oF2)_{ave}} \qquad (2)$$

Hence. the data that was analysed consists of *D(foF2)* of respective hourly values of *foF2* on April 11-15, 1981. The reference for each hour is the average value of *foF2* for that hour calculated from the five quiet days April 5-9, 1981, preceding the storm. The use of *D(foF2)* rather than *foF2* provides a first-order correction for temporal. seasonal and solar cycle variations so that geomagnetic storm effects are better identified. Furthermore, the criterion used in selecting the stations is such that storm variations represented real changes in electron density not simply redistribution of the existing plasma (Chukwuma, 2003b; Soicher, 1972).

We want to note that in the present analysis of *D(foF2)* variations, positive and negative storms ionospheric are defined by changes in amplitude (the maximum absolute value of *D(foF2)* of more than 10% (Danilov, 2001), and changes of *D(foF2)* of ~ 30% are regarded as intense or large (Huang et al., 2002 and references therein).

Results

Geomagnetic and Interplanetary Observations

The top panel of Figure 1 presents the *Dst* variations for April 11-15, 1981 and shows that *Dst* > -30 nT for most of April 11. This is with the exception of 15:00 UT when *Dst*= -31. After this time the *Dst* index increased to -25 nT at 16:00 UT before reaching 11 nT at 22:00 UT. *Dst* showing a positive change at this time is an indication of a storm sudden commencement. Thereafter, *Dst* decreased sharply to 107 nT at 2:00 UT on April 12. It is reasonable at this point to suggest from the value of *Dst* that an intense storm commenced at ~2:00 UT on April 12. *Dst* reached the minimum value of -163 nT at 5:00 UT and thereafter started to recover, first gradually to -100 nT at 21:00 UT, and then sharply to -31 nT at 23:00 UT. Observe that the recovery was not concluded before *Dst* again decreased abruptly to the minimum peak of -311 nT at 6:00 UT on April 13. The *Dst* again recovered immediately, first sharply, to -209 at 9:00 UT and thereafter gradually for the rest of the day until it got to a value of -100 nT at 7:00 UT on April 14 marking the end of the intense storm.

The *Dst* profile for the period April 11-15, 1981 that is shown and described appear to represent a Type 2 intense geomagnetic storm during the interval April 12-14, 1981. But a Type 2 storm must satisfy the following two conditions (Kamide et al., 1998):

1. First decrease in *Dst* should partly subside before the second decrease follows sometime later. And if A represents the magnitude of the first *Dst* decrease, while C quantifies *Dst* recovery, then A>C>0 nT. Furthermore, if C/A> 0.9,, it is not classified as a Type 2 storm, but simply a Type 1 storm with a magnitude of A.

2. The two peaks in *Dst* must be separated by more than 3 hours, $T + T^1 > 3$ hours. Here T is the duration of recovery for the first storm, while T^1 is the duration of the main phase of the second storm. This condition is meant to exclude cases where apparent decreases in the *Dst* magnitude are caused by such substorm effects as the so-called current wedge, not by a true decrease in the storm time ring current.

Presently with A =174 nT , C = 132 nT , C/A ~ 0.76, T = 18 hours, T" = 7 hours and T + T" = 25 hours. These results confirm the intense storm of April 12-14, 1981 a Type 2 storm. According to Kamide et al. (1998a) and Kozyra et al. (2002), two-step storms result from successive imparts of different regions of southward IMF B_Z on the magnetosphere. The first impact triggers a magnetic storm, which does not have time to recover before the second impart begins. The second decrease in *Dst* index is usually deeper than the first although the magnitude of the second interval of southward B_Z is, in general, not significantly different from the first interval.

It is noteworthy that the aforementioned mechanism by Kamide et al. (1998a) and Kozyra et al. (2002) is an illustration of solar wind-magnetosphere interaction through magnetic reconnection. It now accepted that the physical mechanism for solar wind energy transport into the magnetosphere is magnetic reconnection between the southward IMF B_Z and northward geomagnetic fields (Dungey, 1961). Interconnection of interplanetary magnetic fields and geomagnetic fields leads to magnetic erosion on the dayside magnetosphere by magnetic reconnection, and magnetic field accumulates in the nightside magnetotail region. The magnetic reconnection in the tail results in deep injection of plasma sheet plasma towards the Earth in the nightside. The latter leads to the formation of the storm time ring current, which causes a reduction in geomagnetic field. Given that magnetic storms have their origin in solar wind structures, understanding the present storm would require the explanation of the roles played by the various solar wind parameters, hence the *Dst* variation of this stormed is interpreted using the proton density, solar wind speed, V_{SW} and the IMF B_Z component.

The proton density plot in Figure 1 shows N_{SW} increasing steadily from 7.3 cm^{-3} at 0:00 UT to 11.4 cm^{-3} at 13:00 UT on April 11. At 15:00 UT it increased abruptly to 30.3 cm^{-3}. Thereafter it started to fluctuate rather sharply within a value range of 11.4 -34.1 cm^{-3} between 13:00 and 19:00 UT. At ~20:00 UT, N_{SW} increased sharply from ~16.9 cm^{-3} to 58.1 cm^{-3} at 22:00 UT. The large increase in the proton number density at 15:00 and 22:00 UT respectively signals the arrival of a shock in the interplanetary medium (Nielsen and Honary, 2000; Strickland et al., 2001) at these times. As a consequence, the enhanced solar wind density at 22:00 UT drove the plasma sheet density leading to the injection of the ring current and this caused the sharp depression in *Dst* in the interval between 0:00 and 5:00 UT on April 12. This assertion derives from the fact that plasma sheet density is found to correlate well with high solar wind density (Borovsky et al., 1998). Borovsky et al. (1998) and references therein, have shown that the solar wind density drives plasma sheet density, with the source of the ring current particles being the plasma sheet. Observe that the increase in N_{SW} at 15:00 UT on April 11 resulted in *Dst* index registering a brief weak storm with *Dst* = -31. It appears the proton density enhancement and the consequent injection of the ring current at this particular time was insufficient to cause an intense magnetic storm. The proton density plot further shows N_{SW} decreasing abruptly to 14.8 cm^{-3} at 2:00 UT on April 12. Between 5:00 and 21:00 UT on this same day, available data show that N_{SW} maintained pre-storm values of between 25.4 and 11.9 cm^{-3}. At 23:00 UT N_{SW} increased abruptly to 45.5 cm^{-3} in what appears as the first of a series of three consecutive shocks, as shown N_{SW} increased from 9.1 cm^{-3} at 1:00 UT on April 13 to 27.4 cm^{-3} at 4:00 UT and also from 13.1 cm^{-3} at 7:00 UT to 24.2 cm^{-3} at 9:00 UT.

. The Solar wind speed plot shows the existence of a slow stream in the period 0:00-8:00 UT, April 11 with V_{SW} < 400 kms^{-1}. Between 9:00 and 13:00 UT, the solar wind exhibited a relatively slow stream with V_{SW} = ~400 kms^{-1}. At 15:00 UT with V_{SW} = ~506 kms^{-1}, a high speed solar wind started to come on stream. The high speed stream continued its flow with V_{SW} = ~506 ±20 kms^{-1} until 23:00 UT on April 12 when the speed increased to 669 kms^{-1}. According to Gonzalez et al. (2001) and Gonzalez et al. (2002), intense magnetic storms (D_{st}<100 nT) occur when the solar wind speed is substantially higher than the "average" speed of ~ 400 km/s. V_{SW} decreased to 563 kms^{-1} at 1:00 UT, April 13 then increased again to 638 kms^{-1} at 4:00 UT. It also increased from 567 kms^{-1} at 7:00 to 630 kms^{-1} at 9:00 UT. Note that the coincident increases in N_{SW} and V_{SW} indicate the arrival of shocks (Strickland et al., 2001).

The B_Z plot shows B_Z was northward from 0:00 to 7:00 UT but rotated southward at 8:00 UT with B_Z = -3.2 nT, then oscillated weakly northward at 10:00 UT and was southward again at 11:00 UT. B_Z reached a minimum value -7.6 nT at 14:00 UT before rotating northward at 15:00 UT reaching an intense 16.3 nT at 16:00 UT. B_Z remained intensely northward until 22:00 UT. Thereafter B_Z rotated southward at ~23:00 UT on April 11 and was intense at 0:00-1:00 UT, April 12 with B_Z values at ~14.0 to 18.0 nT. The B_Z plot further shows that B_Z was intensely northward at 5:00 and 22:00 UT on April 12 which was respectively followed by a southward rotation at 7:00 and 23:00 UT. While paucity of data may not allow comments on the nature of B_Z immediately after the southward rotation at 7:00 UT, available data indicates that after the southward turning at 23:00 UT, B_Z became very intense at 0:00 UT on April 13 with B_Z =-26.3nT and remained southward and intense until 14:00 UT of the same day. It is well established that the B_Z component of the IMF is the most important influence on the magnetosphere and high-latitude ionosphere, as it controls the fraction of the energy in the solar wind which is extracted by the magnetosphere. When B_Z is strongly negative, as presently the case, magnetic reconnection between the IMF and the geomagnetic field produces open field lines which allow mass, energy and momentum to be transferred from the solar wind to the Earth's magnetosphere (Davies et. al., 1997). Therefore it convenient to suggest that the B_Z plot during the period under investigation, presented an essential interplanetary requirements which is needed to activate the magnetosphere through reconnection.

The first *Dst* recovery began after the minimum *Dst* at 5:00UT and lasted to 23:00 UT, April 12 when *Dst* attained the value *Dst* = 31nT, and is most probably due to relatively low proton density. Observe that N_{SW} in this period was at the prestorm values. Furthermore, V_{SW} was not significantly higher than the "average" speed of ~ 400 km/s. Note also that B_Z was strongly northward at 5:00 and 22:00 UT with respective values of 15.8 and 13.6 nT, and was weakly southward in the intervening period. Geomagnetic activity is known to decrease precipitously whenever IMF is directed northward (Chaman-Lal, 2000).

According to Gonzalez et al. (1994), the principal characteristic of the *Dst* representation of a geomagnetic storm is the main phase. The main phase of the second step appears to have resulted in part from the sharp increase in N_{SW} that occurred at 23:00 UT, April 12. According to Daglis (1997) and Kamide et al. (1998b), if a new major particle injection occurs it leads to a further development of the ring current with *Dst* index decreasing a second time. Furthermore, the sharp increase in N_{SW} is accompanied essential interplanetary structures which are needed to activate the magnetosphere through reconnection; V_{SW} increased sharply from 483 kms^{-1} at 21:00 UT to 669 kms^{-1} at 23:00 UT and B_Z rotated southward at 23:00 UT, reaching peak intensity of -26.3 nT at 0:00 UT on April 13.

Given the variations of the solar wind parameters as presently observed. it is convenient to suggest that the same magnetospheric process played the leading role in the two successive enhancements in the ring current. Both the first and second enhancements in the ring current. that is. the first and second *Dst* decrease. may be due to the enhanced solar wind density which drove. under southward B_Z conditions. the plasma sheet density leading to the injection of the ring current and this caused the observed sharp depressions in *Dst*. It is pertinent to note that plasma sheet density is found to correlate well with high solar wind density (Borovsky et al.,1998). Borovsky et al.(1998) and references therein have shown that the solar wind density drives plasma sheet density with the source of the ring current particles being the plasma sheet. Furthermore, according to Wang et al.(2003) and references therein, variations of the the *Dst* index can be interpreted as a measurement of the kinetic energy of the particles that make up the ring current.

Ionospheric Response

Ionospheric F region electron density is determined mainly by photoionization, 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 positive or negative ionospheric storm respectively. Ionospheric response to interplanetary forcing is central to space weather research. Presently our primary interest lies, in part, in explaining the response of the ionosphere to the intense geomagnetic storm of April 12-14, 1981 mainly by considering its remarkable features.

The *D(foF2)* variations at the East Asian ionosonde stations are shown in Figure 2 (a) and (b). The stations, as listed in Table 1, consist of the high latitude stations of Yakutsk and Magadan, the mid latitude stations of Khabarovsk, Wakkanai, Akita, Kokubunji and Okinawa, and the low latitude of Manila *D(foF2)* plot for Yakutsk shows that with the exception of a moderate negative storm that occurred between 3:00 and 4:00 UT on April 11. the ionosphere above this station was devoid of storms until about midday. However, beginning from ~13:00 UT *foF2* decreased sharply reaching a minimum value that 53% from the reference level at 16:00 UT indicating the commencement of an intense negative storm which last throughout the period under investigation. Note that the peak depletion occurred at 16:00 UT followed the large increase in the proton number density at 15:00 UT and preceded the present intense storm. The *D(foF2)* variation shows *foF2* recovering to 30 % depletion at 20: 00 UT. But following the sharp increase in N_{SW} at 22:00 UT. *foF2* began to decrease again recording 50% and 61% depletion at 2:00 UT and 11:00 UT respectively on April 12. *foF2* recovered to 42% at 22:00 UT. April 12 but thereafter started to decrease again. *foF2* decreased 52% at 1:00 UT on April 13 before reaching peak depletion of 63% at 13:00 UT the same day. It is convenient to suggest that large depletion of *foF2* beginning from 1:00 UT, April 13 is a consequence of the large increase in the proton number density at 22:00 UT, April 12.

The ionosphere at Magadan did not record any ionospheric storm until ~13:00 UT, April 11. But beginning from this hour the *D(foF2)* plot shows that *foF2* decreased sharply reaching a peak value representing a depletion of 48% from the reference level at 16:00 UT indicating the commencement of an intense negative storm which last throughout the period under investigation. Observe that the peak depletion occurred at 16:00 UT also followed the large increase in the proton number density at 15:00 UT and preceded the present intense storm. The *D(foF2)* variation shows *foF2* recovering to 24 % depletion at 17: 00 UT but immediately began to decrease again recording 51% depletion at 23:00 UT the same day and 69% depletion at 12:00 UT and on April 12. Note again that these large decreases in *foF2* followed the sharp increase in N_{SW} at 22:00 UT, April 11. And following the sharp increase in N_{SW} at 22:00 UT, April 12, *foF2* decreased respectively to 63% and 74% at 2:00 and 11:00 UT on April 13.

Available ionosonde data at Khabarovsk for April 11 appear to indicate the absence of ionospheric F2 region response to the interaction between interplanetary structures and the magnetosphere until after 19:00 UT. Observe that the *D(foF2)* variations show the ionosphere developing a negative storm at 20:00 UT and attained peak depletion of 22% at 22:00 UT. Note the coincidence of this depletion in *foF2* with the large increases in the proton number density at 15:00, 19:00 and 22:00 UT which according to Nielsen and Honary (2000) and Strickland et al. (2001) respectively indicate the arrival of a shock in the interplanetary medium at these times. Insufficiency of data would not allow comment for the period 0:00 -6:00 UT on April 12. but available data indicates the existence of a negative storm in the period 8:00-13:00 UT. The plot further indicates an abrupt depletion of *foF2* beginning at 15:00 UT which lead the peak depletion of 53% at 18:00 UT on the same day. *foF2* recovered to 33% depletion at 23:00 UT but the ionosphere maintained the negative phase that lasted until 21:00 UT on April 13 when *foF2* attained 12% depletion. after which commenced a positive phase with 21% enhancement at 23:00 UT.

The *D(foF2)* plot for Wakkanai appear to show that there were no ionospheric response to the magnetospheric processes in the period 0:00-15:00 UT, April 11. At 16:00 UT, the ionosphere registered a brief negative phase with 17 % depletion of peak electron density. Starting from ~20:00 UT, *foF2* began to decrease rapidly leading to an intense negative storm at 22:00 UT April 11 with 30% depletion of *foF2*. Observe the coincidence of these depletions in *foF2* with the large increases in the proton number density at 15:00, 19:00 and 22:00 UT. Furthermore negative storm at this station also preceded the intense magnetic storm. The negative storm at this station lasted throughout April 12-13 with the peak depletion of 49% occurring at 23:00 UT on April 12.

Available *foF2* data at Akita appear to indicate a rather weak ionospheric F2 region to the interaction between interplanetary structures and the magnetosphere until about 23:00 UT on April 11. At this hour the ionosphere recorded a negative storm with 16% depletion of *foF2*. However, beginning from 4:00 UT on April 12, this station started to record a negative storm with *foF2* decreasing rather sluggishly to attain a peak of 42% depletion of *foF2* at 22:00 UT. This peak depletion of *foF2* occurred nearly coincidentally with the peak at the sharp increase in N_{SW} at 22:00 UT, April 12. Thereafter *foF2* began to recover sluggishly but maintained the negative phase which lasted throughout April 13.

The *D(foF2)* plot for Kokubunji also shows a rather weak ionospheric F2 region response to the first enhancement of solar wind density throughout April 11. Note however the brief negative phase at 17:00 UT and a positive phase between 18:00 and 20:00 UT. But beginning from ~5:00 UT on April 12, this station started to record a negative storm with *foF2* decreasing rather sluggishly until ~12:00 UT when *foF2* decreased abruptly to 33% depletion at 13:00 UT. *foF2* tried to recover but decreased again to 32% depletion at 22:00 UT indicating the existence of an intense negative storm. The *D(foF2)* variations also shows *foF2* decreasing again from about 5:00 UT. April 13. At 14:00 UT the peak electron density at Kokubunji has been depleted to 38% from the reference level.

The *D(foF2)* variations for Okinawa also shows weak ionospheric F2 region response to the magnetospheric processes in the period 0:00 - 12:00 UT. April 11. At 18:00 UT. the station recorded a negative storm which was followed by a positive storm at 23:00 UT. And But beginning from ~4:00 UT on April 12, *foF2* started to decrease rather sluggishly reaching 42% depletion at 14:00 UT indicating the commencement of an intense large storm which lasted until ~21:00 UT. Thereafter, *foF2* recovered to a positive storm at 23:00 UT which lasted to about 3:00 UT on April 13. And beginning from 5:00 UT on this day *foF2* started to decrease but recovered abruptly only to depress sharply at 10:00 UT to reach 50% depletion at 15:00 UT. By 23:00 UT *foF2* had recovered to a weak positive storm.

The *D(foF2)* plot for Manila shows a weak ionospheric response in the period 0:00-10:00 UT, April 11. Thereafter, *foF2* started to decrease lead to a negative phase between 12:00 and 17:00 UT. *foF2* recovered to an intense positive storm at 5:00 UT on April 12. The *D(foF2)* plot shows that the ionosphere at Manila is mostly characterized by positive storm during the period under investigation. The *D(foF2)* variations further shows negative phases at 20:00 UT, April 12 with 25% depletion and on April 13 at 20:00 UT with 23% depletion of peak electron density.

The analysis of the *D(foF2)* plots appear to reveal these significant features:

1. Occurrence of strong negative phase at the low latitude station of Manila before the beginning of a geomagnetic storm.
2. Occurrence of positive ionospheric storm at the mid latitude station of Kukobunji before the beginning of a geomagnetic storm.
3. Absence of positive ionospheric storm effects at high and mid latitudes on the dayside during the initial phase of the magnetic storm.

4. Simultaneous existence of negative storm at high and middle latitudes during April 12-13, 1981
5. Simultaneous intense depletion of *foF2* at all latitudes at ~ 20:00 UT , April 12 (6:00 LT, April 13).
6. Appearance of negative storm at the low latitude station in the period 12:00-17:00 UT, April 12 (21:00 LT, April 12-2:00 LT, April 13).

According to Danilov (2001), a significant feature of the negative is its equatorward shift during the storm from the auroral latitudes to middle latitudes with the amplitude of the effect decreasing during the shift. However, the *D(foF2)* plots do not appear to reveal the aforementioned features of the negative phase. In an earlier study of the F2-region global response Chukwuma (2003a) has also shown, using *foF2* data obtained during the intense storm of March 13-14, 1989($Dst \sim -600$ nT), that the depletion of *foF2* could be simultaneous at high, middle and low latitudes.

Danilov (2001) has suggested the appearance of positive storm before the beginning of a geomagnetic disturbance in the mid-latitudes and the occurrence of strong negative phase at the equator as two of the unsolved problems ionospheric that needs investigation. Presently, this study has revealed the appearance of positive storm before the beginning of a geomagnetic disturbance in the mid-latitudes and the occurrence of strong negative phase at a low latitude station. The observed phenomena appear to be caused by the combined effect of large increase N_{SW} at ~ 15:00 UT and southward turning of B_z at ~ 14:00 UT. The proton density plot shows N_{SW} increasing steadily from 7.3 c at 0:00 UT to 11.4 at 13:00 UT before increasing abruptly to 30.3 cm^{-3} at 15:00 UT. The large increase in the proton number density at 15:00 signals the arrival of a shock in the interplanetary medium (Nielsen and Honary, 2000; Strickland et al., 2001). And the southward B_z appear to have presented essential interplanetary requirements which are needed to activate the magnetosphere through reconnection. Note the depletion of *foF2* also occurred at both high and mid latitudes.

The simultaneous intense depletion of *foF2* at all latitudes at ~ 20:00 UT, April 12 appear to suggest that during the very intense geomagnetic storm of April 12-14, 1981, the *foF2* depletion at all the stations may not be mainly due to changes in neutral composition resulting from neutral wind produced predominantly in the region of Joule heating in the aurora zone. According to Prolss (1995) and references 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. It is important to note that Maih (1989) has reported this low energy (soft) particle precipitation at F2 heights in the equatorial zone. And precipitating particles have also been suggested as the source of heating of the lower part of the thermosphere (Danilov, 2001), which may lead to thermospheric composition changes. Given that particle precipitation is known to occur at both higher and lower latitudes during very intense geomagnetic disturbances (Prolss, 1995 and references therein), particle precipitation as a mechanism may account for the present simultaneous depletion *foF2*.

According to Appleton and Piggott (1953), if a magnetic storm at a station starts near midnight hours there will be an immediate negative storm the next day. On the other hand, if the magnetic storm starts during the period 8:00 to 13:00 local time there will probably follow a positive storm which will be succeeded by a negative storm the following day. According to Prolss (1993) and references therein, independent support for this pattern comes from the observation that negative ionospheric storms commence frequently in the early morning and rarely in the noon and afternoon sectors. It appears from the present results that the processes that give rise to a positive or negative phase of an ionospheric storm are more involved. Observe that the *Dst* plot shows the intense storm commencing at ~11:00 LT (2:00 UT) on April 12 but the *D(foF2)* plots do not appear to indicate the results of Appleton and Piggott (1953) and Prolss (1993) and references therein. According to Chandra and Spencer (1976), during geomagnetic storm an equatorward wind resulting from the heating in the polar region tends to drive the plasma up field lines where electron loss rate is diminished. This process competes with the increase in the loss rate caused by an enrichment of molecular nitrogen (Danilov, 2001). Thus the increase or decrease in *foF2* depends upon the relative effectiveness of the two processes.

Conclusion

We have studied the double step intense geomagnetic storm of April 12-14, 1981 and the F2-region response using *foF2* data obtained from ionosonde stations in East Asian longitudinal sectors. It was found that the leading single magnetospheric process that was responsible for both the first and second *Dst* decrease was the enhancement of the plasma sheet. An enhanced solar wind density drove, under southward B_Z conditions, the plasma sheet density leading to the injection of the ring current. The F2-region response appears characterized by.

- Occurrence of strong negative phase at the low latitude station of Manila before the beginning of the geomagnetic storm.
- Occurrence of positive ionospheric storm at the mid latitude station of Kukobunji before the beginning of a geomagnetic storm.
- Absence of positive ionospheric storm effects at high and mid latitudes on the dayside during the initial phase of the magnetic storm.
- Simultaneous intense depletion of *foF2* at all latitudes at ~20:00 UT, April 12.
- Appearance of negative storm at the low latitude station in the period 12:00-16:00 UT, April 12 (21:00 LT, April 12-2:00 LT, April 13)

The observed simultaneous depletion of *foF2* at all latitudes does not appear to support the previously held notion that the depletion of F2-region plasma density is due to changes in neutral composition resulting from neutral wind produced predominantly by Joule heating in the aurora zone, but rather suggests that particle precipitation does contribute to depletion of *foF2* at all latitudes during intense magnetic storms.

Table I: Ionosonde stations.

Station	Geographic co-ordinates		Geomagnetic co-ordinates		Difference between LST and UT (in hours)
	(°N)	(°E)	(°N)	(°E)	
East Asian sector					
Yakutsk	62.00	129.60	50.90	206.90	+9
Magadan	60.00	151.00	51.90	213.40	+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
Kokubunji	35.70	139.50	26.17	207.50	+9
Okinawa	26.30	127.30	15.30	197.80	+8
Manila	14.70	121.00	4.05	191.9	+8

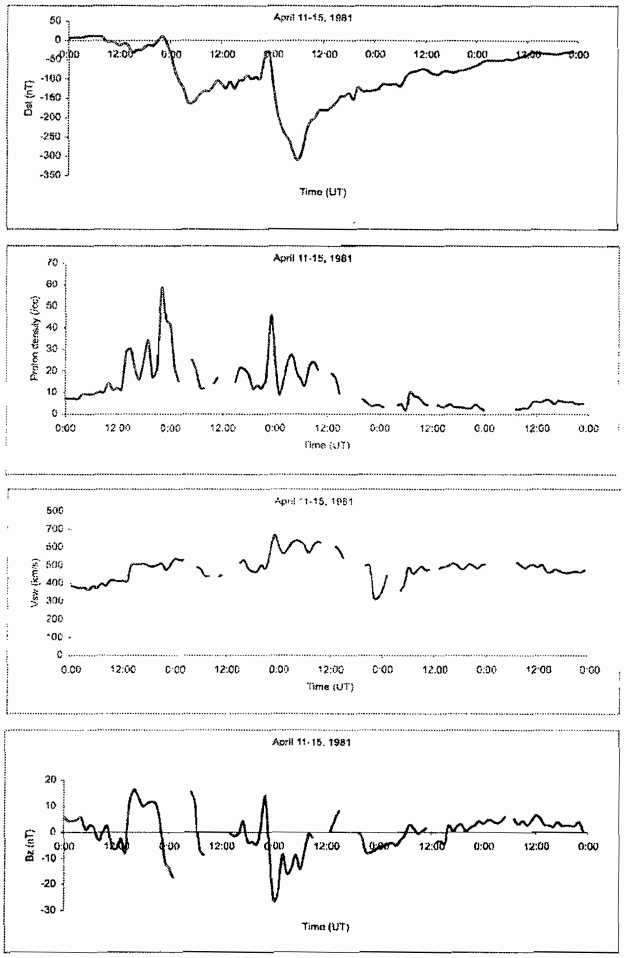

Fig.1: Composition of interplanetary and geomagnetic observations for April 11-15, 1981.

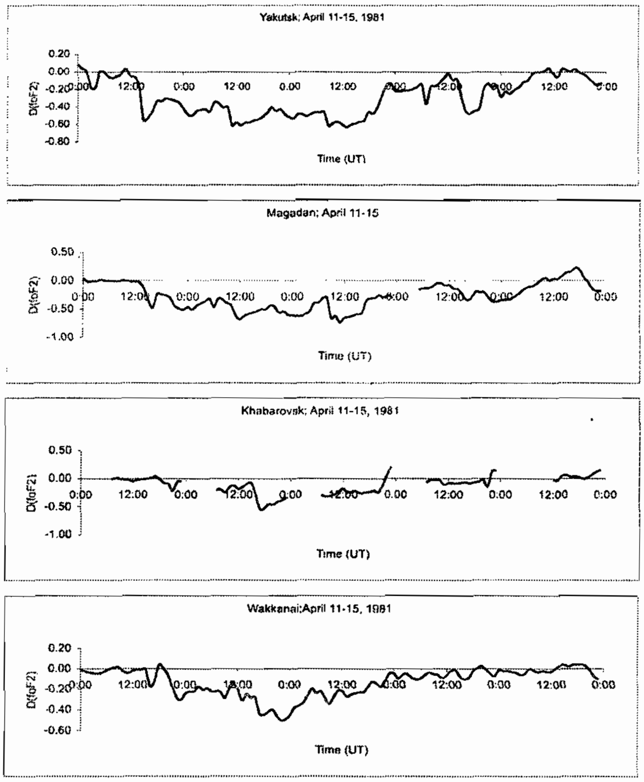

Fig. 2 (a): Variations in *D* (*foF2*) for high latitude stations of Yakutsk and Magadan, and the mid latitude stations of Khabarovsk and Wakkanai for April 11-15, 1981.

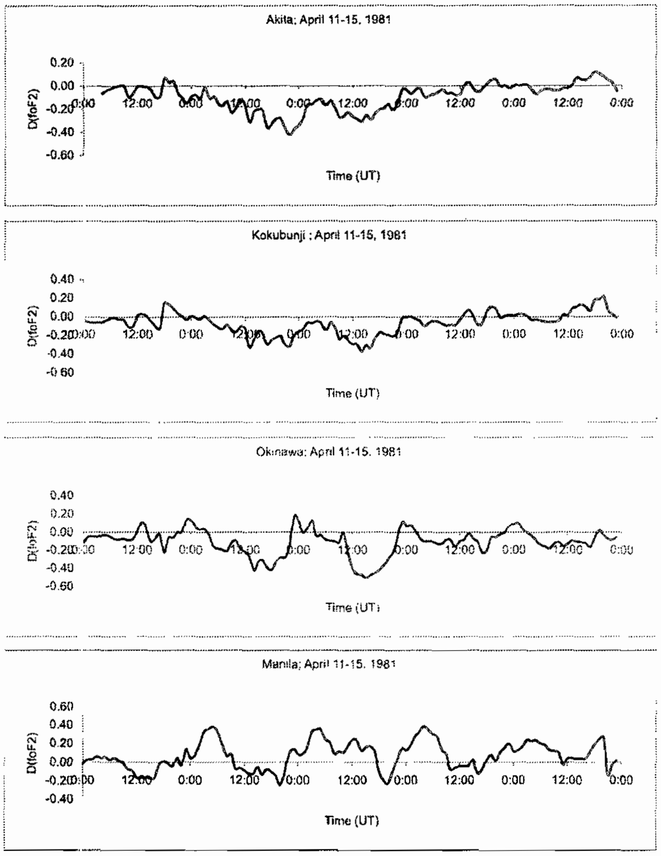

Fig. 2(b): Variations in *D* (*foF2*) for the mid latitude stations of Akita, Kokubunji and Okinawa, and the low latitude of Manila for April 11-15, 1981.

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