VARIABILITY IN THE F1 AND F2 REGION ELECTRON DENSITY DURING A GEOMAGNETIC ACTIVITY AT MID – LATITUDE

Adebesin, B O; Bakare N.O and David T.W.
Department of Physics, Olabisi Onabanjo University, P.M.B.2002, Ago- Iwoye. Nigeria.
f_adebesin@yahoo.co.uk

This paper investigated the variation in the F1 and F2 region electron density during a geomagnetic activity at East Asian mid-latitude stations. In this analysis, D(foF1) and D(foF2) representing deviation of the critical frequency for the F1 and F2 ionospheric regions respectively were employed. The F1 region appears to be much more stable than the F2 layer during the stormy event, as there was no significant effect on the F1 layer in most of the ionospheric stations under investigation. It was also observed that independent of the sign of the storm effect on NmF2, the electron density, if any, in the F1 region is always negative. Moreover, no F1 ionospheric response was observed at midnight (0000UT) throughout the storm event in all the stations; but recorded its maximum effects between 0600UT-1800UT during the day. Conclusively, there is a considerable intra-hour variability of F2 electron density NmF2 during ionospheric disturbances.

***Keywords**: electron density, geomagnetic storm, critical frequency, ionospheric response*

ABSTRACT

INTRODUCTION

The geomagnetic storm is the most important phenomenon in the complex chain of solar terrestrial relations and space weather. However, the storm is supplied by the solar wind energy, captured by the magnetospheric and transferred and dissipated in the high and mid-latitude ionosphere and atmosphere (Buresova and Lastovick, 2001). According to Danilov (2001), the response of the ionospheric disturbances is different from that of the lower ionosphere. The difference is due to the differences in physical mechanisms responsible for the changes of the electron concentration [e]. While in the lower regions, the primary reason of the [e] changes is the variation of the ionization rate because of corpuscular intrusions, there is no considerable change of the ionizing source intensity in the F2 region during geomagnetic disturbances and so the electron concentration variations are due to indirect factors.

The geomagnetic storm effects on the F2-region ionization at a given location depend, in a complicated way, on the time, season and storm onset time (Kilifurska, 1998; Prolss, 1993a). Physical causes of the negative and positive response of the F2- region to a geomagnetic storm have been studied exclusively (Prolss, 1993a,b; Condreseu et al., 1997; Mikhailov and Schlegel, 1998). This paper deals with the variation in F1-layer ionization response to a geomagnetic storm at mid-latitude in comparison with changes in the F2-layer electron density NmF2 for the same storm event.

DATA AND METHOD

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 Space Physics Interactive Data Research {SPIDR), 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).

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

The present study is concerned with variability in the F1 and F2 region electron density during the intense geomagnetic storm of January 10-11, 1976 at mid-latitude. 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

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

Hence the data under analysis consists of D(foF2) & D(foF1) of respective hourly values of foF2 and foF1 respectively on January 5-12, 1976. The reference for each hour is the average value of foF2 and foF1 for that hour calculated from the five quiet days in January 5-9, 1976, preceding the storm. The use of D(foF2) and D(foF1), the normalized deviations of the critical frequency rather than the critical frequency itself provides a first-order correction for temporal, seasonal and solar cycle variations, so that geomagnetic storm effects are better identified (Chukwuma, 2003b).

IONOSPHERIC OBSERVATIONS AND RESULTS

Figures 1 and 2 show D(foF2) and D(foF2) plots for the period of January 10-12, 1976 for the six East Asian mid-latitude ionosonde stations of Khabarovsk (48.5^{0}N), Wakkanai (45.4^{0}N), Akita (39.7^{0}N), Kokunbunji (35.7^{0}N), Yamagawa (31.2^{0}N) and Okinawa (26.3^{0}N). Ionospheric F region electron density is determined mainly by photoionisation, neutral composition and winds during geomagnetic quiet periods. However, the focus is on the response of the F1 and F2 regions of the ionosphere to the intense geomagnetic storm of January 10-11, 1976 and the electron density variations between the two.

F2 Region Response

The D(foF2) plot at Khabarovsk (Figure 1) shows a positive storm between 0000UT and 0300UT on January 10. The D(foF2) variations show the ionosphere developing a negative storm at 0800UT and attaining a 28% depletion level from the reference. It was also observed that the peak depletion in foF2 at 0800UT, 1500UT, January 10 and 0000UT and 1000UT, January 11 coincides with the large increases in proton number density (Figure 3b) at this same points, which according to Strickland et al (2001) indicated the arrival of a shock in the interplanetary medium. However, between 0600UT 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 0600UT and 2100UT, January 12, a positive phase storm with 30% enhancement level was observed.

The ionospheric response at Wakkanai showed that there were no immediate response between 0000UT 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 1900UT and 2100UT, January 10 and 0600UT, January 11. Furthermore, negative storm observed at this station also preceeded the intense magnetic storm. There was 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 showed a predominantly negative phase storm between 0000UT 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. The enhancement between 0000UT and 0900UT, January 11, was observed to have a 37% peak enhancement value.

Available foF2 data at Kokubunji was similar to the D(foF2) plot at Akita except that a negative phase storm was observable between 0000UT 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 0300UT and 2300UT, January 12.

The plot of the ionospheric response at Yamagawa as seen from the figure 1 indicates a rather irregular pattern between 0000UT and 1800UT, January 10, but more of negative storm. Note the enhancement between 0000UT 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 coincided with the minimum peak value of Dst, thus indicating the presence of an intense storm.

The situation at Okinawa was not different, an existing positive phase storm was observed between 0500UT, January 10 and 0200UT, January 11. Depletion in foF2 was observed between 0200UT and 2200UT, January 11; and 0300UT and 1200UT, January 12. Apart from these two points, the F2 response was predominantly positive.

F1 Region Response

The F1 region electron density response at Khabarovsk is shown in Figure 2. There was no data available for January 10. However, the plot for January 11-12 showed little or no response as the observations were close to the reference line. The situation was the same at Wakkanai. Here, the negative storm effect observed was not up to 10% depletion and cannot be regarded as an appreciable response. The D(foF1) plot at Akita showed no immediate response in the ionosphere until around 0300UT, January 11 showing a rather weak storm effect up till 2300UT. However, with effect from 0300UT, January 12, a negative storm of about 23% depletion level was experience till 2300UT of same day.

The situation at Kokubunji (Figure 2) showed an ionospheric activity beginning around 0800UT, January 10 with a sharp fall in the F1 region response to about 40% depletion, and thereafter maintaining this value till 2000UT of same day. The time of activity increase at this station coincided with the time of storm sudden commencement (SSC) on the Bz plot (Figure 3a). Paucity of data would not allow comment on the remaining days. The ionospheric response at Yamagawa was similar to that of Kokubunji except for the negative phase storm experienced around 2300UT, January 11. The condition at Okinawa could also be regarded as no effect on the F1 region.

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 was extracted by the magnetosphere. Hence, the storm experienced at some of the mid latitude stations after storm commencement appear to be caused by the short duration southward turning of Bz giving δBz = -12nT between 0600UT and 0800UT on January 10. It thus appear that this southward turning with δBz = -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 appearance of the positive storms at the high latitude stations under investigation was due to 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 (Danilov, 2001). 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. Strickland et al (2001), had shown that negative ionospheric storm effects are indeed correlated with the region of enhanced molecular mass.

From Figure 4, the following characteristics were observed.

i) the storm event does not have any effect on the F1 region electron density at midnight (0000UT) in all the stations.
ii) the maximum effects on the F1 ionosphere was observed between 0600UT-1800UT during the daytime.
iii) Independent of the sign of the storm effect on NmF2, the effect on electron density, if any, in the F1 region has always been negative.
iv) the F1 region appears to be much more stable than the F2 layer during the geomagnetic activity as there is no significant effect on the F1 layer in most of the stations under investigation.
v) there was a considerable intra-hour variability of NmF2 during the event.

The above observed characteristics suggested that going down from the F2 region maximum, the effect of geomagnetic storms on the neutral thermosphere becomes less dramatic. According to Buresova and Lastivicka (2001), the influence of ionization and photo-chemistry processes on the ionospheric storm becomes more important due to shorter lifetime of free electrons in the more dense atmosphere. Thus, the F1 region is the region where both the changes in the neutral atmosphere (dominant in F2 region) and the changes in the ionization rate and photo-chemistry (dominant in the lower ionosphere) play an important role. Different types of atoms/molecules and maximum number of electrons in each region are shown in Table 2.

CONCLUSION AND SUGGESTION

The variability of F1 and F2 region response to the geomagnetic activity of January 10-11, 1976 at East Asian mid-latitude stations have been studied, and the following observations were made.

- The F1 region appeared to be much more stable than the F2 layer during the storm event. This is because there is no significant effect on the F1 layer in most of the ionospheric stations under investigation.
- Independent of the sign of the storm effect on NmF2, the electron density, if any, in the F1 region is always negative.
- No F1 ionospheric response was observed at midnight (0000UT) throughout the storm event in all the stations; but recorded its maximum effects between 0600UT-1800UT during the day.
- There is a considerable intra-hour variability of NmF2 during ionospheric disturbances.

All the six mid-latitude ionospheric stations investigated are consistent with the conclusions above. In other words, the conclusions are valid for all the six stations. However, the analysis of the variability between the two layers cannot be completely concluded due to a limited data set (of considering its response to only one storm event). In light of this, we are compiling a larger database of storm events and to also investigate the phenomenon beyond the mid-latitude alone, but rather extending our investigation to high and low latitudes.

REFERENCES

Buresova, D., and Lastivicka, J. (2001): Changes in the F1 region electron density during geomagnetic storms at low solar activity. Journal of Atm and Sol. Terr. Phys. 63, 537-544.

Chukwuma, V.U. (2003b) Interplanetary Phenomenon, Geomagnetic and Ionospheric Response associated with the storm of October 20-21, 1989. Acta Geophysica Polonica Vol. 51, No 4, 459-472

Chukwuma, V.U (2007): On positive and Negative Ionospheric Storms. Acta Geod. Geoph. Hung., vol. 42(1),1-21.

Condreseu , M. Fuller-Rowell, T.J., and Kutiev, I.S., (1997): Modelling the F layer during specific geomagnetic storms. Journal of Geophysical Research 102 (A7), 14,315-14,329.

Danilov, A,D. (2001) F2 region response to geomagnetic disturbance, J. Atoms. Sol. Terre. Phys. **63**,431 – 440

Kilifurska, N.A. (1988): Longitudinal effects in the ionosphere during geomagnetic storms. Advances in Space Research 8 (4), 23-26

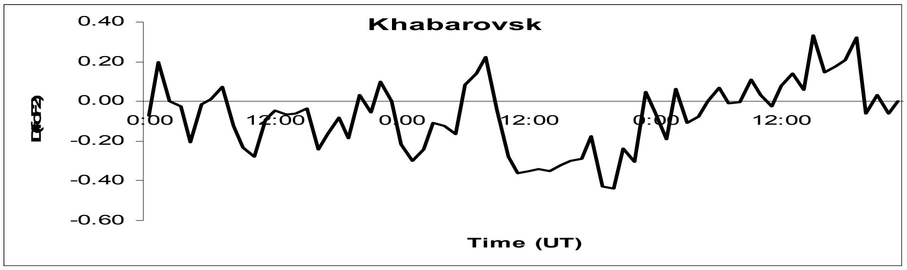
Mikhailov, A., and Schlegel, K. (1998): Physical mechanism of strong negative storm effects in the daytime ionospheric F2 region observed with EISCAT. Annales Geophysicae 16, 602-608.

Oyinloye, J.O. (1988): A Review of Ionospheric Disturbance at Midnight *Atmos. Terr. Phys.* **50**, 519.

Prolss, G.W. (1993a): On explaining the local time variation of ionospheric storm effect. Annales Geophysicae 11, 1-9.

Prolss, G.W. (1993b): Common origin of positive ionospheric storms at mid latitudes and the geomagnetic activity effect at low latitudes. Journal of Geophysical Research 98, 5981-5991.

Strickland, D.J; Daniel, R.E; Craven, J.D (2001): Negative ionospheric storm coincident with DE-1 observed thermospheric disturbance on October 14, 1981, J. Geophys. Res., 106, 21, 049.



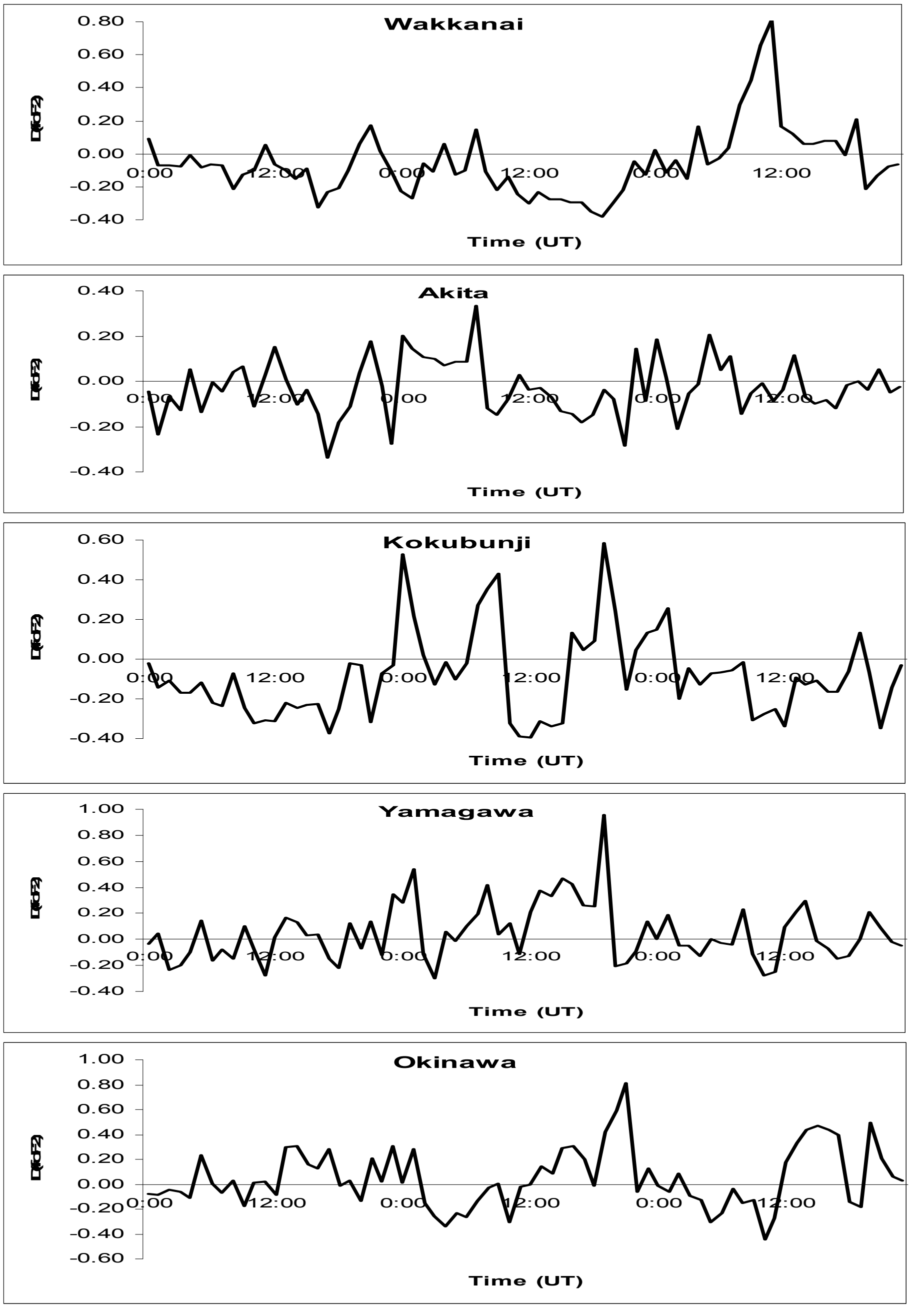
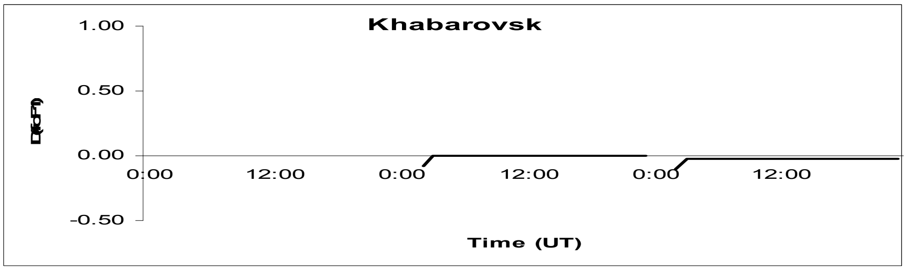


Figure 1: Variations in D(foF2) for the mid latitude stations of Khabarovsk, Wakkanai, Akita Kokubunji, Yamagawa and Okinawa for January 10-12, 1976



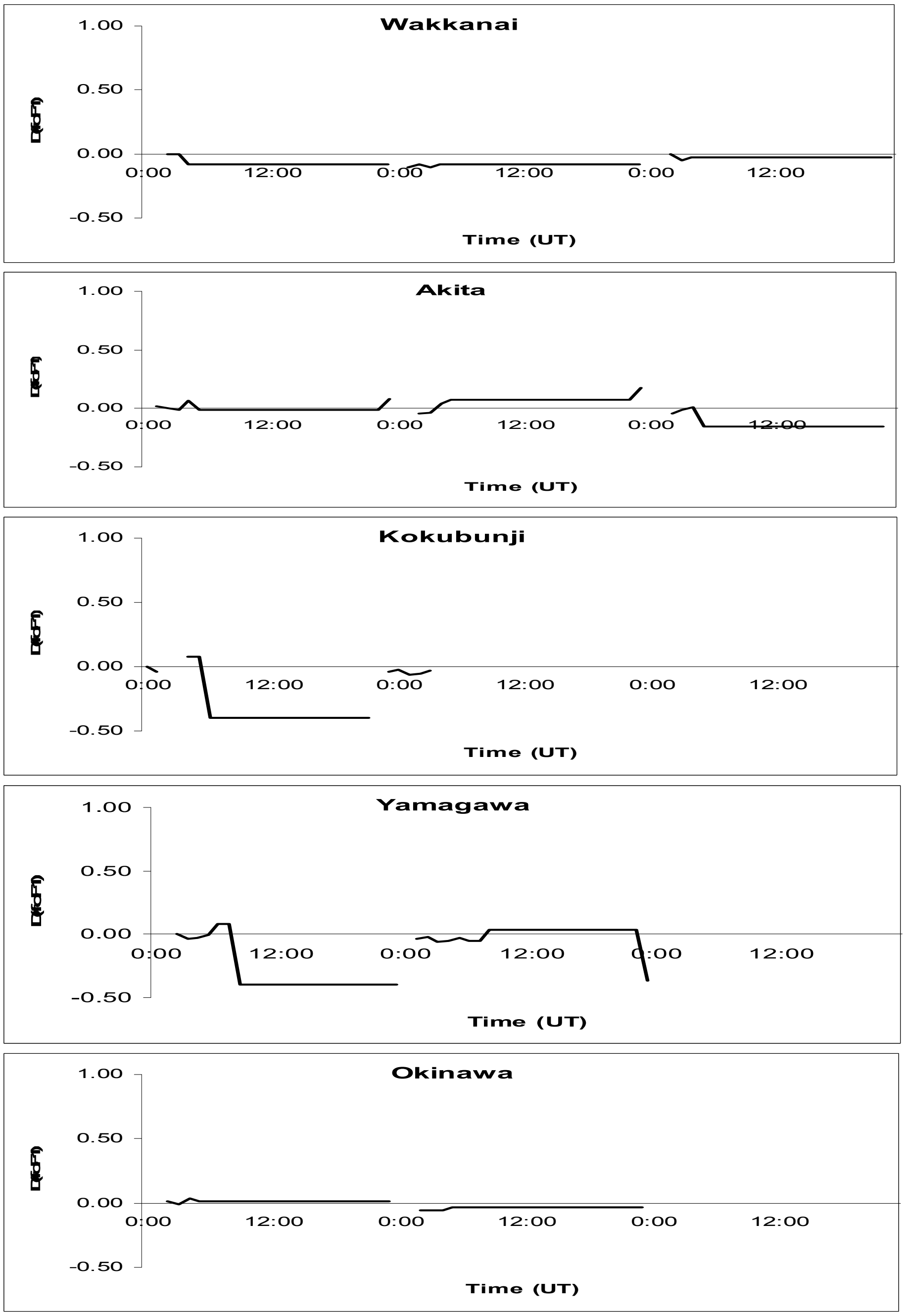


Figure 2: Variations in D(foF1) for the mid latitude stations of Khabarovsk, Wakkanai, Akita Kokubunji, Yamagawa and Okinawa for January 10-12, 1976

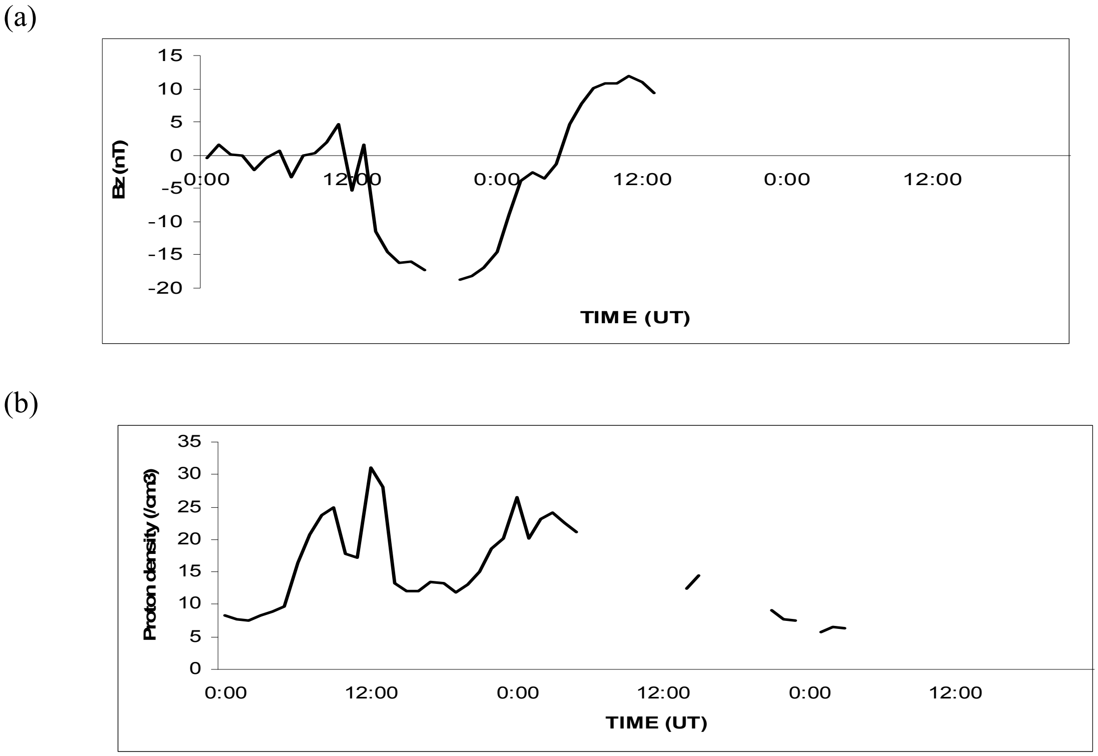


Figure 3**:** Composition of interplanetary observations for January 10-12, 1976,

TABLE 1: IONOSONDE STATIONS

STATIONS	**GEOGRAPHIC CO-ORDINATES**		**GEOMAGNETIC CO-ORDINATES**		**DIFFERENCE BTW LST and UT (Hours)**
	Φ (°N)	λ (°E)	Φ (°N)	λ (°E)	
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

TABLE 2: TYPES OF ATOMS/MOLECULES AND MAXIMUM NUMBER OF ELECTRONS IN EACH REGION.

Regions	Atom/Molecule Present	Maximum no of electron
D	N_2, O_2	10^8-10^{10} electron/m^3 (day)
E	$N_2 > O_2 > O$	10^{11}e/m^3 (day), 10^9e/m^3 (night)
F_1	$N_2 > O > O_2$	10^{12}e/m^3 (day)
F_2	$O > N_2 > O_2$	10^{12}e/m^3 (day), 5x10^{10}e/m^3 (night)

(Oyinloye, 1988)

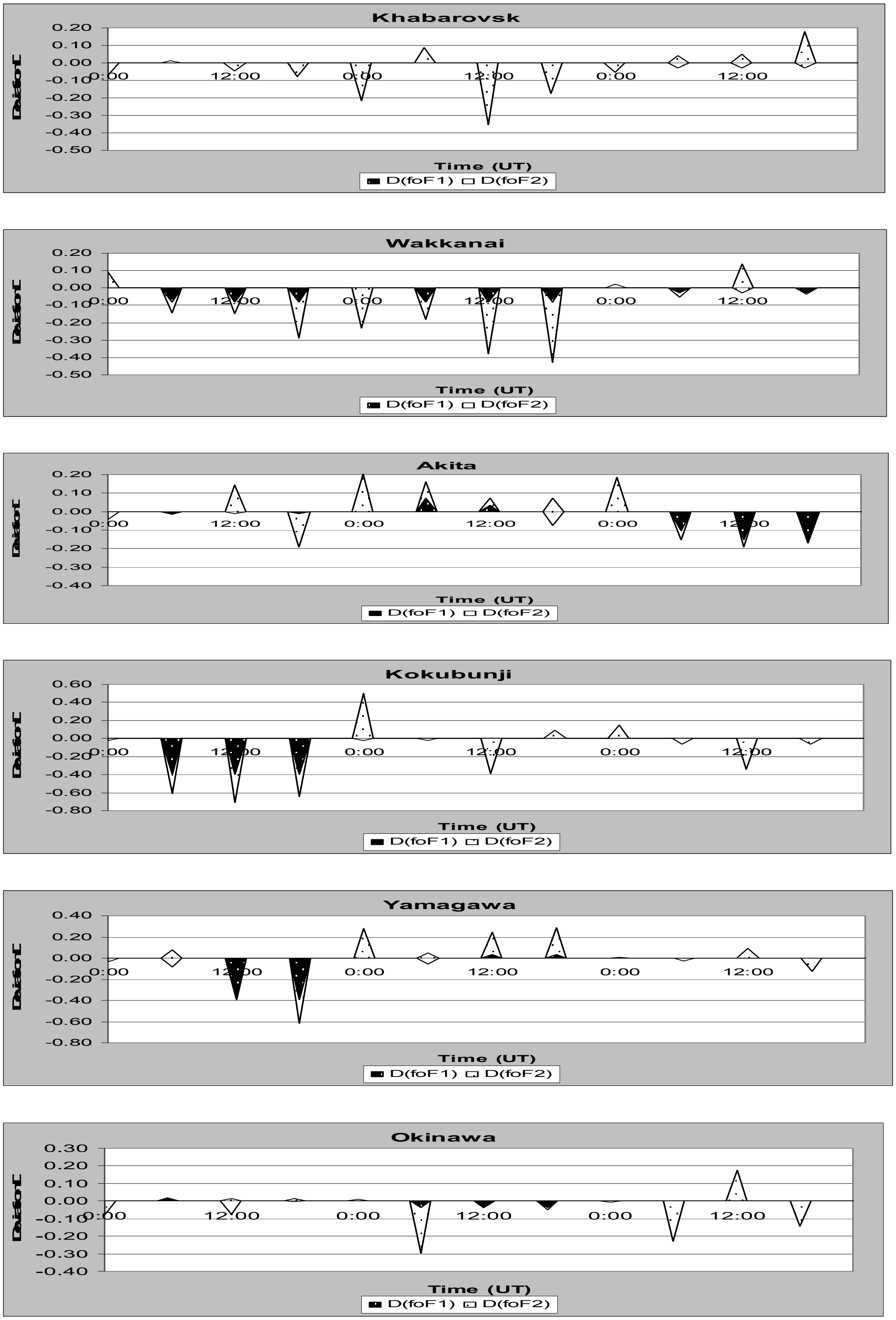


Figure 4: Six hours interval sampling in the variations in D(foF1) and D(foF2) for the mid latitude stations for January 10-12, 1976.