Geofísica Internacional
ISSN: 0016-7169
silvia@geofisica.unam.mx
Universidad Nacional Autónoma de México
México

Mansilla, Gustavo A.
Thermosphere-ionosphere disturbances during two intense geomagnetic storms
Geofísica Internacional, vol. 40, núm. 2, april-june, 2001, pp. 135-144
Universidad Nacional Autónoma de México
Distrito Federal, México

Geofísica Internacional (2001), Vol. 40, Num. 2, pp. 135-144

Thermosphere-ionosphere disturbances during two intense geomagnetic storms

Gustavo A. Mansilla
Laboratorio de Ionosfera - Departamento de Física, Universidad Nacional de Tucumán
Consejo Nacional de Investigaciones Científicas y Técnicas, Argentina

Received: July 17, 2000; accepted: April 4, 2001.

RESUMEN

Mediciones de composición de neutros (nitrógeno molecular N_2, oxígeno atómico O y argón Ar) realizadas por el satélite Dynamic Explorer 2 y de frecuencia crítica de la capa F2 obtenidas con ionosondas, se utilizan para examinar las respuestas de la ionosfera y de la termosfera a dos tormentas geomagnéticas intensas que ocurrieron el 13 de julio y el 21 de septiembre de 1982. Después de la fase inicial de las tormentas, se observan aumentos y descensos en la concentración de O en altas y bajas latitudes, y aumentos de N_2 y Ar. Los incrementos de la relación N_2/O y las tormentas ionosféricas negativas están correlacionados con los cambios de composición producidos por la circulación global debida a las tormentas. Se concluye que pocas horas después del comienzo de las tormentas, el comportamiento de la ionosfera en altas y bajas latitudes está fuertemente controlado por la composición de neutros.

PALABRAS CLAVE: Termosfera, ionosfera, tormenta geomagnética.

ABSTRACT

Neutral gas composition data (molecular nitrogen N_2, atomic oxygen O and argon Ar) from the Dynamic Explorer 2 satellite, and critical frequency of F2-layer obtained with ionosondes, are used to examine the response of the ionosphere-thermosphere system during two intense geomagnetic storms on July 13, 1982 and September 21, 1982. After the initial phase of the storms large fluctuations of O density at high and low latitudes and increases of N_2 and Ar densities are produced. Increases of N_2/O ratio and negative ionospheric storms are correlated and the composition changes are produced by a storm-time circulation. It is concluded that the behavior of the ionosphere is strongly compositionally controlled at high and low latitudes a few hours after storm commencement.

KEY WORDS: Thermosphere, ionosphere, geomagnetic storm.

INTRODUCTION

A transient large amount of energy in the high-latitude region during storm periods changes the meridional pressure gradient and drives a global circulation: the neutral winds flow from high to low latitudes. These winds transport the neutral gas composition changes. The variations in neutral composition (increases in molecular nitrogen and decreases in atomic oxygen) are responsible for the decreases of electron density (negative ionospheric storms); it was demonstrated from measurements that disturbances of the neutral composition and decreases of the peak electron density of the ionospheric F2-layer are closely correlated (Prölss, 1980).

The aim of this paper is to investigate the latitudinal structure of the atmospheric response to intense geomagnetic storms (peak |Dst| > 100 nT) and the disturbance of the critical frequency of F2 layer, foF2. Changes in neutral gas composition control the variation of the ionospheric peak electron density. The storms occurred on July 13, 1982 (peak Dst= -325 nT) and September 21, 1982 (peak Dst= - 228 nT). The storm of July 13, 1982 was the eighth largest storm within the interval from 1957 to 1986 (Tsurutani *et al.*, 1992).

OBSERVATIONS

Simultaneous composition measurements of molecular nitrogen (N_2), atomic oxygen (O) and argon (Ar) between 280 and 300 km of altitude were obtained by the Dynamic Explorer 2 (DE 2) spacecraft. Ground-based foF2 data were obtained with ionosondes.

The upper atmosphere storm effects are analyzed on the storm day and the following day.

Figure 1 shows the development of the geomagnetic index Dst during July 13-14, 1982. The sudden commencement of the storm (sc) was at 1617 UT, the Main Phase Onset (MPO) was around 17 UT on July 13 and the Main Phase End (MPE) on July 14 at 02 UT.

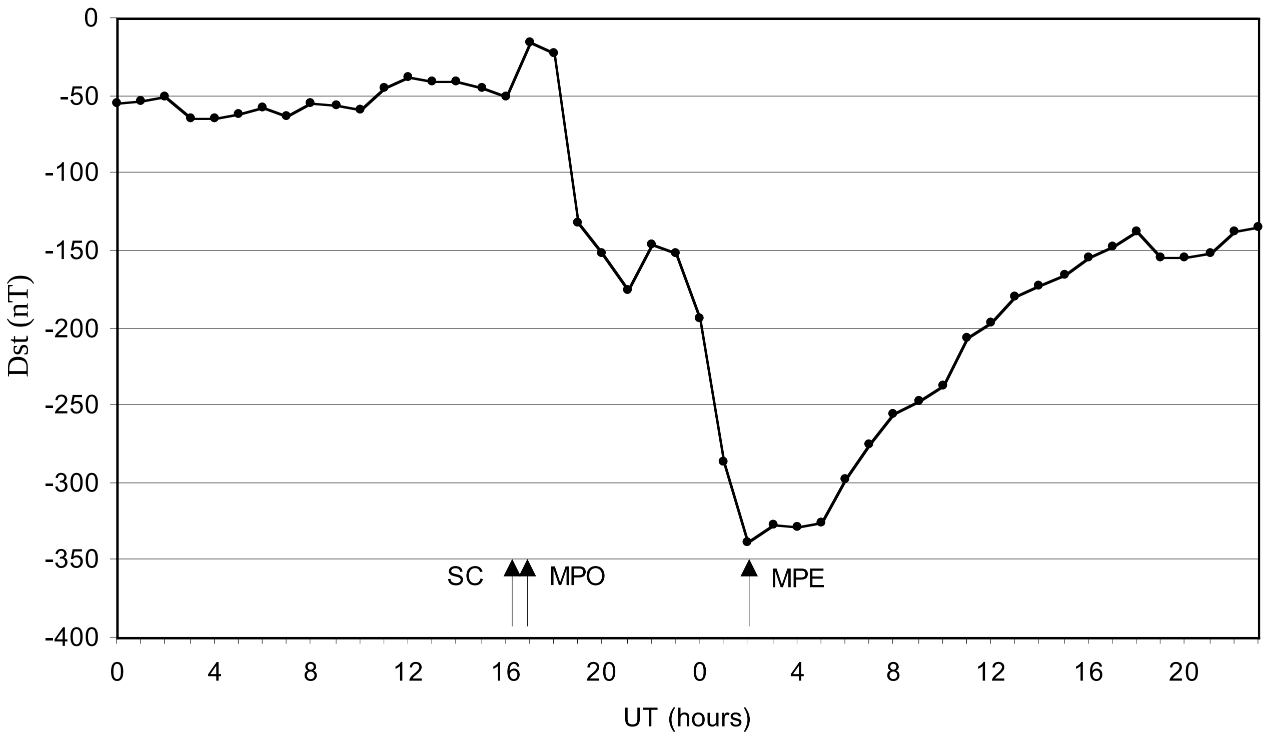

Fig. 1. Hourly Dst geomagnetic index on July 13-14, 1982.

The neutral composition measurements were made at approximately 1500 hours solar local time. The numbers (1) to (5) in Figures 2 to 4 indicate different UT of observation, as follows:

July 13: (1) 1545 UT – 1553 UT; geographic longitude (E): -156°, -157°
(2) 2028 UT – 2036 UT; -79°, -81°
(3) 2203 UT – 2210 UT; -103°, -104°
July 14: (4) 1342 UT – 1353 UT; 19°, 22°
(5) 2000 UT – 2011 UT; -73°, -75°

Figure 2 shows the equatorial and low latitude structure of molecular nitrogen in response to the geomagnetic storm. Measurements of molecular components prior to storm commencement are taken as a quiet-time reference. During the main phase of the storm, a significant and irregular increase of the amplitude and latitudinal extension of N_2 is observed (curves 2 and 3). Relative deviations from reference values, of around 79% and 135% at 20° and 35° geographic latitude respectively, are observed. On July 14, N_2 concentration is decreased; however, a smaller but significant increase occurs at northern low latitudes at around 20 UT (curve 5). No changes which indicate a perturbation propagating equatorward are observed between –10 and 0 degrees.

Figure 3 shows the atomic oxygen density during the storm. O concentration decreases during the main phase of the storm, and N_2 increases. Relative changes in O of about 20% and 39% at 20° and 35° are observed. The oxygen concentration remains low during the recovery phase of the storm at equatorial and low latitudes, while nitrogen concentration increases.

Latitude variations of Ar are illustrated in Figure 4. The largest increase during the main phase of about 615 % occurs at around 35°. After the recovery phase of the storm, Ar values are low. There is no change between –10° and 0°, and a small increase at around 20 UT between 0° and 25°, as for N_2 concentration.

The delayed change in neutral concentration suggests the arrival of a new surge of composition changes possibly caused by a sustained energy injection at high latitudes.

Ionization is proportional to the atomic oxygen density, while the loss of ionization depends on the molecular nitrogen. The N_2/O concentration ratio is a suitable indicator to explain the changes in ionization density.

The latitudinal structure of the N_2/O ratio is shown in Figure 5. Latitude dependence during the main phase of the

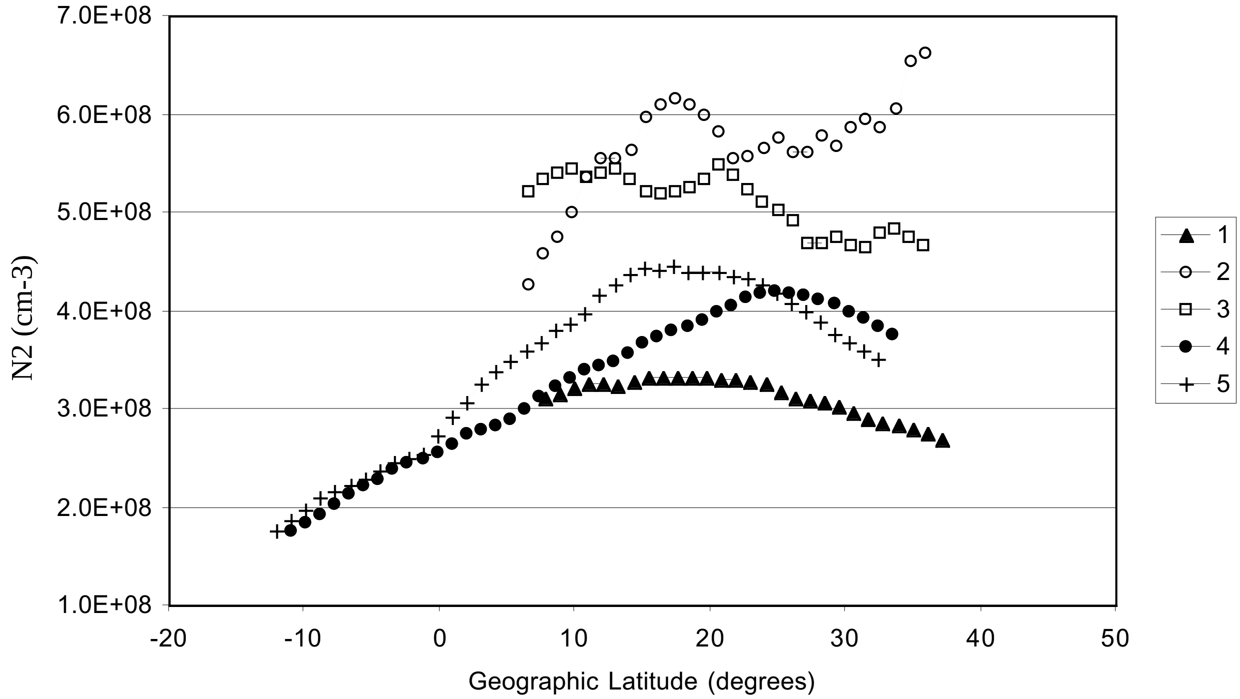

Fig. 2. Equatorial and low latitude structure of molecular nitrogen during five satellite passes on July 13-14, 1982.

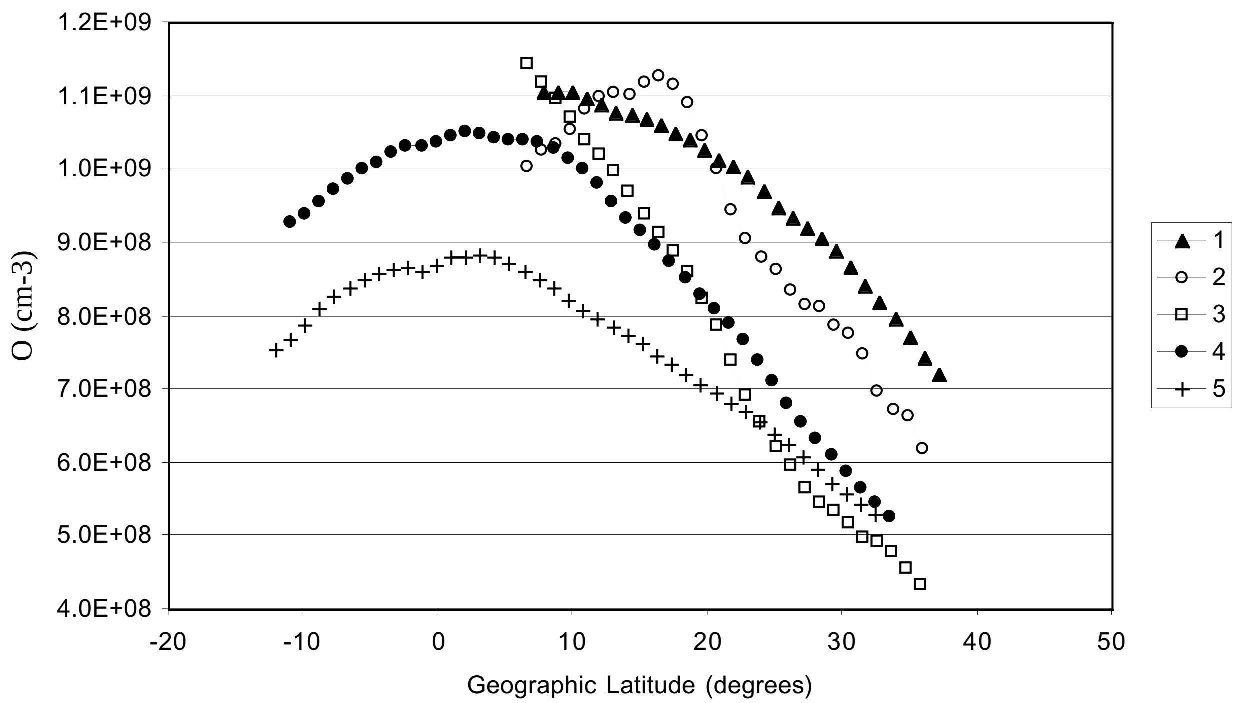

Fig. 3. The same as Figure 2, for atomic oxygen.

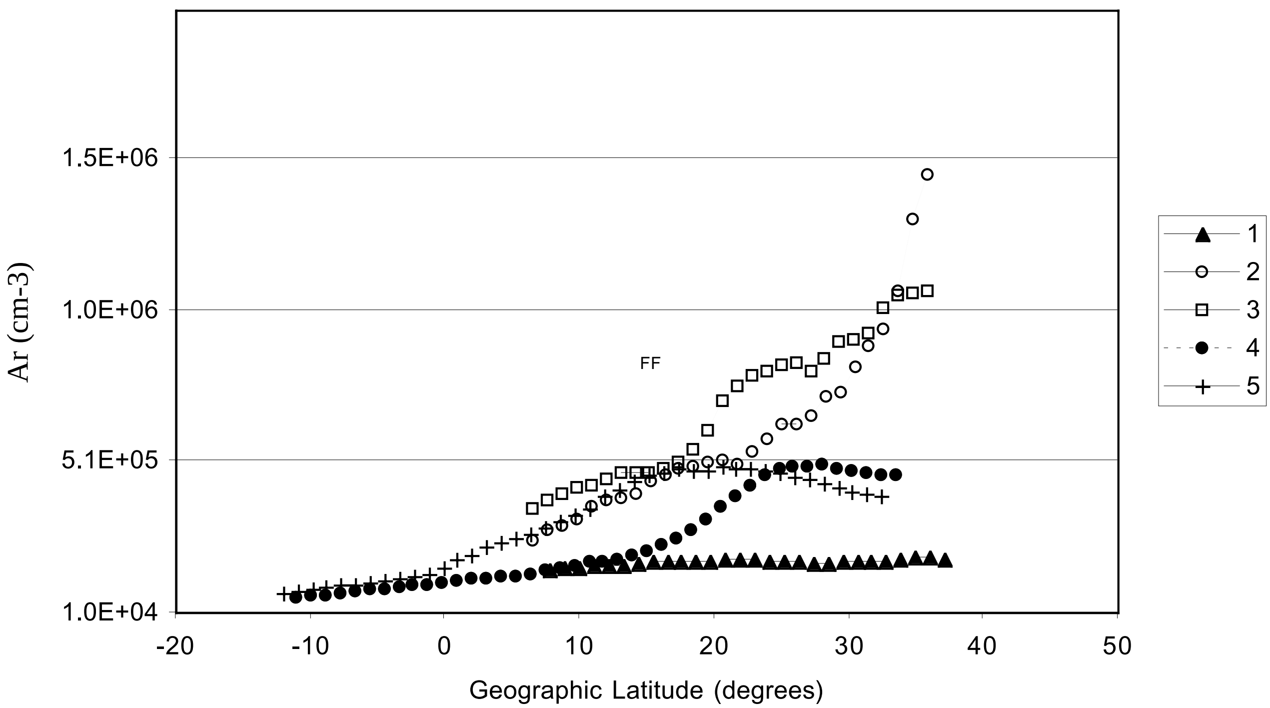

Fig. 4. The same as Figure 2, for argon.

storm is a consequence of increase of molecular nitrogen and decrease of atomic oxygen densities. The small increase of the N_2/O ratio observed at northern low latitudes during the recovery phase is due to simultaneous O decrease and N_2 increase, while the small increase of the N_2/O ratio at latitudes between –10° and 0° is due to O density depletion. This is the cause of the long-lasting negative storm effects at low latitudes.

foF2 data from stations Okinawa (26° N, 127° N), Yamagawa (31° N, 131° E), Kokubunji (36° N, 139° E), Sofia (43° N, 23° E) Bekescsaba (47° N, 21° E) and Rome (42° N, 23° E) show the perturbation during the storm. We use the differences dfoF2 = foF2 – foF2(q), where foF2 (q) are the values corresponding to a quiet geomagnetic day for the month of the storm. The evolution of the differences on storm day and following day are shown in Figure 6.

Negative storm effects begin a few hours after the storm commencement. The decreases begin around 20 UT on 13 July, during the final stage of the main phase of the storm. The negative storm effects continue through July 14 with decreasing amplitude. A new decrease of ionization at around 20 UT is observed at lower latitude stations with an increase of the N_2/O ratio.

Figure 7 shows the evolution of the Dst geomagnetic index on September 21-22, 1982. The sc and MPO of this storm were at 0339 UT and at 16 UT on September 21, while the MPE was at 08 UT next day.

In Figures 8 to 11 the atmospheric response to the storm is shown. The neutral composition measurements were made at approximately 1100 hours of solar local time, as follows:

September 20: (1) 2016 UT – 2019 UT; geographic longitude (E): -144°
September 21: (2) 0712 UT – 0715; 51.7°
(3) 1153 UT – 1156 UT; -18.6°
September 22: (4) 0156 UT – 0159 UT; 130°
(5) 0637 UT – 0640 UT; 60°, 62°
(6) 2039 UT – 2043 UT; -151.7°, -151.9°

The measurements of neutral gas densities on September 20 are taken as a quiet-time reference.

Figure 8 shows the high latitude nitrogen molecular density during the storm. An enhancement in response to the onset of the storm, followed later by a small decrease before the MPO, is initially observed. During the first stage of the main phase of the storm, N_2 concentration increases. The relative deviation is 150% at around 02 UT on September 22 for 80° of geographic latitude. At the end of the main phase, N_2 concentration begins to fall, tending to the reference values during the recovery phase (curve 6).

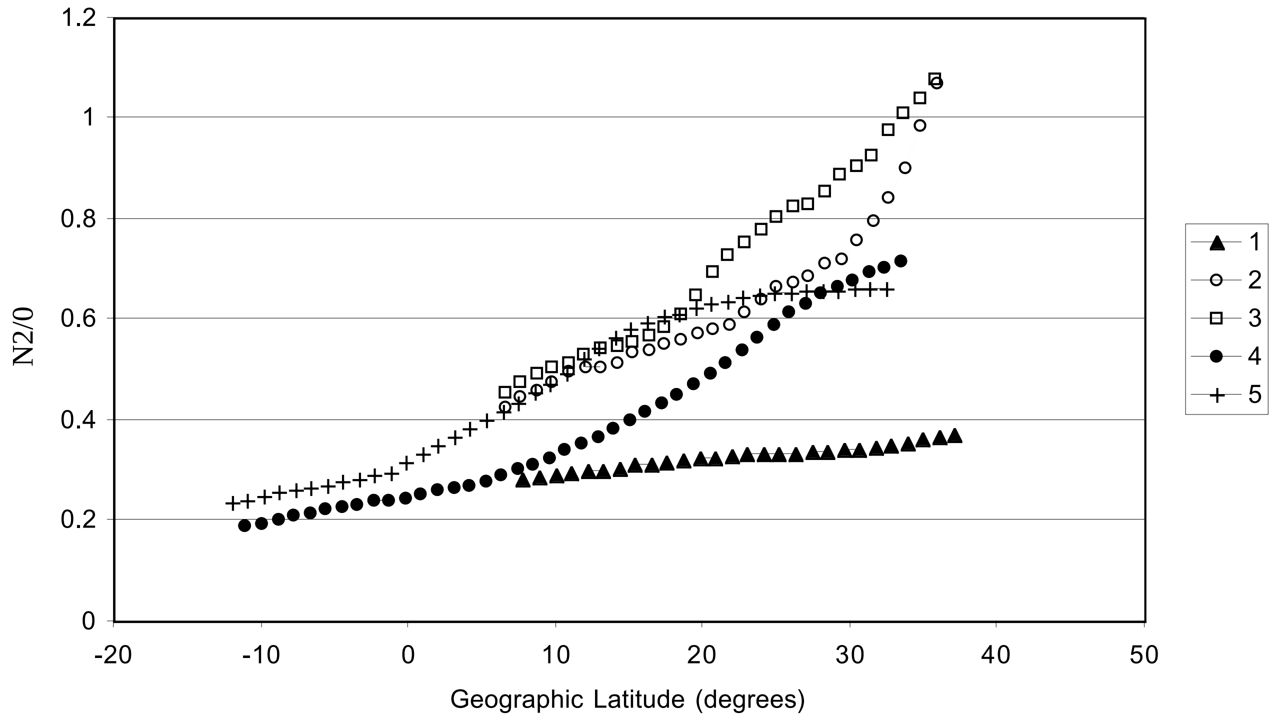

Fig. 5. The same as Figure 2, for molecular nitrogen to atomic oxygen concentration ratio (N_2/O).

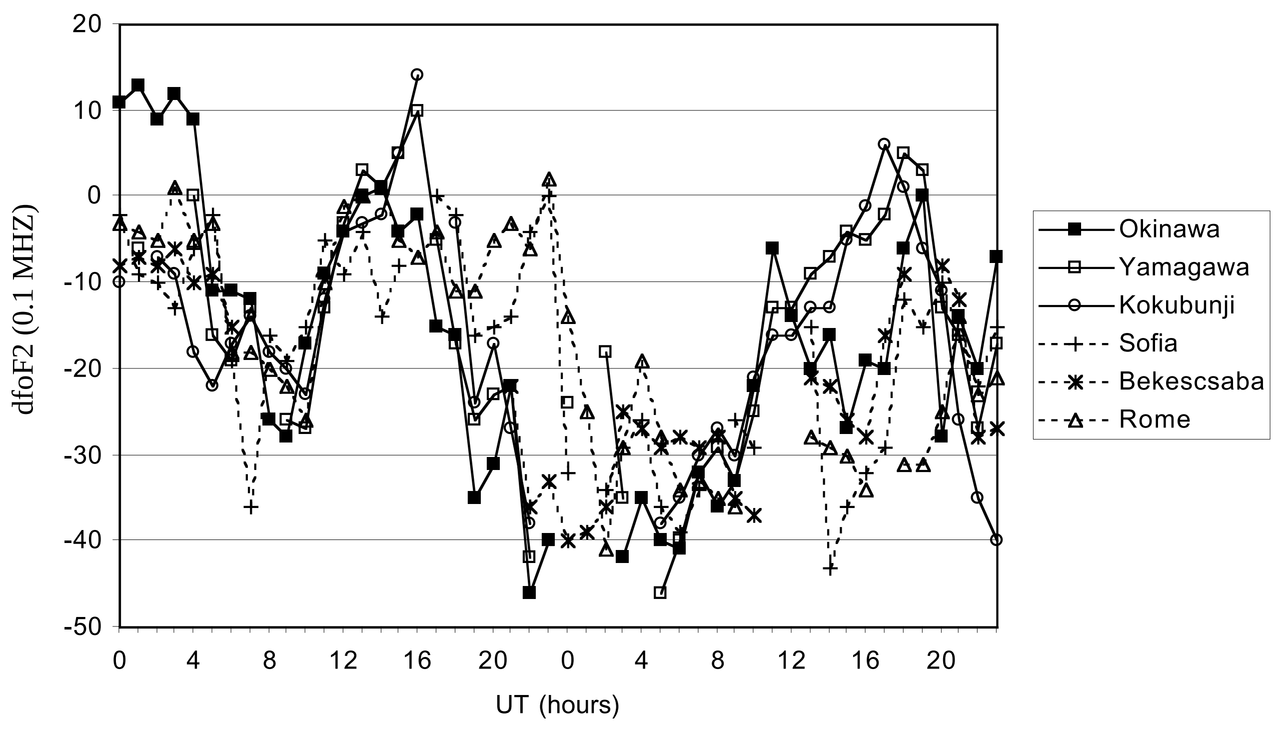

Fig. 6. Temporal evolution of dfoF2 at low latitude stations on July 13-14, 1982.

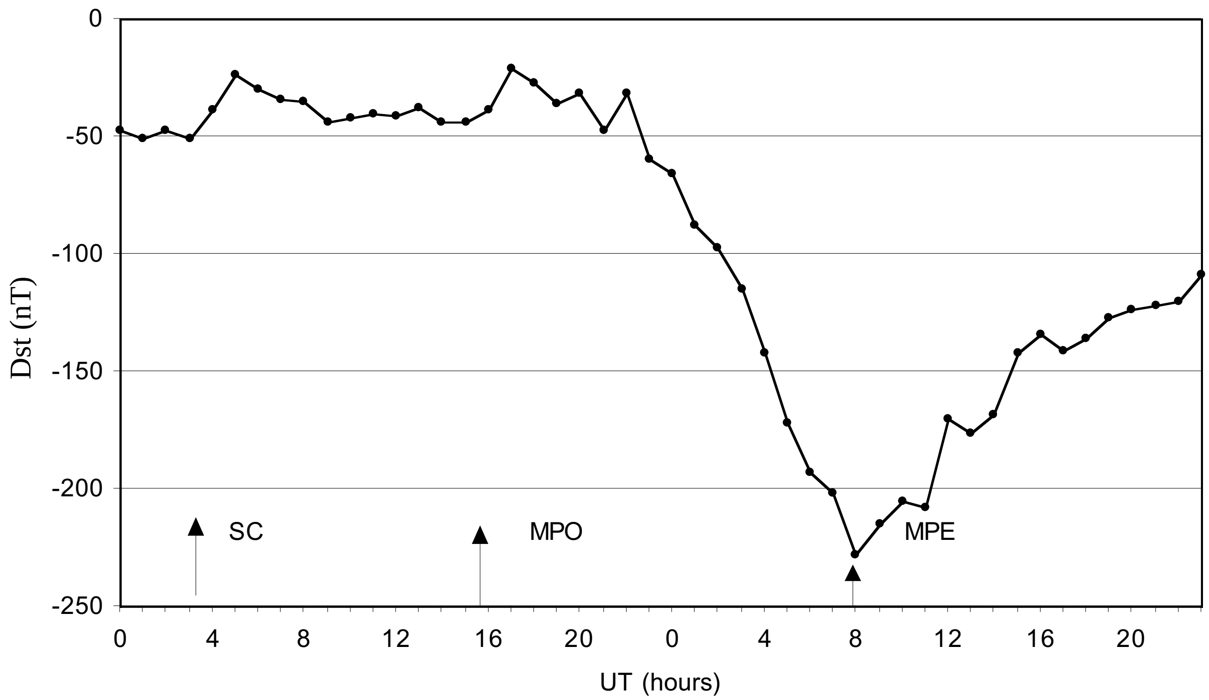

Fig. 7. Hourly Dst geomagnetic index on September 21-22, 1982.

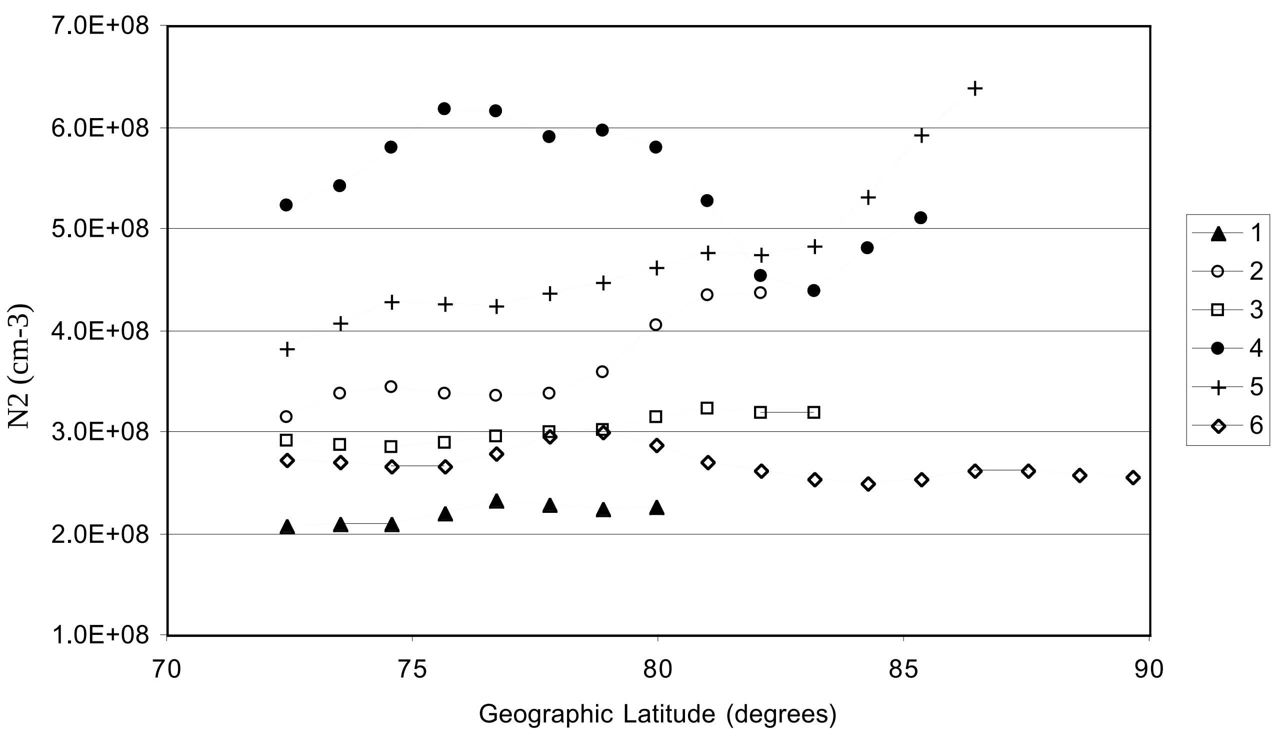

Fig. 8. High latitude structure of molecular nitrogen during six satellite passes on September 20-21-22, 1982.

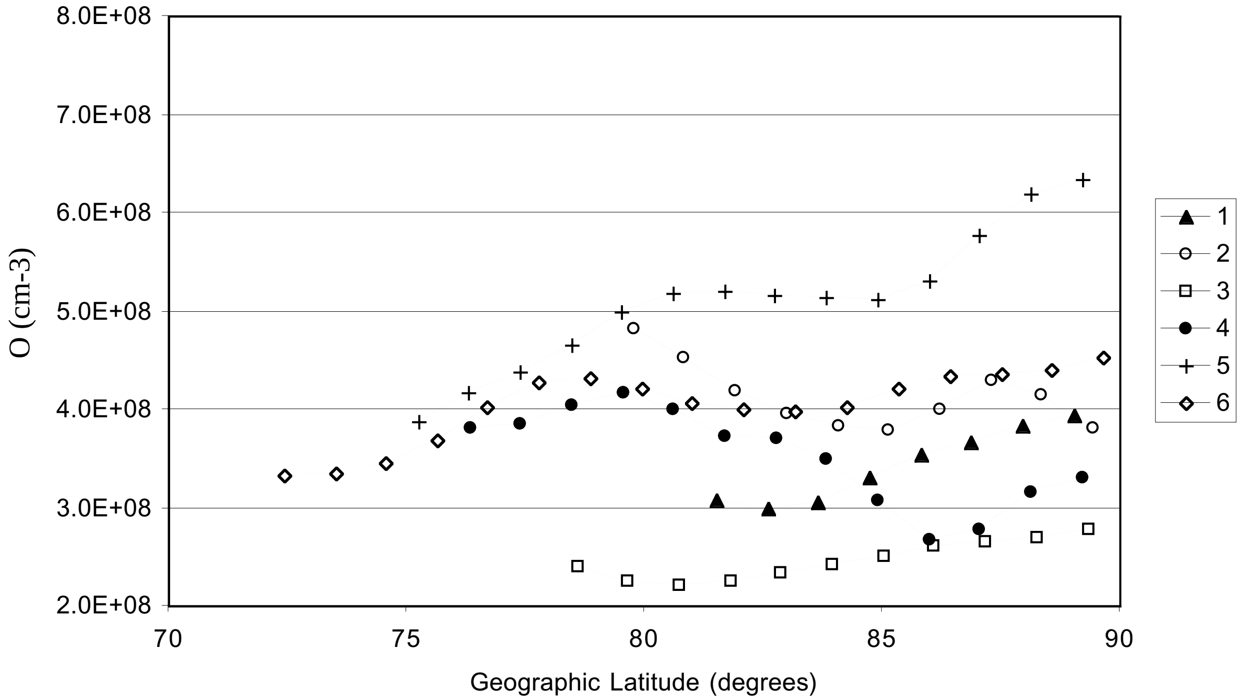

Fig. 9. The same as Figure 8, for atomic oxygen.

Figure 9 shows the atomic oxygen data. In contrast with N_2 behavior, during the initial phase of the storm (before the MPO) oxygen density increases initially, followed by a subsequent reduction. During the main phase of the storm, O concentration continuously increase at all represented latitudes. For instance, the deviation respect to reference values is 53% at around 0640 UT and at 85°. Finally, during the last stage of the storm decreasing values are observed, indicating the recovery (curve 6).

Figure 10 shows the high latitude behavior of the Ar density data during the storm. They significantly increase in response to the storm onset until before the main phase end. A relative deviation of about 947% at 85° of latitude is obtained. The fall to “undisturbed” values begins before the recovery stage of the storm (curves 5 and 6).

The behavior of the N_2/O ratio values is shown in Figure 11. They initially increase from the initial stage of the storm until before the MPE. Afterwards they decrease close to the reference values at around 20 UT.

A few stations from middle to high latitudes with a reasonable amount of foF2 measurements have been found (Figure 12). The stations are Uppsala (60° N, 18° E), Magadan (60° N, 151° E), Yakutsuk (62° N, 129° E) and Resolute Bay (74° N, -95° E). The stations present ionization below quiet conditions on storm day and the following day, and the greater variations seem to occur after MPO.

DISCUSSION

Major changes in neutral densities are observed at low, middle and high latitudes during both magnetic storms. Increases in Ar and N_2 and decreases in O during the main phase of the storms are produced. The largest variation is for argon, followed by molecular nitrogen and atomic oxygen.

The delay time between the onset of the geomagnetic storm and the significant density disturbances suggests that the perturbations are produced by a thermal expansion of the high-latitude atmosphere during the active phase of the geomagnetic storm, which causes strong upward winds that transport density-rich air from lower to higher altitudes and enriches the molecular species at these levels (Prölss, 1998). Upper thermospheric temperatures rise by several hundred Kelvin (Maeda *et al.*, 1989).

Neutral winds then redistribute this dense air over the high-latitude region. After several hours these storm time winds arrival at middle and low latitude regions as part of the global circulation that is set up by the auroral heating.

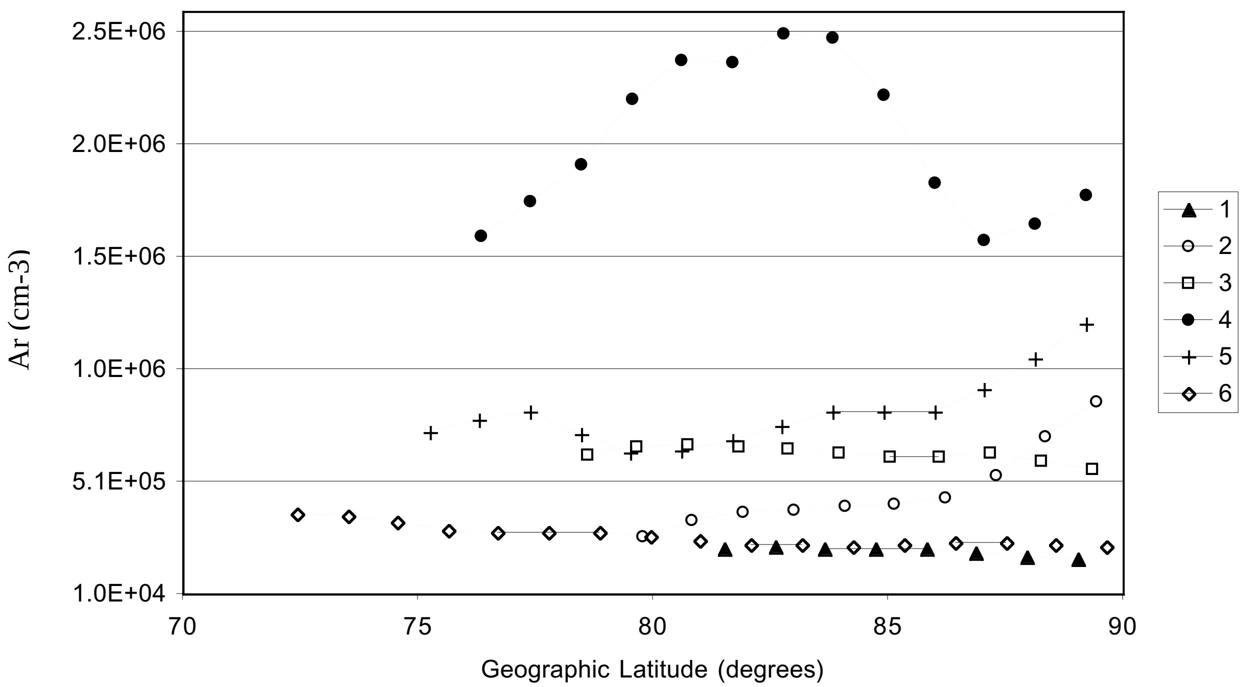

Fig. 10. The same as Figure 8, for argon.

The negative storm effects are closely related to increases in the N_2/O ratio. The increase in the molecular nitrogen density and the decrease in the atomic oxygen density may contribute to reduce the ionization density at peak F2-region height. Enhancement of O concentration at high latitudes is observed, while negative storm effects prevail at the stations. Notice that during the main phases of storms at high latitudes O and N_2 concentrations are nearly comparable, while O concentration is greater than N_2 concentration at low latitudes.

These results suggest that the negative ionospheric storms are caused by an increase in the molecular nitrogen and by a decrease in the oxygen atomic, which are associated to storm-induced winds. The conspicuous falls of ionization are delayed respect the onset of the storm making evident that they are produced by neutral winds because several hours are required between the generation and the propagation toward low latitudes of these winds carrying composition changes.

Two mechanisms involved in F2-layer storm phenomena play important roles at low and high latitudes during the initial stage of storms.

In day-time an equatorial east-west electric field of magnetospheric origin, in conjunction with the geomagnetic field, causes a drift of ionization from a region where the loss rate is greater into a region where the loss ratio is lower. Ionization diffuses along the geomagnetic field lines toward higher latitudes, thus causing a depletion of electron density around the equator and two crests on both sides of the equator. This effect is the Appleton or equatorial anomaly. During storm periods a temporary enhancement of the eastward-directed electric field is produced. This enhancement increases the upward drift and occurs a subsequent drainage from equatorial latitudes.

At night, the direction of the electric field reverses and the drift of ionization is in the downward direction. It is reasonable to assume that the depletion of ionization observed at low latitudes during the initial phase of the geomagnetic storm on July 13, 1982 may be caused by an enhanced electric field since these disturbances are produced nearly simultaneously at different latitudes (e. g. Yamagawa, Kokubunji and Okinawa).

CONCLUSIONS

Changes of neutral gas composition (N_2, O and Ar) and their relation with ionospheric disturbance effects during intense geomagnetic storms have been studied.

Important changes of neutral gas composition were

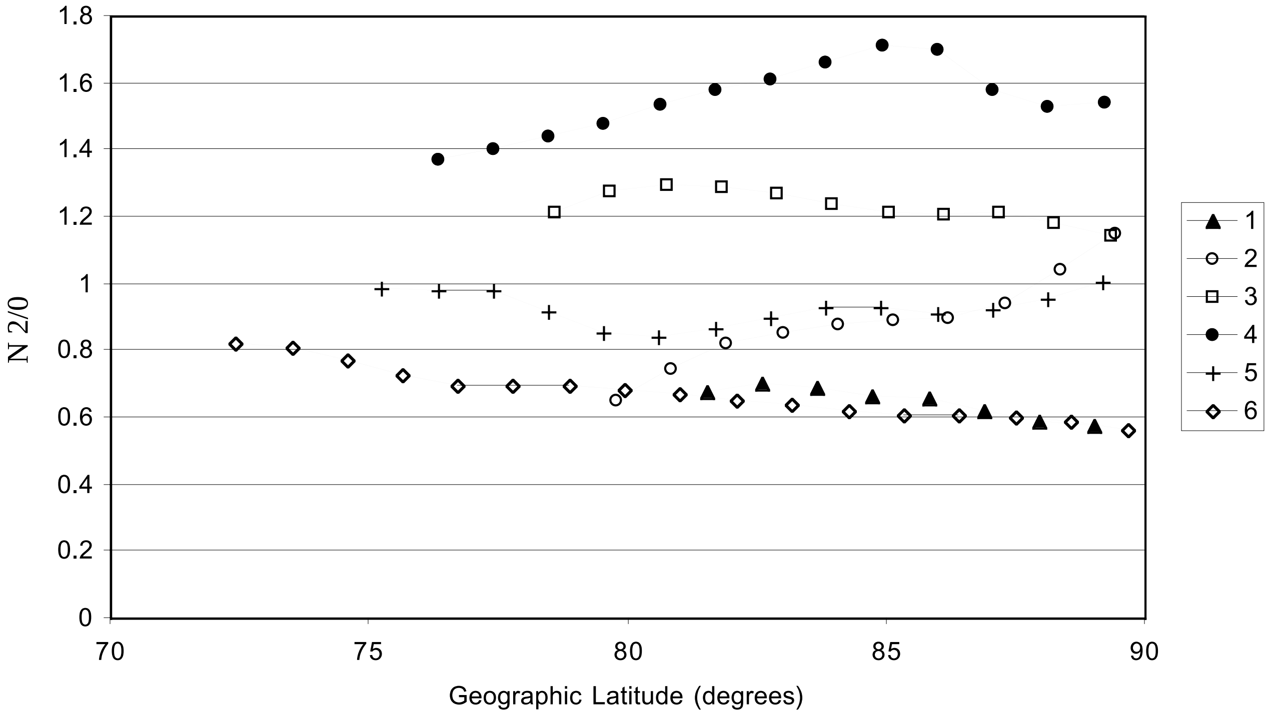

Fig. 11. The same as Figure 8, for molecular nitrogen to atomic oxygen concentration ratio (N_2/O).

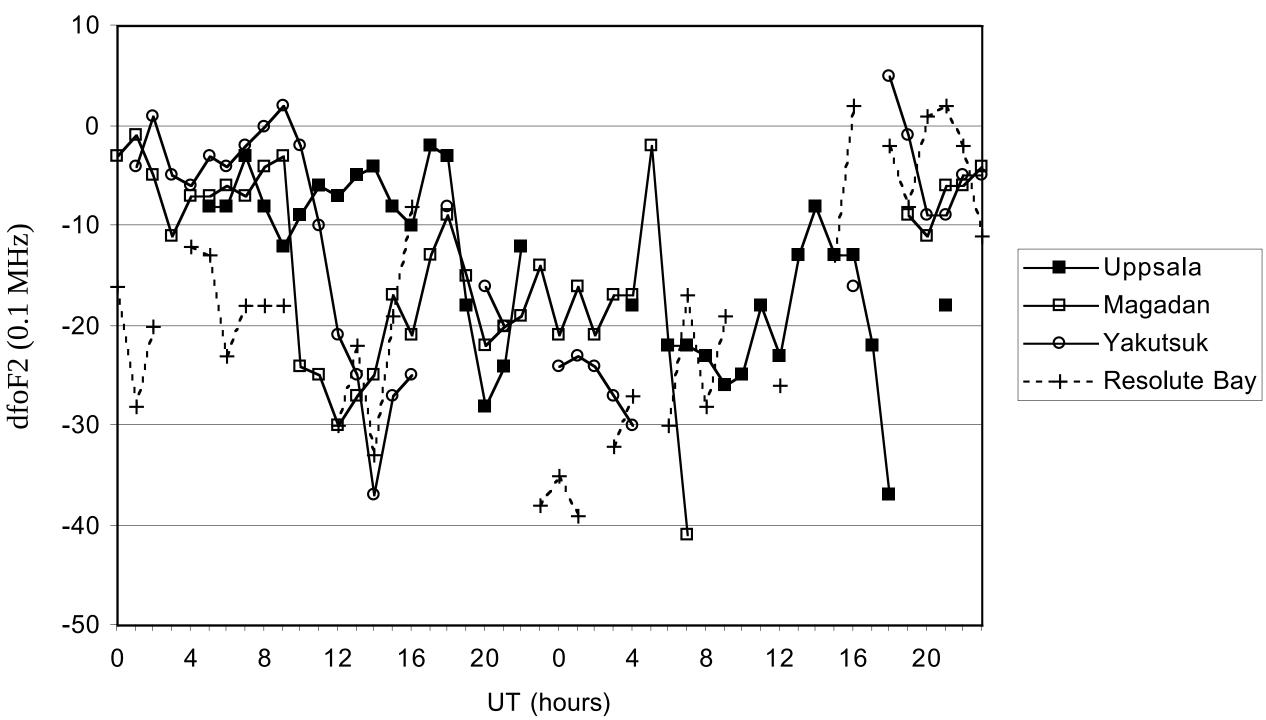

Fig. 12. Temporal evolution of dfoF2 at middle-high latitudes stations on September 21-22, 1982.

found at low and high latitudes at heights between 280 to 300 km and also in the ionosphere.

(a) Increases of N_2 and Ar densities are observed at high and low latitudes during the main phase of storms.

(b) Decreases at equatorial and low latitudes and increases at high latitudes of the O density are also produced at this stage.

(c) The increases in the N_2/O ratio and the negative ionospheric storms correspond closely. This suggests that the behavior of the ionosphere is strongly compositionally controll ed when the global circulation is established.

(d) The increase of O density at high latitudes when N_2 density is enhanced is not sufficient to generate positive ionospheric storm effects. Possibly these increases of ionization may depend on a relative increase of O over N_2.

BIBLIOGRAPHY

MAEDA, S., T. J. FULLER-ROWELL and D. S. EEVANS, 1989. Zonally Averaged Dynamical and Compositional Response of the Thermosphere to Auroral Activity During Sept 18-24, 1984, *J. Geophys. Res.*, 94, 16869-16883.

PRÖLSS, G. W., 1980. Magnetic Storm Associated Perturbations of the Upper Atmosphere: Recent Results Obtained by Satellite-Borne Gas Analyzers, *Rev. of Geophys. and Space Phys.*, 18, 183-202.

PRÖLSS, G. W., 1998. Magnetic Storm Associated Perturbations of the Upper Atmosphere, Magnetic Storms, *Geophysical Monograph Series 98, Ed. American Geophysical Union*, 227-241.

TSURUTANI, B. T., W. D. GONZALEZ, F. TANG and Y. T. LEE, 1992. Great Magnetic Storms, *Geophys. Res. Lett.*, 19, 73-76.

Gustavo A. Mansilla

Email: gmansilla@herrera.unt.edu.ar
Laboratorio de Ionosfera - Departamento de Física, Universidad Nacional de Tucumán
Av. Independencia 1800
4000-San Miguel de Tucumán,
Argentina