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Upper-atmosphere perturbations at subauroral latitudes during an intense geomagnetic storm

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RESUMEN

Mediciones de composición de neutros (nitrógeno molecular N_2 y oxígeno atómico O) obtenidas entre 310 y 330 km por el satélite Dynamic Explorer 2, y de frecuencia crítica foF2 obtenidas con ionosondas, se utilizan para examinar las respuestas de la termosfera y de la ionosfera a una tormenta geomagnética intensa ocurrida el 5 de septiembre de 1982. Los resultados obtenidos representan una comparación de mediciones simultáneas de perturbaciones en la composición de los gases neutros *in situ* y del pico de densidad electrónica. Se observan incrementos en la concentración de N_2 y disminuciones de O, siendo mayor la variación de N_2 que la de O. Ambos cambios contribuyen a explicar los descensos de densidad electrónica observados. Incrementos de ionización retardados respecto al comienzo de la tormenta se atribuyen a una precipitación de partículas antes que a un transporte de ionización.

PALABRAS CLAVE: Termosfera, ionosfera, latitudes subaurorales, tormenta geomagnética.

ABSTRACT

Neutral gas density data of molecular nitrogen N_2 and atomic oxygen O between 310 km and 330 km altitude as obtained by the Dynamic Explorer 2 satellite and ground-based foF2 data with ionosondes were used to examine the response of the thermosphere-ionosphere system to the intense geomagnetic storm of September 5, 1982. A comparison of simultaneous measurements of gas composition and peak electron density was obtained. Increase of N_2 concentration and concurrent decrease of O concentration is observed. The N_2 variation is greater than the O variation. Both changes contribute to explain the reduction in ionization density. Delayed increases of ionization are attributed to particle precipitation rather than to ionization transport.

KEY WORDS: Thermosphere, ionosphere, subauroral latitudes, geomagnetic storm.

INTRODUCTION

Significant disturbances in the upper atmosphere are produced during geomagnetic storms. However, many features of atmospheric disturbances remain poorly understood.

The study of these perturbations is of great practical importance because intense storms disturb radio communications, shorten the lifespan of satellites and degrade satellite ephemeris predictions (Richards *et al.*, 1994; Prölss, 1998).

A transient of energy is deposited in the auroral region during storm periods. This leads to the development of a disturbance zone in the neutral composition and to a change in the meridional pressure gradient, driving a global circulation in which neutral winds flow from high to low latitudes.

The neutral winds transport the neutral composition changes into the ionospheric F region. The changes are then advected away from the auroral zone by the global circulation set up by auroral heating.

The upward and equatorial flow of oxygen atoms (O) forces the ionospheric plasma upward along equatorward geomagnetic field lines, thus causing enhanced electron densities (positive ionospheric storms).

The storm time circulation also transports molecular nitrogen (N_2), which causes accelerated ion-atom charge transfer reaction between O^+ and N_2, leading to depressed electron densities (negative ionospheric storms).

In this paper, temporal variations of neutral composition at subauroral latitudes, and their association with ionospheric disturbance effects during different phases of the intense geomagnetic storm of September 5, 1982 (peak Dst= - 289 nT), are analyzed.

In situ neutral density data are often incomplete during storm periods since they have low time resolution (one orbital period). However, this geomagnetic storm has a fairly good amount of data.

The atmospheric data are molecular nitrogen and atomic oxygen concentrations between 310 km and 330 km altitude taken by the instruments aboard the Dynamic Explorer 2 (DE 2) satellite at a common solar local time (23.6-23.7 hours). The ionospheric data are the critical frequency of the F2 layer (foF2) from ionospheric stations located inside the zone of magnetic storm associated with neutral composition changes.

OBSERVATIONS

The Dst geomagnetic index was used to specify the different phases of the geomagnetic storm. Figure 1 shows the evolution of Dst on September 5, 6 and 7, 1982 in universal time (UT). The storm sudden commencement (sc) was at 2250 UT on September 5. The abrupt positive change following the sc (initial phase of the storm), caused by the compression of the magnetosphere by the arrival of a solar wind disturbance at the magnetopause, remains around 1 hour. The large decrease of Dst after the initial phase (main phase of the storm), associated with the growth of the ring current in the magnetosphere, was from 00 UT to around 13 UT on September 6, with a decrease to – 289 nT. Finally, the gradual recovery of Dst, a consequence of the decay of the ring current (recovery phase of the storm), lingers through more than 36 hours.

The measurements of neutral constituents were taken by the satellite every 15 seconds from around 290 to 650 km. Data at heights of the F2 ionospheric region (310 – 330 km) have been selected. Numbers (1) to (6) in Figures 2 to 4 indicate different UTs of observation (satellite passes), as follows:

September 5: (1) 4:43 UT – 4:45 UT
September 6: (2) 12:32 UT – 12:35 UT
(3) 17:14 UT – 17:16 UT
September 7: (4) 8:52 UT – 8:54 UT
(5) 16:41 UT – 16:43 UT
(6) 19:49 UT – 19:51 UT

The temporal evolution of the latitudinal structure of N2 composition during the satellite passes is shown in Figure 2. Measurements of neutral constituents prior to storm commencement are taken as reference (curve 1). Significant increases at the end of the main phase and also during the first stage of the recovery phase are observed (curves 2 and 3). As example, at 50 degrees of invariant latitude an enhancement of 169 % from the reference value is seen; N_2 increases with decreasing latitude. A slow decay toward reference values during the recovery phase of the storm is observed.

Figure 3 shows the corresponding atomic oxygen concentration variation. It is quite different to that of the N_2 concentration. O is depressed at the end of the main phase, increasing the fall until around the end of the recovery phase, when it begins to increase (curve 6). Depletions of 7 % and 30 % are observed at the end of the main phase and during the recovery phase (curve 5) respectively, at around 50 degrees of invariant latitude. Note that O concentration remains low when N_2 is tending towards reference values (curve 5).

The molecular nitrogen to atomic oxygen (N_2/O) concentration ratio is a suitable indicator to explain the changes in the ionization density. The N_2/O ratio variation during the storm is shown in Figure 4. The significant increases during the end of the main phase and in the first stage of the recovery make evident a control of N_2 composition. The decrease and subsequent increase observed during the recovery phase (curves 4 and 5) seem to be principally controlled by the fall of atomic oxygen. At the end of the recovery of the storm the N_2/O ratio decreases again.

Since the molecular nitrogen to atomic oxygen ratio is above reference values throughout the storm period, a direct relation between N_2/O increases and electron density depletions is expected.

foF2 data from the stations Uppsala (59.5N; 17.4E), Juliusruh (54.6N; 13.2E), Dourbes (50.1N; 4.6E), Tomsk (56.5N; 84.9E), Yakutsk (62.0N; 129.4E), Gorky (56.1N; 44.2E) and Sverdlovsk (56.4N; 61.0E) have been used in order to verify the correlation between neutral atmospheric

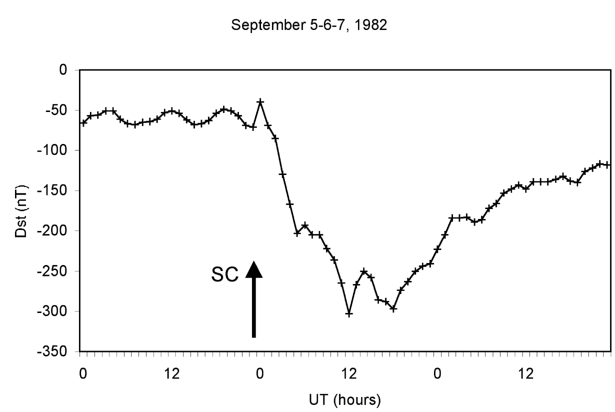

Fig. 1. Hourly Dst geomagnetic index on September 5, 6 and 7, 1982 (in UT).

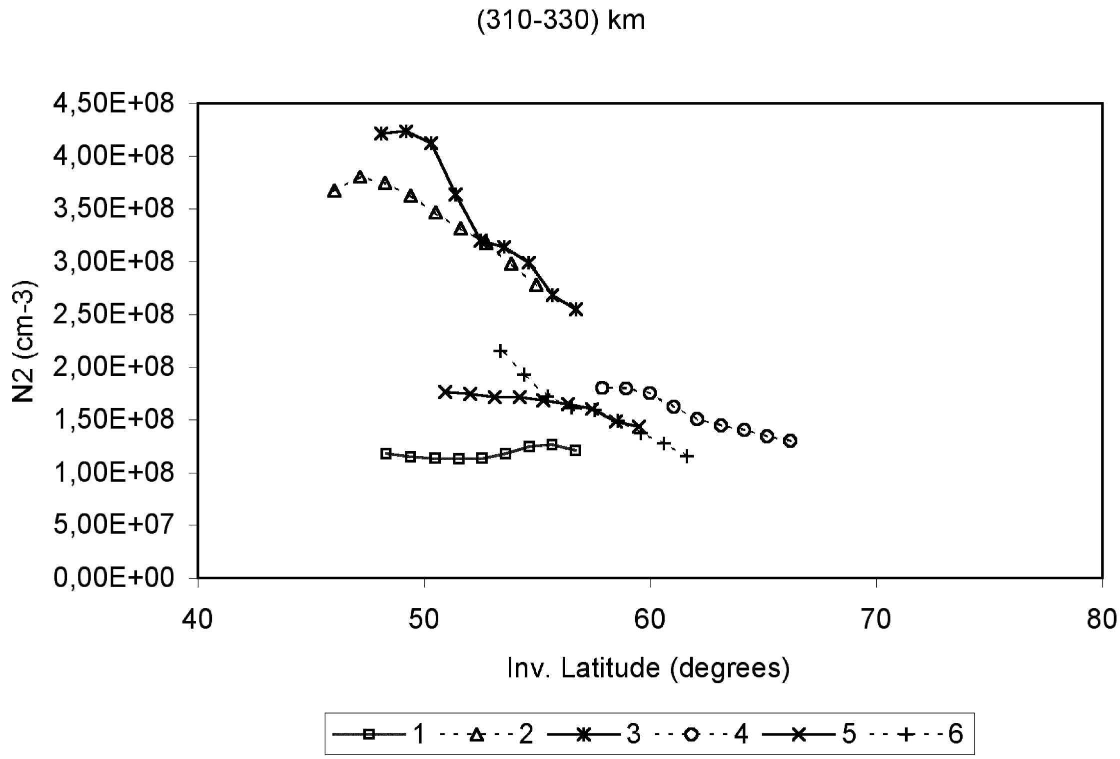

Fig. 2. Latitudinal structure of molecular nitrogen from 310 to 330 km during six satellites passes on September 5, 6 and 7, 1982.

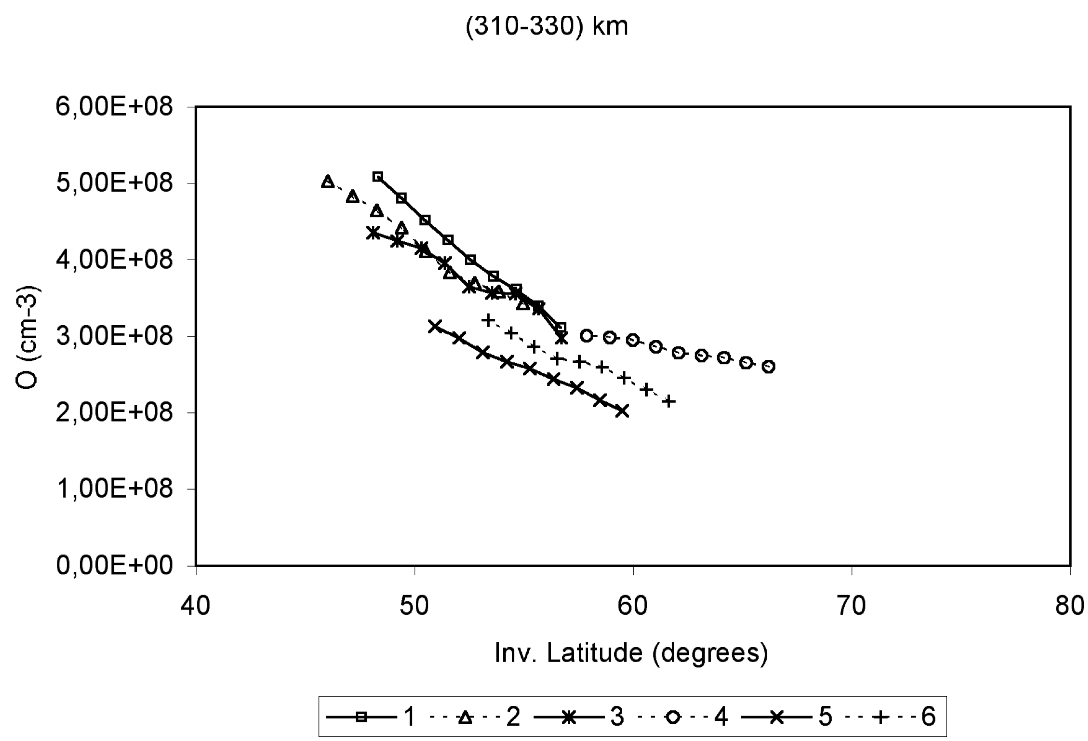

Fig. 3. The same as Figure 2, but for atomic oxygen.

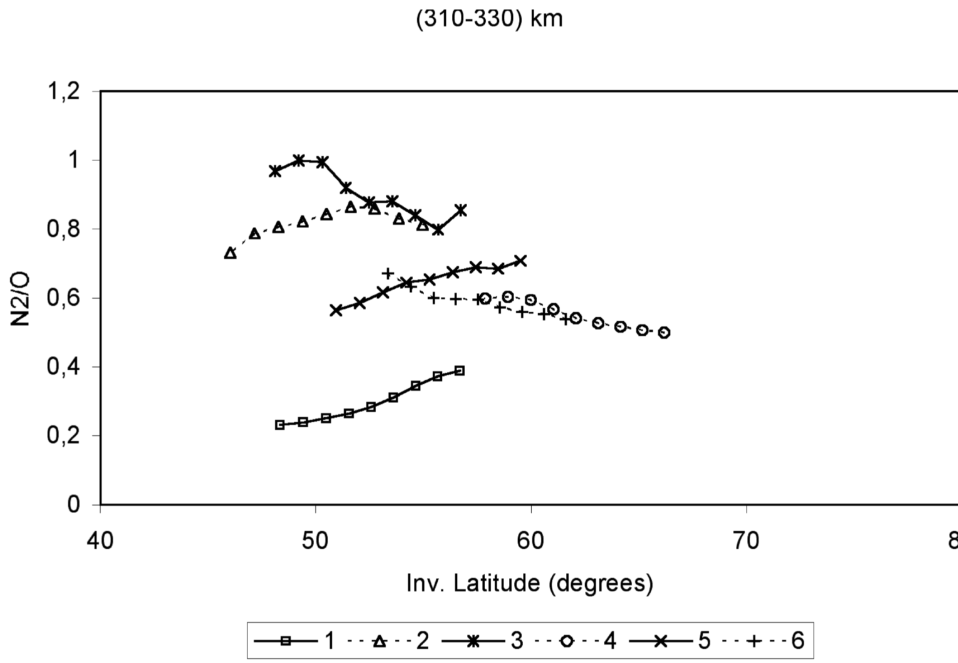

Fig. 4. The same as Figure 2, but for molecular nitrogen to atomic oxygen concentration ratio (N_2/O).

disturbances and negative ionospheric storms. Uppsala, Juliusruh and Dourbes are located below satellite passes (1) and (2), Tomsk and Yakutsk are below (3) and (5) respectively, while Gorky and Sverdlovsk are below satellite pass (6). There are no data during the storm period from stations located below satellite pass (4).

In order to show the perturbation degree during the storm, the differences dfoF2 = foF2 – foF2(q), where foF2(q) are the values corresponding to a quiet geomagnetic day of the month of the storm were computed. The ionospheric storm effects on the storm day and on the two following days (in UT) are presented in Figures 5 and 6.

Significant long duration decreases of ionization shortly after the sc are observed in the stations confirming the correlation between storm time N2/O ratio increases and peak electron density decreases. However, the temporal evolution of the ionospheric disturbances is quite irregular.

The negative ionospheric storms remain for around 28 hours at low latitudes (Juliusruh and Dourbes), followed by positive ionospheric storms with amplitude increasing with decreasing latitude. At high latitudes the negative storm effects remain for around 48 hours.

Positive dfoF2 values observed at Juliusruh and at Dourbes from around 6 – 7 UT on September 7, while the N_2/O ratio is increased above the reference values, may be caused by local particle precipitation.

DISCUSSION AND CONCLUSIONS

At the altitudes considered (310 - 330 km), it is observed that O concentration is greater than N_2 concentration before storm commencement (reference values) and during almost the entire storm period. However, the relative deviation for N_2 is considerably greater than O principally during the end of the main phase and during the first stage of the recovery phase.

A correlation is verified between increases in the N_2/O ratio and electron density depletions. The original suggestion that these depletions are caused only by a reduction of the atomic oxygen concentration (e.g., Chandra and Herman, 1969) is incomplete since both the increase in molecular nitrogen and the concurrent decrease in atomic oxygen contribute to the development of negative ionospheric storms. The higher relative variation in N_2 is dominant in causing these effects.

As is mentioned, no data are available from ionospheric stations located within the neutral composition disturbance zone associated with satellite pass 4. This makes it impossible to analyze the effects produced by a decrease in the N_2/O ratio on the electron density observed around 0850 UT on September 7 (curve 4).

As is seen, important electron density depletions begin at the stations nearly simultaneously in response to geomagnetic storm shortly after the sc. A few hours are required for

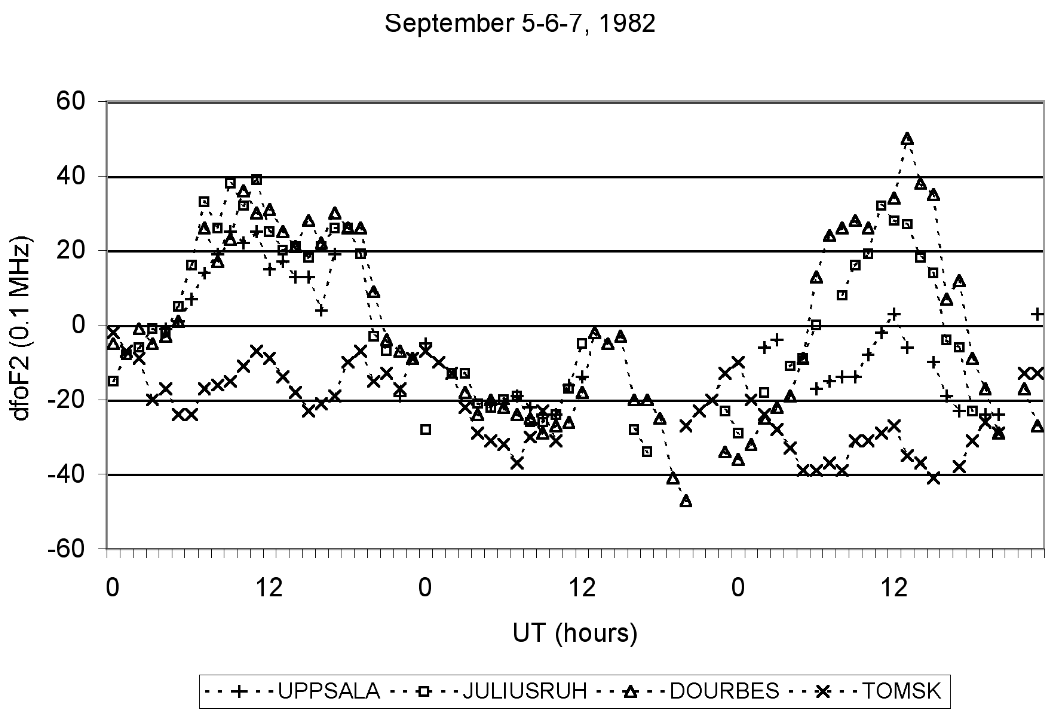

Fig. 5. Temporal evolution of dfoF2 at Uppsala (59.5N; 17.4E), Juliusruh (54.6N; 13.2E), Dourbes (50.1N; 4.6E), and Tomsk (56.5N; 84.9E) on September 5, 6 and 7, 1982.

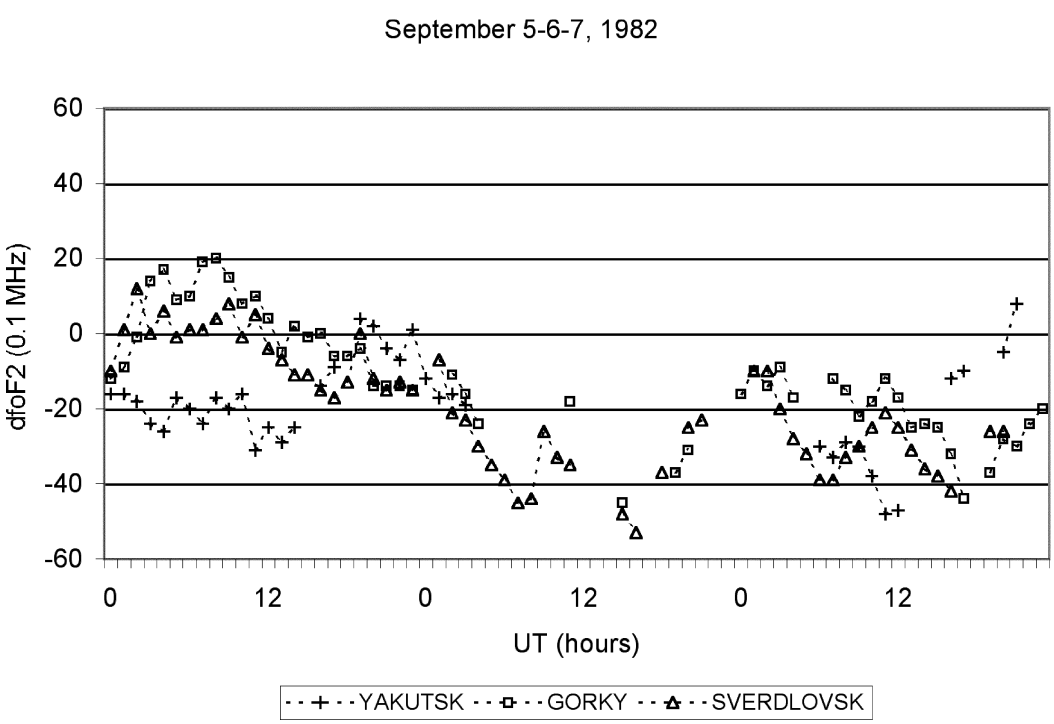

Fig. 6. Temporal evolution of dfoF2 at Yakutsk (62.0N; 129.4E), Gorky (56.1N; 44.2E) and Sverdlovsk (56.4N; 61.0E) on September 5, 6 and 7, 1982.

the storm time winds to generate and to propagate from auroral to middle-high latitudes; also, the onset of the perturbation should be delayed with decreasing latitude. The results suggest that the initial ionospheric response is a consequence of an electric field effect during the first stage of the storm because these perturbations require a fairly rapid mechanism. The resulting electrodynamic drift produces a depletion of the F-region ionization density. In the following hours, driven by Joule heating in the auroral zone, the storm-induced thermospheric circulation is established (transporting changes of composition), which substitutes the initial effect of the electric field.

The delayed positive ionospheric storms have been attributed to changes in the neutral gas composition (e.g., Rishbeth *et al*., 1987; Rodger *et al*., 1989; Rishbeth, 1991). The storm induced large-scale thermospheric circulation transports air rich in atomic oxygen producing a moderate decrease of the N_2/O density ratio. The resulting reduction of the ionospheric loss rate may contribute to any increase of electron density. However, O concentration is decreased while N_2 concentration is increased at the stations with delayed positive ionospheric storms. Thus, the composition changes does not explain these increases of ionization.

Therefore, additional disturbance mechanisms must be operative in this region. According to recent literature (e. g, Rodger *et al*., 1986; Senior *et al*., 1987; Prölss, 1991; and references therein) there is no simple explanation for the electron density enhancement. Local ionization production by incident low energy electrons and medium-energy ions and/or ionization transport from higher latitudes may play important roles to produce these positive ionospheric storms.

If the positive ionospheric storm were produced by ionization transport one can expect the perturbation propagating toward lower latitudes. This is not the case; a speculative but nonverifiable explanation of the observed behavior may be attributed to a local particle precipitation since they are not observed at higher latitudes.

In brief, in this paper a sequence of *in situ* measurements of N_2 and O concentrations taken by the DE 2 satellite in a common solar time sector and ground-based foF2 measurements are used to examine the ionospheric and thermospheric responses to an intense geomagnetic storm. The results represent a comparison of simultaneous measurements of storm disturbances in the gas composition and the peak electron density of the ionospheric F-region.

Although the atmospheric features for this storm may not generalize to other storms because the geomagnetic storms and the upper atmosphere response to them are so variable, the significance of the N_2 relative deviation compared to O is a feature that should be emphasized as well as lack of observational evidence found in support of delayed positive ionospheric storms produced by changes in the atomic oxygen composition.

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