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RECENT SATELLITE MEASUREMENTS OF UPPER ATMOSPHERIC COMPOSITION

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Two mass spectrometer experiments were included among the instruments on a recently launched US Air Force research satellite. The satellite was designed to study the density, composition and heating sources in the thermosphere. Measurements were performed during a geomagnetic storm of moderate intensity. Results show the N_2 density was enhanced by a factor of two, Ar by a factor of ten, and O is unchanged or slightly lowered near the 150 km region. At higher altitudes near 400 km, the O and N_2 concentrations are both increased. These results substantiate the earlier measurements of this laboratory and recent results of other groups.

During the period of 8—12 November 1974, a sudden commencement and the early development of a geomagnetic storm were studied. The larger effects of the sudden commencement of 8 November were delayed by about one day. The effects of the geomagnetic storm of 11 November followed the time history of *Kp* at low altitudes in the auroral region with a delay of about 6 hours at mid-latitudes. The largest changes in the neutral atmosphere occurred in the auroral region between 65° and 80° geomagnetic latitude.

1. Introduction

A recently launched US Air Force research satellite was instrumented to perform measurements of atmospheric density and composition as well as measurements of some of those parameters associated with heating processes in the atmosphere. The satellite has a perigee near 150 km to study the low altitudes and a high apogee to allow a 6—9 month lifetime. The satellite is programmed by ground commands to turn on the experiments and record data below 500 km. The experiment complement includes accelerometers, density gauges, mass spectrometers, and measurements of ion density and temperature, energetic electrons and solar ultraviolet radiation. The first results of the mass spectrometer measurements will be discussed in this paper.

The satellite is spin stabilized at 5 rev min^{-1} and the spin vector is maintained normal to the orbit plane by magnetic torqueing control. The mass spectrometers and other density measuring instruments are mounted perpendicular to the spin axis so that they sample along the direction of motion once each spin period.

2. Experiment Description

Two mass spectrometer experiments were included on the satellite. The first uses an enclosed ion source of the type previously used on the CV 3-6 satellite [1] and the OV 1-15 satellite [2]. The atmosphere is sampled through a thin orifice and passes through a spherical thermal accommodation chamber before entering the ion source. The incoming gas is ionized by 40 eV electrons and detected by a secondary emission multiplier after passing through the quadrupole field. The source density is monitored by a hot filament density gauge technique to allow for any change in multiplier gain. The configuration and calibration of this instrument allow high accuracy measurements to be made. A complete error analysis has not yet been performed but the stability and linearity over the range of operating conditions is better than $\pm 5\%$ for densities $> 10^6$ cm^{-3} and the densities are expected to be accurate to within $\pm 15\%$. Fig. 1 shows a sample spectrum of the data from the instrument for an early orbit near perigee.

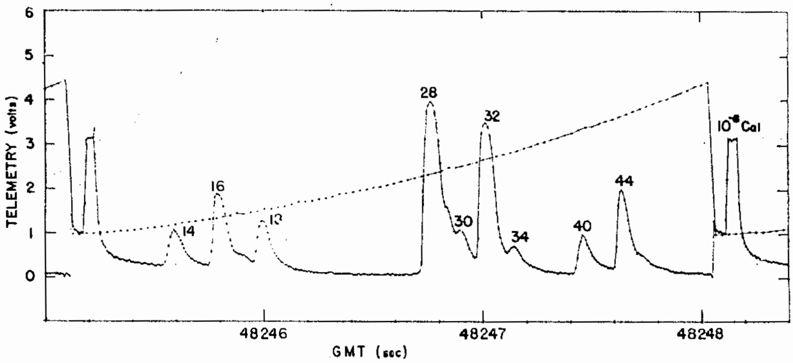

Fig. 1. A sample mass spectrum is displayed along with a monitor of the rf voltage which is proportional to mass number. The 14 and 16 amu peaks are dissociative products of N_2 and O_2 respectively, 18 is H_2O background, 34 is $^{16}O^{18}O$, 40 is Ar and 44 is CO_2. The spectrum is produced from a computer plot of the raw telemetry voltages.

The second instrument is a combination of the Velocity Mass Spectrometer, [3] which was first successfully demonstrated on the OV 1-21 satellite, and an rf quadrupole mass spectrometer. This instrument has the advantage that those species which collide with surfaces or degas from the surfaces can be separated from atoms or molecules of direct atmospheric origin. The ion source produces ions which have essentially the same energy as the neutral gas possessed due to the relative motion of the satellite. A similar technique has recently been used successfully by Nier et al. [4]. The ions are formed by a sheet of electrons focused across a low field region and either energy analyzed or drawn directly into the instrument. The instrument performed well and the results will be forthcoming. Here attention will be concentrated on observations of the first mass spectrometer mentioned.

3. Analysis and Results

The currents associated with the mass peaks, as shown in Fig. 1, are corrected to zero angle of attack using a well defined sampling function [5]. Since the incoming gas makes an average of 100 collisions in the sphere before entering the ion source, the species are thermally accommodated and the laboratory calibration is quite valid. Mass discrimination of about 5% was detected during the calibration and this was taken into account in the analysis. The N_2 and Ar signals are readily converted to number densities. The atomic oxygen density is determined from the 32 and 44 amu measurements. Atomic oxygen entering the instrument is recombined into mainly O_2, with some forming CO_2 particularly during the early lifetime. A calculation of the flux of the atomic oxygen which would provide the measured O_2 and CO_2 signals leads to a value of the atomic oxygen density. The signal that would be due to atmospheric molecular oxygen, calculated from the measured N_2 density, is removed. This correction is only significant near perigee. The 30 amu signal is treated as if it were a measurement of atmospheric N. There has been some justified reluctance to call a measured 30 amu signal NO for a number of reasons [1, 6, 7]. However, because of the fact that examination of the data does not reveal suspicious correlations between the 30 amu behavior and measurements of other species and because the measured values seem reasonable compared with our present knowledge [8–11], the 30 amu signal is identified as N. The identification is further justified by the scale height and because of the atomic oxygen remaining adsorbed in the accomodation sphere which is available to react with incoming N. The amount of NO generated by the ion source is low because of the small amount of dissociatively ionized species and should amount to no more than observed with N_2 and O_2 samples in laboratory calibration. A mechanism that could be of significance would be chemical reactions taking place on surfaces of the accommodation sphere. The identification should still be viewed with some caution but at least it provides an upper limit on the sum of the N and NO densities.

The results from the measurements obtained on two orbits are shown in Figs. 2 and 3. Orbit 59 shows data which are typical of the several days of quiet geomagnetic conditions that existed prior to the storm which began on 8 November 74. Orbit 141, $Kp = 6_-$, exhibits large variations from the smooth density profiles of the quiet period. Near perigee, the N_2 density is increased by a factor between 2 and 3 and the Ar density increased by a factor of 10. The O and N densities exhibit some variable structure but showed no significant enhancement at lower altitudes. The O variation is under some conditions in phase and other times out of phase with the N_2 variation. The cause of the phase relation between the O and N_2 is difficult to determine. It could be associated with several competing factors including raising the turbopause [12], enhanced diffusion from regions of localized heating, or response to large scale circulation and convection.

The magnitude of the change in N_2 and Ar implies several interesting points. First, the only way that such large increases can occur at 160 km is that the region of maximum heating lies well below this altitude. The region of heat input probably lies near 120 km and, in fact, a portion of the heating is probably near the turbopause region. Second, if the temperature profile through the lower thermosphere remains at all similar to its normal profile, increasing the exospheric temperature that defines that profile will not account for the changes observed in the N_2 and

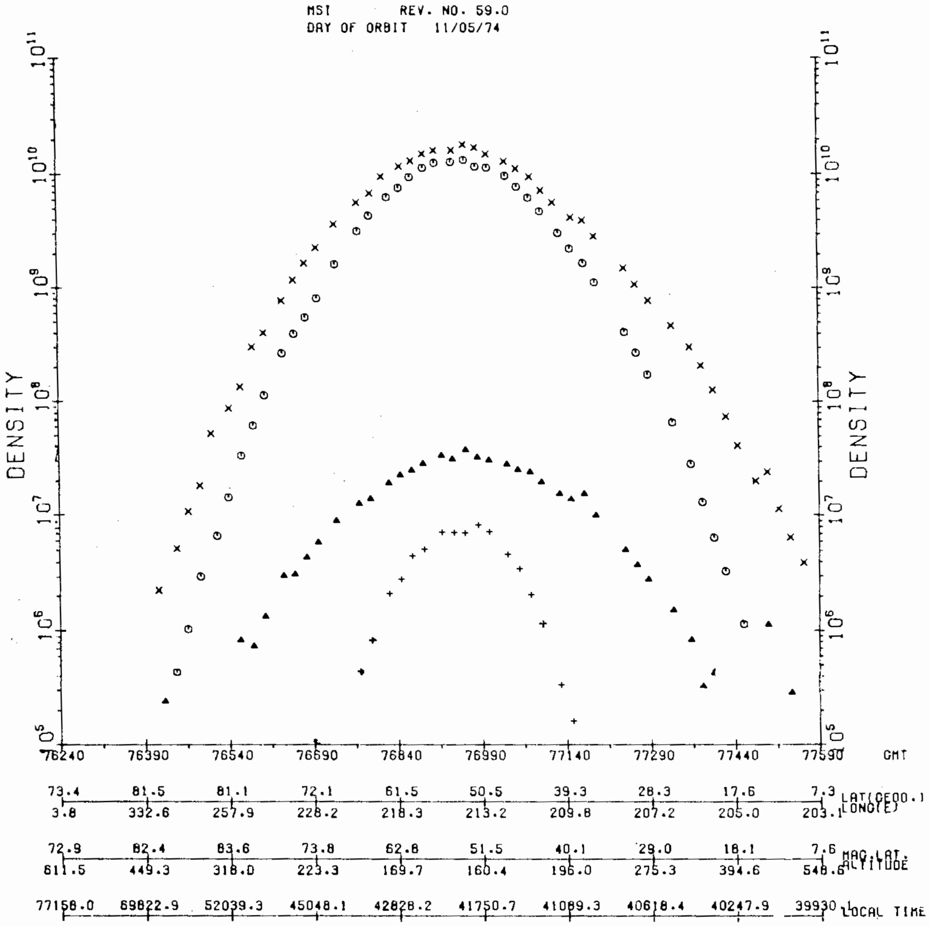

Fig. 2. The neutral composition measurements, typical of a quiet geomagnetic period, are shown for orbit 59, with perigee at 159 km.

($\odot$ = N_2, $\times$ = O, + = Ar, ▲ = N.)

Ar at the lower altitudes. Storm effects observed at an altitude of 450 km by Taeusch et al. [13] on OGO 6 could be explained by an increase in the exospheric temperature by 400—500 °K. Their results and these measurements at high altitudes can be satisfied by a temperature increase alone, but the low altitude data cannot. The measurements would imply that a significant change in turbopause level occurs during a period of heating. The ESRO 4 results reported by Blum et al. [14] at 280 km showed that a combination of temperature increase and higher turbopause could account for the measurements. The temperature profile is probably distorted due to localized heating at low altitudes and comparisons with a static diffusion model may not be valid at lower altitudes in the auroral zone.

The satellite perigee was in the 65° N region during the period in early November 1974 which included a sudden commencement on 8 November at 1114 GMT and

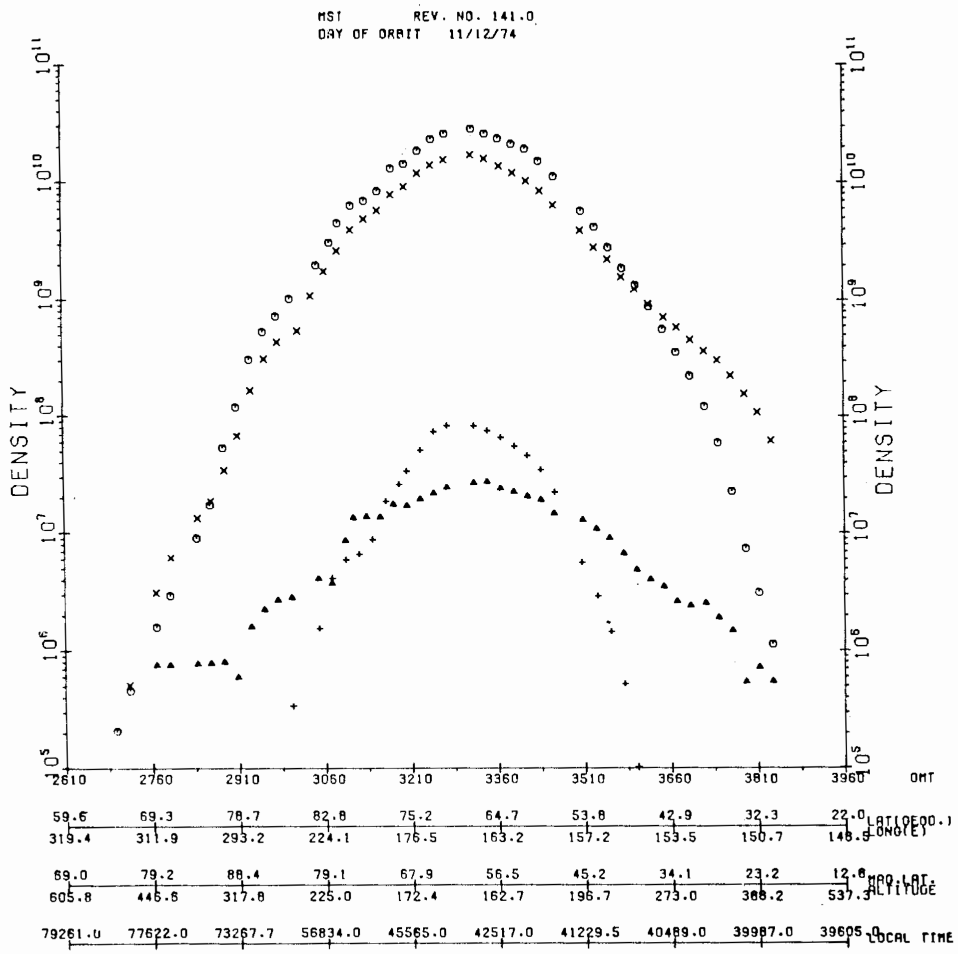

Fig. 3. The neutral composition measurements typical of a disturbed geomagnetic period are shown for orbit 141, with perigee at 161 km.

(⊙ = N_2, × = O, + = Ar, ▲ = N.)

a geomagnetic storm beginning on 11 November. The time of the orbit was nearly constant at 1130 LT. Fig. 4 shows an example of the variation of the species densities at 160 km during the period between 8 and 12 November. Large enhancements are seen in the N_2 and Ar densities while smaller variations are observed in O and N densities with often a tendency to decrease when the N_2 and Ar densities are enhanced. The large variations in the N_2 and Ar densities have been previously studied using mass spectrometers on several satellites, OV1-15 [2], OGO 6 [13], ESRO 4 [15, 16], and Cosmos 274 [17]. Even though only 21 of the 40 orbits during this four day period have been analyzed, several interesting points can be made. Maximum heating is found to occur in the region of the auroral oval between 65° and 85° geomagnetic latitude with the largest effects between 70° and 75°. From 45 minutes before the sudden commencement through the build-up of the magnetic storm, wavelike structures in the densities are seen at high geomagnetic latitudes. It is uncertain whether this structure could be associated with propagating waves [18], with localized corpuscular heating [19], or some other source. A general periodicity is observed which is correlated with the geomagnetic latitude and possibly associated with that reported by Reber and Hedin [20] for quiet geomagnetic periods. The density increases associated with the 11 November storm at low altitudes are seen to start with the increase in geomagnetic activity and reach a maximum at the same time as the geomagnetic index. The maximum effects of the 8 November storm are delayed at all altitudes and both higher and lower latitudes by about 24 hours following the sudden commencement or about 12 hours after the peak in the *Kp* index. The effects of the 11 November storm which followed the *Kp* increase at perigee are delayed in reaching higher altitudes (200—300 km) and mid-latitudes by 6 to 8 hours, in general agreement with drag analysis [21].

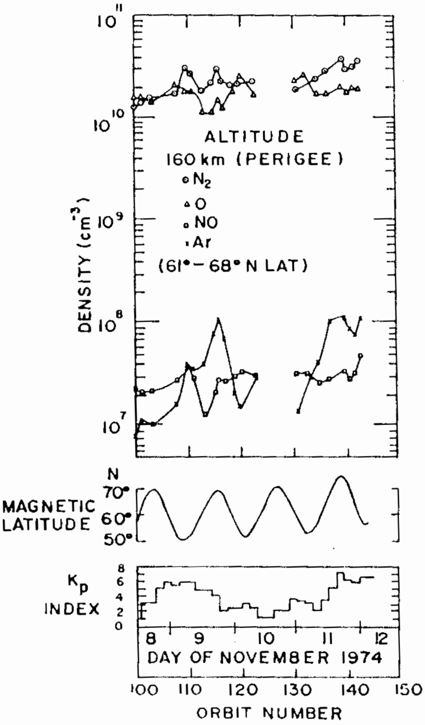

Fig. 4. The species densities measured at 160 km for the period 8—12 November 1974 showing the effects associated with a sudden commencement on 8 November and a magnetic storm on 11 November. Measurements are near 65° N latitude at 1130 LT.

This paper presents some of the results of one storm period from one of three satellites operating during the latter part of 1974 and during the first half of

1975. When these data are studied together with the measurements of the AEROS B [22] and the AE-C [23, 24] satellites, a much better description of atmospheric disturbances should result.

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