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SATELLITE MEASUREMENTS OF NEUTRAL ATMOSPHERIC COMPOSITION IN THE ALTITUDE RANGE 150 TO 450 km

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Measurements have been obtained from similar pairs of mass spectrometers flown on the OV3-6 and OV1-15 satellites. On each satellite, an instrument using an enclosed ion source and one using a semi-open ion source were used to measure the neutral species. The atmospheric species measured include O, N_2, Ar, N and NO. The results from these experiments have allowed a study of the variations of the atmosphere with local time, latitude, altitude and various geophysical parameters. The [O/N_2] ratio has an average value of unity near 200 km but can vary over a considerable range. The composition measurements exhibit significantly larger variations than presently allowed by atmospheric models and point out the inadequacies of static diffusion models.

1. Introduction

Mass spectrometer measurements from satellites during the past few years have significantly improved our understanding of the composition of the neutral upper atmosphere and variations which occur there. This paper summarizes some of the results obtained from the OV3-6 and OV1-15 satellite mass spectrometer experiments. Prior to these two satellites, most of the data on upper atmospheric composition had been obtained from the Explorer 17 satellite [1] and from several rocket experiments, e.g. [2—4]. More recently, the OGO 6 satellite [5—7] has provided data in the region between 450 and 600 km. Also, during the past few years, incoherent scatter radar experiments [8, 9] have provided important insights into atmospheric variations.

2. Description of the Experiments

The OV3-6 satellite was launched in December 1967 into a circular polar orbit near 440 km. The mass spectrometers were mounted parallel to the spin axis on opposite ends of the satellite. The spin vector was in the plane of the orbit and the instrument axes became parallel with the velocity vector near the equator on either side of the orbit. Mass Spectrometer I utilized an enclosed ion source geometry and complete orbit tape recorded data were obtained for local times between midnight and sunrise during the period of December 1967 through March 1968. The Mass Spectrometer II was of a semi-open ion source design. The instrument recorded data over a complete orbit between noon and sunset for the same time period. Real-time data (10-minute acquisitions) were obtained from both instruments until re-entry in March 1969. Fig. 1 shows the instrument configuration for each of the RF quadrupole mass spectrometers. All of the ion source

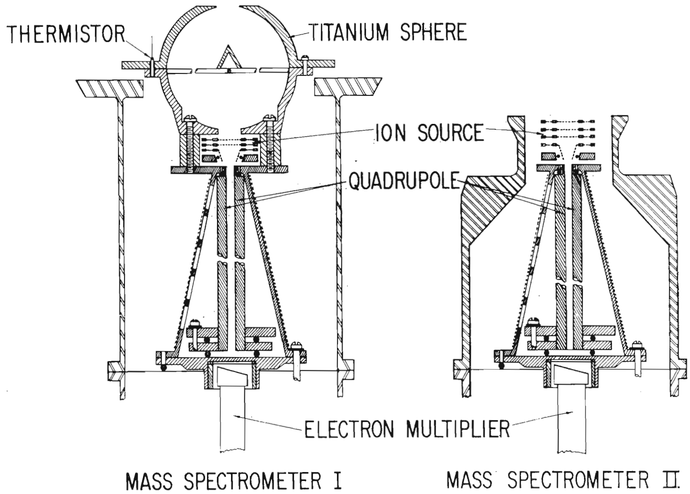

Fig. 1. The instrument configuration of Mass Spectrometers I and II which were flown on the OV3-6 and OV1-15 satellites.

parts and the sampling sphere were made of commercially pure titanium or were plated with titanium in an effort to reduce the recombination of atomic oxygen [10]. A similar ion source was used for each instrument. The ion source was cylindrically symmetric and a three mil diameter tungsten filament was used. The instruments were programmed to sweep the mass range from 1 to 32 amu in a 5 second period.

The OV1-15 satellite was launched into an elliptical orbit at altitudes between 160 and 1800 km on 11 July 1968. Data were obtained by two instruments similar to those on the OV3-6 satellite until re-entry during November 1968. The instruments were mounted on opposite sides of the satellite with their axes perpendicular to the satellite spin axis. The spin axis was actively controlled in an effort to maintain it perpendicular to the orbit plane. In this configuration the instrument samples along the direction of motion once each spin period. The spin period was initially about 6 seconds and became about 12 seconds near the end of satellite life time. The programmed operation of the instrument included measurement of each of four masses (He, O, N_2, Ar) for a period of 12 seconds followed by a mass scan of 1 to 44 amu during 12 seconds.

3. Discussion of the Results

The data from the OV3-6 satellite has led to several interesting conclusions [11—14]. Since the orbit was nearly circular at $\sim$400 km altitude, the latitudinal and temporal variations could be readily studied. The mass spectrometer and density gauge data from the same satellite have been compared and found to be in general agreement. The atomic oxygen was found to exhibit a broad maximum in the mid afternoon between 1400 and 1530 LT. The density maximum appeared to be in the summer hemisphere and poleward of the subsolar point. The molecular nitrogen concentration was found to change considerably with local time and exhibited a larger latitudinal variation than did the atomic oxygen. The N_2 concentration was a few per cent in the late afternoon and was only a few tenths of one per cent in the early afternoon. The N_2 concentration reached a maximum near 1530 to 1600 LT. Comparison of the local time variation of O and N_2 led to the conclusion that the times of the density and temperature maxima are out of phase near 400 km. It was inferred from the data that the N_2 variation may provide a good indication of atmospheric temperature. This result is in agreement with the incoherent scatter results which have shown that the temperature maximum occurs during the late afternoon near 1600 LT [8, 9].

The N_2 concentration was found to have a large variability in the auroral region which is associated with energy sources in the polar atmosphere. A density trough which is more pronounced in the molecular nitrogen profile occurs inside the auroral oval near the magnetic pole in most orbits.

In the equatorial latitudes, relatively large (10—50%) variations occur. These troughs in the neutral atmosphere are correlated with the magnetic equator. The fact that these variations are strongly tied to the magnetic equator suggests that strong coupling exists between the neutral atmosphere and the ionosphere. In most cases, symmetric variations were observed on both sides of the magnetic equator located in the regions 10—15° from the magnetic equator. In a few cases the observed effect was a single trough centered on the magnetic equator. This effect has also been observed recently in the OGO 6 data [6].

Titanium surfaces were used for the ion sources and entrances in an effort to reduce the recombination of atomic oxygen. After a period of a week or so in orbit, the surfaces have encountered a large flux of atomic oxygen and a rather stable surface condition exists. After this period, the adsorption and desorption of atomic oxygen appears to follow a Langmuir characteristic with short and long period components. The recombination to molecular oxygen occurs only during the ram portion of a spin cycle and suggests a recombination coefficient of about 10^{-2} [12]. During the wake portion of a spin cycle O_2 drops below the limit of detectability and O is the major desorption peak.

The elliptical orbit of the OV1-15 satellite allows study of vertical profiles of the atmospheric species [15]. Data for one orbit of the OV1-15 with an equatorial perigee is shown in Fig. 2. The density was determined by comparison of the total measured composition at 200 km for six orbits (between orbits 1110 and 1130) with the mass density determined from an accelerometer on the satellite [16]. This determination of instrument sensitivity was necessary since an offset occurred between laboratory calibration and first turn-on in orbit. In Fig. 2 the measured points are shown with a connecting line to aid in following the profiles. The O and N_2 profiles cross near 180 km for this orbit.

In order to display some of the interesting features in the data, the 200 km crossings for ascent and descent are shown in Fig. 3. The values $[O/N_2]$, $[N_2]$, $[O]$ are shown with the latitude, local time, date and Ap index through the satellite lifetime. The $[O/N_2]$ ratio shows an average value slightly less than unity at 200 km. The ratio drops rapidly between orbits 100 and 300 due largely to the change in atomic oxygen density during this period. This large change in atomic

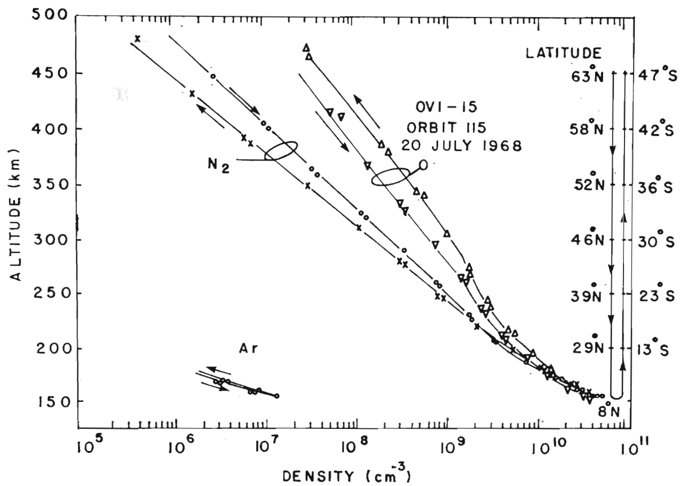

Fig. 2. Altitude profiles for O, N_2 and Ar are shown with the corresponding latitude for descent and ascent of orbit 115 of the OV1-15 satellite.

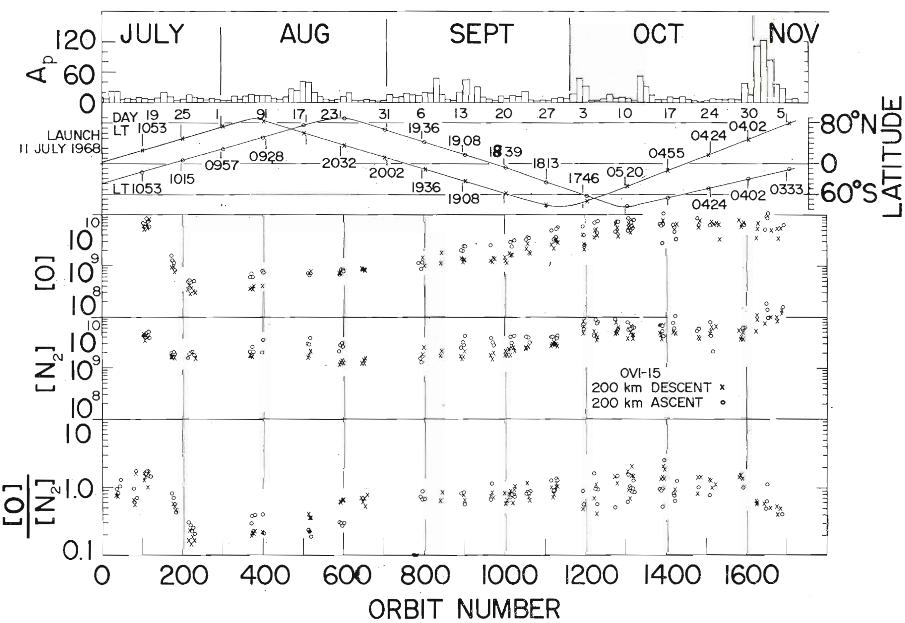

Fig. 3. Measurements of the [O/N_2] ratio, [N_2] and [O] are shown for the 200 km crossings for ascent and descent obtained by Mass Spectrometer I on OV1-15.

oxygen is difficult to understand. It is interesting that the decrease during this period and the gradual increase in later orbits is in the direction expected for the combined annual and semi-annual variation [17]; however the magnitude observed is much larger than would be allowed in current models. Also the [N_2] variation is in phase with the [O] variation although smaller. The fact that the [N_2] is in phase with the [O] variation is not in agreement with the model of Mayr and Volland [17].

Between orbits 500 and 700 the descent portion of the orbit was shadowed and the ascent was sunlit. From orbit 700 to 900 both the ascent and descent were shadowed and for orbits beyond 900 the data collection period was sunlit. During that period from orbit 500 to 700 the ascent and descent values of [O] are the same but the [N_2] values are significantly higher on the sunlit ascent than on the shadowed descent. This shows the sensitivity of the [N_2] to the atmospheric temperature.

Near the end of the lifetime, a geomagnetic disturbance occurred which caused a large increase in the [N_2]. The [O] was not substantially changed and thus the [O/N_2] ratio decreased. The [N_2] increased by about a factor of two at 200 km and the [Ar] increased about a factor of four at 150 km.

The composition measurements from the OV 3-6 and OV 1-15 cannot be satisfactorily compared with presently available models. Many of the features which have been used for empirical models of atmosphere density will not apply because of their two-dimensional character. Advances in the dynamical or three-dimensional models should develop rapidly as more composition data become available.

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