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MEASUREMENTS OF ATMOSPHERIC COMPOSITION NEAR 400 KM

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Measurements near 400 km altitude of atmospheric composition and density on the circular, polar-orbiting OV3-6 satellite have shown marked departure from atmospheric models. The results have shown that the molecular species constitute a much larger percentage of the atmosphere near local sunset than near local noon. Near local sunset (from observations made in December 1967), the N_2 to O concentration ratio is a few per cent and near local noon (March 1968), the ratio is a few tenths of 1% or less. The results would indicate that the temperature maximum is near local sunset; however, the measurements indicate a broad density maximum between 1400 and 1600 hours. The results show that diffusive equilibrium models must be reconsidered with regard to dynamics and heating sources of the atmosphere. In addition, the measurements exhibit a significant minimum in the density of each of the species in a large percentage of the orbits near equatorial latitudes.

1. Description of Experiment

The OV3-6 (ATCOS 2) satellite was launched into a circular polar orbit of approximately 440 km in December 1967. The purpose of the satellite was to study the atmospheric and ionospheric composition and density. Data from two mass spectrometers and a density gauge were obtained from December 1967 to re-entry in March 1969. Tape recorded acquisitions over a full orbit were obtained at a frequency of about five per week for the first four months of the satellite lifetime. For the rest of the satellite lifetime, density gauge data were obtained over full orbits about three times a week and real time (10 minute pass) data were obtained from the mass spectrometers about ten times per week.

The mass spectrometer and the density gauge were located side by side with their instrument axis parallel to the spin axis. The spin axis became parallel to the velocity vector near the equatorial crossings. Since the orbit was almost exactly polar and the eccentricity of the orbit was quite small, the precession of the orbit was almost negligible. The local time variation of the orbital plane of about 1° per day resulted in a local time change from near sunset in December to noon in March. The results presented in this paper will be confined to the measurements of one of the mass spectrometers and the density gauge data obtained over this four-month period.

An rf quadrupole mass spectrometer with a semi-open ion source was used to measure the neutral composition. This instrument could be switched by ground command from measurements of the neutral composition to measurements of the ionospheric composition. All metal parts in the ion source region were made from titanium or, in the case of the grids, coated with titanium, in an effort to reduce the recombination of atomic oxygen. The atmospheric density was measured using a cold cathode, inverted magnetron type, density gauge.

2. Satellite Results

An example of spectra obtained from the mass spectrometer is shown in Fig. 1. Internal calibration levels of the five-decade logarithmic electrometer are shown at 10^{-8} and 10^{-11} A. The primary neutral constituents in the atmosphere are seen to be atomic oxygen (16 amu) and molecular nitrogen (28 amu). The molecular oxygen (32 amu) peak is probably due in large part to recombination of atomic oxygen on the surfaces. It should be noted however, that the atomic oxygen peak shown in the spectra is considerably larger than that of molecular oxygen, resulting in a relatively small correction to the atomic oxygen. The background outgassing of the instrument and spacecraft can be seen at 18 amu (H_2O) and 12 amu (resulting from dissociation of CO_2) in the

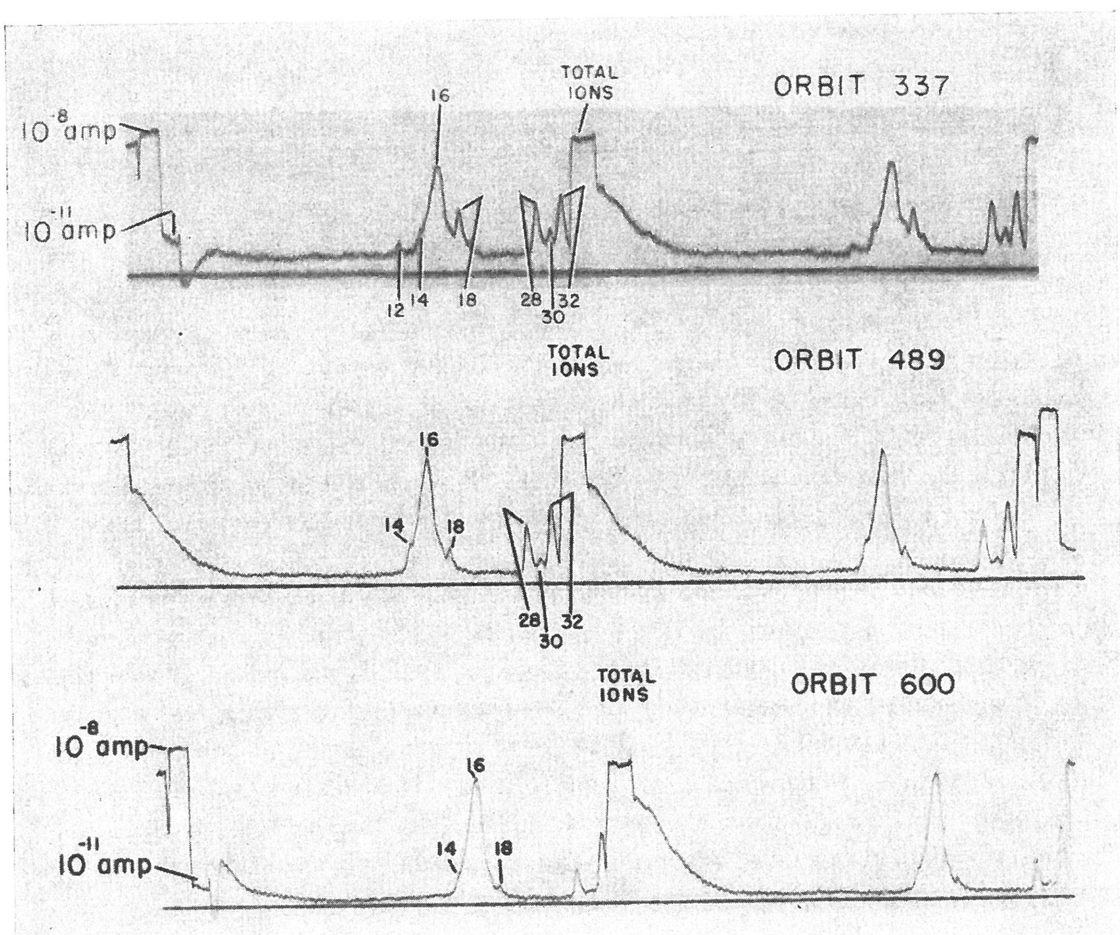

Fig. 1. Sample spectra from three orbits of the satellite.

early orbits. It is uncertain whether the NO (30 amu) is of atmospheric origin or whether it is created by chemical reaction within the ion source. The 18 amu peak in the early orbit is due to H_2O but before orbit 600 the 18/16 ratio is proper for the ^{18}O isotope. The 14 amu peak on orbit 337 is due to dissociation of N_2. On orbit 489 the 14 amu peak is twice the value expected for N_2 dissociation while on orbit 600 the 14 amu peak is almost equal to the N_2 peak. The ambient atomic nitrogen which causes the higher 14 amu peak is not a clean measurement because of the resolution of this spectrometer. The values inferred from it are likely to be too high because of the breadth of the 16 amu peak.

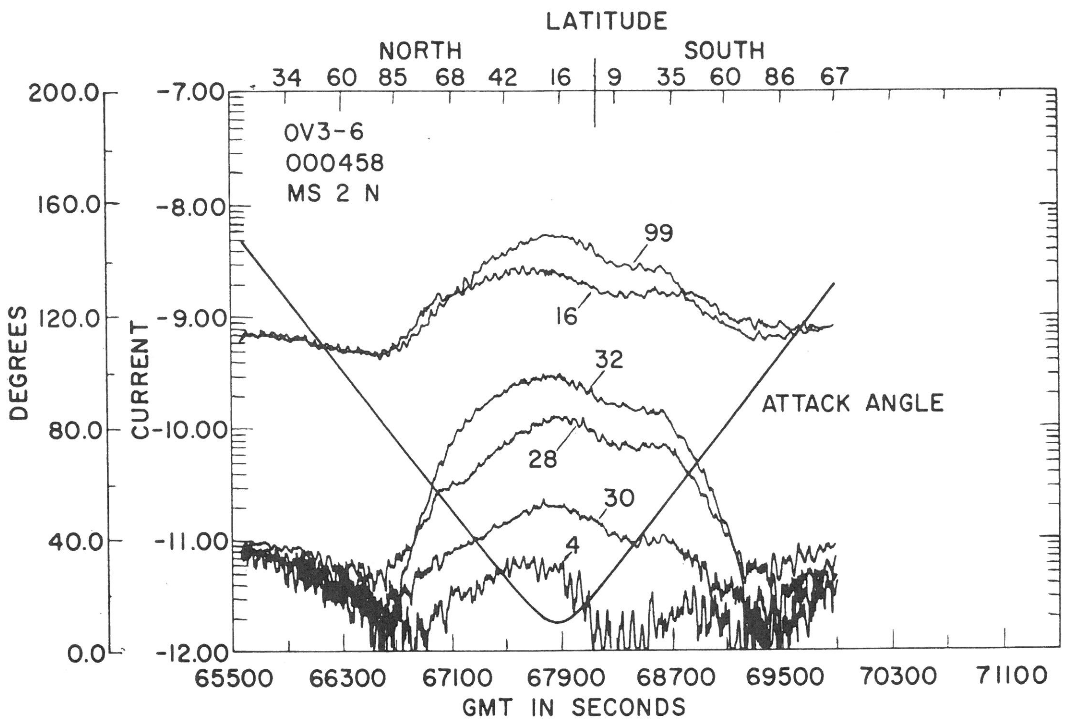

Fig. 2. Plot of the raw peak currents for orbit 458, 4 January 1968.

The peak current for each of the masses is shown over one orbit in Fig. 2. A spectrum is obtained each five seconds providing about 1200 points for each mass over an orbit. The sampling function of the instrument is reflected in the shape of the 28 and 32 amu curves and has been fitted well using the theory of Hughes [1] for this experiment and a similar instrument on the OV1-15 satellite where the spin period was sufficiently short that atmospheric variations did not affect the sampling function. It is apparent in this orbit that a density trough occurs south of the equator (actually centered about the magnetic equator). The large ram-to-wake variation of 28 and 32 amu indicates a relatively small effect due to adsorption and desorption of molecular nitrogen and recombined atomic oxygen. On the other hand, the 16 amu (atomic oxygen) shows a very strong adsorption and desorption effect. The report of Morgan and Schiff [2] had indicated a very low recombination coefficient for atomic oxygen on titanium surfaces. These satellite data are in agreement that the chemical adsorption is a relatively small effect whereas the physical adsorption effects are significant. The curve labeled as 99 is the measurement from the quadrupole obtained by its operation as a high pass filter.

In about 50% of the orbits, minima in the density of each of the species are seen in the vicinity of the magnetic equator. A single trough is seen in Fig. 2, however, more frequently a pair about the magnetic equator are observed as shown in Fig. 3. The mass spectrometer density profiles shown in Fig. 3 and

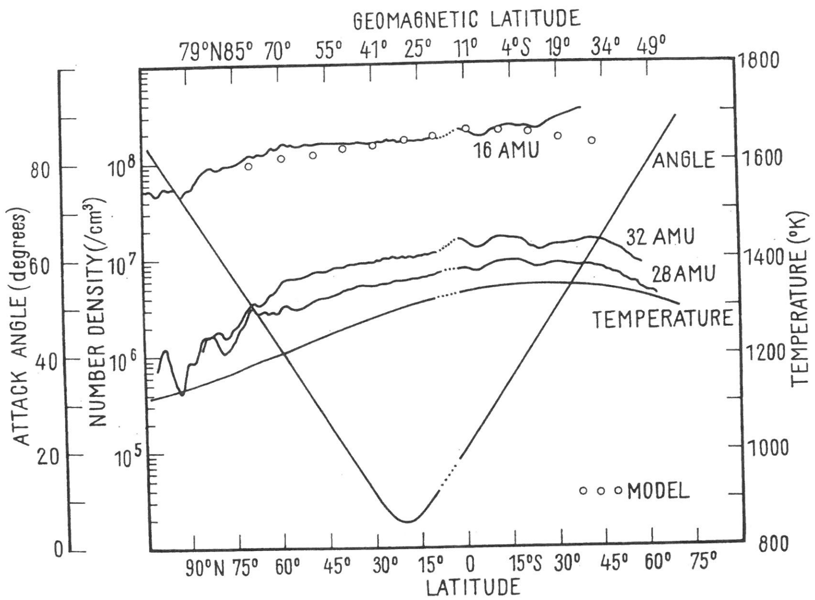

Fig. 3. Mass spectrometer measurement of composition for orbit 368, 29 December 1967.

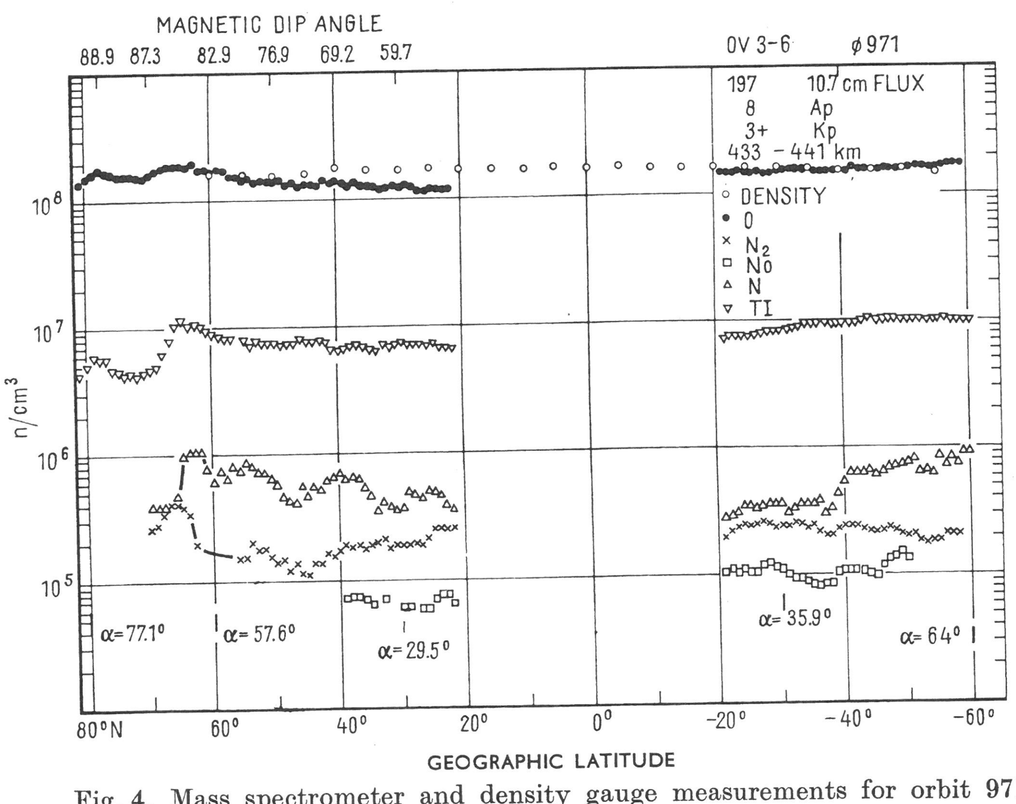

Fig. 4. Mass spectrometer and density gauge measurements for orbit 971, 6 February 1968.

for all of the other orbits were obtained using a sensitivity factor for the instrument which was determined by normalizing the average value of one set of ten spectra of one orbit to the total density expected from the Jacchia 1964 model [3].

The minima shown in orbit 368 and other orbits are a reasonably persistent feature between 20° N and 30° S. The magnitude of the effect is usually between 15 and 40% departure from the smooth profile. Irregularities in the density profile of each of the species are frequently seen in the polar region. Some

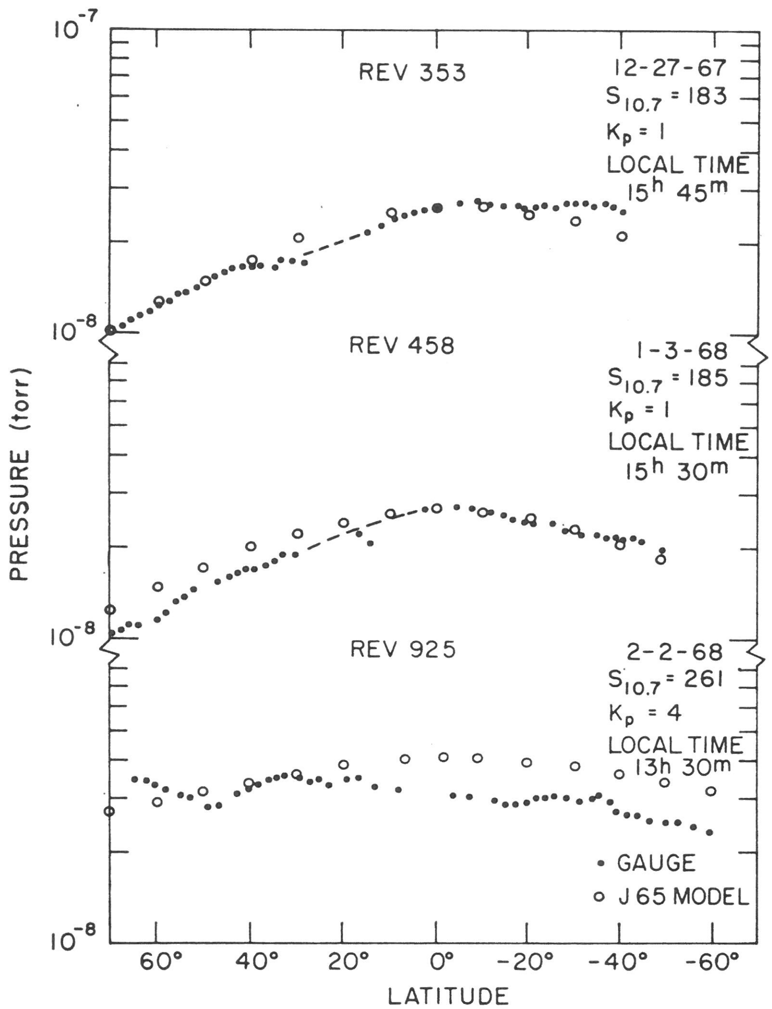

Fig. 5. Density gauge measurements obtained on three orbits compared with model values.

irregularity is seen above 65° N geomagnetic latitude in orbit 368; however much larger variations are seen in this region on other orbits. The departure from the model in the atomic oxygen below 30° S is due to the effects of atomic oxygen desorption from the instrument surfaces. The altitude change over the orbit was from 435 km near the north pole to 408 km near the equator.

The measurements of the mass spectrometer in Fig. 4 show a density bulge followed by a trough which lies between the auroral oval and the magnetic pole. The latitudinal profiles of O, N_2, and N are shown. The density values corresponding to NO are shown assuming that it may be of atmospheric origin. If it is due to processes within the ion source, the values can be construed as an upper limit on the NO concentration in the vicinity of 440 km. The density gauge values are shown for reference.

The density gauge results are compared with model values for three orbits in Fig. 5. The agreement between gauge results and the density model is very good for the orbits 353 and 458 which correspond to low Kp values and moderate solar flux. This agreement is found to be generally true for most of the orbits. However, on some orbits the departure between the measured values and the

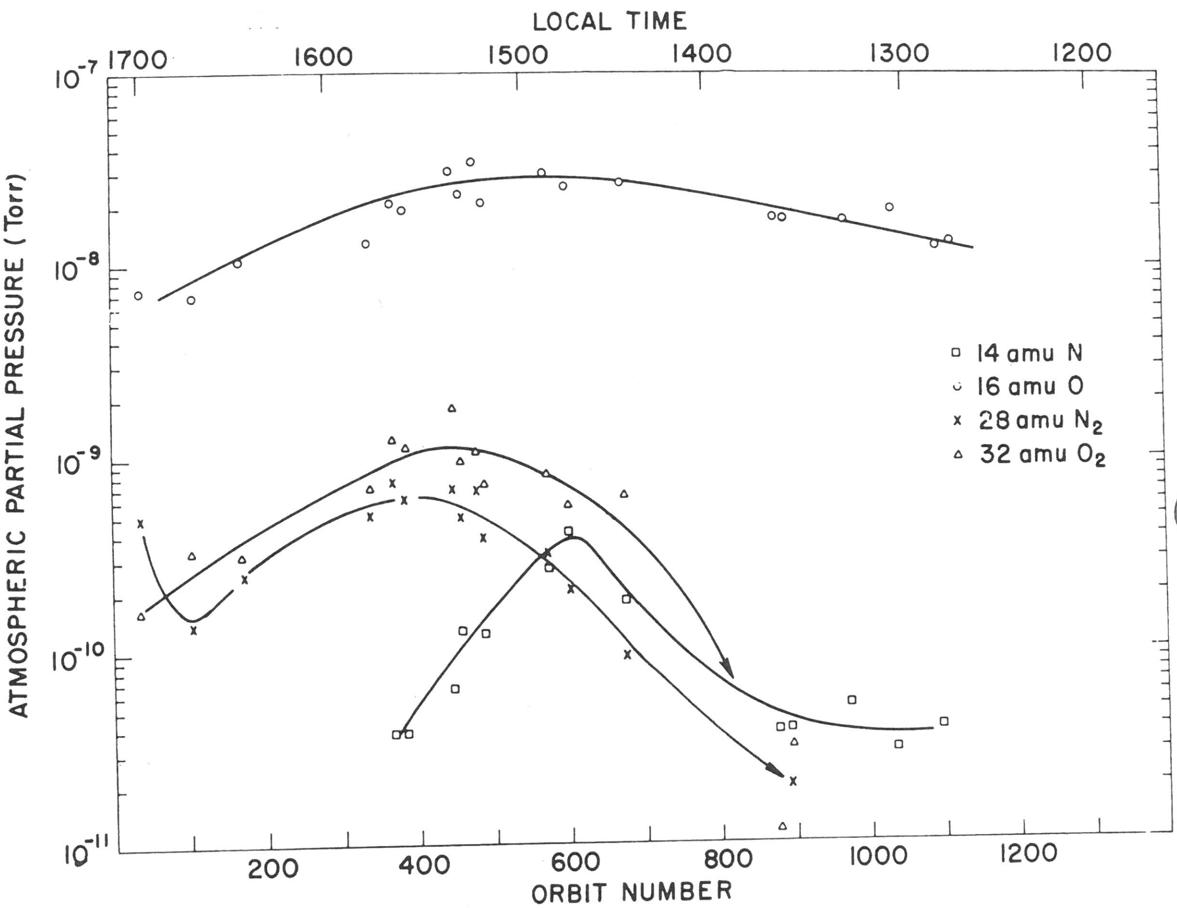

Fig. 6. Local time change of the composition near 400 km between noon and sunset.

model values can be large. The data shown for orbit 925 indicate the magnitude of the difference for higher Kp and solar flux.

The mass spectrometer measurements for several orbits are shown in Fig. 6. The points shown are taken from individual orbits between 30° N and the equator (omitting a density trough should one occur in the particular orbit). The variation of the atmosphere as a function of local time between noon and 1700 is shown. The scatter in the atomic oxygen points is probably indicative of the variability of the atmosphere in the vicinity of 400 km. The N_2 variation with local time would indicate a temperature maximum near 1600 local time. The first point on the N_2 profile is high due to initial outgassing of CO on the first turn-on of the experiment. The O_2 profile is probably due to recombination of atomic oxygen on the instrument's surfaces; however, if this is the case, then the surface properties must change with time in order to explain the large increase in the O to O_2 ratio after orbit 700. The atomic nitrogen values around orbit 400 must be assigned a large error bar (a factor of 2 or more) due to the comparatively large amount of 14 formed from dissociation of 28 in the ion source; however, the measurement improves as the N_2 density decreases in later orbits.

3. Conclusions

The results from a mass spectrometer and density gauge on the OV3-6 satellite have yielded a better understanding of the atmospheric composition and density and its variation with latitude and local time. The fact that the satellite orbit was near circular helped significantly in investigating atmospheric changes with local time and latitude. The measurements of atomic nitrogen are the first reported for a satellite. The variation of the composition with local time has shown that the molecular nitrogen concentration varies from a few per cent in the late afternoon (from observations made in winter, December 1967) to a few tenths of 1% or less near local noon (in spring, March 1968). The Jacchia model shows generally good agreement with the measurements of the density gauge and mass spectrometer under normal conditions. The measurements have shown density variations from a normally smooth profile at both high and equatorial latitudes. The variation at the polar latitudes appears as a density bulge at the auroral oval followed by a trough between the oval and the magnetic pole. The variation at equatorial latitudes is normally exhibited as a trough in the vicinity of the magnetic equator or a pair of troughs, located one on either side of the magnetic equator. These two effects indicate a significant dependence of the neutral atmosphere on magnetic latitude which suggests significant coupling between the neutral atmosphere and the ionosphere in these regions.

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