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NEW KNOWLEDGE OF
THE EARTH'S ATMOSPHERE
FROM THE AERONOMY SATELLITE
(EXPLORER XVII)

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ABSTRACT

New Knowledge of the Earth's Atmosphere from the Aeronomy
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The Explorer XVII satellite performed direct, very localized measurements of the total neutral particle density, the concentration of neutral particle masses 4, 14, 16, 28, and 32 and the temperature and concentration of thermal electrons, between the altitudes of 258 km and 920 km over those regions of the earth where the satellite was accessible to the Minitrack network, and in particular between $\pm 58°$ latitude. Pressure gages on the satellite showed that the total density at 280 km was about 50% lower than is given by the appropriate atmospheric models based on satellite drag measurements. Daily variations in total density are more strongly dependent on a_p (the magnetic index) than had been believed previously. Neutral mass spectrometers showed that H_e is the predominant neutral constituent above 600 km, 0 is predominant between 250 km and 600 km, and N_2 is predominant below 250 km. The scale heights of the various constituents agree in general with the corresponding model atmospheric scale heights. Langmuir probe results confirmed the global extent of thermal non-equilibrium ($T_e > Tg$) and provided high resolution of the diurnal variation of electron temperature and density at several stations. For example, the electron temperatures near the F_2 maximum over Blossom Point show a nighttime value of about 1100°K, followed by a mid-morning maximum of 2800°K and an afternoon plateau of 2200°K. A consistent and strong latitude effect, evident particularly at Blossom Point, caused a significant positive gradient in electron temperature (the order of 25°K/degree of latitude) and an inverse gradient in electron density in a manner approximately in accord with recent theories of Hanson and Dalgarno.

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INTRODUCTION

The Explorer XVII satellite, Figure 1, was designed to provide direct measurements of aeronomic parameters as a basis for new studies of the physics of the Earth's upper atmosphere. Thus, instruments were selected for the satellite which would provide both total and relative concentration of the neutral particles, and high-resolution measurements of the electron temperature and density; all of considerable significance in studies of the physical processes controlling the upper atmosphere. These data would help also to (a) clarify and define the structural properties of the atmosphere, previously established primarily through inferences from satellite drag measurements, and (b) investigate the variability and dependence of the atmosphere on solar conditions.

The technological advance of measurement techniques was also an objective of the project, as part of a continuing effort to improve experimental capability. The application of laboratory-developed techniques required engineering as well as measurement technique re-finement and adaptation to new environments. The atmospheric data to be obtained, if it were to be of maximum benefit consistent with its timeliness, required computer usage for processing the large quantity of data (the order of 2×10^9 bits of information).

Four independent pressure gage experiments were employed: two Bayard-Alpert type (thermionic cathode) ionization gages and two Redhead type (cold-cathode, magnetic) gages. Each sensor was equipped with a special vacuum-sealed orifice that could be opened after the satellite was in orbit. Thus it was possible for the sensor to be properly cleaned, calibrated, sealed under vacuum, and opened on command to the space environment. This procedure, whose validity was previously established through rocket experience, assured the necessary high degree of vacuum cleanliness for the sensors.

The use of both cold and thermionic cathode gages was considered essential because of uncertainties in (a) the response of a hot-cathode gage in a sometimes predominately atomic oxygen environment (not subject to adequate laboratory calibration) and, (b) the general applicability of ionization gages to the high-velocity satellite environment. At the same time, a desirable redundancy was accomplished and valuable studies of the usefulness of the two fundamentally different sensors were made possible. Each pressure gage was provided with an appropriate electrometer amplifier and other electronic support devices which enabled conversion of the sensor output current to a voltage suitable for telemetry. The electronic systems also included provision for in-orbit current calibration of the amplifiers once during each operation of the gages.

Neutral Particle Mass Spectrometers - Two identical double focusing magnetic mass spectrometers were employed for the determination of the local concentrations of atmospheric helium (mass 4), atomic nitrogen (mass 14), atomic oxygen (mass 16), molecular nitrogen (mass 28) and molecular oxygen

relationships between the measured ion currents and the ambient atmosphere were computed on the basis of these three mechanisms and the laboratory gas calibrations. The validity of these calculations is demonstrated by the fact that the total mass-density measured by the spectrometer is in satisfactory agreement with that obtained independently by the companion pressure gage experiments described above.

Langmuir Probes - Two independent Langmuir probe systems, based on established techniques and previous rocket usage (Spencer, Brace, Carignan, 1962) (Brace, Spencer, Carignan, 1963) (Nagy, Brace, Carignan, Kanal, 1963) were employed to provide measurements of the ion concentration (N_i), and the electron temperature (T_e) of the ionosphere. Each probe system used a cylindrical electrode (projecting into the plasma) whose potential was varied with respect to the satellite shell. The resulting current to the probe was converted to a voltage suitable for telemetry.

Using the following equation, the temperature was derived from the electron current to the probe as it was swept from the satellite potential to the plasma potential:

$$\frac{d \log_e i_e}{dV} = \frac{e}{kT_e} \qquad (1)$$

To localize the T_e measurement, the electron temperature probe was swept at a rate of 10 sweeps per second; and to maximize the resolution, the voltage was swept in two ranges, 0 to + 3/4 V and 0 to 1 1/2 V, respectively. As a result, each temperature measurement was completed in less than 400 meters of the satellite path, and to that extent represents a point measurement. The

SUPPORTING SYSTEM

Interpretation of the data from the various sensors required detailed knowledge of the instantaneous angle between any sensor and the direction of motion of the satellite. This information was provided through the use of a multiple optical sensor arrangement, which enabled sensing the direction of the sun and/or moon and the instants of passage, during spin, of the Earth's horizons.

Direct measurement sensors like those employed in Explorer XVII provide time rates-of-change of data requiring high telemetry sampling rates. For example, the spectrometers and pressure gages required 60 samples per second and the "high speed" Langmuir probe required 180 samples per second. To meet these needs a pulse code modulation (PCM) telemetry system capable of 1000 samples per second was selected. This system had the additional advantage of providing a digital format which facilitated computer data processing.

The satellite was powered exclusively by silver-zinc cells, since solar cells presented the possibility of local contamination of the atmosphere. The 150 pounds of cells which were employed provided adequate energy to operate the entire satellite system for a total of 75 hours. A command-and-control system permitted the experiments to be turned on for four-minute periods, each of which was terminated by an internal programmer. Because a tape recorder was not employed, responses were confined to geographic regions of approximately 4000 kilometers diameter about each minitrack command station. Figure 2 illustrates the geographic coverage attained by showing the path of the satellite during each data-producing response.

TABLE I

EXPLORER XVII STATISTICS

Launch Date	April 3, 1963
Inclination	58°
Perigee	258 km
Apogee Range	920-870 km
Useful lifetime	100 days
Perigee motion	+39° to +58° to −18°
Data responses	650 on command
Telemetry	PCM − 8640 bits/sec
Spin rate	90 RPM
Power supply	Chemical
Size and shape	1 meter sphere
Weight	410 pounds

densities by a small amount.

It is observed that the densities determined from drag are systematically 40% to 50% greater than the normalized densities measured by the gages, and that this separation is just outside the combined, stated uncertainties of the two sets of data. This difference is significant but at this time is not considered serious, since it could be accounted for by modest changes in the altitude to which the drag data are assigned, the drag coefficient, or the gage calibration constants.

Figure 5 shows measured atmospheric density-versus-altitude for the altitude range 258 to 600 km. These data result from approximately 60 passes for an A_p between 0 and 10, $F_{10.7}$ between 70 and 100, and most local times. It is seen that considerable variation in the atmospheric density occurs, resulting primarily from the differences in local time, a factor of 5 diurnal variation at 360 km being observed. The Harris and Priester model densities (S = 90) for 0400 and 1400 hours are shown for comparison purposes.

Continued analysis of the Explorer XVII data is currently underway to further define:

   (1) The quiet atmosphere and its variation with local time.

   (2) The variations from the quiet atmosphere resulting from solar and geomagnetic disturbances.

   (3) Other effects not now apparent.

TABLE II

TABULATED MASS SPECTROMETER DATA

Pass & Station	Date	Local Time	α	Geo. Lat.	Geo. Long.
#15 BP	4/4/63	21.15 hrs.	6°	38.5°	-75.0°
#50 COL	4/6/63	0.65	16°	57.0°	-149.0°
#80 COL	4/8/63	0.99	9°	55.0°	-147.0°
#80 FTM	4/8/63	4.89	63°	18.0°	-92.0°
#118 BP	4/10/63	18.81	70°	37.0°	-72.0°
#120 GF	4/11/63	20.32	51°	51.0°	-98.5°
#138 BP	4/12/63	2.51	12°	37.0°	-84.0°
#152 BP	4/13/63	2.01	14°	39.5°	-68.5°
#167 BP	4/14/63	1.65	20°	39.5°	-75.0°
#182 BP	4/15/63	1.54	25°	37.0°	-78.0°
#183 QUI	4/15/63	3.26	23°	4.5°	-79.0°
#197 BP	4/16/63	1.43	27°	34.0°	-81.5°
#211 BP	4/17/63	0.53	45°	41.5°	-71.5°
#226 BP	4/18/63	0.48	53°	38.5°	-74.0°
#241 BP	4/19/63	24.19	62°	38.0°	-79.5°
#242 MOJ	4/19/63	0.64	54°	31.0°	-121.5°
#254 NFL	4/20/63	22.75	82°	49.0°	-53.0°
#270 BP	4/21/63	23.30	80°	41.5°	-71.5°
#271 GF	4/21/63	22.88	85°	45.0°	-101.0°
#708 NFL	5/20/63	7.18	39°	49.5°	-49.5°
#795 OOM	5/26/63	15.81	63°	-34.0°	137.5°
#800 JOB	5/26/63	15.90	65°	-37.5°	19.0°
#888 JOB	6/1/63	13.24	33°	-27.0°	25.0°

The local sun time, angle of attack (α), geographic latitude and
longitude are averaged over the four minute pass. The stations involved
are:. BP - Blossom Point, Md.; COL - College, Alaska; FTM - Fort Myers, Fla.
GF - Grand Forks, Minn.; QUI - Quito, Equador; MOJ - Mojave, Calif.; NFL -
Newfoundland; OOM - Woomera, Australia; JOB -Johannesburg, South Africa.

The average in-pass change in T_e implies a latitude gradient near Blossom Point of approximately 25° K per degree of latitude, corresponding to about a 10% change in T_e within a pass. With few exceptions the changes in T_e within a pass are accompanied by an inverse change in N_i which is even greater than 10%.

Plots similar to Figure 9 have been prepared from T_e and N_i measurements at two other latitudes (10° N at Quito, 60° N at College), and the resulting gross diurnal variation curves at all three latitudes are shown in Figure 10. These data also correspond to the region of the F_2 maximum (below 400 km).

The T_e variation at the F_2 maximum at all latitudes shown is characterized by a steep morning rise, a midmorning maximum, and afternoon plateau, and a gradual decrease near sunset. The nighttime values of T_e are somewhat variable but are always significantly above the neutral particle temperature (Harris and Priester, 1962), particularly at College, Alaska where the summer night at F_2 altitudes is short or non-existent.

The values of N_i rose gradually throughout the day, reaching a maximum density in the late afternoon, except at College where the maximum occurred in the early afternoon.

It should be noted that the curves in Figure 10 represent direct "in situ" measurements above specific geographic locations during the late spring and summer of 1963, and therefore should not be considered models of the diurnal variation at other altitudes, longitudes, and seasons.

ACKNOWLEDGEMENTS

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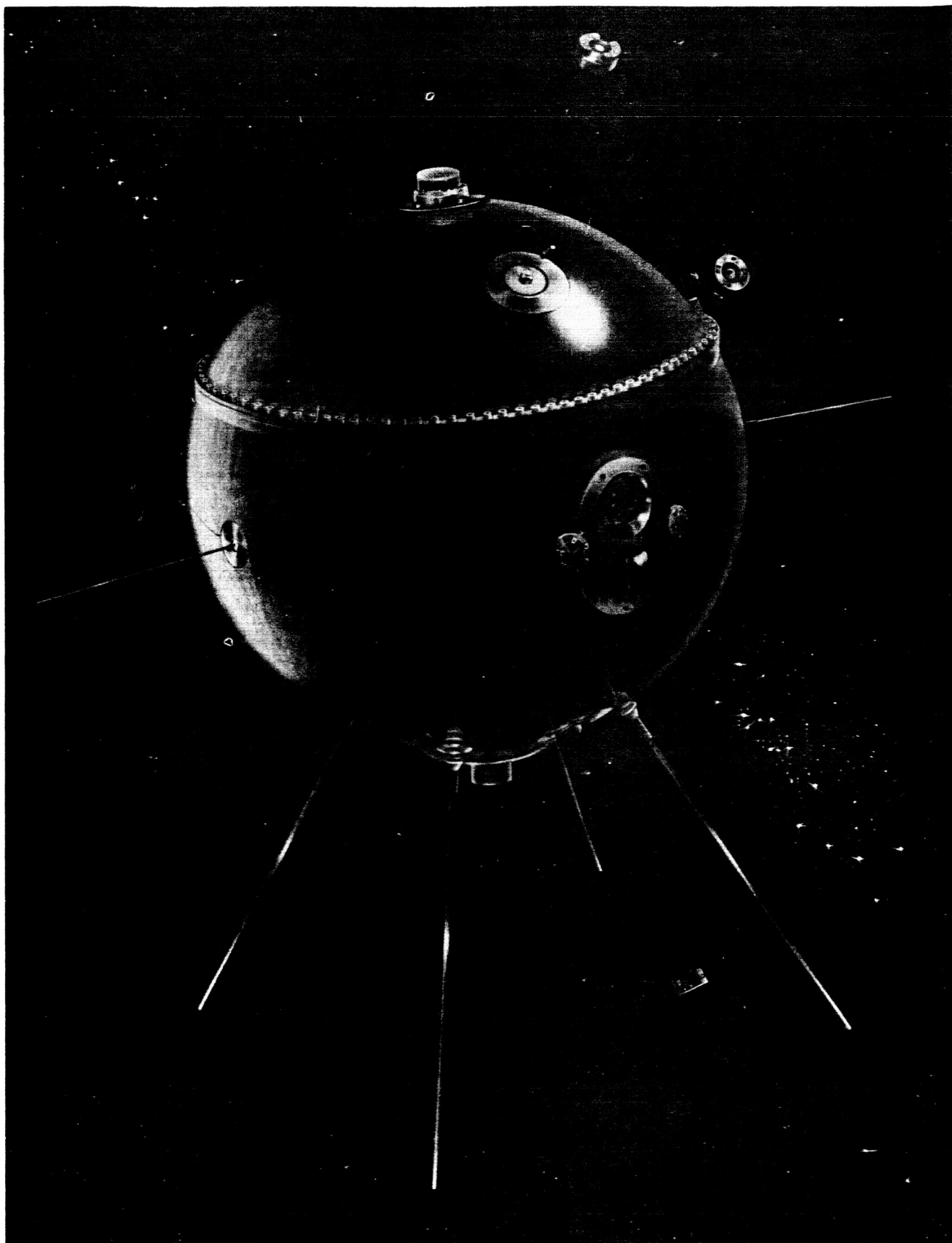
Fig. 1 - Artist's conception of Explorer XVII in orbit

EXPLORER XVII GEOGRAPHIC COVERAGE
(SATELLITE PATHS WHEN DATA WERE RECORDED)

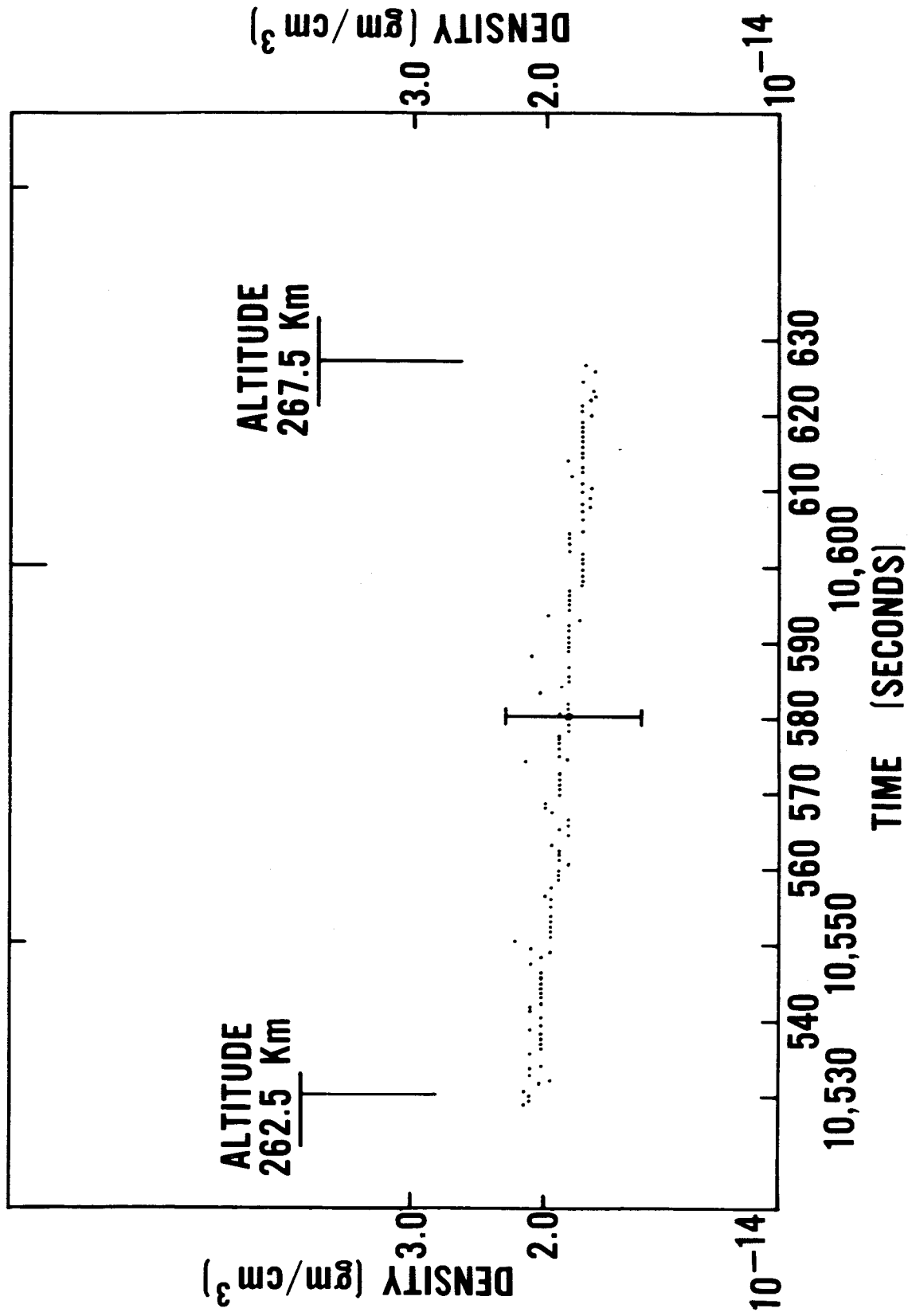Fig. 2 – Explorer XVII Geographic coverage

Fig. 3 — Density data derived from a single pass over Grand Forks, Minn. demonstrating the resolution of the pressure gage data
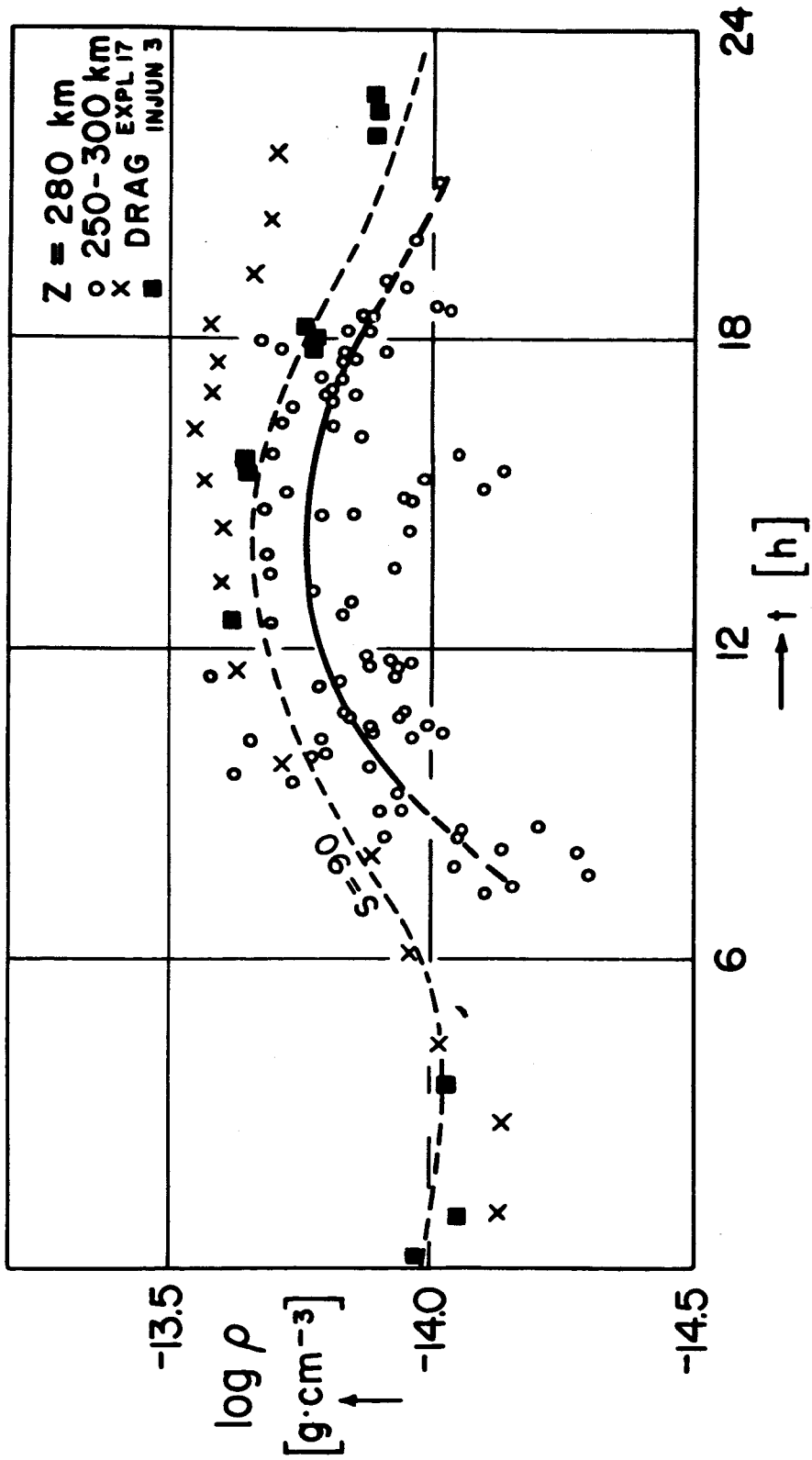
Fig. 4 – Comparison of directly-measured and drag-
derived atmospheric densities
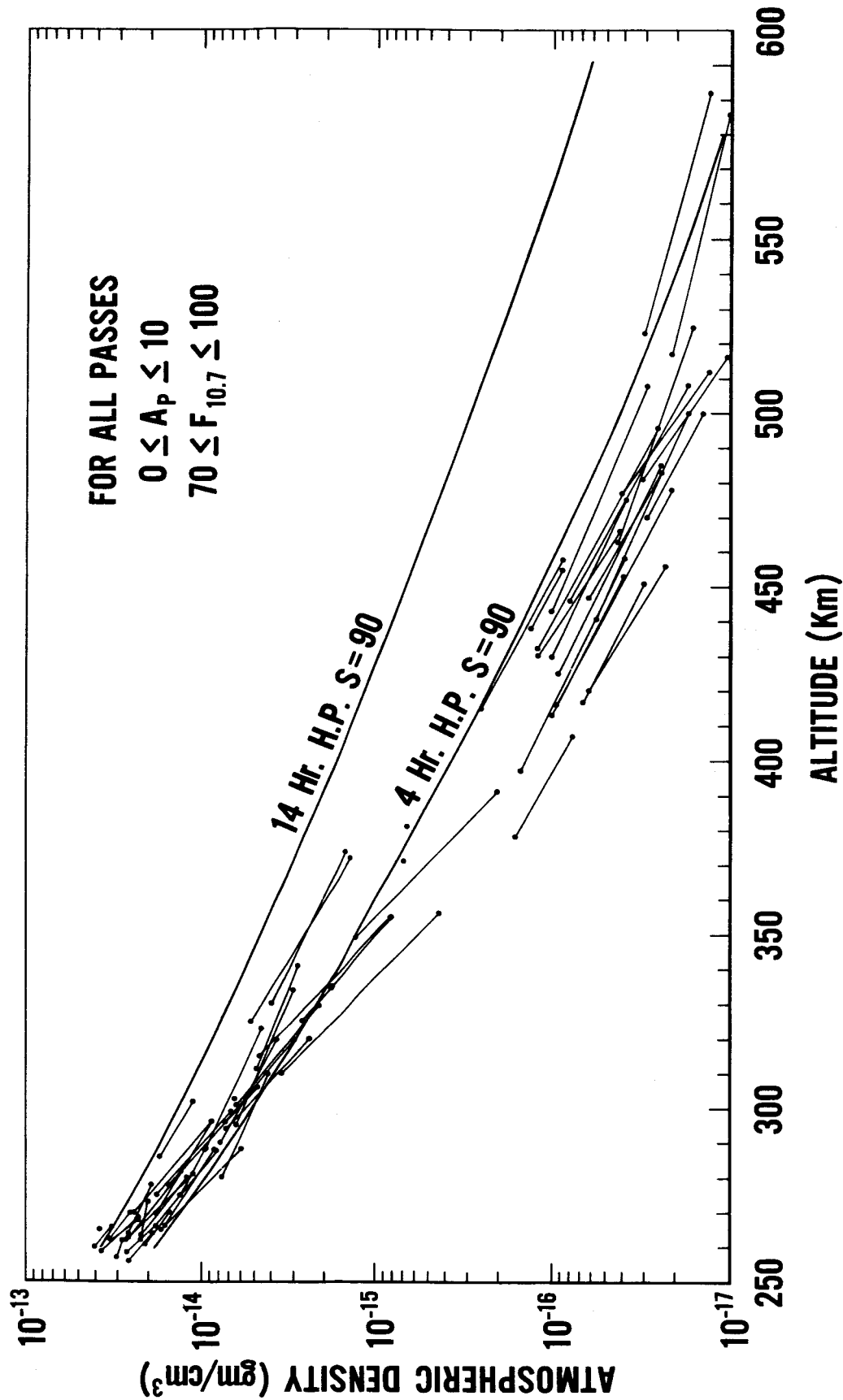
EXPLORER XVII

ATMOSPHERIC DENSITY VS ALTITUDE

Fig. 5 – Atmospheric density versus altitude
measured by the pressure gage experiment

EXPLORER XVII

NUMBER DENSITY VS. ALTITUDE
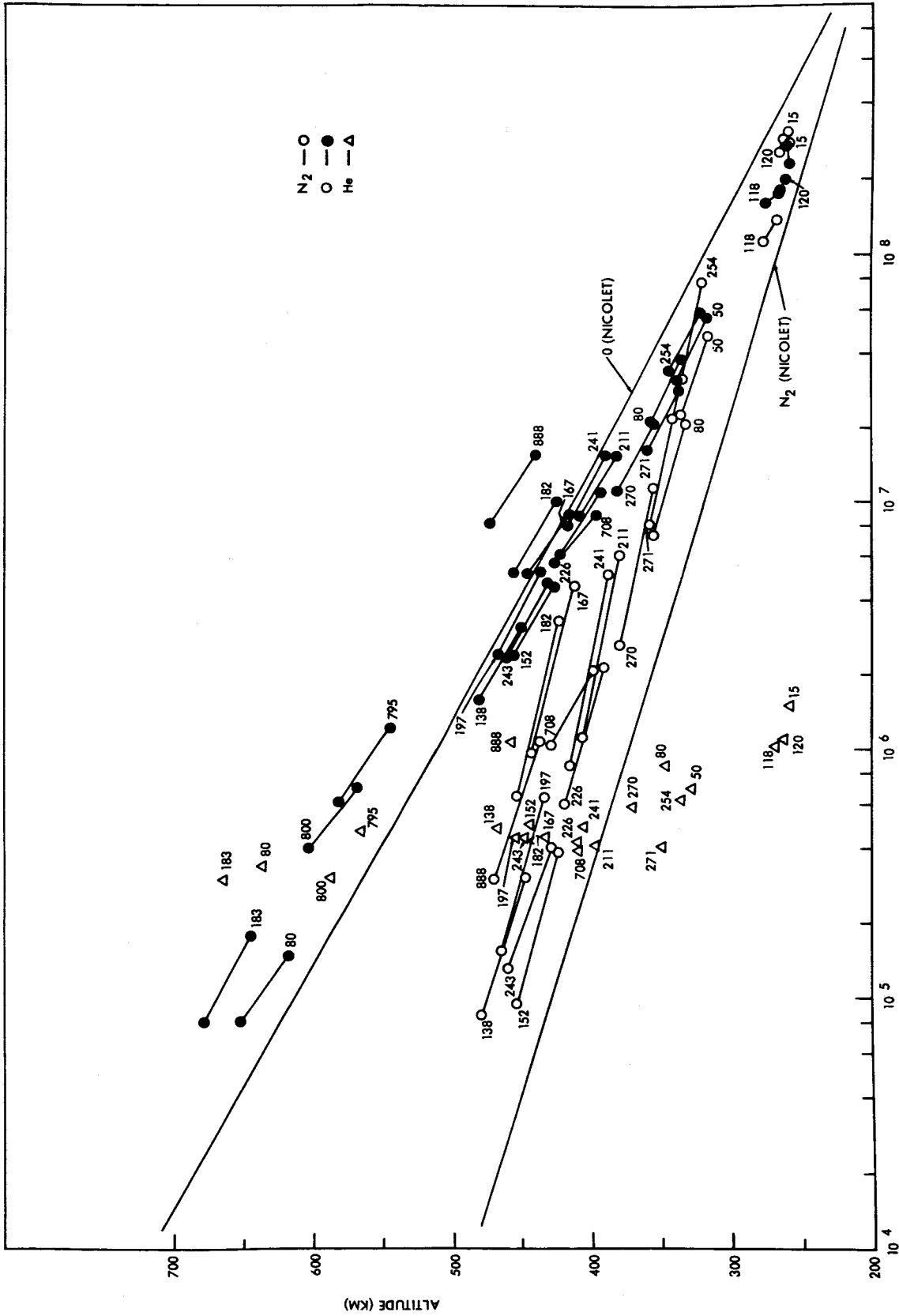
Fig. 6 — Average daytime and nighttime concentrations of He, O, and N_2 from Explorer XVII mass spectrometer experiment
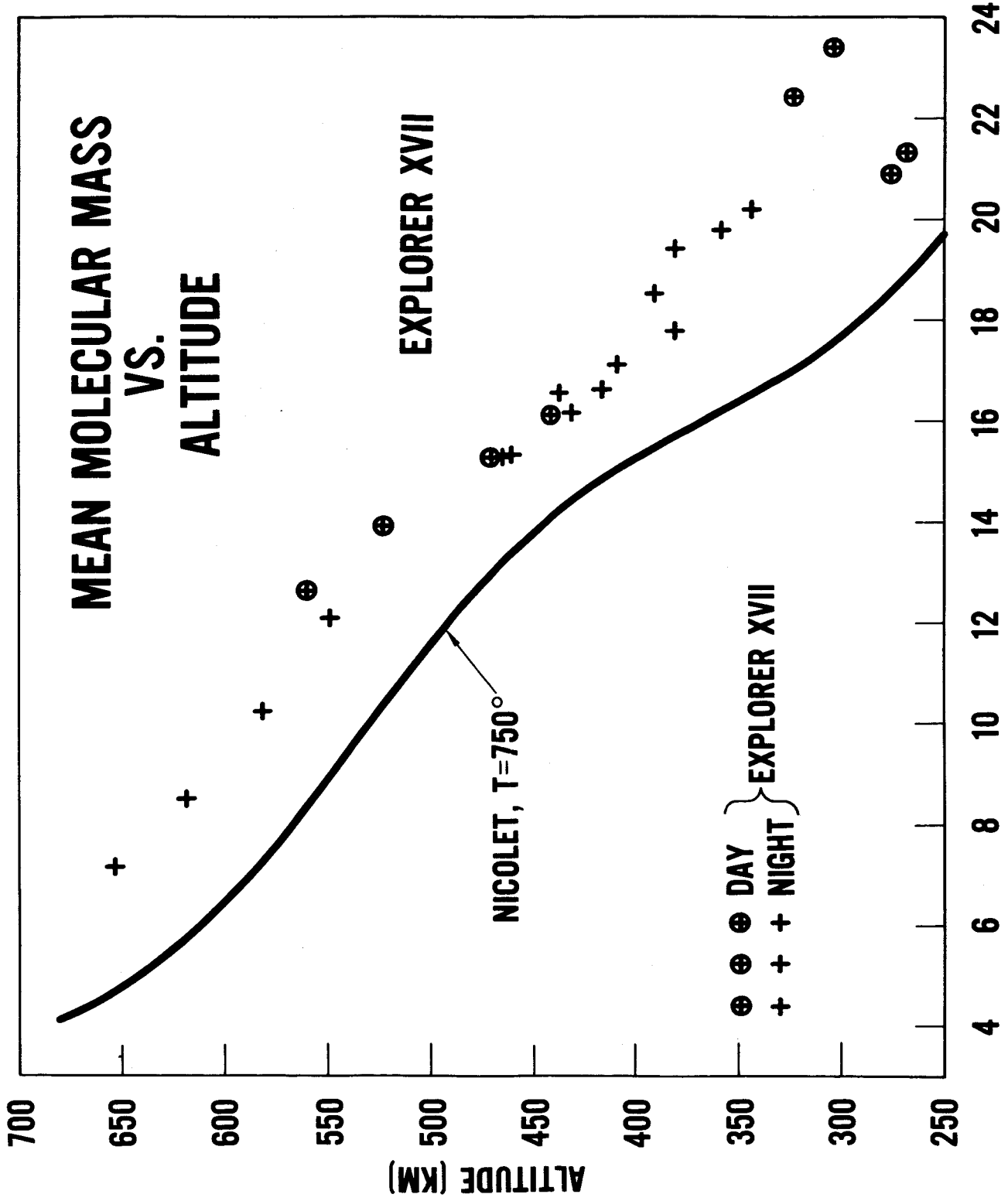
Fig. 7 – Mean molecular mass versus altitude from mass spectrometer
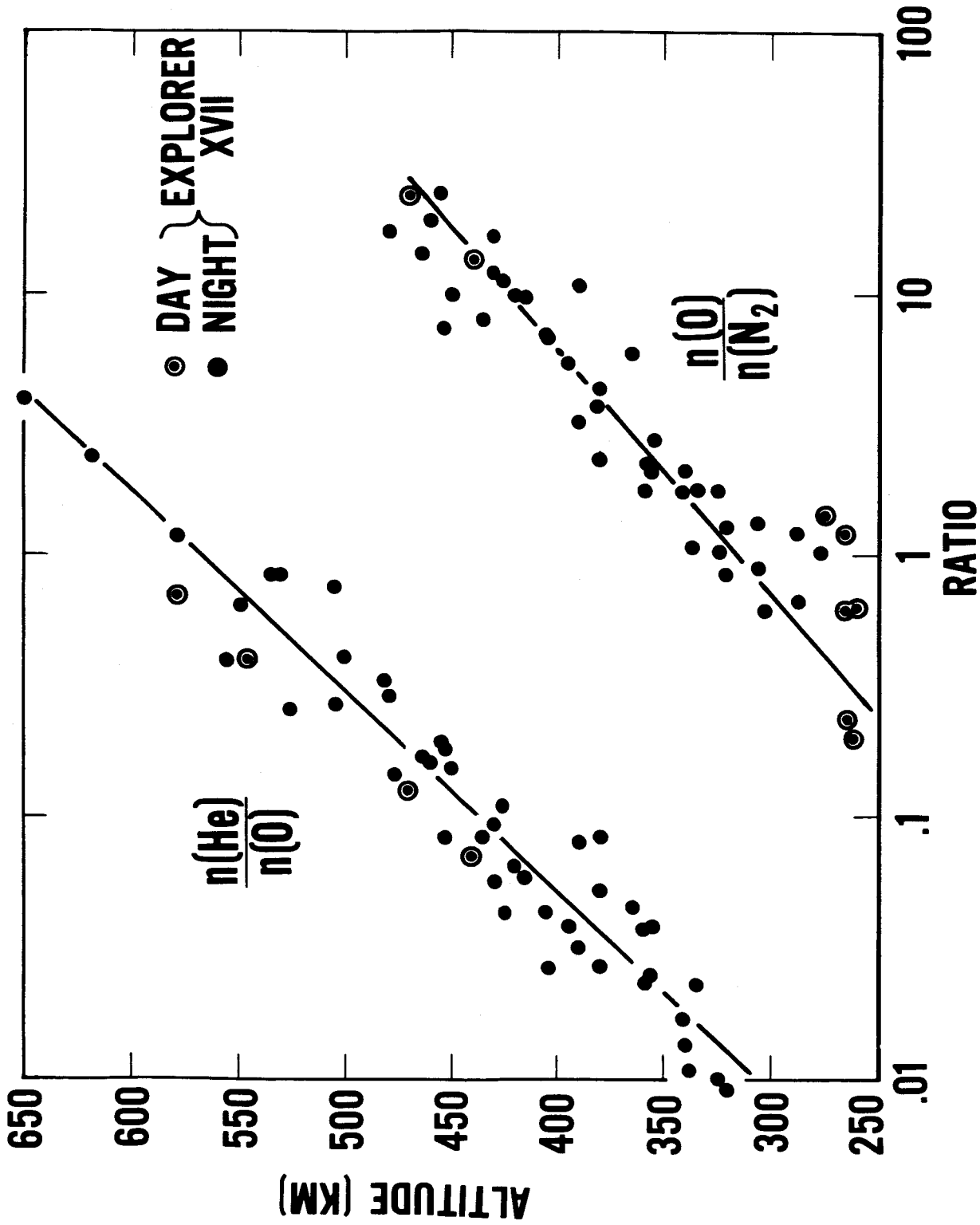
Fig. 8 — Ratios of n(He)/n(O) and n(O)/n(N₂) versus altitude from mass spectrometer experiment
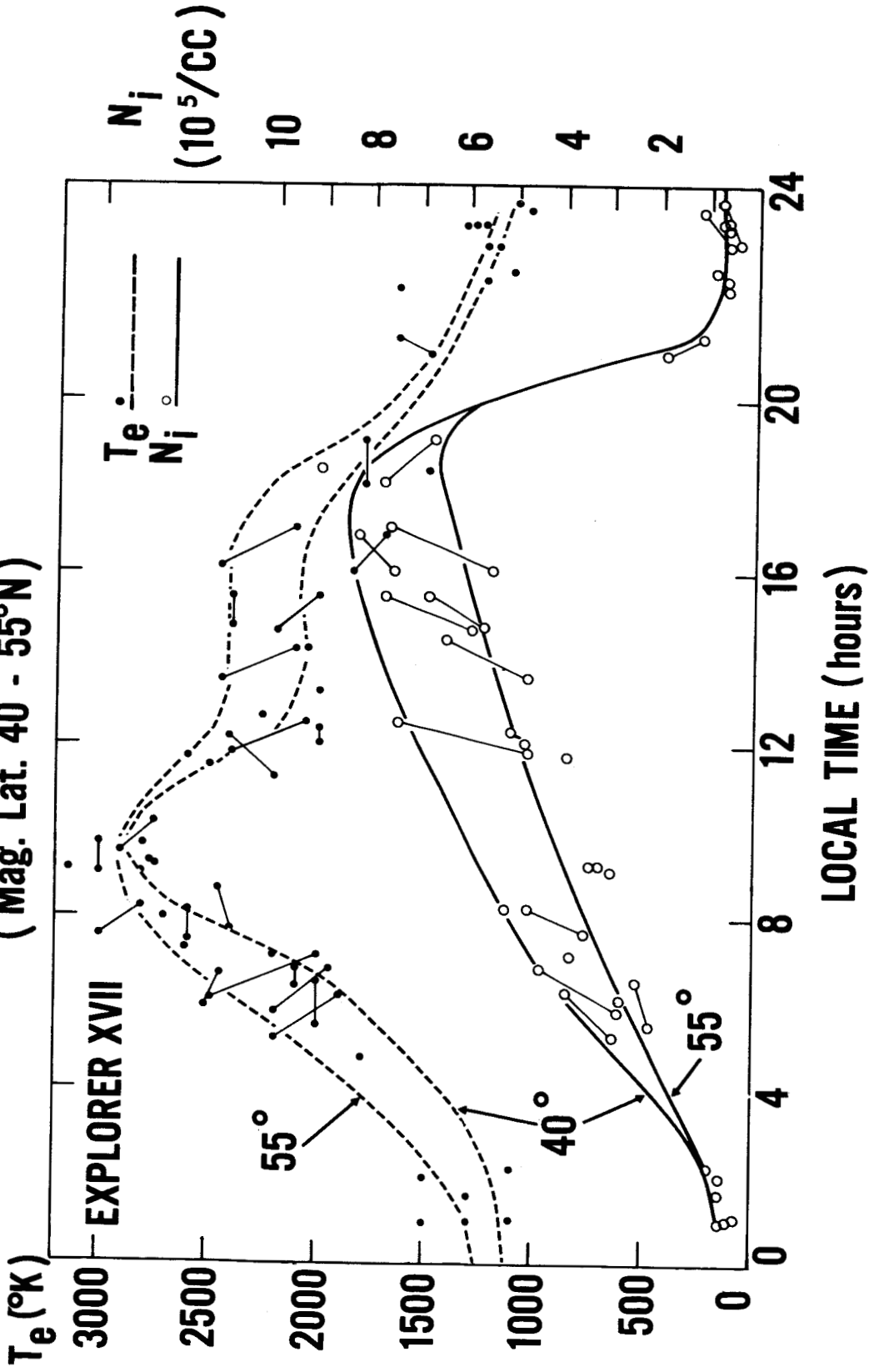
Fig. 9 – Diurnal variation of T_e and N_i for magnetic latitudes 40-55°N and altitudes 258 to 350 km, from the Langmuir probes
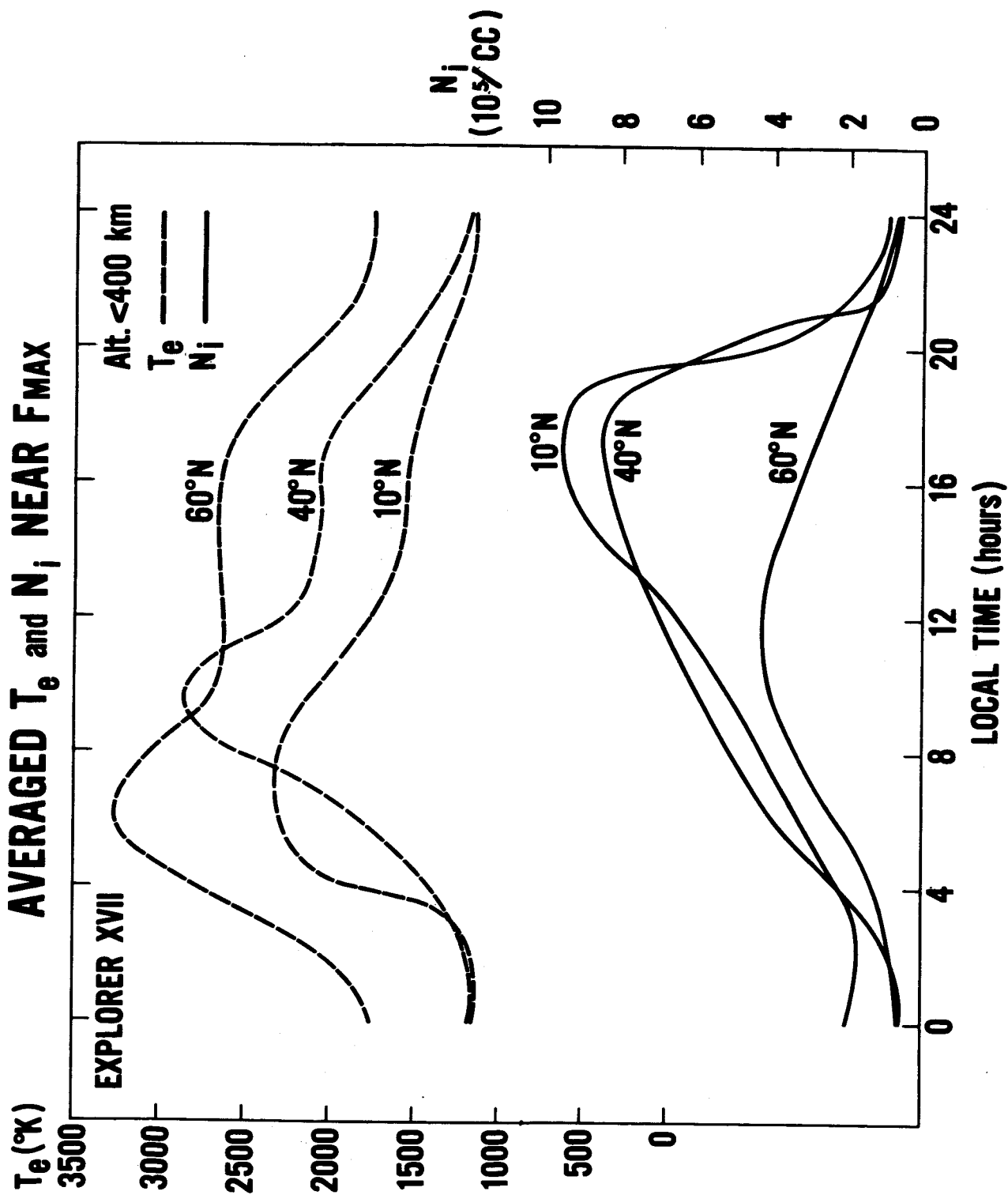
Fig. 10 - Averaged T_e and N_i showing the diurnal variation above three selected stations: Quito (10°N), Blosson Point (40°N) and College (60°N)