SYSTEM FOR COLLECTING WORLD-WIDE LOWER THERMOSPHERE DATA

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SYSTEM FOR COLLECTING WORLD-WIDE LOWER THERMOSPHERE DATA

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Abstract

To obtain lower thermospheric data on a world-wide basis, logistical considerations dictate that a satellite system be used rather than rockets. A pair of satellites is needed, with their orbits at right angles to one another (i.e., separated by six hours in local time), to give satisfactory time resolution. The orbits should have high inclination; 97° inclination (i.e., 83° retrograde) is desirable so that the local time of observation remains fixed as the orbits precess. As low an altitude should be utilized as is practical from the vehicle viewpoint (about 200 km if possible). The most important measurements are composition, airglow, and total density; a spinning satellite with its spin axis perpendicular to the orbit plane should be used to permit the determination of temperature from the shape of the response functions. Theoretical considerations must be used to extrapolate the measurements downward from the satellite altitude to the lower thermosphere; the theories at present are somewhat speculative and should be checked and refined as necessary by use of altitude profiles obtained from sounding rockets.

[redacted]

In order to engage in any meaningful discussion of a system for collecting lower thermosphere data on a world-wide basis, one must first decide what data are desired, and also what practical limitations are to be placed on the hardware system. I think that it must be agreed at the outset that we must talk about satellite systems, as only satellites can gather data on a world-wide basis without encountering unacceptable logistics problems. It might be the case that more desirable observations could be made in rockets, but a network of rocket launching stations that covers the globe cannot realistically be contemplated; not even a truly world-wide radiosonde network has proved attainable, even though the logistic support required for this would be small compared to the requirements for a rocket network.

With regard to the data that might be obtained, one can emphasize the neutral atmosphere or its ionized component, the ionosphere. Although one should not contemplate an observing program that wholly ignores either of these, it is probable that the satellite system and the detailed observations will depend in considerable degree upon whether primary concern is directed at the one or the other. It will be assumed in this discussion that the primary concern is with the neutral atmosphere, and that interest exists in the ionosphere only to the extent that it influences the behavior of the neutral atmosphere in a significant degree.

The data most needed now for the thermosphere are those that describe the geographical distribution of atmospheric constituents and its time variation. This need is well illustrated by the uncertainties that exist concerning the location of the diurnal atmospheric bulge that occurs at high altitudes due to the effects of solar heating. It was at first thought to lie at the latitude of the subsolar point, following the sun back and forth between the hemispheres with the seasons (Jacchia, 1964). Then additional data made it appear that the bulge did not migrate in latitude, but that it remained centered on the geographic equator and that it was elongated in the north-south direction compared to the east-west (Jacchia and Slowey, 1966). Next, Keating and Prior (1966) found that the atmospheric bulge at altitudes above 550 km was located in the winter hemisphere, not the summer, at about the same distance from the equator as the subsolar point, and they attributed this to a temperature maximum at temperate latitudes in the winter hemisphere. Later, Keating and Prior (1967) found that the winter bulge was at very high latitude and that it was caused, not by a temperature maximum, but by an excess of helium over the winter polar region. Obviously, what is needed to confirm or clarify this picture is a systematic world-wide survey of atmospheric composition, density, and temperature.

Sensors

The most important sensor that is required is a mass spectrometer to measure the concentration of various atmospheric constituents. Its importance derives from the great changes that take place in atmospheric composition above 100 km. These in turn result from two factors: the dissociation of oxygen into atomic form by solar ultraviolet radiation; and the relatively rapid diffusion of atmospheric constituents through one another so that each constituent becomes distributed in the gravitational field as if the others were not present - a condition generally referred to as diffusive equilibrium. The sorts of distributions that prevail are indicated in Figure 1, which describes conditions approximating those of the U. S. Standard Atmosphere 1962. In addition to the mass spectrometer, the instrumentation should include a vacuum or total pressure gauge. In general, the best way to use these sensors is in a spinning vehicle that has its spin axis perpendicular to the orbit plane so that the sensor looks directly into the airstream once each vehicle revolution. Not only does this simplify the data analysis, it should also permit the determination of atmospheric temperature from the shape of the response profiles for non-reactive species. In such a rarified atmosphere, this is one of the few means of measuring the neutral gas temperature, as heat transfer devices will not work. Atomic oxygen is an especially important constituent to measure, and it is especially difficult because of recombination processes in the instrument and even on the satellite surface. To handle this problem, two mass spectrometers, one with an open ion source and one with an enclosed source, might be advisable.

At the very least, the neutral gas measurements described above should be augmented by a Langmuir probe to measure several properties of the ion-electron gas - the ion and electron temperatures and the electron (or ion) concentration. These measurements can be related to the energy input to the neutral atmosphere at the satellite altitude. Still other sensors that should be included are airglow detectors, especially at 5577 Å to monitor oxygen recombination and probably also at 1216 Å to monitor the atomic hydrogen distribution. The only known excitation process for 5577 Å radiation at night is oxygen recombination, and observations of this line should prove useful in developing a fuller understanding of the oxygen problem. Figure 2 shows calculated distributions of atomic oxygen and other constitutents under the combined influence of molecular diffusion, eddy diffusion, recombination, and photodissociation, where the eddy diffusion coefficient has been assumed to have a value of 5×10^6 cm^2 sec^{-1} at all altitudes. The atomic oxygen concentrations decrease below 95 km because of the recombination processes. Observation of 5577 Å radiation should prove useful in furthering the understanding of eddy mixing patterns and large scale vertical motions. The measurements should be made with a narrow-field-of-view instrument that would observe the intensity at night as the field of view sweeps across the horizon. Atomic hydrogen measurements would be made in a similar manner, but during the daytime. Atomic hydrogen escapes from the upper thermosphere, requiring a diffusive flow upward of atomic hydrogen in the lower thermosphere; this flow is relatively so rapid that the atomic hydrogen distribution follows that of the total atmosphere up to well above 200 km rather than achieving diffusive equilibrium at a lower altitude.

Sensors for the ionosphere, such as an ion mass spectrometer and a retarding potential ion trap, should also be included in the payload instrumentation, but the priority for these instruments is not quite as high. A set of solar ultraviolet detectors might also be optically included.

An important feature to include in the satellite is data storage sufficient to permit the accumulation of data from at least one complete orbit. Otherwise, world-wide coverage cannot be achieved.

Orbits

The optimum type of orbit for world-wide data acquisition is one that is nearly circular. If an eccentric orbit were used, the information content of the data might be just as great, but it is much more difficult to classify the data from an eccentric orbit in a meaningful way, and the significant patterns and variations can be recognized only after much intensive analysis. Obviously, the use of an eccentric orbit would provide data at a variety of altitudes, but this would be at the expense of time or spatial resolution at a given altitude and it leads to the possibility of confusing diurnal variations with geographical and seasonal variations and traveling disturbances. For the neutral atmosphere especially, it is important to give priority to good geographical coverage at some reference altitude even though this must be at the expense of obtaining data over a wide altitude range. If primary attention is focused on the ionosphere, then there is a greater requirement for data over a wide altitude range, but even in this case there is some reason to doubt that as useful a set of observations can be obtained from an eccentric orbit as from a circular orbit.

It is of course impossible to obtain an absolutely circular orbit, and, even if an orbit were circular, there would still be altitude variations of 22 km around a polar orbit because of the earth's ellipsoidal shape. However, if the orbit is nearly circular, the atmospheric composition data can be referred to an average altitude by making corrections according to a set of distribution functions such as those shown in Figure 1. As long as the distances involved in the corrections are small, the corrections can be made with considerable accuracy. Further, if the temperature of the neutral atmosphere at the satellite altitude is measured, as it should be, the corrections can be made according to a simple analytic expression.

The orbit altitude should be as low as possible commensurate with an adequate lifetime, preferably in excess of a year. This favors the use of a small heavy satellite, or one with propulsion capability to readjust the orbit from time to time. A low orbit eases the sensitivity requirement on the mass spectrometer and of course favors the lower thermosphere as the desired region in which to make measurements. There should be no problem in keeping an orbit as low as 300 km, and less than 200 km should be realizable with a satellite that has propulsion capability. If a compromise is needed because of vehicle limitations, a lifetime as short as a month might be accepted, as no alternative scheme appears to exist for securing the required data. However, the state of space technology appears adequate to give the required orbit and lifetime; it is primarily a question of whether or not the resources required by this important problem are made available or not.

Very arbitrary choices must be made with regard to orbit inclination. In order to avoid changes in the local time of observation and the resultant possibility of confusing seasonal and local-time variations, an 83° retrograde orbit might be chosen; this orbit precesses in such a way as to maintain a fixed orientation relative to the sun, or a fixed local time for observations at any particular point in the orbit. Two satellites crossing the equator near 2:00 and 8:00 o'clock would give rather systematic and reasonably complete global coverage. This would give four observations a day above any point on the earth's surface, and this is about the minimum sufficient to map such features as the diurnal bulge. These orbits could be usefully supplemented by a third orbit of low inclination, 30° or less, to give improved coverage in local time; however, this should carry lesser priority than the two high inclination orbits.

Rockets

The most important part of the thermosphere is probably the very lowest part, that which lies roughly between 80 and 120 km. Here is where most of the chemistry occurs that significantly influences the neutral atmosphere at higher altitudes. It is also here that the transition takes place from a mixed atmosphere to one in diffusive equilibrium, or where eddy and molecular diffusion compete with one another. However, satellites cannot fly this low. All one can do with satellite is make observations at higher altitudes and then make use of the calculated distributions, such as those indicated in Figure 2, for downward extrapolation of the measure quantities.

One might imagine that it is an ideal task for rockets to map the 80 to 120 km region, but there are two limitations. The first has already been mentioned - to map on a world-wide basis with rockets is impractical because thousands of firings would be required at hundreds of launching sites. The second limitation is that instrumentation has not been developed sufficiently to make the critical in-situ observations of composition as low as 80 km in the neutral atmosphere. Efforts should of course be expended to improve the instrumentation in this regard, but the possibility of making the critical in-situ measurements of composition is speculative at best.

The appropriate role of rockets in the world-wide acquisition of lower thermosphere data should be to obtain vertical profiles from the lowest altitudes possible up to the satellite altitude at a few locations. The theories must be tested by such comparisons, and improved where possible. But we must in the long run count on the theories for adequate extrapolation from the satellite altitude to the base of the thermosphere to provide most of our information. This extrapolation can be augmented by some forms of remote sensing, such as the airglow measurements. Some types of microwave radiometers also appear to have potential for remote sensing near the base of the thermosphere; these scan across a strong atmospheric absorption line, and a temperature profile can be deduced from the observations.

Another important role for rockets is of course to describe the patterns of wave dynamics, particularly on a continental scale. Attempts should be made to recognize perturbations at satellite altitudes that relate to typical patterns of dynamical behavior near the 100 km level.

Vehicle

Goddard Space Flight Center has studied the feasibility of using a Tiros vehicle for upper atmospheric measurements. Owing to a considerable interest in the ionosphere, this study emphasized the use of a highly eccentric orbit. However, the system would be ideal for circular orbit measurements, as it can be spun about an axis perpendicular to the orbit plane, and enough propulsion capability is included in the concept to permit several adjustments of the orbit. The system includes the capability of reorienting the spin axis by magnetic interactions with the geomagnetic field, and this is required if the spin is to be kept perpendicular to the orbit plane as the orbit precesses.

Conclusion

A systematic collection of data from the lower thermosphere is urgently needed and could be acquired with presently available technology if the necessary resources were made available for this important problem. It is very surprising that in the tenth year of the satellite age so few data on the geographic distributions of atmospheric constituents at high altitudes are available. Unless an effort comparable to the one described here is undertaken soon, we will probably find a nearly total ignorance of the large scale patterns of thermospheric behavior still with us five years or more hence.

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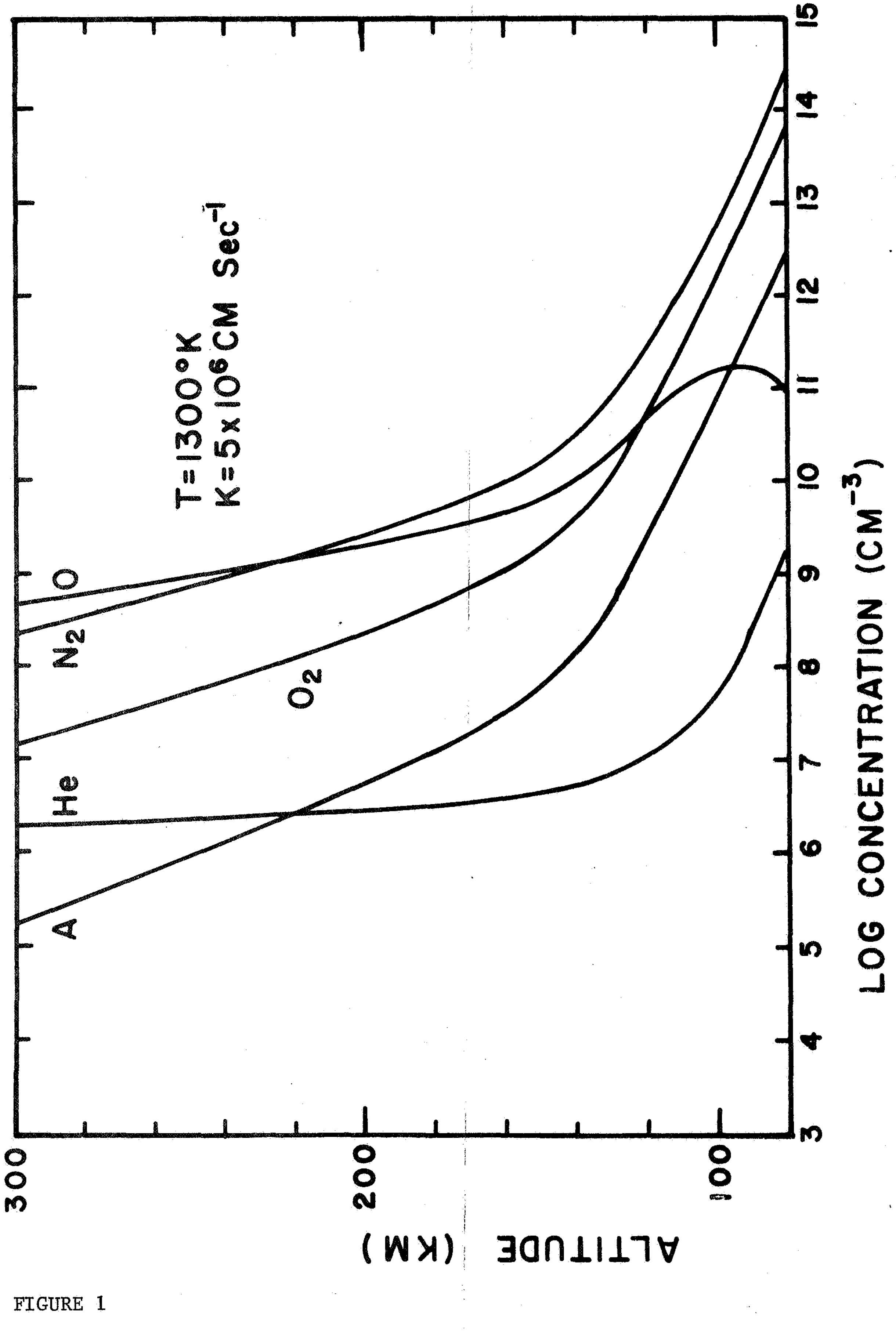
T=1300°K
K=5x10⁶CM Sec⁻¹
O
N₂
O₂
He
A
3
4
5
6
7
8
9
10
11
12
13
14
15
LOG CONCENTRATION (CM⁻³)
300
200
100
ALTITUDE (KM)

FIGURE 1

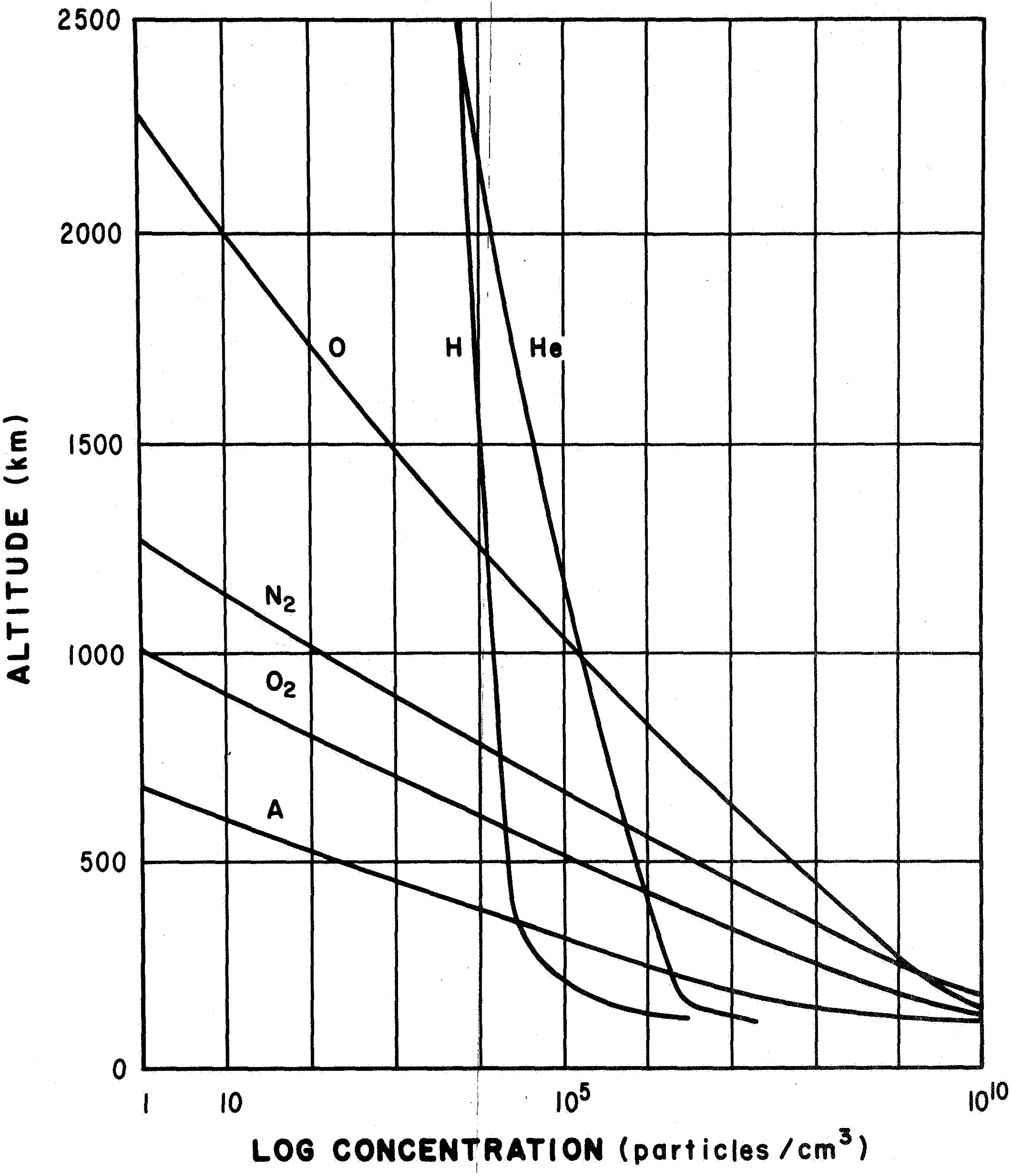
2500
2000
1500
1000
500
0
ALTITUDE (km)
O
H
He
N$_2$
O$_2$
A
1
10
10^5
10^{10}
LOG CONCENTRATION (particles/cm^3)

FIGURE 2