nearly normal in terms of snow water content but have slight differences in character. The second year (1969–70) snowpack averaged 75 to 80 percent of normal water content. Snow accumulated at a relatively even rate, and maximum water contents were reached in March (*5*). The third year (1970–71) snowpack averaged 90 to 135 percent of normal. Snow accumulated rapidly early in the year, and near-maximum water contents were reached in January; it thawed from mid-January through February, and more accumulated in March (*5*). Exceptional winds near the Sierra crest resulted in notable drifting during the third year [(*4*), including figure 1].

A comparison of D : H values for identical stations in the second and third years shows that 16 of the 26 stations have D : H values for the third year that are lower than those for the second year, and 10 have values that are higher. The average of the differences between the D : H values for identical stations is only 2 per mil. The inconsistency in the isotopic character at identical stations may be due to the factors inherent in snow core samples that were described above. However, the pattern of the D : H distribution is very similar in both years, which indicates that there were no fundamental differences in the magnitudes of storms or directions of storm tracks during these 2 years.

The important fact that emerges is that snow cores collected in 1969—a very abnormal year—are depleted in deuterium relative to cores collected in both of the more normal years that followed. We have suggested (*1*) that differences in the deuterium content of snow cores collected in different years at the same place can be used to characterize the weather patterns of the respective winters. The comparisons made in this report show that winters with very different weather patterns can be distinguished easily in this way, but that similar or nearly normal winters cannot. Also, the winter of 1968–69 may have resembled the Pleistocene in both isotopic character and increased precipitation. Our preferred explanation for the weather pattern of that winter provides a reasonable model for the climate of the Pleistocene compared with present climates in this area.

IRVING FRIEDMAN
U.S. Geological Survey,
Denver Federal Center,
Denver, Colorado 80225
GEORGE I. SMITH
U.S. Geological Survey,
345 Middlefield Road,
Menlo Park, California 94025

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Terrestrial Atmospheric Composition from Stellar Occultations

Abstract. *Stellar ultraviolet light transmitted through the earth's upper atmosphere is strongly absorbed by ozone and molecular oxygen. The stellar ultraviolet photometers aboard the Orbiting Astronomical Observatory (OAO-2) satellite have measured the intensity changes of several stars during occultation of the star by the earth's atmosphere. From the occultation data the nighttime vertical number density profiles of molecular oxygen at altitudes from 120 to 200 kilometers and of ozone at altitudes from 60 to 100 kilometers have been obtained.*

In the earth's upper atmosphere, stellar ultraviolet light is strongly absorbed in the Schumann-Runge continuum of O_2 and the Hartley continuum of O_3. By monitoring the intensity of ultraviolet starlight in these continuum regions from a satellite as the star is occulted by the earth's atmosphere, we are able to obtain information on the number density profile of O_2 in the lower thermosphere and O_3 in the upper mesophere (*1, 2*). In this report we describe the technique used to obtain the number density profiles from stellar occultation measurements. The data were obtained by the University of Wisconsin stellar photometers aboard the Orbiting Astronomical Observatory (OAO-2) satellite. We discuss here the inversion process and also show the O_2 and O_3 distributions determined from a typical occultation scan.

In the occultation technique classical absorption spectroscopy is used to determine the number density profile of the absorbing species in the upper atmosphere. The star is the source of ultraviolet light, the OAO stellar photometers are the detectors, and the atmosphere between them is the absorption cell. During the occultation process, the ultraviolet light is selectively absorbed in spectral regions for which O_2 and O_3 have large absorption cross sections. The intensity of the transmitted ultraviolet light is related to the number density along a tangential column of the absorbing species (N_i) by Beer's law

$$I(\lambda,r_0) = I_\infty(\lambda)\ \exp\left[-\sum_i \sigma_i(\lambda)\cdot N_i(r_0)\right] \quad (1)$$

where $I_\infty(\lambda)$ is the unattenuated intensity above the atmosphere of the star at wavelength λ, $\sigma_i(\lambda)$ is the absorption cross section of the *i*th absorbing species, and $N_i(r_0)$ is the tangential column number density of the *i*th absorbing species at a tangent ray height r_0. The star's spectrum is measured above the atmosphere by the OAO ultraviolet spectrometer. By also knowing the absorption cross section, one can relate $N_i(r_0)$ to the intensity of the transmitted ultraviolet light. In practice, Eq. 1 must be integrated with respect to wavelength because of the finite passband of the ultraviolet filter. The best

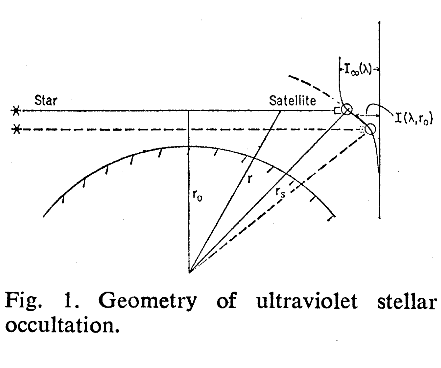

Fig. 1. Geometry of ultraviolet stellar occultation.

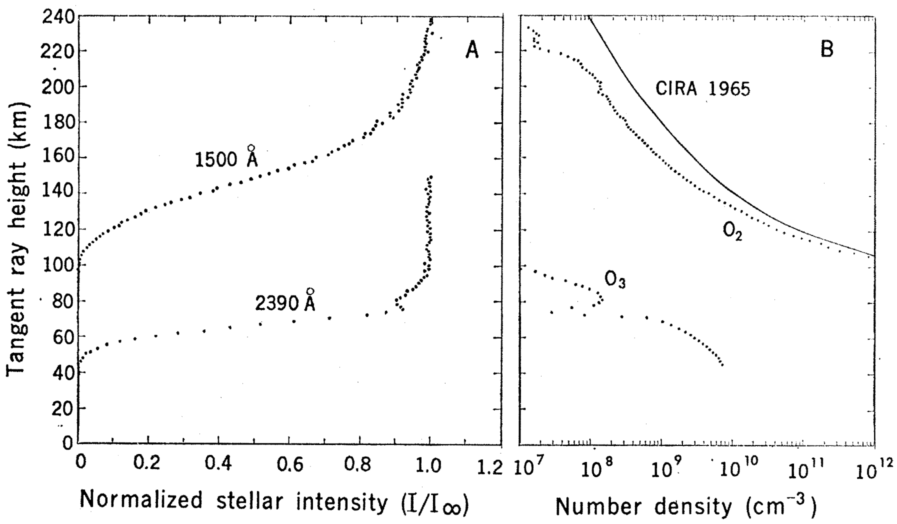

Fig. 2. (A) Normalized intensity of a star as a function of the tangent ray height during occultation of the star by the earth. The curves correspond to the intensity measured in the 1500-Å and 2390-Å channels of the University of Wisconsin stellar photometers aboard the OAO-2 satellite [22 August 1970, 04 hours 22 minutes (local time), 25°N, 39°E]. (B) Number densities of O_2 and O_3 as a function of tangent ray height determined from the occultation measurements. The solid line is the O_2 number density from the CIRA 1965 model atmosphere.

results are thus obtained when a single species dominates the absorption process, and the OAO filters were, therefore, selected accordingly.

Once $N_i(r_0)$ is known, it is a simple matter to invert the data and obtain the vertical number density profile of the absorbing species at the occultation tangent point. A simple geometrical argument (Fig. 1) shows that $N_i(r_0)$ along the ray path for a spherically stratified atmosphere can be written as

$$N_i(r_0) = 2\int_{r_0}^{\infty} \frac{n_i(r)\, r\, dr}{(r^2 - r_0^2)^{1/2}} \qquad (2)$$

where $n_i(r)$ is the number density of the *i*th absorbing species at radius r. Equation 2, the Abel integral equation (*1, 2*), is easily inverted to give the number density of the absorbing species at a tangent ray height r

$$n_i(r) = \frac{d}{dr}\left[-\frac{1}{\pi}\int_{r}^{\infty} \frac{r}{r_0} \frac{N_i(r_0)\, dr_0}{(r_0^2 - r^2)^{1/2}}\right] \qquad (3)$$

Thus, the stellar occultation technique can be used to obtain the vertical density profile of any absorbing atmospheric species which can be spectrally isolated.

Hays and Roble (*2*) have calculated the tangential ultraviolet transmission of the earth's upper atmosphere. Their results show that both the strong atmospheric absorption of O_2 in the Schumann-Runge continuum near 1500 Å and the strong atmospheric absorption of O_3 in the Hartley continuum near 2500 Å occur in spectrally isolated regions in which the stellar ultraviolet absorption is primarily due to a single species. The absorption cross sections of O_2 and O_3 at these wavelengths have a peak around 10^{-17} cm^2. Therefore, we are able to determine the distribution of these species near altitudes at which N_i is approximately 10^{17} cm^{-2}. If a spectral region away from the peak cross section is utilized, one is able to observe higher tangential column number densities or, equivalently, to measure the number density at lower altitudes within the atmosphere. The ultraviolet light in the wavelength interval from 1400 to 1600 Å is absorbed primarily by O_2 at altitudes from 130 to 230 km. In the wavelength interval from 2400 to 2600 Å, the ultraviolet light is absorbed primarily by O_3 at altitudes from 60 to 100 km (*2*).

The normalized intensity data obtained during one of the many occultations are shown in Fig. 2A for two stellar photometers having filters centered at 1500 and 2390 Å. The normalized intensity is obtained as a function of time; however, by knowing the star's position and the orbital elements of the satellite, we are able to relate time to the tangent ray height of the occulting star. Because of high-altitude absorption, the normalized intensity in the O_2 channel at 1500 Å decays first. Then the intensity in the 2390-Å channel decays rapidly at altitudes where O_3 absorption becomes important. The excellent quality of the data obtained by the OAO-2 stellar photometers allows determination of detailed structure. The data in the 1500-Å channel were inverted, and the results are shown in Fig. 2B where the O_2 number density profile is shown as a function of height. For comparison, the O_2 profile of the Committee on Space Research (COSPAR) CIRA 1965 (*3*) model atmosphere is shown also. These data are only a sample of the approximately 20 stellar occultation scans that have been reduced thus far, but they illustrate the quality of the data obtained from the occultation measurements.

Most of the O_3 scans obtained with the 2390-Å and 2460-Å filters aboard the OAO-2 satellite have a normalized intensity scan similar to the one shown in Fig. 2A. The intensity of the occulting star decreases as the starlight penetrates into the atmosphere until a slight increase in the intensity curve occurs at a tangent ray height near 70 km. These data, when inverted, give the number density profile of O_3 shown in Fig. 2B. The structure in the measured intensity curve is caused by a bulge in the nighttime O_3 number density profile, with the peak occurring near 82 km and a minimum near 75 km for this particular scan. The stellar occultation measurements clearly define the structure of the nighttime O_3 profile at high altitudes where no previous measurements had been made.

The occultation technique has also been used with the sun as the light source. The measurements, however, are restricted to sunrise and sunset, and a general review of the subject has been given by Link (*4*).

P. B. Hays

University of Michigan, Ann Arbor 48105

R. G. Roble

National Center for Atmospheric Research, Boulder, Colorado 80302

A. N. Shah

University of Michigan, Ann Arbor

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