Venera 8: Measurements of Solar Illumination Through the Atmosphere of Venus

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ABSTRACT

Measurements of the flux of downward solar radiation through the atmosphere of Venus and at the planetary surface are reported. These were obtained with the interplanetary spacecraft Venera 8 which landed on the surface of Venus on 22 July 1972 after a 55-min parachute descent through the atmosphere.

A significant flux of solar radiation was found to penetrate the entire thickness of the atmosphere, with the amount at the ground ~1.5% of that incident on the top of the atmosphere. The variation of flux with altitude indicates that the clouds have a lower boundary at an altitude of ~35 km.

1. Introduction

Measurements of the vertical distribution of solar radiation are of major importance for determining the nature of the Venus atmosphere. Such measurements can determine the distribution of absorbed solar energy, the range of visibility and contrast at the planetary surface, and the structure and optical properties of clouds. Knowledge of the absorbed solar energy is required for an understanding of the atmospheric circulation and the reason for the high temperature of the planetary surface. Since observations from the Earth or from the surface of Venus are not sufficient to solve these problems, it is essential to obtain measurements by means of instruments on board descending entry probes.

Venera 8 was the first atmospheric probe to land on the solar-illuminated side of Venus. Its landing site was ~1000 km south of the intensity equator of the planet and ~600 km from the sunrise terminator [cf. Fig. 1 of Marov et al. (1973a)], corresponding to a solar zenith angle ~84.5° ± 2.5°. A flux meter on Venera 8 was used to measure the solar flux from an altitude of ~50 km to the ground.

The measurements of solar radiation are described here; measurements of temperature, pressure and wind velocity by Venera 8 are given in a companion paper in this journal (Marov et al., 1973a). A more detailed account of the Venera 8 results will be published in Icarus (Marov et al., 1973b) including measurements of gamma radiation from the surface material.

2. Measurements

Venera 8 was equipped with a special photometric device for measuring the light flux (i.e., photometric illumination) in the Venus atmosphere for ambient temperatures and pressures up to ~500°C and 100 atm. The flux meter was designed with a sensitivity covering five orders of magnitude, since the amount of light absorption in the atmosphere and the sun elevation above the horizon were not precisely known beforehand. The accuracy of the experiment was enhanced by the inclusion of two identical flux meters, each consisting of a detector and electronic unit.

The detector was covered with thermal insulation and included a heat sink to stabilize the temperature of the sensitive element, a cadmium-sulfide photoconductor. The light flux was directed to the photoconductor along a glass light guide. The flux meters were installed in a vertical position in the parachute compartment of the entry probe and observed light flux from the upper hemisphere. The deployed parachute occupied ~1% of the field of view, so its influence on the measurements was insignificant.

The electronic unit located inside the probe transmitted signals in proportion to the logarithm of the light flux. Signals were transmitted along two channels: one with flux in the range 0.002–2 W m⁻² and a second for 0.2–200 W m⁻². To increase the accuracy of the results the temperature sensitivity of the flux meter was measured before flight and used for calibrations. For this purpose the temperatures of the photoconductor and electronic unit were measured by a thermistor during the entire descent. In addition, the flux meter included a miniature standard source which was employed during ground calibration and two weeks before landing on Venus; this resulted in a 12% correction due to an apparent increase in the detector sensitivity during flight. The total error in the measured flux is estimated to be ±30%.

The flux meter measures the quantity

\[ W = 2\pi \int_0^{\pi/2} d\varphi \int_0^{\infty} I(\lambda, \varphi) P(\varphi) \sin \varphi S(\lambda) d\lambda \]  

(1)

where \( I(\lambda, \varphi) \) is the spectral intensity of radiation (W m\(^{-2}\) \(\mu m\)\(^{-1}\) ster\(^{-1}\)) at the angle \( \varphi \) from the vertical axis of the flux meter, \( S(\lambda) \) is the relative spectral sensitivity of the instrument (Fig. 1), and \( P(\varphi) \) its angular sensitivity (Fig. 2).

The spectral sensitivity \( S(\lambda) \) was calibrated for various temperatures of the detector and various flux levels. The thin lines in Fig. 1 are an indication of the uncertainty in \( S(\lambda) \) during the measurements on Venus due to photoconductor heating. For an isotropic intensity of the spectral distribution of sunlight, the flux meter would yield \( W = 0.25F_0 \), where \( F_0 \) is the flux for \( S(\lambda) = 1 \).

The angular sensitivity \( P(\varphi) \) depends on the geometry of the upper part of the light guide, which was in the shape of a cone with an apex angle of 60°. This provided a significant sensitivity over the entire upward hemisphere of \( 2\pi \) ster. \( P(\varphi) \) satisfies the normalization condition

\[ \int_0^{\pi/2} P(\varphi) \sin \varphi d\varphi = 1, \]  

(2)

and is a fair approximation to \( \cos \varphi \) which would be the ideal sensitivity, i.e., that which would yield the true downward flux for any angular distribution of intensity.

The measured values of \( W \) as a function of altitude are shown in Fig. 3. The altitude was obtained from the measured temperature and pressure (Marov et al., 1973) by using the hydrostatic equation, perfect gas law, and
mean molecular weight $\mu = 43.4$. For comparison, the results are also shown with the altitude taken from the radar altimeter. The thin lines represent the estimated uncertainty due to possible systematic errors. The random error, defined by the dispersion of experimental points about the average curve, is less than 10%.

Fig. 3 illustrates that the variation of $W$ with altitude undergoes a sharp change at an altitude of $\sim 32$ km. If the influence of atmospheric density is removed by replacing the altitude $h$ with the corresponding altitude in a homogeneous atmosphere,

$$H(h) = \frac{1}{\rho_0} \int_0^h \rho dh,$$  \hspace{1cm} (3)

where $\rho$ and $\rho_0$ are the density of gas at the altitude $h$ and at the surface, the change in the nature of the curve at $h = 32$ km is even sharper (Fig. 4).

The elevation of the sun above the horizon at the location where Venera 8 landed was $5.5^\circ \pm 2.5^\circ$. Thus, the flux of solar energy normal to the top of the atmosphere was $260 \pm 130$ W m$^{-2}$, which is equivalent to a measured flux $W = 65 \pm 35$ W m$^{-2}$ (weighted by the spectral response of the flux-meter). The initial measurement of $W \approx 10$ W m$^{-2}$ indicates that the atmosphere above 50 km attenuates the light by a factor of $\sim 7$. There is then a further reduction in the flux by a factor of 3 between 50 and 32 km, and by still another factor of 3 between 32 km and the ground.

3. Interpretation

The degree of light attenuation in the altitude range 0–32 km and the near-linear nature of the curve $W(H)$ indicate that the quantity of aerosols in that region is insignificant and the reduction in the flux is primarily due to Rayleigh scattering. At altitudes above 32 km the strong attenuation of light may be due to aerosol scattering or to real absorption. One possible interpretation is the existence of rather dense clouds above $\sim 32$ km.

Some evaluation of atmospheric optical properties has been made on the basis of the flux measurements. Between the upper boundary of the clouds, at an altitude 65–70 km (Marov, 1972), and the altitude 50 km there is an attenuation of the light by a factor of 7, while between 50 and 32 km the attenuation is only a factor of 3. Thus, the optical density in the 70–50 km region is greater than that in the lower atmosphere.

For the region below 32 km an estimate has been made of the range of optical properties (scattering coefficient, single scattering albedo and ground albedo) consistent with the measured $W(H)$. This was done by computing a theoretical $W(H)$ for a wide range of optical properties and comparing the results with the measurements, taking into account the possible experimental error. The results show that 1) the scattering coefficient does not exceed that for Rayleigh scattering by more than 30%, 2) the single scattering albedo is greater than 0.99, and 3) the ground albedo is between 0 and 0.6. In addition, it can be assumed that the radiation in this lower part of the atmosphere is diffuse and that the red part of the spectrum predominates.

An approximate value for the total solar energy reaching the planetary surface can be obtained from the measurements by taking into consideration the spectral composition of the flux at the surface. At the landing site, where the solar zenith angle was $\sim 84.5^\circ$, the estimated flux for the entire spectrum is 2–4 W m$^{-2}$. Extrapolating this to the case of zero solar zenith angle yields a flux of 20–40 W m$^{-2}$; thus 10–20 W m$^{-2}$ is an average for the solar-illuminated side of Venus. This estimated flux does not contradict the assumption that a "greenhouse" mechanism is responsible for the heating of Venus (Sagan, 1969; Marov, 1972; Marov and Shari, 1973).

The illumination at the landing site, obtained from the measured $W$ and a theoretical estimate for the spectrum of solar radiation at the planetary surface, is 100–300 lux. When the sun is at the zenith it is probable that the illumination is at least 1000–3000 lux.

In summary, the radiation measurements conducted aboard Venera 8 have yielded the absolute value of the solar flux in the atmosphere of Venus, including its dependence on altitude. The attenuation of light in the atmosphere below about 32 km is explained well by Rayleigh scattering in CO$_2$. Above 32 km it is necessary to assume the presence of either additional aerosol scattering or a real absorption. This suggests the existence of a cloud cover with a lower boundary at an altitude near 32 km. Only a small part, $\sim 1\%$, of the incident solar flux reaches the surface of Venus. However, the flux is sufficient to create a significant illumination on
the surface by terrestrial standards and to maintain a high temperature in the lower atmosphere.

REFERENCES