NOTES AND CORRESPONDENCE

Venera 8: Measurements of Temperature, Pressure and Wind Velocity on the Illuminated Side of Venus[1]

M. YA. MAROV, V. S. AVDUEVSKY, V. V. KERZHANOVICH, M. K. ROZHDESTVENSKY, N. F. BORODIN AND O. L. RYABOV

Academy of Sciences, Moscow, USSR

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Measurements of the temperature, pressure and wind speed in the atmosphere of Venus are reported. These were obtained with the interplanetary station Venera 8, which was the first entry probe to telemeter data from the solar-illuminated side of Venus.

One component of the horizontal wind velocity was obtained, for the direction from the landing site to the sub-Earth point, ~25° from the zonal direction. This component was found to decrease from ~100 m sec^{-1} at an altitude of 50 km to ~0 at the ground, with the direction of flow from the day side of the planet toward the night side at all altitudes.

1. Introduction

On 22 July 1972 the automatic interplanetary spacecraft Venera 8 reached the planet Venus and landed on its surface at $12^h32^m16^s$ Moscow time[2] after a 55-min parachute descent through the atmosphere. Receipt of telemetered information from the descending spacecraft began at $11^h37^m27^s$ and continued through the descent and 50 min of operation on the surface of Venus.

Venera 8 landed near the equator on the illuminated side of the planet ~600 km from the sunrise terminator. The landing sites of Venera 4–8 are indicated by stars in Fig. 1. The vertical lines in the figure give the location of the sunrise terminator with the cross hatching extending toward the dark half of the planet; α and β are areas of high radar reflectivity; and zero latitude is defined by the subsolar point and zero longitude by the sub-Earth point at inferior conjunction.

The basic configuration of Venera 8 was similar to the earlier probes in the Venera series. Based on measurements made by Veneras 4–7 and the resulting atmospheric model (Marov, 1972), the descending apparatus was designed to operate under ambient temperatures and pressures as high as 770K and 120 atm.

2. Measured quantities

Venera 8 was equipped to measure several different quantities during its descent and while on the planetary surface. In this paper the results of measurements of the temperature, pressure and wind velocity are reported. In the companion paper in this journal (Avduevsky *et al.*, 1973) measurements of the flux of solar radiation through the atmosphere are reported. A more detailed account of the Venera 8 measurements will be published in *Icarus* (Marov *et al.*, 1973).

Several devices were employed for measuring temperature and pressure during the parachute descent and on the surface of the planet. Four resistance thermometers were used with their ranges of operation designed to be 320–860K, 480–710K, 670–810K and 290–880K. Pressure[3] was measured by three aneroid manometers and one capacitor sensor which were designed for the ranges 0–220 kg cm^{-2}, 0–150 kg cm^{-2}, 0–100 kg cm^{-2} and 0–80 kg cm^{-2}, respectively. The average errors of these devices are estimated to be $\pm 1.5\%$ of full scale.

Measurements of wind speed on Venus were obtained by utilizing a technique similar to that used in previous Venera flights. During the entire descent a radio signal from the probe was received on earth and from the Doppler frequency shift a measurement was obtained of the radial velocity, i.e., the velocity component of the apparatus in the Venus-Earth direction, which formed an angle of ~38° with the local vertical on Venus. The frequency of the on-board transmitter was obtained from a highly stable thermostated oscillator. Calibrations of the oscillator frequency were performed several times in the interplanetary phase of the mission and the

[1] Presented at XVI-th COSPAR meeting, Konstanz, FRG, 23 May–6 June 1973.

[2] The indicated times refer to the receipt of radio signals on the earth, which was ~3^m36^s after their transmission from Venus.

[3] Throughout this paper the units kg cm^{-2} are used for pressure. This stands for kg-weight cm^{-2} for an acceleration of gravity $g=1000$ cm sec^{-2}. To convert to bars the indicated values should be multiplied by 1.020. To convert to atmospheres the indicated values should be multiplied by 1.033.

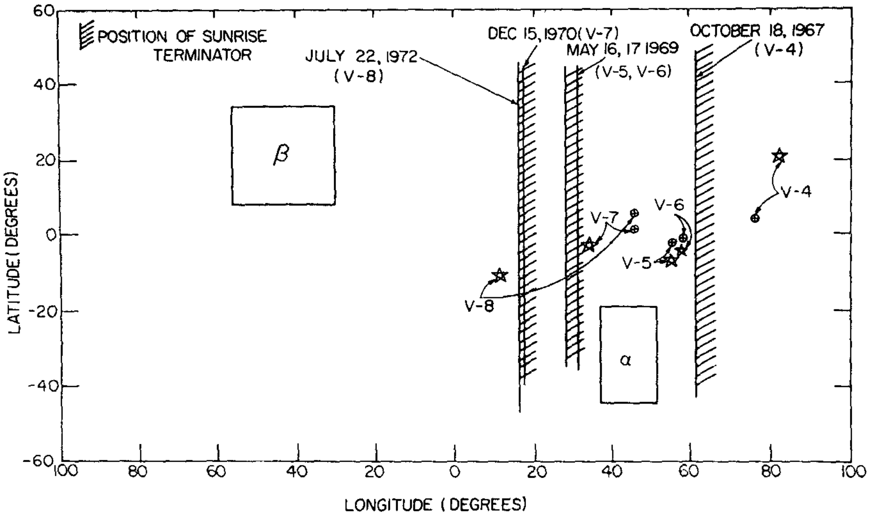

FIG. 1. Schematic map of Venus showing Venera landing areas (stars) and the corresponding sub-earth points (circles). The vertical lines represents the terminator at the times of landing, with the cross hatching extending into the dark half of the planet. α and β are areas of high radar reflectivity.

resulting error in the radial velocity is estimated to be less than 0.2 m sec^{-1}.

The radial velocity of the descending spacecraft varied from 130–140 m sec^{-1} immediately after the first (partial) parachute deployment ($\sim 11^h37^m$) to 6.5 m sec^{-1} at the planetary surface. At $11^h48^m40^s$ a sharp velocity variation was registered as the full parachute deployment occurred with an increase in the parachute dome area. At $12^h32^m16^s$ the frequency jumped by 20 Hz, as the spacecraft landed on the surface of Venus.

The entry probe also carried a pulse-type radio altimeter for the purpose of correlating the atmospheric measurements with altitude above the planetary surface. The rms measurement error of the altimeter is estimated to be $\sigma_h = \pm(40+3.4\,h)$, where σ_h is in meters and h is the measured altitude in kilometers.

3. Temperature and pressure

Measurements of the temperature and pressure as a function of time are shown in Fig. 2, with individual symbols representing the different sensors. The solid line in Fig. 2 is a least-squares polynomial fit to the measurements; in obtaining this curve the accuracy of

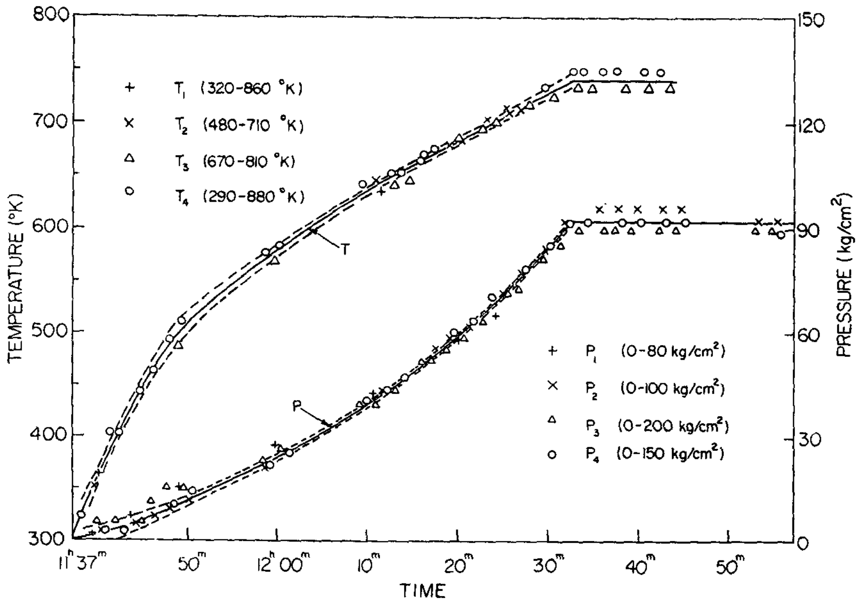

FIG. 2. Temperatures and pressures measured by Venera 8 as a function of time. Individual symbols are used for different sensors. The dashed curves represent 95% confidence limits.

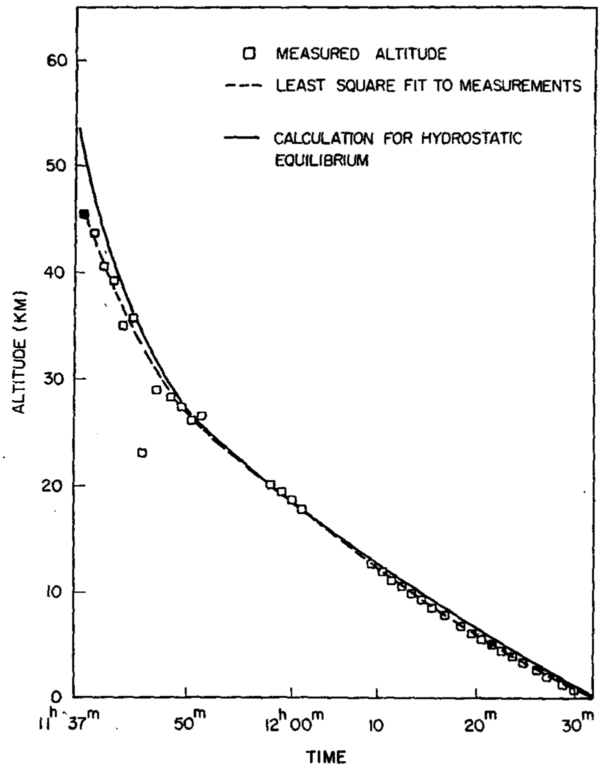

Fig. 3. Altitude of the entry probe above the planetary surface during descent. The measurements were obtained with the radar altimeter. The solid curve was computed from the hydrostatic equation, using the measured temperatures and pressures of Fig. 2.

the individual sensors was taken into account. The rms errors for the temperature and pressure are $\sigma_T = 8.1$K and $\sigma_P = 1.2$ kg cm^{-2} before full parachute deployment ($11^h48^m40^s$), and $\sigma_T = 2.1$K and $\sigma_P = 1.4$ kg cm^{-2} after deployment. The dashed curves in Fig. 2 represent 95% confidence limits.

Measurements of the probe altitude above the planetary surface as a function of time, obtained from the radar altimeter, are given in Fig. 3. In addition, the probe altitude can be calculated from the measured temperatures and pressures by using the hydrostatic equation and perfect gas law. For a mean molecular weight $\bar{\mu} = 43.4$, corresponding to measured gas abundances (Vinogradov *et al.*, 1970), the altitudes given by the solid curve in Fig. 3 are obtained.

There is a significant difference between the direct measurements and the computed altitudes, particularly above 30 km. The initial measurement of altitude occurred at $11^h37^m53^s$ and yielded 45.4 km, while the distance of vertical fall from that moment until the landing on the surface was 51.3 ± 3 km for the computed altitudes. It it is assumed that this difference is real, it could be accounted for by an assumption that the probe descended over a slope while being moved by wind in the horizontal direction. The measurements of wind velocity (Section 4) indicate a horizontal movement of ~45 km between the point of initial parachute deployment and the height of 25 km, with the descent velocity varying from ~70 m sec^{-1} at 54 km to ~15 m sec^{-1} at 25 km (~8 m sec^{-1} at the ground). With this

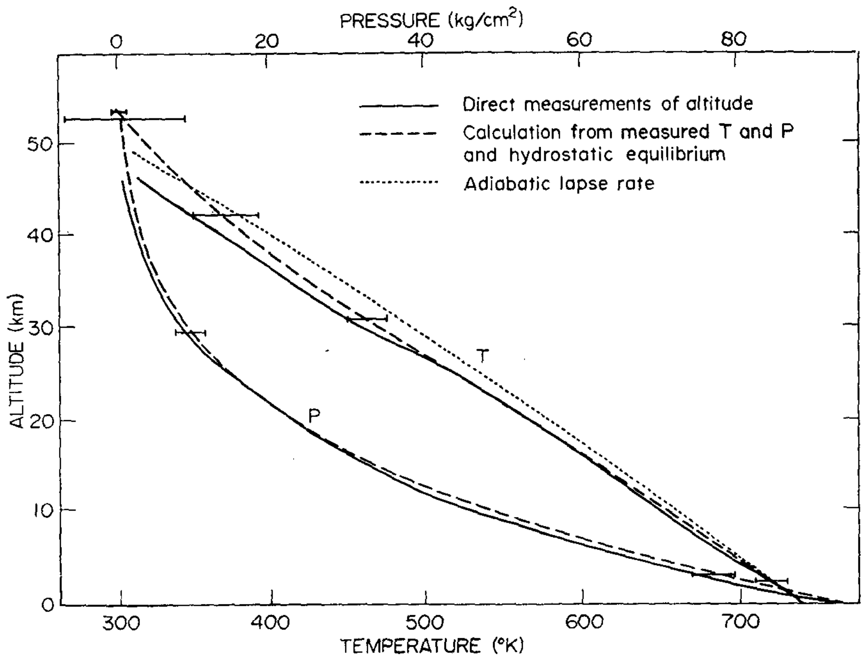

Fig. 4. Altitude profiles of temperature and pressure. The solid curves are based on the radar-altimeter measurements of altitude. The dashed curve is for altitudes computed from the measured temperature and pressure and the hydrostatic equation.

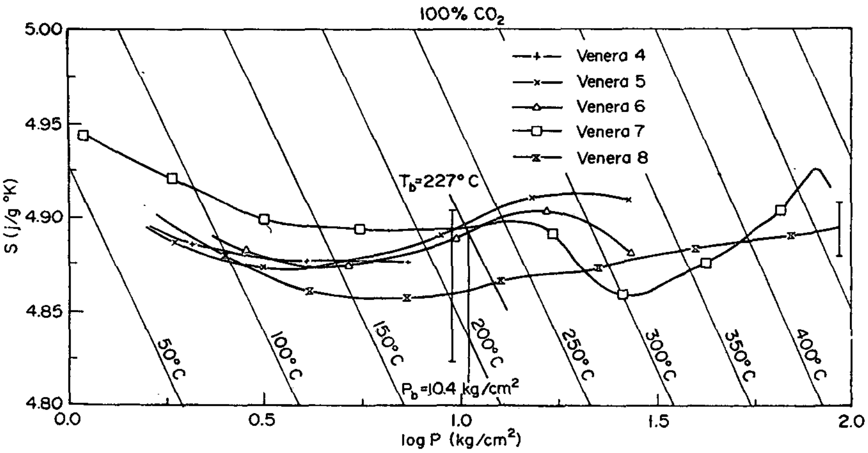

FIG. 5. Entropy diagram for 100% CO_2 and the temperatures and pressures measured by the Veneras. T_b and P_b are the measured temperature and pressure at the point of full parachute deployment. The vertical bars correspond to the measurement errors for T and P.

amount of horizontal motion a surface slope of $\sim 7°$ is required to account for a 5-km discrepancy in altitude.

Fig. 4 shows the measured temperature and pressure as a function of altitude. The temperature of the atmosphere at the surface is $T_0 = 741 \pm 7$K and the surface pressure is $P_0 = 93 \pm 1.5$ kg cm^{-2}. These temperature and pressure profiles are in close agreement with the measurements on the night side of the planet by Veneras 4–7. Venera 7, the only previous spacecraft to measure the surface temperature and pressure, found $T_0 = 747 \pm 20$K and $P_0 = 90 \pm 15$ kg cm^{-2} (Avduevsky *et al.*, 1971). Thus, it may be concluded that there are no pronounced diurnal variations near the sunrise terminator of Venus.

Fig. 4 also illustrates that the temperature profile is close to the adiabatic lapse rate. This is in agreement with an earlier conclusion (Marov, 1972) that the Venus atmosphere is adiabatic to the surface, and in contradiction with the hypothesis of an isothermal layer near the ground. The adiabatic state indicates that there is a good mixing of the atmosphere due to local convection and/or the general circulation.

Fig. 5 is an entropy-pressure diagram for the atmospheric gas (assumed to be 100% CO_2), showing the experimental data obtained by Veneras 4–8. It is clear that the altitude variation of atmospheric parameters measured by Venera 8 is approximated rather accurately by isoentropy. The addition of, for example, 3–5% N_2 does not noticeably change this conclusion. In the intervals where measurements were performed by different probes the agreement is good.

Superimposing the profiles of pressure measured by Venera 8 and Mariner 5 (with coincidence at the point $P = 4$ kg cm^{-2}) yields $r = 6051.7$ km as the distance from the Venera 8 landing site to the planetary gravitational center. This is close to radar estimates of the mean radius of the planet [$r = 6050 \pm 0.5$ km; Campbell *et al.* (1972)].

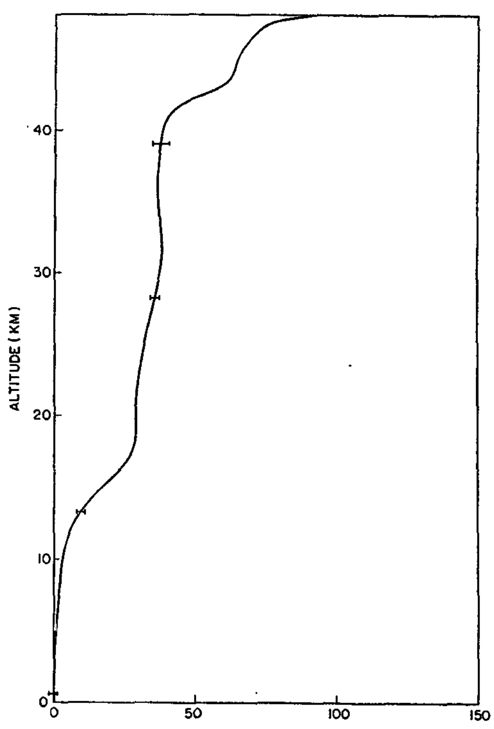

FIG. 6. Horizontal wind velocity measured by Venera 8 as a function of altitude. The measurements refer to the component of the horizontal wind in the direction from the sub-Earth point to the landing point of Venera 8 (Fig. 1).

4. Wind velocity

A measure of the wind velocity in the atmosphere of Venus was obtained from the radial velocity of the probe after subtracting all velocity components due to the relative motion of the surface of Venus and the receiving station on Earth. In addition, corrections were made for temperature-frequency drift of the on-board generator and for the frequency change due to variation of the atmospheric index of refraction with altitude (Kerzhanovich *et al.*, 1972).

The radial velocity in the atmosphere, V_R, can be divided into two parts: the vertical velocity, $V_R \cos\delta$, and a horizontal velocity, $V_R \sin\delta$, where $\delta \approx 38°$ is the angle between the Venus-Earth direction and the local vertical in the region of descent. Since δ was $\lesssim 15°$ for Veneras 4–7, Venera 8 provides the best opportunity so far for measuring a horizontal wind velocity. Only one component of the horizontal velocity is obtained, namely that in the direction from the sub-Earth point to the point of landing. For Venera 8 this direction was ~25° from the zonal direction (cf. Fig. 1).

The vertical velocity component of the radial velocity is removed by computing it in several different ways: 1) from the time variation of altitude obtained from the measured temperatures and pressures and the hydrostatic equation, 2) from the time variation of altitude measured by the radar-altimeter, and 3) from the descent velocity computed with the aerodynamic drag expected for the parachute-probe system. Over most of the descent these different methods give vertical velocities which agree within 1–2 m sec^{-1}; in the 100 sec following the initial parachute deployment the differences are within 5–8 m sec^{-1}. The differences between these computations for the vertical velocity are used to determine the estimated error in the horizontal wind.

Fig. 6 shows the profile of horizontal wind velocity obtained by Venera 8. This is the measured component of the wind velocity in the direction from the sub-Earth point to the landing point, corresponding to an azimuth of 115° (Fig. 1); the positive value for the measured velocity corresponds to a motion from the night side toward the day side for this velocity component (i.e., in the direction of planetary rotation). Although the direction of measurement is essentially zonal, it is not possible to be certain of the true wind direction. If the net horizontal wind velocity is exactly zonal, the net wind speed would be ~1.1 times that in Fig. 6. However, the measurements are also consistent with a wind which is exactly meridional (from the equator toward the south) with a net wind speed ~2.4 times that in Fig. 6.

The altitude profile for the measured component of the wind has several outstanding characteristics. The velocity increases with altitude from 0–0.5 m sec^{-1} near the surface to 100–140 m sec^{-1} at altitudes above 48 km, and is in the same direction at all altitudes. In the altitude range 20–40 km the wind velocities are nearly constant and equal to 30–36 m sec^{-1}. The wind appears to be weak in the lower troposphere at altitudes of 0–10 km. Regions of strong gradients in the wind velocity are located at altitudes 12–18 km and above 48 km.

An increase of wind velocity with altitude was also found in the measurements of Veneras 4–7 (Kerzhanovich *et al.*, 1972). Although the possible systematic errors were larger in these earlier measurements, they also yielded a constant wind velocity for altitudes 20–40 km. However, the wind velocities measured by Venera 8 at these altitudes are much larger. [Venera 7 obtained velocities $\lesssim 5$ m sec^{-1} in the 20–40 km altitude range; Veneras 5 and 6 could not obtain a horizontal velocity, since they descended within a few degrees of the sub-Earth point; Venera 4, measuring essentially in the meridional direction (Fig. 1), obtained a zero horizontal velocity for 20–40 km, within the ~12 m sec^{-1} estimated error.] The Venera 8 measurements verify the Venera 7 data of a small wind velocity near the surface of Venus. This suggests that there is little dust in the lower atmosphere and weak erosion of the surface by winds.

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