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Venus Wind and Temperature Structure: The Venera 8 Data

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Our analysis of the Venera 8 measurements yields equatorial morning terminator horizontal and vertical winds that are similar in a number of respects to the winds we obtained from our analysis of the Venera 7 measurements. The lower boundary of the horizontal retrograde '4-day' wind is defined by a 50–60% decrease in wind speed in the vicinity of 44 km, and there exists a retrograde wind 'plateau' of 15- to 40-m/s winds extending from 40 km down to the vicinity of 18 km, where the winds decrease rapidly to the order of 0.1 m/s near the surface. Updrafts of 2–5 m/s exist in the vicinity of 20–30 km and are apparently associated with a slightly superadiabatic lapse rate.

The location of the descent of the Venera 8 probe [Marov *et al.*, 1973a, b] is shown in solar coordinates in Figure 1. Descent started on the light side of the planet approximately 600 km from the morning terminator and 1000 km south of the equator. At this location the geometric position of the sun was roughly 5.5° above the horizon, and the atmosphere had been in sunlight for approximately 18 earth hours. The direction of earth was $N65^\circ E$ at 38° from the zenith. During descent the strong retrograde equatorial wind carried the probe approximately 80 km to the west toward the sun. The basic atmospheric data [Marov *et al.*, 1973a] that we have used comprise descent probe measurements of (1) temperature versus time $T(t)$, obtained by means of four gages having ranges of approximately 320–860, 280–710, 470–810, and 290–880 K, (2) pressure $P(t)$, obtained by means of four gages having ranges of 0–77, 0–97, 0–145, and 0–193 atm, and (3) altitude $h(t)$, obtained by means of a pulse radar. In addition we use the Doppler content $f(t)$ of the descent probe telemetry signal received on earth.

VERTICAL WINDS

Vertical wind speed was obtained by subtracting the actual probe descent speed from the theoretical probe descent speed computed for wind-free conditions. The computations assumed the ideal gas law, hydrostatic equilibrium, and a mean molecular mass $m = 43.3$ g/mol (appendix). There is considerable uncertainty in the resulting vertical wind profile because the vertical winds were small in comparison with both the measured and the theoretical wind-free probe descent speeds. Both of these descent speeds were based upon measurements that were difficult to interpret, either because of the use of interval encoding or because of unexplained deviations. In an attempt to make clear the extent of these uncertainties we shall present the results from three different methods for computing vertical winds. Two of these methods were based solely on the Venera 8 measurements; the third examined the effect of combining Venera 8 measurements with Venera 4, 5, and 6 measurements.

Vertical wind profile number one shown in Figure 2 was computed from the Venera 8 $T(t)$ and $P(t)$ measurements along with v_0 , the probe descent speed just prior to probe impact with the surface, as obtained from the Doppler measurements. It was the first computation and thus was not biased by any prior knowledge of results. The number one $T(t)$ and $P(t)$ profiles, shown in Figures 3 and 4, were determined primarily by the measurements from gages TB2, TB4, DB2,

and DB4. A study of the number of measurements, instrument range and stability, and mutual consistency has led us to believe that these gages presented the most accurate data. We assume that the method used for interval encoding of the Venera 8 gage outputs was the same as the method implicit in the description of the Venera 4 gage outputs by Avdukevsky *et al.* [1969] and Mickhnevich and Sokolov [1969] where the resulting temperature and density profiles were found to form upper bounds for the data points. It is clear from Figures 3 and 4 of Mickhnevich and Sokolov [1969] that for the intermittently sampled interval-encoded Venera 8 gage outputs the actual temperature and pressure profiles, shown in our Figures 3 and 4, will lie above almost all of the recorded data points. In Figure 5 we show the relation between actual descent probe altitude as computed from the number one $T(t)$ and $P(t)$ profiles and as measured by the descent probe radar. The $P(T)$ profile and temperature lapse rate profile resulting from method number one are shown in Figures 6 and 7, respectively.

Vertical wind profile number two was computed from the Venera 8 $T(t)$ and $h(t)$ measurements along with the reference speed v_0 . The transmitted signal of the radar altimeter was reflected back to the probe from an area of the Venus surface with a 'diameter' roughly 0.4 times the probe altitude, and thus we assume that averaging of the radar signal return would have prevented altitude deviations such as those shown in Figure 5 for descent from 45 to 25 km. It is possible that the altimeter points lying above curve 2 in Figure 5 represent range increases due to swinging of the descent probe on its parachute with an excursion of as much as 23° . It can be observed from the low-altitude region of Figure 5 that because of greater resolution the output of the radar altimeter did not present the uncertainty in interpretation associated with the intermittent sampling of the interval-encoded $T(t)$ and $P(t)$ measurements. The pressure profile $P(t)$ and the $P(T)$ profile resulting from method number two are shown in Figures 4 and 6, respectively.

Vertical wind profile number 3 was based on the assumption that the $P(T)$ characteristic of the Venus atmosphere in the vicinity of the equatorial morning terminator and lying in the dense atmospheric region from 2 to 30 atm remains essentially unchanged with time. An attempt was made to obtain the best possible agreement in this region between the Venera 8 $P(T)$ profile and the composite Venera 4, 5, and 6 AH72 $P(T)$ profile obtained by Ainsworth and Herman [1972] and shown in Figure 6 and at the same time achieve $T(t)$, $P(t)$, and $h(t)$ profiles that were consistent with the constraints presented by the Venera 8 measurements. The resulting data used for ver-

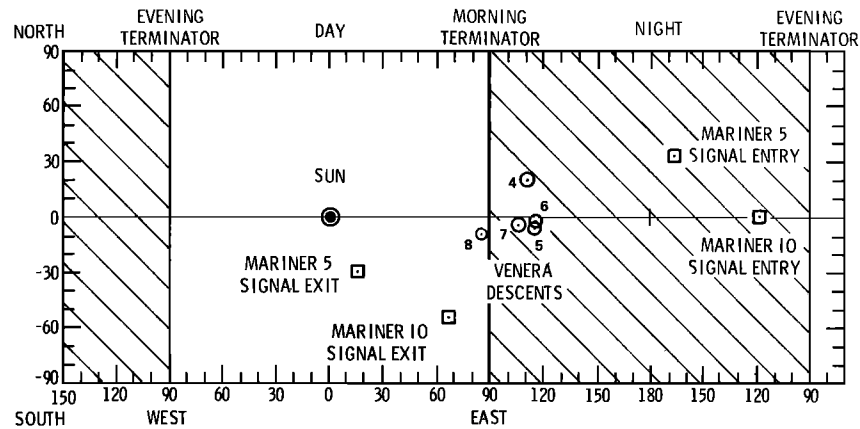


Fig. 1. The positions of the Venera probe descents [Marov *et al.*, 1973a, b] and the regions in which the Mariner 5 radio signals [Fjeldbo *et al.*, 1971] passed through the Venus atmosphere are shown in their solar coordinates.

tical wind profile number three were essentially the same as the AH72 $P(T)$ values shown in Figure 6, except near the Venus surface. The temperature, pressure, and altitude profiles associated with method number three are shown in Figures 3, 4, and 5.

It is evident from Figure 2 that although there remains considerable uncertainty as to the exact structure of the vertical

wind above 26 km during the Venera 8 descent, there existed a substantial updraft in the region from 20 to 26 km. All attempts to eliminate the calculated 5-m/s updraft at 23 km have failed. An attempt to reduce the updraft to 2.5 m/s at 23 km required $T(t)$, $P(t)$, and $h(t)$ profiles that were clearly inconsistent with the measurements and in addition led to what seems to be an excessive temperature lapse rate, 14 K/km, at

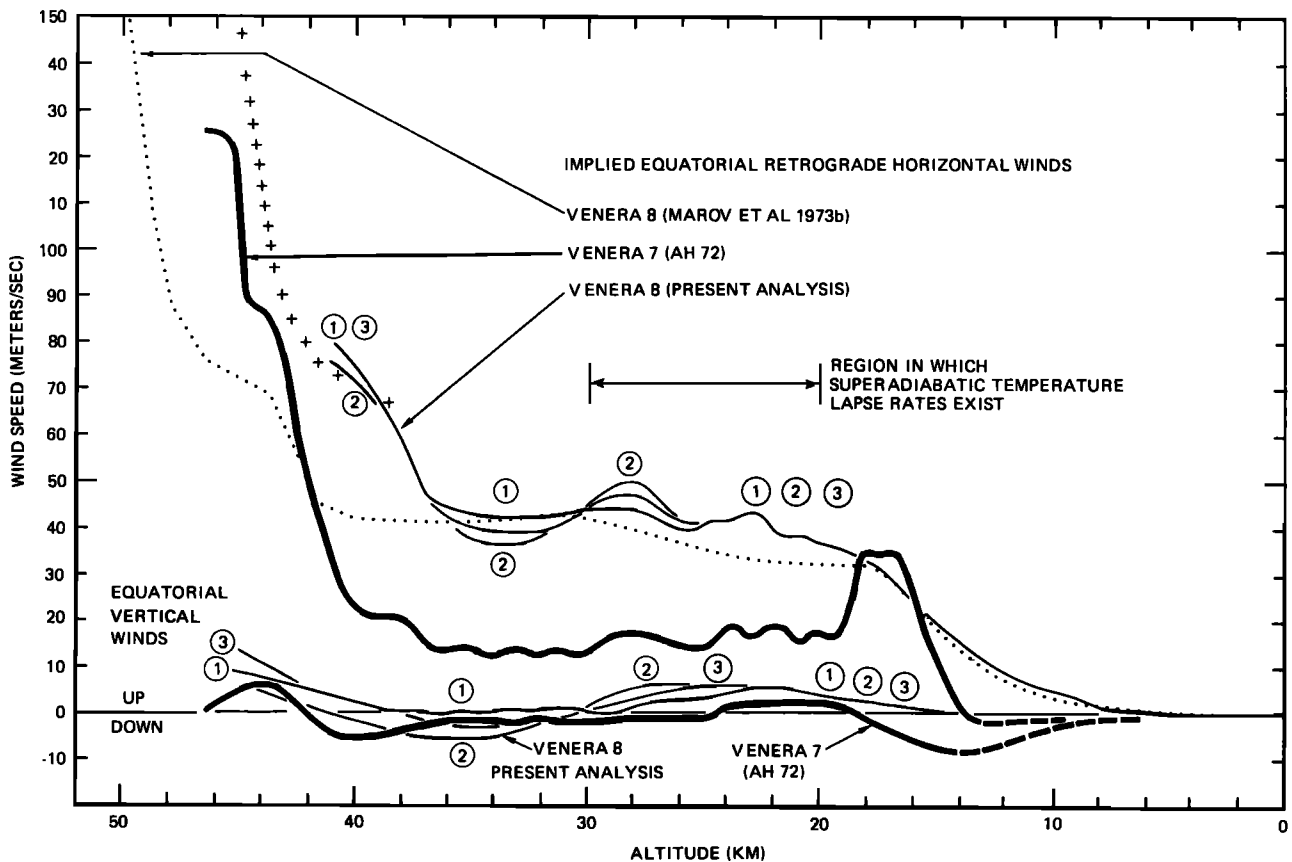


Fig. 2. The Venera 7 equatorial retrograde horizontal wind and vertical wind profiles obtained by Ainsworth and Herman [1972] are shown by the two thick line curves labeled AH72. The dashed line extrapolation of the Venera 7 horizontal wind represents either a prograde or a south-directed wind. The dotted line curve is the implied Venera 8 equatorial retrograde horizontal wind based upon the computation of the horizontal wind by Marov *et al.* [1973b]. The thin line curves are various possible Venera 8 equatorial retrograde horizontal and vertical wind profiles resulting from the three different methods of analysis described in the text. The crosses are an extrapolation of our results and are drawn parallel to the dotted line wind profile of Marov *et al.* [1973b]. Shown in relation to the updraft is the region in which superadiabatic temperature lapse rates are found.

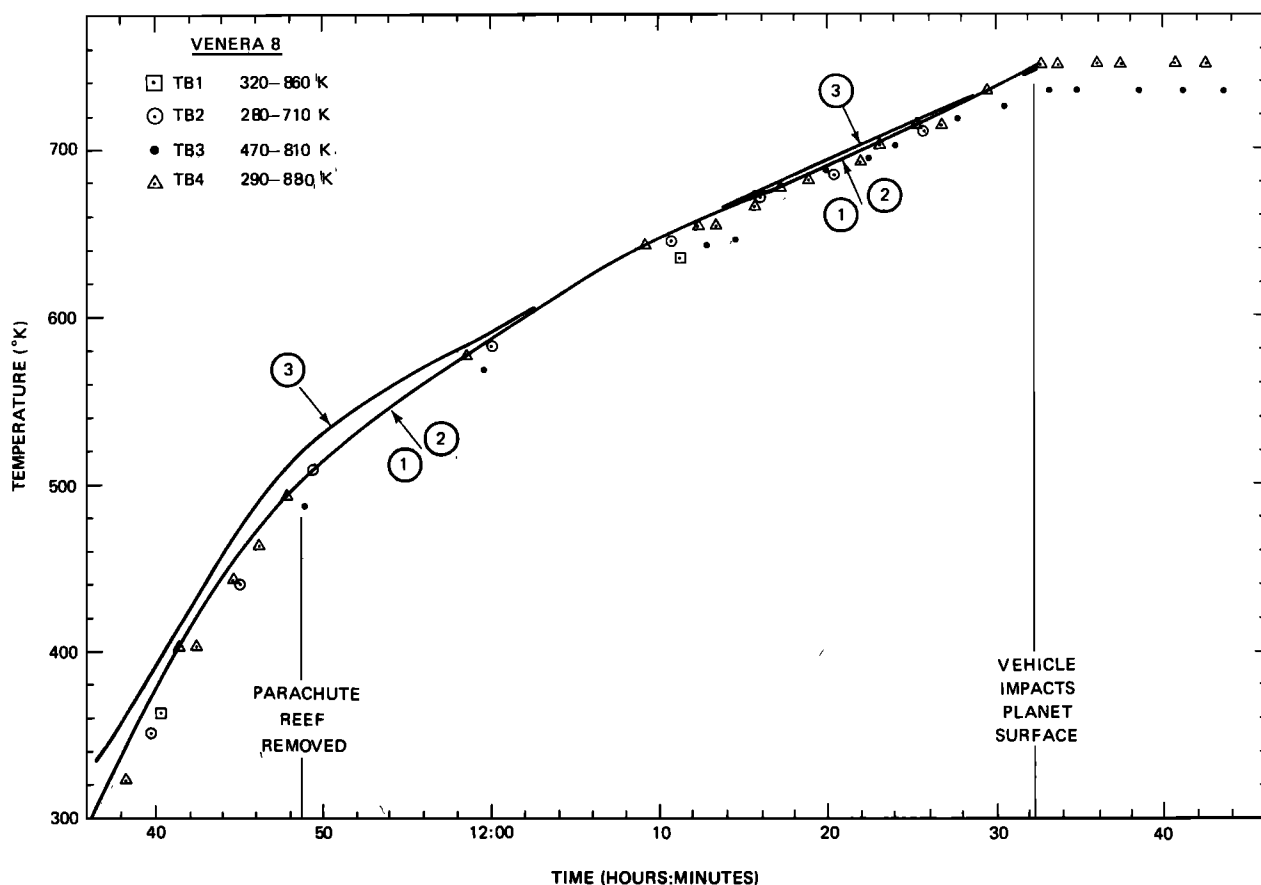


Fig. 3. Shown are three possible temperature profiles consistent with the Venera 8 temperature data. As was explained in the text, the temperature profiles are expected to form an upper bound for the digital data points.

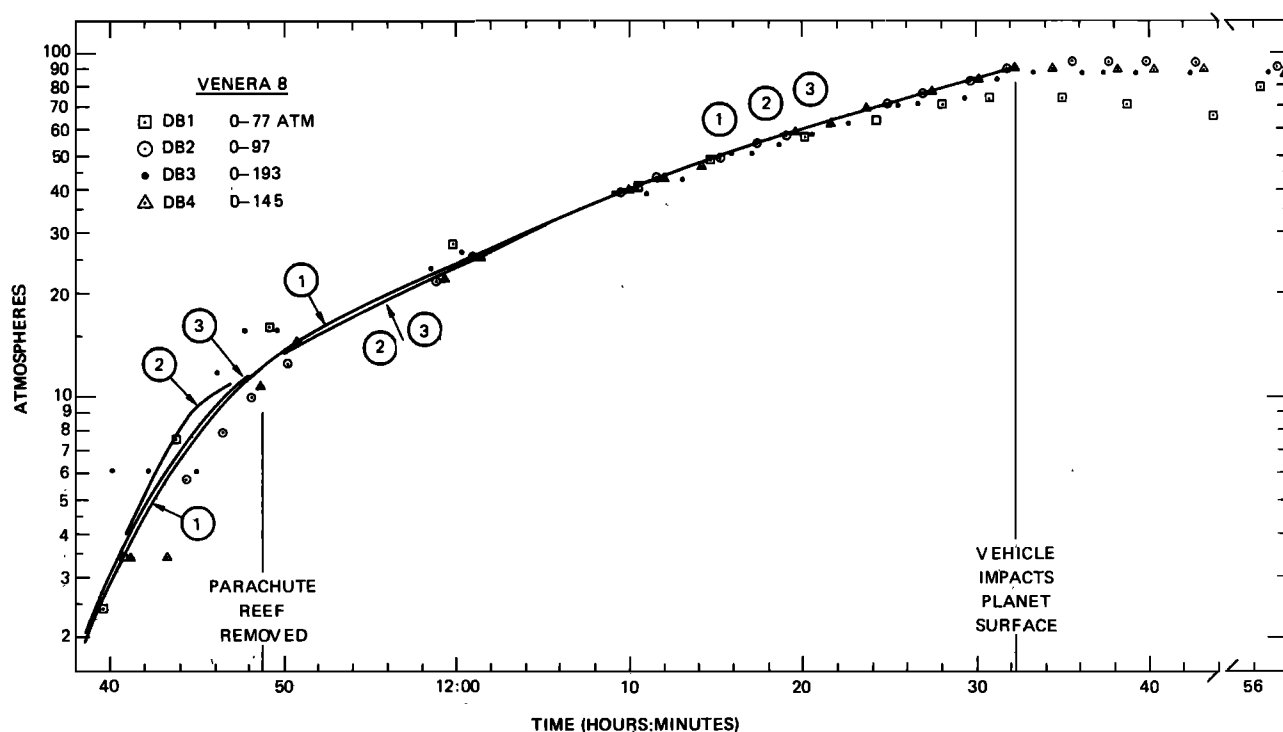


Fig. 4. Shown are three possible pressure profiles consistent with the Venera 8 pressure data. As was explained in the text, the pressure profiles are expected to form an upper bound for the digital data points.

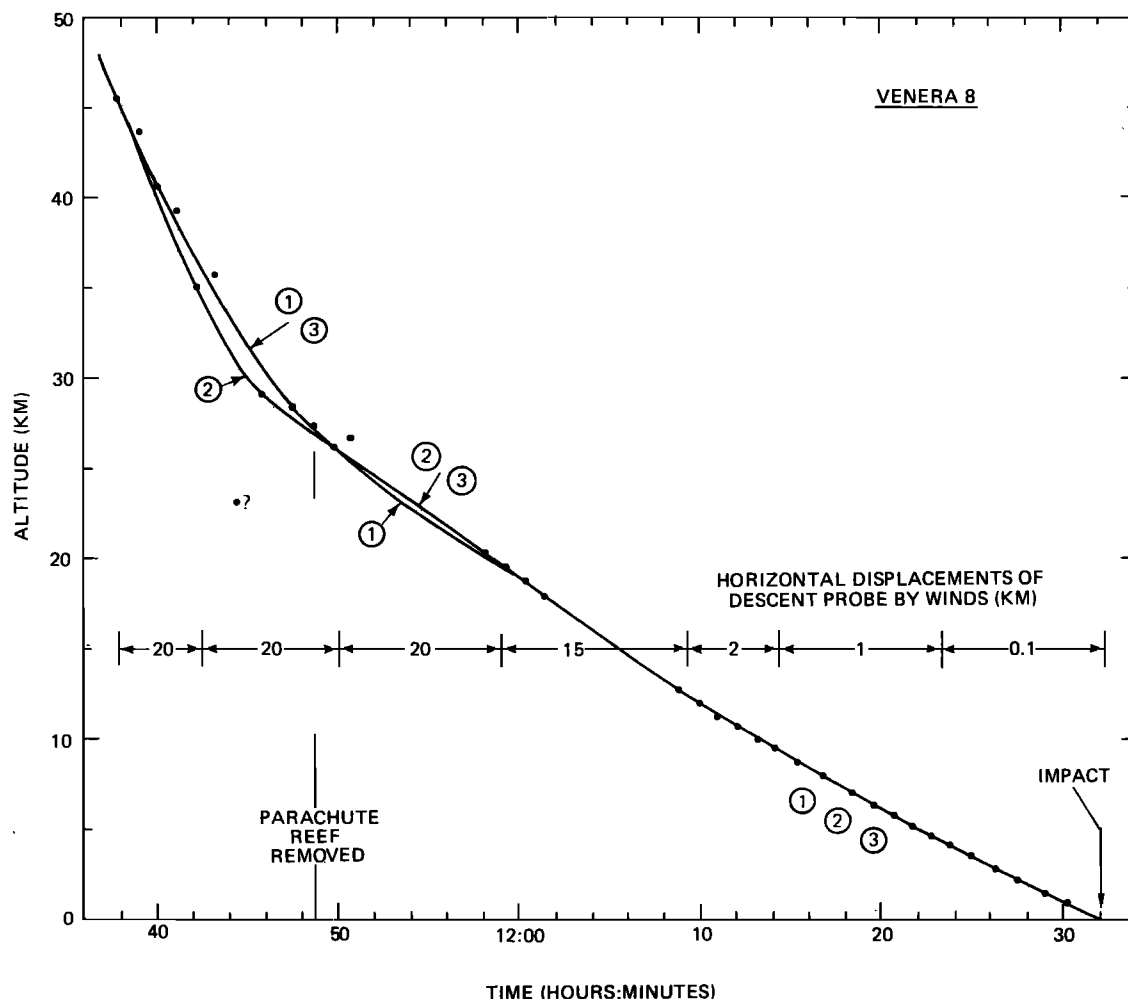


Fig. 5. The Venera 8 radar altimeter measurements and three possible $h(t)$ profiles. Also shown are horizontal distances over which the probe was driven by the equatorial retrograde wind during different portions of the probe's descent.

this altitude. The existence of a large positive gradient in the vertical wind in the vicinity of 18 km for both Venera 7 and Venera 8 suggests that this gradient may be a recurrent or permanent feature in the region of the equatorial morning terminator.

HORIZONTAL WINDS

The altitude profiles shown in Figure 5 were used to determine the probe descent speed, which was then used with the measured Doppler frequency $f(t)$ to construct the horizontal wind profile (appendix). We assume that this wind, which moves along the Venus surface on a great circle away from the subearth point, is a projection of a retrograde wind that moves along the equator, and we plot the implied Venera 8 equatorial retrograde wind profile in Figure 2. For comparison we have converted the Venera 8 horizontal wind profile of Marov *et al.* [1973b] to obtain the implied equatorial retrograde wind profile shown by the dotted curve in Figure 2. It is evident from curves one, two, and three in Figure 2 that the horizontal wind computed from the Venera 8 measurements is relatively insensitive to uncertainties in interpreting the radar altimeter measurements.

The Venera 8 equatorial horizontal wind resulting from our work shows a large gradient in the vicinity of 38 km, whereas the equatorial horizontal wind obtained by Marov *et al.*

[1973b] shows a similar large gradient in the vicinity of 42.5 km. For both cases the altitude associated with these horizontal wind profiles was computed by means of the temperature and pressure measurements, and thus the 4.5-km difference in altitude between these similar large gradient regions must result primarily from the way in which the measurements were used to obtain the temperature and pressure profiles. Marov *et al.* [1973b] used a least squares polynomial fit to the measurements and at the beginning of descent obtained an altitude that is 5 km higher than that determined from the radar measurements. They suggest that this 5-km difference could be accounted for by the assumption of a 5-km decrease in surface radius that occurred while the descent probe was displaced roughly 45 km to the west by the horizontal wind. As was discussed in the preceding section on vertical winds, we have assumed that the temperature and pressure profiles for descent form upper bounds for the interval-encoded digital temperature and pressure measurements. From the temperature and pressure profiles derived with our assumption we obtain an altitude profile in good agreement with the radar measurements. The altitude profile computed from temperature and pressure by method number three is also in good agreement with the radar altimeter measurements. It must be noted, however, that both the agreement of our computed altitude profile number one with the radar altitude at 38

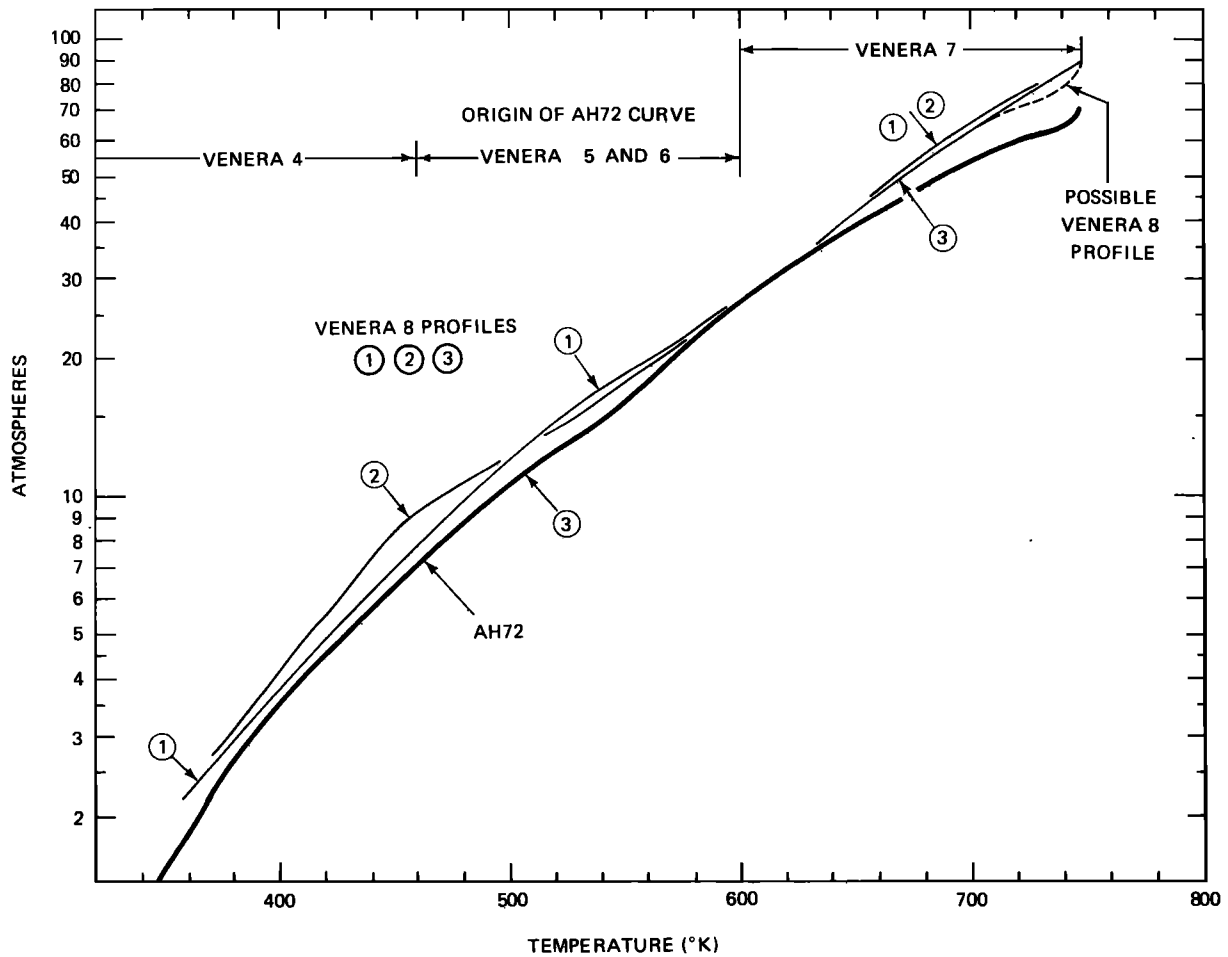


Fig. 6. The thick line AH72 curve represents the $P(T)$ characteristic obtained by Ainsworth and Herman [1972] from an analysis of the Venera 4, 5, 6, and 7 measurements. Also shown are three possible Venera 8 $P(T)$ profiles resulting from our work.

min (45.5 km) and the 5-km additional altitude computed by Marov at 38 min are determined primarily by the slopes of the temperature and pressure profiles in the time interval 38–44 min. An inspection of our Figures 3 and 4 and of Figure 2 from Marov *et al.* [1973b] suggests rather strongly that because the gage outputs are interval encoded there is an insufficient number of temperature and pressure measurements in this time interval to indicate which altitude profile is more nearly correct. But in view of the agreement of the radar measurements with the altitude profiles derived by our method number one using the Venera 8 measurements and our method number three with its strong dependence upon the Venera 4, 5, 6, and 7 measurements and because of the lack of independent evidence for a decreasing surface radius during probe descent, we shall assume that the large gradient in the horizontal wind speed occurs in the vicinity of 38 km instead of 43 km.

The Venera 7 and Venera 8 horizontal wind profiles show a number of prominent features that apparently represent either recurrent or permanent conditions in the vicinity of the equatorial morning terminator: (1) Large gradients in the wind speed occur in the vicinity of 44- and 15-km altitude. The former gradient, which apparently defines the lower boundary of the '4-day' (111-m/s) retrograde wind layer, is also obtained from our analysis [Ainsworth and Herman, 1972] of the Venera 4 measurements. (2) There is a wind 'plateau' from 40 to 20 km in which the wind speed remains relatively constant at 15–40 m/s. (3) The altitudes of the sharp lower boundaries of the 4-

day wind and the wind plateau remain essentially constant at 44 and 15 km, respectively. These altitudes are apparently not influenced by the separation of the Venera 7 and Venera 8 descents by roughly 19° (2000 km) in longitude in both solar and surface coordinates or by the 3.6-km difference in their surface radius values of 6055.5 and 6051.9 km, respectively [Ainsworth and Herman, 1974]. (4) Winds at the surface are of the order of 0.1 m/s or less.

TEMPERATURE LAPSE RATES

In Figure 7 it can be seen that the uncertainty in the use of the measurements has resulted in considerable uncertainty in determining the lapse rate profile. But despite this uncertainty, Figure 7 and the results of the previously described effort to eliminate the updraft clearly indicate that in the region from 30 to 20 km the lapse rate becomes superadiabatic by 1–2 K/km and that there is no apparent method consistent with the measurements by which the lapse rate can be reduced to the adiabatic value or lower throughout this region. The fact that this superadiabatic region, or a portion of it, was established by Mariner 5 [Fjeldbo *et al.*, 1971], Venera 4, 5, and 6 [Ainsworth and Herman, 1972], and Venera 8 suggests that it is either a recurrent or a permanent feature in a band around the equator from 30°S to 30°N . In Figure 2 we see that strong updrafts exist in this superadiabatic region.

In the region from 14 to 7 km the Venera 8 temperature measurements limit the average lapse rate to the adiabatic

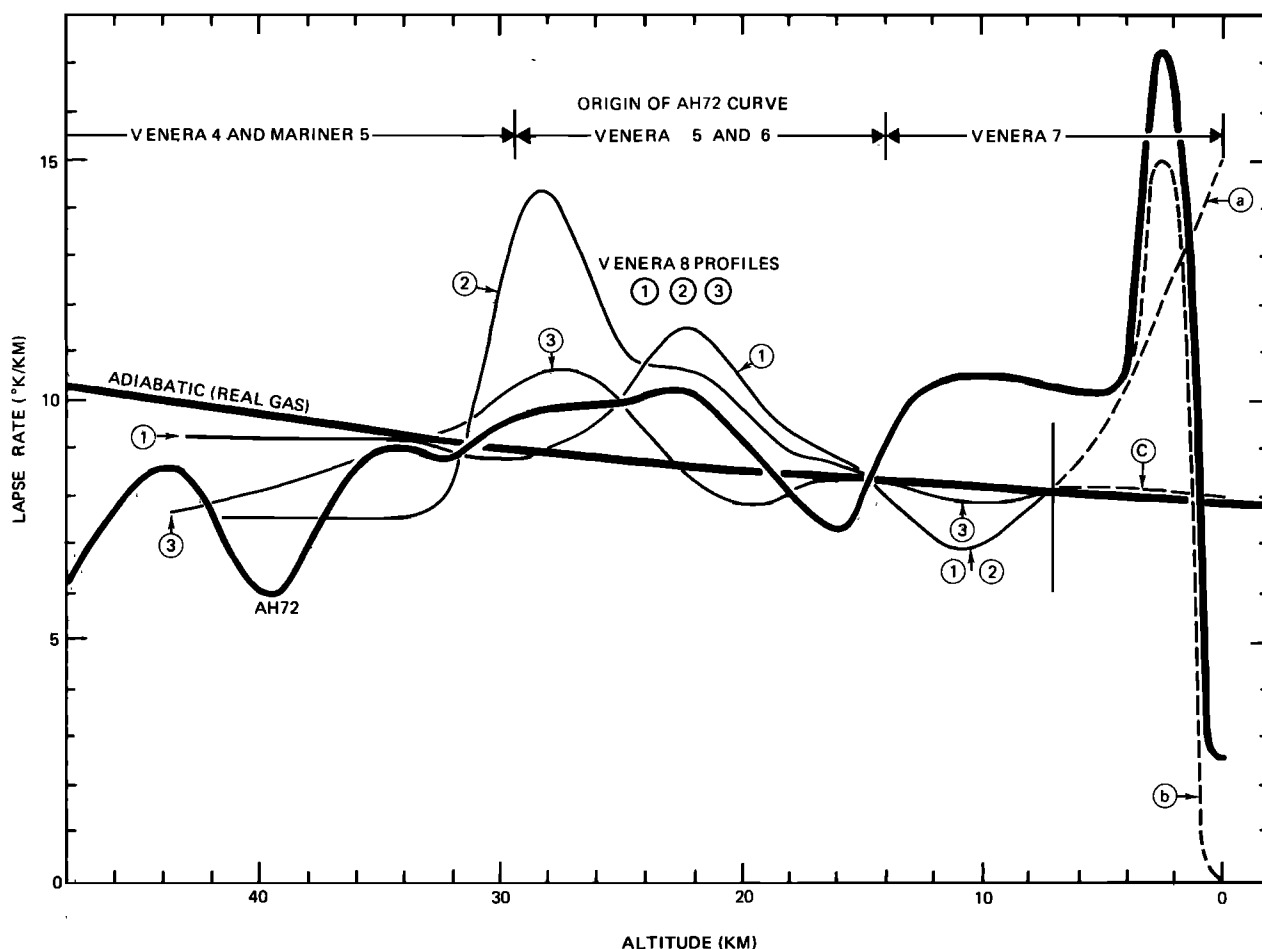


Fig. 7. The thick line curves present the adiabatic lapse rate for the Venus atmosphere and the lapse rate profile obtained by Ainsworth and Herman [1972] from the Mariner 5 and Venera 4, 5, 6, and 7 measurements. The thin line curves are several possible Venera 8 lapse rate profiles. The dashed line curves indicate the wide range of lapse rates that are consistent with the uncertainty in interpreting the Venera 8 measurements near the surface.

value or slightly less. In the region from 7 km to the surface the uncertainty in interpreting the temperature measurements prevents a useful determination of the lapse rate. The lapse rates shown by the dashed curves *a*, *b*, and *c* in Figure 7 are all possible within the constraints set by the temperature measurements.

Our analysis of the Venera temperature measurements yields surface temperatures of 748 ± 11 K for Venera 7 and 750 ± 12 K for Venera 8. Since the Venera 7 surface was 3.6 km higher than that of Venera 8, these temperatures yield a variation of surface temperature with altitude that is smaller than the adiabatic atmospheric temperature lapse rate of 7.9 K/km near the surface and suggest a surface temperature variation that is consistent with the value of 2.5 ± 2.5 K/km obtained for a band around the equator by Ainsworth and Herman [1972] from consideration of the Venera 7 data, the microwave interferometer data of Sinclair *et al.* [1972], and the equatorial topography data of Campbell *et al.* [1972]. Ainsworth and Herman [1972] concluded that the most likely value for the change of surface temperature with altitude in this band was between 2.5 K/km and isothermal.

The lapse rate profile and pressure profile results lead us to prefer Venera 8 trial profile numbers 3, 1, and 2 in that order. It follows from Figure 6 that the equatorial atmospheric structure resulting from the Venera 8 measurements is essentially the same as that determined from Venera 4, 5, 6, and 7 by

Ainsworth and Herman [1972] except when we approach the planet surface where a rather substantial difference exists. This difference results from the fact that the surface radius at the Venera 8 landing site was 3.6 km smaller than that at the Venera 7 landing site. With this decrease in altitude the pressure at the surface increased from 71 to 89.5 atm, while the surface temperature remained essentially constant, as discussed above.

The appearance of a superadiabatic temperature lapse rate in equatorial morning terminator measurements taken in the 30- to 20-km region (7–17 atm) over a period of roughly 5 years suggests highly stable conditions in this region. It is reasonable to expect an even higher degree of stability in the region near the surface where the atmosphere is more massive (50–89.5 atm), where both vertical and horizontal atmospheric motions are greatly reduced in speed and where less than 2% of the incident solar radiation penetrates. In view of these conditions we shall assume that the sharp peak in the Venera 7 temperature-lapse rate profile at 2.5 km, shown in Figure 7, also existed at the time of the Venera 8 descent and is a permanent feature in the vicinity of the equatorial morning terminator.

SUMMARY

In the vicinity of the equatorial morning terminator the lower boundary of the 4-day (111-m/s) equatorial retrograde wind layer is defined by a 50–60% decrease in wind speed in the

vicinity of 44-km altitude. Between 40 and 20 km there is a retrograde wind plateau of 15- to 40-m/s winds followed by a second large decrease in wind speed in the vicinity of 15-km altitude. Winds at the surface are of the order of 0.1 m/s or less. Updrafts of 2–5 m/s are found to exist in the vicinity of 20- to 30-km altitude and are apparently associated with lapse rates 1–2 K/km larger than the adiabatic value. The above features represent either recurrent or permanent conditions in this region. The superadiabatic lapse rate has additional extent and may occur in a band around the equator from 30°S to 30°N. The variation of surface temperature with altitude is less than the adiabatic atmospheric lapse rate near the surface and is consistent with the value of 2.5 ± 2.5 K/km obtained by Ainsworth and Herman [1972] for a band around the equator.

APPENDIX

Vertical Wind Speed Computations

Method number one. The actual probe descent speed is

$$V_A(t) = \frac{dh(t)}{dt} = \frac{RT(t)}{\bar{m}g(t)} \frac{d \ln P(t)}{dt} \quad (1)$$

The theoretical probe descent speed for wind-free conditions is

$$V_T(t) = C_1 \left[\frac{g(t)}{\rho(t)} \right]^{1/2} = C_2 \left[\frac{g(t)T(t)}{P(t)} \right]^{1/2} \quad (2)$$

where $C_2 = 97$ is determined by using v_0 . The C_2 is modified to obtain $C_2' = 119$ prior to parachute dereefing by use of the change in descent speed during dereefing as obtained from the change in Doppler frequency.

The vertical wind speed is

$$V_V(t) = V_T(t) - V_A(t)$$

where positive values of $V_V(t)$ indicate an updraft.

Method number two. The actual probe descent speed is

$$V_A(t) = \frac{dh(t)}{dt}$$

where $h(t)$ is the altitude obtained from the descent probe radar. The theoretical probe descent speed for wind-free conditions is calculated as follows: obtain $P(t)$ from

$$P(t) = P_0 \exp \left[\frac{-h(t)\bar{m}g(t)}{RT(t)} \right]$$

and use (2) to obtain $V_T(t)$.

Method number three. The same procedure is used as that for method number one.

Horizontal Wind Speed Computations

The horizontal wind speed is

$$V_H = V_e \csc \theta$$

where $\theta = 38^\circ$ is the angle of earth from the probe zenith and V_e is the component of the horizontal wind speed in the direction of the earth-probe line. We obtain V_e from $V_e = V_m - V_A \cos \theta$, where V_m is the measured probe speed along the earth-probe line as obtained from Doppler frequency measurements and V_A is the actual probe vertical descent speed as obtained from the radar altitude profiles shown in Figure 5.

Acknowledgments. The Editor thanks E. K. de Rivas and G. Schubert for their assistance in evaluating this paper.

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(Received May 29, 1974;
accepted October 2, 1974.)