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ON THE REALITY OF THE VENUS WINDS

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ON THE REALITY OF THE VENUS WINDS

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ABSTRACT

An examination of the effect of assumptions in the interpretation of the Venera wind data is made as a rebuttal to suggestions that the 140m/s Venera 8 horizontal wind at 45km may be either spurious or anomalous. The Venera measurements of wind speed along with the Mariner measurements of a lower-region of strong turbulence are evidence for a wide band of variable high speed retrograde horizontal winds which girdle Venus at the equator. In the prevalent interpretation of the Mariner 10 UV photographs the 20km region above the top of the visible cloud is characterized by variable high-speed retrograde horizontal winds which orbit Venus with an average period of 4 Earth days, and by many features indicating vertical convection. This interpretation, together with the possibility of atmospheric corotation due to frictional coupling, suggests that the Venera-Mariner band of winds at 45km extends to the top of the UV cloud and beyond, and that the upper-region of strong turbulence detected by the Mariners may result in part from vertical convection currents carried along by high speed horizontal winds. In an alternate interpretation of the Mariner 10 UV photographs the predominate motions are attributed to wavelike disturbances with a 4-day period. For this case the upper-region of strong turbulence may be due in large part to vertical wind-shear resulting from a rapid decrease in wind speed within a relatively short distance above the Venera-Mariner band of high speed winds.

ON THE REALITY OF THE VENUS WINDS

Attempts to measure Venus winds have been made 1) from Earth by means of spectroscopic measurements and low resolution UV photographs, 2) from near Venus by means of the high resolution Mariner 10 UV photographs, and 3) at Venus by means of the Venera probes during their descent through the Venus atmosphere. The remote spectroscopic measurements have indicated the presence of retrograde wind speeds of as much as 100m/s in the vicinity of the top of the visible cloud C_2 shown in Figure 1. The remote and near UV photographs, which reveal motions in a region extending 20km above the top of the visible cloud, have been interpreted as indicating either variable retrograde winds which cause the atmosphere to rotate about the planet with an average period of 4 Earth days (i. e. an average speed of 111m/s) or a retrograde motion of wavelike disturbances with a 4-day period. The in situ Venera 7 and 8 measurements have indicated the presence of the 125-140m/s retrograde winds shown in Figure 1 in the vicinity of 45km altitude.

Young (1975) has questioned the interpretation of the spectroscopic measurements and states that "the bulk of the somewhat contradictory evidence seems to favor slow motions, on the order of 5m/s, in the atmosphere of Venus; the 4-day 'rotation' may be due to traveling wavelike disturbances, not bulk motions, . . . ". As part of Young's discussion in support of low wind speeds he suggests that the 140m/s retrograde horizontal wind measured by the Venera 8 descent probe (spacecraft) may be greatly in error because the data was "reduced in such a way as to force the speed to be zero at the surface of Venus; hence any unrecognized drift in the spacecraft oscillator will appear as a wind increasing with height." To obtain the Venera vertical profiles of the horizontal wind requires the use of the Doppler shift of the radio signal transmitted from the descent probe to Earth in combination with the true probe descent speed computed from the various descent probe measurements such as atmospheric temperature and pressure, and probe altitude (Ainsworth and Herman 1972, 1975). The Doppler measurements made use of a master-oscillator on the descent probe, rather than a turn-around-transponder and thus, as pointed out by Young, use of the Doppler measurements requires both the assumption of a reference speed at the Venus surface, and the detailed knowledge of the thermal, mechanical, and electrical stability and environment of the master-oscillator necessary to accurately determine the amount of oscillator drift occurring during probe descent.

Our studies suggest that, contrary to Young's concern, the error in the Venus high speed winds due to unrecognized deficiencies in the master-oscillator is insignificant; most of the error has its origin in the descent probe measurements

of altitude and atmospheric temperature and pressure which are used to determine the true probe descent-speed. But even the largest estimates of the error in determining the true probe descent-speed have been found to be far from sufficient to result in the spurious generation of 125-140m/s winds (Ainsworth and Herman 1972, 1975). In this work we shall limit our discussion to an examination of those sources of Venera measurement error suggested by Young and to a brief summary of the possible implications of the presently available evidence for Venus atmospheric motions above 45km altitude.

The obvious choice for a reference speed is zero probe speed immediately after the probe comes to rest on the surface of Venus. The difficulty which arises with this choice is that the difference between the zero-referenced Doppler speed and the Earth-directed component of the computed true descent-speed, just before the probe hits the surface, can be interpreted as due to either a horizontal wind at the surface or to an off-set in the probe master-oscillator frequency caused by a 50 to 1000g landing shock (Ainsworth and Herman, 1972), or to some combination of both. It should be noted that the wind error resulting from a frequency off-set due to impact will contribute the same error in the wind speed at all altitudes. For Venera 8, Marov et al. (1973) assumed zero probe speed when the probe first came to rest on the surface of Venus and obtained a horizontal surface wind of roughly 0.1m/s. There is no evidence, such as high wind shear near the surface (Andreev et al., 1974; Kerzhanovich and Marov, 1974), that this result was in gross error due to a frequency off-set caused by landing shock. If, however, the principal error in the Venera 8 wind measurements was frequency off-set during landing, it would be necessary to assume a prograde surface wind of roughly 140m/s in order for the Venera 8 measurements to yield winds of the order of 5m/s at 45km. For Venera 7, Ainsworth and Herman (1972) also assumed zero probe speed when the probe first came to rest on the Venus surface and obtained a retrograde horizontal surface wind of 26m/s. This result was suspect since no gradient in the horizontal wind was evident in the Venera 7 Doppler data in the first 100 meters above the surface of Venus and the speed of the horizontal wind increased at most by 3m/s in the first 3.5km above the surface. Furthermore, unless there is some mechanism for causing particles lying on the surface to cohere, surface winds of even as much as 5m/s in a high density atmosphere would cause severe erosion (Ronca and Greene, 1970) — sufficient to have leveled a large area of the Venus surface. But no evidence for large leveled areas appears on the radar maps of Venus (Goldstein and Rumsey, 1970; Rumsey et al., 1974). For these reasons we discarded the 26m/s wind at the surface and for our reference speed we forced the horizontal wind speed at the surface to be zero with the result that the computed horizontal wind speed at 45km decreased from 151m/s to 125m/s. The discarded 26m/s surface wind was assumed to have resulted from a permanent oscillator frequency off-set of -16 Hz which occurred at the instant of landing as a result of a shock of 200g or more (Ainsworth and Herman, 1972).

The evidence is also against the possibility that unrecognized oscillator-drift could have led to the appearance of spurious 125 to 140m/s horizontal winds. By use of the frequency-temperature characteristic of the Venera 8 probe master-oscillator, along with direct telemetry measurements of the temperature within the probe during descent and after landing, Marov et al. (1973) obtained a maximum oscillator-drift correction corresponding to a wind speed correction of less than 0.7m/s. They estimated that the maximum error in the horizontal wind measurements, due to uncorrected thermal oscillator-drift, was less than 0.2m/s, nearly three orders of magnitude less than the measured 140m/s horizontal wind speed. By use of laboratory measurements of the thermal and electrical characteristics of the Venera 7 probe, and the measured temperature of the Venus atmosphere during probe descent, the maximum error in the Venera 7 horizontal wind due to uncorrected thermal oscillator-drift was estimated by Kerzhanovich et al. (1972) to be less than 1.5m/s, nearly two orders of magnitude less than the 125m/s Venera 7 horizontal wind speed obtained by Ainsworth and Herman (1975). The fact that unrecognized oscillator-drift was small during the descent of the Venera 7 probe is implicit in the Doppler record (Avduevsky et al., 1971) for the period when the probe rested on the hot surface of Venus. An examination of this portion of the Doppler record with a resolution corresponding to a horizontal wind error of 1m/s reveals that no evidence for thermal oscillator-drift appears until 5 minutes after landing. We applied our estimate of the ability to correct for thermal oscillator-drift to this portion of the Doppler record and found that the error due to unrecognized drift did not exceed the 1.5m/s error given by Kerzhanovich for the descent until after the Venera 7 probe had rested 15 minutes on the 750K surface of Venus. Our studies of 1) the Venera 7 Doppler record, 2) Venus probe thermal-design and descent simulation testing, 3) the Venera entry and descent environment, and 4) the characteristics of highly-stable temperature-controlled oscillators available at the time of the design of the Venera probes make it difficult to entertain the possibility of unrecognized Venera 7 and 8 thermal oscillator-drifts which were nearly two to three orders of magnitude larger than expected.

We have studied and rejected the possibility that significant oscillator-drift resulted from probe entry or parachute deployment deceleration, or from the accelerations indicated by the Doppler record during descent such as those caused by de-reefing or deterioration of the parachute, by probe swinging or swooping, or by gusts (Ainsworth and Herman, 1972). Probe deceleration exceeded 300g for as much as 1.5 seconds during entry into the atmosphere (Cheremukhina et al., 1974) but the expected response to large accelerations is frequency off-set rather than drift. As discussed above, the impact of the Venera 7 probe on the surface at 200g or more resulted in an immediate permanent frequency off-set, but no drift. Accelerations of the order of several g

obtained during parachute release and probe descent produced no noticeable effect. There is, for example, no evidence in Figure 1 that Venera 7 and 8 parachute dereefing caused either off-set or drift.

Additional evidence supporting the existence of the measured horizontal winds of 125-140m/s at 45km is suggested by the overall similarity of the Venera 7 and 8 horizontal wind profiles shown in Figure 1. These similarities exist despite differences in the thermal and mechanical design of the Venera 7 and 8 probes, different entry and descent decelerations, and descent times of 35 and 55 minutes respectively. We have been unable to correlate any of these differences with differences in the wind profiles.

The Venera 4 measurements can also be interpreted as indicating the presence of a large retrograde horizontal wind speed in the vicinity of 45km (Ainsworth and Herman, 1972; Kerzhanovich and Marov, 1974). Since Veneras 5 and 6 are reported to have landed too close to the sub-Earth point on Venus to allow a credible Doppler measurement of horizontal winds (Kerzhanovich et al., 1972) the Venera 4, 7, and 8 high speed horizontal winds at 45km can be considered as resulting from successive measurements at intervals of 3.2 and 1.6 years. The fact that these measurements were successive and at large intervals of time suggests that it is probable that high speed winds occur a large percentage of the time in the vicinity of the equatorial morning terminator.

Kerzhanovich et al. (1972) have pointed out that there exists a high probability of turbulence in the region of high wind-shear at 41km, see, Figure 1, since the Richardson number is equal to or less than the critical value of 0.5 to 1.0 in this region. The diametrically located night-side and day-side occultation measurements of both Mariner 5 and Mariner 10 presented evidence for regions of strong turbulence (Woo et al., 1974; Woo and Yang, 1975) centered about altitudes of approximately 45 and 60km, with average thicknesses of 8 and 10km respectively, and from 50 to 135° removed from the Venera measurement locations. We have changed the altitudes of the regions of strong turbulence to correspond to their altitudes above a Venus ellipsoid with an average radius of 6054km (Ainsworth and Herman, 1974) and in Figure 1 we show the relation between the lower-region of strong turbulence and the Venera 4, 7, and 8 region of large wind-shear. The Mariner 5 and Mariner 10 regions of strong turbulence were observed successively with an interval of 6.3 years. The fact that the successively observed, diametrically located, and widely separated Mariner lower-regions of strong turbulence are readily interpreted as due to large wind-shear, and coincide in altitude with the successive Venera 4, 7, and 8 measurements of wind-shears for which the Richardson number indicates a high probability of turbulence, strongly implies that a permanent band of variable high speed retrograde winds girdles the Venus equator above 45km and extends from at least 30° S to 30° N.

The prevalent explanation of the period of 4 Earth days observed by Murray et al. (1974) in the Mariner 10 UV photographs is that it represents the average period for retrograde rotation of the atmosphere in the 20km region above the top of the visible cloud C₂. Based upon this explanation and upon the possibility of atmospheric corotation due to frictional coupling we select a model in which the Venera-Mariner band of variable high speed retrograde winds extends from its lower boundary at 45km to beyond the top of the region of the UV measurements. In this model it is assumed that the presence of visible cloud C₂ causes an increase in the rate of heating of the atmosphere within the upper-region of strong turbulence on the day-side so that the observed turbulence may be due in part to small scale vertical convection swept along by the horizontal winds. This explanation is consistent with the observation by Murray et al. (1974) and Suomi (1974) of many vertical-convection features in the Mariner 10 UV photographs. Since the time-constant for radiative cooling in the vicinity of the visible cloud is an order of magnitude larger than the rotation period of 4-days (Dickinson, 1972), the upper-region of turbulence on the night-side of Venus may also result in part from small scale vertical convection. This expectation is consistent with the observation of Woo et al. (1974) that the Mariner 5 measurements indicate slightly weaker upper-region turbulence on the night-side than on the day-side.

According to Young the 4-day period observed in the Mariner 10 UV photographs may characterize traveling wavelike disturbances rather than atmospheric rotation, and typical wind speeds in this region and in the region of the spectroscopic measurements may be "closer to 5m/s than to 100m/s." If these conditions exist it is necessary that a rapid decrease in wind speed occur within a relatively short distance above the Venera 7 and 8 measurements of high speeds winds. This requirement suggests that the upper-region of strong turbulence results from wind shears similar to those occurring in the lower-region of strong turbulence, and is illustrated by the extrapolated Venera 7 profile shown by the lower dashed curve in Figure 1. It should be noted, however, that this suggested symmetry of wind-shear and turbulence is not matched by a similar symmetry in the temperature lapse-rate profile obtained by Ainsworth and Herman (1972) from the Venera 4 and Mariner 5 measurements. The lower-region of strong turbulence is centered about a lapse-rate minimum while the upper-region contains a lapse-rate maximum which may result from an increased rate of atmospheric heating caused by the presence of visible cloud C₂.

SUMMARY

Based on examination of the underlying assumptions in the interpretation of the Venera data we conclude that the Venera high speed winds at 45km are neither spurious nor anomalous. Together with the Mariner measurements of a

lower-region of strong turbulence they provide evidence for a wide band of variable high speed retrograde horizontal winds which girdle Venus at the equator. In the prevalent interpretation of the Mariner 10 UV photographs the 20km region above the top of the visible cloud is characterized by variable high-speed retrograde horizontal winds which orbit Venus with an average period of 4 Earth days, and by many features indicating vertical convection. This interpretation, together with the possibility of atmospheric corotation due to frictional coupling, suggests that the Venera-Mariner band of winds at 45km extends to the top of UV cloud C₁ at 78km and beyond, and that the upper-region of strong turbulence detected by the Mariners may result in part from vertical convection currents carried along by high speed horizontal winds.

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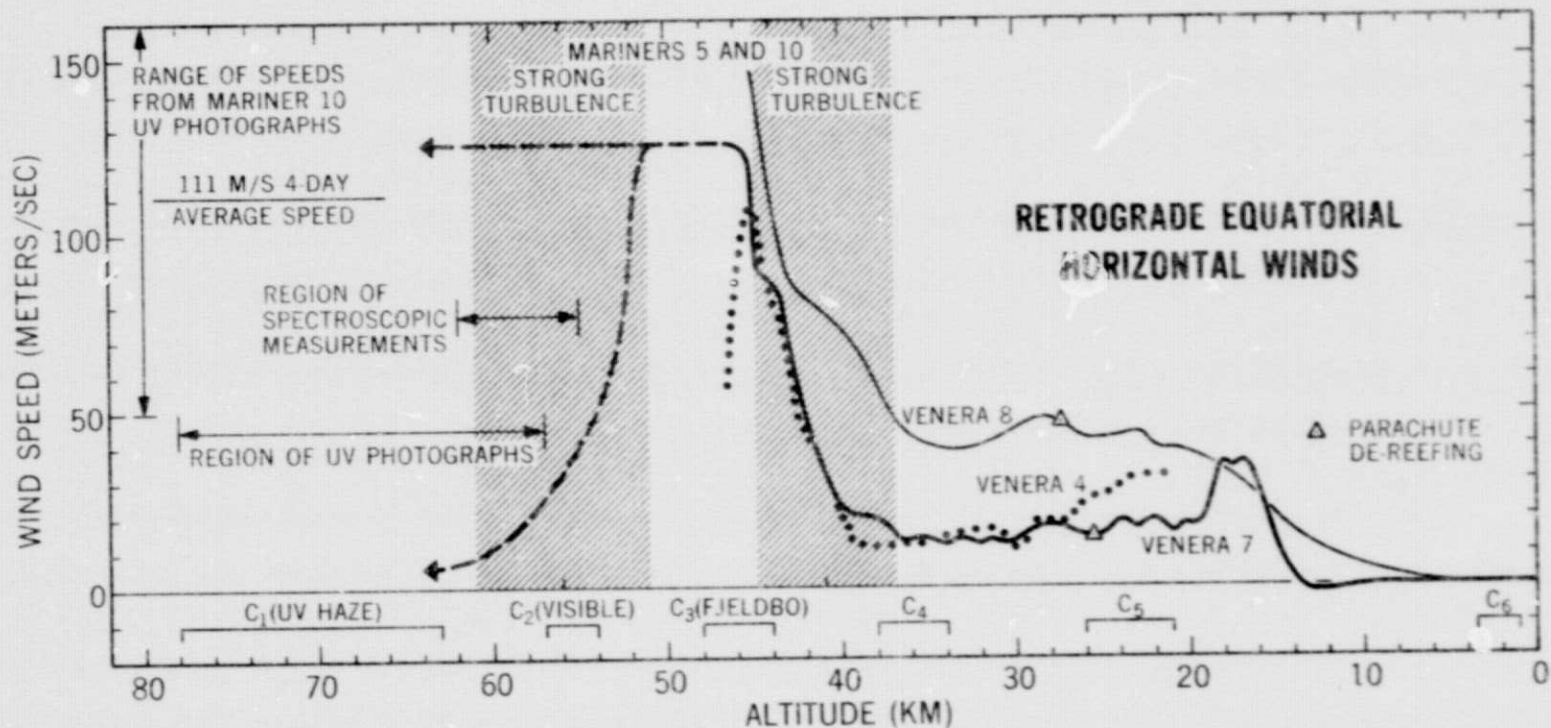


Figure 1. Shown are the implied Venera 4, 7, and 8 retrograde equatorial horizontal wind profiles (Ainsworth and Herman, 1972, 1975), the two regions of strong turbulence measured by Mariners 5 and 10 (Woo et al., 1974; Woo and Yang, 1975), the range of wind speeds suggested by the Mariner 10 UV photographs (Suomi, 1974), and the locations of clouds C_1 to C_6 (Ainsworth and Hermar., 1972; Fjeldbo et al., 1971; Murray et al., 1974). The lower dashed curve is an extrapolation of the Venera 7 wind profile consistent with Young's (1975) suggestion of motions of the order of 5m/s in the region of the spectroscopic and UV photographic measurements.