lar to the north profile except below 27 km, where it begins to deviate with an indication of heating. The start of this deviation is simultaneous with the inception of off-scale readings in auxiliary SNFR voltage-offset data. Although no direct evidence of corresponding flux channel degradation has been found, the offset behavior suggests caution in interpreting the night probe data below this altitude until spare instrument performance tests under similar conditions can be completed.

The day probe profile indicates heating below 27 km, presumably because of solar energy deposition. If the solar net flux below the clouds can be estimated even crudely by differencing the day and night (or north) profiles, it is about four times larger than that expected from large probe solar flux measurements (*14*) after solar zenith angle adjustments. Aside from small effects caused by spectral response differences, this seems to imply significant differences in the clouds at the day and large probe sites above about 60 km.

It is likely that the three layers identified have important implications relevant to the general circulation. In the bottom layer, low latitude heating and high latitude cooling, in the absence of other driving forces, could give rise to a slowly overturning cell with meridional motion toward the equator near the surface (*15*, *16*). Although the flux divergences are small, significant mass transport is possible because the temperature profile is nearly adiabatic in this layer. In the cloud layer, strong circulations have already been observed by Mariner 10 (*17*). The different dynamical regime that was found in the polar region is probably reflected in the significantly different cloud structure found there by several Pioneer Venus experiments as discussed earlier. Although the strong heating observed below 60 km in the high latitude clouds coupled with cooling at the top would ordinarily tend to produce local overturning, the strongly subadiabatic lapse rates there suggest that the energy transport is provided instead by circulations on a much larger scale. This is consistent with motions seen in Mariner 10 images as well as the cloud structural features seen in these images and in orbiter data (*12*), which together indicate large-scale vertical motions in the polar cloud cap. In the middle layer the flux variations are most likely the result of compositional stratifications. The stability of this layer and the similarity of structure from probe to probe again suggest a planetary scale circulation probably driven indirectly by other layers.

The picture of the general circulation should become much clearer when a complete set of winds from the DLBI experiment (*16*) is available. The general circulation and its connection to surface heating and the greenhouse effect will be one subject of future investigations. We also plan to investigate the implications of the SNFR measurements for identifying cloud and gaseous constituents.

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15. Preliminary results of the DLBI experiment (*16*) indicate that the opposite is true, that is, the bottom of the atmosphere appears to have meridional motion toward the pole, suggesting that the lower cell is indirectly driven.
16. DLBI is the acronym for the differential long-baseline interferometry experiment [see C. C. Counselman III, S. A. Gourevitch, R. W. King, G. B. Loviott, *Science* **205**, 85 (1979)].
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18. We thank the engineering and technical staff of the University of Wisconsin Space Science and Engineering Center for excellent work in developing the SNFR instrument; especially significant contributions were made by E. E. Richards, R. M. Dombroski, R. A. Herbsleb, R. F. Sutton, G. Bucholtz, J. C. Sitzman, S. Burns, M. Shah, D. Ford, D. Otto, T. Wendricks, R. Dedecker, and E. Grindey. We also acknowledge the efforts of C. Hall and his personnel in the Pioneer Project Office; special thanks are due to L. Polaski, R. Twarowski, J. Terhune, and C. Leidich.

15 May 1979

Venus Winds Are Zonal and Retrograde Below the Clouds

Abstract. *Winds in the lower atmosphere of Venus, inferred from three-dimensional radio interferometric tracking of the descents of the Pioneer day and north probes, are predominantly easterly with speeds of about 1 meter per second near the surface, 50 meters per second at the bottom of the clouds, and more than 200 meters per second within the densest, middle cloud layer. Between about 25 and 55 kilometers altitude the average flow was slanted equatorward, with superimposed wavelike motions and alternating layers of high and low shear.*

The Pioneer Venus differential long-baseline interferometry (DLBI) experiment (*1*) was designed to obtain, for the first time, profiles of vector wind velocities as functions of altitude in the lower atmosphere of Venus. Here we report the first results of the experiment, from the tracking of the day probe, which descended about 12° west of the morning terminator at about 30°S latitude, and the north probe, which descended about 35° east of this terminator at about 60°N latitude. So far we have obtained wind profiles only for altitudes below 55 km for the day probe and below about 40 km for the north probe. We expect eventually to extend the profiles for these probes to approximately 65 km altitude and to obtain similar results for the night and sounder probes.

Preliminary results for the day probe, for altitudes up to 49 km, are given in Fig. 1. All three components, locally downward, westward, and northward, of the probe's velocity vector are plotted against altitude relative to the impact point. The probe's vector position relative to this point was estimated as a function of time directly from the earth-based radio observations. Differencing of the estimated positions at ~ 60-second intervals yielded the velocity components shown here. Our results for the altitude and its time derivative, the vertical component of velocity, agree with completely independent determinations (*2*) based on the assumption of hydrostatic equilibrium, the equation of state of the atmospheric gas, and the in situ pressure and temperature measurements, within our estimated uncertainties of about 1 km and 1 to 2 m sec^{-1}, respectively. Since, in our experiment, the vertical component of velocity is unlikely to have been determined correctly unless the horizontal components were correct at a similar

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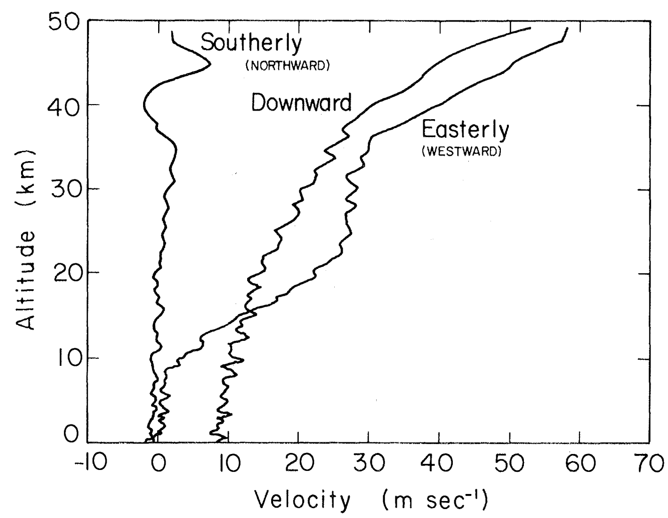

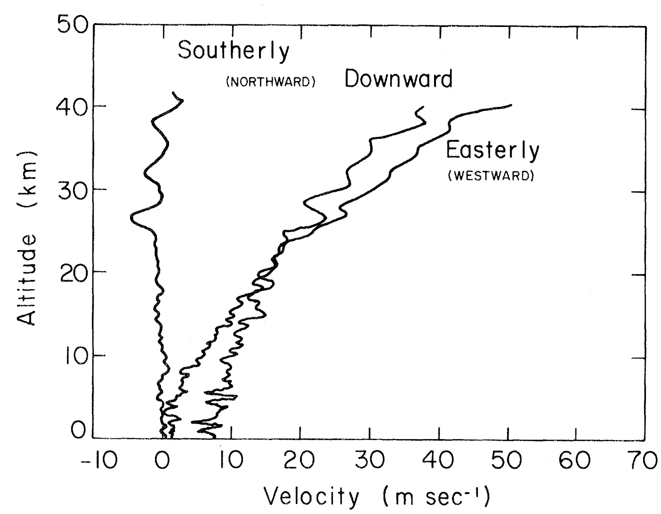

Fig. 1 (left). Velocity vector components of the Pioneer Venus day probe, determined by differential interferometric and Doppler radio tracking and averaged over 1-minute time intervals. With this averaging, the horizontal components of the velocity of the probe are essentially identical with those of the ambient wind. Both the high-frequency noise and the systematic-error levels are believed to be in the range 1 to 2 m sec^{-1} for the downward and westward components and about 1 m sec^{-1} for the northward component. Fig. 2 (right). Like Fig. 1, but for the north probe. Estimated uncertainties are of the order of 2 to 3 m sec^{-1} for the downward and westward components and about 1 m sec^{-1} for the northward component.

level of accuracy, we conclude that our velocity results for the day probe are probably accurate at the stated level in all components (*3*). At or slightly below this level, certain systematic errors are known to be present, which we hope to largely remove in the near future. For examples, we have not accounted for the effect of the atmospheric refraction of Venus on the radio signal propagation or for the effect of the nonsphericity of the planet's gravitational field on the reference bus orbit.

Figure 2 shows our preliminary results for the north probe. Most of the comments made about Fig. 1 apply here as well. However, our estimates of the probable systematic errors here are significantly larger, about 2 to 3 m sec^{-1}, due mainly to the uncertainty of our present, preliminary estimate of this probe's entry location. The noise level is also slightly higher, in part because the geometry of our interferometric observations was less favorable for this probe.

For the day probe between 49 and 55 km altitude, we have received the radio tracking data so far from only three of the four stations. With data from only three stations we can estimate the three components of the probe's velocity uniquely, but we lack the important consistency check that the fourth station might provide. As yet, no external check is available for altitudes above 49 km. Thus, we defer presentation of detailed results for this region. The main features, however, are probably accurate: from 49 to 55 km, the southerly (that is, northward or equatorward) component of velocity rises sharply from 2 m sec^{-1} to 20 to 25 m sec^{-1}, while the easterly velocity rises to more than 200 m sec^{-1}. Strong variability, indicative of turbulence, is observed in all three velocity components, and large fluctuations in the received radio signal strength suggest that the probe may have undergone large excursions in attitude, also due to turbulence.

For both probes, our results at the higher altitudes tend to confirm the original suggestion based on Earth-based ultraviolet observations that the upper atmosphere of Venus has strong easterly winds of ~100 m sec^{-1} (*4*), and contradict the later suggestion that these same observations instead represent wave motions with actual zonal winds of only ~5 m sec^{-1} (*5*). The flow we observe between about 25 and 55 km altitude is, on the average, slanted equatorward, whereas images of the cloud tops seem to show poleward velocities of a few meters per second (*6*). Both results would appear consistent with the planetary circulation being driven by radiative heating in the middle cloud layer, as we discuss below.

At lower altitudes our results can be compared to those derived from one-way Doppler tracking of Veneras 4, 5, 6, and 7 (*7*), Venera 8 (*8*), and Veneras 9 and 10 (*9*). The different Veneras, having descended at various locations with respect to the subearth point, yielded various mixtures of Doppler sensitivities to the zonal and the meridional wind components. Veneras 5 and 6 entered very near the subearth point and were therefore not suitable for accurately determining horizontal velocities. Veneras 4, 8, 9 and 10 yielded horizontal wind profiles that are at least qualitatively similar to ours and are consistent with the winds being predominantly easterly, as we have observed. The Venera profiles differ among themselves in detail, as do our day and north probe profiles. The Venera 7 profile, which represented mainly the zonal component and indicated a maximum easterly velocity at 48 km of 5 to 14 m sec^{-1}, does not appear consistent with our results at all, but further comment must await our reduction of data for the more nearly equatorial sounder probe.

Let us denote the westerly and southerly wind components as u and v, respectively, and the altitude as z. For the day probe, zonal wind shear $\partial u/\partial z$ is relatively low between $z = 0$ and 9 km, high from ~9 to 22 km, low from ~22 to 36 km, and high above 36 km. This pattern may reflect large-scale wave motions. Matching features are not present in the wind profile observed with the north probe, although periodic features with a vertical wavelength of ~5 km do appear in the winds between about 25 and 40 km altitude for that probe (see Fig. 2). The latter features may also have been detected by the north probe accelerometer (*10*) and net flux radiometer (*11*). We note that the atmosphere is quite stable between 35 and 45 km, with Richardson numbers $Ri \approx 8$, but is convectively unstable between about 20 and 30 km, with $Ri \approx -4$ (*10*).

For the day probe, a close examination of the meridional wind profile replotted with only 12-second time averaging has also revealed an alternation of high-and low-shear "layers" 1 to 3 km in vertical thickness, throughout the range 35 to 55 km altitude. These meridional shear layers may be related to alternations in the divergence of the net radiative flux observed on the day probe (*11*) below the clouds, and to the variations in particle density within the clouds (*12*). High shear seems to be associated with local radiative heating and with high cloud density. Particularly large values of uv are seen in the regions from 43 to 47 km and above 50 km. In the middle cloud at 55 km, $uv \approx -5000$ m^2/sec^2 and the sense is such as to provide an equatorward flux of easterly momentum. Convergence of this flux toward lower latitudes could provide easterly acceleration in equatorial regions. The very large values observed for both $\partial u/\partial z$ and $\partial v/\partial z$ in these upper regions also suggest the possibility of very large vertical advection of horizontal momentum. Since temperatures measured by the probes at the 1-bar level (*10*) appear to increase by up to 9 K from the equator to 30°S, then at 55 km $v(\partial T/\partial y) \approx -6$ K day^{-1}; a very significant local heating by equatorward advection by the meridional wind is indicated. Leovy (*13*) has also suggested that on Venus a cyclostrophic balance is present between the zonal winds and the meridional pressure gradient. A preliminary comparison of our wind measurements with the measured pressure differences between the north and day probes (*10*) appears, to first order, to confirm this hypothesis. We will examine the hypothesis more critically as soon as we have reduced the DLBI data for all four probes.

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15 May 1979

Measurements of Turbulence in the Venus Atmosphere Deduced from Pioneer Venus Multiprobe Radio Scintillations

Abstract. *The 2.3-gigahertz log-amplitude fluctuations observed in the radio links of the Pioneer Venus entry probes during Venus encounter have been used to study turbulence in the Venus atmosphere. The deduced estimates of the upper bound of structure constant* c_n *of the refractive index fluctuations* ($c_n \lesssim 4 \times 10^{-8}$ $cm^{-1/3}$) *are inconsistent with similar entry probe measurements by Veneras 4 to 8 but are consistent with the radio occultation measurements by flyby (Mariners 5 and 10) and orbiting (Venera 9) spacecraft. The Pioneer Venus measurements therefore provide a resolution of the long-standing order of magnitude discrepancy between these earlier measurements of* c_n.

The radio links of the Pioneer Venus orbiter and probes offer an excellent opportunity for conducting complementary measurements of turbulence in the Venus atmosphere based on an analysis of the observed radio scintillations. So far only the multiprobe data have been processed, and these results are discussed in this report.

The Pioneer Venus multiprobe measurements are especially interesting because they should help resolve the order of magnitude difference between estimates of the structure constant c_n of the refractive index fluctuations (*1*) deduced from the earlier entry probes Veneras 4 to 8 (*2*) and those inferred from the radio occultation measurements by Mariners 5 and 10 (*3*) and Venera 9 (*4*). This important discrepancy and its implications in terms of the dynamics of the Venus atmosphere have been the subject of much discussion (*5*).

The mission features of the Pioneer Venus multiprobe Venus encounter on 4 December 1978 have been described by Colin (*6*). The communication angles (the angle the line of sight makes with the local Venus zenith) for the four probes ranges from 53° to 61°. Figure 1 shows the power level time histories of the 2291- to 2293-MHz radio-frequency (RF) signals received from the probes at the 64-m Deep Space Network (DSN) station in Canberra, Australia, during the Venus encounter. These narrowband data, recorded at a sampling rate of one per second, were intended for station monitoring purposes only, but are displayed here to show major events and features. The corresponding altitude of the probes as a function of time has been discussed previously (*7*). It is clear from Fig. 1 that while the intensity of the amplitude fluctuations increases for the small probes after RF blackout, it does not in the case of the large probe. Furthermore, the high-frequency fluctuations in the day probe signal are reduced considerably after landing on Venus, but a slowly varying component with a period of the order of minutes persists.

To analyze the observed amplitude fluctuations, we used the higher-quality wideband (approximately 1 kHz) recordings made at the 64-m DSN stations in Goldstone, California, and Canberra, Australia. These recordings also represent the source of data for the Pioneer Venus differential long-baseline interferometry (DLBI) experiment and have already been described (*8*). The RF spectra for the day probe shortly before and after impact on Venus are shown in Fig. 2. We further reduced the bandwidth of the 1-kHz data to 2 Hz by using a digital phase lock loop procedure. Fluctuation power spectra of log amplitude were produced by using a fast Fourier transform (FFT) algorithm; the results for the large and day probes for time intervals A through E defined in Fig. 1 are shown in Fig. 3.

The downturn at about 1 Hz in every