the VEGA-2 nephelometer except for instrument temperature. The VEGA-1 backscatter results are still uncertain by a constant offset factor because the nephelometer was deployed within the cloud and its response for zero backscatter is not known. In the initial results presented here, this problem was resolved by choosing a zero signal offset value that gave mean backscatter values comparable to results obtained by earlier descent probes (*9, 10*). Errors introduced by this approximation will shift the results plotted in Fig. 1E up or down by as much as 5×10^{-5} (m sr)$^{-1}$, but they will produce much smaller changes in the relative amplitudes of the backscatter values shown there.

Our initial backscatter results indicate the following. (i) No totally clear (zero backscatter) regions were observed in those parts of the middle cloud layer sampled by this balloon. (ii) Large-scale backscatter variations correlate to some extent with variations in the ambient pressure and temperature, indicating that the cloud density increases with depth. (iii) Small-scale backscatter fluctuations with amplitudes as large as 2×10^{-5} (m sr)$^{-1}$ and durations as short as 5 minutes were encountered at all levels of the middle cloud layer. (iv) Backscatter readings near 43 hours U.T. were more than 50 percent larger than any values measured previously in the Venus middle cloud layer (*9, 10*), but their validity is supported by the simultaneous decrease in the measured ambient light level (Fig. 1D).

The VEGA balloons encountered a wide range of atmospheric conditions in the Venus middle cloud layer as they drifted westward from the midnight meridian into the sunlit hemisphere. Large vertical velocities encountered by both balloons added substantially to the data returned by this mission, since they forced the balloons to sample the atmosphere over a much greater range of altitudes than would have been possible in their absence. Efforts to refine these data sets and to incorporate them into more complete models of the Venus atmosphere are currently in progress.

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Determination of Venus Winds by Ground-Based Radio Tracking of the VEGA Balloons

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A global array of 20 radio observatories was used to measure the three-dimensional position and velocity of the two meteorological balloons that were injected into the equatorial region of the Venus atmosphere near Venus midnight by the VEGA spacecraft on 11 and 15 June 1985. Initial analysis of only radial velocities indicates that each balloon was blown westward about 11,500 kilometers (8,000 kilometers on the night side) by zonal winds with a mean speed of about 70 meters per second. Excursions of the data from a model of constant zonal velocity were generally less than 3 meters per second; however, a much larger variation was evident near the end of the flight of the second balloon. Consistent systematic trends in the residuals for both balloons indicate the possibility of a solar-fixed atmospheric feature. Rapid variations in balloon velocity were often detected within a single transmission (330 seconds); however, they may represent not only atmospheric motions but also self-induced aerodynamic motions of the balloon.

THE RETROGRADE ZONAL ROTATION of the cloud tops of Venus was first noted by Earth-based observations (*1*). Previous Venera (*2*) and Pioneer Venus (*3*) probes into the Venus atmosphere have determined essentially instantaneous vertical profiles of the wind, showing a vertical profile in wind speed ranging from about 100 m sec^{-1} at the visible top of the clouds (about 65 km altitude) to near 0 at the surface. Ultraviolet images of the cloud tops from both Mariner 10 (*4*) and the Pioneer Venus orbiter (*5*) have yielded details of planetary circulation and waves. The VEGA balloons provided a means of measuring variations in the wind at a nearly constant altitude below the tops of the clouds. The ground-based radio tracking data should provide information about temporal and spatial changes in the motions of the atmosphere, allowing studies to be made of phenomena such as turbulence, eddy motions, waves, constancy of zonal flow, heat and momentum transport, and meridional flow. We will briefly discuss the concept of the wind measurement experiment and then present initial results.

At least three antennas had to observe simultaneously each balloon and its associated flyby spacecraft at 1.7 GHz to determine a complete set of three-dimensional position and velocity components relative to Venus. The method of determining the balloon velocity was similar to that used with the Pioneer Venus probes (*3*). The radial velocity component was derived from measurements of the signal Doppler shift at a single station. Transverse (plane-of-sky) velocity information was obtained by differencing measurements of the signal Doppler shift

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received at widely separated antennas [a form of very long baseline interferometry (VLBI)]. Each antenna pair measures only the component of transverse velocity along the sky projection of the baseline between the antennas.

The method of determination of balloon transverse position was similar to the VLBI techniques used to navigate the Voyager spacecraft (*6*). The transverse position was obtained by observing the phase difference between two coherent tones transmitted by each balloon at each of two widely separated antennas. This provided only the component of transverse position along the sky projection of the baseline. The radial component of position was estimated from balloon altitude derived from in situ pressure measurements.

Simultaneous observations of the signals from the balloon and flyby spacecraft were algebraically differenced to cancel common errors, providing information only about the relative position of the balloon and flyby. The trajectory of the flyby relative to Venus was used to infer balloon position and velocity relative to a Venus-centered reference frame.

The 20 ground antennas used to track the balloons are identified in Fig. 3 of the companion report by Sagdeev and colleagues (*7*). The total array allowed simultaneous observations on at least two long baselines with large orthogonal components for 22 hours each day. The array also provided redundancy to allow for antenna failure. All antennas appear to have acquired data successfully. Velocity measurements were made during each transmission from the balloons (every half-hour or hour), while position measurements were made only every 2 hours when two simultaneous tones were transmitted (*8*). For a single transmission, the typical accuracies (1σ) of velocity and position component estimates are expected to be about 1 m sec^{-1} and 15 km, respectively.

Analysis of single-antenna Doppler (radial velocity) data has provided initial information about both the long-term zonal drift of the balloons and rapid balloon motion during each 330-second transmission. Determination of three-dimensional winds and balloon positions for single transmissions will require more lengthy analysis.

The horizontal motion of each balloon was modeled by two adjustable parameters: a constant zonal wind and a frequency offset for the onboard oscillator. The latitude and longitude of injection were fixed at the values estimated from the trajectory of the entry capsule. The latitude of each balloon was assumed to be constant throughout its flight because the Doppler data have poor

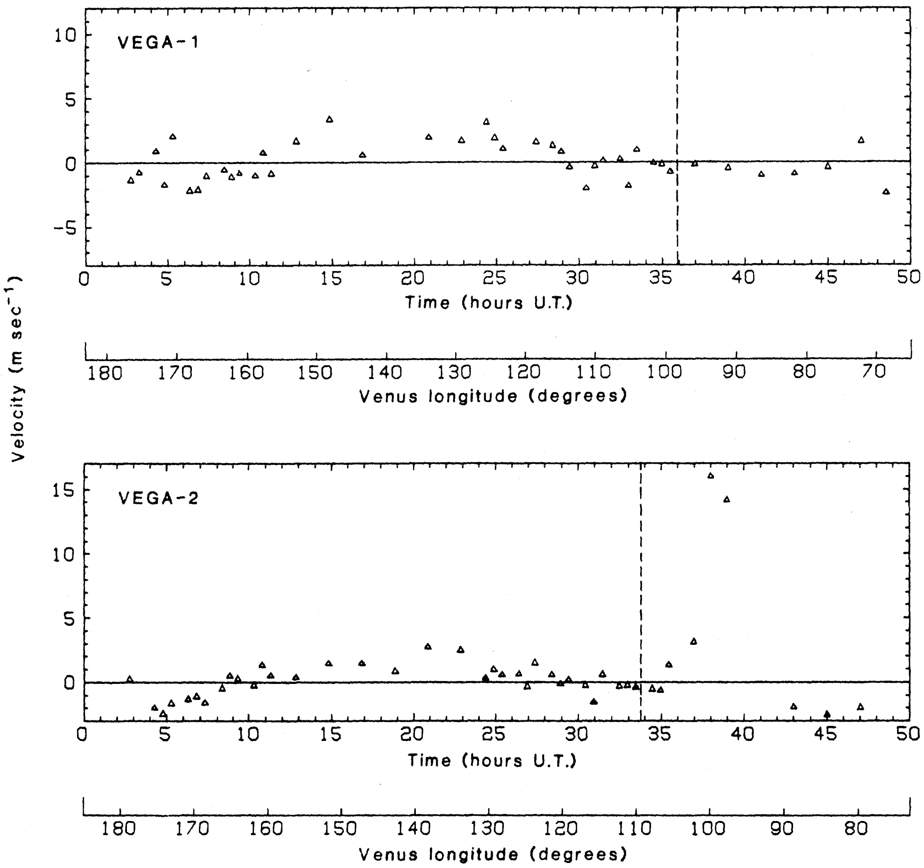

Fig. 1. Doppler residuals with respect to the model of constant zonal wind for each balloon. Dotted vertical lines indicate estimated times of crossing into the sunlit hemisphere.

sensitivity to north-south motion, and Pioneer Venus results indicate meridional velocities of at most a few meters per second. The balloon altitudes were assumed to be fixed at 53 km as indicated by the mean value of in situ pressure. The assumptions of constant latitude and altitude should affect the accuracy of the mean zonal wind estimate by less than 1 m sec^{-1}.

Plots of the Doppler residuals (observed minus model values) relative to the best-fit model for a constant zonal wind for each balloon are shown in Fig. 1. The data were measured by the six large Soviet and NASA antennas with an instrumental precision of 1 Hz (0.2 m sec^{-1}). Drifts in the onboard oscillator frequency may also cause long-term (~24-hour) Doppler variations with amplitudes of about 1 m sec^{-1}.

The estimated mean zonal wind for balloon 1 was 69 ± 1 m sec^{-1}. This speed carried the balloon about 109° of longitude to the west, or about 31° of longitude into the day side. The estimated mean zonal wind for balloon 2 was 66 ± 1 m sec^{-1}, carrying it 105° of longitude and 35° into the day side. Details of the balloon flights deduced from these models are given in Fig. 2 of the companion report by Sagdeev and colleagues (*7*) and in Table 1.

The deviations between the measured radial velocities and the models of constant zonal atmospheric flow were in all cases less than 4 m sec^{-1} except for a striking anomaly about 36 hours into the flight of balloon 2, where the Doppler residual reached a maximum of 16.0 m sec^{-1} (anomalous points not included in fit). Two independent tracking antennas detected this anomaly. This event corresponded in time with a period of strong vertical motion of the balloon as indicated by in situ measurements. However, the vertical speed of the balloon never exceeded 2 m sec^{-1} in this region. Thus, if the event is to be associated with atmospheric motions, it must be related mostly to changes in horizontal velocity. Since the balloon at this time was less than 15° from the subearth point according to the model of constant zonal flow, the amplitude of the change in the horizontal velocity vector must have been many times 16.0 m sec^{-1} [of order 16/(sin 15°), or ~60 m sec^{-1}]. An addition to the model of constant zonal flow to allow simple horizontal flow variations in this region shows that the data could be explained by zonal flow speed variations combined with an excursion in latitude of a few degrees. Tests of a spare model of the balloon oscillator indicate that some of the large residual may also be explained by thermal sensitivity of the onboard oscillator, and more investigation is needed. The VLBI data should eventually clarify what horizontal (transverse) motions took place.

According to our simple model of constant zonal flow, the midpoint of this anomaly occurred when the balloon, located at about 98° longitude and −7° latitude, was over some of the highest mountains on Venus in the Aphrodite region. The present uncertainty in balloon longitude is about 2° and, although the Doppler data are not sensitive to latitude motion, Pioneer Venus probe results (*3*) indicate that the balloon should not have drifted more than a few degrees in latitude. The possibility of the influence of surface topography on the balloon flight is considered in the companion paper by Blamont and co-workers (*9*).

The Doppler residuals of the two balloons show almost identical long-term variations during the first 30 hours of flight. The residuals slowly grew during the first half of the interval and decreased during the second half, with the peak value about 3 m sec^{-1} higher than the values at the ends of the interval. Since the history of the longitude difference between balloon position and the subsolar point was nearly the same for both balloons, these signatures suggest the possibility of a solar-fixed variation in the atmospheric winds [see Blamont and co-workers (*9*) for more detail]. The data could also be explained by a surface-fixed atmospheric feature, but this seems to be less likely. Simple models of changes in zonal wind speed show that these variations could be explained by an increase in wind speed of a few meters per second during this period, but the VLBI results should provide a more definitive answer.

The variations in Doppler residuals from one transmission to the next (0.5 or 1.0 hour) were usually less than 2 m sec^{-1}. Because the balloons were injected near the east limb of Venus as viewed from Earth, the scatter in the Doppler residuals near the beginning of each balloon flight is a direct measure of variations in balloon zonal velocity. At this time in the balloon flights, the balloon 1 residuals showed more variation than those for balloon 2, with changes as large as 4 m sec^{-1} during a half-hour interval. Sagdeev and colleagues (*10*) note from in situ data that this was also a period of large vertical motion in the flight of balloon 1, while the vertical motions of balloon 2 were relatively mild. Thus horizontal and vertical balloon motions seem to correlate.

At the Soviet tracking station at Eupatoria, the history of the Doppler variations within many of the 330-second transmissions was determined with a sampling resolution of 0.5 second. These data allow analysis of very high-frequency variations in the balloon velocity. Figure 2 shows an example of large Doppler variations from a transmission early in the flight of balloon 1, which were some of the largest amplitude high-frequency variations recorded. These variations are principally a measure of zonal balloon motions. The known gondola pendulum frequency of 7 seconds appears to be one component of the high-frequency variations shown in Fig. 2. Other early transmissions from the balloons were similar, while some showed almost no high-frequency variations. Intermittent high-frequency variations were also seen in the Doppler data from near the subearth point. These variations are principally a measure of vertical balloon motions.

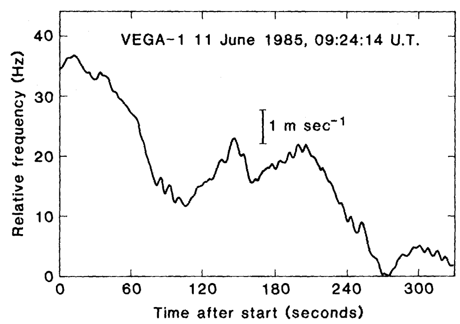

Fig. 2. Example of short-term variations in received frequency within a transmission. Larger scale drift in frequency during the transmission (330-second duration) is due principally to the motion of the Eupatoria tracking station with respect to Venus. The noise level is about 0.5 Hz (10 cm sec^{-1}). The start time of transmission is given.

During the lifetimes of both balloons, the amplitudes of these high-frequency velocity variations within single transmissions typically ranged from near 0 to about 1 m sec^{-1}, with a maximum of about 2 m sec^{-1} recorded for balloon 1. During the early portion of the balloon flights, the fine-scale velocity variations (principally zonal) for balloon 1 were generally larger than those for balloon 2, while during the later portion of the flights, the variations (principally vertical) for balloon 2 were generally larger than those for balloon 1.

The balloons should have roughly followed short-term fluctuations in both horizontal and vertical atmospheric velocity when the period of the fluctuations was greater than about 1 minute and the velocity of the atmosphere relative to the balloon was small (*11*). However, during periods of large atmospheric velocity relative to the balloon, determination of short-term wind fluctuations from the tracking data will be complicated by possible self-induced aerodynamic oscillations of the balloon (*12*).

Analysis of the VLBI data should enable precise determination to be made of the trajectory and velocity history of each balloon. These trajectories and their correlation with in situ measurements will give additional insight into the motions of the Venus atmosphere.

Table 1. Details of the models of balloon motion.

Point in flight	Time* (U.T.)	Longitude (degrees)	Latitude† (degrees)	Change in longitude from injection (degrees)	Longitude from terminator (degrees)	Distance traveled (km)
			Baloon 1			
Injection	02:00	177.7	+7.3	0	84.3	0
Central meridian crossing	35:47	98.2	+7.3	−79.5	0.5	8,400
Terminator crossing	35:59	97.7	+7.3	−80.0	0	8,450
Final transmission	48:32	68.2	+7.3	−109.5	−31.2	11,600
			Balloon 2			
Injection	02:00	180.7	−6.6	0	75.6	0
Terminator crossing	33:45	109.1	−6.6	−71.6	0	7,600
Central meridian crossing	34:19	107.8	−6.6	−72.9	−1.3	7,700
Final transmission	48:32	75.8	−6.6	−104.9	−35.2	11,100

*Measured from 00 hours U.T. on the day of injection. †Assumed to be fixed.

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