racy of the instrument was about 10^{-5} m^{-1} sr^{-1} in ambient backscattering cross section and that changes of about 2×10^{-6} m^{-1} sr^{-1} were resolvable. The entire unit was packaged in a box about 2.0 by 5.5 by 6.5 cm and was mounted in the battery compartment viewing the ambient atmosphere through two apertures in the side of the container (Fig. 1). The sensitive volume extended from about 4 cm to about 1 m from the wall of the battery box.

REFERENCES AND NOTES

1. R. Z. Sagdeev *et al.*, *Science* **231**, 1407 (1986).
2. R. A. Preston *et al.*, *ibid.*, p. 1414.
3. R. Z. Sagdeev *et al.*, *ibid.*, p. 1411. The gaps in the data shown in the figures of this reference reflect the off periods in the radio transmission schedules.
4. V. M. Linkin *et al.*, *ibid.*, p. 1417.
5. B. Ragent and J. Blamont, *J. Geophys. Res.* **85**, 8099 (1980).
6. M. Y. Marov *et al.*, *Icarus* **44**, 608 (1980).
7. This research was supported in part by NASA Ames Research Center and the Jet Propulsion Laboratory.

23 October 1985; accepted 24 January 1986

Overview of VEGA Venus Balloon in Situ Meteorological Measurements

R. Z. Sagdeev, V. M. Linkin, V. V. Kerzhanovich, A. N. Lipatov, A. A. Shurupov, J. E. Blamont, D. Crisp, A. P. Ingersoll, L. S. Elson, R. A. Preston, C. E. Hildebrand, B. Ragent, A. Seiff, R. E. Young, G. Petit, L. Boloh, Yu. N. Alexandrov, N. A. Armand, R. V. Bakitko, A. S. Selivanov

The VEGA balloons made in situ measurements of pressure, temperature, vertical wind velocity, ambient light, frequency of lightning, and cloud particle backscatter. Both balloons encountered highly variable atmospheric conditions, with periods of intense vertical winds occurring sporadically throughout their flights. Downward winds as large as 3.5 meters per second occasionally forced the balloons to descend as much as 2.5 kilometers below their equilibrium float altitudes. Large variations in pressure, temperature, ambient light level, and cloud particle backscatter (VEGA-1 only) correlated well during these excursions, indicating that these properties were strong functions of altitude in those parts of the middle cloud layer sampled by the balloons.

The VEGA balloons provided the first opportunity to obtain in situ meteorological measurements for an extended period of time within the middle cloud layer of the Venus atmosphere. Each balloon collected data for approximately 22.5 hours of its 46.5-hour active lifetime. Data sampling and transmission schedules are described in the companion paper by Kremnev and co-workers (*1*). Approximate trajectories for the balloon flights are given by Sagdeev and co-workers (*2*). We summarize the meteorological measurements obtained by VEGA balloons 1 and 2 in Figs. 1 and 2, respectively. These results are plotted on a common time axis to facilitate their comparison.

The pressure and temperature records for both balloons correlate strongly because variations in these quantities were primarily caused by vertical motions of the balloons in an atmospheric region with a large (10.2 K km^{-1}) vertical temperature gradient. This correlation indicates that thermal contamination by the gondolas did not alter the temperature measurements by more than 0.2 K while the balloons were on the night side of Venus. Once the balloons were on the day side, solar heating of the temperature sensors may have increased the measured temperatures by as much as 12 K above the ambient values (*3*). We have not attempted to correct for this spurious effect in the results presented here.

Pressure and temperature measurements (Figs. 1 and 2) indicate that both balloons rose rapidly from a deployment altitude near 50 km (900 mbar) to an equilibrium float altitude near 53.6 km (535 mbar) after about 30 minutes. These altitudes were derived from the VEGA-2 lander data (*3*). The equilibrium float altitudes decreased from about 535 mbar to about 620 mbar during the missions as the balloons slowly lost gas. We estimate (*4*) that each balloon lost less than 5 percent of the original 2.1 kg of helium during the mission. This value is comparable to that expected from the diffusion of gas through the balloon skin, and it rules out appreciable leaks.

Once the balloons reached their equilibrium float altitudes, excursions from this level occurred as they encountered vertical motions in the atmosphere. Figures 1C and 2C show that the balloons measured vertical winds that were predominately downward, with gusts that often exceeded 1 m sec^{-1}. Vertical winds as large as 3.5 m sec^{-1} were observed by both balloons. VEGA-1 experienced many large downward excursions throughout its lifetime, with the largest ones occurring near the beginning and end of its flight. VEGA-2 recorded no large vertical winds during the first few hours of its flight, but after 20 hours it began to encounter more activity. About 33 hours after injection [35 hours universal time (U.T.)], VEGA-2 was caught in a series of strong downdrafts that lasted almost 8 hours and pushed it to levels as deep as 900 mbar. In situ pressure and temperature measurements show that the balloon was able to recover to its equilibrium float altitude after this event. The Doppler tracking results (*5*) show that VEGA-2 may have experienced a large change in its zonal motion for a period around 39 hours U.T., while it was encountering these vertical winds. No corresponding event was observed in the VEGA-1 Doppler results.

Relations among the measured pressures, temperatures, and vertical velocities are plotted with much greater temporal resolution in Figs. 3, 4, and 5. Three short intervals are shown there: two from near the beginning and end of the VEGA-1 flight, and one from near the end of the VEGA-2 flight. The interval beginning at 7.9 hours U.T. of the VEGA-1 flight (Fig. 3) was typical of several periods for this balloon in that small regular oscillations in pressure, temperature, and vertical velocity were evident. Pressure and temperature varied with a period of 12 to 15 minutes and amplitudes of approximately 5 to 7 mbar and 0.5 to 0.7 K, respectively. Similar fluctuations were seen in the vertical wind velocity and in the vertical velocity of the balloon. For these small oscillations, the amplitudes of these two velocities were comparable, and the balloon was a good tracer of atmospheric vertical motions. The behavior of VEGA-1 was different during the period beginning at 33 hours U.T. (Fig. 4). Then, the pressure

R. Z. Sagdeev, V. M. Linkin, V. V. Kerzhanovich, A. N. Lipatov, A. A. Shurupov, Space Research Institute, 117810 Moscow, U.S.S.R.
J. E. Blamont, Centre National d'Etudes Spatiales, 75039 Paris Cedix 01, France.
D. Crisp and A. P. Ingersoll, Division of Geological and Planetary Sciences, California Institute of Technology, Pasadena 91125.
L. S. Elson, R. A. Preston, C. E. Hildebrand, Jet Propulsion Laboratory, California Institute of Technology, Pasadena 91109.
B. Ragent, A. Seiff, R. E. Young, NASA Ames Research Center, Moffett Field, CA 94035.
G. Petit, Institut Geographique National S.G.N.M., 2 Avenue Pasteur, 94160 Saint-Mandé, France.
L. Boloh, Centre National d'Etudes Spatiales, 31055 Toulouse Cedex, France.
Yu. N. Alexandrov, N. A. Armand, R. V. Bakitko, Institute of Radio and Electronics, Academy of Sciences, 103907 Moscow, U.S.S.R.
A. S. Selivanov, State Center for Study of Natural Resources, State Meteorology Committee, 123376 Moscow, U.S.S.R.

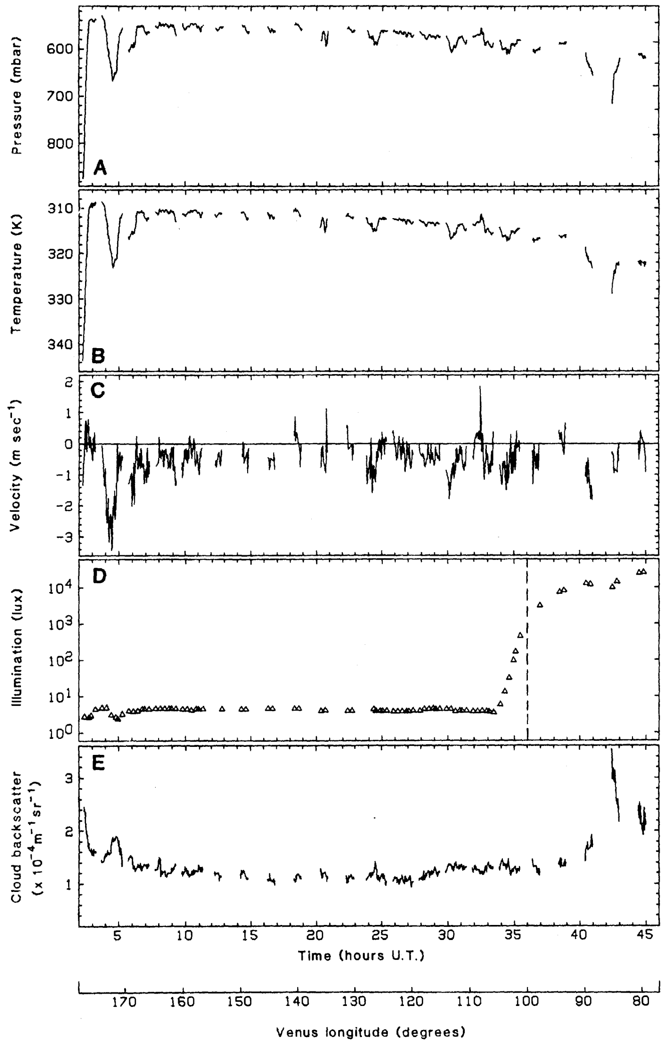

Fig. 1. Mission history for VEGA-1 showing pressure (A), temperature (B), inferred atmospheric vertical velocity (C) [see (*4*)], ambient light level (D), and cloud backscatter (E) as functions of universal time relative to 0 hour U.T. on the day of injection (11 June 1985). Venus longitudes, derived from ground-based Doppler tracking results (*5*), are also shown on the abscissa. The approximate position of the terminator is shown as a dashed line in the ambient light plot (D). Gaps in the data sets indicate times when no in situ measurements were transmitted by the balloons [see (*1*)].

and temperature changes were irregular, with magnitudes of about 15 mbar and 2 K, respectively, and durations shorter than 10 minutes. Vertical winds occasionally exceeded 1 m sec^{-1} during this period. This kind of behavior was seen many times during the flights of both balloons, but large upward winds like those seen here were not common. Figure 5 shows the beginning of the large downward excursion near the end of VEGA-2's flight (36 hours U.T.). During this half-hour period, the pressure and temperature increased by about 210 mbar (about 2.3 km) and 18 K, respectively, as the balloon descended in response to 2 m sec^{-1} downward winds. For these large vertical winds, the vertical velocity of the balloon was less than half as large as that of the atmosphere.

The VEGA balloon ambient light experiment was designed to document fluctuations in ambient illumination as a measure of atmospheric inhomogeneities and to detect transient light events (lightning) (*1*). Light measurements were obtained with 12-bit accuracy, but only the least significant 6 bits (LSB's) of each data word were reported. Ambiguities introduced by this data compression scheme were resolved by choosing the most significant 6 bits (MSB's) subject to the constraint that the resulting measured light level be as close as possible to earlier descent probe measurements obtained at comparable solar zenith angles (*6, 7*). At other solar zenith angles and on the night side, the MSB's were chosen to produce smooth variations in the light level. This simple method for choosing MSB's should be adequate, since the day-side light measurements shown in Figs. 1D and 2D never differ from the earlier measurements by more than a factor of 3, while an error of 1 count in the MSB changes the light level by more than a factor of 30. Such large changes are unlikely at these altitudes in the Venus atmosphere.

A number of small variations in the output of the VEGA-1 light sensor were recorded during the first 5 hours of the flight, while the balloon was on the night side of Venus (Fig. 1D). These fluctuations may have been caused by spurious thermal effects on the sensor or its electronics. A problem of this kind should have little affect on the day-side light measurements, since the temperature fluctuations encountered after sunrise were much smaller than those observed at the beginning of the flight.

Sunlight was first detected by VEGA-1 at 33:50 U.T., only 3 hours (Earth time) before Doppler tracking results (*5*) indicate that this balloon crossed the morning terminator. The duration of twilight was short, spanning less than 7° of longitude, because the balloon floated near the equator, where the sun rises almost perpendicular to the horizon. Once on the day side, the VEGA-1 light level increased steadily from 36:50 to 40:30 U.T. and then decreased slightly as strong downward winds pushed VEGA-1 deeper into the middle cloud layer (Fig. 1, A, C, and D). Cloud particle backscatter measurements (Fig. 1E) indicate that a concurrent increase in cloud thickness also contributed to this decrease in illumination. The ambient light level began to increase after 42:30 U.T. as VEGA-1 rose back to its equilibrium float altitude.

The VEGA-2 ambient light measurements were contaminated by an instrument malfunction that produced spurious small-scale fluctuations throughout the data set. This problem produced errors as large as 30 percent in the calibrated results (Fig. 2D), but these data still indicate that sunlight was first detected by VEGA-2 at approximately 33:00 U.T.

VEGA-1 light measurements indicate that the balloon crossed the terminator around 36:00 U.T. and show a mean night-side westward zonal wind speed of 69 m sec^{-1}. VEGA-2 crossed the terminator at approximately 33:00 U.T., indicating a mean night-side zonal velocity of 66 m sec^{-1}. These zonal wind estimates are uncertain by more than 2 m sec^{-1}, but they agree with the more precise results from the Doppler tracking experiment (*5*) and earlier entry probe results (*8*).

At present it seems that no reliable transient events were recorded in the data of the lightning experiment on VEGA-1. One event was recorded by the lightning experiment on VEGA-2, but this event is suspicious because it consisted of a change in the signal of the middle level counter only (*1*). This would require that the low-level counter be saturated at that time. It must also be cautioned that this event took place only 7° (3 Earth hours) from the terminator, an area where VEGA-1 began to see the effects of twilight.

Both VEGA balloons included a nephelometer experiment to document variations in cloud particle backscatter in the Venus middle cloud layer (*1*). Backscatter measurements were received for the entire VEGA-1 flight (Fig. 1E). No data were received from

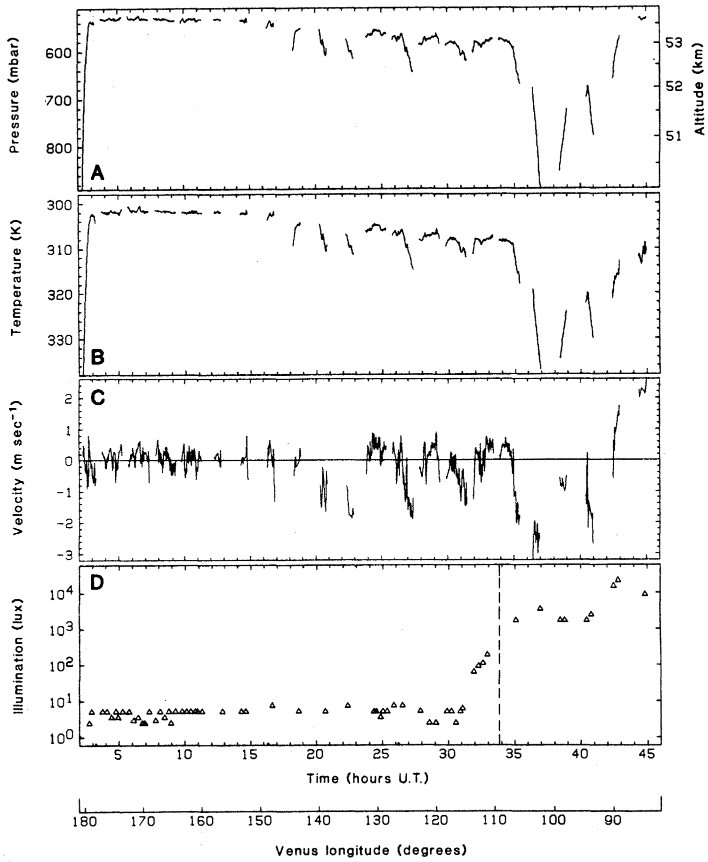

Fig. 2. As in Fig. 1 but for VEGA-2. Time is measured from 0 hour U.T. on 15 June 1985. Cloud backscatter values are not displayed.

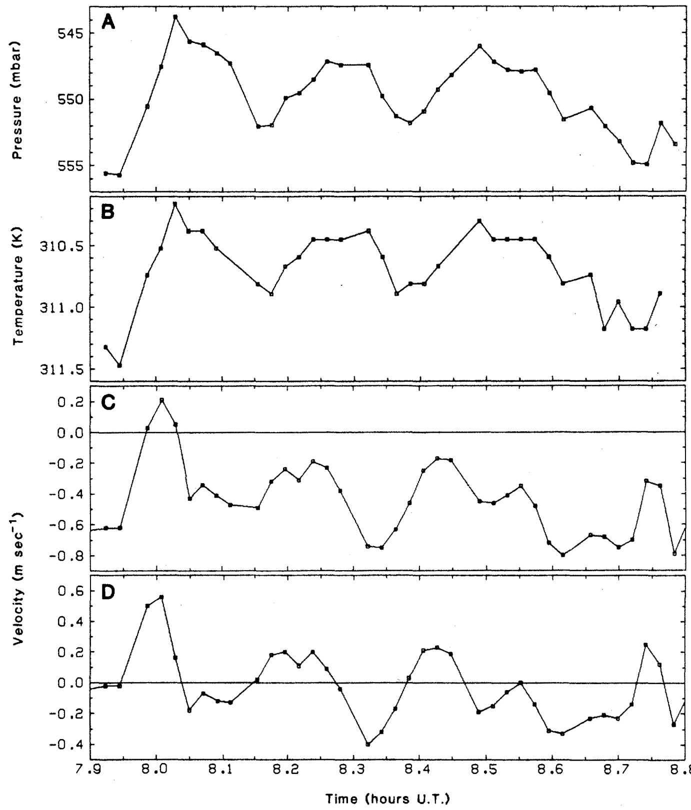

Fig. 3. Pressure (A), temperature (B), atmospheric vertical velocity (C), and balloon vertical velocity (D) from a period near the beginning of the VEGA-1 flight, shown at higher temporal resolution than in Figs. 1 and 2 to illustrate relations among these quantities.

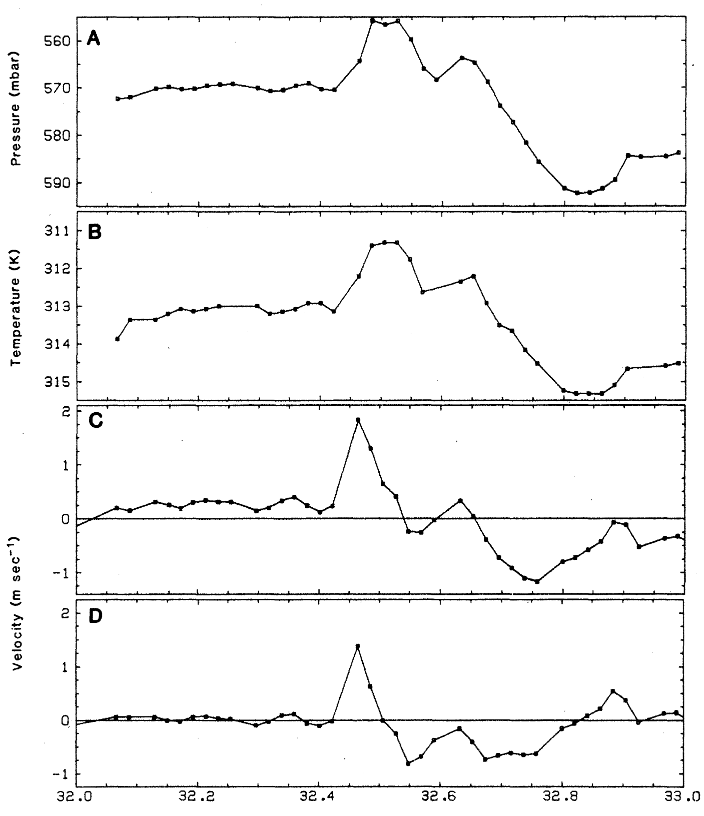

Fig. 4. As in Fig. 3 but for VEGA-1 values at mid-mission.

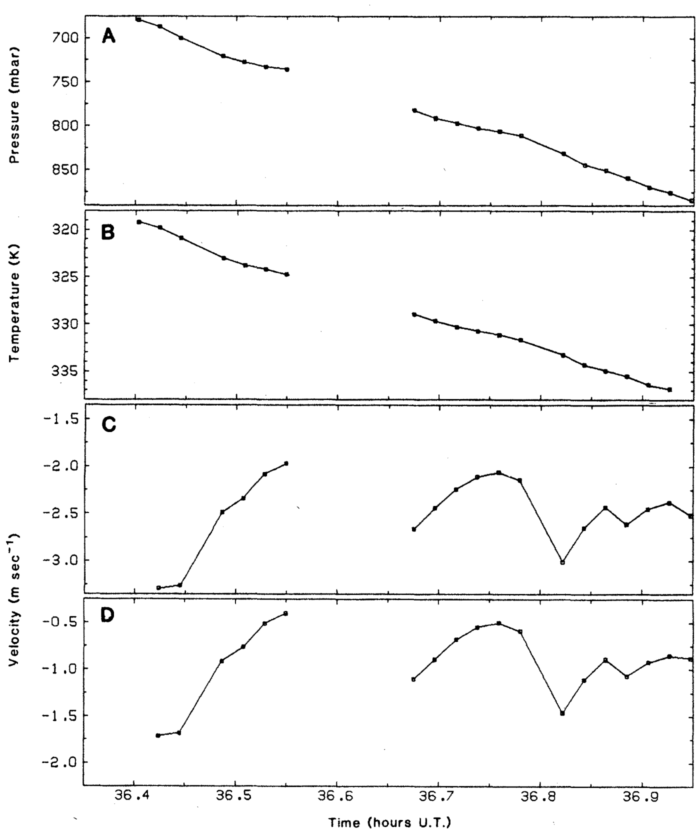

Fig. 5. As in Fig. 3 but for VEGA-2 values near the end of the mission. The data gap is due to the sampling schedule [see (*1*)].

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.

REFERENCES AND NOTES

1. R. S. Kremnev *et al.*, *Science* **231**, 1408 (1986).
2. R. Z. Sagdeev *et al.*, *ibid.*, p. 1407.
3. V. M. Linkin *et al.*, *ibid.*, p. 1420.
4. V. M. Linkin *et al.*, *ibid.*, p. 1417.
5. R. A. Preston *et al.*, *ibid.*, p. 1414.
6. M. G. Tomasko *et al.*, *J. Geophys. Res.* **85**, 8161 (1980).
7. A. P. Ekonomov *et al.*, in *Venus*, D. M. Hunten, L. Colin, T. M. Donahue, V. I. Moroz, Eds. (Univ. of Arizona Press, Tucson, 1983), pp. 632–649.
8. G. Schubert, *ibid.*, pp. 681–765.
9. B. Ragent and J. Blamont, *J. Geophys. Res.* **85**, 8099 (1980).
10. M. Ya. Marov *et al.*, *Cosmic Res.* **21**, 269 (1983) (in Russian).

11. Supported in part by NASA at the Ames Research Center and the Jet Propulsion Laboratory, California Institute of Technology.

23 October 1985; accepted 24 January 1986

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

R. A. Preston, C. E. Hildebrand, G. H. Purcell, Jr., J. Ellis, C. T. Stelzried, S. G. Finley, R. Z. Sagdeev, V. M. Linkin, V. V. Kerzhanovich, V. I. Altunin, L. R. Kogan, V. I. Kostenko, L. I. Matveenko, S. V. Pogrebenko, I. A. Strukov, E. L. Akim, Yu. N. Alexandrov, N. A. Armand, R. N. Bakitko, A. S. Vyshlov, A. F. Bogomolov, Yu. N. Gorchankov, A. S. Selivanov, N. M. Ivanov, V. F. Tichonov, J. E. Blamont, L. Boloh, G. Laurans, A. Boischot, F. Biraud, A. Ortega-Molina, C. Rosolen, G. Petit

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

R. A. Preston, C. E. Hildebrand, G. H. Purcell, Jr., J. Ellis, C. T. Stelzried, S. G. Finley, Jet Propulsion Laboratory, California Institute of Technology, Pasadena 91109.
R. Z. Sagdeev, V. M. Linkin, V. V. Kerzhanovich, V. I. Altunin, L. R. Kogan, V. I. Kostenko, L. I. Matveenko, S. V. Pogrebenko, I. A. Strukov, Space Research Institute, 117810 Moscow, U.S.S.R.
E. L. Akim, Department of Computer Mathematics, Academy of Sciences, 125047 Moscow, U.S.S.R.
Yu. N. Alexandrov, N. A. Armand, R. V. Bakitko, A. S. Vyshlov, Institute of Radio and Electronics, Academy of Sciences, 103907 Moscow, U.S.S.R.
A. F. Bogomolov and Yu. N. Gorchankov, Energy Institute, Ministry of High Education, 111250 Moscow, U.S.S.R.
A. S. Selivanov, Center for Study of Natural Resources, State Meteorology Committee, 123376 Moscow, U.S.S.R.
N. M. Ivanov and V. F. Tichonov, Flight Center, 141070 Kaliningrad, U.S.S.R.
J. E. Blamont, Centre National d'Etudes Spatiales, 75039 Paris Cedex 01, France.
L. Boloh and G. Laurans, Centre National d'Etudes Spatiales, 31055 Toulouse, France.
A. Boischot, F. Biraud, A. Ortega-Molina, C. Rosolen, Observatoire de Paris-Meudon, 92195 Meudon, France.
G. Petit, Institute Geographique National, 94160 Sainte-Mande, France.