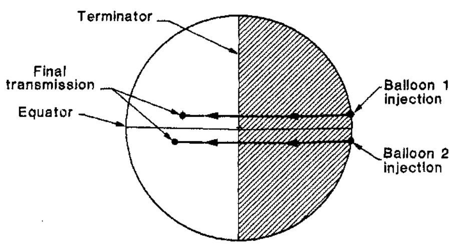

Fig. 2. Track of balloons across the face of Venus as viewed from Earth.

and cloud properties of the Venus atmosphere at the float altitude. It was expected that new insight would be gained into such phenomena as turbulence, eddy motions, waves, meridional flow, and heat and momentum transport. Two types of measurements were planned: in situ measurements transmitted by telemetry, and ground-based determination of balloon motion by differential very long baseline interferometry (VLBI) between each balloon and its associated flyby. Both types of measurements were provided by signals transmitted directly from the balloons to Earth at 1667 MHz. Because of Earth's rotation, continuous reception of telemetry data required the use of antennas widely distributed in longitude. In addition, the VLBI measurements required a high density of antennas widely spaced in both longitude and latitude. Therefore, the tracking network consisted of an array of 20 antennas distributed over the globe (Fig. 3). These stations were organized in two separate but coordinated networks: the Soviet network (6 antennas), coordinated by IKI and composed of existing antennas on Soviet territory and a new 70-m antenna at Ussurisk, U.S.S.R., that was constructed for this experiment; and an international network (14 antennas), coordinated by CNES and composed of the 3 sensitive NASA 64-m antennas together with 11 radio astronomy observatories.

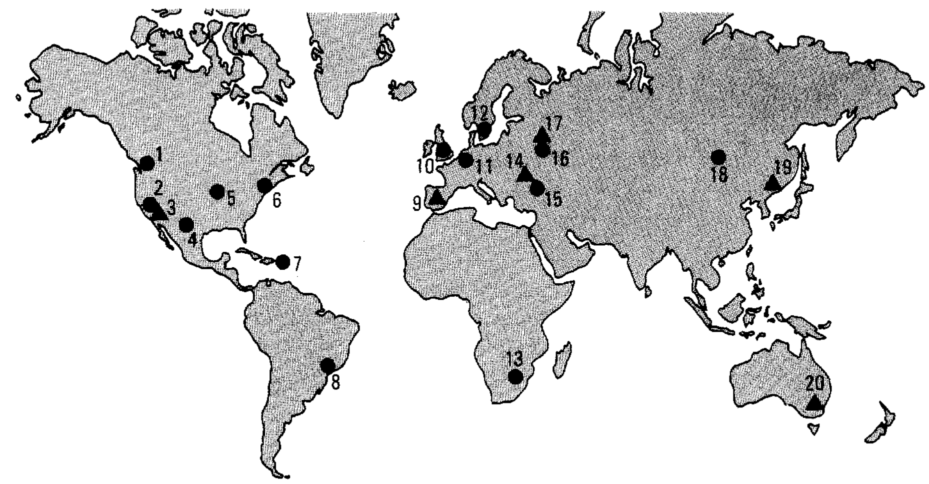

Fig. 3. The balloon-tracking network. Symbols: (●) VLBI data; (▲) VLBI and telemetry data. Key: (1) Penticton, British Columbia (dish diameter, 26 m); (2) Big Pine, California (40 m); (3) Goldstone, California (64 m); (4) Fort Davis, Texas (26 m); (5) North Liberty, Iowa (18 m); (6) Westford, Massachusetts (37 m); (7) Arecibo, Puerto Rico (213 m); (8) Atibaia, Brazil (14 m); (9) Madrid, Spain (64 m); (10) Jodrell Bank, England (26 m); (11) Effelsberg, Federal Republic of Germany (100 m); (12) Onsala, Sweden (26 m); (13) Hartebeesthoek, South Africa (26 m); (14) Eupatoria, U.S.S.R. (70 m); (15) Simeiz, U.S.S.R. (22 m); (16) Pushino, U.S.S.R. (22 m); (17) Medvezhi Ozera, U.S.S.R. (64 m); (18) Ulan-Ude, U.S.S.R. (25 m); (19) Ussurisk, U.S.S.R. (70 m); and (20) Canberra, Australia (64 m).

The float altitude, signal strength, and balloon lifetime were very close to planned values. All 20 ground tracking stations performed well. In situ sensors returned data on pressure, temperature, vertical wind velocity, cloud particle backscatter, ambient light level, and frequency of lightning. Initial results from this pioneering balloon experiment in the atmosphere of another planet are presented in the following reports.

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

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VEGA Balloon System and Instrumentation

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The VEGA Venus balloon radio transmissions received on Earth were used to measure the motion of the balloons and to obtain the data recorded by onboard sensors measuring atmospheric characteristics. Thus the balloons themselves, the gondolas, the onboard sensors, and the radio transmission system were all components of the experiment. A description of these elements is given, and a few details of data sampling and formatting are discussed.

The Venus-Halley (VEGA) mission included the deployment of two balloon and gondola systems into the Venus atmosphere (*1*) to investigate the characteristics of the atmosphere at altitudes from 53 to 54 km. The principal experiments conducted involved (i) radio tracking to measure the motion of the balloons as tracers of the winds and (ii) in situ sensors to measure atmospheric temperature and pressure, vertical wind, cloud density variations, light intensity variations, and possible lightning events.

The balloon was a spherical, closed, superpressure structure fabricated from a specially woven Teflon plastic cloth matrix coated with Teflon plastic, reinforced and stiffened mechanically at critical points. The diameter of the helium-filled balloon at a nominal superpressure of 30 mbar was 3.54 m, and the total weight of the balloon-gondola system was nominally 21 kg (12 kg for the balloon structure, reinforcements, and so forth, 2 kg of helium gas for inflating the balloon, and 6.9 kg of gondola and instrument payload). Tests of the balloon

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indicated that the nominal zero superpressure volume of 19.4 m^3 increased in a viscoelastic manner by about 1.25 m^3 for 10 mbar of superpressure and that the rate of helium loss by diffusion was slow enough that the balloon could maintain superpressure for 5 days.

The gondola (Fig. 1) was approximately 1.2 m long and was suspended below the balloon by a tether 13 m long. The upper section (37 cm long) consisted of a conical antenna 14 cm in diameter at its base. The middle section and lower sections were suspended from the upper section by straps (Fig. 1). The upper part of the middle section contained the radio transmitter and modulator, the data-handling system, signal-conditioning and -processing electronics, and power-regulating electronics. The middle section also contained the pressure and light sensors and supported a deployable arm on which the temperature sensors and anemometer were mounted. The lower section, hanging by straps from the middle section, contained the nephelometer cloud sensor and battery power supply. Approximate dimensions of the middle and lower sections were 40.8 by 14.5 by 13.0 cm and 9.0 by 14.5 by 15.0 cm, respectively. Surfaces of the gondola were covered with a special white coating to resist corrosion by sulfuric acid clouds in the Venus atmosphere and to increase the surface albedo.

The in situ sensors collected data continuously, and all but the lightning and illumination detectors were sampled once every 75 seconds. The lightning counter readings were sampled once every 10 minutes, and the ambient illumination was sampled twice during each 30-minute measurement period. All in situ measurements were collected and stored during a period of 30 minutes in the onboard 1024-bit memory and then transmitted to Earth or discarded, depending on the data transmission mode.

The radio transmitter operated in two modes. The first was a telemetry mode (TM). In this mode, a 48-bit synchronizing word and the 852 bits of data collected by the onboard sensors during the preceding 30 minutes were transmitted. The transmission rate was 4 bits per second for the first 840 bits and 1 bit per second for the remaining bits. This transmission lasted 270 seconds and was preceded and followed by a 30-second period of pure carrier used in the very long baseline interferometry (VLBI) experiment to determine the velocity of the balloon (*2*). In the second mode of transmission, called the KI mode (Fig. 2), two tones with a suppressed carrier were transmitted for a period of 330 seconds. These transmissions were used in the VLBI experiment to determine the balloon position and velocity. The TM and KI modes were transmitted in the sequence shown in Fig. 2. During the first 10 hours of the balloon flights, and for a 12-hour period extending from about 22 to 34 hours into the flight, there were three consecutive TM transmissions and one KI transmission every 2 hours. During the periods extending from 10 to 22 hours and from 34 hours until the end of the mission, the number of transmissions was reduced to one TM and one KI each 2 hours to conserve battery life (*3*).

The carrier signal frequency of 1.6679 GHz was suppressed by 3 db during data telemetry, which took place on 254-Hz sidebands on either side of the carrier. During the KI mode of transmission, tones at 3.25 MHz on either side of the carrier were transmitted for 330 seconds along with a 20-db suppressed carrier. For both transmission modes, simultaneous reception of similar carrier or tone signals from the flyby spacecraft enabled error sources common to both balloon and flyby signals to be eliminated.

The radiated power of the transmitter was about 4.5 W, although the effective radiated power varied from 2 to 4.5 W because of the changing position of Earth in the balloon's antenna pattern, which was aligned with the balloon-gondola axis. The balloon was transparent to the radio-wave transmissions. Short-term stability of the onboard ultrastable oscillator ($\Delta f/f$) was about 5×10^{-11}, allowing coherent integration periods of several seconds. The 15° half-angle conical antenna transmitted left-circularly polarized radiation, and the antenna gain, including all losses, was approximately 0.5 at 80° from its conical axis and 1.1 on-axis.

The power supply, carried in the lower

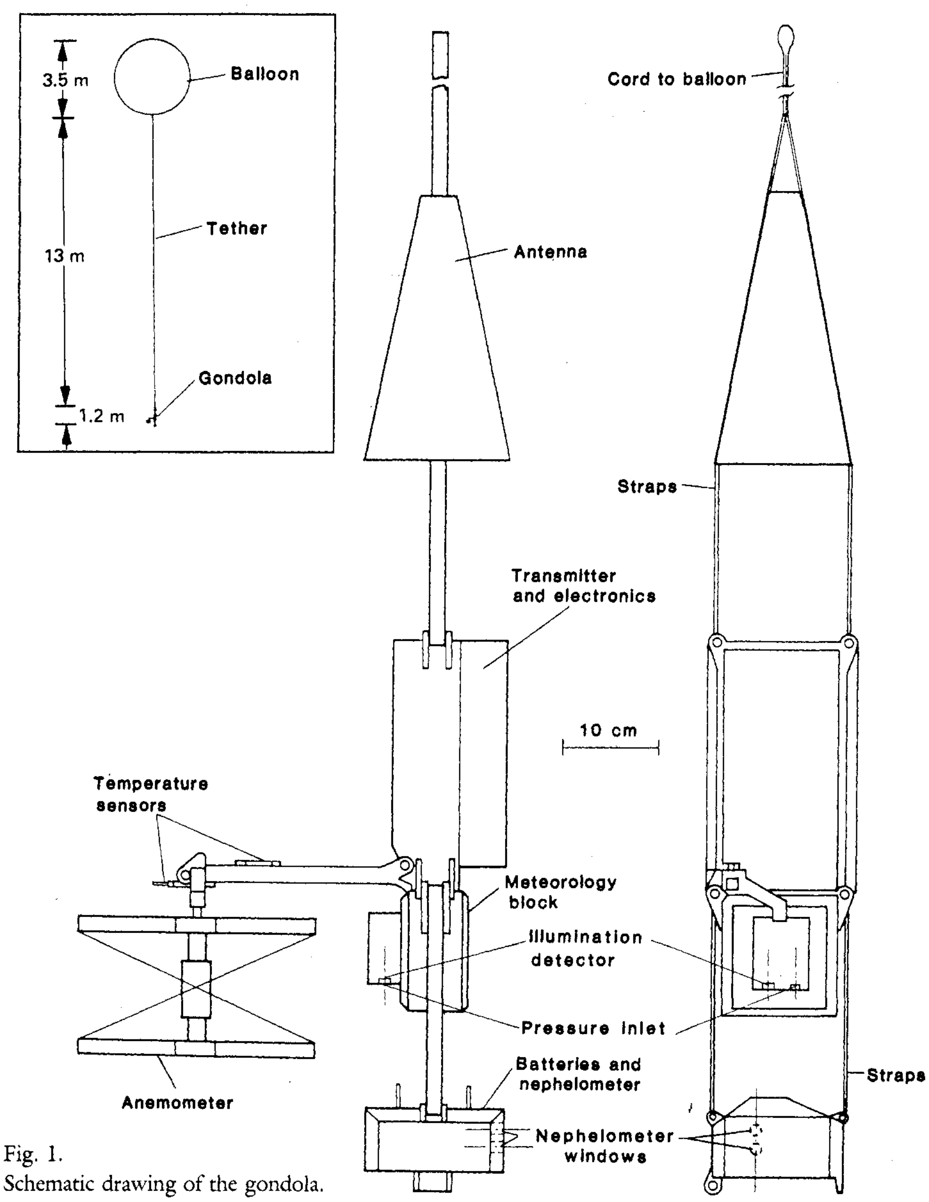

Fig. 1.
Schematic drawing of the gondola.

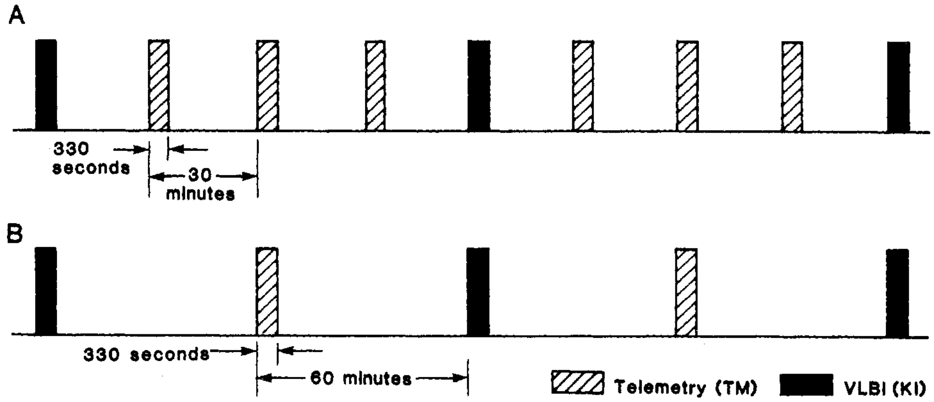

Fig. 2. Telemetry and VLBI modulation sequences. (A) Zero to 12 hours and 24 to 36 hours (no transmission 0 to 2 hours); (B) 12 to 24 hours.

section of the gondola, consisted of lithium batteries weighing a total of 1 kg with a capacity of 250 W-hours. Expected battery lifetime as judged from tests was 46 to 52 hours.

The pressure sensor, mounted in the center section of the gondola, sampled the ambient atmosphere through a port. The sensor consisted of a vibrating quartz beam whose oscillating frequency was a function of the mechanical stress imposed by the ambient pressure and was therefore a measure of the pressure. Absolute accuracy was about 0.25 mbar, and the resolution was about 0.13 mbar over a dynamical range of 0 to 1.5 bars. Temperature dependence, although small, was taken into account in interpreting the data. Drift was negligible, and the response time of the sensor and readout system to a step change in pressure was less than 2 seconds (the counter accumulation period). The frequency output of the sensor was measured, and the difference between the measured frequency and a standard offset frequency was recorded every 75 seconds.

Two temperature sensors were mounted on a deployable carbon-fiber boom extending horizontally from the gondola (Fig. 1). One was mounted on the end of the boom about 25 cm from the middle section of the gondola and the other about 12 cm from that section. The sensors were thin-metal-film resistance thermometers in the form of a raster laid down on a flexible dielectric substrate of polyamide (0.7 by 0.7 cm; 50 μm thick). The sensitive element was protected by a dielectric (1 μm thick) covering its exposed side. The resistance, about 35 ohms, was monitored with a bridge circuit and recorded every 75 seconds to 12-bit accuracy. Calibration indicated absolute accuracies of 0.5 K and resolution of 0.1 K over a range of 263 to 353 K. (Dynamic response times to a step change in temperature were a few seconds for airflow at velocities of 1 m sec^{-1}.)

Pressure and temperature were measured with 12-bit accuracy, but the most significant 6 bits (MSB's) were reported only three times during a 30-minute measurement period to conserve available bit rates. Only the least significant 6 bits (LSB's) were reported the remaining 21 times during this period. LSB's and MSB's were never reported simultaneously. When the pressure or temperature was changing rapidly, this scheme sometimes produced ambiguities in the choice of the appropriate MSB's for given LSB's. In practice, these ambiguities could usually be resolved by comparing the temporal behavior of pressure with that of temperature.

A specially developed anemometer was used to measure atmospheric flow relative to the axis of the gondola (nominally vertical). It consisted of a deployable propeller mounted on and hanging below the 24-cm deployed carbon-fiber boom (Fig. 1). It was packaged to erect itself on deployment of the boom. The device, consisting of four plastic spiral blades, each composed of a Mylar-polyethylene-Mylar sandwich and with a pitch of 90°, was mounted vertically between two arms about 15.5 cm apart. The diameter of the rotating anemometer was 25 cm. The rotor was mounted on ball bearings, and rotation was monitored by a coded disk and two sets of light-emitting diode (LED) light sources and solid-state detectors. The maximum air velocity necessary to start rotation was 0.25 m sec^{-1}. Two revolutions were required to advance the 6-bit counter (always reading in the range 0 to 64) by one count in the data format, and the count value registered was transmitted every 75 seconds. Rotation could be either positive or negative, depending on whether the relative wind direction was upward or downward. There was therefore an ambiguity in that the same final count value could be reached by either positive or negative rotation, when counter rollovers occurred. Additional ambiguity was introduced by high vertical wind velocities, which caused multiple rollovers of the counter (64 counts ≅ 1.4 m sec^{-1}). These ambiguities could be resolved in most cases by following the time history of the anemometer or by considering the balloon dynamics and data from other sensors (*4*). The stopping time for the rotor was several seconds. Sensitivity to crosswinds (horizontal winds) was negligible.

The light sensor used for both the ambient illumination and lightning experiments was a silicon PIN diode mounted in the bottom of the small container extending to one side of the middle gondola unit. This sensor looked downward with a field of view of ±60°. The battery and nephelometer box was directly in the field of view of this detector, but because of the wide field of view the detector also could see around the box. The detector was sensitive to radiation over a spectral range from about 400 to 1100 nm. The output was preamplified and then, for the illumination experiment, logarithmically amplified to provide a dynamic range of about seven decades. Although a 12-bit analog-to-digital converter was used to digitize the output of the amplifier, only the last six LSB's were transmitted twice during every 30-minute telemetry period. The electronics for the lightning experiment processed the signal from the preamplifier by counting the number of times the detector output exceeded the threshold of three discriminators, each set at roughly three times the level of the next lowest level. The number of events counted by the lowest level discriminator was registered on a 4-bit counter, whereas the two upper levels each registered in only a 1-bit counter. Thus, the entire lightning experiment record was reported in a 6-bit word at 10-minute intervals. Only the changes in this word from reading to reading were significant because the registers for these data were not reset.

The nephelometer was a simple backscatter device, similar in principle to those flown on the Pioneer Venus and Venera missions (*5, 6*). It consisted of a pulsed gallium-arsenide LED light source emitting radiation at about 930 nm, a silicon PIN diode and solar-light rejection filter-detector package, appropriate field-defining transmission and reception path optics, and appropriate electronics to process the signals and to provide proper timing, pulsing, and power regulation. A thermistor was included in each package to monitor the internal nephelometer temperature, and a special circuit was included to measure the position of the instrument baseline, since the instrument was to be deployed in a region of appreciable signal stimulus. Calibration and environmental tests indicated that the absolute accuracy 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.

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7. This research was supported in part by NASA Ames Research Center and the Jet Propulsion Laboratory.

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Overview of VEGA Venus Balloon in Situ Meteorological Measurements

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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

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