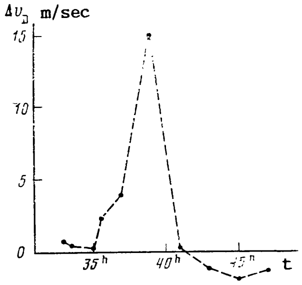

FIG. 2. Residual of measured relative to computed Doppler velocity during the anomaly observed as the Vega 2 balloon overflew Aphrodite Terra. Abscissa, elapsed time after 1985 June $15^{d}00^{h}$ UT.

contributing error to the measured balloon positions and velocities. We generally anticipate rms uncertainties of about 15 km in the coordinates and 1 m/sec in the velocities. The main factor limiting the accuracy of the transverse-velocity determinations is the interplanetary plasma, a highly variable error source, difficult to assess. From spacecraft tracking data and quasar radio interferometry as well as theoretical arguments we expect the average uncertainty in velocity to be ≈ 0.6 m/sec.

The data reduced thus far consist chiefly of the Doppler measurements at the five "main" tracking stations. Within intervals of overlap the measurements with the different antennas agree to better than 1 Hz. In a model of pure zonal atmospheric motion these preliminary results indicate an average wind velocity of 69 $\pm$.1 m/sec for the Vega 1 balloon and 66 $\pm$1 m/sec for Vega 2. Provisional balloon trajectories have also been determined, and some material has been obtained bearing on the small-scale turbulence in the Venus atmosphere. Further details are given in two accompanying letters[5,6] and in our report in the special issue of Science.[7]

Doppler data based on the signals recorded with the international radio telescope network have yielded the profile plotted in Fig. 2, which depicts a major "anomaly" encountered along the Vega 2 balloon path.

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Meteorological data along the *Vega 1, 2* float paths

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The *Vega* balloons transmitted *in situ* measurements of pressure, temperature, vertical wind velocity relative to the balloon craft, cloud-particle backscatter coefficient, and ambient light level in the Venus middle cloud layer. Doppler tracking has yielded estimates for the velocities of atmospheric motion.

During their flight through the Venus atmosphere the Vega 1 and Vega 2 balloon craft measured the pressure and temperature of the ambient medium, the vertical wind-velocity component (relative to the gondola), the cloud-layer backscatter coefficient, the mean illumination level, and the number and time of possible lightning flashes. In addition, the ground radio telescope network measurd the balloon positions and drift velocities by the differential VLBI technique; these data are now being processed.

The zonal component of the wind velocity has been derived from the Doppler shift of the balloon radio-signal frequency. All parameters were measured during the 46-h operational flight of each balloon as it drifted westward with the wind, nearly parallel to the Venus equator. The local time of the

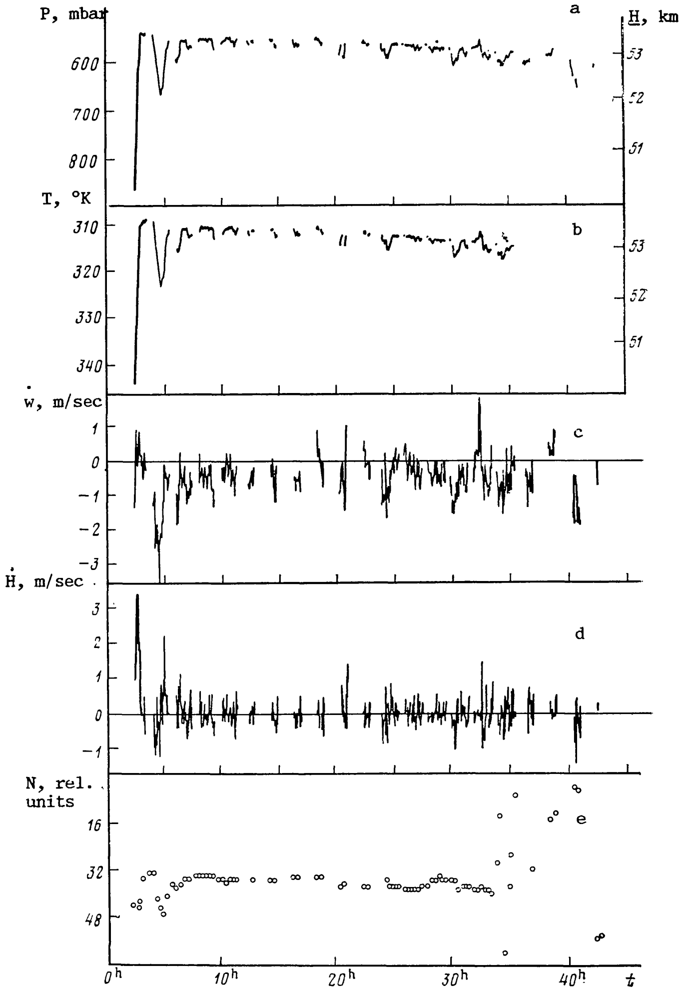

FIG. 1. Vega 1 balloon meteorological measurements; a) pressure; b) temperature; c) vertical wind velocity; d) vertical velocity of balloon; e) illumination sensor readings. Time zero is 1985 June 11^d00^h UT.

balloon insertion points was close to midnight; the active mission concluded on the dayside hemisphere 30°-35° beyond the morning terminator.

Figures 1, 2 chart the time profiles of the ambient parameters measured aboard the gondolas over the full course of the two balloon flights. These time lines include successive periods of measurement and telemetry to earth. The data transmitted by each balloon over its 46-h life were collected during 90-min or 30-min intervals distributed along the trajectory; the cumulative measurement time was 22^h30^m.

From comparison of curves a and b in each figure, it is clear that the pressure and temperature fluctuations are strongly correlated. Evidently these variations reflect the vertical motions of the balloons, but the strong correlation also suggests that the balloons and their gondolas did not contaminate the temperature measurements. The minimum temperature and pressure variations compatible with these correlations (δT = 0.1°K, δP = 0.1 mbar) argue for a high level of sensitivity and stability in the sensors and the electronics.

After their ballast was jettisoned the two balloon craft rapidly rose from their deployment height of ≈ 50 km (P ≈ 900 mbar) to their mean float ceiling of ≈ 53 km (535 mbar). At this stage, according to preflight estimates, the overpressure in the balloon skin was ≈28 mbar. Overpressure was retained throughout the active flight of the Vega 1 balloon and for the first 32^h of Vega 2. Their float heights diminished gradually from the ≈ 535-mbar level to ≈ 620 mbar by the end of the second day of drift, as the helium slowly leaked out. The initial mass of helium in each balloon and the helium loss rate have been derived from the telemetry data by using measurements obtained when the vertical component of the relative wind velocity was zero (that is, below the anemometer sensitivity threshold). During flight each balloon lost less than 0.5% of its original 2.1 kg of helium. As this value is approximately the nominal loss indicated by preflight tests of the rate of helium diffusion through the balloon skin, we rule out any appreciable leakage due to microcracks in the fabric.

Both balloons exhibited a great many excursions from their equilibrium float height due to vertical motions in the atmosphere. The fluctuations in the float height are shown by curves d in Figs. 1, 2; the corresponding vertical atmospheric velocities by curves c. These vertical motions have a substantially higher amplitude and velocity than expected. Vega 1 executed large vertical movements repeatedly during its life, the largest excursion occurring in the first few hours of flight. The Vega 2 balloon, on the other hand, floated very calmly for the first 20^h; the

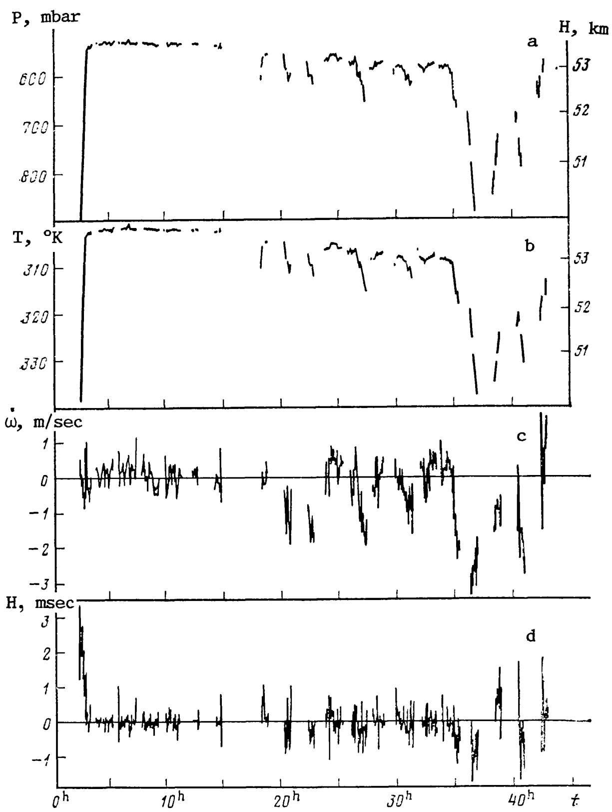

FIG. 2. Vega 2 balloon meteorological measurements. Parameters a-d as in Fig. 1. Time zero is 1985 June $15^{d}00^{h}$ UT.

amplitude of its vertical motions was ≈ 100 m. Then its behavior changed, coming to resemble that of Vega Vega 1. Near the morning terminator, 34^{h} after deployment, Vega 2 several times plummeted deeply to about the 900-mbar level. Calculations based partly on preflight measurements indicate that during these downdrafts the overpressure in the balloon dropped to zero below the 650-mbar level. Nevertheless, according to the final period of telemetry received by the ground stations Vega 2 subsequently recovered its equilibrium float altitude.

This loss of overpressure in the balloon during strong downdrafts would have significantly altered the balloon's response to vertical gusts. So long as overpressure persists, the amplitude of the vertical excursions from the equilibrium float height should be proportional to the vertical wind-velocity component (for long-term disturbances). As overpressure is lost the balloon will approach the boundary of the stable float zone, and the amplitude of the vertical displacements will increase sharply. This effect is readily apparent from comparison of curves a and c in Fig. 2. To lower the float altidude by an amount corresponding to a 100-mbar change in pressure requires a 3-m/sec vertical wind; in a 4-m/sec vertical flow the drop in height corresponds to a pressure differential three times larger.

The quantity measured in situ in each gondola was the vertical component of the relative wind velocity. In order to obtain the vertical component of the atmospheric wind velocity a correction was applied for the balloon's own motion as indicated by the pressure data. Prior to the Vega flights strong vertical winds were not envisaged, so the anemometer telemetry was encoded with an ambiguity[1] repeating every 1.35 m/sec. This ambiguity was resolved by appeal to a mode for the balloon motion.

Curve e in Fig. 1 plots the output of the light sensor on Vega 1; the parallel data for the Vega 2 balloon have not yet been analyzed. The illumination sensor was designed to record the variations in the external 4000-11,000 Å radiation flux as a measure of cloud-layer inhomogeneities, thereby establishing the time when the morning terminator was crossed and the length of the dawn period. This same detector served to register any fast changes in the light level.

The points on curve 1e express the ambient illumination along the Vega 1 balloon path in telemetry units. An increase in the telemetry number corresponds to a decline in the exterior radiation flux. When the balloon was drifting on the planet's nightside, several cases were recorded of a rise in the light level. Slight fluctuations amounting to one or two units are being ignored for the time being, as they are comparable with the sensor and electronics noise. Certain nightside flux variations correlate with major changes in temperature and pressure. These effects are well above the instrumental errors (one or two telemetry units) throughout the ambient temperature range. They might reflect some modification of the attenuation coefficient for the ≈ 10,000 Å thermal-emission tail of the planetary-surface, or changes in the coefficient for scattering of this infrared radiation by the cloud deck below.

According to the Doppler tracking of the zonal wind flow, sunlight was first recorded by Vega 1 about 3^{h} (earth time), or $7^{\circ}.5$, before it crossed the morning terminator. Once the balloon reached the dayside, the light level rose very steeply. Since the telemetry supplied only the six least significant bits of the twelve in the sensor signal, curve 1e shows abrupt jumps after dawn, as changes occurred in the nontransmitted most significant bits.

Even though the telemetry data are still being analyzed and a different interpretation of the results may seem preferable in the future, we are inclined at this time to draw the following conclusion regarding flashes of lightning: neither balloon detected any appreciable number of light flashes during the intervals for which the telemetry has thus far been processed. Altogether these intervals comprise ≈ 7^{h} of observations distributed more or less evenly over the two flight paths. Just once, on Vega 2, the light sensor recorded an event that might represent either lightning in the atmosphere or a transient (shorter than 30 min) change in the average illumination.

Both balloons carried a backscatter nephelometer for monitoring variations in the ambient cloud-layer density. Only the Vega 1 nephelometer yielded data for all the telemetry sessions. Preliminary analysis of these measurements indicates that:

1. In the middle cloud layer where the measurements were made, the overall structure is devoid of any very clear regions, although some density variations of large temporal scale were in fact encountered along the flight path. Such events correlate with decreases in the light flux and rises in temperature.

2. Cloud-layer fine structure was detected on the flight, the fluctuations amounting to about 20% of

the average backscatter level. On the whole these variations anticorrelate with the ambient temperature.

An absence of large density variations in the Venus middle cloud layer has been reported from earlier probe missions[2] and is consistent with intensive convection and zonal flow in the atmosphere, as well as with a long survival time for the cloud particles.

The decreases in the amount of coud-particle backscatter recorded on relatively long time scales might have occurred as the balloon sank into a less dense zone of clouds, as is apparent, for example, from comparison against the cloud-structure observations by various probes of the Venus atmosphere.

The authors have discussed these wind and other meteorological measurements further in two of the Science papers.[3,4]

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Thermal structure in the Venus middle cloud layer

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Thermal structure measurements obtained by the two *Vega* balloons show the Venus atmosphere in the middle cloud layer to be near-adiabatic, on the whole; but discrete air masses are present that differ slightly from one another in potential temperature and entropy. The *Vega 1* temperatures are 6.5 K warmer than measured by *Vega 2* at given pressures. Measurements taken by the *Vega 2* lander on descent through these levels agree with the *Vega 2* balloon data.

The two Vega balloons did not float calmly at their equilibrium height in the Venus atmosphere[1] but from time to time moved vertically by a few kilometers because of the sizable vertical flows that they encountered. The concomitant temperature and pressure variations contain some interesting information on the atmospheric structure between the 54- and 50-km levels, a region that dominates the middle cloud layer.[2,3] As pointed out on an earlier occasion[4] the thermal stratification is slightly unstable there, and convection presumably is taking place.

When plotted in the (P, T) plane the temperature and pressure measurement by each Vega balloon fall along a straight line; the departures in T amount to only about ±0.5°K. Although some isolated points do deviate from the prevailing line by several degrees, they are generally confined to time intervals when an ambiguity was present in the most significant bits of the temperature telemetry, which reported readings every 10 min. Thus the (P, T) data obtained by each balloon separately exhibit a strong correlation between temperature and pressure.

For equal pressures, however, the temperatures measured by the two balloon probes differ uniformly by about 6.5°K, the Vega 1 temperatures being higher. Since the balloons were deployed at points approximately symmetric relative to the equator (latitudes 7°.3 N, 6°.6 S), the offset between the two (P, T) lines is rather surprising.

Figure 1 plots the temperature and pressure measurements acquired in the 45°-180° interval of east longitude. Notice that the differential between the (P, T) data sets for the two balloons shows no appreciable longitude dependence. The cause might be an inherent feature of balloon measurements — the tendency of a balloon to move along with some particular air mass. During their flight the two Vega balloons evidently were located within air masses that had different thermal histories, with each balloon spending most of its time in the same air mass as it floated one-third of the way around Venus.

The source of this temperature differential is of great interest for the atmospheric dynamics. Waves in the atmosphere could induce an adiabatic compression, but they would account for the temperature disparity only if their wavelength were comparable with the planet's circumference; otherwise the temperature difference should vary with longitude. Another possibility is that the difference in T reflects transient variability in the atmosphere, or it might be evidence for an asymmetry between the northern and southern hemispheres.

To check on the calibration of the data sensors we have compared the P, T measurements by the Vega 2 balloon against the data returned by the Vega 2 landing capsule as it descended through the middle cloud layer. As Fig. 1 indicates, the balloon and lander data lie along the same straight