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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 $\pm 0.5°K$. 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

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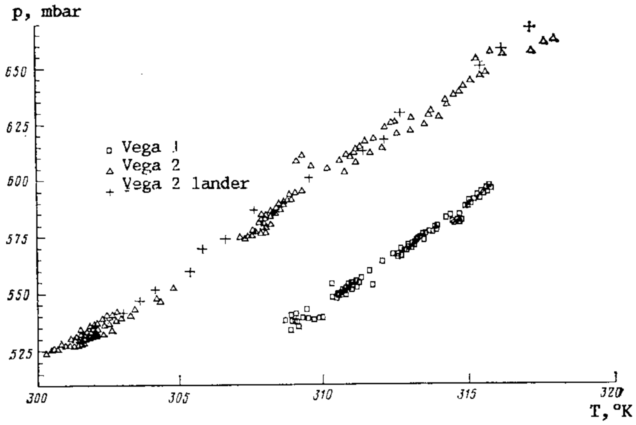

FIG. 1. Pressure and temperature measurements by the Vega 1 and Vega 2 balloons.

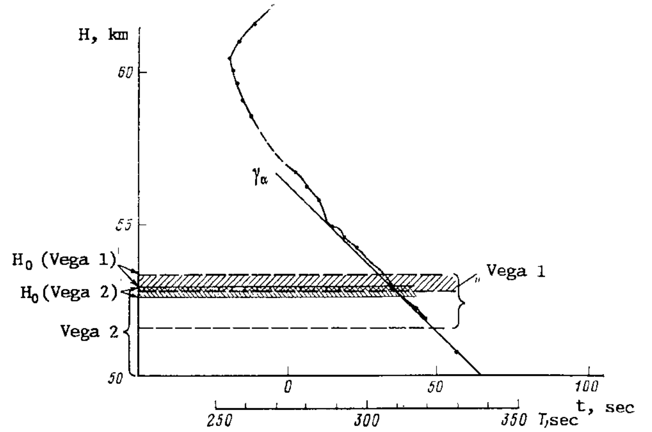

FIG. 2. Temperature profile indicated by the Vega 2 landing module, compared with the adiabat γ_a. The bands at H_0 represent the balloon equilibrium float heights.

line; the deviations are less than 0.5°K. Moreover each balloon carried a second temperature sensor, mounted inside the nephelometer. On both Vega 1 and Vega 2 the temperatures measured by the two sensors are within ≈1°K of each other on the planet's night side, where the nephelometer was not overheated by solar rdiation.

Figure 2 shows the temperature profile measured by the Vega 2 lander down to the 50-km level. The float heights of both balloons are specified as well. Heights along the Vega 2 lander curve have been computed from the P, T measurements by that vehicle. We see that below 55 km the lander (P, T) relation is nearly adiabatic.

The temperatures measured by the Pioneer Venus Large Probe[4] lie in between the values obtained by the two balloons for corresponding pressures. The derivatives dT/dP determined from the balloon data and from the Large Probe, which descended through the atmosphere at latitude 4°.4 N, have nearly equal values. In hydrostatic equilibrium, $dT/dz = -\rho g \cdot dT/dP$, so the vertical temperature gradients also are about the same.

Although the mean temperature lapse rate can be calculated from the whole data set for each balloon, it is best determined for separate measurement periods. To illustrate, Fig. 3a plots the (T, P) data for Vega 2 frame B39, taken at a time of fast ($w_d = 2.5 \pm 0.5$ m/sec) downflow during which the balloon droped by 0.57 km. The variation in measured T with P is essentially linear. Also plotted here is the adiabat corresponding to an entropy S = 26.45R (R is the gas constant). Clearly the atmosphere is practically adiabatic in this instance. (The slight departure of the points from the adiabat in this frame might be a regular effect, indicating a mildly stable stratification of about 0.3 °K/km.) The adiabat shown in Fig. 3a serves as a reference line in the other panels of this figure.

Figure 3b presents analogous data for frame B55, taken just after the terminator was crossed. Again the points follow an adiabat, but it is offset from the reference line by 0.6°K. Actually the data from this frame conform to two different adiabats, spaced 0.24°K apart. The measured points migrate from one adiabat to the other, a behavior not attributable to erroneous decoding of the telemetry (the ambiguity in the high-order bits). Most likely the measurements are evidence for a new air mass participating in the downward motion dring this frame, with a vertical velocity w_d = 2-4 m/sec.

One interpretation of the offset between the adiabats in Fig. 3b could be that when air is flowing downward over the balloon from above, the sensors might find themselves either in a new air parcel, in an old one entrained by the downflow, or in a mixture of new and old air masses. Thus the measured temperature might take values in the temperature range covered by these air parcels. During this telemetry period the downflow persisted for more than 30 min, and the air mass could have descended from a level several kilometers above the balloon.

Similar (P, T) comparisons are shown in Figs. 3c, d for two other periods when the Vega 2 balloon encountered smaller vertical velocities. The balloon spent most of frame B3 floating at nearly constant height (at any rate the vertical shift was no more than 100 m, the pressure varying between 534 and

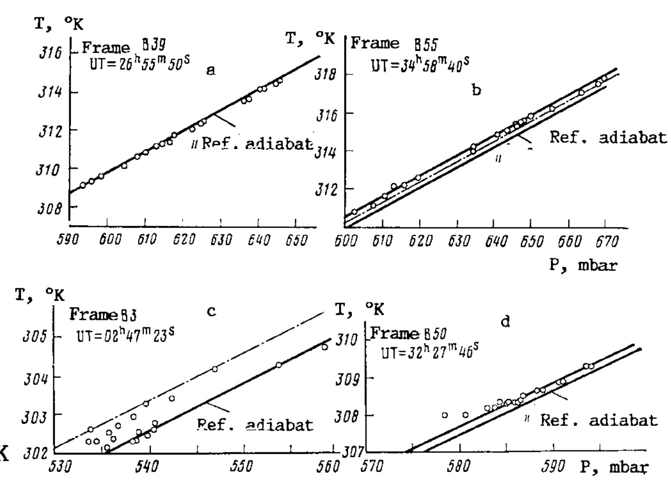

FIG. 3. Thermal structure of the Venus middle cloud layer according to measurements by the Vega 2 balloon during four brief telemetry intervals. The lines represent different adiabats, as explained in the text.

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542 mbar); the vertical atmospheric velocity ranged from +0.5 to −0.8 m/sec. Nevertheless the measured temperatures are distributed between a pair of adiabats 0.6 °K apart, migrating between them four times, in 20 min. For a vertical atmospheric velocity $w_a \approx$ 0.5 m/sec, this 5-min time scale would correspond to a vertical scale of ≈150 m for the various air parcels).

Throughout frame B50, except for the last few points (T = 308.0 °K), the data lie between two adiabats separated by 0.2 °K. In this instance the vertical wind velocity was −0.5±0.5 m/sec.

We conclude by summarizing the main results from our preliminary analysis of the Vega balloon data bearing on the thermal structure of the middle cloud layer on Venus[5]: 1) during vertical excursions of each balloon, temperature correlates strongly with pressure; 2) Vega 1 and Vega 2 were immersed in air masses differing systematically by 6.5 °K (at given pressure) throughout the longitude range 180°-70° E; 3) in the middle cloud layer the atmosphere is nearly adiabatic, confirming earlier probe soundings; 4) the slight deviations from a uniform adiabat suggest the presence of discrete, small-scale air parcels.

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Mean zonal winds on Venus from Doppler tracking of the *Vega* balloons

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Doppler measurements of the two balloons yield provisional estimates for the mean zonal wind velocity at the 53–54 km level in the Venus atmosphere: 69 ± 1 m/sec for *Vega 1* and 66 ± 1 m/sec for *Vega 2*, with westward flow. The wind data show a perturbation which might be evidence for solar tides.

That strong winds might exist in the upper cloud layer of the Venus atmosphere was first suggested by ultraviolet photography from the earth.[1] Subsequent Doppler tracking of the Venera probes,[2,3] followed by similar measurements of the Pioneer Venus probes,[4] showed that from the 65-km level down to heights of about 10 km the Venus atmosphere is caught up in a strong zonal flow moving in the same sense that the planet is rotating. This phenomenon has not yet been adequately explained, nor has it been studied phenomenologically.

Fundamentally new information on the diurnal–longitudinal variations in wind velocity can be acquired by sounding the Venus atmosphere with balloons. The wind velocity can be determined from measurements of the trajectory of a balloon comoving with the wind. We will have a complete three-dimensional picture of how the Vega balloons moved, as soon as the signals recorded by the global VLBI network of 20 radio telescopes[5,6] have been suitably processed. To arrive at a provisional assessment of the mean zonal circulation as well as the small-scale turbulence, we have utilized Doppler measurements of the balloon signal frequency, carried out and interpreted in much the same way as on the Venera 4 to Venera 8 missions.[7]

Each Vega balloon transmitted a signal whose frequency was generated by a thermostatically controlled quartz master oscillator. The departure of the reception frequency f_3 from its nominal value f_0 is the sum of two terms: the Doppler shift f_D, which is proportional to the line-of-sight projection of the balloon velocity relative to the reception point, and the running deviation $\Delta f_1(t)$ of the oscillator frequency from the nominal frequency. In determining the balloon velocity from the measured frequencies

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