Conceivably the 30-130 sec velocity fluctuations may represent the evolution of small convection cells, while the 30-90 min alternation of calm and turbulent zones may be associated with large cells. The travel speed of the windblown balloons was ≈70 m/sec, so in 60 sec (the average time scale of the turbulence) they covered ≈ 4 km, and in 330 sec (the length of a telemetry period) about 20 km. Between successive telemetry frames the balloons moved 130-250 km. Presumably the convection cells would have been treaveling somewhat more slowly than the mean zonal flow, at velocities a few meters per second below the average wind speed. In this event the 60-sec velocity fluctuations would correspond to cells several hundred meters across, and the 30-60 min variations to big cells measuring tens of kilometers in diameter. Interestingly, cells of this size were in fact observed at the top of cloud deck in the ultraviolet photographs [10] taken by Mariner 10, and they lasted several tens of minutes, similar to the lifetime indicated by the Vega Doppler tracking.

Both balloons were floating near the 54-km level, right between the presumed turbulent layers at 49 and 60 km which, according to Woo and Armstrong,[4] cause the fluctuations in radio-signal amplitude observed in radio sounding experiments. The balloon data confirm the findings from the Venera missions that the middle cloud layer is strongly turbulent as well, but with a more uniform turbulence distribution. The reason for this seeming discrepancy, as suggested previously,[2] might be that the radio amplitude fluctuations exhibit the effects of temperature pulsations, which in turn could stem from wind-speed pulsations that would disturb balloons floating in the atmosphere.

[1] V. V. Kerzhanovich, B. N. Andreev, and V. M. Gotlib, Dokl. Akad. Nauk SSSR 194, 288 (1970) [Sov. Phys. Dokl. 15, 797 (1971)].

[2] V. V. Kerzhanovich and M. Marov, iin: Venus, ed. D. M. Hunten et al., Univ. Arizona Press (1983), p. 766.

[3] A. S. Gurvich, Izv. Akad. Nauk SSSR Fiz. Atmos. Okeana 5, 1172 (1969) [Izv. Acad. Sci. USSR Atmos. Oceanic Phys. 5, 675 (1970)].

[4] R. Woo and J. W. Armstrong, J. Geophys. Res. 85, 8031 (1980) [in: Pioneer Venus, Am. Geophys. Union, Washington].

[5] T. S. Timofeeva, A. I. Efimov, and O. I. Yakovlev, Kosm. Issled. 18, 775 (1980) [Cosmic Res. 18, 563 (1981)].

[6] B. C. Murray, M. J. S. Belton, G. R. Danielson, et al., Science 183, 1307 (No. 4131) (1974).

[7] I. R. Scoggins, J. Appl. Meteorol. 4, 139 (1965).

[8] V. M. Linkin, J. E. Blamont, A. N. Lipatov, et al., Pis'ma Astron. Zh. 12, 36 (1986) [Sov. Astron. Lett. 12, 15 (1986)].

[9] V. M. Linkin, V. V. Kerzhanovich, A. N. Lipatov, et al., Science 231, 1420 (No. 4744) (March 1986).

[10] M. J. S. Belton, G. R. Smith, D. A. Elliott, K. Klaasen, and G. E. Danielson, J. Atmos. Sci. 33, 1383 (1976).

Implications of preliminary *Vega* balloon results for the Venus atmosphere dynamics

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The typical 1–2 m/sec vertical winds encountered by the *Vega* balloons probably result from thermal convection. The consistent 6.5-kelvin differential between the *Vega 1* and *Vega 2* temperatures is attributable to disturbances of synoptic or planetary scale. According to the Doppler tracking the winds were stronger than on earlier missions, perhaps because of solar thermal tides. The motions of *Vega 2* may have been affected by waves from mountainous terrain.

The Vega balloon experiment was designed to investigate certain characteristics of the Venus atmosphere at the float height, including the horizontal and vertical winds as well as the structure and properties of the cloud layer, with a goal of learning more about the dynamical processes at work there. In this letter we offer a provisional interpretation of the balloon measurements. Since the data are still being reduced, our comments are subject to future modification and supplement. In fact some of the experimental results, such as the VLBI trajectory determinations, are not yet available.

The vertical transport of momentum and heat is one of the principal factors controlling the general atmospheric circulation, so the Vega balloon vertical-wind measurements are of much interest. Among the most notable features of the data processed thus far is the high value of the vertical wind speed w, encountered not only on the day side but on the night side of the planet. The w values typically exceed 0.5 m/sec, and the peak vertical velocities reach 4-5 m/sec. Since the vertical-wind data contain a telemetry ambiguity, [1] the peak amplitudes might be smaller than we have reported,[2] but the mean amplitudes would not be affected.

Presumably the occurrence of substantial vertical

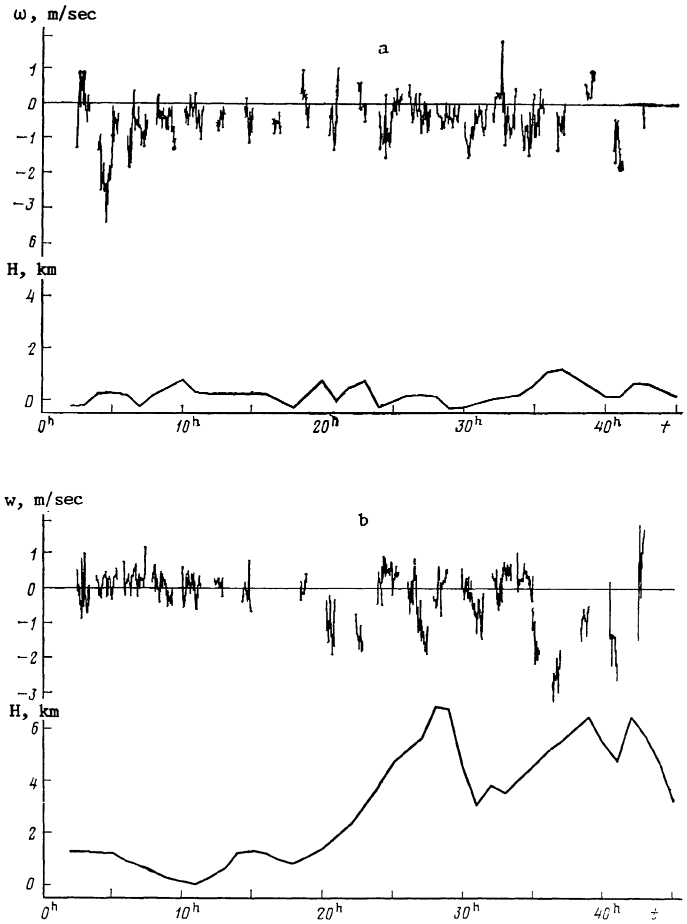

FIG. 1. Comparison of the vertical winds encountered by (a) the Vega 1 balloon and (b) Vega 2 against the Pioneer Venus radar profiles of the terrain along the balloon trajectories.

gusts in a region with little static stability [3,4] located within the middle cloud layer [5,6] will seriously affect the cloud physics and the atmospheric circulation. Large vertical movements might also influence such microphysical properties as the size distribution of the cloud particles and the charge separation. Intensive momentum and heat exchange in a neutrally stable region (low static stability) would probably produce significant local effects in the wind field. For example, the Venera[7] and Pioneer Venus[8] probes measured a near-zero vertical shear in the zonal wind velocity here — almost surely a consequence of intensive mixing in this region. Convective motions could generate atmospheric waves that penetrate surrounding regions where the static stability is relatively high. Such waves might affect the momentum distribution at levels well away from the convective region itself.

The average observed vertical winds w are generally consistent with the convective motions estimated from mixing-length theory[9]:

$$|w| \sim \left(\frac{Fgl}{4\rho c_p T}\right)^{1/3} \approx 2 \text{ m/sec}$$

where the convective heat flux F is taken to be 40 W/m^2, the global average solar radiation flux at the 54-km level; g is the gravitational acceleration, C_p is the specific heat at constant pressure, ρ is the atmospheric density at the balloon float height, T is the the corresponding temperature, and ℓ is the mixing length.

The rationale for this choice of F is as follows. The energy which the convective motions transport upward through the convection zone originates with the infrared radiation of the lower atmosphere. We have assumed that essentially all the upward infrared flux is absorbed (although the |w| value given by the mixing-length expression is insensitive to the value of F). Since the infrared flux depends on temperature, which does not undergo much horizontal variation in the Venus atmosphere, we may adopt the average solar radiation flux.

A 5-km mixing length ℓ has been chosen, about the same as the scale height; if ℓ were shortened to 1 km, the |w| estimate would change by less than a factor 2. However, the large vertical winds (3-4 m/sec amplitude) recorded by both balloons, especially on the night side, probably stem from other processes.

Mixing-length theory also gives an estimate for the the average temperature fluctuations ΔT corresponding to 2-m/sec vertical winds[9]:

$$\Delta T = 8T\frac{|w|^2}{gl} \approx 7.5\cdot 10^{-2}\,\mathrm{K}.$$

In the individual 30-min telemetry frames whose data have been analyzed to date, the temperature fluctuations have an amplitude of just this order (0.1 kelvin) in some cases, while in others T reaches 0.5-0.7 kelvin. Definite conclusions will have to await a more thorough analysis.

Doppler tracking has disclosed small-scale motions of the balloons,[10] the velocity varying by ≈1 m/sec on time scales ⩾ 60 sec. As yet we cannot be sure whether these excursions derive wholly from turbulence or whether they are inherent in the aerodynamics of steady wind flow around the balloon. But the earlier Venera-probe results show that turbulent pulsations in the wind velocity at the Vega balloon heights occur with rather high probability[7] and may reach 2-3 m/sec.

Another aspect of the vertical winds encountered by the balloons is that they are predominantly downdrafts. This behavior probably is not so much a property of the atmosphere as an artifact of the balloon sounding. From the measurements made by the Vega landers we know that the balloons floated mainly in the upper layers of the convection zone. The rapid increase in static stability above those layers acts as an "upper lid" on the convection zone, since vertical velocities will diminish as the static stability of the atmosphere becomes greater. In the upper part of the convection zone the downdraft regions will be associated with regions of horizontal-wind convergence, while updraft regions will correspond to horizontal divergence. Under these conditions the balloon will tend to prefer regions of downflow and that is just the what the sampling indicates.

Furthermore, the Vega 1 and Vega 2 balloon data show a difference in potential temperature (temperature on a constant-pressure surface) amounting to ≈6.5 kelvin over practically the whole flight periods.[4] Consequently, the two balloons spent most of their time moving in air masses having different histories. As to how this noteworthy circumstance ties in with the atmosphere dynamics, either there may be a significant asymmetry between the northern and southern hemispheres, enough to be apparent from the balloons' ≈14° separation in latitude, or the atmospheric structure may be subject to variations in time and/or longitude.

Both these mechanisms may contribute to the temperature differential observed; but the 6.5-kelvin potential-temperature offset, as we have indicated, is much larger than can be attributed to turbulent mixing in the convective layer. Most likely, then, large-scale processes are responsible. It seems improbable that an averaged hemispheric asymmetric could play any major role in maintaining so substantial a potential-temperature difference. The disturbances that apparently account for the observed differential are of synoptic or global scale. In vertical dimension these disturbances should be comparable with or greater than the convection-layer thickness, in order not to weaken too severely across the layer. In addition, to keep the potential-temperature difference between the two balloons uniform, the disturbances would have to propagate zonally at approximately the mean flow velocity.

Evidence for possible large-scale disturbances is provided by the Doppler data. From Fig. 2 of an accompanying letter,[11] which plots the departure of the Doppler velocity from the values computed for a constant wind, we see that the residuals vary comparatively smoothly from Venus midnight to dawn (in amplitude and sign) for both balloons. At the moment we cannot say whether this effect is due solely to zonal wind, to meridional wind, or to both. A definite answer should be forthcoming once the radio-interferometric determinations of the balloon trajectories are available. To judge from the behavior of the Doppler residuals the balloons probably experienced a disturbance associated with the sun or with the planet. The most probable form of stationary disturbance of planetary scale would be a solar thermal tide. Semidiurnal thermal tides have in fact been identified in the upper Venus troposphere (at the 65-km level) in measurements with the Pioneer Venus Orbiter infrared radiometer.[12]

One sign that temporal disturbances are present is the fact that the Vega balloons measured a significantly higher (6-10 m/sec) mean zonal flow velocity than did previous experiments.

An especially interesting feature of the Vega data is the differing time behavior of the vertical winds measured by the two balloons. Throughout its life the Vega 1 balloon encountered strong downdrafts. The strongest occurred near the start of the mission, when the downflow reached 3 m/sec. Vega 2 spent its first 20 h in very calm flight, staying within 100 m of its mean float height. Then the character of its vertical excursions changed and came to resemble the Vega 1 motions. Prominent downdrafts are distinctly apparent both in the temperature and pressure data[2] and in the Doppler measurements.[10]

Very large fluctuations in the Doppler residuals (corresponding to a horizontal-velocity variation of tens of meters per second) and in height, temperature, and pressure were observed in the 35^h-40^h elapsed-time interval (relative to the 00^h UT start) for the Vega 2 balloon. It is intriguing that although the superpressure in the Vega 2 balloon shell dropped to zero on descent to the 700-mbar level (thereby amplifying the craft's response to vertical winds), even prior to loss of superpressure the T, P fluctuations were at maximum amplitude. Evidently the character of the Vega 2 data variations between 35^h and 40^h UT and even earlier may reflect an influence of the surface terrain upon the atmospheric motions.

Figure 1 shows approximate cross sections of the topography overflown by each balloon (lower curves). The balloon trajectories have been estimated from the Doppler tracking[11] on the premise of pure zonal winds. The surface relief heights are based on measurements by the PVO radar altimetry. These findings, of course, have to be treated with reserve: in the first place the trajectories are still very provisional, and furthermore the real terrain could be quite different from what the altimeter indicated (the altimeter measured average elevations above a 3000-4000 km^2 surface area).

Three conclusions may be drawn from Fig. 1. First, the anomalously large variations in the parameters measured by Vega 2 definitely occurred above the mountainous terrain in Aphrodite Terra. Second, the terrain overflown by Vega 2 has much more vertical relief than that along the Vega 1 path. Finally although Vega 2 crossed the terminator at about the same time it was floating over the peaks in Aphrodite, the terminator crossing itself is unlikely to have had any special significance, because no peculiar vertical disturbances were encountered when the terminator was crossed by Vega 1.

If the topography in the Aphrodite Terra region does influence the temperature and wind fields at the balloon float height, then either of two mechanisms might be responsible. The first possibility, although an unlikely one in our opinion, is the presence of an active volcano. On this interpretation it would be rather difficult, but not out of the question, to understand how an eruption could make the balloon sink. A more plausible alternative would be mountain waves, or downwind (lee) waves. Although the appropriate calculations have not yet been done, Schubert and Walterscheid[14] have shown that for realistic static-stability and wind-speed profiles certain types of gravity waves induced by the surface relief would indeed be capable of reaching the upper Venus atmosphere. Their calculations indicate that under certain circumstances the wave amplitude could be significantly reinforced there. Further work will of course be needed before one can be confident that the topography does modulate the balloon float height.

Thus even a preliminary analysis of the Vega 1 and Vega 2 balloon measurements testifies to their uniqueness in both quantity and quality, and to their value in furthering our understanding of the Venus atmosphere dynamics.

A few additional arguments are set forth in the authors' parallel discussion published in the Vega Venus issue of Science.[15]

[1]R. S. Kremnev, A. S. Selivanov, V. M. Linkin, et al., Pis'ma Astron. Zh. 12, 19 (1986) [Sov. Astron. Lett. 12, 7 (1986)].
[2]R. Z. Sagdeev, V. M. Linkin, J. E. Blamont, et al., Pis'ma Astron. Zh. 12, 30 (1986) [Sov. Astron. Lett. 12, 12 (1986)].
[3]A. Seiff, D. B. Kirk, R. E. Young, et al., J. Geophys. Res. 85, 7903 (1980) [in: Pioneer Venus, Am. Geophys. Union, Washington].
[4]V. M. Linkin. J. E. Blamont, A. N. Lipatov, et al., Pis'ma Astron. Zh. 12, 36 (1986) [Sov. Astro. Lett. 12, 15 (1986)].
[5]M. Ya. Marov, E. N. Lystsev, V. N. Lebedev, N. L. Lukashevich, and V. P. Shari, Icarus 44, 608 (1980).
[6]R. Knollenberg, L. Travis, M. Tomasko, et al., J. Geophys. Res. 85, 8059 (1980).
[7]V. V. Kerzhanovich and M. Ya. Marov, in: Venus, ed. D. M. Hunten, et al., Univ. Arizona Press (1983), p. 766.
[8]C. C. Counselman, S. A. Gourevitch, R. W. King, G. B. Loriot, and E. S. Ginsberg, J. Geophys. Res. 85, 8026 (1980).
[9]J. Cox and R. Giuli, Principles of Stellar Structure 1, Gordon and Breach (1968).
[10]V. V. Kerzhanovich, Yu. N. Aleksandrov, R. A. Andreev, et al., Pis'ma Astron. Zh. 12, 46 (1986) [Sov. Astron. Lett. 12, 20 (1986)].
[11]R. A. Andreev, V. I. Altunin, N. A. Armand, et al., Pis'ma Astron. Zh. 12, 41 (1986) [Sov. Astron. Lett. 12, 17 (1986)].
[12]J. T. Schofield and F. W. Taylor, Quart. J. Roy Meteorol. Soc. 109, 57 (1983).
[13]H. Masursky, E. Eliason, P. G. Ford, et al., J. Geophys. Res. 85, 8232 (1980).
[14]G. Schubert and R. L. Walterscheid, J. Atmos. Sci. 41, 1202 (1984).
[15]J. E. Blamont, R. E. Young, A. Seiff, et al., Science 231, 1422 (No. 4744) (March 1986).

The Soviet 18-cm wavelength VLBI network

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The five antennas comprising the Soviet radio interferometer network provide baselines ranging from 100 to 7000 km. Each is equipped with a hydrogen frequency standard, low-noise amplifier, and a recording system of 2-MHz bandwidth. Now functioning mainly at $\lambda \approx 18$ cm but soon to be extended to to 1.35 cm, the network is designed both for astrophysical observations and for astronautical and geodetic purposes.

1. INTRODUCTION

Very long baseline radio interferometry (VLBI) is one of the most valuable tools available to radio astronomy today. Advances in VLBI techniques have yielded fine-resolution images of quasars and radiogalaxy nuclei; extended stellar envelopes have been studied, as have the birthplaces of stars and planetary systems. The method is finding wide application, for example, to astrometry, space navigation, and geodynamics. In fact modern interferometers whose antennas record signals independently can achieve a remarkably sharp angular resolving power — a few tens of arc microseconds, or several orders finer than the resolution of the best optical telescopes.

At present VLBI networks are successfuly operating that encompass practically all the world's larger radio telescopes, thereby forming a unique global instrument. Among the component antennas is the RT-22 of the Crimean Astrophysical Observatory near Simeiz. For several years a 1.35-cm wavelength interferometer consisting of two 22-m antennas and one of 70-m aperture has been giving satisfactory service within the Soviet Union.[1] With the aim of further developing VLBI activities in our country, several other radio telescopes, includ-

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