Dust in the Lower Atmosphere of Venus

Abstract. *Terminal velocities of dust particles have been calculated for two model atmospheres of Venus; data are derived from measurements of Mariner V and Venera 4. The vertical wind velocities required to maintain dust aloft in the lower atmosphere of Venus are less than one-half the magnitude of those needed on Earth. Since the lower atmosphere of Venus appears to be hot, dry, and strongly convective, it probably contains much more dust than that of Earth.*

The composition of the lower atmosphere of Venus is of great importance in the determination of surface conditions. One of the most important problems associated with the atmosphere of Venus is the exact nature of its particulate medium. This medium could be of fundamental importance in the relation between the radiative and dynamic properties of the atmosphere. One way to better understand the possible generation, persistence, range of particle size, and other properties of dust clouds on Venus is to determine the falling rates of dust (particles) in its atmosphere. I here report calculations of the terminal velocities of spherical particles (density 3.0 g/cm^3), 1 to 10,000 μ in diameter, for two nightside model atmospheres of Venus from 0 to 25 km; data are derived from measurements of Mariner V and Venera 4.

Dust is present in the atmosphere of Earth. Inasmuch as the lower atmosphere of Venus seems to be dry and strongly convective (*1*, *2*), it would appear to favor the presence of a greater amount of dust (*3*). One way to establish the degree to which dust may exist in the lower atmosphere of Venus is to compare the magnitude of the vertical winds required to maintain a dust particle of a given size aloft in the atmospheres of Earth and Venus. The relative magnitudes of the vertical winds can be estimated from calculations of the terminal velocities of particles falling in the respective atmospheres. The equations used (*4*) are based on a least-squares fit to experimental data covering a wide range of Reynolds numbers for spheres. The computational scheme used to calculate the rates of falling particles for Venus has been used for dust clouds on Mars (*5*). Terminal velocities can be calculated for a spherical particle of a given density and diameter if the density and temperature of the atmosphere are known as a function of altitude. Table 1 gives values of the pressure, temperature, and density for the two model atmospheres, at intervals of 5 km from the surface out to 25 km, for the nightside of Venus. The Soviets state that the data from Venera 4, Mariner V, radio astonomy, and radar cross sections are all in good agreement if the radius of the planet is taken to be approximately 6080 km (*6*, *7*). However, data from Venera 4, which reports a surface pressure of 18.5 kg/cm^2 (17.9 atm) (*6*), conflict with measurements from Mariner V if these are coupled with the radar determination of the radius of Venus (*8*). If systematic errors in the radar measurements are ruled out, this difference can still be accounted for, at least in part, on the assumption that Venus is not perfectly spherical. Inasmuch as the discrepancy between the data of Venera 4 and Mariner V probably will not be resolved until new measurements are made, the two model atmospheres (Table 1) will be used for calculations. Both the Venera 4 and the Mariner V model assume that the surface is located 6050 km from the center of Venus. Values of Mariner V are based on a calculated nightside pressure of 92 atm and a surface temperature of 748°K, resulting from an adiabatic extrapolation of a measurement from 35 km to the surface in an atmosphere consisting of 90 percent carbon dioxide (*1*).

The only other quantities needed for the calculation of terminal velocity are the coefficient of viscosity, the mean free path, the acceleration of gravity, and the particle density. Using the values of temperature T (Table 1), one can derive the coefficient of viscosity η (in gram second^{-1} centimeter^{-1}) (*5*, Eq. 4) from the empirical equation

$$\eta = 1.011 \times 10^{-4} + 5.122\ (T-200) \times 10^{-7} \quad (1)$$

Equation 1 represents an accurate straight-line fit to data for the viscosity of CO_2 (*9*). The value of the equivalent

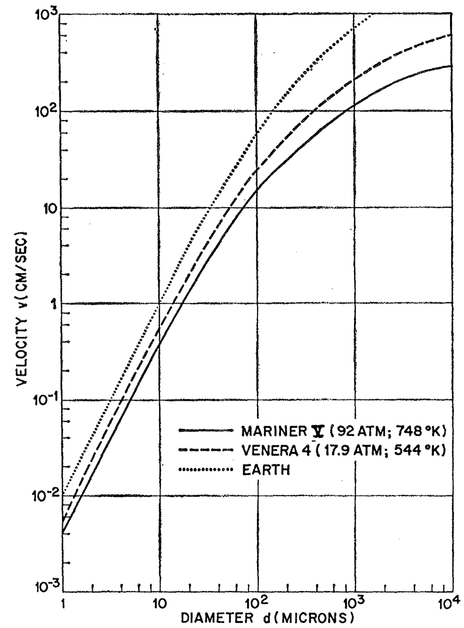

Fig. 1. Terminal velocity v plotted against particle diameter d for spherical particles (density = 3.0 g/cm^3) falling near the surface of Venus in two model atmospheres. The solid curve is calculated using data from the Mariner V night model at 0 km; the dashed curve is calculated using data from Venera 4 at 0 km; the dotted curve (*11*) represents falling rates in the lower atmosphere of Earth (1000 millibars, 280°K).

elastic-sphere diameter ($\sigma = 4.59 \times 10^{-8}$ cm), used to calculate the mean free path L (*5*, Eq. 11), is appropriate for 100 percent CO_2. Hence

$$L = 1.068 \times 10^{14}/n \quad (2)$$

where n is the number density. The variation in the acceleration of gravity from 0 to 25 km is slight (less than 1 percent); therefore, an average value of 877 cm/sec^2 was used (*10*). The particle density can only be estimated; a value of 3.0 g/cm^3 was used for the spherical particles (*2*). Variations in particle density and shape have been neglected in this analysis.

The equations used for Mars (*5*, Eqs. 2–7) and Eqs. 1 and 2 were programmed for an electronic computer

Table 1. Properties of the neutral atmosphere of Venus from 0 to 25 km for two models based on Mariner V and Venera 4 data (*1*, *6*).

Altitude (km)	Mariner V Pressure (atm)	Mariner V Temperature (°K)	Mariner V Density ($\times 10^{-2}$ g/cm^3)	Venera 4 Pressure (atm)	Venera 4 Temperature (°K)	Venera 4 Density (g/cm^3)
0	92	748	6.60	17.9	544	1.77×10^{-2}
5	64	709	4.85	11.6	499	1.25×10^{-2}
10	49	669	3.93	7.1	455	8.38×10^{-3}
15	36	628	3.07	4.2	410	5.50×10^{-3}
20	26	588	2.38	2.3	366	3.37×10^{-3}
25	19	548	1.86	1.2	321	2.01×10^{-3}

(Univac 1108). Calculations of the terminal velocities of spherical particles from 1 to 10,000 μ in diameter were made for each pair of temperature-density values (Table 1) for the Mariner V and Venera 4 atmospheric models. The difference between the velocities of dust particles for both the Mariner V and Venera 4 model atmospheres increases both with size (starting from 10 μ) and altitude. The velocities of dust particles for the Venera 4 model atmosphere are 1.38 (10 μ, 0 km) to 3.29 (10,000 μ, 25 km) times those of the Mariner V model atmosphere. The difference occurs principally because the Mariner V model atmosphere is more dense at a given altitude than that of Venera 4. Figure 1 shows three curves of terminal velocity v plotted against particle diameter d. The falling rates near the surface on Earth are at least twice as high as those on Venus, primarily because the density of Earth's atmosphere is much lower. For particle sizes between 1 and 10,000 μ, the vertical winds required to maintain particles aloft in the denser, lower atmosphere of Venus are less than one-half the magnitude of those needed on Earth. Therefore, for the same degree of convective activity, one would expect more dust in the lower atmosphere of Venus than on Earth. Studies of dust storms and volcanic ash indicate that particles as great as 50 μ in diameter can persist over relatively great distances in the atmosphere of Earth (*11*). Persistent particles in the atmosphere of Venus (Fig. 1), with the same terminal velocity as a 50-μ particle near the surface in Earth's atmosphere, could be as large as 130 μ. If convective activity on Venus is the same as on Earth, the dust on Venus could contain larger particles than that on Earth, ranging up to over 100 μ in diameter. If the convective activity on Venus is much greater than on Earth, as is probable, then it is likely that Venus has a great deal more atmospheric dust than Earth, with dust particles on Venus ranging in size to perhaps 500 μ in diameter. Support for strong convective activity is given by calculations (*12*) which indicate that the lower atmosphere of Venus contains a thick (5 to 10 km) superadiabatic atmospheric layer on its surface. The presence of such a marked convective layer and the influence of its accompanying vertical velocities on dust particles may have profound effects on the dynamics of the lower atmosphere of Venus (*13*).

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22 October 1968

Archeological Evidence for Utilization of Wild Rice

Abstract. *The use of wild rice during the late prehistoric period is suggested by charred wild rice grains associated with fire hearths and threshing pits in historically known, specialized harvesting sites. Similar wild rice grains imbedded in the clay lining of specialized threshing pits called "jig pots" confirms the prehistoric use.*

The question of the prehistoric use of wild rice (*Zizania aquatica*) as a foodstuff by the native populations of the western Great Lakes region was raised many years ago by Jenks (*1*), who felt that the intensive use of this aquatic grass depleted stands rapidly, leading him to speculate that the historic intensive use of wild rice was very recent in origin. Kroeber subsequently discussed the high population density of this region in the early historic period, noted the lack of any unique natural food source other than wild rice, and attributed to wild rice a causal role in regional population growth (*2*).

Kroeber also suggested the possible prehistoric utilization of wild rice in this region in noting the overlap of prehistoric burial mound concentration and the distribution of productive wild rice lakes. While there is extensive literature on *Zizania*, there has been little published on the time of its utilization. Dickinson records two statements that suggest a prehistoric use of wild rice (*3*), and Wilford also infers prehistoric use based on site location (*4*). One reason for the lack of data on use of wild rice in prehistoric periods may be the lack of evidence of the plant in previous excavations. I now describe the evidence that does exist, based on field excavations in the Mississippi River headwaters of Minnesota.

Indirect evidence comes from the location and nature of certain sites of wild rice harvesting. Such sites are located adjacent to contemporary shallow lakes that produce wild rice, and until recent Minnesota harvesting regulations forced a change in the Indian pattern of harvesting, many of these sites were occupied seasonally in late August and early September by Minnesota Chippewa Indians. These people in the modern period, as in the earlier historic period, not only harvested the wild rice but did much of the preparation of the grains for storage at the same location. The latter involves an initial period of sun drying on mats, parching the grains in a kettle or steel drum over an open fire, threshing the parched wild rice to remove the husk, and winnowing the grains to remove the chaff (*1*, *5*).

One of several such harvesting sites is located on the east edge of Lower Rice Lake in Clearwater County; another is the Mitchell Dam site located at the outlet of Rice Lake, Becker County. Where permanent Chippewa villages are located very close to the rice beds, special harvesting and preparation localities are found adjacent to the village. Harvest sites of this nature are those at Nett Lake, near the contemporary Chippewa village of Nett Lake in St. Louis County, and at Petaga Point on Lake Ogechie, located near the Chippewa community of Vinland in Mille Lacs County (Fig. 1). These latter sites were not used as camping areas but the activities associated with wild rice harvesting and preparation were carried on here during the harvest season.