Venus: An Isothermal Lower Atmosphere?

Abstract. *Use of Earth-based microwave data in extrapolating the atmospheric profile of Venus below the region probed by Mariner V and Venera 4 reveals an isothermal layer at 670° ± 20°K that extends to an altitude of 7 ± 2 kilometers. This model gives a value of 6054.8 kilometers for the radius of Venus, and agreement with brightness spectrum, radar cross sections, and results of microwave interferometry.*

A study of the lower atmosphere of Venus, which correlates the results from Mariner V (*1*) and Venera 4 (*2*) with Earth-based observations of the planet in the microwave region (*3–6*) and laboratory measurements of microwave absorptivity (*7*), demonstrates that a substantially isothermal layer may exist adjacent to the surface. This result is in contrast to a recent study by Wood *et al.* (*8*), who extrapolated atmospheric profiles from Mariner V and Venera 4 adiabatically to the surface.

Figure 1 illustrates the relation between microwave optical depth, surface temperature, and planetary radius. The figure shows that, with data on the atmospheric composition and general structure of the atmosphere derived from the results of recent probes, any two of the above three parameters, deduced from Earth-based observations, determine the third as well as the polarized interferometric visibility (not shown in the figure). In fitting a specific model of the lower atmosphere to this overdetermined set of data, a least-squares criterion has been used.

In addition, our atmospheric models assume that no significant unidentified atmospheric substances affect the microwave radiation and that the latter is thermal. For reasons given by Gale and Sinclair (*9*), we assume a laterally uniform atmosphere, with temperature and pressure dependent only on altitude. The value of the microwave absorptivity α is taken from Ho *et al.* (*7*), and the values of the median fractional composition were determined by Venera 4: $f_{CO_2} = 90$ percent, $f_{H_2O} = 0.4$ percent; the remaining fraction is assumed to have the properties of nitrogen. Consequently, the optical depth of the atmosphere

$$\tau(\lambda) = \tau_0/\lambda^2$$

where τ_0 is the optical depth at a wavelength of 1 cm.

The value of τ_0 is obtained from measurement of the radar cross section of Venus which accordingly can be expressed as

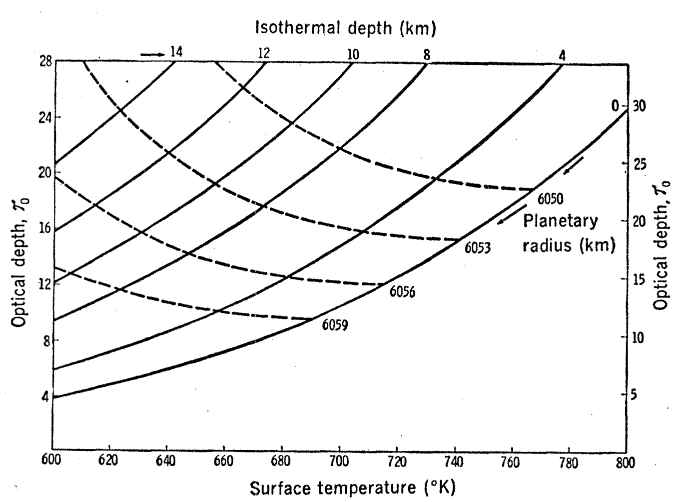
$$\sigma_V(\lambda) = \sigma_0 \exp(-2\tau_0/\lambda^2)$$

by ascribing the entire wavelength dependence to atmospheric attenuation. Although measurements of σ_V at fixed wavelength give fluctuations on the order of 100 percent, these are likely to result from surface properties at the subradar point that vary between measurements. Thus measurements at successive conjunctions (*3–5*) are used. In view of the fact that at inferior conjunction Venus presents the same face to Earth (*10*), these refer to nearby and overlapping subradar regions. These give $\tau_0 = 14.9 \pm 4$ and $\sigma_0 = 0.14 \pm 0.02$; from these values the surface dielectric constant $\varepsilon = 4.4 \pm 0.4$ can be determined after the roughness correction of Carpenter (*4*) has been applied.

The profile of the upper portion of the atmosphere below the tropopause is taken to be adiabatic, as measured by Venera 4. In the lower portion simplified models for the atmospheric profile have been studied that allow for the possibility that Venera 4 did not reach the planetary surface. In that region the adiabatic profile is continued to an altitude z_i. Following a suggestion by Thaddeus (*11*), we take the atmosphere below z_i to be isothermal. Such a subadiabatic layer might imply substantial absorption of solar radiation above the surface.

For given values of z_i and surface temperature T_s, the temperature profile is fixed throughout the atmosphere, and the pressure profile can be determined from a knowledge of both temperature and pressure at a single point. From Venera 4 we choose the data pair $p =$ 4.0 atm at $T(4.0\ \text{atm}) = 404° \pm 8°\text{K}$.

With the dependence of pressure and temperature on altitude prescribed in this manner, τ_0 is obtained from the



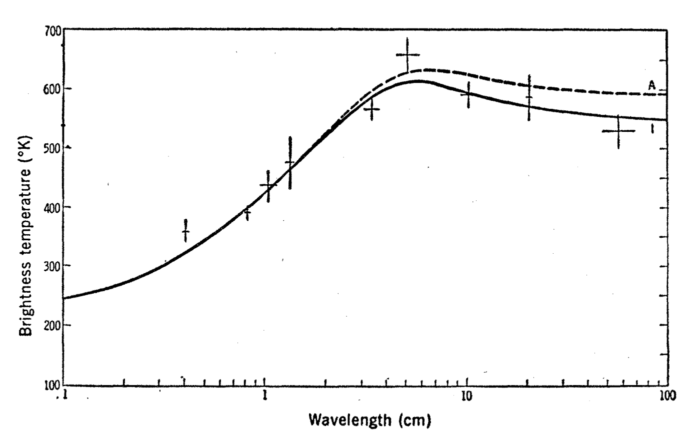


Fig. 1 (left). Relation between optical depth (τ_0), surface temperature (T_s), isothermal depth (z_i), and planetary radius (R_V). Any two of these values determine the other two by locating a point on the graph. The left scale for τ_0 is that appropriate to the values of f_{CO_2}, f_{H_2O}, and T(4.0 atm) used here. The right scale is that appropriate to increasing f_{CO_2} or f_{H_2O} or decreasing T(4.0 atm) by one standard deviation (*2*). Fig. 2 (right). Brightness temperature spectrum $T_B(\lambda)$ of Venus. Crosses represent the results of at least three different observers, weighted inversely to their quoted error. The horizontal bar indicates the range of wavelengths averaged; the vertical bar indicates the root-weighted mean square error from the average. The predictions of the best isothermal and adiabatic models are shown by curves I and A.

integration of absorptivity over height. We calculated the brightness temperature spectrum according to the method of Ho *et al.* (*7*), adding the contribution from the isothermal layer below z_i. We calculated the polarized interferometric visibility as Clark and Kuz'min did (*12*, eq. A3). Furthermore, within this model, the altitude of a reference temperature (taken as 450°K) measured by Mariner V at a distance of 6085 ± 2 km from the center of Venus determines the planetary radius.

The most likely values of T_s and z_i, the variable parameters of our model, are then obtained by calculating the weighted sum of the squares of the deviation of all items enumerated in the preceding paragraph. The square of the deviation of calculated values from their corresponding experimental values is divided by the variance of each set of experimental data. The brightness temperature spectrum and visibility curve and the single "points" of optical depth and planetary radius are treated equally by dividing the sum of squares for the respective curve by the number of points taken along that curve. The weighted sum of the squared deviations reaches its minimum with $T_s = 670° \pm 20°$K and $z_i = 7 \pm 2$ km. These values yield $\tau_0 = 15.4$; a planetary radius $R =$ 6054.8 km as compared to a value of 6050 to 6056 km obtained from radar echo delay (*13*); polarized interferometric visibility ΔF (wavelength $\lambda = 10.6$ cm, normalized base line length $\beta = 0.6) = 5.5$ percent [Clark and Kuz'min (*12*) reported a value of 5.6 ± 1 percent]; the brightness temperature spectrum based on the most likely values of T_s and z_i is presented in Fig. 2.

Figure 2 also presents the brightness temperature derived from an adiabatic temperature profile investigated by setting z_i equal to 0. With this value of z_i, the surface temperature minimizing the weighted sum of the squared deviations is $T_s = 720° \pm 20°$K. Other results of this model are $\tau_0 = 12.6$, $R =$ 6055.5 km, and ΔF ($\lambda = 10.6$ cm, $\beta = 0.6) = 6.3$ percent. The weighted sum of the squared deviations is, however, about two and one-half times greater than that obtained with the above isothermal model.

The best fit of all data is thus obtained with the isothermal model. Current interferometric observations of Venus at 11 cm should permit refined measurement of polarized interferometric visibility and yield the unpolarized visibility with sufficient accuracy to enable one to distinguish between the models. Simultaneous measurement of the radar cross section of Venus at several frequencies can be expected to yield greatly improved estimates of microwave optical depth.

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Cyclic and Geographic Trends in Seawater Temperature and Abundance of American Lobster

Abstract. *In Maine, fluctuations in the abundance of American lobster* (Homarus americanus) *and in seawater temperature have correlated well during the years since the first temperature measurements were made in 1905. Recent record catches in chronological sequence from the northern limit of range in Newfoundland to New York, while temperatures measured in Maine declined from higher to lower than optimum, suggest that at the present rate optimum conditions should reach the southern limit of the lobster's range by the mid-1970's.*

The temperature of the sea surface, as measured daily since 1905 at Boothbay Harbor, Maine, by the U.S. Fish and Wildlife Service, has fluctuated as distinct climatic subcycles, including (i) the years before 1917, (ii) the period from 1917 to 1939, and (iii) the years since 1939 (Fig. 1) (*1*).

The period since 1939 has been of special biological and meteorological interest. The second coldest year on record, 1939, terminated a relatively low-temperature subcycle that had commenced in 1917; it also initiated a 14-year warming trend that culminated in the record high of 11.1°C in 1953 which, in turn, was followed by an equally precipitate decline, reaching an average of 7.3°C by 1967.

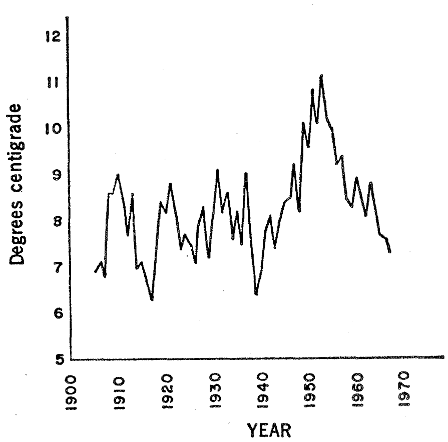

Fig. 1. Sea surface temperature (Boothbay Harbor, Maine) measured by U.S. Fish and Wildlife Service, 1905–1967. (Temperature means for 1905, 1948, and 1949 were estimated from 9, 11, and 8 months, respectively.)

Temperature data as indicators of climatic trends appear to be consistent with sea surface temperature variations recorded elsewhere along the northwest Atlantic coast (*2*). It is assumed that temperature fluctuations at Boothbay Harbor are representative of climatic trends throughout the range of the American lobster (*3*) and that the 28 percent contribution of Maine to the catch for the period from 1939 to 1967 is reasonably representative of resource behavior in terms of both abundance and availability (Fig. 2).

A linear correlation of .8 between lobster production in Maine and elsewhere for the period from 1939 to 1967 supports the assumption that factors causing fluctuations in Maine landings also influence yield elsewhere (Fig. 3). From the 6.4°C annual mean in 1939, when relatively high production occurred in Connecticut and a record high catch was made in Rhode Island, a northeasterly trend in greater yield of the traditional American lobster trap fishery developed coincident with the 14-year cycle of the increasing temperature of the sea surface. The increase in