The Transmittance of the Atmosphere for Solar Radiation on Individual Clear Days[1]

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ABSTRACT

Calculations of the mean daily transmittance of the atmosphere for solar radiation based on only one independent variable, surface vapor pressure, are demonstrated to be equally as accurate for Phoenix, Ariz., as similar calculations averaged on a monthly basis over several years. A correlation coefficient of 0.92 is obtained for the linear regression of the calculated on the measured values, with a standard error of estimate of only 0.009.

1. Introduction

The transmittance of the atmosphere for solar radiation is a function of absorption and scattering by water vapor, absorption and scattering by dust, and absorption and scattering by the dry, dust-free air (Houghton, 1954). Although atmospheric dust is quite variable and important in this process, Idso (1969) has demonstrated that monthly averages of the atmospheric transmittance may be calculated to within about 1.5% of measured values by assuming the dust content of the air invariant, at the degree of loading proposed by Houghton. The transmission of the atmosphere is then specified by only one meteorological variable, precipitable water. Furthermore, the study of Idso indicated that surface vapor pressure may be capable of specifying precipitable water sufficiently well that the use of this latter, more difficultly measured, parameter may not be required.

The question of practical concern which these observations raise is whether a similar situation may exist for individual days. There is much evidence to believe that it would not. Since the particulate matter over a city arises in large measure from a variety of point sources not necessarily evenly distributed in area, wind shifts could conceivably cause large day-to-day variations in the atmospheric dust load at the site of the solar radiation sensor. Such effects are noted quite often in air pollution studies (McCormick and Baulch, 1962; Philip, 1964; Ahlquist and Charlson, 1967; Panofsky and Prasad, 1967). Also, it is questionable how reliable the relation between surface vapor pressure and precipitable water is on a daily basis. Reitan (1963) found the relation to be excellent in terms of monthly means (correlation coefficient=0.98), but Bolsenga (1965) found it somewhat reduced (correlation coefficient =0.85) for daily values. Smith (1966) demonstrated that errors as large as 50% may result with these relations, even for monthly means; and he provided a table with seasonal and latitudinal values of a parameter characteristic of the atmospheric moisture profile which he hoped would improve the situation. Schwarz (1968), however, gave an example which indicated that even this procedure may still be subject to "large errors."

The object of this paper is to test the procedure of Idso (1969) with data for individual clear days, to see whether there is any reduction in the accuracy of calculated atmospheric transmission coefficients for solar radiation when carried out on a daily basis as compared with monthly mean values. If it can be demonstrated that the procedure works equally well for individual days, in spite of the potential limitations discussed above, it should greatly enhance its usefulness to solar radiation reception studies.

2. Procedure

An entire year (July 1968–June 1969) of clear-day solar radiation data obtained at the U. S. Weather Bureau Station, Phoenix, Ariz., were acquired. These data, after being corrected for ambient temperature and mean zenith angle effects characteristic of Epply pyranometers (Robinson, 1966; Idso, 1969), and after being divided by the daily extraterrestrial insolation, adjusted for variations in earth-sun distance and calculated with a solar constant of 1.94 cal cm^{-2} min^{-1} (based upon recent determinations of 1.95 by Stair and Ellis, 1968; 1.95 by Drummond *et al.*, 1968; and 1.91 by Murcray *et al.*, 1968), yielded a total of 100 measured transmittances, ranging from 0.712–0.804.

These measured values were used as a basis against which to compare the calculated values, obtained by the method described in detail by Idso. Briefly, these

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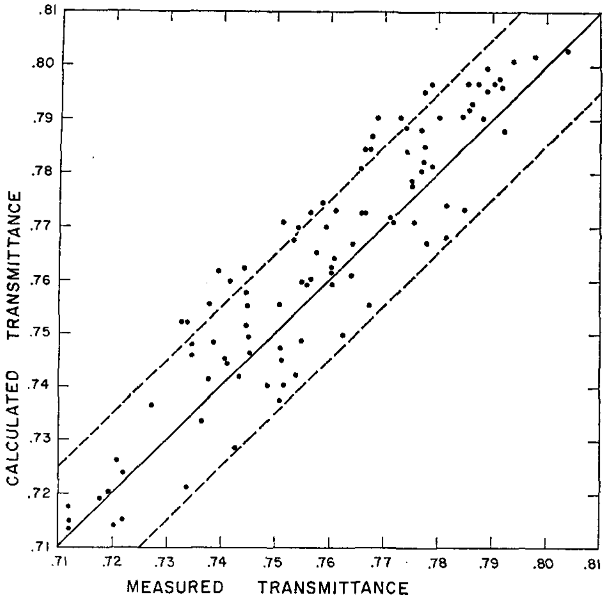

FIG. 1. The calculated atmospheric transmittance for solar radiation as a function of the measured transmittance for individual clear days at Phoenix, Ariz.

values were obtained as follows. An expression developed by McDonald (1960) for the absorption of solar radiation by water vapor was used in conjunction with the product of daily weighted mean optical path length and precipitable water (determined from surface vapor pressure) to yield the fractional depletion of the solar beam by water vapor absorption. The further depletion of the solar beam by dust was then calculated by the formula of Houghton (1954), expressible solely in terms of optical path length. Half of this depleted energy flux was considered to reach the earth as diffuse radiation. The Houghton relations for solar radiation transmission in the presence of scattering water vapor and the basic atmospheric constituents (derived from Smithsonian Institution data) then yielded, based upon precipitable water and optical path length, a final transmittance of the direct beam and a second scattered component. The sum of half of this scattered component, the fractional transmittance of the direct beam, and the component scattered downward by dust then yielded the total atmospheric transmittance.

The precipitable water-surface vapor pressure relation used in the preceding scheme was

$$\log U = -0.579 + 0.247\sqrt{e}, \qquad (1)$$

where U is the mean daily precipitable water content of the atmosphere (cm) and e the mean daily surface vapor pressure (mb). It has been determined from a least-squares linear regression involving 190 paired values of U and e obtained during June, July and August in 1955, 1956 and 1957. The correlation coefficient for the regression was 0.913.

3. Results and discussion

Fig. 1 contains the calculated daily transmittance plotted as a function of the measured transmittance. Also included is a solid 45° or "1:1 correspondence" line and two dashed lines depicting a departure of $\pm 1.5\%$ from this line. Only 17 of the 100 total points, or 17% of them, fall outside of this interval, and even these points do not lie very far from it. A least-squares analysis of the data of Fig. 1 yields a line of slope 1.003 and zero intercept of 0.002, with a correlation coefficient of 0.921. The standard error of estimate is further calculated to be only 0.009.

The assumption of a constant dust load in the atmosphere, although not necessarily true, is thus seen to be *operationally* valid for the calculations, since if there are variations in the dust load from day to day, the consequent variations in the direct solar beam are apparently nearly compensated by inverse variations in scattered radiation. Considering the strong forward-scattering properties of dust and haze materials, such an adjustment would be quite plausible. In any event, the data indicate that, indeed, at least for the Phoenix location, the method of Idso (1969) provides an accurate and reliable means of calculating the transmittance of the atmosphere for solar radiation on individual clear days from only surface vapor pressure as a single independent variable.

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