Estimating the Effect of Cloudiness on Incoming Solar Radiation

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A report on research conducted under contract No. CWB-9918 between the US Weather Bureau and Colorado State University

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ABSTRACT

A second-order polynomial regression of net incoming solar radiation on total cloudiness is made, using as original data 104 observations of daily insolation and mean total cloudiness made at sea west of Mexico and Central America during 1956-1959 on cruises of the Scripps Oceanographic Institution. This curve, with a minor modification at low cloudiness, fits the adjusted data quite well and appears reliable at cloudiness less than 7.2 oktas. At cloudiness less than 6 oktas, it estimates less radiation reduction than does the linear formula published in 1942 by Sverdrup (The Oceans, p. 102); above 6 oktas, the radiation is sharply reduced.

In computation of energy transfer processes at the sea-air interface, the incoming solar-short-wave radiation able to penetrate through the entire depth of the atmosphere enters as a major factor. Although fairly reliable tables of this quantity for clear-sky and average cloudiness conditions, as functions of geographic position and time of year, have long been available (Kimball, 1928), its estimation for specific amounts of total cloudiness has been somewhat in doubt. Sverdrup (1942, p. 102) has published a linear reduction formula:

$$\left(\frac{Q_{net}}{Q_{clear}}\right)_{incoming} = 1 - 0.071C,$$

where C is cloudiness in tenths (for C in oktas, the constant becomes -0.089). However, he notes its approximate nature, giving as reason the truism that the single number C is but a first approximation to the state of the sky.

A recent paper by Pike (1961) made use of this formula in computing the oceanic heat budget of the northwest Gulf of Mexico after the passage of hurricane Audrey (1957). The evaporation required to satisfy oceanic heat balance, obtained as a residual, seemed rather low when compared to that computed with the turbulence method (cf. Riehl, 1951, p. 611), suggesting that the computed incoming solar radiation might also have been low. On this account, it was decided to pursue the subject further.

Data kindly supplied by Dr. R. W. Holmes of Scripps Oceanographic Institution of La Jolla, California enabled us to make a statistical study of observed Q_{net} as a function of cloudiness. These data, consisting of 104 daily reports, were obtained on several cruises over the tropical eastern

North Pacific, west of Mexico and Central America, during 1956-1959; they were tabulated in the form of observed daily incoming solar radiation without albedo correction as a function of date, position, and observed day-mean total cloudiness. As the observations were made at rather low latitudes, 4N to 27N, it was thought proper to ignore intra-seasonal variations and divide the reports into two broad classes: November-February, 53 reports and April-September, 51 reports. Next, each reported radiation amount was reduced to a standard latitude of 15 N by a ratio function dependent on latitude and season (fig. 1) derived from Smithsonian Tables (1958) table 134, a chart of daily solar radiation at the top of the atmosphere. The reduced observations were then plotted for each season as $Q_{\text{(net incoming)}}$ vs. cloudiness in figs. 2a and 2b.

One notes immediately the similarity of these two figures; although there is a moderate scatter in each, very definite non-linearities are noted with an indicated much sharper radiation decrease with increasing considerable cloudiness than with increasing scattered cloudiness. This trend may be connected with a tendency, especially in low latitudes, for considerable cloudiness to be predominantly stratiform and nimboform, indicating higher radiation interference efficiency per unit horizontal corss-section, and for scattered cloudiness to be cumuliform and very patchy cirroform, indicating lower interference efficiency. Of course, it is possible that the tendency for observers to overestimate low cloudiness amounts contributed to the non-linearities. The geometrical and range-of-cloudiness similarity of the two $Q_{\text{(net incoming)}}$ vs. cloudiness profiles led us to adjust each November-February report to an April-September level by multiplication by the ratio of the mean of the April-September reduced reports to that of the November-February reduced reports:

$$\frac{545 \text{ ly day}^{-1}}{414 \text{ ly day}^{-1}} = 1.316;$$

these were combined with the reduced April-September reports to yield fig. 3.

The first regression curve fitted to the data of fig. 3, a simple second-order polynomial in C, appears satisfactory; its use was prompted by the lack of any quantitative physical hypothesis for the form of $Q_{(\text{net incoming})}(C)$. After division by the indicated $Q_{(\text{net incoming})}(C = 0)$ and generalization to a ratio formula like Sverdrup's, its equation is:

$$\left(\frac{Q_{\text{net}}}{Q_{\text{clear}}}\right)_{\text{incoming}} = 1 + 0.038C - 0.014C^2 \text{ for C in tenths, or}$$

$$\left(\frac{Q_{\text{net}}}{Q_{\text{clear}}}\right)_{\text{incoming}} = 1 + 0.048C - 0.022C^2 \text{ for C in oktas.}$$

It is plotted as the solid curve in fig. 3. The extremely rapid approach of $Q_{(\text{net incoming})}$ to zero indicated by this formula at very high C seems unrealistic; our formula appears unreliable when $C > 9$ tenths (7.2 oktas), probably since we had no observations in this range. An accidental characteristic is that the maximum of $Q_{(\text{net incoming})}$ occurs at $C = 1.4$ tenths (1.1 oktas) instead of at $C = 0$; since no orographic influences were present in the original data, it is advisable to ignore this bulge of Q_{net} at low cloudiness, using instead, with C in oktas:

$$\left(\frac{Q_{net}}{Q_{clear}}\right)_{incoming} = 1 \qquad \text{when } C \leqslant 1.1 \text{ oktas, and}$$

$$\left(\frac{Q_{net}}{Q_{clear}}\right)_{incoming} = 0.975 + 0.047C - 0.022C^2 \quad \text{when } 1.1 \text{ oktas} < C \leqslant 7.2 \text{ oktas.}$$

The proper form of the curve when $C > 7.2$ oktas is uncertain.

For comparison with Sverdrup's linear formula, our curve appears therewith in fig. 4. We note that it estimates less reduction of incoming radiation by cloudiness than does Sverdrup's for $C < 6.0$ oktas; the maximum difference within this range, 19 per cent, occurs at $C = 2.8$ oktas. As the cloudiness over the northwest Gulf did not exceed 4 oktas during the post-Audrey computation, application of our formula increased the net incoming radiation and permitted greater evaporation, as was desirable.

We note that a non-linear relation between incoming radiation and sky cover also was found by Fritz (1955) for several stations of the continental United States.

As our formula was derived from observations made within 30 degrees of the equator, its use at higher latitudes is not encouraged. Its use on land as well as at sea in the tropics would not seem to be improper, except where local orography influences the cloud patterns significantly. Of course, it should be remembered that, for computation of solar energy actually absorbed by ocean or land, the appropriate albedo must be taken into account.

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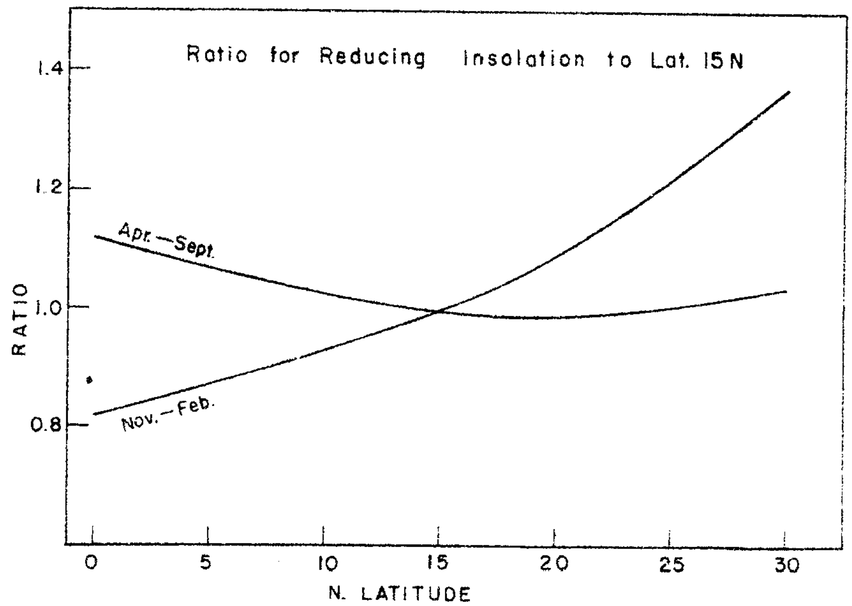

Fig. 1. Ratio for reducing insolation to latitude 15 North.

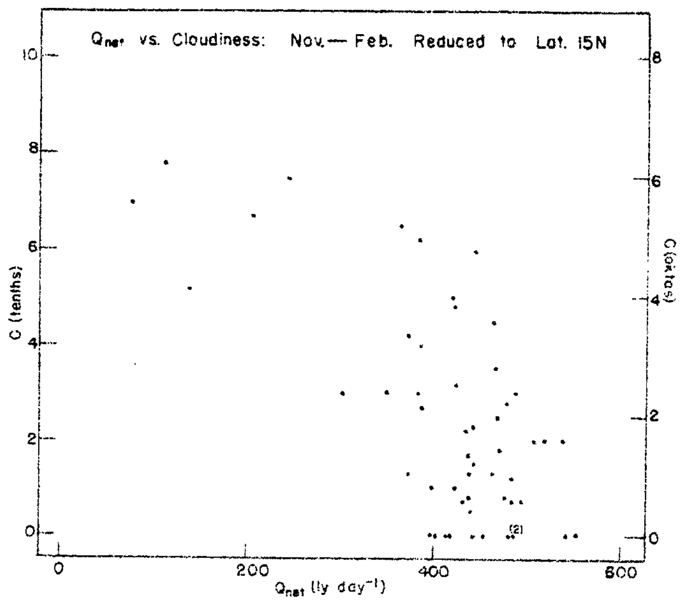

Fig. 2a. Insolation, reduced to lat. 15N, vs. cloudiness for November-February reports.

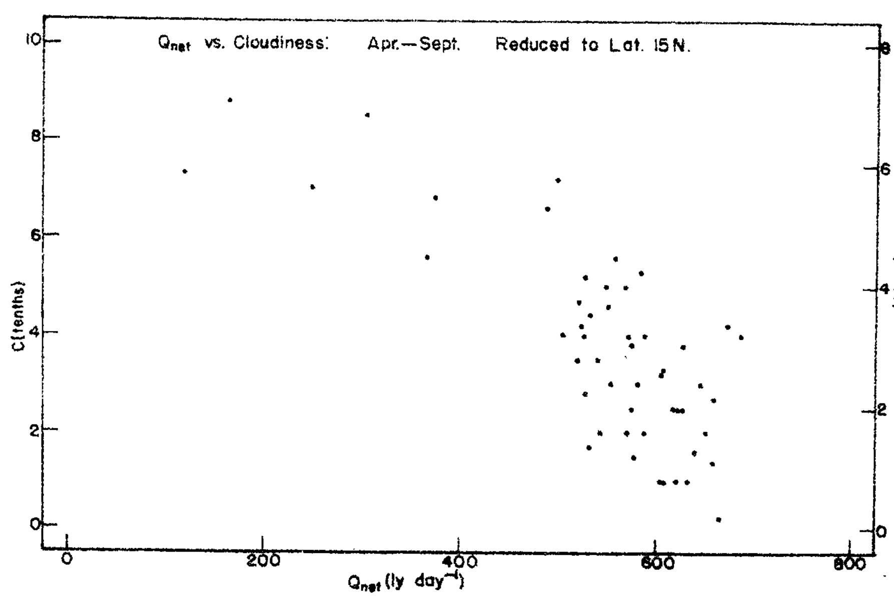

Fig. 2b. Insolation, reduced to lat. 15N, vs. cloudiness for April-September reports.

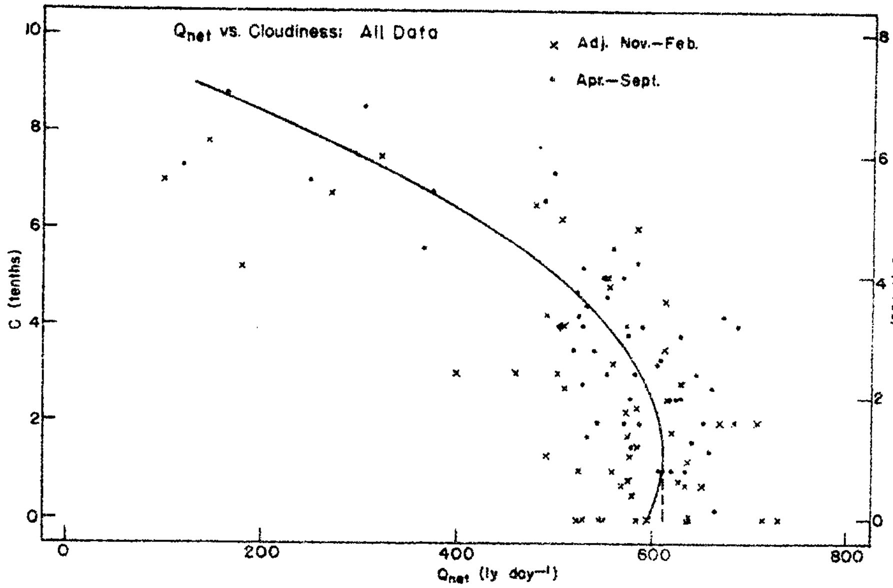

Fig. 3. Insolation vs. cloudiness for all reports; November-February reports adjusted to April-September level.

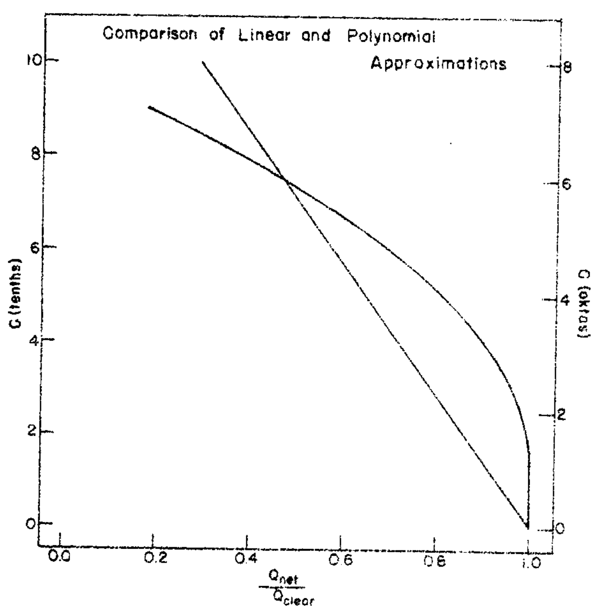

Fig. 4. Comparison of linear (Sverdrup, 1942) and quasi-polynomial approximations to $\left(\frac{Q_{net}}{Q_{clear}}\right)_{incoming}$.