357

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DISTRIBUTION OF GLOBAL RADIATION OVER CHILE

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SUMMARY

Global radiation charts of Chile are presented. A regression technique between global radiation and sunshine duration supplied values of global radiation at places with sunshine duration measurements only and served to extend the period of observations. Statistical tests confirmed the applicability of the regression method.

1. INTRODUCTION

In the global radiation literature until 1962 we find data for Chile only in charts dealing with worldwide distributions. The first charts on the distribution of solar energy over northern Chile were presented by Hirschmann (1).

This work intends to show the distribution of global radiation over the South American territory of Chile.

2. METHOD OF COMPUTATION

All over the world, few radiation measuring stations are found with series of global radiation data long enough for climatological purposes. For this reason, in every region indirect methods must be used to calculate the space distribution of global radiation. Aims of the indirect method must be, first, to obtain values of global radiation over places with no stations and second, to extend the period of observations. The most common indirect methods are based on correlations with cloudiness or sunshine duration.

Correlation with cloudiness has been applied to construct worldwide maps (2). However, because of the subjective estimation of cloudiness observations, the different transmissivities shown by some types of clouds and the lack of reports on the cloud distribution over the sky, correlation between global radiation and cloudiness is relatively low (3).

The sunshine duration method avoids the disadvantages mentioned above. Correlation coefficients between daily global radiation and daily sunshine duration are relatively high, as shown in table 1. There, the lowest values are much greater than $r_{90} = 0.27$ or $r_{60} = 0.33$, i. e. values of correlation coefficients at $P = 0.01$ level of significance for 90 and 60 degrees of freedom respectively. Table 1 also shows that we can use a linear statistical relationship for computing global radiation from sunshine duration.

The method used in this work is a regression between global radiation and sunshine duration, which is expressed by the equation -

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$$R = \overline{R} + r \frac{\sigma_R}{\sigma_S}(S - \overline{S})$$

where R and S are daily sums of global radiation and sunshine duration respectively, $\overline{R}$ and $\overline{S}$ are their mean values for a given month, r is the correlation coefficient and σ_R and σ_S are the standard deviations of R and S respectively. Regression is applied separately for each month to account for annual variations.

Application of this method is not limited to any given frequency distribution, the only condition to be fulfilled is that differences between observed and computed values in every abscissa interval must have a Gaussian distribution with zero mean. Although this condition seems to be justified in this kind of investigation (4), January and July months of station Cerro Calán (*) were controlled, dividing the whole range of S data into two equal intervals. Application of a chi-square test confirmed the above hypothesis.

This method differs from a rather extended one, originally proposed by Ångström (5), which has the form

$$\frac{R}{R_o} = k + (1 - k)\frac{S}{S_o}$$

where k is a constant, R_o and S_o are values of global radiation and sunshine duration for clear days. In a completely overcast day,

$$\frac{R}{R_o} = k$$

so it is only necessary to know the average daily global radiation for clear and overcast days to find the value of k.

Although both methods have the same linear form R = A + B.S, constants in this equation are calculated by different ways. Ångström's method may introduce an uncompensated error, because it uses only the two extreme points to define the linear equation. As a matter of fact, complete overcast is produced at many places by clouds which are much thicker than intermediate cases.

3. DATA AND RESULTS

Basic data of this work are daily sunshine duration and daily global radiation. Sunshine duration is obtained by Campbell-Stokes recorders. Global radiation is measured by Robitzsch bimetallic actinographs.

Records obtained from these instruments are evaluated carefully (twice by different persons) to minimize errors. Nevertheless, errors due to instruments can be as high as 10% (6). No special correction is applied to the results.

Data available at the beginning of this work corresponded to 42 stations: 14 of them had simultaneous measurements of global radiation and sunshine duration long enough to apply the regression method (two years of data at least), 3 stations had global radiation measurements only and the remaining 25 had sunshine duration measurements only. Radiation data covered the period 1964-66. Available sunshine duration data extended mainly from 1948 to 1957 and from 1964 to 1966. Statistical analysis of the series of sunshine duration from Santiago and Concepcion showed that the most used period (1964-66) does not differ significantly from the long period data.

Due to its 4200 Km of north-south length, Chile presents a variety of climates associated with several solar radiation regimes. A comparison of the regression constants computed for every month and the radiation regimes of different stations leads to the definition of five zones in the country. Yearly variations of global radiation for stations in these zones are shown in Fig. 1.

The zone of the Andes range between 18° and 20° S is represented by Parinacota, which shows a relatively high radiation value with small yearly amplitude. In the summer months, convective clouds probably cause a secondary wave. The rest of the northern region until 32° S is represented by Copiapó, which shows a definite yearly variation, as the other southern zones do. Three additional zones were defined: a central zone between 32° and 38° S (represented by Santiago and Cerro Calán), a transitional zone from 38° to 42° S (represented by Pullinque) and a southern zone beginning at 42° S (represented by Colonia). These last three zones differ mainly in the values of the regression constants.

(*) Locations are listed in Table 3.

In each zone, regression constants corresponding to the most representative station were used to transform monthly means of sunshine duration to monthly means of global radiation for stations which measured only sunshine duration. Table 2 gives the error introduced by the regression method, using sunshine duration data of the same representative station to evaluate global radiation. For monthly means, the maximum error is less than 3%. However, when data of the other stations in the zone are used, the error can be as high as 10%.

A comparison between stations at the same latitude located in the coastal, middle and mountain regions showed no appreciable differences in the sunshine duration and radiation regimes southwards of 32° S. Northwards of 32°, coastal stations presented sunshine duration regimes different to those of middle and mountain regions (Fig. 2a). This difference between coastal and middle or mountain stations could lead to a separated coastal zone in northern Chile, but available data were not enough to define it.

Figure 2a shows almost constant values throughout the year of sunshine duration for a coastal station, which can be explained by the presence of a stratocumulus layer of the semipermanent subtropical anticyclone over the southeastern Pacific Ocean. In spite of the differences in sunshine duration, global radiation regimes are much more similar, showing a typical annual variation. (Fig. 2b).

Radiation and sunshine duration data transformed by the regression method were used to draw the charts of global radiation shown in Fig. 3. Isolines were drawn bearing in mind the relief and climatic distribution of cloudiness (7). The density of stations is very low in some parts of the country, 50% of them are located in the central region between 32° and 40° S. The northern region, under the influence of the semipermanent anticyclone which make climatic conditions very uniform and constant and similar orographic features along the north-south direction, gives some value to the isolines in that zone. South of 40° S, density is also low and the orography complicated; the isolines drawn there are only tentative.

4. ACKNOWLEDGEMENTS

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TABLE 1

CORRELATION COEFFICIENTS BETWEEN SUNSHINE DURATION AND GLOBAL RADIATION AT FOUR CHILEAN STATIONS

	Jan.	Apr.	Jul.	Oct.
Parinacota	0.94	0.90	0.76	0.88
Copiapó	0.76	0.87	0.91	0.55
Pullinque	0.96	0.88	0.88	0.71
Colonia	0.64	0.81	0.82	0.78

TABLE 2

$\frac{\sigma_{Reg}}{R} \cdot 100$ values at four in Chile (%).
σ_{Reg} standard deviation of estimated values from regression.
n number of observations.

	Jan.	Apr.	Jul.	Oct.	Mean	$\frac{1}{\sqrt{n}}$ Mean
Parinacota	6.7	6.9	6.2	7.5	7.8	1.0
Copiapó	5.7	10.5	7.2	8.1	8.0	1.0
Pullinque	8.2	23.8	26.1	28.5	19.0	2.7
Colonia	20.0	21.7	22.8	17.6	21.6	2.7

TABLE 3

Location of stations quoted in the text.

	Latitude (S)	Longitude (W)
Parinacota	18°12'	67°17'
Copiapó	27°21'	70°20'
Santiago	33°27'	70°42'
Cerro Calán	33°24'	70°32'
Concepción	36°50'	73°02'
Pullinque	39°35'	72°12'
Colonia	47°20'	72°51'

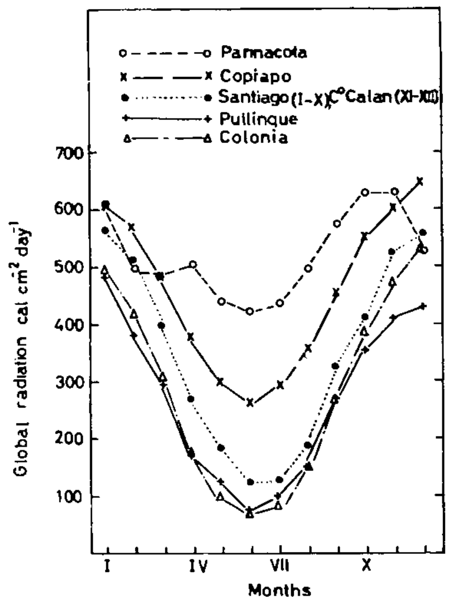

Fig.1 Radiation regimes of five representative stations of the zones defined in the country.

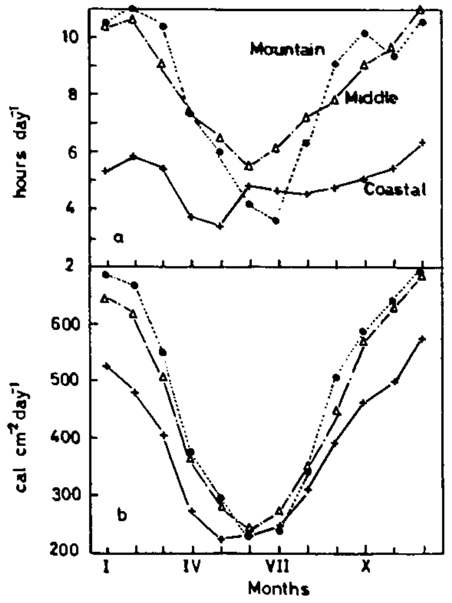

Fig.2 a) Sunshine duration regimes for 3 stations located between 30-31°S.
b) Global radiation regimes for the same stations.