Atmósfera (1993), **6**, *pp. 189-198*

Irradiance and potential land uses in Guerrero state, Mexico

SERGIO GUZMAN RUIZ, WALTER RITTER ORTIZ

Centro de Ciencias de la Atmósfera, Universidad Nacional Autónoma de México, 04510, México, D. F., México

AGUSTIN MUHLIA VELAZQUEZ

Instituto de Geofísica, Universidad Nacional Autónoma de México, 04510, México, D. F., México

(Manuscript received May 6, 1992; accepted in final form May 26, 1992)

RESUMEN

En este estudio, se realiza una clasificación agroclimática con base en el cálculo de potenciales de radiación cuando se consideran la altitud, la orientación y la pendiente de las montañas. Se consideró una atmósfera limpia (sin nubes) con una visibilidad de 23 km. Para calcular los flujos de radiación solar se utilizó el modelo de Kuznetzov.

Las zonas de máxima radiación calculadas por el modelo, coinciden con los lugares más calientes ya conocidos en el estado. Estos resultados generan una gran confianza en el modelo y la metodología para la planeación del uso del suelo en zonas montañosas.

Para 113 estaciones del estado de Guerrero, se encontraron cinco microzonas de máxima radiación, las cuales aparecen para todas las orientaciones y pendientes consideradas. Una microzona es la región comprendida entre Cutzamala de Pinzón, Altamirano y Tlalchapa, otra corresponde a Chichihualco, otra es la región de Iguala, parte de Huitzuco y parte de Tepecoacuilco, otra microregión sería entre Atlixtac y Atlamajalcingo del Monte y la última donde se juntan los municipios de La Unión, Coyuca de Catalán, Tecpan de Galeana y Petatlán.

ABSTRACT

In this study, an agroclimatic classification is made based on the calculation of the solar radiation potentials, taking into consideration the altitude, the orientation and the tilt of the mountains. A clear (cloudless) atmosphere with a visibility of 23 km was considered. For the calculation of the solar radiation the Kuznetzov model was used.

The zones of maximum radiation generated by the model are coincident with the hottest areas of the state. Therefore, the model and metodology are to be trusted for the planning of land use of a hilly zone.

For 113 stations in the state of Guerrero, five micro zones of maximum radiation were found which appear for all the considered orientations and slopes. One of these micro zones corresponds to the region between Cutzamala de Pinzón, Altamirano and Tlalchapa, another one to Chichihualco, a third in Iguala, part of Huitzuco and part of Tepecoacuilco, a fourth in the region between Atlixtac and Atlamajalcingo del Monte and the last one where the municipalities of La Unión, Coyuca de Catalán, Tecpan de Galeana and Petatlán join together.

Introduction

In the Republic of México, the zones of rainfed agricultural production on mountains are predominant. The principal characteristics of these zones are their fragility and their inconsistent production, which are caused by strong and multiple climatic interactions.

Cultivation fields with different inclinations and orientations are subject to distinct solar radiation. This is particularly important for the country, wich is constituted by a very rough topography. This signifies different hours and distinct quantities of solar radiation.

We know that the quantity of solar radiation that is received by plants is vital for their growth and transpiration. It also has considerable influence on the quality of fruits and the chemical composition of the plant.

The different orientation and slopes on a mountain have an influence not only on the solar radiation but also on other micro climatic elements. For this reason, zones of this type should not be cultivated unless their characteristic features are taken into account.

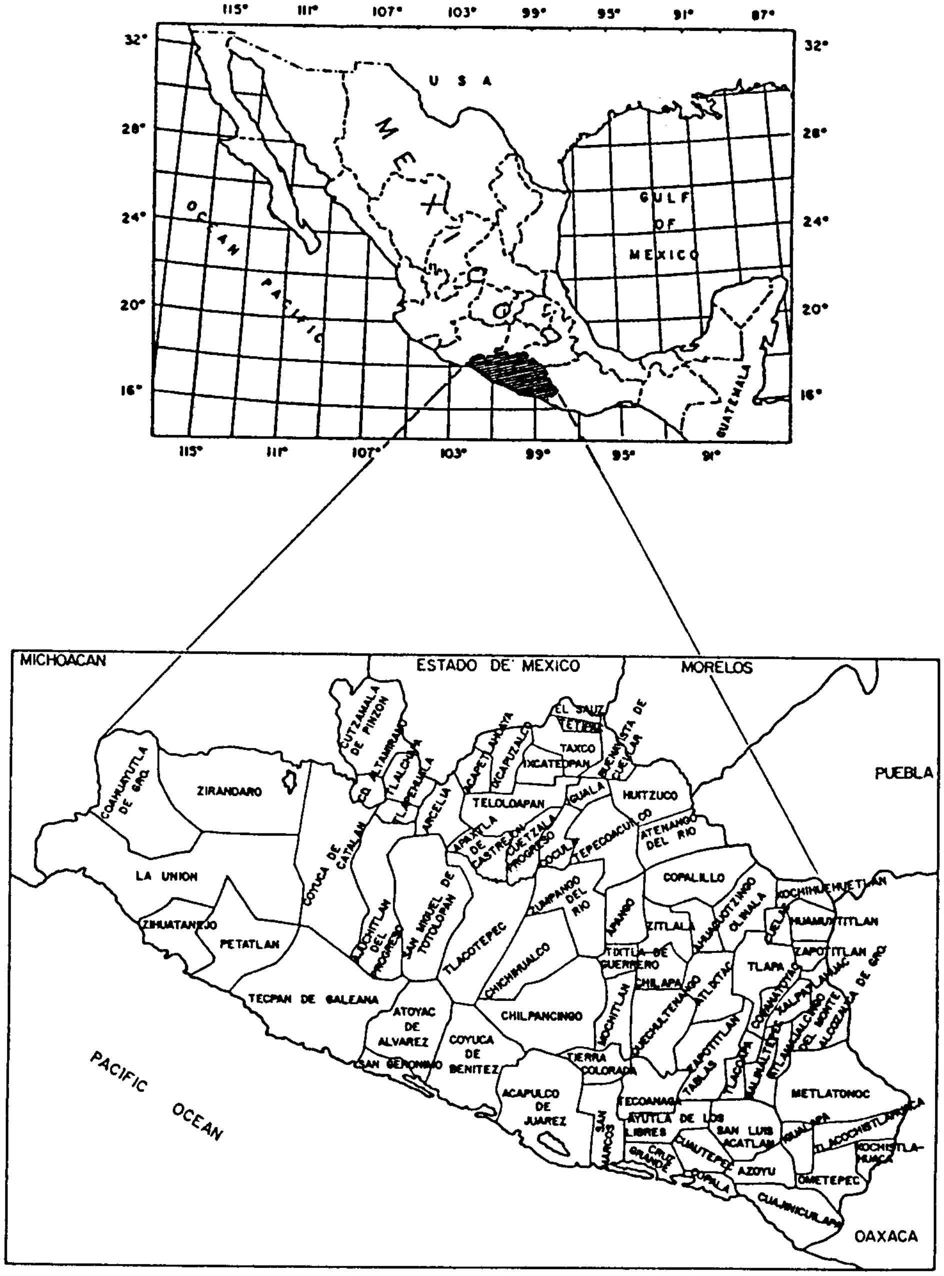

Fig. 1. Geographical location of Guerrero state, México.

The purpose of this paper is to determine the general characteristic features for agroclimatic purposes that will help in the administration and use of the land. For this, in this example, we have calculated some of the solar radiation potentials for the principal orientations and surface inclinations, for the state of Guerrero, Mexico, Figure 1. Potential is defined as the maximum possible radiation at noon in the upper part of the atmosphere or on the terrestrial surface for a clear atmosphere.

2. Procedures

For the calculation of the global irradiance on the terrestrial surface, the Kuznetzov model (Wieder, 1982) was used. Diffuse and direct solar irradiances were calculated, from which the global irradiances incident upon surfaces of any inclinations with the horizontal and any solar azimuth angles were obtained.

This simplified model takes into account the following considerations: i) the diffuse radiation component is much smaller than the direct radiation component, ii) the diffuse radiation component in the downward direction incident upon a horizontal surface is isotropic, iii) the underlying surface or terrain is Lambertian, that is, the radiation it reflects is isotropic regardless of the nature of incident radiation.

Based on these suppositions it can be seen that the diffuse radiation flux is constituted by a downward isotropic flux $F^{\downarrow(dif)}$ and an upward isotropic flux $F^{\uparrow(dif)}$.

Furthermore, the total diffuse flux intercepted by a tilted surface depends upon the angle of inclination Δ of the perpendicular to the surface with the vertical.

Based on isotropic fluxes upward and downward and on geometric considerations, the total diffuse flux intercepted by an inclined surface is

$$F^{(dif)} = \left| \frac{1+\cos\Delta}{2} \right| F^{\downarrow(dif)} + \left| \frac{1-\cos\Delta}{2} \right| F^{\uparrow(dif)}. \tag{1}$$

In this way the total flux, direct radiation plus diffuse radiation also called global irradiance, intercepted by the same surface is given by

$$F^{(tot)} = f I_o \mu \exp(-\tau/\mu_o) + \left| \frac{1+\cos\Delta}{2} \right| F^{\downarrow(dif)} + \left| \frac{1-\cos\Delta}{2} F^{\uparrow(dif)} \right. \tag{2}$$

In this expression, I_o is the solar constant at the mean earth-sun distance, f is the correction factor of the mean earth-sun distance, $\mu = \cos\theta$, $\mu_o = \cos Z_o$, where Z_o is the zenith angle between the sun's rays and the vertical at the place, and θ is the angle of the sun rays with the normal to the tilted surface in the geographic location being considered, and

$$\cos Z_o = \sin\delta_o \sin\varphi + \cos\delta_o \cos\varphi \cos H_o, \tag{3}$$

where δ_o is the sun's declination, φ is the latitude of the location, and H_o is the hour angle, and

$$\cos\theta = \cos Z_o \cos\Delta + \sin Z_o \sin\Delta \cos(A_o - \psi), \tag{4}$$

in this expression $(Z_o,\ A_o)$ are the angular local coordinates of the sun, A_o being the azimuth of the sun, and $(\Delta,\ \psi)$ are the angular coordinates of the normal to the tilted surface, ψ is the azimuth, τ is the mean optical thickness of the atmospheric layer due to the effect of scattering and absorption and is defined as $\tau = \int_o^\infty k_\lambda(z)dz$, here k_λ is the coefficient of spectral attenuation of the direct solar radiation along the vertical coordinate z; τ and the coefficient of transparency P are related by

$$\tau = -\ln P. \tag{5}$$

$F^{\downarrow(dif)}$ and $F^{\uparrow(dif)}$ are obtained as solutions of the simplified equation of the radiative transfer (Wieder, 1982). With the considerations previously mentioned, the resulting equations entail three basic environmental parameters: the optical thickness of the atmosphere τ, the single scattering albedo $\tilde{\omega}_o$, and the reflectivity of the terrain R. The albedo is defined as $\tilde{\omega}_o = \tau(scat)/\tau$, where $\tau(scat)$ is the optical thickness due to the effect of scattering, of the disperse phase of the atmosphere, and the reflectivity is defined as $R = F^\uparrow/F^\downarrow$, where $F^\uparrow$ and $F^\downarrow$ are the total incident and reflected fluxes of the underlying surface, respectively.

The environmental parameters $\tilde{\omega}_o$ and R are dependent on the wavelength of the radiation, but for practical purposes averaged values along the actinometric spectrum can be used (Wieder, 1982).

In the case of $\tilde{\omega}_o$, an average value was estimated from the values calculated using the theory of G. Mie (Leyva *et al.*, 1985), in which a standard dry distribution of atmospheric aerosol particles of Junge (Junge, 1952) was considered, and with an effective refraction index of the particles of $m = 1.65 - 0.005i$ (Zuev *et al.*, 1973), where $i = \sqrt{-1}$.

For R a mean value of 0.2 was used, corresponding to the majority of the terrain of the area being studied. The optical thickness of the atmosphere was calculated using the model of Hottel (Hottel 1976) considering an atmospheric visibility of 23 kms, which corresponds to a clear day without clouds.

Based on these parameters, the upward and downward diffuse radiation fluxes at surface level are respectively:

$$F^{\uparrow(dif)} = fRI_o\mu_o(1+G)^{-1}(Ge^{\gamma^+\tau} + e^{\gamma^-\tau}), \tag{6}$$

$$F^{\downarrow(dif)} = fI_o\mu_o[(1+G)^{-1}(Ge^{\gamma^+\tau} + e^{\gamma^-\tau}) - e^{-\tau/\mu_o}], \tag{7}$$

where

$$G = -(\gamma^- + D - AR)(\gamma^+ + D - AR)^{-1}e^{(\gamma^- - \gamma^+)\tau}, \tag{8}$$

$$\gamma^\pm = \left[(B-D) \pm ((B+D)^2 - 4AC)^{1/2}\right]2^{-1}, \tag{9}$$

and

$$A = \tilde{\omega}_o, \quad B = 2 - A, \quad C = A/2\mu_o, \quad D = B/2\mu_o.$$

These expressions verify that in the absence of scattering, the downward diffuse radiation flux is zero ($\tilde{\omega}_o = 0$, $F^{\downarrow(dif)} = 0$). It is also evident that when the reflectivity of the terrain is zero, the upward diffuse radiation flux is also zero ($R = 0$, $F^{\uparrow(dif)} = 0$). It is to be noted that the downward diffuse flux depends on R through the function G, because the reflected radiation can be reflected again downward by the atmosphere.

3. Results and conclusions

For the type of atmosphere considered in this study (for a clear day without clouds), and for 113 climatological stations in the state of Guerrero, the surface irradiances were calculated in watts per square meter, for the principal orientations and slopes between 0° and 30° , in 10° intervals. The values of great interest were those corresponding to the north, south and east orientations. The west orientation takes the same values as the east orientation.

Figure 2 shows that the south orientation receives the greatest solar radiation throughout the year. The north orientation receives the smallest solar radiation, regardless of geographic altitude. The south orientation with 30° inclination has the smallest fluctuation throughout the year and should therefore be considered as a climatic stable zone, adequate for agricultural products that need great amounts of solar radiation and little annual climatic variation. Nevertheless, a high value of evaporation is also to be expected, which implies a low availability of humidity in the soil, since the slope is pronounced it is recommended for fruit trees like mango, tamarind, carob, etc.

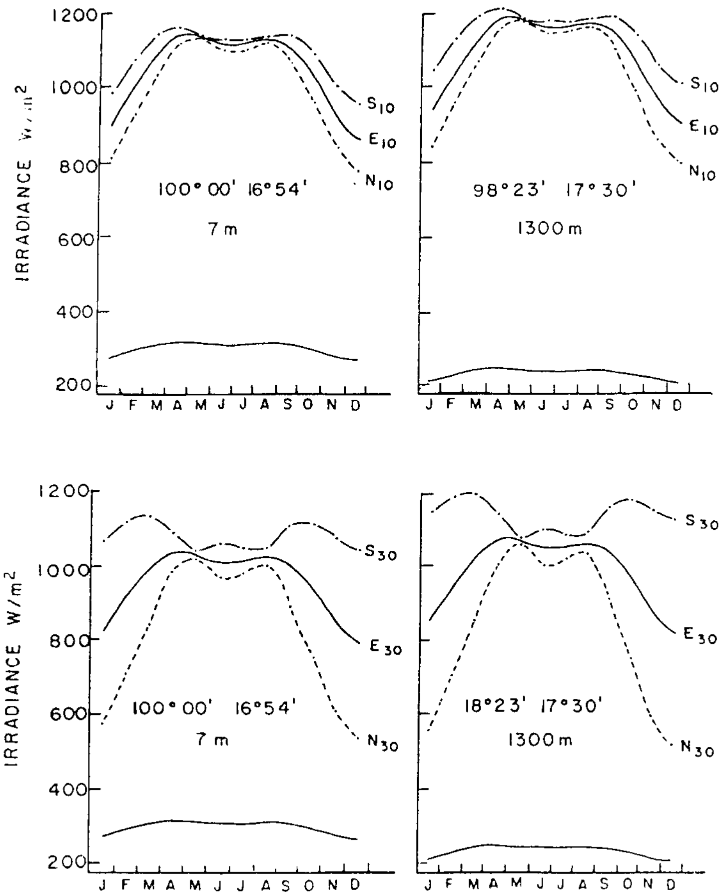

Fig. 2. Irradiance (W/m^2) for the different months of the year, and two locations, (16° 54', 100° 00') and (17° 30', 98° 23'), with 7 and 1300 meters of altitude respectively, with south, east and north orientation and slopes of 10° on the upper part and 30° on the lower, as well as the diffuse irradiance on the lower line of each figure.

In contrast, the north orientations with 30° inclination present two completely different seasons: the winter with extremely low values and the summer with high values of solar radiation. They have a high annual instability and the highest fluctuations which would produce a high stress index in plants of the annual type, for this reason crop rotation is recommended. During the winter season a high availability of humidity is to be expected due to low evaporation and the presence of dew which can take a maximum value for this zone.

During the summer season, the solar radiation values of the different orientations tend to coincide, making the availability of energy indifferent of the orientation. The same kind of crop could be introduced regardless of the orientation. The slopes of 10° during summer have a greater similarity in their values than the slopes of 30° , although in winter exists for the values the same tendency to diverge for the different orientations, these divergences are minimal for the east orientation, reaching a maximum ratio of 3 to 1 for slopes of 30° versus 10°.

In regard to absolute values, it is interesting to note that the east orientation with 10° inclination has higher values during the year than the corresponding ones for 30°, it is also observed that with these slopes, if the altitude increases, the values also rises.

The minimum values of direct solar radiation occur in December, with 767 and 958 W/m^2 . The maximum values correspond to the month of April with 1185 and 1073 W/m^2 , and the secondary maximum correspond to the month of September with similar magnitudes, for slopes of 10° and 30° respectively.

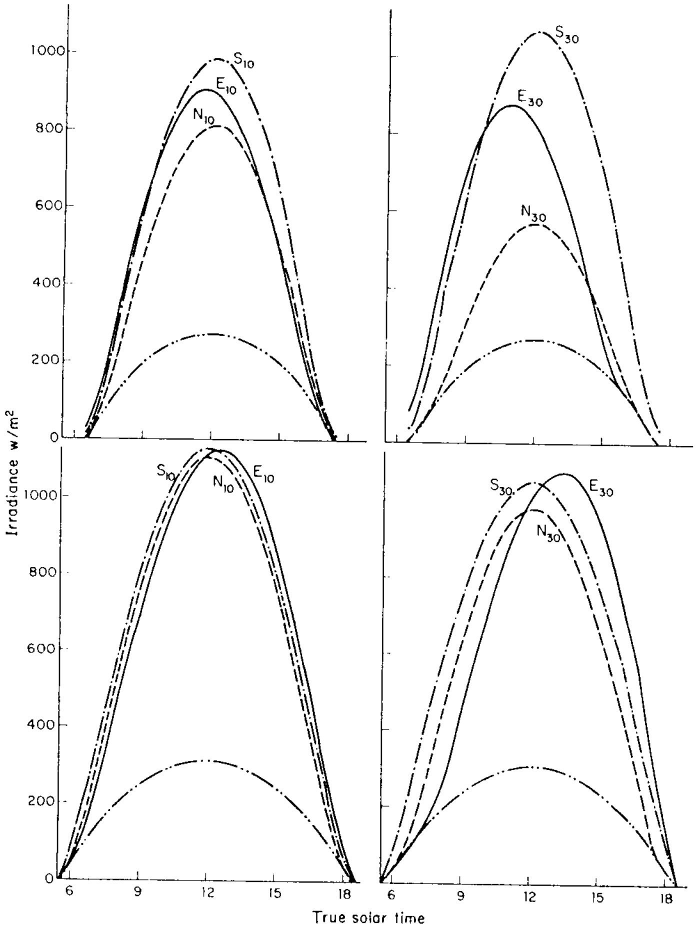

Fig. 3. Irrandiance for the different hours of the day, with orientations and slopes already considered, in (16° 54', 100° 00'), and for the 15th of January and July, respectively.

The maximum values for the north orientation and for the different slopes occur in May and August, coinciding with the minimum values observed for the south orientation with a 30° slope.

The maximum values for the south orientation vary for the different slopes, occurring in March and October for slopes of 30° and in April and September for slopes of 10°.

It is to be noted that for the month of May a remarkable similarity on the values for all the orientations and slopes considered, when the longitude, latitude and altitude are the same. The values of diffuse radiation are influenced by altitude, that is, they decrease with increasing altitude.

Figure 3, shows the global irradiance for the different hours of the day, for the orientations and slopes already considered, for one location, and for the 15th of January and 15th of July respectively. It can be seen that for 10° slopes and for the time where the maximum values occur, the values are of similar magnitude and small variation. The hour for maximum value in January tends to be similar to the one in July. The south orientation receives the maximum values of solar radiation and is exposed to solar radiation for a longer period of time. For more pronounced slopes, the maximum values and their time of occurrence tend to have a greater divergence. Also, it can be seen that the different orientations present different times of maximum solar radiation, even for the month of July where a greater homogeneity would be expected. During January, the south orientation presents the greatest values in magnitude and number of hours, for this reason it is recommended for delicate crops that can not bear the effects of freezing.

In Figure 4 the same parameters are compared for the 15th of January with respect to the values observed for the horizontal. It can be seen that the south orientations receives more radiation than the horizontal, where as for the north orientation it is less. The divergence increases as the slopes increases, this effect being more pronounced for the north orientation than for the south orientation.

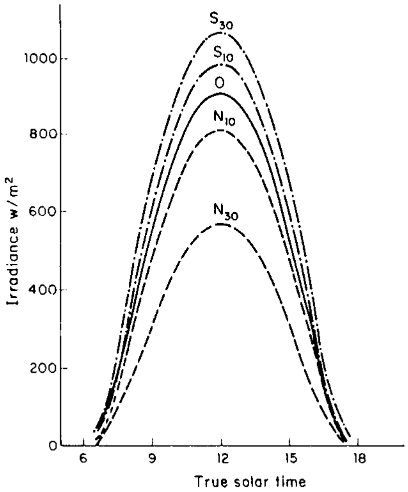

Fig. 4. Irradiance for the different hours of the day, in 15th of January with respect to the values observed on the horizontal (o).

For the south orientation, Figures 5 and 6 show that as the slopes increase, the radiation also increase and that as we pass from winter to summer there is a greater homogeneity in the micro-zones. In all of them five micro-regions of maximum direct radiation appear for the east, south and west orientations and for all the slopes. One of these micro regions corresponds to the

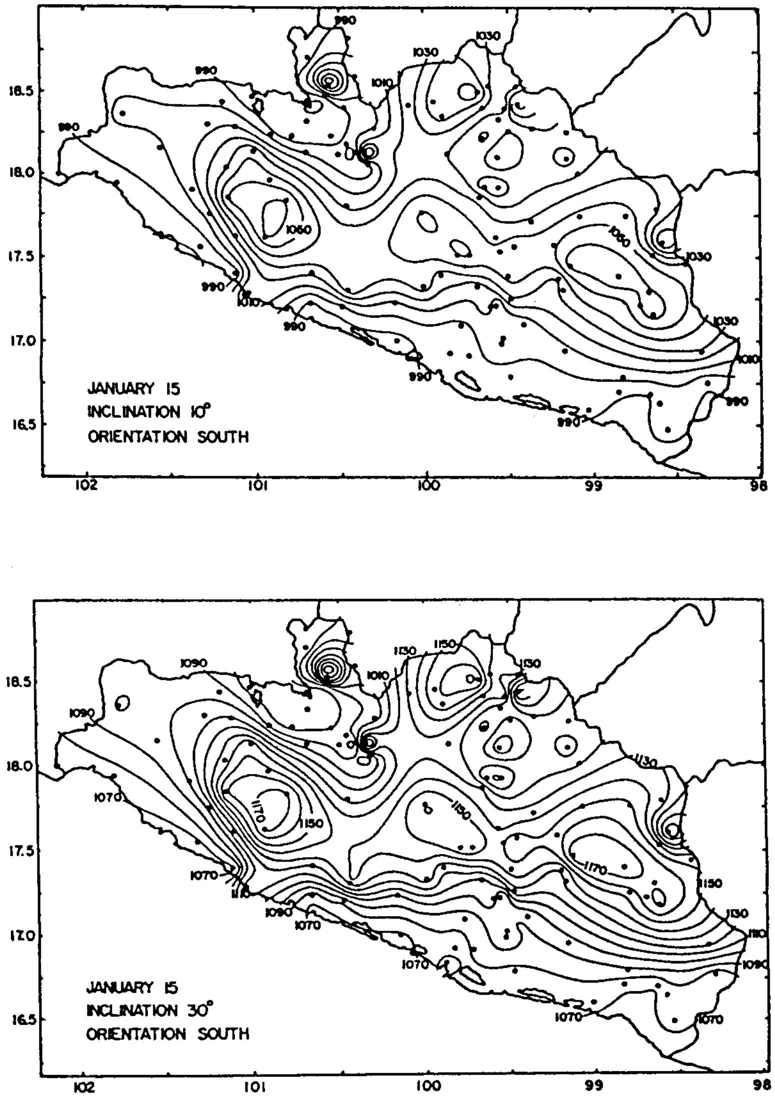

Fig. 5. Irradiance isolines for the Guerrero State with south orientation in January 15 and 10° and 30° slope respectively.

region between Cutzamala de Pinzón, Altamirano and Tlalchapa, another one to Chichihualco, another one to Iguala, part of Huitzuco and part of Tepecoacuilco, another one to the region between Atlixtac and Atlamajalcingo del Monte and the last one where the municipalities La Unión, Coyuca de Catalan, Tecpan de Galeana and Petatlan join together. It is interesting to observe for small inclinations for the same orientation, when passing from winter to summer the radiation values increase, whereas for inclinations of 30° they decrease. For the east orientation, and for 10° slopes, gradient intensities is almost the same when passing from winter to summer.

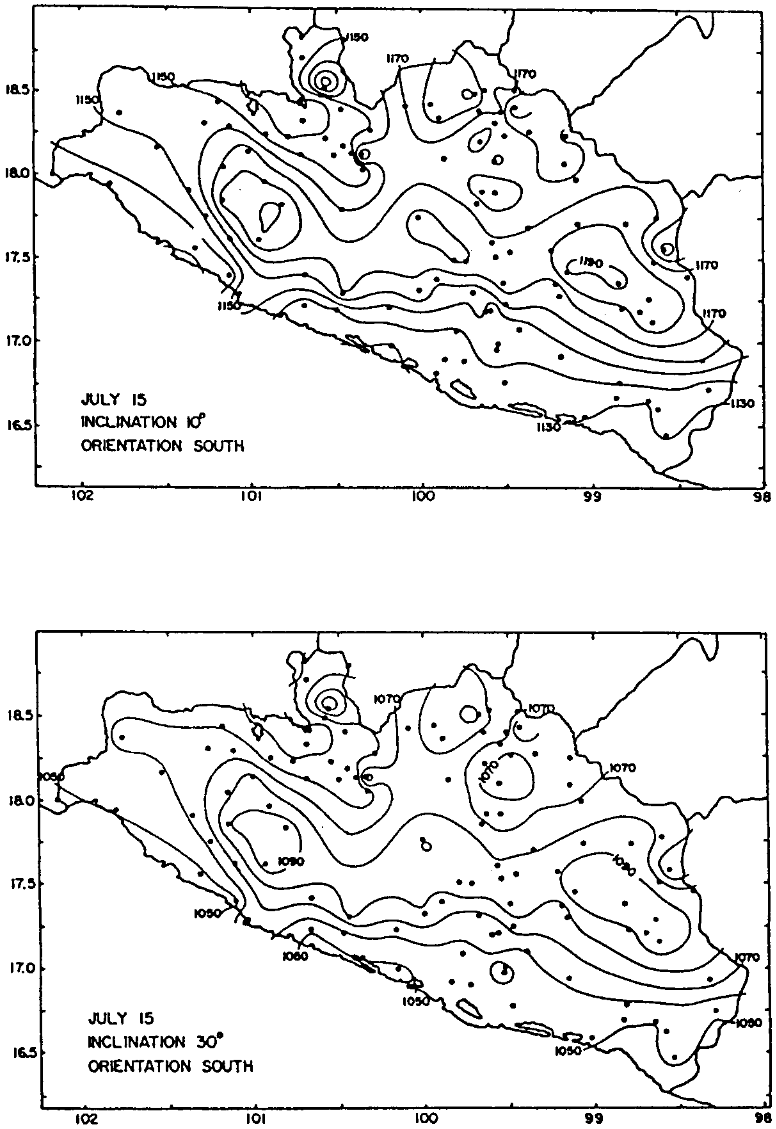

Fig. 6. Idem Figure 5, for July 15.

This is not the case for the magnitudes of the solar radiation which are greater in the summer. We can conclude that the methodology being used, which is based on the knowledge of the availability of energy in zones of rough topography, presents excellent possibilities of application, principally in the production of food of agricultural origin growth in environments of optimum comfort increasing the quantity and quality of these products.

Acknowledgements

We are indebted to Dieter Berhoff and Alfonso Estrada B. for his technical support.

REFERENCES

Hottel, H. C., 1976. A simple model for estimating the transmittance of direct solar radiation through clear atmospheres. *Solar Energy*, **18**, 129-134.

Junge, Ch. E., 1952. Gesetzmässigkeiten der Grössenverteilung Atmosphärischer Aerosole über dem Kontinent. Ber. Oeut. Wetterd. U. S. - Zone No. 35, 261.

Leyva, A., A. Muhlia y O. B. Vasiliev., 1985. Acerca del cálculo de las características del campo de radiación dispersado por partículas de Mie. *Geofís. Int.*, **24**, 265-294.

Wieder, S. 1982. An Introduction to Solar Energy for Scientists and Engineers. John Wiley & Sons, New York, 58-60.

Zuev, U. Ye., L. S. Ivliev and K. Ya. Kondratyev., 1973. Recent results from studies of atmospheric aerosols. *Izv. Atmosph. Ocean. Phys.*, **9**, **4**, 204-371.