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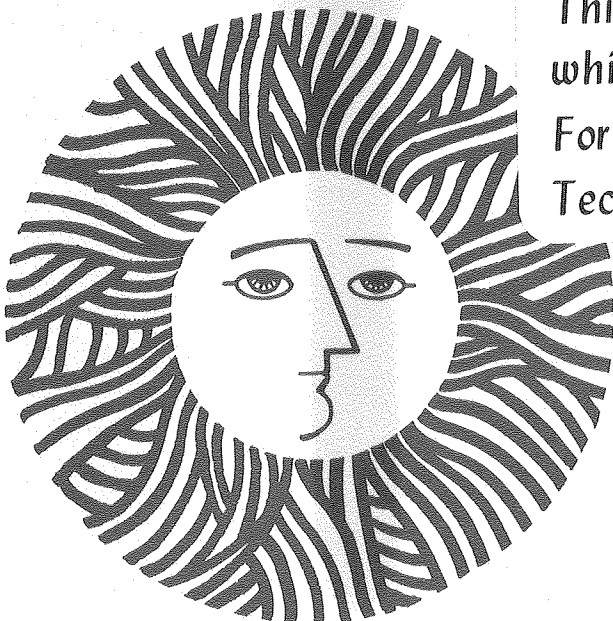
THE EFFECT OF CIRCUMSOLAR RADIATION ON THE ACCURACY OF PYRHELIOMETER MEASUREMENTS OF THE DIRECT SOLAR RADIATION

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The Effect of Circumsolar Radiation on the Accuracy of Pyrheliometer
Measurements of the Direct Solar Radiation

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ABSTRACT. Because of circumsolar radiation (the solar aureole) a pyrheliometer of usual design will yield an overestimate of the direct solar radiation (originating from the disk of the sun). An effort has been underway to use specially developed "circumsolar telescopes" to measure the angular and wavelength dependence of the circumsolar radiation for application to concentrating solar energy systems. In this paper data from these instruments are used to provide information on the pyrheliometer overestimate. Presented are: sample measurements of the telescopes, the range of values (overestimates) obtained over the course of a month, and the long term average effect. A brief discussion is given on the relationship of the results to concentrating solar energy systems.

INTRODUCTION. Circumsolar radiation (the solar aureole) results from the scattering of direct sunlight through small angles by atmospheric aerosols (dust, water droplets or ice crystals in thin clouds, etc.). A pyrheliometer of usual design will have a field-of-view about 5° wide, as compared to the $1/2^\circ$ angle subtended by the sun. As a consequence, the reading of the pyrheliometer will include not only the direct solar radiation (originating from the disk of the sun) but a substantial fraction of the circumsolar radiation. Thus, the reading of a pyrheliometer is an overestimate of the direct solar radiation.

A typical concentrating solar energy system will have a field-of-view that (like the pyrheliometer) accepts the direct sunlight and some fraction of the circumsolar radiation. This fraction will be different from (and usually less than) that for the pyrheliometer, and hence there will be some error involved in using the pyrheliometer measurement to estimate the amount of sunlight available to such systems.

An effort has been underway for some time to measure the angular and wavelength dependence of the circumsolar radiation in a systematic way, in order to provide detailed information on the amount of solar (direct plus circumsolar) radiation available to concentrating systems (1,2). The information presented here will be largely limited to a discussion of the error (or overestimate) made by a pyrheliometer in estimating the direct solar radiation. Some brief remarks will then be made on concentrating systems.

INSTRUMENTATION. The instrument systems (called Circumsolar Telescopes) were designed and fabricated at LBL. Each system has a "scanning telescope" mounted on a precision solar tracker. The telescope is

mechanically scanned thru an arc of 6° with the sun at the center of the arc. A digitization of the brightness of the sun or circumsolar radiation is taken every $1.5''$ of arc, with a complete scan taking one minute of time. A thermal detector is used in order to obtain measurements over the entire solar spectrum. A pyrheliometer of the Active Cavity Radiometer (ACR) type (3) is included in the instrumentation system. The ACR provides the usual normal incidence measurement as well as a calibration factor for the telescope scan. The telescope and pyrheliometer have matched ten-position filter wheels: one open or "clear-filter" position, eight interference filters that divide the solar spectrum into eight intervals of roughly equal energy content, and one opaque filter to monitor detector noise. A complete measurement cycle takes ten minutes of time, and thus any given measurement, such as the clear filter scan, is available once every ten minutes. The instruments are automated and function during all sky conditions.

The telescopes have been operated primarily at locations for which the instruments can play a dual role: (a) characterization of a region or climate and (b) provision of site specific data for proposed or actual concentrating solar energy systems. Locations include Albuquerque, New Mexico, Ft. Hood, Texas, the Mojave desert area of California, and Atlanta, Georgia.

Although work has been done on the colored filter measurements (4), the clear filter (all wavelengths) data are most relevant to the current discussion and are the only ones that will be considered in this paper.

SAMPLE TELESCOPE SCANS. Two sample scans of the telescope are displayed in Figure 1. Fig 1(a) is for clear sky conditions, and Fig 1(b) for a sky with haze or thin clouds. For each graph, the brightness, $I(\theta)$, of the sun and circumsolar region is plotted as a function of angular distance, θ , from the center of the sun. In Fig. 1(a) the brightness of the circumsolar radiation is observed to be several orders of magnitude down from that of the sun's disk. In the case of Fig. 1 (b), a substantial amount of the light from the sun's disk has been scattered into the circumsolar region.

Let θ_r be one solar radius ($\approx 1/4^{\circ}$), and θ_s refer to the end of the telescope scan of $\approx 3^{\circ}$. The Direct Solar radiation, S , and the Circumsolar radiation, C , are then defined as:

$$S = \int_0^{\theta_r} I(\theta) d\Omega \quad , \quad C = \int_{\theta_r}^{\theta_s} I(\theta) d\Omega$$

where Ω is the solid angle. To provide a measure of the relative amount of radiation in the circumsolar region it proves useful to define the Circumsolar Ratio, R , as

$$R = C/(C+S)$$

The full scan angle of the telescope of 6° is about the same as the 5-6 $^{\circ}$ field-of-view of the usual pyrheliometer. The relationship between the telescope scan and a pyrheliometer is then:

$C+S \cong NI$, the normal incidence pyrheliometer reading

$C/(C+S) \cong$ the error (overestimate) made in estimating the direct solar radiation.

The values of $C/(C+S)$ and NI are indicated on each graph in Fig. 1. For the clear sky case the normal incidence value is a relatively high 932 w/m^2 , and the circumsolar ratio is less than 1%. For the purposes of estimating the amount of solar radiation available to a concentrating solar energy system, this amount would generally be considered negligible. For the graph for hazy skies (Fig. 1(b)) the circumsolar ratio is quite significant (over 20%) for a moderate to high normal incidence level of 623 w/m^2 . Under such sky conditions a measure of the circumsolar radiation would be required to properly calculate the amount of sunlight available to an operating highly-concentrating system.

DISTRIBUTION OF VALUES OVER A MONTH. Figure 2(a) plots, for a month of measurements from Albuquerque, the circumsolar ratio against the normal incidence reading of the pyrheliometer. The same data, but selected for the middle of the day (defined as the period from three hours after sunrise to three hours before sunset) are shown in Fig 2(b). This selection reduces to a minimum the effect on the data of variations in air mass. The cluster of values at high NI and low $C/(C+S)$ correspond to clear-sky conditions during the middle portion of the day. The tail of rapidly decreasing NI values and slowly increasing $C/(C+S)$ values (seen in Fig. 2(a) but not Fig. 2(b)) corresponds to clear sky conditions towards sunrise and sunset when atmospheric absorption processes dominate the attenuation of the sunlight. The band of high circumsolar levels during the middle of the day (see esp. Fig 2(b)) corresponds to periods of time when aerosol scattering from haze or thin clouds dominates the attenuation processes. These values are the most interesting since they show that there is a significant fraction of the time when the pyrheliometer can be in error by several percent to tens of percent for moderate to high levels of solar radiation.

The general pattern of Figure 2 is characteristic of data obtained from the telescopes from the various locations and for the various seasons of the year. However the relative intensity of the different parts of the pattern does show considerable month-to-month variation.

LONG TERM AVERAGE. A concentrating solar energy system will be operating under essentially all of the sky conditions represented in Figure 2. It is of interest, then, to compute the average effect of the circumsolar radiation. Displayed in Fig. 3(a) is the energy-weighted monthly average circumsolar ratio for the Mojave desert area over a three year period. [The ratio is obtained by separately summing the direct solar (S) and the circumsolar (C) radiation in energy units over the course of a month, and then forming the circumsolar ratio as defined above.] This quantity is approximately the same as the fractional overestimate that a pyrheliometer would make in estimating the monthly total direct solar radiation. Fig. 3(b) shows the ratio of the monthly total direct solar radiation to the extraterrestrial value. This quantity (similar to the commonly used K_t of Ref. 5) compensates for the seasonal changes in the length of the day and the varying earth-sun distance and hence can be taken as an indicator of "cloudiness." The circumsolar ratio shows a distinct seasonal dependence with a winter peak of as much as 7% and

summer minima of about 2%. There is also a noticeable correlation with the total/extraterrestrial parameter; with a tendency for cloudy months to have high circumsolar levels. Comparable data from Albuquerque (not shown) do not have any obvious seasonal dependence. Rather, the circumsolar ratio shows a trend of increasing values from 2-3% in May-June, 1976, to 4-5% in February-March, 1977, and then, with considerable fluctuations, a more or less steady value thereafter. Data from non-desert areas have a generally higher average value of the circumsolar ratio.

CONSIDERATIONS WITH RESPECT TO CONCENTRATING SYSTEMS. Even the most highly concentrating systems will have a field-of-view that is somewhat greater than the angle subtended by the sun. Thus the overestimate of a pyrhelimeter for such systems will be less than the overestimate of the direct solar radiation. The data from the circumsolar telescopes has been applied both to specific designs and to general classes of concentrating systems in other studies (2, 6). Although the effect is reduced, the general conclusions are much the same:

- 1) For sky conditions such as haze and cirrus clouds, a measure of the circumsolar radiation is necessary to understand the performance of an operating, highly-concentrating system.
- 2) On the average the effect is a few percent; which is on the same order as many other energy loss mechanisms for concentrating systems, and should therefore be considered in the design of such systems.

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REFERENCES

1. D.F. Grether, D. Evans, A. Hunt, and M. Wahlig, "Measurement and Analysis of Circumsolar Radiation," Proceedings of the Annual DOE Insolation Resource Assessment Program Review, Davis, Calif., August 1980; Lawrence Berkeley Laboratory report LBL-11645, October 1980.
2. D. F. Grether, D. Evans, A. Hunt and M. Wahlig, "Application of Circumsolar Measurements to Concentrating Collectors," Proceedings of the 1979 International Congress of the International Solar Energy Society, Atlanta, Ga., June 1979; Lawrence Berkeley Laboratory report LBL-9412, June 1979.
3. R. C. Willson, "Active Cavity Radiometer," Applied Optics, vol. 12, 1973, p. 810.
4. D.B. Evans, D.F. Grether, A.J. Hunt, and M. Wahlig, "The Spectral Character of Solar and Circumsolar Radiation," Proceedings of the Annual Meeting of the American Section of the International Solar Energy Society, Phoenix, Ariz., May 1980; Lawrence Berkeley Laboratory report LBL-10802, June 1980.

5. B.Y.H. Liu and R.D. Jordan, "The Interrelationship and Characteristic Distribution of Direct, Diffuse, and Total Solar Radiation," Solar Energy, vol. 4, no. 3, 1960, p. 1.
6. P. Bendt and A. Rabl, "Effect of Circumsolar Radiation on Performance of Focusing Collectors," Solar Energy Research Institute report SERI/TR-34-093, April 1980.

FIGURE CAPTIONS

Fig. 1(a) A sample scan of the circumsolar telescope for clear-sky conditions at Atlanta, Georgia. The various quantities given on the graph are described in the text. The solid, vertical line indicates an empirically determined edge of the sun.

(b) A sample scan for hazy sky conditions at Barstow, California.

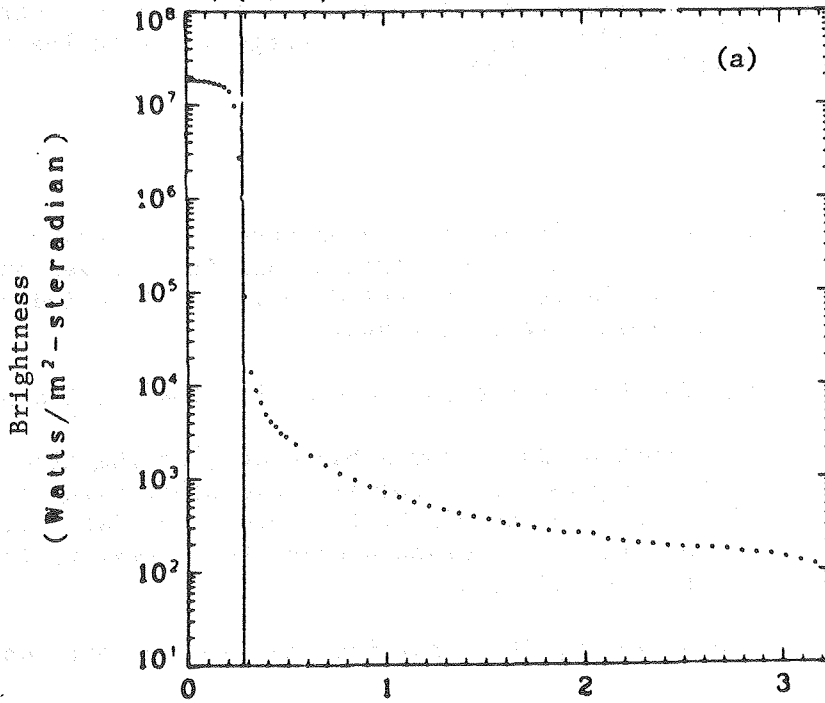
Fig. 2(a) A plot, for a month of data from Albuquerque, of the circumsolar ratio, $C/(C+S)$, versus the normal incidence reading of the pyrheliometer. The notation "66 HAD NI<12" refers to data points that were excluded from the graph because the normal incidence reading was negligible ($< 12 \text{ w/m}^2$).

(b) The same data as in Fig 2(a), but for the middle portion of the day.

Fig. 3(a) The monthly value of the circumsolar ratio, as defined in the text, plotted from July, 1976 thru December, 1979 for the Mojave desert area: China Lake, then Barstow, and finally Edwards, California. The small vertical arrows indicate the changes from one telescope location to the next.

(b) The corresponding value of the monthly total direct solar radiation divided by the extraterrestrial solar radiation.

ATLANTA (SCOPE 1)
79/02/20 10:33 SOLAR TIME
 $C/(C+S) = .46\%$ NI = 932 W/m²



BARSTOW, CA (SCOPE 4)
79/05/06 12:24 SOLAR TIME
 $C/(C+S) = 25.3\%$ NI = 623 W/m²

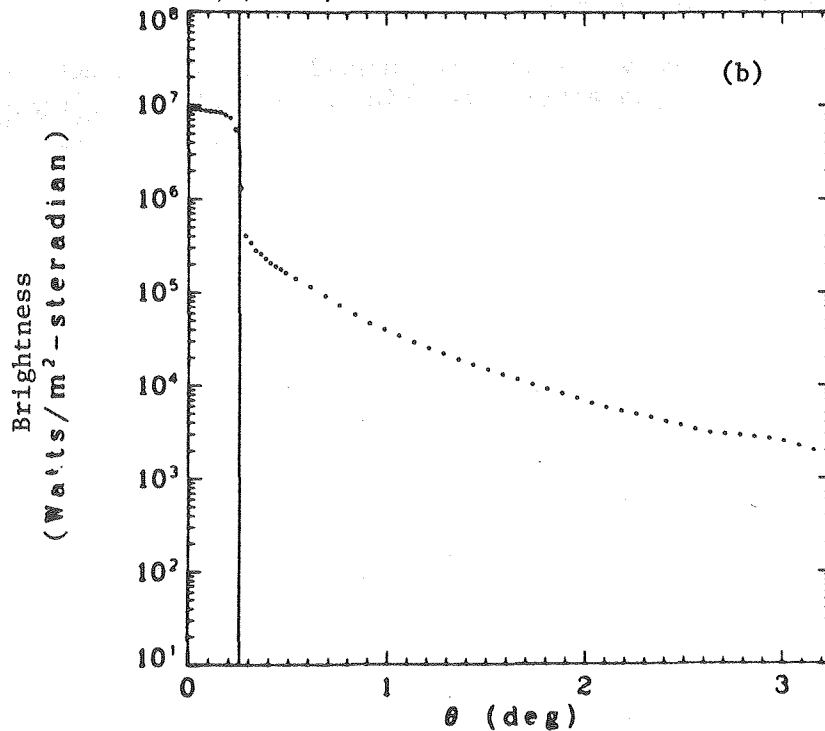
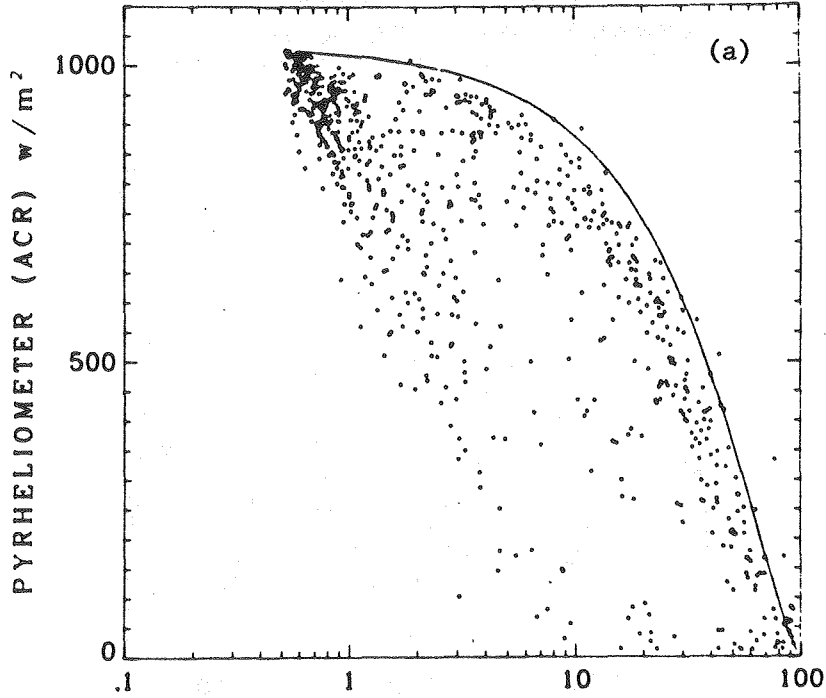


Figure 1

ALBUQUERQUE OCT 1979
ALL SKY CONDITIONS
771 PTS SHOWN. 66 HAD NI<12



MIDDLE OF DAY
382 PTS SHOWN. 4 HAD NI<12

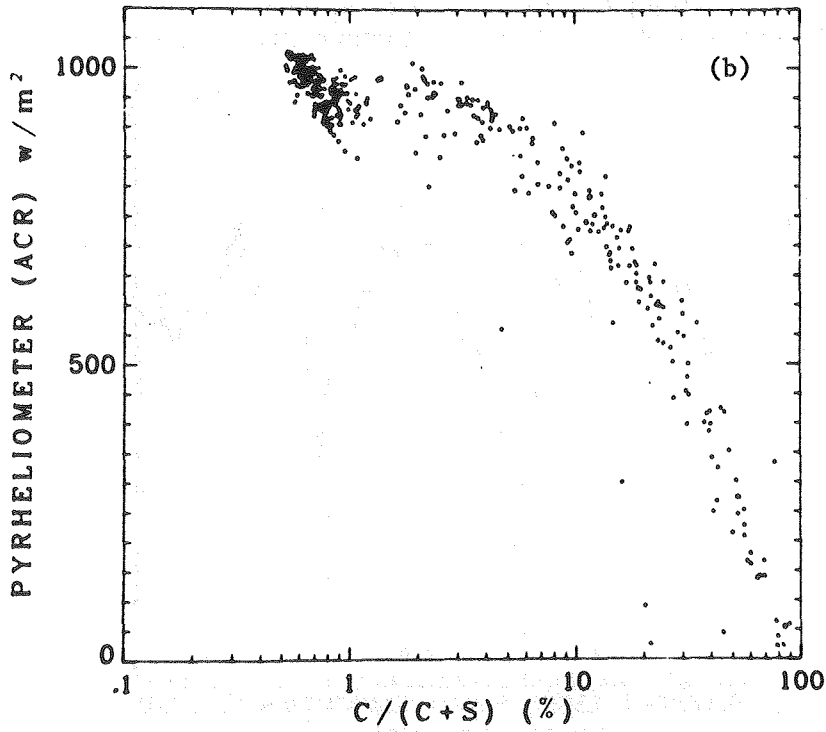
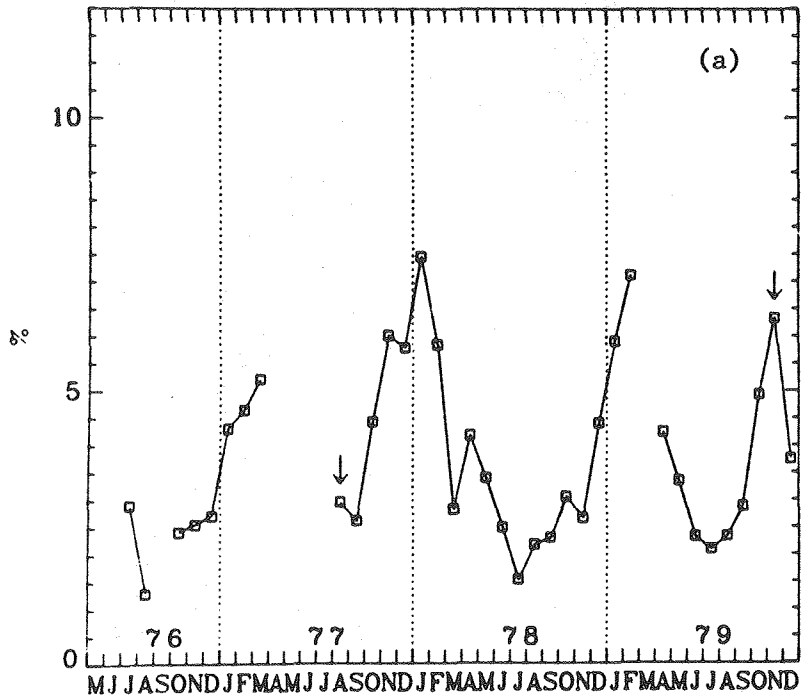


Figure 2

CHINA LAKE/BARSTOW/EDWARDS CA
CIRCUMSOLAR RATIO
THRESHOLD = 50 w/m²



TOTAL ENERGY/EXTRATERRESTRIAL
THRESHOLD = 50 w/m²

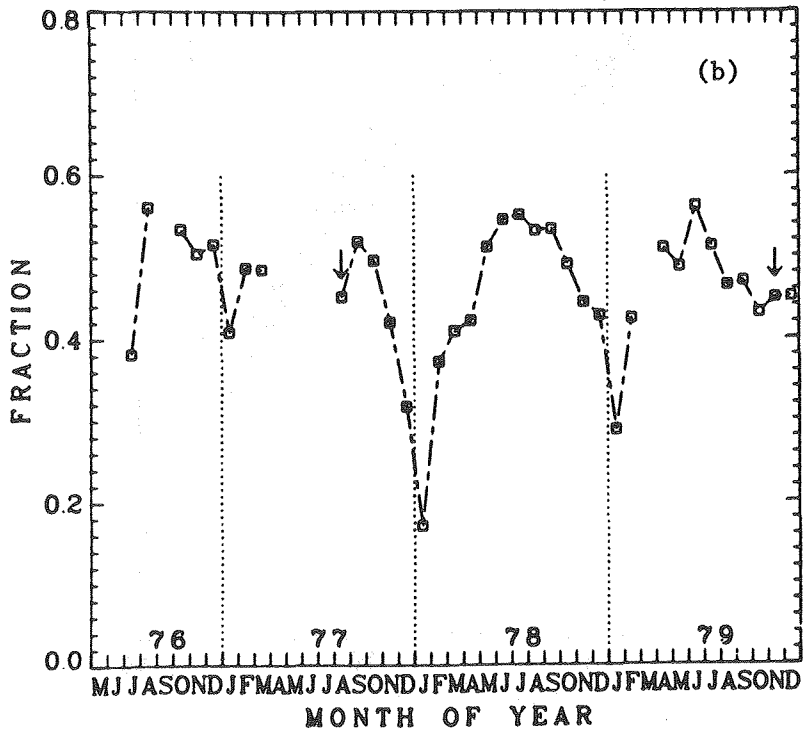


Figure 3