AEROSPACE REPORT NO.
ATR-80(7747)-1, VOL. I

Measurements of Typical Insolation Variation at Daggett, California

Volume I: Methodology and Sample Data

Prepared by
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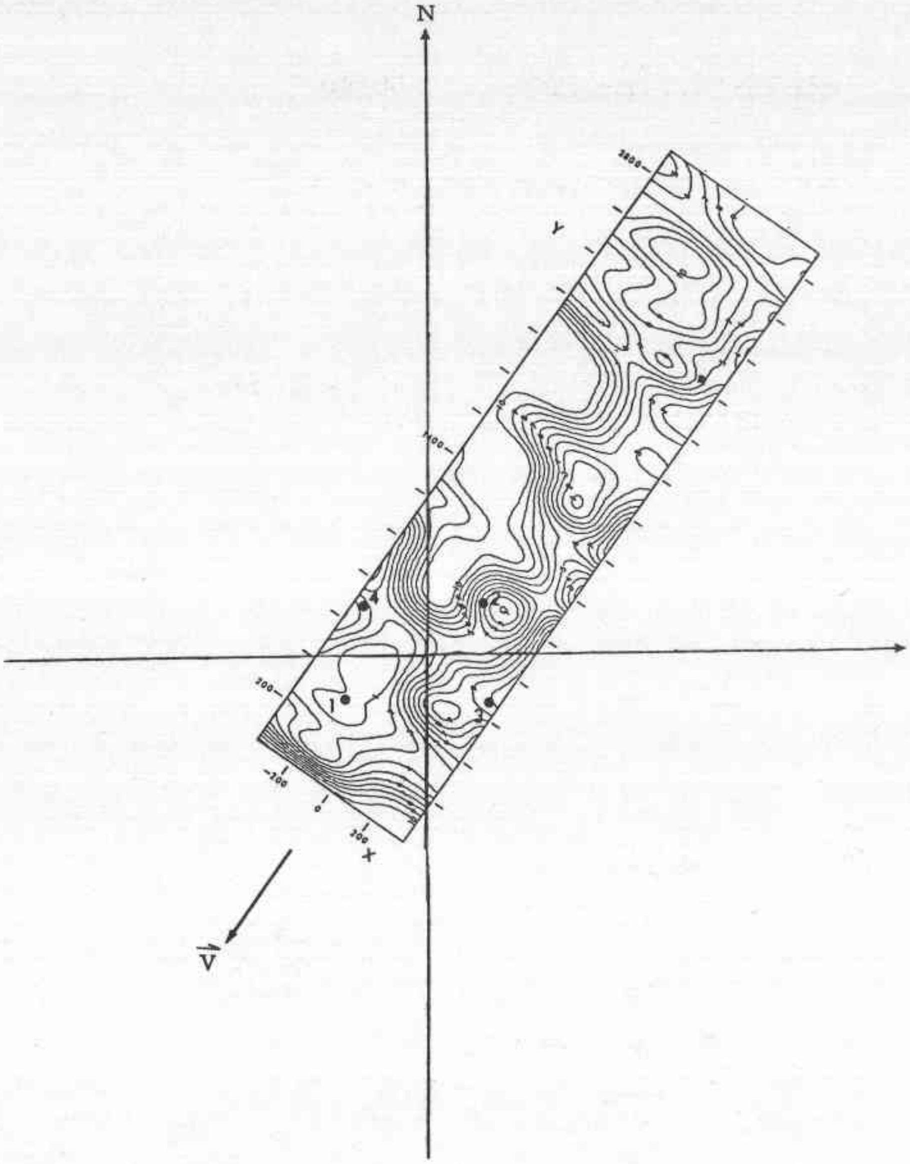
Chemistry and Physics Laboratory

1 March 1980

Prepared for
U.S. DEPARTMENT OF ENERGY
San Francisco Operations Office
Oakland, California 94612

Contract No. DE-AC03-78ET20517

Laboratory Operations
THE AEROSPACE CORPORATION



Insolation Transmittance Map

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ABSTRACT

Observations of insolation variation for a site representative of the Ten-Megawatt Solar Thermal Pilot Plant (approximately 600 meters in size) were made at 16-second intervals for the period from August 1978 through October 1979 at a location near Barstow, California. The analysis of data from this experiment is reported. Insolation variations over the experiment site indicate partly cloudy conditions existed approximately 25 percent of the time for the one-year experimental period. During these partly cloudy periods, shadows with dimensions less than the pilot plant heliostat field size were observed. Rates of insolation change greater than 30 W/m^{-2} sec^{-1} were also observed; however, these observations were limited by the sampling rate of the experiment. A procedure was developed to interpolate to any point within the experiment array by means of insolation variation maps. Detailed data packages are supplied for eight days that were determined to be typical of the different partly cloudy conditions observed during the year. These measurements indicate that variations are much more severe than were originally assumed in the derivation of the Ten-Megawatt Solar Thermal Pilot Plant operating requirements. These data are useful for determining the thermal cycling that the pilot plant receiver will experience and for determining the control strategy necessary for operating the plant under partly cloudy conditions.

ACKNOWLEDGMENTS

The results reported were obtained only through the dedicated cooperation of the people and organizations listed below. The authors of this report are deeply grateful for all contributions.

1. R. N. Schweinberg, Solar Ten-Megawatt Project Office, provided direction, funding, and means for coordination of the experiment.
2. Sandia Laboratories contributed instruments, a trailer to house the base station, and cables to link the remote stations to the base station.
3. Southern California Edison Company provided the site, installed the basic facilities for the experiment, and conscientiously maintained the experiment. R. J. Yinger provided coordination. C. L. Coss, Coolwater plant engineer, supervised the experiment operation, which was carried out by F. Henry, D. Haskell, D. Anderson, and D. Whitney, instrument technicians.
4. E. C. Flowers, National Oceanic and Atmospheric Administration, Environmental Research Laboratories, provided the normal incidence pyrheliometer, calibrated against national standards, which forms the basis of the calibration of the present experiment.
5. The personnel of the Federal Aviation Agency Flight Service Center, Daggett, California, supported this experiment by directly supplying us with copies of the hourly surface weather observations at Daggett.
6. Enthusiastic support and coordination were provided by Energy Projects Directorate Project Manager H. D. Eden, Aerospace; post-experiment calibrations were done by J. Sandstrom, Aerospace.

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FIGURES

FIGURES (Continued)

TABLES

I. INTRODUCTION

The design of control systems and the analysis of thermal stress cycling of a central receiver solar thermal energy system requires information concerning the variability of the insolation spatially over the area associated with the collector field and temporally on a time scale comparable to the thermal time constant of the receiver. Because these insolation data did not exist for the solar thermal electric pilot plant to be built at Daggett, California, an experiment was deployed in August 1978 to obtain data from which the appropriate parameters could be extracted. The experiment and initial data analysis have been described in detail in an earlier report (Ref. 1). Only a brief summary of the experimental description is included in this report.

A statistical analysis of data from four days in August 1978 is included in Ref. 1. The objective of that analysis was to characterize the insolation variation by a few statistical parameters that could be used for initial determinations of energy system parameters. The significant conclusions of that preliminary analysis are:

1. Significant insolation variations occur over the collector field. There are cloud shadows with dimensions smaller than the collector field.
2. The rate of insolation change at a point can be greater than 30 W m^{-2}-s^{-1}. Direct insolation can go from full on to off in a time period equal to, or shorter than, the 16-second sampling interval of the experiment.
3. Partly cloudy conditions occur during a significant portion of the daylight hours, even for a desert location such as Barstow.

The experiment operated continuously for more than 14 months (3 August 1978 through 17 October 1979) except for occasional power outages and equipment malfunctions. The extensive data obtained support our preliminary conclusions. The analysis of data from 12 months of operation is discussed in this report. A somewhat different analytical approach is used here in order to (1) provide detailed data for the simulation of typical partly cloudy sequences and (2) to estimate how frequently these partly cloudy events occur. In Sections II and III, these problems are addressed. Section IV is a summary of the results of the present study with recommendations for future work. Detailed data packages for eight representative days are provided in Appendix A.

The experiment consists of insolation sensors placed approximately at the corners of a quadrilateral circumscribing an area approximately equivalent to the pilot plant collector field. For security, the experiment was located within the fenced area surrounding the evaporation pond at the Southern California Edison (SCE) Company Coolwater Generating Station. (The actual pilot plant site is located adjacent to the northeast corner of this area.) A sketch of the experiment layout is provided in Fig. 1-1.

The instruments used, their location with reference to Fig. 1-1, and their respective data channels are given in Table 1-1. The trailer located at Station 4 also housed the data acquisition system and power supplies for the entire experiment. To minimize the initial expense and maintenance requirements, only Licor 200S sensors were used at the remote stations, i.e., Stations 1 through 3.

The analog output from each sensor was converted to a pulse rate proportional to the sensor analog output and transmitted to the data acquisition system over a balanced line for immunity from electrical noise. The balanced line from each sensor was connected to a separate digital counter. Every 16 seconds, the number of pulses accumulated in each counter was recorded on an IBM compatible magnetic tape with an incremental tape recorder. The counters were then reset for the next sampling interval. The data recorded were the number of counts, which is proportional to the energy received by the sensor during that 16-second interval. The storing of data on the tape and the resetting of the counters took place within approximately 1 msec, so the time period over which data were averaged was essentially identical for all sensors.

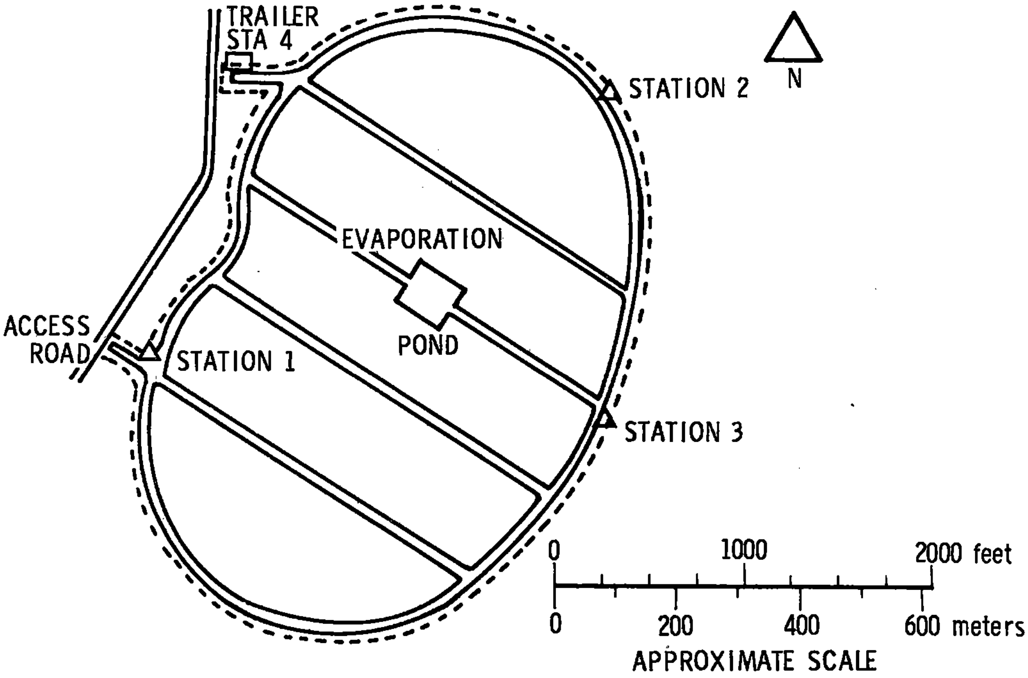


Fig. 1-1. Insolation Variation Experiment Site at Southern California Edison Company Coolwater Generating Station at Daggett

Table 1-1. Instrumentation for Insolation Variation Experiment at Daggett

Data Channel	Station	Instrument
0	4	Eppley Precision Spectral Pyranometer (PSP)
1	1	Licor 200S Pyranometer
2	2	Licor 200S Pyranometer
3	3	Licor 200S Pyranometer
4	4	Licor 200S Pyranometer
5	4	Eppley Shade Ring with Licor 200S Pyranometer
6	4	Eppley Model 8-48 Black and White Pyranometer
7	4	Eppley Normal Incidence Pyrheliometer (NIP)

The experiment was serviced by Southern California Edison Coolwater Generating Station personnel. They normally visited the site at least three times a week, resetting the normal incidence pyrheliometer (NIP) pointing and cleaning the sensors. Once a week, the data tape on the recorder was replaced and mailed to Aerospace. At Aerospace, the data were plotted on a computer line printer in the format shown in Figs. 1-2 and 1-3. On these plots, instruments are identified by data channel number. Where two or more channels coincide, an X replaces the channel number. The plots were used to identify the occurrence of problems with the experiment equipment and to screen the data in order to select periods for more detailed analysis.

The accuracy of data from this experiment depends on the calibration of the sensors and the calibration and stability of the analog-to-frequency (A/F) converters used to transmit the data from the sensors to the tape recorder. These are discussed in detail in Appendix B.

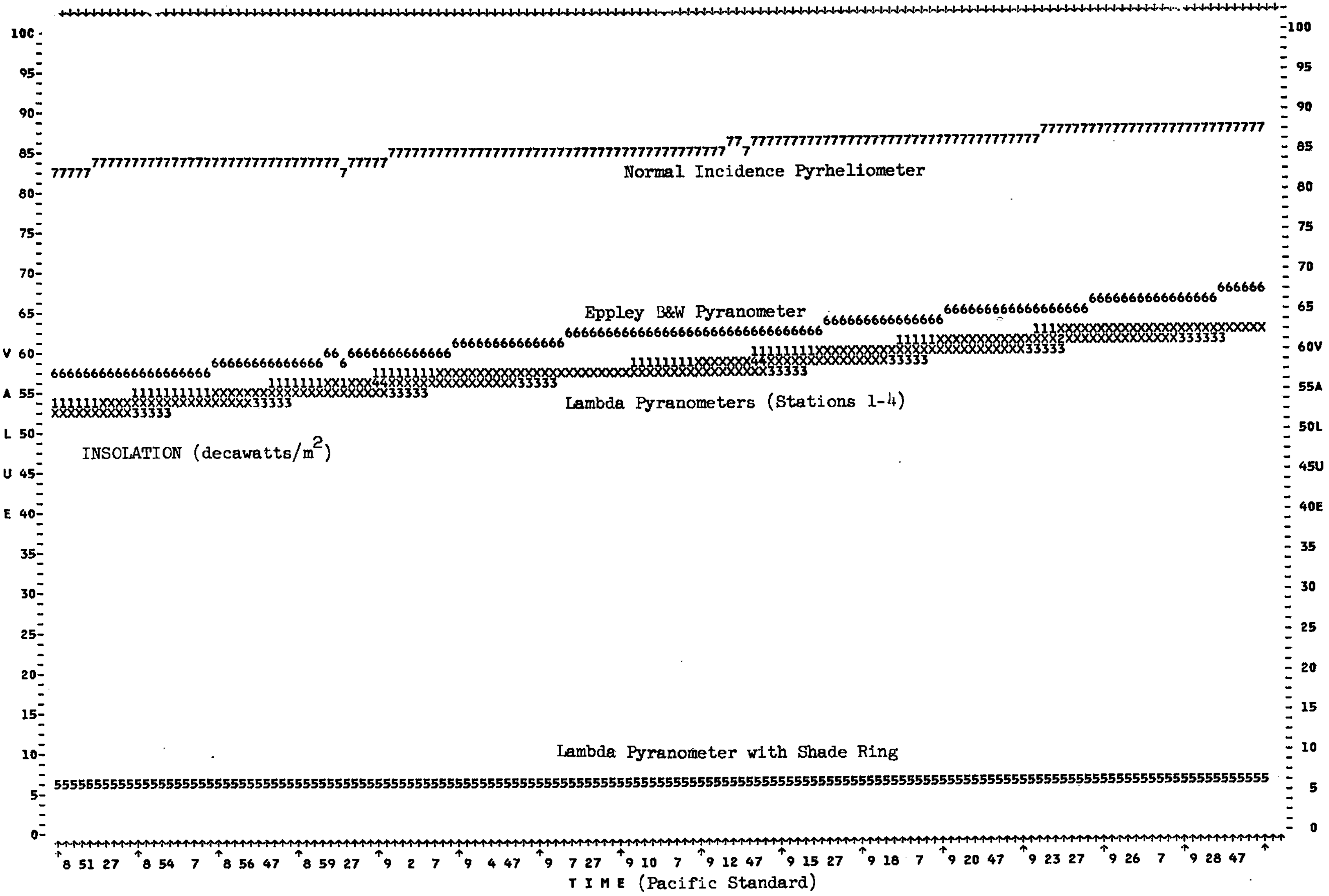


Fig. 1-2. Raw Data Display for Clear Day, October 1978

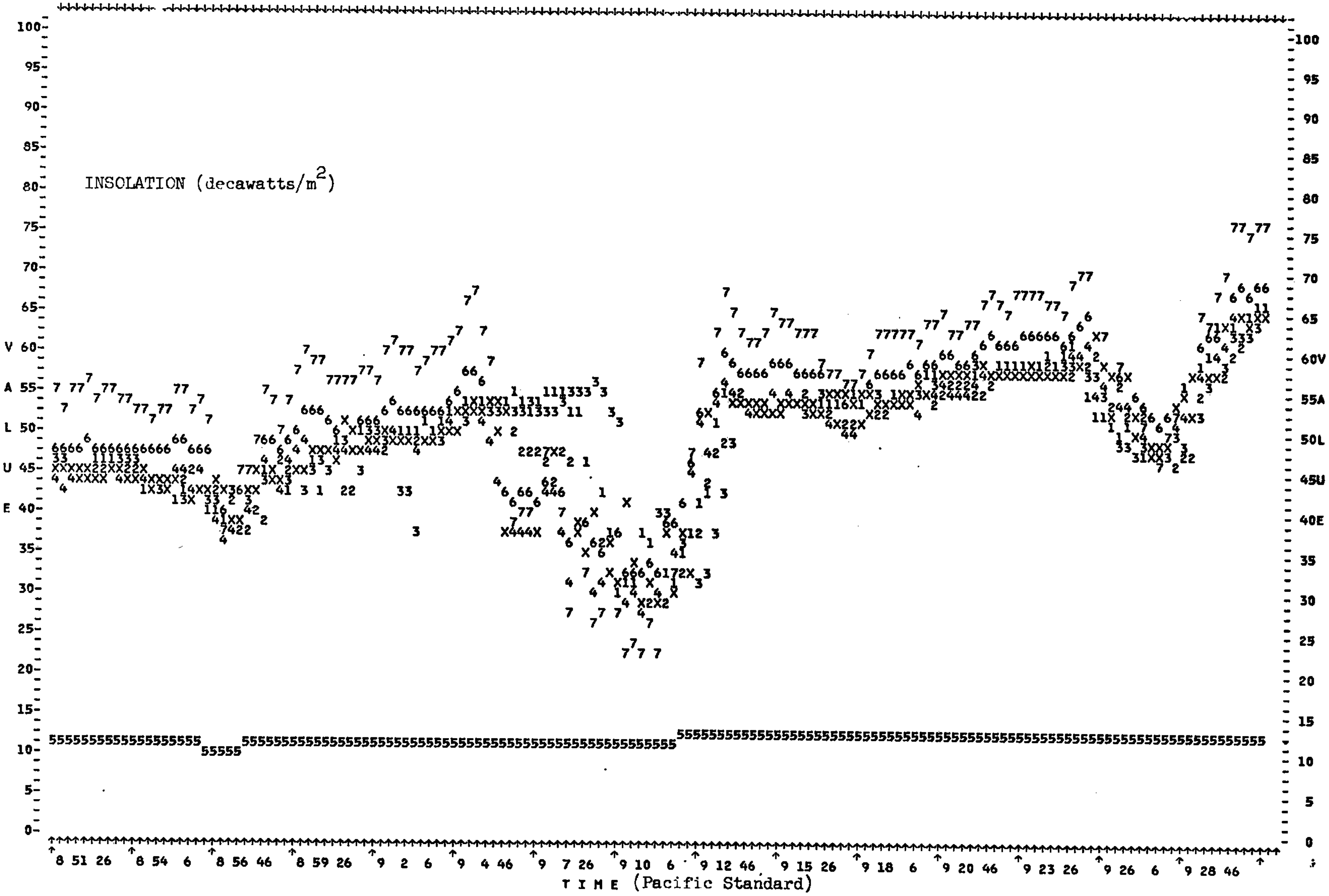


Fig. 1-3. Raw Data Display for Cloudy Day, 8 October 1978

II. TYPICAL INSOLATION VARIATION SCENARIOS

Insolation variation for selected scenarios is described in detail in this section. This part of the study was carried out in two stages (1) the identification of typical scenarios and (2) the description of the insolation variation pattern. The processes used in these two stages are discussed, and examples are given. The results of the analyses for each of the selected scenarios are included in Appendix A.

A. INSOLATION VARIATION SCENARIO SELECTION

The selection of a small number of insolation scenarios to characterize the wide variety of partly cloudy conditions at Barstow was difficult. Developing any objective scheme would involve several parameters, and it would be a major effort. Furthermore, the cost of processing all data in sufficient detail to obtain several parameters would have been outside the scope of this project. Therefore, instead of the use of extensive computer processing, typical scenarios were selected by visual observation.

In the first stage, all the computer printer plots (of which Figs. 1-2 and 1-3 are examples) were separated into four categories: clear, partly cloudy, completely overcast, and experiment not working. The result was a series of monthly plots (Figs. 2-1a through 2-1ℓ). The criteria used to separate the data into the first three categories were based on the following NIP data:

1. Clear days indicated by notation or no line. No cloudy periods of over 10 minutes observed and the direct insolation level greater than 80 percent of normal clear day values for that time.

2. Partially cloudy periods indicated by broken lines. Characterized by frequent changes in direct radiation for periods lasting at least 10 minutes. The direct values return to greater than 50 percent of clear day values.

3. Overcast periods indicated by solid lines. Characterized by a drop in direct insolation with few (less than one per 10 minutes) returns to direct insolation greater than 50 percent of clear day values.

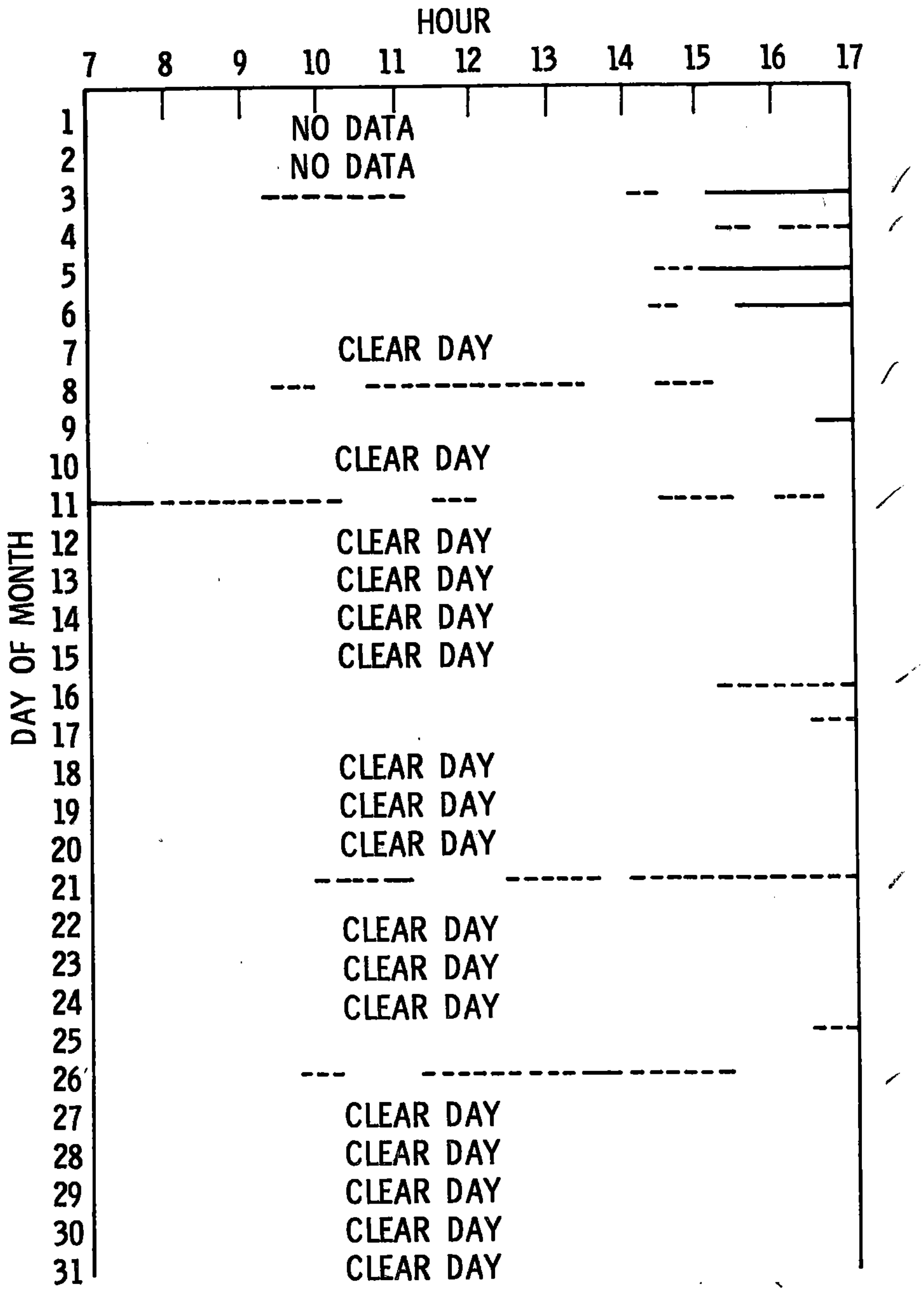


Fig. 2-1a. Cloudy and Partly Cloudy Periods at Daggett, August 1978

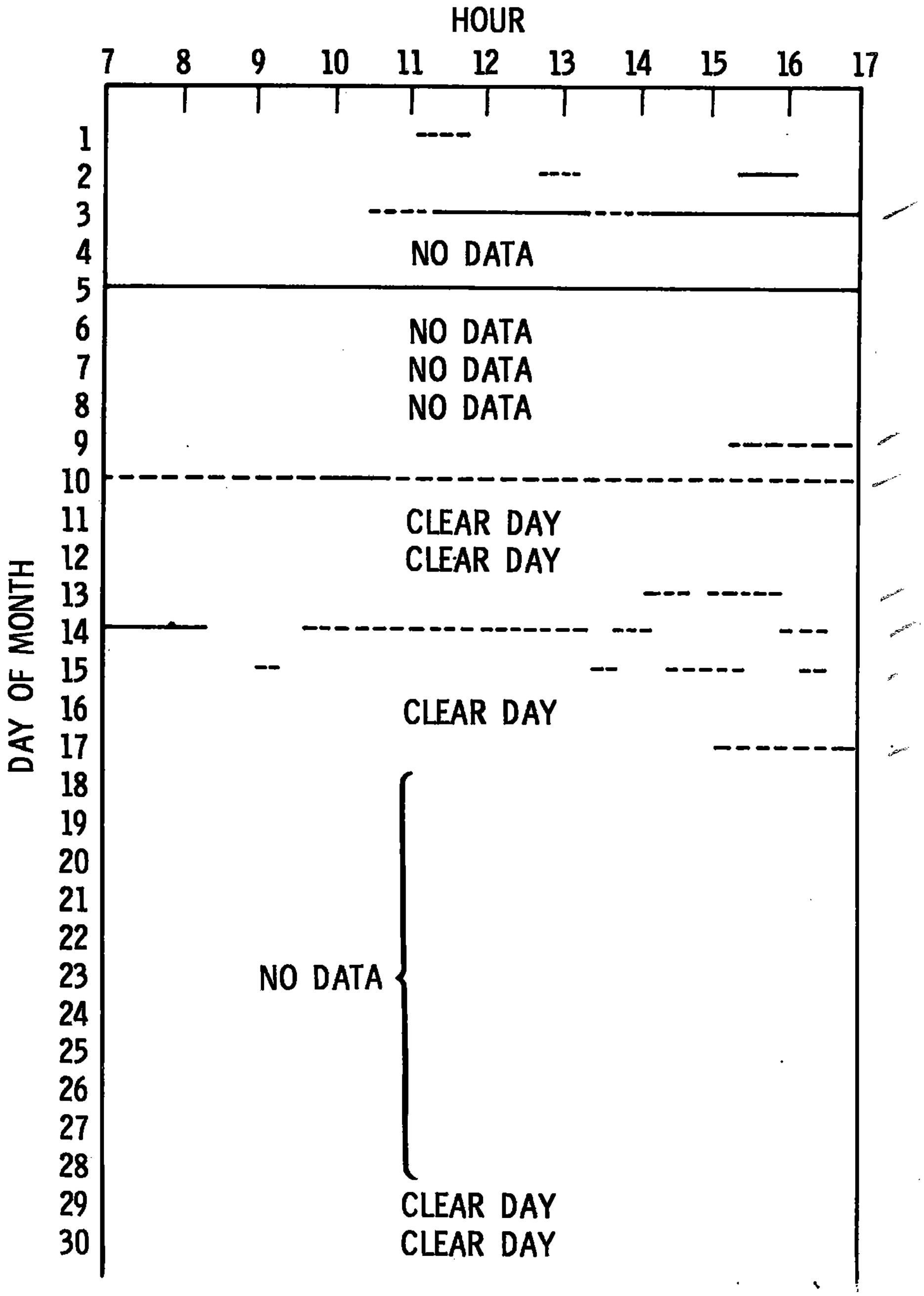


Fig. 2-1b. Cloudy and Partly Cloudy Periods at Daggett, September 1978

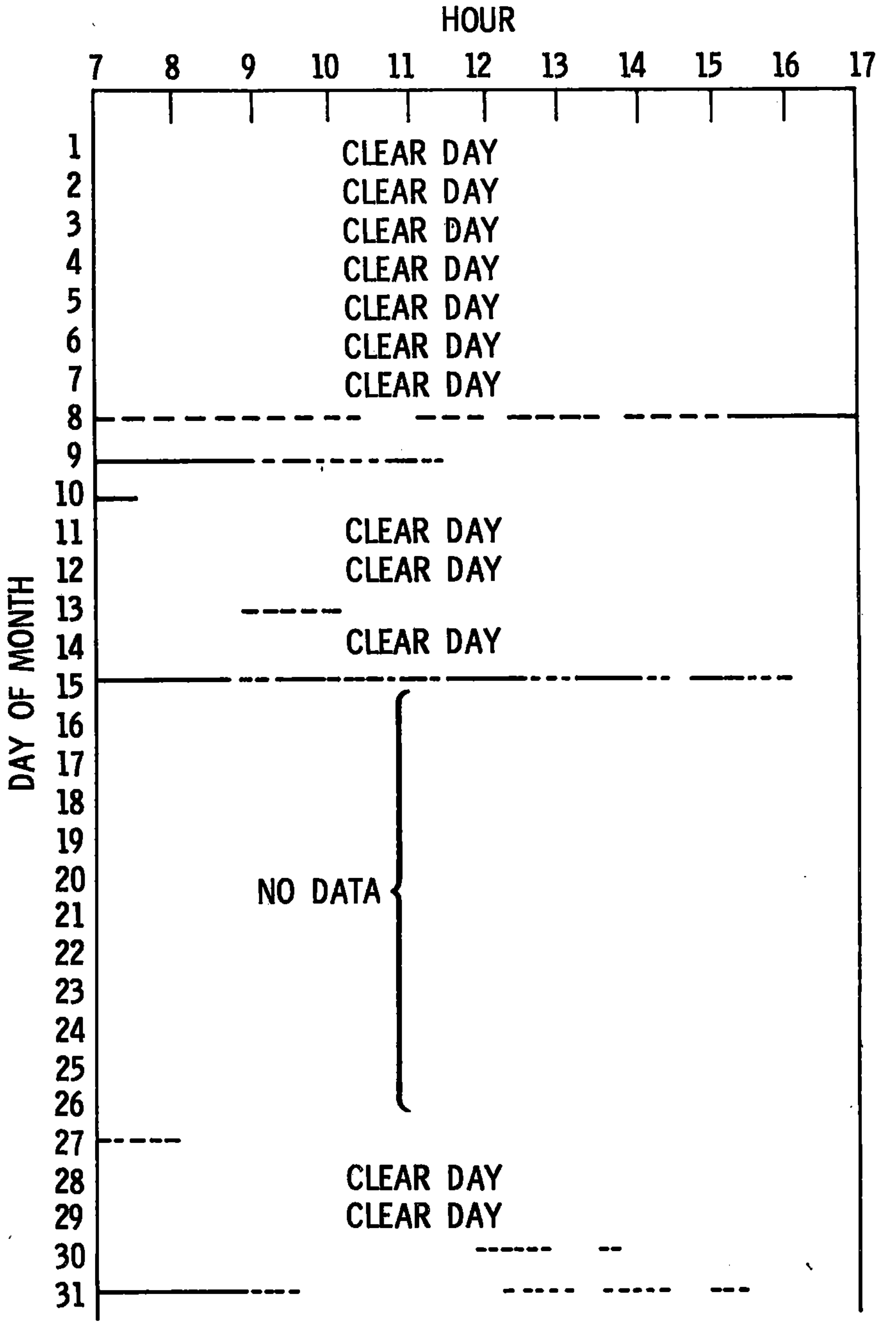
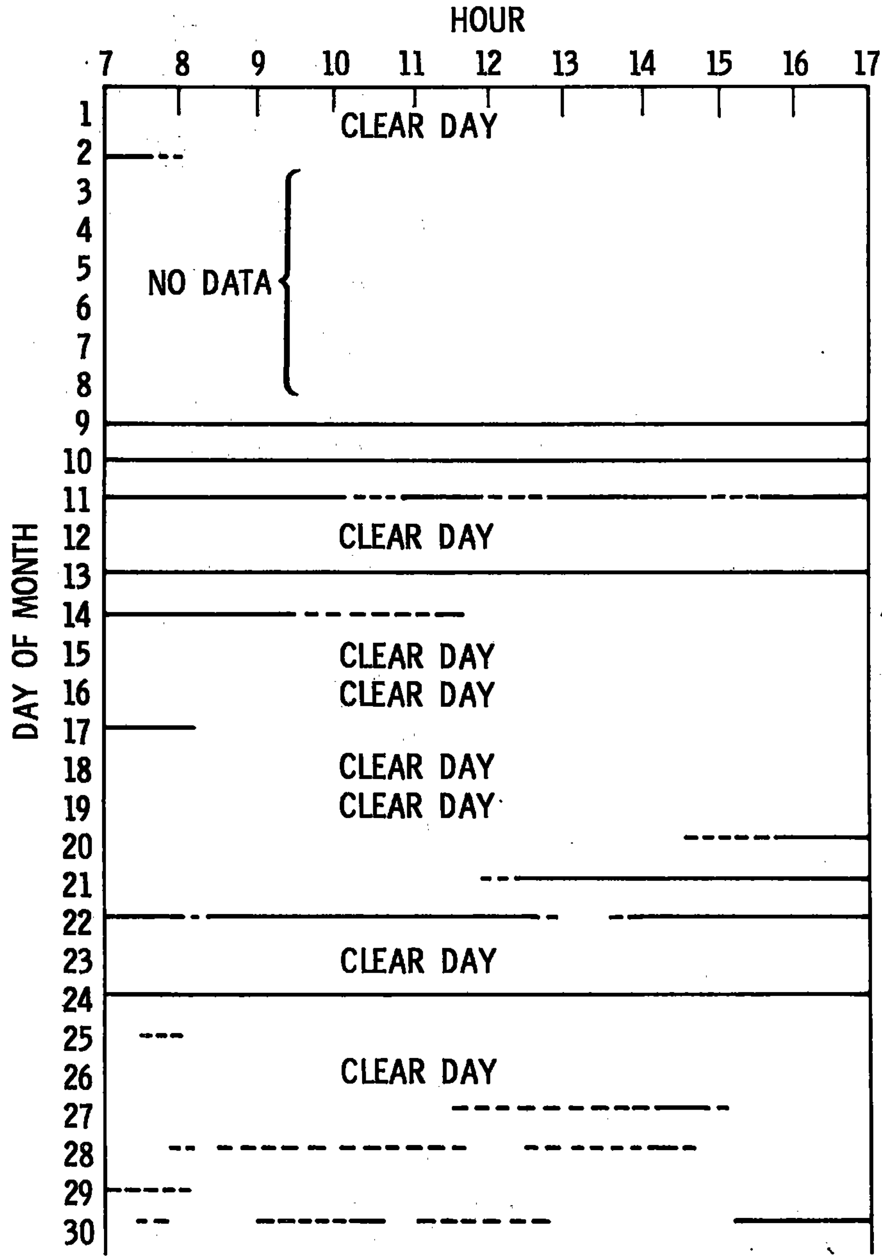


Fig. 2-1c. Cloudy and Partly Cloudy Periods at Daggett, October 1978



26 thru Nov

Fig. 2-1d. Cloudy and Partly Cloudy Periods at Daggett, November 1978

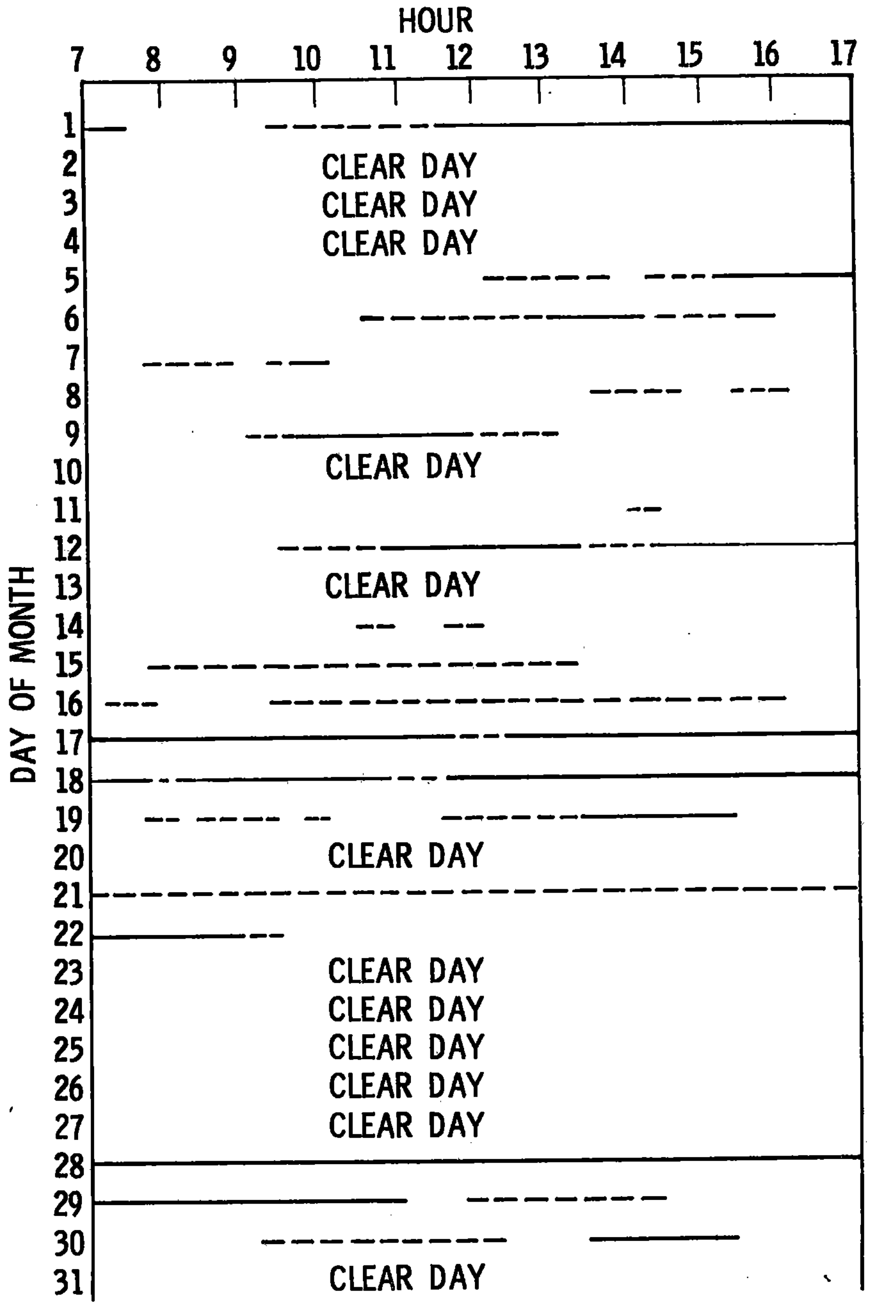


Fig. 2-1e. Cloudy and Partly Cloudy Periods at Daggett, December 1978

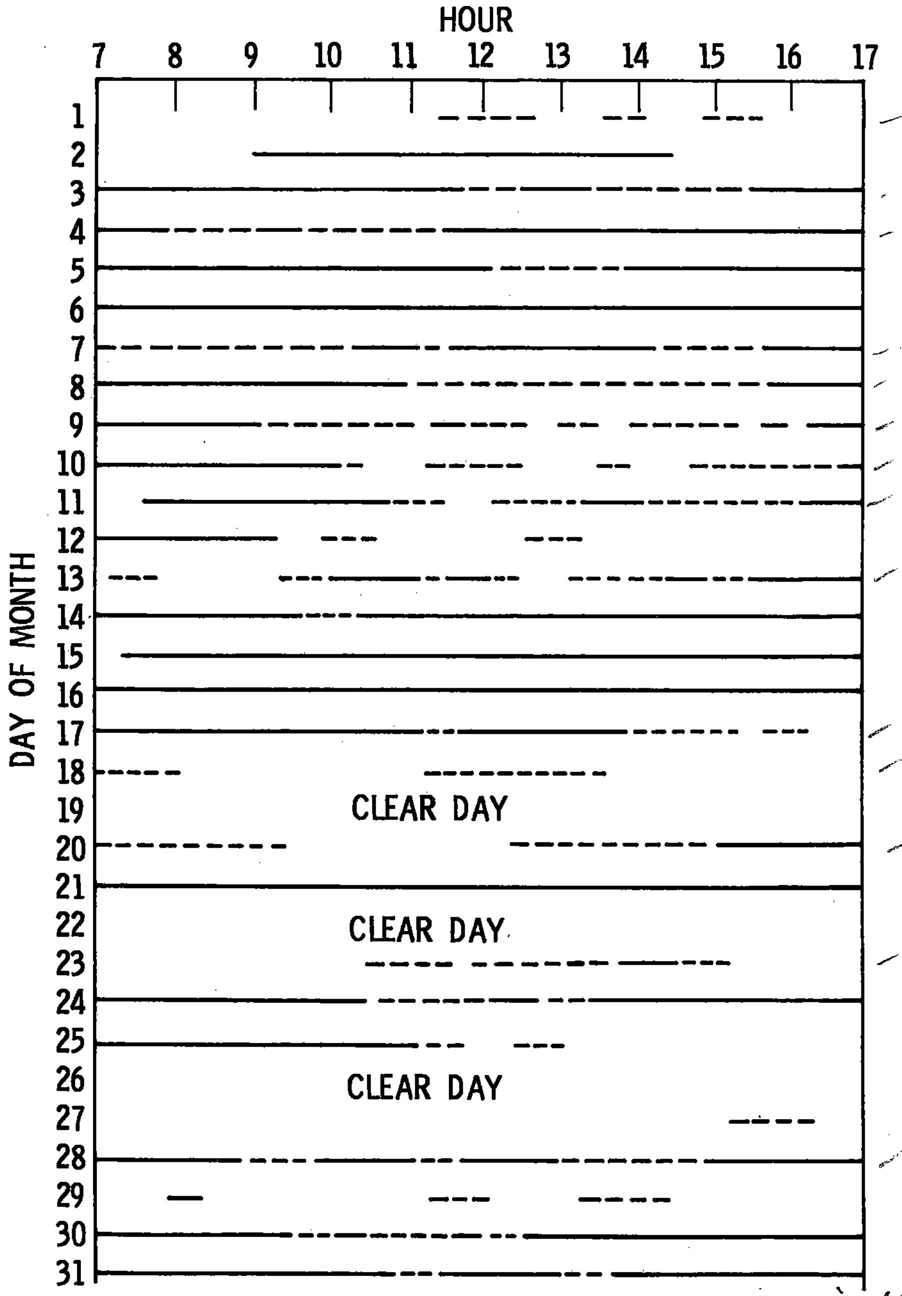


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Fig. 2-1f. Cloudy and Partly Cloudy Periods at Daggett, January 1979

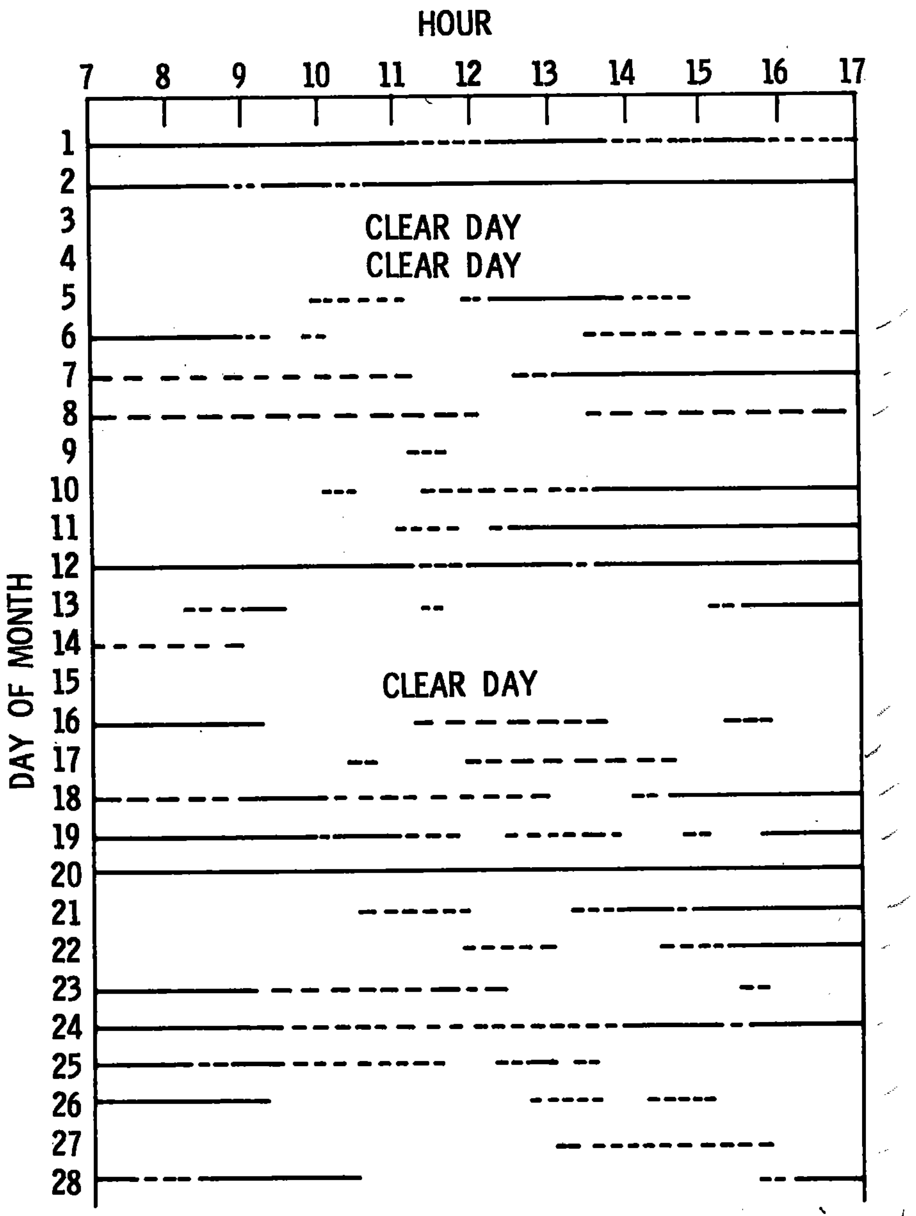

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Fig. 2-1g. Cloudy and Partly Cloudy Periods at Daggett, February 1979

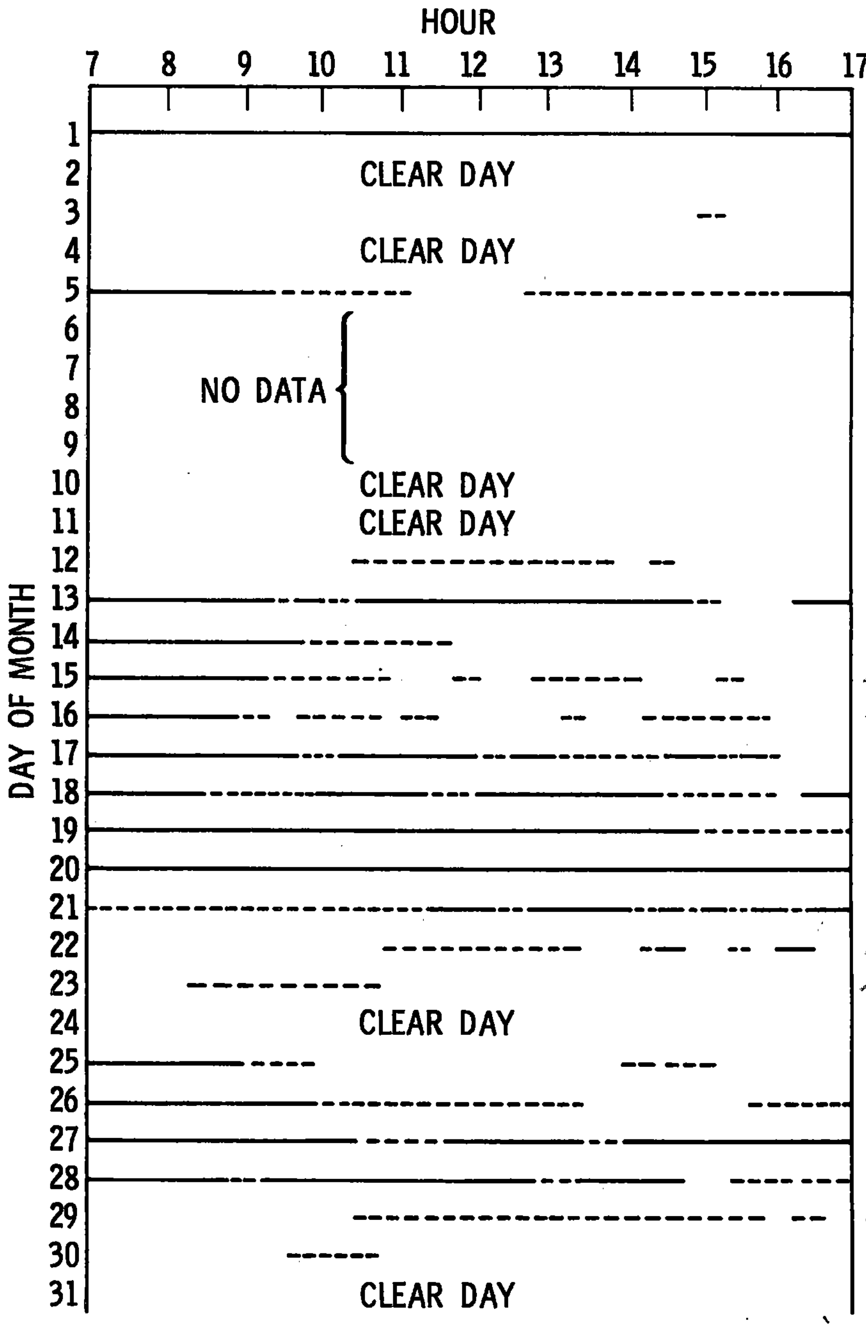

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Fig. 2-1h. Cloudy and Partly Cloudy Periods at Daggett, March 1979

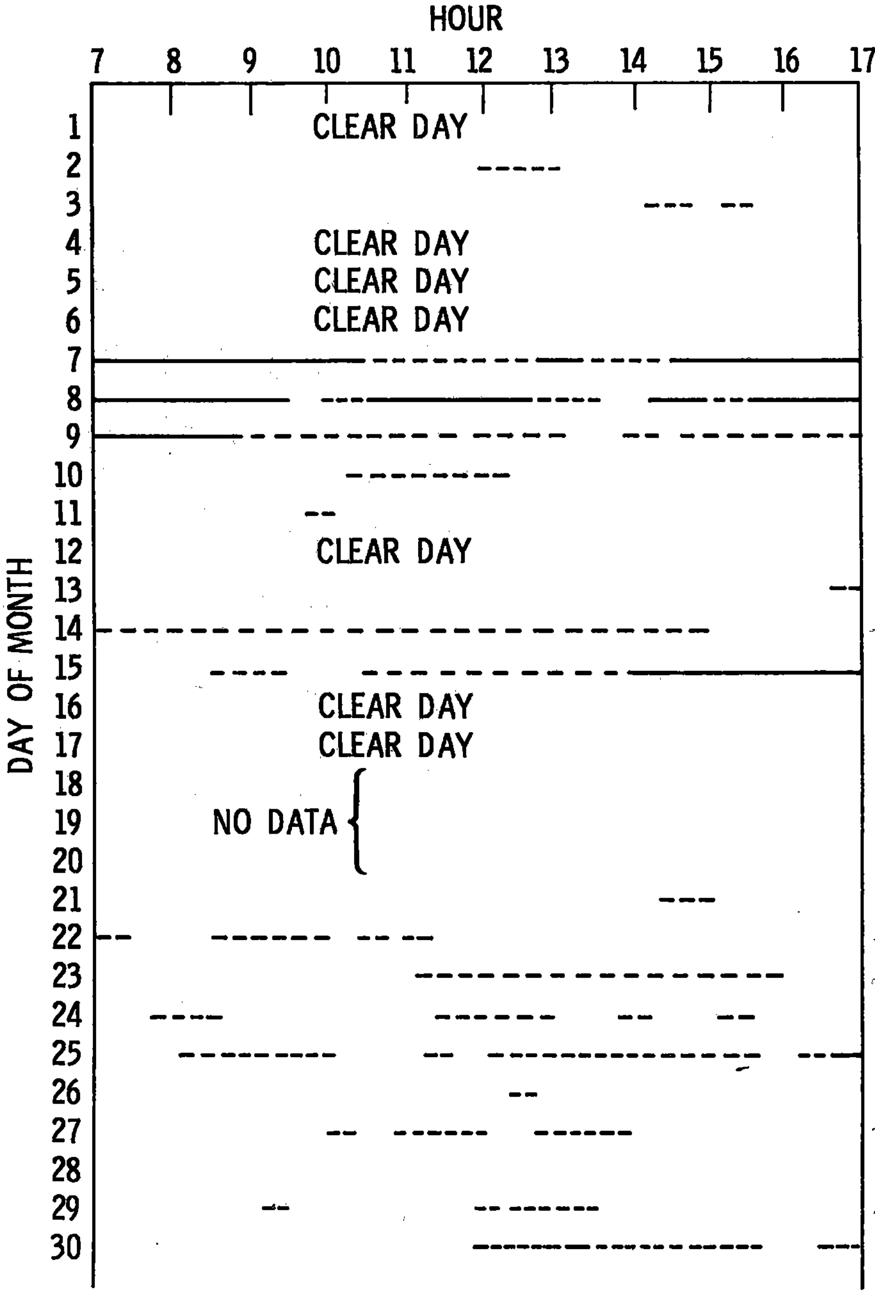

Fig. 2-1i. Cloudy and Partly Cloudy Periods at Daggett, April 1979

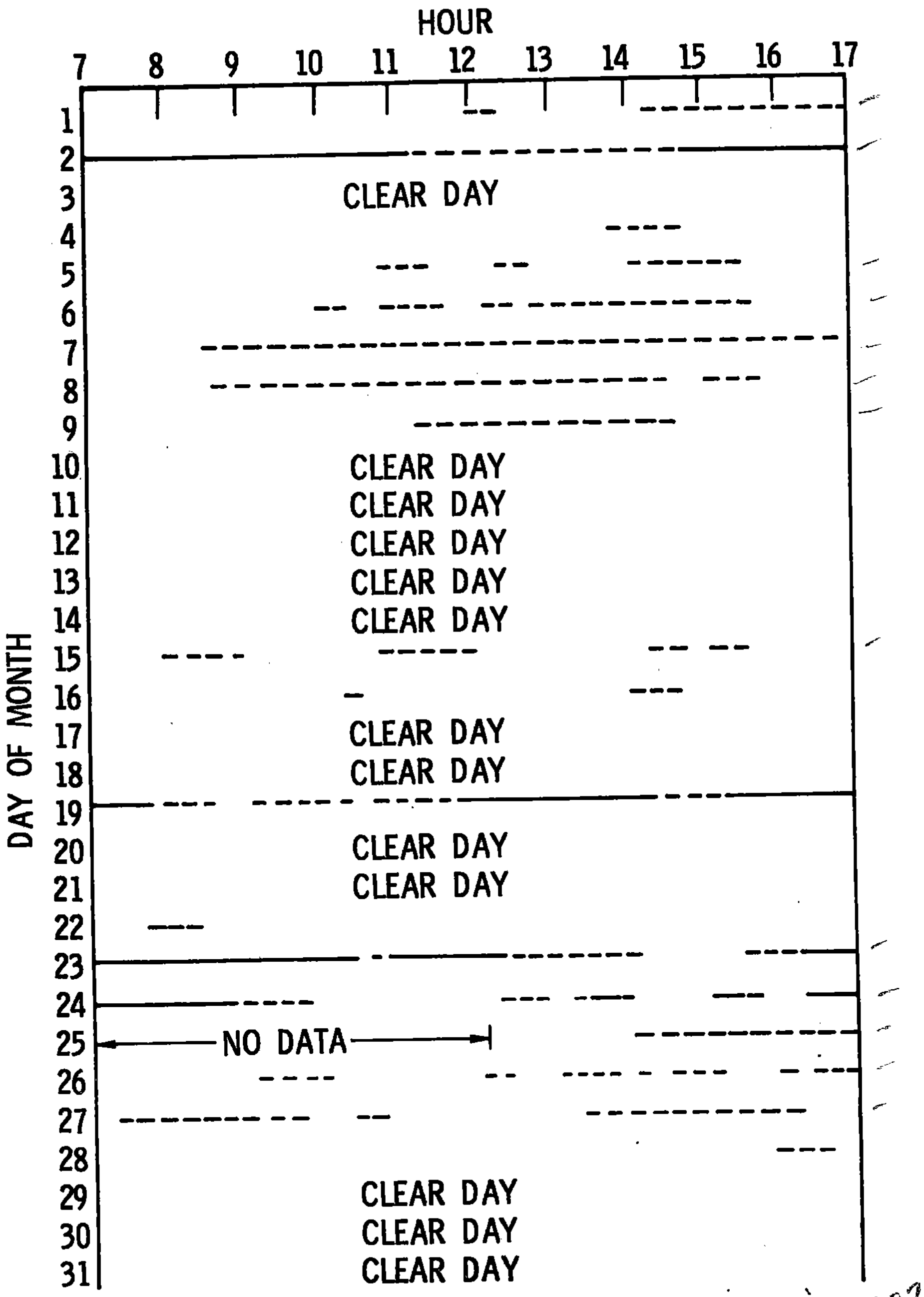

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Fig. 2-1j. Cloudy and Partly Cloudy Periods at Daggett, May 1979

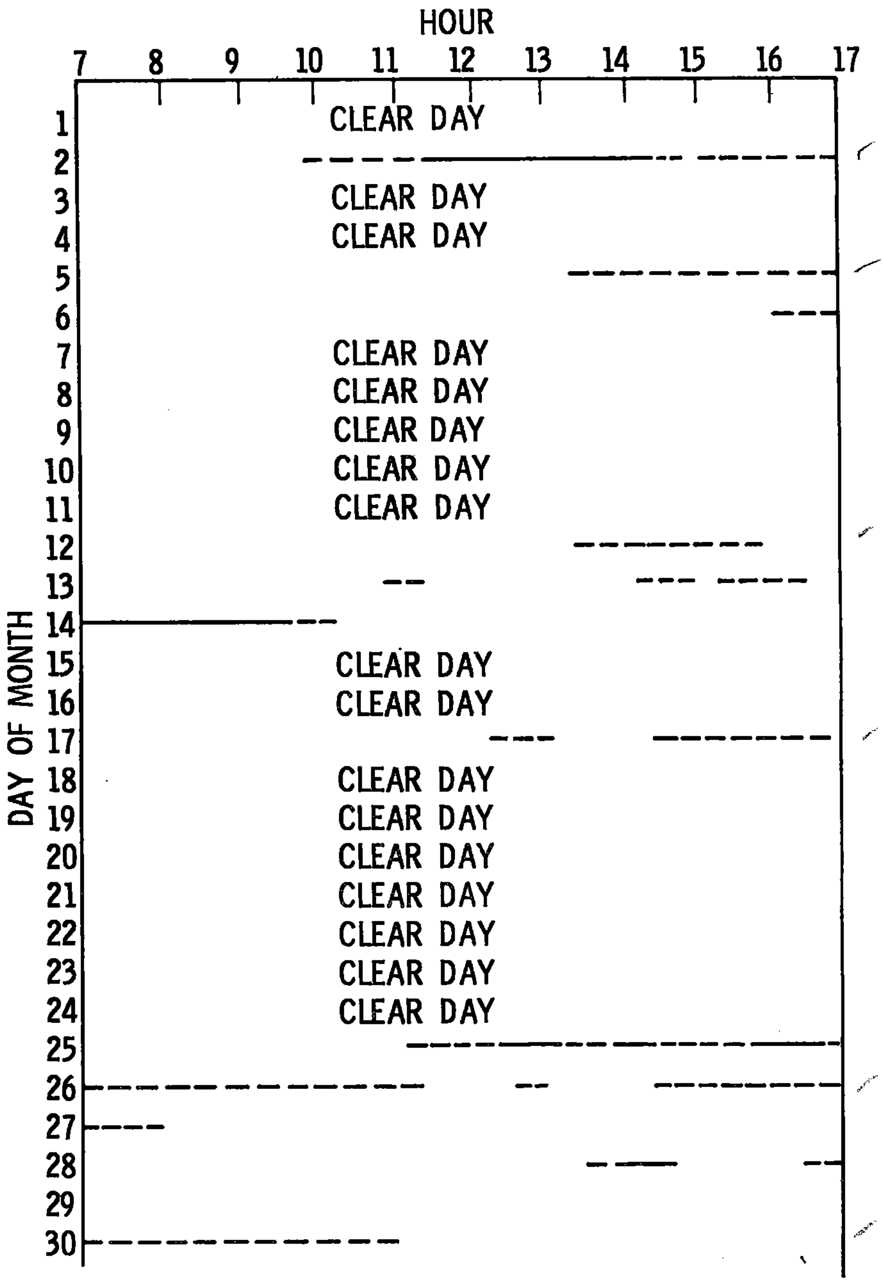

Fig. 2-1k. Cloudy and Partly Cloudy Periods at Daggett, June 1979

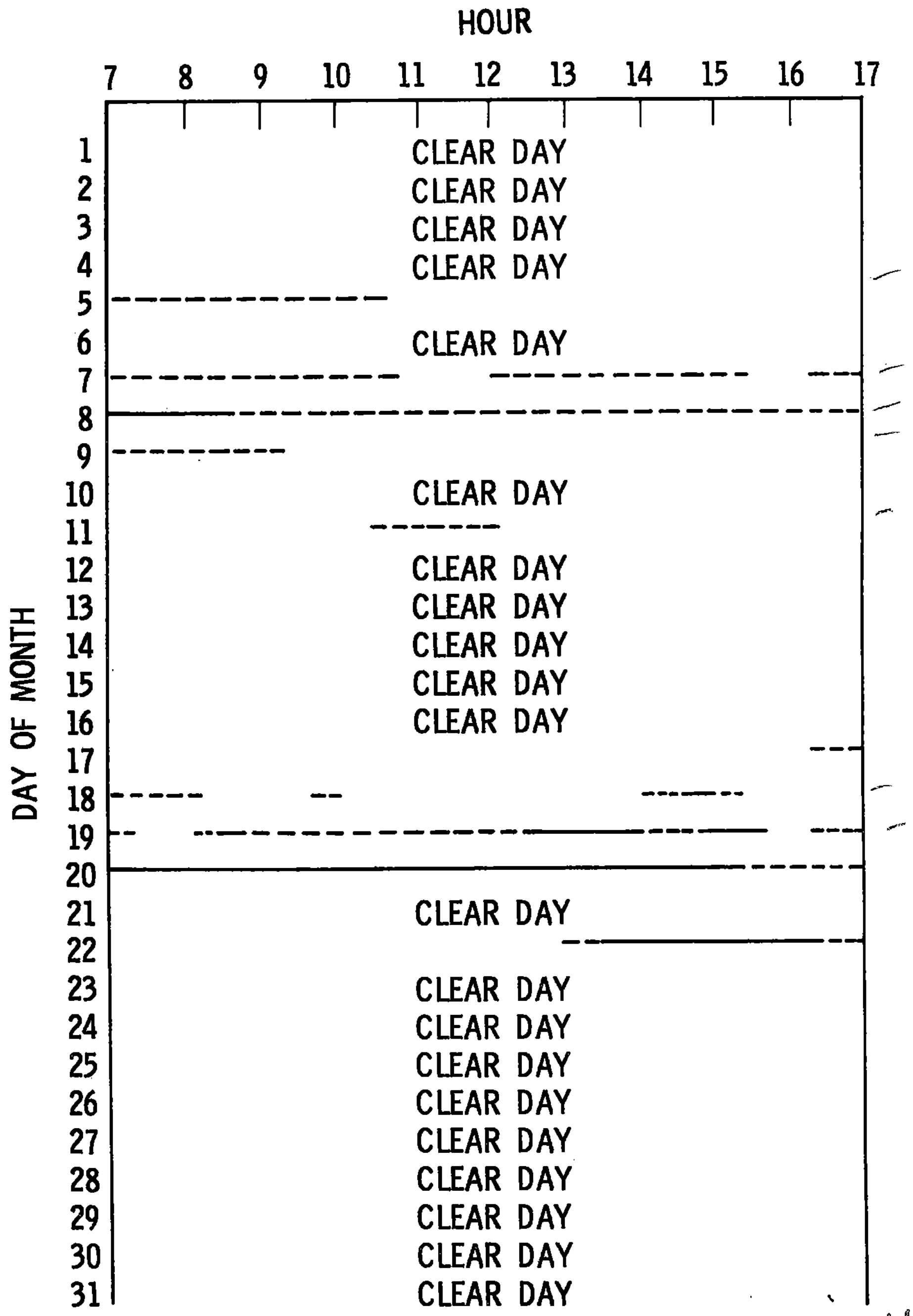

Fig. 2-1ℓ. Cloudy and Partly Periods at Daggett, July 1979

Each category is easily identified by visual observation, but less easily by computer because of variations caused by servicing, birds, and power outages. The data presented in Figs. 2-1a through 2-1ℓ thus include an element of subjectivity.

See Table 2-1

For most of the days when partly cloudy conditions existed (Fig. 2-1a through 2-1ℓ), one-minute mean values of the NIP data were plotted. Figure 2-2 is an example of one of these plots. The resultant 82 plots were then separated into several categories using qualitative characteristics of the NIP trace. After the initial separation was made, the plots within each category were compared with each other and with plots for similar categories. A few categories were eliminated by this review as not being significantly different, and some individual days were reassigned. A most-typical trace was then determined for each category. Table 2-1 provides the qualitative description of each of the selected days. Appendix A contains a package of data characterizing the insolation and other meteorological parameters for each of these eight scenarios including the one-minute mean NIP insolation plot.

B. INSOLATION VARIATION DESCRIPTION

The insolation variation for each of the eight scenarios was characterized in several ways in order to provide data for various solar energy system problems. An example of each data presentation format for 29 March 1979 is presented. Results for each of the eight days are included in the data packages in Appendix A. They are discussed here in the order in which the data are presented for each day in Appendix A. In addition to the insolation data, an abstract of the Daggett Hourly Meteorological Observation Record for the day is included in Appendix A. The presentation of the data is divided into three sections: (1) statistical characterization, (2) power values for simulation, and (3) insolation variation maps representing the detailed variation data.

1. STATISTICAL CHARACTERIZATION

The most useful of the statistical parameters developed for the analyses presented in Ref. 1 were calculated for the selected scenarios. Figure 2-3 is a plot of the direct insolation data averaged over 15-minute intervals. These

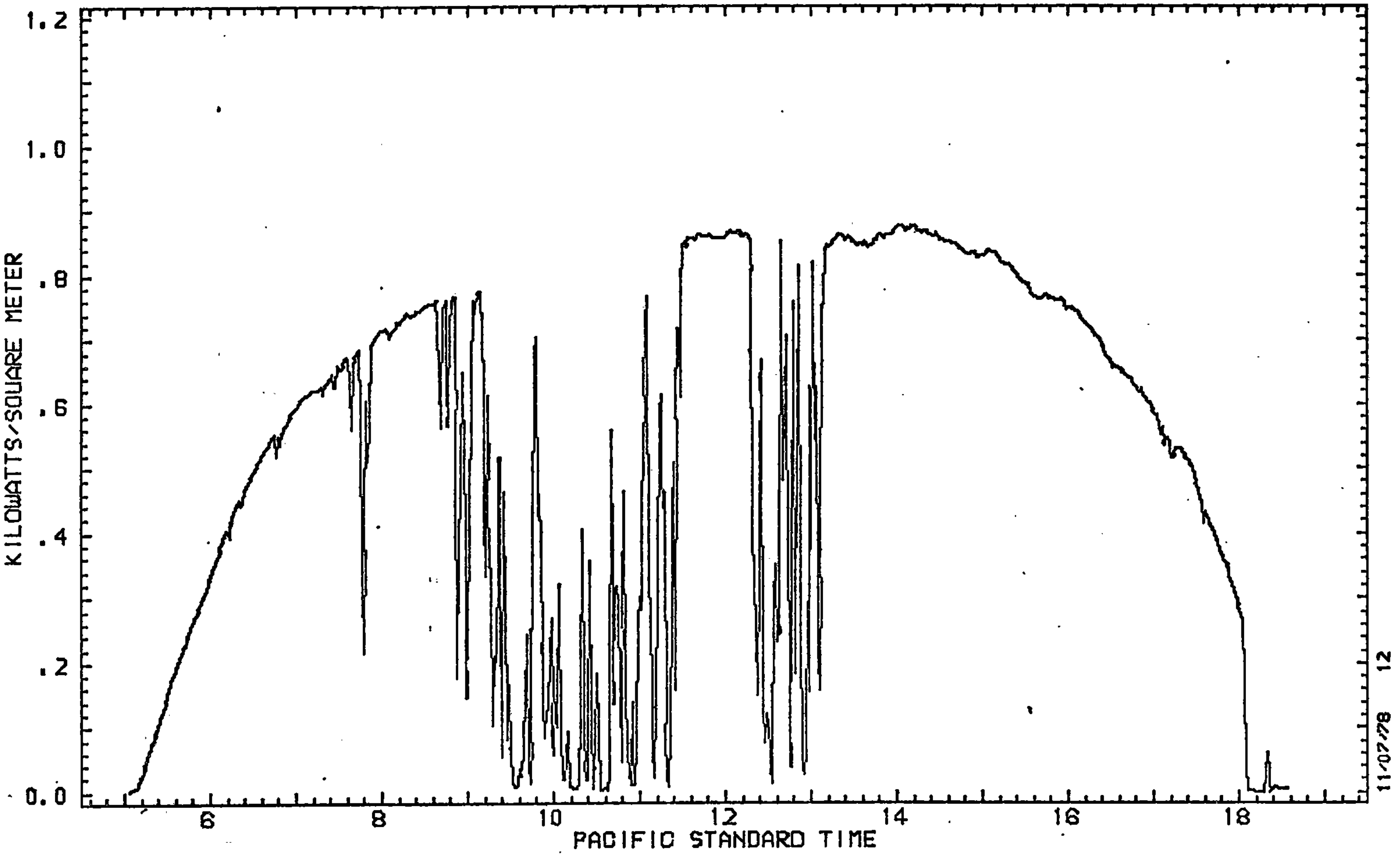

Fig. 2-2. One-Minute Average Direct Insolation at Daggett, 8 August 1978

Table 2-1. Typical Insolation Scenario Summary

Number	Salient Characteristic	Number of Cases	Date	Total Energy for day, kW-hr/m^2
1	Isolated sharp transition	7	26 April 1979	8.1
2	Very high frequency variations, does not go to zero	7	26 August 1978	9.4
3	High frequency fluctuations, does go to zero	25	8 August 1978	7.1
4	Frequent sharp transitions between full off and full on	8	29 March 1979	6.1
5	Variations not going to zero, medium frequency	8	8 July 1979	7.3
6	Medium to low frequency variations, more off than on	13	15 October 1978	3.9
7	Slow variations, transmittance significantly affected	7	20 January 1979	5.3
8	Very slow variations bounded by clear conditions	7	9 December 1978	5.1
		82 days		

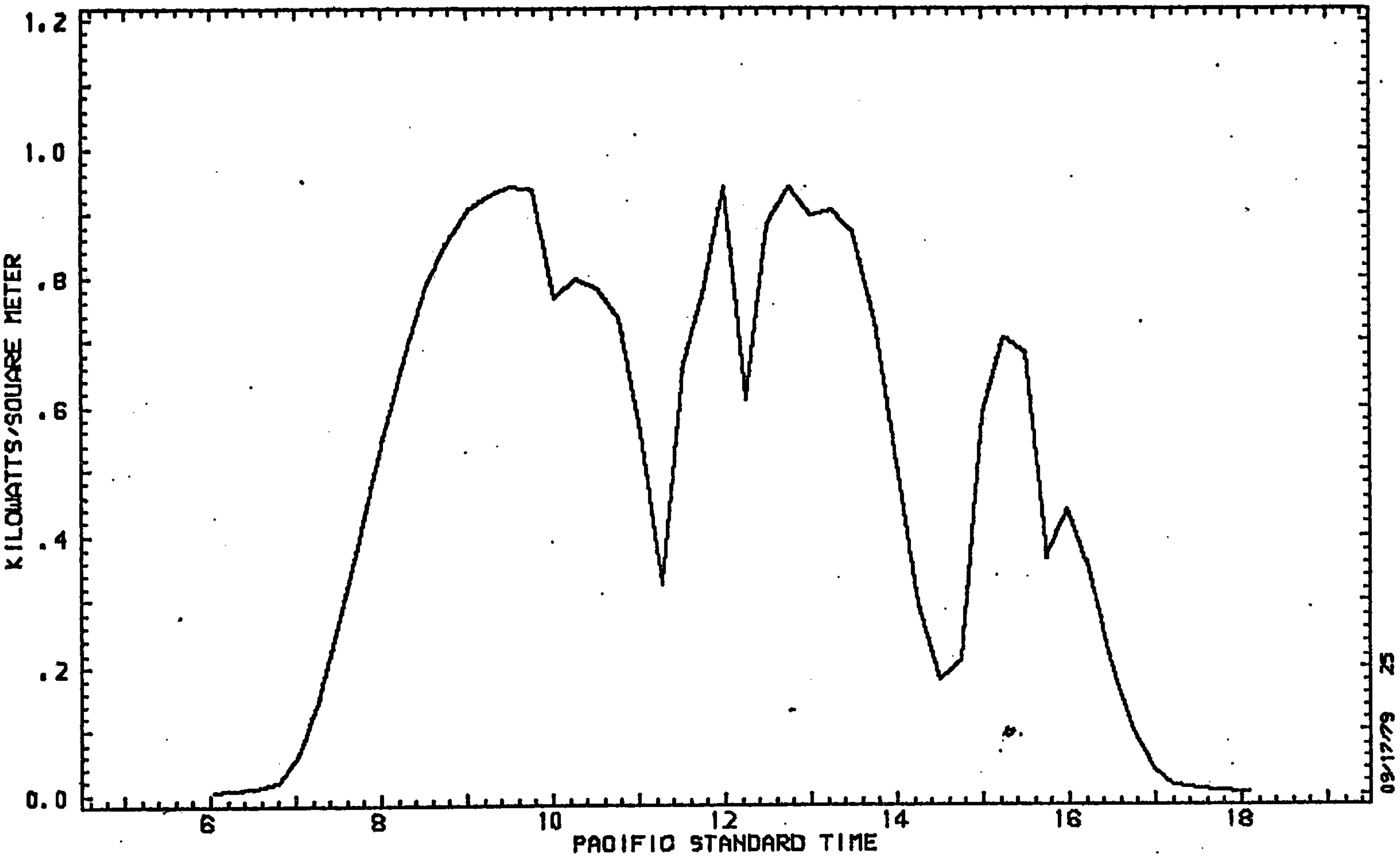

Fig. 2-3. Fifteen-Minute Average Direct Insolation at Daggett, 29 March 1979

plots provide a means of comparing values with the observations taken at this time resolution by the Southern California Edison Company at their facility in Barstow, California.

A one-minute average of NIP data is presented in Fig. 2-4. The rapid fluctuations begin to become apparent. This is the highest time resolution that can be accommodated on a single-page graph covering an entire day. These plots were used for determining typical insolation scenarios. The maximum resolution of the NIP data for the portion of the same day selected for further analysis is shown in Fig. 2-5. The results of the increased resolution become very apparent. Note that the time coordinate has been changed from clock time to a scale in 16-second increments.

The uniformity of insolation over the collector field as a function of time is indicated in Fig. 2-6, in which the root-mean-square (RMS) variation (variance) in insolation values over the field at any given time is shown. For this plot, the values from the four corners plus adjacent time element values were related in accordance with the definition of the array average (Ref. 1) and are used to compute the RMS variation at each time point.

The rate of change of insolation is shown in Figs. 2-7 through 2-12. Figure 2-7 provides the numerical difference between successive 16-second energy levels observed by the NIP divided by 16 seconds. When ascertaining the impact of these figures, the fact that the 16-second averaging imposes a somewhat artificial upper limit on the magnitude of the rate of change must be taken into account. Even an instantaneous change from full direct sunlight (approximately 1000 W/m^{-2}) to zero sunlight at the instant the averaging counter is reset will appear as a finite rate of change, $\Delta D/\Delta t = (1000 - 0)/16 = 62$ W/m^{-2}-sec^{-1}. At a number of points in Fig. 2-7, $\Delta D/\Delta t > 50$ W m^{-2} sec, indicating that this slow sampling rate is indeed limiting the response of the experiment.

Figure 2-8 provides the cumulative distribution function (CDF) in percent of the various values of the rate of power change shown in Fig. 2-7. Figure 2-8, as do Figs. 2-5 and 2-7, deals with data from only one instrument, the NIP. The full impact of the rapidly changing insolation is not felt at the

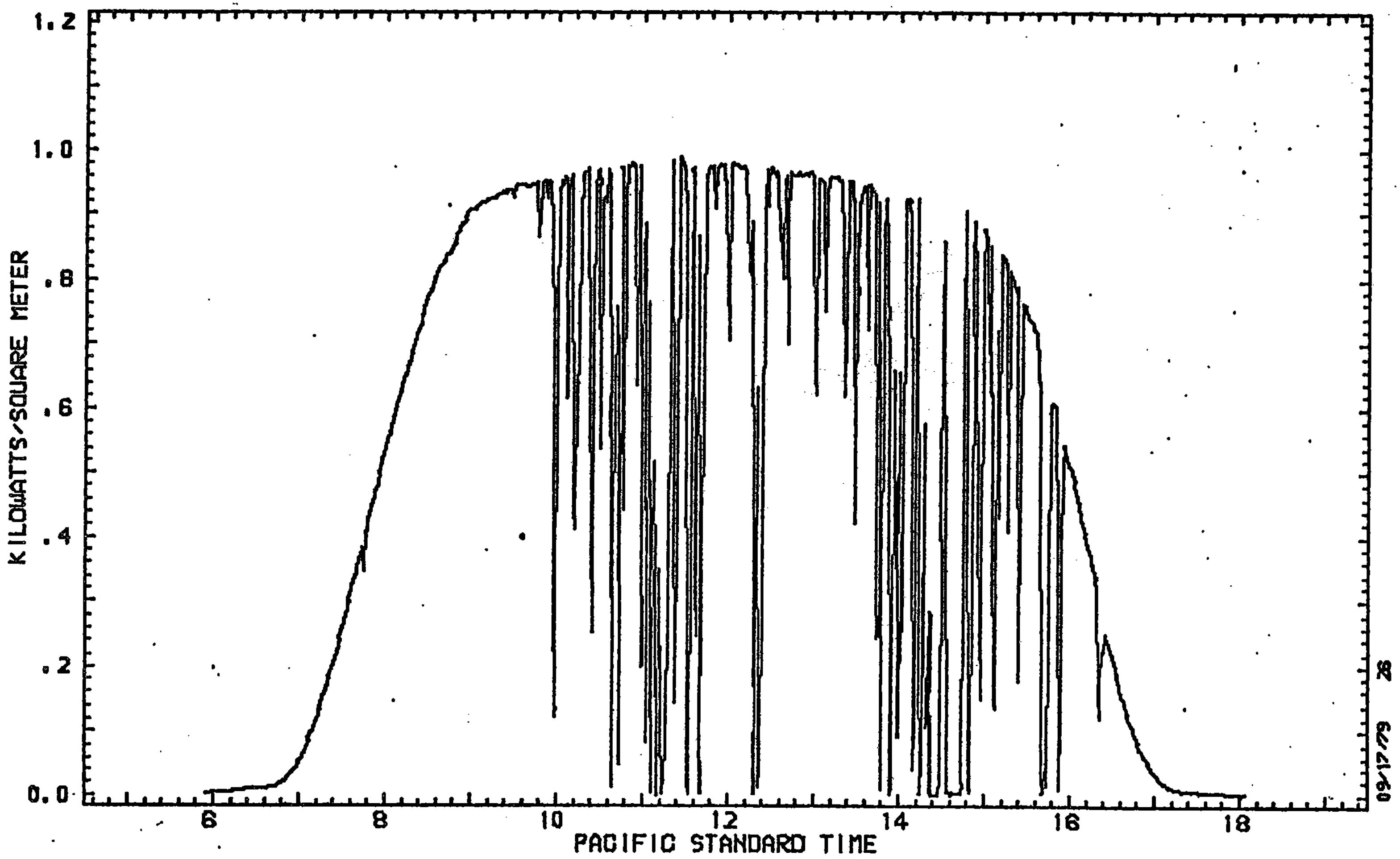

Fig. 2-4. One-Minute Average Direct Insolation at Daggett, 29 March 1979

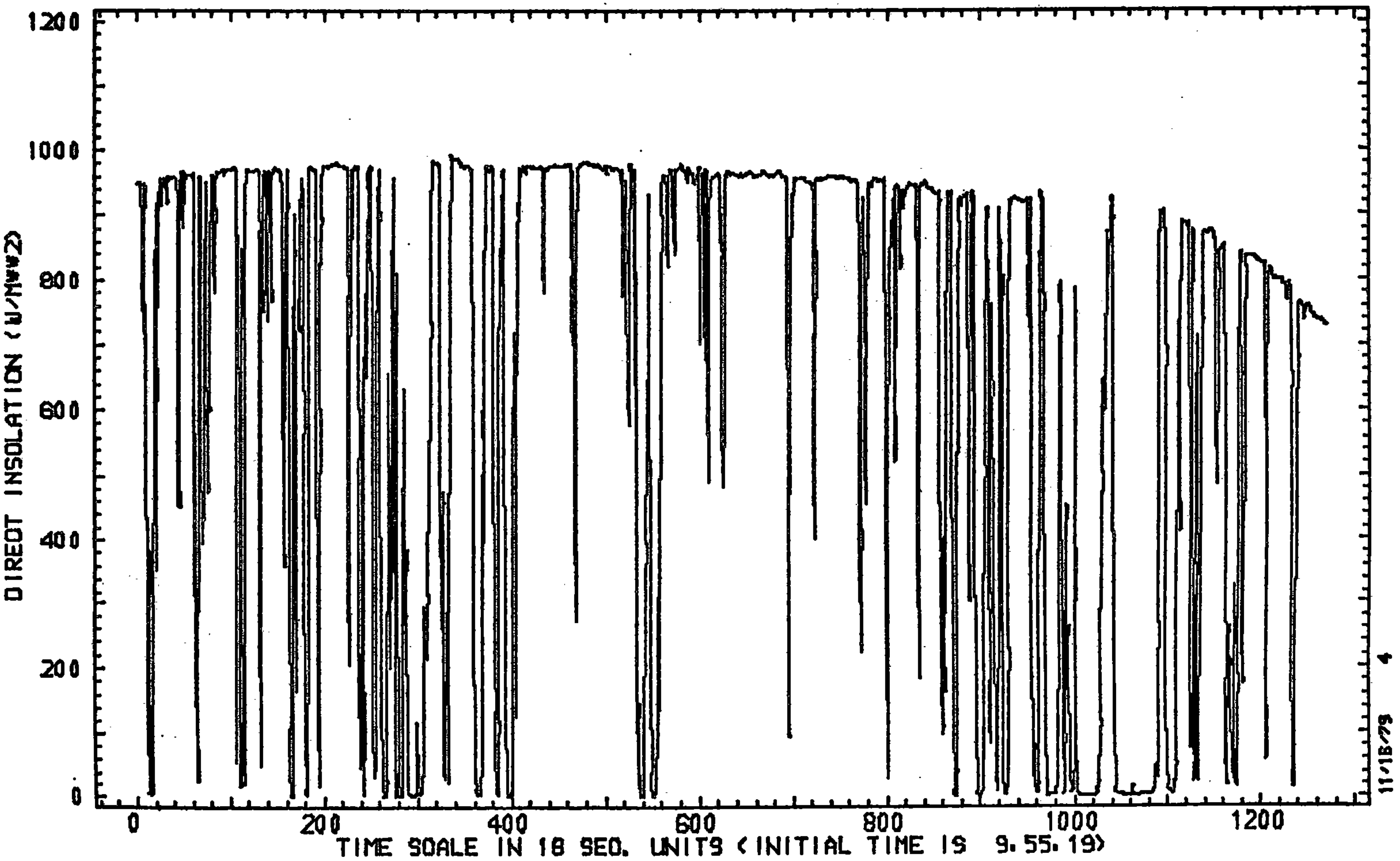

Fig. 2-5. Direct Insolation at Station 4 at Daggett, 29 March 1979

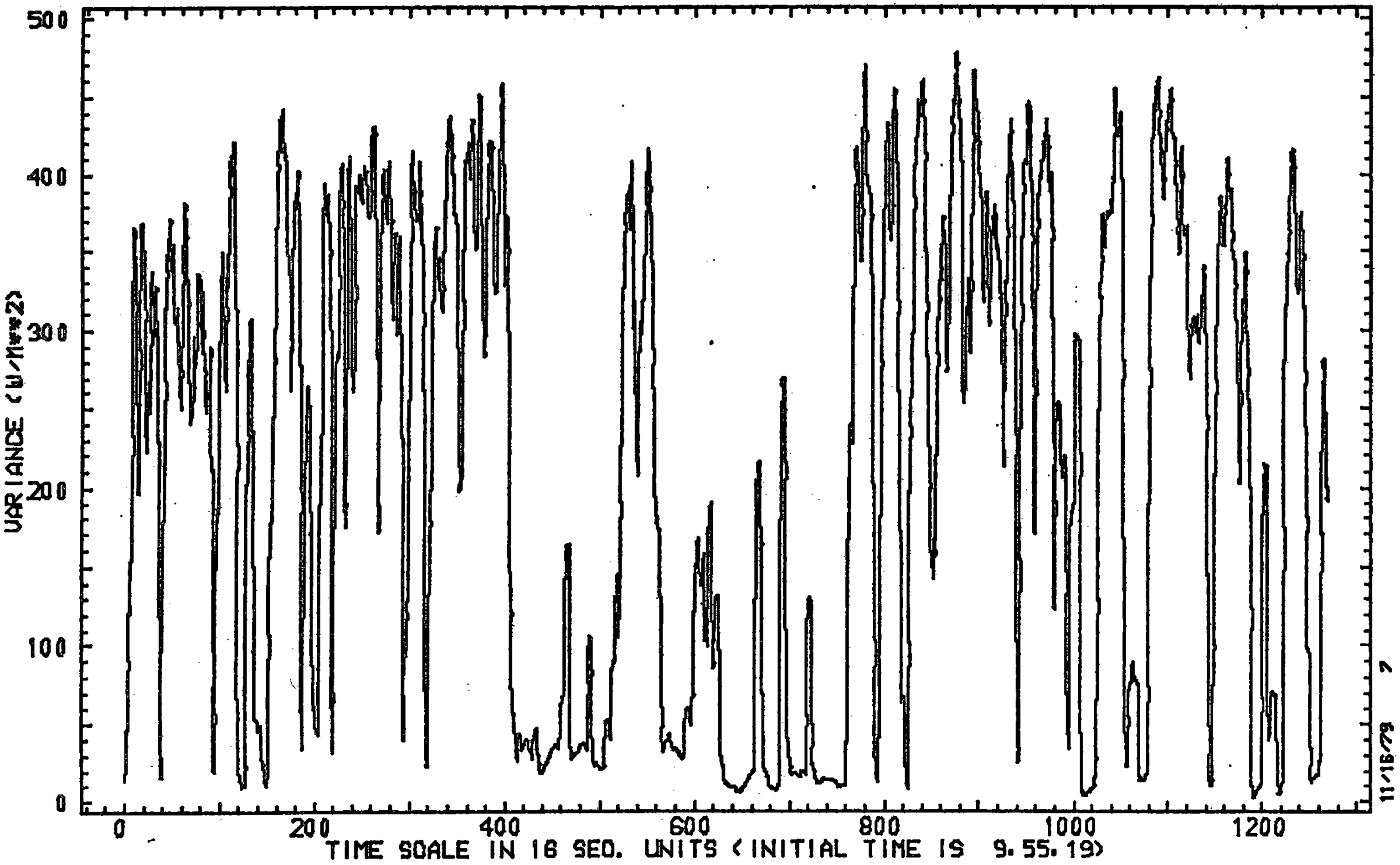

Fig. 2-6. Spatial Variance Over Array at Daggett, 29 March 1979

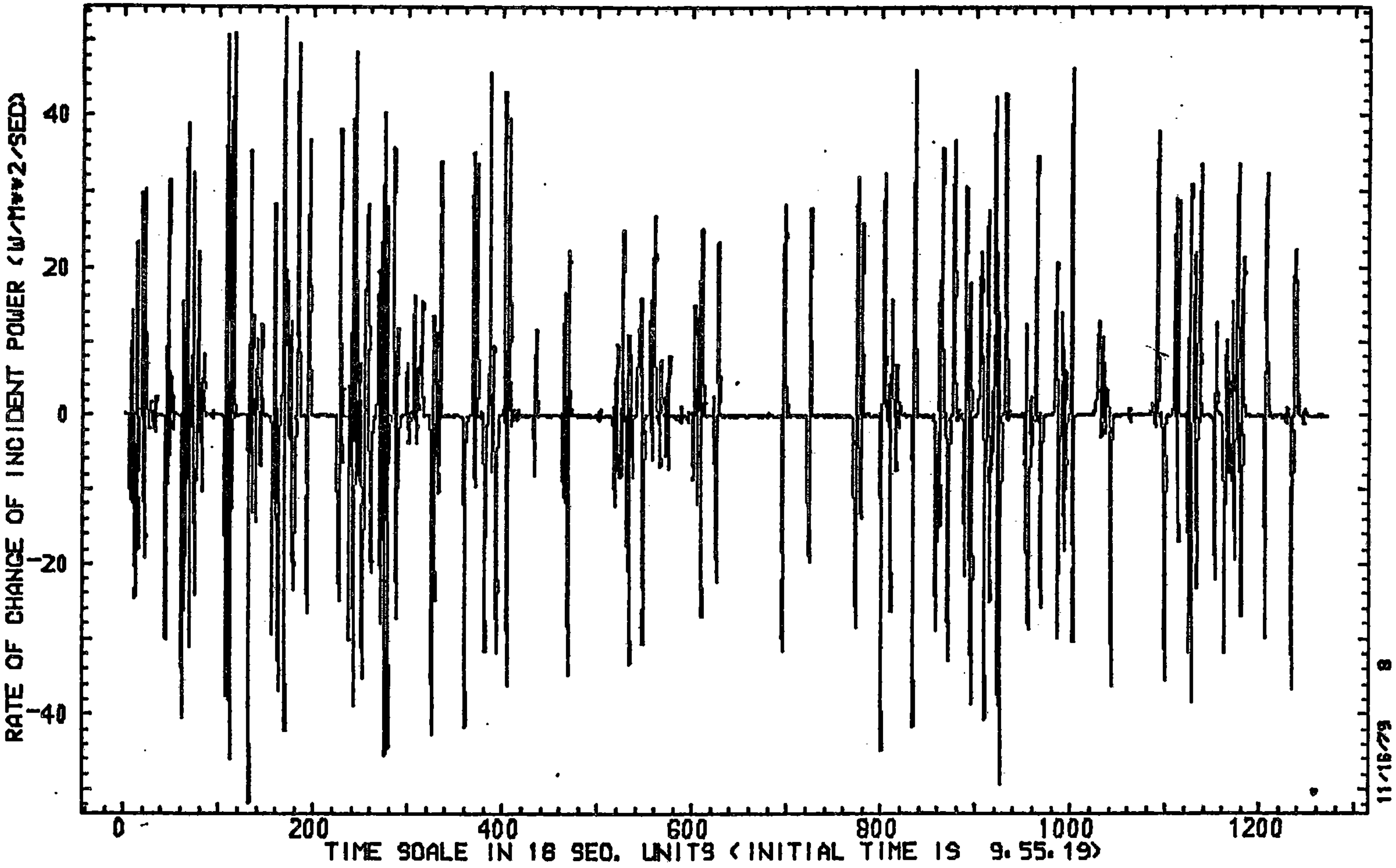

Fig. 2-7. Rate of Direct Insolation Change at Station 4 at Daggett, 29 March 1979

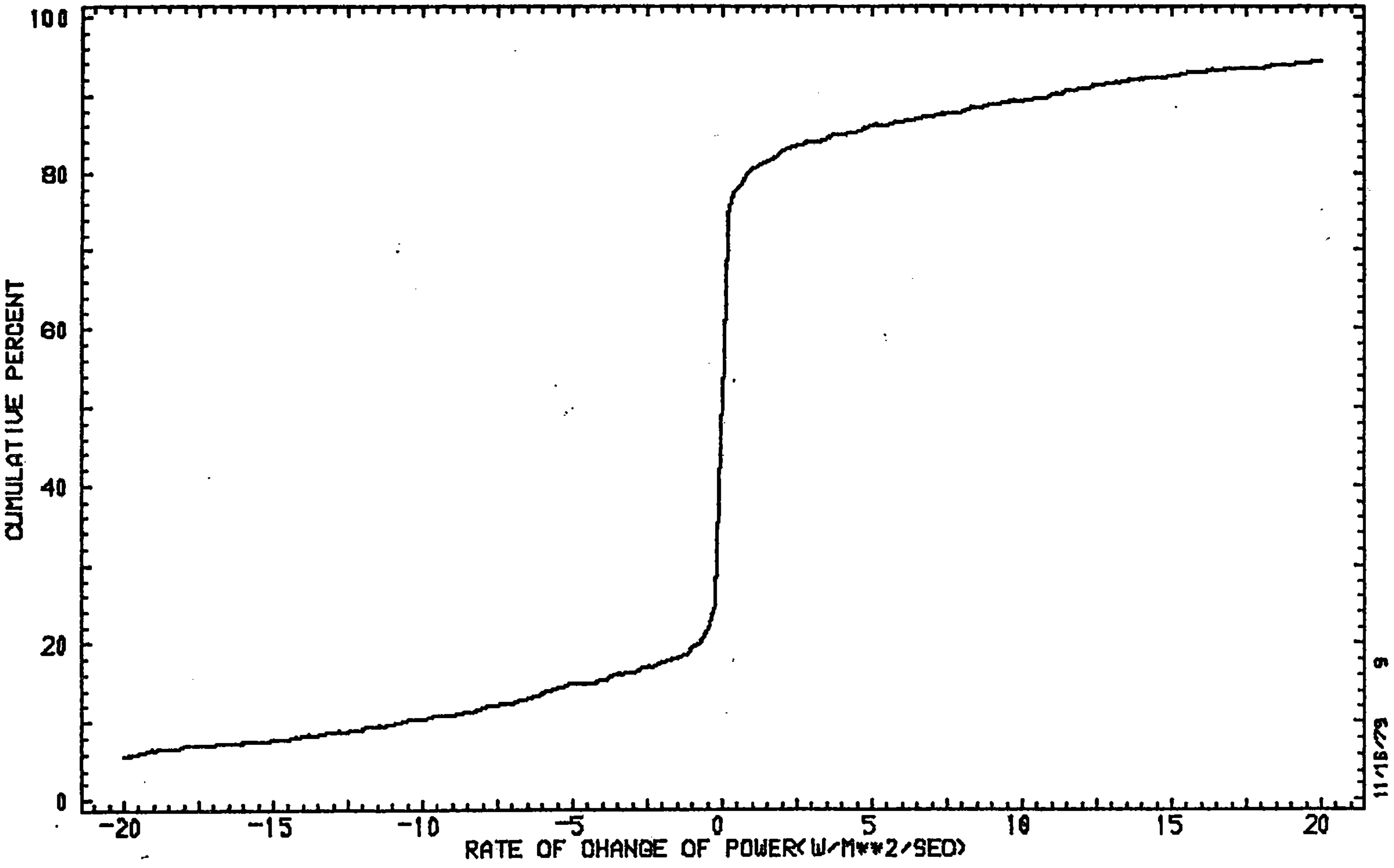

Fig. 2-8. Cumulative Distribution of Rate of Insolation Change at Station 4 at Daggett, 29 March 1979

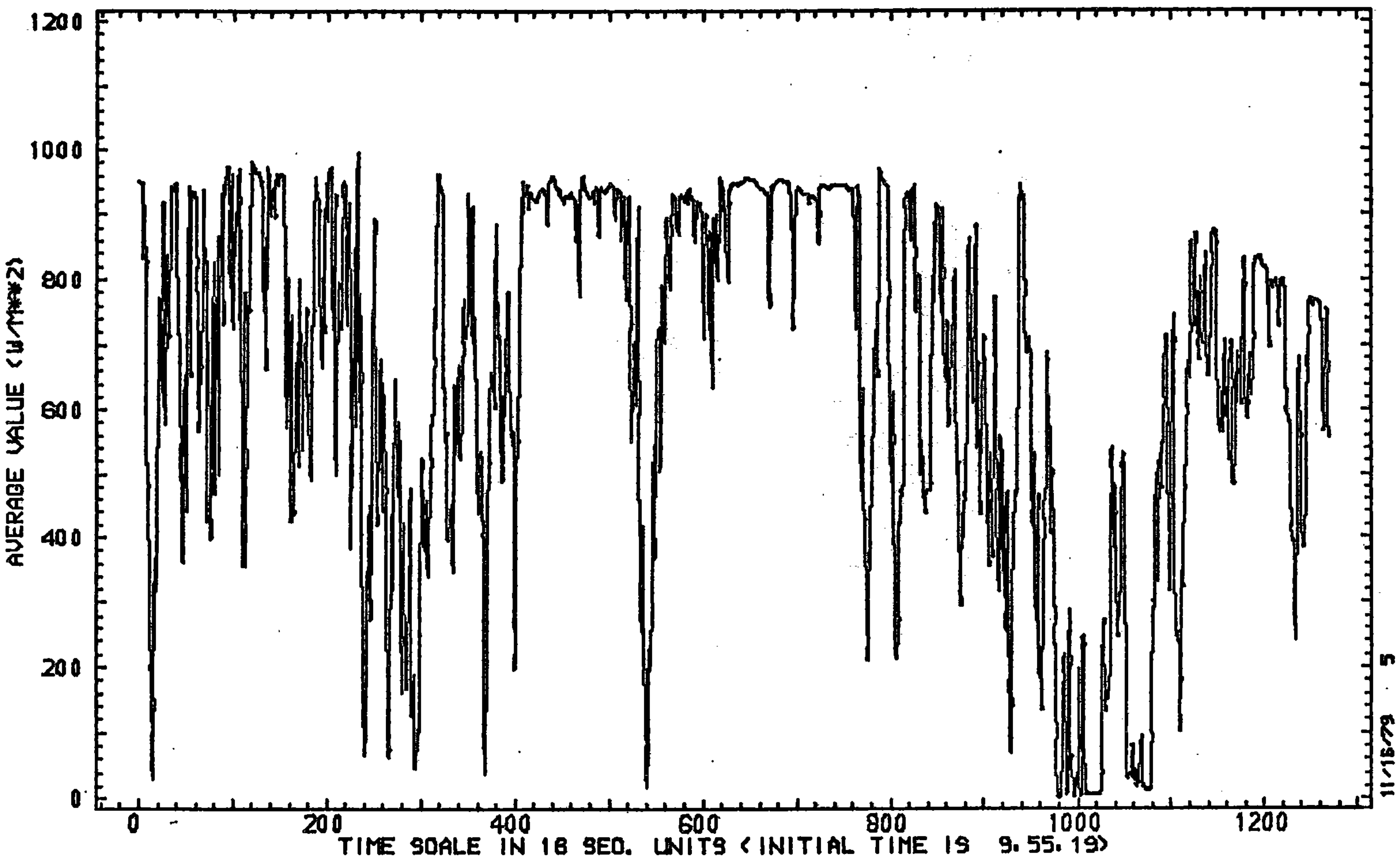

Fig. 2-9. Direct Insolation Averaged Over Stations 1, 2, 3, and 4 at Daggett, 29 March 1979

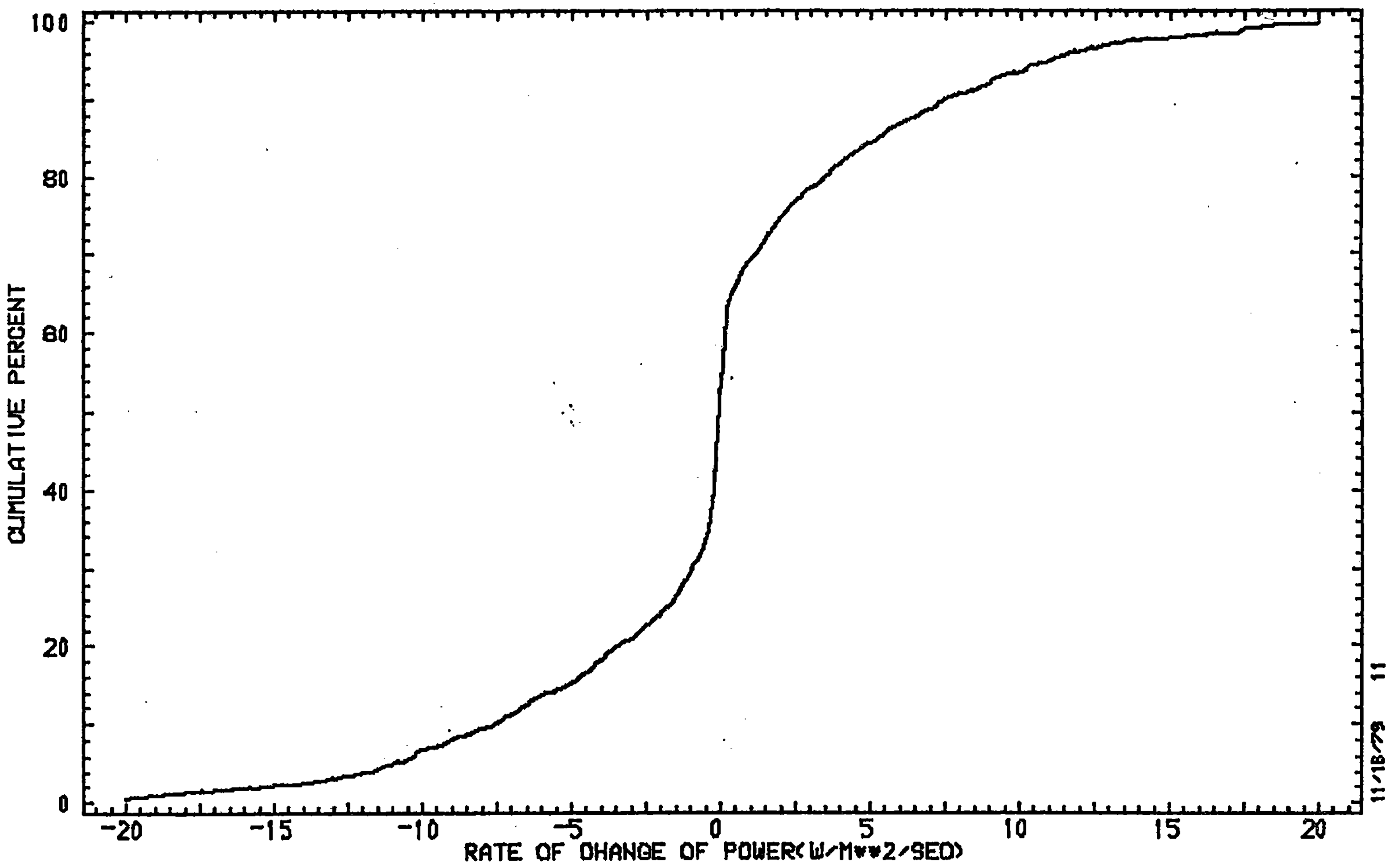

Fig. 2-10. Average Over Stations 1, 2, 3, and 4 at Daggett, 29 March 1979

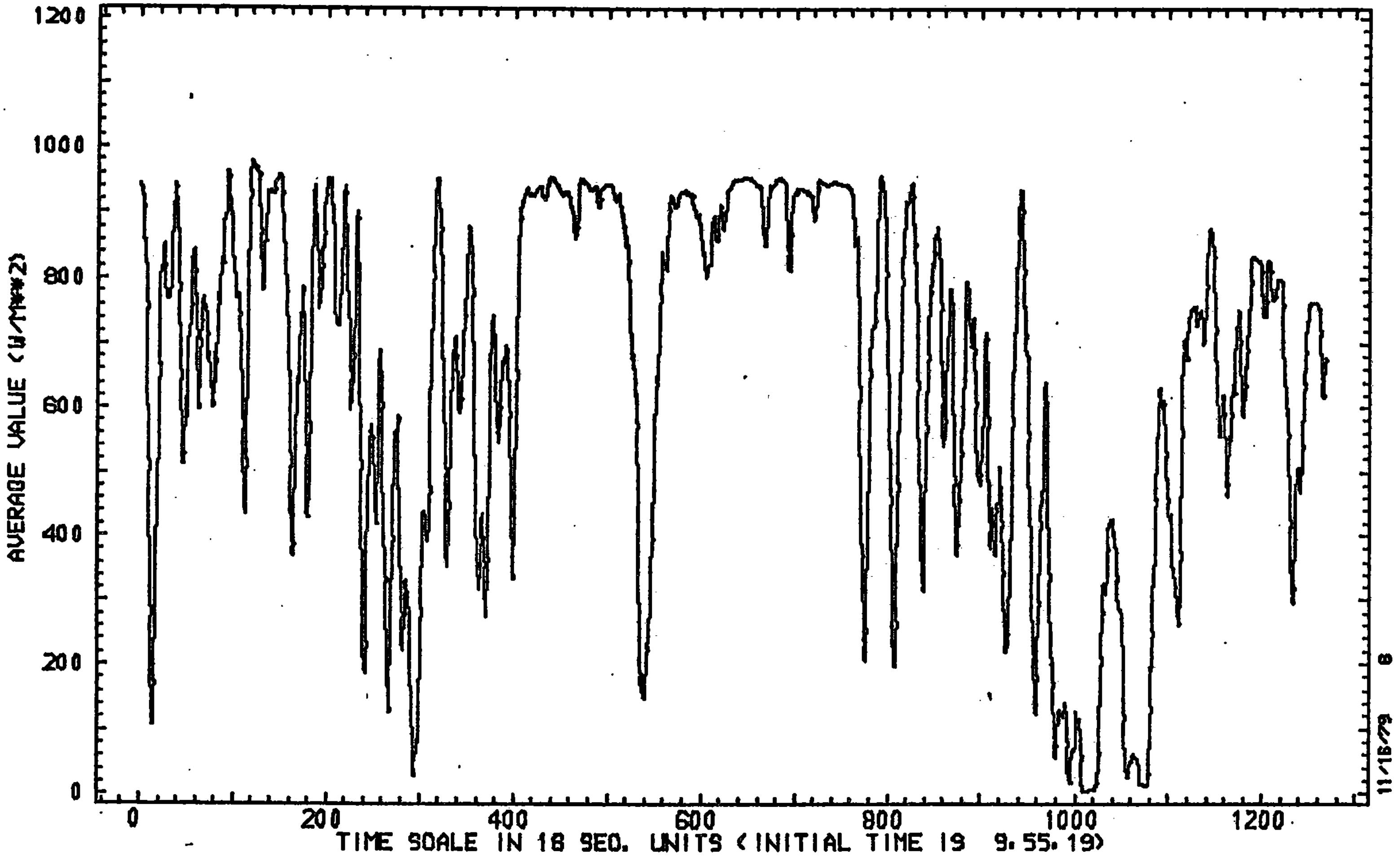

Fig. 2-11. Direct Insolation Averaged Over Array at Daggett, 29 March 1979

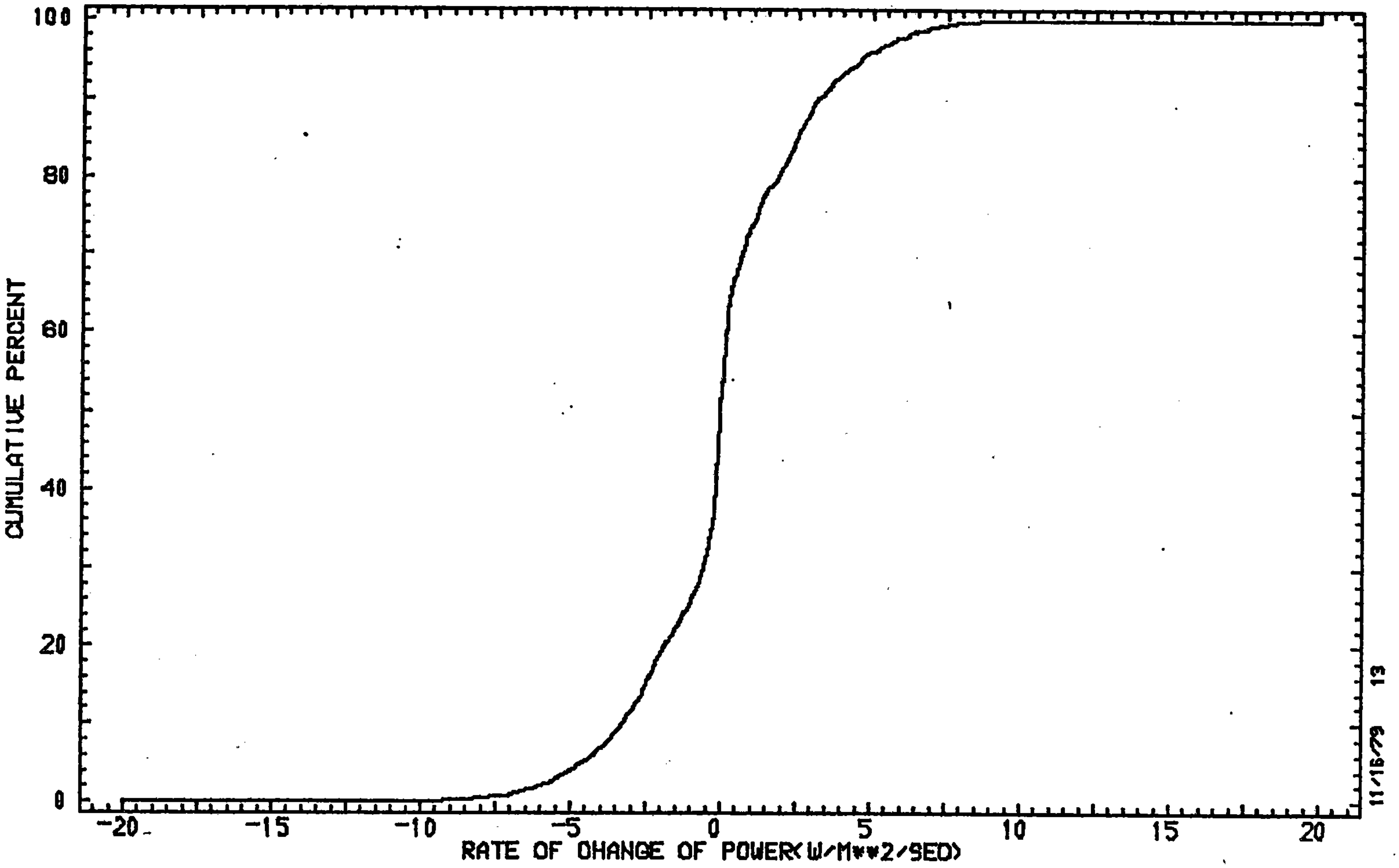

Fig. 2-12. Average Over Entire Array at Daggett, 29 March 1979

heliostat but rather at the receiver panels where the control system must compensate for this modulation. At each of these panel locations, power arriving from a significant combined heliostat surface area is averaged. This is expected to lower the effective rates of change. While the exact averaging is weighted by the efficiencies of the various heliostats, a parametric idea can be obtained by considering one receiver point, the four corner measurement points weighted equally, and finally an array average previously defined in Ref. 1. The insolation traces for the averages of the four corners are shown in Fig. 2-9. The associated CDF plot for these rates of change is shown in Fig. 2-10. The average insolation from the array is shown as a function of time in Fig. 2-11, and the associated CDF plot for insolation change is shown in Fig. 2-12. A comparison of Figs. 2-8, 2-10, and 2-12 reveals that the spatial averaging for this case does reduce the frequency of occurrence of large changes in power.

2. POWER VALUES FOR SIMULATION

The average powers available from (1) a single point, (2) the four corners of the array, and (3) the array average as defined in Ref. 1 are provided every 16 seconds through the cloudy period. Plots of these data are presented (Figs. 2-5, 2-9, and 2-11). These average data provide an input for simulating the performance of a power plant, exclusive of the heliostat and receiver. For example, it is this type of variation that the master control system must compensate for in order to provide a constant input to the turbine-generator. The plots analogous to Figs. 2-9 and 2-11 for the other days have been omitted from the data sets in Appendix A. These data are also available on magnetic tape. The format of this tape is given in Appendix C.

3. DETAILED VARIATION DATA

The insolation variation over the field as a function of time was mapped for short intervals during five of the eight scenarios in which significant variation of insolation occurred over the experiment area. Figure 2-13 shows, on an expanded scale, the interval selected to derive the insolation variation map. Figure 2-14 is the map derived for the interval shown in Fig. 2-13.

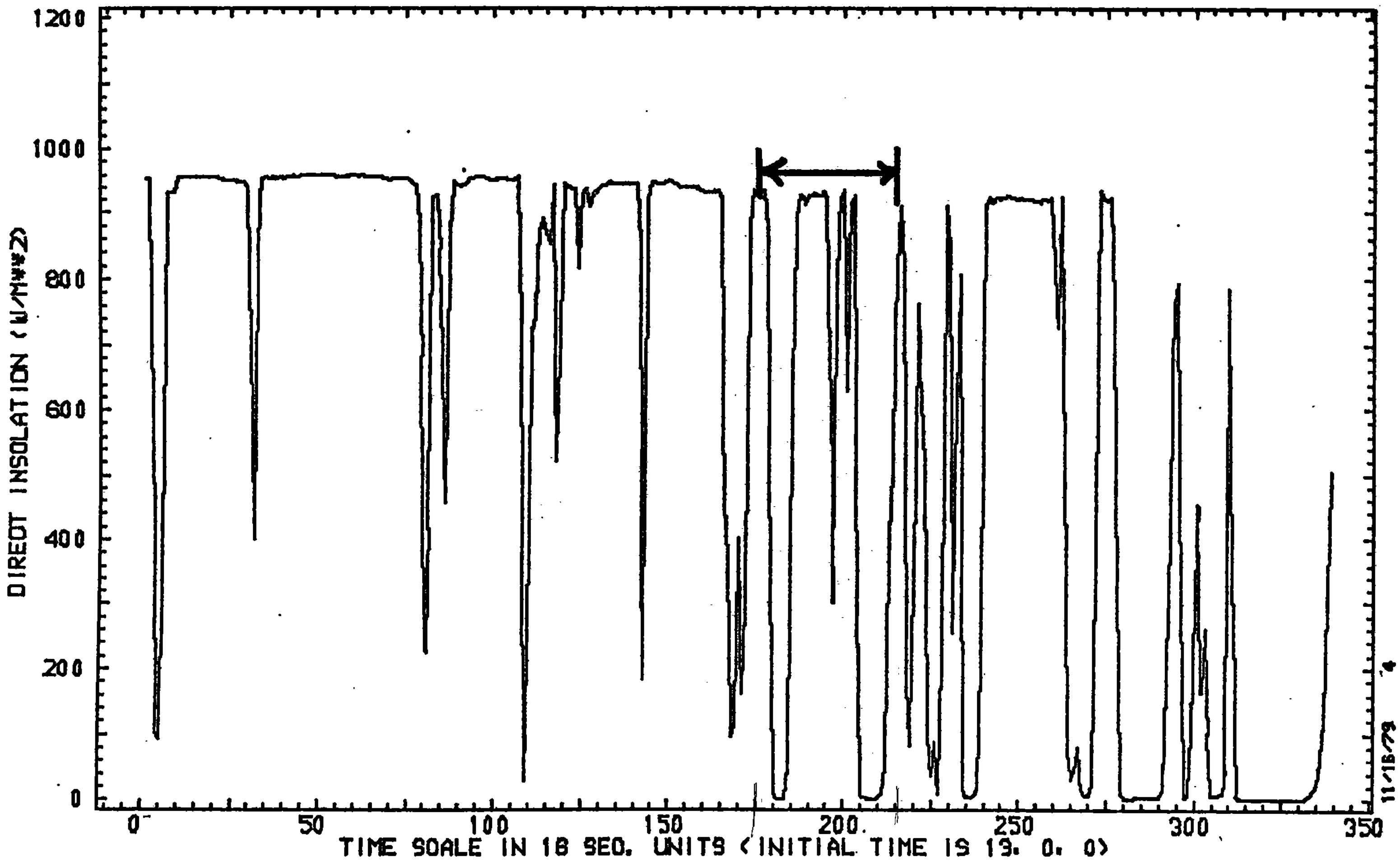

Fig. 2-13. Direct Insolation at Station 4 at Daggett, 29 March 1979. The period selected for preparation of the insolation variation map is indicated by the arrows.

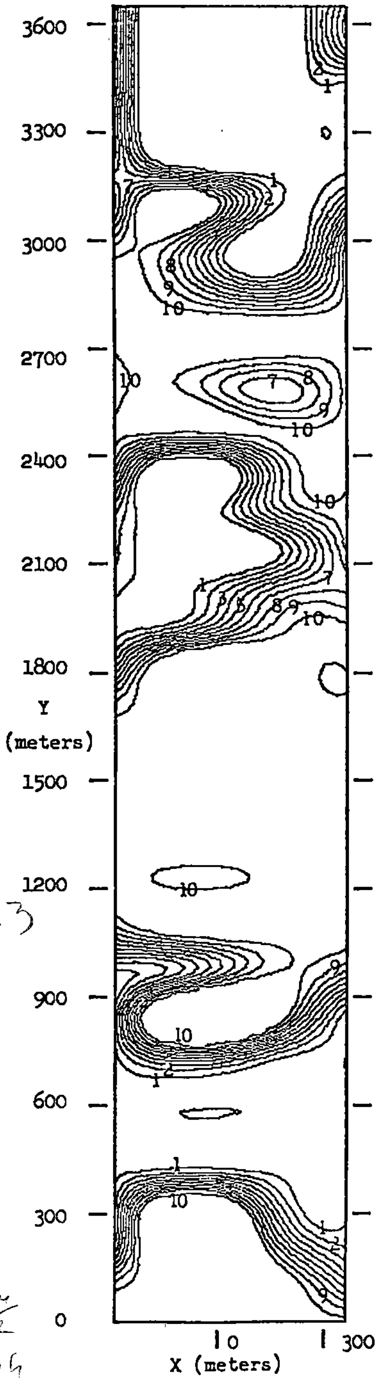

Fig. 2-14. Insolation Variation Map for 29 March 1979. (Contours are 10 percent apart. 10 corresponds to 95 percent. 1 corresponds to 5 percent)

640 seconds from 2-13

5.6 m/sec

= 12.5 mph

540 sec p 2-31 → 6.6 m/s

= 14.7 mph

The map is a contour plot of the transmittance of that portion of a cloud layer that passed over the field during the selected time interval. The width of the map (x-axis) is approximately equal to the diameter of the field, whereas the length (y-axis) is the distance that the cloud layer moves during the time interval (approximately 9 minutes).

The insolation at any point in the field during this interval of time can be calculated by pulling the contour map across a map of the field with a velocity equal to the cloud velocity (Fig. 2-15). The instantaneous insolation at the point is then obtained by multiplying the instantaneous transmittance at the point by the clear day value of insolation. The contour map was constructed so that the insolation values calculated by this procedure are equal, at the four stations, to the measured results during the selected 9-minute time interval. Of course, this whole process, depicted as one map sliding over another, in actuality is carried out numerically on a digital computer.

The contour map is constructed by the following four-part procedure: (1) A correlation analysis of the insolation data (Ref. 1) is performed in order to calculate the cloud velocity V. (2) The insolation values recorded at the four stations are then propagated downwind from each station with the cloud velocity V, providing insolation values at points lying along four parallel lines, each line passing through one of the stations. (See the discussion of pseudo-stations in Ref. 1.) The points are spaced a distance Wt*V apart along each line. (V is the cloud velocity and Wt = 16 sec.) (3) The insolation values at these points are converted to transmittances by dividing by the clear-day insolation. (4) The transmittances at these discrete points are interpolated to generate a continuous smooth field of values.

C. INSOLATION INTERPOLATION PROCEDURE

Let $T(x,y)$ be the transmittance at coordinate location x,y and $T_{i,j} = T(x_i,y_j)$ be the experimentally known values at the discrete locations x_i, y_j ($i = 1, N$; $j = 1, M$). It is the objective of the interpolation procedure to generate a function $F(x,y)$ to approximate the exact and unknown transmittance function $T(x,y)$. Obviously, there is no unique solution to this problem.

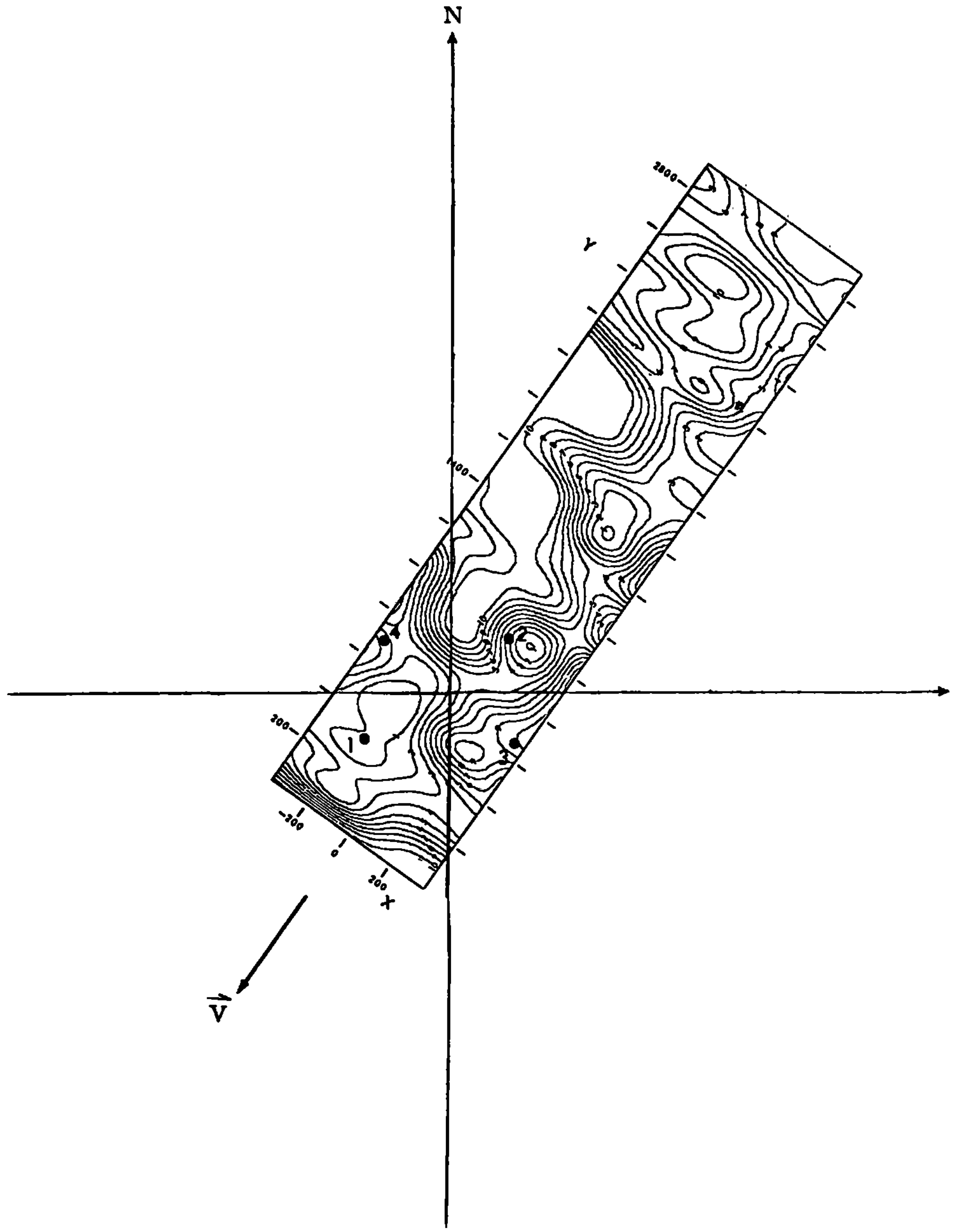

Fig. 2-15. Schematic Diagram of Translation of Insolation Transmittance Map with Arbitrary Vector Velocity V Across Array of Experimental Sensors. (Sensor positions are indicated by vertical numbers 1 through 4. See Fig. 2-14 and text for an explanation of contour labels.)

However, the following reasonable requirements should be fulfilled by the interpolation procedure:

1. The interpolated function should be equal to the experimental values at the data points, i.e., $F(x_i, y_j) = T_{i,j}$.
2. The interpolated value at x,y should be most strongly influenced by the values of the nearest data points, with the influence decreasing with increasing distance from x,y.
3. The function should be reasonably smooth, i.e., it should not be discontinuous or have very large oscillations between data points.

A function that reasonably fulfills these requirements is the following:

$$F(x,y) = \sum_{i=1}^{N} \sum_{j=1}^{M} \frac{C_{i,j} W_{i,j}(x, y)}{\sum_{i=1}^{N} \sum_{j=1}^{M} W_{i,j}(x,y)} \tag{2-1}$$

where $W_{i,j}(x,y)$ is defined as

$$W_{i,j}(x,y) = \exp - \left[\frac{(x - x_i)^2}{S_x^2} + \frac{(y - y_i)^2}{S_y^2} \right] \tag{2-2}$$

The parameters S_x and S_y determine the range of this Gaussian weighting function. We have determined that the best interpolation is obtained when S_x is approximately equal to the average spacing between the data points in the x-direction, and S_y is equal to the constant ($V^* \Delta t$) spacing between points in the y-direction. The coefficients $C_{i,j}$ in Eq. (2-1) are determined by the requirement that the interpolated function is equal to the experimental values at the discrete data points, i.e.,

$$F(x_i, y_j) = T_{i,j} \tag{2-3}$$

By substituting Eq. (2-3) into Eq. (2-1), we obtain a set of linear equations that can be solved by standard matrix techniques for the unknown factors $C_{i,j}$.

It is possible in some cases for the interpolated results calculated with the use of Eq. (2-1) to slightly undershoot the lower limit $T = 0$ or overshoot the upper limit $T = 1.0$ of the transmittance. In this case, we simply truncate the results to 0 and 1.0, respectively.

A Fortran-coded computer subroutine TRANSM was developed to carry out the computation of Eq. (2-1). This subroutine is provided in Appendix D. The subroutine is called by specifying values of the position coordinates X and Y (in meters). The subroutine returns a value for the transmittance at X and Y in variable T.

The parameters required by TRANSM to carry out the computation of Eq. (2-1) are obtained by reading a number of data cards. A sample data deck is shown in Table 2-2. The first card provides data concerning the event on which the rest of the cards are based. The information provided is the date (month, day, and year), the speed of shadow motion in the original data set (feet per second), the direction of shadow motion (degrees from north), and the number of cards containing $C_{i,j}$ parameters (NCRD). The next card contains the parameters that remain for this data set. These parameters are in order from left to right across the card (1X, 7F10.0) S_x, S_y, x_1, x_2, x_3, x_4, and Δy, where x_{1-4} are the x locations (feet) of the $C_{i,j}$, and Δy is the spacing betweens y location of $C_{i,j}$. The next NCRD cards contain the values of $C_{i,j}$.

A time period 35 samples long (35 × 16 seconds, or approximately 9 minutes) was selected from five of the eight partly cloudy scenarios. For each of these 9-minute time periods, the $C_{i,j}$ were computed by means of this procedure described. Table 2-2 is an example of the values of $C_{i,j}$ for the time period on 29 March 1979. Tables for the other scenarios are included in the detailed data packages in Appendix A.

Table 2-2. Data Cards for Cloud Transmittance Subroutine TRANSM

ft/sec = 15 mph   o from n

```
CARD 1, ------------- FORMAT(I10,2F10.0,I10)
CARD 2, ------------- FCRMAT(7F10.0)
CARDS 3 THRU 37, ---  FCRMAT(4F10.5,35X,I5)

     32979       22.      100.        35
     1200.      350.     -939.     -682.      805.     1178.      352.
  -3.11068   5.48926  -3.75495   5.60046                                   1
  13.89915 -12.92992  14.55983 -11.92919                                   2
 -31.72630  33.46786  -8.80698   6.60731                                   3
 -43.18163  47.09407 -16.79964  12.80954                                   4
  19.12005 -20.84267   7.63714  -5.88290                                   5
  -8.14184   8.91229  -4.00113   3.24620                                   6
   5.66824  -6.29948   4.62489  -4.07395                                   7
  -6.02262   6.93538  -9.08078   8.40101                                   8
 -48.52546  51.32844    .03001  -3.44528                                   9
  28.21537 -31.77083  12.60846  -7.77266                                  10
 -17.50853  21.06550  -6.08478   6.49076                                  11
   7.91404  -6.42722   3.80200  -1.28368                                  12
   -.78227   2.89286    .10577   1.66683                                  13
   1.37759    .52523   1.81432    .13960                                  14
    .79079   1.23836    .79533   1.13916                                  15
  -2.27364   4.34955   -.54445   2.29594                                  16
   9.81335  -8.13959   4.09027  -1.46000                                  17
 -35.98009  38.64587  -9.76280   8.79428                                  18
  17.76526 -19.61253   7.75722  -3.67702                                  19
   1.01169  -1.42898   6.83335  -5.18670                                  20
   3.52733  -2.05138 -13.94159  14.79714                                  21
    .73918  -1.39257   7.97956  -5.49597                                  22
  49.19806 -50.67933  14.57952  -8.63514                                  23
 -14.43666  17.37300    .23452    .83779                                  24
  -4.91751   7.80051 -11.45846  11.98880                                  25
   -.84116   2.79172   2.44111   -.41857                                  26
   3.09646  -1.69891   5.14889  -2.55330                                  27
  -5.99156   9.61556 -12.69327  12.79861                                  28
  -5.01834   8.88220 -18.13409  18.39663                                  29
 -51.46560  55.18158 -20.20369  16.07327                                  30
  37.27890 -37.51006  13.07370 -10.48788                                  31
  19.22770 -18.95662   3.15130  -1.53291                                  32
  37.43359 -38.09541  17.28470 -14.98523                                  33
  17.92688 -16.28288  -8.59930  10.92810                                  34
  26.85186 -26.01709   1.46823   1.01577                                  35
```

III. FREQUENCY OF PARTLY CLOUDY EVENTS

The frequency of partly cloudy events influences the strategy the operator of a solar thermal electric plant must use to cope with the variations. If they occurred infrequently, the plant could simply be shut down on those occasions. However, this does not appear to be possible at Barstow, since the present experiment indicates partly cloudy conditions existed on about 25% of the days in the 1978 to 1979 time period. A technique for utilizing the long-term meteorological data from Barstow to indicate the expected frequency of partly cloudy events over a period of several years was developed.

A. METHOD

The data base that provides a historical perspective of Daggett meteorology was complied from Federal Aviation Administration (FAA) observations made at the Daggett airport, which is approximately two miles east of the pilot plant site. These data were obtained from the National Climatic Center in the 1440 tape format and cover the time period 1948 to 1976. Data for the 1977 to 1979 period were obtained directly from the FAA Daggett Flight Service Center and transcribed to computer compatible format at Aerospace.

In relating these historical cloud data to the insolation variation observations, four different quantitative measures were used for what is colloquially spoken of as cloudiness. Since it is relationships between these measures that permit us to use the historical data, a clear understanding of the significant terms is important.

1. SKY COVER

Sky cover is determined by visual estimates made by a trained observer of the fraction of the sky covered by clouds. The estimates are usually made once per hour and are expressed in tenths. Two types of sky cover are usually estimated. Opaque sky cover is that fraction of the sky covered with clouds dense enough to obscure the disk of the sun or moon. Total sky cover is that fraction of the sky covered with clouds of any type. Herein the terms will be used to mean an arithmetic average of observed values. Mean-daily mean opaque sky cover and daily mean total sky cover are for the hours between 0700 and 1700.

The "daily mean" is usually not used. The values are expressed in percent. Note derivatives of the word cloud are not used. Values of daily-mean opaque sky cover and daily-mean total sky cover were computed for each day of the entire 30-plus-year-long FAA data base.

2. INSOLATION INFERRED VALUES

The daylight portion of each day the present experiment operated was divided into clear, partly cloudy, and overcast fractions according to the procedures described in Section II.

1. Partly cloudy is that fraction of the day during which insolation varies, as described in Section II.
2. Overcast is that fraction of the day during which no direct insolation is observed, according to the criteria described in Section II.
3. Total cloudiness or simply cloudiness is that fraction of the day during which either partly cloudy or overcast conditions exist. It is the sum of the partly cloudy and overcast fractions.

Values of partly cloudy, overcast, and totally cloudy (partly plus overcast) fractions were computed for each day of the period from August 1978 through July 1979. The results are presented in Fig. 2-1. For the period of overlap of these data with the FAA data (August 1978 through June 1979), relationships between the FAA sky cover observations and the insolation-based cloudiness observations were explored in order to develop an insolation variation estimation technique to be applied to the remaining FAA data base.

The mean-daily total sky cover was found to be linearly correlated with the insolation-inferred total cloudiness (partly cloudy and overcast periods taken together) with a correlation coefficient of approximately 0.9 for the total year.

The relationship between the insolation-inferred partly cloudy fraction and total sky cover is more complicated. Summer months tend to have a 45-

degree linear relationship. In winter months, there are many instances where the partly cloudy fraction is very low for high total sky cover, which corresponds to the total opaque sky cover, which is common during storms. No simple linear relationship exists between these observations.

Regression relationships involving insolation-inferred partially cloudy fractions and total opaque sky cover indicated considerable variation by month and were not chosen for estimation purposes, since no consistent relationship or set of relationships was defined by the limited number of data points.

In the absence of available regression relationships, a stochastic process was adopted for estimating the frequency of cloud-induced insolation effects. This procedure is similar to that used elsewhere by the authors (Ref. 2) and will be described here only briefly. The procedure is based on deriving a frequency distribution for the variable to be estimated for each value, or range of values of the parameter chosen as an estimator. These empirical frequency distribution functions derived from a limited data set are then assumed to describe the probability distributions for a larger set of values of the estimating parameter.

Mean-daily total sky cover (0700 to 1700 hours) was chosen as the estimating parameter because it was more highly correlated with the insolation variation effects to be estimated than was the mean-daily total opaque sky cover, and these two sky cover estimates were the only applicable parameters available for a climatologically significant period at Daggett. Mean-daily observed total sky cover was divided into "bins" 10 percent wide. For each total sky cover bin, three distributions were derived from the 12 months of observations of insolation-inferred cloudiness available from the present experiment; the distribution of values of total cloudiness, the distribution of values of partial cloudiness for winter (November to March), and the distribution of values of partial cloudiness for summer (April to October). The derived distributions expressed as cumulative distribution functions, or ogives, are presented in Table 3-1.

These distributions, based on one year of data, are then used with the 1948 to 1977 mean-daily total sky cover to make estimates of cloud-induced

Table 3-1. Cumulative Distribution Functions (Ogives) of Insolation Derived Cloudiness for Various Sky Cover Amounts and Seasons

All Year Percent Total Cloudy	Total Sky Cover (tenths)										
	0-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10	10
0 < 10	.86	.57	.13	.05	.17	0.00	.15	0.00	.06	0.00	0.00
10 < 20	.95	.77	.33	.21	.22	0.00	.15	0.00	.06	0.00	0.00
20 < 30	.96	.87	.73	.47	.33	0.00	.15	0.00	.06	0.00	0.00
30 < 40	.97	.93	1.00	.79	.39	.25	.15	0.00	.06	0.00	0.00
40 < 50	.97	1.00	1.00	.89	.56	.42	.31	.08	.06	0.00	0.00
50 < 60	.98	1.00	1.00	.89	.94	.75	.46	.33	.11	.05	0.00
60 < 70	.98	1.00	1.00	.95	1.00	.92	.62	.38	.17	.05	0.00
70 < 80	.99	1.00	1.00	1.00	1.00	.92	.85	.54	.22	.05	0.00
80 < 90	1.00	1.00	1.00	1.00	1.00	1.00	.92	.83	.44	.14	0.00
90 < 100	1.00	1.00	1.00	1.00	1.00	1.00	.92	.88	.61	.18	0.00
≤ 100	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

Summer Percent Partly Cloudy	Total Sky Cover (tenths)										
	0-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10	10
0 < 10	.85	.67	.44	.10	.30	0.00	.67	.11	.33	0.00	0.00
10 < 20	.93	.89	.67	.50	.40	.17	.67	.22	.33	0.00	0.00
20 < 30	.95	.89	.89	.70	.60	.33	.67	.33	.33	0.00	0.00
30 < 40	.96	.94	1.00	.90	.70	.50	.67	.56	.67	.50	0.00
40 < 50	.98	1.00	1.00	1.00	1.00	.67	1.00	.67	.67	.50	0.00
50 < 60	.99	1.00	1.00	1.00	1.00	.67	1.00	.67	.67	.50	0.00
60 < 70	.99	1.00	1.00	1.00	1.00	1.00	1.00	.78	.67	1.00	0.00
70 < 80	.99	1.00	1.00	1.00	1.00	1.00	1.00	.89	.67	1.00	0.00
80 < 90	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	.67	1.00	0.00
90 < 100	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.00
≤ 100	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

Winter Percent Partly Cloudy	Total Sky Cover (tenths)										
	0-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10	10
0 < 10	.91	.67	0.00	.11	.13	0.00	.10	.13	0.00	.50	.86
10 < 20	1.00	.92	.50	.33	.25	.17	.20	.33	.07	.75	.86
20 < 30	1.00	1.00	.83	.89	.38	.17	.50	.47	.47	.85	1.00
30 < 40	1.00	1.00	1.00	1.00	.88	1.00	.50	.80	.67	.85	1.00
40 < 50	1.00	1.00	1.00	1.00	1.00	1.00	.70	.80	.80	.95	1.00
50 < 60	1.00	1.00	1.00	1.00	1.00	1.00	.90	1.00	.87	.95	1.00
60 < 70	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	.87	.95	1.00
70 < 80	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	.93	.95	1.00
80 < 90	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	.93	1.00	1.00
90 < 100	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	.93	1.00	1.00
≤ 100	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

insolation effects. For each day of the entire 29-year period, five random entries are made into each of the two appropriate empirical distributions, corresponding to the observed mean-daily total sky cover. The resultant five estimates of the partly cloudy percentage for that day are then averaged to estimate the partly cloudy percentage for that day. A similar procedure is used to estimate the total cloudy percentage for the day. Estimates of these two quantities are made for every day of the 29-year period from 1948 to 1977 and form the basis of the statistical summaries presented in the next section.

B. ESTIMATED FREQUENCY OF CLOUDY PERIODS AFFECTING INSOLATION

The daily values of partly cloudy percentage and total cloudy percentage produced by the procedures outlined in the preceding section have been averaged to provide mean-daily values by month and year for each of the months and years considered. These results are presented in Tables 3-2 and 3-3, respectively.

The values in the bottom rows of Tables 3-2 and 3-3 are the mean of the columns. The distribution of the values about these means is also important because it indicates the likelihood of months occurring with particularly cloudy or clear conditions. The full distributions for partly cloudy percentage and totally cloudy percentage are presented as cumulative frequency distributions for January and June in Figs. 3-1 and 3-2. The distributions for other months are, in general, intermediate between the distributions for January and June and therefore have not been included here. However, selected percentile values for all months are provided in Tables 3-4 and 3-5.

The typicality of the year from August 1978 through July 1979 for which detailed insolation variation measurements are available now may be investigated. For example, the mean-daily partly cloudy percentage for January 1979 was observed to be 19.7 percent (Fig. 2-1). Using the distributions of this quantity (Fig. 3-1 and Table 3-4), we find that this value corresponds to approximately the 72nd percentile, indicating about 70 percent of previous Januarys had more time without partly cloudy conditions than did January 1979. A similar analysis of the total cloudy percentage indicates that in

Table 3-2. Estimated Monthly Mean Percentage of Daylight Hours with Partly Cloudy Conditions Affecting Insolation from 1948 to 1977

					MONTH								
YEAR	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	ANNUAL
1948											12.0	21.4	
1949	15.3	19.5	23.9	24.1	16.9	11.5	11.0	11.3	10.6	14.4	14.2	14.7	15.9
1950	21.5	16.4	21.2	14.2	12.3	11.2	15.6	10.8	16.2	12.3	20.5	18.6	15.9
1951	22.3	23.1	13.7	20.4	15.4	11.4	15.5	13.8	10.3	15.1	17.6	18.9	16.5
1952	22.3	16.4	21.6	17.8	17.5	11.3	10.3	13.0	11.2	12.0	18.2	19.0	15.9
1953	22.2	16.9	10.5	23.0	15.3	16.3	11.6	14.1	11.9	12.3	12.6	17.2	15.3
1954	14.0	18.8	14.9	20.3	15.1	12.8	11.6	17.1	10.3	9.5	11.2	15.2	14.2
1955	18.2	17.4	18.0	13.6	13.5	13.1	3.7	15.2	13.9	9.0	12.5	19.9	14.9
1956	19.5	20.6	14.1	14.4	21.0	14.1	10.5	14.8	10.6	9.3	16.1	8.5	14.5
1957	14.5	19.4	25.4	25.0	20.0	18.8	15.5	14.6	12.4	20.4	16.8	24.3	19.0
1958	16.9	19.0	26.8	24.0	21.7	18.0	16.8	8.6	20.4	13.1	14.1	17.0	18.0
1959	13.7	23.1	20.7	10.6	22.2	21.1	10.2	13.4	18.1	16.8	13.5	19.4	16.9
1960	16.5	19.0	23.5	23.5	18.0	17.1	17.8	8.8	15.5	14.4	12.6	14.5	16.8
1961	14.3	12.9	16.2	18.1	18.3	13.2	13.2	10.0	14.4	20.6	10.9	18.6	15.1
1962	16.1	18.6	18.0	22.8	17.6	17.9	14.2	10.1	11.7	11.1	9.8	12.5	15.0
1963	15.7	16.1	12.0	23.2	15.2	20.3	15.2	12.2	12.4	15.5	16.9	16.1	15.9
1964	21.5	14.0	20.9	8.4	15.1	18.8	20.9	11.4	12.8	22.0	9.6	13.4	15.7
1965	15.7	14.2	24.2	21.7	19.0	25.1	17.3	15.4	10.5	20.7	13.8	12.0	17.5
1966	14.4	20.1	20.7	19.9	20.0	25.2	13.0	13.4	14.0	15.1	9.9	18.7	17.0
1967	18.3	21.1	16.9	18.7	17.7	26.1	19.7	14.9	15.7	16.8	23.3	14.0	18.6
1968	15.0	18.8	15.7	22.7	24.7	15.8	15.8	13.8	12.2	17.4	15.2	8.6	16.4
1969	21.6	19.2	20.9	26.7	21.3	18.6	17.0	13.2	14.9	16.6	18.0	13.3	18.4
1970	15.9	16.2	23.4	21.2	19.7	24.8	18.6	15.6	16.5	18.5	19.7	12.5	18.6
1971	15.8	19.5	23.5	22.0	18.4	16.3	13.9	17.6	15.2	14.2	17.6	13.1	17.8
1972	14.4	17.7	18.5	16.5	22.4	17.5	22.2	12.0	19.3	18.6	14.7	18.5	17.7
1973	23.9	19.1	18.7	17.2	20.0	23.9	22.0	13.0	17.3	15.9	13.7	11.2	18.0
1974	10.7	13.0	22.3	24.5	21.2	18.5	26.4	13.3	18.5	9.8	22.8	11.1	17.7
1975	11.5	18.5	16.9	17.2	18.7	20.3	17.8	20.5	15.7	11.8	14.9	12.2	16.4
1976	16.0	12.4	14.9	14.1	14.8	23.4	20.6	18.0	15.3	12.7	17.4	10.5	15.8
1977	24.3	20.3	14.2	9.4	20.6	17.8	14.6	23.9	24.4	21.9	18.4	23.3	19.5
MEAN	17.5	18.0	19.1	19.2	18.6	17.9	16.0	13.9	14.6	15.1	15.3	15.6	16.7

[illegible] 3-4

Table 3-3. Estimated Monthly Mean Percentage of Daylight Hours with Cloudy (Partly and Overcast) Conditions Affecting Insolation from 1948 to 1977

YEAR	JAN	FEB	MAR	APR	MAY	MONTH JUNE	JULY	AUG	SEPT	CCT	NOV	DEC	ANNUAL
1948											15.7	37.6	
1949	59.3	30.6	38.7	36.6	23.2	17.6	14.3	17.2	11.8	19.6	22.5	33.8	27.1
1950	35.8	38.1	37.9	20.1	19.5	13.1	26.4	12.5	23.5	14.6	29.6	35.1	25.5
1951	37.3	34.7	30.0	34.5	26.5	15.8	23.0	19.0	11.6	18.7	31.8	30.1	26.1
1952	48.8	31.3	41.7	26.2	27.6	13.2	11.4	21.1	12.8	16.5	30.7	30.5	26.0
1953	43.8	28.1	17.8	32.2	27.3	25.7	17.3	19.0	14.7	13.6	19.7	31.2	24.2
1954	23.3	39.7	26.5	30.7	20.2	18.0	14.7	28.0	13.8	9.4	14.2	27.8	22.2
1955	38.1	27.2	29.6	18.2	32.5	18.0	11.2	25.3	22.4	8.7	17.7	35.6	23.7
1956	39.0	34.4	24.3	19.3	36.1	17.8	12.2	25.6	11.9	9.9	21.1	11.4	23.6
1957	22.1	39.6	61.8	53.6	32.5	34.8	21.1	19.0	17.7	28.7	26.4	41.3	33.2
1958	32.6	27.0	54.5	44.2	34.1	28.6	22.9	9.1	33.5	15.7	18.2	28.8	29.1
1959	25.1	35.7	35.2	16.9	35.2	31.4	12.3	17.1	26.1	22.9	17.5	34.1	25.8
1960	28.9	44.7	41.0	39.4	26.3	24.5	27.8	10.3	19.7	16.7	16.3	23.3	26.6
1961	25.5	21.3	30.8	27.0	29.7	16.2	18.2	12.6	19.6	33.1	12.3	30.4	23.1
1962	30.5	36.1	29.0	42.9	28.9	28.7	21.4	11.6	13.4	11.9	10.8	21.0	23.9
1963	26.0	24.7	25.3	33.7	28.7	32.1	25.4	14.3	15.3	21.4	25.8	30.9	25.7
1964	32.7	20.7	30.3	11.6	23.9	29.6	32.4	15.6	15.8	30.8	10.4	16.8	22.6
1965	27.0	23.9	45.5	40.9	30.8	48.6	26.7	26.7	11.8	34.3	18.2	17.3	29.3
1966	24.7	56.6	40.8	44.1	32.0	39.7	20.7	18.5	18.2	22.4	11.0	24.3	29.4
1967	34.0	44.3	24.3	32.9	29.5	46.0	28.2	21.2	21.2	26.4	35.0	20.3	30.3
1968	25.3	37.1	39.6	44.7	51.7	27.9	22.3	20.0	16.2	28.9	18.6	9.0	28.4
1969	29.1	34.3	44.1	57.4	45.1	32.3	25.1	20.4	21.0	25.6	27.4	16.2	31.5
1970	24.7	34.2	36.9	53.4	39.0	46.0	27.4	21.2	24.3	31.4	28.5	16.3	31.9
1971	23.2	32.0	44.8	38.9	29.3	24.7	27.8	28.6	21.7	21.4	25.2	16.6	27.9
1972	18.0	30.3	39.3	32.7	38.2	28.1	38.2	14.5	33.1	27.6	19.4	25.5	28.7
1973	34.0	38.7	30.6	29.8	39.6	43.9	37.2	18.2	26.9	23.9	18.1	15.6	29.7
1974	11.0	18.2	33.6	38.4	43.3	28.1	45.5	18.1	25.4	11.2	39.8	12.9	27.2
1975	12.6	31.5	31.5	30.9	31.3	38.7	28.5	30.9	22.5	14.4	22.9	14.3	25.9
1976	20.4	19.3	21.7	18.8	21.4	40.7	30.6	26.5	25.3	15.8	23.3	14.0	23.2
1977	35.4	31.2	22.0	14.4	52.4	43.9	27.9	35.5	40.3	32.6	29.2	32.7	33.1
MEAN	29.9	33.3	34.8	33.4	32.3	29.4	24.1	19.9	20.4	21.0	21.9	24.5	27.1

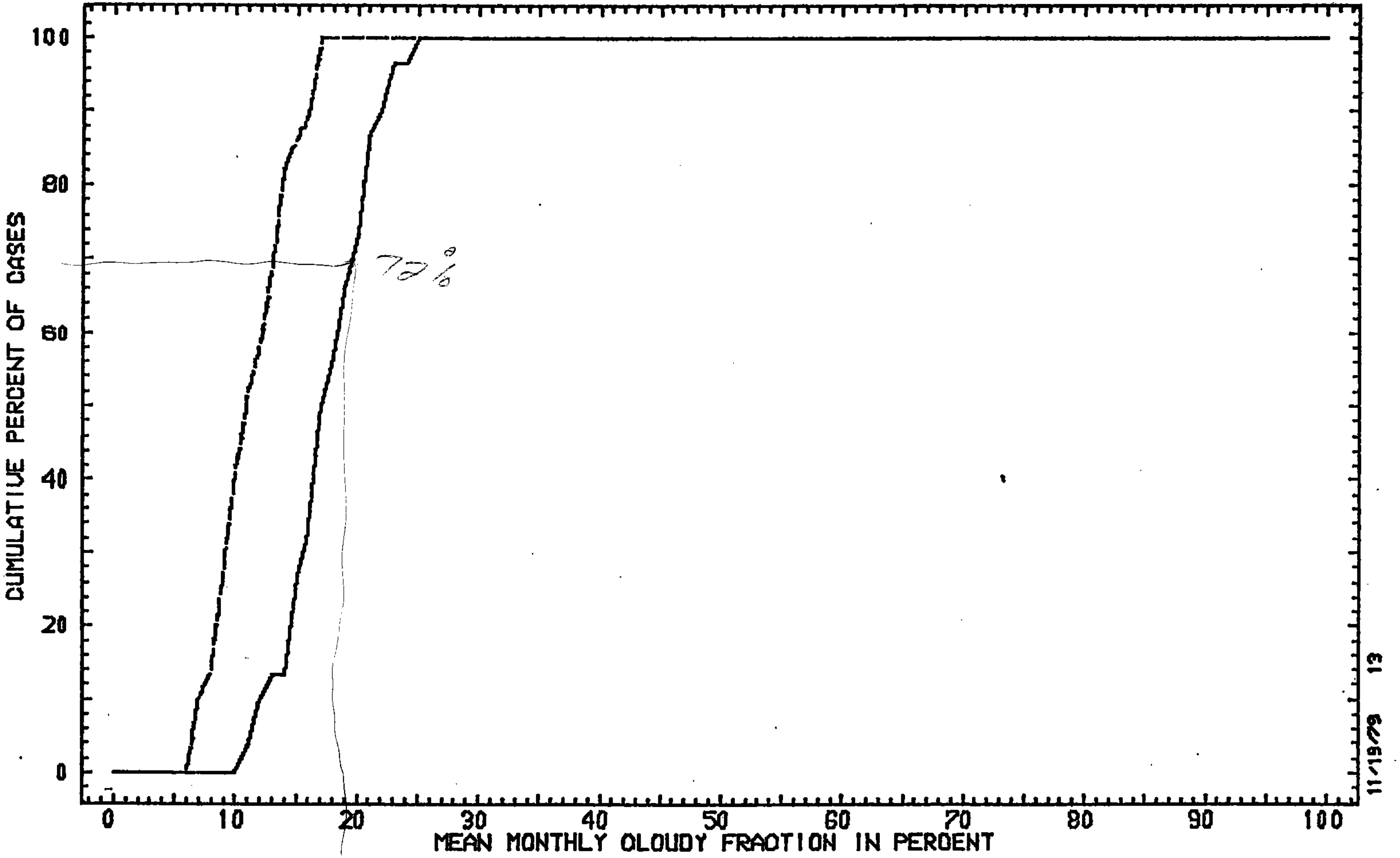

Fig. 3-1. Frequency of Partly Cloudy Events (Ogives for January 1979, Solid Curves, and July 1979, Dashed Curves)

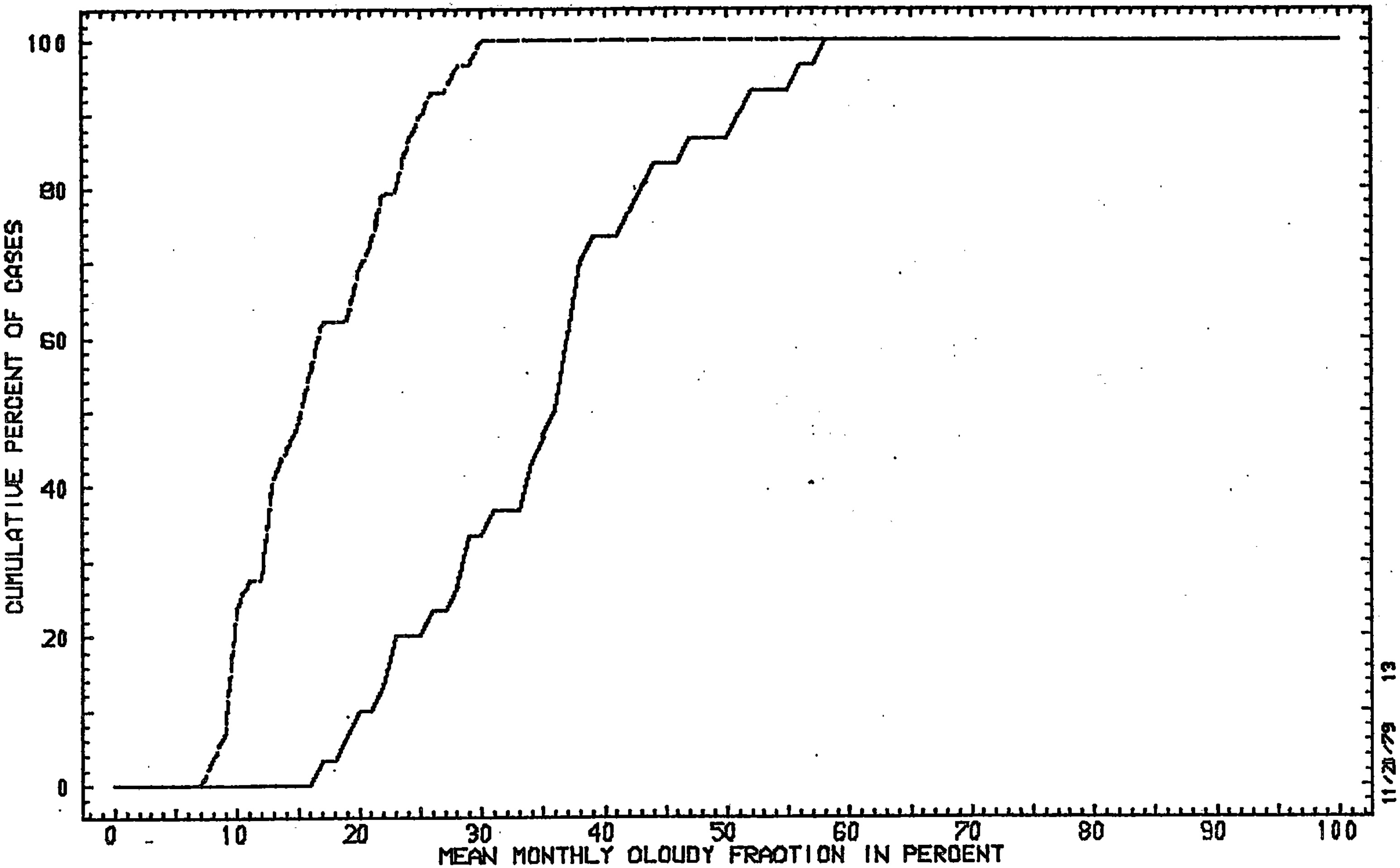

Fig. 3-2. Frequency of Cloudy Events (Ogives for January 1978, Solid Curves, and July 1979, Dashed Curves)

Table 3-4. Percentiles of Frequency of Partly Cloudy Conditions Causing Varying Insolation at Daggett(1)

	Monthly Mean Daylight Hours, %				
	Percentile				
	0	10	50	90	100
Month					
January	10	12	17	22	25
February	6	13	17	21	25
March	8	12	17	22	24
April	11	13	18	23	25
May	10	11	15	19	23
June	8	9	13	16	20
July	6	7	11	16	17
August	8	9	13	20	22
September	6	8	11	19	23
October	6	8	12	18	22
November	6	10	15	18	22
December	7	12	16	20	22
Mean	8	10	15	20	23

(1) Estimates are based on sky-cover data from 1948 to 1977.

Table 3-5. Percentiles of Frequency of All Cloudy Conditions Affecting Insolation at Daggett[(1)]

	Monthly Mean Daylight Hours, %				
	Percentile				
Month	0	10	50	90	100
January	16	20	36	51	58
February	10	24	36	52	60
March	14	22	30	43	52
April	16	23	28	38	47
May	12	17	25	32	39
June	10	12	19	25	32
July	7	9	15	25	30
August	9	11	20	31	38
September	6	9	14	31	34
October	6	9	16	29	33
November	9	15	27	36	45
December	12	21	30	43	58
Mean	11	16	25	36	44

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(1) Estimates are based on sky cover data from 1948 to 1977.

January 1979 a larger fraction of the time insolation was affected by clouds than in any of the months of January considered in the long-term study. A similar analysis was carried out for the other eleven months in the current study, and the results are given in Table 3-6.

The winter of 1978-1979 appears to have been unusually cloudy, according to the results of Table 3-6. If the percentiles derived were from a normal distribution, November, January, February, and March are more than 1.5 standard deviations from the mean and September and December are more than 0.6 standard deviation from the mean. Since the percentiles corresponding to observed partly cloudy percentage are usually less than the percentiles for total cloudy percent, it is probable that the increased cloudiness was the result of large clouds.

The summer of 1978 appears to be much more typical in terms of the percentiles presented in Table 3-6.

That clouds will affect pilot plant operation a significant fraction of the time is one of the qualitative conclusions that may be drawn from Tables 3-4 and 3-5. More quantitatively,

1. For 90 percent of the months, at least 10 to 15 percent of daylight hours will have varying insolation, characterized here as partly cloudy.
2. For 90 percent of the winter months (November to March), clouds will affect the insolation at least 15 to 25 percent of the daylight hours.
3. For 90 percent of the summer months (April to October), clouds will affect the insolation at least 10 to 20 percent of the daylight hours.

Table 3-6. Insolation-Determined Cloudy Periods for 1978 to 1979 with Estimated Occurrence Percentiles

	Insolation-Determined Cloudiness, %		Estimated Occurrence Percentile	
	Partial	Total (Partial and Overcast)	Partial	Total (Partial and Overcast)
August 1978	7.7	10.	0.0	2.0
September 1978	16.6	27.7	83.5	90.0
October 1978	9.3	15.0	19.0	38.0
November 1978	8.3	37.1	2.5	93.0
December 1978	16.4	35.0	58.0	73.0
January 1979	19.7	69.0	72.0	100.0
February 1979	25.3	56.3	100.0	98.0
March 1979	20.4	51.1	67.0	97.0
April 1979	20.0	27.2	70.0	46.0
May 1979	18.5	25.7	88.0	58.0
June 1979	11.0	14.8	29.0	23.0
July 1979	11.2	16.3	51.7	58.0

IV. CONCLUSIONS AND RECOMMENDATIONS

This study has provided insolation measurements at a 16-second time resolution for approximately one year. The following qualitative conclusions previously drawn on the basis of only one month's data remain valid:

1. A significant variation in insolation can take place over the spatial scale of the collector field. This is confirmed by the frequent large values in the plots of RMS insolation variation.

2. The rates of change of power can exceed 30 $W/m^{-2}-sec^{-1}$ (limited by the time resolution of the observations).

On the basis of the data and analysis reported here, the following conclusions were made:

1. Partly cloudy conditions occur frequently at Daggett. Although the winter of 1978-1979, during which time the experiment was carried out, appears to have been unusually cloudy, the median expected fraction of daylight hours with cloudy conditions affecting insolation exceeds 25 percent for all the winter and spring months from November through March and is 36 percent for January and February (Table 3-5).

2. The present study has provided detailed quantitative data for analysis of the system effects of rapid insolation variations. This analysis has only begun, and therefore, conclusions concerning the impact of these variations on real power plants are premature. However, there are indications (Ref. 3) that more uneven heating of the pilot plant receiver panels may occur as a result of the spatial variations reported here.

The following recommendations concerning future experiments of this type were made on the basis of the experience gained in the present experiment.

1. The time resolution of the experiment should be increased, at least during partly cloudy episodes. Users of our data indicate the pilot plant receiver panels have time constants as low as 10 seconds under some conditions. Data at 5-second resolution would be helpful for studying these effects. Our analysis indicates that we are not capturing the highest rates of change. The direct measurement of the rate of insolation change should also be considered.

2. The spatial resolution of the experiment should be increased. The four-station configuration is an absolute minimum. Many future systems may have collector fields smaller than the pilot plant, and hence, the present data are of only limited validity.

3. Better cloud observations are required. The paucity of cloud type observations available to us in the present study precluded making use of the inherently attractive approach of partitioning our data sets according to cloud type. The simplest technique would be an all sky camera set to take pictures every 15 minutes or so.

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3. C. L. Lawrence, Collector Field Optimization Report (RADL Item 2-25), Report SAN/0499-22, MDC G8214, McDonnell Douglas Astronautics Company (October 1979).

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