Determination of an Optimum Sampling Rate for the Collection of Solar Radiation Data

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ABSTRACT

An analysis of total sky and direct component shortwave solar radiation data is presented in order to determine an optimum sampling rate for recording these data. The accuracy of total and direct component irradiances integrated over various time periods is examined as a function of the sampling rate for various types of cloudiness. Integrated daily values of total sky irradiance were accurate to within 1.0% of the true daily value for sampling intervals as large as 120 seconds. The same sampling interval was acceptable for daily integrated direct irradiances when totally overcast data were excluded. For accuracy of direct irradiances integrated over a three hour period the data should be sampled no less frequently than every minute, if totally overcast data may be ignored. Sampling intervals as long as 1200 seconds resulted in an average error of daily accumulated irradiances of less than 5%.

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1.0 INTRODUCTION

The purpose of this report is to summarize the rationale used in determining an adequate sampling rate for the collection of solar radiation data.

Total component radiation is collected by an hemispheric pyranometer, responsive in the shortwave from about 0.3 μ meters to 3.0 μ meters. Direct component data are collected by a shortwave pyrheliometer responsive in the same wavelength region as the pyranometer. Unlike the pyranometer, however, the field of view of this instrument is about 5^{o}.

Both instruments generate voltages proportional to the incident radiative power per unit area. A continuous record of the data may be conveniently collected using a strip chart recorder, for example. However, if the data must be analyzed in any manner (such as obtaining means, variances, sums, etc.), it is more practical to digitally record the data so that they may be machine processed. If the latter method of data acquisition is chosen, the sampling rate must be selected based on the accuracy desired and the cost of the data processing. This report attempts to depict the tradeoff which is made as the sampling rate is decreased in order to minimize the cost of data processing. The analysis utilizes data collected at the Department of Atmospheric Science, Colorado State University in 1976 on days 146-153 for various types of sky cover. The test statistic is the accuracy of total and direct irradiances integrated over various time periods as a function of the time increment used in the integration.

2.0 COMPUTER COST CRITERIA

The data processing cost is nearly proportional to the amount of data, which is, of course, directly related to its quality (based on the test statistic defined above). The cost for this particular program was broken down according to each phase of the processing as indicated in the flow diagram, Fig. 1. It was determined from actual computer runs that 43% of the computer time would be used in steps 2 and 3 for decoding the recorded data. Likewise, 50% of computer time costs were attributed to processing binary information into real dimension values and outputting these values. The remaining 7% of the costs result from the purchase of magnetic tape. When put in terms of absolute costs, it was found that processing four channels of data, which was collected by scanning every ten seconds, resulted in a per diem cost of about two dollars.

3.0 DATA SAMPLING RATE CRITERIA

In order to determine an adequate sampling interval the accuracy of various integrations of the data sample was examined as the sampling rate was decreased. Since the response time of the radiometers employed was determined to be about three seconds, data from such a sampling rate were assumed to represent the actual continuum of radiation values. Then various quantities based on data samples taken at multiples of the basic three second interval were compared with similar quantities obtained from the three second data continuum.

For example, quantities of total daily accumulated irradiation were computed as a function of the sampling rate.

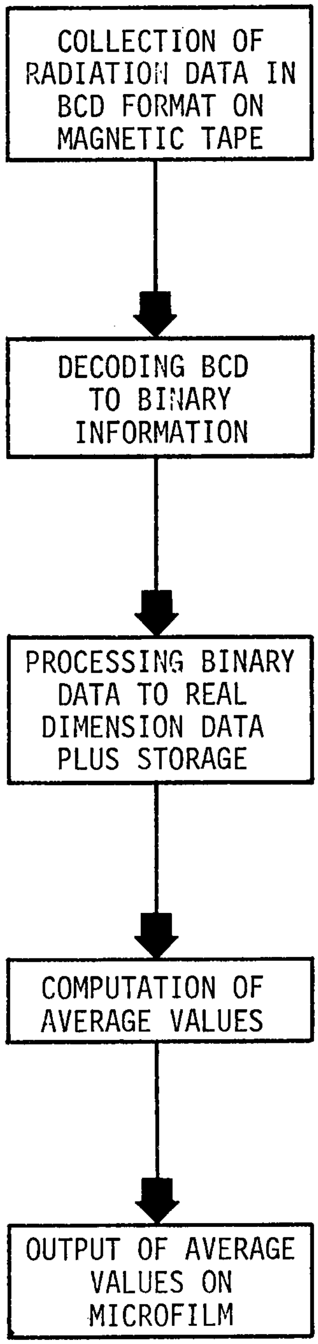


Figure 1. Data Flow Diagram.

Comparison of these results is made in Tables 1 and 2 which show the ratios of daily irradiances computed from various sampling intervals to corresponding daily irradiances computed from the three second interval. Both direct and total irradiance comparisons are shown along with a legend which gives an approximate idea of the type of sky cover for each day. As is seen in the tables, the most serious relative errors occur on very overcast days when the resulting accumulated irradiances are extremely low. The absolute errors on these days are actually quite small. Next, standard deviations of these ratios were computed in order to represent the variation of daily integrated irradiance as a function of sampling rate when several days of varying cloud cover are considered. A plot of the standard deviations of the ratios of (S_x/S_3) is shown in Fig. 2 as a function of x, where S_x is the total daily irradiance as computed from a sample utilizing an interval of x seconds between data scans. The relatively smooth variation of these standard deviations for the total radiation case contrasts with the erratic variation for the direct radiation case (Fig. 3) because of the difference in the field of view of the two radiometers used to gather the respective data sets.

On a somewhat smaller time scale, a similar comparison was made for the direct radiation accumulated over a three hour period. The direct component case was analyzed because it is the more susceptible to changes with scan interval. Plots of the direct component for various different three hour periods

TABLE 1

RATIOS OF DAILY ACCUMULATED IRRADIANCES
DEPENDING ON SAMPLING INTERVAL

PYRANOMETER

DAY \ SAMPLING INTERVAL (SEC)	6	15	30	60	120	240	300	600	1200
146	1.000	1.000	1.000	1.000	1.001	.999	1.002	1.003	1.003
147	1.000	1.000	.999	.998	.996	.999	1.017	1.018	1.034
148	1.000	.998	.997	.994	.991	1.001	.969	.949	.923
149	1.000	1.001	.999	.999	.998	.994	1.007	1.012	1.010
150	1.000	1.001	1.001	1.003	1.002	1.027	.991	.990	.999
151	1.000	1.000	.997	1.000	1.000	1.001	1.012	1.019	1.073
152	1.000	1.000	.999	1.000	1.003	1.002	.993	.990	.983
153	1.000	1.000	.999	.997	.995	.994	1.004	.994	.998

DAY	TYPE OF CLOUDINESS
146	Extremely Clear All Day
147	Heavy Variable Cloudiness
148	Heavy Overcast All Day
149	Heavy Overcast All Day
150	Clear Morning - Variable Afternoon Cloudiness
151	Scattered Morning - Heavy Afternoon Cloudiness
152	Clear Morning - Light Scattered Clouds Afternoon
153	Mostly Clear Until 14:00 - Moderately Cloudy After 14:00

TABLE 2

RATIOS OF DAILY ACCUMULATED IRRADIANCES
DEPENDING ON SAMPLING INTERVAL

PYRHELIOMETER

DAY \ SAMPLING INTERVAL (SEC)	6	15	30	60	120	240	300	600	1200
146	1.000	1.000	1.000	1.000	.998	.996	.994	.990	.977
147	1.000	1.000	.999	.993	.994	1.001	1.041	1.043	1.043
148	.997	.973	.941	1.008	.989	1.107	1.087	1.078	1.041
149	.997	.998	.981	.966	.952	.954	.988	1.093	1.134
150	1.000	1.000	1.000	1.004	1.002	1.002	.991	.986	.974
151	1.000	1.000	.996	.999	.995	1.000	1.008	1.007	1.046
152	1.000	1.000	1.000	.999	1.003	1.004	.989	.977	.971
153	1.000	1.000	.999	.998	.998	.999	1.005	.997	.995

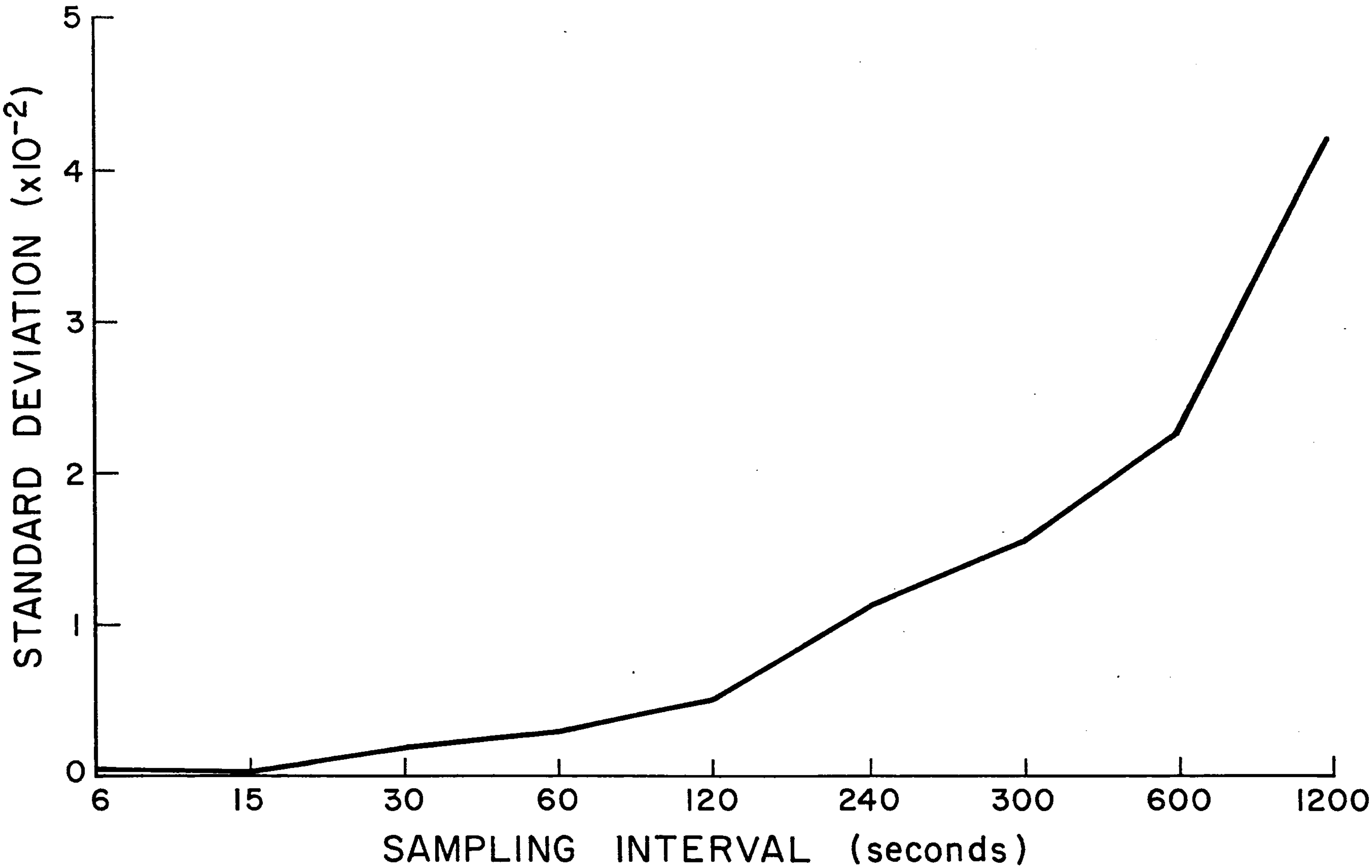


Figure 2. Standard deviation of the ratio $\frac{S_x}{S_{3\ SEC}}$ as a function of scan interval. Total component comparison.

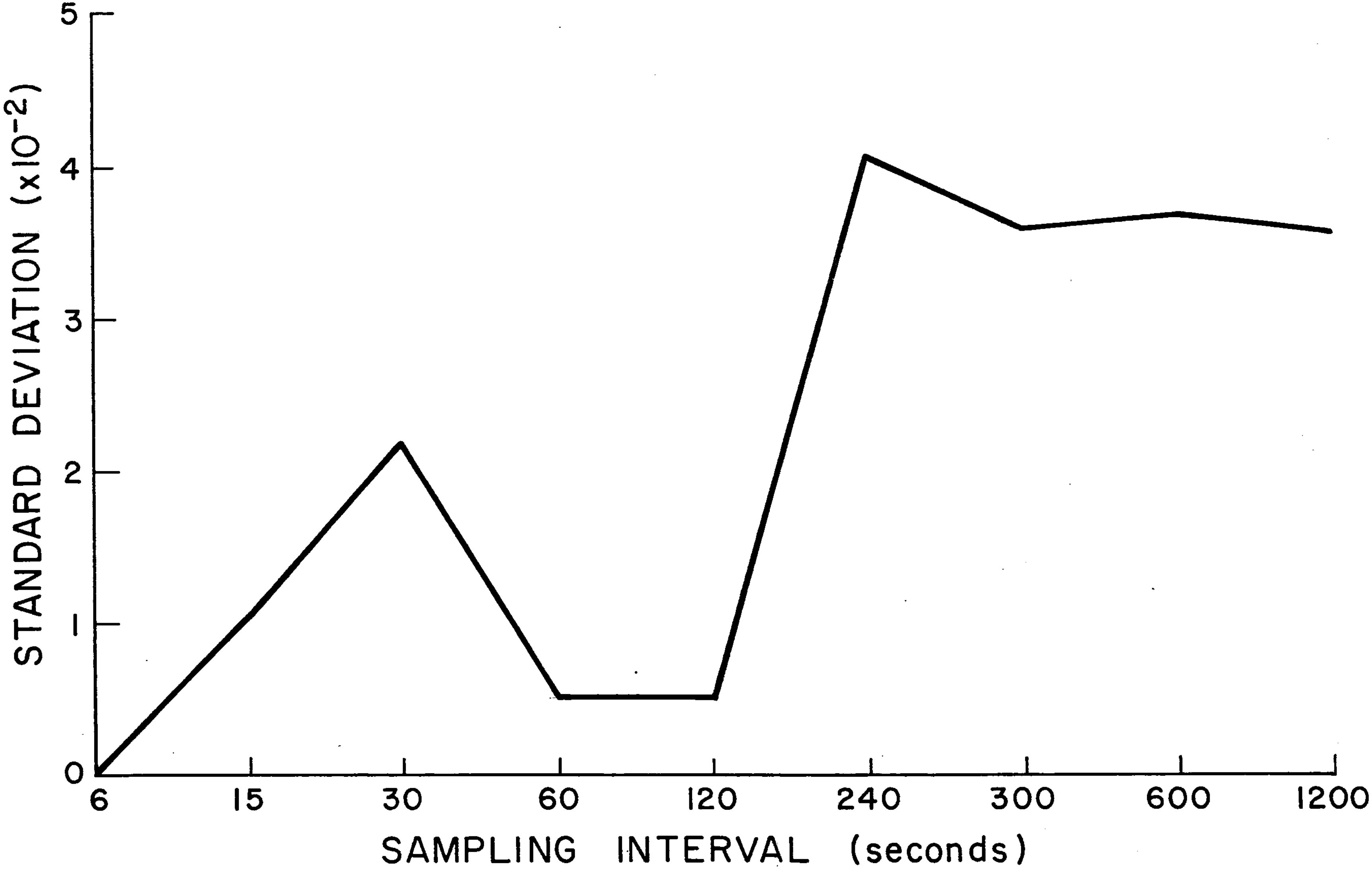


Figure 3. Standard deviation of the ratio $\frac{S_x}{S_{3\ SEC}}$ as a function of scan interval. Direct Component Comparison.

along with "scan interval dependent" ratios for corresponding accumulated direct radiation are shown in Figs. 4 through 8.

From inspection of the graphs and tables presented, no clear cut point can be found which divides accuracy from inaccuracy. There seems to be no problem with daily accumulated total values until a 240 second scan interval is attained, at which point, on a day when total irradiance values are fairly large, a 2.7% error is encountered. At larger scan intervals relative error increases in frequency and magnitude. For the daily accumulated direct case, on extremely overcast days, a 2.7% error is encountered at an interval of only 15 seconds. However, as the interval is increased, accuracy improves before deteriorating completely. On days with other than totally overcast conditions, accuracy is good up to an interval of about 240 seconds.

The standard deviation plots indicate that the standard error in the daily total irradiance is in an acceptable range for intervals as long as 300 seconds. The daily direct case shows that the standard error may in fact be too large even at 30 second intervals. These results, however, include the large relative errors resulting from totally overcast conditions. Figure 9 shows a corresponding plot with these days (147, 148) excluded. From this second plot it is seen that the erratic behavior results primarily from the error contributions of totally overcast days. A glance at a three hour plot of direct irradiance from one of these two days, Fig. 6, shows this component to be so small that attempts to measure variation of relative error may well be meaningless. The total accumulated

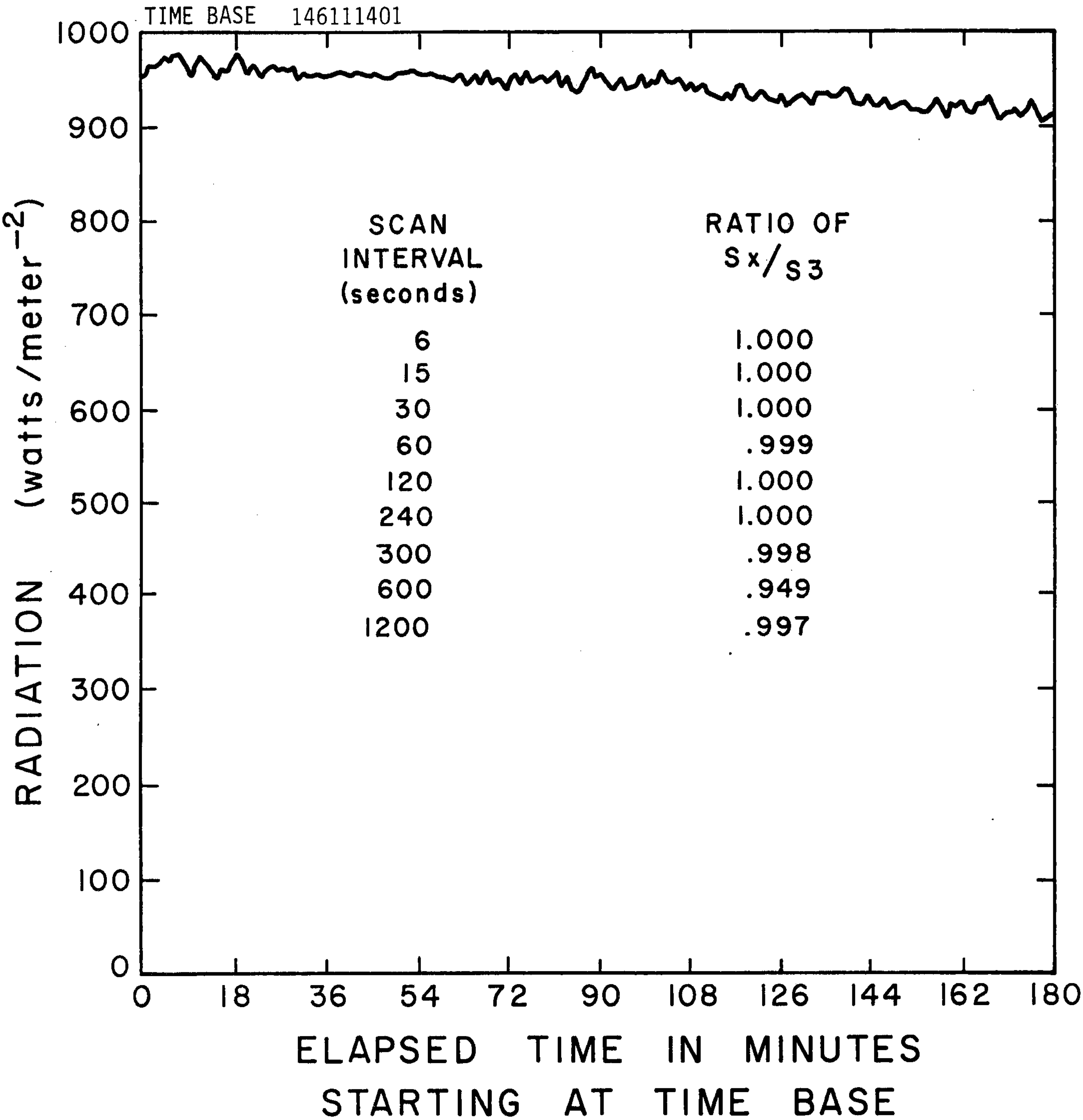


Figure 4. Direct Radiation vs. Time.

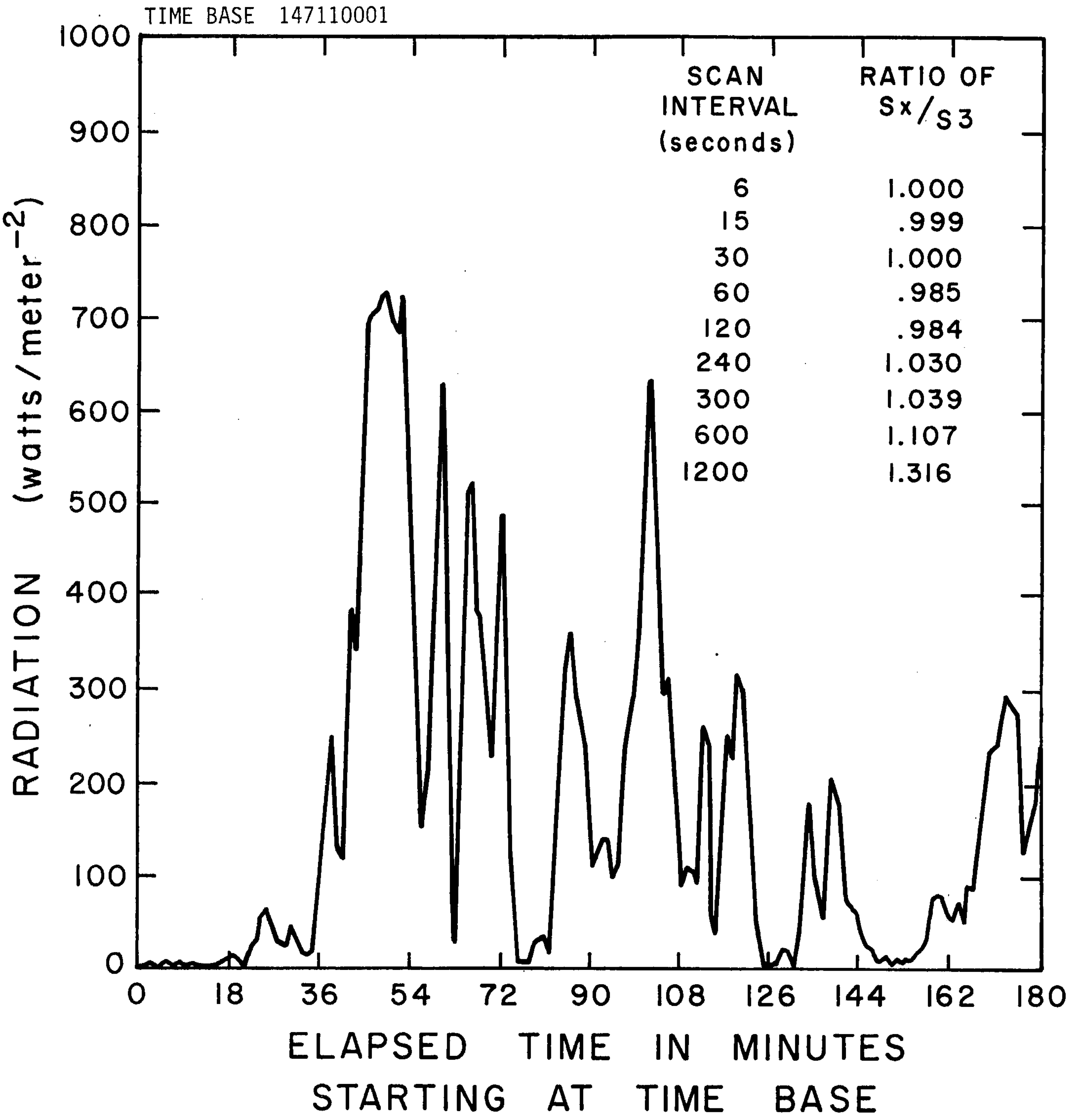


Figure 5. Direct Radiation vs. Time.

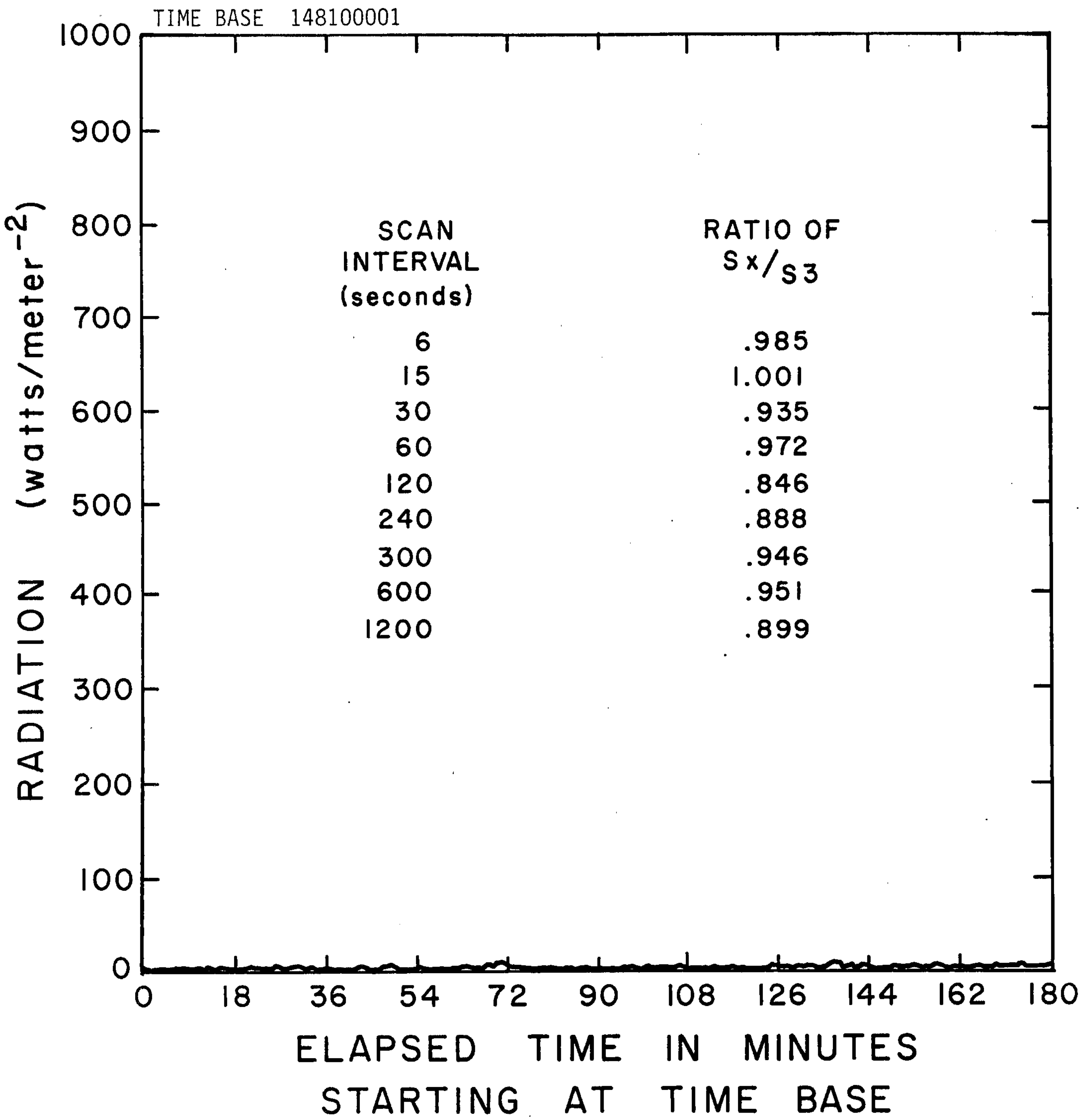


Figure 6. Direct Radiation vs. Time.

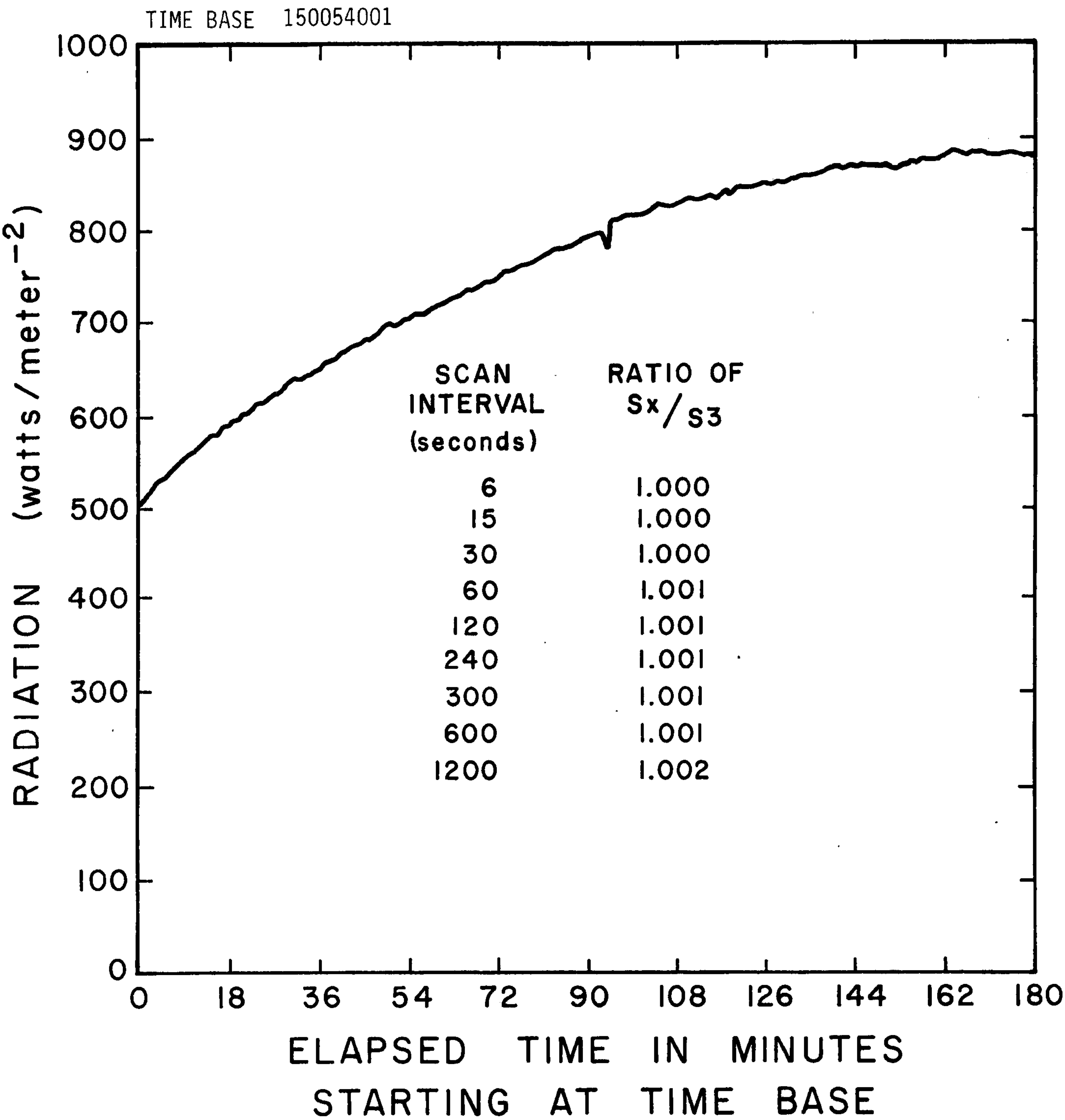
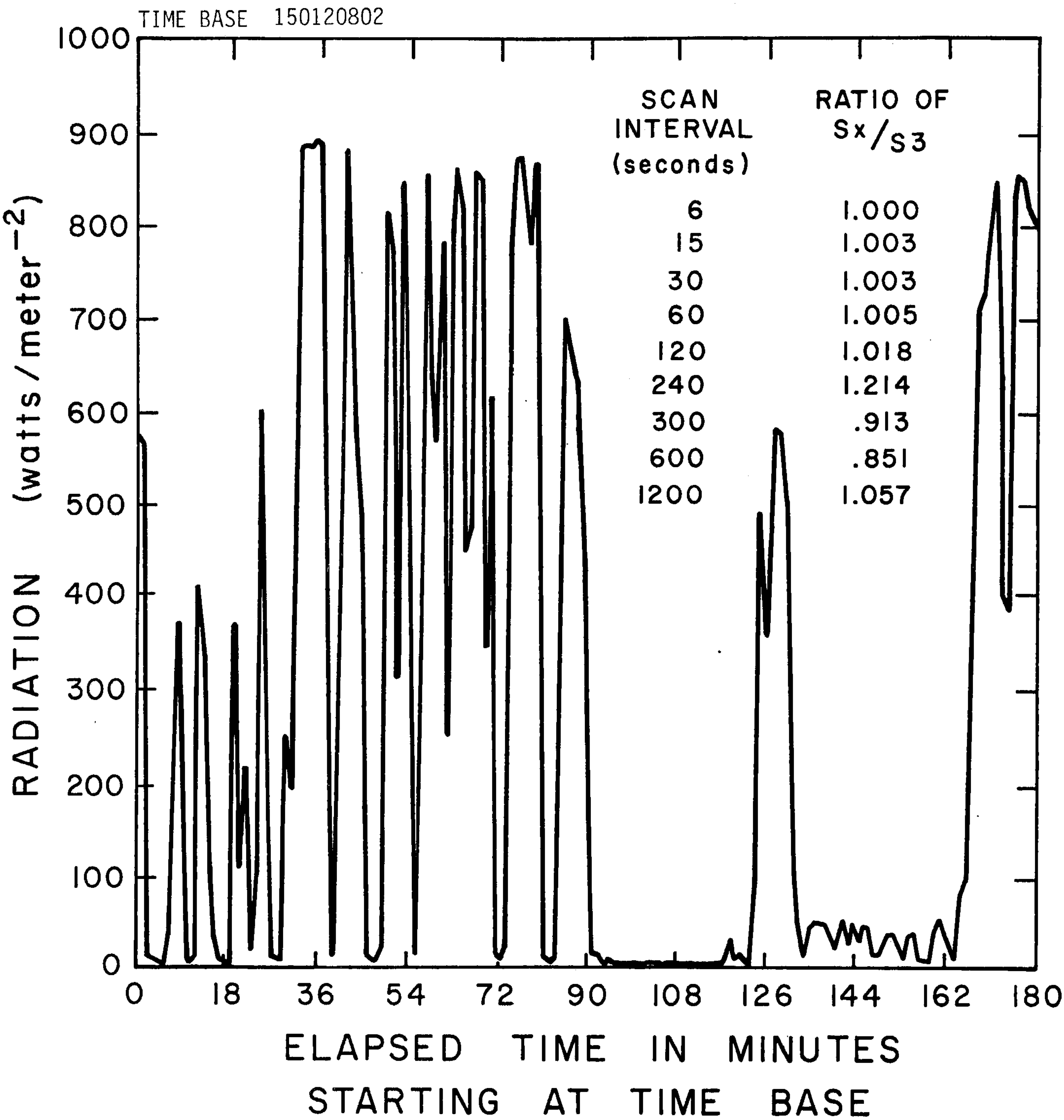


Figure 7. Direct Radiation vs. Time.



SCAN INTERVAL (seconds)	RATIO OF S_x/S_3
6	1.000
15	1.003
30	1.003
60	1.005
120	1.018
240	1.214
300	.913
600	.851
1200	1.057

Figure 8. Direct Radiation vs. Time.

direct irradiance on day 148 was measured at about 1×10^5 joules, which is an order of magnitude smaller than a value which might be expected to be accumulated during one hour of clear sky at high sun. Including a relative error from such days in the calculation of the standard deviations gives enormous weighting to small absolute errors occurring on these days and so their effects are best eliminated from the plots. As a result, it was determined from the plot in Fig. 9 that daily accumulated direct values may be within an acceptable range for sampling intervals up to 300 seconds, if the relative error on overcast days is allowed to be high.

Examination of the ratio computed from radiation accumulated over a three hour period again shows no obvious optimum scan rate. For the overcast case, the large relative error at small sample intervals results from the low level of total irradiance over the period. For the cases of cloudless sky, no sizeable error is evident even at 1200 second scan intervals. It is only in cases of variable cloud cover that a trend is observed. In both such cases, a 2.5% error is evident at the 60 and 120 second scan intervals. Longer scan intervals result in larger errors in almost every case. Table 3 shows the variation of the ratios of three hour accumulations with sampling intervals along with the corresponding variation in computer costs.

4.0 CONCLUSIONS

From the data analyzed in this research, it appears that the largest acceptable pyranometer and pyrheliometer sampling

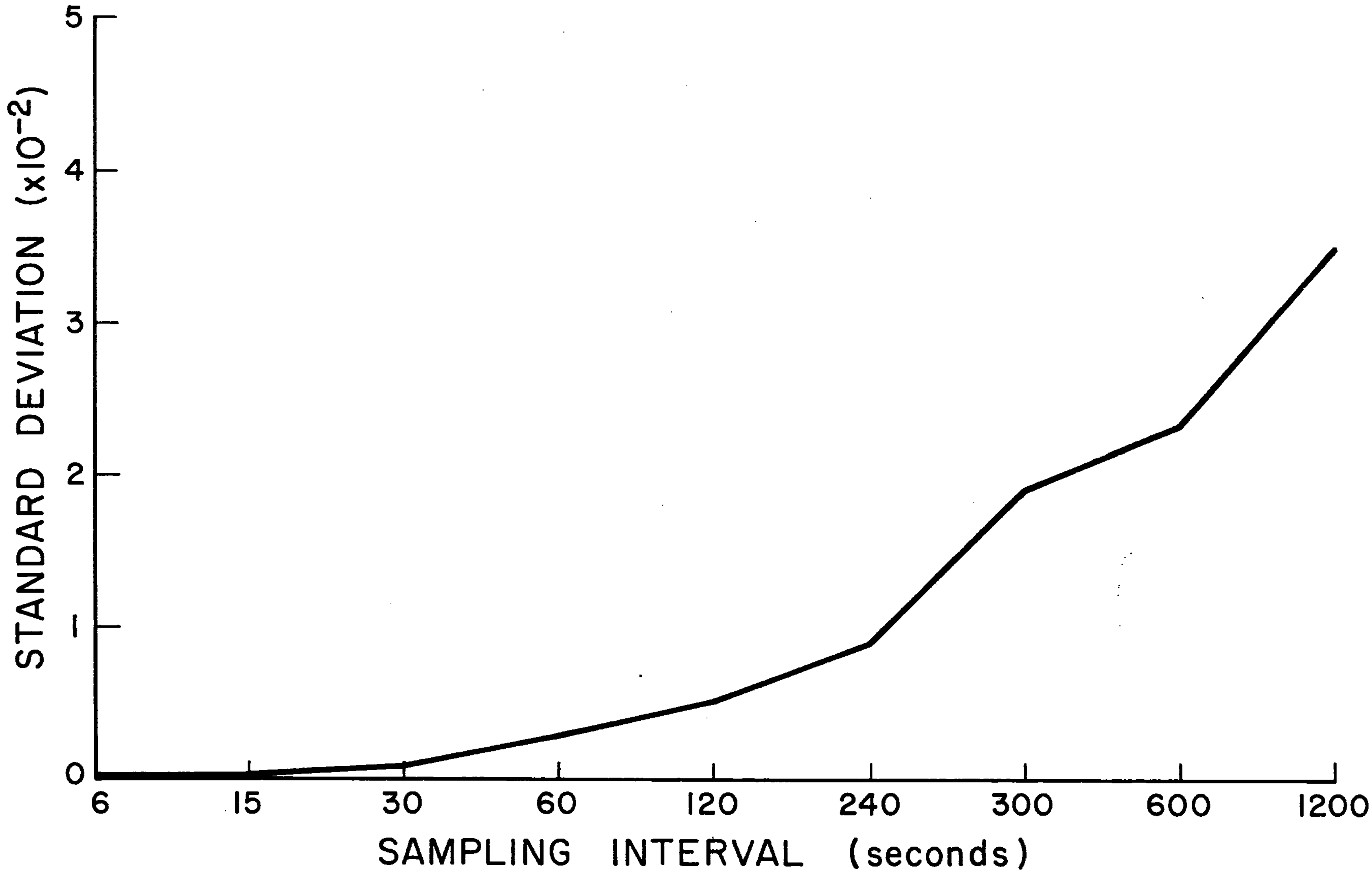


Figure 9. Standard Deviation of the ratio $\frac{Sx}{S_3}$ as a function of scan interval. Direct Component Comparison. (Data from overcast days excluded.)

TABLE 3

VARIATION OF THE RATIO OF THREE HOUR DIRECT ACCUMULATED RADIATION

(ALL CASES) WITH CORRESPONDING SAMPLING INTERVALS AND COMPUTER TIME COSTS

SAMPLING INTERVAL IN SECONDS	6	15	30	60	120	240	300	600	1200
RATIO OF Sx/S_3 FROM FIGS. 4 THROUGH 8 RESPECTIVELY	1.000 1.000 .985* 1.000 1.000	1.000 .999 1.001* 1.000 1.003	1.000 1.000 .935* 1.000 1.003	.999 .985 .972* 1.001 1.005	1.000 .984 .846* 1.001 1.018	1.000 1.030 .885* 1.001 1.214	.998 1.039 .946* 1.001 .913	.949 1.107 .951* 1.001 .851	.997 1.316 .899* 1.002 1.057
COMPUTER TIME COSTS IN DOLLARS PER YEAR**	1220	488	244	122	61	30	24.4	12.2	6.1

*COMPUTED FROM DATA COLLECTED DURING A TOTALLY OVERCAST PERIOD

**BASED ON PROCESSING OUTLINED IN FIGURE 3, AT 1976 RATES interval is 120 seconds; this sampling interval produced daily integrated irradiances within one percent of those calculated with nearly continuous sampling in all cases except for the pyrheliometer on overcast days. In this latter instance the agreement was within five percent; on overcast days the magnitude of the direct component is very small so even at five percent relative error, the absolute error is quite small.

For the largest sampling interval examined, 1200 seconds, the daily integrated irradiance determined from the pyranometer degraded in accuracy to as much as 8 percent; likewise the direct component determined from the pyrheliometer degraded to 13 percent accuracy in the worst case considered.

It is clear from the analysis presented above that larger sampling intervals do degrade the quality of hemispheric and direct solar observations. This report attempts to quantify this relationship so that a user can obectively weigh the impact of a particular sampling frequency upon the accuracy of his data. Of course, this is only one factor in the selection of a sampling frequency and data handling and recording constraints are more often the final determining factors.

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Supplementary Notes

Abstracts

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