

FIRST RESULTS FROM THE SITE TESTING PROGRAM
OF THE MILLIMETER-WAVE ARRAY

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D. Hogg, F. Owen, and M. McKinnon

I. Introduction

The scientifically-driven specifications for the proposed millimeter-wave array impose certain important constraints on the site for the instrument. The goal of undertaking 0.1 arcsec imaging at 230 GHz implies array baselines of at least 3 km. The need to make the images rapidly requires that the many elements be distributed widely in some two-dimensional array, so that the beam that is synthesized in a short observation is approximately elliptical with both low axial ratio and low sidelobe levels. Finally, the interest in doing sensitive imaging at high frequencies (to 350 GHz) requires that the array be located on a high site having low atmospheric opacity.

There have been a number of studies which attempted to identify sites that would be suitable for optical or infrared telescopes, and some work was done on potential millimeter-wave sites during the course of the millimeter-wave dish project. With these studies for guidance, it was clear that, from maps of the south-west U.S., a list of potentially viable sites for the array could be made. The list could be focussed to a smaller number of prime candidates by using radiosonde data and cloud-cover statistics from the weather satellites. However, for the final selection, it would be most useful to have direct measurements of the transmissivity and stability at millimeter wavelengths of the atmosphere over the more promising sites. Such data do not currently exist. We therefore decided

to undertake a program to measure the atmospheric opacity at selected sites, using a radiometer operating at 225 GHz. This report briefly describes the instrument and the observational technique, and presents a summary of the data obtained during the first year of observations at the first site. Subsequent reports will contain the data from other sites, as they become available; ultimately, the several sites that have been surveyed will be compared. *

II. The 225 GHz Atmospheric Receiver

The receiver is fed by a rotatable mirror which gives a beamwidth at 225 GHz of 4 degrees. The mirror can be stepped from zenith to horizon, enabling a traditional tipping curve to be made. The receiver switches in turn between the sky, a reference hot load maintained at 65 C, and a second reference load maintained at 45 C. The dual-load system allows the gain of the radiometer to be calibrated. Local oscillator power is derived from a 75 GHz Gunn oscillator. The system is controlled by a desk top computer, which in addition logs the data. The system is described in much more detail in Millimeter Array Memo No. 41, "225 GHz Atmospheric Receiver-User's Manual," written by Zhong-Yi Liu.

III. Observations and Data Reduction

Every ten minutes, 24 hours a day, a tipping scan is made with the radiometer. The antenna temperature observed as a function of zenith angle is used to obtain the value of the atmospheric opacity at the zenith. As a check, the antenna temperature observed at the zenith itself is used to independently estimate the zenith opacity. In general the agreement between the two measurements is quite good, although the opacity inferred from the antenna temperature at the zenith has a larger dispersion.

A detailed account of the calibration sequences, the data analysis, and the possible sources of error is given in Millimeter Array Memo No. 40, "Measurement of Atmospheric Opacity Due to Water Vapor at 225 GHz," written by Mark McKinnon.

In the subsequent analysis, the volume of the data was further reduced by taking the median value of the six opacities measured each hour. In the following discussion a data point will be one of these hourly medians. In addition, for this first site, we concluded that periods during which the opacity exceeded 0.5 at 225 GHz would be essentially unusable for the array, and so we recorded all such values simply as 0.5. Thus in the analysis and in the plots the points at an opacity of 0.5 should be considered to be 0.5 or greater.

Some sources of error are described in MMA Memo No. 40. However, a quantitative estimate of the precision of the measurement is perhaps best derived from looking at the scatter of the 10-minute values during periods when the opacity is low and changing only slowly. We find that the rms of a single estimate of opacity, from a 4-minute observation, is typically less than 0.001 under good conditions. However, systematic errors as large as 10 per cent may exist due to uncertainties in the effective temperatures of the two loads and the assumed atmospheric temperature profile.

Although the instrument is nominally in operation at all times, there inevitably are times when data are lost. The majority of the lost time is because of failure in the instrument. Much of the data lost in the first several months of operation at the site summarized in this report occurred as a result of a failure in the recording system. Other failures involved problems with the control of the physical temperature inside the radiometer box, and with the control of the position of the mirror as it

was stepped from zenith to horizon. A very small fraction of the lost time is due to weather, when, for example, the mirror is wet from rain or is covered by snow or the outside temperature has dropped to levels which the heating elements inside the box cannot overcome. However, the bulk of the lost time arises because of instrumental failure unrelated to weather or to zenith opacity, and we argue therefore that the results are not biased by the absence of data from the periods when the instrument was off the air.

IV. Measurements at the JOCR (South Baldy) Site

One of the more promising sites for the array is at the Magdalena Mountains, between latitudes 33-56 and 34-06 and longitudes 107-08 and 107-12. The highest point is South Baldy, at elevation 10780 MSL. Because of its proximity to the VLA site, with its logistical support, this site was chosen for a first attempt with the monitoring/testing program. The observations were conducted at the Joint Observatory for Cometary Research (JOCR) near but not at the summit of South Baldy, although for brevity the data are described as being from "South Baldy". Observations began on November, 1986, and have continued to the present. A total of more than 6800 hours of observations have been logged through November, 1987.

Perhaps the single most useful measure of the quality of a prospective site is the fraction of the time that the zenith opacity lies below a given value. Appendix 1 gives for each month a tabulation of the fraction of the time sampled and the fractional occurrence of selected opacity values, as well as a plot of the latter. To summarize, Figure 1 shows for each month the percentage of the time for which the opacity lies below a given value.

From this first year of data, we conclude that for six months of the year (approximately November through April) there are many excellent periods. The zenith opacity at 225 GHz is less than 0.1 about one-third of the time, and is less than 0.2 two-thirds of the time. The zenith opacity is much higher during the other six months, although there are some short times during May, June, and October when observations could be made at this frequency. This is of course a reflection of the onset of the well-known summer "monsoon", although the duration seems to have been unusually great during this particular period.

For a synthesis instrument, and especially for the millimeter-wave array, because of the requirement for mosaicking of large fields, it is important to have long periods during which the atmospheric condition is good. Accordingly, another useful criterion is the number and duration of "good" periods. To make this quantitative, we define a "good" period as one in which the zenith opacity at 225 GHz is less than 0.1 for a minimum of six consecutive hours, and which lasts until the zenith opacity rises above 0.1 for three consecutive hours, or until the opacity exceeds 0.15. We have searched the data base for such periods, and they are listed in Table 1.

The characteristics of the good periods are summarized in Figure 2. Figure 2(a) gives the fraction of the time included in the good periods. The fraction is nearly equal to the fraction of the time that the opacity is less than 0.1, suggesting that when the transparency of the atmosphere becomes low, it stays low for several hours. Figure 2(b) shows that during the period November to April there are of order seven good periods each month. Figure 2(c) shows that the average length of a good period is 22 hours, but that periods of up to 40 hours occurred each month, and that

in December, 1986 there was one stretch of 90 hours which met the criteria.

In order to show the data in somewhat more detail, a number of plots are given in Appendix 2. First the data are grouped into intervals of three months, selected so as to correspond roughly with the changing seasons (November-January; February-April; May-July; and August-October). For each quarter there is a plot of the fraction of the time for which the zenith opacity is less than a given value. Then follows a plot of all of the individual hourly medians for the quarter. Obvious in these plots are the extended periods during which the opacity remains low. Finally, all of the data are plotted against local time, with the median values shown for each hour. The diurnal effect is small, at least in the winter quarter.

V. Future Work with the Radiometers

We propose to continue the patrol at South Baldy. A second system began operation at the VLA site in January, 1987, and a report on the first year of these observations will be made soon. Two additional systems have been built and will be installed at other sites during the first quarter of 1988. It is also expected that the system currently at the VLA will be relocated to one of the prospective array sites sometime in the middle of 1988.

TABLE 1

PERIODS OF LOW OPACITY AT SOUTH BALDY

DATA WERE DRAWN FROM THE PERIOD 86NOV08-87DEC31

A GOOD PERIOD HAS OPACITY LESS THAN 0.10 FOR AT LEAST 6 HOURS
 IT CAN HAVE PERIODS OF UP TO 3 HOURS WHEN THE OPACITY IS HIGHER.
 HOWEVER, THE OPACITY AT WORST MUST BE LESS THAN 0.15

IN ALL, THERE WERE 57 GOOD PERIODS

RUN	FIRST				LAST				DURN HRS	OPACITY		
	Y/M/D/HR	Y/M/D/HR	Y/M/D/HR	Y/M/D/HR	MEDIAN	AVG	MIN					
1	86	11	8	15	86	11	9	7	17	0.068	0.069	0.058
2	86	11	10	11	86	11	12	4	42	0.068	0.071	0.038
3	86	11	23	22	86	11	24	4	7	0.072	0.075	0.062
4	86	11	27	4	86	11	28	21	42	0.076	0.074	0.037
5	86	11	30	1	86	11	30	13	13	0.067	0.068	0.036
6	86	11	30	20	86	12	2	19	48	0.060	0.062	0.037
7	86	12	3	9	86	12	3	20	12	0.090	0.089	0.079
8	86	12	11	22	86	12	15	17	92	0.055	0.059	0.025
9	86	12	19	1	86	12	19	6	6	0.083	0.086	0.079
10	86	12	23	9	86	12	23	14	6	0.046	0.046	0.039
11	86	12	26	2	86	12	27	3	26	0.064	0.068	0.044
12	86	12	29	11	86	12	31	21	59	0.055	0.054	0.028
13	87	1	2	12	87	1	3	7	20	0.070	0.068	0.031
14	87	1	4	8	87	1	4	16	9	0.090	0.091	0.086
15	87	1	8	21	87	1	9	7	11	0.053	0.054	0.035
16	87	1	20	18	87	1	23	5	60	0.080	0.075	0.036
17	87	1	24	11	87	1	24	20	10	0.079	0.079	0.066
18	87	1	25	15	87	1	27	8	42	0.067	0.069	0.050
19	87	2	1	5	87	2	1	14	10	0.088	0.087	0.078
20	87	2	2	2	87	2	3	1	24	0.080	0.078	0.058
21	87	2	3	6	87	2	3	11	6	0.098	0.094	0.080
22	87	2	5	16	87	2	6	7	16	0.052	0.053	0.044
23	87	2	21	15	87	2	23	5	39	0.047	0.053	0.034
24	87	2	26	21	87	2	28	3	31	0.060	0.061	0.035
25	87	2	28	7	87	3	1	21	39	0.082	0.076	0.034
26	87	3	3	9	87	3	6	10	74	0.042	0.049	0.024
27	87	3	6	13	87	3	6	21	9	0.054	0.060	0.044
28	87	3	11	2	87	3	11	12	11	0.076	0.078	0.059
29	87	3	12	2	87	3	12	16	15	0.076	0.080	0.060
30	87	3	13	3	87	3	13	8	6	0.090	0.090	0.082
31	87	3	13	20	87	3	14	12	17	0.064	0.070	0.050
32	87	3	15	5	87	3	15	10	6	0.082	0.084	0.072
33	87	3	17	22	87	3	18	11	14	0.085	0.085	0.065
34	87	3	18	21	87	3	19	12	16	0.075	0.078	0.064
35	87	3	23	9	87	3	23	16	8	0.049	0.051	0.036
36	87	3	26	19	87	3	27	7	13	0.068	0.065	0.022
37	87	3	28	6	87	3	28	11	6	0.061	0.068	0.054
38	87	3	30	9	87	3	31	17	33	0.069	0.067	0.040
39	87	4	2	16	87	4	3	12	21	0.060	0.059	0.026
40	87	4	12	20	87	4	14	15	44	0.054	0.056	0.027
41	87	4	14	21	87	4	15	13	17	0.068	0.071	0.053
42	87	4	15	20	87	4	16	14	19	0.081	0.084	0.066
43	87	4	20	9	87	4	20	17	9	0.079	0.078	0.063
44	87	4	22	9	87	4	22	21	13	0.072	0.074	0.058
45	87	6	19	3	87	6	19	9	7	0.049	0.058	0.042
46	87	11	20	17	87	11	21	12	20	0.056	0.057	0.041
47	87	11	21	21	87	11	22	8	12	0.081	0.082	0.074

48	87	11	24	3	87	11	25	15	37	0.064	0.066	0.038
49	87	11	26	1	87	11	26	8	8	0.070	0.071	0.058
50	87	11	27	1	87	11	29	2	50	0.065	0.071	0.047
51	87	11	30	5	87	12	1	19	39	0.085	0.084	0.050
52	87	12	6	3	87	12	6	8	6	0.093	0.087	0.066
53	87	12	7	18	87	12	7	24	7	0.064	0.064	0.048
54	87	12	8	3	87	12	8	10	8	0.055	0.058	0.048
55	87	12	10	19	87	12	11	2	8	0.082	0.083	0.072
56	87	12	14	15	87	12	14	23	9	0.046	0.052	0.036
57	87	12	15	8	87	12	15	19	12	0.065	0.065	0.046

THE TOTAL NUMBER OF HOURS INVOLVED IN THESE PERIODS IS 1261
 AN AVERAGE PERIOD LASTS 22 HOURS, AND HAS A MEDIAN OPACITY OF 0.069

*

Captions to the Figures

Figure 1 The percentage of the time the opacity measured at 225 GHz is less than a given value; averages for each month are plotted for the period November 1986-December 1987.

Figure 2 Some characteristics of "good" periods, defined as those in which the opacity is less than 0.1 for six hours or more.

- (a) Percentage of the time included in "good" periods.
- (b) The number of "good" periods each month.
- (c) The duration in hours of a "good" period. Dashed line - longest period. Solid line - average duration.

SUMMARY OF DATA FOR SOUTH BALDY
 DATA WERE DRAWN FROM THE PERIOD 1986 NOVEMBER
 THE TOTAL NUMBER OF HOURS POSSIBLE IS 552
 THERE WERE 444 VALID DATA POINTS, OR 80 PERCENT.
 THE RECEIVER WAS BROKEN FOR 108 HOURS, OR 20 PERCENT.
 THERE WERE 0 NULL VALUES RECORDED, OR 0 PERCENT.

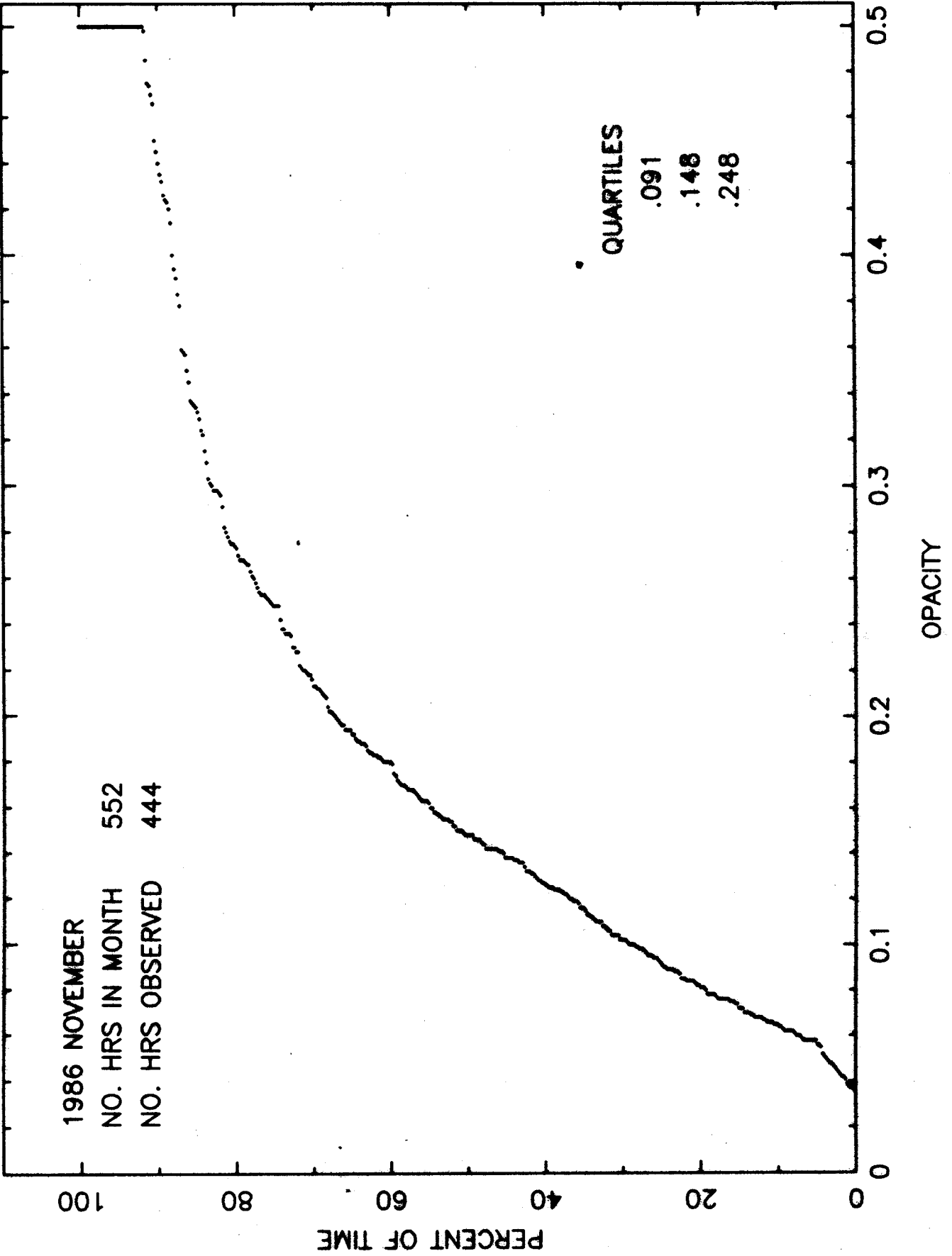
ASSUME WATER= $(\text{OPACITY}-0.005)/(0.056)$
 NOW FOLLOWS THE PERCENTAGE OF THE TIME
 FOR WHICH THE OPACITY LAY BELOW A GIVEN VALUE

OPACITY	MM WATER VAPOR	PERCENT OF TIME
0.061	1.0	8
0.117	2.0	36
0.173	3.0	59
0.229	4.0	72
0.285	5.0	82
0.341	6.0	86
0.397	7.0	88
0.453	8.0	90
0.091	1.5	25
0.148	2.6	50
0.248	4.3	75
0.050	0.8	4
0.100	1.7	29
0.150	2.6	51
0.200	3.5	67
0.250	4.4	76
0.300	5.3	83
0.350	6.2	86
0.400	7.1	88
0.450	7.9	90
0.500	8.8	96

Appendix I

Monthly Summaries of Observations

PERCENT OF TIME OPACITY IS LESS THAN A GIVEN VALUE DATA FOR SOUTH BALDY

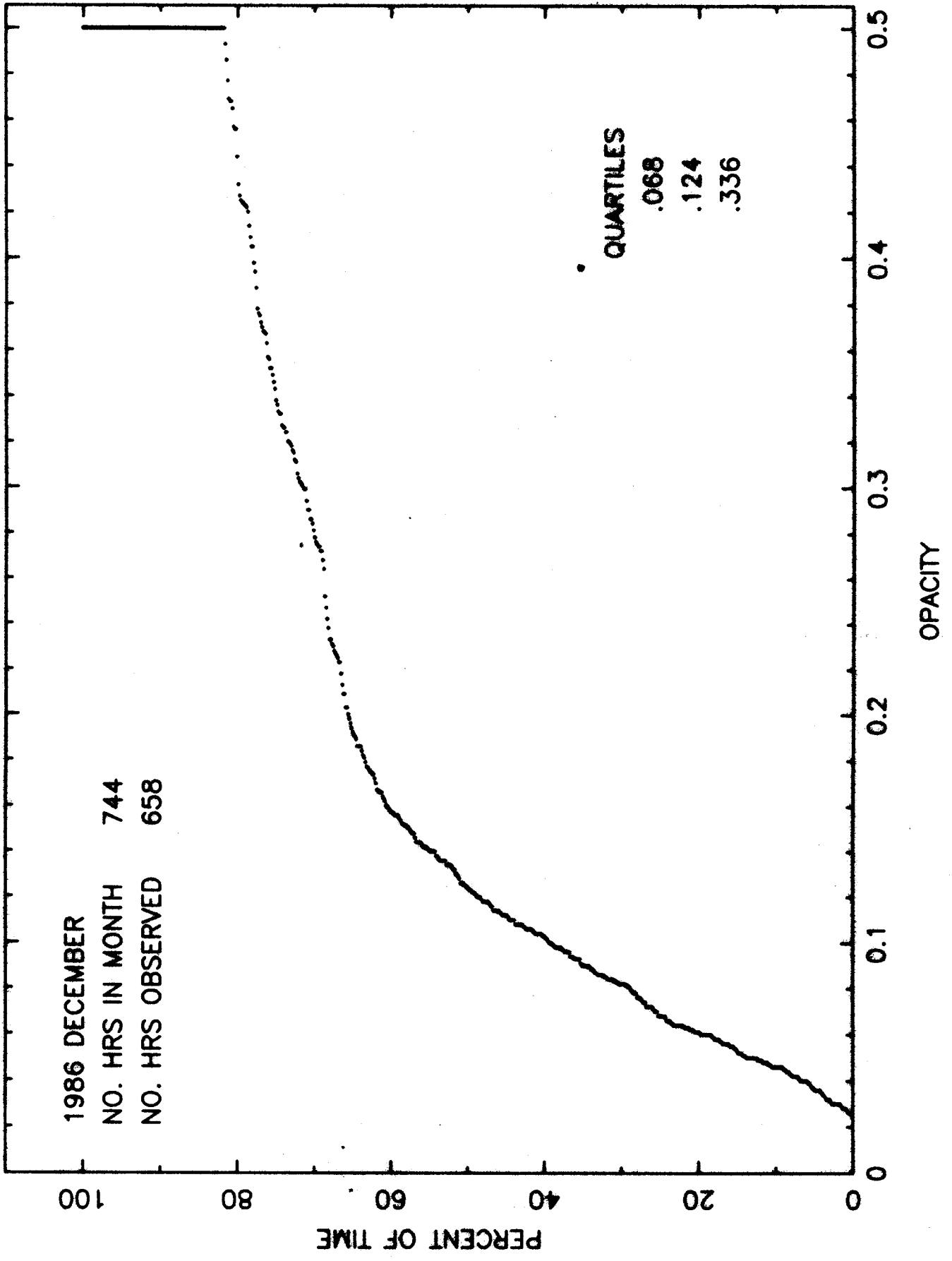


SUMMARY OF DATA FOR SOUTH BALDY
 DATA WERE DRAWN FROM THE PERIOD 1986 DECEMBER
 THE TOTAL NUMBER OF HOURS POSSIBLE IS 744
 THERE WERE 658 VALID DATA POINTS, OR 88 PERCENT.
 THE RECEIVER WAS BROKEN FOR 44 HOURS, OR 6 PERCENT.
 THERE WERE 42 NULL VALUES RECORDED, OR 6 PERCENT.

ASSUME WATER-(OPACITY-0.005)/(0.056)
 NOW FOLLOWS THE PERCENTAGE OF THE TIME
 FOR WHICH THE OPACITY LAY BELOW A GIVEN VALUE

OPACITY	MM WATER VAPOR	PERCENT OF TIME
0.061	1.0	20
0.117	2.0	47
0.173	3.0	62
0.229	4.0	67
0.285	5.0	70
0.341	6.0	75
0.397	7.0	78
0.453	8.0	80
0.068	1.1	25
0.124	2.1	50
0.336	5.9	75
0.050	0.8	13
0.100	1.7	39
0.150	2.6	58
0.200	3.5	66
0.250	4.4	69
0.300	5.3	72
0.350	6.2	76
0.400	7.1	78
0.450	7.9	80
0.500	8.8	91

PERCENT OF TIME OPACITY IS LESS THAN A GIVEN VALUE DATA FOR SOUTH BALDY



SUMMARY OF DATA FOR SOUTH BALDY
 DATA WERE DRAWN FROM THE PERIOD 1987 JANUARY
 THE TOTAL NUMBER OF HOURS POSSIBLE IS 744
 THERE WERE 490 VALID DATA POINTS, OR 66 PERCENT.
 THE RECEIVER WAS BROKEN FOR 250 HOURS, OR 34 PERCENT.
 THERE WERE 4 NULL VALUES RECORDED, OR 1 PERCENT.

ASSUME WATER=(OPACITY-0.005)/(0.056)
 NOW FOLLOWS THE PERCENTAGE OF THE TIME
 FOR WHICH THE OPACITY LAY BELOW A GIVEN VALUE

OPACITY	MM WATER VAPOR	PERCENT OF TIME
0.061	1.0	9
0.117	2.0	43
0.173	3.0	69
0.229	4.0	81
0.285	5.0	89
0.341	6.0	94
0.397	7.0	95
0.453	8.0	96
0.088	1.5	25
0.129	2.2	50
0.199	3.5	75
0.050	0.8	4
0.100	1.7	32
0.150	2.6	62
0.200	3.5	75
0.250	4.4	86
0.300	5.3	90
0.350	6.2	94
0.400	7.1	95
0.450	7.9	96
0.500	8.8	98

225 GHz Opacities At South Baldy
(Opacity of 0.1 Corresponds to 1.7 mm H₂O)

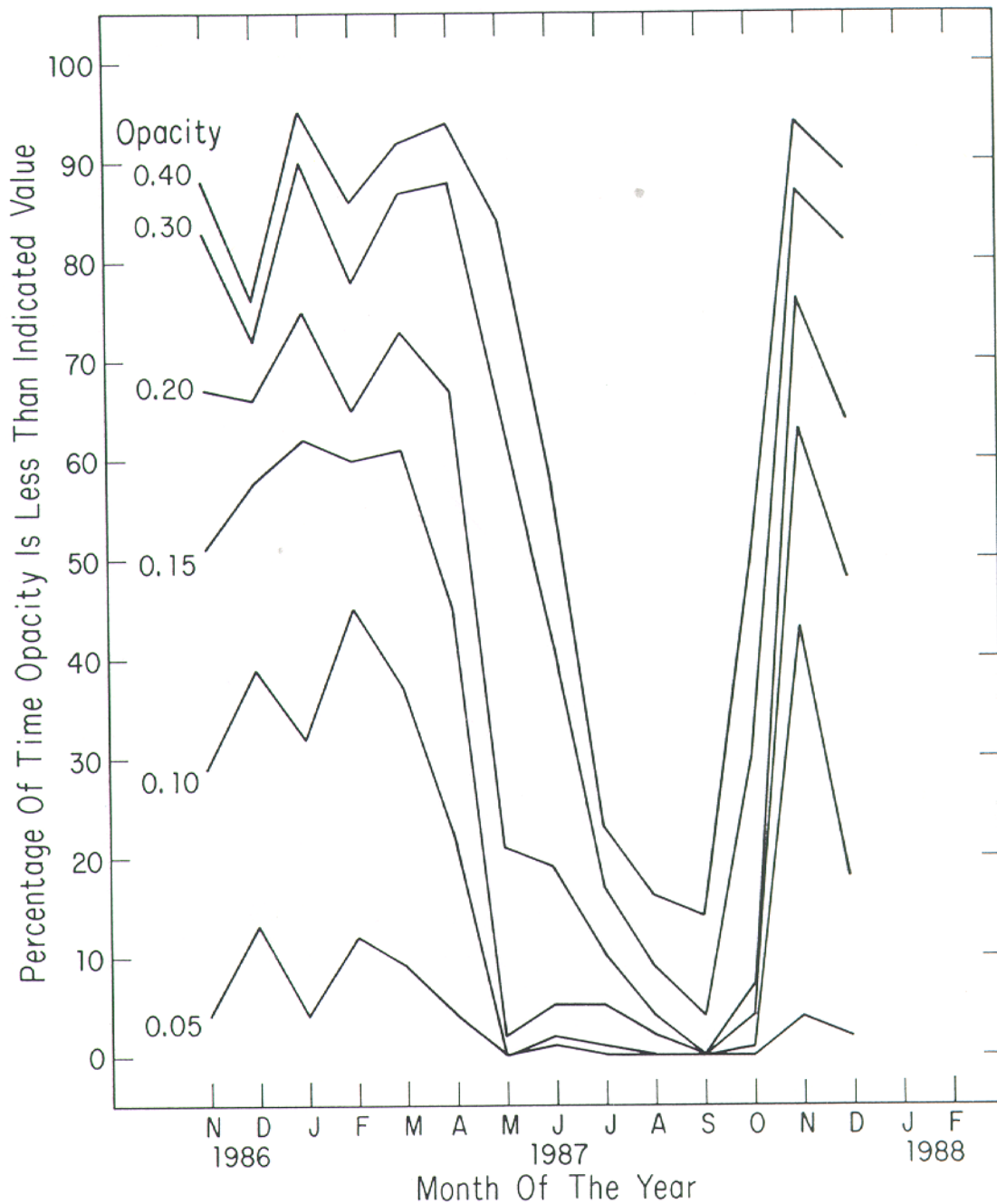


Figure 1

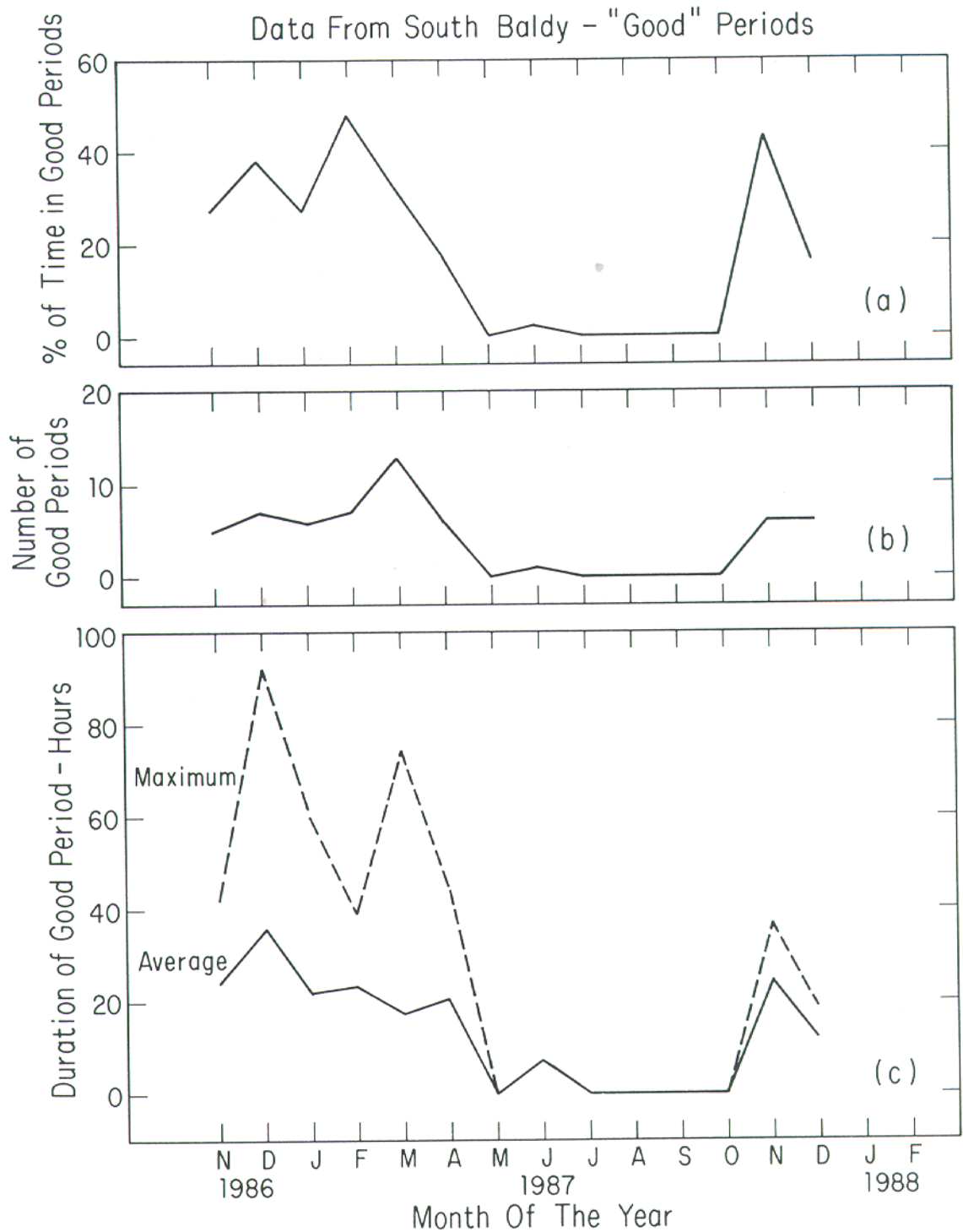
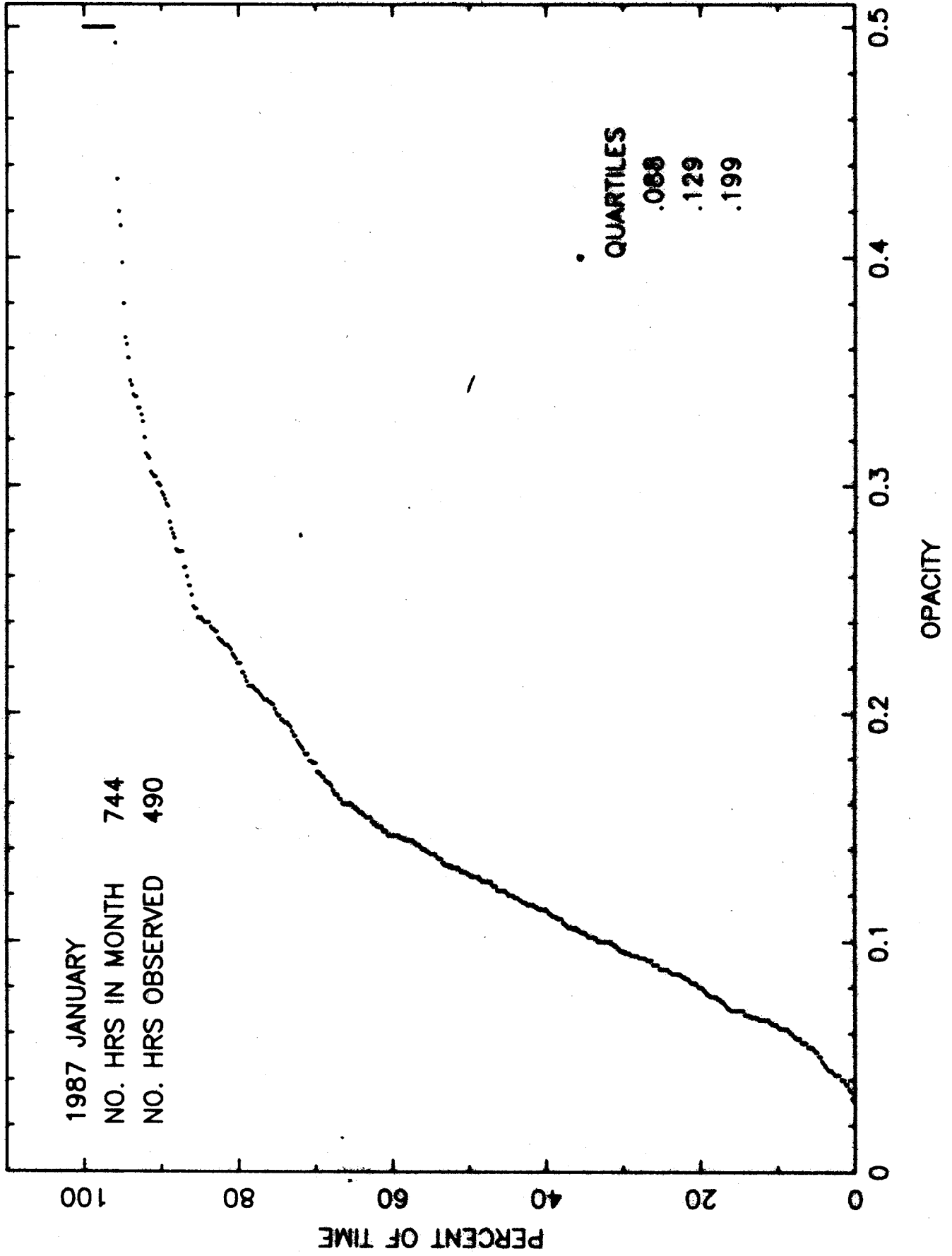


Figure 2

PERCENT OF TIME OPACITY IS LESS THAN A GIVEN VALUE DATA FOR SOUTH BALDY

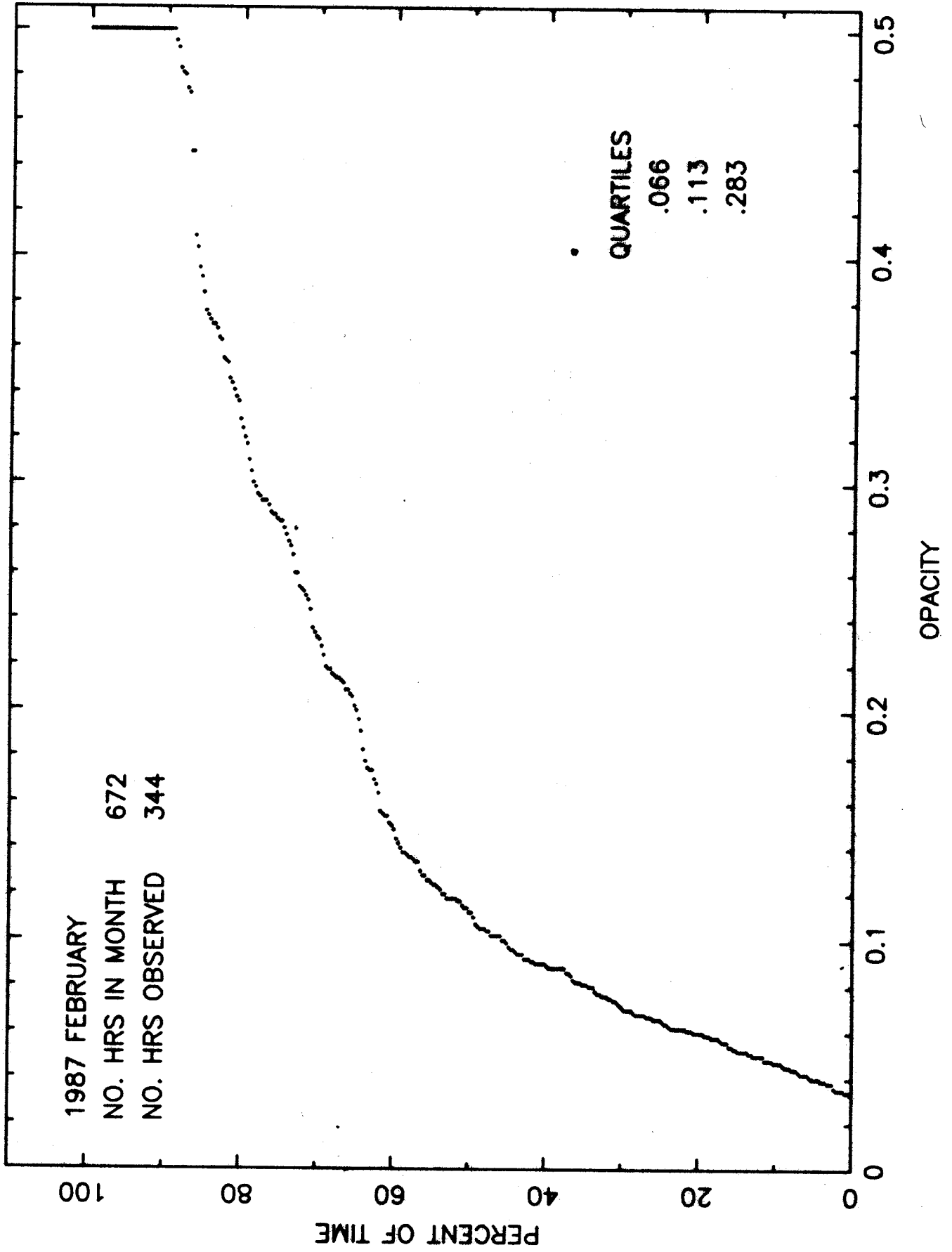


SUMMARY OF DATA FOR SOUTH BALDY
 DATA WERE DRAWN FROM THE PERIOD 1987 FEBRUARY
 THE TOTAL NUMBER OF HOURS POSSIBLE IS 672
 THERE WERE 344 VALID DATA POINTS, OR 51 PERCENT.
 THE RECEIVER WAS BROKEN FOR 297 HOURS, OR 44 PERCENT.
 THERE WERE 31 NULL VALUES RECORDED, OR 5 PERCENT.

ASSUME WATER- $(\text{OPACITY}-0.005)/(0.056)$
 NOW FOLLOWS THE PERCENTAGE OF THE TIME
 FOR WHICH THE OPACITY LAY BELOW A GIVEN VALUE

OPACITY	MM WATER VAPOR	PERCENT OF TIME
0.061	1.0	21
0.117	2.0	51
0.173	3.0	62
0.229	4.0	69
0.285	5.0	75
0.341	6.0	81
0.397	7.0	86
0.453	8.0	87
0.066	1.1	25
0.113	1.9	50
0.283	5.0	75
0.050	0.8	12
0.100	1.7	45
0.150	2.6	60
0.200	3.5	65
0.250	4.4	72
0.300	5.3	78
0.350	6.2	82
0.400	7.1	86
0.450	7.9	87
0.500	8.8	94

PERCENT OF TIME OPACITY IS LESS THAN A GIVEN VALUE DATA FOR SOUTH BALDY



SUMMARY OF DATA FOR SOUTH BALDY
 DATA WERE DRAWN FROM THE PERIOD 1987 MARCH
 THE TOTAL NUMBER OF HOURS POSSIBLE IS 744
 THERE WERE 719 VALID DATA POINTS, OR 97 PERCENT.
 THE RECEIVER WAS BROKEN FOR 0 HOURS, OR 0 PERCENT.
 THERE WERE 25 NULL VALUES RECORDED, OR 3 PERCENT.

ASSUME WATER= $(\text{OPACITY}-0.005)/(0.056)$
 NOW FOLLOWS THE PERCENTAGE OF THE TIME
 FOR WHICH THE OPACITY LAY BELOW A GIVEN VALUE

OPACITY	MM WATER VAPOR	PERCENT OF TIME
0.061	1.0	13
0.117	2.0	50
0.173	3.0	68
0.229	4.0	77
0.285	5.0	86
0.341	6.0	89
0.397	7.0	92
0.453	8.0	92
0.083	1.4	25
0.117	2.0	50
0.212	3.7	75
0.050	0.8	9
0.100	1.7	37
0.150	2.6	61
0.200	3.5	73
0.250	4.4	81
0.300	5.3	87
0.350	6.2	90
0.400	7.1	92
0.450	7.9	92
0.500	8.8	97

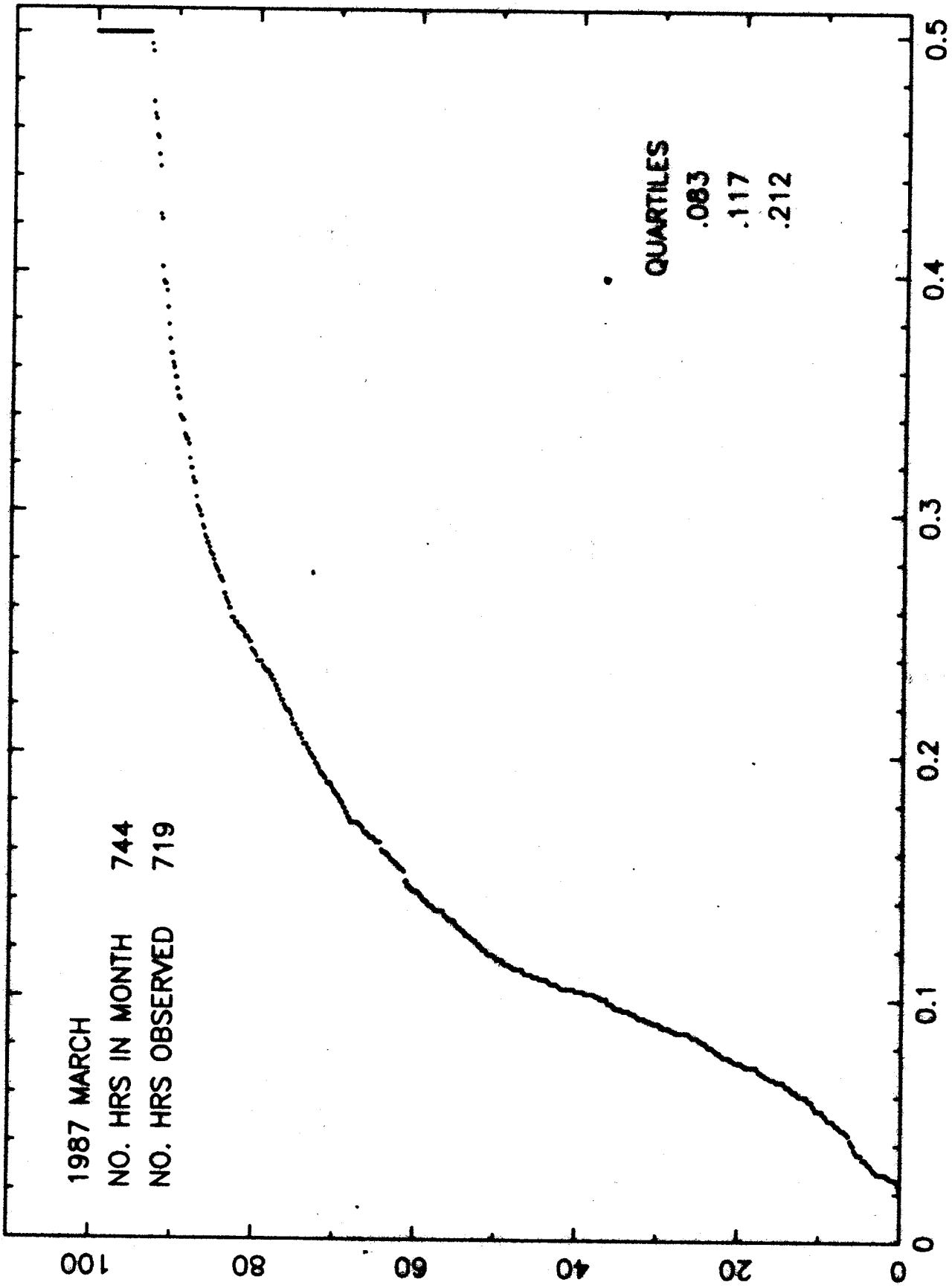
PERCENT OF TIME OPACITY IS LESS THAN A GIVEN VALUE DATA FOR SOUTH BALDY

1987 MARCH

NO. HRS IN MONTH 744

NO. HRS OBSERVED 719

PERCENT OF TIME



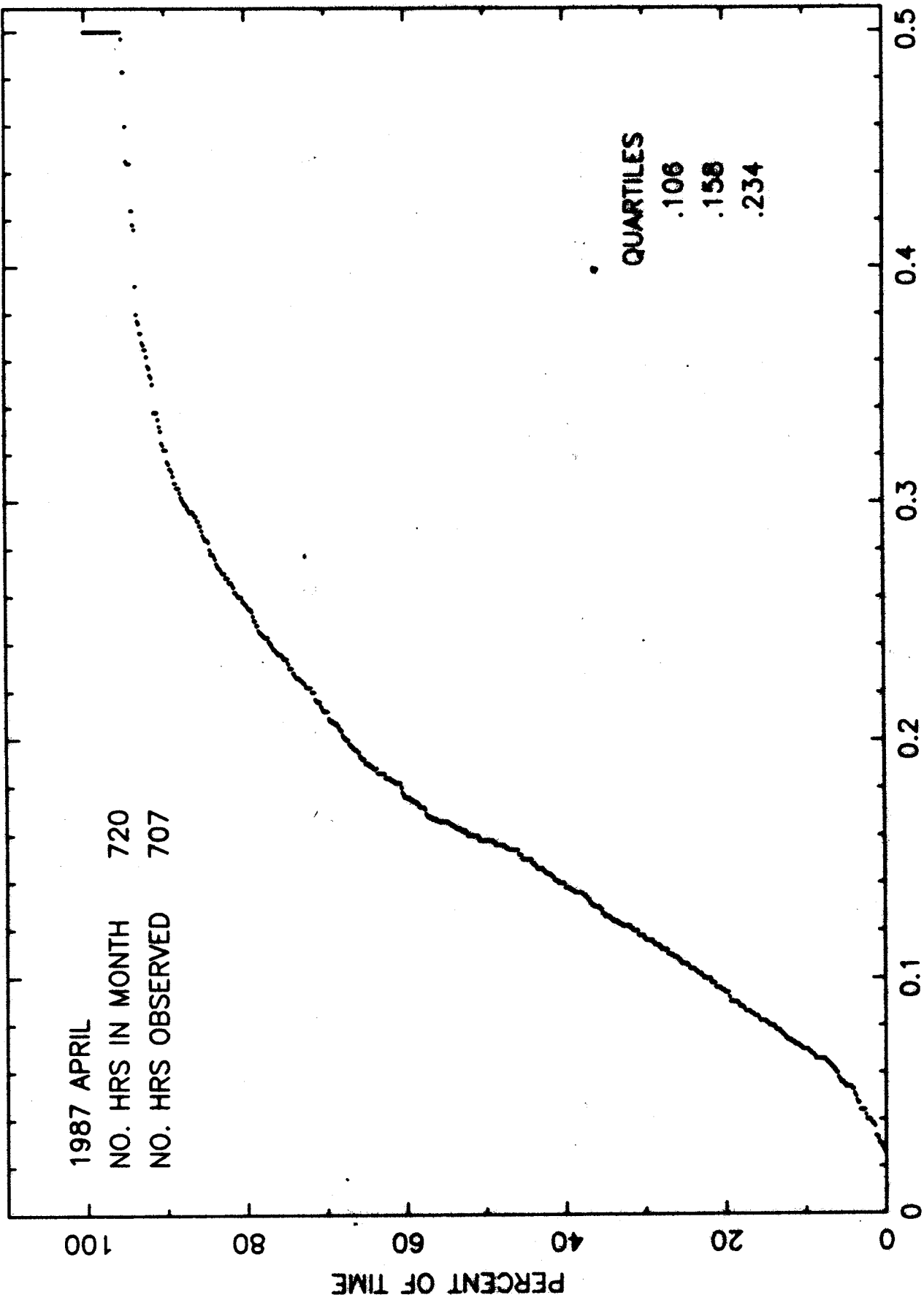
OPACITY

SUMMARY OF DATA FOR SOUTH BALDY
 DATA WERE DRAWN FROM THE PERIOD 1987 APRIL
 THE TOTAL NUMBER OF HOURS POSSIBLE IS 720
 THERE WERE 707 VALID DATA POINTS, OR 98 PERCENT.
 THE RECEIVER WAS BROKEN FOR 1 HOURS, OR 0 PERCENT.
 THERE WERE 12 NULL VALUES RECORDED, OR 2 PERCENT.

ASSUME WATER=(OPACITY-0.005)/(0.056)
 NOW FOLLOWS THE PERCENTAGE OF THE TIME
 FOR WHICH THE OPACITY LAY BELOW A GIVEN VALUE

OPACITY	MM WATER VAPOR	PERCENT OF TIME
0.061	1.0	6
0.117	2.0	30
0.173	3.0	58
0.229	4.0	74
0.285	5.0	85
0.341	6.0	91
0.397	7.0	94
0.453	8.0	95
0.106	1.8	25
0.158	2.7	50
0.234	4.1	75
0.050	0.8	4
0.100	1.7	22
0.150	2.6	45
0.200	3.5	67
0.250	4.4	79
0.300	5.3	88
0.350	6.2	92
0.400	7.1	94
0.450	7.9	95
0.500	8.8	98

PERCENT OF TIME OPACITY IS LESS THAN A GIVEN VALUE DATA FOR SOUTH BALDY

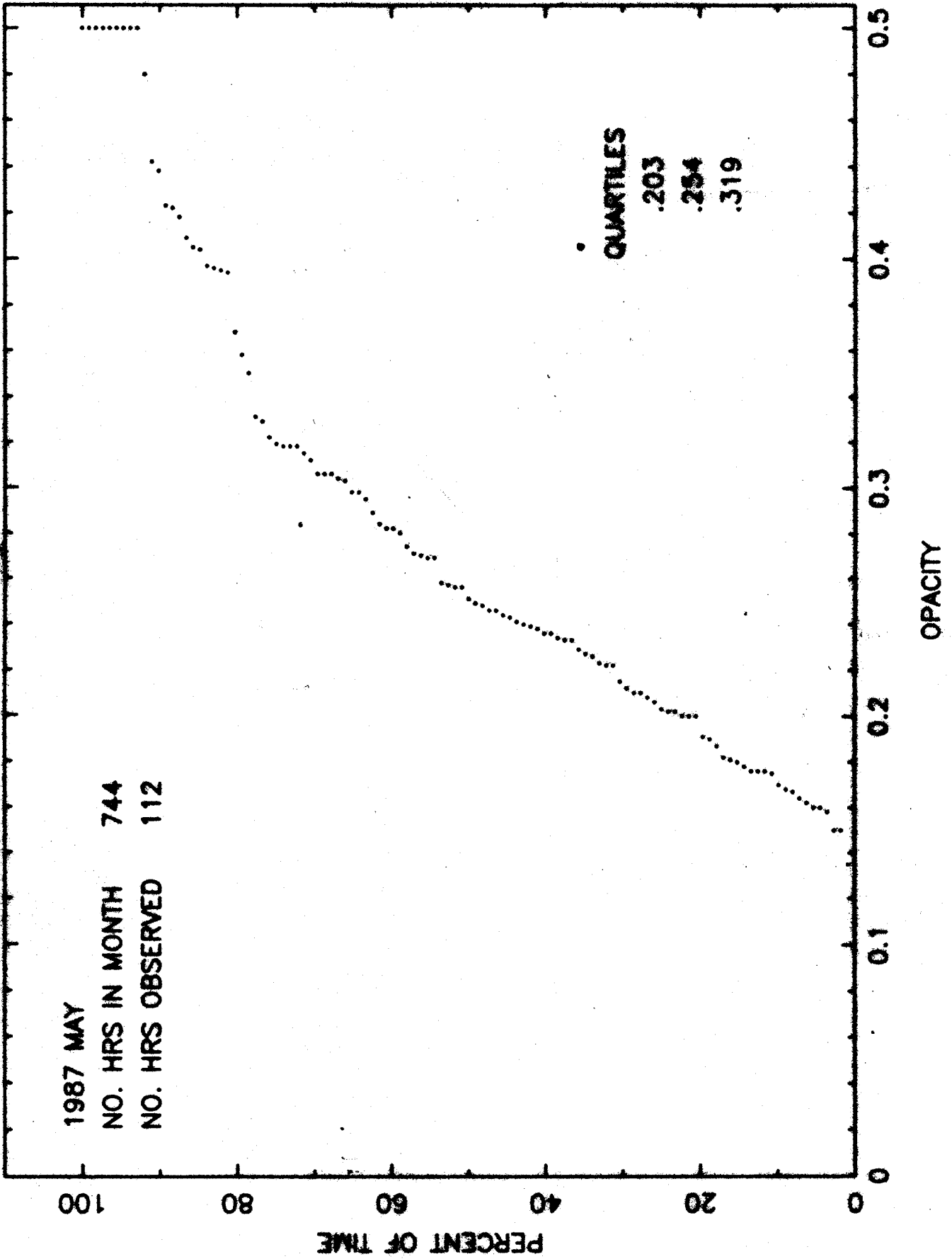


SUMMARY OF DATA FOR SOUTH BALDY
 DATA WERE DRAWN FROM THE PERIOD 1987 MAY
 THE TOTAL NUMBER OF HOURS POSSIBLE IS 744
 THERE WERE 112 VALID DATA POINTS, OR 15 PERCENT.
 THE RECEIVER WAS BROKEN FOR 632 HOURS, OR 85 PERCENT.
 THERE WERE 0 NULL VALUES RECORDED, OR 0 PERCENT.

ASSUME WATER= $(\text{OPACITY}-0.005)/(0.056)$
 NOW FOLLOWS THE PERCENTAGE OF THE TIME
 FOR WHICH THE OPACITY LAY BELOW A GIVEN VALUE

OPACITY	MM WATER VAPOR	PERCENT OF TIME
0.061	1.0	0
0.117	2.0	0
0.173	3.0	10
0.229	4.0	36
0.285	5.0	62
0.341	6.0	78
0.397	7.0	84
0.453	8.0	91
0.203	3.5	25
0.254	4.4	50
0.319	5.6	75
0.050	0.8	0
0.100	1.7	0
0.150	2.6	2
0.200	3.5	21
0.250	4.4	49
0.300	5.3	65
0.350	6.2	79
0.400	7.1	84
0.450	7.9	91
0.500	8.8	96

PERCENT OF TIME OPACITY IS LESS THAN A GIVEN VALUE DATA FOR SOUTH BALDY

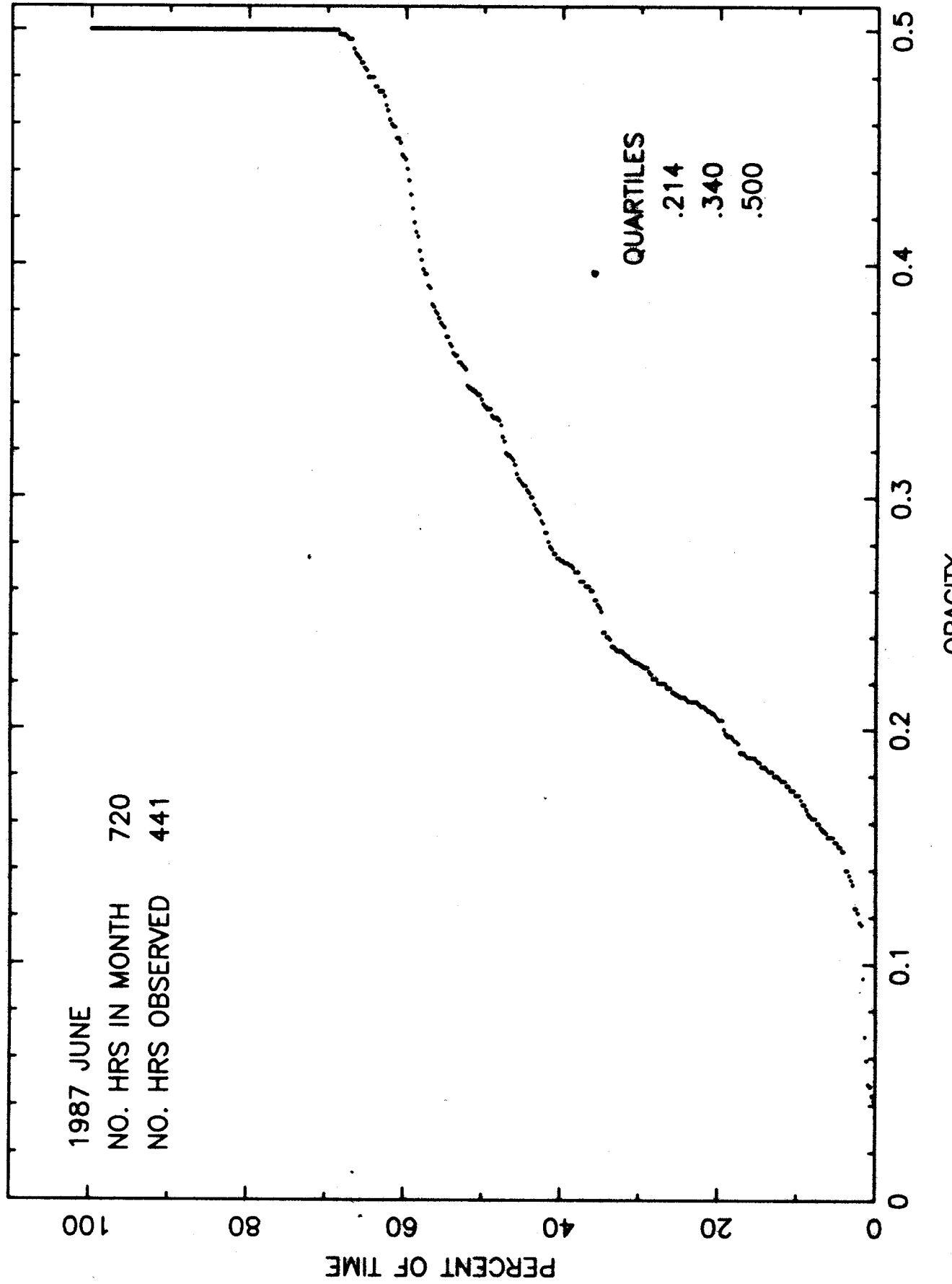


SUMMARY OF DATA FOR SOUTH BALDY
 DATA WERE DRAWN FROM THE PERIOD 1987 JUNE
 THE TOTAL NUMBER OF HOURS POSSIBLE IS 720
 THERE WERE 441 VALID DATA POINTS, OR 61 PERCENT.
 THE RECEIVER WAS BROKEN FOR 279 HOURS, OR 39 PERCENT.
 THERE WERE 0 NULL VALUES RECORDED, OR 0 PERCENT.

ASSUME WATER- $(\text{OPACITY}-0.005)/(0.056)$
 NOW FOLLOWS THE PERCENTAGE OF THE TIME
 FOR WHICH THE OPACITY LAY BELOW A GIVEN VALUE

OPACITY	MM WATER VAPOR	PERCENT OF TIME
0.061	1.0	1
0.117	2.0	2
0.173	3.0	10
0.229	4.0	30
0.285	5.0	42
0.341	6.0	50
0.397	7.0	58
0.453	8.0	61
0.214	3.7	24
0.340	6.0	50
0.500	8.8	75
0.050	0.8	1
0.100	1.7	2
0.150	2.6	5
0.200	3.5	19
0.250	4.4	35
0.300	5.3	44
0.350	6.2	52
0.400	7.1	58
0.450	7.9	61
0.500	8.8	84

PERCENT OF TIME OPACITY IS LESS THAN A GIVEN VALUE DATA FOR SOUTH BALDY

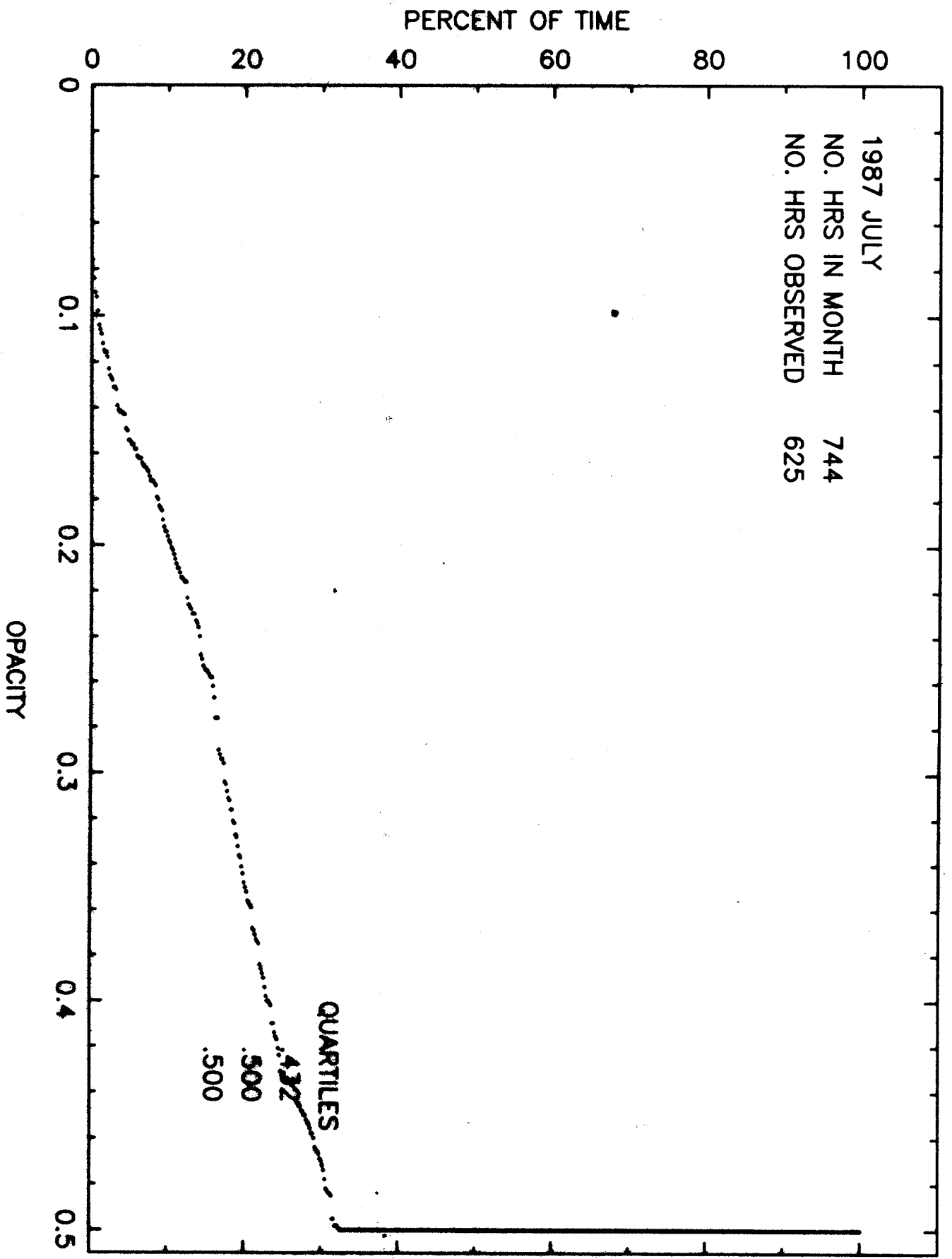


SUMMARY OF DATA FOR SOUTH BALDY
 DATA WERE DRAWN FROM THE PERIOD 1987 JULY
 THE TOTAL NUMBER OF HOURS POSSIBLE IS 744
 THERE WERE 625 VALID DATA POINTS, OR 84 PERCENT.
 THE RECEIVER WAS BROKEN FOR 119 HOURS, OR 16 PERCENT.
 THERE WERE 0 NULL VALUES RECORDED, OR 0 PERCENT.

ASSUME WATER= $(\text{OPACITY}-0.005)/(0.056)$
 NOW FOLLOWS THE PERCENTAGE OF THE TIME
 FOR WHICH THE OPACITY LAY BELOW A GIVEN VALUE

OPACITY	MM WATER VAPOR	PERCENT OF TIME
0.061	1.0	0
0.117	2.0	2
0.173	3.0	8
0.229	4.0	13
0.285	5.0	16
0.341	6.0	20
0.397	7.0	23
0.453	8.0	28
0.432	7.6	25
0.500	8.8	50
0.500	8.8	75
0.050	0.8	0
0.100	1.7	1
0.150	2.6	5
0.200	3.5	10
0.250	4.4	14
0.300	5.3	17
0.350	6.2	20
0.400	7.1	23
0.450	7.9	28
0.500	8.8	66

PERCENT OF TIME OPACITY IS LESS THAN A GIVEN VALUE DATA FOR SOUTH BALDY

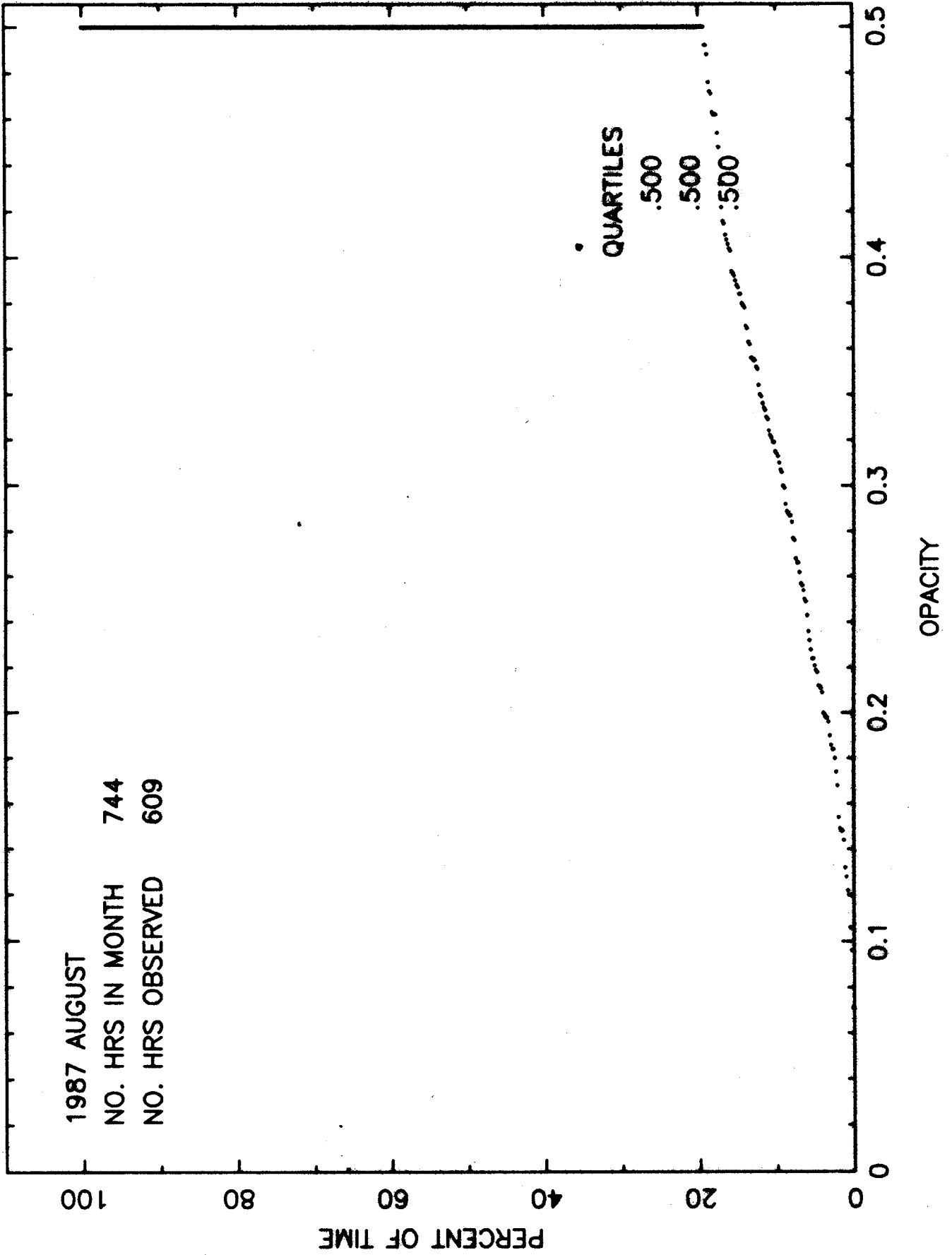


SUMMARY OF DATA FOR SOUTH BALDY
 DATA WERE DRAWN FROM THE PERIOD 1987 AUGUST
 THE TOTAL NUMBER OF HOURS POSSIBLE IS 744
 THERE WERE 609 VALID DATA POINTS, OR 82 PERCENT.
 THE RECEIVER WAS BROKEN FOR 135 HOURS, OR 18 PERCENT.
 THERE WERE 0 NULL VALUES RECORDED, OR 0 PERCENT.

ASSUME WATER= $(\text{OPACITY}-0.005)/(0.056)$
 NOW FOLLOWS THE PERCENTAGE OF THE TIME
 FOR WHICH THE OPACITY LAY BELOW A GIVEN VALUE

OPACITY	MM WATER VAPOR	PERCENT OF TIME
0.061	1.0	0
0.117	2.0	0
0.173	3.0	2
0.229	4.0	6
0.285	5.0	8
0.341	6.0	12
0.397	7.0	16
0.453	8.0	17
0.500	8.8	60
0.500	8.8	50
0.500	8.8	75
0.050	0.8	0
0.100	1.7	0
0.150	2.6	2
0.200	3.5	4
0.250	4.4	6
0.300	5.3	9
0.350	6.2	12
0.400	7.1	16
0.450	7.9	17
0.500	8.8	60

PERCENT OF TIME OPACITY IS LESS THAN A GIVEN VALUE DATA FOR SOUTH BALDY



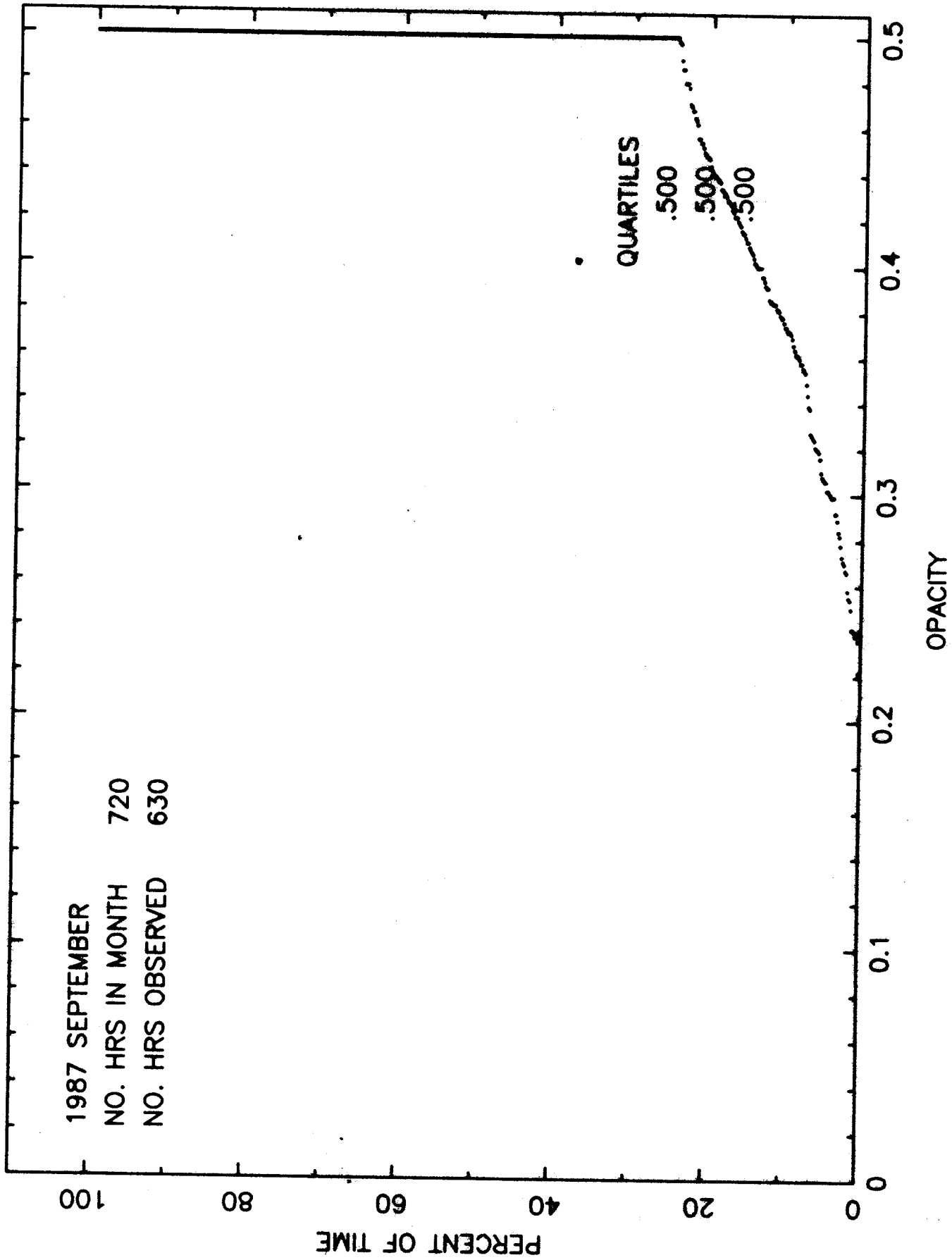
SUMMARY OF DATA FOR SOUTH BALDY
 DATA WERE DRAWN FROM THE PERIOD 1987 SEPTEMBER
 THE TOTAL NUMBER OF HOURS POSSIBLE IS 720
 THERE WERE 630 VALID DATA POINTS, OR 87 PERCENT.
 THE RECEIVER WAS BROKEN FOR 90 HOURS, OR 12 PERCENT.
 THERE WERE 0 NULL VALUES RECORDED, OR 0 PERCENT.

ASSUME WATER= $(\text{OPACITY}-0.005)/(0.056)$
 NOW FOLLOWS THE PERCENTAGE OF THE TIME
 FOR WHICH THE OPACITY LAY BELOW A GIVEN VALUE

OPACITY	MM WATER VAPOR	PERCENT OF TIME
0.061	1.0	0
0.117	2.0	0
0.173	3.0	0
0.229	4.0	0
0.285	5.0	3
0.341	6.0	7
0.397	7.0	13
0.453	8.0	21
0.500	8.8	62
0.500	8.8	50
0.500	8.8	75
0.050	0.8	0
0.100	1.7	0
0.150	2.6	0
0.200	3.5	0
0.250	4.4	1
0.300	5.3	4
0.350	6.2	8
0.400	7.1	14
0.450	7.9	21
0.500	8.8	62

PERCENT OF TIME OPACITY IS LESS THAN A GIVEN VALUE DATA FOR SOUTH BALDY

1987 SEPTEMBER
NO. HRS IN MONTH 720
NO. HRS OBSERVED 630

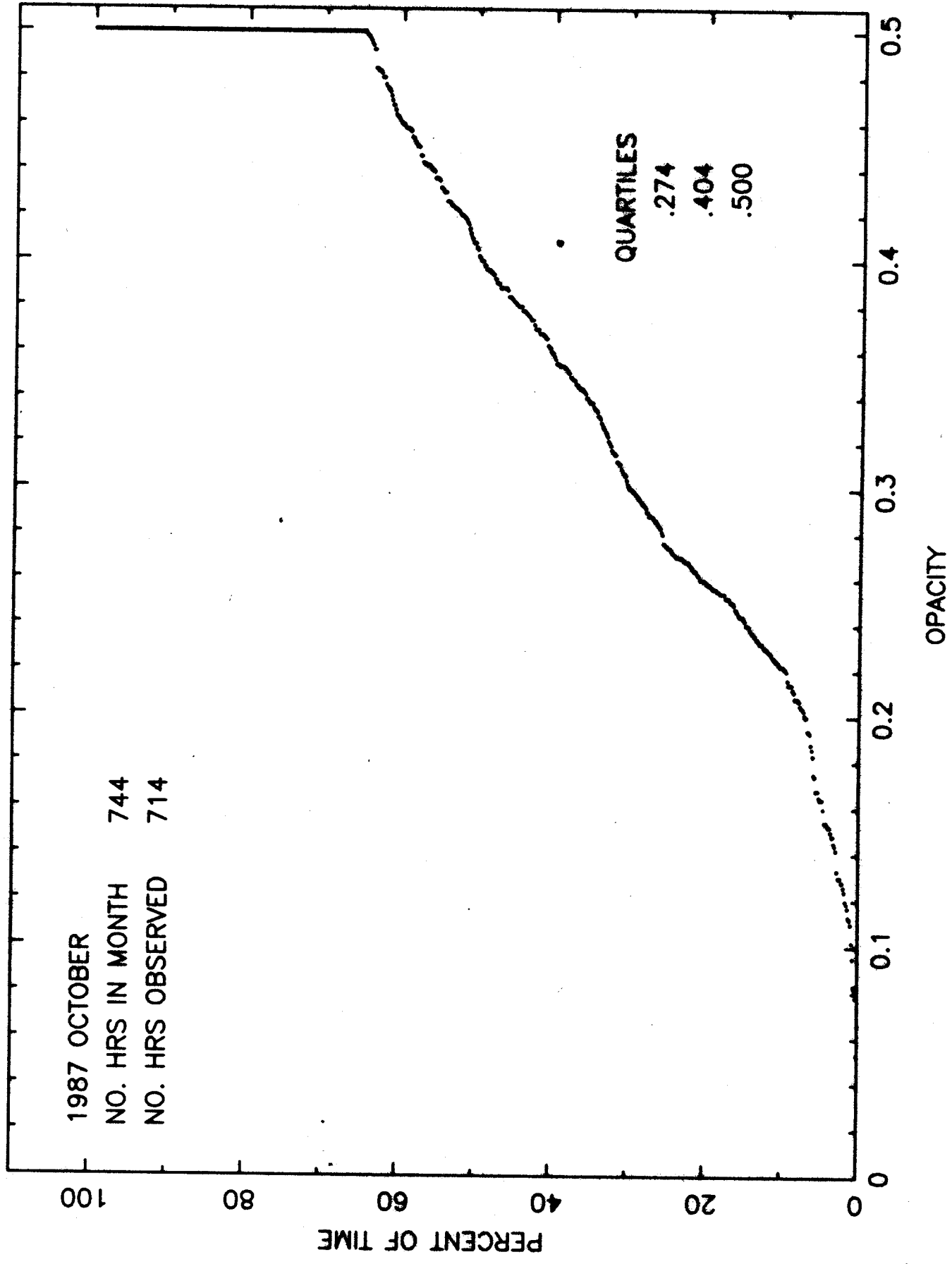


SUMMARY OF DATA FOR SOUTH BALDY
 DATA WERE DRAWN FROM THE PERIOD 1987 OCTOBER
 THE TOTAL NUMBER OF HOURS POSSIBLE IS 744
 THERE WERE 714 VALID DATA POINTS, OR 96 PERCENT.
 THE RECEIVER WAS BROKEN FOR 30 HOURS, OR 4 PERCENT.
 THERE WERE 0 NULL VALUES RECORDED, OR 0 PERCENT.

ASSUME WATER- $(\text{OPACITY}-0.005)/(0.056)$
 NOW FOLLOWS THE PERCENTAGE OF THE TIME
 FOR WHICH THE OPACITY LAY BELOW A GIVEN VALUE

OPACITY	MM WATER VAPOR	PERCENT OF TIME
0.061	1.0	0
0.117	2.0	1
0.173	3.0	6
0.229	4.0	12
0.285	5.0	26
0.341	6.0	36
0.397	7.0	49
0.453	8.0	59
0.274	4.8	25
0.404	7.1	50
0.500	8.8	75
0.050	0.8	0
0.100	1.7	1
0.150	2.6	4
0.200	3.5	7
0.250	4.4	17
0.300	5.3	30
0.350	6.2	38
0.400	7.1	50
0.450	7.9	58
0.500	8.8	82

PERCENT OF TIME OPACITY IS LESS THAN A GIVEN VALUE DATA FOR SOUTH BALDY



SUMMARY OF DATA FOR SOUTH BALDY
 DATA WERE DRAWN FROM THE PERIOD 1987 NOVEMBER
 THE TOTAL NUMBER OF HOURS POSSIBLE IS 720
 THERE WERE 344 VALID DATA POINTS, OR 48 PERCENT.
 THE RECEIVER WAS BROKEN FOR 376 HOURS, OR 52 PERCENT.
 THERE WERE 0 NULL VALUES RECORDED, OR 0 PERCENT.

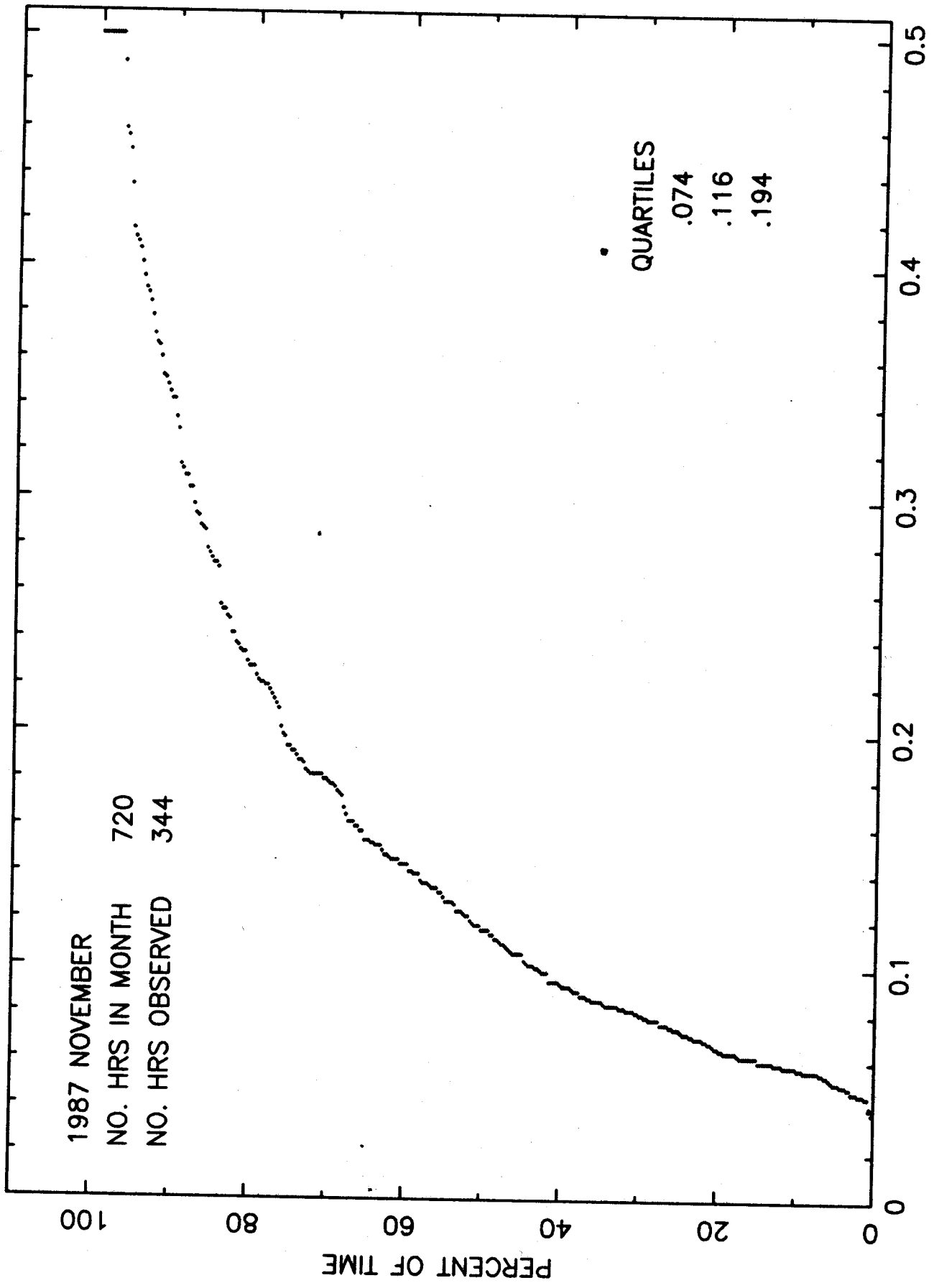
ASSUME WATER- $(\text{OPACITY}-0.005)/(0.056)$
 NOW FOLLOWS THE PERCENTAGE OF THE TIME
 FOR WHICH THE OPACITY LAY BELOW A GIVEN VALUE

OPACITY	MM WATER VAPOR	PERCENT OF TIME
0.061	1.0	15
0.117	2.0	50
0.173	3.0	68
0.229	4.0	80
0.285	5.0	86
0.341	6.0	90
0.397	7.0	94
0.453	8.0	96
0.074	1.2	25
0.116	2.0	50
0.194	3.4	75
0.050	0.8	4
0.100	1.7	43
0.150	2.6	63
0.200	3.5	76
0.250	4.4	83
0.300	5.3	87
0.350	6.2	91
0.400	7.1	94
0.450	7.9	96
0.500	8.8	99

PERCENT OF TIME OPACITY IS LESS THAN A GIVEN VALUE DATA FOR SOUTH BALDY

1987 NOVEMBER
NO. HRS IN MONTH 720
NO. HRS OBSERVED 344

QUANTILES
.074
.116
.194



SUMMARY OF DATA FOR SOUTH BALDY

DATA WERE DRAWN FROM THE PERIOD 1987 DECEMBER

THE TOTAL NUMBER OF HOURS POSSIBLE IS 744

THERE WERE 439 VALID DATA POINTS, OR 59 PERCENT.

THE RECEIVER WAS BROKEN FOR 302 HOURS, OR 41 PERCENT.

THERE WERE 3 NULL VALUES RECORDED, OR 0 PERCENT.

ASSUME WATER- $(\text{OPACITY}-0.005)/(0.056)$

NOW FOLLOWS THE PERCENTAGE OF THE TIME

FOR WHICH THE OPACITY LAY BELOW A GIVEN VALUE

OPACITY	MM WATER VAPOR	PERCENT OF TIME
0.061	1.0	5
0.117	2.0	30
0.173	3.0	57
0.229	4.0	73
0.285	5.0	82
0.341	6.0	86
0.397	7.0	89
0.453	8.0	90
0.108	1.8	24
0.157	2.7	50
0.237	4.1	75
0.050	0.8	2
0.100	1.7	18
0.150	2.6	48
0.200	3.5	64
0.250	4.4	78
0.300	5.3	82
0.350	6.2	86
0.400	7.1	89
0.450	7.9	90
0.500	8.8	95

PERCENT OF TIME OPACITY IS LESS THAN A GIVEN VALUE DATA FOR SOUTH BALDY

1987 DECEMBER

NO. HRS IN MONTH 744

NO. HRS OBSERVED 439

PERCENT OF TIME

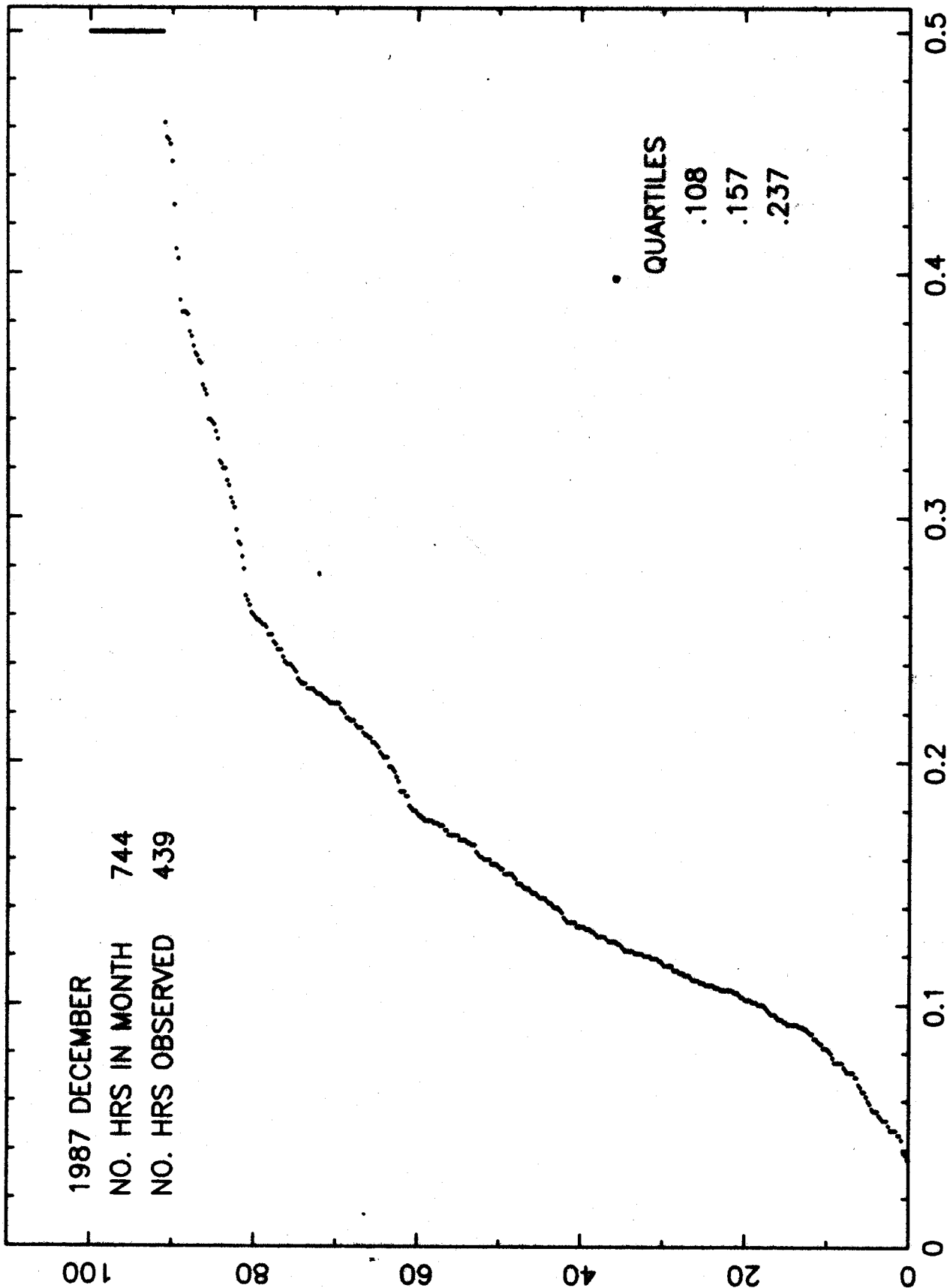
OPACITY

QUANTILES

.108

.157

.237

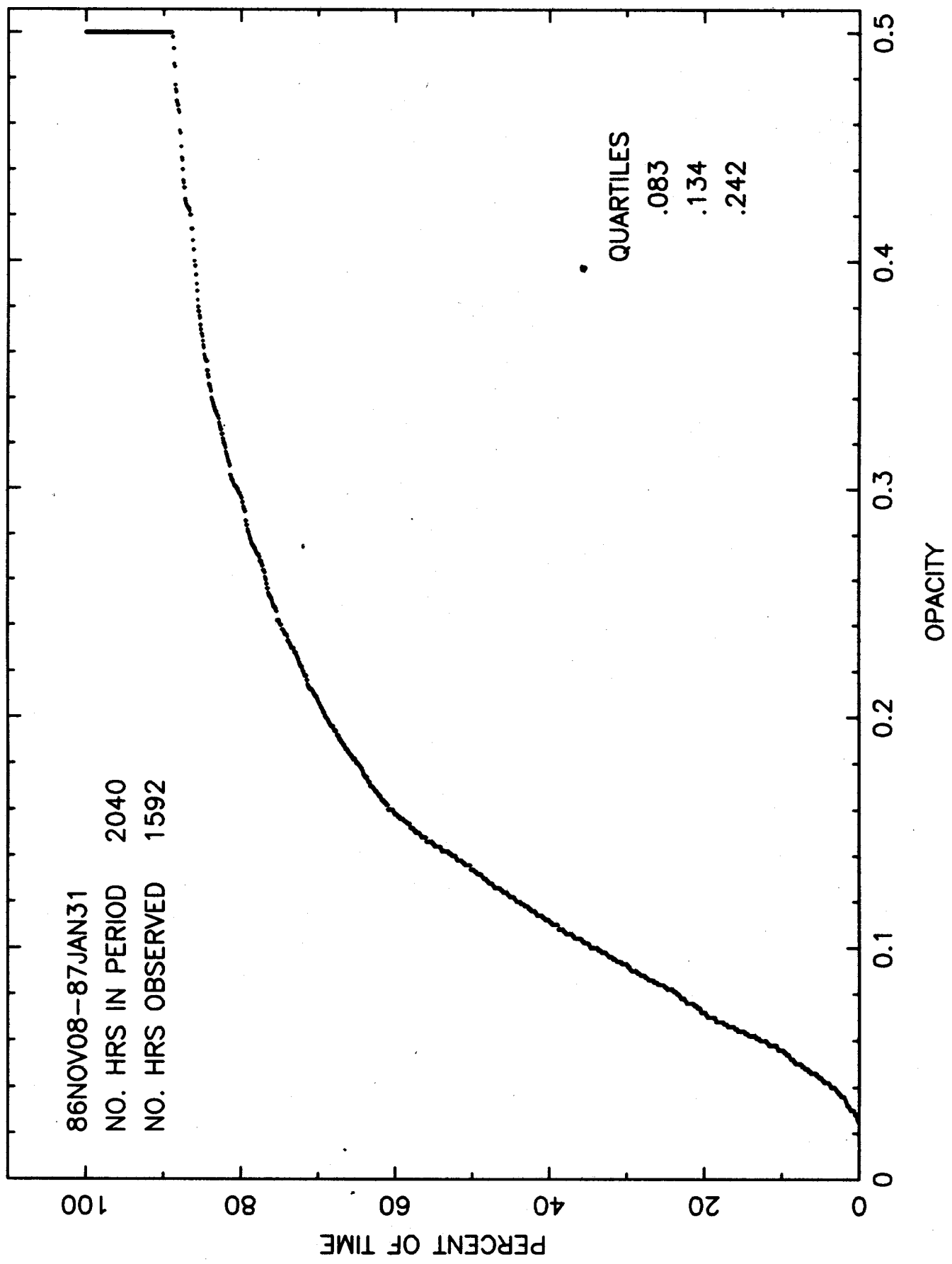


Appendix II

Quarterly Summaries of Observations

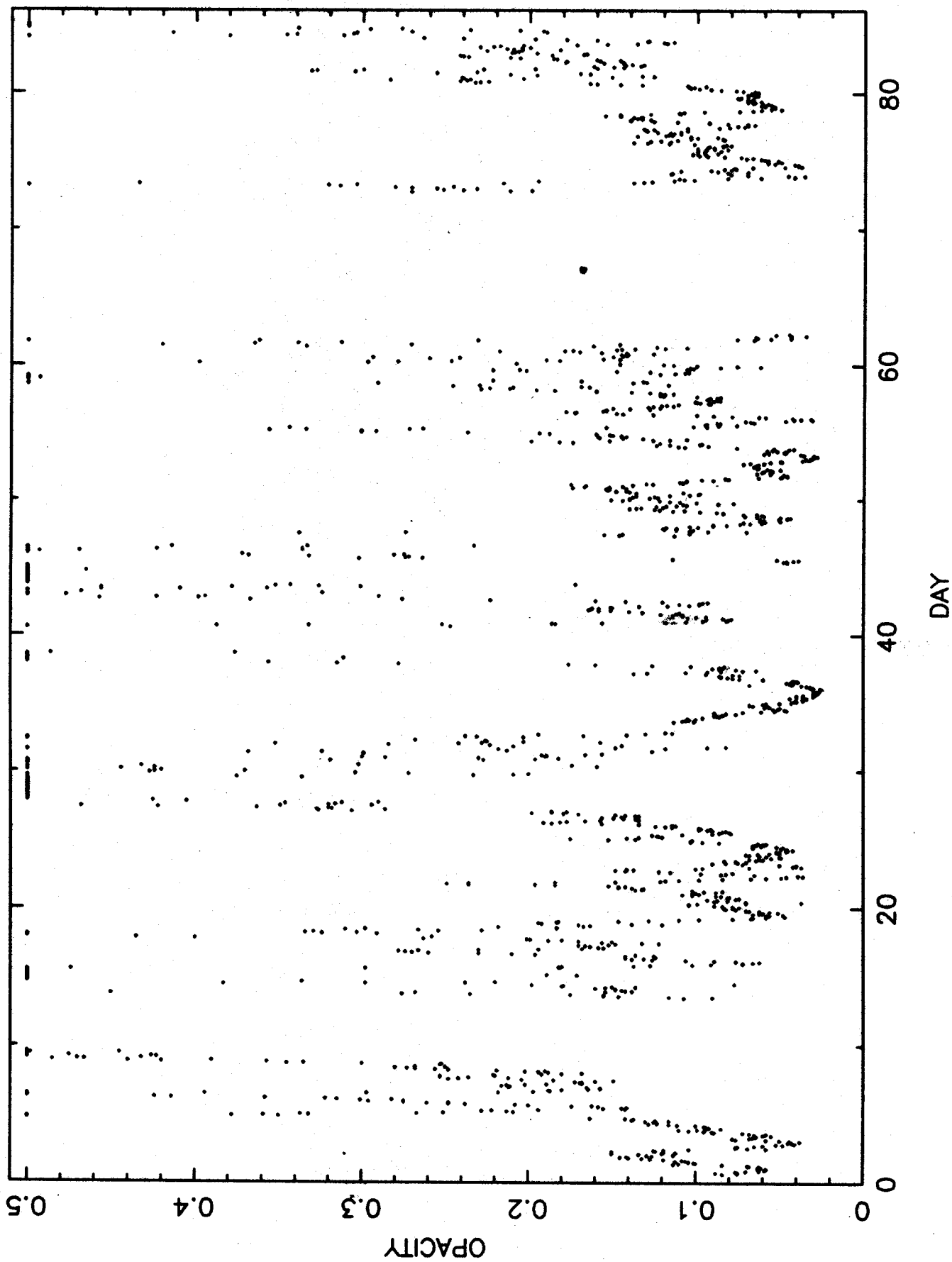
PERCENT OF TIME OPACITY IS LESS THAN A GIVEN VALUE DATA FOR SOUTH BALDY

86NOV08-87JAN31
NO. HRS IN PERIOD 2040
NO. HRS OBSERVED 1592

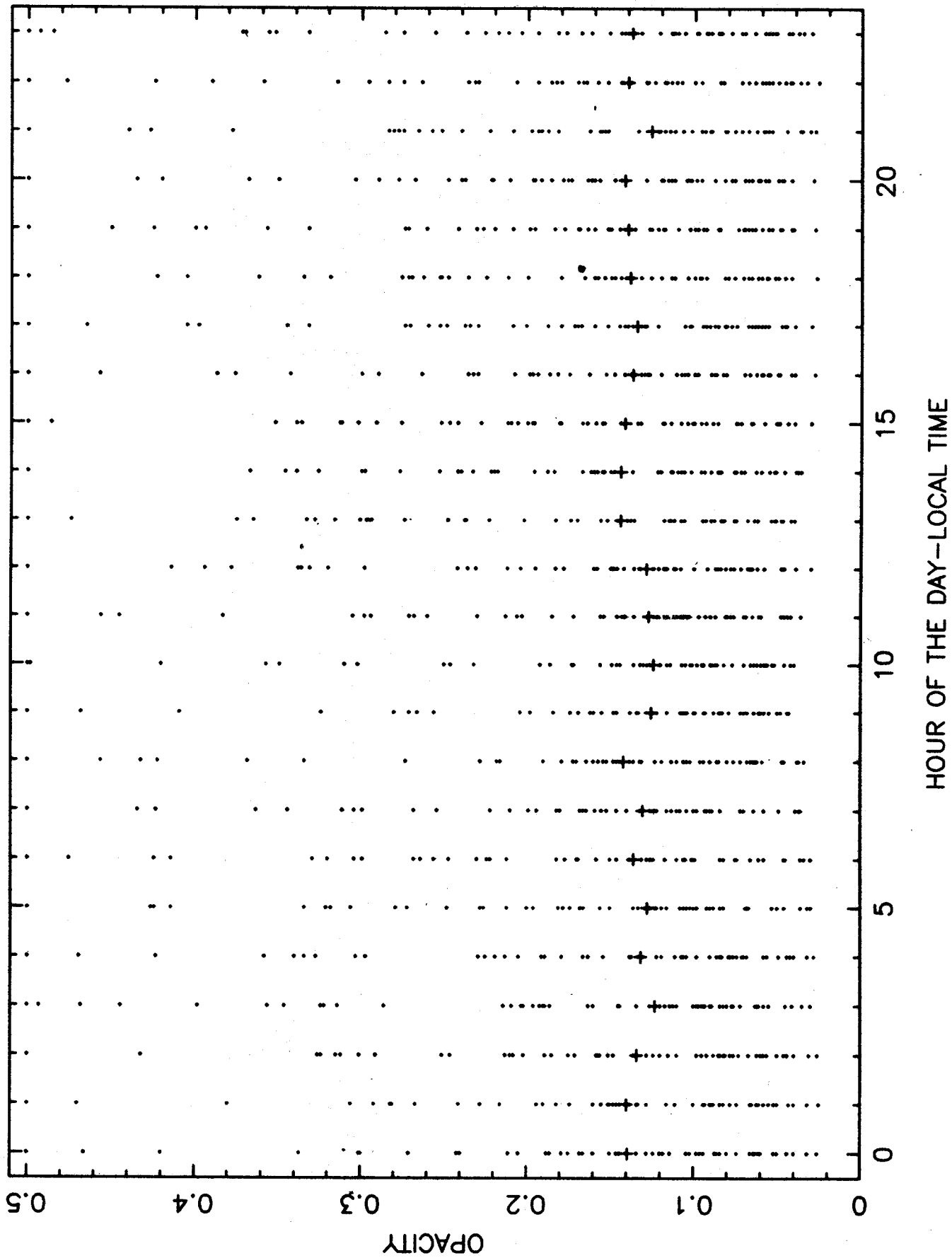


SOUTH BALDY DATA
86NOV08-87JAN31

NO. POINTS 1592



86NOV08-87JAN31 SOUTH BALDY HOURLY MEDIANS NO. POINTS 1592



PERCENT OF TIME OPACITY IS LESS THAN A GIVEN VALUE DATA FOR SOUTH BALDY

87FEB01-87APR30

NO. HRS IN PERIOD 2136

NO. HRS OBSERVED 1770

PERCENT OF TIME

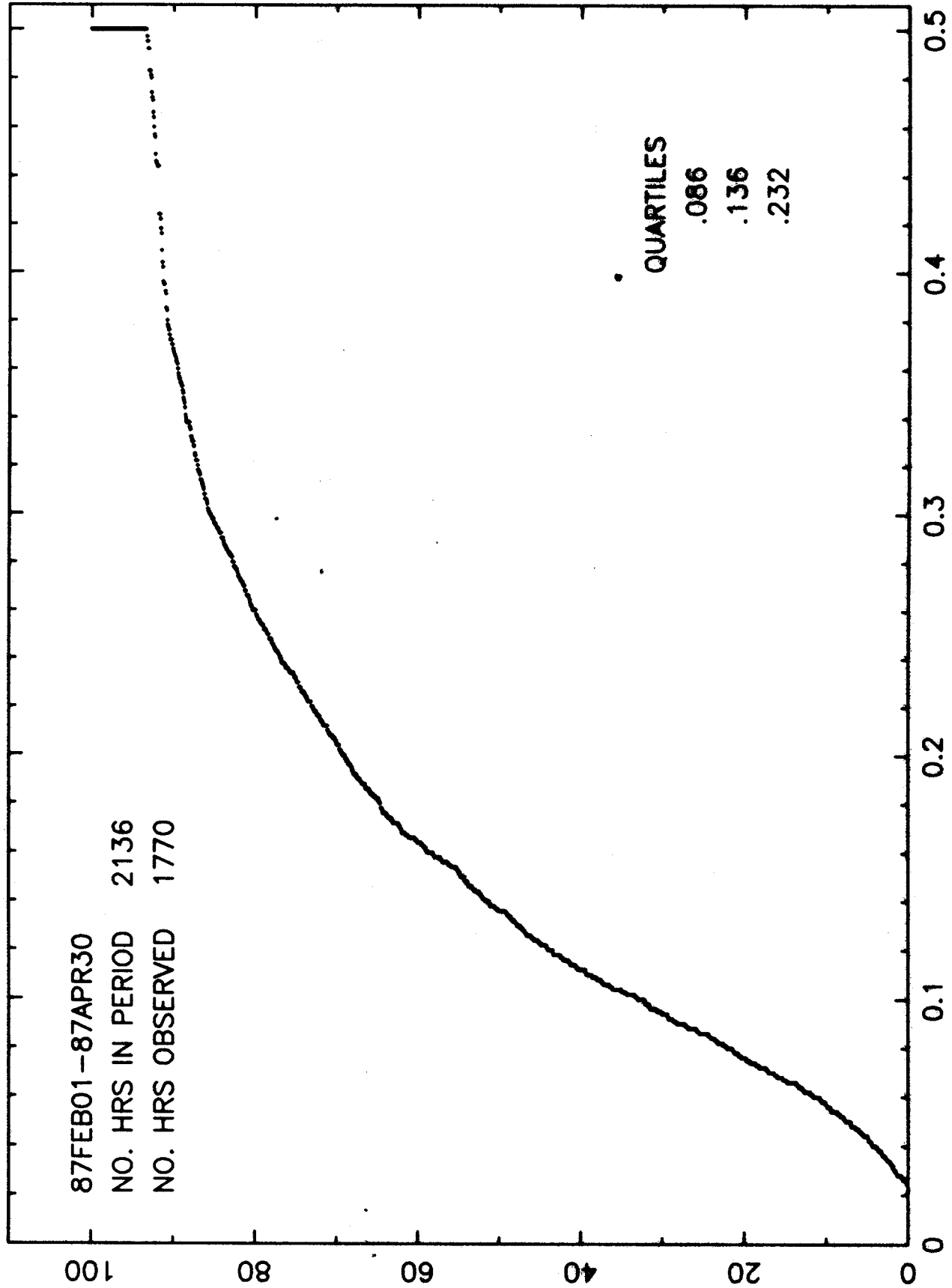
OPACITY

QUANTILES

.086

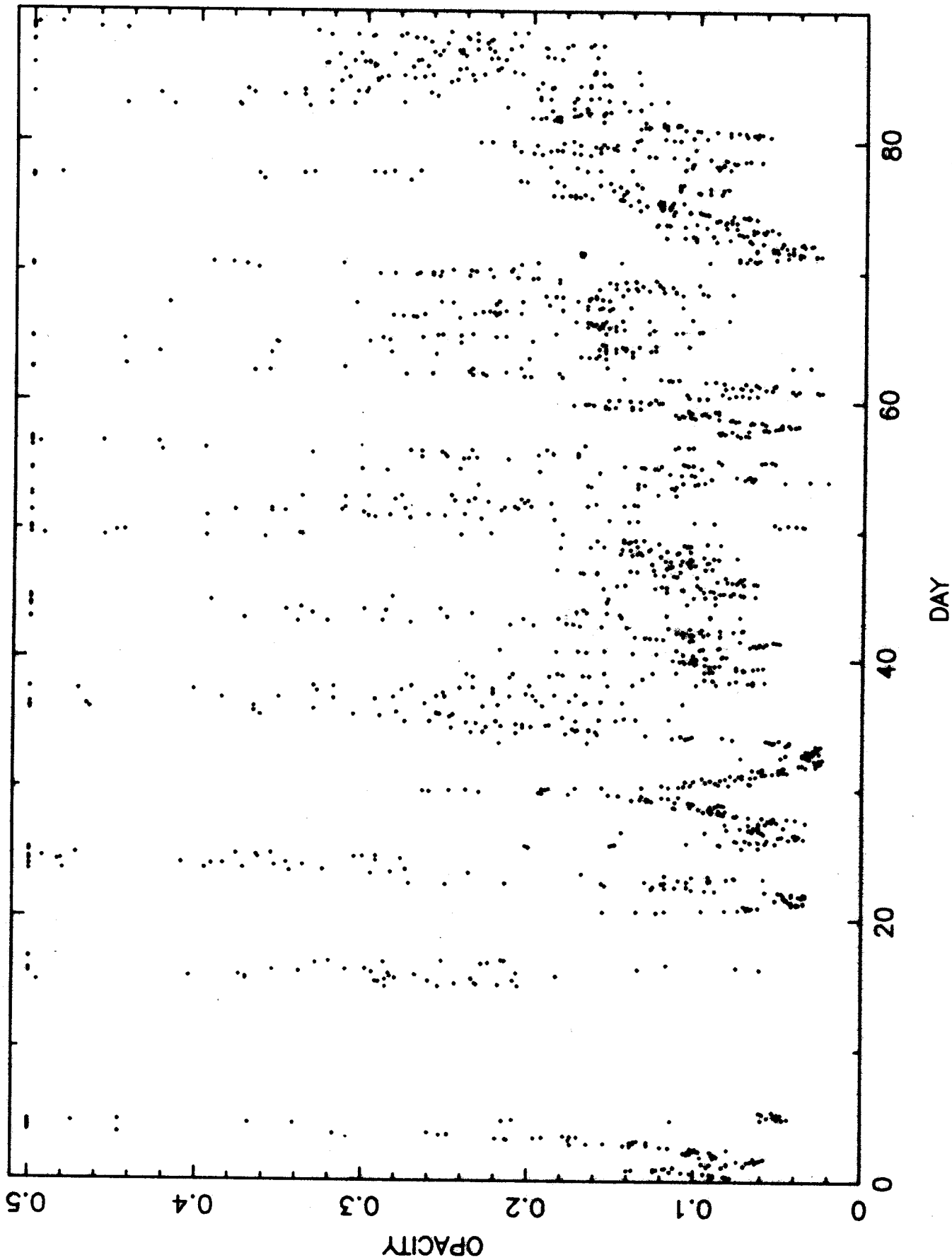
.136

.232

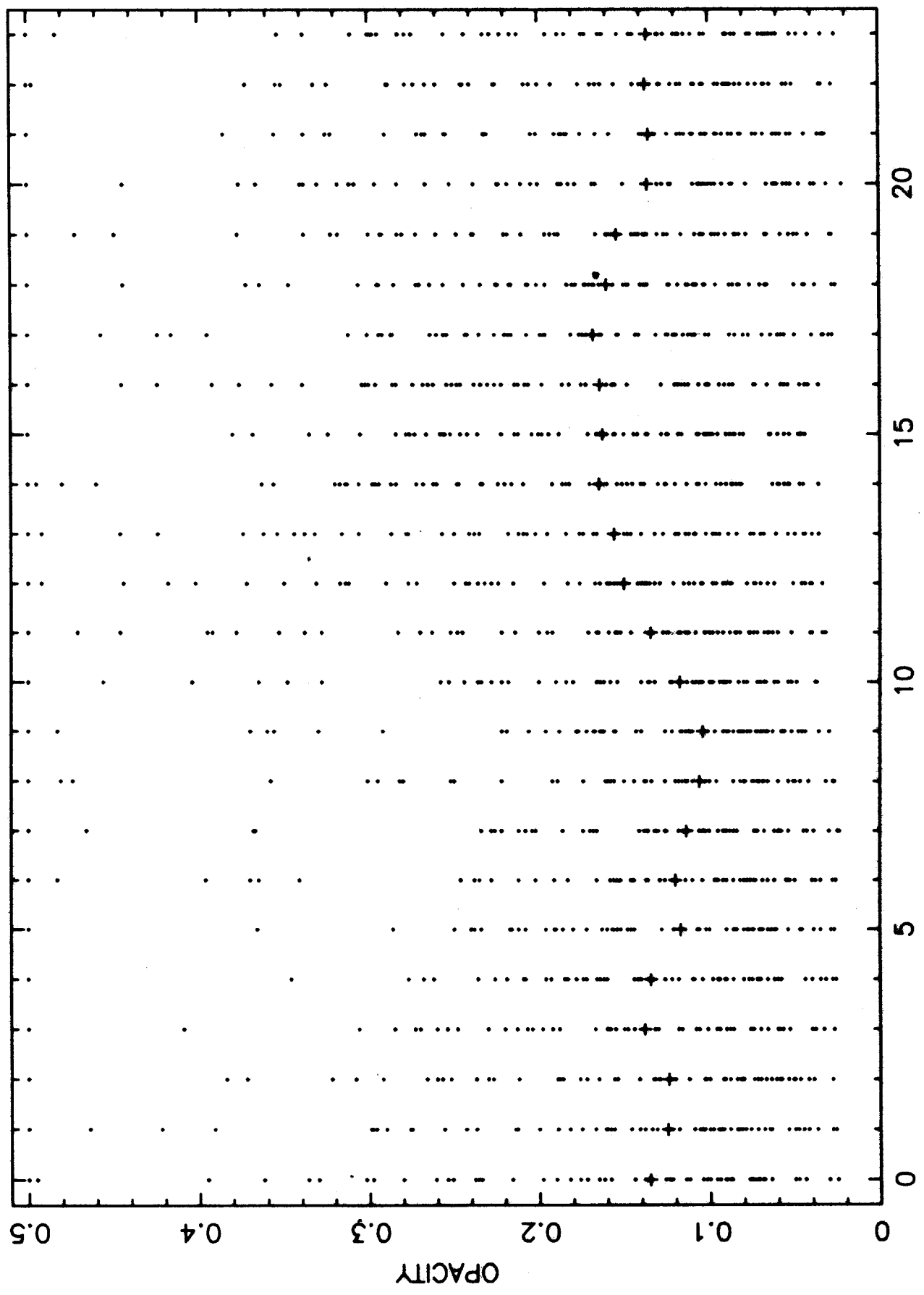


SOUTH BALDY DATA
87FEB01-87APR30

NO. POINTS 1770

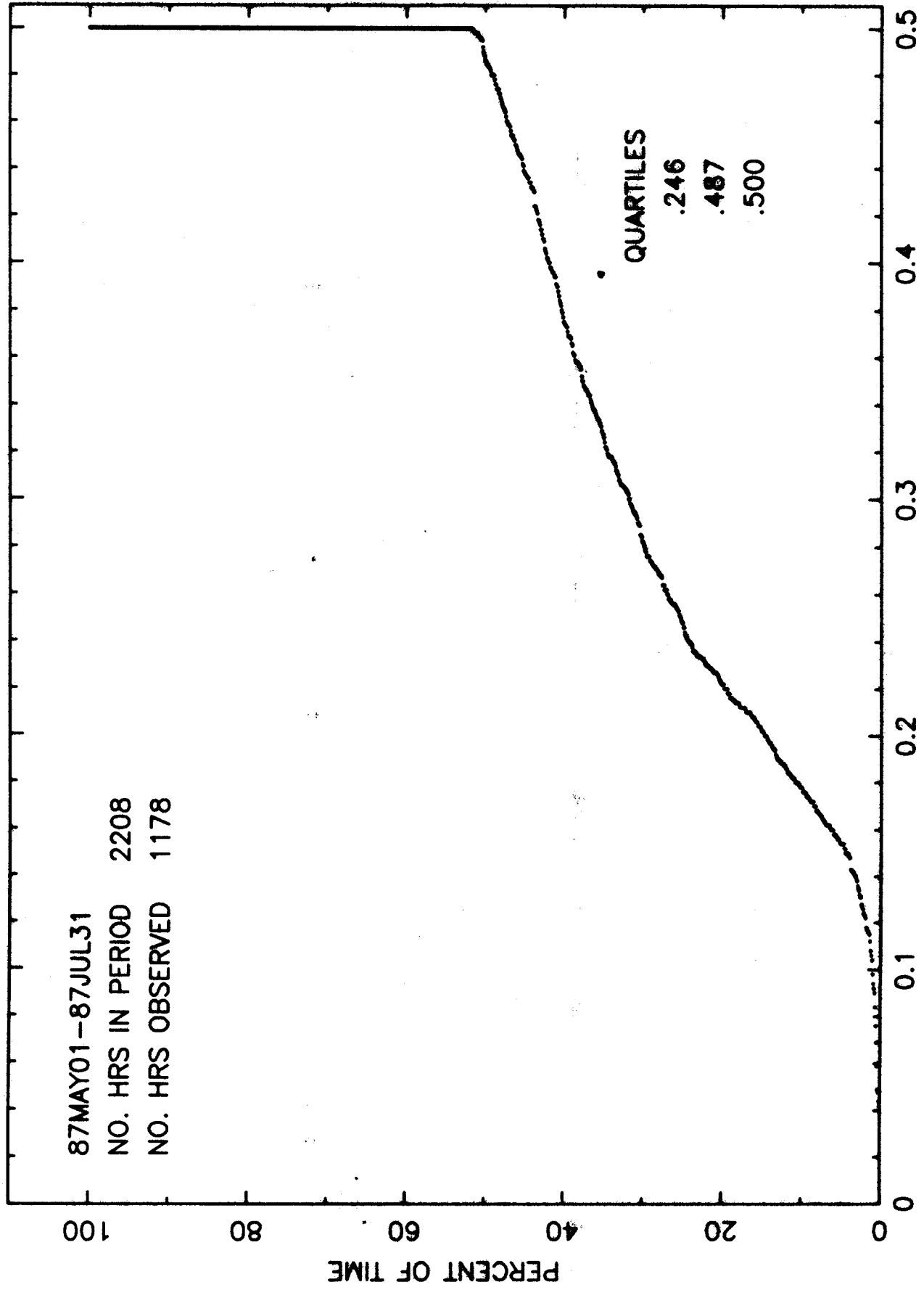


87FEB01-87APR30 SOUTH BALDY HOURLY MEDIANS NO. POINTS 1770



PERCENT OF TIME OPACITY IS LESS THAN A GIVEN VALUE DATA FOR SOUTH BALDY

87MAY01-87JUL31
NO. HRS IN PERIOD 2208
NO. HRS OBSERVED 1178



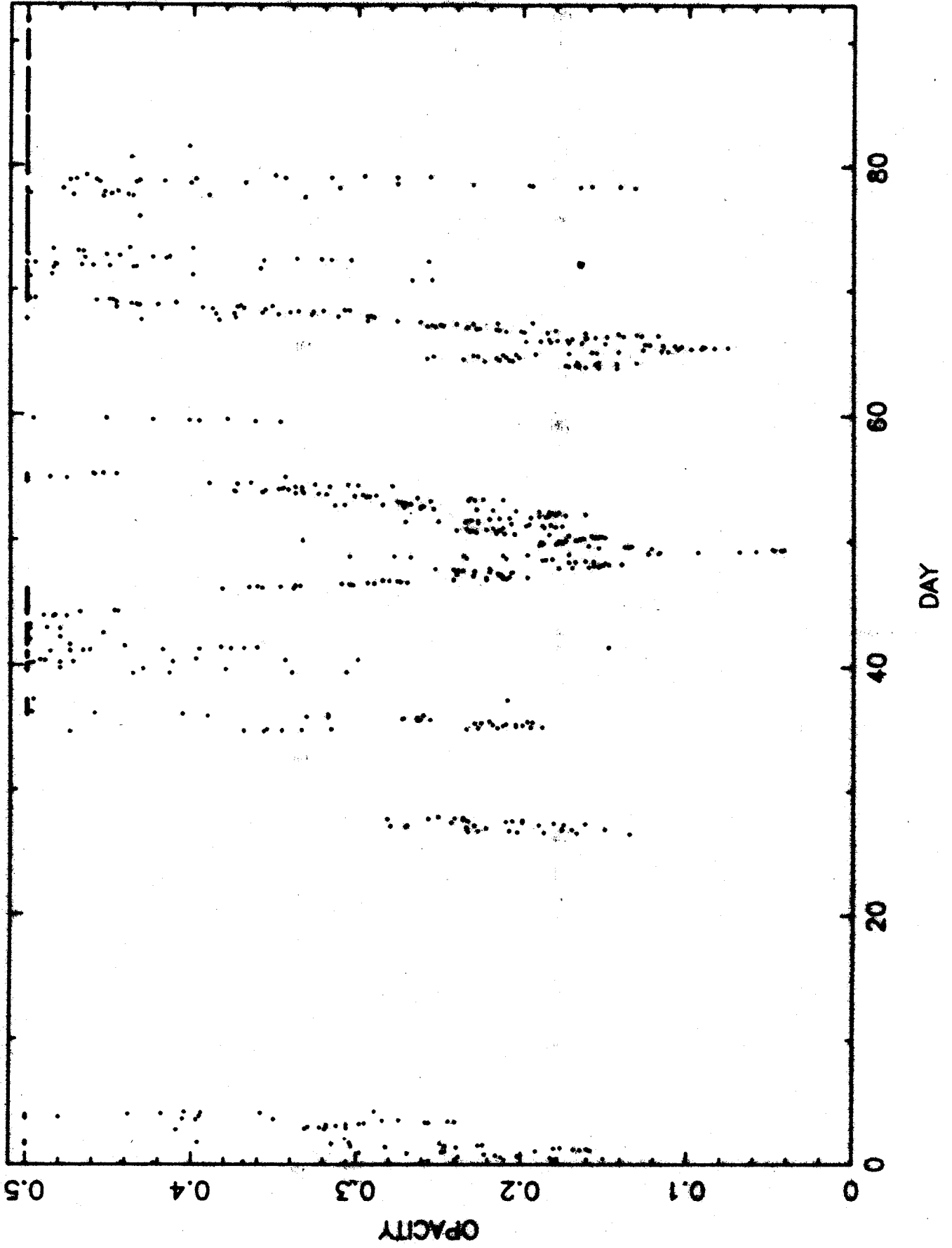
OPACITY

SOUTH BALDY DATA

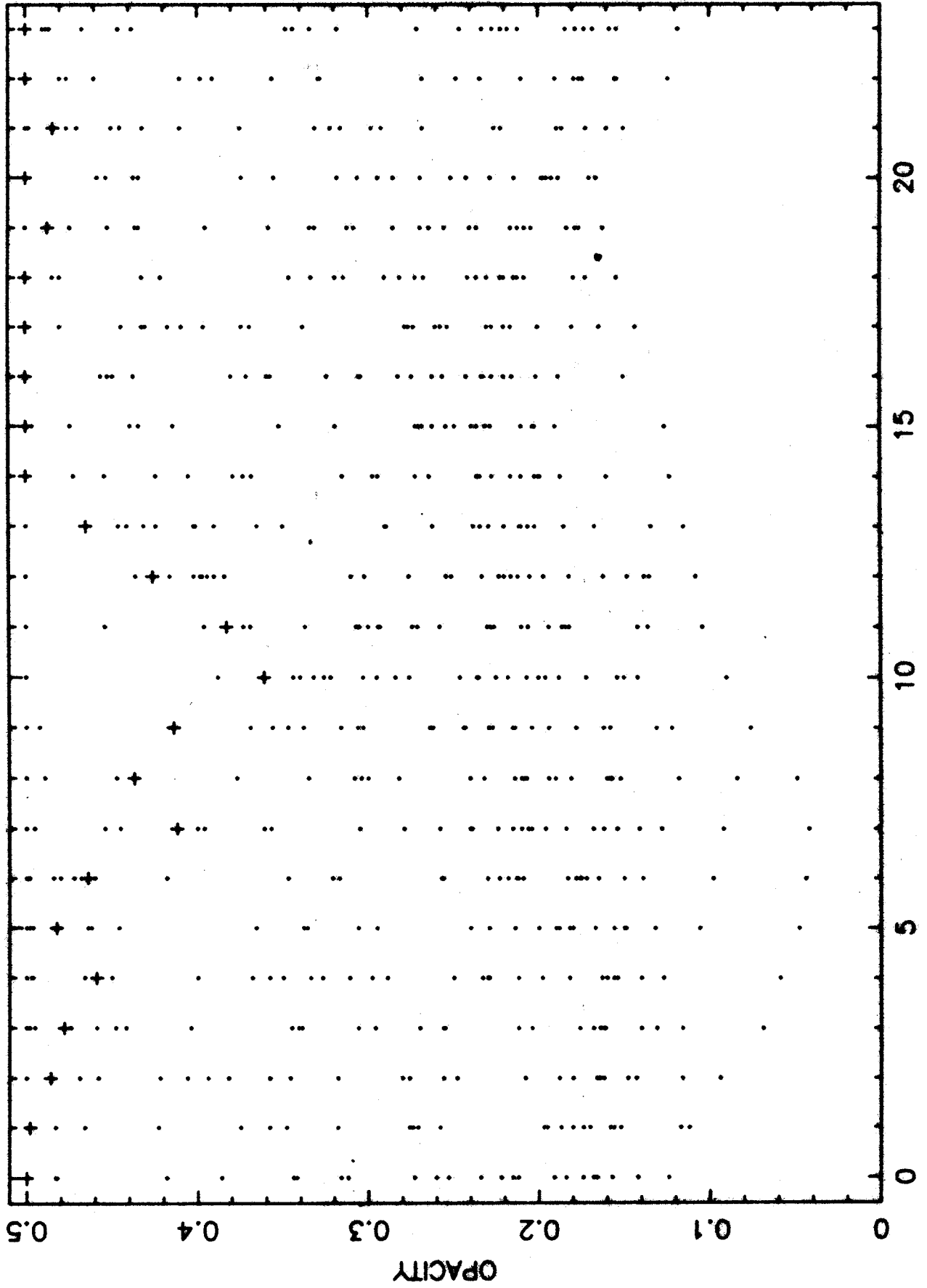
87MAY01-87JUL31

NO. POINTS

1178

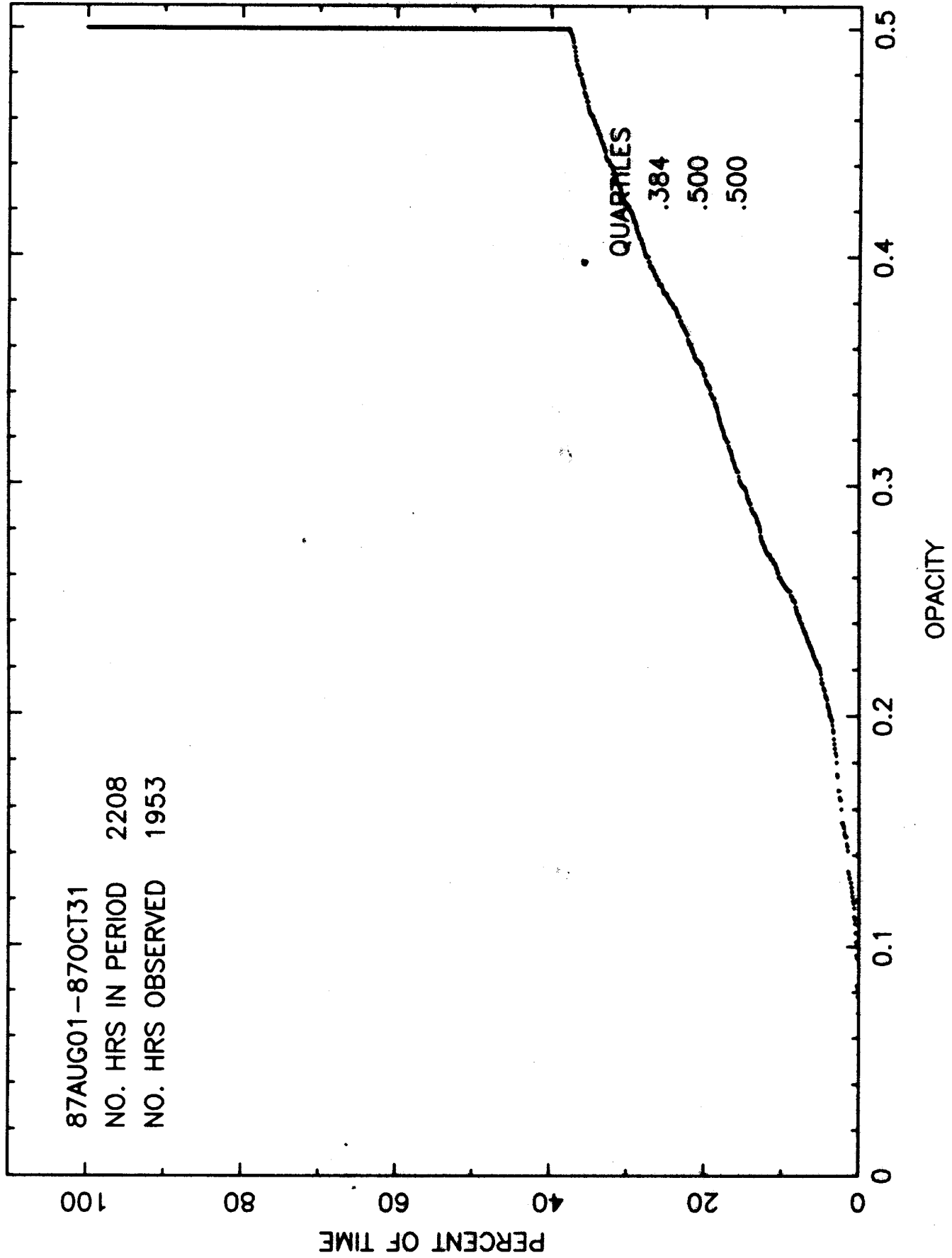


87MAY01-87JUL31 SOUTH BALDY HOURLY MEDIANS NO. POINTS 1178



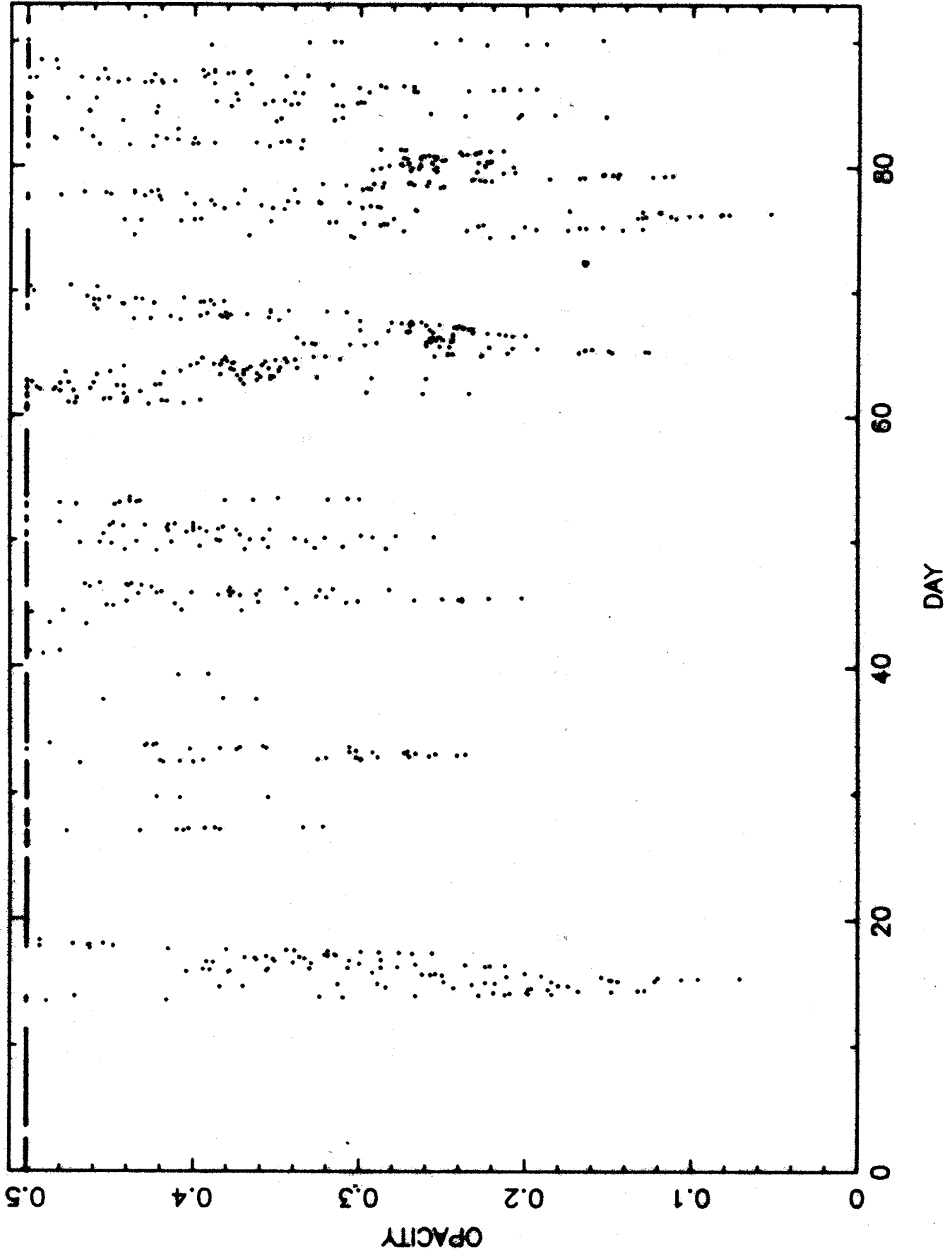
HOUR OF THE DAY-LOCAL TIME

PERCENT OF TIME OPACITY IS LESS THAN A GIVEN VALUE DATA FOR SOUTH BALDY



SOUTH BALDY DATA
87AUG01-87OCT31

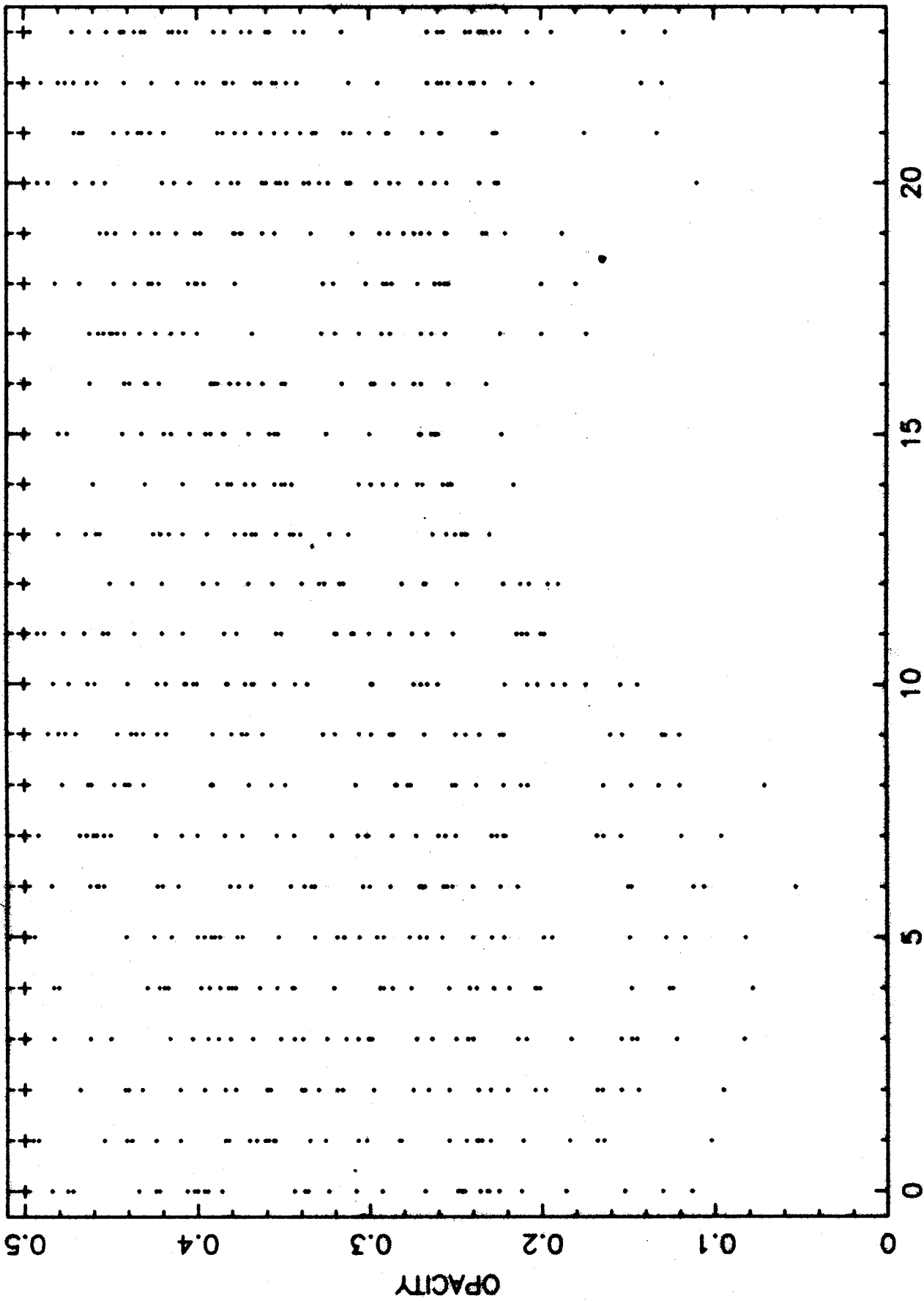
NO. POINTS 1953



SOUTH BALDY HOURLY MEDIANS

87AUG01-87OCT31

NO. POINTS 1953

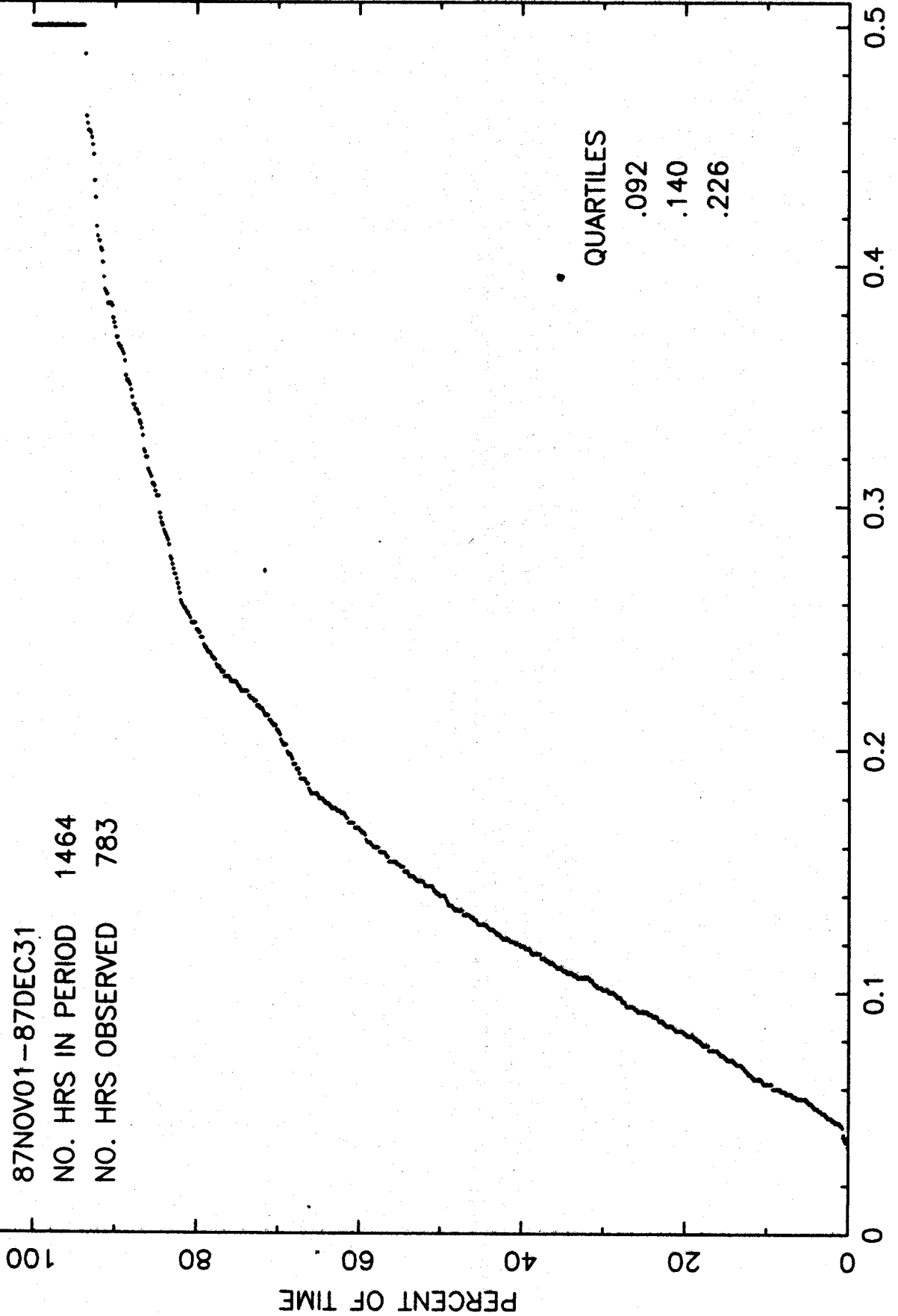


PERCENT OF TIME OPACITY IS LESS THAN A GIVEN VALUE DATA FOR SOUTH BALDY

87NOV01-87DEC31

NO. HRS IN PERIOD 1464

NO. HRS OBSERVED 783

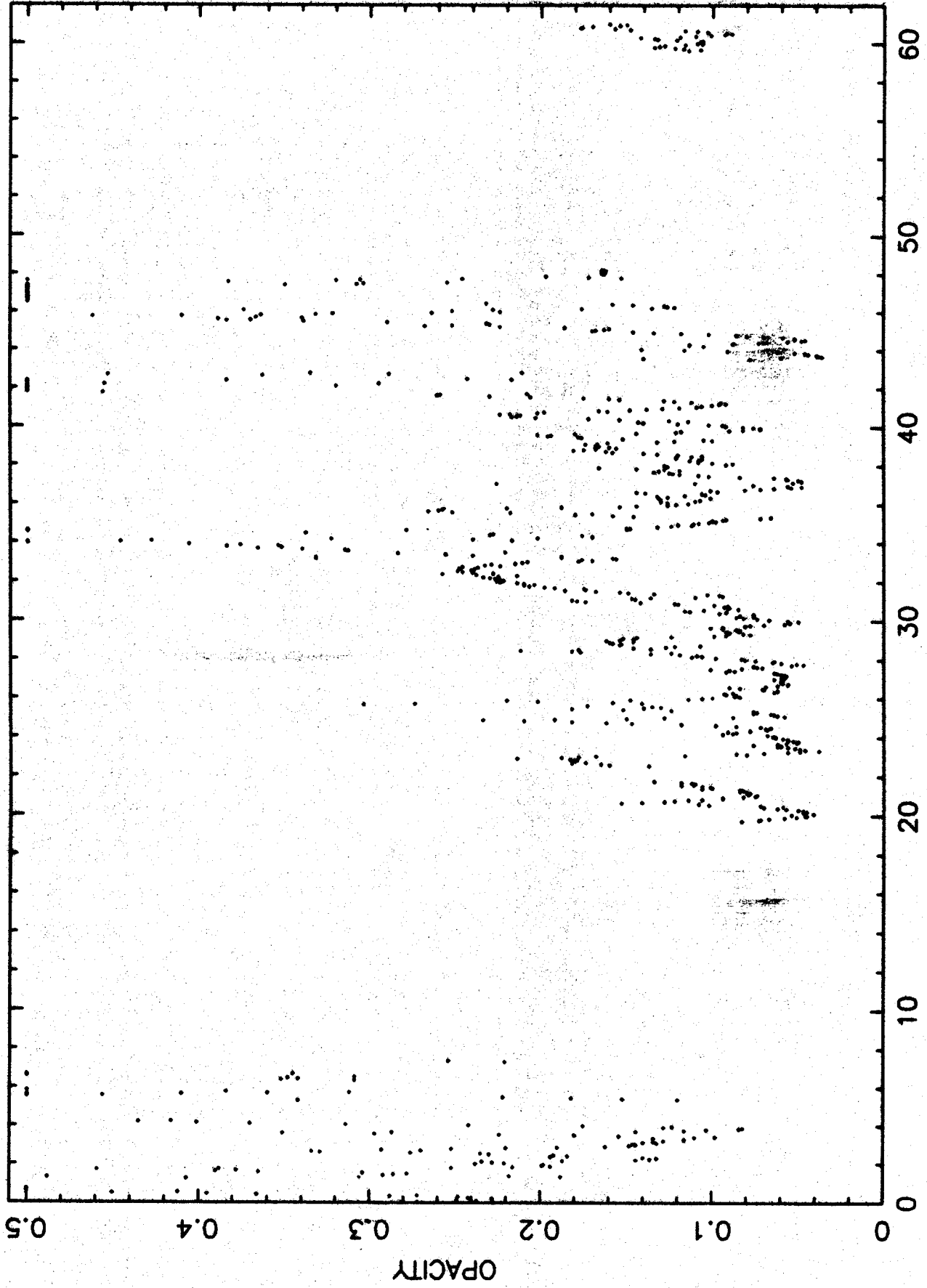


SOUTH BALDY DATA

87NOV01-87DEC31

NO. POINTS

783



87NOV01-87DEC31 SOUTH BALDY HOURLY MEDIANS NO. POINTS 783

