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Solar Emission Levels At Low Radio Frequencies

W. C. Erickson
University of Maryland
College Park, Maryland

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Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

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ABSTRACT

Solar radio emission could seriously interfere with observations made by a low frequency (1-10 MHz) array in space. This problem is of particular concern because a previous study (JPL Publication 88-30) showed that terrestrial interference would be so severe that the only location from which a space array would be able to operate near the Earth would be on the sunlit side where the ionosphere would shield the system from signals generated at ground level. Thus the system would be open to interference from the Sun.

In this study ISEE-3 radio data has been used to determine solar emission levels. The results indicate that solar emission should seriously disturb less than ten per cent of the data, even during the years of solar maximum. Thus it appears that solar emission should not cause a disastrous loss of data. This study also provides the information needed to design procedures to excise solar interference from the data produced by any low-frequency array.

ACKNOWLEDGEMENTS

I wish to acknowledge very helpful discussions with Drs. Robert MacDowall, Robert Stone, and Hilary Cane of the Goddard Space Flight Center. However, this is not to dilute my responsibility for all errors and omissions. The ISEE-3 data were provided to me by Drs. Stone and MacDowall of the Radio Astronomy Group at GSFC.

PREFACE

The work reported in this publication has been supported by the JPL Director's Discretionary Fund task entitled "Low Frequency Radio Astronomy Using GASCAN Satellites." Dr. Erickson of the University of Maryland, Department of Physics and Astronomy, College Park, Maryland 20742 (present address: Department of Physics, University of Tasmania, GPO Box 252C, Hobart, Tasmania 7001, Australia), is a co-investigator on the task with the following JPL staff: Michael A. Janssen (Principal Investigator), Dayton L. Jones, Thomas B. H. Kuiper, Michael J. Mahoney, Robert A. Preston, and Stephan P. Synnott. This survey of the low-frequency interference environment was undertaken because natural and man-made interferences are recognized as potentially serious obstacles to the implementation of a low-frequency VLBI array of small satellites in Earth orbit, or even a near-side lunar array.

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SOLAR EMISSION LEVELS AT LOW RADIO FREQUENCIES

I. INTRODUCTION

The radio astronomy experiment aboard the International Sun-Earth Explorer (ISEE-3) provides the best data available concerning solar radio emission at low frequencies. This spacecraft was located at the inner libration point, L1, ~240 R_E from Earth towards the Sun. It carried a radio receiving system that operated in the 30 kHz to 2 MHz band. The spacecraft was launched in August, 1978; its ecliptic-plane dipoles were extended to 92 m tip-to-tip and data acquisition began in September. The spacecraft also possessed a 15 m dipole in the Z-direction (perpendicular to the ecliptic plane), but only the data from the 92 m dipoles was used for this study. The spin period of the spacecraft was three seconds and the modulation that this imposes upon the dipole outputs was used to determine the direction of the source in the ecliptic plane. ISEE-3 remained at the inner libration point through solar maximum until late in 1982 when it was sent through the Earth's magnetotail and then renamed ICE and sent to the Comet Giacobini-Zinner.

Through the kind cooperation of Drs. Robert Stone and Robert MacDowall of the ISEE-3 radio astronomy group, 90-second averages of the spin-demodulated data at 513 kHz, 1000 kHz, and 1980 kHz (the highest ISEE-3 frequency) were obtained. The pointing data at 1000 kHz were also obtained in order to ensure that any observed emission was of solar origin. These data extend from launch until early 1983. Figure 1 shows a typical section of these data for a four-hour period on 22 November, 1980. It contains a small, isolated group of solar Type III bursts in addition to the galactic background. The background antenna temperatures are about $10^{7.4}$ K, and at the burst the antenna temperatures rise to over 10^{10} K.

II. DATA ANALYSIS

At Goddard Space Flight Center the data were selected and transferred from magnetic tape to 1.2 Mbyte floppy disks. Subsequent analysis was performed on a Personal Computer. The data were analyzed separately for intervals about one-half year in length in order to have enough data in each interval to derive valid statistics and yet to check for solar-cycle variations. As recorded, some of the data were redundant and these redundant data were discarded. The number of observations at each frequency was then determined. This number varies slightly from frequency to frequency because of gaps in the data.

In order to determine the amount of the time when the antenna temperature exceeded various levels because of solar emission, the number of points above various fixed levels during each interval were then found. Two sets of fixed levels were employed, a "low" range from $10^{7.30}$ K to $10^{8.30}$ K in steps of $10^{0.05}$ K or 0.5 dB, and a "high" range from $10^{7.0}$ K to $10^{17.0}$ K in steps of $10^{0.5}$ K or 5 dB. The low range permits a study of the statistics of weak bursts resulting in antenna temperatures near the galactic background and the high range describes the statistics of strong bursts that far exceed the background. The results of this analysis are given in the Appendix.

III. RESULTS

Figures 2-13 depict the percentages of time when the ISEE-3 antenna temperatures exceeded various levels. The data were separated into one-half year intervals, but all of the intervals yielded basically similar results. Above an antenna temperature of $\sim 10^{7.8}$ K, the percentages are highest at 513 kHz and lowest at 1980 kHz. This is to be expected since the durations of solar bursts decrease with increasing frequency. Above this temperature the direction finding also indicates that essentially all of the bursts are of solar origin. Weaker bursts are mostly of solar origin as well but the apparent source directions become noisy as the burst intensity decreases. The galactic background levels at each frequency can be estimated from the point where the curves drop below 100%. This drop is normally quite sharp with the percentages being down 30% to 70% within 1 dB above the background level. The results are summarized more succinctly in Table 1.

We see that signal levels 3 dB above the background occur nearly half of the time at 513 kHz, about 20% of the time at 1000 kHz, and only 10% of the time at 1980 kHz. The peak of the solar cycle occurred late in 1979, but a secondary increase occurred in the last half of 1981. This variation is shown by a number of measures of solar activity, including the data summarized in Table 1. Unfortunately, similar data are not available for solar minimum or for higher frequencies but it would be reasonable to consider the results given in Table 1 to be a "worst case scenario". Burst durations vary approximately as the reciprocal of the frequency and solar activity decreases by a factor of ten or more near solar minimum.

Figures 2-10 cover the period from 1978:228 to 1982:243 while ISEE-3 was near L1. Figure 11 covers the period from 1982:244 to 1982:291 when ISEE-3 left L1 and approached the Earth to about 40 R_E on the sunlit and evening side. Figure 12 covers the passage

Table 1. Percentages of time when signal levels exceeded the background by 3, 6, and 10 dB.

Interval	1980 kHz			1000 kHz			513 kHz		
	3dB	6dB	10dB	3dB	6dB	10dB	3dB	6dB	10dB
1978:228-365	7.3%	2.1%	0.7%	14.7%	5.8%	2.0%	34.3%	17.0%	8.0%
1979:001-183	9.2	3.3	1.2	17.8	8.9	3.6	33.9	21.4	11.4
1979:184-365	12.3	5.1	2.7	22.0	11.6	6.0	46.7	29.5	16.0
1980:001-183	11.2	3.9	1.7	24.7	11.3	4.4	51.4	33.7	17.9
1980:184-366	10.6	3.7	1.4	21.2	9.1	3.6	43.0	26.7	12.1
1981:001-183	8.6	2.7	1.2	18.7	7.1	2.9	41.9	24.3	11.1
1981:184-365	15.0	5.9	1.9	28.1	14.2	5.7	52.8	35.5	19.1
1982:001-183	12.6	4.9	2.0	22.1	10.9	4.4	42.7	27.2	15.3
1982:184-365	7.2	3.7	1.8	17.4	7.0	3.5	41.2	26.2	12.2
Grand Average	10.4	3.9	1.6	20.7	9.5	4.0	43.1	26.9	13.7

through the magnetotail, while Figure 13 covers a later period as ISEE-3 traveled out to an apogee at about 200 R_E in approximately the 3 AM local time direction. The small differences that exist between these figures can be explained by the occurrence or non-occurrence of strong solar bursts during some of these restricted intervals. The spacecraft was apparently shielded from terrestrial interference at 1980 kHz and below by the ionosphere even on the nighttime side of the Earth and no evidence of Auroral Kilometric Radiation is seen at 513 kHz or above.

In retrospect, it appears to have been unnecessary to obtain and analyze the whole time span of ISEE-3 solar data. Any interval of a year or so in length would have yielded the same conclusions. However, once the procedures were set up and the programs were written, little extra effort was required to analyze the whole time span, and it does give extra reliability to the conclusions.

IV. CONCLUSIONS

It appears that interference caused by solar bursts should not present insurmountable problems to a space array operating in the 1-10 MHz range. If, for example, all data were to be discarded when the signal level due to interference was 3 dB or more above background, only 10% or less of the data would normally be lost. It would then be necessary to develop techniques to cope with the remaining low-level interference level within 3 dB of the background, but this should be possible. If such techniques could cope with higher interference levels, then even less data would need to be discarded. The curves shown in Figures 2-13 should guide the design in that they show how much extra data could be obtained from a given effort to design systems to cope with higher interference levels.

Synthesis observations with a space array on the sunlit side of the Earth, shielded by the ionosphere from terrestrial interference, appear to be possible. For a lunar-based array this also means that solar interference should not prevent lunar-daytime observations.

FIGURE CAPTIONS

Figure 1a. A sample of ISEE-3 data at 1980 kHz. The first panel represents the phase between the Z-dipole and the ecliptic plane dipoles. The second panel, phi, is the direction of the source relative to the sun. The third panel describes the spin modulation depth of the signal, a measure of source size. The fourth panel is the logarithm (base 10) of the despun ecliptic-plane antenna temperatures and of the Z-dipole temperature.

Figure 1b. A sample of 1000 kHz data. The format is identical to Figure 1a.

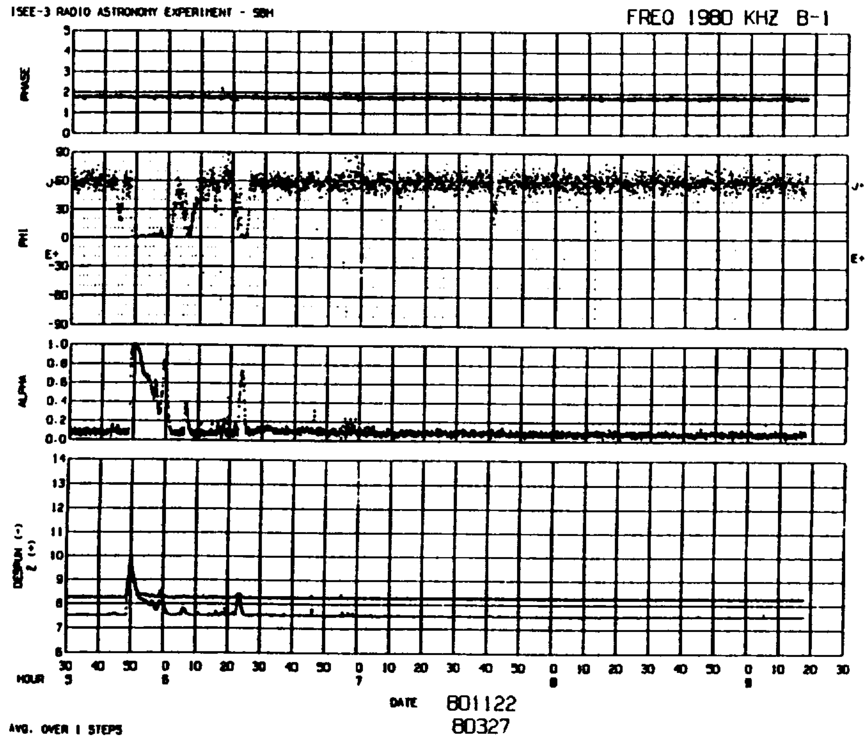
Figure 1c. A sample of 513 kHz data. The format is identical to Figure 1a.

Figure 1d. A grey scale plot of the data shown in Figures 1a-c. A Type III burst at 0550 UT is clearly visible.

Figure 2a. The percentage of time that the antenna temperature exceeded different levels in the "Low" range from $10^{7.3}$ K to $10^{8.3}$ K during the time interval from 1978:228 to 1978:365. The heaviest line (which is highest at Log_{10}(AntTemp) = 8.3) represents the data for 513 kHz. The next heaviest line represents the 1000 kHz data and the solar pointing data converges with it. The lightest line (which is lowest at Log_{10}(AntTemp) = 8.3) shows the 1980 kHz data.

Figure 2b. The same as Figure 2a for the "High" antenna temperature range from 10^{7} K to 10^{15} K.

Figures 3-14. Pairs of figure the same as Figures 2a and 2b except for different (later) time intervals.



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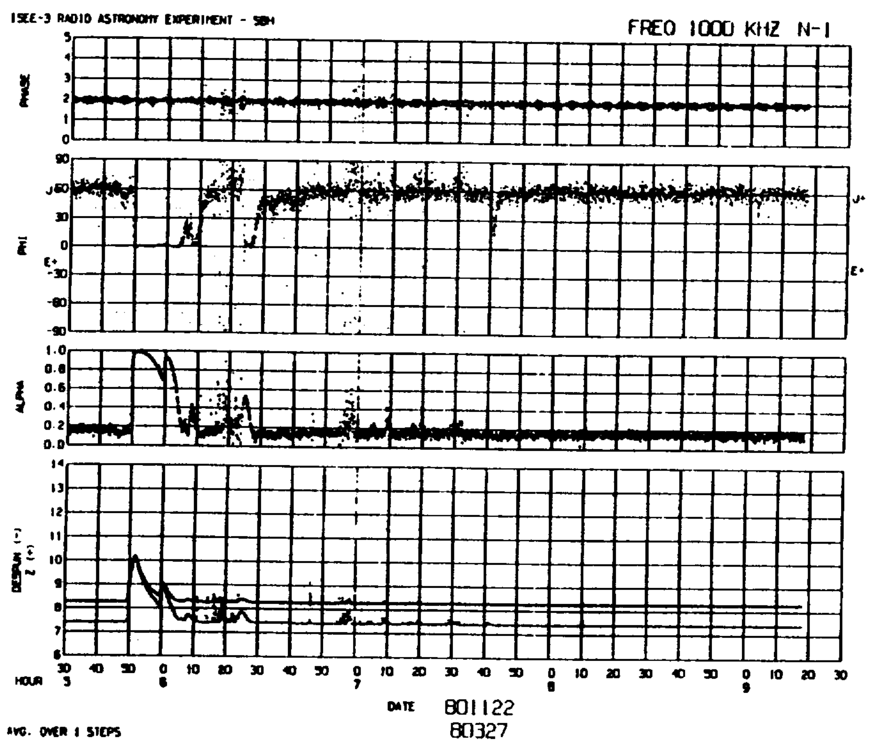
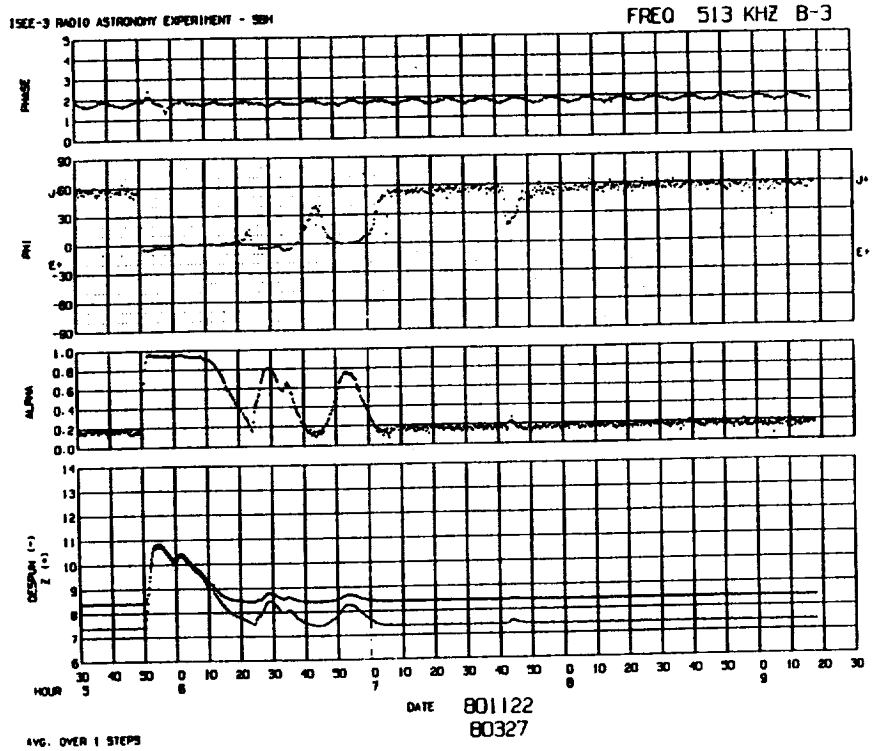


Figure 1b.



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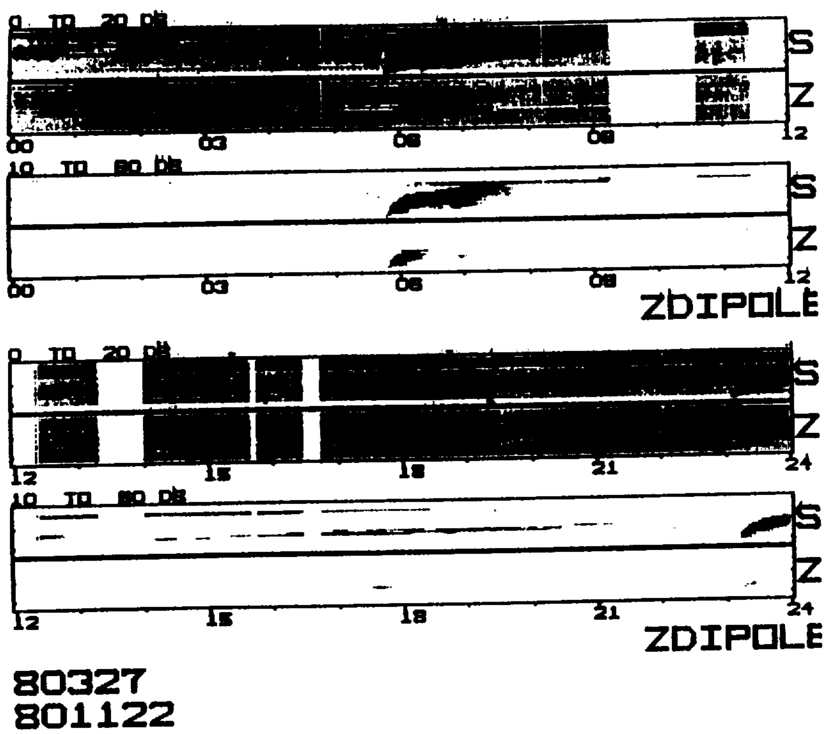

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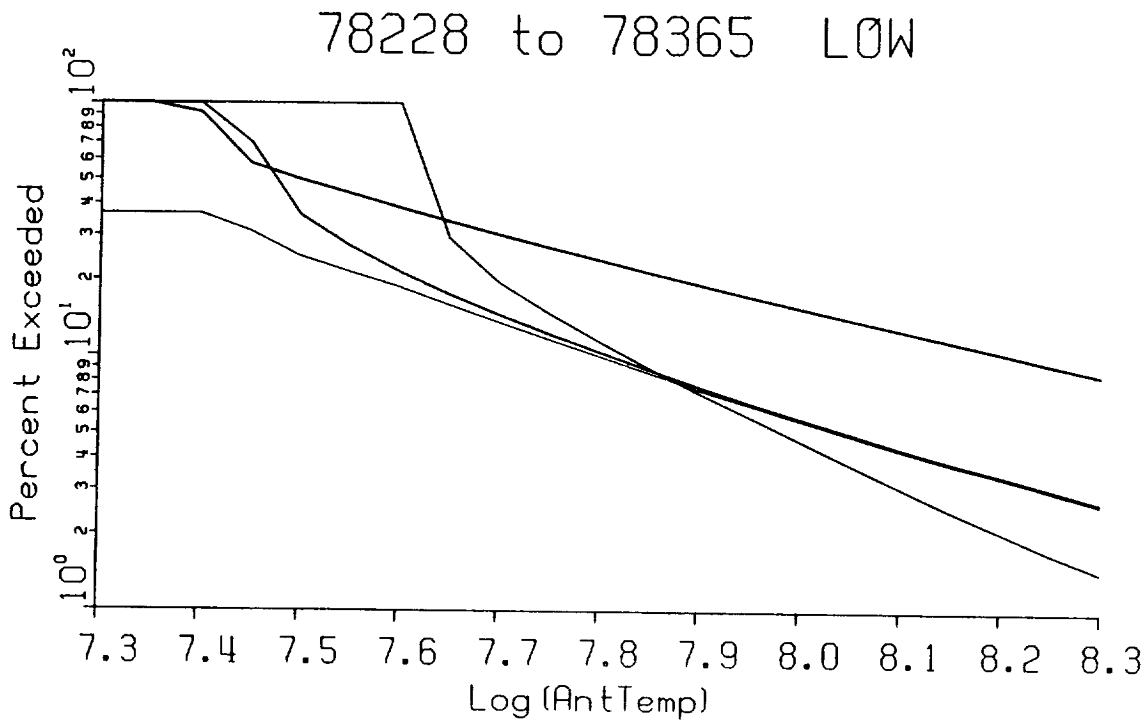


Figure 2a.

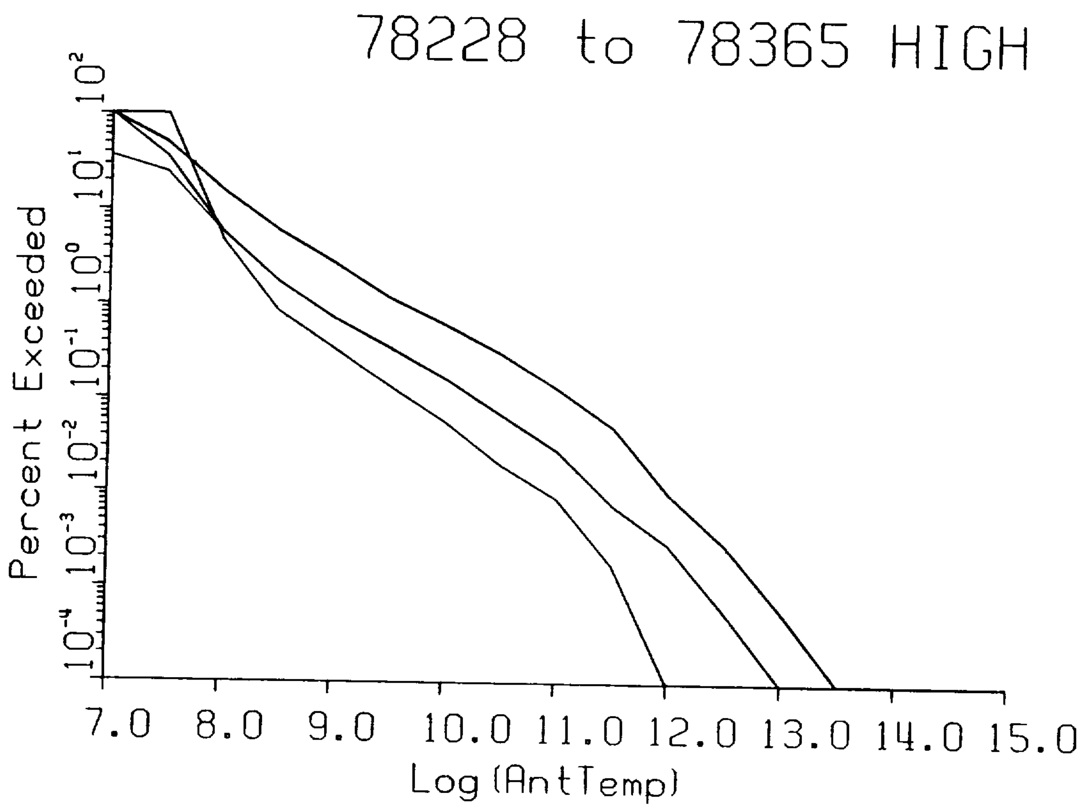
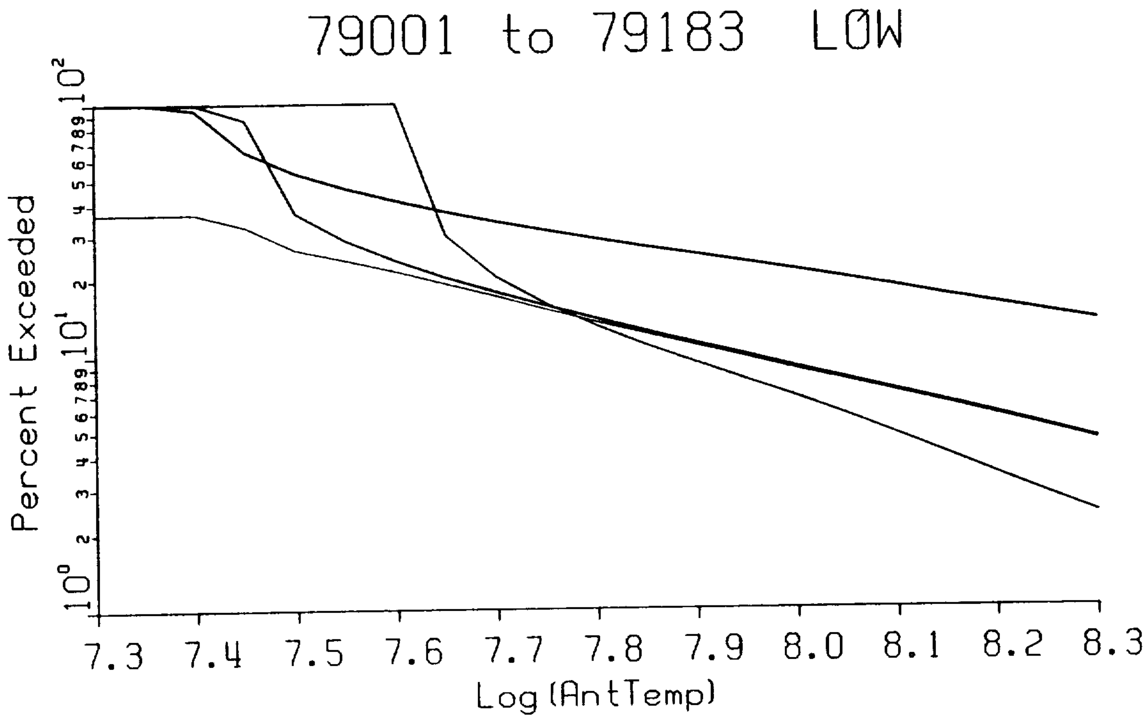


Figure 2b.



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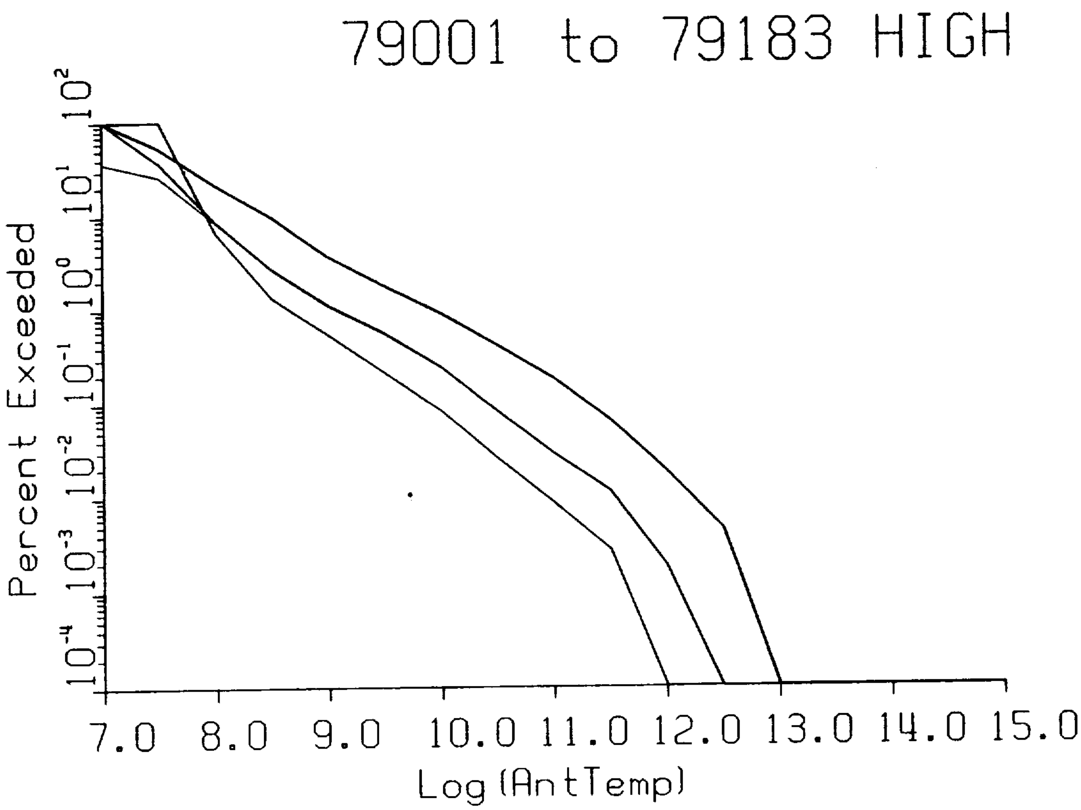
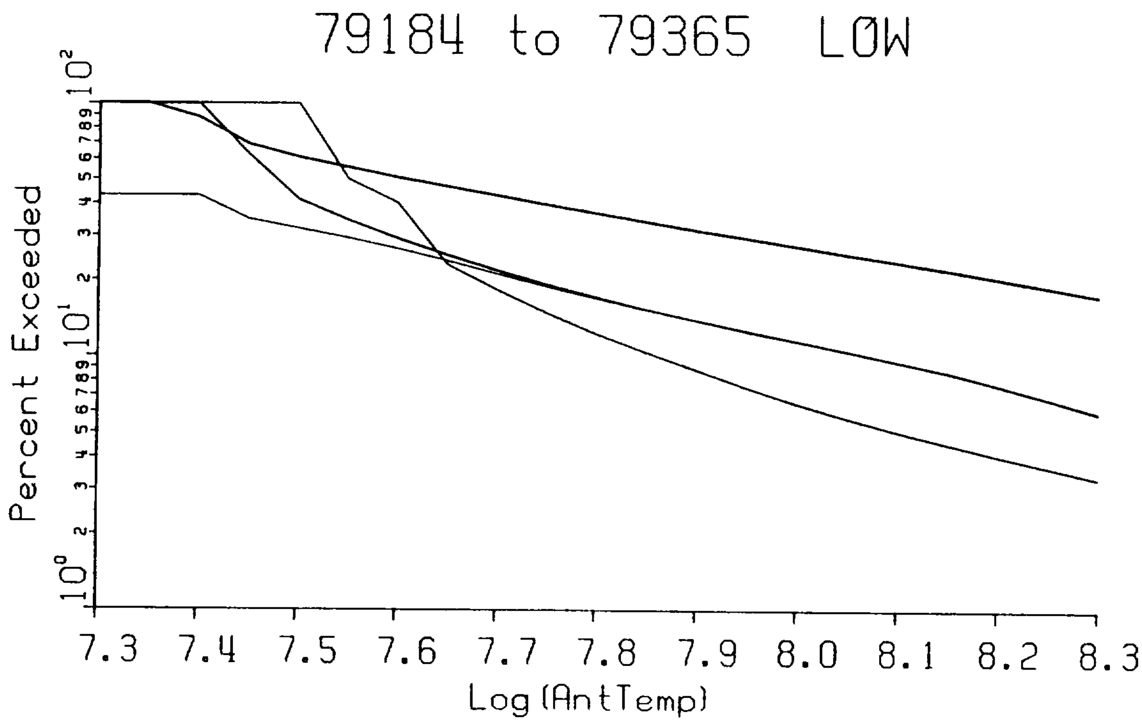


Figure 3b.



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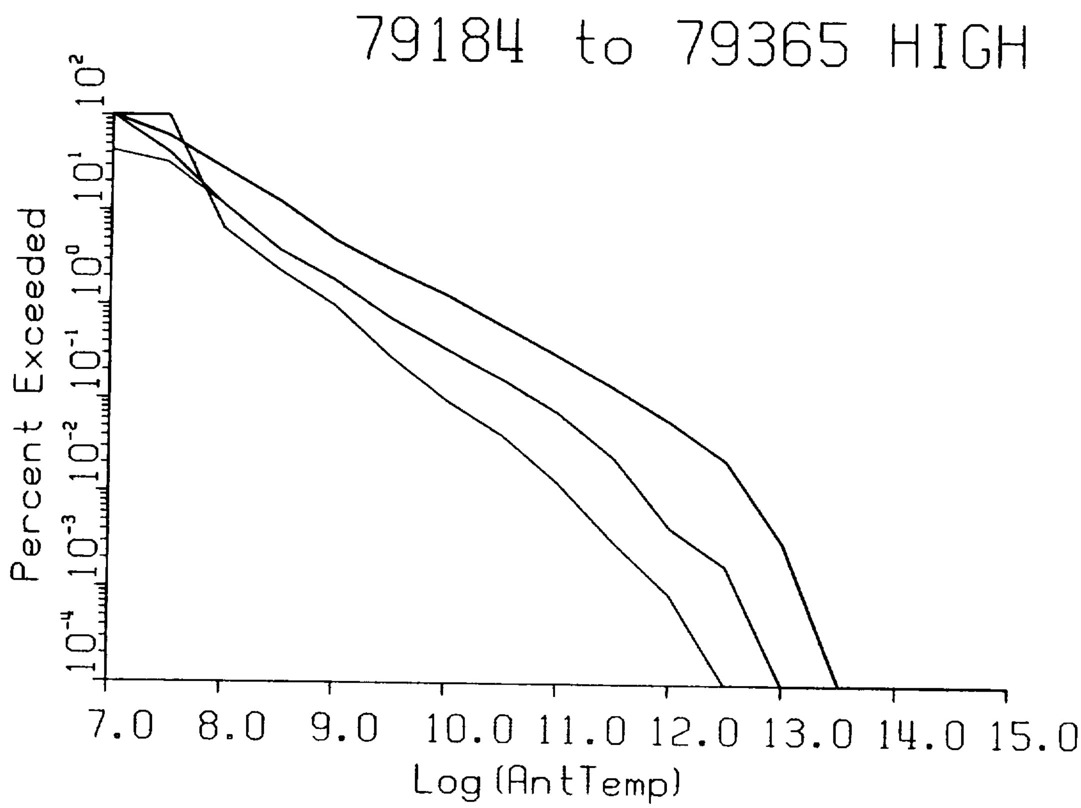

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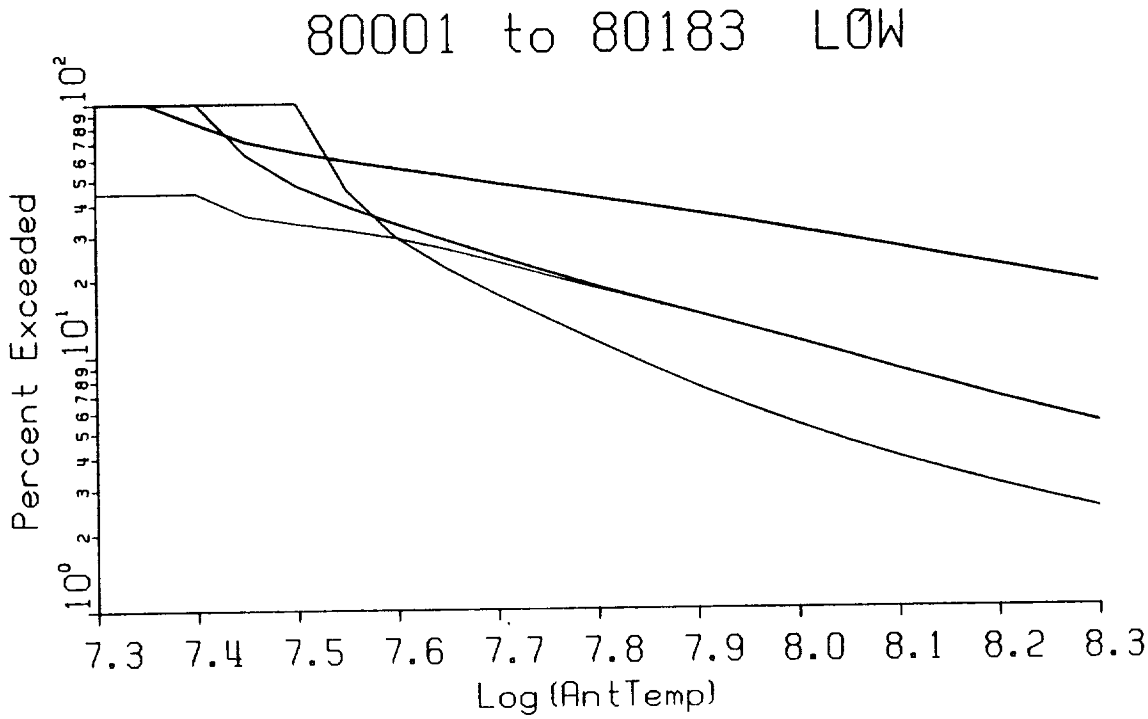

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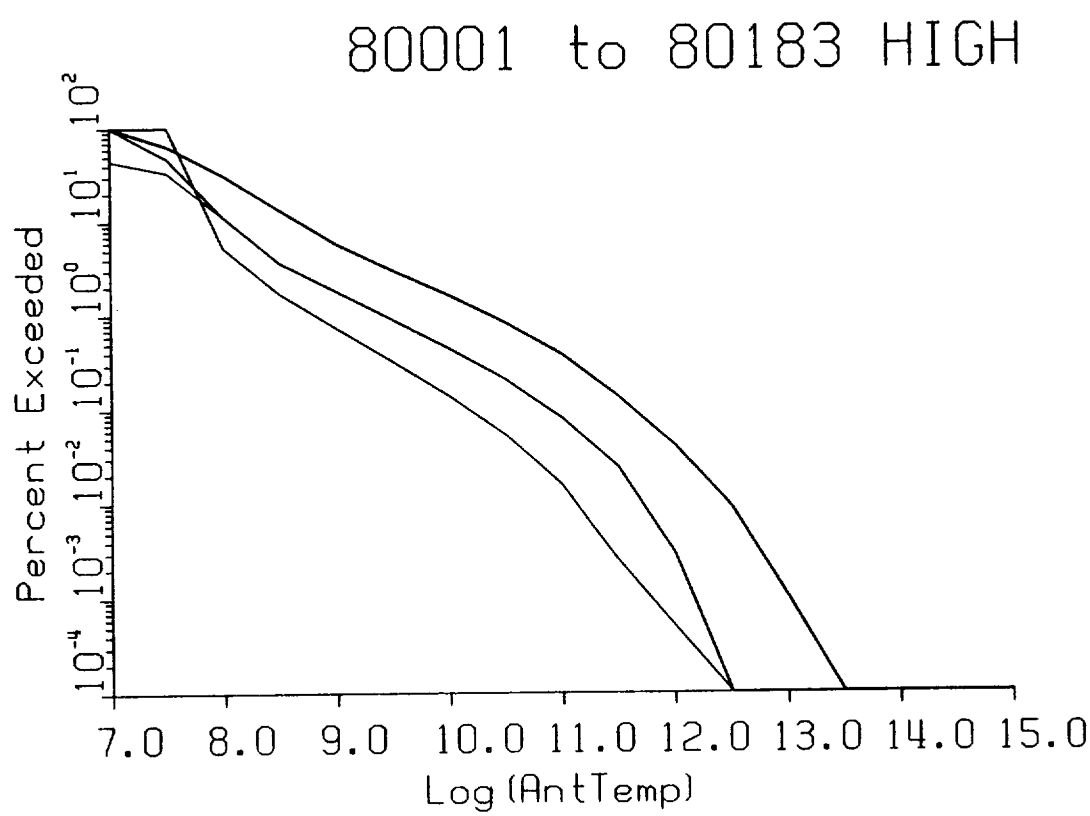

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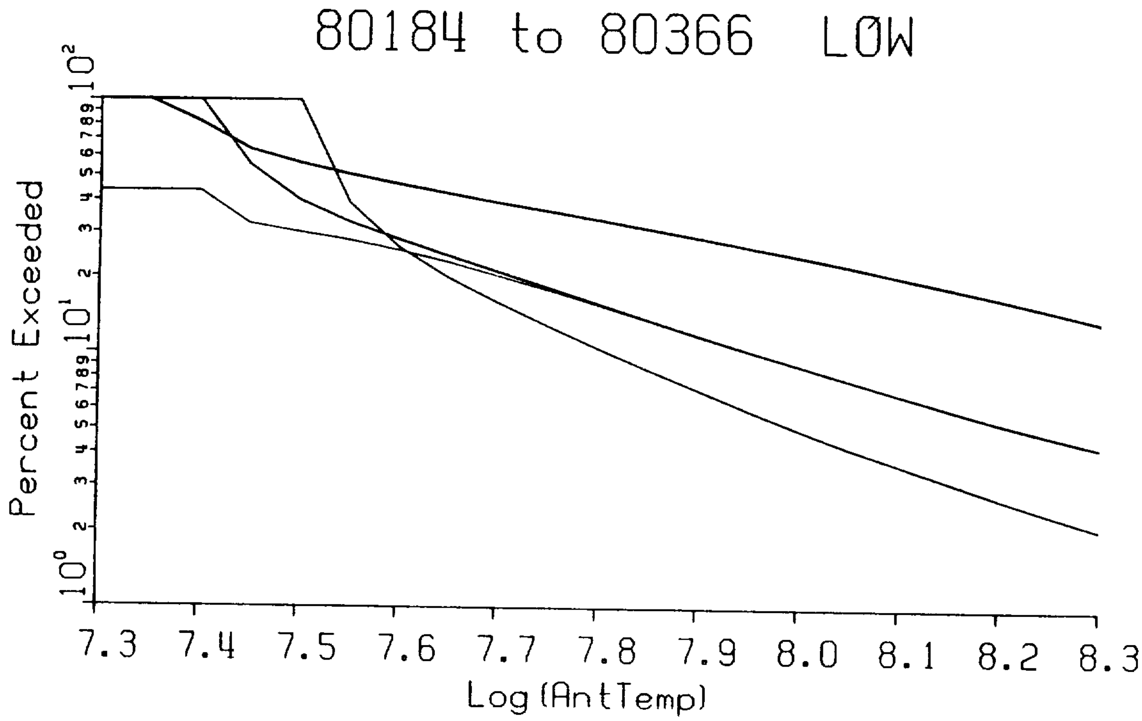

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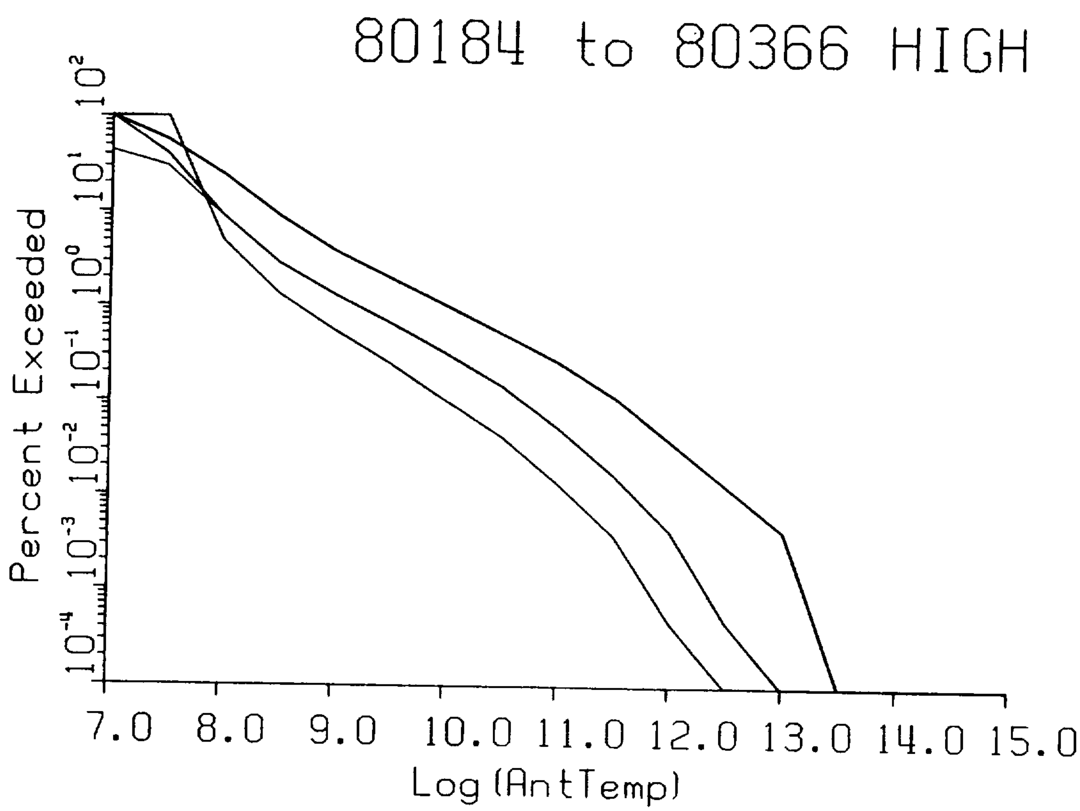

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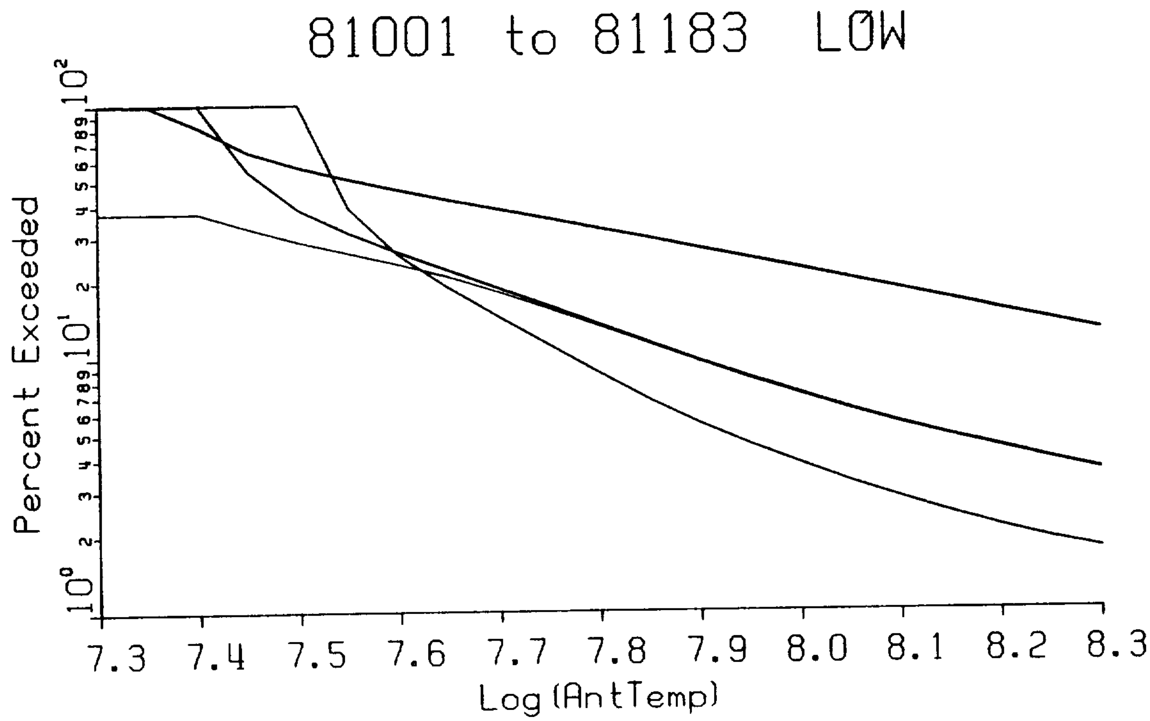

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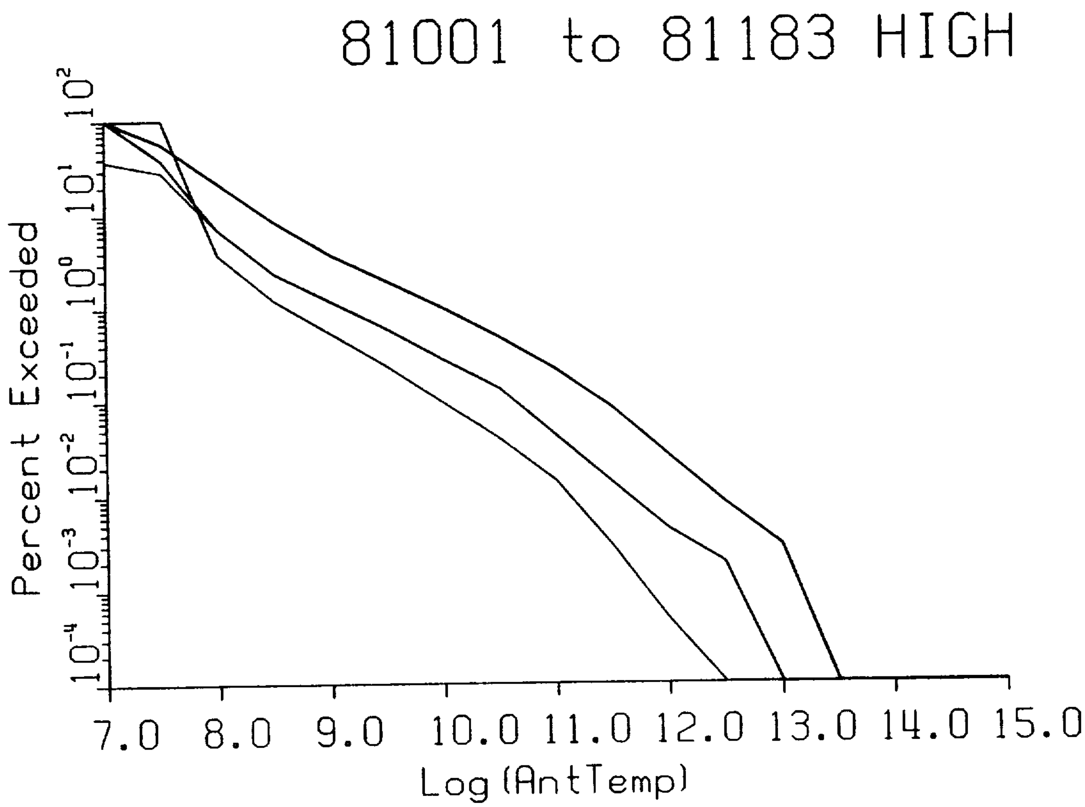

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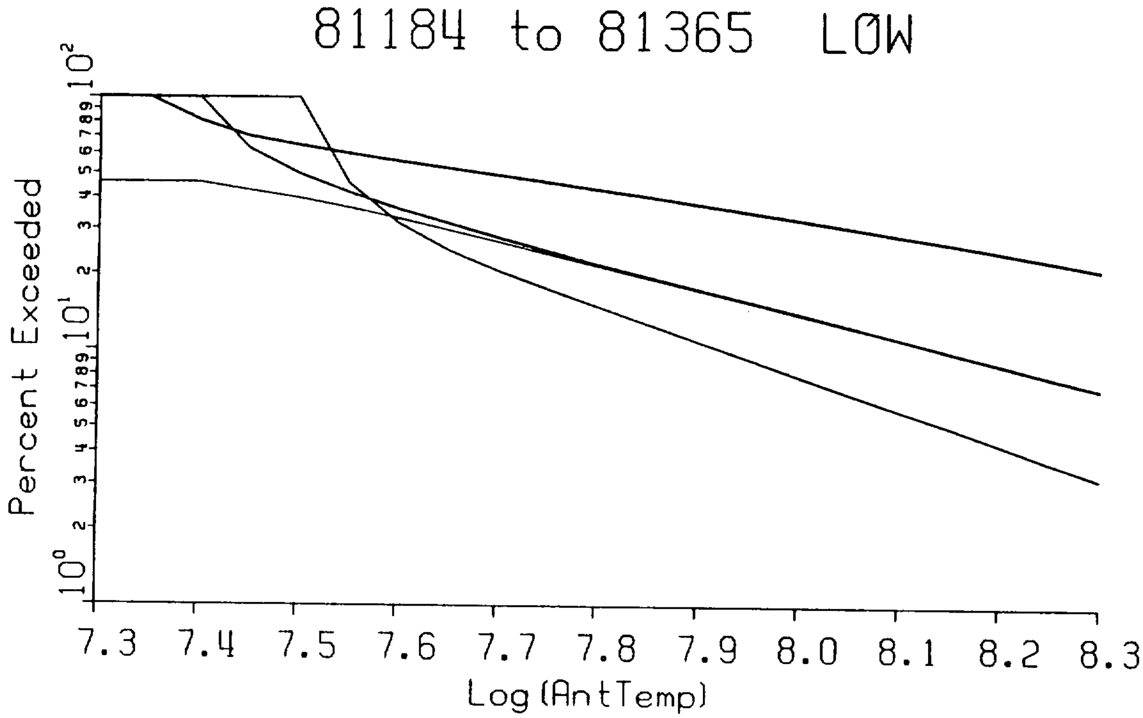

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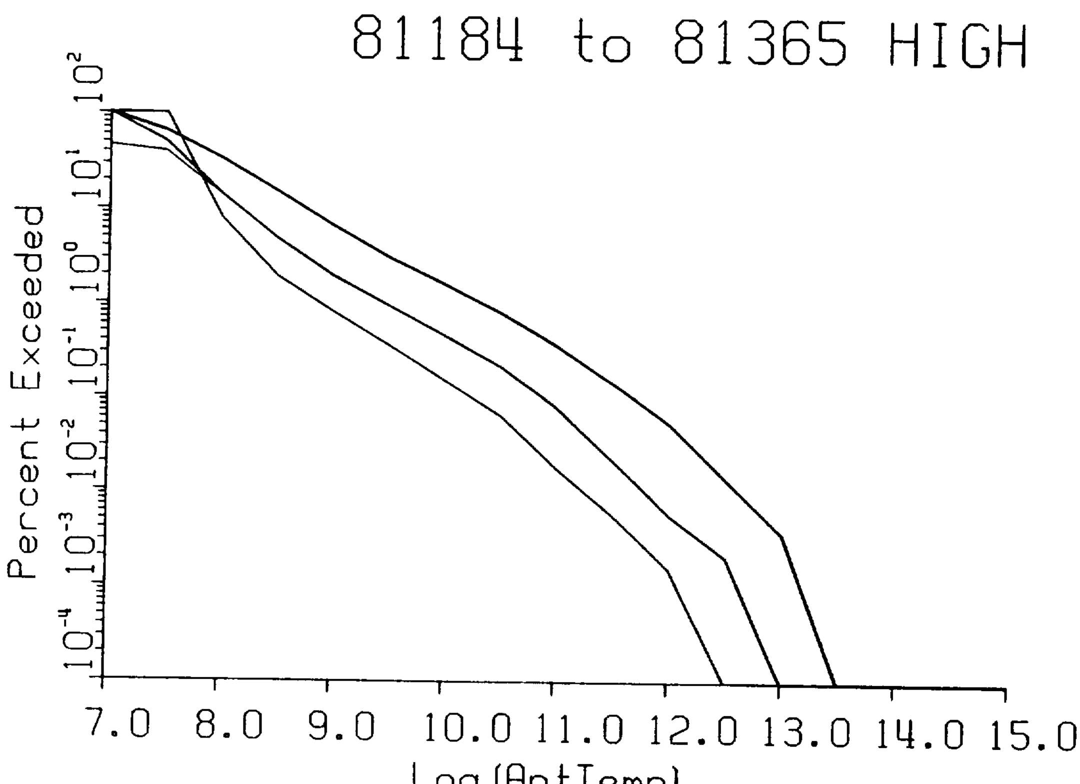

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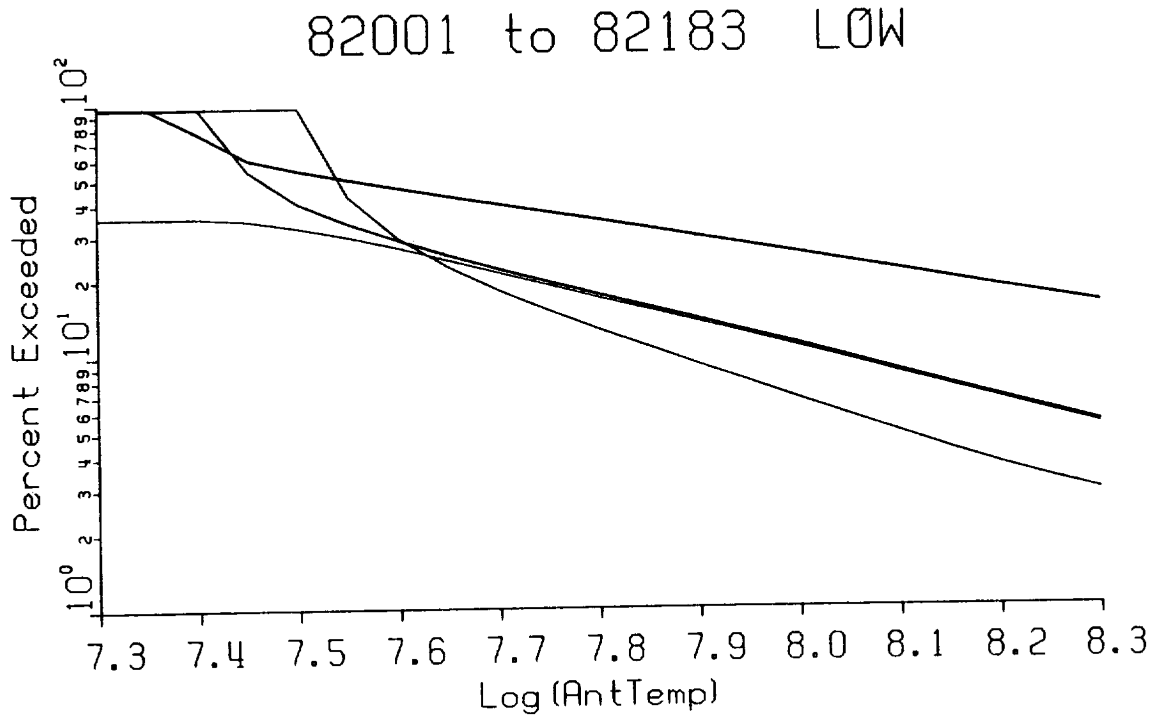

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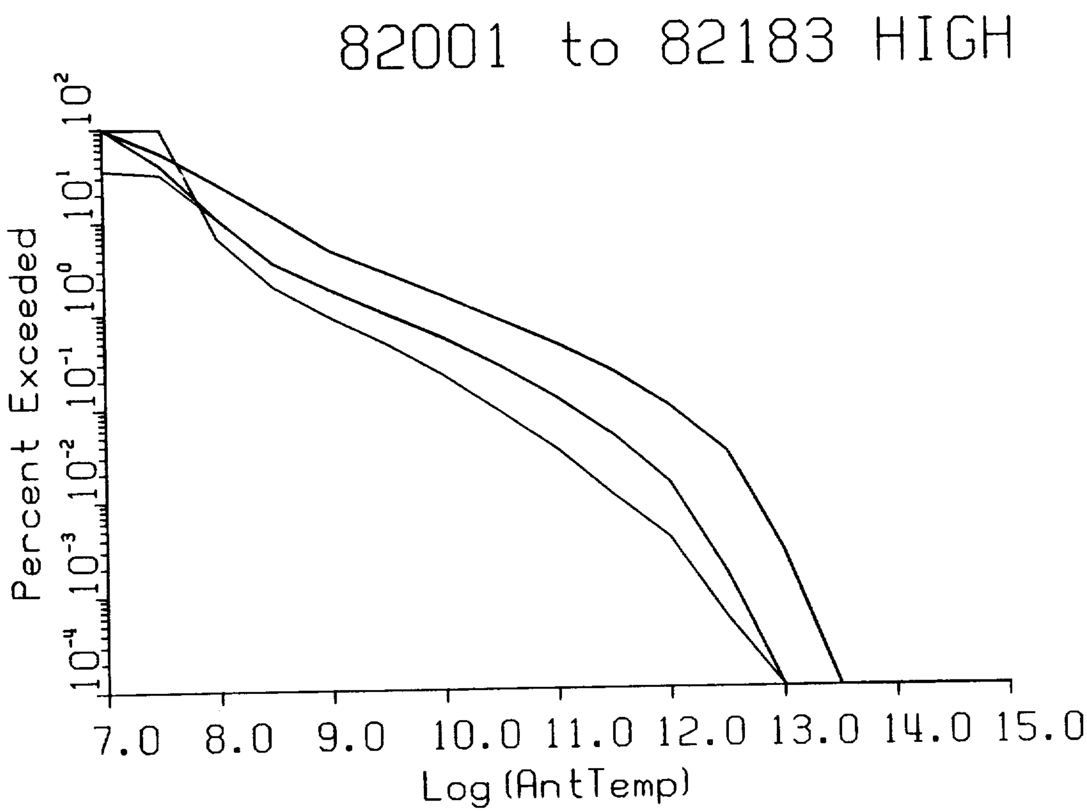

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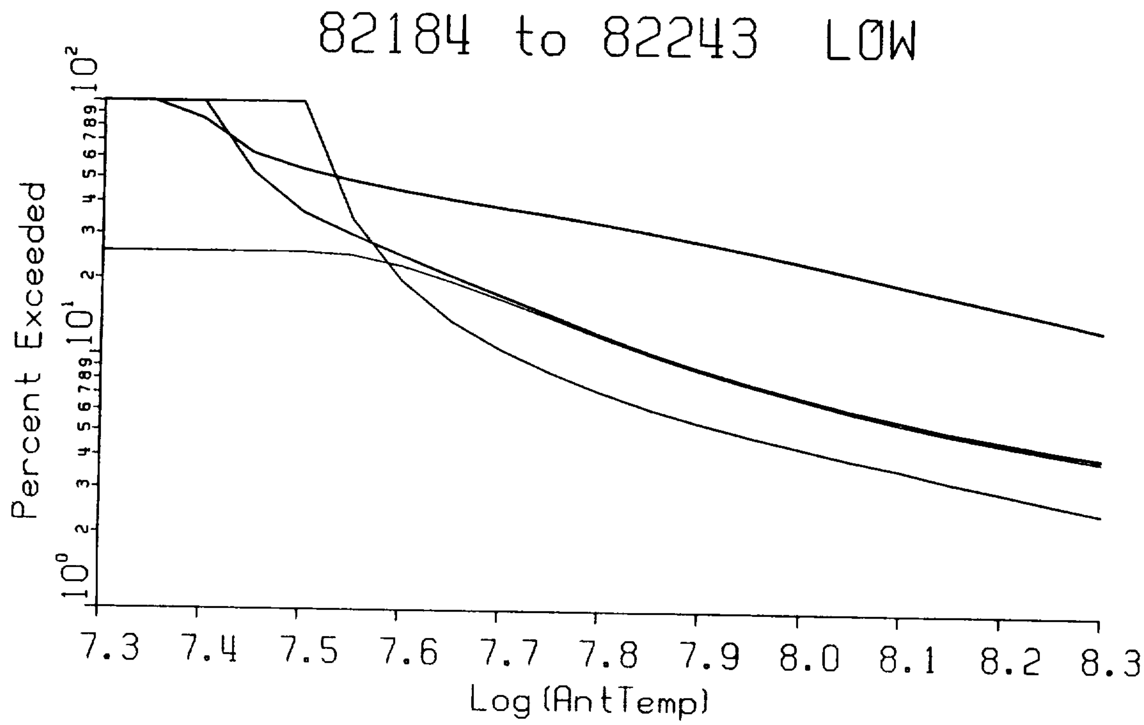

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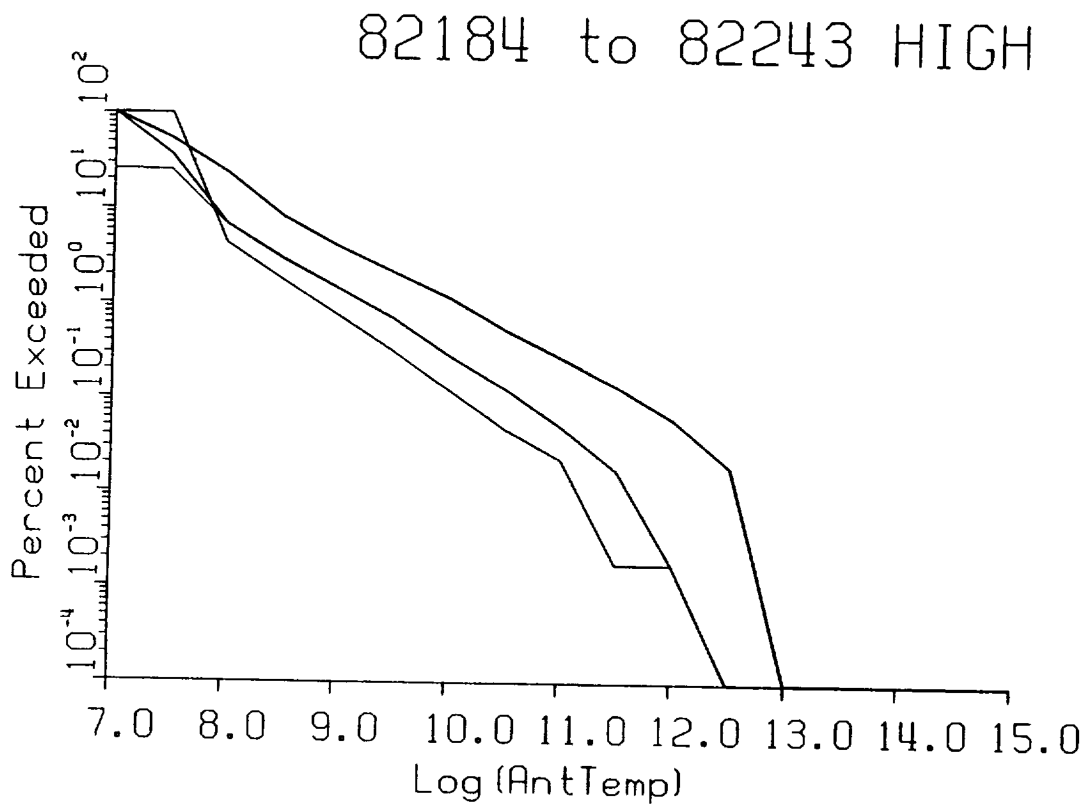

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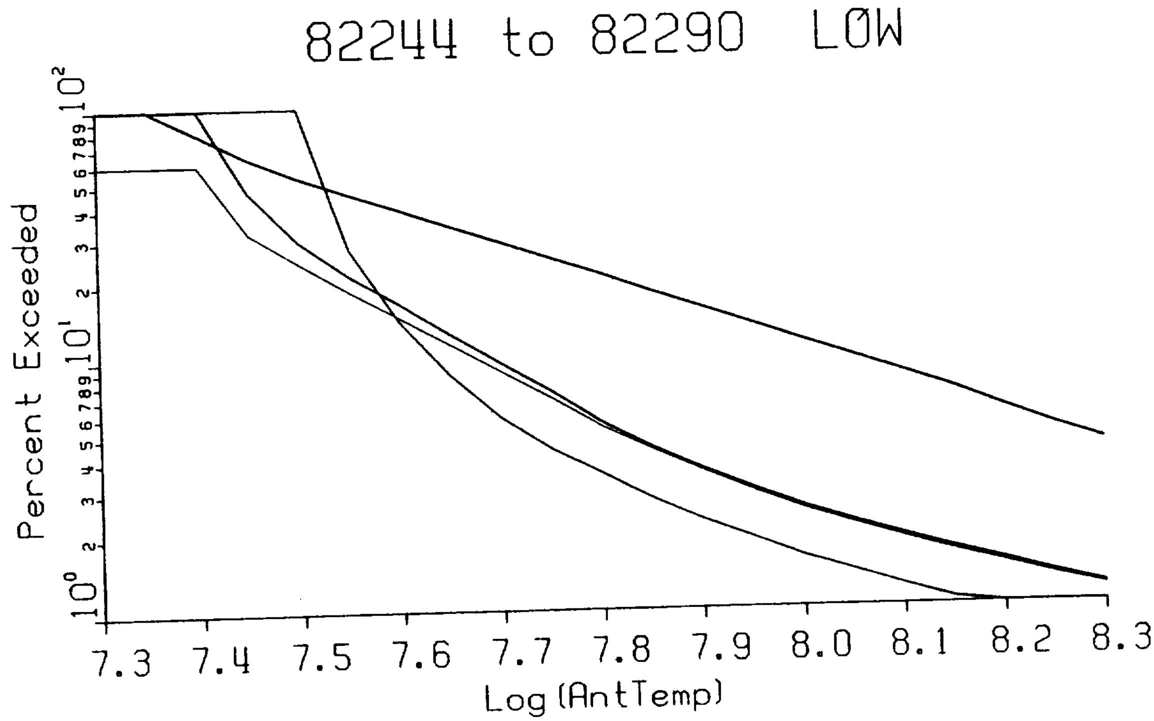

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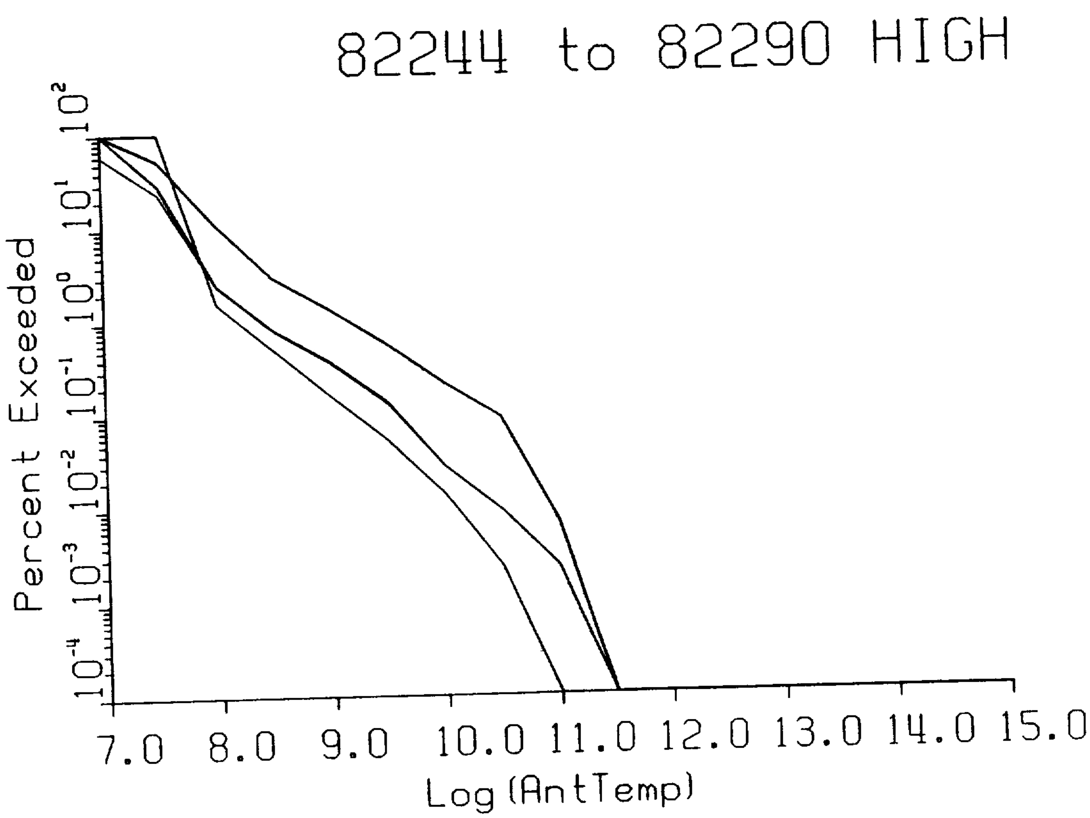

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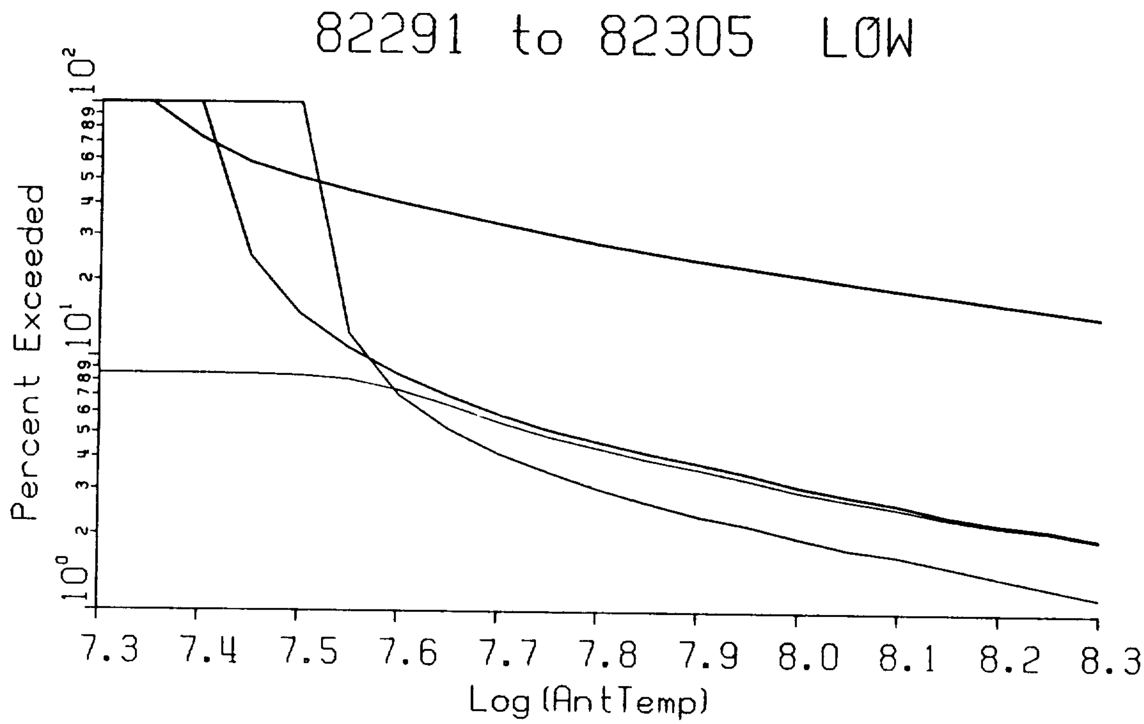

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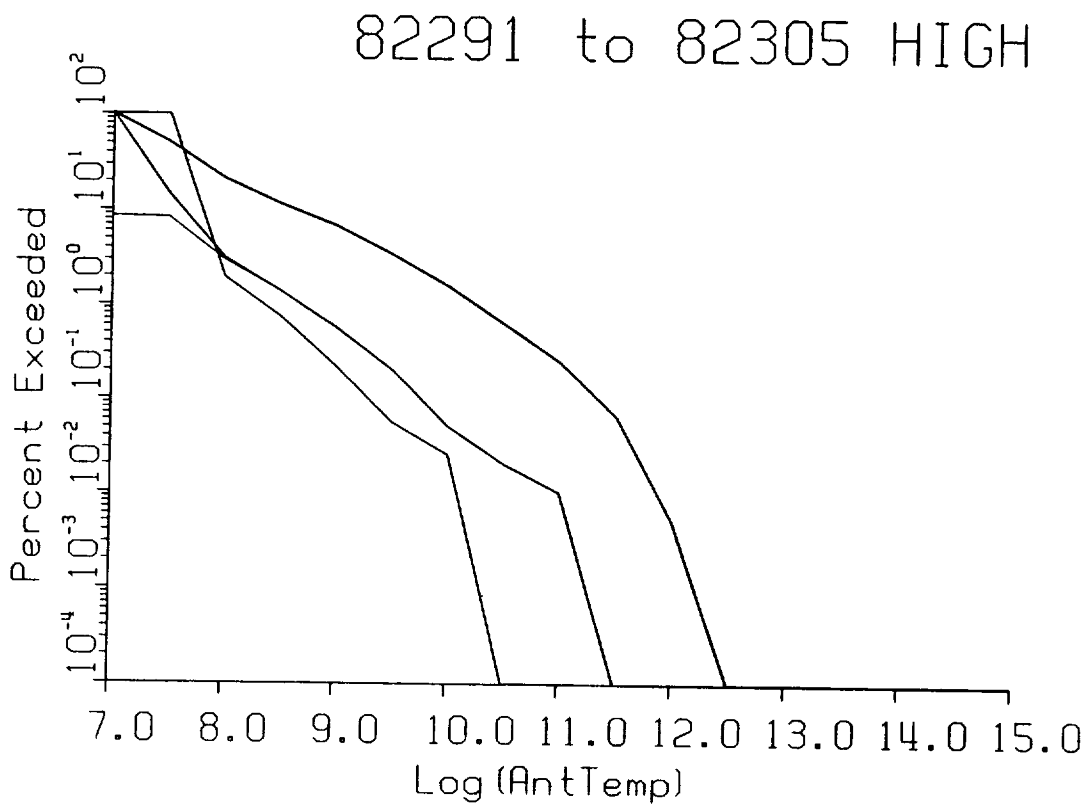

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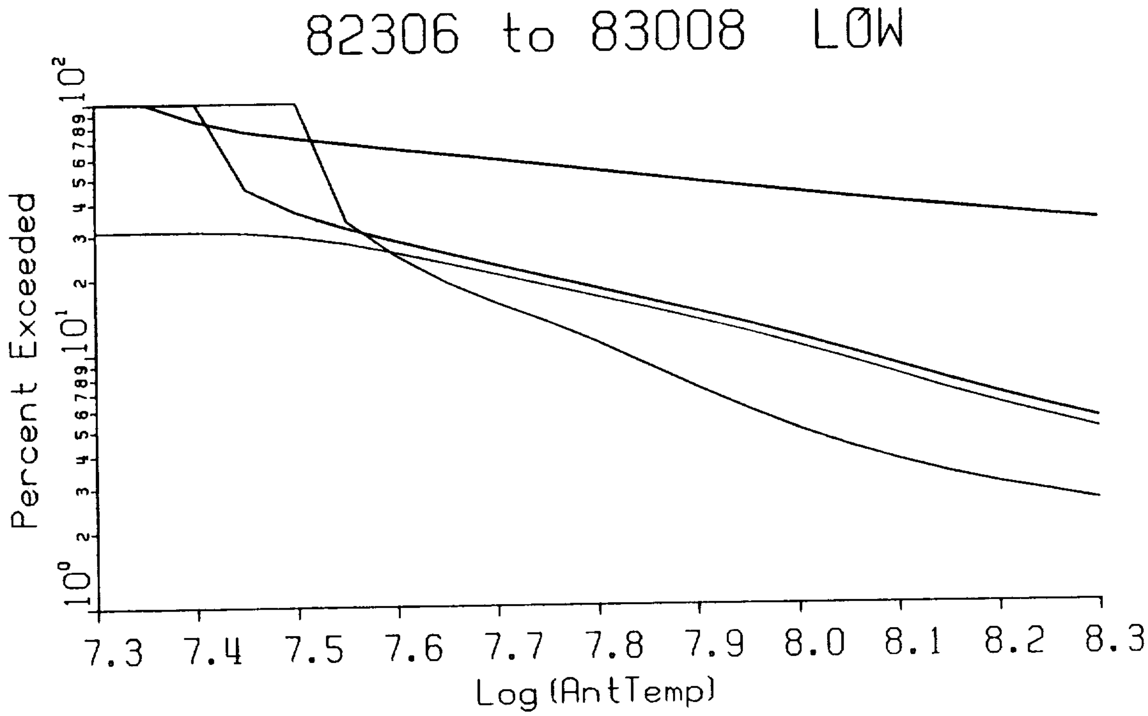

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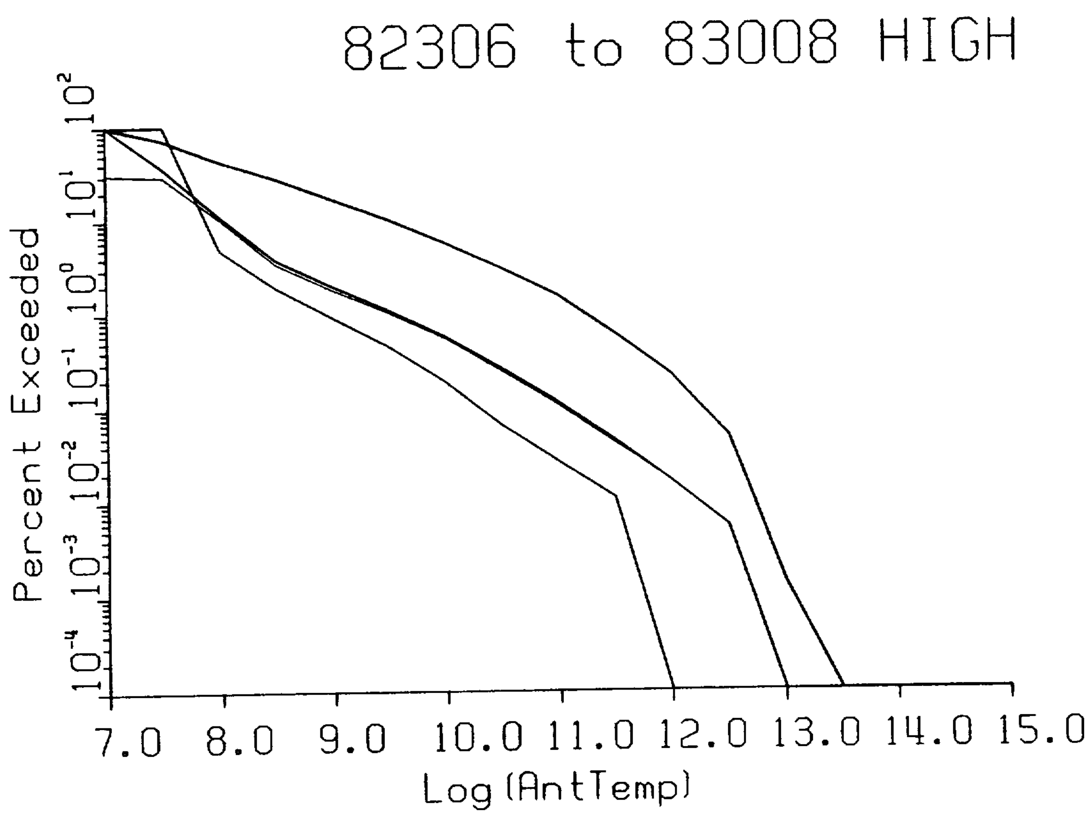

Figure 13b.

APPENDIX

TABLES OF ANTENNA TEMPERATURE STATISTICS

Each page gives the data employed to form the histograms of Figures 2-13 for given intervals of time. The time interval is given in the first line. The "Number of points" are the total number of 90-second observations at each frequency during the interval and the "Total observation times" are the total times of observation in seconds (90 x Number of points). The "Maxima" are the maximum antenna temperatures recorded during the whole interval. Columns of numbers under each frequency give the number of observations in which a given antenna temperature was exceeded. These numbers fall by 30 to 70% within ≤ 1 dB of the background temperature at any frequency. The background temperature is relatively independent of frequency in this range and runs from $\sim 10^{7.35}$ K at 513 kHz to $\sim 10^{7.50}$ K at 1980 kHz. A recalibration results in a small variation of these measured background temperatures before and after 1979.5.

The column labeled "Solar" gives the number of observations in which the ecliptic longitude of the source at 1000 kHz appeared to be within $\pm 10°$ of the Sun. Note that this direction finding was done with a dipole antenna which could not distinguish between the solar and anti-solar direction. The direction finding tends to place the source of Galactic emission at the Galactic Center. Emission more than about 3 dB above the background appears to be of solar origin in almost all cases. A few of the bursts could be of Jovian origin but they are not statistically significant and they have not been studied in detail.

The first 21 lines of data represent the numbers for the "Low" range of antenna temperatures and the next 21 lines represent the "High" range.

Histograms for 78228 to 78365

	1980 kHz	1000 kHz	513 kHz	Solar
Number of points	172315	172310	172299	
Total observation times	15508350	15507900	15506910	
Maxima	11.85	12.66	13.09	
Log(AntTemp) 7.30	172296	172224	172218	63072
Log(AntTemp) 7.35	172292	172209	172209	63068
Log(AntTemp) 7.40	172274	172179	157680	63066
Log(AntTemp) 7.45	172256	120451	99212	53702
Log(AntTemp) 7.50	172225	62209	85732	42846
Log(AntTemp) 7.55	172079	46838	75442	37066
Log(AntTemp) 7.60	171999	37296	66549	32437
Log(AntTemp) 7.65	50603	30402	58928	27655
Log(AntTemp) 7.70	33884	25308	52260	23623
Log(AntTemp) 7.75	25609	21310	46530	20218
Log(AntTemp) 7.80	19865	18116	41591	17399
Log(AntTemp) 7.85	15672	15490	37239	15011
Log(AntTemp) 7.90	12550	13257	33468	12928
Log(AntTemp) 7.95	10134	11485	30065	11248
Log(AntTemp) 8.00	8199	10005	27087	9810
Log(AntTemp) 8.05	6601	8740	24437	8583
Log(AntTemp) 8.10	5374	7626	22081	7493
Log(AntTemp) 8.15	4384	6732	19982	6617
Log(AntTemp) 8.20	3612	6025	18105	5921
Log(AntTemp) 8.25	2966	5340	16324	5247
Log(AntTemp) 8.30	2495	4719	14763	4641
Log(AntTemp) 7.00	172314	172289	172270	63094
Log(AntTemp) 7.50	172225	62209	85732	42846
Log(AntTemp) 8.00	8199	10005	27087	9810
Log(AntTemp) 8.50	1472	3068	10384	3020
Log(AntTemp) 9.00	593	1259	4810	1239
Log(AntTemp) 9.50	237	613	2052	603
Log(AntTemp) 10.00	98	285	1065	281
Log(AntTemp) 10.50	34	119	526	117
Log(AntTemp) 11.00	15	49	224	48
Log(AntTemp) 11.50	3	13	88	13
Log(AntTemp) 12.00	0	5	17	5
Log(AntTemp) 12.50	0	1	5	1
Log(AntTemp) 13.00	0	0	1	0
Log(AntTemp) 13.50	0	0	0	0
Log(AntTemp) 14.00	0	0	0	0
Log(AntTemp) 14.50	0	0	0	0
Log(AntTemp) 15.00	0	0	0	0
Log(AntTemp) 15.50	0	0	0	0
Log(AntTemp) 16.00	0	0	0	0
Log(AntTemp) 16.50	0	0	0	0
Log(AntTemp) 17.00	0	0	0	0

Histograms for 79001 to 79183

		1980 kHz	1000 kHz	513 kHz	Solar
Number of points		219011	219010	218999	
Total observation times		19710990	19710900	19709910	
Maxima		11.99	12.30	12.98	
Log(AntTemp)	7.30	219011	219010	218999	80347
Log(AntTemp)	7.35	219011	219010	218999	80347
Log(AntTemp)	7.40	219010	219010	207599	80347
Log(AntTemp)	7.45	219009	190061	141718	71401
Log(AntTemp)	7.50	219006	80887	116485	57661
Log(AntTemp)	7.55	219004	62611	101371	52330
Log(AntTemp)	7.60	218996	52076	90214	47209
Log(AntTemp)	7.65	65609	44594	81387	42104
Log(AntTemp)	7.70	44694	38934	74242	37408
Log(AntTemp)	7.75	34799	34273	68225	33185
Log(AntTemp)	7.80	28532	30426	62965	29588
Log(AntTemp)	7.85	23853	27194	58357	26508
Log(AntTemp)	7.90	20246	24320	54345	23764
Log(AntTemp)	7.95	17251	21783	50513	21321
Log(AntTemp)	8.00	14744	19446	46962	19038
Log(AntTemp)	8.05	12440	17473	43562	17119
Log(AntTemp)	8.10	10443	15698	40286	15386
Log(AntTemp)	8.15	8716	14113	37087	13841
Log(AntTemp)	8.20	7241	12617	34274	12386
Log(AntTemp)	8.25	6084	11252	31734	11058
Log(AntTemp)	8.30	5109	9983	29420	9812
Log(AntTemp)	7.00	219011	219010	218999	80347
Log(AntTemp)	7.50	219006	80887	116485	57661
Log(AntTemp)	8.00	14744	19446	46962	19038
Log(AntTemp)	8.50	2916	5968	21556	5857
Log(AntTemp)	9.00	1180	2439	8032	2386
Log(AntTemp)	9.50	469	1222	3855	1203
Log(AntTemp)	10.00	182	535	1960	528
Log(AntTemp)	10.50	56	182	897	179
Log(AntTemp)	11.00	19	63	402	63
Log(AntTemp)	11.50	6	25	142	25
Log(AntTemp)	12.00	0	4	40	4
Log(AntTemp)	12.50	0	0	10	0
Log(AntTemp)	13.00	0	0	0	0
Log(AntTemp)	13.50	0	0	0	0
Log(AntTemp)	14.00	0	0	0	0
Log(AntTemp)	14.50	0	0	0	0
Log(AntTemp)	15.00	0	0	0	0
Log(AntTemp)	15.50	0	0	0	0
Log(AntTemp)	16.00	0	0	0	0
Log(AntTemp)	16.50	0	0	0	0
Log(AntTemp)	17.00	0	0	0	0

Histograms for 79184 to 79365

	1980 kHz	1000 kHz	513 kHz	Solar
Number of points	225319	225319	225315	
Total observation times	20278710	20278710	20278350	
Maxima	12.30	12.97	13.15	
Log(AntTemp) 7.30	225319	225319	225315	96792
Log(AntTemp) 7.35	225319	225319	225315	96792
Log(AntTemp) 7.40	225319	225318	198098	96791
Log(AntTemp) 7.45	225319	141040	154900	78573
Log(AntTemp) 7.50	225315	93486	137473	72088
Log(AntTemp) 7.55	112389	77845	125032	66212
Log(AntTemp) 7.60	90886	66089	114195	60250
Log(AntTemp) 7.65	52098	56857	105230	54131
Log(AntTemp) 7.70	41451	49473	97134	48066
Log(AntTemp) 7.75	33646	43541	89708	42842
Log(AntTemp) 7.80	27764	38783	82999	38411
Log(AntTemp) 7.85	23401	34806	76900	34579
Log(AntTemp) 7.90	19963	31481	71342	31310
Log(AntTemp) 7.95	17028	28550	66378	28406
Log(AntTemp) 8.00	14697	26085	61775	25961
Log(AntTemp) 8.05	12918	23803	57575	23698
Log(AntTemp) 8.10	11478	21639	53664	21540
Log(AntTemp) 8.15	10274	19635	49920	19546
Log(AntTemp) 8.20	9229	17503	46236	17421
Log(AntTemp) 8.25	8351	15471	42823	15397
Log(AntTemp) 8.30	7529	13618	39507	13550
Log(AntTemp) 7.00	225319	225319	225315	96792
Log(AntTemp) 7.50	225315	93486	137473	72088
Log(AntTemp) 8.00	14697	26085	61775	25961
Log(AntTemp) 8.50	5325	8800	28649	8748
Log(AntTemp) 9.00	2241	4212	11068	4182
Log(AntTemp) 9.50	637	1666	5515	1655
Log(AntTemp) 10.00	221	775	2925	770
Log(AntTemp) 10.50	93	374	1396	373
Log(AntTemp) 11.00	29	166	665	166
Log(AntTemp) 11.50	7	54	306	54
Log(AntTemp) 12.00	2	10	134	10
Log(AntTemp) 12.50	0	4	51	4
Log(AntTemp) 13.00	0	0	7	0
Log(AntTemp) 13.50	0	0	0	0
Log(AntTemp) 14.00	0	0	0	0
Log(AntTemp) 14.50	0	0	0	0
Log(AntTemp) 15.00	0	0	0	0
Log(AntTemp) 15.50	0	0	0	0
Log(AntTemp) 16.00	0	0	0	0
Log(AntTemp) 16.50	0	0	0	0
Log(AntTemp) 17.00	0	0	0	0

Histograms for 80001 to 80183

		1980 kHz	1000 kHz	513 kHz	Solar
Number of points		201631	201630	201625	
Total observation times		18146790	18146700	18146250	
Maxima		12.12	12.32	13.02	
Log(AntTemp)	7.30	201631	201629	201625	89580
Log(AntTemp)	7.35	201631	201629	201462	89580
Log(AntTemp)	7.40	201631	201629	168357	89580
Log(AntTemp)	7.45	201630	126400	142015	72812
Log(AntTemp)	7.50	201629	95639	129001	67678
Log(AntTemp)	7.55	91799	79207	119392	63858
Log(AntTemp)	7.60	59390	67370	111098	59046
Log(AntTemp)	7.65	44429	57695	103649	53225
Log(AntTemp)	7.70	34947	49743	96648	47294
Log(AntTemp)	7.75	28038	43061	90324	41682
Log(AntTemp)	7.80	22635	37605	84355	36784
Log(AntTemp)	7.85	18382	33097	78755	32665
Log(AntTemp)	7.90	15084	29237	73252	29005
Log(AntTemp)	7.95	12546	25817	67935	25668
Log(AntTemp)	8.00	10602	22729	62638	22629
Log(AntTemp)	8.05	9057	19957	57638	19876
Log(AntTemp)	8.10	7852	17454	52933	17393
Log(AntTemp)	8.15	6907	15342	48570	15298
Log(AntTemp)	8.20	6119	13498	44752	13464
Log(AntTemp)	8.25	5476	11942	41201	11916
Log(AntTemp)	8.30	4917	10670	37900	10648
Log(AntTemp)	7.00	201631	201630	201625	89580
Log(AntTemp)	7.50	201629	95639	129001	67678
Log(AntTemp)	8.00	10602	22729	62638	22629
Log(AntTemp)	8.50	3396	7314	26956	7298
Log(AntTemp)	9.00	1473	3599	11601	3590
Log(AntTemp)	9.50	648	1798	6014	1792
Log(AntTemp)	10.00	281	889	3238	886
Log(AntTemp)	10.50	106	415	1648	414
Log(AntTemp)	11.00	31	161	755	161
Log(AntTemp)	11.50	5	48	275	48
Log(AntTemp)	12.00	1	6	81	6
Log(AntTemp)	12.50	0	0	18	0
Log(AntTemp)	13.00	0	0	2	0
Log(AntTemp)	13.50	0	0	0	0
Log(AntTemp)	14.00	0	0	0	0
Log(AntTemp)	14.50	0	0	0	0
Log(AntTemp)	15.00	0	0	0	0
Log(AntTemp)	15.50	0	0	0	0
Log(AntTemp)	16.00	0	0	0	0
Log(AntTemp)	16.50	0	0	0	0
Log(AntTemp)	17.00	0	0	0	0

Histograms for 80184 to 80366

		1980 kHz	1000 kHz	513 kHz	Solar
Number of points		206136	206136	206135	
Total observation times		18552240	18552240	18552150	
Maxima		12.40	12.60	13.15	
Log(AntTemp)	7.30	206136	206136	206135	89827
Log(AntTemp)	7.35	206136	206136	206104	89827
Log(AntTemp)	7.40	206136	206097	167690	89824
Log(AntTemp)	7.45	206136	114082	131189	66874
Log(AntTemp)	7.50	206110	83032	115779	62097
Log(AntTemp)	7.55	81001	68265	104975	57940
Log(AntTemp)	7.60	54288	58265	96138	52848
Log(AntTemp)	7.65	41334	50435	88612	47504
Log(AntTemp)	7.70	32939	43707	81834	42101
Log(AntTemp)	7.75	26613	37953	75917	37040
Log(AntTemp)	7.80	21791	32784	70294	32272
Log(AntTemp)	7.85	17984	28386	64957	28099
Log(AntTemp)	7.90	14928	24622	59931	24451
Log(AntTemp)	7.95	12408	21458	55123	21341
Log(AntTemp)	8.00	10413	18741	50618	18661
Log(AntTemp)	8.05	8838	16360	46275	16300
Log(AntTemp)	8.10	7622	14385	42122	14340
Log(AntTemp)	8.15	6597	12684	38441	12643
Log(AntTemp)	8.20	5691	11210	34830	11172
Log(AntTemp)	8.25	4954	10008	31422	9975
Log(AntTemp)	8.30	4322	9011	28246	8984
Log(AntTemp)	7.00	206136	206136	206135	89827
Log(AntTemp)	7.50	206110	83032	115779	62097
Log(AntTemp)	8.00	10413	18741	50618	18661
Log(AntTemp)	8.50	2798	6052	18868	6032
Log(AntTemp)	9.00	1141	2776	8156	2767
Log(AntTemp)	9.50	514	1376	4194	1370
Log(AntTemp)	10.00	213	662	2153	657
Log(AntTemp)	10.50	88	307	1082	305
Log(AntTemp)	11.00	28	110	540	109
Log(AntTemp)	11.50	8	35	237	35
Log(AntTemp)	12.00	1	9	80	9
Log(AntTemp)	12.50	0	1	27	1
Log(AntTemp)	13.00	0	0	9	0
Log(AntTemp)	13.50	0	0	0	0
Log(AntTemp)	14.00	0	0	0	0
Log(AntTemp)	14.50	0	0	0	0
Log(AntTemp)	15.00	0	0	0	0
Log(AntTemp)	15.50	0	0	0	0
Log(AntTemp)	16.00	0	0	0	0
Log(AntTemp)	16.50	0	0	0	0
Log(AntTemp)	17.00	0	0	0	0

Histograms for 81001 to 81183

	1980 kHz	1000 kHz	513 kHz	Solar
Number of points	206962	206962	206962	
Total observation times	18626580	18626580	18626580	
Maxima	12.05	12.74	13.14	
Log(AntTemp) 7.30	206962	206962	206962	77354
Log(AntTemp) 7.35	206962	206962	206002	77354
Log(AntTemp) 7.40	206962	206962	170187	77354
Log(AntTemp) 7.45	206962	113826	135045	67530
Log(AntTemp) 7.50	206962	79879	117605	59456
Log(AntTemp) 7.55	80932	64356	105132	53708
Log(AntTemp) 7.60	52287	53846	95262	48417
Log(AntTemp) 7.65	38951	45709	86739	43060
Log(AntTemp) 7.70	29761	38734	79270	37362
Log(AntTemp) 7.75	22944	32873	72597	32068
Log(AntTemp) 7.80	17754	27813	66308	27304
Log(AntTemp) 7.85	13898	23513	60514	23176
Log(AntTemp) 7.90	11183	19869	55096	19593
Log(AntTemp) 7.95	9248	16930	50206	16718
Log(AntTemp) 8.00	7770	14637	45787	14470
Log(AntTemp) 8.05	6580	12716	41682	12587
Log(AntTemp) 8.10	5668	11196	37884	11088
Log(AntTemp) 8.15	4942	9990	34422	9898
Log(AntTemp) 8.20	4350	8987	31237	8908
Log(AntTemp) 8.25	3897	8066	28434	8000
Log(AntTemp) 8.30	3565	7278	25830	7217
Log(AntTemp) 7.00	206962	206962	206962	77354
Log(AntTemp) 7.50	206962	79879	117605	59456
Log(AntTemp) 8.00	7770	14637	45787	14470
Log(AntTemp) 8.50	2490	4913	17597	4873
Log(AntTemp) 9.00	1105	2431	7702	2417
Log(AntTemp) 9.50	491	1239	3996	1234
Log(AntTemp) 10.00	197	576	2046	574
Log(AntTemp) 10.50	81	279	989	279
Log(AntTemp) 11.00	29	87	441	87
Log(AntTemp) 11.50	6	28	171	28
Log(AntTemp) 12.00	1	9	53	9
Log(AntTemp) 12.50	0	4	17	4
Log(AntTemp) 13.00	0	0	6	0
Log(AntTemp) 13.50	0	0	0	0
Log(AntTemp) 14.00	0	0	0	0
Log(AntTemp) 14.50	0	0	0	0
Log(AntTemp) 15.00	0	0	0	0
Log(AntTemp) 15.50	0	0	0	0
Log(AntTemp) 16.00	0	0	0	0
Log(AntTemp) 16.50	0	0	0	0
Log(AntTemp) 17.00	0	0	0	0

Histograms for 81184 to 81365

		1980 kHz	1000 kHz	513 kHz	Solar
Number of points		192527	192527	192527	
Total observation times		17327430	17327430	17327430	
Maxima		12.35	12.99	13.15	
Log(AntTemp)	7.30	192527	192527	192527	88427
Log(AntTemp)	7.35	192527	192527	192527	88427
Log(AntTemp)	7.40	192527	192527	155594	88427
Log(AntTemp)	7.45	192527	120598	134929	82079
Log(AntTemp)	7.50	192523	95751	124146	76712
Log(AntTemp)	7.55	88146	80739	115494	70515
Log(AntTemp)	7.60	61029	69671	108003	63905
Log(AntTemp)	7.65	48082	61240	101314	57791
Log(AntTemp)	7.70	39857	54051	95258	52041
Log(AntTemp)	7.75	33890	47794	89424	46616
Log(AntTemp)	7.80	28936	42484	83821	41779
Log(AntTemp)	7.85	24657	37924	78517	37435
Log(AntTemp)	7.90	21023	33927	73253	33583
Log(AntTemp)	7.95	17961	30424	68333	30156
Log(AntTemp)	8.00	15355	27250	63772	27026
Log(AntTemp)	8.05	13147	24339	59403	24151
Log(AntTemp)	8.10	11321	21725	55356	21562
Log(AntTemp)	8.15	9813	19309	51565	19159
Log(AntTemp)	8.20	8382	17273	47817	17142
Log(AntTemp)	8.25	7141	15428	44217	15309
Log(AntTemp)	8.30	6153	13828	40775	13717
Log(AntTemp)	7.00	192527	192527	192527	88427
Log(AntTemp)	7.50	192523	95751	124146	76712
Log(AntTemp)	8.00	15355	27250	63772	27026
Log(AntTemp)	8.50	3700	9220	28965	9133
Log(AntTemp)	9.00	1576	3764	12649	3717
Log(AntTemp)	9.50	682	1825	5872	1806
Log(AntTemp)	10.00	293	877	3090	870
Log(AntTemp)	10.50	123	411	1534	410
Log(AntTemp)	11.00	34	154	691	154
Log(AntTemp)	11.50	11	42	277	42
Log(AntTemp)	12.00	3	11	103	11
Log(AntTemp)	12.50	0	4	26	4
Log(AntTemp)	13.00	0	0	7	0
Log(AntTemp)	13.50	0	0	0	0
Log(AntTemp)	14.00	0	0	0	0
Log(AntTemp)	14.50	0	0	0	0
Log(AntTemp)	15.00	0	0	0	0
Log(AntTemp)	15.50	0	0	0	0
Log(AntTemp)	16.00	0	0	0	0
Log(AntTemp)	16.50	0	0	0	0
Log(AntTemp)	17.00	0	0	0	0

Histograms for 82001 to 82183

		1980 kHz	1000 kHz	513 kHz	Solar
Number of points		185992	185992	185991	
Total observation times		16739280	16739280	16739190	
Maxima		12.62	12.78	13.14	
Log(AntTemp)	7.30	179049	179127	179427	66076
Log(AntTemp)	7.35	179032	179106	179321	66060
Log(AntTemp)	7.40	179022	179087	142723	66047
Log(AntTemp)	7.45	179015	101063	111771	64153
Log(AntTemp)	7.50	179010	74865	101076	59880
Log(AntTemp)	7.55	79761	62288	92843	55099
Log(AntTemp)	7.60	54361	53517	85722	49782
Log(AntTemp)	7.65	41755	46611	79484	44418
Log(AntTemp)	7.70	33735	41032	73828	39591
Log(AntTemp)	7.75	27965	36361	68615	35242
Log(AntTemp)	7.80	23458	32317	63673	31381
Log(AntTemp)	7.85	19926	28834	58944	28026
Log(AntTemp)	7.90	16930	25707	54518	25032
Log(AntTemp)	7.95	14480	22813	50531	22252
Log(AntTemp)	8.00	12318	20278	46660	19806
Log(AntTemp)	8.05	10533	17972	43049	17579
Log(AntTemp)	8.10	9057	15886	39857	15559
Log(AntTemp)	8.15	7763	14042	36830	13768
Log(AntTemp)	8.20	6721	12470	34029	12229
Log(AntTemp)	8.25	5918	11059	31473	10846
Log(AntTemp)	8.30	5277	9818	29123	9618
Log(AntTemp)	7.00	182301	182089	182314	66142
Log(AntTemp)	7.50	179010	74865	101076	59880
Log(AntTemp)	8.00	12318	20278	46660	19806
Log(AntTemp)	8.50	3631	6574	20723	6424
Log(AntTemp)	9.00	1679	3378	8849	3295
Log(AntTemp)	9.50	860	1821	5041	1776
Log(AntTemp)	10.00	399	1004	2807	981
Log(AntTemp)	10.50	163	499	1527	492
Log(AntTemp)	11.00	63	225	840	224
Log(AntTemp)	11.50	20	90	426	89
Log(AntTemp)	12.00	7	27	181	27
Log(AntTemp)	12.50	1	3	58	3
Log(AntTemp)	13.00	0	0	5	0
Log(AntTemp)	13.50	0	0	0	0
Log(AntTemp)	14.00	0	0	0	0
Log(AntTemp)	14.50	0	0	0	0
Log(AntTemp)	15.00	0	0	0	0
Log(AntTemp)	15.50	0	0	0	0
Log(AntTemp)	16.00	0	0	0	0
Log(AntTemp)	16.50	0	0	0	0
Log(AntTemp)	17.00	0	0	0	0

Histograms for 82184 to 82243

	1980 kHz	1000 kHz	513 kHz	Solar
Number of points	57175	57175	57173	
Total observation times	5145750	5145750	5145570	
Maxima	12.07	12.11	12.82	
Log(AntTemp) 7.30	57175	57175	57173	14590
Log(AntTemp) 7.35	57175	57175	57173	14590
Log(AntTemp) 7.40	57175	57173	48541	14590
Log(AntTemp) 7.45	57175	30020	35494	14589
Log(AntTemp) 7.50	57175	20954	30767	14561
Log(AntTemp) 7.55	19735	17049	27736	14204
Log(AntTemp) 7.60	11297	14141	25481	12907
Log(AntTemp) 7.65	7845	11813	23562	11225
Log(AntTemp) 7.70	6055	9925	22002	9609
Log(AntTemp) 7.75	4928	8348	20574	8146
Log(AntTemp) 7.80	4124	7007	19152	6857
Log(AntTemp) 7.85	3542	5952	17682	5830
Log(AntTemp) 7.90	3115	5141	16238	5036
Log(AntTemp) 7.95	2774	4490	14864	4400
Log(AntTemp) 8.00	2512	3989	13555	3905
Log(AntTemp) 8.05	2277	3560	12328	3480
Log(AntTemp) 8.10	2093	3235	11137	3160
Log(AntTemp) 8.15	1889	2944	10113	2873
Log(AntTemp) 8.20	1724	2726	9172	2657
Log(AntTemp) 8.25	1572	2528	8332	2462
Log(AntTemp) 8.30	1440	2361	7505	2297
Log(AntTemp) 7.00	57175	57175	57173	14590
Log(AntTemp) 7.50	57175	20954	30767	14561
Log(AntTemp) 8.00	2512	3989	13555	3905
Log(AntTemp) 8.50	1032	1766	4812	1715
Log(AntTemp) 9.00	436	856	2342	836
Log(AntTemp) 9.50	181	407	1254	401
Log(AntTemp) 10.00	70	164	671	162
Log(AntTemp) 10.50	27	73	306	73
Log(AntTemp) 11.00	13	29	158	29
Log(AntTemp) 11.50	1	10	78	10
Log(AntTemp) 12.00	1	1	35	1
Log(AntTemp) 12.50	0	0	11	0
Log(AntTemp) 13.00	0	0	0	0
Log(AntTemp) 13.50	0	0	0	0
Log(AntTemp) 14.00	0	0	0	0
Log(AntTemp) 14.50	0	0	0	0
Log(AntTemp) 15.00	0	0	0	0
Log(AntTemp) 15.50	0	0	0	0
Log(AntTemp) 16.00	0	0	0	0
Log(AntTemp) 16.50	0	0	0	0
Log(AntTemp) 17.00	0	0	0	0

Histograms for 82244 to 82290

		1980 kHz	1000 kHz	513 kHz	Solar
Number of points		43331	43331	43330	
Total observation times		3899790	3899790	3899700	
Maxima		10.63	11.02	11.26	
Log(AntTemp)	7.30	43331	43331	43330	26110
Log(AntTemp)	7.35	43331	43331	43330	26110
Log(AntTemp)	7.40	43331	43331	34688	26110
Log(AntTemp)	7.45	43331	20317	27630	13838
Log(AntTemp)	7.50	43331	12775	23046	10497
Log(AntTemp)	7.55	11846	9296	19633	8080
Log(AntTemp)	7.60	6085	7159	16905	6315
Log(AntTemp)	7.65	3685	5390	14476	4890
Log(AntTemp)	7.70	2498	4111	12417	3802
Log(AntTemp)	7.75	1862	3151	10646	2969
Log(AntTemp)	7.80	1488	2360	9160	2276
Log(AntTemp)	7.85	1174	1887	7790	1845
Log(AntTemp)	7.90	963	1539	6681	1507
Log(AntTemp)	7.95	811	1274	5712	1243
Log(AntTemp)	8.00	679	1073	4870	1048
Log(AntTemp)	8.05	591	931	4174	908
Log(AntTemp)	8.10	515	815	3595	796
Log(AntTemp)	8.15	453	718	3075	699
Log(AntTemp)	8.20	397	641	2570	625
Log(AntTemp)	8.25	356	567	2168	555
Log(AntTemp)	8.30	328	509	1878	499
Log(AntTemp)	7.00	43331	43331	43330	26110
Log(AntTemp)	7.50	43331	12775	23046	10497
Log(AntTemp)	8.00	679	1073	4870	1048
Log(AntTemp)	8.50	216	355	1270	347
Log(AntTemp)	9.00	68	159	576	153
Log(AntTemp)	9.50	23	59	244	56
Log(AntTemp)	10.00	6	12	91	12
Log(AntTemp)	10.50	1	4	39	4
Log(AntTemp)	11.00	0	1	3	1
Log(AntTemp)	11.50	0	0	0	0
Log(AntTemp)	12.00	0	0	0	0
Log(AntTemp)	12.50	0	0	0	0
Log(AntTemp)	13.00	0	0	0	0
Log(AntTemp)	13.50	0	0	0	0
Log(AntTemp)	14.00	0	0	0	0
Log(AntTemp)	14.50	0	0	0	0
Log(AntTemp)	15.00	0	0	0	0
Log(AntTemp)	15.50	0	0	0	0
Log(AntTemp)	16.00	0	0	0	0
Log(AntTemp)	16.50	0	0	0	0
Log(AntTemp)	17.00	0	0	0	0

Histograms for 82291 to 82305

	1980 kHz	1000 kHz	513 kHz	Solar
Number of points	19309	19309	19309	
Total observation times	1737810	1737810	1737810	
Maxima	10.38	11.09	12.01	
Log(AntTemp) 7.30	19309	19309	19309	1648
Log(AntTemp) 7.35	19309	19309	19308	1648
Log(AntTemp) 7.40	19309	19308	14053	1648
Log(AntTemp) 7.45	19309	4794	11196	1644
Log(AntTemp) 7.50	19308	2861	9744	1626
Log(AntTemp) 7.55	2384	2093	8689	1570
Log(AntTemp) 7.60	1361	1646	7802	1428
Log(AntTemp) 7.65	1003	1359	7092	1245
Log(AntTemp) 7.70	803	1146	6452	1070
Log(AntTemp) 7.75	679	999	5880	937
Log(AntTemp) 7.80	586	897	5376	845
Log(AntTemp) 7.85	515	807	4985	764
Log(AntTemp) 7.90	460	740	4624	701
Log(AntTemp) 7.95	422	671	4335	637
Log(AntTemp) 8.00	379	601	4069	574
Log(AntTemp) 8.05	343	553	3811	532
Log(AntTemp) 8.10	324	514	3585	496
Log(AntTemp) 8.15	296	465	3375	454
Log(AntTemp) 8.20	269	434	3174	425
Log(AntTemp) 8.25	245	414	2998	406
Log(AntTemp) 8.30	223	383	2819	377
Log(AntTemp) 7.00	19309	19309	19309	1648
Log(AntTemp) 7.50	19308	2861	9744	1626
Log(AntTemp) 8.00	379	601	4069	574
Log(AntTemp) 8.50	145	271	2221	270
Log(AntTemp) 9.00	43	111	1318	111
Log(AntTemp) 9.50	11	40	662	40
Log(AntTemp) 10.00	5	10	310	10
Log(AntTemp) 10.50	0	4	123	4
Log(AntTemp) 11.00	0	2	49	2
Log(AntTemp) 11.50	0	0	13	0
Log(AntTemp) 12.00	0	0	1	0
Log(AntTemp) 12.50	0	0	0	0
Log(AntTemp) 13.00	0	0	0	0
Log(AntTemp) 13.50	0	0	0	0
Log(AntTemp) 14.00	0	0	0	0
Log(AntTemp) 14.50	0	0	0	0
Log(AntTemp) 15.00	0	0	0	0
Log(AntTemp) 15.50	0	0	0	0
Log(AntTemp) 16.00	0	0	0	0
Log(AntTemp) 16.50	0	0	0	0
Log(AntTemp) 17.00	0	0	0	0

Histograms for 82306 to 83008

		1980 kHz	1000 kHz	513 kHz	Solar
Number of points		74254	74254	74253	
Total observation times		6682860	6682860	6682770	
Maxima		11.88	12.81	13.06	
Log(AntTemp)	7.30	74254	74254	74253	23024
Log(AntTemp)	7.35	74254	74254	74253	23024
Log(AntTemp)	7.40	74254	74254	63274	23024
Log(AntTemp)	7.45	74253	33810	56990	22731
Log(AntTemp)	7.50	74252	27237	53583	21944
Log(AntTemp)	7.55	25099	23606	50801	20565
Log(AntTemp)	7.60	18275	20927	48209	18815
Log(AntTemp)	7.65	14282	18670	45786	16995
Log(AntTemp)	7.70	11730	16663	43515	15316
Log(AntTemp)	7.75	9811	14933	41258	13771
Log(AntTemp)	7.80	8100	13399	39155	12393
Log(AntTemp)	7.85	6555	12013	37064	11146
Log(AntTemp)	7.90	5311	10717	35175	9945
Log(AntTemp)	7.95	4349	9551	33408	8848
Log(AntTemp)	8.00	3625	8418	31793	7789
Log(AntTemp)	8.05	3109	7397	30231	6818
Log(AntTemp)	8.10	2722	6471	28885	5946
Log(AntTemp)	8.15	2435	5646	27658	5166
Log(AntTemp)	8.20	2211	4976	26543	4542
Log(AntTemp)	8.25	2048	4423	25493	4027
Log(AntTemp)	8.30	1888	3954	24489	3601
Log(AntTemp)	7.00	74254	74254	74253	23024
Log(AntTemp)	7.50	74252	27237	53583	21944
Log(AntTemp)	8.00	3625	8418	31793	7789
Log(AntTemp)	8.50	1401	2801	20755	2545
Log(AntTemp)	9.00	672	1453	12434	1324
Log(AntTemp)	9.50	331	804	7477	757
Log(AntTemp)	10.00	140	417	4201	400
Log(AntTemp)	10.50	48	190	2227	179
Log(AntTemp)	11.00	19	83	1103	78
Log(AntTemp)	11.50	8	33	440	31
Log(AntTemp)	12.00	0	12	164	12
Log(AntTemp)	12.50	0	4	37	4
Log(AntTemp)	13.00	0	0	1	0
Log(AntTemp)	13.50	0	0	0	0
Log(AntTemp)	14.00	0	0	0	0
Log(AntTemp)	14.50	0	0	0	0
Log(AntTemp)	15.00	0	0	0	0
Log(AntTemp)	15.50	0	0	0	0
Log(AntTemp)	16.00	0	0	0	0
Log(AntTemp)	16.50	0	0	0	0
Log(AntTemp)	17.00				

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16. Abstract

Solar radio emission could seriously interfere with observations made by a low frequency (1-10 MHz) array in space. This problem is of particular concern because a previous study (JPL Publication 88-30) showed that terrestrial interference would be so severe that the only location from which a space array would be able to operate near the Earth would be on the sunlit side where the ionosphere would shield the system from signals generated at ground level. Thus the system would be open to interference from the Sun.

In this study ISEE-3 radio data has been used to determine solar emission levels. The results indicate that solar emission should seriously disturb less than ten per cent of the data, even during the years of solar maximum. Thus it appears that solar emission should not cause a disastrous loss of data. This study also provides the information needed to design procedures to excise solar interference from the data produced by any low-frequency array.

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