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A GEOPHYSICAL EVALUATION OF THE SHORT-PERIOD LASA/SAAC SYSTEM

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13 ABSTRACT

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The system operates in two parts. The Detection Processor (DP) performs data acquisition and signal detection in an on-line computer. Throughout 1971 DP operated with a detection threshold of 10 db signal/noise ratio where the signal measurements are equivalent to zero to peak, and noise measurements are 28.8 second averages of filtered beams. The average DP detection rate was 450 signals per day.

The Event Processor (EP) analyzes signals in an off-line computer to recognize true signals and false alarms and to extract event parameters, refine locations, and publish an earthquake bulletin. Throughout the last 8 months of 1971 EP operated with a threshold of 14 db signal/noise ratio. The average daily rate of signals analyzed by EP was only a third of those detected by DP.

As programmed in 1971 the system requires analyst editing. Of the daily average of 56 events acceptable to EP, only 24 were acceptable to the analysts editing EP outputs on the display console. The main categories of EP events misidentified as teleseisms and rejected by the analysts were non-teleseismic events, side lobe detections on teleseismic beams, and weak or misaligned signals.

At the parameter settings used during 1971, for all events within 30° to 85° epicentral distance of LASA, discrete recurrence curves indicate that LASA/SAAC detected 90% at magnitude 3.8. Cumulative recurrence curves indicate that LASA/SAAC 90% of all events greater than magnitude 3.7 within 30° to 85° epicentral distance.

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I. INTRODUCTION

The purpose of this report is to bring up to date the geophysical evaluation of the short-period LASA/SAAC system[1] described in SAAC Report No. 1 (Dean *et al.*, 1971). The SAAC automatic data acquisition and processing programs, known as the Integrated Seismic Research Signal Processing System (ISRSPS), were developed by the IBM Federal Systems Division under ARPA contracts F19628-67-C-0198 and F19628-68-C-0400. This report covers the routine operation of the ISRSPS programs and the LASA Daily Summary (earthquake bulletin) from February 1, 1971 through December 31, 1971.

The ISRSPS system operates in two parts: the Detection Processor (DP) performs data acquisition and signal detection; the Event Processor (EP) is designed to recognize true signals and false alarms and to extract event parameters, refine locations, and publish an earthquake bulletin. The Event Processor is programmed to work either in an automated mode in which the computer analyzes events and publishes the bulletin without help from a seismological analyst, or to act as an aide to the analyst who can edit the event processing on a

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[1] The evaluation of the long-period system is discussed in SAAC Reports No. 4 (Mack, 1971) and No. 6 (Mack, 1972). The SAAC equipment evaluation is discussed in SAAC Report No. 7 (McCoy, 1971).

display console. Throughout 1971 (1 February through 31 December) we have always operated the SAAC/LASA system with analyst editing. In this way we can compare both the automated system performance (what DP and EP provide the analyst for editing) with the system performance using analyst editing.

II. OPERATIONAL PARAMETERS

In addition to data acquisition and recording, the Detection Processor (DP) performs the following functions:

1. subarray beamforming in the SPS (IBM Special Processing System 4103);
2. filtering in the SPS;
3. array beamforming in the IBM 360/40A;
4. short-time averaging (STA) in the IBM 360/40A to measure signal plus noise energy;
5. long-time averaging (LTA) in the IBM 360/40A to measure noise background;
6. signal-to-noise ratio thresholding by using STA/LTA, and checking spacial coherency of signal arrivals in the IBM 360/40A.

From 1 February through 31 December 1971, we operated SAAC full time and published a full-time earthquake bulletin (LASA Daily Summary), except for periods of equipment failures and preventive maintenance. The DP system parameters during this period were as follows:

1. The subarray beamforming is described in SAAC Report No. 1 (Dean, et al., 1971). We did not change these parameters throughout 1971.
2. The filtering of subarray beams uses a three-pole recursive Butterworth filter with pass band of 0.9 to to 1.4 Hz as described in SAAC Report No. 1 (Dean, et al., 1971). We did not change these filter parameters throughout 1971.

3. Array beamforming is done in two partitions. In Partition I there are 300 fine beams composed of 17 subarray beams consisting of the A-ring through the E-ring at LASA. In Partition II there are 299 coarse beams composed of 9 subarray beams, A-ring through the C-ring at LASA. Beam Set No. 133 deploys the 300 fine beams into the active seismic regions and known test sites, most of which are 30^{o} to 100^{o} from LASA. Beam Set No. 140 deploys 299 coarse beams (uniformly in U-space) over the entire world in view of LASA (20^{o} to 180^{o}). Throughout 1971 we have used Beam Set No. 133 for Partition I and Beam Set No. 140 for Partition II (for beam set specifications see IBM ISRSPS Reference Manual 113S, Section 6-19. For maps of Beam Sets 133 and 140 see Appendix II, SAAC Report No. 1, Dean, et al., 1971).

4. Short-time averaging (STA) is a recursive low pass filtering of rectified beam outputs. Averages of the rectified beam outputs are computed over 1.8 seconds of beam data traces and up-dated every 0.6 seconds (see SAAC Report No. 1, pages 11 & 12, Dean, et al., 1971). Throughout 1971 we have made no changes to the STA parameters.

5. Long-time averaging (LTA) is a recursive low pass filtering of rectified beam outputs. Averages of the recitifed beam outputs are computed by a filter with an exponential time constant of 28.8 seconds

(see SAAC Report No. 1, page 12, Dean, et al., 1971). Throughout 1971 we have made no changes to the LTA parameters.

6. The detection of signal is based on two criteria; spatial coherency and signal-to-noise threshold. The test is performed at 0.6 second rate. When STA is computed at this rate, the beam with maximum STA is also selected. The signal detection must satisfy: (a) at least P beams of max STA must lie within k rings of beams with center at the beam of highest max STA. (b) the STA/LTA must exceed the threshold of T db Q times out of Q' consecutive tests in at least one of these beams that satisfy (a).

We have maintained T at 10 db; k = 2 rings and Q, Q' at 3 throughout the year. The spatial coherency condition, P, was set to 3 in January and the first three weeks of February 1971 but was changed to 4 on February 23, 1971, and remained the same throughout the rest of the year.

Note that signal-to-noise ratio as indicated in this report is actually STA/LTA, which is the ratio of mean amplitudes of signal and noise respectively.

III. DP STATISTICS

As reported in SAAC Report No. 1 (pages 14 and 15, Dean, et al., 1971), the average daily detection rate was 1129 $\pm$ 160 when operating under 3 out of 3 detection logic. Under 4 out of 4 the rate dropped to 558 signals per day with a standard deviation of 59. These figures represent both partitions and include double listings of most signals. Most events listed in the LASA Daily Summary (97%) are detected with the strongest signal-to noise ratios on the fine beam set (Partition I, 300 beams using A- to E-ring subarrays). Thus a truer picture of the LASA/SAAC detections is obtained from Partition I results alone. Figure 1 shows the daily Partition I detections versus days of the year. Table I shows that the average daily detection rate in Partition I (days with no detections due to equipment failure omitted) was close to 230 throughout 1971.

The number of signals detected decreases rapidly as the signal-to-noise ratio increases. Figure 2 shows the cumulative number of detections greater than a given signal-to-noise ratio when the DP threshold is set at 10 db. Figure 2 is derived from all detections recorded on Partition I between 1 May and 31 December 1971. Slightly less than 33% of the detections recorded by DP will be processed with an EP threshold of 14 db

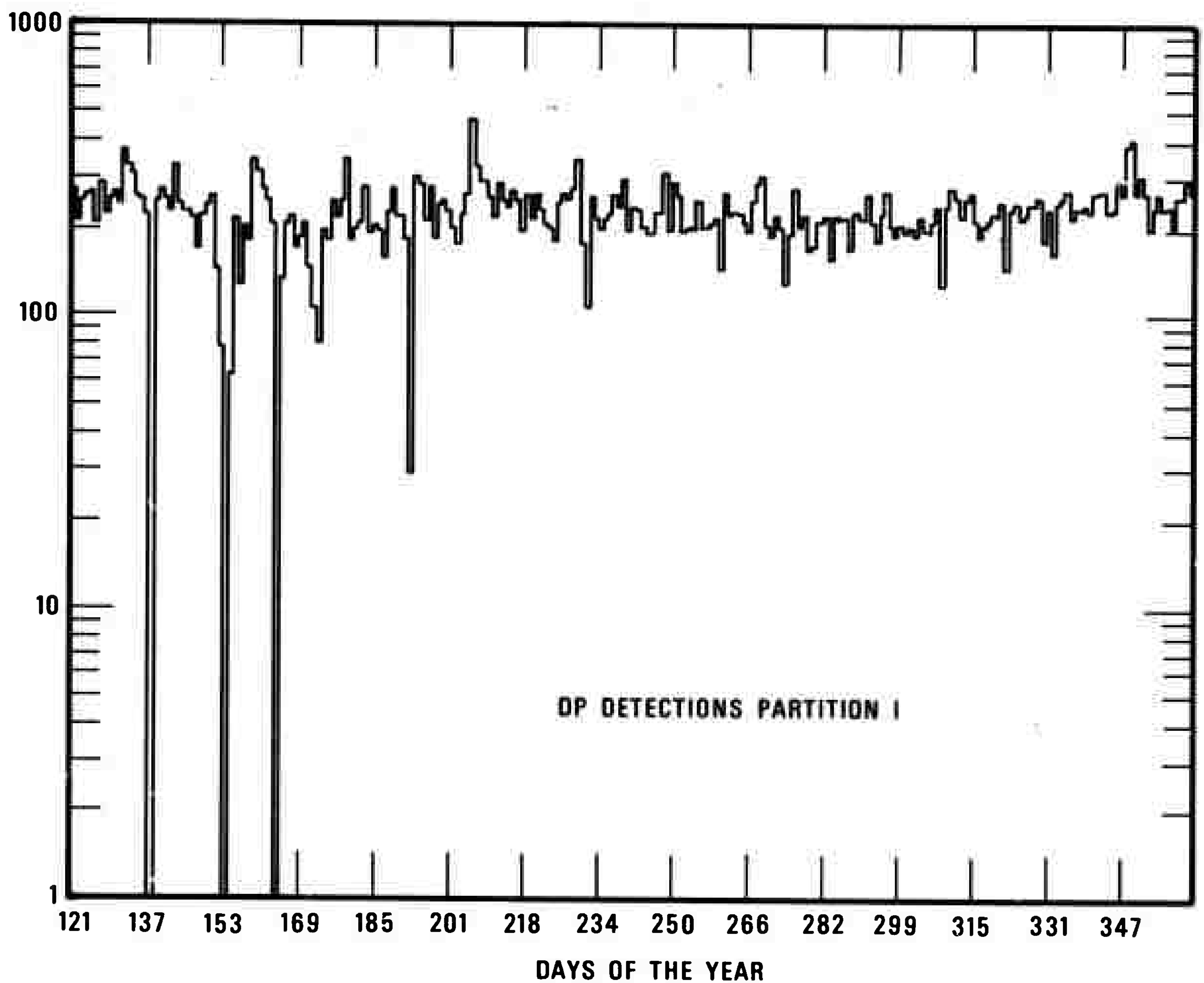

Figure 1. DP detections - Partition I.

6b

(300 Fine Beams - A-ring through E-ring subarrays, Beam Set No. 133)

Period in 1971	No. of days	Daily Average	Standard Deviation
May 1 - Dec 31	242	230	± 52
May 1 - Aug 31	120	232	± 61
Sept 1 - Dec 31	122	227	± 41

System Parameters:

- filter: 0.9 to 1.4 Hz
- S/N threshold: 10 db
- Detection logic: 4 out of 4

Table I. DP Detections/Day on Partition I

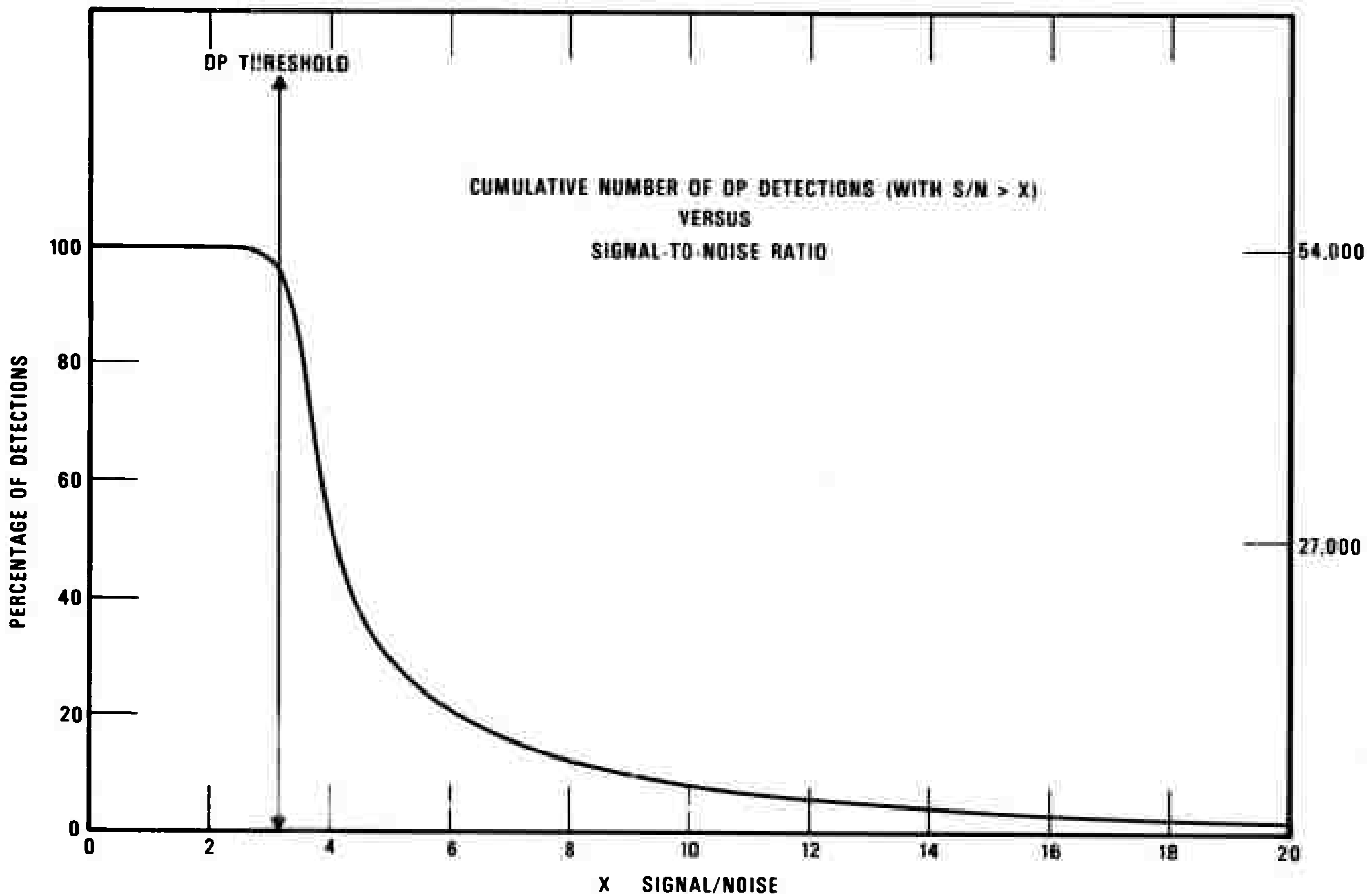

Figure 2. DP detection vs signal/noise ratio.

(signal/noise ratio of 5/1) and 20% will be processed with an EP threshold of 16 db (signal/noise ratio of 6.3/1).

IV. EP STATISTICS

The Event Processor (EP) analyzes all detections listed by DP which exceed the EP threshold. As we have operated SAAC in 1971, there are two types of reductions to the list of DP detections. The first is performed automatically by the computer, while the second is performed by the analysts editing the EP list of events which has been accepted by the computer.

The history of the computer automatic detection log reduction for the months of June through December 1971 is shown in Table II. During this time period the DP and EP system paramters were held fixed whereas system changes in the operating parameters had occurred previously. A complete table of detection log reduction for individual months as well as the time period for February through May 1971 is given in the appendix. The biggest reduction of signals to be processed occurred by setting the EP threshold at 14 db, 4 db above the DP detection threshold. Approximately two-thirds of all signals were rejected by this threshold setting. These signals were not lost to our analysts however, since we can analyze on reruns any signal above a 10 db threshold and below a 14 db threshold which was missed by our routine processing.

Period Covered: June through December 1971

No. of DP detections 10 db	96,611	100%
EP threshold failures 14 db	63,483	65.6%
DP detections 14 db	33,128	34.4%
Duplicate detections (on both partitions)	7,955	8.25%
Non-duplicate detections 14 db	25,173	26.1%
Later phases	9,349	9.7%
	15,824	16.4%
Priority threshold failures	2,620	2.7%
No. High rate tapes available	91	.1%
Selected for EP analysis	13,113	13.6%
Reruns	481	.5%
Signals Analyzed	13,594	14.1%

Table II. Detection Log Reductions via Computer Editing

In the EP computer analysis the major causes of signal rejection include duplicate detections and later phases. DP does not recognize that the fine beam set using 17 subarrays and the coarse beam set using 9 subarrays monitor overlapping regions. Many signals detected on both partitions are listed twice as independent signals. EP recognizes that these duplicate detections come from the same signal source and rejects the one with the lower signal-to-noise ratio.

EP recognizes subsequent detections on the same beam (i.e. same position in velocity space) within 30 seconds of a previous detection as later phases of the same event. Of the 34% of DP detections greater than 14 db, the computer rejected 8% as duplicate detections and 10% as later phases leaving only 16% as bona fide events.

From this point the detection log reduction continues via analyst editing. Table III shows the history of analyst editing for the period June through December 1971. Of the total number of signals accepted by EP, the analysts approved roughly 37% and reported them in the LASA Daily Summary. The main categories of EP events rejected by the analysts included non-teleseismic events (16%), side lobe detections (17%), and weak or mis-aligned signals (10%).

Period Covered: June through December 1971

Signals to be analyzed from EP	13594	100%
Computer Malfunctions	196	1.4%
Velocity Failures (greater than 25 km/sec)	1446	10.6%
EP System Events	11952	87.9%
Analyst Editing		
Events not reviewed, lack of time	0	0.0
Non-teleseismic Activity	2152	15.8%
Side Lobe Detections	2276	16.8%
Later Phases	338	2.5%
Data Dropouts	419	3.1%
Weak or Misaligned Signals	1349	9.9%
	6534	48.1%
Summary Events	4652	34.2%
Rerun Summary Events	131	1.0%
Extended Processing Events 545		
Failed 271		
Other 28		
Added to Summary (net)	246	1.8%
Double Events	35	0.3%
Events Reported on LASA Daily Summary	5064	37.3%

Table III. Detection Log Reductions via Analyst Editing

Figure 3 shows the number of EP events accepted by the computer as a function of the signal-to-noise ratio measured by DP. The period covered is 1 May through 31 December 1971. Figure 3 represents a histogram of the number of events within each interval of 0.1 in signal-to-noise ratio. However, the first interval ($5.0 \geq S/N \geq 5.1$) is actually less than 0.1 since the EP threshold of 14 db defines the minimum signal-to-noise ratio as 5.012 rather than 5.0. As a result, the number of events in the first interval is smaller than expected. Figure 4 shows these same data plotted in cumulative form.

Figure 5 shows the EP events on Partition I accepted by the computer as a function of day of the year May 1 through December 31. This same figure shows the average noise levels for that day associated with these events plotted vs. day of the year. The few days of large signal activity also show a large increase in noise level. This effect is caused by noise measurements (LTA's) being taken in the coda of previous events. On days of normal seismic activity, the general trends of these two curves on Figure 5 show an inverse correlation between the number of events and the noise level. During the fall and winter months the average noise level at LASA increases and a corresponding decrease occurs in the EP events accepted by the computer.

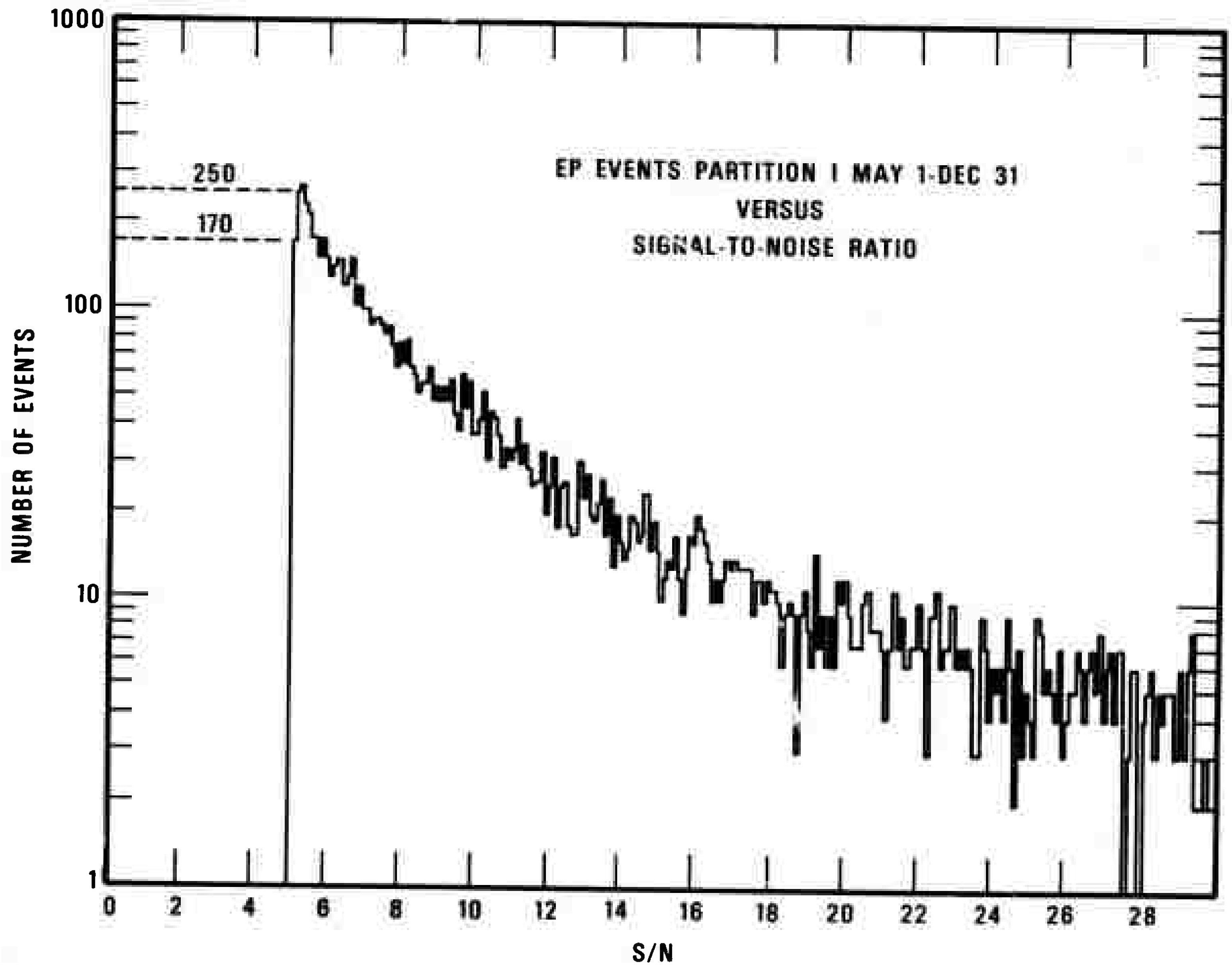

Figure 3. EP events - Partition I, May 1 through December 31, 1971.

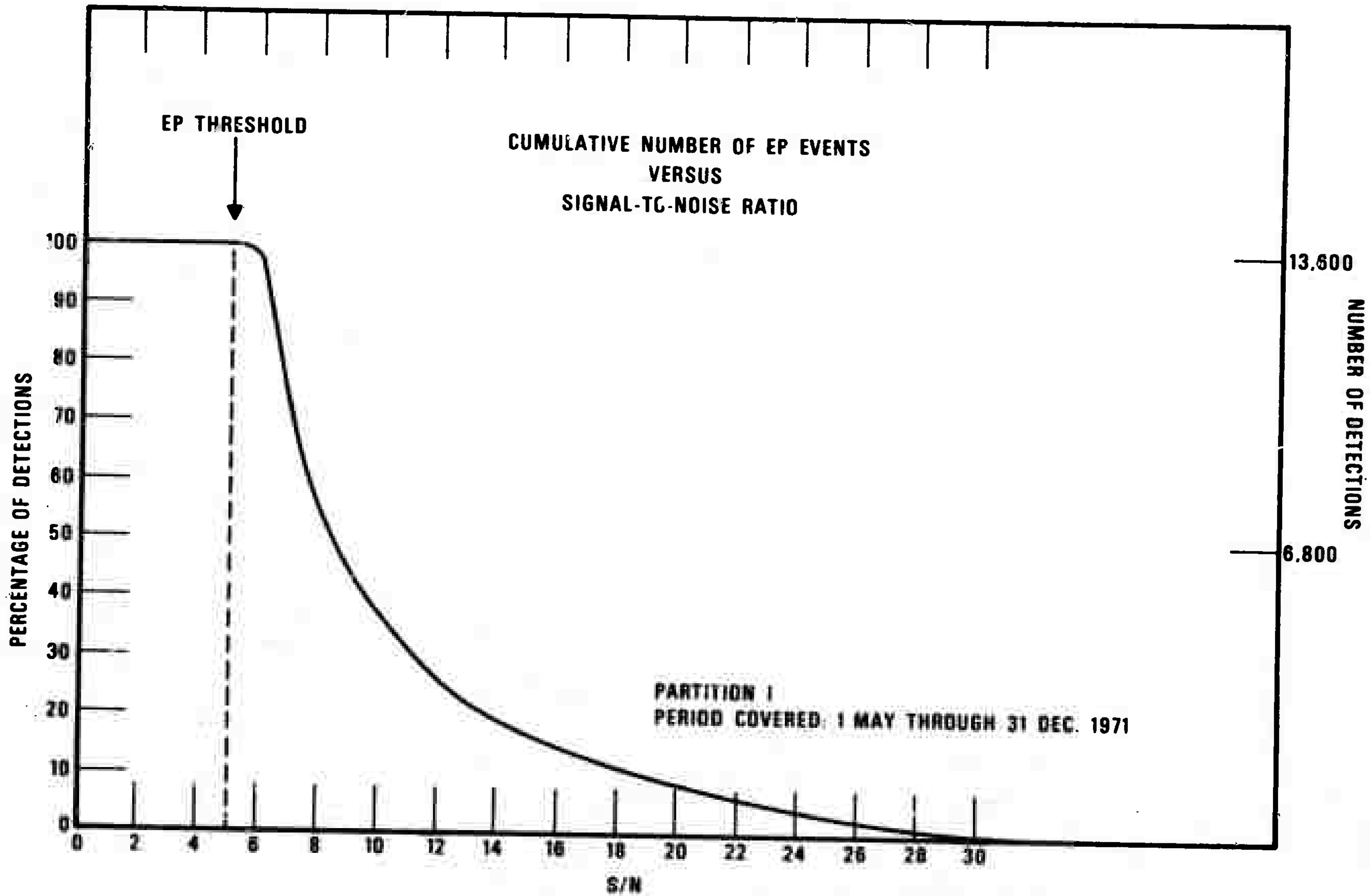

Figure 4. Cumulative number of EP events versus signal-to-noise ratio.

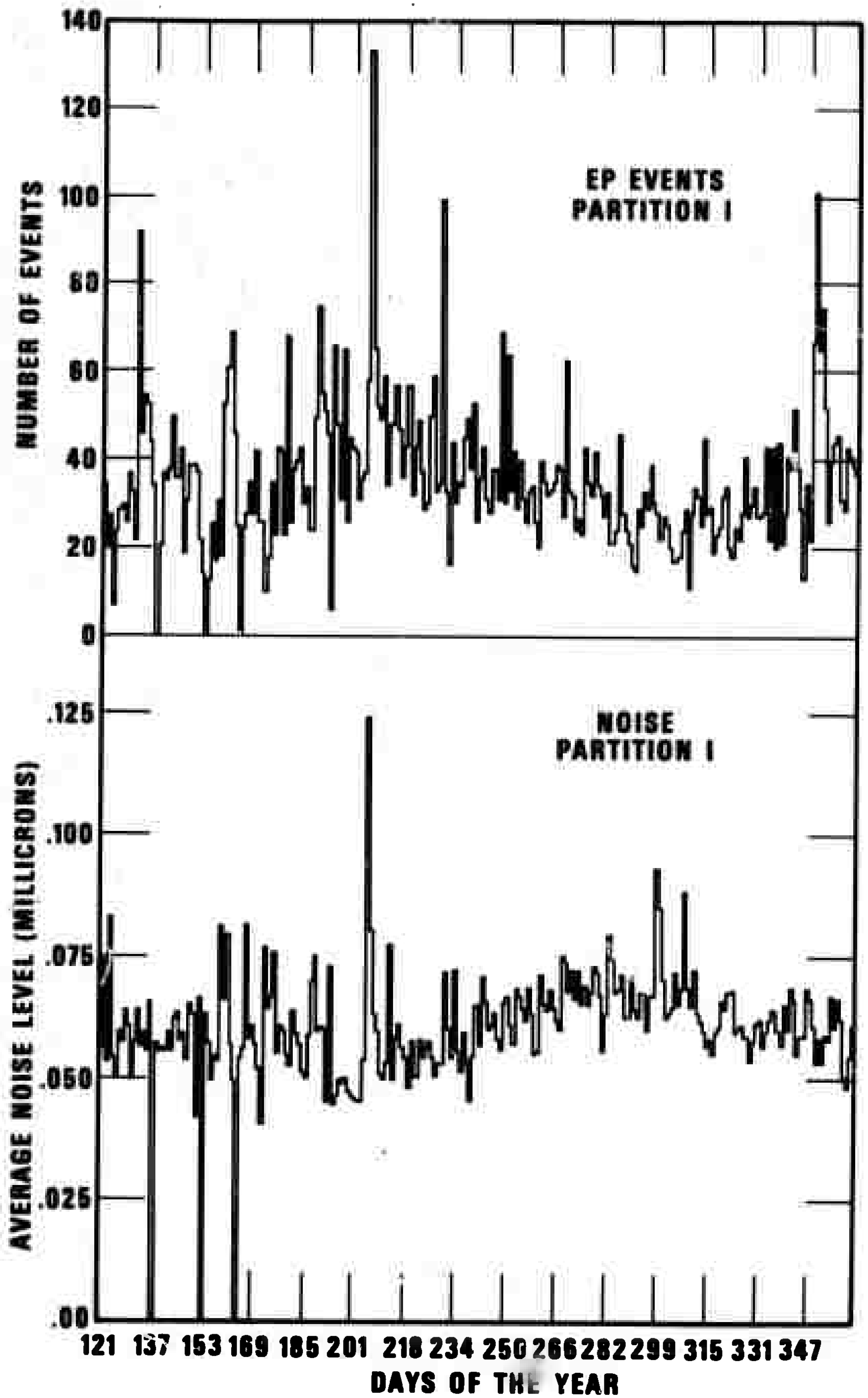

Figure 5. EP events and noise on Partition I versus day of the year.

Another view of the correlation between noise and detection rates is shown in Figure 6. There hourly rates for DP detection, noise, and EP events averaged over four months in the summer and again over four months in the fall and winter are plotted versus hour of the day at LASA (Montana time). These curves show that the noise at LASA is higher during the daylight hours. Also DP detections are higher at night when the noise level is lower. The rate of EP events does not correlate well with the noise except for one feature. In the late afternoon, both in winter and summer, the noise level, the DP detection rate, and the EP events all show a marked increase. This seismic activity is due to quarry blasts in the Montana region which are traditionally conducted in the late afternoon hours. Since the LASA/SAAC system is not programmed to recognize local events, EP will often mis-assign these signals to some teleseismic beams via side lobe detections. These local events are recognized as such and rejected by the analysts.

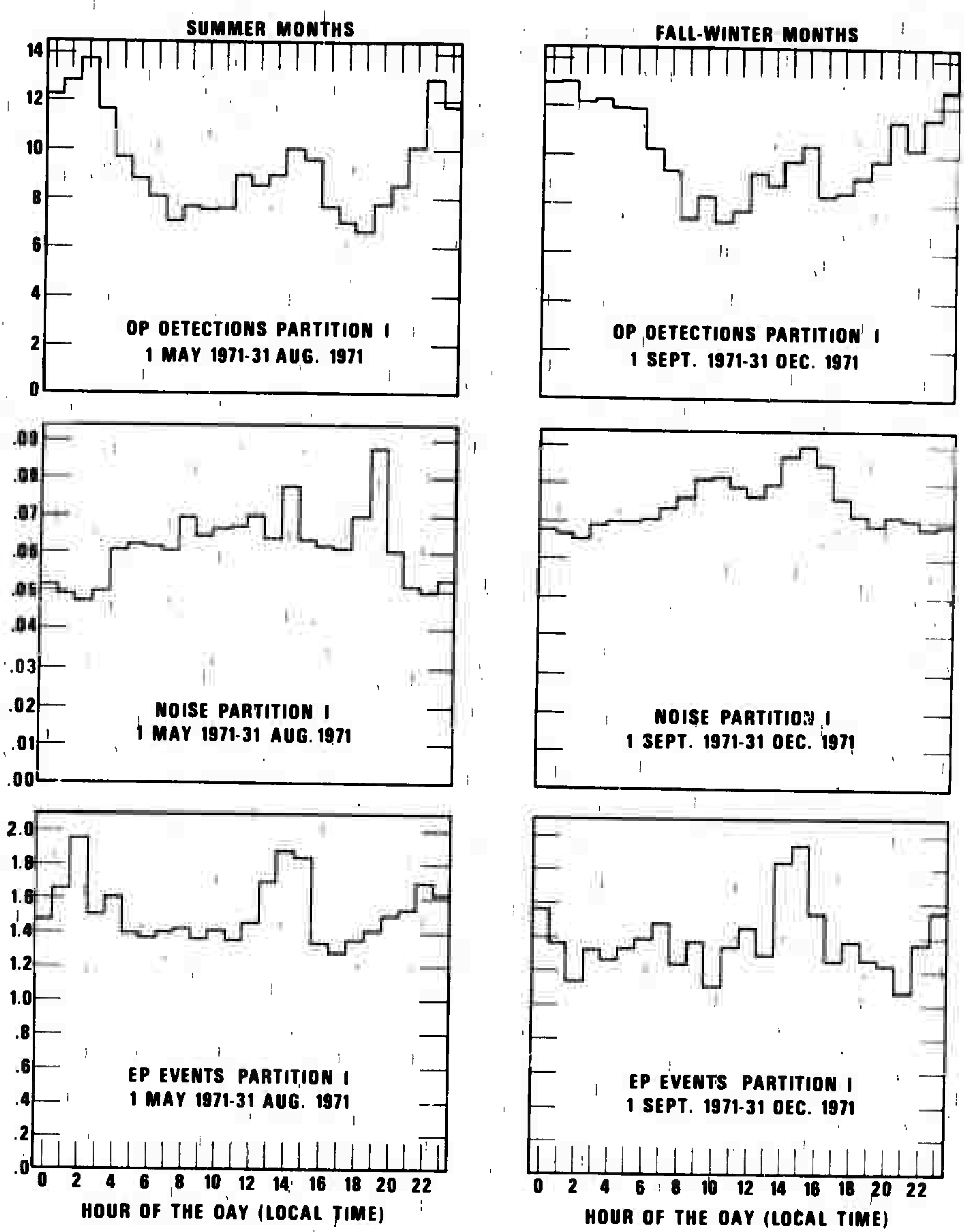

Figure 6. Correlation of hourly detection, noise, and EP event rates in winter and summer months.

V. RECURRENCE CURVES FOR LASA/SAAC

The events reported on the LASA Daily Summary include only those which were accepted by EP and were not rejected by the analysts. The number of these events reported in 1971 versus day of the year are shown in the histogram on Figure 7. Using these 6944 events we gain some estimate of the LASA/SAAC threshold as it operated during 1971 from the recurrence curves in the following figures.

The cumulative and discrete recurrence curves (number versus body wave magnitude m_b) for all 6944 events listed during 1971 is shown in Figure 8. For events from all distances the discrete curve falls to 90% of its trend line at an m_b of approximately 4.1. The cumulative curve falls to 90% of its trend line near an m_b of 3.8. Both curves have three-point smoothing applied.

The recurrence curves for the limited teleseismic range of 30° to 85° are shown in Figure 9. Again, three-point smoothing has been applied. The 90% threshold for the discrete curve is near an m_b of 3.8 and the 90% threshold for the cumulative is near 3.7. These results of 4884 events from 1 February to 31 December 1971 do not differ appreciably from those of 508 events in the 30° to 85° range from the month of May (Figure 25, Dean, et al., 1971).

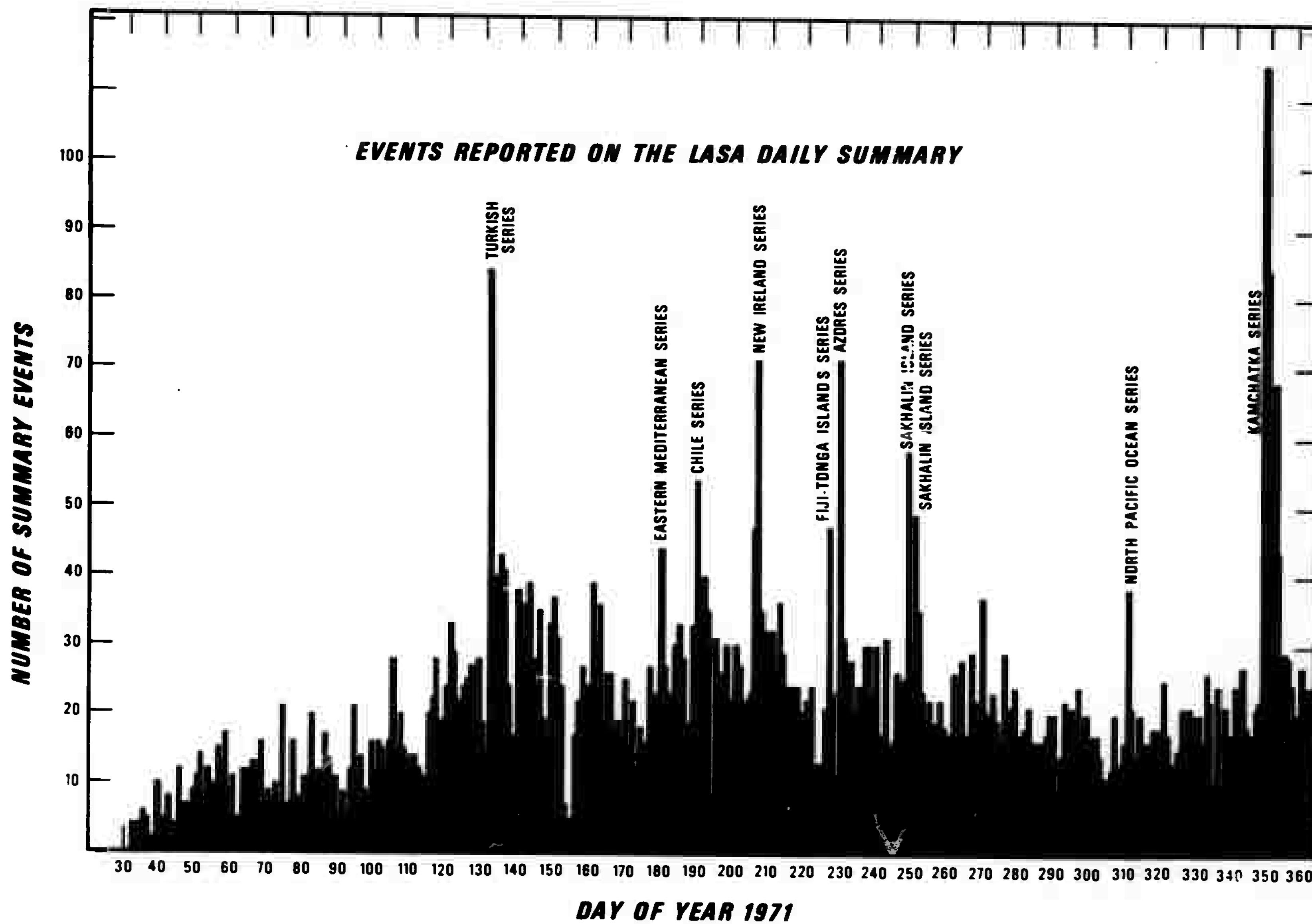

Figure 7. Events on LASA Daily Summary vs day of the year.

15b

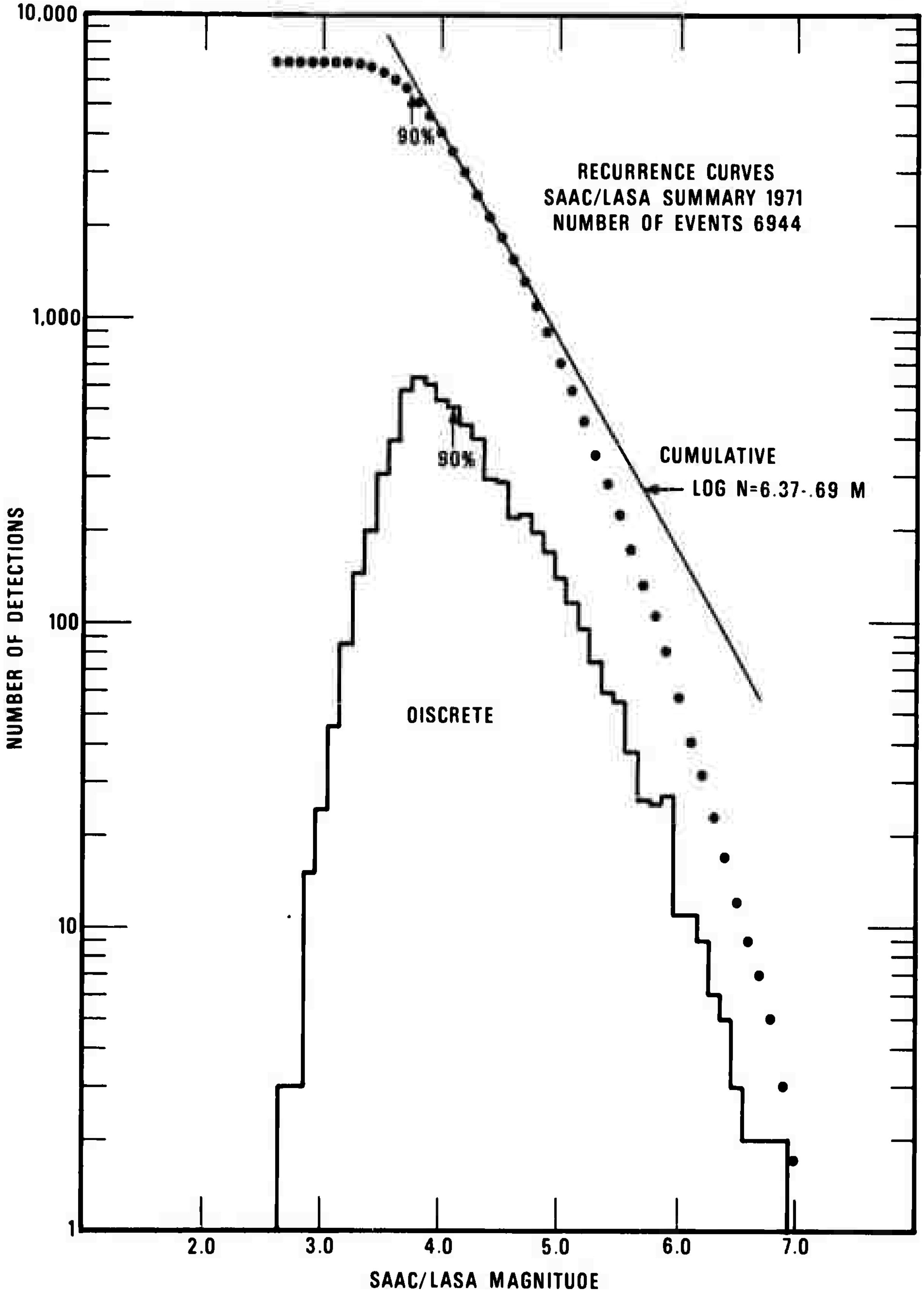

Figure 8. Recurrence curves of all events from the SAAC/LASA summary of 1971 vs m_b.

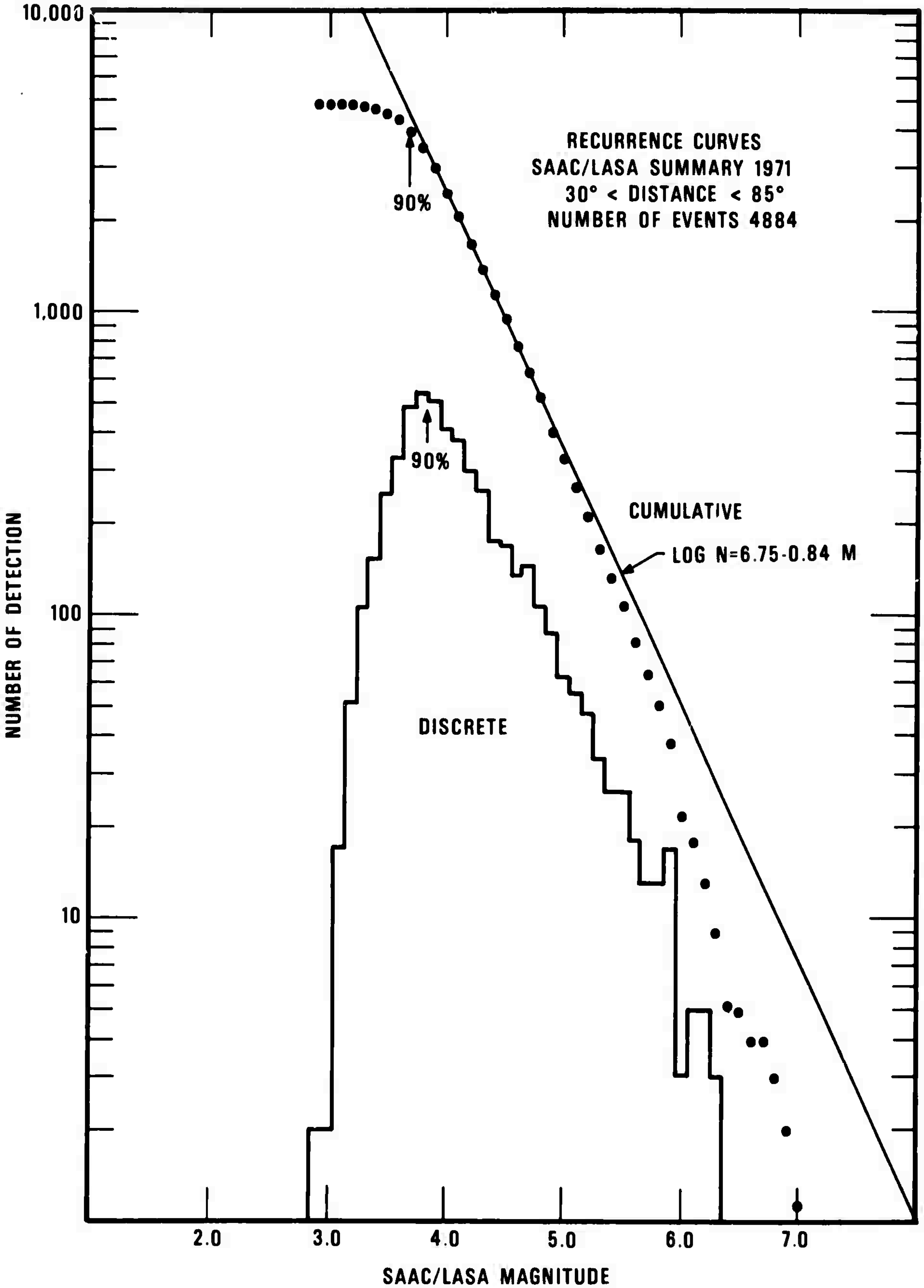

Figure 9. Recurrence curves for events greater than 30° but less than 85° from LASA versus m_b.

The confusion of the B factor (empirical correction) of body wave magnitude with epicentral distance can be removed by plotting the recurrence curves versus log (A/T) instead of versus m_b directly. Figure 10 shows the cumulative and discrete recurrence curves for all 6944 events listed in the LASA Daily Summary during 1971. Here the 90% threshold on the discrete curve is near a log (A/T) value of 0.1 and the 90% threshold on the cumulative curve is near a log (A/T) value of 0.0. Thus the amplitude (zero peak) of signals at the 90% cumulative threshold of LASA during 1971 was approximately 1.0 millimicrons.

We can see how the LASA/SAAC system improved its performance throughout 1971 by plotting recurrence curves for each quarter. Figure 11 shows these results. The first quarter has only two months of data, February and March, since the system was being moved and under checkout and training procedures in January.

During the last half of 1971 we discovered that the travel time anomalies used on the DP system were not correct. The correct anomalies were used in EP and entered onto DP in the same subarray order. However DP orders the subarrays differently than EP. Consequently the travel time anomalies were assigned to the wrong subarrays. These mis-assigned subarrays will be corrected in 1972. Hence the system threshold may continue to improve during the first part of 1972.

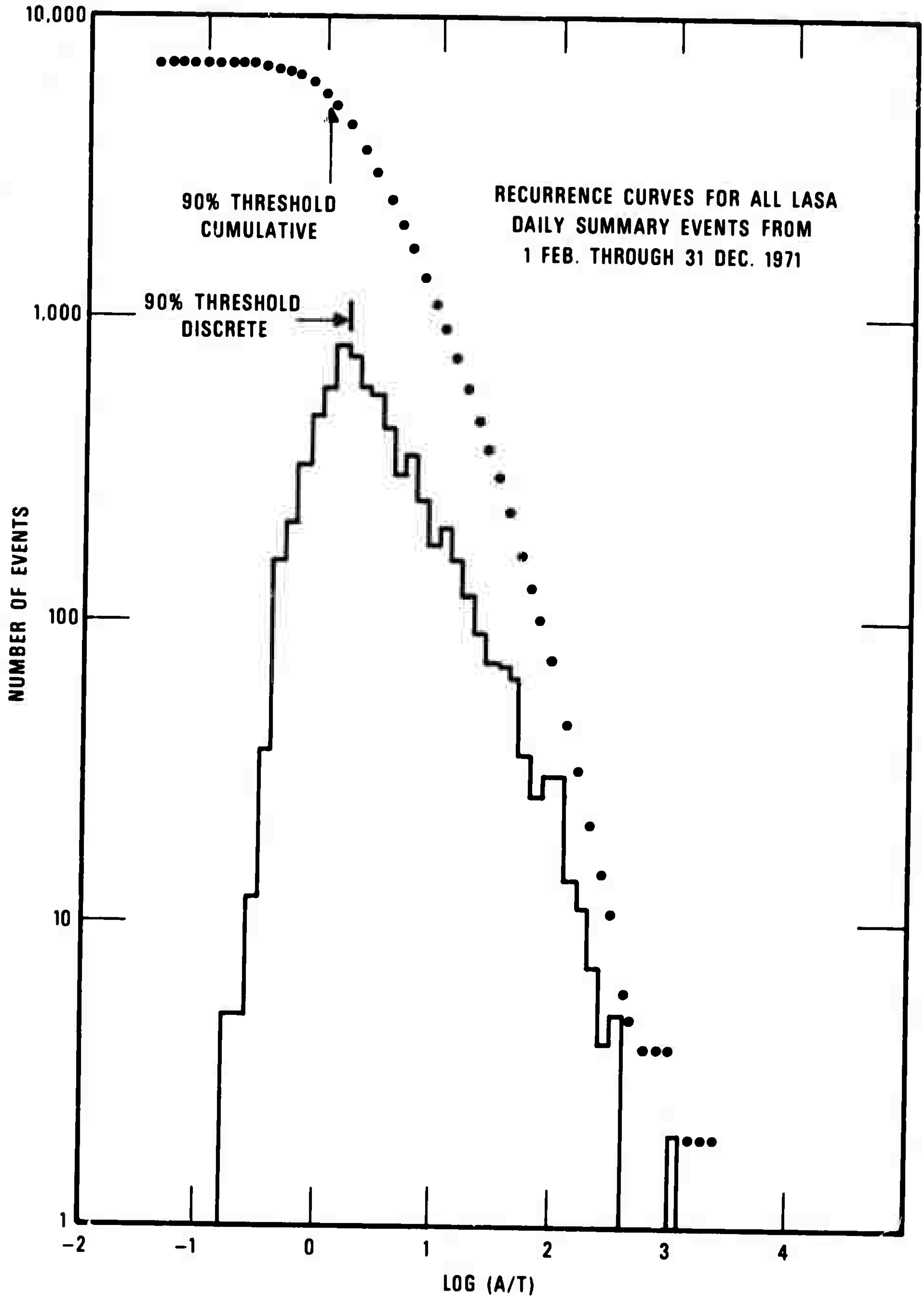

Figure 10. Recurrence curves for all LASA Daily Summary events from 1 February through December 1971.

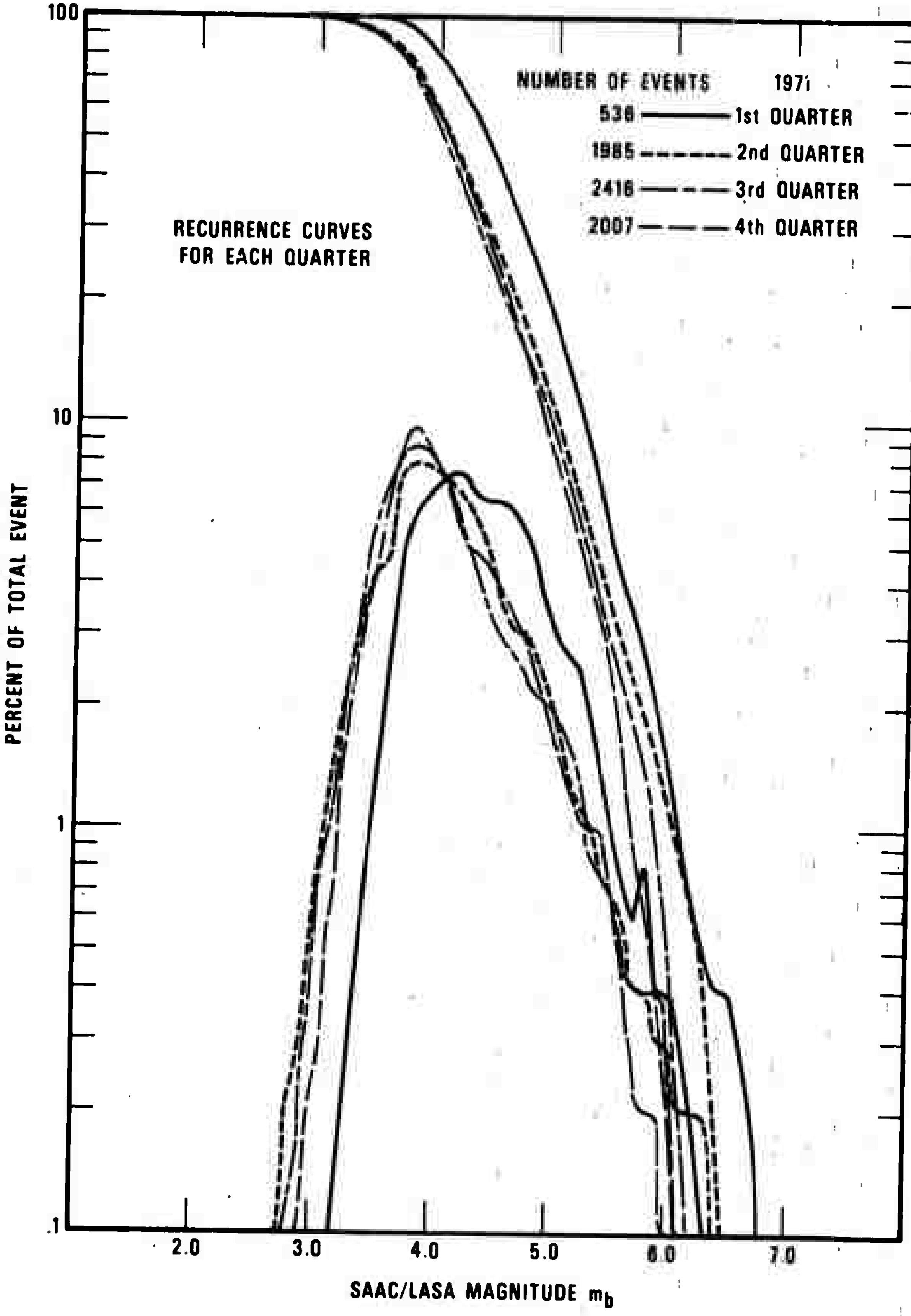

Figure 11. Recurrence curves for each quarter of 1971 vs m_b.

VI. CONCLUSIONS

A total of 6944 events were listed in the LASA Daily Summary from 1 February through 31 December 1971. During the first three months we varied the system parameters (DP detection logic and EP event threshold). From 1 May through 31 December 1971 the system parameters were held fixed, and a total of 5990 events were listed in the LASA Daily Summaries. Primarily based on these events, we arrived at the following conclusions:

1. With system parameters fixed at 10 db for the DP threshold, 14 db for the EP threshold, 3 out of 3 threshold logic, 4 out of 4 detection logic, 300 E-ring surveillance beams, and 0.9 to 1.4 Hz detection filters, the LASA/SAAC system listed an average of 450 detections per day greater than 10 db, 155 detections per day greater than 14 db, 56 events per day accepted by EP, and 24 events per day accepted by the analysts and listed in the LASA Daily Summary.
2. Of the 5990 LASA Daily Summary Events reported from 1 May through 31 December 1971, most (81.5%) are from 30° to 85° from LASA. The LASA threshold falls rapidly (B factor increases) for events beyond 85°. The LASA/SAAC system has no programming to recognize and locate events much closer than 30° and hence tends not to report them.

3. As the LASA/SAAC system is programmed we find that analyst editing is necessary. Only three of every seven events acceptable to EP are accepted by the analysts.

4. During the latter half of 1971 the two categories of signals greater than 14 db which were rejected by EP were velocity failures (10.6%) and computer malfunctions (1.4%).

5. The major categories of signals acceptable to EP but unacceptable to the analysts were non-teleseismic events (15.8%), side lobe detections (16.7%), and weak or misaligned signals (9.9%).

6. The detection level at LASA is inversely proportional to the noise level. The noise level goes up during the daylight hours and the detection rate shows a corresponding decline.

7. For events within 30^{o} to 85^{o} of LASA, discrete recurrence curves show that the LASA/SAAC system as operated in 1971 detects 90% of the events at a magnitude of 3.8. The cumulative recurrence curves indicate a 90% threshold at a magnitude of 3.7.

8. With the distance factor removed, recurrence curves of signal amplitude (number versus log (A/T) indicate a discrete 90% threshold at log (A/T) = 0.1 and a cumulative 90% threshold at log (A/T) = 0.0. Thus the cumulative 90% threshold for LASA is equivalent to the B factor (zero-to-peak) curve.

9. The SAAC/LASA system operated through 1971 with the travel time anomalies applied correctly in EP but assigned to the wrong subarrays in DP. The mis-assignment was not discovered and hence not corrected until after December 31, 1971. After correcting the DP travel time anomalies the number of signals rejected as false alarms or misaligned signals and the detection threshold may go down from the levels quoted in this report.

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APPENDIX I

Summary of Detection Log Reduction & Analyst Review and Edit Procedures

	Feb 1 to May 16	Jun	Jul	Aug	Sep	Oct	Nov	Dec
No. DP Detections	63,071	12,906	15,351	14,070	12,865	12,784	13,267	15,368
Basic EP Threshold Failures (6)	48,620	8,365	8,863	8,910	8,498	8,924	9,744	10,179
Duplicate Detections (7 & 37)	3,619	1,097	1,495	1,228	1,091	942	851	1,251
Later Phases (8)	4,036	1,167	2,163	1,422	1,114	1,021	911	1,551
Polarity-Threshold Failures (0)	2,700	536	533	382	314	318	261	276
No High Rate (3)		11	13	17	26	7	0	17
Selected for EP (1 & 33 & 5)	4,096	1,730	2,284	2,111	1,822	1,572	1,500	2,094
Reruns	614	199	62	40	64	44	18	54
Computer Malfunctions	429	84	28	12	28	15	16	13
Velocity Failures	693	262	383	278	167	141	79	136
EP System Events	3,588	1,583	1,935	1,861	1,691	1,460	1,423	1,999
Non-Reviewed Events (due to time limit)	471	0	0	0	0	0	0	0
Local Event Activity	310	262	236	329	318	327	356	424
Side Lobe Detections (duplicate & others)	288	396	439	297	296	279	238	321
Later Phases	73	42	67	73	40	56	35	25
Data Drop Outs	64	26	26	134	58	25	64	86
Weak or Misaligned Signals	866	200	224	203	201	169	152	200
Summary-Events		587	887	740	667	489	477	805
Rerun Summary Events		*31	*15	*12	*20	*12	*5	*36
Extended Processed Events		*39	*41	*73	*91	*103	*96	*102
Failed		27	26	39	58	42	39	40
Other		0	0	0	2	10	9	7
Add to Summary		12	15	34	31	51	48	55
Double Events		3			2	4	1	25
Events Reported on Daily Summary	1,516	633	917	786	720	556	531	921

*Added to sum