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RAYLEIGH WAVE ANALYSIS OF ATMOSPHERIC EXPLOSIONS

31 December 1968

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AIR FORCE TECHNICAL APPLICATIONS CENTER
Washington, D. C.

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TELEDYNE, INC.

Under

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RAYLEIGH WAVE ANALYSIS OF ATMOSPHERIC EXPLOSIONS

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ABSTRACT

During the months of July through September, 1968, a series of atmospheric nuclear explosions was detonated by France in the South Pacific. The events analyzed are those of July 7, July 15, August 3, August 24, and September 3, 1968. The analysis includes matched filtering for relative amplitude (â) measurements, body and surface wave magnitude comparisons phased summing, and ARZ-ERZ measurements. The events are discussed individually, and a summary of pertinent data is presented in several figures and tables.

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INTRODUCTION

During the months of July through September, 1968 a series of atmospheric nuclear explosions was detonated by France in the South Pacific. The events from that series analyzed in the report are those of July 7, July 15, August 3, August 24, and September 8, 1968. The analysis includes matched filtering (Alexander and Rabenstine, 1967a, 1967b) for relative amplitude ~~($\hat{a}$)~~ measurements, body and surface wave magnitude comparisons (Lambert and Turnbull, 1968), phased summing, and ARZ-ERZ measurements (Turnbull and Lambert, 1968). The events are ~~will be~~ discussed individually in the following sections, with a summary of pertinent data presented in several figures and tables.

Data Analysis

The five events of interest occurred essentially at the same coordinates. The data we wished to analyze were those recorded at LASA, TFO, UBO, and five LRSM stations (LCNM, MNNV, PGBC, RKON, and SV3QB). The data from TFO and UBO proved unusable because neither LP array was yet operational.

The LASA data were recorded digitally at 5 samples per second and decimated to 1 sample per second for analysis. The LRSM data were recorded on analog tape, digitized at the SDL at 5 samples per second, and then decimated to 1 sample per second for analysis.

The LASA data were demagnified using results of .04 Hz sine wave electro-magnetic calibrations recorded in March 1967.

Obviously these calibrations are not accurate for current data, but they are the most recent that we have available. This, however, should not affect the relative amplitude (â) values. The LRSM data were demagnified by comparison with the film records and indicated magnifications.

Only the sensors in the A,D,E, and F subarrays at LASA were used, in order to assure incoherent noise (Alexander and Rabenstine, 1967b).

The primary technique of our analysis was the matched filter. A search for events which originated in the same source region with sufficient magnitude to generate a good dispersed wavetrain was undertaken using the library program DEPTHMAG. The source region was shown to be extremely aseismic, with only one event meeting the needed specifications (i.e., within 10°). An earthquake occurred at 18.4S, 132.9W of magnitude 5.5 on March 6, 1965. LASA was not in operation at that time. However, an ideal matched filter was furnished by one of the explosions itself; the event of August 24. The body wave magnitude was 4.8 and the surface wave magnitude was found to be 4.7. A dispersed wavetrain with good S/N was readily visible on the records at LASA. Thus, the â values measured are amplitudes of the various events relative to the event of August 24.

The bandpass filter which was used on the raw data either before phased summing or when matched filtering was simply a shaping applied to the Fourier transform. The transform was multiplied by a linear taper which went from 1.0 to 0.0 as the frequency went from 0.02 to 0.0167 Hz and 0.1 to 0.125 Hz. Transform values outside the frequency range of 0.0167 to 0.125 Hz were set to zero.

A. July 7

Long period analysis of this event by all techniques proved quite futile. Approximately one-half hour before detonation, an earthquake of magnitude 5.1* (m_b) occurred in Mindanao, Phillipines (9.6N, 126.5E). The paths were such that the wavetrains of the earthquake and the explosion overlapped at LASA and most LRSM stations. Results of the phased sum are shown in Figure 1 and of the matched filter and phased sum in Figure 2.

B. July 15

This event was determined to have a body wave magnitude (m_b) of 4.3* and a surface wave magnitude (Ms) of 4.1. The surface wave magnitude is considerably larger than that for an underground nuclear explosion of comparable body wave magnitude (approximately two orders of magnitude), an indication that an atmospheric nuclear explosion generates a great deal more long period energy. In a plot of Ms vs. m_b (Figure 13), the events of this series are shown along with earthquakes and underground nuclear explosions. For the same order body wave magnitude, we find that atmospheric explosions generate even more long period energy than earthquakes. The energy difference is further displayed in plots of ARZ vs. m_b (Figure 14) and ERZ vs. m_b (Figure 15).

The signal as recorded at LASA was readily visible (Figure 3). The records of eleven long-period instruments

* All body wave magnitudes are from the LASA bulletin; all surface wave magnitudes are computed in the ARZ-ERZ program (Turnbull and Lambert, 1968).

were band-pass filtered from 10 to 50 seconds (period) and phase summed using a velocity of 3.75 km/sec. From an average S/N ratio of 4.0 for each channel, the sum channel S/N was 9.5.

The LASA matched filter output was quite impressive, as could be expected from the visible signal (Figure 4). The S/N ratio of the matched filter output had an average of 11.2 ($\hat{a}$ avg. = 0.248), and the S/N ratio of the sum of the matched filter outputs from eleven channels was 34.7 ($\hat{a}$ = 0.238). The summed matched filter output was quite symmetric and narrow indicating high correlation between the filter and event. The standard deviation of the $\hat{a}$ values was 14% of the mean value.

When the five LRSM signals were matched filtered and beam formed with the LASA matched filter outputs on 4 km/sec, a further S/N enhancement to 47.1 was achieved (Figure 5), with an $\hat{a}$ of 0.209 on the sum. The mean of all $\hat{a}$ values was 0.234 with a standard deviation of 16%.

C. <u>August 3</u>

This event was determined to have a body wave magnitude (m_b) of 4.1 and a surface wave magnitude (Ms) of 4.3. As in the July 15 event, a great deal more long period energy than in an underground explosion of the same m_b is generated. However, the signal as recorded at LASA was not as discernible as the July 15 event (Figure 6), the average S/N being 3.1 and the S/N of the phase summed trace of eleven channels only 3.8.

This reason for the very small indicated increase in S/N is probably that the signal levels measured on the individual traces were too high because of noise being mistakenly measured as signal.

The LASA matched filter output, though, showed a greater improvement upon summation (Figure 7). While the average S/N for eleven matched filtered channels was still only 3.1 ($\hat{a}$ avg. = 0.0695), the sum S/N was 8.3 ($\hat{a}$ = 0.06). The standard deviation of $\hat{a}$ values was 32%, again due to the relatively low S/N ratios.

Once again beamforming the 5 LRSM matched filtered signals with the LASA matched filtered signals on a velocity of 4 km/sec increased the S/N to 9.56 (Figure 8) with a sum trace $\hat{a}$ of 0.057. The mean of all $\hat{a}$ values was 0.0698 with a standard deviation of 24%.

D. August 24

This event had a body wave magnitude (m_b) of 4.8 and a surface wave magnitude (M_s) of 4.75. The Rayleigh-wave train was very well defined on the LASA records, hence its use as the matched filter for the other events (Figure 9). The S/N for an average band pass filtered channel was 17.9, while the S/N of the phased sum of thirteen channels is 51.7.

E. September 8

This event was the second largest of the series and had a body wave magnitude of 4.6. The surface wave magnitude was measured to be 4.6, and the signal at LASA was well recorded. The previous conclusions on surface wave energy from atmospheric explosions are again verified.

The beam forming of the band pass filtered surface waves at LASA worked quite well giving an improvement in S/N from a mean of 6.3 on the individual traces to 14.1 on the sum trace (Figure 10.).

The matched filter also worked well, as expected with a large signal. The LASA matched filtered traces achieved a mean S/N of 13.51 ($\hat{a}$ avg. = 0.541) and summed to give a S/N of 37.77 ($\hat{a}$ = 0.508) (Figure 11). The LRSM matched filtered data, which had mean S/N of 11.35 ($\hat{a}$ avg. = 0.449), combined with the LASA data to give a sum S/N of 42.33 ($\hat{a}$ =0.488) (Figure 12). The standard deviation of all the $\hat{a}$ values was 22% of the mean.

CONCLUSIONS

1. In comparing atmospheric explosions with underground explosions, we find the former generate more long period energy than the latter, with the surface wave magnitudes generally two orders of magnitude greater.

2. The "best" matched filter proved to be a large atmospheric shot from the same region.

3. The LRSM matched filtered data was beam formed with the LASA matched filtered data to give S/N values very near that which is predicted for coherent signals in incoherent noise. The exception was a case where the actual values of S/N on the individual LASA channels were too low to measure accurately.

4. Reasonably consistent values of $\hat{a}$ were obtained across the network of stations used.

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Alexander, S.S., and D.B. Rabenstine, 1967a, Detection of surface waves from small events at teleseismic distances, SDL Report No. 175.

Alexander, S.S., and D.B. Rabenstine, 1967b, Rayleigh wave signal to noise enhancement for a small teleseism using LASA, LRSM, and observatory stations, SDL Report No. 194.

Lambert, D.G. and L.S. Turnbull, 1968, Personal Communication.

Turnbull, L.S. and D.G. Lambert, 1968, Rayleigh wave discrimination techniques between underground explosions and earthquakes, SDL Report No. 211.

Table I Summary of $\hat{a}$ Values

	15 JULY			3 AUGUST			8 SEPTEMBER		
	$\hat{a}$	(S/N)	n	$\hat{a}$	(S/N)	n	$\hat{a}$	(S/N)	n
LASA									
MEAN	.2475	(11.20)**	11	.0695	(3.13)**	11	.5407	(13.51)**	12
MAX	.3021	(7.63)*		.1007	(4.99)*		.8482	(14.55)*	
MIN	.1758	(12.56)*		.0361	(1.47)*		.3191	(16.31)*	
SQ. MEAN	.061256			.0048289			.292356		
MEAN SQ.	.062469			.0051970			.307805		
VARIANCE	.001213			.0003681			.015449		
STO OEV	.0348			.0192			.1243		
SUM VAL	.2379	(34.68)*		.0605	(8.33)*		.5075	(37.77)*	
LRSM									
MEAN	.2041	(15.76)**	5	.0706	(2.53)**	5	.4485	(11.35)**	5
MAX	.2255	(16.44)*		.0820	(2.73)		.4862	(17.46)*	
MIN	.1467	(13.95)*		.0566	(1.86)*		.3779	(8.2?)*	
SQ. MEAN	.041657			.0049855			.201152		
MEAN SQ.	.042536			.0050672			.202810		
VARIANCE	.000879			.0000817			.001658		
STD. OEV	.0296			.0090			.0407		
SUM VAL	.1620	(34.30)*		.0480	(4.06)*		.4355	(29.66)*	
ALL									
MEAN	.2340	(12.63)**	16	.0698	(2.94)**	16	.5136	(12.88)**	17
MAX	.3021	(7.63)*		.1007	(4.99)*		.8482	(14.55)*	
MIN	.1467	(13.95)*		.0361	(1.47)*		.3191	(16.31)*	
SQ. MEAN	.054756			.0048776			.263785		
MEAN SQ.	.056240			.0051564			.276924		
VARIANCE	.001484			.0002788			013139		
STO. OEV	.0385			.0167			.1146		
SUM VAL	.2085	(47.08)*		.0570	(3.56)*		.4879	(42.33)*	

* S/N of trace with with indicated $\hat{a}$
** Mean S/N of traces in set
n = number of traces in set

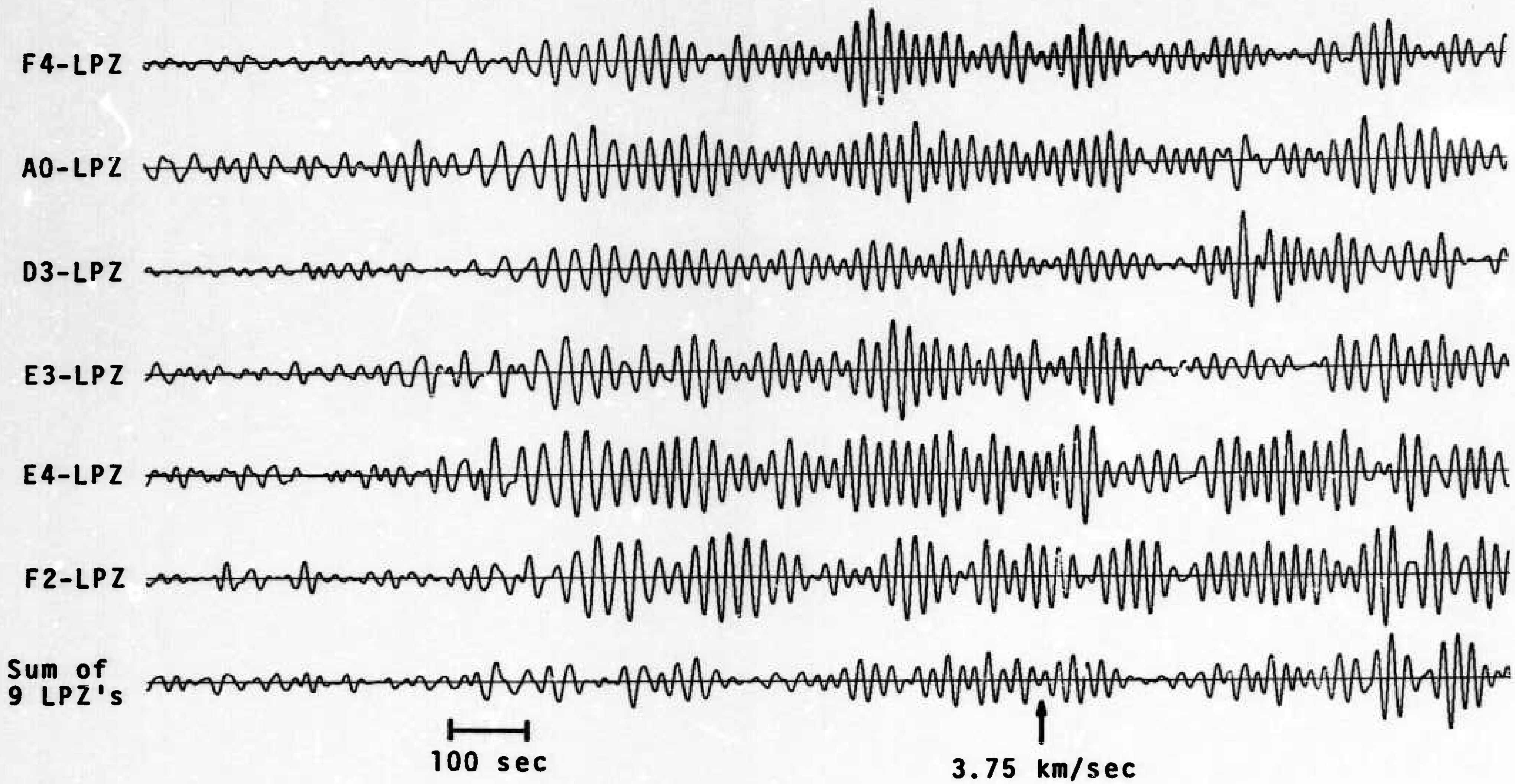

Figure 1. Event of 7 July 1968. LASA LPZ Rayleigh waves, band pass filtered (10-50 sec. period) and beam formed on 3.75 km/sec. Visible event is the Philippine event described in the text.

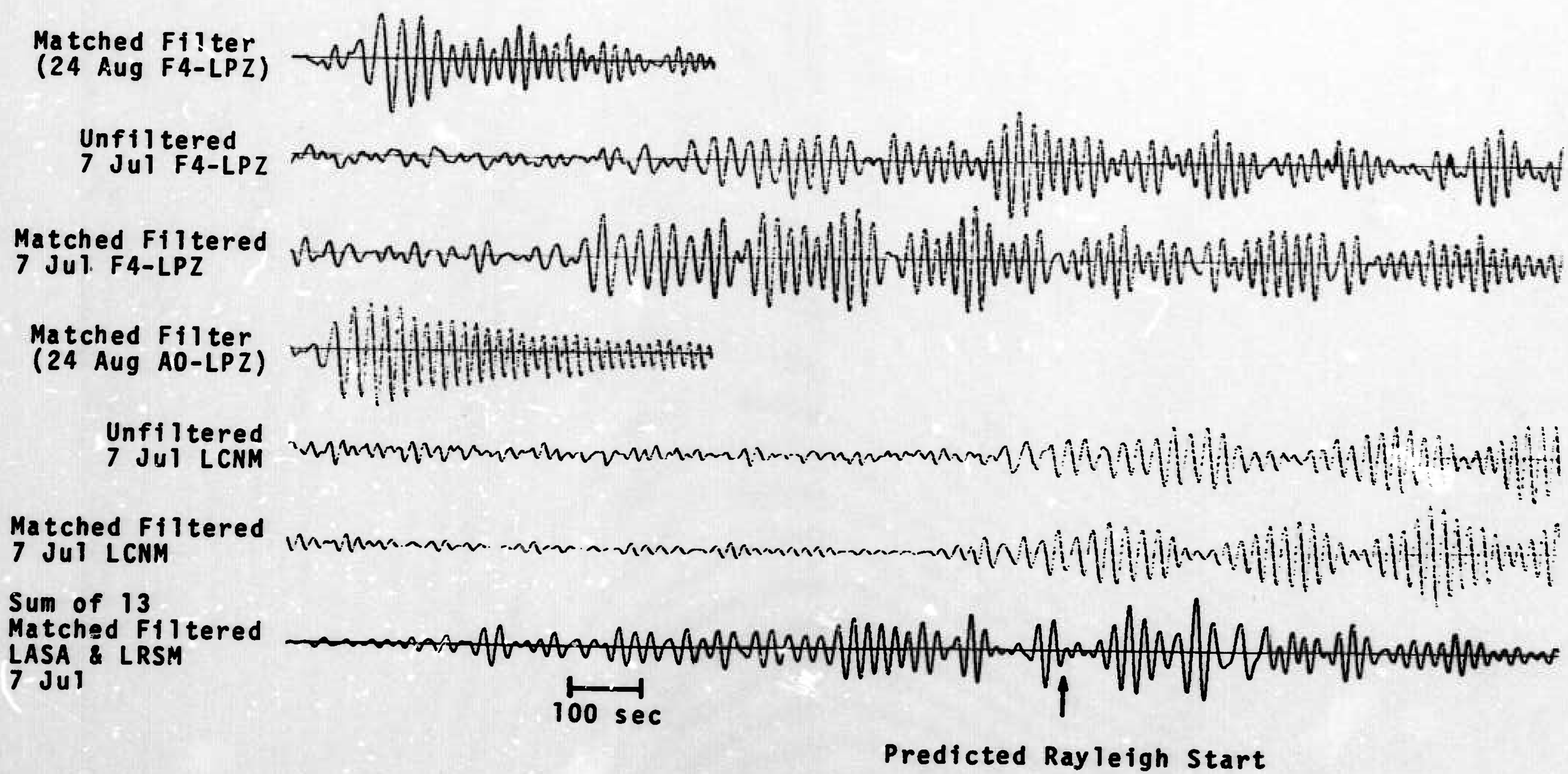

Figure 2. Event of 7 July 1968. LASA & LRSM LPZ Rayleigh waves, matched filtered with signals from the event of 24 August 1968. Interfering event is the Philippine event described in the text.

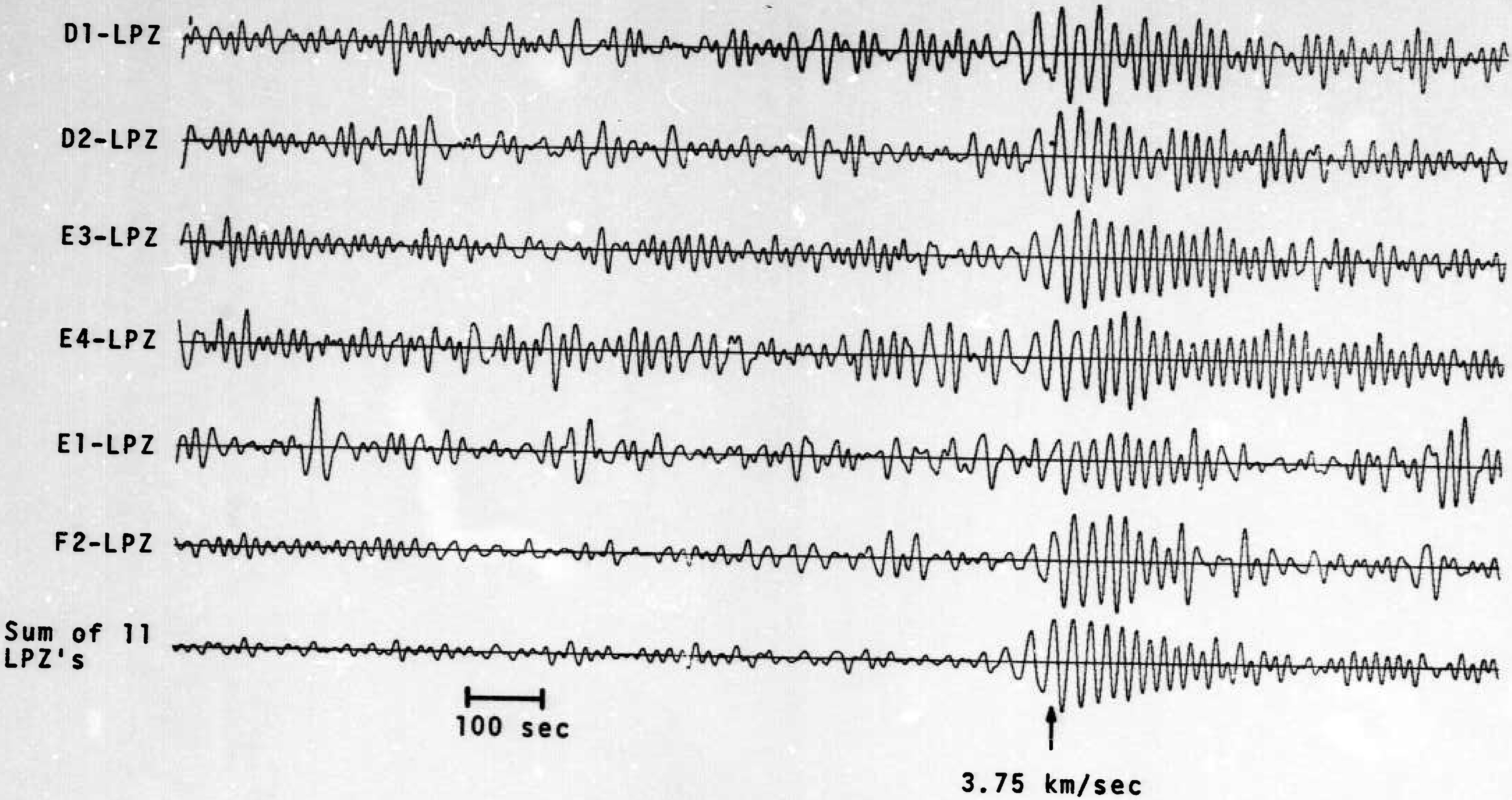

Figure 3. Event of 15 July 1968. LASA LPZ Rayleigh waves, band pass filtered (10-50 sec. period) and beam-formed on 3.75 km/sec.

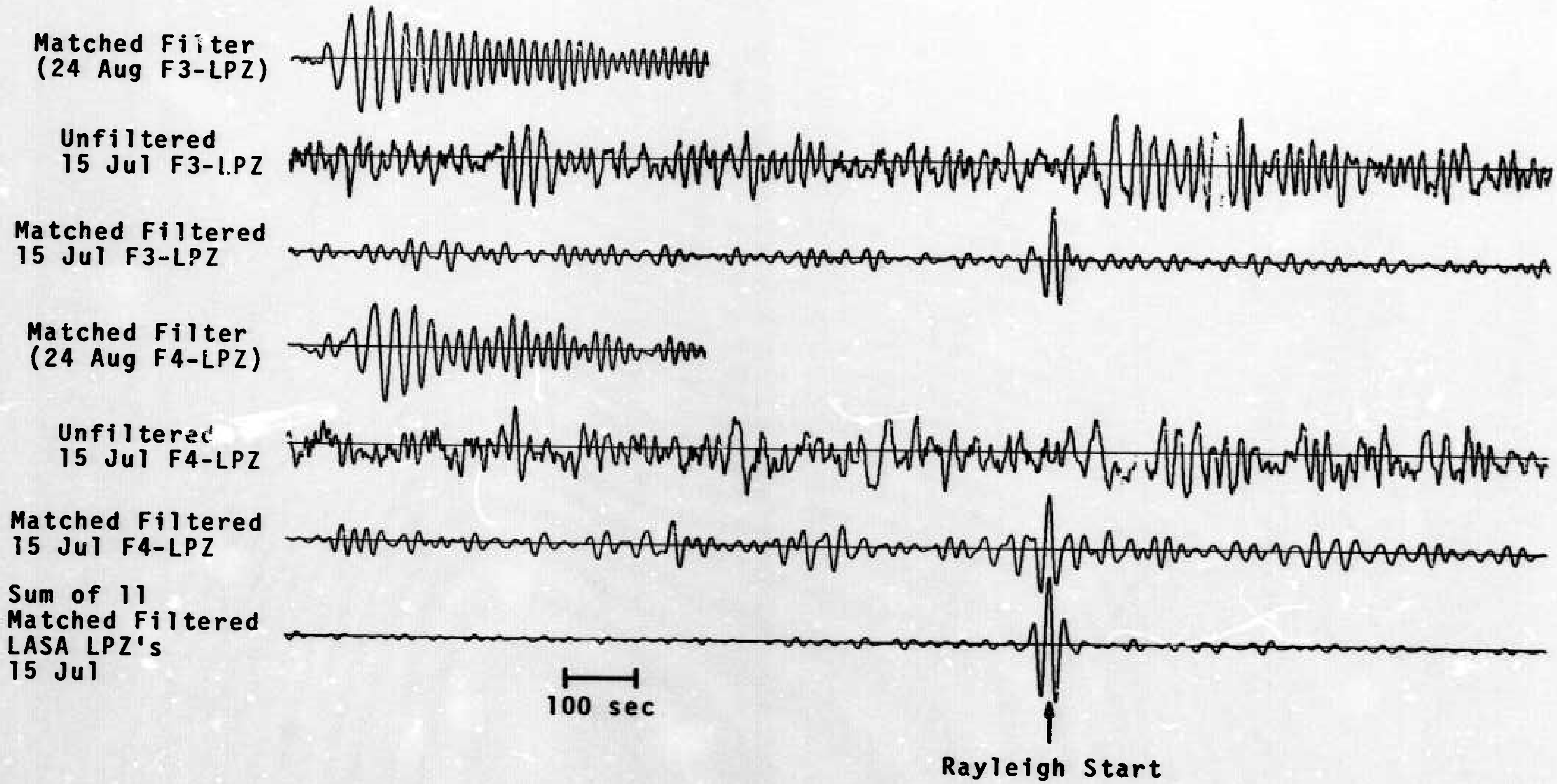

Figure 4. Event of 15 July 1968. LASA LPZ Rayleigh waves, matched filtered with signals from event of 24 August 1968. Sum of LASA matched filtered signals.

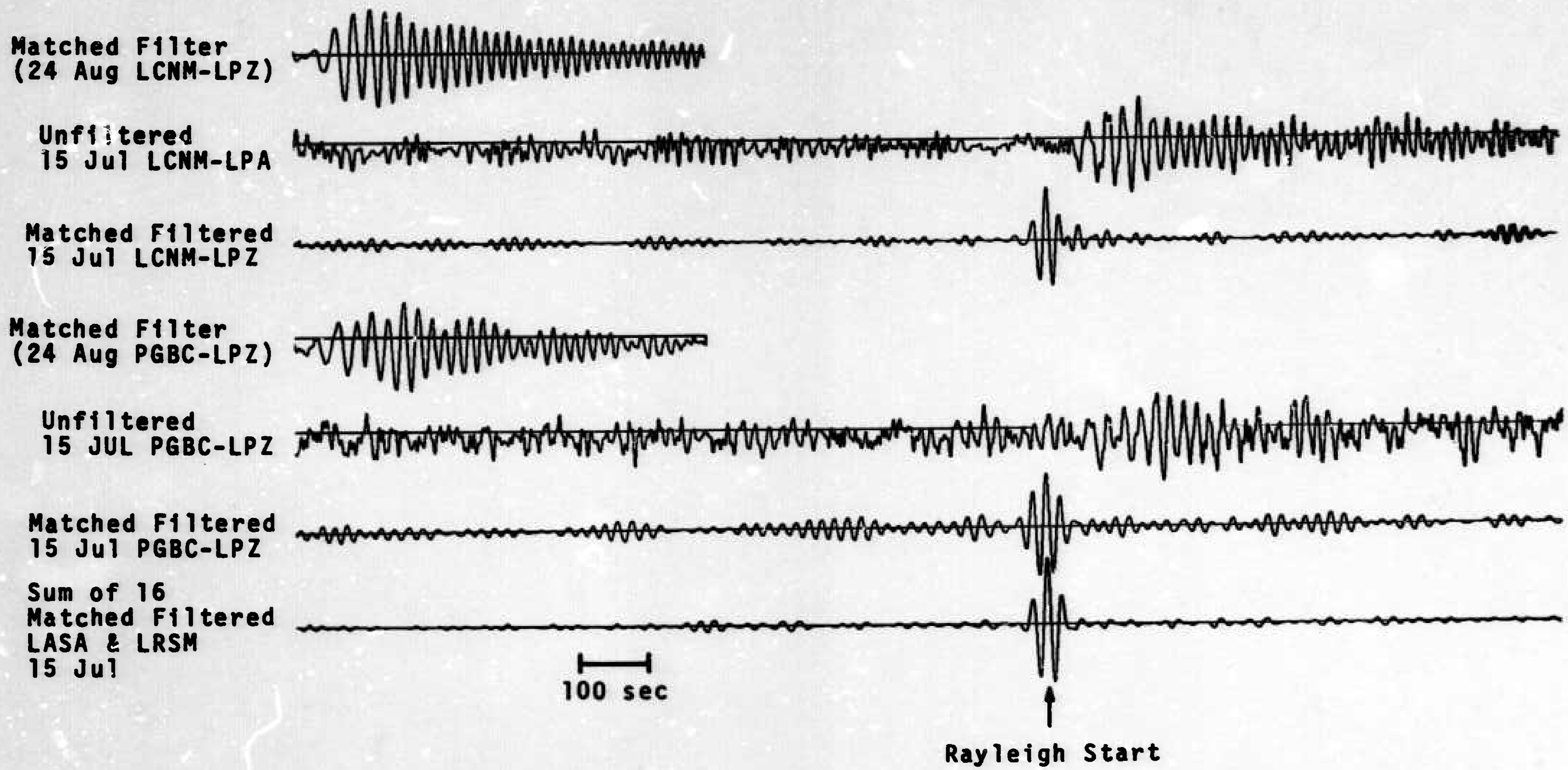

Figure 5. Event of 15 July 1968. LRSM LPZ Rayleigh waves, matched filtered with signals from event of 24 August 1968. Sum of LASA and LRSM matched filtered signals.

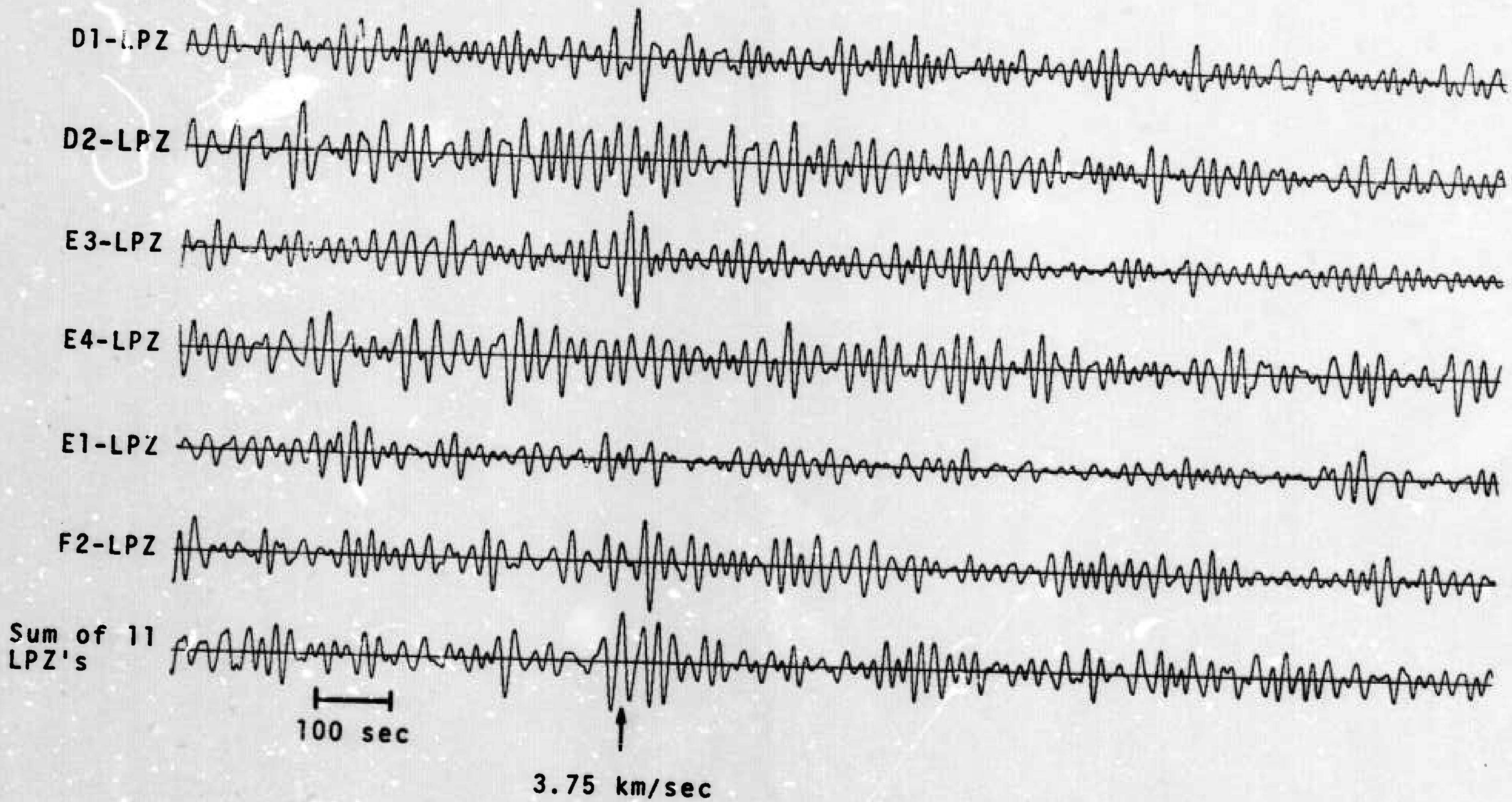

Figure 6. Event of 3 August 1968. LASA LPZ Rayleigh waves, band pass filtered (10-50 sec. period) and beam-formed on 3.75 km/sec.

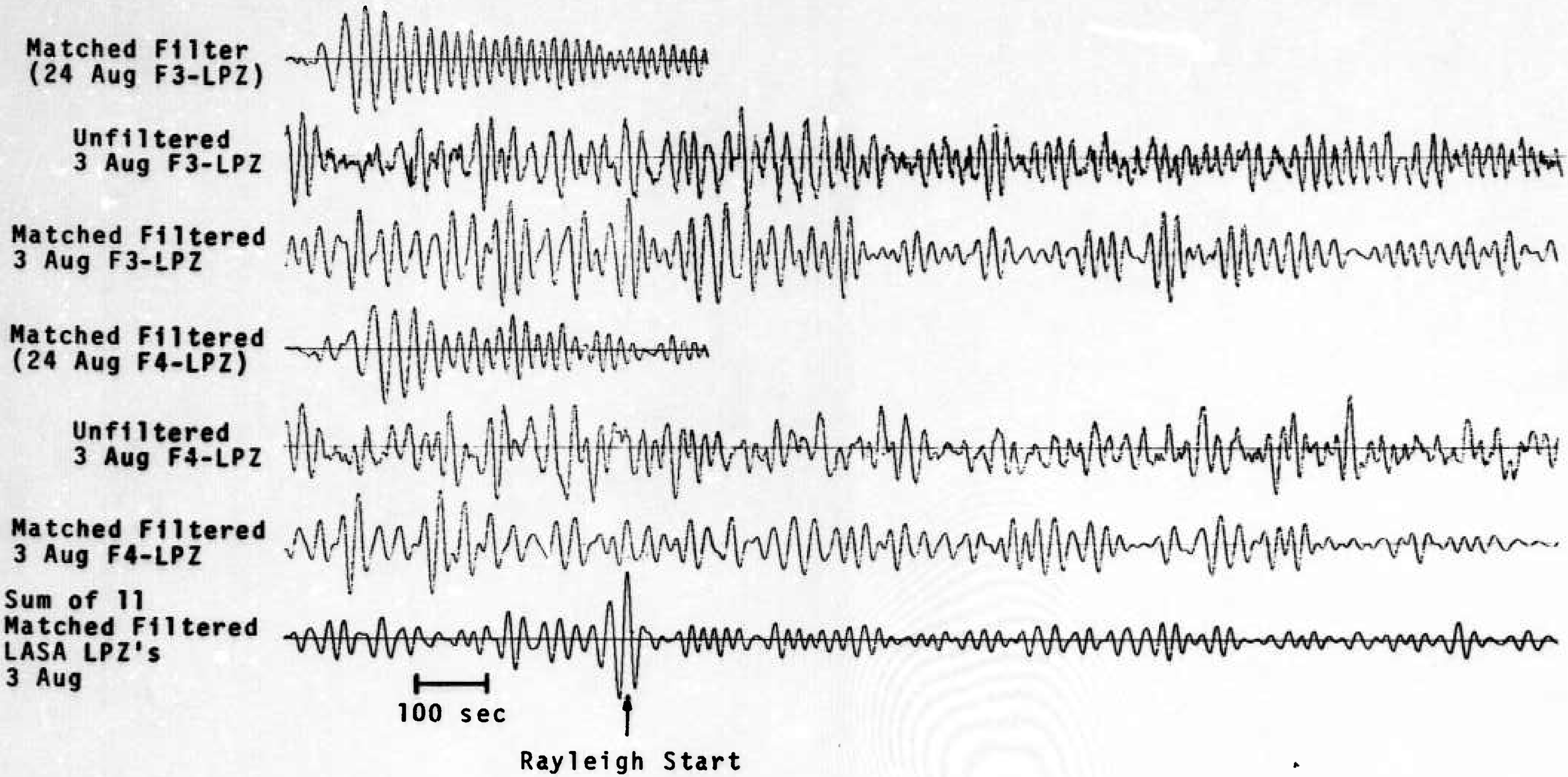

Figure 7. Event of 3 August 1968. LASA LPZ Rayleigh waves, matched filtered with signals from event of 24 August 1968. Sum of LASA matched filtered signals.

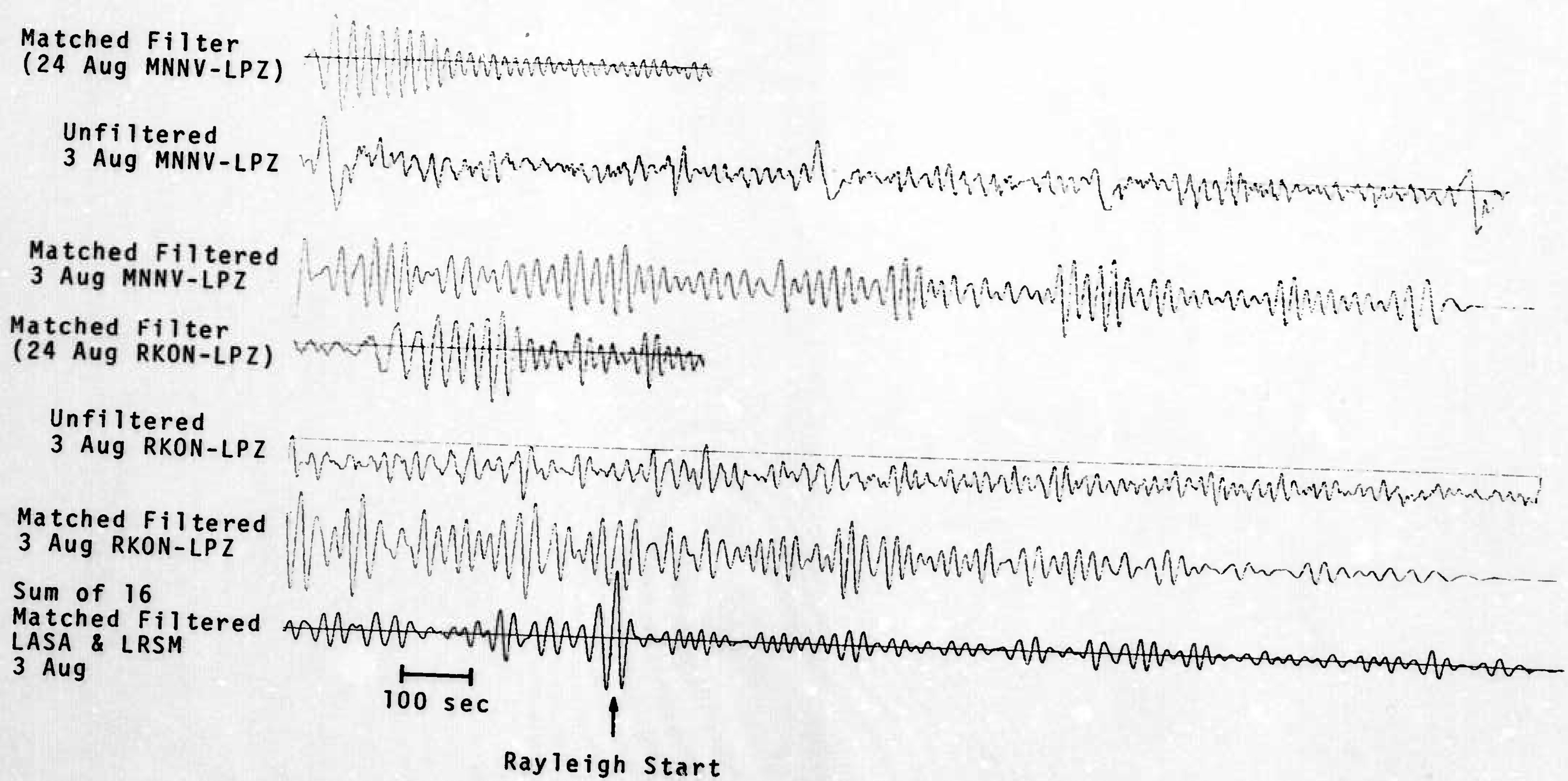

Figure 8. Event of 3 August 1968. LRSM LPZ Rayleigh waves, matched filtered with signals from event of 24 August 1968. Sum of LASA and LRSM matched filtered signals.

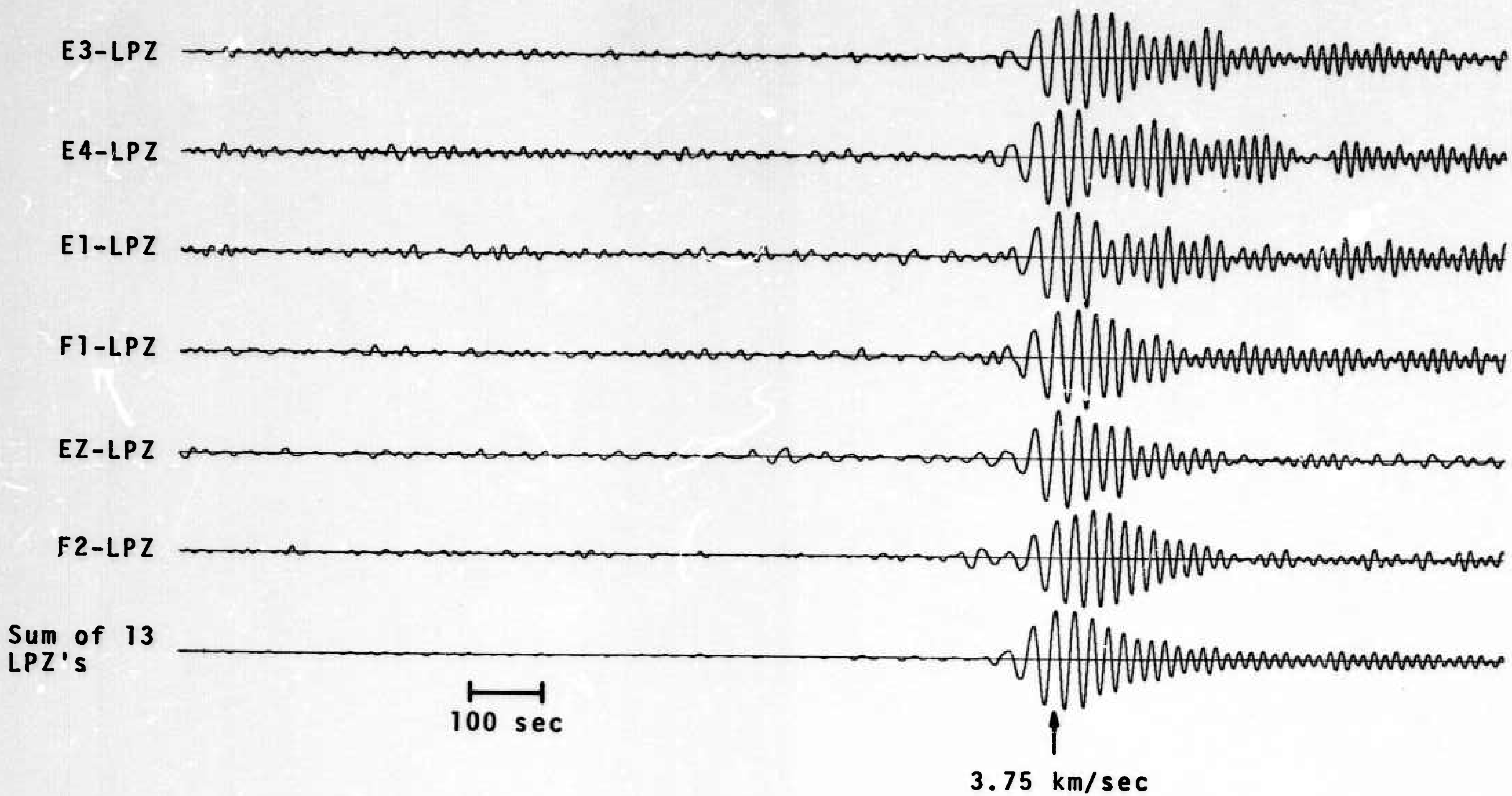

Figure 9. Event of 24 August 1968. LASA LPZ Rayleigh waves, band pass filtered (10-50 sec. period) and beam-formed on 3.75 km/sec.

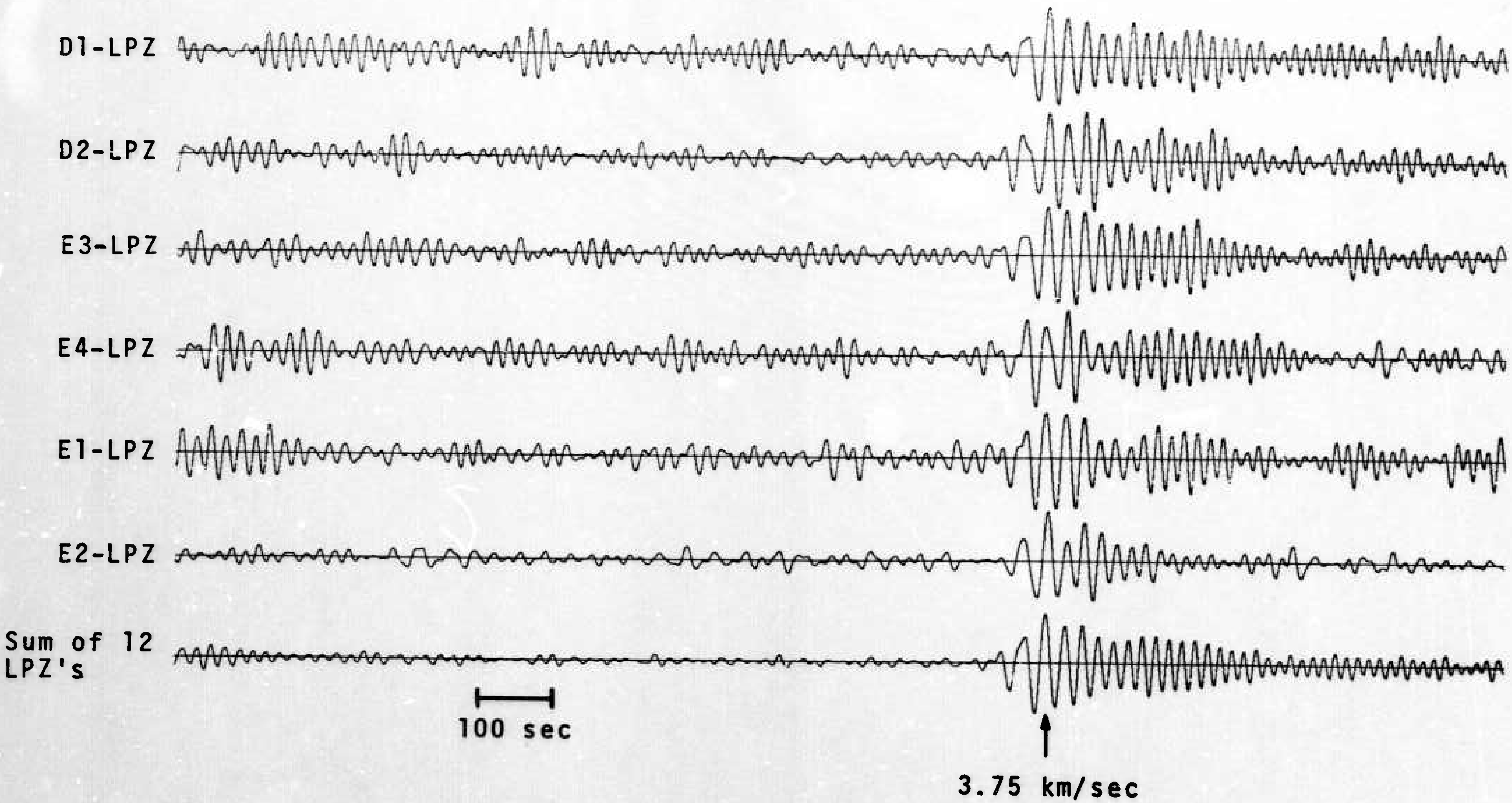

Figure 10. Event of 8 September 1968. LASA LPZ Rayleigh waves, band pass filtered (10-50 sec. period) and beam-formed on 3.75 km/sec.

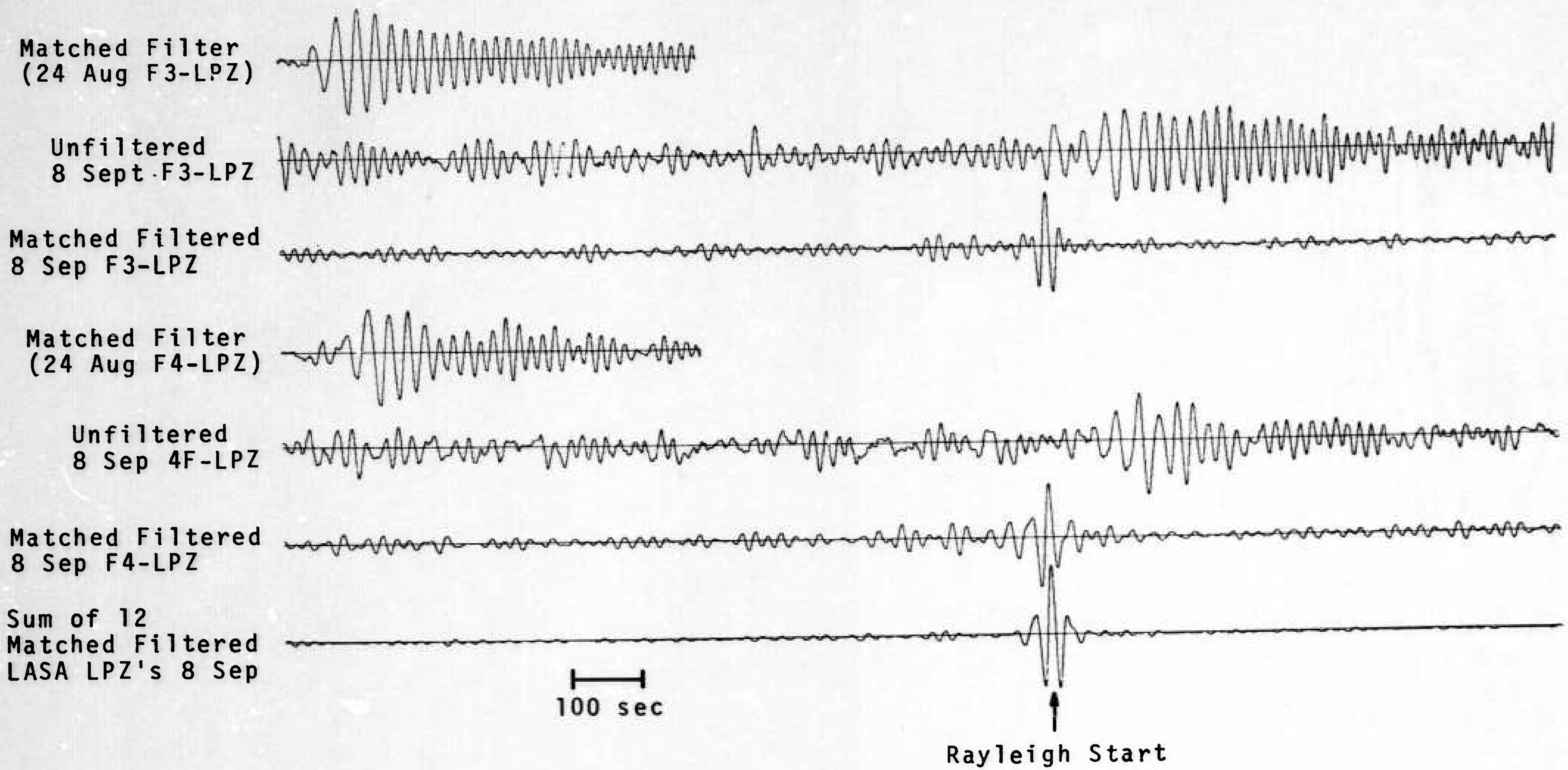

Figure 11. Event of 8 September 1968. LASA LPZ Rayleigh waves matched filtered with signals from event of 24 August 1968. Sum of LASA matched filtered signals.

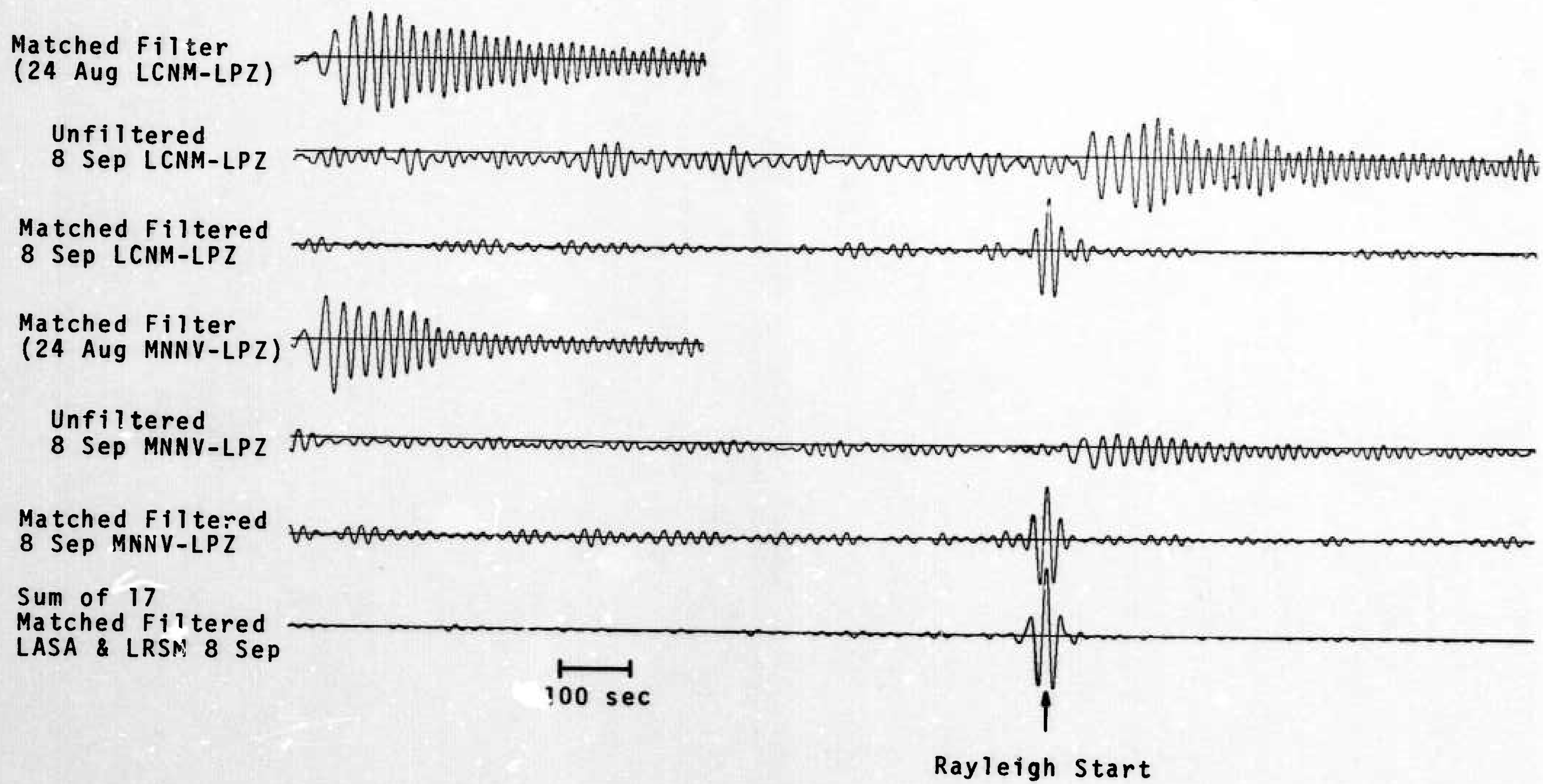

Figure 12. Event of 8 September 1968. LRSM LPZ Rayleigh waves, matched filtered with signals from event of 24 August 1968. Sum of LASA and LRSM matched filtered signals.

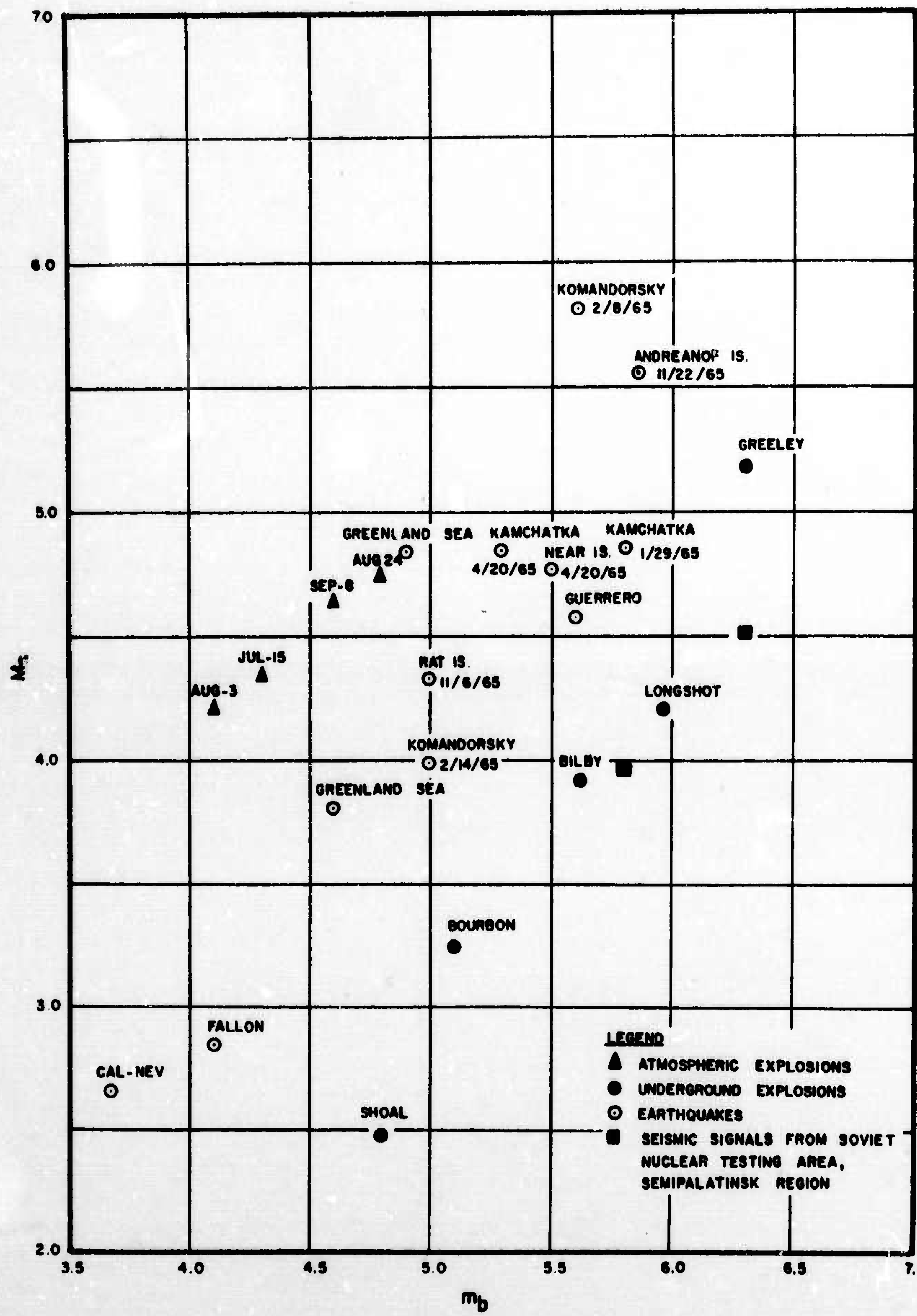

Figure 13. M_s vs m_b comparison of various seismic signals

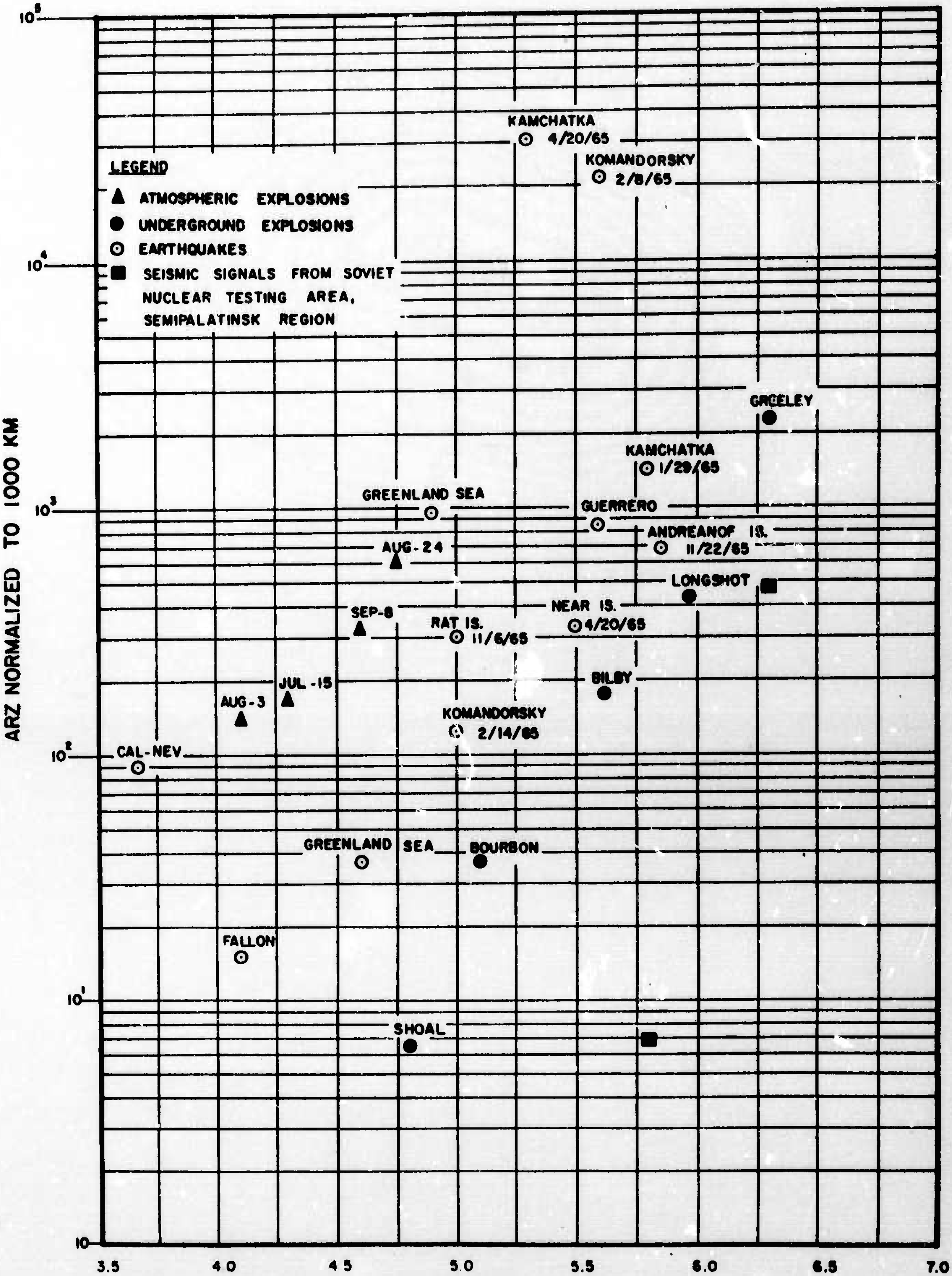

Figure 14. ARZ vs m_b comparison of various seismic signals

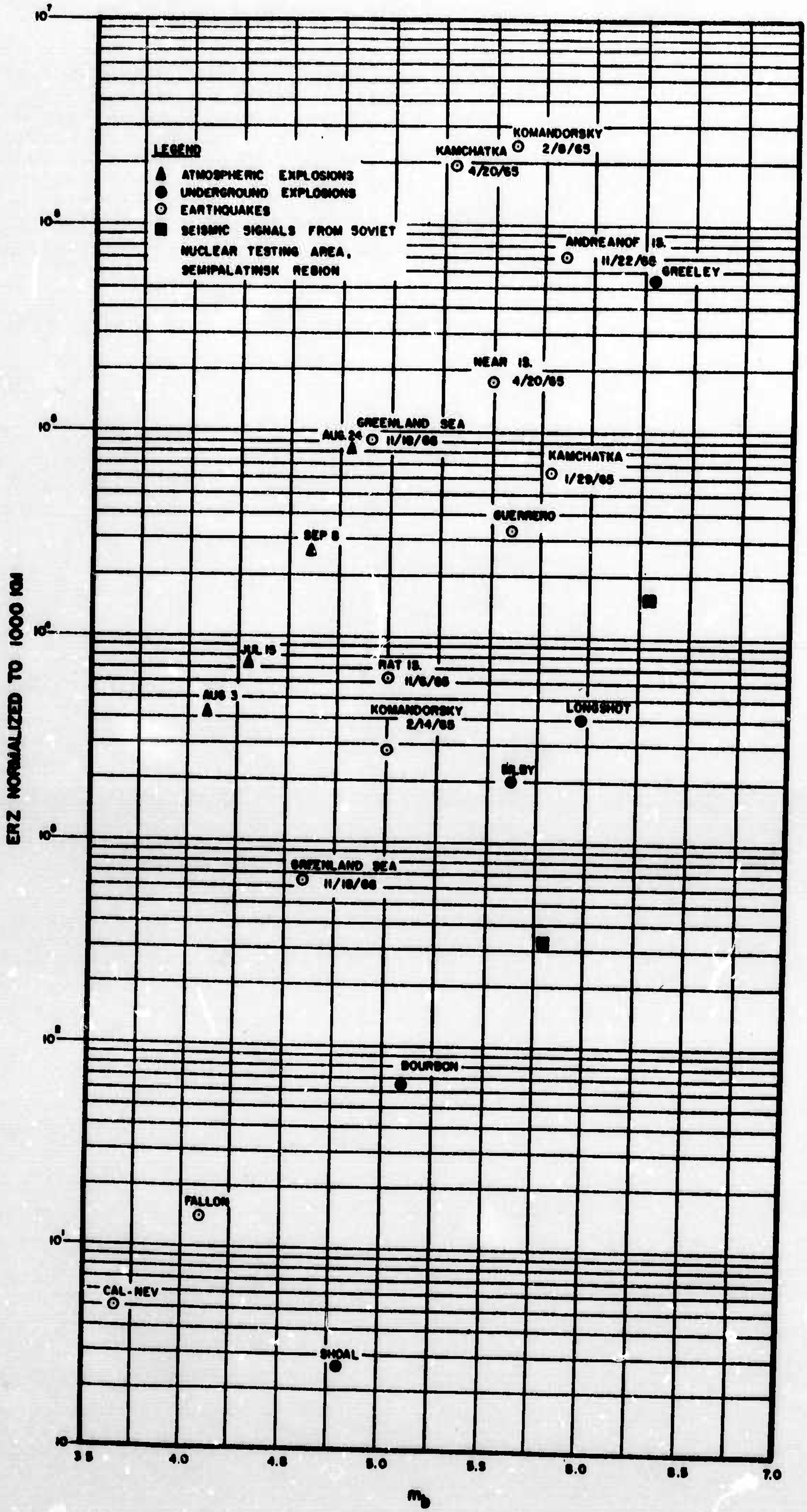

Figure 15. ERZ vs m_b comparison of various seismic signals

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13. ABSTRACT

During the months of July through September, 1968, a series of atmospheric explosions was detonated in the South Pacific. The events analyzed are those of July 7, July 15, August 3, August 24, and September 3, 1968. The analysis includes matched filtering for relative amplitude (â) measurements, body and surface wave magnitude comparisons phased summing, and ARZ-ERZ measurements. The events are discussed individually, and a summary of pertinent data is presented in several figures and tables.

14. KEY WORDS
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