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7.2 Analysis of data from the British station GAM near Garm, USSR for Soviet nuclear explosions

This contribution is a follow-up to earlier work (Ringdal and Marshall, 1989; Hansen *et al*, 1989; and Hansen and Ringdal, 1989) aimed at evaluating the stability of seismic Lg magnitudes for yield estimation purposes. In particular, these efforts have involved analyzing available Lg data from Soviet nuclear explosions at the Shagan River, Semipalatinsk test site, and conducting comparative analyses of Lg and P recordings at various seismograph stations.

Hansen *et al* (1989) analyzed data recorded at four digital stations installed by IRIS in the Soviet Union, and found an excellent correspondence between Lg measurements at these stations and the NORSAR M(Lg) estimates published by Ringdal and Marshall (1989). Furthermore, they noted the very high Lg signal-to-noise ratio observed at the IRIS stations, in particular ARU and GAR, and concluded that reliable Lg measurements at these stations would be possible for explosions as small as $m_b = 4.0$, assuming normal noise conditions.

Hansen and Ringdal (1989) extended the analysis to data from the China Digital Seismograph Network (CDSN), which is operated by the USGS in cooperation with the State Seismological Bureau, Beijing. Two of the CDSN stations, WMQ in Urumqi and HIA in Hailar, have particularly good Lg propagation paths from Semipalatinsk, and they based their analysis on data from these two stations.

In this paper, we extend the analysis to data from a broad-band seismic station, GAM, installed very near the IRIS station near Garm, USSR (The BSVRP Working Group, (1989)). This data supplements the previously sparse data from GAR and allows the comparison of two closely separated seismic stations.

Fig. 7.2.1 shows the locations of several stations in the USSR and China in relation to the test site, as well as locations of the NORSAR. (The GAM station and GAR IRIS station are located at the same place on the map and indicated only by the GAR symbol.) The station GAM at a distance of about 1380 km shows excellent Lg recordings of Semipalatinsk explosions, as illustrated by the examples in Fig. 7.2.2.

In the analysis of GAM Lg recordings, we have employed the exact same procedure as described for IRIS data by Hansen *et al* (1989), and the details will not be repeated here. Data from a total of 6 Shagan River explosions, dating back to 1988, were provided to us for this analysis by the BSVRP Group in Britain. Table 7.2.1 lists these events along with the estimated parameters.

Fig. 7.2.3 shows a comparison of GAM and NORSAR log RMS (Lg) estimates for these 6 events. The slope of the plot is 0.92, and the orthogonal standard deviation of the differences between the two stations is only 0.035 units. This is essentially the same scatter found earlier by Hansen *et al* (1989) when comparing data from NORSAR and the Soviet station ARU, and confirms the excellent stability of the RMS Lg estimates.

As a contrast to these well recorded events, Fig. 7.2.4 illustrates the capabilities of the GAM station to record an m_b(P) 3.8 event from the Shagan River test site on day 270 (September 26) of 1988. (This magnitude is based on the NORSAR m_b(P) of 4.3 with an assumed regional correction of 0.5 units for comparison to world wide m_b estimates and therefore must be considered somewhat uncertain). The unfiltered broad band trace at GAM essentially shows no signal for this event, however the band pass filtered trace clearly shows energy arriving that can be identified as Lg with a signal to noise ratio of about 2. (Similar SNR was obtained by Hansen *et al* (1989) for the recording at ARU for this event.) This SNR is near the lower limit of about 1.5 for allowing reliable RMS Lg estimates at a single site.

Fig. 7.2.5 illustrates the stability of the RMS Lg amplitudes by comparing GAM and ARU. These stations are chosen as they are the only pair for which we have Lg recordings of the m_b(P) 3.8 event shown in Fig. 7.2.4 and so illustrate the stability of measurement covering a span of two full magnitude units. Here we again have a slope of very nearly one still with an orthogonal standard deviation of only 0.026 logarithmic units (i.e. magnitude units).

Fig. 7.2.6 compares the signal-to-noise ratios (SNR) (defined as RMS Lg signal to pre-P RMS noise in the 0.6 to 3.0 Hz band) for stations at various distances, using 5 large explosions. The range in magnitude (m_b) is from 5.2 for the event on day 317 of 1988 to 6.1 for the JVE event on day 258 of 1988. The event on day 317 indicates the minimum for which RMS Lg was measured at NORSAR at a distance of about 4200 km with a signal to noise ratio of about 1.1. For this same event a signal to noise ratio of about 30 is observable at ARU and GAR at a distance of about 1500 km and about 80 at WMQ at a distance of 950 km. Again, the event at day 258 of 1988 in Fig. 7.2.6 (shown with the open circle around a plus sign) shows an SNR gain of nearly 100 between NORSAR with an SNR of 3.5 and WMQ with an SNR of 331. (It should be noted that the low SNR for this event at ARU is due to the fact that this event was only recorded on the low gain channel which does not adequately resolve the background noise.) It can be seen that the SNR for GAM fits nicely to the trend as a function of distance, and actually is slightly better than for GAR for all common events.

In conclusion, our studies confirm that Lg magnitude estimates of Semipalatinsk explosions are remarkably consistent between stations widely distributed in epicentral distance and azimuth. It thus appears that a single station with good signal-to-noise ratio can provide m_b(Lg) measurements with an accuracy (one standard deviation) of about 0.03 magnitude units. Therefore, Lg signals appear to provide an excellent basis for supplying estimates of the yields of nuclear explosions even down to below one kiloton, when such signals are recorded at high-quality digital in-country seismic stations, and when calibrated by access to independent (non-seismic) yield information for a few nuclear explosions at the test sites of interest. For a review of previous studies of Lg amplitudes and a more detailed account of this work see Hansen *et al* (1990).

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References

The BSVRP Working Group (1989): The British Seismic Verification Research Project (BSVRP), *Q. J. R. Astr. Soc.*, 30, 311-324.

Hansen, R.A., F. Ringdal and P.G. Richards (1989): Analysis of IRIS data for Soviet nuclear explosions, *NORSAR Semiannual Tech. Summary, 1 Oct 1988 - 31 Mar 1989*, NORSAR Sci. Rep. 2-88/89.

Hansen, R.A. and F. Ringdal (1989): Analysis of data from the China Digital Seismograph Network (CDSN) for Soviet nuclear explosions, *NORSAR Semiannual Tech. Summary, 1 Apr 1989 - 30 Sep 1989*, NORSAR Sci. Rep. 1-89/90.

Hansen, R.A., F. Ringdal and P.G. Richards (1990): The Stability of RMS Lg Measurements, and Their Potential for Accurate Estimation of the Yields of Soviet Underground Nuclear Explosions. Manuscript accepted by *Bull. Seism. Soc. Am.*.

Ringdal, F. and P.D. Marshall (1989): Yield determination of Soviet underground nuclear explosions at the Shagan River Test Site, *NORSAR Semiannual Tech. Summary, 1 Oct 1988 - 31 Mar 1989*, NORSAR Sci. Rep. 2-88/89.

No.	Date	m_b	GAM Lg
1	88258	6.03	3.184
2	88270	3.8	1.196
3	88317	5.20	2.521
4	88352	5.80	3.034
5	89022	6.0	3.161
6	89043	5.90	2.923

Table 7.2.1 Magnitudes (m_b) and log RMS Lg values at GAM for 6 explosions analyzed in this study.

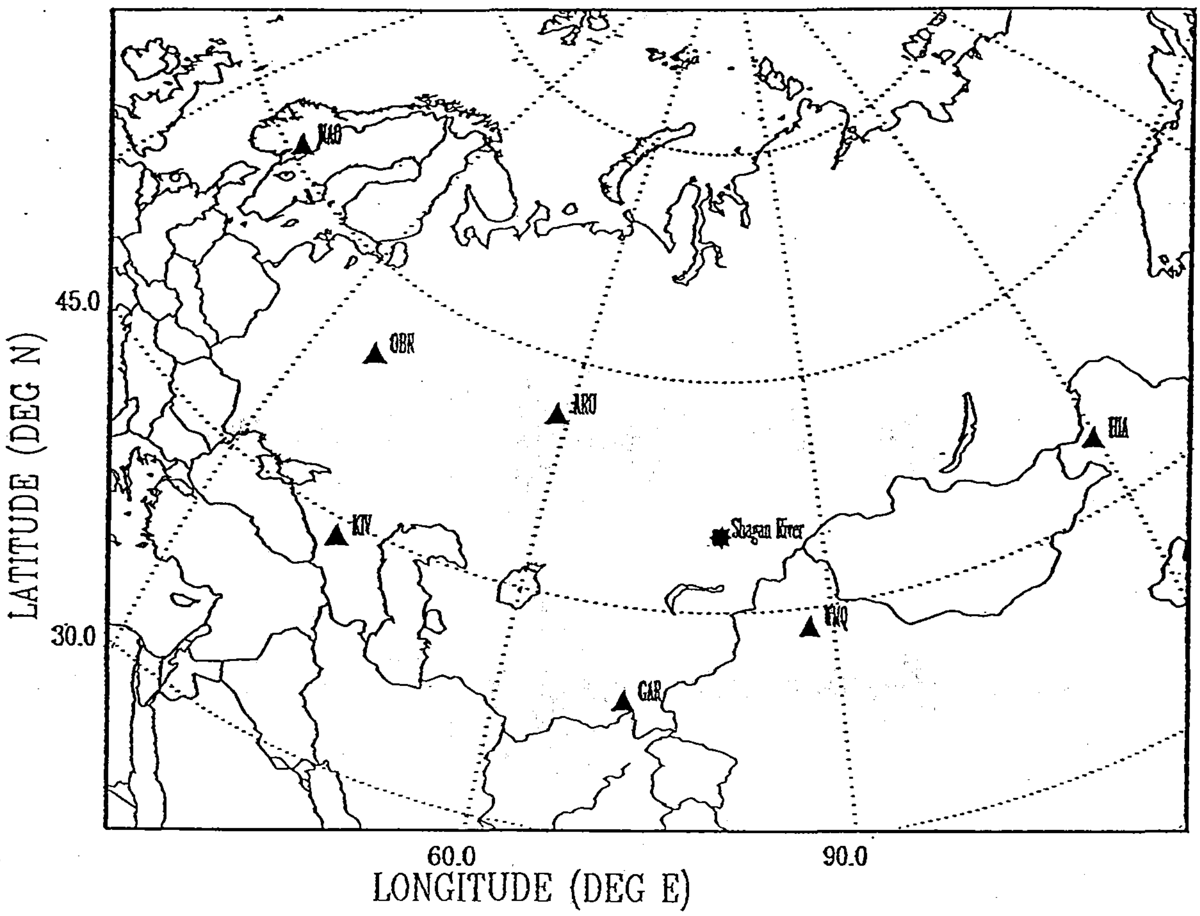

Fig. 7.2.1 Map indicating the locations of the Shagan River Test Site, the IRIS and British stations in the USSR, the NORSAR array in Norway and the stations WMQ and HIA in China. The NORESS array is collocated near the NORSAR array, and the station GAM is collocated near the GAR station.

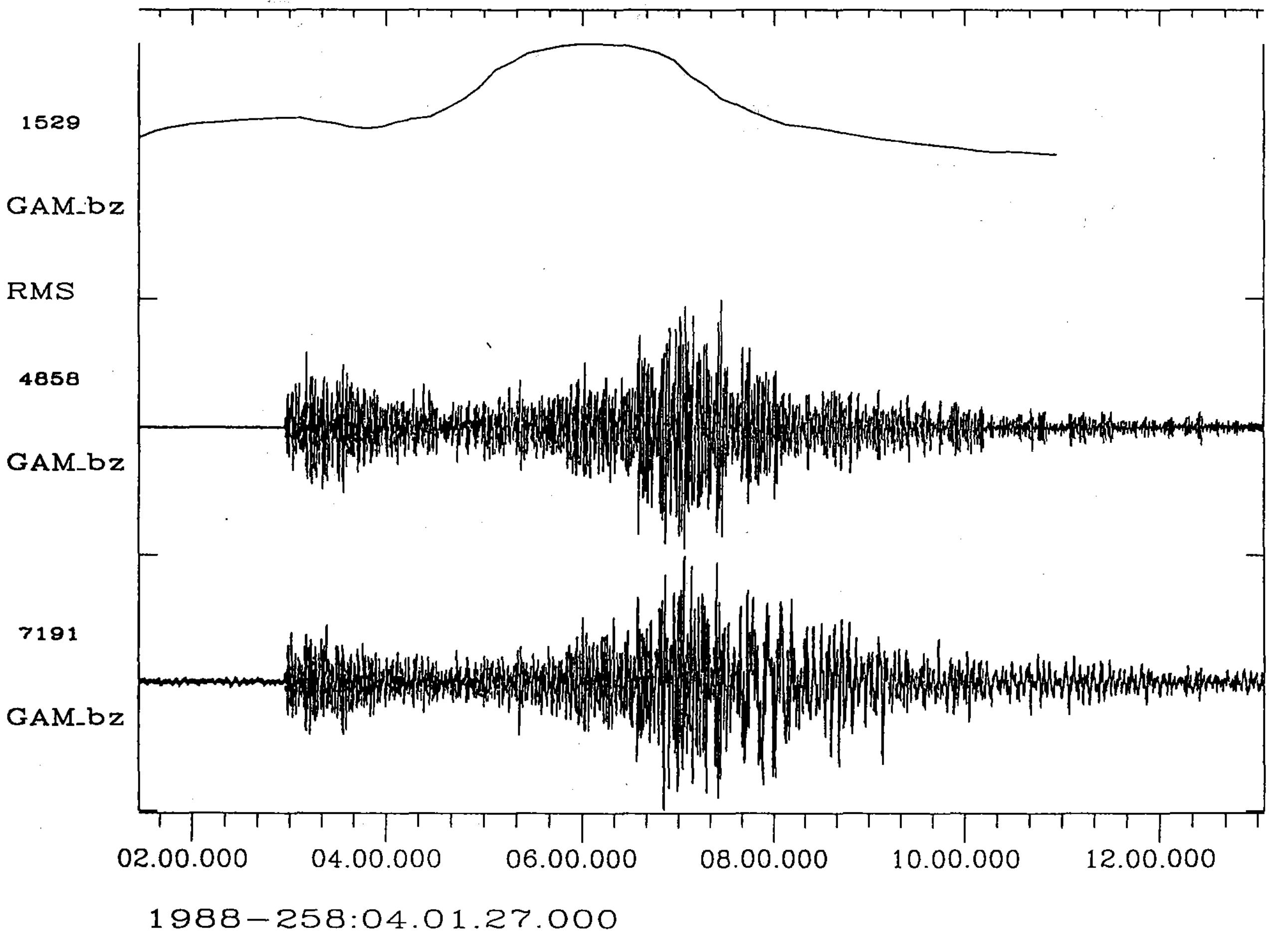

Fig. 7.2.2 Example of recordings from a Soviet nuclear explosion (14 Sept 1988) at the station GAM. For each of the three components we show the unfiltered trace (bottom), the filtered trace (0.6–3.0 Hz) and the 120-second window RMS measure (top) as a function of time.

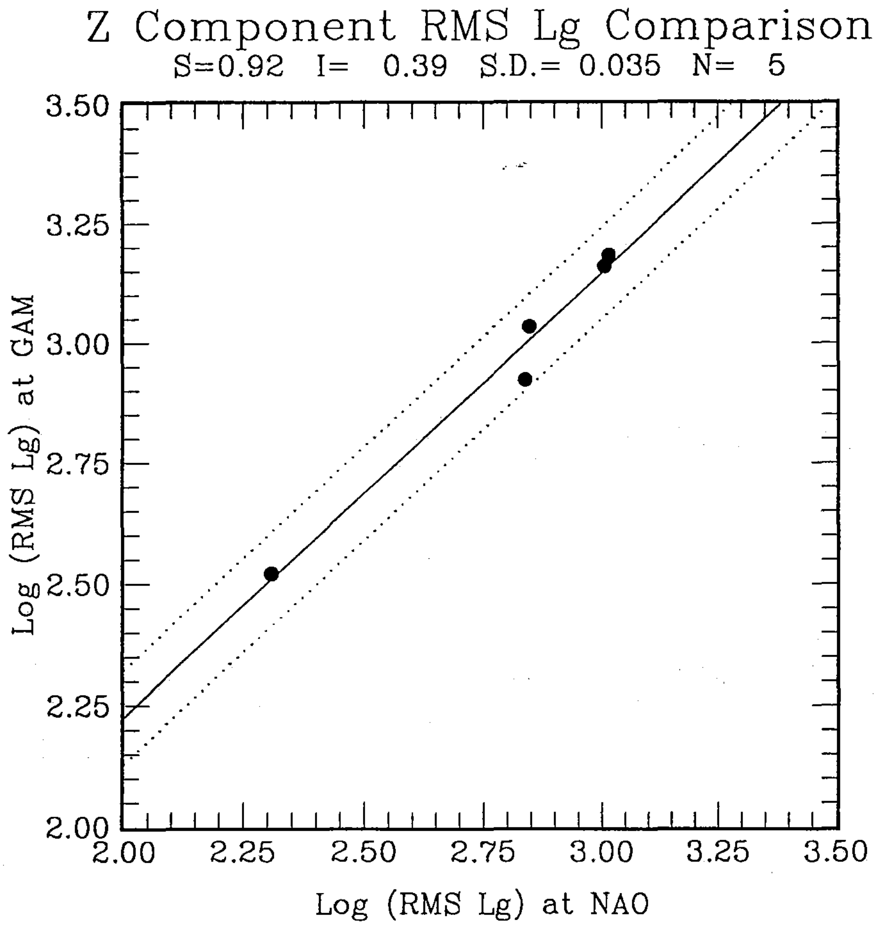

Fig. 7.2.3 Comparison of log RMS Lg measurements obtained at GAM and NORSAR. The standard deviation of the differences is 0.035 orthogonal to the line. The dotted lines correspond to plus or minus two standard deviations.

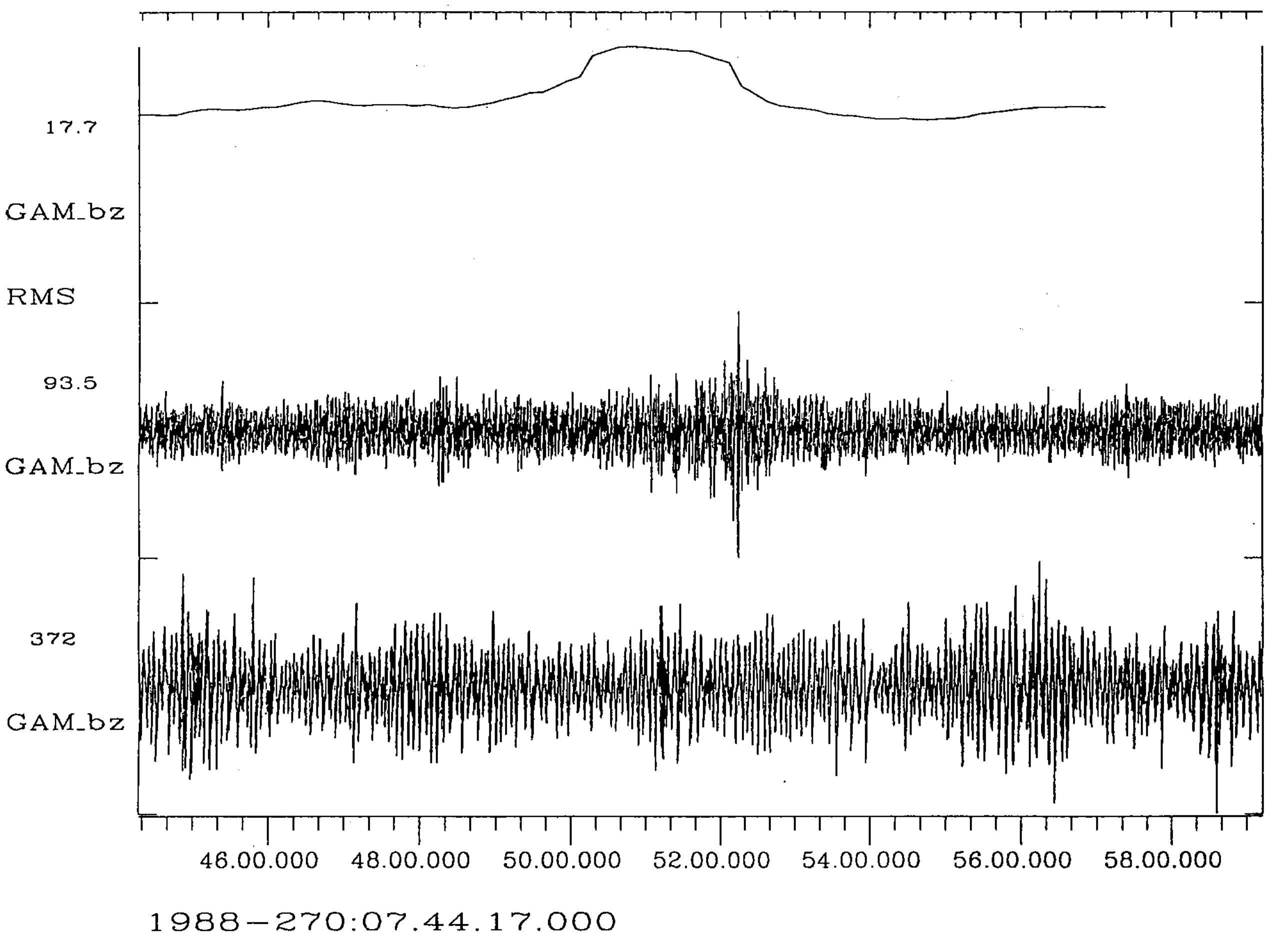

Fig. 7.2.4 The GAM vertical component seismogram from the m_b 3.8 explosion on September 26, 1988. The lower trace is the unfiltered seismogram, the middle trace is the band pass filtered seismogram between 0.6 Hz and 3.0 Hz, and the upper trace is the RMS amplitude as a function of time.

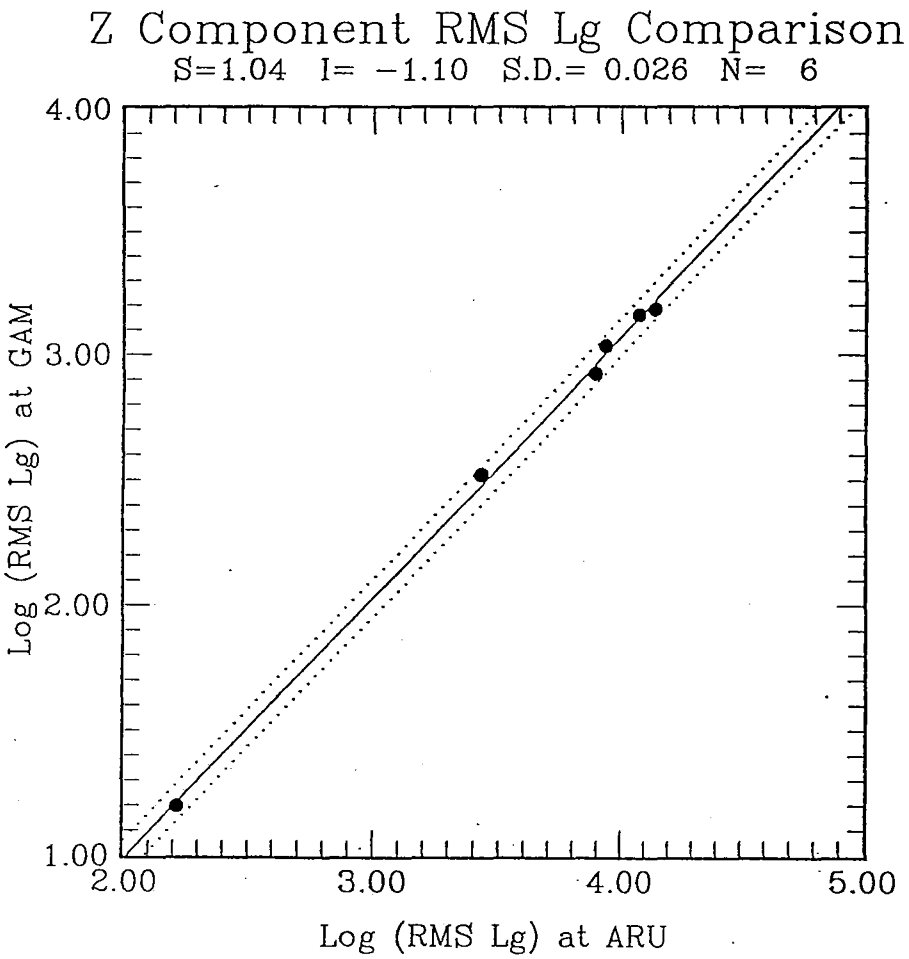

Fig. 7.2.5 Comparison of log RMS Lg measurements at ARU and GAM. The slope of the line is 1.04 and the standard deviation of the misfit of the line to the data is 0.026 orthogonal to the line. The dotted lines correspond to plus or minus two standard deviations. Note the remarkable stability of measurement between the two stations over two full magnitude units.

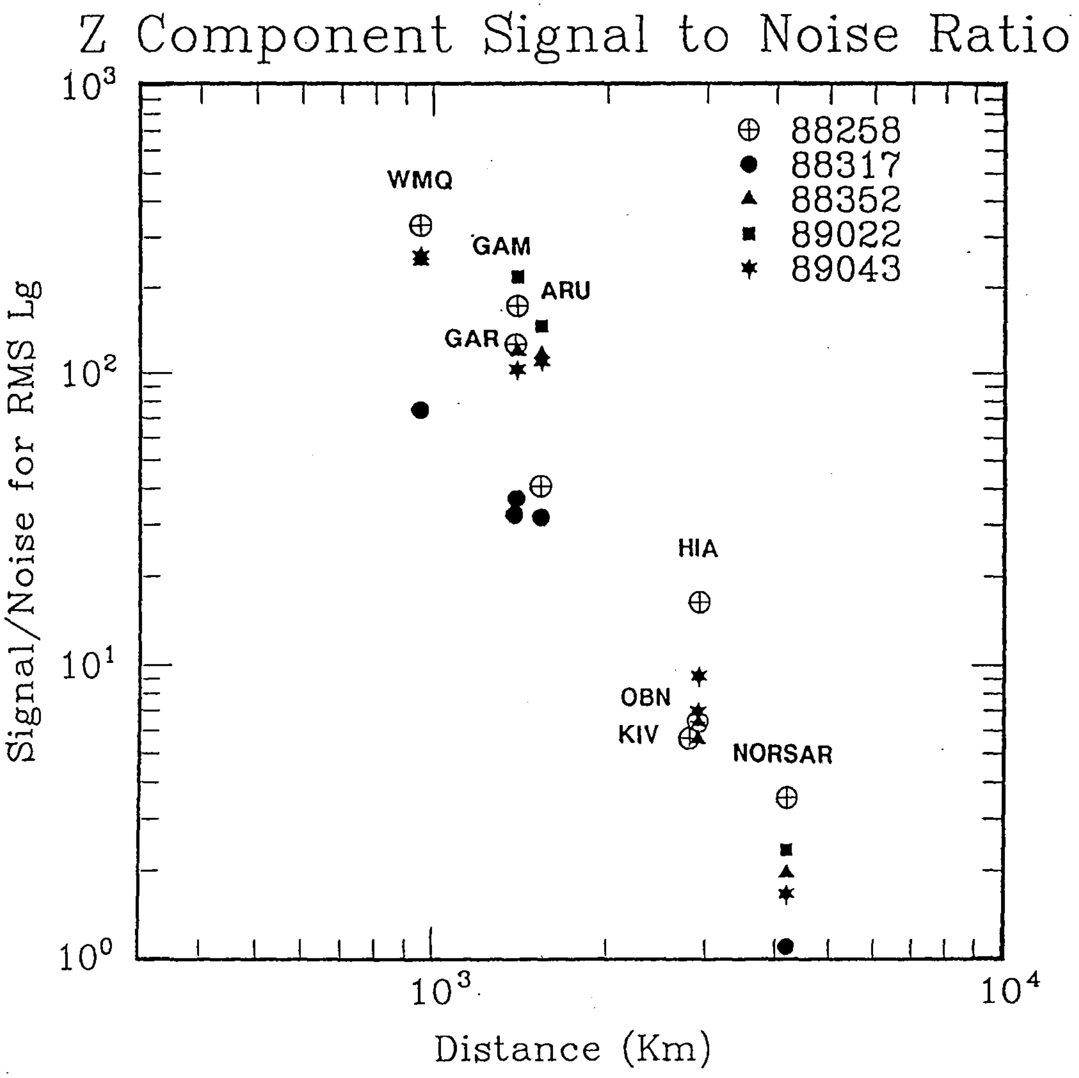

Fig. 7.2.6 Graph showing the variation of the signal-to-noise ratios (log RMS minus log RMS noise) among GAM, the four IRIS stations, the NORSAR array and the CDSN stations WMQ and HIA. Epicentral distance to the test site is plotted along the horizontal axis.