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# Semiannual Technical Summary

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## VII.8 Analysis of IRIS data for Soviet nuclear explosions

**Introduction**

In previous NORSAR Semiannual Technical Summaries, Lg measurements from NORSAR and Grafenberg recordings (at distances greater than 4000 km) have been suggested as a means to provide stable estimates of magnitudes for large underground nuclear explosions. Such estimates are considered stable in that the Lg phase exhibits a much reduced amplitude variability across the arrays compared to the P phase. In this way, the Lg magnitude estimates show promise to provide a valuable supplement to $m_b$ in estimating yield for nuclear explosions. Now data have become available from four modern digital seismic stations installed within the Soviet Union by IRIS (Given and Berger, 1989) for recent explosions in the Semipalatinsk area (see Table VII.8.1, Table VII.8.2 and Fig. VII.8.1). These new data allow the comparison of the stability of the RMS Lg measurement technique (Ringdal and Hokland, 1987) for stations at various distances. As part of our current work, we will compare the detectability and Lg amplitudes of events recorded at the IRIS stations to those of NORSAR, NORESS and ARCESS.

We have found the IRIS recordings to be of excellent quality, providing high resolution digital data with large dynamic range over a wide frequency band. So far, however, the IRIS data comprise only a small number of explosions, and in addition, we did not have complete station coverage for all events (only one station, ARU, had recordings for all explosions in Table VII.8.1, and only vertical components were used for some events in this study). It is therefore too early to state any firm conclusions from this initial study. However, some preliminary results can be summarized as: a) the IRIS stations provide a much improved signal-to-noise ratio for events near Semipalatinsk as compared to NORSAR, b) the scaling of RMS Lg amplitudes between different sized events recorded at the same IRIS site appears to be consistent with that of NORSAR, c) a possibility of reduced scatter in RMS Lg measurements at single sites may be accomplished by averaging the three-component recordings, and d) RMS Lg amplitudes may be made to about 1.5

magnitude units lower than at NORSAR or Grafenberg allowing a much lower threshold for yield determination.

**Data analysis**

Examples of the IRIS recordings are shown in Figs. VII.8.2 through VII.8.4. Fig. VII.8.2 shows the recordings from all four IRIS sites for the explosion of September 14, 1988. In this figure are the unfiltered 3-component data along with bandpass filtered versions in the frequency range from .6 Hz to 3 Hz. (This frequency range was chosen to obtain consistency with analysis of NORSAR recordings.) On top of each filtered trace is a 120 second window RMS measure of the amplitude. The first striking feature of the three-component seismograms is that the horizontal instruments consistently exhibit a larger value for the Lg phase than the verticals. The closer stations, ARU and GAR, at a distance near 1500 km, show this Lg phase as the largest amplitude, while stations OBN and KIV at a distance nearer to 3000 km have the P phase as the largest amplitude. The station KIV has no discernible Lg phase for this explosion, presumably because Lg does not propagate efficiently in the crustal structure associated with the Caspian Sea.

As a contrast to this well-recorded event, Fig. VII.8.3 illustrates the capabilities of the ARU station to record an $m_b$ 3.8 event from the Shagan River test site on day 270 (September 26) of 1988. (This $m_b$ magnitude is based on the NORSAR $m_b$ of 4.3 with an assumed regional correction of .5 $m_b$ units for comparison to world-wide $m_b$ estimates and therefore must be considered uncertain.) The unfiltered broadband trace essentially shows no signal for this event, however, the bandpass-filtered trace clearly shows energy arriving that can be identified as significant Lg signal with a signal-to-noise ratio of about 2.

In an attempt to enhance the detectability of other phases, the vertical component was filtered in several pass bands as illustrated in Fig. VII.8.4. Even considering frequency bands up to the Nyquist frequency of 10 Hz, we found no additional enhancement of the P phase or other phases. (It may be noted that ARU and GAR are at distances within a shadow zone for P waves from seismic sources in East Kazakhstan.) The NORESS beam deployment for this event is clearly capable of detecting the P wave arrival as illustrated in Fig. VII.8.5. Therefore, even though the ARU station may not be capable of detecting the event in an automatic fashion, regional arrays such as NORESS and ARCESS can correctly detect the event while the analysis of the Lg phase at a much closer station can provide an estimate of the RMS Lg magnitude suitable for giving independent information on explosion yield.

The seismograms from the IRIS stations were all processed in a manner similar to that used for the NORSAR recordings by first bandpass filtering the seismograms as illustrated above and measuring RMS amplitude for the phase of interest. In this respect, no allowance was made for a particular group velocity window for analysis at this early stage, but rather the same length window of 120 seconds was chosen for all distances and centered at the 3.5 km/sec group velocity arrival time. The RMS measure of Lg was calculated for the particular 120 second window for all recordings stations (and individually for all components of recording). Likewise, an RMS measurement of the noise preceding each event arrival was calculated and applied as a correction term for calculating the Lg amplitude measure as originally defined by Ringdal and Hokland (1987). In contrast to NORSAR, IRIS stations are single-site stations, so no averaging of vertical component measures was possible. However, IRIS stations do provide the possibility to average data from the three components, and we thus computed both individual component RMS data as well as average values to see whether reduced scatter could be achieved in this way.

The first result we wish to illustrate is shown in Fig. VII.8.6. Here we show the variation in the signal-to-noise ratio of the RMS Lg for five events from the Semipalatinsk area as a function of distance. The range in magnitude ($m_b$) is from 5.2 for the event on day 317 of 1988 to 6.1 for the 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 still observable at ARU and GAR at a distance of about 1500 km.

In order to verify the stability of the RMS Lg amplitudes within the Soviet Union, the amplitudes were compared with NORSAR amplitudes for common events. Since the instrument response of the different IRIS stations varied as a function of time as well as among themselves (each being different than that of a NORSAR station), we decided for this preliminary study to convert all measurements to the equivalent response of a typical NORSAR short period instrument in the .6 to 3 Hz range. The variation of RMS Lg amplitudes as a function of event size and distance is illustrated in Figs. VII.8.7 and VII.8.8.

First, in Fig. VII.8.7, we compare the difference in log RMS Lg between two events recorded at the same stations. The stations are NORSAR (~4200 km), ARU (~1500 km) and OBN (~3000 km) for the $m_b$ 6.1 event on day 258 of 1988 minus the $m_b$ 5.9 event on day 352 of 1988. We first note that all three stations indicate that the former event has a larger Lg signal by about 0.2 magnitude units, and the observations are thus quite consistent. Furthermore, we see a variation among the three components of ARU and OBN typically on the order of .07 magnitude units. However, the average of the three components is more stable compared to NORSAR, with a variation of only about 0.02 magnitude units. From observing the behavior of similar plots for other events it appears the difference between NORSAR and single station three-component averages may vary by about ± .05 magnitude units on the average.

For comparison of actual measurements of RMS Lg amplitudes between NORSAR and ARU for all common events, we plot in Fig. VII.8.8 only the vertical component of RMS Lg (Table VII.8.3). This is necessary when comparing ARU to NORSAR, since from Fig. VII.8.2 we see horizontal amplitudes of Lg are consistently larger than vertical and NORSAR measurements were made on only vertical instruments. A line fit to these data with a fixed slope of 1.0 yields a standard deviation of .032 (dotted line on the figure corresponds to 2 standard deviations).

Although the straight-line fit is excellent, it is necessary to interpret this plot with caution, in view of the sparse data. Additional event data will be required before any reliable assessment of the slope and data scatter can be made.

Given this fit with a slope of one, and that Ringdal et al (this volume) have convincingly shown the RMS Lg at NORSAR fits to reported $m_b$ magnitudes also with a slope of one, we plot in Fig. VII.8.9 the RMS Lg amplitude at ARU against $m_b$ magnitudes for all recorded events at Shagan River with an imposed slope of one. The standard deviation of the fit is .154. The Shagan River events with magnitude greater than 5 lie very close to the line with slope of one which strengthens the conclusion that the ARU estimates correlate well with $m_b$ estimates in the same way as the NORSAR data. The exception is the small magnitude 3.8 Shagan River event on day 270 of 1988. If we fit a line to these Shagan River events, we obtain a slope of 1.2 with a standard error of .050. The only objection to this is that the magnitude 3.8 event is contributing too heavily to this fit given the great uncertainties tied to both the $m_b$ estimate (as noted above), and the RMS Lg estimate taken from Fig. VII.8.3. It is for this reason that we display the data with an arbitrary line of slope 1. If, for example, we were to find the $m_b$ estimate was too low, the standard error we obtained of .154 would very much improve.

**Discussion**

This preliminary study has shown that RMS Lg amplitudes estimated from IRIS stations within the Soviet Union for Semipalatinsk explosions appear to be quite consistent with NORSAR RMS Lg estimates. This has several important implications:

1. RMS Lg appears to be a stable source size estimator when computed at widely distributed stations, and would therefore provide a reliable magnitude estimate once the proper correction term has been estimated for each station.

2. The IRIS stations (notably ARU and GAR) can be used to estimate Lg magnitudes for explosions of much lower yield than is possible using the more distant NORSAR and Grafenberg arrays. Our preliminary analysis indicates that the signal-to-noise ratio improvement allows RMS Lg estimates to be made down to approximately $m_b$ 4.0 at ARU, compared to a threshold of about $m_b$ 5.5 at NORSAR.
3. Although single stations do not offer the increased stability obtained through array averaging, this is partly compensated by the higher signal-to-noise ratio, which means that modest noise fluctuations will be insignificant for the Lg measurements. Also, a possibility of decreasing scatter of magnitude estimates through averaging the three components of each station exists. Our initial analysis indicates that such an approach could be useful, but it may be necessary to determine correction terms for each component individually.
4. As more data (and possible additional stations) become available, a data base will be developed that will enable us to compute network averages, based on individual station data "calibrated" to NORSAR $m_b$(Lg). This would allow for both improved uncertainties of future explosions, as well as maintain a comparison to historic data. Potentially, the calibration could be done using direct, independent, yield information.

We have not, in this paper, addressed in detail such topics as the selection of optimum filter band and Lg time window for the IRIS stations. This needs to be done, and it would also be desirable to develop a theoretical basis to allow for correction of attenuation of the Lg phase. Finally, extension of the study to other nuclear explosion sites will be desirable. Of particular interest here is to study the possible differences between the Shagan River and Degelen Mountains regions.

**Acknowledgements**

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## References

Given, H.K. and J. Berger (1989): IRIS/IDA stations in the USSR: An update. Am. Geoph. Union meeting, May 1989.

Ringdal, F. and B.Kr. Hokland (1987): Magnitudes of large Semipalatinsk explosions using P coda and Lg measurements at NORSAR. In: Semiannual Tech. Sum., 1 Apr - 30 Sep 1987, NORSAR Sci. Rep. 1-87/88, Kjeller, Norway.

| Year | DOY | Month | Day | $m_b$ | IRIS Stations | Test Site |
|---|---|---|---|---|---|---|
| 1988 | 258 | 9 | 14 | 6.1 | ARU, KIV, OBN, GAR | Shagan River |
| 1988 | 270 | 9 | 26 | 3.8 | ARU | Shagan River |
| 1988 | 292 | 10 | 18 | 4.9 | ARU, GAR | Degelen Mountain |
| 1988 | 317 | 11 | 12 | 5.3 | ARU, GAR | Shagan River |
| 1988 | 328 | 11 | 23 | 5.3 | ARU, OBN, GAR | Degelen Mountain |
| 1988 | 352 | 12 | 17 | 5.9 | ARU, OBN | Shagan River |
| 1989 | 022 | 1 | 22 | 6.0 | ARU | Shagan River |
| 1989 | 043 | 2 | 12 | 5.9 | ARU, OBN | Shagan River |
| 1989 | 048 | 2 | 17 | 5.0 | ARU | Degelen Mountain |

Table VII.8.1. List of events and recording stations used in this study.

| Station | Latitude | Longitude | Elevation (m) |
|---|---|---|---|
| OBN | 55.10 N | 36.60 E | 160 |
| ARU | 56.40 N | 58.60 E | 250 |
| KIV | 43.95 N | 42.68 E | 1206 |
| GAR | 39.00 N | 70.32 E | 1300 |

Table VII.8.2. IRIS station coordinates.

| Event Date | NORSAR log RMS Lg | ARU z log RMS Lg |
|---|---|---|
| Sept 14, 1988 | 3.014 | 4.142 |
| Nov 12, 1988 | 2.307 | 3.429 |
| Dec 17, 1988 | 2.846 | 3.935 |
| Jan 22, 1989 | 3.005 | 4.076 |
| Feb 12, 1989 | 2.836 | 3.891 |

Table VII.8.3. Values of log RMS Lg amplitudes as plotted in Fig. VII.8.8. Note that for comparison the values for ARU have been adjusted to the response of a NORSAR instrument.

IRIS and NORSAR Seismographic Station Locations

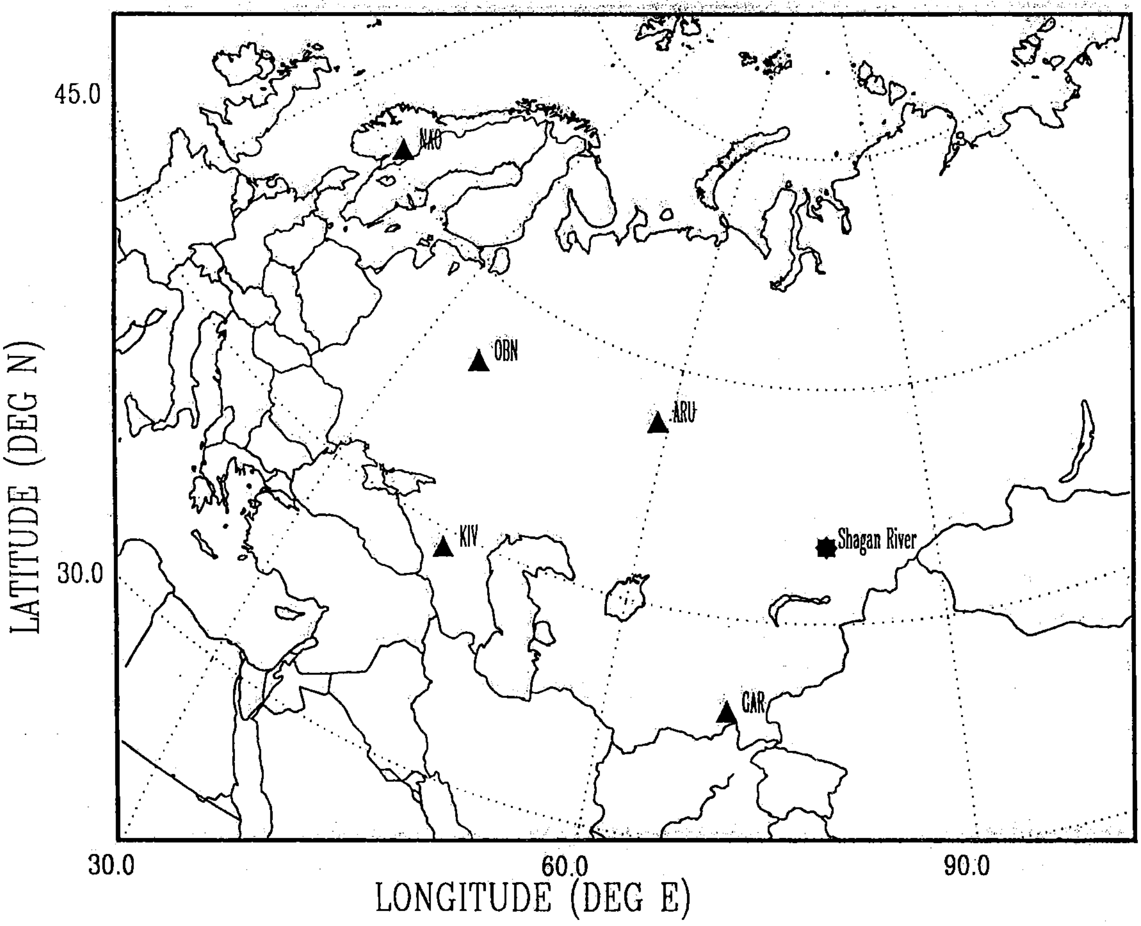


Fig. VII.8.1. Map indicating locations of the Shagan River test site and the IRIS stations in the USSR along with the location of NORSAR array in Norway.

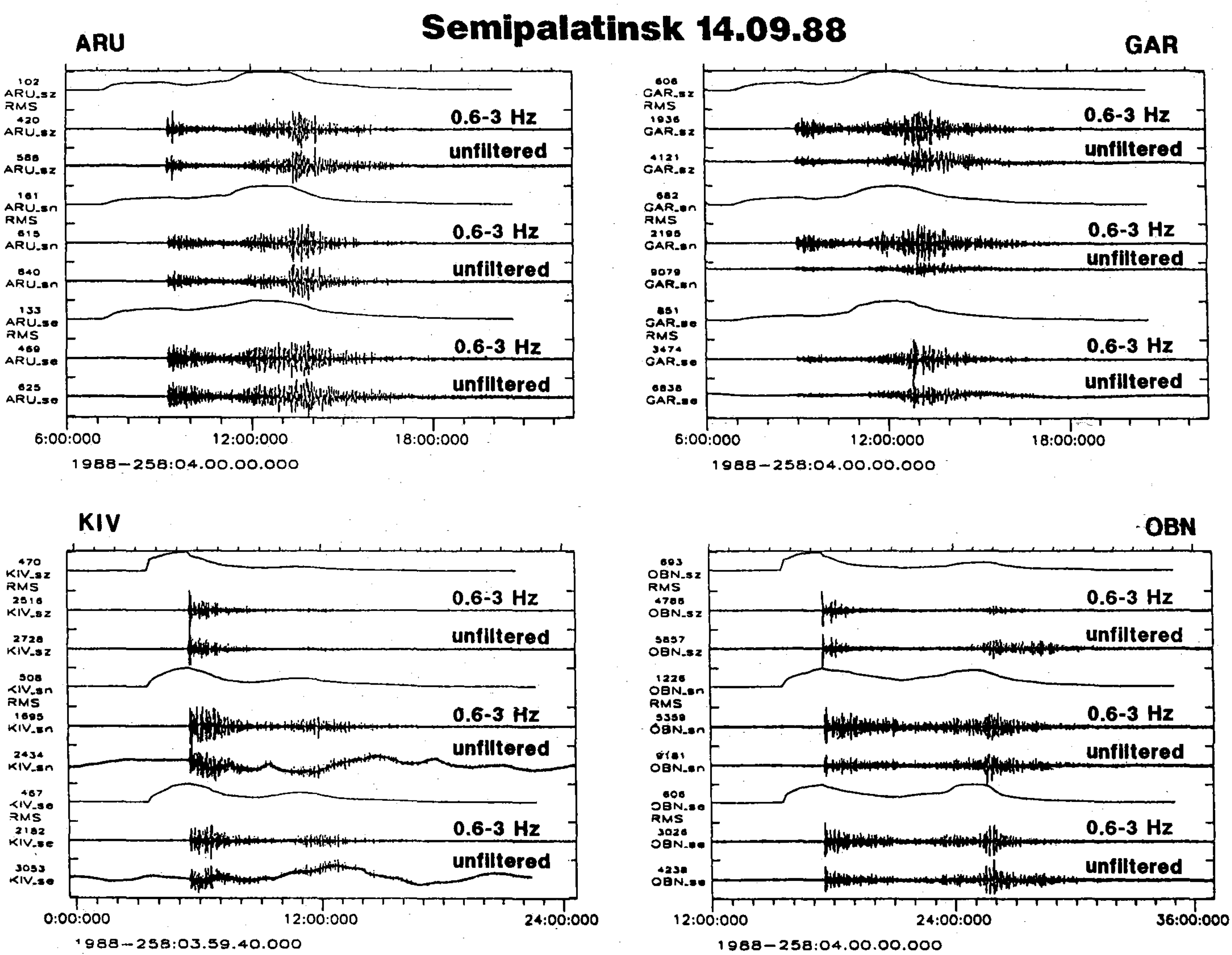


Fig. VII.8.2. Plots of the data recorded on the four IRIS stations located in the USSR for the explosion of September 14, 1988. For each of three components at each site are the unfiltered trace, a filtered version in the band 0.6 to 3 Hz, and the 120 second window RMS amplitude measure as a function of time.

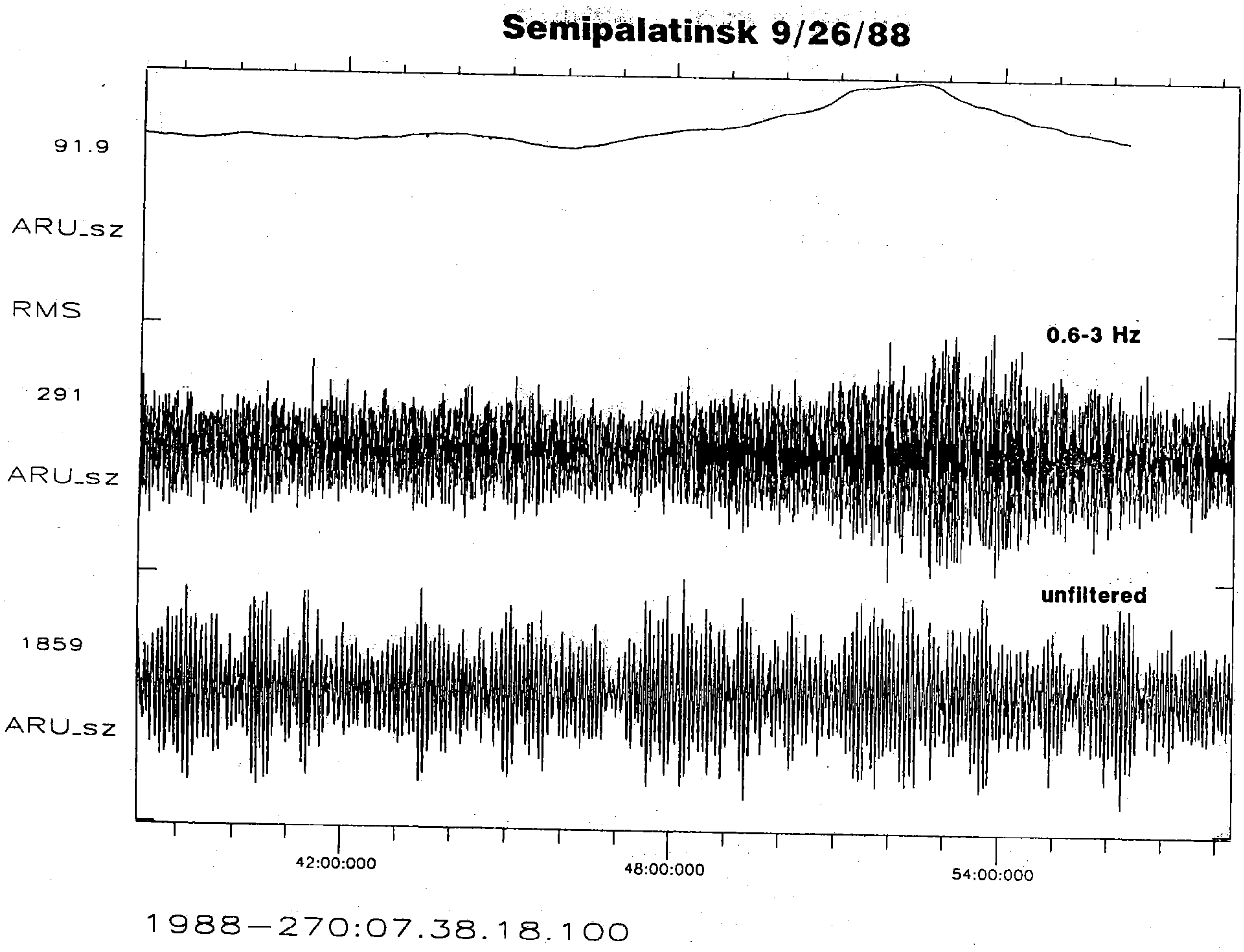


Fig. VII.8.3. The ARU vertical component seismogram from the $m_b$ 3.8 explosion on September 26, 1988. The lower trace is the unfiltered seismogram, the middle trace is the bandpass filtered seismogram between 0.6 and 3 Hz, and the upper trace is the RMS amplitude as a function of time.

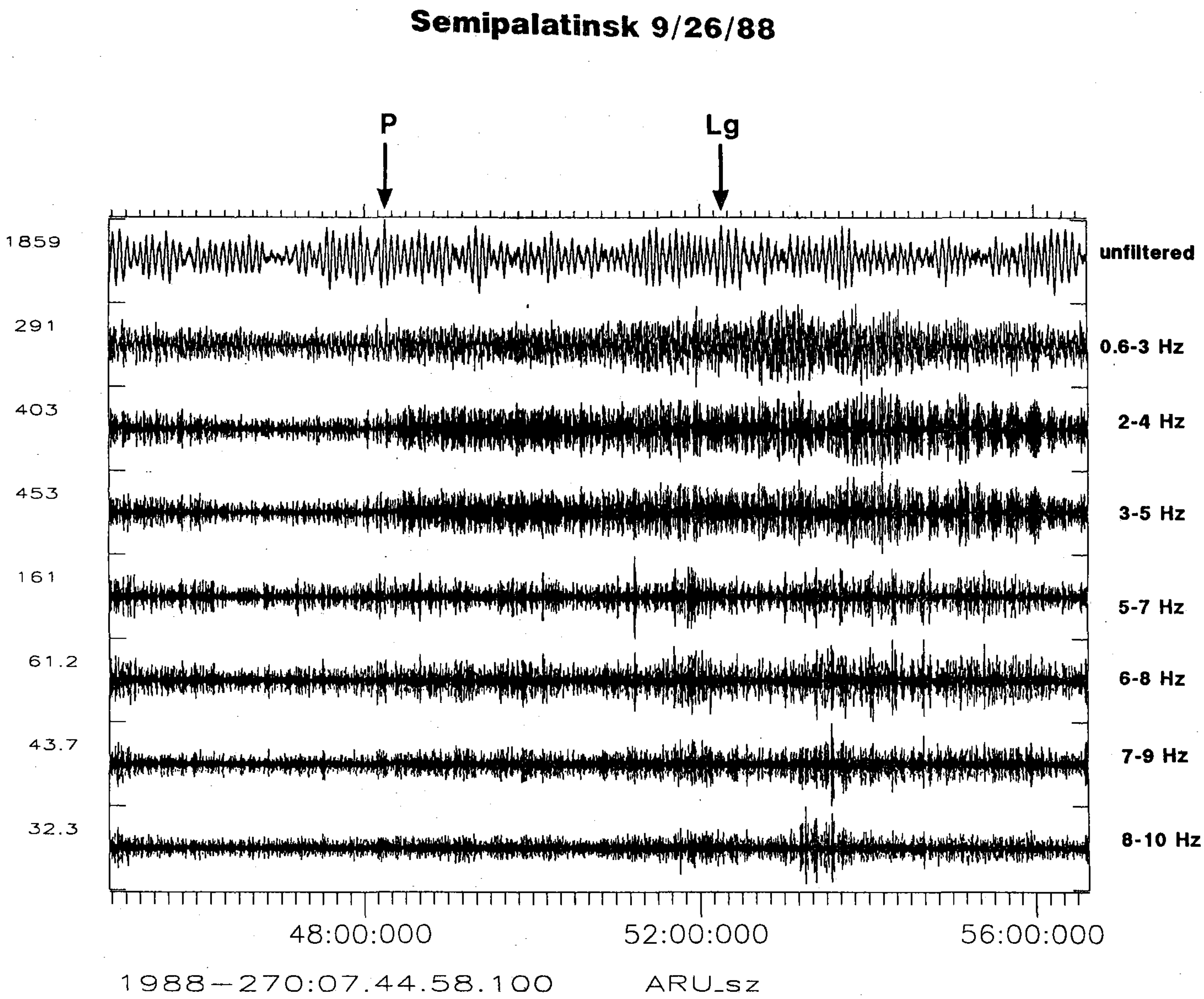


Fig. VII.8.4. The ARU vertical component seismogram from the $m_b$ 3.8 explosion on September 26, 1988. The top trace is the unfiltered seismogram, while subsequent traces show the seismogram resulting from successively higher bandpass frequency intervals. Predicted arrival times of P and Lg (3.5 km/s) are marked as arrows.

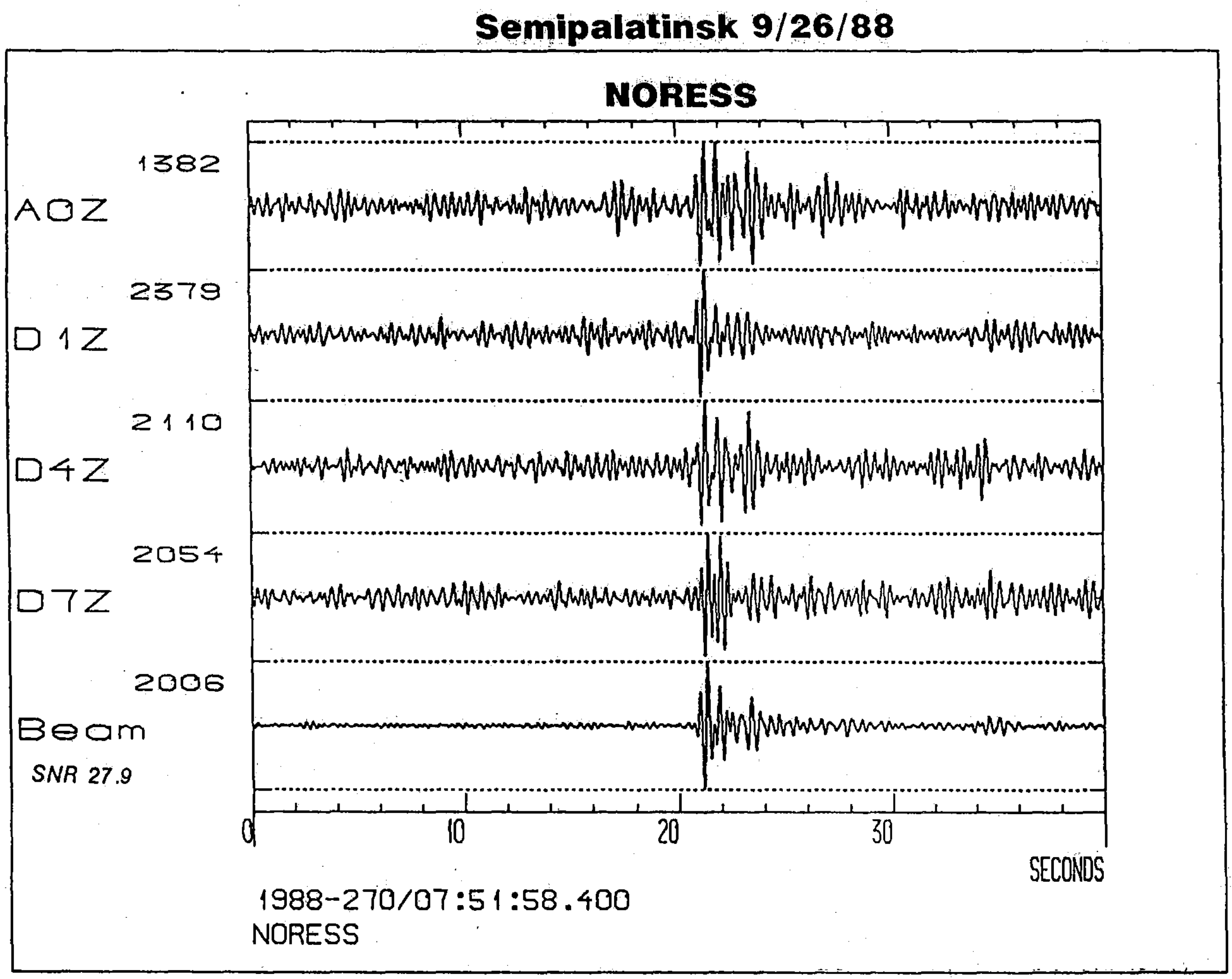


Fig. VII.8.5. Example of three vertical component seismograms from the NORESS array in Norway for the $m_b$ 3.8 explosion on September 26, 1988. Shown on the bottom trace is the beam formed by steering toward the explosion site.

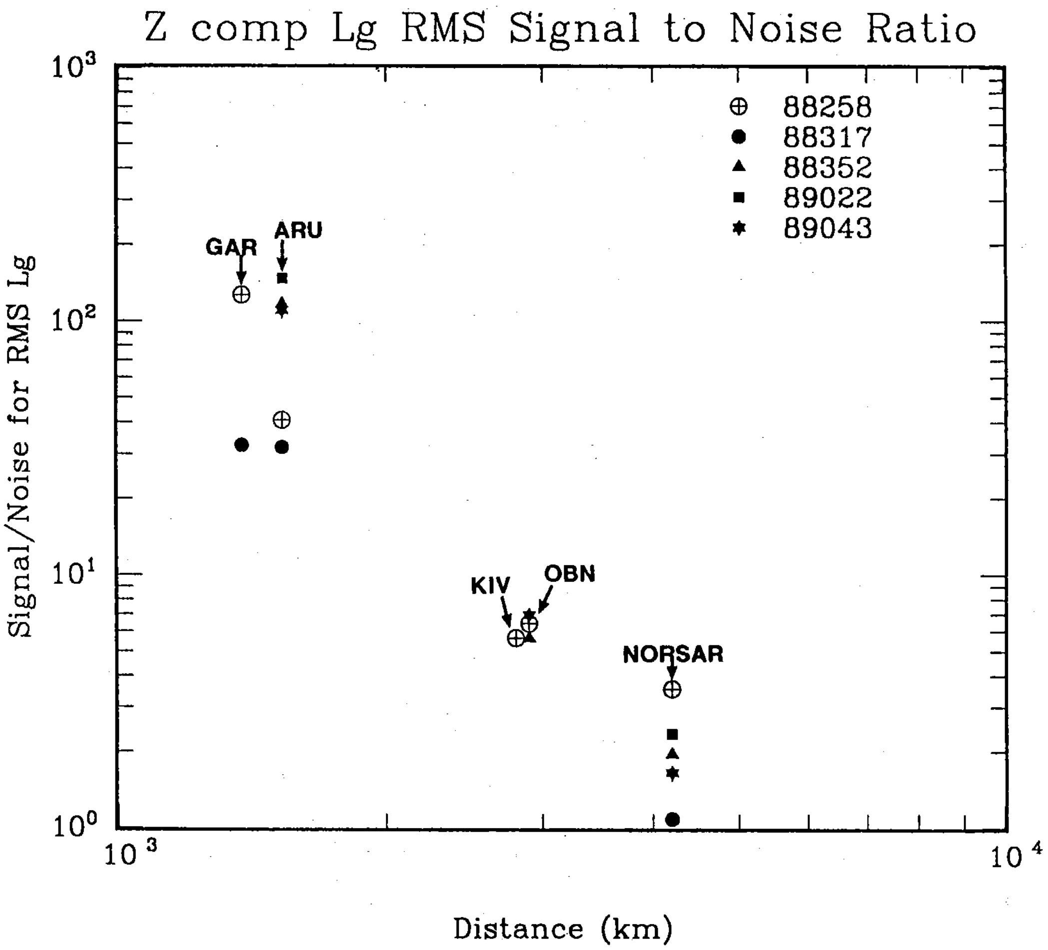


Fig. VII.8.6. Graph showing the variation of the signal-to-noise ratio of the RMS Lg amplitude readings from the four IRIS stations and the NORSAR array on logarithmic scales.

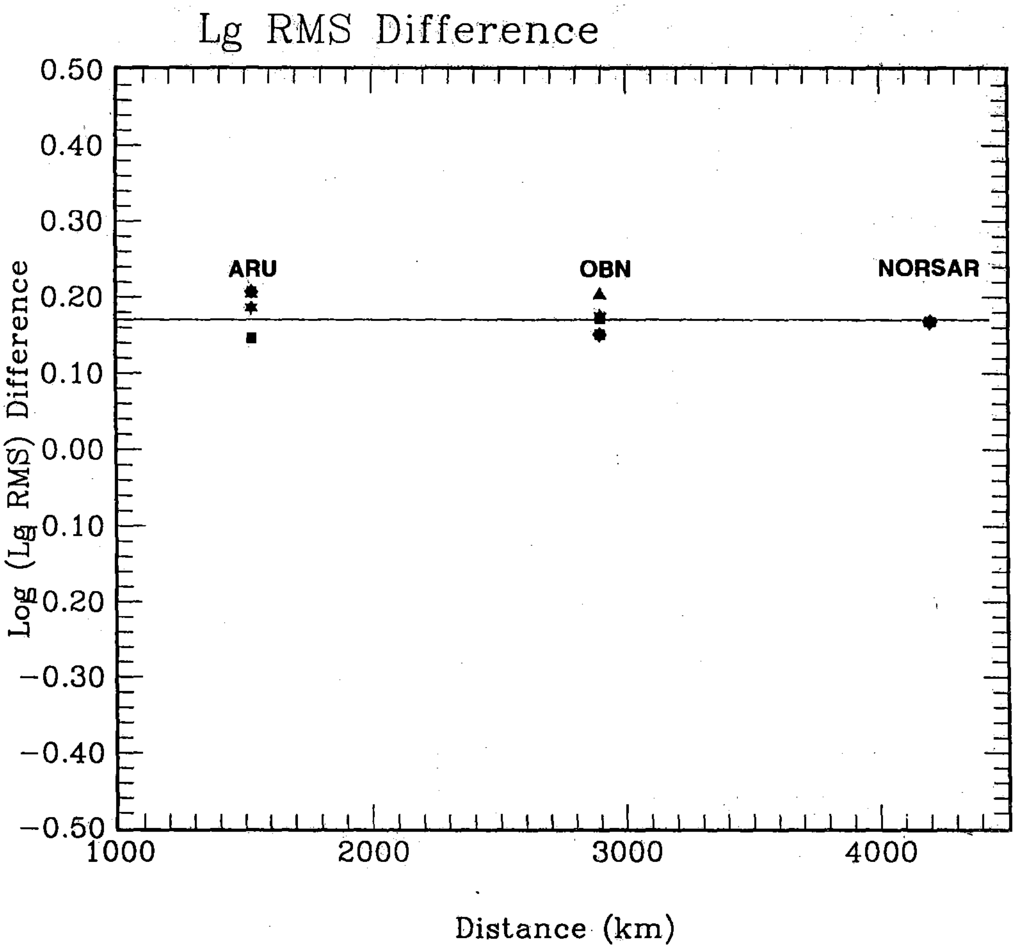


Fig. VII.8.7. The difference in RMS Lg amplitudes (or magnitudes) between the 6.1 $m_b$ explosion on September 14, 1988, and the 5.9 $m_b$ explosion on December 17, 1988 (Day 352) for two IRIS stations and the NORSAR array. The IRIS stations show vertical (8 point star), N-S (triangle) and E-W (box) components and the average (6 point star). The NORSAR point represents the average of readings from vertical instruments.

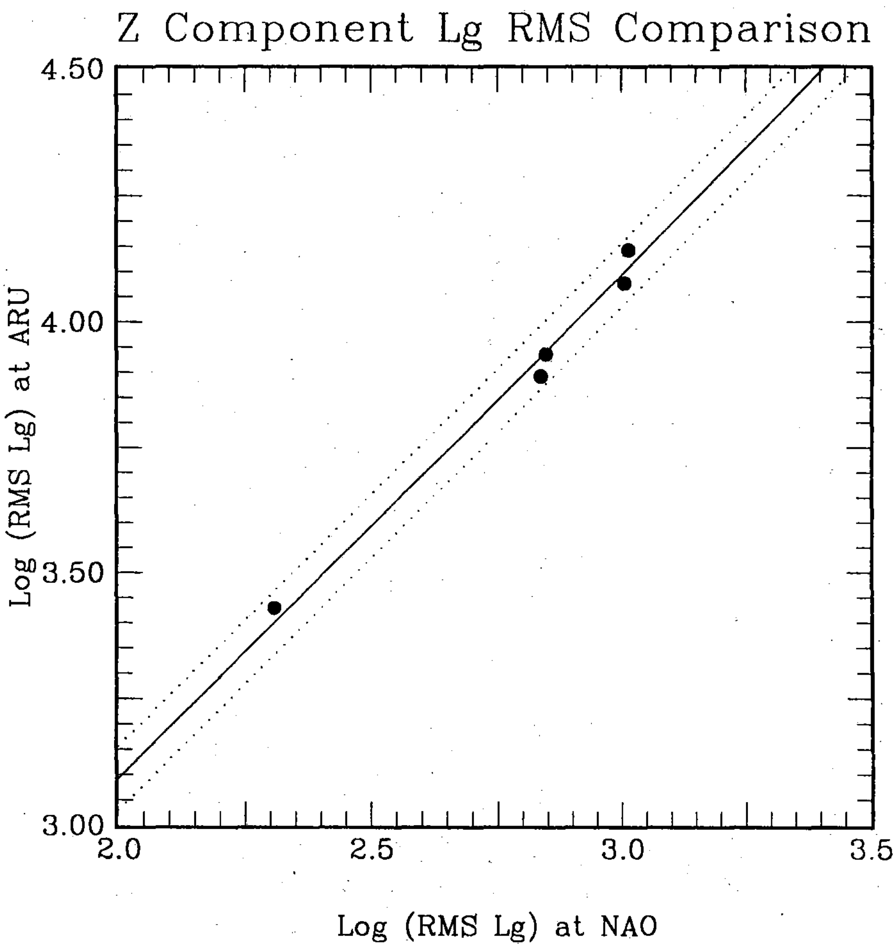


Fig. VII.8.8. Comparison of the RMS Lg amplitudes recorded at ARU and NAO. The solid line represents a slope of one. The standard deviation of the data from the solid line is 0.032. The dotted lines give the plus or minus two standard deviation levels.

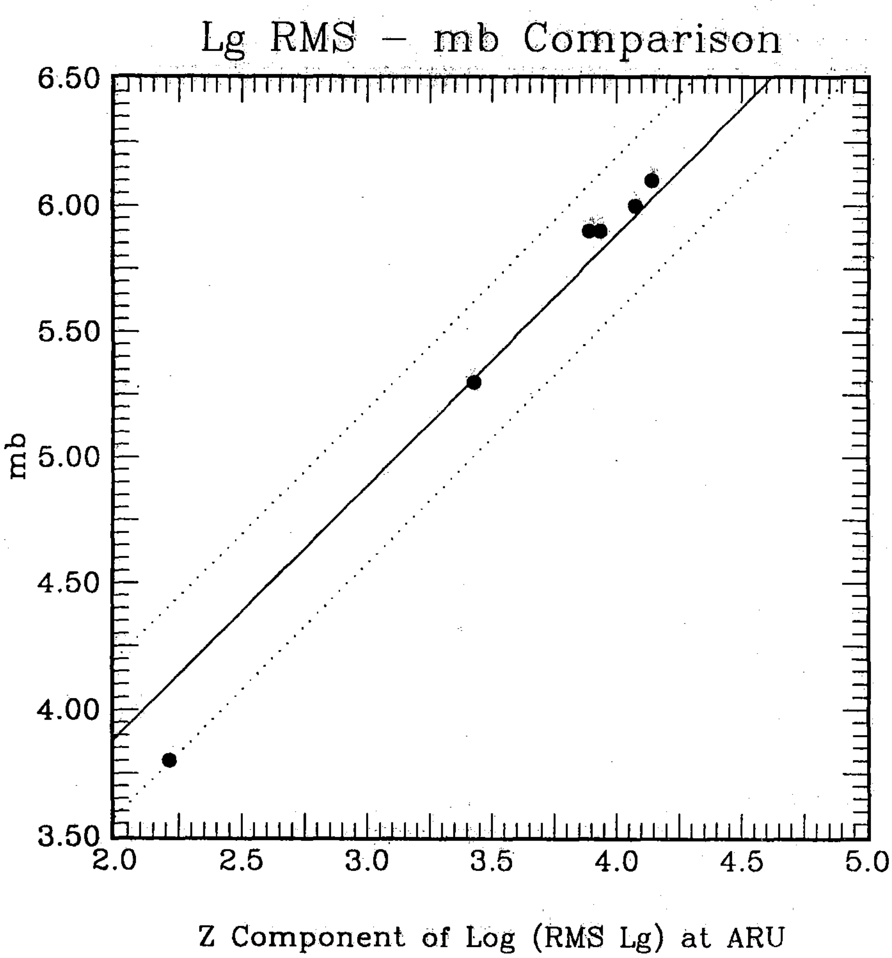


Fig. VII.8.9. Comparison of the vertical component readings of RMS Lg amplitude to world-wide $m_b$ magnitude. The solid line represents a slope of one. The standard deviation of the data from the line is .152. The dotted lines give the plus or minus two standard deviation levels.