REGIONAL MAGNITUDE STUDIES IN CHINA AND SURROUNDING AREAS

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ABSTRACT

Magnitude research at Los Alamos National Laboratory is focused on improving the transportability of mb(LgCoda) and mb(Lg) through the application of advanced calibration methods and better characterization of scaling relationships with respect to yield or a surrogate, such as mb(P). In addition, we are investigating the scaling behavior between regional magnitudes, motivated by the constraint that mb(LgCoda) should transition into mb(Lg) at small magnitudes as signal-to-noise limitations restrict the use of coda waves.

We investigate the use of regional coda for magnitude determination because scattered coda waves smooth over path effects and provide redundant, thus precise, measurements that can be tied to moment, magnitude or yield following calibration. In heterogeneous regions, such as China and central Asia, however, we find that path averaging is not complete and regionally varying corrections must be applied. We do this using tomographic imaging techniques, applied to amplitude differences in order to eliminate unknown source effects. Tomography gives RMS log10 amplitude residuals of 0.06-0.08 for coda and 0.10-0.14 for direct Lg in bands near 1 Hz. Results correlate well with regional geology, while coda images are smoother than those of direct Lg due to partial path averaging. After applying corrections that flatten earthquake spectra below estimated corners and shift results to match waveform modeled estimates of moment, we obtain precise moment rate spectra for earthquakes and apparent source spectra for explosions that include coupling and near source path effects. The regional calibration enables comparing spectra from widely spaced sources and results can be tied to estimates of magnitude and yield for monitoring purposes.

After regional corrections are applied and magnitudes computed, we investigate scaling relationships for explosions with plots of regional magnitude versus mb(P). Since material coupling variations should be common for all seismic radiation, regional and teleseismic, P and S waves alike, comparisons of the relationships between test sites can also be used to investigate differences in energy partitioning. The energy partitioning for the Nevada Test Site (NTS) is particularly anomalous on plots of mb(P) versus mb(Lg) for 1 Hz compared to nuclear tests in central Asia. Indeed, the anomaly is so great that it must be caused mainly by mis-calibration of Lg Q for NTS explosions. This is consistent with independent results that suggest that Nuttli (1986) and Patton (1988) under-estimated the Lg Q using the method of Herrmann (1980).

For explosions, regional magnitudes, mb(LgCoda) and mb(Lg), need not scale 1-to-1 with mb(P) due to effects of a near-source transfer function that converts the initial compressional wavefield into S waves making up Lg and coda waves. We show evidence for variability in the scaling with mb(P) for different test sites and even for different areas within test sites. But there is no consensus that the variations are significant, and some questions arise whether the results are consistent for mb(LgCoda) and for mb(Lg). This raises questions about the generation mechanisms of Lg and coda waves by explosions, which many argue should be tightly linked. We are investigating the issue of a common source for Lg and coda waves through the development of scaling relationships between mb(LgCoda) and mb(Lg).

OBJECTIVE

We calibrate regional phase amplitudes, both direct and coda, to understand source effects and to determine magnitude and yield. Our objective is to develop a transportable methodology that can be used to characterize small events over broad areas.

RESEARCH ACCOMPLISHED--CODA

We calibrated coda amplitudes for 26 stations and their surrogates in China and central Asia (Figure 1). These data include Borovoye explosion records obtained from the Lamont-Doherty Earth Observatory (LDEO) (Kim *et al*., 2001). Of the available Borovoye data, we used short-period (1.5-s) records from the KS (gain 4500, 164 events, 1974-), KSM (gain 1000, 38 events, 1985-) and KSVM (gain 50, 45 events, 1984-) instruments (Kim and Ekstrom, 1996). We manually repaired glitches in these records and marked saturated or otherwise poor data sections to avoid in later processing. Except for saturated and noisy intervals, envelopes from these records matched well between instruments and with BRVK envelopes in the few cases where common events could be found.

Following the regional coda methods of Mayeda (1993), we obtained coda amplitudes by fitting distance-calibrated peak amplitude and coda shape curves in a series of narrow bands, 0.03 – 8 Hz. Path corrections were then obtained using tomographic images based on coda amplitude differences for events recorded at multiple stations. We assumed isotropic source radiation to perform the tomography, with the advantage that source-scaling effects are removed by taking differences. The path corrections give precise relative amplitudes within each band, residual RMS 0.06-0.08 log10 units, covering the entire study area. Relative levels between bands were adjusted by inverting for corrections that flatten earthquake spectra below estimated corners, based on mb (Taylor and Hartse, 1998). This step was carried out using an L1 simplex method. Finally, the absolute spectral level was determined to match scalar moments from waveform modeling for a small number of events (Figure 1). The resulting scatter between coda and waveform moments was 0.18 Nm.

Our calibration strategy using earthquake data has corrected for deep path effects but cannot be expected to account for near-source effects such as coupling, Rg to Lg conversion, or shallow path effects on explosion data. Earthquake moment rate spectra are expected to be accurately characterized; however, because near source effects remain in the explosion results, we term these “apparent source spectra.”

Apparent source spectra results show low levels of scatter for explosions recorded at multiple stations (Figure 2). This scatter has been minimized during tomographic inversion. Central Asia explosions show a marked peaked behavior that scales with size, as can be seen in the results from Degelen Mountain (Figure 3). Note that the Omega series, 100-T chemical shots continue this behavior. The peaks are similar to behavior observed at NTS, but occur in higher bands, which will cause transportability problems between these areas.

RESEARCH ACCOMPLISHED --Lg

Calibration of amplitude decay corrections is critical for the determination of regional magnitudes. A great deal of effort has been expended developing Q tomography for regional phases in central Asia. The results for areas that LANL is working on are relatively mature for Lg and coda waves, and we are reasonably sure that determinations of mb(Lg) and mb(LgCoda) have path effects removed to first order. This is an important milestone as we move ahead with studies of the scaling of regional magnitudes with respect to yield and teleseismic mb for explosions detonated in a variety of testing environments.

Coupling variations, as we know from experience at NTS, can introduce significant variations into magnitude-log yield relationships. In an absolute sense, coupling variations pose a major challenge for yield estimation. For our studies of transportability, we would like to mitigate the effects of coupling so that other transportability issues can be studied. These issues include: (1) whether or not 1-Hz mb(Lg) and mb(LgCoda) based mainly on shear-wave energy scale 1:1 with mb(P), (2) quantifying regional effects on mb(P) determinations, as well as (3) testing regional amplitude corrections for other areas of the world where nuclear explosions have been tested.

One way to mitigate the effects of coupling variations for explosions detonated in a variety of media is to plot magnitude versus magnitude. This is because the coupling efficiency is largely uniform for the entire elastic wavefield, regional and teleseismic, P and S waves alike. For example, gas porosity of the emplacement media has virtually the same effect on teleseismic mb as it has on regional mb(Lg) for NTS explosions (e.g., Patton, 1988).

In our studies of regional mb(Lg) scaling with teleseismic mb, we have been careful to use as often as possible maximum-likelihood estimates of mb(P) to avoid problems with censoring bias at small magnitudes.

The graph in Figure 4 shows a summary of observations for explosions detonated at NTS and at test sites in central Asia (Balapan, Degelen, and Lop Nor; see figure caption for details). A line mb(Lg) = mb(P) is shown for reference. The population of NTS explosions as a whole is large enough to say unequivocally that mb(Lg) and mb(P) do not scale 1-to-1. There are scaling variations (not shown) between test areas at NTS. At this stage in our work, the numbers are too few to say anything definitive about non-unity scaling for explosions at test sites in central Asia. We are currently working on measuring mb(Lg) and mb(LgCoda) for a larger number of Soviet peaceful nuclear explosions (PNEs) and Semipalatinsk explosions to add to this plot.

Offsets between explosion populations detonated at different test sites are of interest in light of possible regional effects on teleseismic mb. This is referred to as test site bias, which has been attributed to upper mantle attenuation effects. There are no discernable offsets between central Asia explosions detonated at Balapan, Degelen, and Lop Nor. On the other hand, the offset between NTS and central Asia is large. Test biases were estimated for NTS, Balapan, and Degelen by Nuttli in the 1980s, but his estimates do not agree with the results in Figure 4. Independent of Nuttli's results, numerous studies using different methods have consistently shown that a regional magnitude bias is pervasive for areas of the western United States, and its effect is to reduce the mb(P) by about 0.3-0.4 mu. It is notable that correcting teleseismic mb of NTS explosions upward by 0.4 mu falls far short of closing the gap between NTS and central Asia populations in Figure 4.

Given our confidence in the path calibrations for Lg Q used to determine mb(Lg) for central Asia, the remaining offset must reflect either real differences in the energy partitioning between P and S waves for NTS explosions compared to three test sites in central Asia with uniform results, or a problem with the Lg path calibration for western United States. Recent evidence suggests a problem with the path calibration for western United States.

CONCLUSIONS AND RECOMMENDATIONS

Apparent source spectra of central Asia explosions have been estimated using coda techniques. These spectra feature peaks that scale with size and could result from overshoot in the time function of explosions or from Rg-to-Lg scattering in the source region. The peaks occur in higher bands than does similar behavior at NTS, which makes transportability of a single-band amplitude-magnitude formula difficult between all test sites. Other, multi-band formulae could show more transportable behavior. Otherwise better characterization and correction for the spectral peaks will be necessary.

It appears that Lg Q was underestimated by Nuttli (1986) and Patton (1988) using the coda-wave frequency dispersion method of Herrmann (1980). At the 2001 23rd Seismic Research Review, we presented results for central Asian explosions where Nuttli's magnitudes were found to be systematically large compared to mb(Lg) values determined from stations much closer to the source. As is the case for NTS, the Lg Q determined from coda-wave dispersion on paths to Scandinavian stations was underestimated. New estimates of Lg Q based on coda amplitude decay for NTS explosions are significantly larger compared to the Q determined by Nuttli and Patton. We are using the new Lg Q values to re-calibrate NTS.

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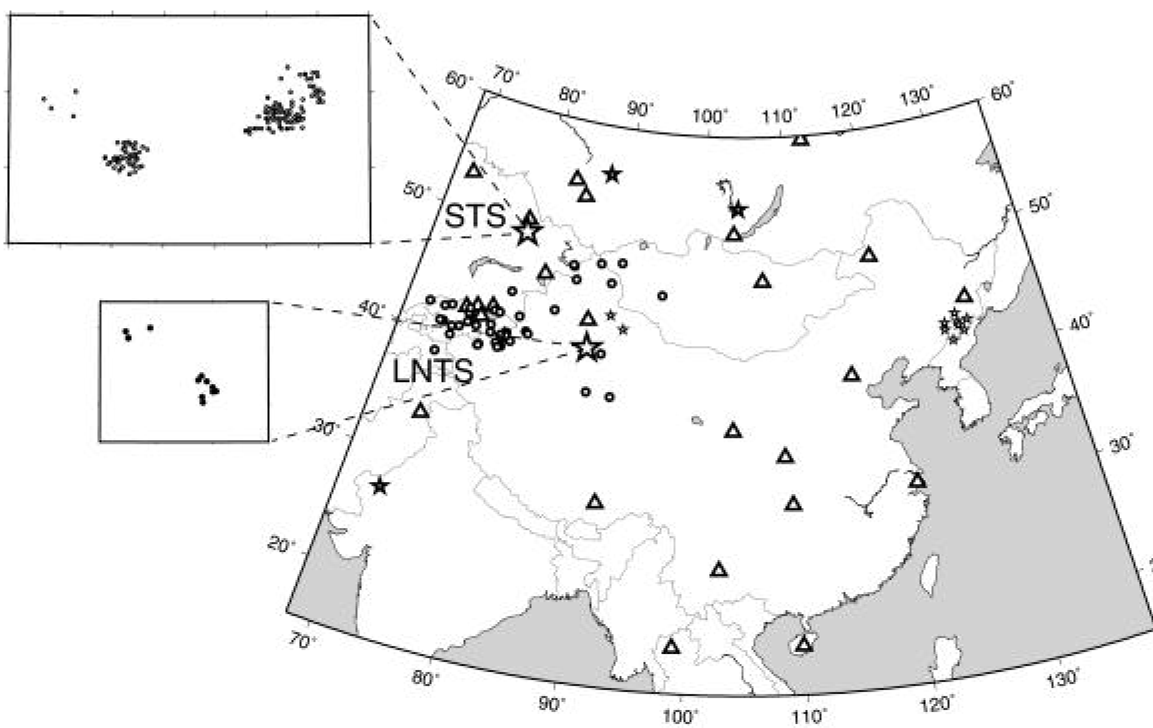

Figure 1. Stations and explosions used in the coda study. A 26-station network is shown (triangles); many stations include surrogates from multiple deployments. Test sites and isolated nuclear and single-shot chemical explosions are shown by stars, with insets giving event distributions at Semipalatinsk and Lop Nor. Earthquakes for which independently determined moments are available and were used to set absolute spectral levels are shown by circles.

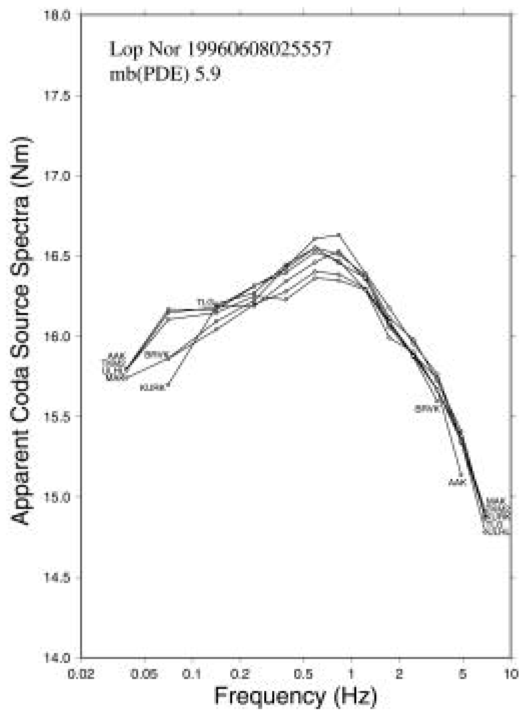

Figure 2. Apparent source spectra determined using coda wave data from seven stations, for a Lop Nor test. Stations are indicated at spectra endpoints. The inter-station consistency is especially good for bands above 1 Hz.

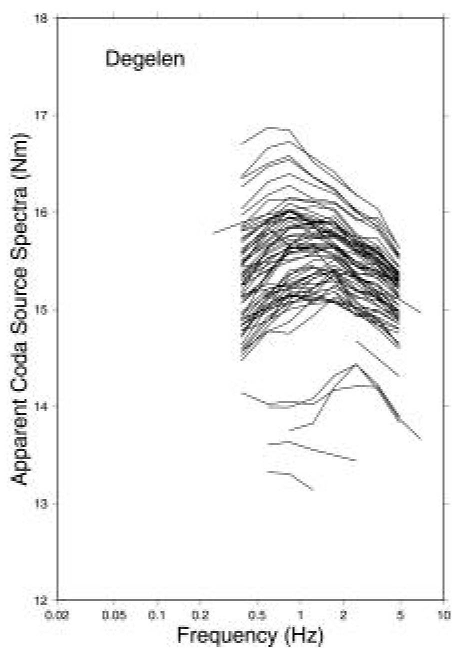

Figure 3. Apparent source spectra from coda for Degelen Mountain. events, including Omega series, 100T chemical explosions.

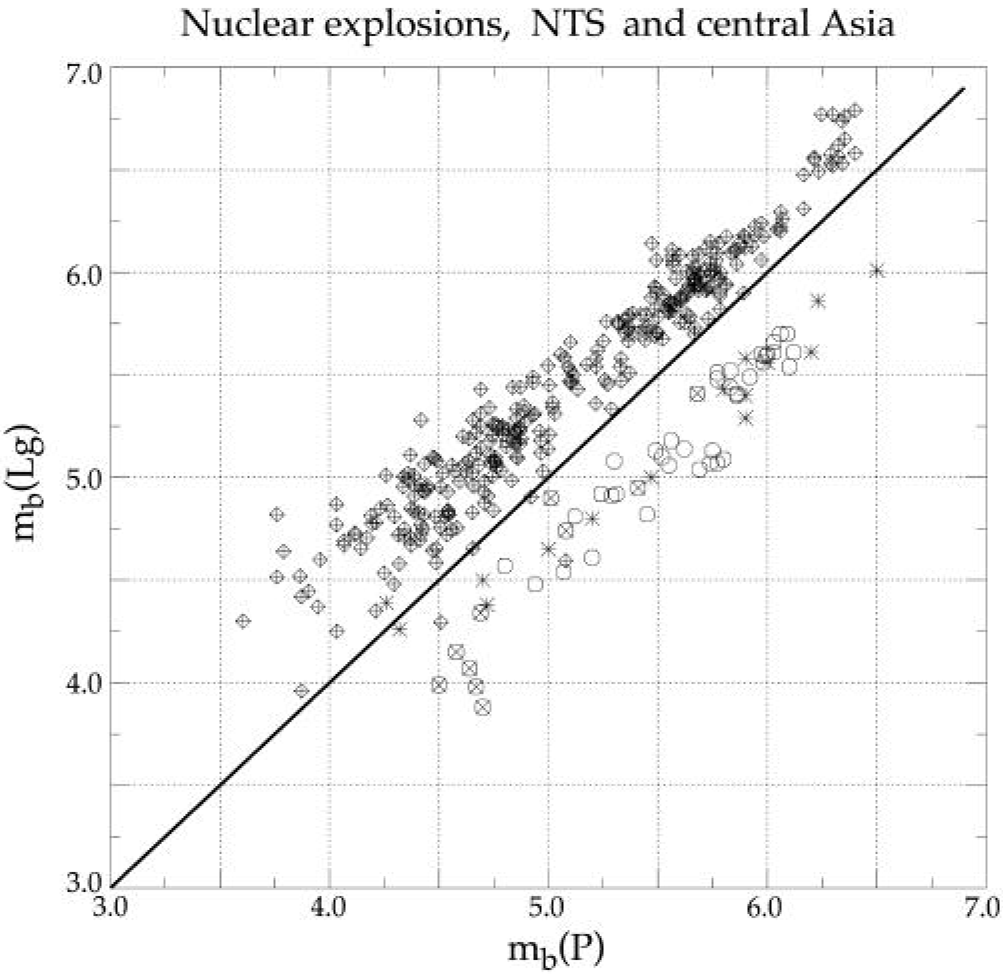

Figure 4. Measurements of mb(Lg) and teleseismic mb for over 325 nuclear explosions at the Nevada Test Site (grey diamonds) and at test sites in central Asia. Thirty-seven explosions at Balapan are plotted as open circles, 10 Degelen explosions as x's enclosed by circles, and 15 Lop Nor explosions as asterisks. All mb(P) values for NTS explosions are AWE (Atomic Weapons Establishment, Blacknest; Marshall and Lilwall, pers. comm.) determinations using maximum likelihood methods. A majority of the mb (P) measurements for central Asia explosions are also AWE determinations, although there are several Degelen shots for which mb(Pn) was substituted and about half of the mb(P) for Lop Nor shots are from the International Seismological Centre (ISC) catalog. mb(Lg) values for NTS explosions are from the work of Nuttli (1986) and Patton(1988), while mb(Lg) for central Asian explosions were determined in this study using waveform data from the Borovoye digital archive (Kim *et al*, 2001), and from stations AAK, MAK, NIL and WMQ.