DISCRIMINATION STUDIES IN THE YUNNAN REGION, SOUTHWEST CHINA

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ABSTRACT

The Lg/Pg ratio has been shown to improve in discriminant performance as the frequency content increases, with frequencies higher than 5 Hz leading to good separation of explosion and earthquake populations in most regions where it has been tested (National Research Council, 1997). Some further studies (e.g., Baumgardt and Schneider, 1997; Rodgers and Walter, 1997; Walter *et al.* 1997) have observed significant variability of regional phase ratios, such as Pn/Lg or Pg/Lg, which are generally powerful regional discriminants. Their characteristics vary significantly from one tectonic or geographic region to another and may also be strongly dependent on frequency (e.g. Baumgardt and Der, 1994). Southwestern China is known to have complex geology with large Q variations (e.g. Qin and Kan, 1986), so that several combinations of distinct source and receiver regions will need to be calibrated. It is important to understand and quantify these differences in order to accomplish improved regional discrimination in a region of complex geology, such as the Yunnan region in southwest China.

The Yunnan region is situated in a transitional tectonic region between the uplifted Tibetan plateau to the west and the Yangtze continental platform to the east. The region displays varying crustal thickness from 35 km to over 60 km with seismic activity strongly associated with the mapped active faults. The Yunnan region also has the strongest seismic zones in China. In this study, we built up a waveform database that consists of over 30,000 waveforms recorded at 23 broadband stations in the Yunnan provincial digital seismic network, as well as waveforms of earthquakes and explosions recorded by some portable arrays. Most of the waveform data have been reduced to absolute ground velocity in m/sec. The digital data so reduced are quality controlled, have their P and S-arrival times picked, and are filtered in narrow frequency bands. Then the spectral analysis is conducted in each frequency band. The scaling of the S energy is studied extensively for distance correction. Vertical component velocity seismograms are used to characterize high frequency S-wave propagation. The signals are processed to examine the peak ground motion and Fourier velocity spectra in the frequency range of 1-12 Hz. Analysis involves a two step process: first, modeling of peak S-wave motions in terms of EXCITATION, DISTANCE, and SITE; and is followed by a parameterization in terms of geometrical spreading, frequency dependent, Q and distance dependent duration. Observations are in the distance range of 30-700 km. The result has provided constraints on the amplitude-distance relation of 1-12 Hz high frequency ground motion in the distance range of 30-600 km in Yunnan, China, and surrounding provinces of China. The Pg/Lg ratio has been found to be a good discriminant in Yunnan region. As a test case of the process, we have successfully screened out an industry explosion with our discrimination analysis.

OBJECTIVE

Introduction

The Lg/Pg ratio has been shown to improve in discriminant performance as the frequency content increases, with frequencies higher than 5 Hz leading to good separation of explosion and earthquake populations in most regions where it has been tested (National Research Council, 1997). For example, in their study of discrimination between NTS explosions and earthquakes, Walter *et al*. (1995) noted improved performance at higher frequencies. Other examples are the regional discrimination study of explosions and earthquakes in the eastern United States and in southern Russia by Kim *et al*. (1993, 1997) who observed significantly improved discrimination capability of the amplitude ratio P/Lg in the 5-25 Hz band than in the lower frequency bands.

Several recent studies (e.g., Baumgardt and Schneider, 1997; Rodgers and Walter, 1997; Walter *et al.* 1997) have observed a significant variability of regional phase ratios, such as Pn/Lg or Pg/Lg that are generally powerful regional discriminants. Their characteristics vary significantly from one tectonic or geographic region to another, and may also be strongly dependent on frequency (e.g., Baumgardt and Der, 1994). Southwestern China is known to have complex geology with large Q variations (e.g., Qin and Kan, 1986), so that several combinations of distinct source and receiver regions will need to be calibrated. It is important to understand and quantify these differences in order to accomplish improved regional discrimination in a region of complex geology, such as southwestern China.

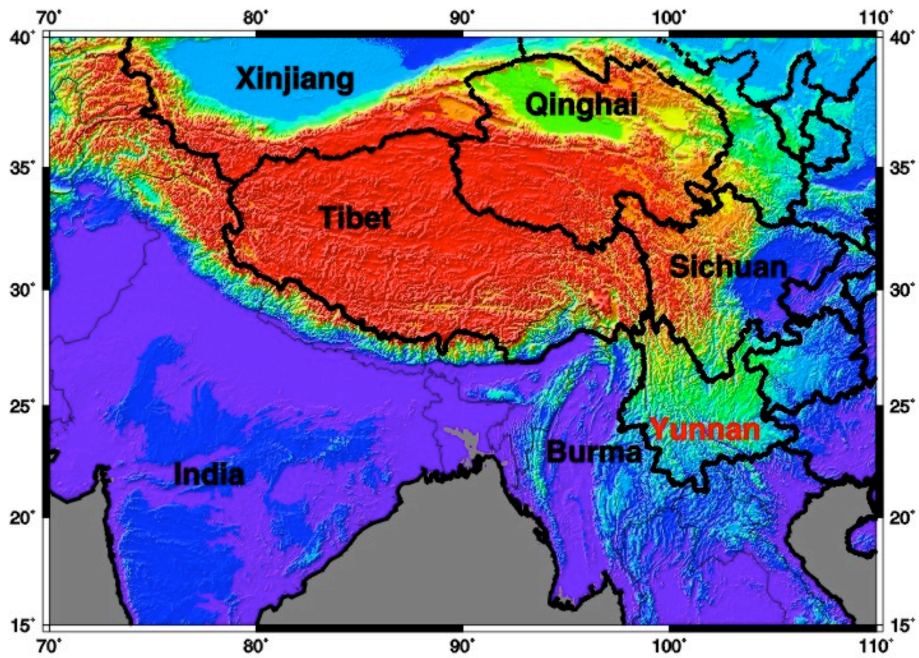

Figure 1. Yunnan and its surrounding area.

Yunnan Province is located at the south segment of the North-South Earthquake Zone in China, close to the Himalaya Orogenic Belt (Figure 1). Tectogenesis is strong in the region. Long and deep earthquake faults crisscross and spread over almost the entire region, and strong earthquakes occur frequently. As one of the most seismogenically active regions in China, western Yunnan is an earthquake prediction experiment field operated by the China Seismological Bureau. There is a well-developed seismic network in the region and a large volume of seismic data has been collected. Considerable efforts have been made on the study of the geological and geophysical features in the region. Wang, et al. (1994) investigated the 3-D velocity structure under Kunming seismic network and found an uplift of the Moho in central Yunnan. They also found that the Red River Fault cuts through the Moho discontinuity. Liu, et al. (1993) studied the 3-D crustal and upper mantle structure in Yunnan and the vicinity and found that there are strong correlation between the upper crustal structure and the topography in the region. Complex crustal velocity structures, including low velocity plume, low velocity layers were also revealed in the study. Lin, et al. (1993) found significant lateral heterogeneity in the crustal structure in western Yunnan based on several DSS profiles. They concluded that the velocity in the crust increases from south to north. Regional seismic characteristics in such an area are of high interest for discrimination studies.

Technical Objectives

The challenge for verification using the International Monitoring System will be to maintain reliable discrimination of small seismic events in diverse regions of the world by using sparsely distributed recording stations. At regional distances, Lg is often the largest seismic phase from both explosion and earthquake sources, and may sometimes be the only reliably observed phase from small events. The ratio of S- to P-wave energy (or Lg/Pn and Lg/Pg for regional data) has so far been found to be the most promising regional discriminant for earthquakes and explosions. Use of broadband data, whenever available, will allow us to investigate how low- and high-frequency data may be combined to enhance regional discrimination. The spectral characteristics of regional phases are known to vary drastically from one region to another. It is therefore important to investigate the variability of regional discriminants in a geologically complex region such as the southwest China. Results of the proposed research will lead to more effective and reliable discrimination of small events in various geological settings.

The objectives of this project include: 1) construction of a digital seismic waveform and ground truth database for southwest China; 2) regional discrimination studies, including location, spectral ratio, regional structure inversion, and structure tomography (combined with other projects); and 3) product delivery. This is the third year of this project. The waveform database has been built and is ready for delivery. A final report is in preparation. This paper is a brief summary of the three years' work. The tomography results are to be presented separately.

RESEARCH ACCOMPLISHED

The Waveform Database

We have constructed a database of digital waveforms recorded by both regional digital broadband network and the portable seismic arrays.

1) Data Recorded at the Regional Digital Broadband Network

There have been propositions from the Chinese central government that in their 1995 Five-Year-Modernization Plan efforts will be made to upgrade the Chinese Digital Seismic Network. Additionally, certain regional analog stations should be upgraded to digital recording format. The Chinese Digital Seismic Network consists of national digital seismic networks, regional digital seismic networks, portable digital seismic networks, regional seismic arrays, and digital strong earthquake networks. A regional digital seismic network has 30 digital broadband seismic stations, including telemetric ones. The bandwidth of the digital broadband seismograph is about 20 sec - 20 Hz (Figure 2). Each seismic station has digital broadband seismographs and short period seismographs with 16-bit data sampling board, data processing, and transfer facilities. The major specifications of the regional digital seismographs are: (1) sensitivity of $1\sim2\times10^{-8}$m.s^{-1}/LSB; (2) dynamic range greater than 90dB; (3) resolution greater than 2^{-15}, 16-bit; (4) linearity greater than 10^{-3}; and (5) time error less than 1 ms. The center of the regional digital seismic network has the function of seismic data collection, storage, processing, and maintenance.

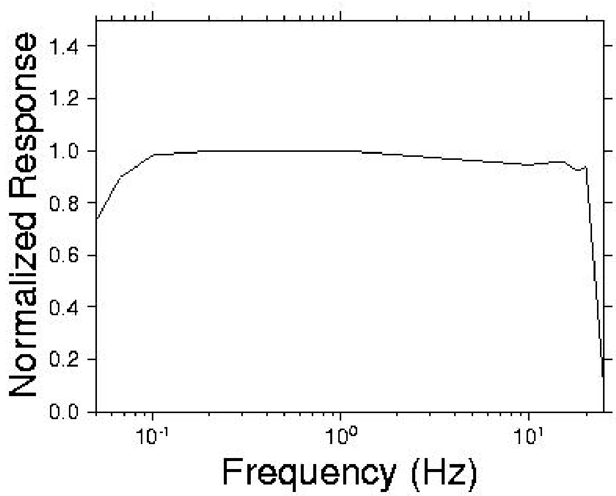

Figure 2. Instrument response of the digital broadband seismographs used in the regional digital seismic network in Yunnan, China.

Twenty-three digital broadband seismographs have been implemented in the Kunming regional digital seismic network in recent years (Figure 3). This network is the first fully functional, regional, digital seismic network in China that provides high-quality continuous 3-componant digital broadband waveform data. The seismographs are velocity recording with a 50-Hz sample rate and 16-bit sampling board. The network has been in operation since 1997 and a large volume of good quality digital seismic data have been collected. Multimax has obtained and examined the digital waveform data for over 900 seismic events recorded by the Yunnan regional digital seismic network. These data are the first time that the high-quality regional digital broadband waveform data from China are available to the U.S. seismologists. Figure 4 shows a comparison of the events recorded at this regional network with those reported by ISC, IDC, and IRIS DMC for the same period. Clearly, the regional network has a much better coverage of the regional seismic events, which are very important for regional seismic studies.

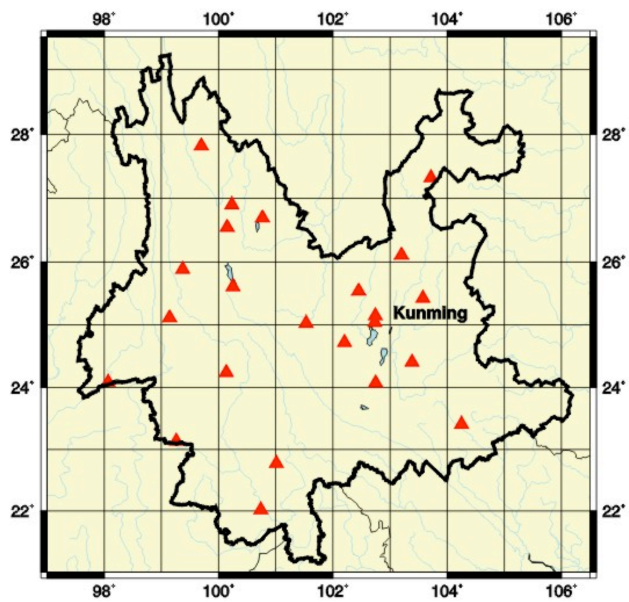

Figure 3. The digital broadband seismic network in Yunnan.

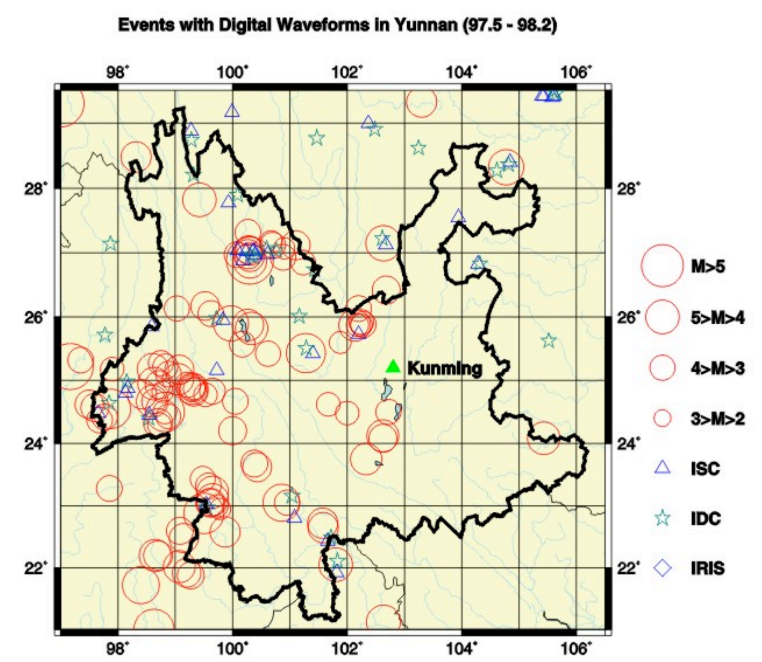

Figure 4. A comparison of the regional events recorded at the Yunnan digital network and those reported in several other global catalogs.

As an example, Figure 5 shows the vertical component of the waveforms recorded by the regional network for a M5.5 local earthquake. A typical 3-component waveform recording for a local event 110 km away is shown in Figure 6. We have established a data retrieval mechanism to access the digital broadband data from the regional digital seismic network through our Chinese collaborators. Over 30,000 waveforms with the same quality have been obtained in this project. There are an abundance of seismicity and mining activities in Yunnan, which provides a valuable data source for the study of regional seismic discriminants.

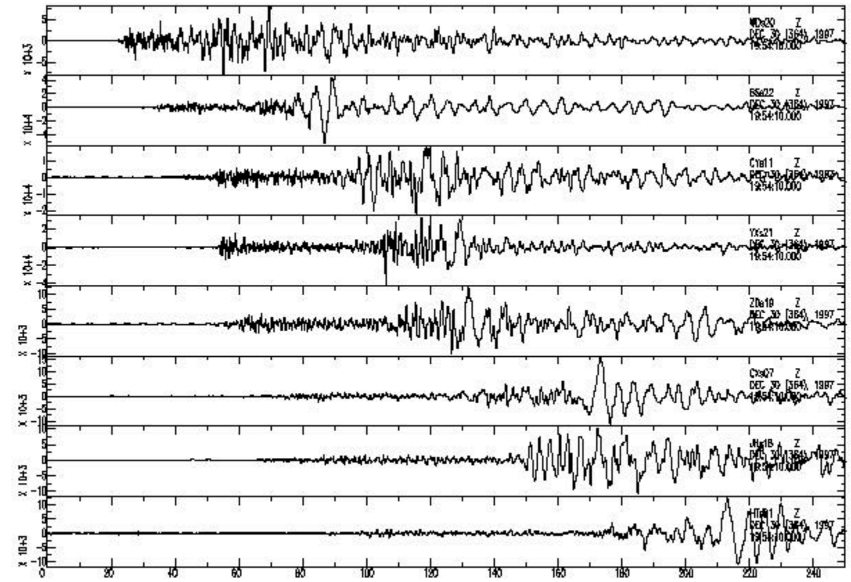

Figure 5. The vertical component of the waveforms of a M5.5 event recorded at the regional digital network.

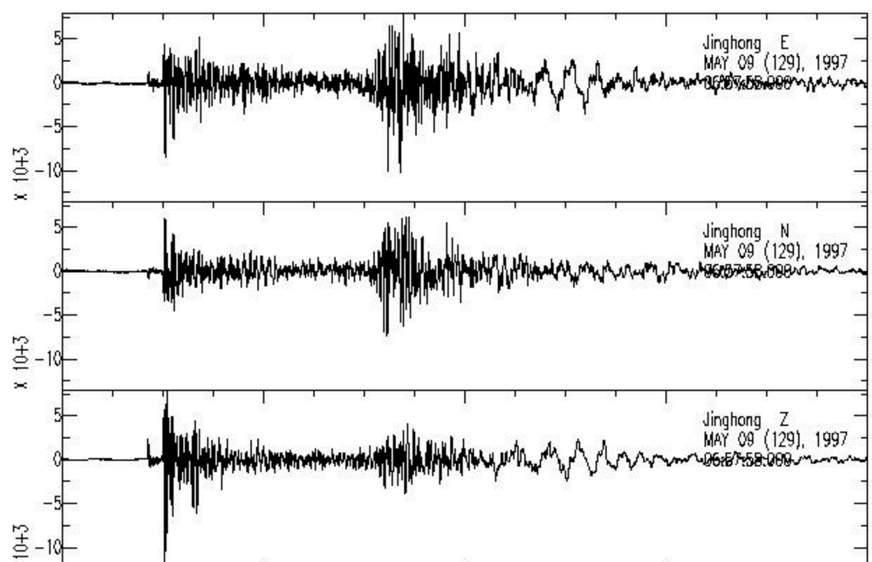

Figure 6. An example of 3 component waveforms of a local event (110 km away) recorded at one station of the regional digital network.

2) Data Recorded by Portable Broadband Arrays

We have also collected the waveform data recorded at 2 portable broadband seismic arrays for 7 underwater or underground explosions and 4 local earthquakes. All explosions are controlled ones in the southwest China, and of about 1,000 kg TNT. Figure 7 shows the waveform of one underwater explosion recorded at the portable broadband array. These controlled explosion data are high quality ground-truth information. Figure 8 shows the waveform of a local earthquake recorded by a similar portable array in the same area of the explosions. Such data sets provide very good opportunities for discrimination studies.

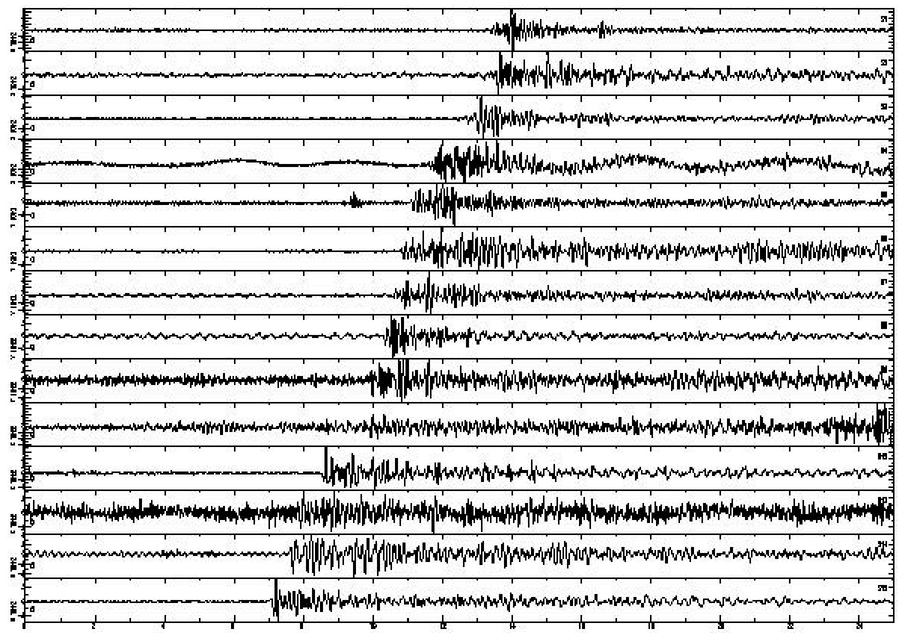

Figure 7. The vertical component of waveforms of an underwater explosion recorded by a portable broadband seismic array.

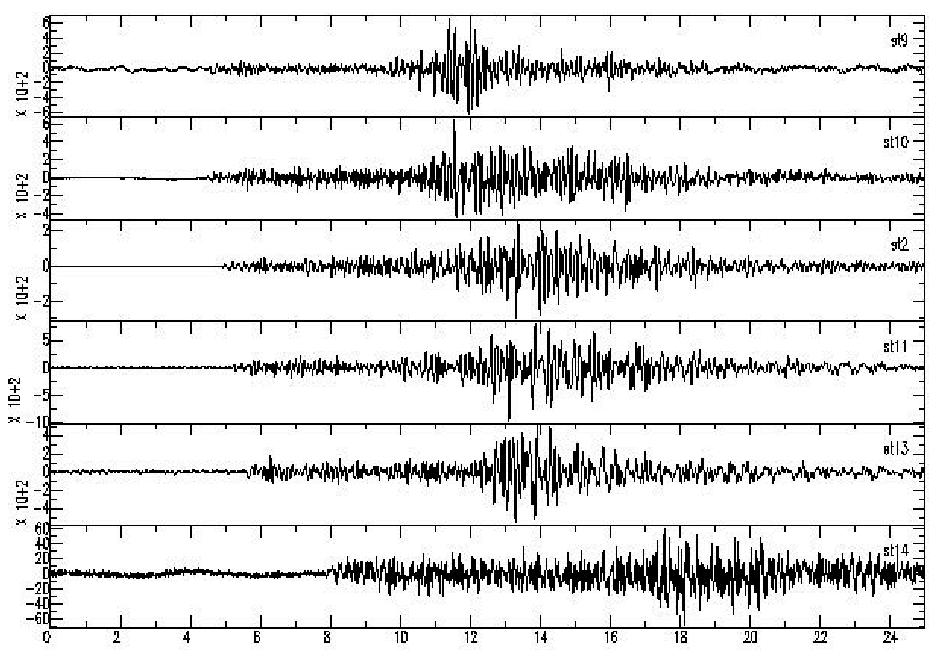

Figure 8. The vertical component of waveforms of an earthquake recorded by a portable broadband seismic array in the same area as the explosion shown in Figure 7.

The Spectral Ratio Analysis

Most of the waveform data have been reduced to absolute ground velocity in m/sec. The digital data so reduced are quality controlled, have their P and S-arrival times picked, and are filtered in narrow frequency bands. Then the spectral analysis is conducted in each frequency band. A table is finally created for further multivariate statistical analysis from each filtered waveform that contains event–station information, peak filtered motion, smoothed Fourier velocity spectra, duration, and signal envelope information. To give an example of the spectral analysis, the spectral ratio for a local earthquake and a local explosion is shown in Figure 9 and Figure 10, respectively. All the phase picks are also assembled together with other data obtained by Multimax Inc. into a comprehensive bulletin for the region. Figure 11 gives the Pg/Lg spectral ratio for the explosions (red) and the earthquakes (black) recorded at the same array. The separation of the two groups is very good, with only one or two exceptions.

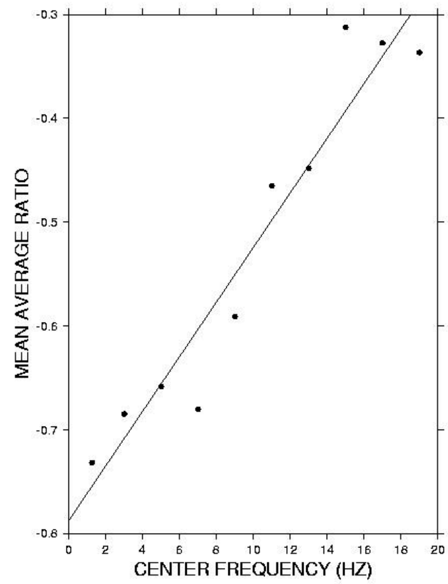

Figure 9. Spectral ratio of Pg/Lg for an earthquake.

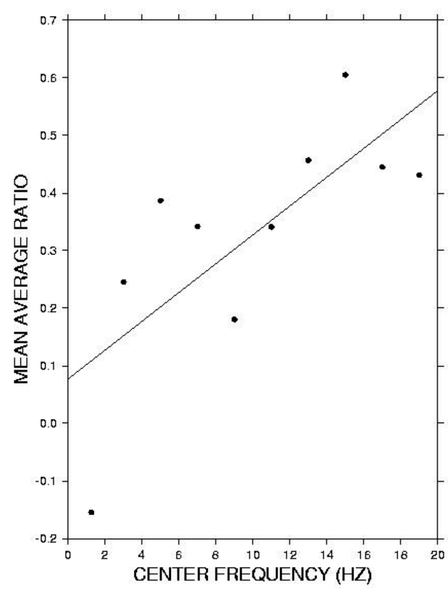

Figure 10. Spectral ratio of Pg/Lg for an underground explosion. Note the difference from the previous figure.

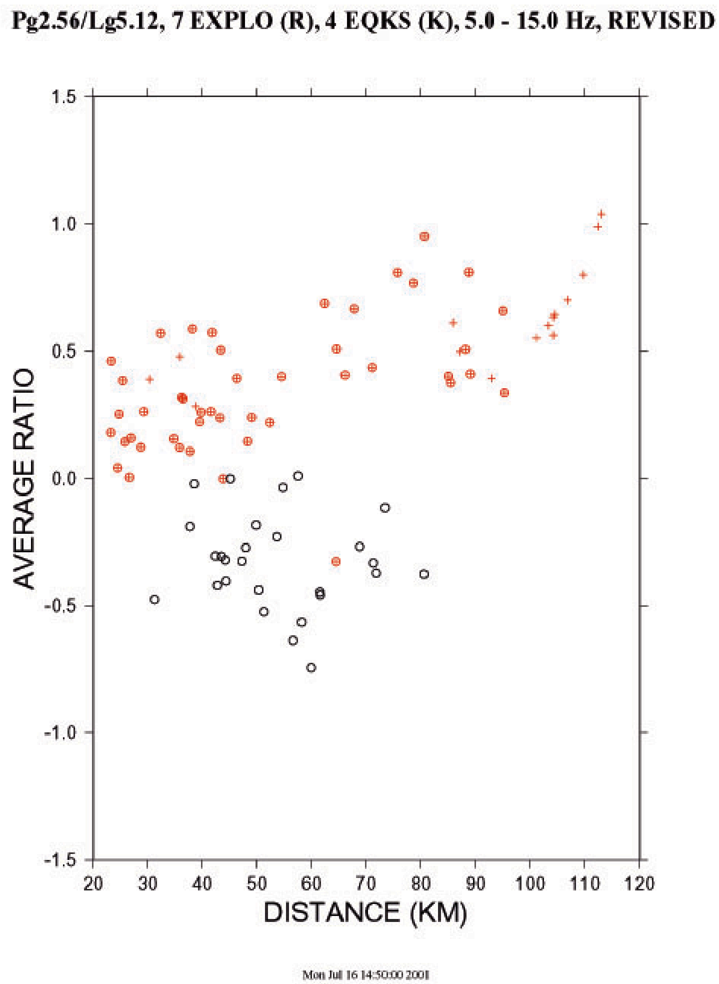

Figure 11. Spectral ratio of Pg/Lg averaged from 5–15 Hz for the explosions (red) vs. that for the earthquakes (black) recorded at the same array

<u>High Frequency Ground Motion Scaling</u>

Vertical component velocity seismograms from Yunnan digital seismic provincial network in Yunnan, China, are used to characterize high-frequency S-wave propagation. The signals are processed to examine the peak ground motion and Fourier velocity spectra in the frequency range of 1–12 Hz. Analysis involves a two-step process: first, modeling of peak S-wave motions in terms of EXCITATION, DISTANCE, and SITE terms; this step is followed by a parameterization in terms of geometrical spreading, frequency dependent Q and distance dependent duration. The data set from 05/97–02/98 and 02/99–01/00 consists of over 6,000 waveforms from 23 stations and 325events. Observations are in the distance range of 30–700km. The data are processed for purposes of defining the parameters needed for the application of Random Vibration Theory to predict high frequency earthquake motions. Figure 12 shows part of the regression results at 1.0 Hz using

$$\log A = D(r) + E(rref) + S$$

where A is observed motion, D(r) is distance term, E(rref) is the excitation term at the reference distance, and S is a site term. D(r) is a piecewise linear continuous function defined by distance nodes, whose frequency dependence is shown in Figure 13. The Fourier ground motion excitation fit is shown in Figure 14.

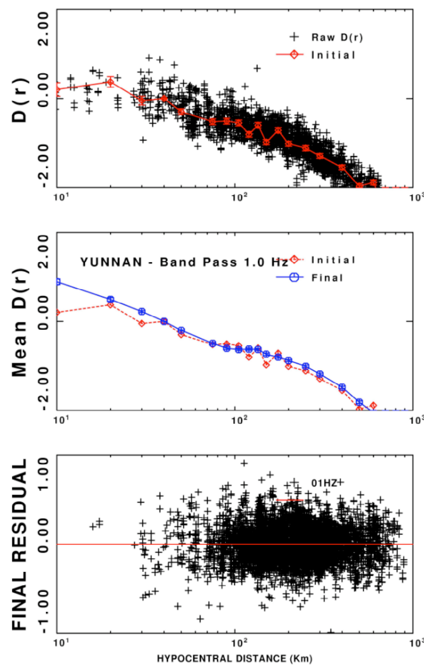

Figure 12. Regression results for processing the peak S motion at 1.0 Hz: Top) Estimate of the D(r) term using the coda normalization technique; Middle) Comparison of coda normalization (red) and regression (blue) results; Bottom) regression residuals as a function of distance. The uniform distribution of residuals and the lack of significant outliers indicate uniform calibration of instruments.

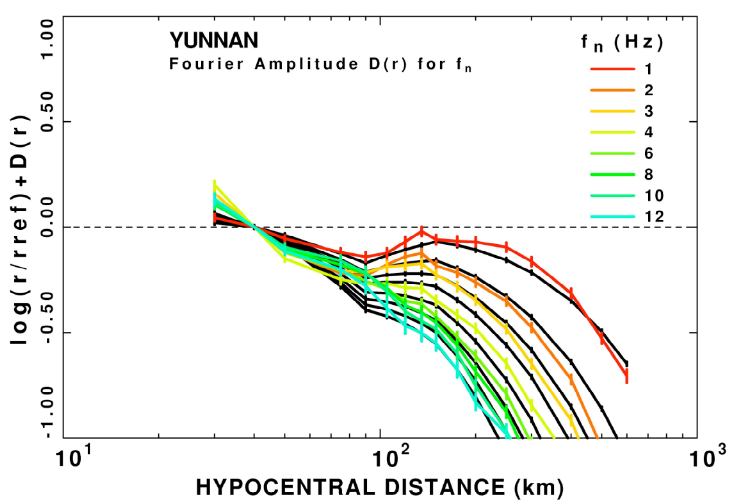

Figure 13. The frequency dependence of D(r).

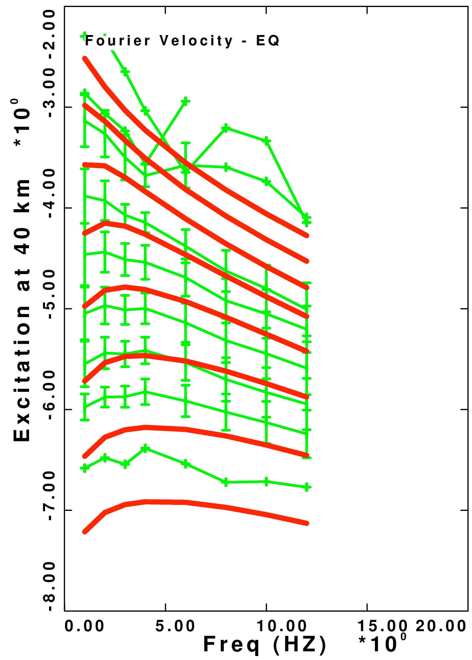

Figure 14. Comparison of model fit to the Fourier velocity excitation terms. The green curves are averages of the regression excitation terms into groups that are separated by 0.5 log units in level at 3.0 Hz. The red curves are the predicted excitation terms for the model for moment magnitudes of 2.0–5.5 at increments of 0.5 moment magnitude units. The high frequency level for small events is not a function of stress drop. The largest events in the data set had moment magnitudes of 5–5.5. Averages are used to be able to see the trends.

Inversion of Regional Structure

The waveform in the database have been used to inverse the regional structures. Two methods were conducted in our analysis: receiver function and surface wave dispersion. Figures 15 and 16 show one example of each method at one station, respectively. The results from the two methods are consistent. For example, both show a crust thickness of about 48 km under the station.

Screening the Outlier of Pg/Lg Spectral Ratio and Relocation

We tested Pg/Lg spectral ratio as a discriminant by screening for outliers. Figure 17 shows an example of a possible explosion recorded by 5 of our stations, which occurred on September 26, 2001, and was clearly recorded at Nanjian station. This event was not listed in the Chinese local catalog, so we searched for its waveforms recorded at some other stations. It turned out that it was recorded at five, with all positive first arrivals whenever it is clear enough to tell (Figure 17 a and b). Then we went further to do the Pg/Lg spectral ratio analysis and location of this event. The Pg/Lg spectral ratio of this event (the red plus signs in Figure 18) is close to the mean value of the ratio for all the events (a mixture of explosions and earthquakes) at low frequencies but well above the mean at high frequencies. This is a typical explosion pattern. Locating this event by LocSAT gives an initial time of 12h59m59.5s pm local time and a position at (100.2824E, 24.8783N). The initial time is almost on the hour, which is characteristic of industrial explosions in China. The location of this event is close to the on-going construction sites of two large dams and several highways. It is very likely that this event was a shot of one of these construction projects.

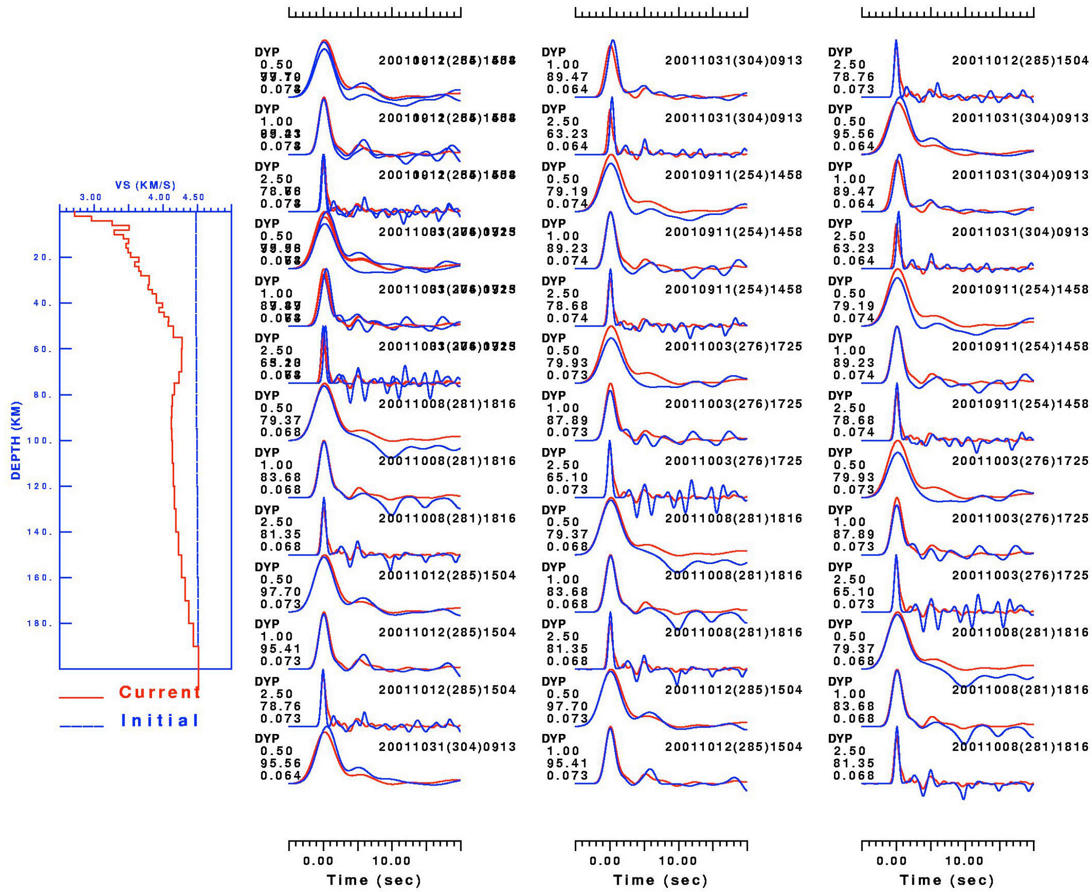

Figure 15. The receiver function inversion at Dayao station.

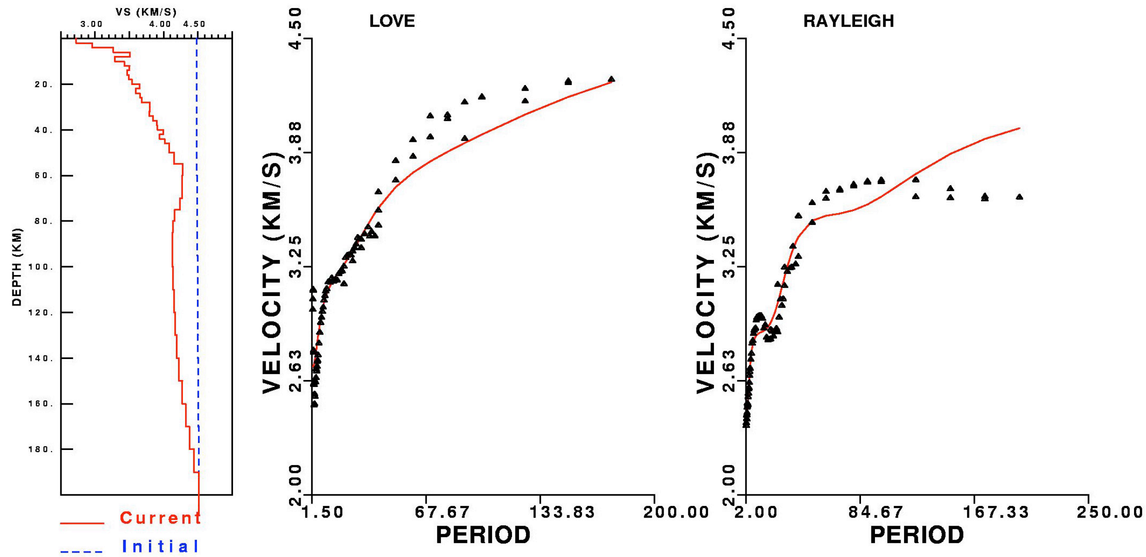

Figure 16. The surface wave dispersion analysis at Dayao station.

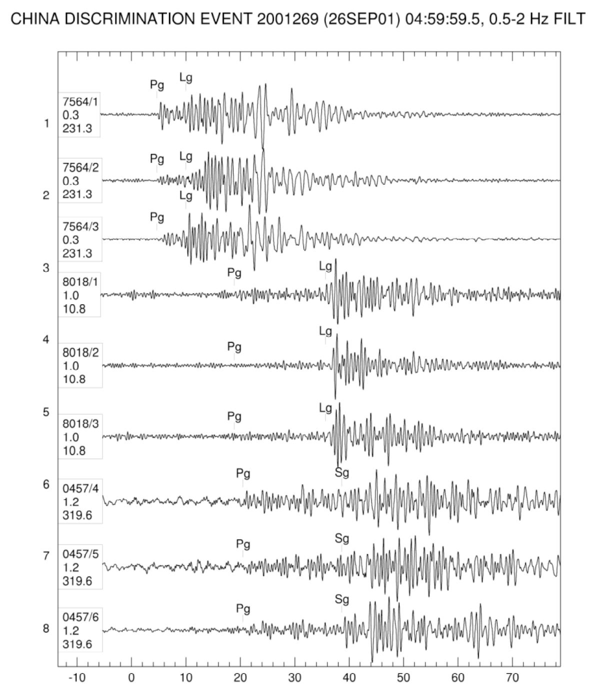

Figure 17a. The waveforms of an event on September 26, 2001, that is not in the Chinese catalog recorded at 5 stations in our network (part 1).

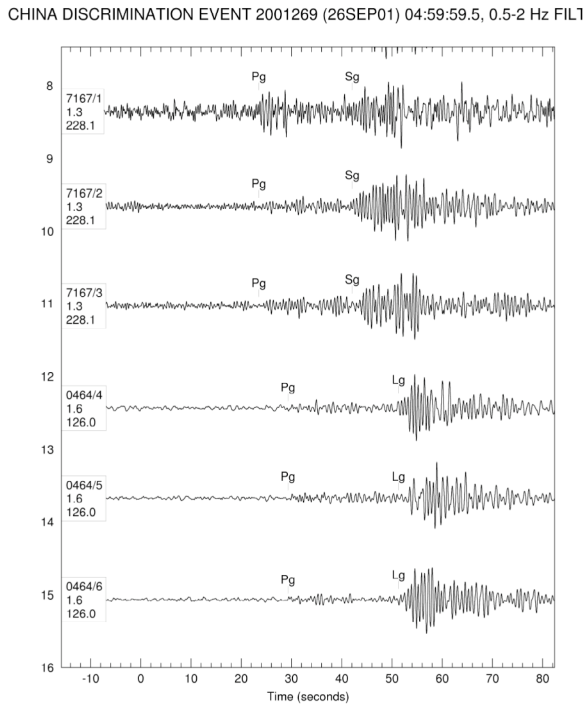

Figure 17b. The waveforms of an event on September 26, 2001, that is not in the Chinese catalog recorded at 5 stations in our network (part 2).

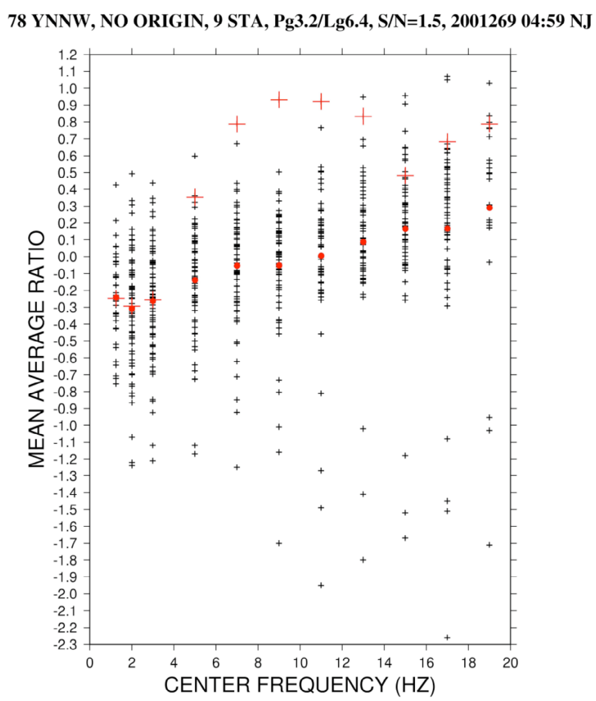

Figure 18. Pg/Lg spectral ratio for 78 events that are not in the Chinese catalog we have screened so far (black crosses). Red dots: the average Pg/Lg spectral ratio for all events. Red cross: the Pg/Lg spectral ratio for the event of September 26, 2001.

CONCLUSIONS

In summary, we have accomplished the following research of this project for studying the regional seismic characteristics in southwest China:

1. **Compiled a regional waveform database**. This is the first digital waveform database from China regional networks. Currently, over 30,000 waveforms reduced to the absolute ground velocity have been archived in the database. The database is ready for delivery.
2. **Assembled local bulletins with arrivals and phase picks**. Such bulletins have much better coverage than the national or global bulletins. They are very useful in relocation and tomography studies.
3. **Obtained ground-truth information for 7 local explosions**. These data contribute tremendously to the regional discrimination studies.
4. **Analyzed high frequency ground motion scaling**. The characteristics of the ground motion scaling were obtained through multivariate analyses. The results could be used for distance corrections.
5. **Inversed regional structures**. Both receiver function and surface wave dispersion analyses were conducted to inverse for the regional structures. The results are consistent from the two methods.
6. **Conducted Pg/Lg spectral ratio analysis**. Our analysis shows that Pg/Lg ratio is a good discriminant in the study area. As a test case, we have shown a successfully screened industry explosion.

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