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Regionalization and Calibration of Seismic Discriminants, Path Effects and Signal-to-Noise for Station ABKT (Alibek, Turkmenistan)

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ABSTRACT

We report measurements and analysis of regional seismic phase amplitude ratios and signal-to-noise for earthquakes observed at the International Monitoring System primary station ABKT (Alibek, Turkmenistan). We measured noise and phase amplitudes of the regional phases \( P_n \), \( P_g \), \( S_n \) and \( L_g \) in four frequency bands between 0.75-9.0 Hz. Measurements were made in both the time and frequency domains. The spatial variation of amplitude ratios (e.g. \( P_n/L_g \), \( P_g/L_g \), \( P_n/S_n \), \( P_g/S_n \)) and signal-to-noise (phase/noise) reveal significant path effect differences between the Hindu Kush, Kazakh Platform, Iranian Plateau and Caspian Sea. In order to represent this behavior, we have investigated several techniques for characterizing the data. These techniques are: 1) correlation with along-path distance and waveguide properties; 2) sector analysis; and 3) spatial averaging.

Along-path waveguide properties, such as mean elevation and rms topographic slope are found to be the strongest factors related to \( P_g/L_g \) amplitude ratios at the lowest frequencies (< 3.0 Hz). Other path properties such as mean crustal thickness and basement depth are not strongly correlated with \( P_g/L_g \) ratios. For sector analysis we divided the data into four (4) azimuthal sectors and characterized the data within each sector by a distance trend. Sectors were chosen based on the behavior of \( P_n/L_g \), \( P_g/L_g \) and \( P_n/S_n \) amplitude ratios as well as topographic and tectonic character. Results reveal significant reduction (up to a factor of two) in the scatter of the \( P_n/L_g \) and \( P_g/L_g \) amplitude ratios for the sectorized data compared to the entire data set from all azimuths. Spatial averaging involves smoothing and interpolation of the ratios projected at the event location. Methods such as cap averaging and kriging will be presented at the meeting.

Key words: CTBT Monitoring, Regional Discriminants, Path Effects, Station ABKT, Middle East

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OBJECTIVE

As ratification of the Comprehensive Test Ban Treaty (CTBT) and entry into force approaches, research efforts need to focus on calibration of the International Monitoring System (IMS). In particular, seismic discriminants need to be measured for the earthquake population so that meaningful identification and analysis of outliers can be performed. It is now well accepted that regional seismic P/S ratios can discriminate earthquake and explosion sources, particularly at frequencies above 3.0 Hz (e.g. Walter et al., 1995; Taylor, 1996; Hartse et al., 1997). Station ABKT (Alibek, Turkmenistan) is an IMS primary seismic station and is located within regional distances of Iran, Afghanistan and many Former Soviet Republics. This region has abundant, but unevenly distributed seismicity. However, great variability in earthquake Sg and Lg amplitudes has been reported for this station (Rodgers et al., 1997a). The regional phases Pn and Sn mostly sample the mantle, while Pg and Lg sample the crust. The variability in earthquake generated Pn/Lg, Pg/Lg and Pn/Sn ratios (up to two orders of magnitude) is greater than the typical separation of earthquake and explosion populations. Thus, the spatial variation of earthquake P/S ratios needs to be determined in order to map out discriminant behavior.

The objective of this research is to measure, map and characterize regional P/S discriminants (e.g. Pn/Lg, Pg/Lg, Pn/Sn, Pg/Sn) for station ABKT. In addition we measured the signal-to-noise for each regional phase (Pn, Pg, Sn and Lg). Results of this study are maps of P/S discriminant behavior and individual phase signal-to-noise ratios. We have also attempted to represent the observed spatial variation of discriminant behavior by correlation with along-path distance and crustal waveguide properties, sector analysis and spatial averaging. We have processed and analyzed data at all broadband stations in the Middle East and southern Eurasia (AAK, ANTO, BGIO, KEG, KIV and NIL), but because of the large data set available for ABKT and its importance as an IMS primary station we are focusing on ABKT. Because of the large variability observed at ABKT, this station provides a good data set to test techniques for spatial averaging regional P/S discriminants.

RESEARCH ACCOMPLISHED

Data Processing

Three-component waveform data was requested from the Incorporated Research Institutions for Seismology-Data Management Center (IRIS-DMC) for station ABKT for regional events spanning the period 1993-1995. Event locations and origin times were taken from the National Earthquake Information Center-Preliminary Determination of Epicenters (NEIC-PDE) catalog. We restricted data to depths less than 50 km and body-wave magnitudes greater than or equal to 4.0. All waveforms were previewed and a first-arriving P-wave was picked when possible. Noisy data were immediately discarded. Regional phases were isolated with the following group velocity windows: Pn 8.0-6.2 km/s; Pg 6.2-5.0 km/s; Sn 4.6-4.0 km/s; Lg 3.6-3.0 km/s. In order to account for event dislocations and timing errors, the origin time was shifted so that the Pn phase arrives at 7.9 ms. This is an appropriate average value for the region (Hearn and Ni, 1994). Normally, this shift was less than about five seconds. Noise was taken as a 35 second window ending 5 seconds before the P-wave. Regional phase and noise amplitude measurements were made on vertical component waveforms in both the time and frequency domains following the procedures outlined in Rodgers et al. (1997b). Time domain measurements were made on bandpass filtered waveforms using the rms amplitude in the phase window. Frequency domain measurements were made on broadband waveforms as the log10-mean amplitude of the phase window spectrum for the given pass band. Differences between these and other regional phase amplitude ratio measurement techniques are described in Rodgers et al. (1997b). P/S amplitude ratios were found in four frequency bands (0.75-1.5, 1.5-3.0, 3.0-6.0 and 6.0-9.0 Hz). The resulting data set contained over 300 earthquakes.
Spatial Variation of $Pg/Lg$ and $Pn/Sn$

Figure 1 shows the event locations, ABKT location and the major topographic/tectonic provinces of the region. Seismicity is dominated by the Hindu Kush and Zagros Mountains. The spatial variation in the individual $Pg/Lg$ and $Pn/Sn$ amplitude ratios are shown in Figures 2 and 3, respectively. For these maps amplitudes were measured in the time domain using the rms and only data for which the Pn/pre-Pn noise ratio was greater than 2.0 were plotted. $Pg/Lg$ and $Pn/Sn$ amplitude ratios span nearly two orders of magnitude. Two points are immediately notable from these maps. Firstly, as the frequency pass band increases (> 3.0 Hz) most of the paths from the Zagros fail the signal-to-noise criteria, whereas paths from the Hindu Kush survive the signal-to-noise criteria. Note that the signal-to-noise criteria is based only on the Pn/pre-Pn ratio. Signal-to-noise for other regional phases behaves similarly and will be shown at the meeting. Secondly, the $Pg/Lg$ and $Pn/Sn$ amplitude ratios show good spatial coherence with the Hindu Kush showing low $Pg/Lg$ and $Pn/Sn$ and the Zagros showing high $Pg/Lg$ and $Pn/Sn$. It is important to note, however, that these two regions are at roughly the same distance (about 1100 km) from ABKT. This indicates that there exist different path effects between these two regions. In order to reduce the variability of these amplitude ratios, it is appealing to group paths together on the basis of their topographic and tectonic character as well as their $Pg/Lg$ and $Pn/Sn$ behavior.

Variability of Sn and Lg amplitudes in the Middle East (including observations at ABKT) was reported by Rodgers et al. (1997a). Weak Sn energy corresponds to the high elevations of Iranian Plateau, recent volcanism and low Pn velocities (Hearn and Ni, 1994). The simultaneous occurrence of these observations probably results from partial melt in the shallow mantle. Lg amplitudes are reduced for paths crossing the Zagros relative to paths from the Hindu Kush. Paths crossing the southern Caspian Sea show very little Lg energy, probably due to the remnants of oceanic crust.

Distance Corrections, Along-Path Waveguide Effects and Sector Analysis

Recent discrimination studies have illustrated the importance of correcting amplitude ratios for distance effects before constructing discrimination plots (Taylor, 1996; Hartse et al., 1997). Distance corrections can remove the effects of attenuation and geometric spreading as well as possibly account for other path effects. A recent study of path effects on regional discriminants in China by Fan and Lay (1997) found that distance is an important path parameter along with mean path elevation, topographic roughness, mean crustal thickness and mean basement depth.

Figure 4 shows the log10 $Pg/Lg$ amplitude ratios for the four frequency bands versus distance along with a linear regression fit to a straight line. The symbols are coded by the sectors shown in Figure 1. The linear correlations ($r$) are rather weak (< |0.4|) and the data are very scattered. The standard error about the regression fits (sd) are 0.16-0.27 log-10 $Pg/Lg$ amplitude. We investigated the relationship between $Pg/Lg$ ratios and other along-path parameters. These included: mean elevation, surface roughness (rms elevation), rms slope, elevation skewness, mean basement depth and mean crustal thickness. Topography was taken from ETOPO5; basement and Moho depths were taken from the (Soviet) Institute of Physics of the Earth complied maps.

For ABKT we found that rms slope is well correlated with the $Pg/Lg$ ratios, but only for frequencies less than 3.0 Hz. Figure 5 shows the $Pg/Lg$ ratios vs. rms slope. Note that the linear correlations are stronger for rms slope than for distance, but the standard error about the regression fits (sd) are only slightly smaller. For this plot the data are symbol-coded by sector as in Figure 4. Grouping of the ratios by sector is also seen: Hindu Kush paths (circles) have lower rms slope than Zagros paths (triangles). Pn/Lg showed more scatter, but slightly stronger distance dependence.
When the data is subdivided by azimuthal sector, as shown in Figure 1, the Pg/Lg ratios are strongly correlated with distance. Figure 6 shows the distance trends for each sector. The data demonstrate less scatter and have stronger linear correlations (up to 0.7) than the data set for all azimuths. The largest reduction in scatter is seen for the Hindu Kush and Zagros at frequencies less than 3.0 Hz. But for these sectors the data sampling is not evenly distributed over distance. Slightly smaller scatter reduction was obtained by sector subdivision of the Pn/Lg ratios.

**CONCLUSIONS AND RECOMMENDATIONS**

Regional seismic P/S discriminants observed at station ABKT for a large earthquake population show great variability. However, this variability results from regional (azimuthal) variations in path effects. We have shown that reduction in the scatter of regional discriminants can be achieved by subdividing the data into azimuthal sectors and characterizing the data within each sector by a simple distance correction. We are currently investigating the relationship of regional discriminants with along-path topographic and waveguide properties (similar to Fan and Lay, 1997) and spatial averaging (such as cap-averaging and kriging). Hopefully by the meeting we will be able to compare the performance of these three techniques for characterizing the spatial variation of regional discriminants. Performance will be judged by the predictive capabilities of each technique.

Although the reduction of regional discriminant scatter obtained by sector analysis for low frequencies (< 3.0 Hz) is encouraging, the scatter remains and signal-to-noise is low for higher frequencies (> 3.0 Hz). Large reduction in discriminant scatter for low frequencies was obtained by correlating amplitude ratios with along-path crustal waveguide properties (Fan and Lay, 1997). Regional discrimination studies typically find better discriminant performance for higher frequencies (e.g. Walter et al., 1995; Taylor, 1996; Hartse et al., 1997). The low signal-to-noise we report for the Iranian Plateau is probably due to higher lithospheric attenuation and may lead to higher detection thresholds for this region.

**REFERENCES**


Figure 1. Locations of station ABKT and the regional events studied. Major topographic/tectonic units are labeled. Heavy grey lines mark the azimuthal boundaries of the sectors described in the text.
**ABKT Pg/Lg**

Amplitude Ratio

Time domain: Rms

Pn/noise > 2.0

- Pg/Lg < 0.5, Lg efficient
- 0.5 <= Pg/Lg <= 1.0, Lg intermediate
- Pg/Lg > 1.0, Lg weak

**Figure 2.** Map of Pg/Lg amplitude ratios observed at ABKT for the four frequency bands considered.
ABKT Pn/Sn
Amplitude Ratio
Time domain: Rms
Pn/noise > 2.0

- Pn/Sn < 0.5, Sn efficient
- 0.5 <= Pn/Sn <= 1.0, Sn intermediate
- Pn/Sn > 1.0, Sn weak

0.75-1.5 Hz

1.5-3.0 Hz

3.0-6.0 Hz

6.0-9.0 Hz

Figure 3. Map of Pn/Sn amplitude ratios observed at ABKT for the four frequency bands considered.
**ABKT Pg/Lg vs. Distance**

![Graphs showing correlations of Pg/Lg ratios versus distance](image)

**Symbols coded by sector**
- Hindu Kush
- Southeast
- Zagros
- Caspian

**Figure 4.** Correlations of Pg/Lg ratios observed at ABKT (0.75-9.0 Hz) versus distance. Symbols are coded by the sectors shown in Figure 1. The number of data (n), linear correlation (r) and the standard error about the fit (sd) are shown. Note that the Pg/Lg ratios tend to group by sector.

**ABKT Pg/Lg vs. Rms Topographic Slope**

![Graphs showing correlations of Pg/Lg ratios versus Rms Topographic Slope](image)

**Figure 5.** Correlations of Pg/Lg ratios observed at ABKT (0.75-9.0 Hz) versus along path distance. Symbols are coded by the sectors as shown above. The number of data (n), linear correlation (r) and the standard error about the fit (sd) are shown. Note that the Pg/Lg ratios tend to group by sector.
ABKT Pg/Lg Distance Trends for the four Sectors

Figure 6. Correlations of Pg/Lg observed at ABKT (0.75-9.0 Hz) for the four sectors shown in Figure 1. The number of data (n), linear correlation (r), slope of the regression fit (k) and the standard error about the fit (sd) are shown. Note that the scatter in the data are reduced and the linear correlations are increased relative to those shown in Figure 4.