REGIONAL TRAVEL TIME AND AMPLITUDE RATIO CORRECTION SURFACES IN THE MIDDLE EAST

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ABSTRACT

We have begun work on creating travel time correction surfaces in order to significantly improve event locations, and have applied the methodology to two stations in the Middle East. These two stations (BRTR and ABKT in central Turkey and Turkmenistan, respectively) were chosen because our Geographical Information System (GIS) database includes detailed geological and geophysical information for this region. In order to calculate a surface (or volume) of travel time correction values one must first derive a method for calculating the travel time between two arbitrary points in a cross section or volume. A technique was chosen that was originally pioneered by Vidale (1988) and further developed by Matarese (1993) which uses a finite difference technique rather than tracing of rays. This technique essentially propagates wave fronts radially outward from an arbitrarily defined point source location using each timed point as a secondary source for each successive grid point.

This procedure allows us to calculate the travel time of the first arriving P- or S-wave to any point within a given area or volume. This is much more efficient than any two-point ray tracer which would need to propagate rays for each source-station pair in the same volume. Furthermore, the finite difference methodology is able to model diffracted first arrivals that might occur in regions of negative velocity gradients or “shadow” zones; regions in which ray tracers have difficulty in converging to an accurate solution. Our three dimensional regional models were constructed by taking the Moho and basement surfaces and inserting crustal velocities from IASP91 velocity model and Pn velocities from Hearn and Ni (1994) in the upper 220 km of our models. Beneath 220 km we have used the upper mantle model from IASP91. We have found that this 3-D model produces large (up to 4 seconds) travel time corrections with respect to the IASP91 radial velocity model. Such correction surfaces will help reduce systematic location errors at regional distances.

We have also created correction surfaces for selected regional phases in the Middle East. In order to decipher the character and pattern of regional seismic phase propagation we have compiled a large data set of regional and local seismograms recorded in the Middle East. We have mapped zones of blockage, inefficient, and efficient propagation for Lg and Sn. Two tomographic techniques have been developed to objectively determine regions of efficient and inefficient regional phase propagation. Previous observations of regional wave propagation in this region based on data recorded by sparsely distributed stations has indicated that Sn and Lg propagation is very complex; hence the station density from our data set in this region is invaluable. We observe major Lg blockage across the Bitlis suture in southern Turkey and across the Zagros Fold and Thrust Belt, corresponding to the boundary between the Arabian and Eurasian plates. Our observations indicate that in the northern portion of the Arabian plate (south of the Bitlis suture) there is also a zone of inefficient Sn propagation that is not in agreement with prior measurements of Pn velocities. The documented and tomographically mapped lateral variations in attenuation of Sn appear to be related to the complex regional tectonics of the region, and especially to Cenozoic and Holocene volcanism.

Key Words: Travel Time Corrections, Amplitude Ratios, Regional Wave Propagation, Middle East

OBJECTIVE

The CTBT requires the development of credible strategies for effective monitoring, including the ability to detect, locate, discriminate, and characterize any suspect events for any region on earth. In order to accomplish this task necessary models and fundamental observations concerning seismic event location and regional wave propagation are required. Examples of such critical models are travel time models for individual IMS stations that can be used to correct for three-dimensional variations in seismic velocity structure. One dimensional travel time models are not sufficient for regions that contain substantial lateral variations in crustal thickness and uppermost mantle velocity. Furthermore, observations are required for the propagation of several key regional phases in the Middle East and North Africa since current knowledge is insufficient to accurately characterize regional wave propagation in this complex region. New seismological data are required to constrain both travel time and wave propagation models of very low yield events at regional distances. In order to make our final results available to the monitoring community we will include our data and results on the Middle East and North Africa into the Cornell GIS database.

Our objective is to expand the existing geophysical/seismological information and to provide new knowledge of the Middle East and North Africa using data from both short period national networks as well as broadband temporary and global networks. In this paper we give two examples of techniques and observations that are critical to improving seismic event location and discrimination in the Middle East and North Africa.

RESEARCH ACCOMPLISHED

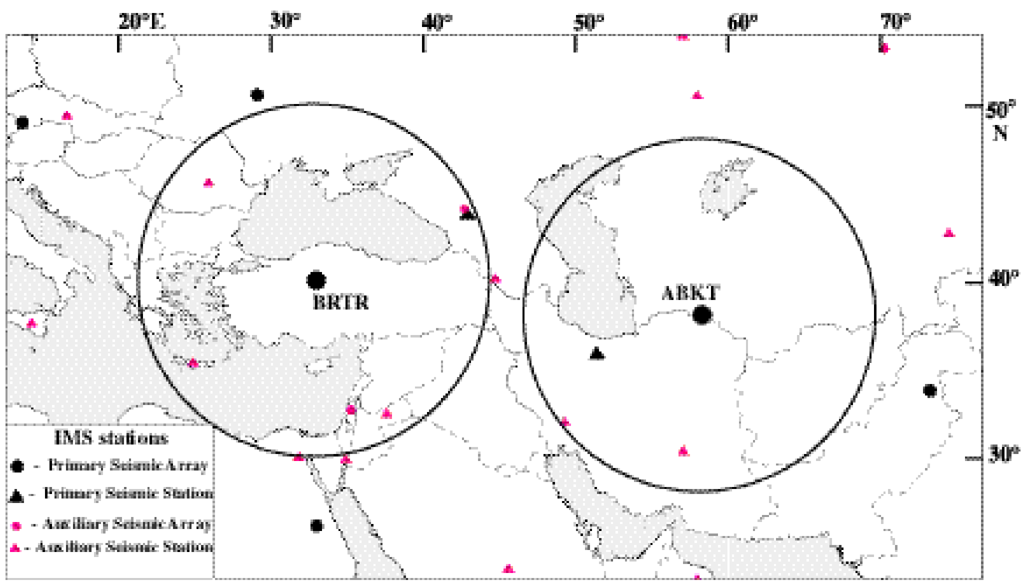


Figure 1. A map showing the two IMS stations used in our travel time correction surface calculations. The circles show the area for which we have calculated a travel time correction surface (radius of 10°).

Travel Time Correction Surfaces

We calculated travel time correction surfaces for two stations in the Middle East (Figure 1). Firbas (1996) demonstrated the importance of using accurate regional models for seismic event location in Europe. We have chosen these two stations such that we have relatively good GIS data coverage that we have collected in the Middle East. These data sets include depth to basement, depth to Moho, and Pn velocity. All travel time corrections surfaces were calculated relative to IASP91 travel times.

In order to calculate a surface (or volume) of travel time correction values one must first derive a method for calculating the travel time between two arbitrary points in a cross section or volume. We have chosen a technique originally pioneered by John Vidale (Vidale, 1988) which uses a finite difference technique rather than tracing of rays. This technique propagates wave fronts outward from an arbitrarily defined point source location (although in practice it is not difficult to use a linear or planar source rather than a point) using each timed point as a secondary source for each successive grid point. This procedure allows us to calculate the travel time of the first arriving P- or S-wave to any point within a given area or volume. This technique is much more efficient than any two-point raytracer that would need to propagate rays for each source-station pair in the same volume. Furthermore, the finite difference methodology is able to model diffracted first arrivals that might occur in regions of negative velocity gradients; regions in which ray tracers have difficulty in converging to an accurate solution. Such convergence problems are not an issue with the finite difference approach.

Matarese (1993) has extended the original method of Vidale (1988) to include the use of heap-sorting techniques, which speed the travel time calculations up considerably. Also, Matarese (1993) has included stencils in order to find the fast path to each grid point. These modifications have made the finite difference approach even more computationally efficient and accurate when compared to ray tracing algorithms (within 0.1 seconds to 10 degrees). The only computation limitation to this technique is that the entire slowness grid and the travel time grid must be stored in the computer memory cache (RAM) otherwise the problem becomes computationally intractable. This limits the size of the slowness model for which travel time can be computed. However, given the size of RAM memory for state-of-the-art computers (~4 GBytes) travel time calculations for three-dimensional models are feasible.

Due to the limited size of RAM available to us at present we have limited ourselves to 2-D travel time calculations using both Cornell GIS regional velocity models as well as IASP91 velocity models. This allowed us to compare the results of these two different velocity models in 2 dimensions. In order to construct our travel time volumes we have calculated 2-D travel time cross sections for every 1° throughout our 3-D regional velocity model. We then interpolated between all 360° 2-D travel time cross sections to form an evenly spaced travel time volume. The zero depth (or surface) of this volume corresponds, for a particular station, the travel time corrections for surface focus seismic events. In order to obtain the correction surface for different hypocentral depths we simply took a slice at the appropriate depth through our travel time volume.

Our regional velocity models were constructed by taking the IPE Moho and basement surfaces and use the crustal velocities used in the crustal portion of the IASP91 velocity model. We have assigned a linear velocity gradient for the sediments overlying the basement, starting at 4.5 km/s at the surface and reaching 5.8 km/s at the top of the basement. We have assigned the lower crust in our model a 6.5 km/s. We placed the upper crustal and lower crustal velocity contrast (5.8 km/s to 6.5 km/s) half way between the top of the basement and the Moho boundary. We have used the Pn velocities from Hearn and Ni (1994) in the upper 220 km of our models. Beneath 220 km we have used the upper mantle model from IASP91.

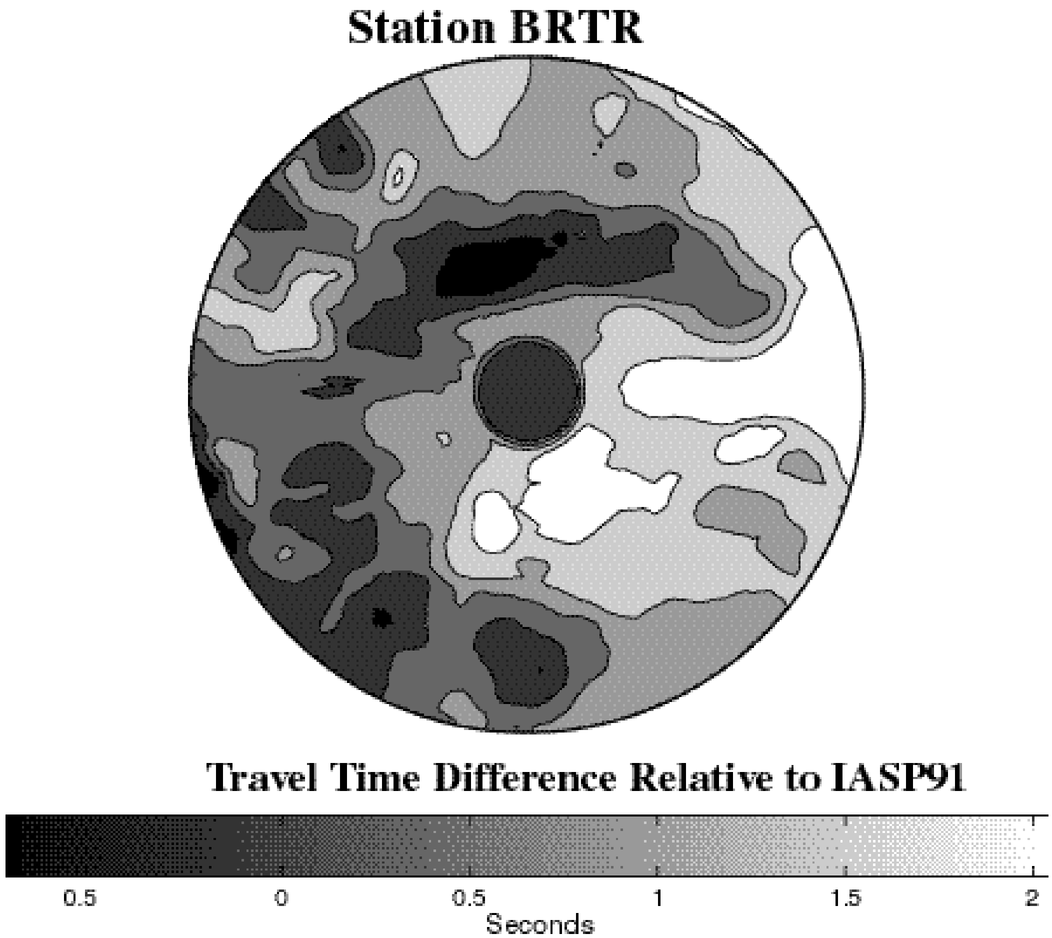


Figure 2. Travel time correction surface for station BRTR in central Turkey for events with no focal depth. The radius of this surface is 10°.

We found significant travel time differences (up to 3 seconds) for calculations using our regional model for the Middle East and IASP91 (Figures 2 and 3). We found the largest discrepancy for paths that crossed regions where crustal thickness exceeded 40 km or where the uppermost mantle was anomalously slow as compared to IASP91 mantle velocities. The largest travel time anomalies for station BRTR occurred in the Anatolian plateau where the uppermost mantle P-velocity is approximately 7.6 km/s (Hearn and Ni, 1994) and IPE Moho depths are between 40 and 50 km. We found that Moho depth was the primary factor responsible for the travel time anomalies for station BRTR (Figure 2). We found similar results for station ABKT in Turkmenistan (Figure 3). Sedimentary basin thickness also affected travel time calculations for station ABKT since the station is located in the southern edge of a large sedimentary basin. At distances larger than 300 km, Moho depth has the most significant impact on the size of the travel time anomalies for this station. Regions where the crust exceeded 60 km in thickness produce very large travel time differences (> 3 seconds) with respect to IASP91.

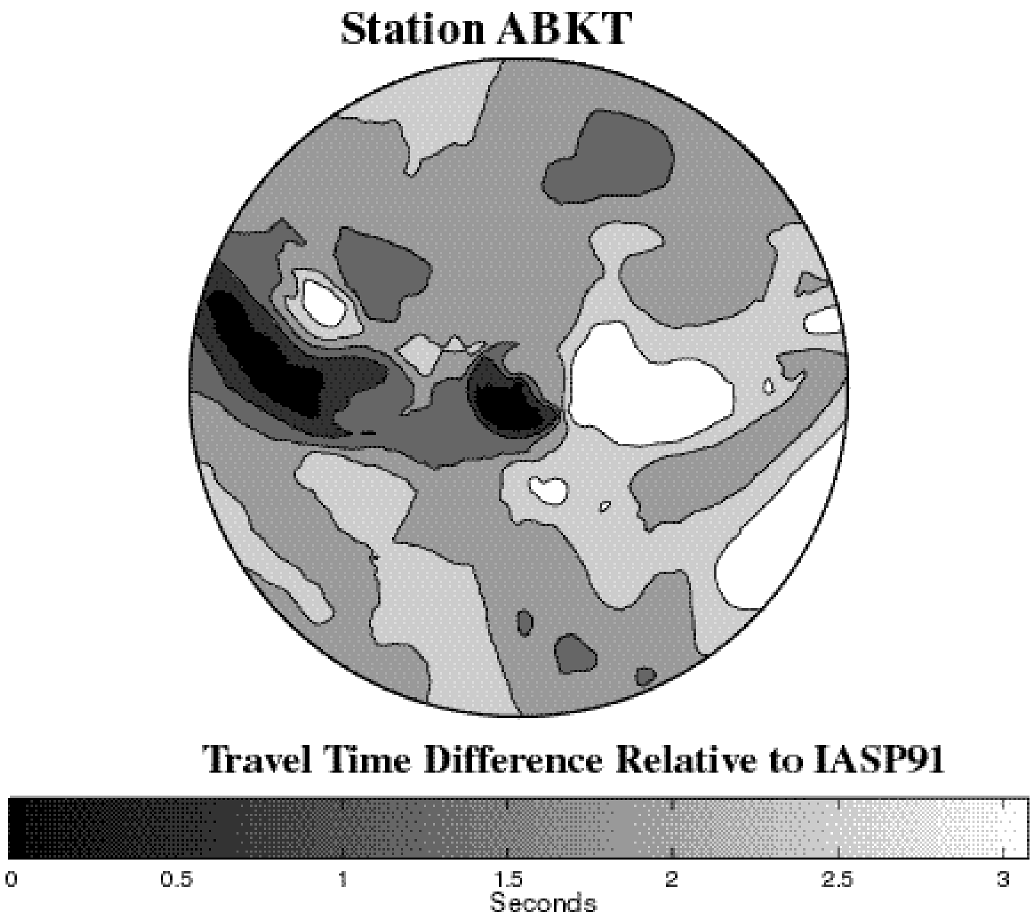


Figure 3. Travel time correction surface for station ABKT in Turkmenistan for events with no focal depth. The radius of this surface is 10°.

Reliable travel time correction surfaces/volumes will be essential for accurately locating small magnitude events, regionally recorded by a sparse network. Travel time corrections will be used to correct for systematic location errors caused by crustal and upper mantle velocity structure. In order to determine accurate travel time correction surfaces reliable regional models must be obtained. Currently in the Middle East there are regions where little is known about the crustal structure, however, we plan over the next years, through collaborative agreements with local scientists, to begin to develop a reliable regional crustal and upper mantle model for the Middle East which will be used to calculate reliable travel time corrections for all IMS stations in the region.

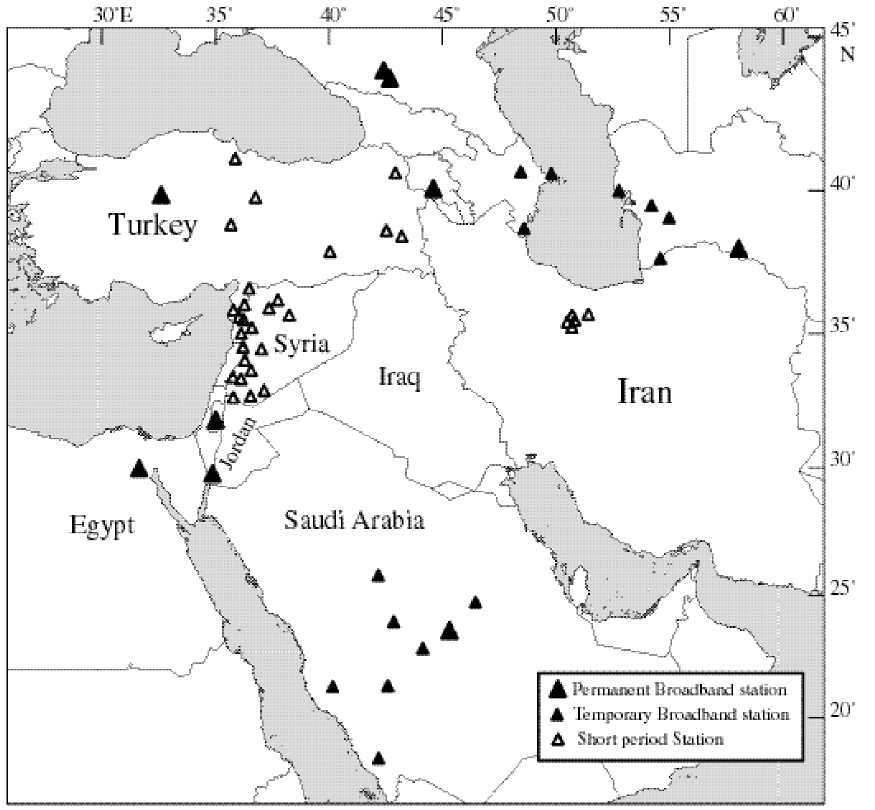


Figure 4. A map of all stations used to characterize Lg and Sn propagation in the Middle East.

Regional Wave Propagation in the Middle East

Observations of regional wave propagation in this region, based on data recorded by sparsely distributed stations have indicated that Sn and Lg propagation is very complex in the Middle East. Therefore, it is necessary to use a large number of seismic stations to accurately characterize regional wave propagation in this region. We have compiled a large data set of regional and local seismograms recorded in the Middle East (Figure 4). This data set is comprised of approximately four years of data from national short period networks in Turkey and Syria, data from temporary arrays in Saudi Arabia and the Caspian Sea region and data from GSN, MEDNET, and GEOFON stations in the Middle East. We have used this data set to decipher the character and pattern of regional seismic wave propagation. We have mapped zones of blockage as well as inefficient and efficient propagation for Lg, Pg, and Sn throughout the Middle East. Two tomographic techniques have been developed to objectively determine regions of lithospheric attenuation in the Middle East. The first technique used Lg/Pg ratios to characterize crustal attenuation as well as to determine the path effects on this commonly used discriminant. The second technique used discrete Sn propagation efficiencies that we defined after examining over 4000 seismograms. This technique allowed us to map the regions of inefficient and efficient Sn propagation in the Middle East.

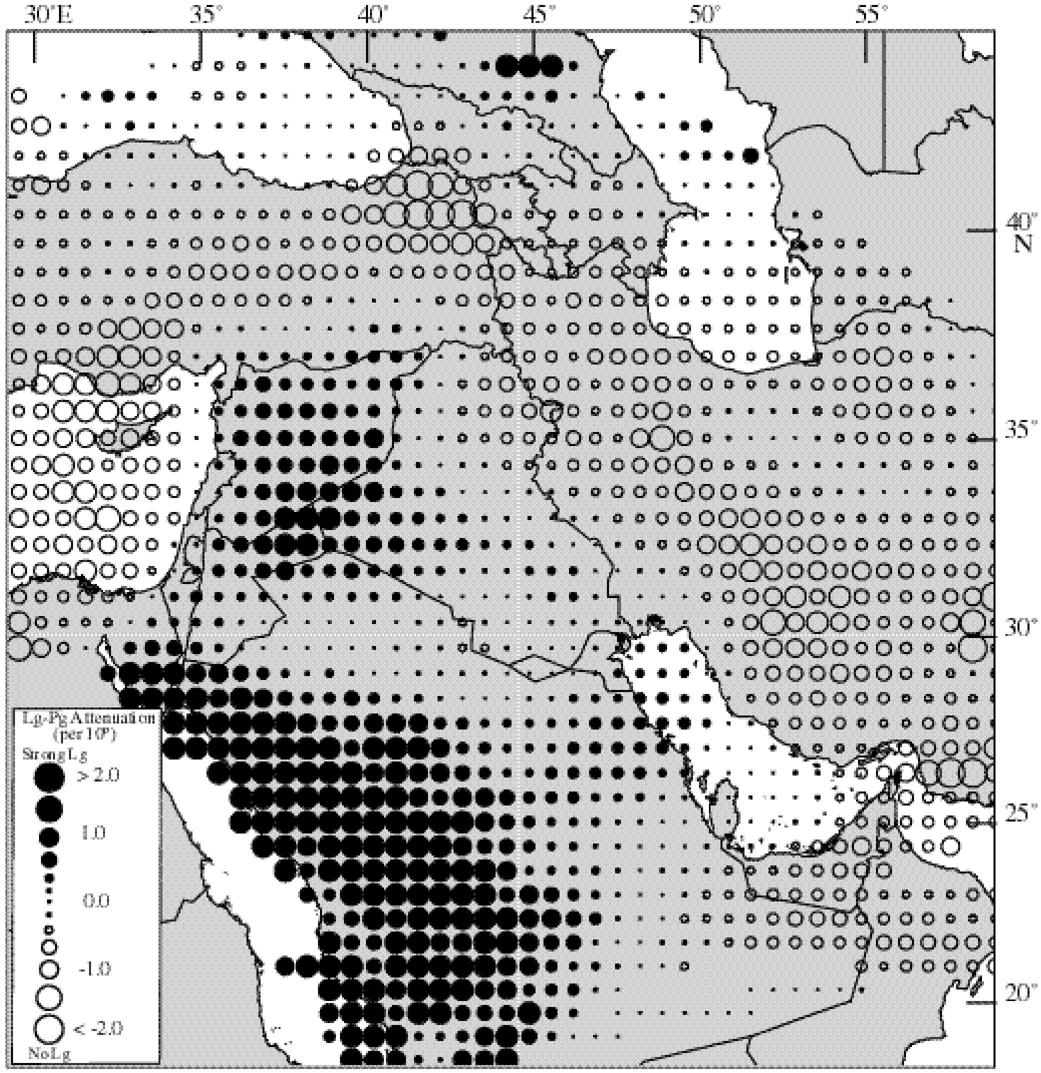
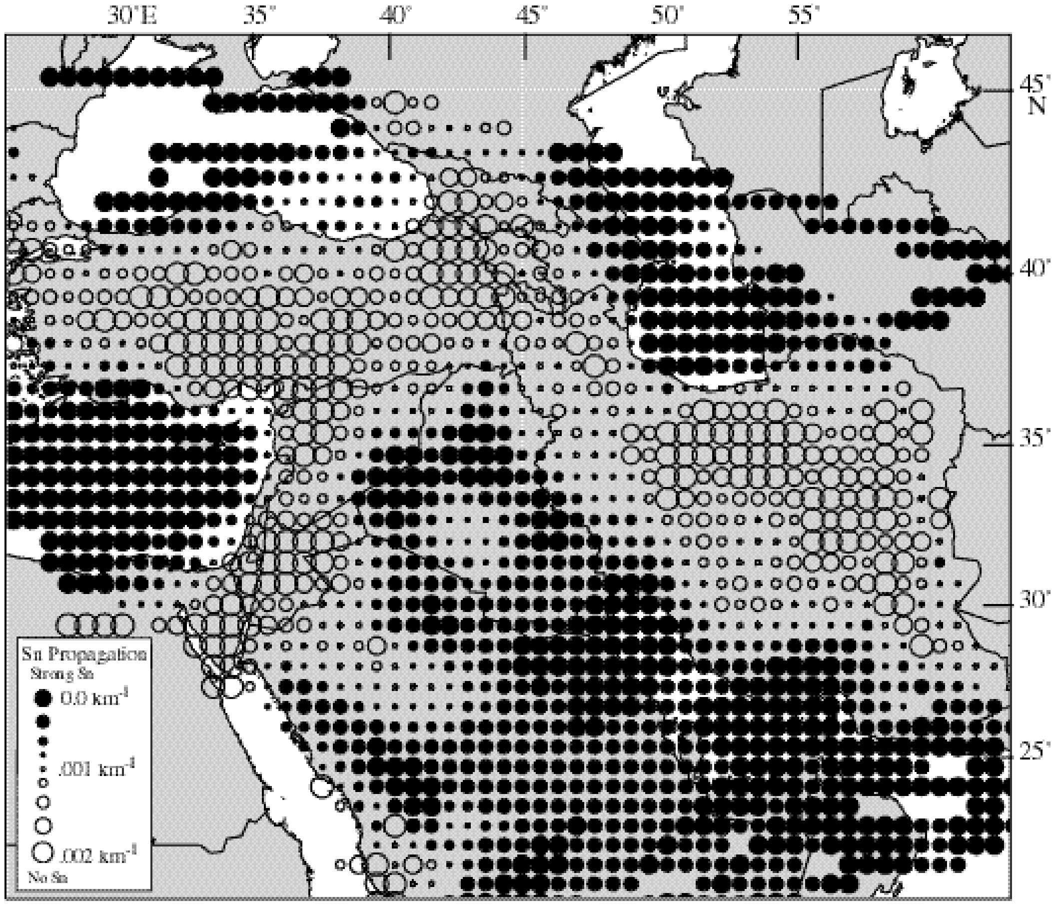


Figure 5. A map showing an image of Lg/Pg ratio tomography in the Middle East. This image is based upon approximately 4400 Lg/Pg waveform observations.

We observe evidence for a significant increase in crustal attenuation across the Bitlis suture and the Zagros fold and thrust belt, corresponding to the boundary between the Arabian and Eurasian plates (Figure 5). Generally Lg was blocked when the ray paths crossed either of these major tectonic boundaries. We also observed Lg blockage in the Mediterranean and southern Caspian Seas. We also observe inefficient Lg propagation, relative to Pg, in the lesser Caucasus and easternmost Anatolia. We also found that within the Middle East, Lg propagation is most efficient in the Arabian Shield and in eastern Jordan and Syria although typically Lg was efficient throughout most of the Arabian Plate. Similarly the Dead Sea fault system had little effect on Lg blockage.

We also observe a zone of inefficient Sn propagation along the Dead Sea fault system (Figure 6) that coincides with low Pn velocities along most of the Dead Sea fault system and with previous observations



of poor Sn propagation in the Gulf of Aqaba (Rodgers et al., 1997). Our observations indicate that in the northern portion of the Arabian plate (south of the

Figure 6. A map showing a tomographic image of Sn propagation efficiency in the Middle East. The model parameters in this tomographic image are the reciprocal of the Sn extinction path length. This image is based on 4200 Sn waveforms.

Bitlis suture) there is also a zone of inefficient Sn propagation that would not have been predicted from prior measurements of Pn velocities. The mapped lateral variations in attenuation of Sn correlate well with the regional tectonics of the region. Regions of Cenozoic and Holocene basaltic volcanism correspond with regions of high Sn attenuation.

CONCLUSIONS AND RECOMMENDATIONS

We found that three-dimensional travel time calculations using a regional velocity model taken from our GIS database in the Middle East produce large variations from the IASP91 travel time tables. These large travel time deviations (as much as 3 seconds) could have very large effects on seismic event location. We also found that in the Middle East crustal thickness is the most important factor in travel time anomalies. Our study of regional wave propagation demonstrates that there are dramatic variations in Lg and Sn propagation in the Middle East. Furthermore using Lg/Pg ratio tomography can, for the most part, determine the path effects on Lg/Pg ratio calculations and thereby is a method for isolating the source effects on Lg/Pg amplitude ratios.

Our study of travel time correction surfaces for two stations in the Middle East indicate strongly the need to use the best regional models to correct for lateral changes in crustal and upper mantle velocity structure. Also, both of our studies presented in this paper demonstrate that local network data are essential to both calibration and verification of regional travel time models and regional wave propagation models.

We plan to test these models and validate them using very reliable event locations. We will use dense local seismic network locations as well as the GT5 catalog to verify our regional velocity models for each IMS station in the Middle East. Furthermore, we will test and improve our regional models using seismic data we plan to collect to verify the crustal thickness and upper mantle velocity structure in the Middle East.

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