CALIBRATION OF REGIONAL SEISMIC STATIONS IN THE MIDDLE EAST WITH SHOTS IN TURKEY

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ABSTRACT

Two sets of calibration shots are planned in Turkey in 2002 and 2003 for the calibration of regional seismic stations and to improve knowledge of earth models in the region. The shots will be at Keskin in central Turkey, and at Lake Van in eastern Turkey. Keskin is where the short-period array of the Belbasi Station is located. Belbasi Station comprises a long-period array located in Ankara, and the aforementioned short-period array located in Keskin. The Keskin short-period array is designated as an International Monitoring System (IMS) station (PS43). The primary objectives of the experiments are: (1) calibrate the regional travel times and propagation characteristics of seismic waves across the Middle East and Eastern Mediterranean region; (2) calibrate local and regional models for specific IMS stations in Turkey; (3) conduct a reciprocal experiment to provide dense local and near regional calibration of the Keskin Belbasi IMS array in Turkey; and (4) provide data to enhance IMS detection, location, and discrimination capabilities.

The first calibration shot (two tons of explosives in boreholes) will be conducted near Keskin in October 2002. We expect that the shot will be recorded within a radius of about 500 km. It will provide reciprocal calibration for the nearby Keskin short-period array, Incorporated Research Institutes in Seismology (IRIS) station ANTO, and the long-period Belbasi array.

In this paper we present detailed three dimensional (3-D) crustal models of the region, calculated travel times, and synthetic seismograms. Well located (GT-5) local and regional earthquakes around the Keskin array are identified and areas of anticipated seismic activity will be instrumented. The information will guide the deployment of stations for the recording of the Keskin shot, and expedite the analysis of the data.

OBJECTIVES

The primary objectives of the project are to: (1) calibrate the regional travel times and propagation characteristics of seismic waves across the Middle East and Eastern Mediterranean region; (2) calibrate local and regional models for specific IMS stations in Turkey; (3) conduct a reciprocity experiment to provide dense local and near regional calibration of the Keskin Belbasi IMS array in Turkey; and (4) provide data to enhance IMS detection, location, and discrimination capabilities.

A two-ton shot will be fired in boreholes near the Keskin array (an IMS station) in central Anatolia (Asian part of Turkey) in November 2002, for calibration of stations within 300-500 km. This shot will provide a reciprocal calibration for the Keskin array, as well as for nearby IRIS station ANTO, and the long-period array operated jointly by AFTAC and Turkey. The long-period array is located around Ankara. Figures 1a and 1b show the general tectonic setting and the arrays, respectively. Turkish national network stations are also shown in Figure 1b.

RESEARCH ACCOMPLISHED

The primary activity during this period has been the planning of the experiment site selection for the shot, deployment plan for portable instruments, and gathering of data for generating local and regional models for seismic wave propagation. Using these models, 3-D travel-time calculations are carried out, for local (up to 500 km) and regional (up to 2,000 km) distances. Synthetic seismograms are calculated for the Keskin shot.

Three-Dimensional Velocity Model

Turkey and surrounding areas form a tectonically complicated region. Crustal and upper mantle structures in the region are influenced by the thermal and mechanical processes related to motions between the several plates in the region. The Keskin array is located in the middle of the Anatolian Plate surrounded by major plate boundaries as well as significant active intra-plate deformation as shown in Figure 1a.

Crustal structure and seismic attenuation vary greatly in the region (Ginzburg *et al*., 1981; Sholpo, 1993; Hofstetter *et al*., 1991; Laske *et al*., 2001; Hearn and Ni, 1994; Priestly, 1997; Mangino and Priestly, 1998; Shapiro and Ritzwoller, 2001.) Crustal thickness averages about 35-40 km in the Anatolian plateau, 40-50 km in the east toward the Iranian Plateau (Nowroozi, 1971; Bird *et al*., 1975). Hearn and Ni (1994) used a tomographic technique to obtain Pn velocities for Anatolia and surrounding regions. They used data from the International Seismological Centre (ISC) catalog and found that Pn velocity is approximately 7.8 km/s in central Anatolia. Sandvol *et al*. (1998) used receiver function inversion to determine site-specific crustal velocity and thickness models. They found crustal thickness values of 37 km in central Anatolia (ANTO), 43 km in northeastern Caucasus (KIV), and 64 km in central Caucasus (GNI).

Gurbuz and Evans (1991) determined basement depths to be between 6 and 10 km with a velocity of 6.15 km/s in the Salt Lake (Tuz Golu) basin, located approximately 150 km SSE of Ankara. Mindevalli and Mitchell (1989) measured fundamental mode Rayleigh and Love wave group velocities in the 8- to 50-s period range for the ANTO seismic station. They found the shear wave (Sn) velocity to be 4.2 km/s and an approximate crustal thickness of 40 km. Necioglu *et al*. (1981) analyzed travel times from 43 earthquakes occurring in western Turkey recorded by a number of regional stations and found the Pn velocity to be 7.80 in the vicinity of Ankara. Canitez and Toksoz (1980), using travel-time residuals of teleseismically recorded P wave velocities, concluded that P wave velocities in the uppermost mantle are 7.9 km/s in central and eastern Turkey. Turkelli *et al*. (1996) applied a two-station method for stations in east Anatolia and found that Pg and Pn velocities vary between 5.5-6.6 km/s and 7.6-7.9 km/s, respectively. Similarly, they found Sg and Sn wave speeds varying between 3.3-3.9 km/s and 4.3-4.8 km/s, respectively.

Using receiver function waveform inversion and dispersion of surface waves in western Turkey, Saunders et al. (1998) found ~37.5 km crustal thickness beneath Ankara. Shear velocities were between about 3.3 km/s and 3/5 km/s in the lower crust and 4.5 km in the uppermost mantle. Similarly, Sandvol et al. (1998) used a grid-search

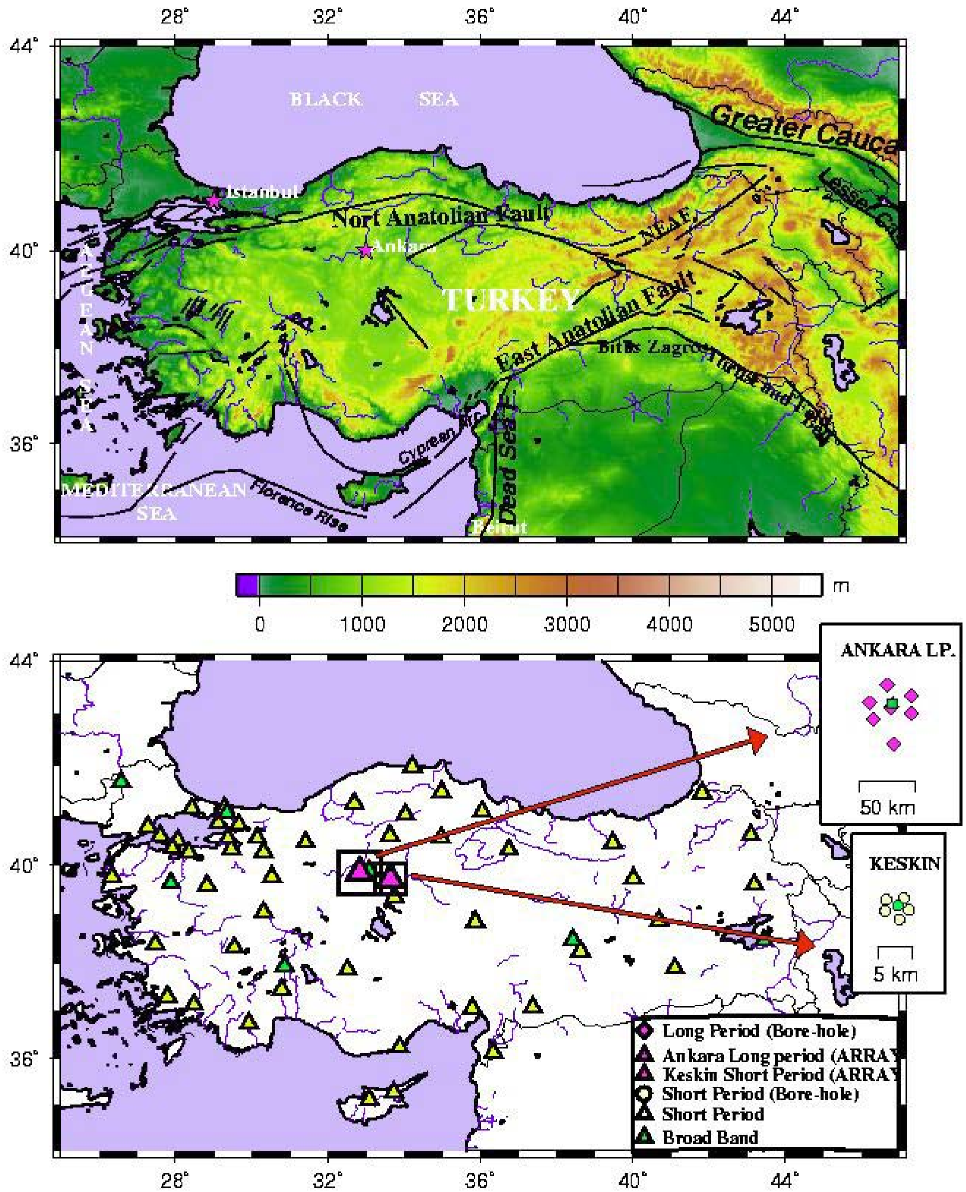

Figure 1. (a) Morphology (GTOPO30) and active tectonics features of the Turkish plate and surroundings.
(b) Permanent seismic station network of Kandilli Observatory and Earthquake Research Center (KOERI). Enlarged inserts show the Belbasi long-period array (upper box) and the Keskin short-period seismic array (lower box) (Kuleli *et al*., 2001).

approach to receiver function waveform modeling and found a crustal thickness of 37.0 and an average crustal shear velocity of 3.6 km/s. South of the Marmara Sea, Gurbuz *et al*. (1980) obtained a crustal thickness of 28-29 km and a Pn velocity of 8.1 km/s from a quarry blast experiment. A complementary study in the greater Marmara region by Kalafat *et al*. (1987) using the Pn phase reading at stations operated by KOERI in southwest Turkey indicated that the seismic Pn velocity is about 7.8 km/s. Crampin and Ucer (1975) investigated seismic velocities beneath the

Marmara Sea by examining four earthquake recordings at 35 seismic stations. In this study the crustal velocities were 5.8-6.0 km/s.

Saunders *et al*. (1998) found a normal upper mantle velocity, approximately 8.1 km/s, at Kula in western Turkey. Taymaz (1996) used S-P wave travel-time residuals, which confirmed the lateral velocity variation in the region, and found higher velocity beneath the Crete and lower velocity beneath the Aegean Sea than the J-B model. Kuleli *et al.* (1997) and Spakman (1991) found high (8.1 km/s) uppermost mantle velocities beneath the northern Aegean coast where Hearn and Ni (1994) found a lower velocity of about 7.9 km/s. Beneath the Marmara region, the Hearn and Ni values are about 8 km/s. Other studies extended the coverage into Greece (Allesandrini *et al*., 1997; Papazachos *et al*., 1995; Papazachos and Nolet, 1997), reporting that the velocity distribution in the shallow layers is strongly influenced by the variation of the depth of the Moho discontinuities.

Model-Based Station-Specific Source Correction for the Keskin Array

A 3-D regional velocity model was generated for $\Delta=20°$ distance around the Keskin array using the global models of Laske *et al*. (2001), Shapiro and Ritzwoller (2001) and others cited in the previous section. The model-based travel times were calculated using a 3-D ray tracer. Travel-time corrections relative to IASPEI91 were calculated. The region around the Keskin array for which travel times are calculated, Pn velocities in the region, and travel-time corrections relative to IASPEI are shown in Figure 2.

These calculations are repeated for a smaller region (about 500-km radius) around Keskin using a more detailed crustal model. The model and travel-time corrections are shown in Figures 3a and 3b.

Seismic Attenuation

There have been numerous studies of the attenuation of Sn and Lg waves in the region (Nuttli, 1980; Kadinsky-Cade *et al*., 1981; Seber and Mitchell, 1992; Rogers *et al*., 1997; Gok *et al.,* 2000; Sandvol *et al*., 2001). These studies show high attenuation in eastern and some parts of central Turkey. Plans for deployment of portable stations take into account the attenuation properties. Synthetic seismograms were calculated using an averaged 1-D velocity model with the discrete wave number code and different attenuation values. A typical set of seismograms is shown in Figure 3c. We expect to obtain both travel times and attenuation values from the Keskin shot. A number of well-located earthquakes that are within a radius of 500 km from Keskin that qualify as GT-5 have been selected. Figure 4 shows a subset of such events and distribution of local network stations used for their locations. Each event location is validated by observed surface faulting or isoseismals. The epicenters will be instrumented for reciprocity experiments.

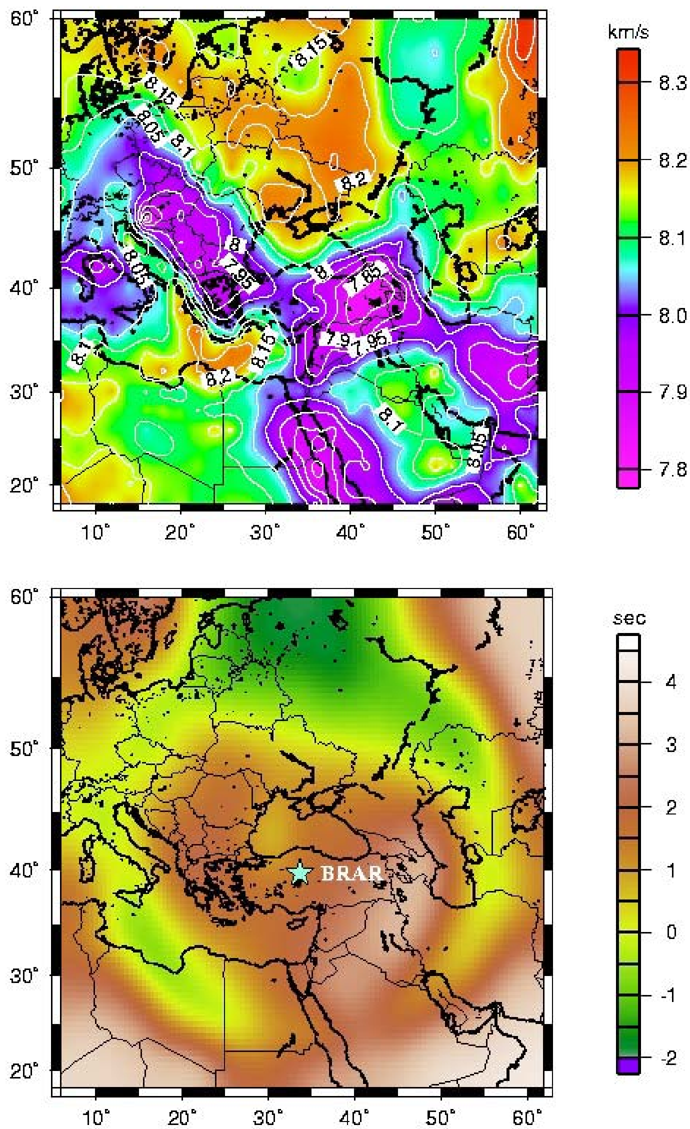

Figure 2. Model-based source specific station corrections for the IMS station BRAR (e.g., Keskin array). The crust upper mantle regional velocity model is from Laske et al. (2001) and Shapiro and Ritzwoller (2001) and others cited in the text. Three-dimensional ray tracing is used to calculate travel times. (a) Pn velocities of the regional model. (b) Travel-time corrections relative to IASPEI-91.

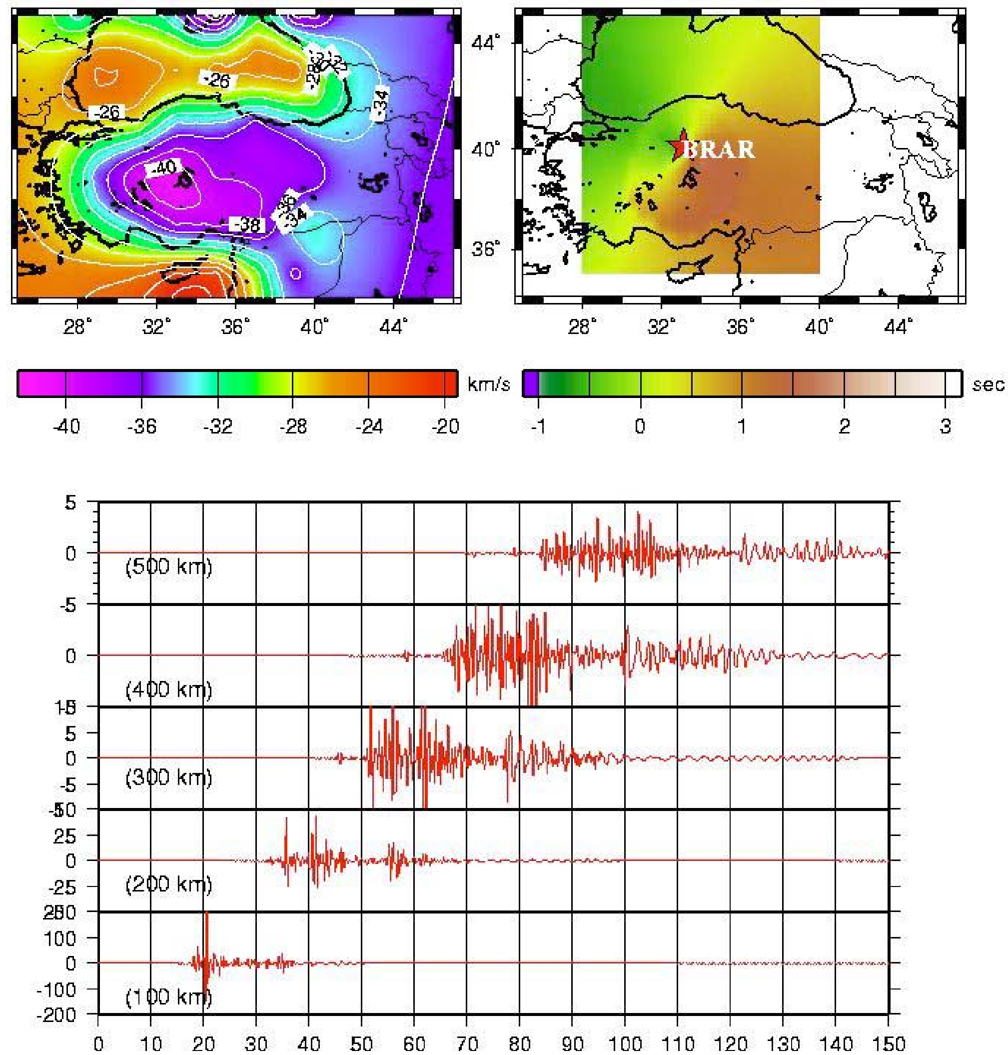

Figure 3. Local crustal model and travel-time corrections for BRAR. (a) Depth to Moho. (b) Travel-time residuals relative to IASPEI91 generated using a 0.5° x 0.5° grid local model. (c) Synthetic seismograms calculated for an explosive source at 100-m depth. An averaged 1-D velocity model (based on Figure 3a) is used for calculations.

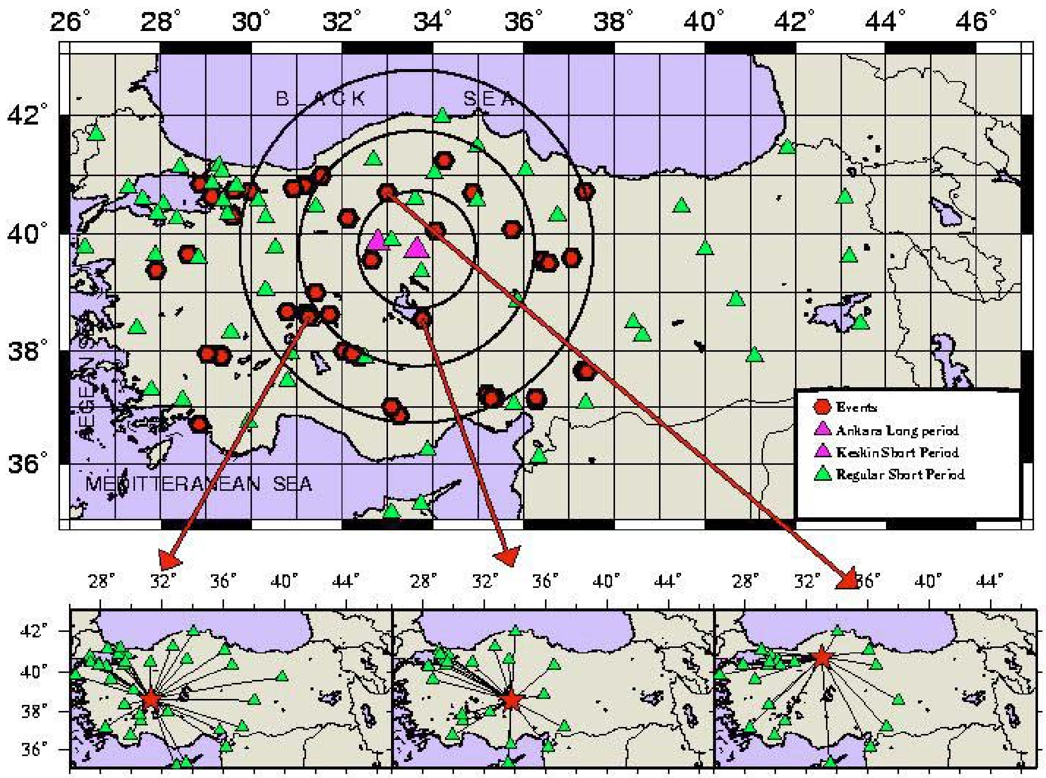

Figure 4. Selected GT events for reciprocity experiments. Events are selected using the KOERI database for the period 1985–2002. Circles indicate 1, 2, 3 degree radius from the Keskin station.

CONCLUSIONS AND RECOMMENDATIONS

Preliminary studies have been carried out to guide the distribution of portable network instruments around the Keskin shot that will take place in November 2002. These studies will expedite the analysis of the data from the shot.

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