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SURFACE WAVE TOMOGRAPHY USING AMBIENT NOISE CROSS-CORRELATION FOR THE AZERBAIJAN TERRITORY

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ABSTRACT. This paper presents the current status of ambient noise data processing as it has developed over the past several years and is intended to explain and justify this development through salient examples. The Ambient Noise Tomography (ANT) method provides a powerful tool for sampling the Earth's shear-wave-velocity structure (e.g., Campillo and Paul 2003; Shapiro et al. 2005). Noise correlations between pairs of stations at hundredths of kilometer distances, stacked over time, provide Green's functions of largely surface wave propagation between the stations. These signals are most robust at 5-20 s periods where fundamental-mode Rayleigh waves sample the crust and uppermost mantle, allowing 3D imaging at these depths (e.g., Harmon et al. 2008; Bensen et al. 2009).

We studied the Rayleigh wave group and phase velocities beneath the Azerbaijan territory using ambient seismic noise tomography. Noise data were gathered from 35 broadband seismological stations in and around the republic.

One approach of ambient noise tomography is to estimate surface wave dispersion maps at multiple spatial scales over a broad period band. The group/phase velocity approach is one way of doing ambient noise tomography; some people invert the GF directly. The technique provides a means to make observations of short period surface waves along inter station paths in seismically inactive regions. Because earthquakes are primarily limited to plate margins and tectonically active regions the tomography of tectonically quiescent regions requires the observation of teleseisms or the use of active sources. Shorter period surface waves which are most sensitive to the crust are preferentially attenuated and scattered often leading to poor constraints on the crust from teleseismic earthquake observations. In addition the distribution of azimuths from earthquakes is restricted by the timing and location of natural events. In contrast with traditional earthquake surface wave tomography ambient noise tomography is limited by the number and path density of inter station paths. For the technique to provide high resolution results across large areas requires both dense instrumentation and widely distributed stations.

Introduction

The Caucasus-Caspian region exhibits large seismic velocity variations due to its complex geologic and tectonic setting. The Arabian-Eurasian collision led to complex lithospheric structures of diffused deformation and deep sedimentary basins. As a result of northwestward movement of Anatolian plate, Lesser and Greater Caucasus mountains are formed. A comprehensive lithospheric model is crucial in understanding the complex tectonic and geologic setting of the Caucasus-Caspian region and essential in mapping the regional wave propagation, therefore improving regional earthquake hypocenter locations and source parameterization. To develop a 3D velocity model we use three years of continuous broadband seismic recordings from the Azerbaijan Seismic Network, consisting of 35 stations, and perform ambient noise cross correlation to obtain fundamental Rayleigh wave group and phase velocity dispersion. Initial results show slower group and phase velocities in the basin and faster velocities in the Greater and Lesser Caucasus, consistent with the geologic structure. The resulting dispersion curves are used to invert for Rayleigh wave group velocity maps. Additional constraints on Moho thickness from receiver functions will be included when available.

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Regional tectonics

Azerbaijan lies in a complex yet relatively poorly understood tectonic region of the Eastern Caucasus. It is bounded to the north by the Greater Caucasus, to the south by the Lesser Caucasus and Iranian Plateau, and to the east by the South Caspian basin. The Greater Caucasus is a zone of active shortening and the Lesser Caucasus comprises of a variety of faulting structures and significant volcanism. Separating the two Caucasus is the Kura basin with sediments up to 15 km thick and inferred to be the foreland basin to both Caucasus. The Kura basin is structurally separated from the South Caspian Basin by a ridge of uplifted basement and the inferred West Caspian fault. Although poorly constrained, high Pn and Sn velocities appear to extend into the Kura basin from the South Caspian.

Triangles are broadband stations from the Azerbaijan seismic network, and major tectonic features are labeled as well.

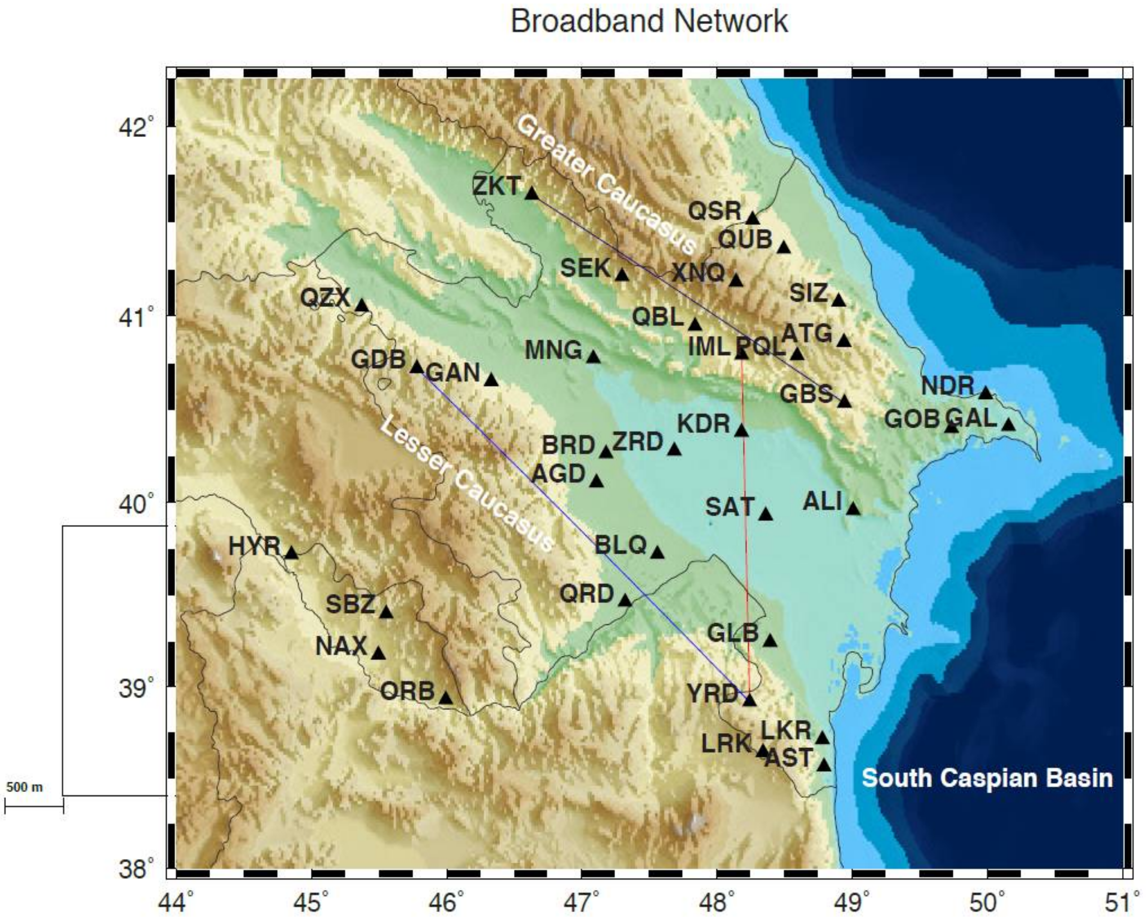

Figure 1. Azerbaijan Broadband Seismic Network.

Previous work

Gok et al. (2011) developed 3D lithospheric velocity model of the much broader Anatolian plateau-Caucasus-Caspian region from joint inversion of teleseismic receiver functions and surface wave dispersion measurements from data recorded at networks in Turkey, Georgia and Azerbaijan. In this study we focus our efforts on modeling velocity variations across Azerbaijan where a network of 35 broadband stations within the country provided us the opportunity to model the velocity structure using ambient noise surface wave tomography.

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Theoretical studies have shown that the cross-correlation of diffuse wavefields (e.g. ambient noise, scattered coda waves) can provide an estimate of the Green function between the stations (e.g. Weaver, Lobkis 2001a,b, 2004; Derode *et al.* 2003; Snieder 2004;Wapenaar 2004; Larose *et al.* 2005). Seismic observations based on crosscorrelations between pairs of stations have confirmed the theory for surface waves using both coda waves (Campillo, Paul 2003; Paul *et al.* 2005) and long ambient noise sequences (Shapiro, Campillo 2004; Sabra *et al.* 2005a) and for crustal body waves using ambient noise (Roux *et al.* 2005).

Data Processing

We apply the following signal processing procedure described in Bensen et al. (2007) to vertical component seismograms:

1. Instrument correction, remove mean, detrending, bandpass filtering and down-sampling.
2. Apply temporal normalization using the running average method.
3. Apply spectral whitening.
3. Compute daily cross-correlations and stack three years of daily correlations.

The resulting correlations are often asymmetrical due to the inhomogeneous distribution of the noise source, and although temporal normalization is defined on data bandpass filtered between 15 and 50 seconds spurious precursory signals are still observed.

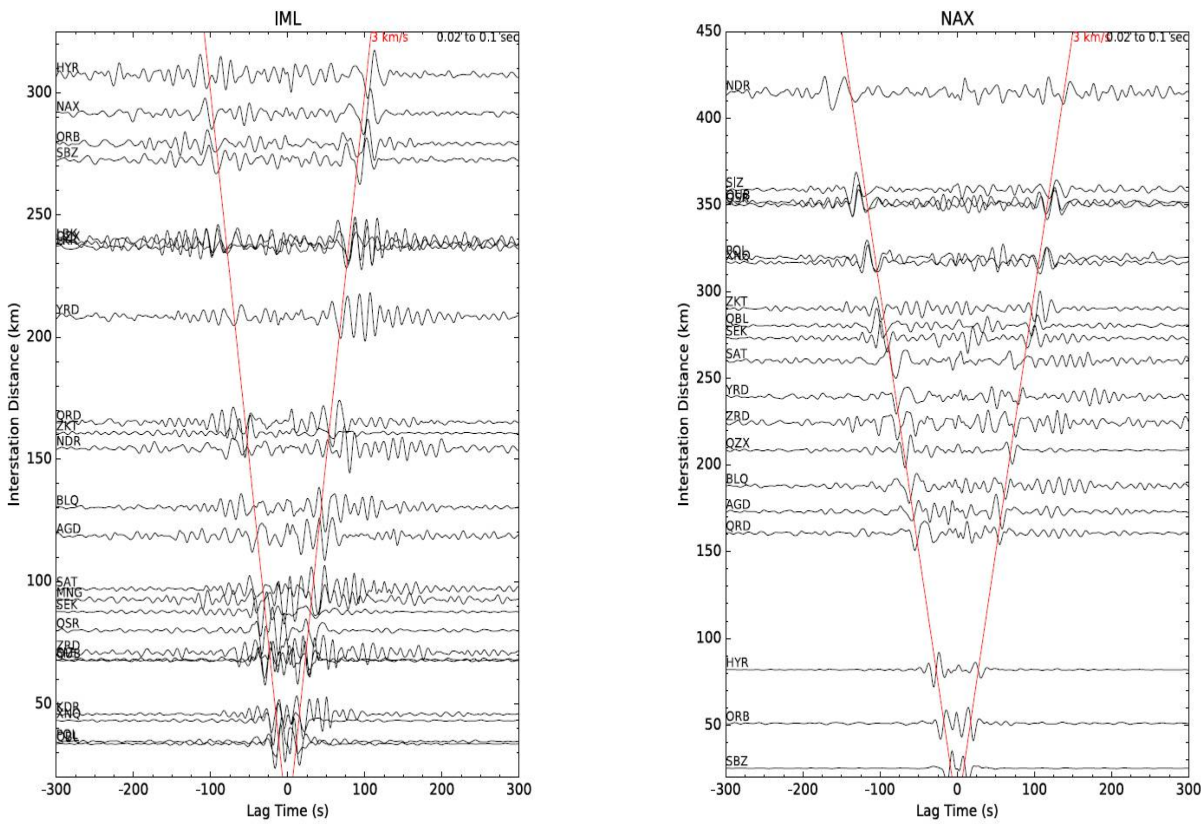

Figure 2. Ambient Noise Correlations from station IML and NAX.

Noise correlations are bandpass filtered from 10 to 50 seconds and sorted by distance. The correlations are mostly asymmetric due to inhomogeneous distribution of the noise source. Three years of data were used to compute the correlations. IML and NAX are located in the Greater and Lesser Caucasus, respectively.

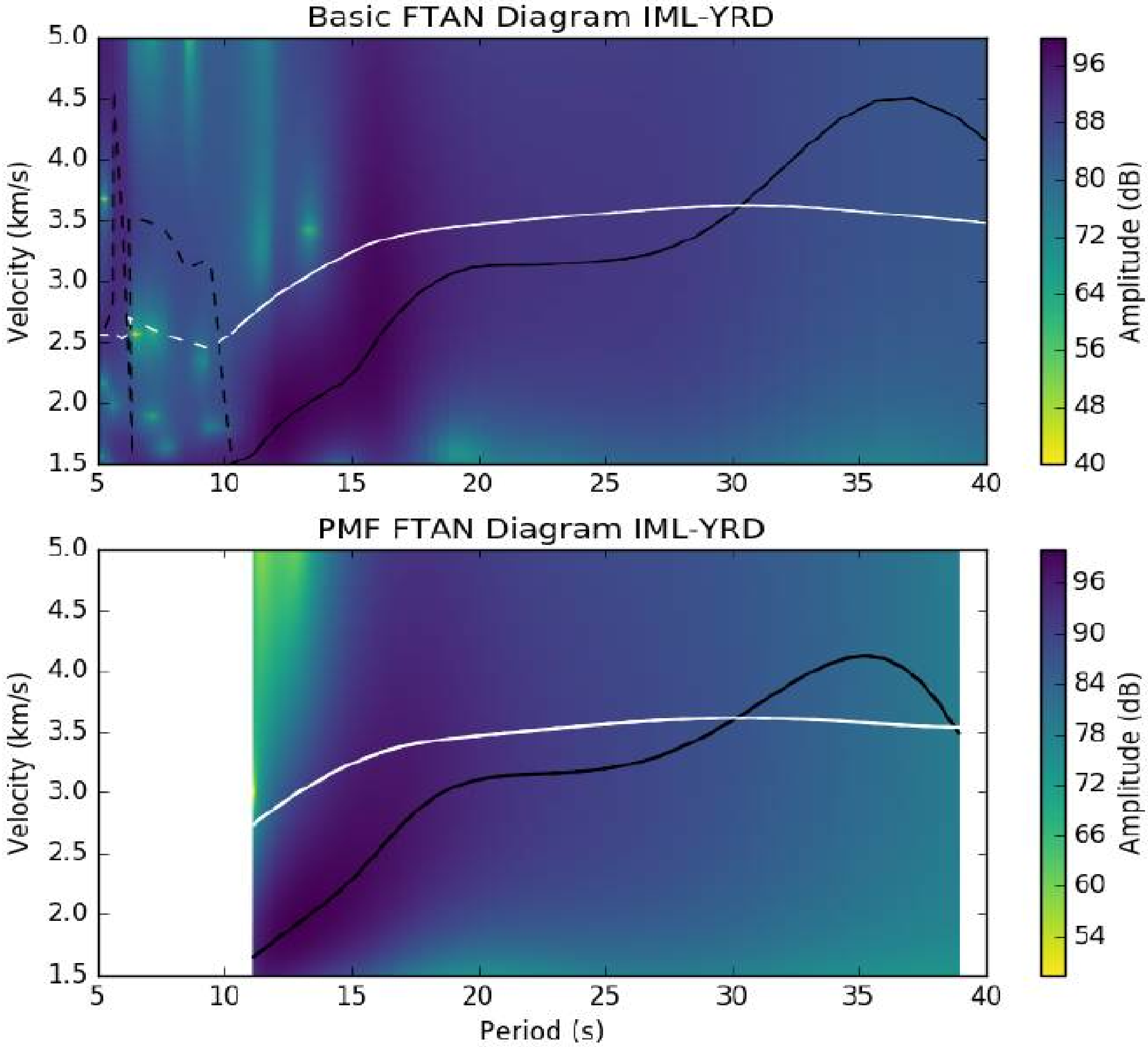

Figure 3. Frequency-Time Analysis (FTAN) for IML-YRD.

Rayleigh wave group (black) and phase (white) velocity curves with and without phase-matched filtering. SNR is typically weak at long periods for ambient noise correlation. We stack and fold the correlations to obtain the symmetric correlations, and perform frequency-time analysis (FTAN) to measure Rayleigh wave dispersion. We use the method from Levshin and Ritzwoller (2001) for the FTAN analysis. We see variation in wave speed across different tectonic regions (Fig. 4).

Velocities for three different tectonic regions: Greater Caucasus (black), Kura basin (red) and Lesser Caucasus (blue).

Single station data preparation

The first phase of data processing consists of preparing waveform data from each station individually. The purpose of this phase is to accentuate broad-band ambient noise by attempting to remove earthquake signals and instrumental irregularities that tend to obscure ambient noise. Obscuration by earthquakes is most severe above about 15 s period, so this step of the data processing is most important at periods longer than the microseism band (5 to 17 s period). In addition, because

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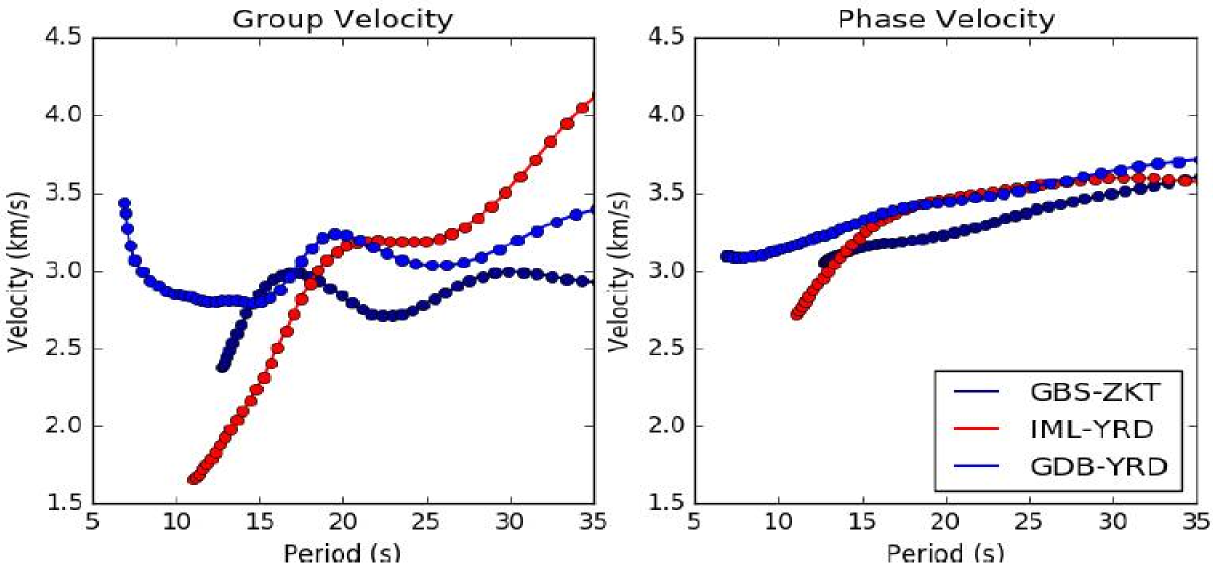

Figure 4. Group and Phase Velocity Curves.

the spectral amplitude of ambient noise peaks in the microseism band, methods have to be devised to extract the longer period ambient noise from seismic records.

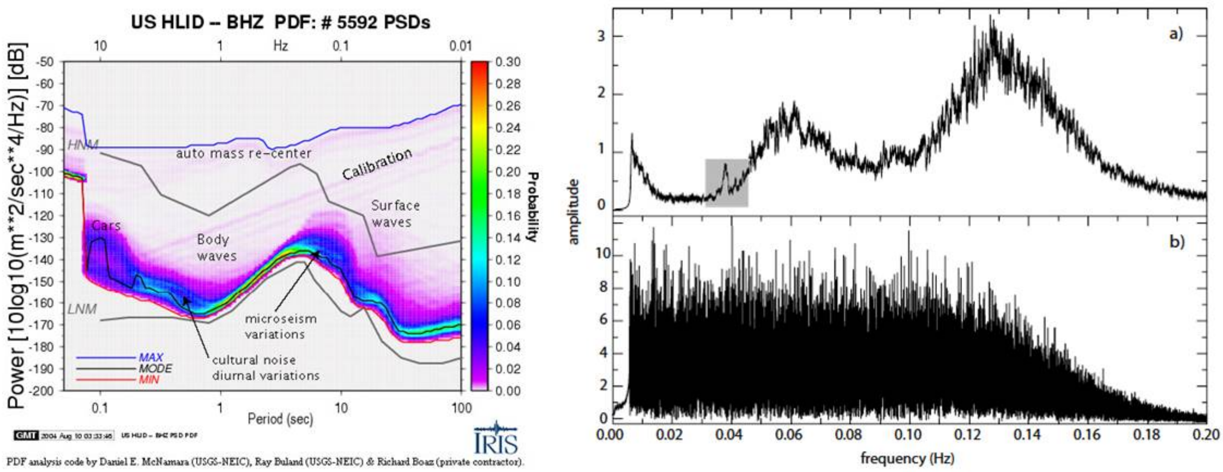

Figure 5. Processing seismic ambient noise data to obtain reliable broad-band surface waves.

One application of the surface wave models is to invert the dispersion results to derive models of the crust and upper mantle structure. This is particularly useful in aseismic regions that are poorly sampled by other data sets.

Surface wave tomography

At 14 and 20 seconds we see low surface wave velocities in the Kura Basin, indicative of the shallow sediments, and high velocities at the Caucasus. At 28 seconds we see high velocity features below the Kura Basin. The low velocity upper crust overlying a high velocity lower crust is similar to what has been observed in Gok et al. (2007, 2011). The Moho depth range between 35-40 km around this region. Due to the station distribution velocities are better resolved at the Kura Basin and Lesser

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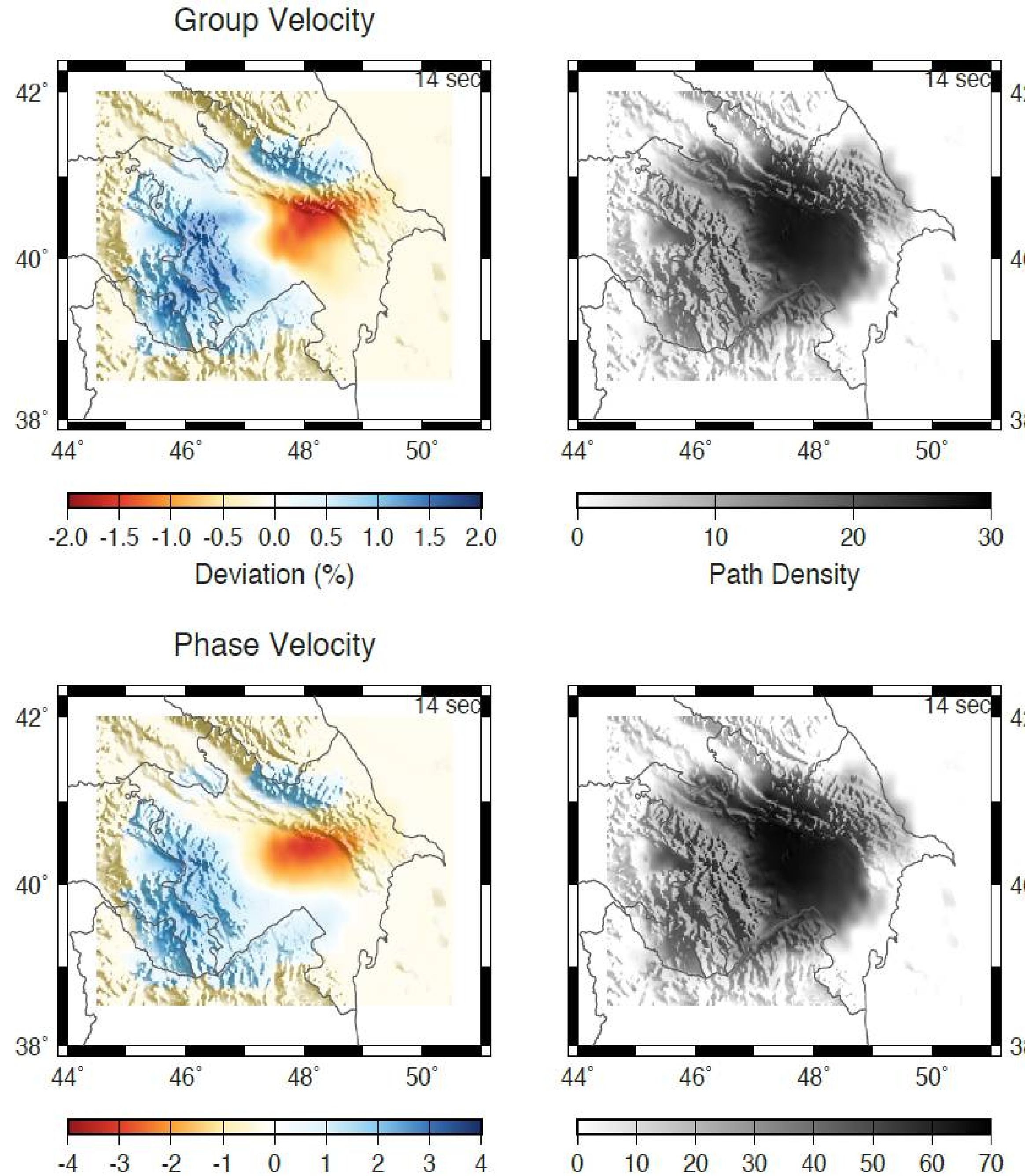

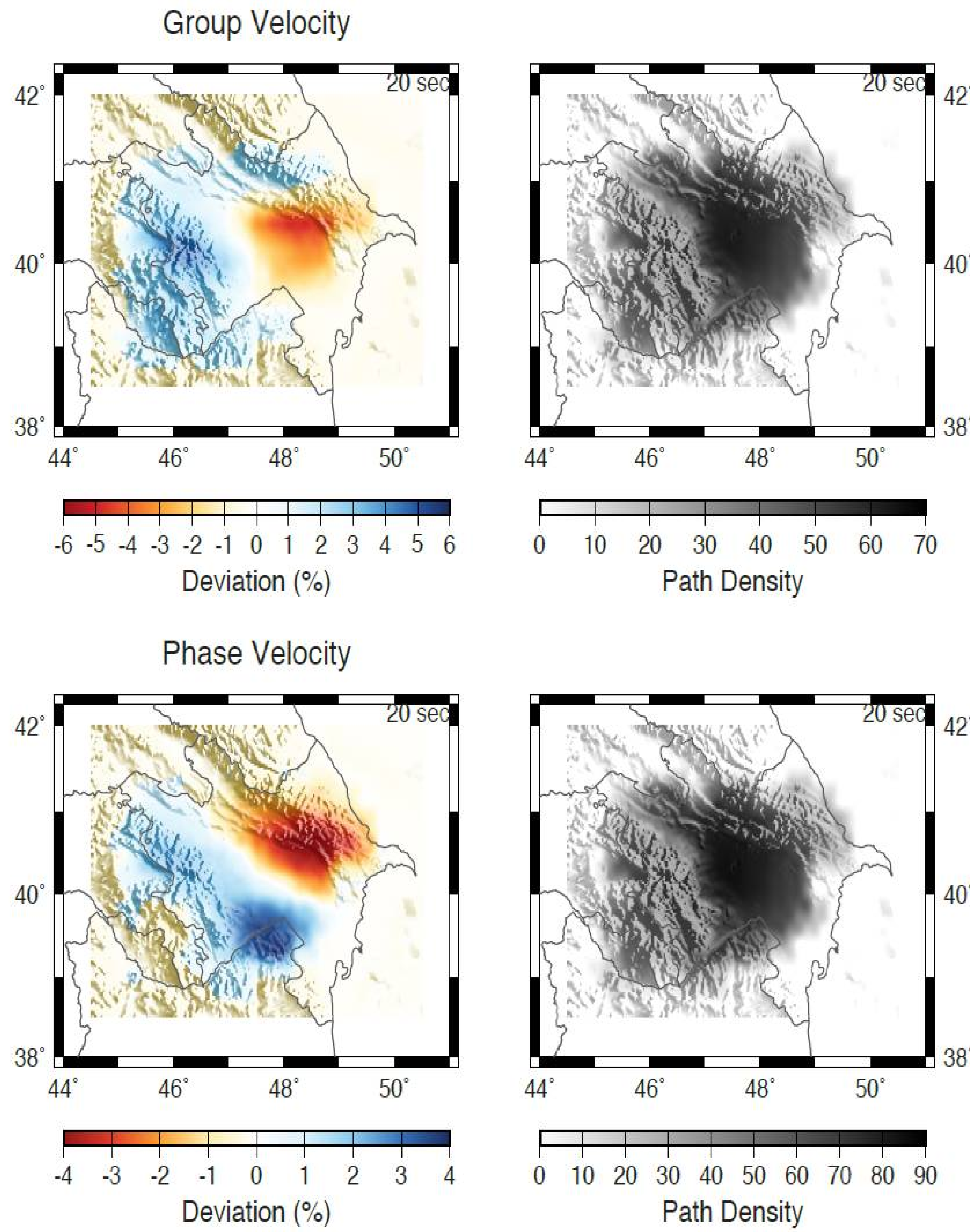

Figure 6. Group and Phase Velocity Maps.

Rayleigh wave group and phase velocities at 14, 20 and 28 seconds and their corresponding path densities. Path density is defined as the number of rays intersecting a 0.25 degree cell (~770 km2). The inversion is performed using the technique developed by Barmin et al. (2001).

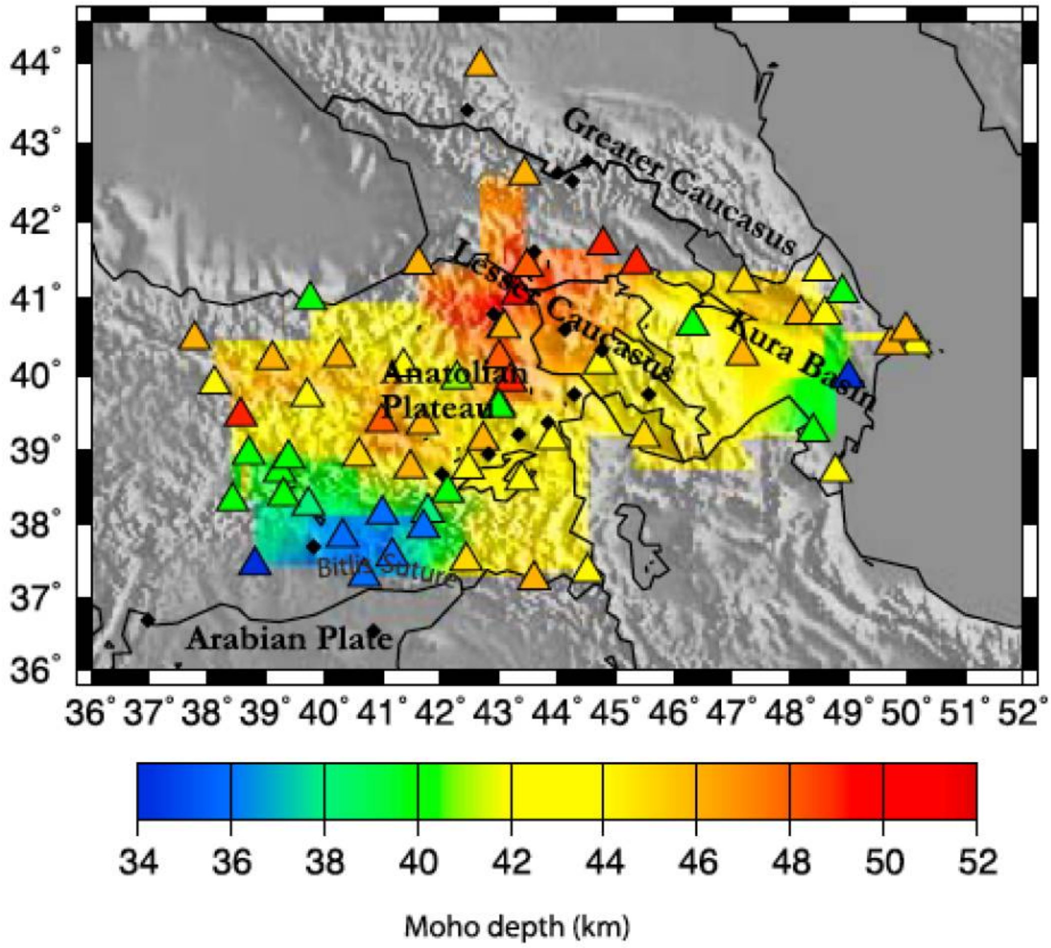

Figure 7. Moho Depths from Gok et al. (2011).

Conclusion

Eastern Caucasus is a region of complex geology where we expect to see large variations in wave propagation speeds. From three years of continuous ambient noise correlations we measured the Rayleigh wave surface dispersion. Group and phase velocity curves show different wave speeds correspond to the three major tectonic regions: the Greater Caucasus, the Lesser Caucasus and the Kura Basin. The inverted group and phase maps at shorter periods show high velocities at the Caucasus and low velocities at the Kura basin. At 28 seconds high velocities are observed underneath the Kura basin, which agrees with previous results. Event-based dispersion measurement should be included to model long period structure (>40 seconds) and include more continuous data to increase the noise correlation SNR, particularly at shorter periods. The next step is to invert for the velocity structure using the group and phase velocity maps, and include receiver functions to constrain the Moho depth.

Besides it, the obtained results as well as the additional studies will allow revealing the geodynamic anomalies, to perform the computed distribution of tensions of the region of study by data of the main axes of solutions of the earthquake focuses' mechanisms, to compare the various geodynamic processes and to reveal the interrelation between these processes. It allows compiling the digital maps to forecast the active zones of dislocations and risk in the region of study. The obtained results within Azerbaijan will allow defining reliably the active zone of fault and to reveal the risk

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potential in zone of seismic hazard along which the pipelines run and oil producing rigs allocate. The obtained results will also express the scientific value when studying the earthquakes forerunners. Besides it, the results will have the commercial significance and will be proposed to various petroleum and insurance companies and the authorities. The proposed investigations play a significant role in preservation of oil and gas deposits of Absheron peninsula and the Caspian Sea owing to increase of seismic activity in the peninsula.

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