BROADBAND NETWORK OPERATION AND SHEAR VELOCITY STRUCTURE BENEATH THE YANQING-HUAILAI BASIN, NW OF BEIJING

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ABSTRACT

We continue the operation of the Southern Methodist University-Institute of Geophysics, China Earthquake Administration (IGPCEA) broadband seismic network. The current operating network includes 3 stations NW of Beijing and 10 stations in Haicheng, NE China.

We conducted joint inversion of teleseismic received functions and surface wave phase velocities for crustal shear velocity structure. The focus area of the joint inversion is the Yanqing-Huailai Basin, 120 km northwest of Beijing. The data set is from a broadband seismic network that is part of a PASSCAL deployment in the basin and includes 34 teleseismic events from 2003 to 2005.

Within the Yanqing-Huailai Basin, earthquake risk and propagation path assessment are important because of the basin's historical seismicity and proximity to Beijing's large population. This setting motivated the deployment of portable broadband instruments consisting of STS-2 seismometers deployed in hard rock vaults and recorded on Quanterra Q-330 digitizer and Baler. The high-quality data set recorded by 7 stations around the basin provides us the opportunity to study the detailed velocity structure beneath this region using both teleseismic and regional signals.

The receiver functions from the teleseismic events are simple and similar around the Yanqing-Huailai Basin. They exhibit little variation with azimuth. The inverted velocity models reflect small path differences and are consistent with the shallow local geology. The resulting velocity models all produce a positive gradient from surface to approximately 5 km with shear wave velocity increasing from 2.4-2.7 km/sec to 3.4 km/sec. A low velocity layer was found to start between 5 and 10 km with shear velocity dropping to 3.1 km/sec and extending to about 13 km.

Long period surface wave observations (20-100 sec) are used to further constrain the crust and upper mantle. The crustal components of these models are developed and compared to shallow crustal structures determined from the analysis of intermediate period (2-15 sec) surface waves generated by moderate size regional events and recorded at the same stations. The regional analysis produces shear wave models for the top 15 km of the crust that are consistent with the models constrained by teleseismic data.

OBJECTIVES

The goals of the collaborative study between the SMU and the IGPCEA (formerly IGCSB) are to develop a database of earthquakes and human-induced events; to refine event locations in Yanqing-Huailai Basin and Haicheng area; to understand source characterization of natural and human-induced events; and to separate source and propagation path effects at regional distance.

The deployment of the broadband seismic network operated by SMU and IGPCEA has been completed. The current operating network includes 3 stations around the Yanqing-Huailai Basin, NW of Beijing and 10 stations in the Haicheng, NE China (Figure 1). The seismic data have been archived into the Incorporated Research Institutions for Seismology (IRIS) Data Management System Portable Data Collection Center (DMC) database.

Beijing and Haicheng are two regions of historical natural and human-induced seismicity as well as a seismic hazard. The region includes the site of the first successful earthquake prediction in 1975 near Haicheng and the great Tangshan earthquake in 1976. The broadband seismic network provides near-source and regional coverage for the study area. Data from this network have been used to constrain the preliminary velocity structure around Beijing (Zhou, 2004) from surface wave study and investigate event discrimination for mining explosions (Zhou et al., 2006).

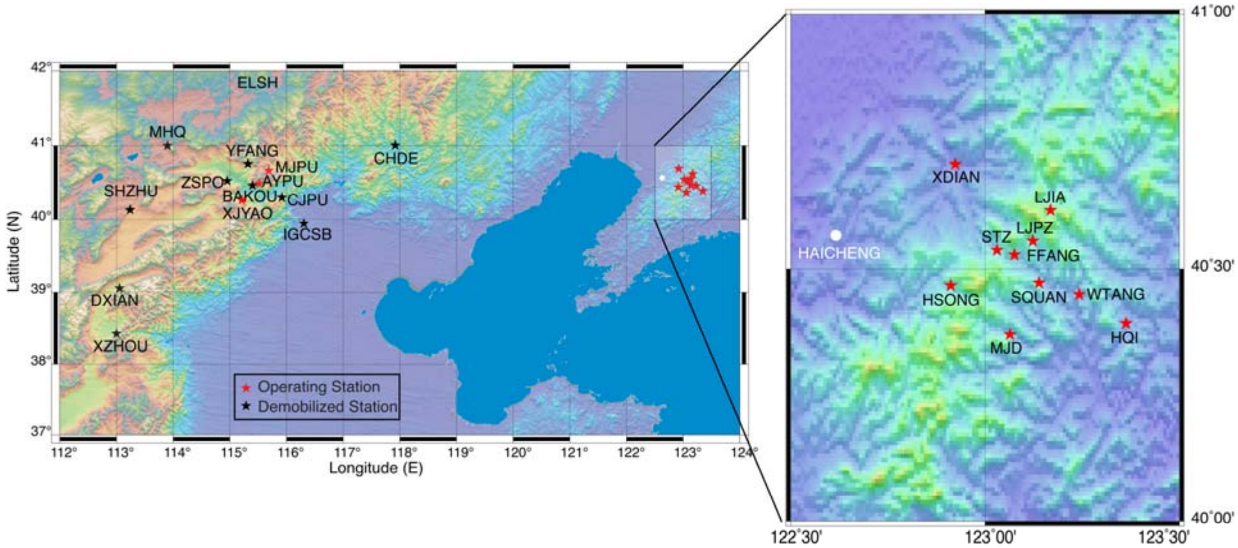

Figure 1. Map of the SMU-IGPCEA Broadband Seismic Network (Operating stations: red stars; Demobilized stations: black stars)

RESEARCH ACCOMPLISHED

Operation of the Broadband SMU-IGPCEA Network

The deployment of the broadband SMU-IGPCEA network was completed and is summarized in Figure 1. To date, 13 broadband seismic stations are operating, including 3 stations (AYPU, MJPU and XJYAO) around the Yanqing-Huailai Basin and 10 stations in Haicheng, Liaoning Province. Data through December 2005 have been converted to SEED format and archived at IRIS DMC.

Shear Structure Beneath the Yanqing-Huailai Basin

Regional Setting and Seismicity

The Yanqing-Huailai Basin is located in the area of 40°00′N – 40°38′N and 115°04′E – 116°14′E, about 90 to 140 km northwest of Beijing, China (Figure 2). The Yanqing-Huailai basin is a collection of four intermountain basins:

Yanqing, Huailai, Zhuolu and Fanshan basin (Zhang et al., 1996), in which the Yanqing and Huailai basins are two sub parallel elongated half-graben basins bounded to their NNW by normal faults (Pavlides et al., 1999). Historically, two large earthquakes occurred in Yanqing-Huailai Basin. One was the Huailai earthquake with magnitude 6.5 on September 8, 1337; the other one was the Shacheng earthquake with magnitude 6.75, near Shacheng on July 12, 1720 (Fig. 2). Recently, the seismicity is increasing in this area. Based on signals recorded by the Beijing Telemetered Seismograph Network, China Seismological Bureau, there are 15 to 20 earthquakes with magnitude equal or greater than 2.0 every year in the Yanqing-Huailai basin and its adjoining area (Chen et al., 1998). On July 20, 1995, a M_L 4.1 earthquake occurred in the Yanqing-Huailai Basin followed by approximately 450 aftershocks (Chen et al., 1998).

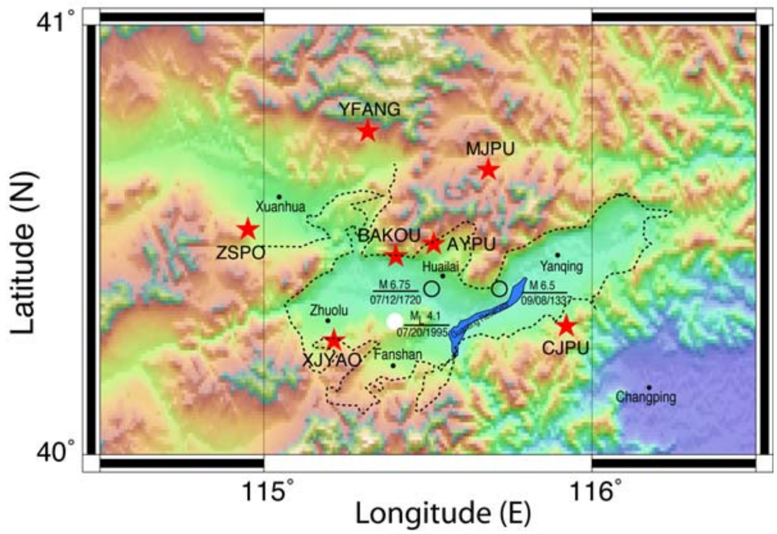

Figure 2. Topographic map of Yanqing-Huailai Basin (dotted line) and adjacent area. Broadband seismic stations of the SMU-IGPCEA Huailai Seismic Network are designated as stars. Open circles are locations of two historical earthquakes in 1337 and 1720. The white dot is the epicenter of a M_L 4.1 earthquake on July 20, 1995. Solid dots are towns in the area.

Receiver Functions

Thirty-four, high signal-to-noise ratio, teleseismic events with great circle epicentral distances in the range of 30-80 degrees from 2003 to 2005 have been chosen for the receiver function and surface wave joint inversion. Source parameters of these events were obtained from the Preliminary Determination of Epicenters (PDE) bulletins provided by the United States Geology Survey (USGS) National Earthquake Information Center (NEIC) and are listed in Table 1. Figure 3 is the map of these 34 teleseismic events with azimuthal equidistant projection centered at AYPU. The distribution of teleseismic sources illustrated the coverage in which the local earth structure is well sampled by the events from the three azimuths to the northeast, southeast and southwest. The three-component seismograms of a magnitude 6.2 event (2003089, which occurred at -3.17°N and 127.54°E on March 30, 2003) are presented in Figure 4 as a typical example of data recorded by the SMU-IGPCEA broadband seismic network.

Receiver functions are extracted from the three-component broadband recordings of teleseismic *P* waves at distances ranging from 30° to 80° (Figure 3). The extraction procedure is described by Langston (1979) and consists of a deconvolution of vertical component seismograms from the radial and transverse components. The deconvolution is performed in the frequency domain using a Gaussian filter and spectral trough filler. It is important to recognize that these receiver functions, although developed from *P* waveforms, are most sensitive to the shear velocity structure beneath the station, since *P* to *S* conversions dominate the horizontal components after source effects are eliminated (Owens et al., 1984). Ammon et al. (1991) suggest that the absolute amplitude of a receiver function supplies an additional constraint on the near-surface shear wave velocity, which also helps avoid inaccuracies due to the presence of dipping layers (Cassidy, 1992).

Table 1. Event Parameters

Even Code	Date (Y-M-D)	Time (hhmmss.mm)	Latitude (°N)	Longitude (°E)	Magnitude	Depth (km)	Distance to AYPU (degree)	AYPU Back-Azimuth (degree)
2003076	2003-03-17	163617.31	51.27	177.98	7.1	33	43.4030	53.841
2003089	2003-03-30	181334.09	-3.17	127.54	6.2	33	45.0290	162.9029
2003141	2003-05-21	184420.10	36.96	3.63	6.9	12	80.5659	311.2685
2003166	2003-06-15	192433.15	51.55	176.92	6.5	20	42.7017	53.6157
2003174	2003-06-23	121234.47	51.44	176.78	7.0	20	42.6352	53.798
2003339	2003-12-05	212609.48	55.54	165.78	6.7	10	35.8562	47.9734
2003360	2003-12-26	015652.44	29.00	58.31	6.8	10	47.5414	274.7492
2004039	2004-02-08	085851.80	-3.66	135.34	6.9	25	47.7394	152.7885
2004107	2004-04-16	215705.41	-5.21	102.72	6.0	44	47.1908	197.498
2004114	2004-04-23	015030.22	-9.36	122.84	6.7	65	50.3108	170.5935
2004162	2004-06-10	151957.75	55.68	160.00	6.9	188	32.6250	47.1192
2004180	2004-06-28	094947.00	54.80	-134.25	6.8	20	67.7271	35.7656
2004316	2004-11-11	212641.15	-8.15	124.87	7.5	10	49.4031	167.7677
2004353	2004-12-18	064619.87	48.84	156.31	6.2	11	29.7939	59.9279
2005022	2005-01-22	203017.35	-7.73	159.48	6.5	29	62.9309	129.4202
2005023	2005-01-23	201012.15	-1.20	119.93	6.3	11	41.8874	173.3834
2005036	2005-02-05	033425.73	16.01	145.87	6.6	142	35.9156	124.1009
2005036-2	2005-02-05	122318.94	5.29	123.34	7.1	525	35.8981	166.6349
2005046	2005-02-15	144225.85	4.76	126.42	6.6	39	37.0547	161.7708
2005050	2005-02-19	000443.59	-5.56	122.13	6.5	10	46.4530	170.9008
2005061	2005-03-02	104212.23	-6.53	129.93	7.1	201	48.8588	160.8297
2005089	2005-03-30	161941.10	2.99	95.41	6.4	22	41.6663	211.0916
2005093	2005-04-03	005921.42	0.37	98.32	6.0	30	43.0583	205.6601
2005093-2	2005-04-03	031056.47	2.02	97.94	6.3	36	41.6333	207.0177
2005099	2005-04-09	151627.89	56.17	-154.52	6.0	14	57.3372	41.3998
2005100	2005-04-10	102911.28	-1.64	99.61	6.7	19	44.5634	202.981
2005100-2	2005-04-10	172439.40	-1.59	99.72	6.4	30	44.4830	202.8524
2005106	2005-04-16	163803.90	1.81	97.66	6.4	31	41.9274	207.3021
2005118	2005-04-28	140733.70	2.13	96.80	6.3	22	41.9354	208.6745
2005130	2005-05-10	010905.10	-6.23	103.14	6.4	17	48.0911	196.6372
2005134	2005-05-14	050518.48	0.59	98.46	6.8	34	42.8045	205.5722
2005139	2005-05-19	015452.85	1.99	97.04	6.9	30	41.9789	208.2643
2005165	2005-06-14	171016.64	51.23	179.41	6.8	51	44.2879	53.6387
2005186	2005-07-05	015202.95	1.82	97.08	6.8	21	42.1231	208.1173

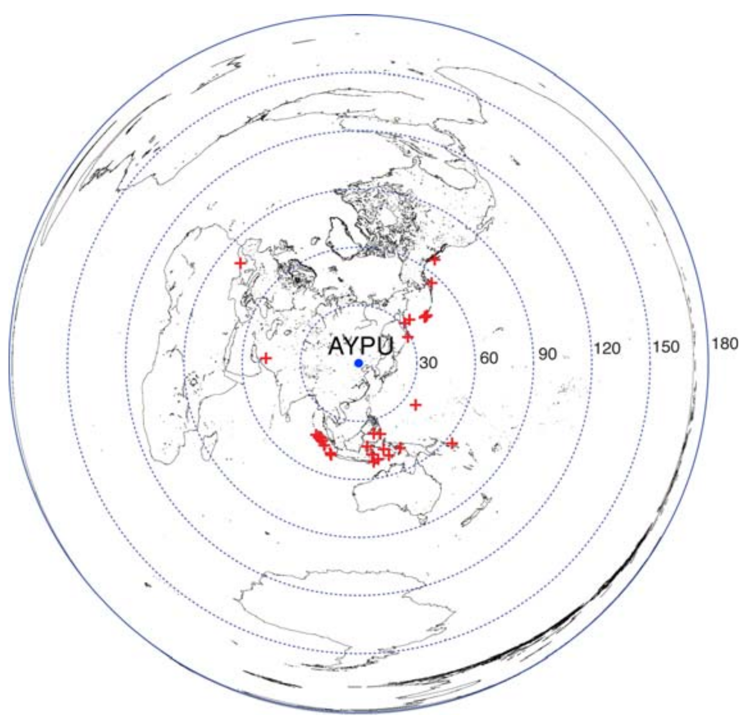

Figure 3. Map (azimuth equidistant projection centered at AYPU) of events (plus) used in the receiver function study. Dotted lines are great circle distance ranges in degrees from AYPU (dot).

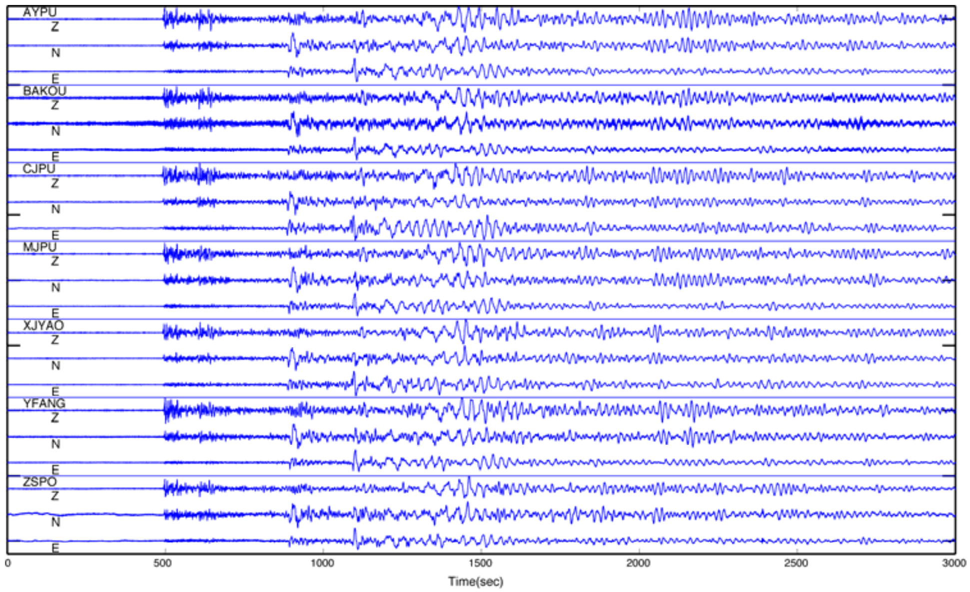

Figure 4. Three components seismograms from Event 2003089 recorded by the network.

Typical radial component receiver functions from Event 2003089 with different Gaussian filter parameters at 6 stations of the SMU-IGPCEA broadband seismic network are reproduced in Figure 5. The signal to noise ratio at BAKOU was low on the north and east component for this event and so data from this station for this event are not included in the subsequent analysis.

The receiver functions were extracted from all 34 events in Table 1 and Figure 3. The radial component receiver functions at stations AYPU and XJYAO are plotted as a function of azimuth in Figure 6. The radial component receiver functions are simple, have little azimuthal variation and are similar around the Yanqing-Huailai Basin. This similarity led us to a simple one dimensional receiver function analysis.

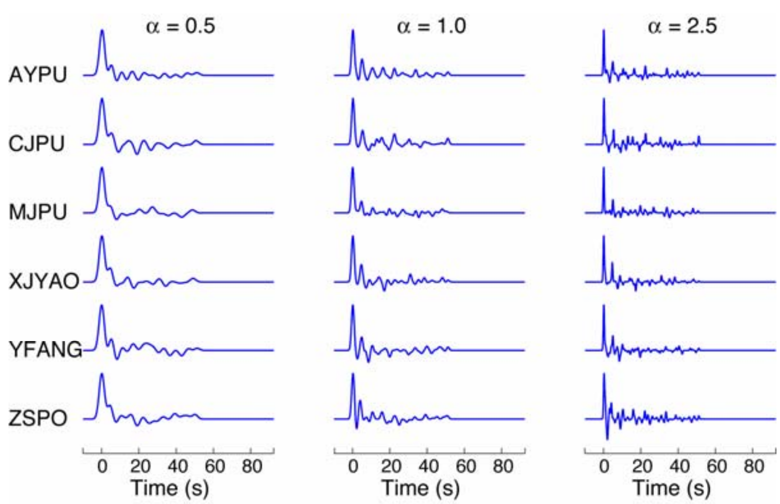

Figure 5. Receiver functions from Event 2003089 on March 30, 2003 with Gaussian window parameters α of 0.5 (left), 1.0 (mid) and 2.5 (right).

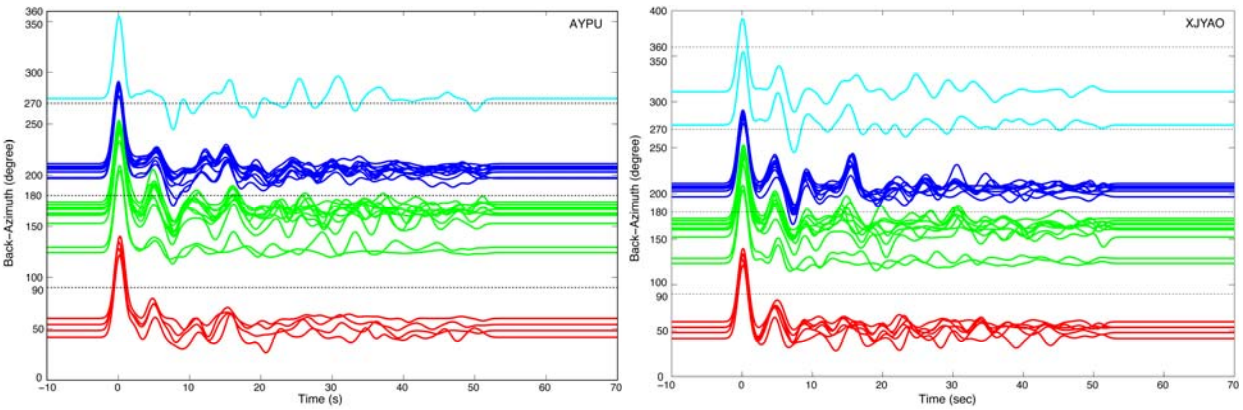

Figure 6. Receiver functions versus back-azimuth for all events recorded at stations AYPU (27 events) and XJYAO (27 events).

Surface Wave

McMechan and Yedlin (1981) described a technique to obtain phase velocity dispersion from an array of seismic traces. This technique relies on a *p*-τ stack followed by transformation into the *p*-ω domain (Mokhtar et al., 1988) and is applied to our data set. For each teleseismic event in our data set, the long period surface waves were extracted by using the Multiple Filter Analysis (Dziewonski et al., 1969) and Phase Matched Filtering (Herrin and Goforth, 1977). The fundamental mode Rayleigh waves extracted from Event 2003089 in the period range of 20 to 100 seconds are reproduced in Figure 7. Group velocity dispersion curves from 20 to 100 sec in period were recovered and phase velocity stacks from 3.45 to 4.20 km/sec are also included in Figure 7.

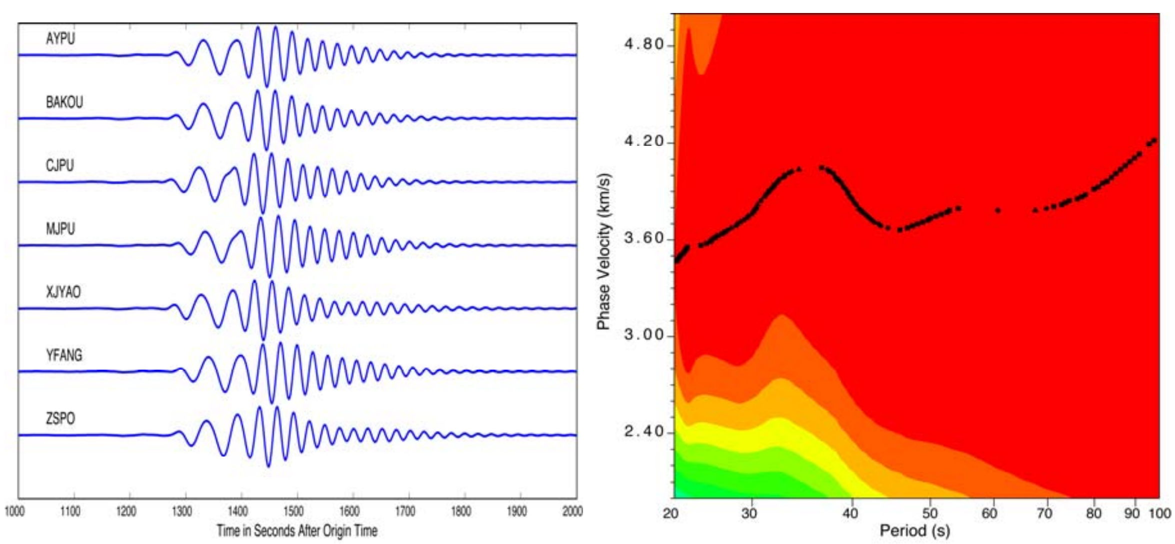

Figure 7. Left: Fundamental Rayleigh waves extracted from Event 2003089 and Right: Phase velocity stacks of the Rayleigh waves for Event 2003089.

Joint Inversion

A joint inversion of the receiver functions and phase velocities across the Yanqing-Huailai Basin has been conducted. The starting model is given in Figure 8 in black with the velocity model resulting from the joint inversion in green. Observed (blue) and predicted (red) receiver functions at station AYPU are also plotted. The predicted receiver functions fit the observed well for the events at all azimuths and distance ranges. The resulting velocity models at each station are summarized in Figure 9. All stations give consistent velocity models except CJPU and ZSPO, which only recorded useful data for 8 and 10 events, respectively. There are differences in the very shallow portions of the models as illustrated by top 2 km for stations in the Yanqing-Huailai Basin which have a slower shear velocity of about 2.4 km/sec compared to stations outside the basin. All velocity models have a positive velocity gradient from surface to approximately 5 km with shear wave velocity increasing from 2.35/2.8 km/sec to 3.4 km/sec. All models have a low velocity zone in the upper crust starting between 5 and 10 km with a shear velocity oft 3.2 km/sec. A slight negative gradient in velocity starts at about 15 km resulting in an extended constant velocity layer to approximately 25 km. The crustal thickness in this region is between 35 and 42 km from studies of wide-angle reflection and refraction surveys (Zhang et al., 1996; and Zhao et al., 2005) that is consistent with our models.

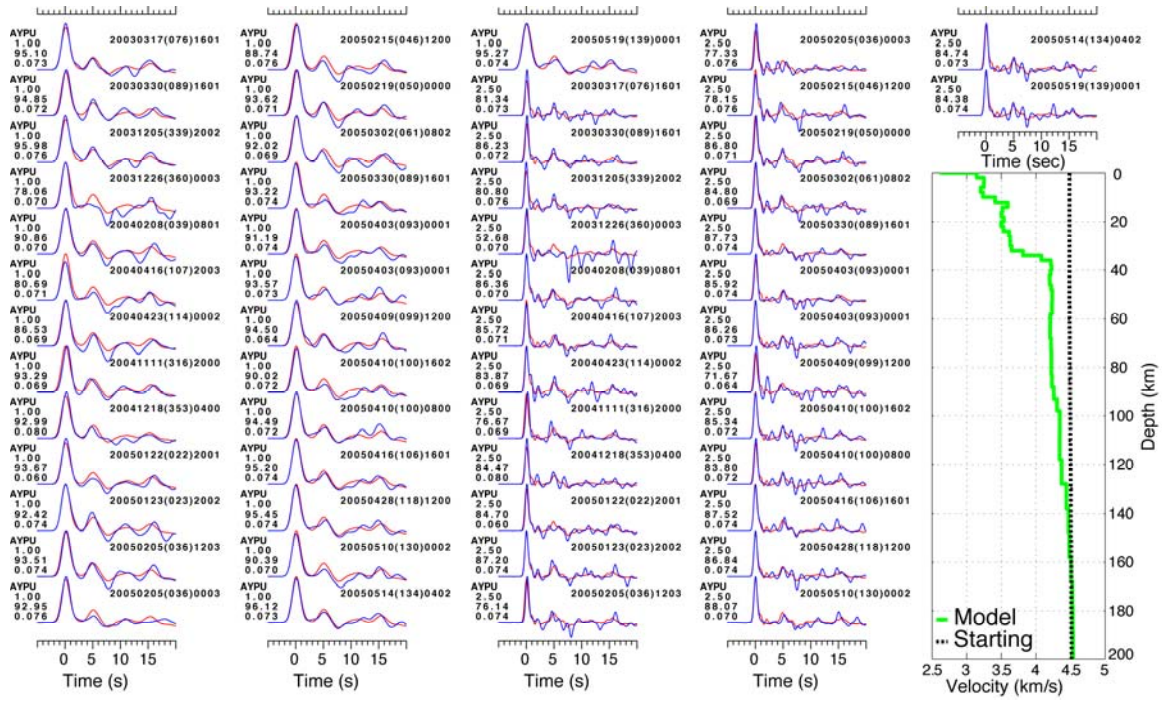

Figure 8. Comparison between observed (blue) and predicted receiver functions (red) at AYPU. The starting shear wave velocity model is the dashed black line and the velocity model from the joint inversion at AYPU is given in green.

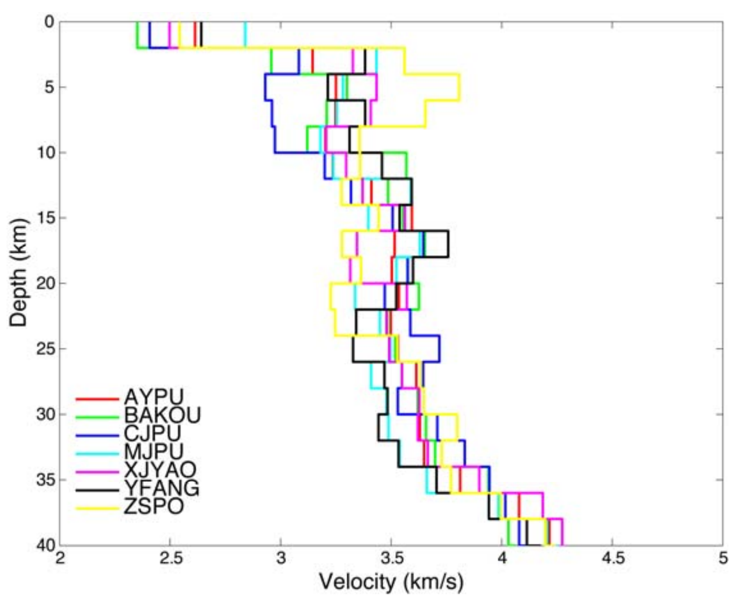

Figure 9. Velocity models resulting from joint inversion at all 7 stations in and around the Yanqing-Huailai Basin.

Model Comparison

An average shear velocity model was estimated by inverting all the receiver functions from the 7 network stations. This average velocity model is compared to the published velocity model based on the wide-angle reflection and refraction profile along the Fengzhen-Huailai-Shunyi (Zhang et al., 1996; and Zhao et al., 2005) in Figure 10. The predicted first arrival times of P and S wave from the two models are also compared in the figure. The *P* wave arrival times for the two models agree to 300 km. The *S* wave arrival times agree to about 170 km with our model predicting later arrival times for *S* waves at the larger ranges.

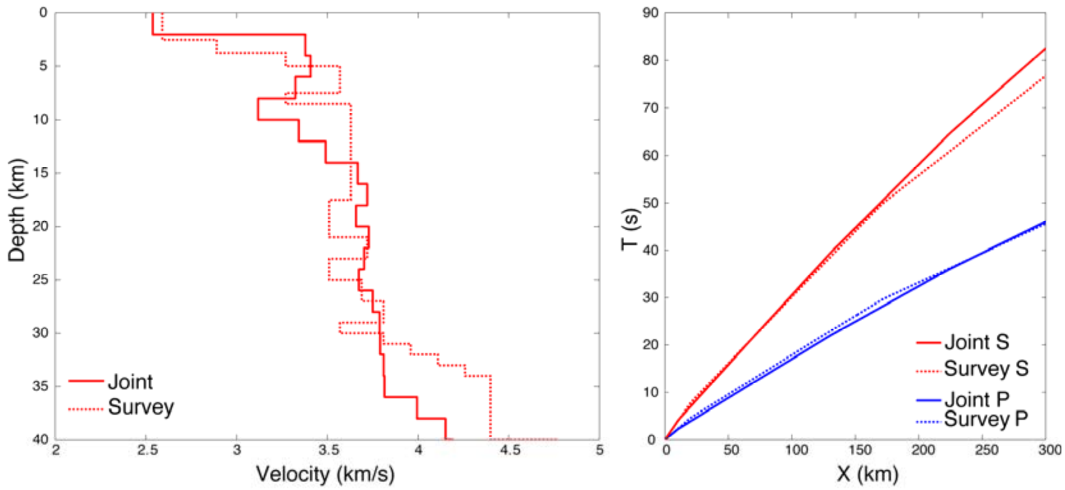

Figure 10. Left: Comparison between the joint inversion model (solid red) and the model from a wide-angle reflection and refraction survey (dotted red). Right: Predicted first arrival times of P (blue) and S wave (red) for jointed inversion model (solid) and the model from a wide-angle reflection and refraction survey (dotted).

CONCLUSIONS AND RECOMMENDATIONS

The operation of the SMU-IGPCEA broadband seismic network is continuing. The data through December 2005 has been archived at the IRIS DMC.

A joint inversion of teleseismic receiver functions and surface wave phase velocities for crustal shear velocity structure beneath the Yanqing-Huailai Basin has been completed. The inversion results indicate that the top 2 km beneath the Yanqing-Huailai Basin has a slower shear velocity of about 2.4 km/sec compared to stations outside the basin. A positive velocity gradient exists at all stations to a depth of 5 km with S wave velocity increasing to 3.4 km/sec. A low velocity layer was found to start between 5 and 10 km with shear velocity dropping to 3.1 km/sec and extending to about 13 km. Crustal thickness around Yanqing-Huailai basin is about 40 km consistent with the wide-angle reflection and refraction survey results.

Predicted first arrival times of *P* waves from the joint inversion model fit well with the wide-angle reflection and refraction results to distances of 300 km. The new shear wave model predicts S arrivals that are late relative to previous model beyond 170 km.

The velocity models from inversion at stations CJPU and ZSPO are different from the others because of the smaller number of the events recorded. This difference suggests that more events should be added to the inversion procedure in the future.

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