BROADBAND NETWORK OPERATION AND SHEAR VELOCITY STRUCTURE BENEATH THE XIUYAN AREA, NE CHINA

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ABSTRACT

We continue the operation of the Southern Methodist University (SMU)-Institute of Geophysics, China Earthquake Administration (IGPCEA) broadband seismic network. The current operating network includes three stations NW of Beijing and ten stations in Xiuyan, Liaoning Province, NE China.

On November 29, 1999, an earthquake of M_S 5.9 occurred in Xiuyan, Liaoning of China. This earthquake was followed by a number of aftershocks. To study the characteristics of this fault system and the structure beneath this area, 10 portable broadband seismometers were deployed around this region beginning August 2004. Instrumentation consists of STS-2 seismometers connected to Quanterra Q-330 digitizers and Baler recording systems located in hard rock vaults. The high-quality data set recorded by these 10 regional stations provides the opportunity to study the detailed velocity structure beneath this region using both teleseismic and regional signals.

Short-period surface wave dispersion curves from ambient noise were obtained using four months of data. Receiver functions and surface wave phase velocities from 42 teleseismic events that occurred between August 2004 and March 2006 have been determined. The combination of passive noise data and active earthquake data is being used to invert for crustal shear velocity structure beneath the Xiuyan area, NE China. This analysis is the first step in a more detailed source study of local and regional events.

Infrasound gauges originally destined for China have been installed in two arrays in Utah, with a third planned for summer of 2007. The array at station NOQ was installed May 2006 and the array at BGU May 2007. Data from these arrays are telemetered in real-time to the University of Utah and are archived at the Incorporated Research Institutions for Seismology (IRIS) Data Mangement Center DMC. The arrays consist of four infrasound sensors with approximate 200-m separation sampled at 100 samples per second. NOQ is located close to the Bingham open-pit copper mine, one source of infrasound signals. BGU is located near the Utah Test and Training Range (UTTR) of the Hill AFB, which routinely detonates large surface explosions from 40,000 to 80,000 lb. Cooperation with the group at Hill AFB has been initiated and resulted in initial attempts to model time varying atmospheric effects using data from the NOQ array. We plan to utilize these stations in combination with an experimental deployment of seismic and infrasound sensors to better characterize local and regional infrasound propagation from explosive sources (see, Seismic and Infrasound Energy Generation and Propagation at Local and Regional Distances, Stump et al., these Proceedings).

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 the Yanqing-Huailai Basin and the 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 three 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 IRIS DMC Portable Data Collection Center 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) as well as joint inversion of receiver functions and surface-wave dispersion for the detail structure beneath the Yanqing-Huailai Basin, NE of Beijing (Zhou et al., 2007).

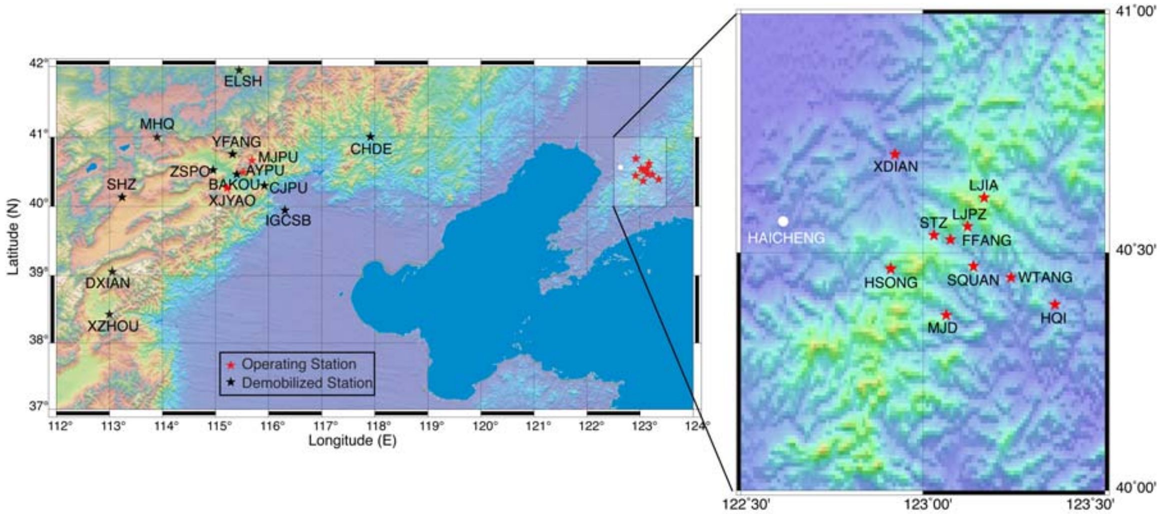

Figure 1. Map of the SMU-IGPCEA Broadband Seismic Network (operating stations: red stars; demobilized stations: black stars).

A final objective in this research is the instrumental quantification of seismic and infrasound signals observed at regional distances. The goal in this case is an investigation of man-made and natural sources of both infrasound and seismic waves. Initially, infrasound gauges were to be co-located with the seismometers deployed. After acquisition of the infrasound gauges, the deployment was made in the US at two (and soon three) seismic stations that are part of the University of Utah Seismic Stations.

RESEARCH ACCOMPLISHED

Study Area

In summer 2004, we demobilized five stations from Beijing area and installed them around the Haicheng area (Figures 1 and 2), the second focus area of this cooperative project and focus region of this study. To date, 13 broadband seismic stations have been installed and operated in the two regions (Figure 1).

The 1975 Haicheng Earthquake, the first predicted earthquake in China, occurred in this region and motivated an interest to understand seismicity for hazard reduction. The Haicheng area is also rich in natural resources such as iron, zinc, coal, oil and natural gas. Mining activities related to resource recovery provide additional sources of seismic waves. Historically, a few larger earthquakes in addition to the 1975 event have occurred in the Haicheng-Xiuyan seismogenic zone (Haichenghe-Dayanghe fault) and surrounding area. Three earthquakes with magnitude 5.25, 5.5, and 5.9 occurred around Yinkou on September 19, 1859; April 7, 1885; and May 18, 1978, respectively (Wang et al., 2002). According to the bulletin from the Liaoning Digital Telemetry Network, the Haicheng-Xiuyan earthquake swarm started from two earthquakes, M_L 4.1 and M_L 4.2 on November 9, 1999. By the time the mainshock, M_S 5.9, occurred on November 29, 1999, 205 earthquakes had been recorded, including 28 M_L 2.0 ~ 2.9 earthquakes, 10 M_L 3.0 ~ 3.9 earthquakes and five earthquakes with M_L 4.0 ~ 4.9. The largest foreshocks were two M_L 4.4 events that occurred on November 25 and 26. These events reflect the seismic activity in this region. Figure 2 is a map of major faults and historical earthquakes around the Haicheng and Xiuyan area with the first 5 SMU-IGPCEA broadband seismic stations superimposed on the image.

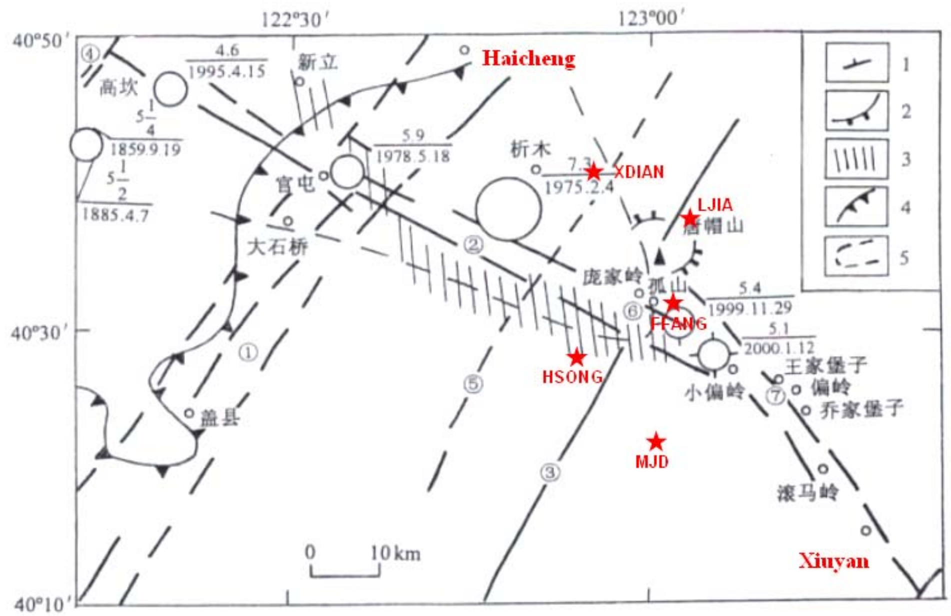

Figure 2. Map of major faults and historical earthquakes around Haicheng and Xiuyan area (Wang et al., 2002) superposing with SMU-IGPCEA stations (red stars). Major faults: (1) Jinzhou Fault; (2) Haichenghe-Dayanghe Fault; (3)Tanghe-gushan Fault; (4) Niuju-Youyangou Fault; (5) Ximu Fault; (6) Kangjialing Fault; and (7) Wangjiabuzi Fault.

Noise Correlation and Extraction of Intermediate Period Surface Waves

Using ambient noise and correlation techniques to extract surface waves between pairs of stations has evolved significantly since the first work by Shapiro et al. (2005). These techniques have proven to provide useful constraints on shallow crust and upper mantle structure in regions with few regional events that generate intermediate period surface waves. Continuous vertical-component seismic data from the initial five stations deployed in the Haicheng-Xiuyan region (FFANG, HSONG, LJIA, MJD and XDIAN, Figure 2) recorded during the first five months of 2004 provide an opportunity to apply this analysis approach. Stacked cross-correlation functions between pairs of these five stations are illustrated in Figure 3. Fundamental Rayleigh waves were extracted using Multiple Filter Analysis and Phase Matched Filter techniques and are reproduced in Figure 4.

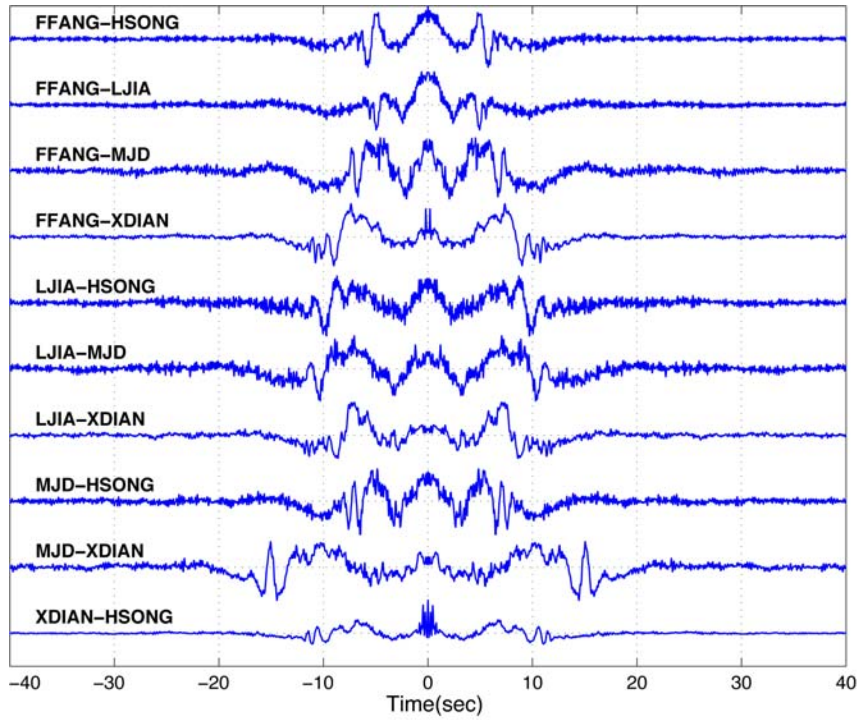

Figure 3. Cross-correlation functions between station pairs from continuous vertical-component seismic data from the five stations (FFANG, HSONG, LJIA, MJD and XDIAN) deployed in the Haicheng-Xiuyan region over the first five months of 2004.

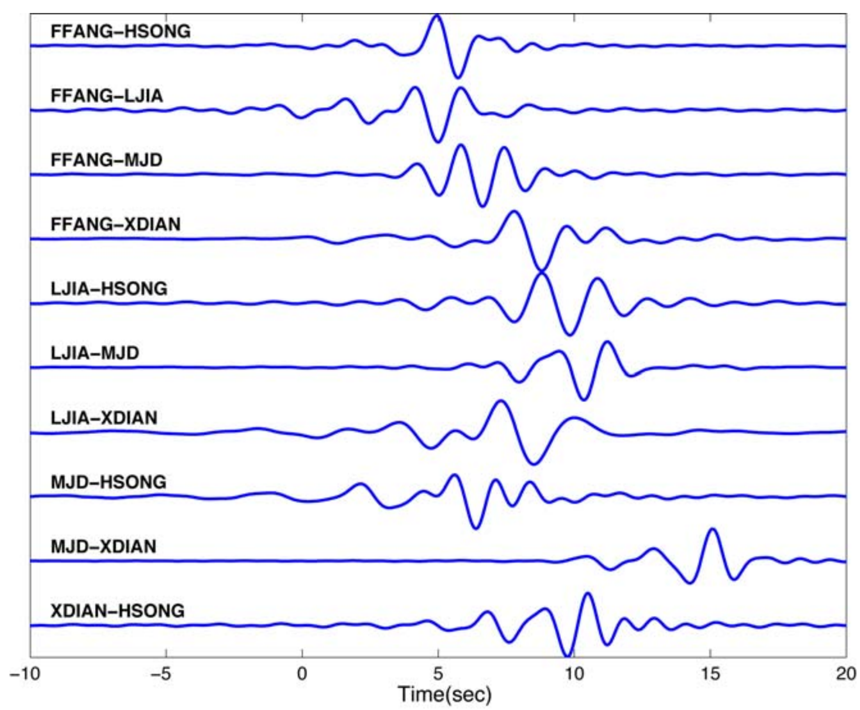

Figure 4. Fundamental Rayleigh waves extracted from cross-correlations in Figure 3 and station pairs illustrated in Figure 2.

Receiver Functions

Forty-two, high signal-to-noise ratio, teleseismic events with great circle epicentral distances in the range of 30-80 degrees from 2004 to 2006 have been chosen for receiver function analysis. This approach follows an earlier study in the Huailai Basin (Zhou *et al.,* 2007) and provides an opportunity to document variations in crust and upper mantle structure in NE China. 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 with the distance ranges and back-azimuth of the events to station FFANG.

Receiver functions were computed using the iterative, time-domain deconvolution of Ligorría and Ammon (1999), an implementation of the Kikuchi and Kanamori (1982) technique. The receiver functions were extracted from all 42 events in Table 1. The radial component receiver functions at station FFANG with Gaussian window parameter α of 1.0, and 2.5 for Event 2004314 are plotted in Figure 5. Figure 6 is a plot of all receiver functions as a function of azimuth for the 41 events recorded at station FFANG. The radial component receiver functions are simple and demonstrate little azimuthal variation. The similarity of these receiver functions motivates the simple one dimensional receiver function analysis that follows.

Table 1. Event Parameters in the Receiver Function Study

Event Code	Date (Y-M-D)	hhmmss.mm	Latitude (°N)	Longitude (°E)	Magnitude	Depth (km)	Distance to FFANG (degree)	FFANG BackAzimuth (degree)
2004263	2004-09-19	202604.10	52.21	174.03	6.2	25	36.2030	53.6813
2004278	2004-10-04	192034.98	14.55	146.99	6	7	33.3010	134.3848
2004282	2004-10-08	082753.54	-10.95	162.16	6.9	36	62.8830	135.9383
2004314	2004-11-09	235823.65	-11.15	163.71	6.9	13	63.8796	134.6334
2004331	2004-11-26	022503.31	-3.61	135.4	7.2	10	45.5589	162.6404
2004366	2004-12-31	022400.52	7.12	92.53	6.3	14	43.1053	227.5609
2005001-E1	2005-01-01	062544.82	5.1	92.3	6.7	11	44.9091	226.2114
2005001-E2	2005-01-01	190807.80	7.34	94.46	6.1	55	41.8587	225.3843
2005002	2005-01-02	153556.72	6.36	92.79	6.4	30	43.5898	226.6287
2005004	2005-01-04	091312.25	10.67	92.36	6.1	23	40.3174	230.8754
2005016	2005-01-16	201752.76	10.93	140.84	6.7	24	33.4962	147.1242
2005017	2005-01-17	105032.56	10.99	140.68	6.1	12	33.3759	147.3374
2005022	2005-01-22	203017.35	-7.73	159.48	6.5	29	58.7492	136.5358
2005023	2005-01-23	201012.15	-1.2	119.93	6.3	11	41.8271	184.7185
2005024	2005-01-24	041647.44	7.33	92.48	6.3	30	42.9603	227.7951
2005036	2005-02-05	122318.94	5.29	123.34	7.1	525	35.2394	179.5434
2005039	2005-02-08	144821.97	-14.25	167.26	6.7	206	68.3876	133.3971
2005046	2005-02-15	144225.85	4.76	126.42	6.5	39	35.8949	174.3090
2005050	2005-02-19	000443.59	-5.56	122.13	6.5	10	46.0968	181.3060
2005053	2005-02-22	022522.92	30.75	56.82	6.5	14	53.4676	281.7589
2005057	2005-02-26	125652.62	2.91	95.59	6.8	36	45.0564	220.6328
2005061	2005-03-02	104212.23	-6.53	129.93	7.1	201	47.4796	170.7419
2005089	2005-03-30	161941.10	2.99	95.41	6.3	22	45.0763	220.9094
2005100	2005-04-10	102911.28	-1.64	99.61	6.7	19	47.2859	212.8012
2005101	2005-04-11	170853.94	-21.98	170.61	6.7	68	76.5471	135.3024
2005118	2005-04-28	140733.70	2.13	96.8	6.2	22	45.1520	218.6064
2005130	2005-05-10	010905.10	-6.23	103.14	6.4	17	50.2233	206.1693
2005134	2005-05-14	050518.48	0.59	98.46	6.8	34	45.7602	215.5464
2005139	2005-05-19	015452.85	1.99	97.04	6.9	30	45.1620	218.2150
2005165	2005-06-14	171012.28	51.24	179.31	6.8	17	39.5385	54.8414
2005186	2005-07-05	015202.95	1.82	97.08	6.8	21	45.2933	218.0528
2005205	2005-07-24	154206.21	7.92	92.19	7.5	16	42.6406	228.6387
2005309	2005-11-05	104821.28	-3.16	148.14	6.4	25	49.3349	146.1065
2005323	2005-11-19	141013.03	2.16	96.79	6.5	21	45.1303	218.6389
2005331	2005-11-27	102219.19	26.77	55.86	6.1	10	56.2551	278.1349
2005345	2005-12-11	142043.79	-6.57	152.2	6.6	10	54.1781	143.3937
2005347	2005-12-13	031606.38	-15.27	-178.57	6.8	10	77.6688	122.7911
2006002	2006-01-02	221340.49	-19.93	-178.18	7.2	582	81.4169	125.6328
2006008	2006-01-08	113455.64	36.31	23.21	6.7	66	73.7483	304.2130
2006027	2006-01-27	165853.67	-5.47	128.13	7.6	397	46.2325	173.0243
2006073	2006-03-14	065733.86	-3.6	127.21	6.7	30	44.2908	174.0854
2006090	2006-03-31	211447.24	3.79	126.37	6.2	54	36.8585	174.5142

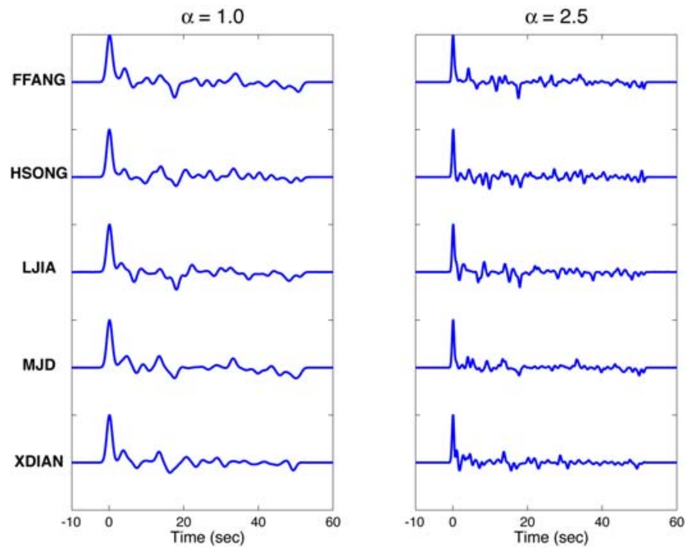

Figure 5. Receiver functions from Event 2004314 on November 09, 2004 with Gaussian window parameters α of 1.0 (left), and 2.5 (right).

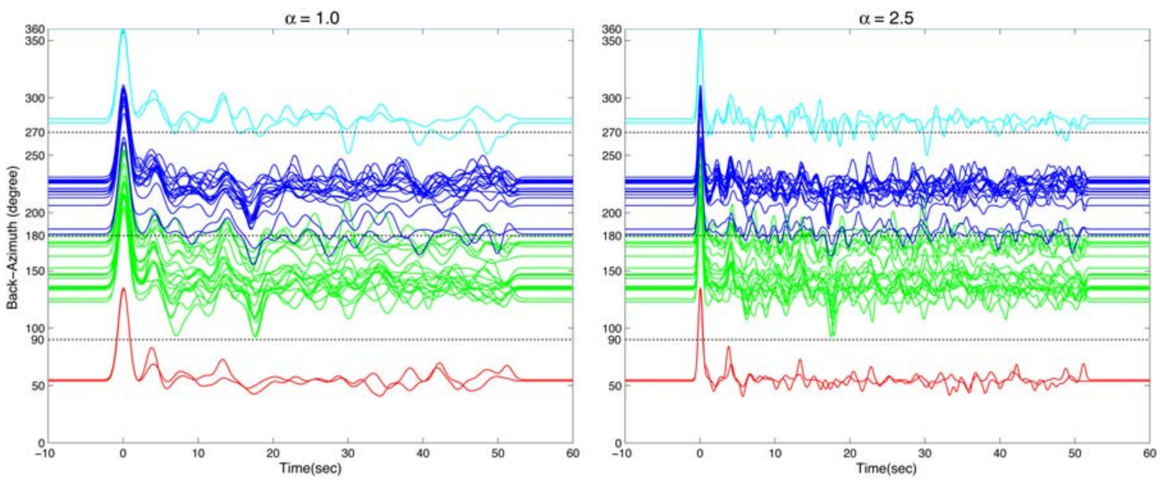

Figure 6. Receiver functions versus back-azimuth for all events recorded at stations FFANG (41 events) with Gaussian window parameters α of 1.0 (left), and 2.5 (right).

Joint Inversion

For the 42 events analyzed, the numbers of receiver functions obtained at each station vary: FFANG has 41, HSONG 14, LJIA 18, MJD and XDIAN 5 and 8, respectively. Based on this variability and the similarity of the FFANG receiver functions with azimuth, a joint inversion using all of the receiver functions at the five stations and group velocities from the ambient noise analysis has been conducted in order to estimate an averaged velocity model for this region. The starting model is given in Figure 7 in black with the final velocity model resulting from the joint inversion in blue.

A number of studies of crustal and upper mantle structure have been conducted in the area of northeast China after the 1975 Haicheng Earthquake (Lu, 1985; Lu et al., 1987; Lu et al., 1990; Niu et al., 2000; Pan, et al., 2001; and Lu et al., 2005). Their results indicated that the depth of Moho discontinuity is 31–34 km under Haicheng-Xiuyan area and a low velocity layer exists at the depth range around 21–28 km. Our averaged velocity model for this region is consistent with these earlier studies.

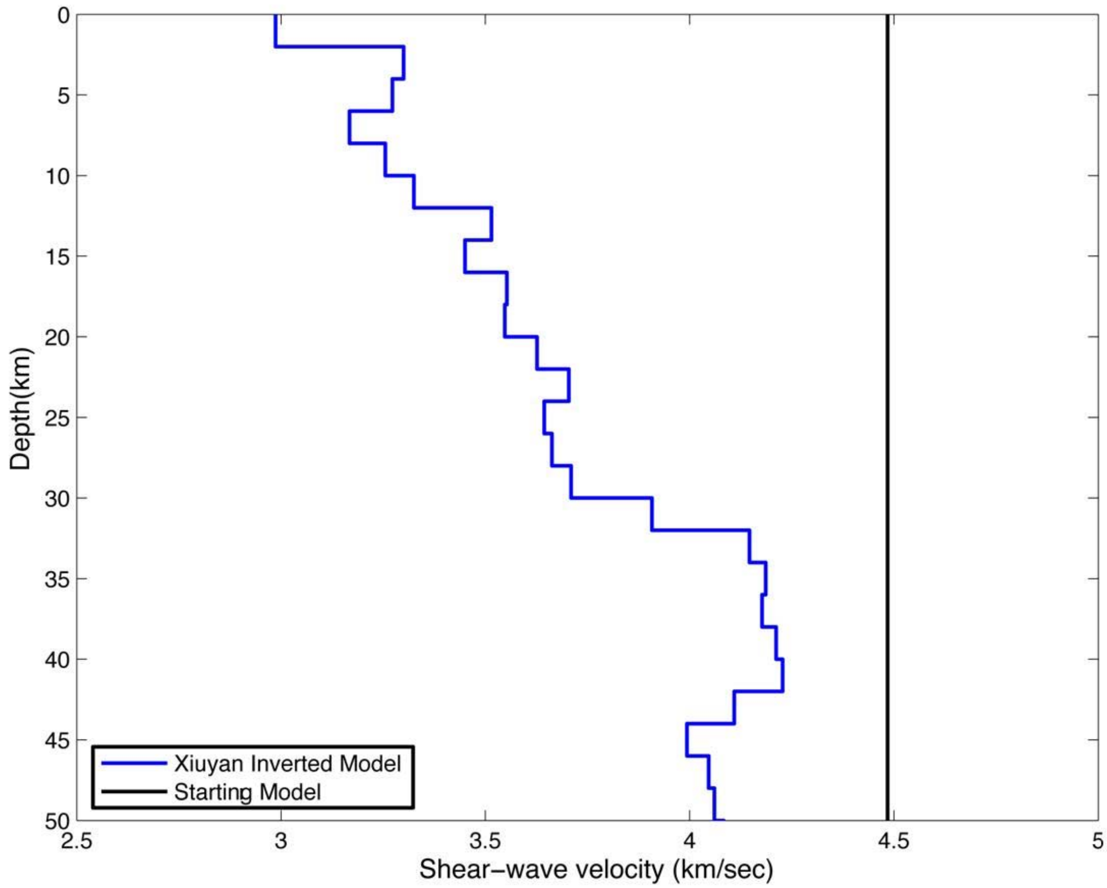

Figure 7. The starting shear wave velocity model (black) and the velocity model from the joint inversion (blue).

CONCLUSIONS AND RECOMMENDATIONS

The operation of the SMU-IGPCEA broadband seismic network is continuing. The data through June 2006 has been archived at the IRIS DMC.

A joint inversion of teleseismic receiver functions and surface wave group velocities from ambient noise analysis has been conducted and the shallow crustal shear velocity structure around Xiuyan area estimated. Crustal thickness beneath the Xiuyan area is about 34 km, which is consistent with the results from other geophysical studies in this region.

These new results can be compared to similar analysis in the Huailai Basin to the west (Figure 1). The estimated crustal thickness in the Haicheng-Xiuyan area appears to be slightly thinner than that previously estimated for the Huailai Basin (Zhou et al., 2007) as illustrated in Figure 8. Estimates of upper mantle velocity are also slightly larger in the region around the Huailai Basin.

Infrasound gauges were deployed in two (soon to be three) four and five element arrays in Utah for the purposes of assessing the utility of combined seismic and infrasound data for event characterization. The sites in Utah were co-located with existing University of Utah Seismograph Stations, providing both infrasound and seismic recordings in a region rich in explosive sources as well as earthquakes. These three arrays have become part of a larger field deployment planned for the summer of 2007 for the purpose of documenting large and frequent surface detonations of rocket motors at the UTTR. During the past year, over 21 rocket motor explosions have been observed acoustically and have provided the foundation for the planning of the larger experiment to document range and azimuth variations in infrasound propagation. The details of this database are discussed in the companion paper in these proceedings, Seismic and Infrasound Energy Generation and Propagation at Local and Regional Distances, Stump et al.,2007.

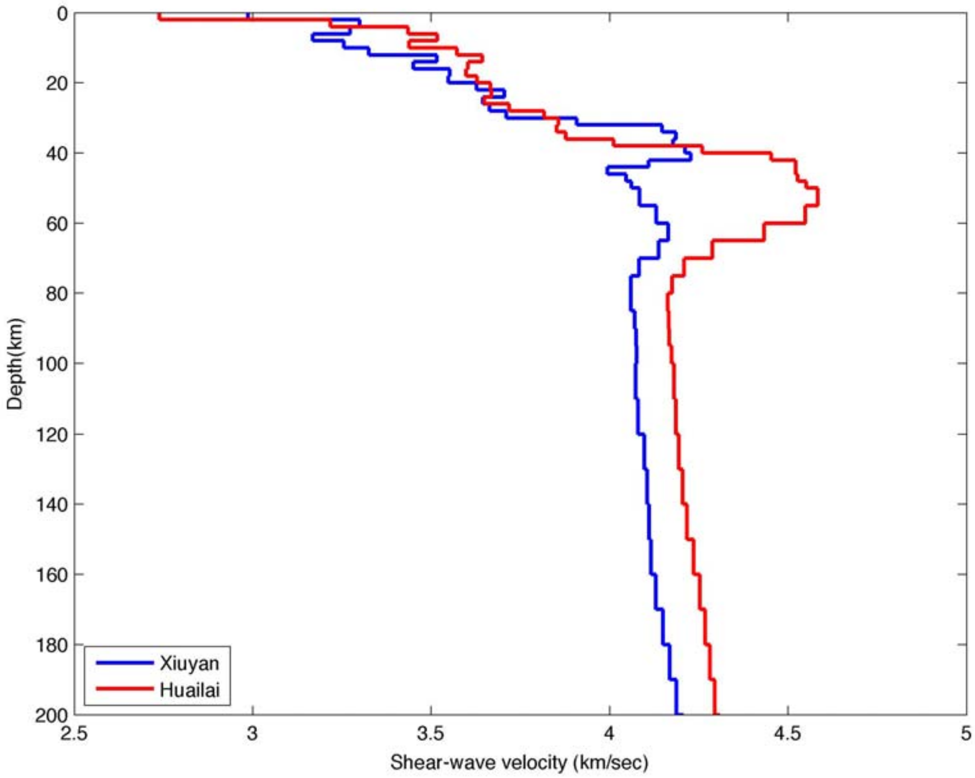

Figure 8: Comparison of shear wave velocity models developed for the Huailai Basin and the Haicheng-Xiuyan region illustrating variations in crustal thickness and upper mantle velocity in NE China.

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