



## Present Status of Monitoring Earthquakes in Kurdistan, Iraq

Fadhil I. Khudhur<sup>1</sup>, Bakir S. Ali<sup>2</sup>, Aras M. Tawfiq<sup>2</sup>, Hafidh A. A. Ghalib<sup>3</sup> & Ghassan I. Aleqabi<sup>4</sup>

*1 Directorate General of Meteorology and Seismology, Erbil, Iraq, e-mail: [fazilibrahim75@gmail.com](mailto:fazilibrahim75@gmail.com)*

*2 Directorate of Meteorology and Seismology, Sulaimaniyah, Iraq, e-mail: [bakirsaeed958@yahoo.com](mailto:bakirsaeed958@yahoo.com)*

*3 Array Information Technology, 5130 Commercial Drive, Suite B, Melbourne, FL 32940, USA, e-mail: [hafidh.ghalib@arrayinfotech.com](mailto:hafidh.ghalib@arrayinfotech.com)*

*4 Washington University in Saint Louis, Campus Box 1169, One Brookings Drive, Saint Louis, MO 63130, USA, e-mail: [ghassan@mantle.wustl.edu](mailto:ghassan@mantle.wustl.edu)*

### Article info

*Original: 06.10.2015*

*Revised: 15.05.2016*

*Accepted: 16.06.2016*

*Published online:*

*01.07.2016*

### Key Words:

*NISN*

*KSIRS*

*Kurdistan*

*Iraq*

*Earthquakes*

*Seismic Network*

*Seismic Stations*

### Abstract

Kurdistan, Iraq, is located at the leading northeastern edge of the Arabian plate. Its tectonic framework is a manifestation of the northeast translational and counterclockwise rotational motion of the plate and its collision with the Iranian and Turkish plateaus. Historically, this dynamic setting has subjected the region to frequent seismic activity. Starting in 2005 Kurdistan embarked on collaborative projects to establish an advanced seismographic network that covers the region. The goal is to collect an unprecedented wealth of high quality data that can be effectively used to understand the seismotectonic framework and eventually the seismic risk throughout the region. In 2006 the North Iraq Seismographic Network (NISN) was deployed. It consists of ten three-component broadband stations equipped with STS-2 seismometers, 24 bits Q330 digitizers and 20GB Baler storage devices. In 2008, the five-element KSIRS array was added to further improve the network's local and regional monitoring capabilities. KSIRS is equipped with STS-2 seismometers, 26 bits Q330HR digitizers, 16GB Marmot data loggers, and radio and satellite communication systems. The data are analyzed using the Antelope software system installed at the centers in Sulaimaniyah and Erbil. Since inception some of the NISN stations have been relocated. Plans are underway to build permanent underground vaults and equip all the stations with telemetry. So far this seismographic network has outperformed the international community's reporting of the regional seismicity by 8:1. Participation in the virtual Middle East Seismographic Network (vMESN) has also greatly enhanced the NISN network performance.

### Introduction

As illustrated in *Figure: 1*, the Arabian plate boundaries are delineated by the Taurus/Bitlis and Zagros continental collision zones to the north and east, the Dead Sea transform fault and the Red Sea floor spreading zones to the west, and the Aden Sea floor spreading and the Owen fracture zone to the south. The major physiographic regions of the plate feature a relatively young metamorphosed Arabian shield, a transitional platform zone, and a foredeep of thick sediments. *Figure 2* shows the motion of the Arabian plate relative to the African and Eurasian plates.

Global Positioning System (GPS) derived velocity field (1988–2005) measurements indicate

counterclockwise rotation of a broad area of the Earth's surface including the Arabian plate, adjacent parts of the Zagros, and central Iran and Turkey relative to Eurasia at rates in the range of 20–30 mm/yr [1, 2]. As a result most of the seismicity is interplate associated with the tectonic activity along the boundaries of the plate, including the foothills of the Taurus/Bitlis and Zagros folded belts, whereas intraplate earthquakes are infrequent and rarely exceed magnitude 4.5  $m_b$ .

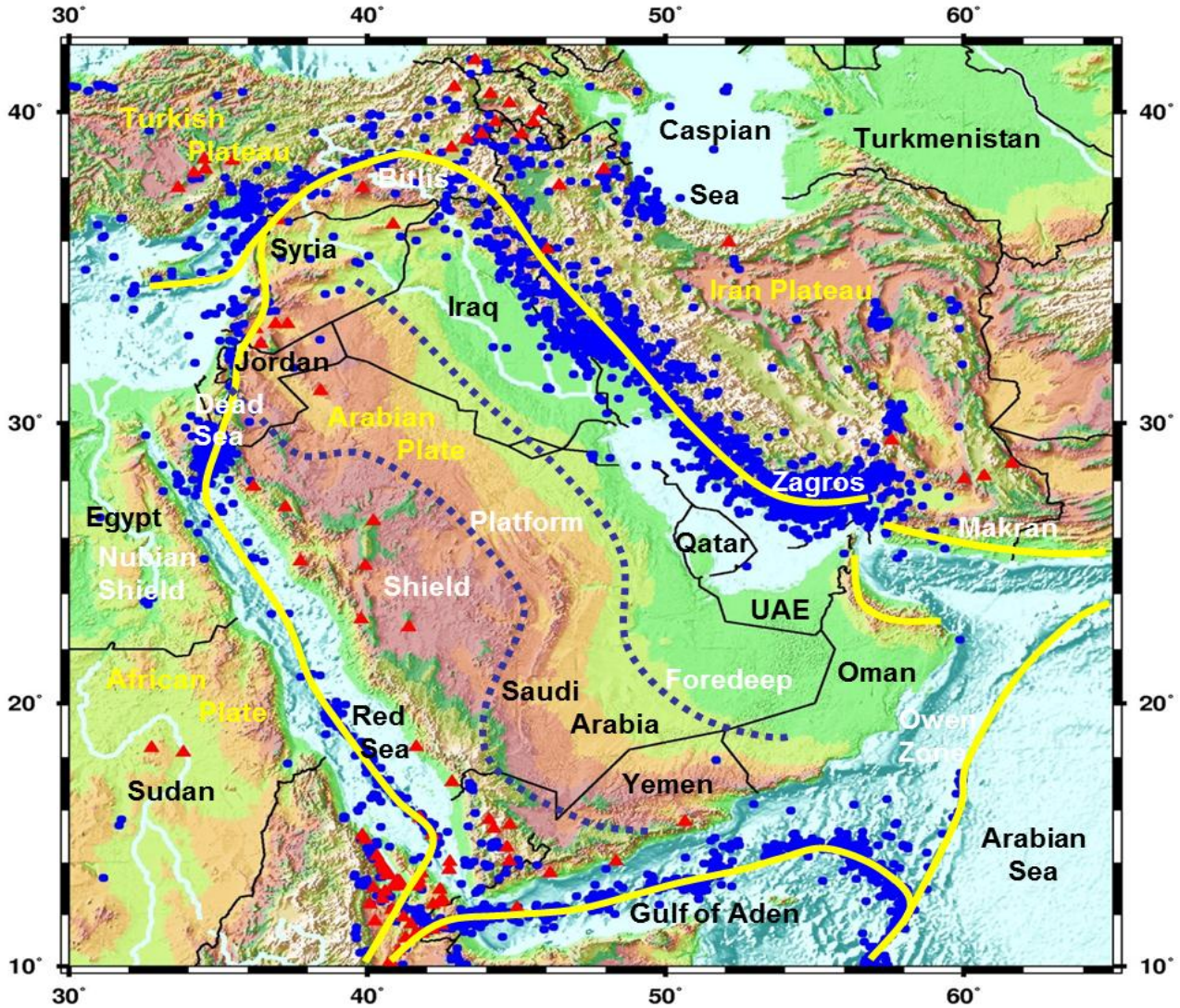


Figure-1: Map showing the seismotectonic framework of the Arabian plate; boundaries (yellow solid lines), seismicity (blue dots) volcanoes (red triangles). It also shows the major physiographic zones of the plate (*i.e.*, Arabian shield, platform and foredeep).

Kurdistan is located at the northern and northeastern leading edges of the Arabian plate. In 1979, the Seismology Unit of Iraq Scientific Research Council, Building Research Center, inaugurated Baghdad Seismological Observatory and station BHD [3, 4]. This marked the inception of the old Iraq Seismographic Network (ISN), which at the time was planned to consist of five permanent stations, each equipped with three Short Period (SP) and three Long Period (LP) seismograph systems. *Table-1* shows the location of the original ISN stations. Station BHD was the first to be established, followed by stations MSL, SLY and RTB. Station BSR was planned for 1988, but it was not established because of the Iraq-Iran war. By 1990 old ISN ceased to function as planned. It is unfortunate that even the established stations did not concurrently operate to collect invaluable analog data for a significant period of time.

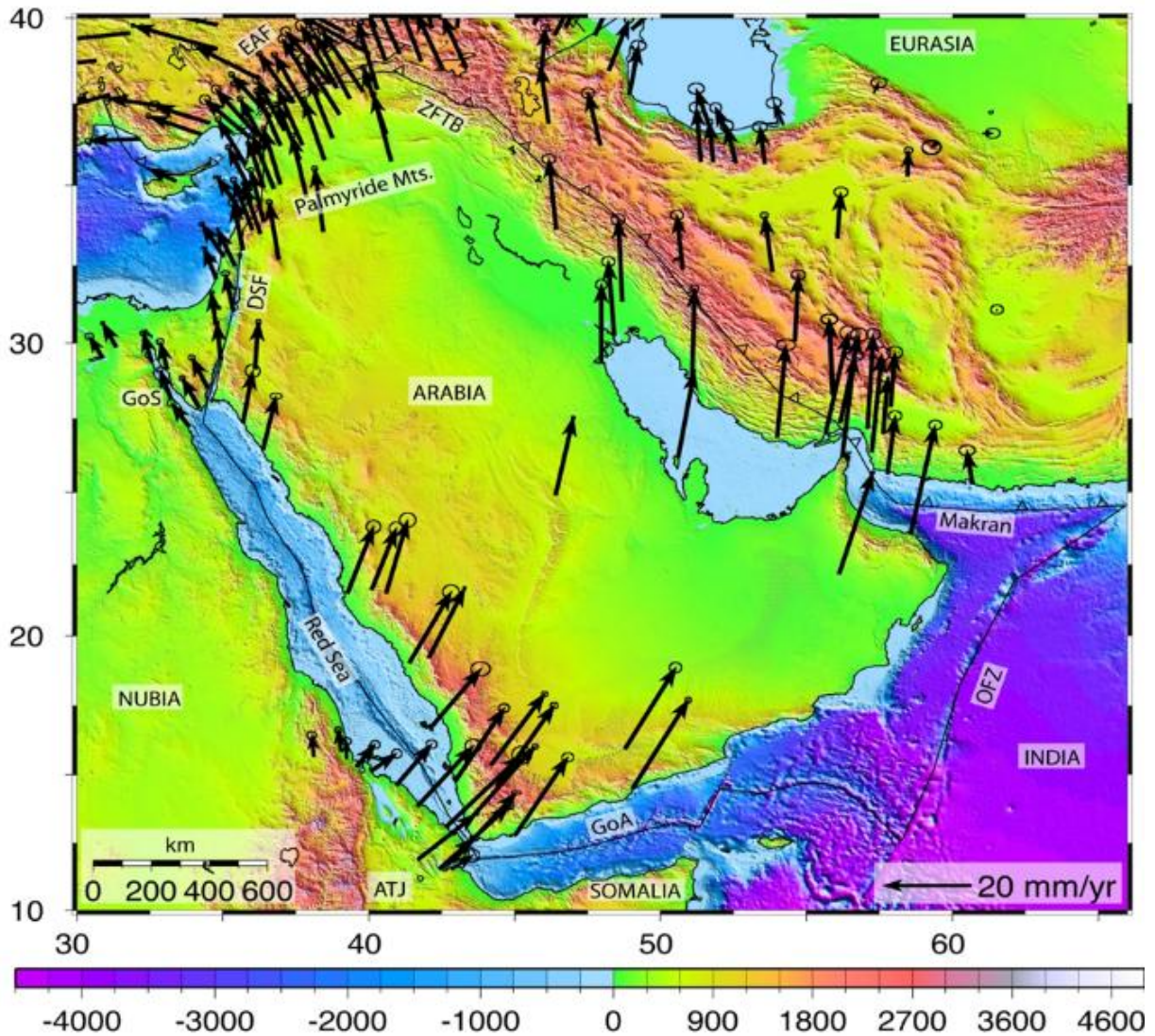


Figure-2: Map showing counterclockwise rotation of the Arabian plate determined from GPS velocities relative to Eurasia [1].

Table-1: Old and new Iraq Seismographic Network (ISN) stations and parameters.

Old ISN				New ISN			
Station	Latitude (degrees)	Longitude (degrees)	Elevation (meters)	Station	Latitude (degrees)	Longitude (degrees)	Elevation (meters)
BHD	33.2744	44.3858	32	BHD	33.2744	44.3858	32
MSL	36.3817	43.1483	242	MSL	36.3817	43.1483	242
SLY	35.6315	45.4694	1548	IBDR	33.1132	45.9335	98
RTB	33.0295	40.3040	660	RTB	33.0295	40.3040	660
BSR	30.6000	47.8000		NSR	31.0270	46.2483	5
				IKRK	35.4097	44.3489	331

The new and reconfigured ISN was established in 2009. It is comprised of six broadband stations (Table-2) powered by solar panels and equipped with three-component Streckeisen STS-2 seismometer and Quanterra 24 bits Q330 digitizer. Some of the stations use a satellite communication system to transmit the data to Baghdad Seismological Observatory (BSO), whereas others store the data onsite using 20 GB PB14F Baler data storage hard drives.

**NISN**

In 2005, Kurdistan Directorate General of Meteorology and Seismology (KDGMS), Array Information Technology and Washington University in Saint Louis reached an agreement to establish what has become known as North Iraq Seismographic Network (NISN) [5]. Considering most of the seismic activity in Iraq occurs within the Kurdistan province, the objective of this network is to monitor the seismicity throughout this region, which is primarily comprised of the tectonically active Taurus/Bitlis and Zagros foothills, a region of extensive folding and faulting [6, 7].

NISN was initially set up as a temporary deployment since little is known about the distribution of the seismicity of Kurdistan, the ambient noise level at various sites and other logistical considerations, which led to relocating some of its stations (Figure: 3). NISN is comprised of ten broadband stations. The parameters for these stations are given in Table-3. Stations KSLY and ERBL were the first to be temporarily deployed at Sulaimaniyah and Erbil Seismological Observatories (SSO and ESO, respectively) for training and testing until the sites selection survey is completed. These stations were later shut down, and the equipment moved to selected sites. Until the new ISN was established in 2008, two of NISN stations were installed at the sites of stations BHD in Baghdad and MSL in Mosul, and all the NISN data were shared with BSO.

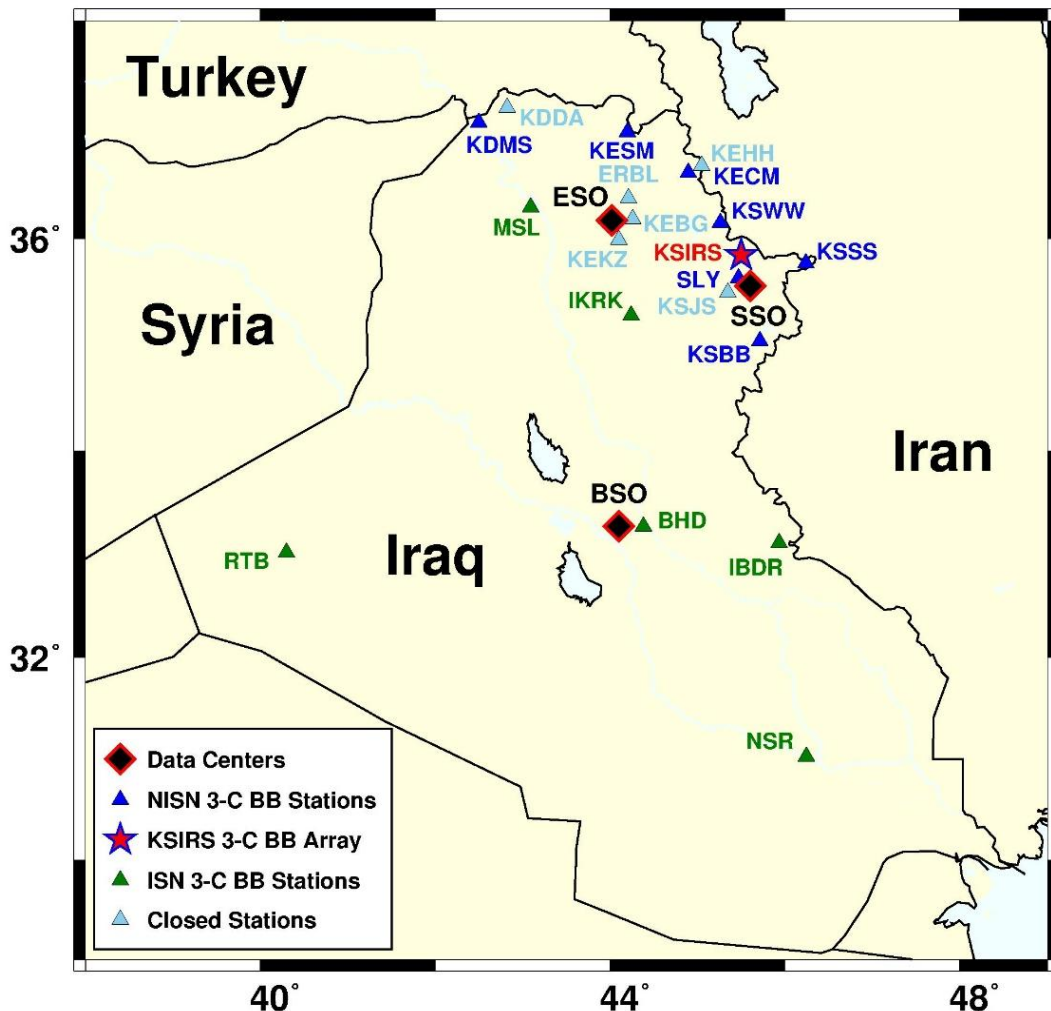


Figure-3: Map showing the location of NISN stations (blue), seismoacoustic array KSIRS (red star), data centers, and new ISN stations (green). NISN data centers are depicted in red and black diamonds.

All the NISN stations are equipped with Streckeisen STS-2 seismometers, Quanterra 24 bits Q330 digitizer, 20GB PB14F Baler data storage hard drive and GPS timing, and powered by 65W solar panels and 265Ah batteries. Figure: 4 show examples of NISN station deployment.

Table-2: NISN stations parameters and deployment history.

Station	Latitude (degrees)	Longitude (degrees)	Elevation (meters)	Date Installed	Date Closed	Remarks
<i>KSBB</i>	35.0415	45.7092	550	25/11/2005		
<i>KSSS</i>	35.7696	46.2362	1515	26/11/2005		
<i>KSWW</i>	36.1493	45.2624	1310	28/11/2005	08/06/2015	<i>Instrumentation Problem</i>
<i>KSJS</i>	35.4965	45.3452	825	27/11/2005	12/05/2011	<i>Replaced by SLY</i>
<i>KEHH</i>	36.6764	45.0470	1725	30/11/2005	12/04/2012	<i>Replaced by KECM</i>
<i>KECM</i>	36.6137	44.8938	1390	13/08/2013		
<i>KESM</i>	36.9846	44.1981	1027	01/12/2005	15/06/2014	<i>Instrumentation Problem</i>
<i>KDDA</i>	37.2125	42.8207	750	02/12/2005	28/02/2008	<i>Replaced by KDMS</i>
<i>KDMS</i>	37.0731	42.4972	620	10/11/2010		
<i>KEKZ</i>	35.9893	44.0970	450	03/12/2005	25/06/2009	<i>Replaced by KEBG</i>
<i>KEBG</i>	36.1842	44.2581	722	26/06/2009	24/09/2014	<i>Being moved to a new site</i>
<i>SLY</i>	35.6315	45.4694	1548	19/07/2014		
<i>KSLY</i>	35.5559	45.4534	912	08/23/2005	04/04/2006	
<i>ERBL</i>	36.3772	44.2086	1115	21/08/2005	29/11/2005	
<i>BHD</i>	33.2744	44.3858	32	11/04/2006		<i>Replaced by new ISN equipment</i>
<i>MSL</i>	36.3817	43.1483	242	06/04/2006		<i>Replaced by new ISN equipment</i>



Figure-4: Photographs of NISN stations (a) KSSS and (b) KESM. Buried in the ground and protected by separate plastic barrels are the (c) the STS-2 sitting on a concrete pier cemented to the bedrock and temperature insulated by a thermos, and (d) the Q330 digitizer, Baler, power controller and battery.

**KSIRS**

To further advance the practice of Seismology in Kurdistan, and to enhance NISN’s earthquakes monitoring capability the seismoacoustic array KSIRS (depicted by a red star in *Figure: 3*) was established in 2008. As shown in *Figure: 5*, it is a circular five elements (KI01-KI05) array with an approximate diameter of one kilometer. It is designed to better detect and locate small local and regional earthquakes, which frequently occur in this region, using advanced data processing techniques (*e.g.*, FK analysis and beamforming that are built into the Antelope software system to improve the signal-to-noise ratio and constrain backazimuth estimations). When utilized in routine processing, these techniques will help surmount the shortcoming of NISN sparse coverage of northern Iraq.

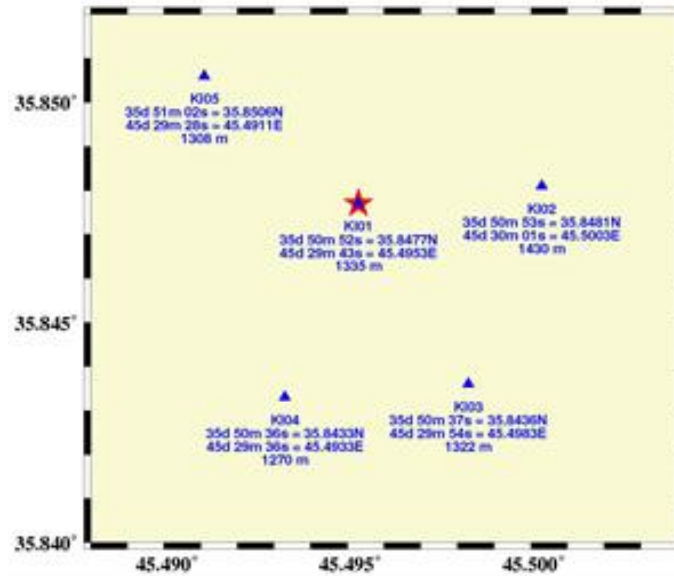


Figure-5: Location and spatial configuration of the seismoacoustic array KSIRS stations.

KSIRS stations KI01-KI05 are equipped with three components broadband Streckeisen STS-2 seismometers (whose instrument response is shown in *Figure: 6*), 26 bits high resolution 6-channels Quanterra Q330HR digitizers, GPS timing, 16GB Marmot data loggers, Chaparral 2.5 infrasound sensors, 2.4 GHz spread spectrum full-duplex wireless Ethernet bridge radios, dual 85W solar panels and two 92Ah batteries.

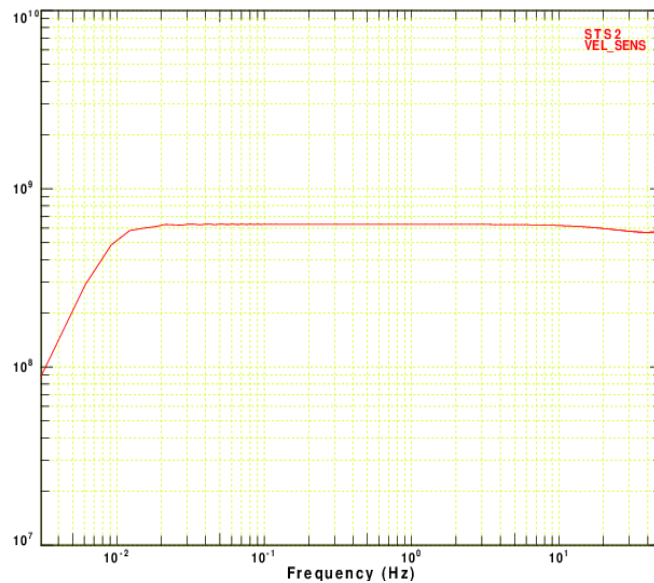


Figure-6: STS-2 seismometer velocity response.

The stations' equipment is housed in underground concrete vaults to minimize the impact of wind and ambient noise on recorded signals (*Figure: 7*). At the center station of the array, in addition to station KI01 equipment, the vault also houses the satellite communication and power systems. The digital data are transmitted in real-time from each station to the array center via radios. The data are also simultaneously stored in each station's Marmot for backfilling in case of communication interruptions.

Figure-7: Photograph showing the inside of a KSIRS underground concrete vault with the data acquisition and power systems are placed on the built-in shelf. The seismometer is sitting on the pier and covered by an inverted thermos to minimize the effect of temperature variation.



## Data Centers

As indicated in *Figure: 3* there are three data centers in Iraq. SSO was the first center to be established when NISN was deployed in 2005. In 2008, the data centers systems were upgraded. Initially SSO, ESO and BSO were equipped with fully loaded Sun Ultra 25 computers, running the Solaris operating system and Boulder Real Time Technologies (BRTT) Antelope software for real-time data acquisition, forwarding and processing. SSO is also equipped with a fully loaded Sun Ultra 45 computer to manage (*i.e.*, acquire and forward) the telemetered data.

*Figure: 8* shows SSO data center. At present, only SSO, ESO and AIT data center computers are operational, networked, and sharing data. In 2014, the Sun Ultra 25s were replaced by more powerful computers running the Ubuntu Linux operating system. This has allowed the SSO and ESO staff to remotely monitor (24/7) the system operation and seismic activity through Ubuntu laptops.

Figure-8: SSO data analysis office at Azmar, Kurdistan.



## Data

The NISN, including KSIRS, digital waveform data are recorded continuously at a rate of 100sps, and stored using the internationally-standardized MSEED format designated by the Federation of Digital Seismic Networks (FDSN) [8]. The telemetered KSIRS, SLY, and soon the new Erbil station data are relayed to the Sun Ultra 45 computer at SSO through an Internet link. The non-telemetered NISN data are stored onsite and manually retrieved during periodically scheduled maintenance visits to the stations. Real-time and interactive

processing of the digital waveform data are performed on standalone computers also running Antelope at SSO, ESO and AIT. So far the amount of collected high quality three-component broadband waveform data has exceeded 2TB. *Figure: 9* shows a seismicity map of the region for the period 2006-2009. The number of events (7923) significantly exceeds those reported by the international monitoring community due to a variety of reasons, *e.g.*, stations coverage and mission.

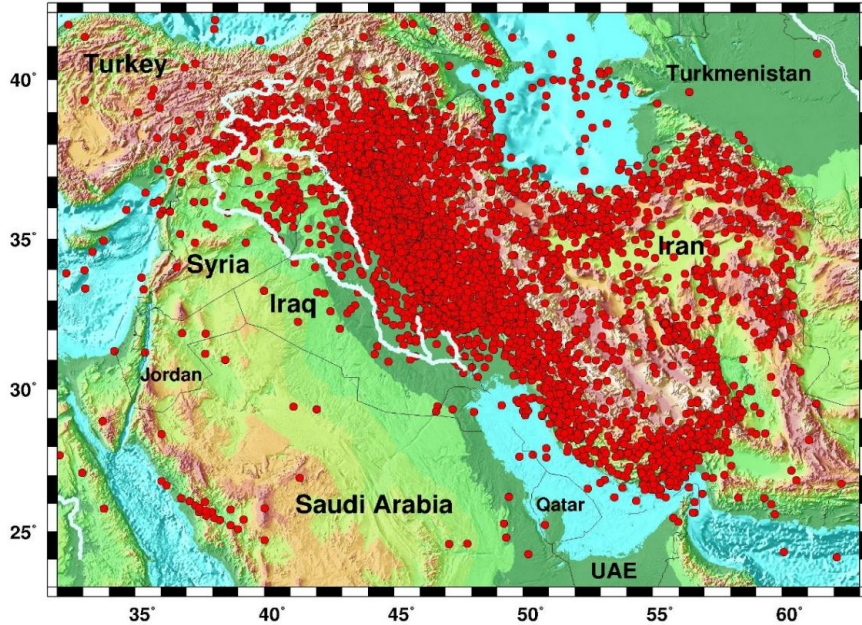


Figure-9: Seismicity map for the period 2006-2009. A total of 7923 events were located using NISN waveform data and neighboring countries' bulletins.

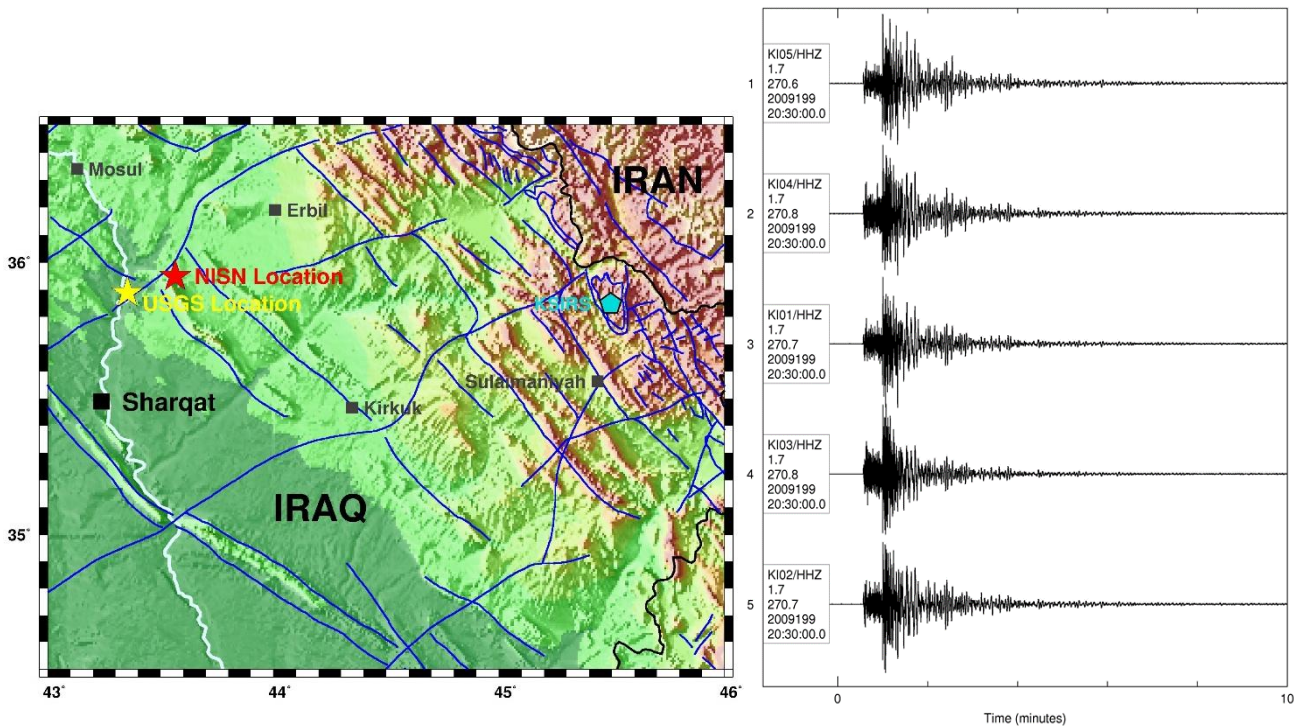


Figure-10: Map showing the NISN and USGS locations of the 18 July 2009 earthquake. To the right is an example of the high quality vertical component (HHZ) waveforms recorded at stations KI01-KI05 of the KSIRS array. The epicenter is 270.8 degrees backazimuth due west and 1.7 degrees distance from the center of the array.

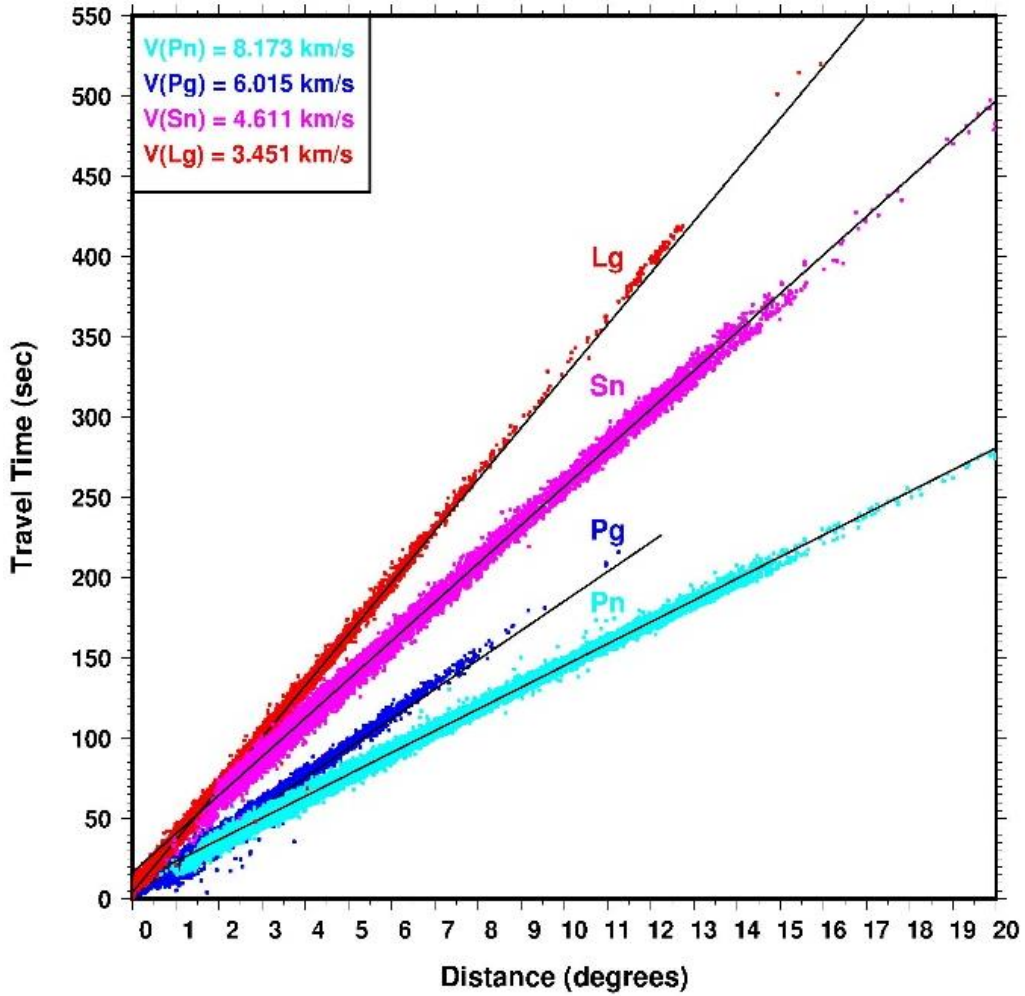


Figure-11: Travel time of regional phases corresponding to the seismicity map presented in *Figure: 9*.

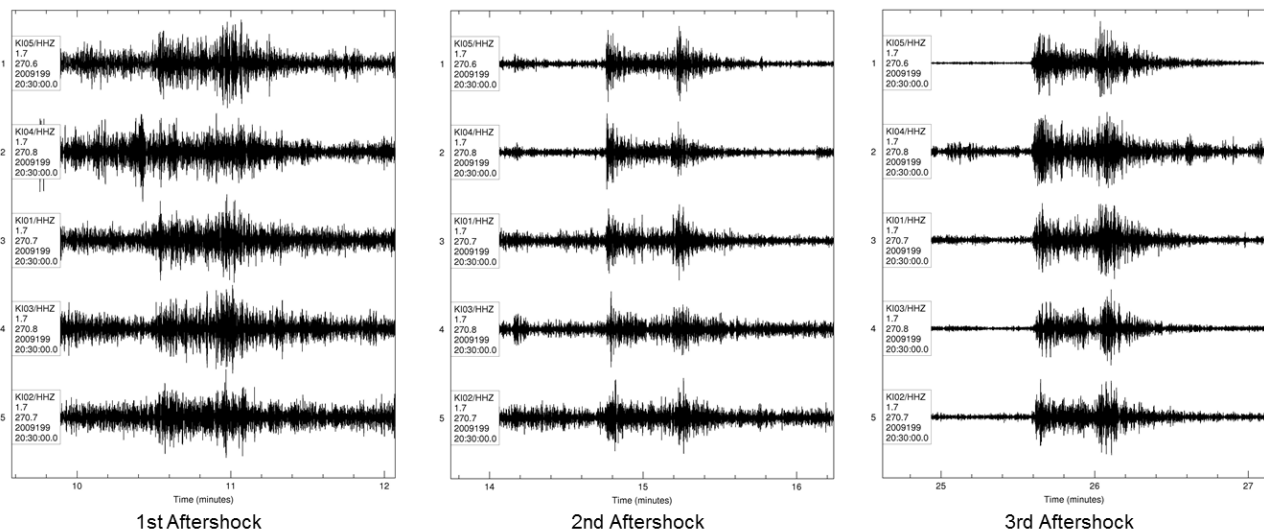
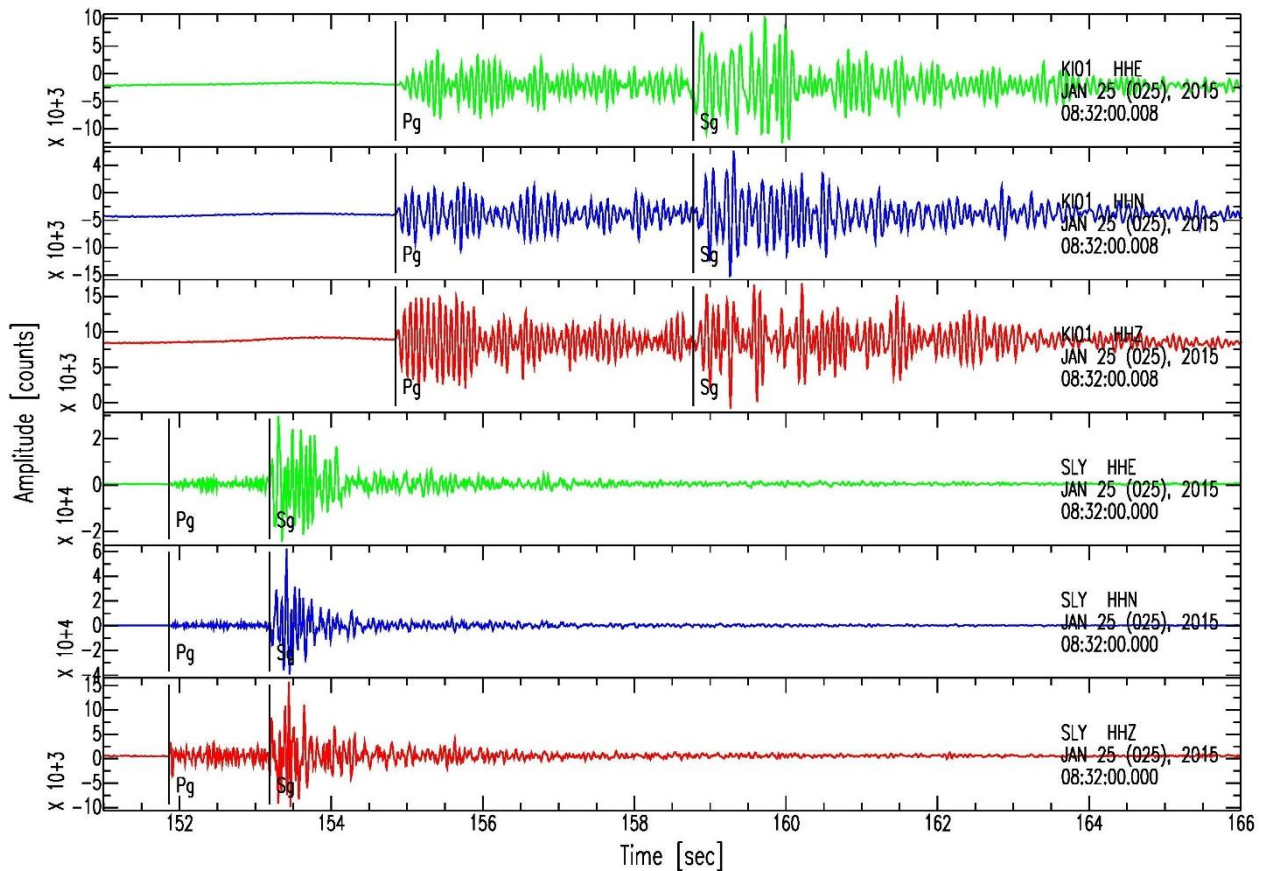


Figure-12: Waveforms of three aftershock events that followed the 18 July 2009 Sharqat earthquake. The waveforms were recorded by the KSIRS array.

To further illustrate the quality of NISN waveforms, *Figure: 13* shows an example from a recent swarm of over 160 events that occurred near the city of Sulaimaniyah during the period 24/1/2015-10/2/2015 and recorded at the KSIRS array and station SLY. The origin time for this sample event, which occurred on

25/1/2015, is 08:34:25.3. It is evident that there are significant differences between the waveforms recorded at these two stations (SLY and KI01) that may be attributed to the increasing heterogeneity of the geology



along the wave propagation path from the source to the station. SLY is the closer station to the source with a Sg-Pg time of 1.33s, whereas station KI01 time difference is 3.93s.

Figure-13: Sample three components waveforms of the Sulaimaniyah swarm recorded at the KSIRS array (top 3 traces) and station SLY (bottom 3 traces).

## Training

Training of the SSO, ESO and BSO staff started as early as 2006 following the agreement to establish NISN and continued through the installation of NISN stations and the KSIRS array in 2008 (Figure: 14). It consisted of training on the Sun computers, Solaris and Linux operating systems and the use of Antelope for data acquisition, processing and analysis at SSO. The staff was also trained on installing, operating and maintaining the station. It also included training on manually collecting and organizing the data. In addition, classroom training on the basics and practice of Seismology was held at the campus of the University of Sulaimaniyah.

## Future Plans

In 2014, station SLY facility was refurbished, re-equipped and integrated into NISN. It became the first NISN station with data telemetry. KDGMS plans for NISN are to:

- Install at SSO a standalone data processing Linux based computer using Antelope.
- Build underground concrete vaults for each of the 10 stations in a manner similar to those at the KSIRS array.
- Equip each station with telemetry through radios and Internet.
- Conduct research to update the developed seismicity map and study the seismic risk in the region.
- Incorporate FK-Analysis and beamforming in the routine processing of waveform data.

- Install a Tremble GPS system at station KI01 site to monitor the tectonic motion of the Arabian plate.
- Incorporate all the stations into the virtual Middle East Seismographic Network (vMESN) [10].
- Issue events bulletins and updated seismicity maps.
- Implement automatic notification mail and text messaging.
- Continue maintaining all the station sites and equipment.



Figure-14: Training of the SSO, ESO and BSO staff at the SSO observatory, the field and in the classroom at the University of Sulaimaniyah.

## **Conclusions**

With the establishment of NISN and KSIRS, Kurdistan has achieved a significant leap forward in the practice of Seismology in the province. The expectation now is that similar advancements may take place in the:

- Education of Seismology and earthquake engineering at various levels.
- Research leading to better understanding of the seismicity and seismotectonics of the region.
- Estimation of seismic risk, mitigation and the establishment of a realistic seismic code for the region.

## **Acknowledgments**

The authors thank Kurdistan Ministry of Transportation and Communication; Governorates of Erbil, Sulaimaniyah and Duhok; Directorates of Meteorology and Seismology for supporting the project. The authors also thank the University of Sulaimaniyah for accommodating the classroom training. The Khaffaf Company is acknowledged for constructing the vaults.

Acknowledgements are due to Matthew Sibol, Robert Wagner, Yajun Wang and Pierre Caron for analyzing and reviewing the data; Roland Gritto, Adam Sargent, Obadiah Grantland, Kevin Rogers and David Kallus for installing and maintaining the stations and data centers; Borhan Salih, Shaho Abdullah, Ali Abdulkhaliq, Basoz Ali, Layla Omar, Nokhsha Aziz, Nian Hama, Mohammed Ismael, Hemin Hashm, Dasne Taha, Sangar Ali, Beston Sherzad, Delan Tahsen, Sakar Mohammed, Zardasht, Omar, Abdulaziz Salim and Hamed Hassan for helping with maintaining the stations and collecting the data; Rashid Zand, Mohammed Abdul Rahman, Omed Mohammed Mahsum and Dara Hassan for their administrative support. Wilmer Rivers and Florence Martin are appreciated for reviewing and editing the text.

The maps in this article were created using the Generic Mapping Tools [11]. The Seismic Analysis Code [12] and the Geotool waveform measurement software were used to plot the waveform.

## References

- [1] Reilinger, R., *et al.* (2006), GPS constraints on continental deformation in the Africa-Arabia-Eurasia continental collision zone and implications for the dynamics of plate interactions, *J. Geophys. Res.*, 111, B05411, doi:10.1029/2005JB004051.
- [2] Reilinger, R. F., (2009). Seismotectonics of the Arabian Plate and its boundaries III, *EOS Trans AGU*, 90 (52), Fall Meeting Suppl. Abstract T54C-2011.
- [3] Fahmi, K. J. (1982). Seismology in Iraq, *USGS Earthquake Inf. Bull.* 14, 108.
- [4] Fahmi, K. J., B. S. Ayar, and M. A. Al-Salim (1987). The Iraqi Seismological Network: Current Status and Future Trends, *EOS*, Vol 68, No. 10, March 10, pp. 137, 141-143.
- [5] Ghalib, H. A. A., G. I. Aleqabi, B. S. Ali, B. I. Saleh, D. S. Mahmood, I. N. Gupta. R. A. Wagner, P. J. Shore, A. Mahmood, S. Abdullah, O. K. Shaswar, F. Ibrahim, B. Ali, L. Omar, N.I. Aziz, N. H. Ahmed, A. A. Ali, A.-K. A. Taqi, and S. R. Khalaf (2006). Seismic characteristics of Northern Iraq and surrounding regions, *in Proceedings of the 28<sup>th</sup> Seismic Research Review: Ground-Based Nuclear Explosion Monitoring Technologies*, pp. 40-48.
- [6] Seber, D., D. Steer, E. Sandvol, C. Sandvol, C. Brindisi, M. Barazangi (2000). Design and development of information systems for the geosciences: an application to the Middle East, *GeoArabia*, v.5 (2), pp. 269-296.
- [7] Jassim, S. Z. and J. C. Goff (2006). Geology of Iraq. Dolin, Prague and Moravian Museum, Brno , Czech Republic, p. 341.
- [8] Aleqabi, G. I., R. B. Herrmann, M. E. Wyssession, H. A. A. Ghalib, M. S. Sibol, B. S. Ali, and A. A. Ali (2009). Moment tensor analysis of the July 18, 2009 Sharqat, Iraq, earthquake, *International Workshop on Active Tectonic Studies and Earthquake Hazard Assessment in Syria and Neighboring Countries*, Damascus, Syria.
- [9] Ahern, T.K. (2003) "The FDSN and IRIS Data Management System: Providing easy access to terabytes of information," *The International Handbook of Earthquake and Engineering Seismology*, Vol. Part B, p. Academic Press
- [10] Ghalib, H. A. A., G. I. Aleqabi, W. A-Tarazi, T Al-Yazjeen, O. Q. Ahmed, B. S. Ali, K. Qadr, A. A. Ali, A proposal to establish a Middle East seismographic network, *7<sup>th</sup> Gulf Seismic Forum*, January 22-25, 2012, Jeddah, Saudi Arabia.
- [11] Wessel, P., and W. H. F. Smith, New, improved version of Generic Mapping Tools released, *EOS Trans. Amer. Geophys. U.*, vol. 79 (47), pp. 579, 1998.
- [12] Goldstein, P. (1996), SAC2000; seismic signal processing and analysis tools for the century, *Seismological Research Letters*, 67(2)