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The virtual Middle East Seismographic Network (vMESN); Concept and Implementation

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Abstract

At the 7th Gulf Seismic Forum on January 22-25, 2012, Jeddah, Saudi Arabia, Ghalib *et al.* (2012) proposed the establishment of vMESN. It is a virtual seismographic network that all Middle East countries operating telemetered seismic stations can equally exploit to monitor earthquakes in and around their respective territories. The overarching goal of vMESN is to advance the teaching and practice of seismology and research among member countries. It is a scientifically and economically rewarding concept with high return on modest investment in resources and infrastructure. It is also technically feasible to implement at member data centers to greatly improve the capability and coverage of their national networks when augmented with international stations in the region. The integrated real-time data that vMESN provides is invaluable for research and development in seismology and earthquakes engineering. Presently, vMESN is implemented and operational at Jordan, Erbil and Sulaimaniyah Seismological Observatories (JSO, ESO and SSO, respectively) and at Array Information Technology (AIT) data center in Maryland, USA. At no cost to the host and member countries, AIT is contributing real-time data from the international stations in the region; Jordan is contributing real-time data from their Jordan Seismological Network (JSN), and Kurdistan from their KSIRS array and some of the North Iraq Seismographic Network (NISN) stations. Three-component data from a total of 72 stations is currently being automatically shared and independently processed at the aforementioned data centers. The Antelope, and soon SeisComp3, real-time software system is configured to automatically acquire, forward and process the data. The invitation is open to all countries in the Middle East to join vMESN, if they commit to the requirement of sharing data in real-time over Internet. Each member country continues to maintain full control over their networks' data and over what to acquire and forward to others. Also, each member country continues to independently process the data and publishes bulletins in accordance with its technical practices, standards and regulations.

Introduction

The calls for establishing seismographic networks in the various Middle East (ME) and North Africa (NA) countries date back to the mid-1960s *[1, 2, 3, 4, 5]*. In 1978 the First Arab Seismological Seminar, held in Baghdad, Iraq, adopted a proposal to establish a standardized seismic network. In response to the Arab Fund for Economic and Social Development Bank request in 1981, the United Nations Educational, Scientific and Cultural Organization (UNESCO) issued a detailed feasibility study on the prospect and planning for seismological development in the Arab region that was endorsed by the Second Arab Seismological Seminar, held in Rabat, Morocco, in 1982. Details of the UNESCO program for "Assessment and Mitigation of Earthquake Risk in the Arab Region" (PAMERAR) can be found in *[6]*. To ensure maximum return on the investment in this costly project, the report emphasized the importance of hardware and software systems standardization and the need for collaboration among the interested countries, which is the major point that led to this study.

Traditionally, the performance of a seismographic network is evaluated after its stations' installation and operation for a significant period of time. Then either new stations are added or some are relocated to improve the network coverage over the area of interest. This trial-and-error practice is undoubtedly costly and time consuming, and it leads to loss of irretrievable data during the network re-configuration process. Since one of the challenges of building a highly effective network is the geographic distribution of its seismic stations, in 1985 *[7]* published an optimal design for a seismographic network that covers all the Arab countries in the ME and NA. Although the preliminary design *[7]* presented is theoretically optimal and demonstrated the effectiveness of their technique, it also highlighted the need for further geological, seismotectonic, logistical and planning information to better constrain the problem. Regardless, at the time most of the concerned ME and NA countries had neither the political nor the scientific initiatives necessary to collaborate on establishing and operating an optimally designed and standardized seismographic network.

There is no doubt that PAMERAR has had a positive impact on advancing the practice, but not the teaching, of Seismology in many of the ME and NA countries. At present there is a national seismographic network operating and accumulating valuable seismic waveform data in every Arab country in the ME (*Figure: 1*). The stations in Turkey and Iran are also included in the figure to suggest that this abundance of stations can easily form one of the largest and maybe densest seismographic networks in the world if their resources are shared.

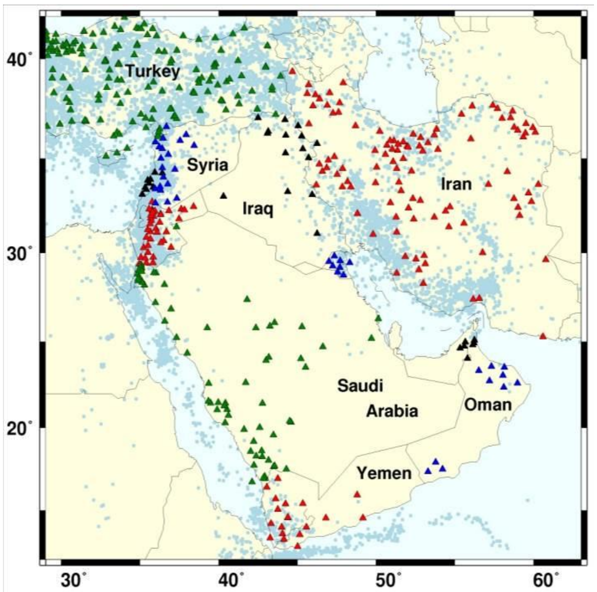


Figure-1: Map showing the abundance of seismic stations and national seismographic networks that currently exist in the Middle East (including Turkey and Iran). They are color coded by their respective countries.

The national networks of seismographic stations depicted in *Figure: 1* were all established with the narrow goal of monitoring the intra-country seismicity, as if earthquakes are confined by political borders rather than the geology and tectonics of a region. A case in point is the interaction between the Arabian plate, the Turkish and Iranian plateaus. *Figure:.2*. shows that the Arabian plate boundaries, which encompass the Arab countries in the ME, 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.

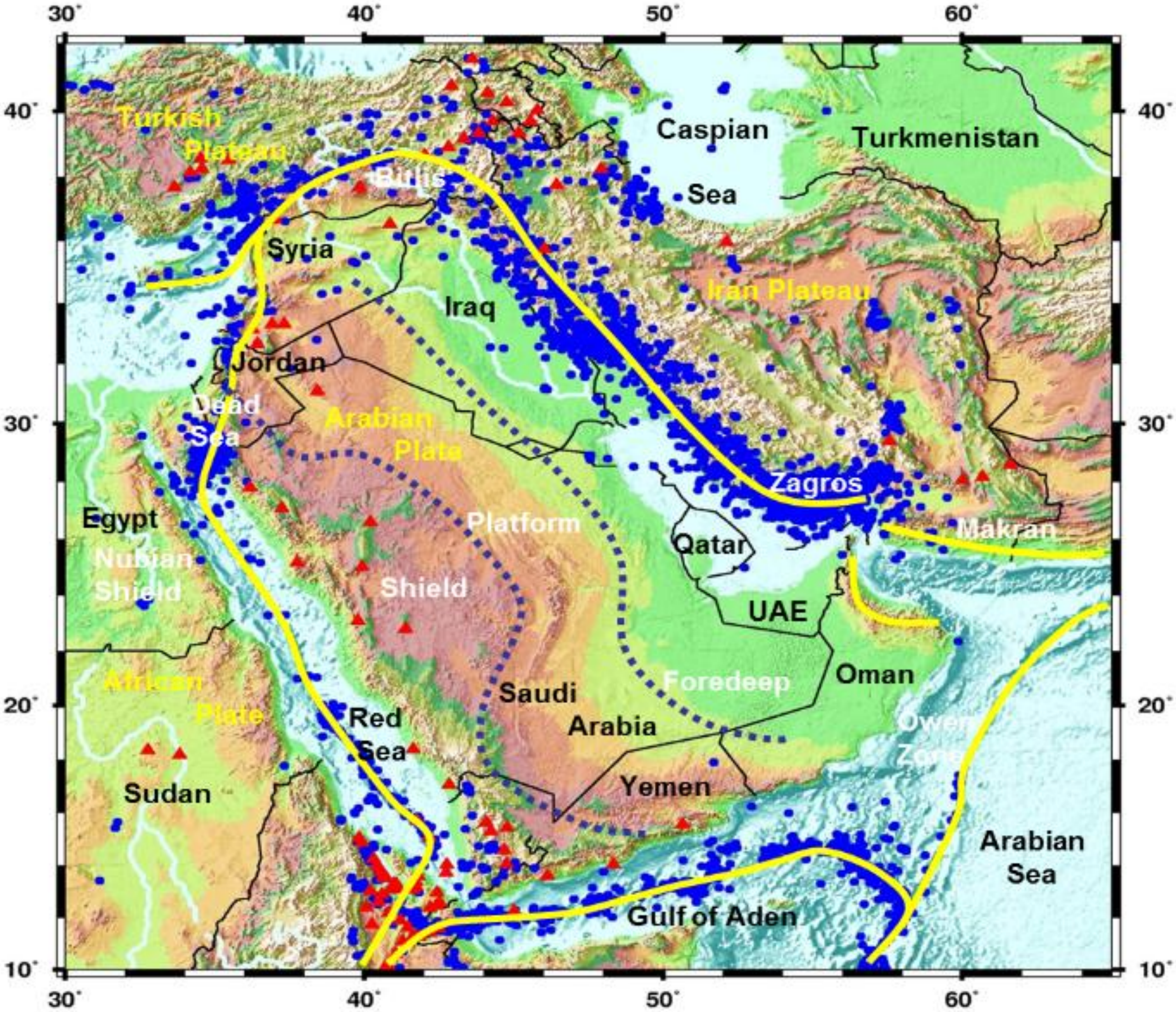


Figure-2: Map showing the seismotectonic framework of the Arabian plate; boundaries (yellow solid lines), seismicity (blue dots) and volcanoes (red triangles). It also shows the major physiographic zones of the plate (*i.e.*, Arabian shield, platform and foredeep).

The major physiographic regions of the plate include a relatively young metamorphosed Arabian shield, a transitional platform zone, and a foredeep of thick sediments. *Figure: 3* shows the motion of the Arabian plate relative to the African and Eurasian plates. Velocity field (1988–2005) measurements derived from the Global Positioning System (GPS) 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 *[8, 9]*. As a result, most of the seismicity is interplate and 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.

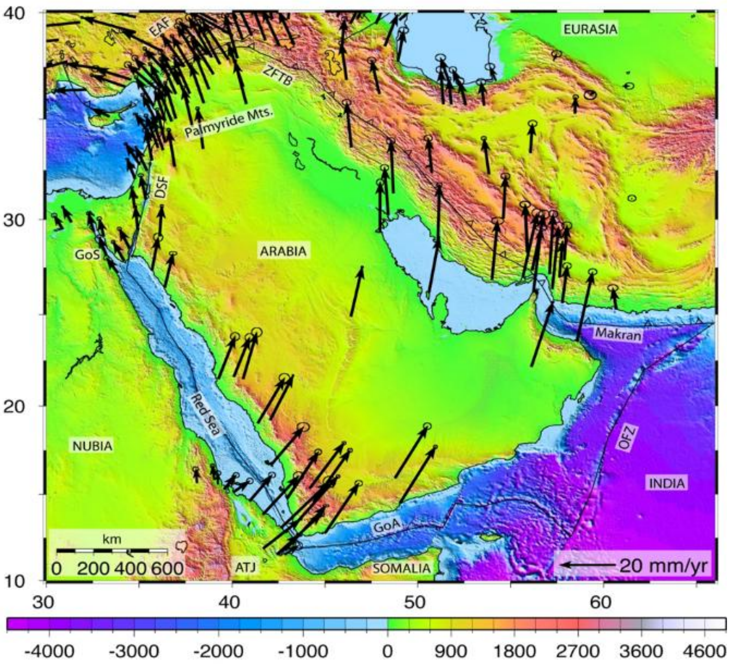


Figure-3: Map showing counterclockwise rotation of the Arabian plate determined from GPS velocities relative to Eurasia *[8, 9]*.

Seismicity

Since the establishment of North Iraq Seismographic Network (NISN) in 2006 *[10]* over 2TB of high quality three-component broadband waveform data have been collected and analyzed. *Figure: 4* shows a seismicity map of the region for the period 2006-2009. The number of earthquakes (7923) significantly exceeds reports of the international monitoring community due to a variety of reasons, *e.g.*, stations coverage and mission.

This version of the seismicity map shows that most of the earthquakes are aligned with the trend of the Zagros and Bitlis-Taurus continental collision zones between the Arabian and Eurasian plates, because the events were located using the NISN onset times augmented with those reported in the Turkish, Iranian, National Earthquake Information Center (NEIC) bulletins. A much more complete picture of the region's seismicity would emerge if data from all the stations shown in *Figure: 1* were to be incorporated into the process of detecting and locating earthquakes in the ME. For example, if data from the networks in Jordan, Syria and Lebanon were to be included in the analysis, earthquakes along the Dead Sea Transform Fault would be much better delineated than shown in *Figure: 3*. Also, if data from the networks in Saudi Arabia, Yemen, Oman and United Arab Emirates, Qatar and Kuwait were to be included in the analysis, the seismicity along the Red Sea, the Gulf of Adan and the Arabian Sea would be much better delineated. Moreover, including all of these data would greatly help delineating the Arabian intraplate seismicity more completely than is shown in *Figure: 3*. It is well understood that detecting, precisely locating, and estimating the depth and magnitude of an earthquake depends not only on the number of stations recording it but also on the azimuthal distribution of the stations around the event. It is also well understood that advanced analytical techniques (*e.g.*, Moment Tensor and Receiver Function analysis) require waveforms recorded at stations with favorable azimuthal coverage and varying epicentral distances.

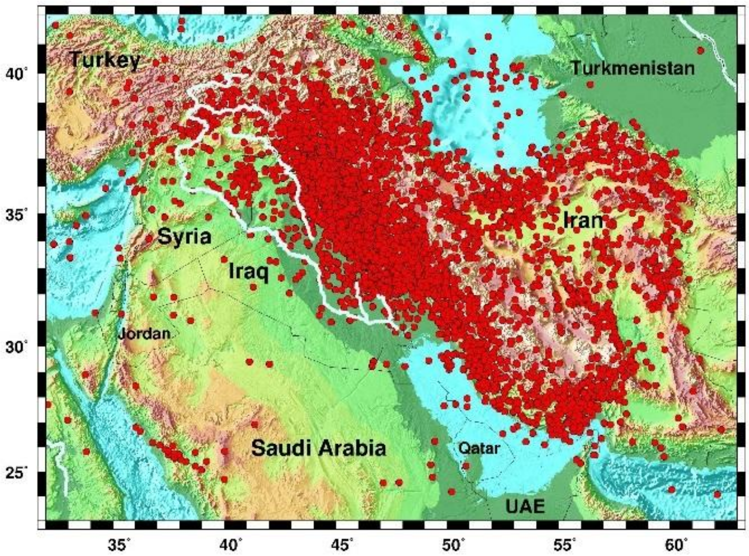


Figure-4: Seismicity map for the period 2006-2009. A total of 7923 events were located using NISN waveform data and neighboring countries' bulletins.

vMESN Concept

The proposal to establish vMESN was first introduced in 2012 *[11]*. The concept is simple, cost effective, and highly rewarding, and it will likely help advance the teaching, research and practice of Seismology in the ME countries through collaboration. It is "virtual" because the vMESN network itself is expected to be comprised of exiting telemetered stations that share continuous seismic waveforms in real-time using standardized exchange format (*e.g.*, SEED or MSEED) *[12]* over Internet through the data centers of participating countries.

Figure: 5 shows the potential ME countries that can voluntarily participate in and contribute to vMESN. There is no fee or cost associated with joining vMESN or sharing the real-time seismic data, but there is an unwavering commitment to freely forward, acquire and independently process the data in operational, research and educational settings.

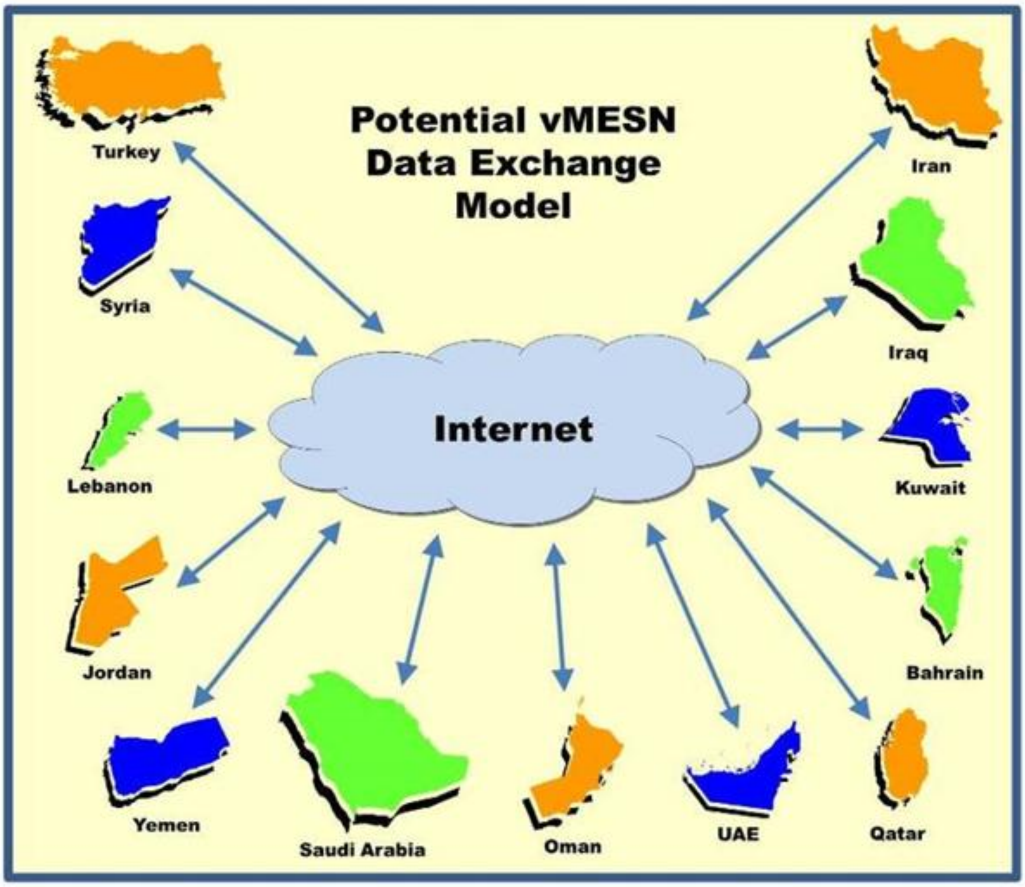


Figure-5: The ME countries that currently have the means and potential to participate in and contribute to vMESN.

As discussed earlier, at present there are many standalone national seismographic networks operating in the ME that are not realizing their full potential and cannot possibly fulfill their intended scientific objectives. In addition, there are over 50 international stations in the ME that are part of the Global Seismographic Network (GSN) and GEOFON whose data are also not being exploited by the ME national networks. Combining all of this wealth of real-time data would undoubtedly create one dense and highly capable vMESN network that can serve all countries alike without having to expend more funds, time and effort on building more stations that will contribute little, if any, to the routine practice of monitoring earthquakes in and around each country. Under vMESN, every participating country is expected to:

- Commit to contributing data to vMESN.
- Have no obligation toward any other participant country other than sharing the data.
- Continue to maintain full sovereignty over their seismic systems, computers and data.
- Continue to use their data acquisition, forwarding and processing software (*i.e.*, Antelope or SeisComp3).
- Provide Internet link to their respective data center, but not the individual stations.
- Independently operate and maintain their stations, network and data center.
- Independently manage and archive their data, including the acquired vMESN data.

- Share their seismic data (preferably from all stations and components) in real-time with the other participants.
- Receive seismic waveform data from all participants in real-time.
- Exchange metadata information (inventory information; stations lists and instruments) with all participants.
- Independently process the seismic data in accordance with their processes and procedures.
- Continue to use their favorite seismic data analysis software (*e.g.*, Antelope, SeisComp3, Geotool, SAC, *etc.*).
- Independently publish seismic bulletins.
- Freely use the seismic data in research and education.
- Freely distribute their own network data, but not the acquired vMESN data.

The vMESN model is a scientifically, professionally and economically rewarding initiative for monitoring earthquakes in the ME. It is an example of a high-return venture on modest investment in resources and infrastructure. It is technically straightforward to implement in a short period of time, because it exploits existing data centers and stations to significantly improve the performance, capability and coverage of standalone national networks. This initiative is an exceptional opportunity to create an unprecedented database of seismic waveform data that can be used in research and development in Seismology and Earthquakes Engineering. Furthermore, it promotes scientific interchanges through meetings, workshops and conferences.

vMESN Implementation

The most important requirement for a successful implementation of vMESN in a given country is the unwavering political and scientific commitment in support of unrestricted exchange of seismic data in real-time. This commitment would insure support for intra-country dialogues, negotiations and interactions to proceed without interruptions at all levels during the technical implementation, operation and maintenance periods of the project. This would also facilitate subsequent collaboration between the participating countries on geophysical research and development projects.

A prototype of the vMESN system (using Antelope) began operation at the Array Information Technology (AIT) data centers in December 2013. It initially processed real-time data from most of the international stations in the ME shown in *Figure: 6*. At present, vMESN is running at the Sulaimaniyah Seismological Observatory (SSO) and Erbil Seismological Observatory (ESO) in Kurdistan, Iraq, and at Jordan Seismological Observatory (JSO) in Amman, Jordan, data centers (*Figures: 7 and 8*). The latest version of vMESN incorporates real-time data from the NISN and Jordan Seismological Network (JSN) in addition to the international stations.

Figure-6: Map showing the distribution of ME stations currently being used in vMESN at AIT, Kurdistan, Iraq, and Jordan.

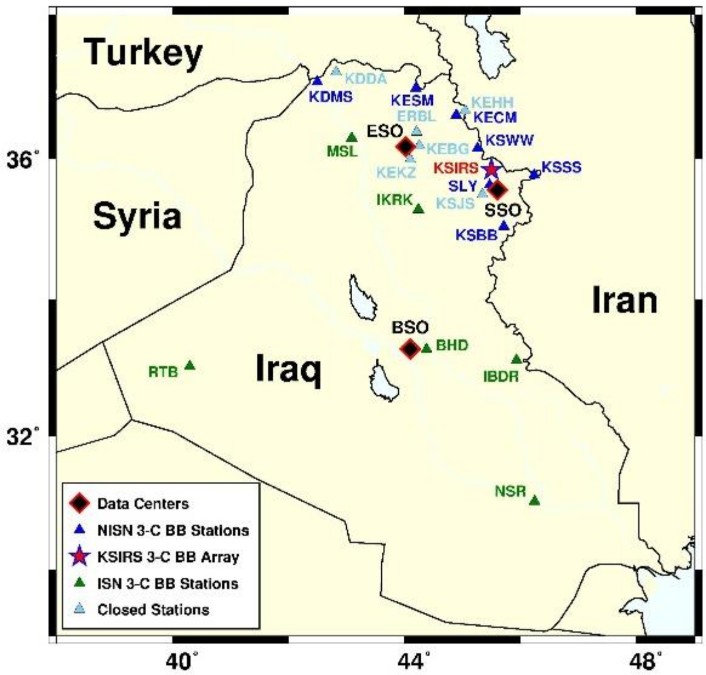


Figure-7: Map showing the location of NISN stations, KSIRS array, and the ISN stations.

Assuming all the stations are equipped with a form of telemetry and are sending data in real-time to their respective country's data center, the hardware needed to run vMESN consists of:

- A reasonably powerful personal computer running the Linux operating system and with ample memory and storage space.
- A high speed Internet link.
- A recent version of the Antelope or SeisComp3 software systems configured for vMESN operation.

Depending on the amount of shared data, number of destinations and speed of Internet links, the implementation of vMESN can be accomplished in either or both of the following ways:

1. vMESN Data Center

This approach entails establishing a well-equipped and appropriately staffed data center in one of the ME countries that can serve all participant countries equally. Although it is costly to establish, having a dedicated data center connected to the Internet is the better way to run a network the size of vMESN (*Figure: 1*) if most of the ME countries *Figure: 2* participate. The advantages of having a vMESN data center is to fulfil the functions of:

- A data clearing house that continuously acquires seismic data from, and forwards the data to, all national data centers over Internet.
- A common data archiving and backup post capable of backfilling data in case of communication disruption.
- An off-site data backup facility.
- Minimizing the data management load on all national data centers connected to it through Internet.

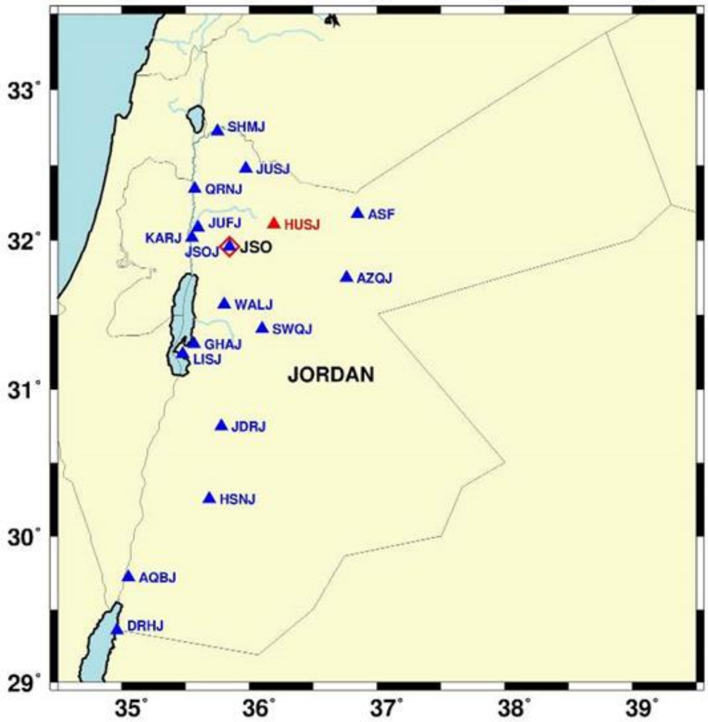


Figure-8: Map showing the location of JSN stations (blue triangles) and data center in Amman, Jordan (red diamond). Station HUSJ (red triangle) was recently installed by AIT.

2. Peer-to-Peer Exchange

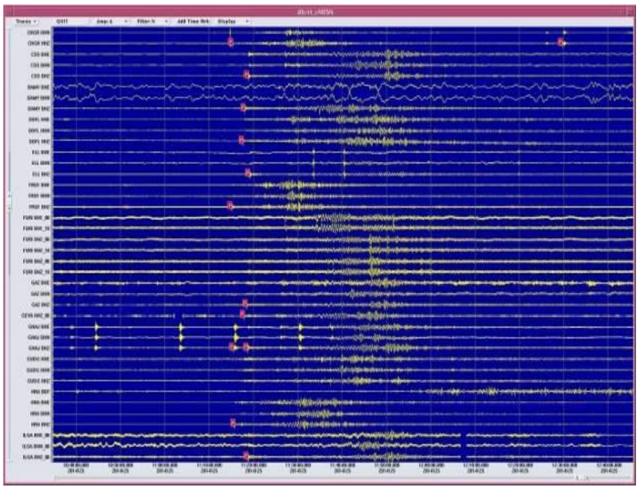
This approach is less costly because it entails that participating countries bilaterally exchange data in real-time over Internet. It is a viable initial solution when only a few countries exchange their data. As the number of countries and stations increases, the load on their national data centers becomes unmanageable. Kurdistan, Iraq, and Jordan are currently attempting to implement a peer-to-peer data exchange over Internet.

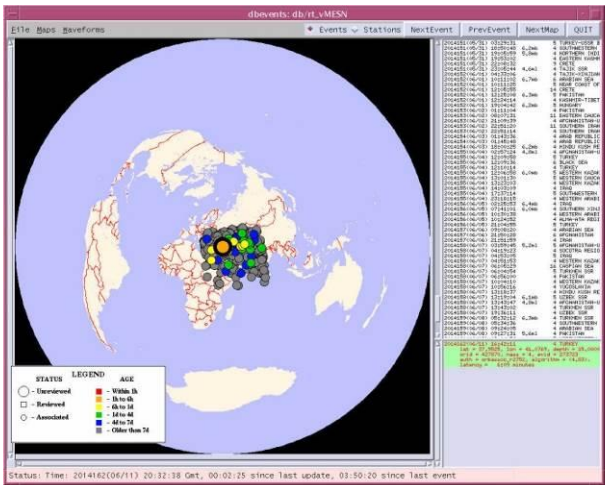
Also, the Directorate General of Meteorology and Seismology have submitted to the Arab League an open invitation to all countries to join vMESN *[13]*.

Technical Aspects

The vMESN system is a customized configuration of either the Antelope or SeisComp3 software packages. These are two leading and popular software systems that are capable of real-time data acquisition, forwarding, (automatic and interactive) processing, and production of seismicity maps and bulletins. Antelope is a software system developed by the Boulder Real Time Technologies (BRTT) company, whereas SeisComp3 is developed by the GEOFON (GEOFOrschungsNetz) Program at Helmholtz Centre Potsdam, GFZ German Research Centre for Geosciences and Gempa GmbH. Both software systems make use of the SeedLink, among other protocols, to exchange data in real-time.

The brief description of vMESN presented herein is based on the Antelope system (*Figure: 9*). It shows the system in the process of automatically detecting seismic signals, associating the detections, locating the events and displaying their location on a map in two different projections. The output solution (events' origin times, detections of seismic phase arrivals, association of arrivals to events, *etc.*) is archived in database tables in CSS3.0 format.





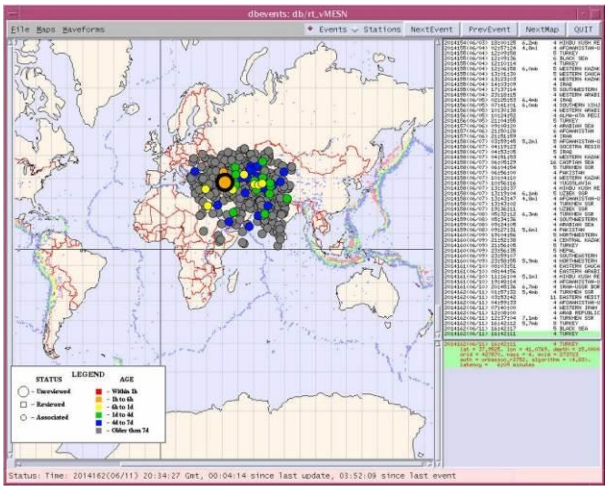


Figure-9: The top left screen shows seismic waveforms being acquired, and automatically processed by vMESN. The screens to the top and bottom right show the seismicity maps in Global and Mercator projections. The located events are colored to show chronological order.

For the events location process a travel time grid was created with a spacing of 8 km centered at latitude 27.5° N and longitude 52.0° E and extending for 25 degrees in N-S and E-W directions from the reference location, effectively 50 degrees across. This grid is designed to locate local and regional events with few stations, but not teleseismic events, since that is not a goal of vMESN. The Antelope system pulls real-time data from all data centers or stations simultaneously and performs several automatic signal processing tasks after it stores the data in a ring buffer. The automatic association process runs a detector on waveform data using the ratio of short term average and long term average windows (STA/LTA) technique, and then it associates the detections according to rules to form events. Once the automatic processing is complete, the events and their data become available for interactive processing by an analyst.

Conclusions

This is certainly an opportune time for the ME countries, and the Arabs in particular, to establish their own vMESN and data center that can help them advance the practice, research and education of Seismology in their countries. The vMESN program and model is rewarding, because it promotes collaboration through the sharing of continuous seismic data in real-time, and it can be proficiently expanded to include many of the African countries. All of the ME countries identified in *Figure: 5* are at present capable of individually or collectively investing into and exploiting the features and resources of vMESN to the benefit of their respective scientific and engineering institutions at no or little cost. The U.S. Geological Survey (USGS), the Incorporated Research Institutions for Seismology (IRIS), GEOFON, the European-Mediterranean Seismological Center (EMSC), the International Seismological Center (ISC) and the Mediterranean Network (MedNet) are excellent examples to learn from and follow their lead. Earthquakes can have devastating social and economic impacts if the regional seismotectonic framework and seismic risk in a given country are not well understood.

Acknowledgments

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The maps in this article were created using the Generic Mapping Tools *[14]*, and the Seismic Analysis Code (SAC) *[15]* and the Geotool waveform measurement software were used to plot the waveform.

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