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Seismic Characteristics of RAYN / GSN Station, Saudi Arabia

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Abstract. The IRIS/IDA station RAYN, Saudi Arabia is one of the newest stations in the IRIS Global Seismographic Network (GSN). Ambient seismic ground noise levels and minimum detectable magnitudes were estimated for this station. Noise conditions showed that RAYN station was very quiet with noise levels near the USGS Low Noise Model for frequencies higher than 0.1 Hz. At lower frequencies, the horizontal components showed increased noise levels, possibly due to instrumental characteristics. High frequency (1Hz) noise varied as much as 10 dB between day and night. Seasonal noise levels also varied, with April to June being the quietest and with October to December being the nosiest months. Slight changes in peak microseism frequency also occurred seasonally. Generally, noise levels were quietest at night and noisiest during morning and early afternoon, as expected for cultural noise. The most significant variations occurred at frequencies above 1 Hz. Minimum detectable magnitudes were estimated for RAYN using the observed noise levels over 1 Hz. The m_b detection threshold for the distance range of 5 -10 degrees is about $m_b = 2.7$-3.0 assuming a signal-to-noise ratio of 3 dB or better. The magnitude estimates increase with increasing frequency.

Introduction

The Incorporated Research Institutions for Seismology / International Deployment of Accelerometers (IRIS/IDA) station RAYN, Saudi Arabia is one of the newest stations in the IRIS Global Seismographic Network (GSN) and is proving to be an extraordinarily valuable addition. The station was established in 1996 under a memorandum of understanding between the King Abdulaziz City for Science and Technology (KACST), the IRIS Consortium, and the University of California, San Diego (UCSD), with key support from the King Saud University (KSU) Department of Geology.

The IRIS/IDA station RAYN has noise characteristics which place it among the quietest seismic stations in the world. Set upon the Arabian Shield far from sources of cultural noise, the sensors at the site routinely record background noise that approaches Peterson's Low Noise Model [1] over much of the frequency band.

Ambient seismic ground noise levels at RAYN station were estimated to identify the factors that influence ground noise levels in the Arabian Shield and Platform and to characterize potential sites for permanent seismic facility installation. In addition, seismic data obtained from this station will be used to observe and characterize the propagation of regional phases across the Arabian Shield over a broadband of frequencies as well as to provide data on sources of infrasonic signals such as a quarry blasts.

Ar Rayn's position relative to a number of seismically active zones make it a superb location to site seismographic equipment. This paper describes the geotectonic setting, the equipment used there, broadband seismic characterization, and examples of high quality data seismologists may expect to obtain from this station.

Geotectonic Setting

Rayn is located on the border of the Arabian Shield and Arabian Platform at 23.52° N, 45.50° E, elevation 792 m, approximately 250 km southwest of Riyadh. The borehole containing the KS-54000 seismometer which is sunk into late Pre-Cambrian granodiorite of the Arabian Shield and cased to a depth of 103 m (Fig. 1). The surface vault rests on the granodiorite and is buried in 2 m of weathered material. Cables connect the vault and well head to recording equipment in a building 75 m away.

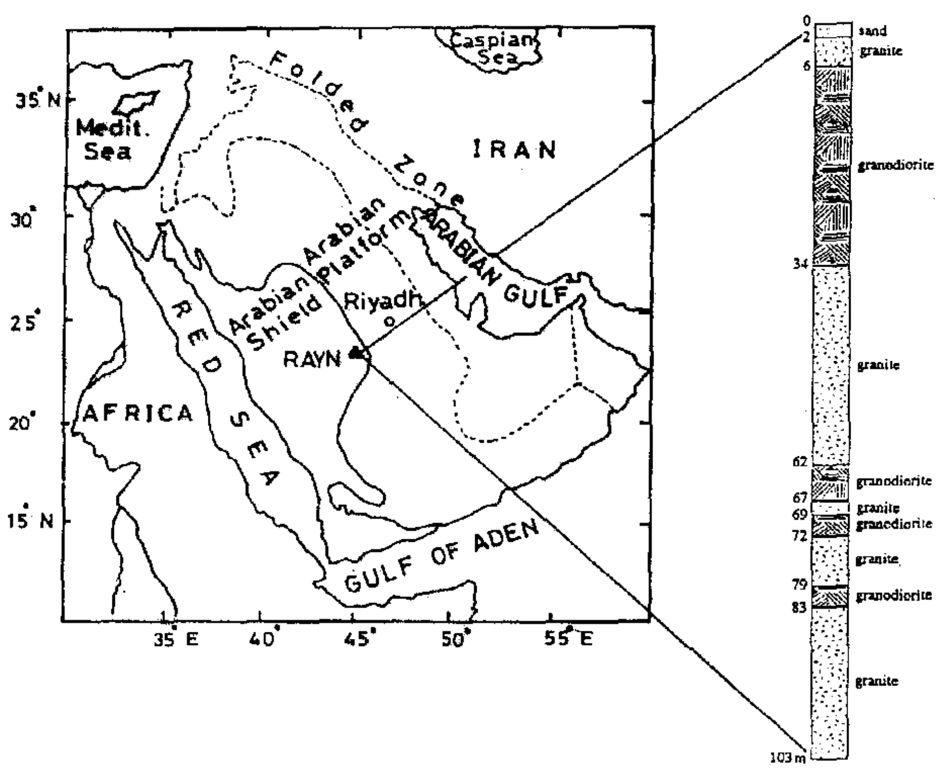

Fig. 1. Location map of Ar Rayn GSN station showing borehole cross-section. The borehole containing the KS-54000 seismometer which is sunk into late Pre-cambrian granodiorite of the Arabian Shield and cased to a depth of 103 m.

Ar Rayn's position relative to a number of active seismic zones makes it ideal as a recording location. To the northwest and west, lie the Dead Sea transform fault and the Red Sea rift, respectively, the Gulf of Aden to the south, and the Zagros folded belt in Iran to the northeast. Boundaries of four plates, the African, Eurasian, Indian and Arabian, all lie with 20 degrees distance from the station. Given this, it is not surprising that nearly 2500 events were detected at Ar Rayn during 1997.

The Arabian Shield was the subject of a US Geological Survey seismic refraction profile running from near Riyadh to the Red Sea in 1978. Mooney *et al.* [2] suggest that the geology and velocity structure of the Arabian Shield can be explained by a model in which the Shield developed in the Precambrian by suturing of island arcs. They interpret the boundary between the eastern Shield and the Arabian Platform as a suture zone between crustal blocks of differing composition. To first order, the Arabian Shield consists of two layers, each about 20 km thick. Average seismic P- velocities are 6.3 and 7.0 km/sec, respectively. The depth to the Moho averages about 40 km, thinning slightly from northwest to southeast. The upper mantle velocity is 8.0 - 8.2 km/sec.

The seismic characteristics of the Arabian Shield and Platform have been the subject of a number of papers [3-7]. Prodehl [8] noted that the upper crust of the eastern Shield appears to be more uniform than that of the western Shield.

More recently, the crustal model of the western Arabian Platform obtained by Al-Amri [9] shows a slightly higher P-velocity for the upper crust in the Shield than in the Platform, and the crustal Platform seems to be thicker than the Shield by about 3 km. The Moho discontinuity beneath the western Arabian Platform indicates an upper mantle velocity of 8.2 km/sec at 42 km depth. Estimates of lithospheric velocity and discontinuity structure beneath nine broadband stations in the Arabian Shield from teleseismic receiver functions are reported by Sandvol *et al.* [10]. They show that the crustal thickness of the Arabian Shield varies from 35 to 40 km in the west, adjacent to the Red Sea, to 45 km in central Arabia.

Equipment and Data Processing

After many months of preparation, data began to be collected at Rayn station in June, 1996, from an initial deployment of a Streckeisen STS-2 three component broadband seismometer (pass band between 0.008 Hz and 50 Hz) and a Kinemetrics FBA-23 strong motion accelerometer. In February 1997, a Teledyne broadband KS-54000 (pass band between 0.0003 Hz and 8 Hz) borehole package was added. The KS-54000 is emplaced in a borehole at a depth of 103 m to insure the quietest possible recording environment. The STS-2 and FBA-23 are located within a surface vault buried at a shallow depth. The output of the STS-2 is recorded at a sample rate of 40 samples / sec by a REFTEK RT72A-08 datalogger. The purpose of installing the STS-2 is to provide much better coverage of high frequencies than would be possible with the KS-54000 alone. The FBA-23 is in place to record ground motion from earthquakes either too large or too close to be recorded on-scale by the KS-54000 and STS-2.

All sensors are recorded on an IRIS-3 high-resolution data acquisition system [11]. The data logger samples the three components of the KS-54000 at rates of 20 Hz (designated BH*), 1 Hz (LH*), and 0.1 Hz (VH*) at a 24-bit resolution of 5.8 exp(-10) m/sec/digital count. The STS-2 components are recorded at two gains, low (SL*) and high (SH*), to ensure that the full dynamic range of the sensor is exploited. Each of these channels is recorded at 40 Hz. Finally, the FBA-23 is logged at 1.0 Hz continuously (LG*) and 100 Hz triggered (EG*). To this date, no event large enough has occurred to trigger the high rate accelerometer channels. Precise timing accurate to 1 msec or better is provided by a Magellan global positioning system (GPS) clock interfaced to the data logger. The recording system is unique among IRIS/IDA recording systems in that it uses a Seagate ST51080N 1.8 gigabyte removable disc pack to record the data. The disc pack is swapped once every 7-10 days when the station operator performs routine station maintenance and returned to King Saud University where the pack's contents are transcribed to Digital Audio Tapes (DAT) and mailed to the IRIS/IDA Data Collection Center (DCC) at UCSD.

Data are also available in Near Real-Time System (NRTS) via the IDA [12]. Telemetry is achieved by using spread-spectrum radios to connect the data logger to a modem at another site 2 km distant. The station is dialed nightly from the DCC to retrieve state-of-health information and also upon demand when requests for specific data, usually following a large earthquake, are received.

Seismic Signal and Noise Characteristics

The value of the station can be quickly realized by looking at the level of seismic background noise. The goal of this noise survey is to characterize the power spectral density (PSD) and to identify consistent variations in noise levels with time. The PSD was computed using Welch's averaged periodogram method with overlapping windows of 5000 points tapered with a Hanning taper. This information is useful in identifying specific sites for future deployments, in calibrating detection thresholds, and in identifying instrumental problems. Units for the power spectral density plots are decibels relative to acceleration units $((1\ m/sec^2)^2/Hz)$.

Figures 2 and 3 show the power spectral density of noise for the KS-54000 broadband and STS-2 short period sensors, respectively. Superimposed on the plot is the Peterson's New Low Noise Model, shown here as a dashed line. Certainly for periods shorter than 30 sec (<0.033 Hz), both sensors approach the Low Noise Model over a wide frequency band. The broadband vertical sensor conforms to the New Low Noise Model to even longer periods, 200-300 sec or more. Both the vertical and horizontal noise reach approximately the Low-Noise Model to at least 2 Hz. For the KS-54000, where the seismometer depth is 103 m, low-frequency horizontal noise (0.01- 0.1 Hz) is almost as low as vertical noise (Fig. 2). At frequencies greater than 0.1 Hz, the noise level between the vertical and horizontal components of the STS-2 sensor (at 10 m depth) varies by about 10 to 20 dB (Fig. 3).

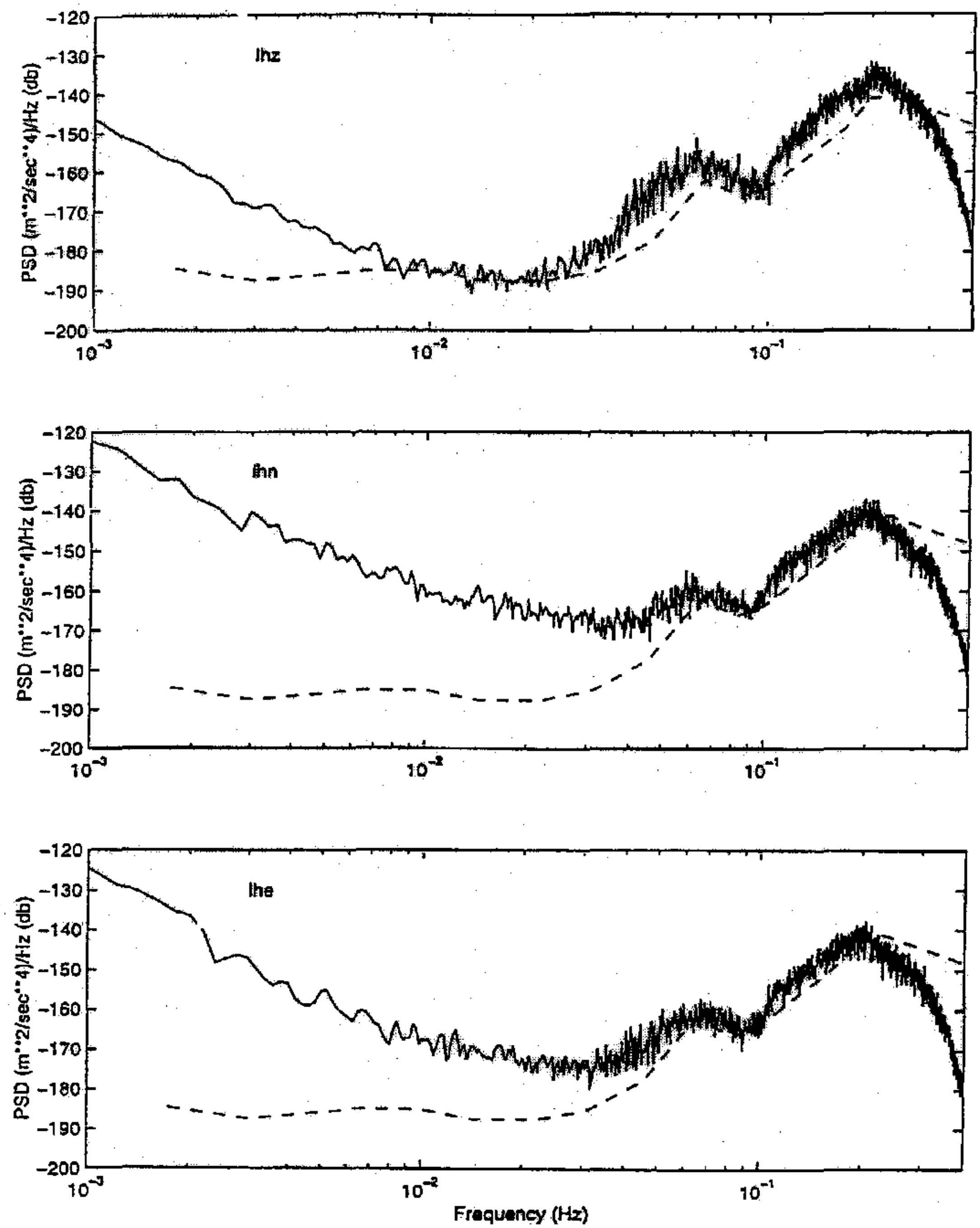

Fig. 2. Power spectral density in decibels relative to acceleration units of ambient ground noise at RAYN station from 0.001 to 0.4 Hz. The spectral density for a 40,000 second long time series from the three components of the KS-54000 seismometer. The sample length was selected at random and covers a period half at night and half during the day. The dashed line represents the Peterson Low Noise Model, based on a sample of stations worldwide.

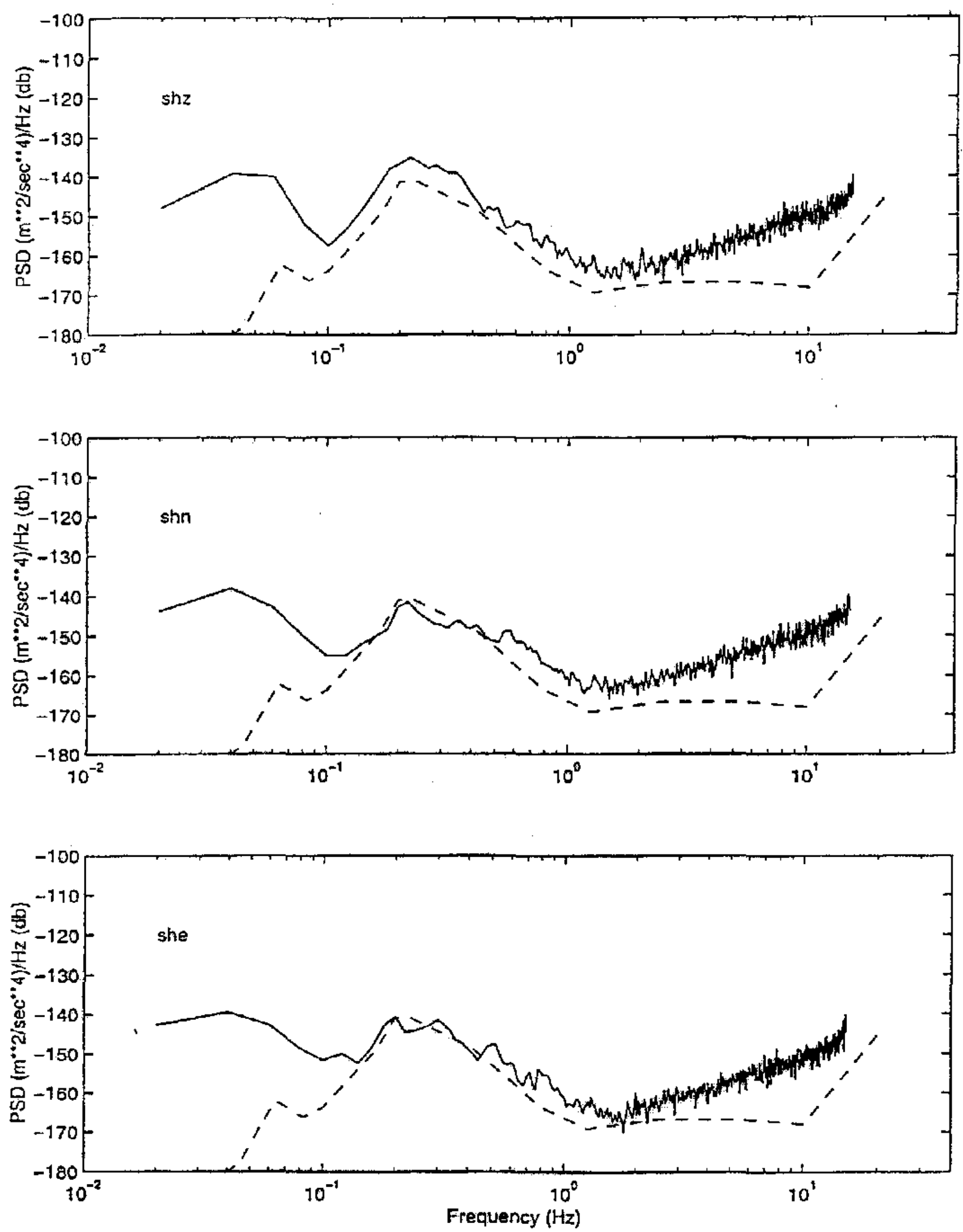

Fig. 3. Power spectral density in decibels relative to acceleration units of ambient ground noise at RAYN station from 0.01 to 30 Hz. The spectral density for a 500 second long time series from the three components of the STS-2 seismometer. The dashed line represents the Peterson Low Noise Model, based on a sample of stations worldwide.

Mellors [13] showed that noise levels at nine broadband stations (STS-2) across the Arabian Shield are similar for all channels for a given station for frequencies greater than 0.9 Hz. Between 0.9 Hz and roughly 0.1 Hz, the vertical is slightly noisier than the horizontals, and at frequencies less than 0.1 Hz, the horizontals are much noisier. The difference in decibels between 'day' and 'night' noise samples between 1 Hz to 10 Hz indicates that daytime noise increases slightly over nighttime noise, reaching an 10 dB increase on all components. Night and day differences are usually significant only above 1 Hz and depend on the soundness of the vault. Between 0.1 to 1 Hz, 'day' and 'night' noise levels are equal. This could be interpreted to mean that noise source in this band is dominated by RAYN's location on a stable shield.

Seasonal noise levels also varied, with April to June being the quietest and with October to December being the nosiest months. Slight changes in peak microseism frequency also occurred seasonally. Absolute noise levels near the microseism frequency (0.1 to 0.2 Hz) were about equal for all seasons at -140 dB. Above 1Hz, RAYN station shows an increase in seasonal variations from -140 dB in the summer to -160 dB in the winter.

Generally speaking, the diurnal and seasonal variations in background noise are not great, averaging on the order of 3 dB for all components of both the borehole and short-period sensors. This is not surprising because the station is distant from sources of cultural noise, and there is a pronounced lack of vegetation near the site. Although the wind blows often and varies in intensity throughout the daily cycle, there is little to couple this motion of air into the ground. This low noise level allows small events that might otherwise be buried in the noise to be well observed at the station.

Figures 4 and 5 show seismograms from two events to illustrate this. The first event occurred in the Zagros Mountains at a distance of 850 km and had a magnitude of m_b = 3.8. A number of phases are clearly visible in the wavetrain, and the signal-to-noise ratio is very high in the frequency band 1-5 Hz displayed (Fig. 4). The second event occurred in the Sea of Okhotsk at a distance of 73.8 degrees. Although it was relatively small (m_b = 4.6) and distant, the P-wave arrival is well recorded on the borehole sensors (Fig.5). These two events are very representative of the quality of data available.

Based upon the signal-to-noise ratio for representative events like these, one can estimate the detection threshold for the station. If one used the frequency band 1-10 Hz, it would perhaps be possible regularly to detect events in the distance range 5-10 degrees as small as m_b =2.7-3.0. A signal detection used at the IDA DCC regularly identifies an average of 11 signals/day having a signal-to-noise ratio of 3 dB or better. Given the results of studies of the rate of seismicity in nearby fault zones, this seems to be consistent with the above estimate of the detection threshold. Vernon and Berger [14] suggest that many sites in the Arabian Shield are extremely quiet with ground noise near or equal to the low noise model in the frequency band from 1-10 Hz and appear to be among the best sites in the world for the properties of detection thresholds and ground noise level. The low noise also contributes to the very low detection threshold of events with m_b >= 3.5 at distances from 10 to 100 degrees.

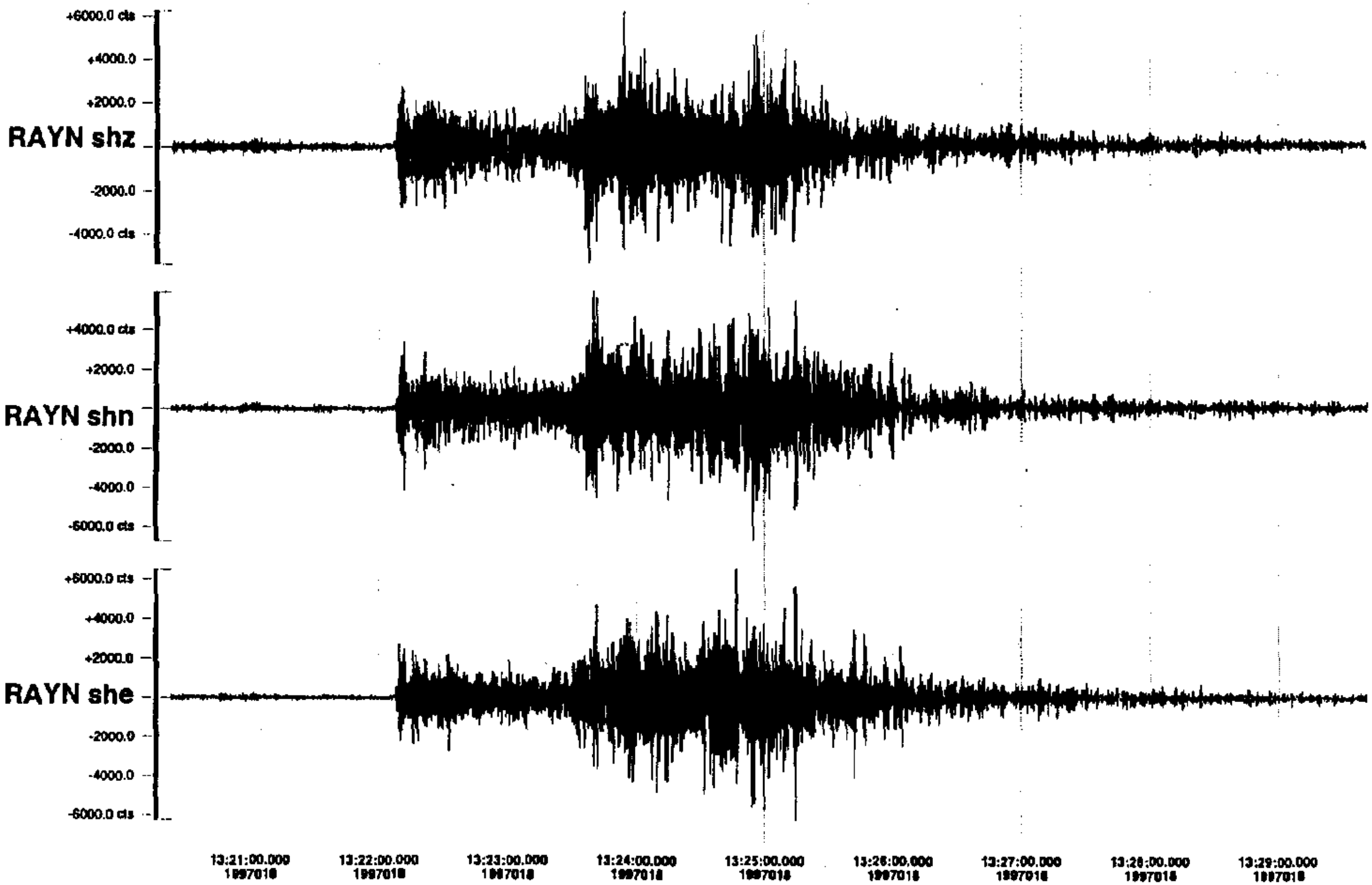

Fig. 4. **Earthquake event 850 km distant in the Zagros thrust belt recorded on the STS-2 sensors. Event parameters reported were lat 29.2° N, long = 51.1° E, m_b = 3.8 and origin time is 1997, 018-13:20:14.2.**

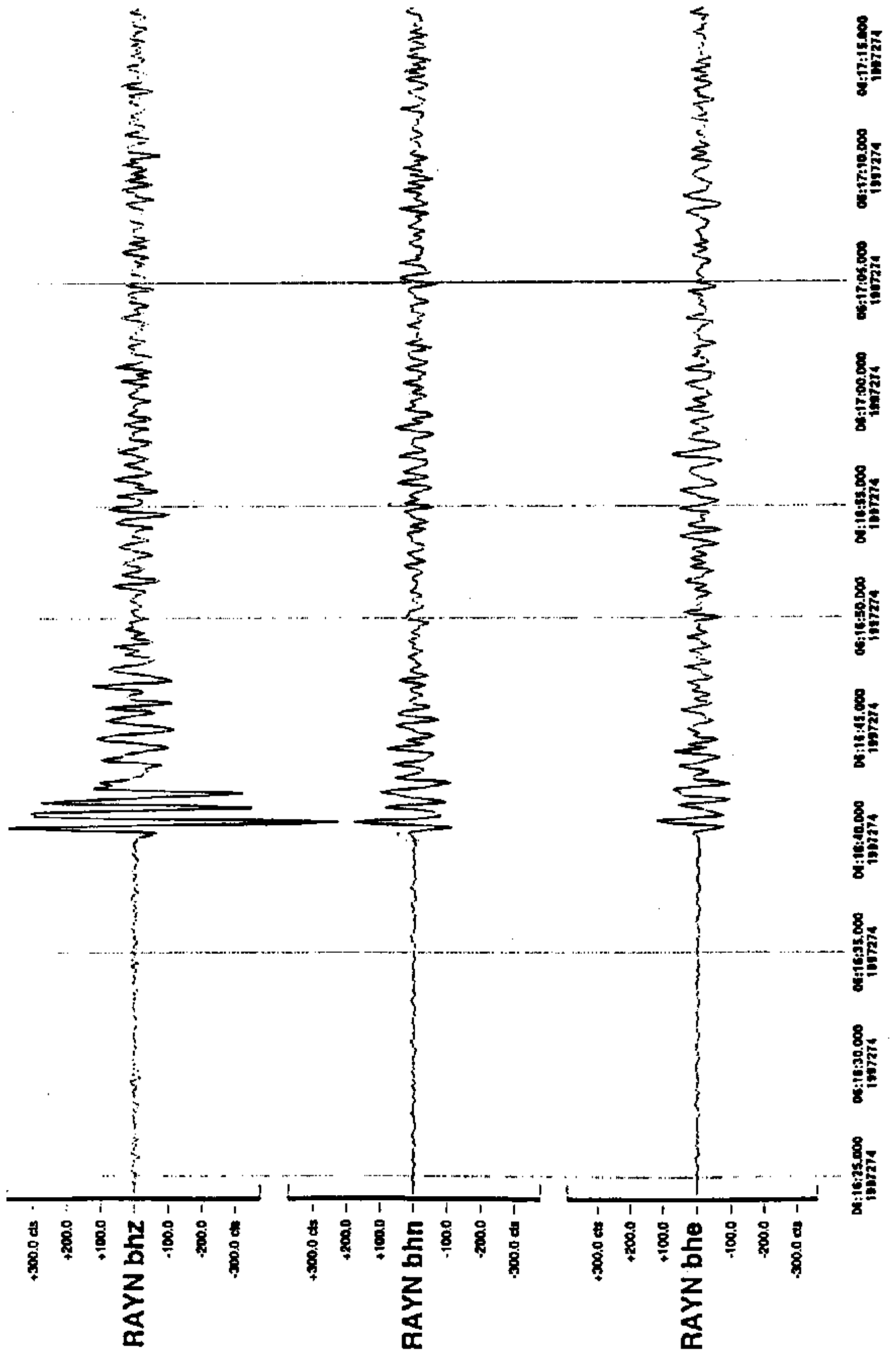

Fig. 5. Earthquake event 73.8 degree distant in the Sea of Okhotsk recorded on the KS-54000 sensors. Event parameters reported were lat 46.2^0 N, long = 136.1^0 E, depth = 418 km, m_b = 4.6 and origin time is 1997, 274-6:05.2.

Conclusions

Based on the background noise level observed at this station and the quality of seismograms from numerous events in the region, this station should prove to be a very valuable addition to the Global Seismographic Network.

The increase in day over night noise can be significant from 1 to 10 Hz reaching an 10 dB increase on all components of the STS-2 seismometer. Between 0.1 to 1 Hz, noise levels range from -170 dB to -140 dB relative to $(1\text{m}/\sec^2)^2/\text{Hz}$ and have not been observed to increase significantly during the day. Absolute noise levels near the microseism frequency (0.1 to 0.2 Hz) were about equal for all seasons at -140 dB. Above 1Hz, RAYN station shows an increase in seasonal variations from -140 dB in the Summer to -160 dB in the winter.

The most obvious discrepancy between the noise levels at RAYN station and the Low Noise Model is at the horizontal long periods. Horizontal components are significantly noisier than vertical at frequencies less than 0.1 Hz. At frequencies greater than 0.1 Hz, the noise levels between the verticals and the horizontals varies greatly (by up to 40 dB). The source of the long-period noise is not clear and may be due to small tilts. These tilts affect the horizontal components more than the verticals because horizontal tilts greatly increase the effect of the local gravity vector. If the tilt is great enough, is quite large compared to the signals normally recorded.

Future plans exist now to deploy a permanent broadband seismic array adjacent to RAYN station, which will aid in studying seismotectonics of the Arabian Plate, improving regional seismic monitoring capability and developing reliable crustal structure models of the Arabian peninsula and its environs.

Acknowledgment. We would like to express our thanks and gratitude to technicians of the King Saud University (KSU) and King Abdulaziz City for Science and Technology (KACST) for collecting earthquake data and routine maintenance and operation of the station. The RAYN station is currently funded by KACST, IRIS/ IDA, and the University of California, San Diego.

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الخواص السيزمية لمحطة الرين الدولية المملكة العربية السعودية

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(استلم للنشر في ١٤١٩/٣/١٩هـ؛ وقبل للنشر في ١٤١٩/٨/١٣هـ)

ملخص البحث. تعتبر محطة الرين الواقعة بمركز الرين واحدة من أحدث محطات الشبكة الدولية للزلازل التابعة لمعاهد أبحاث الزلازل التعاونية IRIS/IDA.

تم تقدير مستويات الضوضاء السيزمية وحساب أقل قدر زلزالي أمكن رصده في محطة الرين. أوضحت ظروف الضوضاء السيزمية أن محطة الرين هادئة تماما بمستوى مقارب لنموذج الضوضاء المنخفض للمساحة الجيولوجية الأمريكية للترددات التي أعلى من ٠,١ هيرتز. ودلت المركبات الأفقية على زيادة في مستويات الضوضاء عند الترددات المنخفضة ومن المحتمل أن يرجع هذا إلى خواص الأجهزة. أما عند الترددات المرتفعة (١ هيرتز) فإن مستوى الضوضاء يتغير في حدود ١٠ ديسبل بين النهار والليل. كذلك تتغير مستويات الضوضاء الفصلية. حيث تبين أن أهدأ الأشهر ضوضاءً من أبريل إلى يونيو، وأكثرها ضوضاءً من أكتوبر إلى ديسمبر.

عموما، إن مستوى الضوضاء السيزمي يكون أهدأ ليلا وأكثر ضوضاءً خلال فترات الصباح وبعد الظهر، وتحدث التغيرات اليومية والفصلية عند ترددات أعلى من ١ هيرتز.

تم تقدير الحد الأدنى للتقديرات الزلزالية التي سجلتها محطة الرين بواسطة ملاحظة مستويات الضوضاء للترددات التي أعلى من ١ هيرتز. حيث تراوح القدر الزلزالي للموجات الباطنية (Mb) ما بين (٢,٧ - ٣) عند مسافة تتراوح ما بين (٥ - ١٠) درجات عندما تكون نسبة الإشارة إلى الضوضاء ٣ ديسبل أو أكثر. ويزداد حساب القدر الزلزالي مع زيادة التردد.