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Microseism and Microtremor Analyses over an Oilfield in Abu Dhabi - Implications for Cyclone and Hydrocarbon Detection

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SUMMARY

The characteristics of background seismic noise over an onshore carbonate oilfield in Abu Dhabi, UAE, have been investigated by means of spectral amplitude and array analysis within frequency range of 0.17 - 10 Hz.

The study reveals a strong correlation of seismic noise spectral amplitude with meteorological and anthropogenic noises. In the frequency range of 0.17 - 1 Hz, the dominant feature is the double frequency peak of microseism generated by oceanic storms in the Indian Ocean. We observed that the strongest spectral amplitude of double-frequency microseism occurs when cyclone Gonu was present over the Arabian Sea and battering the coast of Oman.

A narrow-band of microtremor in the range of 2.5 -2.8 Hz is present in all locations. The microtremor signal has no clear correlation with the microseism signals. Using arrays of 3-components broadband instruments, we are able to determine the apparent velocities and the azimuth of the wave fronts of the recorded microtremor events. The results indicate that the observed signals are most likely due to some type of surface waves with the azimuth to the source pointing towards the nearest coastline in the area (the Arabian Gulf).

Introduction

The ambient Earth noise, or background noise, has been studied by numerous researchers (e.g. Kedar and Webb, 2005). At low frequency, the natural activity of ocean dominates through the *microseisms* band, usually between 5 x 10^{-2} – 10^{-1} Hz for primary band (Oliver and Ewing, 1957) and 10^{-1} – 2 x 10^{-1} Hz for the secondary band, producing a peak of noise amplitude at ~0.2 Hz, visible anywhere on the Earth (e.g. Longuet-Higgins, 1950). At high frequency (> 1 Hz), seismic noise field is mainly dominated by cultural or wind-generated noise (e.g. Peterson, 1993), with wind noise being the predominant high-frequency noise source at remote sites (e.g. Withers et al., 1996) and traffic and factories being the major source of noise in urban sites (Marzorati and Bindi, 2006).

In this paper we present the results of an investigation carried out over an onshore carbonate oilfield in Abu Dhabi to determine the spectral content, apparent velocities and the azimuth of the wave fronts recorded in the *microseism* and *microtremor* bands. This study is a follow up of the work presented by Berteussen et al. [2008].

Study Area and Data Acquisition

The experiment was carried out between 21st May and 17th June of 2007 on an onshore oil field in Abu Dhabi (Figure 1). During the acquisition of the data a powerful tropical cyclone (Cyclone Gonu) hit on the coast of Oman. Gonu developed in the eastern Arabian Sea on 1 June 2007, to attain peak winds of 240 km/h on June 3 and struck the eastern coast of Oman on 5 June 2007 with winds of 150 km/h, becoming the strongest tropical cyclone to hit the Arabian Peninsula (De Bhowmick et al., 2007). It then turned northward into the Gulf of Oman, and dispersed after moving ashore along southern Iran on 7th June 2007.

The experiment included acquisition of 12 arrays of varying aperture (15 m to 1800 m) of typically 24 hours each (Figure 1b). The arrays were centred at location A (over the maximum oil column of the reservoir) and B (over an area that presumably contained no oil).

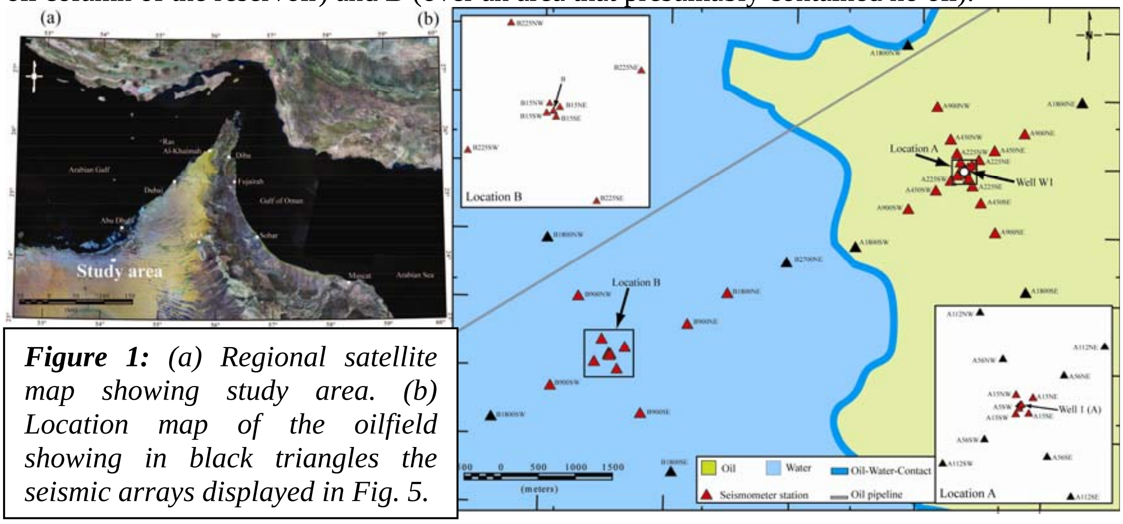


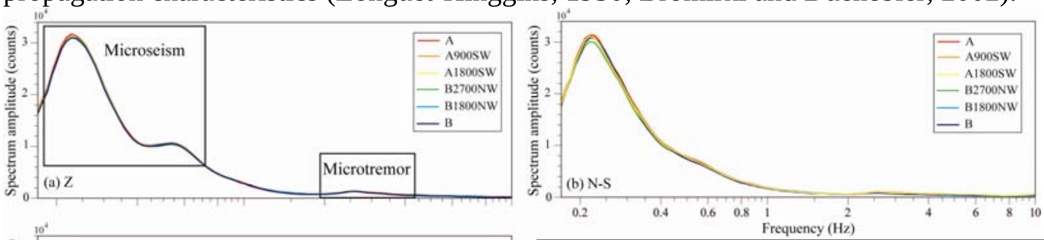
Figure 1: (a) Regional satellite map showing study area. (b) Location map of the oilfield showing in black triangles the seismic arrays displayed in Fig. 5.

Ambient Earth Noise Sources

The ambient noise levels observed at the site generally falls into two frequency bands: *Microseisms* (~0.17-1 Hz) and *microtremor* (2.5-3 Hz). In this section we detail the noise spectra amplitude estimated for the site in these bands.

Microseism

Figure 2 illustrates that the noise spectrum is dominated by a strong easily recognizable *microseism* peak called the double-frequency peak (Longuet-Higgins, 1950) at ~0.25 Hz with secondary peak at ~0.55 Hz. It is believed to be as a result of interaction between two same frequency ocean swells but propagating in opposite directions (Longguet-Higgins, 1950; Kedar and Webb, 2005). The conditions generating nonlinear interaction of two oppositely propagating waves may arise in the centre of cyclonic depression due to oppositely travelling ocean waves arriving all directions (Kedar and Webb, 2005). *Microseism* energy propagates as primarily fundamental Rayleigh waves that do not attenuate rapidly (Bromirski and Duennebier, 2002). As a result, the double-frequency *microseism* is observed in the background noise at all sites worldwide including at continental sites far removed from the coastlines (Peterson, 1993). The level of double-frequency *microseism* depends on the amplitude of the interacting ocean waves, the size of the area of interaction and on the propagation characteristics (Longuet-Hingins, 1950; Bromirki and Duenebier, 2002).



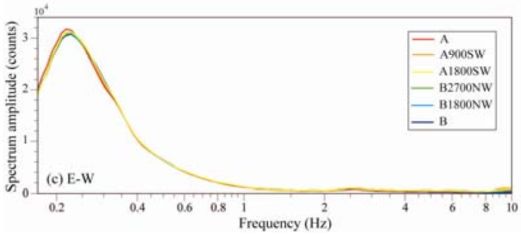
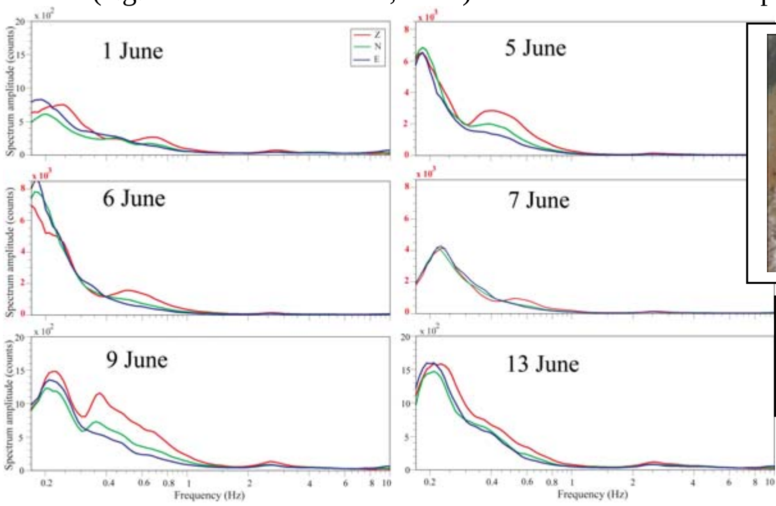


Figure 2*: Typical spectral amplitudes showing microseism and microtremor signals. Processing window of 60 seconds and 5% cosine taper was applied to the data to reduce spectral leakage.*

The correlation between the double-frequency *microseism* peak and the presence of ocean storms is supported by the temporal variation of spectral levels of the double-frequency *microseism* during the time interval of Cyclone Gonu. Figure 3 illustrates that the spectral amplitudes of ambient noise level between 0.17 – 0.25 Hz increased when Cyclone Gonu approached on the coast of Oman (4-7 June). The spectral amplitude reached their maximum on June 6 and dropped when the cyclone passed the region. Increased spectral amplitudes are consistent with increased intensity and proximity of the cyclone as show on the satellite image in Figure 4. In addition, we observe that as the cyclone develops, spectral levels are initially highest at frequencies in the range of ~0.25 Hz. As the storm intensifies, the wave energy peak shifted towards lower frequencies at around ~0.2 Hz. This is in agreement with other studies (e.g. Marzorati and Bindi, 2006) which observed similar phenomenon.



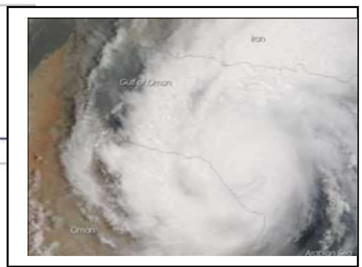


Figure 4*: Satellite image of Cyclone Gonu on June 6,*

Figure 3*: Comparison of spectral amplitudes at location B during the time interval of Cyclone Gonu. The spectral amplitudes of microseisms increased when Cyclone Gonu approached on the coast of Oman. Note the change of amplitude scale for the 5 -7 June data.*

Microtremor

Figures 2 and 3 show distinct spectral anomaly, referred as '*microtremor*' in the frequency band of ~2-3 Hz. The signals are observed over all locations (both above and outside the reservoir) and all three components (N-S, E-W and Z) record the signal. Figures 3 indicates that there is no clear relationship between the strength of *microtremor* and *microseism* signals. During the period in which Cyclone Gonu was battering on the Oman coast the *microseism* signal increased by a factor of ~10 whereas the *microremor* signal was unchanged. Hanssen and Bussat (2008) have also noted that there is no correlation between the low frequency (1-6 Hz) band and *microseism* signal (< 0.25 Hz). This contradicts with Holzner et al. (2005) who suggested that the driving force of the generation of low frequency signal is the *microseism* which controls the strength of the low frequency signal

Array Analysis

The experiment was conducted using 3-component instruments configured in 2-dimensional seismic arrays of varying aperture (Figure 1). High-resolution frequency-wave number (*f*-*k*) spectral analysis (Capon, 1969) is used to determine the apparent velocity and azimuth of the wavefront. Figure 5 shows the slowness maps for two frequency bands (top: centre frequency = 0.2 Hz bottom: centre frequency = 2.5 Hz) with varying apertures. The propagation azimuth (from the source) of the 0.2 Hz wavefront is between 302°-330° (front north) with apparent velocity of ~3600 m/s for both Arrays A and B. The wavefront is interpreted as a microseism event generated by Indian Ocean/Arabian Sea. The higher apparent velocity indicates that the wavefield interacted with deeper more compacted carbonate rocks. This analysis confirms the interpretation of the spectral amplitude.

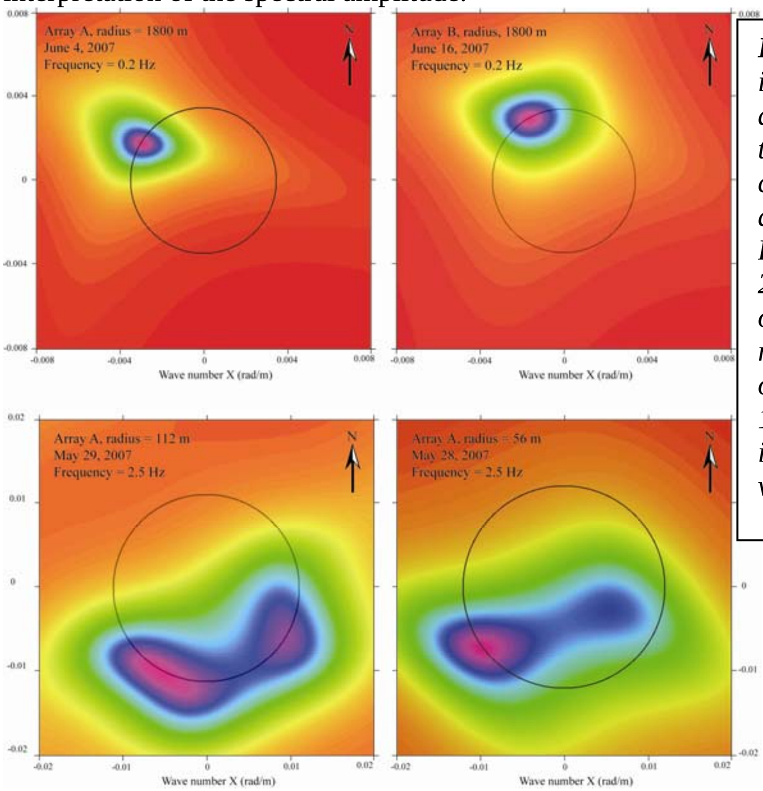


***Figure 5**: Energy response in slowness space for arrays A and B showing two frequency bands. Top: centre frequency = 0.2 Hz, array radius = 1800 m. Bottom: centre frequency = 2.5 Hz) with array radius of 112 m and 56 m respectively. For locations of the sensors see Figure 1b.The black circles indicate the apparent velocities of the waves.*

The propagation azimuth of 2.5 Hz wavefront is 205°-233° with apparent velocity of 1300-1400 m/s. In the study area there few meters of unconsolidated sand which lies directly over relatively hard carbonate layers having P-wave velocities far above 1400 m/sec. Therefore the observed wavefront cannot be an ordinary P-wave originated from the reservoir. If the waves were coming from directly below the array then they would arrive at the same time at all instruments (i.e. the apparent velocity would be infinite and the azimuth undefined). Therefore, on the bases of this observation, the origin of the ambient noise at low frequency measured in this experiment is interpreted as S-type wave or more likely some sort of surface-coupled wave that originated from the Arabian Gulf. This observation is in apparent contrast with other studies (e.g. Dangel et al., 2003; Holzner et al., 2005; Walker, 2008) which correlated the spectral peak of the *microtremor* event with the location of the hydrocarbons.

Conclusions

Observations from the analyses of the spectral amplitudes and high-resolution *f-k* of the data revealed the following results:

- Double-frequency *microseisms* are observed within the frequency band of 0.17-0.25 Hz. The *microseisms* spectral amplitudes have been correlated well with cyclone Gonu that was developed on Indian Ocean/Arabian Sea. The *microseisms* spectral amplitudes increase when cyclone Gonu approached on the coast of Oman and drop when the cyclone passed the region.
- *Microtremor* signal is observed in the frequency band of ~2-3 Hz. There is no apparent correlation between the *microtremor* and *microseism* signals. Therefore, the driving force of the micrtremor signal cannot be the *microseisms*.
- The apparent velocity and propagation azimuth (from source) of *microseisms* are ~3600 m/s and 302°-330° respectively for both Location A and B. This suggests that the source of the *microseism* is the ocean swells in the Indian Ocean/Arabian Sea.
- The apparent velocity and propagation azimuth of *microtremor* are ~1300-1400 m/s and 205°-233° respectively. The results indicate that the observed *microtremor* signals originate from some type of surface waves with an azimuth from the source pointing towards the nearest coastline in the area (the Arabian Gulf).

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