Acoustic travel-time perturbations due to shallow-water internal waves in the Yellow Sea

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ABSTRACT

Internal waves in shallow-water cause sound speed profiles variations, leads to acoustic travel-time perturbations. In summer 2007, a combined acoustics/physical oceanography experiment was performed to study both the acoustical properties and the ocean dynamics of the Yellow Sea. The internal waves were recorded by the thermistor arrays. The hydrophones receiving array is enabled to monitoring of acoustic travel-time fluctuations over the internal waves. It is shown that the activity of high frequency internal waves occurs frequently during the experiment and dominated the experiment area. In the paper, we compare the high frequency of internal wave with acoustic fluctuations and analyse the correlation between them.

I. INTRODUCTION

The acoustic fluctuation by internal waves in shallow water has received considerable attention in recent years (James F. Lynch, 1995, M.Badiey, 2007, GAO Da-zhi, 2008). Internal waves cause sound speed profiles variations and have strong effects on acoustic propagation and scattering, especially high frequency internal waves can cause acoustic travel-time perturbations. The 1995 SWARM experiment (R.H.Headrick, 2000) concentrated on acoustic pulse amplitude and travel-time variations as well as the physical oceanography of the nonlinear internal wave filed. The PRIMER experiments examined both internal wave and coastal front effects on acoustic propagation and so on. One of the first indications of strong internal wave induced fluctuations came from the Yellow Sea work of Zhou (J. X. Zhou, 1997) and his co-workers, where anomalously large, frequency and azimuth dependent propagation losses were noted in tandem with high internal wave activity. The thermocline of Yellow Sea is the thin layer but the difference in temperature is relatively great. The specific ocean environment in Yellow Sea gives rise to this kind of particular ocean phenomenon and high frequency internal waves with sharp peak occurs frequently in the sea area. In summer 2007, a combined acoustics/physical oceanography experiment was performed to study both the acoustical properties and the ocean dynamics of the Yellow Sea. The high frequency internal wave and the acoustic travel-time fluctuation were compared in the time and frequency domain and investigate the internal wave effect on the acoustic propagation.

II. ACOUSTIC PROPAGATION EXPERIMENTS

The combined acoustics/physical oceanography experiment was conducted in the yellow sea in summer 2007. The source of 300Hz was moored in 34m of seafloor. Hydrophones were used to receive signals and the spacing of adjacent elements was 1.5m and spanned the water column from 8.5m to 13m.The range between the source and the receiving array was 8.7km during the propagation experiments. The water depth of experiments site is almost 34m and relatively flat bottom. A 1-min repeating sequence was transmitted by the launched transducer. This included a 5s linear frequency modulation (LFM) with 6.8s silence and the swept band was 260-340Hz. Then 1s sine pulse signal with 6.9s silence and 5s long sine pulse signal with 10s silence were transmitted closely. The final two signals were 8.5s 8 order pseudo random M sequence code with 7.9s silence, 0.1s short sine pulse signal with 9.8s silence. During 3 hours acoustic propagation experiment, 180 repeating sequence signals were recorded. Figure 1 showed the transmitted signal wave form and frequency spectrum. The two thermistor-chains were employed to record the temperature variation during the experiments. The 40 hours temperature variation near the receiving hydrophones was recorded and showed in the figure2. The isothermal of the temperature variation showed in figure3 is equal to the variation of the high frequency internal wave.

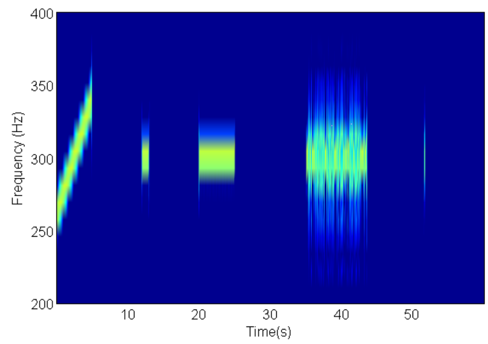


Figure 1. Frequency spectrum of transmitted signal wave form

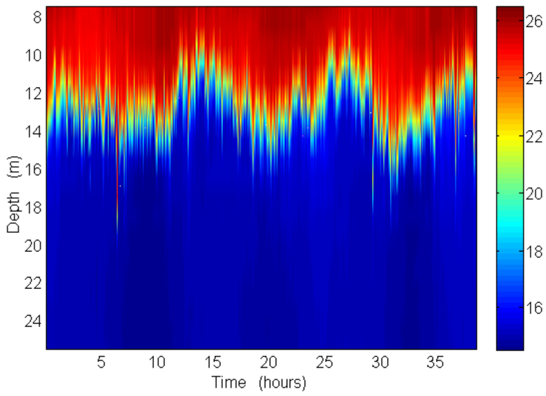


Figure 2. Temperature variation near the receiving hydrophones (40 hours)

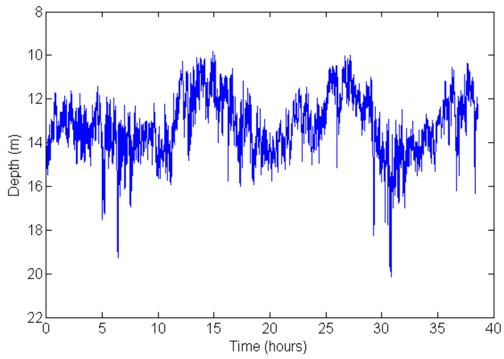
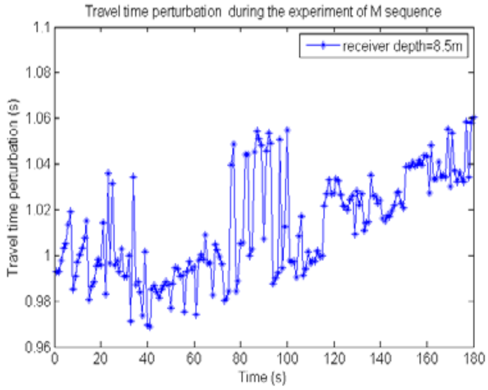


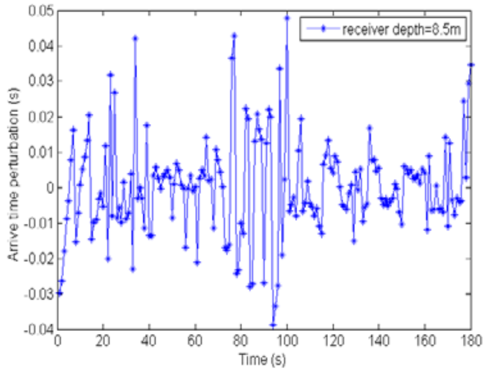
Figure 3. The isothermal of the temperature variation

III. DATA ANALYSIS

In this section we present the comparison result between the high frequency internal waves with acoustic fluctuations and analyse the correlation between them. We only choose the two signal form, one is LFM signal and the other is M-sequence code. The first step in data processing is each receiving signal of the each hydrophone correlated with the original signal and the acoustic travel-time perturbation was obtained. Figure4a showed the travel time perturbation of the receiver signal during the experiment of M sequence at the 8.5m hydrophone site. After filtered, low-frequency signal is filtered basically showed in figure4b. From the figure4, the travel time present the fast fluctuation during the whole propagation experiment when the internal wave crossed the source site of experiment area. The peak to peak value was almost 60ms. The similar fast fluctuation appeared at the other hydrophones. As the source was moored under the seafloor and the experiment time was 3 hours which was short relatively, the reason from tail to the tide and source jitter was excluded. The high frequency internal waves were considered as the major reason induced the fast fluctuation of the signal travel time.



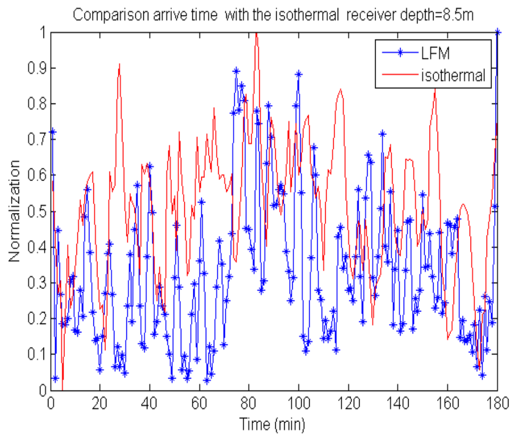
(a) Travel time perturbation at the receiver depth 8.5m



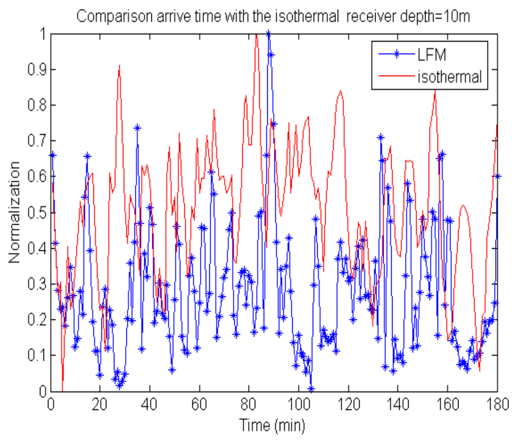
(b) Filtered travel time perturbation

Figure4. Travel time perturbation during the experiment

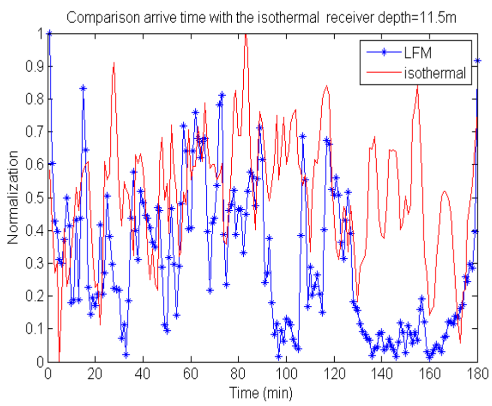
The second step is computing the cross correlation of their waveforms during the corresponding experiment time. The waveform of travel time perturbation is compared with isothermal. The receiver depths of hydrophones are 8.5m, 10m, 11.5m and 13m respectively. In figure5 and figure6, the solid line represented the isothermal during the experiment. The star line in figure5 represented the travel time perturbation of the LFM signal and in figure6 represented the one of M sequence mode signal. The curves were the normalization result. Form figure5 and figure6, the travel-time perturbations are in accord with the isothermal when the different signal form such as the LFM or M sequence code and different receiver depths were chosen. In other words, the travel-time perturbations were induced by the internal wave and in accord with the variation of the high frequency internal waves. We used the actual sound speed profile when the internal waves crossed the source site to simulate the group velocity of normal mode. The group velocity of the same mode varied with the sound speed profile induced by high frequency internal waves.



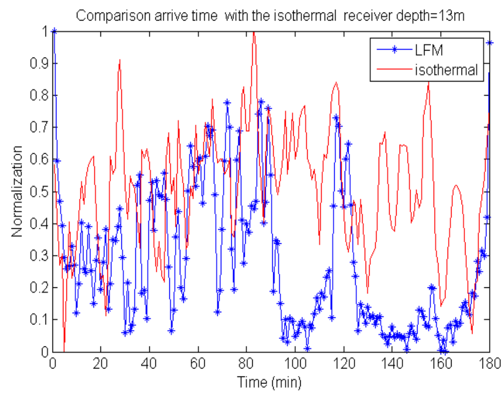
(a) Receiver depth=8.5m



(b) Receiver depth=10m

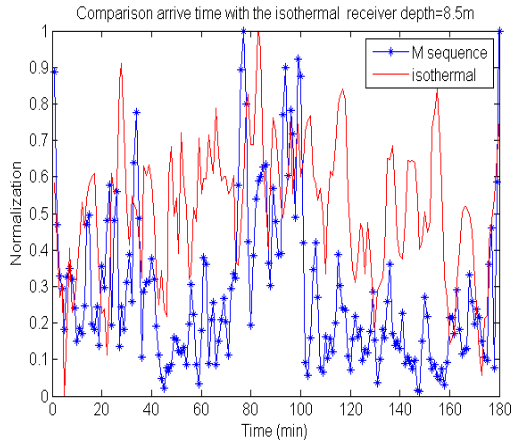


(c) Receiver depth=11.5m

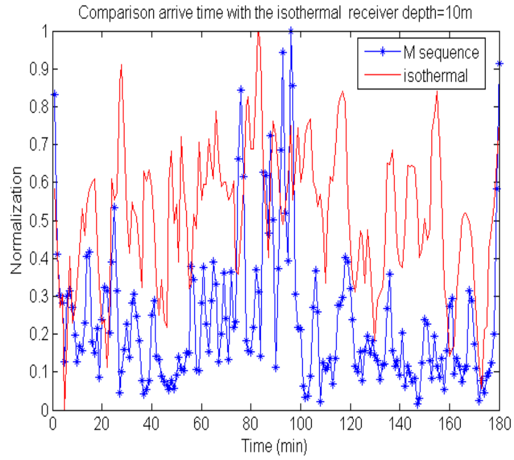


(d) Receiver depth=13m

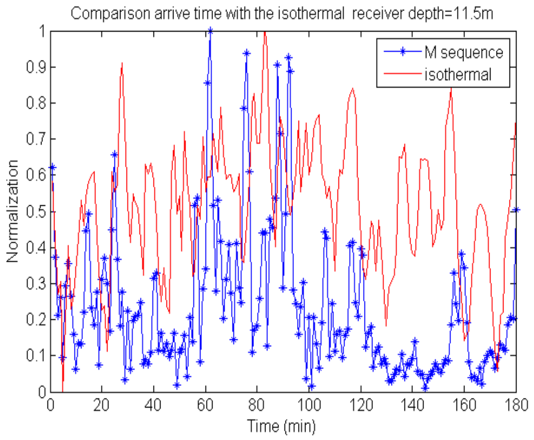
Figure 5. Waveform comparison between the isothermal with the LFM signal travel-time perturbations



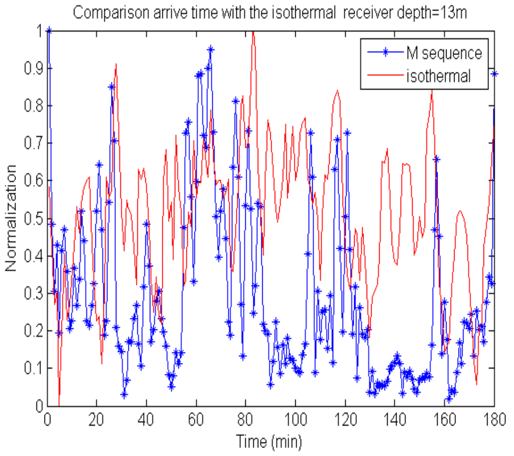
(a) Receiver depth=8.5m



(b) Receiver depth=10m



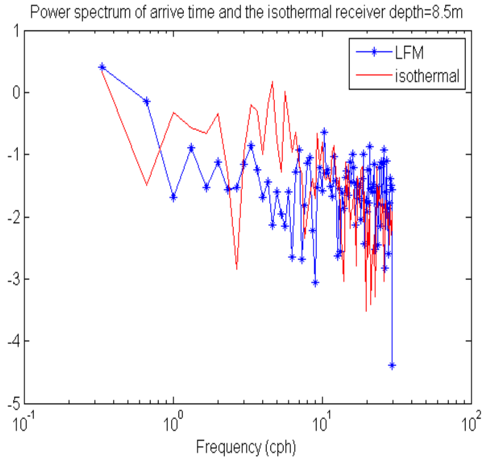
(c) Receiver depth=11.5m



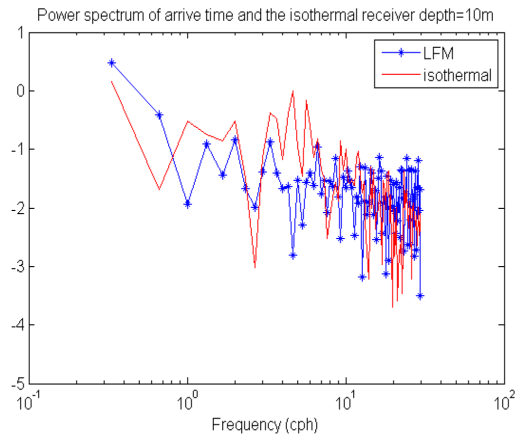
(d) Receiver depth=13m

Figure 6. Waveform comparison between the isothermal with M-sequence code travel-time perturbations

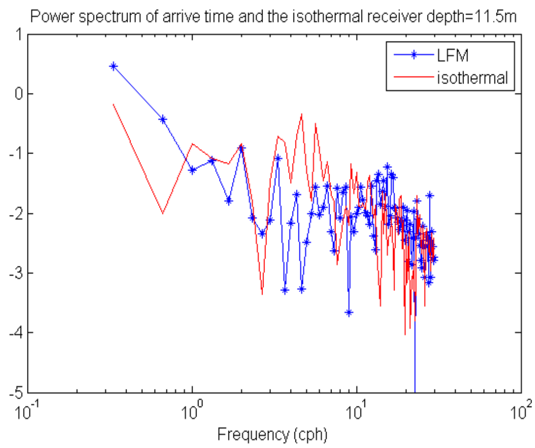
In order to observe the high frequency internal wave effect on the acoustic travel-time, the power spectrum of isothermal and the travel-time fluctuation were analysed. The fast Fourier transform (FFT) of each hydrophone travel-time perturbation curve to transform to the frequency domain. Similarly, a fast Fourier transform of the isothermal to transform to the frequency domain. The travel-time perturbation is compared with isothermal in the frequency domain. The integration time for the FFT of the acoustic travel time perturbations and the thermocline depth was the whole experiment duration. In figure7 and figure8, the solid line represented the isothermal during the experiment. The star line in figure7 represented the power spectrum of the travel time perturbation of the LFM signal and in figure8 represented the one of M sequence mode signal. The curves were the normalization result. Figure7 and figure8 showed the comparison results of two kind of signal forms and receive depth respectively. The same conclusion was drawn which the travel-time was in accord with isothermal and the above result was verified.



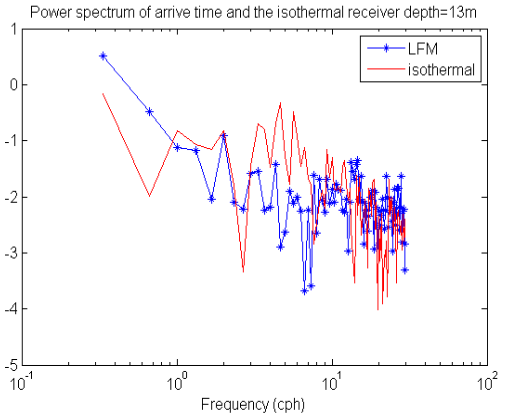
(a) Receiver depth=8.5m



(b) Receiver depth=10m

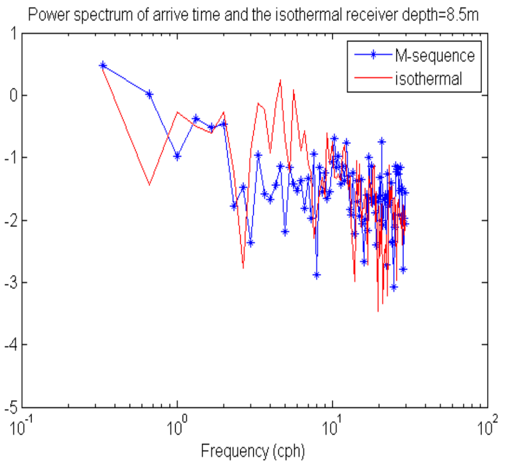


(c) Receiver depth=11.5m

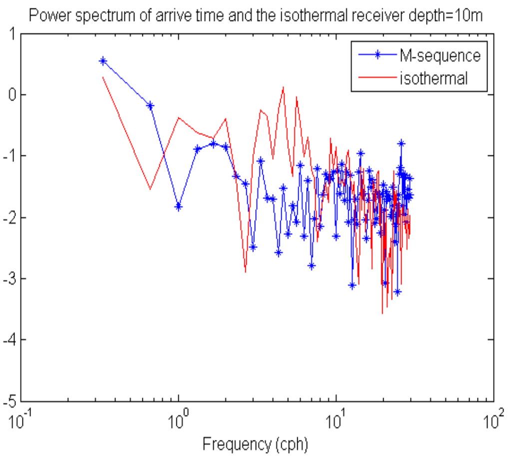


(d) Receiver depth=13m

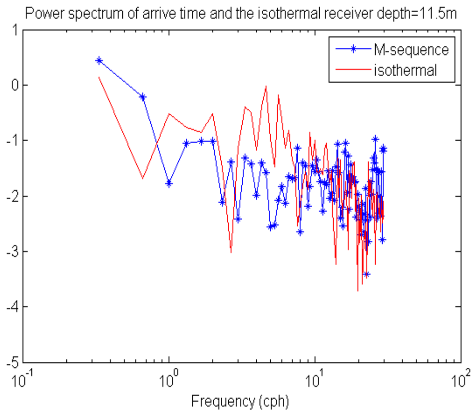
Figure7. Power spectrum comparison between the isothermal with the LFM signal travel-time perturbations



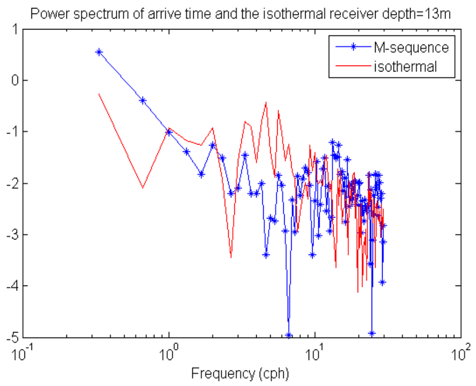
(a) Receiver depth=8.5m



(b) Receiver depth=10m



(c) Receiver depth=11.5m



(d) Receiver depth=13m

Figure 8. Power spectrum comparison between the isothermal with M-sequence code travel-time perturbations

IV. CONCLUSION

The experiment data indicated that the fast fluctuation of the acoustic travel time induced by the internal waves existed in Yellow sea and the time delay almost reached 60ms. The paper presented the internal wave of Yellow sea effect on the acoustic travel-time perturbations and the results showed that the acoustic travel-time fluctuations were in accord with internal wave for different signal form and receiver depth. In turn, the Correspondence could be used to predict and correct the velocity of internal wave propagation. The further research focus on the internal waves effect on arrive time perturbation from the formation mechanism of internal waves.

REFERENCES

James F. Lynch, Guo liangjin 1995, 'Acoustic travel-time perturbations duet to shallow-water internal waves and internal tides in the Barents Sea Polar Front: Theory and experiment', *J. Acoust. Soc. Am.*, vol. 99, pp: 803-821.

R. H. Headrick, J. F. Lynch, J. Kemp and etc 2000, 'Acoustic normal mode fluctuation statistics in the 1995 SWARM internal wave scattering experiment', *J. Acoust. Soc. Am.*, vol. 107, pp: 201–220.

M. Badiey, B. G. Katsnelson, J. F. Lynch, and S. Pereselkov 2007, 'Frequency dependence and intensity fluctuations due to shallow water internal waves', *J. Acoust. Soc. Am.*, vol. 122, pp: 747–760.

J. X. Zhou ,P.H. Rogers, G. W. Caille , R. Zhang, G. Jin, L.Lei, P. H. Dahl, R.C.Spindel, and Z. Gan, "Overview of the joint China-U.S. Yellow Sea 96 experiment," in Shallow-Water Acoustics, edited by R. Zhang and J. Zhou, China Ocean Press, April 21-25,1997. pp17-22

GAO Da-zhi, LIU Jin-zhong , WANG Ning , WU Li-xin, 2008, 'Travel time fluctuation of normal mode: AEYFI05 experiment', *ACTA ACUSTICA*, Vol. 33, no. 3, pp: 212-219.