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Acoustic Propagation Fluctuation Caused by Internal Waves in the Yellow Sea

Tao Hu, Li Ma, Zhongyuan Guo, Ning Jia and Shengming Guo

Key Laboratory of Underwater Acoustic Environment, Chinese Academy of Sciences, Beijing, China
Institute of Acoustics, Chinese Academy of Sciences, Beijing, China

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ABSTRACT

An acoustic propagation experiment in the Yellow Sea was fielded at summer 2009, a suit of acoustic and oceanographic sensors were deployed to collect high quality environmental and acoustic data. One goal was to investigate ocean variability effects on low frequency sound propagation. In experiment, nonlinear internal was not observed, and internal tide and high frequency internal waves were very strong. This study continues an investigation of monochromatic signal from the two south and east propagation tracks. This paper only gives one track's result. On this track, internal waves led to acoustic modes coupling. As water depth of experiment site is only 36.5 m and acoustic signal frequency is 260 Hz, only one or several acoustic modes were observed when distance of source and vertical receiving array was about 11 km. It is easy to find acoustic modes coupling appeared. During acoustic experiment, receiving sound field often had only one mode. Alternate of mode 2 and mode 1 was observed. It led to acoustic field energy appeared strong fluctuation at almost every receiving depth. The peak to peak value of energy fluctuations exceeded 20 dB. Acoustic fluctuations between upper receiving depths and lower receiving depths were opposite. Fluctuation phasic difference of upper and lower depths was about 180 degree. The transition point depth was about 24 m. This depth lied in zero value position of mode 2 and closed to maximum value depth of mode 1.

INSTRUCTIONS

Internal waves are common in the shallow waters of continental and adjacent seas, and have been shown to have strong effects on acoustic propagation and scattering. An early study in the Yellow Sea [1] showed a strong absorption of low frequency sound due to scattering by internal waves. At low frequencies, internal waves, especially nonlinear internal waves can cause acoustic modes coupling [2], decorrelation of acoustic modes [3], and horizontal refraction [4] etc. In this paper, an acoustic propagation flucatuation data, caused by internal tide and high frequency internal waves, were analysed in 2009 Yellow Sea experiment. Paper is organized as follows. Following this Introductions, we present in Section I oceanographic result. Thermistors data show internal tide and high frequency internal waves in experiment site. In section II, acoustic data are described. Acoustic data of different receiving depth are analysed. Results show mode 1 and mode 2 alternated in receiving sound field caused by internal waves and led to acoustic fluctuations in different depths were very diffenert. The peak to peak values of energy fluctuation exceeded 20dB. The results are discussed in Section III.

I. OCEAN DATA

Figure 1 shows the positions of the acoustic assets relative to the oceanographic mooring. A moored vertical receiveing array's position defines the origin. Two thermistor-chains are labelled 1 and 2. Chain 1 was near the position of acoustic source, and chain 2 was near the position of receiving array. Because thermistor-chain 1 had a longer recording time, measuring dada of chain 1 is giving. Figure 2 shows the internal waves effect on sound speed during this experiment. The sound speed is plotted as a function of depth for 60 hours. For this section of data, the M2 tide period and high frequency internal waves were observed. Internal tide's amplitude was about 2 m. High frequency internal wave rided on the internal tide. The whole internal waves spanned from 15 m to 21 m. after 25 hours from meansuring began, internal waves' amplitude decreased. Two black solid lines show the time of acoustic experiment in figure 2.

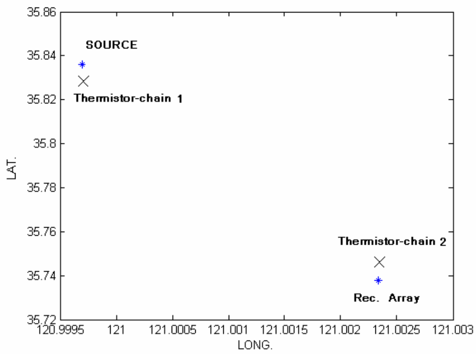

Figure 1 Positions of deployed. A moored vertical receiveing array's position defines the origin. Two thermistor-chains are labelled 1 and 2. Acoustic source's center frequency is 260 Hz, and source depth was fixed at 11.2 m depth. Distance of source and vertical receiving array was 10.85 km.

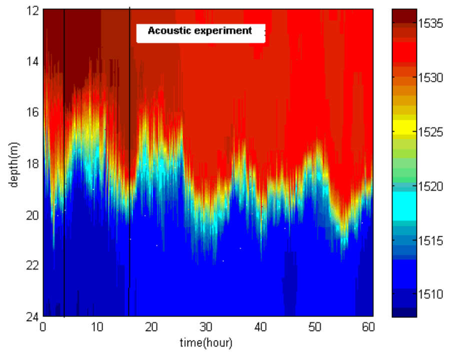

Figure 2 Sound speed as function of depth for 60 hours. It came from measuring dada of thermistor-chain 1.

II. ACOUSTIC DATA

Acoustic data was collected for 10 hours. The center frequency 260Hz source was fixed at 11.2 m depth, 10.85 km from the 16-element moored receiving array. The source repeatedly transmitted a 260Hz monochromatic signal 1s, and shut off 29s. The vertical line array receovers were positioned so as to look at the acoustic field and its fluctuations versus time. This array spanned the water column from 9.4 m to 31.9 m, with a hydrophone spacing of 1.5 m.

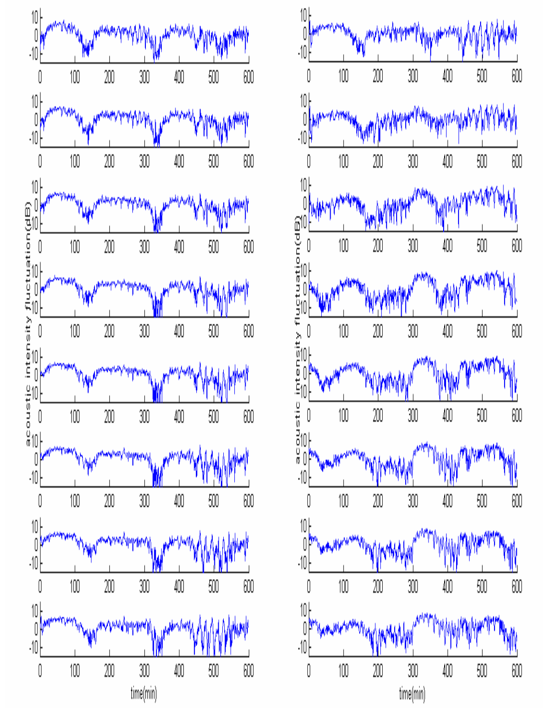

Figure 3 Array receiving signals intensity fluctuations as function of time. From left to right and from up to down respectively give fluctuations from shallow to deep receiving depth.

During 10 hours acoustic propagation experiment, 1200 monochromatic signals were recorded by 16-element array. FFT (Fast Fourier Transform) was used to achieve the amplitudy of receiving signals and intensity values. Figure 3 shows array receiving signal's intensity fluctuations vs time for 10 hours. Left panel shows fluctuations of the upper receiving depths, respectively were 9.4 m, 10.9 m, 12.4 m, 13.9 m, 15.4 m, 16.9 m, 18.4 m, 19.9 m from up to down. Right panel shows fluctuations of the lower receiving depths, respectively were 21.4 m, 22.9 m, 24.4 m, 25.9 m, 27.4 m, 28.9 m, 30.4 m, 31.9 m from up to down.

In figure 3, 260 Hz receiving signals intensity fluctuations were very strong at every depth. The peak to peak values of intensity fluctuations exceeded 20 dB in some time. Acoustic fluctuations curves upon 22 m depth were alike, and fluctuations curves down 25 m depth were alike. The fluctuations upper receiving depths and lower receiving depths were opposite. The transition point depth was about 24 m.

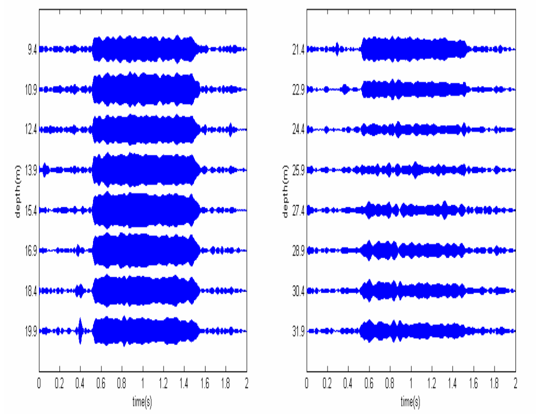

Figure 4 Receiveing signals waveforms sample of array. Receiving time was 50 minutes after acoustic experiment began.

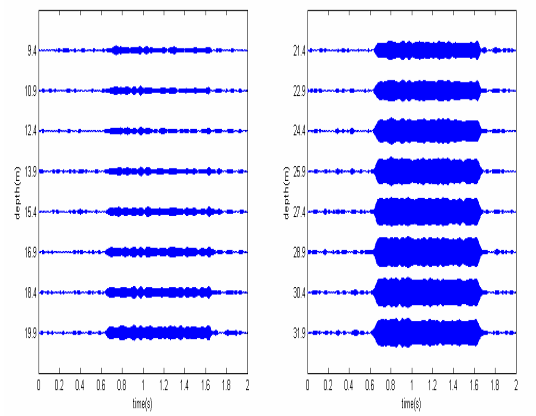

Figure 5 Receiveing signals waveforms sample of array. Receiving time was 330 minutes after acoustic experiment began.

Figure 4 and figure 5 show two groups array receiving signals samples of different recording time. Receiveing signal's recording time in figure 4 was 50 minutes after acoustic experiment began. From figure 3, this time was that acoustic fluctuations of upper depths were in peak value, and fluctuations of lower depths were in trough value. In figure 4, Signal to Noise of upper depths was big and signal to noise of lower depths was small.

The receiving signal's recoeding time in figure 5 was 330 minutes after acoustic experiment began. This time was that acoustic intensity fluctuations of upper depths were in trough value, and fluctuations of lower depths were in peak value. From figure 5, the Signal to Noise of upper depths was small and signal to noise of lower depths was big. Depth distribution of signals intensity was coincided with shape of mode 1.

From figure 3, 4 and 5, we can find that internal waves led to strong signal's intensity fluctuation. The most important thing was that internal waves led to the variety of signal intensity's depth distribution. Signal intensity fluctuations of diffenert depths were very different, especially the intensity fluctuations up 25 m depths and down 25 m were completely opposite.

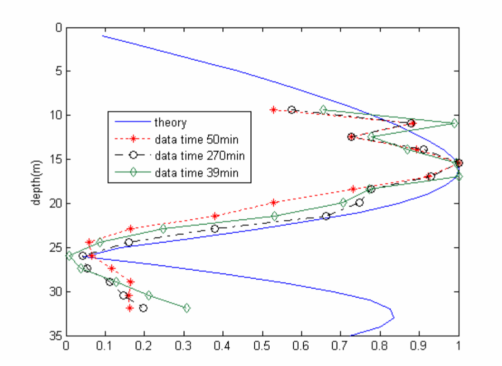

Figure 6 Signal amplitudy's depth distribution in different times, such as 39minutes, 50 minutes and 270 mintues, comparing with mode 2 of simulating sound fields.

To find the reason of those fluctuations character, signals amplitudy's depth distribution of different recording times were given. Figure 6 shows 39 minutes, 50 minutes and 270 minutes array receiving signals amplitudy's distribution vs depth. Those times were when fluctuations curves of upper depths were in the peak position. Blue solid line in figure 6 is the shape of mode 2. Shape of mode 2 was calculated using mean sound speed profile and known seabed parameters [5]. Figure 8 shows the mean sound speed profile. Seabed compress wave sound speed is 1600 m/s, density is 1.7 kg/m^3, compress wave attenuation coefficient is $0.26 dB/\lambda$.

In figure 6, signals amplitudy's depth distribution almost were coincided with the shape of mode 2. It means that mode 2 occupied the whole part of receiving sound field in those times. So in upper depth from 9.4 m to 21.4 m, signals were very strong and in about 25m depth, signals amplitudy were the smallest.

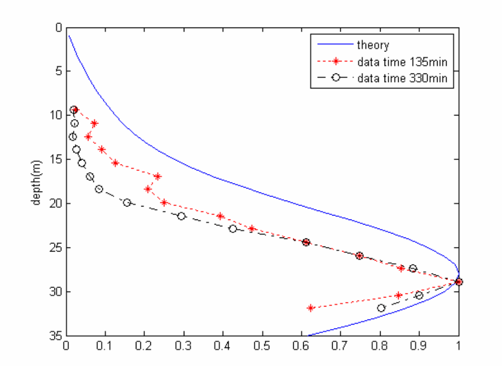

Figure 7 Signal amplitudy's depth distribution in different times, such as 135 minmtes and 330 minutes comparing with mode 1 of simulating sound fields.

Figure 7 shows 135 minutes and 330 minutes array receiving signals amplitudy's distribution vs depth. Those times were when fluctuations curves of lower depths were the peak position. Blue solid line in figure 7 is the shape of mode 1. From figure 7, we can find that in those times, signals amplitudy' depth distribution almost were coincided with the shape of mode 1. It means that mode 1 occupied the whole part of receiving sound field in those times. So in upper depths, signals were very small and in about 30m depth, signals intensitys were the biggest.

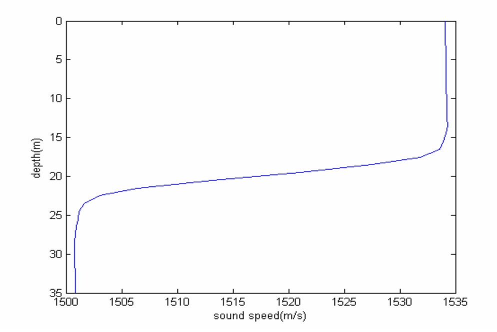

Figure 8 Mean sound speed profile

From figure 3, 6, and 7, in array's position, the upper depths sound fields' energy, especially up 25 m, was supplied by mode 2. The lower depths sound fields' energy, especially down 25 m, was supplied by mode 1. Because source depth was 11.2m, this position is near zero value of mode 1 and near the maximum value of mode 2. The source excited strong mode 2 and weak mode 1. Internal waves led to energy of mode 2 and mode 1 flucatuate as function of time. In some time energy of mode 2 coupled to mode 1, energy of mode 1 increased and energy of mode 2 decreased. The lower depth sound field energy increased, and upper depth sound field energy decreased to zero.

So signals intensity fluctuation in upper receiving depths can approximately be used to express mode 2 energy fluctuation caused by internal, especially in 15m depth, which was the maximum value position of mode 2. Signals intensity fluctuation in 29 m depth can approximately be used to express mode 1 energy fluctuation caused by internal waves. The more precise result of mode energy fluctuation caused by internal waves will be gotten using mode decomposing for array data, which is our nest work.

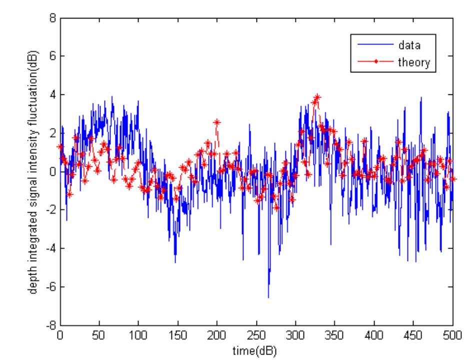

Figure 9 Depth integrated intensity fluctuationgs comparing data (blue solid line) and simulating result (red dish line)

Figure 9 shows the depth integrated intensity fluctuations as function of time. The blue solid line is result of experiment and red dish line is the simulating result. From figure 9, the depth integrated intensity fluctuation was not strong. The maximum peak to peak value was 8 dB, in most time was 4dB. To simplifing simulation internal waves' effect on depth integrated intensity fluctuations, we give three suppositions. First internal wave's bearing is same with acoustic propagation. Second waveform of internal waves is changeless. Third internal wave's speed is 0.34 m/s, which was that we measured in Yellow Sea. Using those suppositions, the vertical fluctuation VS time of internal waves was expanded horizontal coordinate, and horizontal distribution of sound speed profile led by internal waves was gotten. Using horizontal distribution of sound speed profile led by internal waves, acoustic fields vs. time through internal waves was approximately calculated. Simulating result in figure 9 very approached experiment result.

III. SUMMERY AND FUTURE WORK

This paper just gives some analytic results of acoustic data of 2009 Yellow Sea experiment, not involves internal waves data and combines internal waves data and acoustic data. So we will have a lot of work to do in the future. Through analysing acoustic data, some results were gotten.

Internal tide and high frequency internal waves were observed during acoustic experiment and caused 260 Hz sound propagation mode coupling. During acoustic experiment, array receiving signals amplitudy's depth distribution show that receiving sound field has only one mode in some time. Alternate of mode 2 and mode 1 was observed, which means that mode coupling caused by internal waves existed. Mode coupling caused strong energy fluctuation of receiving acoustic field at almost every depth. The peak to peak value of energy fluctuation exceeded 20 dB. Acoustic fluctuations between upper receiving depths and lower receiving depths were opposite. The transition point depth was about 24 m. This depth was the zero value depth of mode 2 and closed to maximum value depth of mode 1.

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