ANALYSIS OF ACOUSTIC MODE AND ITS VARIATION IN THE SOUTH CHINA SEA

Linus Y.S Chiu, Andrea Y.Y Chang, Chi-Fang Chen

a No. 1, Sec. 4, Roosevelt Road, Taipei, 10617 Taiwan

Chi-Fang Chen
Department of Engineering Science and Ocean Engineering, National Taiwan University
No. 1, Sec. 4, Roosevelt Road, Taipei, 10617 Taiwan
Fax: +886-2-33665762
Chifang@ntu.edu.tw

Abstract: Recent research has shown the evolutions of internal tides and nonlinear internal waves in coastal region in the South China Seas (SCS). Depression waves were observed on the slope and shelf region in Asian Seas International Acoustics Experiment (ASIAEX) SCS experiment. The propagating internal waves (or tides) would cause acoustic mode coupling and result in intensity fluctuations or arrival pattern variations. This paper investigates the variations of the modes at the vertical line array (VLA) location by using of the pseudo-inverse (PI) filter with the acoustic data of ASIAEX and simulations based on ocean data of ASIAEX. The results show that the influence of the nonlinear internal waves on the mode fields is different from that of internal tides.

Keywords: Acoustic mode, Mode filtering, Mode variation, South China Sea
1. INTRODUCTION

South China Sea has extreme water volume interactions that affect the acoustical propagation. A series of observation by oceanographers inferred that the water column is impact by both the tides and its interaction with the bathymetry. Such instability sound speed profile might cause the acoustical modal coupling, and the coupled mode is the main factor of the variation of the received signal structure.

Modal theory was begun with the work of Pekris in 1948 [1]. He implied that the acoustic pressure field in shallow water is well described by superposition of normal modes. The basic property and concept of normal mode is that acoustic signal carried by modes which have the vertical distribution of energy. A mode can be regarded as a standing wave pattern among the waveguide, and it is, in fact, the convergence of reflection wave with the same grazing angle to the upper and lower boundary.

According to the ASIAEX researches, the internal tide and internal wave were probably generated near the Batan Island, and propagated northwesterly toward the shelf break [2]. Because the internal tides and internal waves move from deep water to the slope and shelf, the amplitude and the horizontal scale of them would change gradually [3]. If the water depth keeps decreasing, the internal waves and internal tides could reach the turning point and transfer from depression wave to elevation wave [4]. This transformation results in different mechanism of motion, and may have different influence on the acoustic propagation [5].

On the other hand, the analyses of the acoustic data in ASIAEX showed that the nonlinear internal wave or the internal tide would bring about acoustic mode coupling when it passed through the acoustic propagation path. And it furthermore caused the variability of the spatial distribution of the sound intensity, especially the nonlinear internal wave [6].

A propagating mode is the important physical quantities in shallow water acoustics. The papers which had been published do not put much effort on modal analysis in this test area. This paper is aimed to the observed water column activity of this area, divides into three oceanographic environments, the background-, the internal tides- and the internal wave fields. The PI mode filtering method was exploited.

2. THE ASIAN SEAS INTERNATIONAL ACOUSTICS EXPERIMENT

ASIAEX was conducted in South China Sea (SCS) and East China Sea (ECS) to perform the survey of acoustics, oceanography, and geology. There were four acoustic mooring components deployed in the test area, included two source moorings and two receiver arrays. The horizontal- and vertical-array were resided at the 120-m water depth (on the shelf break). Two source clusters were placed along-shelf (120-m, east of the receiver) and across-shelf (350-m, south of the receiver) from the receiver, so that we could examine the differences among these two transmission geometry on the propagation. In this paper, the analysis of across-shelf propagating path is concentrated, and the acoustical data were collected from the VLA of this system.

We also present temperature data from four environmental moorings, one was a near-receiver mooring at 120-m, called env120; one was near the southern source at 350-m, called env350, and one was moored in between, called env200. These three moorings approximately covered the southern acoustical path and monitored the temperature.
variation by time. The 10 temperature sensors were also attached on the VLA, and the data could provide the sound speed information at receiver. Sampling rates of these three moorings were half-minutes, one minute and two minutes.

3. IMPLEMENTATION

3.1. Environmental Temperature Data

As described above, a cross-shelf acoustic channel was studied. There were three thermometer string named env-350, env-200, and env-120 deployed along this track, which are corresponding to water depth of 350 m, 200 m, and 120 m, respectively. Additionally, several thermometers were attached on the VLA neat Env-120.

Fig. 2 illustrates the portion of temperature time series, (a), (b), and (c) gives that of env350, env200 and env120. From top to bottom in each panel are the data from 4 to 11 May. Both the illustration of geometry from Fig.1 and the temperature data at about 08:00 on May 8 reveal that the huge leading of nonlinear internal waves entered the acoustical propagation path, passed through env200 about 12:00, and finally arrived at env120 and deviated the propagation path about 15:00 on that day.

Fig. 2 The temperature data collected in ASIAEX. From left to right are the temperature data recorded by Env-350, Env-200, and Env-120, respectively.

Furthermore, the environment could be separated into three different periods by the observation of the temperature data: May 4-5 were with a much less energetic field, called the internal tide field; May 6-11 were with the passage of several huge solitons that depressed the thermocline to the sea bottom, called the nonlinear internal wave field. On the contrary, during the neap tide, the less energy were carried by tidal waves, nonlinear phenomena was not apparent to bring the huge solitons but the internal tides. Compare this two separated oceanographic phenomena, the internal tides had less height wave amplitude but the larger horizontal scale, that means, the internal tides might have more coverage of the acoustical path but had less depress on isotherms.

In this paper, the focus is on the explaining and contrasting the modal variation and signature in three separated periods having extreme environments: background, internal tides and nonlinear internal wave field. The definition is followed as the solid-frame, dash-frame and dot-dash frame in the Fig.2, respectively. Solid-frame in Fig2 is the time of background case, which is during AM2:00-AM7:00 on May 5. In the whole picture of Fig.2, this time period had very calm sea state among the acoustical track, it means, no violent current or tidal motion occurred during that period. This could be regarded as the common, calm and in general case of the ocean, and called the background case which has the typical downward refracting sound speed profile.
The tidal field was chosen at AM8:00-13:00 on May 4, since the internal tide had entered env350 at about 08:00, that means, the entrance of the internal tide was starting to affect acoustical path from 08:00 and still approaching the VLA among these 5 hours. By the observation of env120 data, the leading edge of the internal tide was passing the env120 at 13:00, this 5 hours period was chosen to guarantee that the internal tide covered the whole acoustical propagation path.

In contrast, the nonlinear internal wave field was picked from AM8:00-13:00 on May 8. By the data of env350, the water was extremely shaken by the soliton packets; it could cause the exceeding 150-m isothermal depressions to the path. Alike the time length of tidal period, the 5 hours period of dynamic nonlinear internal wave field were selected to guarantee the coverage of propagating path by the solitons. These three time periods were all 5 hours and the further acoustical analysis and results will be addressed in the next section.

4.2 Mode Filtering

Fig.3 shows the local mode function obtained by the temperature strings which attached on the VLA. From left to right column are the mode 1 and mode 3 on May 5, 4 and 8, x-axis and y-axis gives the time of the day and the depth label, respectively, heavy color implies the peak amplitude of the modal function. Among the range labeled by two dash-lines, from left to right are the case of background, internal tides and nonlinear internal wave field defined in this paper.

Since the local mode functions were obtained, the estimation of mode amplitude was followed the algorithm of section 2, the received signal of 16 hydrophones at each time period were given in $P$, the mode function as described in Fig3 were given in $U$, therefore, the mode amplitudes were estimated from Eq. (4) by using PI method for three separated time period. The 16 mode amplitudes were calculated by following the detail formula described in section 2.

Fig.4 shows the probability density function of estimated mode amplitudes of 16 modes. The first raw of Fig. 4, from left to right are the probability distributions of the estimated modes among the background, internal tide and nonlinear internal wave cases. Sample times were all 5 hours, x- and y axis gives the value (dB scale) of the estimated mode amplitude and mode number. Heavy color expresses the higher probability. On the bottom row, from left to right, are both the mean and standard deviation function of the mode amplitudes corresponding to each upper panel among 5 hours. The transverse lines are the S.D. and the dots are the mean value.
Fig. 5 and Fig. 6 show the more details of mean function and standard derivation of three separated cases, both y-axes label the mode number, and x-axis in each figure labels the magnitude of the mean value and S.D. respectively. Solid line, solid-star line and solid-square line in these two figures are the case of background, internal tides and nonlinear internal wave field.

According to the mean function in Fig.5, due to the interaction of bathymetry and water column activity, mode 2-5 were all the dominated modes at the receiver for these three cases.

In the background case, the mean of mode 1 amplitude is apparently higher than other higher order modes, but the standard deviation are also higher than other modes. For the result of higher S.D. of mode 1, is that the it had two concentrations of samples among its distribution, which means mode 1 amplitude at some period had more intense energy, and this needs to be investigated further in the future.

From Fig.5, the mean of amplitudes of mode 4, 14 and 15 are slightly raising, but those of mode 7 and 9 are decreasing, that means, as the internal tides and nonlinear internal waves were propagating among the acoustic track, the coupled energy had the tendency from lower to higher mode, especially in mode 1.

Moreover, according to the S.D. shown in Fig.6, the S.D. of the dominated modes (2-5) and higher modes were much higher than those of the background case as the internal tides and waves were in the path.

But for the case of nonlinear internal wave, only mode 7 had the S.D. identical to that of the case of background, all the other modes had increasing variation on S.D. The higher standard deviation both in the case of tides and waves affirmatively imply that, the sound field was not merely or once affected by the depression of isotherms by the tide or waves, but it could repeatedly interact both with bathymetry and water column property range by range. This may cause the very different mode amplitudes even if the specific mode was tracked when the depression waves were propagating. Otherwise, one may not observe the very higher std among the 5 hours whatever in the case of tides or waves.

4. CONCLUSION

The variations of the mode amplitudes via the shelf bathymetry in three extremely different environments, background, internal tides, and nonlinear internal waves, were analyzed in this paper. The results show that the acoustic fields were all dominated by mode 2-5, but mode 1 has the maximum energy in the case of background. Since in the background case, the water column was not extremely shaken by the depression of the
tidal- or nonlinear-waves, the very slight variation of the standard deviation on dominated modes were sensibly expected. The energy exchange among modes while in the case of internal tides or nonlinear internal waves were clearly observed in the mean value of the modes, this indicates that, as the water column were highly agitated or diffused by the energetic internal activity of water column, such as waves or tides, the redistribution of vertical structure of sound field would appear.

As the tides and waves entered and moved along the path, higher standard deviation of each mode amplitude occurred, this gives the explanations for the scattered intensity patterns among the whole water column observed by Chiu [10] and Tuda [12]. Even though the vertical line array did not span the whole water column (only covered the lower two-third water column), that is to say, less-than-perfect mode filtration competence would came up by the geometry (the lack of one-third information), but the observed sound speed profile modulated the sound channel to concentrate the most energy in the lower water column, still resulting in good result even if the lack of the information of the upper water column.

Internal wave activities are very acute and intense in the South China Sea, one would also observe the entirely different propagating waves, called the elevation waves, from the collecting data. Those were conjectured to cause the different influence on acoustical propagation and needed more effort on it to distinguish the impact on acoustics by the typical waves generated in the South China Sea.

REFERENCES