Mode-2 internal solitary waves offshore Central America discovered by seismic oceanography method

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1. Introduction

With the advancement of on-site observation instruments, the mode-2 ISWs developed in the ocean have been gradually observed over the past 20 years. The sea water along the Pacific coast of Central America (Western Nicaragua) has the seafloor depths between 100 m and 2000 m. Previous scholars have done little research on the internal waves in this area, focusing more on the effects of the winter Tehuantepec monsoon, Papagayo monsoon and Panama monsoon on the sea surface temperature distribution and circulation. In the past, most of the internal solitary waves discovered by seismic oceanography method were the mode-1 ISWs. Recently, seismic oceanography method has been used to reprocess the existing seismic data of the Pacific coast of Central America, and we find the mode-2 ISWs group on the survey line. This ISW group is a relatively complete mode-2 ISWs group discovered by seismic oceanography method for the first time. Based on the current results and previous work, we will mainly study the mode-2 ISWs in the Pacific coast of Central America about the vertical structure characteristics, and the internal solitary wave propagation characteristics.

2. Data and methods

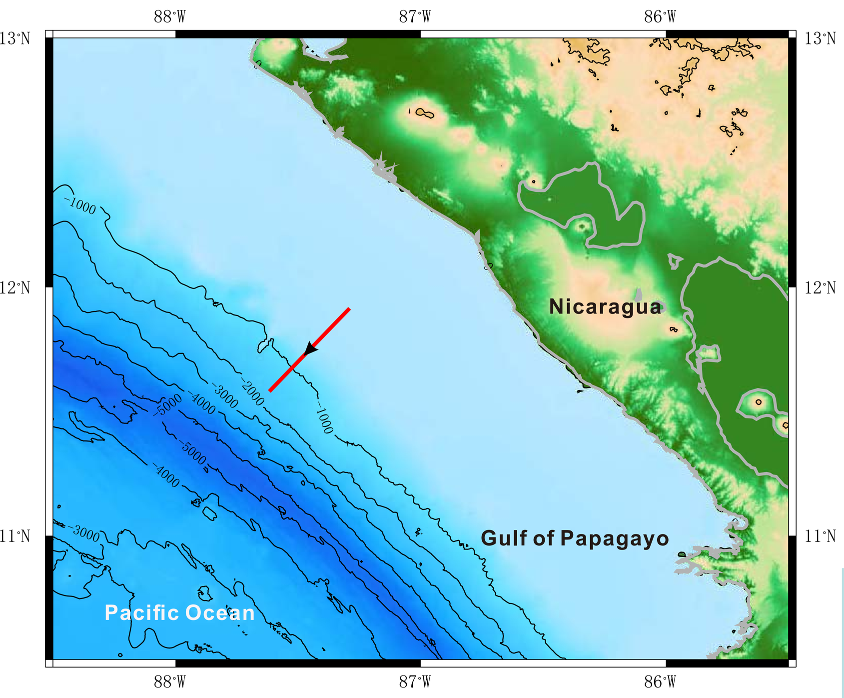


Figure 1. Distribution of multi-channel seismic data. The red line shows the survey line 88 position. The black arrow on the line indicates the ship direction.

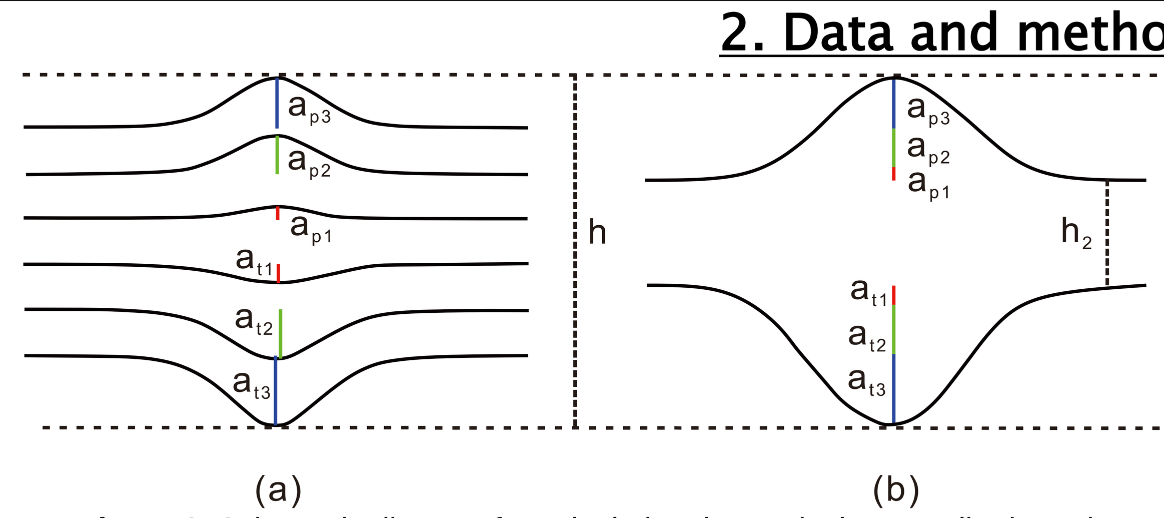
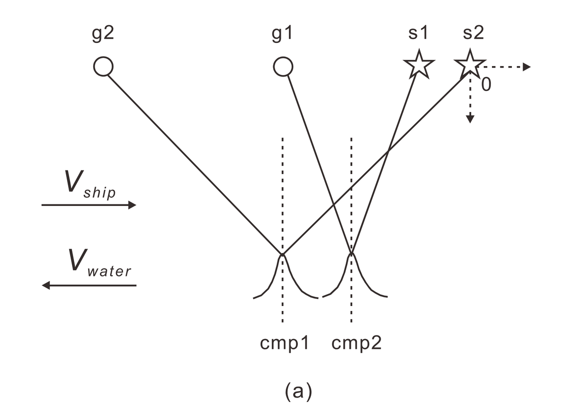


Figure 2. Schematic diagram for calculating the equivalent amplitude and equivalent pycnocline thickness for mode-2 ISWs .

For the mode-2 ISWs with a multilayer structure (Figure 2a), the peak amplitudes of each ISWs (a_{p1}, a_{p2} and a_{p3}) are obtained. The sum of the peak amplitudes of all ISWs (the sum of a_{p1}, a_{p2} and a_{p3} is a_p) is taken as the equivalent peak amplitude of the mode-2 ISWs with a three-layer model structure (Figure 2b).



The horizon velocity of the ISWs trough or peak (v) can be expressed as: $v=(cmp2-cmp1)/T=(cmp2-cmp1)/[(s2-s1)*dt]$. where *cmp1* and *cmp2* are the ISWs trough or peak positions at different time, *s1* and *s2* are the shot numbers corresponding to *cmp1* and *cmp2*, and *dt* is the time interval for shots.

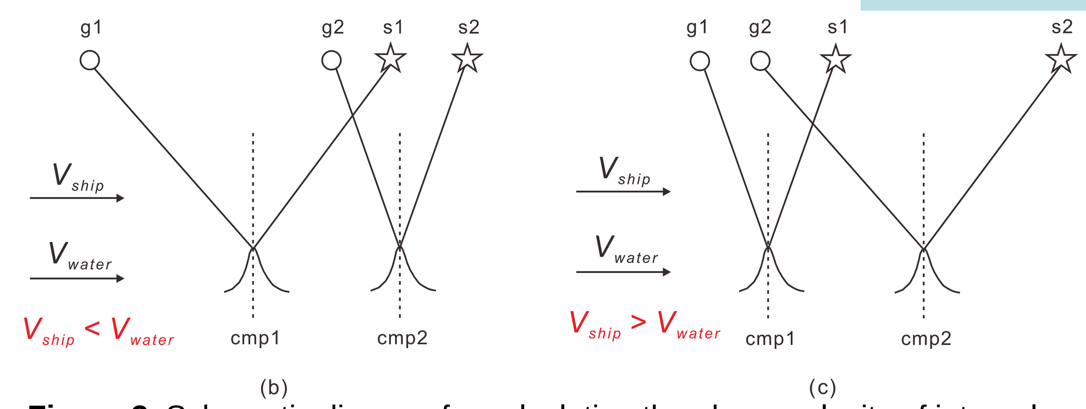


Figure 3. Schematic diagram for calculating the phase velocity of internal solitary waves.

When the ISWs propagates in the opposite direction to the ship, as the offset increases, the CMP number corresponding to the same one ISWs during movement decreases, and the shot number increases (opposite trend, Figure 3a). Vice versa.

3. Mode-2 ISWs vertical structure

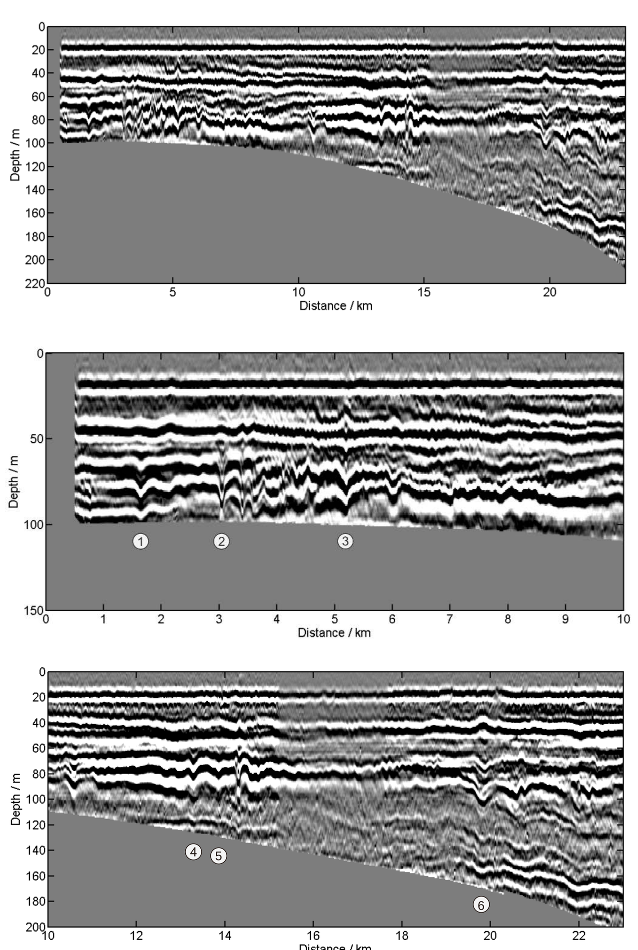


Figure 4. Mode-2 internal solitary wave in seismic stacked section for survey line 88. Line acquisition time is 00:36:20 - 06:22:41, December 17th, 2004.

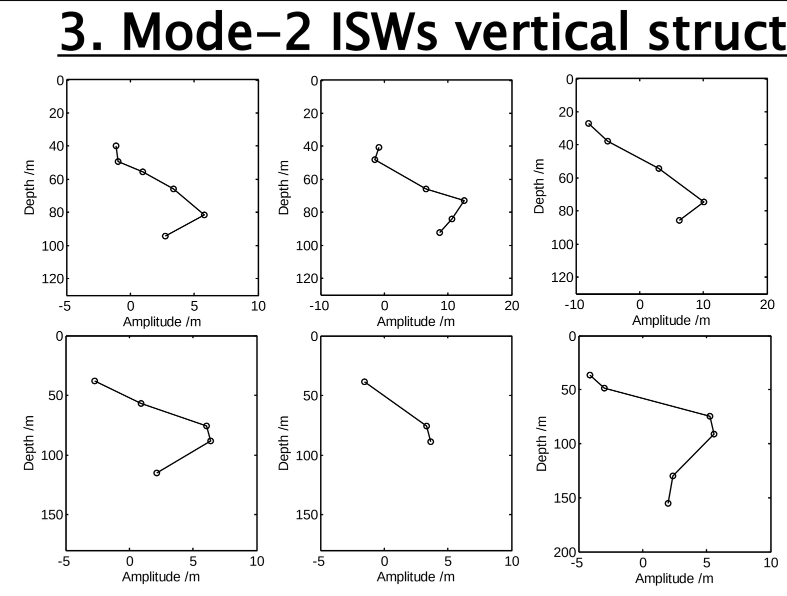


Figure 5. The amplitude of the six mode-2 internal solitary waves selected in survey line 88 varies with the water depth.

The amplitudes of the mode-2 ISWs generally decrease first, then increase, and finally decrease with the increase of depths (Figure 5).

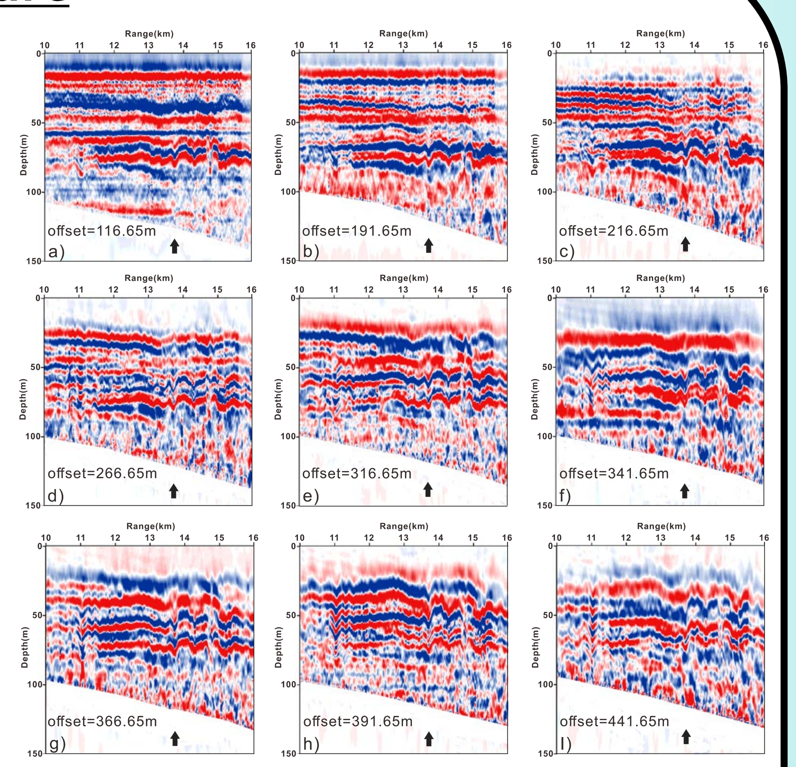


Figure 6. Pre-stack migration observes the changes in the fine structure of the mode-2 ISWs ISW4 in the survey line 88.

As to the ISW4, during the acquisition of about 50 seconds, the bifurcation and merger of the reflection event appear (Figure 6).

The dimensionless amplitudes of ISW1, ISW3-ISW6 correspond to the case of $2a/h_2<2$, which are the small-amplitude mode-2 ISWs. The dimensionless amplitude of ISW2 corresponds to the case of $2a/h_2\geq4$, which is the mode-2 ISW with very-large amplitude. Its wave front is smoother, and the tail is unstable.

For ISW3- ISW6 with large pycnocline deviations, their waveforms become asymmetrical. The high frequency internal waves are more developed at their tail side.

Table 1. Characteristic parameters of the six mode-2 internal solitary waves in survey line 88.

ISW#	*H* (m)	*Am* (m)	h_2 (m)	*a* (m)	$2a/h_2$	*hc* (m)	1/2*H* (m)	*Op*(%*H*)
1	106.95	5.79	39.58	12.71	0.64	52.52	53.48	0.9
2	105.53	12.55	11.11	38.46	6.92	54.29	52.77	1.4
3	107.93	10.14	26.06	19.48	1.5	47.05	53.97	6.4
4	132.83	6.38	58.9	15.49	0.53	48.59	66.42	13.4
5	135.75	3.64	41.6	6.88	0.34	56.18	67.88	8.6
6	173.93	5.57	84.22	27.43	0.65	60.57	86.97	15.2

***H*, seafloor depths; *Am*, maximum amplitudes; h_2, equivalent pycnocline thicknesses; *a*, equivalent ISWs amplitudes; *hc*, the mid-depths of the pycnocline; *Op*, the degree to which the mid-depth of the pycnocline deviates from 1/2 seafloor depth.**

4. Mdoe-2 ISWs phase velocity

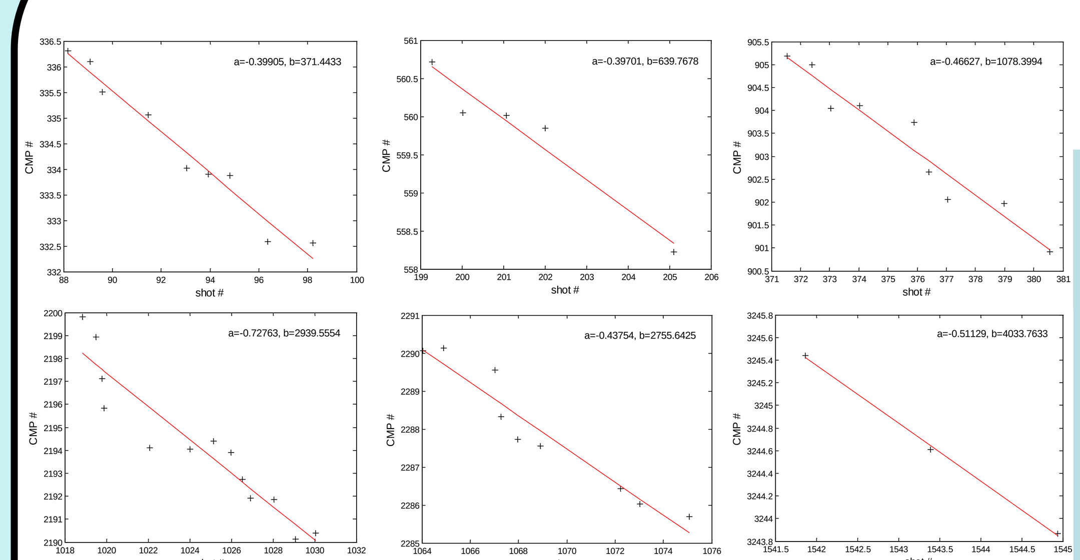


Figure 7. The fitting curves of CMP-shot pairs obtained from the pre-stack migration sections of the COGs

The apparent phase velocities of these mode-2 ISWs calculated by the pre-stack migration profile using COG are about 0.5 m/s, and their apparent propagation directions are from SW to NE along the seismic line. The apparent phase velocity of mode-2 ISWs generally increases with the increasing depth of water (comparing ISW1, ISW3 and ISW5). In addition, the apparent phase velocity of the mode-2 ISWs with a larger maximum amplitude is generally larger (comparing ISW3 with ISW5).

Table 2. Apparent phase velocities of the six mode-2 internal solitary waves in survey line 88.

ISW#	*H* (m)	*Am* (m)	V_{seis} (m/s)	*Da*	V_{KdV} (m/s)
1	106.95	5.79	0.48±0.08	44°N	0.41
2	105.53	12.55	0.48±0.22	44°N	0.44
3	107.93	10.14	0.57±0.13	44°N	0.43
4	132.83	6.38	0.88±0.21	44°N	0.41
5	135.75	3.64	0.55±0.14	44°N	0.4
6	173.93	5.57	0.64±0.31	44°N	0.41

***H*, seafloor depths; *Am*, maximum amplitudes; V_{seis}, apparent phase velocities obtained from seismic observation; *Da*, apparent propagation directions; V_{KdV}, phase velocities obtained from KdV model.**

5. Discussion

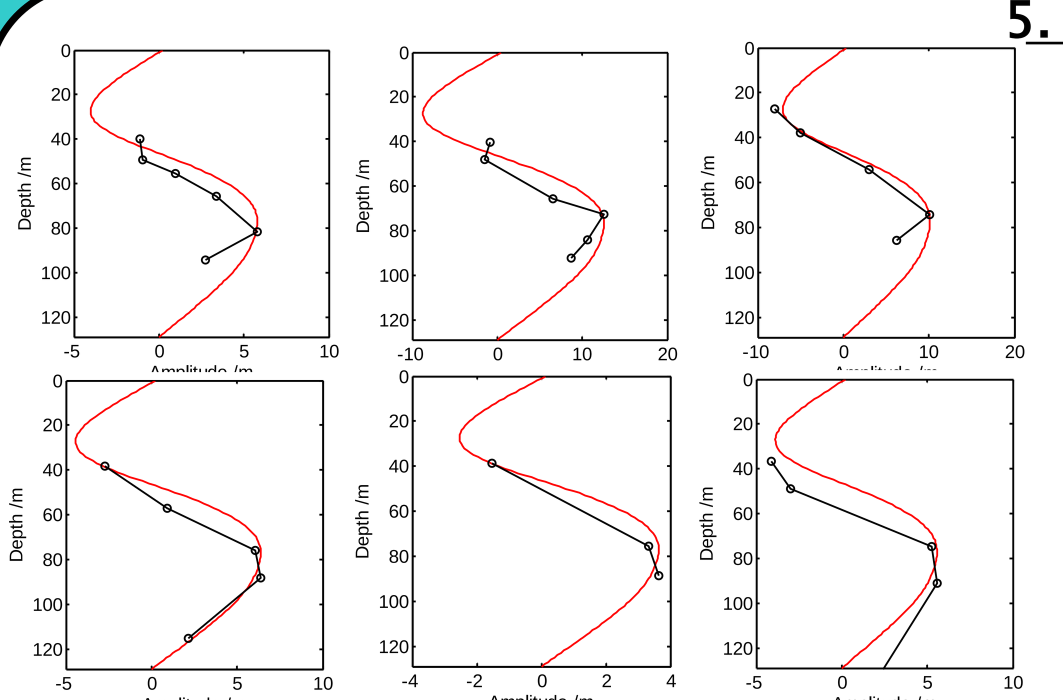


Figure 9. KdV theory fits the vertical amplitude distributions of the mode-2 ISWs.

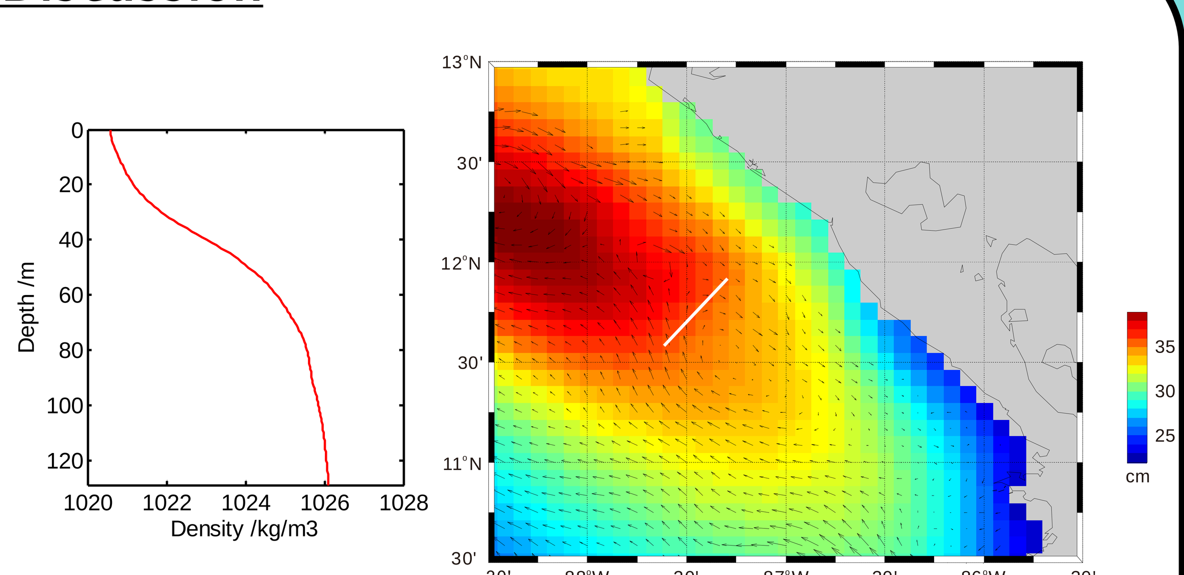


Figure 10. The density curve at ISW1 (left). The corresponding geostrophic current velocity (the depth is 78 m below the sea surface) and sea surface height during the acquisition of the survey line 88 (right).

The red curves in Figure 9 are the vertical amplitude distributions of the mode-2 ISWs calculated by the KdV equation. The depths of the maximum vertical mode values are basically the same as the depths of the ISWs maximum amplitudes, and the observed variation trends of the ISWs amplitudes are also close to the theory. It can be seen that the survey line 76 is affected by the anticyclone edge (Figure 10). Anticyclone will increase the depth of the thermocline in the surrounding sea water, while the deepening of the thermocline (pycnocline) is conducive to the generation of the mode-2 ISWs.

Conclusions

✓As to the mode-2 ISWs ISW4 located on the land slope, during the acquisition of about 50 seconds, the bifurcation and merger of the reflection event appear.

✓The apparent phase velocities of these mode-2 ISWs calculated by the pre-stack migration profile using the Common Offset Gather (COG) are about 0.5 m/s, and their apparent propagation directions are from SW to NE along the seismic line (44 N, 0° pointing north).

✓The apparent phase velocity of mode-2 ISWs generally increases with the increasing depth of water. In addition, the apparent phase velocity of the mode-2 ISWs with a larger maximum amplitude is generally larger.

Acknowledgments

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