

# AMBIENT NOISE INDUCED BY LARGE-AMPLITUDE INTERNAL WAVES IN THE OCEAN

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*Experimental data on the ambient noise generated by large-amplitude internal waves in the ocean are considered. The data are obtained by us during oceanic expeditions in the Indian Ocean and South China Sea. In both cases the generation of noise was caused by solitary internal waves with 50-m amplitudes. The internal waves were accompanied by strong orbital currents (up to 1.5 m/s) which created intense convergence with choppy surface waves at the sea surface. Simultaneous observations of internal waves and parameters of the ambient noise were carried out from a drifting vessel during calm weather. In both cases, the increase in the level of the ambient noise coincided with the passages of internal waves. The analysis of experimental data and the data of numerically modeling are presented.*

## INTRODUCTION

Until recently, it was believed that the influence of internal waves on ambient noise in the ocean is limited mainly to noise modulation, with the amplitude and periods determined by the parameters of internal waves. For instance, a horizontally oriented acoustic antenna placed within a thermocline layer can record a passage of internal waves on the basis of fluctuations in the noise from surface sources [1]. However, direct generation of noise by the internal wave is also possible. Investigators of large-amplitude internal waves in the ocean have known this for the long time: the appearance of these waves is accompanied by generation of intense surface rips (bands of rough water) and noises easily distinguished by the human ear. The band of rough

water is formed at the convergence of orbital currents of the internal wave and represents a field of chaotically chopping waves on the ocean surface with the collapse of surface waves, foaming, and entrainment of air bubbles and their transportation to depths by orbital movements of internal waves. The nonlinear interaction between surface waves, which is undoubtedly typical for of the rips band, might result in acoustic radiation to water [2, 3]. Entrapped air bubbles also generate ambient noise. We have measured twice characteristics of noise generated by large-amplitude internal waves in the Ocean. It was carried out near the Mascarene Ridge in the Indian Ocean and in the Luzon Strait of the South China Sea. To show results of the measurements is the main task of this paper.

## 1. OBSERVATIONS AT THE MASCARENE RIDGE

The Mascarene Ridge in the Indian Ocean, where simultaneous studies of ambient noises and internal waves were carried out during the cruise of the R/V Akademik Nikolay Andreyev in December 1990, is well known for the generation of anomalous large-amplitude internal waves [4]. Internal waves have been measured during ship drifting using a line temperature sensor placed within the upper thermocline layer and CTD sonde for “yo-yo” sounding. In addition, the movement of the rip bends across the ocean surface was controlled by the ship radar.

Ambient noise was measured using a receiver system consisting of four vertically distributed high-frequency (5 – 100 kHz) and one low-frequency (0.1 – 20 kHz) hydrophones. The receiver system was placed at a depth of 100 m. The observations were made during calm weather. Vertical sound speed profile was characterized by the following parameters: the uniform near-surface layer (1540 m/s) reached a depth of 50 m; the zone with maximal gradient of sound speed corresponded to the depth interval of 60-200 m; the axis of the underwater sound channel was located at a depth of 1500 m (1493 m/c); and the sound velocity near the bottom (depth 2.8 km) was 1504 m/s.

The solitary nonlinear internal wave (approximately 50 m high) coming from the direction of the underwater ridge passed beneath the drifting ship between 14:00 and 17:00 LT, December 6 (Fig. 1). The wave was accompanied by a wide (approximately 1.5 km) rip band, which was clearly distinguishable on the radar screen and was propagating to the south-east direction with a velocity of 2.5 m/s.

For technical reasons, the salience regime on the ship could not be maintained during measurements. Therefore, spectral noise levels measured at frequencies below 0.3 kHz were superimposed by substantial additional noises from ship equipment and were filtered using high-frequency filter. Recording was started at 15:29 LT (when the rip band approached the ship for a distance of 0.7 miles) and terminated at 16:16 LT.

Processing of the records yielded the spectra of underwater ambient noises and the functions of their coherence during the vertical displacement of hydrophones at different moments of the rip band passage, as well as temporal variations in noise levels in the third-octave bands. Figure 2 demonstrates changes in the spectral characteristics of ambient noises during the rip band movement across the ocean surface. It shows, in particular, the record of temporal changes in the level of ambient noise received by the low-frequency hydrophone in the wide frequency band (Fig.2a), as well as spectral levels (Fig.2b) and coherence functions (Fig. 2c) at

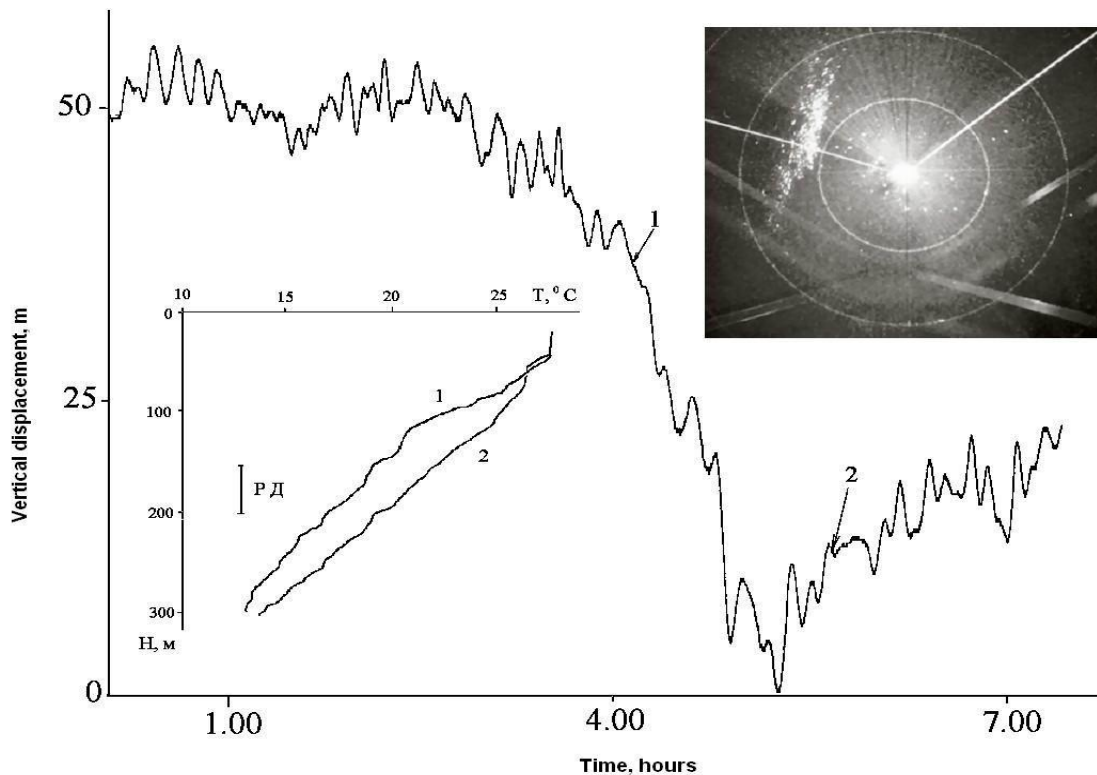


Fig.1. Record of the 50-m internal wave made by the line temperature sensor (near the Mascarene Ridge, December, 6, 1990) and radar image of the rip band (15:00 LT, December, 6). The rip band approaches the drifting ship from northwest. The passage of the rip band corresponded to the sharp sink of thermocline. Inset shows vertical temperature profiles for moments corresponding to (1) 16:11 LT and (2) 17:38 LT and position of line temperature sensor

frequencies of 1-50 kHz that were measured by the high-frequency hydrophone at the moments marked by solid dots in Fig.2a (1-4). The lower curves in Fig.2b and 2c correspond to the receiver system noise level. The onset of the noise increase in the receiver system correlates with the arrival time of the rip band front to the receiver system-overlying ocean surface point. The analysis of results obtained shows that the lateral rip band's movement across the ocean surface results in significant (up to 18 dB at frequencies of 5-15 kHz) increase in the level of underwater noise. In this case, the coherence function (Fig. 2c) obtained for the neighboring hydrophones vertically spaced at a distance of 4 cm tends to unity. This indicates that the majority of powerful noise sources were located near the ocean surface; i.e., they were generated by the rip band.

To model the process of generating the noise during the strip of rips over the receiving hydrophone, the computer code [5] for calculating noise characteristics in the uniformly layered ocean was updated. In the ray approximation, such a code allows one to model the effects accompanying the passage of an internal wave. Those effects exhibit themselves in changing the angular width of the refraction minimum in the vertical anisotropy of the noise field under the influence of the change in the sound speed at the reception horizon affected by the internal wave.

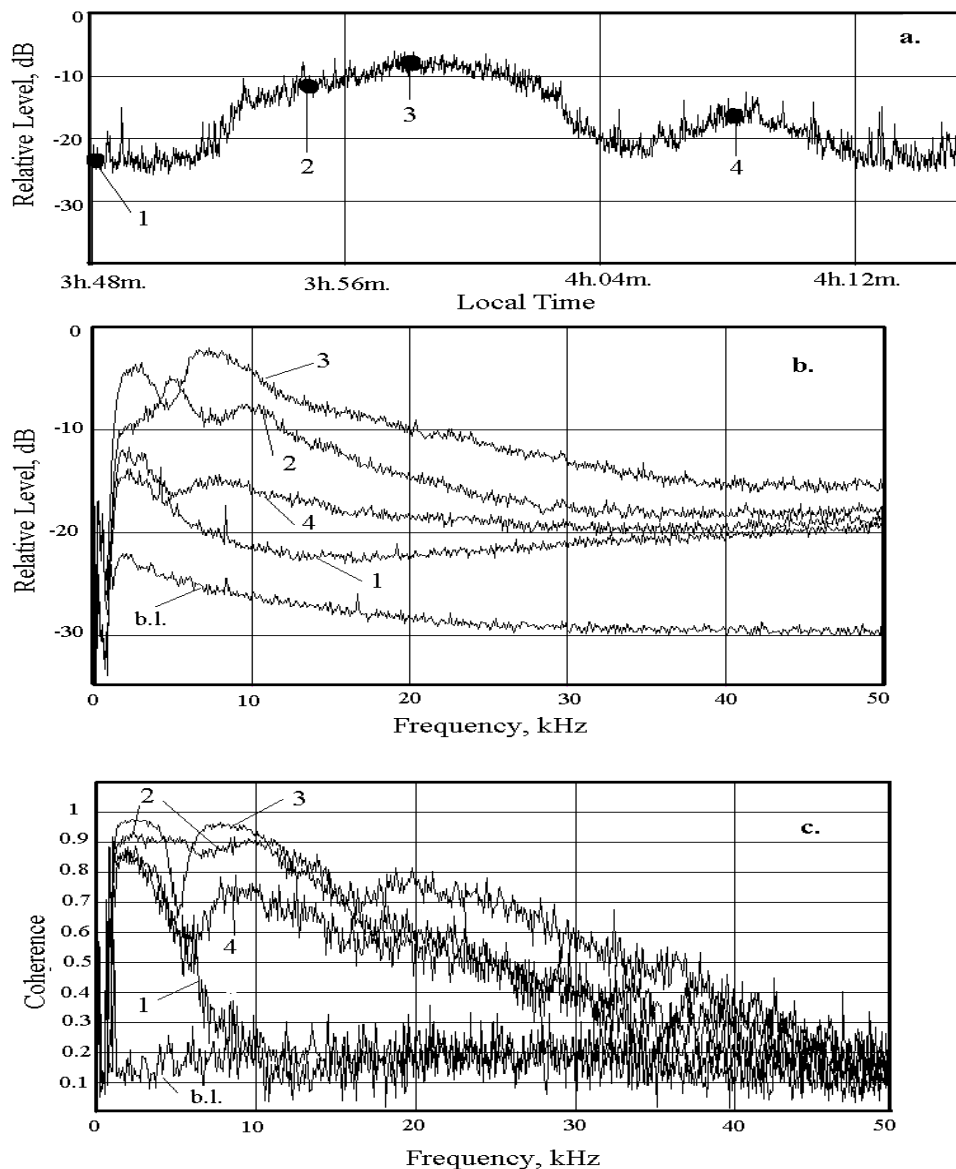


Fig.2. Effect of the rip band on spectral characteristics of oceanic noises.(a) Temporal changes of the noise level received by omnidirectional hydrophone in the wide frequency band (low-frequency hydrophone); (b) spectral noise levels at moments marked by nos. 1- 4 in Fig. 2a (high-frequency hydrophone); (c) noise coherent functions at moments marked by nos. 1-4 in Fig. 2a ((high-frequency hydrophones)

In such a process, the power density of the surface noise sources is assumed to be constant over the entire noise-generating zone [6]. The updated computer code can model the rip strip propagating over the ocean surface in the form of an area of a specified width and infinite length in which the noise sources (their surface power density and directivity pattern) may differ from those at the rest of the area. An example is shown in Fig. 3 where the calculation of the variation in the noise level received by an omnidirectional hydrophone is presented for the case of passing

the rip strip with a width of 1500 m. The point with the zero coordinate on the abscissa axis corresponds to the position of the front of the rip over the receiving hydrophone while the 4500-m point corresponds to its farthest frontier in its removal. The reception depth is 100 m, the frequency is 1 kHz, the vertical profile of the sound speed corresponds to the environment of the Mascarene Ridge in the Indian Ocean. The level of the noise generated by the wind-driven surface sources corresponds to a wind speed of 5 m/s over the noise-inducing area, the directivity pattern of the noise sources is specified as  $\sim \text{Cos}^2\alpha_{in}$  where  $\alpha_{in}$  is the incidence angle at the surface. In the calculations, the power density of the noise sources in the rips was specified by 12 dB higher than those at the rest of the area but the directivity pattern was not changed. Figure 3 shows that the level of the noise decreases to that generated by the wind at a distance of the order of the rip width from the nearest rip boundary. It is worth mentioning that the influence of the rips on the received noise level can decrease slower or steeper according to the profile of the sound speed and the reception depth.

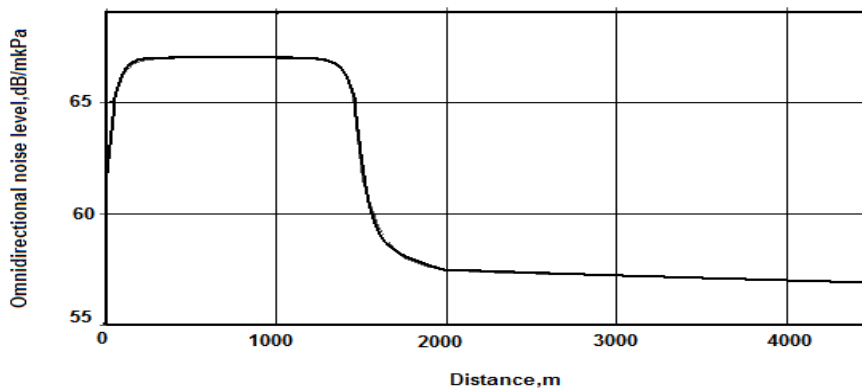


Fig.3. Calculated variations of the level of noise received by the omnidirectional hydrophone during the passage of the rip strip with a width of 1500 m over the sea surface

## 2. OBSERVATIONS IN THE LUZON STRAIT

The measurements in the South China Sea were carried out at the Luzon Strait, on May 2006. The South China Sea is a unique place where internal waves of highest amplitudes exist (lately, an internal wave of as high as 170 m was recorded here). We performed the measurements from «Ocean Researcher 1» vessel of the National Taiwan University. The experiment was carried out in the second part of May, with calm weather, several days after the passage of the Chinchu typhoon.

The noises were measured by a system that consisted of a hydrophone (1—20 kHz) mounted in a neutral-buoyancy body, at a depth of 70 m. The hydrophone was connected with the drifting vessel by water-isolated wires (see Fig. 4). The neutral-buoyancy body was equipped with a depth sensor to control the horizon of the hydrophone. To monitor the parameters of internal waves, the EK 500 echo-sounder and the ADCP 150 kHz were used, along with the radar data. The aforementioned instruments and the STD sensor are standard facilities of the vessel.

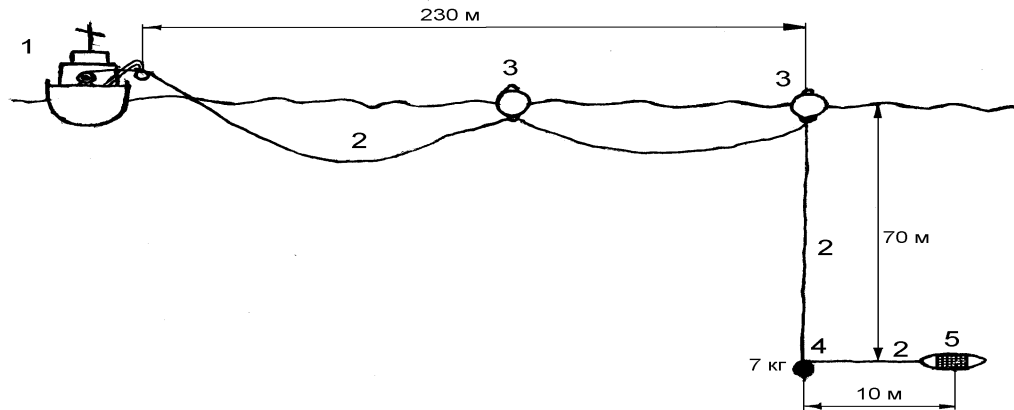


Fig.4. Layout of the noise measurements: (1) drifting vessel; (2) water-isolated connecting the hydrophone (5) with the data-acquisition system aboard the vessel; (5) hydrophone mounted in the neutral-buoyancy body; (3) buoy; (4) load

The measurements were performed during two passages of intense internal waves, on May 23 and 24. In the first experiment of May 23, a solitary wave with a height of 50 m passed under the vessel with a speed of 3.3 m/s in the north-west direction (the estimates are preliminary). The passage of the internal wave was accompanied by a wide strip of the rips that was recorded by the radar of the vessel and a numerical photographic camera (Fig. 5). An extraordinary feature of the observed solitary wave consisted in that it belonged to the second mode (the fact that was established from the echo-sounding data). Note that the propagation speed of the wave was higher than 3m/s, the value that is a record one, even for the South China Sea.



Fig.5. Sea surface during the passage of the solitary internal wave (at the left) and after the passage (at the right). Observations of May 23

The second observation was made on May 24. It coincided with the passage of a train of internal waves with heights of 25—30 m, and a group of rip strips was observed. In both cases, the passages of the strips were accompanied by enhancing the underwater noise. In the first case, the neutral-bouncy body was stable or slightly moved upwards. However, in the second case, it was carried by as high as 10 m in vertical. In passing the rips, surface waves with sharpened crests, rips, and repeated breakdowns appeared. The lengths of the surface waves were several meters, their heights were 0.5—0.8 m.

The data recorded by the hydrophone were processed. Figure 6 presents the record of the level of the noise filtered within a band of 1—2 kHz over the entire period of passing the solitary internal wave on May 23. It can be clearly seen that the signal level first sharply increases and then steeply decreases down to the background one in 10 min. The increase by 5—8 dB takes place during the passage of the face front of the internal wave. Such a feature was observed by us in the measurements in the region of the Mascarene Ridge as well.

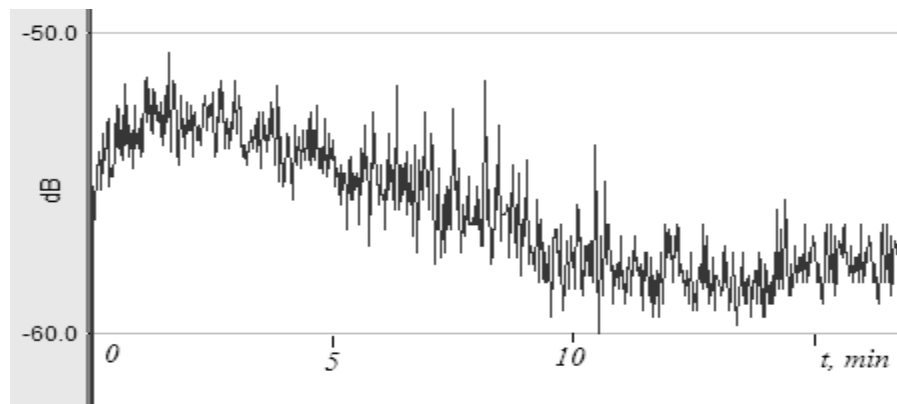


Fig. 6. Variations of the noise level at a frequency of 1 kHz during the passage of solitary internal wave, May 23.

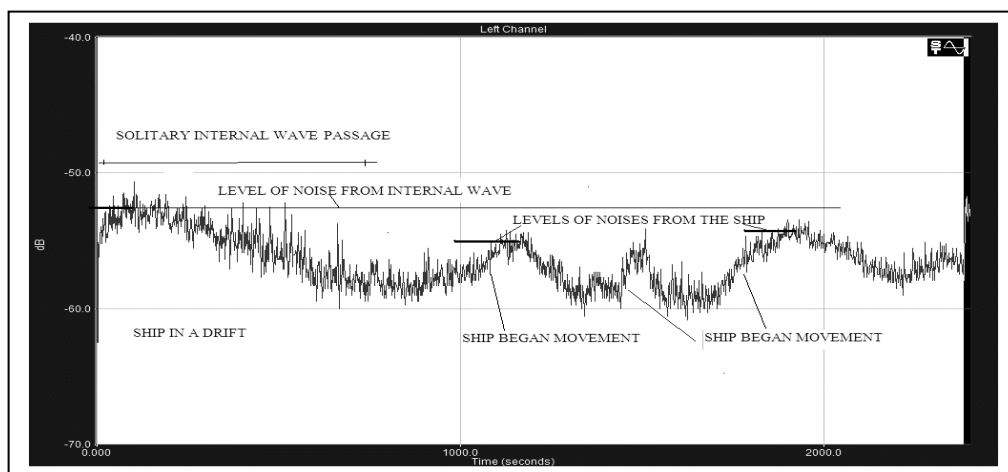


Fig. 7. Comparison of noises generated by the internal wave and the moving vessel at a frequency of 1 kHz

After the passage of the solitary wave, the record of the signal received by the hydrophone was not terminated up to uplifting the system. The entire record obtained on May 23 is shown in Fig. 7. To accelerate the uplifting, the vessel moved back several (three) times and slowly went towards the buoy with the receiving system. As a result, the record exhibits three moments of increasing the level of underwater noise. However, those levels do not reach that of the noise generated by the internal wave with the 50-m height.

No increase in the level of the underwater noise was recorded in the observation of May 24 when the train of internal waves, up to 25 m in height, existed with rip strips accompanying them. The vessel does not allow one to set the silent regime, the characteristic that complicated the work.

### 3. CONCLUSIONS

Thus, the experiments performed in the Luzon Straight yielded new data on the generation of underwater noises by internal-wave solitons in the ocean. Those data approve and supplement earlier observations in the region of the Mascarene Ridge. At the same time, new questions arise. An interest feature consists in generating the second mode by the internal wave (the generation by the first-mode internal wave was observed in the Indian Ocean). The high speed of the internal wave is also an extraordinary phenomenon. Generally, in view of the fact that intense internal waves inducing rip strips are quite common, one can consider the aforementioned mechanism of noise generation to be prevailing at the ocean areas.

### ACKNOWLEDGEMENTS

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