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Boundary Effects on the Shape of Internal Temperature Waves

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1. Introduction

In the sea the temperature variation with depth is usually characterised by a rapid change in the thermocline. However, the depth of the thermocline fluctuates with reference to time and distance. In the Bay of Bengal the depth of the thermocline undergoes an annual cycle, as well as oscillations with periods equal to that of tidal cycles (LaFond and Poornachandra Rao 1954). In addition, along the west coast and the northern part of the Bay, vertical oscillations of shorter period were observed (LaFond 1958). These were found to be related to sea surface slicks (Fig. 1) and to move in a progressive, wave-like fashion. The cause of the short-period internal waves in the sea are believed to be due to oscillating currents over shallow topography and the interaction of water masses, both horizontally and vertically. This paper presents new evidence on the shape of short-period internal waves in shallow water.

2. Observations

The study was made possible by a new instrument called an isotherm follower (LaFond, *see ref.*). The sea unit of the instrument is capable of seeking out any desired temperature, locking onto the temperature, and following it up and down as the internal temperature waves move past the measurement site. With this instrument, recordings of the continuous depth of an isotherm in the thermocline with reference to time provide a plot of the shape of internal waves. Nearly continuous recordings of internal wave shape were made for 5 summer months off Southern California in 60 ft of water.

It was found that the shape of internal waves was dependent upon the depth of the thermocline and thus its proximity to the sea surface and sea bottom. In turn the nature of the sea surface slick related to the internal wave depended on the depth and shape of the internal wave.

3. Discussion

Internal waves are present most of the time on the thermocline or density boundary, which separates lighter density water, ρ', from the underlying heavier water, ρ. They are frequently found when the general depth of thermocline is changing, that is, when it is either rising or sinking, implying that a water mass boundary is passing. When the thermocline was at a mid-depth the internal waves were found to have rounded crests and rounded troughs, and were nearly sinusoidal in shape (Fig. 2A). Whenever the thermocline containing internal waves rose toward the surface, and the crests nearly reach the surface, there is a surface rippling due to the increased horizontal speed of water flowing over the crests (LaFond 1959).

The horizontal speed

$$u' = \frac{a\,c \cos (kx - \sigma t)}{h' - a \cos (kx - \sigma t)}$$

where, h'=average thickness of the upper layer,

a=amplitude of internal wave,

c=wave velocity.

The speed is maximum when h' is minimum and the phase angle $(kx - \sigma t)$ is zero.

However, the ruffled surface does not persist over long distances of wave propagation. Instead, after a dozen or so waves pass, their crests become eroded away by the strong current. Thus the crests become broad and flat (Fig. 2B) as contrasted with the sinusoidal shape observed at mid-depth (Fig. 2A). This type of internal wave has been observed off Southern California when the thermocline remains at depths around 5 to 15 ft.

After the crests become broad and flat and the troughs narrow, the speed of current over the broad crests associated with progressive wave motion is reduced. This is caused by the volume of water in the trough being lessened and the constriction over the crests being largely eliminated. On the other hand when the thermocline approaches the bottom the sinusoidal nature of the troughs soon become eroded by the friction forces of current through the constriction between the trough and sea floor. Then the internal wave troughs become broad and flat and the crests become sharp and pointed (Fig. 2C). When the troughs are near the bottom the increased current under them can be effective in moving sediment. However, when the troughs become flat the effect of sediment-moving-current, created by horizontal motion set up by internal waves is reduced.

The shallow, near-surface thermocline, the internal waves of which are characterized by broad flat crests and narrow troughs, creates a sharp surface convergence at a position between the crest and following trough. This convergence develops an accordingly narrow sea surface slick usually with foam on the surface (Fig. 1). Foam is believed produced by the gravity wave and internal wave turbulence in the near surface layer which is usually supersaturated with gas. The bubbles thus formed rise to the surface and flow toward the convergence zone. Here they remain for long period of time as foam. This is due to the reduced surface tension in the slick region, which contains an organic film (LaFond and Bhavanarayana 1960).

As the thermocline deepens, the circulation in the convergences becomes less intense and the associated surface slicks grow less distinct. When the thermocline is near the bottom, the convergence at the surface is so weak that the slicks are indistinct and sometimes break up in patches. However, when comparison is made of relative wave-motion circulations, the amplitude of the internal wave must be taken into account.

4. Summary

It has been established by observation that the shape of internal waves changes with their proximity to the sea surface and sea floor in shallow water. The internal waves on the thermocline are not sinusoidal, but flattened on crests when the thermocline is shallow and peaked on crests when the thermocline is deep. Any statistical compilation of thermocline depths would be skewed to the shallow side or deep side when the thermocline is shallow or deep, respectively. With the same sized waves, the sea surface slicks become narrow with shallow thermoclines and broad with deep. Thus the characteristics of the underlying thermal structure of the sea may be deduced from the shape, appearance, and motion of sea surface slicks.

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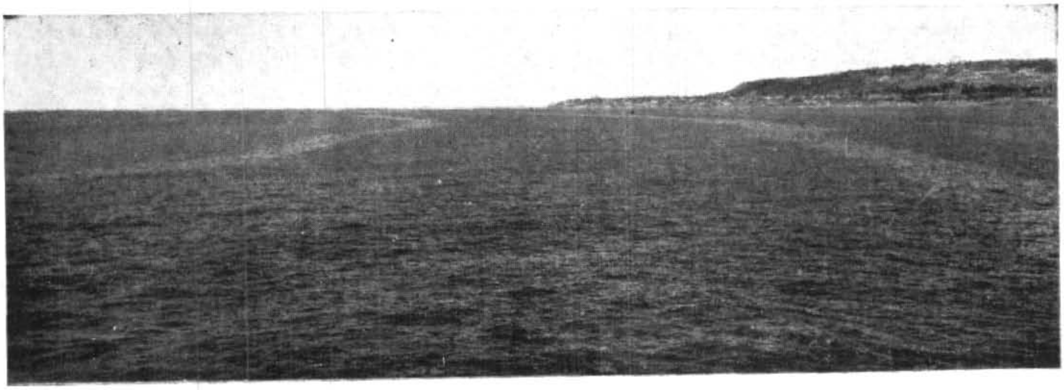

Fig. 1. Narrow sea surface slicks indicative of a shallow thermocline

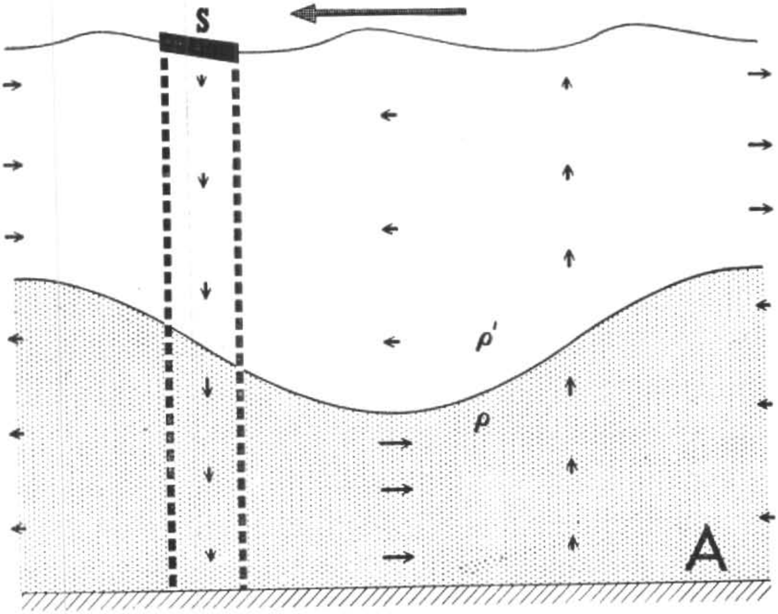

Fig. 2(A). Mid-depth thermocline

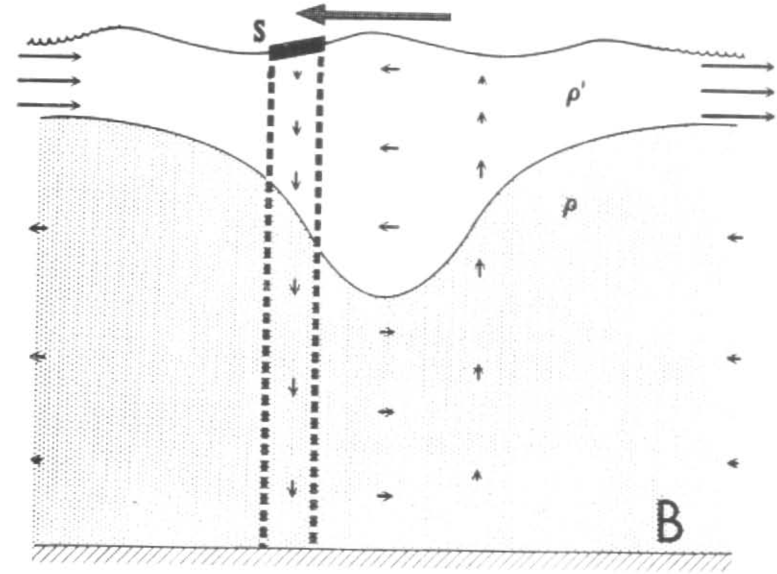

Fig. 2(B). Near surface thermocline

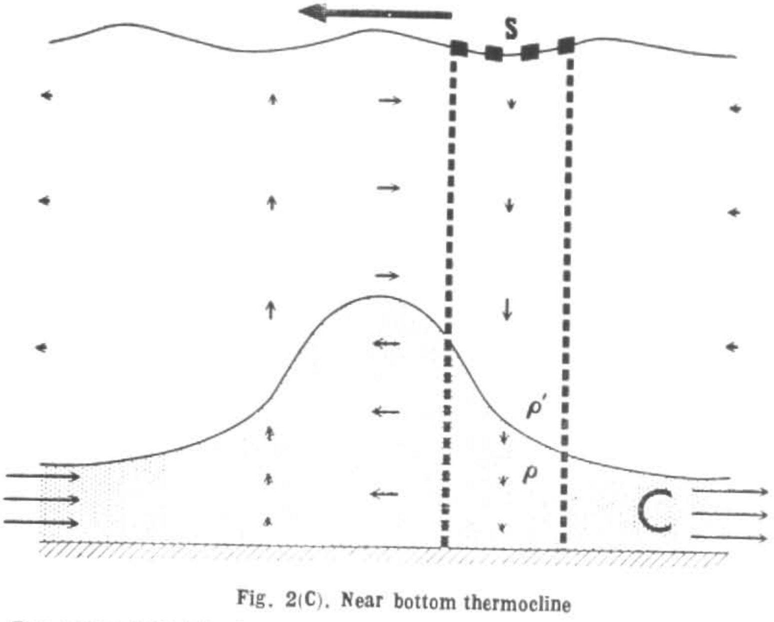

Fig. 2(C). Near bottom thermocline

Figs. 2(A) to 2(C). The shape of internal temperature waves in shallow water and the nature of the related sea surface slicks