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Sea surface features and internal waves in the sea

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On several oceanographic cruises conducted by Andhra University, an unusual sea-surface phenomenon was observed which consisted of long streaks of alternately smooth and rough water. On one occasion at the northern end of "Swatch of No Ground", temperature structure was measured at the same time as a passing of such series of wide sea surface streaks (Fig. 1 A). From the set of the ship while traversing the streak, as well as the vertical temperature structure and the relative position of streaks, it was concluded that the long bands of alternately smooth and rough water have a rotary motion and they were therefore called "rotary currents" (La Fond and Borreswara Rao 1954).

A surface circulation phenomenon similar to these rotary currents has been found off the Southern California Coast in a study of sea-surface slicks. Slicks are streaks or patches of relatively calm surface water surrounded by rippled water (Fig. 1B). The very small wavelets are reduced in the slick, thus giving it a glassy appearance in contrast to adjacent water. In daylight the well-developed slick may be identified because it reflects the sky better than the adjacent rougher area. However, when close to the slick the difference between rough and smooth water is difficult to ascertain.

The material comprising the surface film of slicks was collected and examined by P. V. Bhavanarayana of Andhra University, Zoology Department (La Fond 1957). He found that it was composed of an oily film of biological origin. Other samples skimmed from the surface showed that the surface tension was reduced on an average to 68·8 dynes per cm at 20°C from the normal 70·5–73·5 for surface water with no slicks visible.

Slicks have been observed around the world on the open sea, bays, and lakes (Shuleikin 1941, Dietz and La Fond 1950, Woodcock and Wyman 1947, Ewing 1950a). They are especially prominent off the east coast of India during the winter when the wind is just strong enough to ripple the water, yet not strong enough to produce white caps (Beaufort force 3). Frequently slicks take the shape of broad spiderweb-like connecting bands. In shallow water over the continental shelf of Southern California, they frequently appear as long bands, more or less parallel to themselves and to the coast (Ewing 1950a, 1950b).

Recently, off California continuous temperature structure was measured by means of a vertical string of thermistor beads. At the same time the position of band slicks was precisely located with reference to the internal waves. The resulting records for two days' observations are shown in Fig. 2. On these days it can be seen that the temperature isotherms fluctuate widely in a vertical direction in a short period of time. The sea surface slick bands occupy much less time (and distance) than the intervening rough areas. The most significant feature is that most of the slicks occur at a time in which the isotherms are descending, and not over either the crest or the trough of the internal wave. Some exceptions are apparent but most occur just before the trough and there is almost one slick for each major oscillation of the isotherms. In shallow water, sea-surface band slicks move generally shoreward at a speed of upto 0·4 kt. This motion indicates that the internal waves with which the slicks are associated are progressive waves.

Progressive internal waves are common in the sea and occur between the various density boundaries. The nature of progressive waves between two liquids of different densities is given by Lamb (1932).

The vertical displacement at the interface of a two layer density system, ρ and ρ', is given by

$$\eta = a \cos (kx - \sigma t)$$

and the horizontal velocity of flow, u' in the upper layer is

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

where

h' = average thickness of the upper layer

a = amplitude of wave at interface

c = wave velocity at interface

If there is no appreciable flow in the y direction (normal to propagation) and no appreciable transport of surface water in the direction of propagation, the same volume of ρ' water per unit width must pass over the trough. The speed of flow in a horizontal direction must be inversely proportional to the thickness of the upper layer, Z',

where

$$Z' = h' - a \cos (kx - \sigma t)$$

Therefore, the average horizontal velocity in the upper layer becomes

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

This indicates that u' is maximum and in the opposite direction of propagation to c when h' approaches a and the phase angle $(kx - \sigma t)$ is zero.

An illustration of such motion is given in Fig. 3. The motion over the crest of shallow internal waves is strong. The water formerly over the trough is funneled through this constriction. If the crests are very near the surface the speed of flow is greater. This funneling of water over the crest and the reduced speed just beyond the crest is believed to cause turbulence and ripples at the surface. It has also been observed that internal turbulence occurs at the interface where shearing action of opposite velocities are found. When the internal crests approach the sea surface this turbulence may also enhance the formation of ripples as shown in Fig. 1A. Such ripples, 6-8 inches high, were observed at the head of the Bay of Bengal. At that time the crests of the internal waves nearly reached the surface.

It can also be seen in Fig. 3 that the region of convergence or downward motion falls half-way between the crest and trough, that is, immediately after the passing crest. This is the location of the slick with respect to the internal wave as found from the observed temperature structure given in Fig. 2. Here too, internal waves are largely responsible for the location and orientation of slicks.

The development of internal waves is not fully understood. However, once they are formed they may travel great distances with little loss of energy. One observation indicates that they may be related to the sub-surface topography. In addition to those observed to be forming at the head of the "Swatch of No Ground", they have also been observed to appear at the head of the Monterey Canyon off Monterey, California and emanate towards shore.

Another observation shows that band slicks are more prevalent at the edge of the

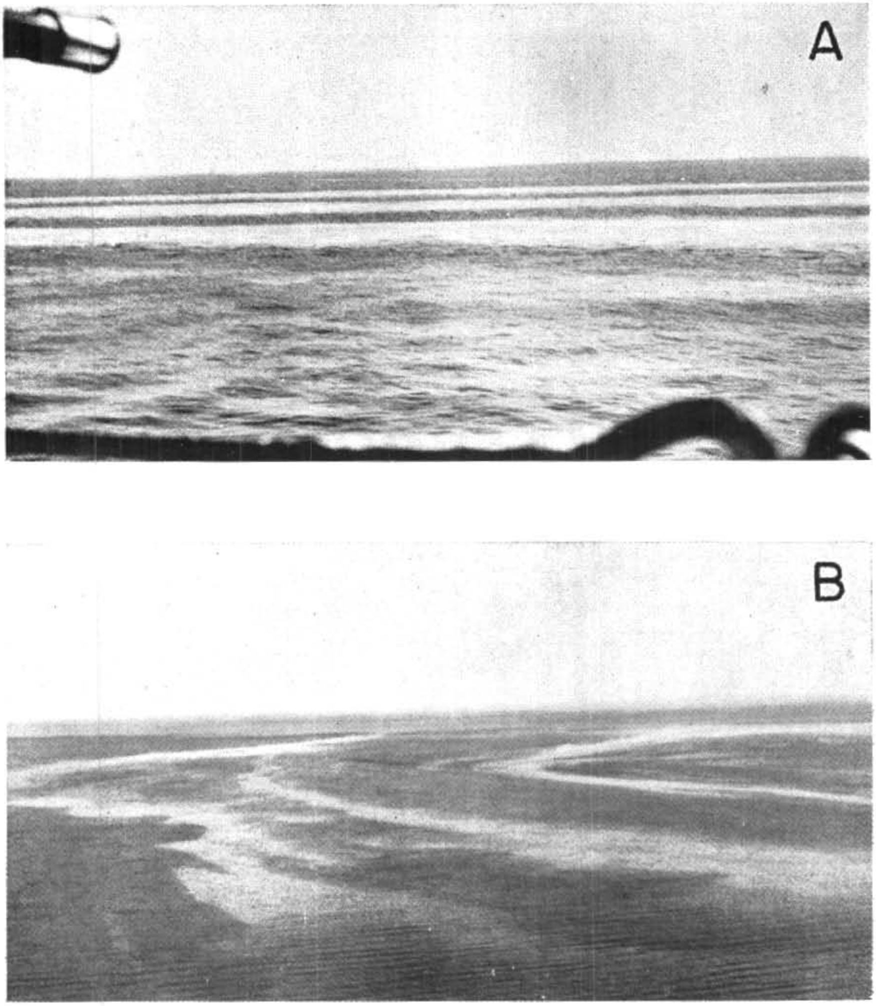

Fig. 1

A—Sea surface streaks in the Bay of Bengal

B—Sea surface slicks off California

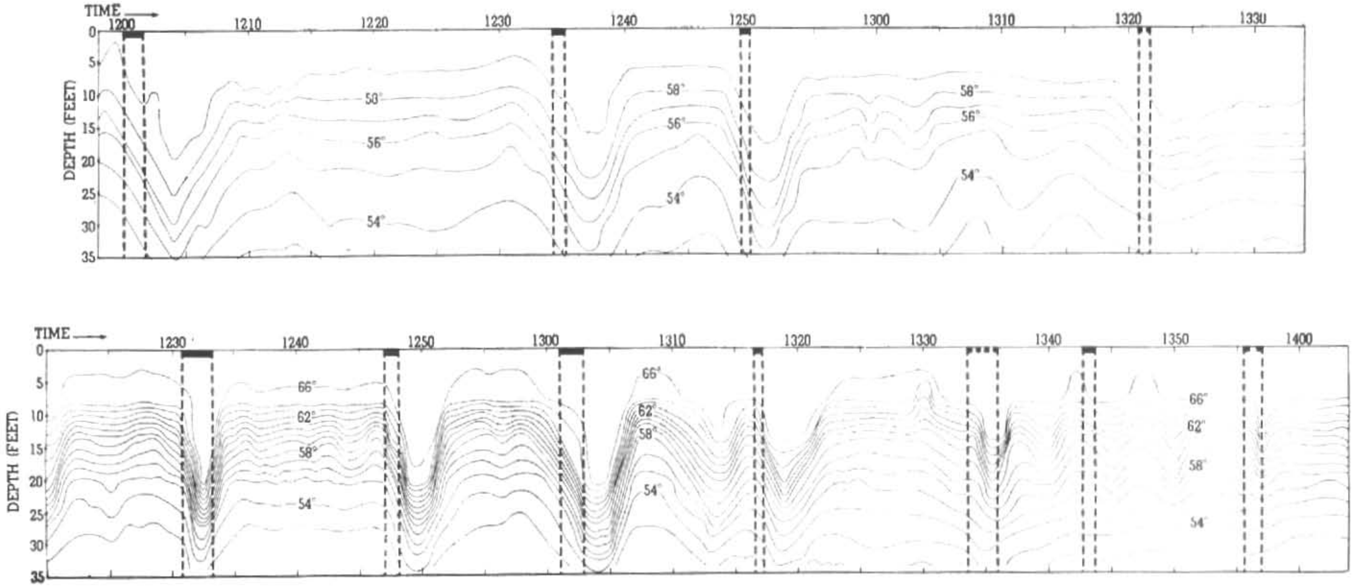

Fig. 2. **Temperature—depth structure of the water plotted with respect to time for two different days (Upper diagram—12 June, Lower diagram—9 July) off Southern California**

The heavy bars at the surface with vertically connecting dashed lines respresent the position of sea-surface slicks with respect to the underlying vertically oscillating isotherms. Since the internal waves are moving from right to left the slicks are usually found over the descending slope.

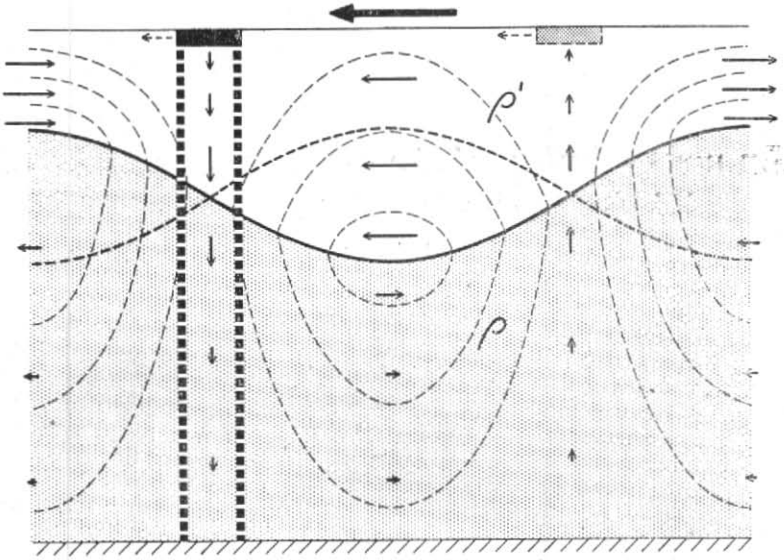

Fig. 3. Motion in a progressive wave between water of two different densities, ρ and ρ'

The usual position of sea surface slicks (heavy bar) is found where the surface water is converging and sinking

continental shelf, which would imply that internal waves were forming at that location. It is known that internal waves are refracted towards the shallower water and normally become parallel to the shore.

In summary, it is concluded that sea-surface features such as rotary currents and sea-surface slicks may be manifestations of shallow progressive internal waves between two layers of different density water.

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