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TIDAL INFLUENCES IN SHALLOW-WATER SOUND PROPAGATION; THE NORMAL-MODE EFFECTS

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Introduction

The propagation of sound has been studied for several years in the shallow waters of the Bristol Channel - see especially ref. 1. One feature of the work is the employment of fixed bottom-laid projectors and receivers, recently covering a wide range of frequencies around 1kHz. About a dozen different fluctuation mechanisms have been identified.

The purpose here is to discuss the relations among these mechanisms and review the subject generally. A feature is made of the division into tidal and non-tidal effects. This paper treats the tidal influences; and also concentrates on those which are directly associated with the normal-mode nature of the propagation. A companion paper [2] follows on with the non-tidal influences, many of which show a diurnal variation. There is particular reference to those effects associated in some degree with fish. It may be noted that the present paper deals mainly with the moon, whereas [2] is concerned largely with the sun.

Both papers draw heavily on the work of several colleagues, especially those named in the references, and their contribution to the investigations is acknowledged with gratitude.

Single mode colouration

The colouration phenomenon described here can occur in shallow water when the sea-bed is exposed rock, or rock with a very thin sediment layer superposed. In isovelocity water any normal-mode may be considered as equivalent to two plane waves, one upgoing and one downgoing. At the so-called cut-off frequency for the mode the downgoing wave is incident on the bottom at the critical angle, and on simple theory there is no reflection loss. Just below this frequency the angle is steeper, and there is a large loss by coupling into longitudinal waves in the rock. Just above the cut-off frequency the angle is shallower, and there is now a small loss by coupling into shear waves in the rock. Transmission over a distance involves many bottom bounces, and so there is selectively good propagation at the cut-off frequency.

Only a single mode is necessary for this effect to be demonstrated. But in general a transmission peak will tend to occur at the cut-off frequency of all the modes. There is a tidal modulation of this colouration effect since the cut-off frequency is inversely related to the water depth.

The evidence for mode colouration is a little indirect, and it is hoped to present it in more detail later. There are two sets of observations in the Bristol Channel area. One set refers to the acoustic energy from underwater explosions, which arrives greatly spread out in time. The ground wave branch comes in first and shows the expected colouration very clearly, at the order of 10Hz for the first mode. Another set refers to the low-frequency spectrum of ambient noise. Under suitable wind conditions this shows the expected set of peaks corresponding to the lowest half-dozen modes.

Interference patterns with a few modes

If there are two modes present they will beat together regularly in space, because their phase velocities are not quite the same. If there are a few modes the resulting pattern will still be fairly simple, and on a relatively large scale. The modal phase velocities, and the scale of the interference pattern too, depend on the water depth. The tidal changes in water depth therefore sweep a small part of the pattern to and fro past the fixed receiver. An example is shown in Figure 1*, taken from a much longer sequence in the work reported in [1].

Interference patterns with several modes

If there are several modes present the pattern will be more complicated. The tidal variation in depth may sweep a few cycles of this pattern past the receiver. This point is illustrated in [3], which also demonstrates the two-dimensional pattern obtained by displaying a set of traces for neighbouring frequencies.

Interference patterns with many modes

When there are large numbers of modes it is found [4] that the mutual interference of these modes can sometimes define suprisingly sharp beams of sound. These beams come together at a series of characteristic ranges, and a series of focal points are formed. The effect may be demonstrated in Wood's model propagation experiments [5]. Wood's results may also be used to show that the characteristic or focal distance varies with water depth in the predicted manner.

Asymmetric interference patterns

The changes in the interference patterns as described above are due to variations in water depth, and are therefore symmetrical about the times of high water and low water. Indeed, such symmetrical patterns commonly occur. But there are also mechanisms tending to make the patterns asymmetrical, or skewed in time. One is the shear flow or depth-dependence of tidal streaming, which produces a varying refraction [6]. A second is the tidal introduction of water of different temperature and velocity structure. A third which is closely linked to the second is the possibility of tidal period internal waves. It is difficult to separate the effects of these three mechanisms, but asymmetric and repeating patterns have been found, particularly near springs [1, 3].

Other tidal effects

For the sake of completeness three further tidal effects will be mentioned, although they do not involve so closely the modal nature of the propagation. Internal waves affect the acoustic propagation, and tend to occur at fixed times in the

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* The written version of this paper, prepared as a preprint, contains only one line drawing which illustrates the most basic effect. Other illustrations which may not reproduce so well are reserved for the spoken version. See also the references.

tidal cycle [7]. (In fact, Figure 1 includes a rather poor example between +2 and +3 hours). This is because for our shallow water site the criterion for propagation of internal waves involves both the shear flow and temperature structure, which vary regularly through the cycle. Surface waves have marked acoustic influences, and although their amplitude does not depend obviously on the tidal cycle, their effectiveness in causing fluctuations certainly does [1]. This is because surface wave effects are relatively much more important near the minimum than near the maximum of the interference patterns. Lastly, the gross tidal streaming produces regular changes in the signal phase [1].

Conclusions

The main purpose here has been to tell the normal-mode story rather than draw detailed conclusions. But this has shown how the characteristics of shallow water propagation depend critically on the number of effective modes, and information on this point is essential to both qualitative and quantitative understanding of any transmission problem. See also [2].

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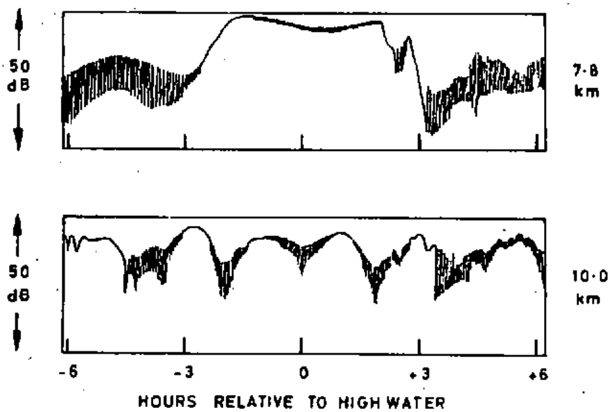

FIG. 1 MODAL INTERFERENCE AT 2kHz SHOWING SIGNAL SYMMETRY OVER ONE TIDAL CYC..E, AM 7th JUNE 1964