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A REVIEW OF UNDERWATER ACOUSTIC FLUCTUATION MEASUREMENT

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ABSTRACT A brief survey indicates the considerable extent of the published measurements of ocean acoustic transmission fluctuations. Many different mechanisms are responsible and it is useful to classify the results accordingly Important measurement techniques include the use of coded transmissions, the provision of compact displays, and the employment of very long measurement periods. The several advantages of the latter are illustrated. Fluctuation or variability is of significance for many reasons, and one demonstration shows effects on a reverberation display of fish.

Introduction

This paper concentrates on the problem of measuring the amplitude fluctuations of an acoustic signal transmitted in the ocean. It is not primarily about phase fluctuations, nor fluctuations in other environmental parameters, nor related quantities such as coherence. It is not primarily about the significance of fluctuations, although some reference is made at the end. It is not about theory, and is quite successful in avoiding mathematics. It did not set out to present results, but results do creep in and the paper would be dull and rather unbalanced without them. In fact the interplay between measurement techniques and the nature and scale of the fluctuations turns out to be the main theme of this brief review.

Literature on Experiments

Fluctuations are omnipresent and thus the literature is extensive. For example at the last scientific meeting of the IOA Underwater Acoustics Group we had a presentation on the subject, drawing on work in the Arctic (Mikhalevsky 1984). In general detailed individual citations will not be made since they would swamp the paper, but we can refer to a previous review covering work since 1963 (Weston and Rowlands 1979). This previous review does now need updating, and in addition was restricted to relatively long-range guided propagation.

Figure 1 will serve to introduce the flavour of the subject, representing some of the most recent ARE work by J S Pyett et al, in collaboration with MSDS. The experiments involved transducers on each of two ships, changing range in the NE Atlantic, so that the result is a mix of temporal and spatial effects. Wild fluctuations in level may be seen to occur, on this occasion for propagation in the depressed sound channel.

It is always difficult to know which experiments to mention and which not, but I believe it is worth listing the following because they all represent extended <u>sets</u> of measurements -

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FLORIDA STRAITS, code-name MIMI, shallow and intermediate depths, fixed transducers, J C Steinberg et al.

BRISTOL CHANNEL, shallow water, fixed transducers, D E Weston et al. (The experience here is responsible for most of the writer's views and prejudices on the subject.)

BERMUDA-ELEUTHERA, deep water, fixed and ship-borne transudcers, many investigators.

COBB SEAMOUNT, deep water, fixed transducers, T E Ewart et al.

AZORES, code-name AFAR, deep water, fixed transducers, A W Ellinthorpe et al.

Although this list is far from complete it is sufficient, even on its own, to show that our subject is no longer in its infancy. Thus the sea has been heavily sampled as an acoustic transmission medium, and we will shortly see that general understanding is good. But quantitative detail and the ability to predict are usually missing, the subject is not fully grown. Perhaps we should recognise fluctuations research as adolescent.

Mechanisms

The last section suggested an arbitrary division into qualitative aspects aimed at understanding, and quantitative aspects aimed at numerical summaries and prediction. Together these should control the form of the experiments.

The first stage of understanding is the realisation that many different mechanisms are operating, and one set of groupings is set out below (compare Weston and Rowlands 1979).

SEASONAL Worse in summer due to destruction of surface ducts, general layering, increased fish population. Worse in winter due to higher winds.

FLOW PATTERNS Eddies, Rossby waves, meanders.

DIURNAL Fish attentuation on summer nights, "afternoon" effect.

STORMS Drastic surface losses, profile changes.

TIDES Tidal changes in depth and current shear, internal tides, and tidal advection all convert spatial (multipath interference etc) into temporal variability.

SEICHES Applicable only to restricted areas.

INTERNAL WAVES From the inertial to the buoyancy period. Also effects of turbulence and random inhomogeneities.

LOCAL FISH Fish near source or receiver.

SURFACE WAVES Effect depends on position in the multipath interference pattern.

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PATH EFFECTIVENESS   Different paths may come and go, eg gradient changes may destroy a duct.

Time Scales and Spectra

If we wish to be quantitative we must pay attention, among other matters, to geographic position, season, propagation path, range, geometry and general environmental conditions, carrier frequency, carrier bandwidth and original modulation. The time scale of the effects is particularly important, and can be specified by a fluctuation or modulation spectrum.

Life is complicated because the basic or stage-1 modulation may itself be modulated. We can identify some stage-2 modulations as follows -

SEASONAL   Affecting storms, diurnal effects, local fish.

LUNAR CYCLE   Affecting tidal mechanisms.

WEATHER PATTERNS   Affecting surface waves.

DIURNAL   Affecting local fish fluctuations.

TIDAL   Affecting internal and surface waves.

This tabulation hides the fact that for local fish effects the modulation could have been expressed as a 3-stage affair. In one Bristol Channel example we start with a carrier frequency of 2kHz, and see a stage-1 10-minute modulation due to bladder fish swimming near the receiver. The stage-2 diurnal modulation arises becauses the fish are only active in daytime. A stage-3 seasonal effect comes about because the fish are only present during the summer.

Figure 2 shows a first attempt to enter amplitude spectra for all the likely mechanisms in one set of conditions, based on Bristol Channel experience. The spectrum for each is represented as nominally flat over an octave, with F^2 law at the lower frequencies (even more nominal than the rest!) and F^{-2} at the higher, where F is fluctuation frequency. Peak level S is expressed in terms of $(dB)^2/Hz$ as a practical unit, and given by

$$S = m^2 p/2.4\ F_o.$$

Here m is rms fluctuation in dB, p is proportion of time for which fluctuation is present, F_o is centre frequency and F_o^{-1} is typical period in seconds, all set out in Table 1.

The dashed line in figure 2 shows a broad fit to the overall spectrum, reasonable over a span of 10^8 in F, and specified by

$$S = 4\ F^{-1}.$$

With this spectrum the band level is 4 ln (F_2/F_1), or 1.7dB rms for any octave and 3.0dB for any decade.

Note that if one end of the path is allowed to move F_o may change, but the change will be such that the part spectrum will merely slide parallel to the F^{-1} line.

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Table 1 - Spectral Levels for Mechanisms in Figure 2

Mechanism	m	p	F_o^{-1}	S
a seasonal	5	1	2×10^7	2.1×10^8
b diurnal	3	0.3	10^5	1.1×10^5
c storms	7	0.03	5×10^4	3.1×10^4
d tides	7	1	10^4	2.1×10^5
e internal waves	3	0.5	600	1.1×10^3
f local fish	2	0.1	80	14
g surface waves	3	1	10	38

Note also the analogy with F^{-1} noise, still somewhat of a mystery in electronics. In our case the F^{-1} law must result if we have many mechanisms spread relatively evenly in logarithmic time scale over the total band, and each producing the order of 100% modulation (or in principle the same lesser modulation).

Techniques

We may now ask how to design experiments in order to meet the qualitative and quantitative needs referred to above. Basically an experiment is very simple: a projector in one place and a receiver in another, and we watch how the signal varies. But there are a number of magic techniques which can greatly improve the experiment, they are not necessarily very clever but they are important -

CODED PULSES - allow the simultaneous assessment of amplitude, of phase or time-of-flight, and of dispersion or spreading.

LONG DURATION - might be continuous transmission, a continuous pulse sequence or merely frequent sampling over a long period.

FIXED TRANSDUCERS - reduce complications, facilitate long durations.

COMPACT DISPLAY - makes long durations feasible, a computer can process data but eventually the information must be presented to the analyst. May display versus frequency as well as time.

All four techniques can be used together, but we can alternatively select as appropriate. All four have been used at ARE. Of these techniques some are more magic than others, and I am very impressed by the virtues of long duration. All one has to do is switch on and then go away, perhaps for a month or two, so that one is not tempted to tinker. The story continues in the next section with illustrations of the various benefits of long duration taken from the Bristol Channel studies. These benefits are different but are admittedly all closely related.

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Illustrated Benefits of Long Duration

a. For long-period fluctuations. It is rather obvious that in order to see and to measure a long-period fluctuation one needs a long-duration experiment. Out of many possible examples we select the high attenuation at night due to the dispersal of the fish shoals (figure 3). In addition the magnitude of this diurnal effect varies in an apparently random manner from day to day, and is typically present only in the summer and autumn. Experiment duration should be several days, preferably it should be several years!

b. For mysterious fluctuations. One observed example concerns fluctuations of period several minutes, lasting for an hour or two. The effect might not recur for several days, and there were ideas but no firm conclusions on the cause. The answer came after noticing that the timing in the tidal cycle was always the same (figure 4), and this of course needed long-term observation. Our fluctuation turns out to be due to an internal wave which is only permitted when the Richardson number exceeds ¼ - and the Richardson number varies through the tidal cycle.

c. For random or rare fluctuations. A good example of a random fluctuation is that due to a storm, where the resulting surface waves scatter the energy out of the shallow-water duct and thus attenuate the signal, especially in high frequencies (not directly illustrated here, but see figures 3 and 7). A rare effect, seen only once, appeared with a storm in the summer daytime. The attenuation was seen first at the middle frequencies, around 1kHz, and apparently due to the turbulence breaking up the fish shoals. To catch such random and such rare events right from their beginning one must run the equipment patiently and just hope they come along.

d. For unencumbered fluctuations. If one is lucky one may sometimes see a given fluctuation type when other fluctuations are virtually absent, and unable to mess it up. My example concerns modal interference patterns which vary through the tide. Commonly (and especially at neaps) the pattern is symmetrical about the times of high and low water, being controlled almost entirely by the water depth. But sometimes at springs we see as in figure 5 an asymmetrical but repeating pattern, due to the combination of three extra effects. These are the tidal advection of water with a different profile, tidal changes in current shear and tidal-period internal waves. Such unencumbered fluctuation records come only by the accumulation of many records.

e. For absolute level. A proper understanding of absolute level can be achieved only after allowance has been made for all extra or fluctuation effects. For example figure 6 shows a summertime loss some 30dB greater than the nominal or "expected" value, despite the measurements relating to daytime when fish attenuation is minimised. But through having a year's record we can see that the discrepancy is restricted to the summer, and at the 870Hz frequency shown it is thought to be due to residual fish effects as well as layering. Thus even in daylight a proportion of the fish will swim as individuals or in small groups, and not congregate in large shoals where the resulting attenuation is small.

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Significance

Some fluctuation is present in every underwater acoustic measurement, and there are many effects on performance of underwater acoustic systems (Weston 1981). I cannot resist including one illustration, thus figure 7 is a 1kHz sonar reverberation display in the Bristol Channel showing fish shoals (of the display type introduced in Weston and Revie 1971). The main fluctuation is the fish attentuation at night which acts to reduce the range showing structure, perhaps on the night of 18/19th this was aided by a minor storm. Notice in particular the white "tramlines" near dawn and dusk due to the fish dispersing temporarily through the whole water column. In addition there are spatial and temporal interference patterns, visible most clearly in the structure at night.

Acknowledgements

I wish to acknowledge the contribution of all those colleagues with whom I was associated in the Bristol Channel studies, mostly their names appear on one or more of the published papers. In particular I should mention Jack Revie who was the energetic Officer-in-Charge of the Perranporth outstation, and Pamela Ching for her collaboration on the as yet unpublished storm observations in addition to much else.

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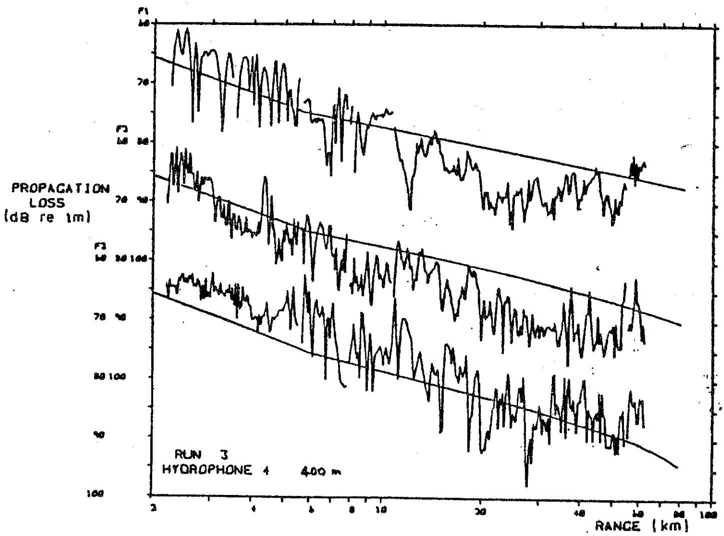

Fig 1 Propagation loss at 301 Hz (top) 800Hz (middle) and 1324Hz (bottom).

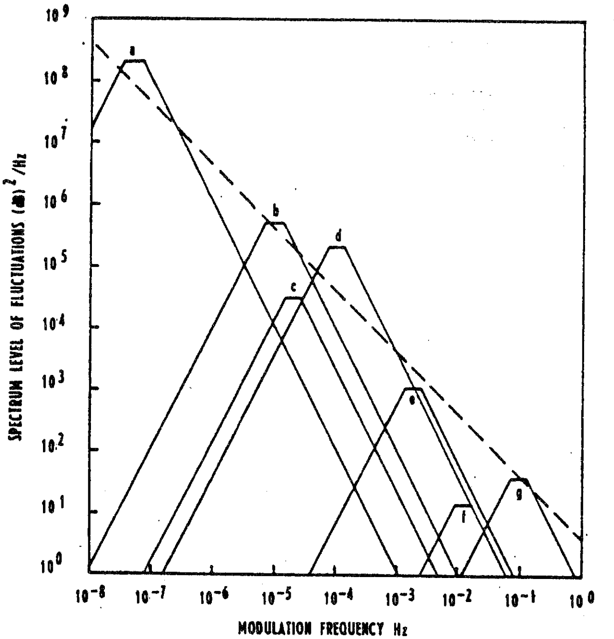

Fig 2 Shallow-water spectra at a few tens of km at audio frequencies.
a Seasonal, b diurnal, c storms, d tides, e internal waves, f local fish, g surface waves.

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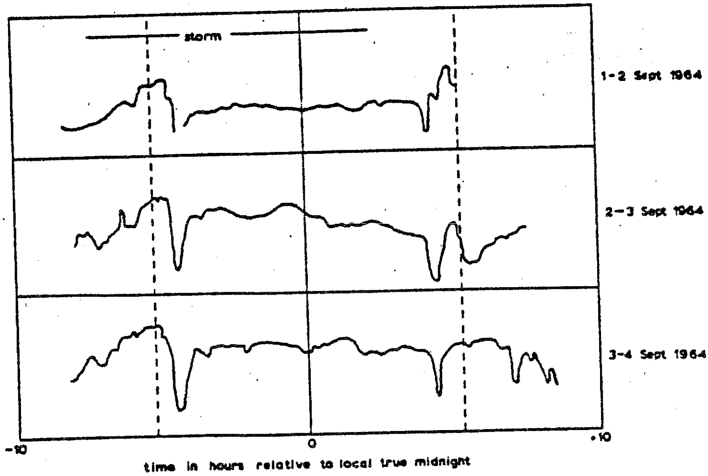

Fig 3 Records through the night for 1kHz over 23 km (50dB scales), showing fish attenuation.

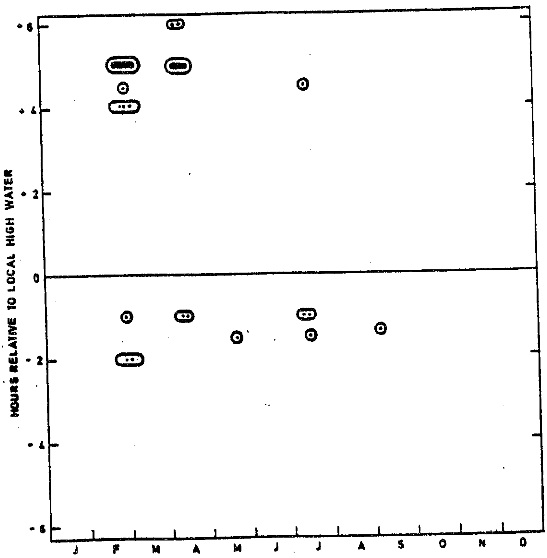

Fig 4 Timing for all observed internal wave acoustic fluctuations over a 23 km path, 1968.

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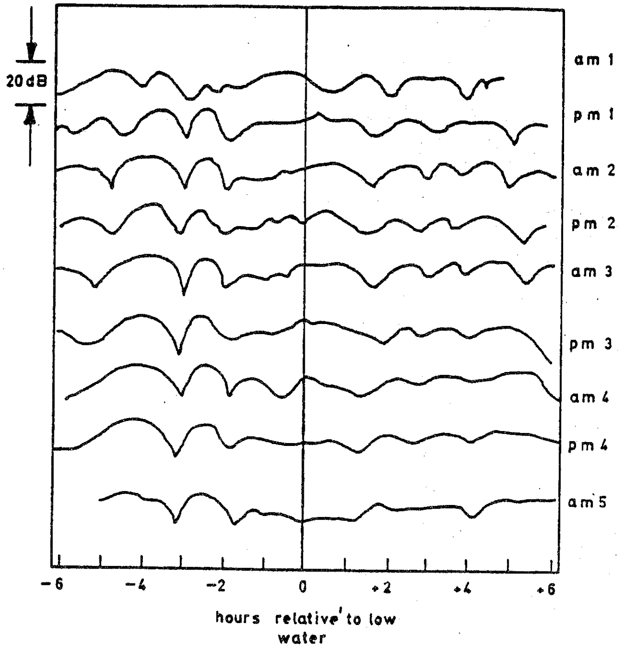

Fig 5 Repeating asymmetrical interference patterns for 1.9 kHz over 23 km, March 1968. Springs occur 1st March.

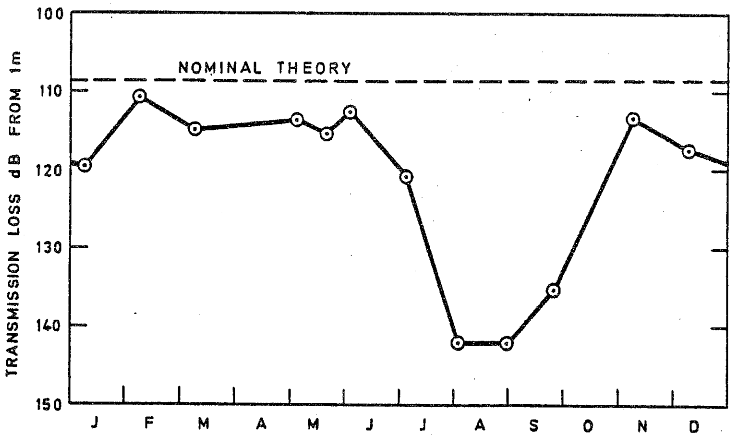

Fig 6 Seasonal change in transmission loss for 870 Hz over 137 km, based on maximum daytime levels.

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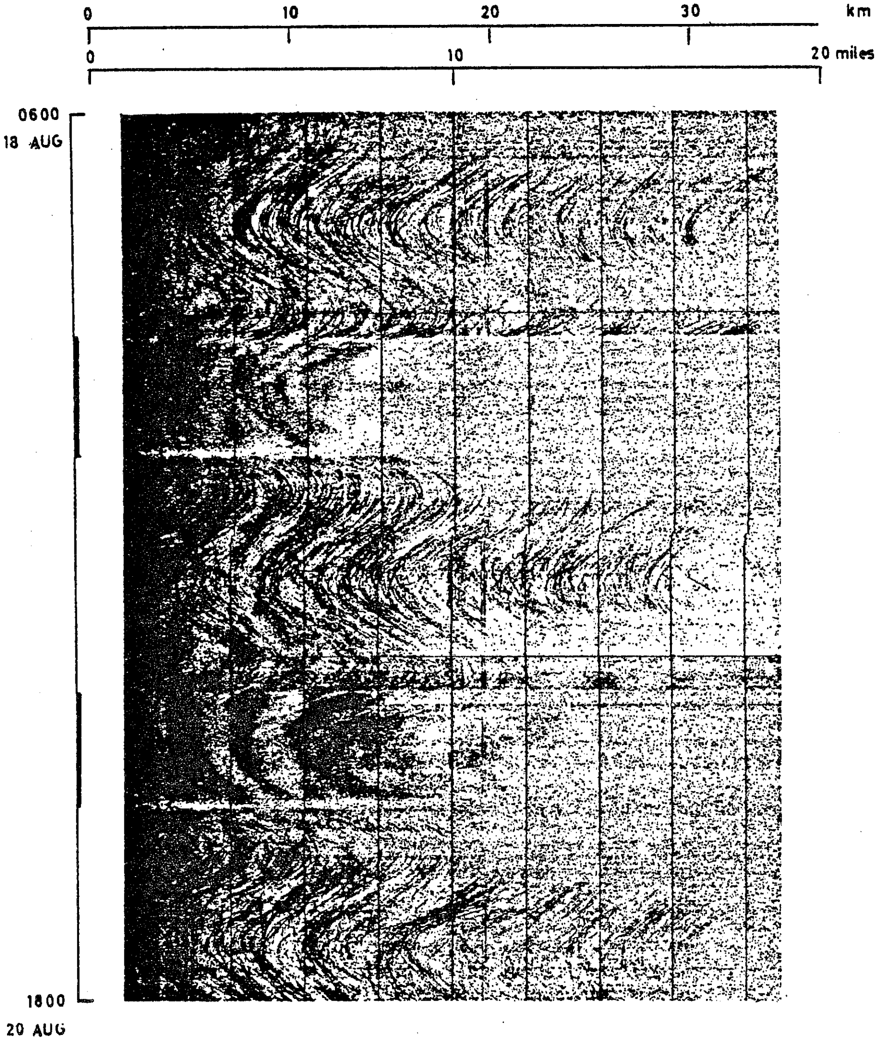

Fig 7 Echo-ranging record showing returns from pilchard, 1968, with propagation fluctuations.