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On origin of fluctuations of sound transmissions in the sea

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ABSTRACT. Fluctuation in transmitted intensity of sound when there is no relative movement of transducers and no interference from reflection at sea surface, has been usually assigned to thermal microstructure of the oceans. Thermal microstructure can affect the transmission in two possible ways, by scattering due to small changes of velocity of sound or due to interference of neighbouring rays going through varying number of thermal patches and reaching the same receiving hydrophone. Both these effects require very prominent and practically impossible thermal structure in order to explain the observed fluctuations. A hypothesis is put forward that this may be due to the presence of discrete scatterers in the form of tiny air bubbles which may be free or what is more likely part of zooplankton. On confirmation this may yield a powerful tool for measuring average production of plankton in the sea of various sizes depending upon the selected sound frequency. The fluctuation of 15·5 Kc frequency sound transmissions suggests that air bubbles or zooplankton air sacks of size ½ mm should occur at the rate of one in every 76 litres of sea water in the ocean west of Cochin, South India.

1. Introduction

Fluctuations in acoustic transmissions in the sea are of large magnitude. There is no correlation between successive received pulses if the time interval is more than a fraction of a second or if the receiving hydrophone is shifted by a few inches. This has been ascribed to (*a*) physical movement or oscillations of the sender or receiver or of both and (*b*) for relatively long pulses to interference caused by reflection from the surface of the sea. But when precautions are taken to rule out effect of movements of hydrophones and of interference caused by the reflection from the surface, some fluctuation still remains. It is customary to say that this fluctuation is due to thermal microstructure of the ocean.

Fluctuation usually assigned to thermal microstructure was measured by means of receiving short echo sounder signals on an auxiliary hydrophone and it is shown that the severe thermal microstructure required to explain the magnitude of the fluctuation is not likely to be in existence. A hypothesis is put forward that air bubbles that can be associated with plankton may give rise to the fluctuation.

2. Experimental observations

In order to eliminate effects due to movements of transmitting and receiving hydrophones, one must use a transmitting or receiving hydrophone of wide directivity pattern preferably non-directional one, and the hydrophones should be suspended by flexible cord over a ship anchored fore and aft in relatively calm sea. These conditions were approximated by choosing a day of calm sea in December off Cochin. A wide pattern echo sounder in a Naval Frigate was used as transmitting transducer and listening was done by means of a sensitive Massa hydrophone suspended by a flexible cord from the side to a depth of about 40 ft from the same frigate. Horizontal distance of receiving hydrophone from echo sounder is about 100 ft. Apparently the direct transmission does not reach the receiver, the received signal is a single pulse presumed to be the bottom echo. In future experiments it may be a good idea to record electrically the transmitted signal as a monitor both for the constancy of the transmitted signal as well as for identification of the received signal. The ship unfortunately could not be anchored, but was allowed to drift. This did not materially matter much since drift was very small during any set of observations and the sea state was not more than unity. This arrangement also avoided the interference due to surface reflection since the echo sounder points downwards and not much surface reflection occurs at the proper time to interfere with the observations. The pulse width was also very small of the order of 5 milliseconds and due to the depth of the receiving hydrophone being about 40 ft, any possible reflection would be received

$$\frac{2\times 40}{5000}\times 1000=16 \text{ milliseconds}$$

after the echo. Any noise etc, picked up by the hydrophone was removed by means of a high-pass filter. The output of the receiving hydrophone was amplified and fed to an oscilloscope and photographed by a continuously moving film. The film speed was 1·08″/sec. Though this speed is not enough to resolve the reflection from sea surface from the direct echo, yet the temporal separation is sufficient to avoid interference, only the larger signal will be read from the record which is more likely to be the direct echo than the one after reflection from sea surface. Still it would have been better had larger film speed been used. The response time of the Massa hydrophone is also small and this also eliminates interference. Another possible way out would be to increase the depth of the receiving hydrophone ; the delay of the reflection from surface will then be still further increased.

The amplitudes were measured by means of a divider and a scale while the film was illuminated from below. Two series of observations are as follows—At a depth of 60 fms, the different amplitudes ranged from ·66 cm to ·50 cm, *viz.*, ·60, ·55, ·53, ·65, ·65, ·50, ·62, ·65, ·65, ·60, ·65, ·65, ·65, ·63, ·66. These 16 observations make one set. This is rather small for a statistical set and actually we should have made about 100 observations, but at that time importance was being given to some other asdic observations and these were only some auxiliary measurements. A second set of similar measurements was made at a depth of 250 fms and the amplitudes ranged between ·27 cm and ·57 cm, there being only eight measurements, *viz.*, ·35, ·43, ·39, ·29, ·27, ·57, ·35, ·45 cm. The pulse interval in all above is 2·8 seconds.

Assuming the absence of contribution to fluctuation by all extraneous factors, namely, movement of transmitter and receiver, drift over possible bottom topography and interference due to surface reflection, we shall investigate other possible causes of this fluctuation between wide limits, *viz.*, between ·66 and ·50 cm for a path length of about 240 metres and cross-section 13·8 sq. cm (being the cross-section of the receiving hydrophone).

3. Extinction due to scattering from thermal microstructure

Let us assume that in the sea there are small patches of varying sound velocity, the variation being both + ve and — ve about the over-all value. For simplicity assume that patch size is A cm and within an element of linear dimension A, the velocity differs from over-all velocity by $\triangle c$. This $\triangle c$ can be +ve or —ve and is of a fixed value, *i.e.*, $\triangle c/c$ is constant all over the volume of interest to us. Under these conditions volume scattering coefficient (Nat. Res. Coun.—see reference)

$$m=\frac{1}{2A}\left(\frac{\Delta c}{c}\right)^2\times \frac{1}{(1+\lambda^2/16\,\pi^2A^2)^2}$$

In order to choose A for a given $\triangle c/c$ for largest m, one could maximize the above equation which happens at $A=2\cdot 3$ cm.

If in a fluctuation experiment, the amount of fluctuation that is present, necessitates a variation δm in m, then the least value of m is δm, though most probable value is much larger. Substituting the observed δm for m and 2·3 cm for A, one finds that required $\triangle c/c$ is very large requiring a temperature variation of about $\pm$ 1°C every inch or so. From observed values ·65 and ·50,

$$\delta m = \frac{1}{13.8\times 240\times 100}\log_e\left(\frac{66}{50}\right)$$
$$=0\cdot 9\times 10^{-6}$$

$$\therefore \frac{\triangle c}{c} = (0\cdot 9\times 10^{-6}\times 4\cdot 6\times 1\cdot 25)^{\frac{1}{2}}$$

$=\cdot 23\%$ which corresponds to a change of 1°C

δm is of the same order for the second set of observations. Thus we get a very strong microstructure which is not likely to occur in nature.

4. Fluctuation due to thermal microstructure and finite size of the receiving hydrophone

A second possible way thermal microstructure could bring about changes in reception is due to interference of a bundle of rays reaching the hydrophone, different rays experiencing slightly varying microstructure at each observation.

The hydrophone that was used in these observations had a radius of about 2·1 cm (area of cross-section =13·8 sq. cm). Let us assume the patch size to be 2·3 cm as before, and divide the area of cross-section into a central zone of diameter 2·3 cm and a second zone of annular width 0·95 cm. One may assume that when observed amplitude is highest, all the zones receive amplitudes practically in the same phase in spite of the paths being made of a large number of patches in the microstructure. But when the amplitude is least, the statistical variation in the number of patches in the paths is such that intensity received at the successive zones is away in phase by a certain angle θ from that received at the previous zone.

Radius of the first zone is 1·15 cm and area 4·15 sq. cm and area of the second annular zone is 9·6 sq. cm. Thus when fluctuation occurs from highest ·66 to least ·50 cm, following relation should hold—

$$\frac{13\cdot 8}{4\cdot 2+9\cdot 6\cos\theta} = \left(\frac{\cdot 66}{\cdot 50}\right)^{\frac{1}{2}} = 1\cdot 15$$

$$\text{or } \cos\theta = \cdot 82$$

which gives $\theta = 35°$ or time lag of

$$t = \frac{35\,T}{360}$$

where T is the period of the waves. Since frequency is 15·5 Kc/sec, $t=6\cdot 2\ \mu$ sec. This phase difference is to arise due to statistical fluctuation of the number of patches traversed. The number of patches with either +ve or —ve Δc is

$$\frac{240\times 100}{1.094\times 2\times 2\cdot 3} = \cdot 48\times 10^4$$

The fluctuation in this number is $(\cdot 48\times 10^4)^{\frac{1}{2}}$ =69. If fluctuations in adjacent rays is to boost each other, the phase difference is due to different velocity in 2×69=138 patches.

The time difference introduced is

$$t = \frac{138\times 2\cdot 3}{c} - \frac{138\times 2\cdot 3}{c+\Delta c} = \frac{317\ \Delta c}{c^2}$$

Equating this to observed t we get

$$\frac{\Delta c}{c} = c\times\frac{6\cdot 2\times 10^{-6}}{317}$$

$$= \frac{15{,}5000\times 6\cdot 2\times 10^{-6}}{317} = \cdot 31\%$$

This requires a temperature microstructure of about 1·6° C variation in every inch or so. This effect is also out of question. Such high temperature fluctuations are not likely to be present in the vertical direction. Even in the horizontal direction one cannot imagine such fluctuations to occur. One can at most expect only patch size of one yard and temperature oscillation of less than ·4°C. For such a possible microstructure, from arguments as outlined above, the fluctuation in the transmission would be very small.

5. Possible origin—air bubbles either free or associated with Plankton

The above failure of thermal microstructure to explain fluctuation compels us to look for some other source. It is well-known that sea animals have air sacks which can cause scattering of sound. Assuming these air sacks to occur as air bubbles for simplicity, one requires (Nat. Res. Coun.—see reference) for resonant scattering of 15·5 Kc/s, a bubble of size $R=\cdot 023$ cm. The damping factors δ_r corresponding to this is experimentally observed to be ·15. The extinction coefficient per bubble

$$= \frac{2R\lambda}{\delta_r} = \frac{2\times\cdot 023\times 10}{\cdot 15} = 3\ \text{sq. cm}$$

Now, for N and N' bubbles occurring for useful cross-section of the whole path and omitting geometric spreading,

$$I = I_0 \, e^{-3N}$$

$$\text{or } N = \frac{\log_e I_0 - \log_e I}{3}$$

Various values of N can be calculated for different values of I and a mean is obtained as follows—

$$\overline{N} = \frac{\log_e I_0 - \overline{\log_e I}}{3}$$

The standard deviation is given by

$$\sigma^2 = \frac{(\log_e I - \overline{\log_e I})^2}{9\,(n-1)}$$

where n is the number of observations.

Now assuming the bubbles or plankton to be obeying Poisson distribution, σ^2 should be equal to $\overline{N}$ which gives us $\log_e I_0$. Substituting this value in equation for $\overline{N}$, the same can be found. For our first set of 15 observations $\overline{N}$ is seen to be ·00084. From known volume $= \dfrac{240 \times 100 \times 13 \cdot 8}{1 \cdot 094 \times (100)^3}$ cubic metres, one obtains the result that one such bubble should occur in about 360 cubic metres.

Calculating in the above manner for second set of observations one gets the figure one bubble of diameter ·046 cm in 200 cubic metres. No plankton measurements were actually made, but it is not too much to expect an organism having enclosed air of diameter $\frac{1}{2}$ mm in every 200 cubic metres or so of the ocean at the time and place of these experiments. One may even expect to find some free air bubbles in the ocean of this size.

6. Conclusion

The only possible explanation of observed fluctuations in reception of underwater sound when obvious sources like movement of transducers or interference by surface reflections are avoided is due to statistical fluctuations in the number of air bubbles of resonant size occurring freely or as air sacks of zooplankton in the path. Actual acoustic observations off Cochin suggest that there should be one organism having resonant air cavity of size $\frac{1}{2}$ mm in every 200 cubic metres of sea water. Conversely this gives us a powerful method of measuring roughly plankton population in the oceans, assuming absence of free air bubbles. Actual plankton observations will be necessary to confirm this conclusion.

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REFERENCE

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