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Correlation between acoustic scatterers and temperature gradient

by G. T. Kaye[1]

ABSTRACT

A correlation has been found between acoustic scattering intensity at 87.5 kHz and small-scale vertical temperature gradients. Prior to the rise of the Sound Scattering Layer (SSL), there was a positive correlation, which persisted for about an hour after the upward evening SSL migration. After this time a diffuse downward migration was observed until the correlation was significantly negative. Possible rationales for this behavior are suggested.

1. Introduction

Several researchers have qualitatively associated the depths of Sound Scattering Layers (SSL) with high-gradient thermoclines at the bottom of the mixed layer (e.g., Cushing *et al.*, 1956; Weston, 1958). Others have used SSL depth fluctuations as remote tracers of internal wave activity (Andreyeva and Makshtas, 1977). The implication of those reports is that the acoustic scatterers are neutrally-buoyant organisms, who may act as passive scalars of the water density profile. Thus, within certain depth regions that are amply populated by these scatterers, it would be reasonable to expect that variations of the populations may, in turn, be indicative of variations in the water density profile. However, most of these reports have also shown that a major portion of these populations are hardly passive, but migrate diurnally over depth ranges greater than 100 m. Our understanding of why mid-water fishes distribute themselves within either the vertical or horizontal dimensions is poor (Badcock and Merrett, 1976). This paper is then concerned with more quantitative estimates of the relatedness between scatterer distributions and the vertical temperature profile on time scales comparable to short period internal waves.

We have been using a high-frequency, narrow-beam echosounder to study acoustic reverberation below the wind-mixed layer from the Research Platform *Flip*. The sonar operating frequency is 87.5 kHz and the beamwidth of the transmitter directivity pattern is 1°. Use of very short pulse durations has made it possible to resolve the reverberation into discrete returns from point scatterers, which have spatial densities ranging from 0.05 to 50 individuals per 1000 m^3 (Kaye, 1978). Based upon these

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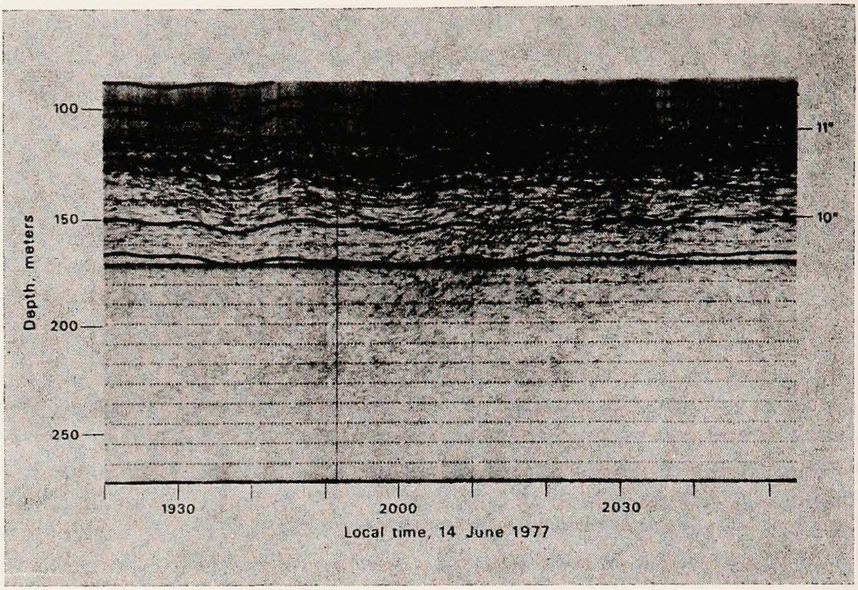

Figure 1. Echosounder record with isotherm depth histories superimposed. Contour increment between isotherms is 0.25 C°.

densities and the return signal amplitudes, it was concluded that the scatterers were most likely fish, but might also have been other animals of similar size. Individual plankton have insufficient reflectivities to be observed *in situ* as individuals, but they have been observed acoustically as a shallow thin layer and as patches (Barraclough *et al.*, 1969). For these data we have used only the returns from large point scatterers, so that the acoustic scattering intensity is an excellent indicator of the nekton population.

2. Data collection and reduction

In June 1977 the R. P. *Flip* was towed to a position approximately 200 km west of San Diego in the California Current, where the water depth was near 1200 m. Although the platform was not moored, drift rates were measured to be 1/2 kt or less. The echosounder was mounted near the stern of the vessel, so that when the platform was in an upright position, the instrument was at a water depth of 85 m. The transmitter repetition rate was once per second and the pulse duration was 0.1 msec for an in-water pulse length of 15 cm. The data were recorded on analog tape and displayed in real-time upon a recorder with some time-varying gain. After the trip the data were digitized at a 6250 Hz rate, providing a sample nearly every 12 cm in the water column.

In addition, a profiling system (Pinkel, 1975) was used from *Flip* to provide a vertical temperature sampling every 125 sec. With these data, time histories of isotherm depths were constructed for direct comparison with scatterer depth fluctuations. Figure 1 is a portion of the analog record with the isotherm depth histories superimposed upon the acoustic data. Contour increment between isotherms is 0.25 C°. The depth spacing between isotherms is a rough indicator of the vertical temperature gradient. The scatterer concentration at 120 m appears to be associated with a tight banding of isotherms. Below 130 m the temperature gradient is much weaker and there were correspondingly fewer scatterers. The internal wave oscillations, with periods of about 15 minutes, are accurately depicted by the acoustic data.

To quantify these observations, correlation coefficients were computed between profiles of the water temperature gradient and the received acoustic scattering intensity. For each temporal sample of temperature, the profile was divided into 65 equal depth steps of 0.95 m for depths ranging from 105.0 to 165.8 m, the region of overlap between the temperature data and the useful acoustic data. The temperature data were then linearly interpolated to determine the temperature at each step. Temperature differences between adjacent steps was determined, forming an array of 64 approximately meter-scale temperature gradients. These data were then low-passed with a three-point running mean for smoothing. The acoustic data had been sampled on a finer scale in both depth and time. Consequently the acoustic intensity depth profiles were summed into groups of eight range samples, which corresponded with the 0.95 depth scale of the temperature differences. The intensity groupings were then averaged in time over 125 consecutive pings, centered around the temperature sampling time. The resulting averaged intensity profiles were also low-passed with a three-point running mean for smoothing. Correlation coefficients between the two 64 point arrays were computed for each temporal sample.

Figure 2 is a display of the temperature gradients, scattering intensities and the associated correlation coefficients. The gradients and intensities were converted into gray shades and plotted with a digital recorder. Greater gradients and stronger intensities are shown as darker shades. The dark band in the acoustic record near 140 m is an artifact, due to backscattering from a portion of *Flip's* hull that was received through the backlobe of the transducer. Prior to the rise of the SSL, the correlations between temperature gradient and scattering intensity are significantly positive. Not shown in this figure is a 2½ hour period from 1530 to 1800, when the correlation coefficient had a mean value of 0.46. The SSL migration can be seen as a dip in the correlation, as numerous scatterers in transit destroy the correlation. After the transition the correlation remains positive for approximately an hour. Around 2200 the scatterers begin to readjust their depths until there is a negative correlation by 2315. On scales of 10 m, the correlation is excellent by inspection. Small-scale features in the change of the temperature gradient, especially the internal wave activity, can be seen reflected in the acoustic information.

The significant change in correlation around 2200 might be interpreted as merely

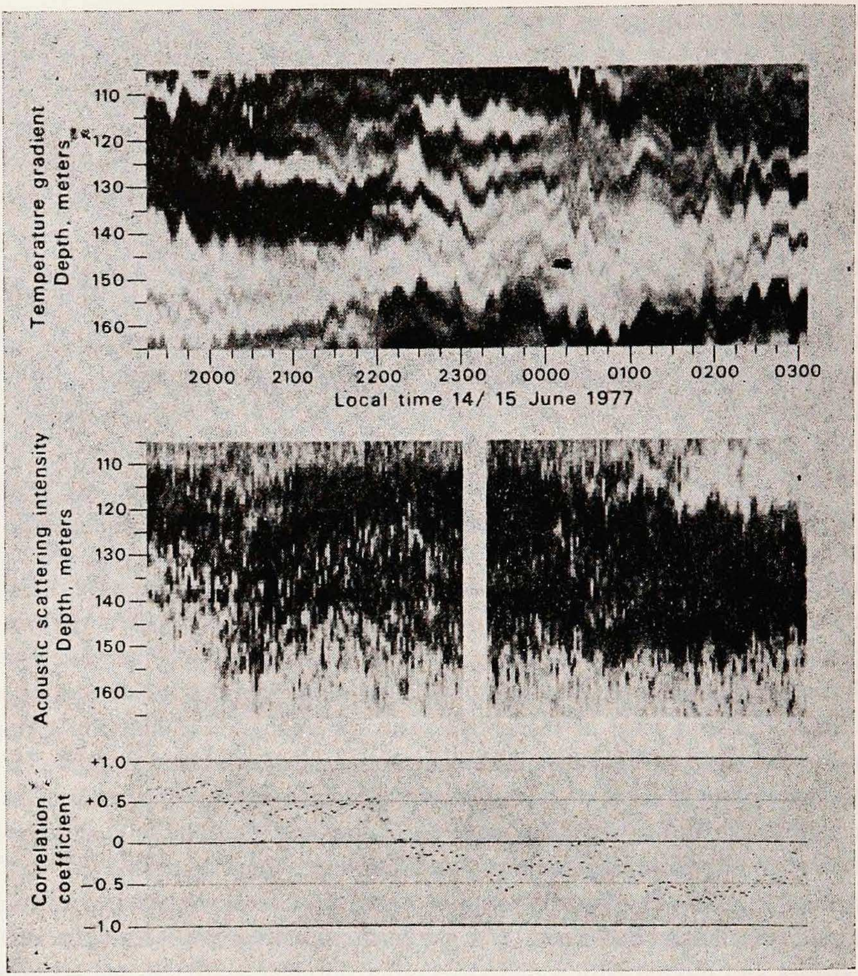

Figure 2. Concurrent plot of vertical temperature gradient, averaged acoustic scattering intensity and correlation coefficients.

a change in the temperature gradient profile beginning at that time. However, as can be seen in Figure 3, this is misleading. This figure shows the acoustic record from before sunset to just after midnight. The feature at 170 m is also an artifact due to a sea surface reflection as received through the backlobe. Before the SSL migration there is little vertical scatterer motion except for that due to internal waves. Beginning around 2050, numerous scatterers are seen to migrate downward. The scatterer concentration near 120 m diminishes greatly as a new concentration can be seen forming near 140 m. Thus not only temperature gradient, but also the scatterer populations can be seen changing markedly around 2200.

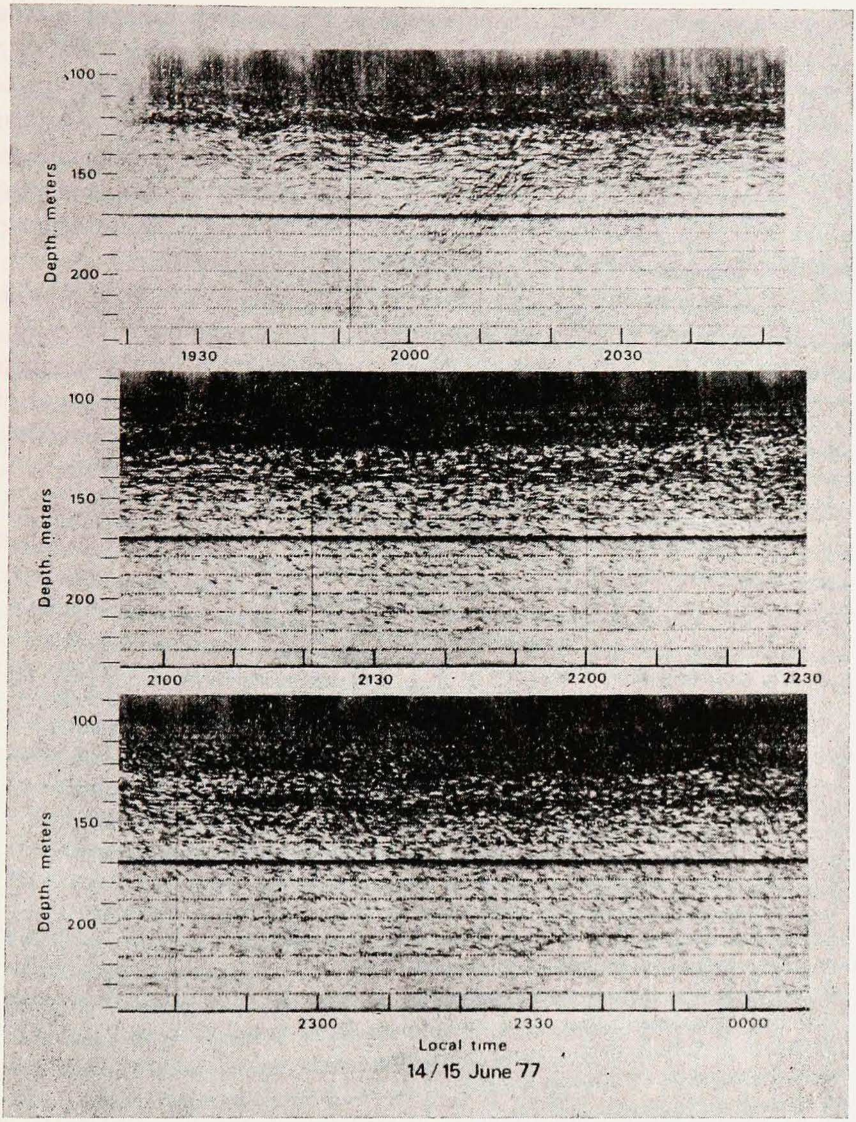

Figure 3. Echosounder record showing (top) the rise of the DSL followed by a diffuse downward migration (bottom).

3. Discussion

Since there was no biological sampling, the rationale for the day-night difference in the correlation coefficients is unknown. However, even if this sampling had been done, we can see from the figures that the depth excursions allowable for the trawl should have been ± 10 m or less, in order to have observed the correlation change with temperature gradient. The daytime population appears to be composed of neutrally-buoyant organisms, who have little vertical movement and whose vertical distribution is similar to the temperature gradient distribution. The nighttime population, including the SSL animals, is initially also distributed vertically in consonance with the temperature gradient structure. However, within two hours after migration, they have redistributed so that they are negatively correlated with temperature gradient. Since their vertical motions are, in the mean, representative of the internal wave field, we conclude that they are still ballasted neutrally-buoyant.

Downward migrations that are not associated with sunrise have been previously observed. Badcock and Merrett (1976), in their paper on midwater fishes in the eastern North Atlantic, noted that post-larvae and juveniles of Macrorhamphosus migrated downward at night nearly 200 m from their daytime near-surface depths. They suggested that this behavior was a characteristic of the species rather than of a particular growth stage. Kaye (1978) noted a mid-night downward migration of scatterers from the mixed layer to depths of 160-200 m that coincided with the passage of rain squalls. The majority of the scatterers returned to the mixed layer after the squalls had passed, but many continued their downward migration prior to sunrise. Friedl *et al.* (1977) in the tropical North Pacific south of Baja Mexico, observed repeatedly, but not always, a diffuse downward scatterer migration from near the surface to depths of around 200 m that generally commenced two hours after the evening upward movement. This behavior was observed geographically only within a region which typically had minimal surface dissolved oxygen values.

Numerous reasons for the reverse migration that we have observed could be proposed. Three of these are: 1) the animals have moved from the high-gradient position of the thermocline in response to a change in the photo-environment; 2) the organisms have encountered the food distribution during their upward migrations and are moving downward to feed; and 3) the scatterers have migrated beyond a tolerable physiological limit and have moved downward to a preferred habitat.

Kampa (1970) has shown direct correlations between isolumes of light intensity and depth variations of sound scattering layers on successive evenings. Although our data were obtained under complete cloud cover, it is realized that these animals can perceive changes in sky state that would have been undetected by us. Consequently a small increase in the ambient irradiance could easily result in isolume depth increases of 20 m and possibly explain the reverse migration.

The second proposal is an extension of the concept that scattering layers may use vertical migration as a tactic for finding food. It has been suggested (Isaacs *et al.*, 1974) that the animals, because of their vertical migrations, are carried from unproductive regions to areas of greater standing crop due to the current shear between surface and sub-surface waters. Arriving at a new point some 5-10 km distant from the previous night's position, the SSL may detect the standing stock at slightly different depths. If, as these authors propose, the standing crop increases the local turbidity, the predators may be responding to local variances in the light field to accomplish this detection.

The third suggestion concerns the temperature range tolerable to the organisms. This can be a dominant bound as noted by Davies (1976), who observed the arrest of a relatively-slow upward SSL migration by a positive thermal gradient in the Kurile Trench off the Kamchatka Peninsula. Although light intensity may determine upper and lower bounds of the migrators, these could be modified by the temperature-depth distribution. Robison (1972) observed distributions of the myctophid species, T. Mexicanus, within the Gulf of California. Absolute temperature could not explain the depth limit variations between the range of his specimens and those of Paxton (1967), who sampled myctophid distributions in the San Pedro Basin off California. Similarities between these observations were the oxygen concentrations at daytime depths and the temperature difference between the daytime and nighttime depths, causing Robison to propose that temperature differential might have been the dominant bound on the range. Since myctophids, including T. Mexicanus, comprised a major portion of the catch of Friedl *et al.* in the California Current and since myctophids are excellent sound scatterers, it could be expected that the SSL might also be quite sensitive to variations in temperature gradient.

4. Conclusion

A daytime population of acoustic scatterers has been shown to be correlated positively with small-scale temperature gradients in the thermocline below *Flip*. The temperature gradients were determined on a vertical scale of 95 cm and were sampled every 125 seconds, providing a detailed look at this correlation not previously reported. After the evening upward migration of the Sound Scattering Layer, the correlation remained positive for approximately an hour. After this time a diffuse downward migration was observed and the scatterer population became negatively correlated with the temperature gradient profile. Correlation of SSL depth fluctuations with observed internal waves indicates that the scatterers were ballasted neutrally-buoyant. Because our understanding of the depth distributions is poor, this reverse migration cannot be explained without additional measurements of numerous factors, including the light, nutrient and plankton abundance profiles. However, it is concluded that these scatterers should not be considered as passive scalars of the temperature profile, even though they may serve as tracers of internal wave activity.

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