A Synoptic View of the Gulf Stream Front with 70-kHz Sonar: Taking Advantage of a Closer Look

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Acoustical scattering across the near-surface frontal zone of the Gulf Stream off Cape Hatteras was greatest in the thermal front. Little biological scattering was evident in the colder Slope water, but in the Gulf Stream, scatterers formed five horizontal bands. Interpretation and new applications of acoustical information in biological oceanography are discussed.

La diffusion acoustique dans la zone frontale près de la surface du Gulf Stream au large de Cape Hatteras est plus élevée dans le front thermique. On a observé peu de diffusion biologique dans les eaux de versant plus froides mais, dans le Gulf Stream, il y avait cinq bandes horizontales. On discute de l'interprétation et des nouvelles applications des données acoustiques en océanographie biologique.

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We present a striking example of 70-kHz acoustical scattering across the northeast edge of the Gulf Stream in relation to temperature, vertical change in temperature, and depth from 14 to 150 m (Fig. 1). Because sound scattered by density gradients is negligible, we attribute the scattering to the biota present. Organisms that scatter this frequency of sound are generally 1 cm or more long and include some of the largest zooplankton and all of the nekton, animals large enough to swim independently of water movements.

Nekton aggregate in frontal zones (Bowman and Esaias 1978; Owen 1981). Sonar techniques make possible the study of fine-scale biological structure in dynamic frontal zones. Murav'yev and Shirshov (1984), for example, have found that nektonic organisms are concentrated spatially and temporally at water density gradients. Our sonar transect displayed in Fig. 1 highlights the pattern in the distribution of small nekton at an ocean front including high concentrations in the areas of maximum change in physical parameters.

The traditional hypothesis proposed to explain the concentration of biota in a frontal zone is that primary and secondary producers are passively concentrated by the physical dynamics to locations where nutrients and light stimulate production. An alternative hypothesis, which may be consistent with the first, has been proposed from the perspective of those who study animals in which behavior is not a passive, but rather an active reponse to the environment. This hypothesis suggests that the concentration of biota in certain areas results from the direct behavioral responses of fish or other nekton to environmental factors such as temperature and food abundance (Crowder and Magnuson 1983). Answering these questions and other biological questions in complex dynamic areas like the Gulf Stream front would perhaps be impossible without an ability to obtain rapid synoptic views of biota such as pictured here.

Methods

The acoustical scattering and temperature profile were obtained from the R/V *Cape Hatteras* on 12 July 1983, along a 14.5-km transect 115 km east–northeast of Cape Hatteras from 35°47.98′N, 74°37.67′W (1248) to 35°41.25′N, 74°28.80′W (1545). The northeast to southwest direction of the transect progressed from Gulf Stream water overlying Continental Slope water to Gulf Stream water alone. A Simrad EY-M echosounder with an 11° beam width was operated at 70 kHz with a pulse duration of 0.6 ms. The transducer faced downward and was towed 4 m below the surface. An echo processor (Powell and Stanton 1983) simultaneously calculated echo peaks and the integrated echo in individual 1-m depth intervals and transferred the processed data to an Apple II microcomputer which, in turn accumulated echo data from 120 transmissions (approximately 2 min) to obtain the (average) integrated echo and a probability density function (PDF) of echo peaks. Data were analyzed from 12 to 150 m, owing to the range limitations of this sonar system. The arithmetic mean of the relative integrated echo was calculated for each water type and was converted into the commonly used volume scattering strength which is on a decibel scale (Urick 1975; Clay and Medwin 1977). We determined the resolution of scatterers from an examination of PDF values (Stanton 1985a, 1985b).

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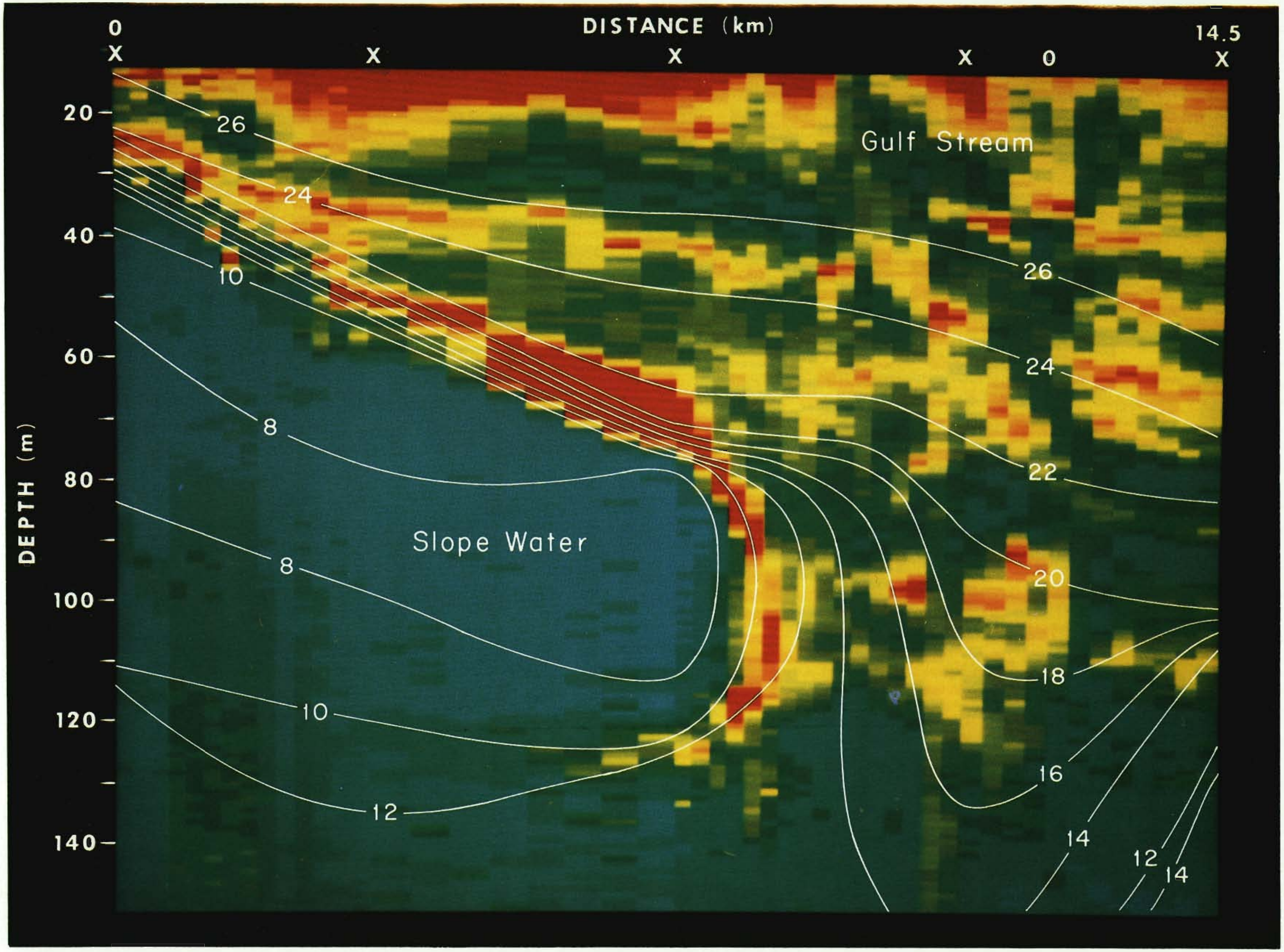

FIG. 1. Relative abundance of biological scatterers of 70-kHz sound in relation to depth and temperature along a 14.5-km transect crossing the near-surface frontal zone of the Gulf Stream during the daytime on July 12, 1983, 115 km east-northeast of Cape Hatteras. Vertical resolution is 1 m, horizontal resolution is approximately 300 m, and the color scale is logarithmic in 21 steps passing from blues to greens to yellows to reds. Locations of the XBT casts are indicated by ×. 0 indicates the location of a 2-min column of acoustic data deleted owing to interference from porpoise sounds. See methods for more explanation.

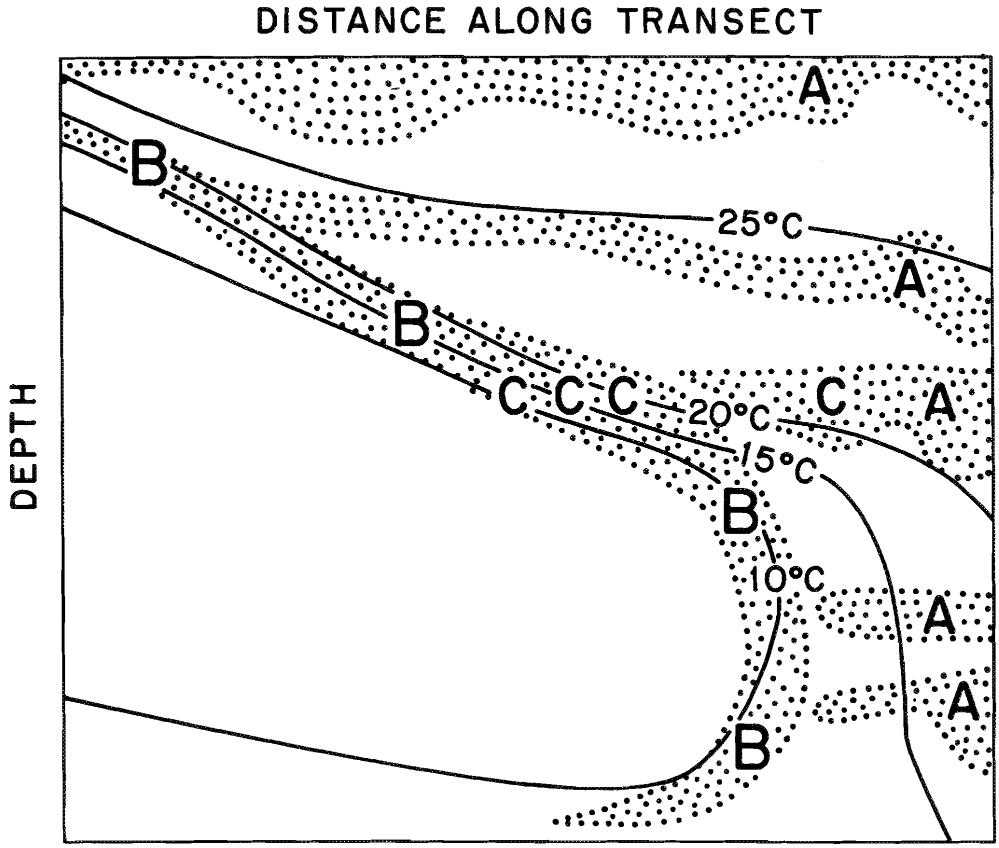

FIG. 2. Location of net samples to test whether (A) each acoustic surface is biologically distinct, (B) the biological structure of the same acoustic surface changes with depth, and (C) the biological structure of an acoustic surface changes with temperature. Letters on the figure show locations for replicated net sampling. Stippled areas are acoustic surfaces approximated from Fig. 1.

We contoured the temperature profile from five expendable bathythermograph (XBT) releases along the transect. Changes in temperature with depth (degrees Celsuis per metre) also were calculated, smoothed over 3 m, and contoured.

Results

Throughout the area, echoes of the individual scatterers overlapped each other (i.e. the organisms were not resolvable by sonar), indicating minimum densities of organisms (>1 cm long) of at least $28/1000\ m^3$ at 20 m to at least $0.5/1000\ m^3$ at 150 m.

The transect was divided into three water types, Slope water (<12°C), Gulf Stream water (>20°C), and thermal boundary water between the Slope and Gulf Stream waters (Fig. 1). The three types of water differed greatly in biological sound scattering characteristics. Slope water, the uniform blue area in the lower left corner of Fig. 1, had the lowest scattering strength (mean −83 dB where the decibel level represents the fraction of acoustical energy returned from one cubic metre of water on a logarithmic scale. For example, if the fraction is $10^{-8.3}$, the "dB" level is −83). Scattering strength in the thermal boundary water, the red diagonal, J-shaped band (Fig. 1), was extremely heterogeneous. In Gulf Stream water, the area in the upper and right side (Fig. 1), scattering strength revealed reddish yellow horizontal striations in the distribution of organisms.

In the thermal boundary water the integrated echo data indicated relatively high concentrations of scatterers in a continuous band located at approximately 20 m at the northwestern end of the transect and sloping to approximately 80 m near the middle of the transect. Scattering strength varied from −76 dB between 28 and 55 m to −68 dB in the most intense scattering area between 51 and 77 m and −74 dB between 72 and 95 m. In the intense scattering area at 60–70 m (Fig. 1) the echo signal was so strong that it saturated the processor amplifier; thus the values underestimate relative integrated echo strength. In the deeper portion of the thermal boundary, scattering follows the 10–12°C isotherms and recurves into the Slope water.

In the Gulf Stream the distribution of scatterers was horizontally striated but the scattering strength averaged −75 dB. Four (possibly five) horizontal striations are evident, located at approximate depths of (I) <12 m, (II) 35–50 m, (III) 60 m, (IV) 90–100 m, and (V) 100–110 m. The three deeper striations (III, IV, and V) appear to cross into the sharp thermal gradient whereas striation II slopes upward along the 24–26°C isotherms and off the transect to the northwest. Striations III, IV, and V culminate in or are adjacent to a higher level of scattering at the sharp thermal gradient. The upper striation was intense and saturated the sonar system.

The maximum horizontal temperature gradient was approximately 0.015°C/m whereas the maximum vertical temperature gradient was aproximately 3.0°C/m. A plot of the smoothed vertical temperature gradient indicated an area from 50 to 80 m in the thermal boundary water where the gradient was >1°C/m.

The most intense backscattering occurred in this area of greatest temperature change in the vertical field.

Discussion

This acoustic transect provides a rapid, high-resolution view of the distribution of nekton biomass in a complex dynamic area at the edge of the Gulf Stream. In this presentation, we have the ability to resolve the distribution of biomass over 1-m depth and approximately 300-m horizontal intervals. If we had not averaged over 120 pulses at sea, horizontal resolution could be increased to about 20 m (approximately 8 pulses) at the speed we traveled. More traditional biological sampling with towed nets usually integrates over tens of metres in the vertical scale and over kilometre scales in the horizontal. If we used a net sampling strategy of lower spatial resolution of one sample per 10 m of depth in each kilometre, 225 net samples would be needed for the 150 m by 15 km area. To complete this design for daylight periods only would require at least 4 d of net sampling during which the structure would have probably changed. This time frame compares with 2 h 17 min for the acoustic transect. With onboard computer facilities the final results can be displayed either "real time" or shortly after (10–15 min) the completion of a transect. Biological information extracted from net catches often requires months or years of laboratory sample processing.

For the biologist, one logical application of acoustic observations is in conjunction with net sampling. With our acoustic profile, we can design net sampling protocols at sea to test hypotheses on factors governing the small-scale distribution of biomass in the ocean. For example, the location of scatterers suggests an efficient sampling design to test whether each concentration of biological sound scatterers is a distinct taxon or assemblage of species or whether the biological composition of the same band changes when it crosses isotherms or depth levels (Fig. 2). An inherent, but testable assumption in this approach is that the biological structure observed with acoustics delineates biologically meaningful surfaces. Experience with studies of deep scattering layers (Farquhar 1971) and the application of sonar by commercial and recreational fishers certainly suggests that the assumption has some validity.

A second interesting application of acoustics by biologists is to use the sonar information itself to characterize and analyze the biology of complex, dynamic areas such as ocean fronts. Acoustics can be used as a new sensor without nets to view and rationalize biological oceanography at time and space scales possible only with acoustics. To operate at these scales, taxonomic resolution must be sacrificed. Hierarchy theory (Allen et al. 1984; Sugihara et al. 1984; Magnuson et al. 1986) provides a context for such an approach where acoustics can be used both to identify biological surfaces and examine the grain within surfaces at several scales of spatial resolution. Acoustic observation not only can give some estimate of biomass density, but also under certain conditions can yield information on numerical density and size structure of the biota. Pieper and Holliday (1984) have an operating acoustic system, for example, to estimate size structure of zooplankton in situ at sea. Clay (1983) and Ehrenberg et al. (1981) have developed two separate methods to estimate body sizes of nekton acoustically in situ at sea. Such analyses can be accompanied with net or pump sampling to add traditional biological information at lower levels of time and space resolution. Our working hypothesis is that analyses of the acoustic records themselves at levels of biological organization above the species may initially lead to a broader and more innovative comprehension of complex, dynamic areas such as the Gulf Stream front.

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