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Acoustic methods for water mass delineation in coastal marine ecosystems

J. Proni, J. Stamates, T. Carsey, J.-Z. Zhang, C. Sinigalliano and K. Sullivan

AOML/NOAA, 4301 Rickenbacker Cswy, Miami, FL 33149, USA
john.proni@noaa.gov

Acoustical methods play an important role in identifying sources of nutrient to coral reef ecosystems in the South Florida coastal waters. Nutrient fluxes into the coastal ocean are associated with distinct water masses such as inlet discharge plumes, wastewater outfall discharge plumes, and up-welling of deep oceanic water. Various nutrient-bearing water masses can be identified by water column acoustic backscatter profiles, obtained via either ship-borne instrumentation or in-situ instrumentation. Such multidimensional images of water masses can be used to optimize the design of chemical and biological sampling efforts. Examples of water mass imaging will be presented as well as the use of such images in the design of water quality sampling programs.

1 Introduction

A central problem in coastal ocean chemical and biological sampling programs is to identify the water mass from which the samples are taken. Our studies through the years have shown that active acoustic systems operating in the frequency range from kilohertz to megahertz, can yield valuable insight into the spatial distribution of the water masses from which samples are gathered. The water mass boundaries are smaller and change faster in the coastal ocean than that in the open ocean. Significant changes exist in the vertical distribution of water masses at even smaller scales. Acoustical methods are an excellent approach for stratifying the ecosystem into resident water masses for more efficient chemical and biological sampling. The usefulness of acoustical methods is illustrated in the case studies of anthropogenic waste discharges in the coral reef ecosystem off southeast Florida USA (Fig 1) and in the continental shelf system off New York USA. (Fig 10)

2 Case Study One: South Florida Coastal Ocean

A map of the study area is shown in Figure 1. Two of the ecosystem questions which arose in this study are: (1) "What are the sources of nutrients, both naturally occurring and anthropogenic, to the coral reef ecosystem located in south Florida coastal waters?" (2)"What are the exposures of the coral reefs to said sources?" The principal direct anthropogenic source of nutrients to the coastal ocean was suggested to be the series of secondary treated waste water effluent outfalls. The locations of the principal outfalls, together with the principal inlets discharging into the coastal ocean, are shown in Figure 2.

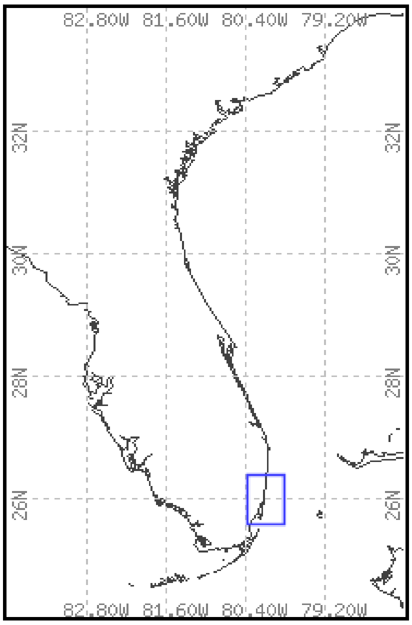

Figure 1

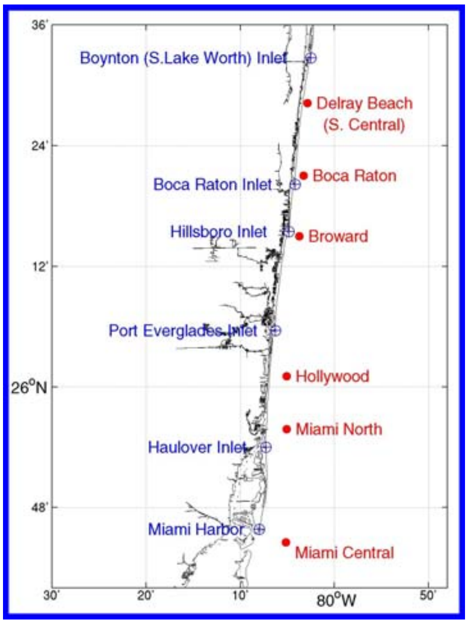

Figure 2

In order to design an effective sampling scheme for the nutrients and microbiology contained within an effluent plume, a knowledge of the sub-ocean surface distribution of plume as a function of time is required. In Figure 3 is shown an acoustic visualization of the sub-ocean surface distribution of the effluent plume from one of the outfalls.

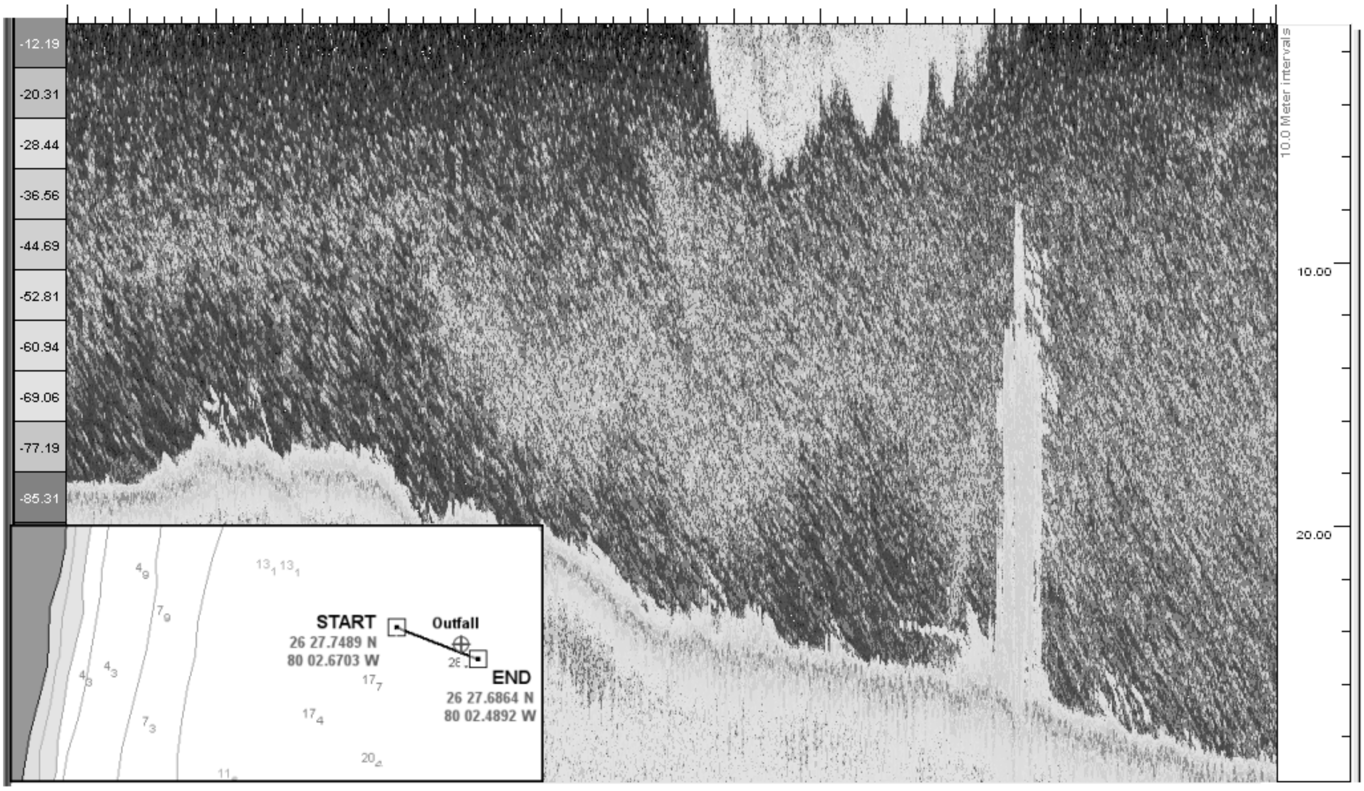

Figure 3

The acoustic visualization is created by plotting the spatial distribution of the acoustic backscatter obtained using a down ward looking 200kHz narrow beam acoustical system towed from a surface ship. The principal hypothesis of using the backscatter field as a guide for chemical and biological sampling is that the backscatter field gives a good estimate of both the dissolved and particulate component fields of effluent plume. Many studies have shown that this hypothesis is indeed reasonable. From Fig. 3 it may be seen that the effluent field rises to the ocean's surface and occupies the upper 10 meters of the water column.

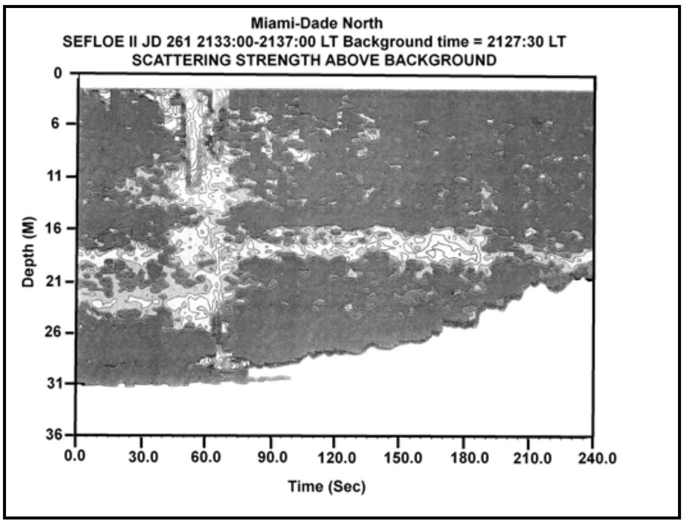

Figure 4

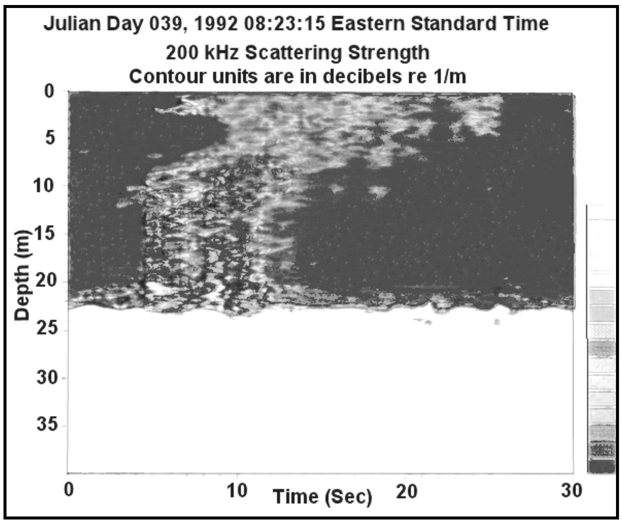

Figure 5

In Figures 4 and 5 are shown two other outfall plumes with some trapping of plume at different depths in Figure 4 and multiple plumes exiting a diffuser section of the outfall pipe in Figure 5. The acoustical data clearly indicates that chemical and biological sampling of these plumes should be concentrated in the upper part of the water column. Acoustical methods for tracking of plumes may extend to several kilometers in range from the discharge site. To extend ranges of plume observation to tens of kilometers the tracer Sulphur Hexafluoride may be used (Wanninkhof et al 2005).

Figure 6

Anther possible source of nutrients is the many inlets discharging into the coastal ocean. Shown in Figure 6 is a satellite image of one of the plumes exiting an inlet on an outgoing tide.

An acoustic visualization of the sub-ocean surface inlet plume distribution is shown in Figure 7 (right panel). From this Figure it can be seen that the exiting inlet plume is distributed over, approximately, the top 70 meters of the water column. Also shown are concurrently obtained transmissometer (left panel) and temperature data (center panel). Comparison of the left and right panels shows that both acoustical and optical devices record the presence of the Port of Miami inlet plume.

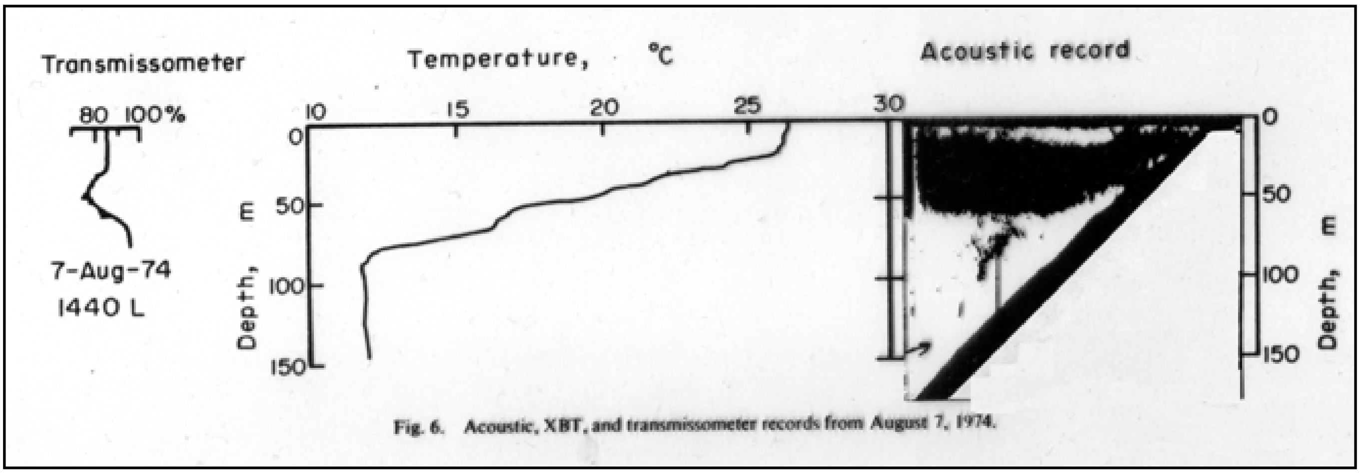

Figure 7

A third possible source of nutrients to the coastal ocean is upwelling. It is well known that the ocean waters below the pycnocline are often rich in nutrients. The question of interest for the south Florida coastal ocean is the extent to which the deeper, nutrient-rich water is “up-welled“ to the area of the coral reefs. Figure 8 shows the temperature recorded at a site in the coral reefs of south Florida and also shows the acoustic backscatter time series obtained from a collocated, bottom-mounted ADCP.

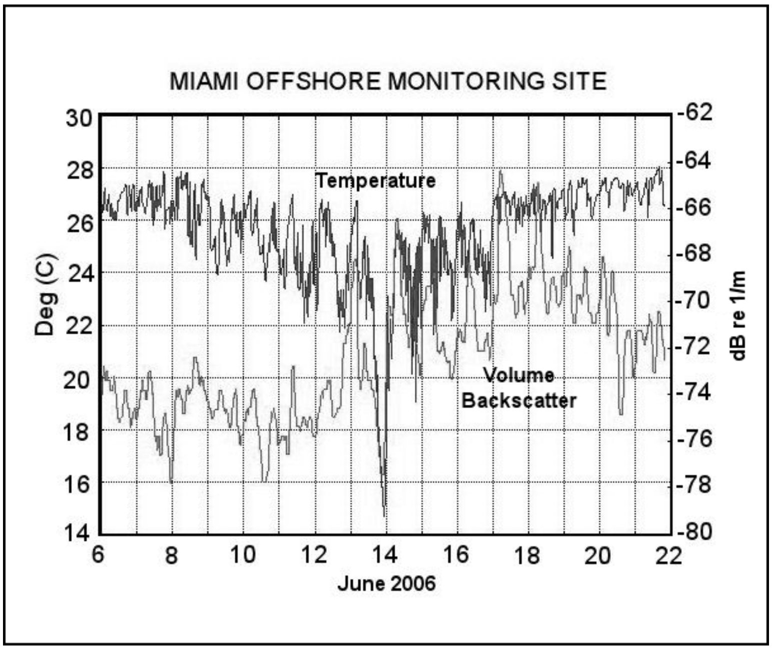

Figure 8

Temperature and particulate concentration time series data may be used to detect the presence of colder up-welled water, such as was observed on June 14, 2006 (Figure 8). It can be seen that the suspended sediment (estimated by acoustic backscatter) decreased with the sharp decrease in temperature. However, over the period of several days (June 12 through 22), the acoustic backscatter is seen to have increased. This suggests that the up welled water was relatively lower in particulate concentration, while the overall effect of the passage of the upwelling event was to increase the particulate concentration in the waters at the site of the measurement.

3 Case Study Two:
The New York Continental shelf

Figure 9 shows an acoustic visualization of the Hudson-Raritan river plume on June 22, 1976. This image was made using a towed 20kHz acoustical backscatter system and extends over approximately 5km. Also shown in this image is a packet of internal waves approaching the frontal boundary of the plume from the deep ocean. Water quality sampling at this location benefits greatly from the acoustic visualization since samples can be determined to be from within river waters or continental shelf waters.

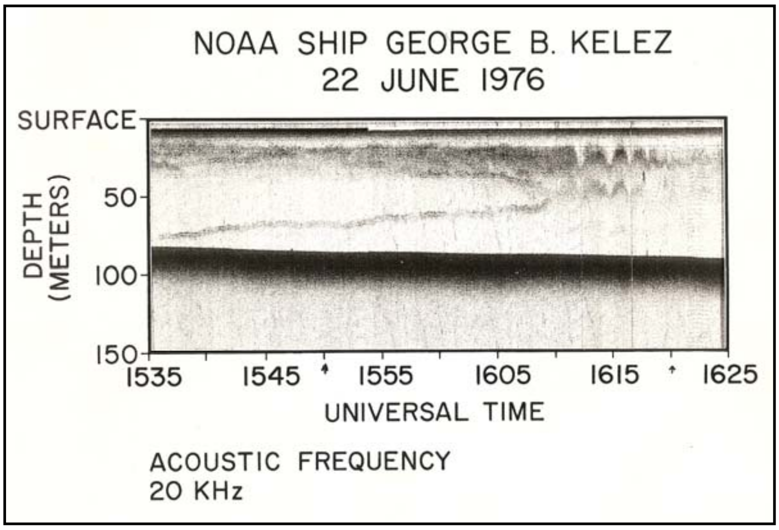

Figure 9

Figure 10 shows a satellite image of the Hudson-Raritan river plume taken in June of 1976. An exploded view of a region in the southeast quadrant of the image (inset) shows a packet of internal waves impinging on the river plume.

Figure 10

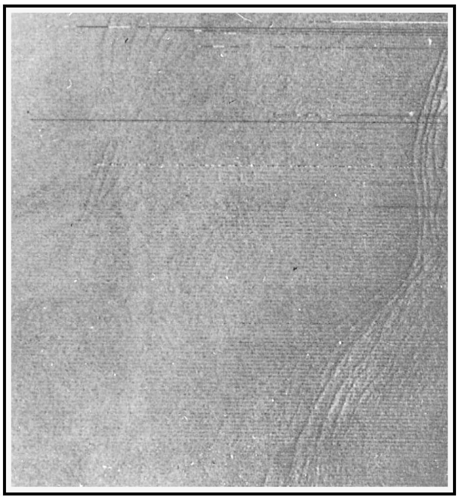

Figure 10 (inset)

Figure 11 shows an acoustic visualization of a sewage sludge discharge. Two passes are made over the discharge. In the first pass detrainment of the sludge material in the pycnocline is visible. In the second pass over the discharge, it can be seen that internal waves have been created by the discharge have been Doppler up shifted by the motion of the ship towards the point of discharge.

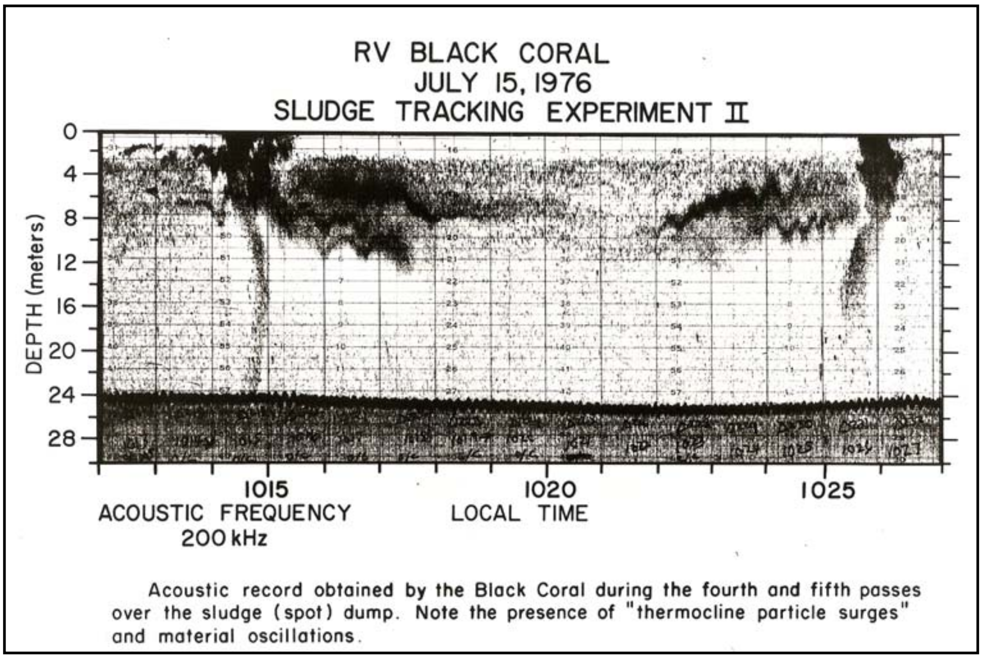

Figure 11

4 Summary

The application of acoustical methods for water mass identification and delineation has been illustrated through two specific case studies. In these studies inlet plumes, sewage-related discharges and up-welled waters have applications have been illustrated. Once an initial acoustic reconnoitre of the coastal water region of interest has been carried out a water quality sampling effort can be designed based upon the acoustic visualizations obtained.