# Acoustic Imaging and Visualization of Plumes Discharging from Black Smoker Vents on the Deep Seafloor

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## Abstract

Visualization and quantification methods are being developed to analyze our acoustic images of thermal plumes containing metallic mineral particles that discharge from hot springs on the deep seafloor. The acoustic images record intensity of backscattering from the particulate matter suspended in the plumes. The visualization methods extract, classify, visualize, measure and track reconstructions of the plumes, depicted by isointensity surfaces as 3D volume objects and 2D slices. The parameters measured, including plume volume, cross sectional area, centerline location (trajectory), surface area and isosurfaces at percentages of maximum backscatter intensity, are being used to derive elements of plume behavior including expansion with height, dilution, and mechanisms of entrainment of surrounding seawater. Our aim is to compare the observational data with predictions of plume theory to test and advance models of the behavior of hydrothermal plumes through the use of multiple representations.

## 1 Introduction

We are developing innovative new acoustic and visualization methods to image and analyze thermal plumes containing metallic mineral particles with the appearance of black smoke that discharge from hot springs on the deep seafloor [1, 2]. Our objective is to advance understanding of the dynamics of the black smoker plumes as major agents of dispersal into the ocean of heat and chemicals derived from the Earth's interior. The plumes consist of a stem and a cap. The stem is formed of particles suspended in thermally expanded fluids which mix with surrounding seawater. The fluids buoyantly rise up several hundred meters to a level of neutral buoyancy where they spread laterally to form the cap. Plume studies prior to our development of the plume imaging sonar have used a combination of other techniques including: video and photo imagery which illuminates only small volumes within meters of a vent (owing to rapid attenuation of light in seawater); construction of 2D cross sections of plumes from asynchronous individual profiles of temperature, conductivity (salinity) and optical light attenuation or scattering properties versus depth (Conductivity-Temperature-Depth profiling method); records made with standard sonar instruments; and laboratory tank simulations. Of these various approaches, acoustic methods are particularly well suited to synoptically image 3D hydrothermal plumes since they are large (linear dimensions $10^1 - 10^3$m) and contain suspended particulate matter.

## 2 Acoustic Imaging

Acoustic imaging of black smoker plumes is based on Rayleigh backscattering from the metallic mineral particles suspended in the entire volume of the plume. The particles are small (microns) relative to the wavelength of the acoustic frequency employed (~1cm at 330 kHz; [3]). Our initial calculations indicated that this type suspended particulate matter could be detected at ranges of up to hundreds of meters using acoustic frequencies of hundreds of kHz [3]. We modified an existing sonar system to calculate specifications (frequency 330 kHz; pulse duration 100 microseconds; transmit power level of 220 dB).

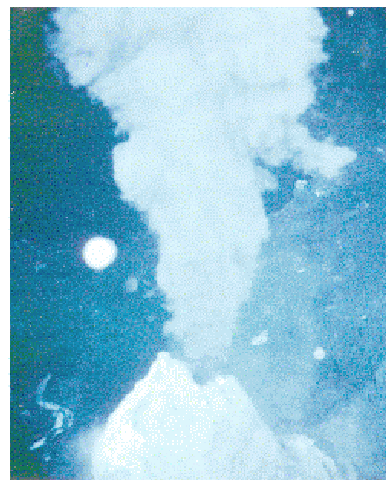

Figure 1: Photograph of one of the deep sea plumes that was imaged.

The sonar device was mounted in a forward-looking configuration on a submersible, and it imaged plumes discharging from black smoker-type vents at a depth of 2300m at a known field of hot springs at latitude $21°N$ on a submerged volcanic mountain range, the East Pacific Rise just south of the Gulf of California [4]. A photograph of the plume is shown in Figure 1. The imaging was done with a fixed geometry by setting the submersible on the seafloor with the sonar transducer about 10m from two black smoker vents several meters apart. The sonar transducer mechanically scanned the two plumes emanating from the vents in azimuth ($0.9°$ azimuthal steps) at successively higher elevations ($2°$ elevation steps). About 30 minutes was required to record a "frame" of data consisting of the set of scans in azimuth and elevation angles that define a plume volume by stacking of individual scans [4].

## 3 Visualization Methods

Our goal is to compare the observed data to plume parameters that are defined in plume theory [5] and that elucidate plume behavior. In order to apply these methods, the acoustic data was resampled onto an evenly spaced 3D rectangular grid with 0.25m spacing. Each grid point is considered to be the center of a cubical volume element, or voxel of uniform density, whose edge is equal to the grid spacing. The set of voxels collectively forms a volume object if the voxels are connected and lie above a threshold level. In this case, the thresh-

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