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A particle sedimentation model of buoyant jets: observations of hydrothermal plumes

Karen BEMIS[1], Deborah SILVER[2], Peter RONA[1] and James COWEN[3]
(1) *Institute of Marine and Coastal Sciences and the Department of Geological Sciences, Rutgers University, 71 Dudley Rd, New Brunswick, NJ, 08901 USA; fax 732-445-3374. Email: bemis@rci.rutgers.edu*
(2) *Department of Electrical and Computer Engineering, Rutgers University, Piscataway, NJ, USA*
(3) *Department of Oceanography, University of Hawaii at Manoa, Honolulu, HI, USA*

Abstract: We extend the application of exponential settling to hydrothermal plumes to predict hydrothermal sediment patterns on the seafloor by using acoustic observations of particle velocities and concentrations instead of the predictions of dynamic models used by previous studies. We assume settling occurs only from the margins of the plume, which corresponds to the transition from a net upwards force on the particles in the plume to a net downwards force outside. In each volume element where the net force changes from downwards to upwards, the loss of sediment from the volume element is calculated. The losses for five particle sizes are summed to determine the sediment mass deposited. We applied this sedimentation model to acoustic observations of particle concentration and flow velocity in hydrothermal plumes at Grotto Vent on the Endeavour Segment of the Juan de Fuca Ridge. The overall mass flux decreases if the particle size distribution is shifted towards smaller particles or particle density is decreased (as for biological particles). While improvements in both observations and model algorithms are needed, we demonstrate that quantitative predictions of sedimentation can be made successfully from direct observations of plumes.

Keywords: Particle sedimentation model • Buoyant jets • Hydrothermal plumes • Larval transport

Introduction

Most plume sedimentation models incorporate predictions of flow velocity and particle concentration in the plume based on the initial conditions at the vent. In this study, we adapt the sediment transport theories used in many studies of sedimentation for use with direct observations of flow velocity and particle concentration throughout the plume.

A common assumption of sediment transport theories is that the rate of sediment concentration decrease in a suspended layer can be described as exponential decay (Hazen, 1904; Martin & Nokes, 1988). A number of models have applied an exponential decay relationship for sediment mass concentration to settling of particles from the margins of the buoyant stems of volcanic eruption clouds and hydrothermal plumes (Sparks et al., 1991; Bursik et al., 1992; Ernst et al., 1996). These earlier studies used an integral (time-averaged) model, based on Morton et al. (1956), to describe the plume and to compute the fraction of the initial particle mass that settles and its radial dependence. This model depends on knowledge of the source buoyancy flux (difficult to measure for hydrothermal plumes) and total particle mass available (not meaningful for hydrothermal plumes where sedimentation occurs over decades).