

# **Chalk-Ex: Transport of Optically Active Particles From the Surface Mixed Layer**

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## **LONG-TERM GOALS**

To determine the mass balance of optically active particles within the surface boundary layer and to identify the processes responsible for particle redistribution.

## **OBJECTIVES**

1. Perform manipulative experiments in which a known quantity of optically active particles are introduced at the surface and tracked over time and space. This approach effectively removes uncertainty in the production term of the mass balance equation.
2. Identify and quantify the relevant physical and biological processes that remove optically active particles from the mixed layer (e.g., vertical mixing, sinking, dissolution, aggregation, and grazing-related "repackaging" into fecal pellets).

## **APPROACH**

Chalk-Ex consists of a sequence of multidisciplinary field experiments to be done in cooperation with W. Balch and C. Pilskaln (Bigelow Lab for Ocean Sciences) and H. Dam and G. McManus (University of Connecticut). Patches of optically active particles will be created within the mixed layer by dispersal of Cretaceous chalk ( $\text{CaCO}_3$ ) from the stern of a research ship. Two deployments are planned during each of two cruises: November 2001 and Summer 2003. Each chalk deployment calls for ~13 tons of chalk to make a patch of approximately 2 square km. During each cruise, deployments will be made at an oligotrophic site outside the Gulf of Maine and a more eutrophic site within the Gulf of Maine. Patch evolution will be determined from a combination of time series and spatial survey measurements over a period of about 3 days. Associated with the chalk deployments and spatial surveys (Balch), will be drifting sediment trap deployments (Pilskaln) and measurements of grazing and aggregation from in-situ samples (Dam/McManus).

Our part of the project focuses on three issues: (1) Determining the surface forcing during and after each chalk deployment; (2) Tracking the chalk patch with Lagrangian drifters; and (3) Measuring temperature (T), salinity (S), and horizontal velocity (U, V) with high vertical (5 m) and temporal resolution (5 min) within the upper 100 m of the water column. Surface forcing will be determined from shipboard meteorological observations. Tracking will be addressed by the deployment of

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Lagrangian drifters which will follow the near-surface (upper 1 m) flow and transmit their position in near real-time. The drifters will be deployed (and redeployed as necessary) near the center of the patch. The drifter positions will be available onboard the ship during the experiment, and will serve as a reference for "Lagrangian surveys" (as done, for example, during Iron-Ex I [Stanton *et al.*, 1998]). Upper ocean hydrography will be measured from an instrumented drifter deployed near the center of the patch. This drifter will consist of a small surface buoy with 100 m of instrumented line below it. This drifter will be only quasi-Lagrangian and will require periodic repositioning to remain in the patch.

## WORK COMPLETED

The first Chalk-Ex cruise was completed during 10–19 November 2001 on the R/V *Endeavor* out of Portland, Maine. Two sites were occupied. The "northern" site was near 43°50'N, 67°45'W in the Jordan Basin and the "southern" site was near 39°45'N, 67°45'W, just seaward of the New England continental shelf. Approximately 13 tons of CaCO<sub>3</sub> were injected at each site. Following the chalk deployments, the interdisciplinary research team conducted a variety of operations while the patch was being tracked and mapped. At present, data analysis is still underway. The description below focuses on preliminary results from the physical oceanography component. The field data have not yet been submitted to a national archive.

## RESULTS

Surface conditions during operations at the southern site (wind speed 7–14 m/s, average heat loss 315 W/m<sup>2</sup>) favored rapid vertical mixing, and the mixed layer depth (MLD) was maintained at 50–70 m depth. As a result, the chalk was rapidly diluted after injection, and proved difficult to detect. Conditions during and following chalk injection at the southern site (wind speed 4–7 m/s, average heat gain 40 W/m<sup>2</sup>) were more favorable for chalk detection. The chalk patch was detected and mapped within the upper 30 m during three surveys over a period of about 2 days. The results described below focus on the southern site deployment.

Time series of T and S in the upper 40 m were used to compute density and estimate the MLD, defined as the depth where density was 0.01 kg/m<sup>2</sup> greater than the value at 1 m (Figure 1). Time series from two acoustic Doppler profilers provided concurrent velocity data (not shown). During chalk injection, the MLD was about 20 m, but within a few hours it shoaled to about 6 m as a result of a near-surface intrusion. The MLD remained ≤ 6 m for the next 19 hours and < 15 m for the next 36 hr. Thus, the MLD at the time of injection represented the maximum depth to which chalk was mixed by physical processes. Indeed, the survey data showed the majority of chalk confined to the upper 25 m. Shear between the surface and 20 m, and the separation of Lagrangian drifters drogued at different depths, indicated that the chalk patch would be stretched into a "streak," oriented roughly east–west. This was confirmed by the first spatial survey, which showed an elongated patch oriented from northwest to southeast. Between the first and second surveys, an intrusion of deeper water was observed, coincident with an increase in the shear between the surface and 20 m depth. The expectation was for further elongation of the patch, and in particular for the deeper part of the patch to be separated from the 2–10 m layer being tracked by the drogued drifter. This was consistent with the second survey, which showed maximum chalk concentrations between 5 and 15 m depth. Thus, although vertical mixing dictated the initial penetration depth of the chalk, patch development during the first 48 hours was controlled primarily by horizontal advection during a period of restratification.

## **IMPACT/APPLICATIONS**

These experiments are designed to quantify the major loss terms for optically active particles. This knowledge is critical to understanding and predicting the evolution of the underwater optical field on horizontal scales from 1 m to 10 km, vertical scales from 1 to 100 m, and temporal scales of hours to days.

## **TRANSITIONS**

None.

## **RELATED PROJECTS**

We are working closely with Balch/Pilskaln and Dam/McManus to analyze results from the first cruise and prepare for the second cruise in the summer of 2003. A small surface buoy design developed for the Remote Environmental Monitoring UnitS (REMUS) vehicle program was adapted for use with the instrumented drifter. Instrumentation obtained as a part of an NSF Major Research Instrumentation grant was used to enhance the T-only measurements originally proposed for the instrumented drifter to T/S measurements.

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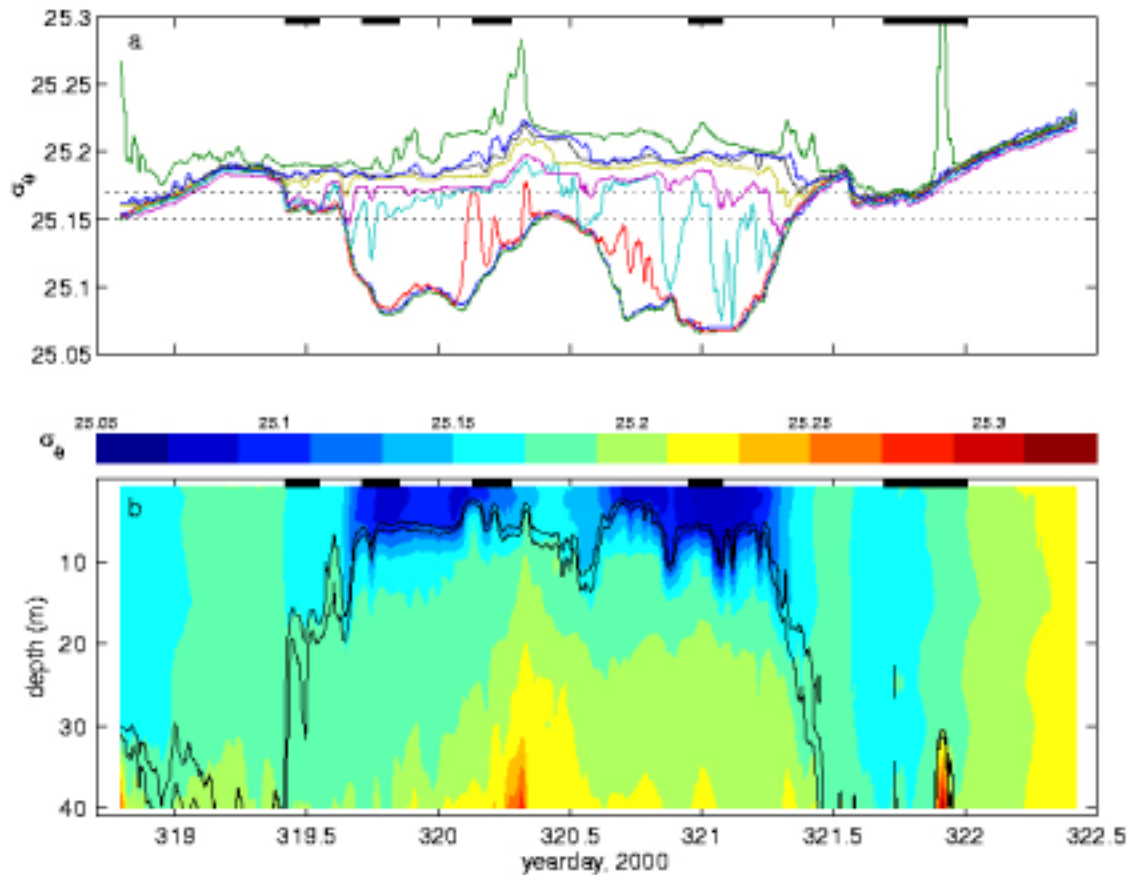
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## **PATENTS**

None.



**Figure 1. Evolution of the density field during operations at the southern site during the November 2001 cruise. (a) Time series of density at 10 depths between 1 and 40 m. (b) Contours of density in the upper 40 m with two different estimates of the mixed layer depth overlaid (thin solid lines). The bars at the top of each panel represent the chalk injection period (first bar) and four successive shipboard surveys. The chalk was injected in water with potential density between about 25.15 and 25.17, shown as dotted lines in (a). [The upper panel emphasizes changes in density with time and shows that the water column was relatively weakly stratified leading up to the chalk deployment, more strongly stratified during the first three surveys, and weakly stratified again during the fourth survey. The lower panel emphasizes changes in density with depth and shows that the mixed layer was about 20 m deep at the time of chalk deployment and less than 10 m deep during the first three surveys.]**