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 processes responsible for their redistribution.

OBJECTIVES

1) Perform manipulative experiments in which a known quantity of optically-active $CaCO_3$ particles are introduced into the surface mixed layer, and tracked over time and space. This approach effectively removes uncertainty in the production term of the mass balance equation.

2) To quantify the relevant physical and biological loss terms that remove optically-active particles from the mixed layer (vertical mixing, sinking of discrete particles, particle aggregation, dissolution, and grazing-related repackaging of particles into fecal pellets).

APPROACH

This work will involve not only Balch and Pilskaln, but also Dr. Al Pleuddemann (WHOI; physical studies) and Drs. Hans Dam and George McManus (Univ. Connecticut; grazing/aggregation studies). Their work is not included in this report.

We will make two deployments of Cretaceous chalk during each of two cruises planned for November 2001 and Summer 2003. The purpose of the deployment is to understand the fate of optically-active particles within the mixed layer (when the production term is known absolutely). Our cruise plan calls for deploying ~13 tons of chalk to make a patch in the surface mixed layer at an oligotrophic site, outside the Gulf of Maine and a more eutrophic site within the Gulf of Maine. The rationale for this approach is that at the oligotrophic site, physics will dominate biology in removing particles from the mixed layer. The sinking rate of the $CaCO_3$ particles is so slow (10cm d^{-1}; (Honjo 1976; Balch et al. 1996)) that the mass of $CaCO_3$ in the oligotrophic patch should not decrease significantly during the course of the experiment from sinking of the 2μm particles, as long as aggregation and grazing rates

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are minimal. At the eutrophic site, we would expect easily detectable decreases in the mass of the mixed-layer patch due to intense grazing activity (e.g. grazing rates of 0.5-1 d^{-1}), and repackaging this $CaCO_3$ into fast-sinking fecal pellets. Changes in the mass of chalk in the patch should be consistent with the fluxes caught in the sediment trap, unless major dissolution occurs (which could also be associated with grazing (Harris 1994; Milliman et al. 1999)).

Patch deployment and surveys

Chalk will be diluted with surface seawater in a 1900 liter (500 gal.) tank prior to being dispersed through a horizontal spreader on the fantail, which will direct the liquid into the ship's wake. Patch size will be ~1.5km^2. While one batch of the chalk/seawater slurry is being spread, the next will be prepared in a second tank and spread when the first tank is empty.)

We estimate that patch deployment will take approximately 5h. By starting deployment just before dawn, the patch will be deployed in time for the daytime overpasses of SeaWiFS and MODIS ocean color satellites. Following the deployments of chalk, the following work will be performed: deployment of drifting hydrographic arrays and sediment traps, surface optics surveys, vertical optics profiles, aerial surveys of the patch size and shape (using a towed balloon). Final recovery of traps and drifters will occur 3d after chalk deployment.

Optical measurements- Balch

Surface underway optical measurements of attenuation, absorption, scattering and backscattering will be made during the wagon-wheel surveys of the patch. Water-leaving radiance and downwelling irradiance (for calculating remote sensing reflectance) will be measured from the bow of the ship using a Satlantic SeaWiFS Aircraft Simulator (SAS). High-resolution free-fall vertical profiles of spectral downwelling and upwelling radiance will be made using a Satlantic radiance profiler. This will allow high resolution estimation of diffuse attenuation coefficients. For vertical profile stations, discrete water samples will be taken with a rosette sampler, at 6-8 depths within and below the mixed layer. Subsamples will be filtered for suspended $CaCO_3$ analyses (Fernández et al. 1993).

Sediment Trap Program and Particle Fluxes- Pilskaln

In order to quantify the vertical export below the patch of Cretaceous chalk (due to biological and/or physical aggregation of the chalk particles), VERTEX-style MultiPIT drifting sediment traps (Knauer et al. 1979; Knap 1993) will be deployed just below the base of the mixed layer within and outside each patch on the two cruises. MultiPIT trap "crosses" consisting of 8 collection tubes, will be attached to a drifter mooring inside each patch. Outside the patch, we will deploy a drifting sediment trap array with one MultiPIT trap cross located at the same depth as the trap cross within the patch. Following the deployment of the un-instrumented surface drifter into the patch and a rough determination of the surface drift, we will deploy the inside-patch trap array and track it for 2 days.

Of the trap crosses on each array, four trap tubes will be designated for stable isotope analyses. Cretaceous chalk has a unique del-^{18}O signature relative to modern planktonic carbonates that makes it easy to trace in the water column and will provide us with the means to verify that collected material in the traps originated from the patch. The second set of four trap tubes per drifting array (inside and outside the patches) will be designated for microscopic and geochemical analyses. Fecal pellets will be picked and counted from quantitative splits of the above traps to determine pellet mass fluxes and to estimate the overall contribution of zooplankton fecal packaging to the mass flux removal of particle matter/chalk from the mixed layer.

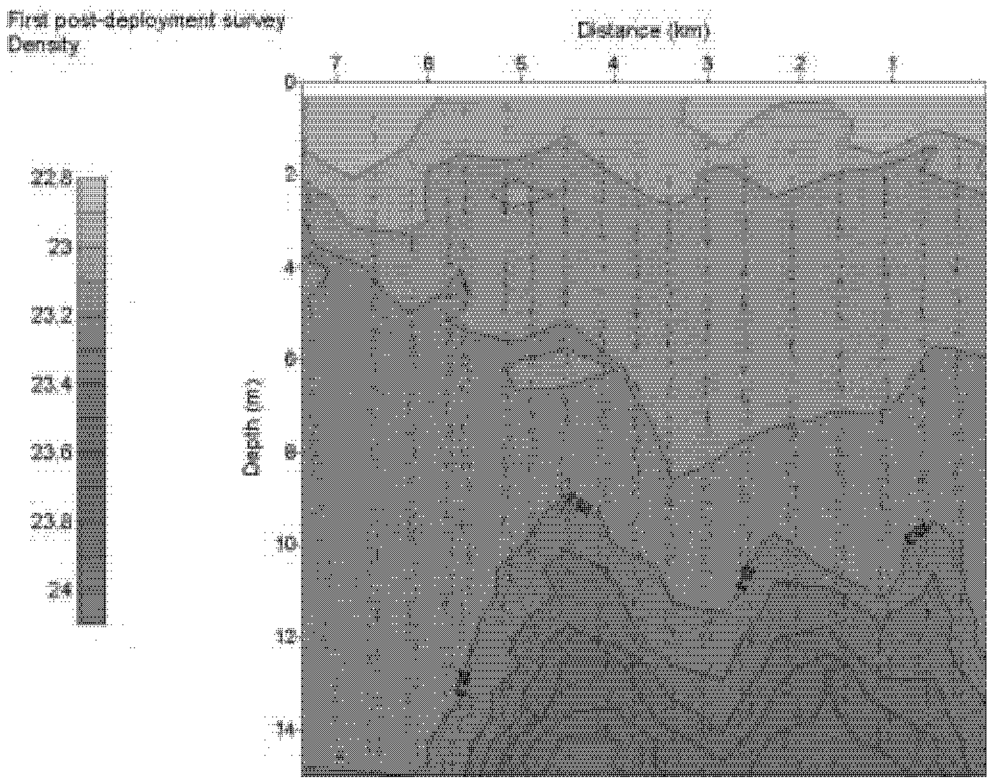
WORK COMPLETED

Elements of Chalk-Ex have been applied to preliminary lab and field experiments to check feasibility of the experimental design and optical properties of the chalk. Two preliminary field experiments have been performed in the Gulf of Maine using small quantities of the chalk, diluted in seawater in order to check the resultant optical properties. A third experiment was performed in conjunction with a NASA experiment during FY01. In this work, we experimented with large-scale methods for diluting and dispersing chalk. Our original proposal was for cruise #1 to begin during summer of 2001 but due to ship scheduling problems, this was postponed to November 2001. Now, with budget cutbacks, the second cruise has not been scheduled until Summer 2003.

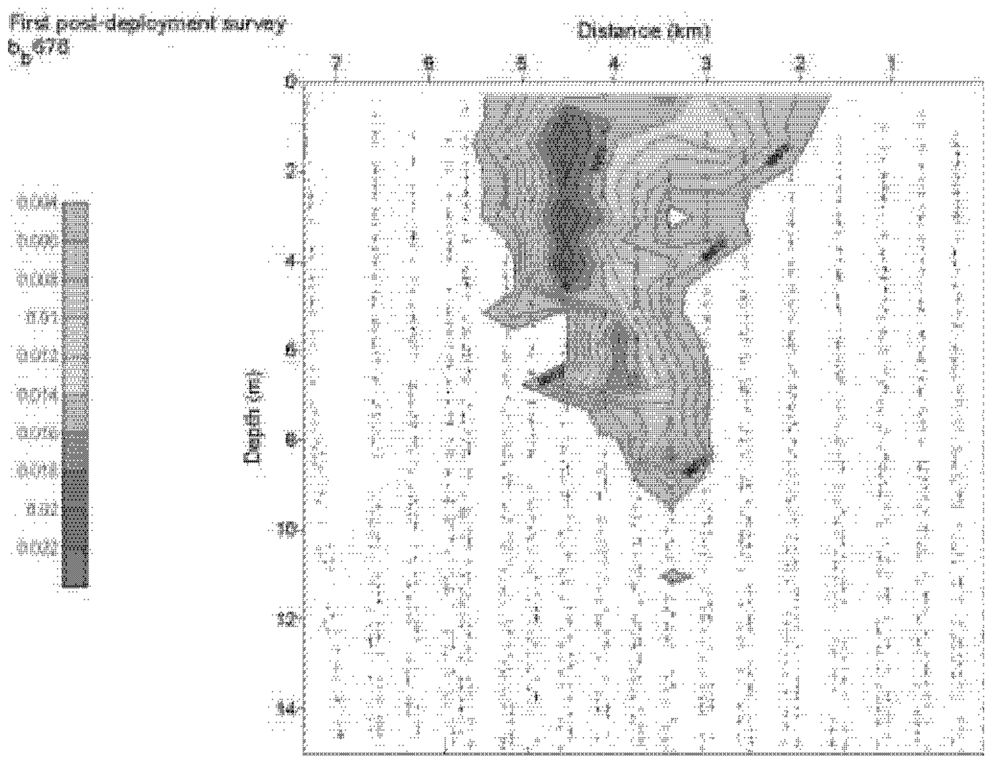
RESULTS

Given that our major field campaign was delayed, we don't have results from our first cruise to report here. Nevertheless, we have done considerable preliminary work with the chalk to test the feasibility of our approach. In our proof-of-concept field experiments with the Cretaceous chalk, we targeted initial $CaCO_3$ concentrations of 0.08 mol m^{-2}, less than a real coccolithophore bloom (0.56 mol m^{-2}), but still enough to significantly increase backscattering over ambient. Vertical rofiles of b_b showed 1-2m depth penetration of the chalk over 5h. We measured b_b and above-water radiance along swaths through test patches. These data demonstrated that chalk can produce a highly reflective patch with nLw values 5X ambient, a patch size of 0.28km^2 per ton, surface concentrations of 0.035mM, and integrated $CaCO_3$ concentrations of 0.038 mol m^{-2}. Estimates of total chalk mass (measured optically) demonstrated closure within 5% of the total deployed mass. Values of b_b reached 0.08 m^{-1} in the preliminary patch experiments, and the 2μm chalk particles remained in the top 3-4m over several hours. Stable isotope results for the chalk showed clear differentiation of the chalk with $\delta^{18}O$ of –4 to –5 o/oo (as opposed to Gulf of Maine *E. huxleyi* coccoliths $\delta^{18}O$ values of 0.65+/-1.1 o/oo (Paull and Balch 1994)). This will be useful in our upcoming work, for tracking the particles into the sediment traps.

A


First post-deployment survey
Density
Distance (km)
Depth (m)

B


First post-deployment survey
Distance (km)
Depth (m)

IMPACT/APPLICATIONS

These experiments are designed to identify the major loss terms of optically-active particles. This is critical for understanding the evolution of the underwater optical field and prediction of underwater visibility on horizontal and verticfal spacial scales of 1-10,000 m and 1-100m, respectively, and time scales of hours to several days.

TRANSITIONS

As the field program will not begin until November, no transitions have occurred. We plan to transition this large-scale manipulative approach to other optically-active materials in the sea.

RELATED PROJECTS

Other co-PI's in this project are Dr. Al Plueddemann (Woods Hole Oceanographic Inst.) and Drs. Hans Dam and George McManus (Univ. Connecticut). Dr. Howard Gordon (U. Miami) and I have collaborated in earlier chalk experiments as part of a NASA MODIS contract to derive a remote sensing algorithm for the determination of $CaCO_3$ from space. A DURIP grant, "Upgrading instrumentation to measure light scattering in the sea" was also funded as part of this project (co-authored with J. Vaughn, [Univ. New England] .

REFERENCES

Balch, W. M., K. A. Kilpatrick, P. M. Holligan, and C. Trees. 1996. The 1991 coccolithophore bloom in the central north Atlantic. I. Optical properties and factors affecting their distribution. Limnol. Oceanogr. **41:** 1669-1683.

Fernández, E., P. Boyd, P. M. Holligan, and D. S. Harbour. 1993. Production of organic and inorganic carbon within a large scale coccolithophore bloom in the northeast Atlantic Ocean. Mar. Ecol. Prog. Ser. **97:** 271-285.

Harris, R. P. 1994. Zooplankton grazing on the coccolithophore *Emiliania huxleyi* and its role in inorganic carbon flux. Mar. Biol. **119:** 431-439.

Honjo, S. 1976. Coccoliths: Production, transportation and sedimentation. Mar. Micropaleontol. **1:** 65-79.

Knap, A. H. 1993. Bermuda Atlantic time-series study-BATS Method Manual US JGOFS Plann. And Coord. Off., Woods Hole Oceanogr. Inst., Woods Hole, MA. version 3.

Knauer, G. A., J. H. Martin, and K. W. Bruland. 1979. Fluxes of particulate carbon, nitrogen and phosphorus in the upper water column of the northeast Pacific. Deep-Sea Res. **26:** 97-108.

Milliman, J., P. J. Troy, W. Balch, A. K. Adams, Y.-H. Li, and F. T. MacKenzie. 1999. Biologically-mediated dissolution of calcium carbonate above the chemical lysocline? Deep-Sea Res. **46:** 1653-1669.

Paull, C. K., and W. M. Balch. 1994. Oxygen isotopic disequilibrium in coccolith carbonate from phytoplankton blooms. Deep-Sea Res. **41:** 223-228.

PUBLICATIONS ACKNOWLEDGING ONR SUPPORT- LAST 5 YEARS

Balch, W.M., Vaughn, J.M., Novotny, J.F., Drapeau, D.T., Goes, J.I., Lapierre, J.M., Scally, E, Vining, C.L., Ashe, A., and Vaughn, J.M. Jr. Fundamental changes in light scattering associated with infection of marine bacteria by bacteriophage. Submitted to Limnology and Oceanography.

Balch, W. M., D. Drapeau, J. Fritz, B. Bowler, and J. Nolan. Optical backscattering in the Arabian Sea- Continuous underway measurements of particulate inorganic and organic carbon. In press. Deep Sea Res. I.

H. R. Gordon,1 G. C. Boynton, W. M. Balch, S. B. Groom, D. S. Harbour , and T. J. Smyth. Retrieval of Coccolithophore Calcite Concentration from SeaWiFS Imagery. Geophysical Research Letters, 28: 1587-1590.

Balch, W.M., Vaughn, J., Novotny, J., D. T. Drapeau, R.D. Vaillancourt, J. Lapierre, and A. Ashe, 2000. Light scattering by viral suspensions. Limnology and Oceanography. 45:492-498.

Vaillancourt, R. D. and W. M. Balch. 2000. Size distribution of coastal sub-micron particles determined by flow, field flow fractionation. Limnology and Oceanography. 45: 485-492.

Balch, W. M., D. Drapeau, and J. Fritz. 2000. Monsoonal forcing of calcification in the Arabian Sea Deep Sea Research II, 47: 1301-1333.

Milliman, J., P.J. Troy, W. Balch, A.K. Adams, Y.-H. Li, and F.T. MacKenzie . 1999. Biologically-mediated dissolution of calcium carbonate above the chemical lysocline? Deep-Sea Res. I. 46: 1653-1669.

Balch, William M., David T. Drapeau, Terry L. Cucci, and Robert D. Vaillancourt, Katherine A. Kilpatrick, Jennifer J. Fritz. 1999. Optical backscattering by calcifying algae-Separating the contribution by particulate inorganic and organic carbon fractions J. Geophys. Res. 104: 1541-1558.

Voss, K., W. M. Balch, and K. A. Kilpatrick. 1998. Scattering and attenuation properties of Emiliania huxleyi cells and their detached coccoliths. Limnol. Oceanogr. 43: 870-876.

Balch, W. M., B. Bowler, and C.F. Byrne. 1997. Sea surface temperature gradients, baroclinicity, and vegetation gradients in the sea. J. Plank. Res. 19: 1829-1858.

Balch, W. M., J. J. Fritz, and E. Fernandez. 1996. Decoupling of calcification and photosynthesis in the coccolithophore *Emiliania huxleyi* under steady-state light-limited growth. Marine Ecology Progress Series. 142: 87-97.

Bidigare, R. R. , M. Latasa, Z. Johnson, R. T. Barber, C. C. Trees, and W. M. Balch. 1997. Observations of a *Synechococcus*-dominated cyclonic eddy in open-oceanic waters of the Arabian Sea. Society of Photo-Optical Instrumentation Engineers, Vol. 2963. pp. 260-265.

Balch, W. M., K. A. Kilpatrick, P. M. Holligan and C. Trees. 1996. The 1991 coccolithophore bloom in the central north Atlantic I- Optical properties and factors affecting their distribution. Limnology and Oceanography. 41: 1669-1683.

Balch, W. M., K. Kilpatrick, P. M. Holligan, D. Harbour, and E. Fernandez. 1996. The 1991 coccolithophore bloom in the central north Atlantic II- Relating optics to coccolith concentration. Limnology and Oceanography. 41: 1684-1696.

Fernandez, E., J. J. Fritz and W. M. Balch. 1996. Growth-dependent chemical composition of the coccolithophorid *Emiliania huxleyi* in light-limited chemostats. Submitted. J. Exp. Mar. Biol. Ecol. 207: 149-160.

Fritz, J. J. and W. M. Balch. 1996. A coccolith detachment rate determined from chemostat cultures of the coccolithophore *Emiliania huxleyi*. J. Exp. Mar. Biol. Ecol. 207: 127-147.

Balch, W., M. and K. A. Kilpatrick. 1996. Calcification rates in the equatorial Pacific along 140^{o}W. Deep Sea Research. 43: 971-993.

Fernandez, Emilio, E. Maranon and W. M. Balch. 1996. Intracellular carbon partitioning in the coccolithophore Emiliania huxleyi. J. Marine Systems. 9: 57-66.