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**Optical Assessment of Large Marine Particles: Development of
an imaging and analysis system for quantifying large particle
distributions and fluxes.**

FINAL REPORT

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INTRODUCTION

The central goal of DOE's Ocean Margin Program (OMP) has been to determine whether continental shelves are quantitatively significant in removing carbon dioxide from the atmosphere and isolating it via burial in sediments or exporting it to the open ocean (Program Announcement, 1991). The overall objective of our work within OMP was to develop an instrument package to measure the large aggregate population of particles in the shelf/slope environment at a rate sufficient to integrate the observed particle distributions into the coupled physical and biogeochemical models necessary to understand the shelf and slope as a system. Pursuant to this we have developed a video and optical instrument package (LAPS: Large Aggregate Profiling System) and assembled the computer and software methods to routinely measure a wide spectrum of the large aggregate population of particles in the shelf/slope environment. This particle population, encompassing the "marine snow" size particles (diameters > 0.5 mm), is thought to be the major pathway of material flux in the ocean (McCave, 1975; Asper, 1987; Walsh and Gardner, 1992). The instrument package collects aggregate abundance and size spectrum data using two video camera/strobe subsystems with a third subsystem collecting CTD, beam attenuation and fluorescence data. Additionally, measurements of particle flux were made with sediment traps deployed on the continental slope in conjunction with the physical oceanography mooring program.

We envisioned three stages of development of the instrument package: (1) design, assembly, and laboratory testing of all components and the package as a whole, (2) a short period of laboratory and field testing of the instrument package to determine the best operational parameters, and (3) operations within a framework of complementary analytical sampling such as an appropriate process study funded under the OMP. The first two stages were covered by this proposal and completed. The third stage was limited to scoping work with the LAPS and deployment of sediment traps. Processing of the sediment trap samples will be performed under a sub-contract from Sequoia Scientific.

RESULTS

The Instrument Package

Pursuant to the proposal the DOE Large Aggregate Profiling System (DOE LAPS) has been developed, tested and used for scoping work in the Cape Hatteras field area (Figure 1). A second testing cruise was made in the Gulf of Mexico to test the fully configured system (with the inclusion of a CTD and ac-3 meter), with particular attention to

the ability to turn the system around. The DOE LAPS consists of two aggregate imaging systems, a CTD with beam attenuation and chlorophyll sensors, and the frame and bridle which hold the sub-systems. The aggregate imaging systems were produced to our specifications by Deep-Sea Power and Light (San Diego, Ca.). Each of the aggregate imaging systems consists of a Sony FX-77 Hi-8 camcorder (400 line resolution) in a pressure case with a seawater optically compensating hemispherical dome and control electronics, a Sea-Strobe, and a 12 volt SeaBattery. The SeaStrobes are mounted behind collimating light boxes with adjustable parallel plates to produce a slab of light perpendicular to the camera (Figures 1, 2 and 3).

The strobe light output is synchronized to its camera such that the camera records a full second of video within which a single frame is illuminated by the strobe. The camera returns to standby while the strobe recharges and waits for the appropriate time lapse. The current system allows strobe firing intervals from 5 to 15 seconds, controlled with a dip-switch. In practice a firing interval of 12 seconds with a lowering rate of 10 to 30 m per minute yields the best coverage of the water column (an image every 2 to 6 m) without overstraining the battery recharge cycle. The imaging systems are set up to image an overlapping size range of particles. During the testing period the large aggregate system imaged a 4.12 l volume of water (34 cm x 25 cm x 5 cm) with a pixel size of 548 μm . The small aggregate system imaged a 0.44 l volume of water (11.5 cm x 8.6 cm x 5 cm) with a pixel size of 186 μm . The small aggregate camera is at full telephoto for this image volume and in-lab testing showed a less than 5% change in apparent object size between the back and front of the light slab. The large aggregate camera uses a wide angle setting to image the chosen volume. In lab testing showed that the change in apparent object size for a light slab thickness of 5 cm was less than 10%. Assuming a random distribution of particle location in the light slab, this effect should have no impact on the resultant size distributions. The images are calibrated by attaching a calibration rod to the frame such that the rod appears in the strobed imaging volume. The LAPS is lowered into the water for a short period of time (long enough to record a dozen frames), after which the rods are removed for data operations and the profiling sequence is initiated.

Data Analysis System

One of the goals of the research done under this proposal was to enhance the speed of data analysis from the time of acquisition to the resultant profile. The overall goal was to develop a system that would enable an operator to produce the profiles at sea. Previous systems (using film) had required data analysis to begin only after the development of the images on shore. Furthermore, using film negatives as the image source required the

DOE Large Aggregate Profiling System (LAPS)

Figure 1. The DOE LAPS being brought on board the R/V Gyre during its final testing cruise, 10/23/94.

DOE LAPS Design

Figure 2. Schematic diagram of the major components of the DOE Large Aggregate Profiling System (LAPS)

Large Aggregate Imaging Schematic

Small Aggregate Imaging Schematic

Figure 3. Schematics of the DOE LAPS camera/strobe system imaging volumes.

negatives to be digitized prior to image analysis, a laborious process during which utmost care had to be taken to avoid dust on the negatives. This process alone required five minutes per image, a significant time commitment considering that each profile consists of hundreds of images.

Significant strides have been made in this process; a combination of high quality video digitizing boards becoming available at reasonable prices, and our development of software linking programs to speed the reduction of data from video image to spreadsheet. (Figure 4). The video tapes are digitized at 60 fields per second at the 85% JPEG compression level (high to most quality) directly to a high capacity hard disk (about 3 meg/s) using a Radius VideoVision Studio card installed in a Macintosh Quadra 800 with 40 meg RAM. Adobe Premiere video editing software is used to select and save strobe frames as individual PICT files. Particle analysis is performed using NIH Image. The effect of compression on image quality was tested by digitizing to a RAM disk with no compression, and using NIH Image to compare the uncompressed image to the compressed image by image subtraction. No apparent artifacts are produced by this level of compression, an unsurprising results as the strobe output is a black and white signal, so there is plenty of null data to be compressed.

Each image is analyzed for the total number of particles and each particle's area, perimeter length, length of major and minor axis, and the angle of the major axis. Equivalent spherical diameter is calculated from each particle's area. The particles are binned into size ranges based on the equivalent spherical diameter. Particle volume is calculated assuming sphericity and diameters equal to the arithmetic means of the size ranges. A nine point moving average filter is used to smooth the data and produce a continuous profile. Further transformations of the aggregate data, e.g. into aggregate mass concentration and mass flux can be calculated from estimated settling velocity and diameter/density relationships (Alldredge and Gottshalk, 1988; Walsh and Gardner, 1994).

Data From Testing

Although the minimum pixel size determines the absolute smallest size particle imaged for each camera, in practice we have adopted a minimum size of 4 pixels to distinguish particles from noise. We tested the effectiveness of this cut-off by counting all particles during the testing phase. Using data from a cast during R/V Gyre cruise 94G04 to the OMP field area, the effective cut off for each system (based on the observed increase in the abundance rather than the expected decrease with increasing size range), is 1.5 mm E.S.D. for the large aggregate system and 0.5 mm E.S.D. for the small particle system (Fig. 5). For the overlapping size range of 1.5 to 2 mm, the small aggregate imaging

Figure 4. Flow chart of steps from video to measurement files showing the image pathway and associated programs and macros.

Figure 5. Results from a scoping cruise to the OMP field area, R/V Gyre 94G04. Histograms of the average particle size distribution between the surface and 125 m at Station 11, 36° 0.06' N, 74° 50.5' W. The station had a nominal depth of 100 m, but at the time of the LAPS cast the ship had drifted such that $z > 500$ m. The heavy black lines indicate the lower limit of the effective size range of each camera system. The stippling connects the effective overlapping size range.

Figure 6. Results from a LAPS cast taken during a scoping cruise to the OMP field area, R/V Gyre 94G04. Profiles of the abundance and volume concentration of aggregates from the large and small volume imaging systems at Station 11, $36^{\circ} 00.6' \text{ N}$, $74^{\circ} 50.5' \text{ W}$.

Figure 7. Results from a scoping cruise to the OMP field area, R/V Gyre 94G04 at Station 1, $36^{\circ} 4.5' \text{ N}$, $74^{\circ} 43.8' \text{ W}$. Profiles of the abundance of aggregates from the large aggregate camera system compared to transmissometer and fluorometer traces from a CTD cast. Note that good agreement is seen in the upper 100 m, with a high degree of correlation at 40 m. In contrast, the strong aggregate nepheloid layers seen below 300 m are not reflected in the transmissometer or fluorometer traces.

Figure 8. Results from a scoping cruise to the OMP field area, R/V Gyre 94G04 at Station 1, 36° 4.5' N, 74° 43.8' W (700 m) and Station 12, 36° 00' N, 74° 15' W (2400 m). Profiles of the abundance of aggregates from the large aggregate camera system. Note the coherence of the profiles in the upper 500 m. Note also that the benthic aggregate nepheloid layer increases in thickness and particle abundance with depth. The intermediate aggregate nepheloid layer at Station 12 suggests lateral transport in that depth range.

system recorded an average of 5.2 particles per liter while the large aggregate system recorded an average of 4.2. For the overlapping size range of 2 to 2.5 mm the small aggregate system recorded just 0.7 particles per liter while the large aggregate system recorded 3.2 particles per liter. Hence, the effective size range for the small aggregate system is 0.5 to 2 mm and for the large aggregate size range is 1.5 mm to an unbounded size that we set at 5 mm. While the upper limit of the large aggregate size range is unbounded, our experience has been that the total number of particles in the upper size range (>10 mm) is on the order of one per thousand liters, or approximately one per cast. Since we have found that there are very few particles greater than 5 mm E.S.D., we do not feel that we have sufficient data for reliable statistical analysis of these rare particles and have therefore conservatively chosen to clip the size range of interest to 5 mm at this time. All individual particle data are retained so that it will be possible to focus on the largest particles if future analysis seems warranted.

CURRENT STATUS AND LIMITATIONS

The DOE LAPS is now an operational system. The major limitation on the system at this time is battery power. Testing and use has shown that over 600 images can be made on a single cast. On the Gulf of Mexico test cruise transects of the slope were made. Five casts were successfully completed within 24 hours during one transect (casts at 50, 100, 300, 600 and 1000 m), and four casts made on a subsequent transect one day later (casts at 50, 300, 600 and 1000 m). For both transects the DOE LAPS performed almost flawlessly. Batteries were recharged between casts. The effective minimum is 2 hours between casts for battery recharging. However, for short (i.e. shelf) casts multiple casts can be made between charges. This test shows that a sustained program of multiple casts per day is feasible with the current system and sufficient personnel support.

The other major limitation of the LAPS remains the time required for post-deployment processing of the imaging data. Current efforts to streamline the computing steps required (e.g. capture, thresholding, particle counting, data sorting and binning, data compilation) have reduced the overall time significantly. However, the total process still requires four to five hours per cast. On-board, post-cast processing and further refinements to the computer programs will reduce the amount of data that needs to be processed ashore. A further limitation on the LAPS is that profiles made during the day need more extensive image processing to account for the ambient light field. However, given that film based systems cannot produce profiles in an ambient light field at all, the ability to produce profiles under any lighting conditions is significant.

Two OSU Tracer-15 multicup sediment traps were deployed on the physical oceanography mooring 27 in February, 1996. The mooring was recovered in May 1996. Samples were collected from 2/13/96 to 5/8/96. Both sediment traps were recovered and preliminary processing indicates that the high resolution (6 day interval) sampling sequence was followed with both traps. However, the trap within the benthic boundary layer appeared to have clogged after the first three sample periods. The first three cup were almost completely filled with material. Subsequent cups had only a small amount of fresh material. The 'mid-water' trap collected a highly variable sequence of samples. The data from these samples in conjunction with the physical oceanographic data set should yield important clues to the extent of wintertime and event-related export in the study area. Further processing of the sediment trap samples will be performed under a sub-contract from Sequoia Scientific.