Simultaneous Multispectral Optical Measurement of Phytoplankton and Acoustical Measurement of Zooplankton

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LONG-TERM GOAL

To understand the physical and biological dynamics controlling the micro- and fine-scale distributions of phytoplankton and zooplankton in the ocean.

OBJECTIVES

To use multispectral optical measurements and three-dimensional acoustic imaging to quantify the microscale and fine-scale vertical patchiness of several taxa of phytoplankton and large zooplankton *in situ*.

APPROACH

Our approach was to develop a multispectral *in situ* imaging system: LUMIS (Low light level Underwater Multispectral Imaging System). Using a sheet of laser light to irradiate a ~1 l sample volume, phytoplankton fluorescence from chlorophyll a and phycoerythrin were imaged with a sensitive CCD camera. In addition to the two fluorescence wavelengths, optical backscatter and water Raman scattering were imaged simultaneously.

WORK COMPLETED

A prototype LUMIS system was constructed and tested extensively in the laboratory tank system. The resolution and sensitivity of the system were explored using test cultures, and image patterns were used to co-register the various channels spatially. Algorithms are being developed by Mr. David Zawada to map the distorted images onto a rectangular reference frame. As deployed, the LUMIS system acquired images at 0.5 Hz, with an imaging area of 30x30 cm and 0.3x0.3 cm resolution (102x102 pixels). The LUMIS platform included a vertical array of thermistors, and two S4 electromagnetic current meters and pressure sensors to give further information on the three-dimensional physical environment of the plankton. A 3.2 Watt ship-board Nd:YaG laser was used to stimulate fluorescence through an optical fiber conduit to the LUMIS package.

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Laboratory techniques were developed to measure individual copepod gut fluorescence for comparison to the LUMIS backscatter and chlorophyll a images.

The first deployment of LUMIS was on a cruise in Saanich Inlet, British Columbia, in August of 1997. Though a strong dinoflagellate bloom was present outside the inlet, the chlorophyll concentrations were relatively low in the inlet. The subsurface oxygen minimum zone led to strong vertical stratification of biological properties, which were clearly reflected in our data. Due to the coastal nature of our sampling, little signal in the phycoerythrin channel was expected, or observed. Extensive net and bottle sampling of zooplankton and phytoplankton was undertaken during the profiling in order to ground-truth the LUMIS data.

A second cruise was completed in November of 1997; however the strong El Ni–o led to very reduced phytoplankton concentrations along the southern California Bight, so the chlorophyll signal was low. Dr. Sally MacIntyre and her student Mr. Kevin Flynn joined the cruise and deployed their SCAMP microstructure profiler to give auxiliary measurements of the microscale physical regime. 10 deployments were made over 5 days from the R/V Sproul, which was anchored 2-10 km offshore of San Diego during the profiling. LUMIS profiles were complemented by profiles of a CTD/fluorometer/transmissometer package.

RESULTS

Laboratory experiments showed that the LUMIS system could clearly distinguish between phytoplankton containing chlorophyll a versus those with phycoerythrin (*Synechococcus*). The sensitivity of the system varied, depending on shutter speed and illumination intensity, but chlorophyll a levels down to 0.1 mg/m^3 were resolvable.

While the chlorophyll a levels were particularly low during our cruise, it became apparent that the LUMIS system could distinguish individual zooplankters in the optical backscatter channel, and assess their gut fluorescence in the chlorophyll a channel. This finding gives us a unique potential to quantify trophic couplings *in situ*. For example, copepods migrating from deeper waters with empty guts would appear only in the backscatter channel. As they begin to forage in the chlorophyll-rich waters nearer the surface, they will begin to appear as bright spots in the chlorophyll a channel. As they digest their food, they will again disappear from the chlorophyll a channel. Careful registration of the locations of points in the four channels will allow us to determine how the various spatially resolved signals in the images align. Examination of these individual events will be supplemented with calculation of statistical measures of the spatial variability of fluorescence.

These statistical measures have allowed us to explore the relative contributions of physical and biological dynamics in structuring the phytoplankton community on micro- and fine-scales. Analyses of several profiles has shown that the spatial spectra do not conform to the usual models of tracers embedded in a turbulent fluid (e.g. Batchelor, 1959; Denman and Platt, 1976; Powell and Okubo, 1994). Rather than showing a steep (-5/3) decline in the spectral variance with increasing wavenumber, our data show a rather gradual fall off down to ~3 cm scales, with a steep roll off at smaller scales. This spectrum suggests a random field of fluorescence variance from ~70 cm scales to ~3 cm scales, imposed upon the larger-scale vertical structure of a subsurface chlorophyll maximum. One interpretation of these results is that there is some underlying random distribution of phytoplankton

patches, with a slight erosion of variance at the smallest scales due to weak turbulence. Another interpretation is that the fluorescence variance is driven by biological aggregation, leading to large flocs floating randomly throughout the water column. Dense layers (>1 m thick) of phytoplankton are highly structured (random patchiness) rather than homogeneous at scales less than 1 m.

IMPACT/APPLICATION

We have developed a unique instrument for the study of microscale patchiness and trophic interactions in the ocean. Our ability to measure two-dimensional spatial distributions of induced fluorescence in the same range as the inertial subrange of turbulence will finally allow us to test models of microscale patchiness of plankton. The observation of zooplankton in both the backscatter and chlorophyll fluorescence channels will give us unprecedented views into the direct couplings of primary and secondary production, *in situ*, on the scales of the organism's ambits. Observations made from this platform will allow us to test hypotheses concerning zooplankton foraging behaviors in a dynamic and patchy environment, and to explore the processes structuring the phytoplankton on the microscale. Furthermore, the multispectral capability of the LUMIS system may allow us to assess the nutritional status of the phytoplankton, *in situ*, based on the ratios of fluorescence emission at two wavelengths (chlorophyll a and accessory pigments, Heath et al., 1990). This would give a unique capability to diagnose trophic couplings and controls on primary production in the world's oceans.

TRANSITIONS

The LUMIS and FishTV systems will be integrated into a free-fall profiler, funded by an NSF award to Jaffe and Franks (start date 10/1/1998, two-year award). This profiler will obviate the effects of ship heave on the images and reduce any impacts the instrument has on the imaged fields. It will also allow the deployment of the instrument package under a range of sea states, particularly those which will generate extensive vertical mixing.

RELATED PROJECTS

1 – Mr. David Zawada, a student in Dr. Jaffe's group, is using the LUMIS system to image fluorescence from corals. Images obtained in May, 1998, on the COBOP field expedition indicate the LUMIS can be used to quantify chlorophyll a and phycoerythrin fluorescence on entire coral heads using strobe illumination.

2 – The OASIS (Optical-Acoustic Submersible Imaging System) program, funded by NSF (Dr. Mark Ohman, co-PI with Dr. Jaffe), integrates acoustic and optical imaging of zooplankton. The addition of spatially and spectrally resolved images of phytoplankton distributions to the OASIS imaging system will provide a powerful tool for observing interactions between zooplankton and phytoplankton *in situ*.

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