

Bioluminescence Potential in the Transition Zone to Very Shallow Water (VSW)

Mark A. Moline

Biological Sciences Department
California Polytechnic State University
San Luis Obispo, CA 93407

phone: (805) 756-2948 fax: (805) 756-1419 email: moline@marine.calpoly.edu

Award Number: N00014-03-1-0341

<http://www.marine.calpoly.edu/auv>

<http://www.marine.calpoly.edu/live>

LONG-TERM GOALS

The long-term goal is to advance our understanding of the ecology of bioluminescent organisms and the mechanisms governing the temporal and depth-dependent variability of bioluminescence in the coastal ocean. With improvements in technology, finer-scale resolution and concurrent physical, chemical and biological data are available to advance our understanding of the forcing mechanisms governing the temporal and depth-dependent variability of bioluminescence in environments of Naval relevance.

OBJECTIVES

General patterns of bioluminescence potential in surface waters indicate that there is an increased signal in near shore waters. While present regional and coastal models are able to show this coastal enhancement, the model grids are not scaled to the physical dynamics governing the transition zone from the near shore to the shoreline. In addition, few measurements of bioluminescence have been made in this transition region because of limitations in both platforms and sensors. This is despite the stated need in a recent report (National Research Council 2003). The report highlights bioluminescence as an environmental variable that often influences planning and execution of naval missions, and, in general, the need for more understanding of littoral processes. The objective of this proposal is to better characterize bioluminescence in the transition zone from the near shore to very shallow water (VSW) environments. Measurements of bioluminescence and other parameters will be made in conjunction with other ONR-sponsored physical oceanographers and near shore modelers to provide a basis for a global understanding of how bioluminescent organisms respond in these turbulent and high shear environments. Specifically the objectives are to; 1) Focus measurements in the transition zones from the near shore to VSW environments (including the surf zone) in conjunction with other physical measurements. 2) Relate cross-shore and along-shore measurements to the shoreline types and shoreline morphologies, including entrances to ports and harbors over a range of relevant time scales (i.e. tidal). 3) Elucidate differential responses between autotrophic and heterotrophic organisms to turbulent and high shear environments.

APPROACH

The approach to address the primary objectives above was to take advantage of two ongoing studies in California in collaboration with two ONR-funded physical oceanographers (R. Guza, SIO and E.

Report Documentation Page

Form Approved
OMB No. 0704-0188

Public reporting burden for the collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to a penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.

1. REPORT DATE 30 SEP 2007		2. REPORT TYPE Annual		3. DATES COVERED 00-00-2007 to 00-00-2007	
4. TITLE AND SUBTITLE Bioluminescence Potential In The Transition Zone To Very Shallow Water (VSW)				5a. CONTRACT NUMBER	
				5b. GRANT NUMBER	
				5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S)				5d. PROJECT NUMBER	
				5e. TASK NUMBER	
				5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) California Polytechnic State University, Biological Sciences Department, San Luis Obispo, CA, 93407				8. PERFORMING ORGANIZATION REPORT NUMBER	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)				10. SPONSOR/MONITOR'S ACRONYM(S)	
				11. SPONSOR/MONITOR'S REPORT NUMBER(S)	
12. DISTRIBUTION/AVAILABILITY STATEMENT Approved for public release; distribution unlimited					
13. SUPPLEMENTARY NOTES code 1 only					
14. ABSTRACT					
15. SUBJECT TERMS					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT Same as Report (SAR)	18. NUMBER OF PAGES 8	19a. NAME OF RESPONSIBLE PERSON
a. REPORT unclassified	b. ABSTRACT unclassified	c. THIS PAGE unclassified			

Thornton, NPS), with specialties in the surf zone and near shore transition environments. One was in Huntington Beach, CA, and the other in Monterey Bay. The primary focus of these studies was to examine the effects of offshore wave energy (where the depth is greater than $1/20^{\text{th}}$ of the wavelength of the wave) as it propagates inshore and influences, near shore waves, shear/turbulence fields and along- and cross-shore flows. Temporal and spatial measurements of bioluminescence were made as part of this studies in a continuing effort to define the distribution of near shore bioluminescence (see below). In addition to these efforts, a continued effort to obtain a long time series of bioluminescence is ongoing as well as involvement in a number of ancillary ONR projects to address the long-term goals stated above.

WORK COMPLETED

In order to address questions related to bioluminescence in the surf zone, the REMUS-100 vehicle the REMUS AUV platform equipped with a bioluminescence bathyphotometer (Blackwell *et al.*, 2002; Moline *et al.*, 2005) was deployed repeatedly in two location; Huntington Beach, CA and Monterey Bay, CA. In Huntington Beach, CA, 6 bioluminescence missions were conducted from September 20th to October 7th, 2006. The mission grid was set up to examine the transition zone from the surf zone offshore and was 1.5 km by 0.5 km oriented alongshore. An initial survey of the location of breaking waves alongshore was made and used in setting up the grid. The grid entered the surf zone to the greatest extent in the northern corner. There was a gap in the grid around the in situ surf zone instrumentation. An onshore-offshore transect was also part of each mission to examine the vertical distribution of bioluminescence and currents in this region. In Monterey Bay, three deployments were made from May 19th through the 21st, 2007 off of Sand City, CA. The deployment strategy was much like the one set up for Huntington Beach (see above), however the alongshore extent was reduced. The water depths within the programmed grid ranged from 11 to 4 m. During the deviation the vehicle was in 2 m water depth. The wave heights measured during the experiment were consistent at 2 m and normal to the angle of the beach (data not shown). The vehicle operated at 1 m during the 19th of May and was reprogrammed to 2 m on the two subsequent missions.

Complementary Studies

Temporal measurements of bioluminescence have been ongoing in San Luis Obispo Bay. The vertical record from the automated profiler is now over 27 months long. Time series analysis is now being applied to this data set to elucidate the major forcing mechanisms leading to bioluminescent events. We were able to integrate into the Layered Organization in the Coastal Ocean (LOCO) ONR-DRI at the invitation of the PIs. For 8 successive nights, bioluminescence measurements were made with the AUV around the central study area in support of previous sampling objectives. Additionally, 3 additional sampling deployments were conducted in Monterey Bay in conjunction with K. Benoit-Bird acoustic measurements. Efforts to analyze these data and integrate within the larger study are ongoing. As an aside, the REMUS AUVs in the Moline lab have now surpassed 2,800 km of underwater measurements, the majority related to the bioluminescence work.

RESULTS

HUNTINGTON BEACH 2006

As this was the first attempt at operating in and around the surf zone, it was important to establish the operational performance of the vehicle in this environment. Long Baseline (LBL) acoustic navigation

was used for these missions using 4 transponders, three alongshore and one offshore in a “T” pattern to ensure coverage both within the grid and along the transect. The transponders remained on moorings throughout the experiment to improve logistics. There was good LBL coverage in the grid, with mean Inband SNR above 50 (dB), however, as the vehicle entered the surf zone, acoustic coverage occasionally dropped out and was dependant on sea state and wave conditions. The area of no coverage under these circumstances was restricted to the inshore 30 m of each leg. In this region, dead reckoning by compass was the default and was used for each of the inshore turns. The bathymetry in the grid ranged from 3.5 to 9 m with the offshore transect extending to 25 m. The 6 hour missions were monitored from the zodiac using a acoustic ranger as well as the iridium, with the vehicle calling in at the offshore extent of the transect each time. The vehicle completed all 6 missions totaling 244 km underwater without any deviation from the planned route and with no data gaps.

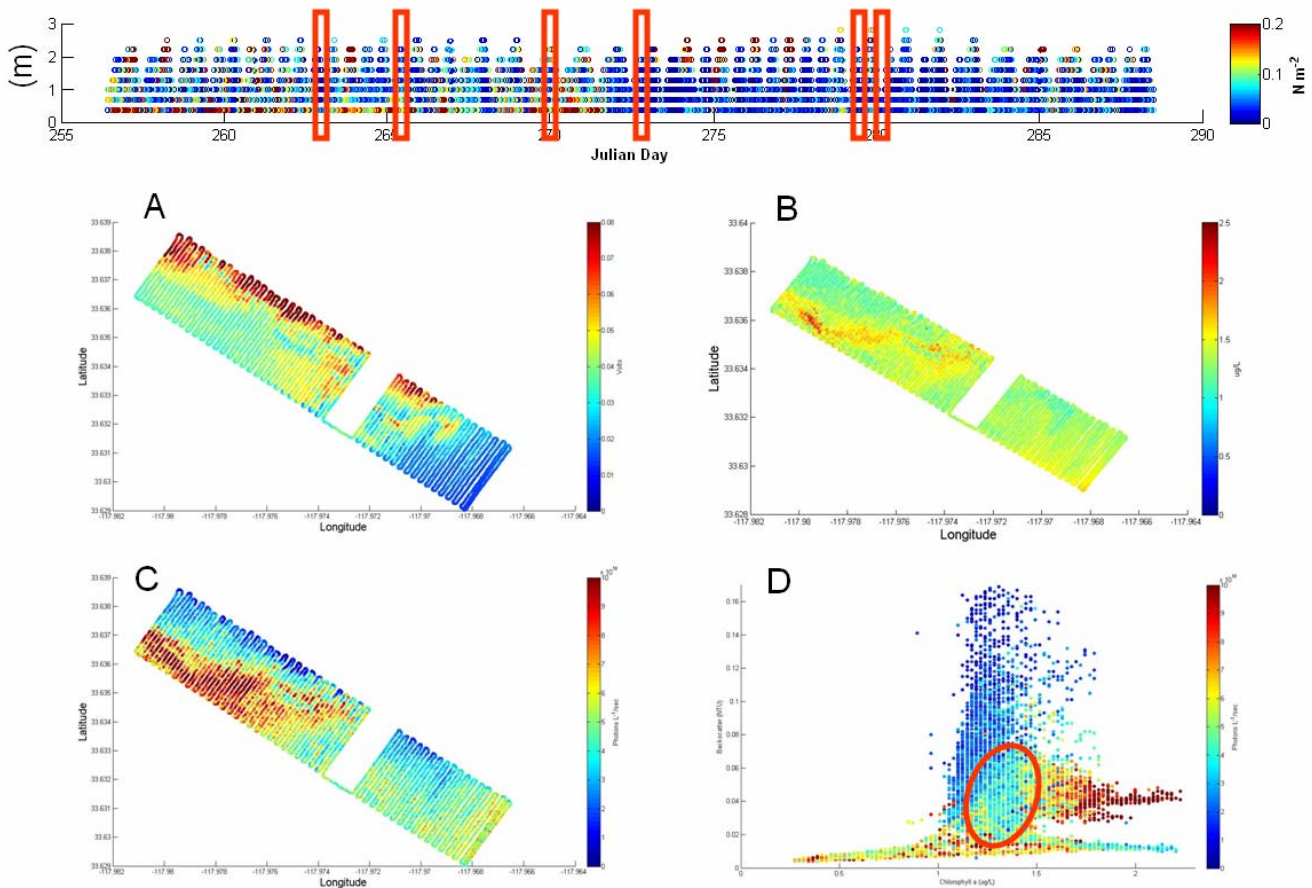


Figure 1. AUV Data From Huntington Beach, CA in 2006 [(upper panel) Depth distribution of estimated shear stress measured during the Huntington Beach experiment during September and October, 2006. Open rectangles depict the timing of AUV missions. Distribution of (A) backscatter, (B) chlorophyll fluorescence, (C) bioluminescence potential along the surf zone. (D) Combined plot of A-C showing an area (red circle) of high chlorophyll fluorescence high scattering and low bioluminescence, where bioluminescence potential is exhausted from the high shear stresses.]

Physical data indicated that there was generally a declining wave height over the study period. For the periods of UUV deployment, the wave period was consistent around 10 s. Deployments were also conducted at different times during the tidal cycle as they required deployment between 22:00 and 04:00 for the bioluminescence measurement (Moline *et al.*, 2000). The wave angle was consistently from the south throughout the experiment with variability of +/- 10°. The angle of the waves shifted by about 10° halfway through the experiment and was found to directly effect the alongshore currents, with higher currents (20 cm/s) to the northwest during the first half of the experiment (data not shown). Cross shore exchange offshore varied with wave height increasing to 10 cm/s during the initial peak wave heights on September 20th, 2006. In this study location there was no measured onshore flow.

Data measured from the UUV on September 23rd, 2006 showed high bioluminescence potential in the grid, with a decreasing signal onshore (Figure 1). This was significantly different than the distributions of fluorescence and backscatter, which had higher values inshore. Separating these two distinct distributions was a cold alongshore filament. High backscatter was associated with particles, particularly sediment, which was associated with the surf zone mixing. It was clear that the northern region of the grid and area to the southeast of the grid gap, where the in situ instruments were moored, had higher turbidity and were areas associated with breaking waves and offshore flow, as mentioned above. The bioluminescence in this region was significantly reduced, however it was not clear whether this was a result of the physical environment or the composition of the bioluminescent organisms. High bioluminescence associated with high fluorescence generally indicated that a major portion of the bioluminescence signal originates from autotrophic dinoflagellates. High signal in the absence of fluorescence indicates heterotrophic dinoflagellates or other zooplankton. The following mission on September 27th, 2006 was consistent with the other 5 missions, showing a consistent pattern between bioluminescence and fluorescence. In this case, there was a band of high bioluminescence in the northern portion of the grid. The high bioluminescence and fluorescence signals we associated with another relatively cool parcel of water. Unlike the distributions on the 23rd of September, the distribution of bioluminescence and fluorescence were consistent across much of the grid domain. The exception to this was most pronounced inshore on the northern corner. Here, the fluorescence continues to be high as part of the large patch, however bioluminescence was at least an order of magnitude less. This was consistent with the organisms having a decreased bioluminescent capacity resulting from the increased turbulence associated with breaking waves and the influence of the surf zone in that location. The backscatter data showed high values in that location that was consistent with the previous deployment.

MONTEREY BAY 2007

Acoustic transponders were also used in this study to better insure operation within the edge of the surf zone, however communications were poor throughout the entire experiment and had some influence on navigation. During the mission on May 19th, 2006, the vehicle with poor acoustic navigation positioning, continued on its inshore leg into the surf zone. On reaching its deviation threshold, the vehicle surfaced in the surf, received a GPS position and then pushed back through the oncoming waves to continue the mission. Data from the May 20th, 2006 shows patterns similar to those in Huntington Beach. Fluorescence, although increasing to the north, was consistent in the cross shore legs. Bioluminescence however showed a pronounced decrease on the shoreward side of the grid. This was consistent with the backscatter signal that showed increased turbidity near shore, particularly to the south of the grid. There were three “plumes” of material evident in the scattering and these were consistent with the decreases in bioluminescence. These features were spaced 150 m apart and were consistent with the rip tide pattern for this area based on real time imagery. These results indicate that

rip currents can significantly alter the distribution of bioluminescence in these regimes (decreased bioluminescence signals in the rip channels) and may be important for applied problems related to bioluminescence. In addition, these experiments demonstrate the robustness of UUVs, the advantage of sensor integration into these platforms, and their utility in understanding surf zone transition processes.

TIME SERIES PROFILER

In May, 2005, the automated profiler on the Cal Poly pier in San Luis Obispo Bay began operation and with intermittent breaks, it has been profiling continuously since then. The profiler has been set to measure the vertical structure of bioluminescence potential in conjunction with physical variables every half hour. Elevated levels are consistent with the phytoplankton growth period from May through August. Very high values are associated with late season dinoflagellate blooms occurring during atmospherically quiescent periods with high solar insolation. Over the period of performance, there have been periods without data were due to power interruption to the profiler, cable replacement and an upgrade from a generation-2 sensor to a generation-3 sensor, in collaboration with UCSB. The profiler has been recently upgraded and has the following instrumentation; 3 BP units, a transmissometer, fluorescence, backscatter, CTD and 2 plankton samplers. Time series analysis of the data is ongoing to examine the seasonal growth patterns, periods of local advection events, and separation of autotrophic and heterotrophic plankton communities. The sampler is also being used to collect a time series of samples for the population genetics study of D. Iglesias-Rodriguez with *Lingulodinium polyedrum*.

IMPACT/APPLICATION

Deployments are detecting patterns in the surf transition zone that have not previously been examined. This is also true for the continuing temporal data set. Integration into other existing programs also provides additional opportunities to examine bioluminescence patterns, structuring mechanisms and potential impacts (i.e. organismal/Naval).

TRANSITIONS

This project adds a high-resolution nighttime bioluminescence capability to an existing network designed to predict the 3-dimensional structure of coastal currents in the surf zone and transition zone. Fine-scale vertical bioluminescent measurements coupled with ancillary physical/biological measurements will improve the ability to predict bioluminescent events in the near shore littoral regions of interest to Naval operations and tactical mission planning. The sensors developed through S&T funds and used in this study are currently in transition by industry (Wetlabs) under an STTR.

RELATED PROJECTS

1 – This project is being conducted in conjunction with two near shore State supported programs in California. Surf zone and transition zone data will be analyzed in collaboration with R. Guza and E. Thornton. 2 – Integration and collaboration with the LOCO scientists will be ongoing to examine layering dynamics in plankton and nekton. 3 – A new STTR project in collaboration with A. Barnard (Wetlabs) and J. Case (UCSB) will help evaluate the new Wetlabs UBAT sensor for bioluminescence measurements. 4- The profiler is also being used to collect a time series of samples for the population genetics study of D. Iglesias-Rodriguez with *Lingulodinium polyedrum* funded under ONR code 32 OB.

REFERENCES

- Blackwell, S., J. Case, S. Glenn, J. Kohut, M. A. Moline, M. Purcell, O. Schofield and C. VonAlt. 2002. A new AUV platform for studying near shore bioluminescence structure. In: (P. J. Herring, L. J. Kricka and P. E. Stanley, eds.) *Proceedings of the 12th International Symposium on Bioluminescence and Chemiluminescence*, World Scientific, London, pp. 197-200.
- Moline, M.A., E.K. Heine, J.F. Case, C.M. Herren and O. Schofield, 2000. Spatial and temporal variability of bioluminescence potential in coastal regions. In: *Proceedings of the 11th International Symposium on Bioluminescence and Chemiluminescence*. J.F. Case, P. J. Herring, B. H. Robison, S. H. Haddock, L. J. Kricka and P. E. Stanley, eds, World Scientific, Singapore, 123-126.
- Moline, M. A., Blackwell, S. M., Allen, B., Austin, T., Forrester, N., Goldsborough, R., Purcell, M., Stokey, R. and C. von Alt. Remote Environmental Monitoring UnitS: An Autonomous Vehicle for Characterizing Coastal Environments. *J. Atmos. Oceanic. Technol.*, in press.
- National Research Council. 2003. *Environmental Information for Naval Warfare*. National Academies Washington D.C, 203 pp.

PUBLICATIONS

The following papers were partially or fully supported by this grant award:

- Chao, Y., J. Farrara, Z. Li and M. A. Moline. On the Impact of the Autonomous Underwater Vehicle (AUV) Measurements on Coastal Ocean Monitoring and Forecasting. *Limnol. Oceano*. [in press, refereed]
- Cetinic, I., R.E. Todd, B. H. Jones, R. E. Davis, M. A. Moline, D. L. Rudnick, and O. Schofield. Application of Autonomous Gliders in an Urban Coastal Ocean. *Limnol. Oceano*. [in press, refereed]
- Blackwell, S. M., M. A. Moline, A. Schaffner and Grace Chang. Defining Sub-Kilometer Length Scales in Coastal Waters. *Cont. Shelf Res.* [in press, refereed]
- Connolly, J., C. Knight, M.J. Oliver, J. Beaulieu, M.A. Moline. The Evolution and Ecology of Genome Size Variation in Diatoms (Bacillariophyceae). *Journal of Phycology*. [in press, refereed]
- Moline, M.A., S. M. Blackwell, J. F. Case, S. H. D. Haddock, C.M. Herren, C.M. Orrico, E. Terrill. Structure and interaction of coastal planktonic communities using bioluminescence. *Deep-Sea Res.* [in press, refereed]
- Moline, M. A., M. J. Oliver, C. D. Mobley, L. Sundman, S. M. Blackwell, T. Bergmann, W. P. Bissett, J. Case, E. H. Raymond and O. M. E. Schofield. Bioluminescence in a Complex Coastal Environment: Part 1 Night-time Water-leaving Radiance in Optically Complex Coastal Waters. *J. Geophys. Res.* [in press, refereed]
- Oliver, M. J., Moline, M. A., C. D. Mobley, L. Sundman and O. M. E. Schofield. Bioluminescence in a Complex Coastal Environment: Part 2 Prediction of Bioluminescence Source Depth from Spectral Water Leaving Radiance. *J. Geophys. Res.* [in press, refereed]
- Moline, M.A. and I. Robbins. 2007. UUV Measurement of Bioluminescence within the Surf Zone. *Proceedings of the 15th International Symposium on Unmanned Untethered Submersible Technology*. [published]
- Robbins, I., Moline, M. A., Barnard, A. H. and C. M. Orrico. Autonomous cDOM Plume Mapping in Penobscot Bay, Maine: REMUS Operation and Modularity. *Proceedings of the 15th International Symposium on Unmanned Untethered Submersible Technology*. [published]

Moline, M.A., D.L. Woodruff and N.R. Evans. 2007. Optical Delineation of Benthic Habitat Using an Autonomous Underwater Vehicle. *J. Field Robotics* 24 (6): 461-471. DOI: 10.1002/rob.20176. [published, refereed]

Robbins, I.C., G.J. Kirkpatrick, S.M. Blackwell, J. Hillier, C.A. Knight and M. A. Moline. 2006. Improved monitoring of HABs using autonomous underwater vehicles (AUV). *Harmful Algae*, doi:10.1016/j.hal.2006.03.005. [published, refereed]

HONORS/AWARDS/PRIZES

Mark A. Moline, California Polytechnic State University, 2006-2007 Distinguished Scholarship Award, California Polytechnic State University.