A National Oceanographic Partnership Program Award

Ocean Response Coastal Analysis System

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Long-Term Goals

The joint goal of the Naval Research Laboratory (NRL) and the Commander, Meteorology and Oceanography Command (CNMOC) is to develop a capability to describe diver visibility and vulnerability, and demonstrate how new, innovative technology allows a better 3D/4D representation of the optical field for Navy applications. The new technology that is explored in this research is the use of self-contained, small portable optical/ biological/chemical moorings. These data will be used to validate and/or improve visibility and vulnerability estimates for operational scenarios.

Objectives

The joint objectives of NRL and CNMOC in this program are to test and improve existing diver visibility and vulnerability algorithms using sensors that are to be incorporated onto the Ocean Response Coastal Analysis System (ORCAS). Sensors to be tested include a bioluminescence profiling package (University of Southern California at Santa Barbara) and the multi-angle scattering sensor and 20-channel multi-spectral absorption and attenuation meter (WET Labs, Inc.). The goal is to test and validate new optical instrumentation and to apply the resulting data toward tailored optical products via the Naval Oceanographic Office (NAVOCEANO) to support Naval and Joint operations.

The development of ORCAS small autonomous profiling instruments will allow more accurate 3D/4D representation of the optical field in realtime. However, algorithms that use the output of these instruments must be compared against a more complete optical set of measurements as well as actual diver visibility and vulnerability measurements. Thus, the project Gauging Littoral Optics for the Warfighter (GLOW) has joined the ORCAS team to collaborate to apply the developing profiler technology to specific military applications.

Approach

In support of diver operations in any area of interest, the Navy (via NAVOCEANO) provides optical planning products to support the mission. At present, these products depict estimates of diver visibility in the horizontal (addressing the issue of how far they will be able to see) and the vertical (addressing the issue of how easily they will be seen; i.e., vulnerability). These products depict either a monthly or seasonal average; however, they are inadequate to support most littoral operations and do not forecast for areas where the optical properties can change over finer scales than modeling and remote imagery reveal. Given recent developments in optical instrumentation and the application of collected data to Navy issues, the technology now exists to provide better estimates of diver visibility and vulnerability. CNMOC established the GLOW project to forward this goal and to identify and mitigate gaps in R&D and transition processes. The limited case of the Preisendorfer algorithms (Duntley, 1952; Preisendorfer 1976, 1986) used by NAVOCEANO to generate diver visibility products is $4/c$, and in some cases $4/[c+K\cos(\theta)$ is used when sufficient data are available. However, previous GLOW exercise results indicate this may be so limited an application, that an expanded version of these algorithms may be necessary for littoral waters.

Until recently, optical measurements used to support diver visibility and vulnerability have relied on Secchi-depth values taken from surveys as far back as the 1930's. These data are difficult to use in depicting the strong dynamic nature of the coastal environment where very shallow-water operations occur. With the advent of relatively new instruments such as the absorption-attenuation meter and three-angle scattering sensor (WET Labs, Inc.) and the absorption/ attenuation-backscattering instruments (HOBI Labs, Inc.), improved measurements of optical properties are available. Such data do or will populate the optical databases of NAVOCEANO and thus are vital source material for fleet support products. However, the algorithms that derive visibility from optical properties were either formulated prior to the development of these modern in situ instruments, or as in the case of the DiVA (Diver Visibility Algorithm) model, there is concern about the measurement parameters themselves and use of an instrument-specific model. Therefore, the algorithms must be tested in light of these improved measurements to determine if the models of the past are applicable and to determine the optimized products given our improved measurement potential.

Five GLOW experiments have been conducted since it was initiated in 1998, two preceding ORCAS and three since. In all experiments, existing algorithms for diver visibility were applied to field data and then compared to actual visibility as observed by Navy divers. Results of the preliminary GLOW experiments indicate that, indeed, visibility algorithms need to be reviewed and most likely revised (actual diver visibility was generally underestimated by theory by a factor of 2 to 3). However, there were questions concerning angle of approach, ambient light, and direct light versus scattered light that was visible to the Navy divers. GLOW identified the R&D need to revalidate/ revise existing diver visibility algorithms and to standardize the elements of both daytime and nighttime vulnerability. In response to the uncertainty in diver visibility, McBride (unpublished) extended the Preisendorfer algorithms to handle varying target reflectivity, target tilt angle, and an azimuthally symmetric radiance distribution. Under the current ORCAS/GLOW research, Bowers (2002) has further expanded this CTT implementation to include stratified in-water optical conditions, bottom effects, and more complex radiance distributions.

For both visibility and vulnerability experiments, any available remote ocean color imagery will also be included in the analyses. Although in situ measurements and resultant capabilities are the focus of this work, remote imagery is an important complement for characterizing the synoptic field and for potentially gathering preliminary data in “denied access” regions prior to the covert deployment of an operational ORCAS system in the future. It also allows for the direction of the study into potentially important areas of either high/low visibility and high/low vulnerability.

Work Completed

During the third and final year of this NOPP project, a fifth exercise was conducted off the Texas coast. Operations were planned to support daytime visibility and vulnerability studies, as well as nighttime vulnerability. Weather difficulties complicated logistics and nighttime diver operations were cancelled. However, data collected using the USC/SB bioluminescence profiling sensor were collected as part of the ORCAS effort. Three days of daytime visibility and vulnerability measurements were collected coincident with in-water diver observations. Collected data from all GLOW/ORCAS exercises confirm that the NAVOCEANO implementation of the Contrast Transmittance Theory (CTT) is extremely limiting and therefore is not a good predictor of the distance a diver will see an underwater target. Figure 1 shows an example of the data collected during these exercises.

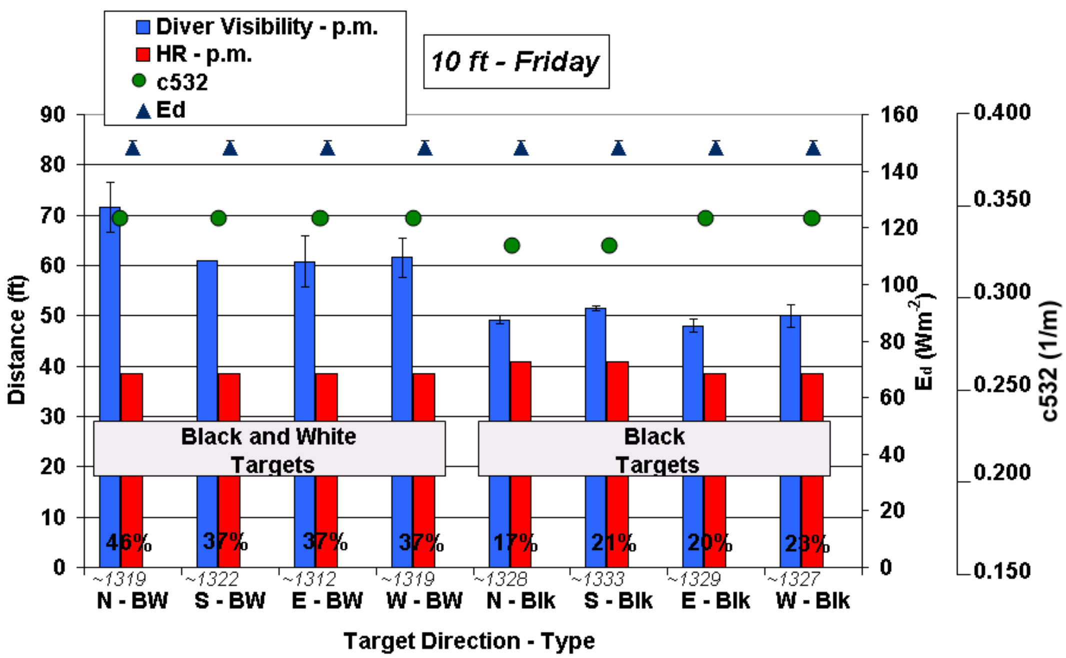


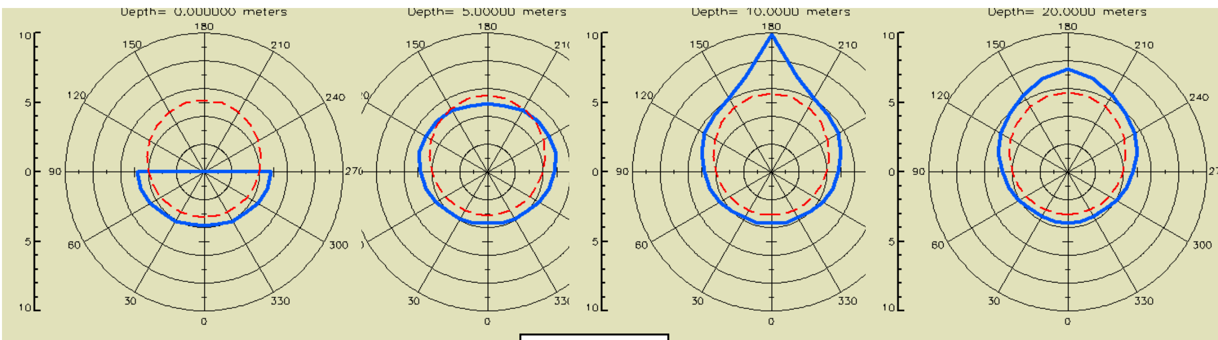
Figure 1. Example of data collected during GLOW/ORCAS exercises indicating the difference between hydrologic range (as determined from the 4/c implementation of CTT- red lines) and the distance at which divers observed underwater targets – blue lines.

Data collected during the GLOW/ORCAS exercises was used to develop an enhanced application of CTT to better predict diver visibility using ambient conditions, and will be presented in partial fulfillment of Master's degree requirements at the University of Southern Mississippi later this year. A brief discussion of this implementation is described in the following section. Data collected during all GLOW-related exercises will be available upon request on a CD to be available in October 2002.

Results

Based on the data from the GLOW exercises, an enhanced implementation of CTT, has been developed. The Bowers Implementation of CTT, or BIC, is a radiance-based approach that computes inherent target field and background radiances for all depths and observer angles, then applies results via CTT to calculate a visibility distance. In general, this approach requires parameters that have been assumed as constant in the *4/c* implementation to be either input by a user or calculated based on user inputs. Specifically, BIC allows for inputs of solar irradiance, stratified optical properties, bottom reflectivity, target properties, and the angle of a diver's approach.

Figure 2 shows some example results from BIC. These figures show the computed visibility distance for all angles of approach, with 0 ^{o} looking straight down at a black (0% reflectivity) target and 180 ^{o} looking straight up at the same target for depths of 0, 5, 10, and 20 meters, respectively. Concentric circles indicate an interval distance of 2-meters. BIC results are given as a blue line, in comparison to a slightly expanded version of CTT, $4/[c+K\cos(\theta)]$, which is shown by a dashed red line.



←North

Figure 2. BIC results for simple case of homogeneous optical properties, sun angle directly overhead, and 0% reflective black target, at waters depths of 1, 5, 10, and 20 meters.

As one can see from an analysis of these plots, even under simplistic environmental scenarios, the distance at which a diver can detect the target is not consistent with depth or with angle of approach. In fact, under certain conditions (20-m water depth at 180 ^{o} for example), the limited application of CTT significantly underestimates this distance. Note too that the differences between the $4/[c+K\cos(\theta)]$ implementation and BIC are not linear. Adding more complex environmental scenarios (stratified conditions, varying sun angles, more realistic target reflectivity) serves to further complicate the 'rosette' determined by BIC.

Results for the daytime vulnerability data have been much less rigorously analyzed, due to time and funding constraints. An informal report was generated that reviewed data collected from GLOW III and GLOW IV exercises more closely. This report suggests that Secchi data may have a significant application in fleet programs as a rough determination of the vulnerability of a diver under various optical (in-air and in-water) conditions. From looking at the data from these two exercises, it appears that the distance at which a diver will be detected can be estimated at one-half the Secchi depth (observer located on ship's deck and looking down along the side of the ship). If an observer is placed in the water and does not have the effects of the air/water interface as an additional observational barrier, this distance increases greatly (to a factor of two times the Secchi depth, based on observations only). This remains consistent with previous research (Preisendorfer, 1986), but emphasizes the application of such a measurement.

The GLOW program was designed to provide additional insight into the quantification of diver vulnerability at night. However, there were a number of circumstances (sensor development and integration, logistics of divers and equipment, severe weather) that prohibited coincident sensor and diver observations. Additional exercises will be recommended for any future GLOW program support.

Impact and applications

National Security

There are two impacts on the work to national security. The first is the development of diver visibility algorithms and initial work with bioluminescence sensors. With models of diver visibility, the need for "watches" and the area search patterns for force protection are impacted. As part of homeland security vessels need to be examined for foreign objects. The ability and time required to do this is impacted by diver visibility. The algorithm developed under the NOPP program helps determine the approach angle and look directions to maximize diver visibility and thus reduce search time. In a second effort this project determined diver vulnerability and potential detection due to bioluminescence. This phenomena and its measurement can be useful not only in the ingress to hostile countries but also in the detection practices and monitoring of USA coastal waters. If bioluminescence signals are too great then some assets are more vulnerable.

Economic Development

This project included the testing of a bioluminescence from USCB (Dr. James Case) that is being considered for incorporation on platforms such as REMUS or profiling systems. While of limited sales, such instrumentation can be used in indicating the presence of dinofallegate blooms which is important to many coastal management and in regions of habitat changes.

Quality of Life

The ORCAS program as an entity was designed to help monitor public and ecosystem health and assist in ecosystem management (see report by Percy Donaghay). From the diver visibility and vulnerability perspective, visibility is often used as an indicator in changing habitats and water quality. Often reduce visibility by divers is the first indication of water changes or in changes that may effect an ecosystem such as regions with coral outcrops. The determination of diver visibility helps interpret such reports and puts the variance observed in visibility reports into perspective when several observations seem to disagree greatly.

Science Education and Communication

Underwater visibility and the occurrence of bioluminescence is always of interest to science classes, however, at the present time there has been no demonstration to the public education system. There is a connection with the Naval Postgraduate School where based on the NOPP project and an ONR Code 32 funded model validation effort, an attempt is being made to get visibility and remote sensing into their studies. This would be a major accomplishment since warfighters seldom have course work in oceanographic applications (see transitions).

Transitions

National Security

The diver visibility model has been presented to the Mine Warfare Community and too ONR Code 32 and is being considered as one of the possible models for operational use. This would require validation funding and evaluation with 6.3 funding and then final transition. The model is also being examined by NAVOCEANO for possible use at the present time. The experimental results of this program, and the collaborative effort funded by Code 32 (Dr. Cleveland), are being used to develop training tools for possible use by EOD and NSW personnel. The instrumentation developed is being considered for future systems for long-term monitoring of coastal waters both CONUS and other.

Science Education and Communication

This NOPP provided the basis for attempting to start a curriculum at the Navy Postgraduate School in diver visibility and vulnerability. The purpose of this effort was to inform the warfighter of the hazards associated with bioluminescence and also indicate how diver visibility could be estimated prior to operations in areas of denied access. There was a need to put information into a formal educational program that targets Navy personnel.

Consideration for Excellence in Partnering Award

Ocean Sector Diversity: This NOPP project involved all aspects of the oceanographic community. The academic interests and issues of purely scientific interest were addressed by Dr. Percy Donaghay and his group. The NOPP partners also included WetLabs Inc., and SubChem Inc., both which demonstrated new technology that is being advanced into the commercial market as product lines (see Donaghay report), and from the applications side the partners included the EPA, Naval Research Laboratory Stennis Space Center (NLRSSC)., and Command Meteorology and Oceanography Command (CNMOC). The Navy interests were addressed in total cooperation with all of the other partners. The partners went out of their way to accommodate the schedules of Reservists and shiptime that was brought to the program by the Navy. The academic interests also presented methods to display the data to other researchers and to the Navy personnel that often do not have time or experience to understand all of the details. The EPA has indicated that the results of the project may impact their sampling strategies and equipment used in the future.

Partner Involvement: All the partners participated in all aspects of this program. In instrumentation requirements and design, the lead PI (Donaghay) and the commercial partners and customers (EPA and Navy) meet to discuss what sensors and system would best meet the needs of the group. This interaction was critical for the deployment of the proper sensors. In the field exercises, the Navy (CNMOC) provided the shiptime and the reserve divers. This required the partners to schedule their activities around an often fixed ship availability and reservists travel opprotunities. The partners all contributed to insuring that every goal of each partner was achieved. The Navy was limited in its site selection by the visibility requirements, while the URI and SubChem needed structure in the water column. Compromises were common to best meet everyone's needs. When instrumentation provided by the Navy failed, URI and Wetlabs contributed significantly, and when instrumentation needed checking, Navy divers helped with this. All partners had a place to contribute to this program. Please describe the level of effort and involvement by each partner.

Matching Contributions: Contributions included everything from shiptime and divers (Navy) to personnel, equipment, and facilities for studies (EPA, URI, and SubChem). The NRLSSC leaveraged other projects as well to help with the visibility and optical instrumentation development. All of the major partners contributed in-kind to this project. The Command Naval Meteorology and Oceanography Command (CNMOC) is a proponent of this project and considers this project a success in the combining of their resources and the R&D and commercial companies. The contractors that helped CNMOC and NRLSSC with the visibility and bioluminescence modeling (Planning Systems Inc.,) have further developed this capability and presented this to NAVOCEANO and as a Master's thesis by Todd Bower's to the University of Southern Mississippi. The contributions by EPA have resulted in a new site for the testing of oceanographic equipment.

Partner Long-Term Commitment: CNMOC and NRLSSC have a long standing relationship that has now been enhanced to include several academic and commercial representatives through this program. URI and NRLSSC are continuing our effort to provide the Navy with instrumentation that is vital to the monitoring and surveying the oceanic environments. The relationships made during this NOPP have resulted in several questions being asked by NAVOCEANO and other optical groups on new instrumentation that may be available in the coming years. All of the partners are pursuing future collaboration in areas of harmful algal blooms, hypoxia layers, and optical signatures that can have military and environmental significance. The work with SubChem and URI is leading to examining capital procurements by NRLSSC in FY06 of emerging technology that may arise from this NOPP that will benefit oceanographic measurements and provide links between biological, physical, chemical, and optical phenomena.

Success in Project Objectives: From the Navy's perspective the project successfully produced a potential model that can use the optical properties measured by the ORCAS instrumentation that can help with diver visibility and vulnerability questions. The prototype system still requires further testing for the full four dimensional capability which is the primary interest of the Navy for predictive model utility. The program still needs to concentrate on the miniaturization of the instrumentation to a level that makes it more useful for routine survey operations. This also includes an improved data transmission and real-time display. The work of the partners toward meeting this goal still takes place on individual projects but has now been slowed up as the NOPP comes to a close. The success of the chemical and optical suite will have high payoff in the national security issues as chemical monitoring becomes more important in harbors. The use of the system by the Navy is represented by the consideration of the system for procurement by NRLSSC. Even if the ORCAS system itself is not procured, the technology developed under this program has provided CNMOC and NRLSSC with capabilities to improve our oceanographic research and development activities (NRLSSC) and the survey requirements (CNMOC/NAVOCEANO).

<u>Related Projects</u>

Evaluation of the a-Beta Instrument and DiVA Model, ONR Code 32, PI: Alan Weidemann, NRL.

Validation of the Distance Visibility Algorithm (DiVA) and the Impact of the Mesoscale Approximation to Mine Warfare Applications, ONR Code 32, PI: Alan Weidemann, NRL.

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