

## Distance Visibility Algorithm (DiVA) Transition

Robert A. Maffione  
Hydro-Optics, Biology, and Instrumentation Laboratories  
P.O. Box 859  
Moss Landing, California 95039  
Phone: (831) 884-9409 Fax: (831) 884-9411 Email: [maffione@hobilabs.com](mailto:maffione@hobilabs.com)

Award Number: N0001401C0218  
<http://www.hobilabs.com>

### LONG-TERM GOALS

The immediate goal of this project is to develop a robust and viable method for estimating underwater visibility that will aid Navy mine hunting efforts in actual operation. The overall long-term goal is to transition this method, called DiVA (Distance Visibility Algorithm), to the operational Navy.

### OBJECTIVES

There are three major objectives of this DiVA transition effort: 1) Conduct diver visibility experiments in a range of optical water types to obtain a database for testing and refining the DiVA model; 2) Develop a Monte Carlo model that will be used to perform computer experiments of the DiVA for any combination of water optical properties, environmental conditions, and various types of underwater (incoherent) imaging systems; 3) Provide to the Navy a fully documented DiVA model that can be independently tested and validated; 4) Develop and deliver a real-time, stand-alone computer program for processing in-situ data and providing graphic and numeric output of visibility range.

### APPROACH

The Navy has several types of optical mine-hunting systems, including divers, that are deployed from ships. It is highly desirable, and in some cases critical, for the Navy to have accurate performance predictions of these systems prior to deployment. The DiVA method is designed to provide the operators, in real time, with accurate system performance estimates based on actual measurements of water optical properties. Real-time in-situ optical measurements are feasible since at least one ship is already on station – the ship that deploys the mine-hunting system. Prior to deploying this system, a rapid profile of the water column is performed using a robust, self-contained, simple to deploy instrument that measures the necessary optical properties for estimating system performance. Two instruments have been developed for this purpose,  $a$ - $\beta$  and  $c$ - $\beta$ .  $a$ - $\beta$  measures the diffuse attenuation, absorption, and backscattering coefficients and  $c$ - $\beta$  measures the beam attenuation and backscattering coefficients. For imaging systems and divers,  $a$ - $\beta$  is used, and for laser-based systems  $c$ - $\beta$  is used. When performance estimates are needed for both types of systems, both  $a$ - $\beta$  and  $c$ - $\beta$  can be deployed together.

As soon as a profile is completed, the  $a$ - $\beta$  measurements are fed into the Distance Visibility Algorithm (DiVA) which then computes a profile of the maximum visibility, or target acquisition distance for divers or a particular imaging system. The DiVA, which was developed on this project, is

| Report Documentation Page                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |                                    |                                     | Form Approved<br>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<br><b>30 SEP 2001</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |                                    | 2. REPORT TYPE                      |                                                           | 3. DATES COVERED<br><b>00-00-2001 to 00-00-2001</b> |                                 |
| 4. TITLE AND SUBTITLE<br><b>Distance Visibility Algorithm (DiVA) Transition</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |                                    |                                     |                                                           | 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)<br><b>Hydro-Optics, Biology, and Instrumentation Laboratories,,P.O. Box 859,,Moss Landing,,CA, 95039</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |                                    |                                     |                                                           | 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<br><b>Approved for public release; distribution unlimited</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |                                    |                                     |                                                           |                                                     |                                 |
| 13. SUPPLEMENTARY NOTES                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |                                    |                                     |                                                           |                                                     |                                 |
| 14. ABSTRACT<br><b>The immediate goal of this project is to develop a robust and viable method for estimating underwater visibility that will aid Navy mine hunting efforts in actual operation. The overall long-term goal is to transition this method, called DiVA (Distance Visibility Algorithm), to the operational Navy.</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |                                    |                                     |                                                           |                                                     |                                 |
| 15. SUBJECT TERMS                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |                                    |                                     |                                                           |                                                     |                                 |
| 16. SECURITY CLASSIFICATION OF:                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |                                    |                                     | 17. LIMITATION OF ABSTRACT<br><b>Same as Report (SAR)</b> | 18. NUMBER OF PAGES<br><b>6</b>                     | 19a. NAME OF RESPONSIBLE PERSON |
| a. REPORT<br><b>unclassified</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       | b. ABSTRACT<br><b>unclassified</b> | c. THIS PAGE<br><b>unclassified</b> |                                                           |                                                     |                                 |

an analytical algorithm that computes image contrast as a function of range and, inversely, maximum visibility distance as a function of (minimum) image contrast threshold. A depth profile of maximum visibility range is then provided to the appropriate Navy personnel who can use this information to decide on appropriate search methods or whether a system should be deployed at all.

Our approach to completing the successful transition of DiVA to the operational Navy is to conduct further in-water visibility experiments to better verify the model, and develop a Monte Carlo visibility model that can be used to extensively investigate, test and refine the visibility algorithms.

## WORK COMPLETED

HOBILabs has developed a Distance Visibility Algorithm, DiVA, that rapidly computes both image contrast as a function of range and the maximum visibility distance for divers and underwater camera systems using either active or ambient lighting conditions. DiVA is a mathematically rigorous model derived from radiative transfer theory that uses one input variable, a quasi-diffuse attenuation coefficient denoted  $K_L$ . This variable is measured directly with the  $\alpha$ -beta, an in-situ instrument that is completely self-contained, robust, and easy to operate off of any ship. Our approach to verifying and refining the DiVA model includes conducting visibility measurements at sea and developing a Monte Carlo model to simulate visibility under a wide range of conditions. Thus far we have completed all of the sea experiments, collecting extensive visibility measurements of a black and white target. We have also completed the development of a Monte Carlo model that calculates target contrast as a function of range for nearly any type of environmental conditions.

## RESULTS

The DiVA mathematical model is described elsewhere (see FY00 ONR report or Maffione, 2001). One form of the algorithm gives the target contrast  $C$  as a function of range  $R$  and can be expressed succinctly by

$$C(R) = C_0 \left\{ 1 + 2\Lambda \left[ \frac{\exp(K_L R) - 1}{K_L} \right] \right\}^{-1}, \quad (1)$$

where  $C_0 = C(R=0)$  is the inherent contrast of the image.  $K_L$  is the attenuation coefficient measured by  $\alpha$ -beta and  $\Lambda$  is the “path-radiance” factor. This factor is the only free parameter in the model and can be found by either making measurements of  $C(R)$  or calculating it with a Monte Carlo radiative transfer model.  $\Lambda$  is then found by performing a least-squares regression to  $C(R)$  using either the measured or modeled results. Figure 1 shows recent measurements of  $C(R)$  taken in Monterey Bay. The solid curve is a least-squares regression to the data using Eq. 1. Note how well the model fits the data. The value of  $K_L$ , as measured by the  $\alpha$ -beta, was  $0.26 \text{ m}^{-1}$ . Figure 2 shows calculations of  $C(R)$  using our recently developed Monte Carlo model. These calculations were performed over a range of optical properties as expressed by the single scattering albedo,  $b/c$ . Note again how well these results fit the DiVA equation, which are shown by the solid lines. Figure 3 shows the free parameter  $\Lambda$  that results from the regressions to the MC results for the range of optical properties,  $b/c$ . This exciting results shows that  $\Lambda$  is a nice linear function of  $b/c$ , indicating that it should be easy to model for any type of optical condition.

## IMPACT/APPLICATIONS

Understanding underwater visibility has been an important subject of investigation for many decades. Because DiVA is the first underwater visibility model that has been tested and validated, it will no doubt have a profound impact on both the science of understanding underwater visibility and on underwater imaging systems. DiVA may provide the key model to properly interpreting the huge database of Secchi depth measurements in terms of inherent optical properties. For the operational Navy, DiVA has the proven potential for providing critical information to divers and operators of mine-hunting systems.

## TRANSITIONS

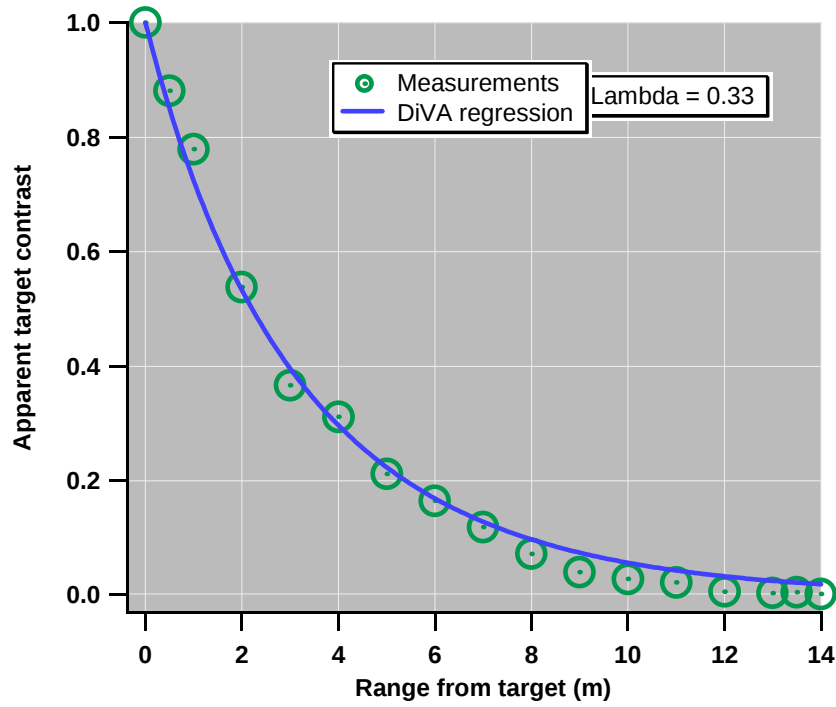
DiVA was demonstrated to the Navy for the first time during the GOMEX / MIREM 99 and FBE-HOTEL mine-hunting exercises and the results were used in real-time by two mine-hunting systems, the SLQ-48 and a laser-line scanning system. The DiVA method and results from these exercises are currently being used by NRL scientists who are investigating underwater visibility problems. These personnel include Robert Arnone and Alan Weidemann (Stennis) and contractor Walter McBride. Recently, the Navy decided to fund a three-year project for a rapid transition of DiVA to the fleet.

## RELATED PROJECTS

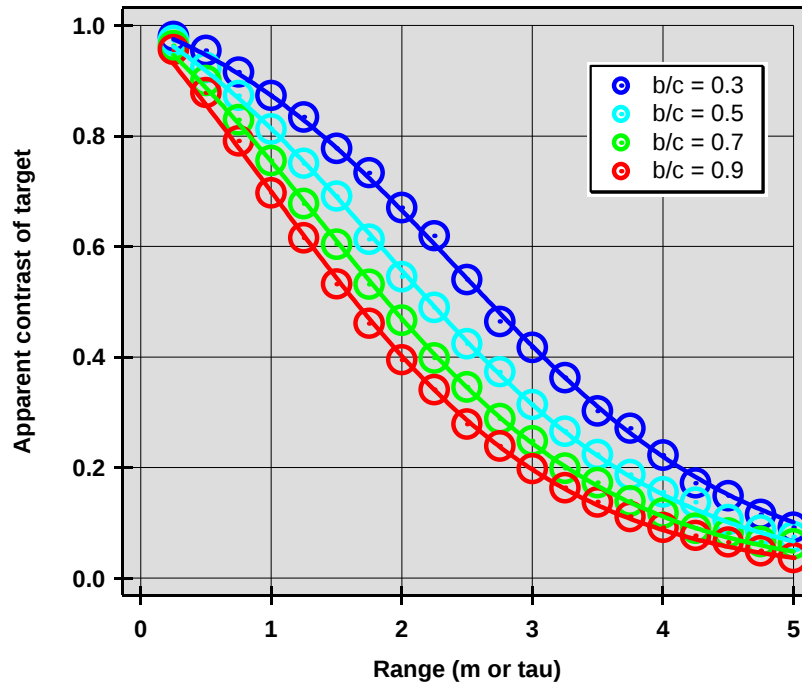
- 1 – The  $a$ -beta and  $c$ -beta instruments are being used by Robert Arnone's group at NRL as part of their underwater visibility work and they will undoubtedly be conducting their own tests of DiVA.
- 2 – The  $a$ -beta and  $c$ -beta instruments are being used by Mike Contarino and Linda Mullen (NAWC) on their project to develop new lidar technology for measuring water-column optical properties and detecting submerged targets.
- 3 – The  $a$ -beta and  $c$ -beta instruments were used by CSS (in collaboration with Mike Strand) during the deployment of their laser-line scan system on the CoBOP program in the Bahamas.
- 4 – I am working closely with program managers to further demonstrate the utility of DiVA to the Navy and eventually transition it to the fleet.

## REFERENCES

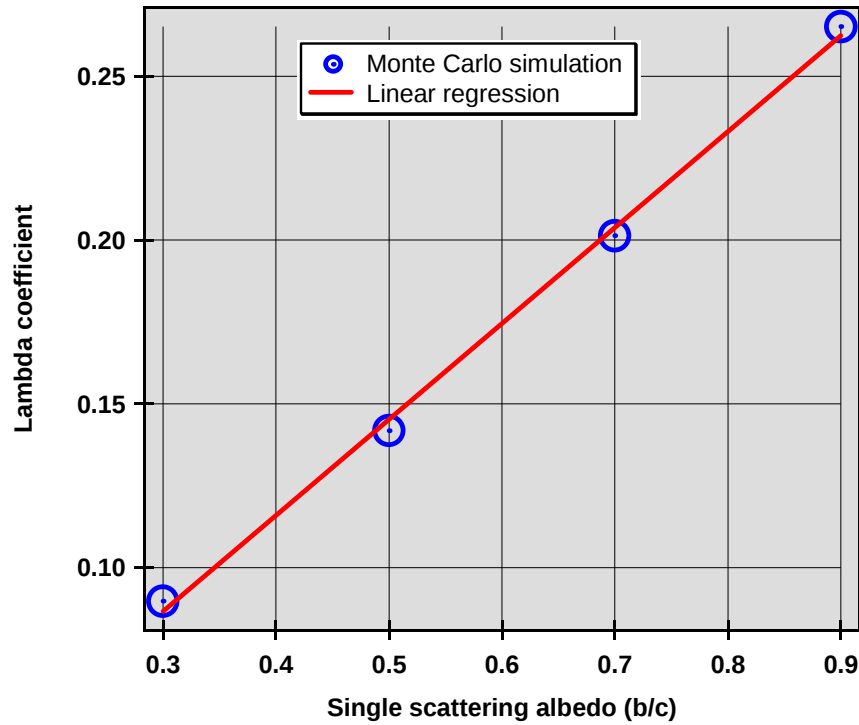
- Dana, D.R., and R.A. Maffione, 1998. A new instrument for measuring the backward scattering and absorption coefficients simultaneously, Ocean Optics XIV, S.G. Ackleson, Editor, Proc. SPIE.
- Maffione, R.A., (in progress). Method for estimating underwater visibility in daylight and active lighting conditions, to be submitted to Appl. Opt.



**Figure 1.** Circles are measurements of target contrast as a function of range. The solid curve is a least-squares regression fit of the data to the DiVA model. These measurements were taken in Monterey Bay on a sunny day at 6 m depth.



**Figure 2.** Circles are computations of target contrast as a function of range for various optical properties using our Monte Carlo model. The solid curves are regressions to the MC results using the DiVA model. The Monte Carlo model allows us to investigate visibility over all kinds of environmental conditions.



**Figure 3.** Graph of the path radiance factor  $\Lambda$  as a function of water optical properties as expressed by the single scattering albedo  $b/c$ . The values of  $\Lambda$  were obtained by a regression to the MC results using the DiVA equation. Note that  $\Lambda$  is a smooth, nearly linear function of  $b/c$ , indicating it should be straightforward to model for any optical conditions.