Defining the Uncertainty of Electro-Optical Identification System Performance Estimates Using a 3D Optical Environment Derived From Satellite

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ABSTRACT

Current United States Navy Mine-Counter-Measure (MCM) operations primarily use electro-optical identification (EOID) sensors to identify underwater targets after detection via acoustic sensors. These EOID sensors which are based on laser underwater imaging by design work best in "clear" waters and are limited in coastal waters especially with strong optical layers. Optical properties and in particular scattering and absorption play an important role on systems performance. Surface optical properties alone from satellite are not adequate to determine how well a system will perform at depth due to the existence of optical layers. The spatial and temporal characteristics of the 3d optical variability of the coastal waters along with strength and location of subsurface optical layers maximize chances of identifying underwater targets by exploiting optimum sensor deployment. Advanced methods have been developed to fuse the optical measurements from gliders, optical properties from "surface" satellite snapshot and 3-D ocean circulation models to extend the two-dimensional (2-D) surface satellite optical image into a three-dimensional (3-D) optical volume with subsurface optical layers. Modifications were made to an EOID performance model to integrate a 3-D optical volume covering an entire region of interest as input and derive system performance field. These enhancements extend present capability based on glider optics and EOID sensor models to estimate the system's "image quality". This only yields system performance information for a single glider profile location in a very large operational region. Finally, we define the uncertainty of the system performance by coupling the EOID performance model with the 3-D optical volume uncertainties. Knowing the ensemble spread of EOID performance field provides a new and unique capability for tactical decision makers and Navy Operations.

INTRODUCTION

Current Navy Mine countermeasure (MCM) operations use divers and electro-optical identification (EOID) sensors to detect, identify and neutralize mine threats. These methods of detection yield the classification of mine-like objects from the detection phase of operations and classify as either threat on non-threat. Using an EOID sensor allows rapid spatial coverage of an area reducing the risk to Navy personnel mainly divers (Mahoney, 2008). These EOID systems work best in clear water environment. The performances of these systems are limited in coastal environments where the turbidity of the water increases (absorption and scattering) and where strong optical layers exist in the water column. Prior knowledge of the optical environment of the operational area is very critical for tactical decision making during MCM operations.

Ocean optical properties are highly variable on small spatial and temporal scales in the coastal ocean where most MCM operations take place. Remote sensing from satellite offers sampling of the optical environment close to these space and time scales. Limitations of remote sensing data are 1) the satellite can only see the upper few meters of the ocean and cannot resolve the optical properties of the entire water column which is important to know the strength and location of optical layers if present, 2) Consistent cloud cover can be an issue for real-time operations, and 3) Repeat coverage of and area of interest may only happen once a day. Surface optical properties alone are not adequate. Real-time

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measurements of the vertical optical properties of the water column are often used for operations in predicting how well an EOID sensor will perform. These measurements are limited spatially and the data may not represent the surrounding environment. By knowing the limitations of both surface satellite observations and insitu measurements during MCM operations, extending the two-dimensional (2D) satellite image into a three-dimensional (3D) optical volume using a Gaussian model, tuned using real-time insitu measurements taken in operational area, is critical. This capability would allow tactical decision makers in the MCM community to estimate EOID sensor performance for a given day's environmental conditions and forecast.

We demonstrate methods using a 3D Optical Volume to produce EOID system performance estimates. Finally, we will evaluate the uncertainties of the system performance estimates by coupling the performance model and the uncertainties of the optical volume.

METHODS

The performance estimates for this study was produced by the fusion of satellite surface optical properties, modeled 3D physical parameters temperature and salinity, and optical insitu measurements of the entire water column. The fusion of these data sets was used to generate the 3D optical environment for input to the Electro-Optical Detection Simulator (EODES) to produce EOID system performance estimates (Figure 1).

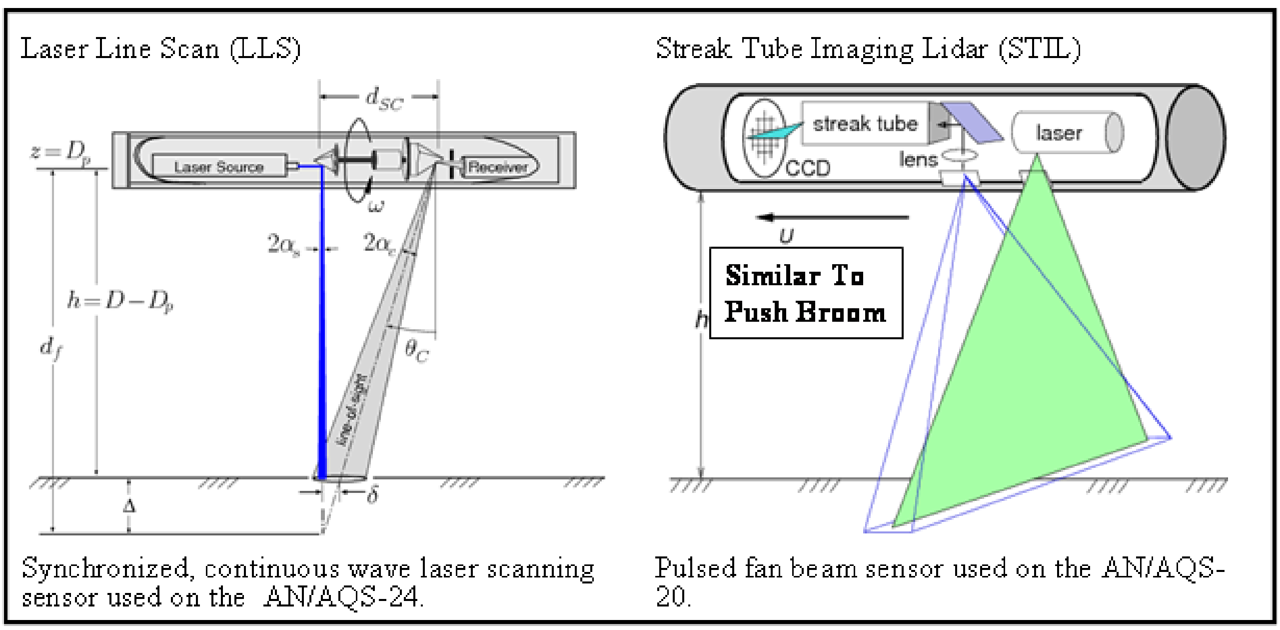

Figure 1. Active underwater EOID imaging sensors used for MCM operations and available in EODES software (Giddings 2008).

Generation of 3D Optical Volume
Insitu measurements were collected during the BIo-Optical Studies of Predictability and Assimilation for the Coastal Environment (BIOSPACE) experiment held in Monterey Bay California in June 2008. High resolution numerical models were run in real-time along with the processing of Moderate Resolution Imaging Spectrometer (MODIS-Aqua) satellite data. Insitu optical and physical properties were measured using a shipboard profiling package, Slocum gliders, and a towed scanfish. Satellite data provided a daily snapshot of the surface ocean chlorophyll concentration (OC3M). Insitu observations provided discrete point, vertical profiles (surface to near-bottom) of chlorophyll fluorescence. These data clearly showed a "chlorophyll maximum" layer somewhere between the surface and 30 meters that were not observed by the satellite. The coupling of the measured chlorophyll fluorescence and physical properties (temperature, salinity and density) yielded a relationship (Gaussian) between the optics and physics for Monterey Bay. This

relationship was used to then couple the surface satellite chlorophyll and the numerical model to produce a 3D optical volume of the entire operational area.

EOID Performance Prediction

Electro-Optical Detection Simulator (EODES) makes an EOID system performance prediction expected under a specific set of optical conditions (Giddings, 2008). Inputs for this code include sensor type, vehicle towing altitude above bottom, information on the vertical optical environment which is obtained from the 3D optical volume and bottom depth. Outputs include probability of identification (Pid) of a target along with optimal towing altitude to get an identification (Figure 2). Target identification is dependent on system towing altitude, target depth and the location and strength of the optical layers. System performance estimates from EODES are used to support Navy MCM operations for underwater target detection and identification. EODES provides sophisticated physical models for better performance prediction (Giddings 2008). These models take into account the details of the system configuration and operation, the influence of optical properties of the water column, presence of ambient light, and the correlation between system resolution, optical blurring, and signal-to-noise. Optical properties of absorption and scattering are most important and surface optical properties from satellite are not adequate to predict system performance. Using the 3D optical volume to predict system performance for an entire image gives better spatial coverage than using glider profiles in a certain location.

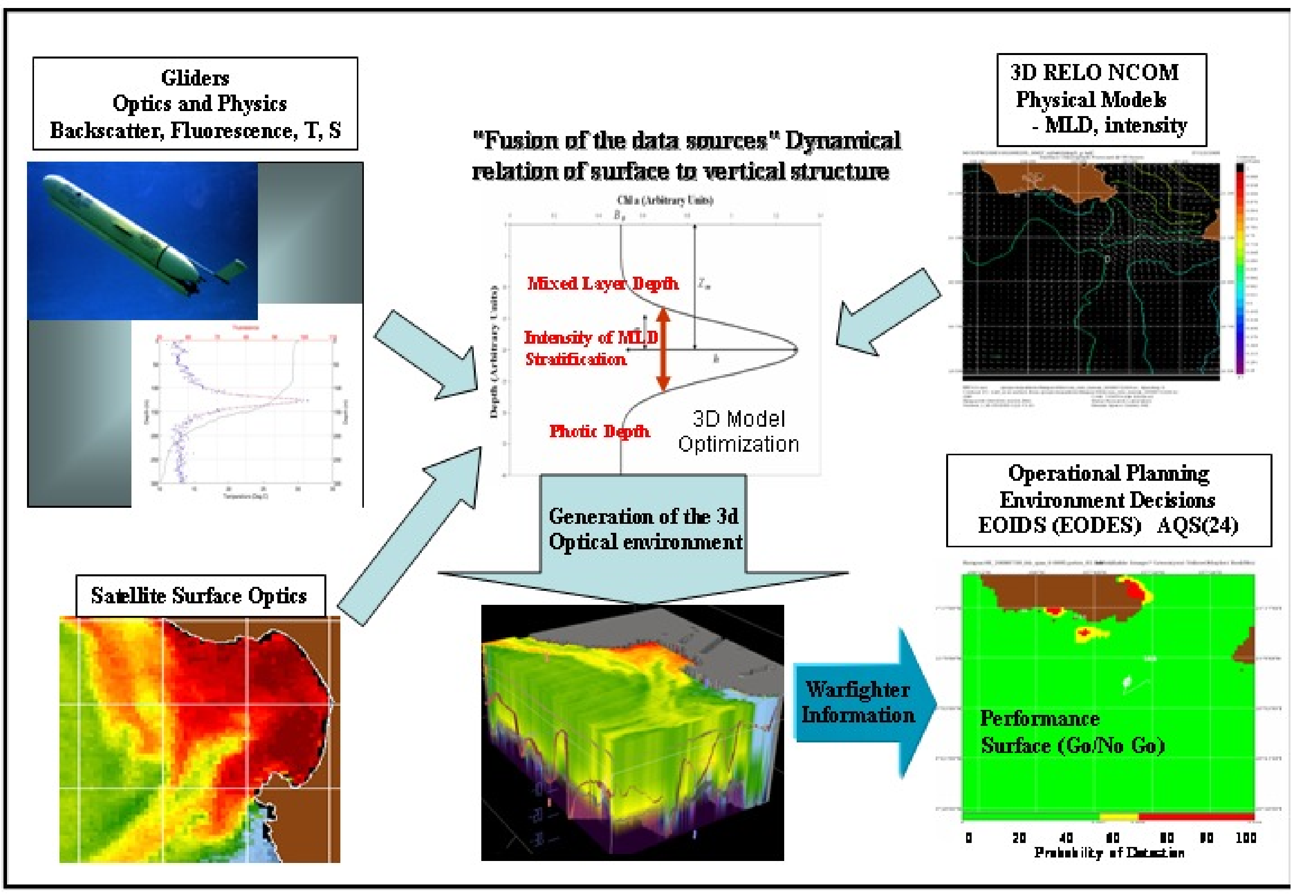

Figure 2. Flow diagram showing the method of fusing glider optics, physical models and satellite surface optical properties resulting in a 3D optical volume that can be used estimate system performance (Arnone, 2009).

RESULTS

The emphasis here is on applications of performance prediction for active underwater EOID systems for Navy MCM operations (Strand 1995). Simulated images from these systems provide a way for tactical decision makers to evaluate the performance of the EOID system being used in operations. The EODES model provides a measure of relative performance using a simplified rating scale patterned after a General Image Quality Equation (GIQE). The performance measure of Image Quality (IQ) is based on a predefined scale using a simple traffic light decision aide of red (no go), yellow (questionable) and green (go) that supplies a level of confidence that a particular EOID sensor will work in the operational area under a specific set of optical conditions. The IQ rating is a function of Ground Sampled Distance (GSD), Relative Edge Response (RER) and Signal-to-Noise Ration (SNR). The EODES image quality metric is a measure of image degradation due to limited resolution (GSD), blurring (RER), and contrast loss and noise (SNR) (Leachtenaur 2001).

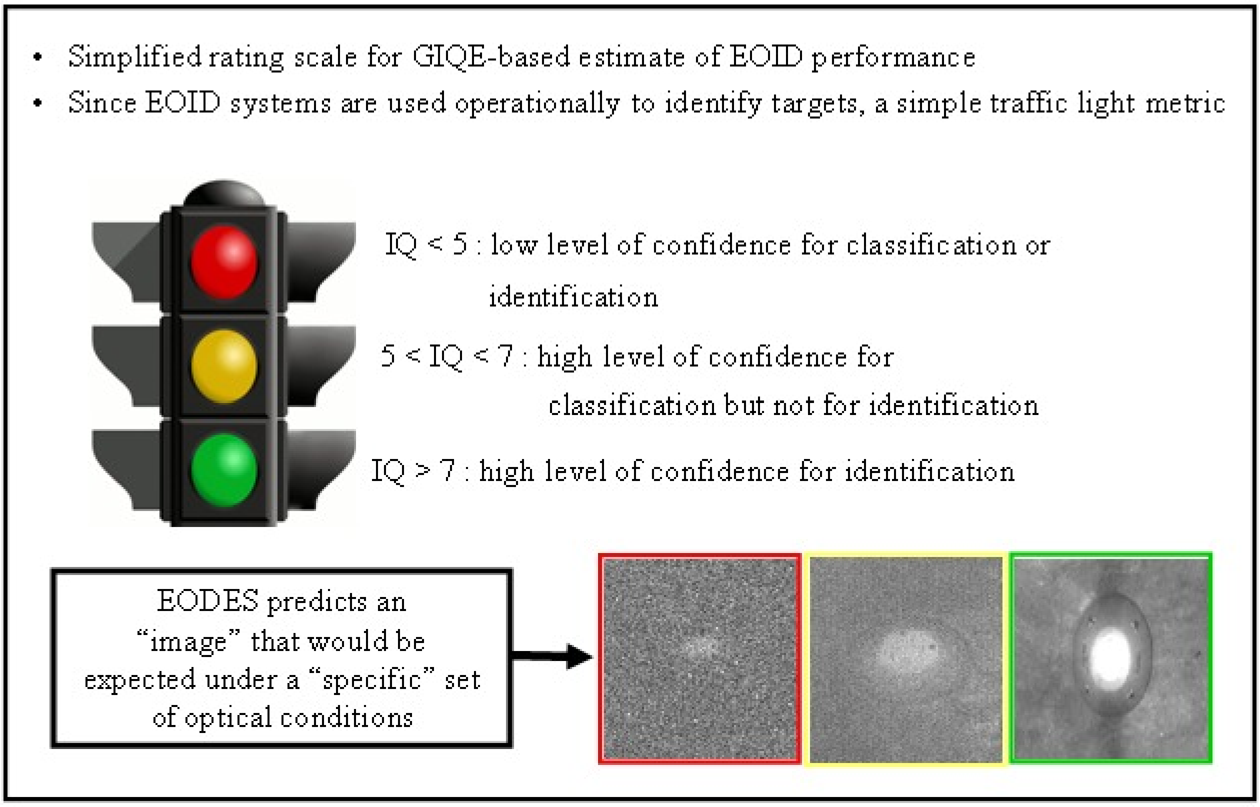

Figure 4. Simplified rating scale (traffic light) used operationally to identify targets using a specific EOID system. Red (Image quality rating less than 5) meaning a low level of confidence for classification or identification of a target. Yellow (Image quality rating between 5 and 7) meaning high level of confidence for classification but not for identification of a target. Green (Image quality rating greater than 7) meaning that there is a high level of confidence for identification of a target (Giddings, 2008).

Optical properties in the operational environment can be highly variable and be the most critical factor in the EOID system performance. The accuracy of the system performance in the operational environment is significant in tactical planning to meet MCM mission objectives. The Naval Research Laboratory has developed a Gaussian model that relates the physical properties of the water column to the optical properties (Arnone 2009). This relationship along with surface optical properties from satellite and physical models is used to derive a 3D optical volume. The following two figures show the procedure of using the 3D optical volume in the EODES model to derive system performance estimates (image quality, optimal towing altitude above the bottom and a go-no-go decision aide) on a pixel-by-pixel basis. Note that modifications were made to the EODES model to ingest the optical volume, i.e. not a single glider profile, and allow the user to skip a specified number of pixels for a more timely execution if necessary.

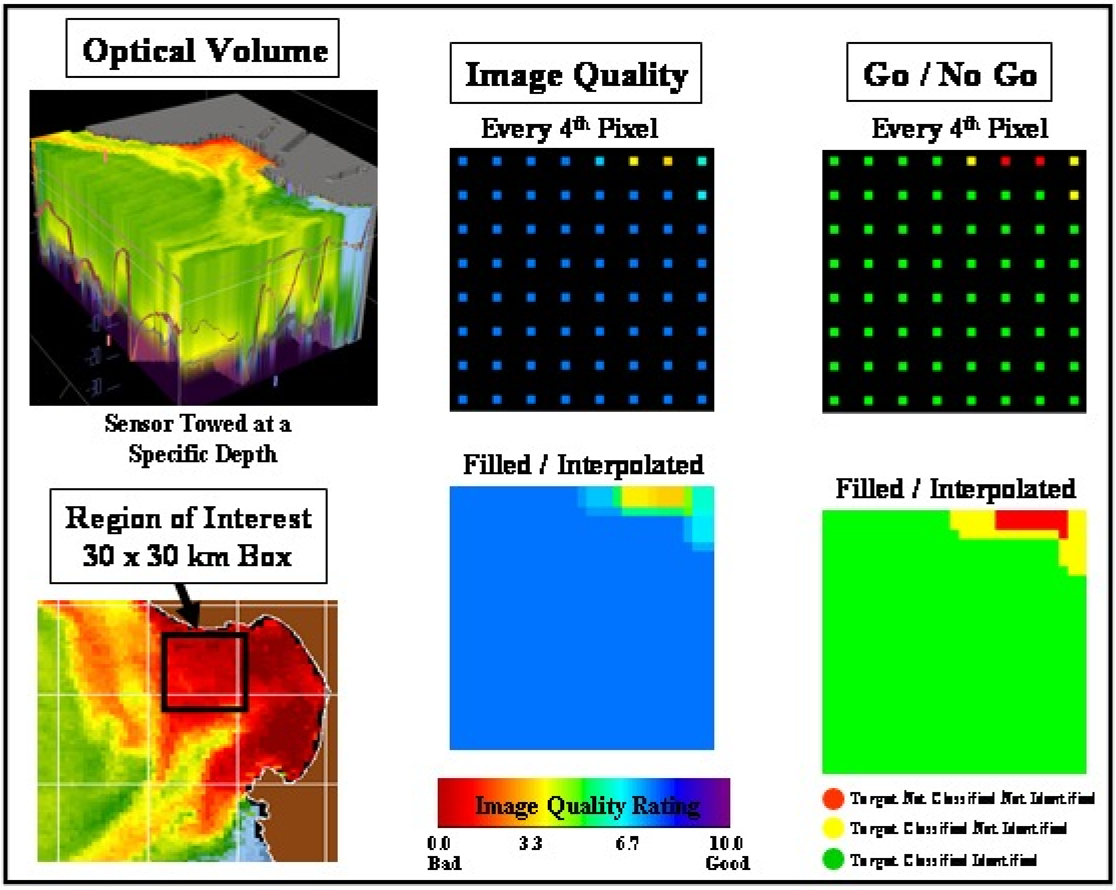

Figure 5. Example showing the image quality rating and decision aide (go or no go traffic light scenario) derived using the EODES model along with a 3D optical environment from satellite. Note that in a timely situation, a number of pixels can be skipped and interpolated to speed up the delivery of the decision aide.

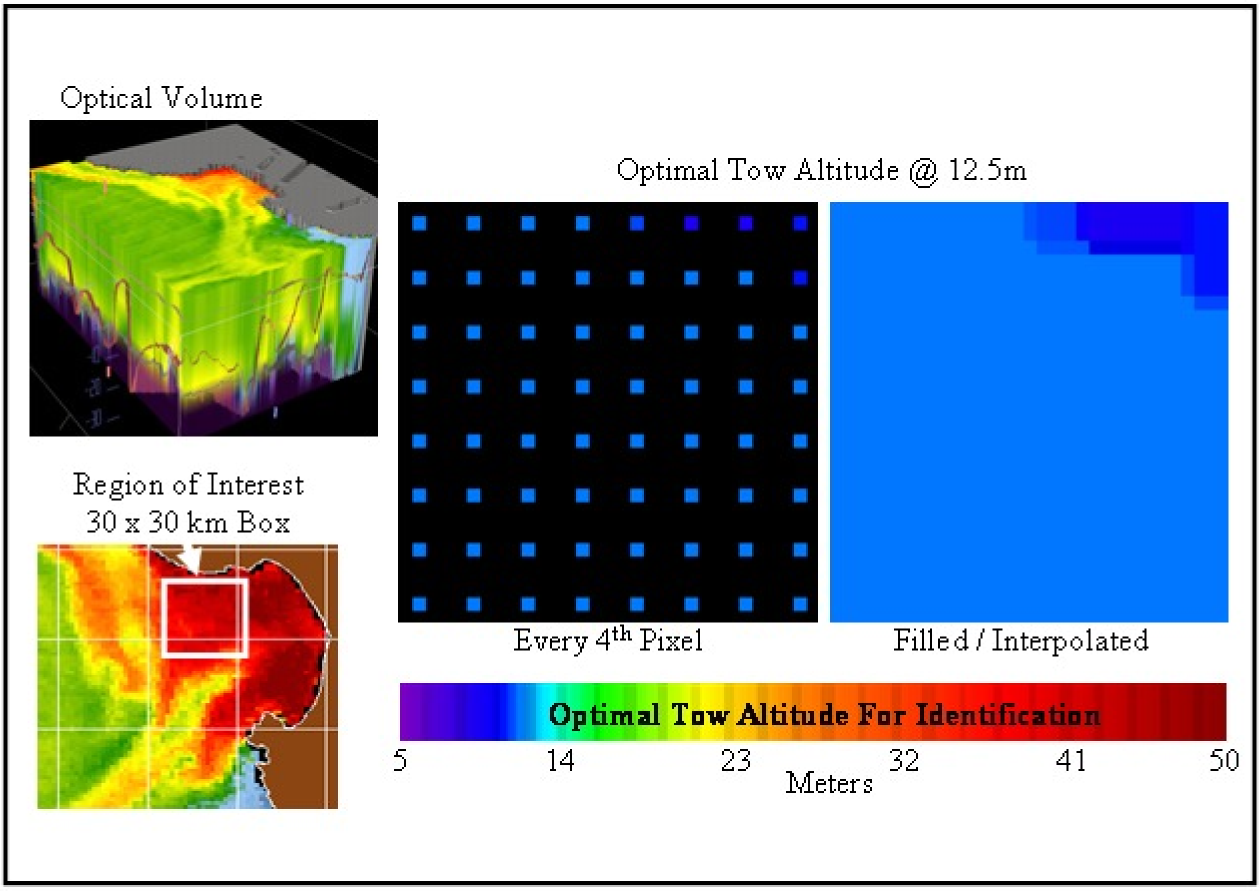

Figure 6. Example showing the optimal towing altitude for target identification derived using the EODES model along with a 3D optical environment. In this case, the optimal towing altitude was around 12.5m above the target.

The statistical uncertainty of the system performance is determined by coupling the EOID performance model with 3D optical volume uncertainties or standard deviation. Physical and optical profiles from gliders are used individually to come up with different physical to optical relationships. A separate set of optimized "coefficients" are derived for each glider profile producing a volume of the entire operational area known as an ensemble. In addition, a single volume is created using an optimal set of coefficients that best describes all glider profiles. Statistics are produced using all ensemble runs to determine the uncertainty of the optical volume in relation to the variance in the vertical optical properties caused by variances in the Mixed Layer Depth location and optical layer strength and location. Knowing the variance of all the optical volumes, i.e. ensembles, yielding an uncertainty estimate of the EOID system performance field provides a new and unique capability for tactical decision makers and Navy Operations.

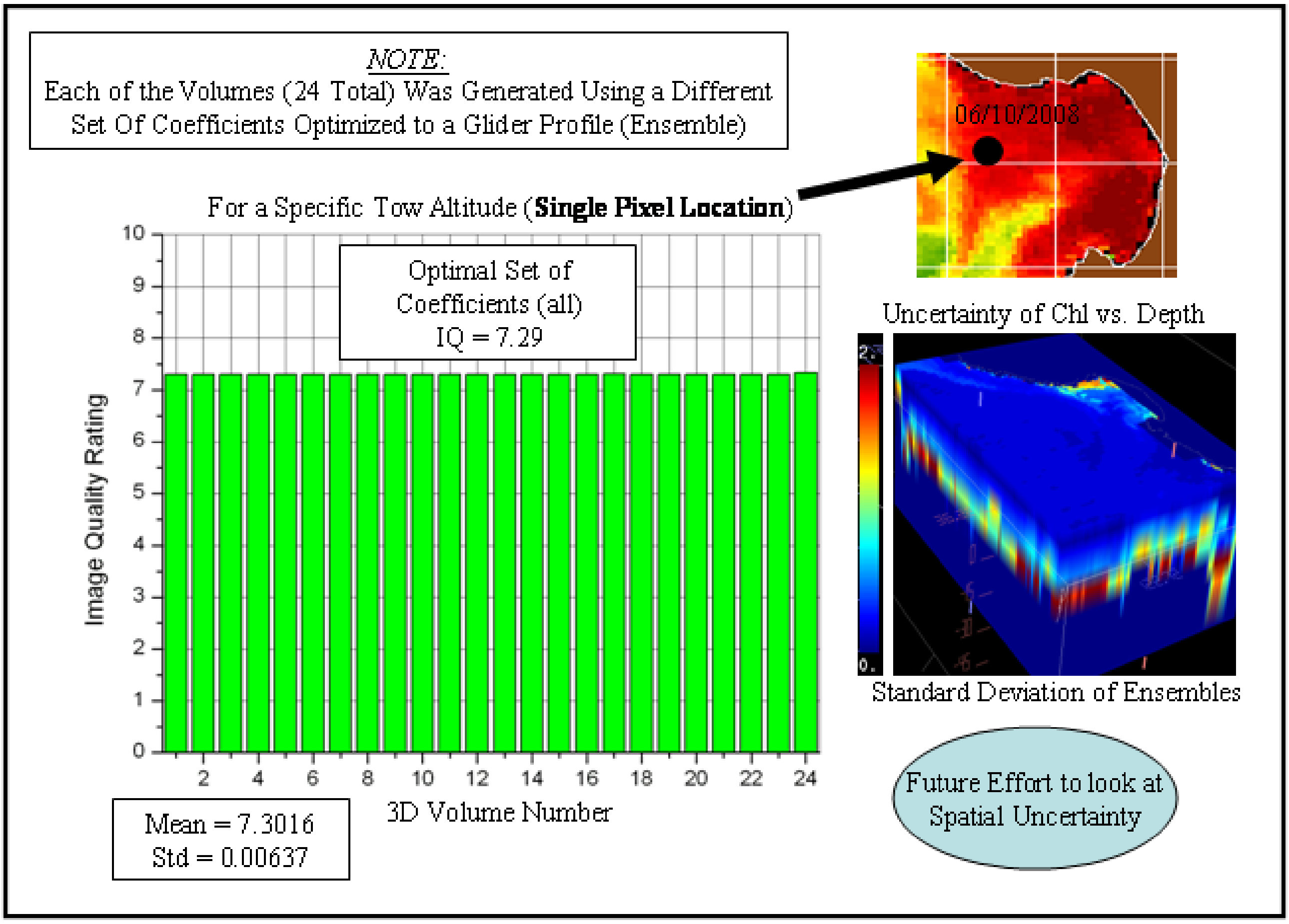

Figure 7. Example showing the uncertainty in the system performance in relation to the statistical standard deviation of all the 3D optical volume ensembles. Note this study is showing the system performance uncertainty for a single pixel location. In this study, the variance of the optical volume has little to no effect on the system performance (Mean IQ = 7.3016, Std = 0.00637). The IQ derived from using the optical set of coefficients for all glider profiles shows a similar result (IQ = 7.29). This result confirms, at this pixel location, that the optimal set of coefficients is sufficient.

CONCLUSION

As a proof-of-concept satellite data merged with glider profiles and numerical models to derive a 3D optical volume can be used to derive tactically relevant products for EOID missions. The capability of knowing when and where EOID sensors will perform will reduce the timeline of MCM missions. Methods used for this study represent a fusion satellite optical properties, glider optical profiles, and physical models to characterize the optical battle space environment.

Knowing that a target can be detected and identified at a specific EOID sensor towing altitude or the optimal towing altitude over a large spatial region is critical. We present a method that extends the capability provided by point measurements from gliders and the satellite surface optics to create a real-time Nowcast of the optical battle space. With increased data from gliders and satellites, uncertainties of the optical environment and system performance can be reduced. Known uncertainties in the EOID performance estimates provide a new and unique capability for tactical decision makers to know when and where to trust EODES system performance estimates. The final goal and future implementation will be to forecast the 3D optical environment using a Eularian advection scheme, and subsequently the EOID performance predictions, in coastal and littoral regions that are of most interest to Navy.

ACKNOWLEDGMENTS

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