Glider Optics and TODS Components in Supporting MIW Applications

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ABSTRACT

In situ data is critical to the understanding of the battlespace environment and related modeling efforts. Unmanned underwater vehicles are becoming an increasingly important platform in oceanographic research and operational oceanography. Profile data collected by ocean gliders require quality control (QC) before assimilation into downstream applications. A unified approach is necessary for consistent data validation and archival, considering the vast amount of data expected from gliders continuously deployed across large areas and over long durations. This presentation discusses the procedures and structures in place to ensure such success, in terms of physical and especially complex optical data, and their storage in Local Automated Glider Editing Routines (LAGER). Other components of the Tactical Ocean Data System (TODS), including optical forecast (OpCast) for forecasting optical environments using satellite observations and circulation models, and 3D optical generator (3DOG) based on optimizing glider observations, are also discussed. Performance prediction, as output of TODS, is presented as a MIW example, as part of the Electro-Optical Identification System (EODES) for AQS 24 mine hunting system.

INTRODUCTION

The capability to sense and monitoring vast areas of the ocean in detail, with accuracy is of vital interests to Navy applications, including mine warfare (MIW) and anti-submarine warfare (ASW). One of the key obstacles in operational oceanography is difficulties associated with sampling and measurements in the field, due to lack of easy access to the vast areas of the ocean which covers approximately 70% of the planet surface. Remote sensing techniques, both active and passive, especially those from space, have been proven to offer synoptic surface coverage with adequate accuracy, when sensors are calibrated and validated correctly with help from in situ measurements, while the effects of atmosphere are also estimated correctly. Even so, such signals are heavily weighted, thus biased towards the features from the surface layer. Ocean circulation models offer much needed 3-dimentionality to the mix, that allow the features extending beyond the surface layers, on top of the 2D synoptic coverage. With the initial boundary conditions properly determined, which can be obtained from *in situ* measurements and satellite observations, the 4th dimensionality, or forecast, can be included in the framework. This philosophy has been realized in the Tactical Ocean Data System (TODS) framework.

Traditional ship-based ocean research sampling techniques are still widely used today. Advances have been made in great stride recently by numerous *in situ* observation systems on moorings, buoys, floats, flow-through sensors, unmanned underwater vehicles (UUVs), such as gliders,

autonomous underwater vehicles (AUVs), and remotely operated Vehicles (ROVs), integrated sensor networks, and observatories. These are vibrant research and development areas and generate the most accurate three-dimensional (3D) data available, often in real-time, and are less affected by adverse conditions. However, spot sampling lacks the rapid, broad coverage that are critical in high-level, real-time operational decision making. *In situ* observations at times are not available for unsafe or denied-access environments. Remote sensing techniques can be used to fill the needs, when precise protocols are in place to maintain data coherence and accuracy. Further, modern defense and security needs demand that accurate information be provided when and where it is needed (e.g. Battlespace on Demand, BonD). Ocean sensing must provide not only timely and accurate data, but also offer insights regarding overall 3D and future – or forecasted-environmental conditions. The combined use of *in situ* observations, remotely sensed data, and physical models is a rapidly evolving field, although improved assimilation of available data into models still poses a challenge. The ability to sense, integrate, and predict is vital in establishing a true real-time, four-dimensional (4D) cube of verified and validated information for ocean nowcast and forecast, as shown in Figure 1, in terms of Tactical Ocean Data System (TODS). We see that glider observations provide critical input to one of the key elements in BonD tier 0 structure.

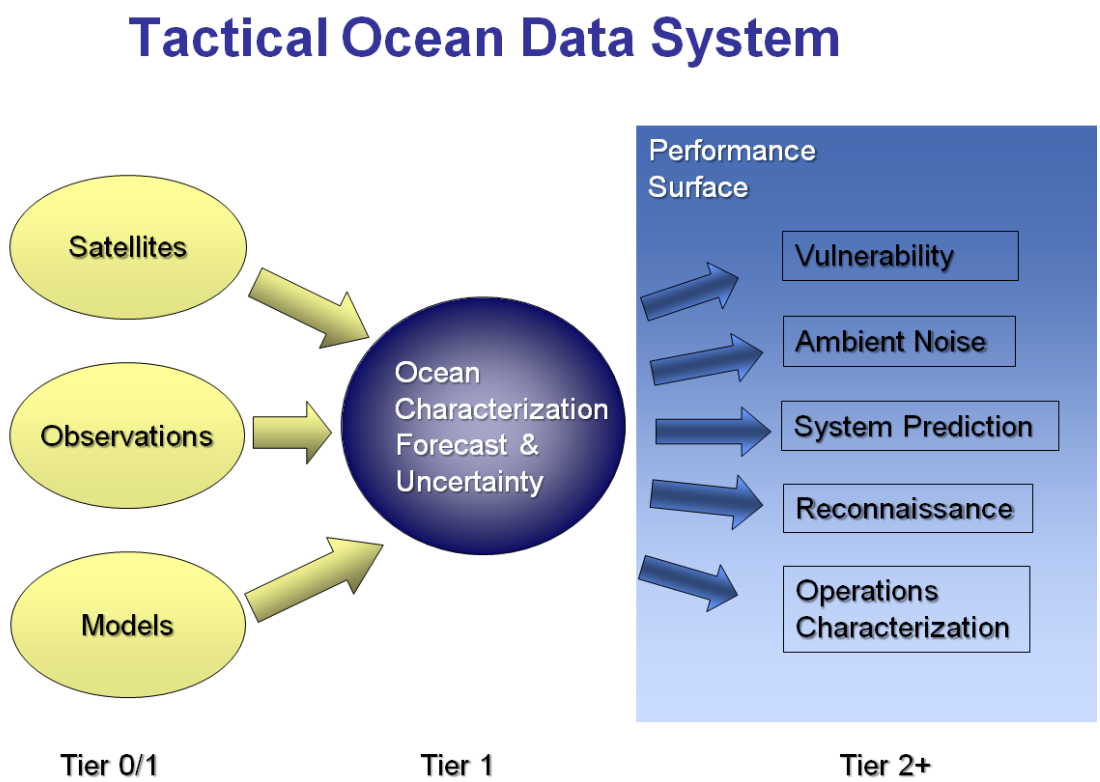

Figure 1. Tactical Ocean Data System (TODS) component chart.

Glider observations provide inputs that are not only limited to localized or spot events, but are also capable of long-range, long-term, in-depth data throughout the water column. One good example is the recent 7-month voyage by a Rutgers University Slocum glider crossing the Atlantic Ocean, sampling the ocean structures along the way. The vast data stream generated by gliders contains a

wealth of much needed information for topics discussed above. Automated QC and analysis of these data is the only way for the timely assimilation to models and the framework above.

This paper describes the capabilities of glider optical measurements at the Naval Research Lab (NRL) and the Naval Oceanographic Office (NAVOCEANO), efforts associated with the development of automated optics QC processes, along with TODS components (OpCast and 3D optics) in supporting MIW applications.

GLIDER OPTICS MEASUREMENTS AND PROCESSING

To answer the needs of MIW, ASW, safety of navigation, monitoring global climate change, and battlespace environment sensing, optical sensors have been fitted and tested on different types of gliders, and have proven successful in assessing optical conditions in a variety of water masses. These sensors provide inputs for optimizing ocean optical models used to generate and forecast electro-optical identification (EOID) performance surfaces, diver visibility and asset vulnerability products, which can aid in tactical decision making during fleet operations (Figure 1).

Name	Description	Units	Typical value	Range	Resolution (step)	possible channel #s	Bandwidth (nm)	Instruments
bb	backscatter	m^{-1}	0.004	0~0.1	0.0001	<255	30	bb2f,bb3slo
Ed	Irradiance	wm^{-2}	10	0~500	0.1	<512	10	OCR504/7I (*)
c	beam attenuation	m^{-1}	0.2	0~100	0.01	<255	10	BAM (x)
b	Scattering	m^{-1}	0.1	0~100	0.01	<255	10	AUVb
vis	visibility	m	10	0.1~100	0.1	<255	-	AUVb,SAM, BAM
PAR	photo. avail. rad.	mEinstein. m^{-2}	100	0~2500	1	<255	-	ECO-PAR (x)
Fl-chl	[Chlorophyll-a]	mg m^{-3}	0.5	0~100	0.01	470/695	10	bb2f,fl3
Fl-phyco	phycoerythrin	ppb	0.05	0~100	0.005	540/570	10	fl3
Fl-cdom	color dissolved	ppb QS	2	0~2000	0.1	370/460	10/70	bb2f,fl3

Table 1. NRL/NAVOCEANO glider optical parameters table.

An automated QC process for optical measurements from gliders is designed and implemented, as part of the Local Automated Glider Editing Routine (LAGER) [1][2]. The optical algorithms are used to process data from available glider optical sensors (Table 1), including instruments that measure the beam attenuation coefficient (c), the total scattering coefficient (b), the backscatter coefficient (b_b), the fluorescence returns and thus derived concentrations of chlorophyll, *phycoerythrin*, and colored dissolved organic matter (CDOM), downwelling irradiance (E_d), phytosynthetically available radiation (PAR), and other derived optical parameters, such as diver visibility (Table 1). All current optical sensors, including the ECO series from Wetlabs (bb2f, bb2slo, fl3, SAM, BAM, AUVb, ECO-PAR), and OCR504/7 from Satlantic, are embedded in the current version, with flexibility built in to allow for expansion to meet future needs, such as firmware and data format change. Additionally, Table 1 outlines the typical range, resolution,

bandwidth, and channel limits of the optical sensors, which are used in the LAGER Optics routines and will be discussed in later sections. The data flow can be viewed as a 5-step process, with the inclusion of optics, as shown in Figure 2. Notice that the process can be enabled such that all data will be (1) sent to manual editing, (2) physical parameter processing only, (3) or physical and optical parameters combined.

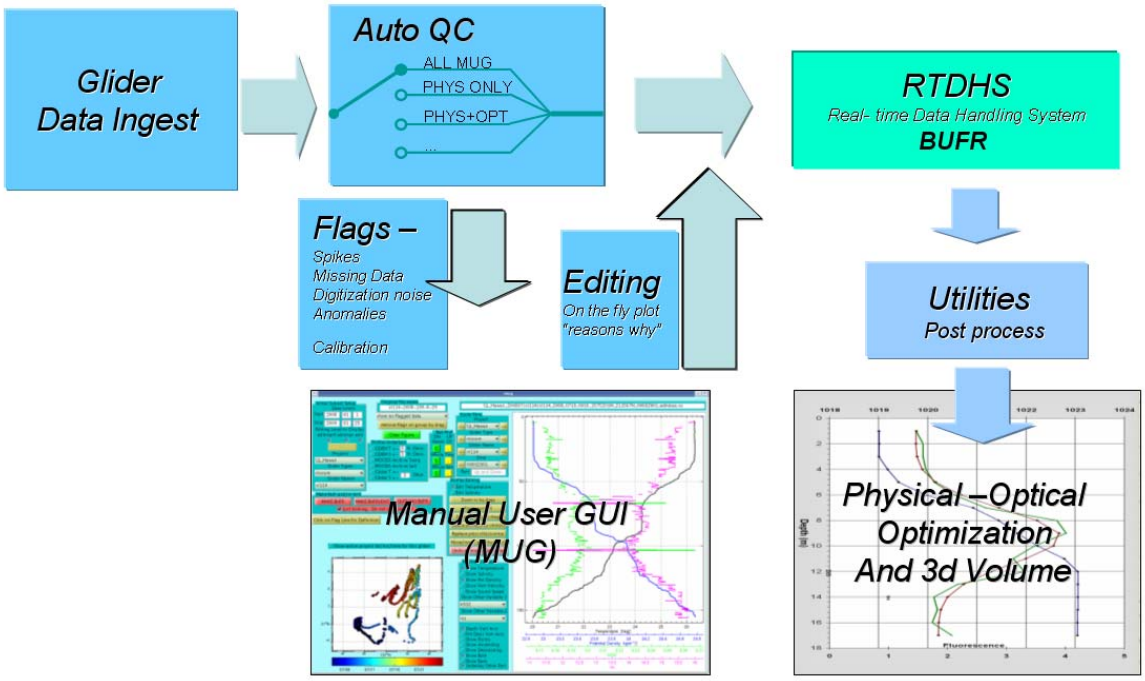

Figure 2. Data flow chart of LAGER Optics.

Glider data ingest module reads in real-time raw data at the NAVOCEANO Glider Operation Center (GOC), and converts to Network Common Data Form (NetCDF) format. Automated QC is the key step in LAGER Optics. It uses flags to classify different types of erroneous data points and the combined quality of the flags determines whether Manual User GUI (MUG) is needed for closer inspection. The resulting data is then sent to the database in a binary universal format for representing meteorological data (BUFR) format required by the real-time data handling system (RTDHS) at NAVOCEANO [4].

The automated optical QC program structure can be found in [2] [4]. Briefly, QC tests for optical variables implemented in LAGER, follow certain algorithms and conventions for detecting and flagging bad data that were developed for processing the physical variables, such as the temperature (T), and the salinity (S). However, because of the multiplicity of optics variable types and frequency bands, a 2D variable array structure is used in contrast to the 1D vector approach used individually for T and S. The reader is referred to [1] for details of the physical data QC implementation. Two of the physical QC algorithms implemented in LAGER are used with minor adaptations for the Optics QC (OQC). These are the global bounds check and the spike test. The latter defines a spike to be a single datum departing significantly from its neighboring values (single-point spike). It has the

additional feature of being able to detect such a spike in the presence of a gradient (as a function of depth) of the relevant hydrographic or optical variable. Since segments of anomalous optical data may span several data points, a method to detect these cases, in the form of a running standard deviation filter, is also included in the OQC. This filter finds and flags data that depart significantly in value from a local mean computed inside a 'running' window (depth interval) that is moved through the entire sampled depth range of the profile. In addition to the variable value range check, the depth of each sample point is also checked and 'chopped' short, if necessary, to eliminate values that appear to lie above, or too close to the surface, where processes such as wind waves and bubbles could make optical measurements, such as backscattering and downwelling irradiance, either invalid or difficult to interpret reliably. If this depth is shallower than a given depth (default 1 m), or is negative, the variable value is flagged accordingly. A constant profile check is also done to determine if the values for a particular optics variable are constant throughout the sampled depth range, which was proven critical in assessing real-time electro-optical sensor performance, such as those during the RIMPAC 2008 exercise [3]. This might occur for a variety of reasons, such as instrument sampling faults, or sensor contamination, which suggest the data are invalid.

The above automated QC routines are in place and have been tested under different conditions, using data from different types of gliders. The results [2] show that under the most complicated situations, involving complexities associated with data transmission as well as environmental variability, as much as 30% of profiles require manual examination by operators. The failure rate in detection of bad profiles is less than 0.4% of the profiles examined, which is associated with sparseness of the data, and single point spikes likely due to subsurface optical layers.

OPCAST

Optical forecast is needed for naval operations to support Navy diving operations and MIW mine hunting system performance prediction. The OpCast software is aimed for "Forecasting the Coastal Optical Properties using Satellite Ocean Color". This forecasting capability is using Navy Coastal Ocean Model (NCOM) and satellite imagery from the Automated Processing System (APS). Satellite ocean color has been providing a monitoring capability for bio-optical properties in coastal regions using several ocean color sensors for decades. Applications of these data for operations and researchers are limited by coverage and the ability to "forecast" the changing conditions. We examine the capability to couple satellite bio-optical properties with physical forecast circulation models to provide a "real-time" prediction of 24 hour bio-optical distribution along coastal regions. A real-time and long term evaluation of the optical forecast is assessed by comparison with the next day imagery. The forecast is based on Eulerian advection which does not account for biological and optical degradation and growth processes. However, for near real-time (~ 24 hours) coastal applications, this assumption appears valid and provides a new capability for planning and coastal management.

For validation of the forecast products, the 24-hour forecast was compared to the actual image that came in the next day. Figure 5 shows the comparison and validation of forecast backscattering (551nm) for Oct 20, 2009. Figure 5a. shows the 24 hour forecast. Figure 5b. is from MODIS imagery on Oct 20, 2009, and includes clouds and atmospheric correction failures. Figure 5c. shows the difference between the observation from the Moderate Resolution Imaging Spectroradiometer

(MODIS) and 24h forecast output for valid retrievals only. White areas are zero difference, red areas are over-estimation and blue areas indicate underestimated values. The black indicates the area of no data (ND) due to the contaminated pixels, i.e. clouds, glint, algorithm failures including those in atmospheric correction.

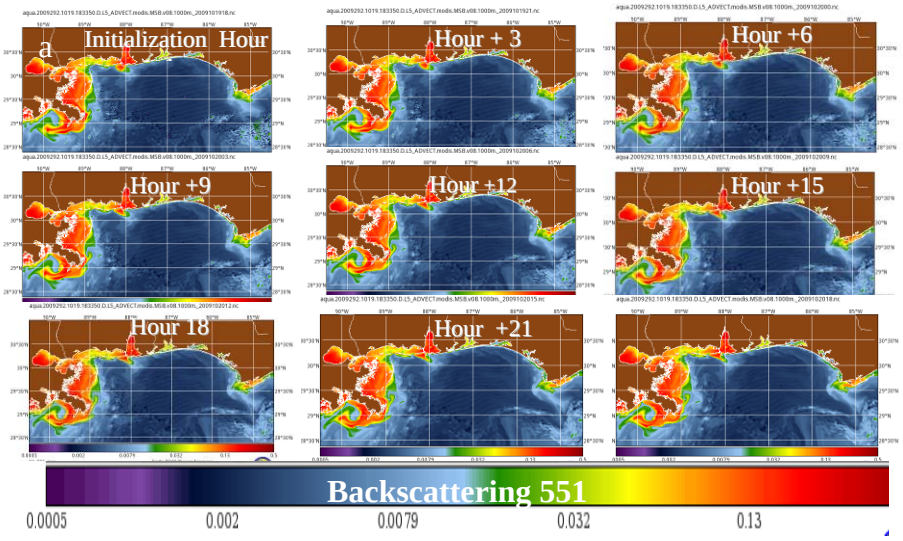

Figure 3. Examples of OpCast for the MS Bight show the progression of the optical properties, using backscattering at 551nm.

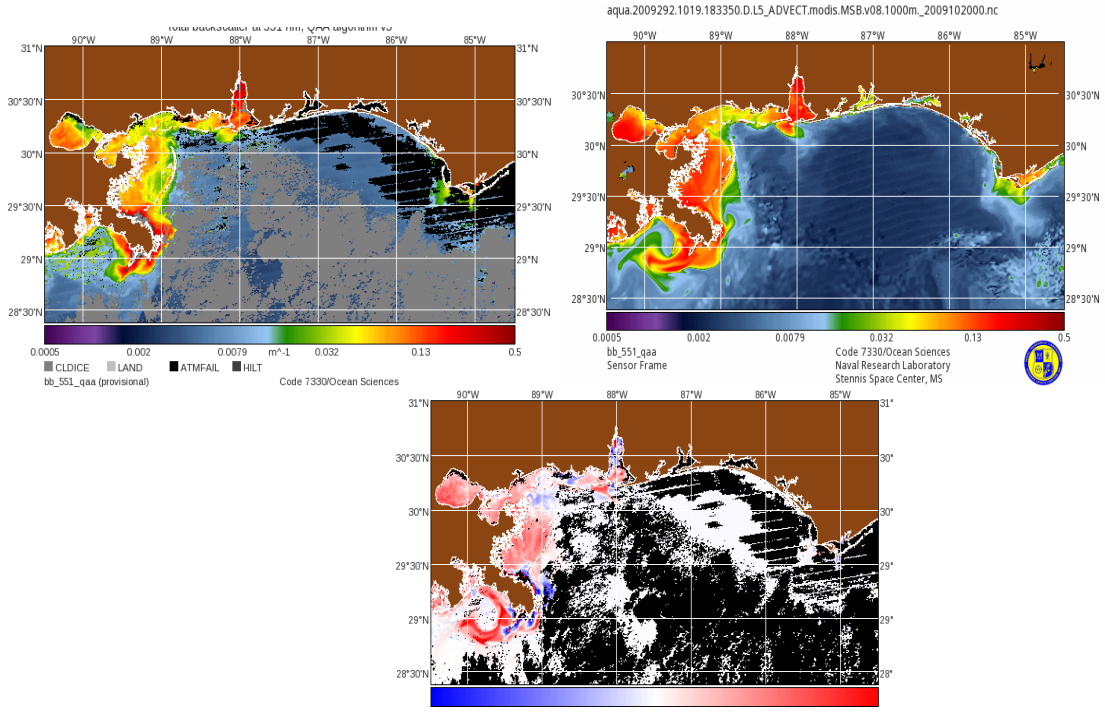

Figure 4. Comparison of OpCast output and satellite observations.

OPTIMIZATION AND 3D OPTICAL VOLUME

3DOG is developed to provide a real time characterization of the optical environment. This will be used to define the MCM performance surface for specific laser systems. The software requires inputs from:

1) Glider profiles of optical and physical properties which we obtain from the optical LAGER processing (below) which are being driven by NAVOCEANO.
2) Satellite surface bio-optical properties and 1% light level from MODIS and the medium-spectral resolution, imaging spectrometer (MERIS) which are generated by the APS software that is transitioned to NAVOCEANO Ocean Measurement Department.
3) NCOM – model fields of vertical density and temperature fields.

The procedure to develop a 3d optical volume is illustrated below in Figure 5. The first step (red lines) is to develop the region specific coefficients which are derived based on the optimization of gliders and satellite data. The second step (black) is to use these coefficients with the surface satellite optics and the 3d physical NCOM models which yield density, mixed layer depth, intensity of mixed layer depth, and upwelling/downwelling radiance to generate the 3d optical volume.

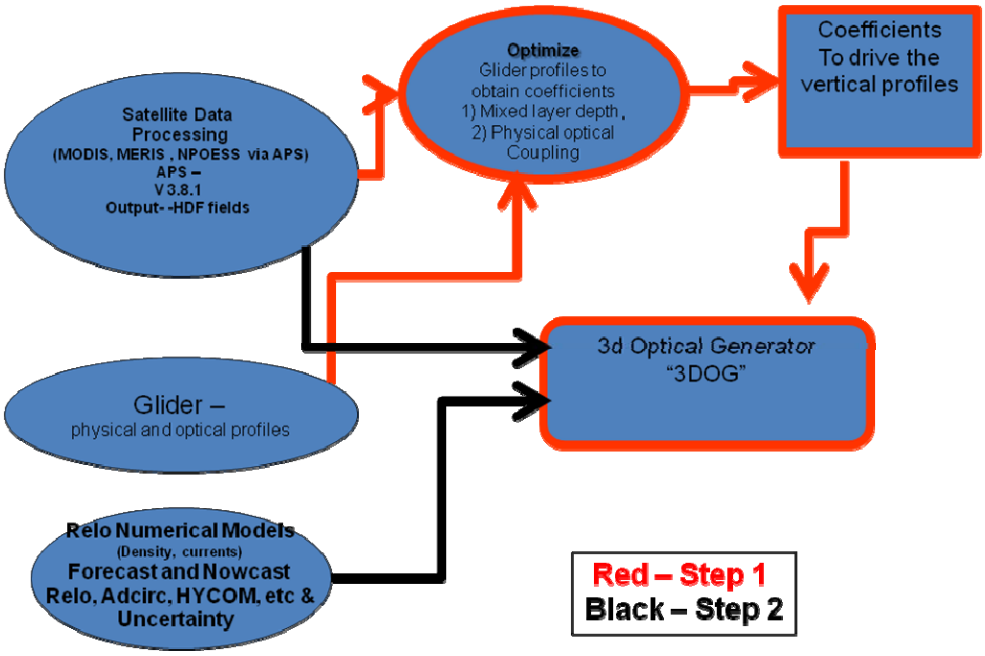

Figure 5 Flow chart of 3DOG.

The coefficients from the optimization code are used with the 3DOG software to generate a 3-dimentional optical volume. This software is written in IDL and has inputs:

1) NetCDF from NCOM to determine the Mixed layer depth and the intensity of the mixed layer depth (IMLD) for each grid location using the same Brunt-Vaisala Frequency (BVF)

[1] and Temperature thresholds as the optimization obtained from ASCII file generated from optimization code.

2) The satellite bio-optical property of chlorophyll or backscattering and the 1% light level at each grid location.

3DOG takes these inputs and the coefficients from the optimization and constrains the surface bio-optical field using the satellite optical properties as truth. The vertical profiles are constrained over the first attenuation length and not to exceed the 1% light level depth. Examples are shown in Figure 6.

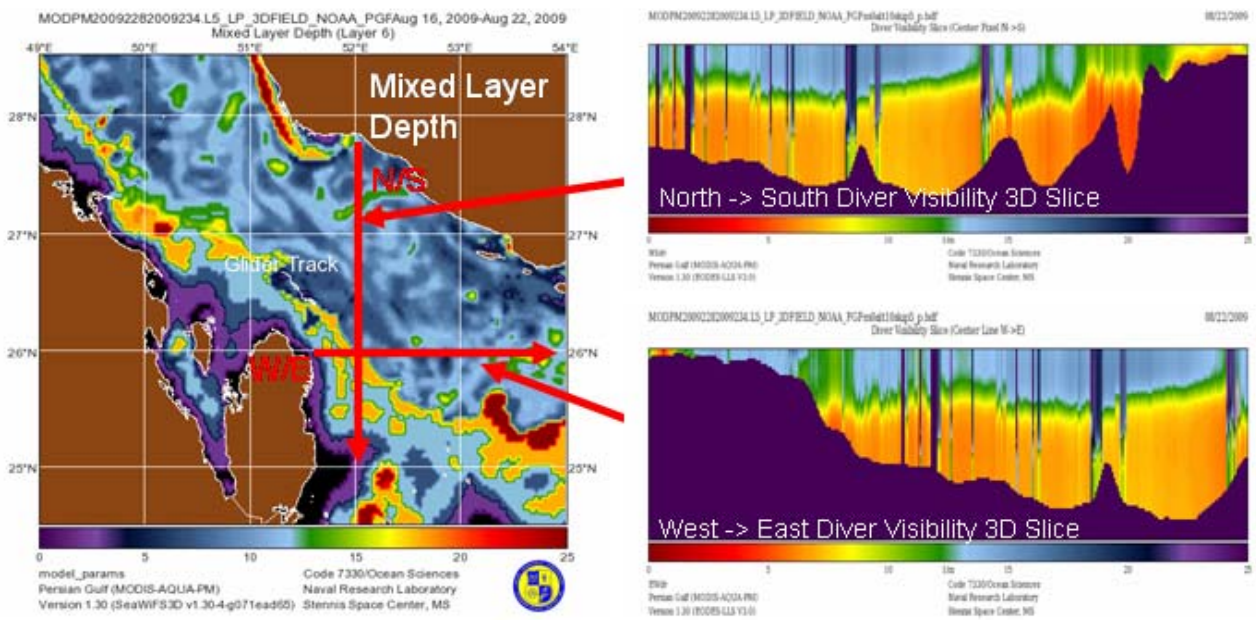

Figure 6. Example image of the derived Mixed Layer Depth with 3D slices of Diver Visibility along North to South and West to East Transects (Red Lines).

The 3d bio-optical data volume has been integrated in the Electro-Optical Identification System (EODES v3.0) developed by Metron Inc [3], which defines the performance field of a underwater laser mine hunting system. The inputs to the EODES model are the vertical profile of the optical properties including the beam attenuation coefficient, backscattering coefficient, system specifications, and tow altitude above bottom or desired probability of identification. The outputs of the EODES model include image quality of a target image and optimal towing altitude to detect and identify subsurface objects under defined optical conditions given by the 3d optical volume. These outputs provide methods to determine where and the optimal height above the bottom to tow the AQS 24 mine hunting system. The 3DOG volume has been linked to the EODES model to create a 2D performance field showing regions where targets of interests cannot be identified (red), possible identification (yellow), and positively identified (green), as illustrated by examples in in Figure 7. The EODES software was modified to allow the user to run the system performance model skipping (n) pixels in the image to cut down on computation time it takes to generate the performance field. In

addition, an option was added to allow the user to specify a smaller box inside the image grid for performance estimates to allow for timely support. This has been utilized to support field exercises such as RIMPAC 08 [3].

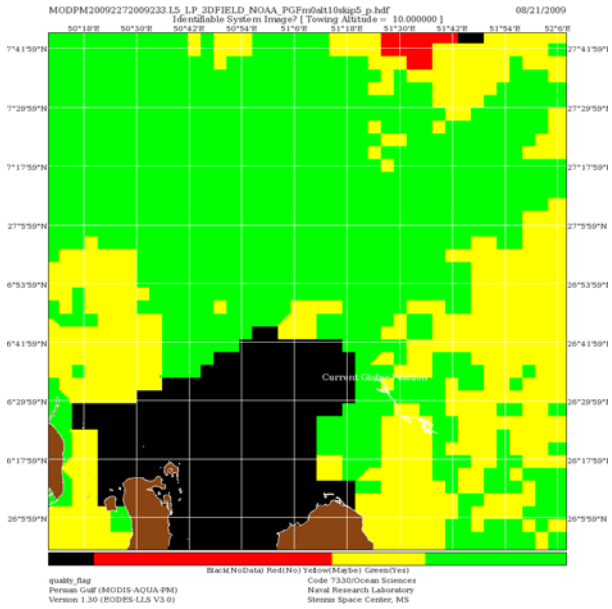

Figure 7. 2D Performance Field (Red = No Target Identification, Yellow = Possible Target Identification, and Green = Target Identified

SUMMARY

Glider optical measurements provide critical input to establish an accurate optical ocean sensing and forecasting system, that fuses observations from satellite remote sensing sensors and outputs from ocean circulation models. Together, a 4D verified data cube can be utilized in real-time operational MIW decision making. An automated glider optics QC package is needed to handle large the volume of input data, while it outputs much needed information for downstream optical products, including 3D optimization. When combined with OpCast, it allows performance surface predictions for electro-optical identification (EOID) sensors.

REFERENCES

[1] M. Carnes, LAGER Manual (Local Automated Glider Editing Routine) Version 1.0, (2008)

[2] W. Hou, D. Burrage, M. Carnes, R. Arnone, Development and Testing of Local Automated Glider Editing Routine for Optical Data Quality Control, NRL MR 7330--10-9247, (2010)

[3] K. Mahoney, K. Grembowicz, B. Bricker, S. Crossland, D. Bryant, M. Torres, T. Giddings, RIMPAC 08: Naval Oceanographic Office glider operations, Ocean Sensing and Monitoring. Edited by (Will) Hou, Weilin. Proceedings of the SPIE, Volume 7317 (2009)., pp. 731706-731706-11 (2009).

[4] Hou, W., Carnes, M., Burrage, D., Arnone, B., Weidemann, A., Bryant, D., Grembowicz, K., Mangin, S. R., Mahoney, K., Torres, M., "Glider optical measurements and proposed BUFR format for data QC and storage" in Ocean Sensing and Monitoring II, edited by Weilin (Will) Hou, Robert A. Arnone, Proceedings of SPIE Vol. 7678 (SPIE, Bellingham, WA 2010) 76780F.