Verification and Validation of NASA-Supported Enhancements to the Near Real Time Harmful Algal Blooms Observing System (HABSOS)

Version 3.2

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Executive Summary

This report discusses verification and validation (V&V) assessment of Moderate Resolution Imaging Spectroradiometer (MODIS) ocean data products contributed by the Naval Research Laboratory (NRL) and Applied Coherent Technologies (ACT) Corporation to National Oceanic Atmospheric Administration's (NOAA) Near Real Time (NRT) Harmful Algal BloomS Observing System (HABSOS). HABSOS is a maturing decision support tool (DST) used by NOAA and its partners involved with coastal and public health management.

In 1999, NOAA began providing nowcasts and forecasts of harmful algal blooms (HABs) through the HAB Bulletin, which became operational as the HAB Forecast System in 2004. The need to distribute the background data was recognized, as well as the ability to conduct retrospective analyses of HAB events. HABSOS was originally developed in 2001 to address these needs. HABSOS started as a system for managing, integrating, and communicating historic data pertaining to the Gulf of Mexico. HABSOS was expanded in 2004 to include two Internet map server (IMS) systems: one system for historic HAB data and one system for NRT HAB data. The NRT HABSOS includes a wealth of NRT environmental information from the NRL and ACT Corporation, including MODIS ocean data products, Navy Coastal Ocean Model (NCOM) modeling output, and multitemporal animation products from the fusion of MODIS and NCOM output. The NRT HABSOS may provide a comparable test bed with potential for improving the NOAA HAB Bulletin.

This V&V study aimed to assess how the MODIS ocean data products compare to product metadata specifications and how the NRL MODIS data product enhancement of the NRT HABSOS meets the needs of HABSOS end-users. In the process, a literature review and interviews of HABSOS Federal agency developers were performed to assess available information on end-user requirements. All available metadata were reviewed and assessed for completeness as a precursor for verifying how MODIS data products resident to the NRT HABSOS compare to product specifications. MODIS data products were also validated against perceived known end-user requirements. Efforts were also made to characterize parameters not specified in the metadata yet important to HABSOS end-users.

NRT HABSOS end-users include coastal and public health managers, as well as those involved with the development of decision-making information products, such as geospatial models used in HAB detection, monitoring, forecast warning, and other kinds of modeling. Some end-users need a HAB geospatial data visualization capability, whereas others need access to actual data output for use in modeling. HABSOS end-users vary in their ability to understand and exploit the potential of remote sensing data products in HAB mapping applications. Some HABSOS end-users perform state-of-the-art advanced oceanographic information extraction from satellite imagery, although most end-users are novice- to intermediate-level users of remote sensing ocean data products.

The results of the V&V analysis indicate that the MODIS ocean data products generally compare well to the metadata, although not all of the desired product specification variables are included in the metadata. For example, accuracy of the NRT HABSOS MODIS data products is not specified in the metadata, presumably due to the research or provisional status of such products. The metadata also did not include information on atmospheric correction, an important pre-processing step in developing accurate ocean data products from satellite imagery.

The V&V study also enabled several recommendations on how to improve the NRL MODIS data product enhancements to the NRT HABSOS. Efforts should be made to provide additional information on the potential of individual MODIS ocean data products for aiding HAB mapping applications. HAB modelers need MODIS ocean data products to be downloadable as pseudocolor imagery, preferably in floating

point format. The inclusion of real time or NRT in-situ HAB data would greatly enhance the utility of the NRT HABSOS MODIS ocean data products. HAB modelers need a means to download such data as well to exploit MODIS ocean data products more effectively.

The NRT HABSOS is impressive from the geospatial data visualization standpoint, although the software lacks a means to interactively swipe one image data product across another—a feature commonly available with commercial–off-the-shelf (COTS) remote sensing and geographic information system (GIS) desktop computer software. COTS and open-source GIS freeware packages are becoming better equipped to incorporate multitemporal animation products as a layer in a two-dimensional or three-dimensional GIS. Once the ESRI® ArcIMS® software can accommodate the NRL fusion animation products derived from MODIS and NCOM output, such products should be directly integrated into HABSOS instead of being hyperlinked. The NRL, ACT Corporation, and NOAA should also provide additional metadata on the MODIS data products resident to the NRT HABSOS, including more information on atmospheric correction and thematic map accuracy.

The NRL produces MODIS ocean data products that are not currently resident to the NRT HABSOS but that may have utility in HAB applications. Based on available literature, additional NRL-developed MODIS data products should be considered for HABSOS inclusion. In addition, NASA-developed MODIS fluorescence image data products that have been shown to be useful for HAB detection and assessment should also be considered for inclusion into HABSOS.

This study did not directly employ end-users involved with real-world HAB applications. A follow-up study may be needed using real end-users to help evaluate the NRT HABSOS once subsequent improvements are made, based on recommendations given herein.

1.0 Introduction

The Harmful Algal Blooms Observing System (HABSOS) is a decision support tool (DST) maintained by the National Oceanic and Atmospheric Administration (NOAA) to aid public health and coastal management of harmful algal bloom (HAB) events in the Gulf of Mexico. HABSOS began in 2001 as an interagency effort for managing and communicating geospatial HAB environmental data pertaining to the Gulf of Mexico. Doing so required contributions of several Federal and State agencies to the NOAA HAB data repository. Mexican states along the Gulf of Mexico have also contributed data to HABSOS, though to a lesser extent. HABSOS integrates various input data into a common geographic information system (GIS) readable format and then allows end-users to visualize and query these data using commercial Internet GIS technology. In doing so, HAB and other environmental resource management professionals can exploit HABSOS for specific mapping applications, such as HAB event assessment, forecasting, monitoring, mitigation, and management. HABSOS gives its end-users an enhanced ability to assess environmental conditions surrounding HAB events as they occur and may ultimately be useful for developing HAB forecast models with quantitative probabilities.

NOAA's National Coastal Data Development Center (NCDDC) oversees the development and maintenance of HABSOS, including public- and controlled-access HABSOS Web sites. Coastal and public health managers access the suite of HABSOS Web sites at http://www.ncddc.noaa.gov/habsos (NCDDC, 2006a). HABSOS enables state managers to enter HAB data in real or near-real time. HABSOS includes two Internet GIS mapping systems: an Internet map server (IMS) for historic HAB data and a comparable system for near-real-time (NRT) HAB environmental data. Both of these systems deploy ESRI® ArcIMS® software and include in-situ baseline geographic data on static features of the Gulf, in-situ oceanographic data, in-situ data on HAB cell counts, meteorological model data, and Moderate Resolution Imaging Spectroradiometer (MODIS) satellite image data products depicting assorted environmental surface parameters. The Naval Research Laboratory (NRL) produces the MODIS products in conjunction with the Applied Coherent Technologies (ACT) Corporation as part of a Research, Education, and Applications Solutions Network (REASoN) project that is supported by NASA. The NRL posts daily MODIS ocean color and sea surface temperature (SST) data products on the NRT HABSOS IMS.

HABSOS is one example of an emerging DST in which NASA contributions (data, models, and expertise) may lead to improved decision making by Federal and State government agencies. Implementation is a multi-step process: 1) evaluation of the DST for potential of NASA contribution; 2) verification and validation (V&V) of the NASA contribution to the DST; and 3) benchmarking of the NASA contribution to the DST (see Appendix B.1 for additional information).

This report documents an effort to verify and validate the degree to which MODIS ocean data products enhance the NRT HABSOS IMS DST. In doing so, it discusses the NRT HABSOS IMS before and after infusion of MODIS data products, methods for conducting V&V analyses, results of the V&V analyses, conclusions, and recommendations for future work.

2.0 Description of NRT HABSOS Internet Mapping System

This section describes the NRT HABSOS Internet Mapping System, before and after the infusion of NASA MODIS ocean data products being developed and posted by the NRL and ACT Corporation.

2.1 HABSOS IMS Prior to NRL MODIS Production Integration and NRT Capabilities

The Environmental Protection Agency (EPA) and NOAA led the initial effort to develop HABSOS as a pilot project, which ran from 2001 through 2004. This initial effort regarded development of a Gulf of Mexico HABSOS for historic HAB data. Several publications discuss the pilot HABSOS effort, including those by Malone (2001), Fisher et al. (2003), Pennock et al. (2004), and NOAA CSC (2005).

For the initial HABSOS, NOAA NCDDC integrated environmental HAB data donated by the states of Alabama, Florida, Louisiana, Mississippi, and Texas. NOAA collected, converted, and georegistered all relevant data into common standard formats for compatibility with ArcIMS. Once built, the IMS was made available to the HAB management community at large, including Federal and State employees working to develop HAB prediction, forecasting, transport modeling, and monitoring capabilities.

The initial HABSOS effort included Gulf of Mexico case studies to assess trends in environmental conditions for select years with prolific (1996 and 2000) as well as scarce (1997) HAB occurrence. Such case studies aided the development of remote sensing techniques now used in producing the HAB Bulletin, NOAA's DST for alerting state managers about HAB threats. The effort focused on the West Shelf of South Florida, where red tide creates havoc nearly every year. According to Culver (2003), the HAB Bulletins can predict favorable conditions for red tide in southwest Florida with an estimated success rate of 80 percent or more in the summer and fall. Such promising results helped NOAA to transition the HAB Bulletin from research to operational status as of fall 2004.

The HAB Bulletin has shown that satellite-based HAB environmental information can be useful for assessing when and where HABs may occur. However, HAB managers still need better forecasting capabilities to improve management decision-making. Additional new remote sensing ocean data products and new modeling techniques will improve HAB forecasting accuracy from both a user and a producer prospective. However, assimilation of such products into HAB forecasting involves not only integrated product research and development, but also V&V of such products.

The initial HABSOS IMS for historic HAB data helped to identify and to develop the technologies needed for HAB forecasting. However, the IMS did not include current data, which is needed most for HAB forecasting. Consequently, the HABSOS team developed a NRT IMS for HAB environmental data. This prototypical NRT HABSOS IMS was developed during the closing months of the HABSOS pilot study described above. The initial NRT system included in-situ data from buoys and boats, meteorological and oceanographic modeling data, satellite data depicting chlorophyll concentration from the Sea-viewing Wide Field-of-view Sensor (SeaWiFS), and wind speed and direction from the Quick Scatterometer (QuikSCAT) SeaWinds sensor. From the outset, the NRT IMS included a few satellite remote sensing data products. The University of South Florida provided the chlorophyll remote sensing data products, while the NRT IMS QuikSCAT data products came from NASA's Jet Propulsion Laboratory (JPL) Physical Oceanography Distributed Active Archive Center (DAAC).

2.2 NRT HABSOS IMS After NRL MODIS Production Integration

In the summer of 2004, NOAA NCDDC expanded the NRT HABSOS system to include a broader range of satellite ocean data products (Mesick, 2004). This expansion occurred through partnership with NASA, the NRL, and the ACT Corporation. Over the past decade, the NRL has worked with NASA and others in the oceanographic community to produce a comprehensive suite of satellite-based ocean color and SST data products, including those generated from the MODIS Aqua and Terra satellite data. Starting in 2003, the NRL partnered with ACT Corporation in a reimbursable Space Act Agreement with NASA to develop MODIS ocean data products and product delivery services (see Appendix A). Part of the ACT/NRL

REASoN project involves producing NRT MODIS ocean color and SST products and posting these products on the NRL Web site, from which the products are subsequently posted on the NRT HABSOS IMS. NOAA NCDDC integrates such products with other environmental HAB data from satellites, buoys, boats, and model runs. Figure 1 depicts the data flow into HABSOS, showing where the data is integrated and served outward to the HAB end-user community via the Internet.

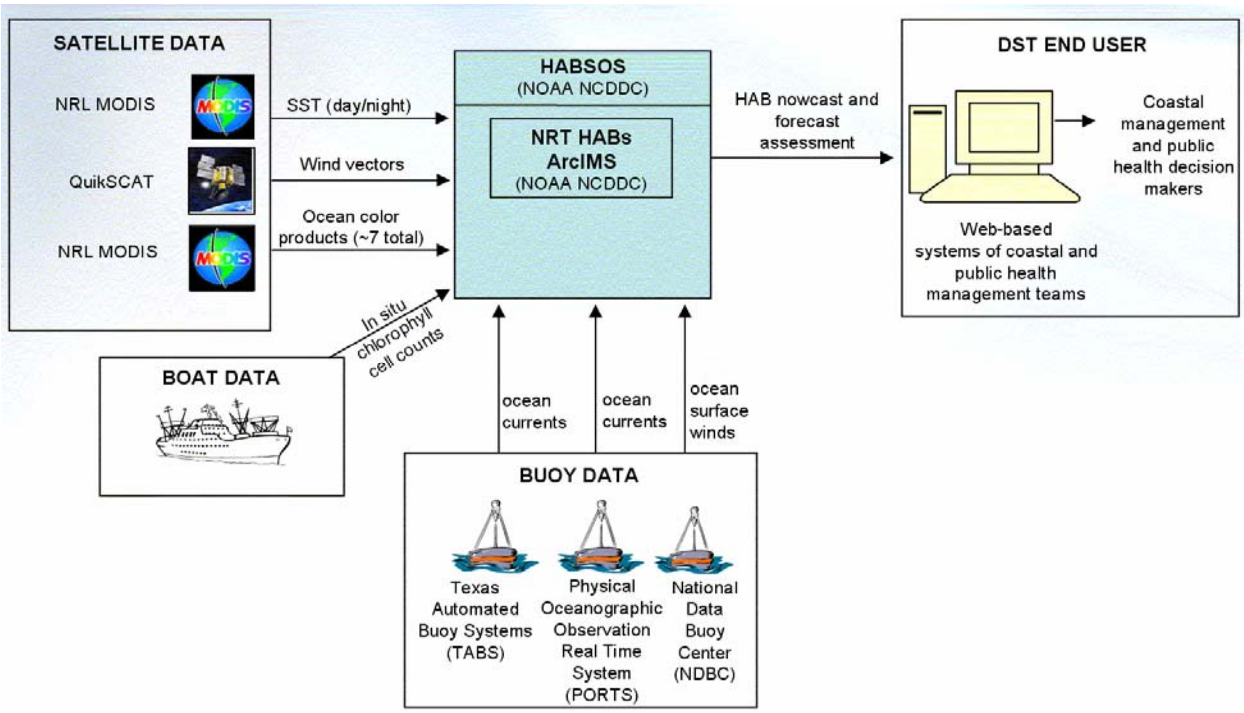

Figure 1. Generalized flow of data to and from NRT HABSOS IMS.

NOAA's NCDDC compiles and integrates several datasets and also provides and maintains the system architecture for the NRT HABSOS IMS. Depending on the data type, input HAB environmental data to this IMS is refreshed daily to weekly. Older data is reformatted and sent to NOAA's National Oceanographic Data Center for archival (Mesick, 2004). Currently the NRT HABSOS IMS does not include NRT in-situ HAB data or satellite-based image products predicting HAB phytoplankton concentration. The HABSOS system will include in-situ HAB cell counts once the NOAA Coastal Services Center Harmful Algal Blooms Mapping System (HABMapS) is folded into the NRT HABSOS IMS as discussed by NOAA in the 2004 HABSOS/Gulf of Mexico Coastal Ocean Observing System (GCOOS) Workshop (NOAA CSC, 2005).

While NOAA leads the HABSOS development effort, several State and Federal agencies also contribute data, models, and expertise. Federal agency partners include the EPA, NRL, and NASA. State partners provide most of the in-situ data regarding HAB events. Because HABs occur in Florida almost annually, the Florida Fish and Wildlife Research Unit constitutes one of the most important state agency contributors to HABSOS and has effectively monitored and managed HAB events in Florida coastal waters for over 25 years.

To date, the NRT HABSOS system has incorporated several NRL MODIS products, including eight MODIS ocean color and two SST data products (Table 1). NOAA NCDDC pulls these products from a NRL Web site on a daily basis. As new MODIS data products are posted in HABSOS, the old data products are removed from the IMS and are archived. NOAA CSC (2005) considers the current system to be an operational prototype, with the implication that facets of the system will eventually be adopted for operational applications, such as the GCOOS discussed by Malone (2004), Spinrad (2004), and NOAA CSC (2005). Note that the NRL MODIS ocean data products in the NRT HABSOS are a subset of the NRL data products (see Appendix E). Information on ocean color terminology can be found in Appendix B.2.

Table 1. NRL MODIS ocean data products resident to the NRT HABSOS IMS system.

Assigned Product Number	NRL MODIS Ocean Data Product Description
1	Total absorption at 443 nm (7-day latest pixel composite (LPC))
2	Absorption from color dissolved organic matter (CDOM) at 412 nm (7-day LPC)
3	Absorption from phytoplankton at 443 nm (7-day LPC)
4	Backward scattering at 555 nm (7-day LPC)
5	Chlorophyll-a (7-day LPC)
6	Turbidity (7-day LPC – Only For Mississippi Bight)
7	Latency (day) (Date of latest cloud-free pixel value for 7-day time frame)
8	Latency (night) (Date of latest cloud–free pixel value for 7-day time frame)
9	Sea Surface Temperature (day) (7-day LPC)
10	Sea Surface Temperature (night) (7-day LPC)

At this time, the capability of the NRT HABSOS IMS is new, still developing, and under evaluation by the DST end-users. End-users who are not remote-sensing savvy have a low awareness about the actual and potential HAB information value of MODIS products posted in the NRT HABSOS, such as posting of basic metadata for each geospatial data layer, including the MODIS data products.

3.0 Methods for V&V of MODIS Product Assimilation into the NRT HABSOS IMS

NASA's Engineering & Science and Project Directorates includes efforts to enhance decision support tools with NASA remote sensing data products, model, and expertise. NASA works to enhance DSTs by using system engineering principles and practices. The enhancement of a DST with remote sensing data products includes the following processes: 1) evaluation of the DST and its potential for enhancement with NASA contributions; 2) V&V of the enhanced DST compared to the DST before NASA enhancement; and 3) benchmarking of the NASA-enhanced DST.

Ideally, the V&V component includes systematic characterizations of product specifications and end-user requirements. It addresses whether the products are as advertised and whether these products fit the needs of the end-users. The ability to conduct DST V&V assessments can be limited by the maturity of the DST. However, by applying the V&V processes to an immature DST, the resulting information can help to accelerate the maturity of the DST. See Appendix B.1 for a glossary of standard V&V terminology.

The V&V first step assessed NRT HABSOS IMS end-user requirements with a focus on NOAA, EPA, and state agency HABSOS end-users' needs for HAB management and mitigation (e.g., detecting, monitoring, modeling, prediction, and forecasting). The V&V second step assessed the NASA remote sensing products being used to enhance the DST (NRL-developed MODIS ocean data products) and how such products may contribute to HABSOS applications and end-user decision-making capabilities.

HABSOS includes two general categories of MODIS ocean data products now integrated into the NRT IMS: 1) daily refreshed still-frame MODIS ocean data products of specific environmental parameters, and 2) animations of multi-temporal MODIS chlorophyll still frames merged with oceanographic model data.

V&V analysis was performed for each MODIS still-frame product to ensure that product parameters were documented, measured as feasible, and validated against metadata. All of the NRL MODIS still-frame products in the NRT HABSOS IMS have corresponding metadata that can be downloaded using the IMS graphical user interface (GUI). The metadata was used in part to develop summary tables describing the MODIS data products resident to the NRT HABSOS IMS. Individual MODIS data products were also queried and visualized using the HABSOS DST (Figure 2). Analysts also employed the NRT HABSOS IMS to view MODIS ocean data products in relation to other geospatial data in the GIS (Appendix D lists all geospatial data in the IMS). In addition, analysts downloaded examples of each MODIS data product from the NRL source Web site used by NOAA (http://cobalt.nrlssc.navy.mil:8000/dods-bin/nph-dods/browse/lvl4/blended). The NCDDC employs this Web site to refresh the NRT HABSOS IMS usually on a daily basis. MODIS products downloaded from the NRL were subsequently imported into ERDAS IMAGINE® software to verify product specifications against metadata supplied by the NRL to the NCDDC. In addition, each product was further described in a systematic manner in terms of additional image quality parameters not given in the metadata yet obtainable from other sources.

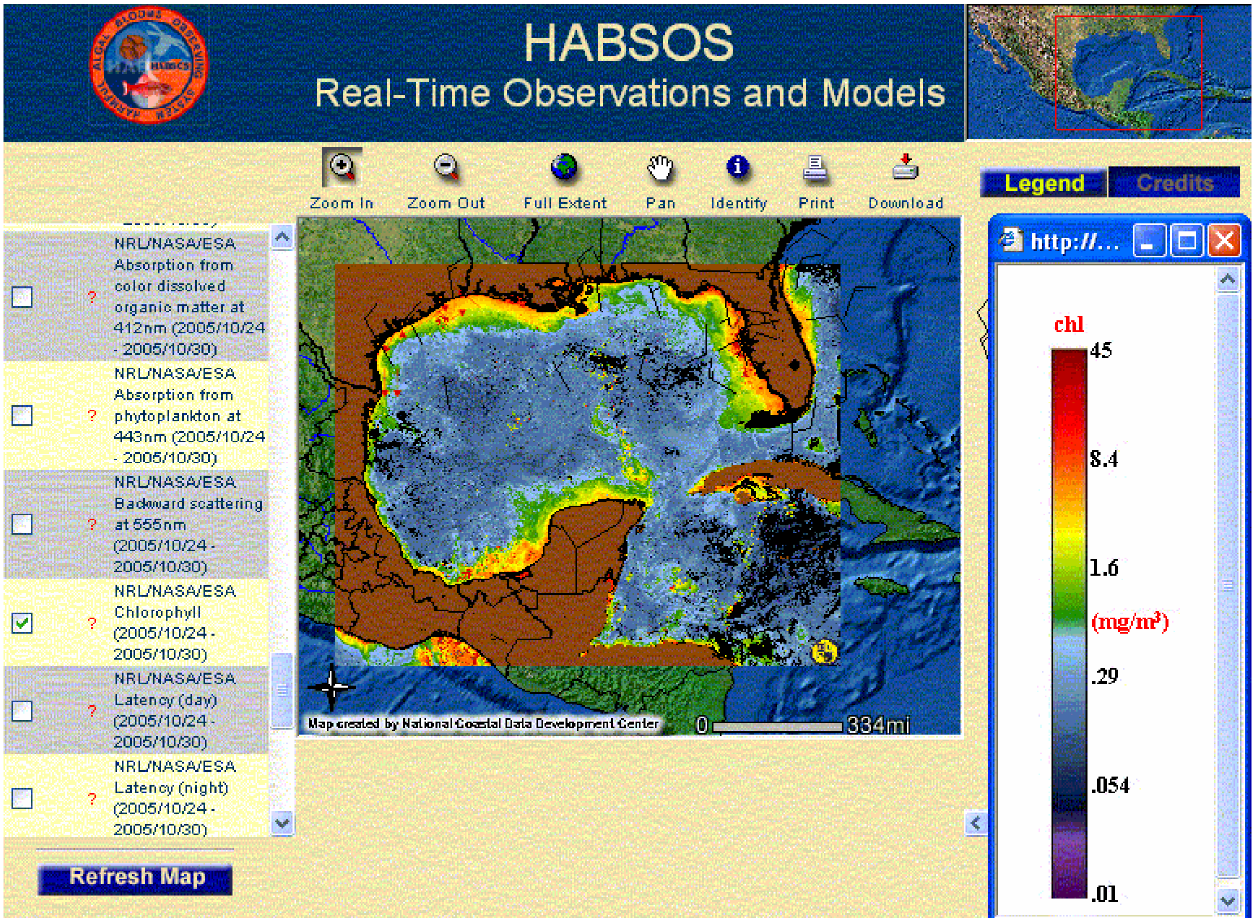

Figure 2. NRT HABSOS display with NRL MODIS chlorophyll product in foreground.

MODIS still-frame products were also compared to standard products being used by NOAA to develop HAB Bulletins, which typically employ chlorophyll products generated by NOAA CoastWatch from SeaWiFS satellite data. The HAB Bulletin also employs SST data products generated from the NOAA Advanced Very High Resolution Radiometer (AVHRR) satellite data produced by NOAA CoastWatch. The HABSOS IMS for historic HAB data also uses these NOAA standard satellite SST and chlorophyll products.

The V&V analyses considered all MODIS ocean data products currently in the NRT HABSOS system, which includes the ArcIMS component described above as well as a component for viewing multitemporal movies of oceanographic conditions derived in part from MODIS data products.

Additional V&V analysis was conducted to assess multi-frame animation products of MODIS chlorophyll imagery fused with oceanographic modeling output from the Navy Coastal Ocean Model (NCOM) (Figure 3). Such products regard a sequential series of still-frame data merges of MODIS chlorophyll containing a latitude-longitude grid, ocean circulation flow direction, sea surface salinity (SSS), and sea surface elevation (SSE) also shown as overlain vectors, with each still frame of the chlorophyll concentration representing the latest cloud-free pixel composite from a 7-day time sequence. Example animations were assessed quantitatively and qualitatively for potential in assessing HAB movement and transport.

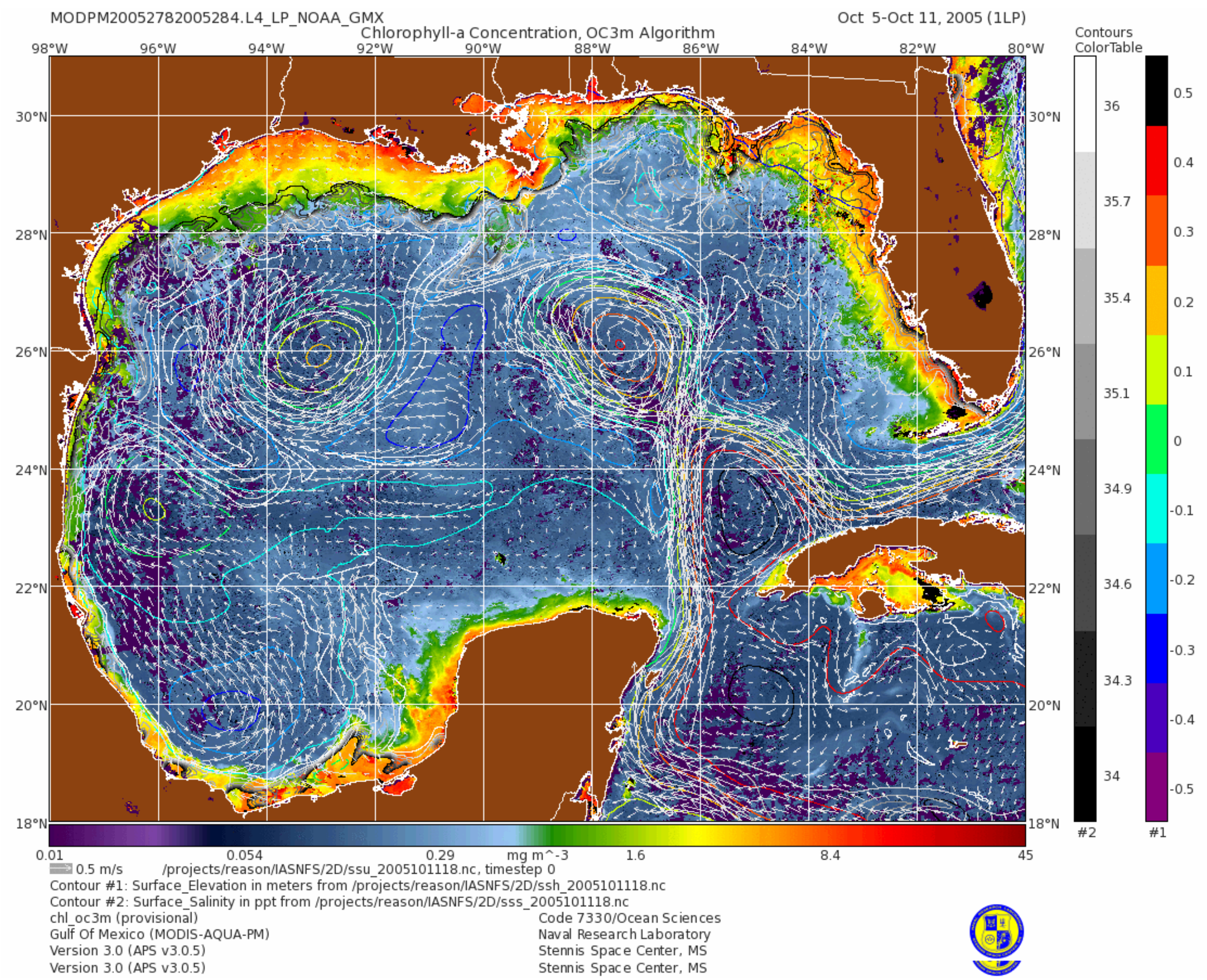

Figure 3. NRT HABSOS display of NRL MODIS/NCOM fusion animation product.

Software and hardware (e.g., data volume) requirements were documented for replicating the NRT HABSOS IMS with the NRL MODIS product feed. The product delivery time was quantified and assessed to document the average time frame from retrieval of MODIS data by the NRL to posting of NRL MODIS products.

4.0 Results of V&V Analyses

The V&V of the NRL MODIS products within the NRT HABSOS is discussed in terms of the following subsections: 1) Summary of HABSOS End-user Requirements; 2) Characterization of Still Frame MODIS Data Product Inputs to the NRT HABSOS IMS; and 3) V&V Analysis for Multitemporal MODIS/NCOM Fusion Animation Products Resident to the NRT HABSOS IMS.

4.1 Summary of HABSOS End-user Requirements

End-users of the NRT HABSOS system vary by organizational representation and need. The primary end-users work for Federal and State agencies responsible for monitoring, managing, and mitigating HAB events in relation to affected coastal communities and industries. This group includes coastal and public health managers. HABSOS stakeholders can be assessed by viewing the list of pilot project participants on the HABSOS Web site (see Appendix F). HABSOS end users also include researchers working to develop and refine techniques for HAB event detection, prediction forecasting, and monitoring (Appendix B.3 provides HAB forecasting terminology). It was not possible to obtain a detailed, quantitative summary on the population of actual HABSOS end-users, though efforts were made to do so. By law, NOAA is restricted in using the HABSOS Web site to collect this kind of information (Sharon Mesick (NOAA), personal communication). However, much basic information on the HABSOS end-user community can be gleaned from several workshops related to HABSOS (NOAA CSC, 1997; NOAA et al., 2000; GMPO, 2003; and NOAA CSC, 2005).

The HABSOS end-user community needs an up-to-date, integrated, GIS-based ocean observation system with real-time and near-real-time HAB environmental data sufficient to enable improved means to detect, predict, forecast, and monitor HAB events. Since its initiation in 2001, HABSOS has functioned as a test bed for HAB managers and researchers to apply and assess the HAB geospatial data and GIS technologies for HAB mapping applications. The HABSOS IMS development initially focused on historic HAB data that was applied to HAB hindcasting studies. Lessons learned from the HABSOS IMS for historic data aided NOAA in developing HAB event prediction, mapping, and monitoring techniques. In this way, HABSOS has contributed to the development of the HAB Bulletin into an operational DST. NASA, NOAA, and NRL collaborators on the NRT HABSOS project believe the contribution of NRL MODIS ocean data products will help to further improve HAB related mapping and decision support by enabling satellite, in-situ data, and modeling results to be integrated and posted in near real time (McPherson and Beard, 2005; Friedl and Hall, 2005).

4.2 Characterization of NRL MODIS Still-Frame Data Products within NRT HABSOS IMS

The NRT HABSOS IMS presently includes 10 NRL-contributed MODIS ocean data products listed in Table 1. These products constitute the only satellite-based synoptic mapping products resident to HABSOS, other than QuikSCAT wind speed and direction data products. HABSOS offers a wealth of additional environmental data collected by in-situ observation or by modeling estimates. A complete list of all GIS data layers resident to the NRT HABSOS IMS is located in Appendix D.

NRL MODIS product descriptions and specification verification results are given in Table 2. This table describes 32 product parameters for 10 corresponding NRL MODIS products. These results focused on the metadata and the physical characteristics of the examples for each MODIS data product posted in the NRT HABSOS IMS. When feasible, metadata product specifications were verified using NRL Automated Processing System (APS) software and applicable MODIS data to generate products comparable to those posted in the NRT HABSOS.

Table 2. Verified characteristics of NRL MODIS data products in NRT HABSOS IMS.

Product Parameter		Product Name									
		Total Absorption @ 443 nm	**Absorption CDOM @ 412 nm**	**Absorption of Phytoplankton @ 443 nm**	**Backward Scattering @ 555 nm**	**Chlorophyll Concentration**	**SST (Day)**	**SST (Night)**	**Latency (Day)**	**Latency (Night)**	**Turbidity**
1	*NRL Product Acronyms*										
		a443	adg412	aph443	bb555	Chl	sst_day	sst_night	latency_day	latency_night	beam-c (648)
2	*Image File Format*										
		PNG (RGB)	PNG (RGB)	PNG (RGB)	PNG (RGB)	PNG (RGB)	PNG (RGB)	PNG (RGB)	PNG (RGB)	PNG (RGB)	PNG (RGB)
3	*# Days of Data Used For Product*										
		7-day LPC	7-day LPC	7-day LPC	7-day LPC	7-day LPC	7-day LPC	7-day LPC	7-day LPC	7-day LPC	Daily Mosaic
4	*Algorithm used to generate product*										
		QAA*	QAA	QAA	QAA	NASA (non-specific)	NASA (non-specific)	NASA (non-specific)	No metadata	No metadata	Algorithm not given
5	*Software used to generate product*										
		APS	APS	APS	APS	APS	APS	APS	APS	APS	APS
6	*NRL Processing Level*										
		L4	L4	L4	L4	L4	L4	L4	L4	L4	L3
7	*Blended or not*										
		Blended	Blended	Blended	Blended	Blended	Blended	Blended	Blended	Blended	Not Blended
8	*Map Extent*										
		GOM[†]	GOM	GOM	GOM	GOM	GOM*	GOM	GOM	GOM	MS Bight
9	*Map Projection*										
		Equi-rectangular	Equi-rectangular	Equi-rectangular	Equi-rectangular	Equi-rectangular	Equi-rectangular	Equi-rectangular	Equi-rectangular	Equi-rectangular	Mercator
10	*Map Datum*										
		WGS84	WGS84	WGS84	WGS84	WGS84	WGS84	WGS84	WGS84	WGS84	WGS84
11	*Horizontal Positional Mapping Units*										
		Decimal Degrees	Decimal Degrees	Decimal Degrees	Decimal Degrees	Decimal Degrees	Decimal Degrees	Decimal Degrees	Decimal Degrees	Decimal Degrees	Decimal Degrees
12	*Source of Map Projection Parameters*										
		metadata and pgw files	metadata and pgw files	metadata and pgw files	metadata and pgw files	metadata and pgw files	metadata and pgw files	metadata and pgw files	pgw files	pgw files	metadata and pgw files
13	*Inherent Measurement Units of Main Observable*										
		1/m	1/m	1/m	1/m	mg/m3	° Celsius	° Celsius	# days old	# days old	1/m
14	*Range in Data Values (Based on Map Legend)*										
		.005 to 1.5	0.005 to .50	.0005 to 1.0	.0005 to .50	.01 to 45	16.19 to 32.20	16.19 to 32.20	7 days	7 days	5 to 0.5
15	*Nominal Spatial Resolution X (in Degrees Decimal) - from pgw file*										
		0.010005003	0.010005003	0.010005003	0.010005003	0.010005003	0.010005003	0.010005003	0.010005003	0.010005003	0.002501042

Product Parameter		Product Name: Total Absorption @ 443 nm	Absorption CDOM @ 412 nm	Absorption of Phytoplankton @ 443 nm	Backward Scattering @ 555 nm	Chlorophyll Concentration	SST (Day)	SST (Night)	Latency (Day)	Latency (Night)	Turbidity
16	*Nominal Spatial Resolution Y (in Degrees Decimal) - from pgw file*										
		0.009209653	0.009209653	0.009209653	0.009209653	0.009209653	0.009209653	0.009209653	0.009209653	0.009209653	0.002154452
17	*Measured Spatial Resolution (kilometers)*										
		1.1 km	1.1 km	1.1 km	1.1 km	1.1 km	1.1 km	1.1 km	1.1 km	1.1 km	~250 m
18	*Temporal Resolution (Product Refresh Rate)*										
		1/day	1/day	1/day	1/day	1/day	1/day	1/day	1/day	1/day	1/day
19	*# Color Planes / Image*										
		3	3	3	3	3	3	3	3	3	3
20	*Color Table - Dynamic Range Per Color Plane*										
		8 bits[‡]	8 bits	8 bits	8 bits	8 bits	8 bits[†]	8 bits	8 bits	8 bits	8 bits
21	*Color Table - Total Effective Dynamic Range Per RGB file*										
		24 bits[§]	24 bits	24 bits	24 bits	24 bits	24 bits[‡]	24 bits	24 bits	24 bits	24 bits
22	*Probable Binning of Thematic Map Product*										
		Floating Point	Floating Point	Floating Point	Floating Point	Floating Point	Floating Point	Floating Point	8 bits/file	8 bits/file	Floating Point
23	*Pixels per Channel (X and Y width)*										
		2000x 1740y	2000x 1740y	2000x 1740y	2000x 1740y	2000x 1740y	2000x 1740y	2000x 1740y	2000x 1740y	2000x 1740y	2400x 1200y
24	*Typical Data Volume per Output Product (Mb)*										
		1.6	1.8	1.8	1.8	1.4	2.4	2.8	0.4	0.2	1.7
25	*Accuracy of Estimated Parameter*										
		Unspecified	Unspecified	Unspecified	Unspecified	Unspecified	Unspecified	Unspecified	Unspecified	Unspecified	Unspecified
26	*Can Data Product Be Downloaded from HABSOS?*										
		No	No	No	No	No	No	No	No	No	No
27	*Metadata - % Completeness*										
		~90%	~90%	~90%	~90%	~90%	~90%	~90%	~90%	~90%	~90%
28	*GIS Readability of Product Downloaded from NRL*										
		Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
29	*Direct GIS Queryability - X,Y,Z Values for Selected MODIS Product Using Cursor?*										
		Partial (X,Y)	Partial (X,Y)	Partial (X,Y)	Partial (X,Y)	Partial (X,Y)	Partial (X,Y)	Partial (X,Y)	Partial (X,Y)	Partial (X,Y)	Partial (X,Y)
30	*Indirect GIS Queryability of Z Values for Selected MODIS Product via Map Legend*										
		Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
31	*Direct GIS Queryability - Ancillary Raster Attributes?*										
		No	No	No	No	No	No	No	No	No	No
32	*Can Product Be Directly Input Into A Model?*										
		No	No	No	No	No	No	No	No	No	No

*QAA = Quasi-Analytical Algorithm (Lee et al., 2002) [†]GOM = Gulf of Mexico region (includes non-United States areas) [‡]8 Bits = 256 gray scale values [§]24 Bits = 3 color planes of 8 bits per channel

The NRL MODIS products found in HABSOS are raster-based image map representations of modeling output from the NRL APS software. These products are displayed in singular fashion with vector overlays and corresponding legend. The NRT HABSOS end-user cannot query the value (i.e., digital number) of a given thematic raster map product, in part because of current, state-of-the-art, commercial-off-the-shelf IMS technology. The coordinate information of a given MODIS product can be directly queried on the NRT HABSOS using a cursor.

The map projection information for the MODIS data products is reported collectively in the metadata and in the georeferenced “world” (pgw) file that accompanies the Portable Network Graphics (png) file. The png file is the actual MODIS data product; the pgw sub-file is needed to display a png file properly in a given GIS. The spatial resolution of the NRL MODIS data products are 1.1 by 1.1 square kilometers when re-projected to a map projection scaled in meters (e.g., Albers map projection). The accuracy of the MODIS ocean data product measurements were not specified in the metadata, although the metadata overall appeared to be relatively complete. However, the algorithms used to generate some of the products were not always specifically mentioned. In particular, the metadata referred to the NRL MODIS chlorophyll product algorithm as NASA and not as a specific algorithm. The MODIS data products as Red, Green, Blue (RGB) image maps could not be input into multivariate models. These products cannot be individually downloaded from the HABSOS Web site (NCDDC, 2006a).

In addition, V&V comparisons were made between the NRL MODIS products in HABSOS and the Standard CoastWatch products used to develop HAB Bulletins (Table 3). This analysis yielded some interesting results, focusing on chlorophyll and SST imagery. The MODIS products were produced at a higher spatial resolution and offered a means to mitigate cloud cover by employing the latest pixel composite approach. The CoastWatch products of SST from AVHRR data and chlorophyll concentration levels from SeaWiFS data were single date products, which can be problematic during certain times of the year when cloud cover is persistent (e.g., summer months) in the Gulf of Mexico. On the other hand, the NOAA standard product metadata specified product accuracy, whereas the NRL MODIS product metadata does not specify product accuracy, even with respect to horizontal positional accuracy. The NRL MODIS products are considered provisional products, while the NOAA CoastWatch products are regarded as operational. Neither the NRL MODIS nor the CoastWatch products were in a format suitable for input to multivariate models. This formatting may be attributed to the perceived needs of the products’ end-users. Those needing CoastWatch SST and chlorophyll products with full-resolution thematic maps with real digital numbers as opposed to georeferenced RGB image maps may be able to acquire such data by directly contacting NOAA. The metadata for the NOAA CoastWatch products appears to be more complete when compared to the NRL MODIS product metadata.

Available metadata and other documentation indicate that the NRL MODIS products were blended with MODIS Aqua and Terra data. However, such blending might not occur with more operational products because of issues with the MODIS Terra data quality. The NRL MODIS product line contains more variety of ocean color products than the NOAA CoastWatch product line. The NRL MODIS ocean data products offer additional and/or complementary capability to the NOAA CoastWatch products currently used in HAB mapping applications, such as the HAB Bulletin.

Table 3. Verified characteristics of NRL MODIS products compared to standard NOAA CoastWatch products used in producing the HAB Bulletin.

Product Parameter		NRL MODIS Chlorophyll-a Concentration	NRL MODIS SST (Day or Night)	NOAA Standard Chlorophyll-a (CoastWatch SeaWiFS)	NOAA Standard SST (CoastWatch AVHRR)
1	Product Accessibility	Public Access	Public Access	Public Access	Public Access
2	Satellite Data Product Type	Ocean Environmental Parameter Image Map	Ocean Environmental Parameter Image Map	Ocean Environmental Parameter Image Map	Ocean Environmental Parameter Image Map
3	Product File Format	PNG (RGB)	PNG (RGB)	PNG (RGB)	PNG (RGB)
4	# Days of Data Used For Product	7-day LPC	7-day LPC	Single Date	Single Date
5	Algorithm used to generate product	NASA (non-specific)	NASA (non-specific)	NOAA (Stumpf)	NOAA (non-specific)
6	Software used to generate product	APS	APS	Unspecified	Unspecified
7	Product Processing Level	Level 4 (NRL)	Level 4 (NRL)	N/A	N/A
8	Blended or not (using data from multiple sensors)	Blended (Aqua and Terra)	Blended (Aqua and Terra)	Not Blended	Not Blended (either AVHRR 16 or 17)
9	Map Extent	GOM*	GOM	GOM	GOM
10	Map Projection	Equirectangular	Equirectangular	Mercator	Mercator
11	Map Datum	WGS84	WGS84	WGS84 (inferred)	WGS84
12	Horizontal Positional Mapping Units	Decimal Degrees	Decimal Degrees	Meters	Meters
13	Inherent Measurement Units of Observed Parameter	mg/m^3	Degrees Celsius	mg/m^3	Degrees Celsius
14	Range in Data Values on Map Legend	.01 to 45	16.19 to 32.20	.001 to 64.767	0 to ~36.5
15	Source for Range of Data Value Parameters	Map Legend	Map Legend	Metadata	Map
16	Reported Nominal Spatial Resolution In Degrees (X direction)	0.0100050025	0.0100050025	1.39 km (full resolution)	1.47 km (full resolution)
17	Reported Nominal Spatial Resolution In Degrees (Y direction)	0.0092096534	0.0092096534	1.39 km (full resolution)	1.47 km (full resolution)
18	Information Source for Spatial Resolution Parameter	pgw file	pgw file	png file (main product)	png file (main product)
19	Estimated Spatial Resolution (km) in both X and Y	1.128 km	1.128 km	3.418 km[†]	3.418 km (inferred)
20	Reported Horizontal Positional Accuracy	Unspecified	Unspecified	<= 1 km	<= 1 km
21	Measured Relative Horizontal Positional Accuracy (Overall RMSE in p/m Pixels and # Ground Control Points)	± 1.07 pixels (11 ground control points)	± 1.07 pixels (11 ground control points) (inferred)	± 0.9001 pixels (15 ground control points)	± 0.9001 pixels (15 ground control points) (inferred)

Product Parameter		NRL MODIS Chlorophyll-a Concentration	NRL MODIS SST (Day or Night)	NOAA Standard Chlorophyll-a (CoastWatch SeaWiFS)	NOAA Standard SST (CoastWatch AVHRR)
22	Reference Geospatial Dataset for Horizontal Positional Accuracy Assessment	MODIS Land Cover Product	MODIS Land Cover Product	Geographic Grid on Actual Product	Geographic Grid on Actual Product
23	Temporal Resolution (Refresh Rate of New Products)	1/day (inferred)	1/day (inferred)	1/day	1/day/AVHRR sensor
24	Delivery Rate – Time from Data Collection to Product Delivery	Unspecified	Unspecified	Within 8 hrs of data collection	Within 4 hrs of data collection
25	Color Table - Color Planes	3	3	3	3
26	Color Table - Dynamic Range / Color Plane	8 bits/file‡	8 bits/file	8 bits/file	8 bits/file
27	Color Table - Total Effective Dynamic Range	24 bits/file§	24 bits/file	24 bits/file	8 bits/file
28	Original Binning of Thematic Map Product	Floating Point	Floating Point	Floating Point	Floating Point
29	Measured Image Dimensions (# Pixels X and Y)	2000x 1740y	2000x 1740y	878x 505y	870x 516y
30	Typical Data Volume per Output Product (Mb)	1.4	2.4 (day) to 2.8 (night)	0.4	0.6
31	Accuracy of Estimated Parameter	Unspecified	Unspecified	± 10%	± 2 °C
32	Can GIS Formatted Data Product Be Downloaded?	No	No	Yes	Yes
33	Metadata - % Completeness	~90%	~90%	~95 to 100%	~95 to 100%
34	GIS Readable	Yes	Yes	Yes	Yes
35	GIS Queryability of X,Y,Z Values	Partial (X and Y)	Partial (X and Y)	Partial (X and Y)	Partial (X and Y)
36	GIS Queryability of Ancillary Raster Attributes	No	No	No	No
37	Can Product Be Directly Input Into a Geospatial Model?	No	No	No	No
38	File name with standard naming conventions applied	Yes	Yes	Yes	Yes

*GOM = Gulf of Mexico Region (includes areas outside of United States)
†Estimated Spatial Resolution – Alternative georeferencing via tic marks gave 3.181 km cell size and ± .0138 pixel RMSE
‡8 Bits = 256 gray scale values per channel (i.e., file)
§24 Bits = 3 color planes of 8 bits per channel (24 bits/graphics file)

4.3 V&V of Animated Multi-Temporal MODIS/NCOM Fusion Mapping Products within NRT HABSOS IMS

The animated product V&V results are summarized in Table 4. These animations include one for the Gulf of Mexico at large plus four additional areas of interest within the United States portion of the northern

Gulf of Mexico. All files are in animated graphics interchange format (GIF) with assorted vector data overlain onto chlorophyll-a abundance images derived from MODIS Aqua data. The animation is for a time sequence up to the present date. The number of sampled time frames appears to vary depending on time of month. The documentation on the HABSOS Web site suggests that the time sequence is kept constant at a 7-day time span. However, the HABSOS Web site has shown that the time sequence can include at least 13 sample frames with each frame including a latest pixel composite of a MODIS chlorophyll-a image derived with the OC3m algorithm. These animations are not embedded into the HABSOS IMS but instead are offered as a hyperlink. The vector component of each image map includes: 1) a Latitude/Longitude Grid from the APS software, 2) SSS from NCOM, 3) sea surface height (SSH) from NCOM, and 4) sea surface circulation from NCOM. The animation allows HABSOS viewers to look at trends in sea surface physical properties in coastal areas of interest. For example, this product may be used in part for tracking, assessing, and predicting impacts of an incoming HAB event.

Table 4. Verified characteristics of NRL MODIS/NCOM animation fusion products hyperlinked to NRT HABSOS IMS.

General Product Output Parameters	Specific Regions in Gulf of Mexico with Animated Output Products				
	Gulf of Mexico Overview	Mississippi Bight	Tampa Bay Florida	Texas Gulf Coast	West Shelf Florida
Availability of Product Metadata on HABSOS IMS	No	No	No	No	No
Availability of Metadata on Product Inputs	Some	Some	Some	Some	Some
Product Downloadable From NRL Link	Yes	Yes	Yes	Yes	Yes
Output Format	Animated GIF	Animated GIF	Animated GIF	Animated GIF	Animated GIF
Output Dynamic Range	8 bits	8 bits	8 bits	8 bits	8 bits
Effective Dynamic Range Using Color Tables	24 bits	24 bits	24 bits	24 bits	24 bits
# Pixels in X and Y / Region	1120x 895y	1008x 760y	954x 986y	1033x 733y	970x 868y
Highest Noted Sampled Time Frame / Region	13 frames - each an LPC	13 frames - each an LPC	13 frames - each an LPC	13 frames - each an LPC	13 frames - each an LPC
Data Volume Per Region (Mb)	4.835	2.572	2.994	3.147	3.436
Data Volume Per Frame Per Region (Mb)	0.403	0.214	0.250	0.26225	0.286
Measured Output Pixel Width and Height	2.047 km	0.585 km	0.315 km	0.820 km	0.822 km
Parameters for Product Input 1 - Chlorophyll-a concentration	**MODIS Aqua Chlorophyll**	**MODIS Aqua Chlorophyll**	**MODIS Aqua Chlorophyll**	**MODIS Aqua Chlorophyll**	**MODIS Aqua Chlorophyll**
Data Type	Thematic Raster	Thematic Raster	Thematic Raster	Thematic Raster	Thematic Raster
Measurement Units	mg/cubic meters	mg/cubic meters	mg/cubic meters	mg/cubic meters	mg/cubic meters
Scaling Range	0.01 to 45	0.01 to 45	0.01 to 45	0.01 to 45	0.01 to 45
Source Data	MODIS Aqua	MODIS Aqua	MODIS Aqua	MODIS Aqua	MODIS Aqua
Processing Algorithms	OC3M LPC	OC3M LPC	OC3M LPC	OC3M LPC	OC3M LPC
Source Software	APS software	APS software	APS software	APS software	APS software

Parameters for Product Input 2 - Geographic Coordinate Grid	Geographic Coordinate Grid	Geographic Coordinate Grid	Geographic Coordinate Grid	Geographic Coordinate Grid	Geographic Coordinate Grid
Data Type	Vector Grid	Vector Grid	Vector Grid	Vector Grid	Vector Grid
Measurement Units	Geographic Degrees	Geographic Degrees	Geographic Degrees	Geographic Degrees	Geographic Degrees
Scaling Range	19–31° N and 82–98° W	28.4–30.8° N and 87–90° W	26.4–28.0° N and 82.1–83.7° W	26.5–30.5° N and 91–97° W	26–30° N and 82–87° W
Source Software	APS software	APS software	APS software	APS software	APS software
Parameters for Product Input 3 - Sea Surface Height	**Sea Surface Height**	**Sea Surface Height**	**Sea Surface Height**	**Sea Surface Height**	**Sea Surface Height**
Data Type	Vector Contour	Vector Contour	Vector Contour	Vector Contour	Vector Contour
Measurement Units	meters	meters	meters	meters	meters
Scaling Range	-0.5 to 0.5	-0.5 to 0.5	-0.5 to 0.5	-0.5 to 0.5	-0.5 to 0.5
Source Software	NCOM Model	NCOM Model	NCOM Model	NCOM Model	NCOM Model
Parameters for Product Input 4 - Sea Surface Salinity	**Sea Surface Salinity**	**Sea Surface Salinity**	**Sea Surface Salinity**	**Sea Surface Salinity**	**Sea Surface Salinity**
Data Type	Vector Contour	Vector Contour	Vector Contour	Vector Contour	Vector Contour
Measurement Units	PPT	PPT	PPT	PPT	PPT
Scaling Range	34 to 36	34 to 36	34 to 36	34 to 36	34 to 36
Source Software	NCOM Model	NCOM Model	NCOM Model	NCOM Model	NCOM Model
Parameters for Product Input 5 - Sea Surface Circulation	**Circulation**	**Circulation**	**Circulation**	**Circulation**	**Circulation**
Data Type	Vector Direction	Vector Direction	Vector Direction	Vector Direction	Vector Direction
Measurement Units	Degrees	Degrees	Degrees	Degrees	Degrees
Scaling Range	0 to 360	0 to 360	0 to 360	0 to 360	0 to 360
Source Software	NCOM Model	NCOM Model	NCOM Model	NCOM Model	NCOM Model

4.4 Analysis of Data Volume Requirements for Generating NRL MODIS Products Resident to the NRT HABSOS

MODIS ocean data products resident to HABSOS require a considerable amount of hard drive disk space, which has been a complaint of some potential end-users as an impediment to operational usage. Consequently, one facet of the V&V analysis regarded measurement and extrapolated estimation of the data volume requirements needed for 30 sequential days of MODIS data product postings to the NRT HABSOS. We approximate that at least 106 GB are needed to accommodate a 30-day period, as summarized in Table 5. If MODIS data products were used by the HAB Bulletin production team in the same way as SeaWiFS data products were used, the data volume needed would be at least double because the HAB Bulletin calculates chlorophyll anomalies using SeaWiFS data over a 60-day period. This amount will increase if additional MODIS data products are added.

Table 5. Data Volume Requirements for NRL MODIS Products Posted in NRT HABSOS.

Data Input to APS Software for Generating MODIS Ocean Data Products		
Input Processing Step	**Data Volume/ Day (GB)**	**Data Volume/ 30 Days (GB)**
Ingest of 1 KM HDF Files	1.17036	35.1108
BZIP of HDF Files (eliminates HDF upon BZIP completion)	0.45889	13.7667
Ingest of 1 KM HDF Files (developed from BZIP output)	2.11938	63.5814
Total of All Input Steps	2.57827	77.3481
APS MODIS Ocean Data Product Output		
Output Processing Step	**Data Volume/ Day (GB)**	**Data Volume/ 30 Days (GB)**
HDF Generation (includes other MODIS products not currently used by HABSOS)	0.87545	26.2635
JPG image maps of L3 and L4 Products	0.06396	1.9188
Thumbnails of L3 and L4 Products	0.00285	0.0855
Total of All Output Steps	0.94226	28.2678
Total Data Volume of All APS Input and Output Steps Needed for HABSOS MODIS Products	**3.52053**	**105.6159**

5.0 Conclusions and Recommendations

The NRT HABSOS is a prototypical operational system that includes a variety of MODIS ocean data products and NCOM modeling products from NRL. The V&V analysis of the NRT HABSOS led to the following conclusions:

1. The inclusion of NRL MODIS ocean color and SST data products has enhanced the potential of the NRT HABSOS IMS for HAB event analyses, although more work is needed for the system to be used for comprehensive HAB detection, monitoring, forecasting, and management decision making. While the current system is impressive, the method by which remote sensing products are integrated into the system needs further development and refinement.

2. The NRT HABSOS also does not presently include NRT in situ data on *Karenia brevis* cell count concentration. These data are posted on the HABMapS IMS and will eventually migrate to HABSOS (NOAA CSC, 2005). These in situ data are crucial for end users to evaluate the potential of MODIS data products for HAB applications.

3. The current NRT HABSOS enables the geospatial visualization of MODIS ocean data products, although it does not have a direct means for end users to download data in GIS format. This lack limits the use of such data in HABSOS external mapping and modeling applications.

4. The MODIS data products for the NRT HABSOS are RGB images without direct traceability to the one-channel thematic imagery used to derive the RGB color composite imagery. The ArcIMS software version does not allow use of the pseudo-color imagery that modelers commonly use to integrate raster thematic map-based measurements or predictions. RGB imagery is effective as a display for an IMS, although the product cannot be used as an input to multivariate HAB modeling applications. A solution could be constructed for HAB modelers so that interested end-users could download pseudo-color thematic output for a given MODIS ocean data product displayed on the NRT HABSOS IMS as an RGB. The downloading capability would help the HAB modeling community to better assess the potential of MODIS ocean data products.

5. The present capability does not allow end users to exploit the NRL MODIS data products over a sufficient time frame that permits anomaly detection of chlorophyll-a. The still-frame MODIS data

products are only a snapshot, showing the latest 7-day pixel composite, cloud-free estimation of a given in-water environmental parameter (e.g., chlorophyll). The animation product shows how latest pixel composite chlorophyll levels change over a multi-day time span, although this time span is much shorter than what is used by NOAA with SeaWiFS data to identify chlorophyll anomalies for HAB Bulletins. NOAA National Centers for Coastal Ocean Science uses a 60-day average of SeaWiFS data to compute chlorophyll anomalies needed to generate HAB Bulletins (Stumpf et al., 2003).

6. The description of resident data and metadata for the NRT HABSOS IMS is incomplete with respect to the NRL MODIS ocean data products. More information is needed to aid end-users in assessing and understanding potential and actual utility of the MODIS data products. The metadata does not include information on atmospheric correction algorithms and quality control measures taken to mask out clouds and sun glint. Atmospheric correction techniques can alter the accuracy of ocean data products either positively or negatively. HABSOS does not presently include metadata or other documentation on how to optimally use the MODIS ocean data products with respect to HAB or any other ocean water quality related applications. The HABSOS Web site contains no documentation discussing how to use the MODIS data products for improved HAB decision making (NCDDC, 2006a). A list of relevant Internet sites could be added to the HABSOS Web site to address this deficiency.

7. A review of the map legends for the MODIS data products revealed that some corrections are needed. For example, the map legend for adg412 is indicated as adg443. The low end of scaling for the adp443 product is one decimal place off. The map legend for the turbidity scales read from high to low instead of from low to high (as is the case with the other NRL absorption products in the NRT HABSOS).

Recommendations for improving current NRL MODIS data product contributions to the NRT HABSOS include the following:

1. The data format of MODIS ocean data products should be structured so that the inherent data products can be downloaded and integrated into GIS-based HAB dispersion models.

2. The HABSOS IMS needs to allow MODIS ocean color data products to be downloaded for HABSOS end-users to use in their GIS and other geospatial modeling and visualization software. MODIS ocean color data products resident to HABSOS should be formatted in such a way that the actual digital numbers can be queried. Single channel GeoTIFF with a look-up table should accommodate this need.

3. As indicated by NOAA CSC (2005), the HABMapS NRT system should be folded into the NRT HABSOS IMS to aid end-users in using the MODIS ocean color data products. Doing so would enable in-situ data on HAB distribution and abundance to be compared, at least visually, to MODIS ocean data product displays.

4. Integration of raster and vector data must be improved greatly within the NRT HABSOS IMS so that one layer can be queried with respect to another. The current GIS data visualization capability needs to include more analytical functionality. Users need improved HABSOS screen display visualization capabilities so that one image data product can be swiped across another. HABSOS IMS could benefit from the end-user being able to add GIS data layers to the ArcIMS display.

5. The NRL sea surface particle transport modeling capability using NCOM should be integrated into HABSOS, at least via hyperlink to animated GIFs. The merged MODIS chlorophyll/NCOM model results have great potential for HAB applications because ocean circulation can greatly influence ocean color parameters, such as chlorophyll concentration (Arnone et al., 2005; Blain et al., 2005).

Additional geospatially enabled animation product development of this type is needed for HABSOS end-users to more fully utilize this potential within the Internet GIS environment. As with the MODIS still-frame products, documentation should be provided on how to optimally use these multitemporal ocean color/NCOM animation products. In particular, it would help to include spatial resolution information on the NCOM modeling output used in the MODIS/NCOM fusion products.

6. HABSOS IMS could also be improved by enabling access to data external to the NRT IMS online data holdings. It may help to look back in time at MODIS ocean data products posted before the currently posted products. A hyperlink to the data archive of MODIS ocean data products would be useful. Such an archive could contain thumbnails and quick looks of MODIS ocean data products with additional links to full-resolution data products or other ArcIMS compatible data products.

7. Portions of the SST imagery can be of suspect quality, apparently due to clouds or other atmospheric contamination. The current color table could be compared to other modeled SST to mask out anomalously low values.

8. The NRL MODIS SST product color look-up tables show very low contrast for certain times of year for the Gulf of Mexico (GOM) region, especially with respect to midsummer. The color tables should be adjusted so that the color ramp is spread through the predominant range of temperatures evident across the GOM. The SST color tables from NRL MODIS data also do not match the SST color table from the NRL oceanographic modeling. This disagreement should be alleviated using a standard color table.

9. The metadata for the NRL MODIS Ocean Data Products should be revised to better indicate the source of algorithms used to generate each product, at least when applicable. For example, the metadata does not indicate which specific algorithm is being used to generate chlorophyll concentration image products from MODIS data. The abstract description indicates that NASA algorithms are being used, though this is probably not always the case, based on APS software documentation (the NRL uses APS to generate the MODIS Ocean Color and SST data products). No information is given on the metadata regarding the atmospheric correction and preprocessing of the MODIS data before product derivation. The metadata would also benefit from the addition of information on expected accuracy of a given MODIS ocean data product, citing representative published studies. Inclusion of MODIS quality assessment/quality control flag data products may be useful for end-users to gauge the effectiveness of the MODIS ocean color data products.

10. Additional V&V is needed with participation of state agency end-users, such as the State Departments of Marine Resources. The V&V analyses discussed here did not involve direct participation of NRT HABSOS end-users. After the MODIS data contribution to the NRT HABSOS is refined, benchmarking is needed to quantify the value of NASA-enhanced HABSOS compared to the baseline HABSOS. Such benchmarking should be preceded by a research and development phase that responds to recommendations given in the V&V report. The benchmarking report ideally should include testimonial documentation on how HABSOS end-users employed HABSOS resident data for HAB decision support, mitigation, and other management activities.

The NRT HABSOS may also benefit from inclusion of additional MODIS data products, based on a review of available literature. HABSOS developers might consider the following suggestions:

1. The NRT HABSOS could benefit from inclusion of MODIS true color RGB color composite imagery for visual comparison to MODIS ocean color products. The latter is useful for assessing visual correlation of patterns on the MODIS ocean data products to the patterns on the true color reflectance RGBs used to derive those products. Coastal managers can compare the true color RGBs to what can be seen in the field with the naked eye.

2. The NRT HABSOS could also benefit from inclusion of MODIS Fluorescence products. Hu et al. (2005) found that these products had the potential to detect HABs in water with high concentrations of CDOM.

3. Additional NRL products could be generated from MODIS data and incorporated into HABSOS. One example is RGB imagery composed of MODIS-based detritus (CDOM) and chlorophyll concentration loaded into the RGB color guns. Arnone et al. (2004) have employed this RGB product for classifying water mass types in the Gulf of Mexico.

4. Additional gains could be made via effective pan sharpening of MODIS ocean color data into 250-meter resolution datasets. NOAA standard chlorophyll products from SeaWiFS and comparable products from MODIS are generally 1 km resolution, which is good to within 2 km of the coastal shoreline according to Stumpf (2001). More effective pan sharpening of MODIS ocean data products would better enable prototyping of future ocean color satellite systems such as the National Polar-Orbiting Environmental Satellite System (NPOESS) and the Geostationary Operational Environmental Satellites (GOES-R). The pan-sharpening needs to be done in a way that retains spectral qualities of multispectral data at 1 km yet includes the spatial information content of higher resolution panchromatic band(s) at 250-meter resolution. Multiple algorithms could be evaluated to determine if such a data fusion approach is feasible for HABSOS MODIS data products.

5. NRL should consider the benefits of computing and comparing MODIS 250-mand 1-km c-beam turbidity products to gauge the differences between these two products. HABSOS end-users would be able to better evaluate spatial resolution differences if MODIS 250-m and 1-km c-beam products were posted on the NRT HABSOS.

6.0 References

Additional non-cited references are listed in Appendix H.

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Appendix A. Summary of NASA REASoN Project with ACT Corporation and NRL

WHO: Applied Coherent Technology (ACT) Corporation – Erick Malaret (Principal Investigator); subcontract to Naval Research Laboratory – Robert Arnone (Lead)

WHAT: *Sensor to User – Applying NASA/EOS Data to Coastal Zone Management Applications Developed from Integrated Analyses*

HOW MUCH: $2,020,000

DELIVERABLES:

- Generate new products and improve existing products from Earth science satellites and models to support coastal-ocean resource managers
- Integrate model and satellite output to address coastal management issues identified from NOAA and other partners
- Enable real-time ocean properties to be easily assembled and distributed into coastal products through Web technology
- Cooperate with NOAA National Ocean Service and NOAA National Environmental Satellite, Data, and Information Service to ensure useful product creation and integration with current NOAA DSTs and priority needs of the coastal resource management community
- Partner with the NASA Earth Science Information Partner Federation and Strategy for Evolution of ESE Data Systems (SEEDS) Working Groups[1] to support and address issues facing the Standards and Interface Working Group and the Technology Infusion Working Group; and
- Link the ESE Application Division's strategy with the SEEDS process

<u>REFERENCES</u>: 1) *Coastal Management Element Plan: 2004 – 2008*. NASA Earth Science Enterprise, National Applications Program, Earth Science for Coastal Management. 2) Technical Evaluation of the Proposed Budget for the Applied Coherent Technology Corporation proposal titled *Sensor to User – Applying NASA/EOS Data to Coastal Zone Management Applications Developed from Integrated Analyses* received January 30, 2004.

[1] The former NASA Earth Science Enterprise (ESE) is now the NASA Science Mission Directorate; the Earth Science Applications Division is now the Earth-Sun System Division.

Appendix B. Glossaries

The glossaries below describe V&V, ocean color, and HAB terminology.

B.1. V&V Terminology: Decision Support Tool Enhancement[2]

Benchmark – The process of determining the improvement in performance of a decision support tool (DST) after enhancement compared to an earlier state. Benchmarking can also be done to compare performance of the enhanced DST to an accepted standard level of performance. Benchmarking aims to measure and document benefits and values due to DST enhancement.

Evaluation – The process of assessing a DST regarding potential for enhancement with NASA science, data, and modeling capabilities using system engineering principles and practices.

Validation – The process of determining the degree to which a geospatial information product enhancement is accurate and useful for a given DST application.

Verification – The process of determining that a geospatial information product is accurate with respect to product specifications. Verification provides quality assurance that a product is as claimed. Note that verification and validation are often employed in tandem (referred to as V&V) as techniques in order to characterize science data, models, and other data products.

B.2. Ocean Color Terminology

Absorption – The ability of matter to absorb light energy impingent on it. This light energy is converted into heat, or in the case of plant matter, it is converted into photosynthetic energy or secondary energy processes such as fluorescence emission. The net light lost from an incident beam of light is referred to by the absorption coefficient or absorbance. The amount of light absorbed by materials in the water depends on the materials themselves and the wavelength of light incident upon them. By varying the wavelength of light, one can deduce information relating to specific material in the water. This is a basic principle behind spectrophotometry (Source: Wet Labs Glossary, http://www.wetlabs.com/glossary.htm).

Aerosols – Aerosols are liquid or solid particles of between 10^{-3} and 10 microns. They have various origins and are of different types. The major classes of aerosol are as follows: stratospheric aerosols of sulfuric acid, mainly from volcanic eruptions, tropospheric marine aerosols from the oceans, desertic aerosols of dust from desert or semi-desert areas, anthropogenic aerosols from urban pollution or fires, and aerosols from chemical transformations. (Source: POLDER and Ocean Color, http://ceos.cnes.fr:8100/cdrom-00b/ceos1/satellit/polder/science.htm).

Apparent Optical Property – Water properties that depend on ambient light and inherent optical properties. They depend on the angle of the sun, whether it is day or night, and the amount of cloud cover. Apparent optical properties include the irradiance attenuation coefficient, the irradiance reflection coefficient, and the Secchi disk depth (Source: Wet Labs Ocean Color Glossary, http://www.wetlabs.com/glossary.htm).

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[2] Sources of Information for V&V Definitions - http://science.hq.nasa.gov/earth-sun/applications/cross.html, http://science.hq.nasa.gov/earth-sun/applications/index.html#Approach, http://research.hq.nasa.gov/code_y/nra/current/NNH04ZYO010C/AppendixA.html, and http://www.grc.nasa.gov/WWW/wind/valid/tutorial/glossary.html.

Atmospheric Correction –Digital processing of electro-optical radiance imagery to eliminate or reduce spectral influences from atmospheric constituents such as aerosols and water vapor. Regards correction made to remotely sensed radiance imagery to account for effects related to the intervening atmosphere between the earth's surface and the satellite sensor (Source: Based on American Meteorology Glossary of Meteorology, http://amsglossary.allenpress.com/glossary).

Attenuation – Loss of electromagnetic energy (solar radiation) as it passes through the atmosphere owing to absorption and scattering by atmospheric particles and molecules (Source: MERIS Ocean Color Glossary, http://envisat.esa.int/dataproducts/meris/CNTR5-2-6.htm#eph.meris.gloss.index.ocean).

Backward Scattering (Backscattering) – Light scattered from particles scattered at angles greater than 90° with respect to the incident direction of the source as it impinges on particles in the water. Backscattering is particularly useful in applications that tie remote ocean color images from satellites and planes to in-water optical processes (Source: Wet Labs Glossary, http://www.wetlabs.com/glossary.htm).

Beam Attenuation – A decrease in light energy from a collimated beam that is passing through a water sample with a specific path length. It is an inherent optical property (Source: Wet Labs Glossary, http://www.wetlabs.com/glossary.htm).

Beam Attenuation Coefficient (c) – The attenuation experienced by a hypothetical perfectly collimated beam of light. Represented as c, it is equal to a (absorption coefficient) + b (scattering coefficient) Source: Hydro-Optics, Biology and Instrumentation Laboratories Glossary, http://www.hobilabs.com/cms/index.cfm/37/1288/1301/).

Blended – Describes satellite ocean data products which were derived from multiple sensors. For example, NRL MODIS data products can involve the blending of results from MODIS Aqua and Terra satellite data.

Color Dissolved Organic Matter (Gelbstoff) – Fluorescence attributed to colored dissolved organic matter in the ocean. In coastal areas this can provide an indication of how much organic carbon material is getting washed into the ocean. In the ocean, it provides an indication of carbon cycling into the oceanic pool from decaying phytoplankton and other life forms (Source: Wet Labs Glossary, http://www.wetlabs.com/glossary.htm).

Chlorophyll-A Concentration – Chemical compounds occurring in plants that enable radiant energy to be converted to chemical energy in the process of photosynthesis; there are several types (e.g., denoted as chl *a*, *b*, etc.) with chl *a* typically the most common form present. (Source: Optical Oceanography Glossary, http://swhite.me.washington.edu/faculty/McCormick/glossary.htm).

Clarity – A qualitative measurement of the ability of water to transmit light. Clarity can be assessed using transmissometers and turbidity sensors. In terms of water observation, clarity can be considered synonymous with visibility (Primary source: Wet Labs Glossary, http://www.wetlabs.com/glossary.htm).

Detritus – The particulate decomposition or disintegration products of plankton, including dead cells, cell fragments, fecal pellets, shells, and skeletons, and sometimes mineral particles in coastal waters (Source: Optical Oceanography Glossary, http://swhite.me.washington.edu/faculty/McCormick/glossary.htm).

Diffuse Attenuation Coefficient (K_d) – More precisely known as the Irradiance Attenuation Coefficient, this quantifies the attenuation of plane irradiance under solar illumination. This is often referred to as an apparent optical property because it depends not only on the water properties but also on the sun angle, sky conditions, depth, and shadowing by the measurement platform or the measuring instrument itself. However it has been shown that at great enough depths, K_d reaches an asymptotic value that depends only on the properties of the water. This asymptotic K_d can be considered an inherent optical property (Source: Hydro-Optics, Biology and Instrumentation Laboratories Glossary, http://www.hobilabs.com/cms/index.cfm/37/1288/1301/).

Inherent Optical Property – Water properties that depend only on the content of the water, regardless of light conditions. Inherent optical properties include absorption, attenuation, scattering, fluorescence, and volume scattering function (Primary source: Wet Labs Glossary, http://www.wetlabs.com/glossary.htm).

Latency – Delay time between when a device requests access to a network and the time it is granted permission to transmit. Can also be a delay between the time a device receives a frame and the time that frame is forwarded out the destination port. Latency is an integrated technology term used to describe the time needed to transfer a digital data product across a network from the initial producer to the eventual end user. In terms of NRT satellite data products, this can be considered the lag time between data collection, data download, data processing into a preliminary product, data processing into final product, and data transfer of the final product (Primary source: Cisco Systems Glossary, http://www.cisco.com/univercd/cc/td/doc/cisintwk/ita/index.htm).

Sea Surface Temperature – The temperature of the layer of seawater (approximately 0.5 m deep) nearest the atmosphere (Source: NASA Earth Observatory, http://eobglossary.gsfc.nasa.gov/Library/glossary.php3?xref=ocean%20color).

Sea Surface Salinity – a measure of the quantity of dissolved salts in surface ocean water; defined in terms of the conductivity of a defined salt solution; has no units but is nearly equal to the weight in grams of dissolved salts per kilogram of seawater. Also regards the natural concentration of salts in surface water. This is influenced by the geologic formations underlying the area. Salinity is lower in areas underlain by igneous formations and higher in areas underlain by sedimentary formations. Higher salt concentrations are also more likely in arid regions where water evaporates leaving the same amount of salt in less water and thus increasing the salinity (Source: Ocean World Glossary, http://oceanworld.tamu.edu/resources/glossary.htm).

Sun Glint – A pattern seen in visible imagery when the sun’s rays are reflected off a highly reflective surface such as water or sand. Sun glint patterns vary in shape, size, and brightness depending on the type of satellite, solar sub point, sea state, and low level distribution of aerosols and moisture. Can also be thought of as the specular reflection of solar flux on an ocean or sufficiently large water body (Primary source: State University of New York at Albany, Course Glossary for Meteorological Remote Sensing, http://www.atmos.albany.edu/deas/atmclasses/atm335/glossary.pdf).

Total Suspended Sediment – The sediment that, at any given time, is maintained in suspension by the upward components of turbulent currents or that exists in suspension as a colloid (Source: Glossary for the U.S. Geological Survey's National Water Quality Assessment (NAWQA) Program's Apalachicola-Chattahoochee-Flint (ACF) River basin study, http://ga.water.usgs.gov/nawqa/glossary.html).

True Color Composite Image – Refers to a color image in which the bands assigned to the red, blue and green color guns also correspond to reflected energy from the visible red, green, and blue portions of the electromagnetic spectrum, respectively. The end result is a color composite image that is similar in appearance to what the human eye can see (Source: Based on Natural Environment Research Center Earth Observation Data Center remote sensing glossary, http://www.neodc.rl.ac.uk/tutorials/glossary/glossary.htm).

Visibility – In terms of underwater diving, visibility is the distance a diver can see underwater that is typically measured in feet or meters. Underwater visibility products can be produced from MODIS data and may be useful for HAB mapping applications (Source: Definition adapted from Underwater Australia Diving Glossary, http://www.underwater.com.au/article.php/id/1546/).

Water Mass – a body of water with a common formation history, such as convection from surface cooling that originates in a particular region of the ocean. Water masses can be identified by their temperature, salinity, and other properties such as nutrients or oxygen content. They have exclusive occupation of an oceanic region only in their formation region; elsewhere they share the ocean with other water masses with which they mix. Just as air masses in the atmosphere, water masses are physical entities with a measurable volume (Source: American Meteorology Glossary of Meteorology, http://amsglossary.allenpress.com/glossary).

B.3. HAB Forecasting Terminology

Detection – the process of determining and recording the presence of a certain condition, pattern, process, or phenomenon (e.g., HAB patch) within an observed area of interest. Change detection regards the recognition of change in an observed environmental parameter of interest within an observed area of interest. Such change can be referred to as an anomaly, when compared to normal measurements. Detection is a precursor to monitoring.

Early Warning – a prediction of dangerous conditions that a HAB event may occur in relation to coastal resources and human populations, warranting management actions to manage or mitigate impacts of impending event.

Forecast – a multifaceted prediction of where, when, and how much of a meteorological and/or oceanographic event may occur. For example, a weather forecast can include the estimated amount of precipitation as well as wind speed and direction.

Prediction – although similar to forecasting, but more specific in the sense that forecasts can encompass multiple predictions. Frequently based on modeling and measurement, prediction describes where and when a future event will occur. Numerical predictions tend to include a quantified probability that a future event will occur.

Monitoring – the process of observing and measuring physical properties of targeted environmental patterns, processes or phenomenon over multiple time intervals.

Modeling – an investigative suite of techniques that uses a mathematical or physical representation of a physical pattern, process, system or theory that accounts for all or some of its known properties. In terms of system engineering, models are often used to test the effects of changes of system components on the overall performance of the system (Source modified from the NASA JPL physical oceanography DAAC Web site, http://podaac.jpl.nasa.gov/glossary/).

Simulation – the deployment or application of a model.

Appendix C. Acronyms and Initialisms

ACT	Applied Coherent Technology (Corporation)
APS	Automated Processing System (NRL software)
AVHRR	Advanced Very High Resolution Radiometer
ArcIMS	a commercial, scalable Internet map server developed by ESRI, Inc.
BZIP	compressed data file format
CDOM	color dissolved organic matter
CSC	Coastal Services Center (NOAA)
DAAC	Distributed Active Archive Center
DST	decision support tool
EPA	Environmental Protection Agency
ESRI	Environmental Systems Research Institute, Inc.
GCOOS	Gulf of Mexico Coastal Ocean Observing System
GIF	graphics interchange format
GIS	geographic information system
GOES-R	Geostationary Operational Environmental Satellites
GOM	Gulf of Mexico region
GUI	graphical user interface
HAB	Harmful Algal Bloom
HABMapS	Harmful Algal Blooms Mapping System (NOAA)
HABSOS	Harmful Algal Blooms Observing System (NOAA)
HDF	Hierarchical Data Format
IMS	Internet map server
JPL	Jet Propulsion Laboratory (NASA)
LPC	latest pixel composite
METAR	Meteorological Aerodrome Report

MODIS	Moderate Resolution Imaging Spectroradiometer (NASA)
NCDDC	National Coastal Data Development Center (NOAA)
NCOM	Navy Coastal Ocean Model
NOAA	National Oceanic and Atmospheric Administration (Department of Commerce)
NPOESS	National Polar-Orbiting Environmental Satellite System
NRL	Naval Research Laboratory
NRT	near real time
NWS	National Weather Service
pgw	"world" file that accompanies a reference map image stored as a .png file and contains information about the exact location and size of the image
png	Portable Network Graphics
QAA	Quasi-Analytical Algorithm
QuikSCAT	Quick Scatterometer (NASA satellite containing SeaWinds sensor)
REASoN	Research, Education, and Applications Solutions Network (NASA)
RGB	Red, Green, Blue
SeaWiFS	Sea-viewing Wide Field-of-view Sensor (ORBIMAGE)
SSE	sea surface elevation; a.k.a. sea surface height
SSH	sea surface height; a.k.a. sea surface elevation
SSS	sea surface salinity
SST	sea surface temperature
V&V	verification and validation

Appendix D. GIS Data Layers Resident to the NRT HABSOS IMS [3]

Meteorologic Data	
Product #	**Product Description**
1	Winds (from buoys)
2	Winds (from QuikSCAT)
3	NWS* Air Temperature (24 hr forecast)
4	NWS Air Temperature (48 hr forecast)
5	NWS Air Temperature (72 hr forecast)
6	NWS Percent Precipitation (24 hr forecast)
7	NWS Percent Precipitation (48 hr forecast)
8	NWS Percent Precipitation (72 hr forecast)
9	NWS Precipitation Amounts (24 hr forecast)
10	NWS Precipitation Amounts (48 hour forecast)
11	NWS Precipitation Amounts (72 hr forecast)
Oceanographic Data	
Product #	**Product Description**
1	Currents (from buoys)
2	NRL Surface Currents (nowcast)
3	NRL Surface Currents Speeds (nowcast)
4	NRL Surface Currents (24 hour forecast)
5	NRL Surface Currents Speeds (24 hour forecast)
6	NRL Surface Currents (48 hour forecast)
7	NRL Surface Currents Speeds (48 hour forecast)
8	NRL Surface Currents (72 hour forecast)
9	NRL Surface Currents Speeds (72 hour forecast)
10	NRL Sea Surface Heights (nowcast)
11	NRL Sea Surface Heights (24 hour forecast)
12	NRL Sea Surface Heights (48 hour forecast)
13	NRL Sea Surface Heights (72 hour forecast)
14	NRL Sea Surface Salinities (nowcast)
15	NRL Sea Surface Salinities (24 hour forecast)
16	NRL Sea Surface Salinities (48 hour forecast)
17	NRL Sea Surface Salinities (72 hour forecast)
18	NAVO Sea Surface Temperatures
19	NRL Sea Surface Temperatures (nowcast)
20	NRL Sea Surface Temperatures (24 hour forecast)
21	NRL Sea Surface Temperatures (48 hour forecast)
22	NRL Sea Surface Temperatures (72 hour forecast)

[3] Source: HABSOS Web Site at: http://www.ncddc.noaa.gov/habsos/Mapping/

MODIS Ocean Data Products	
Product #	**Product Description**
1	Turbidity (250 m resolution)
2	Total absorption at 443 nm
3	Absorption from color dissolved organic matter at 412 nm
4	Absorption from phytoplankton at 443 nm
5	Backward scattering at 555 nm
6	Chlorophyll
7	Latency (day)
8	Latency (night)
9	Sea Surface Temperature (day)
10	Sea Surface Temperature (night)
GIS Basemap Data	
Product #	**Product Description**
1	US River Gages
2	US METAR† Stations
3	Cities
4	Rivers (generalized)
5	US Shellfish Areas
6	US County Boundaries
7	States
8	Other Land Masses

*NWS: National Weather Service
†METAR: Meteorological Aerodrome Report

Appendix E. NRL Ocean Data Products Derived from MODIS and SeaWiFS Data [4]

E.1. Level 3 (daily and composites)

MODIS (Terra and Aqua)

RRS – 412,443,488,531,551,667,678,
K532
Chlorophyll (MODIS, Carder, OC3m)
absorption (total, l) (Arnone, Carder, QAA)
adg 412 (Carder, QAA)
aphi443 (Carder, QAA)
adg 443 (Carder, QAA)
bb412,443,488,531,551 (Arnone, Carder, QAA)
c531 (Carder, QAA, Arnone)
True Color
SST (SST2 and SST4)
Horizontal Vis (QAA, Arnone)
Vertical Vis (QAA, Arnone)
Cloud Albedo
Flags
250M – True Color for MS Bight (only)
c670 (G&A)

SeaWiFS

RRS – 412, 443,490,510,555,670
K532,
Chlorophyll (OC4, Carder)
absorption (total, l) (Arnone, Carder, QAA)
aphi443 (Carder, QAA, Gould, Stumpf)
adg412 (Carder, QAA, Stumpf)
adg443 (Carder, QAA)
ad412 (Gould)
acdom (Gould)
bb555 (Arnone, Carder, QAA)
c555 (Carder, Arnone, QAA)
c670 (Carder)
Horizontal Vis (QAA, Arnone)
Vertical Vis (QAA, Arnone)
Particulate Organic matter (Gould)
Particulate Inorganic Matter (Gould)
Total Sus Sed (Gould)
Water Mass (Gould)
Cloud Albedo
L2 Flags

[4] Source: Arnone, Robert. 2004. *Integrated Coastal Analyses: Demonstration Project in the Gulf of Mexico.* Review of ACT/NRL NASA REASoN project, John C. Stennis Space Center, December 16, 2004.

True Color

E.2. Level 4 (Binning, Latest Pixel Composite)

MODIS (Terra and Aqua)

K532
Chl (OC3M)
absorption (total, 443) (Arnone, Carder, QAA)
adg 443, (QAA)
aphi443 (Carder, QAA)
adg 412 (Carder)
bb551 (Arnone, Carder, QAA)
Horizontal Vis (QAA, Arnone)
Vertical Vis (QAA, Arnone)
SST (SST2)
Latency

Blended
Chlorophyll OC3m, OC4
atotal 443 (QAA)
adg (QAA)
bb555 (QAA)
aphi (QAA)
sst day (SST2)
sst night (SST2)

SeaWiFS

K532,
Chlorophyll (OC4)
absorption (total, 443) (Arnone, Carder, QAA)
aphi443 (Carder, QAA)
adg412 (Carder, QAA)
bb555 (Arnone, Carder, QAA)
Horizontal Vis (QAA, Arnone)
Vertical Vis (QAA, Arnone)
Latency

Appendix F. HABSOS Pilot Project Participants [5]

Environmental Protection Agency (EPA)

1 Gulf of Mexico Program Office (GMPO)
2 National Health and Environmental Effects Research Laboratory-Gulf Ecology Division (NHEERL)

National Oceanic and Atmospheric Administration (NOAA)

3 National Environmental Satellite, Data, and Information Service (NESDIS)
4 NESDIS CoastWatch - GOM Node Site down due to Hurricane Katrina
5 National Oceanographic Data Center (NODC)
6 National Coastal Data Development Center (NCDDC)
7 National Ocean Service (NOS)
8 NOS Center for Coastal Monitoring and Assessment (CCMA)
9 Coastal Services Center (CSC)
10 Commander, Naval Meteorology and Oceanography Command (CNMOC)
11 U.S. Naval Oceanographic Office (NAVOCEANO)
12 Naval Research Laboratory (NRL)

Additional Federal Agency Partners

13 NASA Applied Sciences Directorate (NASA)
14 U.S. Food & Drug Administration (FDA) - Office of Regulatory Affairs, SE Region
15 U.S. Army Corps of Engineers (USACE), Waterways Experiment Station

National Organizations

16 National Office for Integrated and Sustained Ocean Observations (IOOS)
17 National Association of Marine Laboratories (NAML)

Non-Government Organizations

18 Belle W. Baruch Institute for Marine Biology and Coastal Research
19 University of Colorado, Colorado Center for Atmospheric Research (CCAR)

State of Florida

20 Florida Marine Research Institute (FMRI)
21 Florida Department of Agriculture and Consumer Services (FDACS)

State of Alabama

22 Dauphin Island Sea Lab (DISL)
23 Alabama Department of Conservation and Natural Resources (ADCNR)
24 Alabama Department of Public Health (ADPH)

State of Mississippi

25 Mississippi Department of Marine Resources (DMR)
26 Mississippi Department of Environmental Quality (MDEQ)
27 USM Gulf Coast Research Laboratory (GCRL)

State of Louisiana

28 Louisiana Department of Environmental Quality (LDEQ)
29 Louisiana Universities Marine Consortium (LUMCON)
30 Louisiana Department of Health and Hospitals (LDHH)

State of Texas

31 University of Texas Marine Science Institute (UTMSI)

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[5] Source: NCDDC [National Coastal Data Development Center]. 2006. Participants. *HABSOS: Harmful Algal Blooms Observing System.* National Oceanic and Atmospheric Administration, http://www.ncddc.noaa.gov/habsos/Contact%20Information/Participants (accessed July 21, 2006).

32 Texas Department of Health (TDH)
33 Texas Parks and Wildlife Department (TPWD)

Industry

34 Marathon Oil Company, Climatology and Simulation of Eddies Project (CASE)
35 Planning Systems Incorporated (PSI)
36 Neptune Sciences Inc. (NSI)
37 Anteon Corporation
38 Radiance Technologies

Appendix G. NASA MODIS Ocean Data Products Generated for Global and Regional Earth Science Research [6]

Parameter #	Product ID	Parameter Name	Description
1	MOD18	nLw_412	normalized water-leaving radiance (412 nm)
2	MOD18	nLw_443	normalized water-leaving radiance (443 nm)
3	MOD18	nLw_488	normalized water-leaving radiance (488 nm)
4	MOD18	nLw_531	normalized water-leaving radiance (531 nm)
5	MOD18	nLw_551	normalized water-leaving radiance (551 nm)
6	MOD18	nLw_667	normalized water-leaving radiance (667 nm)
7	MOD18	nLw_678	normalized water-leaving radiance (678 nm)
8	MOD37	Tau_865	aerosol optical thickness (865 nm)
9	MOD37	Eps_78	epsilon of aerosol correction (765 & 865 nm)
10	MOD37	aer_model1	aerosol model identification number 1
11	MOD37	aer_model2	aerosol model identification number 2
12	MOD39	eps_clr_water	epsilon of clear water aerosol correction (531 & 667 nm)
13	MOD19	CZCS_pigment	chlorophyll-a + phaeopigment (fluorometric, empirical)
14	MOD19	chlor_MODIS	chlorophyll-a concentration (HPLC, empirical)
15	MOD19	pigment_c1_total	total pigment concentration (HPLC, empirical)
16	MOD20	chlor_fluor_ht	chlorophyll fluorescence line height
17	MOD20	chlor_fluor_base	chlorophyll fluorescence baseline
18	MOD20	chlor_fluor_effic	chlorophyll fluorescence efficiency
19	MOD23	susp_solids_conc	total suspended matter concentration in ocean
20	MOD25	cocco_pigmnt_conc	pigment concentration in coccolithophore blooms
21	MOD25	cocco_conc_detach	detached coccolithophore concentration
22	MOD25	calcite_conc	calcite concentration
23	MOD26	K_490	diffuse attenuation coefficient at 490 nm
24	MOD31	phycoeryth_conc	phycoerythrobilin concentration
25	MOD31	phycou_conc	phycourobilin concentration
26	MOD21	chlor_a_2	chlorophyll-a concentration (SeaWiFS analog - OC3M)
27	MOD21	chlor_a_3	chlorophyll-a concentration (semianalytic)

[6] Sources: http://modis-ocean.gsfc.nasa.gov/userguide.html, http://oceancolor.gsfc.nasa.gov/PRODUCTS/, http://picasso.oce.orst.edu/ORSOO/MODIS/code/Table1Products.html, and http://picasso.oce.orst.edu/ORSOO/MODIS/code/Table11params.html

Parameter #	Product ID	Parameter Name	Description
28	MOD22	ipar	instantaneous photosynthetically available radiation
29	MOD22	arp	instantaneous absorbed radiation by phytoplankton for fluorescence
30	MOD24	absorp_coef_gelb	gelbstoff absorption coefficient at 400 nm
31	MOD36	chlor_absorb	phytoplankton absorption coefficient at 675 nm
32	MOD36	tot_absorb_412	total absorption coefficient (412 nm)
33	MOD36	tot_absorb_443	total absorption coefficient (443 nm)
34	MOD36	tot_absorb_488	total absorption coefficient (488 nm)
35	MOD36	tot_absorb_531	total absorption coefficient (531 nm)
36	MOD36	tot_absorb_551	total absorption coefficient (551 nm)
D1	MOD28	sst	sea surface temperature (daytime) (11 micron)
D2	MOD28	sst4	sea surface temperature (daytime) (4 micron)
N1	MOD28	sst	sea surface temperature (nighttime) (11 micron)
N2	MOD28	sst4	sea surface temperature (nighttime) (4 micron)
QC parameters			
41, D1		bright20	channel 20 brightness temperature (daytime)
42, D2		bright22	channel 22 brightness temperature (daytime)
43, D3		bright23	channel 23 brightness temperature (daytime)
44, D4		bright31	channel 31 brightness temperature (daytime)
45, D5		bright32	channel 32 brightness temperature (daytime)
46, D6		raw20	channel 20 radiance (daytime)
47, D7		raw22	channel 22 radiance (daytime)
48, D8		raw23	channel 23 radiance (daytime)
49, D9		raw31	channel 31 radiance (daytime)
50, DA		raw32	channel 32 radiance (daytime)
51		U_Wind	U_Wind
52		V_Wind	V_Wind
53		Pressure	Pressure
54		Humidity	Humidity
55		Ozone	Ozone
56		Latitude	Latitude
57		Longitude	Longitude
58		SolarZenith	solar zenith angle

Parameter #	Product ID	Parameter Name	Description
59		SolarAzimuth	solar azimuth angle
60		SatelliteZenith	satellite zenith angle
61		SatelliteAzimuth	satellite azimuth angle
62		nLw670	normalized water-leaving radiance at 670 nm
63		La765	aerosol radiance at 765 nm
64		Ray443	Rayleigh radiance at 443 nm
65		Lg865	glint radiance
66		Lf865	whitecap radiance
67		aer_model1	aerosol model identification number 1
68		aer_model2	aerosol model identification number 2
69, N1		bright20	channel 20 brightness temperature (nighttime)
70, N2		bright22	channel 22 brightness temperature (nighttime)
71, N3		bright23	channel 23 brightness temperature (nighttime)
72, N4		bright31	channel 31 brightness temperature (nighttime)
73, N5		bright32	channel 32 brightness temperature (nighttime)
74, N6		raw20	channel 20 radiance (nighttime)
75, N7		raw22	channel 22 radiance (nighttime)
76, N8		raw23	channel 23 radiance (nighttime)
77, N9		raw31	channel 31 radiance (nighttime)
78, NA		raw32	channel 32 radiance (nighttime)

Appendix H. Bibliography: NOAA HABSOS and Related NOAA HAB Geospatial Decision Support Tools

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